1983ApJ...275..247H

THE ASTROPHYSICAL JOURNAL, **275**:247–250, 1983 December 1
© 1983. The American Astronomical Society. All rights reserved. Printed in U.S.A.

SS 433: IMPROVED EVIDENCE FOR A PERSISTENT 160 DAY PHOTOMETRIC PERIOD

GARY D. HENSON, JAMES C. KEMP, MARK S. BARBOUR, AND DANIEL J. KRAUS
Department of Physics, University of Oregon

AND

ELIA M. LEIBOWITZ AND TSEVI MAZEH
Department of Physics and Astronomy and the Wise Observatory, Tel Aviv University
Received 1983 March 11; accepted 1983 May 5

ABSTRACT

We present photometric observations of SS 433 in V band obtained during the four-year period 1979–1982. The increased length of the data string has made detection of a true 160 day periodicity possible. A power spectrum analysis of the data now reveals a period of $161^{d}.5 \pm 0^{d}.3$. The structure of the 160 day light curve favors the accretion-disk model for the system, but it implies a need for asymmetry associated with the disk.

Subject headings: stars: binaries — stars: individual — stars: variables

I. INTRODUCTION

Spectroscopic observations have long shown the existence of a 160 day period in the moving lines of SS 433 = V1343 Aquilae. Recent narrow-band photometry (Anderson, Margon, and Grandi 1983*a*) has also shown strong evidence for this period. Leibowitz *et al.* (1983) find a period of $160^{d} \pm 10^{d}$ in their broad-band photometry using three years worth of data. In this paper, we combine an additional year's data with those of Leibowitz *et al.* so that the data string now covers approximately seven cycles of the 160-day period. In previous analyses, the available data strings were not long enough to test for a true 160 day periodicity using, particularly, the power spectrum method. This circumstance was noted by Anderson, Margon, and Grandi (1983*a*).

A 13 day orbital period can also be seen in the light variations of SS 433. A more detailed analysis of the 13 day photometric periodicity, specifically, and of its interaction with the 160 day process, can be found in Leibowitz *et al.* (1983). Our interest here lies in showing an improved significance of the 160 day period.

II. OBSERVATIONS

The observations consist of 443 data points obtained from 1979 July to 1982 December. They include data from observatories in Oregon, USA; Israel; and Japan. The observations were made in the standard V band centered at 5530 Å, or in a slightly narrower band at the same wavelength called V' (Kemp *et al.* 1981). Typical measuring errors per data point where ± 0.08 mag. The observational procedure used can be found in Kemp *et al.* (1981).

III. RESULTS

In Figure 1 we show a real time plot of our observations from 1979 July to 1982 December. The 1982 data obtained in Oregon showed more irregular light variations than usual for SS 433. For example, a brief drop to the lowest brightness ever recorded for the object occurred during this time (the point at day 1170 in Fig. 1; Henson, Kemp, and Kraus 1982). Although the extreme variability of the object on short time scales is clearly evident, the smooth curve representing the $161^{d}.5$ sinusoid fits the 1982 data well enough to improve the overall significance of this period.

Power spectra of the data obtained by a direct Fourier summation technique (Kemp *et al.* 1981) are presented in Figure 2. Prominent peaks are seen at $161^{d}.5 \pm 0^{d}.3$ and $6^{d}.5403 \pm 0^{d}.0007$ in Figure 2*a*. A peak at $13^{d}.051 \pm 0^{d}.005$ is also evident although it is weaker. Figure 2*b* is a higher resolution spectrum around the $161^{d}.5$ peak. Analysis of the data shows peak A, the only other strong peak in this period range, to be merely a sampling alias of the $161^{d}.5$ peak. The dashed spectrum was made with the $161^{d}.5$ sinusoidal variation removed from the data; peak A also vanishes. A least mean squares fit to a first harmonic sinusoid with a period of $161^{d}.5$ gave a probability of $< 10^{-4}$ that the peak was due strictly to random noise in the data. Thus, our detection of the period is well established.

