Revolution evolution: accretion disc-regulated spin down of low mass, pre-main sequence stars

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Introduction

If all angular momentum was conserved during the gravitational contraction from their natal molecular cloud cores, stars would reach rotational velocities in excess of break-up. Instead, stars with accretion discs are observed to rotate at much slower rates, suggesting significant angular momentum removal mechanisms must operate. In light of recent substantial updates to spectral type estimations and newly established intrinsic colours, effective temperatures and bolometric corrections for pre-main sequence stars, we re-address the theory of accretion disc-regulated angular momentum evolution for fully convective members of the Orion Nebula Cluster and Taurus-Auriga.

Fully convective limit

Fully convective stars rotate as solid bodies (Skelly et al. 2008; Carroll et al. 2012; Donati et al. 2014), allowing us to use photometric rotation periods from a single latitude to probe rotation rate.

Gregory et al. (2012) defined the mass-dependent age for which pre-main sequence stars of masses above ~ 0.35 $M_\odot$ (M2) develop radiative cores to be

$$t_{core} \approx \left(1.494\frac{M_\odot}{M_*}\right)^{2.364} \quad \text{Myr}$$

based on Siess et al. (2000) evolutionary models. Less massive stars remain fully convective during their contraction and further main sequence evolution.

The sample: Orion Nebula Cluster (ONC) and Taurus-Auriga

- Non-members, binaries and multiple systems removed from sample.
- Multiple sources of rotation periods in the literature used to exclude those exhibiting beats or aliasing.
- *Spitzer* IRAC fluxes used to classify stars as disc-hosting or disc-less.
- Recalculated stellar masses, ages and radii in fully consistent manner using recent updates to spectral typing and newly established intrinsic colours, effective temperatures and bolometric corrections for pre-main sequence stars (Pecaut & Mamajek 2013).
- Final sample composed of 227 ONC and 24 Taurus-Auriga fully convective accretion disc-hosting and disc-less pre-main sequence stars for which the specific angular momentum, j_*, could be calculated.

Mass-dependent rotation and the large-scale stellar magnetic field

- Accretion disc-hosting sample rotates slower than disc-less sample.
- The slower rotators in the disc-less sample have likely lost their discs more recently than their more rapidly rotating counterparts.
- The faster rotators in the accretion-disc hosting sample are likely to have larger mass accretion rates or weaker dipole magnetic field components than their slower rotating counterparts. Thus, they truncate their discs at smaller radii and spin at a faster disc-locked rotation rate.
- Low mass sample rotates faster, on average, than high mass sample as they truncate their discs closer to their photospheres due to their more complex large-scale magnetic fields.

