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# A NEW ASTEROID OBSERVATION AND SEARCH TECHNIQUE[*]

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An observatory designed for artificial satellite work can be reconfigured to search for and observe asteroids. It will be used to conduct searches for Earth-approaching asteroids.

*Key words:* minor planets—search technique

## I. Background

M.I.T.'s Lincoln Laboratory has been supporting the Electronic Systems, Division of the Air Force Systems Command in the development of the GEODSS (Ground-based Electro-Optical Deep Space Surveillance) program. This is a network of computer-controlled optical observatories (40-inch (1-m) telescopes), equipped with large-format, low-light-level, television cameras of the intensified silicon-diode array type. It will replace the Baker-Nunn photographic camera system for artificial satellite tracking within the next few years. One element of this assistance has been the ab initio construction of a prototype observatory (the Experimental Test System or ETS) near Socorro, New Mexico. The discrimination of distant artificial satellites (angular speed $\approx 15'' \text{ sec}^{-1}$ from stars is performed in real time on the basis of the satellites' proper motion. It seemed logical to try the same technique to observe and search for minor planets (angular speed $\approx 0\overset{\prime\prime}{.}01 \text{ sec}^{-1}$). This has necessitated some hardware modifications, which have been successfully performed, and asteroids can now be routinely observed and searched for at the ETS (see Taff 1980).

## II. The Observatory

The ETS is a duplex observatory. One-half of it consists of two telescopes comounted on an equatorial mount. The main telescope is a 31-inch (79-cm), $f/5$, $f/2.8$ Ritchey-Chrétien unit, providing nominal 1° and 2° ($6\overset{\prime\prime}{.}5$ pixel size) fields of view on a flat 80-mm face plate located in the focal plane. The auxiliary telescope is a 14-inch (36-cm) $f/1.7$ folded Schmidt unit, providing a nominal 7° field of view on an 80-mm faceplate. Operations are controlled from a console in a separate building. The main computer is a MODCOMP IV-25 which provides 256 kilobytes of core and includes 50 megabytes of disk memory. The satellite file (containing $\simeq 500$ "deep-space" element sets) and the *Smithsonian Astrophysical Observatory Star Catalog* are the major files to which the computer has fast access.

After a series of field tests in 1972, it was decided that low-light-level, beam-scanned, television camera tubes of the intensified silicon-diode array type, generically called Ebsicons, possessed the necessary detection capability for real-time work. These tests also indicated the usefulness of an external, single-stage, image-converter tube coupled to the Ebsicon. Another important advantage was realized by the use of a 2:1 demagnifying image converter. Finally, the increased prescan electron gain ($\simeq 25$) provided by the external converter allowed the use of uncooled, 7.5 MHz video preamplifiers under the darkest skies at ETS. In addition, the camera target is etched with a fiducial mark to facilitate repeated, accurate positioning of the telescope (see Fig. 1). More detailed descriptions of the observatory and its hardware can be found in Weber (1979*a*,*b*).

## III. Asteroids

As a typical asteroidal geocentric proper motion is $\simeq 30'' \text{ hr}^{-1}$ images of minor planets can easily be discriminated from those of both fixed objects and artificial satellites. One need only acquire two images whose time separation is equivalent to (several resolution elements)/(typical angular speed) and subtract them. The result, when there is a minor planet in the field, will be a matching set of displaced dots. Fixed objects will be cancelled and objects moving so fast that they have left the field before the comparison image is recorded will leave only one dot. Figure 1 illustrates several successful discriminations.

The hardware we use to perform this function consists of the ordinary image-forming system described above, an analog disk video storage device for storing the reference image, and a digital video integration/storage device for increasing the signal-to-noise ratio. The observational sequence is quite simple. First the telescope is pointed at a particular position and the output of the camera integrated (typically for $\sim 2$ sec) in a Quantex Corporation model DS-20 storage unit until saturation occurs. This instrument stores 12 bits/resel of amplitude information in a $512 \times 512$ resolution element format. The integrated image (the reference frame) is then stored, as a single frame, in an Echo Science Company model EPS-1A Discassette recorder. This is performed on any one of 200 randomly accessible locations. We

