The evolution of baby Sun-like stars

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Does a forming star with a disc spin-up when it develops a radiative core?

When forming Sun-like stars emerge from their parent dust clouds they are located on the birthline of the Hertzsprung-Russell (H-R) diagram (Fig.1); a plot of stellar luminosity vs stellar atmospheric temperature. Initially, they are surrounded by discs of gas/dust, the birthplace of planets. As they contract under gravity, stars of different mass follow different paths across the H-R diagram, until they settle on the main sequence when nuclear fusion begins in their cores.

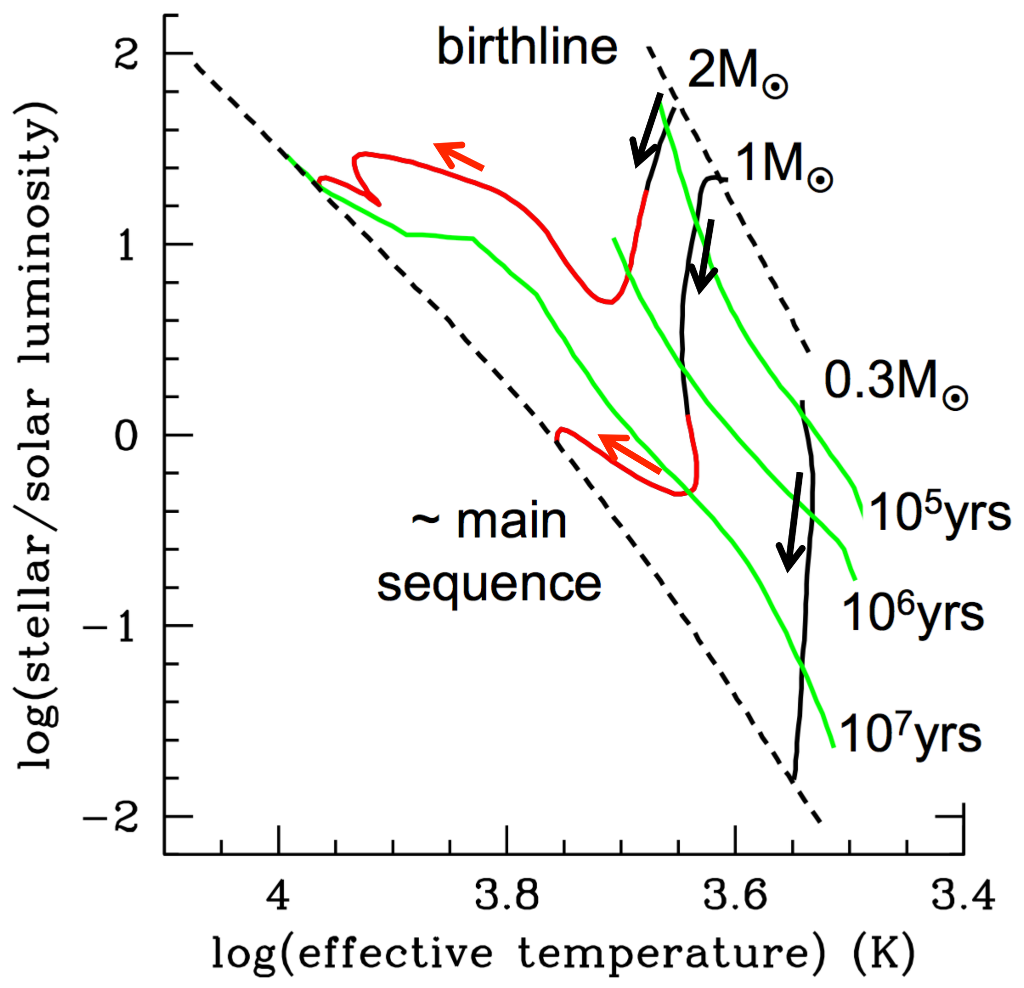

Fig. 1: The stellar internal structure changes from fully convective (black segments of the mass tracks) to part convective with a radiative core (red segment) as stars age. The stellar luminosity decreases (Hayashi track) and then increases (Henyey track) once the star is mostly radiative.