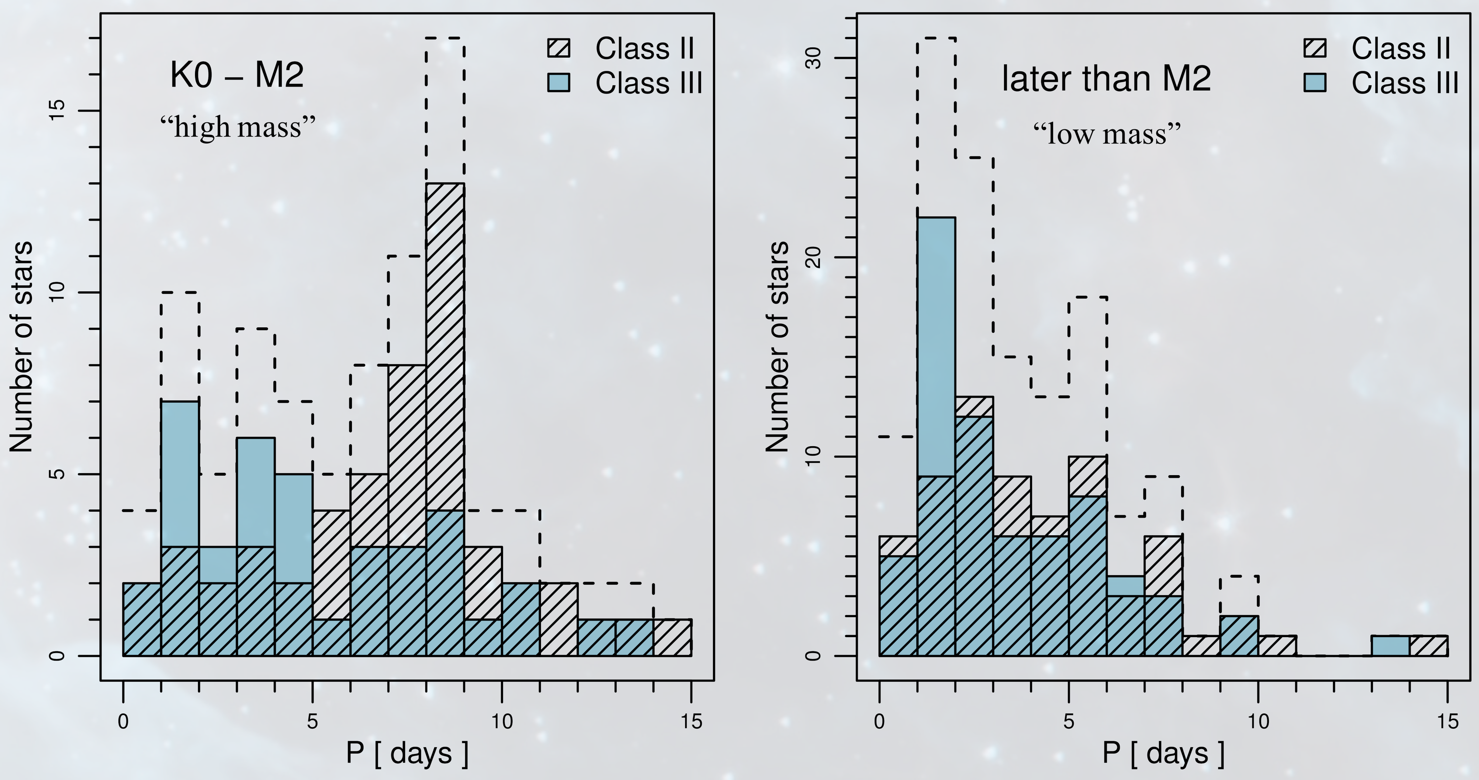

Figure 1: Rotation period histogram

Specific stellar angular momentum evolution

Theoretical expectation

- Specific angular momentum of a fully convective star given by:

$$j_* = \frac{2\pi k^2 R_*^2}{P}$$

- Disc-hosting stars contract at a constant rotation rate (i.e. disc-locked) such that we would expect to observe $j_* \propto t^{-n}$ where $n = 2/3$.
- Disc-less stars maintain constant angular momentum ($n = 0$).

