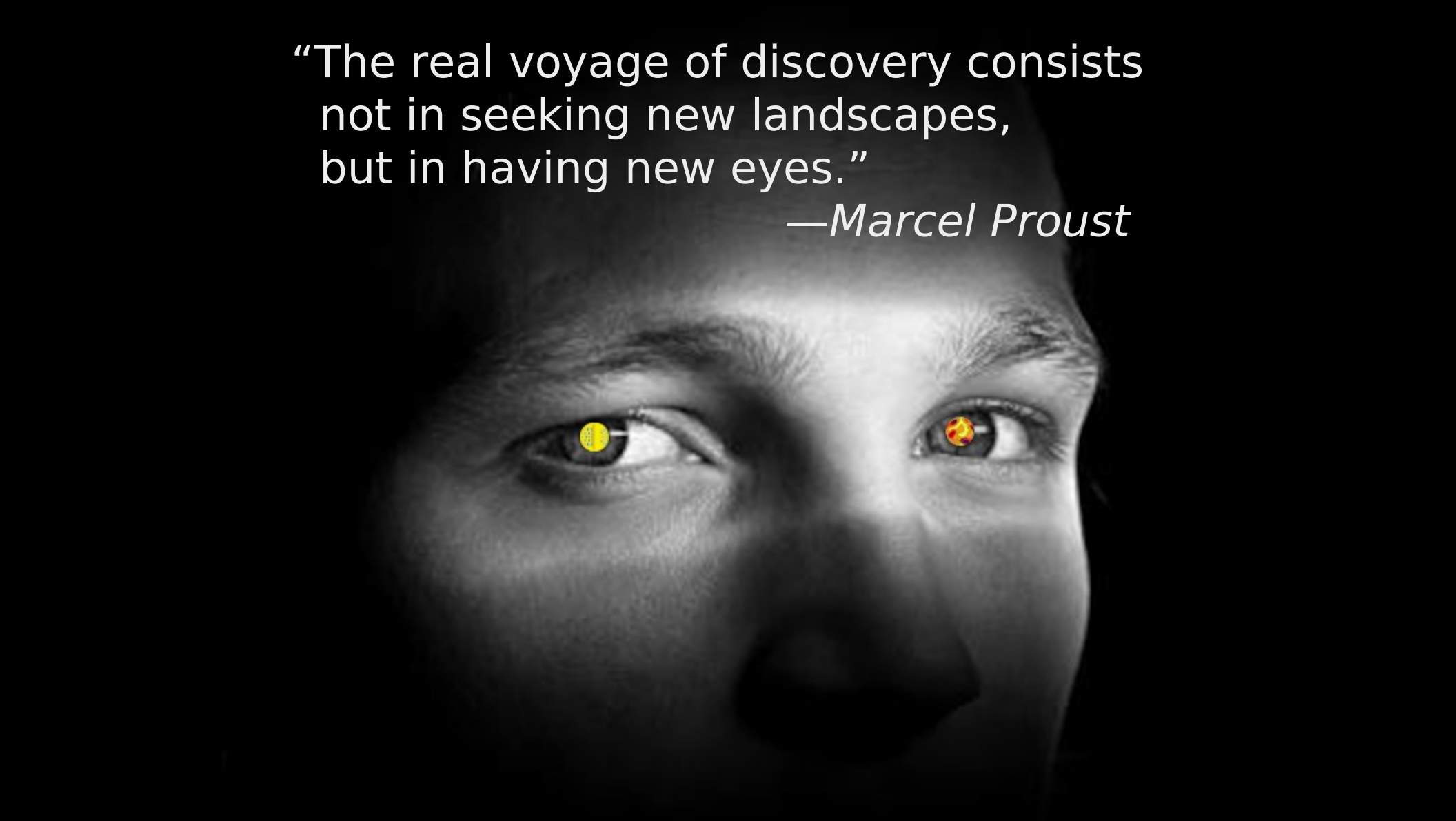
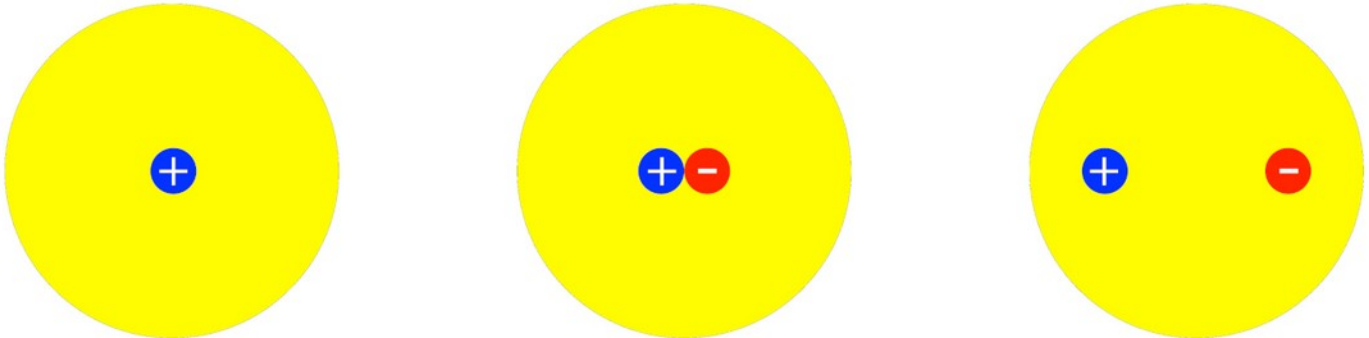
Probing Magnetic Stellar Evolution with Asteroseismology and Spectropolarimetry

