EMISSION MEASURE MODELING AND ABUNDANCE DETERMINATION OF AT MIC OBSERVED BY MEANS OF RGS AND EPIC-MOS ON BOARD XMM-NEWTON

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Abstract

The X-ray spectrum of the late-type M-dwarf binary AT Mic (dM4.5e+dM4.5e) is observed in the wavelength range from 1 - 40 Å by means of RGS and EPIC-MOS on board XMM-Newton. To these data we have performed a 4-temperature fit and a self-consistent DEM-modeling using the SPEX-code. Here we report the temperature distribution, Emission Measure (EM) and abundances of this bright X-ray source. The temperature range stretches from 1 to 80 MK. The total volume emission measure in this temperature interval is $\sim 10.5\times10^{51}$ cm^{-3}. The dominant line-forming emission measure is around 8 MK. The high-resolution spectrum of AT Mic, obtained by RGS, is dominated by the H- and He-like transitions of C, N, O, and Ne and by Fe XVII lines. The EPIC-MOS spectrum below 10 Å shows H- and He-like Si and the iron K-shell transitions. The abundance pattern in AT Mic suggests the depletion of low-FIP elements relative to high-FIP elements, indicating the presence of a possible IFIP effect in this active star.

Key words: Stars: individual: AT Mic – stars: coronae – stars: late-type – missions: – XMM-Newton

1. Introduction

Hot outer atmospheres (coronae) are very common for relatively cool stars in the spectral classes F-M. Many of these coronae are characterized by magnetic loops and temperatures up to 20 MK and densities $n_{\rm e} > 10^{10}$ cm^{-3}. High-resolution spectroscopy of stellar systems available from Chandra and XMM-Newton (Brinkman et al. 2000; Brinkman et al. 2001, Canizares et al. 2000) has shown coronal behaviour clearly different from the solar situation. Late type stars (M and K dwarfs) show more magnetic activity and therewith higher coronal temperatures than the Sun. To understand the mechanisms that underly the high temperatures and variety in the coronal systems we investigate the X-ray spectra of F-M stars. Here we present the investigation of the more active late-type M-star AT Mic. AT Mic is an dM4.5+dM4.5 binary at a distance of 10.22 pc and a position $20^h41^m51.15^s$, $-32^o26'06.8''$ (SIMBAD catalogue, 2000). Both components are known to have the capability of flaring (Joy & Wilson 1945).

2. Observations

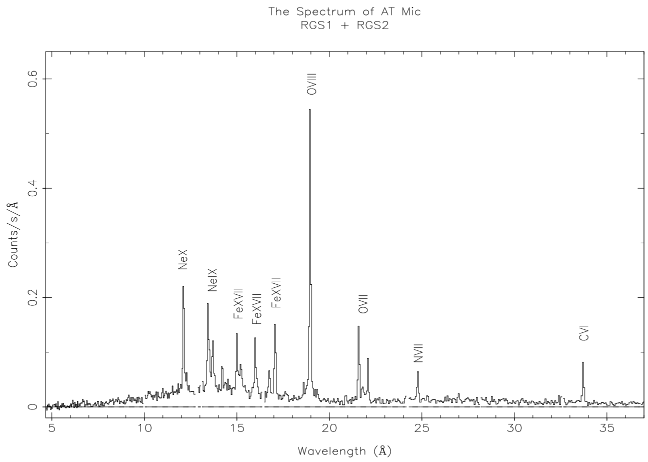

Figure 1. The spectrum of AT Mic observed by RGS1 and RGS2 in the wavelength region from 5 to 37 Å.

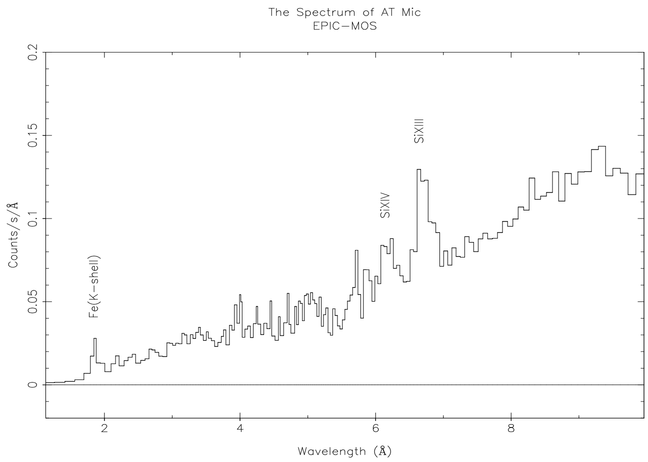

Figure 2. The spectrum of AT Mic observed by EPIC-MOS in the wavelength region from 1 to 10 Å.

