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CLOSEST APPROACH OF AN ASTEROID TO A STAR

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The moment of closest (angular) approach of an asteroid to a star can be found from a suitable set of positions of the asteroid spaced around the epoch of event. The following is a procedure which allows us to obtain the date of the event and the angles of closest approach and position with respect to the star.

Introduction

The apparent motions of asteroids naturally allow them to make frequent close approaches to stars. Starting with a basic data set, it is possible to compute the timing of the closest approach as well as the separation and angle between the star and the asteroid. We begin with the matrix:

$$\begin{array}{ccc} t_1 & \alpha_1 & \delta_1 \\ t_2 & \alpha_2 & \delta_2 \\ \vdots & \vdots & \vdots \\ t_i & \alpha_i & \delta_i \\ \vdots & \vdots & \vdots \\ t_n & \alpha_n & \delta_n \end{array} \qquad (\alpha_s, \delta_s)$$

where n is the number of observations, (α_i, δ_i) are the coordinates of the asteroid at time t_i and (α_s, δ_s) are the coordinates of the star. All the angles are reduced to the same equinox and the same origin of coordinates and expressed in radians. If T is the date of the event, these data are accepted when $t_1 < T < t_n$.

Procedure

Polynomials

Now, we make use of the points (t_i, α_i) and (t_i, δ_i) to make two polynomial functions:

$$\text{Polynomials}\begin{cases} \alpha(\mathrm{t}) \\ \delta(\mathrm{t}) \end{cases} \qquad [1]$$

Both are functions of the independent variable t. To make the polynomials we shall consider the following: a) each one of the variables t_i, α_i, δ_i have an associated error (e.g. experimental error in astrometric measurements) and, b) the order of the polynomials must be determined empirically. The former can be resolved using the method of least squares polynomial regression. This technique minimizes the sum of the squares of the residuals between the polynomial function and each data point. Using this method, different polynomials with orders 1,2,...,m (m less than $n-1$) can be obtained. To decide which of the m polynomials (e.g. in α) is the better we may use the formulae:

$$\Omega_k = \sum_{i=1}^{n}\left[\alpha_i - \alpha^k(t_i)\right]^2 \Big/ (n - c_k) \qquad [2]$$

where k=1,2,..,m is the order, c_k is the number of constants needed to resolve the polynomial of k order and $\alpha^k(t_i)$ is the value of α as calculated with the polynomial of k order at a time t_i. The smallest value of Ω corresponds to the best functional relationship. Least squares techniques can be found in books cited in the references below.

Star-asteroid angle

If the star and asteroid are joined along a great circle on the celestial sphere, their angular separation is described by:

$$\cos G = \sin\delta(t)\sin\delta_s + \cos\delta(t)\cos\delta_s\cos(\alpha(t) - \alpha_s) \qquad [3]$$

The closest approach occurs when function G is a minimum.

Minimum of G

Using the concept of maximum and minimum of a function, we proceeded to derive the function G with respect to time and then set the derivative function equal to zero.

$$dG/dt = -U' \Big/ \left(1 - U^2\right)^{0.5} = 0 \qquad [4]$$

where

$$\begin{aligned} U' = {} & \cos\delta(t)\sin\delta_s\,\delta'(t) + \\ & -\sin\delta(t)\cos\delta_s\,\delta'(t)\cos(\alpha(t) - \alpha_s) + \\ & -\cos\delta(t)\cos\delta_s\sin(\alpha(t) - \alpha_s)\,\alpha'(t). \end{aligned}$$

Symbol (′) denotes the first derivative and the function $U = \cos(G)$. The root of equation [4], in the interval (t_1, t_n), is T, the date of closest approach.

Date of closest approach (T)

To find the root of [4] we use the Newton-Raphson method. This demands us to derive one more time the function dG/dt. Then we have

$$d^2G/dt^2 = -\left(U''\left(1-U^2\right)+U'^2\right)/\left(1-U^2\right)^{1.5} \qquad [5]$$

where

$$\begin{aligned} U'' = {} & \sin\delta_s\left[\cos\delta(t)\delta''(t)-\sin\delta(t)\delta'(t)^2\right]+ \\ & +\cos\delta_s\cos\left(\alpha(t)-\alpha_s\right)\times \\ & \quad \times\left[-\cos\delta(t)\delta'(t)^2-\delta''(t)\sin\delta(t)-\cos\delta(t)\alpha'(t)^2\right]+ \\ & +\cos\delta_s\sin\left(\alpha(t)-\alpha_s\right)\left[2\sin\delta(t)\delta'(t)\alpha'(t)-\alpha''(t)\cos\delta(t)\right] \end{aligned}$$

Symbol (″) denotes second derivative. Calling *PD* to [4] and *SD* to [5] the root T is found by successive iterations beginning with an approximate value of T_0 ,this is

$$T_{j+1} = T_j - PD/SD, \quad j = 0,1,2,\ldots \qquad [6]$$

The process is concluded when $|t_{j+1} - t_j|$ is as small as we please.

Angle of closest approach (CA)

This angle is found replacing value T in [3].

Position angle (PA)

The position of the asteroid with respect to the star is:

$$\operatorname{tg} Q = \sin\left(\alpha(T)-\alpha_s\right)/\left(\cos\delta_s \operatorname{tg}\delta(T)-\sin\delta_s\cos\left(\alpha(T)-\alpha_s\right)\right) \qquad [7]$$

To determine the quadrant, in BASIC language, we express the procedure as:

```
2000   IF (α(T)-αs)=> 0 AND Q=> 0 THEN 2010 ELSE
2020

2010   PA=Q        : GOTO 2030

2020   IF (α(T)-αs) < 0  AND Q < 0  THEN PA=2*π+Q
ELSE PA=π+Q

2030   PRINT"PA (degree) =";PA*180/π
```

NOTE : To establish the sufficient condition, at the computation of minimum of G, we must confirm that $d^2G/dt^2 > 0$ when $dG/dt = 0$ in the point t=T.

Numerical Example

Table I below shows six astrometric positions, reduced to Geocentric coordinates, for asteroid 39 in the interval 1998, February 12-15. According to table "Close approaches of minor planets to naked eye stars in 1998" by E.Goffin (MPB 25,1), an event of maximum approach must occur with the star PPM121441 on February 13.

```
Star PPM121441 :     αs =  1.52519165 rad.
                     δs = +0.22080694 rad.
```

Polynomials :

$$\alpha(t) = C0 + C1t + C2t^2 + C3t^3$$

$$\delta(t) = K0 + K1t + K2t^2 + K3t^3 + K4t^4$$

where

```
C0= 1.548731742105854     K0= 0.7316328681885501
C1=-0.005006329692310     K1=-0.1567216528961141
C2= 0.000328664725949     K2= 0.0176011913810952
C3=-0.000006677305676     K3=-0.0008678820181676
                           K4= 0.0000160112697583
```

are the polynomial coefficients. Then, the derivatives $\alpha'(t)$, $\alpha''(t)$, $\delta'(t)$ and $\delta''(t)$ can be easily computed. Beginning with T0= 14 UT we computed [3],[4],[5] and [6] to obtain T1, etc. (Table II).

