BeppoSAX observations of CF Tuc and TY Pyx

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Abstract. We present the results of BeppoSAX observations of the
RS CVn binary systems CF Tuc and TY Pyx. A long-duration flare was
detected on CF Tuc just at the beginning of the observation; a second
smaller flare occurred about half period later. The light curve of TY Pyx
shows a significant orbital modulation of the quiescent emission with pos-
sible evidence for eclipses, and strong flares. An analysis of the quiescent
and flaring emission for both stars is presented and discussed.

1. CF Tucanae

CF Tuc (HD 5303) is a partially eclipsing RS CVn binary consisting of a G0V
primary and a K4IV secondary, with an orbital period of 2.8 days and an in-
clination $i = 64^\circ$. During a ROSAT pointed observation it underwent one of
the most energetic and longest stellar X-ray flares ever observed (Kürster &
Schmitt 1996), with rise and decay times of 1.5 and 7 days and peak tem-
perature of $\sim 70$ MK. Variable X-ray emission was observed during the ROSAT
All-Sky Survey, and was interpreted as rotational modulation induced by two
active regions associated with photospheric spots (Kürster & Dennerl 1993). An
interesting characteristic of CF Tuc is its low metal abundance: Randich et al.
(1993) found photospheric iron abundances $\sim 0.32$ and $\sim 0.13$ solar for the G
and K star, respectively. Comparison of ROSAT and EUVE observations also
indicates a low coronal metallicity $\sim 0.1$ solar (Schmitt et al. 1996).

We have observed CF Tuc with BeppoSAX on July 18–21, 2000 for 315
ksec, corresponding to $\sim 1.3$ orbital periods. The MECS light curve is shown in
Fig. 1. A moderate, long-duration flare was detected just at the beginning of the
observation. The count rate increased by a factor $\sim 3$ in 5 hours and returned
to a quiescent level after 17 hours. A second smaller flare occurred about half
period later; this flare had a rise time of $\sim 1.7$ hours and a decay to the quiescent
level $< 10$ hours. During the second half of the observation the star was at a
quiescent level; some low-level variability is present, but we find no evidence of
rotational modulation of the X-ray emission.

We have performed spectral analysis of the LECS and MECS data in four
separate time intervals covering the two flares and the quiescent emission (see
Fig. 1). All spectra have been fitted with 2-T MEKAL models with variable global abundance, assuming $N_H = 2 \times 10^{19}$ cm$^{-3}$, as expected for the distance of CF Tuc (86 pc). The best fit parameters are given in Table 1. During quiescence we find temperatures of $\sim 9$ and $\sim 24$ MK, with emission measures of $3.4 \times 10^{53}$ and $5.4 \times 10^{53}$ cm$^{-3}$; the luminosity in the 0.1–10 keV band is $L_X \sim 9 \times 10^{30}$ erg s$^{-1}$. Both temperatures increase significantly during the first flare, reaching values of $\sim 21$ and $\sim 37$ MK; the peak luminosity is $L_X \sim 2 \times 10^{31}$ erg s$^{-1}$.

We find that the best fit metallicity is $Z \sim 0.1 - 0.2 Z_{\odot}$, thus confirming the previous ROSAT and EUVE results (Schmitt et al. 1996). The coronal metallicity is also consistent with the low photospheric abundance derived by Randich et al. (1993)

2. TY Pyxidis

TY Pyx is an eclipsing RS CVn binary system ($i = 88^\circ$) consisting of two nearly equal G5IV stars orbiting each other with a period of 3.2 days, and located at a distance of 55 pc. This system was observed for a full rotational period by EXOSAT (Culhane et al. 1990; Pres et al. 1995). During the observation strong flares were detected; both primary and secondary eclipses were evident in the 0.05–2.0 keV band, but were not observed at higher energies, implying a more extended distribution of the higher temperature component.

TY Pyx has been observed by BeppoSAX twice, in December 2000 and in May 2001. The first observation was performed on December 14–19, 2000, in two runs, lasting 305 and 70 ksec, separated by a gap of $\sim 6$ hours; in total, the observation covered $\sim 1.4$ orbital periods. The second observation was performed on May 9–11, 2001 and lasted 144 ksec, i.e. half orbital period. The MECS light curves for both observations are shown in Fig. 2.
Table 1. Best-fit parameters of the 2-T models for CF Tuc. Errors are 90% confidence ranges for three interesting parameters