Travis Metcalfe
White Dwarf Research Corp.

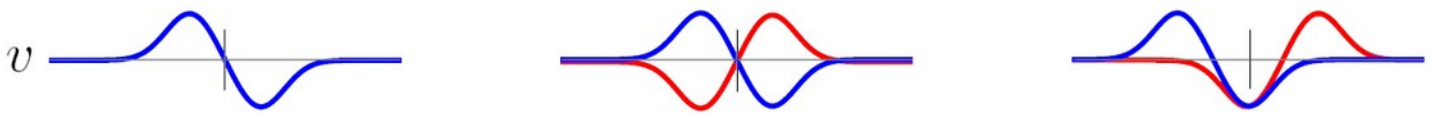
Collaborators: Jennifer van Saders, Marc Pinsonneault, Klaus Strassmeier, Sarbani Basu, Adam Finley, Ilya Ilyin, Oleg Kochukhov, Victor See & others


“The real voyage of discovery consists
not in seeking new landscapes,
but in having new eyes.”
—Marcel Proust

Geometry

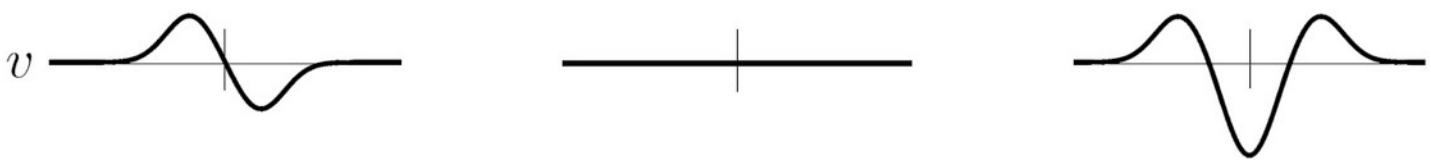


Stokes V signal (components)



Signals doppler shifted due to rotation

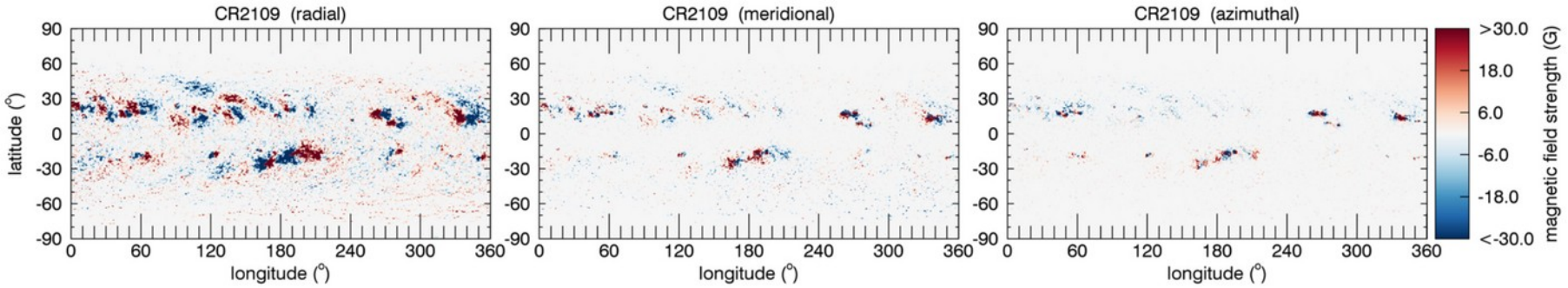
Stokes V signal (net)



