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THE 1978 ECLIPSE OF R AQUARII

The light curve of the symbiotic Mira variable R Aqr is characterized by highly variable minima, with the deviations from a normal Mira light curve usually ascribed to activity on the part of a hot sub-main sequence companion. (For a discussion of the light curve of R Aqr see Mattei and Allen 1979). During the enhanced activity of 1928-35 the maximum of the Mira component was suppressed at the same time that the minimum was raised, giving rise to speculation that in fact only a single star might be involved (Wallerstein and Greenstein 1980).

Although the behavior of minimum light from 1974 to 1980 has been very different from that of 1928-35 (Fig. 2) the maximum brightness has again been reduced by over two magnitudes. If the irregular variations in minimum light are due to activity centered around the hot companion, then the depression of

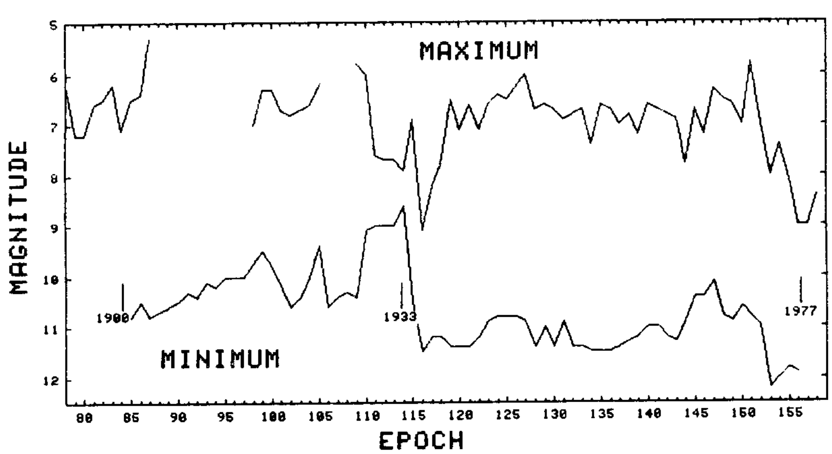

Figure 2. Magnitude at maximum and minimum light of the Mira component. The pronounced dips in the brightness at maximum in 1934 and 1978 are indicated, and the anticipated dates of previous eclipses are in 1890 and 1846.

the maximum can be interpreted as the result of an eclipse of the Mira component by an extended accretion disk or cloud around the secondary. This interpretation is supported and suggested by a comparison of the photometry of Barnes (1973) and of Lockwood (1972) done in the late 1960s with the more recent infrared photometry of Catchpole et al. (1980) (Fig. 1). A normal Mira energy distribution is consistent with the late 1968 photometry and with 3-14 micron measurements of R Aqr in 1968 by Stein et al. (1969). However, the 1975-77 spectrum is both fainter and redder in the 1-3 micron region than would be expected from the normal Mira distribution and the previous measures. These JHKL band results are consistent with the visual magnitude range during 1975-78 if the normal energy distribution is assumed to have been subjected to an intervening absorption $A_V \gtrsim 2$ magnitudes in 1975-78,

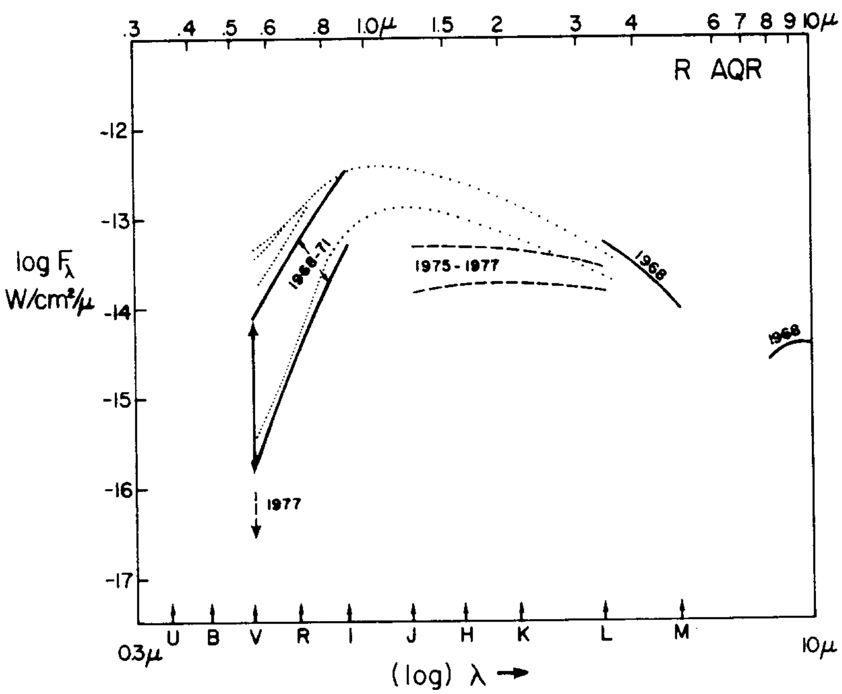

Figure 1. The energy distribution of R Aquarii in 1968 - 1971 (solid lines) and 1975 - 1977 (dashed lines) compared with a normal Mira distribution (dotted lines). VRI photometry is from Barnes (1973); the 3-14 micron measurement in 1968 was by Stein et al.(1969); the 1975 - 1977 JHKL photometry is taken from Catchpole et al. (1980). The normal Mira distribution was obtained by analysis of Mendoza's (1967) photometry for ο Cet and χ Cyg.

but not in 1968-71. From observations made in 1977, Wallerstein & Greenstein (1980) found internal $A_V \sim 2$ from the Balmer line ratios. It is therefore likely that the suppressed maxima in 1934 and 1978 are the result of the Mira component in the system being eclipsed by an extended gas cloud around the secondary star in the system.

