X-RAY EMISSION FROM THE OLD CTTS MP MUSCAE.

C. Argiroffi, *DSFA, Università di Palermo, Piazza del Parlamento 1, 90134 Palermo, Italy, (argi@astropa.unipa.it)*, A. Maggio, *INAF - Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, 90134 Palermo, Italy*, G. Peres, *DSFA, Università di Palermo, Piazza del Parlamento 1, 90134 Palermo, Italy.*

Abstract

We study the properties of X-ray emitting plasma of MP Mus, an old classical T Tauri star. XMM-Newton/RGS spectra allow us to measure the plasma electron density, which probes whether X-ray emission is produced in the accretion process. X-ray emission from MP Mus originates from high density cool plasma but a hot flaring component is also present, suggesting that both coronal magnetic activity and accretion contribute to the observed X-ray emission. From the soft part of the X-ray emission from MP Mus, mostly produced by plasma heated in the accretion shock, we derive the accretion parameters and the characteristics of the shock-heated plasma.

Introduction

Young late type stars are intense sources of X-rays. This emission is due to the presence of coronal plasma, similar to that of active late-type main sequence stars. On the other hand in classical T Tauri stars (CTTSs) X-ray emission can be produced also by the accretion process: gas falls from the circumstellar envelope reaching velocities of $\sim 300-500\,\mathrm{km\,s^{-1}}$ near the stellar photosphere, where a shock forms and the accreted gas is heated to temperatures of a few MK (Calvet & Gullbring 1998). X-ray luminosity due to shock-heated plasma can be comparable to coronal one.

Three CTTSs (TW Hya, BP Tau, and V4046 Sgr Kastner et al. 2002; Schmitt et al. 2005; Günther et al. 2006) for which high-resolution X-ray spectroscopy has been performed show cool plasma components ($2-4\,\mathrm{MK}$) with high electron densities ($10^{11}-10^{13}\,\mathrm{cm^{-3}}$). On the contrary, cool quiescent coronal plasma of active late-type stars displays low electron density (($N_e \approx 10^{10}-10^{11}\,\mathrm{cm^{-3}}$ at $T\sim 2\,\mathrm{MK}$, Testa et al. 2004; Ness et al. 2004). The high electron density of cool plasma, observed in CTTSs, has been interpreted as evidence for X-ray emission due to an accretion shock. Note however that the CTTS T Tau (Güdel et al. 2007) and the Herbig star AB Aur (Telleschi et al. 2007) do not show high electron density of the cool plasma component.

We present an *XMM-Newton* observation of MP Muscae. It is a K1 IVe star of the Lower Centaurus Crux (LCC) association, with enhanced Hα emission (EW$\sim$ 40 Å), and surrounded by an optically thick circumstellar disk (Carpenter et al. 2005; Silverstone et al. 2006). Mamajek et al. (2002) derived three different ages for MP Mus, 7, 14, and 17 Myr, depending on the adopted theoretical evolutionary tracks. The estimated age of the LCC association, to which MP Mus belongs, is between 16 and 23 Myr. Hence MP Mus is one of the oldest known CTTSs.

Data analysis and results

MP Mus was observed with *XMM-Newton* for a duration of $\sim$ 110 ks on 2006 August 19–20. Data processing is described in Argiroffi et al. (2007). The X-ray light curve (Fig. 1) shows hints of flaring activity, produced by coronal plasma.

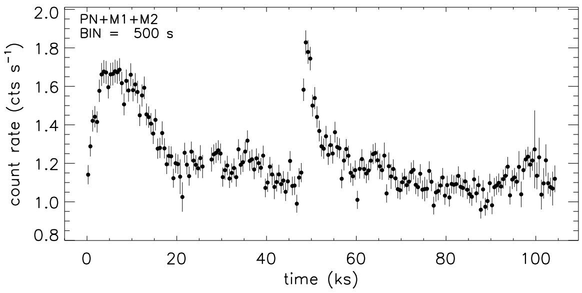

Figure 1: Background-subtracted light curve of MP Mus obtained by adding the three EPIC instrument data.

