The Origin of Weakened Magnetic Braking

Travis Metcalfe

White Dwarf Research Corp.

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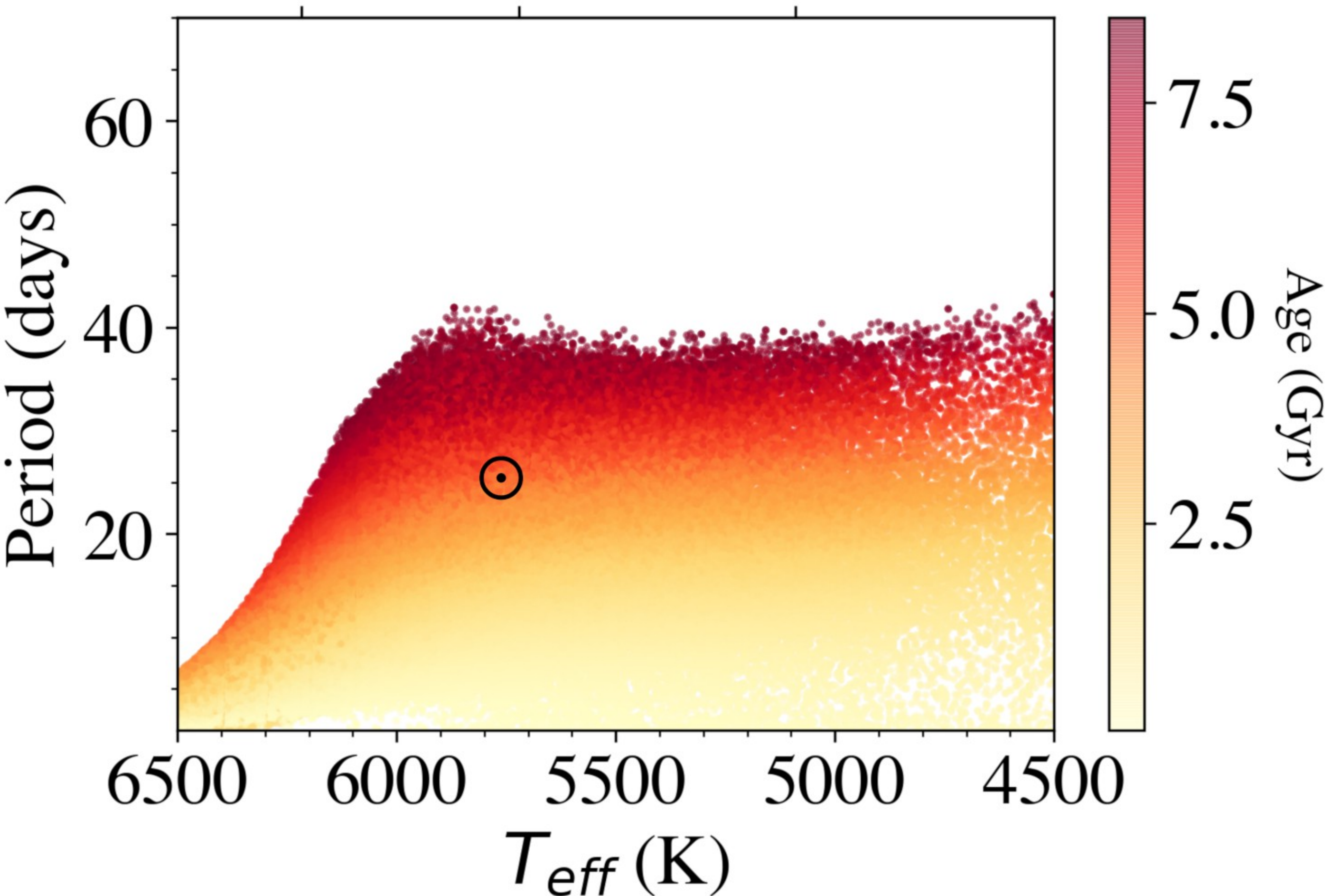
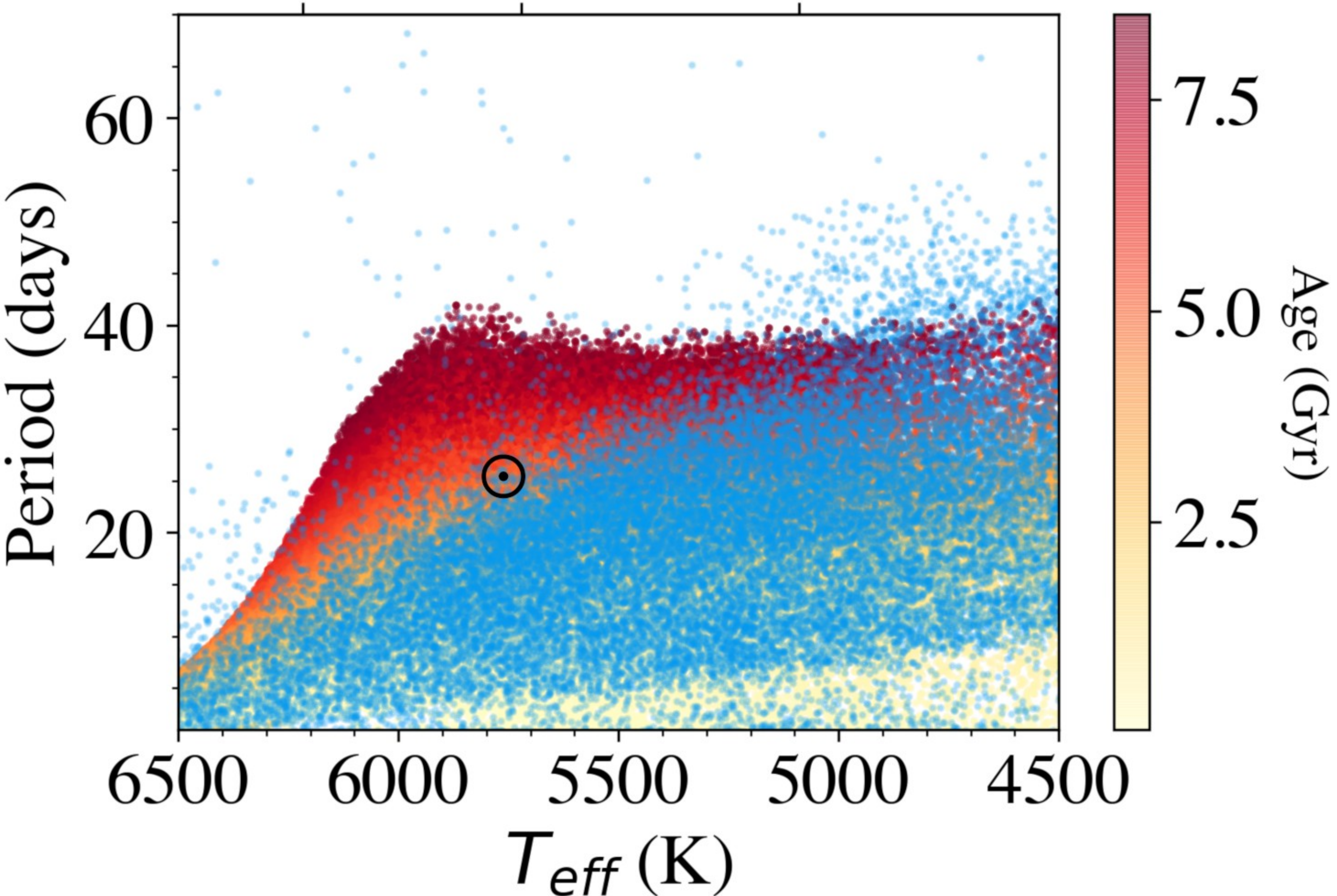
<u>Collaborators</u>: Adam Finley, Oleg Kochukhov, Victor See, Thomas Ayres, Keivan Stassun, Jennifer van Saders, Catherine Clark, Diego Godoy-Rivera, Ilya Ilyin, Marc Pinsonneault, Klaus Strassmeier, Pascal Petit