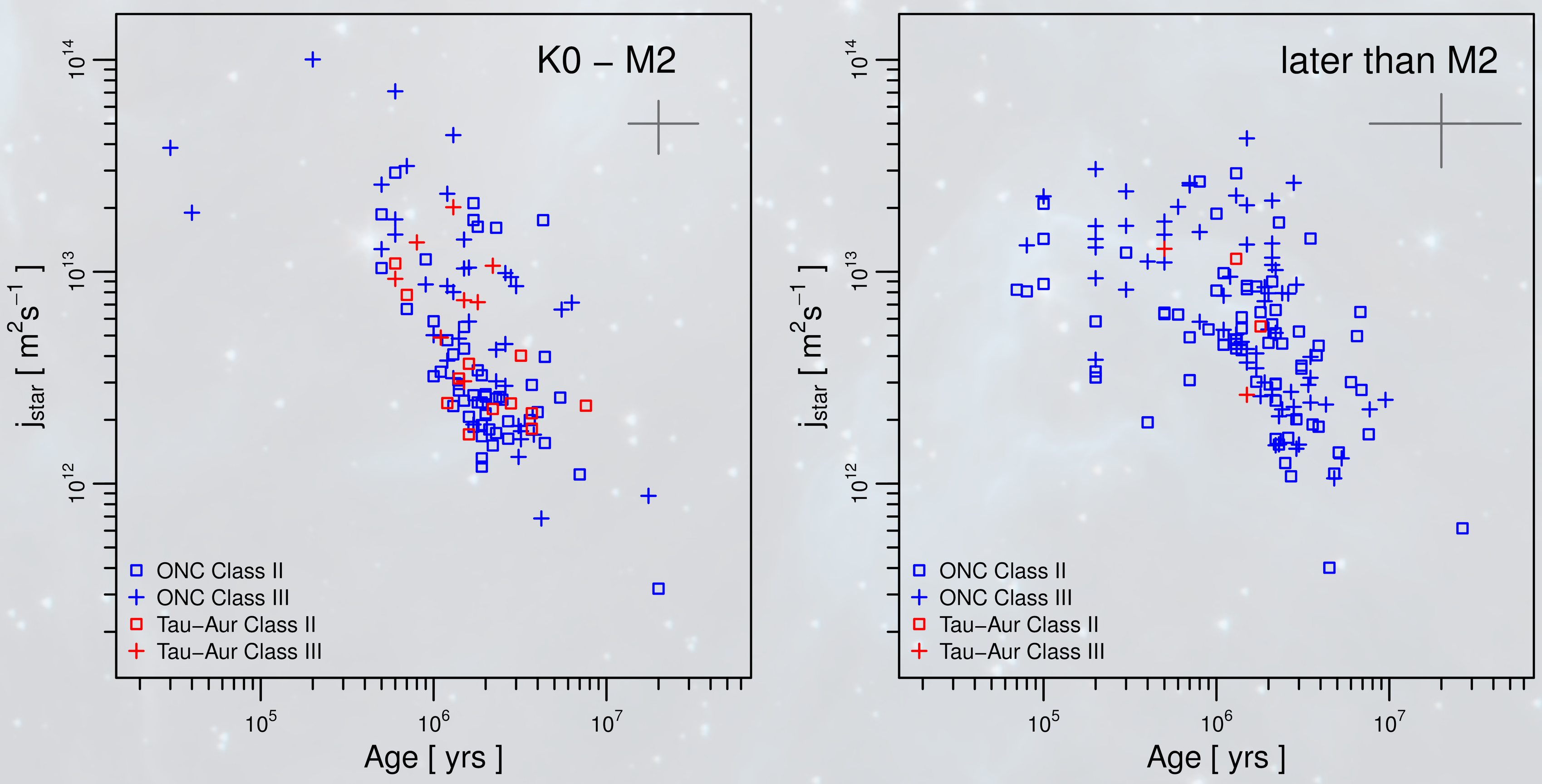

Figure 2: Evolution of specific stellar angular momentum

Observational results

- On average, disc-hosting stars harbour less angular momentum than disc-less stars.
- Angular momentum removal rate is greater than expected: observe $2 < n < 2.5$.
- An efficient angular momentum removal mechanism operates in the star-disc system allowing accretion disc-hosting stars to ***spin down*** as they contract.

Summary and Conclusions

- Accretion disc-hosting stars rotate slower than disc-less stars, on average, in support of accretion disc-regulated angular momentum removal mechanisms.
- The observed rotation rate is dependent on the disc lifetime, the mass accretion rate and the strength of the dipole component of the stellar magnetic field.
- Stars later than M2 rotate faster than higher mass fully convective stars due to their more complex large-scale magnetic fields.
- Accretion disc-hosting stars lose angular momentum more efficiently than can be explained by simple disc-locking theories (i.e. contraction at fixed rotation rate). An additional mechanism must operate, likely in the form of an outflow.
- The range of disc lifetimes and magnetic field strengths across our sample produce a range of rotation periods at the moment the star is released from its disc. This, combined with the observed age spread, hides the expected evolution of disc-less stars at constant angular momentum.

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