Winds of Stars and Exoplanets
Proceedings IAU Symposium No. 370, 2023
A. A. Vidotto, L. Fossati & J. S. Vink, eds.
doi:10.1017/S1743921322003702

Check for updates

Magnetic confinement in the wind of low mass stars

Rose F. P. Waugh and Moira M. Jardine

School of Physics and Astronomy, University of St Andrews, Scotland

Abstract. Magnetic confinement of material is observed on both high and low mass stars. On low mass stars, this confinement can be seen as slingshot prominences, in which condensations are supported several stellar radii above the surface by strong magnetic fields. We present a model for generating cooled field lines in equilibrium with the background corona, which we use to populate a model corona. We find prominence masses on the order of observationally derived values. We find two types of solutions: footpoint heavy "solar-like prominences" and summit heavy "slingshot prominences" which are centrifugally supported. These can form within the open field region i.e. embedded in the wind. We generate Hα spectra from different field structures and show that all display behaviour that is consistent with observations. This implies that the features seen in observations could be supported by a range of conditions, suggesting they would be common across rapidly rotating stars.

Keywords. stars: activity, stars: coronae, stars: individual: AB Dor, stars: low-mass, stars: magnetic field, stars: pre-main-sequence

1. Introduction

Magnetic confinement is observed in both high and low mass stars. One form of this in low mass stars is "slingshot prominences". With masses of 10-100 times solar prominences and confined at distances of a few stellar radii, they are particularly well observed on AB Doradus (Collier Cameron 1999). We present a model for populating model coronae of *rapidly rotating stars* with cooled field lines, in equilibrium with the background corona, as published in Waugh et al. (2022).

2. Modelling the cooled field lines

We assume a 2D background dipolar field who axis can lie either in the equatorial plane or along the rotation axis. This dipole can also be altered to become purely radial at the "source surface" (r_{ss}). The shapes of cooled field lines are found from the conservation of momentum:

$$\mathbf{0} = -\nabla p + (\mathbf{B}.\nabla)\frac{\mathbf{B}}{\mu} - \nabla\left(\frac{B^2}{2\mu}\right) + \rho\mathbf{g}, \tag{2.1}$$

which combines, from left to right: the gradients of gas pressure, magnetic tension and magnetic pressure forces and the gravitational force. We note that $\mathbf{g}$ is the effective gravity, as equations are constructed in the co-rotating frame: $\mathbf{g} = (-\frac{GM_\star}{r^2} + \omega^2 r \sin^2\theta)\hat{r} + (\omega^2 r \sin\theta\cos\theta)\hat{\theta}$.

Equation 2.1 can be solved along the field line to give the distribution of the gas pressure. Within the equatorial plane, the gas pressure is constant with longitude but

© The Author(s), 2023. Published by Cambridge University Press on behalf of International Astronomical Union. This is an Open Access article, distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike licence (https://creativecommons.org/licenses/by-nc-sa/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the same Creative Commons licence is included and the original work is properly cited. The written permission of Cambridge University Press must be obtained for commercial re-use.

https://doi.org/10.1017/S1743921322003702 Published online by Cambridge University Press

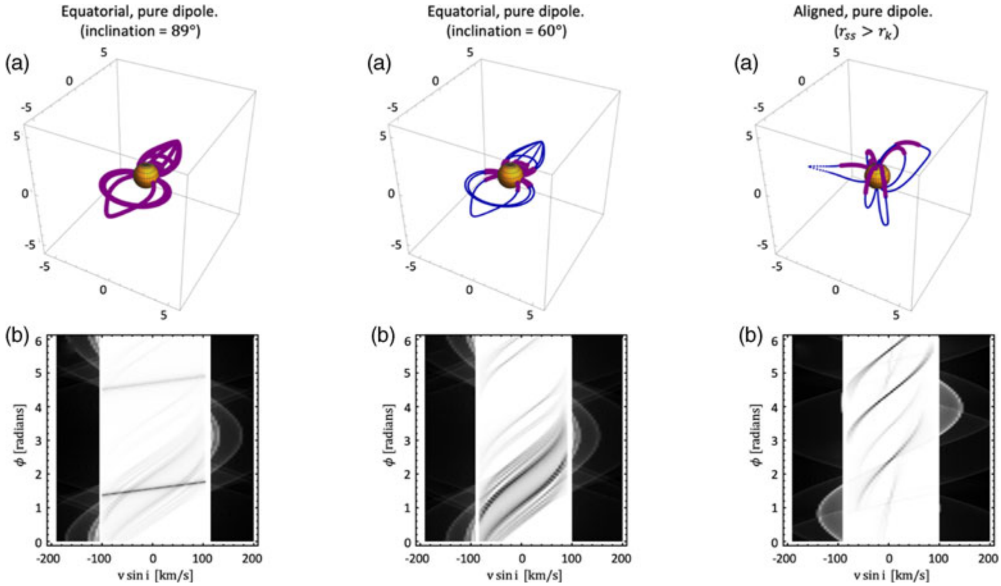

Figure 1. Example magnetic field lines (blue) and visible sections (purple) and below, the associated Hα trails.

decreases with radius, reaching a minimum at the co-rotation radius and then increasing beyond this. In meridional planes the gas pressure shows the same behaviour, however, it is not constant with latitude. The component of the momentum equation perpendicular to the field line, which is a 2nd order ODE, then yields the shape of the cooled field line.

3. Generating synthetic dynamic spectra

Two types of solution are found in this model: loops with summits below co-rotation, with low-density summits and high-density footpoints and very tall loops with high-density summits. The second of these result in dark, slowly transiting features in the Hα spectra, whilst the summits of the low-lying loops do not generate clear absorption features. The dense footpoints can be seen as fast travelling absorption features. Examples of these spectra are shown in Figure 1. All field structures here generate spectra that have features consistent with slingshot prominence observations. Equatorial dipoles differ from aligned dipoles in these spectra by the number of absorption features associated with any given loop: both footpoints are visible for equatorial dipoles whereas only one leg of the loop is visible for an aligned dipole. The inclination of star determines if the summits of the tall, slingshot loops transit the disc and thus are visiblein the spectra, which can be seen by comparing the two most left hand images in Figure 1. This suggests that many field structures could be consistent with the observations for slingshot prominences, adding to the evidence that they could be common features on young stars. Despite this, the stellar inclination is crucial in determining if a prominence will be visible or not.

References

Collier Cameron, Andrew, 1999, ASP Conference Series, 158, 146
Waugh, Rose F. P. and Jardine, Moira M., 2022, MNRAS, 514, 5465

https://doi.org/10.1017/S1743921322003702 Published online by Cambridge University Press