REVISED ELEMENTS (I) FOR EH CANIS MAJORIS, SV PUPPIS, TW OPHIUCHI, HO LYRAE, AND FW DELPHINI

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Received 26 July 1989

Abstract

Five long period variables - EH CMa, SV Pup, TW Oph, HO Lyr, and FW Del - considered for the HIPPARCOS observing program have been studied using the Harvard College Observatory photographic plate collection. Previously published elements have been revised.

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HIPPARCOS, the European Space Agency's **HI**gh **P**recision **PAR**allax **CO**llecting **S**atellite, scheduled to be launched in mid-1989 for a 2-1/2 year mission, will collect positions, parallaxes, and proper motions for approximately 120,000 stars with an accuracy far greater than that of previous ground-based astrometric surveys. HIPPARCOS's Input Catalog (INCA) team has requested the AAVSO's assistance in scheduling the observation of approximately 300 long period variable stars in the satellite's observing program (see Mattei 1988).

This paper is the first in a series of four in which a total of twenty-three Miras and semiregulars are examined. These stars are in HIPPARCOS' observing program, but little or no visual data exist for them in the AAVSO's files. In order to revise elements published in the **General Catalogue of Variable Stars** (Kholopov et al. 1985) (GCVS), and to provide long-term data for analysis by INCA, the Harvard College Observatory photographic plate collection was searched in the regions containing these stars. Photographic data were collected from patrol plates (RH, RB, BM, ER (1928 - 1952) and Damon (1962 - present) series) plates.

O-C values could not be calculated for most of the stars as there were very few well-defined maxima in the data. Two period search techniques were used to revise the periods. The first was a Lafler & Kinman period search (Lafler and Kinman 1965), which minimizes the vertical distance between adjacent observations in phase space in order to find the best values for the period. The second was a date-compensated discrete Fourier Transform (DCDFT) period search (Ferraz-Mello 1981), which finds periods by Fourier analysis. The Lafler & Kinman period search was used on only two of the twenty-three stars: the DCDFT method was preferred because it is faster, more rigorous, and has the added advantage of a sinusoidal filter which can be utilized to rule out aliases or find secondary periods. Both period searches are FORTRAN programs which were kindly supplied to the AAVSO by Dr. Emilia P. Belserene, the director of the Maria Mitchell Observatory in Nantucket, Massachusetts. For a detailed overview of period search techniques, see Fullerton (1986).

Mean curves were calculated by a Maria Mitchell Observatory BASIC program which superimposes cycles, sorts the data into phase bins, and calculates the mean magnitude of the observations in each bin.

Table I lists the stars examined in this paper, revised periods and photographic ranges of variation, and other pertinent information regarding the stars. Finder charts and photographic sequences are in

Figures (1a) - (1e). Photoelectric (**V**) magnitudes are also listed for SV Pup.

1. **EH Canis Majoris**

EH CMa is a Mira variable discovered by Kaho (1956), who assigned it the following elements:

$$JD_{(max)} = JD\ 2434393 + 290^{d}\ E. \quad (1)$$

Analysis of 123 observations (1928 Nov - 1988 Feb) was done using the Lafler & Kinman period search. The revised elements are:

$$JD_{(max)} = JD\ 2447119 + 295^{d}.5\ E. \quad (2)$$

The mean curve is shown in Figure 2.

2. **SV Puppis**

SV Pup is a Mira discovered by Woods (1921). Different authors have published different values for its period; the GCVS reports that the period is variable:

Elements		Interval (Julian Date)	
$JD_{(max)} = JD\ 2419010 + 166^{d}.6\ E$		2413660 - 18000	(3a)
23090 + 169.8 E		18000 - 23100	(3b)
26782 + 167.8 E		23100 - 27500	(3c)
36284 + 166.52 E		27500 -	(3d)

The interval listed for equation (3c) includes the beginning of the Harvard data, so O-C values were calculated from 152 observations from the Harvard plates (1930 Dec - 1988 Feb) and published maxima (Payne-Gaposchkin 1952; Huth 1951; 1961; and Solov'ev 1952), using C as defined by equation (3c). The resulting O-C curve (Figure 3) is a periodic function (P ~ 20,500 days), evidence that SV Pup is multi-periodic.

