The longest X-ray observation of AB Dor

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A set of XMM observations of AB Dor (K1 V-IV) has been collected totalling more than 460 ks (see Table). The spectra corresponding to its highest and lowest emission levels are presented in order to compare the Emission Measure Distribution, abundances and electron density of the two "extreme" stages of this well known young star. The results are compared to those obtained with *Chandra*/HETGS and EUVE for the same source.

Table 1
XMM-Newton observations of AB Dor

Rev.	Date	pn	mos	RGS t_{exp}(ks)	RGS 2 cts/s
072	1 May 2000	X	–	40+12	1.24
091	**7 Jun 2000**	**X**	**–**	**54**	**1.01**
162	27 Oct 2000	X	X	57	1.26
185	11 Dec 2000	X	X	56+8+20	1.40
205	**20 Jan 2001**	**X**	**X**	**51**	**1.78**
266	22 May 2001	X	X	48	1.28
338	10 Oct 2001	–	X	38	1.24
375	26 Dec 2001	–	X	4	1.30
429	12 Apr 2002	X	X	43	1.07
462	18 Jun 2002	X	X	35	1.51

Table 2
AB Dor observations with other instruments sensitive to similar temperature range

Instrument	Date	t_{exp}(ks)
EUVE	4 Nov 1993	146
EUVE	12 Nov 1994	102
Chandra/HETGS	9 Oct 1999	52

Note that the two EUVE spectra were summed for the EMD analysis [1].

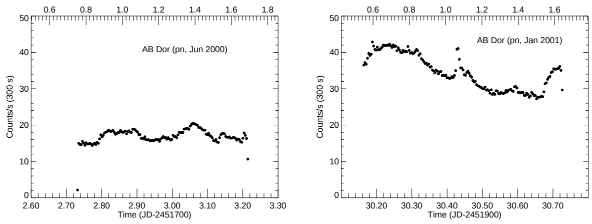

Figure 1. XMM-Newton/Epic-PN light curves of AB Dor in rev. #091 (*left*) and #205 (*right*). Upper axis corresponds to rotational phase. The observation of rev. #205 is suggestive of rotational modulation.

1. Introduction

AB Dor (K1 V-IV) is a well-known active young star, with a period of $P_{\rm phot}$ ~12.3 hr, and two wide companions that do not contribute significantly to the X-ray emission. A set of XMM observations of AB Dor (K1 V-IV) has been collected totalling more than 460 ks (see Table 1). The spectra corresponding to its highest (rev. # 205) and lowest (rev. # 091) emission levels are analyzed in this work. The X-ray light curves during these observations are shown in Fig. 1 and the spectrum of rev. # 091 in Fig. 2. Previous *Chandra*/HETGS and EUVE observations have been considered (see Table 2) in order to compare the performance and results from different high spectral resolution instruments which provides information on lines formed in similar ranges of temperature.

2. Methodology

A line-based method is employed in the analysis, considering first the Fe lines only, and incorporating progressively other elements that allow us to extend the temperature range on which the plasma Emission Measure distribution (EMD) is reconstructed. An iterative procedure is followed as explained below:

1.– 2-T fit of selected line-free regions in the spectra. This fit yields an initial estimate of the continuum, needed for the line measurements.

2.– Measurement of the lines. The MIT/CXC *Interactive Spectral Interpretation System* (ISIS, [2]) software allows us to use delta functions convolved with the Line Response Function of either *Chandra* or *XMM*/RGS data. Simultaneous fit of

