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AUTOMATED DETECTION OF ASTEROIDS IN REAL-TIME WITH THE SPACEWATCH TELESCOPE

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Abstract

The Spacewatch telescope on Kitt Peak is being used to survey for near-earth asteroids using a Tektronix TK2048 CCD in scanning mode. We hope to identify suitable low Δv candidates amongst the near-earth asteroid population as possible exploration targets, to identify those objects which pose a danger to life on earth, and to study the physical properties of the objects in near-earth space. Between 1990 September and 1991 June, 14 new earth-approaching asteroids including 1 Aten, 9 Apollo, and 4 Amor type asteroids were detected by automated software and discriminated by their angular rates from the rest of the detected asteroids in near-real time by the observer. The average of about 1.5 earth-approaching asteroids per month is comparable to the total number found by all other observatories combined. One other Apollo type asteroid was detected by the observer as a long trailed image. The positions of this last object were measured and the object was tracked by the observer in real time. This object was determined to be a 5-10 meter diameter object which passed within 170 000 kilometers of earth. Of the 14 automatically detected earth-approaching asteroids, 10 have been found at distances in excess of 0.5 AU from earth. An average of more than 2000 asteroids are detected each month. Positions, angular rates, and brightnesses are determined for each of these asteroids in real-time.

REAL-TIME AUTOMATED DETECTION

We are surveying for near-earth asteroids with a TK2048 CCD operated in the scanning mode (Gehrels, *et al.*, 1991). We use the Spacewatch 0.91-meter Newtonian telescope of the Steward Observatory on Kitt Peak in Arizona during 18 nights centered on each new moon. The image data are read out of the CCD by a PC-AT compatible computer and immediately transferred into a Solbourne 5/600 "Sun" compatible multi-processor workstation located at the telescope. Software running on the Solbourne which we call the "Moving Object Detection Program," or MODP, employs the 3 Sparc CPU's to look for streaked images of nearby asteroids during the first 2 passes of a 3 pass scan set over the same area of sky. During the third pass, the software compares the locations of each star brighter than a selected threshold in all three scans to identify sets of images which display consistent motion. The locations of each of these candidates is marked for the observer in the scrolling image data. The motion vectors, positions, and brightnesses found for each object are displayed for the observer in real time in a separate text window (Rabinowitz, 1991a). Each month, in the course of our search for earth-approaching asteroids, we commonly identify several thousand other asteroids which, by their rate of motion, are most likely in the main belt. We verify each detection after discovery by visually inspecting the recorded images, but do not make follow-up observations unless the object has rates which make it a likely earth approacher suspect.

NEAR-EARTH ASTEROID IDENTIFICATION

After a night of observing, a review program collects snapshots 256x256 pixels on a side centered on the location of each of the candidates from all three scans of each survey region observed during the night. The observer then makes the final determination of which detections are of real asteroids and which are artifacts from the CCD or from the analysis by examining the character of all three images. As each real asteroid is selected by the observer, its rates of ecliptic motion are plotted in order to determine the object's probable orbit type (e.g. main belt, Hungaria, Trojan, or earth approacher) (Rabinowitz, *et al.*, 1990). Figure 1 shows the rate plot of all 2200 asteroids detected near opposition during the 1990 October observing run along with the rates of some of the 15 earth-approaching asteroids detected and discriminated by Spacewatch during the first 10 months of full time operation. These rate plots reveal distant earth-approaching asteroids with rates comparable to those of the main belt and smaller than the rates of some Hungaria and Phocaea type asteroids.

Figure 2 shows the rates of the 2200 asteroids detected in 1990 October, along with the rates of all the fast moving objects detected between 1981 and 1991 whose angular velocities fall within the plot. In the photographic surveys during those 10 years, most of the earth-approaching asteroids were discovered only when their rates of motion strongly differed from those of the background asteroid population.