Weakened magnetic braking



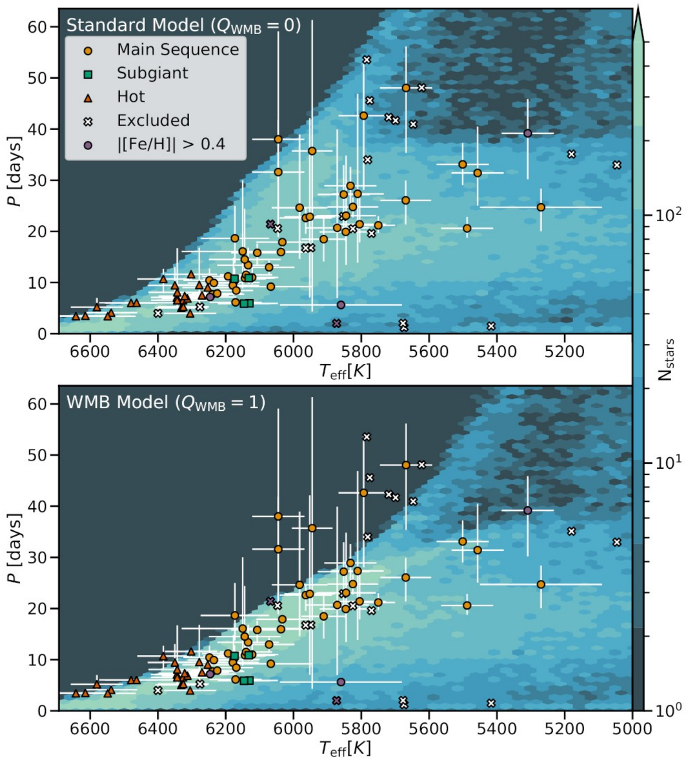
van Saders+2019

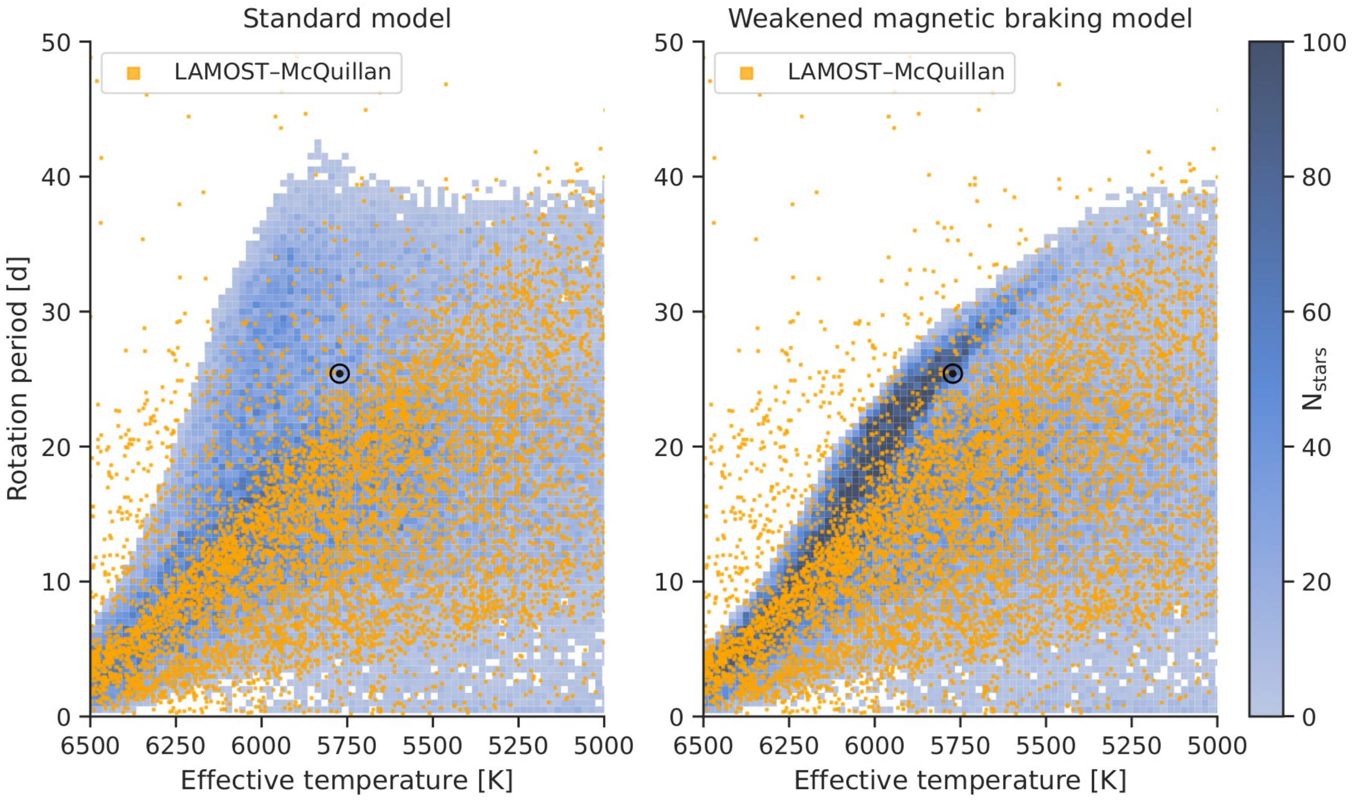
Weakened magnetic braking



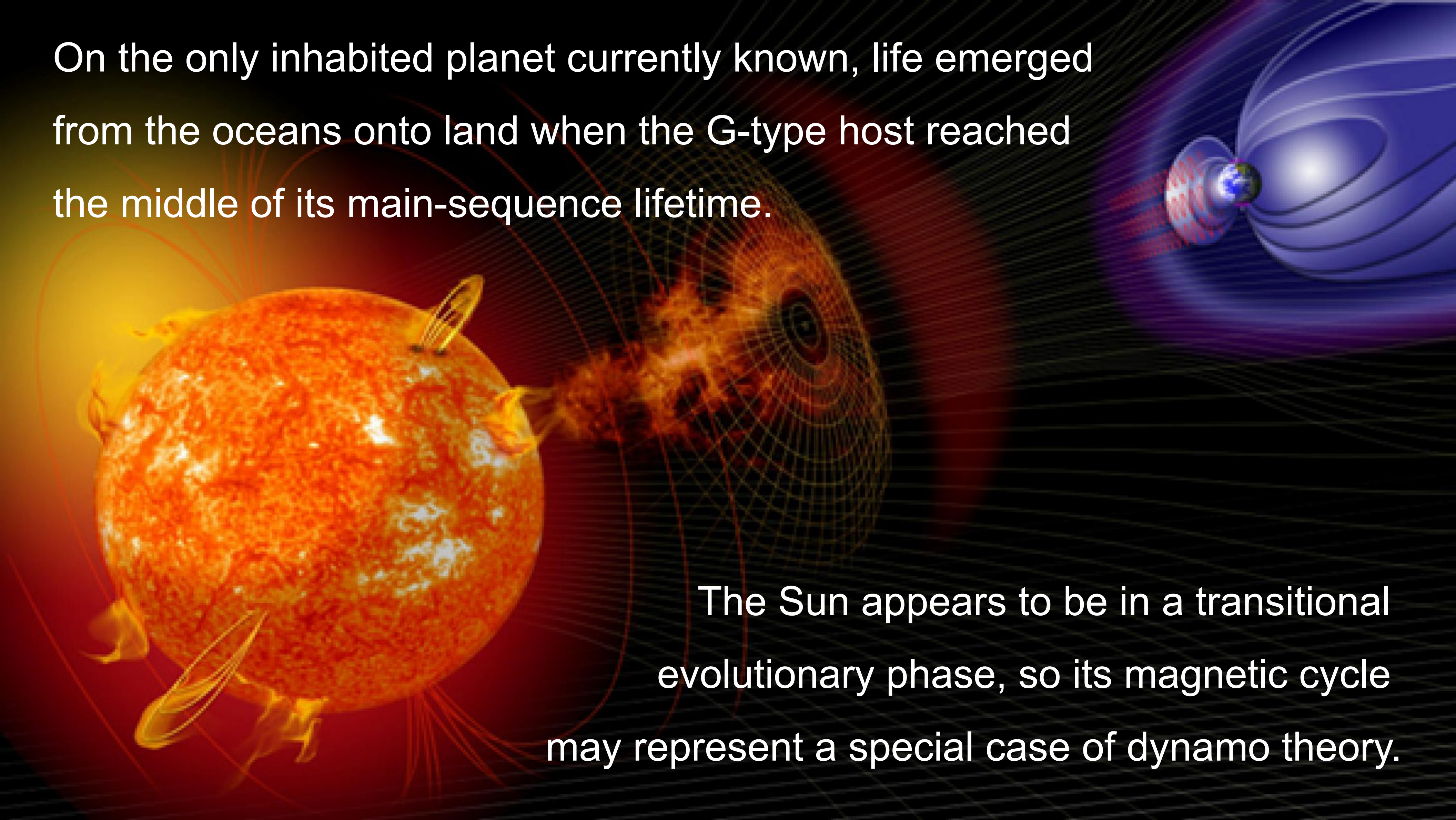
van Saders+2019

- **No detection bias:** asteroseismic rotation rates show similar distribution
- **Pile-up confirmed:** precise T_{eff} shows range of ages at long-period edge