Proc. Symposium *'New Visions of the X-ray Universe in the XMM-Newton and Chandra Era'* 26–30 November 2001, ESTEC, The Netherlands
ESA SP-488, August 2002 eds. F. Jansen & TBD

The X-ray spectrum of AT Mic was observed by RGS and EPIC-MOS on board XMM-Newton on 14 October 2000 during revolution 156. The exposure time was 28.3 ks for RGS and 25.4 ks for EPIC-MOS. The observed spectra are shown in Fig 1 (RGS) and Fig 2 (EPIC-MOS).

The RGS spectral resolution is $\Delta\lambda \sim$0.07 Å, with a maximum effective area of about 140 cm^2 around 15 Å. The wavelength uncertainty is 7-8 mÅ. As can be seen from Fig 1 and Fig 2, EPIC-MOS has a low resolution, but a high sensitivity compared to RGS. The total RGS spectrum runs from 5 to 37 Å. From the EPIC-MOS spectrum we used the wavelength range up to 14 Å. For more instrumental details on RGS and EPIC-MOS see den Herder et al. (2001) and Turner et al. (2001), respectively. The obtained data were processed by means of the XMM-Newton SAS using the calibration of September 2001.

3. Analysis

From the figures 1 and 2 it is clear that the X-ray spectrum obtained by RGS in the wavelength range from 5 to 37 Å is dominated by H- and He-like transitions of C, N, O, and Ne and by Fe XVII lines, while the low-resolution (high sensitivity) EPIC-MOS spectrum shows the Fe K-shell transitions around 1.9 Å and the H- and He-like transitions of Si. The spectrum shows the corona of AT Mic in a "quiescent" state. No time-variability or flaring, as observed e.g. by Pallavicini et al. (1990), is seen in our observations. The data have been described with a 4-T model using the SPEX code (Kaastra et al. 1996a) in combination with the MEKAL (Mewe et al. 1995) database[1]. The 4 temperatures are shown in Table 1. They cover a range from 1 to 30 MK. Also given in Table 1 are the emission measures in 10^{51} cm^{-3}, together with abundances. The absolute abundances are strongly correlated to the emission measure and are difficult to determine relative to the continuum. However, the abundance *ratios*, normalized to oxygen, are more robust. Therefore the ratios A/O are given in Table 1. The values are normalized to their corresponding solar photospheric values (Anders & Grevesse 1989), except for iron. For Fe we have changed the value of log A_{Fe} from 7.67 (Anders & Grevesse 1989) into 7.51. Here log A_{Fe} is the logarithmic of the Fe-abundance relative to log A_H=12.0. The values given in Table 1 are values averaged over the different fits, together with their standard deviations (within parentheses). The (less active) solar corona shows a F(irst)I(onization)P(otential) effect (Feldman et al. 1992). This effect implies that elements with a low value for the first ionization potential show enhanced coronal abundances, relative to photospheric values. Compared to solar photospheric abundances the value of Fe is relatively low, indicating an inverse FIP-effect. The same was observed by Güdel et al. (2002) and Audard et al. (2002) for active late-type stars.

