Above: The Moon is shown glowing from the heat of the asteroid and comet impacts that shaped its surface. Of course, these impacts were scattered over time, but concentrated in the Moon's first billion years. Yet these impacts continue to this day, at a greatly reduced pace.

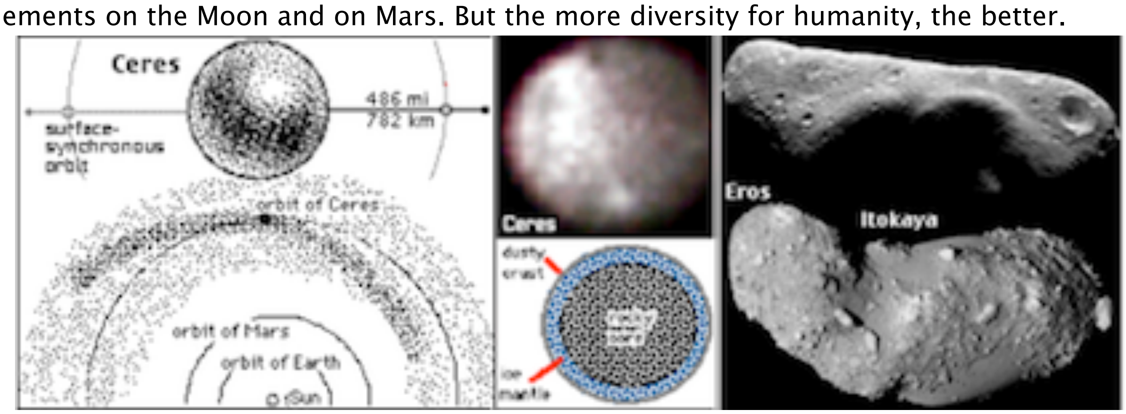
While there have been relatively few articles on asteroids and comets in the pages of MMM over the years, their significance for the Moon's future is as great as it has been for the Moon's past. There is a good sampling of asteroidal materials mixed into the Moon's rock powder surface blanket, 2-5 yards/~meters thick, and of comets as well, in the icy deposits to be found in north and south polar craters that have seen no sunlight for eons. Asteroids and comets are thus logical sources of the rare elements we find in the "regolith" blanket but in insufficient amounts to meet the Lunar Frontier's industrial and biospheric needs.

We will include articles on **Phobos and Deimos**, the two small moonlets of Mars, which some have felt may be captured asteroids of carbonaceous chondrite composition. If so, these two small bodies could be major sources of volatiles for the Moon. The development of these resources could conveniently piggyback on a regular and ever increasing Earth-Moon <> Mars traffic. So their collocation with Mars puts them at the top of the list for ease and regularity of access. While Earth<>Mars launch windows are 25.5 months apart, solar sails could establish a virtual pipeline from Mars to the Moon with liquid methane CH_4 and ammonia NH_3 always going into the "pipeline" at Mars and always coming out of the faucet at the lunar end.

Comets, quite different in composition and origin from asteroids, are also small bodies that abound in the solar system and have in the past endowed the Moon with valuable resources. And there are "depleted" comets that pose as asteroids. So we also include them in this issue.

Near Earth asteroids may be relatively nearby and require little fuel expenditure and "Delta V" to reach, but there is a double Catch-22 involved, with inconveniences that counterbalance the conveniences, and we will deal with that issue also.

Some of the larger asteroids, notably **Ceres**, **Pallas**, and **Vesta**, may someday host settlements. Their material resources and **cultures** will be quite different from those of settlements on the Moon and on Mars. But the more diversity for humanity, the better.



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MMM #6 June 1987

M IS FOR MISSING VOLATILES: The Moon, as compared to our bountiful Earth, is very poor in elements with low boiling points, especially hydrogen (and thus water), nitrogen, and carbon (volatile in its usual form as carbon monoxide and/or carbon dioxide.) Other relatively volatile elements, like sodium and phosphorus, for examples, while present in usable and probably sufficient quantities, are less abundant than on Earth. This volatile depletion is one of the tests to which any theory of the Moon's origin must be put.

More importantly, this depletion sets constraints on what is economically possible on the Moon.

1. Any Lunar civilization must import the bulk of the hydrogen (barring polar permashade ice fields*), carbon, and nitrogen it needs for biomass and life-support.
2. Such a civilization must seek to find inorganic substitutes for non-life related uses to which these elements are put on Earth: wood, paper, plastics, coatings, adhesives, oil, and grease, etc.

[This was written eleven years before the exciting confirmation by the Lunar Prospector orbiting geochemical mapper that such polar ice reserves do, in fact, exist. But even at "billions of tons" this is a very limited resource which must be used wisely only for recyclable purposes. – Ed.]

M is for METHANE & 'MMONIA: poetic license)

The easiest way to ship the missing volatiles is to combine them as methane (CH_4) and ammonia (NH_3) which are easier to liquefy and handle than liquid hydrogen, especially. But any excess needed hydrogen* would have to be imported in the pure form. (Some hydrochloric acid and hydrofluoric acid might be shipped to co-import any needed chlorine -- to combine with Lunar sodium to make salt -- and fluorine. Both may be needed to endow recycling ore extraction processes.)

To increase import efficiency to 100%, containers can be used which are made exclusively of elements the Moon needs to import. Such usable "tare" could be of metal, like copper, or of easily reduced solid hydro-carbons like polypropylene, (-CH(CH3)CH2-)^n.

*[Actually, of H, C, and N, it is Nitrogen which will probably be in shortest supply in comparison to the amounts we will need, solely as a buffer gas used with oxygen for breathable "air". Nitrogen can be conserved by reducing the interior air pressure to half sea-level normal, but with the same amount or partial pressure of oxygen, reduced nitrogen accounting for all of the reduced air pressure. If indeed this shortage does turn out to be critical, it will be a strong incentive to keep ceilings low, thus reducing the cubic volume of air needed per square foot of inhabited space. Goodbye visions of high-domed megastructures for the time being! - Editor.]

M IS FOR MINIMIZATION OF THE COST OF IMPORTING METHANE, AMMONIA, HYDROGEN, ETC.

The Moon's top priority in its program to minimize the cost of its import burden will be to learn to replace (with native elements) or do without non-life-related usages of missing elements. Next in priority will be to develop sources of its import staples (hydrogen, methane, ammonia) that are less costly than upporting [up Earth's deep gravity well] them from Earth. Any infant Lunar civilization must (or die!) open up other parts of the solar system as part and parcel of an integral and viable NTM economy (NTM = non-terrestrial materials).

Mars is so close to having everything that is needed that may be a tendency of Martian Pioneers to be isolationist, not caring to open other space markets.

If you want to guarantee widespread Solar System development, best to put your eggs in a basket that is strategically deficient!

To have an interesting system-wide economy and commerce you need a system-wide community of interdependent places. Any extraterrestrial game in which the name of the start square is not "LUNA" will be a dud. To those who say the Moon lacks the resources to support a civilization, we have a one-word answer: "Japan."

M IS FOR MANNED MISSIONS TO MARS AND ITS MOONS FROM THE MOON: If you want a mission which is not going to be an Apollo-type dead end, or so weight-restricted as to be a token effort you can do two things:

1. Source as much of your throw weight as possible from the Moon. The spacecraft can be made largely from Lunar materials with their bootstrapping 20:1 advantage.
2. Depart, fuel tanks topped off (at least Liquid Oxygen), from high on the shoulder of Earth's gravity well, for example from the L1 Lagrangian point about 40,000 Miles in from the Moon towards Earth. While this would restrict departure to the period of the full moon to head you in the right direction with maximum velocity, the advantage will be so great that you could launch from L1 at several successive full moons on either side of the every-780-days window for the same energy cost as departure from LEO -- low Earth orbit -- at the the heart of the "window."

Looking down the road, manufacturing the building, construction, and mining equipment for use on Mars, Phobos, and Deimos will be a growth industry for the young Lunar settlements. Earth could not compete! [That, in many respects, mining and processing "regolith" on Phobos and/or Deimos will be very similar to operations on the Moon, makes such synergy all the more sensible. * MMM

Mars PHOBOS Deimos

By Peter Kokh kokhmmm@aol.com

Some several millions of years from now, Phobos is expected to spiral in towards Mars' equator, probably disintegrating under tidal stress to form a dark ring around the ocher planet. But for the near term, spirals with one end on Phobos or Deimos will be of freight out-ward to the Moon & LEO, and of freight and hopeful settlers inward to a sandy Martian destiny.

Compared to Earth's Moon, of course, Phobos (12.4x14.3x17.4 miles) and Deimos (6x7.4x10 miles) are small "potatoes." Yet this works out to a surface area of 1,800 square miles for Phobos, 500 square miles for Deimos. [Compare with Rhode Island at 1212 sq. miles.] It has long been theorized that these moonlets are captured asteroids and indeed their reflectance spectra resemble that of carbonaceous chondrites, one of the major asteroid/ meteorite classes. This is what leads us to expect that they are rich in hydrogen, carbon, and nitrogen in one form or another as well as silicates and other oxides. The upcoming* Soviet PHOBOS mission will hopefully confirm this and set the stage for some very serious planning. *[**This mission ended in failure**]

While it requires less energy for a round trip from LEO to the PhD twins than from LEO to the Moon, it is discreditingly ridiculous to suggest that LEO stations and depots get their liquid oxygen from the Martian moons rather than from the Moon. The Moon is handy all the time via a two or three day trip. The Martian moons are available only every twenty-five or so months and only via journeys from 6 months to two years long. Liquid hydrogen is quite another matter as the Moon cannot provide it (barring rich polar deposits**) and will need it even more than LEO. Hydrogen, methane, and ammonia can be processed on Deimos or Phobos and shipped to the Moon for perhaps a third of the cost of transporting them up the steep well from Earth -- that is, discounting initial capital investment.

***Lunar Prospector did discover ice reserves** on the Moon at both poles in 1998. But this is a limited resource that, in our opinion, should be reserved for recyclable uses in food production, biosphere maintenance, and industry for lunar settlements, and not blasted out the nozzle of rockets in a squandering one-time use. - PK]

Now often one reads that the real action will be in "Earth-crossing" and "Earth-approaching" asteroids and/or extinguished comets. The energy cost of round trips to these bodies will be even less than to PhD because one will not be infringing on even the shoulder of a planet-sized gravity well. But this expectation conveniently (naively ?) overlooks one of the paradoxes of celestial mechanics: the more neighborly are the orbits of two bodies (e.g. Earth and asteroid 1982B) the less frequent are the synodic launch windows between them. With such bodies we are talking about opportunities decades apart, not just every 25-26 months! That is not to say that unique one-shot opportunities shouldn't be seized. But for regular trade in volatiles, Phobos and Deimos have it all sewed up.

If LEO (low Earth orbit)-based commercial interest haven't already developed volatile processing on the "hurtling moons of Barsoom", any newborn Lunar settlement will be sure to do so as a matter of its own survival. An initial highly automated small crewed/-tended station on Phobos/Deimos would be coupled with an advance Mars' pre-exploration base that would continue Martian studies from orbit and via teleoperated rovers, planes, balloons, and dirigibles. As (and if) permanent habitation of this precociously legendary planet begins, the PhD outposts will grow into major transportation/ logistics nodes adding some home-grown wares to the heavy equipment being transshipped to Mars from the Moon. Logical items: plastics and pharmaceuticals, both hydrocarbon rich, to be shipped both to the Moon and down to the rustic settlements on the frigid deserts below.

But how could humans live on Phobos or Deimos, except in rotating tours of duty, with their physiology-wise negligible gravities? One possibility: a maglev train of habitat-cars on a steeply (89+ degrees) banked track within the lip of 3 mile wide Stickney crater on Phobos circling about every 114 seconds (307 mph) would simulate the 0.38g of Mars itself. MMM

Seizing the Reins of The MARS BANDWAGON

(excerpts) Commentary by Peter Kokh

[snip, snip]

It is common to portray our Society as the Moon party, the Planetary Society as the Mars party. We accept and encourage such a distinction at our peril. People on both sides of the Moon–Mars "debate" do the future of humankind in space a serious disservice by escalating this impatient, misbegotten polarization. What we sorely need is a Moon–Mars consensus.

Those who believe that we can build an autonomous spacefaring civilization based on volatile–poor Lunar resources alone are surely living in the land of Oz. Those who think that this Lunar resource shortfall can be made up by **Earth–approaching asteroids** (which owing to infrequent windows can hardly be more than sporadic targets of opportunity in the near term) ignore the laws of orbital mechanics. Without the additional regularly accessible resources of Mars' companions, **Phobos and Deimos**, and Earth–Moon economy will be doomed to inevitable collapse, however valiant and brilliant an effort is made to make a go of it –– a futile exercise.

Imagine an alternative solar system in which neither "Earth" nor "Mars" have natural satellites (even as Mercury and Venus do not) and in which there are no asteroids. Then try to construct a scenario by which a solar system ranging civilization might arise despite such handicaps. Hard, isn't it? Yes, we are blessed –– by chance or by design is not to the point. But to blueprint a spacefaring society while petulantly (yes! that is the right word!) ignoring those assets handed us on silver platter is patently stupid.

The Moon needs "Mars PhD" Mars needs Phobos, Deimos –– and the Moon. This inter–world trade economy will be the keystone of our future in space. Without this axis, we cannot economically fill Cislunar space with space colonies and solar power satellites. Without this backbone, we cannot realistically develop **asteroidal and cometary resources**. Without this anchoring, we cannot access the wealth of the Outer Solar System.

Those of us who want to postpone a "choice" between the Moon and Mars **PhD** are just as off track as those of us who want to rush such a "choice." The truth is that in the end, we will either have both or we will have neither.

The one pragmatic strategy which alone promises us this Moon–Mars synergism is to court the considerable ranks of Mars advocates and convince them that what they really want is not just a quickie release of pent–up curiosity in a one–shot exploratory picnic à la Apollo, but a sustained opening to Mars leading to permanent human presence there, to development and self–continuing settlement. Instead of pooh–poohing the chances for such a realization, we ought to be at the forefront – brainstorming the options.

Once Mars hopefuls are converted to the goal of making Mars a second homeworld for humanity, Lunar settlement and economic development will be assured, since it is the only way such an opening to Mars can be sustained in the face of certain and inevitable political and media disenchantment.

A Mars program worth pursuing will include the Moon and the Moon's needs. It enlists government financing of the infra–structure and technologies needed to open the Moon: deep space vehicles, closed loop life support systems, pocket–sized hospitals, etc. And then it leaves the way open to private enterprise and multi–national consortia to take it from there. **MMM**

Colonist Mars Quiz

QUESTIONS [1–2; 4–7 snip]

3. Mars orbits the Sun just inside the **Main Asteroid Belt**. Why, especially when time is more important than price, will the Moon, not Mars nor Phobos/Deimos be the logical supply and resupply base for future "Belters?"

ANSWERS [1-2; 4-7 snip]

3. First, **Mars will have little need of asteroidal resources**, **whereas the Moon's need will be one of "do or die."**

Second, one **commonly overlooked consequence of orbital mechanics** is that the closer any two orbits lie in their periods, the less frequent are the Hohmann trajectory launch windows between them. To illustrate, windows open between Mars and Vesta every 47 months, between the Moon and Vesta, every 16.5 months; similarly there are opportunities every 38 months between Mars and Ceres, but suppliers need wait only 15.3 months for Moon-Ceres openings. The Lunar advantage is considerable, when fuel costs are secondary to timeliness. Yet science fiction writers and others commonly assume that Mars will be "Asteroid Belt Central."

MARS: OPTION TO STAY

By Peter Kokh - kokhmmm@aol.com (snip - **Excerpts** - snip)

SCENARIO 1: Timeline 2010 (+10 -5)

√ A Complete Phobos Base:

A united (NSS, TPS, SSI, WSF, USSF, etc.) Mars front sells the government(s) on a beefed-up Mars Mission, successfully making the point that one deluxe mission will be cheaper than two economy expeditions and less dangerous. The government(s) have been convinced that **a forward base on Phobos is necessary for success of the effort**. This base will produce and stockpile fuels for the actual Mars landing and for the return trip to Earth and do the final preparatory Mars tele-science from its forward position.

Phobos (and / or **Deimos**) Base will teleoperate rovers on the Martian surface to do ground truth-checks to compare with data gathered by an armada of orbiting instruments monitoring the weather (monitoring developing dust storms and dust devils), do landsat geochemical resource mapping (to help make wiser final site selections for a more productive mission), survey for permafrost and possible thermal hot spots and areas with abnormal radioactivity levels, do detailed high resolution altimetry and radar mapping (to get an idea of potential drainage patterns and routing choices), monitor a network of seismic penetrator stations listening for marsquakes, and sniff the atmosphere for recent and ongoing volcanic gas emissions. Surface rovers will also collect many samples for relatively cheap return to a Phobos lab only 3700 miles above rather than the long, time-consuming, and expensive return to the Earth-LEO labs many millions of miles away -- thus boosting the amount of soil samples that can be checked by many, many times. Phobos/Deimos could also teleoperate drone photo reconnaissance airplanes and dirigibles in the thin atmosphere below.

Meanwhile, Phobos Base will earn its keep by also processing volatiles (carbon, hydrogen, and nitrogen) in the form of methane (CH_4) and ammonia (NH_3) for back-shipment to thirsty Luna. There may well be a steady stream of "tackliner" cargo freighters -- container pods hauled to and fro most efficiently by great solar sails, accelerating slowly but persistently to give some measure of freedom from launch windows and building up caches of supplies from Mars orbit to be on hand when the sprinting human crews arrive.

Finally, Phobos Base could oversee the carefully plotted siting of parachute-landed robotic production plants on the Martian surface to stockpile nitrogen, oxygen, argon, carbon monoxide, water, methane, and ammonia -- all processed from the atmosphere -- to be ready for the base-to-be and handy for refueling the various planned cross-terrain expeditions. It might be possible, too, to drop auto-mated facilities that would produce and store some fall-back food staples such as algae cakes. [written prior to publication of Robert Zubrin's "Mars Direct."]

The Phobos Base would then have a joint mutually reinforcing mission: to vastly enhance the chances of success for a crewed Mars surface mission and to assist the economic bootstrapping of the early Moon Settlement so that it could manufacture and ship some items ["M.U.S.-c.l.e." in MMM #18] at considerably less expense than they could be sourced from Earth. [snip] **MMM**

Telling Time on Phobos and Deimos

Telling time on Mars with its convenient 24h 39m day should not entail major adjustments to the internal clocks of the pioneers. But what about those poor wretches working the mines on Deimos or manning the Port of Mars Authority installations on Phobos?

These two moonlets have their own day-night cycles. Fate, or something like it, is on the side of convenience here.

On Phobos:

Its day-night routine is just 20.6 minutes shy of an Earth-style 8 hour shift. Put three of these to a Phobos date (100 seconds shy of 23 hours) and thirty of these would be just 17 minutes shy of a standard 28 date Martian month. So while Phobos work details might use local time, at least they could synchronize their “months” with those of the rusty dusties down below. To avoid confusion, Phobos-dates could be lettered or counted down, or rely on some other tell-tale indicator.

On Deimos:

However, the day-night cycle or sol is inconveniently long at 30 hours and 21 minutes, a difficult, but not impossible adjustment for the human system. Yet obligingly, 3/4 of this period would give us Phobos-like dates 22.77 hours long (4 dates per 3 periods.) The lighting patterns would repeat every 4th, 8th, 12th etc. dates (an 8 day week would work well for pattern repeat purposes.) And again, 30 such shorter dates would mesh well with the Martian 28-date month pace. In both cases, thanks to digital timekeeping, preserving a solar system wide standard second and minute, and even the hour, would be no problem at all. A digital watch can reset to zero at any odd preprogrammed sum of hours, minutes, and seconds. Such a watch could be devised to show the time alternately on Mars (specify time zone, please,) Phobos and Deimos.
PK

MMM #24 - April 1989

Introduction to this Asteroid theme issue

By Peter Kokh

There’s a lot to say about asteroids and we won’t be able to cover it all in one issue. But we hope to give you some insights you’ll find nowhere else. Much attention is now given to Earth-approaching asteroids easier to reach than those in the Main Belt, we will point out some interesting possibilities for the Belt’s “Big Three” that others have missed.

We’ll have only space to hint at the many fascinating cultural & social aspects of some future “Belter” civilization, but that will give us excuse to do a future follow-up issue.

Two Pesky Questions for Debate

(1) Will Earth citizens’ fears, justified or not, of possible collisions with asteroid “bergs” being brought back by mass driver, lead to herding them to one of the Earth-Sun Lagrange points instead of near-Earth orbits? If so, a whole complex of space colonies might be located out there, processing the incoming ores into manufactured goods for shipment to Earth and Moon.

(2) Will environmental concerns about using mass drivers for propulsion lead to requiring them to maintain a debris stream exit velocity sufficient to escape the solar system least their orbiting clouds of exhaust shot add to space travel hazards?

Colonist's I.Q. Quiz on Asteroids

Questions

[1] True or False. The asteroids are all that remains of a lost planet that once circled the Sun between the orbits of Mars and Jupiter, and which disintegrated in some unknown catastrophe.

[2] True or False. The Asteroid Belt is thin like Saturn's rings.

[3] True or False. The main portion of the Asteroid Belt is so thick that from the surface of any one asteroid, many others should be visible to the naked eye.

[4] True or False. All asteroids are irregular in shape much like little Phobos and Deimos, the tiny moons of Mars, themselves possibly former asteroids.

[5] True or False. There is a correlation between the types of meteorites we have found an Earth and the various classes of asteroids.

[6] The asteroids being so small and far away, how is it possible that we know anything about them at all beyond their orbital statistics?

[7] Are any asteroids important enough in their own right to be more than chance targets of opportunity?

[8] How many asteroids have so far been discovered in "Earth-Trojan" orbits, preceding/ following Earth in its orbit in stable L4/L5 Earth-Sun Lagrange points?

Answers

[1] The theme of several science fiction stories, this is one of those romantic notions (much like that of Atlantis) that dies hard. The overwhelming evidence and the mainstream opinion is that no single planet was able to form at this distance from the Sun because of the disruptive effects of Jupiter's gravity, evident today in the several gaps (e.g. Kirkwood gap) or zones of avoidance in the belt where the orbital period would not be a simple harmonic of Jupiter's. The total mass of the known (about 4,000) and conjectured asteroids together, is much less than that of the Moon, which would have made for a small planet indeed.

While most people now reject the “Lost Planet theory”, many still cling inadvertently to another theory that stands or falls with it, namely that before the hypothetical Lost Planet broke up, it had become differentiated with heavy metals towards the core, stone and water to the outside, and that same fragments must be incredibly rich pure metal as a result.

Instead it seems certain that denser, stonier asteroids formed nearer the Sun, water-rich carbonaceous ones further from the Sun. The original family of asteroids has probably all been broken up and reassembled by mutual impacts in the 4 billion years since plus formation. But it is unlikely that any of the original number, Proto-Vesta being the sole possible exception, was ever large enough or hot enough to undergo differentiation.

[2] False. The range of orbital inclinations to the mean plane (represented by the Earth-chauvinistic ecliptic or much better by Jupiter's orbital plane) is quite high, averaging about 10 degrees with some stragglers inclined as much as 43 degrees (#944 Hidalgo). The greater the inclination of an orbit, the harder (more delta V) it will be to reach from Earth.

[3] False. The image of a packed belt may set a mean stage for science fiction stories and movies, but the “Belt” is mostly empty space. Take a thickness of 100-200 million miles, a depth about the same, and a circumference on the order of 600-1000 million miles and sprinkle with a few thousand asteroids and they will all be pretty lonely. Occasionally asteroids will pass one another close enough to be seen with the naked eye. But Earth, Mars, Jupiter, and Saturn will thoroughly dominate asteroid skies.

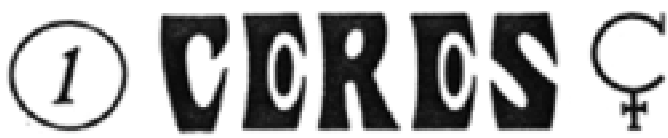
[4] In theory, any body of 250 miles diameter or more will have sufficient mass to shape itself 'in time' into a body with an equipotential surface: a sphere. The evidence from Voyager views of the small moons of Saturn fits this well (Hyperion clearly suffered from a geologically recent major impact, and is an exception). In fact, **Ceres**, by far the largest, may be the only asteroid that fits this spherical mold.

[5] True. The spectral analysis of light from various asteroids seems to coordinate very closely with meteorite classes, signifying that the Belt is their source.

[6] As we have just indicated, asteroid light can be passed through a spectrograph which, acting like a prism breaks up the light into its component colors, gives a clue to the surface composition. Photometric studies of light fluctuations can tell us about a body' s rotation rate and even its polar inclination. Polarization and albedo light reflectance studies can tell us more about composition and granulation. Only a few asteroids have been thoroughly studied in this way, a neglected field crying for amateur attention. Only **Vesta** has been crudely mapped by the new process of speckle interferometry.

[7] **Vesta** seems far and away the most interesting for several reasons. **Ceres**, the largest, and **Pallas** to a lesser degree, are inviting targets – see the articles that follow. The rest all fall into well-known classes any of whose members will probably yield as much information as any other. All the asteroids so far mentioned for flyby encounters on the road to Jupiter and beyond are targets of opportunity, no more.

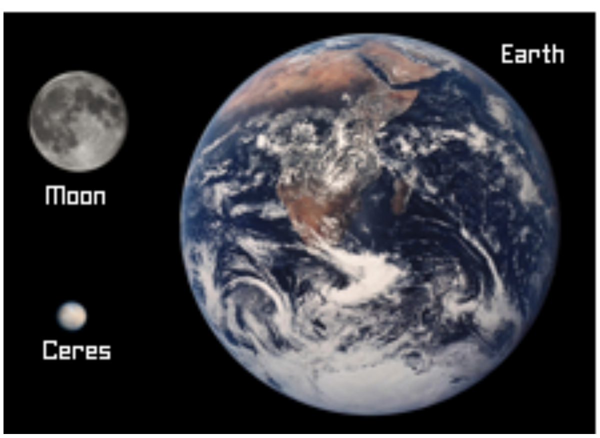
[8] Despite careful searches that should have turned up anything larger than a couple of kilometers across, no such Earth co-orbital bodies have yet been detected. As such bodies would provide continuous travel opportunities at very low delta-V, their apparent absence is disappointing.



CERES

DIAMETER: 1003 kilometers or 621 miles.

SURFACE AREA: 3,160,000 km2 (1,219,000 mi2)



COMPARISONS: slightly larger than either of:

- all the U.S. east of the plains states (not Dakotas thru Texas)
- all the U.S. west of the plains states

● Queensland + Northern Territory (AUS) ● All the Moon's nearside seas except the Ocean of Storms,

CLASS AND COMPOSITION: Carbonaceous chondrite. Stony (silicates and metal oxides) with admixed ice and hydrates.

ROTATION PERIOD (one sol): 9.08 hrs. **POSSIBLE RATIONALIZATION:** A two date cycle of 5 periods would yield dates of 22 hrs 42 min. A three date cycle of 8 periods would yield 24 hrs 12.8 min.

GRAVITY: 19% Moon's, 8.31% Mars', 3% Earth's.

DISTANCE FROM SUN: 381-447 million km = 237-278 million mi. = 2.55-2.99 A.U. [1 A.U. or astronomical unit = the Earth's average distance from the Sun

COMPARISONS: Ceres averages 2.77 times the Earth/Moan distance from the Sun. To collect the same amount of solar energy as a 1 meter diameter collector on the Moon (or a 1.512 meter collector on Mars), a collector on Ceres would have to be 2.77 meters in diameter (7.67 x the area).

Ceres was the first asteroid to be discovered and is by far the largest and may contain as much as one third of the total asteroidal mass. As you can see from the 'illustrated' statistics above, Ceres may be a small body in comparison with Earth and even the Moon, but it is quite a big little world all the same. In diameter Ceres compares to the Moon (1:3.48) as the Moon to Earth (1:3.67). What would it be like to live on Ceres? All the clues lie in the data above.

Outposts on Ceres

Ceres' gravity, the largest in the Belt at 33 cm/sec2, may yet be too low for human physiology to adjust to without degrading to a level most might consider unacceptable. All the same, it is a sure bet that some humans will ignore the recommendations and make that adjustment for better or for worse.

Those not wishing to put human adaptability to the test, could have any level of gravity they desired, Lunar, Martian, or Terrestrial, if they lived in a rotating habitat. This could be achieved in three basic ways:

[1] a rotating space habitat in orbit about Ceres -- synchronous orbit would be 486 mi. or 782 km above Ceres' equator -- elevator anyone?

[2] on the surface riding a properly banked and sized mag-lev rail or Gravittrack™

[3] on the surface and suspended in pairs or otherwise counterbalanced from a rotating pole like an amusement park ride or Maypole.

Each of these would require radiation shielding. The second option would be the easiest to shield, the third possibly the cheapest to build.

It is likely **Ceresian**s (**Cerians**?, **Cerealians**?) would spend part of their day on the low-grav surface, the rest in the higher- grav habitat. What works for Lunar architecture will not work on Ceres. On the Moon (and Mars), internal habitat air pressure can be counterbalanced, at least in part, by the shielding soil overburden.

In Ceres' low gravity, it would take five to six times as much shielding mass as on the Moon to achieve the same stress relief. So habitats on Ceres must be built as if they were spaceships or surface vehicles, i.e. cylindrical or spherical.

Secondly, the soil on Ceres may be in a permafrost condition. It would then be necessary to excavate a larger trough and backfill with dry rock to prevent the heat-radiating habitat from slowly settling deeper into the soil.

What purpose could an outpost on Ceres serve? The asteroid itself probably has enough of everything (clay-like hydrate silicates, some metals, water-ice, carbon-rich compounds etc.) to supply its essential needs but is unlikely to have export grade mineral wealth. Rather, such an outpost would serve as a regional outfitting, resupply, maintenance, and service center (including hospital, educational, judicial, cultural etc.) for mining ventures to more richly endowed asteroid bits within easy delta-V range.

Ceres' "Service Area"

If the stats for the first 100 asteroids to be discovered are typical, 44% have orbital periods within 1O% of Ceres' so that one third of these or **almost 15% of all asteroids would be within 60° of Ceres at any given time and remain there for fifteen years or longer before drifting out of range.** Some asteroids will 'fly in formation' with Ceres for centuries. Two target groups suggest themselves: **the 'out-fronts'** ahead of Ceres but in slower larger orbits, and **the 'in-backs'** behind Ceres but in faster smaller orbits. At any rate access to 15% of the Belt should do us well for quite a while.

To compliment Ceres as regional centers, 210 km wide #88 Thisbe (takes 1415 yrs to drift 120° with respect to Ceres) and 163 km wide #39 Laetitia (3540 yrs to drift 120°) might serve well.

Facilities on Ceres

In time, engineering development for belt needed equipment (prospector ships and tools, mining equipment, mass drivers, smelting equipment) could switch from the Moon to this regional center. Experience gained on this colder, wetter world could prove useful for ventures beyond the Belt.

A Short Pool of Names

Those who go to Ceres will want to name features and installations and they might find some inspiration from these historical and mythological trivia. **PIAZZI** discovered Ceres in **PALERMO**, **SICILY** on the first day of **CENTURY NINETEEN**. Ceres was the Roman goddess of grain, and she chose the mortal **TRIPTOLEMUS** to carry her knowledge (the plow, agriculture) to mankind. The **AMBARVAILIA** were rites of spring celebrated by Roman farmers in Ceres' honor.

Of course, miners will also bring with them more whimsical names e.g. The King Solomon's Mines Hotel (a real rat trap!) **MMM**

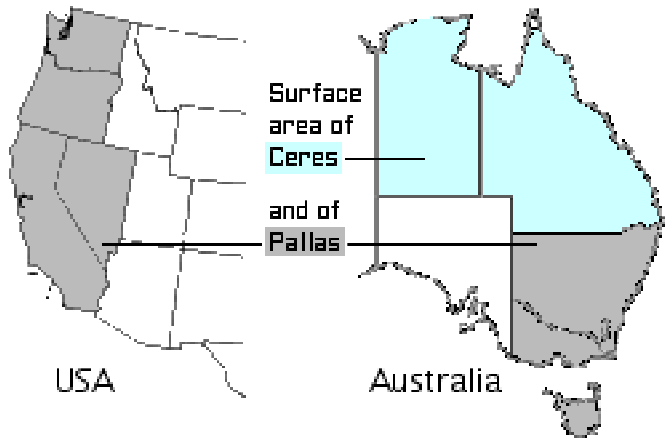
② PALLAS ⚴

PALLAS

The Basics

With an average diameter of 608 km or 378 miles, Pallas, the second asteroid to be discovered, is a smaller world than Ceres. It's surface area compares with Mare Imbrium + Serenitatis; or with

Washington + Oregon + California + Nevada



or **New South Wales** + **Victoria** + **Tasmania** – Still enough land in which to get lost!

Pallas is classified as 'peculiar chondrite' and from its radar signature appears to be rather smooth.

While its orbit is much more elliptical(bringing it about 66 million km or 41 million miles closer to the Sun than Ceres and taking it the same distance further out), its mean distance from the Sun is almost exactly the same as Ceres'.

There are reports that Pallas has a 90 km satellite orbiting some 300 km above the surface. If confirmed*, this could be quite an asset especially if the composition of this body is complementary.

[Observations since have ruled out such a large satellite.]

Pallas has a 10 hr day-night cycle. Pioneers would experience 12 of its days to every five of ours.

Pallas is a "World Apart"

The most significant statistic about Minor Planet #2 is its **35° orbital inclination** to the ecliptic. We'd like to suggest that Pallas' relatively smooth surface is due to less total exposure to micrometeorite bombardment owing to this high orbital inclination. Seven other asteroids have orbits with a family resemblance but only a few very small ones have orbits more steeply inclined.

Pallas would thus be considerably harder to reach, requiring extra Delta V. This could make it a mecca or haven for "**intentional communities**" wanting a world as "off-the-beaten-path" as possible, isolated and insulated from the cultural, religious, social, or economic ways of the rest of the Solar System. As influx of fresh blood will be inhibited, they might want to start with as diversified a gene pool as possible.

Palladians [an adjective coined by the Romans] might trade knowledge and information gathered in their monastic isolation, via radio for essential imports by drone rocket. This world is very poorly placed to be a regional outfitting, supply, and service center.

One reason for an outpost on Pallas

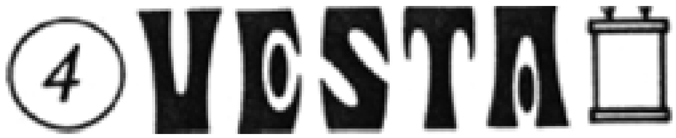
Yet precisely because of this high inclination, **Pallas offers easily the best observatory platform in the Solar System for studies of the Sun's north and south polar regions,** when it is either high above or deep below the ecliptic on opposite legs of its 4.6 year long orbit. And this could be reason enough for establishing an outpost there.

