Is the efficiency of magnetic braking limited by polar spots?

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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.

- Existing qualitative models of wind braking do not take into account the variation with latitude of some important physical quantities

- Use of a specific analytical 2-D model 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)

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

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

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

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

The model

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

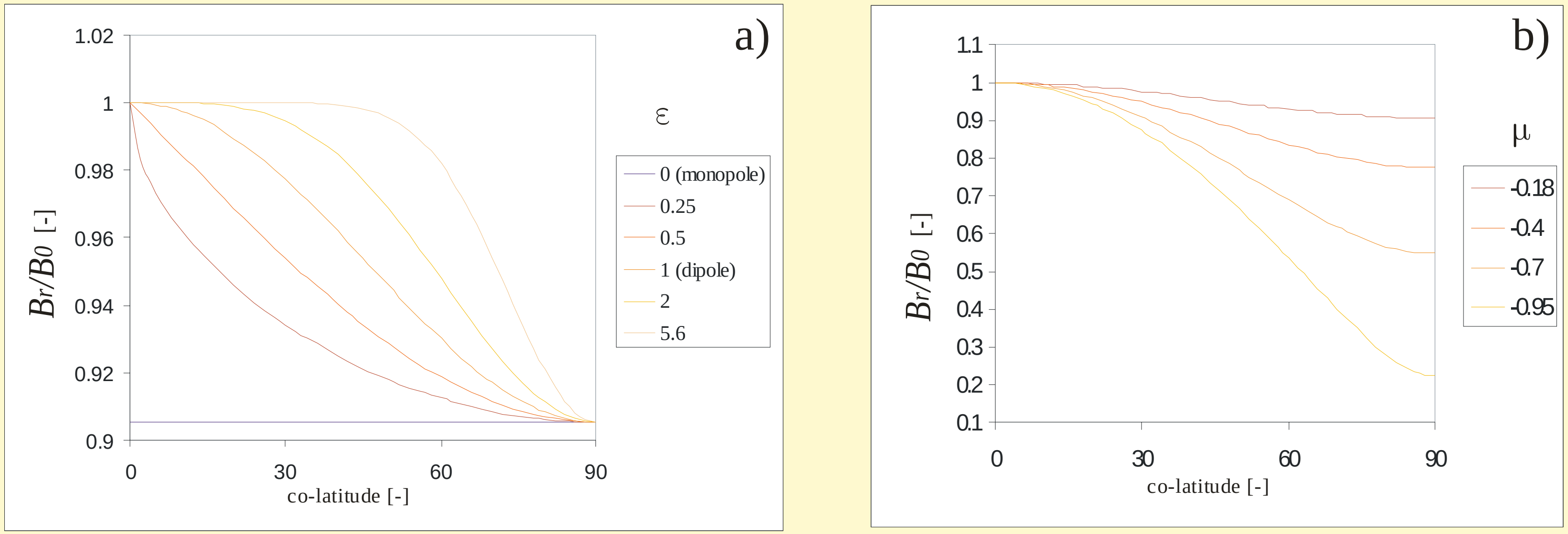

Fig. 1: Different profiles for the radial component of the magnetic field. a) variation with ε; b) variation with μ

Understanding the results of the model

- For a fixed value of μ:

As ε increases

- the angular momentum loss decreases
- the field becomes less concentrated at the poles
- the angular momentum loss per unit mass turns higher at the equator than at intermediate/larger latitudes.
- however, the mass efflux diminishes

➢ The overall effect is a reduction of the braking.

- For a fixed value of ε:

As $|\mu|$ increases

- the field becomes more concentrated at the poles
- B_0 also increases
- however the integration term goes the opposite way.

➢ The angular momentum loss can evolve distinctly, depending on which effect dominates.

Understanding the results of the model

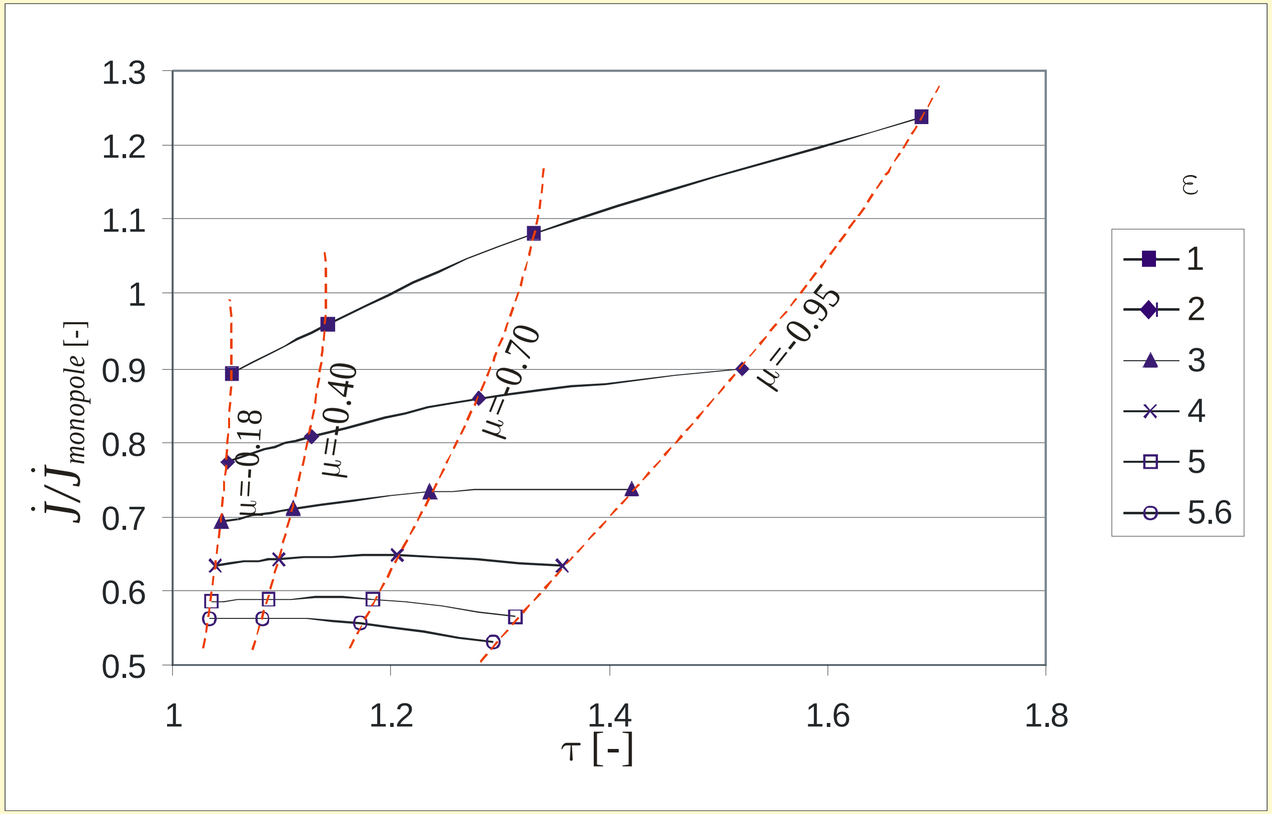

Fig. 2: Total angular momentum loss variations as a function of field concentration towards the pole, τ, for different sets of ε and μ.

Understanding the results of the model

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 $|\mu|$. 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 $|\mu|$.
- The surface rotation is larger at lower/intermediate latitudes.
- As $|\mu|$ 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

- 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.