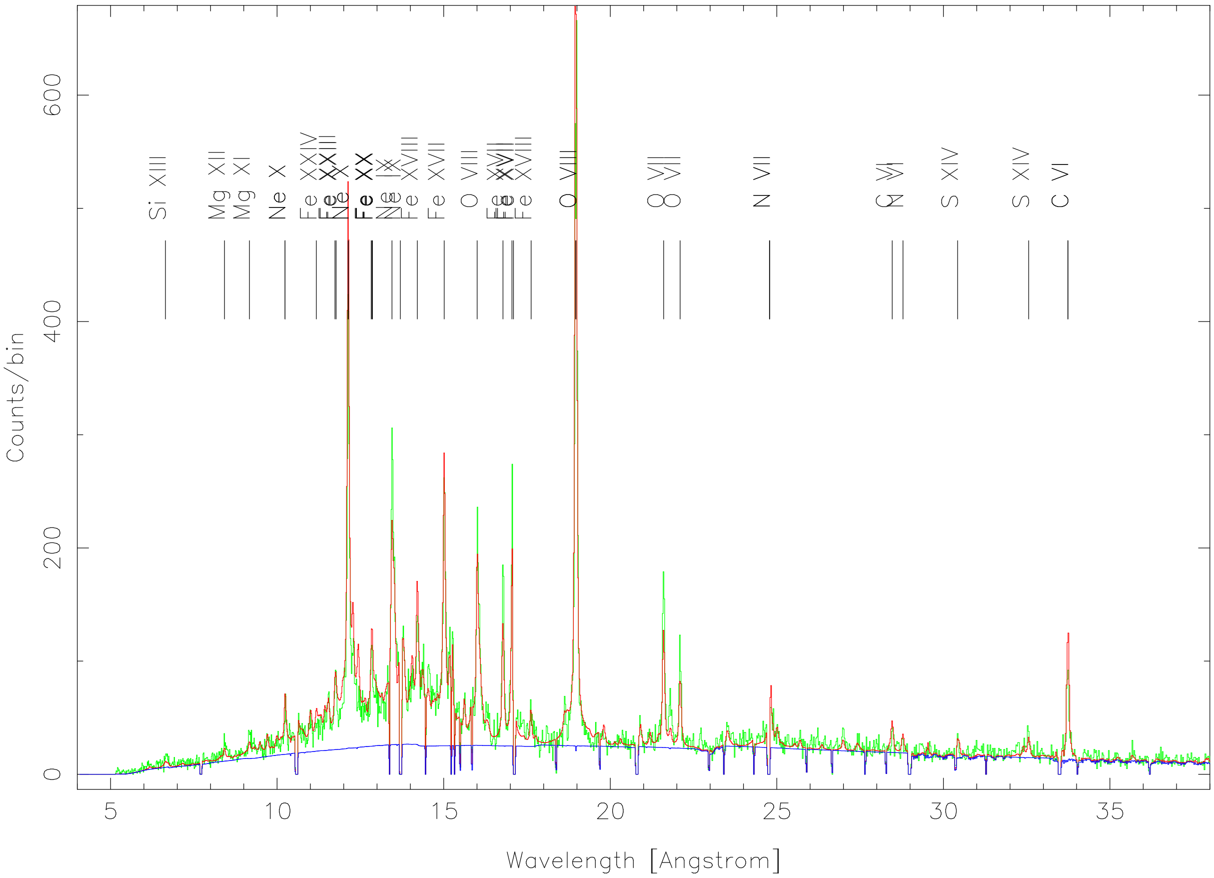

Figure 2. AB Dor RGS 1 spectrum in rev. 091 (*green*), and model derived from Chandra/HETG EMD (*blue*: continuum only, *red*: continuum+lines). Note that a false continuum is created by the LSF of the lines, making difficult the measurements in the range 8–18 Å. Most prominent lines are marked.

groups of lines is required in most cases.

3.– Theoretical fluxes are calculated using APED 1.2 and a trial EMD. Only Fe lines are employed to avoid abundance uncertainties. Theoretical fluxes are compared to observed fluxes in order to improve "by hand" the EMD. Electron densities, derived from He-like triplets, can be included in the analysis.

4.– Neon lines are added to the analysis to extend the EMD to lower temperatures. The Ne abundance is determined in the process. Oxygen lines provide information down to log T(K)$\sim$6.2, and the O abundance is estimated.

5.– The rest of the elements are added one by one in the analysis, in order to calculate the abundances that better fit their fluxes, leaving the EMD unchanged.

6.– Recompute the continuum and repeat steps 2–6, allowing changes of the EMD shape once all elements are included in the fit.

