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The planet Venus as drawn by the French observer M. Maksyrowicz on 1983 OCT 23 at 08 h 55 m U.T. He used a $20-\mathrm{cm}$. ( $8-\mathrm{in}$.) reflecting telescope at 67 X and 133X with no filter, recording the seeing as $3-4$ (on the A.L.P.O. Scale of $0=$ worst to $10=$ best), and the transparency as excellent. South is at the top and celestial east to the right. Note the brilliant north cusp cap. The planet's diameter was 28.4 arc seconds and the predicted phase (proportion of disk sunlit) was 0.434 . See the report on the 1983-84 and 1985-86 Morning Apparitions of Venus on pages 93-101 of this issue.

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## IN THIS ISSUE

THE 1983-84 AND 1985-86 WESTERN
(MORNING) APPARITIONS OF VENUS:
VISUAL AND PHOTOGRAPHIC OBSERVATIONS, by Julius L. Benton, Jr. ..... pg. 93
THE METEOROLOGY OF MARS-PART III, by J. D. Beish and D. C. Parker ..... pg. 101
GALILEAN SATELLITE ECLIPSE TIMINGS: 1985/86 REPORT, by John E. Westfall ..... pg. 114
COMET NOTES: XI. 1987’S COMET HARVEST, by David H. Levy ..... pg. 129
OBSERVING METEORS: XI, by David H. Levy ..... pg. 129
A.L.P.O. SOLAR SECTION OBSERVATIONS FOR ROTATIONS 1771-1783 (1986 JAN 14 TO 1987 JAN 03), by Richard E. Hill ..... pg. 131
COMING SOLAR SYSTEM EVENTS:
JANUARY - FEBRUARY, 1988 ..... pg. 135
BOOK REVIEWS,
Coordinated by J. Russell Smith ..... pg. 136
ANNOUNCEMENTS ..... pg. 138

By: Julius L. Benton, Jr., A.L.P.O. Venus Recorder
Abstract. --Visual and photographic observations of the 1983-84 and 1985-86 Western (Morning) Apparitions of the planet Venus are summarized, emphasizing the sources of data and the instruments employed in the observation of this planet. There is a statistical analysis of the categories of features on the apparent surface, seen or suspected in visual wavelengths, for both observing periods. A similar treatment is given to the cusps, cusp-caps, and cuspbands, as well as a discussion of the Ashen Light and other curious darkhemisphere phenomena. Comparative studies are described with reference to observers, the instruments utilized, visual and photographic data, simultaneous observations, and so forth. Illustrations are included in order to help one's overall appreciation of the variable phenomena observed in the atmosphere of Venus throughout $1983-84$ and 1985-86 by members of the A.L.P.O. Venus Section.

## Introduction

This analytical report concerns the cumulative results of a fairly extensive evaluation of visual and photographic observations of the planet Venus throughout the periods given below (where "U.T." stands for Universal Time; data from reference [7]):


A total of 34 observations was collected for the $1983-84$ period, while 27 reports were received for 1985-86. Figure 1 (below) shows histograms of the distribution of observations by month for the two apparitions.


Figure 1. Histograms of the number of observations of Venus received for the 1983-84 and 1985-86 Western (Morning) Apparitions.

Observational coverage of Venus was quite poor during both apparitions. During 1983-84, 68 percent of the observations were made during the months of October and November, 1983, when Venus was near greatest elongation west and greatest brilliancy. Figure 1 shows that the situation was about the same in 1985-86, with 85 percent of the observations during the months of May, June, and July, 1985.

In both apparitions, observational programs began fairly early in the observing season, and began falling off soon after greatest elongation. Individuals are encouraged to try to follow Venus from very early in each apparition through its maximum elongation until near the time of solar conjunction.

A reasonable number of drawings and a few photographs of Venus were submitted for each apparition. During the months of maximum observational coverage in both apparitions there were almost daily observations. Daily studies of Venus, a goal for all observers when weather permits, increase the frequency of simultaneous observations. Ultraviolet photographs of Venus were completely absent from the material submitted during either period; and an observational program of regular ultraviolet photography, together with concurrent visual work would be of tremendous comparative value.

Table l , below, describes the eight individuals who contributed observations during the apparitions described here.

## Table 1. Observers and Instruments: Western (Morning) Apparitions of Venus, 1983-84 and 1985-86.

| Observer and Location | No. of $\mathrm{Ob}-$ servations |  | Instruments Used |
| :---: | :---: | :---: | :---: |
|  | $\begin{array}{r} 1983- \\ \quad 84 \\ \hline \end{array}$ | $\begin{array}{r} 1985- \\ \quad 86 \\ \hline \end{array}$ |  |
| Julius L. Benton, Jr.; New Hope, PA | 2 | 4 | 15.2 cm. ( 6.0 in .) RR |
| O. Dacio Dalavia; Rio Grande do Sol, Brazil | 0 | 10 | $6.0 \mathrm{cm}$. ( 2.4 in.$) \mathrm{RR}$ |
| Mark A. Gelinas; St. Hubert, Quebec | 6 | 10 | $20.3 \mathrm{~cm} .(8.0 \mathrm{in})$. |
| David L. Graham; Brompton-on-Swale, England | d | 1 | 10.2 cm . (4.0 in.) RR |
| Walter H. Haas; Las Cruces, NM |  | 0 | $31.8 \mathrm{~cm} .(12.5 \mathrm{in})$. |
| Alan W. Heath, Nottingham, England | 12 | 0 | 30.5 cm . (12.0 in.) N |
| M. Maksyrowicz, Chapet, France | 5 | 2 | $15.0 \mathrm{~cm} .(5.9 \mathrm{in})$.N ; |
| Robert Robotham, Waterloo, Ontario | 8 | 0 | $20.0 \mathrm{~cm} .(7.9 \mathrm{in})$. |
| , Robothan, Water100, Ontario |  |  | 15.2 cm . (6.0 in.) N |


Note: Under instruments; "RR" = Refractor, "SC" = Schmidt-Cassegrain Reflector, and "N" = Newtonian Reflector.

I extend my warmest thanks to each of the observers listed here for their continued systematic and dedicated participation in the programs of the A.L.P.O. Venus Section.

Visual Observations of Details on the Apparent Surface
As noted in recent reports on apparitions of Venus which have appeared in this Journal [2,3,4], the conventional methods and techniques of making visual studies of the somewhat vague and elusive "markings" on the apparent surface of Venus [actually, of course, the cloud tops of its atmosphere; Ed.] have been outlined in various Venus Section publications. [1,5] Study of these sources, along with previous Venus Reports, is strongly suggested for those unfamiliar with the nomenclature or with the basic observational methods.

This apparitional report is based upon descriptive notes, accompanied by drawings and photographs, taken at visual wavelengths. A few representative drawings and photographs for both apparitions covered are reproduced here as illustrations [Front Cover and Figures 2-8 on pp. 98-99].

Evaluation of the visual and photographic data for 1983-84 and 1985-86 revealed that nearly all categories of dusky markings and bright atmospheric phenomena on Venus were reported, being of the types covered in depth in the literature already cited. [1,3,5] A quantitative analysis of these data, following the same procedure as in earlier Venus Apparition Reports, comprises Table 2 , below, which shows the percentages of the 34 observations in 198384 and the 27 observations in $1985-86$ which reported specific categories of features.

Table 2. Frequency of Occurrence of Types of Markings on the Apparent Surface of Venus During the 1983-84 and 1985-86 Apparitions.

| Marking Categories (Apparent Surface) | 1983-84 Apparition <br> (34 Observations) | $\begin{aligned} & \text { tions Showing Marking } \\ & \hline 1985-86 \text { Apparition } \\ & \text { (27 Observations) } \end{aligned}$ |
| :---: | :---: | :---: |
| Banded Dusky Features | 24 \% | $11 \%$ |
| Radial Dusky Features | 24 | 15 |
| Irregular Dusky Features | 41 | 4 |
| Amorphous Dusky Features | 50 | 30 |
| Terminator Shading | 76 | 44 |
| No Markings Depicted | $26 \%$ | 52 \% |
| Bright Spots or Regions (exclusive of cusps) | $6 \%$ | $15 \%$ |

## Notes to Table 2

1. For the 1983-84 observations, the phase coefficient $k$ (the proportion of the apparent disk that was illuminated) ranged from $0.1 \overline{2} 2$ (1983 SEP 14) to 0.968 (1984 APR 22). In 1985-86, the observed range of $k$ was from 0.010 (1985 APR 04) to 0.716 ( 1985 AUG 02).
2. Areas devoid of any shadings or obvious markings on the bright illuminated hemisphere of Venus were typically assigned a relative numerical jntensity of 8.5 in 1983-84 and 8.8 in 1985-86. The mean assigned intensity in integrated light for all the dusky shadings (the first five items in Table 2 ) was about 5.8 in 1983-84 and 6.8 in 1985-86. The bright spots and regions had a mean assigned intensity value of 9.2 in 1983-84 and 9.8 in 1985-86. (The scale of intensities used is the standard A.L.P.O. Scale, wherein 0.0 is totally black shadow and 10.0 is the most brilliant possible condition.)
3. The scale of conspicuousnesses was used more effectively in 1983-84 and 1985-86 than in previous apparitions. In 1983-84, the mean conspicuousness rating was 7.0 for the first five items in Table 2 (dusky features), interpreted as meaning that most observers strongly suspected the markings but were not completely certain of their existence. With regard to the bright spots and regions (the last category), the rating was 3.0 for 1983-84, suggesting that such features were quite vague at best. For the 1985-86 Apparition, the conspicuousness rating for all categories of features averaged about 5.0, indicating that the conspicuousness of all features tended to lie between vague suspicions and strong indications of their presence. In comparison, dusky features were usually less obvious in 1985-86 than in 1983-84, but bright spots or regions were more pronounced in conspicuousness in 1985-86 than in 1983-84. [The conspicuousness scale ranges from 0 (nothing seen or suspected) through 3 (nothing certain, only vague suspicions) and 7 (markings strongly suspected although not certain) to 10 (markings certain). Ed.]
4. Seeing conditions were evaluated on the A.L.P.O. Scale of $0-10$ (where 0 denotes the worst possible seeing and 10 implies perfect conditions) and had a mean value of 4.6 in 1983-84 and 4.7 in 1985-86; thus usually "fair" at best. Note that seeing conditions were about the same for both apparitions.
5. Transparency conditions, normally expressed as the visual magnitude of the faintest star detectable by the unaided eye on a clear, dark night in the region of the planet, were difficult to evaluate due to the fact that nearly all observations were carried out against a twilight or sunlit sky. In any case, most observers were able to get some idea of transparency by carefully evaluating the sky clarity in the region of Venus at the time of observation. Usually, the transparency in both apparitions ranged from average to very good.

There is undoubtedly some subjectivity inherent in the quantitative data, particularly with the absence of simultaneous observations. However, some tentative but useful conclusions may be drawn from the values in Table 2 .

About one-quarter of the observations of Venus in 1983-84 depicted the planet as completely devoid of any shadings or markings in any of the categories cited. In 1985-86 no markings were seen in slightly more than half of the observations submitted. Thus, markings of various types were more commonly detected in 1983-84 than in 1985-86. It is a well-established fact that the markings on Venus' apparent disk are highly elusive, both for the novice and the experienced observer; and it is very desirable to have ultraviolet photographs in order to bring out dusky shadings. It is also true that markings revealed in the ultraviolet region of the spectrum differ somewhat from those occasionally seen at visual wavelengths, particularly radial dusky patterns.

Terminator shading was commonly reported during both apparitions, but especially so in 1983-84. As in past apparitions, the gradation toward a light tone (i.e., increasing intensity value) for the terminator shading was noticed as one proceeded from the region of the terminator toward the illuminated limb of Venus (where in several cases the gradation terminated in the bright limb band). The shading usually extended from one cusp to the other, and this feature was most often seen in both apparitions from the period of crescentic phase to near dichotomy. No photographs in either apparition showed obvious terminator shading. [However, a photograph by Alan W. Heath, reproduced here as Figure 4 (p. 98), has a suggestion of terminator shading. Ed.]

In 1983-84, the majority of the dusky markings fell into the category of "Amorphous Dusky Features," with a substantial number also classed as "Irregular Dusky Features" ( 50 and 41 percent respectively of all observations). In the 1985-86 Apparition, the majority of the dusky features were also classified as "Amorphous Dusky Features," but this category was then followed by "Radial Dusky Features" ( 30 and 15 percent respectively of all observations). Table 2 indicates that there were equal frequencies of "Banded Dusky Features" and "Radial Dusky Features" in 1983-84 (24 percent in both categories); it is useful to recall that dusky features were more obvious in 1983-84 than in 1985-86. Note the marked reduction in the incidence of "Irregular Dusky Features" from 1983-84 to 1985-86. Also recall the fact that all dusky features in 1985-86 were less obvious and less certain than in 1983-84, as the percentages in the various categories in Table 2 illustrate.

Excluding the cusp regions, bright regions or mottlings (both classified as "Bright Spots/Regions" in Table 2 ) were more frequently detected in 198586 than they were in 1983-84.

No photographs in either apparition showed dusky regions of any significance, nor did they show bright spots or regions. Visual color filter observations with W21 (Wratten; orange), W15 (yellow), W23A (red), and W47 (blue) filters showed some instances of increased contrast and visibility of bright features and dusky markings, although as in previous apparitions, colorimetric interpretations were largely impossible due to a lack of systematic employment of the filters cited. Clearly, a systematic program of color filter work, together with studies in integrated light (no filter), as well as variabledensity polaroid filter observations, can be valuable.

The accompanying drawings and photograph will give the reader an appreciation of the controversial and elusive nature of the features discussed in this section of the report.

Cusps, Cusp-Caps, and Cusp-Bands
The most contrasting and conspicuous features on Venus are seen at or near the cusps of the planet, usually when the phase lies between $k=0.1$ and 0.8 . These cusp-caps frequently appear on Venus, and are sometimes bounded by darkish, often diffuse cusp-bands . Table 3 (p. 97) presents cusp-cap and cusp-band statistics for the 1983-84 and 1985-86 Apparitions.

When the southern and northern cusp-caps were detected during 1983-84 they were almost always seen together ( 76 percent of the 34 observations). On a few occasions, the north cusp-cap was detected by itself ( 6 percent), while the south cusp-cap was never detected alone. The times when neither cusp-cap could be detected were fairly infrequent ( 18 percent). The southern and northern cusp-caps were often equal in size ( 56 percent), but on occasion either the southern cap was the larger ( 15 percent) or the northern one was ( 12
percent). In terms of cusp-cap brightness in 1983-84, both caps were equally bright much of the time ( 47 percent). When they were unequal, it was more likely that the northern cusp-cap would be the brighter ( 21 percent) than the opposite ( 15 percent). In 1983-84, the cusp-bands, seen bordering the cuspcaps, were usually reported in both the southern and northern cusp regions at the same time ( 26 percent) with only two observations in which the cusp-band could be detected in only one cusp area. Cusp-bands were absent on most observing dates during that apparition ( 68 percent of the observations).

In 1985-86, the southern and northern cusp-caps were always either seen together or, more often ( 70 percent), not at all. There were times when the cusp-caps in both hemispheres were seen as equal in size (11 percent); but when one was seen as the larger, it was always the northern cusp-cap ( 19 percent of all observations, or 62 percent of those in which the cusp-caps could be seen). The northern cusp-cap was more likely to be seen as the brighter of the two ( 19 percent), although the caps were sometimes seen as equally bright ( 7 percent). The southern cusp-cap was rarely noted as the brighter ( 4 percent). The bordering cusp-bands were largely absent ( 89 percent). When only one was seen, it was always the southern cusp-band (11 percent).

Table 3. Cusp-Cap and Cusp-Band Frequency of Occurrence on the Apparent Surface of Venus During the 1983-84 and 1985-86 Apparitions.

Percentage of Observations

| Category | (34 Observations) | (27 Observations) |
| :---: | :---: | :---: |
| South Cap Alone Visible | 0\% | $0 \%$ |
| Both Caps Visible | 76 | 30 |
| North Cap Alone Visible | 6 | 0 |
| Neither Cap Visible | 18 | 70 |
| South Cap Larger Size | $15 \%$ | $0 \%$ |
| Both Caps Equal Size | 56 | 11 |
| North Cap Larger Size | 12 | 19 |
| South Cap Brighter | $15 \%$ | $4 \%$ |
| Caps of Equal Brightness | 47 | 7 |
| North Cap Brighter | 21 | 19 |
| South Cusp-Band Alone Visible | 3\% | 11 \% |
| Both Cusp-Bands Visible | 26 | 0 |
| North Cusp-Band Alone Visible | 3 | 0 |
| Neither Cusp-Band Visible | 68 | 89 |

## Notes to Table 3

1. The mean relative numerical intensity of the cusp-caps was 9.6 in 1983-84 and 9.4 in 1985-86, while the corresponding values for the cusp-bands were 7.6 for both apparitions..
2. Regarding seeing, transparency, and phase, see the notes for Table 2 .

## Extension of the Cusps

Very slight suspicions of cusp extensions of Venus were detected during 1983-84 and 1985-86. The cusp extensions were seldom depicted clearly enough in drawings to facilitate measurements, and they were shown in no photographs. Near the start of each apparition several observers described impressions of a suspected "twilight arc or halo" encircling part of the dark hemisphere of Venus, and some persons suggested an asymmetric distribution of light around the periphery of the unilluminated hemisphere of the planet.

## Bright Limb Band

In 1983-84, 35 percent of the observations submitted showed indications of a bright limb band on the planet opposite the terminator. In 1985-86, 22 percent of the reports showed a conspicuous limb band. In both apparitions, the bright limb band was most often noted as extending from cusp to cusp, and the mean numerical relative intensity was 9.9 for both periods. [Text continued on p. 100.]

