Common dynamo scaling in late-type main sequence and evolved stars

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ROTATION–ACTIVITY RELATION

Both magnetic activity and the magnetic field strengths of late-type stars are observed to scale up with stellar rotation up to a certain saturation level. We have analysed the rotation–activity relation of main sequence (MS) stars and evolved subgiants and giants using chromospheric Ca II H&K activity indices derived from the Mount Wilson HK project dataset.

ROSSBY NUMBERS

Expressing the rotation–activity relation in terms of the Rossby number, Ro = $P_{\rm rot}/\tau_c$, requires estimating convective turnover times, τ_c, for the stars. These were derived from the YaPSI stellar evolution models (Spada et al. 2017) in relation to stellar temperature, luminocity, and metallicity. Fig. 1 shows that τ_c increases steeply towards the red giant branch.

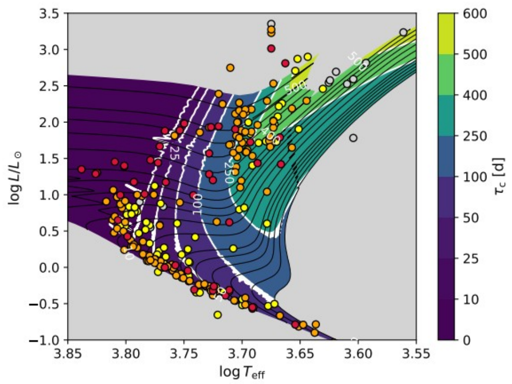

Fig. 1. The sample stars against the YaPSI evolutionary tracks with colour coding for τ_c. Grey and yellow stars have low activity emission while the orange and red ones have high activity emission.

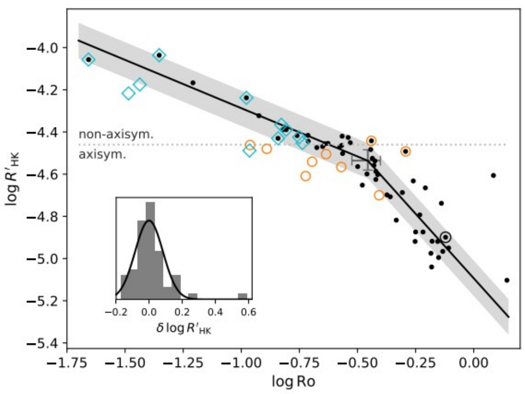

Fig. 3. Two-piece power law fit to the MS rotation–activity relation (Lehtinen et al. 2021). Orange circles and cyan diamonds denote stars with axisymmetric and non-axisymmetric spot distributions, as observed from long term photometry (Lehtinen et al. 2016).

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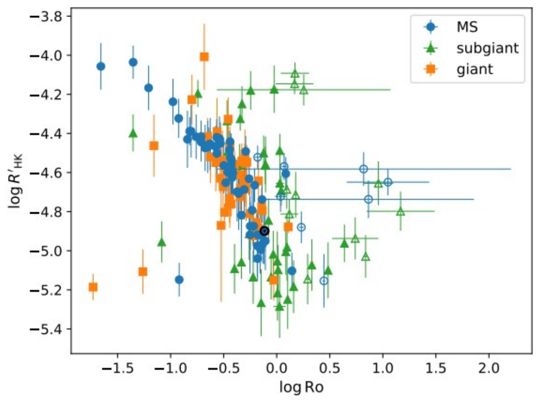

Fig. 2. Rotation–activity relation for the MS and evolved stars. The open symbols denote stars with low and uncertain τ_c values (Lehtinen et al. 2020)

COMMON DYNAMO SCALING

We find that that the activity levels of both the MS and evolved stars follow the same scaling relation against the Rossby number (Fig. 2). This unification can only be achieved in terms of the Rossby number. Alternate ways of expressing the rotation–activity relation, which do not include τ_c correctly, always lead to two separate branches for the MS and evolved stars and fail to explain this dichotomy (Lehtinen et al. 2020).

We conclude that turbulent convection, parametrised by τ_c, is thus a vital component of the stellar dynamo alongside stellar rotation. On the other hand, the same turbulent dynamo seems to be present in both MS and evolved stars, despite their very different internal structures.

Our sample does not contain the rotation-independent activity regime at small Ro, but it is expected that also this is present on the fastest rotating giant stars.

ACTIVITY KNEE

More detailed modelling of the rotation–activity relation reveals a localised knee at mid activity levels (Lehtinen et al. 2021). This is especially clear on the MS stars (Fig. 3). Here we find a discrete break between two power law regimes at $\log R'_{\rm HK} = -4.54 \pm 0.05$. This is very close to the transition between axisymmetric and non-axisymmetric activity configurations seen in starspot activity at $\log R'_{\rm HK} = -4.46$ (Lehtinen et al. 2016).

We interpret the knee in the rotation–activity relation to be connected with the transition between axisymmetric and non-axisymmetric dynamo modes (Viviani et al. 2018; Viviani & Käpylä 2021). This indicates that the axisymmetric and non-axisymmetric dynamo modes have a different dependence to the stellar rotation.

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