[1] http://saturn.sron.nl/~ kaastra/spex/line.ps.gz

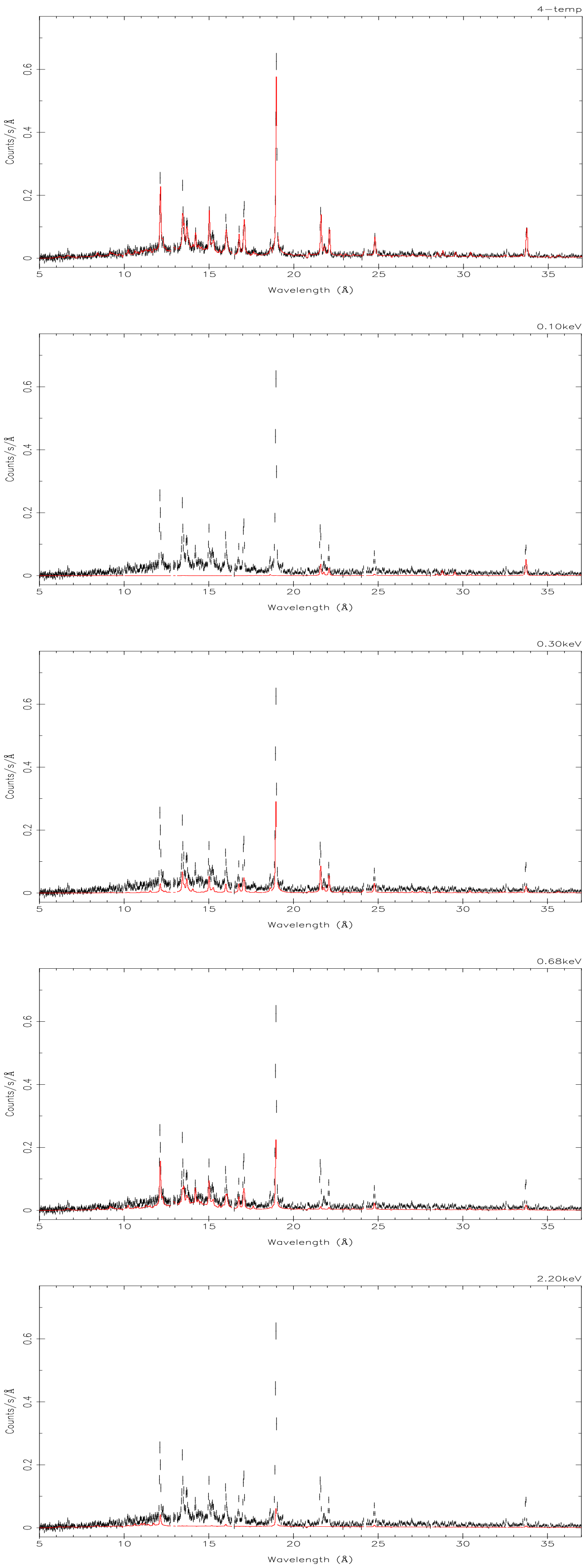

Figure 3. Top panel: RGS spectrum of AT Mic with the 4-T best-fit model. The panels below give the contributions of each individual T-component

Table 1. 4-T model fit to the RGS and EPIC-MOS spectrum of AT Mic. Values in parentheses are standard deviations. Abundances are relative to the solar photospheric values except for Fe (see text).

Parameter	Value
log N_H [cm^{-2}]	18.30
T_1 [keV]	0.09(0.03)
T_2 [keV]	0.30(0.02)
T_3 [keV]	0.68(0.01)
T_4 [keV]	2.20(0.04)
EM_1 [10^{51}cm^{-3}]	1.2(0.5)
EM_2 [10^{51}cm^{-3}]	1.7(0.4)
EM_3 [10^{51}cm^{-3}]	4.2(1.5)
EM_4 [10^{51}cm^{-3}]	4.6(0.4)
O	1.13(.24)
C/O	1.04(0.16)
N/O	1.38(0.07)
O/O	1
Ne/O	2.19(0.34)
Fe/O	0.55(0.12)
Distance of AT Mic	10.22pc

Figure 3 shows the spectrum fitted with four temperature components (upper panel) and the individual contributions of the four temperature components (4 lower panels). From this figure it is clear that the line spectrum is mainly produced by T_2 (0.30 keV) and T_3 (0.68 keV), while the hot component (2.20 keV) contributes to the continuum below 10 Å and the Fe K-shell lines in the EPIC-MOS observation. The influence of the cool component (T_1) is not very obvious. The total emission measure of the three hotter components is $10.5(1.6)\times10^{51}$ cm^{-3}. Monsignori Fossi et al. (1995) have determined an emission measure maximum of about 3×10^{51} cm^{-3} around 10 MK (their Figure 5), based on EUVE observations. This agrees well with our emission measure for T_3(0.68keV). Pallavicini et al. (1990) observed AT Mic with EXOSAT during a flare. They obtained prominent temperatures of about 40 MK, but with a higher emission measure, due to the flaring state in which the count rate increased by a factor of $\sim$ 7. Their high temperature confirms our hot component, but with a smaller emission measure.