The DCDFT period search was used to find the interacting periods. The resulting periodogram (Figure 4) displays peaks at P ~ 166, 83, 108, and 305 days, in order of descending power. The data were "prewhitened" for each of these periods in order to remove aliases and identify the true primary and secondary periods. Prewhitening (Fullerton 1986) is a sinusoidal filtering process in which a given period is extracted from the data and its residuals are analyzed. The primary was found to be 166.25 days, and the secondary period 305: days; there may also be higher harmonics, but the statistical significance of periods found by prewhitening breaks down after successive trials. The noise level of the residuals of the other two periods was excessive: they were thus ruled out as spurious.

The DCDFT period search was then conducted on the most recent data interval. The revised elements are:

$JD_{(max)} = JD\ 2436284 + 166^{d}.52\ E$		27500 - 33800	(3e)
44729 + 168.66 E		44600 - present.	(3f)

No data exist for JD 2433800 - 44600 due to a gap in the Harvard College Observatory plate collection. The mean curve for JD 2444600 - present is shown in Figure 5.

3. **TW Ophiuchi**

The GCVS reports that TW Oph is a type-b semiregular variable. These stars display poorly-defined periodicity and often experience intervals of irregular or non-periodic behavior. TW Oph's period is

listed as approximately 185 days; secondary variations in brightness of maximum on the order of 2000 days have been reported by Gaposchkin (1950) and Dragomiretskaya (1962). Dragomiretskaya also reports a variable nebula surrounding the star.

DCDFT analysis of 259 observations (1928 Mar - 1987 Aug) produced a periodogram with peaks at P ~ 415, 330 and 230 days (Figure 6). Due to the irregular behavior of this star, prewhitening was of little use in determining which of the three is the true period: the residuals of all periods were equally noisy. Examination of the plotted data, however, shows P ~ 230 days to agree best with the recent data (see Figure 7):

$$JD_{(max)} = JD\ 2446600 + 230^{d}: E. \quad (4)$$

The light curve undergoes irregular variations in period, amplitude, and shape from cycle to cycle, which is typical of b-type semiregular variables.

4. HO Lyrae

HO Lyr was discovered by Beljawsky (1936). Chernova (1949) reported that it is a Mira with the elements:

$$JD_{(max)} = JD\ 2430584 + 100^{d}.4\ E. \quad (5)$$

Tsesevich (1952), however, found much different elements:

$$JD_{(max)} = JD\ 2428780 + 140^{d}\ E. \quad (6)$$

The Lafler & Kinman period search found only a few weak periods in the set of 206 observations (1928 Mar - 1988 Apr), so the data were broken down and separate period searches were conducted. For the earlier data (JD 2425000 - 34000) P = 100.3 days, and for the recent data (JD 2442500 - present), P = 99.6 days. No data exist for JD 2434000 - 42500 due to the gap in the Harvard plate collection. The revised elements are:

$$JD_{(max)} = JD\ 2429483 + 100^{d}.3\ E \quad \text{prior to JD 2434000.} \quad (7a)$$
$$46286 + 99.6\ E \quad \text{JD 2442500 - present} \quad (7b)$$

The mean curves for these two intervals are shown in Figures 8a and b.

5. FW Delphini

FW Del is a Mira discovered by Romano (1958); its position was later corrected by Lochel (1962), who found the elements:

$$JD_{(max)} = JD\ 2437093 + 343^{d}\ E. \quad (8)$$

The data agree with the maxima predicted by these elements, but there were too few data to conduct a period search in order to further refine the period. Of the 217 observations from the Harvard plates (1929 Jul - 1988 Apr), 191 did not appear on the particular plate examined, but were designated "fainter than" the faintest visible comparison star. The elements were revised on the basis of the most recent observed maximum:

$$JD_{(max)} = JD\ 2446699 + 343^{d}\ E. \quad (9)$$

FW Del's mean curve is shown in Figure 9.

A variable must be brighter than $13^{m}.0$ pg for at least 65% of its cycle in order to be suitable for observation by HIPPARCOS. All of the variables in this paper except for SV Pup have been eliminated from the

satellite's observing program, in part due to the research presented here.

Members are encouraged to observe SV Pup, as more data are needed in order to better describe its behavior and to aid in scheduling its observation. Anyone wishing to assist the AAVSO in this collaboration may obtain charts from AAVSO Headquarters.

