Angular Momentum Evolution During Star And Planetary System Formation

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INTRODUCTION

During the collapse from molecular clouds, stars must lose angular momentum to avoid reaching break-up velocities [1]. This can occur via accretion-driven stellar winds, disc-winds or disc-locking. The former two mechanisms take angular momentum away from the star-disc system whereas the latter of these enables the transfer of angular momentum from the star to the circumstellar disc.

Previous studies of disc-locking [2, 3] have focused on differences between rotational period distributions of Class II and Class III pre-main sequence stars. Due to the availability of multi-wavelength data for nearby star forming regions, namely the Orion Nebula Cluster (ONC) and Taurus-Auriga (Tau-Aur), it has been possible to calculate the stellar and disc angular momenta directly from observations.

METHODS OF CALCULATING ANGULAR MOMENTA

Assuming the star is fully convective, it undergoes solid body rotation (fig 1). Therefore, the stellar angular momentum is given by

$$J_* = \frac{4\pi M_* R_*^2}{5P}$$

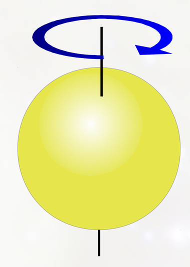


Fig 1: Star as a solid body rotator.

The disc is flat and in Keplerian rotation, with the same axis of rotation as its host star (fig 2). The bulk of material in the disc is at outer radii so disc angular momentum is given by

$$J_{disc} = 0.5 M_{disc} \sqrt{G M_* R_{disc}}$$

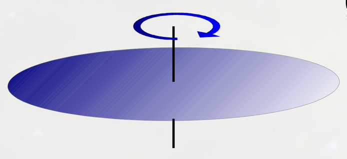
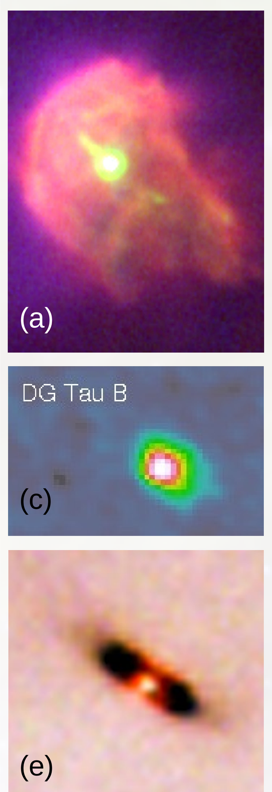


Fig 2: Disc undergoing Keplerian rotation.

Calculations of stellar and disc angular momenta require measurements of stellar mass, stellar radius, rotation period, disc radius and disc mass.

AVERAGE SURFACE DENSITY PROFILE FOR THE ONC



Only 2 stars in the ONC had all the required data. Another 22 were only missing disc masses. An average surface density profile was produced to expand the dataset:

$$M_{disc}(r) = \int 2\pi r \Sigma(r) dr \quad \text{and} \quad \Sigma(r) = \Sigma_0 \left(\frac{r}{R_0}\right)^{-p}.$$

Using the 45 ONC stars with disc mass and radius measurements, the best fits to the parameters were found using χ^2 fitting to

$$\log(M_{disc}) = \log\left(\frac{2\pi \Sigma_0 R_0^p}{2-p}\right) + (2-p)\log(R_{disc})$$

The masses for the 22 additional sources were then calculated using

$$M_{disc} = \frac{2\pi \Sigma_0 R_0^{\ p}}{2-p} R_{disc}^{(2-p)}.$$

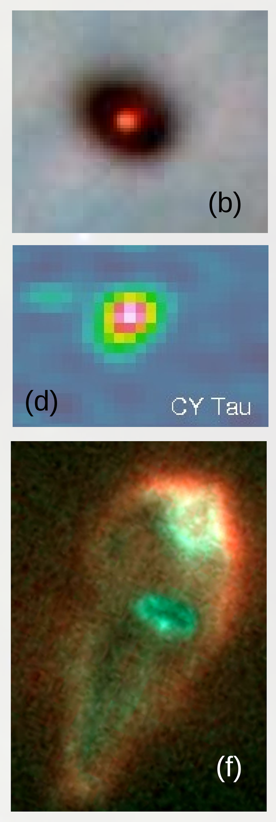


Fig 3(a-f): Observations of discs. (a), (b), (e) and (f) are HST images of the ONC [4]. (c) and (d) are submm images from Taurus-Auriga [5].

