IUE OBSERVATIONS OF THE PULSATION OF RY SGR

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Presented at the 87th Annual Meeting of the AAVSO, October 31, 1998

Abstract

The correlation of the onsets of RY Sgr's deep minima with pulsational phase suggests that the formation of dust is somehow driven by the pulsation. Observations were obtained using the International Ultraviolet Explorer (IUE) to investigate whether every pulsation cycle is accompanied by the condensation of small amounts of dust. During the 46-day interval covered by this data set, temperature and geometrical variations contributed 0.85 magnitude and 0.55 magnitude, respectively, to the visual light curve. Dust formation was a smaller effect, but may contribute 0.27 magnitude to the light curve. The phase of maximum extinction found here coincides with the phase at which the deep minima preferentially begin.

1. Introduction

Jacchia (1933) first noted that RY Sgr, in addition to having the deep minima typical of R CrB-type variables, also showed small-amplitude, semi-regular pulsations. This pulsation had a period of about 39 days and a peak-to-peak amplitude about 0.5 magnitude. Since then, the pulsations of RY Sgr have been studied by a number of researchers, including Alexander *et al.* (1972), Pugach (1977), Lawson *et al.* (1990), and Clayton *et al.* (1994). In addition to the photometric light curve, RY Sgr shows corresponding radial velocity variations (e.g., Alexander *et al.* 1972; Lawson *et al.* 1991). Like all R CrB stars, RY Sgr has a helium-carbon atmosphere (Danziger 1965); its pulsation appears to be the helium star analogue of the Cepheid phenomenon (Saio and Wheeler 1985).

Pugach (1977) and Lawson *et al.* (1992) found that onsets of RY Sgr's deep minima typically occur near the time of maximum of the pulsational light curve. These deep minima are caused by the formation of a cloud of carbon dust along our line of sight to the star (Loreta 1934; O'Keefe 1939; Alexander *et al.* 1972; Holm *et al.* 1982; Holm *et al.* 1987). The findings of Pugach and of Lawson *et al.* suggest that there is a link between the formation of dust and the pulsation. That being the case, the question arises as to whether every pulsational cycle is accompanied by the condensation of small amounts of dust, whether, in fact, one component of the light variation might be cyclical changes in circumstellar obscuration caused by the formation and dissipation of dust. The goal of this paper is to examine this question using ultraviolet spectroscopy from the IUE.

Investigating the link between pulsation and dust formation is difficult with ground-based photometry because the wavelength-dependent characteristics of thermal variation and of changes in obscuration are quite similar in the optical. However, obscurational and thermal effects can easily be distinguished in the ultraviolet because the effects of obscuration are largest at 2400Å to 2500Å, while the temperature effects increase toward shorter wavelengths.

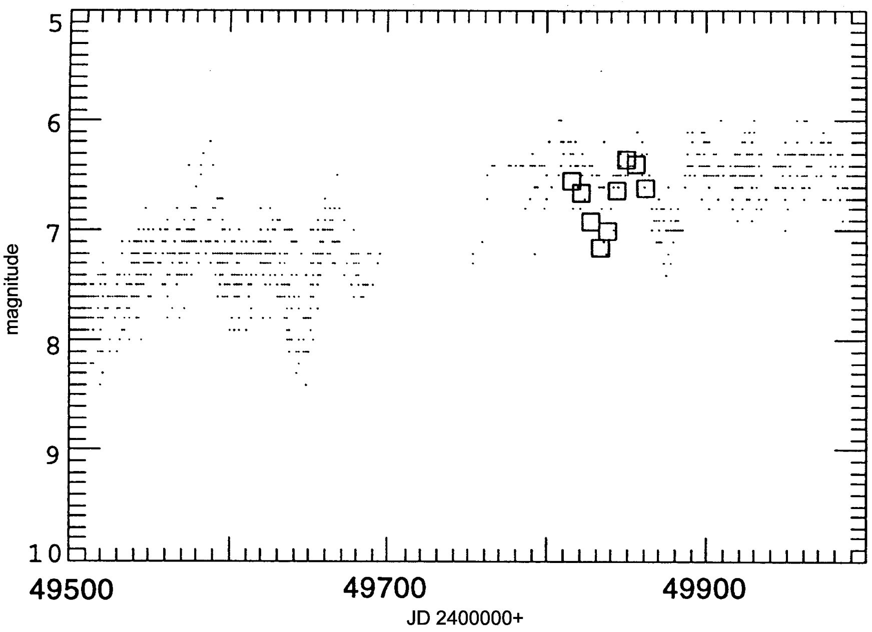

Figure 1. RY Sgr light curve from AAVSO visual observations (dots) and IUE's fine error sensor (squares). At the time of the IUE observations, the star appears to be almost fully recovered from its deep minimum of JD 2449160 to JD 24492270.

