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A PHOTOMETRIC GEODESY PROGRAM FOR MAIN BELT ASTEROIDS

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This article describes a long-term program to measure the lightcurves of several main belt asteroids, to test whether they have shapes similar to fluid bodies in equilibrium. To use our telescope time most efficiently, our group has developed a series of observing procedures and aids whose use could extend beyond our present project.

Introduction

Are most large asteroids huge chunks of competent material assuming any random shape that their collisional history has molded them into as they spin about their rotation axes? Or are they more like battered heaps of rubble, held together by their own gravity but so weak that they assume shapes dictated by the laws of fluid mechanics?

To answer this question, we have undertaken a multi-year program to test whether or not large, rapidly rotating main belt asteroids have shapes similar to those of fluid bodies in equilibrium. On a gross scale, large bodies such as planets and major satellites behave as fluid bodies since the pressures throughout their interiors, caused by gravitational compression, cause the matter to flow like a viscous fluid. To a large extent, the shape of such fluid bodies depends only on their rotation rate and density: nonrotating bodies would be spheres. Slow and moderate rotations deform into Maclaurin Spheroids, which are flattened at the poles and bulging at the equator (like Jupiter and Saturn), while rapid rotators assume the shape of Jacobi ellipsoids, with three unequal-length axes. Asteroids are so much smaller than big moons or planets, yet some of them also may have shapes like fluid bodies.

The answer lies in the collisional environment of the asteroid belt. Asteroid orbits were stirred up by some process in the past that produced a tangled pattern of intersecting orbits which led to collisions between asteroids. Collisional outcomes depend principally on the sizes of the bodies, since the impact speed is always about 5 km/sec. Small projectiles hitting large targets simply crater them, but as the projectile becomes larger relative to the target, the size of the crater increases until the target is shattered into many fragments. The fate of these fragments depends on the target's size; if it is small, the ejecta depart onto their own heliocentric orbits, but if the target is large enough to have an appreciable gravity field, then the fragments may not have enough energy to escape and instead they collapse back into a single body. In such a fashion, an initially coherent body can be converted into what we call a "gravitationally bound rubble pile." Repeated collisions would further pulverize the fragments and jostle them into assuming a shape like that of a fluid body, just like shaking a box containing sand causes it to relax toward a flat surface.

We have selected 16 large, rapidly rotating (periods less than about 6 hours) asteroids as the best candidates for testing the hypothesis that "gravitationally bound rubble piles" assume quasi-equilibrium shapes (Table I). We also observe other objects covering a range of sizes and compositional classes as controls. To determine the bulk shape of our asteroids requires obtaining lightcurves at different aspects, or angles between the Earth and the asteroid's rotational axis, relative to the rotational poles. Thus the amplitude and mean magnitude of the lightcurve will vary depending on the viewing direction. Our goal is to obtain lightcurves spaced in intervals about 10 degrees apart in ecliptic longitude spanning 60-100 percent of the non-ambiguous 180 degree range for the ecliptic longitude of each asteroid's pole position. Thus the basic data set will consist of well over 200 lightcurves on our highest priority objects.

This data set will allow us to determine pole positions for most of our target asteroids, and in some cases, the sense of rotation as well. We will derive their shapes by comparing the ensemble of lightcurves with synthetic ones computed for ellipsoidal model shapes, or use complex mathematical inversion methods recently developed by S. Ostro and R. Connelly of Cornell University. If the relative dimensions of the three axes are consistent with those of equilibrium Jacobi ellipsoids, then we can conclude that these asteroids are indeed "gravitationally bound rubble piles." In that case, the theory describing such objects will allow us to compute their bulk densities, and hence to infer something about their compositions.

Observing Procedures

At the telescope, each object is sampled at least 6 times per hour in one color (V filter) with a target precision of 1 percent photometry (0.01 magnitude). Since we need a point every ten minutes, it is possible by working rapidly to interleave data points on two or even three asteroids, and thus obtain several lightcurves simultaneously.

Most of our data have been acquired at the Number 2 0.9-m telescope at Kitt Peak National Observatory, an ideal telescope for our program. It's large aperture allows us to observe in reasonable time to V magnitudes as faint as 15. More important, it has a high pointing accuracy and is computer controlled, allowing us to find targets quickly and efficiently.

Positional information for each asteroid and comparison star is entered into the telescope's computer during the day and these data are called up as the telescope slews toward the position of the first asteroid's comparison star. The photometer begins a series of three 5-second integrations of the comparison star, after which the telescope automatically offsets a minute of arc (usually to the north) so that it can measure the sky background which is subsequently subtracted. This procedure is then followed for the asteroid, which is usually within a degree of the comparison star, so that the telescope is capable of slewing to the object by itself. Enough integrations are obtained so that we obtain at least 20,000 net photon counts. That number provides the required 1 percent precision if the sky is dark and moonless. However, we have found that on moonlit nights we need more counts than this and have derived a formula that takes excess sky brightness into account. We repeat this entire procedure for up to three asteroids at once, and since our program requires us to observe each asteroid 6 times per hour, our nights are busy!

As the night advances, both observer and assistant continue to gather data at a pace that ranges from moderately challenging to furious. We move from comparison star to background to asteroid to background to new object, trying to return to the first object within 10 minutes, all the while keeping watch on the sky for possible cirrus clouds. Because there is no easy access to the outside from the 0.9-m dome, the sky watch is a cumbersome but necessary adjunct to our observing program. As the data continue to come in, they are checked in two ways: first, the three or more integrations that make up a single observation should be within one percent of each other, and second, the comparison stars should remain consistent with earlier readings. At high airmasses the comparison stars appear to change more radically. Although each asteroid has but one comparison star, at any hour we are observing two or possibly three comparison stars as well as a series of well known standard stars.

Real-Time System

To give us a better immediate idea of the behavior of the asteroids we are watching, one of us (CRC) devised a real-time monitoring system. Using an inexpensive Color Computer with cassette recorder and television monitor that are connected to the Kitt Peak computer, we obtain almost instantaneous displays of the lightcurve data which we have collected.

The advantages of the real-time system are threefold. First, we can quickly verify that we have located the correct object by its changing brightness, which is helpful if the asteroid is moving slowly; second, we can favor the observation of a particular object if we know that it is near an extremum in its lightcurve; third, we can discover instantly if the period of any of our objects is incorrect as published. This happened recently with 683 Lanzia, formerly a priority 1 object with a reported 4.3 hour period. When we discovered during one frustrating night that Lanzia satisfies a much longer period, the object was dropped from our program which thus saved us several months of observing before the new period would have shown up in our normal reductions.