3. Instrument comparison

The analysis results from the different instruments (see Figs. 3, 5) yield some differences in the EMD (note that this could eventually influence the determination of the element abundances), possibly due to several reasons, beside variability:

EUVE:

– The range log T(K)$\sim$6.2–6.7 is poorly constrained for stars with hot coronae. There are only 3 lines of Fe XV and Fe XVI, also affected by the uncertain correction for the interstellar

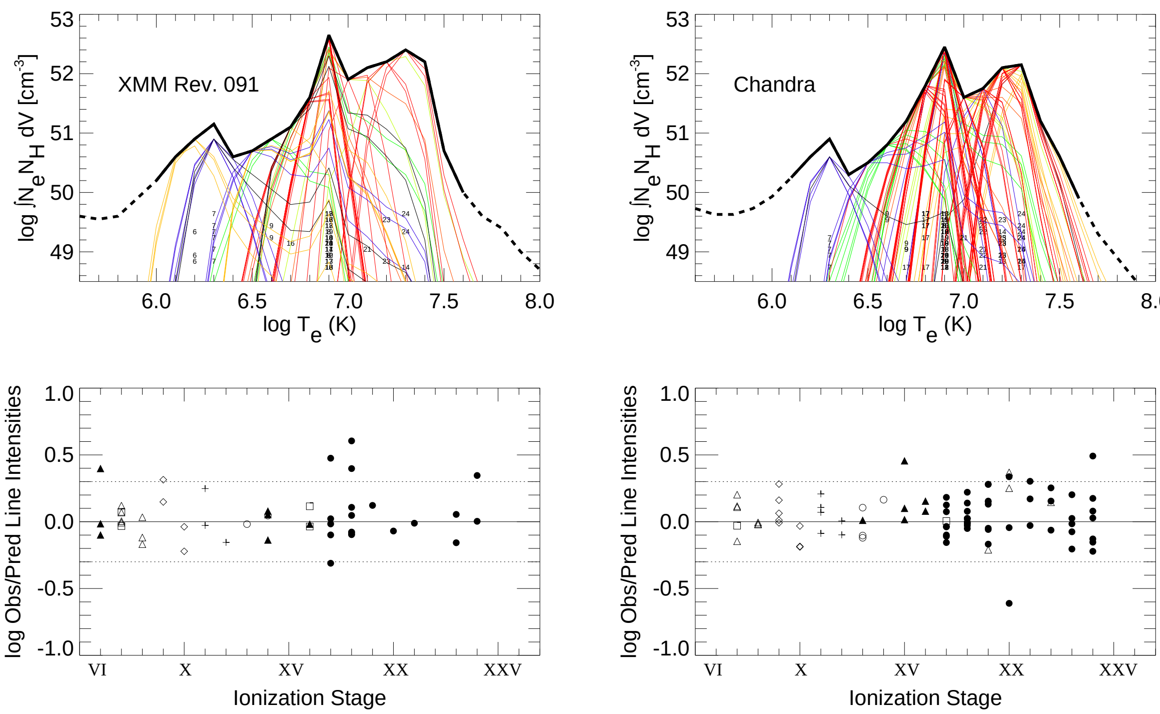

Figure 3. Emission Measure Distribution (EMD) of *XMM* rev #091 (*left*) and *Chandra*/HETG (*right*). Upper panel shows the EMD (thick line) and the contribution of each line employed in the fit, weighted by the EMD (thin lines). Symbols in lower panel are Fe (filled circles); Ne (diamonds); Mg (+); N, Ar (squares); O, Ni (open triangles); C, S, Ca, Al (filled triangles).

medium (ISM) absorption.

– The range log T(K)$\sim$7.2–7.4 is also poorly constrained (only 3 lines present in the EUVE range).

– For AB Dor, abundances from other elements can not be obtained, since only Fe lines are available.

– *However*, EUVE provides the largest temperature coverage using only one element (Fe).

XMM/RGS

– Calculation of abundances may condition the shape of the EMD in the range log T(K)$\sim$6.2–6.6.

– Difficulties for line measurements due to extended LSF (see Fig. 2).

– Possible problems of flux calibration in RGS.

– No information below log T(K)$\sim$6.0 (AB Dor-like stars).