<table>
<thead>
<tr>
<th></th>
<th>Z/Z⊙</th>
<th>kT1 (keV)</th>
<th>kT2 (keV)</th>
<th>EM1 (10^53 cm^-3)</th>
<th>EM2/EM1</th>
<th>χ²</th>
<th>dof</th>
</tr>
</thead>
<tbody>
<tr>
<td>peak1</td>
<td>0.11^+0.26_{-0.11}</td>
<td>1.83^+1.54_{-0.56}</td>
<td>3.21^+0.75_{-0.55}</td>
<td>4.5</td>
<td>2.3</td>
<td>0.62</td>
<td>87</td>
</tr>
<tr>
<td>dec1</td>
<td>0.23^+0.34_{-0.18}</td>
<td>0.71^+0.93_{-0.52}</td>
<td>2.08^+0.32_{-0.26}</td>
<td>1.7</td>
<td>5.8</td>
<td>0.51</td>
<td>69</td>
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<tr>
<td>fl2</td>
<td>0.20^+0.58_{-0.20}</td>
<td>0.75^+0.75_{-0.54}</td>
<td>2.81^+0.75_{-0.54}</td>
<td>2.3</td>
<td>4.2</td>
<td>0.56</td>
<td>42</td>
</tr>
<tr>
<td>q</td>
<td>0.12^+0.18_{-0.07}</td>
<td>0.80^+0.40_{-0.41}</td>
<td>2.08^+1.25_{-0.35}</td>
<td>3.4</td>
<td>1.6</td>
<td>0.56</td>
<td>122</td>
</tr>
</tbody>
</table>

Figure 2. MECS light curves of TY Pyx in Dec 2000 (top) and May 2001 (bottom). The intervals in which spectral analysis has been performed (labels as in Table 2) and the intervals corresponding to primary (P) and secondary (S) eclipses are also indicated.

In both cases the star was very active, showing strong flares, with increases in the count rate up to factors of 10, and typical rise and decay times of \(\leq 1\) hour and \(\sim 3 - 4\) hours, respectively. The quiescent emission shows significant
variability; the mean level of the emission is the same for both observations. We have folded the Dec 2000 quiescent light curve with the orbital period (Fig. 3): the quiescent emission is clearly modulated with the orbital period, with higher count rates during phases 0–0.5. The MECS light curve shows a small dip around the time of primary eclipse and possibly at secondary eclipse (see right panels of Fig. 3); however, given the quality of the data, we cannot exclude that they are due to intrinsic variability rather than to real eclipses. There is no evidence of eclipses in the May 2001 observation (Fig. 2).

Table 2. Best-fit parameters of the 2-T models for TY Pyx. Errors are 90% confidence ranges for three parameters.

<table>
<thead>
<tr>
<th></th>
<th>December 2000</th>
<th>May 2001</th>
</tr>
</thead>
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<tr>
<td></td>
<td>$Z/Z_\odot$</td>
<td>$kT_1$ (keV)</td>
</tr>
<tr>
<td>$f_1$</td>
<td>0.73$^{+0.79}_{-0.40}$</td>
<td>0.82$^{+0.24}_{-0.18}$</td>
</tr>
<tr>
<td>$f_2$</td>
<td>0.46$^{+0.50}_{-0.36}$</td>
<td>0.89$^{+0.50}_{-0.36}$</td>
</tr>
<tr>
<td>$q$</td>
<td>0.57$^{+0.34}_{-0.19}$</td>
<td>0.77$^{+0.08}_{-0.16}$</td>
</tr>
<tr>
<td></td>
<td>0.42$^{+0.67}_{-0.21}$</td>
<td>1.07$^{+0.28}_{-0.31}$</td>
</tr>
<tr>
<td></td>
<td>0.62$^{+0.50}_{-0.25}$</td>
<td>0.80$^{+0.10}_{-0.14}$</td>
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</table>
We have performed spectral analysis of the quiescent emission and of the strongest flares observed in both December 2000 and May 2001 (see Fig. 2), using 2-T MEKAL models and assuming $N_H = 1.2 \times 10^{19}$ cm$^{-3}$. The best-fit parameters are given in Table 2. The parameters of the quiescent emission are very similar in both observations, indicating that the corona of TY Pyx is quite stable over several months. We find temperatures of $\sim 9$ MK and $23 - 25$ MK, with emission measures of $\sim 1.6 \times 10^{53}$ and $\sim 2.1 - 2.4 \times 10^{53}$ cm$^{-3}$, respectively. Note that these values are very similar to those found for CF Tuc (apart from a 30\% difference in the EMs). The quiescent X-ray luminosity in the 0.1–10 keV band is $L_X \sim 6 \times 10^{30}$ erg s$^{-1}$. During the flares temperatures up to $\sim 50$ MK are reached, with peak luminosities of $2 \times 10^{31}$ erg s$^{-1}$.

We find that the coronal metallicity of TY Pyx is $Z \sim 0.5 - 0.7Z_\odot$. This value is consistent with the measured iron photospheric abundance of 0.63 solar (Randich et al. 1993).

3. Conclusions

- There is a very close similarity between the coronae of CF Tuc and TY Pyx (similar 2-T structure with only a small difference in the emission measures). Both stars have subsolar coronal metallicities.
- The derived subsolar abundances are in good agreement with the measured photospheric metallicities of the same stars (lower for CF Tuc than for TY Pyx).
- Both systems show high erratic variability with frequent flares detected.
- The quiescent emission of TY Pyx is modulated with the orbital period, but there is little evidence for eclipses. No modulation is observed on CF Tuc.
- There is no evidence of hard X-ray emission in the PDS instrument in both cases, consistently with the moderate temperatures reached during the flares.

References

J.F. Linsky & S. Serio, p. 443
Norbert Schulz prowled around the conference room, intimidating the other attendees