after rescaling) are more likely to show up in the sky background annulus than the signal circle simply due to the difference in pixel area of these two regions. When these artifacts are in the sky background annulus they may reduce the asteroid's apparent brightness, whereas when they appear in the signal aperture they may make the asteroid appear brighter. The brightenings may be less frequent but they can produce larger errors. Consider also the case of an asteroid becoming fainter (due to rotation or changing observing date); faint and bright asteroids moving through similar star fields will exhibit different levels of systematic errors due to star ghosts. This may account for the one very low datum in Fig. 3 when the asteroid was faintest. Based on the appearance of Fig. 3 we estimate that when an asteroid as faint as 46053 is moving though a crowded star field (~21 degrees from the galactic center) the ghost artifacts due to incomplete star subtraction produce a component of varying systematic error of ~0.15 magnitude. However, as also can be seen from Fig. 3, these ghost artifacts come and go with a period of ~1/2 hour, which in this case is comparable to the time it takes the asteroid to move a distance of ~3*FWHM. Therefore, the image subtraction is unlikely to seriously impair the task of establishing an asteroid's rotation light curve.

Conclusion

It is possible to perform image subtraction for the purpose of establishing rotation lightcurves of faint asteroids using standard, Windows-based astronomical image analysis programs, such as MaxIm DL. Considering the many user-commanded procedures required in this analysis it is not known whether a program or script could be written that would perform most of the image subtraction tasks. We do not anticipate widespread enthusiasm for such a labor-intensive procedure. Nevertheless, this report demonstrates that amateurs are capable of measuring rotation light curves for faint asteroids in crowded star fields with a commonly-used Window-based astronomical image processing program such as MaxIm DL.

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IN SEARCH OF STATIONARY ASTEROIDS

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Modern asteroid surveys are optimized for the discovery of new fast moving objects, but the angular rate of an asteroid can be very low when the body is observed near the geocentric stationary points. This paper is an introduction to the search for new asteroids on the ecliptic near the most probable stationary points.

Nowadays there are several operating near-Earth objects (NEO) surveys. The goal is to perform a complete inventory of Earth-crossing objects. The modern surveys are specialized to detect moving objects with high angular rate. For automatic search of fast objects the time order of magnitude between consecutive scan, of the same sky region, is one hour.

However, as seen from Earth, all the solar system bodies are liable to a period of very low angular rate. Normally the bodies move eastward (direct motion) but, sometimes, the motion reverses to the opposite direction, or retrograde. During the motion inversion from direct to retrograde (and vice versa) the angular rate is near zero (stationary points), making it difficult to detect the displacement on different CCD images taken one hour apart. It will be better to compare different images taken one day apart.

Thus, the detection of new asteroids near stationary points is a job more suited for an amateur astronomer, that has more time to devote to the same sky region. Moreover, with a low angular rate, it is possible to observe objects more faint than usually. Due to "opposition effect", the apparent luminosity of a stationary asteroid is lower than during the opposition but in this period the angular rate reach the maximum and the detection is very easy on an interval time of few minutes. Such objects are readily found by professional surveys so, from an amateur standpoint, it is more probable the discovery of new stationary asteroids.

The Asteroids Stationary Points

The most interesting solar system regions to explore for new objects are the main asteroid belt, with distances of 2.2 - 3.3 AU from the Sun (Lewis, 1997) and the Edgeworth-Kuiper belt, with distances of 30 – 50 AU from the Sun (Morbidelli et al., 2003). Suppose an asteroid on a heliocentric circular orbit on the ecliptic plane (Figure 1). Where are the stationary points on the geocentric celestial sphere? If $\vec{\Delta}(t)$ is the Earth-asteroid vector at time *t*, and $\vec{\Delta}(t+dt)$ is the same vector at time *t+dt*, when the asteroid is stationary the two vectors must stay parallel. With this condition we can calculate the geocentric position of stationary points on the ecliptic. If λ_E and λ_A are the Earth and asteroid heliocentric longitude, the radius vectors will be:

$$\vec{r_E} = r_E\left(\cos(\lambda_E)\vec{x} + \sin(\lambda_E)\vec{y}\right) \tag{1}$$

$$\vec{r_A} = r_A\left(\cos(\lambda_A)\vec{x} + \sin(\lambda_A)\vec{y}\right) \tag{2}$$

In the preceding formulae, $\vec{x}$ and $\vec{y}$ are the vectors, while r_E and r_A are the orbital rays of the Earth and asteroid. Considering that $\vec{r_E} + \vec{\Delta} = \vec{r_A}$ (Figure 1), we can obtain the Earth-asteroid vector:

$$\vec{\Delta}(t) = \left(r_A\cos(\lambda_A) - r_E\cos(\lambda_E)\right)\vec{x} + \left(r_A\sin(\lambda_A) - r_E\sin(\lambda_E)\right)\vec{y} \tag{3}$$

If we divide Eqn (3) by r_E, all the distance are measured in AU, we can replace r_A with *r*. Now, if in (3) we replace *t* with *t+dt* and perform a Taylor series development to the first order we have:

$$\vec{\Delta}(t+dt) = \vec{\Delta}(t) + \left(\sin(\lambda_E)d\lambda_E - r\sin(\lambda_A)d\lambda_A\right)\vec{x} + \left(r\cos(\lambda_A)d\lambda_A - \cos(\lambda_E)d\lambda_E\right)\vec{y} \tag{4}$$