Pallas and Ceres

It takes Ceres almost 3000 years to lap Pallas – an extreme example of the disadvantage of orbital proximity. This century they are about 60 degrees apart (about 270 million miles) but as seen from Ceres, Pallas swings alternately nearly 100 million miles above and below its mean position. Travel in between is unlikely.

Name pool:

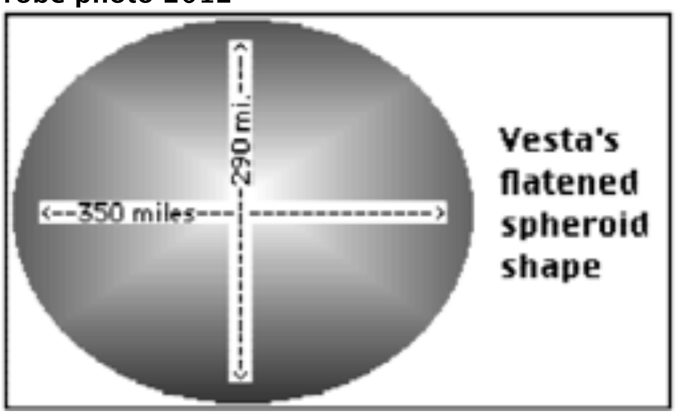
Second in order of discovery, Pallas was discovered by Wilhelm **OLBERS** in **BREMEN** (now part of Germany). The **PALLADIUM** was a famous statue of Pallas (Minerva). Name seekers might also consider Romance- and mystery-filled names that suggest out-of-the-way and hard-to-reach places such as **New Timbuktu**, **Shangri-La**, etc.



VESTA

Recent speckle interferometry studies of Vesta, Minor Planet #**4 in order of discovery**, and the **brightest as seen from Earth**, have revealed a wealth of new information.

A crude map of the surface has been constructed from the data which shows that Vesta is not quite spherical, but more like a 'flattened watermelon' 564 x 531 km (350 x 330 mi.) in diameter at its equator by 467 km (290 mi.) along its polar axis. **Below right: actual Dawn Probe photo 2012**



Date and Time-keeping on Vesta

Vesta rotates about its axis in a mere 5 hrs 20.5 min. A two date cycle of nine such periods gives dates 24 hrs 2.2 min long.Pioneers might organize their schedules accordingly.

Vesta’s Surface Composition

Unlike either Ceres or Pallas, both dark bodies, Vesta's surface is relatively bright making it **the only asteroid that is ever visible to the naked eye on Earth**- but only in dark-sky country!

Spectral studies seem to indicate a basaltic (as are the dark nearside lunar seas or maria), drier stony (eucritic) composition, not unlike the Moon (which, however, is much less reflective). The surprising presence of basalt indicates that at some time in its past, Vesta's interior had melted. A radioactive isotope of Aluminum seems to be the only likely source of the heat required in a body so small and would have done its work swiftly making any lava flow seas on Vesta some hundreds of millions of years older than the Moon's. Some think Vesta may be the parent body of most stony meteorites.

A dry basaltic surface has both advantages and disadvantages. Some Lunar type construction methods might be appropriate. But it is possible that an outpost there would need to import some volatiles.

Vesta's gravity might be not much less than Ceres' given its probable higher density. Its surface could include Moon-like lava filled basins and cratered highlands.

Both surface sampling and orbital mapping are top priorities. A French probe to piggyback on a 1994 Soviet Mars mission is under study. [Ed. This Vesta mission never flew.]

The “Florida” of the Belt?

Vesta is also considerably closer to the Sun than Ceres or Pallas, ranging from 322 – 383 million km (200 – 238 million mi.) making the circuit in a year less time (3.63 yrs). One can imagine that Ceres-Vesta oppositions every seventeen years one month apart may someday be the occasion of much ado in the Belt, commercial, social, and what have you.

Tourist hype might refer to Vesta as the 'Florida' of the Belt. Yet it receives 2.4 times less solar energy per unit of surface area as does Mars (and 5.5 times less than Earth/Moon).

If volatiles are not a problem, Vesta may well be a regional outpost, quite possibly before Ceres itself. Except for the drier soil, the construction game plan will be similar.

Vesta as a Mecca for Physicists?

But Vesta could be most preeminent as a mecca for Physics. While it was once apparently molten, it is too small to have retained any heat. Add to this its probably dehydrated state, and it may be the **only body of size in our system in which it is possible to bore a shaft clear to center**.

Imagine a large room with **negative zero gravity** (equal canceling pulls in all directions) shielded by 150 some miles of rock in all directions. That should be good for something! Such conditions could not be equaled nowhere else in the System. Given such an asset, an Vesta outpost or settlement might someday include a major university or physics institute.

Physics Homework

Here is some physics homework for someone: a 10 meter [33 ft] wide shaft to the core would involve removing about 75 million metric tons of rock material. How fast would this much matter have to be ejected in pulverized form out the end of a mass driver, easterly along Vesta's equator to slow significantly Vesta's swift rotation?

A terraformer's dream perhaps, but if Vesta's rotation could be slowed to once per orbit (sun-locked) a sizable 'sub-solar' region would then receive as much total sunshine as any spot on Mars, or about three times as much as presently. As a bonus, Vesta's 'farside' would then be the coldest spot in the solar system.

A short pool of names

Pioneers looking names for features and installations on Vesta could consider these trivia facts: Wilhelm **OLBERS** discovered it in 1807 from **BREMEN**; Vesta was the Roman goddess of the **HEARTH** (home, warmth) suggesting words for "hearth" in other languages. **VESTALIA** were ceremonies in her honor by the vestal virgins. **MMM**

ASTROBITS

• How will Prospectors Stake an Asteroid Claim?

They will radio all the identifying information to some central claims office, of course; but perhaps they will want to put an actual marker on the particular orbiting berg they've prospected. A convention of some sorts would be needed to standardize procedure. One possibility would be to put a strobe beacon or radio beeper on the body's north (or south) pole.

A hitch here is that, as we discovered with Halley's Comet, a small body can have two axes of rotation at once. In such cases the shortest axis or the one with the shortest period could be picked. Is there a better way to say “keep out!?” Suggestions welcome.

• A Capital for the Belt?

It is a tossup whether Belt communities would ever choose to federate or even loosely associate and thus need a "Capital City". If so, there is no logical spot within the Belt, Ceres' and Vesta's bids to the contrary, that will be easily accessible from anywhere.

The Moon offers much more frequent and regular launch windows than any asteroid and will be a major, or the major source of supplies. That's if Belters can stand its (to them) crushing gravity.

Phobos and **Deimos** might offer space for such a headquarters, though with much less frequent launch windows. If Belters insist on an asteroid site headquarters, however, oddly shaped 36 x 15 km (22.3 x 9.3 mi.) **Eros** would be the best of a poor set of choices, offering reasonable launch window frequencies to most of the Belt yet accessible with perhaps politically desirable difficulty from both Earth and Mars.

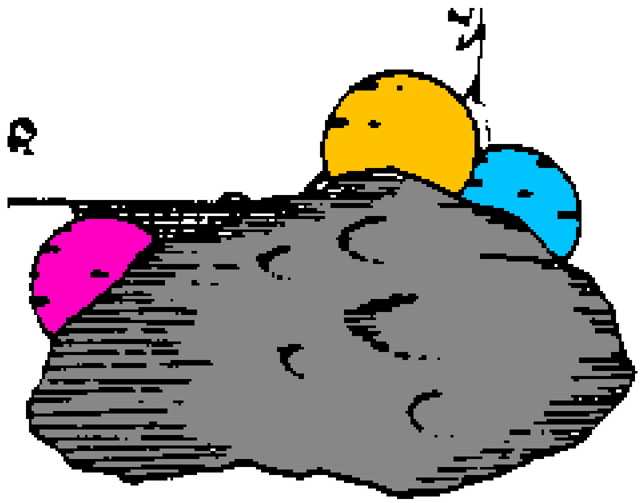
Of the other Earth-approaching asteroids, 35 km **Ganymed** is easily the largest but it has a very eccentric, highly inclined orbit with an inconveniently long period.

• This would be Eros' 3rd "Oscar"

When the asteroid (#433) was discovered in 1898, it became instantly famous as the first known minor planet to come within the orbit of Mars.

Later, as its cigar-shape was deduced from its light curve, Eros inspired some to foresee the possibility of hollowing out suitably shaped asteroids and spinning them up to provide artificial gravity on the new inside surfaces and serve as great space colonies or even as star-bound arks, inspiring many (such as this writer) long before the days of Gerard O'Neill's Space Settlements vision. **MMM**

MMM #25 - May 1989



Asteroid Odds & Ends

By Peter Kokh

PALLAS & AN ASTROLOGICAL SCHISM

Potential settlers with a (mental) weakness for astrology and an aptitude for creativity, will have an opportunity for a fresh start. With Pallas' high orbital inclination, 35.85 degrees to our own orbital plane about the sun, ITS ZODIAC (the circle of constellations through which the Sun appears to travel) will be quite different from our own, having only two "houses" in common, where Pallas' orbit crosses the plane of our own, on the downswing in Pisces and on the upswing in Virgo. Palladians' unique set of "signs" would also include Serpens, Ophiuchus, Aquila, either Equuleus or Delphinus, Pegasus, Cetus, Eridanus, Lepus, Canis Major, Hydra, and Sextans -- ten great beginnings for a whole new round of sheer nonsense.

CERES (and the Belt in general)

At opposition, Jupiter will be as beacon-bright in Ceres' sky as Venus ever gets in our own. It may then be possible to pick out Jupiter's four great moons, Io, Europa, Ganymede, and Callisto with the naked eye, the latter two being easiest to spot.

PODOKINETICS (FOOT POWER SYSTEMS)

Future Belters and others electing to make it the best they can without artificial gravity could do well with residual legs, there being little use for then, UNLESS, they adopted (as a

"Protestant Work Ethic" sort of thing) the stricture that electric power for all luxury devices (personal entertainment and personal comfort etc.) be derived from pedal operated generators (possibly with power assist where the output, however well intended, would be insufficient, e.g. hot instead of cold shower water). If the VCR, the compact disk player, the cookie jar lock, the vibrator, the telephone, etc. would not work or open without pedaling, most would pay the price gladly. This would not work well unless it was a community-wide decision and we can foresee arguments as to whose turn it is to pedal up the community holovision!

Podokinetics would not maintain the body in Earth-normal tone by any means. But it could offer a badly needed physiological boost.

Podokinetic devices should be developed now, as a health fad device, so they are ready when gravity-less construction shacks are set up in space.

All the same, the residual legs of human dwarfs would be no handicap at all. Bare feet may be normal in many living and working conditions; and anyone with even remotely prehensile feet would be at a definite competitive advantage.

Our final comment on being footloose among the asteroids - in the very light gravity these worlds offer, pogo stick races may be the outdoor sport.

TOWARDS EZ-GRAV

For those unwilling to accept the consequences of sustained life at minimal or no gravity, the easiest way to provide artificial gravity in space itself is not with rotating toruses, spheres, or cylinders, but with the tether. If all Belter ships were designed in polarized manned vs. tended sections (facilities whose automated systems needed to be tended only intermittently, minimizing transit from the one section to the other) the two sections, when not united for acceleration or deceleration boosts, could be easily split by tether to revolve around their common center of gravity. (see MMM # 21 Lunar Overflight Tours). [republished in MMM Classics #3, downloadable pdf file from www.moonsociety.org/publications/mmm_classics/

Such 'binary' ships should be on the drawing boards now. Of course, that tether had better be strong and fail safe!

GRAVITY BY TETHERED ANCHORS

The combination of low gravity and typically fast asteroid rotation allows anchoring to an asteroid and paying out a tether beyond synchronous orbit distance to a point where the tether would whip the ship, station, or colony around the asteroid in step with the latter's rotation and provide through constant change in angular momentum whatever artificial centrifugal gravity one desired, "down" then becoming away from the asteroid.

As the required radius would be many hundreds to some thousands of miles in length, the spin-dizziness that will affect some persons on conventional space colonies would never arise. Such stations would be quite flat-floored, without the tight curvatures previously associated with artificial gravity.

Tethers of the necessary strength should be available by the time needed. A simple tether following cage would provide transit to the asteroid "up" below. A massive flywheel in the plane of orbit probably doubling as an energy storage device would keep the colony of station from twisting on the end of the tether.

Docking could be at the asteroid-synchronous mark along the tether, between asteroid and station. This would also be the logical point for a surface to station elevator to switch orientation from floor towards-asteroid to floor-towards-station. Outside excursions would be risky - loose your grip and go on a real crack-the-whip fling!

WHERE WILL THE BELT WEALTH GO?

Given that most people going out to the Belt will be making an all but irrevocable commitment to a permanent life at low-G, minimal-G, or no gravity at all, the dream that lures them outward will not be to go to the Belt to make a fortune, then come back to Earth (or the Moon or Mars) to spend it. The spending will be out there. Mineral wealth sent on its way to markets in the inner solar system will pay for imports of consumer goods out to Belt distribution centers. These can be either fixed (e.g. on Ceres, Vesta, etc.) or roving "gypsy general stores" that make the rounds between mining stations on prearranged itineraries. Of course we can expect specially configured minimal-G gin and sin traps set up in orbit around the major planets to snare some of those earnings before the suckers head for home.

MMM #28 - September 1989

Asteroid Types

From Stephen L. Gillett gillett@seismo.unr.edu

[Stephen L. Gillett (cf. "Lunar Ores" MMM #22 p2) now of Carson City, Nevada, sends the following correction to the impression we gave in our reply to "Colonist's I.Q. Quiz" question #1 in our April "Asteroid Special" - MMM # 22]

"It looks as though metallic and stony asteroids are derived from the breakup of small differentiated bodies, which initially heated up enough to mostly melt, thereby separating into a metallic core and silicate mantle. Then over geologic time, most such bodies were broken up by subsequent impact (see, e.g., Sonett & Reynolds; Scott; both in Gehrels [ref. below], 1979). (Vesta may be a survivor!

"Although such small bodies could not differentiate now, not having enough sources of internal heat (i.e., too little natural radioactive elements), at the formation of the Solar System, sources of heat probably did exist: short-lived radioactive elements that are now extinct.

"The most popular candidate is Aluminum-26, a suggestion that like so many others, goes back to Harold Urey. Al-26 has a half-life of about 0.5 million years and releases a relatively large amount of energy on decay. Also, Mg-26, its daughter product, has been found in aluminum minerals in the meteorite Allende.

"In fact, there probably are metallic asteroids, pieces of the core material broken out from such early differentiated bodies; they are probably spectroscopic type M amounting to a few percent of the total (Zellner, in Gehrals, '79).

"Other evidence that the asteroids were never gathered together in a single body is geochemical, from meteorites: some, especially the carbonaceous ones, are low temperature mechanical mixtures of phases far out of equilibrium, which would be rapidly destroyed by even modest heating, as would result from being incorporated in a larger body.

"Additionally, the isotopic "clocks" in meteorites all yield ages on the order of that of the Solar System. Such "clocks" result from the accumulation of daughter elements from the decay of natural, long-lived radioactive isotopes, and again, it takes little heating to have the daughter elements diffuse away and thus reset the clock.

"I would also recommend to MMM readers the collection from which the paper cited above comes:

Asteroids edited by T. Gehrels, University of Arizona Press, 1979. It is technical, but although getting a bit old is still an excellent asteroid sourcebook. It's one of a number of highly recommended technical volumes on planetary science put out by University of Arizona Press."
<SLG>

MMM #35 May 1990 Asteroid Theme Issue

PORTS OF PARDON

Ports of Pardon: A Social Experiment with a Precedent

"Ports of Pardon" by Peter Kokh

Bring up the idea of using convicts to open up the less attractive and more remote reaches of the space frontier, and you are likely to get immediate and mixed reactions. Some will shrink in horror at the "cruel and unusual punishment" seemingly implied. Others will be more open, invariably citing the origins of New South Wales in Australia, back in 1788.

In that instance, the "Sirius" was the flagship of a fleet that included an armed trader, three store-ships and six transports. Aboard were 202 marines of various ranks, five doctors and a few mechanics, 40 women, and 756 convicts.

They landed at Botany Bay at first, then moved to Port Jackson, the heart of modern Sydney. Later other convict ships arrived. The first "free settlers" arrived five years later in 1793.

However, that is not exactly the sort of situation whose applicability to the space frontier we wish to examine. It would be prohibitively expensive to use space destinations of whatever kind as "prison sites" far Earth's unwanted criminals.

The ultimate Alcatraz or Devil's Island is not our topic here. Quite the contrary! First, we propose to send there, not criminals from Earth, but those from Space and Lunar Settlements who prove to be resistant to reform. Second, we are looking at "Quarantine Sites" not prison sites. Unlike the situation at Botany Bay, these "convicts" would have neither wardens nor guards. Once on their way, unable to return or to change course, they would no longer be convicts, but freed men (and women in more nearly equal proportions - another difference from New South Wales) in collective charge of their own destinies.

Those readers who have read the essay by Louise Rachel [in Moon Miners' REVIEW # 4, January 1989] entitled "Ruminations On The Uses of a Frontier" will recall one of her well-taken points that many persons who inevitably become misfits in a settled and highly structured society are able to function quite healthfully and productively in a wide open frontier.

A hypothetical Gallup Poll might show most people to be of the impression that "the guards" keep the order in any prison. But that is no more than a superficiality. From time immemorial, in prisons throughout the world, it is the prisoners themselves who both structure and maintain whatever real semblance of order there is in such places. Like chic-kens or wolves, any group of felons will quickly find its own system or "pecking order".

No, no guards or wardens need stand by, so long as escape is unlikely

For example - and for sake of argument - a one-way settlement expedition could proceed for Ceres or some other potential Regional Belt Center, wholly crewed by convicts "pardoned" for freely accepting the option. They would have on board all the equipment and the knowledge stores needed to set up a self-sufficient settlement that will not need resupply other than by drone freighters for the near term. When it comes to opening up boondock areas of the space frontier having all the popular appeal of some latter-day Siberia, such a scheme might be an acceptable way to get the job done.

In such a situation, not only would "convicts" be legally pardoned, they would tend to cease acting "like criminals." Up against a hostile and barren environment, their survival would depend on mutual cooperation, a lesson that would sink in at the earliest inevitable opportunity.

Nor need they be pre-trained for the mix of jobs and tasks needed to guarantee the settlement's survival. So long as the needed knowledge was stored in libraries on board, individuals would quickly self-select their niches in the do-or-die community-to-be, highly motivated to learn all they could to make themselves valuable if not indispensable (the one sure means of individual self-protection) during the long months of the outbound passage.

Never again, would they have a like opportunity to enter a society on an equal footing with everyone else. For this settlement would be started from scratch socially as well as physically. The stubborn would quickly find themselves examples of harsh frontier justice.

Yes, the society that would emerge would be rough and crude at first. What may pass for justice might seem a parody of what we hold dear. But that would all change. Contrary to the doctrines of some, criminal behavior is not "in the genes" at least not in a sense that such behavior is necessarily inherited.

> Revisit such a "Port of Pardon" a generation or two later, and you will find a society with increasingly genuine legitimacy, with deserved civic pride, and real achievements, both industrial and cultural, worth boasting about.

Extending the invitation

Convict settlement opportunities need not be restricted to those already in serious repeated trouble with the law in lunar or space colonies. Those still operating within the law – just, and chaffing at the bit, could apply to join any such endeavors. They would need to sign releases holding harmless established authorities for untoward personal consequences of joining such groups.

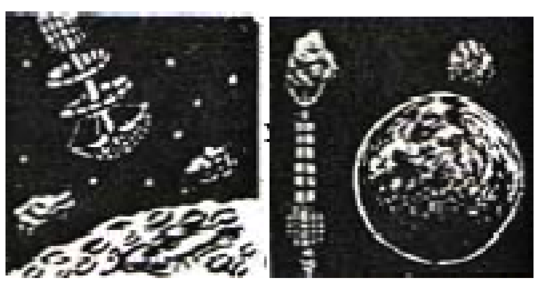
Such a proposal achieves these three goals in the most economical fashion:

1. Establishment of badly needed settlements in unattractive locales without the lure of very expensive inducements.
2. An alternative to building and maintaining expensive traditional prisons in space or on the Moon.
3. A sure-fire way of self-rehabilitation for those who just don't fit in, while protecting mainstream society in the process.

The Ultimate Rehabilitation

The alternatives of traditional imprisonment are not only considerably more expensive but also rather unproductive in comparison. Nor are customary options more just by any standards that will bear scrutiny.

It'd be a costly mistake for all concerned to dismiss such kill three-birds-with-one-stone options without an honest trial. The bottom line is that there may be no other way to attract volunteers to the solar boondocks in sufficient numbers to get needed jobs done. If prisoners find themselves, develop hidden talents and end up living fulfilling lives, they gain also. Furthermore, it will be their choice. **MMM**



Artwork by Dan Moynahan

Wildcatting Comet Crude: Searching for Impostor Asteroids

By Peter Kokh

The Stage is Set

The Moon, having been formed “hot” is relatively depleted in the volatiles necessary to support life: hydrogen, carbon, and nitrogen. We do not know yet whether the permanently shaded areas of the Lunar Poles harbor comet-derived ice, or whether, if so, how feasible it will be to tap. It could be that Lunar Settlements can make do. If not?

The Thirst For Volatiles, elements in short supply on bodies like the Moon that may have formed "hot" and have been able to hold on only to those elements with high melting and boiling points, will be the organizing driver for opening and settling the space frontier. Included are water/ice (or at least the hydrogen needed to make water from scratch with abundant lunar oxygen), carbon, and nitrogen, and other elements needed in considerably less quantities.

Thanks to our harvest of the meteorites that have fallen to Earth (i.e. the ground), we have found that a considerable proportion of their parent source bodies contain economically recoverable amounts of such elements. Matching the laboratory spectra of these meteorites to those obtained at the end of a telescope trained on various asteroids, we are able to classify many of the latter, according to mineral content, with a fair degree of confidence.

Carbonaceous Chondrites offer us the prize we seek, a volatile content in the 20% range "soaked" in comparison to the Moon! Among the best known of such bodies are Ceres (far and away the largest asteroid), Pallas, and possibly the Martian moonlets: Phobos and Deimos. Some of their volatile content may be in ice form, but some is also chemically loosely bound, molecule(s) to molecule as "water of hydration". Examples of hydrates (which feel dry, not wet despite their content) are gypsum, soapstone, concrete, and blue vitriol (copper sulfate).

One already popularized scheme for recovering such volatiles would begin with identifying mountain-sized carbonaceous chondrite astrobits. A mass driver would be attached, using the unwanted "dirt cheap" silicates for mass to be ejected at velocity. This means would kill two birds with one stone: bring the asteroid chunk into handier proximity to the Earth-Moon system; and begin the process of volatile extraction.

While many are excited about such prospects, we wonder if there are not much richer caches of ice in similarly near- Earth orbits, promising much more of a reward. The unexamined common viewpoint is that asteroids are asteroids and comets are comets, the latter being principally volatile in content so that if they approach the Sun much closer than Jupiter, they begin to outgas producing the familiar comae and tails. Harvesting active comets may seem a very tricky business; we'll leave that for a future article.

Comet tails disappear in time as comets choke in their own slag and become comatose

The one salient comet-fact almost universally overlooked is that as comets lose more and more of their mass with each orbital swing in towards the Sun, some of the less volatile, and possibly more viscous stuff, does not get carried away as gas and dust in the tail, but accumulates in an ever thicker blanket of "slag" on the surface.

The amazing photographs taken of Comet Halley - no thanks to Congress! - revolutionized our picture of what comets are like. Yes, we still see them as great dirty snowballs, but now we know that they accumulate slag crusts, and that all the great outrushing of vaporized materials comes not from the surface in general, but only from the few open pores that the slowly growing slag layer has not yet succeeded in plugging!

Prior to this discovery it was the common belief (and still is for those who have yet to make the paradigm switch these photos call for) that comets continue to outgas, getting ever smaller, until they just waste away, to nothing. That is probably not their common fate. Instead it now seems far likelier that comets eventually suffocate themselves, plug their flash pores and "turn off", retiring into a cocoon of slag that they have gradually spun for themselves. They await a metamorphosis, a butterfly transformation into rich water reservoirs for thirsty "homo circumsolaris". For the vast bulk of the original endowment of dusty ice/snow remains "dormant" inside. Comets do not just die. They fall into a deep coma, awaiting some future "resurrection" and final justice.

The only article coming to our attention that hints at such a pregnant end to active comet life was written by Sheboygan (WI) NSS member Harald Schenk and appeared early last year in Shores beyond, the independent newsletter he edits for the Sheboygan Space Society. We reprinted this piece in the Aug. '89 **Moon Miners REVIEW**.

In "Transition Comets', Schenk reviews work done by Brian Marsden and others which indicates that some bodies classified now as asteroids may be indeed "impostors", dormant comet hulks. The evidence that gets behind their incognito masks does not come from ground-truth penetrators, nor from tele-spectral studies, but from orbital analysis.

Most comets have characteristically wilder orbits than asteroids, not clustered within 10° to 30° of the common plane of the Solar System (the Earth-orbit-defined ecliptic continues to be the inappropriate standard in use), indeed as often as not orbiting in a direction opposite to the otherwise system-wide common one (anti-clockwise viewed from the north by arbitrary convention).

Thus asteroids in highly inclined or retrograde orbits, and those in extremely eccentric orbits, should be under suspicion as pretenders. The next step (with the highest priority and urgency!) will be to do thorough spectrographic, photo-metric, and radar studies of such non-conformist asteroids to see if they have a common tell-tale signature. We suspect this will be the case.

Once so armed, we can then turn our attention back to the vast majority of asteroids with more commonplace orbits and examine them one by one for the same giveaway quirks in the light they reflect towards us. For luckily not all comets have orbits wildly askew from asteroidal norms. Comet orbits are statistically random, and a definite percentage of them will have the "delta-V reachable" orbits of Earth-approaching asteroids. And these too must eventually grow comatose. It will be this cluster of Sleeping Beauties that become targets for the adventurers wildcatting for comet crude.

How do we “wildcat comet crude?” Well that is another article, one which we are not ready to tackle, and which might better be made the subject of an engineering design competition. For it will be a most challenging proposition. Someday, no doubt, it will be done, if the demand for volatile crude is great enough. **MMM**

FEUDALISM

Feudalism in the Asteroid Belt?

By Peter Kokh

A life prospecting and mining "off the beaten track" out in the Asteroid Belt is an appealing future for many. Out there in all that vast empty space, is escape from the sometimes suffocating and choking pressures of life in those highly structured and more densely populated regions of the familiar human range.

Such a romantic vision, as effective as it has been in inspiring the research necessary to make it possible, bears closer examination. Our purpose here, is not to rain on anyone's parade, but to make sure we take an umbrella along.

Yes, all that vast empty space! It's far far emptier than most of us would expect, given the Science-Fiction image of Asteroid Belt crossings as fraught with the peril of imminent collision with closely spaced astrochunks. So we continue to be amazed that none of the two Pioneer craft, or of the two Voyager probes even "noticed" that they were passing through this infamous zone.

Astronomers have now identified, numbered, and calculated orbits for 3000-some asteroids, “minor planets”, as they are more accurately called. We have caught fleeting glimpses of another 2000 or so, and now suspect that there may be as many as 50,000 mountain-size or larger bodies orbiting the Sun between the orbits of Mars and Jupiter.

Seem like a lot? Let's roughly calculate typical random spacing in the belt between asteroid neighbors orbiting in formation or passing by in various crisscrossing orbits.

For sake of argument, lets stake out the region from 180 to 380 million miles out from the Sun and with a thickness above and below their mean orbital plane of a combined 100 million miles. That gives us about 3,500,000 million million million cubic miles or 700 million million million cubic miles for each. Take the cube root of that and you have an average close pass of 9 million miles

Limit the survey to larger asteroids, and their real mutual isolation becomes even more apparent.

Now remember that for the foreseeable future, the percentage of this "horde" that will bask in the new-found warmth of human attention will be rather small.

Now **if** the driving force of that activity is "economic", there can be no possible effective source of law and order to police such a vast beat! Whether we are dealing with lone prospectors, homesteading families, large roving rival companies, or a scattered few settlements engaged in service, repairs, and supplies, this "legal" void will be inescapable. Even with a horrendously expensive thou-sand unit asteroidal police force, average response time to even the most dire emergencies would be hopelessly slow.

It would be naive to imagine that in such raw frontier conditions there would be no claim-jumping, no piracy, no extortion, or no rape and plunder. High reward has always been associated with high risk. Opportunities for hermit-like freedom to do one's own thing will come hand in hand with unimaginable material hardships (the nearest K-mart may be a year's journey away, one way!)

Crimes of opportunity as well as those of passion, may well be a problem. But, even allowing for some magical angellification of the human species between now and then, other life and death emergencies are sure to arise - and dialing 911 won't help much.

"Belters" will need to face unflinchingly and without regret whatever unpredictable and not-personally intended dangers and disasters come with the territory of great opportunity. Those who can't do this cheerfully are best advised to "stay in Baltimore" - or wherever life is more genteel. "Belting" won't be for everyone!

What can happen? Medical emergencies, such as a disease or trauma that can't be handled locally; equipment breakdowns after one has used the last salvageable spare parts; pressurization failure; an imminent failure of the life-support system; contamination of food supplies; an irreversible crop failure; not to mention mischievous interference from "visitors".

Most such crimes will have have to be borne without recourse to rescue or outside assistance even from the willing. There will be rare times, however, when aid is just barely possible from a "neighbor" or from a ship cruising within range. But more than likely, such aid will involve extreme inconvenience for the would-be rescuer: changing course and possible forced cancellation or permanent interruption of one's travel course or otherwise expending critical precious fuel reserves; dropping one's own important duties and projects for a lengthy rescue mission; etc. In truth,

> Belters will prudently minimize the risks by choosing from among suitable asteroids within a tolerable range of full service centers

(like Ceres, Vesta, etc.) or those within fair range at least temporarily. To do otherwise would be to tempt fate rashly.

HELP, AT A PRICE: Cooperative Mutual Assistance Pacts

Prudence will also give rise to cooperative mutual assistance pacts. These will have to spell out terms for compensation for economic consequences of going to another's rescue. Even such pacts cannot be expected to offer anything approaching full coverage of one's exposed butt.

Suppose some disastrous equipment failure in your mining camp threatens not only operations but the lives and safety of your employees and possibly the families they may have been allowed to bring along. There is no one within range or who can come to your rescue without accepting critical financial harm to himself. Mercy and compassion aside, what gain could possibly drive anyone to jeopardize his own probably precarious financial position by acting like a knight in shining armor?

Suppose there is nothing that can be done to save your operation and habitats and that all you can hope for is a lifeline? It would seem that you are doomed unless you and your charges agree to work as indentured servants of your rescuers for a negotiable number of months or years. Some may choose to perish.

Certainly some sort of generally accepted code for crisis situations will need careful consideration. It will be advisable to have tentative protocols adopted BEFORE Belt development begins in earnest. These could be gradually adapted and supplemented as real-life experience warrants.

In the face of the possibility of real-life situations which, through some debt of rescue or by outright piracy, could result in the loss of freedom and influence over one's destiny, would-be belters will further lessen the contrary odds by carrying survival pods and lifeboats and by conducting periodic disaster drills. They might also carry along courtesy drone rescue lift-rafts to toss one another. Concluding a binding Mutual Aid pact with other parties may depend upon both being so equipped.

There should also be Special Courts in the full service center settlements to adjudicate any debts incurred in rescue efforts and to arbitrate the length of agreed upon indenture service. There would be courts in such centers anyway to take care of claim conflicts, payment disputes, and all other ordinary judicial fare.

To get a better grasp and appreciation of the challenging situations Belters could find themselves in and of the social consequences which would tend to follow, we would do well to study some of the loose parallels from other times in human history. Population sizes are likely to be individually very small: we might ask what aspects of Hunter-Gatherer life would translate to Belter experiences to come? A Belt-wide law enforcement fleet is quite impractical.

A similar vacuum of authority had existed throughout the Middle Ages: what aspects of medieval feudalism are we likely to find reappearing in the Belt? It is not only law, order, and crises management on which we need to get a handle. The severely isolated situations in which Belter mining parties and small communities will find themselves has little real precedent in human history.

Even the earliest Polynesians in their far-flung island chains were effectively much closer together, the incidence of their interactions being higher. What effect would such an extreme scattering have on cultural continuity and or educational opportunities? Will inbreeding be the norm? Or will chance encounters be taken advantage of for hastily arranged marriages and liaisons with little time left for such relatively recent luxuries as 'first falling in love'?

In Australia, serving the scattered little railroad hamlets strung in a well-starched line across the Nullarbor (means "treeless") plain, there is a regular train affectionately called "**The Tea And Sugar**" which stops at each of these places. This train serves as the sole life-line for those living along this desolate route. One could imagine Belter operations preferentially so arranged that some sort of Catering Caravan or at least single Trader Ships could service them by some reasonable route. Working against this idea is the fact that the asteroids each have their own orbits, differing in period and thus in orbital speed. As a result, any route-logical array of mining operations and hamlets will will only be a fleeting one. The premium will be on suit-able asteroids with an orbital period and velocity as close as possible to one of the various service centers so as to maintain formation with it over a period of some decades. [See MMM # 24 April '89, "CERES" - reprinted above]

Talk of wanting "to Pioneer the Asteroids" is perhaps somewhat dishonest in the light of these realities. Or it may be better to say that it betrays a dual ignorance, first of the bitter 'geographical' facts of life in the Asteroid Belt, second of the depth of one's own readiness to cope with the full intensity of the isolation that such a life may entail. A bitter fruit!

Some will question this assessment, leaping forward to the prospects of great new propulsion systems that will offer "easy and swift" casual travel to shrink the great distances into irrelevancy. Or perhaps the reader will insist that the mineral wealth to be gained is so great that the expense of maintaining whatever police force may be necessary will seem minor. They may be right, and optimistic Science-Fiction scenarios may turn out to be accurate forecasts after all.

Perhaps the truth lies in between. The early decades for Asteroid Pioneers will be ones of harsh privation and sometimes tragic hardship. But in time, any tentative colonization of the Asteroids will whither and die out if the conditions and quality of life do not vastly improve.

If you still want to be on of the earliest trailblazers, all the same, you have my respect. "May the Force Be With You." You are going to need it! **And we will do it!** **MMM**

TEA & SUGAR

The "Tea and Sugar" By Peter Kokh

In the preceding article, we made mention of the famous traveling "Grocery Store Train" that crosses the hundreds of barren miles through the states of South Australia and Western Australia. [An illustrated article on the "**Tea and Sugar**" is featured in NATIONAL GEOGRAPHIC, Vol. 169, NO. 6, June 1986, pp. 737-57]. **http://en.wikipedia.org/wiki/Tea_and_Sugar_Train**

Perhaps such ensembles will one day service the far flung outposts of humanity on these lesser worlds 'swarming' beyond the orbit of Mars. Whether they will be mini-fleets, single larger ships, or perhaps variable "consists" more on the analogy of river barge trains, they would ply ever changing "routes of opportunity" between mining outposts as the host asteroids continually shift their collocation patterns in their endless orbit-jockeying.

