X-Ray Emission from Magnetically Confined Winds

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Abstract. We consider the effect of large scale magnetic fields on the circumstellar environment of hot stars. In these stars, magnetic fields of order of 100 G lead to magnetically confined wind shocks (MCWS) and then to the existence of large X-ray emitting region. MCWS lead also to the presence of corotating cooling disks around hot stars.

We discuss the case of θ^1 Ori C, which is perhaps the hottest analog to Bp stars and consider the effect from rotation and instabilities. We finally discuss the case of the Herbig Ae-Be HD 104237 and show that MCWS might also explain the X-ray emission from this star.

1 Magnetically confined wind shocks

Magnetic fields certainly play a major role in the wind variability, also X-ray variability, of hot stars (i.e. Fullerton, Henrichs this meeting). The O7V star θ^1 Ori C is perhaps one of the most impressing case. It presents a strong periodic variability in the wind absorption and emission lines (e.g. Stahl 1996) and an X-ray variability with the same period (Gagné et al. 1997). These variations are interpreted as a possible signature of a strong magnetic field. In Babel & Montmerle (1997b), and based on the MCWS model developed by Babel & Montmerle (1997a, BM97a) for Bp stars, we modelised the wind of θ^1 Ori C in presence of a dipolar magnetic field.

The main effect of a dipolar field is to confine the wind component from the two hemispheres towards the magnetic equator, where the components collide leading to a strong shock. We modelise then the postshock region postshock region and X-ray emission from θ^1 Ori C (BM97b). We compute the X-ray emission spectra from each point of the magnetosphere, the 3-D absorption by the surrounding "cold" wind and by the interstellar media, and convolve with the detector effective area. The theoretical and observed *ROSAT* HRI count rate are shown in Fig. 1. The observed X-ray luminosity and variability are well explained by the MCWS model and by an oblique rotator provided that a dipolar magnetic field with $B_d = 270 - 370$ G (strength at the pole for $r = R_*$) is present. This value is much lower than the lower limit of 1.6 kG obtained by Donati & Wade (1998).

The variability is well explained by an oblique rotator model and by eclipses caused by the cooling disk and the star, and by the varying absorption from the "cold" wind. In Fig. 1, we also see that Hα emission has

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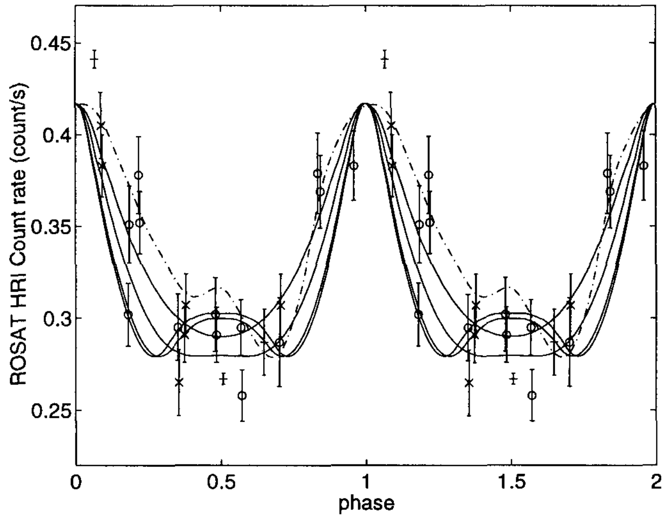

Fig. 1. Theoretical *ROSAT* HRI count rate for the MCWS model (closed case) for a magnetic field of 370 G, and for various angles i and β (see BM97b). The points are for the HRI observations by Gagné et al. Is also plotted (dotted line) the ligntcurve of Hα emission in arbitrary vertical units (Stahl et al. 1996).

a variability quite similar to the X-ray one. We also note that some features in the Hα lightcurve, like the two minima around phase 0.5, are strongly reminiscent of those predicted by the MCWS model for the X-ray lightcurve. This strongly suggests that the Hα emitting region is located close to the X-ray emitting region and thus close to the cooling disk (see also Shore in this meeting). This also indicates an inclination angle i between about 30^o and 50^o with $\beta + \imath \simeq 90^o$ (note the typo in BM97b).

2 Instabilities and effect from rotation on MCWS

Rotation and instabilities play also an important role in the expected X-ray emission and structure of the MCWS.