I would like to thank Dr. Janet A. Mattei for her guidance; Dr. Martha L. Hazen, curator of the Harvard College Observatory Photographic Plate Collection, for her assistance with the plates and iris photometer; Dr. Emilia P. Belserene of the Maria Mitchell Observatory for providing computer programs; and the staff at AAVSO Headquarters for their support. I gratefully acknowledge NASA grant No. NAGW-1493 to the AAVSO, which funded this project; and the Fund for Astrophysical Research, which provided computer equipment.

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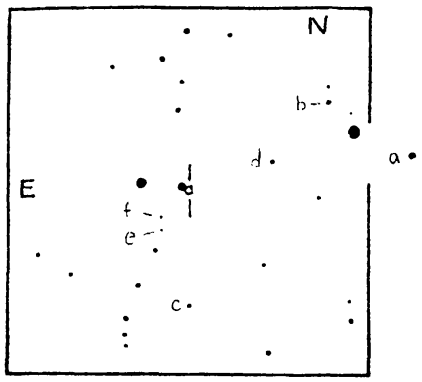
TABLE I

Summary Table for EH CMa, SV Pup, TW Oph, HO Lyr, and FW Del

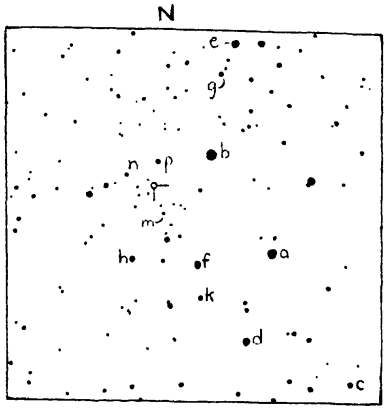
Star	Position (1950) R.A.	Dec.	Type	Spec.	Revised Period	Revised Max.	ptg Min.	No. Obs.	Remarks
EH CMa	$06^h15^m19^s$	$-31^o00'.6$	M	M8e	295.5	<11.3>	<14.7>	123	4,5
SV Pup	08 14 57	-13 39.0	M	M5e	168.66	10.0	(13.6	152	1,4,6
TW Oph	17 26 47	-19 26.1	SRb	C5,5	230:	11.0	14.2	259	4
HO Lyr	19 18 31	+41 35.2	M	M2e	99.6	<11.45>	<13.30>	206	2,4,5
FW Del	20 24 02	+20 17.2	M	M5e	343	<12.85>	(13.9	217	3,4,5,7

Remarks:
1. Period is variable: see equations (3a)-(3f). Listed period is valid for JD 2444000 - present.
2. Period is variable: see equations (7a) and (7b). Listed period is valid for JD 2442500 - present.
3. Value of minimum is from Lohel (1962).
4. Information in Columns 3, 4, and 5 is from GCVS.
5. < > in Maximum or Minimum indicates mean photographic magnitudes.
6. (in Maximum or Minimum indicates variable fainter than magnitude.
7. GCVS gives 18 mpg for the minimum.



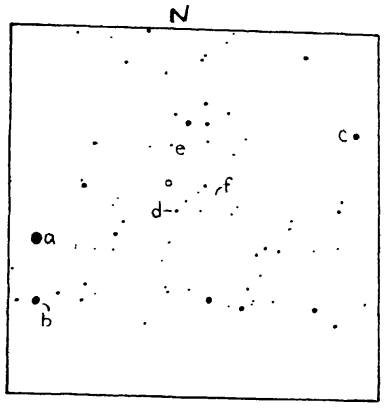
a = 9.m6 pg
b = 10.7
c = 11.5
d = 12.4
e = 13.5
f = 14.7

Figure 1a. EH CMa. Chart and magnitudes **a** - **e** from Kaho (1956). Each side is 1°. Magnitude for **f** found by iris photometry at Harvard College Observatory.



a =	10.m2 (B)	9.m9 (V)
b =	10.4	9.6
c =	10.6	10.1
d =	10.8	10.3
e =	10.9	10.8
f =	11.6	10.8
g =	11.6	11.2
h =	12.0	11.5
k =	12.8	12.2
m =	13.1	12.6
n =	13.5	12.9
p =	13.6	12.1

Figure 1b. SV Pup. Chart from an AAVSO (d) scale chart. Each side is 35′. Photoelectric magnitudes by Menzies (Bateson 1975).



a = 9.m7 pg
b = 11.2
c = 11.8
d = 12.7
e = 13.6
f = 14.2

Figure 1c. TW Oph. Chart from an AAVSO (d) scale chart. Each side is 35′. Photographic magnitudes from Dragomiretskaya (1962).