Final result

```
T= T3= feb. 13, 22hs 26.1m
CA= G(T)= 95.94 arcsec.
PA= 279.5 deg.
```

According to MPB 25, pp 3, T=22hs 25.1m, CA= 97.45, PA= 279.

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Table I: Geocentric positions for asteroid 39 Laetitia in 1998,February

DATE UT	R.A.(J2000.0) rad.	DEC. rad.	Std.Dev. "	"
12.01282	1.5244398	+0.2178728	1.0	1.0
12.05730	1.5244510	+0.2179380	1.1	1.1
13.06643	1.5245334	+0.2195200	1.2	1.9
14.02825	1.5247517	+0.2210273	1.8	0.6
14.05069	1.5247480	+0.2210618	0.1	0.9
15.01711	1.5250563	+0.2225731	1.4	1.4

Table II. Algorithm convergence.

T0	G	dG/dt	d^2G/dt^2
14.00000	0.0004759	+0.0003269	+0.0047815
13.93164	.	.	.
13.93479	.	.	.
13.93479	0.0004651	+0.0000000	+0.0051364>0

|T3-T2| <0.000001.

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CCD PHOTOMETRY OF ASTEROID 347 PARIANA AT THE US AIR FORCE ACADEMY OBSERVATORY

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CCD photometry of asteroid 347 Pariana taken during January and February 1999 at the US Air Force Academy observatory are reported. A rotational period of 4.05288 ± 0.00012 hours was determined from four nights of observations. The observed lightcurve amplitude was 0.424 ± 0.006 magnitudes.

This research was conducted as part of a cadet independent research project. Potential asteroid targets were selected by compiling a list of minor planets in a particular range of right ascension and declination that were brighter than 15th magnitude using Project Pluto's Guide CD-ROM star charting software. The software was also used to determine Earth-asteroid and Sun-asteroid distances. The resulting list was checked against the Minor Planet Center's Minor Planet Lightcurve Parameters webpage (Harris 1997) and only those objects with no previous lightcurve or period were retained. It is always desirable to find an asteroid with a short rotational period in order to determine a precise lightcurve with a limited number of observations. This task was accomplished by observing several asteroids from the final candidate list on the first night. After one night of observations, the asteroid showing the most favorable lightcurve was chosen for continued observations. 347 Pariana was chosen as our primary target this time.

All observations were made through a standard Johnson R-band filter using a liquid nitrogen cooled Photometrics CCD and 61-cm Cassegrain telescope. The field of view for all images was 3.7' x 3.7'. All images were bias subtracted and flat fielded using NOAO's IRAF package and differential photometry of the asteroid with respect to nearby stars was performed. Differential photometry between several stars in the field of view was also conducted to ensure the comparison stars were not variable.

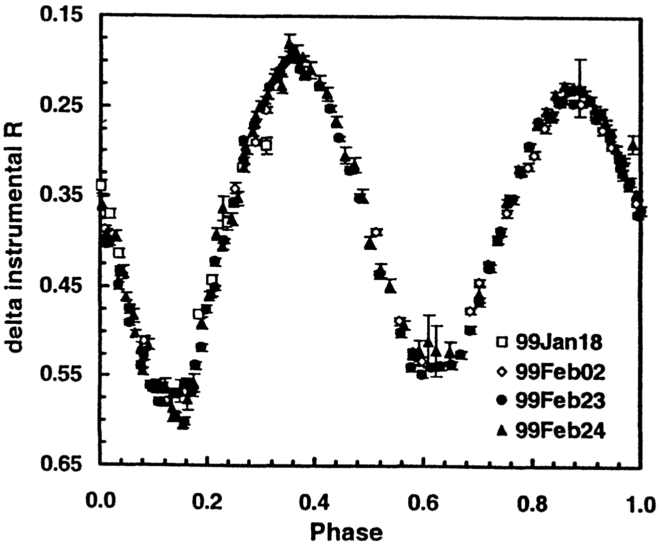

Figure 1. Composite lightcurve for 347 Pariana based on a P=4.05288 ± 0.00012 hour period. Zero phase = UT 1999 Jan 18, 03:33:00. Lightcurve is corrected for light travel time.

Asteroid 347 Pariana was measured 198 times during the course of four nights: 8 measurements were taken on UT 1999 Jan 18 over a 1.2 hour period, 33 measurements were taken on UT 1999 Feb 02 over a 3.2 hour period, 77 measurements were taken on UT 1999 Feb 23 over a 5.8 hour period, and 80 measurements were taken on UT 1999 Feb 24 over a 6.1 hour period. On UT 1999 Feb 23, the asteroid passed in front of two stars and as a result, useful photometry for 8 of the images proved to be impossible.

The rotational period was determined using a modification of Lafler and Kinman's method (Lafler and Kinman 1965). The method we developed is based on the minimization of the sum of the distances between consecutive points on a phase plot. A possible range of periods is supplied to a computer program which in turn calculates the sum of the distances between consecutive points on a period specific phase plot. The distance between two points is weighted with the error in the magnitude measurements. The period with the shortest distance sum produces the best phase plot and is, therefore, the correct period. The error in the period is determined by visual inspection of the phase plot for periods close to the correct period. This method allows very accurate and precise period determination.

By using the distance sum method we determined the rotational period of asteroid 347 Pariana to be 4.05288 ± 0,00012 hours. The composite lightcurve using this period is shown in Figure 1 and contains two maxima and two minima. The observed amplitude was 0.424 ± 0.006 magnitudes.

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CCD PHOTOMETRY OF ASTEROIDS AT THE US AIR FORCE ACADEMY OBSERVATORY DURING 1998

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In addition to observations of 583 Klotilde reported earlier (Burtz and Wetterer 1998), six other asteroids (177 Irma, 358 Apollonia, 418 Alemannia, 576 Emanuela, 3687 Dzus, and 4215 Kamo) were observed during 1998 at the US Air Force Academy observatory and the CCD photometry is reported here. These asteroids were observed as part of the ongoing cadet and faculty research on asteroid lightcurves. Periods and amplitudes were determined for Irma (14.4 ± 0.5 hours/ 0.375 ± 0.019 magnitudes) and Alemannia (4.680 ± 0.024 hours/ 0.270 ± 0.008 magnitudes). Best guess period and amplitude limits were found for the others: Apollonia (>24 hours/ >0.04 magnitudes), Emanuela (>26 hours/ >0.1 magnitudes), Dzus (? hours/ (0.02 magnitudes), and Kamo (12.6 ± 1.4 hours/ 0.21 ± 0.03 magnitudes).

