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The Changing X-Ray Properties of γ Cas

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1. Introduction

The origin of the hot X-ray emission from γ Cas has been a subject of long debate, with some authors advocating that it arises from a supposed undetected degenerate companion. Parmar et al. (1996) concluded that X-ray properties alone limited one's ability to understand this source. Thus, Smith et al. (1998, "SRC") obtained $\approx$1 day's simultaneous X-ray and UV spectroscopic and photometric coverage with the RXTE/PCA and HST/GHRS space-borne instruments on 14–15 March 1996. The observed 2–10 keV X-ray light curve was found to have two distinct components; short duration bursts ('shots)' superimposed on a slowly varying background, termed the "basal" flux, which modulates on a timescales of hours. SRC found two maxima in the RXTE light curve separated by 10 hours. These features coincided with the appearance of two "dips" in the UV continuum light curve sampled near λ1400. From these light curves and other arguments, SRC concluded that γ Cas's X-ray and UV continuum flux originated near the surface of the star and were modulated in intensity as the star rotated with a period of 1.123 days. This period was deduced by phasing of the X-ray minima obtained from our RXTE data with ASCA observations taken 10 days earlier and from comparisons of UV minima observed with the GHRS with similar minima seen in IUE observations taken two months earlier.

2. Refining the rotation period with archival IUE data

In order to check the generality of the rotation period derived by SRC, we have searched the IUE archive for intensive campaigns of γ Cas and found additional datasets in 1982.2 and 1982.7. Using a common period of 1.12277 days, we are able to bring the "dip" signatures of UV continuum light curves generated from high-dispersion SWP-camera into agreement, as shown in Figure 1. We note a repetition of the dips at times $\approx$14 and 41 hours, even though the amplitude of the second dip is much weaker than the first. Similarly, the dip at 24 hours probably corresponds to a strong one seen in recovery at time 0.0.

3. RXTE observations

In November 1998 we again used the RXTE to observe γ Cas for two rotation cycles to confirm the rotational modulation hypothesis. In this section we review the characteristics of this data and compare then with the data taken in 1996.

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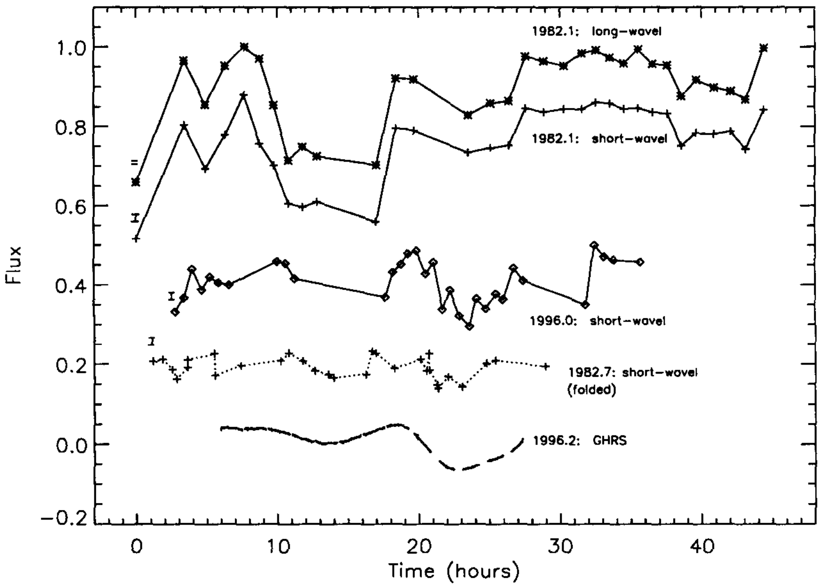

Figure 1. Folded UV light curves for γ Cas for four epochs.

3.1. Analysis of the X-ray flux variations

To check for rotational modulation effects we first separated the basal component from the shots by using the lower envelope of the observed fluxes. The mean basal flux in Nov 1998 was only ~60% of the earlier 1996 level, but it showed a much higher level of variability, with fluctuations occuring on a time scale of 1–2 hours rather than 10 hours. We believe that this variability masked the rotational effects since the basal X-ray fluxes seen in the second rotation cycle did not closely match those seen during the first. Thus, using two independent cross-correlation techniques, we have been unable to find any recurrent patterns in the basal flux timeseries. Remarkably, however, when we cross-correlate the *reciprocals* of the fluxes (which emphasize durations of low X-ray flux) we find cross-correlation peaks at multiples of 7.5 hours, including very strong maxima at 30 and 37.5 hours. These recurrent features are shown in Figure 2 for both the 1998 and 1996 datasets. We are not aware of other X-ray sources, Be or otherwise, which show this trait.

The shots have a wide distribution of maxima and durations ranging from a few seconds to at least several minutes. The median HWHM and amplitudes in 1996 & 1998 remained much the same at 25s and 30 cts s^{-1}, resp. Yet during this two year interval the contribution of the shots to the total flux fell from 33% to 21%. By subtracting the basal fluxes from the data we identified individual shots. We found that the occurrence rate of shots (flares) with a given energy decreased exponentially with increasing energy in both epochs, with the slope in 1996 being shallower than in 1998. This distribution differs from that of flares in active cool stars, a power-law, a fact which could have implications for an alternative flare-generation mechanism.

