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X-rays from magnetic intermediate mass Ap/Bp stars

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Abstract

The X-ray emission of magnetic intermediate mass Ap/Bp stars is reviewed and put into context of intrinsic as well as extrinsic hypotheses for its origin. New X-ray observations of Ap/Bp stars are presented and combined with an updated analysis of the available datasets, providing the largest sample of its type that is currently available. In the studied stars the X-ray detections are found predominantly among the more massive, hotter and more luminous targets. Their X-ray properties are quite diverse and beside strong soft X-ray emission significant magnetic activity is frequently present. While a connection between more powerful winds and brighter X-ray emission is expected in intrinsic models, the scatter in X-ray luminosity at given bolometric luminosity is so far unexplained and several observational features like X-ray light curves and flaring, luminosity distributions and spectral properties are often similar to those of low-mass stars. It remains to be seen if these features can be fully reproduced by magnetospheres of intermediate mass stars.

The article discusses implications for magnetically confined wind-shock models (MCWS) and stellar magnetospheres under the assumption that the intrinsic model is applicable, but also examines the role of possible companions. Further, related magnetospheric phenomena are presented and an outlook on future perspectives is given.

Keywords: X-rays: stars; Stars: Ap/Bp; Stars: intermediate mass

1. Introduction

The X-ray emission from stars can be roughly separated into two fundamental regimes. Cool, low-mass stars of spectral type F to M have magnetic coronae that contain hot plasma at MK temperatures. Magnetic activity is driven by stellar dynamos and related to convection and rotation and observed activity levels cover a broad range of about $-7 < \log L_X/L_{\rm bol} < -3$. The stellar dynamos become less efficient as the outer convective layer becomes shallower and magnetic activity steeply declines towards higher masses. The X-ray emission of late A stars is already quite faint and subsequently fades towards hotter stars. For a discussion of coronal X-rays from the nearby A7 star Altair and similar objects, i.e. stars with masses of $\lesssim 2.0 M_\odot$, see e.g. Robrade and Schmitt (2009). In hot, massive stars of spectral type early B the instabilities in their radiatively driven winds become sufficiently strong to give rise to X-ray emission from wind shocks. Basically, in O and early B stars X-ray luminosity correlates with wind power and bolometric luminosity at a level of about $\log L_X/L_{\rm bol} \approx -7$.

Main-sequence stars of intermediate mass at spectral type mid A to mid B, also known as tepid stars, neither drive sufficiently strong winds to produce X-rays in wind shocks, nor possess an outer convection zone to generate magnetic activity and coronae via dynamo processes. Consequently they should be virtually X-ray dark and this is indeed likely true for all 'normal' main-sequence stars. See e.g. Güdel and Nazé (2009) for a more detailed overview on stellar X-ray emission.

The Ap/Bp stars are magnetic intermediate mass stars that belong to the group of chemically peculiar (CP) stars.

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The origin of their magnetic field is likely fossil, consistent with the finding that only a small fraction of about 5–10% of the early-type stars are magnetic A fossil origin of the magnetic field is supported by studies of pre-main sequence intermediate mass stars, the HAeBe stars, where the fraction of stars with large-scale magnetic fields is similar to those of main-sequence intermediate mass stars as shown by spectropolarimetric surveys (Alecian et al., 2013). In addition, the magnetic field strength of Ap/Bp stars and their rotation period are independent and the presence of abundance spots caused by diffusion indicates a stable photosphere, both suggesting that the strong magnetism is not related to dynamo processes. Furthermore, the magnetic fields in Ap/Bp stars are dominated by rather simple large scale structures like a dipole and hence they are fundamentally different from the complex field geometry of magnetically active late-type stars, see e.g. the review by Landstreet (1992).

In Ap/Bp stars X-ray production may arise from magnetically confined wind-shocks (MCWS) as proposed by Babel and Montmerle (1997) to describe the remarkably soft X-ray emission observed from the A0p star IQ Aur. Already in the RASS (ROSAT All-Sky Survey) several Ap/Bp stars were detected as X-ray sources (Drake et al., 1994). The MCWS model was also successfully applied to magnetic massive stars like θ^1 Ori C (Gagné et al., 2005), but other studies ended up with more mixed results. In an X-ray study of magnetic late B- and A-type stars several objects remained undetected (Czesla and Schmitt, 2007), showing that the pure existence of a strong magnetic field is not a sufficient criterion for X-ray emission. Similarly, Oskinova et al. (2011) studied magnetic early B-stars and find that strong and hard X-ray emission not necessarily correlates with the presence of a magnetic field.

