# Occultation Newsletter

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## SATELLITE OF MINOR PLANET (532) HERCULINA DISCOVERED DURING OCCULTATION

David W. Dunham

A satellite of (532) Herculina was discovered visually, and confirmed photoelectrically at another station, when the asteroid occulted 6.2-mag. SAO 120774 on June 7. A finder chart and brief predictions were published in the last issue of *O.N.* A brief account of the amateur-professional cooperation which led to this remarkable discovery is given below. More information will be given in articles in ***Nature, Icarus,*** and ***Sky and Telescope*** (1978 September issue).

The occultation occurred less than ten days after the successful observation of the May 29 occultation of SAO 85009 by Pallas, on which astrometrists concentrated their attention, partly due to the fact that the Kuiper Airborne Observatory was going to attempt it (see OBSERVATIONS OF THE OCCULTATION BY PALLAS, p 156, this issue). The expected path crossed the Pacific Ocean, starting off the coast of Mexico and passing between New Zealand and Australia, from which the event would be visible in case of a small shift. I sent copies of IOTA Special Bulletin #5, giving details about the event, to many observers in New Zealand and southeastern Australia. I also sent copies to Lowell Observatory, Flagstaff, AZ, and to two observers in California, since I said in the bulletin, "An improbable, but not impossible, 2$''$0 north shift would cause the occultation to be visible from the populous southwestern part of California at about $11^h27^m$ U.T. at about 8° altitude above the western horizon." Two nights before the event, William Penhallow obtained three astrometric plates of Herculina and the star at Quonochontaug Observatory, Rhode Island. He reduced his measurements of the plates and telephoned me the observed positions 32 hours before the event. I recalculated the path, finding that it would shift 2$''$1 north of the nominal prediction; the expected path now crossed Arizona (at very low altitude) and the San Gabriel Mountains north of Los Angeles! A plate taken a few weeks earlier could have spotted such a large ephemeris error and shown that the probability of the event occurring in the southwestern USA was good. In any case, I telephoned many IOTA members and professional astronomers interested in occultations, throughout California and Arizona. Observers in Mexico, Nevada, and Hawaii also were alerted, and Wayne Warren sent a telex message from Goddard Space Flight Center to Mt. Stromlo Observatory in Australia (unfortunately, the message did not get through to David Herald, who might have alerted observers in Townsville, Queensland, from which the occultation would have been visible). The occultation shadow crossed California's Mojave Desert, where it was timed visually by IOTA members Keith Horne at Rosamond (duration 17$^s$3) and James McMahon near Four Corners (duration 20$^s$6). Mike A'Hearn, visiting from the University of Maryland, and Ted Bowell also recorded a 23$^s$5 occultation photoelectrically with Lowell Observatory's 42-inch telescope. Fortunately, observing conditions were excellent and the observation successful in spite of the 2½° altitude above the western horizon (with the sun 9° down in the east)! Mike A'Hearn set a record which probably will not be beaten soon, since he also recorded the occultation by Pallas on May 29. Bowell's analysis of the timings gives 217 km for Herculina's diameter, in good agreement with results from radiometry and polarimetry; the observational residuals were only a few kilometers, probably due at least as much to mountains and valleys on Herculina as to timing uncertainties. The fade of the spectral-type M2-III star at disappearance and at reappearance lasted a few tenths of a second and was noticed visually and photoelectrically, as expected (see ANGULAR DIAMETERS OF STARS TO BE OCCULTED BY MINOR PLANETS [in #16]). The derived stellar angular diameter is 0$''$0029, with considerable uncertainty due to the low altitude.

McMahon waited until the following weekend to analyze his tape recording carefully before telephoning me the results. He said that observing conditions were good at his site, and claimed that the star disappeared completely six times within ± 2 minutes of the main event. During the 6 minutes that he observed before this interval, and the 4 minutes that followed it (after which he stopped observing), the star appeared fuzzy due to the ~ 8° altitude, but its brightness remained steady. Most of the secondary events were quite short, perhaps involving objects too small to occult the star at the other stations, but one 97 seconds before the primary occultation had a 4$^s$0 duration. The Lowell photoelectric trace was examined at the corresponding point, and a 5$^s$3 occultation is evident there, with indications of the fade due to the star's diameter. The observations are consistent with a dynamically possible satellite 50 km in diameter and 0$''$9 or 990 km from Herculina projected in the plane of the sky. The southern limit of the satellite occultation should have passed a few km north of Horne, so the fact that he saw no secondary occultation is consistent. The satellite should be about 3 magnitudes fainter than Herculina, which was mag. 9.3 at the time. At favorable elongations, such an object should be detectable with area scanners or by visual or photographic observation techniques; such observations are in progress at Lowell. The period of revolution about Herculina is probably 60 ± 30 hours.

Although this is the first confirmed satellite of a minor planet, a number of such objects have been suggested by previous observations (see FURTHER SUPPORT FOR MINOR PLANET MULTIPLICITY, p. 152). Herculina's satellite was nearly in line with its apparent motion, while the object which may be orbiting Hebe was perpendicular to that asteroid's movement. Some special observing strategies are recommended to establish whether the causes of secondary occultations are terrestrial or celestial:

1. Visual observers should observe in pairs about a km apart, close enough to see the same secondary occultation but far enough apart for truly independent observation; coincidental timings would imply a celestial origin.
2. Photoelectric observers should also observe visually, if the expected magnitude drop is great enough to see, either with a guide scope or (better, to prevent inadvertently bumping the main instrument) with another telescope nearby. Visual observations can establish whether dips in the photoelectric record are due to guiding or other instrumental problems, or due to the star's actually disappearing.
3. High-speed (usually digital recording is needed) photoelectric observations can record the Fresnel diffraction pattern as the star is occulted by the asteroid. The diffraction pattern will be modified by the star's angular diameter, and perhaps by close duplicity. Hence, if the star's signature appears in the diffraction

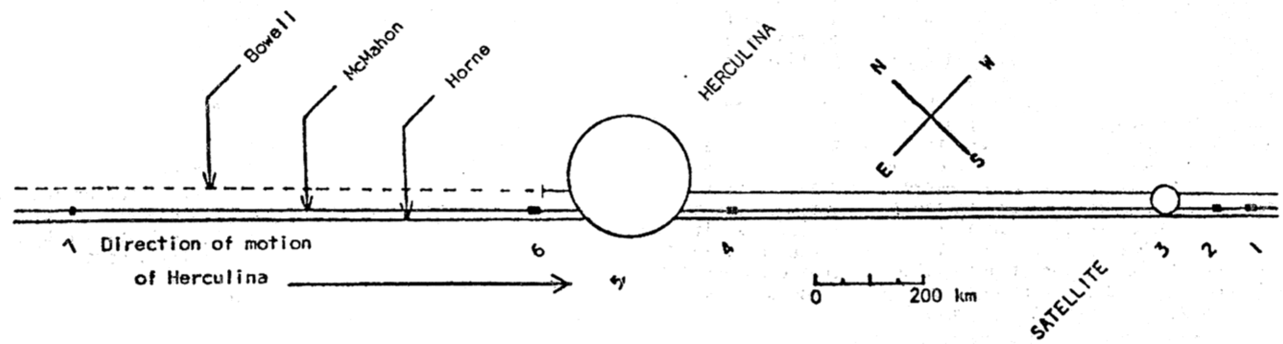
pattern for a secondary occultation, it safely can be assumed to be celestial.

Since asteroidal satellites are probably common objects, it may be useful to record all negative (miss) observations reported during asteroidal occultations which are observed somewhere. I have received negative reports of the Herculina event from observers in Tokyo, Japan; San Jose, Fresno, Wrightwood, Glendora, and San Diego, CA; Honolulu and Mauna Kea, HI; and Woden, Australia. The northern limit of the Herculina occultation probably passed about 15 km south of Fresno, CA, while the southern limit probably passed just north of Palmdale, CA, in accord with the miss observations. Herculina will occult a 7.8-mag. star, probably in South America, on August 22. Since the asteroid will be nearly 1 A.U. farther from the earth than in June, the magnitude drop will be nearly as great as for the June 7 event (see the last issue of *O.N.*, p. 142). It will be important to watch all future occultations by minor planets carefully, to see which types of asteroids have the most satellites. They may provide important clues about the formation of the asteroid belt. Due to greater geographic dispersion, amateurs may be more likely than professionals to discover asteroidal satellites, but observations must be made carefully for confirmation.

Brian Marsden suggests that the satellite be provisionally designated "1978 (532) 1," indicating that it is the 1st satellite of (532) Herculina to be discovered in 1978. This essentially follows the adopted I.A.U. prctice for satellites of major planets. If direct observations of the satellite are obtained so that an orbit can be determined well enough to predict its future motion, a permanent designation such as "(532) I" will be assigned.

Addendum received 1978 July 15:

James McMahon discusses his historic observations in a paper, "The Discovery of a Satellite of an Asteroid," which he distributed with the July bulletin of the China Lake Astronomical Society and which he also used as a first draft of a paper to be presented at the Astronomy West '78 joint convention in San Luis Obispo, CA, July 27-30. All observations, including the five extinctions of the star which he saw and for which there were not equivalent observations at the other stations, are plotted in his diagram reproduced here. Note that Bowell's observations were terminated 6 seconds after emersion from Herculina, just before McMahon's extinction #6.




He discusses the interpretation of the observations, from his statement of June 9, "I would sooner believe that elephants could fly than that asteroids could form into stable clusters," to Edward Bowell's statement of June 28, "These two independent observations constitute incontrovertible evidence of a secondary occultation for which the most likely explanation is a satellite of Herculina." McMahon points out that the discovery might not have been made at all if the truck his group used had not failed to start after they stopped at the site north of Four Corners from which the observations were made. They did not want to use the site due to lights behind a hill a few miles to the west, but their plan to observe instead from a location a few miles farther south to escape the light pollution was foiled by the starter failure. At the more southerly location, the 50-km satellite which produced the secondary occultation at Lowell probably would not have occulted the star, so that there would not have been two independent observations. Fortunately, they were able to start the truck and return to China Lake after the observations had been made.