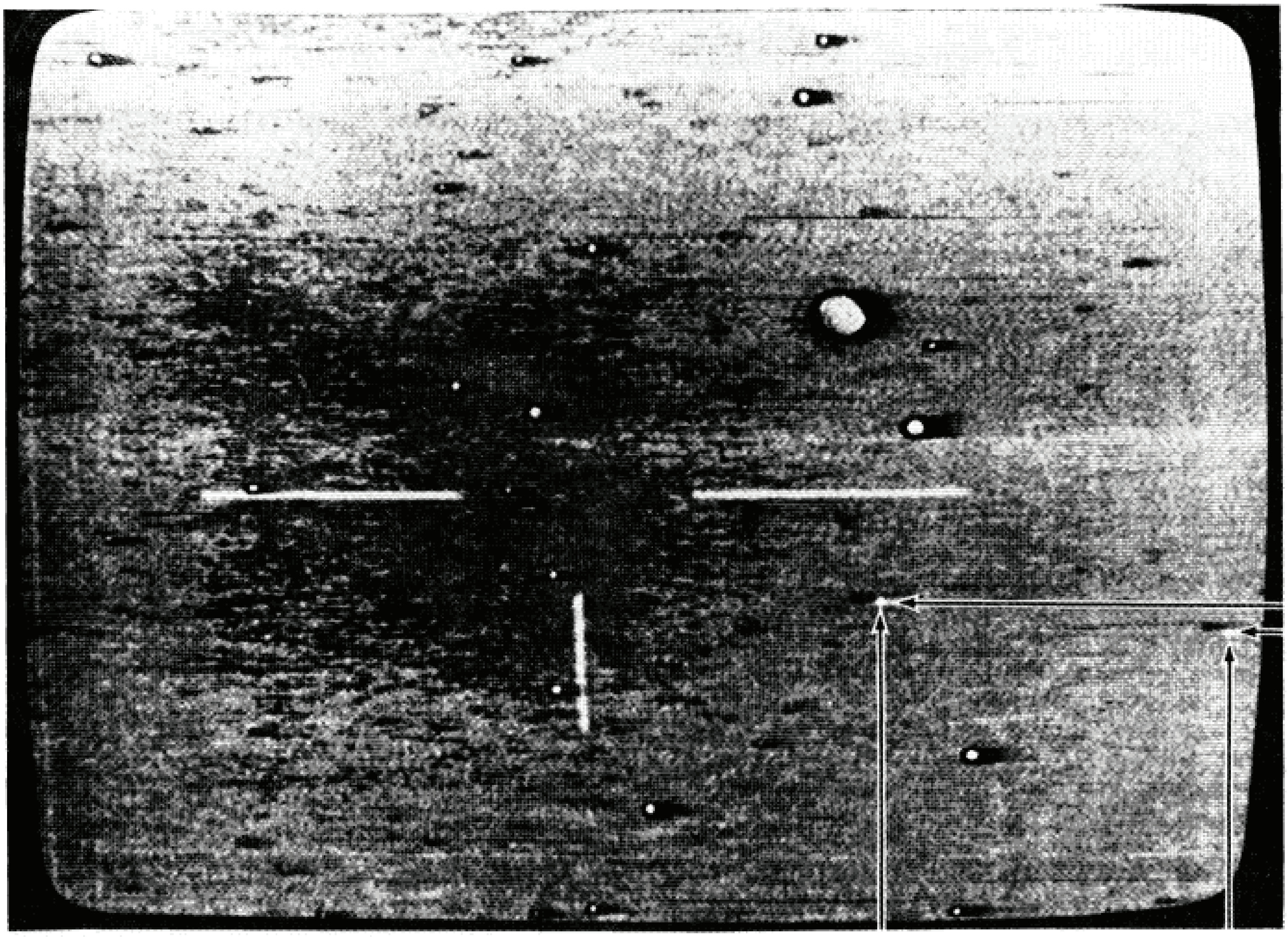

FIG. 1—Detection of 855 Newcombia (leftmost of pair) and another main belt asteroid. East is left and north is up. The separation is about 30″.

now wait for the appropriate time interval to pass and then return to the original position. A new image (the comparison frame) is acquired and the DS-20 unit used as a differencer between this image and the one stored in the EPS-1A unit. The differenced image is displayed on a video monitor where it is visually inspected for the pair of uncancelled dots characteristic of an asteroid. This is the detection stage.

