SPACEWATCH SEARCH FOR MATERIAL RESOURCES NEAR EARTH

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Abstract

Since 1989 the Spacewatch Project has discovered more than 192 Near-Earth Objects (NEOs). By virtue of a fainter limit of detection compared to other surveys, Spacewatch finds a higher proportion of small asteroids (less than 300 meters in diameter). One of these, 1998 KY_{26}, is the most accessible to spacecraft among asteroids with well-known orbits. Spacewatch has provided the first- and so far the only- empirical information on the critical specific energy and tensile strength of asteroid material. These parameters are relevant to the mechanics of large-scale mining. Our new 1.8-meter telescope will reach a magnitude fainter than the venerable 0.9-m Spacewatch Telescope. It will help NEOs discovered on previous apparitions to be recovered years later, thus improving knowledge of their orbital elements well enough that they will not be lost. A second major enhancement to Spacewatch is a mosaic of CCD detectors covering ten times as much sky as the present detector. It should detect 300 Earth-approachers per year. The combination of the wide field coverage of the 0.9-m telescope and the high sensitivity of the 1.8-m telescope will provide Spacewatch with a most comprehensive capability for thorough exploration of space near Earth's orbit.

Observing by Spacewatch

Since 1983, Spacewatch has been surveying the night sky with the 0.9-m telescope of the Steward Observatory on Kitt Peak. The principles of Spacewatch observing have been described.[1-10] Approximately 2000 deg^2 are surveyed per year with the 0.9-m telescope to a limiting V magnitude of 21.5.

NEO Discoveries by Spacewatch

Spacewatch was the first to discover an NEO with a CCD (1989 UP), first to discover an NEO by software (1990 SS), and has discovered about 28% of all NEOs known to date. About 20% of the objects we discover are larger than 1 km in diameter and 26% are smaller than 100 m. Spacewatch can find the large NEOs while they are as far away as the main asteroid belt, near the aphelia of their orbits. It is important that the discoveries of NEOs are made with a system of known biases and known absolute efficiency so that the true distributions versus absolute magnitude and orbital elements and the total number of objects can be extrapolated accurately. The absolute sensitivity and efficiency of Spacewatch scans have been characterized.[10,11]

With more NEOs found with the well-understood Spacewatch system and more thorough analyses, more refined understanding of the present distributions of NEOs as well as the mechanism by which they left the main belt should be possible. Spacewatch initially debiased in the four "dimensions" of (a, e, i, H), a procedure that is appropriate for surveys which are not able to provide the three angular orbit elements (ù, Ù, *M*), for small sample populations, and for data with distributions that are expected to be "flat" with respect to the three angular elements.[11] The new technique will allow debiasing in all seven elements (a, e, i, ù, Ù, *M*, H). It will be applied to new Spacewatch data and will provide theoreticians with the debiased observational distributions they need to compute the relative contribution to the overall NEA population from each major resonance in the main belt.[12,13]

Small NEOs and the Physical Properties of Asteroid Material

The rotation rates and distribution of sizes of NEOs smaller than 300 m are keys to the mechanical strength of asteroid material. Our faint limiting magnitude and visual examination of scan imagery during the night for faint streaks caused by Very Fast Moving Objects (VFMOs) yield a higher proportion of small asteroids than do NEO search programs that rely on detecting motion of pointlike images. Among the 11 known asteroids with minimum orbital intersection distances (MOIDs) less than 0.001 AU, six were found by Spacewatch.[14] Notable discoveries of small objects by Spacewatch include the smallest known asteroid (1993 KA_2 with absolute magnitude H=29.2 => 4-9 meters diameter), the closest observed approach of any asteroid to the Earth (1994 XM_1 at 105,000 km), and the most rapidly rotating NEO (1998 KY_{26} in 10.7 min). This is so rapid that it cannot be held together by gravity alone, so it is the best example of a monolithic asteroid. 1998 KY_{26} is also more accessible to spacecraft than any other asteroid with a well known orbit.[15]

Spacewatch has been filling in the gap of knowledge in the range of NEO sizes between meteoroids and asteroids (6-300 meters) in three ways. First, Spacewatch observations have shown an enhancement in the numbers of NEOs smaller than 100 m in diameter compared to a power-law extrapolation from larger sizes.[16] This can be explained if the NEOs originate in the main belt and there are bumps in the size distribution of larger main belt asteroids.[17,18] Analysis of Spacewatch observations of the main belt showed there are indeed departures from a power law distribution of absolute magnitudes.[11] More recent Spacewatch data will dramatically improve knowledge of the distribution of sizes of NEOs.

Secondly, we will better resolve the shape of the size distribution of NEOs in the range of sizes where collision dynamics are believed to make a transition between gravity-dominated and strength-dominated conditions. (Knowledge of the cohesion of asteroid material is relevant to mining.) The slope of the absolute magnitude distribution and a kink at absolute magnitude $H \approx 13$ have already been used to derive information about the critical specific energy and the collisional processing of asteroids.[19] High resolution knowledge of the size distribution between the diameters of 40 m and 600 m should provide a more direct determination of this strength parameter.