McMahon notes that two pairs of the extinctions he observed, #4 and 6, and 2 and 7, were very symmetrical with respect to the Herculina mid-occultation time. The possibility of their being caused by narrow rings is intriguing, but hard to reconcile with the absence of corresponding observations at the other sites. Due to the low altitude, quick and/or partial events might be lost in the noise of the Lowell photoelectric record, which, as noted above, was terminated soon after the emersion from Herculina. McMahon notes that the small aperture he used may have been an advantage for seeing the secondary events, which appeared as complete to him, while in fact they may have been deep partial events. He reported that the star's image remained steady, but was somewhat diffuse during an 8-minute period centered on the occultation. While he observed, the star's image remained sharp at other times before and after this interval. He noticed haze in the desert air as dawn brightened after the event, but again, the symmetry is curious. Could a cloud of dust, surrounding Herculina somehow diffuse the star's light, or was the dust only in the earth's atmosphere? In summary, there is much to look for during future asteroidal occultations, which should be carefully observed.

Note added 1978 July 18:

G. Taylor's and D. Dunham's recent analyses of the the observation showed that the diameter of Herculina is 243 km. The 217 km value computed at Lowell resulted from a combination of coordinate and program errors. When these were corrected, they also obtained 243 km. A new solution for the satellite gives a diameter of 46 km. If the albedos are similar, the $\Delta m$ would be 3.6, indicating that the satellite probably would be too faint to detect directly. The new solution indicates that Fresno, CA was about 10 km south of the northern limit, but G. Wimer is certain that a miss occurred there. This is possible, since the 3 observed chords were well south of the center of Herculina (more so than indicated in McMahon's diagram). The Fresno observations imply that the true average diameter may be at least a few kilometers less than the 243 km value derived from the formal solution

[Ed: As Dr. Dunham mentioned, McMahon's paper was a first draft. The final report will be prepared prior to the Astronomy West convention, will have improved figures, and will be printed in black by photo-offset, rather than in the purple ditto of the first draft. Mr. McMahon has agreed to provide a copy of the final report to each U.S. requestor who includes a stamped (28¢), self-addressed, long (ca. 4¼ X 9½) envelope (James H. McMahon; 109-P Blandy Ave.; China Lake, CA 93555). European requestors should make arrangements with H.-J. Bode. Other non-U.S. requestors may contact the editor (Mr. DaBoll) for further information.]

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## FURTHER SUPPORT FOR MINOR PLANET MULTIPLICITY

Richard P. Binzel

Paul Maley's observation of an event occurring well outside the main path of the 1977 occultation of the star $\gamma$ Ceti by the minor planet 6 Hebe was initially greeted with much skepticism. Because of the experienced Maley's certainty in his observation, David Dunham recognized that he probably had observed an occultation by a satellite of Hebe [*O.N.*, *1* (11), 115-7 (July '77)]. The question of minor planet multiplicity has been raised several times previously in astronomical literature but has never gained much attention. Now in the light of recent occultation observations, multiple minor planet systems are becoming generally accepted.

Minor planet multiplicity was first conjectured in 1901 by the French astronomer Ch. Andre,[1] who was struck by the similarity in the light curves of 433 Eros and the eclipsing variable β Lyrae. This led him to conclude that Eros is actually a double planet system. Recent theoretical work also has proposed that 624 Hektor is a "binary asteroid."[2]

Interestingly, several visual observers have reported actually seeing Eros as double. During the 1924 opposition of Eros, R. T. Innes at the Union Observatory in Johannesburg noted on one night that, as seen through their 22.5-cm refractor, Eros appeared "bar-like, or similar in appearance to a close double star."[3] W. H. van den Bos and W. S. Finsen, observing with the 56-cm refractor at Johannesburg in 1930, noted on several nights near opposition, the image of Eros appeared, "certainly a figure-of-eight, resembling that of a 'notched' or nearly separated double star of about 0″18 distance."[4] Their observations listed a 0.2-magnitude difference between the components, and a period of revolution of $5^h17^m$.

Van den Bos and Finsen also made an additional very interesting observation involving another minor planet in 1926. While sweeping a zone in search of new double stars, they found and measured one which they could not identify in any atlas. Further research revealed that the new "double star" was actually Pallas![5] Van den Bos also stated that he had observed Titan to be double in 1929 and 1930 (unpublished).[4]

Only in the last few years have observers had success in observing the not particularly rare phenomena involving occultations of stars by minor planets. In each case where such an occultation has been observed successfully, there have been observations which support the notion of minor planet multiplicity. An occultation of a star by 2 Pallas in February of 1973 was observed from three locations near the shadow path, and yielded seemingly confusing results. The observers at the extremes both reported certain occultations, while the central observer was certain he saw no occultation at all. In 1973 October, Harold Povenmire observed a brief occultation of a star by 129 Antigone from southern Florida, even though astrometric measurements made shortly after the event showed that the main path had passed through Colombia, far to the south of Povenmire. Larry Nadeau and several other observers, located well outside the main path of the occultation of κ Geminorum by 433 Eros in 1975, also reported brief or "partial" occultations.[6] However, even after Maley's observation of 6 Hebe, which led Dunham to propose the idea of satellites of minor planets, most preferred to rationalize away the secondary events, all by visual observers, as being spurious or due to atmospheric conditions.

Confirming evidence for the existence of minor planet satellites came when one of the secondary events observed visually by Jim McMahon during the occultation of a star by 532 Herculina on 1978 June 7 was in perfect agreement with a secondary event found in the photoelectric record of the occultation made by Ted Bowell at Lowell Observatory. This event has been recognized as caused by a satellite of Herculina, and this object has been officially designated 1978 (532) 1 in IAU Circular 3241. In retrospect, Richard Radick of Prairie Observatory in Illinois found that he had recorded photoelectrically a secondary event during the 1978 May 29 occultation of a star by Pallas. One other observer of the Pallas occultation recorded a possible secondary event.

If the resulting discovery of a satellite of Herculina allows us to infer that the observations of secondary events seen during all prior occultations of stars by minor planets were actually due to the presence of satellites, then it is necessary to conclude that, in order for us to be fortunate enough to have detected them, minor planets must be surrounded by swarms of such bodies. Furthermore, since it seems that these bodies have been detected during each observed occultation, it indicates that multiple minor planet systems may be the rule, rather than the exception.

References


1. *Astronomische Nachrichten, 155*, 27 (1901)
2. *Physical Studies of Minor Planets*, NASA SP-267, p. 155 (1971)
3. *Astronomische Nachrichten, 241*, 55 (1931)
4. *Astronomische Nachrichten, 241*, 329 (1931)
5. *Monthly Notices of the R.A.S.C., 86*, 209 (1926)
6. *Icarus, 28*, 133 (1976)


## IOTA NEWS

David W. Dunham

A meeting of the IOTA officers was held in Highland Park, IL, on June 23. At that time, the IOTA treasury and records were turned over to John Phelps. Although he was named Treasurer last year, the records were not brought up to date and organized well enough to turn over to him until this June. An extra $250 was received from the organizers of last year's National Amateur Astronomers' convention, which was, at final accounting, even more successful than expected (see *O.N.*, *1* (12), 121).

An IOTA meeting was held June 29 during the Astronomical League's meeting in Madison, WI. Asteroidal occultations were a main topic of discussion. Improvements in the USNO total occultation predictions which I have made this year and which are planned for the future, and the recent USNO prediction versions, also were discussed. IOTA plans for observing the 1979 February 26 solar eclipse, mainly from locations just inside the path of totality (see *O.N.*, *1* (14), 144), were described during an A.L. eclipse session which preceded the IOTA meeting.

We now have enough material on hand to publish two issues of *O.N.* Some of the articles mentioned in this issue will be published in issue #16, which may be distributed less than a month after this issue. Like issue #12, issue #16 probably will not include lists of double stars and grazes observed, but will include some of the text for the articles associated with the lists published in this issue.

The *O.N. Volume 1* index can not be published until about October, to give time to include the material in issue #16. We have decided to break up the indexing job, which is rather big for one person. Volunteers are sought (or arms will be twisted) to prepare sections of the index concerning, for example, double stars, grazes, planets, asteroids, special objects, publication abstracts, erroneous star positions, and clusters. An author index is needed. The star numbers in the double star and graze lists are being keypunched so that lists sorted in star number order can be generated by computer, but volunteers are needed to go through the associated written articles. I will try to coordinate the overall indexing effort. USNO Z-numbers will be converted to X-numbers for the index (see IMPORTANT INFORMATION REGARDING GRAZING OCCULTATIONS AND USNO PREDICTION VERSIONS, p. 155).