COMPARING TAU-AUR AND THE ONC I: DISC PROPERTIES

Used all stars for which the disc mass and disc radius were known. ONC and Tau-Aur samples consisted of 45 and 21 stars, respectively.

Disc Radii

- KS test: 0.03% probability of being drawn from same sample.
- 'Old' discs (age > median) preferentially larger than 'young' (age < median).
- Tau-Aur discs are older and larger than ONC discs.

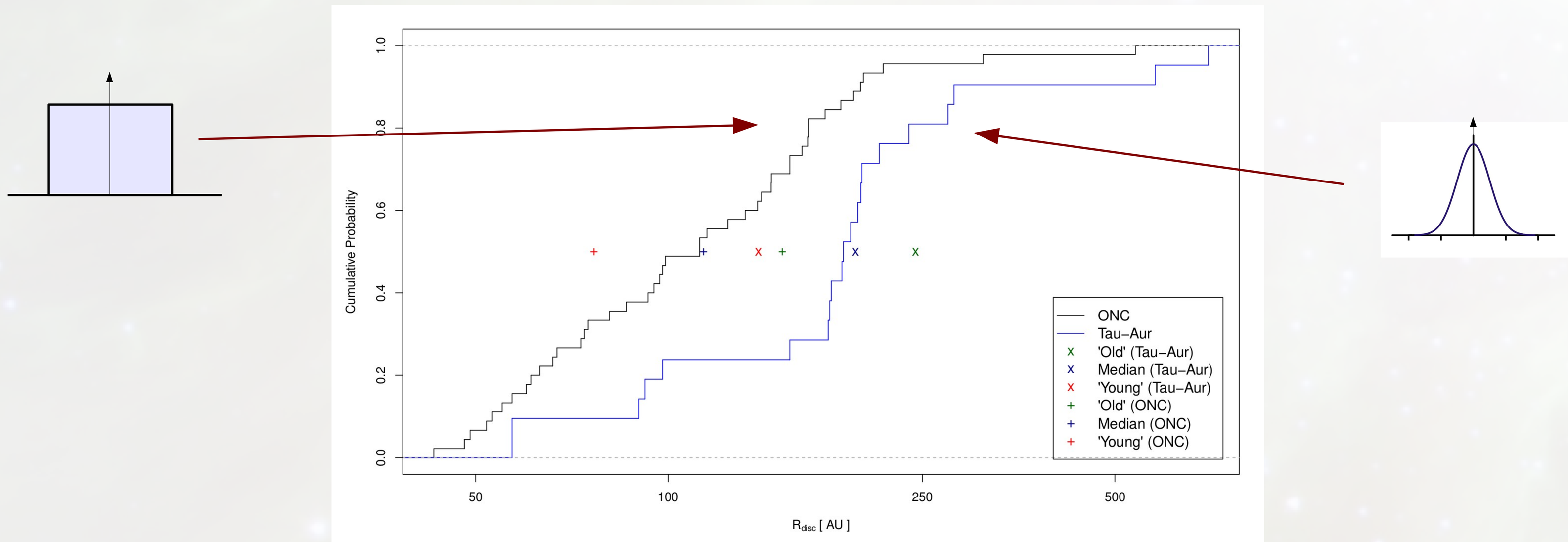


Fig 4: Cumulative distributions of disc radius for Tau-Aur (blue) and ONC (black). Median disc radii for 'young', 'old' and 'median age' stars are shown by crosses. ONC disc radii are rectangularly distributed whereas Tau-Aur discs are Gaussian distributed.

Disc Masses

- KS test: 0.18% probability of being drawn from same sample.
- 'Old' discs preferentially contain less mass than 'young' within each region.
- Tau-Aur sample's stars are older than ONC sample's stars but discs contain more mass.