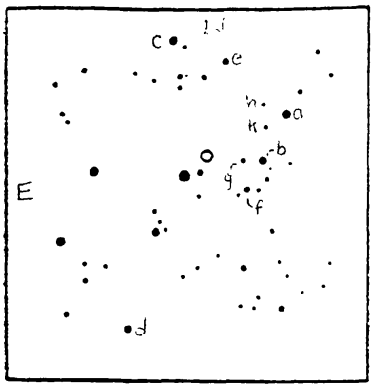


Figure 1d. HO Lyr. Chart and photographic magnitudes from Chernova (1949). Each side is 30′.

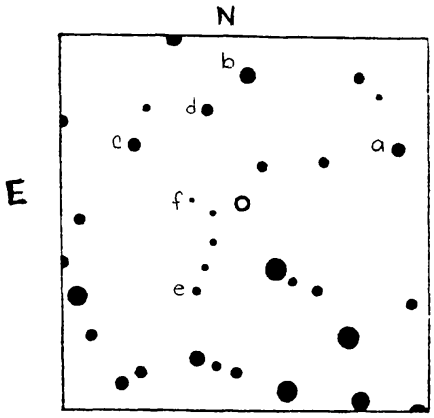


Figure 1e. FW Del. Chart and magnitudes **b** - **f** from Löchel (1962). Each side is 13′. Magnitude for **a** is from Romano (1958).

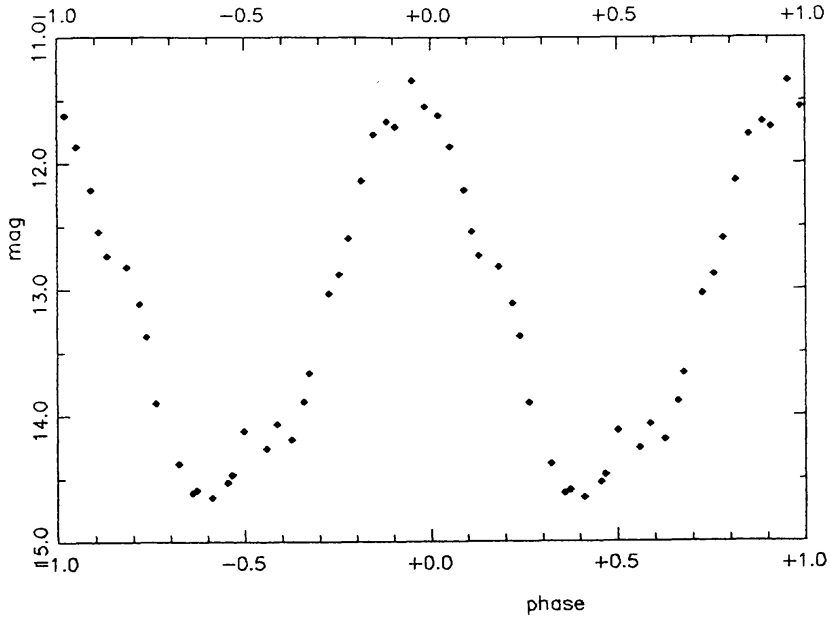


Figure 2. Photographic mean curve for EH CMa.

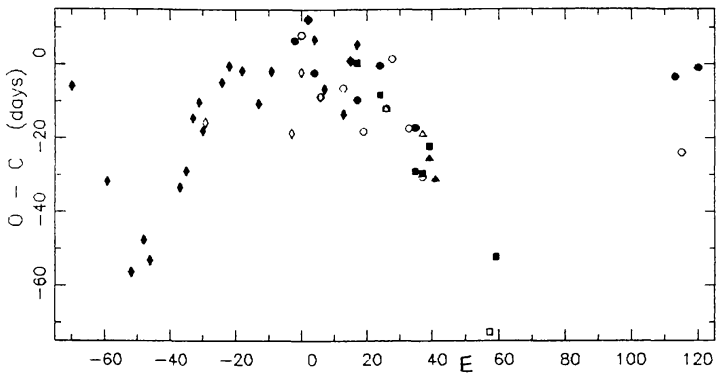


Figure 3. O-C curve for SV Pup. Circles are points calculated from maxima found on Harvard College Observatory photographic plates; diamonds are from maxima published by Payne-Gaposchkin (1953); squares are from Huth (1951, 1961); and triangles are from Solov'ev (1952). C is defined by equation (3c).