## COMPARISON OF ZODIACAL SUBSETS OF THE PERTH 70 AND SAO CATALOGS

David W. Dunham

From 1967 to 1973, astronomers from Hamburg Observatory, German Federal Republic, set up a photoelectric meridian circle at Perth Observatory, Western Australia, and systematically measured accurate positions of 24,000 stars as part of the Southern Reference Star (SRS) program. The density is about one star per square degree south of declination +5°, but many stars, most brighter than sixth magnitude, were also observed between +5° and +35°. The average mean error at the observation epoch is ±0″17. Proper motions were generally derived from other catalog data, and introduce further error at current epochs, but at 1980, the total mean error for Perth 70 stars is expected to average less than 0″3. The coordinate system defined by Perth 70 is a smoothed FK4 system with smaller local errors than FK4 itself at epoch 1970.[1]

The SAO catalog relies mainly on the Yale and Albany General (G.C.) Catalogs, with observation epochs around 1930 and 1890, respectively, so the positions in the Perth 70 catalog are expected to be a big improvement over SAO positions. Lunar occultation predictions are currently computed using a zodiacal subset (ecliptic latitudes between -6°40' and +6°40', maximum possible topocentric ranges for lunar occultations) of the SAO catalog, with all data taken instead from the Zodiacal Catalog[2] (Z.C.), N30, FK4S, and FK4 for about 14% of the stars. This "SZ" catalog, ordered by 1950 R.A., was constructed by Van Flandern at the U. S. Naval Observatory in 1967.[3]

I recently formed a Zodiacal subset of the Perth 70 catalog and made a computer comparison with the SZ catalog, the catalog data being provided on magnetic tape by USNO. The stars were matched by coordinates (maximum differences allowed were 0ˢ2 in R.A. and 3" in Dec.) and positional differences computed for the epochs 1975 and 1980. The resulting list should be especially useful for predicting shifts for grazing occultations (see final paragraph). Of the 2848 zodiacal Perth 70 stars, two (SRS 42779 and 11277) of which are apparently the same star, Z.C. 1849 = SAO 139022 = B.D. -2°3593, only 23 were not matched with SZ stars. For four of these stars, the R.A. was not observed at Perth (three others in this category had been eliminated earlier). The computer logic somehow failed (actual coordinate match was rather good) for one star, SRS 10983 = B.D. +0°2942 = SAO 138774 = Z 11893. Eleven stars are not in the SAO or SZ, but are in the USNO K-catalog which I compiled from non-SAO stars from the Z.C., Yale, and AGK3 catalogs; these are listed in Table 1.

Table 1
Zodiacal non-SAO Perth 70 Stars

| USNO K# | SRS# | Z.C., AGK3, or DM # |
|---|---|---|
| K00049 | 2960 | AGK3 N04°17 = BD +4° 8 |
| K00626 | 3611 | AGK3 N02°117 + BD +2°161 |
| K07196 | 14185 | BD -18° 4519 |
| K07199 | 14255 | BD -21° 4626 |
| K07259 | 14651 | Z.C. 2620 = BD -20° 5003 |
| K07312 | 14862 | BD -20° 5147 |
| K07328 | 14948 | BD -18° 5008 |
| K07348 | 15018 | BD -20° 5240 |
| K07454 | 15596 | Z.C. 2862 = CD -26° 14337 |
| K07513 | 16789 | BD -20° 6212 |
| K07521 | 17264 | Z.C. 3257 = BD -18° 6084 |

The Perth 70 magnitudes are much brighter than the K-catalog magnitudes for some of these stars: K00049, mag. 8.8, Perth 70 mag. 7.9; K00626, 10.7, 10.0; K07328, 8.2, 7.0; and K07348, 7.9, 7.3. K07328, at the corrected mag. 7.0, is the brightest star in the K-catalog and is now being occulted. The others are SZ stars with poor position matches, usually slightly over 0ˢ2 difference in R.A., and are listed in Table 2. The coordinate matching was so successful partly because doubles involving relatively bright secondaries with separations of a few arc seconds or less were excluded from Perth 70.

Table 2
Zodiacal Stars whose Perth 70 - SAO Positional Differences at Epoch 1980 Exceed 3″0

| USNO Ref. # | SAO # | SRA # | DM Number | 1980 Pos. Difference Sep. | P. A. | Mag |
|---|---|---|---|---|---|---|
| Z12334 | 139087 | 11347 | -3° 3385 | 4″87 | 88°7 | 8.6 |
| Z18444 | 186683 | 14778 | -28 14476 | 4.38 | 277.5 | 8.4 |
| Z19917 | 162311 | 15351 | -19 5344 | 3.69 | 255.0 | 8.5 |
| Z20141 | 187990 | 15428 | -28 15685 | 3.92 | 275.3 | 8.8 |
| Z20307 | 188112 | 15488 | -22 5100 | 5.26 | 222.2 | 6.8 |
| Z22409 | 163996 | 16461 | -17 6129 | 4.03 | 254.4 | 7.4 |
| Z24357 | 165326 | 17676 | -11 5933 | 3.31 | 276.8 | 8.4 |

The epoch 1980 mean differences (in the sense, Perth 70 - SZ) for all computer-matched stars were -0″58 in R.A. ($\Delta\alpha\cos\delta$) and 0″00 in Dec. The mean R. A. difference for FK4 stars is less than 0″2 in zodiacal declination zones (Ref. 1, p. 47), so the large mean R.A. difference probably represents the failure of corrections applied to the Yale, Z.C., and G.C. systems to bring them to the FK4 system at epoch 1980.* The mean *separation* of Perth 70 positions from SZ positions was found to be 0″97 at 1975 and 0″98 at 1980, emphasizing the utility of Perth 70 data for setting up observing sites for grazes. The 1980 separations for many stars, especially those where the SAO source was G.C., exceeded 2".

Richard Schmidt and others at USNO are working with Perth 70 data, as well as FK4-corrected data from many other observational astrometric catalogs available in machine-readable form, to derive the best possible positions and proper motions for many zodiacal stars, including all SZ stars and most (probably all) K-catalog stars, to compile a more accurate and more comprehensive "XZ" catalog which will supersede the SZ (and K) catalogs for all occultation work. The XZ catalog will be available with USNO's version (basis) 79A. If "79A" (or higher number) is printed for the basis on your ACLPPP profile, the prediction has been corrected using the improved XZ position of the star. However, many ACLPPP profiles have been computed with the earlier 75 and 76 USNO versions (see IMPORTANT INFORMATION REGARDING GRAZING OCCULTATIONS AND USNO PREDICTION VERSIONS, on page 155).

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1. Høg, E. and von der Heide, J., "Perth 70, a Catalog of Positions of 24900 Stars," ***Abhandlung aus der Hamburger Sternwarte, 9*** (1976).
2. Robertson, J., "Catalog of 3539 Zodiacal Stars," ***Astronomical Papers prepared for the use of the American Ephemeris and Nautical Almanac, 10***, Part II (1940). The Z.C. is a compilation catalog with mean epochs around 1910.
3. Van Flandern, T. C., "A Discussion of 1950 - 1968 Occultations of Stars by the Moon," Ph. D. thesis, Yale (1969).


*A similar comparison of AGK3 with the SZ matched 11984 stars with mean differences of -0″26 in R.A. and -0″06 in Dec. at 1980, probably for the same reasons noted above for Perth 70 - SZ. The AGK3, with a southern declination limit between -2° and -3°, sampled only the northern part of the SZ, while Perth 70 concentrated on the southern part. The mean AGK3 - SZ separation was found to be 0″92 at 1975 and 1″00 at 1980. Although the mean AGK3 epoch is in the early 1960's, the positions (derived from photographic plates) are not as good as Perth 70. Graze observations have generally shown only slight improvement when AGK3 shifts were applied to the SZ predictions.

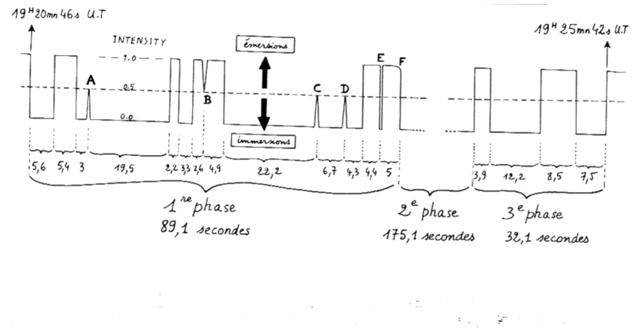
## GRAZES REPORTED TO IOTA

David W. Dunham

Graze reports should be sent to my current address, P.O. Box 488, Silver Spring, MD 20907, U.S.A. As usual, if possible, a copy also should be sent to H. M. Nautical Almanac Office, Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, E. Sussex BN27 1RP, England. There is more information about reporting data on p. 93 of #10. The table of observed grazes is in the same format used in previous issues.

The first known observations of a graze of Aldebaran (ZC 0692) were made on 1978 April 11. Rick Wright and two others attempted to observe the graze from Southeastern Oklahoma State University in Durant, OK. Observation was difficult due to low altitude in the daytime sky and glare from nearby white buildings. A half-minute occultation was seen but could not be timed accurately. A few observers to the north timed the total occultation. At Fick Observatory, Ames, IA, Beavers recorded the disappearance photoelectrically, but the low daytime altitude made the record so noisy that only the time of the event could be determined. A large weather front with heavy rain prevented observation by several other planned expeditions in North America east of Oklahoma.

The weather was more favorable in Europe, where the same occultation occurred shortly after sunset. Three successful expeditions are listed in the table. The chart showing the 19 events timed from a site near Villers-La-Faye, France, is from Jacques Fulgence's report of his visual observations. The intensity of the star's light is shown as a function of time, with 0.0 indicating that the star is completely occulted and 1.0 showing it unocculted. He recorded three partial flashes (A, C, and D), one partial blink (B), one complete blink (E), and a gradual disappearance (F). Another expedition, to Ferté-St. Aubin, France, composed of 9 observers



(mostly Belgian) led by Schwaenen Jean obtained 62 timings. Some of these, made with 2 or 3 telescopes at the same site, seem to be redundant. A number of gradual events due to Aldebaran's angular diameter were seen. Some unresolved questions, about some of the positions, remain. The expedition will be listed in a future issue when they are answered. Wolfgang Beisker, a member of the Astronomische Arbeitskreis Hannover, recorded the total occultation disappearance photoelectrically with a 22-cm Cassegrain telescope at Hannover University. They estimate the angular diameter from their record to be 0".021 ± 0".003.

The ICTA expedition to Billings, MT, for the May 9 graze of Aldebaran was canceled due to an uncertain weather forecast for the area. Paul Asmus had planned to drive there from Denver, but was prevented from doing so by an unusual late storm which dumped two feet of snow on the city. An expedition near Penticton, B.C. was clouded out. An observer from Great Falls, MT traveled to the predicted limit, where he observed one occultation of the star. He missed one of the contacts due to a small cloud which passed in front of the moon at the wrong time.

Walter Morgan reports that he saw 12 events during the July 2 graze of Aldebaran, making it the best he's seen. The graze occurred shortly after sunrise. Apparently over 30 timings were obtained by his 7-station expedition south of Reno, NV. The graze probably also was observed from California.