The stellar structure change from fully to partially convective has been found to increase the complexity of the large-scale magnetosphere (Donati et al 2011 MNRAS 417 472; Gregory et al 2012 ApJ 755 97), decreasing the magnetic field strength at the inner disc (Fig. 2) and allowing the disc to push closer to the star. As the disc material is in Keplerian rotation (rotation rate increasing with decreasing distance from the star) accretion of this material will exert a torque on the star causing it to spin-up. *This should mean that stars that still have discs when they become partially convective should be faster rotators than stars with discs that are fully convective.*

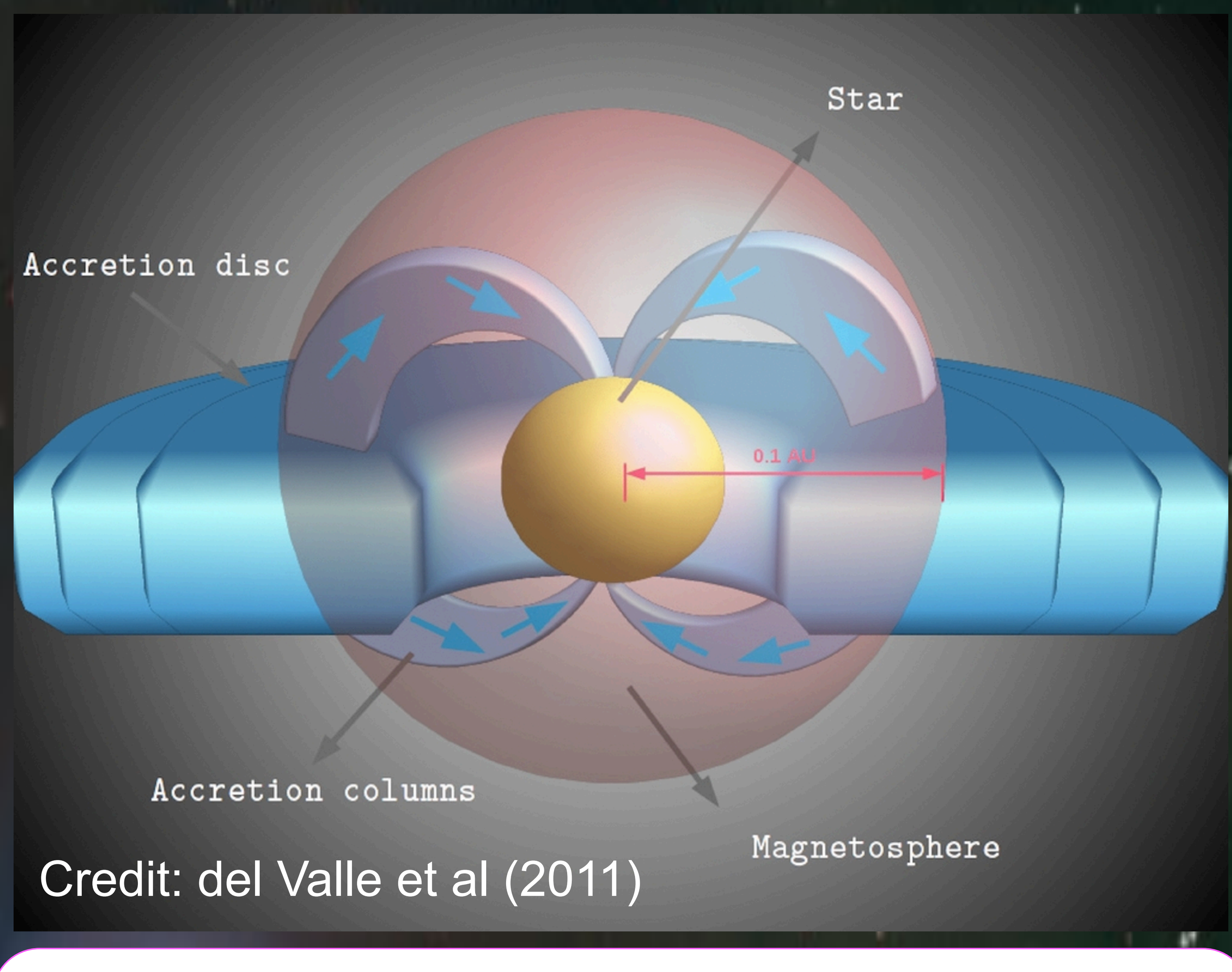

Fig. 2: Illustration of a young star interacting with its disc. Gas from the disc accretes along the large-scale magnetic field lines on to the stellar surface.

Observations

We used an existing dataset of stellar masses, rotation periods, and stellar internal structure information, for ~500 forming stars in five of the best studied star forming regions: ONC, IC 348, NGC 2264, NGC 6530 & NGC 2362 (Gregory et al 2015, submitted.). Those which are still surrounded by a disc show excess near-infrared emission due to the reprocessing of starlight by dust within the disc. We collated archival data from the Spitzer space telescope, when available, in four wavebands centred on [3.6], [4.5], [5.8] & [8.0] μm. Using differences in the Spitzer magnitudes, we used the conditions from Davies et al (2014 MNRAS 444 1157) & Gutermuth et al (2009 ApJS 184 18) to determine which stars had discs.