These figures have south at the top and celestial east to the right. "Rr." indicates a refractor and "R1." a reflector. Unless otherwise stated, seeing is in the $0-10$ scale, with 10 best; and transparency is the limiting naked-eye magnitude. "Dia." refers to the apparent disk diameter, while $k$ is the calculated phase.


Figure 2. Drawing and diagrams by Rob Robotham on 1983 OCT 07, 10h 50m - 11h 30m U.T. 8.3-cm. Rr., 115 X and 146 X , no filter. Seeing 7-8, transparency 5 (1-5 scale). Dia. $=35^{\prime \prime} .0, \mathrm{k}=0.324$. A shaded drawing is to the left. The diagram to the lower left shows conspicuousness, and the one to the lower right, intensity, on the $0-10$ scales described on page 95 .


Figure 3. Two drawings by Alan W. Heath on 1983 OCT 24, 07 h 40 m U.T. $30-\mathrm{cm}$. R1., 318X. Seeing fair to good; daylight. Dia. = 27".9, $k=0.440$. The drawing on the left was with no filter; that on the right was with a W47 (blue) filter.


Figure 4. Photograph by Alan W. Heath; same data as the left drawing in Figure 3 , done simultaneously. Note the similarity between that drawing and this photograph. $1 / 25-s e c$. exposure, Tri-X Film.


Figure 5. Drawing by M. Maksyrowicz on 1983 NOV 13, 9h 00m-05m U.T. 20-cm. R1., 133X and 205X, no filter. Seeing 3-4, transparency $=$ 7.8 (0-10 scale). Dia. = $22^{\prime \prime} .3, k=0.549$.


Figure 6. Drawings by M. Maksyrowicz on 1985 APR 28. From left to right (1) 08h 45m U.T., no filter; (2) 08h 50m U.T., bl'. (OG395) filter; (3) 08h 55m, red (RG630) filter. $15-\mathrm{cm}$. R1., 113X. Seeing 2-3, transparency 10 ( $0-10$ scale). Dia. $=45^{\prime \prime} .9, k=0.161$.


Figure 7 (left). Drawing by David L. Graham on 1985 MAY 28, 09h 10m-22m U.T. 10.2-cm. Rr., 108X, no filter. Seeing III (Antoniadi scale; i.e., moderate with large air tremors). Dia. = $28^{\prime \prime} .9, k=0.402$.


Figure 8. Drawing and diagrams by Marc Gelinas on 1985 JUN 07, 13h 13m-22m U.T. 20-cm. R1., 226X, W47 (blue) filter. Seeing 7, transparency 4.0. Dia. $=25^{\prime \prime} .3$, $\mathrm{k}=0.465$. A shaded drawing is to the left. The diagram to the lower left shows conspicuousness, and the one to the lower right, intensity, on the $0-10$ scales described on page 95.


## [Text continued from p. 97.] <br> Terminator Irregularities

The circle that separates the illuminated and dark hemispheres of Venus, called the terminator, displayed occasional deformations in 1983-84 but none in 1985-86. For 1983-84, 9 percent of the observations submitted noted deformities along this otherwise-regular boundary. Amorphous or irregular dusky features and, to a lesser extent, banded and radial dusky markings showed interaction with the terminator shading and with possible reported terminator irregularities in the 1983-84 apparition. [Walter Haas comments, "Over the 52 years or so that I have observed Venus I have become increasingly suspicious that humps along the terminator are spurious effects of brighter features and that hollows similarly result from darker features." Ed.]

## The Ashen Light and Other Dark Hemisphere Phenomena

There were fleeting glimpses of possible dark-hemisphere phenomena in 1983-84, chiefly reported as an unilluminated hemisphere that was darker than the background sky. There were absolutely no instances of suspected darkhemisphere illumination (Ashen Light) in either apparition. However, Venus was observed exclusively against a twilight or daylight sky.

Estimates of Phase and Dichotomy
The "Schroeter Effect" on Venus, a discrepancy noted between the observed and the predicted dates of dichotomy (half phase; $k=0.500$ and the phase angle, $i=90$ ), was reported in 1983-84 and 1985-86. The predicted and the observed dates of dichotomy, and the differences between them, are given in Table 4 , below.

Table 4. Theoretical and Observed Dichotomy Dates With Discrepancies.

|  | 1983-84 Western (Morning) Apparition | $\begin{gathered} \text { 1985-86 Western } \\ \text { (Morning) Apparition } \end{gathered}$ |
| :---: | :---: | :---: |
| Theoretical Dichotomy | 1983 NOV 03.8 | 1985 JUN 13.6 |
| Observed Dichotomy (Mean) | 1983 NOV 05.4 | 1985 JUN 17.7 |
| (Observed - Theoretical) | d | d |
| Discrepancy: Days | +1.6 | +4.1 |
| Phase (k) | -0.009 | -0.021 |
| Phase Angle (i) | +1.02 | +2.45 |

Conclusions
Dusky features were fairly obvious on Venus in 1983-84, with only limited occasions when the disk was reported as completely blank. Activity in 1985-86 was less obvious, and the planet appeared devoid of detail about half the time. In 1985-86, however, there was a greater incidence of bright spots (exclusive of the cusps) than in 1983-84.

It is hoped that readers will be encouraged to join the A.L.P.O. Venus Section and to participate in our various observational endeavors. Venus is a planet that presents many observational difficulties; yet persistent effort on the part of dedicated individuals with their telescopes, particularly with respect to simultaneous observations, can yield interesting and useful results. Anyone desiring information about the Venus Section, observing instructions, or other assistance is cordinally invited to contact the author at the address given on the inside back cover.

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THE METEOROLOGY OF MARS--PART III.
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Abstract. --This paper is the final Part of the A.L.P.O. Mars Section Reports on the meteorology of Mars. This report is dedicated to the many fine Mars observers of the Association of Lunar and Planetary Observers and especially to the late Charles F. (Chick) Capen, who inspired this study in the first place. Final statistical analyses are presented along with tables and graphs of the Martian meteorology observed during the apparitions from 1964-66 through 1983-85. Tables are presented in order to be used as test cases for predicting the Martian meteorology observed during the 1985-87 and 1987-89 Apparitions.

## Introduction

The Martian atmosphere, although extremely thin in comparison with our own, nevertheless exhibits many of the same characteristics as the Earth's. Fine dust particles and ice crystals of $\mathrm{CO}_{2}$ and H 20 exist in both atmospheres, suspended for days or even months at a time. Surlight is scattered by the Martian atmospheric particles and is reflected back into space so that the astronomer watching Mars sees bright blue-white and yellowish patches against the orange-ochre disk. This property of the planet's atmosphere enables the telescopic observer to distinguish surface albedo features from the aerosols and other condensates that make up the Martian clouds, limb and polar region clouds and hazes, ice-fogs or possible snow patchs, and Yellow Dust Clouds. The Martian desert regions have been found to be especially likely areas for bright aerosols, making the latter's detection difficult without the aid of color filters.

For many years, before technology enabled us to visit Mars with space probes, astronomers suspected that the transient bright areas observed on the planet were clouds or fogs of some nature. Some astronomers suspected the occurrence and locations of these phenomena to be coupled to the seasonal thawing and condensation of the polar caps; but too little information about the Martian atmosphere's temperatures, pressure, composition, and so forth, was available at the time to make a proper determination. Still, the behavior of the bright areas suggested that the Martian atmosphere contained suspended particles and vapors.

Only after we sent the Mariner and Viking Spacecraft to Mars did we confirm that the bright patches which we observed were actually atmospheric and were suspended aerosols or, in some cases, near-surface condensates. Long before the final signals were received from the Viking Landers, we realized that ground-based astronomers had been given a new beginning to observing and understanding the dynamic world of the Red Planet, Mars. Our great space program had opened a new era in planetary astronomy, which led to the formulation of this series of papers on the meteorology of Mars. [1, 2, 3]

The meteorological survey that led to these reports was inspired by the late Charles F. (Chick) Capen, who made available the many volumes of data contained in the A.L.P.O. Mars Section Observational Report Library. Without Chick's help and guidance, this project would have been postponed for a long time. Results of the meteorological survey of Mars, based on the 1969, 1971, 1973, 1975, 1978, 1980, 1982, and 1984 opposition years, are presented, with some earlier data from the 1965 and 1967 opposition years. [6,7]

Part I of this report [6] presented tables and graphs of statistical analyses of Martian meteorology during the $1966-68$, 1968-70, 1970-72, and 1981-83 Apparitions. Data for the 1966-68 Apparition were supplied by C.F. Capen then at the Table Mountain-JPL Observatory in California. The 1968-70 and 1970-72 meteorological data were supplied by C.F. Capen from the A.L.P.O. Mars Section Observational Report Library, while the 1981-83 data were contributed by the Institute for Planetary Research Observatories (I.P.R.O.). [6] Part I presented the results of the first evaluation of the meteorological data for Mars by the I.P.R.O. and was employed to develop methods and computer programs that were used in the remaining two Parts of this report.

Part II [7] presented statistical analyses from the additional data acquired from A.L.P.O. observations in order to complete the meteorological surveys of Mars for the $1968-70$, 1970-72, 1972-74, 1974-76, 1976-79, 1979-81, 1981-83, and 1983-85 Apparitions of Mars. Data from the Table Mountain-JPL Observatory records for the 1963-68 period were obtained from C.F. Capen.

The data used to develop the tables and figures of Part III here were made available from the A.L.P.O. Mars Section Observational Report Library, which contains nearly 10,000 observations of Mars. This meteorological survey is the result of the study of 8,000 visual report forms ( 3 drawings each), 1,500 photographs, and nearly 500 additional written observations of Mars from 1963 through 1985. Observations of Mars are contributed freely each apparition by 60 to 80 individual members of the International Mars Patrol (I.M.P.), located around the world in at least 14 countries.

Statistics for this survey are based simply on the number of periods during which meteorological activity was observed versus the total number of such periods actually observed by ground-based astronomers. When simultaneous observations of a particular meteorological phenomenon are evident, the occurrence of the phenomenon is then recorded as a single event. Some types of meteorology, such as Limb Clouds and Hazes, or polar region phenomena, change rapidly with time and therefore may be counted more than once. Whether this is done depends, of course, on the amount of time elapsed between observations. Statistical periods are measured in terms of degrees of planetocentric longitude of the Sun ( $\mathrm{L}_{\mathrm{s}}$ ). Percentages are also given in the form of averages for seasons defined by $90^{\circ}$-Ls intervals, in terms of the proportion of degrees of L s when clouds, white Areas, and so forth were observed, with comparison graphs for Limb Hazes and Polar Hazes.

Violet Clearing (formerly called "Blue Clearing") has been included in this study in the form of graphs (/Figures 10/and/15/, pp. 107-108) in order to determine its seasonal behavior and whether this phenomenon is connected in any way to other Martian phenomena that have been observed. The true nature of the Violet Clearing is yet to be understood and has been given considerable attention over the years.

## Meteorological Trends

A trend analysis for each type of meteorological phenomenon is presented in order to reflect general trends in Martian meteorology over the past 17 earth-years. In order to fully document all the seasons on Mars, at least two complete apparitions would have to be studied so that a greater portion of each Martian season could be used in the survey. [Even better, observations should extend over at least one entire 17 earth-year perihelic cycle, as is the case in this study. Ed.] Mars, the most Earth-like of the other planets, exhibits four seasons which are slightly less than twice as long as those of the Earth. As Spring arrives in a particular Martian hemisphere, that hemisphere's polar cap begins to thaw, and an increase in the frequency of clouds and hazes is observed. The Northern Spring and Summer appear to produce more cloudiness than do the same Southern seasons. Of course, phenomena occurring on the side of Mars hidden from our view cannot be included. However, the Mars Section attempts to reduce such omissions through an international network of observers, thus covering as much of the planet as is possible during each 24 -hour period. Table 1 (p. 103) presents a comparison of seasons on the Earth and Mars.

For this study, the Martian year has been subdivided into 90 -degree seasonal periods, measured in degrees of $L_{s}$; and the terms Spring, Summer, Autumn, and Winter will be identified with those seasons in the Northern Hemisphere. Further statistics are presented for twelve 30 -degree sub-seasonal periods ("months"), prefixed in order "early-," "mid-," and "late-."

Table 1. Seasonal Durations on Earth and Mars.

| Areocentric |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| of the Sun | Northern | Southern | Ma |  | Earth |
| ( $\mathrm{L}_{\mathrm{s}}$ ) | Hemisphere | Hemisphere | MD | TD | TD |
| - |  |  |  |  |  |
| 000-090 | Spring | Autumn | 193 | 199 | 92.8 |
| 090-180 | Summer | Winter | 178 | 183 | 93.6 |
| 180-270 | Autumn | Spring | 143 | 147 | 89.8 |
| $270-360$ | Winter | Summer | 154 | 158 | 89.0 |
|  |  |  | 668 | 687 | 365.2 |

Note: "MD" represents Martian Days; "TD", Terrestrial Days.

The histograms in Figures 9-14 (pp. 106-108) present overall apparition means of the percentage chance that an observer will see either a Cloud Band, Violet Clearing, Limb Haze, or Polar Haze during that apparition. The mean percentage chance by season of observing Violet Clearing is presented in Figure 15 (p. 108).

Trend-line curves are included in Figures 16 and 17 (pp. 109-110) in order to represent the general likelihood of observing Martian Limb Hazes and Polar Hazes for the eight apparitions covered by this survey, where the percentages express the chance that an observer will see a particular phenomenon on Mars during any 30 -degree $\mathrm{L}_{\mathrm{s}}$ period.

Tables and charts are given for Martian clouds and White Areas, which include seasonal-index curves and percentage-chance curves for Limb Clouds, Discrete Clouds, White Areas, and Yellow Clouds. Index numbers in these tables and figures indicate the mean departure from the straight-1ine trend developed for the 30 -degree subseasonal periods. Figures 18-20 (pp. 1ll-112) present curves for the seasonal-trend indices and percent-chance values and are tabulated in Tables 2,3 , and 4 ( pp . 105-106) respectively. Seasonal indices are derived from standard time-series analysis. [9]

> Rarely Observed Phenomena

Rarely observed is the Planetary System Cloud Banding, or Equatorial Cloud Band (ECB) as it is sometimes called. The ECB is a faint violet or blue-white band of high-altitude ice crystals and appears as a broad and diffuse hazy streak crossing the Martian Equatorial Zone. Cloud Bands are detected visually by using a deep blue (W47B) or blue (W47) Wratten Filter or are photographed in ultraviolet or violet light. Cloud Bands are probably composed of thin $\mathrm{CO}_{2}$ ice crystals carried aloft by high-altitude winds.

Cloud Bands are observed most often during the Martian Northern Summer. However, with the limited data available the behavior of these clouds remains speculative. Systematic blue-filter observations will someday unravel the mystery of the behavior of these clouds.

The exact nature of Violet Clearing is unknown at this time. This phenomenon can be observed during periods of either clear or cloudy Martian skies, and has even been seen during dust storms, which poses more interesting questions about its nature and Mars' atmosphere. Violet Clearing is usually observed in selected regions of Mars, but at times can be seen to affect the entire planet. This phenomenon is visually observed with a blue filter (W47) at wavelengths from 425 nm to 455 nm and is photographed in ultraviolet light in wavelengths of 400 nm and shorter.

## Limb Hazes and Polar Region Meteorology


#### Abstract

Limb Hazes , often called "limb arcs," are observed during most apparitions as misty arcs of light on the sunrise or sunset limb of Mars. ${ }_{o}$ Evening (sunset) Hazes are often described as a thin haze which can extend $10^{\circ}$ to $20^{\circ}$ from the limb. Morning Hazes are slightly larger, extending $20^{\circ}$ to 300 from the limb. Limb Hazes appear as thin and smooth arcs which often cover $70^{\circ}$ to $90^{\circ}$ in latitude; however, at times they are even observed to extend from pole to pole. Limb Hazes do not rotate with the axial rotation of the planet, and


are best observed in blue-green, blue, and violet light. The appearance of these Limb Hazes suggests that the temperature near each limb varies little with Martian latitude and that $\mathrm{CO}_{2}$, water vapor, or both condense evenly over large areas near the limbs.

Figures 11 and 12 show overall frequency distributions of the observed occurrences of Limb Hazes for each opposition year indicated. Figure 16 illustrates the seasonal behavior of each form of Limb Haze. It is apparent from the curves that Evening Hazes are more frequent in Northern late-Summer and early-Autumn. Morning Hazes appear to have a similar curve; however, these hazes appear to be more evenly distributed.

Arctic and Antarctic Meteorology is of special interest to the planetary meteorologist. Considerable frozen water is contained in the polar caps and contributes to the Martian atmospheric clouds and hazes as the spring and summer cap thaw becomes more rapid. Many interesting cloud or fog formations appear in the North Polar Region (NPR) during late-Spring as the subsolar point moves northward upon Mars.

During the years when the Martian NPR can be observed, a thick hood is observed to appear suddenly over the polar region between $70^{\circ}$ and $80^{\circ} \mathrm{L}_{\mathrm{s}}$. This formation has been called the "aphelic chill" by astronomers and most likely is caused by sudden outgassing of water vapor from the cap which then condenses rapidly in the frigid atmosphere above the polar region. Polar Hoods and Hazes are best observed in violet or blue light, but are bright in integrated light as well. At times these clouds appear to form long waves near the polar cap edge, similar to to the "frontal waves" often seen on the Earth. The South Polar Region (SPR) appears to behave similarly to the NPR. However, the NPR appears to produce a larger number of clouds than does the SPR.

The histograms in Figures 13 and 14 show that both polar regions were meteorologically active during all the apparitions studied. Figure 17 illustrates the mean seasonal frequency distributions for both polar regions and shows peak frequency periods similar to those of the Limb Hazes.