Harold Povenmire has finally assembled reports of his large expedition for the 1976 August 28 graze of Spica (ZC 1925). See *o.N.*, *1* (10), 94 and 109. Unfortunately, a cloud covered the moon during part of the graze for many observers, causing many lost timings. Adding the results of all expeditions, a total of 147 timings was obtained, making it the 7th most sucessfully observed graze.

Unfortunately, the first known injury requiring hospitalization resulting from an attempt to observe a graze occurred on 1978 December 29 at Fredericksburg, VA. There were 8 stations in the joint Richmond - D.C. expedition for the graze of ZC 1381. Glare from the highly gibbous waning moon and atrocious winter seeing (temperature was 12° F) prevented any useful observations. While driving through Fredericksburg after the graze, the automobile of one of the Richmond observers was struck by another fast-moving automobile, knocking the observer unconscious and breaking one of his arms.

For the graze of ZC 806 On 1978 May 10, an asterisk precedes the shift value, indicating that it is a mean value. The timings made during the graze occurred in two groups, one before and one after central graze. DaBoll notes that for Watts angles below 185°, the shift was 0".15 *north*, while for W.A.'s greater than 186°, it was 0".36 *south*. Apparently, there is a discontinuity in Watts' data there caused by his difficulty in defining a spherical datum where the eastern and western hemispheres join near the poles. Most of the ACLPPP profile points are in accuracy class 1.

An 8-station Richmond - D.C. joint expedition led by Emil Volcheck set up near Stony Creek, VA, to observe the graze of ZC 1271 on March 20. About an hour before the graze, clouds moved in from the north and west. I decided to drive to a site in the limit over 10 miles to the southeast (the small roads in the area did not go conveniently in that direction) to get away from the clouds. Railroad tracks almost coincident with the predicted northern limit allowed me to know quickly where I was with respect to the limit. The clouds overtook me at my new site, where I assembled my telescope and equipment only minutes before the graze started. The sky looked discouraging, with only a few small breaks in the clouds. A few seconds after central graze, a long break in the clouds occurred, so I was able to make 3 timings during 1½ minutes before the clouds closed in again. The observers who stayed in Stony Creek were completely clouded out.

J02291, whose graze was observed on 1978 May 11, is B.D. +18° 1123.

The graze of Z03748 = SAO 94021 at Tomsk on 1976 January 13 had not been predicted, but since Morosov normally uses a printing chronograph for timing occultations, he was able to time the four events which occurred during a half-minute span.

[Ed: Thomas Campbell, Jr. (5405 98th Ave.; Temple Terrace, FL 33617) plans to lead large expeditions in Florida, for the Aldebaran grazes on Sept. 22 and Nov. 16, and the Venus partial on Dec. 26. For details, send him a long, self-addressed, stamped envelope.]

| Mo | Dy | Star Number | Mag | % Snl | CA | Location | # Sta | # Tm | C C | Ap cm | Organizer | St | WA | b |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1976 | | | | | | | | | | | | | | |
| 1 | 13 | Z03748 | 7.2 | 87+ | | Tomsk, Siberia | 1 | 4 | | 13 | A. Morosov | | | |
| 4 | 4 | 0654 | 6.0 | 20+ | | Yeniseisk, Siberia | 1 | 2 | | 11 | V. Kharevich | | | |
| 8 | 28 | 1886 | 5.7 | 14+ | 6S | Kroonstad,R.S.A. | 10 | 52 | 9 | 8 | M. D.' Overbeek | 5S | 173 | 18 |
| 8 | 28 | 1925 | 1.2 | 15+ | 7S | Wabasso Bch., FL | 33 | 103 | 9 | 6 | Harold Povenmire | | | |
| 1977 | | | | | | | | | | | | | | |
| 3 | 12 | 2050 | 8.1 | 43+ | | Coimbra,Portugal | 1 | 1 | 3 | 15 | Jose Osório | | | |
| 7 | 24 | 2114 | 5.8 | 61+ | 3S | Parys, S. Africa | 2 | 13 | 7 | 10 | Jan Hers | 20S | 177 | -29 |
| 12 | 15 | Z23942 | 7.9 | 34+ | | Oliv.deAzem.,Port. | 1 | 1 | 2 | 15 | Jose Osório | | | |
| 12 | 18 | 0053 | 6.9 | 60+ | S | Palmerston N.,N.Z. | 1 | 7 | | 8 | N. Munford | | | |
| 1978 | | | | | | | | | | | | | | |
| 1 | 3 | 1946 | 7.2 | 40- | -2N | Victoria, TX | 1 | 3 | 7 | 25 | Don Stockbauer | | | |
| 2 | 11 | 0058 | 7.7 | 15+ | 4N | Dacono, CO | 1 | 0 | 4 | 20 | Paul Asmus | S | 6 | 4 |
| 2 | 12 | Z01042 | 8.3 | 22+ | 1N | San Antonio, FL | 4 | 6 | 6 | 25 | Thomas Campbell | 1N | 3 | 16 |
| 2 | 12 | Z01042 | 8.3 | 22+ | 1N | Titusville, FL | 1 | 1 | | 20 | Robert Berry | | 3 | 16 |
| 2 | 13 | 0310 | 7.7 | 32+ | 3N | Freiheit, TX | 3 | 11 | 7 | 15 | Don Stockbauer | 0 | 5 | 32 |
| 2 | 13 | 0310 | 7.7 | 32+ | 6N | Reddick, FL | 3 | 7 | 7 | 20 | Thomas Campbell | 2S | 8 | 32 |
| 2 | 13 | 0310 | 7.7 | 32+ | 7N | Daytona Beach, FL | 1 | 4 | | 25 | Robert Berry | 1S | 8 | 32 |
| 2 | 14 | 0437 | 7.4 | 43+ | 6N | Kyle, TX | 3 | 13 | 8 | 15 | Don Stockbauer | 4S | 8 | 45 |
| 2 | 17 | 0814 | 5.3 | 70+ | 1N | Calgary, Alberta | 4 | 4 | | 15 | John Howell | | 2 | 70 |
| 2 | 22 | 1428 | 3.8 | 99+ | 23N | Calgary, Alberta | 3 | 4 | | 8 | John Howell | | 358 | 51 |
| 2 | 22 | 1428 | 3.8 | 99+ | 27N | Greenville, WI | 3 | 6 | 8 | 15 | Homer DaBoll | CO | 3 | 51 |
| 3 | 4 | 2789 | 7.3 | 23- | S | Tolaga Bay, N.Z. | 1 | 3 | | 20 | Glen Rowe | | | |
| 3 | 11 | 0247 | 6.7 | 9+ | 4N | Oviedo,Domin.Rep. | 1 | 4 | | 20 | John Van Allen | | | |
| 3 | 16 | 0823 | 6.6 | 48+ | 8N | San Miguel, P.I. | 1 | 6 | | 8 | Oscar de los Alas | | | |
| 3 | 20 | 1271 | 5.9 | 80+ | 9N | Joyner, VA | 1 | 3 | 6 | 25 | David Dunham | 2S | 4 | 64 |
| 3 | 31 | 2685 | 7.0 | 53- | 6S | Shady, FL | 2 | 4 | 6 | 25 | Thomas Campbell | 10S | 186 | -61 |
| 3 | 31 | 2685 | 7.0 | 53- | 6S | Mims, FL | 1 | 6 | | 25 | Robert Berry | | | |
| 4 | 10 | Z02522 | 7.5 | 6+ | 2N | St.Petersburg, FL | 8 | 20 | 7 | 25 | Dan Bricker | 8N | 10 | 48 |
| 4 | 10 | 0454 | 5.8 | 6+ | -1S | Mason, IL | 1 | 4 | 7 | 20 | Homer DaBoll | 2N | 189 | 50 |
| 4 | 11 | 0692 | 1.1 | 17+ | S | Vill.LaFaye,France | 1 | 19 | | 21 | Jacques Fulgence | | | |
| 4 | 11 | 0692 | 1.1 | 17+ | S | Vallorbe, Switz. | 1 | 6 | 9 | 20 | Hans-Joachim Bode | | | |
| 4 | 11 | 0692 | 1.1 | 17+ | S | Possens, Switz. | 1 | 2 | | 20 | Maurice Roud | | | |
| 4 | 12 | Z03972 | 7.1 | 19+ | -4S | Gilroy, CA | 2 | 2 | 6 | 25 | James Van Nuland | 0 | 187 | 68 |
| 4 | 14 | Z06094 | 8.1 | 36+ | 5N | Wallingford, CT | 1 | 0 | | 10 | Edward Wetherbee | 3S | | |
| 4 | 14 | 1003 | 7.2 | 36+ | 6N | Pleasonton, KS | 3 | 11 | 4 | 15 | Robert Sandy | 0 | 8 | 73 |
| 4 | 14 | 1091 | 6.7 | 44+ | N | L.Cb.S.Juan,Spain | 5 | 10 | | 6 | Luiz Quijano | | | |
| 4 | 15 | 1106 | 3.6 | 45+ | -7S | Lake City, FL | 1 | 5 | | 15 | Harold Povenmire | | | |
| 4 | 15 | Z07277 | 9.1 | 45+ | 6N | Fredericksburg,VA | 1 | 1 | 2 | 25 | David Dunham | C | 7 | 72 |
| 4 | 16 | Z08230 | 9.3 | 55+ | 7N | Potomac, MD | 2 | 2 | 2 | 20 | David Dunham | C | 6 | 67 |
| 5 | 10 | 0806 | 5.1 | 8+ | 2S | Petersburg, IA | 1 | 6 | 7 | 20 | Frank Olsen | | 188 | 71 |
| 5 | 10 | 0806 | 5.1 | 8+ | 2S | Oswego, IL | 5 | 13 | 7 | 13 | Homer DaBoll | *2S | 188 | 71 |
| 5 | 11 | J02291 | 9.2 | 13+ | 1N | Silver Spring, MD | 1 | 1 | 2 | 25 | David Dunham | CO | 7 | 72 |
| 5 | 13 | 1281 | 6.4 | 37+ | 0S | Lugano,Switzerld. | 1 | 4 | | 15 | Alge Edi | | | |
| 6 | 12 | 1478 | 7.2 | 32+ | -0S | Holland, TX | 1 | 3 | 5 | 15 | Don Stockbauer | | | |
| 6 | 13 | Z11155 | 8.3 | 50+ | | S.D.Avelines,Belg. | 1 | 6 | | 20 | Jean Bourgeois | | | |
| 6 | 14 | 1692 | 6.8 | 52+ | 1N | Jefferson, AR | 1 | 1 | 8 | 20 | Homer DaBoll | C | 0 | 16 |
| 6 | 24 | 3155 | 6.8 | 83- | 6S | Summerville, TX | 1 | 1 | 7 | 25 | Don Stockbauer | | | |