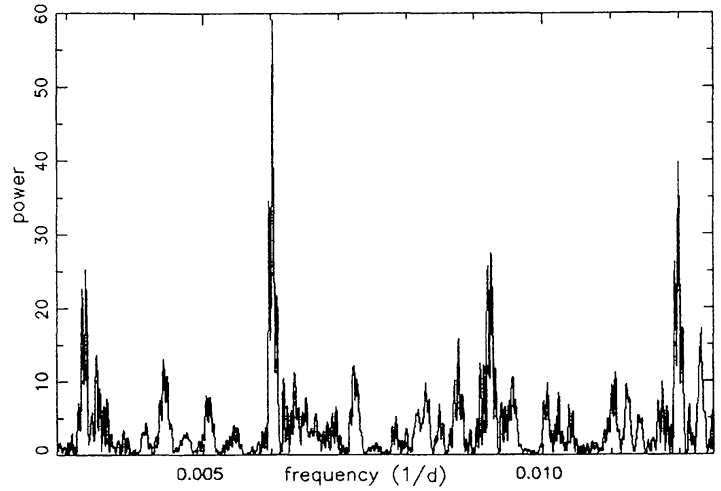


Figure 4. Periodogram for SV Pup. Power is defined by Scargle (1982). Peaks occur at P ~ 305, 166, 108 and 83 days (f ~ 0.0033, 0.0060, 0.0093, and 0.0120 d^{-1}).

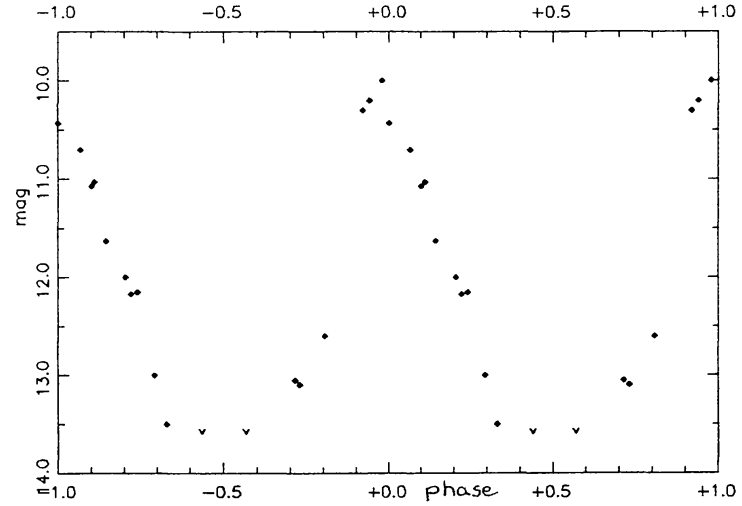


Figure 5. Mean curve for SV Pup, JD 2444000 - present. "v" means "fainter than".

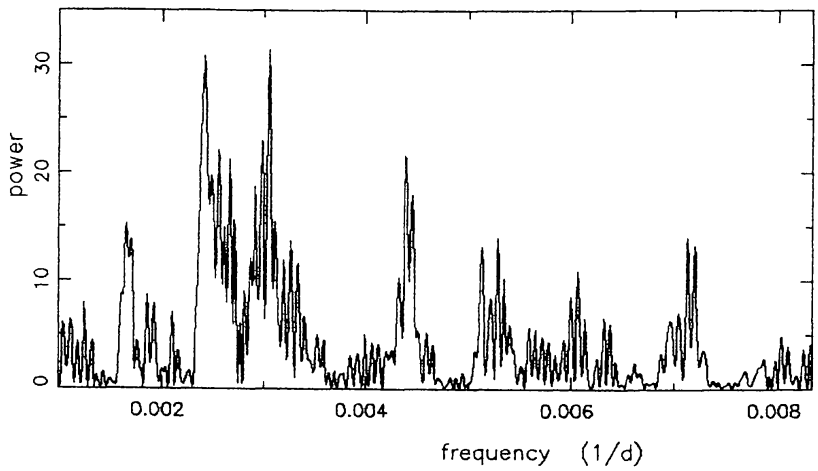


Figure 6. Periodogram for TW Oph. Peaks occur at P ~ 415, 330, and 230 days (f ~ 0.0024, 0.0030, and 0.0043 d^{-1}).