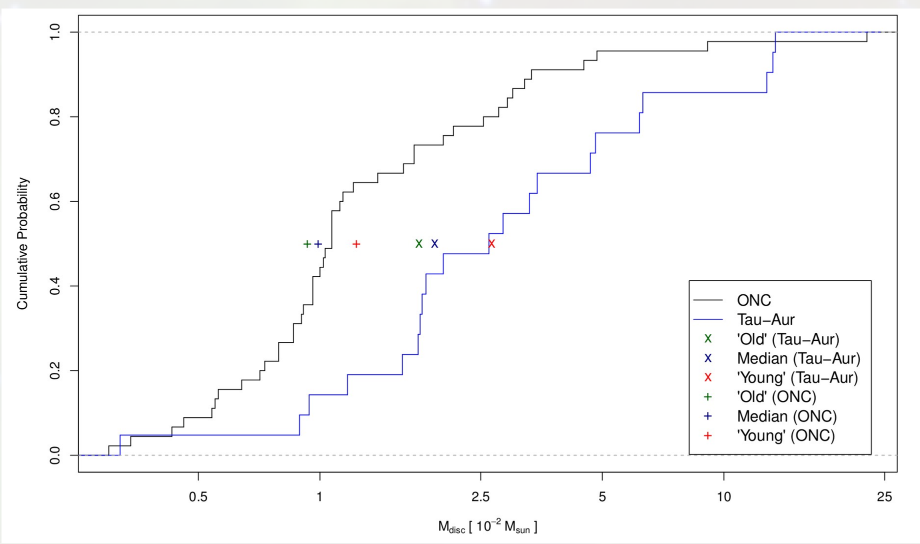
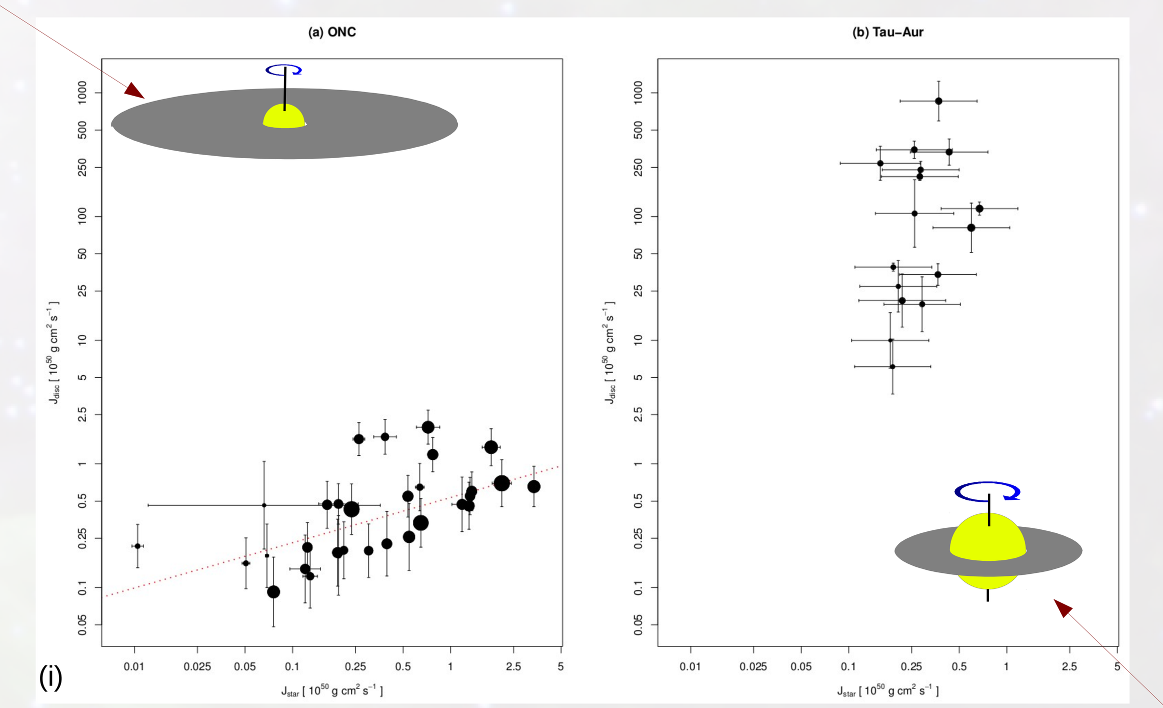


Fig 4: Cumulative distributions of disc masses for Tau-Aur (blue) and ONC (black). Median disc radii for 'young', 'old' and 'median age' stars are shown by crosses. ONC disc masses are Gaussian distributed whereas Tau-Aur discs are rectangularly distributed.