## Clouds and White Areas

Martian Evening Limb Clouds tend to gather on the evening limb, particularly in the equatorial zone, and do not rotate with the axial rotation of Mars. Evening Limb Clouds are more numerous during the Northern Spring and Sumer and usually cover a larger area than the Evening Limb Clouds of the Northern Autumn and Winter. The Mars observer should expect to see an increase in the number of clouds from Northern Spring to Summer but will observe a decrease in their size as Autumn approaches. The number and size of the clouds fall off dramatically for the remainder of the Martian year, from midSumer through mid- Winter, as is readily apparent from the seasonal indices.

Clouds of this type tend to change shape quite often, usually cling to the limb regions, and are thought to be caused by convection arising from the Martian surface due to its diurnal heating.

Morning Limb Clouds are usually large, hazy cloud formations that remain near the equatorial limb regions. They often dissipate rapidly as the solar altitude increases and do not extend more than a few degrees from the limb. A quick look at the trend-line curves in Figure 18 reveals that both Morning and Evening Limb Clouds follow very similar patterns; an increase in number from late Northern Winter through Spring and a peak during early-Summer, followed by a dramatic decrease from mid-Summer through mid-Winter.

Clouds that are observed on the morning limbs are probably not the remnants of the previous evening's Limb Clouds; however, the aerosols and vapor contained in them are most certainly of the same origin. We speculate that Evening Clouds may precipitate to the surface during the cold Martian night [when, of course, we are unable to obseve them. Ed.] and rise in the morning through sublimation as the Martian atmosphere receives its first sunlight of the day.

Figure 18 illustrates the frequency of the number of clouds observed for both limbs. Comparison of Limb Hazes in Figure 16 with Limb Clouds in Figure 18 will show that not all limb activities occur at the same times. Limb Haze frequencies appear to peak about $110^{\circ}$ of $\mathrm{L}_{\mathrm{s}}$ later than do those of Limb Clouds. When comparing Figure 17 with Figure 18, one can see that Polar Hazes also lag behind Limb Clouds by the same amount as do Limb Hazes. [Text continued on p. 109.]

Table 2. Seasonal Trend Analysis of Martian Evening and Morning Limb Clouds for the Opposition Years of $1969,1971,1973,1975,1978,1980$, 1982, and 1984.


NOTES: The "Adj. Trend" (Adjusted Trend) in the table above is a linear trend based on the apparent long-term trend between apparitions. The "Seas. Index" (Seasonal Index) is found by dividing the " 8 -Yr. Total" by the Adjusted Trend and then multiplying the result by a constant ( 0.012053 for Evening Clouds and 0.015133 for Morning Clouds); this causes the mean Seasonal Index for all 12 "months" to equal 1. "Percent Chance" gives the percentage of degrees of $L_{s}$ in which Evening or Morning Limb Clouds were present.

Table 3. Seasonal Trend Analysis of Martian Discrete Clouds and White Areas for the Opposition Years of 1969, 1971, 1973, 1975, 1978, 1980, 1982, and 1984.


Table 4. Seasonal Trend Analysis of Martian Yellow Clouds for the Opposition Years of $1969,1971,1973,1975,1978,1980,1982$, and 1984.



Figure 9. Histogram of Cloud Band Frequencies (1965 -1984 Apparitions). "N/A" indicates data not available yet.


Figure 10. Histogram of Violet Clearing Frequencies (1965 -1984 Apparitions). "N/A" indicates data not available yet.


Figure 11. Histogram of Evening Limb Haze Frequencies (1965 -1984 Apparitions). "N/A" indicates data not available yet.


Figure 12. Histogram of Morning Limb Haze Frequencies (1965 -1984 Apparitions). "N/A" indicates data not available yet.


Figure 13. Histogram of Arctic Cloud and Haze Frequencies (1965 -1984 Apparitions). "N/A" indicates data not available yet.


Figure 14. Histogram of Antarctic Cloud and Haze Frequencies (1965 1984 Apparitions). "N/A" indicates data not available yet.


Figure 15. Graph of the mean seasonal percentage probability that Violet Clearing will be observed. Based upon observations for the opposition years 1969, 1971, 1973, 1975, 1978, 1980, 1982, and 1984. "SS" indicates Northern Summer Solstice.


Figure 16. Graphs of the mean seasonal percentage probability that Evening Haze (top) or Morning Haze (bottom) will be observed. Based on observations for the opposition years 1969, 1971, 1973, 1975, 1978, 1980, 1982, and 1984. "SS" indicates Northern Sunmer Solstice.

## [Text continued from p. 104.]

Discrete Topographic Clouds and Orographic Clouds tend to rotate with the planet's diurnal rotation. These types of phenomena are identified by their location near historically cloudy regions and high mountainous areas. Discrete Clouds are often observed on both limbs and are sometimes distinguished from normal Limb Clouds by the astute observer's simply being aware of known cloudy areas. When comparing the trend-1ine curves, it is evident that Discrete Clouds are more numerous during the Northern Sumer and appear to follow trend lines similar to both Evening and Morning Limb Clouds. Discrete Clouds continue to increase after Limb Clouds begin to decrease, and the former peak during Northern mid-Summer. Their number and frequency slowly drop off in late-Summer through the remainder of the Martian year.

It is interesting to note that Discrete Clouds appear to lag behind Limb Clouds, as is shown in Figures 18 and 19. The peak period for the observed number of Discrete Clouds appears to be at the time of the maximum rate of retreat of the Northern Polar Cap. Discrete Clouds peak $65^{\circ}$ of $\mathrm{L}_{\mathrm{s}}$ later than do Limb Clouds.


Figure 17. Graphs of the mean seasonal percentage probability that Arctic Haze (top) or Antarctic Haze (bottom) will be observed. Based on observations for the opposition years $1969,1971,1973,1975,1978,1980,1982$, and 1984. "SS" indicates Northern Summer Solstice.

White Areas are a form of ice-fog or surface frost that are identified by their location and by a systematic use of color filters. White Areas are bright in all colors, much more so than other bright phenomena. These bright spots are often confused with other meteorology and are a constant source of error for the statistician. White Areas have been observed to appear in regions after dense white clouds had been seen there, which suggests that surface snow might be a possible explanation for some White Areas. Also, as with Discrete Cloud and Haze activity, White Areas appear to occur later than Limb Clouds by nearly $20^{\circ}$ of $\mathrm{L}_{\mathrm{s}}$; see Figure 19.

The trend curve for Yellow Clouds reveals three periods of high activity. Historically, major ("planet encircling") dust storms are observed most often during perihelic apparitions of Mars. [10] Initial Yellow Clouds associated with the major dust storms have been observed during the Martian Southern Spring and Summer ( $204^{\circ}-300^{\circ} \mathrm{L}$ ). Localized and short-duration dust storms are recorded during the aphelic apparitions as well. These latter Yellow Clouds often go undetected because they usually do not spread over large areas. Often the polar regions become yellowish during or shortly after a local dust storm. The curve in Figure 20 and data in Table 4 present the time-series trend analysis of all Yellow Clouds observed during the 17-year period of study. It is apparent from the figure and the table that Yellow Clouds are frequently observed during: (1) Southern late-Spring (peak $255^{\circ}$ $L_{\rho}$ ), (2) Southern mid-Summer (peak $315^{\circ} \mathrm{L}_{\mathrm{s}}$ ), and (3) Northern early-Summer (peak $100^{\circ} \mathrm{L}$ ). The height of the curve during Northern Summer is due to the unusual number of local dust storms that occurred then in the 1983-85 Apparition. [11]


Figure 18. Graphs of seasonal indices for (solid line; lefthand scale) and probability of observing (dotted line; righthand scale) Evering Limb Clouds (top) and Morning Limb Clouds (bottom). Based on observations for the opposition years 1969, 1971, 1973, 1975, 1978, 1980, 1982, and 1984. "SS" indicates Northern Summer Solstice. Derived from Table 2 .

## Systematic Errors

Systematic errors have been reduced by applying least-squares regression to near-simultaneous observations of a particular Martian feature as made by three or more observers. When possible, photographs were used to cross check and confirm phenomena which were reported visually.

Statistical errors are also present in our data as a result of the nature of the reporting of Mars observations. We might think of these observations as discrete samples in time or "snapshots" of the conditions on Mars. This is due to the fact that we cannot possibly record every moment of Mars' history, even with the excellent longitudinal coverage provided to us by our worldwide network of observers. Large gaps in areographic longitude go unobserved. Identifying simultaneous observations of clouds or White Areas that are seen by several astronomers is much less difficult than separating limb phenomena. This is due to the fact that Limb Hazes and Clouds appear to remain close to the limb while other phenomena rotate with the planet.

Also, the areocentric declination of the Earth ( $\mathrm{D}_{\mathrm{e}}$ ) can be 20 degrees or more from the equator for much of an apparition, which prohibits observation of those regions near the hidden pole. Thus, areas within 20 degrees or more of each pole are often hidden, as well as the entire averted and night hemispheres. All of these impossible observations go into the "bucket of the unknown." [Other likely sources of bias are the greatly varying distance of Mars from the Earth, the period near conjunction with the Sun when Mars cannot be observed, and the changing value and sign of the phase angle $i$, which must also complicate the observation of hazes and clouds near the Martian sunrise or sunset terminator. Ed.] [Text continued on p. 113.]


Figure 19. Graphs of seasonal indices for (solid line; lefthand scale) and probability of observing (dotted line; righthand scale) Discrete Clouds (top) and White Areas (bottom). Based on observations for the opposition years 1969, 1971, 1973, 1975, 1978, 1980, 1982, and 1984. "SS" indicates Northern Summer Solstice. Derived from Table 2 .


Figure 20. Graphs of seasonal indices for (solid line; lefthand scale) and probability of observing (dotted line; righthand scale) Yellow Clouds. Based on observations for the opposition years 1969, 1971, 1973, 1975, 1978, 1980, 1982, and 1984. "SS" indicates Northern Summer Solstice. Derived from Table 2.

As a result of the spacecraft missions to Mars during the 1960 's and $1970^{\prime} \mathrm{s}$, a new impetus has been given to ground-based telescopic observing of the Red Planet. Astronomers are now armed with new knowledge about Mars that was made available through closeup surveillance by the Viking Landers. However, those machines which gave us a short period of closeups of Mars are now just space junk and will send back no more data.

Astronomers have suspected for many years that water vapor and dust particles are present in the Martian atmosphere. To what extent these aerosols are present remained unknown until the Vikings landed on the surface of Mars. Much of what we already suspected was confirmed and, of course, new questions arose. With this new knowledge, we have adjusted or corrected our methods of observing Mars and are ready to carry out long-term and systematic data collection of Martian meteorology from the Earth.

The tables in this report will be used to test the meteorological activity on Mars for the years 1986 through 1988, and will then be applied to the next 17-year apparition cycle of Mars during the $1990^{\prime}$ s and 2000's.

Meteorological phenomena requiring the use of color filters for their detection have gone unreported for many of the Mars observations made before C.F. Capen made their use popular. Cloud Bands are one of these types of phenomena which require more study. Either they are extremely rare, or most of them go undetected during their peak periods.

Violet Clearing, the nature of which has been debated for years, needs much more study. It is evident from the study of its frequency, locations, and duration that this phenomenon can be observed at any time during a particular apparition, regardless of the meteorological conditions observed on the Red Planet. Is Violet Clearing tied to atmospheric conditions, or is it a surface condition?

Limb Hazes can be indicators of stable temperatures and atmospheric conditions near the sunset or sunrise regions of the planet. They are observed during all apparitions of Mars, but they vary in frequency. Are Limb Hazes affected by dust in the Martian atmosphere? Are they $\mathrm{CO}_{2}$ or $\mathrm{H}_{2} \mathrm{O}$ vapors or ice crystals?

The Martian Arctic and Antarctic appear to be very active areas for meteorology. Both polar regions exhibit similar behavior during their respective early-Spring periods. Each emerges from its winter darkness with a dull-grey hood, which begins to dissipate as Spring progresses until the brilliant polar cap peeks out and begins to retreat poleward. As the polar region is exposed to more and more sunlight, erratic behavior is detected; and clouds and hazes are frequently observed. Is there any apparent difference in the behavior of each polar region?

Limb Clouds appear to have frequencies of occurrence that are similar to those of Polar Clouds and Hazes; they tend to be more frequent during the Northern late-Spring and early-Summer. As a result of the buildup of convective clouds near the sunset areas of Mars, Evening Limb Clouds tend to be larger than Morning Limb Clouds. Both types are observed most often in the Martian equatorial zone.

The seasonal phase lags between the different types of phenomena described in this report may be significant. The seasonal-trend curve indicates that Discrete Clouds increase in frequency near the Northern Summer Solstice and then slowly decrease in frequency after mid-Summer. This type of cloud is more often observed in the bright desert and mountainous regions of Mars. Discrete Clouds are observed at all latitudes of Mars and do not favor the equatorial zone.

White Areas follow a seasonal-trend curve similar to that of the Limb Clouds. White Areas are sometimes confused with Discrete or Yellow Clouds and are observed at all latitudes on Mars.

Yellow (Dust) Clouds vary in size and intensity depending on the seasonal period in which they appear. Dust Clouds are observed most often during the Southern Spring and Summer seasons, but have been frequently observed in the Northern Summer as well. Major or "planet-encircling" dust storms are reported most often when Mars is observed during perihelic apparitions. Yellow Clouds become extremely difficult to count or to track during these major storms, which of course affects the results of this survey.

The study of Mars' climate will help in the understanding of our own planet's climate. The methods derived from the meteorological survey of Mars, using A.L.P.O. observations and modern techniques, will continue to increase our knowledge of the planet Mars and to indicate that the amateur has earned a place in modern science.

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GALILEAN SATELLITE ECLIPSE TIMINGS: $1985 / 86$ REPORT
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Introduction
This report covers the ninth Jovian apparition studied by the A.L.P.O. Jupiter Section's Galilean Satellite Eclipse Timing Program. Through the 1985-86 Apparition we have received and analyzed a total of 2541 visual and 8 electronic timings of the disappearances and reappearances of the satellites Io, Europa, Ganymede, and Callisto as they enter and leave the shadow of Jupiter. These timings are compared with two published ephemerides in order to improve our knowledge of the orbits of these satellites. The first ephemeris is that published by R.A. Sampson in 1910, and was used for the Astronomical Almanac and several other publications through the year 1986. The second is the "E-2" ephemeris developed by Jay Lieske of the Jet Propulsion Laboratory, which is used for planning the Galileo space mission and in studying the effects of tides on Io in changing its orbit; beginning in 1987, the E-2 ephemeris has been used for the predictions in the Astronomical Almanac as well. Previous reports on our program have been given in "Galilean Satellite Eclipse Timings: 1975-82 Report" (J.A.L.P.O. , 30 , 45-53, 105-115, and 145-154; Oct., 1983, and Jan. and Apr., 1984), "Galilean Satellite Eclipse Timings: 1982/83 Report" (J.A.L.P.0., 31 , 105-119; Jan., 1986), and in "Galilean Satellite Eclipse Timings: $1983 / 85$ Report" ( J.A.L.P.O. , 31 , 198-206 and 249-258; July and Nov., 1986).

Fully 335 visual and 4 photoelectric timings were received for the 1985/ 86 Jupiter Apparition, which in theory covered the period 1985 JAN 14-1986 FEB 18 (dates of conjunction; opposition was on 1985 AUG 04). Timings came from members of the A.L.P.O., the National Association of Planetary Observers (Australia), and the Royal Astronomical Society of New Zealand. A.L.P.O. members contributed 53 percent of the observations (176) and comprised 60 percent of the observers (24 out of 40). Due to Jupiter's southerly declination ( -18.0 degrees at opposition), Southern Hemisphere observers had an advantage during this apparition. Table l below, provides some statistics on the observations that were received.
$\xrightarrow{\text { Table 1. Summary Statistics: } 1985 / 86 \text { Galilean }} \frac{\text { Satellite Eclipse Visual Timings. }}{\underline{\text { Sin }}}$


* As will be done throughout this report, satellites are numbered as follows: $1=$ Io, $2=$ Europa, $3=$ Ganymede, and $4=$ Callisto. $\underline{D}$ represents eclipse disappearance, and $\underline{R}$ represents reappearance.

Jupiter's inner Galilean satellites were timed more often than its outer ones simply because the closer a satellite is to Jupiter, the shorter is its orbital period and thus the more often that it is eclipsed. As usual, more timings were made of eclipse reappearances ( 184,55 percent) than of disappearances ( 151,45 percent), chiefly because many disappearances occur at inconvenient early morning hours. This factor also meant that more timings were made after opposition (189; 56 percent) than before ( $146 ; 44$ percent), as is shown in the monthly frequency column above. The earliest timing was on 1985 MAR 06 at elongation 39 degrees west, and the last was on 1985 DEC 28 at elongation 41 degrees east. As with previous apparitions, it appears impractical to make eclipse timings within six or seven weeks of conjunction.

As has been the case for several apparitions, 20 cm . was by far the most popular aperture. Nonetheless, successful timings were made with instruments as small as $6-c m$. aperture and a few observers employed relatively large telescopes in the 32 to $53-\mathrm{cm}$. category. The mean aperture used was 18 cm ., and the smaller instruments were more common than the larger. Each visual timing that was received will be listed individually in the Appendix to this Report.

## Reduction

The procedure for converting timings into residuals from an ephemeris prediction was described in the previously-cited $1975-1982$ report. For each satellite, four analyses are done because the two ephemerides are treated separately as are eclipse disappearances and reappearances. For both timing and orbital residuals, a positive value means that an event was observed later than predicted (the ephemeris was "fast"), and a negative residual indicates that the event was observed earlier than the ephemeris predicted (the ephemeris was "slow"). For each case, a linear regression model fits the residuals to the reciprocal of the aperture of the telescope in centimeters. As a check of this method, each satellite's diameter is estimated on the basis of the difference between its disappearance and reappearance residuals, which indicates the time taken by Jupiter's shadow edge to cross the disk of the satellite.