DISCOVERY CIRCUMSTANCES FOR NEAR-EARTH ASTEROIDS

Figure 3 shows the discovery location and relative rates of motion for the earth-approaching asteroids detected between 1981 and 1991 exclusive of the Spacewatch discoveries. The majority of the

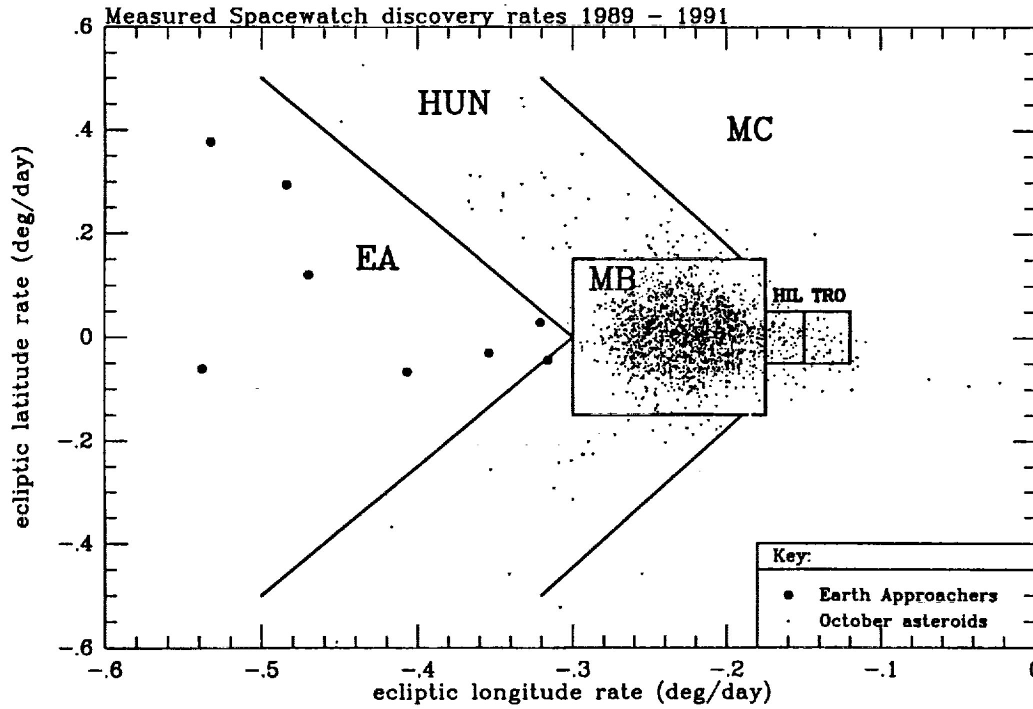

Figure 1 - The rate plot for the asteroids detected during the 1990 October observing run along with the rates of some of the earth-approaching asteroids detected and discriminated by Spacewatch during the first year.

