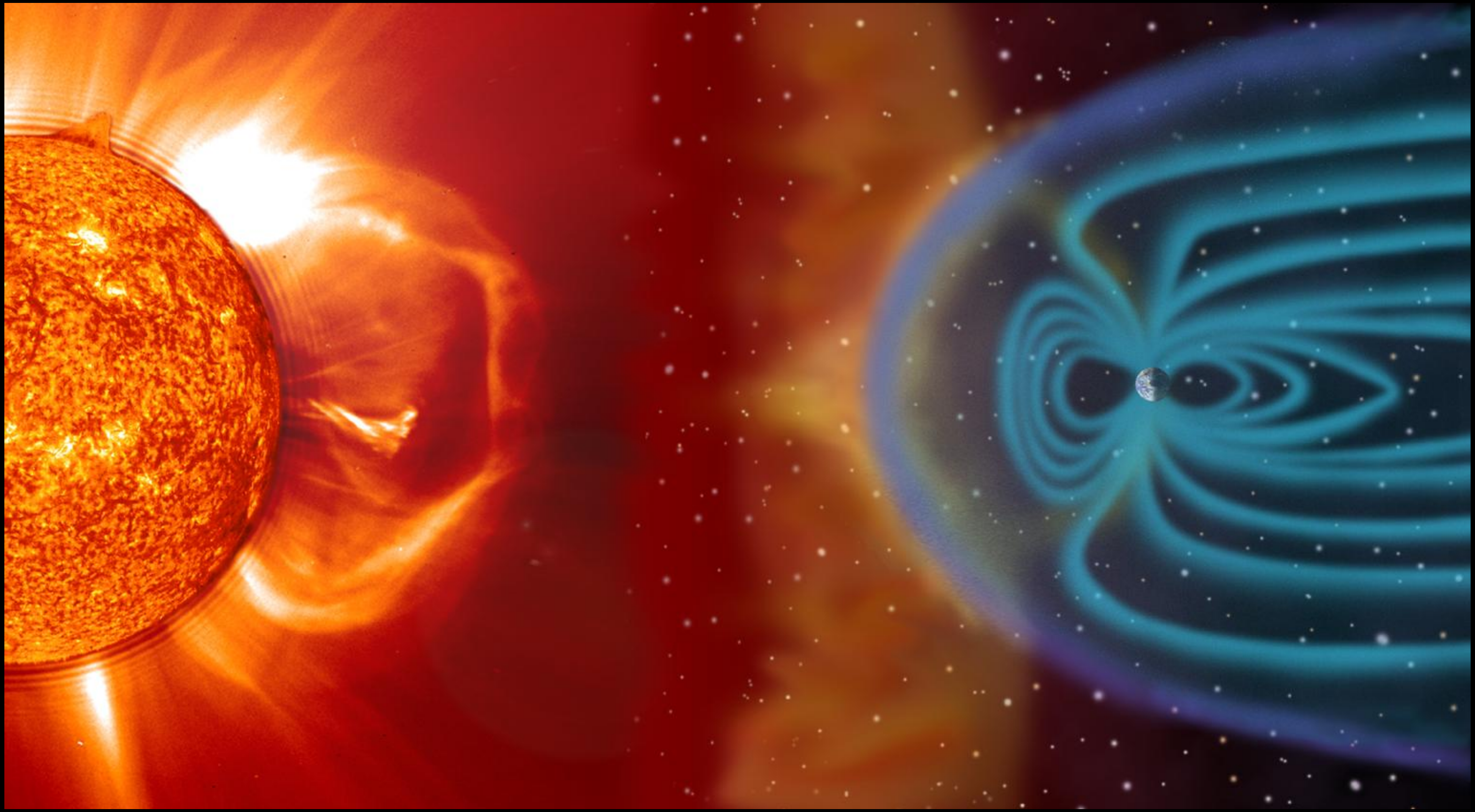
Exoplanetary environments and Radio Signatures