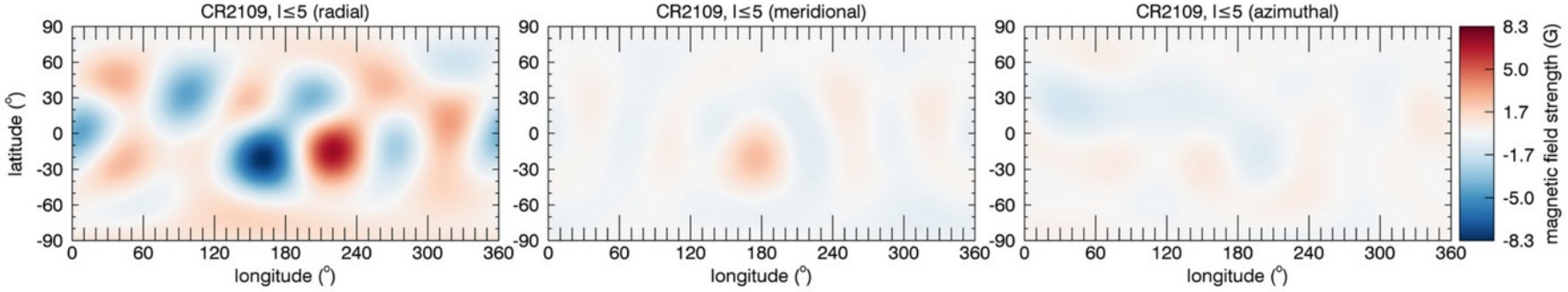
slide: Victor See

radial meridional (N-S) azimuthal (E-W)

obs



ℓ<5



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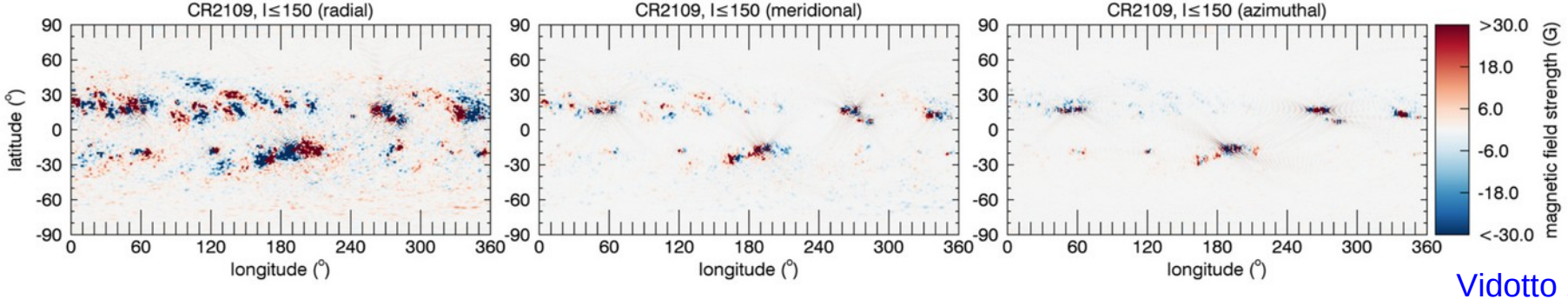
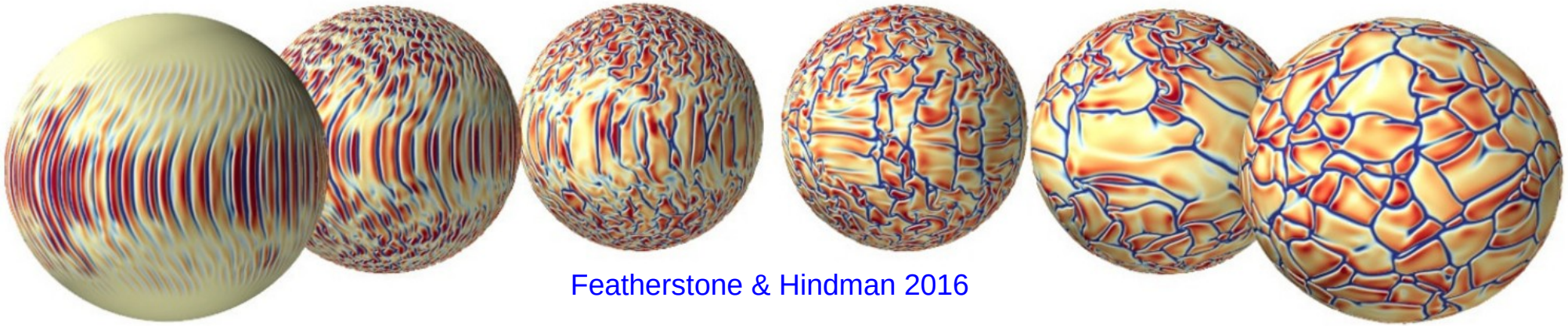


