Limitations of Gyrochronology for Old Field Stars

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Spin-down stalls near middle-age

- Beyond middle-age, stars rotate more quickly than expected from Skumanich.

- Discrepancy appears at a critical Rossby number, $\text{Ro} = (P_{\text{rot}} / \tau_c) \sim \text{Ro}_\odot$

- Bright stars with ages from asteroseismology follow this same pattern.

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

- Stalled braking coincides with longer activity cycles and lower amplitudes
- Old stars eventually reach constant activity state, or cycle is undetectable
- Observed in hotter and cooler stars at faster and slower rotation (~ $R_{\odot}$)
1. Slow rotation becomes non-differential

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

\[ \Omega \text{ effect (poloidal} \rightarrow \text{toroidal field)} \]

Higgins (2012)
3. Decaying large-scale field stalls braking

dipole  quadrupole  octupole

Reville+ (2015)
4. Global dynamo gradually shuts down

Egeland+ (2017)
Evidence from the Mount Wilson sample

- Gyro and chromo ages generally agree over a large range of activity
- Most significant outliers are at the lowest activity levels ($\log R'_\text{HK} < -5$)
- Surface gravities, Gaia luminosities, absence of cycles $\rightarrow$ evolved stars

Barnes (2007); Metcalfe & Egeland (2019)
Evidence from PEPSI spectropolarimetry
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88 Leo: detect large-scale field

ρ CrB: no significant detection
Evidence from TESS asteroseismology

- Given stellar properties of subgiant, predict current rotation period \( (47 \pm 4 \text{ d}) \)

- Stalled magnetic braking beyond stellar middle-age yields: \( P_{\text{rot}} = 48 \pm 4 \text{ days} \)

- Standard spin-down for complete main-sequence yields: \( P_{\text{rot}} = 78 \pm 7 \text{ days} \)
The activity-age relation is continuous

- Magnetic activity declines continuously with age, so it's still useful for old stars
- Easier to get one Ca HK spectrum than a full time series for rotation period
- Old stars have constant activity, so one spectrum likely to be representative
Summary of conclusions

• Slow rotation becomes uniform, breaks the $\Omega$-effect, stalls magnetic braking as global dynamo shuts down

• Hot stars from the Mount Wilson survey have already made this transition, gyro and chromo ages diverge

• PEPSI spectropolarimetry supports the disappearance of large-scale field in hot stars that span this transition

• TESS asteroseismology of a Mount Wilson subgiant requires stalled braking to explain current rotation rate