What facilities, tradesmen, and amenities could such **Tea & Sugar**s offer to the isolated pockets of humanity they'd serve? Bear in mind that to some extent everyone in an outpost will need to be a jack of many trades. Yet in such small and isolated samplings of humanity, there cannot possibly be represented the full range of abilities, talents, trades, arts and professions needed to stave off an inevitable cultural and social decline through sheer malnourishment.

While each outpost will most surely have a general practice physician, the Tea & Sugar could have a clinic with a pediatrician, a geriatrician, a neurosurgeon, an orthodontist, and other specialists. A magistrate to take care of minor legal loose ends; troubleshooters in electronics and mechanics to handle stubborn problems; experts in agriculture, waste recycling, air and water quality, and general small biosphere maintenance; dietitians; a habitat architect - all of these would be welcome visitors at what is likely to be irregular long intervals.

This visiting caravan could include a stable of craftsman and artists. In the long intervals between stops, they would make things for sale at the next stop. Or conversely, the T&S could take on arts and crafts on a consignment basis at each stop to trade at the stops to follow.

Young lads and lasses in these scattered outposts might soon learn the little their elders could teach them, probably far less than their capacities and aptitudes would take them if they could have access to a larger population. So when the T&S calls, their parents might send them off on this traveling boarding school to learn from the tradesmen, artisans, and specialists aboard; to benefit socially from the companionship of youngsters from other outposts before the T&S brought them back home the next trip around.

Thus the T&S could serve well as a traveling school also, even offering certificates, validating diplomas, etc. For this purpose, several teachers and tutors might be aboard, perhaps having signed up for a tour of "public service" duty out of some home port population center on one of the major asteroids like Ceres or Vesta.

Such a chance to get away and see the worlds would provide an essential element of education that could not possibly be offered within a lone outpost, no matter how well-stocked its library and data banks.

The young people would have a chance to visit other outposts at each port of call, to see and experience other ways of doing and living. A spirit of kinship would grow that would stay with them throughout their lives and generate a sense of Asteroid Co-nationality.

Friendships made on the T&S might well be the seeds of future marriages, partnerships, and joint ventures of various kinds.

The Tea & Sugar type caravan plying these shifting Belt-lanes, would clearly be more than just a nice luxury making Belt life bearable. It would provide the glue holding all of Belt Civilization together.

Paying for the “Tea and Sugar”

These caravans would swiftly become the "Mobile" Infrastructure without which any opening of the Asteroid Belt would not long succeed. How would an outpost pay for T&S services? Surely not by public taxes! A Belt-wide government is just as much a wild-eyed impracticality as the police forces needed to maintain it.

Outposts will of necessity produce their own fuel to run generators, machinery, and vehicles. They could refuel the T&S caravans for free, and replenish some pantry supplies. Further they could trade some of the mineral wealth they have mined.

The problem does not seem to be that outposts would not be able to afford such a service. Rather the problem is that outposts cannot survive without the T&S caravans whose operators will have the miners at their mercy, able to extort more in payment than is fair, reasonable profit included. Nor will competition keep the costs of outpost visits down. There may not be enough of a traffic pie to divvy up. The pragmatic solution may lie in cooperative ownership of the T&S companies by the mining operators themselves. Time will tell. < **MMM** >

MMM #39 - October 1990

OORTFOAM

Oort Foam - By Peter Kokh

Consider for a moment how a fire-devastated virgin forest slowly rises up from its ashes; only few plant species colonize the wasted area at first, then as they grow, niches are created that can be exploited by other plants. It can be a century or more before the original biodiversity of the forest is restored. If the visiting devastation is very widespread, some areas may stabilize with a quite different mix of species than before. This is just a hint of what must have happened after a number of episodes of near global slate-wiping caused by large asteroid or comet impacts. When whole species, and sometimes whole families, of plants and wildlife are wiped out, hierarchical rebuilding of the niche-plexes of various ecosystems must chart fresh paths. Surviving plants and animals, previously held in check by now exterminated dominant species, are suddenly freed to exploit new opportunities and effectively 'encouraged' to evolve to do so.

The actual course of evolution has apparently been critically dependent on adventitious intervention of heedless celestial impactors. This periodic burst of freedom from the bonds of its own
internal logic may be the only way it can be freed of its own ruts, even as the seed of some pine species can be freed of the host cone only through intense heat in an eventual forest fire.

Asteroids these days take much of the blame, or credit as I see it, for these clutch-hitting escapes from could-be evolutionary dead-ends. But comets, despite their lower densities, can arrive with far greater momentum if coming from well beyond the Asteroid Belt, indeed from well beyond the outer Solar System.

There are short- and long-period comets, tame (or tamed?) inhabitants of the realm of known planets. They revisit the coma-inducing warmth of the inner Solar System on a regular basis. Then there are those rare visitors throwing out hoary tails along one-night-stand hyperbolic trajectories from out among the stars, with too much speed to keep them from returning thence.

In between there comes the infrequent visitor on a scarcely parabolic path which will bring it back Sunward some thousands of years hence. If we assume that such gelid objects could not have formed in such eccentric paths, but must have coalesced in some more rational more circular zone of protostar cloud material, where might that conjectured birthplace be? The answer according to Dutch astronomer Jan Oort, writing in 1950, was a vast spherical shell of pristine comet hulks thousands of times more distant from the Sun than Neptune or Pluto. Known as the Oort Cloud ever since, this region has been commonly imagined to drip Sunward great swarms of virgin comets whenever some passing star made an incur-sion into the neighborhood, clumsily disturbing their orbits in wholesale fashion. Balderdash!

One of the central assumptions behind all modern attempts at a scientific cosmology (or better, cosmogony: theory of the origin of the Universe as we now observe it to be) is the idea that

What holds true anywhere, must, all else being equal, hold everywhere.

Astonishingly, as religiously dedicated as most astronomers are to this principle, their seemingly unquestioning mass-attachment to the idea of Oort Cloud disturbances as the font of episodic cometary invasions of near-Sunspace gives it the lie.

SQUELCH ONE:

That comets with slow but enormous momentum in orbits tangential to the Sun, should somehow lose all of that momentum, and no less, so as to fall straight inwards, should happen "about as often as every other lifetime of the universe." In other words, "it ain't too likely.'

SQUELCH TWO:

What's good for the Sun should be good for any other system-laden star. To think, even by default, that we are alone in having an Oort Cloud (if we do indeed have one, but that is not my dispute) borders on being discrediting. If, like two ships passing in the night, the Sun and another Oort-sporting star pass are another relatively hard-by (this should happen every few hundred thousand years or so) then

It is far more likely that the Sun and its planets pass through the Oort Cloud shell of the other star, than that the other star create precisely the kind of gravitational wake which will send <u>any of our own</u> Oort Cloud comets dead-on Sunward.

Whatever comets may, throughout the eons have restarted the stalled elan of evolution on occasion, have had at us from their orbits around other suns.

We are a long way from some General Theory of Planetogenesis and Solar System Formation that will cover all the wide range of star and system types so as to allow us to say much more about "**comparative oortology,**" if you will. But one thing is clear. Oort clouds are, according to the original theory which it is not my purpose to question, too far out from their host suns, in comparison to average interstellar distances, not to loose members steadily by being routinely disturbed into some wide-ranging "Brownian" dance. The number of rogue comets no longer belonging to the gravitationally shepherded flock of any star, must be rising steadily since the onset of star formation in the galaxy.

Nearer home, all our probes bound for Jupiter and the outer planets (both Pioneers and both Vikings) have passed through the Asteroid Belt ('thick' only in the imagination of artists and writers of space opera) as if it wasn't there. Even the thickest parts of the nearer Kuiper and remoter Oort comet clouds are considerably less densely populated than the Asteroid Belt. However, the 'urgency' of comet population density (if one can speak so) is effectively relative to speed. Our proxies passed through the much thicker asteroid belt at a relatively slow 10 klicks a second.

A people-entrusted interstellar craft slicing through our galaxy-wide "Oort Foam" at perhaps a mere 10% of the speed of light i.e. 30,000 times swifter, would effectively densify comet spacing by that same factor. The odds against an actual (annihilating) collision (the force of the impact increasing with the square of relative velocity) are still favorable perhaps, but only statistically. An ample time warning system seems a long shot. Traveling at near light speeds may cut down on exposure time to cosmic rays, the amount of non-recyclable consumables needed for the trek (energy-generating needs) and other dangers, but it'll surely demand its own special courage. **MMM**

MMM #46 – June 1991

"FOOTLOOSE" AMONG THE ASTEROIDS

By Peter Kokh

The vision of a hardy population of prospectors, miners, entrepreneurs, traders, gypsies, pirates, hookers, and get-away-from-it-all pioneers-in-general slowly humanizing the Asteroid Belt has long been an established theme in Science Fiction and, toned down a bit in expectations, in the earnest forecasts of space development proponents. The challenges are more sobering than most imagine or would care to admit. In MMM #35 MAY '90 "Ports of Pardon", "Feudalism", and "Tea & Sugar" [above: pp. 13-14; 16-19] we tried to bring a sense of realism to the discussion by illustrating how dauntingly vast and sparsely-islanded the Asteroid Belt really is, and how pioneers might cope in such an ultimate boondocks. These articles deal more with sociological and political considerations.

A more immediate challenge is how asteroid trailblazers and the pioneers who follow them will cope with very-low gravity, not just for a mission, but long term - lifelong, generation after generation. Some writers have passed this off rather casually, predicting that homo zero-G will develop into a stable subspecies with its own selected/bioengineered/inherited physiological adjustments. Perhaps. But the first asteroid-busters will be humans as we know them, humans like you and me. And it is this vicarious expectation that grabs our interest.

The problem is real. The 'highest' gravity level we will come across our there is a scant 3% Earth-normal (1/6th lunar-normal) on Ceres, by far the largest and most massive of the minor planets [diameter 1003 km or 616 mi with a surface area equal to the continental U.S.

west of the Mississippi]. But Ceres is quite atypical. In fact, while major repair, service, trade, and manufacturing nodes in the Belt may be located on the likes of Ceres, Vesta, and a handful of other relatively large asteroids, it is at least reasonable to suppose that most resource exploitation will involve smaller bodies, perhaps much smaller ones even than Phobos. Deimos, or Gaspra.

OUT-VAC (Out on the surface, in vacuum):

Setting aside for now the question of how settlers on the larger worldlets will adapt physiologically to life at very-low gravity (or whether such permanent adaptation is even possible), let's consider how prospector-miners will be able to negotiate their surroundings - where the gravity is so negligible that anyone with still-good muscle tone will be able to launch h--self into space with a simple jump, or by a momentarily stuck backpack thruster, or even by an over-energetic twist of an old-fashioned wrench on a stub-born nut or pipe! (Special torque-free tools have already been developed for shuttle astronauts and MIR osmonauts; so this in theory is no problem; but what if the needed tool is broken and one must make do with a gizmo that does not compensate for torque?)

Even on asteroids as large as Ceres, it may be impossible to "walk" by some exaggerated caricature of the now-famous lunar shuffle or kangaroo hop. Traction will be effectively zero. How will one be able to move from one work spot on the surface to another, efficiently (sans exhausting waste motions) and safely?

MMM Assistant Editor Mike Thomas (Seattle L5) has written a couple of interesting pieces lately that serve as an introduction. in "LOCOMOTION - Mobility in Very Low Gravity Environments" [cf. MMM #42 FEB '91 pp12-3] Mike describes some mobility aids prospector-miners can use. Cables anchored to the ground at intervals by harpoons driven into the surface as the cable is paid out from a hovering spacecraft, would serve as an attachment guide for slip-ring tethers [why not electric trolley grippers?] along routinely traveled corridors. For getting around "off the tethered track", Mike describes a pair of "claw-walkers" which would alternately dig in and close and open and pull out of the loose surface 'lith.

The leverage provided by the engaged claw walker would assist in pulling out the mate, advancing it, and driving it into the soil a distance ahead. If one wanted to cover a greater distance more rapidly, telescoping handles on the claw walkers would allow one to 'stilt' along above the surface in a more open 'stride'. [A pair of tethered bazooka (recoilless) fired harpoons with remotely closed and opened anchor heads might function similarly for more rapid negotiation of even greater distances.] Such tools depend on the compact-ness of the soil about which we can now make only intelligent guesses based on lunar experience and an analysis of forces working on asteroids to compact vs. to fluff up the soil. Hoe like tools could be used where the soil is less dense, and as drag-brakes. Magnet-tipped stilts might work on iron rich asteroids. But then, so might magnetic boots.

In MMM #45 MAY '91 pp12-3 Mike describes VLG (very low grav) Regolith Tractors with rototiller like wheels and plowshare like ground-hugging assistance. The vehicle could be ballasted with local regolith to increase its mass and act as a motion stabilizer - an elegant suggestion!

Much of the problem of VLG surface motion disappears if indeed the motion is "smoothed out". Walking is a very jerky staccato motion that works where gravity overwhelms. But even where gravity is minimal, provided motion can be smoothed out sufficiently, surface vehicles should work. This might require very sensitive active suspensions, touchy and gentle both, heavy ballasting as Mike suggests, and a speed deliberate enough to allow these systems to work. [Computer simulation called for. Attention buffs!]

For personal mobility, an open frame spherical Squirrel Cage with the operator harnessed to a heavily-ballasted platform suspended within from the axle (i.e. below the center of gravity) might provide both smoothness and traction. While the gross unevenness of small-world terrain might suggest a problem negotiating inclines, both upwards and downwards, one should bear in mind that in VLG these topographic features are effectively very flat. Vehicles generally of this design could be developed for profit as competition to dune buggies here on Earth, with races, rallies, annual competitions etc. [Entrepreneur Alert!]

INDOORS, MIDDOORS:

The challenge to personal locomotion will not be limited to situations on the exposed asteroid surface. Even in the pressurized safety of habitat interiors (construction shack or full-blown settlement) 'on' or 'in' such miniworlds, getting about may be accomplished by means more reminiscent of Skylab and MIR than of any everyday gravid experience. Stairs and ladders, ramps too, will be useless. Hallways of conventional architecture would likewise serve poorly. Instead, passageways, whether horizontal, vertical, or sloped, might better be designed as tubes with suitably spaced handholds, or better, handrails running their length. A pair of bidirectional moving cables in a recess in the wall/ ceiling could serve as something to grab on to (by hand or by hand-held grappling device) thus allowing one to hitch a ride and "trolley along". If the day comes when there are belter settlements large enough to require transit systems, such a simple Personal Trolley System based on "hitching cables" might take care of 'traffic' needs quite well.

To be sure, there will be and up and down in very low gravity environments - not of the let's-pretend variety (for the sake of orientation and convenience) as aboard the planned space station, but in a real sense. For even very low gravity is sufficient to keep things in place on a floor or shelf. But such placement will be touchy as the slightest movement or vibration could set items in motion or toppling.

Maritime experience will point the way with the many convenient stay-put aids now in use for bobbing boats. Velcro pads and spots ("a place for everything and everything in its place" will become an entrenched way of life, not mere good advice). Item-specific countersunk holes, pegs, and grappling hooks will also be helpful to reinforce the feeble place-keeping effects of the local semblance gravity. Sub-maritime underwater (but in-water rather than in submarines or seafloor habitats) simulations here on Earth could help ferret out the practical problems we need to address in preparation for very-low gravity life.

While things will fall, they will do so with dream-like slowness, to be watched, not glimpsed. And within habitat situations, this might seem at first blush to warrant a lessened concern with fragility. However, items will need to be resilient all the same, for the real danger will be from crashing into things. Like the drunk who cannot confine his path of motion to item-free pathways, mini-grav pioneers will be a threat to any-thing fragile. For the less the gravity, the less the traction, the less the ability to self-brake, slow down, turn, or maneuver in any way.

This suggests that rooms will be furnished quite differently. There will be no islands of furniture, potential obstacles and hazards to motion. Furniture and furnishings would best be put in alcoves and small cubbyholes or in railed-off/fenced-off areas to segregate them from even light domestic traffic flow. Alternately, in-room trafficways could be demarcated by motion-confining handrails or railings. Those who have had the experience of having to rearrange their home to accommodate a person who has just lost his/her sight, so as to put things out of harm's way, will appreciate the problem.

LEG OF HUMAN:

A number of science-fiction yarns dealing with life in the Belt have pointed out that the leg-amputees will be at no disadvantage in such environments but may even adjust better. Face it! Of what use will be one's legs? In such low gravity, locomotion by hand or hand-held assists will be more than adequate. Legs may be of some use to the worker who has to brace his/ herself to "lean into" his work (e.g. using a drill, wrench, screw-driver, etc.) when there is something handy to brace against! But beyond that...?

Will legs be a liability, useless appendages requiring food to maintain bulk with no purpose? Might newborns have them amputated as a matter of course, even as the puppies of some dog breeds have their tails bobbed or ears cropped? Repulsive as this may seem to our aesthetic sense, it may become the 'reasonable' thing in the brave new world out among the asteroids.

In truth, hypothetical sapient technologically self-advancing species based on an octopus-like body architecture would seem to be better suited for zero-G and very-low-G life than 'bipeds' like us. ("Octopus", Greek for eight-footed, is really a misnomer. "Octochir" [pronounced octokeer] for eight-handed, would have been a more descriptive term.)

A far better solution is to find new duties for our legs, things they can do to keep the rest of the body free and more productively occupied. After all, we have effectively "reassigned" our hands/arms to duties other than grasping Tarzanian vines and peeling tasty bananas! That still ongoing reassignment is a good candidate for Best Actor in the drama of the rise of human civilization and culture.

The idea of leg-duty reassignment was the basis of my earlier short piece on "PODOKINETICS" [Greek: Foot Power Systems] in MMM #25 MAY '89 p.3 [pp. 11-12 above] in which we suggested an amendment to the "Protestant Work Ethic" in which those living and working indefinitely in Zero-G or very-low-G environments allow themselves only such electronic and electrically operated conveniences and personal luxuries (TVs, radios, stereos, personal computers, etc. etc.) in which the power was provided not by plug-in or battery-supplied electricity but by foot/pedal-operated generators. This custom could be extended to cover things like power tools, and small kitchen appliances, even the heat of one's shower water, etc. Such things could be developed now as a health fad. [Entrepreneur Alert!]

In reality, such "make-work" jobs for legs and feet will make more sense for those who find them-selves in low-G situations for only temporarily periods - a simple way to keep fit without setting aside blocks of time for explicit exercise. But as to exercise, where 'middoor' spaciousness permits, specially designed "Belter": sports in which leg-action is the dominant feature, might be a wise and popular choice. [**Attention, Computer Game Designers and simulators!**].

But getting back to the "Brave New World" theme of those "forsaking high gravity worlds forever, such atrophication-stalling remedies may be pointless. A more straightforward approach would be to replace the legs with a second set of much more versatile arms and hands. Using them would be no problem as instinct follows or flows from body equipment, not some inherited brain-set. This could be done by genetic engineer-ing, producing an inherited feature, or (my preference) by a routine procedure on the early fetus. Such a choice would allow reversion to 'normally' bipedal offspring at any time, as a personal family choice, e.g. in anticipation of a permanent return to the terrestrial homeland, or of a child's university education on Earth, or of the opening up of some new high-gravity frontier in the solar system or beyond.

More than any other part of our body, our legs and feet have evolved to negotiate the gravity-structured environment of life on Earth's highly up/down polarized surface. Making sense out of this evolved inherited equipment in environments not so intensely vertically structured will provide a central theme for adjustment to life out there. As we move out of our traditional eco-range we will have to take ever less and less for granted. <<< MMM >>>

MMM #58 - September 1992

Xities* Serving Asteroid Miners

*Pronounced KSIH-tees, not EX-ih-tees

[**Human communities beyond Earth's cradling biosphere**]

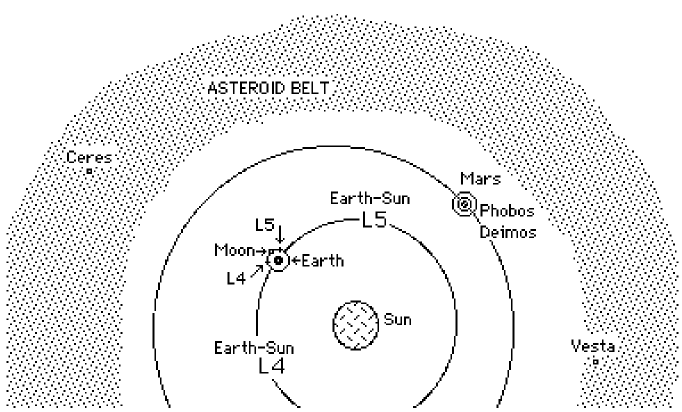
By Peter Kokh

It has been customary in Science Fiction to portray asteroid mining and prospecting as essentially a matter of small scale group, Mom & Pop, or even individual operations. This romantic notion appeals especially to those of us who fancy ourselves more ruggedly individualistic and self-reliant than we really are, and serves as a let's pretend outlet for the frustrations we all feel in dealing with a large pluralistic society. There's lot's of elbow room out there, and operations WILL be scattered, millions of miles and months of travel time between the early pioneers. Apparent real freedom!

Yet, whatever the scale of operation, there will still need to be a handy few centers where a prospecting or mining effort can purchase new or reconditioned equipment and fresh supplies: vehicles, tools, food rations, etc. There will still need to be places where these hardy folk can come for postponed treatment of neglected health conditions. There will need to be assay offices and markets for their production, courts to settle their disputes, shops to repair their space vehicles and mining equipment, labor markets to find replacement and additional help as well as simple relief from loneliness. Opening up the asteroids will require strategically placed frontier towns just as did the opening of the American West.

Where?: Most Science Fiction yarns dealing with the subject, take place in the Main Belt – that's all that was known to the writers. Until recently, we'd only discovered a very few Earth approaching asteroids, straying, or residing, well inwards of the main population between the orbits of Mars and Jupiter. Eros, Hermes, and Apollo and a few others were found years ago. Today we suspect that there are probably a few thousand lesser astrobits that range much closer to Earth. They are for the most part small objects a couple of miles across at best, and most of them no more than flying mountains, an attractive plus. A small astrochunk can be herded, substantially intact, to near Earth processing sites by means of a mass driver. We could thus presume that the Xities serving asteroid mining operations would initially be those in Earth orbit and on or near the Moon.

We've suggested previously that political considerations like the perception of safety, may lead to the shifting of primary corralling and subsequent processing of herded asteroid lodes out further, perhaps to the Earth-Sun L4 /L 5 "Trojan yards" centering some 93,000,000 miles from the Earth-Moon system at points preceding and trailing our twin home worlds in their orbit around the Sun. Travel between these points and Earth/Moon would be via low-energy trajectories as well as "window-free" i.e. able to be undertaken at will, at any time. So we may see some xities serving asteroid mining operations at these formation-flying "Earth Equilateral" locations.



Locations for Xities Serving Asteroid Miners
The Moon, Low Lunar Orbit, Earth-Moon L4 & 5
Earth-Sun L4 & 5, Deimos, Ceres, Vesta, other Belt Asteroids

However, it would be surprising if our growing space-foraging economy did not soon need to range further afield. For one thing, it is not at all clear that the "asteroids" to be found in Earth approaching orbits are typical of the Main Belt population. A number of investigators are becoming more and more expectant of finding that perhaps more than half of such objects are really “retired” comet hulks, their vent pores plugged with dust and slag, choking off their former cometary head and tail making activities even this close to the Sun.

Actually this is very good news for those searching for handy cheap volatiles necessary for life, agriculture, and industry with which the Moon is poorly endowed, e.g. carbon, nitrogen, and hydrogen especially. (Such sourcing, if it can be done on a dependable basis, might slow the growth and evolution of a human presence in the Mars System, whose two moonlets Phobos and Deimos are likely alternate sources of such volatiles. Turned-off comet hulks would present a much richer, though trickier to develop supply.)

[See “**Wildcatting Comet Crude**” above.]

By the same token, those seeking lucrative metallic ores could find slimmer pickings than they had previously expected. The most rewarding enriched ore deposits may just happen to lurk out in the Main Belt, beyond the orbit of Mars. For most first-thought-is-last-thought “visionaries” this means that Deimos, Mars outer moonlet is likely to be the “Asteroid Central”: launch point and the place for provisioning and outfitting Belt expeditions, and for repairs and marketing.

Mars orbital proximity to the belt, could be, counter-intuitively, a drawback. It is a corollary of orbital mechanics that the closer the orbits of two objects, the less frequent are the windows of opportunity for launching from one to the other by minimum energy Hohmann transfer trajectories, the only economic choice for chemical rockets. For personnel and goods originating in the Earth-Moon system, it makes more sense to go direct. Once similar goods and services are available at Mars, it may still make sense to use Earth/Moon as a supply source when urgency of delivery, rather than fuel cost, is the essential consideration. Yet Deimos (Mars) is a logical sources of planned regular “pipeline” shipments. So Deimos should play a support role, but maybe not much more.

HOHMANN TRANSFER **Window Frequency**:

(more often from the vicinity of the Moon)			months
Moon/L4&5	to	Ceres, vice versa	**15.3**
(Mars)Deimos	to	Ceres, vice versa	20,3
Moon/L4&5	to	Vesta, vice versa	**17.1**
(Mars)Deimos	to	Vesta, vice versa	27.1
Ceres	to	Vesta, vice versa	17.08 yrs

HOHMANN TRANSFER **Travel Times**:

(quicker from the vicinity of the Moon)			months
Moon/L4&5	to	Ceres, vice versa:	**15.5**
(Mars)Deimos	to	Ceres, vice versa	18.9
Moon/L4&5	to	Vesta, vice versa	**13.1**
(Mars)Deimos	to	Vesta, vice versa	16.3
Ceres	to	Vesta, vice versa	24.7 yrs

LESSON: When fuel expenses are secondary to timeliness, resupply from the Moon or from space xities near Earth, will often be preferable to using Deimos, depending upon where each are in their orbits about the Sun.

If/when nuclear propulsion becomes the norm, there will be more freedom to travel at less than ideal “window” times by less fuel-efficient, quicker trajectories. Then the ideal service center will be the one that happens to be the nearest at the time. How close Mars’ orbit is won’t matter if it happens to be in the wrong part of it at the moment. Asteroid pioneers will need to be covered by a number of resupply options.

Ultimately, xities in the Belt itself will be economic imperatives for logistic reasons. Ceres and Vesta are two likely hosts. [See CERES, PALLAS, VESTA. above]

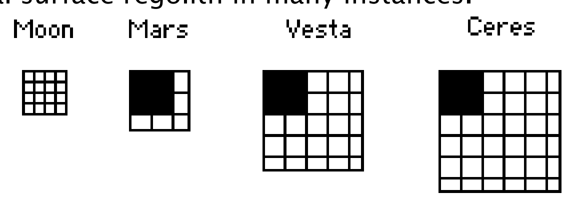
A Xity on or at Ceres could be a communications and education center. It could be a processing and refining complex as well as a warehousing center where small loads of this and that could be cachéd for eventual co-op shipment to various other locations. It could also serve the many neglected social needs small scattered bands of asteroid pioneers will have. [For one scenario of asteroid settlement see "PORTS OF PARDON" above.].

Route-plying supply and service ships could play a supporting role and these could eventually take on trappings of nomadic Xities in flight. [TEA & SUGAR above.]

Salient differences between xities at Belt range and those closer to the home planet:

Energy Considerations

These differences loom large and will affect xity plans and architecture radically. First, while the full suite of minerals and volatiles available to Belt xity pioneers from which to build their habitats and and support themselves will offer a first glance advantage, upon closer inspection, we find that belt locations will present some energy supply problems in that some of the easier options for lunar and cislunar xities will be denied them. First, the asteroids will be less richly endowed with **Helium-3** than is the Moon, by the inverse square of their mean relative distance from the Sun, (the Solar Wind is both weaker and thinner) and possibly by the relative youth of asteroidal surface regolith in many instances.



RELATIVE SOLAR COLLECTOR SIZES NEEDED FOR IDENTICAL TYPE COLLECTOR ARRAYS

And by the same inverse square of distance ratio, they will need that much more collector area to harness available **solar energy**. At the range of Ceres, 7.67 times as much collector will be needed to produce the same amount of electricity as the same type collector on the Moon or in Earth orbit. For solar energy users, this disadvantage will put a definite premium on cost-be-damned ultra efficient collector designs

For Belt xities, the need for adequate energy supplies will be especially critical. Such **food-exporting** settlements, feeding and provisioning not only themselves but a relatively more numerous dependent "rural" population of prospectors and miners as well, will need excess power (by Earth-vicinity/ Lunar standards) for agriculture, processing & manufacturing.

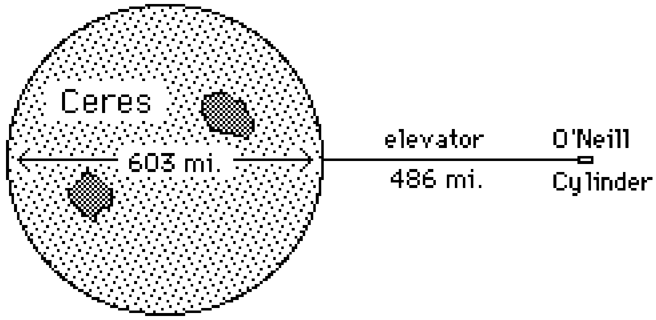
A consolation prize may be that much less attention may need to be paid to **radiator arrays** to carry away excess heat produced in the xity. The ambient environment will be significantly colder, providing much more of a heat sink.

Nuclear power, fission and fusion (probably with Helium-3 purchased from the Moon), will be more attractive for both backup and baseline needs. Building a Belt xity will be a much more demanding and expensive proposition.

Gravity Considerations

Providing a physiologically minimum level of **gravity** (our suggested 1/6th G "Lunar Standard") would seem to limit Belt xities to free orbiting constructs: sphere, torus, cylinder, or helix types that can provide the semblance of gravity against their out-facing hulls through rotationally induced centrifugal force. Xities of these types could be independently orbiting within the Belt, or in orbit about major asteroids.

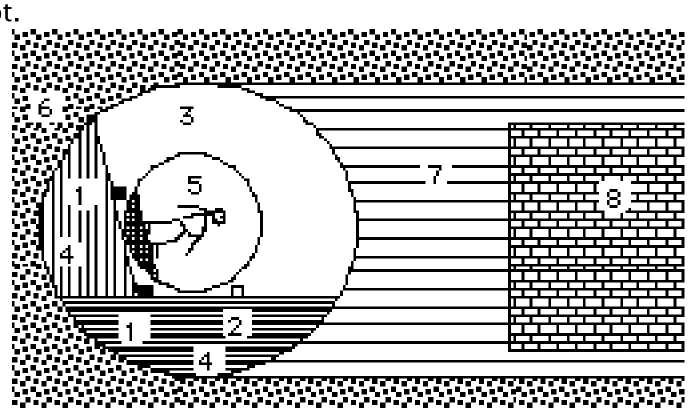
For example, a xity 486 miles or 782 km above the surface of Ceres would orbit in synch with the terrain below and could easily be tethered to it or physically joined by a coaxial elevator system. (Placing the xity just slightly higher would supply the counterweight needed for such an elevator.)



* LOCATION of a hypothetical O'Neill Cylinder Space Xity "Piazzi" (xity scale exaggerated) orbiting Ceres in synch with the asteroids rotation at a distance of 1.38 radii above the surface to which it is further physically locked by a cable-conduit-elevator system. At this distance from the Sun, solar power collectors attached to the cylinder may be impractical and power, either from extensive surface solar arrays or nuclear plants may be piped up by conduit. This frees the cylinder to orient itself so that its axis points at Ceres. The asteroid and tethered xity system, rotates every 9.08 hours. A date cycle of 8 periods per 3 dates would give dates 24 hr 12.8 mn long. Commutes to the surface may take about an hour each way.

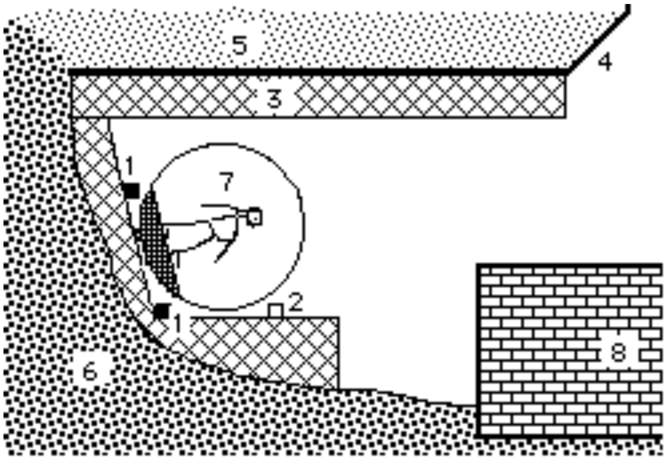
But what if it is desirable to have **surface xities** on the asteroid itself? Gravity on even the largest asteroids is very "slow". At a maximum 3/100ths of a G on Ceres and Vesta, asteroidal gravities are sufficient to keep undisturbed items in place – period. Such "mini-g" levels are likely insufficient to support most gravity-assisted physiological processes. The human body might as well float loose in freefall.

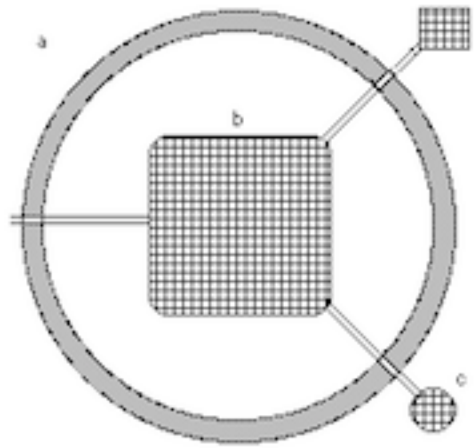
The "**gravitrack**" might be an answer. As much of the settlement as practical could actually "ride" a steeply banked mag-lev track to produce the centrifugal force desired. A variably banking transfer vehicle on a side rail would accelerate to meet, then dock with such a "**train-xity,**" then undock and decelerate to dock with surface-stationary facilities. Alternately, the whole train-xity would periodically spin down, then back up, say every eight hours, to let people on or off. However this simpler access option would either present some major problems in emergency situations if schedules were adhered to, or result in frequent general chaos if they were not.



CRUDE SCHEMATIC OF GRAVITRACK SECTION:

KEY: 1 banked mag-lev rails; 2 safety rail 3 tunnel cavity ring of mag-lev train-xity
4 support work for mag-lev rails 5 mag-lev xity habitat etc. showing effective nadir
6 rock and soil; 7 torus of tunnel 8 stationary mini-g environment buildings at center





ALTERNATE MAG-LEV XITY SCHEME: Banked track (1, 2) is situated inside the lip of an appropriate-sized crater. 3) Space Frame support for shielding shed; 4) shed retainer; 5) regolith shielding; 6) crater bedrock; 7) mag-lev torus section module; 8) surface-stationary mini-g xity facilities in mid-crater.