All observations were made at the U.S. Air Force Academy observatory. A Photometrics (PM512) CCD camera attached to a 61-cm Cassegrain telescope was used to take three to five minute exposures of the asteroids through a standard Johnson R-band filter. All images were processed using NOAO's IRAF package and differential photometry of the asteroids with nearby stars was performed. Differential photometry between stars was also accomplished to ensure the comparison stars were not variable. These asteroids were chosen using the Project Pluto's Guide CD-ROM star charting software and referenced with the Minor Planet Center's Minor Planet Lightcurve Parameters webpage (Harris 1997) for known rotational periods. Only Alemannia had a previous period reported based on a fragmentary lightcurve.

177 Irma was observed 23 times over a 5.3 hour period (1.8 to 7.1 hours UT) on UT 1998 Jan 27, 21 times over a 5.3 hour period (1.6 to 6.9 hours UT) on UT 1998 Jan 28, and 5 times over a 0.6 hour period (3.2 to 3.8 hours UT) on UT 98 Mar 01. On the first night, the asteroid dimmed from a probable maximum to a definite minimum in 3.6 ± 0.5 hours, and then started to brighten. On the second night, the asteroid first dimmed to a definite minimum, and then brightened to a definite maximum in 3.6 ± 0.7 hours. Assuming a double minima lightcurve, the period thus lies between 11.6 hours and 17.2 hours. Overlaying these two nights, the possible periods are 10.7 ± 1.2 and 21.4 ± 0.3 hours (same minima although not symmetric) and 14.4 ± 0.5 hours (different minima and symmetric). It seems probable that the true period is thus 14.4 ± 0.5 hours with an amplitude of 0.375 ± 0.019 magnitudes. The last night of observations was of such a short duration that the data could not be used to significantly restrict the period any further. Figure 1 displays the composite lightcurve using a period of 14.208 hours.

358 Apollonia was observed 13 times over a 7.1 hour period (4.2 to 11.3 hours UT) on UT 1998 Sep 03. For most of this time, Apollonia was observed to remain at a constant brightness with an increase in brightness by about 0.04 magnitudes during the last hour. Indications are a lightcurve with a long period and low amplitude.

418 Alemannia was observed 24 times over a 5.3 hour period (2.3 to 8.6 hours UT) on UT 1998 Jan 27 and 24 times over a 6.3 hour period (1.0 to 7.3 hours UT) on UT 1998 Jan 28. On both nights, the asteroid appears to go through a number of maxima and minima. The rotational period was determined using a modification of Lafler and Kinman's method (Lafler and Kinman 1965) and assuming a short period. The method is based on the minimization of the sum of the distances between consecutive points on a phase plot. The error in the period is determined by visual inspection of the phase plot for periods close to the correct period. The period was determined to be 4.680 ± 0.024 hours with a maximum amplitude of 0.270 ± 0.008 magnitudes. Figure 2 displays the composite lightcurve using a period of 4.680 hours. The previously reported period (Lagerkvist et al.

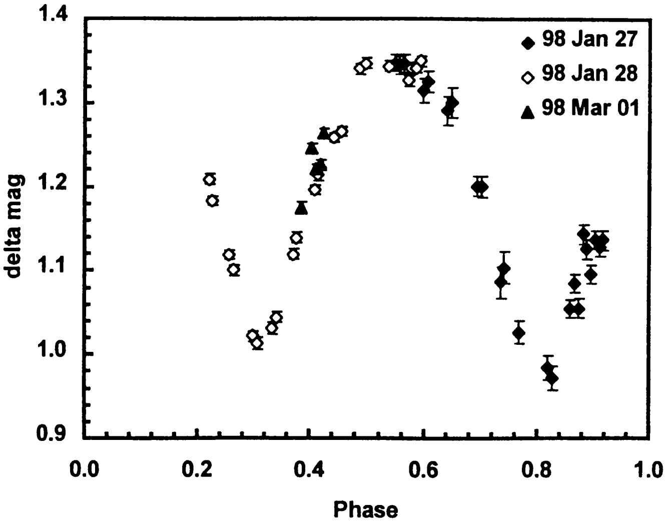

Figure 1. Composite lightcurve for 177 Irma based on a 14.208 hour synodic period. Zero phase = UT 1998 Jan 27, 01:30:00. Lightcurve is corrected for light travel time.

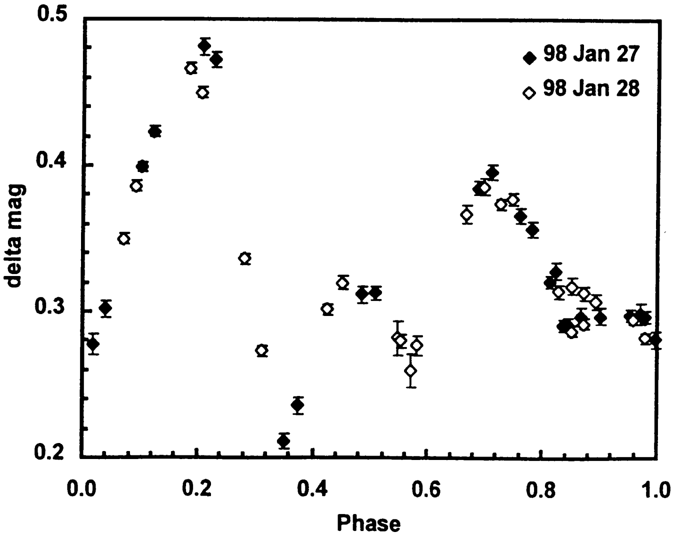

Figure 2. Composite lightcurve for 418 Alemannia based on a 4.680 hour synodic period. Zero phase = UT 1998 Jan 27, 02:15:00. Lightcurve is corrected for light travel time.

1987) is 5.82 hours with an amplitude of 0.12 magnitudes. This period is a sidereal day alias to 4.68 hours and yields a decidedly inferior lightcurve.

576 Emanuela was observed 36 times over a 6.6 hour period (2.5 to 9.1 hours UT) on UT 1998 Oct 07. Emanuela was observed to decrease in brightness by 0.1 magnitudes during this time period. Assuming a symmetric double minima lightcurve and if indeed at most one fourth of the period was observed in this time, Emanuela's period is greater than 26 hours.

