Is the efficiency of magnetic braking limited by polar spots?

Aibéo, Alexandre[*,1,2]; Ferreira, Miguel[1,3]; Lima, João[1,4]

[1]Centro de Astrofísica da Universidade do Porto, Portugal;[2] Escola Superior de Tecnologia de Viseu, Portugal;[3] Universidade dos Açores, Portugal;[4] Dep. Matemática Aplicada FCUP, Portugal *e-mail: aaibeo@infante.ipv.pt

Centro de Astrofísica da Universidade do Porto

Abstract

The presence of high latitude spots on the surface of rapidly rotating cool-stars and the subsequent concentration of magnetic flux near the poles, has lead to the idea that this causes a reduction in the angular momentum carried away by the stellar wind.

We apply the analytical MHD wind model of Lima *et al.* (2001) to determine the influence of the surface flux distribution on the efficiency of the magnetic braking. We determine the angular momentum loss rate for different surface field distributions.

Our results clearly show that the density, pressure, velocity and toroidal magnetic field variations are as important as the surface field distribution in determining the angular momentum carried by the wind. For realistic surface rotation profiles, the angular momentum loss increases as the field concentration increases towards the poles, contrary to what one would naively expect!

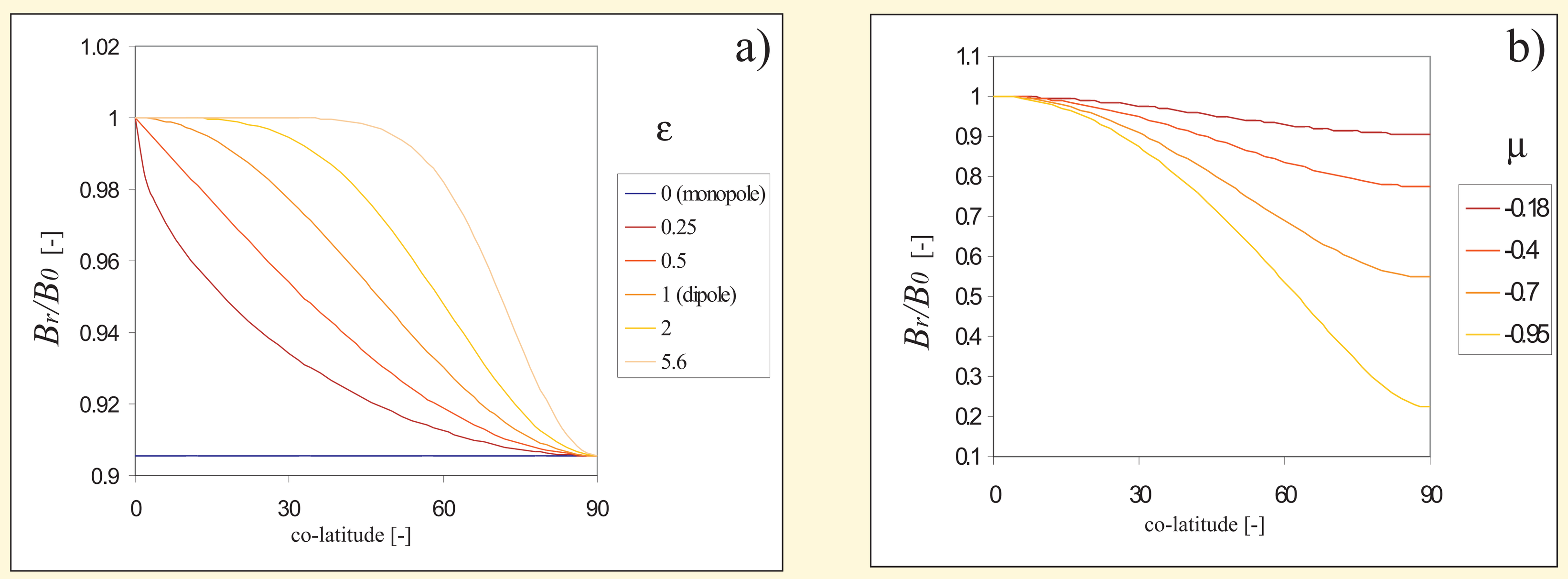

Fig. 1: Different profiles for the radial component of the magnetic field. a) variation with ε; b) variation with μ

Introduction

- The angular momentum evolution of cool stars is dictated by the interaction of the stellar magnetic field with the outgoing wind
- The existence of late-type, very rapid rotators in young main sequence clusters indicates a saturation in the angular momentum loss rate
- Several mechanisms have been proposed, such as:
  - Saturation of the dynamo
  - Decrease of the fraction of open magnetic flux
  - Polar magnetic activity inhibiting angular momentum loss.

