OCCULTATION ASTRONOMY

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The era of occultation astronomy, studying dark objects by observing occultations of bright ones, has begun. The paper of Duncan, Quinn and Tremaine, "The Origin of Short-Period Comets", *Astrophys. J. Letters*, **328**, 69–73 (1988), greatly improved the prospects for occultation astronomy by demonstrating the existence of a second comet reservoir, the Kuiper Belt, much closer to us than the Oort Cloud and concentrated toward the ecliptic plane. Charles Alcock at Livermore (private communication) has begun work on a practical system of small telescopes to observe occultations of stars by comets. I here propose a system similar in concept of Alcock's but using different hardware. We need to try various systems on a small scale to find out which are most cost-effective. My proposal is based on the Multiple Telescope Robotic Observatory (MTRO) developed by Boyd and Genet at Fairborn Observatory in Arizona. See Russell M. Genet, "Multiple-Telescope Robotic Observatories in Space", submitted to P.A.S.P. (1990).

The following calculations are very rough and should be corrected by more careful estimates. As seen from a star near to the ecliptic, the Kuiper belt projects onto an area of 100 AU East-West by 10 AU North-South. The projected area is

$$10^3(\mathrm{AU})^2 = 2.10^{19}\,\mathrm{km}^2 .$$

Assume that we have an array of telescopes extending 100 km in a North-South direction, packed densely enough so that every comet crossing the array as seen from the star will be detected. The earth's orbital motion causes the array to sweep out the projected area at the rate of

$$3000\,\mathrm{km}^2/\mathrm{sec} .$$

Suppose that there are 10^{12} comets in the belt large enough to be detected. Then the star will be occulted by comets crossing the array at an average rate of one every 2 hours. Suppose further that each telescope in the array is equipped with a 100-channel photometer monitoring the light-intensity from 100 stars in its field of view. Then the array will detect occultations at an average rate of 50 per hour.

It will be advantageous to point the array at regions of the sky where the galactic equator crosses the ecliptic, at the constellation Taurus in winter and at Sagittarius in summer. These are regions where plenty of suitable background stars will be available. We need only find 100 stars, of solar type or bluer, of magnitude 13 or 14, within a half-degree field of view. These stars will be about 1 kiloparsec distant and will have angular diameters of 10^{-10} radians. Their angular diameter is equal to that of a comet in the Kuiper Belt with linear diameter 1 km. We can expect to observe occultations by comets with diameters as small as 1 km. That is why the estimate of 10^{12} for the number of detectable comets is not absurdly optimistic.

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The diffraction of light will spread the shadow of a comet over a region of size

$$d \sim (\lambda R)^{1/2} \sim 2\,\mathrm{km}\ ,$$

where λ is the wave-length and R the distance to the comet. By observing the occultation in several colors, we may measure both the distance and the absolute size of the comet. In this way we can obtain a three-dimensional map of the Kuiper Belt.

The scale of the diffraction region also determines the maximum spacing of telescopes in the array. For an array of length 100 km, it would probably be adequate to have 100 telescopes arranged in 3 parellel North-South lines, with a spacing of 3 km between telescopes in each line. A comet-shadow crossing the array will be detected in at least 3 telescopes, and the timing of the successive detections will give good discrimination against birds and bats.

Each photometer should be read out at 10^{-2} second intervals with accurate timing. Using stars of magnitude 14, a telescope aperture of 30 cm will be large enough to give good photon statistics. Fluctuations in light-intensity due to atmospheric seeing will be a more serious problem than fluctuations due to photon statistics. In principle, the effects of atmospheric seeing can be overcome by using larger numbers of smaller telescopes. The optimum size and spacing of the telescopes can only be determined by experience.

Finally, I mention briefly Phase 2 of the occultation-astronomy project. After the comet-detection system, which I call Phase 1, is working satisfactorily, we may proceed to Phase 2, the detection of loose Earth-like planets in the galaxy. Here I am following an idea suggested by Bohdan Paczynski in Ap. J. 304, 1 (1986), to look for planets in the galactic halo. I am interested in testing the hypothesis that planets are made before stars when molecular clouds collapse. Perhaps a collapsing cloud produces a large number of loose planets, only a few of which accrete enough gas to grow into stars. If this hypothesis were true, good places to look for loose planets would be young star-clusters such as the Hyades and Pleiades. By a happy accident, the Hyades and Pleiades lie in a part of the sky which is also good for hunting comets.

An Earth-like planet in the Hyades would have the same angular diameter as a comet in the Kuiper Belt, and the light from a background star would be bent around the planet by gravitational lensing to the same extent as the light is bent around the comet by diffraction. The difference between cometary and planetary occultations is mainly a question of time-scale. The cometary occultation is over in 10^{-1} second, while the planetary occultation takes 1000 seconds or longer, depending on the size and distance of the planet.

Planetary occultations will be very rare and we have only a small chance of seeing one. To maximize the chances, we should aim the 100 photometers on our 100 telescopes at 10^4 different background stars instead of looking at the same 100 stars with each telescope. Since the planetary occultations are slow, we can use fainter stars and read out the photometers less frequently. When working in the Phase 2 mode, the array will not be troubled by effects of atmospheric seeing. The gravitational lensing will give each occultation an easily recognizable signature.

The occultation array lends itself very well to time-sharing. All we have to do is to switch the photometers to Phase 1 mode for 54 seconds and to Phase 2 mode for 6 seconds in each minute. We have then complete coverage of planetary occultations using only ten percent of the time, while losing only ten percent of the comets. The possible discovery of an occasional planet comes as an almost free bonus, while the exploration and mapping of the Kuiper Belt continues.