A STUDY OF THE LIGHT CURVE OF R AQUARII, 1933 TO 1981

PETER M. GARNAVICH
12408 Stafford Lane
Bowie, MD 20715

Abstract

The light curve of R Aquarii over a period containing two eclipses was analyzed. An attempt was made to reduce light variations caused by the Mira component, in order to better determine a period for the eclipses. Light variations due to the blue component were apparently unimportant over the years studied. The period of the binary was found to be 47 ± 2 years and, with the Mira variations removed, a second minimum could be seen between the two primary eclipses.

The O-C curve of R Aquarii was also studied, and was found to have a large sinusoidal component with an amplitude of 17 days and a period half that of the binary system.

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R Aquarii is an extremely unusual long-period variable star. It is surrounded by an expanding nebula like that of an old nova (Merrill 1950). It is an eclipsing binary (Willson et al. 1981) whose companion, a small blue star enveloped by an accretion disk, is also variable. Furthermore, the period of the Mira variable seems to change in a cyclical fashion (Kurochkin 1976).

The complicated nature of the R Aqr system results in light variations from three principle sources. First, the Mira type primary, with a period of about 386 days, dominates the light curve with an amplitude of over four magnitudes. See Figure 1. Second, the blue companion varies irregularly. In the period between 1920 and 1934 it was quite active, reaching a maximum of about 8th magnitude compared to its normal brightness of 12th magnitude (Wallerstein and Greenstein 1980). Finally, the light of R Aqr is modulated by the eclipses of the two stars. This third is the most difficult of the three phenomena to detect because of the variation in brightness of the Mira type star, and because the irregular variation of the companion tends to overshadow the variations due to the eclipses. The intrinsic light variations of the two stars can be thought of as "noise" superimposed on the eclipse light curve. We shall attempt to find the light curve of the eclipse.

The region of the light curve of R Aqr chosen for study is shown in Figure 1. This period was picked because the blue companion seemed to be very inactive, thus eliminating it as a major source of noise when looking at the eclipses. The Mira variations are not so easy to remove, however. One way is to assume that the light output of this long period variable can be characterized by an average curve. Then, this mean light curve can be subtracted from each epoch, effectively eliminating the long period variable from the total light curve. This is not a very good assumption, since the maxima of long period variables are never the same from one epoch to the next, but these random fluctuations should not drown out the eclipses.

The mean light curve was calculated using 10-day mean magnitudes from AAVSO data by dividing each epoch into 39 bins, 19 before and 19 after maximum, and averaging the corresponding bins in each epoch. The resulting mean light curve, shown in Figure 2, is the average of nine epochs observed in the 1950's. These nine were chosen because they do not occur near an eclipse, and are well behaved. Mean curves calculated using more epochs do not differ in shape, only in their maximum and minimum values, probably because epochs affected by eclipses were included.

The mean light curve was then subtracted from each epoch, effectively removing the light variations of the long period variable. Figure 3 shows what could be called an "observed minus mean" (O-M) magnitude plot for R Aqr. Although the plot is quite noisy, parts of two eclipses of the Mira star are easily seen at the far left and far right. The noise is a result of the long period variable's deviation from its average brightness. From the plot, the time between eclipses is 47 ± 2 years, the inaccuracy due in part to the fact that less than half of the 1934 eclipse is shown.

The most interesting feature of the O-M plot is that there appears to be a secondary minimum half way between the two primaries. One explanation might be that the small blue companion star is being eclipsed by the Mira, but this is unlikely for three reasons. First, Wallerstein and Greenstein quote G. Herbig as observing "a hot continuum in the late 1950's", during the secondary minimum. This is unlikely if the companion was, in fact, being eclipsed. Secondly, Figure 3 is not a light curve, but rather a difference in magnitude plot, meaning the eclipse of a 12th magnitude star should only be noticeable at the minima of the Mira, and not affect the maxima at all. Both minima and maxima seem equally altered, however. Finally, the duration of the secondary minimum is between seven and eight years, which is inconsistent with a compact star being eclipsed by a Mira variable having a diameter of around 3 A.U. and using Willson's masses and distances (separation about 16 A.U., masses totaling 2 solar masses, and a circular orbit). Thus, the cause of the secondary minimum is probably not the eclipse of the companion star.

What may actually happen is that the accretion disk around the companion, which blocks the light of the Mira during primary eclipses, reflects some of the light when on the far side of the long period variable. The secondary minimum is caused by the Mira moving in front of the accretion disk and blocking its own reflected light. The three problems mentioned above are nicely answered by this explanation.

Not all the puzzles concerning R Aqr are solved, however. Kurochkin showed that the observed minus calculated date of maximum light (O-C) varies with a period of 24.1 years. An analysis of the O-C curve over the last 81 epochs, shown in Figure 4, indicates that it fits closely a cosine with a period of 23.3 epochs (24.6 years) and an amplitude of 17 days. It is probably not a coincidence that the period of the O-C curve is almost exactly half the orbital period of the R Aqr system, although no physical reason is known at this time. The period of the Mira seems to shorten near mid-eclipse (both primary and secondary), and is currently about 10 days less than the average of 386.3 days. Observations of this star would be very useful, especially when it is near the sun, to see if the period continues to vary sinusoidally.

