MINING AN IRON NEA

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Abstract

Less than 20 meter diameter iron NEAs, if they are in very easily accessible orbits, are attractive resources for early exploitation. Only two 2 km NEAs, one an Amor and one an Aten, are presently known. The possibility of finding such iron NEAs with radio telescopes and light spectra is very high. This data is not presently available except for a few of the larger easily seen NEAs which are almost all stones.

Exploitation may be by Antarctic impact, or capture into low Earth Orbit LEO, geosynchronous Earth orbit GEO or highly eccentric Earth orbit HEEO with the aid of atmospheric braking. Antarctic impact will require the least possible impact velocity with magnetic detection of the fragments. Capture into HEEO and orbital modification to reach LEO or GEO will depend upon the orbital vector mechanics of the Earth the NEA and the transfer orbit. Propulsion will be by solar collector electric arc production of high velocity jets of metallic vapor with the iron propellant of the NEA as the anode.

Introduction

The platinum group metals in nickel-iron asteroids have been considered for a long time as attractive resources for exploitation. This paper considers the possible early exploitation of small, less than 20 meter diameter iron NEAs, if they are in very easily accessible orbits. At the present rate of discovery, the possibility of finding a few such NEAs is very good. The discovery of such irons will depend upon detection with radio telescopes and light spectra. This data is not presently available except for a few of the larger NEAs. Easily seen NEAs are just about all stones, and are not easily exploitable.

To exploit the NEA, it may need to be impacted with the Earth, preferably on the Antarctic ice cap. Impact velocity is the vector sum of the Earth's escape velocity and the velocity difference of the Earth and the NEA minus the atmospheric braking velocity reduction. This will result in a deep crater in the ice of the Antarctic ice cap. Much of the NEA will be vaporized. Metallic fragments can be detected magnetically and recovered from the ice cap. Impact velocity should be the minimized to reduce the vaporization of the NEA.

One method of reducing the impact velocity is to capture the NEA into a highly eccentric Earth orbit from a Solar centric orbit. Successive passes through the atmosphere can reduce the eccentricity of the orbit and thus the potential impact velocity. This is to reduce the impact velocity as far as possible below the Earth's escape velocity of 6.95 miles per second.

Other options are available for iron NEAs such as capture into Earth orbit, deflection into non-threatening orbits, crashing into the Moon or deflection into the Sun. In Earth orbit the iron can be recovered for use as propellant for use in moving things in orbit, or for deflection of stony asteroids into non-threatening orbits.

To build solar powered satellites, develop near Earth orbital industries, and support the International Space Station and other activities in LEO and GEO, we need to use resources from some of the more accessible NEAs and possibly Phobos and Deimos, the moons of Mars. The high gravity of the Moon precludes it from being an early major source of raw materials. The present development of space flight precludes manned flight to NEAs, so automated remote systems must be used for early acquisition of constructional materials and supplies. The recent landing of NEAR on Eros, the largest but not most accessible of the NEAs, demonstrates the method of landing on a NEA. Since the initial probes will be too small to be manned, and our ability to send a manned expedition has not been developed, they must be automated and controlled remotely from Earth or Earth orbit.

Options

Options available for threatening NEAs are capture into Earth orbit, deflection into non-threatening orbits, crashing into the Moon or deflection into the Sun. In Earth orbit the iron can be recovered for use as propellant, for structural purposes or for shielding. In solar centric orbit iron asteroids are most useful for moving things in orbit, or for deflection of stony asteroids into non-threatening orbits.

Earth's orbit

The orbital elements of the Earth's orbit are, the semi-major axis $\alpha = 1.000AU$, orbital eccentricity $\varepsilon = 0.0167$, longitude of perihelion $\Pi = 102.416$ °, true longitude at epoch = 276.117 °, mean distance from sun = 149.5×10^6 km, and equatorial radius = 6378 km. The plane of the Earth's orbit defines the plane of the ecliptic, and the autumn equinox points to the first point of Aries ♈, to which all other intersecting orbital planes are referred.

NEA orbits

Near Earth or Earth approaching asteroids are in elliptical solar centric orbits in an orbital plane intersecting the ecliptic plane at an angle i, the line of intersection of the planes forms the line of nodes I, the NEAs ascending node defines an angle Ω with the vernal equinox ♈. The orbit of the NEA is described in its plane by the semimajor axes α, the eccentricity ε, and the position in the orbital plane by the angle between the line of nodes n, and the perihelion major axes ω. This angle is defined by three points, the NEAs ascending node, the Suns center and the perihelion. The position of the NEA in its orbit must also be stated at a particular reference time or epoch (*E*) combining this with the NEAs period (*T*) can define its position at the desired time.

$$\alpha = T^{2/3}$$

α is in astronautical units and (*T*) is in years.