We've already suggested that a ground-based artificial gravity system form the heart of facilities on Phobos, riding the lip of the 5km/3mi wide crater Stickney on an 89°+ banked track at 307 mph (once around in just under 2 minutes or 1/2 rpm) to simulate Mars' 0.38G. [See "Mars, PHOBOS, Deimos" above.]

ASTEROID SURFACE XITY showing a) banked circular Mag-Lev track in tunnel or under shielding shed (along lip of crater?); b) surface-stationary mini-g facilities in middle of complex (or crater center); and c) outlying surface-stationary facilities with linking people and cargo trafficway tunnels.

Living in a **"part time" gravity**-polarized environment will not be new. Those living in "classical" space settlements but working "outside" building new solar power satellites, new space settlements, or running zero-g processing facilities will have pioneered the way. It may be possible to place most residential, recreational, commercial, and office space on such a gravitrack or "nadirrail" even if manufacturing and surface activity functions must be surface-stationary.

If one experiences weight only during sleep time, the benefit will still be appreciable for physiological, if not muscular, health. Recent experiments with bed rest have led investigators to suspect that periodic doses of gravity will prevent much of the physiological deterioration (reduced blood volume, fluid and sodium loss, decreased aerobic performance) we've come to expect of negligible-G.

Shielding needs will be slightly reduced. Cosmic radiation exposure will remain the same, and as on the Moon and Mars, surface settlements will have the built-in advantage of having their backsides covered, of having to shield against only one half the sky - above the horizon. Vulnerability to Solar Flares will also be reduced. Unlike the case on the Moon or Mars, however, the "weight" of the shielding overburden will not significantly compensate for the upward and outward structural stresses caused by normal pressurization.

"Solar access" by mirrored light pipes following a broken path to preserve radiation shield, or by fiber optics will provide less of a psychological boost at these distances from the Sun, simply because the sunlight is so much less intense (about 1/8th of Earth/Moon normal at Ceres, 1/5.5th at Vesta). Public areas of simulated "full-strength" sunlight provided by intense over-illumination, e.g. by a ceiling packed with fluorescents or the equivalent, would prove popular in park and garden settings, places of refuge from daily routine and fatigue.

Xity Construction Materials: When it comes to materials for construction and furnishings, Belt Xities, as those on Mars, will see a return of the "volatiles are free" days of old Earth, unlike the "harsh mistress" situation for early Lunan settlers and those in near-Earth space xities while still dependent primarily on lunar-sourced materials. There, volatiles must be, to all intents and purposes, “rented” by the hour, so to speak, to insure the maximum circulation and minimum banking of scarce exotic lunar-deficient elements (H, C, N).

Could “Cryoplastics” Developed on Ceres Open the Outer Solar System?

As on Mars, the Belt xity’s farms will also raise crops that yield wood and chemical feedstocks for plastics and synthetics. Indeed, it may be out here in the Belt that a new bread of construction materials is developed: **cryoplastics**, [our word coinage] offering superior structural performance without characteristic brittleness in extreme cold.

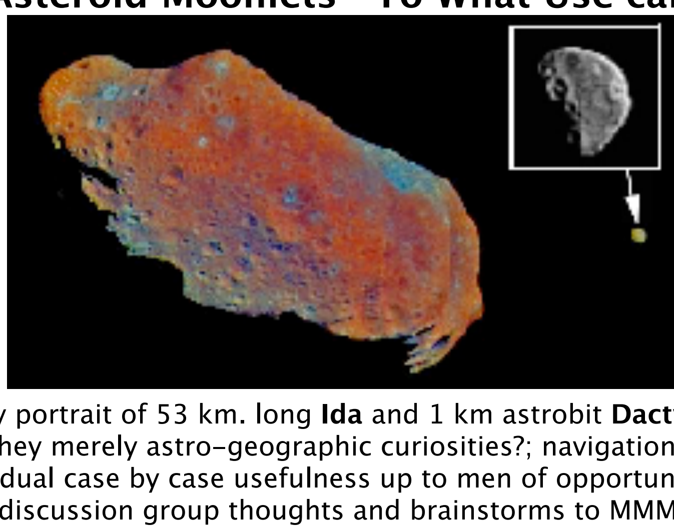
Such materials, if they can indeed be developed, may become critical if and when humanity moves out to the moons of the outer Solar System: Callisto, Ganymede, Europa, and Io around Jupiter, Iapetus and Titan around Saturn, Oberon and Miranda about Uranus, Triton about Neptune, even Pluto and Charon. In all these places the tables will be turned. Ices and other volatiles serving as chemical feedstocks will be relatively abundant, rock-bound silicates and metals relatively scarce - at least by past human experience. It may be in the R&D labs of some future Ceres chemical plant that the seminal brain-storming is done about “in situ” architecture (relying on locally produced materials) for self-sustaining settlements on the strange and exotic “cold hydrocarbon soup” world of Titan.

Xities serving asteroid miners will first arise near to home, then out of sheer logistic necessity follow human trail blazers out into the Belt itself - all in support of a full range economy of mineral wealth to support an enhanced and shared standard of living on a cleaner, greener Earth.

Along the way, new challenges to the viability of the xity will need to be met and mastered. These include the increasing dimness of ambient sunlight, supply lines and resupply lead times stretched to the limit, the natural avail-ability of only mini-gravity, and the steadily increasing cold.

The later is not only a challenge to xity architects and engineers wishing to design for thermal equilibrium. It also poses a challenge to mining engineers on worlds where water-ice acts as a stubborn cement for fractured rock and regolith. That same ubiquitous permafrost could be a problem for surface or near-surface settlements. In the learning process the foundations will be laid for taking humanity’s next step, breakout into the vaster, richer outer Solar System. **MMM**

A Plethora of Asteroid Moonlets -To What Use can we put them?



ABOVE: Family portrait of 53 km. long **Ida** and 1 km astrobit **Dactyl**. There may be hundreds more! Are they merely astro-geographic curiosities?; navigational hazards?; or future bonanzas, their individual case by case usefulness up to men of opportunity to uncover?
Send your or chapter discussion group thoughts and brainstorms to MMM kokhmmm@aol.com

Asteroid Base Design Workshop" at ISDC 1993 in Huntsville
Asteroids come in all shapes and sizes

So, when we were asked to run an "Asteroid Base Design Workshop" at ISDC 1993 in Huntsville, we had our participants break up into three separate groups, each brain-storming a very different scenario.

1) **Major service center settlement on Ceres (shown left with equivalent surface area);**
2) **Mining/ship-ping operation on medium size Gaspra;**
3) **Ma & Pa operation bringing back a mountain-sized chunk to Earth orbit via mass driver;**

⇒ **Part I below.**

A Tale of 3 Asteroids

Primer & Results of a 3-track **Mission Control™ Workshop** at the '93 Huntsville ISDC

Peter Kokh* with Mark Kaehny, Bill Higgins, et alii

Workshop "Primer"

For a moment after having just been asked to chair a 2-hour "Workshop" session on "Asteroid Base Design" at the upcoming '93 International Space Development Conference in Huntsville, I had the sudden sense of dangling in space weight-less without any orientation or reference to up or down, fore or aft, left or right. For as most MMM readers must realize all to well, the word "asteroid" umbrellas a lot of objects dissimilar in physical-chemical-mineral makeup and widely ranging in both size and orbital environment.

On the one hand there is Ceres, a real mini-planet in its own right. Named after the Roman goddess of grain, it lies in the middle of the Main Asteroid Belt, yet in size, if not composition, it is quite atypical. Are we here talking about **a Permanent Main Belt Center on Ceres**? Or on somewhat smaller but still respectably sized Pallas or Vesta?

At the other end of the scale, we have irregularly shaped mountain-size "astrochunks" that as a rule slip by undetected unless they are in unusual "Earth approaching" orbits and in fact wander within a few million miles of the Earth-Moon system. Are we talking about **a Mom & Pop Operation Shepherding a Small Astrochunk into Earth Orbit with the help of a Mass Driver**? Often ore-enriched, small enough to be mass-driveable, these rogue mountains offer the earliest opportunity for the return of asteroid resources to the vicinity of the Earth-Moon - L5 System. We should be able to find many of these mineral-rich objects in orbits handy to Earth. They would require comparatively modest fuel expenditures to reach - or to coax into stable parking orbits in Earth-Moon or Earth-Sun Lagrange point areas.

In between are many thousands of bodies ranging from potato-shapes a few miles in cross section to spheres a couple of hundred miles in diameter. Are we talking about **a Mining & Shipping Outpost on a Mid-size Asteroid such as Gaspra**, recently scanned by the Jupiter-bound Galileo probe? Middle-size asteroids are too big to alter their orbits by mass-drive but with metal- or volatile-enriched compositions that can be mined, the bounty to be shipped Earthwards. Ida and Gaspra examples. This group includes Earth-approachers like Eros and Ganymed as well as Main Belt denizens.

Each of these three scenarios offered very different set of starting points and constraints for "Asteroid Base Design". It instantly seemed clear that all three were worth pursuing. And so we put together a 3 page "primer" for those intending to participate in the Workshop, mentioning whatever we could think of that was intelligent and might be relevant about each of the three scenarios.

If we had enough participants, we would break up into three groups, each "brainstorming" a radically different kind of asteroid "base" starting with the givens and constraints listed in the primer, and going – who knows where? We did have enough participants for all three breakouts.

This strategy could not have worked out better. We had 20-some registrants and after a few introductory remarks were able to break into very even groups of 7-8 brainstormers apiece. Adopting three corners of the room, each group began spirited discussion. Eurekas and laughter and excited talk could be heard from all three tables throughout the hour and 20 minutes arbitrarily available before I called a halt and asked the leader of each group to come to the front of the room and report to all what his group had discussed.

Without exception all three group reports were excited and exciting. Each table uncovered unexpected considerations that affected the direction of their design recommendations; each had come up with surprising and ingenious solutions to the problems they had tackled. After all the reports were heard, we gave each other a rousing round of applause. The Workshop was a great success in itself, and more importantly for each of the participants, perhaps the personal highlight of the ISDC.

==

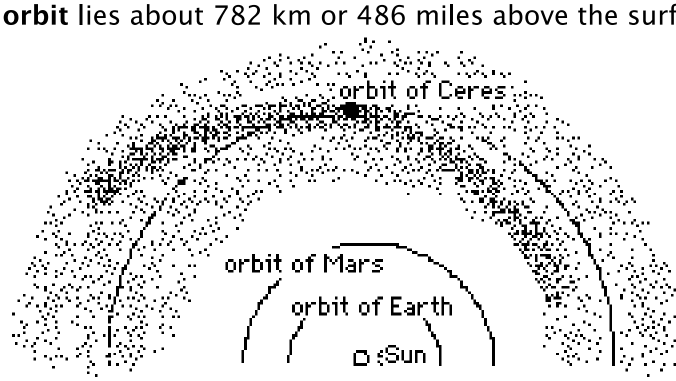
Group 1:
A Permanent Main Belt Service Center on Ceres

Starting Point: Consider:

Ceres, with a diameter of 1000 km or 600 miles has a surface area equal to all of the continental U.S. west of the Mississippi. **Pallas** and **Vesta** each have as much surface as the U.S. east of the Mississippi. They are small by Earth-Moon standards, but not insubstantial!

The gravity on **Ceres** and denser **Vesta** is about 1/6th Lunar standard or about 3% Earth-normal. Enough to be a mechanical assist and keep things in their place, but possibly below the threshold of impact on the human physiology. I.e., as far as the functioning of our bodies are concerned (mobility aside) the environment there may as well be “zero-G”.

Synchronous orbit lies about 782 km or 486 miles above the surface of **Ceres**.



Ceres’ orbit within the main Asteroid Belt and the swath, in relationship to Ceres’ position, in which we’ll find asteroids that will orbit in formation with Ceres for many decades.

If the stats for the first 100 asteroids to be discovered are typical, 44% have orbital periods within 10% of **Ceres**’ so that a third of these, almost 15% of all Main Belt Asteroids lie within 60° of **Ceres** at any given time and remain there for fifteen years or longer before drifting out of range. Some known asteroids (e.g. **Pallas**, **Thisbe**, **Laetitia**) will orbit in formation” with **Ceres** for centuries, even millennia. Much time and fuel energy may be saved by not having to exit Earth, Moon, or Mars gravity wells to maintain and resupply mining operations in the Main Belt as opposed to using a minigrav well in the belt itself, say on Ceres. The fuel energy savings can be banked or spent on faster than minimum trajectories (acceleration and deceleration) to shorten trip times.

Ceres itself is a carbonaceous chondrite type, and should have a volatile component of about 20%. That means water of hydration and/or permafrost. This will be a blessing, as a resource, but possibly also a bane, as a construction obstacle. The exact proportions and makeup of its hydrated silicates, metal oxides, and permafrost water ice awaits an orbital prospector with a gamma ray spectrometer. Even if the settlement is established and planned as a Main Belt Service Center to facilitate more profitable mining operations on outlying smaller and more ore enriched bodies, it will be logical to do some mining on **Ceres** itself to provide the building materials out of which the settlement is to be made, and provide the bulk of its ongoing consumption uses.

Ceres lies 2.77 times further from the Sun than Earth-Moon and so if Solar Power is to be considered, keep in mind that collectors sized to provide a given amount of power would have to have an area 7.7 times 'normal' size.

Your Mission: Explore, list, and rate options:

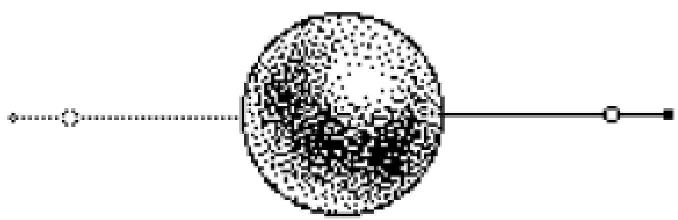
◇ Should at least part of the outpost settlement have higher Lunar-standard artificial gravity, a level high enough to prevent physiological deterioration beyond a Moon-proved acceptable level? If so, rate these options. Are there others:

A **Gravitrack***: part of the habitat area is a Mag-lev "train" on an appropriately banked circular track on the surface, or in a tunnel for shielding.

A **Maypole*:** part of the habitat is tethered to and spun around a pylon. The Pylon has to be tall enough (or the tether has to be tension-reelable) so that the habitat can come to rest on the surface periodically for boarding and deboarding, and for expansion, maintenance, and re-outfitting.

An **Elevator-tethered Synchronous orbit** (see specs above)

Torus or Cylinder:



Distance to scale of orbital Sync Port above Ceres surface, showing elevator/tether and counterweight. Many of Ceres' port functions will be more efficiently conducted at Sync Port.

All of these would be combined with surface mini-g installations and facilities completing the settlement. If such an artificial Lunar-standard gravity facility is provided, what should settlement functions and areas be on board and what should be on the non-gravity-enhanced surface?

- Habitat areas with sleeping and off-hours functions?
- Recreational facilities?
- Industrial facilities, or at least some of these?
- Educational, Judicial, and Administrative facilities?

◇ What are the **power options** available, and how would you rate their feasibility and expense? Solar? Nuclear fission? Helium-3 fusion? Other options?

◇ What types of building materials could be produced from Ceres' own resources? Besides metals, ceramics, glass and composites, and concrete, are cryoplastics, serviceable in low temperature zones, an option?

◇ Besides mining, processing, and manufacturing for local needs, the settlement should serve which specifically **Main Belt Central functions**? A wide range of prospecting and mining activity within the formation-keeping sector asteroids.

√ Outfitting, resupply, maintenance and repairs (of ships, drivers, habitats, CELSS systems)

√ Warehousing

√ Courts, assay offices, mining/extraction/processing R&D
√ Hospital, prison, trauma and chemical-abuse rehabilitation facilities
√ Boarding/day schools, eventually a university
√ Shopping, entertainment, radio, telecommunications social mixers, restaurants, bars, brothels, etc.
√ Home port for circuit-making “trader general store ships”
√ Agriculture: for own needs and export to outlying outposts that can only provide a demoralizingly low portion of their own food needs.
√ Processing, manufacturing, based on both domestic and incoming raw materials, some for local consumption, some to sell back to asteroid boondocks, some to sell to Inner, Outer System markets

Architectural Considerations

◇ A different suite of building materials (clays, hydrates, water available) than that appropriate for the Moon .
◇ Permafrost as a potential unknown construction problem
◇ 3% gravity (19% Lunar standard, 8.3% Martian)
◇ Regolith shielding overburden has negligible pressurization compensatory value (a bit more than 1/5th that on Moon)
◇ Transport and personal mobility problems in mini-gravity: pedestrians, vehicles, etc.
◇ Ceiling heights in mini-gravity, hand holds and railings, moving grab-on cables, etc.

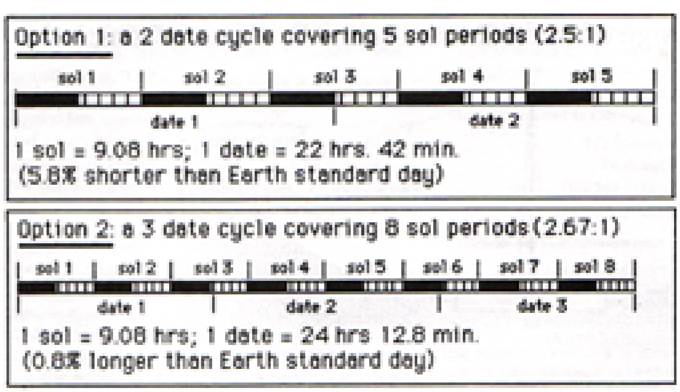
Fitness considerations:

√ Podokinetics (luxury items powered by foot pedals etc.), isometrics, and traditional exercise
√ Gravitrack or Maypoles: “sky-side” shielding must be provided (integral, under ramada sheds, or?)
√ Elevator-tethered space settlements in synch orbit Gravid space for work, leisure, or sleeping?

Ceres’ “**day**” or “sol” is **9.08 hours** long.

This could be “rationalized” in two ways. The first option is a two “date” cycle covering 5 periods and would yield “dates” of 22 hrs. 42 min. The second ‘improved’ option is a three date cycle covering 8 periods giving a “**date**” **24 hrs**. **12.8 min**. long. Either is sufficiently close enough to the standard day to work reasonably well.

The second option comes much closer, but the varying way the lighting cycle lines up will be harder to get used to. See graphic below.



* **NAME POOL: Ceres** was discovered in **Palermo**, Sicily by Giovanni **Piazzi**, on the first day of **Century Nineteen.** The mortal through which the Roman goddess Ceres passed her agricultural secrets to humanity was **Triptolemus**.

======================

WORKSHOP RESULTS: Group 1

GROUP: Peter Kokh, Tomas L. Gonzalez, Joseph S. Kirlik, Julius M. Martin, Peter Palumbo, Bryce Walden.

We spent some time better defining which functions the Ceres Settlement* would fill, and of these, which were appropriate for Ceres' low mini-gravity, which would be better placed in a surface artificial gravity environment, and which would best be filled in an elevator and pipeline cluster tethered synchronously orbiting space facility, the Sync Port", 486 miles above the main Surface Settlement.

ORBITAL SYNC PORT

Solar Energy facility if practical, cabled to surface

Main Port of Call for ships to and from other asteroid belt locations elsewhere in the solar system

Fuel Depot for visiting ships

Light processing, manufacturing incoming resources

Warehouse for goods being transshipped

Traders' Market for ships in port

Repair, maintenance, reoutfitting shops for work that is routine, frequent, and requiring a low mass of equipment

Assay office for incoming mining samples

Hotel for more transient spacer use

Gym for visiting personnel

Other recreation facilities for transient spacers

Administrative offices for handling routine matters for visiting spacers

Medical Outpatient Clinic for visiting spacers

Other functions for personnel, ships, goods in transit

SURFACE, FIXED (some within the main settlement area, some without it)

Mining and processing of local Cerian resources

Manufacturing based on local Cerian resources

Refinery for fuels, volatiles from local resources

Custom manufacturing using imported resources

Warehousing for all of the above

R&D facilities and labs for processing, manufacturing

Repair, maintenance, reoutfitting shops for work needing heavier equipment that is less routine and/or frequent

Main agricultural areas: food for local consumption and for export to other Belt markets

Nature parks

Gym using heavy equipment or for exercises that are not gravity-dependent

Space port for orbit to surface shuttles loads too big or massive for the elevator

Main, permanent Trade Center

Nuclear Fusion (He-3) Plant

Main Hospital

SURFACE, GRAVID (Artificial gravity via Maypole and/or Maglev facility)

Residential area (so all locals spend some time here)

Schools (concern for children in developmental years)

Offices (commercial, administrative)

Gym for gravity-assisted exercise and sports requiring lightweight equipment

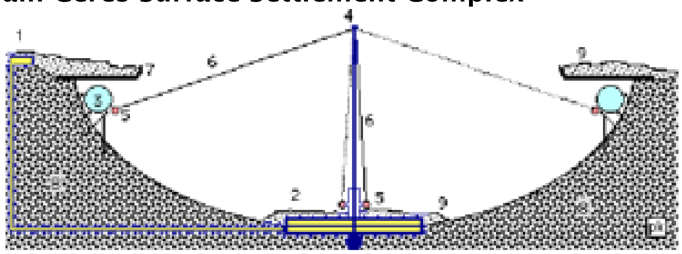
Hospital recovery and rehabilitation areas

Other activities and functions that require little space and little supporting equipment mass

Simply by better defining what activity or function most appropriately goes where, a much clearer picture of the Ceres Settlement Complex arises. And only with that in hand are we ready to begin looking at architectural considerations.

Next, as the design possibilities for artificial gravity habitat facilities in orbit are already fairly well explored, we spent the balance of our time discussing the engineering and design options for providing artificial gravity on the surface.

Schematic Design: Main Ceres Surface Settlement Complex



KEY: 1 auxiliary crater rim surface facilities, elevator and corridor to

2 main crater bottom natural-G installations.

3 Maglev Habitat areas with ‘standard’ 1/6th G lunar gravity shown ‘riding’ two crater slope rails, with third support rail for deceleration to stop for maintenance and adding new modules

4 “Maypole” pylon and bedrock anchor;

5 counterbalanced pair of shuttle modules (original ‘starter’ habitat modules prior to building the settlement expansion Maglev habitat facility), shown both at rest docked with main crater bottom facility and at Maglev matching velocity for docking and transfer of personnel especially at shift change;

6 shuttle tethers which lengthen by reeling out as centrifugal force increases;

7 cantilevered shielding retainer lip; **8** undisturbed soil and rock; **9** shielding soil.

Designing a finished, mature stage complex for Ceres without attention to how it might develop to that final level of complexity as the population grows from say a hundred or so to several thousand, would be an exercise in building sand castles. Thus there is no decision to be made between a Maypole-tethered artificially increased gravity habitat and a Maglev-based facility. Both are needed, and appropriate, at different phases of the settlement’s growth and development.

First a suitably-sized crater must be chosen, one that straddles Ceres’ equator, or as close to it as possible. Inside, a Maypole-based facility would be easily the simplest to install and to engineer and yet be quite adequate for initial foot-in-the-door population levels, especially if it is used just for dormitory purposes, to give everyone some fraction of the day at higher than Cerian mini-G levels. Once the initial “starter” settlement complex is in place and population growth is called for to realize the full potential of this Main Belt center of operations, a Maglev “Gravittrak™” Facility can be built.

When the first Gravittrak car modules are in place and ready to use, the original Maypole-tethered dormitories can be transformed into shuttle transfer cars to ferry personnel to and from crater bottom areas of the settlement, and by transfer there to other outlying surface installations. These shuttles are best operated in counterbalanced pairs, even if at first there is only one Gravittrak module operating. Shuttle service is needed before and after shift changes especially, and perhaps at some scheduled intervals in between.

The Maglev Gravittrak-based complex can be grown sausage-link style from one module to several, up to a filled ring, as the total population on Ceres grows perhaps to several thousand. To make sure there is enough capacity for growth, the car modules can be double or even multi-decked. But the circumference of the Gravittrak being perhaps one to several kilometers in length (depending on the speed of the modules on the track, or rpm), there should be ample room to grow before it is necessary to expand further by building an additional similarly architectured settlement at another site. As the Gravittrak modules and population grows, it will be necessary to add additional and larger capacity Maypole shuttle cars.

The individual car modules might be slung each in a pair of Mag-lev track riding suspension rings, within which they could freely rotate from a highly inclined orientation to one perpendicular to Ceres' surface as they are decelerated to a stop for maintenance work or for coupling additional modules. Normally operational pressurized vestibulation of the modules to one another for passage between them might be inactivated during acceleration and deceleration at such times.

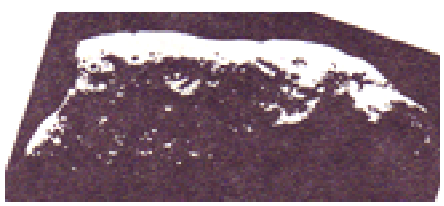
Gravittrak car modules could be clustered into three "villages" according to shift. Each shift could then use artificial lighting so that its members work 'by day' and sleep 'by night'. This arrangement could also simplify shuttle docking schedules. These three villages could either be physically linked or spaced out at 120° intervals along the Gravittrak.

Of course, there can be no protruding surface installations anywhere within the crater that would interfere with the operation of the Maypole shuttles. Such things as radiators and antennae are best located on the crater rim anyway where lines of sight are less restricted. Initial antennae will be relegated to auxiliary standby usage once the Sync Port is built overhead in orbit and the elevator-pipeline-cable-tether complex is in place. For then communications will be routed by cable to orbit-based relay antennae.

On the crater rim, there needs to be a Depot with multiple docking ports for surface transportation to outlying facilities such as mining and processing plants, He-3 fusion plant, and of course to the settlement's auxiliary spaceport used for spacecraft large and small having a reason or desire to land directly on Ceres' surface rather than dock at the Sync Port.

Attention was also given to modes of personal mobility in Ceres' low mini-gravity environment. This can be taken up separately. In sum the workshop's Ceres' team was quite excited about its satisfying brainstorming results. Others are free to use any of the above as a basis for further work. **PK**

MMM #71 - December 1993



A Tale of 3 Asteroids
Part II of a three track Mission Control™ Workshop at the '93 Huntsville ISDC;

Peter Kokh* with Mark Kaehny, Bill Higgins, et alii

Group 2:
A Mining & Shipping Outpost on Mid Size <u>Gaspra</u>

Workshop "Primer"

Starting Point: Consider:

There is some level of false expectation about how rich the ores might be on various asteroid bodies. This hope comes from the now discredited notion that the asteroids are the debris of some former hapless planet that blew up between the orbits of Mars and Jupiter and that had previously differentiated into an iron rich core and mantle and crust areas. [Note: see "correction from Steve Gillette pp. 11-12 above.] At the same time, it is clear that some of the original "planetesimals" did undergo some sort of differentiation, if not from the heat of radioactive uranium and thorium etc. as on Earth, which have relatively long half-lives and take a long time to heat up the masses in which they are embodies, then possibly something with a shorter lifetime such as radioactive Aluminum 40. This seems to have occurred on Vesta at least. We also have evidence from meteorites that some parent asteroid bodies are ore-enriched. Some of these will be too big to herd back Earthwards by mass driver.

These midsize bodies will have negligible or 'micro'-gravity environments. Gravity there is enough to keep undisturbed items in place, but insufficient to facilitate human locomotion, or to be much of a mechanical assist for mining and processing. If people are to be stationed there for any length of time, some sort of appropriately sized rotating facility in which they can spend a routine portion of their time may have to be provided if their physiologies are not to adapt beyond recovery to the effective absence of gravity.

Small outposts will likely consist of prefabricated modules, and the use of local resources for add-on construction needs requiring low performance will be minimal.

Your Mission:

Explore, **rate** (discuss, vote, review), **list options**:

◇ Shielding requirements using local regolith soils.

◇ Surface gravitrack or centrifuge or tethered rotating structure to provide at least part time artificial gravity?

◇ Should a Mass Driver be employed anyway to make use of processing tailings to slowly "improve" either the orbit of the asteroid or to make its rotational period more convenient?

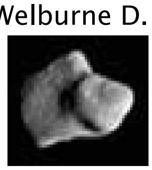
◇ Landing facilities for visiting resupply and trader ships or or orbital rendezvous?

◇ What is an ideal population size and gender and age mix and talent pool considering the tasks of such a mining/shipping outpost? Given that, what sort of facilities and functions ought to be provided for education, recreation, etc.

◇ Given all the above, what further design constraints do you see? What are the design options and your recommendations?

Workshop Results: Group 2

GROUP: Bill Higgins, (moderator) Lucien Faust (Author of the report that follows), Clarice Lolich , David Kalman, Welburne D. Johnson II, M.D., and Jay Robinson.

Target: Gaspra  **Assumptions:**

1. Gaspra (or similar target asteroid) has been probed and determined to have exploitable volatiles, worth mining.
2. Gaspra resembles a potato, about 19x18x12 km, i.e. about 1800 km3 volume; virtually negligible gravity.
3. Gaspra has a "slow" rotation around one major axis, and little if any wobble about any other axis.(Bill Higgins brought a handbook, but time did not permit a thorough review of its entry on Gaspra. [Ed. actually, little was known prior to the Galileo flyby, i.e. when the book was written.])
4. Travel time to Gaspra, about 18-22 months (8 months via nuclear vehicle proposed by Robert Zubrin'). No calculations were done at the workshop.
5. Supplies are available from cislunar vicinity, and will not all have to be lifted out of Earth's gravity well.

Mission Needs:

Crew – about 18 people, to include many skills, manpower, 3-shift rotation as needed (6 on duty, 6 off duty but on stand by, 6 asleep – this allows some off-time for 'just living" and allows for coverage needed because of accident or illness.) It was assumed that major medical care would not be needed, but that emergency medicines and a substantial medical kit would serve the expedition adequately.

Radiation shelter

Onsite power

Life support – recycling system with biological assist.

Consumables – Air, water, food; food may be part packaged, part fresh-grown veggies (tending the salad garden would provide a therapeutic change of pace while on-station).

Tools – basic and also high-tech: The crew needs the ability to repair anything. Yet the tool manifest should be compact and lightweight. And provision should be made to allow repairs in shirtsleeve environments where possible. Question: what sort or operations are possible without EVA?

R&R [Rest and Recreation] for "off-duty" time. The quality of life must be bearable.

Laboratory; Millwright shop; Refinery equipment

Packing/Shipping facility – Afterthought (Faust): Mission will need shipping containers (tanks) if product is volatiles. [Ed. or the capacity to manufacturer them on site from local materials. This capacity is essential if the operation is to be open-ended!]

Lots and lots of delta-V capability for:

- Journey to target asteroid (Gaspra etc.)
- Matching velocities
- Launching product into translunar trajectory
- Crew rotation to an accessible R&R spot; and to "home"

Afterthought:

(Faust): Should the expedition depend on resupply, or include sufficient energy and reaction mass so the entire crew could move about the Asteroid Belt, visit larger bases, if not all the way home to Earth-Moon space? The mission will need sufficient reaction mass/energy to ship its product, unless it depends on an "ore-boat" which visits only after sufficient "mined" product has been accumulated.

[**Editor:** it seems highly unlikely that asteroid belt missions, whether specifically targeted or seeking successive targets of opportunity, will ever be launched unless equipped to produce fuel on site from any of the major types of local resources. Such a facility would be marginal at Belt distances if dependent on solar power, but quite feasible with a small "nuke". Taking all the fuel along from Earth or Moon would be prohibitive, if not impossible.]

Elaborating on the Above

Crew skills: First Phase tasks will include initial on site analysis of Gaspra's mineral resources and assembly of habitat and mill/ refinery. This phase might occupy 6 months. Skills needed next could come with a relief crew tasked with more detailed physical and chemical analysis, mining, producing, and/or refining "product", packing and storing it, and launching it towards near-Earth recovery areas. Both teams need pilot/ navigator skills and personnel with medical/ emergency skills.

Duration of "tour": Each mining crew's tour might last 5-6 years, with one-third arriving about every 20-24 months, with needed renewable supplies. Crew members could choose to renew their tour for up to 10 years. The minimum period of base operation is assumed to be about 10 years.

(Kalman): The team discussed desirability of some effective combination of suspended animation and yoga, to reduce metabolic consumption during trips out and back. The need, desirability, and reliability of such technology needs a great deal of exploration and discussion.

[Editor. Current thinking is that simply to minimize total radiation exposure, trips of more than a few month's duration are unacceptable – and that therefore missions to Mars and the asteroids will use nuclear power or not be undertaken at all. Shorter trip times will greatly reduce this en route consumption problem.]

(Faust): Tour length could also depend on the success of recruitment efforts and on the training of replacements; the "reenlistment bonus"; crew members' ability to adjust to fellow crew members, tolerate limited environments, and postpone gratifications; and the rate of compounding of deferred compensation "at home".

(Faust): Depending on demand and value of product, the base might be in operation for just a few tours, or even for generations. Extent of economically recoverable materials (demand market), durability of airlock and other seals, equipment, life support system and power supplies in the deep space environment, security of resupply, lifespan of support organization, care for leadership and selection of compatible crews – all would affect how long such a base might last.

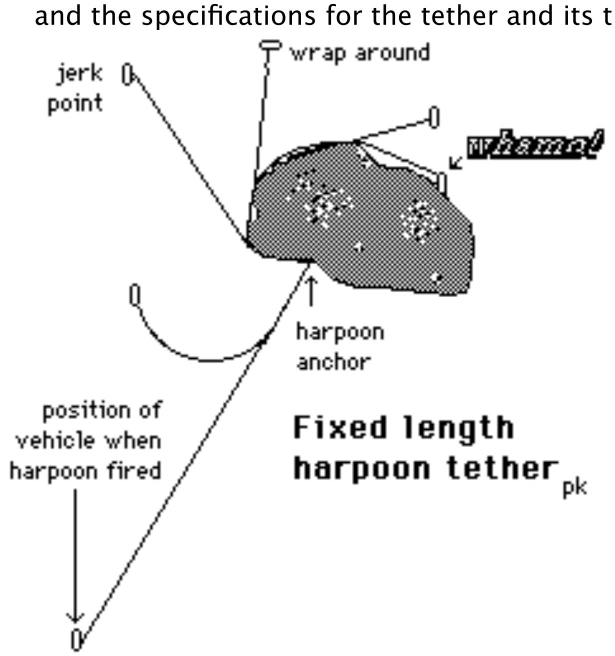
Arrival and method of braking:

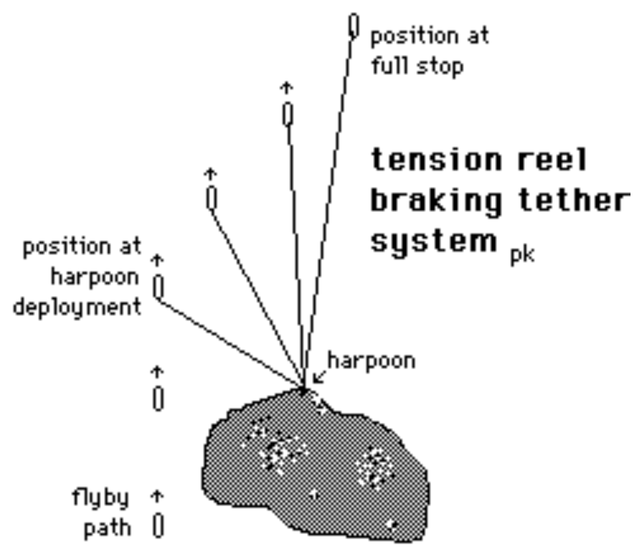
a. Normal retro-braking: could begin slowly at the midpoint of travel, or, to advance arrival time. it could be at higher Gs towards the end of the trip.

b. Tethered penetrator: As vehicle flies by, it could "harpoon" Gaspra with an anchoring device on a high-tensile-strength line and convert its velocity to a tethered orbital form. Some members concerned that

1) The moment of impact would strain the "saddle horn", bring on too-sudden a g-force jerk and/or
2) The tether would wrap around Gaspra and bring the vehicle to final contact at the surface with excessive velocity.