2. Observations and data processing

During April and May 1995, guided by visual observations from AAVSO observers, I obtained low-dispersion (6Å resolution), ultraviolet spectra of RY Sgr, using the IUE on nine occasions during a 46-day interval. During this observing run, RY Sgr went through one pulsational cycle, ranging between $V = 6.3$ and $V = 7.1$ as measured with the IUE's fine error sensor (FES). Figure 1 shows the AAVSO light curve around the time of the IUE observations.

Observations were obtained with the Long Wavelength Prime (LWP) camera, covering 2000Å to 3200Å, and with the Short Wavelength Prime (SWP) camera, covering 1150Å to 1975Å. During 4-hour-long observing sessions, spaced at intervals of 5 to 7 days, at least one optimally-exposed spectrum and one 5-times overexposed spectrum were obtained in the LWP, and one spectrum was obtained in the SWP, all through the large aperture. The 5-times overexposed spectrum was intended to increase the signal-to-usable-amounts in the 2000Å to 2600Å range. When RY Sgr was near the peak of its pulsational cycle, additional spectra were obtained in both the LWP and SWP cameras to increase the signal-to-noise of the results.

At this time, the IUE suffered from sunlight scattered into the telescope by a piece of spacecraft material, called the "Streak." The Streak increased the background level in the FES so that no usable guide stars could be found in the field of RY Sgr. Consequently, the observations were obtained under gyroscopic pointing control. The gyroscopes experience thermal and time-dependent effects, allowing the source to drift on the detector during long exposures and possibly allowing some errors in centering of the source in the aperture at the start of each observation.

For the analysis reported here, I used versions of the images and spectra processed by the IUE observatory using the NEWSIPS package (Garhart *et al.* 1997).

Merged energy distributions were derived for each observing date by combining all suitable spectra. One spectrum (SWP 54656 on May 11, 1995) was omitted from the analysis because excessive gyro drift probably allowed the aperture to move off the target during the 22-minute exposure. Before merging, wavelengths of the spectra were adjusted to correct for miscentering and for small amounts of drift. The amount of the adjustment was determined by cross-correlation with a standard spectrum. LWP and SWP spectra were merged separately, weighted by exposure duration, and then joined at 1975Å.

Scattered light from two sources was checked to ensure that no light contamination affected these results. First, scattering of photons of one wavelength into the detector locations of other wavelengths by the grating (Basri *et al.* 1985) was evaluated by means of modeling software provided by the IUE Data Analysis Facility. This software showed that, even though the stellar flux falls rapidly towards shorter wavelengths, there is essentially no contamination.

The other source of contamination considered was scattered sunlight from the Streak. This was evaluated by measuring the amount of signal coming through IUE's small aperture on two images, LWP 30476, a 22-minute exposure, and LWP 30529, a 26.5-minute exposure, for which the small aperture was pointed at empty sky. In both cases, the scattered light was insignificant, even when multiplied by 30 for the ratio of large-to-small aperture sizes (Garhart 1993).

3. Analysis and conclusions

The wavelength range over which RY Sgr was detected, 1800Å to 5200Å, is well suited to decompose the light curve into components driven by variations in radius, surface temperature, and dust, each of which behaves differently with wavelength. Flux changes caused by surface temperature variations increase monotonically towards shorter wavelengths. For RY Sgr, extinction due to circumstellar dust increases smoothly from the visible into the ultraviolet, has a maximum effect around 2400Å to 2500Å, and then decreases more rapidly toward shorter wavelengths (Holm *et al.* 1982; Holm *et al.* 1987). Purely geometrical variations have no wavelength dependence.

My analysis basically followed that used by Holm and Doherty (1988), with one improvement. As before, discrete light curves were formed using the FES measurement at 5200Å and seven narrow, ultraviolet bands, chosen to minimize the effects of strong absorption lines. The time-dependence of each of the three wavelength-dependent functions (geometrical, thermal, and extinction) was modelled by a sine function. The three sine functions were forced to have the same period, but allowed to have different epochs and amplitudes. An iterative, least-squares procedure was followed to reach a solution.

The principal improvement of the present analysis over that used by Holm and Doherty (1988) is that it uses model atmospheres by Asplund (Asplund *et al.* 1997) to model the variation of flux with temperature change, rather than using a blackbody approximation.