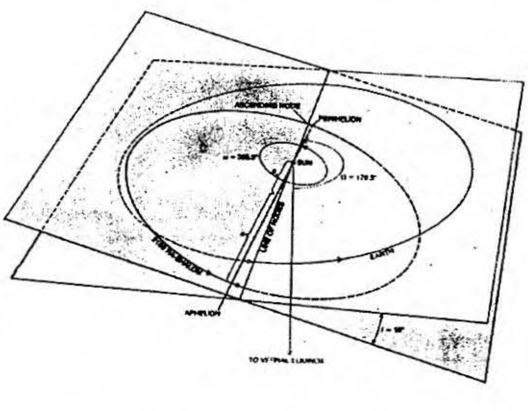

Fig. 1 The orbit of the olivine rich C2 or C3 Aten 2100 Ra-Shalom. The position of the orbit plane with respect to the plane of the ecliptic denoted by ω. The asteroid's position in its orbit is computed from its position at some reference time, the epoch E, and its period T.

Bottke et.al. estimate that there are ~900 kilometer-sized NEAs, of which 29%, 65% and 6% are in Amor, Apollo and Aten orbits, respectively.[5] Roughly 40% of the larger than kilometer-sized NEAs with $H \leq 18$ have been found. The remainder, on highly eccentric and inclined orbits, are more difficult to detect.[5] As of April 2000, ~950 NEAs have been detected that have absolute magnitude H between 10 and 29, corresponding to asteroid diameters between 40 and 0.01 km.[5] Only the 16 NEAs brighter than H ~ 14 (D > 7 km) may have been completely discovered.[5]

About half of the NEAs have $\alpha \geq 2.0$ AU. NEAs in this region are generally removed within a few million years by solar collisions or through close encounters with Jupiter. The remaining NEAs reach $\alpha < 2.0$ AU orbits by encounters with terrestrial planets, though they must first survive multiple resonances between 1.8 and 2.0 AU (that is, 4 : 1 and 5 : 1 resonance with Jupiter). Many NEAs with $\varepsilon \leq 0.40$ and $\iota \leq 10$ ° have been discovered.

Propulsion

Electric arcs using iron from the iron asteroid can be used as propellant in a high intensity electric arc to produce a neutral high velocity jet of iron vapor as in a carbon arc searchlight. The orbit of the iron NEA can be gradually changed so that it can be captured in first a highly eccentric Earth orbit and then finally into a desired Earth orbit. Since the orbits of NEAs are solar orbits rather than Earth orbits, the orbits must be changed so they can be captured as Earth satellites.

The electric arc is a self-sustained discharge having a low voltage drop and capable of supporting large currents. A pool of liquid iron is formed on the anode, the FeNEA surface in a high intensity electric arc. The boiling temperature of the iron anode is 2600 ° K and of nickel is 2450 ° K.[7] The liquid iron-nickel pool is vaporized and ejected in a high velocity jet of neutral plasma.[6,7] The gas temperature of a high-intensity arc can be as high as 40,000 ° K.[7] A significant part of the input energy is delivered to the anode vapor rather than to the anode itself.[6] The power requirement is 1- 4 kW-h / kg of electrode vaporized.

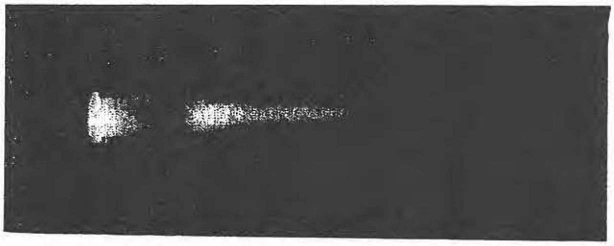

Fig. 2. Pinch Effect constricts plasma jet so that the jet is pulled away from the anode.

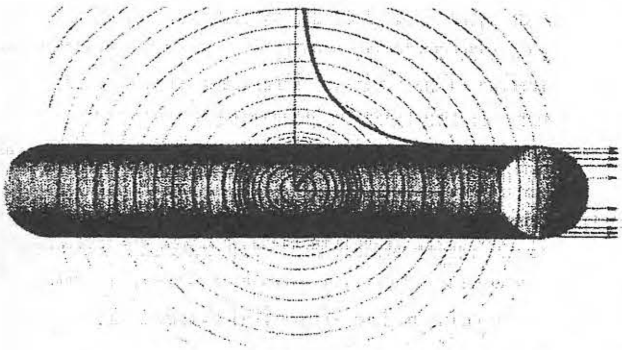

Fig. 3. Magnetic field , self-induced by stream of plasma, causes pinch effect. Field reaches maximum density at edge of the plasma, as indicated by concentric circles and by curve.