3687 Dzus was observed 42 times over a 4.0 hour period (7.4 to 11.4 hours UT) on UT 1998 Sep 17. Fluctuations in magnitude of amplitude ≈0.02 were observed during this time. Because this is close to the uncertainty in each measurement for the data, we will refrain from speculating further.

4215 Kamo was observed 32 times over a 3.5 hour period (4.7 to 8.2 hours UT) on UT 1998 Sep 09 and 50 times over a 7.4 hour period (3.2 to 10.6 hours UT) on UT 1998 Sep 11. The data on UT 1998 Sep 11 clearly shows a maxima and minima with the possibility of a second maxima and a total amplitude of 0.21 ± 0.03 magnitudes (see Figure 3). Assuming a symmetric double minima lightcurve and if indeed more than half the period was observed in this time, Kamo's period is about 12.6 ± 1.4 hours. Unfortunately, due to the faintness of the comparison stars, the data on UT 1998 Sep 09 had large magnitude uncertainties (0.1 magnitudes) and the lightcurve information is lost in the noise.

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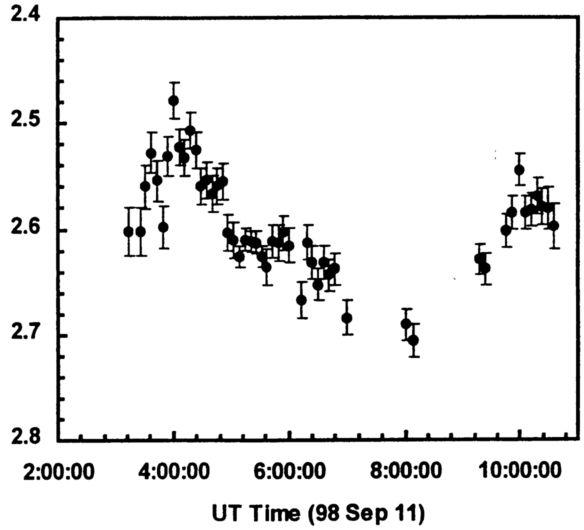

Figure 3. Lightcurve for 4215 Kamo on UT 1998 September 11.

ASTEROID PHOTOMETRY AT THE PALMER DIVIDE OBSERVATORY

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A description is given of the asteroid photometry program at Palmer Divide Observatory along with results on three asteroids. 1022 Olympiada was found to have a period of 4.589h ± 0.002h and shows an amplitude of approximately 0.27 mag. 1600 Vyssotsky has a likely period of 3.2h ± 0.01h with an amplitude of 0.13 mag. 787 Moskva is found to have a period of 5.381h ± 0.006h and an amplitude of 0.55mag. Two other asteroids, 740 Cantabia and 898 Hildegard appear to show longer (>24 hour) periods, but no determination could be made.

I have conducted asteroid photometry off and on since the early 80's, starting with work at Tiara Observatory in South Park, CO, USA, under Prof. Terry Schmidt (Schmidt, 1989). However it was not until settling into my current location approximately 30km north of Colorado Springs, CO, that I implemented a program of my own.

The Palmer Divide Observatory uses an LX-200 25cm f/6.5 SCT and SBIG ST-8 CCD camera that are operated from within my residence approximately 30m from the observatory. Custom software that I wrote is used to control both the telescope and camera so that unattended operations are allowed. This has

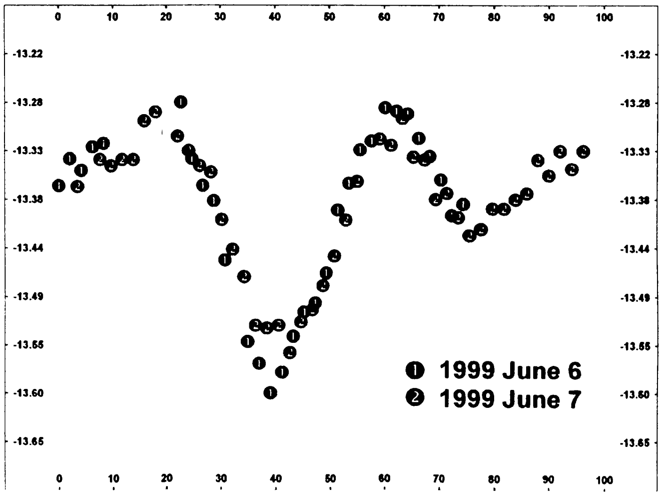

Figure 1. Data for 1022 Olympiada. Although two periods yield nearly identical plots, 4.589 ± 0.002h could be determined as the best solution.

greatly increased the ability to gather data for lightcurve work. A more complete description of the observatory and software has been previously published (Warner 1999) and so will not be covered here. Readers can also contact me directly at the addresses above for further information.

The goal of the asteroid photometry program is to measure the lightcurves of as many asteroids as possible given the limitations of the equipment. Foremost among those is the limiting magnitude where a signal-to-noise ratio of approximately 100 can still be achieved. Such a value is required for 0.01 magnitude accuracy. This is important when one considers that many asteroids have an amplitude range of only 0.1 magnitude or less. According to Dr. Arne Henden of the U.S. Naval Observatory (Henden 1999), the limiting magnitude is approximate 13.5-14.0 for a two-minute exposure. The latter limit is based on the average motion of a main-belt asteroid and is the approximate maximum to avoid significant trailing. The first set of program targets tends to show the upper (brighter) limit is the better estimate.

Initial targets are chosen based on the criteria above with special attention give to those suggested by Drs. Harris and Zappala in their regular article in the Minor Planet Bulletin and to asteroids that have no or only a poorly established lightcurve. Those asteroids are found by checking the list of lightcurves maintained by Dr. Harris (Harris 1997). If possible, two targets are chosen since the telescope control software allows the instrument to "bounce" between the two. At least two nights are dedicated to the initial run for every target. Depending on the preliminary analysis of the data from those two nights, additional runs are allocated as necessary to assure full coverage of the lightcurve with no significant gaps.

For measuring images, again custom software is used. This is primarily to allow automatic storage of the measured magnitudes of the comparison stars and targets for use in a Fourier Analysis program, the original FORTRAN code of which was supplied by Dr. Alan Harris (Harris et al, 1989) and converted to Delphi Pascal. For each night's run, a field with stars of well-known magnitudes is also shot and measured. This establishes the magnitude vs. intensity relationship for the software. For each image of the target, the comparison stars and asteroid are then measured. Once all the images have been measured, the process of trial and error (mostly error) begins with the Fourier Analysis program. If the data from a single night appears to cover at least half a period or more, then an "eyeball estimate" based on a plot of the raw data is used to help narrow the possibilities when using data from two or more nights.