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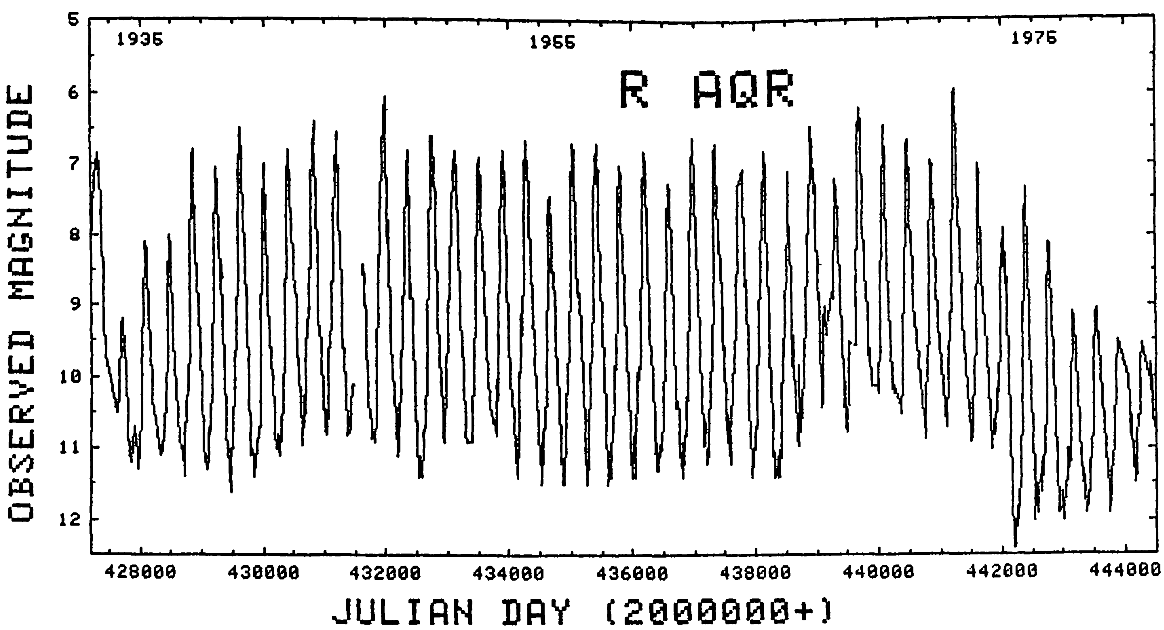

Figure 1. The light curve of R Aqr (1934 to 1981) from ten-day averages of AAVSO data. The period covers the end of the 1933 eclipse and extends through most of the 1977 eclipse. The bright maximum at the far left is due to the blue companion which reached maximum in the early 1930's and then faded rapidly.

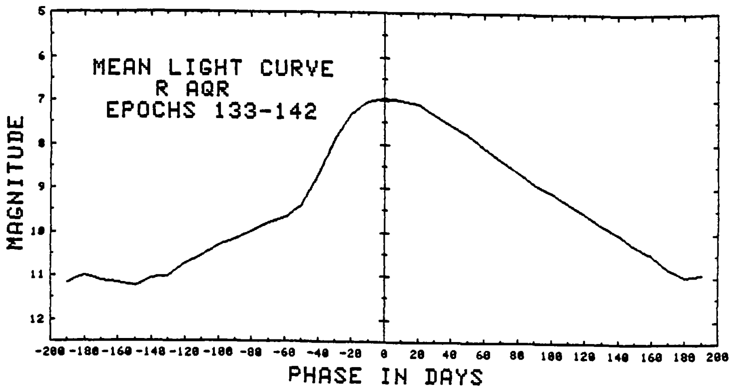

Figure 2. The mean light curve of R Aqr calculated from nine epochs. These nine all turned out to be during secondary minimum. Thus, this is the light curve of the Mira when it is least affected by obscuring material or reflected light.

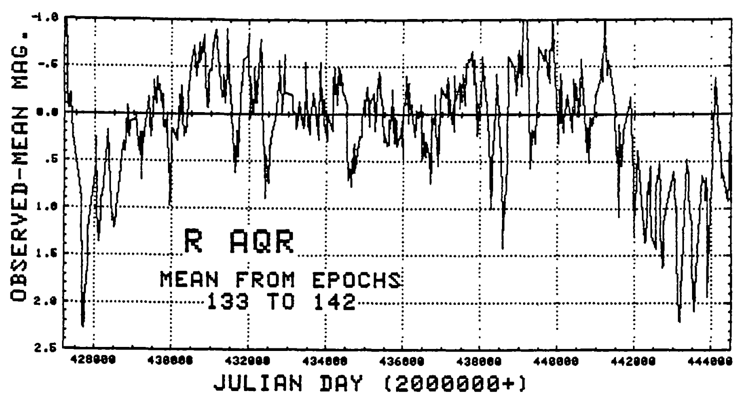

Figure 3. O-M plot of R Aqr from 1934 to 1981, showing the primary eclipses at each end and the possible secondary minimum in the center.

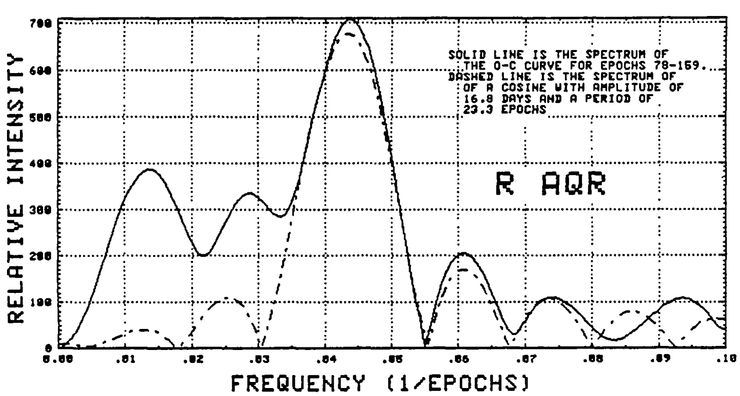

Figure 4. A spectrum of the sinusoidal components making up the O-C diagram of R Aqr (solid line), and a comparison spectrum of a cosine (dashed line) of amplitude 17 days and period 23.3 epochs. The peak at 0.013 results from the sample length being 81 epochs.