Asteroids in Twilight

Thanks to a special reduction program prepared to correct for sky brightness, observations of our asteroids can proceed well into a brightening sky. Since it is often necessary to observe asteroids at extreme phase angles, we find this an extremely useful feature. We consider that the program works so long as the sky can be treated as decreasing or increasing in brightness linearly between the observations of the asteroid and its comparison star. This means that we begin observing in the evening as soon as we can see an asteroid in the telescope and then we continue until we have problems seeing predawn objects. It also means that a December or January observing run can last as long as 13 frigid, windy, uninterrupted hours. With the telescope moving some 700 degrees across the sky to make 60 measurements in a typical hour of observing, this is definitely not an activity for the faint of spirit!

Standard Stars

Standard stars are observed at six opportunities each night in order to serve as controls on the atmospheric and other conditions of our program. We choose three stars, whose characteristic B-V values are well known, from the list of Selected Areas. The evening set is chosen so that it is at a low airmass (between 1 and 1.5) within 2 hours after the evening begins. The three stars and the background sky are observed in two colors, but since the three objects are within a degree of each other, finding them with the telescope is not as time-consuming as it appears.

We next observe the standards when they are at about 1.8 to 1.9 airmasses and then again between 2.3 and 2.5. This final reading occurs generally just before midnight, and shortly after midnight we begin the same procedure with a new set of standards that is rising in the east. We try to adjust our asteroid reading procedure at this point to reduce the time lost because of the need to read standard stars, by reversing the order and reading, for one cycle after the standard set, the asteroid first and then the comparison star. Moreover, by reading the standards when the telescope is already near a target asteroid, we reduce the time lost between asteroid readings. The standards are important because they provide a constant check on the consistency of our data at various airmasses.

History and Plans

During the past year, our nights at the telescope were generally productive with the number of photometric hours somewhat higher than 1982. During one particularly "cost effective" two night run in December 1982, we obtained 8 full light curves and in 4 nights in April 1983 we managed to obtain 10 full and 3 partial lightcurves.

The project has another 18-24 months to proceed, depending to a large extent on the weather. Following that, we will likely need more time to fill in gaps in our data. As our reductions and analysis proceed, we are discovering ways to refine our observing process. We expect that when this project is concluded, we will know much more about both these asteroids and how scientists can best observe them photometrically.

Asteroid	Period (hours)	Diameter (km)	Type	Amplitude (mag)
16 Psyche	4.196	249	M	0.34
22 Kalliope	4.15	175	M	0.30
29 Amphitrite	5.39	199	S	0.13
39 Laetitia	5.14	158	S	0.54
45 Eugenia	5.70	250	UC	0.33
87 Sylvia	5.19	251	P	0.42
107 Camilla	4.85	252	C	0.53
125 Liberatrix	3.969	103	M	0.32
129 Antigone	4.96	113	M	0.32
130 Elektra	5.25	143	U	0.30
201 Penelope	3.75	144	M	0.56
216 Kleopatra	5.39	219	M	1.2
337 Devosa	4.61	100	CSM	0.2
349 Dembowska	4.70	145	R	0.40
354 Eleonora	4.28	156	UR	0.30
511 Davida	5.17	335	C	0.25

Table I
Priority 1 Target Asteroids

PHOTOELECTRIC PHOTOMETRY OF ASTEROID 60 ECHO

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Photoelectric observations of asteroid 60 Echo were made from Gila Observatory on 13 nights between January 29 and February 20, 1984. A synodic rotational period for Echo of 25.208 ± 0.048 hours was determined. The observed amplitude of the lightcurve was 0.22 ± 0.02 magnitudes.

During 1984 the asteroid 60 Echo had a very favorable opposition with a predicted B magnitude at opposition of 11.4. Photometric observations of Echo were undertaken by the authors as part of a program to determine the rotational periods for asteroids with no published lightcurve or whose rotational period is not accurately known, as was the case for Echo.

The observations reported here were made with the 28 cm (11 inch) Schmidt-Cassegrain telescope at Gila Observatory. All photometric observations were made using an uncooled Optec SSP-3 solid state photometer interfaced to a TRS-80 model 3 micro-computer with 16 K of RAM memory. The photometric observations were made using no filters and no transformation of the data to B or V was attempted. However, the unfiltered response of the SSP-3 photometer is most similar to R with a peak response near 8000 angstroms. During the course of the observations described here, the stars SAO 117836, 2 Leo, and SAO 98495 with spectral types G5, F9, and K0, respectively, were used as comparison stars. These comparison stars were never further than 1.5 degrees away from the target asteroid. Differential atmospheric extinction corrections were applied to all data. The choice of near solar-type comparison stars minimized color-dependent variations in atmospheric extinction between the asteroid and comparison star.

Photometric integration times of 90 seconds were used for both the comparison star and the asteroid. Each 90 second integration was composed of three separate 30 second integrations of comparison star or asteroid and four 15 second integrations of the sky background. The sequence of these integrations was sky, asteroid, sky, asteroid, sky, asteroid, sky and sky, comp, sky, comp, sky, comp, sky. Each differential magnitude was derived from a set of three 90 second integrations in the sequence: comparison, asteroid, comparison. An average of six photometric readings of the asteroid were recorded every hour during an observing run. The computer recorded the photometric readings as well as the time of each reading and stored this data in RAM memory for later data reduction. At the completion of a photometric data run, the computer calculated the differential magnitudes taking into account the differential atmospheric extinction between asteroid and comparison star. Atmospheric extinction coefficients were estimated at the beginning of each photometric observing session. The obtained photoelectric data could then be displayed on either the computer CRT or the line printer.

60 Echo has been observed on two previous occasions by Gehrels and Owing (1962) and by Harris and Young (1982). Gehrels and Owing estimated a rotational period of greater than or equal to 30 hours based on a single lightcurve of approximately 8 hours duration. Harris and Young gave a tentative value of 52 hours, based on extensive observations, but noted that interpretation was confused by the fact that one of the comparison stars used was later determined to be a variable star with a period very nearly equal to the rotational period of the asteroid.

Observations of 60 Echo made by the authors on 13 nights between January 29 and February 20, 1984 indicate that a synodic rotational period of 25.208 ± 0.048 hours best fit the observed data. The composite lightcurve shown in Figure 1 is based on this rotational period. The lightcurve shows two broad maxima and minima per rotation with an amplitude of 0.22 ± 0.02 magnitudes.

Radar observations of 60 Echo in the 13 cm wavelength conducted by S. Ostro at the Arecibo Radio Observatory returned no detectable echo from the asteroid. This effect may be explained by a greater than expected Doppler broadening caused by the rotational period for Echo being considerably shorter than the anticipated 52 hours. This evidence lends further support to the assertion by the authors that the rotational period of this asteroid is approximately one-half of the previously assumed value.