Although this method usually significantly reduces the variance (scatter) among the timings, there are often a number of timings which differ markedly from the majority. It is a somewhat subjective decision as to which timings to exclude from analysis. The writer excluded any timings that differed from the regression model at a 5-percent level of significance. This process changes the model; and it is then recalculated, which may result in other timings being excluded; this iterative process is done at most two times. For this apparition, 29 timings ( 8.7 percent of the total) were excluded from the "Sampson" analysis, while 35 ( 10.4 percent) were excluded from the "E-2" analysis. Those timings that were excluded from the regression are marked by asterisks in the "Residual" columns of the Appendix.

## 1985/86 Resu1ts

Figure 21 ( p .117 ) graphs the results of the timing reductions for the 1976/77-1985/86 Apparitions. The results for this last apparition are then described by each ephemeris used. Table 2 (p. 119) gives the results for the Sampson Ephemeris, while Table 3 (p. 120) does the same for the E-2 Ephemeris. In each table, each of the four Galilean satellites is described in a separate column. In interpreting these results, one should bear in mind that the Sampson Ephemeris predictions are given to only l-minute precision, while those of the E-2 Ephemeris are to 1 second. Thus in most cases the standard errors are greater for the Sampson Ephemeris than for the E-2 Ephemeris.

Going down the rows of Tables 2 and 3 , the first group of items is for eclipse disappearances and the second group is for reappearances. For each, the number of timings received is given first, followed in parentheses by the number of timings used for regression. The second item is the coefficient of determination ("R-squared"), which describes the proportion of the variance of the timings that is explained by the aperture-regression model. Third, the two regression coefficients are given with their 1 -standard error uncertainty ranges; all such uncertainty ranges are indicated by the " $\pm$ " symbol. Finally the standard error of estimate for the regression model is given, followed by the predicted time residual for three commonly-used apertures.

The remaining data in each column are derived from the combined disappearance and reappearance data. The first items give the orbital residuals from the ephemeris and their uncertainty ranges in units of seconds of time and in orbital arc in both degrees and kilometers. The last items give the satellite diameters, first in seconds of time, and then in kilometers, both uncorrected ("Prelim.") and corrected ("Corr.") for the satellite's angle of entry into, or its exit from, Jupiter's shadow. The corrected diameter is then compared with the Voyager-derived diameter for the satellite ("Standard;" 3640 km . for Io, 3066 km . for Europa, 5216 km . for Ganymede, and 4890 km . for Callisto). For the coefficient of determination ("R-squared"), the orbital time residual ("Seconds") and the diameter-comparison entries, statistical significance is shown by "-" for not significant, "*" for significance at the 5-percent level, and by "**" for significance at the l-percent level. [Text continued on p. 118.]


Figure 21. Graphs of orbital residuals for the Galilean Satellites from the 1976/77 through the 1985/86 apparitions, showing deviations in kilometers from the Sampson ("Sa") and the E-2 ("E2") ephemerides. The bands represent $\pm 1$ standard error ranges, Note that Callisto did not undergo eclipses during the 1980/81, 1981/82, and 1982/83 apparitions. See also text.

Sampson Ephemeris. --As shown in Table 2 , between 0 and 48 percent of the variances of the individual timings is removed by using the aperture model, which is statistically significant in only 3 of the 8 cases. As expected, the uncertainties of both regression coefficients increase regularly with distance from Jupiter. This is probably a joint effect of the progressively slower satellite velocities, wider penumbra of Jupiter, and fewer timings made, as the distance from Jupiter increases. For all satellites except Europa, the absolute values of the B-coefficients (the effect of aperture) are higher for reappearances than for disappearances; none of these differences are statistically significant, however.

The observed-Sampson orbital residuals, also graphed in Figure 21 , show that the Sampson Ephemeris is in serious error for all four satellites. The absolute amount of error, when compared with the $1983 / 85$ apparition, increased significantly for Ganymede but remained about the same for Io, Europa, and Callisto.

The observed-Sampson residuals of Io, Europa, and Callisto show no clearcut trend over time. Io's residuals varied little over the nine apparitions studied, with a mean value of $-101 \pm 3 \mathrm{sec}$. The residuals of Europa were also fairly constant, with a mean of $-7 \overline{0} \pm 10 \mathrm{sec}$. for the whole period. Results for Callisto showed more scatter, but most values were near the long-term mean of $-155 \pm 26 \mathrm{sec}$. Ganymede is a special case, however. The value of its residual increased fairly consistently between the 1976/77 and the 1981/82 apparitions, but has decreased between 1981/82 and 1985/86 as follows:

|  | s s |  | s s |  | $s$ s |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1967/77. | $-141.0 \pm 14.4$ | 1979/80. | $+95.5 \pm 23.5$ | 1982/83. | $+48.0 \pm 20.0$ |
| 1977/78. | $-113.8 \pm 10.2$ | 1980/81. | $+35.0 \pm 19.8$ | 1983/85. | $+19.4 \pm 11.0$ |
| 1978/79. | $31.2 \pm 10.1$ | 1981/82. | +58.4 $\pm 21.1$ | 1985/86. | $-43.7 \pm 16.6$ |

The observed-Sampson Ganymede residuals above are graphed against time in Figure 22 ( $\mathrm{p}, 121$ ). For the entire period (excluding the deviant value for 1979 80) a good fit (R-squared $=.900^{* *}$ ) to the change in Ganymede's residual is given by the model:

$$
\text { Residual }=-57 \mathrm{sec} .+115 \mathrm{sec} \cdot\left[\sin \left(27.6 \mathrm{~T}-50^{\circ}\right)\right],
$$

where $T$ the number of apparitions since that of $1976 / 77$. The residuals predicted by this model are also graphed in Figure 22. The time argument, 27.6 degrees per apparition, implies that the residual is cyclical with a period of 13.04 Jovian apparitions or 14.25 terrestrial years. It is tempting to postulate a long-term pertubation due to Jovian resonance with Uranus (13.8 years) or Neptune ( 12.8 years), or a combination of the above. Perhaps what is happening to Ganymede as regards the Sampson Ephemeris will be clearer when we have additional data from future apparitions.

The diameters for all four satellites, as calculated from the Sampsonbased eclipse timings, are in good agreement with the Voyager-derived values.

E-2 Ephemeris. --As shown in Table 3 , using the aperture model removeded between 0 and 56 percent of the variance of the timings. Again, the timing uncertainties increase regularly with the distance of each satellite from Jupiter. As with the Sampson Ephemeris, none of the differences between the disappearance and the reappearance absolute $B$-values are significant.

There were no significant differences between our 1985/86 timings and the E-2 Ephemeris predictions for Io, Ganymede, and Callisto. However, this was the third apparition in a row where Europa showed a significant difference from that ephemeris. In 1982/83, Europa's E-2 residual was $+24.1 \pm 5.8 \mathrm{sec}-$ onds; significantly different from that ephemeris but quite close to its residual for the $1983 / 85$ apparition of $+20.5 \pm 3.9$ seconds and to the value for this apparition of $+20.1 \pm 4.7$ seconds. With the results for three successive apparitions in agreement, this effect appears real, and suggests that somehow Europa dropped about 300 kilometers back in its orbit in 1982, when compared to the E-2 Ephemeris, and that it continues behind that ephemeris. This satellite exhibited no such time change in terms of the Sampson Ephemeris, so this effect is unique to the E-2 Ephemeris. [Text continued on p. 121.]

Table 2. Satel1ites Compared With Sampson Ephemeris, 1985/86.

| Satellite: | Io | Europa | Ganymede | Callisto(a) |
| :---: | :---: | :---: | :---: | :---: |
| Disappearance - |  |  |  |  |
| Number of Observations | 71 (63) | 38 (34) | 31 (30) | 11 (10) |
| Coefficients: |  |  |  |  |
| $\begin{aligned} & \text { R-squared } \\ & \text { A (seconds) } \end{aligned}$ | $\begin{gathered} .293 * * \\ +\quad 2.3 \pm 4.4 \\ -238^{ \pm} \pm 47 \end{gathered}$ | $\begin{gathered} .296 * * \\ +55.5 \pm 6.3 \\ -2288^{ \pm} 62 \end{gathered}$ | $\begin{aligned} & .003- \\ & +179.1 \pm 29.0 \\ & -84^{ \pm} \pm 300 \end{aligned}$ | $\begin{aligned} & \quad .000- \\ & +\quad 85.9 \pm 54.2 \\ & +\quad 32 \pm 614 \end{aligned}$ |
| Standard <br> Error (sec.) | $\pm 17.8$ | $\pm 17.9$ | $\pm 80.8$ | $\pm 90.7$ |
| Aperture Residual (sec.): |  |  |  |  |
|  | $-37 \pm 5$ $-22 \pm 2$ -10 | $+18 \pm 6$ +33 +44 +4 | $\begin{aligned} & +165 \pm 29 \\ & +171 \pm 16 \end{aligned}$ | + $91 \pm 63$ +89 +87 +83 |
| 20 cm . |  |  |  | $+87 \pm 33$ |
| Reappearance -- |  |  |  |  |
| Number of Observations | 95 (91) | 49 (42) | 33 (29) | 7 (7) |
| Coefficients: |  |  |  |  |
| R-squared A (seconds) | $\begin{gathered} .190^{* *} \\ -208.2 \pm 5.2 \end{gathered}$ | $\begin{gathered} .091- \\ -171.4 \pm 7.9 \end{gathered}$ | $\begin{aligned} & .098- \\ & -266.5 \pm 16.3 \end{aligned}$ | $\begin{aligned} & .485- \\ & -696.6 \pm 116.9 \end{aligned}$ |
| B | +263 $\pm 58$ | $+183 \pm 91$ | $+261 \pm 152$ | $+2297 \pm 1058$ |
| $\begin{aligned} & \text { Standard } \\ & \text { Error (sec.) } \end{aligned}$ | $\pm 24.9$ | $\pm 26.9$ | $\pm 41.9$ | $\pm 149.2$ |
| Aperture Residual (sec.): |  |  |  |  |
| (6 cm. <br> 10 cm | $-164 \pm \begin{aligned} & \text {-182 } \\ & -1\end{aligned}$ | $-141 \pm 9$ | $-223 \pm \begin{array}{r}14 \\ -241 \\ \hline\end{array}$ | -314 -467 $\pm$ |
| 20 cm . | $-195 \pm 3$ | $-162 \pm 5$ | $-253 \pm 10$ |  |
| $\frac{\text { Orbital }}{\text { Residua }}$ |  |  |  |  |
| Seconds | $-103.0+3.4 * *$ | $-57.9+5.1$ ** | - $43.7+16.6^{*}$ |  |
| Orbital Arc | $-0.243 \pm .008$ | $-0.068 \pm 8.006$ | -0.025 $\pm .010$ | $[-0.048 \pm 0.010$ |
| Kilometers | -1785 $\pm 59$ | -796 $\pm 69$ | - $476 \pm 181$ | $\mid-1585 \pm 339$ |
| Diameter ------ |  |  |  |  |
| Seconds | $210.5 \pm 6.8$ | $226.9 \pm 10.1$ | $445.6 \pm 33.2$ | $562.6+82$ |
| km. (Prelim.) | $3647 \pm 117$ | $3117{ }^{21} \pm 139$ | $4846 \pm 362$ | $4621 \pm 678$ |
| km. (Corr.) | $3644 \pm 117$ | $3097 \pm 138$ | $4819 \pm 360$ | $4510 \pm 662$ |
| Compar. with Standard | + 4 ( $+0.1 \%$ )- | + 31 (+1.0\%)- | - 397(-7.6\%)- | - 380(-7.8\%)- |

(a) Because the B-coefficient for the disappearance of Callisto has the incorrect sign, the residual and diameter values are based on the diapearance and reappearance means, equally weighted and unadjusted for aperture.

Table 3. Satellites Compared With "E-2" Ephemeris, 1985/86.

| Satellite: | Io | Europa | Ganymede | Callisto |
| :---: | :---: | :---: | :---: | :---: |
| Disappearance - |  |  |  |  |
| Number of Observations | 71 (60) | 38 (34) | 31 (30) | 11 (10) |
| Coefficients: |  |  |  |  |
| R-squared | . $565 \% * *$ | . 533 ** | .004- | . |
| A (seconds) | $+106.4 \pm 2.7$ | $+135.0 \pm 4.9$ | $+203.9 \pm 24.4$ | $+345.2 \pm 49.9$ |
| B | $-248 \pm 29$ | $-310 \pm 51$ | $-89 \pm 252$ | -246 $\pm 564$ |
| $\begin{aligned} & \text { Standard } \\ & \text { Error (sec.) } \end{aligned}$ | $\pm 10.5$ | $\pm 13.6$ | $\pm 68.0$ | $\pm 83.4$ |
| Aperture Residual (sec.): |  |  |  |  |
| 6 cm . | $+65 \pm 3$ | $+83 \pm 5$ | $+189 \pm 24$ | +304 $\pm 58$ |
| 10 cm. | +82 $\pm 1$ | $+104 \pm 2$ | $+195 \pm 13$ | +321 $\pm 30$ |
| 20 cm . | $+94 \pm 2$ | $+120 \pm 3$ | $+199 \pm 15$ | $+333 \pm 30$ |
| Reappearance -- |  |  |  |  |
| Number of Observations | 95 (88) | 49 (42) | 33 (29) | 7 (7) |
| Coefficients: |  |  |  |  |
| R-squared | .303** | .108* | .178* | . $424-$ |
| A (seconds) | -99.4 $\pm 3.7$ | $-94.9 \pm 7.9$ | $-242.4 \pm 15.3$ | $-404.8 \pm 111.6$ |
| B | +252 $\ddagger 41$ | +202 $\pm 92$ | +346 $\pm 143$ | +1939 $\pm 1010$ |
| Standard |  |  |  |  |
| Error (sec.) | $\pm 17.2$ | $\pm 26.9$ | $\pm 39.4$ | $\pm 142.4$ |
| Aperture Residual (sec.): |  |  |  |  |
| 6 cm . | $-57 \pm 4$ | $-61 \pm 9$ | $-185 \pm 13$ | $-82 \pm 89$ |
| 10 cm . | $-74 \pm 2$ | $-75 \pm 5$ | $-208 \pm 8$ | $-211 \pm 54$ |
| 20 cm. | $-87 \pm 2$ | $-85 \pm 5$ | $-225 \pm 10$ | $-308 \pm 72$ |
| Orbital |  |  |  |  |
| Residual ------ |  |  |  |  |
| Seconds | + $3.5 \pm 2.3-$ | + $20.1 \pm 4.7 * *$ | - $19.3 \pm 14.4-$ | $-29.8 \pm 61.1-$ |
| Orbital Arc | +0:008 $\pm 0.005$ | +0.024 $\pm .005$ | $-0.011 \pm .008$ | -0:007 $\pm .015$ |
| Kilometers | + $61 \pm 39$ | $+276 \pm 64$ | - $210 \pm 157$ | - 245 $\pm 502$ |
| Diameter ------ |  |  | -------------- | ---- |
| Seconds | $205.8 \pm 4.5$ | $229.9 \pm 9.3$ | $446.3 \pm 28.8$ | $750.0 \pm 122.3$ |
| km. (Prelim.) | $3567 \pm 79$ | $3158 \pm 128$ | $4855 \pm 313$ | $6160 \pm 1004$ |
| km. (Corr.) | $3562 \pm 79$ | $3137 \pm 127$ | -4827 $\pm 311$ | $6012 \pm 980$ |
| Compar. with Standard | - 78 (-2.1\%)- | + 71 (+2.3\%)- | -389 (-7.5\%)- | +1122(+22.9\%)- |



Figure 22. Residual of the satellite Ganymede from the Sampson Ephemeris from the 1976/77 through the 1985/86 Apparitions. Vertical bars represent observed residuals with $\pm 1$ standard error ranges. The curve represents a periodic fit to the residuals, along with its regression formula and coefficient of determination $\left(R^{2}\right)$. See also text.
[Text continued from p. 118.]
The timing-derived satellite diameters that were based on the E-2 ephemeris appear reasonably accurate for all four satellites; none are significantly in error.

## Photoelectric Timings

Four eclipse timings based on photoelectric determinations of the times when the satelite was at one-half its uneclipsed brightness were received for the 1985/86 Apparition. The times thus found were interpreted as marking the middle of the disappearance or reappearance phases. They were made by J. Westfall with a $25.4-c m$. Cassegrain reflector and an Optek photometer and are summarized in Table 4 below. (As in Tables 2 and 3 , statistical significance is shown with the "-", "*", and "**" symbols.)

Table 4. Galilean Satellite Eclipse Photoelectric Timings: 1985/86.

| $\begin{aligned} & 1985 \\ & \text { Date } \end{aligned}$ | Event | Universal Time of Half Brightness | Residual |  |
| :---: | :---: | :---: | :---: | :---: |
|  |  |  | Sampson | "E-2" |
|  |  | h m s | s | s |
| MAY 29 | 4D | $115907.2 \pm 6.3$ | -233** | +12- |
| MAY 30 | 1D | $113859.2 \pm 3.2$ | -121** | - 3- |
| NOV 06 | 2R | $032110.6 \pm 7.3$ | - 49** | +26** |
| NOV 19 | 3R | $042747.2 \pm 6.9$ | - 73** | -37** |

If Table 4 is compared with Tables 2 and 3 , one can see that the photoelectric results usually support the visual ones. In all cases but one there is no significant difference between the two types of observation. The exception is the residual for Io as based on the Sampson Ephemeris. Note also that Europa and Ganymede were found to differ significantly from their positions as predicted by the E-2 Ephemeris, which was true only for Europa with the visual timings. It appears that the photoelectric method can be used consistently to determine the orbital residuals of the Galilean satellites and, given sufficient photoelectric determinations, to fix them in their orbits with much greater accuracy at a finer time resolution than the visual method.