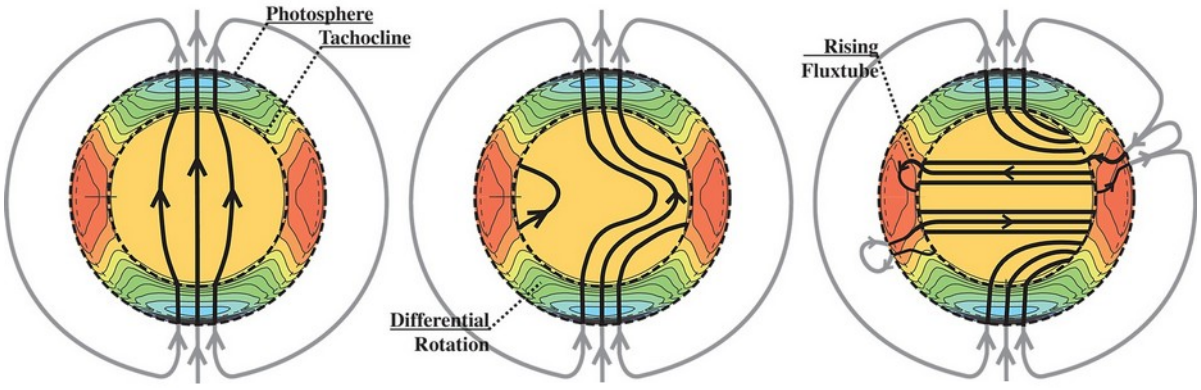
Vidotto 2016

1. slow rotation becomes non-differential



Featherstone & Hindman 2016

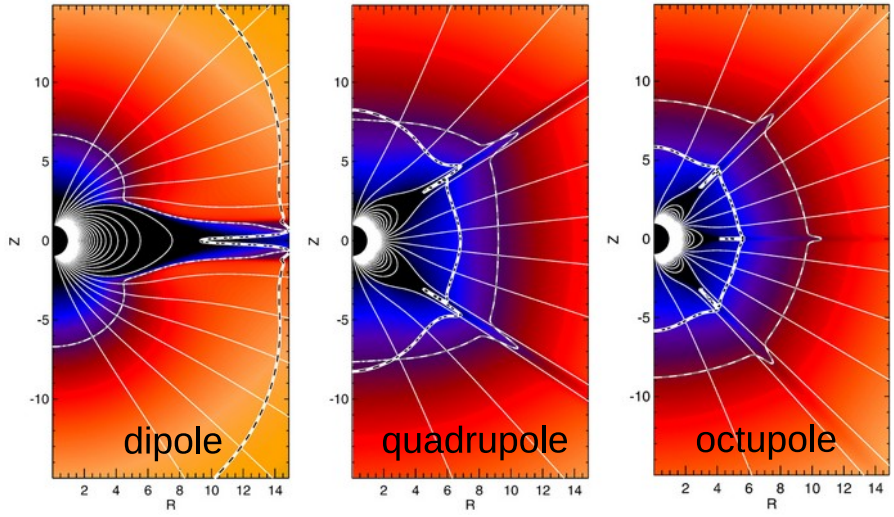
2. loss of shear disrupts field conversion