The solution found by this technique is

period = 42.1 days
epoch of visual maximum = JD 2449852.6
peak-to-peak amplitude at 5200Å due to area changes = 0.55 mag
epoch of maximum area = JD 2449859.3
amplitude due to surface temperature changes = 0.85 mag

epoch of maximum temperature = JD 2449848.8
amplitude due to dust at 5200Å = 0.27 mag
epoch of maximum extinction = JD 2449852.5
linear variation of dust extinction = –0.0006 mag/day

Figure 2 shows the eight simultaneous light curves and this fit to them.

This solution agrees qualitatively with the findings of earlier researchers. The 42-day period found in this study differs by about 10 percent from the 38-day period found by averaging over many cycles. This is not necessarily an indication of problems with the fit, because the actual light curve of this star is not strictly periodic, so it frequently deviates from the average. The epoch of maximum temperature found here is 3.8 days before the derived visual maximum. This is consistent with Alexander *et al.*'s (1972) finding that the bluest (U-B) colors occur before visual maximum. The (U-B) color is affected by both temperature and extinction, but my model indicates that temperature is more important for this star.

The determination of a decrease in extinction of -0.0006 magnitude/day is consistent with the late stages of recovery from RY Sgr's deep minimum which occurred during mid-1993.

This solution did find a cyclical variation in extinction, as would be expected if the condensation of dust was driven by some aspect of the pulsation. Furthermore, the time of maximum extinction, and therefore, maximum dust nearly coincides with the time of visual maximum. This is consistent with Pugach's (1977) finding that the onsets of deep

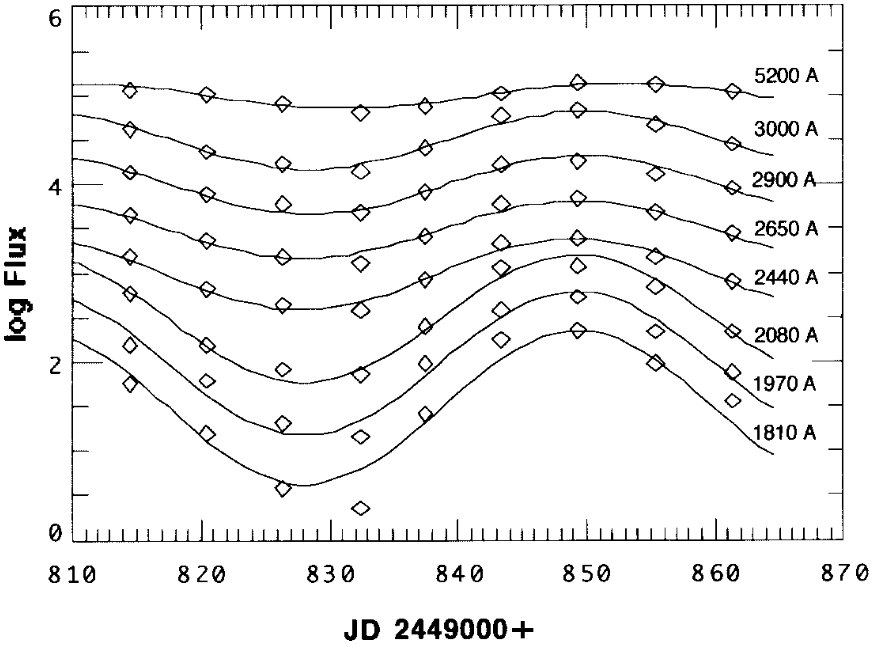

Figure 2. Multifrequency light curves for RY Sgr in seven selected ultraviolet bands and at 5200Å from the IUE's FES. The lines represent the modeled light curves discussed in the text.

minima coincide with the pulsational maxima, if the deep minima are triggered by a statistical fluctuation in a cyclical dust formation process or if, as is probable, dust formation is concentrated over surface locations that move in and out of our line-of-sight as the star rotates.

Because IUE data analyzed here cover only a single cycle, they do not prove that dust forms every cycle or that this dust triggers the deep minima, but they are another piece of evidence supporting this conclusion.

4. Acknowledgements

I thank the AAVSO observers and Headquarters staff for providing the visual estimates needed to select my target and for the evaluated observations needed to determine the context of the IUE data. I thank Dr. Dorothy Fraquelli and Mr. Forrest Hamilton for having obtained some of the IUE observations (while I attended the AAVSO meeting at Stamford, CT). I thank the staff of the former IUE observatory for their customary excellent support. I thank the Space Telescope Science Institute for partial support of my work, and the Laboratory for Astronomy and Solar Physics at Goddard Space Flight Center on whose facilities the analysis was performed. Finally, I thank Dr. Martin Asplund for providing the model atmospheres used here.

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