The benefit of this method is reduced travel time, with braking concentrated at the end of the trip. Concept needs considerable development as to anchor mechanism and reliability, and the specifications for the tether and its tie to the vehicle.





[Ed. But why not version at right instead? Explanation, below.]

[Editor. Of itself, it would seem a tether would only "re-vector" the momentum of the incoming ship, not reduce it. Why not consider how a navy carrier jet is stopped by a flight-deck tension-reeled cable? You'd have to fly past the target asteroid, harpoon its back side, and then pay out the cable, gradually applying the brakes. Questions: Can a secure enough harpoon be devised that the great momentum of the ship wouldn't simply pry loose? How much heat would be produced in the shipboard tension reel and how would it be dissipated? How many kilometers of cable would be needed and would the mass of cable involved be less than the braking fuel avoided?]

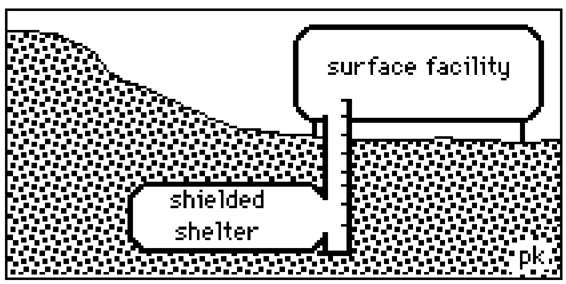
Sources of operating energy:

a. Nuclear reactor: standard fission type or He-3 fueled fusion.

b. Solar-voltaic: solar panels in this vicinity would gather only about a sixth of the solar energy available in Earth-Moon space so they'd need to be proportionately large. (1) panels could be deployed near Gaspra, keep station, and beam power to the base, with the disadvantage of reaction mass/fuel for station-keeping and orientation [Ed. why not a Gaspra-synchronous site which would need no such fuel?] or (2) in the negligible gravity, a large tower could be installed with extended panels, with the problem of maintaining orientation depending on Gaspra's rotation system. Afterthought (Faust): cable-linked leaf-like solar panels might be deployed all around Gaspra's equator [circumference c. 60 km) so that no matter what Gaspra's attitude, there would be enough exposure to solar insolation for operational power needs.

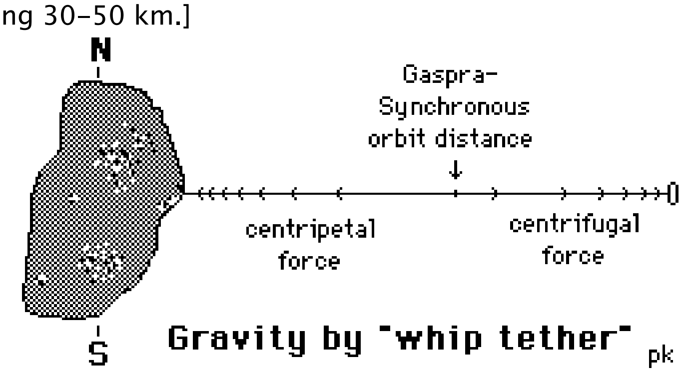
c. Mass-converter. Direct mass to energy conversion is too hypothetical a prospect to merit attention at this time.

Location of base:

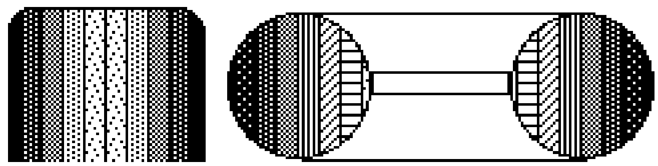


a. On Gaspra, anchored to surface, but with radiation and flare shelter bored into Gaspra to a sufficient depth; this may be the second most economical location as to energy requirements.

b. Tethered at a distance [past Gaspra-synchronous orbit] such that Gaspra-locked rotation will provide for a fractional gravity, for long-term health of miners; winch a vehicle along the tether to go to work or to reach radiation shelter. Low-energy method of obtaining at least a fractional g may be essential to preserve bone mass, fluid distribution, and similar human physiological essentials. A fractional g for extended periods, by rotation, elastic resistance, or other means, is probably a necessary aspect of life support. This solution might develop from the "tethered penetrator" braking approach, and may be the lowest-energy solution. {Editor, assuming Gaspra's mass but not knowing Gaspra's rotation period, a calculation of its synchronous orbit height and thence of the length of the tether needed can't be made. I'd assume we are talking 30-50 km.]

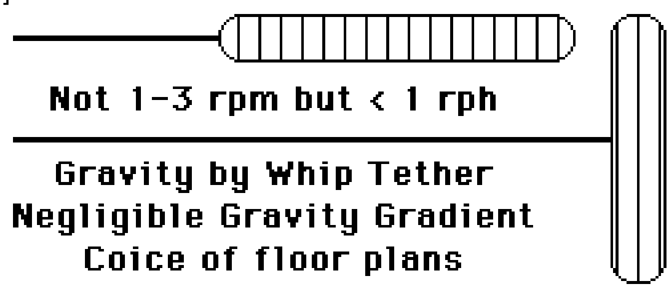


[Ed. cont.: This is an ingenious and elegant solution. In the classic space settlement design, a sphere, torus, or cylinder of substantial radius (1,000 m or more) rotates at 1–3 rpm. There is a noticeable gravity gradient as one climbs inwards towards the axis, or descends toward the periphery. The large radius is needed to produce the desired gravity (1 G or 1/6 G) at tolerable rpm rate. Faster rates result in disorientation, dizziness.]

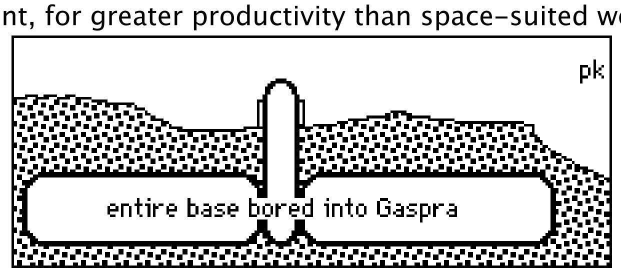


Gravity Gradient Cross sections
of rotating Cylinder and Torus

[Ed. cont.: With a whip tether, however, the habitat or vehicle can be small or large and the floors can run any way so long as they are perpendicular to the tether. There is no noticeable gravity gradient. And the slow asteroid-linked rotation takes hours not minutes or seconds. A glimpse of the future?]



c. Entire base bored into body of Gaspra (no estimate of energy needed to do this). Has advantage of radiation shielding close at hand, enlarging living and working areas with a shirtsleeve environment, for greater productivity than space-suited work.



Consumables and life support:

Fuel, reaction mass, air/oxygen, water, food, repair materials, and machines, spare parts and “stock”, back-up materials and manuals and recreational materials including musical instruments, all need to be taken in sufficient quantities. Recycling of air and water, food and human wastes appears to be essential to keeping take-along mass in bounds.

Amplification (Kalman): A first, automated mission might deliver supplies and consumables with less on route consumption than a the manned mission. [Editor: as in Dr. Zubrin’s Mars Direct scenario, a first uncrewed mission could deliver a reactor and chemical plant to process local volatiles into the consumables that the crew would need in greater abundance upon arrival.] (Team): as many automated missions or craft as necessary might be used for risk reduction, redundancy of supplies. Not everything anticipated may be needed. The other error, leaving out something essential, may be the worst.

Afterthoughts (Faust): A pure “plumbing” system [chemical-mechanical recycling?] probably needs to be supplemented by biotic systems, i.e. plants and bacteria and grow lights to recycle oxygen, purge carbon dioxide, scavenge and reuse human wastes, and grow “fresh” food. The mass, volume, maintenance/training needs and robustness of the two types of systems over the required periods of time need careful review and comparison.

A communication capability and a voluminous technical and cultural library of an evolved CD-ROM type should be taken along. Role-playing and other interactive games may need supervision of psychologically trained crew member(s) to moderate interpersonal relationship strains.

Workshop Postscript: (Faust)

Clearly our team was a self-selected “grab-sample” of attendees at the Huntsville ISDC, rooted in the “here and now”, not yet thinking of our task from a projected perspective of members of a successful spacefaring society; and with only a smattering of the basic information needed for our task. We had a doctor, a physicist, a city planner, a teacher, and two kinds of engineers; we lacked such useful perspectives as those of a contractor, a foreman, a submariner, a construction worker, a miners, a test pilot etc.

Last May when the workshop took place, Biosphere II had not yet cracked open. No one knows yet the workable proportions of air to soil to large animal [humans] to bacterial mass, for a long-term mission in such an environment. Of-hand, probably we need more air mass than we think. And we probably need ways to keep down rusts and algal blooms and mildew and such.

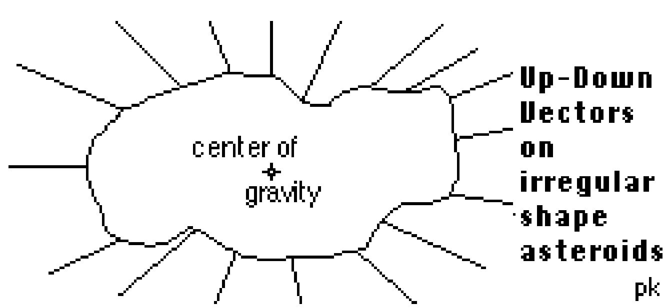
As yet we have no economics. We can only speculate who might pay for exploration, for the journey out, for shipping product back, for the trip home, and retirement benefits and in what coinage; but we think it will be expensive.

No one has reviewed the oceanic exploration analogs; might our leader be a Captain Ahab, a Captain Bligh, or a Captain Cook? Once people are out there, the High Frontier will be a bigger romance than sail, the railroads, and aviation all combined. But the world needs cheaper launch capability for that to open up. Perhaps the old game of China-goads-Japan-goads-America-goads-France-goads-Russia is a viable game, and nationalism on Earth has a high purpose. **LF**

'Stroidbits

 # 243 Ida and Galileo:

The photo of Ida on page 26 is a photomosaic of five frames. Ida was 274 million miles from the Sun (three times the Earth’s distance) at the time. Ida is quite a bit larger than Gaspra, visited two years ago by Galileo, but is even more irregular in shape. Plumb lines hung over its surface would show crazy angles, revealing the elongated ends as “hills”. But since the gravity is so minimal, visitors would hardly notice. More pictures of the asteroid will eventually be transmitted.



Geographos & Clementine (O'Neill probe)

The next asteroid visited may be **1620 Geographos**, an Earth approaching asteroid (named in honor of the National Geographic Society) which came to within 5.6 million miles of Earth in August, 1969. Its next close approach was in '83 when it came to within 8.4 million miles. If the Air Force's Project Clementine O'Neill probe is still functioning after its scheduled January through April lunar polar orbit mission, it is to be redirected to Geographos and put in orbit around it. That would be a first, and would allow the first in depth study of any asteroid, including a mineralogical assay and map. Geographos orbits every 1.39 years and ranges between 0.83 and 1.66 Earth's distance from the Sun.

The "Telurgosphere" or Teleergosphere

What are the practical limits of teleoperation? SSI, Space Studies Institute, has experimented with teleoperated robots with a built in 3 second delay in operator command, device response times. It's a tricky thing to catch on to, but it is possible, and as you may have guessed, kids get the hang of it quicker. We've confirmed our suspicions that teleoperation of some kinds of lunar equipment from Earth is a viable option.

But what about doing the same thing on asteroids temporarily in the vicinity of Earth? How much of a constant response delay can teleoperators master? How far out can this technique be used before the delay length becomes impractical to manage? Five seconds gets you out to twice the distance of the Moon. It is rare asteroids pass that close. At the other extreme, no one imagines Earth-based teleoperation to be an option for Mars and its moonlets, where the delay would be in the 6 to 40 minute range. A simple set of experiments could reveal the limits of this technique. It's something we need to know in order to plan efforts to access asteroidal resources.

This would make a nice chapter project. **MMM**

[Helium-3 and other Solar Wind-derived gases are not the only "Settlement Dowry" from the heavens set aside over the eons!]

ASTROBLEMES

[pronounced: ASS troh BLEEMs; Greek: "star wound"]

Why travel long and far to retrieve asteroid resources?

They may be already accessible, to lunar settlers at least, with no DV at all!

By Peter Kokh

The Asteroids have landed! The asteroids have landed! So might the headlines of the Lunar Frontier Times read one day as ground truth surface expeditions confirm orbital remote sensing indications of atypically metal-rich ores in isolated areas on the Moon's crater-pocked surface. It has been known with certainty since the return of the first Apollo Moon Rocks that lunar craters are the scars of prolonged episodes of savage celestial bombardment, not of wholesale volcanism. Yet the same rocks show that the overall composition of the surface reflects that of the native crust. No economically noteworthy relics of the intruder astrobits have themselves been found.

In general, this is to be expected. The run of the mill impactor is more likely to be a sort of asteroid classified as a carbonaceous chondrite: largely stony with some hydrate volatiles. The stony component would be difficult to distinguish from the Moon's native regolith soils and have no economic value. Any volatiles are likely to have dissipated into space from the heat of impact. Comet fragments should also have been plentiful, but their gift as well would have been largely squandered. Some cometary volatiles may yet be found in near surface lavatubes and polar permashade regions, though indirect indications are rather discouraging.

But what about the metal-rich asteroids that space development advocates dream about? Shouldn't we find buried intact fragments below many crater bottoms? If so, how deeply might they be buried? In and around Sudbury, Ontario, Canada north of Lake Huron's Georgian Bay, lie the economically significant relics of just such a large and rich impactor.

This oval region 40 miles NNW to SSE and 60 miles WSW to ENE at Sudbury has been a major source of Nickel and copper since early this century. This astrobleme is not the only place on Earth nickel can be found in economically recoverable concentrations. While Sudbury once produced 92% of the world's needs, that figure is now less than 50%. Yet this gift of the asteroids is significant and has definitely accelerated our own industrialization. Less well known are the copper deposits, actually worked first. For every ton of nickel around Sudbury, there is nearly half a ton of copper.

So we're lucky and find a similar nickel-iron-copper rich asteroid relic on the Moon. What would that mean? We have other sources of iron, but if we are mining the astrobleme deposits anyway, a major share of the lunar iron supply may come from such a source. But it is the nickel and copper that would be the real prize.

First nickel: 65% of the nickel mined on Earth is used in producing iron and steel alloys. Here is a partial list with the percentage of nickel in the alloy given. Nickel steels (0.5-10), stainless steels (2-26), heat resistant steels (2-26), nickel cast iron (1-5). Another 15% of nickel production goes into alloys with copper: high nickel-copper alloys (65-70), corrosion resistant cupronickel alloys (2.5-26), heat resistant alloys (78), electrical resistance alloys (80-85) (used in heating elements, rheostats etc.), magnetic alloys (29-90), permanent magnet alloys (14-32), high permeability alloys (45-80), controllable expansion alloys (30-60), nickel "silvers" (10-30 plus copper and zinc), and in nickel coins (25-100). Another 15% is used as pure metal in the food processing, chemical, and radio industries. A handy element, no?

And the Copper! Copper is the basis of the world's first useful alloys: bronze (with tin) and brass (with zinc), instrumental in catapulting humanity out of the late stone age towards the industrial age. It has remained vital to successive layers of technology ever since. It is a much better electrical conductor than lunar-abundant aluminum, and for this reason alone, a major lunar copper strike would be a real bonanza!

The Sudbury site also produces gold, silver, and platinum. These were lesser inclusions in the impacting asteroid and that may be typical. These elements are traditional jewelry stuffs but are industrially vital as well. Could asteroids rich in gold, silver, platinum, copper, lead, zinc and other metals of which the lunar crust holds no handy native concentrations, have impacted the Moon and left us a dowry? In 1986, astronomers discovered a highly reflective object in a near Earth swing on its very eccentric orbit. 1986 DA (a temporary name) is a mile wide object estimated to include 10 billion tons of iron, a billion tons of nickel, 100,000 tons of platinum, and 10,000 of gold. Yet such objects must be rare, and for one of them to have impacted the Moon and left recoverable lodes would be a case of extreme good fortune. We can certainly keep our fingers crossed.

Could we detect metal-rich astroblemes by remote sensing instruments on board future lunar polar orbiters? Perhaps we might, if the sensitivity and resolution of the instrumentation is high enough. We could easily test and calibrate such an orbital prospector satellite in Earth orbit to see if it picks up the Ni and Cu of the Sudbury site, and with how much detail. Maybe it would discover new terrestrial mother lodes in the process. This prospect alone would warrant the development and launching of such a satellite, perhaps fully paid for by a mining company consortium rather than by government(s).

Note: at the 2005 Planetary & Terrestrial Mining Sciences Symposium in Sudbury, Ontario, I learned that the local geologists are 100% convinced that the impactor that created this crater did not itself deliver this metal wealth, but had cracked the crust so deep that magma rich in iron, copper, and nickel had seeped up through the fractures. In fact, this ore is not found in the center of the crater, but only in fissures in the crater rim. The upshot is that we cannot count on asteroids to have delivered Platinum Group metals to the Moon – though such impacts could have similarly cracked the lunar crust to let any magma rich in such elements seep upward. That is something to be determined case by case, if we find promising craters.

The most accessible asteroids from a Lunan's point of view are not Nereus (1982 DB) or others in similar orbits but those whose assets have already been hard-landed on the lunar surface. What's the prize? One of the major challenges facing lunar industrial growth and diversification is the lack of mineable ores of the non-engineering metals: **copper, lead, zinc, gold, silver, platinum, etc.** All are indispensable to modern industry and manufacturing, even if the amounts used are quite minor compared to the tonnages of iron, aluminum and titanium. Finding "astrobleme" strikes here and there on the Moon would greatly accelerate the pace of industrial development, greatly improving the Moon's trade balance.

If such endowments are not found, the only options are to "smuggle" such metals in from Earth via "Stowaway Imports" [cf. MMM #63, MAR '93] and/or to support and assist asteroid resource recovery expeditions. **MMM**

MMM #72 - February 1994

A Tale of 3 Asteroids Workshop

Group 3: "A Small-Operation Mass Driver Rig on an Astrochunk to be nudged into High Earth Orbit"

Workshop "Primer" Starting Point: Consider:

Potential loot is an appreciable fraction of the astrochunk's mass. The most profitable approach will be to in effect mine the chunk en route, using the unwanted tailings as mass driver fodder, at least until they run out. Upon arrival at L5 or other destination, we will be left with a processed or beneficiated mass of pure or almost pure ore.

Meanwhile, the "Mom & Pop" team must have comfy quarters for the long journey, a suitable lab, and a "yolk sack" of provisions to see them through with plenty of margin.

Shepherding such an astrochunk may be a trickier-than-you-would-think operation requiring **a**) first stopping the chuck's interfering rotation and **b**) placing the facility so that the center of mass stays directly ahead of the mass driver's axis.

YOUR MISSION: Explore, rate, list options:

Should Mom & Pop enjoy artificial gravity? What would be an appropriately sized facility for this, and what portion of their routine and tasks should or could be spent within it?

Should they have facilities to produce a token but morale-boosting portion of fresh food for their table?

What initial food, CELSS, medical, and equipment backup provisions should be stored?

What other human considerations need to be considered?

What safety considerations need to be taken into account, including shielding, rescue, and/or abort?

How do you maintain the flow of material to the mass driver so that the whole astrochunk gets processed en route and only unwanted "tailings" are used as expulsion mass for the mass driver? How does this affect the design of the habitat-lab-maintenance shop part of the setup?

Mass Driver aside, what further design constraints do you see? What are the design options and your recommendations?

Asteroid WORKSHOP RESULTS: Group 3

Report by Mark Kaehny, Group Leader

Also participating: Richard McNeil and John Turner

Moving Flying Mountains (hills really)

Consider a small (+/- 100 meter diameter) asteroid or comet chunk in an orbit in the inner solar system. The goal is to change its orbit and move it to where it is needed - the Earth-Moon system, the Mars system, etc. Ad described in the work-shop primer, this is to be a "Mom and Pop" operation of a small number of people who may stay with the asteroid. Is this feasible, and what considerations would there be?

Setting the Stage

First some simplifying assumptions. This takes place in a future with a spacefaring civilization. There would be settlements on the Moon, Mars, and perhaps space colonies in some form. This is the only scenario which might make this economically justifiable. It is assumed that this asteroid or comet chunk (we'll call it the "Rock" from now on) consists in large part of "volatiles", Carbon, Hydrogen, Nitrogen, etc. This probably takes the form of water, hydrocarbons, and perhaps ammonia.

Given this composition a logical destination would be the Earth-Moon system for use on the Moon, or in space colonies. This scenario assumes that the asteroid is small enough that it is better to actually move it, rather than process and ship it. (See the other scenarios for that discussion.) For comparison, this Rock, if melted, would fit into one or two large tankers on Earth. It would fit inside the Superdome. This is the size of object we are dealing with.

There is no appreciable surface gravity. A human can't walk on this object -- he or she would take one step and be in orbit, or actually out of orbit depending on the strength of the step. This means that our rock could very easily fall apart if jarred. That puts a limit on the amount of acceleration that may be applied to it.

Other assumptions that we will make is that we have well designed space nuclear power systems, and an efficient and reliable means to use regular mass (stuff we are getting from the Rock) as reaction mass. The power density requirements for this operation make it look like solar power might not be workable. although some kind of beamed power system instead of nuclear might work. The reaction drivers could be some kind of mass driver, or some kind of "dust blaster" (electrostatic and thermal system) or depending on how materials are processed some kind of nuclear thermal or electric thermal rocket. This would need high reliability (say fire constantly for a month at a time) and high thrust (pump out many kilograms of material constantly).

Technical Questions

Is actually moving an object like this technically feasible, and if so, what are the constraints? The mass of the Rock itself would be used for reaction mass. Back of the envelope calculations show that this a time vs. mass tradeoff. The mass we are discussing is on the order of a couple of million tons of material. To move an object this size from an orbit outside that of Mars in to Earth orbit will either take up a significant amount of mass of the Rock (well over a third) to change the orbit in three or four years, or by using less mass, one can move the it in about a decade.

For the fast route --

Only nuclear power or some kind of beamed power will have enough energy density for this method. This would not be a small plant! The amount of mass to be shifted per day, broken down and used for reaction mass would rival the most efficient mining operation on Earth today in terms of tons of material processed per person per day. (Sudbury type figures are comparable.) Machinery would need to run continuously for long periods with little repair or breakdowns. The stability of the Rock would become an issue. The center of gravity would be changing, and the stresses might pull the thing apart.

“Mom and Pop?”

All of these problems suggest that a longer transit time would be chosen. In that case the problem of closed cycle life support would become more challenging. The movement and use of local reaction mass will still be a big deal. Moving tons of material, and using it in one of several ways as propellant is not a trivial operation! The group decided that this could not be a “Mom and Pop” operation unless Mom and Pop had a lot of resources available to them. It would most likely be a corporation, or perhaps some kind of wildcatting group. This would mean that they would have some kind of home base somewhere else available to them.

Living on the "Rock"? or Human-tending it?

The previous point led the group to discuss whether the Rock would have continuous habitation. It might be better, especially if the longer itinerary is used, to just have the Rock be human-tended, that is, someone comes to visit now and again. The arguments for this is that consumables do not need to be taken. Even if we assume a quite good closed life support system, the closed system itself is likely to be a quite massive environment. By only having people on the Rock for a short time, this mass is avoided. This assumes fast, relatively cheap and fast passages to and from the Rock of less total duration than the periods when the Rock is unoccupied. Otherwise, of course, the crew might as well stay put.

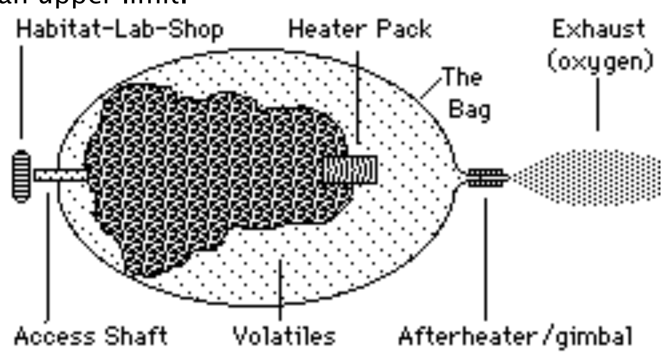
[Editor's Comment: But in most cases, especially with Earth-approaching bodies, there is a Catch-22 which works against this idea. The closer two bodies are in their orbital period, the **less frequent** are the launch windows to and from!]

On the other hand, one reason to keep people on the Rock is to start "beneficiating" the materials. That is, separating and processing the valuable stuff. In our example this means the volatiles. This also becomes almost a necessity, since a long transit time in the inner solar system would mean that much material could be lost to the Solar Wind. Also, since one would want to be very careful how this was moved into the Earth-Moon system, it may be that the Rock is sent closer to the Sun into an orbit whose aphelion is at Earths orbit, so that the Rock catches up to the Moon with a smaller difference in velocities. So, as material is used for reaction mass, it could be processed to remove the most valuable components.

However, the massive quantities used might make it more practical just to waste some mass solely as propellant, without using any machinery (which would need servicing). It can't be forgotten that this Rock masses millions of metric tons, this is not small scale for humans even though it is nothing in Solar System terms. Separating materials must be done some-time so to do it in transit time does make sense.

Mine in a Bag

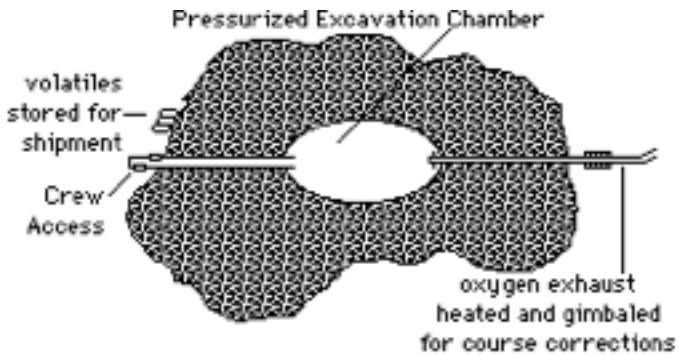
One idea for processing is to "bag" the Rock, that is enclose it in a close-to-airtight container. This wouldn't be that difficult - all one would need is the equivalent of five or six tarpaulins that cover baseball fields in the rain. Obviously they would be made of a much lighter material and thus would make a small cargo. Assume 100 thousand square meters of material (probably far more than needed since a cube 100 meters per side has a surface area of 60 thousand square meters) and 10 kilograms per 100 square meters, which is quite feasible, and we get a total mass of 10 thousand kilograms, about 12 American tons. Not an outrageous mass, and most likely an upper limit.

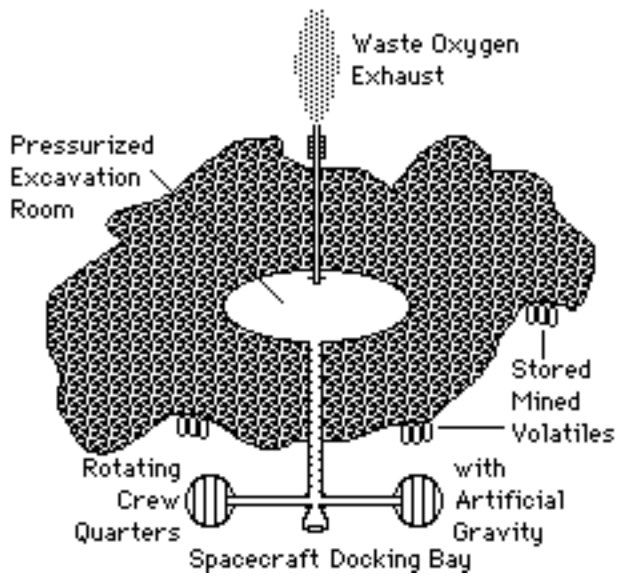


Given this bag, we can heat up the Rock and separate the gases that are given of with a pump. We can also use this gas (say oxygen fraction, since that won't have a lot of value) as propellant, a perfect source of course correction power.

Another suggestion is to work the Rock from inside out. That is, tunnel inside the Rock, make an airtight (or as close to it as practical) chamber, then start processing the materials in a close-to-shirtsleeves environment. This would allow for much more efficient use of human labor.

These two ideas work well together, in that the inside area could be over-pressured relative to the outside bagged area, so that if there are any leaks, the inside air is not lost. This provides an extra layer of security for those working inside.





Also even if the inside air was not breathable, if the pressure can be brought up to a reasonable level, workers could just use some type of air-mask, yet still get the benefit of working unencumbered. Just listen again to some tapes of the astronauts working on Hubble, and what they were actually doing, to see how strenuous it is to work in current space suits.

Living Quarters

Given that people will be living on the Rock for extended periods, artificial gravity might be desirable. In this case (and in any other as well) the living quarters should not be on the Rock, but right next to it, connected directly by flexible connections. This allows for people moving around, shifting things on the Rock without throwing the living quarters around as well.

Consumables vs. Yield: Tradeoffs for Profitability

No matter what style mission, a few years or a decade, we must hold the assumption that closed cycle life support systems will be much advanced from what we have now. Otherwise no matter whether the workers stay uninterruptedly or not, the amount of consumables would amount to something tremendous -- several tons per year per person. Since these would be high cost much processed items, they would probably make the whole capture idea uneconomic. This tradeoff will most likely be the determining factor in what type and speed of orbit is taken, what type of "Rock" that is aimed at, etc. Given a very closed system then some of the objections of permanent habitation go away, and this also changes things in terms of propulsion.

A different , better reason for moving the Rock

If we can process the thing where it is, perhaps small motors that just put the Rock in an intersecting orbit could be used, then as the Rock is processed the different products are shipped as the Rock moves. In this case the Rock may never get to the destination, and the reason for "moving" it is to provide more efficient orbits for "freighters". MK

[ED.: One thing this workshop team (nor, to our knowledge, any previous advocates of asteroid moving) did not consider was the extra challenge posed to any Rock-moving plans by the body's rotation and axial orientation. Unless (illustration below) there are a pair of non-co-rotating mass drivers, dust rockets, etc. at each pole of the body, it may be very difficult to achieve the desired result. It may make more sense to use waste tailings and waste gasses first to zero-out rotation. PK]

Why <Tether *Braking> at Gaspra will work!

By Michael Thomas, Seattle, MMM Contributing Editor

Having introduced the concept of tether braking a few years ago (MMM #30, pg. 11-12) as a means of rendezvousing with Phobos after a craft had aerobraked into a highly elliptical Martian orbit, I have occasionally reflected on the idea of tether braking and problems it presents. The recent second installment of "A Tale of Three Asteroids", in MMM #71, which came out of the Mission Control™ Workshop at the 1993 Huntsville ISDC, poses three critical questions about tether braking. Two of these questions regard technical feasibility and the other regards the economics of the idea. The first question, "Can a secure enough harpoon be devised that the great momentum of the ship wouldn't simply pry loose?", is the most critical. But first let me briefly discuss the others.

The second question asks how much heat the brakes on the cable would generate and how it would be dissipated. This is a straightforward engineering problem and should have a straightforward solution. One idea comes to mind: spray the brake disks with liquid nitrogen and allow it to vaporize and dissipate into the vacuum of space. The third question asks how many kilometers of cable would be required and whether it would weigh less than the fuel required for rocket braking. The answer to this question depends on many variables such as the type of fuel and rockets used (chemical or nuclear) and the tensile strength of the tether. I do not really know the answer to that question.

So why use a tether brake if it does not weigh drastically less than fuel, tanks and rockets? Because it has secondary uses[after arrival (as suggested in the MMM #71 article) such as a space elevator and artificial gravity device (gravity "whip tether"). Another possible secondary use for a tether brake is altering the rotation period of the asteroid to be nearer a convenient fraction of our 24 hour day. If a Gaspra sized body rotated every 7.5 hours, it might be possible to lengthen it to 8 hours. Or it could be used as a rotary mass launcher. If the tether space elevator extends far enough beyond Gaspra synchronous orbit, an object released from it would be traveling at escape velocity and thus be launched into space. With a small body like Gaspra, these uses, rather than weight savings, may be the most substantial reason for developing and using a tether brake. Kudos to the workshop participants for foreseeing that a used tether brake would have such secondary uses! *

The answer to the first question (whether the harpoon will pull out of Gaspra) lies not so much in the design of the harpoon as in the nature of Gaspra itself and the tensile strength of the tether. The more solid Gaspra is the easier it will be to design a "Gaspra harpoon" that will not pull out under the force the cable is able to apply to it. The total momentum of the ship is irrelevant as the tether can only apply so much force without breaking. So the tether, not momentum, determines how much force the harpoon must bear without pulling out. If, for instance, the tether has a tensile strength of 100 tons, and if only 75 tons of force were allowed to be applied to it to prevent danger of breaking, then the harpoon would only have to bear 75 tons of force. The ship could weigh a billion tons and the harpoon would still only have to withstand 75 tons. The great momentum of the ship requires not a stronger harpoon, but a longer tether so it can be gradually decelerated with 75 tons of force. But the less solid Gaspra is, the harder it will be to design a harpoon to hold 75 tons.