Nevertheless this last mechanism and its consequences have never been addressed in detail.

Existing qualitative models of wind braking (Weber & Davis, 1967; Mestel, 1968; Mestel & Spruit, 1987) do not take into account the variation with latitude of some important physical quantities (such as density and velocity) which are crucial for the determination of the angular momentum carried by the wind.

In the present work we use a specific analytical 2-D model (Lima *et al.*, 2001) to address the question of how the change of the magnetic field distribution at the surface affects the angular momentum loss.

The model

- Analytical steady state 2-D model describing an axisymmetric helicoidal magnetized outflow originated by a rotating central object (Lima *et al.*,2001)
- The anisotropy of various flow quantities is determined by three free parameters, μ, ε and δ.
- The surface magnetic field varies with co-latitude, θ, as:

$$B_r(\theta) = B_0\sqrt{1+\mu\sin^{2\varepsilon}\theta}$$

Where B_0 is the value of the radial component of the magnetic field at the polar surface (cf. Figure 1).

- The total angular momentum loss:

$$-\dot{J} = \lambda r_0^3 B_0^2 \int_0^{\pi/2} \sin^{\varepsilon+2}\theta\sqrt{1+\mu\sin^{2\varepsilon}\theta}\,d\theta$$

Where λ is the ratio between the azimuthal velocity at the equator and the radial velocity at the surface pole (V_0).

- B_0 is determined using the condition that all the cases must have the same total magnetic flux:

$$B_0 = \frac{F_0}{2\pi r_0^2\int_0^{\pi/2}\sqrt{1+\mu\sin^{2\varepsilon}\theta}\,\sin\theta\,d\theta}$$

- For the mass efflux the model presents the following relation:

$$\dot{m}(\theta) = \rho_0 V_0 r_0^2\sqrt{(1+\mu\sin^{2\varepsilon}\theta)(1+\delta\sin^{2\varepsilon}\theta)}$$

ρ_0 and r_0 are the polar surface density and the star radius respectively.