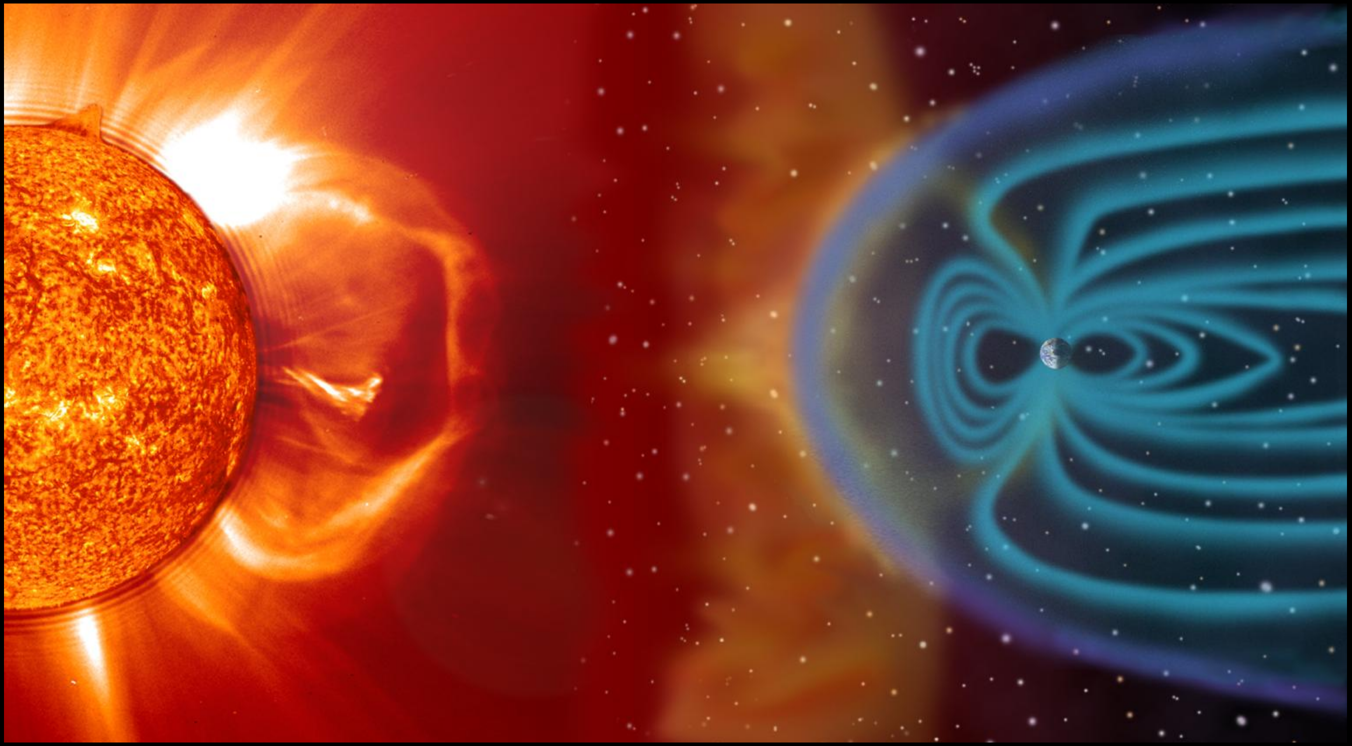
Moira Jardine St Andrews

St Andrews Centre for Exoplanet Science

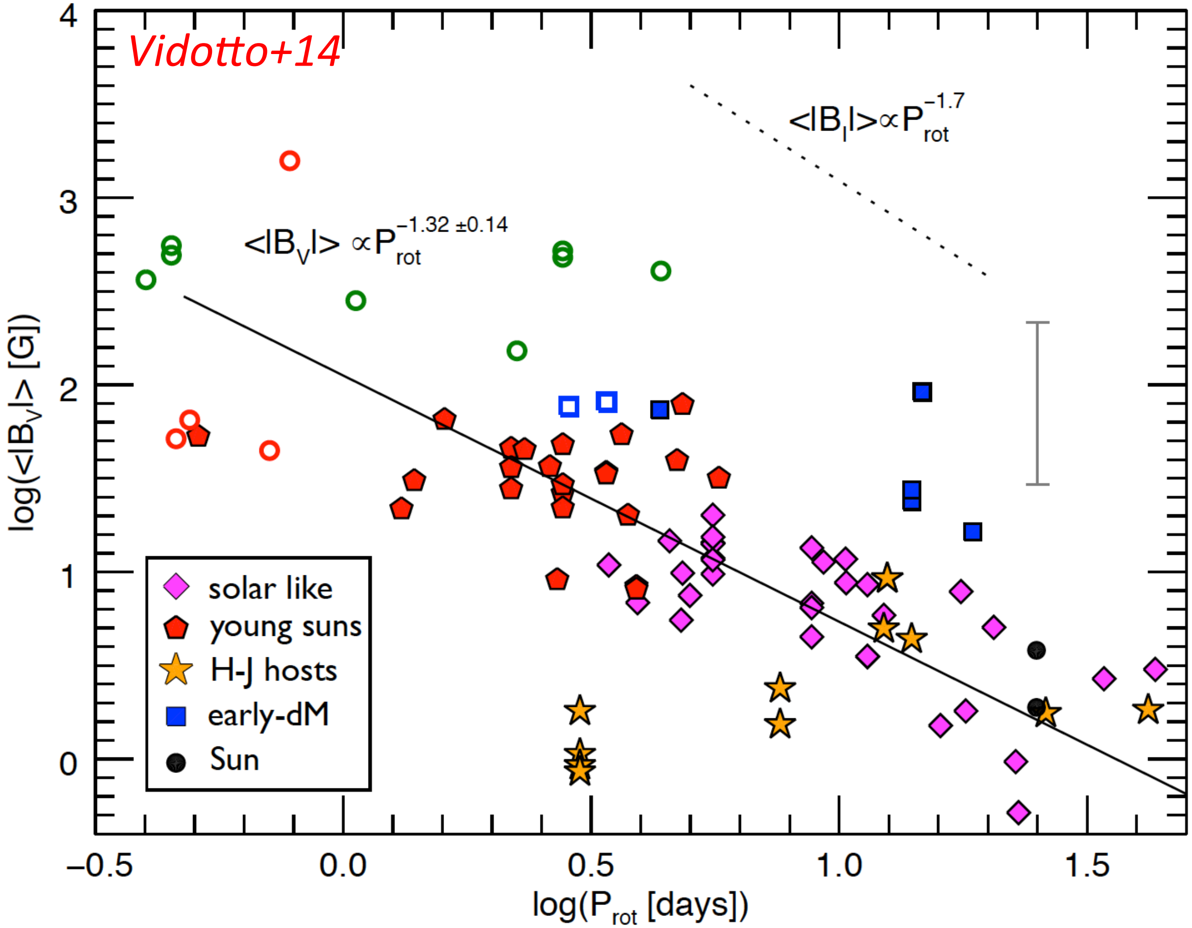
What physical properties determine radio emission?

$$f_{plasma}(Hz) = \sqrt{n_e(m^{-3})}$$

$$f_{gyro}(Hz) = 28 * 10^9 B(T)$$



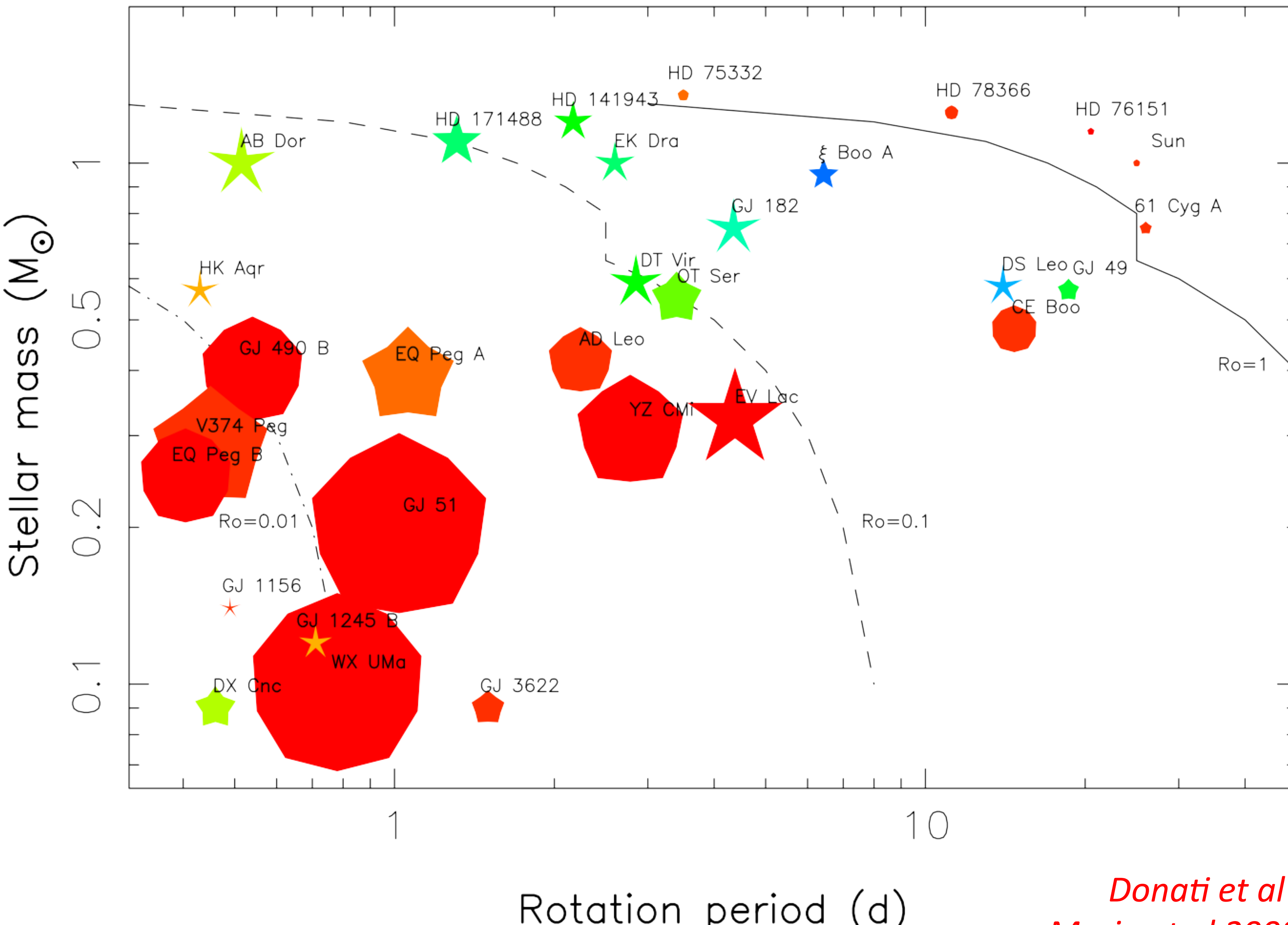
What influences stellar activity?