## IMPORTANT INFORMATION REGARDING GRAZING OCCULTATIONS AND USNO PREDICTION VERSIONS

David W. Dunham

Several important changes (hopefully, improvements) have been made at USNO in recent months by Van Flandern, Richard Schmidt, and others. Until two months ago, graze data were being computed with USNO's version 76B, which is similar to other USNO versions used during the last few years. Version 78A was created in May. It included a revision to many of the SZ star positions north of declination -4°. About 40 observational catalogs in machine-readable form were reduced to the FK4 system and least-squares solutions made to obtain positions and proper motions for the stars, which should be a big improvement over the SAO and Z.C. data for the stars involved. Data from the accurate Perth 70 catalog for mainly southern stars (see COMPARISON OF ZODIACAL SUBSETS OF THE PERTH 70 AND SAO CATALOGS, p. 153) were *not* included. Due to the improved accuracy expected for the northern stars, I computed some of the profile data for the current quarter's grazes on version 78A. Unfortunately, at the time, there was no lunar ephemeris tape ("SMBDN" tape, which includes empirical corrections to be applied to the ephemeris positions based upon analysis of occultation observations) compatible with 78A, so the 76B version SMBDN tape was used. The significance of the errors caused in doing this, especially relative to the improved 78A star data, is currently unknown. An SMBDN tape for 78A has been generated. The lunar ephemeris used for this tape was fitted to lunar laser ranging observations, which should make it rather accurate, but I feel there could be some errors in declination, since there has been no determination of empirical corrections based upon an analysis of occultation data yet. The empirical corrections in declination for earlier versions have amounted to several tenths of an arc second, quite significant for grazes. In early July, version 79A became operational. Rather than using the SZ star catalog, it uses an expanded "XZ" catalog, which is essentially a combination of the SZ catalog (used in all previous versions) and my K catalog (see *o.n.*, *1* (13), 138), but with more accurate star positions and proper motions used (as in version 78A), and Perth 70 data are now included. Hence, the version 79A XZ catalog should have the best possible star positions. The USNO reference numbers will be preceded by X, except for ZC stars, where (as with the current Z) the prefix is blank. An SMBDN tape soon will be available for 79A; it will include empirical corrections based upon the first analysis of all available occultation observations made from 1627 to 1977. Overall, the 79A system should be a vast improvement. A disk file correspondence between the SZ and XZ catalogs has been established at USNO for rapid automatic conversion of Z to X numbers. Both total and graze predictions for 1979 will use X numbers rather than Z numbers for non-ZC stars. These changes cause some problems for grazes. Although the basic graze data through the end of 1979 already have been computed with version 76B, even for grazes occurring now, the predictions can be corrected to version 79A by computing the profile data with version 79A. Watch the version, which is printed on the ACLPPP profiles. Overall, 79A should result in a big improvement in graze prediction accuracy. But shifts observed during past grazes reported in this, and previous, issues of *o.n.* relate to version 76B, which uses completely different (less accurate) lunar ephemerides and corrections, and star positions, from those of 79A. So the reported shifts are meaningless for version 79A. On future graze reports, you should specify the version given on the ACLPPP profile when reporting observed shifts. Hopefully, observed shifts using 79A will be small. I do plan to re-reduce some past graze observations using 79A to see how good it is for graze predictions. It may be necessary, as a result, to change some of the empirical corrections which we've built into the ACLPP Program. Unfortunately, time will not permit the comprehensive analysis that should be done. We will be interested in how well version 79A performs during upcoming grazes; some of the changes in star positions are substantial. I hope the transition to 79A won't cause too many problems. Since the 79A star positions should be the best available, it should no longer be of any use to request shift calculations using the Yale, AGK3, or Perth 70 catalogs. If your profiles used version 78A, I will compute a Perth 70 shift using the same procedures employed earlier for AGK3 shifts: Three or more observers should be planning to observe the graze; the date, star's USNO reference number, star's position source as given in the limit prediction, and P.A. of graze should be specified; and a self-addressed, stamped envelope or card should be enclosed. Requests should be received by me preferably two or more weeks before the event. The 78A star positions should be better than either Yale or AGK3, so shifts computed using those catalogs should not improve the prediction. If your profiles used either 76B or earlier versions, Yale, AGK3, and Perth 70 shifts can be requested, as before, since those catalogs should have better positions than the Z.C. or G.C. In versions 78A and 79A, the position source information in the predictions still will say "Z.C.", "Yale", or "G.C.", for example, when Perth 70 or a combination of other catalog data actually were used for the position and proper motion of the star.

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## OBSERVATIONS OF THE OCCULTATION BY PALLAS

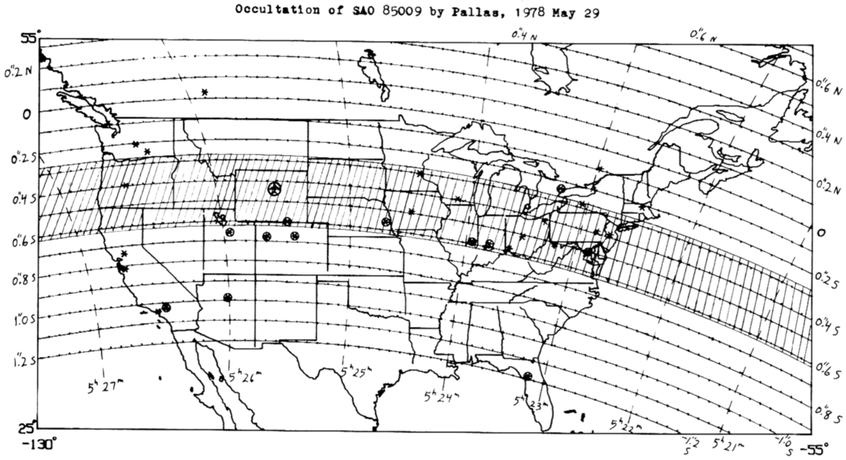
David W. Dunham

The occultation of SAO 85009 by Pallas on May 29 was recorded photoelectrically from seven observatories, making it the most accurately observed occultation by any airless object, including the moon, to date. Although Gordon Taylor issued I.A.U. Planetary Occultation Working Group Bulletin #9 and I distributed IOTA Special Bulletin #4 about this event, most of the astrometry was done at, and most observations coordinated by Larry Wasserman at Lowell Observatory in Flagstaff, AZ. Interest in the event was high due to the wide path (so that careful astrometry could ensure successful observation by the Kuiper Airborne Observatory) and the fact that it was sure to cross the United States and/or southern Canada from coast to coast. There is only one previous photoelectric asteroidal occultation observation, also involving Pallas and made at Naini Tal Observatory, India, on 1961 October 2; only the one chord was observed.

In late March, Bob Millis, Flagstaff, sent me a card reporting that SAO 85009's photoelectric V magnitude was 10.8, much fainter than the SAO magnitude. This was confirmed by Rick Binzel at Macalester College, MN. The visual magnitude drop in case of an occultation would be only 0.2, too small to notice visually; the drop in B would be 0.4, slightly better. Unfortunately, it was then too late to warn visual observers, either in *o.n.* or *Sky and Telescope*, so that a number of spurious visual observations were received. Taylor's and IOTA's bulletins were sent only to known photoelectric observers, due to the star's faintness and to save mailing costs.

A detailed regional map of the occultation, like those for upcoming events in this issue (see PREDICTIONS OF OCCULTATIONS BY MINOR PLANETS on page 157) was prepared and included in Special Bulletin #4. It is reproduced here, with the shaded area showing the approximate actual occultation path. A series of astrometric plates was taken at Lowell and U. S. Naval Observatories in Flagstaff, AZ. A few weeks before the event, indications were that the center of the occultation shadow would shift 0".3 south, as noted in

Occultation of SAO 85009 by Pallas, 1978 May 29



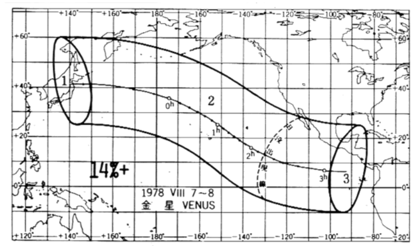
Bulletin #4. During the week preceding the event, up to two days before, the Flagstaff astrometry indicated that the shift would be 0".6 south. There were five mobile photoelectric observers, each of whom wanted to be at the center. But four of the successful fixed observatories were already near 0".6 south. It might have been better if the mobile stations were dispersed more to augment the fixed observatory coverage which, however, was uncertain due to weather and unforeseen equipment problems at some of the observatories. The KAO and a group from Cornell University which planned to observe from West Virginia did shift north somewhat, based on plates taken at Flagstaff the night before the event, which indicated a 0".4 south shift. Taylor had obtained plates with the Astrographic Catalog telescope at the Royal Greenwich Observatory three nights before the event, and sent an updated prediction by TELEX to Goddard Space Flight Center (GSFC); this indicated 0".55 south. The time correction derived from the astrometry was 1.7 minutes later than the times shown on my map, which turned out to be close to the truth. The actual shift was about 0".47 south.