Using this technique, preliminary lightcurves for several asteroids have been determined since the first part of 1999. Figure 1 shows the results from two nights (1999 June 6 and 7) for 1022 Olympiada, a 34km main-belt asteroid. Two periods yield almost identical fits, with the difference being the phase of certain points in the combined data. Those periods are 3.833 ± 0.002 h and 4.589 ± 0.002 h. Both fits show an amplitude of approximately 0.27 mag. However, using the run from 1999 June 7, which covered almost a full period and was just under 4.5h long, I determined the second period to be the correct one.

Figure 2 shows the results the results for three nights (1999 May 5, 8, and 15) on 1600 Vyssotsky, an inner main belt asteroid of approximately 5km size. At the time, the asteroid was near 14th magnitude. The large scatter lend some evidence that this value might be the limiting magnitude of the system. The most likely period is 3.2 ± 0.01h with an amplitude of 0.13 mag. No other periods appeared to fit, but with such large scatter, it's hard to say with any certainty.

Figure 3 shows the results of runs on 1999 May 18, 19, and 22 for 787 Moskva, another main-belt asteroid of about 27km size. The derived period is 5.381 ± 0.006 h and amplitude of 0.55mag.

Two other asteroids were measured, 740 Cantabia and 898 Hildegard, but both showed preliminary periods of >24 hours. In such cases, it's very difficult to obtain data over the entire lightcurve, especially when working during shortened summer nights. Insufficient data was acquired for these targets to report even a "best guess" period.

Considerable thanks go to Dr. Alan Harris of the Jet Propulsion Laboratory for his patience and willingness to teach a neophyte the details of asteroid photometry and for making available the source code to his Fourier Analysis program. Thanks also are in order to Dr. Paul Comba for his years of encouragement and suggestions on asteroid imaging.

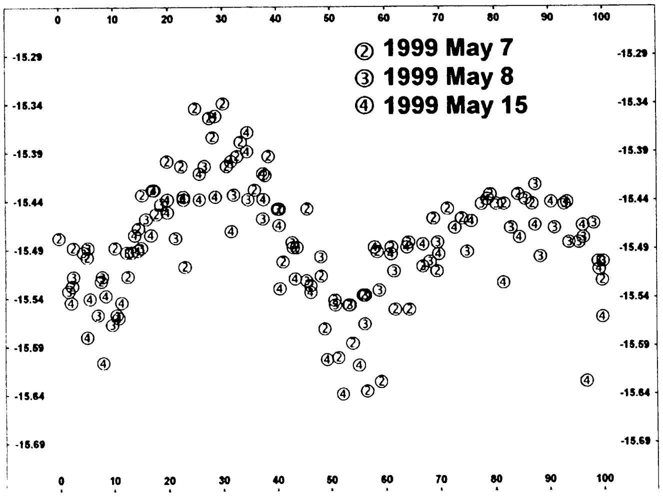

Figure 2. Data for 1600 Vyssotsky. This asteroid was near the limiting magnitude for a sufficient S/N (signal-to-noise) ratio. The best-fit period is 3.20 ± 0.01h.

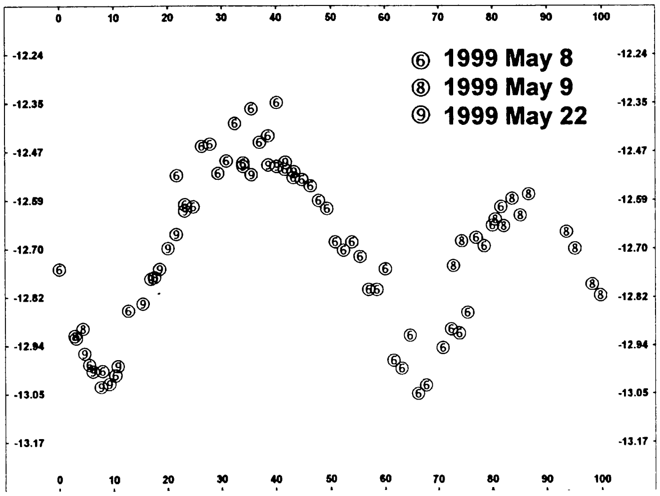

Figure 3. Data for 787 Moskva. A single best-fit period of 5.381 ± 0.006h was found.

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ASTEROID NEWS NOTES

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Two Thousand Two Hundred Ninety One Newly Numbered Asteroids

Since the last installment of News Notes, 2291 asteroids have been numbered, crashing through that magical 10000 level, passing the Dow-Jones stock index, and bringing the numbered total to 11433. Non-main-belt objects among these include:

(9162)	1987 OA	Apollo
(9165)	1987 SJ3	Hungaria
(9172)	1989 OB	Amor
(9202)	1993 PB	Apollo
(9292)	1982 UE2	Mars crosser
(9387)	1994 CA	Hungaria
(9398)	1994 SH3	Cybele
(9400)	1994 TW1	Amor
(9402)	1994 UN1	Cybele
(9430)	1996 HU10	L5 Jupiter Trojan
(9431)	1996 PS1	L4 Jupiter Trojan
(9522)	1981 DS	Cybele
(9551)	Kazi	Mars crosser
(9552)	1985 UY	Cybele
(9554)	1985 XA	Hungaria
(9564)	1987 SG3	Mars crosser
(9572)	1988 RS6	Mars crosser
(9590)	1991 DK1	L4 Jupiter Trojan
(9661)	1996 FU13	Hilda
(9671)	1997 TU9	Mars crosser
(9694)	Lycomedes	L4 Jupiter Trojan
(9712)	Nauplius	L4 Jupiter Trojan
(9713)	Oceax	L4 Jupiter Trojan
(9739)	1987 SH7	Hungaria
(9767)	Midsomer Norton	Mars crosser
(9773)	1993 MG1	Mars crosser
(9790)	1995 OK8	L4 Jupiter Trojan
(9799)	1996 RJ	L4 Jupiter Trojan
(9807)	1997 SJ4	L4 Jupiter Trojan
(9817)	Thersander	L4 Jupiter Trojan
(9818)	Eurymachos	L4 Jupiter Trojan
(9828)	Antimachos	L4 Jupiter Trojan
(9829)	Murillo	Hilda
(9856)	1991 EE	Apollo
(9857)	1991 EN	L4 Jupiter Trojan
(9873)	1992 GH	Hungaria
(9881)	1994 SE	Mars crosser
(9907)	Oileus	L4 Jupiter Trojan
(9950)	1990 VB	Amor
(9969)	Braille	Mars crosser
(9992)	1997 TG19	Mars crosser
(10051)	1987 QG6	Mars crosser
(10063)	1988 SZ2	Hilda
(10115)	1992 SK	Apollo
(10145)	1994 CK1	Apollo
(10150)	1994 PN	Amor
(10165)	1995 BL2	Apollo
(10199)	1997 CU26	Centaur
(10247)	6629 P-L	L4 Jupiter Trojan
(10257)	4333 T-3	Cybele
(10295)	1988 GB	Mars crosser
(10296)	1988 RQ12	Hilda
(10302)	1989 ML	Amor
(10331)	1991 GM10	Hilda
(10370)	1995 DW2	Centaur
(10379)	1996 OH	Cybele
(10416)	1998 VA32	Mars crosser
(10502)	1987 QF6	Mars crosser
(10531)	1991 GB1	Hungaria
(10548)	1992 PJ2	Mars crosser
(10563)	1993 WD	Apollo
(10578)	1995 LH	Mars crosser
(10608)	1996 VB9	Hilda
(10610)	1996 XR1	Hilda
(10632)	1998 CV1	Hilda
(10636)	1998 QK56	Apollo

