THE RADIO AND X-RAY PROPERTIES OF MAGNETIC BP/AP STARS

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ABSTRACT

We present a new set of radio continuum observations of magnetic, chemically peculiar Bp/Ap (hereafter MCP) stars. The radio luminosities of these stars span several orders of magnitude from $10^{14.5}$ to $10^{18.0}$ erg/s/Hz, and are comparable with those of the most active cool stars, such as the RS CVn binary systems. The radio luminosities of the MCP stars correlate with both their bolometric luminosities (or, equivalently, their effective temperatures) and their magnetic field strengths. We have obtained new X-ray observations of some selected MCP stars, and have searched the X-ray catalogs for X-ray data on the remaining stars in our sample. We find that the fraction of X-ray source detections is similar to the fraction of radio emitters, and can be explained to a large extent by emission from low-mass SB or VB companions: in particular, there is no correlation between the radio and X-ray luminosities. viz., their X-ray emission does not follow the Güdel radio to X-ray scaling law obeyed by coronal stars.

Key words: Bp/Ap stars; X-rays; radio emission.

1. INTRODUCTION

Radio surveys carried out using the Very Large Array (VLA) in the period from 1985 onwards, e.g., Linsky et al. (1992), Leone et al. (1994), found that many magnetic chemically peculiar (MCP) stars were radio emitters with typical flux densities from the 0.2 mJy detection threshold to 5 mJy. More focussed follow-up studies found that the radio emission from MCP stars is mildly circularly polarized, has a fairly flat spectrum in the 2 to 20 cm wavelength range, and, in several of the best-studied cases, is variable on the same timescale as the known rotational period. These properties are consistent with a non-thermal emission mechanism, implying that particle acceleration is occurring somewhere in the circumstellar environments of these stars. Specifically, we interpreted these radio data as indicating optically thick gyrosynchrotron emission from a power law distribution of mildly relativistic electrons. In the model proposed by Linsky et al. (1992), centripetal forces on stellar wind plasma flowing outwards on open magnetic field lines disrupt the field lines far from the star in the equatorial plane, forming a current sheet in which field reconnection and electron acceleration to mildly relativistic energies can occur as in the terrestrial magnetotail. These electrons then travel along the magnetic field lines to smaller radii and higher magnetic latitudes where they mirror and emit microwave radiation. This model can qualitatively explain the nonthermal radio emission, and it predicts that these stars should be thermal X-ray sources, although the model does not predict quantitative X-ray fluxes. More sophisticated unified models have subsequently been proposed, e.g., Babel & Montmerle (1997).

X-ray studies in 1990s (Drake et al., 1994; Leone, 1994) found that MCP stars (like other late-B and A-type stars) were weak or undetectable X-ray emitters. The 10% detection rate in X rays is mostly consistent with the emission being due to coronal emission from low-mass companions (the 'extrinsic' hypothesis), with a few exceptions among the hottest MCP stars such as σ Ori E and θ^1 Ori C where it is likely due to magnetically influenced stellar wind emission. The X-ray emission of MCP stars does not otherwise correlate very obviously with other stellar properties such as the magnetic field strength or rotation rate, nor with their radio properties: in particular, they do NOT follow the Güdel Law obeyed by most coronal stars, viz., $\log L_x = \log L_{rad} + 15$, since this would imply X-ray luminosities as high as 10^{33} erg/s for the most radio-luminous members of this class. In contrast, the inferred X-ray luminosities of MCP stars are not particularly high, with only two detections above $10^{30.5}$ erg/s. Finally, the *ROSAT* low-resolution and *ASCA* medium-resolution spectra of MCP stars are, in general, indistinguishable from those of active low-mass stars, which again favors the extrinsic hypothesis for their X-ray emission.