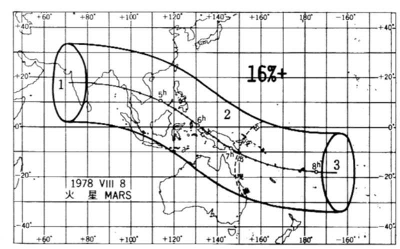
Mike A'Hearn from the University of Maryland and Rick Skillman set up to observe the event with the 36-inch reflector at GSFC's Optical Facility near Beltsville, MD. Wayne Warren and I joined them about an hour before the event after having spent much of the weekend doing some computations and relaying information about the event. Murphy's Law was broken several times that night. Clouds were forecast all weekend, due to a low stalled off the Carolina coast. But Sunday afternoon, the clouds started to break up, and the evening was mostly clear. But when I drove to the Optical Facility, the sky became overcast as low clouds rolled in from Chesapeake Bay. Twenty minutes before the event, first-magnitude stars appeared now and then. A little later, 3rd and 4th-mag. stars appeared, then the Milky Way; a large clear area had formed, with clouds all around. Surely they would close in again before the event, but they didn't until about five minutes afterwards. Subsequently, we didn't see any stars the rest of the night. Before turning the photometer on, we could see Pallas approaching the faint star; I was afraid that an occultation might be rather indistinct. Mike switched on the photometer and chart recorder. Just after $5^h23^m$ U.T. (the uncorrected predicted occultation time), Mike noticed that the paper was going in the top, but not feeding out the bottom of the chart recorder. He stopped the machine, pulled the paper (smeared with much ink) through, and restarted it. $5^h24^m$ U.T. was announced and Mike pressed a button in synch with WWV to put time marks on the record with the second pen. Nine seconds later, the pen swung quickly to the right, by considerably more than the width of the noise, when Pallas occulted the star. Then the paper stopped coming out the bottom again; I thought, "Let it go; it could reappear at any time." But Mike almost instinctively stopped the recorder, opened the door, pulled the paper through, and restarted it. Seconds later, the pen abruptly swung to the left when the star reappeared. Then came the $5^h25^m$ time announcement, and Mike again pressed the second pen button. The occultation lasted 38½ seconds; the second photoelectric record of an asteroidal occultation had been made. Wayne Warren just remarked, "That's not the way it usually happens in astronomy." About ten minutes later, Richard Radick telephoned from the University of Illinois' Prairie Observatory, saying that he also had recorded the occultation.

The asterisks on the map show the locations of photoelectric observers known to have attempted the occultation. Uncircled asterisks indicate observers who were either clouded out or could not observe due to equipment problems. Observers at locations indicated by the circled symbols were successful, recording the occultation or not, depending on whether they were in the occultation path or not. Some questionable observations have not yet been resolved. The location of the KAO is indicated very roughly by the plane symbol in Wyoming; it apparently was the only observatory north of the center of the path, and only a short distance north. The latest results from infrared radiometry and polarimetry indirectly give a radius for Pallas slightly under 600 km, while the values given in recent issues of *o.N.* have been a little larger than 600 km. Larry Wasserman's preliminary analysis gives 540 km, about 10% smaller than the radius from the modern indirect observations, which were thought to have an error of only 5%. The occultation diameters for Hebe and Herculina agreed much better with the indirect measurements, perhaps due to the fact that the latter are S-type objects, while Pallas has unusual spectral characteristics with some C-type features. Or does Pallas have a substantial satellite (the one claimed by van den Bos? See FURTHER SUPPORT FOR MINOR PLANET MULTIPLICITY, p. 152) which passed far to the north or south on May 29? The preliminary solution residuals for the KAO are much larger than for the other stations, considerably larger than can be explained by positional uncertainties in the inertial navigation system. However, I suspect that high-speed photoelectric timing accuracies multiplied by the asteroid's transverse velocity may be smaller than inertial navigation errors. These errors probably can be virtually eliminated when the Global Positioning System (an artificial satellite navigation system which can be used by ships and airplanes) becomes fully operational. Unfortunately, SAO 85009's angular diameter is expected to be very small, subtending only about 13 meters at Pallas' distance, so that its size could not noticeably modify the occultation diffraction pattern; it was one of the few stars occulted by minor planets this year for which the angular diameter could not be determined from a good photoelectric occultation record.

Others who successfully recorded the occultation and who have not been noted above are mentioned below. Nat White (Lowell) observed with the new 92-inch infrared telescope at Jelm Mountain, Wyoming, where the occultation lasted only about 20 seconds. Indiana University's Goethe-Link and Morgan-Monroe observatories recorded $26^s$ and $23^s$ occultations, respectively, due to their approximately 20-km north-south separation and southern location in the path. Harold Reitsema, Lunar and Planetary Lab., Tucson, AZ, successfully observed in two colors with a portable 14-inch Celestron which he had used in Mauritius in March, 1977, for the occultation by Uranus' rings. He observed near Behlen, NB, site of the University of Nebraska's 40-inch, which could not be used as the mirror was being aluminized. It was mostly cloudy, but cleared in the right direction only ½ minute before the occultation!

## LUNAR OCCULTATIONS OF PLANETS



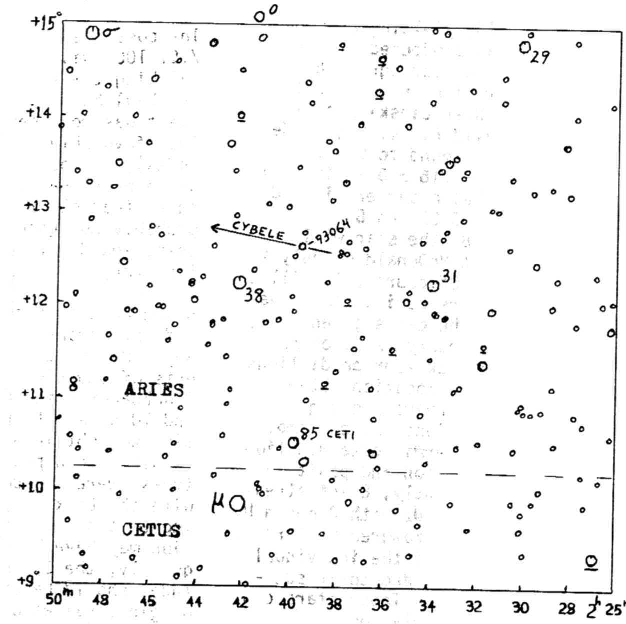




The maps showing the regions of visibility of lunar occultations of planets are reprinted by permission from the Japanese Ephemeris for 1978, published by the Hydrographic Department of Japan. Region 1, only R visible; Region 3, only D visible.

## PREDICTIONS OF OCCULTATIONS OF STARS BY MINOR PLANETS

David W. Dunham

Predictions of occultations of stars by minor planets during 1978 have been tabulated and discussed in *o.N., 1* (13), 134 and (14), 142. Finder charts and maps for some of the upcoming events are published here; some for events later in the year will appear in the next issue. Mitsura Soma, Tokyo, Japan, has recently produced world maps by computer, similar to the maps he has drawn by hand which have been published in previous issues. This time, they have been re-traced by Joseph Zoda, for publication here. The three closely spaced parallel lines show the predicted central occultation line, and the northern and southern limits, with U.T. marked at one-minute intervals and written at five-minute intervals. The two parallel dashed lines show the central occultation path in case the minor planet passes 1".0 north or south (measured perpendicularly to its path in the sky) of its predicted path with respect to the star. Combined ephemeris and star position errors can cause path shifts greater than 1", as the occultation by Herculina on June 7 demonstrated. The sunrise and/or sunset terminator is shown, with hatches indicating the side of nighttime visibility.



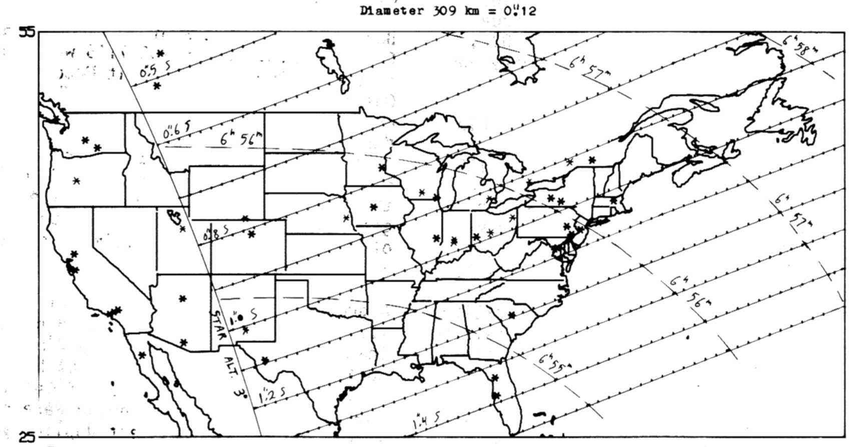

The more detailed regional maps were prepared with a computer program written by Fred Espenak, Bowie, MD, using path data on magnetic tape generated by me at USNO. The parallel curves represent the path of the center of the occultation shadow, considering several different shifts of the minor planet from its predicted path with respect to the star. The nominal path is labeled "0". The parallel curves show the central path for multiples of 0".1 shifts of the asteroid from its predicted path in the sky, measured perpendicularly to the path. Curves are labeled in the map margins at 0".2 intervals, "N" or "S" showing shift direction. Dashed curves show predicted U.T. of central occultation. Low star altitude or twilight boundaries are drawn when appropriate. The expected diameter of the minor planet, in km and in arc seconds, is given in the caption. The nominal paths were computed using SAO data for the stars and accurate astrometric ephemerides which I computed using precise osculating orbital elements supplied by the minor planet centers in Cincinnati and Leningrad; some exceptions to obtain improved predictions, when better data have been available from other sources, have been noted when appropriate. Asterisks show the locations of observatories from which photoelectric occultation observations have been attempted in the past, as far as I know. The regional maps are "false" projections, plotted with a constant linear scale (constant degrees per centimeter) in both longitude and latitude, so that the observer could, for example, plot updated computed path points which might be computed by Gordon Taylor. Note that the width of the occultation path can be estimated on the map from the expected angular diameter.