Hall+2021, David+2022

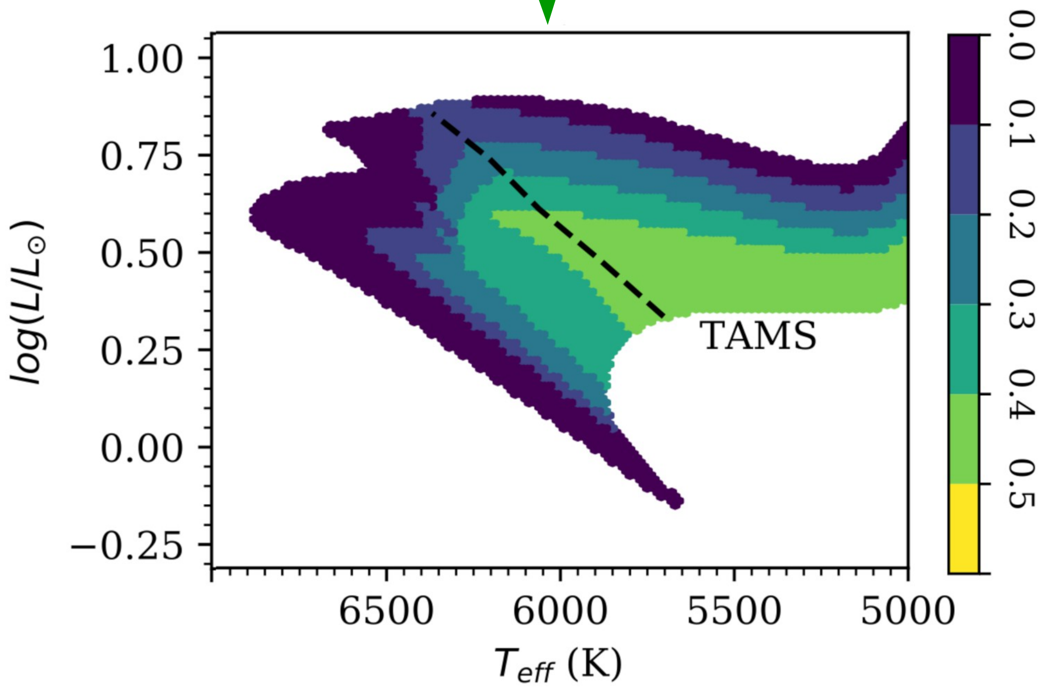

On the only inhabited planet currently known, life emerged from the oceans onto land when the G-type host reached the middle of its main-sequence lifetime.
The Sun appears to be in a transitional evolutionary phase, so its magnetic cycle may represent a special case of dynamo theory.