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Harris, A. W. and Young, J. W. (1982). "Asteroid Rotation IV: 1979 Observations". Icarus <u>54</u>, 59-109.

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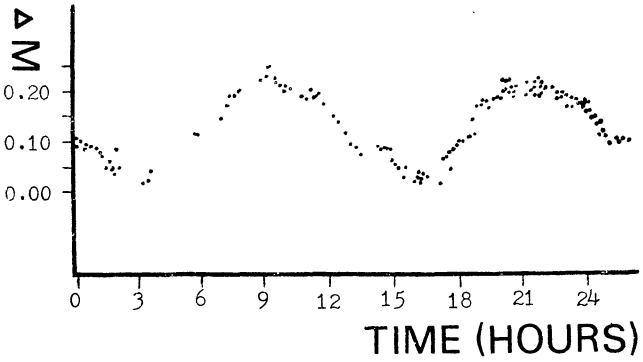

Figure 1. Composite Lightcurve of Asteroid 60 Echo.

THE PHASE COEFFICIENT OF 18 MELPOMENE AS DETERMINED BY VISUAL OBSERVATIONS

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Visual magnitude estimates of 18 Melpomene were made throughout its 1981 apparition. Analysis of the observations made at phase angles > 7 degrees yield a linear phase coefficient of 0.028 ± 0.002 mag/deg, in excellent agreement with the mean value for S-type asteroids. Linear extrapolation to zero degrees phase angle implies a $V(1,0)$ magnitude of 6.88.

The interest generated in this visual observing project was entirely due to Dr. J. U. Gunter's admirable bi-monthly publication <u>Tonight's Asteroids</u>. In the July-August 1981 edition came an appeal by R. P. Binzel encouraging lightcurve observations of asteroid 18 Melpomene during its very favorable opposition in Aquarius.

All observations reported here were made by the first author using a 25 x 105 mm binocular telescope, field 3 degrees, mounted on a portable tripod. Also, a pair of hand-held 15 x 80 mm binoculars, field 4 degrees, was used by the observer comfortably seated in a reclining deck chair with arm rests. Experience has been gained over a number of years in visual magnitude observations of comets and variable stars using various classes of instruments. Particular attention has also been given to monitoring light fluctuations of new and old novae.

The comparison stars were taken from the AAVSO Variable Star Atlas. The magnitude determinations were obtained by the usual variable star techniques by selecting suitable standard comparison stars near the minor planet at the time.

The observations are listed in Table I which gives the UT date, visual magnitude estimate, and the (earth-asteroid-sun) phase angle, α. r and Δ are the sun-asteroid and earth-asteroid distances in AU. $V(1,\alpha)$ is the magnitude of the asteroid corrected to a distance 1 AU from the earth and sun, where

$$V(1,\alpha) = V - 5\,\mathrm{Log}(r\Delta)$$

Figure 1 shows a "phase curve", a plot of $V(1,\alpha)$ versus phase angle. The data show the typical features of a phase curve: a linear portion for $\alpha > 7$ degrees and a non-linear increase for $\alpha < 7$ degrees called "the opposition effect." The opposition brightening is due to the microscopic

1981 Date (UT)		V	α	r	Δ	V(1,α)
June	29.07	9.6	24.8	2.03	1.28	7.5
July	1.05	9.6	24.3	2.02	1.26	7.5
	2.05	9.6	24.1	2.02	1.25	7.6
	8.05	9.4	22.5	2.01	1.19	7.5
Aug.	2.12	8.7	12.2	1.95	0.98	7.3
	3.01	8.5	11.7	1.95	0.97	7.1
	11.13	8.4	7.1	1.93	0.93	7.1
	12.05	8.4	6.5	1.93	0.93	7.1
	23.00	7.6	0.5	1.91	0.90	6.4
	23.91	7.6	1.1	1.91	0.90	6.4
	25.95	7.7	2.4	1.90	0.89	6.6
	26.93	7.7	3.0	1.90	0.89	6.6
	27.91	7.6	3.7	1.90	0.89	6.5
	31.90	7.7	6.2	1.89	0.89	6.6
Sep.	5.90	8.1	9.4	1.88	0.90	7.0
	18.92	8.6	17.0	1.86	0.94	7.4
	22.90	8.7	18.5	1.86	0.95	7.5
Oct.	2.91	9.0	23.0	1.84	1.00	7.7
	20.86	9.3	29.1	1.82	1.14	7.7
	27.91	9.3	30.6	1.81	1.19	7.6

Table I.
Visual Observations of 18 Melpomene

properties of the surface. The slope of the linear portion is called the "phase coefficient" and its value is related to the asteroid's albedo. The linear least squares best fit slope for the data in Table I with $\alpha > 7$ degrees gives a phase coefficient of 0.028 ± 0.002 mag/deg. This line is plotted in Figure 1. Bowell et al. (1979) list Melpomene as an S-type asteroid and the mean phase coefficient for S-types is 0.029 mag/deg (Bowell and Lumme 1979). Thus the visual observations reported here yield a phase coefficient which is in excellent agreement with that of a typical S-type asteroid. If the line in Figure 1 is extrapolated to 0 degrees phase angle, a V(1,0) magnitude of 6.88 is obtained. This is in fair agreement with the 6.61 value from Bowell et al. (1979).

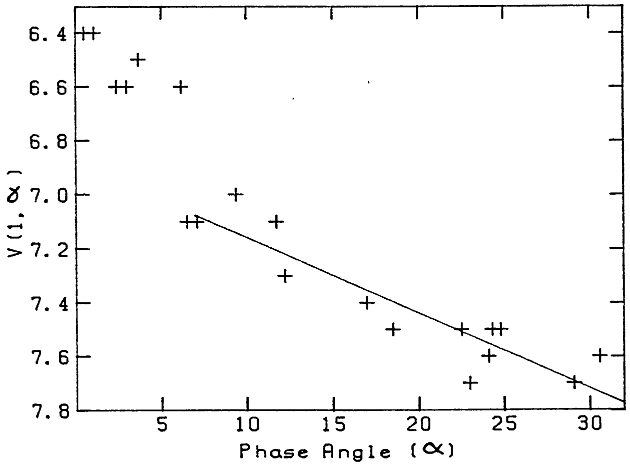

Figure 1.
Phase Curve for 18 Melpomene

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BOOK REVIEW

Solar System Photometry Handbook
Edited by Russell M. Genet
Willmann-Bell, Inc., Richmond, Virginia, 1983
208 pages, $17.95

In the past, photoelectric photometry was an art practiced only by professional astronomers who had access to expensive, custom-made equipment. Recently, however, relatively inexpensive photometers have appeared commercially, thereby providing amateurs the opportunity to obtain photometric observations of various astronomical objects. The professional, however, has a thirty year head-start over the amateur, and many amateurs may wonder if there is anything left for them to do with a photometer on a small telescope. If this is the case for you, then this is the book for you! The book is loaded with discussions of just what opportunities remain for amateur photoelectric photometry of solar system objects.