During the time interval between the acquisition of the reference frame and the comparison frame the telescope is free. Because our storage device can be addressed at random we can profitably spend this waiting time acquiring additional reference frames. With a preprogrammed set of coordinates the sky can be covered almost as fast as we can start, move, and stop the telescope. In practice, including image quality checks etc., we spend 10–15 seconds per field acquiring the reference image. The preprogrammed search patterns we most frequently use are box scans along or perpendicular to the ecliptic and spiral scans starting from opposition. In all cases the field-of-view, overlap, time spent per field, total area to be searched, etc., are adjustable parameters which are entered at the initiation of a search. Repetition of the last search pattern is accomplished by a single button push.

## IV. Astrometry

We determine the position of any celestial object by adapting the classical methods of photographic astrometry to real-time operations. When the program object (asteroid here) is brought to the fiducial mark the observer pushes a button. This causes the computer to store the current position and time, search the SAOC for 5 (preferably, the minimum is 4) stars in the immediate vicinity (preferably $< 0\overset{\circ}{.}53$, the maximum is $0\overset{\circ}{.}75$), and displays a map of the surrounding $1\overset{\circ}{.}5$ including the brighter NGC objects. This electronically generated finding chart allows the observer to correctly orient himself. After all of this is done the computer directs the telescope, one at a time, to the reference stars. The operator completes the placement of the star on the fiducial mark and again pushes a button signifying the successful completion of the task. The software checks his judgment, stores the current position, and moves to the next star. Upon completion of this sequence, which requires 1–2 minutes, the linear "plate model" is constructed using the telescopic positions of the reference stars and their computed topocentric positions. One of the observed stars does not contribute to the model but is used instead to evaluate the systematic errors. Finally, the program object's position is deduced, stored, and printed. Experiments indicate that the overall precision is 4″–5″. This, in turn, is directly due to the digitized ($\simeq 6\overset{''}{.}5$) control of the telescope that the operator has. All of our measurements have been reported to the Minor Planet Center (Taff, Sorvari, and Beatty 1980); see also Taff and Sorvari (1979) for further references). Should an insufficient number of reference stars be in the area of the minor planet, this procedure is inhibited and a single star can be used to differentially deduce a less precise (10″–15″) position for the asteroid.

This work is performed in cooperation with the program of Helin and Shoemaker (1979) so that additional, more precise positions can be rapidly acquired. The longer arc and more accurate positions both contribute to the quick construction of a useful orbital element set. Our positions will certainly enable anyone else to find a particular object and our main purpose is to search.

## V. Expectations

After allowance for overlap, the effective area of a single field is 0.35 square degree. It requires approximately 45 seconds to store and examine a single field (including telescope movement time). This is equivalent to a search rate of 28 square degrees hour$^{-1}$. We search for approximately five hours per night, at most five nights per lunation. Hence, at best we will cover 8400 square degrees year$^{-1}$. We can realistically expect to cover 5000 square degrees year$^{-1}$. Our limiting $B$ magnitude in this mode is about $16\overset{m}{.}5$. Suppose that there are 2000 Earth-approaching minor planets down to $B(1,0) = 18^{m}$ (Helin and Shoemaker 1979). Assuming a mean synodic period of ten years, one-tenth of them are observable in any given year. An all-sky search would (presumably) find 200 but we will only cover about one-eighth of the celestial sphere. Hence, assuming no correlations between time of perigee passage and time of year, we might expect to recover 25 year$^{-1}$. To the best of my knowledge, no Earth-approaching asteroid has been discovered since 1979.

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### REFERENCES

Helin, E. F., and Shoemaker, E. M. 1979, *Icarus* 40, 321.
Taff, L. G. 1980, *Bull. A.A.S.* 12, 666.
Taff, L. G., and Sorvari, J. M. 1979, *Bull. A.A.S.* 11, 619.
Taff, L. G., Sorvari, J. M., and Beatty, D. E. 1980, *Minor Planets Circulars*, pp. 5403–05.
Weber, R. 1979*a*, *Optical Eng.* 18, 82.
——— 1979*b*, *S.P.I.E.* 203, 6.