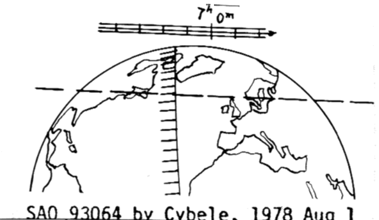
Since these are regional maps, different ones will be published in the different editions of *O.N.* Some regional maps, for areas such as Australia or Japan, will be sent extra to the relatively few subscribers there, rather than using space in *O.N.*

When time and space permit, we will try to publish finder charts at two scales, a detailed chart and a large-area chart showing the area covered by the detailed chart with respect to familiar constellations. Often we can publish only the detailed chart, in which case, we will try to make it cover a large enough area to include at least one star shown in the sky maps published in *Sky and Telescope*.

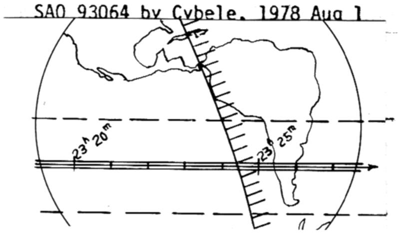
Occultation of SAO 93064 by (65) Cybele, 1978 August 1

Diameter 309 km = 0".12





SAO 93064 by Cybele, 1978 Aug 1



SAO 140552 by Herculina, 1978 Aug 22

## POSSIBLE OCCULTATION BY (2060) CHIRON

David W. Dunham

A possible occultation of the 10.7-mag. star AGK3 +13°203 by Chiron (= 1977 UB, now officially numbered 2060) on July 24 was noted in *O.N., 1* (13), 136-7. J. Derral Mulholland, University of Texas, measured the star's position from a 1952 Palomar Sky Survey plate. The Palomar plate position was in good agreement with the AGK3 position computed for that epoch. Mulholland planned to take a plate with McDonald Observatory's 82-inch telescope in late June, but the star's elongation from the sun was small and the telescope could not point that low in the east. An attempt was going to be made at Flagstaff in early July to obtain a current astrometric position of the star, but unfortunately, Chiron will be too difficult to photograph. The available data indicate that the occultation will miss the earth's surface, but if the Flagstaff observations give any hope that this is not the case, a special bulletin will be sent to observers in the possible region of visibility.

## FROM THE PUBLISHER

IOTA membership generally includes predictions for grazes within specified travel radii, as well as *Occultation Newsletter* and other benefits. A small expiration notice is mailed with the final issue of a subscription; usually (although perhaps not this time) there is time for you to send in your payment and receive succeeding issues without interruption, but if your payment arrives after the next issue is mailed, you probably will have to tell us what issue(s) you may have missed. For subscription purposes, #15 is the first issue of 1978.

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## NEW DOUBLE STARS

David W. Dunham

[Ed: This paragraph consists of extracts from a postponed portion of D.W.D.'s article for #13.] The spectroscopic binaries..from Wilson's catalog..were crossreferenced with USNO's SZ catalog last July..Double star codes will appear in..predictions for 1979. All known data are now on hand for the double star list. Paul Coteau. .is concerned that his information has not been published..The list, as it stands, [is in the hands of] graze computors. I hope we can publish the entire list for all IOTA members [soon]. Before this is done, I need to find time to [perform various tasks].. Progress with the double stars is, and probably will continue to be, excruciatingly slow. During nearly three weeks in July and August, Rick Binzel came to..help me with various projects ..resolved discrepancies..to make the completion of the..double star project at least possible in principle. The Hyades issue of *O.N.*..would have been greatly delayed without his help.

The table lists additions and corrections to the special double star list of 1974 May 9 not listed in previous issues. The columns and general format are the same as in previous issues.

The close duplicity of the A-component of SAO 94554 = 115 Tauri = Z.C. 814, discovered by Robert Hays on 1978 February 17, was indicated in the table of the last issue of *O.N.* An independent discovery of the duplicity was made at McDonald Observatory, TX, when David Evans photoelectrically recorded the same occultation. the photoelectric data give a separation of 0".099 in P.A. 98°.1, with $\Delta m$ = 1.13 ± 0.06 in blue, and 0.90 in red. This is in good agreement with Hays' visual estimates at P.A. 63°, indicating that the true separation and position angle of the close pair probably is close to the McDonald Observatory results.

SAO 93870 = 55 Tauri = Z.C. 636 = ADS 3135 is one of three visual binaries in the Hyades for which orbital elements have been determined. An occultation of the star was recorded photoelectrically at McDonald Observatory on 1978 March 15, yielding a separation of 0".396 as projected onto P.A. 102°.0. This is in good agreement with the 0".457 separation in P.A. 75°.1 computed from St. Wierzbinski's orbit, according to David Evans. Magnitude differences were found to be 1.61 ± 0.06 in blue and 1.16 ± 0.09 in red; the $\Delta m$ from visual observers is 1.0. The combined V = 6.88 and B - V = 0.56. During 1978, the star will be occulted again at McDonald on July 29 and December 13. Of course, it will be occulted for others during other Hyades passages on the dates given in my article in the January issue of *Sky and Telescope*; check your predictions for events at your location. Other photoelectric observers are urged to try these occultations, since combining results will permit determination of the true separation and position angle. More importantly, Evans stresses, observations made with Johnson U, B, V, and perhaps Stromgren filters will permit colors of the individual stars to be obtained and their spectral types estimated. These stars can then be more accurately compared with the mass-luminosity relation. Similar arguments apply to SAO 93926 = ADS 3210; the third Hyades star with visually determined orbital elements, ADS 3475, can not be occulted by the moon.

SAO 98709 = o Leonis = Z.C. 1428 = ADS 7480, mag. 3.5, is a close, double-lined spectroscopic binary with a period of 14.5 days. An occultation of this star was recorded photoelectrically at McDonald Observatory on 1978 Feb. 22, but no evidence for duplicity was noted, apparently due to poor geometry. Evans calculates that the maximum possible separation should be 0".008, so that it should be resolvable at times with photoelectric occultation observations. Data collected at two or more observatories during two occultations at appropriate phases of the star's period could determine the masses of the stars.

SAO 93022 = 31 Arietis = Z.C. 384 was discovered to be a close double at McDonald Observatory on 1977 Sept. 30, as noted in *O.N.*, *1*, 140 (#13). Evans and Fekel note that the period is likely between ½ and 9½ years, and that at certain epochs, double lines might be visible in a high-dispersion spectrogram. Fekel made such observations on 1977 Nov. 3, when no line doubling was found. Since the true separation could be as large a 0".2, visual and speckle interferometry observations are recommended.

The interesting Hyades eclipsing binary V471 Tauri = B.D. +16° 516 = J00004 was described in *O.N.*, *1*, 139 (#13). More accurate data about the system are given by A. Young and B. Nelson in *Ap. J.*, *173*, 653 (1972 May 1); the mean separation of the nearly circular relative orbit is 2.21 × $10^6$ km, and the distance is 60 to 70 parsecs. The maximum angular separation will then be only 0".0002, too small to be detected during lunar occultations.

SAO 94002 = Z.C. 684 = ADS 3297, a visual double in the Hyades, is given in the table, since it was inadvertently omitted from previous lists.

The possible duplicity of SAO 95795 = Z.C. 1003 was not confirmed by others watching the same occultation, including Paul Maley at Houston (where the event was more central, and therefore less favorable for noticing quick fades) and Robert Sandy, observing the graze near the northern limit (he notes that observing conditions were probably not good enough to notice phenomena due to close duplicity of the star).

Based upon a photoelectric observation made at McDonald Observatory on 1977 Sept. 8, the magnitudes of the components of SAO 96634 = ADS 5885 in the Stockbauer list were changed to 9.3 and 10.5. A better McDonald observation was obtained on 1978 Feb. 19. The results, both positional and magnitudes, were in much better agreement with the Lick I.D.S. values, indicating that the 1977 duplicity information may have been spurious. Consequently, the Stockbauer list magnitudes should be changed back to their original values of 9.2 and 11.2.

On 1978 April 15, I observed an occultation of SAO 96746 = λ Geminorum = Z.C. 1106 = ADS 5961 under good conditions. I was able to time the disappearance of the visual secondary, whose magnitude I estimate as 9.5. If it had been as faint as the 10.7 given in the Lick I.D.S., I would not have been able to see it near the moon with my 25-cm reflector. The disappearance of the primary appeared sharp, in agreement with a photoelectric record of the same event obtained by Rick Skillman with a 30-cm reflector at the Goddard Optical Facility nearby. There appears to be no close companion like the possible star noted in *O.N.* #11.

The quick fade during the disappearance of SAO 97618 on 1978 April 16 was also noticed by Joan Dunham and Wayne Warren, who were also in Potomac, MD, where we had attempted to observe the graze of another star.

An occultation of SAO 98146 was observed at McDonald Observatory on 1977 March 3. There is some indication of duplicity, but the data are too noisy for an analysis. Nathaniel White, Flagstaff, AZ, claimed it as a possible double in 1975, as tabulated in *O.N.*, *1*(5), 45.

Both the D and the R of SAO 98267 = α Cancri = Z.C. 1341 = ADS 7115 were recorded photoelectrically at McDonald Observatory on 1977 Sept. 10. The occultation was nearly grazing, with a duration of only ten minutes, with disappearance of the 4.3-mag. star a short distance on the bright side of the thin crescent waning moon. The good-quality traces show no evidence of the close duplicity claimed in *O.N.* *1*, 14 (#2).