The book consists of a preface, two forewords, and ten chapters, each written by a different individual covering a different aspect of photoelectric photometry. Eight chapters cover photometry of just about anything in the solar system you can imagine: asteroids, comets, planets, planetary satellites, the sun, and the moon. Two of the chapters are devoted to discussions of the equipment needed to perform the observations covered in the other eight chapters. The foreword by Dunham is practically a chapter by itself, full of information about various kind of occultation observations. Don't skip over this useful portion of the book!

As one might expect from a multiple-author book, the level at which each chapter is written does vary. For example, the chapter by A'Hearn on photometry of comets is clearly aimed at the professional astronomer and only the most advanced amateurs. The chapter by Binzel on photometry of asteroids, on the other hand, describes observations that can be carried out by the beginning amateur photometrist. The readability of the other chapters, especially the ones covering the equipment, depends to large degree on the level of experience the reader has in those subject areas. Another item to watch out for is inconsistent notation from author to author. In chapter one, the Greek letter 'alpha' is used to represent phase angle, while in chapter two, the Arabic letter 'i' is used for the same quantity. Neither author is wrong; such notation differences are common from one branch of a field to another.

Of particular interest to readers of the Minor Planet Bulletin are the chapters written by R. P. Binzel and A. W. Harris on photometry of asteroids and asteroid occultations, respectively. Binzel's chapter covers observations of lightcurves, colors and phase functions. Transformation of observed magnitudes and colors to a standard system, such as the Johnson system, is not covered, however, and I was a little disappointed to not find any references provided on the subject. Anyone contemplating such work would do well to have another reference book handy, such as Software for Photometric Astronomy, by Silvano Ghedini, also sold by Willmann-Bell. Of course, the classic reference on the subject is the chapter by Hardie in Astronomical Techniques, but this book might not be as easy to acquire. On several occasions, the author mentions that certain observations can be done without a filter. I would recommend the use of an ultraviolet blocking filter in those situations, however, as a matter of good practice. The use of such a filter will eliminate some second-order effects that might otherwise limit the precision of the data. Speaking of second-order effects, if pulse-counting equipment is used and high count rates are encountered (say 0.1 to 1.0 MHz and higher), the first step in the reduction procedure (Section V) should be correction for pulse overlap (also known as dead time). If one sticks to objects of asteroidal brightness on small telescopes, however, the effect can be ignored unless one is shooting for very high precision. High precision will be needed for program number three (page 1-4): rotational color variations. It should be mentioned that the observer will need to correct for lightcurve induced color variations for the rapid rotators. For example, if the brightness of an object is changing 0.01 mag per minute (such as 216 Kleopatra can), and the time difference between the V and B measurements is five minutes, one can introduce a 0.05 mag error in the B-V color. This error will change sign if the order of the filter measurements is interchanged, or if the slope of the lightcurve changes sign, thus artificially producing a rotational color variation of 0.1 mag amplitude! Yes, even professional astronomers have been known to incorrectly claim large rotational color variations because of this effect, so beware! If you're just starting out, I would recommend having a more experienced person check your reduction procedure, just to be on the safe side.

Harris' chapter begins by stating one of the most compelling reasons for observing asteroid occultations: they are fun to observe! His writing style goes on to convey the sense of excitement that asteroid occultations provide. They can also be quite frustrating (I have been involved in several occultation expeditions and have yet to witness a single event!), so be prepared to have multiple encounters with Murphy's Law. Much has been learned from recent occultations, and Harris' advice regarding placement of visual and photoelectric observers, as well as the other aspects of observing an occultation, should not be taken lightly. It will certainly take a lot of self-discipline to position oneself in a location where the probability of seeing an event is small.

Electronically inclined amateurs may wish to construct their own equipment. This book has two chapters to aid in that task. J. L. Hopkins discusses the construction of low-speed equipment and P. C. Chen discusses high-speed equipment. Readers with little or no background in electronics might feel a little intimidated by the frequent use of acronyms in Hopkins' chapter: PEP, DIP, MECL, and TTL are some examples. It is common practice to spell out an acronym the first time it is used in a paper, but many find their way into papers without being spelled out by simple force of habit. Sometimes the author assumes that everyone in the audience is familiar with particular acronyms. (A random person on the street may know what NASA is, but what about CTIO, for example?) More emphasis seemed to be given to the construction of the electronics rather than the photometer head itself, so if you really want to start from scratch, you might want to obtain some sample designs from others who have built photometer heads.

Cosmetically, the book is well-printed with a type size that should present no difficulties to keen-eyed astronomers! My copy arrived very well-packaged and undamaged. The book has soft covers which have a tendency to curl outward under conditions of high humidity, but keep it on the shelf when not in use and it should stay in pretty good shape. Of course, no book is "complete" without some errors, and this book has its share. For example, in Table 1-1 the reader will find two asteroids with the name Iris, numbers 7 and 42. Number 7 is the real Iris; number 42 should be Isis. Also in that same table, the adopted spellings of asteroids 194 and 387 are Prokne and Aquitania, respectively. On page 1-10, the reference to Section IV should be a reference to Section VI. I ran across at least a dozen other typographical errors, but none that critically affect an equation or the understanding of a sentence. In conclusion, if you are looking for something new to do and would like to enter the exciting world of solar system photometry, this book would represent an excellent addition to your library.

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PHOTOELECTRIC PHOTOMETRY OPPORTUNITIES NOVEMBER 1984 - JANUARY 1985

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The table below lists asteroids which come to opposition during the months of November 1984 - January, 1985 that represent useful targets for photoelectric photometry observations. Observations are needed because the asteroid has either an unknown or ambiguous rotational period or because the asteroid will be observable at a very low phase angle. The table also includes asteroids which are candidates for a pole determination or are targets for radar observations (see the articles by Zappala' and Knezevic and by Ostro in MPB volume 10, No. 4). The table gives (in order of opposition dates) the asteroid number and name, opposition date, opposition B magnitude, (the V magnitude is about 0.8 brighter), 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. PHA indicates observations of the phase curve are desired because the asteroid will be at an unusually low phase angle, POL indicates the asteroid is a pole position candidate, and RAD or an asterisk indicate the asteroid is a planned radar target. Calibrated B or V measurements would be useful. Question marks are used to denote uncertain or unknown values. An outline of recommended observing procedures is given in MPB volume 11, No. 1, page 7. Ephemerides for these asteroids are included in this issue. Some of these asteroids may appear on finding charts prepared by Dr. J.U. Gunter, 1411 N. Mangum St., Durham, NC 27701. These charts are free for a self-addressed stamped envelope.