## Summary and Prospects

Once again, our timings have shown the Sampson Ephemeris to have significant errors for Io, Europa, and Callisto, and demonstrate a periodic error for Ganymede. As has been found for previous apparitions, the E-2 Ephemeris has no significant errors for Io, Ganymede, and Callisto, according to our visual timings. The photoelectric timings, though, suggest that the positions of Europa and Ganymede may differ slightly from the E-2 Ephemeris. For the third successive apparition, the E-2 Ephemeris appears to have a significant error for Europa.

For future apparitions, it is clear that our results would have more weight were there more timings made, both visual and photoelectric. Observers should try harder to time as many events before opposition as after. Certainly, given the infrequency of eclipses of Ganymede, and particularly of Callisto, every effort should be made to time those that are visible. Finally, the photoelectric timing method looks very promising, and we urge those observers so equipped to experiment with this method.

We are very grateful to the contributors for the 1985/86 Apparition, particularly those new to our program. We hope that they will stay with us, and we also welcome additional newcomers to our long-term program.

APPENDIX: GALILEAN SATELLITE ECLIPSE TIMINGS
1/14/85-2/18/86 APPARITION
(Received by the A.L.P.0. as of $9 / 23 / 86$.)

| Event <br> Type | $\begin{gathered} \text { Date } \\ \text { (yrmody) } \end{gathered}$ | $\begin{array}{cc} \text { Predicted U.T. } \\ \text { A.A. } & \text { E-2 } \\ \text { (hrmn) } & \text { (hrmnse) } \\ \hline \end{array}$ |  | Observed U.T. <br> (hrmnse) | Ob. No. | Cond. | $\begin{array}{r} \text { Residual } \\ \text { (seconds) } \end{array}$ |  | Geometry |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 D | 850320 | 16:43 | 16:41:23 | 16:42:52 | 39 | 100 | - 8 | + 89 | 0.9/-5 ${ }^{\circ}$ |
|  |  |  |  | 16:43:00 | 40 | 110 | 0 | + 97 |  |
| 1 D | 850327 | 18:37 | 18:35:23 | 18:36:31 | 28 | 100 | - 29 | $+68$ | 0.9/-5 |
| 1 D | 850329 | 13:06 | 13:03:54 | 13:04:36 | 24 | 201 | - 84* | + 42* | 1.0/-5 |
|  |  |  |  | 13:05:17 | 24a | 201 | - 43 | + 83 |  |
|  |  |  |  | 13:05:31 | 12 | 111 | - 29 | + 97 |  |
| 1 D | 850331 | 07:34 | 07:32:21 | 07:33:38 | 7 | 110 | - 22 | + 77 | 1.0/-5 |
| 1 D | 850412 | 16:53 | 16:51:39 | 16:52:45 | 28 | 000 | - 15 | $+66$ | 1.1/-5 |
|  |  |  |  | 16:53:08 | 29 | 001 | + 8 | + 89 |  |
|  |  |  |  | 16:53:09 | 38 | 201 | + 9 | + 90 |  |
| 1 D | 850419 | 18:47 | 18:45:26 | 18:46:30 | 28 | 000 | - 30 | + 64 | 1.1/-4 |
|  |  |  |  | 18:46:53 | 29 | 100 | - 7 | + 87 |  |
|  |  |  |  | 18:46:56 | 25 | 000 | - 4 | + 90 |  |
|  |  |  |  | 18:47:00 | 38 | 000 | 0 | + 94 |  |
| 1 D | 850423 | 07:44 | 07:42:20 | 07:43:45 | 7 | 000 | - 15 | + 85 | 1.1/-4 |
| 1 D | 850428 | 15:09 | 15:07:34 | 15:08:46 | 28 | 000 | - 14 | + 72 | 1.1/-4 |
|  |  |  |  | 15:09:00 | 39 | 020 | 0 | + 86 |  |
|  |  |  |  | 15:09:10 | 40 | 000 | + 10 | +96 |  |
| 1 D | 850430 | 09:38 | 09:36:03 | 09:37:46 | 17 | 000 | - 14 | +103 | 1.1/-4 |
| 1 D | 850505 | 17:03 | 17:01:16 | 17:02:27 | 28 | 010 | - 33 | + 71 | 1.1/-4 |
|  |  |  |  | 17:02:52 | 39 | 010 | - 8 | + 96 |  |
| 1 D | 850507 | 11:32 | 11:29:44 | 11:31:35 | 12 | 111 | - 25 | +111 | 1.1/-4 |
| 1 D | 850512 | 18:57 | 18:54:55 | 18:56:11 | 28 | 010 | - 49 | $+76$ | 1.1/-4 |
| 1 D | 850516 | 07:54 | 07:51:45 | 07:54:27 | 13 | 020 | + 27 | +162* | 1.1/-4 |


| Event Type | $\begin{gathered} \text { Date } \\ \text { (yrmody) } \end{gathered}$ | $\begin{aligned} & \text { Predic } \\ & \text { A.A. } \\ & \text { (hrmn) } \end{aligned}$ | $\begin{aligned} & \text { Led U.T. } \\ & \text { E-2 } \\ & \text { (hrmnse) } \end{aligned}$ | $\begin{gathered} \text { Observed } \\ \text { U.T. } \\ \text { (hrmnse) } \end{gathered}$ | Ob. No. | Cond. | Residual (seconds) <br> A.A. E 2 | Geometry |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 D | 850521 | 15:19 | 15:17:02 | 15:18:09 | 28 | 100 | $-51+67$ | 1.1/-30 |
| 1 D | 850528 | 17:12 | 17:10:40 | 17:11:58 | 28 | 000 | $-2+78$ | 1.1/-3 |
| 1 D | 850530 | 11:41 | 11:39:02 | 11:41:10 | 12 | 110 | + $10+128$ | 1.1/-3 |
| 1 D | 850601 | 06:09 | 06:07:28 | 06:09:25 | 7 | 101 | + 25* +117* | 1.0/-3 |
| 1 D | 850603 | 00:38 | 00:35:51 | 00:37:14 | 35 | 001 | - $46+83$ | 1.0/-3 |
| 1 D | 850604 | 19:06 | 19:04:19 | 19:05:31 | 28 | 010 | - $29+72$ | 1.0/-3 |
| 1 D | 850606 | 13:35 | 13:32:41 | 13:33:57 | 28 | 100 | $-63+76$ | 1.0/-3 |
| 1 D | 850608 | 08:03 | 08:01:07 | 08:02:46 | 17 | 011 | $-14+99$ | 1.0/-3 |
| 1 D | 850613 | 15:28 | 15:26:22 | 15:27:34 | 28 | 010 | $-26+72$ | 0.9/-3 |
|  |  |  |  | 15:27:56 | 29 | 000 | - $4+94$ |  |
|  |  |  |  | 15:27:58 | 25 | 000 | - $2+96$ |  |
| 1 D | 850615 | 09:57 | 09:54:48 | 09:56:20 | 15 | 000 | - $40+92$ | 0.9/-3 |
|  |  |  |  | 09:56:43 | 12 | 110 | - $17+115$ |  |
| 1 D | 850620 | 17:22 | 17:20:05 | 17:21:24 | 28 | 010 | $-36+79$ | 0.8/-3 |
| 1 D | 850622 | 11:50 | 11:48:32 | 11:49:54 | 28 | 100 | - $6+82$ | 0.8/-3 |
| 1 D | 850626 | 00:47 | 00:45:26 | 00:46:51 | 5a | --- | - $9+85$ | 0.8/-2 |
|  |  |  |  | 00:47:10 | 4 | --- | + $10+104$ |  |
| 1 D | 850629 | 13:44 | 13:42:18 | 13:43:58 | 30 | 001 | - $2+100$ | 0.7/-2 |
| 1 D | 850701 | 08:13 | 08:10:44 | 08:11:39 | 24 | 001 | - 81* + 55 | 0.7/-2 |
|  |  |  |  | 08:12:19 | 24a | 101 | - $41+95$ |  |
|  |  |  |  | 08:12:44 | 17 | 111 | - $16+120$ |  |
|  |  |  |  | 08:12:56 | 12 | 110 | - 4 +132* |  |
| 1 D | 850703 | 02:41 | 02:39:14 | 02:40:15 | 9 | 001 | $-45+61$ | 0.7/-2 |
| 1 D | 850706 | 15:38 | 15:36:09 | 15:37:47 | 39 | 000 | - $13+98$ | 0.6/-2 |
| 1 D | 850708 | 10:06 | 10:04:36 | 10:05:29 | 34 | 100 | - $31+53 *$ | 0.6/-2 |
|  |  |  |  | 10:05:40 | 7 | 002 | - $20+64$ |  |
|  |  |  |  | 10:06:03 | 39 | 110 | $+3+87$ |  |
|  |  |  |  | 10:06:52 | 12 | 111 | + 52* $+136 *$ |  |
| 1 D | 850711 | 23:03 | 23:01:35 | 23:02:50 | 5 | --- | $-10+75$ | 0.5/-2 |
| 1 D | 850713 | 17:32 | 17:30:05 | 17:30:55 | 28 | 000 | $-65+50$ | 0.5/-2 |
|  |  |  |  | 17:31:34 | 30 | 000 | $-26+89$ |  |
| 1 D | 850715 | 12:00 | 11:58:33 | 11:59:50 | 28 | 100 | $-10+77$ | 0.4/-2 |
|  |  |  |  | 12:00:08 | 39 | 000 | + 8 + 95 |  |
|  |  |  |  | 12:00:11 | 38 | 100 | $+11+98$ |  |
|  |  |  |  | 12:00:22 | 12 | 111 | $+22+109$ |  |
| 1 D | 850717 | 06:29 | 06:27:05 | 06:28:26 | 7 | 010 | - $34+81$ | 0.4/-2 |
|  |  |  |  | 06:28:48 | 12 | 110 | - $12+103$ |  |
| 1 D | 850720 | 19:26 | 19:24:05 | 19:24:31 | 31 | 110 | $-89^{*}+26^{*}$ | 0.3/-2 |
|  |  |  |  | 19:25:14 | 28 | 000 | - $46+69$ |  |
| 1 D | 850722 | 13:54 | 13:52:35 | 13:53:36 | 31 | 000 | - $24+61 *$ | 0.3/-2 |
|  |  |  |  | 13:54:07 | 39 | 010 | + $7+92$ |  |
| 1 D | 850724 | 08:23 | 08:21:09 | 08:22:50 | 12 | 110 | $-10+101$ | 0.2/-2 |
| 1 D | 850726 | 02:51 | 02:49:40 | 02:50:54 | 11 | 010 | $-6+74$ | 0.2/-2 |
| 1 D | 850729 | 15:49 | 15:46:44 | 15:46:58 | 31 | 000 | $-122^{*}+14^{*}$ | 0.1/-2 |
|  |  |  |  | 15:47:56 | 28 | 200 | $-64+72$ |  |
| 1 D | 850731 | 10:17 | 10:15:19 | 10:14:58 | 31 | 110 | -122*-21* | 0.1/-2 |
|  |  |  |  | 10:15:32 | 28 | 000 | $-88^{*}+13^{*}$ |  |
| 1 R | 850807 | 14:29 | 14:27:06 | 14:25:46 | 40 | 100 | -194-80 | 0.1/-10 |
|  |  |  |  | 14:26:19 | 28 | 000 | -161-47 |  |
| 1 R | 850809 | 08:58 | 08:55:41 | 08:53:52 | 12 | 010 | -248-109 | 0.1/-1 |
|  |  |  |  | 08:54:32 | 24a | 000 | -208-69 |  |
|  |  |  |  | 08:54:46 | 28 | 100 | -194-55 |  |
|  |  |  |  | 08:55:56 | 24 | 000 | $-124^{*}+15^{*}$ |  |
| 1 R | 850811 | 03:26 | 03:24:16 | 03:22:49 | 23 | 010 | -191-87 | 0.1/-1 |
|  |  |  |  | 03:23:02 | 2 | 000 | -178-74 |  |
|  |  |  |  | 03:23:15 | 13 | 000 | -165-61 |  |
|  |  |  |  | 03:23:23 | 16 | 010 | -157-53 |  |
|  |  |  |  | 03:23:53 | 18 | --- | -127-23* |  |
| 1 R | 850814 | 16:23 | 16:21:28 | 16:19:57 | 39 | 000 | -183-91 | 0.2/-1 |
|  | 850816 | 10:52 | 10:50:05 | 10:49:05 | 39a | 000 | -175-60 | 0.3/-1 |
|  |  |  |  | 10:49:19 | 34 | 100 | -161-46 |  |



| Event <br> Type | $\begin{gathered} \text { Date } \\ (\text { yrmody }) \end{gathered}$ | $\begin{aligned} & \text { Predic } \\ & \text { A.A. } \\ & \text { (hrmn) } \end{aligned}$ | $\begin{gathered} \text { ted U.T. } \\ \text { E-2 } \\ \text { (hrmnse) } \end{gathered}$ | Observed U.T. (hrmnse) | Ob. No. | Cond. | $\begin{array}{r} \text { Residual } \\ \text { (seconds) } \\ \text { A.A. } \mathrm{E}-2 \\ \hline \end{array}$ | Geometry |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 R | 851022 | 17:04 | 17:01:58 | 17:00:47 | 35 | 010 | -193-71 | $1.1 /+1^{\circ}$ |
| 1 R | 851024 | 11:33 | 11:30:46 | 11:29:13 | 40 | 121 | -227-93 | 1.1/+1 |
|  |  |  |  | 11:29:32 | 28 | 100 | -208-74 |  |
|  |  |  |  | 11:30:20 | 33 | 120 | -160-26* |  |
| 1 R | 851028 | 00:30 | 00:28:26 | 00:27:00 | 19 | 111 | -180-86 | 1.1/+1 |
|  |  |  |  | 00:27:18 | 18 | 00- | -162-68 |  |
|  |  |  |  | 00:27:48 | 8 | 121 | -132-38 |  |
| 1 R | 851029 | 18:59 | 18:57:16 | 18:55:42 | 3 | $20-$ | -198-94 | 1.1/+1 |
|  |  |  |  | 18:56:11 | 35 | 120 | -169-65 |  |
| 1 R | 851109 | 09:52 | 09:50:18 | 09:48:58 | 30 | 010 | -182-80 | 1.1/+1 |
| 1 R | 851111 | 04:21 | 04:19:07 | 04:17:20 | 12 | 210 | -220-107 | 1.1/+1 |
|  |  |  |  | 04:17:42 | 24a | 000 | -198-85 |  |
|  |  |  |  | 04:18:19 | 24 | 000 | -161-48 |  |
| 1 R | 851116 | 11:48 | 11:45:40 | 11:44:21 | 28 | 000 | -219-79 | 1.1/+1 |
| 1 R | 851220 | 02:55 | 02:53:37 | 02:52:25 | 24a | 210 | -155-72 | 0.8/+2 |
|  |  |  |  | 02:52:43 | 24 | 210 | -137-54 |  |
| 1 R | 851223 | 15:53 | 15:51:19 | 15:50:08 | 35 | 102 | -172-71 | 0.8/+3 |
| 1 R | 851225 | 10:22 | 10:20:10 | 10:20:43 | 28 | 000 | - 77* + 33* | 0.8/+3 |
| 1 R | 851228 | 23:20 | 23:17:49 | 23:17:45 | 7 | 111 | -135-4* | 0.7/+3 |
| 2 D | 850406 | 18:05 | 18:03:43 | 18:05:41 | 38 | 101 | $+41+118$ | 1.6/-12 |
| 2 D | 850424 | 12:31 | 12:29:23 | 12:30:39 | 24 | 000 | - $21 *+76$ | 1.8/-11 |
|  |  |  |  | 12:30:59 | 24a | 100 | - $1^{*}+96$ |  |
|  |  |  |  | 12:31:44 | 12 | 111 | + $44+141$ |  |
| 2 D | 850501 | 15:05 | 15:03:51 | 15:05:29 | 28 | 000 | + $29+98$ | 1.8/-11 |
|  |  |  |  | 15:05:56 | 40 | 000 | + $56+125$ |  |
| 2 D | 850505 | 04:22 | 04:21:07 | 04:22:22 | 6 | 001 | $+22+75$ | 1.8/-10 |
| 2 D | 850508 | 17:40 | 17:38:32 | 17:40:16 | 28 | 000 | + $16+104$ | 1.8/-10 |
|  |  |  |  | 17:40:30 | 39 | 010 | $+30+118$ |  |
| 2 D | 850515 | 20:14 | 20:13:20 | 20:14:37 | 28 | 011 | + $37+77$ | 1.8/-10 |
| 2 D | 850530 | 01:25 | 01:23:32 | 01:24:45 | 9 | 001 | - 15* + 73* | 1.7/-9 |
| 2 D | 850606 | 04:00 | 03:58:56 | 04:00:34 | 7 | 101 | + $34+98$ | 1.6/-9 |
| 2 D | 850609 | 17:18 | 17:16:31 | 17:18:23 | 28 | 010 | + $23+112$ | 1.6/-9 |
|  |  |  |  | 17:18:40 | 39 | 100 | + $40+129$ |  |
| 2 D | 850613 | 06:36 | 06:34:34 | 06:37:00 | 17 | 100 | + $60+146$ | 1.5/-8 |
| 2 D | 850616 | 19:53 | 19:52:13 | 19:53:46 | 28 | 010 | $+46+93$ | 1.4/-8 |
| 2 D | 850620 | 09:12 | 09:10:24 | 09:11:58 | 7 | 110 | - $2+94$ | 1.4/-8 |
|  |  |  |  | 09:12:08 | 15 | 200 | + $8+104$ |  |
|  |  |  |  | 09:12:26 | 11 | 000 | + $26+122$ |  |
|  |  |  |  | 09:13:13 | 17 | 201 | + 73 +169* |  |
| 2 D | 850627 | 11:48 | 11:46:31 | 11:48:05 | 28 | 100 | + $5+94$ | 1.2/-8 |
|  |  |  |  | 11:48:38 | 39 | 010 | + $38+127$ |  |
|  |  |  |  | 11:48:47 | 40 | 010 | $+47+136$ |  |
| 2 D | 850701 | 01:05 | 01:04:20 | 01:06:03 | 5 |  | + $63+103$ | 1.1/-8 |
| 2 D | 850704 | 14:24 | 14:22:50 | 14:24:26 | 28 | 000 | $+26+96$ | 1.0/-7 |
|  |  |  |  | 14:25:02 | 40 | 001 | + $62+132$ |  |
| 2 D | 850708 | 03:42 | 03:40:44 | 03:42:33 | 23 | 000 | + $33+109$ | 0.9/-7 |
| 2 D | 850711 | 17:01 | 16:59:25 | 17:01:04 | 30 | 000 | + $4+99$ | 0.8/-7 |
| 2 D | 850715 | 06:19 | 06:17:26 | 06:19:27 | 7 | 000 | + 27 +121* | 0.7/-7 |
|  |  |  |  | 06:19:39 | 16 | 010 | + $39+133$ |  |
|  |  |  |  | 06:19:42 | 12 | 210 | + $42+136$ |  |
| 2 D | 850718 | 19:37 | 19:36:13 | 19:38:15 | 29 | 002 | + $75+122$ | 0.6/-7 |
| 2 D | 850722 | 08:55 | 08:54:19 | 08:55:03 | 7 | 110 | + $3+44^{*}$ | 0.5/-7 |
|  |  |  |  | 08:55:53 | 34 | 100 | + $53+94$ |  |
|  |  |  |  | 08:55:54 | 28 | 100 | $+54+95$ |  |
|  |  |  |  | 08:56:27 | 37 | 100 | + 87* +128 |  |
| 2 D | 850725 | 22:14 | 22:13:15 | 22:14:50 | 5a | --- | $+50+95$ | 0.3/-6 |
| 2 D | 850729 | 11:33 | 11:31:30 | 11:32:55 | 28 | 000 | - $5+85$ | 0.2/-6 |