Apart from a 4-temperature fit we have performed a self-consistent DEM-modeling to the RGS and EPIC-MOS spectrum of AT Mic, applying the regularization method present in the SPEX-code (see Kaastra et al. 1996b). The advantage of the regularization method is that it produces a smooth distribution over a wide energy range. In this DEM-modeling the abundances, as obtained in the 4-T fitting (Table 1), have been used. The obtained self-consistent emission measure of the corona of AT Mic is shown in Figure 4. This emission measure runs from 1 up to about 80 MK. The indicated uncertainties of the emission measure are given for the individual temperature bins. The uncertainties are small, except for the low temperatures ($T < 1$ MK), corresponding with the T_1 component of the 4-T fit. The DEM temperature structure agrees with the four temperature components from the multi-temperature fit if we take into account the uncertainties corresponding with the standard deviations. Moreover, the total volume emission measure between 1 and 80 MK, as sum over the individual temperature bins, is in agreement with the total emission measure volume obtained from the multi-temperature fit.

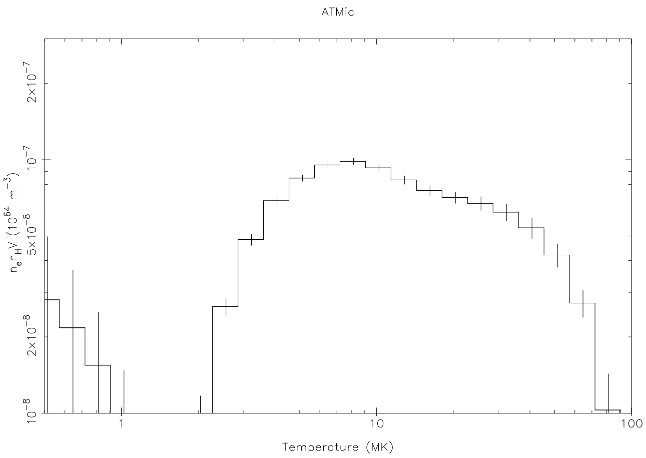

Figure 4. Self-consistent DEM modeling of the spectrum of AT Mic, using the regularization method

The more prominent lines of the RGS spectrum have been measured individually. Monochromatic delta functions were folded through the instrumental response matrix in order to derive integrated line fluxes. No additional width to the delta functions was needed to fit the line shapes. A "background" level was adjusted to take into account the real continuum or the pseudo-continuum, created by the overlap of numerous weak lines. The obtained line fluxes are compared with the fluxes calculated from the emissivities of the 4-T fit. The values, used in this comparison, are collected in Table 2. The first two columns show measured coronal values. The columns 3, 4, and 5 give values and identifications, obtained from the model fit. For the strongest measured line fluxes the uncertainty is about 10% and for the weak ones up to 30%. The uncertainty of the collision strengths and the transition probabilities of the calculated fluxes is about 20% and 25%, respectively.

4. Conclusions

The X-ray spectrum of AT Mic obtained by RGS and EPIC-MOS is dominated by H- and He-like transitions of Ne, O, N, and C and by Fe XVII lines (RGS) and by H-

Table 2. Observed and calculated line fluxes (10^{-4} photons/cm^2/s) in the spectrum of AT Mic.

λ(Å)	Flux(meas)	λ(Å)	Flux(calc)	Ion
12.127	4.42	12.134	3.92	Ne X
13.446	3.10	13.447	1.69	Ne IX
13.532	0.62	13.553	0.92	Ne IX
13.691	1.35	13.700	1.17	Ne IX
15.008	1.81	15.014	2.34	Fe XVII
15.998	1.60	16.007	1.32	O VIII
16.767	1.18	16.775	1.23	Fe XVII
18.620	0.39	18.628	0.28	O VII
18.958	9.65	18.969	10.7	O VIII
21.587	1.47	21.602	2.42	O VII
24.770	1.12	24.781	1.36	N VII
33.713	3.18	33.736	3.86	C VII

and He-like transitions of Si and Mg and Fe K-shell transitions (EPIC-MOS).

The dominant temperatures and emission measures cover a broad temperature range from 1 up to about 80 MK. The total emission measure in this temperature domain is $\sim 10.5(1.6) \times 10^{51}$ cm^{-3}. These temperatures and emission measures are in agreement with former values given by Monsignori Fossi et al. (1995).

Most line features of the RGS spectra are produced in the temperature range from 1-10 MK.

The abundance pattern in AT Mic suggests the depletion of low-FIP elements relative to high-FIP elements, indicating the presence of a possible IFIP effect in this active stars, as has been suggested for other active stars by Audard et al. (2002) and Güdel et al. (2002).

Acknowledgements

The Space Research Organization Netherlands (SRON) is supported financially by NWO. MA acknowledges support from the Swiss National Science Foundation (grant 2100-049343).

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