Ω effect (poloidal → toroidal field)

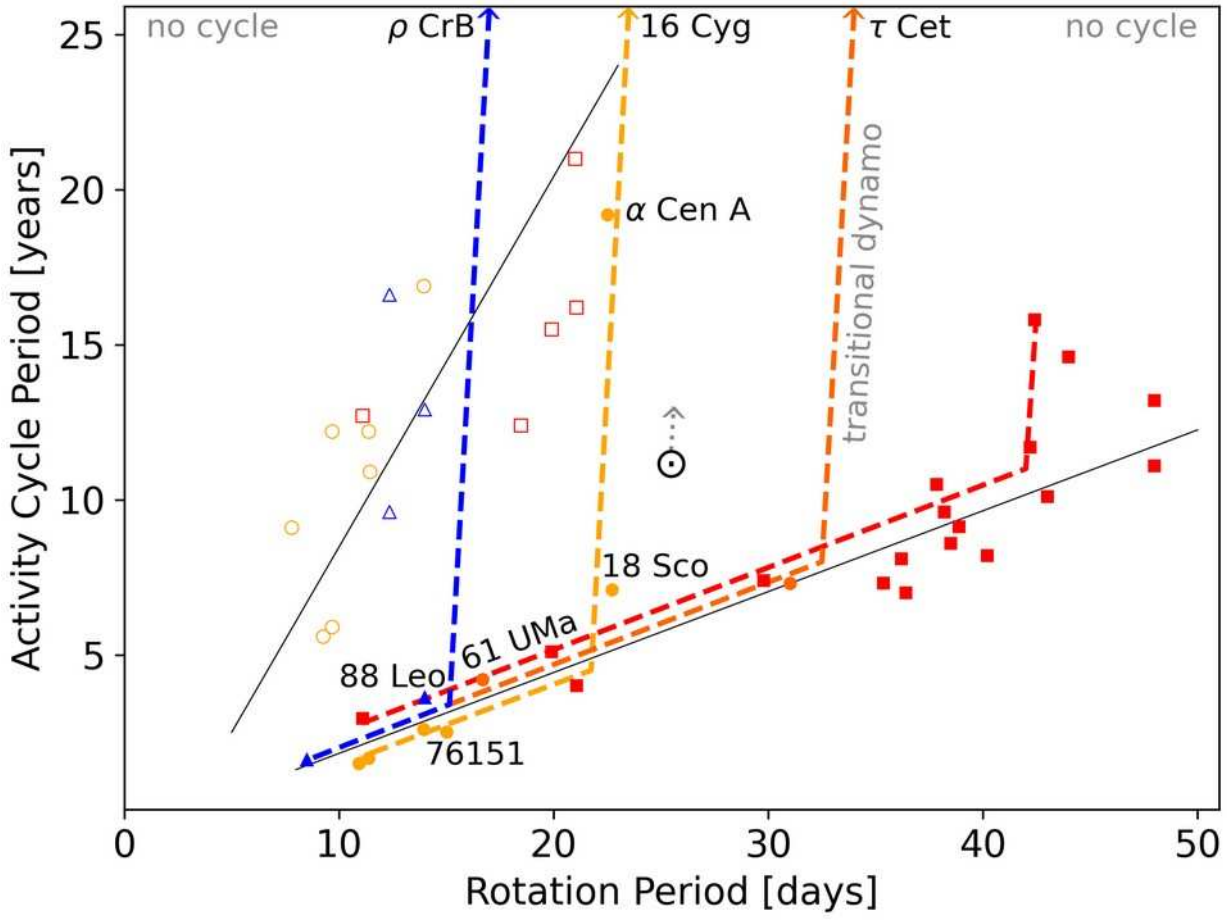
Higgins 2012

3. decaying dipole stalls braking



Reville+2015

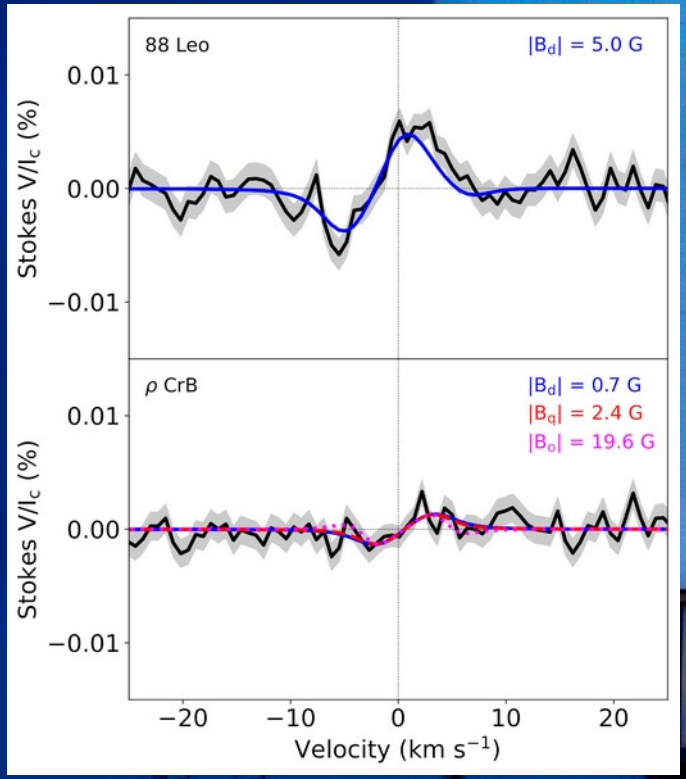
Magnetic evolution: stellar cycles

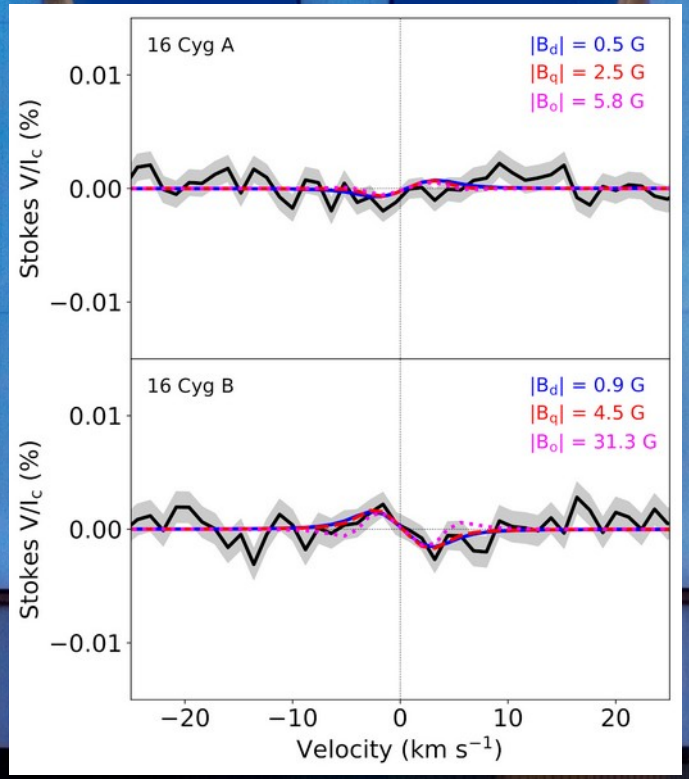


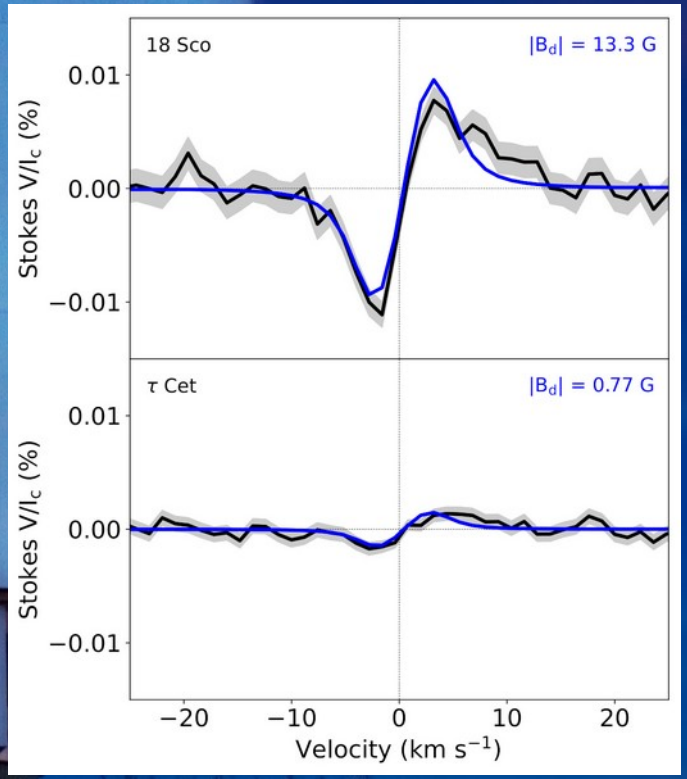
- Stalled rotation coincides with longer activity cycles and weaker variability
- Same pattern observed in hotter and cooler stars at same Rossby number
- Solar cycle appears to be in the transition, and may disappear in a few Gyr

Metcalfe & van Saders 2017, Metcalfe+2019


