A New Understanding of Magnetic Stellar Evolution

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Standard model of rotational evolution

Bouvier (2008)
Old stars rotate faster than expected

- MCMC fit of an empirical gyrochronology relation to clusters and Kepler stars
- Conclusion: “no single relation between rotation period, colour and age can adequately describe all subsets of our data.”

Angus+ (2015)
Weakened braking beyond middle-age

- Deviation from standard spin-down earlier in hotter stars, later in cooler stars

- Dependence suggests critical Rossby number, $\text{Ro} = (P_{\text{rot}} / \tau_c) \sim \text{Ro}_\odot$

- Models with weakened magnetic braking beyond $\text{Ro}_\odot$ reproduce the data

van Saders+ (2016, Nature)
Activity cycle grows longer and weaker

- Stalled braking coincides with longer activity cycles and lower amplitudes
- Old stars eventually reach 'flat activity' state, or cycle becomes undetectable
- Sun appears to be in transition towards longer and weaker cycle

Metcalfe & van Saders (2017)
Evolution of magnetic complexity

- **Saturation regime:** range of rotation rates at constant activity level
- **Skumanich regime:** rotation rate and activity level decline together
- **Decoupled regime:** activity level evolves at constant rotation rate

Garaffo+ (2018)
1. Slow rotation becomes non-differential

Featherstone & Hindman (2016)
2. Loss of shear breaks dynamo loop

\[ \Omega \text{ effect (poloidal } \rightarrow \text{ toroidal field)} \]
3. Decaying large-scale field stalls braking

Reville+ (2015)
4. Cyclic global dynamo shuts down

Egeland+ (2017)
LBT/PEPSI data confirms predictions

- Detection of large-scale field in 88 Leo, dominated by a dipole (2.51 G)
- Chromospheric emission (sensitive to all scales) is 76% as strong in $\rho$ CrB
- Upper limit on dipole field strength in $\rho$ CrB (0.48 G) below expectation (1.9 G)
Activity-age relation from TESS

- Magnetic activity declines continuously with age, so it's still useful for old stars
- Mass dependence puts 88 Leo and ρ CrB below relation for solar analogs
- Gyrochronology age for ρ CrB would place it well below the relation

solar analogs from Lorenzo-Oliveira+ (2018)
Summary of conclusions

• Magnetic stellar evolution takes an unexpected turn beyond the middle of main-sequence lifetimes
• Slow rotation becomes uniform, breaks the $\Omega$-effect, stalls magnetic braking as global dynamo shuts down
• New understanding can help explain why the 11-year solar cycle falls between the two stellar sequences
• Additional tests from future LBT/PEPSI observations combined with asteroseismic properties from TESS