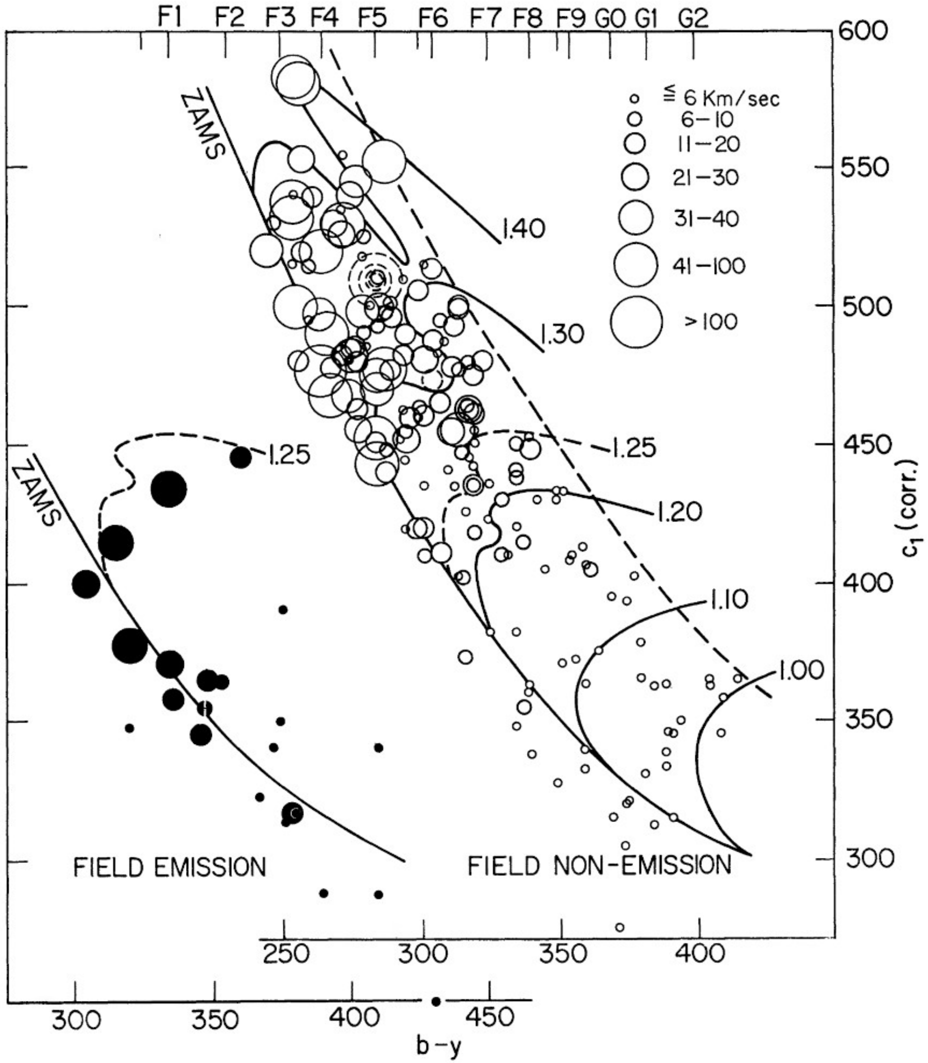
To sustain a magnetic dynamo, the Rossby number cannot be too large!