So how solid is Gaspra: is it concrete solid or a loose aggregate of astro-rubble? The answer is betrayed in Gaspra's elongated, non-spherical shape. It must have a certain strength to support itself against even it's own feeble gravity. If it were merely a heap of rocks and regolith, even Gaspra's feeble gravity would crush it into a more nearly spherical shape. In other words, Gaspra is an internally solid object. It's longest dimension is about 1.58 times it's shortest dimension. This means that Gaspra's interior contains some very solid rock, something a harpoon can hold onto. It is remotely possible that Gaspra is an aggregate of two or three very solid bodies resting against each other and covered by an obscuring blanket of regolith. But each of these pieces would have to be internally solid and as wide as Gaspra's shortest dimension (about 12 kilometers) or the aggregate would collapse to a more spherical shape. A penetrator harpoon of reasonable design and weight would certainly be able to hold onto Gaspra, Ida, or any other body solid enough to support a non-spherical shape in a body this large (over 15 kilometers.)

A tether capable of pulling it out would have to have a tensile strength very many times that of the rock the body were made of. Once in place, the gravity whip tether could be more permanently and securely anchored with rock bolts, wile the harpoon remained as a backup system should the rock bolts ever be damaged or fail. A cable might also be subject to shearing off at or near the surface of the body due to rubbing against sharp, jagged rocks.

Unlike synthetic materials such as kevlar and spectra, titanium is much harder than rocks and would tend to crush the rocks rather than be crushed by them. Also, lunar titanium might be far cheaper in space than terrestrial materials, and thus titanium may be the material of choice even though it's tensile strength is less than that of kevlar.

In conclusion, a tether braking system for asteroidal rendezvous is technically feasible, and it's economics should be judged not only by it's weight (and resulting transportation cost) but also by the fact that it can serve as infrastructure upon arrival. Using a tether brake as a space elevator and gravity whip will be much cheaper than mining ores and building a foundry to construct a space elevator on site. And without a space elevator, there will be expenses for rocket transportation to and from the surface for humans and "first cargoes" until a mass driver, a space elevator and other means are constructed or deployed. Braking fuel is not the only fuel a tether brake turned space elevator will save, therefore it's weight should be compared with all the fuel it will save. MT

[EDITOR: On the reusability of tethers. IF, and that's a big if, one's harpoon could be unanchored by some electronic command carried along the tether cable itself, and then the tether reeled back in aboard the ship, it could be reused later in similar fashion at the next destination. Some of the braking energy captured aboard ship could be used to reel it in. **PK**]

MMM #86 – June 1995

Tapping Near Earth Asteroids: Time for a REALITY CHECK

By Peter Kokh

The intellectual tribalism of space advocates never ceases to amaze me. Our numbers sort out into rabid Moon-Onlies, rabid Asteroid-Onlies, and rabid Mars-Onlies. What can possibly lie beneath the need to “dismiss” alternatives and options by which one is not personally captivated – except intellectual insecurity and emotional immaturity? Beats me.

We are blessed to be situated in a Solar System with diversified assets. We have a natural mineral rich satellite, **The Moon**, and it is a major body, not a token.

We have a rich **Asteroid Belt** of planetesimal debris that is itself handy, plus a considerable list of asteroid strays that are even handier to access.

Of three other “terrestrial planets”, we have one, **Mars**, whose climate and environmental conditions lie not too far beyond the limits of experienced home planet extremes.

It would be stupidly self-limiting not to access all these assets. Yet the "Onlies" of the various tribes would have us do just that, each in their own way. **What right have any of these to limit mankind's future so?**

Today our subject is not the fundamentalist nonsense of either the Moon Onlies or the Mars Onlies, as ridiculous as each is in its turn. We want here to put into perspective the valid points made by (near Earth) asteroid fans, reigning in the ungrounded exaggerations which come from their refusal to consider the trade offs that will apply. For disadvantageous trade offs come with every asset, with every fork in the road. Isn't that just the common universal experience of everyone?

**BASIC CLAIM: It takes "less round trip fuel"
to reach near Earth asteroidal resources
(than it does to tap resources on the Moon)**

For some near Earth objects, this is certainly true, and this is an important consideration. But as an advantage, it has limits within which it is overriding, beyond which it is outweighed by drawbacks and trade offs, and in effect irrelevant. In other words, it is an advantage with a price.

LIMIT ONE: The "Less Fuel Argument" is of major consequence in **unmanned robotic missions only**, whether exploratory only, or involving telerobotic resource recovery.

Fuel is not the only payload of consequence.

For manned missions (where crews are needed to effect mining, processing, shipping, and resource recovery in general) fuel savings pale into insignificance in comparison to **a far heavier burden of life support consumables**.

On the Moon we can derive at least the oxygen locally, and grow some needed food (savings again from incorporating local oxygen which is about 50% of all organic matter by weight).

In contrast, on a long asteroidal mission all consumables will have to be brought along for the journey out, and the amount that can be tapped on site for the stay on location and for the journey back may be limited by the need to apply all available manpower to resource recovery.

LIMIT TWO: Missions to Near Earth Objects are by nature singular opportunities, not repetitive, ruling out resupply and growth. See the "Catch-22" information under "Limit Three."

For sustained human missions, another drawback to the asteroidal option is that the travel times and infrequent windows involved **make resupply, reinforcement, and rescue virtually impossible**. On the Moon, an industrial base can start out small, then grow and diversify naturally, logically, and opportunistically. Travel times are short, launch windows are frequent (when push comes to shove, the lunar window is always open). A mining outpost or shepherding operation (bringing back an astrochunk to Earthspace for handier processing) **must take along all the equipment and personnel and supplies it will need for the duration, even though most of it/them may not be needed until later.** This flies in the face of the modern business revolution based on "just-in-time" resupply and inventory management.

LIMIT THREE: Near Earth Asteroids are each individually **objects of infrequent opportunity only, and not regularly accessible** — by any stretch of imagination.

This is a consequence of orbital mechanics, the laws of which are a subject very poorly understood by most space advocates. Simply put, the closer in period (an object's "year") to Earth, i.e. the closer an object's orbit is to Earth's orbit, the longer the mutual synodic period between launch windows. For example, you can leave for far Jupiter every 13 months, for much nearer Mars only every 25 months, for many near Earth asteroids, only every decade or so — for the Moon, at any time.

We DO NEED Asteroid Resources, but it is clear that robotic missions on which no human life support and consumables are needed, will predominate for some time. The long durations between resupply points make the "low delta V" argument quite superfluous. PK

MMM #107 – August 1997

Magsail Asteroid Survey Mission

(SEI & Stafford) by Stan Love and Dana G. Andrews

The asteroids, lying principally between the orbits of Mars and Jupiter, have long been considered one of the best potential sites for near term access to extraterrestrial resources. To fully assess the value of asteroids for commercial use, and also to gain scientific knowledge about them which is critical to our understanding of the formation of the solar system, it is necessary to examine a large number of them a very close range, perhaps even collecting samples of their surfaces for analysis on Earth. Such a mission is unthinkable with current chemical rockets, however. Each flyby would require a few km/s of velocity change (hence approximately doubling the initial mass of the spacecraft) and no surface landings could occur without expending a prohibitive amount of propellant.

The magnetic sail (Andrews, D.G. and Zubrin, R.M., "Progress in Magnetic Sails," AIAA Paper 90-2367, 1990) suggests a solution to this problem. It would derive its thrust from the interaction of the solar wind with the magnetic field around a loop of super conducting cable several dozen km in diameter. As long as current flows in the cable (once set up, it will continue to flow indefinitely) the sail would develop a small amount of thrust, which could be directed by altering the orientation of the loop or by changing the current, easily accomplished with a modest-sized solar array. Since it would produce a continuous force without expending any propellant, a magsail could orbit the sun in the asteroid belt indefinitely, visiting tens or hundreds of objects at a relative velocity of a few km/s.

Asteroids possess no magnetic fields to hinder the use of a magsail. Neither do they have strong gravitational gradients, which are difficult for any low-thrust vehicle to overcome. If the mission profile allowed the necessary deceleration time, the spacecraft could rendezvous with asteroids to take samples of their surfaces. Proper alignment of the sail and the asteroid could be arranged so that the sail force and the gravitational attraction of the asteroid exactly balance one another, allowing samples to be taken of the surface from a motionless spacecraft. After sampling a number of asteroids, the spacecraft could return to Earth to drop off material samples and undergo routine maintenance. It could then return to the asteroid belt for further exploration. **<SLuGS>**

MMM #111 – December 1997

Lighthouses & Beacons

LIGHTHOUSES & BEACONS on the Moon and elsewhere in Space

By Peter Kokh

They can still be found here and there on Earth, old lighthouses, each distinctive, providing ships with navigational points of reference night and day, guarding harbor entrances and dangerous headlands along ocean and Great Lakes coastal regions. Fewer and fewer are in use these days, as reliance on GPS global positioning system units, becomes more and more widespread and reliable for all aspects of maritime navigation. But lighthouses, each distinctive in their design, majestic and symbolic on their headlands or harbor jetties, have a romance and symbolism that persists and grabs at the onlooker.

ASTEROID BEACONS & LIGHTHOUSES

In space, potentially troublesome pieces of solar flotsam, meandering astrobits, might be tagged with transponders, triggered by proximity sensors or upon being scanned (not gawking all the time when no traffic is around). Radio signals could be modulated to yield the identity of the body in barcode or some analogous fashion. If laser pulses are used, they might be in a color that stands out more easily from the starfield, like the red of the ruby laser.

One question is where to put them on a rotating body? Keep in mind, some of these astrochunks rotate or wobble on more than one axis! Convention might decree tagging the north pole of a body (the pole from which left gives the direction of rotation i.e. east). But that pole may be turned away from an approaching ship. An “equatorial” site, any one would do, would guarantee the signal would face anyone nearby at least half the time – these small bodies usually have short rotation periods of a few hours and one would be approaching them for days. To guarantee visibility/audibility at all times, more than one beacon would have to be used. This is a subject that deserves some discussion with the aim of coming up with the easiest, cheapest, most practical “tagging” method, and a solar-charged beacon that can be triggered when needed only. A few bodies might deserve permanent “always on” beacons.
(snip)

MM #183 – March 2005

Asteroid Impact Computer Simulation

Half mile wide meteor put into the impact estimation program at the U. of Arizona

Results are Staggering (Fwd from Birger Johansson)

Thanks to the hard work of Robert Marcus, H. Jay Melosh, and Gareth Collins

Inputs:

Distance from Impact: 40.25 km = 25.00 miles
Projectile Diameter: 1000.00 m = 3280.00 ft = 0.62 miles
Projectile Density: 3000 kg/m3
Impact Velocity: 21.00 km/s = 13.04 miles/s
Impact Angle: 48 degrees
Target Density: 2500 kg/m3
Target Type: Sedimentary Rock

Atmospheric Entry:

The projectile begins to breakup at an altitude of 57,400 meters = 188,000 ft = 35.67 mi. The projectile reaches the ground in a broken condition. The mass of projectile strikes the surface at velocity 20.7 km/s = 12.9 miles/s The impact energy is 3.37 x 1020 Joules = 8.05 x 104MegaTons. The broken projectile fragments strike the ground in an ellipse of dimension 1.69 km by 1.26 km

Crater Dimensions: Crater shape is normal in spite of atmos-pheric crushing; fragments are not significantly dispersed.
Transient Crater Diameter: 11.7 km = 7.29 miles
Transient Crater Depth: 4.15 km = 2.58 miles
Final Crater Diameter: 16.3 km = 10.1 miles
Final Crater Depth: 0.685 km = 0.425 miles The crater formed is a complex crater.

The volume of the target melted or vaporized is 2.23 km3 = 0.535 miles3. Roughly half the melt remains in the crater , where its average thickness is 20.6 meters = 67.6 feet

Thermal Radiation:

Time for maximum radiation: 0.672 seconds after impact
Visible fireball radius: 13.8 km = 8.56 miles The fireball appears 77.9 times larger than the sun
Thermal Exposure: 9.81 x 106 Joules/m2

Duration of Irradiation: 18.1 seconds

Radiant flux (relative to the sun): 543

Effects of Thermal **Radiation:**

Clothing ignites Much of the body suffers third degree burns. Newspaper ignites. Plywood flames.

Deciduous trees ignite. Grass ignites.

Seismic Effects:

The major seismic shaking will arrive at approximately 8.05 seconds.

Richter Scale Magnitude: 7.9 Mercalli Scale Intensity at a distance of 40.25 km:

Air Blast: The air blast will arrive at approximately 122 seconds.

Peak Overpressure: 823000 Pa = 8.23 bars = 117 psi

Max wind velocity: 684 m/s = 1530 mph (Hurricane Charley would be jealous.)

Sound Intensity: 118 dB (May cause ear pain)

Damage Description:

Multistory wall-bearing buildings will collapse.

Wood frame buildings will almost completely collapse.

Multistory steel-framed office-type buildings will suffer extreme frame distortion, incipient collapse.

Highway truss bridges will collapse.

Highway girder bridges will collapse.

Glass windows will shatter.

Cars and trucks will be largely displaced and grossly distorted and will require rebuilding before use. Up to 90 percent of trees blown down; remainder stripped of branches and leaves.

Significance:

There are several asteroids out there, Earth Grazers, that are much bigger than this hypothetical one. I also assumed a stony core instead of an iron one. An iron meteor would be much worse. Also note this is not a planet shaker, it would simply destroy a 75 mile wide area, with much more extensive secondary damage.

It would make Mount Vesuvius look like a minor disaster.

Supposedly, an asteroid this big hits the Earth once every 67 thousand years. It is big enough to remove entire cities from the map. We have the know how and the ability to do something about this threat, but nothing seems to be in the works to begin this program. It would be a shame the first species on this planet, with the ability to control so much of its destiny, got wiped out because of laziness or political ambition. When are we going to have an asteroid defense system?   <RM/HJM/GC>

Editor's Comment: While it is certainly true that something like this could happen at any time, people play the odds, and the odds of such an event occurring in our lifetime, or even within the lifetime of the next thousand generations is low.

In contrast, it is virtually certain that most of Canada, much of northern Europe and Russia will be wiped clean off the map by the next ice age, 10-20,000 years off.

And no one is losing any sleep over it!

We have to consider what we can do for how much money and go for good return on our investment. Certainly, identifying and cataloging and keeping track of all the potential offenders is job # 1, and yet something that can be done for trivial amounts of money.

Next, once we are out there, in asteroidal space, preferably at some safe distance from home, we can experiment with asteroid trajectory redirection techniques to see what is most effective given various "ETA" warnings from months to many decades. Getting bent out of shape to spend trillions ineffectively is not the answer.   <PK

MMM #188 - August 2005

Japan's Hayabusa Asteroid Sample Return Probe Arrives September 12th at Asterioid ITOKAWA

http://www.jaxa.jp/missions/projects/sat/exploration/muses_c/index_e.htm

Asteroid Itokawa:

Asteroid 1998 SF36, the destination of "Hayabusa" (MUSES-C) spacecraft launched from Kagoshima Space Center on May 9, 2003, had been renamed ITOKAWA by International Astronomical Union after the name of late Prof. Hideo Itokawa, "the Father of Space Development in Japan". For orbital simulation, go to:

http://neo.jpl.nasa.gov/cgi-bin/db?name=1998+SF36

For more information on this asteroid, see:

http://newton.dm.unipi.it/cgi-bin/neodys/neoibo?objects:Itokawa;main

and for physical information,

http://earn.dlr.de/nea/25143.htm

Itokawa is a near Earth object with a perihelion just inside the Earth’s orbit, and with an aphelion outside Mars’ orbit. Itokawa is small, only 607m x 287m x 264m (2000’ x 956’ x 870’) and rotates about its axis every 12.12 hrs. Its year is 556.3 days long, 18.28 months, 1.52 Earth years.

On arrival of the Hayabusa probe, Itokawa was 2.143 A.U. from Earth (199 million miles) and 1.16 A.U. from the Sun (108 million mi.). Photo courtesy NAXA. . Hayabusa was hovering some 20 km (12.5 miles) above the surface.

The probe, launched on 28 months ago on May 9th, 2003, reached its destination courtesy of an ion engine. Itsmission, the most ambitious yet for Japan, is an asteroid sample return, something not yet attempted by NASA. [On Monday, 12 February 2001, four and a half years ago, the NEAR spacecraft touched down on another Near-Earth asteroid, Eros.] If successful, this will be only the second celestial body (after the Moon) to be sampled, discounting impact splashout sampling which was done spectacularly by the Deep Impact probe on last July 4th at Comet Temple 1.

“A soil sample from an asteroid can give us clues about the raw materials that made up planets and asteroids in their formative years, and about the state of the inside of a solar nebula around the time of the birth of the planets. However small the sample amount may be, its scientific significance is tremendous.” [It] “will gather samples and observe the asteroid with various scientific devices and measures. It is equipped with a Telescope Wide-View Cameras and Light Detection and Ranging, as well as with a Near Infrared Spectrometer. It will also employ a hopping robot, which can move around on the asteroid’s surface. When HAYABUSA returns to Earth, a re-entry capsule bearing a surface sample from the asteroid will separate from it and plunge into the atmosphere.” [NAXA]

MM #189 - September 2005

NEW GENESIS:

Tame an Asteroid to Move a Planet

By Robert McGown

If we bring an asteroid into the inner solar system and use an orbital slingshot like a spacecraft uses, we can transfer angular momentum and inertia to an orbiting body. In this way, we can transfer energy between the inner planets and Jupiter, thus moving the planets to a more desired orbit. Using very little energy, an asteroid(s) inertia can be redirected by various means of propulsion. Directing this force over thousands of years would create new solar system orbital paths.

Astronomers studying orbital mechanics have looked at the instability of the Jovian/ Saturnian system for over 300 years. From the historical orbital calculations of La Place to the recent papers of Korycanski, Laughlin and others, modeling concepts of reshaping the planets to more favorable orbits are being explored. They propose using a Kupier belt object as an attractor mass since it would be easier to change its orbit. NASA's new Kupier Belt mission may want to explore possible candidates in the solar system.

My research began in the early 80's: I discussed solar system orbital engineering with some science fiction writers some of whom are also theoretical physicists, like Frank Tipler. I recently had the opportunity hear Dr Laughlin's presentation on the "Future of the Solar System" and discuss solar system models with him. Researchers from the Oregon Chapter of the National Space Society, L-5 researchers have studied the de-orbiting of the retrograde Martian asteroid moons and the orbital consequences & advantages to moving Mars into a more favorable inner orbit. Using ion engines, or a steer- able mass driver to create energy transfer, it is possible to navigate a controlled asteroid to direct Mars closer to the Sun.

Another advantage of using asteroids for tugging on the orbit of Mars is the possible high water content of certain asteroids, such as Ceres. This may be the key for terraforming the ancient oceans of Mars. An asteroid could also be used to reduce total kinetic energy for bringing Mars into an inner orbit. It could be possible to use an asteroid such as Ceres, or other large solar system bodies to add ?V for a gravitational assist to the Earth each time it makes a pass through the earth orbit. The orbital dynamics could be engineered to give a gradual assist to the orbit that would move the Earth further away from the warming sun. This may be a logical step in the protection of the Earth as a whole. Solar system engineering projects, like space development projects, need to be established with respect to their importance, political climate, and funding.

John McCarthy, a computer science instructor from Stanford, in a web-published paper describes of one of the ideas from Korycanski and Laughlin to boost a tame aster-oid, making several thousand passes with Mars, Venus, and Earth, exchanging angular momentum. Using this model requires orbital interaction with two other planets besides Mars. With a gravitational boost (addition or subtraction), it might be possible to move Mars with rocket supplied inertia. He discusses moving Mars directly opposite the Earth, which is the least stable of the Lagrange points. Presently, numerous teams have researched the mathematical models of the solar system. The moving of Mars or the reengi-neering the solar system may take a time scale in the order of tens of thousands of years rather than the millions of years it takes with natural processes.

"Orbital Element Modification" is a general class of proposals for the re-engineering the solar system to improved and favorable to life. The future conditions on Earth will necessitate and prioritize of each such project to counter the effects of our variable star, the Sun, and global warming. Humankind has the potential for getting more than one habitable world and a more stable solar system for future life in the solar system. One logical idea is to move Mars to an AU directly opposite the Sun from the Earth.

Even the early Greeks, had the idea of a hidden world, the anti-chiton. It was a counter world behind the Sun, in the opposite side of Earth's obit. Here we have the similar final goal, moving Mars to approximately 1+/- AU in a leading Lagrange point of the Earth. Mars should not be the only body in the solar system that we may consider moving.

In the old model of the solar system, the Sun swells to a red giant in about 8-10 billion years from the present and engulfs the Earth. The new astrobiology global warming model shows the oceans of the Earth evaporating in one to five million years. What will it be like living on the surface of the Earth in just 200 years with the present rise in global temperature? This model of the Earth's biosphere system in a rapidly warming greenhouse is not the only part of the global warming equation. The study of stellar evolu-tion cycles to better understand our own Sun with the H K Project at Mt Wilson observatory has been an ongoing project for over 40 years. Research indicates that active Sun, a variable star, is also heating up.

Solar System Modeling Considerations

With the discovery of other solar systems in our galaxy, extra solar planets like 51 Pegasi provide us with additional models. Through our observations, we know that planetary systems have migrated in the solar nebula through the lifetime of many solar systems. Even in our own solar system, we have observed the migration of the orbital path of Neptune and possibly Jupiter to another orbital path. Debris in the solar system has changed orbital paths, subtracting kinetic energy of the gas giants within the solar system over long time scales. Using a gravitational boost or the subtraction of orbital kinetic energy, a planet could be moved over long periods of time.

Advanced orbital mechanics and computer modeling of the three body problem will bring about important changes in the way we see the solar system. Propulsion and engineering systems are being designed to give additional DV to push stable asteroids or bodies in slightly unstable orbits like Enceladus. The resonant orbit of Enceladus, of Saturn could be modified to approach the inner solar system. Enceladus, 498 km in diameter, 1.24 gm/cm, is especially interesting, since it has a recently discovered magnetic field revealed by the Casinni spacecraft. The best safe orbit for the greatest the gravitational transfer would be desired. This could act like a gyroscope for the orbiting body.

Ion propulsion systems would be needed to ever so slightly tweak the orbits of bodies that could be used to move the Earth or Mars into more favorable climatic positions for life to thrive in the temperate zone. Even Pluto could be brought into the inner solar system. Calculations and experiments would be required to determine the force required to release Enceladus from Saturn's resonance. Also, other bodies in the solar system in unstable horseshoe orbits could be redirected to transfer kinetic energy through their gravitational influence.

"Trans Neptunian Objects" (TNO) are of a special interest because of their orbital dynamics. Space engineering techniques could also be applied to the orbits of these bodies in the solar system to act as an additional accelerating attractor, tweaking the Earth's orbit in each decadal passing. Some TNO objects have a sporadic orbit that could be altered with rockets at perihelion. If the Earth's global warming gets out of control, we may want as many as 1,000 or more attractor masses to tug the Earth into a more favorable orbit.

Some of these objects, like 2060 Chiron, a 71km diameter, possible a burned out comet) have long term orbits between Jupiter and Saturn that may be steerable from the mid-solar system. One of my astro imaging projects was to image 2060 Chiron, during its last approach. Chiron is now classified as a centaur, the first of a class of objects orbiting between the outer planets. Centaurs are not in stable orbits and will eventually be removed by the giant planets. KBO's may be difficult to use in the inner solar system, due to their remoteness. In the last decade, NASA has proposed manned missions to the asteroid belt and exploration of Near Earth Objects, NEO's. The close approach of Asteroid MN 2029 mission, new NEO mission opportunities are being studied.

It would be better to use asteroidal bodies than comets in orbital modification projects of things, since comets tend to break up after perihelion passing. Some M-Class asteroids would need to be studied with ground penetrating radar to assure their stability when. These asteroids may be the most stable against the tidal forces involved in a close Lagrange orbit of the Earth Moon system. The New space technologies being developed will modify orbital element modifications possible. With the situation of the impactor of the Deep Impact mission, it was able to make last minute orbital adjustments. Such is the case of the "Attractor" mass, a name given to the orbiting body that will add inertial energy into Earth/Moon system over thousands of years to accelerate the Earth to a more favorable orbit. However, last minute orbital adjustments would not need to be made because of the long orbital times of the attractor mass. A specific gravitational acceleration would be added to the Earth/Moon system through precise parallel orbit with the passing of each attractor mass of the body being acted upon. The orbital pass would be carefully timed to not interfere with the tides and the Moons orbit.

Technologies like nanotube ropes and tethers, ice bolt anchors, AI genetic algorithms, and gimbaled stand-off ion engines could be used to tweak the orbits of reactive bodies and control asteroids. The engineering of these systems for the “Zodiac Project” is as important as the development of the present deflection technologies studied in the Deep Impact mission.

Ion engines have been tested with the magnetic sector boundary of the solar wind for negative ionization. The leading edges of an accelerating mass could be shielded from ablation to avoid surface erosion from perihelion approach. An asteroid drive system would need to be engineered with an 80% safety factor to insure the contact for a zero margin of error. NASA also wants beaming techno-logy as demonstrated through the Beaming Prize and research with NASA Institute of Advanced Concepts, NIAC. This technology has demonstrated that it can move objects in space. Taken together with our advances in space engineering show that we will soon have the capability. World space scientists should realize that controlling an asteroid is just as important as deflection technology. In the future, even a solar system like Proxima Centauri or Alpha Centauri systems could be re-engineered to be favorable for life.

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MMM #196 - June 2006

CERES

Ceres - Largest Asteroid? or Mini-Planet?

Peter Kokh, David A. Dunlop, David Dietzler

This contrast-enhanced false-color composite of Ceres is made from Hubble Space Telescope visible and ultraviolet images. http://www.astronomy.com/asy/default.aspx?c=a&id=3478

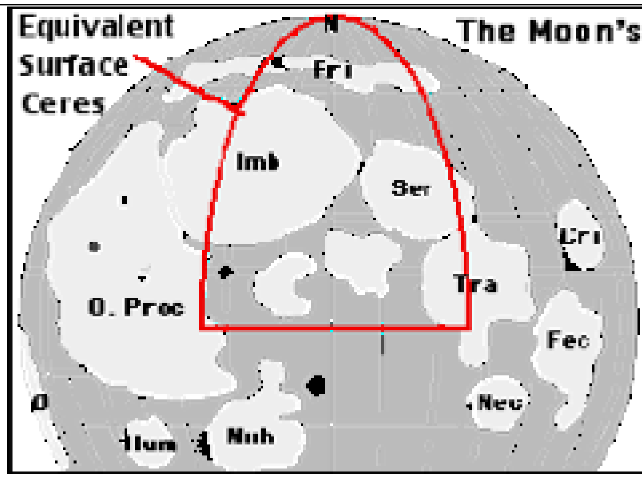
DAWN: NASA's Mission to Vesta & Ceres
http://dawn.jpl.nasa.gov/mission/index.asp
Mission reinstated, March 27, 2006
http://www.nasa.gov/home/hqnews/2006/mar/HQ_06108_Dawn_reinstates.html
Dawn's Early Light online newsletter (html or pdf)
http://dawn.jpl.nasa.gov/DawnMedia/index.asp
First purely scientific NASA solar electric mission
Dates: Launch June or July 2007 on a Delta 7925H
Vesta encounter 2011, orbiting Vesta for 7 months,
Ceres encounter 2015, orbiting Ceres indefinitely
Craft 90% assembled at Orbital Sciences
The occasion for this brainstorming article is the recent announcement that Ceres may have a water-rich mantle.
http://www.astronomy.com/asy/default.aspx?c=a&id=3478e

- We have always known that Ceres was by far the largest asteroid.
- Now we realize that in resources as well as size and location, it may be the best-endowed.
- As such, it is sure to play a major role in humanity's expansion beyond the orbit of Mars. Our aim is to sketch the possibilities.

Sizing Up Ceres

DIAMETER:
equator: ~975 km (~606 mi); polar: ~909 km (~565 mi); mean: ~950 km (~590 mi)
SURFACE AREA: 3,160,000 km2 (1,219,000 mi2)*
[*based on former diameter estimate of 1003 km]
COMPARABLE TO:

- All of India (1,229,737 sq.mi.)
- 40% of the Continental U.S.= either E or W of the plains states (excluding North Dakota thru Texas)
- Queensland plus Northern Territory in Australia
- A slice of the Moon from the Moon's N pole to its Equator, and from 27 °W to 27 °E:

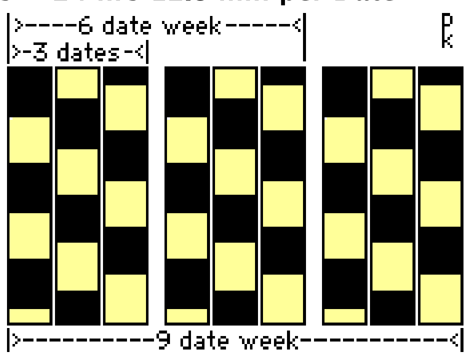


CLASS AND COMPOSITION: Carbonaceous chondrite. Stony (silicates and metal oxides) with admixed water ice and hydrates.

ROTATION PERIOD (one sol): 9.08 hrs.

POSSIBLE TIMEKEEPING SYSTEM: a 2date cycle of 5 periods = dates 22 hrs 42 min long.

A 3-Date cycle of 8 periods = 24 hrs 12.8 min per Date



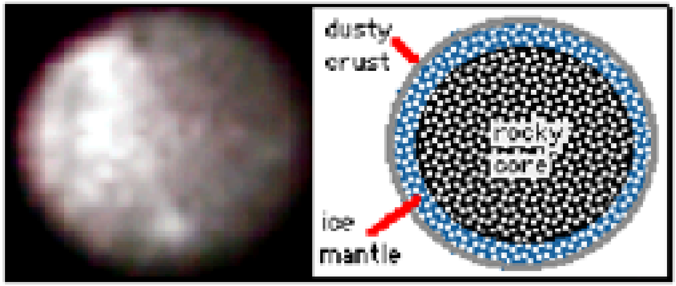
GRAVITY: 19% Moon's, 8.31% Mars', 3% Earth's.That might or might not be just enough to make gravity-dependent body functions work without providing an artificial gravity environment.

DISTANCE FROM SUN: 381-447 million km = 237-278 million mi. = 2.55-2.99 A.U. 1 A.U. or astronomical unit = the Earth's average distance from the Sun. At this distance, Sunlight at Ceres ranges between 15.4% and 11% of that reaching Earth, per square meter. To do the same job, as a solar collector 1 meter on a side on Earth, you would need a collector 3 meters on a side on Ceres. That is still doable.

Synchronous orbit lies about 782 km or 486 miles above the surface of **Ceres**.

Ceres - biggest asteroid or "embryonic-planet?"

New observations of Ceres, the first, and by far the largest, asteroid ever to be discovered, suggest a rocky core surrounded by a substantial water-ice mantle and a thin dusty crust. These are resources that, if properly developed, could make Ceres not only the gateway to the asteroid belt, but perhaps the gateway to the entire outer solar system. See pp. 4-6 for more facts and possibilities.



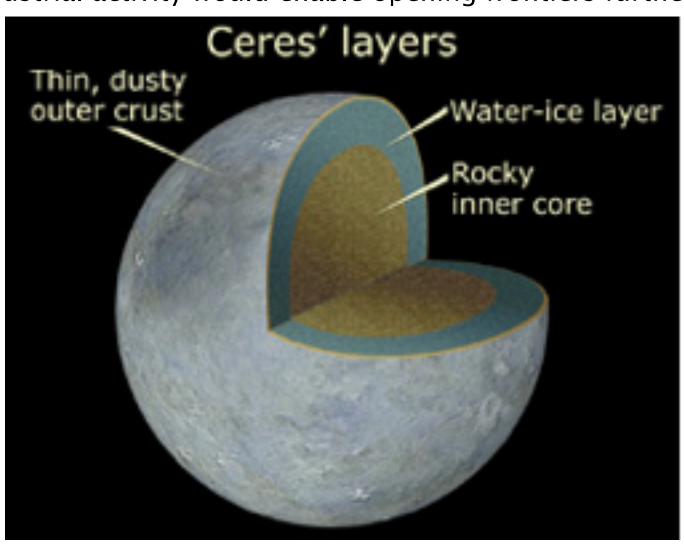
What we "knew" and now "know" about Ceres
www.planetary.org/explore/topics/asteroids_and_comets/ceres.html

Ceres is estimated to contain one quarter of all the mass in the asteroid belt and it had been clear from its crudely calculated density and spectrum (carbonaceous chondrite) that it must contain a good percentage of the water-ice in the Belt. We thought that this resource might be just mixed in with the rock, but we now believe that Ceres may contain a mini subsurface ocean, similar to that on Europa, but on a much smaller scale. Ceres suddenly emerges as a much more complex and interesting "little planet" all by itself, not only the largest of the asteroids, but in a whole league all by itself. Ceres becomes not just an asteroid, but the place to visit and do business in the Belt.

If we were to abandon our fixation with size is everything in deciding what is a planet and what is not, and look at the object's potential to have a roll in the spread of humanity, Ceres might be given the appellation "planet." Maybe we need a new word, not laden with size connotations for objects that will play a major role as a human pioneer frontier of the future. Don't bother to look in a thesaurus. It is of little help. We'll just have to coin something. After all, Europa too needs to be reclassified! Whether a body orbits the Sun directly or indirectly seems irrelevant if they host life!!

The Outlook for Ceres: Phase I:

a. In time, engineering development for belt needed equipment (prospector ships and tools, mining equipment, mass drivers, smelting equipment) could switch from the Moon to this Belt regional center.
b. The presence of considerable amounts of water ice and or ice/rock mixture along with this planetoid's carbonaceous crust means that **Ceres could be biospherically self-supporting** in food, fabrics, plastics, fuels.
c. Ceres could become the principal center in the Solar System for the **development of cryoplastics** including building materials that perform well at cryotemperatures. (-100 to -200 °F ?) This industrial activity would enable opening frontiers further from the sun.



Phase I1:

Given these advantages, Ceres seems destined to become a principal **staging point for exploratory expeditions, outposts, and settlements in the Jovian and Saturnian systems and beyond.**

Ceres vs. Callisto as Gateway to the Outer Solar System

Some writers had previously expected that Callisto, the only one of Jupiter's big four Galilean satellites that is outside Jupiter's radiation belt, would emerge as the gateway to the entire outer system. But Callisto's sphere of influence might be confined to the Jovian system alone, with Ceres having more frequent launch windows to Saturn, Uranus, and Neptune.

Ceres would grow in population and wealth with the spread of asteroid activities (phase 1) and then with the opening of the Jovian Moons (phase II). The limiting factor is the size to which its "SynchPort" could grow at the end of a tether. I'll leave it to science fiction writers to propose a vast "Synch Ring World" above Ceres, some 5,000 miles in circumference, or how artificial gravity would be maintained within it (perhaps this "ring" would be of individually rotating "sausage link cylinders" of the O'Neill variety, with lunar gravity (that of Io, Europa, Ganymede, Callisto, Titan are similar) as the likely standard beyond Earth. **MMM**

MMM#153 March 2002

SENTRY - An Automatic Near-Earth Asteroid Collision Monitoring System

For World Release: 13 Mar 2002 Jet Propulsion Lab

NASA's Near-Earth Object Program Office (http://neo.jpl.nasa.gov) announces the arrival of the Sentry automatic impact monitoring system. In development for nearly two years, Sentry is a highly automated, accurate, and robust system for continually updating the orbits, future close Earth approaches, and Earth impact probabilities for all Near-Earth Asteroids (NEAs).