Figure 3 shows the data folded on the $161^{d}.5$ period, after removal of the 13 day and 6.5 day variations. The data are plotted using bin averages with approximately 20 points per bin. The epoch (phase 0.0) used here is JD 2,444,083.0, the minimum of a $161^{d}.5$ sine wave fitted to the data by linear regression. At the bottom in Figure 3 we show schematically the radial velocity pattern of the moving spectral lines, using a best fit ephemeris from Table 1 of Anderson, Margon, and Grandi (1983*b*). Specifically we used the epoch from their five-parameter fit with a constant period of $162^{d}.7$. They list the epoch t_0 = JD 2,443,561.8, where t_0 is the first crossover point of the lines; in Figure 3 we indicate t_0

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1983ApJ...275..247H

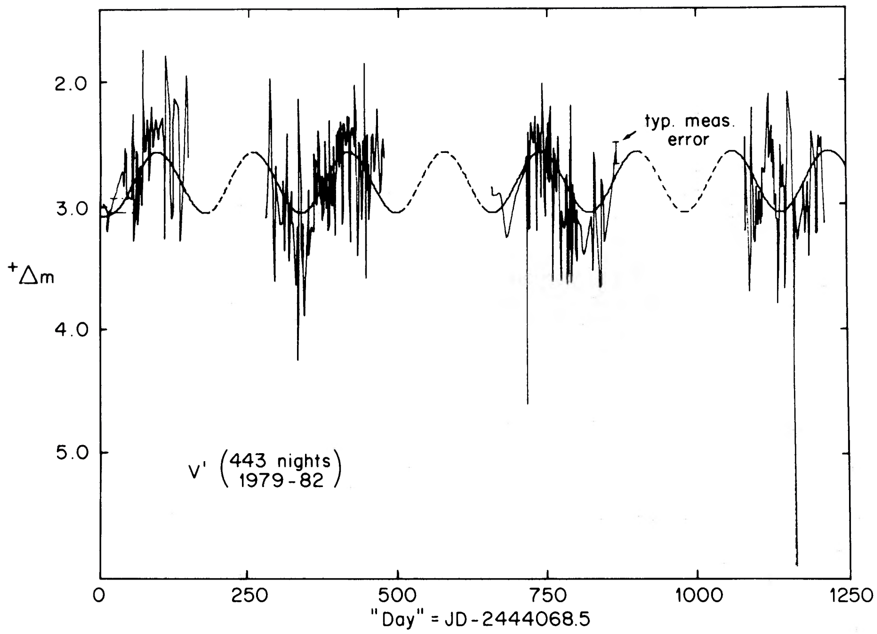

FIG. 1.—Real-time plot of our photometric observations of SS 433 in V band. Day 0.0 = 1979 July 14.0. The continuous jagged lines are not intended to show the short-term variability, but serve only to connect adjacent data points. The smooth curve is a $161^d.5$ sinusoid obtained from least mean square fitting.

with an arrow. The centroid between the two crossovers is approximately 26 days after t_0, and in our phasing the centroid lies at about $\phi = 0.95$. Use of other very slightly different periods and epochs from Table 1 of Anderson *et al.* makes differences here of only ~ 5 days; in general, the phase shift of the centroid between the crossovers relative to the light curve sinusoid is always negative, as in Figure 3. The peak-to-peak amplitude of the light curve sine wave is 0.42 mag.

As is evident, a simple sinusoid is only a first approximation to the light curve shape. There is additional structure.

IV. DISCUSSION

Many models exist which attempt to explain the 160 day process in SS 433. Besides the 160 day variation itself, characteristic features seen in the 160 day light curve must also be explained. There is a definite bump in the light curve of Figure 3 between phases 0.8 and 1.0. This bump is also evident in the curves presented by Leibowitz *et al.* (1983), and we interpret it in a similar manner. Assuming a simple, precessing, thick accretion-disk model for the system (Anderson, Margon, and Grandi 1983*a*; Katz *et al.* 1982), two maxima should be present in the 160 day light curve. In our data, the primary maximum should and does appear at $\Phi = 0.5$ when we see the open face of the disk. The secondary maximum should occur at $\Phi = 0.0$ when the underside of the disk is seen for a short period of time between those points where the disk is seen edge-on (the cross-over points of the moving lines). We should also see two equal minima, one on either side of the secondary maximum, corresponding to viewing the disk edge-on. However, our curve shows the secondary maximum to be displaced 0.1 cycle ($\approx 3\ \sigma$) from $\Phi = 0.0$, at about $\Phi = 0.87$. The minima corresponding to seeing the disk edge-on would appear to show unequal depths. These characteristics imply the possibility of an asymmetrical disk or certainly of some asymmetry in the light-producing regions associated with the disk. We discern a possibly related asymmetry in Figure 3 of Anderson, Margon, and Grandi (1983*a*).

