PERIODOGRAM STUDIES OF THE LIGHT CURVES OF CI CYGNI AND AG PEGASI

MARK H. SLOVAK
Washburn Observatory
University of Wisconsin
475 North Charter Street
Madison, WI 53706

Abstract

Periodograms are presented for two symbiotic variables: the eclipsing system CI Cygni and the spectroscopic binary AG Pegasi.

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1. Introduction

As a class of variable stars, the symbiotic or Z Andromedae variables have long puzzled astronomers. Like the particle-wave duality of photons, these stars display properties which, at times, indicate that they are binary systems, while other features can be understood by viewing them as single stars.

Insight into the nature of the symbiotic variables requires that accurate observations be obtained over many years. However, few major observatories can afford a monitoring program of such duration, so the visual light curves recorded by the amateur astronomers of the American Assocation of Variable Star Observers (AAVSO) have increasingly come to provide a unique and valuable tool to aid in the study of variables with long time scales of activity.

2. Light Curves of Symbiotics

From photographic data and the AAVSO visual observations, two major types of activity can be distinguished in the light variations of symbiotic stars: (1) low amplitude, approximately sinusoidal variations with periods on the order of hundreds of days, and (2) eruptive episodes during which the mean light level abruptly increases by 1 to 2 magnitudes.

The AAVSO visual light curve for AG Pegasi is shown in Figure 1. The monthly mean values reported by AAVSO observers are plotted against Julian date, for observations covering the last eight years. Three cycles of the small-amplitude regular variation are visible in addition to a slow decline ($dm/dt \sim 0.04$ magnitude/year) which has been seen since the star's last eruption in about 1855. Photoelectric observations have been published by Belyakina (1968).

The AAVSO light curve for CI Cygni, spanning the last decade and covering four eclipses of this intriguing system, is seen in Figure 3. An earlier version of these data was published by Mattei (1978). In addition to the eclipses, the most striking feature of the light curve is the sudden increase in the light level near or at the time of eclipse. Both these figures stand as impressive testimony to the dedication and discipline of the observers in the AAVSO.

3. Periodogram Studies

What is a periodogram? A periodogram is a method for unraveling the periodic or regular behavior that may be present in a set of observations. A set of trial periods, P, are adopted and phases are calculated. The observations are ordered by phase and the sum of the absolute values of the differences between successive observations is formed:

$$S = \sum_{i=1}^{N} \left| x_i - x_{i+1} \right| + \left| x_N - x_1 \right|, \qquad (1)$$

where x_i is the i^{th} value in a set of N observations. If the correct period P is chosen and there are no observational uncertainties, this sum will be exactly twice the range spanned by the observations. A periodogram discriminant, D(P), is thus defined by

$$D(P) = \frac{S}{X} - 2, \qquad (2)$$

where $X = x_N - x_1$. A periodogram is produced when D(P) is plotted against the trial periods, as seen in Figures 2 and 4 for AG Peg and CI Cyg, respectively. Where the discriminant reaches its minimum values, the best fitting periods are revealed. Various subtleties can hinder the interpretation of a periodogram and yield erroneous results if care is not exercised. Primarily, one must be aware of the spacing of the observations in time (formally called the data window) because this spacing can introduce the appearance of spurious periodicities in the periodogram itself. These features are generally due to a fixed pattern imposed by the observer or his instrument. For example, the "spiky" appearance of the periodograms in Figures 2 and 4 is due to the use of 30-day mean values. This 30-day "false" periodicity thus appears as a strong yet annoying pattern in the periodogram, and its appearance over and over again is due to an effect called aliasing. Such false periods can be particularly misleading, especially when there may be real periods close to the false values. (See the discussion by Elsworth and James 1981.)

The periodogram technique outlined above was first described by Bopp, Evans, and Laing (1970). This method has become known as the "Deeming String Technique," after its designer, T. J. Deeming. It is a very general means of searching for periodicities in a set of observations, as it makes no assumptions about the nature of the variation (i.e., sinusoidal or otherwise). Furthermore, it is a technique well suited for data unevenly spaced in time.

4. Periodograms for Two Symbiotic Variables

The periodograms calculated from the AAVSO light curves in Figures 1 and 3 are shown in Figures 2 and 4, respectively.

For AG Pegasi, the upper curve in Figure 2 shows the actual periodogram produced from the AAVSO data. Note that the best period (solid arrow) occurs near P = 733 ± 30 days, distinctly different from the orbital period (P ∿ 830 days) indicated by the dashed arrow. The "spiky" appearance of the periodogram below 600 days is due to the 30-day sampling interval and the fact that period instead of frequency (f = 1/P) is used along the bottom axis.

The lower curve in Figure 2 is a periodogram produced by an artificial light curve consisting of a sine curve with a period of exactly P = 733 days, sampled at 30-day intervals. While it reproduces the same general features seen in the actual periodogram, there are also significant differences, indicating that the model used to produce the light curve is not totally satisfactory.