– *However*, XMM/RGS provides the largest collecting area, and it can be used in combination with EPIC.

Chandra/HETGS

– As for XMM, the low temperature tail of the EMD depends on the accuracy of the abundance determination.

– Lower collecting area than XMM.

– Generally no information below log T(K)$\sim$6.1 (AB Dor-like stars).

– *However*, *Chandra*/HETGS has the best spatial and spectral resolution. Its calibration status seems quite stable, and for AB Dor the results are consistent with those of EUVE.

Under ideal circumstances (i.e., same flux levels) the combination of *Chandra*/HETGS and EUVE observations provides the best tool for the analysis of the Emission Measure Distribution. However, when the source is variable some caution must be taken. The initial results obtained with *XMM-Newton* need to be improved by fit-

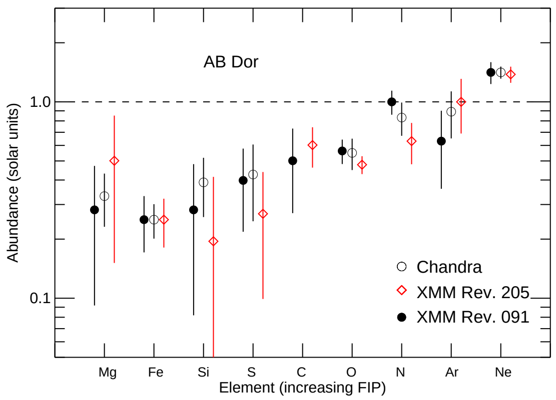

Figure 4. Elements abundances (solar units) in XMM and Chandra/HETG.

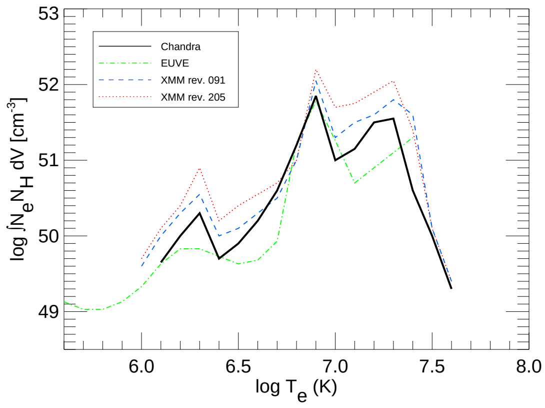

Figure 5. EMD derived from XMM, Chandra/HETG and EUVE observations. Fe solar abundance is assumed for comparison.

ting together a larger number of lines in the range ∼8–18 Å.

4. Abundances and electron densities

Element abundances are generally consistent between *Chandra* and XMM/RGS. During the two observations of XMM no substantial changes are detected in the abundances relative to Fe.

XMM observations do not show a substantial change of density at log T(K)∼6.3 derived from the O VII triplet between the two stages of activity. Density determined in the Chandra spectrum is consistent with the values measured with XMM/RGS. The measured line ratio in the Chandra spectrum of the Ne IX triplet (formed at log T[K]∼6.6), suggests a higher value of the density at that temperature (log $n_e[cm^{-3}]\sim 11.3$). However, an accurate determination of the continuum and an estimation of the blends by other lines is necessary before getting conclusions. EUVE line ratios [1] point towards even higher values (log $n_e(cm^{-3})\sim 12.5$) measured at log T(K)∼7.0, but further confirmation with higher resolution spectra (i.e. Chandra/LETGS) would be desirable.

5. Conclusions

– All EMDs of AB Dor show consistently the main peak at log T(K)∼6.9.

– Secondary peaks are present also at log T(K)∼6.3 and log T(K)∼7.3.

– Abundances calculated during the EMD fit show an inverse-FIP effect, like in other active stars.

– The increment of activity between the two XMM observations seems to affect the whole EMD, and in particular the high-T tail.

– The characteristics of the EMD, densities and coronal abundances in AB Dor are similar to those of active binary systems.

– Comparison between observations of EUVE, XMM/RGS, and *Chandra*/HETG seem to point to the latter as the most reliable instrument for EMD analysis on stars with hot coronae.

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