While the interpretation of the 161 day light variation as a simple disk-projection effect is very appealing, other models cannot be ignored which might better explain the asymmetry and the fine structure. The chaotic variability on time scales of a day may also be difficult to accommodate in standard accretion disk models. Kundt (1981) views the variable light as arising in a large, relatively thin screen or sheath, located between the primary star and a magnetic neutron star. The latter's spin axis precesses with the 161 day period, modulating the screen's geometry. Coriolis effects would cause substantial asymmetry, i.e., a lack of mirror symmetry through a vertical plane containing the primary-secondary axis—as we seem to require.

In any case, due to the extreme intrinsic noise in SS 433 we will need considerably more data to delineate the truly *persistent* finer details in the light curve, before the models can be tested with confidence. We are continuing our photometry during 1983.

We are profoundly grateful to H. Mendelson, K. Takagishi, J. Jugaku, and M. Matsouka for their contributions to this program. Analysis of the data was made possible by NSF grant AST 82-01224.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1983ApJ...275..247H

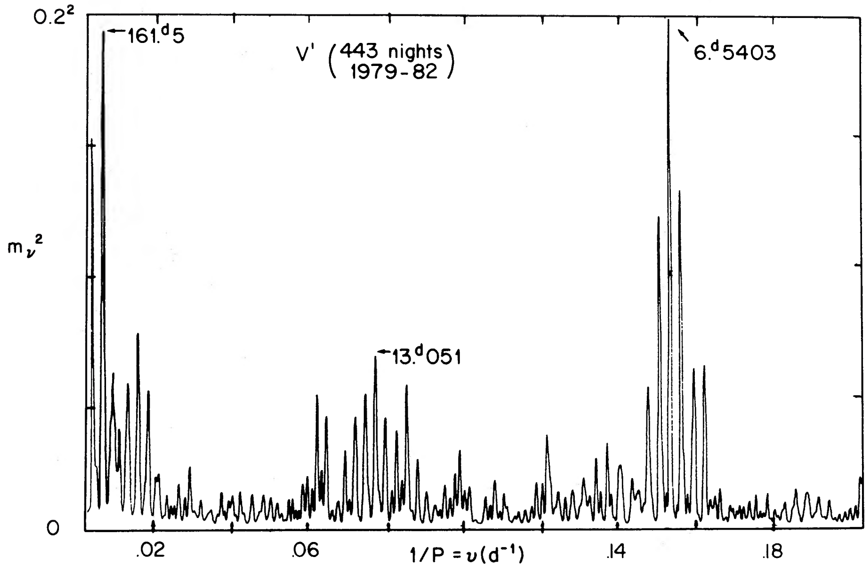

FIG. 2*a*

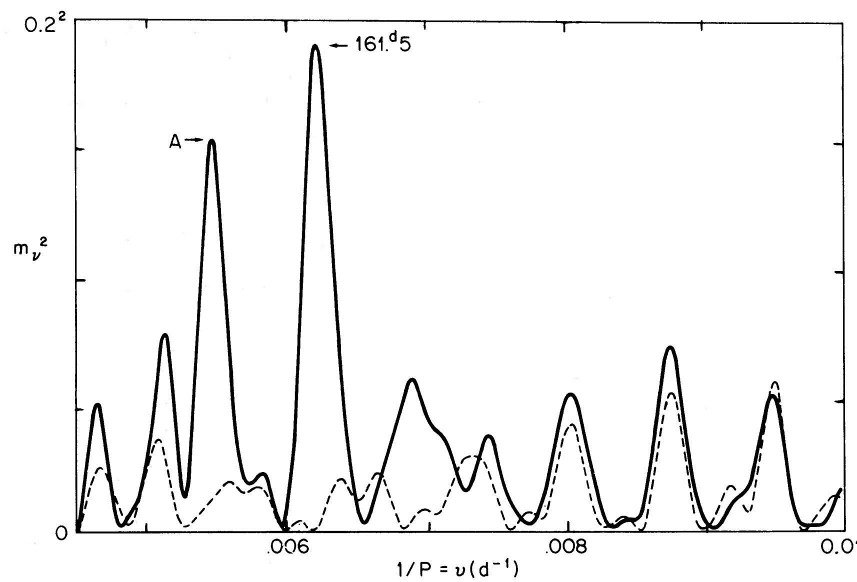

FIG. 2*b*

FIG. 2.—(*a*) Power spectrum of the light variations in SS 433 using a mesh of 1000 discrete frequencies (periods) from 285^d to 4^d.9. (*b*) High resolution power spectrum around the 161^d.5 peak. Peak A is a sampling alias of the 161^d.5 peak. Dashed spectrum is the result of removing the 161^d.5 sinusoid from the data; peak A also disappears.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1983ApJ...275..247H