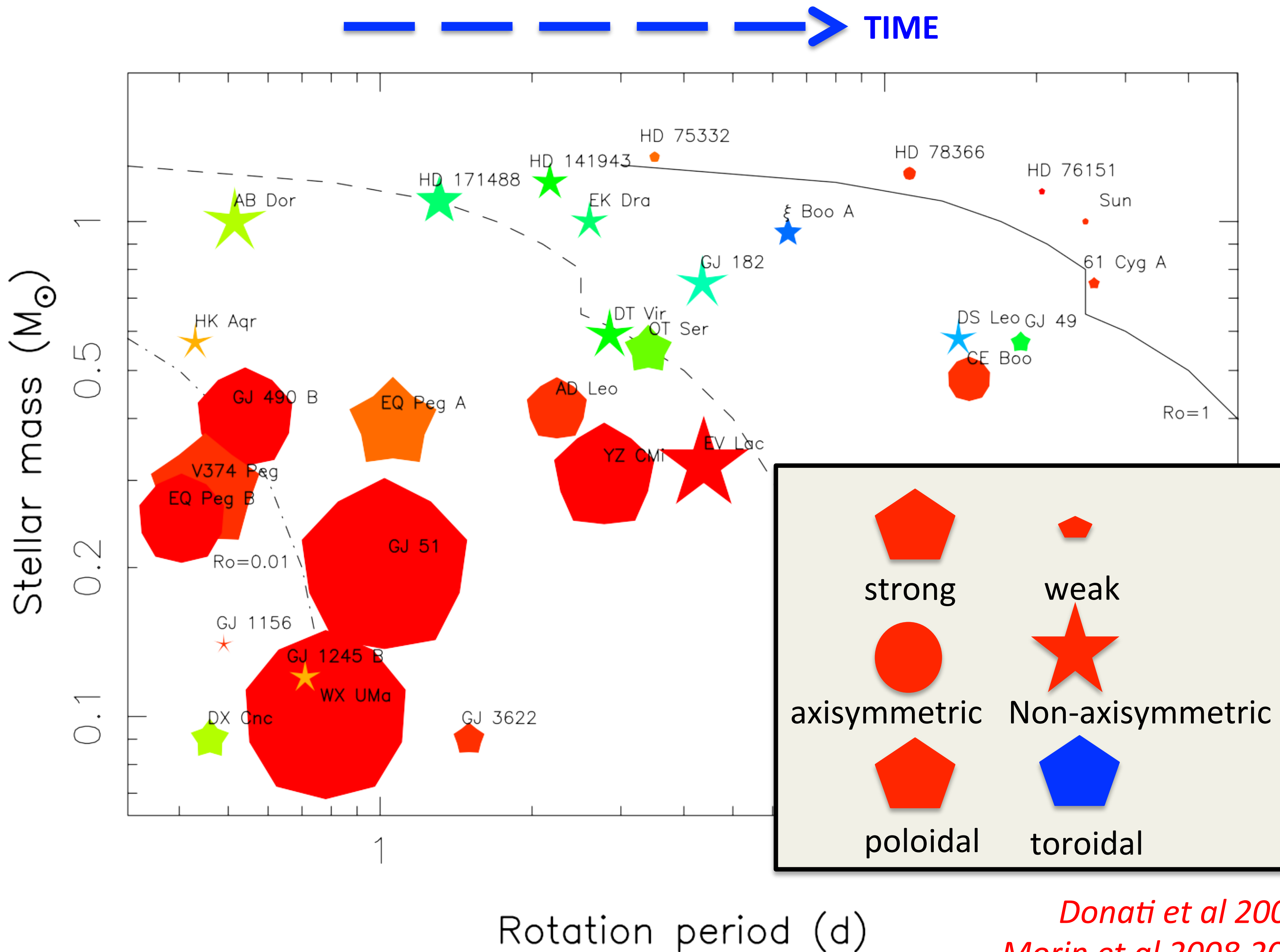
Consistent with linear dynamo:

$$\left\langle \left| B_V \right| \right\rangle \propto \Omega_* \propto P_{rot}^{-1}$$

Mass and rotation rate influence stellar magnetic fields



Donati et al 2008,
Morin et al 2008,2009

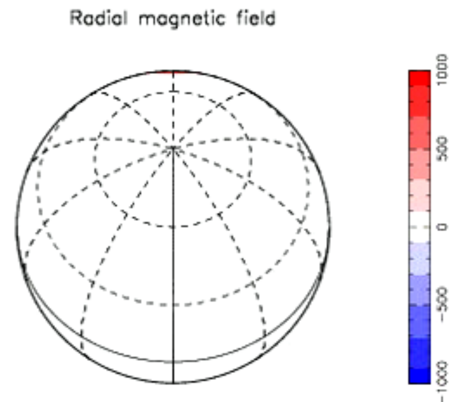


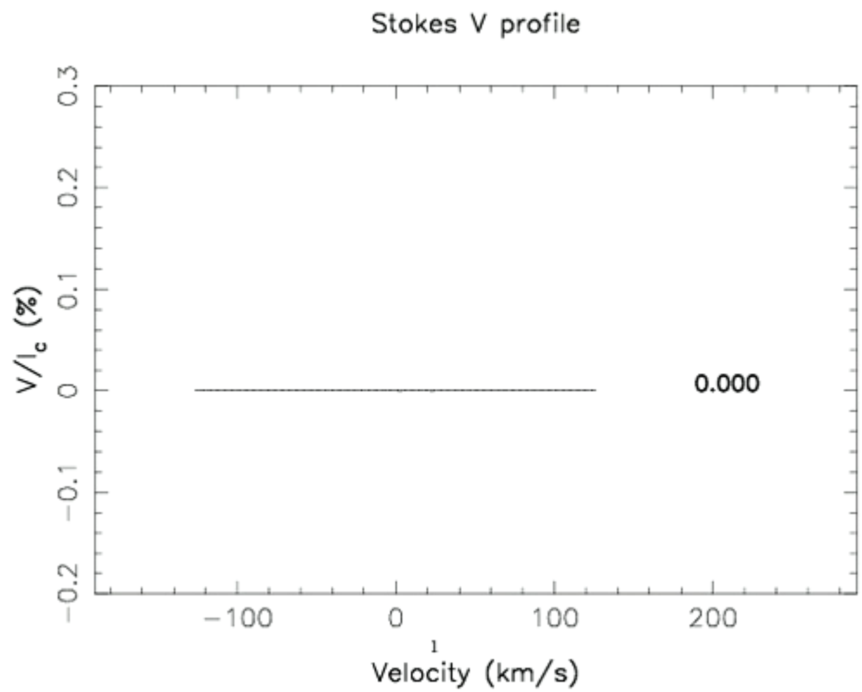
Donati et al 2008,
Morin et al 2008,2009

See Gastine+12,Morin+12,Kochukhov+17

How do we observe the structure of stellar magnetic fields?