Asteroid 337 Devosa is included in this list because observations of this object in 1982 by Binzel were not compatible with the 4.610 hour period listed in TRIAD. The very low phase angle (0.02 degree) reached by 735 Marghanna and its favorable opposition are noted in Tholen's article on low phase angle asteroids in this issue. 7 Iris is expected to be at a nearly polar aspect which will yield a very low lightcurve amplitude. This will make observations of the phase curve for this asteroid more useful since significant lightcurve variations will not interfere.

Asteroid	Opp'n Date	Opp'n B Mag	Per	Amp	
337 Devosa	Oct 7	12.2	4.61?	0.2	PER
735 Marghanna	Nov 7	12.2	?	?	PER+PHA
344 Desiderata	Nov 10	12.6	?	?	PER+PHA
751 Faina	Dec 4	12.0	?	?	PER
198 Ampella	Dec 12	11.7	?	?	PER+PHA
7 Iris	Dec 15	7.9	7.135	0.1	PHA+POL*
6 Hebe	Dec 26	9.2	7.274	0.1	POL+RAD
747 Winchester	Dec 28	10.9	8.	0.1	PER+POL*
40 Harmonia	Dec 29	10.5	9.136	0.2	PHA
96 Aegle	Jan 10	12.3	?	?	PER
488 Kreusa	Jan 15	12.2	>28	0.2	PER

PHOTOELECTRIC PHOTOMETRY OPPORTUNITIES

DATE	R.A. (1950) HR	MIN	DEC. DEG	MIN	MAG B	PHASE ANGLE
Minor Planet	6 Hebe					
Nov 1	6	47.9	4	21.	10.06	25.4
11	6	49.6	3	44.	9.90	23.0
21	6	47.9	3	22.	9.73	19.9
Dec 1	6	42.9	3	20.	9.56	16.1
11	6	34.9	3	41.	9.42	12.2
21	6	24.9	4	28.	9.33	8.9
31	6	14.4	5	38.	9.36	8.0
1985 Jan 10	6	4.8	7	6.	9.51	10.2
20	5	57.4	8	45.	9.74	13.6
30	5	52.9	10	28.	9.99	17.0
Feb 9	5	51.7	12	8.	10.24	19.7
Minor Planet	7 Iris					
Nov 1	5	52.0	25	59.	9.00	24.1
11	5	52.0	25	25.	8.72	19.9
21	5	47.6	24	43.	8.44	14.7
Dec 1	5	39.6	23	54.	8.17	8.7
11	5	29.5	22	59.	7.82	2.2
21	5	19.1	22	4.	8.02	4.3
31	5	10.5	21	12.	8.43	10.3
1985 Jan 10	5	5.0	20	30.	8.79	15.5
20	5	3.3	19	60.	9.14	19.7
Minor Planet	40 Harmonia					
Nov 1	6	59.5	21	21.	11.92	23.8
11	7	2.4	21	30.	11.70	21.5
21	7	1.7	21	46.	11.45	18.4
Dec 1	6	57.4	22	11.	11.19	14.4
11	6	49.7	22	41.	10.92	9.7
21	6	39.3	23	15.	10.62	4.4
31	6	27.7	23	47.	10.39	1.2
1985 Jan 10	6	16.4	24	14.	10.80	6.6
20	6	7.0	24	36.	11.09	11.6
30	6	0.7	24	53.	11.37	15.9
Feb 9	5	58.0	25	6.	11.65	19.3
19	5	59.0	25	17.	11.90	21.9
Minor Planet	96 Aegle					
Dec 1	8	6.3	35	4.	13.10	15.3
11	8	2.6	35	16.	12.88	12.8
21	7	55.8	35	25.	12.66	9.7
31	7	46.4	35	25.	12.46	6.6
1985 Jan 10	7	35.4	35	12.	12.30	4.7
20	7	24.0	34	42.	12.37	6.0
30	7	13.8	33	55.	12.53	9.2
Feb 9	7	5.8	32	56.	12.72	12.5
19	7	0.7	31	49.	12.91	15.4
Mar 1	6	58.8	30	38.	13.09	17.9

DATE	R.A. (1950) HR	MIN	DEC. DEG	MIN	MAG B	PHASE ANGLE
Minor Planet 198 Ampella						
Nov 1	5	44.2	28	52.	12.54	20.1
11	5	39.8	28	20.	12.31	16.0
21	5	31.8	27	38.	12.08	11.2
Dec 1	5	21.1	26	44.	11.85	5.8
11	5	9.5	25	42.	11.58	1.2
21	4	58.5	24	35.	11.98	5.5
31	4	49.7	23	31.	12.32	10.4
1985 Jan 10	4	44.0	22	35.	12.65	14.6
20	4	41.7	21	50.	12.96	17.9
30	4	42.7	21	17.	13.25	20.4
Minor Planet 337 Devosa						
1984 Oct 2	0	54.9	10	35.	12.22	4.1
12	0	44.2	10	13.	12.10	2.9
22	0	34.0	9	47.	12.38	7.6
Nov 1	0	25.7	9	22.	12.62	12.5
11	0	20.1	9	6.	12.86	16.8
21	0	17.7	9	3.	13.10	20.3
Dec 1	0	18.7	9	15.	13.32	23.0
Minor Planet 344 Desiderata						
1984 Oct 2	3	36.3	15	11.	13.26	15.8
12	3	29.4	15	34.	13.08	12.3
22	3	20.0	15	52.	12.91	8.3
Nov 1	3	8.9	16	5.	12.69	3.9
11	2	57.1	16	15.	12.48	0.6
21	2	45.8	16	22.	12.88	4.9
Dec 1	2	36.2	16	31.	13.19	8.8
11	2	28.8	16	43.	13.45	12.1
Minor Planet 488 Kreusa						
Dec 1	8	18.5	25	8.	13.12	16.7
11	8	18.0	26	5.	12.89	14.2
21	8	14.8	27	12.	12.65	11.0
31	8	8.8	28	25.	12.42	7.4
1985 Jan 10	8	0.8	29	37.	12.17	4.1
20	7	51.7	30	43.	12.14	4.0
30	7	42.6	31	36.	12.34	7.3
Feb 9	7	34.9	32	12.	12.53	11.1
19	7	29.6	32	33.	12.73	14.5
Mar 1	7	27.2	32	39.	12.93	17.3
Minor Planet 735 Marghanna						
1984 Oct 2	3	17.5	11	4.	12.94	20.0
12	3	10.8	12	29.	12.68	15.0
22	3	0.5	13	53.	12.44	9.2
Nov 1	2	48.1	15	12.	12.15	2.9
11	2	35.4	16	25.	12.26	3.3
21	2	24.2	17	31.	12.71	9.0
Dec 1	2	15.9	18	32.	13.09	13.9
Minor Planet 747 Winchester						
Nov 1	6	49.2	1	33.	12.01	26.6
11	6	52.8	1	14.	11.83	24.3
21	6	52.9	1	13.	11.63	21.3
Dec 1	6	49.7	1	36.	11.43	17.6
11	6	43.5	2	27.	11.24	13.6
21	6	35.1	3	48.	11.10	9.8
31	6	25.9	5	34.	11.08	8.0
1985 Jan 10	6	17.3	7	38.	11.24	9.4
20	6	10.6	9	50.	11.50	12.6
30	6	6.7	12	0.	11.81	16.0
Feb 9	6	5.9	14	3.	12.11	18.9
Minor Planet 751 Faina						
Nov 1	5	8.7	15	11.	12.70	16.6
11	5	2.1	16	3.	12.45	12.1
21	4	52.5	17	1.	12.21	7.1
Dec 1	4	41.1	18	4.	11.90	2.1
11	4	29.4	19	8.	12.10	4.5
21	4	19.0	20	12.	12.44	9.4
31	4	11.2	21	14.	12.74	13.9
1985 Jan 10	4	6.6	22	14.	13.04	17.5
20	4	5.7	23	14.	13.31	20.4