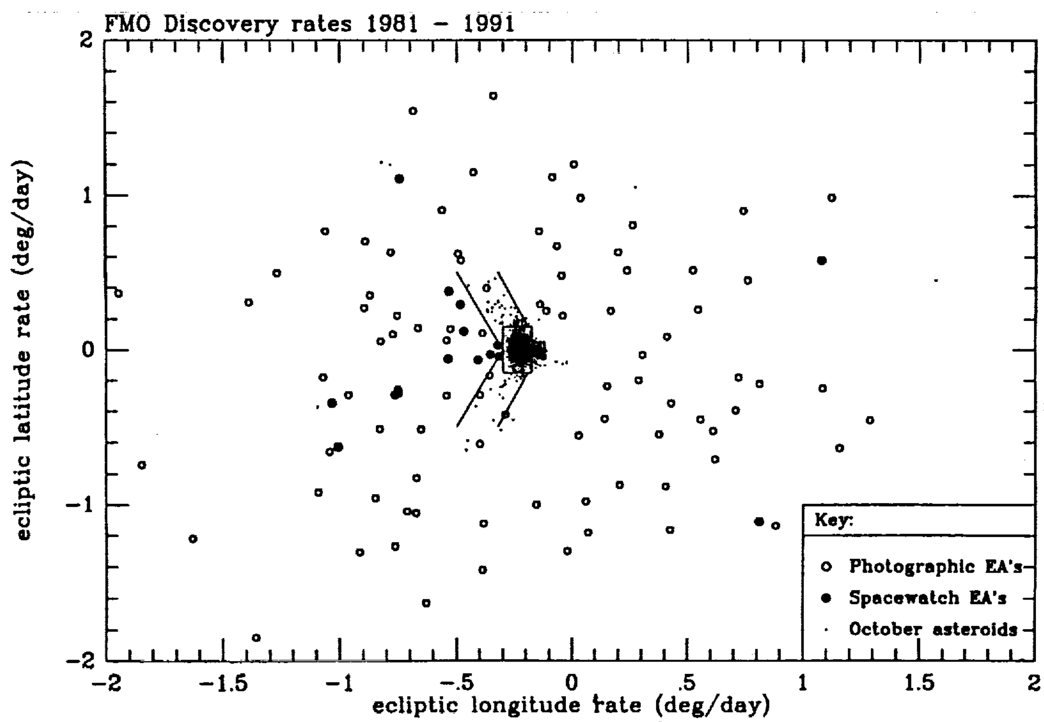

Figure 2 - The rate plot of Figure 1 along with the rates of all the fast moving objects detected between 1981 and 1991 whose rates fall within the limits of the plot.

photographic discoveries were made while the asteroid was well away from the opposition point. The discovery locations are nearly uniformly distributed in the region of opposition longitude ±30 degrees and latitude 0 degrees to +20 degrees. This nearly uniform distribution can be accounted for by the method used to detect the majority of the earth-approaching asteroids. The systematic surveys have concentrated on the region of opposition, but have been able only to discriminate those asteroids which are near the earth and moving fast. The observer had to be within the swarm in order to locate the earth-approaching asteroids. The bias towards the relative number of northern hemisphere observers is also apparent in the number of objects discovered north of the ecliptic compared to south of the ecliptic.

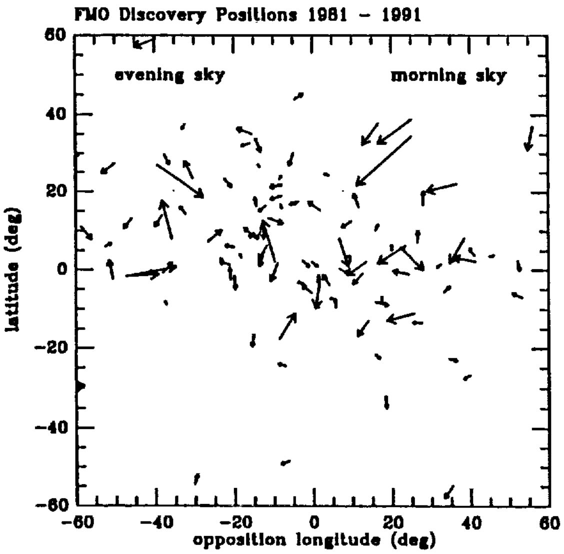

Figure 3 - The discovery location and angular motion vectors for the earth-approaching asteroids detected between 1981 and 1991 by observers other than Spacewatch.

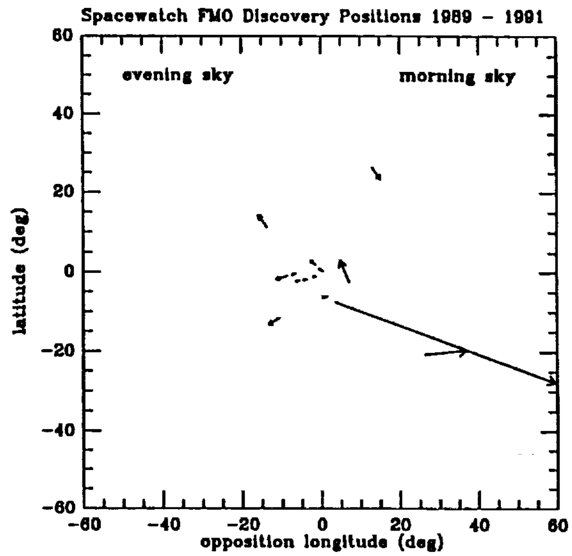

Figure 4 - The same plot as Figure 4, but for the earth-approaching asteroids discovered with the Spacewatch telescope. The long vector pointing towards the lower right is for 1991 BA.

Figure 4 shows the same plot for the Spacewatch discoveries. The majority of the Spacewatch discoveries have been made near the opposition point where the phase effect brightens the objects and where the rates can be used to discriminate the earth-approaching asteroids most effectively. Although the area within ±30 degrees in longitude and ±10 degrees in latitude has been the focus of the Spacewatch surveying, most of the discoveries have been made within ~10°of the opposition point.