(10653)	6030 P-L	Cybele
(10664)	5187 T-2	L4 Jupiter Trojan
(10667)	1975 UA	Hungaria
(10737)	1988 DZ4	Mars crosser
(10841)	1994 PP1	Hungaria
(10860)	1995 LE	Amor
(10889)	1997 AO1	Hilda
(10984)	3507 T-3	Mars crosser
(10989)	1973 SL1	L4 Jupiter Trojan
(11054)	1991 FA	Amor
(11058)	1991 PN10	Hungaria
(11066)	1992 CC1	Apollo
(11089)	1994 CS8	L5 Jupiter Trojan
(11152)	1997 YH5	Mars crosser
(11175)	1998 FY67	Hilda
(11188)	1998 KD50	Cybele
(11217)	1999 JC4	Hungaria
(11249)	1971 FD	Hilda
(11251)	1973 SN1	L4 Jupiter Trojan
(11252)	1973 SA2	L4 Jupiter Trojan
(11273)	1988 RN11	L5 Jupiter Trojan
(11274)	1988 SX2	Hilda
(11275)	1988 SL3	L5 Jupiter Trojan
(11279)	1989 TC	Hungaria
(11284)	1990 BA	Amor
(11304)	1993 DJ	Hungaria
(11311)	1993 XN2	Apollo
(11318)	1994 XZ4	Mars crosser
(11351)	1997 TS25	L4 Jupiter Trojan
(11388)	1998 VU4	Hilda
(11395)	1998 XN77	L4 Jupiter Trojan
(11396)	1998 XZ77	L4 Jupiter Trojan
(11397)	1998 XX93	L4 Jupiter Trojan
(11398)	1998 YP11	Amor
(11405)	1999 CV3	Apollo
(11410)	1999 FU34	Hilda
(11411)	1999 HK1	Hungaria
(11428)	4139 P-L	L4 Jupiter Trojan
(11429)	4655 P-L	L4 Jupiter Trojan

New Asteroid Names

The highest numbered asteroid that is also named is currently (10642) Charmaine, while the lowest numbered asteroid that remains unnamed is now (3360) 1981 VA. The previous holder of this distinction, (3109) 1974 DC, was finally named Machin. The total of numbered but unnamed asteroids jumped from 3122 to 4537, so there are now 6896 named asteroids (not counting the unnumbered near-Earth object Hermes), which means there have been 876 new names attached to numbered asteroids since the last installment of News Notes. Some of the familiar names include places, including the university that hosted the 1999 ACM meeting:

(3297) Hong Kong
(7462) Grenoble
(8084) Dallas
(8088) Australia
(8250) Cornell
(8489) Boulder
(10195) Nebraska

For (8088), I think I would have voted for the name "Intel". Of course, that's a play on its number, but that's nothing new. For example, we also now have:

(7919) Prime
(9007) James Bond
(10000) Myriostos

7919 just happens to be the 1000th prime number, and you just KNEW that Bond, James Bond, would get an asteroid number ending in 007. One can only wonder whether this asteroid, during the course of collisional fragmentation, was shaken, not stirred. As for Myriostos, read the next news item. The Apollo 11 trio was honored with the namings of:

(6469) Armstrong
(6470) Aldrin
(6471) Collins

More Spacewatch team members appeared among the new asteroid names with:

(7656) Joemontani
(7657) Jefflarsen

More comets, a spacecraft, and a telescope showed up among the asteroids:

(3728) IRAS
(4299) WIYN
(9133) d'Arrest
(9134) Encke

Then we have a singer, composers, the creator of the outstanding science fiction television series "Babylon 5", and the film maker who brought us "2001: A Space Odyssey" along with that story's astounding computer:

(7934) Sinatra
(8181) Rossini
(8379) Straczynski
(9000) Hal
(9913) Humperdinck
(10221) Kubrick

Notable scientists, mathematicians, and experimenters from history...

(5102) Benfranklin
(8103) Fermi
(8208) Volta
(10101) Fourier
(10111) Fresnel
(10183) Ampere

...and from the present, including former fellow graduate students:

(7553) Buie
(7554) Johnspencer

Buie and the writer collaborated on the observation of Pluto-Charon mutual events. Another good friend of the writer's, Roy Tucker, named his backyard observatory Goodricke-Pigott. The former already has an asteroid named after him. Roy saw to the latter also getting an asteroid name:

(10220) Pigott

If somebody beat Kuiper to the suggestion of a source region for short period comets just beyond the orbit of Neptune, it would be:

(3487) Edgeworth

The leader of a religious reformation movement:

(7100) Martin Luther

The late CNN reporter who covered not only the beginning of the Gulf War from Baghdad, but also numerous space shuttle launches, and reported on other news from astronomy:

(6711) Holliman

Lastly, we have that mysterious entity who works at the Minor Planet Center all night long and who goes by the initials A. U.:

(7767) Tomatic

1999MPBu...26...33T

Pluto Remains A Planet

In hopes of giving asteroid number (10000) to a significant object, while also recognizing its relationship to other objects in the Kuiper belt that have 3:2 resonance orbits with Neptune, Pluto was proposed as (10000), with the first Kuiper belt object, 1992 QB1, as (10001), the second Kuiper belt object, 1993 FW, as (10002), and so on. The proposal was met with stiff opposition, including the committee representing the American Astronomical Society's Division for Planetary Sciences. The uproar eventually elicited a reassuring statement from the IAU General Secretary that Pluto would not be assigned an asteroid number. Surprisingly, none of the Kuiper belt objects that had been planned for numbering along with Pluto were actually numbered.