LOW PHASE ANGLE ASTEROIDS

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As promised in the last issue, here is a continuation of the list of low phase angle asteroids. This issue's listing has been expanded to include those asteroids reaching phase angles of 0.15 degrees or less; the list, given in Table I, is complete through 1985 January 31 for asteroids up to and including number 3000.

This issue's list is somewhat more deficient in bright asteroids. Do note, however, the excellent apparition of 735 Marghanna, which is predicted to reach a blue magnitude of 11.91 on November 5. Here is an excellent opportunity to add a high-numbered asteroid to your list.

As mentioned in the last issue, the alert reader should realize that at such low phase angles, an asteroid would pass through the earth's penumbra. A quick "back of the envelope" calculation was performed to estimate the amount by which an asteroid's brightness would be diminished. The even more alert reader would have realized that my calculations were defective! To do the calculation, I pulled a couple of numbers off the top of my head: the diameter of the sun (as seen from a distance of 1 AU), which we all know is about 1/2 degree, and the diameter of the earth (also as seen from 1 AU), which I estimated as 8.8 arcsec. The 8.8 figure I recalled is known as the horizontal parallax of the earth. What I failed to recall at the time is that the horizontal parallax refers to the apparent angular radius of an object. Thus I underestimated the angular size of the earth by a factor of two. Curiously, no reader called my attention to this error; come on, MPB readers, wake up! You shouldn't let me get away with such mistakes.

For the record, let's do the calculation right. The horizontal parallaxes of the sun and earth are 959.641 and 8.794 arcsec, respectively. At a distance of 1.919 AU, the sun subtends 1000 arcsec (diameter), and at a distance of 0.914 AU, the earth subtends 19.2 arcsec (diameter). The area ratio earth/sun is therefore 1/2700, which converts to 0.0004 mag, about four times larger than the number derived last time, but the conclusion remains unchanged: the loss of light is unmeasurable. Theoretically, one could collect enough photons to measure the brightness of an object to 0.0004 mag precision; in practice, the fluctuations produced by the atmosphere and the rotation of the object would mask such a small variation by many times over.

TABLE I

Asteroid	Phase Angle	Mag B	UT Date	Time
673 Edda	0.15	14.56	1984 Nov 4	2 hr UT
1909 Alekhin	0.09	16.97	1984 Nov 4	10
24 Themis	0.04	11.94	1984 Nov 4	14
1340 Yvette	0.13	17.22	1984 Nov 4	16
735 Marghanna	0.02	11.91	1984 Nov 5	17
1486 Marilyn	0.07	16.20	1984 Nov 8	9
1841 Masaryk	0.07	16.27	1984 Nov 11	21
2286 Fesenkov	0.09	16.19	1984 Nov 17	4
1752 van Herk	0.01	16.15	1984 Nov 19	9
90 Antiope	0.05	13.43	1984 Nov 30	3
1185 Nikko	0.03	14.49	1984 Dec 3	16
1109 Tata	0.02	15.51	1984 Dec 20	2
637 Chrysothemis	0.14	15.53	1984 Dec 21	15
514 Armida	0.13	13.59	1984 Dec 24	21
2264 Sabrina	0.03	16.46	1984 Dec 25	19
677 Aaltje	0.13	14.40	1984 Dec 26	14
2039 Payne-Gaposchkin	0.11	17.28	1985 Jan 1	0
2324 Janice	0.10	16.77	1985 Jan 1	12
2593 Buryatia	0.13	16.39	1985 Jan 2	1
2403 Sumava	0.03	16.73	1985 Jan 10	4
2800 4585 P-L	0.14	18.10	1985 Jan 10	3
1778 Alfven	0.11	17.09	1985 Jan 13	10
2066 Palala	0.04	16.66	1985 Jan 16	13
2217 Eltigen	0.14	16.89	1985 Jan 18	17
2237 1938 TB	0.06	16.29	1985 Jan 21	10
1383 Limburgia	0.02	17.01	1985 Jan 23	2
2123 Vltava	0.08	16.54	1985 Jan 23	21
1966 Tristan	0.12	17.31	1985 Jan 29	9
1748 Mauderli	0.07	17.75	1985 Jan 30	21

LETTER TO THE EDITOR

Dear Editor,

I enjoyed reading "William Herschel and the First Two Asteroids" (MPB v. 11 p. 3), but author Cunningham failed to tell you an interesting fact about the meeting of Herschel and Piazzi. According to Isaac Asimov, (Asimov's Biographical Encyclopedia of Science and Technology) when Piazzi visited England ". . . he had the doubtful privilege of falling off the ladder at the side of Herschel's great reflector and breaking his arm."

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COMPUTER TRACKING CHARTS

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(Received: 2 April Revised: 4 June)

To aid in photographing asteroids, a computer program is used to generate finding charts for the selection of guide stars. The data base contains all asteroids with a given minimum magnitude and the stars from the Yale catalogue down to 7th magnitude. Parameters may be set that allow the charts to be plotted in many different formats. The charts will be sent to interested readers for a small charge to cover costs for copies and postage.

It's very time consuming work to find guide stars for photographing asteroids, especially if they are invisible in the telescope itself. The normal procedure is to take the ephemerides from the EMP (Ephemerides of Minor Planets by the Institute of Theoretical Astronomy in Leningrad) or ephemerides from the Minor Planet Center and plot the positions by hand on a star chart with a good scale so that finding guide stars for long focus exposures is possible.