THE SPACEWATCH NEAR-EARTH ASTEROIDS

Table 1 shows the 16 earth-approaching asteroids discovered by Spacewatch. The relative number of Apollo, Amor, and Aten type asteroids closely match those found by the photographic survey programs (Shoemaker, *et al.*, 1990). The types of orbits are also similar to those found in earlier surveys. The principle difference is in the geocentric distances of the asteroids at the time of their discovery. Of the 14 near-earth asteroids detected automatically, 10 were located while at geocentric distances of 0.5 AU or more. Objects whose absolute magnitude H is brighter than about 18.0 (about 1 kilometer diameter) are easily detected while they are within 1.0 AU of earth. Additionally, those objects located nearby include three of the smallest asteroids yet detected. Asteroid 1991 BA, for example, was found to have $H = 28.9$ which would correspond to a 5 to 10 meter diameter (Scotti, *et al.*, 1991). The population of these small objects, in the range of 5 to 10 meters up to about 150 meters, are a population of objects only observed previously by their passage through the atmosphere of the earth as meteors and fireballs. We have found that the estimated number of these small objects are enhanced when compared to the number extrapolated from our observations of larger near-earth asteroids (Rabinowitz, 1991b). Early detection and rapid follow-up with physical studies may aid in the comparison of the meteorite population with their parent bodies.

SUMMARY

The first 10 months of full time surveying with the Spacewatch telescope and automated CCD detection system has produced 15 new earth-approaching asteroids. We can detect earth-approaching asteroids when they are located in the inner half of the main belt of asteroids and are moving with rates comparable to the background asteroids. As with other photographic surveys, we can also detect the nearby objects. The higher quantum efficiency offered by CCD detectors allows us to detect smaller nearby objects, allowing study of meteoroid sized debris in the near-earth environment. With improved

Table 1 – Spacewatch Near Earth Asteroid Discoveries

1989 October – 1991 June

Design.	*a*	*e*	*i*	*V*	Δ	H	D	class
1991 FE	2.19	.455	3.9	17.9	1.509	14.9	4.8	AMO
1990 TG1	2.48	.692	9.1	19.1	1.900	15.0	4.6	APO
1991 AM	1.70	.695	30.0	18.6	0.913	16.5	2.3	APO
1991 EE	2.24	.624	9.8	19.4	0.888	17.5	1.5	APO
1991 FA	1.98	.447	3.1	18.7	0.830	17.5	1.5	AMO
1991 LH	1.35	.729	51.1	20.6	1.201	17.7	1.4	APO
1991 CB1	1.69	.622	15.8	21.1	1.552	18.0	1.3	APO
1990 SS	1.70	.475	19.4	18.9	0.623	19.0	0.9	APO
1990 VA	0.99	.279	14.2	17.9	0.229	19.5	0.6	ATE
1991 BN	1.44	.398	3.4	20.9	0.672	20.0	0.5	APO
1990 UO	1.23	.758	29.3	20.5	0.585	20.5	0.4	APO
1990 UP	1.33	.169	28.1	18.1	0.218	20.5	0.4	AMO
1989 UP	1.86	.473	3.9	15.8	0.061	20.7	0.3	APO
1991 JR	1.40	.260	10.1	19.5	0.090	22.5	0.15	AMO
1990 UN	1.71	.528	3.7	19.9	0.119	23.5	0.09	APO
1991 BA	2.24	.682	2.0	17.5	0.005	28.9	0.008	APO

Table 1 - The 16 earth-approaching asteroids detected by Spacewatch. Two, 1989 UP and 1991 BA, were detected by visual examination of the real-time display available at the telescope while the remaining 14 were detected automatically by MODP as either streaked images or by their consistent motion: a is the semimajor axis in AU, e is the orbital eccentricity, i is the orbital inclination in degrees, V is the observed brightness at discovery, Δ is the geocentric distance at the time of discovery in AU, H is the absolute magnitude, and D is the estimated diameter in kilometers using the mean of the diameters derived from assumming the mean albedoes of a C type and an S type asteroid.

detectors, larger telescopes and more of them, the population of earth-approaching asteroids can be surveyed much more rapidly and with a larger volume of spatial coverage.

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