Credit: NOAO


88 Leo
$|B_d|$ = 5.0 G
ρ CrB
$|B_d|$ = 0.7 G
$|B_q|$ = 2.4 G
$|B_o|$ = 19.6 G
Stokes V/I$_c$ (%)
0.01
0.00
−0.01
−20
−10
0
10
20
Velocity (km s^{-1})


16 Cyg A
$|B_d|$ = 0.5 G
$|B_q|$ = 2.5 G
$|B_o|$ = 5.8 G
16 Cyg B
$|B_d|$ = 0.9 G
$|B_q|$ = 4.5 G
$|B_o|$ = 31.3 G
Stokes V/I$_c$ (%)
0.01
0.00
−0.01
−20
−10
0
10
20
Velocity (km s^{-1})


18 Sco
$|B_d|$ = 13.3 G
τ Cet
$|B_d|$ = 0.77 G
Stokes V/I$_c$ (%)
0.01
0.00
−0.01
−20
−10
0
10
20
Velocity (km s^{-1})

Credit: NOAO

The Astrophysical Journal, 921:122 (10pp), 2021 November 10 https://doi.org/10.3847/1538-4357/ac1f19

Magnetic and Rotational Evolution of ρ CrB from Asteroseismology with TESS

Travis S. Metcalfe[1,2], Jennifer L. van Saders[3], Sarbani Basu[4], Derek Buzasi[5], Jeremy J. Drake[6], Ricky Egeland[7], Daniel Huber[3], Steven H. Saar[6], Keivan G. Stassun[8], Warrick H. Ball[9,10], Tiago L. Campante[11,12], Adam J. Finley[13], Oleg Kochukhov[14], Savita Mathur[15,16], Timo Reinhold[17], Victor See[18], Sallie Baliunas[6], and Willie Soon[6]

The Astrophysical Journal Letters, 933:L17 (6pp), 2022 July 1 https://doi.org/10.3847/2041-8213/ac794d

