BROAD-BAND SPECTROSCOPY OF LATE-TYPE STARS WITH EXOSAT

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ABSTRACT

We analyze 6-300 Å observations of late-type stars obtained with EXOSAT. We discuss the problem of deriving source temperature and other physical parameters from broad-band EXOSAT observations.

1. INTRODUCTION

We have observed a number of late-type stars using the EXOSAT satellite. Our targets include active solar type stars of spectral types F8 to G5, as well as a group of flare stars of the BY Dra type. Preliminary results have been presented elsewhere (Landini et al. 1984a). In this paper we discuss the problem of deriving source temperatures from broad-band EXOSAT observations and we investigate whether an isothermal model can be used to adequately fit EXOSAT data.

2. OBSERVATIONS

The observations discussed in this report were obtained with the Low Energy Experiment LE1 on EXOSAT, using the Channel Multiplier Array (CMA) at the focal plane. Several filters were used in conjunction with the CMA. All targets were observed using the two softer filters 6 and 7 (Al/P and 3-Lexan, respectively), plus occasionally filter 3 (4-Lexan). For a few targets, we also detected weak signals using filter 8 (Boron), which has a harder spectral band, more similar to that of the EINSTEIN IPC. Background subtraction and source identification were performed using stardard procedures developed at ESOC.

The data have been analyzed using the model spectrum of Landini and Monsignori-Fossi (1984) which is appropriate for an optically-thin low-density plasma. The adopted spectrum has been proven to be in good agreement with similar calculations by Kato (1976), Mewe and Gronenschild (1981) and Gaetz and Salpeter (1983).

Since the Position Sensitive Detector (PSD) on EXOSAT was unavailable for our observations, source temperatures must be derived by comparing observed CMA count rates through different filters. This provides a colour temperature for the isothermal plasma emitting the observed broad-band fluxes. The details of the procedure are given in the following section.

3. SOURCE TEMPERATURES AND EMISSION MEASURES

As all our targets were observed using at least filter 6 (Al/P) and filter 7 (3-Lexan), a temperature can be derived from the ratio of count rates in these two filters. This procedure, although simple, is quite crude and results in large uncertainties on the derived colour temperatures.

A more refined procedure is to construct for each CMA filter the locus of emission measure (EM) vs temperature (T) allowed by the observed count rates (including errors) and to search for regions of common interception. An example for the star 111 Tau is shown in Fig. 1. As seen from the figure, EM vs T curves for the softer EXOSAT filters (Al/P and 3-Lexan) cross at a temperature of $(4.5\pm1.0) \times 10^6$ K, corresponding to an emission measure of $(2.0\pm0.2) \times 10^{29}$ cm^{-5}. This solution however is not unique, and other regions exist for which the isothermal approximation gives an acceptable fit (once errors are taken into account). One such region is at $T \simeq 5 \times 10^5$ K and the other is at all temperatures between $\simeq 10^7$ and 10^8 K. This behaviour is typical for all stars observed in our program.

The ambiguity can be reduced if one has observations in substantially different spectral bands, such as the Boron filter on EXOSAT or the EINSTEIN IPC. In particular, the addition of IPC data allows us to exclude the solution at $T \simeq 5 \times 10^5$ K, while the Boron filter reduces the ambiguity at temperatures larger than $\simeq 10^7$ K.

Fig. 1 shows also the existence of a systematic effect. The IPC and Boron curves run lower than what expected from the crossing point of the Al/P and 3-Lexan filters, thus suggesting a somewhat lower source temperature. This effect is typical of all our observations. The agreement between the Boron filter and the IPC argues against temporal variability as the cause of the discrepancy. More likely, this effect may be due to one of the following causes. Either fluxes in the EXOSAT Al/P and 3-Lexan filters are overestimated, for instance owing to contamination by UV photons, or the assumption of an isothermal source is not very good. The first alternative is unlikely. We have estimated the degree of UV contamination of EXOSAT filters and we have found it to be negligible (less than 1%) for all stars in our program. More likely, a fraction of the fluxes measured by the Al/P and 3-Lexan filters (and also by the 4-Lexan filter) may be due to plasma at a much lower temperature than that responsible for the emission in harder spectral bands.