| Event <br> Type | $\begin{gathered} \text { Date } \\ \text { (yrmody) } \\ \hline \end{gathered}$ | $\begin{aligned} & \text { Predic } \\ & \text { A.A. } \\ & \text { (hrmn) } \\ & \hline \end{aligned}$ | $\begin{gathered} \text { ted U.T. } \\ \text { E-2 } \\ \text { (hrmnse) } \end{gathered}$ | $\begin{gathered} \text { Observed } \\ \text { U.T. } \\ \text { (hrmnse) } \end{gathered}$ | Ob. <br> No. | Cond. | Residual (seconds) |  | Geometry |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 3 D | 850915 | 12:39 | 12:38:43 | 12:38:47 | 31 | 000 | - 13* | $+4^{*}$ | $0.1 /-2^{\circ}$ |
|  |  |  |  | 12:40:57 | 30 | 000 | +117 | +134 |  |
|  |  |  |  | 12:41:20 | 29 | 000 | +140 | +157 |  |
|  |  |  |  | 12:41:40 | 27 | 000 | +160 | +177 |  |
| 3 D | 850922 | 16:40 | 16:39:13 | 16:41:38 | 27 | 100 | + 98 | +145 | 0.4/-2 |
| 3 D | 850929 | 20:41 | 20:39:56 | 20:41:43 | 21 | 002 | + 43 | +107 | 0.6/-2 |
|  |  |  |  | 20:42:12 | 22 | 121 | + 72 | +136 |  |
|  |  |  |  | 20:42:25 | 5 | --- | + 85 | +149 |  |
|  |  |  |  | 20:42:42 | 35 | 000 | +102 | +166 |  |
|  |  |  |  | 20:44:05 | 3 | 10- | +185 | +249 |  |
| 3 D | 851007 | 00:42 | 00:41:32 | 00:43:04 | 13 | 000 | +64 | +92 | 0.7/-1 |
|  |  |  |  | 00:44:35 | 18 | $20-$ | +155 | +183 |  |
|  |  |  |  | 00:44:56 | 23 | 000 | +176 | +204 |  |
| 3 D | 851014 | 04:43 | 04:42:49 | 04:45:37 | 2 | 000 | +157 | +168 | 0.8/-1 |
| 3 D | 851021 | 08:45 | 08:44:42 | 08:47:43 | 34 | 000 | +163 | +181 | 0.9/-0 |
| 3 D | 851028 | 12:46 | 12:45:48 | 12:49:05 | 40 | 201 | +185 | +197 | 0.9/+0 |
| 3 D | 851104 | 16:47 | 16:46:49 | 16:49:24 | 35 | 200 | +144 | +155 | 0.9/+1 |
| 3 D | 851119 | 00:50 | 00:48:59 | 00:50:41 | 14 | 101 | + 41 | +102 | 0.8/+2 |
| 3 R | 850327 | 16:21 | 16:20:31 | 16:16:44 | 39 | 100 | -256 | -227 | $0.5 /-14^{\circ}$ |
|  |  |  |  | 16:20:28 | 28 | 210 | - 32* | - 3* |  |
| 3 R | 850425 | 08:19 | 08:18:30 | 08:17:44 | 13 | 000 | - $76 *$ | - 46* | 0.9/-12 |
| 3 R | 850509 | 16:18 | 16:17:27 | 16:13:33 | 38 | 000 | -267 | -234 | 1.0/-11 |
|  |  |  |  | 16:14:28 | 28 | 010 | -212 | -179 |  |
| 3 R | 850516 | 20:17 | 20:16:59 | 20:14:42 | 28 | 001 | -138 | -137 | 1.0/-11 |
| 3 R | 850531 | 04:17 | 04:16:22 | 04:13:10 | 7 | 101 | -230 | -192 | 0.8/-10 |
| 3 R | 850607 | 08:16 | 08:15:34 | 08:11:29 | 17 | 010 | -271 | -245 | 0.6/-9 |
|  |  |  |  | 08:12:07 | 11 | 000 | -233 | -207 |  |
|  |  |  |  | 08:13:01 | 13 | 001 | -179 | -153 |  |
| 3 R | 850614 | 12:15 | 12:14:41 | 12:09:38 | 28 | 000 | -322 | -303 | 0.4/-9 |
|  |  |  |  | 12:10:39 | 12 | 212 | -261 | -242 |  |
| 3 R | 850818 | 00:15 | 00:14:40 | 00:10:28 | 19 | 000 | -272 | -252 | 0.8/-5 |
|  |  |  |  | 00:10:53 | 8 | 000 | -247 | -227 |  |
|  |  |  |  | 00:11:03 | $3$ | 00- | -237 | -217 |  |
|  |  |  |  | 00:11:15 | 20 | 110 | -225 | -205 |  |
|  |  |  |  | 00:11:20 | 5 | --- | -220 | -200 |  |
|  |  |  |  | 00:11:44 | 9 | 000 | -196 | -176 |  |
| 3 R | 850825 | 04:16 | 04:15:20 | 04:12:16 | 11a | 020 | -224 | -184 | 1.1/-4 |
|  |  |  |  | 04:12:47 | 7 | 110 | -193 | -153 |  |
| 3 R | 850901 | 08:17 | 08:16:38 | 08:12:30 | 15 | 000 | -270 | -248 | 1.5/-4 |
| 3 R | 850908 | 12:18 | 12:17:14 | 12:15:09 | 28 | 000 | -171 | -125 | 1.8/-3 |
|  |  |  |  | 12:16:05 | 26 | 000 | -115* | - 69* |  |
| 3 R | 850915 | 16:18 | 16:17:47 | 16:13:14 | 27 | 000 | -286 | -273 | 2.1/-3 |
| 3 R | 850930 | 00:20 | 00:19:14 | 00:15:23 | 19 | 111 | -277 | -231 | 2.5/-2 |
|  |  |  |  | 00:15:24 | 18 | 00- | -276 | -230 |  |
|  |  |  |  | 00:15:30 | 13 | 000 | -270 | -224 |  |
| 3 R | 851007 | 04:22 | 04:20:56 | 04:16:23 | 2 | 000 | -337 | -273 | 2.7/-1 |
|  |  |  |  | 04:18:10 | 14 | 201 | -230 | -156 |  |
| 3 R | 851014 | 08:23 | 08:22:16 | 08:18:35 | 28 | 001 | -265 | -221 | 2.8/-1 |
| 3 R | 851021 | 12:25 | 12:24:09 | 12:25:09 | 34 | 200 | + 9* | + 60* | 2.9/-1 |
| 3 R | 851112 | 00:28 | 00:27:15 | 00:23:57 | 8 | 020 | -243 | -198 | 2.9/+1 |
|  |  |  |  | 00:24:31 | 14 | 211 | -209 | -164 | 2.9/1 |
| 4 D | 850306 | 17:48 | 17:43:47 | 17:49:53 | 38 | 101 | +113 | +366 | $3.2 /-24^{\circ}$ |
|  |  |  |  | 17:49:54 | 32 | 201 | +114 | +367 |  |
| 4 D | 850409 | 05:53 | 05:49:52 | 05:55:02 | 7 | 111 | +122 | +310 | 4.6/-20 |
| 4 D | 850512 | 17:59 | 17:55:21 | 18:00:51 | 28 | 000 | +111 | +330 | 5.1/-16 |
| 4 D | 850529 | 12:03 | 11:58:55 | 12:07:07 | 12 | 011 | +247 | +492 | 4.8/-14 |
| 4 D | 850615 | 06:08 | 06:03:32 | 06:06:25 | 13 | 100 | -95 | +173 | 4.1/-12 |
|  |  |  |  | 06:08:42 | 18 | -0- | + 42 | +310 |  |
| 4 D | 850702 | 00:12 | 00:08:26 | 00:13:07 | 5 | --- | + 67 | +281 | 3.0/-10 |
| 4 D | 850718 | 18:18 | 18:14:22 | 18:19:47 | 29 | 002 | +107 | +325 | 1.6/-8 |
| 4 D | 850923 | 18:53 | 18:49:02 | 18:48:22 | 21 | 112 | -278* | - 40* | 2.2/-0 |
| 4 D | 851010 | 13:04 | 12:59:42 | 13:04:55 | 27 | 000 | + 55 | +313 | 2.9/+2 |


| Event | Date | Predicted U.T,A.A.E-2 |  | Observed |  |  | Residual |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Type | (yrmody) | (hrmn) | (hrmnse) | (hrmnse) | No. | Cond. | A.A. | E-2 | Geometry |
| 4 R | 850529 | 16:43 | 16:39:02 | 16:35:22 | 28 | 000 | -458 | -220 | 2.9/-140 |
| 4 R | 850615 | 10:51 | 10:46:13 | 10:39:21 | 12 | 110 | -699 | -412 | 2.2/-12 |
|  |  |  |  | 10:41:36 | 15 | 001 | -564 | -277 |  |
| 4 R | 850821 | 11:23 | 11:18:55 | 11:16:03 | 30 | 101 | -417 | -172 | 1.6/-4 |
| 4 R | 850907 | 05:33 | 05:28:22 | 05:22:59 | 15 | 000 | -601 | -323 | 3.1/-2 |
| 4 R | 850923 | 23:43 | 23:39:07 | 23:35:02 | 8 | 002 | -478 | -245 | 4.1/-0 |
|  |  |  |  | 23:41:17 | 14 | 102 | -103 | +130 |  |

Key:
a. Predictions: A.A. = The Astronomical Almanac. 1985. E-2 $=$ E-2 Ephemeris (J. Lieske, Jet Propulsion Laboratory; a Delta-T value of +55 sec . was used to convert E.T. to U.T.)
b. Observed Time: $p=$ timing made on previous U.T. date.
c. Conditions: 1st digit = Seeing; 2nd digit = Transparency; 3rd digit $=$ Sky brightness. $\quad 0=$ Condition not perceptible; no effect on timing accuracy; $1=$ Condition perceptible; possible minor effect on timing accuracy; 2 = Condition serious, definite effect on timing accuracy; - = Condition not recorded.
d. Residual: Residual = Observed U.T. - Predicted U.T. $*=$ Excluded from analysis due to significant deviation from regression model for aperture class or to insufficient precision.
e. Geometry: The first figure is the apparent distance of the satellite from the adjacent Jovian limb in units of the Jovian equatorial diameter. The second figure is the latitude (in degrees) of the satellite in relation to the shadow center.
f. Observer Code: In parentheses are the aperture used and the number of visual timings. Code numbers 1-24a refer to A.L.P.O. contributors, 25-32 to N.A.P.O. contributors, and $33-40$ show R.A.S.N.Z. contributors. (Nos. 28, 29, and 30 contributed to both the N.A.P.O. and the R.A.S.N.Z.)

| $1=$ Baroni, S. (20 cm., 1) | $25=$ Abrahams, W. (15 cm. , 2) |
| :---: | :---: |
| $2=$ Barton, J. (32 cm., 8) | $26=$ Basterfield, K. (10 cm., 3) |
| 3 = Bulder, H. (30 cm., 6) | $27=$ Bembrick, C. (25 cm., 9) |
| $4=$ Cano, J. ( $35 \mathrm{cm},$.l ) | $28=$ Kerr, s. (7.5 cm., 53) |
| 5 = Casas, R. (16 cm., 7) | 29 = Lowe, D. (20 cm., 8) |
| $5 \mathrm{a}=\mathrm{c}$ " " (20 cm., 2) | $30=$ Rogers, D. ( $20 \mathrm{cm}$. , 9) |
| $6=$ Correa, 0. ( $6 \mathrm{cm},$.1 ) | 31 = Smith, G. ( $25 \mathrm{~cm} ., 10$ ) |
| 7 = Dalavia, U. (6 cm., 18) | $32=$ von Treifeldt, L. (20 cm., 1) |
| $8=$ da Silva, L. (6 cm., 4) | $33=$ Blow, G. ( $20 \mathrm{cm}$. , 2) |
| $9=$ de Pontieu, - (11.5 cm., 3) | $33 \mathrm{a}=" \quad "$ (41 cm., 1) |
| $10=$ Filho, A. ( $6 \mathrm{cm},$.1 ) | $34=$ Brickell, A. (11.4 cm., 6) |
| 11 = Gonzalez, G. ( $20 \mathrm{cm},$.4 ) | $35=$ Buttner, D. (6.3 cm., 9) |
| $11 \mathrm{a}=$ " " (10 cm., 1) | $36=$ Cole, D. (15 cm., 1) |
| $11 \mathrm{~b}=\quad " \quad "(53 \mathrm{cm}, 1$. | $37=$ Dodson, A. ( $20 \mathrm{cm},$.3 ) |
| 12 = Langhans, T. (36 cm., 29) | $38=$ Kearney, P. ( $20 \mathrm{cm}$. , 6) |
| $13=$ Leavens, G. (26 cm., 11) | $39=$ Loader, B. (20 cm., 15) |
| $14=$ MacDougal, C. ( $6 \mathrm{cm}$. , 6) |  |
| $15=$ Newbill, C. (15 cm., 9) | $40=$ Priestley, J. (20 cm., 13) |
|  |  |
| $16=01 i v e r$, D. ( $20 \mathrm{cm}$. , 7) |  |
| 17 = Ross, T. (32 cm., 6) |  |
| $18=$ Sinnott, R. (7.6 cm., 11) |  |
| 19 = Teixeira, R. (11 cm., 9) |  |
| $20=$ Vandenbulcke, G. (21.5 cm., 3) |  |
| $21=$ Verhaegen, W. (15 cm., 3) |  |
| $22=$ Vingerhoets, P. (20 cm., 3) |  |
| $23=$ Webster, C. (20 cm. , 4) |  |
| $24=$ Westfall, J. (10.2 cm., 10) |  |
| $24 \mathrm{a}=\mathrm{l}$ |  |

## COMET NOTES: XI. $1987^{\prime} \mathrm{S}$ COMET HARVEST

By: David H. Levy, A.L.P.O. Comets Recorder
There was a time when three or four observable comets in a year was the best that anyone could expect. However, during the 1960's the number of comets discovered or recovered began to rise sharply, reaching 14 in 1967 for example. That was an especially productive year for Seki, who found both 1967b (Seki) and 1967n (Ikeya-Seki), as well as for Tomita, who recovered all the periodic comets for that year; in eight cases he was the sole recoverer.

At the time of writing (September, 1987), this year's latest news is Comet Rudenko, designated 1987u, which is a loth-magnitude object in the evening sky in the Northern Hemisphere; at present no orbital information is available. While Comet Rudenko is visible, Comet Bradfield (1987s) should be seen. The latter was discovered by William Bradfield on August 11 th and, being his thirteenth discovery, makes him the most prolific comet discoverer of the Twentieth Century! Comet Bradfield will be a conspicuous telescopic comet in the evening sky for much of the rest of 1987.

This year got off to a record start with seven comets being found during January. Comet Levy 1987a was a faint llth-magnitude diffuse patch at discovery. Although it was found in Ophiuchus, low in the southeast, it had been much better placed for several months earlier and theoretically would have been more easily discovered then. The second comet of 1987 was discovered by Jennifer Wiseman, a college student working for a short period at Lowell Observatory. Inspecting a plate that had been taken by observer Brian Skiff, she found a condensed diffuse object that, when confirmed, was announced as Comet Wiseman-Skiff, 1987b.

The third comet of 1987 was named for the first three of its four Japanese discovers; Nishikawa-Takamizawa-Tago, 1987c. This was a bright 9thmagnitude comet when discovered, giving a fine performance until it began to get very diffuse in early May.

January's fourth find was Terasko, 1987d, a bright comet hurtling rapidly away from the Sun when it was found. Although it was poorly placed for observing, low in the southwestern sky, 1987d was brighter than the 7th magnitude and displayed a beautiful antitail that was easy to see during the first two weeks after the comet's discovery.

While the brightest comet of recent months was Wilson (19861), it was prominent only in the Southern Hemisphere; and by the time that it had swung northwards it was a difficult object, low in the southwestern sky. This comet displayed a single jet, pointing northwards. The jet was first observed early in September, 1986, and maintainted its strength and structure during most of the comet's apparition.