$$Ro \equiv P_{rot} / \tau_c$$

too short

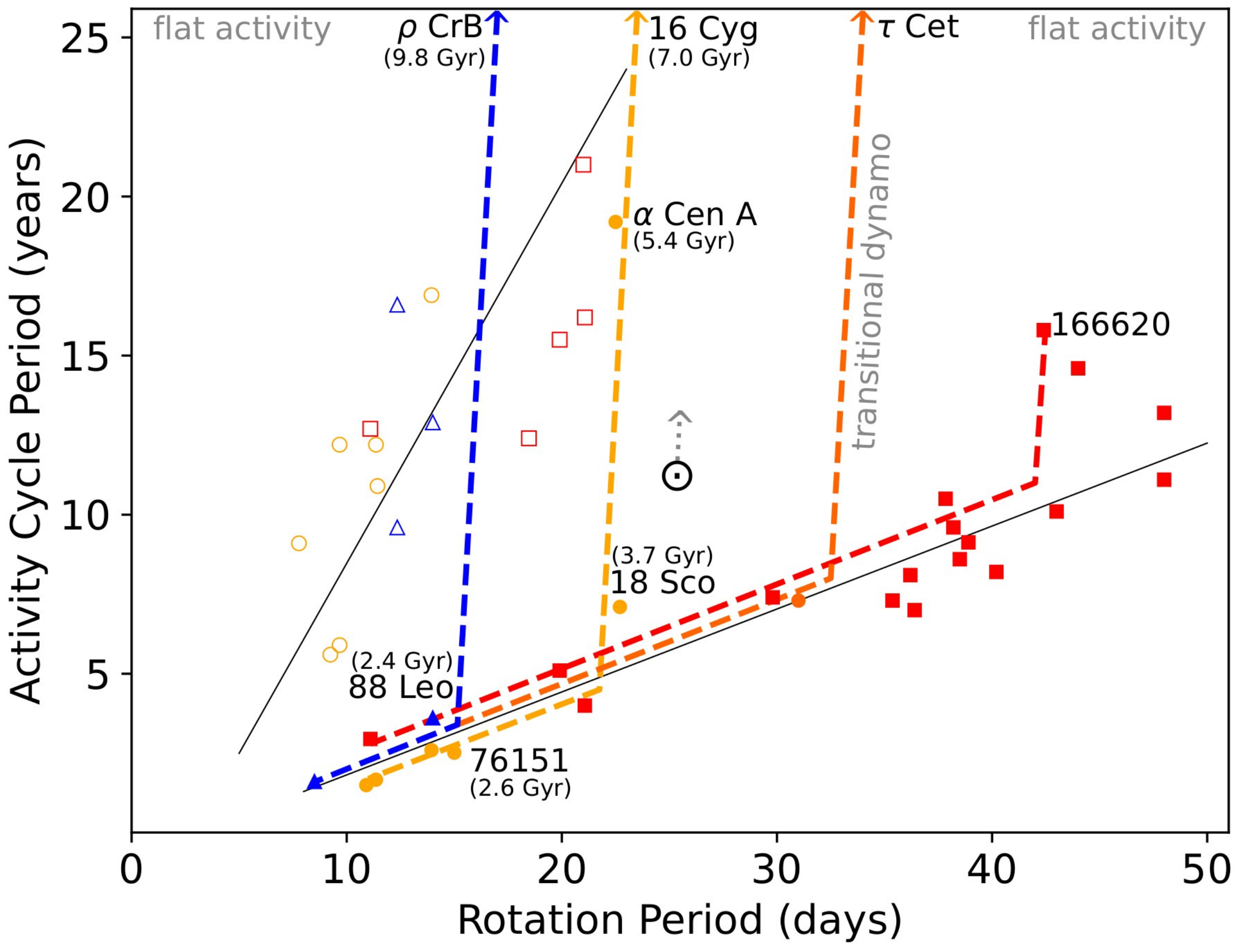
too long





Durney & Latour 1978, van Saders 2022, Kraft 1967

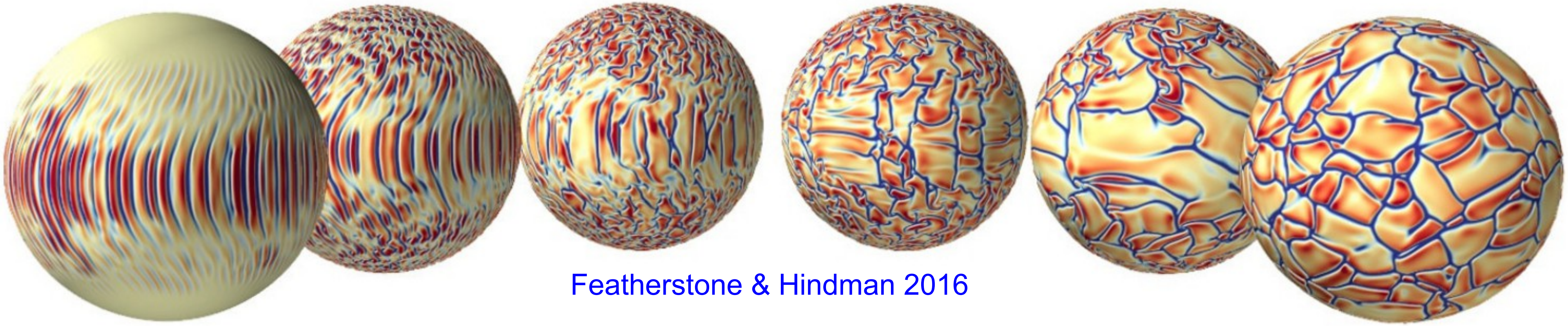
Cycles grow longer and weaker in old stars



- Stalled rotation coincides with longer activity cycles and weaker variability
- Same pattern observed in hotter and cooler stars at same Rossby number
- Prediction: younger stars should have strong dipole while older stars will not

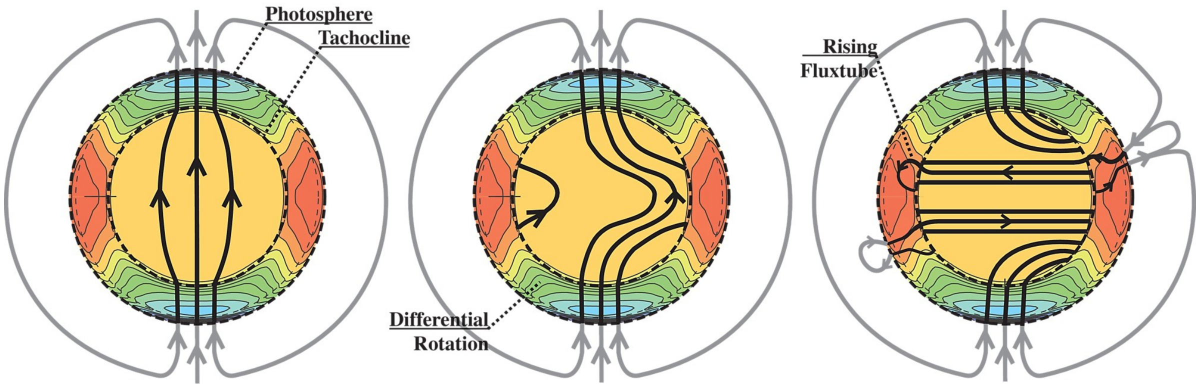
Metcalfe & van Saders 2017

1. slow rotation becomes non-differential



Featherstone & Hindman 2016

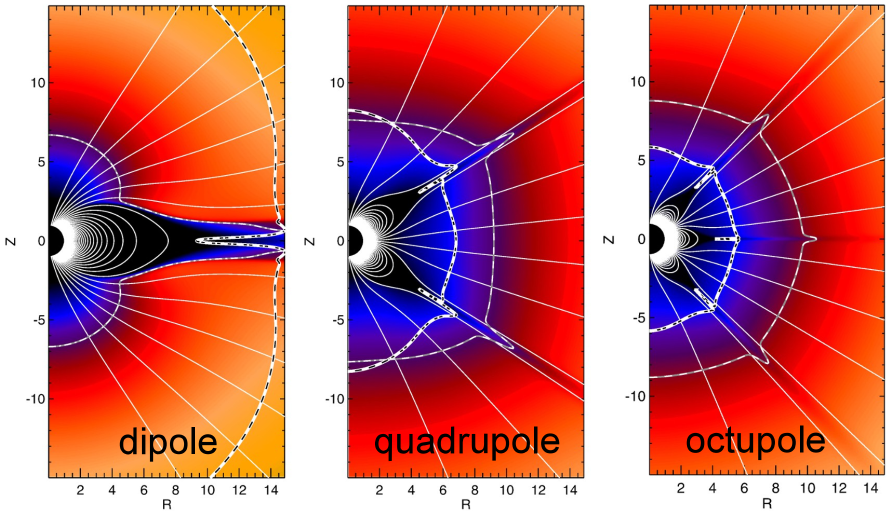
2. loss of shear disrupts α-Ω dynamo



Ω effect (poloidal → toroidal field)