Because this is too much work for all asteroids, I decided to do this with a computer. At first I typed all the elements of the EMP in to my computer files, which was very hard work, but there is no computer readable version available to my knowledge. Then I took star positions from the Yale catalogue which contains about 9000 stars down to 7th magnitude. This is the limiting magnitude for guide stars for most amateurs, I think.

Now the problem was to bring both data sets together in a form which was best for quickly planning the exposures. At first I wrote a program to calculate ephemerides with errors under 20". An example of this is presented in Table I. In addition to the normal data like date (day.month.year), right ascension (hh.mmmm), declination (ddd.mmm), and magnitude, the radius (asteroid-sun distance) and earth-asteroid distance (both in AU) are given. (For example, the first entry is for 27 August 1984 and the coordinates are R.A. 4 hours 21.42 minutes and declination -8 degrees 28.2 minutes.) The table also gives the time (in minutes) for the asteroid to move 5 arc seconds (5"), the motion of the asteroid (in arc seconds) in 15 minutes (15 m), the elongation from the sun, the phase angle, and the daily motion in right ascension and declination (M-A and M-D are in minutes and arc minutes, respectively). The top of the table lists the number and name of the asteroid, the interval (in days) covered by the ephemeris, and the date of the printing.

The motion data are very useful for calculating whether or not the asteroid is bright enough to bring enough light to a point on the film. Therefore you must also know your guiding error and the resolution of the film. For example: if the greatest value phemerides of 183 Istria days: 170 printed in 20.03.84

Date	Rektas.	Declin.	Magn.	Radius	Distan	5 °	15m	Sun	Pha	M-A	M-D
27. 8.1984	4.2142	-8.282	14.00	1.840	1.520	4	20	92	33	+2	-9
24. 9.1984	5.1094	-14.091	13.66	1.820	1.320	5	16	102	33	+1	-13
22.10.1984	5.3984	-20.258	13.34	1.820	1.170	8	9	114	30	+1	-11
19.11.1984	5.3996	-24.169	13.08	1.850	1.080	16	5	127	25	+0	-2
17.12.1984	5.1824	-21.426	13.04	1.900	1.070	7	11	135	22	+0	+14
14. 1.1985	5.0298	-12.242	13.38	1.970	1.200	5	15	129	23	+0	+24
11. 2.1985	5.1164	-1.199	13.98	2.050	1.450	5	15	113	26	+1	+22

Table I.

Example ephemeris for 183 Istria. Explanation of the columns is given in the text.

of resolution and guiding error is 2" and the guiding error is 2", your film must be able to reach 13th magnitude in 6 minutes on 1984 Nov. 19 (see table).

I have defined the beginning and end of an asteroid's apparition as when the asteroid's elongation is increasing or decreasing, respectively, above or below a specified value. In addition, the magnitude must also be below a fixed value. For the ephemeris in the table and figure, I set the minimum elongation at 35 degrees and the magnitude limit at 14.0.

The finding charts (see Figure 1) are for the epoch 1950.0, but the epoch is not very interesting because I use the finder chart for the guide stars at the telescope. The area in Figure 1 is a very popular region of the sky (Orion). On the horizontal axis at the bottom is printed the right ascension (labeled every hour) and on the left side is the declination (labeled every 15 degrees). Listed at the top of the chart is the number and name of the asteroid, the dates for the beginning, middle, and end of the opposition where the magnitude on these dates is given in parenthesis. Also given on the top line is the plotting date. On the right vertical axis is the interval in days covered by the chart.

The use of the charts in practice is simple. Note the marks on the asteroid track. The large marks are at 28 day intervals (about one period of the moon) and these marks correspond to the dates in the ephemeris. The smaller marks are in 7 day intervals. An arrow at the end of the track indicates the direction of motion. Suppose you want to photograph 183 Istria on 1985 January 28. You look at the ephemeris and see that the nearest date is 1985 January 14. After a short examination of the chart you find the large mark on the track for this ephemeris date. Moving forward along the track by two smaller marks (14 days) you have located the asteroid's position for January 28. After viewing the field around this position you notice: "Oh, a fine, bright star about two degrees north of the asteroid". (It's Beta Eridani). So, for example, you can photograph the asteroid with about a 400 mm focal length lens on 24 x 36 mm film while guiding on this star. (The diameter of the exposed field for this system is about 4 degrees.)

The charts can also be used for planning over a long time. Because most observers (amateur astronomers) observe on weekends you can step along each small mark on the track (one week). The large marks quickly show the asteroid's position at full (or better new) moons.

For computing I use a SIEMENS 7.882 computer. The language is Fortran 77 and the program may be run with a minimum of 400 KB RAM. In the future I'm planning to take as a base for star positions the SAO catalogue for special asteroids (very bright ones and also fast moving asteroids). Interested observers are requested to send a minimum of DM 16 to cover the cost of copies and postage.

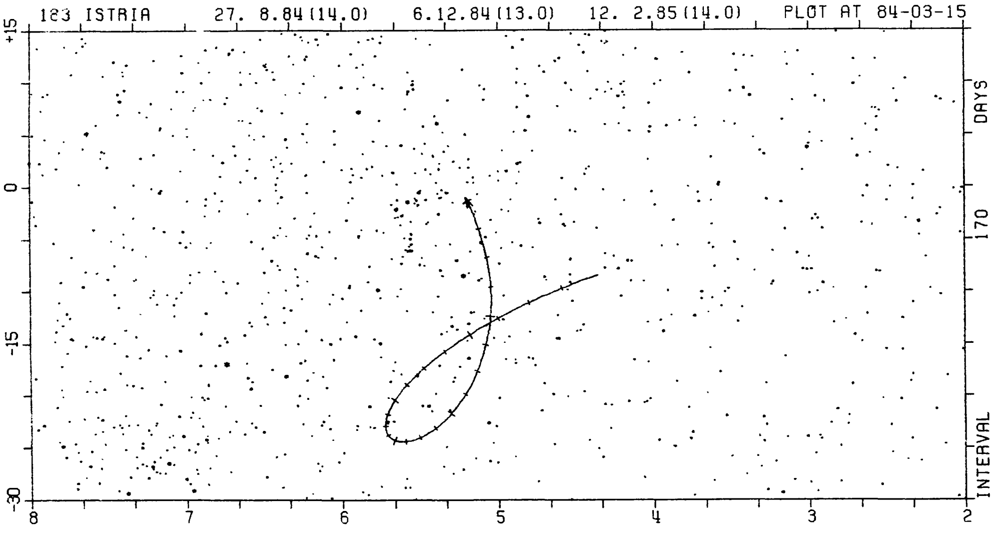

Figure 1.