Table 1. Previously Unpublished Radio Detections of Magnetic Bp Stars

Star	Spectral Type	S_ν (mJy)	λ (cm)
α Psc A	A2p SiSrCr	0.37 ± 0.09	3.6
56 Ari	B8p Si	0.45 ± 0.12	3.6
56 Tau	A0p SiCr	0.38 ± 0.02	6.
		0.33 ± 0.02	3.6
V1156 Ori	B6p He-wk	0.29 ± 0.07	3.6
BD -02 1241	B6p He-wk	2.97 ± 0.10	3.6
V1093 Ori	B8p He-wkSi	0.49 ± 0.06	3.6
HR 1906	B3V var?	0.51 ± 0.07	3.6
V1148 Ori	B9p He-wkSi	0.60 ± 0.07	3.6
V682 Mon	B9p Si	0.27 ± 0.05	3.6
36 Lyn	B9p He-wkSiMn	0.45 ± 0.05	3.6
α^2 CVn	A0p EuSiCr	0.29 ± 0.03	3.6
CU Vir	B9p Si	4.07 ± 0.14	3.6
HZ Lup	B9p Si	0.24 ± 0.07	3.6
HR Lup	B9p Si	4.08 ± 0.16	3.6
LL Lup	B9p Si	0.50 ± 0.07	3.6
V771 Her	B9p SiCrSr	0.30 ± 0.05	3.6
ϕ Dra A	A0p Si	0.45 ± 0.05	3.6
V545 Lyr	B5p He-wk	0.46 ± 0.05	3.6
V2015 Cyg	B8p Si	3.00 ± 0.07	3.6

2. NEW OBSERVATIONS

We and others have continued to obtain radio observations of MCP stars in recent years, and, to date, 29 MCP stars have been detected as radio sources (out of 138 observed), mostly of the He-wk and Si sub-types of MCP stars. Radio emission is strongest in the MCP stars which are the hottest (earliest spectral type) and most luminous, i.e., stars such as the B2 Vp star σ Ori E ($L_{rad} \approx 10^{18}$ erg/s/Hz), and falls to near the current detection limit ($L_{rad} \approx 10^{14.5}$ erg/s/Hz) for A0 Vp stars like α^2 CVn; later-type Ap stars, e.g., ϵ UMa (A1p), are not detected as radio emitters, with radio luminosities $L_{rad} < 10^{14}$ erg/s/Hz. The newly radio-detected MCP stars are listed in Table 1.

X-ray observations of MCP stars have been made with the current X-ray observatories, e.g., *XMM-Newton*. One of the best cases of an MCP star which was already known to be an X-ray and radio emitter, 56 Tau, was simultaneously observed on Feb 29, 2004 by both *XMM-Newton* and the VLA. This new observation showed that 56 Tau is not associated with the *ROSAT* All-Sky Survey X-ray source. The EPIC observation shows that the ROSAT X-ray source which had been identified with 56 Tau actually splits into two X-ray sources (one on each side of 56 Tau) when observed with *XMM-Newton*'s higher spatial resolution. The brighter X-ray source (hereafter XMM 1) is at the position of a recently discovered radio source (14" away from 56 Tau), and a second X-ray source (XMM 5) lies 40" North and 27" West of XMM 1: there is no obvious X-ray source at the position of 56 Tau. The 0.5 mJy radio source associated with the X-ray source XMM 1 is also a fairly bright ($J = 9.5$) 2MASS source, suggesting it is a star rather than a background extragalactic object. If it is a physical VB companion to 56 Tau, then $\log L_{rad} = 15.7$ and $\log L_x = 30.0$, consistent with the expected emission from an active low-mass companion.

3. CONCLUSIONS

MCP stars can have radio emission luminosities comparable to the most active late-type stars, but their X-ray luminosities are much less pronounced, and it has proven difficult to disentangle any intrinsic emission from the coronal X-ray emission of low-mass companion stars. There is no obvious stellar property which correlates with the presence or level of X-ray emission in MCP stars (or in late-B and A-type stars, in general). Some of the best candidate X-ray emitters among MCP stars discovered in the ROSAT All-Sky Survey, e.g., HR 5624 (Stelzer et al., 2003) and 56 Tau (this paper), have turned out to be cases where the X-ray emission is from nearby companions and/or unrelated objects. It seems likely that there must be weak intrinsic X-ray emission from some, if not all, MCP stars, given the existence of the high-energy nonthermal electron population which produces the radio emission, but unless this X-ray emission has a very different spectrum than that of coronal stars, this emission will be hard to separate from the emission from low-mass companions. The high spatial resolution of *Chandra* will be invaluable in ruling out X-ray emitting close visual binary companions.

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