- In presence of magnetic field, lines split by Zeeman effect
- Difference between left and right circularly polarised components is Stokes V
- Track Stokes V - get *line of sight* field
- Note max amplitude at disk centre
- *Only large-scale field detected*

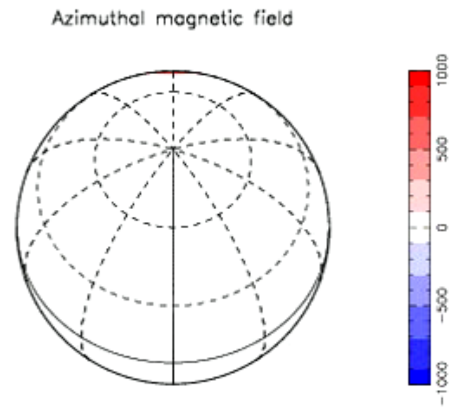


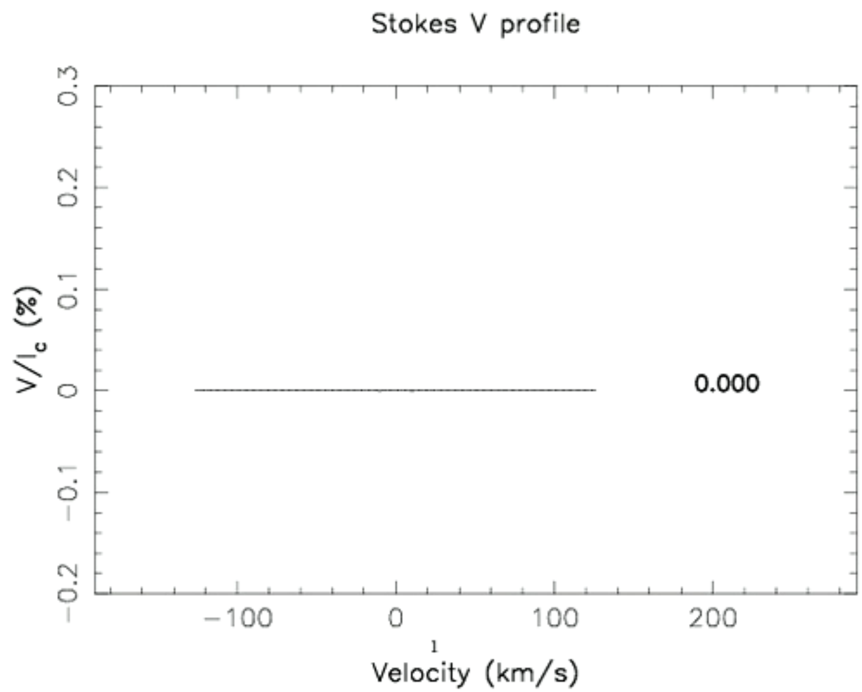


Azimuthal field

- Note max amplitude on the limb

- Note change of polarity at disk centre

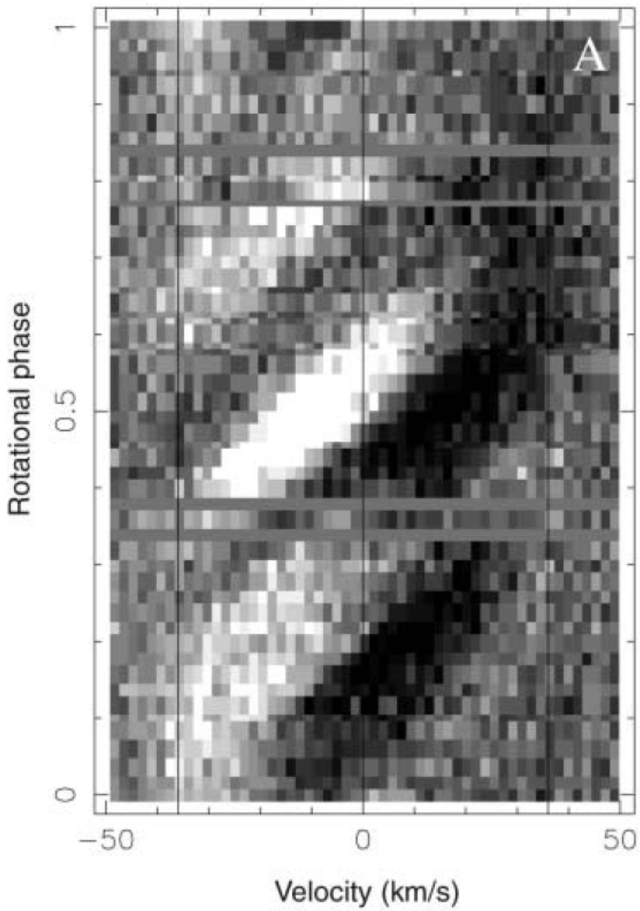




Imaging stellar magnetic fields

Fit Stokes profiles with spherical harmonics

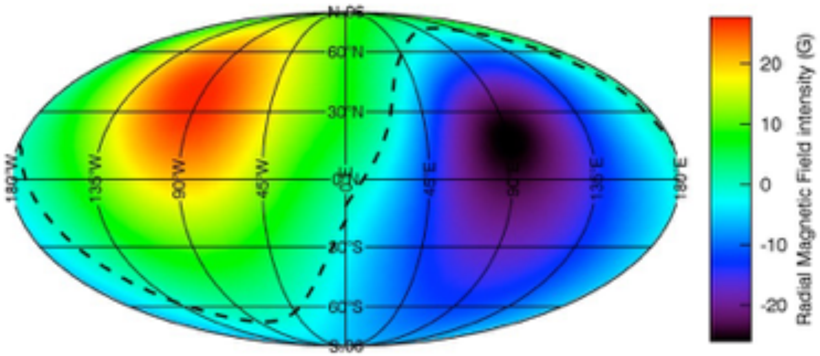
$$
\begin{aligned}
B_r(\theta,\phi) &= -\sum_{\ell,m} \alpha_{\ell,m} Y_{\ell,m}(\theta,\phi) \\
B_\theta(\theta,\phi) &= -\sum_{\ell,m} (\beta_{\ell,m} Z_{\ell,m}(\theta,\phi) + \gamma_{\ell,m} X_{\ell,m}(\theta,\phi)) \\
B_\phi(\theta,\phi) &= -\sum_{\ell,m} (\beta_{\ell,m} X_{\ell,m}(\theta,\phi) - \gamma_{\ell,m} Z_{\ell,m}(\theta,\phi))
\end{aligned}
$$