The two vectors $\vec{\Delta}(t)$ and $\vec{\Delta}(t+dt)$ are parallel if their vectorial cross product is zero:

$$\vec{\Delta}(t) \times \vec{\Delta}(t+dt) = \vec{0} \tag{5}$$

It can be verified that the preceding formula is true if the following relation is satisfied:

$$\cos(\lambda_E - \lambda_A) = \frac{r^2\omega_A + \omega_E}{r(\omega_A + \omega_E)} \qquad (6)$$

Here ω_A and ω_E are the asteroid and Earth heliocentric orbital angular velocity. When this condition is satisfied the asteroid is stationary if observed from Earth. Now we can know the Earth-asteroid distance when the asteroid is stationary:

$$\Delta = \sqrt{1 + r^2 - 2r\cos(\lambda_E - \lambda_A)} \qquad (7)$$

In this formula r and Δ are in AU. From (6) and (7) it follows that the angular distance, measured on the ecliptic, between the stationary point and the current opposition point (the point on the ecliptic opposite to the Sun) is:

$$\sin(\alpha) = \frac{r}{\Delta}\sin(\lambda_E - \lambda_A) \qquad (8)$$

The α value can be positive or negative. With (8) we can identify the two stationary points on the ecliptic. Equations (6), (7) and (8) are applicable also in the case of a circular orbit inside the Earth orbit. In this case α is the asteroid geocentric solar elongation.

The distribution of asteroids inside the main asteroid belt is uneven, they seem to avoid some areas known as the Kirkwood gaps. The greatest asteroid concentrations are near 1.9, 2.4, 2.6 and 3.10 AU from the Sun. The outcome of this situation is that the stationary points where new discoveries are most probable are at ±48°, ±52°, ±54° and ±57° on the ecliptic from the current opposition point. For the Trans-Neptunian Objects (TNOs), the greatest object concentrations are at 39 and 44 AU, so the stationary points are at ±81° and ±82° from the current opposition point (Table I, Figure 2).

During the stationary phase a residual contribution to the asteroid angular rate is given by the parallax due to Earth rotation that can shift the observer by a quantity comparable to Earth's diameter. For main-belt objects the residual mean velocity is between 1.3 and 0.6 arcsec/hour while for TNOs down to zero (about 0.4 arcsec/hour). This "parallax angular rate" is at minimum during stationary point rising and setting and reach the maximum value at local meridian transit. These residual angular rates are low if compared with angular rate during opposition (from 46 to 31 arcsec/hour for a main-belt body), and don't change the substance of the preceding results. Another residual contribution to angular rate may come from the orbit inclination on the ecliptic. Fortunately most asteroids orbits are near the ecliptic plane.

The search strategy

The search strategy for new low angular motion objects is similar to the search for new fast moving objects (i.e. with sky regions comparison), with the important difference that the interval time between two consecutive scan is measured in days instead in hours. Of course the best sky region to explore are on the ecliptic near the stationary points given in Table I. For a given night, thanks to the time available, it is possible to scan large sky region around stationary points, and putting together many CCD images with a long exposition time. The same thing can be repeated next night. Comparing the subsequent scan will be possible to discovery new objects with very low proper motion.

References

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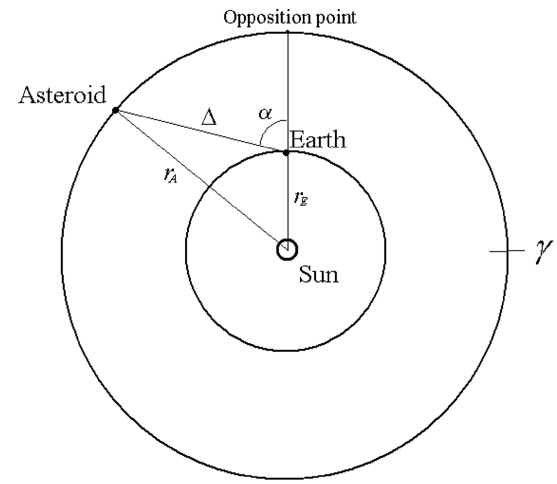

Figure1: Adopted geometry for the Sun-Earth-asteroid system.

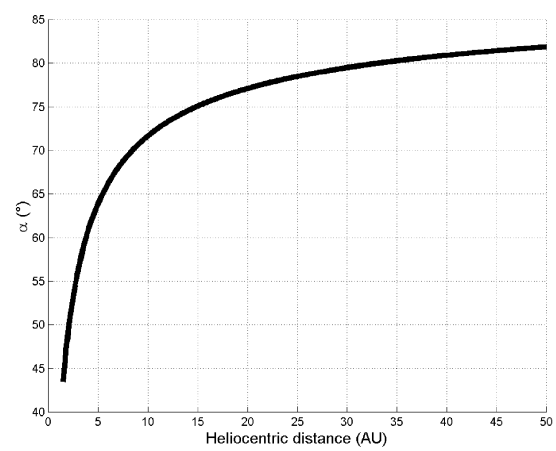

Figure 2: Stationary points vs. heliocentric distance.

r (AU)	Orbital period (days)	ω_A (°/day)	Δ (AU)	α (°)
1.90	972	0.3705	1.10	±48
2.40	1358	0.2651	1.66	±52
2.60	1531	0.2351	1.88	±54
3.10	1994	0.1805	2.44	±57
39.0	88958	$4.05\cdot10^{-3}$	38.8	±81
44.0	106603	$3.38\cdot10^{-3}$	43.8	±82

Table I: Stationary points for the greatest asteroids concentration of the asteroid main belt and Kuiper belts.