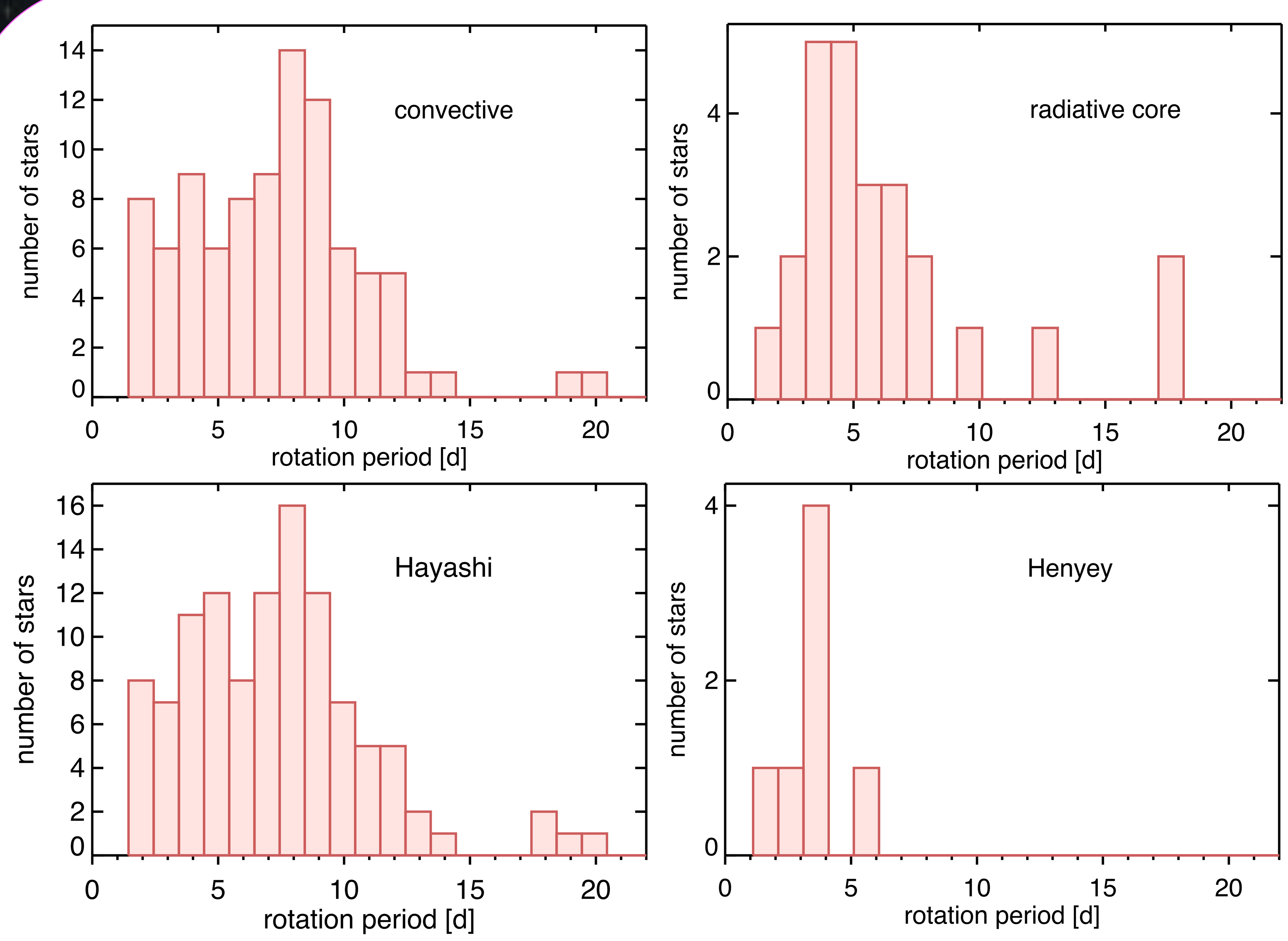

Fig. 3: Rotation period distributions for forming stars with discs with fully convective interiors; with radiative cores; and located on Hayashi & Henyey tracks in the Hertzsprung-Russell diagram (see Fig. 1).

Results

For stars with discs and of spectral type M2 and earlier (roughly those of mass $>0.35\ M_\odot$, all of which will develop radiative cores) we find median rotation periods of 7.49 & 5.04 d for stars with fully convective & part convective (radiative core) interiors respectively. Comparing Hayashi track to Henyey track stars the median rotation periods are 7.04 & 3.31 d respectively.

Two sided Kolmogorov-Smirnov tests show the rotation period distributions (Fig. 3) are significantly different: P(0)=0.022 comparing convective/radiative core; 0.003 comparing Hayashi/Henyey.

This tentatively supports the idea that forming stars spin-up through the star-disc interaction when they develop radiative cores. More rotation periods/disc data are required to confirm this.