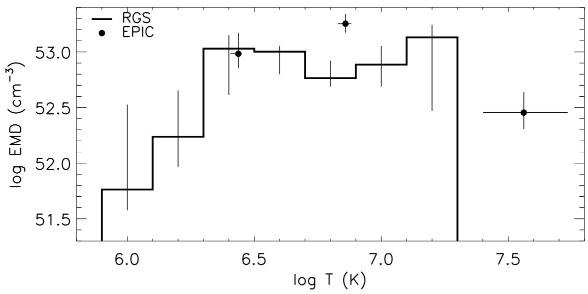

Figure 2: Emission measure distribution derived from the RGS line fluxes (solid line) and 3-T model derived from the EPIC spectra (black dots).

We derived the characteristics of the X-ray emitting plasma of MP Mus by fitting PN and MOS, adopting an optically-thin plasma emission model with three isothermal components, We obtained: $T_1 = 2.7^{+0.1}_{-0.2}$, $T_2 = 7.2^{+0.4}_{-0.5}$, $T_3 = 36^{+18}_{-11}\,\mathrm{MK}$, $EM_1 = 9.6^{+5.2}_{-2.5}$, $EM_2 = 17.9^{+4.0}_{-3.0}$, $EM_3 = 2.9^{+1.5}_{-0.8}$ in units of $10^{52}\,\mathrm{cm^{-3}}$. The best-fit 3-T model also provided individual O, Ne, Fe, and S abundances: O$=0.25^{+0.08}_{-0.07}$ Ne$=0.76^{+0.23}_{-0.15}$, S$=0.28\pm0.20$ Fe$=0.09^{+0.04}_{-0.02}$ with respect to solar abundances of Asplund et al. (2005).

We measured the fluxes of the strongest lines by fitting the RGS spectra with a Lorentzian profile. From the measured line fluxes we derived the emission measure distribution (*EMD*$= N_e N_H \mathrm{d}V$) by applying the MCMC method of Kashyap & Drake (1998), over a $\log T$ grid ranging between 6.0 and 7.2, with a bin size of 0.2. The *EMD* reconstruction also provided these abundances: C$=0.25^{+0.10}_{-0.09}$, N$=0.28^{+0.14}_{-0.10}$, O$=0.18^{+0.09}_{-0.03}$, Ne$=0.46^{+0.14}_{-0.06}$, with respect to solar abundances of Asplund et al. (2005) and assuming Fe=0.09 as derived from the EPIC spectra.

The observed O VII lines (indicated as r, i, and f in Fig. 3)

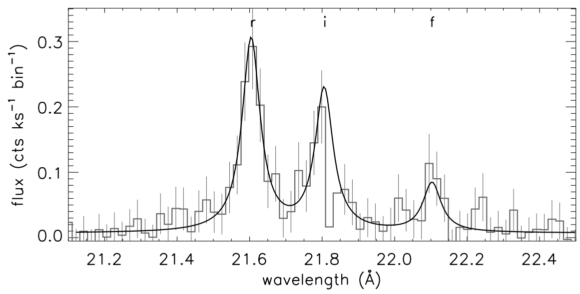

Figure 3: RGS1 spectrum in the wavelength region of the OVII triplet (gray) with the best fit Lorentzian line profile (black).

in the RGS1 spectrum provide a density-sensitive ratio $f/i = 0.28 \pm 0.13$, which implies an electron density $\log N_e = 11.7 \pm 0.2$ for the plasma at $T \sim 2$ MK. The NeIX line flux measurements are affected by large uncertainties due to the strong blending with Fe lines. However NeIX triplet suggest a density $\log N_e > 11$.

Discussion

We find that the cool plasma component in MP Mus has a density significantly higher than typical coronal values. It suggests that shock-heated plasma contributes significantly to the observed X-ray emission from MP Mus. The peak at 3 MK in the *EMD* supports this finding, in fact coronal plasma usually displays only a peak at T$\geq$ 10 MK. Moreover, MP Mus also shows clear evidence of intense coronal activity, as indicated by the flares (see Fig. 1) and by the hot plasma component.