The Origin of Weakened Magnetic Braking in Old Solar Analogs

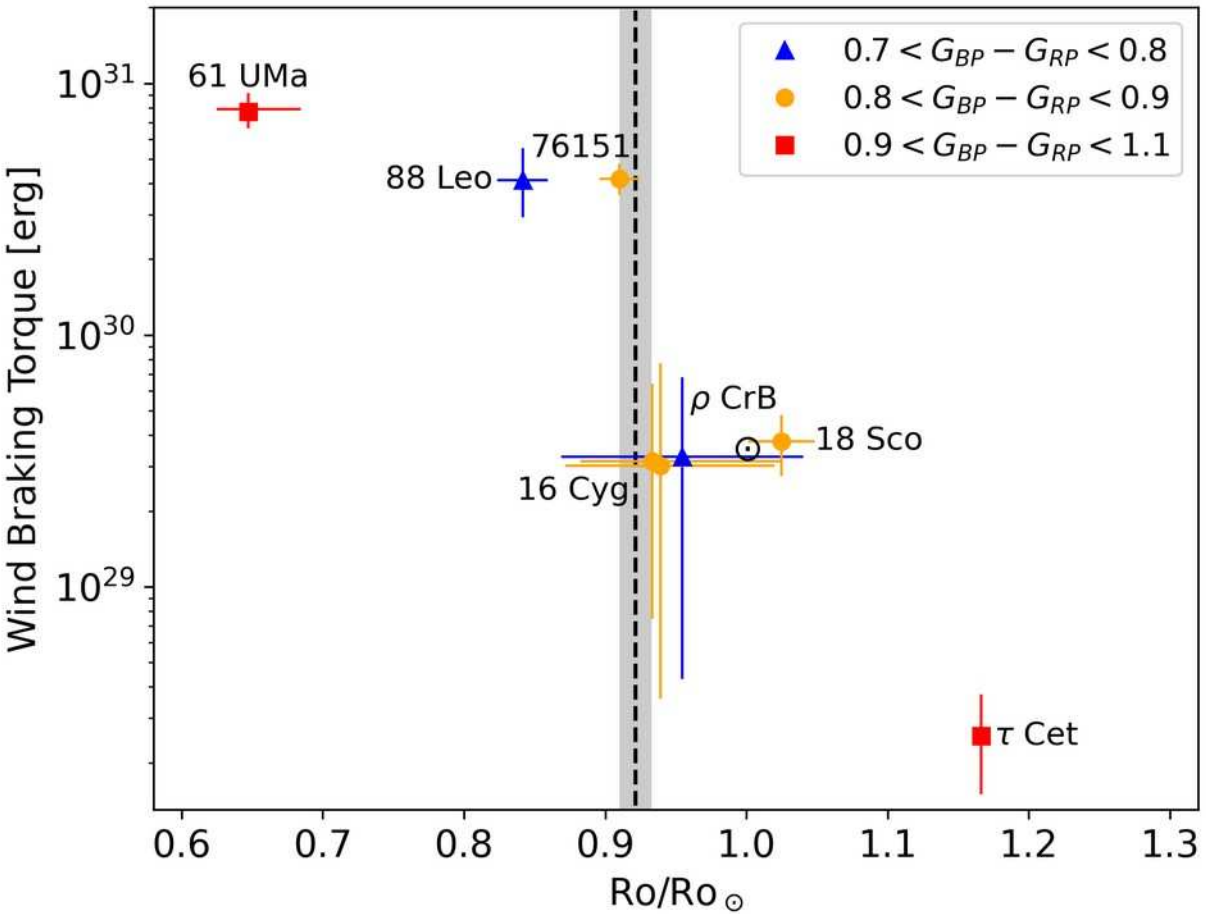
Travis S. Metcalfe[1], Adam J. Finley[2], Oleg Kochukhov[3], Victor See[4], Thomas R. Ayres[5], Keivan G. Stassun[6], Jennifer L. van Saders[7], Catherine A. Clark[8,9], Diego Godoy-Rivera[10,11,12], Ilya V. Ilyin[13], Marc H. Pinsonneault[10], Klaus G. Strassmeier[13], and Pascal Petit[14]

The Astrophysical Journal Letters, 948:L6 (5pp), 2023 May 1 https://doi.org/10.3847/2041-8213/acce38

Constraints on Magnetic Braking from the G8 Dwarf Stars 61 UMa and τ Cet

Travis S. Metcalfe[1], Klaus G. Strassmeier[2], Ilya V. Ilyin[2], Jennifer L. van Saders[3], Thomas R. Ayres[4], Adam J. Finley[5], Oleg Kochukhov[6], Pascal Petit[7], Victor See[8], Keivan G. Stassun[9], Sandra V. Jeffers[10], Stephen C. Marsden[11], Julien Morin[12], and Aline A. Vidotto[13]

Magnetic evolution: braking torque



- Braking torque weakens by ~300x between Ro of 61 UMa and τ Cet
- Empirical value of critical Ro (shaded) constrained by HD 76151 and 16 Cyg
- Larger uncertainties when we only have upper limits on the large-scale field

Metcalfe+2023

Summary of conclusions

- At a critical Rossby number comparable to the solar value, magnetic field loses large-scale organization
- At constant rotation period, the magnetic cycle grows longer and weaker on stellar evolutionary timescales
- As stars evolve below a critical activity level, the wind braking torque abruptly decreases by at least 13x
- Magnetic braking weakens from mass-loss rate (early) and field strength & morphology (dominates later)