From the spacing between the dips in the plot of magnitude at maximum light, the orbital period must be 44 years (41.5 times the period of the Mira, ensuring that alternate eclipses are difficult to observe due to the position of R Aqr near the sun at maximum light). The duration of the eclipse is $\lesssim$ 8 cycles = 8.5 years. In order to have an eclipse duration $\sim$20% of the orbital period one must have a) nearly equal masses and the occulting material filling the Roche Lobe of the secondary and/or b) a highly eccentric orbit with periastron occurring at an orbital phase opposite the current, eclipse, phase. Since the mass of the Mira is probably 1-2$M_\odot$ and the secondary, presumably a white dwarf, .5-1$M_\odot$, the period of 44 years implies a separation 14-18 A. U.: the Mira component, with $R \simeq$ 1-2 A. U., is nowhere near filling its Roche lobe. The material which is currently occulting the Mira must therefore have been accreted from a spontaneous wind from the Mira rather than from Roche Lobe overflow. The orbital velocities predicted from this are ~10 km/s, with maximum displacement expected in 1967 and 1945.

The interpretation of the anomalies in the light curve of R Aqr in terms of an eclipse is supported by the appearance of the O-C diagram for R Aqr (Figure 3). The current and 1934 "events" do not produce obvious effects on

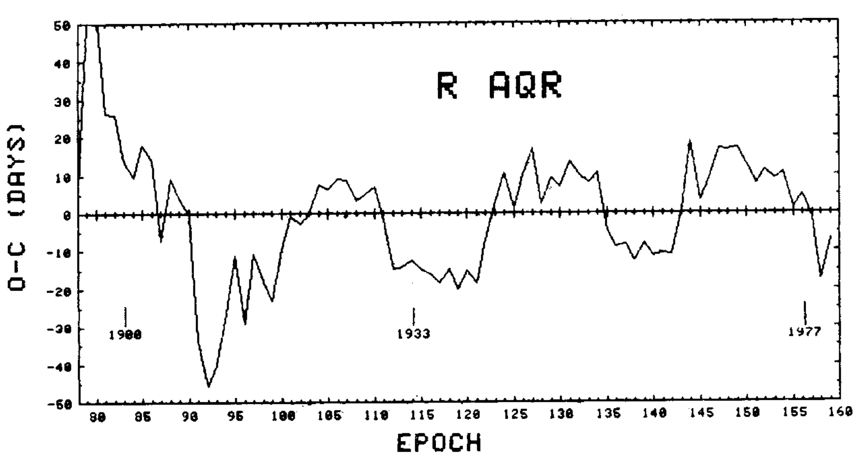

Figure 3. Observed - Calculated (O-C) times of maximum light for the Mira component. Calculated maxima use C = JD 2382892.4 + 386.30 E. The eclipse epochs are indicated on the figure.

the timing, as they would almost certainly do if they were caused by changes in the condition of the Mira component. However, if the anomalies in the light curve are caused by a combination of activity on the companion and the orbital geometry, no effect is expected on the timing of maximum light. There is a hint in the O-C of a possible resonance between the O-C period and the orbital period. (Mira O-C plots are very complicated in general, however, so this one must be interpreted with great caution. See Heiser (1975) for normal Mira O-Cs for comparison).

Previous eclipses of the Mira must have occured in 1890 -- when, as presently, R Aqr would have been difficult to observe at maximum and the data are correspondingly sparse -- and in 1846, where although there are not many observations available the maximum does appear to have been no brighter than 8th magnitude. Townley _et al_. (1928) noted that a spectrum of R Aqr taken in 1893 showed a faint nebular band and emission lines of hydrogen with no trace of an M type spectrum, confirming the likelihood of an 1886-94 eclipse.

A corollary of this hypothesis is that the true light curve of the Mira component alone is probably that seen in 1950-1965, with $\langle v_{max} \rangle = 6^{m}.9$ and $\langle v_{min} \rangle = 11^{m}.2$, rather than $\langle v_{max} \rangle = 6^{m}.5$ and $\langle v_{min} \rangle = 10^{m}.3$ as usually quoted (_General Catalogue of Variable Stars_).

The current eclipse should be nearly over, although observations made in late 1981 or early 1982 may still show effects of some intervening material from the outer parts of the circumstellar cloud or disk of the secondary. By mid 1982, however, the visual lightcurve and the energy distribution should be back to their normal values. The next eclipse is then expected in 2018-2026 AD.

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