When interpreting the Sentry Impact Risks Page (http://neo.jpl.nasa.gov/risk/), where information on known potential NEA impacts is posted, one must bear in mind that an Earth collision by a sizable NEA is a very low probability event. Objects normally appear on the Risks Page because their orbits can bring them close to the Earth's orbit and the limited number of available observations do not yet allow their trajectories to be well-enough defined. In such cases, there may be a wide range of possible future paths that can be fit to the existing observations, sometimes including a few that can intersect the Earth.

Whenever a newly discovered NEA is posted on the Sentry Impact Risks Page, by far the most likely outcome is that the object will eventually be removed as new observations become available, the object's orbit is improved, and its future motion is more tightly constrained. As a result, several new NEAs each month may be listed on the Sentry Impact Risks page, only to be removed shortly afterwards. This is a normal process, completely expected. The removal of an object from the Impact Risks page does not indicate that the object's risk was evaluated mistakenly: the risk was real until additional observations showed that it was not.

While completely independent, the Sentry system is meant to be complementary to the NEODyS CLOMON impact monitoring system operated in Pisa, Italy. Personnel from both the Sentry and NEODyS systems are in constant communication, cross chec-king each other's results and providing constructive feedback to continuously improve the efficiency, accuracy, and robustness of both systems.

The Sentry system was developed largely by Drs. Steve Chesley and Alan Chamberlin with significant technical help from Dr. Paul Chodas. Ron Baalke provided web site updates. Donald K. Yeomans manages NASA's Near-Earth Object Program Office.

MMM #160 November 2002

In FOCUS: Killer Asteroids versus Killer Space Debris

Size is sexy, catastrophe is sexy. The threat of killer asteroids gets good press and sells movie tickets. And yes, the danger is real. However it is also statistically remote. Space debris is peanuts. Who cares? It poses no problem to the Earth.

Yet there are ample grounds to suspect that in the next century, which is what we should be more concerned about, it is perhaps a million times more likely that a Shuttle Orbiter or the International Space Station itself will be fatally compromised by debris impact than that a sizable astrochunk will strike a killer blow to the Earth itself. "So what?," you say. "No comparison!"

That depends on the consequences. There are many interests and causes that compete for attention with space development, and a mortal blow to the heart of manned space operations could just mean the end of the Space Age, for now. Anyone who thinks such a hiatus would be brief should consider how long the hiatus in manned lunar missions has been. Indeed, the time path from Kitty Hawk to Tranquility Base may prove shorter than that from Apollo 17 to the next manned Moon Landing.

And were that to happen, a debris-caused halt to manned space operations, what would happen to our still-on-the drawing boards "Planetary Defense Systems?" Those who are serious about asteroid impact threats should be serious about keeping the door open for manned space operations. Space Debris could close that door.

The most promising space development to come may just be space tourism. But nothing could more effectively foreclose on those dreams than uninsurability due to escalating danger from space debris. So Space Tourism advocates ought also to be concerned about debris.

The sad thing about space debris is that it is unnecessary. The overwhelming majority of space debris items are the result of the traditional western refusal to interiorize life-cycle costs. It is cheaper to throw some-thing away, to jettison something, than to dispose of it properly. It is cheaper to make it someone else's problem. While it may be true that Russian space missions are dirtier in the debris they scatter, it is only a relative difference and we have no cause to be proud.

What we propose is a series of international workshops, each to zero in on a different source of space debris. When all the workshops have reported their findings, another series of workshops can begin to look at commonalities and where problem areas impinge on one another. Finally the time may be ripe for an International Conference on Space Debris charged with writing the language for a proposed International Treaty of Space-craft Design and Launch Standards aimed at drastically curtailing the current rate of debris production.

What could come out of such a study? We have some ideas but they may well be naive. We leave it to the engineers and spacecraft designers. As to the bean counters, it is hard to see how they can be part of the solution, since it is the bean counting practice of dismissing life-cycle costs that is at the heart of the problem. Could this be an opportunity for redemption?

It may take ten years for such a process to run its course, if people begin to take it seriously now. Sadly, it may take a killer blow for people to become concerned enough to be willing to accept design inconveniences and upfront costs necessary in the long run to keep the Space Age an open-ended Age. Even if we were to start today, there's no guarantee we could finish such a process in time.

Our attitude towards space debris is like that towards icebergs and sharks. Sure, there out there. So is lightning. So what?

Our advice is for the minority who do care to start the process quietly on their own. Rather than look for ways to cleanup what's out there, we should concentrate on slowing the generation of new debris by spacecraft yet to be launched. Once we've plugged the leaks in the damn, then we can turn our attention to mopping up. – PK

Killer Debris vs. Killer Asteroids

By Larry J. Friesen < ljfriesen@ev1.net >

On the "In Focus" Editorial Essay in MMM # 60, "Killer Asteroids versus Killer Space Debris," you seem to belittle the danger from rogue asteroids (and comets). I know something about both topics, both serious concerns. Compare them is like comparing apples and oranges; they are very different types of dangers, involving hugely different time scales.

The Threat of Asteroid Impacts: To put the danger from impacting asteroids and comets in perspective, the chances that any person will die in a meteoric impact are about the same order as the chances that they die in an airplane crash, based on the past rate of impacts on Earth, as well as we can reconstruct and estimate it. A major difference is that most deaths from meteoric impacts will be due to extremely rare bolides large enough to devastate a large region, a continent, or perhaps the entire planet. It may be tens or hundreds of thousands of years between "state busters," and perhaps millions or tens of millions of years between "continent busters" or "planet busters". But when they do occur they will kill huge numbers of people; perhaps millions or even billions at a time.

Many people – including the news media – have a difficult time dealing seriously, both on an intellectual level and an emotional level, with events that are extremely rare, but have enormous effects when they do happen. It seems difficult on the one hand to avoid the "giggle factor" and take the matter seriously at all, and on the other hand to avoid overblowing it. How we get the average person to get over that mental "hump" I don't know.

We've apparently got the media past the "giggle factor." But we may not yet have gotten them to get enough perspective on it to keep from overblowing things. It may be difficult to get them to take a calmer perspective, because news media seem to thrive on sensation.

The Threat from Orbital Debris: Turning to the very serious problem of orbital debris, I've worked in that area. as a part of the NASA – Johnson Space Center (JSC) orbital debris study group. It may interest you to learn that there have been a series of international workshops on the topic, such as you propose. I've participated in a few. NASA's orbital debris experts, along with interested parties from DOD and other agencies, would meet with our counterparts from ESA, Russia (then still the U.S.S.R.,) Japan, etc. We would exchange information about what we'd learned about various aspects of space debris, discuss policy recommendations for our various space agencies, and so forth.

Although I'm not currently working in this area, I have no reason to think that these international workshops are not still being held, on a fairly regular basis.

I'm not so sure about a treaty governing practices for reducing the creation of space debris,. I had some interesting discussions about this with Joseph P. Loftus, now retired, who was then one of the associate or assistant directors for JSC. He was a participant in the orbital debris study group, and led many of the discussions, especially those behind the scenes, to push various national space agencies, and international regulatory bodies (UN bodies and others) to adopt sensible policies that would minimize the generation of debris from space operations.

What he, and the rest of us, didn't want to do was to freeze a set of mandatory policies in place by treaty. First, we were getting very good cooperation from nearly every nation with space launch capabilities by presenting recommended policies in the frame of "these are practices that wise spacefaring nations should follow," with a sort of "Good Housekeeping Seal of Approval". It is not too difficult to explain matters to the leading scientists and engineers of nations that have, or are developing, space launch capability, and to get them to realize that when it comes to orbital debris, it is literally true that "what goes around comes around": any junk a nation puts into orbit is as much a danger to its own satellites as it is to every other's.

Second, we were still studying the orbital debris situation, and while we felt we had some useful policy recommendations to make, we weren't sure we completely understood everything yet. In particular, we weren't absolutely sure we knew what the best policies would ultimately be. Joe Loftus pointed out something you may already suspect: that if we fixed a set of rules in place with a treaty, it would thereafter be infernally difficult to change them, even if further research showed that there were better ways to deal with the problem, or even showed that some of the original rules did more harm than good.

Having been away from the orbital debris world for awhile, I am not certain how mature the present researchers now feel our understanding of the situation is. Perhaps now would be an appropriate time to solidify debris reduction policies in a treaty. But my gut feeling is no. If the present policy regime is effective, that is if space-faring nations, agencies, companies, etc. are following the recommended policies and living up to them, I would prefer to keep the situation on the present level, so that engineers and scientists can have flexibility to recommend changes if their research indicates new hazards or potential improvements in ways to avoid generating space debris.

What would be useful, in this country anyway, is to budget more money to study the space debris situation. What I keep hearing, from my friends and acquaintances who are still in the field, is that most serious players in the space business agree that orbital debris is a serious problem that very much needs to be studied. But in a time of tight budgets, everyone wants someone else's department or program to pay for the research, not theirs.

We can ask our congresspeople to vote for more money to study the orbital debris problem. <LJF>

MMM #196 - JUNE 2006

Ceres - Largest Asteroid? or Mini-Planet?

Peter Kokh, David A. Dunlop, David Dietzler

This contrast-enhanced false-color composite of Ceres is made from Hubble Space Telescope visible and ultraviolet images.
http://www.astronomy.com/asy/default.aspx?c=a&id=3478

Relevant Reading from Past Issues of MMM

MMM #24 April '89, "Ceres, Pallas, Vesta" pp. 4-6
republished in MMM Classics #3, pp. 23-24
www.lunar-reclamation.org/mmm_classics/mmmc3_Jan2005.pdf

MMM #70 Nov. '93, "Asteroid Workshop, Part I, A Permanent Main Belt Service Center on Ceres, pp. 3-8
republished in MMM Classics #7, pp 62-66.
www.lunar-reclamation.org/mmm_classics/mmmc7_Jan2006.pdf

DAWN: NASA's Mission to Vesta and Ceres

http://dawn.jpl.nasa.gov/mission/index.asp

- **Mission reinstated**, March 27, 2006
http://www.nasa.gov/home/hqnews/
2006/mar/HQ_06108_Dawn_reinstates.html
- **Dawn's Early Light** online newsletter (html or pdf)
http://dawn.jpl.nasa.gov/DawnMedia/index.asp
- **First purely scientific NASA solar electric mission**
- **Dates:** Launch June or July 2007 on a Delta 7925H
Vesta encounter 2011, orbiting Vesta for 7 months,
Ceres encounter 2015, orbiting Ceres indefinitely
- **Craft 90% assembled** at Orbital Sciences

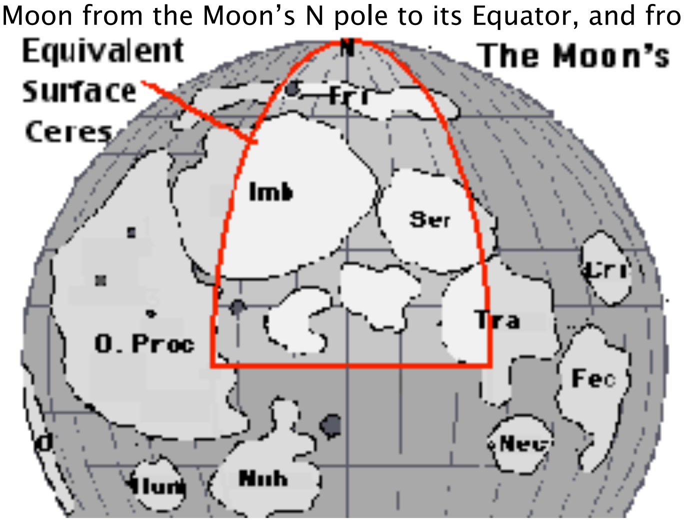
The occasion for this brainstorming article is the recent announcement that Ceres may have a water-rich mantle. http://www.astronomy.com/asy/default.aspx?c=a&id=3478e.

We have always known that Ceres was by far the largest asteroid. Now we realize that in resources as well as size and location, it may be the best-endowed. As such, it is sure to play a major role in humanity's expansion beyond the orbit of Mars. Our aim is to sketch the possibilities.

Sizing Up Ceres

Diameter: equator ~975 km (~606 mi); polar~909 km (~565 mi); mean: ~950 km (~590 mi)
Surface Area: 3,160,000 km2 (1,219,000 mi2)* [*based on diameter estimate of 1003 km]
COMPARABLE TO:

- **All of India** (1,229,737 sq.mi.)
- **40% of the Continental U.S.**= either east or west of the plains states (i.e. excluding North Dakota thru Texas)
- **Queensland plus Northern Territory** in Australia
- A slice of the Moon from the Moon's N pole to its Equator, and from 27 °W to 27 °E:

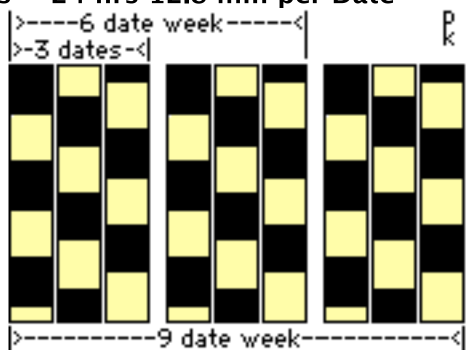


CLASS and COMPOSITION: Carbonaceous chondrite. Stony (silicates and metal oxides) with admixed water ice and hydrates.

ROTATION PERIOD (one sol): 9.08 hrs.

POSSIBLE TIMEKEEPING SYSTEMS: a 2-date cycle of 5 periods would yield dates 22 hours 42 minutes long.

A 3-Date cycle of 8 periods = 24 hrs 12.8 min per Date

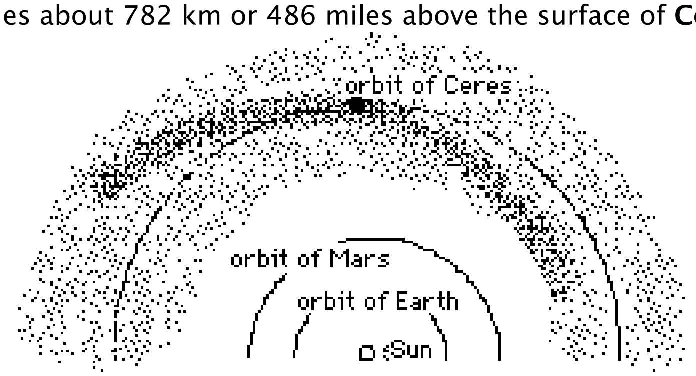


GRAVITY: 19% Moon's, 8.31% Mars', 3% Earth's.

That might or might not be just enough to make gravity-dependent body functions work without providing an artificial gravity environment.

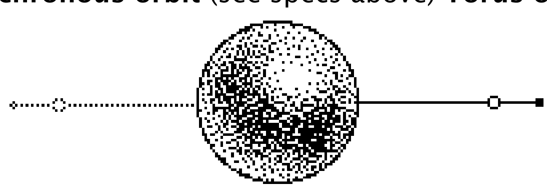
DISTANCE FROM SUN: 381-447 million km = 237-278 million mi. = 2.55-2.99 A.U. 1 A.U. or astronomical unit = the Earth's average distance from the Sun. At this distance, Sunlight at Ceres ranges between 15.4% and 11% of that reaching Earth, per square meter. To do the same job, as a solar collector 1 meter on a side on Earth, you would need a collector 3 meters on a side on Ceres. That is still doable.

Synchronous orbit lies about 782 km or 486 miles above the surface of **Ceres**.

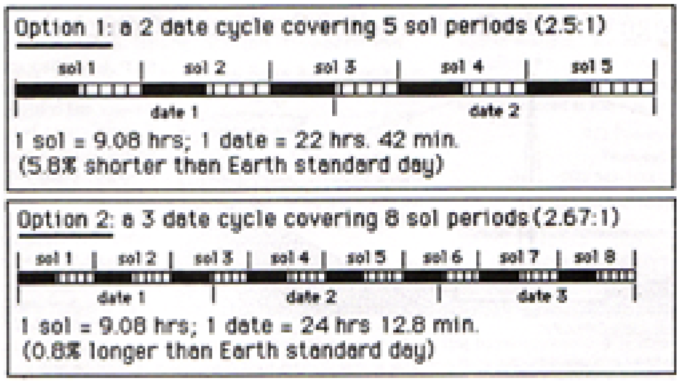


Ceres' orbit within the Main Asteroid Belt and the swath, in relationship to Ceres' position, in which we'll find asteroids that will orbit in formation with Ceres for many decades.

An **Elevator-tethered Synchronous orbit** (see specs above) **Torus or Cylinder.**



Distance to scale of orbital Sync Port above Ceres surface, showing elevator/tether and counterweight. Many of Ceres' port functions will be more efficiently conducted at Sync Port.



Ceres' "Service Area"

If the stats for the first 100 asteroids to be discovered are typical, 44% have orbital periods within 1O% of Ceres' so that one third of these or almost 15% of all asteroids would be within 60 degrees of Ceres at any given time and remain there for fifteen years or longer before drifting out of range.

Some asteroids will 'fly in formation' with Ceres for centuries. Two target groups suggest themselves:

- **the 'out-fronts'** ahead of Ceres but in slower larger orbits
- **the 'in-backs'** behind Ceres but in faster smaller orbits.

At any rate access to 15% of the Belt should do us well for quite a while.

A Supply and Staging Center for Belt Operations:
Should it be Mars or Ceres?

The Catch-22 of orbital mechanics, something that is commonly ignored, is that the closer two bodies are in orbital period, the less frequent, on the average, are the launch windows between them in either direction. That Mars is closer to the Belt is a liability, not an asset. In fact, the Moon is the better choice. But in time, as facilities on Ceres grow, it would become the center of operations within as much as a third of the Belt. Especially for asteroids orbiting in loose formation with Ceres, craft could come and go at most any time with the only the trade off between speed and most economical use of fuel being the only real variable. As most of these trajectories will not be very eccentric, speed will minimally increase or diminish over the coasting route. in between

Facilities on Ceres

In time, engineering development for belt needed equipment (prospector ships and tools, mining equipment, mass drivers, smelting equipment) could switch from the Moon to this regional center. Experience gained on this colder, wetter world could prove useful for ventures beyond the Belt.

While mining, processing, and manufacturing facilities would be on Ceres' surface, the space port may not be.

- a rotating space habitat in orbit about Ceres in a synchronous orbit would be 486 mi. or 782 km above Ceres' equator -- elevator anyone?

We spent some time better defining which functions the Ceres Settlement* would fill, and of these, which were appropriate for Ceres' low mini-gravity, which would be better placed in a surface artificial gravity environment, and which would best be filled in an elevator and pipeline cluster tethered synchronously orbiting space facility, the Sync Port", 486 miles above the main Surface Settlement.

ORBITAL SYNC PORT

- **Solar Energy facility** if practical, cabled to surface
- **Main Port of Call** for ships to and from other asteroid belt locations elsewhere in the solar system
- **Fuel Depot** for visiting ships

- **Light processing, manufacturing** incoming resources
- **Warehouse** for goods being transshipped
- **Traders' Market** for ships in port
- **Repair, maintenance, reoutfitting shops** for work that is routine, frequent, and requiring a low mass of equipment
- **Assay office** for incoming mining samples
- **Hotel** for more transient spacer use
- **Gym** for visiting personnel
- **Other recreation facilities** for transient spacers
- **Administrative offices** for handling routine matters for visiting spacers
- **Medical Outpatient Clinic** for visiting spacers
- **Other functions** for personnel, ships, goods in transit

SURFACE, FIXED (some within the main settlement area, some without it)

- **Mining and processing** of local Cerian resources
- **Manufacturing** based on local Cerian resources
- **Refinery** for fuels, volatiles from local resources
- **Custom manufacturing** using imported resources
- **Warehousing** for all of the above
- **R&D facilities** and labs for processing, manufacturing
- **Repair, maintenance, reoutfitting shops** for work needing heavier equipment that is less routine and/or frequent
- **Main agricultural areas**: food for local consumption and for export to other Belt markets
- **Nature parks**
- **Gym** using heavy equipment or for exercises that are not gravity-dependent
- **Space port** for orbit to surface shuttles loads too big or massive for the elevator
- **Main, permanent Trade Center**
- **Nuclear Fusion** (He-3) Plant
- **Main Hospital**

SURFACE, GRAVID (Artificial gravity via Maypole and/or Maglev facility)

- Residential area (so all locals spend some time here)
- Schools (concern for children in developmental years)
- Offices (commercial, administrative)
- Gym for gravity-assisted exercise and sports requiring lightweight equipment
- Hospital recovery and rehabilitation areas
- Other activities and functions that require little space and little supporting equipment mass

A short pool of names from which features and installations might be named.

- Giuseppe PIAZZI discovered Ceres in
- PALERMO, Sicily on the
- first day of CENTURY NINETEEN.
- Ceres was the Roman goddess of grain [hence our word "cereal"], and she chose the mortal TRIPTOLEMUS to carry her knowledge (the plow, agriculture) to humanity. The AMBARVAILIA were rites of spring celebrated by Roman farmers in Ceres' honor.

<MMM>

MMM #197 - August 2006

[A Segue to last month's "Ceres" Article]

Moon Base? Mars Base?

Rock On! Far(ther) Out Man!

By David A. Dunlop dunlop712@yahoo.com

The beginning of the Moon Base agenda story is the rationale and description of the work required to develop a lunar base at its several purposes. The next phase is the rationale and description of the work required to develop a Mars Base and to settle and develop Mars. Kim Stanley Robinson has given us his grand trilogy Red Mars, Green Mars, Blue Mars for that.

Beyond Mars

But, once we have nuclear propulsion to greatly shorten the involved transit times and with it greatly reduce the vulnerability to cosmic rays and solar flares, there are other places that may provide settlement and base opportunities farther out.

Beyond Mars is the asteroid belt. With a mature technologies base including all those needed for the bases on the Moon and Mars we can see the potential to advance another step.

John Lewis' book "Mining the Sky" gives us a rationale for going to the asteroids that for the most part are too small and too poor for consideration of a significant manned base. If there is a case for the Moon, and a case for Mars, is there a case at all for asteroid settlement?

Certainly, if a case can be made for a base on an asteroid it is likely to be of a lower priority than "humans to Mars." Such an effort will require a mature nuclear propulsion transportation technology to deliver what is needed at such distances. A higher level of self-sufficiency will be needed, higher, even, than that needed for Mars. It' will be a pretty long supply chain if essential in situ resources are not available or cannot be developed.

It seems unlikely in the near term that we can realize significant commercial & financial returns for the effort and expense. Perhaps for purposes of astronomy and other sciences and as a base for obtaining especially strategic asteroid resources, a case can be made.

But for the sake of argument, assuming that these issues are no longer a problem, let's consider the physical scale of the first ten asteroids and a few others.

The great bulk of meteorites fall into either of two categories. The most common (92%) are the S-Class Stony meteorites. These are composed mostly of rock: Metal oxides and various silicates. Next in frequency of occurrence (5.7%) are M-Class Metallic Iron/Nickel meteorites.

Since it is presumed that most meteorites come from asteroids from which they were separated by impacts, many asteroids are of S or M Class designation. These classes differ in composition quite clearly in comparison both to each other and to the Earth's crust. Table 2 ⇒.

TABLE 1: Some Candidate Asteroids

#	Name	Diameter (equatorial, polar)	
1	**Ceres**	975 km	909 km

Comments: Spherical, mantle of water ice wrapped around rocky core with thin dusty crust. May have greater volume of water than Earth. Surface area 5 times that of Texas, equal to India. NASA's **Dawn** Probe is scheduled to orbit Ceres from February to July, 2015.

#	Name	Diameter (equatorial, polar)	
2	**Pallas**	570 km	525km x482

Comments: Not spherical. In an orbit inclined by 35 degrees to the ecliptic, or general solar plane. Thus requiring more energy to reach

#	Name	Diameter (equatorial, polar)
3	**Juno**	246 km
4	**Vesta**	525 km

Comments: Not quite spherical, 5hr 20.5 minute day, geologically diverse a large impact basin as well as lunar like basaltic maria formed from magma probably melted by radioactive isotope of aluminum. NASA's **Dawn** Probe is scheduled to orbit Vesta from October 2011 to April 2012.

#	Name	Diameter (equatorial, polar)
5	Astraea	167 km x 123 km
6	Hebe	205 km x 185km x170km
7	Iris	209 km
8	Flora	140 km
9	Metis	365 km
10	Hygiea	430 km
226	Eugenia	226 km

216 Kleopatra	217 km
2060 Chiron	180 km

Comments: Centaur class (orbit beyond Saturn) and Classified as comet

TABLE 1I: Composition Differences between

Column 1: Metal Meteorites & Asteroids (5.7%)
Column 2. Stony Meteorites & Asteroids (92.8%)
Column 3. Earth's Crust

Element	**1**	**2**	**3** Earth Crust
Iron	91.0%	26.0%	5.0%
Nickel	8.5%	1.4%	0.007%
Cobalt	0.6%		(25ppm)
Oxygen	36.0%	49.0%	46.6%
Silicon	18.0%	26.0%	27.7%
Magnesium	14.0%	1.9%	2.1%
Aluminum	1.4%	7.5%	8.1%
Calcium	1.3%	3.4%	3.6%
Sodium		2.6%	2.8%
Potassium		0.4%	2.6%

TABLE 3: Other Meteorite & Asteroid Classes

There are quite a number of spectral classes and beyond the M Class and the S class they do not all look alike, if you're a spectrometer. Fourteen spectral classes are listed below with examples given of notable or well-known asteroids. from information listed at:

http://www.daviddarling.info/encyclopedia & http://www.space.com/3126-asteroids-data-sheet.html

A Class – Reddish color, olivine . Example, #246 Asporina

B Class – Carbonaceous Chondrite subcategory #2 Pallas

C Class – Carbon-rich Meteorites /Carbonaceous Chondrites. Examples #10 Hygiea, #253 Mathilde

D Class – reddish. Eg: Jupiter Trojan, Hektor; Phobos/Deimos Mars moons of suspected Trojan Origin

E Class – rare, often Earth crossing, similar to M Class & P Class. Examples Hungaria Family

F Class – C Class subcategory, UV absorption features; Eg: Nysa-Polana Family, #45 Eugenia (226 km)

G Class – Subcategory of C Class strong ultra violet absorption. Eg: #1 Ceres, 568 miles in diameter

M Class bright, reflective, metallic iron & nickel Spectrally similar to E Class & P class; Examples: # 16 Psyche 248 km, #216 Kleopatra

P Class – dark type spectra similar to E class or M Class but lower albedo. Eg. #87 Sylvia 282 km wide

Q Class – fairly bright, rare. Examples #1862 Apollo and a few others near Earth asteroids similar to ordinary carbonaceous chondrites

R Class – extremely red with high albedo. Ex: Dumboska, most reddish object in the Solar system

S Class – bright, slightly red olivine & pyroxene stony, Iron. Ex: #3 Juno, #7 Iris 208, #29 Amphitrite

T Class – low albedo, rare. Example #114 Kassandra

V Class – high albedo, pyroxene. Example #4 Vesta

Outbound from Mars

Mars will be a big bone to chew on. The investment of exploration and colonization of Mars will be dependent on the profitability and infrastructure development that results from commercial development of the Earth/Moon economy. I suspect the resources for a human colony will be a long way down on everybody's priority list (the everybody on Earth, the Moon, and Mars) especially because of the low G conditions and lack of a significant economic return on that investment. At some point it may be an "affordable" science luxury to go to Ceres like Antarctica is for us in our time.

This could well be a century or more from the present and it might also represent a biological frontier of genetic engineering a subspecies better adapted to low G living. Ceres might therefore represent a strategic adaptive opportunity out of all proportion to its small mini world size. It may be the place where Homo Ceres is developed at the very limits of human society and poised for a break out from the warmth of our native star.

At the first blush it seems that the early best candidate for humans is Ceres that might provide essential in situ resources and become the water station for the asteroid belt. If there is an economic rationale for obtaining metals the water on Ceres might provide the critical in situ resources that enables an Astronomy site and “deep space” settlement that could develop a reasonable level of self sufficiency and provide support logistics for exploration and utilization of asteroid resources. It is hard to think there will be many other near term resources & economic incentives for development for the level of effort and infra-structure needed at this last stop in the inner solar system low G station.

Beyond the inner asteroid belt are the small cold moons of the outer gas planets. These places are far too cold for consideration of human presence unless there were a mature fusion technology and boundless ability to utilize Helium 3 from the atmosphere of Neptune. Without the Helium fusion technology the distances and temperature scale of the outer solar system make proceeding beyond the asteroid belt highly problematic.

Nuclear fission reactors are of course developed technology and provide sophisticated long term propulsion and power technology for the nuclear submarine fleet and the super carriers. Why not just put one of these puppies in a large “2001 style” spinning torus structure and use high ISP ion drive rockets to accelerate to speeds which will allow human to visit and traverse the outer planets, the Kuiper Belt or even the Oort Cloud? Fission reactors put out a large neutron flux that gradually degrades the reactor vessel and leaves the remaining material as radioactive waste. For the distances and long operational life needed to visit and settle on these very cold objects fission reactors seem too much of a stretch.

By preference most people wouldn’t give serious consideration to settlement in these cold remote places. For those brave few who can face a frolic in the low G cold we shall continue this icy-lite conversation where Homo Ceres is poised for breakout! By mixing in some of those carefully preserved Zubrin genes some member of Homo Ceres will write “The Trans Neptunian Cases for Pluto and Zena UB313

Pluto, whose status as the 9th and last of the planets, and as the first of the Kuiper Belt Object” with an inclined orbit of 17 degrees, has a diameter of 1,403 miles, a rotation period of 6 days and 9 hours and orbits the sun in 248 Earth years. It has 0.2% of Earths mass and is 39 AU from the Sun. The International Astronomical Union considers Pluto to be the first member of the class of Trans Neptunian Objects. Pluto’s largest Moon is Charon with a mean diameter of 1212 km and two new small additional moons [Nix and Hydra] have been discovered.

By Golly Clyde Tombough! Pluto is a system!

www.space.com/scienceastronomy/solarsystem/pluto-ez.html

More than 800 Kuiper Belt Objects (KBO) have been found since 1992 when QB1 was found. (Solar System Surprise: A New View of What’s Out There-Nov 24,2004

www.space.com/scienceastronomy/mystery_monday_041122.html

Xena, 2003 UB 313: With a diameter of 2,100 miles, half again as large as Pluto and comparable to the Moon’s 2160 miles. Its orbit moves from 38 to 97 AU over 560 years inclined 45 degrees to the main plane of the ecliptic. Xena might be seen as a planet: it is larger than Pluto, and also has a moon. Its reflectance is high as it’s atmosphere is frozen out. Its temperature ranges during its orbital period range from 405 below zero (Fahrenheit) to 360 degrees. Caltech’s Mike Brown and colleagues Chad Trujillo and David Rabinowitz discovered this. It will take some time to explore and characterize this new real estate. Even with the limited catalog that exists now these big places represent the Manifest Destiny of Homo Ceres.

Sedna, 2003 VB12 is a KBO about 3/4ths the size of Pluto with an upper size limit of 1,000 miles diameter was found two years ago found by Caltech astronomer Mike Brown’ Team, and takes 10,000 Earth years to orbit the Sun **2003 EL61** has a diameter of 1200 km, is smaller than Pluto and has two small satellites. **Quaoar** another KBO was discovered in 2002 has an estimated diameter of 780 miles and orbits the Sun every 288 Earth years. **Orcus, 2004 DW** has an estimated diameter ranging from 840 to 1170 miles with a best estimate of 994 miles and is nearly 47 AU from the Sun. Over 11 KBO with more diameters of 1000 km or more are listed at www.ifa.hawaii.edu/faculty/jewitt/kb.html

Living Nearby, not "on"

Perhaps even larger objects will be found with a higher gravity and a plentiful mix of resources, and with adequate mass for underground protection of high-energy cosmic radiation, that could be considered for eventual human occupation. For extreme environments such as these, the issue is not really settling other "asteroids." Humans will not directly experience such places. Humans will live in "built environments" constructed from the materials derived in such places. Unlike the O'Neill cylinders envisioned in the 70s these environment will not be built to take advantage of a large solar flux but to provide a secure heated stable environment against the terrible cold of a 3° Kelvin background environment. But these settlers cannot live indefinitely without new sources of fuel. Therefore, we must become a low G wanderer species looking for Helium 3 in all the right places.

Want to Get Away?

The limitations of energy technology aside, why would humans want to settle out there? Ideological reasons that would want to make some people settle away from the cultural challenges they face in the inner solar system. Like the Pilgrims they might choose to define their existence apart from a majority religions population they wish to escape. Perhaps they could not sustain their cultural and religious identity in the face of unrestricted competition from other groups. Perhaps there are groups who would flee the IRS, so to speak and rather build their own world rather than life subject to a larger political context. The decision to "create" Homo Ceres is a critical change in biology and in destiny and functional identity

Redesigning Ourselves

Perhaps the lesson of the inner solar system is that terrestrial Homo sapiens is not well suited biologically to live in a low G environment. With a solar system economy ranging from 1G on down to the mini-G levels of large asteroids in the inner belt it may come to pass that genetically engineered subspecies will be bred to better survive the low G settlements. These new humans would not look to the Earth as their home or to the Moon or Mars as their home because of the intensity of the gravity wells. Someone born on Ceres would weigh 6 times normal on the Moon! Homo Ceres, seeking new opportunities, might be the leading edge of humanity beginning on Ceres and then moving far out in the Kuiper Belt and Oort cloud, away from the warmth and abundant solar power of the inner system.

Transitions:

These new humans might "island hop" from such cold objects to others identified even farther out until they find something orbiting in the province of another star and thus transition out of our solar system to another system. After so many generations apart from a planetary existence they will have no emotional tie to our sun. It will be only another star and at one point no longer the closest star.

Such island hopping might continue from the outer regions of one star to another even if there were no identified Earth like planets around a number of stars. Even if we find other Earth like planets, the human-derived species that make the journey may not be able to settle on a larger high G environment unless they reverse engineer their genetics. They would then once again be trapped on a single terrestrial ball in a "wild and extreme" environment with no guarantee of easy settlement. Looking at them-selves and the rich and terrible tradition of human development and history on Earth is not necessarily motivating. Would they as an interstellar adapted species want to "Play It Again Sam" on a new earth even with the attractions of a stable sun for another billion years? Why would they want to go back if the outer regions can commonly provide resources for continued travel? If new planets had their own life, the biological problems of adaptation and coexistence reappear.

Impossible? The cliché "Where you stand depends on where you sit" would seem to apply to this evolutionary set of choices. If we can supply ourselves a body well adapted to an Earth-like planet that is mostly a marine world would we reengineer our selves to be an intelligent marine mammal or an intelligent terrestrial species? Which environment is more attractive, comfortable, and better able to provide a stable base for an intelligent species? Perhaps several intelligent species would be bred under such circumstances.