Higgins 2012

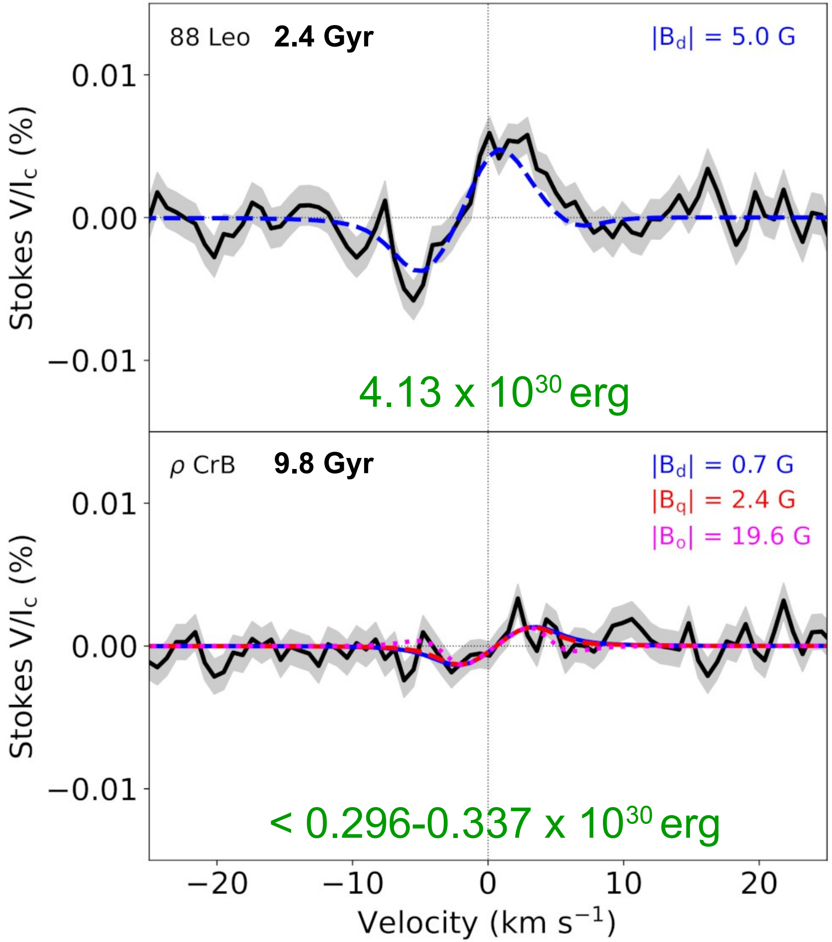
3. decaying dipole stalls braking



Reville+2015

Credit: NOAO

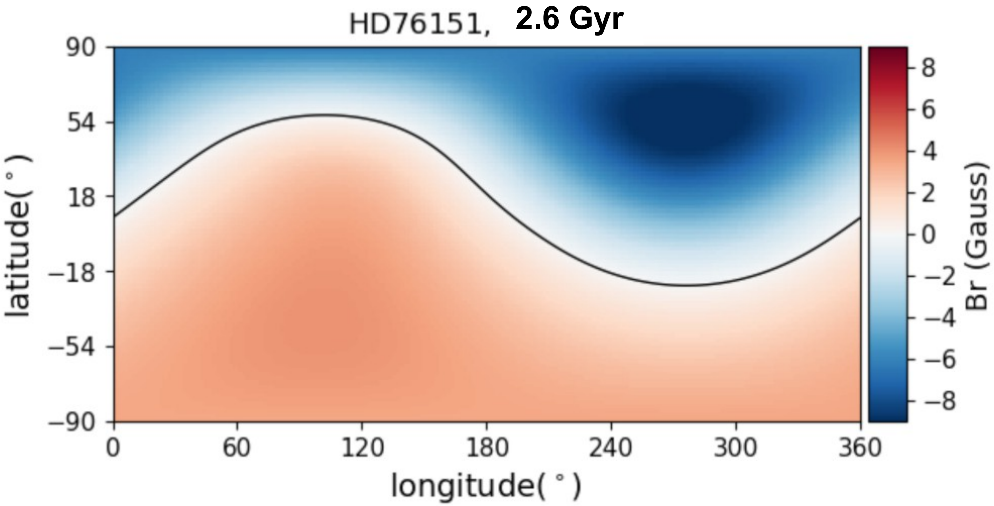
Evolutionary sequence: F-type stars



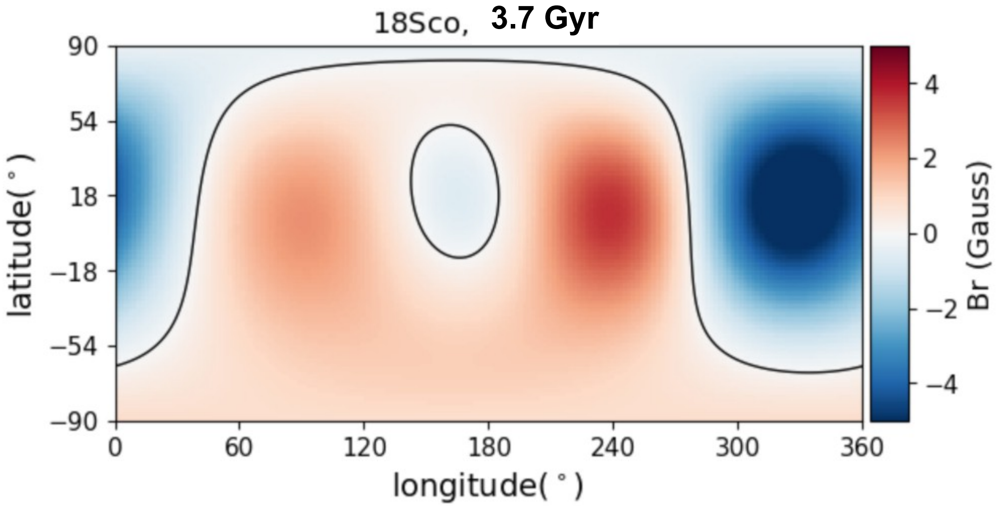
- 88 Leo: detection of large-scale field, modeled by dipole with B_d = 5.0 G
- ρ CrB: upper limits on field strength suggest a torque < 8% of 88 Leo
- Dominated by changes in field morphology, but ZDI needed for confirmation