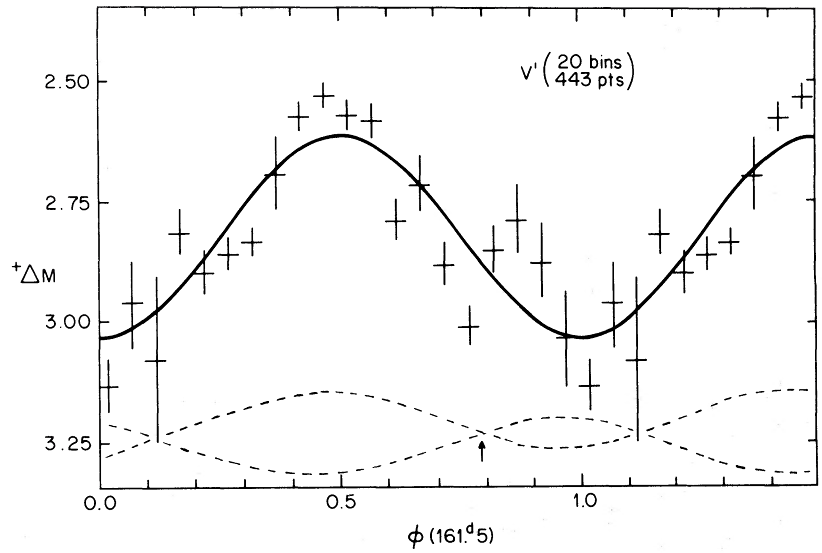

FIG. 3.—Light curve of SS 433 in V band folded onto the 161^{d}.5 period with the underlying 13^{d} and 6^{d}.5 periods subtracted out. The data are plotted using bin averages with errors given for each bin. Phase 0.5 corresponds approximately to the maximum separation of the moving lines. Phase 0.0 corresponds to JD 2,444,083.0. The smooth curve is a 161^{d}.5 first-harmonic sinusoid obtained from least mean square fitting. Dashed curves at bottom are a schematic version of the radial velocity variations of the so-called moving spectral lines; the first crossover point designated with an arrow is the epoch t_0 used in the ephemeris of Anderson, Margon, and Grandi (1983*b*); see text.

REFERENCES

Anderson, S. F., Margon, B., and Grandi, S. A. 1983*a*, *Ap. J.*, **269**, 605.
———. 1983*b*, *Ap. J.*, **273**, 697.
Henson, G. D., Kemp, J. C., and Kraus, D. J. 1982, *IAU Circ.*, 3750.
Katz, J. I., Anderson, S. F., Margon, B., and Grandi, S. A. 1982, *Ap. J.*, **260**, 780.
Kemp, J. C., Barbour, M. S., Kemp, G. N., and Hagood, D. M. 1981, *Vistas Astr.*, **25**, 31.
Kundt, W. 1981, *Vistas Astr.*, **25**, 153.
Leibowitz, E. M., Mazeh, T., Mendelson, H., Kemp, J. C., Barbour, M. S., Takagishi, K., Jugaku, J., and Matsuoka, M. 1983, *M.N.R.A.S.*, in press.

MARK S. BARBOUR: Canada-France-Hawaii Telescope Corporation, Kamuela, HI 96743

GARY D. HENSON, JAMES C. KEMP, and DANIEL J. KRAUS: Department of Physics, University of Oregon, Eugene, OR 97403

ELIA M. LIEBOWITZ and TSEVI MAZEH: Department of Physics and Astronomy and The Wise Observatory, Tel Aviv University, Tel Aviv, Israel

© American Astronomical Society • Provided by the NASA Astrophysics Data System