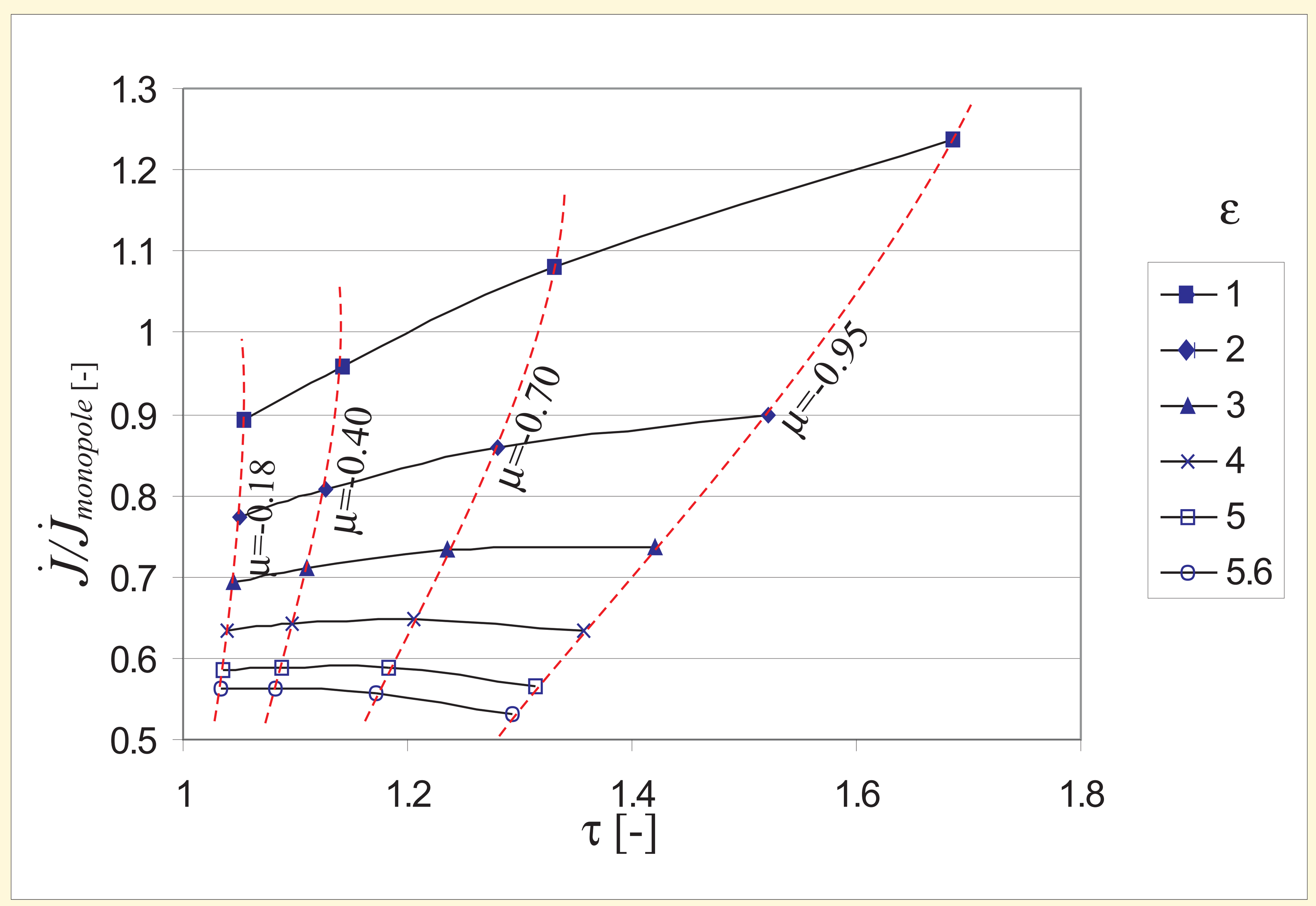

Fig. 2: Total angular momentum loss variations as a function of field concentration towards the pole, τ, for different sets of ε and μ.

Understanding the results of the model

Figure 2 shows the dependence of the angular momentum loss with the field concentration towards the pole, as measured by the parameter τ, with series of different parameters values. Two approaches are presented:

- For a fixed value of μ, as ε increases, the angular momentum loss decreases. In fact, as ε increases, the field becomes less concentrated at the poles and the angular momentum loss per unit mass turns higher at the equator than at intermediate/larger latitudes. However, the mass efflux diminishes and the overall effect is a reduction of the braking.

- For a fixed value of ε, the field becomes more concentrated at the poles as |μ| increases. B_0 also increases but the integration term, of the definition of the angular momentum loss, goes the opposite way. In consequence the angular momentum loss can evolve distinctly, depending on which effect dominates.

Young and rapidly rotating stars show near rigid body rotation profiles with a slightly faster equator (Cameron & Donati, 2002).

⇒ Small values of ε and δ should be evaluated.

⇒ The total angular momentum loss is an increasing function of |μ|. Although there is a decrease of the mass loss rate, it is compensated by an increase of the angular momentum loss per unit mass.

⇒ The higher the polar concentration of the magnetic field, the more efficient is magnetic braking.

On the other hand, for larger values of ε the angular momentum loss first increases and afterwards decreases with growing |μ|.

⇒ The surface rotation is larger at lower/intermediate latitudes.

⇒ As |μ| increases, the field becomes more concentrated at latitudes where the rotation is small leading to an effective decrease in braking efficiency.

Discussion

We show that there are several relevant factors to have into account other than the radial field distribution, when studying the angular momentum loss from a star. In all acceptable solutions, a higher polar field concentration leads to larger braking rates than a smoother field distribution, contrary to what has been suggested.

Still there are important limitations to the model and further research is required to determine whether our results are a consequence of the particular models considered or can be regarded as a general feature.

References

- Cameron, A. & Donati, J., 2002, MNRAS, **329**, L23
- Lima, J.; Priest, E.; Tsinganos, K. 2001, A&A, **371**, 240
- Mestel, L.,1968, MNRAS, **138**, 359
- Mestel L., & Spruit, H. C., 1987, MNRAS, **226**, 57
- Weber, E. & Davis,L.; 1967 ApJ, **148**, 217