Metcalfe+2019,2021

Evolutionary sequence: solar analogs



[B_d=5.13 G, B_q=2.88 G, B_o=1.34 G] 4.77×10^{30} erg

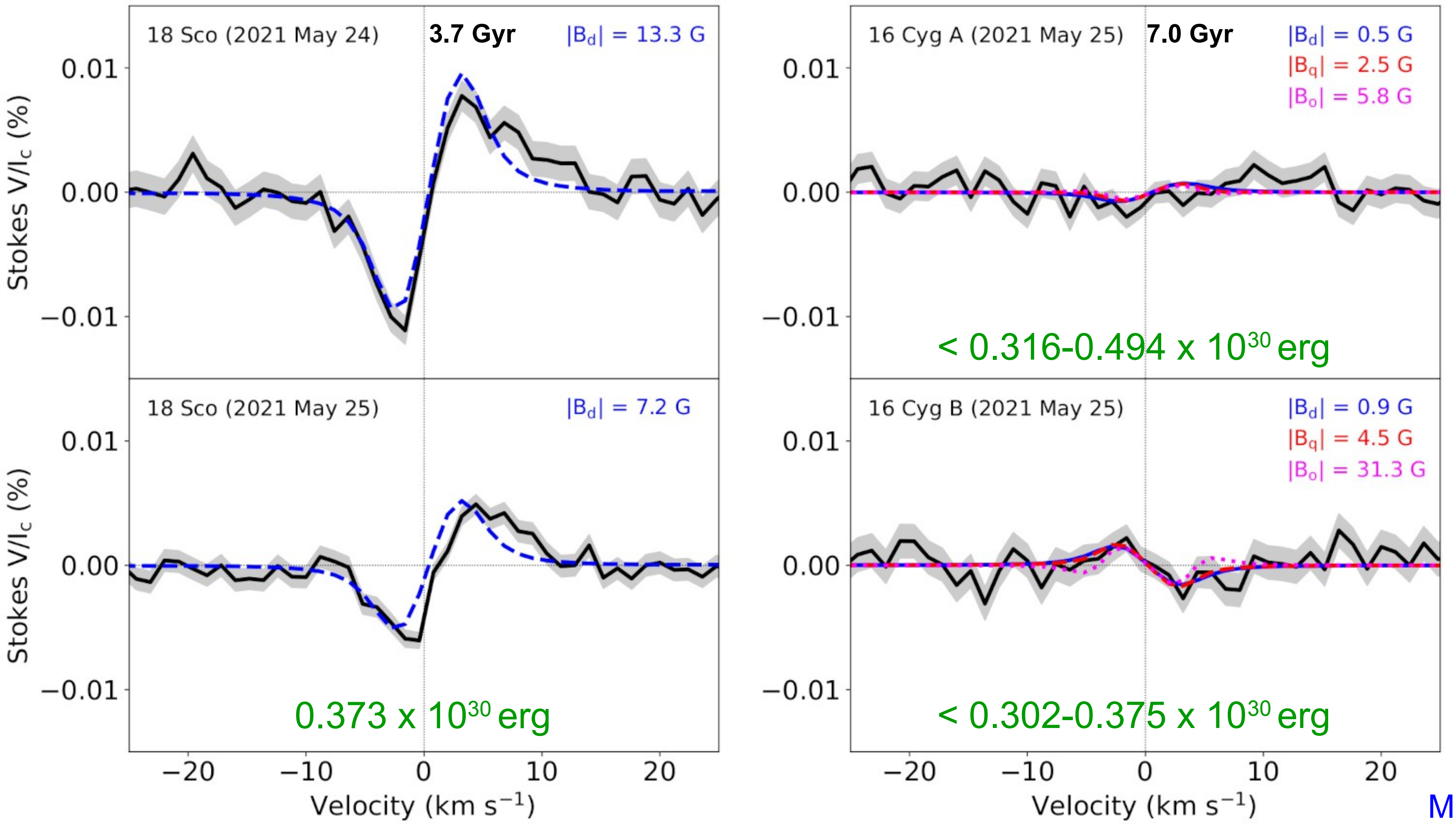


[B_d=1.34 G, B_q=2.01 G, B_o=0.86 G] 0.373×10^{30} erg

- Between 2.6-3.7 Gyr, braking torque decreases by an order of magnitude
- Dominated by changes in mass-loss rate and field strength & morphology

Petit+2008, Boro Saikia+2020, Metcalfe+2022

Evolutionary sequence: old solar analogs

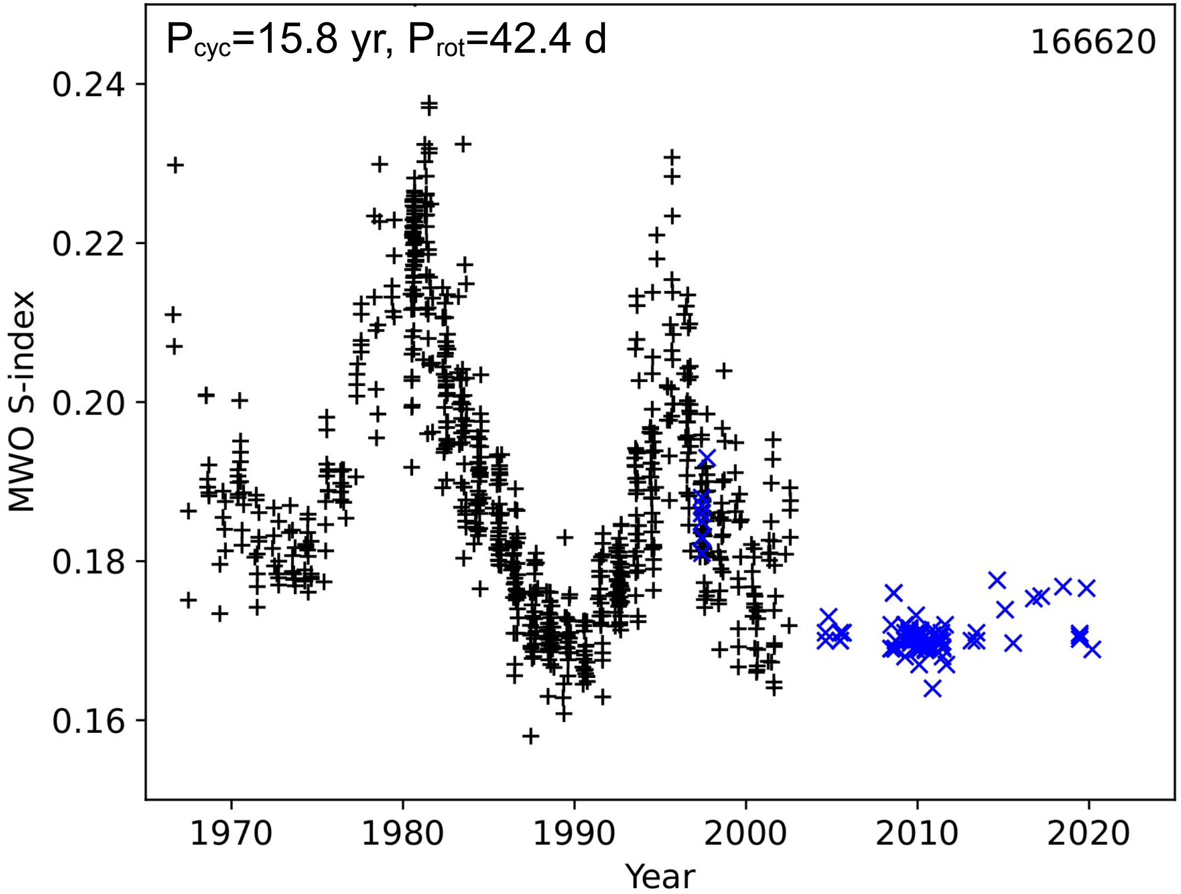


Metcalfe+2022

Summary of conclusions

- Weakened magnetic braking beyond middle-age as the global field shifts toward smaller spatial scales
- F- and G-type stars make this transition at rotation periods between ~15-25 days, enabling direct tests
- LBT spectropolarimetry supports a diminishing dipole field in sequences of stars that span the transition
- Braking torque changes due to mass-loss rate (early) and field strength & morphology (dominates later)