For CI Cygni, two periodograms are seen in Figure 4. The lower one is for the AAVSO observations as shown in Figure 3, i.e. including eclipses. The periodogram reaches a minimum near P = 825 days, differing by almost 30 days from the known eclipse period of 855 days (Mattei 1978). This result is an example of the interference that can arise between the true and spurious periods in such a method. Notice that the "false" period (P = 825 days) differs by a multiple of 30 days from the "true" period (P = 855 days). The true period, in this instance, must be established by carefully examining the O-C diagram.

The upper curve in Figure 4 shows the periodogram produced when the eclipses are excluded from the light curve by interpolating across the eclipse, using values before ingress and after egress. The discriminant still reaches a minimum near 850 days, although the feature is much weaker. Thus, the outbursts in CI Cyg seem to occur near times of eclipse. Perhaps eclipses occur near periastron passage and the mass exchange between the two components increases, driving an eruption. While the full significance of this coincidence is not yet understood, such results will help to define the fundamental nature of the processes which lead to eruptions in the symbiotic stars.

5. Future Work and Aspirations

These examples of analyses of AAVSO light curves of symbiotic variables serve to illustrate the increasing value of the regular and precise visual measurements provided to the astronomical community by the AAVSO.

The author would like to thank Dr. Janet Mattei for providing the AAVSO light curves of symbiotics, in both their original and digitized versions. He also expresses his admiration for the diligent and dedicated members of the AAVSO who have developed the best collection of visual observations in existence for the northern symbiotics. Dr. C. M. Anderson has generously provided computer time on the Midwestern Astronomical Data Reduction and Analysis Facility (MADRAF) to support this research.

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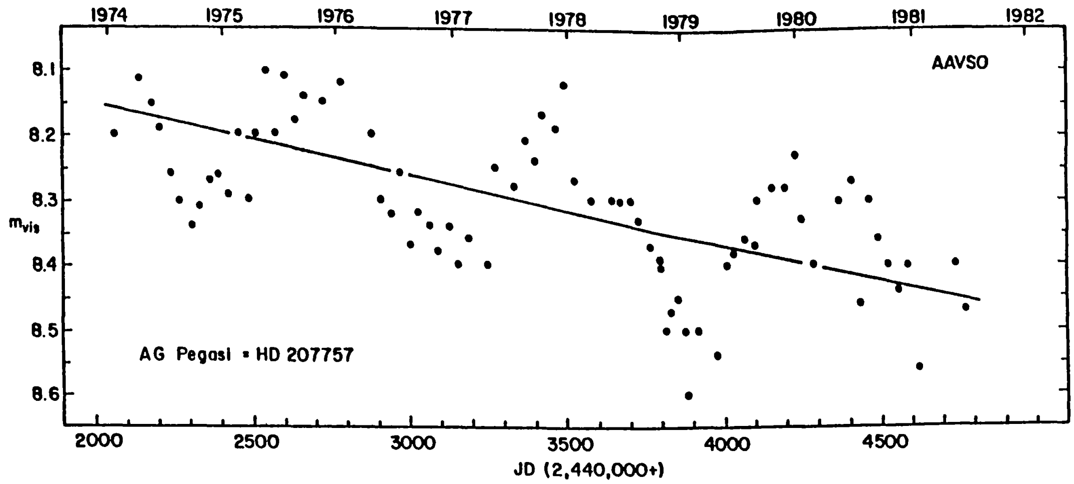

Figure 1. The AAVSO visual light curve of AG Peg. Visual magnitudes (m_{vis}) are displayed against Julian Date. Calendar years are shown on top axis. Note the regular variation and steady decline (solid line).

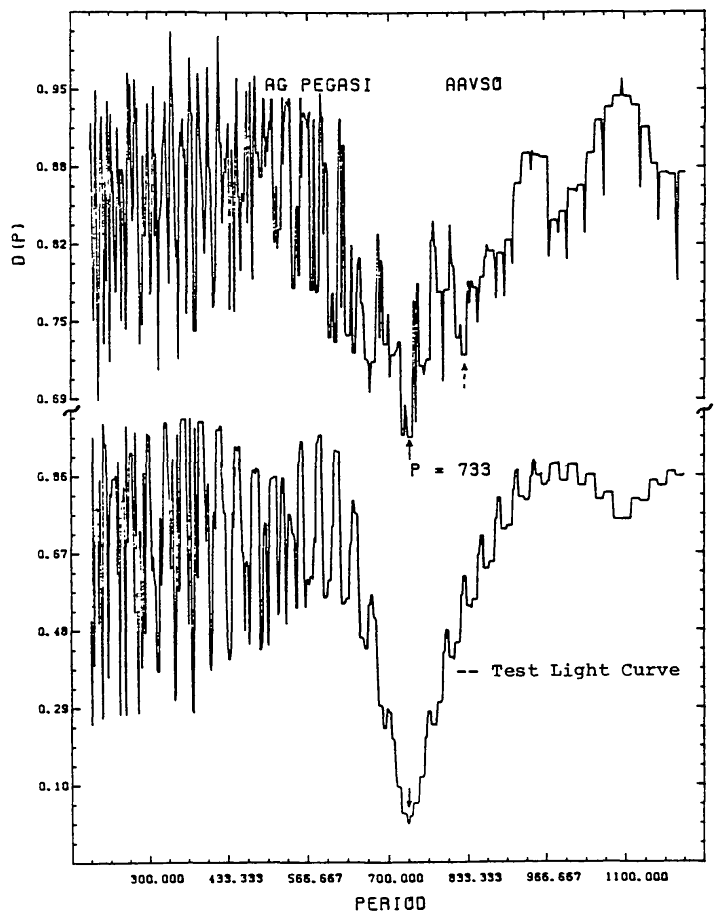

Figure 2. Periodogram of the AAVSO observations of AG Peg in Figure 1. The periodogram discriminant, D(P), is plotted against period, P, in days. The upper curve is for the actual observations; the lower curve is a test light curve with a period of P = 733 days.