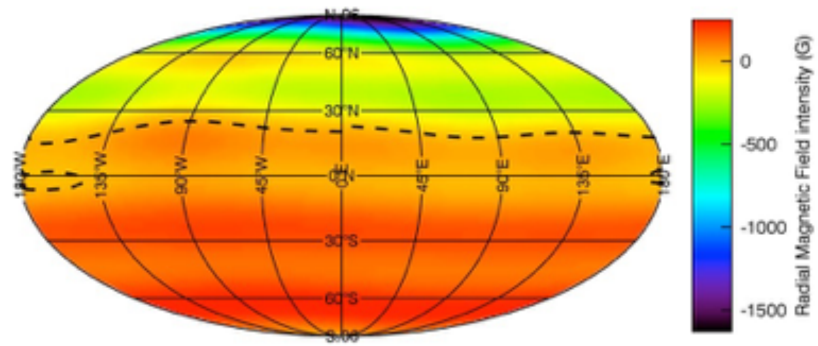
Stokes V

See also: Hussain+02,Folsom+15,Rosen+15,16,

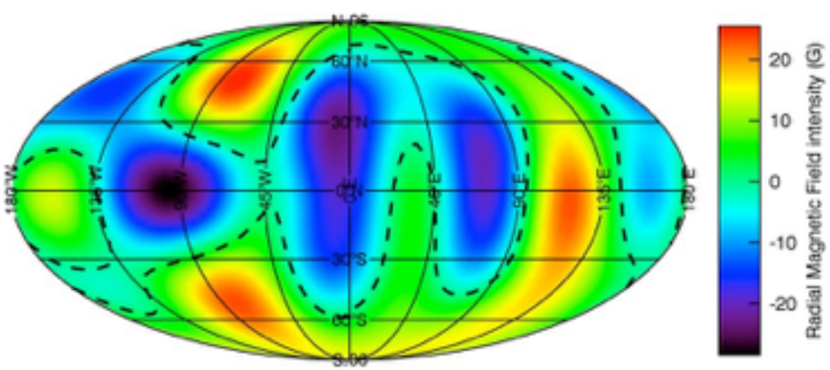
Zeeman-Doppler maps



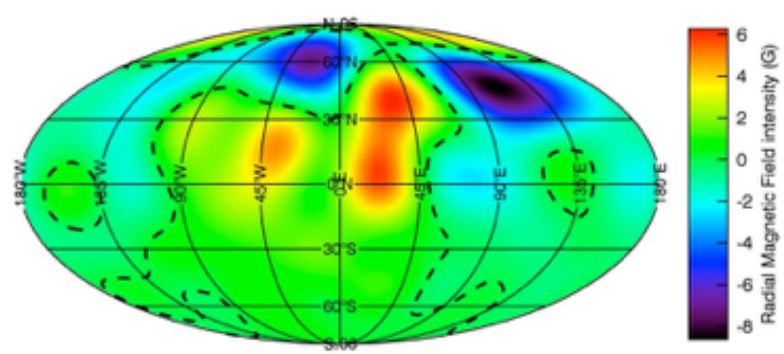
Epsilon Eri - 2007



AD Leo - 2007

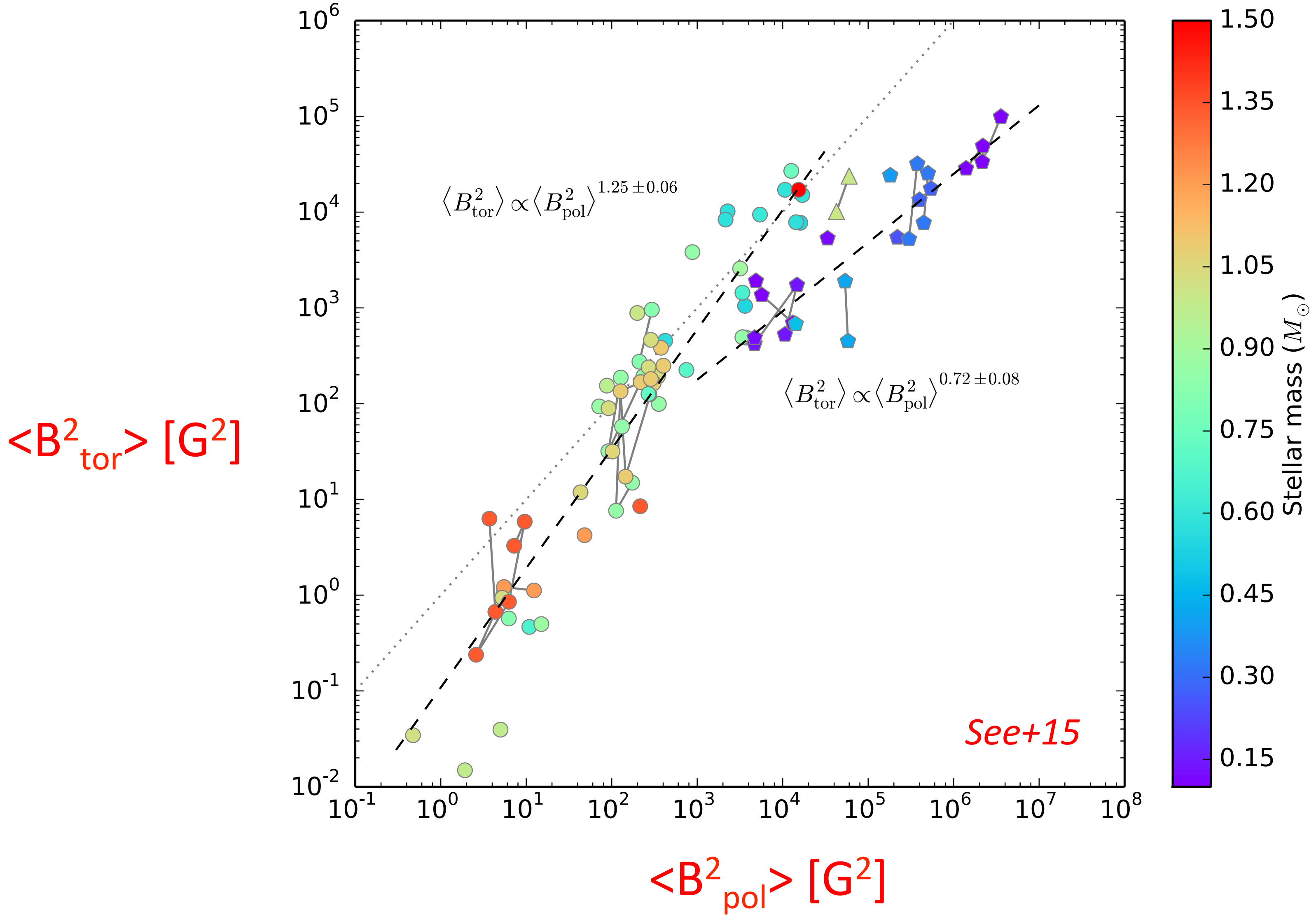


HD 189733 - 2008



Tau Boo - 2011

Do fully convective stars have a different dynamo?



