ROTATIONAL VARIATIONS IN THE NONFLARING OPTICAL AND X-RAY FLUXES OF YZ CMi

B.R. Pettersen
McDonald Observatory and Department of Astronomy
University of Texas at Austin

S. Kahler
American Science and Engineering, Inc.
Cambridge, Massachusetts

and

L. Golub and G.S. Vaiana
Harvard-Smithsonian Center for Astrophysics
Cambridge, Massachusetts

ABSTRACT

Rotational variations in $V$ band fluxes from the dMe star YZ CMi are compared with variations in the quiescent X-ray fluxes observed with Einstein. The $V$ band modulation due to presumed starspots is 12%, but the soft X-ray fluxes vary by no more than 50%, substantially less than expected from a simple extrapolation of the solar case.

I. INTRODUCTION

X-ray observations of dM stars from the Einstein Observatory have recently shown that these stars form a class of soft X-ray emitters (Vaiana et al., 1979; Rosner et al., 1979). The range of X-ray emission is large with the lower end being comparable to that of the Sun.

It has been known that some dMe stars show fairly periodic variations in their optical output beyond those due to binary eclipses or to flares. This phenomenon has come to be called the BY Draconis Syndrome after the star in which it was extensively studied (Knuckles, 1975). The optical variations have been interpreted by various authors as due to spots of lower effective temperatures than that of the surrounding photosphere. The variations occur as the spot regions move into and out of view due to the rotation of the star. The small observed color variations tend to rule out a pulsation hypothesis (Vogt, 1975).

In this paper we present optical observations and Einstein X-ray observations of the nonflaring state of the dMe star YZ CMi. These observations were obtained during and after an Einstein Guest Observer program to search for flares from YZ CMi. The results of that flare program will be presented elsewhere.

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II. OBSERVATIONS

The optical observations were made with the 91 cm telescope at McDonald Observatory using a photomultiplier with UBV (interference filters centered at Hα (9.4 Å and 126 Å FWHM) and Hβ (33 Å and 181 Å FWHM). Ten-second integrations were taken through each of the filters on YZ CMi and on two comparison stars (a and b on Andrews' (1968) finder chart). After sky subtraction and correction for extinction effects, the data were transformed to the standard UBVR system. Figure 1 shows the variations in the apparent V magnitude (λ ~ 5500 Å) of YZ CMi from 27 October to 2 November 1979. Errors in V are about 0.01. The upper panel shows the magnitude difference between the comparison stars.

A sine curve with a total amplitude of 0.12 for ΔV and period of 2.8 days was fitted to the data points. The period of YZ CMi was determined to be 2.78 d by Chugainov (1973). Visual observations during April and October 1979 were found to be consistent with this period. Since a ΔV of 0.12 corresponds to a flux ratio of Lv_{max}/Lv_{min} of 1.12, we have plotted a sinusoidal curve of Lv with a relative flux maximum of 3.36 and a minimum of 3.00 in Figure 2. The extrapolated minimum occurred at ~1100 UT on 25 October and the maximum at ~2000 UT on 26 October.

There were no detectable variations in the color indices U-B, B-V and V-R larger than 0.02. No significant variations were detected in the Hβ and Hα fluxes measured through the two sets of

![Figure 1](image1.png)  
**Figure 1.** Top: The measured V-band magnitude difference between the two comparison stars. Bottom: The apparent visual magnitude of YZ CMi (right scale) and the magnitude difference between YZ CMi and comparison star A. Errors in magnitudes are about 0.01.

![Figure 2](image2.png)  
**Figure 2.** The curve is the variation of the V-band fluxes as extrapolated from the observations shown in Figure 1 to the Einstein X-ray observations. The data points are the Einstein IPC counting rates. Note that the ordinate scale does not show 0.
narrow band filters, but we can only place the conservative limit of \( \pm 40\% \) on the variations of the equivalent widths of those lines during the interval of observations.

The X-ray observations were made in the 0.2 to 4 keV range with the Imaging Proportional Counter (IPC-A) of the Einstein Observatory (Giacconi et al., 1979) on two consecutive orbits of each of three consecutive nights. We found YZ CMi to be a source of quiescent X-ray emission. The quiescent counting rates corrected for gain changes and background counting rates are shown in Figure 2. An X-ray flare occurred during the early part of the second orbit of 25 October and was not used in the analysis. In addition, on 26 October there was a seven minute gap in the coverage of the first orbit and the data coverage of the second orbit was about half that of a normal orbit, so the three observing periods were treated equally for that day. No significant changes occurred in the quiescent X-ray fluxes on 25 and 27 October, but a 5\( \sigma \) increase occurred during the 26 October observations. This increase amounted to a 30\% increase in soft X-ray flux in about 97 minutes which corresponds to an e-folding rise time of 370 minutes. The approximate value of \( 3 \times 10^{28} \text{erg} \cdot \text{s}^{-1} \) which we calculate for the quiescent X-ray emission is similar to the U band emission of \( 4 \times 10^{28} \text{erg} \cdot \text{s}^{-1} \) and yields a value of -3.2 for \( \log L_x/L_{\text{bol}} \) (see Table I).