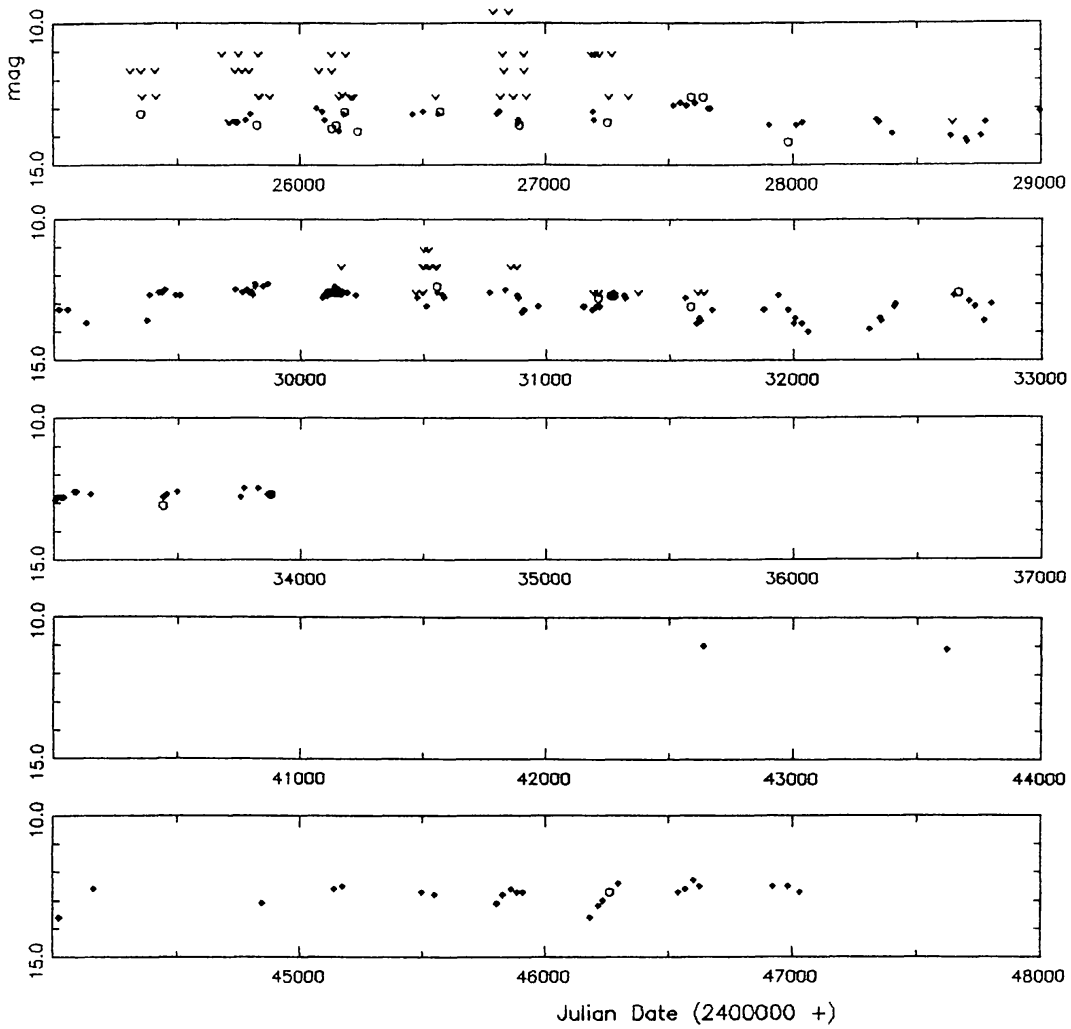


Figure 7. Data from the Harvard College Observatory plate collection for TW Oph. No data exist for JD 2434000 - 42000 due to a gap in the plate collection. Open circles indicate uncertain observations.