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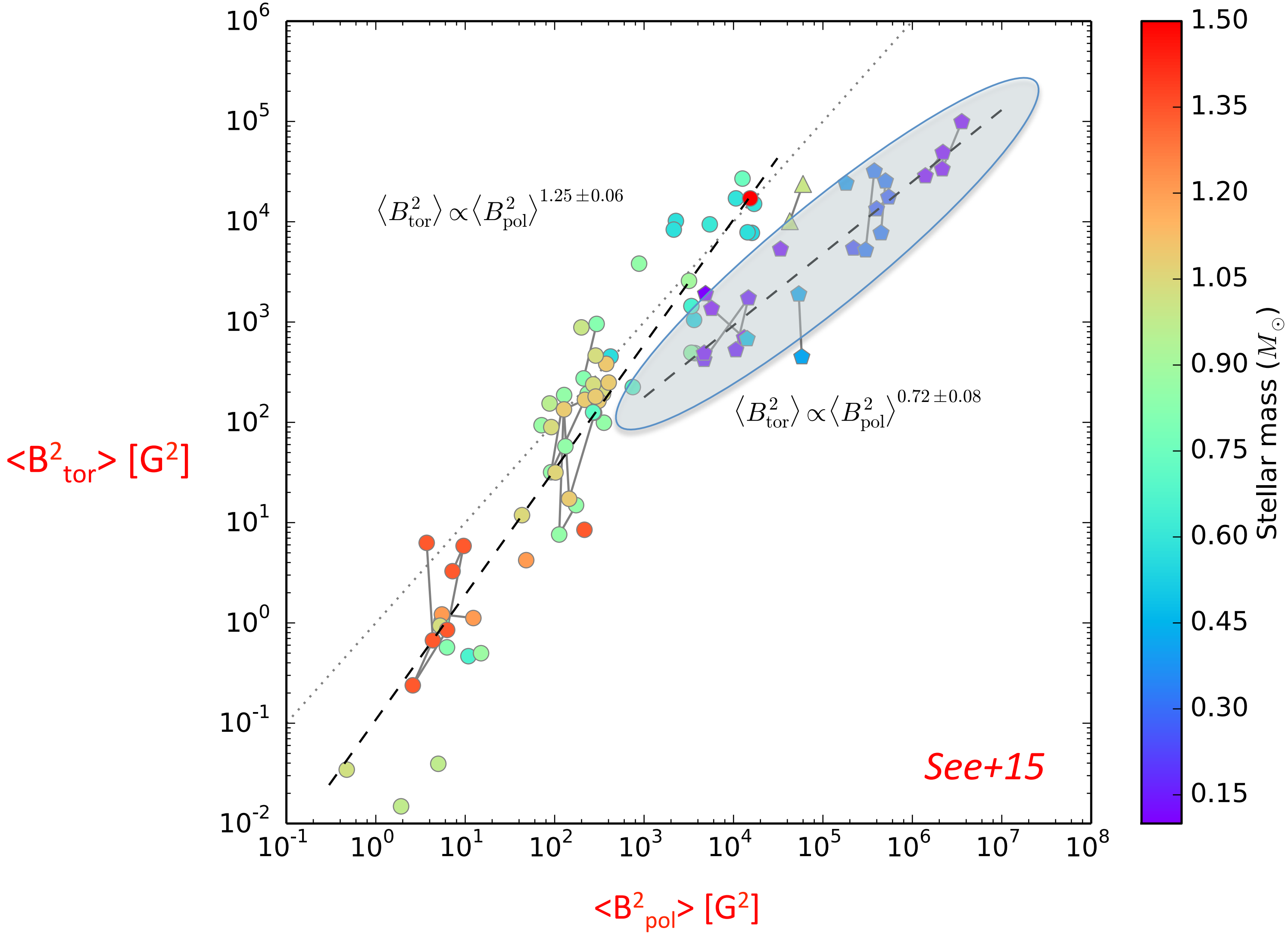
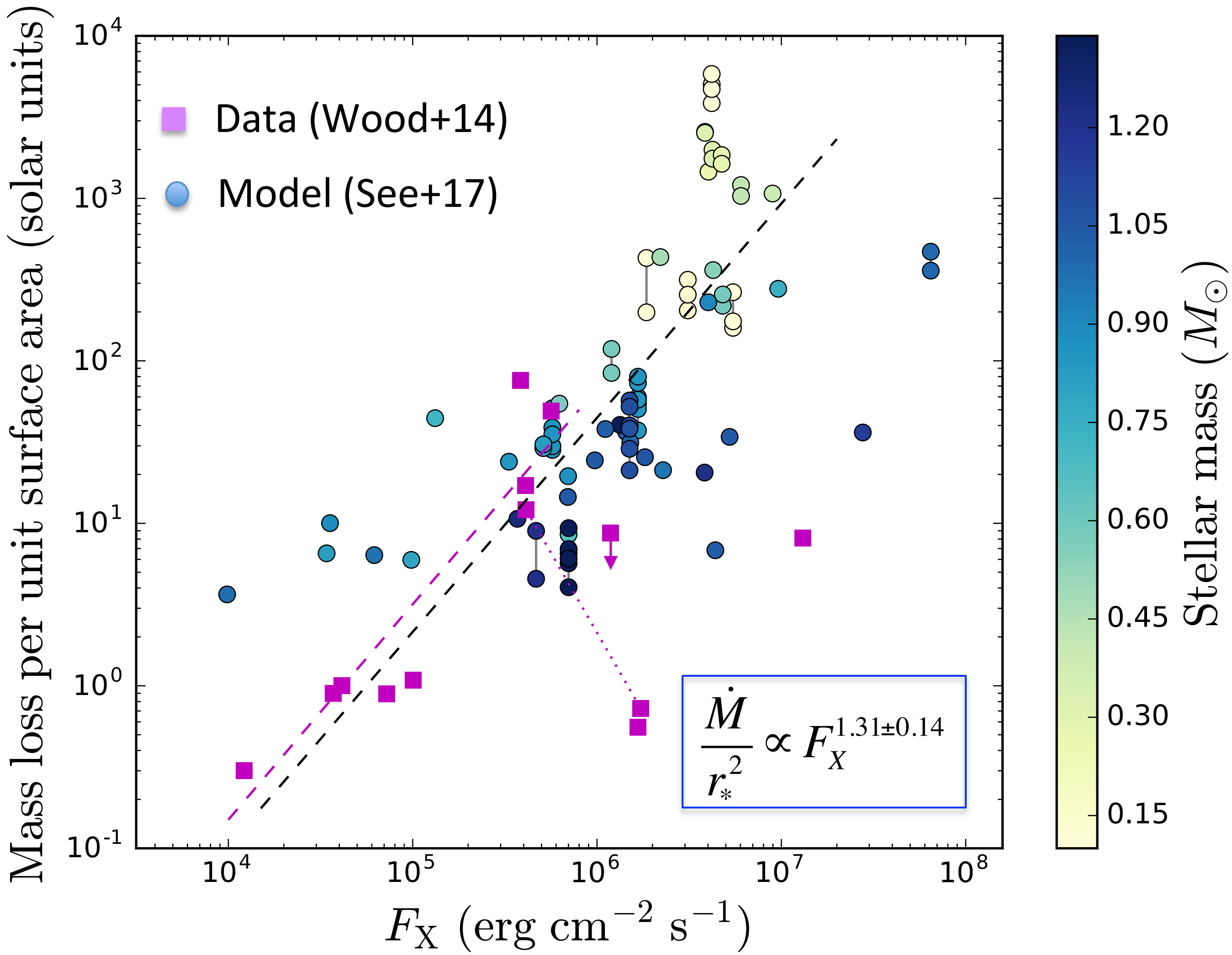
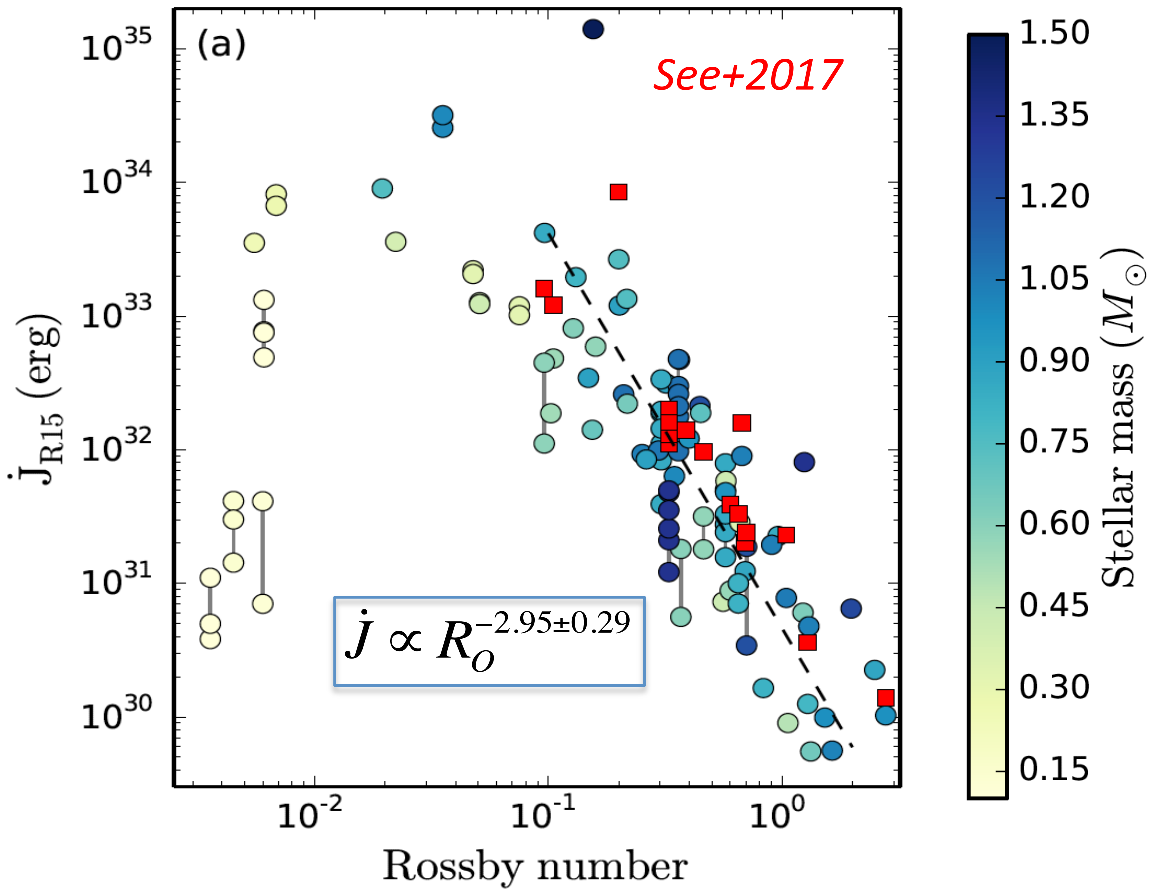