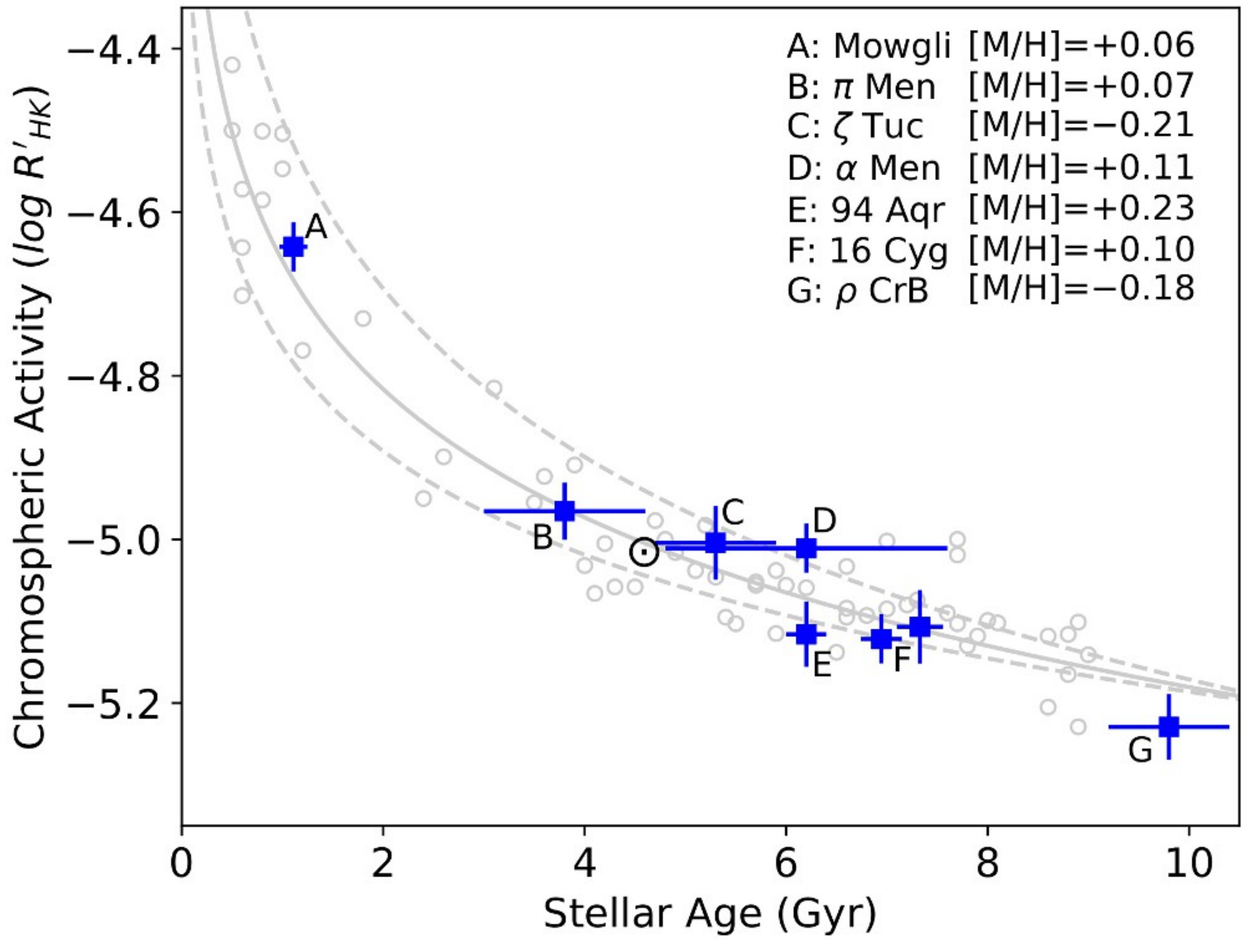
HD 166620: grand minimum



- Showed a clear Sun-like activity cycle during the Mount Wilson survey
- Keck data are consistent in the late-90s, constant activity level after 2003
- Position of cycle above lower sequence is outlier similar to the solar cycle

Baum+2022

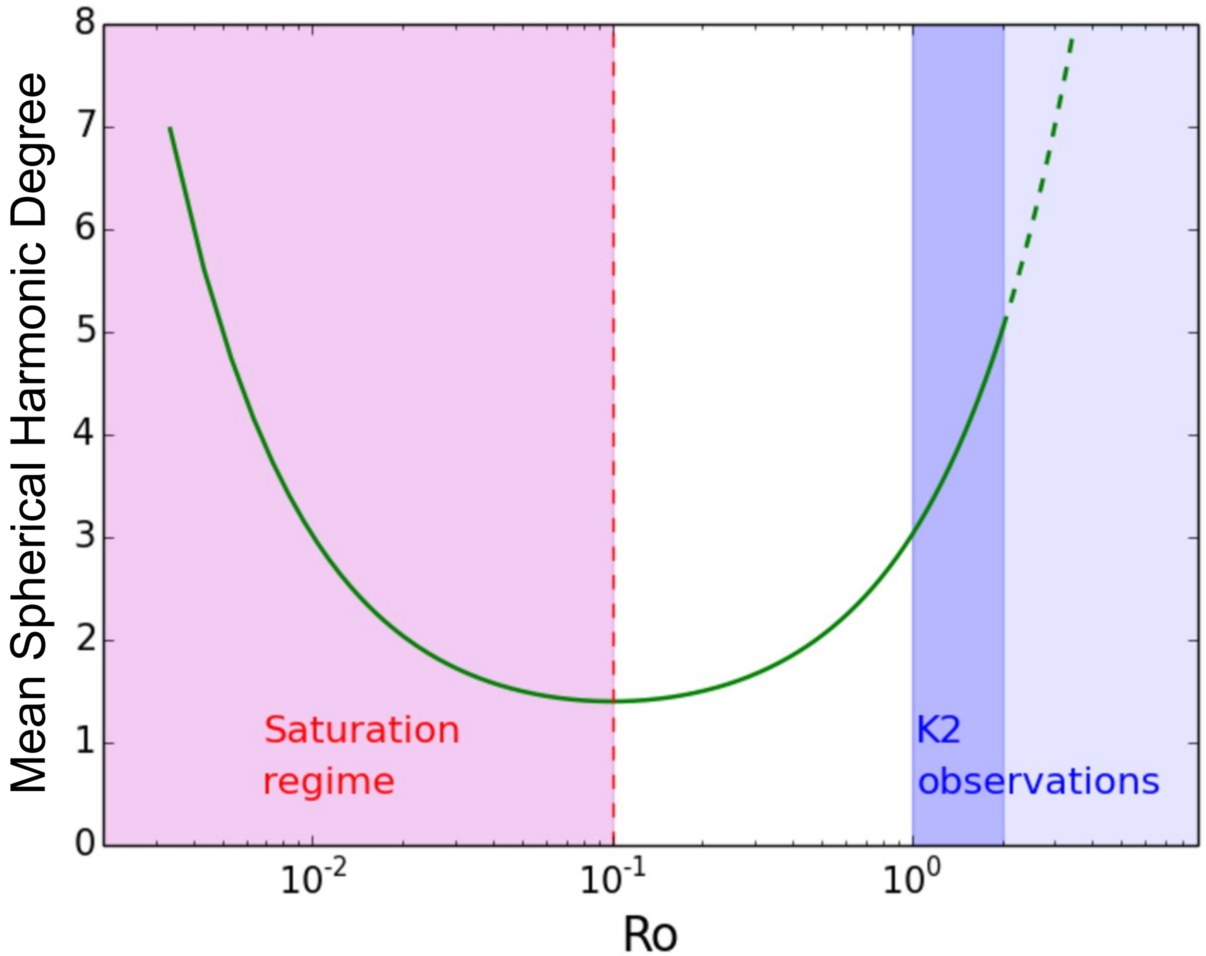
Activity level evolves continuously with age



- Activity of solar analogs and asteroseismic targets decline continuously
- Solar dipole field is ~1G while unstructured quiet Sun has ⟨B⟩ ~170 G
- Disruption of large-scale organization is irrelevant to integrated activity level

Huber+2022

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

Garraffo+2018