The electric arc is chosen over other propulsion methods because of it's simplicity. It bypasses the equipment needed for anchorage, material handling and processing needed for other propulsion methods. It bypasses the anchorage and material handling problems involved in drilling wells into water ice bearing NEAs. It bypasses the anchorage, mining, material handling and complex structural requirements of mass drivers. Anchorage can be magnetic. A source of electrical energy is required for all propulsion methods using NEA materials as propulsion mass. The robotic and communications requirements for control are common to all the systems.

Electric energy for the electric arcs can be obtained from solar cells and or nuclear reactors.

Composition of Iron Meteorites

Meteorite falls are 3% Irons with 99% metallic Fe-Ni-Co alloys. Stony Iron meteorites are 1% of meteorite falls with 50% ferrous metal alloys and 50% silicates. Lebofsky et al. (1990) reported 3 μm absorption indicative of water on some M-type asteroids. This suggests that objects of significantly different composition may be included in the M-type asteroids.[1] Asteroids are being found to often be conglomerations of different materials which may account for the water in some M-type asteroids.

The value of a ten meter diameter iron asteroid will depend on the type of FeNEA found. The values depend upon the chromium cobalt, nickel, gallium, ruthenium, rhodium, palladium, iridium and platinum contents of the iron asteroid. Iron was not considered here to have value except as reaction mass. Ten meter diameter hexahedrites have a value of $5,589,000, coarse octahedrites a value of $36,857,000, very fine octahedrites a value of $47,813,000 and the rare nickel rich ataxites have a value of $91,331,000.

Attachment of the vehicle to the iron or stony iron NEA is quite simple, merely use magnets. This is the simplest method of attachment to a body with negligible gravity that I can conceive.

Space Billiards

To deflect an asteroid threatening collision with the Earth, an iron NEA may be deflected into an orbit that will affect the threatening asteroid in several different ways. One way is the simplest, that is a collision to shatter or deflect the asteroid into a non threatening orbit. Here the NEAs composition and orbital dynamics of the two orbits enters into the problem.

If the target body is not too much larger than the iron NEA, a collision might shatter the target with the parts in new orbits. Loose surface material will merely continue on in the original orbit of the target to hit the Earth as a shower of meteorites, which will do little or no damage, if the particles are not too large. If the target is an agglomeration of asteroidal material, as many asteroids are appearing to be, some of the parts may not be deflected enough to miss the Earth. A loose agglomeration might merely absorb the iron NEA if the collision velocity is not too high. The combined body will assume a new orbit, hopefully not a threatening new orbit. Again loose surface material will be shed to follow the original orbit to impact earth as a meteor shower. Lets hope none of the pieces are too large.

Another option is to rendezvous the iron NEA with the threatening body, if it isn't too large, and use the iron as a propellant to deflect the combined body to a less threatening orbit. Due to the extremely small mutual gravitational attractions of the parts of an aggregate, the body might fragment if thrust is applied to a part of the body. The parts that do not remain attached will continue on to impact the earth. Careful preliminary observation of the target body is indicated before trying to change the orbit of the threatening body.

If a surface part of a nonthreatening NEO agglomeration is iron or a stony iron in composition, it might be removed from the main body of the NEO. This can be done by using the iron as a propellant to remove the iron body against the weak gravitational attraction of the NEO. This part of the NEO can then be pushed into a desired orbit, which is a mining operation. It can then be pushed into an Earth capture orbit. Such an operation will require detailed information about the surface and composition of the target NEO.

Amor asteroid 6178 or 1986 DA is brighter than other radar-detected asteroids which indicates that it is a Ni-Fe asteroid derived from the interior of a much larger object that was melted, differentiated, cooled and was subsequently disrupted in a catastrophic collision. This 2-kilometer asteroid appears smooth at the centimeter to meter scales but is extremely irregular at the 10 to 100 meter scales, might be (or have been a part of) the parent body of some iron meteorites.[2] The semimajor axis $\alpha = 2.81664$ AU, the eccentricity $\varepsilon = 0.58538$, the inclination $\iota = 4.2958$ °, the longitude of the ascending node $\Omega = 64.5355$ °, the argument of perihelion $\omega = 126.704°$, the mean anomaly $M = 358.4117°$, the period is 4.728 years[2], and a rotation period of 3.58 hours[3]. The last perihelion was June 15, 2000 and the next perihelion is March 6, 2005.

Aten asteroid 3554 Amun is a 2.0 kilometer metallic NEO with a perihelion q = 0.70 AU, semimajor axis $\alpha = 0.97$ AU, eccentricity $\varepsilon = 0.280$, and a high inclination $\iota = 23.4$ °.[3,4] This Aten approaches the Earth orbit every 351 days. The last perihelion was February 12, 2001, and the next will be Jan. 29, 2002. This is the most easily accessible of the two known Iron NEOs at this time in spite of the high inclination of 23.4 °. It's large size of 2 km precludes use in the near future, unless a smaller iron fragment is found on it's surface, or if iron fragments can be swept from its surface to be composited into a useful mass of iron propellant for other missions or return to Earth orbit.