Thirdly, accurate orbits and ephemerides of a sufficient number of small NEOs will permit lightcurves and rotation periods of these objects to be observed by others and perhaps ourselves, further establishing limits on the mechanical strength of their materials in a manner similar to that done with 1998 KY_{26}.[15]

NEO Recoveries and Astrometry

Orbits of NEOs need to be known accurately to allow extrapolation to the future dates of spacecraft missions. This usually requires recovering the objects on their next apparitions years after the original discoveries. The need for second-apparition recoveries is rapidly increasing as other wide-area NEO search systems come on line. Due to the selection effect favoring discovery when objects make their closest approaches to Earth, asteroids tend to be much fainter on their return apparitions. Objects found by the survey groups that reach only to the 19th mag may be too faint at their next apparitions for those groups to recover in their routine surveys. Our specialty of faint limiting magnitude is essential in this context. Indeed, many of the asteroids Spacewatch finds are already beyond the reach of followup observers with smaller telescopes, so we very diligently recover and follow up our own objects.

The 1.8-meter Spacewatch Telescope

Our new telescope will extend our limiting magnitude to V=22.5. We hope to have the optics and detector installed before the end of 1999, so the telescope should be on line in the year 2000. The field of view will be 0.8 deg in diameter and the image scale will be 1.0 arcsec/pixel using the same type of detector we presently have on the 0.9-m telescope. The role of the 1.8-m telescope in the context of NEOs will be mostly in recovery of NEOs that are faint on their return apparitions.

This was a year of intensive mechanical engineering on the 1.8-m telescope.[20] The instrument stage that focuses, derotates, and tips and tilts the detector was built and tested in our lab on a custom jig that permits operation through the full range of zenith angles to check for bearing operation at all angles with respect to gravity. It passed. Software to operate all 5 degrees of freedom was worked on.

The telescope itself was successfully pointed and tracked on stars with a TV finder scope. Software to determine and correct for misalignments of the alt-az mount is under development. Performance of the telescope drives was evaluated by consulting engineers to address the issue of unexpectedly high frictional resistance to azimuth motion by the cable wrap assembly and the stabilizer wheels. These consultants also were engaged to design the equipment and procedures for inserting and extracting the primary mirror from the telescope, a procedure that will have to be repeated every year to realuminize the mirror.

The LPL Shop designed experiments to test the adhesive that will suspend the back of the relatively large secondary mirror from a multitude of little tripod "fingers". The epoxy passed thermal cycling and humidity cycling tests at four times nominal load. A procedure for installing the secondary also had to be invented. Fortunately this mirror has a transparent protective overcoat on the aluminum so it will not have to be removed from the telescope periodically for re-aluminizing.

Delivery of the lenses for the coma corrector is expected from Tucson Optical Research Corp. before the end of June 1999. Design of the cell to hold the lenses is well underway.

Detectors

The CCDs we have been using with great success at the 0.9-m telescope have been made by Scientific Imaging Technologies (SITe®) of Beaverton, OR. We received the SITe® 2Kx2K CCD for the 1.8-m telescope, and according to the vendor's quality control sheet it is cosmetically almost perfect, being devoid of column or row defects. The cryostat for the CCD for the 1.8-m telescope, built by Infrared Laboratories, Inc. of Tucson, AZ, was delivered in September 1998. Cooling is by a closed-cycle gas circulation system, eliminating the need for the observer to handle liquid nitrogen. It passed our vacuum and thermal tests. We ordered the CCD controller from Astronomical Research Cameras, Inc. of San Diego and expect delivery by June 1999.

The Mosaic of CCDs

A commercially available CCD has appeared which can be assembled into large mosaics without gaps. It is the EEV, Inc. 2048x4608 three-side buttable CCD with 13.5 micron square pixels adopted by the MMT Observatory for its Megacam. This type of detector costs the same per unit area as our SITe® 2Kx2K non-buttable CCD and has the same high sensitivity and low noise. The fact that a large observatory with many users such as the MMTO has selected this type of CCD gives us confidence that it is available, predictable, and supportable. We have already ordered four detectors, comprising a total of 37.7 million pixels. Delivery is expected in Feb. 2000. The optics have been designed, toleranced, and sent out for bid. With it we will be able to observe sky area 10 times faster than the present rate to the same limiting magnitude, or if we choose, even more sky with a compromise in sensitivity. The latter choice would net more of the larger NEOs, while the former would preserve the same mix of large and small NEOs that we have been detecting. Of course we will continue to use the 1988-vintage SITe® CCD on the 0.9-m telescope until the mosaic goes into operation.

The mosaic detector system will be installed on the 0.9-m Spacewatch Telescope for practical reasons. To keep down the cost of the mosaic of CCDs it is important to use small pixels. To cover an adequate area of sky with small pixels it is necessary to have a short focal length. The pixels of the chosen CCD are 13.5 microns square, so a focal length of 2.7 meters is required for our favorite image scale of 1 arcsec per pixel. This focal length can be achieved more readily with the smaller telescope aperture because it does not produce too fast an f/number for the large achromatic lenses needed to correct for coma and flatten the field of view. The four CCDs will cover a solid angle of 2.9 square degrees, about 9.7 times larger than our present CCD. To limit detections to the 21st magnitude and avoid excessive saturation of the tiny pixels, exposure times will be 60 seconds. Each of the four CCDs can be read out in 20 seconds and they will be read simultaneously. Stare pictures, rather than TDI scans, will have to be used because at this large a field of view the paths of stars projected on the flat CCD would not be straight. The telescope pointing would be reset at the same time the CCDs are being read out, resulting in an efficient use of telescope time.

Summary

We will continue to search for Earth-approaching asteroids with calibrated sensitivity and efficiency so that the statistics of discovered objects can be corrected for observational selection effects, yielding more realistic numbers of objects of the various classes as functions of absolute magnitude and orbital parameters. This information is awaited by theorists who derive evolutionary and physical properties of asteroids. The 1.8-m telescope will be used to recover NEOs and more distant objects that are too faint for other observatories.

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