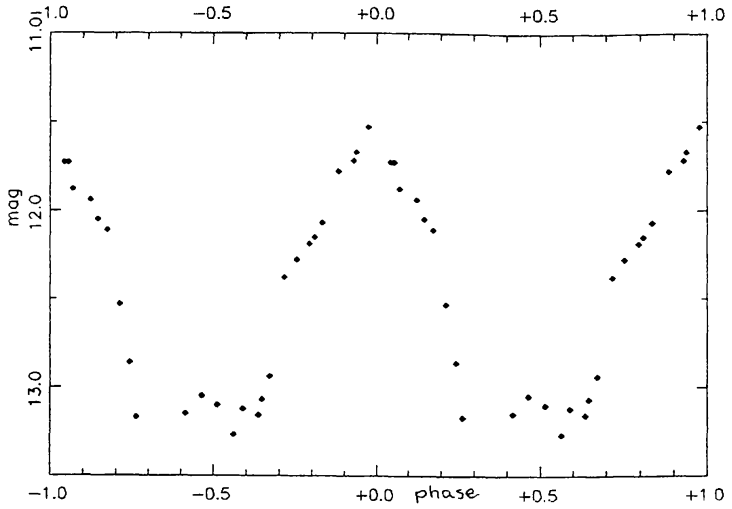


Figure 8a. Mean light curve for HO Lyr, JD 2425000 - 2434000.

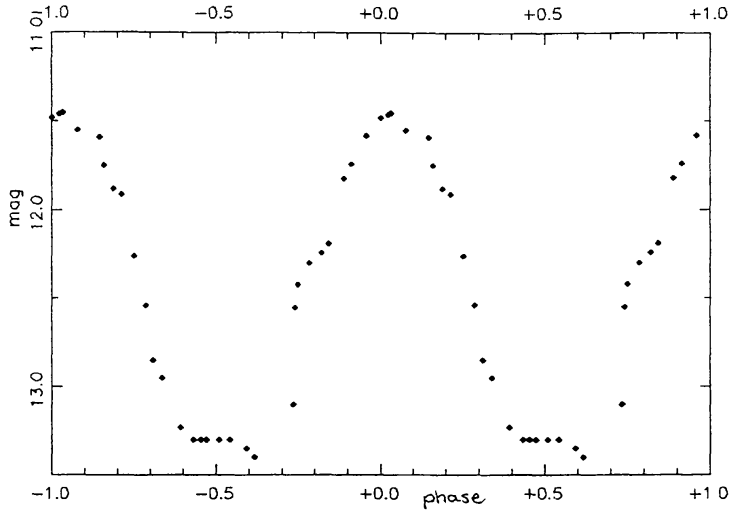


Figure 8b. Mean light curve for HO Lyr, JD 2443500 - present.

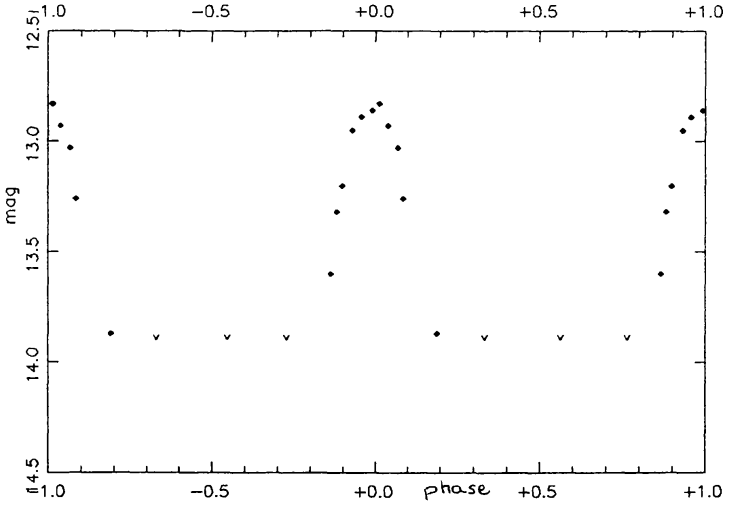


Figure 9. Mean curve for FW Del.