X-ray emitting plasma of MP Mus shows a Ne abundance enhanced with respect to the other elements, as already observed for the three CTTSs showing evidence of X-ray emission due to shock-heated plasma (TW Hya, BP Tau, and V4046 Sgr). Non-solar abundance ratios of the shock-heated plasma may be explained by assuming that the accreting material underwent grain depletion (Herczeg et al. 2002; Stelzer & Schmitt 2004). Drake et al. (2005) showed that TW Hya ($\sim$ 8 Myr old) displays a Ne/O ratio larger by a factor ~ 2 than the uniform value observed in a large sample of coronal X-ray sources. The same high Ne/O value has been found for V4046 Sgr ($\sim$ 12 Myr). This findings support the hypothesis that soft X-ray radiation from TW Hya and V4046 Sgr is not produced by coronal plasma. In contrast the much younger BP Tau ($\sim$ 1 Myr) displays a "normal" Ne/O ratio. Also MP Mus, which is $\sim 10-15$ Myr old, shows a low Ne/O ratio. Hence the stellar age is likely not the only parameter that determines the Ne/O ratio observed in CTTSs with evidence of high density cool plasma.

Accretion properties of MP Mus can be derived from the X-rays produced by the shock-heated plasma. We first assume that the cool X-ray emitting plasma of MP Mus is only due to the accretion shock, with no contribution from coronal plasma. We adopt for MP Mus a mass of $1.2\,M_\odot$ and a radius of $1.3\,R_\odot$ (Mamajek et al. 2002).

From the OVII triplet and the OVIII Lyα lines we infer the electron density ($N_e = 5 \times 10^{11}$ cm^{-3}), temperature ($T = 3$ MK, obtained from the OVIII Lyα and OVII r lines), and emission measure (*EM*$= 2.4 \times 10^{53}$ cm^{-3}) of the post shock plasma. In the strong shock scenario, the relevant plasma parameters are linked by the relations $N_1 = 4N_0$, $v_1 = \frac{1}{4}v_0$, $T_1 = 3\mu m_H v_0^2/(16k)$, where the suffixes 0 and 1 indicate the pre-shock and post-shock plasma, N the density, v the velocity, T the temperature, and μ the mean molecular weight (in our case $\mu = 0.61$).

We infer: a pre-shock velocity of 470 km s^{-1}, a cooling time of 350 s; a characteristic length of the post-shock region $l = 4 \times 10^9$ cm$= 0.05\,R_\star$; a cross section of the infalling stream $A = EM/(N_e N_H l)$ of 3×10^{20} cm^2 (corresponding to a filling factor $f = A/(4\pi R_\star^2)$ of 0.3 % of the stellar surface); and a mass accretion rate of $5 \times 10^{-11}\,M_\odot$ yr^{-1}.

We made the hypotheses that: (1) the cool plasma is produced in the accretion shock; (2) the cool plasma is optically thin; (3) its density is measured from the OVII f/i.

We are confident that the assumption (1) is appropriate. The two flares detected, due to coronal plasma, contribute just 3.6% of the spectrum above 18 Å; moreover the OVII triplet lines indicate that any contribution from low density (i.e. coronal) plasma is at most 20%.

Hence the derived accretion rate, which depends only on hypotheses (1) and (2), but not on N_e, is acceptable, but a larger accretion rate could be possible if part of the X-ray emission is absorbed.

The measured N_e is more uncertain: a small contribution of low N_e coronal plasma to the OVII triplet might cause an underestimation of N_e; conversely an UV field might influence the populations of the OVII atomic levels by photoexcitation and hence mimic a high density plasma. However a sufficiently high UV radiation density can be present only very near the accretion hot spot on the stellar surface, and the photoexcitation hypothesis would anyway indicate that the cool X-ray emitting plasma is close to the base of the accretion funnel.

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