Chomospheric activity to age relationship among Sun-like stars

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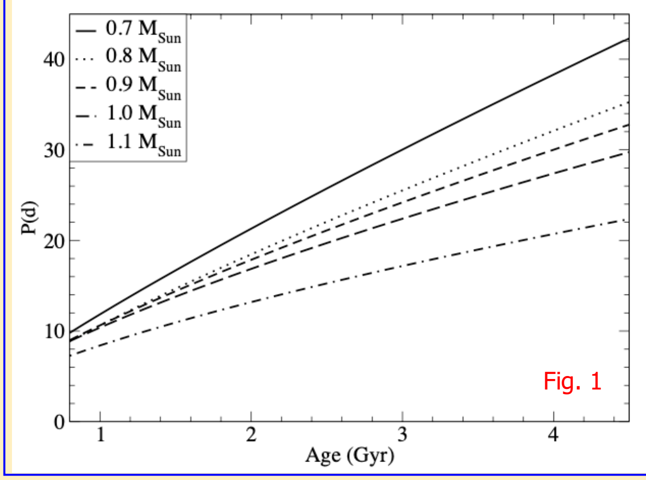
Summary: Although some controversy arose on the use of chromospheric emission as a reliable age indicator, most recent studies have established the viability of deriving usable chromospheric ages for solar-type stars older than 600 Myrs up to at least 6 Gyr, providing that mass and metallicity effects are accounted for (e.g. Booth et al. 2020 Gondoin 2020a).

In order to avoid the uncertainty associated with the age determination of field stars, I characterised the long-term evolution of chromospheric activity on Sun-like stars indirectly, following the approach used in Gondoin (2018). The approach consists of combining a best fit parametric model of the rotation evolution of Sun-like stars in open clusters with rotation-activity relationships. It uses the biunique relationship between the chromospheric activity index R'_{HK} of main-sequence stars and their Rossby number Ro defined as the ratio of the rotation period P over the convective turnover time t_c. While P is time and mass dependent, t_c mainly depends on stellar mass for main-sequence stars. I derived the mean rotation rates of main-sequence stars at intermediate ages from measured rotation periods versus B-V indices or effective temperatures in NGC 6811 (Meibom et al. 2011; Curtis et al. 2019), in NGC 6819 (Meibom et al. 2015), and in M67 (Barnes et al. 2016). These open clusters are 1.0 Gyr (Sandquist et al. 2016), 2.4 Gyr (Brewer et al. 2016), and 4 Gyr (VandenBerg et al. 2004) old respectively, and have solar metallicities (Corsaro et al. 2017, Liu et al. 2019).

Figure 1 shows the interpolated evolution of the rotation periods of 0.7, 0.8, 0.9, 1.0, and 1.1 $M_\odot$ stars between the ages of 1 and 4 Gyr. This evolution depends on stellar mass with a steeper decay for low-mass stars. Figure 2 shows the corresponding chromospheric evolution derived from the the R'_{HK} vs Ro relationship formulated by Mamajek & Hillenbrand (2008).



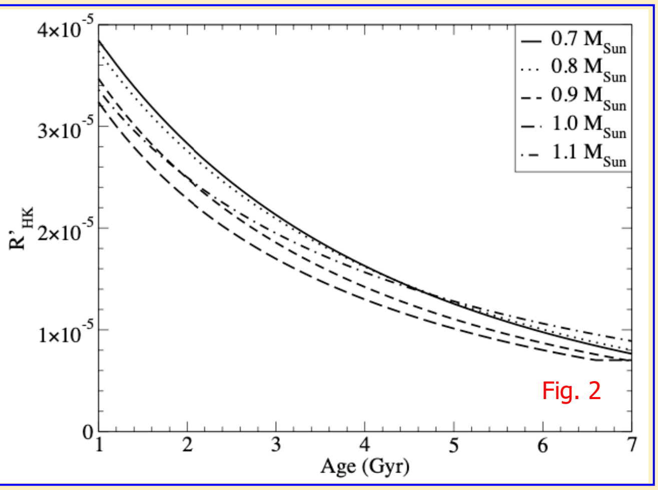
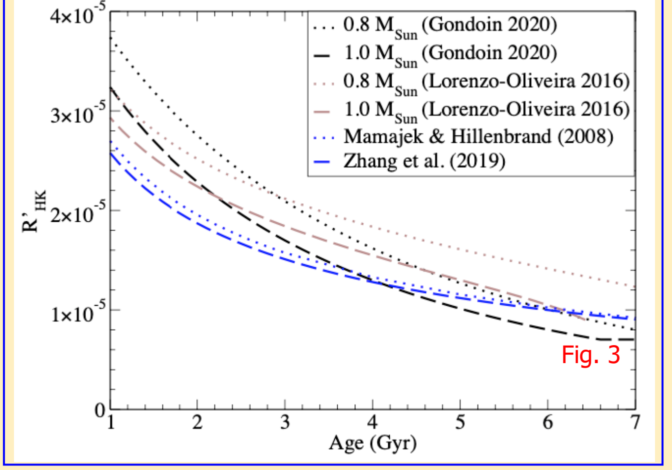


Figure 3 compares the evolution of the R'_{HK} activity index that I derived with the relationships from (i) Lorenzo-Oliveira et al. (2016) applied to 0.8 and 1.0 $M_\odot$ stars with a solar metallicity, (ii) Mamajek and Hillenbrand (2008) , and (iii) Zhang et al. (2019) for stars with 4000 K < T_{eff} < 5000 K.



The decay of the R'_{HK} index that I inferred from rotation period measurements in 1.0, 2.4, and 4.0 Gyr old clusters is steeper than the activity evolution derived by previous studies from best fits to measured R'_{HK} data in young (< 0.7 Gyr) open clusters and in M67 (4 Gyr). The origin of this difference comes from recent observations that stars experience a reduced braking efficiency and stalled spin-down between the ages of 670 Myr and 1 Gyr (Curtis et al. 2019; Spada & Lanzafame 2020).

Conclusion: the chromospheric activity evolution of Sun-like stars with ages between 1 and 6 Gyr and masses between 0.7 and 1.1 $M_\odot$ is steeper than the relationship R'HK ~ $age^{-0.5}$ generally used.

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