If Wilson was the brightest comet so far this year, the most prominent for Northern Hemisphere observers was Sorrells (1986n), which had been discovered in November, 1986, by William Sorrells, a well-known Californian astrophotographer. Well-placed for observation throughout the last part of 1986, Comet Sorrells also displayed a suprisingly consistent brightness of about lOth magnitude.

The other comets of 1987 have been quite faint, including Shoemaker 19870 with its long, straight tail, and Schwassmann-Wachmann 1 , the comet that orbits between Jupiter and Saturn and occasionally undergoes intense outbursts. Early in the Spring of 1987, Tom Gehrels and Jim Scotti detected a weak outburst, during which Schwassmann-Wachmann 1 brightened to about 14 th magnitude. Discriminating observers should watch this comet for signs of its irregular activity, during which it can reach 12 th magnitude.

OBSERVING METEORS: XI
By: David H. Levy, A.L.P.O. Meteors Recorder
This article continues the discussion about radiants in "Observing Meteors: X" (J.A.L.P.O., 32 , Nos. 3-4 [July, 1987], pp. 80-81) and is based on a discussion with, and letter from, Walter Hass, the Founder of the A.L.P.O. In addition to his other accomplishments, Walter has been an active meteor observer since the $1930^{\circ} \mathrm{s}$, and in 1941 his Master's Degree from Ohio State University included a thesis on the calculation of meteoroid orbits.

## Walter comments:

"If the flight of a particular meteor through the atmosphere is observed from at least two locations, then we may use parallax to establish the actual path in space and thus the radiant, the direction from which the meteor appears to come. If the flight is observed at three or more locations, least-squares fitting leads to the same result."

This is one reason why it is always best to observe major showers after considerable planning. With several active observing sites scores of miles apart, there is a better chance that a bright meteor will be seen by observers at more than one site.

Especially when determining new radiants and the radiants of weak poorly represented streams, it is much more convincing to have confirmation from more than one site. However, an observer at a single site can determine a radiant. If an observer sees two meteors, Walter explains,
"..their paths produced backward will obviously intersect in a 'radiant'--ruling out the very rare case that the two meteor paths lie on one and the same great circle. But since any two meteors would give this 'radiant,' whether they have any physical association or not, no intelligent observer would take such a 'radiant' seriously. If three, four, five, and more meteor paths intersect almost in a point, we have increasing confidence that such a point is the actual observed radiant of a swarm of meteoritic particles. In other words, the probability that we have coincidental, random intersections grows less and less. Since there are errors of observation, the intersection of the paths will not be in a point, even if all the actual paths are great circles. Also, the different particles may not all have absolutely identical orbits.
"Some other complications now spoil the simple picture. The observed radiant depends on both the motion of the meteorite just before it enters the Earth's atmosphere and the motion of the Earth in its orbit around the Sun. Since the Earth's motion is changing with time, chiefly in the direction of the velocity vector, it follows that the radiant position must vary with time from this cause. Another effect is the 'zenith attraction,' a change in the position of the observed radiant caused by the Earth's gravitational attraction for a nearby meteorite. This effect can become large when the radiant is near the horizon of the observer; indeed, it can in the worst case displace the radiant by 17 degrees if the meteorite is moving in a parabolic orbit. The radiant is also subject to a diurnal aberration as a consequence of the rotation of the Earth.
"These problems are minimized if we combine meteor paths over a very short span of time in our effort to establish a radiant. When paths are combined over a interval of many hours or even on different nights, such problems should not be ignored. Thus the establishing of a radiant of a weak shower, perhaps giving only one or two meteors an hour, becomes a very troublesome matter."

Walter's comments are especially appropriate when we try to propose new radiants. Observers in Arizona on a November night in 1966 counted some 40 meteors per second coming from a radiant in Leo; one would hardly need multiple stations to define that as a single radiant. However, when someone proposes a weak radiant lasting a month in a wide area of the sky and in a time when other known radiants are active, the argument becomes difficult to prove.

There are some hints to ease our work. Meteors of the same stream usually show a common speed and color. Their physical attributes may result in a tendency to other things that we can observe, such as long-lasting trails. Walter concludes that it is possible, then, for a single observer to determine a valid meteor radiant. However, there is a "..need to be wary of chance intersections of meteor paths, and of the possible substantial change of radiant position with time. The proper analysis of the data will just about require that meteor paths be plotted against the star background, or photographed in some known co-ordinate system on the film."

The Meteors Section keeps a file on suspected new radiants, so if you have suspected one, do let us know about it.

## A.L.P.O. SOLAR SECTION OBSERVATIONS FOR ROTATIONS 1771 - 1783 (1986 JAN 14 TO 1987 JAN 03)

By: Richard E. Hill, A.L.P.O. Solar Recorder
The period covered by this report had the lowest activity ever observed by the A.L.P.O. Solar Section. [It is likely that this period included the minimum of the current Sunspot cycle. Ed.] Over 30 percent of the days were entirely spotless,and the highest count for any day was 76 (in contrast to the last report's highest count of 85 during the period April, 1985, to January, 1986). Changes in sunspot numbers during the 13 rotations covered by this report are shown in Figure 23, below.


Figure 23. Graph of rotation means of $\mathrm{R}_{\mathrm{I}}$ (the International Sunspot Number) and $R_{A}$ (the American Sunspot Number) for Solar Rotations 1771 through 1783.

In this paper, the term "group" will refer only to a white-light collection of sunspots, while "region" will be used to refer to an entire activity area as viewed in all wavelengths. The region numbers used are assigned by the Space Environmental Services Center (SESC) in Boulder, Colorado. All times are given in Universal Time (U.T.). All directions are heliographic and are abbreviated ( $S$, NW, etc.). Other terms and abbreviations used in this report are defined in The Handbook for the White Light Observation of Solar Phenomena, available from this Recorder for \$US 6.00.

The observers who contributed to this report are:

| Observer | Telescope |  |  |  | Location |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | Aperture | f-ratio | Type | Stop |  |
|  | (cm.) |  |  | (cm.) |  |
| Benavides, A. | 20 | $\mathrm{f} / 13.8$ | Refractor | --- | Venezuela |
| Blackburn, N. | 15 | $\mathrm{f} / 15$ | Refractor | --- | Missouri, U.S.A. |
| Garcia, G. | 20 | f/10 | Schmidt-Cassegrain | 6.3 | Illinois, U.S.A. |
| Hill, R. | 6 | f/13 | Refractor |  | Arizona, J.S.A. |
| " " | 20 | f/10 | Schmidt-Cassegrain | 10 | " " |
| Maxson, P. | 15 | f/28 | Reflector | --- | Arizona, U.S.A. |
|  | 15 | f/13.3 | Refractor | --- |  |
| " " | 20 | f/6 | Newtonian | 10\&15 | " " |
| Melillo, F.J. | 20 | f/10 | Schmidt-Cassegrain | 7.5 | New York, U.S.A. |
| Quintana, C. | 20 | $\mathrm{f} / 13.8$ | Refractor | --- | Venezuela |
| Tatum, R. | 18 | $\mathrm{f} / 15$ | Refractor | 9 | Virginia, U.S.A. |
| Timerson, B. | 32 | f/4 | Newtonian | 11 | New York, U.S.A. |
| Young, S. | 20 | f/10 | Schmidt-Cassegrain | 7.5 | California, U.S.A. |

Rotation 1771 (1986 0114.17 to 198602 10.51)


This rotation had two major activity regions, SESC 4711 and 4713. Hill was the first member to observe SESC 4711, making a micrometer measurement of it along with a drawing on $01 / 31$ when its greatest extent was measured as 21 arc seconds. It consisted of a dozen umbral spots, half of them involved in a single penumbra. Maxson observed rapid development from 02/01 to 02/02, when its penumbral area increased more rapidly than did its umbral. There was little coverage from this point on, with Blackburn making the last observation, a photograph, on $02 / 10$, one day before this region passed behind the limb. By this time the region was clearly on the decrease from a high of 800 millionths of the area of the solar disk on 02/04.

Unfortunately, SESC 4713 was so poorly observed by the Solar Section members that little can be said about it.

Rotation 1772 (1986 0210.51 to 19860309.85 )

| Sunspot Number | Mean |  | Maximum (dates) |  |
| :---: | :--- | :--- | :--- | :--- |
|  |  |  |  | Minimum (dates) |
| $\mathrm{R}_{\mathrm{I}}$ | 17.3 | $38(03 / 07)$ | $0(4$ days $)$ |  |
| $\mathrm{R}_{\mathrm{A}}$ | 15.4 | $30(03 / 02,03 / 06)$ | $0(3$ days $)$ |  |



SESC 4717 was the only region of significance during this rotation, in the same location as SESC 4711 in the previous rotation. White-1ight coverage was poor, with only two photographs that showed this region. Athough the coverage in H -Alpha [i.e, in Hydrogen-Alpha light at a wavelength of 6563 Angstroms; Ed.] was equally poor, those observations did show a very interesting structure to the region. Photographs by Melillo and Tatum on 03/01 and 03/02 showed a strong spiral structure, extending out many times the diameter of the white-light spot. This structure is shown to the left on Figure 24. The spiraling direction was counter-clockwise, starting in the NE, then spiraling $W$ and finally extending far to the $S$; this was a very impressive feature. SESC 4717 had greatly decayed by the time it left the disk.

Figure 24. Hydrogen-Alpha photograph of SESC 4717 by Randy Tatum on 1986 MAR 02 at 15 h 20 m U.T., using a 7 -in. (18-cm.) refractor stopped to 3.5 in. ( 9 cm. ) with Kodak Technical Pan 2415 Film at $1 / 15$ second at an effective focal ratio of $f / 60$. North at top and solar west to the left.

Rotation 1773 (1986 0309.85 to 19860406.15 )
Sunspot Number Mean Maximum (date) Minimum (dates)

| $\mathrm{R}_{\mathrm{I}}$ | 8.1 | $19(03 / 23)$ | $0(9$ days $)$ |
| :--- | :--- | :--- | :--- |
| $\mathrm{R}_{\mathrm{A}}$ | 5.7 | $19(03 / 23)$ | $0(12$ days $)$ |

During this rotation there were only about a half-dozen small groups, none over 100 millionths of the solar disk in area or more evolved than Zurich Class B (i.e., no penumbral development). Even in H-Alpha light there was little activity, as shown by drawings and photographs by Young and Melillo.

Rotation 1774 (1986 0406.15 to 19860503.40 )

| Sunspot_Number |  | Mean | Maximum (date) |  |
| :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Minimum (dates) |
| $\mathrm{R}_{\mathrm{I}}$ | 23.4 | $64(04 / 24)$ | $0(04 / 09)$ |  |
| $\mathrm{R}_{\mathrm{A}}$ | 16.9 | $41(04 / 23)$ | $0(3$ days) |  |

Activity continued quite low, with SESC 4726 being the only notable region. Its uneventful white-1ight development and decay were followed in a broken series of drawings and photographs by Benavides, Quintana, and Garcia. In H-Alpha there was more activity, and Garcia showed bright filamentary structure between the main spots on $04 / 26$ and $04 / 27$. On the latter day, an excellent photograph confirmed the Garcia drawing; but there was no information with the photograph, not even the observer's name! [This demonstrates how otherwise-valuable observations are rendered useless if the observer does not adequately document them. Ed.] As this region passed around the limb, some small prominences could be seen, although they were rather quiescent.

Rotation 1775 (1986 0503.40 to 198605 30.62)

| Sunspot Number | Mean | Maximum (dates) | Minimum (dates) |
| :---: | :---: | :---: | :---: |
| $\mathrm{R}_{\mathrm{I}}$ | 12.4 | $30(05 / 21)$ | 0 (9 days) |
| $\mathrm{R}_{\text {A }}$ | 11.1 | $24(05 / 23,05 / 24)$ | 0 (9 days) |

Again, there was little activity and few observations. No regions attained an area even of 100 millionths of the diak. Even H-Alpha observations were scanty and showed little activity.

$$
\text { Rotation } 1776 \text { (1986 } 0530.62 \text { to } 198606 \text { 26.82) }
$$

| Sunspot Number | Mean | Maximum (dates) | Minimum (dates) |
| :---: | :---: | :---: | :---: |
| $\mathrm{R}_{\text {I }}$ | 0.9 | $8(06 / 10,06 / 25)$ | 0 (24 days) |
| $\mathrm{R}_{\mathrm{A}}$ | 0.9 | $9(06 / 01)$ | 0 (24 days) |

With 88 percent of this rotation's days having no visible spots, activity was extremely low. There was only one SESC region, which lasted only two days and never evolved past Zurich Class A [small unassociated spots with no penumbrae; Ed.].

Rotation 1777 (1986 0626.82 to 198607 24.02)

| Sunspot Number | Mean |  | Maximum (date) |  |
| :---: | :---: | :---: | :---: | :---: |
|  |  | Minimum (dates) |  |  |
| $\mathrm{R}_{\mathrm{I}}$ | 17.8 | $36(07 / 12)$ | $0(6$ days $)$ |  |
| $\mathrm{R}_{\mathrm{A}}$ | 17.7 | $37(07 / 12)$ | $0(6$ days $)$ |  |
|  |  |  |  |  |

This rotation had two regions that just barely achieved 100 millionths of the visible disk in area; SESC 4735 and SESC 4736. The former was first observed by Maxson and Garcia as it came around the limb on 07/06. They noted it as a bipolar group of Zurich Class D [a bipolar group in which the largest spots are surrounded by a single penumbra; Ed.]. As it crossed the disk, a discontinuous series of observations showed it to be decaying all the while. SESC 4736's birth on the disk was seen on $07 / 10$, and it rapidly evolved to Zurich Class $D$ and then remained largely unchanged until it left the disk on 07/13. More interesting were several observations made by Young, who noted some large H-Alpha filaments, several extending for one-quarter of the disk diameter, which were in high latitudes and were unassociated with any regions.

$$
\text { Rotation } 1778 \text { (1986 } 0724.02 \text { to } 19860820.25 \text { ) }
$$

| Sunspot Number | Mean | Maximum (date) |  | Minimum_(dates) |
| :---: | :---: | :---: | :---: | :---: |
| $\mathrm{R}_{\mathrm{I}}$ | 7.1 | $18(07 / 30)$ | $0(10$ days) |  |
| $\mathrm{R}_{\mathrm{A}}$ | 6.9 | $17(07 / 30)$ | $0(12$ days $)$ |  |
|  |  |  |  |  |

SESC 4741 was the only significant region in this rotation, and was first observed by Maxson on 08/01 in a photograph, five days after it came onto the diak. He showed this region as one spot with a penumbra, followed by a small umbral spot. By the next day, the following spot had formed a small penumbra. There was little subsequent change until this region left the disk on 08/08.


The only region observed was SESC 4744, which had been SESC 4741 in the previous rotation, and SESC 4735 in the one before that. In this rotation it was observed by Maxson on 08/25 to be a nearly round spot of Zurich Class H [a large spot surrounded by a penumbra with small random spots nearby, extending more than 2.5 in longitude; Ed.]. There was a large facular area to the $S$. The only change noted was a decrease in SESC 4744's area as it crossed the disk.

Rotation 1780 (1986 0916.51 to 198610 13.79)

| Sunspot Number | Mean |  | Maximum (dates) |  |
| :---: | ---: | :--- | :--- | :--- |
|  |  |  | Minimum_(dates) |  |
| $\mathrm{R}_{\mathrm{I}}$ | 11.9 | $32(10 / 09)$ | $0(12$ days) |  |
| $\mathrm{R}_{\mathrm{A}}$ | 5.9 | $14(10 / 06,10 / 07)$ | $0(13$ days) |  |
|  |  |  |  |  |

Two regions, SESC 4746 and 4747, reached maximum areas of about 90 millionths of the disk, but neither was adequately covered by the Solar Section.

Rotation 1781 (1986 1013.79 to 19861110.08 )

| Sunspot Number | Mean |  | Maximum (dates) |  |
| :---: | :---: | :---: | :---: | :---: |
|  |  |  | Minimum (dates) |  |
| $\mathrm{R}_{\mathrm{I}}$ | 39.8 |  | $76(10 / 24)$ | $0(10 / 15)$ |
| $\mathrm{R}_{\mathrm{A}}$ | 26.4 |  | $49(10 / 27,10 / 28)$ | $0(10 / 15)$ |

There was a dramatic increase in solar activity during this rotation and likewise a dramatic increase in the number of observations reported to the Solar Section. The activity was largely confined to three areas: a single region, SESC 4750, and two double regions, SESC 4751/4752 and SESC 4754/4755.


Figure 25. Whitelight photograph of SESC 4750 taken by Paul Maxson on 1986 OCT 18, at 17h 42m U.T., with a 6-in. ( 15 cm. ) refractor. Kodak Technical Pan 2415 Film, 1/500 second with a Wratten 12 (yellow) Filter. North at top and solar west to the left.

SESC 4750 came onto the disk on $10 / 17$ and was well shown in a photograph by Maxson, given in Figure 25 to the left. Young showed an extensive facular region surrounding the entire group in his white-light drawings. In his H-Alpha drawings he showed a large plage region following. [A plage is an area that is brighter than its surroundings at a particular wavelength. Ed.] On 10/18 Maxson observed four main spots and many faculae and attendant umbral spots. One of the main spots appeared to be a piece of another that was cut off by a light bridge. On the same day, Young, Garcia, and Melillo observed in H-Alpha and noted that the plage region had two bright condensations. On 10/19 the central two spots had merged and now lagged the group, drawing closer to the following spot. Late that day, penumbral bridges formed between the two spots. The plage region was now divided into two $\mathrm{N}-\mathrm{S}$ strips with the E strip being the brighter. The next observation of this region was on 10/23, four days later. By then the entire region had changed; and, because of incomplete coverage, we cannot tell how. The region had become one main spot cut in two (N-S) by a light bridge running $E-W$, with many smaller spots and pores on all sides but the NE. Over the next two days, the penumbrae of these two spots merged, and they were then relatively inactive for the remainder of their time on the disk. On 10/23 Young, in the last H-Alpha observation of this region, showed large, massive arches and filaments on either side ( $E$ and $W$ ) of the region. The plage region was greatly reduced in size.

