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3D Perspectives of Stellar Activity: Observation and Modelling

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Abstract. As the Sun emerges from a period of unprecedented low activity, the nature of the Sun's magnetic field compared to that of other stars is a particularly timely question. Just as observations of the full 3D structure of the solar magnetic field are becoming available through STEREO and SDO, advances in spectropolarimetric techniques now allow us to map the surface magnetic fields of other stars, revealing the great diversity of magnetic geometries that stars of different masses and rotation rates can display. This has now been possible for over 60 main sequence stars, with a smaller number of younger, pre-main sequence stars also mapped. Modelling of coronal structures based on these observations is revealing the full nature of stellar magnetic activity and its possible impact on orbiting planets.

Keywords. stars: imaging, stars: low mass, brown dwarf, stars: winds, outflows

1. Introduction

Our understanding of the magnetic activity of the Sun has now reached the stage where we can relate magnetic field evolution at the solar surface to changes in the morphology of the large-scale corona and wind. Studies of stellar activity are of course hampered by the lack of resolved observations and in-situ measurements, but they have the advantage that a greater range of stellar parameters can be sampled. The more traditional studies of the activity-rotation relation have been augmented by studies of stellar winds and prominences whose ejection may contribute significantly to angular momentum loss in young stars (Jardine & van Ballegooijen 2005; Skelly *et al.* 2008; Skelly *et al.* 2009, Aarnio *et al.* 2012). Spectropolarimetric techniques such as Zeeman-Doppler imaging also now allow us to map all three vector components of the magnetic field at the surface of a star (Donati & Landstreet 2009). Coupled with field-extrapolation methods which provide the 3D structure of the coronal magnetic field and plasma, this makes it possible to study the morphology of stellar coronae in ways that were not possible in the past (Jardine *et al.* 2002a,b; Hussain *et al.* 2002).

2. Overview

A comprehensive study of the magnetic fields of low mass stars (Donati *et al.* 2008, Morin *et al.* 2008; Morin *et al.* 2010) shows the trends with stellar mass and rotation rate of the magnetic field strength, axisymmetry and the departure from the lowest-energy (potential) state. Since stars spin down with age, this also sheds light on the changes that may have occurred in the solar magnetic field over the time period when the Earth and other planets were forming. In particular, the decay with time in the ram pressure of the solar wind led to changes in the Earth's magnetosphere and the bow shock around it. Recent observations of an early ingress of the UV transit relative to the optical transit of the exoplanet WASP-12b suggest that such bow shocks may be detectable (Lai *et al.* 2010). Subsequent modelling suggests such detections may allow us to probe the strengths of exoplanetary magnetic fields and the conditions around exoplanets (Vidotto *et al.* 2010; Vidotto *et al.* 2011a,b).

Low mass stars are indeed popular choices as hosts for habitable exoplanets, but studies of their winds based on this survey of their magnetic field topologies suggests that the combination of rapid stellar rotation and high field strengths may lead to very non-solar winds, characterised by a low plasma β and centrifugal driving (Vidotto *et al.* 2011c). The high ram pressure of these winds may crush planetary magnetospheres unless planets have a significant magnetic field. This factor, combined with the very long spin-down times for these stars, may suggest that they are unlikely to be habitable.

Of course, surveys such as this only sample the large-scale field of these stars, as small-scale polarity changes are undetected. Zeeman broadening studies, such as that of Reiners *et al.* (2009), suggest that as much as 85% of the surface magnetic flux may be undetected. A recent study of the impact of this small-scale field on the large-scale coronal topology and the wind demonstrates however that the effect is modest, with a small reduction in the open magnetic flux that carries the wind and influences the spin-down times (Lang *et al.* 2012).

In summary then, studies of stellar activity have progressed enormously in the last 15 years, but with the results from Kepler's survey of around 150,00 stars, there is a very bright future ahead. This promises to allow us to progress from studies of individual stars to statistical studies of a large sample.

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