So, which asteroid did get the coveted number? The honor went to a rather small (3 km diameter), ordinary, main-belt asteroid: 1951 SY. It was more recently named Myriostos, the Greek word for ten thousandth.

Deja Vu: 1999 AN10 Collides With the Media

The furor over 1997 XF11 had hardly died down before news of another potentially dangerous asteroid became a hot topic in the media. This time the suspect was 1999 AN10, an Apollo-type asteroid discovered on January 13 by the LINEAR program. With an estimated diameter of 1.0 km, this object seems capable of producing a global catastrophe. In a paper circulated to colleagues for peer review, A. Milani and coauthors noted that a collision with the Earth midway through the next century could not be ruled out on the basis of the then-available astrometric observations. The paper was made available to these colleagues via a web page that was stumbled upon by the moderator of an on-line forum, who then spread the news prior to the completion of the peer review process. And just like 1997 XF11, but not as rapidly, some prediscovery images of the suspect asteroid were located in the vast photographic archives. In this case, the archival images date back to 1955, changing the five-month arc into a 44-year arc, and completely ruling out any chance of a collision with the Earth in the next century.

Meanwhile, 1998 OX4, lost after only nine days of observation last summer, has enough orbital uncertainty to allow an Earth collision. Fortunately, this object isn't a planet killer, being only about 200 m in diameter, but is still capable of doing serious damage.

No Retrograde Asteroids? Think Again...

Among the many objects discovered by the LINEAR program are 1999 LD31 and 1999 LE31. Orbit solutions have shown both objects to be in Jupiter-crossing orbits that are, surprisingly, retrograde. On about thirteen other occasions, LINEAR has found objects in retrograde orbits, but follow-up observations at other observatories revealed the presence of coma indicative of a comet, so those objects received cometary designations. Deep images (including some made by the writer) have failed to reveal any signs of coma around 1999 LD31 or 1999 LE31, however, so asteroidal designations were assigned. Dynamically, both objects are consistent with cometary orbits. While 1999 LE31 approaches the Sun to only 4.3 AU, and could conceivably remain inactive, even with some water ice, 1999 LD31 has a perihelion distance of less than 2.4 AU, which should make it get warm enough to sublimate water ice. The lack of activity is therefore quite a surprise.

Perhaps some readers might not be surprised by the discovery of a retrograde asteroid. But is anyone NOT surprised by the discovery of two such objects only four days apart? Long time readers of this column may recall the number of times that pair discoveries of near-Earth asteroids were pointed out. Hmm...

Satellite Search Turns Up Centaur

Following in the footsteps of Gladman et al., who discovered two new distant satellites of Uranus in 1997, the writer took several deep CCD images of the sky regions surrounding Uranus and Neptune during the summer of 1998. Three objects sharing Uranus' motion were found by the writer's graduate student, R. Whiteley. Two of them were the 1997 discoveries. The third looked like it might be a new satellite. After a few weeks of observation, however, orbit solutions failed to find any Uranocentric orbit that wasn't hyperbolic. Once the object was recovered following solar conjunction, there was absolutely no doubt that the object was instead a Centaur with an orbit remarkably similar to that of Uranus. 1998 QM107 has a semimajor axis of 20.1 AU, compared to Uranus' 19.2 AU, and the smallest eccentricity of any known Centaur at 0.14, which means it stays relatively close to the orbit of Uranus, as projected onto the ecliptic plane. What keeps the asteroid away from really close encounters is its 9 deg inclination. Currently near its descending node and perihelion, the object will pass below the ecliptic plane when it crosses Uranus' orbit and then reaches the ascending node shortly after aphelion, looping above the ecliptic plane when it next crosses Uranus' orbit inbound.

Here Today, Gone Tomorrow? Make That Gone Today, Here Next Year

It's old news by now, but the NEAR spacecraft failed to rendezvous with Eros as planned early this year. Apparently software thresholds for the amount of allowable vibration were set too tight, so when the bipropellant rocket fired to match orbits with Eros in late December, the on-board computer aborted the burn when those thresholds were exceeded. Automatic systems then tried to control the spacecraft attitude by firing the hydrazine thrusters, which only made matters worse. Eventually, it succeeded at stabilizing itself, but only after a considerable amount of the hydrazine had been consumed. Why the thresholds weren't exceeded during previous burns of the engine isn't known to the writer. Fortunately, the spacecraft was not damaged (though some spacecraft team members may have had their cardiovascular systems strained during the day when personnel were racing the clock to find out what went wrong), and it was possible to gather some data on Eros during a flyby. A successful burn of the engine was conducted some time later to put the spacecraft on course to rendezvous with Eros in early 2000. Stay tuned for further developments.

Deep Space 1 Encounters 1992 KD

The winning entry for the "Name the Asteroid" contest turned out to be rather prophetic. (9969) 1992 KD wound up being named Braille shortly before the encounter took place. The spacecraft's automatic pointing software was apparently fooled by some scattered light, so no close-up images of the asteroid were obtained. Nevertheless, the mission, which is primarily a technology demonstration mission rather than a science mission, was proclaimed a success, having successfully tested several new technologies, including the ion drive system. The spacecraft has been retargeted for a 2001 January flyby of asteroid (4015) and comet 107P/ Wilson-Harrington, and a 2001 September flyby of comet Borrelly.

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More Asteroid Satellites

Score another victory for groundbased adaptive optics. Using images with FWHM of 0.15 arcsec, W. Merline et al. succeeded in detecting a companion to (45) Eugenia using the Canada-France-Hawaii telescope on Mauna Kea. Never more than 0.8 arcsec from Eugenia, the adaptive optics system was able to reveal the presence of a satellite 6 mag fainter than the primary! The images were made during 12 observing sessions on five out of ten nights in 1998 November, with a confirming observation being made in January. The density implied by the nearly circular orbit of 1200 km radius and 4.7 day period is 1.3 grams per cubic centimeter, comparable to what NEAR found at Mathilde, implying that Eugenia is another highly porous asteroid.

Meanwhile, S. Mottola was producing a binary asteroid model for the Apollo-type asteroid 1996 FG3, whose lightcurve had displayed features suggesting that occultation and transit events were occurring at an interval not synchronous with the rotation period of the primary. Unlike other observations (such as secondary stellar occultations), the binary-induced lightcurve events were observed multiple times, and the model does an excellent job of reproducing all of the observed lightcurve features, making 1996 FG3 a very solid case for being the third known binary asteroid.