COMPARING TAU-AUR AND THE ONC II: ANGULAR MOMENTUM

Small, slowly rotating star and large disc



Large, quickly rotating star and small disc

The disc-to-star angular momentum ratio: $J_{ratio} = \frac{J_{disk}}{J_{star}}$

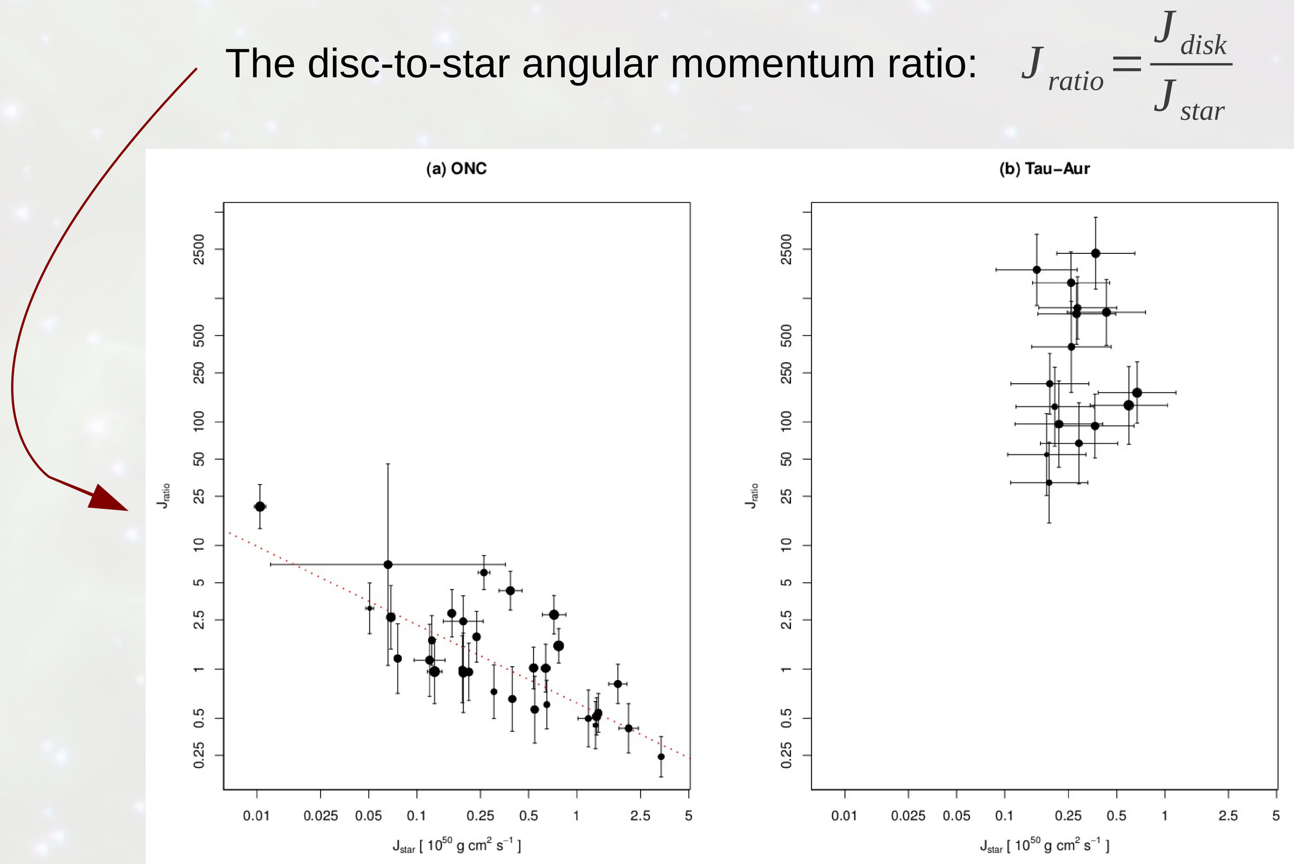


Fig 5: Plots of (i) disc angular momentum against stellar angular momentum for (a) ONC and (b) Tau-Aur and (ii) disc-to-star angular momentum ratio against stellar angular momentum for (a) ONC and (b) Tau-Aur.

CONCLUSIONS

- ONC discs are smaller and less massive than those in Tau-Aur.
- Within each region, older discs are preferentially larger and less massive. These results are consistent with viscous accretion theories and disc dispersal.
- ONC discs are less massive than Taurus discs even though the sample of Taurus discs are older than the ONC sample. Birth cloud environment may be important to disc evolution.
- The older ONC sample stars harbour discs with more angular momentum than the younger sample but the more evolved Tau-Aur 'old' and 'young' samples have consistent disc angular momenta. The 'missing' disc angular momentum in older Tau-Aur discs could be contained within yet-undetected planets.

References:
[1] Bodenheimer, P., 1995, ARA&A, 33, 199
[2] Herbst, W., et al., 2002, A&A, 396, 513
[3] Rodríguez-Ledesma, M. V., et al., 2009, A&A, 502, 883
[4] Ricci, L., et al. 2008, AJ, 136, 2136
[5] www.astro.caltech.edu/~jmc/

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