SESC 4751 and 4752 both formed on the disk, making two parallel rows of spots separated NE-SW by about 150 of heliocentric arc. They reached their maximum development quickly and then spent the balance of their time on the disk decaying, with SESC 4752 vanishing first.

SESC 4754 and 4755 were observed by only one observer on only two days and little can be determined from this inadequate coverage.

$$
\text { Rotation } 1782 \text { (1986 } 1110.08 \text { to } 19861207.40 \text { ) }
$$

| Sunspot Number | Mean | Maximum (dates) | Minimum (dates |
| :---: | :---: | :---: | :---: |
| $\mathrm{R}_{\mathrm{I}}$ | 6.3 | 18 (11/23) | 0 (12 days) |
| $\mathrm{R}_{\mathrm{A}}$ | 6.1 | 15 (11/23, 11/27) | 0 (12 days) |

Activity returned to very low levels in Rotation 1782 , as did the submission of data. Only SESC 4757 was covered, and this region showed only an uneventful decay.

Rotation 1783 (1986 1207.40 to 19870103.73 )
Sunspot Number Mean Maximum(dates) Minimum (dates)

| $\mathrm{R}_{\mathrm{I}}$ | 9.1 | $24(12 / 12,12 / 13)$ | 0 ( 11 days) |
| :--- | :--- | :--- | :--- |
| $\mathrm{R}_{\mathrm{A}}$ | 7.2 | $29(12 / 10)$ | 0 (14 days) |

This report closes with very low activity on the Sun. This rotation presented mostly groups of Zurich Classes A and B (i.e., without penumbrae), and very few observations were made.

## References

1.) Solar-Geophysical Data (prompt reports). Part I, Nos. 498-510, February, 1986 - February, 1987.
2.) Solar Bulletin (A.A.V.S.O.), Vol. 42, No. 1 through Vol. 43, No. 1.

## COMING SOLAR SYSTEM EVENTS: JANUARY - FEBRUARY, 1988

These notes are intended as brief reminders of forthcoming astronomical events. For more information, consult more detailed sources such as the 1988 edition of the A.L.P.O. Solar System Ehemeris. A11 dates and times given here are in Universal Time (U.T.).

Planetary Visibility. --Mercury will be most easily visible in the evening skies of late January as it will reach its Greatest Eastern Elongation (190) on JaN 26. Venus will be much easier to find in the evenings as it moves from $32^{\circ}$ to $43^{\circ}$ east of the Sun during this period; it is also always much brighter than Mercury. However, it will be Jupiter that dominates the evening skies. The Giant Planet will be in quadrature ( $90^{\circ}$ east of the Sun) on JAN 12 and thus will be above the horizon until the late evening.

The morning skies will be more barren. Mars will rise 3 to 4 hours before the Sun but, being opposite the Sun from the Earth, its disk will appear only between $4^{\prime \prime} .4$ and $5^{\prime \prime} .7$ in diameter. Saturn also will be west of the Sun but will probably be lost in the morning twilight before February. Indeed, Saturn, Mars, and Uranus will be close to each other in February. On FEB 13, at 01 h , Saturn will lie $1: 3$ north of Uranus ( $54^{\circ}$ west of the Sun); the first of three Saturn-Uranus conjunctions in 1988. Then, Mars will pass only $41^{\prime \prime} .2$ north of Uranus on FEB 22, at 2lh. Mars will be at magnitude +1.2, and Uranus at +6.1 , so this pair of planets will appear as a striking double star under low magnification. The next day, at 13 h , Mars will pass $l^{8} .3$ south of Saturn. The conjunctions on FEB $22-23$ will occur $63^{\circ}$ west of the Sun; and thus will be well-visible in the morning sky.

Lunar Occultations. --The only occultation of a bright planet by the Moon will be one of Venus on JAN 21, at about 19 h , when Venus will be $37^{\circ}$ E of the Sun. The 10 -percent illuminated Moon will pass over the -4.0 magnitude planet as seen from the South Pacific, central South America, the central Atlantic Ocean, and westernmost Africa.

The Moon will continue to pass through the Pleiades star cluster, doing so on JAN 27, 20 h , as seen from Europe and western Asia (Moon 70 percent sunlit) and a1so on FEB 24, 02h, visible from northern North America (Moon 46 percent sunlit). Also, occultations of Spica will occur on JAN 12 and FEB 08, and Antares will be occulted by the Moon on JAN 15 and FEB 12.

Meteor Showers. --Two recognized showers will occur during this period. The Quadrantids peak on JAN 03 with a normal zenithal maximum rate of about 40 meteors per hour; unfortunately the 13 -day Moon will greatly interfere with observing this shower in 1988. On the other hand, the Delta Leonids peak on FEB 26, when the Moon will be 8 days old and thus will have set by the morning hours when meteors are most frequent.

## BOOK REVIEWS

## Coordinated by J. Russell Smith

Predictive Ephemerides for Selected One-Apparition Periodic Comets. 1987-2000. By Charles Townsend and John Rogers. Self-published; available fron Charles Townsend, 3521 San Juan Ave., Oxnard, CA 93033. No date. 64 pages. Price $\$ 6.00$ Ppd. within continental United States, $\$ 9.00 \mathrm{Ppd}$. elsewhere; paper; make checks payable to "Charles Townsend."

Reviewed by Don Machholz
This booklet covers 29 predicted returns of 23 periodic comets. Each of these comets has made only one known visit to the inner Solar System and is expected to return during the next 13 years. Most will not get very bright; on more than half the returns the comet is expected to remain fainter than magnitude 14 , and one-third will be fainter than magnitude 16 .

For eight comets the orbits are well-determined, and recovery should be no problem for the professional or for the advanced amateur with a large photographic telescope. These comets will probably be magnitude 17 to 20 upon recovery.

The authors list six more comets with uncertain orbits. These would be ideal targets for amateur astronomers to recover. The positions are not so accurate that the professional will immediately find them. However, the patient amateur, searching a small region to magnitude 17 night after night, might succeed in recovering such a comet.

Finally, nine additional comets with "highly speculative" orbits are presented. Despite extensive searches, some of these have been missed on expected past returns subsequent to their discovery. If they ever are to be recovered, it might well be achieved by a diligent comet hunter, as occurred with Comet Denning-Fujikawa in October, 1978. Still, the observer may wish to use the predicted positions listed here as starting points.

The authors list their "updated" orbital elements, which allow the user to compute predicted positions for any date. I think that it would have been helpful if they had explained in more detail how they updated the orbits and why the revised orbits differ from the "starting" orbits, sometimes by many degrees for orbital elements. Also, listing the comets by order of return would have been more convenient than the booklet's system of listing them in order of original discovery. Finally, the authors should have explained the reason why predicted positions for Comet Haneda-Campos are not given for 1991 (it is hidden behind the Sun) and also should have extended some of the predictions for a few more months (i.e., 1986d and 1986e).

Finding lost comets is a difficult task, and some comets may have "burned out" and will never be recovered. Others, with poorly determined orbits, have merely been "misplaced." However, we will continue looking for them. The advent of the large-aperture "amateur" telescope makes these searches possible, as does the advent of the personal computer. Working together, perhaps we can bring home a few more lost comets.

A Hundred Billion Stars. By Mario Rigutti. MIT Press, 28 Carleton St., Cambridge, MA 02142. 1984. 285 pages, illustrated, index. Price $\$ 9.95$ paper (ISBN 0-262-68050-5).

Reviewed by P.K. Mackal

This book is divided into three sections, dealing with the Sun and the inner planets, with the various star groupings within the Galaxy, and with stellar evolution. A serious omission is the author's failure to discuss the outer planets in the first section! However, a highlight of the book is a clear 30 -page exposition of the Sun's dynamic atmosphere.

A Hundred Billion Stars is written for the educated layman whose knowledge of astrophysics and mathematics is minimal. The writing style is quite engaging, and I also enjoyed the author's occasional philosophic asides and plain common sense. On page 230, he refers to Einstein's--rather than Gamow's--1928 theory about the conversion of solar mass into nuclear energy. Another highlight of this book is a logical presentation of galactic structure as it relates to stellar evolution itself (pp. 208-261). One point is that the Galaxy does not evolve, only the various star systems within it! However, Population II objects (such as globular star clusters) have hardly changed at all since they were created, about 10 billion years ago. Quoting Rigutti, "One more thing. Population II stars are never associated with gas and dust. In the globular clusters, as far as we know, there is no trace of either gas or dust." (p.210.) These halo or nucleus clusters, composed essentially of lowmass red giant stars without any heavy metals in their spectra, are all that is left of the primeval Galaxy, situated as they are in 125 randomly spaced globular clusters equally distributed about the galactic plane.

The author spends some time discussing the development of a star. Two dark globules in the Rosette Nebula (NGC 2237) are identified as protostars! Such objects become T Tauri variables, which are basically Population I stars of spectral type $G$ or $K$, located in clumps along the galactic equator in its spiral arms, along with all the remaining Population I stars. The subsequent evolution of stars is also described. You are invited to enjoy the rest of this book at your own pace.

The X-Ray Universe. By Wallace Tucker and Riccardo Giacconi. Harvard University Press, 79 Garden St., Cambridge, MA 02138.1985 .201 pages, illustrated, index. Price $\$ 20.00$ cloth (ISBN 0-674-96285-0).

Reviewed by William G. Dillon
X-ray astronomy is a child of the space age and is thus one of the newer branches of astronomy. The reason for this is, of course, the Earth's atmosphere, which filters out the last of the extraterrestrial $X$ rays about 90 kilometers above our heads. This is good news for life on Earth but is bad news for astronomers impatient to explore a new band of the electromagnetic spectrum. Ninety kilometers is beyond the reach even of high-altitude balloons. At present, only rockets can make observations from these altitudes.

Tucker and Giacconi's book follows X-ray astronomy from its antecedents in the discovery of $X$ rays at the turn of the century to the latest discoveries of the Einstein X-ray telescope in the 1980's. Their book is science writing for the layman at its best, combining generous helpings of history, science, a personal behind-the-scenes viewpoint, and a dash of philosopy; all in the right proportions.

The authors chose an historical framework for their book. I suspect that one reason why this history comes so much to life is that the authors (especially Giacconi) made so much of the history that they recount. Incidentally, Giacconi recently shared the Israeli Wolf Prize in Physics with two other scientists for his pioneering work in X-ray astrophysics.

The story of $X$-ray astronomy began after the close of World War II, when captured German $V-2$ rockets were used to send scientific payloads upward into the fringes of space. In September, 1949, detectors built by a Naval Research Institute group registered $X$ rays coming from the Sun. A new window of the electromagnetic spectrum was opened, and with it a new branch of astronomy.

The decade of the 1950's saw the increasing use of sounding rockets to loft their X-ray detectors above the atmosphere for a few precious minutes of observing time. The first-hand narrative begins here, with Giacconi's joining the American Science and Engineering group (AS\&E). He gives us a fascinating look at a small team of dedicated scientists and engineers, detailing their frustrations (such as rockets that misfired and detector covers that didn't come off) and their triumphs (Giacconi's group was the first to detect $X$ rays coming from outside the Solar System).

The next logical step beyond flying X-ray detectors on sounding rockets was to put them on artifical satellites. We are treated to another first-hand account, this time of the development and launch of the first dedicated $X$-ray satellite, Uhuru. It was data from Uhuru that convinced many astrophysicists that matter accreting onto neutron stars, and in some cases black holes, was behind the enigma of the X-ray stars. The authors devote two chapters to the exciting findings of this satellite.

The rest of the book is chiefly concerned with the successor to Uhuru. To the bureaucrats at NASA, this was known as HEAO-2, for "High Energy Astronomical Observatory." To the engineers who built it and the scientists who designed and used it, HEAO-2 became the Einstein Observatory. The great advance contained in Einstein was its high-resolution X-ray telescope, instead of the low-resolution X-ray detectors flown previously. Amateur telescope makers will appreciate the thought that went into the design of a mirror that worked on a grazing-incidence principle rather than a reflecting principle. The mirror consisted of a series of nested metal parabolas and hyperbolas.

Again we are taken behind the scenes to witness shifting budgets, bureaucratic battles, and the frantic testing to make the launch deadline. The authors conclude with an up-to-date review of the results from Einstein's observations: the $X$ rays radiated by stellar coronas and quasars, the discovery of hot intergalactic gas, and the mysterious X-ray cosmic background.

The X-Ray Universe is lavishly illustrated with over fifty photographs and drawings (five of them in color) which blend in well with the text. The book is printed on acid-free paper and is handsomely bound; something that cannot be said of many hard-cover books these days. It gives a fascinating look at the interplay among science, engineering, and bureaucracy. It is also a first-hand account of what it is like to work on the leading edge of a rapidly developing science. I recommend this book highly.

## ANNOUNCEMENTS

Hubble Space Telescope Proposal Deadine Extended. --With continuing delays in the resumption of Shuttle launches, the HST Amateur Astronomers Working Group has extended the deadline for initial proposals to whenever the next successful shuttle launch takes place (presently scheduled for June, 1988). Initial inquiries should be sent to the American Association of Variable Star Observers (AAVSO), 25 Birch Street, Cambridge, MA 02138. All proposers who met the previous deadline (June 30, 1987) will be asked to prepare detailed proposals and will be mailed detailed proposal packages.

1988 A.L.P.O. Solar System Ephemeris Available. --The 1988 edition of the A.L.P.O. Solar System Ephemeris is now available for $\$ 6.00$ for users in the United States, Canada, and Mexico, and for $\$ 7.00$ for other countries, from the A.L.P.O. Director at the address given on the front cover. (Please make checks payable to "A.L.P.O.") This annual publication of over 90 pages provides predictions of positions and appearances of the Sun, the Moon, each major planet, planetary satellites, and selected meteor showers, comets, and minor planets. Visibility maps for eclipses and of occultations of planets by the Moon have been added in this edition, along with position charts of Uranus and Neptune, Jupiter's Galilean satellites, and the five brightest satellites of Saturn.
A.L.P.O. Section Directory. --In response to a motion passed at our recent Business Meeting in July, 1987, the A.L.P.O. Director has surveyed the observing Sections of the A.L.P.O. and has prepared a Directory of Section personnel, projects, and publications with their prices. This will be provided to all new members as they join, and present nembers may obtain the Directory by sending a SASE to the Director at the address on the front cover. We hope to update this Directory every year.

Microfiche Version of Old "Strolling Astronomers." --Also at our recent Business Meeting, we discussed the possibility of publishing a microfiche edition of the complete 40 -year run of the A.L.P.O.'s Journal , the Strolling Astronomer. Microfiche was felt preferable to paper publication because the latter would involve startup costs of tens of thousands of dollars; and also preferable to microfilm because microfiche readers are less expensive and because members could purchase portions of the run. We anticipate that the entire set would cost between $\$ 125$ and $\$ 150$, but the price depends on the number of copies sold. If you might purchase a microfiche edition of the Strolling Astronomer, please let us know; this information certainly will not commit you, but the more persons who express an interest, the lower the cost. (Of course, if few express any interest, there will be no microfiche publication.)

1988 A.L.P.O. Convention. --A1so in Pomona, we accepted the Astronomical League ${ }^{\text {t }}$ s invitation to meet with them in 1988. The host, place, and date have now been determined: the Omaha Astronomical Society, at Iowa Western Community College (near Council Bluffs), on July 27-30, 1988. More information will appear in future issues. Start planning for ALCON'88!

Foreign Membership Fund. --Another motion passed at the recent Business Meeting was the establishment of a special fund to give A.L.P.O. memberships to deserving amateurs who live in countries where American dollars are not obtainable. A few such persons are already provided for through exchanges of their publications with ours, but there remain active amateurs who would profit from A.L.P.O. membership and would also enhance our organization. Persons to receive this aid would be chosen by the A.L.P.O. Director, with each person awarded a l-volume membership. If you think this a worthy cause, the standard donation is \$US 14. Send it to the A.L.P.O. Director, payable to "A.L.P.O.," but with a note that it is intended for the Foreign Membership Fund.

Address Change for Jose Olivarez. --Mr. Olivarez, who is both our Lunar and Planetary Training Program Recorder and a Jupiter Recorder, has recently changed his mailing address to: 1469 Valleyview Court, Wichita, KS 67212.

Triton Occultation Watch. --John Hewitt ( 418 Boynton Ave., Berkeley, CA 94707) is organizing a program to watch for occultations of stars by Neptune's large moon Triton. Such observations could help us determine Tritons's diameter, orbital position, and possible atmospheric properties and would be of value in planning for the 1989 Voyager 2 flyby. If you have access to a telescope of $30-c m$. aperture or more, you are invited to send a SASE to Mr. Hewitt for more information.

Comets/Meteors Assistant Recorder Honored. --James V. Scotti, the Assistant Recorder of both the Comets and the Meteors Sections, has had a minor planet named for him; it's Minor Planet 3594 Scotti, discovered 1983 FEB 11 by E. Bowell at the Anderson Mesa Station of the Lowell Observatory.

Observatory Opportunity. --Our Charter Member and Secretary/Book Review Editor, J. Russell Smith, is offering his private observatory for sale and has provided the following description: "Skyview Observatory. Custom-made 16-in. Newtonian, $f / 5.5$, 88 -in. focal length; mirror aluminized and in excellent condition. Weight 2500 pounds. 16-in. aluminum setting circles; clock drive. 16.5-ft. Ash Dome; all-weather plywood walls; two-section up-and-over shutter and dome rotation electrically controlled. $\$ 9900$, building included. Contact J. Russell Smith, 8930 Raven Drive, Waco, TX 76710; telephone 817-772-0086."

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