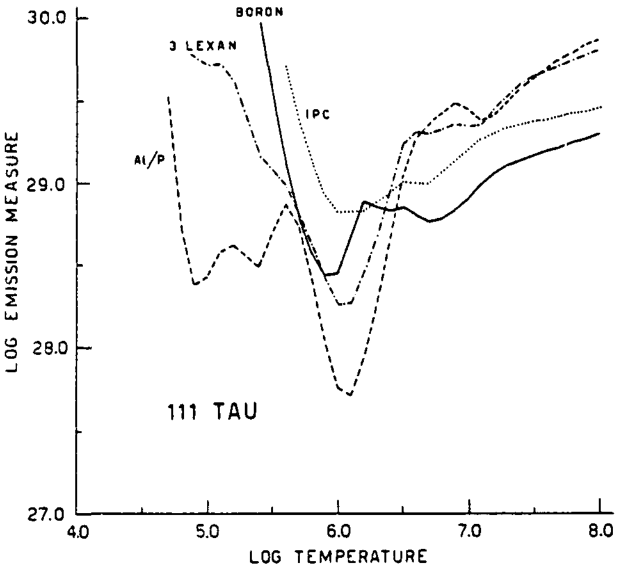

Fig. 1 - Loci of linear Emission Measure vs Temperature allowed by the observed EXOSAT and EINSTEIN X-ray fluxes.

Remaining in the limits of an isothermal approximation, we can derive a better estimate of the coronal temperature by using all available data and by determining the region of minimum deviation of all EM vs T curves from a common interception. When applied to 111 Tau, this procedure gives a temperature of 2.8 x 10^6 K, some 40% lower than the temperature derived using only the Al/P and 3-Lexan observations. The corresponding emission measure is 8 x 10^{28} cm^{-5}.

As a check of the goodness of the isothermal model, we have used the derived temperatures and emission measures to calculate expected count rates in various filters for comparison with observations. The results for 111 Tau are shown in Fig. 2. It appears that, within the errors, the isothermal model is able to give a sufficiently accurate fit to the observed count rates in all EXOSAT filters and in the IPC. However the systematic higher temperatures obtained using softer filters indicates the opportunity to investigate multi-temperature models.

Most stars in our program have temperatures around 3 x 10^6 K and linear emission measures in the range 3 x 10^{28} - 2 x 10^{29} cm^{-5}. For the flare star CC Eri we derive a temperature of $\simeq 10^7$ K and emission measure of 9 x 10^{29} cm^{-5} (cf. Landini et al. 1984a). The derived luminosities in the spectral band 0.04 - 2 KeV are in the range 4 x 10^{28} - 4 x 10^{29} erg s^{-1}, one to two orders of magnitude larger than for the Sun. This is consistent with the relatively high rotation rate and active nature of all stars in our program.

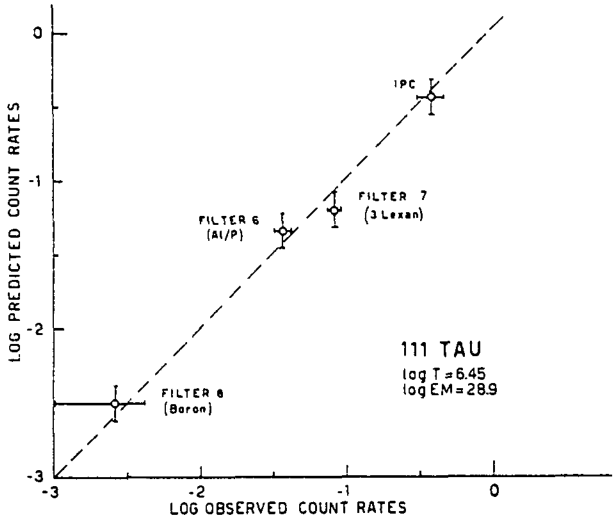

Fig. 2 - Observed and predicted EXOSAT and EINSTEIN count rates for an isothermal model of 111 Tau.

4. CONCLUSIONS

From the analysis above we draw the following conclusions:

a) An isothermal coronal model can be used as a first approximation to interpret EXOSAT observations of late-type stars.

b) Temperatures derived using softer EXOSAT filters (Al/P, 3-Lexan and 4-Lexan) are systematically higher by 30% to 50% than those obtained using also fluxes in harder spectral bands (Boron and/or IPC).

c) The systematically different temperatures obtained using different spectral bands suggest that a multitemperature model will probably fit better our EXOSAT observations.

We are exploring the latter possibility by using the loop model of Landini et al. (1984b). Results of this analysis will be published in a separate paper.

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