A graze of SAO 97843 = 29 Cancri = Z.C. 1271 was observed the same night that Sandy noticed a possible dimming during the total occultation at his location, but observing conditions and the geometry during the graze were not favorable enough to detect duplicity;

see p. 155 about the graze. Using a 20-cm telescope, I didn't notice any evidence of duplicity during an occultation on 1978 June 10, but due to poor seeing at the low altitude, a slight drop before disappearance could have been missed. Bob Panek recorded the same occultation with high-speed photoelectric equipment at Pennsylvania State University. There was no evidence for close duplicity, but a component with a separation as great as that claimed by Sandy would likely be outside the observed time range.

SAO 139058 was flagged as the companion of another SAO star (double star code E) as the result of a matching error when the Stockbauer list was formed; in fact, the star is not a member of any known double star system.

Alfredina do Campo, Observatorio de Lisboa, Portugal, said that the 1977 occultations of SAO 160180 (= Z.C. 2436) and SAO 161848 (= Z.C. 2731) which he observed were gradual; the stars are known close visual doubles.

In the table of new double stars in the last issue, the SAO number 93072 is incorrect; it should be 93070.

The I.A.U. Double Star Commission's Information Circular No. 75 (1978 June) gives new orbital elements for SAO 75671 = Z.C. 438 = ADS 2253 by Costa-Morales and for SAO 163771 = Z.C. 3015 = ADS 14099 by Heintz. These are presumably an improvement over the previously available elements published for these binaries in Finsen and Worley's catalog. At epoch 1979.0, the separations and position angles will be 0".48 and 255°.3 for Z.C. 438 and 0".30 and 113°.0 for Z.C. 3015. These are rather different from the values computed with the previous elements. Neither of the two stars is currently being occulted.

Several new non-SAO (and non-AGK3) double stars also are listed in Circular No. 75 and are given in our list. J00399 is in the Hyades region at 1950 R.A. $4^{h}38^{m}.3$, Decl. +15°25'; it is A.C. +15°$4^{h}36^{m}$ No. 21. The 1950 coordinates for the star listed "anonymous" are R.A. $9^{h}44^{m}.7$, Decl. +14°03'.

The data for SAO 97442 are improved values by Nolthenius, as given. The * indicates that duplicity for the star was previously suspected, in this case by Sincheskul at Poltava in 1975 (see *O.N., 1* (10), 109).

+17°1315 = K03488 = AGK3 N17°666. J02832 is A.C. +18°$6^{h}24^{m}$ No. 511 at 1950 R.A. $6^{h}27^{m}34^{s}.9$, Decl. +17°44'18".

In the latest issue of *Publ. Astron. Soc. Pacific* (*90*, p 330, 1978 June-July), Sarah Lee Lippincott and Michael Worth, Sproul Observatory, announce that SAO 77705 = $\chi^1$ Orionis is an astrometric binary with a period of 14.25 years. "A" has been used for the method code to denote an unseen companion whose presence is detected by periodic variations in proper motion as determined from careful astrometric analysis. $\chi^1$ Orionis is a star very similar to the sun, about 10 parsecs away, according to the Sproul study. The next maximum separation, expected to be about 0".6, will occur in 1982, soon after which a series of lunar occultations of the star will begin. The companion is expected to have about one sixth the mass of the primary; hopefully, it can be resolved and the magnitude determined from a future occultation. If there are any previous photoelectric occultation observations of this star, the secondary may be evident in them, or a lower limit for the magnitude of the secondary might be established.

In an article on p. 288 of the same issue of *P.A.S.P.*, Harold McAlister lists several binary stars, including some occultation binaries, which he could not resolve by speckle interferometry. One of these is SAO 93062 = Z.C. 399 = $\mu$ Arietis, which he lists as having been discovered by speckle interferometry by Blazit *et al* in 1975. Actually, it was discovered with a photoelectric occultation observation by de Vegt at Hamburg Observatory in 1969. Blazit *et al* give a separation of 0".028 in P.A. 147° at epoch 1975.64 and 0".036 in P.A. 145° for 1975.78. According to photoelectric occultation data, the separation was 0".049 in P.A. 263° in 1973 Jan.-Feb.; see *O.N., 1* (10), 109 and (11), 120. Several Pleiades stars were unresolved, probably because their separations are less than 0".01 and hence unresolvable by speckle methods. The components of SAO 139033 have $\Delta m$ = 3.3 which might be hard to resolve at 0".04 expected separation. The unresolved stars are listed in the table below.

Stars Unresolved by McAlister, 1975-6

| SAO | ZC | Other Names |
|---|---|---|
| 76126 | 0536 | 16 Tauri = Celaeno |
| 76131 | 0537 | 17 Tauri = Electra |
| 76155 | 0541 | 20 Tauri = Maia |
| 76199 | 0525 | $\eta$ Tauri = Alcyone |
| 76228 | 0560 | 27 Tauri = Atlas |
| 76425 | 0598 | 36 Tauri |
| 76532 | 0628 | $\omega$ Tauri |
| 78135 | 0946 | $\eta$ Geminorum A |
| 93932 | 0661 | 71 Tauri |
| 94051 | 0702 | $\sigma^1$ Tauri |
| 119164 | 1734 | $\pi$ Virginis |
| 139033 | 1853 | $\psi$ Virginis |

A. Kirichenko, Uzhgorod, USSR, noted that the reappearance of the 4.7-mag. M0 star SAO 94628 = ZC 0832 on 1976 Oct. 13 was gradual. Diffraction enhanced by the star's relatively large angular diameter probably caused this, rather than duplicity.

NEW DOUBLE STARS, 1978 JULY 15

| SAO | ZC | M | N | MG1 | MAG2 | SEP | PA | MAG3 | SEP3 | PA3 | DATE, DISCOVERER, NOTES |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 77705 | 0894 | A | V | 4.4 | | 0".6 | | | | | 1978, S. Lippincott and M. Worth, Swarthmore, PA |
| 93484 | | P | K | 7.0 | 10.5 | .035 | 13° | | | | 1977 Feb 25, D. Evans, McDonald Observatory, TX |
| 93933 | | T | K | 8.7 | 8.7 | 0.02 | 23 | | | | 1978 Mar 15, R. Nolthenius, San Diego, CA |
| 94002 | 0684 | V | M | 6.9 | 7.0 | 3.1 | 277 | | | | Known visual double (ADS 3297) |
| 94358 | | P | K | | | | | | | | 1978 Mar 16, D. Evans, McDonald Observatory, TX |
| 95748 | | T | V | 7.9 | 9.0 | 0.25 | 62 | | | | 1978 Apr 14, P. Maley, Houston, TX |
| 95759 | | T | K | 8.2 | 8.7 | 0.05 | 222 | | | | 1978 Apr 14, P. Maley, Houston, TX |
| 95775 | | T | K | 9.8 | 9.8 | 0.1 | 96 | | | | 1978 Apr 14, P. McBride, Green Forest, AR |
| 95795 | 1003 | T | K | 8.0 | 8.0 | 0.05 | 32 | | | | 1978 Apr 14, P. McBride, Green Forest, AR |
| 95866 | | P | K | 8.5 | 10.3 | .019 | 61 | | | | 1978 Jan 22, Morgan, McDonald Observatory, TX |
| 97356 | | T | K | 8.6 | 9.1 | 0.3 | 270 | | | | 1978 May 13, P. McBride, Green Forest, AR |
| 97395 | | T | K | 9.5 | 9.5 | 0.1 | 90 | | | | 1978 May 13, P. McBride. Green Forest, AR |
| 97442 | | T | X | 8.8 | 9.0 | 0.05 | 124 | | | | * 1978 Feb 20, R. Nolthenius, San Diego, CA |
| 97618 | | T | K | 8.4 | 8.4 | 0.03 | 156 | | | | 1978 Apr 16, D. Dunham, Potomac, MD |
| 97827 | | T | K | 9.1 | 9.6 | 0.3 | 90 | | | | 1978 Jun 10, P. McBride, Green Forest, AR |
| 97843 | 1271 | T | K | 6.4 | 6.9 | 0.25 | 224 | | | | 1978 Mar 20, R. Sandy, Kansas City, MO |
| 98661 | | T | K | 9.0 | 9.5 | 0.4 | 158 | | | | 1978 May 15, J. Van Nuland, San Jose, CA |
| 109560 | 0131 | T | K | 9.0 | 9.0 | 0.1 | 270 | | | | 1976 Jun 21, A. Zhitetski, Kiev, Ukraine |
| 109790 | | P | K | 9.3 | 9.9 | .060 | 272 | | | | 1977 Nov 22, B. Smith, McDonald Observatory, TX |
| 139302 | | T | K | 9.4 | 9.4 | 0.1 | 90 | | | | 1978 Jun 16, P. McBride, Green Forest, AR |
| +17°1315 | | T | K | 10.3 | 10.3 | 0.15 | 92 | | | | 1978 Apr 16, P. McBride, Green Forest, AR |
| +17°1416 | | P | V | 10.1 | 10.5 | .061 | 276 | | | | 1978 Mar 18, D. Evans, McDonald Observatory, TX |
| +14° 530 | | V | C | 9.3 | 10.7 | 5.5 | 44 | | | | 1978.0, W. Heintz, Swarthmore, PA |
| +14° 631 | | V | C | 9.8 | 10.2 | 1.4 | 335 | | | | 1978.0, W. Heintz, Swarthmore, PA |
| +14° 639 | | V | C | 10.4 | 11.6 | 1.3 | 208 | | | | 1978.0, W. Heintz, Swarthmore, PA |
| +14°2167 | | V | C | 9.9 | 12.0 | 7.5 | 6 | | | | 1978.3, W. Heintz, Swarthmore, PA |
| J 00399 | | V | C | 11.8 | 11.8 | 3.9 | 61 | | | | 1978.0, W. Heintz, Swarthmore, PA |
| J 02832 | | T | K | 10.8 | 10.8 | 0.05 | 106 | | | | 1978 Apr 16, P. Maley, Houston, TX |
| Anonymous | | V | C | 10.2 | 10.8 | 2.3 | 349 | | | | 1978.3, W. Heintz, Swarthmore, PA |