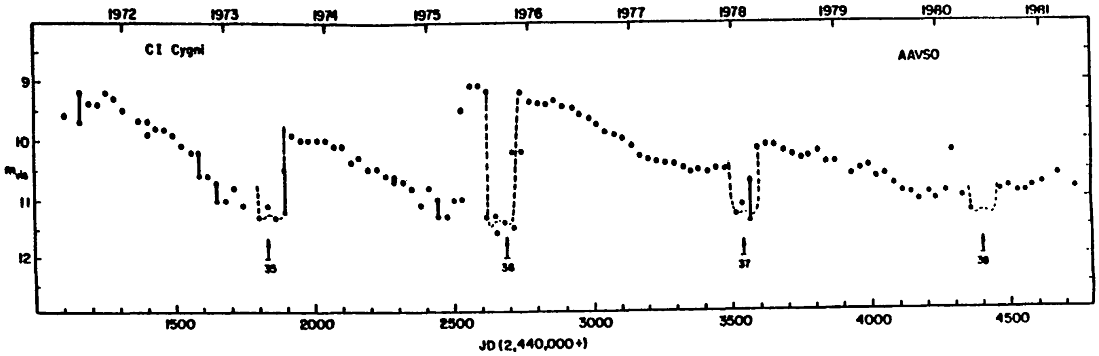

Figure 3. The AAVSO light curve of CI Cyg. Details are as in Figure 1. Note the four eclipses (E = 35, 36, 37, and 38) and the outburst behavior near each eclipse.

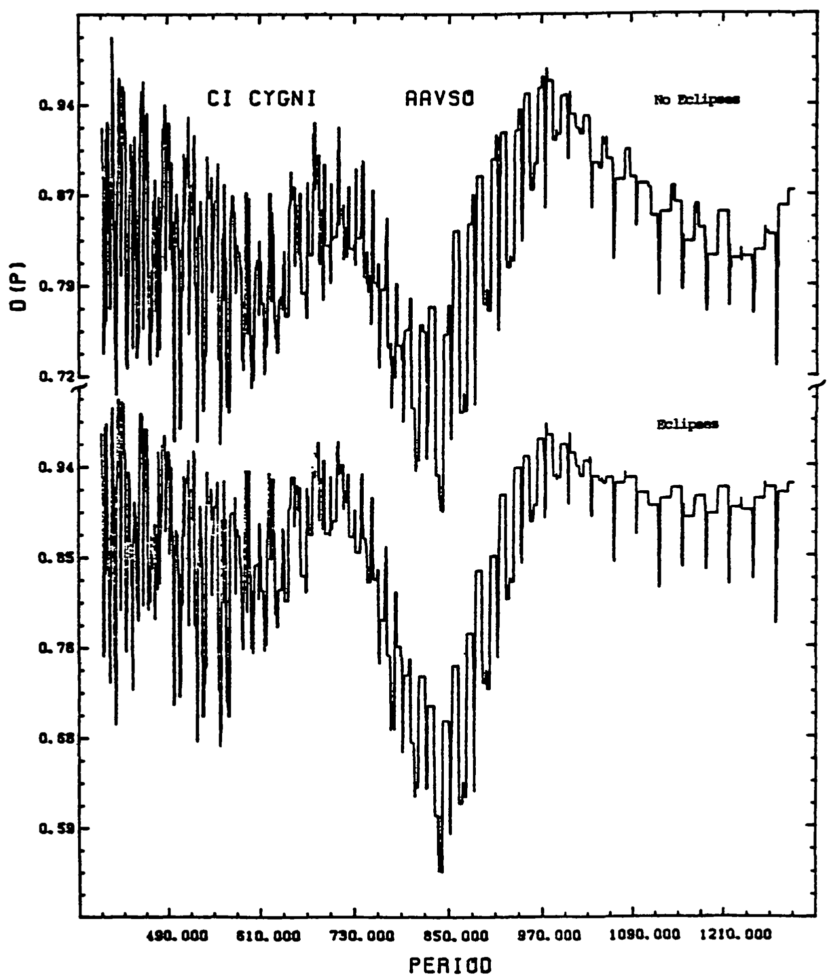

Figure 4. Periodogram of the AAVSO observations of CI Cyg in Figure 3. The upper curve excludes the eclipses, while the lower curve is for all the data. The results indicate that the "outburst cycle" may be connected to the orbital cycle.