Science Team Selected for MUSES-C Asteroid Sample Return Mission

The world's first attempt to return a sample from a known asteroidal source (that is, meteorites don't count) will be made by the Japanese, who are building a spacecraft currently called MUSES-C (the third of the Mu Space Engineering Spacecraft series). NASA is constructing a miniature rover to be deployed on the surface of the asteroid. In the agreement worked out between NASA and ISAS regarding the collaboration, one U.S. scientist would be selected as a team member for each spacecraft instrument team, while one Japanese scientist would be selected as a team member for each rover instrument team. The U.S. scientists selected for the spacecraft instrument teams are A. Cheng (LIDAR), F. Vilas (infrared spectrometer), M. Zolensky (sampler), and the writer (camera). Leading the rover instrument teams are P. Smith (camera, of Mars Pathfinder fame), B. Clark (infrared spectrometer), and T. Economou (x-ray spectrometer). Launch is slated for 2002 July, with arrival at (10302) 1989 ML in 2003 October. After spending six months at the asteroid, the sample will be returned to Earth in 2006 June. More details about the target asteroid are planned for the next edition of News Notes.

ASTEROID PHOTOMETRY OPPORTUNITIES NOVEMBER-JANUARY

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The table below lists asteroids that come to opposition during the months of November through January that represent useful targets for photoelectric or CCD photometry observations. Observations are typically needed because the asteroid has either an unknown or ambiguous rotational period. The table gives (in order of opposition dates) the asteroid number and name, opposition date, opposition V magnitude, the rotational period (in hours), the estimated lightcurve amplitude (in magnitudes), and the designation PER if observations are needed to determine the rotational period. AMB implies that previous period determinations have given ambiguous results and these alternate periods are listed in the table. Question marks are used to denote uncertain or unknown values.

Now that many amateur and other small observatories have CCD capabilities, much fainter targets are accessible to them. Therefore, we have included a selection of fainter targets, down to opposition magnitude 15. Our emphasis among these fainter targets is to reach to the smallest size bodies possible within that magnitude limit. Thus the objects listed tend to be inner-belt asteroids, or even Mars or Earth-crossing objects, at unusually favorable oppositions. To achieve this, we filter the list of all oppositions to include those objects with H (absolute) magnitude >14.0 (roughly <5 km in diameter), but opposition V magnitude <15.0, and then further eliminate any objects for which adequate observations have already been made. Our criteria for the brighter objects remains the same: opposition V magnitude <12.0 and that the period is unknown, very uncertain, or ambiguously determined. We have dropped low phase angle as a criterion for inclusion, as it seems no one has responded to past listings suggesting phase relation observations.

Ephemerides for any solar system object can be calculated with the HORIZONS program; see the web page at http://ssd.jpl.nasa.gov/. Note that the unnumbered object 1997 FW has a particularly large ephemeris uncertainty, perhaps creating a challenge to locate, but a valuable target for both photometry and astrometry.

Asteroid	Opp'n Date	Opp'n V Mag	Per	Amp
1537 Transylvania	Nov 14	14.0		PER
1792 Reni	Nov 20	13.9		PER
1991 XD	Nov 22	15.0		PER
2874 Jim Young	Nov 23	14.8		PER
4613 Mamoru	Nov 25	13.5		PER
1997 FW	Dec 13	14.8		PER
690 Wratislavia	Dec 19	12.0	6.3? 9.9?	0.3 PER
155 Scylla	Jan 8	13.7		PER
1989 BA	Jan 13	14.9		PER
202 Chryseis	Jan 22	11.1	16?	0.1 PER
1708 Polit	Jan 23	14.3		PER

Asteroid Photometry Opportunities

INSTRUCTIONS FOR AUTHORS

The *Minor Planet Bulletin* is open to papers on all aspects of minor planet study. Theoretical, observational, historical, review, and other topics from amateur and professional astronomers are welcome. The level of presentation should be such as to be readily understood by most amateur astronomers. The preferred language is English. All observational and theoretical papers will be reviewed by another researcher in the field prior to publication to insure that results are presented clearly and concisely. It is hoped that papers will be published within three months of receipt.

The *MPB* will not generally publish articles on instrumentation. Persons interested in details of CCD instrumentation should join the International Association of Amateur and Professional Photoelectric Photometers (IAPPP) and subscribe to their journal. Write to: Dr. Arnold M. Heiser, Dyer Observatory, 1000 Oman Drive, Brentwood, TN 37027 (email: heiser@astro.dyer.vanderbilt.edu). The *MPB* will carry only limited information on asteroid occultations because detailed information on observing these events is given in the *Occultation Newsletter* published by the International Occultation Timing Association (IOTA). Persons interested in subscribing to this newsletter should write to: Craig and Terri McManus, 2760 SW Jewell Ave., Topeka, KS 66611-1614.

Manuscripts

All manuscripts should be typed double-spaced and should be less than 1000 words. Longer manuscripts may be returned for revision or delayed pending available space. Manuscripts should consist of the following: a title page giving the names and addresses of all authors (editorial correspondence will be conducted with the first author unless otherwise noted), a brief abstract not exceeding four sentences, the text of the paper, acknowledgments, references, tables, figure captions, and figures. Please compile your manuscripts in this order.

In most cases, the number of tables plus figures should not exceed two. Tables should be numbered consecutively in Roman numerals, figures in Arabic numerals. We will typeset short tables. Longer tables must be output using a 300 dpi or higher quality printer, black text on white paper. Font size should be large enough to allow for clear reproduction within the column dimensions described below. Similarly, figures should be printed at 300 dpi or higher quality, black markings on white paper. Because of their high reproduction cost, the *MPB* will not print color figures. Labeling should be large enough to be easily readable when reproduced to fit within the *MPB* column format. If at all possible, you are strongly encouraged to supply tables and figures at actual size for direct reproduction. Tables and figures intended for direct reproduction to occupy one-half page width should be 8.6 cm wide, or full-page width, 17.8 cm. Size your tables and figures to fit one-half page width whenever possible. Limit the vertical extent of your figures as much as possible. In general they should be 9 cm or less.

References should be cited in the text such as Harris and Young (1980) for one or two authors or Bowell et al. (1979) for more than two authors. The reference section should list papers in alphabetical order of the first author's last name. The reference format for a journal article, book chapter, and book are as follows:

Harris, A.W., and Young, J.W. (1980). "Asteroid Rotation Rates III: 1978 Results". *Icarus* **43**, 20-32.

Bowell, E., Gehrels, T., and Zellner, B. (1979). "Magnitudes, Colors, Types, and Adopted Diameters of the Asteroids". In *Asteroids* (T. Gehrels, Ed.), pp 1108-1129. Univ. Arizona Press, Tucson.

Wood, F.B. (1963). *Photoelectric Astronomy for Amateurs.* Macmillan, New York.

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