### TABLE I.

<table>
<thead>
<tr>
<th>Observed Einstein fluxes (IPC-A).</th>
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<tbody>
<tr>
<td>0.2-4 KeV Emission (ergs s(^{-1}))</td>
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<tr>
<td>----------------------------------</td>
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<tr>
<td><strong>25 October</strong></td>
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<tr>
<td>First Orbit</td>
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<td>Second Orbit</td>
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<tr>
<td><strong>26 October</strong></td>
</tr>
<tr>
<td>First Orbit (1)</td>
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<tr>
<td>First Orbit (2)</td>
</tr>
<tr>
<td>Second Orbit</td>
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<tr>
<td><strong>27 October</strong></td>
</tr>
<tr>
<td>First Orbit</td>
</tr>
<tr>
<td>Second Orbit</td>
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</tbody>
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III. DISCUSSION

We can now ask whether the observed rotational variations in the optical and X-ray fluxes of YZ CMi are consistent with what might be expected on the basis of the starspot hypothesis, using the Sun as a reference. The relative variations in solar X-ray luminosity, generally due to active region emission associated with spots and plages, are far greater than the corresponding optical luminosity variations. Kreplin (1970) reports a variation in the Solrad 44-60 Å fluxes of a factor of 20 from solar maximum to minimum and at minimum typical rotational variations of a factor of 2. Corresponding variations in the 8-20 Å fluxes are much larger. The optical variations due to spots and plages are less than 0.07% (Foukal and Vernazza, 1979). The X-ray variations are generally in phase with the solar rotation period as prominent active regions rotate into and out of view.

On YZ CMi the optical flux variation is 12%. Even if we take into account the smaller surface area of YZ CMi compared to that of the Sun (about 1/7), then the optical variation is more than an order of magnitude greater than solar. However, the largest X-ray flux point of Figure 2 is only 50% higher than the lowest point. The three daily averages of quiescent levels are within 25% of each other as shown in the Table, and the measurements represent nearly complete coverage of a stellar rotation. The X-ray variations are then smaller than typical solar, but the optical variations are far larger than solar. If we assume that the surface distribution of X-ray flux on YZ CMi is similar to that of the Sun except that the starspots are larger or more numerous and unevenly distributed in longitude, then we might expect that the 12% optical variation would result in a larger X-ray variation than the factor of 2 observed on the Sun. We note that this argument is based on a dark starspot model which is suggested by the lack of variation in the color indices (Vogt, 1975).

There is no evidence of any simple phase relationship between the X-ray and optical fluxes. The X-ray observations of 25 October were within 2 hours of the optical minimum and those of 26 and 27 October were about 11 hours before and 12 hours after, respectively, the optical maximum. The maximum and minimum quiescent fluxes were therefore nearly symmetrically situated with respect to the optical maximum. In the simple solar analogy we might expect the slowly increasing fluxes of 26 October to be associated with a starspot rotating into view, causing the optical flux to decrease. This is the opposite of what is observed.

The observational results might be explained if the scale height of the YZ CMi corona were substantially greater than that of the Sun, resulting in emission features large compared to the stellar radius. In the case of the Sun the ratio of the coronal pressure scale height (in which nearly all the X-ray emission occurs) to the radius is \( \sim 0.12 \) for a temperature of 3x10^6 K. Using \( R_{YZ} = 2.6 \times 10^{10} \) cm and a mass of 0.35 M_\odot (Pettersen, 1980), the same ratio for YZ CMi is only 0.14-0.28 for an assumed temperature range of 3-6x10^6 K. This ratio suggests that, as in the case of the Sun, the observed X-ray fluxes from YZ CMi could vary substantially due to rotation if the emitting regions were anisotropically distributed on the stellar surface. The lack of substantial variation seen in Figure 2 suggests that the X-ray sources are rather isotropically distributed over the stellar surface even though spots capable of modulating the optical flux by 12% over a rotation are also present.

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Since the quiescent X-ray emission of YZ CMi is approximately ten times that of the Sun and the area is seven times smaller than solar, it might be supposed that the lack of substantial X-ray flux variations is due to a nearly uniform distribution over the surface of many emission regions. However, this would also require a similar distribution of starspots and would not be consistent with the large optical modulation of 12%.

The gradual rise in the X-ray flux on 26 October may be an indication of coronal anisotropy. The 97-minute period over which the 30% increase occurred corresponds to an angular rotation of ~\( \theta \) for YZ CMi. The corresponding time period for the Sun is about 15 h over which time scale significant flux changes are often observed due to the occultation or reappearance of active regions at the limb.

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REFERENCES