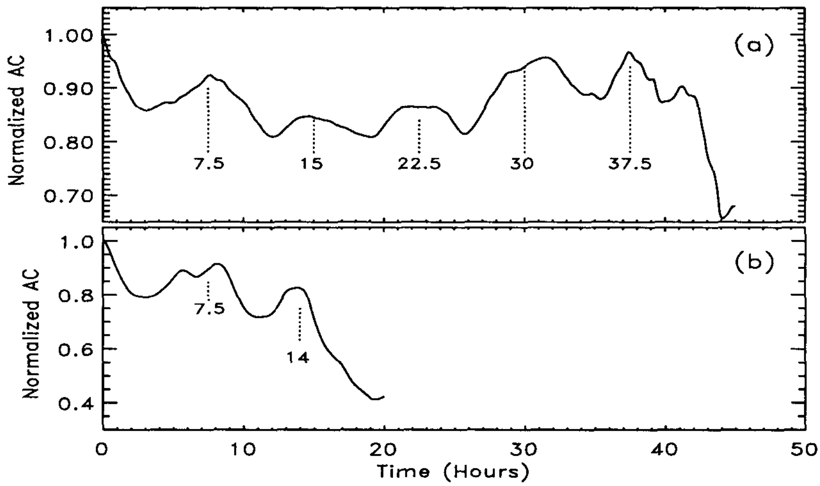

Figure 2. Autocorrelation functions of reciprocal X-ray fluxes for γ Cas during Nov., 1998 & March 1996; note peaks at 7.5 hr. intervals.

3.2. Color and Spectral Variations

The spectra from both epochs showed a continuum consistent with thermal emission, superimposed on which is a faint emission line at 6.8 keV due to Fe. The mean temperatures were nearly identical, 1.29×10^8K ±0.04 and 1.37×10^8K.

In order to examine thermal changes associated with flux changes, our data reduction included the construction of light curves at low ($\leq$4.1 keV) and high ($\geq$ 7.6 keV) energies. A color coefficient, R, was then determined from the ratio of the high to low energy fluxes. The temporal behavior of the color was determined by dividing the time series into 10s bins, calculating the value of R for each bin, and noting whether that bin was characterized by shot or basal emissions. In Figures 3*a* and *b* we compare the colors from the basal and shot components, averaged over each RXTE orbit. In both plots the variations of the two components usually track each other closely (noise is negligible). In 1996 the basal colors are generally smaller ("softer"). This is not true in 1998 when the basal colors are slightly higher. We draw two conclusions from this plot: (1) while the volumes emitting the flares and basal components may be different, the conditions of each are determined by a common factor and (2) the mean temperature differences between the two components can change very quickly.

We also constructed spectra for low- and high-flux states, using 45 counts s^{-1} as a common limit. In 1996 the ratio of the high-flux to low-flux spectra was a linearly increasing function. This is consistent with the lower colors of basal fluxes at those times and suggests that the basal emission was cooler than the shots. However, the same spectral ratio from the 1998 data exhibits a decrease toward higher energies and even a trace of downward curvature, suggesting that the basal emission was hotter than the shots. The contrasting behavior in the color ratios shows that the characteristics and interactions of the basal and flare-emitting volumes change with epoch, or possibly on shorter timescales.

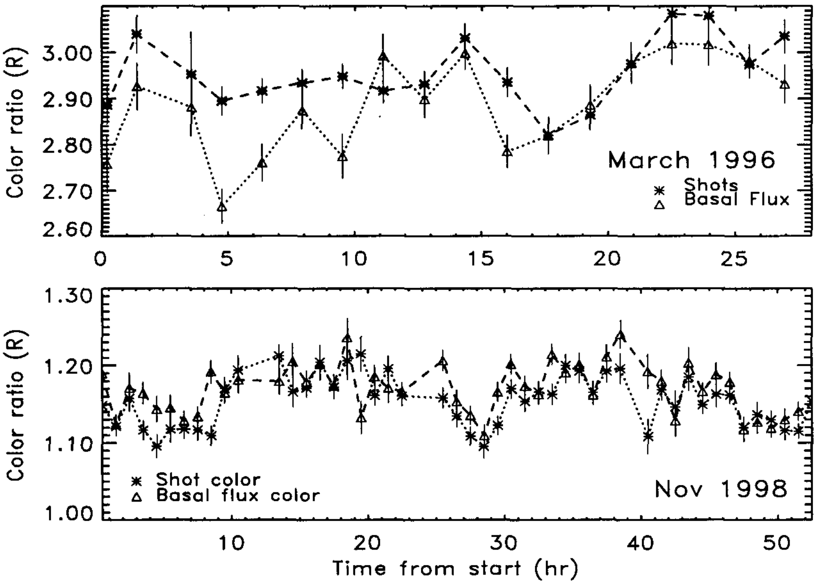

Figure 3. Comparison of X-ray (RXTE) "color" curves for basal and flare fluxes of γ Cas during 1998 (a) and 1996 (b).

4. Conclusions

This study shows that while several properties of the X-ray emission of γ Cas are similar at different times (e.g., mean temperature, average-flare statistics), other attributes can change. These include the mean flux level, the relative incidences of weak to strong flares, and the thermal properties over timescales of hours to several seconds. Additionally, cycle to cycle variations are large for both the IUE and X-ray light curves. Thus, one may not use small segments of a cycle in archival data to determine an ephemeris.

Our most surprising discovery is the cyclic suppression of X-ray shots every 7.5 hours in both epochs. We have no convincing interpretation for this behavior, but we suspect it is related to the influence of an external structure over the star with flare-sites on the star's surface. One possibility is that loops from the star become threaded and tangled with field lines in the one-armed disk.

We interpret the varying thermal characteristics of basal and flares with time, particularly on short timescales, as the responses of surface and "canopy" sites to a common disturbance responsible for their rapid and tremendous heating. Flare-loop models are being developed to quantify these ideas.

References

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