Perhaps on the other hand the picture presented in the film “Independence Day” of a migratory interstellar species is instructive. That species with advanced technology and mega “built environments” moves from planet to planet stripping them of resources needed for its own purposes, then moves on. This could be the evolutionary tactic used to sustain mobile existence for a large number of individuals maintaining a high technology culture in the galaxy.

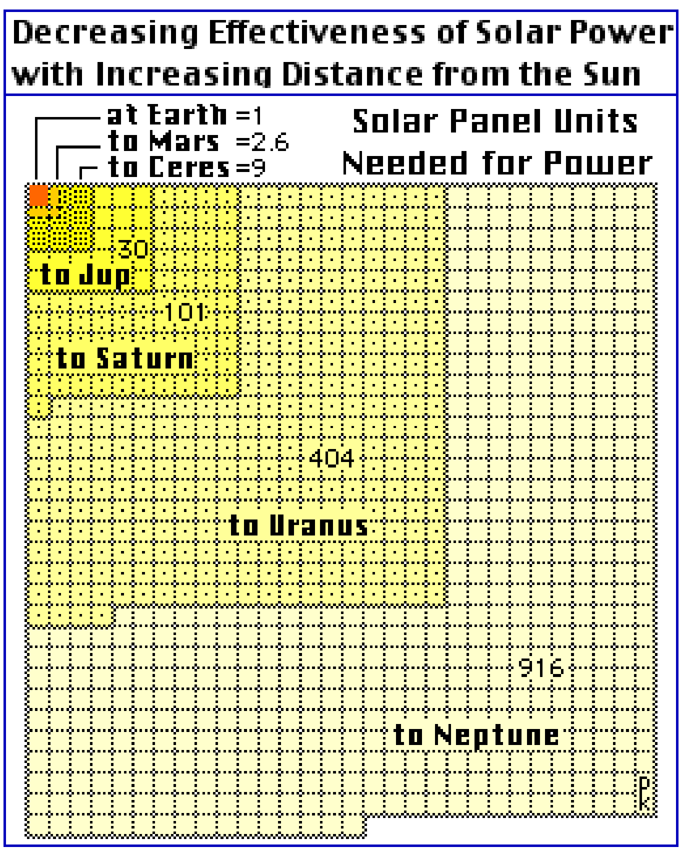
The development of Moon and Mars base technologies may lead not only to a variety of distant places but to distant and different identities. Far Out! Man! <MMM>

The Challenges of Migration into the Cold & Darkness of the Outer Solar System

By Peter Kokh kokhmmm@aol.com

We are not yet back on the Moon, have not yet made our first footfall on Mars. But that does not stop our Ad Astral aspirations from trying to project our presence further out: on the asteroids Ceres & Vesta, on Jupiter’s Callisto and Europa, on Saturn’s Titan & Iapetus, and ever beyond. It is part of the process of imagining far away places from a frontier-perspective.

It will be quite some time before there is any concerted effort to “talk up” and “think out” human expeditions beyond Mars. But that day will come. When it does, what we imagine as possibilities today, may seem quaint, Jules Verne-ish to those who follow with access to science and technology that we can only dimly glimpse. Going further out, will, however, be challenging to the extreme.



These challenges are threefold:

1) As we go further from the Sun, the amount of light and warmth we receive from it diminishes with the square of the distance: at 2x the distance there is only 1/4 the light and heat. This makes solar energy collection ever more difficult and less feasible a way to derive power. Surrounding space gets **ever darke**r, **colder and colder.**

2) The spacing between planets gets larger and larger. Low energy Hohmann transfer orbits take years, decades, even centuries, not just months as to Mars and back. Places to visit become **ever further apart** from one another. Trade in supplies and goods becomes increasingly more difficult, let alone journeys by individuals for business or pleasure.

3) Because of the greater heat in the inner solar system at the time of planet formation, the inner system planets are predominantly rocky: silicates and metal oxides. Further out, the proportion of ice and water, and other volatiles in comparison with rocky elements becomes greater and greater. Indeed, on the icy moons of Jupiter, Saturn, Uranus, and Neptune, and probably the more so on KBOs and TNOs - Kuiper Belt and Trans-Neptunian objects, while water, oxygen, nitrogen, and carbon are abundant for life support, the challenge will be to extract metals for technology. The situation we find on the Moon is stood on its head further out. That could discourage development of human frontier exclaves except in locations where a happy medium can be found.

Perhaps nowhere will trade be more necessary, and at the same time, more difficult to the point of futility, as anywhere in the Outer Solar System except within the planet-moon systems of Jupiter, Saturn, Uranus, and Neptune, a complementary full suite of needed materials may be a very rare occurrence.

What we stand to learn on Ceres - Cryoplastics

On Ceres, the next likely frontier beyond Mars, the availability of both volatiles and rocky elements in an appreciably colder (than Mars) environment, makes a frontier settlement there the ideal testing ground for a greater reliance on new **cryoplastics**, synthetics build of volatile elements but tolerant of temperatures significantly lower even than those we find in the lunar night or in the Martian winter. If it proves possible to develop a versatile suite of such cryoplastics and cryosynthetics, then we will be prepared for the Moons of Jupiter and beyond, as far as the material side of human existence is concerned.

While solar power becomes ever more impractical a solution the further out we go, we might still find a use for it on Ceres. A collector 1 meter on a side on Earth or the Moon would have to be scaled up to 3.5 meters on a side. Nuclear power in some form seems sure to become the solution of choice.

The danger from solar flares will lessen as we go further out, but not that of cosmic radiation. Ice will become the shielding material of choice.

Transportation will be the biggest challenge. Goods and cargo can always be shipped in a continuous pipeline fashion, unmanned ship after ship. How long it takes to go through the pipeline is irrelevant, so long as the “faucet” is always spitting something out on time, and in the amount needed. Special orders, however, will take years, even decades or centuries to fill. That will but ever greater urgency on achieving the highest degree of self-reliance. And that means settling only where all the needed elements are economically available. As we go further out, an ever increasing number of worldlets will not pass that muster.

The low gravity question

Callisto, Ganymede, Europa, Io around Jupiter, and Titan around Saturn have gravity levels between 19% and 15% normal, comparable to the Moon’s 16+%. A population adapted to lunar gravity will have no difficulty adjusting to life on those large satellites. We can hope that the physical deterioration we see in Earth orbit will level off at an acceptable level in lunar sixthweight, meaning that not only will our offspring be healthy, but theirs in turn.

Physiological zero-gravity occurs when the friction within blood vessels is no longer overcome by the gravity gradient. The only instrument worth reading is the body. Ceres’ 3%

gravity may flunk the test. If so, we will become increasingly reliant on artificial gravity. Bioreengineering ourselves is unlikely to be an early generation choice. One danger that may become a growing problem, is too shallow a gene pool, that could spell doom. <MMM>

MMM #214 - April 2008

"Tagging" Asteroid Apophis

Sept. 3, 2006 Planetary Society Announces Apophis Tagging Mission Design Competition

Framing the Challenge:

"A mountain of rock and iron is hurtling towards us from space. Apophis -- a 300 meter diameter asteroid -- is still millions of kilometers distant. But in 2029, it will make a spectacularly close passage by our planet. When it does, its orbit around the Sun will be affected. A shift of just a few hundred kilometers, and Apophis could return in 2036 to slam into Earth, creating widespread devastation.

"Alarming news? Sure. But what's really disturbing about the possibility of Apophis slamming into our planet -- an impact that would unleash the energy of 65,500 Hiroshima-sized atomic bombs -- is the fact that no one, anywhere, knows how to track this asteroid accurately enough right now to properly assess its danger to Earth 30 years from now.

"Which is why we must confirm, one way or another, that there's really no chance of impact. Will Apophis pass through the "keyhole," the small area on its 2029 path that would cause it to hit Earth on its next orbit in 2036? We have to find out, because if an impact is likely to occur, we are going to need all the time possible to plan and implement space missions to deflect it away from Earth.

"You'd think the world's space agencies would quickly seize the chance that Apophis offers to find a solution to one of the biggest threats our planet faces, but you'd be mistaken.

"So it's up to us, the Members of **The Planetary Society**, to make it happen, to inspire humankind to discover more about those potentially dangerous objects swarming around our solar system."

The Results, March 9, 2008

http://planetary.org/programs/projects/near_earth_objects/apophis_competition/ (deleted)

"The Planetary Society has awarded $50,000 to seven winners of the Apophis Mission Design Competition. First place went to the team led by SpaceWorks Engineering, Inc. of Atlanta, GA, teamed with SpaceDev, Inc., Poway, CA, for their mission entitled **Foresight**. The Georgia Institute of Technology, also in Atlanta, took first place in the student category, $5,000.

"We hope the winning entries will catalyze the world's space agencies to move ahead with designs and missions to protect Earth from potentially dangerous asteroids and comets."

The winning designs

"The 1st, 2nd, and 3rd prize winners ... shared a similar approach to solving the tracking challenge: send an instrumented orbiter to rendezvous with the asteroid and analyze its surface and shape up close. Once the initial survey period is complete, the orbiter would position itself in a stable orbit, after which radio tracking of the spacecraft from Earth would provide the necessary precision of the measurements of Apophis' position. The proposers did not consider it sufficient just to track the asteroid, skipping any initial survey, because, they felt, Apophis' shape and surface properties produce important influences on its future orbit due to the Yarkovsky effect.

"However, the proposers differed markedly in how thorough a survey of the asteroid they planned to perform, which directly influenced the size, cost, and complexity of the proposed mission.

"The winning proposal, Foresight, is a low-cost, conventionally propelled orbiter with only two instruments and a single band radio tracking system. The 2nd and 3rd prize winners proposed increasingly complex missions, with increasing costs.

Winning proposal details: (diagram below)

> cost: $137.2 million
> size 0.85x0.85x0.7 meters
> dry launch mass 100.2 kg ~ 220 lbs
> chemical propulsion
> 1.2m^2 solar panel
> camera, laser altimeter, x-band tracking system
> launch date May 9, 2012
> vehicle: Orbital Sciences Minotaur IV
> rendezvous March 15, 2013

"How do you tag and track an asteroid that might be on a collision course with Earth? The winners of our Apophis Mission Design Competition" are announced!

MMM #230 - November 2009

What I Like about the Augustine Commission Recommendations for our Future Manned Space Program

By Tom Heidel

Yes, I have read a lot of the "Oh, woe is us" editorials and commentaries. I understand how long time supporters of NASA's exciting plans to return to the Moon feel. The rug has been pulled out from under them. But has it? Don't kill the messenger if you don't like the message! The single pertinent fact is that NASA's Moon program was underfunded from the gitgo, and, to that extent, a political ploy. Given the current economic times, it is unrealistic to expect that funding level to be increased substantially, much less left at the current level.

But I am not at all sure, that the recommendation that we fly manned missions to some asteroids and maybe even a manned flyby of Mars is a bad alternative. I have a plaque in my office that reads, "the contented man is one who enjoys the scenery along the detours." This alternate plan for manned space activities may seem like a detour. But is it?

First, the rockets and other equipment to support such missions will be ready sooner, so we will get to visit some neat places in the interim. Meanwhile, with NASA detoured from the Moon, the agency may be able to pull off a badly needed "attitude adjustment" to collaboration with other national space agencies.

A NASA only Moonbase effort would be much less robust than one mounted by the **Lunar Infrastructure Development Corporation** proposed by Buzz Aldrin. [p. 9, below] NASA could join a more robust international effort with multinational corporations as partners as well, at much less expense than would be incurred by carrying the current sometimes-occupied not-fully-functional "shelter" it has been planning.

And it would not surprise me that such an inter-national beachhead could become fully functional before NASA's first Altair lander would have killed its descent engines. There is a time for national pride and there is a time for getting the job done right. And that means establishment of an industrial resource-using beachhead on the Moon in a location where all the Moon's resources can be tapped, not just a sexy subset.

What asteroid(s) would a NASA manned crew visit? What science could be done in a mere flyby? What would be gained in sending men around Mars without landing? We've got some suggestions, but NASA will come up with its own, so ours don't matter. Meanwhile, NASA will be doing something, and in the meantime, the alternative International lunar effort, one that could be much more robust, would be taking shape.

I think these “sideshow missions” could be very interesting. And I plan to enjoy the scenery along these detours. Meanwhile, NASA’s Moon plans, without enough money to do in robust fashion, were really much ado about nothing. Sometimes we need a setback to get ourselves on a more secure path forward.

The Moon belongs to all of Earth. Humans will get there, and stay, and our world will have cloned itself. Too many chefs? Well, I am looking forward to tasting the soup! **<TH>**

MMM #239 - October 2010

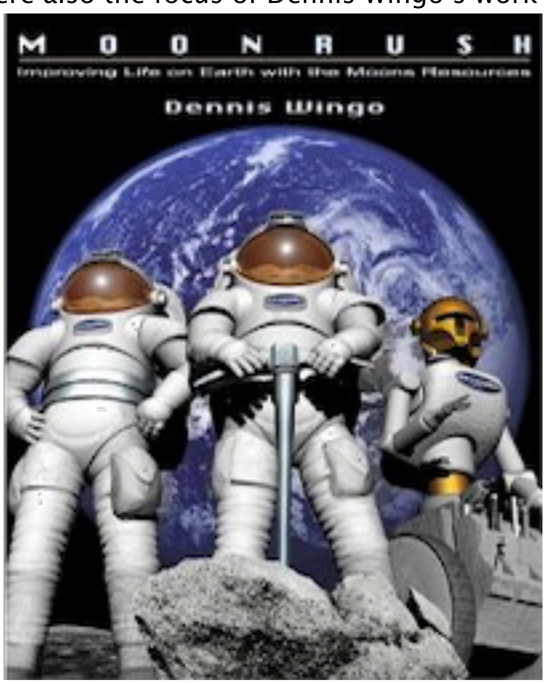
Could the Best Place to Mine Asteroids be on the Moon?

By Peter Kokh

Hey, the asteroids are way out beyond the Moon! But how do you think the Moon got all its craters? Volcanic origins were ruled out long ago. Yes, asteroids are “out there.” But now and then one is gravitationally dislodged into the inner solar system, and sometimes, the Moon or Earth itself is in the way and splat!

The amount of asteroid-sourced material in the moondust or regolith may be relatively small. Much of the impacting asteroid material may have been thrown out into space. But some must remain. Now most of the near Earth asteroid objects seem to be of the stony type, and we have enough rock powder on the Moon! What would be of interest are left-overs from metal-rich asteroids. In general, the Moon is deficient in some of the elements most needed for a technological civilization: copper, zinc, gold, silver, and the most prized element of all: platinum, involved in some 25% of all current manufacturing processes. It is the catalyst of choice for hydrogen-oxygen fuel cells, for example. Copper is so important that a 1% ore on Earth is considered “rich.”

PGMs - Platinum Group Metals - are the focus of the recently published science fiction novel by Bill White, a Moon Society member: “Platinum Moon” which was reviewed in the August issue, MMM #237. PGMs were also the focus of Dennis Wingo’s work “MoonRush.”



Info at: www.univelt.com/univeltdist/apogee.htm#moonrush

Why not mine Platinum and associated metals on asteroids where they are concentrated? John Lewis and many others talk about this extensively. But there are a few awkward details that they aren't sharing with us.

1. **There is an "inconvenient" Catch-22 in Orbital Mechanics that says the closer two bodies** (Earth and a target asteroid) **are in period** (the time they take to go around the Sun, **the farther apart on the average are the launch windows from one to the other**. The wait between launch windows between Mars and Earth in either direction is some 25+ months. Between Earth and a really close NEA or NEO that window may open every two decades or longer! The upshot is that NEOs are hit and miss "targets of opportunity" at best.
2. **But the delta V, the amount of change in velocity (or powered acceleration needed is very low**. Again a Catch-22 – **the lower the delta-V needed, the longer the trip from one to the other**.
3. **But you save so much fuel!** Well, that's okay if you are sending robotic prospectors and miners. But if you are sending humans, **the extra consumables you will need to send along will probably out-weigh the saved fuel.** The journey could take many months, and the wait for a window home could be years, and then the long trip back.

No one told you that? Hmm! I wonder why? We are not opposed to exploring, mining, and even settling the asteroids. In fact there have been many articles about asteroids and the possibilities for using them in past issues of Moon Miners' Manifesto. We have gathered them and republished them in a special Asteroids theme issue. This is a free PDF file download from
www.moonsociety.org/publications/mmm_themes/

Our point is that lunar pioneers can't afford to wait until asteroid mining has developed to the point where shipments from the Belt or elsewhere can fill the settlements' needs for these metals. There must be areas on the Moon where these metals are to be found in amounts worth prospecting for and extracting. No Lunar orbiter yet flown has been equipped to find these metals, especially in small local concentrations.

What do we need to detect and mine PGMs

Until now, the instruments chosen to fly on lunar orbiters have been selected to map concentrations of key elements we know to be fairly abundant on the Moon: iron, aluminum, magnesium, titanium, thorium; and it is fair to say that the driving curiosity has been what the geography of these concentrations says about how the Moon was formed and how it got to its present condition, rather than a search for "resources." Planetary scientists are in charge, and that is appropriate at this stage of the came. The only element that has also been the target of orbital mapping as a resource, is hydrogen, which together with overly abundant oxygen gives us water, water ice, and hydrates. But that is because, water is essential to outposts whether they get into the lunar materials industry business or not. Plus scarce water can be stolen from the precious lunar reserves for one-use non-recyclable exploitation as rocket fuel, when, in the Moon's low gravity environment, other more abundant options are available.

Now some of the targeted elements have usual partners: where there is thorium, there is probably uranium and lead, for example. So we know more.

Additionally, Apollo missions 12, 14, 15, and 17 all found KREEP deposits, rich in Potassium (K), Rare Earth Elements, and Phosphorus primarily in the Mare Imbrium splashout zone. Lunar Prospector in 1998-9 mapped these deposits at low resolution.

Could future lunar orbiter instruments detect PGMs and other valuable but less common elements on the Moon? Both the resolution and sensitivity of the needed instruments would have to be very high. But as so much is at stake, even sketchy indications of where best to look with on the surface techniques would be most helpful, by weeding out extensive areas where concentrations are lower. That said, to the extent that PGMs are a gift from the sky and not from the lunar interior, a statement that may not be totally correct, then their geographic concentrations should not follow well-known surface terrane "provinces" such as the highlands and/or maria. Nor will they be found in connection with certain types of craters, as crater types go by size, density, speed, and impact angle of the object creating them, and not by the object's makeup. That said, after a few PGM concentrations are found, it is possible that we will detect a pattern that will suggest where else on the Moon, the "prospecting prospects" are promising.

Do we need an army of human prospectors? This will be tedious work, and until definite concentrations that might be worth "mining" are found, expensive human efforts would be unwarranted and wasteful. So what can we do?

Orbiter instruments that successfully find some evidence of PGMs should be reflown on orbiters with eccentric orbits that carry them very close to the surface, say 10 kilometers (6 miles) or so, and keep adjusting the orbit until the entire Moon, farside as well as nearside, is mapped to produce the first crude map of PGM abundances. This map may suggest where to look on the surface itself. And here we need robotic rovers.

But because we will need many such assistants, and because there is an area as big as Africa and Australia together to cover, we suggest micro-rovers, working in teams, what I have called "robo-ants." I wrote about these handy critters way back in MMM #45, May 1991, almost twenty years ago. An updated version of this article was recently published in our Moon Miners' Manifesto India Quarterly, issue #5, a free download at:

www.moonsociety.org/india/mmm-india/ or directly at:

http://www.moonsociety.org/india/mmm-india/m3india5_Winter2010.pdf

We need to develop these handy "social mini-bots" anyway. They will come in handy as exospeleologist scouts, creating initial surveys of the interiors of lava tubes on Moon and Mars, and going elsewhere in terrain difficult for humans to traverse, and scour, whether in spacesuits or pressurized vehicles. Now of course, human guidance and teleoperation of these handy assistants from a nearby pressurized field vehicle is certainly an option.

PGMs have not been confirmed on the Moon and that is no surprise. We have not fielded the equipment and technologies needed. But we have every reason to believe that they are there, and that for the very practical reasons outlined above,

The Moon is the best place to mine Asteroid wealth!

The time to start planning how to do this is now! **PK**

An Asteroid Mission that Makes Sense

By Peter Kokh

Background: NASA's current direction

As of September 3, 2010 when I am writing this, NASA's marching orders are not yet set in stone, but all the indications are that the agency wants to concentrate on a Near Earth Object (asteroid) destination as the most feasible given the equipment resources likely to get the go-ahead for development.

Early in January, NASA released a **"Flexible Path" evaluation of a 2025 human mission to an asteroid.**

www.nasaspaceflight.com/2010/01/nasas-flexible-path-2025-human-mission-visit-asteroid/

This would be "a NEO mission in the mid-2020s, a full five to six years after the original target date to return to the moon, as outlined in the Vision of Space Exploration (VSE) – … no longer seen as achievable."

"Today, ~500,000 minor planets are known. Of that number, ~6600 are NEOs; of these ~1100 are PHOs (Potentially Hazardous Objects) – … objects that come within 0.05 AU (7.5 million km – 4.65 million miles) of Earth. PHOs are in orbits that have the potential to make close approaches to Earth, and are large enough to cause significant regional damage in the event of an impact."

So this is not a mission to identify mine-worthy objects and test mining methods. The primary motivation is Planetary Defense. The pace of asteroid discovery in general has accelerated enormously in the past decade and the list of PHOs is likely to mushroom significantly by the time such a mission is feasible.

As of January, NASA had narrowed the list of potential target PHOs to 38. Since then the list has shrunk by application of relevant mission constraints, to just two! But the list is likely to grow again as new PHOs are discovered, and shrink again as mission constraints narrow in on "doability."

http://www.foxnews.com/scitech/2010/09/01/nasa-narrows-targets-manned-asteroid-mission/

Candidate steroids are in eccentric orbits that do not bring them near to the Earth-Moon system on a regular basis, nor frequently. Of the 38 objects previously listed, only two will approach near enough to be visited on a round-trip of a few months time, within the 2020-25 timeframe. A third would come close enough in 2045. So very practical reasons help narrow it down.

And should we not be ready by 2025, and no other PHO has been found that will approach within crew-reach before 2045, well, then all bets are off. So if the nation adopts this destination mission, there can be no delaying by the usual Congressional or Administration budgetary mischief. It will be "do or don't do" - period!

Another constraint is that the selected target must be viewable by large ground-based telescopes. So such a mission choice demands an irreversible commitment that was lacking in the Back to the Moon directive.

Background: initial mission & target constraints

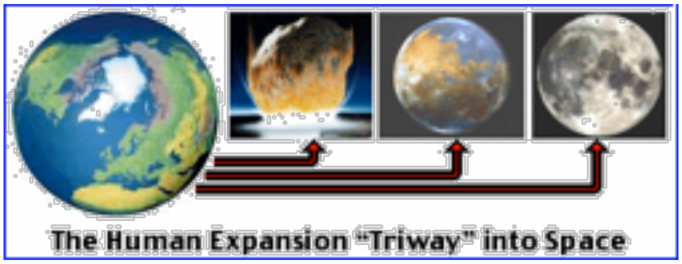
The target must be an object of a minimum size, about 100 meters in longest axis. Yes, that does seem to offer a choice guaranteed to be booooring! But no larger, more interesting target that is also a PHO will come any where near Earth in the coming two decades. And as this is a human mission, it can't go too far afield if the mass of consumables taken along is beyond a certain limit.

The famous **Rose Bowl** is 880 ft long rim to rim, half the length of 1760 ft long **Itokawa** asteroid

Itokawa, visited by Japan's Hayabusa sample return probe, is the smallest asteroid visited to date. NASA's two candidate objects are significantly smaller and would easily fit on the Rose Bowl playing field. But for this purpose, size does mater, only smaller is better. The smaller the size range, the more numerous these objects are. The odds on a really big object hitting us are far, far lower than those of one much smaller, but still able to pack a significantly disruptive punch.

Why we "Moon people" should care

Back in July of 2007, I put together a PowerPoint presentation and PDF Slide Show called "The Human Expansion Triway into Space"



http://www.moonsociety.org/presentations/ppt/Triway1.ppt
http://www.moonsociety.org/presentations/pdf/Triway1.pdf

The point of this presentation is that far from not having our act together, the common impression of the media, of congress, and the public, Moon enthusiasts, Mars enthusiasts, and Asteroid enthusiasts have a common goal: preserving Earth and Humankind. There are three approaches to this directive and tall three need to be, must be, pursued. So while each group pursues different projects, these activities demand to be seen as complementary, not as alternatives.

As you go through the presentation, we show how each of these efforts can help achieve the specific goals of both the others. In other words, from a Moo Society point of view, the opening up of a human frontier on Mars is essential, as is the effort to preserve the Earth we all love from significant destruction by mindless errand astrochunks. Even if the asteroid contingency and the Mars contingency does not do us the courtesy of offering corresponding support to the establishment of a lunar frontier, that does not excuse us from doing the right thing. In short, while a mission to a PHO near Earth Object seems like a diversion and distraction, we sincerely believe that the Moon-enthusiast community should support it.

What we should not be doing, is to petulantly try to derail such a mission in favor of a Constellation type Moon mission guaranteed to end in "Flags & Footprints 2" but this is precisely what many well-known, and understandably disappointed lunar advocates are doing. It serves no purpose to name names. They are identifying themselves quite freely.

But let us go beyond tacit support of this limited asteroid mission, beyond vocal support, to activist insistence that the mission be done right! And that means that the chosen crew should be equipped to do a lot more than just "nose around!"

Mission Goals: Science

That the crew should "characterizes" the chosen object goes without saying. They would determine its **mineralogical makeup** and class (stony?, carbonaceous chondrite?, etc.) and determine its **physical character** (a solid chunk or a clump of loosely bonded rocks covered with dust - the "bean bag" type. Its basic shape and size and probable mass and rotational axes may have been determined by telescopic observations from Earth but will be determined with greater precision by the crew. The experimental value for its gravitational field will tell us its density and mass distribution (homogenous vs. clumpy).

We should also "tag" this chunk, placing a transponder, so that the object emits a signal that will help us determine its whereabouts with extreme accuracy. A complex multi-axial rotation, common to small objects, may well complicate the choice of a tagging site, as well as introduce some level of risk to crew movements, should there be a "whip" movement anywhere in such a complex multi-axial rotation cycle.

Mission Goals: Critical Experiments

But if these are the be-all and end-all of the mission goals, then we are wasting our money. The real mission, after these preliminary investigations are over, should be to put in place two or more experiments, to be operated in tandem, not concurrently, to test various theories of how best to alter orbits of objects of this size and type. "There are several ways to deflect asteroids, though none have ever been tried. The approaches fall into two categories -

impulsive deflectors that nudge the asteroid instantaneously or within a few seconds, and "slow push" deflectors that apply a weak force to the asteroid for many years."

http://geology.com/articles/earth-crossing-asteroids.shtml

Planting a nuke, the "macho" masculine choice, makes no sense if the object is not solid. Punch a bean bag and it just rearranges itself. It makes more sense to take two or three of the most promising "slow push" options and install the needed equipment to activate each in turn, not both or all at once, so we can measure the amount of deflection we get per amount of mass of the installed device(es) to enable us to judge with which system we get the most bang for our buck. Now some caution here: any given system may prove superior for a set size/mass range and set physical makeup of the object in question, but work poorly for other types of objects. Our choice of methods to test with this first visit will be affected by their total cargo mass, and ease or difficulty of deployment, as well as the need for time delays. Now none of these experiments will yield really good data, if we do not "tag" the object first so that we can follow orbital deflection changes with a very high degree of accuracy.

The Planetary Society ran **a design competition**, called "**Tagging Apophis**" with a significant $50,000 prize, and announced the three wining proposals in early 2008. It is notable that none of them decided to place the tagging device anywhere on the surface of the asteroid, but instead, all three chose to put the device in a stable orbit around the object. That avoids periods in which the tagging device might be out line-of-sight from Earth. So this gives us a jump-start on this mission requirement.

On the side of these options being adopted:

For once the curiosity of planetary scientists is not the only lobby to which NASA will listen. There is now a very vocal community of scientists and others, some of them within the agency, concerned about developing asteroid deflection options in the event that a NEO is determined to be a near-term threat, that is, on a course that could result in a near-future impact with Earth of a magnitude to cause significant regional or even global disruption and destruction.

I must admit to having been one of the "asteroid denialists" in the sense that "the odds that Canada and Northern Europe and Russia will be 'wiped clean' by advancing glaciers at sometime in the next 25,000 years is significantly greater than the odds of a really destructive impact in that same period. But no one in Canada, or in northern Europe and Russia is losing any sleep over it." I still feel that way. But that is not the point. **The point is that affordable discretion is better than gambling.**

Asteroids and the Moon

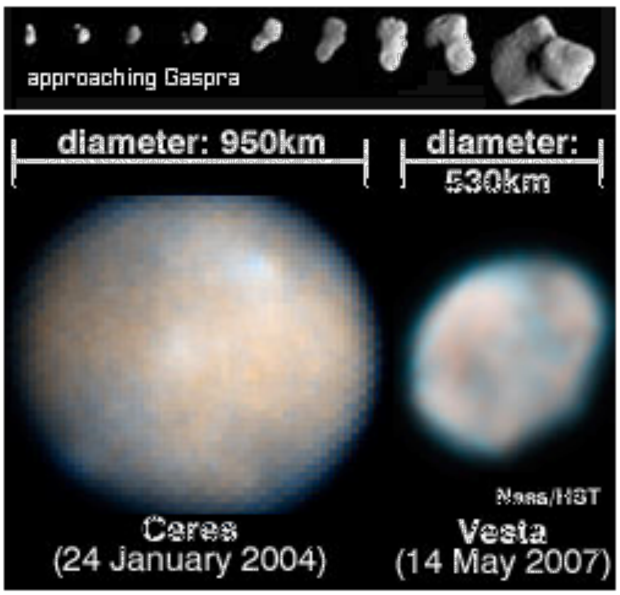
Of course, an errant asteroid could hit the Moon and possibly wipe out a settlement. Actually, Earth's much deeper gravity well makes Earth a likelier target by 8:1 odds. But the lesson is that Planetary Defense is a good thing for a lunar frontier civilization also. So for Moon-enthusiasts also, there is something in this mission for us as well. So we should support this mission, and if we are going to do this, let's make the most of it, or let's not do it at all.

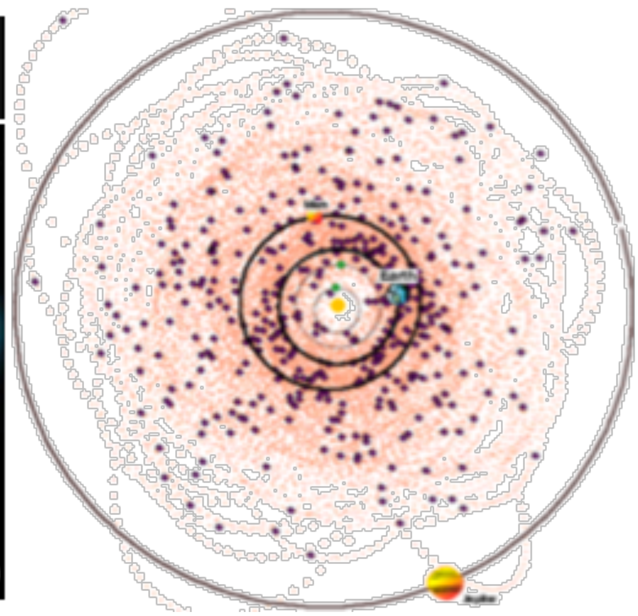
Further, even if we do not go to such a target near Earth object with mining in mind, we are bound to learn things that will prepare future asteroid miners for the conditions that they will face. Now while in the previous article I suggested that near term, we concentrate our asteroid mining efforts on the Moon first. Make no mistake that in time, asteroid sources of badly needed "Moon-deficient" metals and volatiles (notably Carbon, Hydrogen, Nitrogen needed for agriculture and biosphere) will be developed. Earth will need the metals; we will need both metals and volatiles. Trade will benefit all parties and lead to population growth on Moon, Mars, and asteroids as well as "space settlements" in Earth orbit or the Lagrange Points or amongst the asteroids.

Our movement into space cannot be addressed as a set of alternatives. We need to do it all, and each option we pursue increases the long-term viability of the others. The Moon is anything but the "end of the road." It is the key hub, if not in transportation terms, certainly in terms of trade and the Exo-Terrestrial Economy.

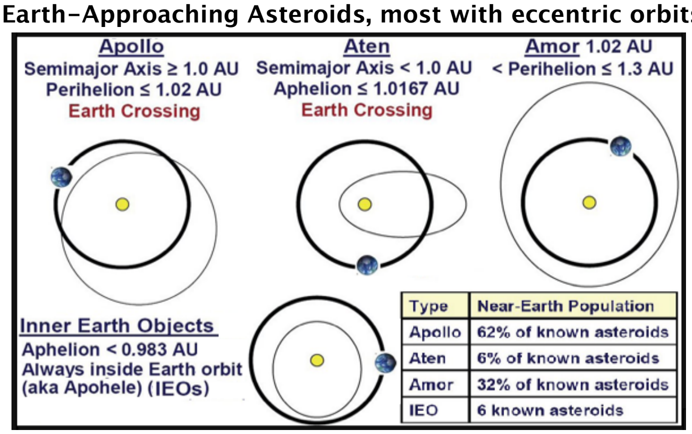
We must stop this adolescent infighting. We must all adopt the Human Expansion Triway to Space mind-set. Separately, we will each fail. Together we will each win. The future of Earth itself, and of Humanity and Gaia, whether Earthbound or expanding through interplanetary space, even someday interstellar, is at stake. **PK**

ASTEROID PHOTO GALLERY

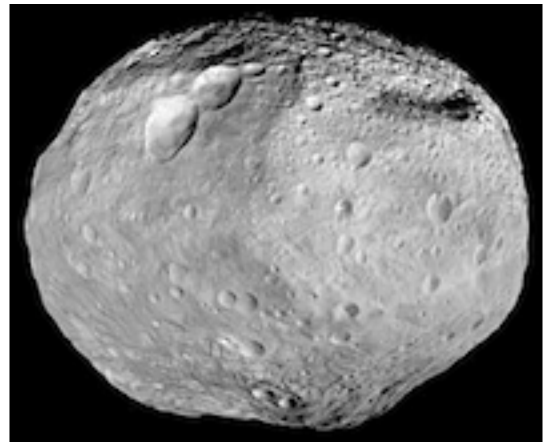




Below: NASA Plot of Earth-Approaching Asteroids, most with eccentric orbits in/out of Main Belt.



Type	Near-Earth Population
Apollo	62% of known asteroids
Aten	6% of known asteroids
Amor	32% of known asteroids
IEO	6 known asteroids



L: Little Itokawa **R:** enormously larger Vesta