Highlights of Astronomy, Volume 14
IAU XXVI General Assembly, 14-25 August 2006
Karel A. van der Hucht, ed.

doi:10.1017/S1743921307010642

Topology of stellar coronae

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Abstract. While the existence of cycles in stellar chromospheric flux has been known for some time, the nature of the corresponding coronal response has been more elusive. We describe recent results on the relationship between cyclic variations in surface magnetic flux and coronal structure and re-assess the role of prominence observations in understanding the topology of stellar coronas. We present a new paradigm for prominence support which allows for extended prominences to co-exist with a compact corona. We discuss briefly the recent results on coronal structure in high- and low-mass stars and their implications for dynamo theory.

Keywords. stars: activity, stars: imaging,stars: magnetic fields.

1. Introduction

In the case of the Sun, the relationship between the surface and coronal structure of the magnetic field is well known, but in the case of other stars the nature of this relationship is less clear. In addition to the surface field, other factors such as the rotation rate may be important. Thus for example, Jardine (2004) showed that the (super) saturation of coronal X-ray luminosity at high rotation rates can be explained by the effect of centrifugal forces stripping away closed field regions. This predicts that supersaturated stars should have a high rotational modulation of their X-ray emission, as is indeed observed in VXR 45 (Marino *et al.* 2003).

Recent advances have however been made in relating the surface magnetic structure (obtained using Zeeman-Doppler imaging, see e.g., Brown *et al.* 1991) and the coronal structure (as implied by X-ray observations, see e.g., Hussain *et al.* 2005). The surface field can be extrapolated into the corona using a *Potential Field Source Surface* model (Altschuler & Newkirk 1969) originally developed to model the solar corona. By assuming a hydrostatic, isothermal corona it is then possible to model the coronal density structure and hence the X-ray emission.

The best-observed example of the application of this technique is to AB Dor, a young, marginally pre-main sequence K-type dwarf of rotation period 0.514 d Donati *et al.* 1997, 1999, 2003). The maps of its magnetic field over the last 10 yr show a complex, multipolar structure at all latitudes, including the pole. Extrapolations of the coronal field (Jardine *et al.* 2002a,b) show a similarly complex structure with many closed-loop regions at high latitudes, some even spanning the pole. Since much of the magnetic flux is at high latitudes, the corresponding X-ray emission modelled using this field distribution also shows many bright regions at the pole, leading to a low rotational modulation in X-rays, which is consistent with the analysis of contemporaneous *Chandra* spectra (Hussain *et al.* 2005). This picture of a compact corona with loops extending at most 1 stellar radius above the surface is at odds, however, with the observation of prominences trapped in co-rotation out to some 5 or 6 stellar radii, far beyond the corotation radius (Jardine *et al.* 1997). These must be confined against centrifugal ejection by closed magnetic field lines. One possible way to resolve this contradiction is to confine the prominences in closed loops that extend *beyond* the X-ray corona into the wind region. Jardine &

van Ballegooijen (2005) have developed a model for the support of such loops on rapid rotators and predict a maximum height $y_m = 0.5(-1 + \sqrt{1 + 8R_k^3})$ where heights are in units of a stellar radius and R_k is the co-rotation radius. This agrees well with observed prominence distributions (Dunstone *et al.* 2006).

The relationship between cycles in surface magnetic field and the corresponding coronal X-ray emission is also of great interest for stars. Mackay *et al.* (2004) and later McIvor *et al.* (2006) showed that different types of surface cycles can lead to very different X-ray cycles (or apparently no cycles at all). If the presence (or absence) of cycles on solar-mass stars is as yet an open question, this is even more true in the case of high and low mass stars. Recent results on the coronal structure of the $15\,M_\odot$ star τ Sco and the fully-convective $0.3\,M_\odot$ star V374 Peg (Donati et al 2006a,b) show surprising results. The complex field topology of τ Sco, and the almost dipolar field of V374 Peg combined with a small or vanishing differential rotation for both presents a challenge for theories of magnetic field generation in stellar interiors and for studies of rotational evolution in low mass stars particularly. The variations in coronal topology along the main sequence, and particularly in the pre-main sequence stage are questions that should be addressed in the next few years.

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