Low mass stars are activity over-achievers



See also Lammer+03, Cohen+15,Garrafo+16,Reville+16,Fichtinger+2017

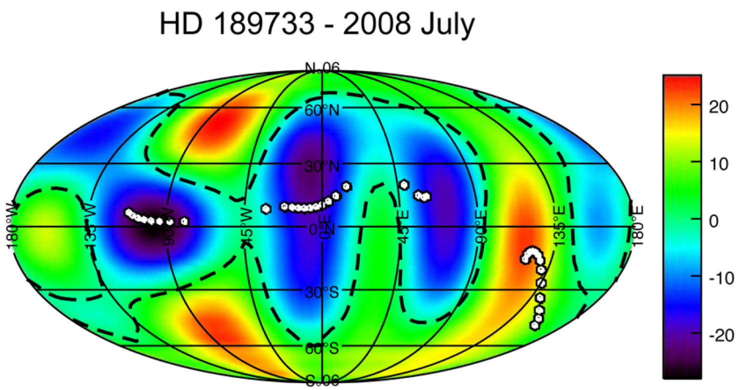
Low mass stars spin down slowly and remain active for longer…



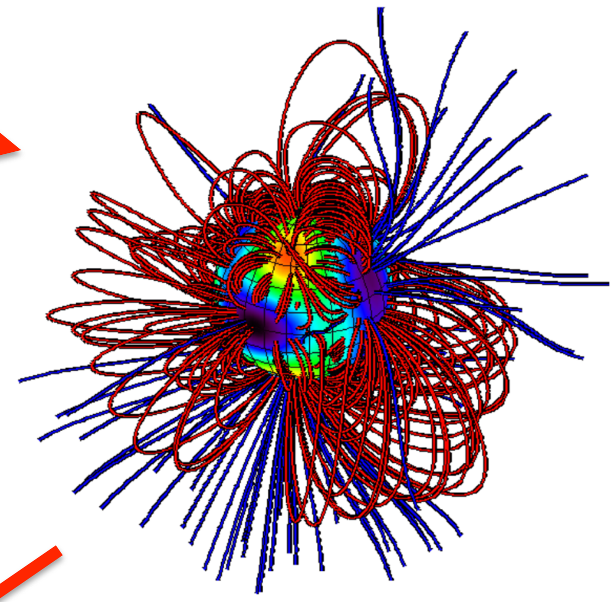
■ *3D MHD models: Llama+13,Vidotto+14,15,do Nascimento+16,Nicholson+16*

Modelling exoplanetary environments

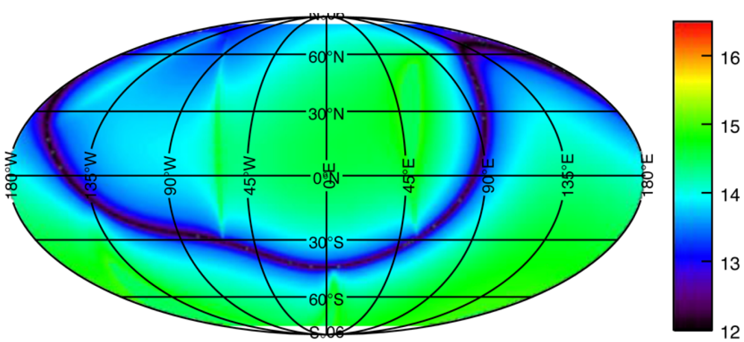
1. Map the star's magnetic field



2. Extrapolate magnetic field and solve for wind



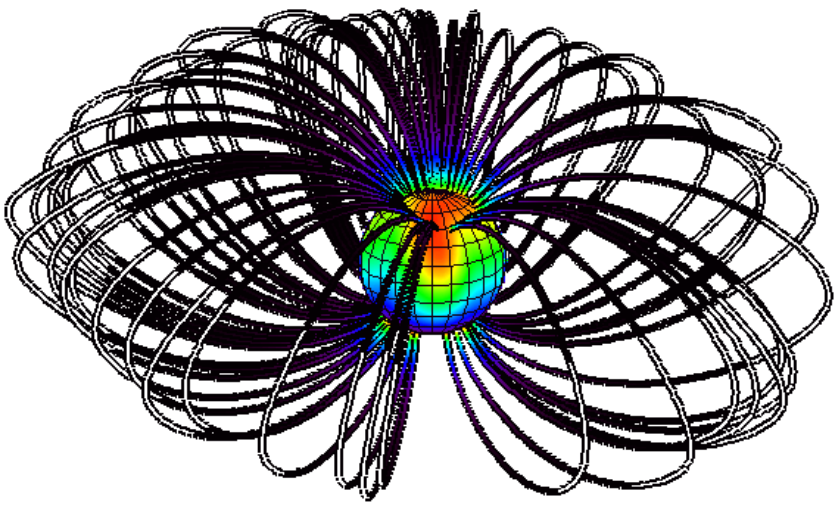
3. Determine local conditions at exoplanetary orbit



