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# Incorporating magnetic field observations in wind models of low-mass stars

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**Abstract.** Stellar winds of cool, main-sequence stars are very tenuous and difficult to observe. Despite carrying away only a small amount of the stellar mass, they are important for regulating the rotation of the star and, consequently, its activity and magnetism. As it permeates the interplanetary space, the stellar wind interacts with any exoplanet encountered on its way, until it reaches the interstellar medium (ISM). These interactions can result in complex physical processes that depend on the characteristics of the wind. To better constrain the wind characteristics, more realistic wind models that account for factors such as stellar rotation and the complex/diverse observationally-derived stellar magnetic field configurations of cool stars are required. In this paper, I present a three-dimensional model of the wind of cool stars, which adopt as boundary condition observationally-derived magnetic maps. I also discuss how these studies are relevant for, e.g., the characterisation of the interaction between stellar winds and planets/ISM, and the propagation of cosmic rays.

## 1 Introduction

Magnetic fields play an important role along the stellar life. For low-mass stars, they are believed to regulate stellar rotation from the early stages of star formation until the ultimate stages of the life of a star. Empirically, the projected rotational velocities $v\sin(i)$ of G-type stars in the main-sequence phase decrease with age $t$ as $v\sin(i) \propto t^{-1/2}$ (Skumanich, 1972). This rotational braking is believed to be caused by stellar winds, which, outflowing along magnetic field lines, are able to efficiently remove the angular momentum of the star (e.g., Parker, 1958; Weber and Davis Jr., 1967).

As the wind flows out of the star, it impinges on any exoplanet encountered on its way, all the way until it reaches the ISM. The interactions between the stellar wind and exoplanets/ISM can result in complex physical processes that depend on the characteristics of the wind. These characteristics depend, among others, on the particular geometry of the stellar magnetic field. Modern techniques, such as Zeeman–Doppler Imaging (ZDI), have made it possible to reconstruct the large-scale surface magnetic fields of other stars (Donati and Landstreet, 2009). This method has now been used to investigate the magnetic topology (i.e., intensity and orientation) of more than 100 low-mass stars. Thanks to this intense observational effort, a more general understanding of how the large-scale field correlates with age, activity and rotation is starting to emerge (Vidotto et al., 2014a). In addition, given all this recent insight gained into the magnetic topology of different stars, we are now able to produce more realistic models of winds of low-mass stars, directly incorporating the observationally derived stellar magnetism into three-dimensional (3-D) numerical simulations.

## 2 Numerical models of stellar winds

To account for the observed 3-D nature of stellar magnetic fields, 3-D stellar wind models are required. Here I present the technique used in Vidotto et al. (2011b, 2012, 2014b), Jardine et al. (2013), and Llama et al. (2013), which incorporates the observationally reconstructed magnetic fields using the ZDI technique. The wind models were simulated

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