MCWS are expected to be quite instables as:

- The flow balance can make the height of the cooling disk grow so much, that the disk pressure against the wind becomes larger than the wind ram pressure. We expect then transient phases of downflows towards the stellar surface (see BM97a).
- The stagnation locus between the flows from the two hemispheres is largely instable. Indeed, in the absence of large rotation, a small asymmetry in the wind flows from the two hemispheres may prevent the building of the stagnation disk at the equator and lead also to downflows, the

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wind from one hemisphere quenching the smaller wind from the other hemisphere.
- Magnetic reconnection may also lead to "flaring" events in the outer parts of the cooling disks.

This may explain the strong and time variable continuum circular polarisation observed by Donati & Wade (1998).

Rotation cause effects mostly in stars with small mass loss rates like Bp stars. In these stars, it hase two effects:

- It affects directly the wind flows at the wind base . This leads first to complex mass loss spots with various shapes like: ring, lunated or elongated spots at the stellar surface (Babel, in preparation) and thus to warped disks cooling disks around these stars.
- It modifies also directly the structure of the postshock region around these stars increasing sometimes largely the X-ray emission (BM97a). In oblique rotator models, this make also the cooling disk move out of the magnetic equator and lay between the magnetic and rotation equators.

3 Conclusion

Magnetic field of order of 100 G have very large effects on the wind from hot stars, leading to MCWS, thus to X-ray emission, and circumstellar disks. Stars like θ^1 Ori C or Bp stars are thus expected to present a large range of variability going from X-ray spectral variability to circumstellar signatures.

Recently, Donati (1998) detected a longitudinal field of order of 50 G in the Herbig Ae-Be HD 104237. This star present also an X-ray emission with a cool component around 0.3 keV and an hotter one not well constrained but above 1.6 KeV (Skinner & Yamauchi 1996). Using the wind observed parameters from HD 104237 and the value of the detected magnetic field, the MCWS model (for a dipole) explains both the X-ray luminosity and the temperature of the cool component. While this star shares little properties with Bp stars, the magnetic field being certainly much more complex and the origin of the wind being not known, the X-ray emission might be a signature of wind shocks at the top of magnetic flow tubes.

References

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Discussion

G. Mathys: If the 270 – 370 G magnetic field value required by your model refers to the polar field strength, the corresponding observable mean longitudinal magnetic field should be on the order of 100 G; the exact value depends on the geometry of the observation. Its definite detection by the kind of techniques described in my talk would accordingly require the measurement uncertainties to be ~10 times less than achieved so far. Hence your model is fully consistent with the constraints currently available.

T. Berghöfer: You mentioned our work from 1994. This paper was entitled "Are late B stars intrinsic soft X-ray emitters?". We still owe the community a final answer. The answer is "no"! It is true that we found 10 % of all B and A stars in the Rosat all-sky survey. The detection rate of Bp and Ap stars is the same. If the X-ray production is related to the magnetic field, one would expect to see higher luminosities for Bp/Ap stars, or at least a higher detection rate. Many of the detected late B/A stars show radial velocity changes and suggest X-ray emitting companions. So what?

J. Babel: As mentioned in your paper devoted to IQ Aur, we expect that most Ap stars have small mass-loss rates, which are not sufficient to lead to an X-ray luminosity detectable in the RASS. Significant winds are only expected during short phases on IQ Aur or in hotter Bp stars. For the latter, the observations of GHz radio emission due to gyrosynchrotron emission from mildly relativistic electrons at the same time as wind signatures, magnetic fields, and X-ray emission much larger than in normal B stars give us much confidence that the X-ray emission is intrinsic (statistically). I agree, however, that for an individual object like IQ Aur we cannot be completely sure that the X-ray emission is intrinsic.

Finally, as has been shown, the model we propose has a much larger application than for Ap stars, as it shows the general consequence of the magnetic confinement of the wind from hot stars on the X-ray luminosity.

S. Shore: To come to your defense, let me add to what I discuused in my talk, i.e., that there is an aspherical wind so there must be a strong shearing interface between the magnetospheric plasma and the wind flow. The result is certainly some non-thermal heating. In fact, this must be present in order to explain the C IV and other high-ionisation lines in the first place. The shear flows, tearing modes, shocks, etc. that result can accelerate the electrons for the radio sources and generate Alfvén waves for heating. Whether you can reach 10^6 K or only a few times 10^4 K is in question.