If a large loose stone fragment, with a desired composition, is on the surface of a NEO, it might be removed by bumping it with the small powered iron NEO. Then the powered iron NEO can catch up with the stone fragment, rendezvous with it, and push it into an Earth capture orbit along with the iron NEO. This is again a mining operation to obtain materials such as structural magnesium, calcium for electrical conductors, aluminum, silicon and oxygen.

Up to 2 km/sec. of excess velocity can be lost by carefully passing by the Moon once or twice on the approach to the Earth's capture cross section. This can help in bringing the FeNEO into the top of the atmosphere for atmospheric breaking to achieve Earth orbit.

Atmospheric braking for capture into a HEEO will require careful aiming as control will be lost when the stone enters the atmosphere. Care will have to be taken to prevent the orbit of the stone from decaying into an Earth impact orbit.

Earth-Orbit capture

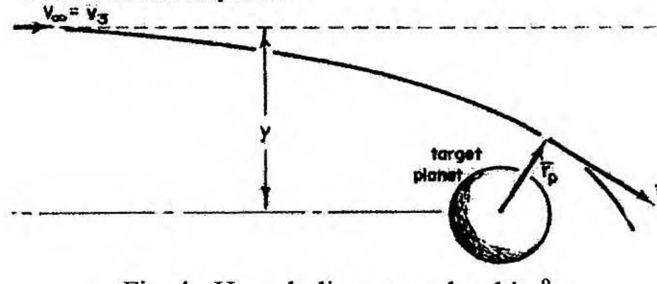

Fig. 4. Hyperbolic approach orbit. [9]

The hyperbolic approach trajectory is shown where $\mathbf{v}_3$ is the hyperbolic excess velocity upon entrance to the Earth's sphere of influence and Y is the offset distance as shown in Fig. 4. [9]

The effective cross section of the Earth represents a rather large target as shown in Fig. 5. To take advantage of atmospheric breaking a much smaller target must be considered; only a thin annulus of radius **b** and width of **db.** [9] The cross section for hitting the atmosphere of the Earth is called the "re-entry corridor" which if it is not entered will result in impact or deflection into the other leg of the hyperbolic orbit, in which case it will be lost.

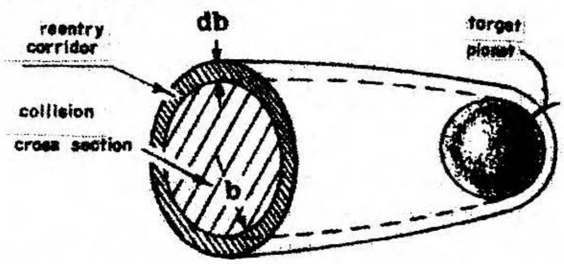

Figure 5. Effective Cross Section [9]

Conclusions

A combination of using solar powered high intensity electric arcs to use the nickel-iron of the small FeNEA as propellant, orbital interaction with the Moon, and atmospheric breaking may all be used to reduce the excess velocity of the FeNEA to achieve Earth orbit. The ability to affect the orbit of the small FeNEA up until it's entrance into the atmosphere should give adequate time to make decisions as to whether to abort the capture into Earth orbit. Even as it enters the capture cross section, it still may be deflected away from the atmosphere into a hyperbolic orbit away from the Earth. Once the FeNEA touches the atmosphere, the solar collectors and other equipment will be destroyed.

After capture into an HEEO, another automated and ground controlled vehicle might be landed on the FeNEO to bring it into LEO or GEO. This is a possible way of bringing NEA resources to Earth orbit for propellant and structural purposes to establish man in space by small remotely controlled automated missions.

The present dearth of compositional information on easily accessible small NEAs makes this approach to exploitation of near-Earth asteroidal resources academic. This and the exploitation of water from NEA water bearing bodies by drilling, are blocked by the same information dearth.[8] Nothing can be planned for the foreseeable future for exploitation of these near-Earth resources without spectral and radar data on these hard to see and hard to access bodies. The bodies of greatest interest have magnitudes of $20 > H > 30$, those with diameters less than 100 meters. Because of their proximity of their orbits to the Earth's orbit, times when they can be observed are rare. Because they are so small, they do not reflect much light. Tracking them is difficult because they move so rapidly across the star field. For those bodies that might contain water, their albedos are very low, making them nearly impossible to find. Radar will be important for determining the metallic content of FeNEAs and stony irons. Again the lack of opportunities to observe these bodies is a problem.

Could some of the discoverers of these bodies get spectra of the faster moving bodies at the time of discovery? Just the discovery of the bodies is not enough. We must have the compositional information for planning any future exploitation of or protection from threatening NEOs. We need this information before we can begin to acquire the resources from NEAs to construct solar power satellites.

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