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Overview

The purpose of Spacewatch is to explore the various populations of small objects within the solar system. Spacewatch provides data for studies of comets and asteroids, finds potential targets for space missions, and provides information on the environmental problem of possible impacts. This grant provided some of the funds for the Spacewatch Project from March 1, 1997 through Nov. 30, 1997. NASA has been requested to continue its support for this project with a new grant entitled "Spacewatch Survey of the Solar System", with McMillan as Principal Investigator.

Moving objects are discovered by scanning the sky with charge-coupled devices (CCDs) on the 0.9-meter Spacewatch Telescope of the University of Arizona on Kitt Peak (McMillan *et al.* 1986; Gehrels 1991; Scotti 1994). Each Spacewatch scan consists of three drift scan passes over an area of sky using a CCD filtered to a bandpass of 0.5-1.0 μm (approximately V+R+I with peak sensitivity at 0.7 μm). The effective exposure time for each pass is 143 seconds multiplied by the secant of the declination. The area covered by each scan is 32 arcminutes in declination by about 28 minutes of time in right ascension. The image scale is 1.05 arcseconds per pixel. Three passes take about 1.5 hours to complete and show motions of individual objects over a one hour time baseline. The limiting magnitude is about 21.5 in single scans.

We have been finding some 30,000 new asteroids per year and applying their statistics to the study of the collisional history of the solar system. As of the end of the observing run of Nov. 1997, Spacewatch had found a total of 153 Near-Earth Asteroids (NEAs) and 8 new comets since the project began in the 1980s, and had recovered one lost comet (P/Spitaler in 1993). The total number of NEAs found by Spacewatch big enough to be hazardous if they were to impact the Earth is 36. Spacewatch is also efficient in recovery of known comets and has detected and reported positions for more than 137,000 asteroids, mostly new ones in the main belt, including more than 16,000 asteroids designated by the Minor Planet Center (MPC).

Distinctions held by the Spacewatch group include:

- First to use CCD-scanning routinely in astronomy,
- First to use CCDs to survey the sky for comets and asteroids,
- First astronomical group to develop automated, real-time software for moving object detection,
- First to discover a near-Earth asteroid (1990 SS) by software,
- First to use a CCD to discover a comet (1991x, which was also the faintest comet at

the time of discovery),

- Detected the smallest known asteroid (1993 KA2 with absolute magnitude H=29.2 which translates to 4-9 meters diameter, depending on whether it is an S or a C type),
- Detected the closest approach of any asteroid to the Earth (105,000 km; 1994 XM1),
- Discovered the S or C type asteroid with closest approach to the Sun (0.120 AU; 1995 CR),
- Discovered four of the seven known Centaur asteroids, which represent a newly-found population in the outer parts of the solar system.

Spacewatch discoveries contribute to the assessment of the impact hazard. This problem is studied in detail in the book *Hazards due to Comets and Asteroids* (Gehrels, ed. 1994). Spacewatch complements other surveys that have wider area coverage at brighter magnitude, by exploring the hazards of objects down to a diameter of 200 m (H > 22) that approach within 0.05 AU of the Earth's orbit.

Scientific Accomplishments

Near-Earth Asteroids: Spacewatch discovered 9 Earth-approaching asteroids (5 Apollos and 4 Amors) between March 1 and November 30, 1997. Four of them are large enough to be considered hazardous if they impacted the Earth.

Comets: Four comets were discovered by Spacewatch observers during the period of performance of this grant. In all of 1997, five comets were found by Spacewatch, which is a record for us. The introduction of a coma corrector in 1995 and a more careful collimation of the telescope in August 1996 may have contributed to an increased sensitivity to objects with genuine coma.

Main Belt Asteroids: Jedicke and Metcalfe completed a study of the magnitude-frequency relations for three distance zones in the asteroid belt (Jedicke and Metcalfe 1997). The de-biasing technique developed by Jedicke and Metcalfe has also been made available to Tim Spahr at the University of Florida for his dissertation on main-belt statistics (with Prof. S. F. Dermott). Spahr and Jedicke have applied these techniques together to derive the completion of the Palomar-Leiden Survey, which is about 96% over the apparent-magnitude range 16-19.

Centaurs: In their analysis of Spacewatch data, Jedicke and Herron (1997) found that the Centaurs, which move in orbits approximately between those of Saturn and Neptune, may have a population about as great as that of the main-belt asteroids.

Hardware Development: A new telescope drive system was installed at the 0.9-m telescope in November 1997 by Spacewatch personnel. This replaces the system that was put into service in 1985. The new system is based on commercially procured servo controller cards controlled by software written in "C" running under DOS or Windows. This represents a major advance over the old system, the computer and electronics for which were unique and difficult to maintain. The old system also had no safety features and provided no opportunity for changes or enhancements to the software.

New Telescope and Building: In 1997, fabrication and installation of the 1.8-m telescope and the construction of its building were completed. This will be the largest telescope in the world dedicated full time to the search for previously unknown members of the solar system. Its 1.8-m aperture, sensitive CCD, and dedication to surveying will extend all of Spacewatch's exploration of the solar system to exciting new limits.

Selected Relevant Publications in the Grant Period

Starting with *Minor Planet Circular* 919 in 1984, Spacewatch has been reporting asteroid and comet observations on a monthly basis.

In *I.A.U. Circulars*, Spacewatch reports the recovery of comets and the discovery of interesting asteroids.

"Spacewatch", 1997, T. Gehrels, in *The Encyclopedia of Planetary Sciences,* J. H. Shirley & R. W. Fairbridge, Eds. London: Chapman and Hall, 774-775.

"Charge-coupled Devices", 1997, R. S. McMillan, in *The Encyclopedia of Planetary Science,* J. H. Shirley & R. W. Fairbridge, Eds. London: Chapman and Hall, 98-102.

"Observational Constraints on the Centaur Population", 1997, R. Jedicke and J. D. Herron, *Icarus* **127**, 494-507.

"The Orbital and Absolute Magnitude Distribution of Main Belt Asteroids", 1997, R. Jedicke and T. S. Metcalfe, *Icarus*, in press.