A systematic X-ray study of Ap/Bp stars by Robrade and Schmitt (2011) has addressed the puzzling mix of X-ray detections and non-detections among the Ap/Bp stars. Within the studied sample focussing on objects with $T_{\rm eff} \lesssim 15,000$ K they find indications for a transition from X-ray dark (or faint) to X-ray emitting Ap/Bp stars occurring at stellar luminosities of around 250 $L_\odot$. This temperature and luminosity regime corresponds roughly to the spectral boundary between B and A type stars, i.e. at significantly later spectral types than in non-magnetic objects. Further, in addition to wind-shocks also magnetic activity is clearly present in several of the studied objects. In the sense that an intrinsic X-ray generation bases on magnetic fields and winds, Ap/Bp stars bridge the 'classical' X-ray regimes of cool and hot stars.

This review focusses on magnetic intermediate mass Ap/Bp stars of spectral types mid/late B to early A, in this respect complementing a study of magnetic massive stars by Nazé et al. (2014). The intermediate mass Ap/Bp stars share, if applicable, with the MCWS an X-ray generation mechanism with the magnetic massive stars (see review by ud-Doula & Nazé, 2016), but provide different environmental conditions with respect to magnetic field and wind strength. The paper is structured as follows. In Section 2 we introduce the MCWS model and discuss the prototypical Ap star IQ Aur in greater detail, in Section 3 we present the current observational status of X-ray emission from Ap/Bp stars as a class including an analysis of the available X-ray data. It also covers a discussion of the X-ray emission in the context of current wind-shock models, the impact of possible low-mass companions and its relation to other magnetospheric phenomena. In Section 4 we give an outlook on future perspectives.

2. The MCWS model in Ap/Bp stars

An important milestone in the field of X-ray studies of Ap/Bp stars was a *ROSAT* PSPC observation that showed the A0p star IQ Aur to be an X-ray source with an X-ray brightness of $L_X = 4 \times 10^{29}$ erg s^{-1} (Babel and Montmerle, 1997). The derived plasma temperature of $T_X = 0.3$ keV is extraordinarily low for a star with this X-ray luminosity. This combination of X-ray brightness and soft spectrum makes a possible low-mass companion, typically put forward as alternative explanation for unexpected X-ray detections of late B/early A stars, an unlikely explanation. To explain the unusually soft X-ray spectrum of IQ Aur they introduced the 'magnetically confined wind-shock' (MCWS) model, where the radiatively driven wind components from both hemispheres are magnetically channeled and forced to collide in the vicinity of its equatorial plane. As a consequence, strong shocks of the nearly head-on wind collision produce sufficiently hot plasma and an equatorial disk is formed. Assuming an efficient conversion of kinetic energy this scenario can give rise to the observed X-ray emission under reasonable assumptions on the stellar wind parameters. Basic predictions from this model are an X-ray luminosity of $L_X = 1/2\dot{M}V_{sh}^2$ and a plasma temperature of $T_{sh} = 1.13 \times 10^5[V_{sh}/(100\ \text{km s}^{-1})]^2$ with V_{sh} being the velocity at the shock (pre-shock), $\dot{M}$ the mass loss rate and T_{sh} the temperature at the shock front (post-shock). Thus wind speeds of 400–600 km s^{-1} generate X-ray emitting plasma with temperatures of 2–4 MK, at 950 km s^{-1} plasma temperatures of 10 MK are reached and a mass-loss rate of a few times $10^{-11} M_\odot$ is required to produce the X-ray emission of IQ Aur.

This seminal idea motivated further developments and dynamic MHD versions of the MCWS model were created and consecutively extended (ud-Doula and Owocki, 2002; ud-Doula et al., 2008; ud-Doula et al., 2014). Up to date versions include e.g. stellar rotation or plasma cooling effects. Adding more physical details also revealed new phenomena and lead to a much more diverse picture than the simple scaling laws of the original model. For example the so-called 'shock retreat', an effect that is especially important for weaker winds, can modify the X-ray luminosity and might lead in its extreme to a total quenching of