Example chart for 183 Istria. Explanation of the chart and axis labels are given in the text.

I thank Mr. Grasshoff for making the Yale catalogue available to me, Mr. Klare for communication about star positions on magnetic tapes and Dr. Marsden for communication about asteroids on tapes. I also thank all who made suggestions for improvements in the charts during the development phase of the chart format.

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ASTEROID NEWS NOTES

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Seventy-two New Asteroids

Through the August batch of *Minor Planet Circulars* (MPCs), 72 new asteroids were numbered, bringing the total to 3104. Most of the new additions are main-belt objects, but there are some notable exceptions. For the first time since (2608) Seneca, an Apollo/Amor has been numbered; in fact, the long dry spell was ended with the numbering of *two* such objects: Amor asteroid 1981 QA was numbered (3102), and Apollo asteroid 1982 BB was numbered (3103). Other non-main-belt objects include (3040) 1979 BA, a Mars crosser; (3043) San Diego, (3086) 1980 XE, and (3101) 1978 GB, all in the Hungaria region; (3092) 6550 P-L and (3095) 1980 RT2, both in the Cybele region; and (3063) 1983 PV, a Trojan asteroid in the cloud leading Jupiter.

Earth-approaching Asteroid Update

If you think you're going to read about twin discoveries again... you're right! As mentioned in the last issue, 1983 TF2 came along to destroy the pattern. Now, along comes 1983 SN to resurrect it! 1983 SN is presumably an Apollo object discovered by the Infrared Astronomical Satellite (IRAS) last September. Unfortunately, a five-day delay in reporting the object and poor weather at ground-based observatories prevented confirmation of the discovery. Nevertheless, of all the potential earth-approaching objects seen only by IRAS, this one has, by far, the most convincing evidence. Thus the Minor Planet Center gave it the official provisional designation 1983 SN.

Just when you thought 1983 was over, and the twin discoveries along with it, along come two new Apollo asteroid discoveries: 1984 KB and 1984 KD, both discovered at Palomar by the Shoemakers. 1984 KD was a remarkable object, passing only 0.03 AU away from the earth on June 19 (as close as Comet IRAS-Araki-Alcock passed last year), and getting as bright as visual magnitude 11. Several visual observers reported variations in brightness of 0.3 to 0.4 mag in a time span of as little as 20 minutes.

Here's a quick review of the twins "born" during the last 14 months: 1983 LB and LC, 1983 RB and RD, 1983 SA and SN, 1983 TB and TF2, 1983 VA and VB, and 1984 KB and KD. Remarkable, no?

New Names

Once again, the newly named asteroids nearly kept pace with the newly numbered objects during the May to July interval (no new names were reported in August). Fifty-five asteroids received new names. Among the honored are (2227) Otto Struve, named for the famous astronomer, and (3043) San Diego, named for the city in appreciation of its decision to install low pressure sodium vapor lamps, which will help Palomar Mountain retain darker skies. Incidentally, (3043) San Diego is now the highest numbered asteroid with a name. Last but not least, the founder of the Minor Planets Section of the Association of Lunar and Planetary Observers, Richard G. Hodgson, was honored with the naming of (2888) Hodgson. As all *MPB* readers know, he deserves the honor. Congratulations!

Not In Icarus

Icarus may be the official journal of solar system studies, but papers on asteroid research can also appear in other professional journals. One which may be of interest to *MPB* readers appeared in the January 22 issue of *Science*. Using the NASA Infrared Telescope Facility (IRTF) and an infrared photometer equipped with a circularly variable filter (CVF), D. P. Cruikshank and W. K. Hartmann observed two of the five known A-class asteroids over the wavelength range of 0.8 to 2.6 microns. The A-class asteroids had been identified by photometry over the wavelength range of 0.3 to 1.1 microns, and are characterized by extremely steep, reddish spectra between 0.3 and 0.7 microns. Longward of 0.7 microns, a strong absorption feature was present. The fact that the spectrum was not observed to turn back up or even flatten out at 1 micron suggested that olivine was present in abundance. Subsequent JHK photometry located the long-wavelength side of the absorption feature and strengthened the case for olivine. The higher-resolution CVF data confirm the earlier results, but in addition, the data show no sign whatsoever of any absorption feature due to pyroxene. Laboratory experiments have shown that such absorption features will be present if pyroxene exceeds ten percent of a olivine/pyroxene mixture. Therefore we can state that these two objects, (246) Asporina and (289) Nenetta, have relatively pure (less than ten percent pyroxene) olivine surfaces. The significance is that olivine is found in such a nearly pure state only as a result of differentiation processes, so we now have evidence that more asteroids have undergone heating, melting, and differentiation. Just how extensively the asteroid belt, in general, is differentiated, is still a subject of some debate, and the answer has major implications for the evolution of the asteroid belt and solar system.

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IMPORTANT ANNOUNCEMENT

Beginning with Volume 12 (the next issue) the Minor Planet Bulletin will be produced using an Apple Macintosh computer. This will provide faster word processing than the current system and will be more convenient for the editor to use. It will also allow authors with similar machines to submit their manuscripts in machine readable form (on disks). A description of the font styles and format for articles may be obtained from the editor. Any reader who has a Macintosh and would be willing to help typeset material for the MPB is encouraged (and begged) to contact the editor.

THE MINOR PLANET BULLETIN is the quarterly journal of the Minor Planets Section of the Association of Lunar and Planetary Observers. The Minor Planets Section is directed by its Recorder, Prof. Frederick Pilcher, Department of Physics, Illinois College, Jacksonville, IL 62650 USA. The MPB is edited and composed by Richard P. Binzel, Department of Astronomy, University of Texas, Austin, TX 78712 USA, and is distributed by Derald D. Nye, Route 7 Box 511, Tucson, AZ 85747 USA. The subscription rate is $7.00 US a year (four issues) for surface mail and $9.00 US a year for overseas air mail. Checks or money orders should be made payable to the "Minor Planet Bulletin". Subscription payments, address corrections, change of address notices, or other subscription business should be sent to Mr. Nye. The numbers in the upper-right corner of your mailing label indicate the volume and issue number with which your subscription expires.

Articles for submission to the MPB should be sent to the editor who also serves as the Photoelectric Photometry Coordinator. Please follow the guidelines given in "Instructions for Authors" in issue 11-1. Visual photometry observations should be sent to: Alain C. Porter, c/o Graduate Housing, California Institute of Technology, Pasadena, CA 99925. Positional observations of minor planets, any type of observation not covered above, and general information requests should be sent to the Recorder.

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The deadline for the next issue (12-1) is November 1, 1984. The deadline for issue 12-2 is February 1, 1984.