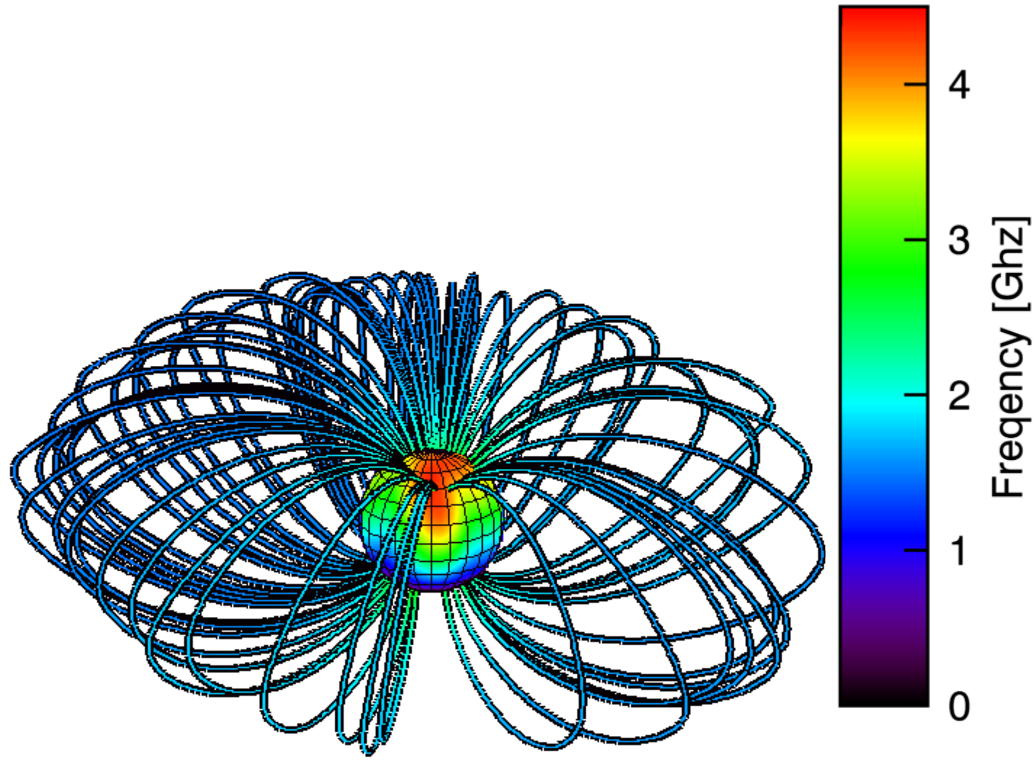
Ram pressure

See+2015

Large pressure scale height of low mass stars -> slow fall-off in plasma frequency

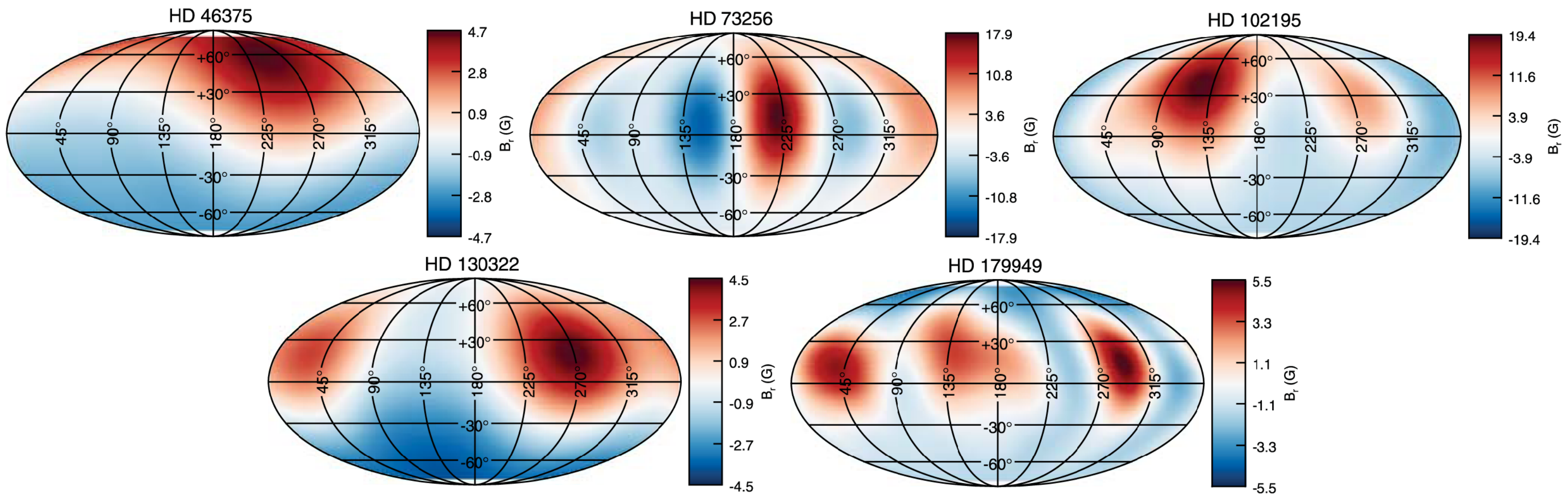


$$f_{gyro}(Hz) = \; 28 * 10^9 B(T)$$



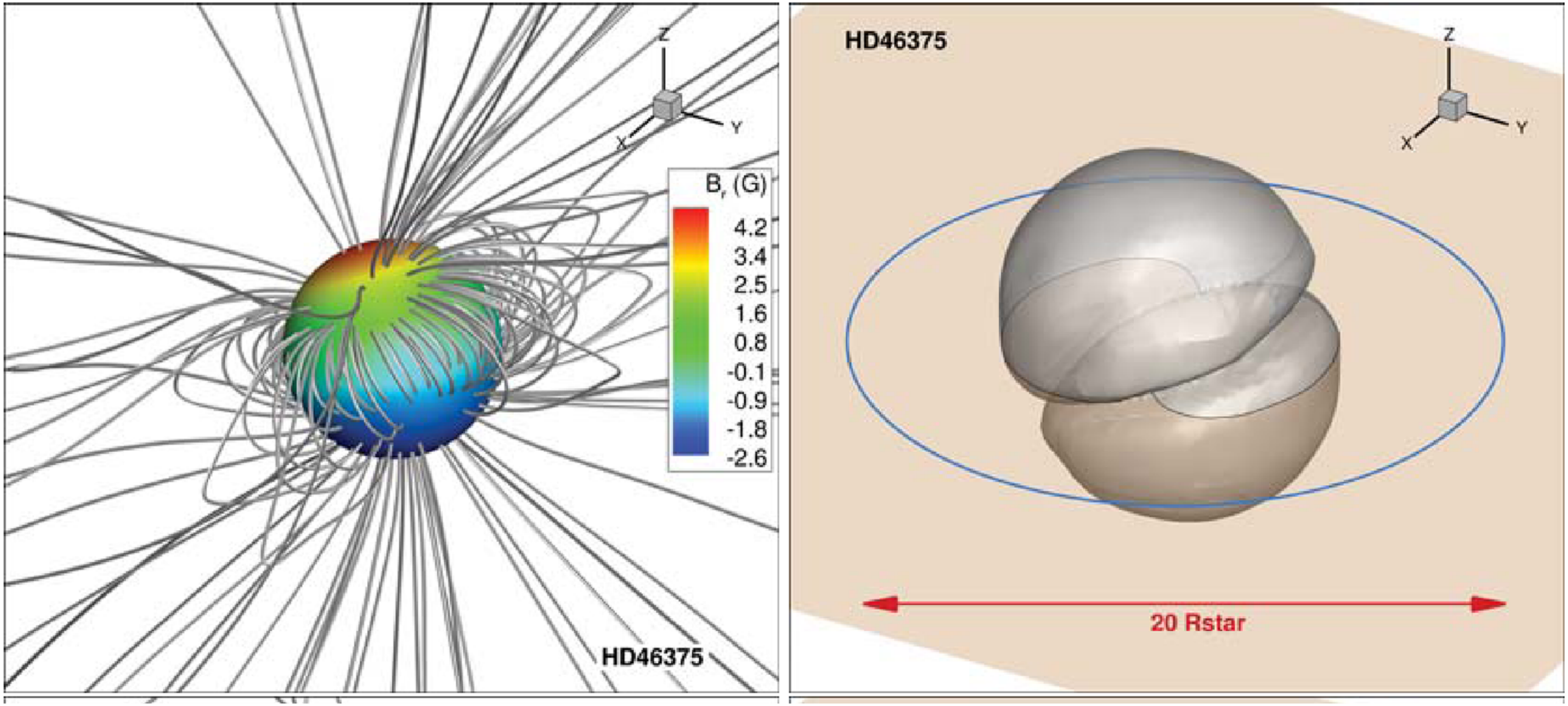
$$f_{plasma}(Hz) = \; \sqrt{n_e(m^{-3})}$$

Magnetic fields of planet hosts



Vidotto+2015

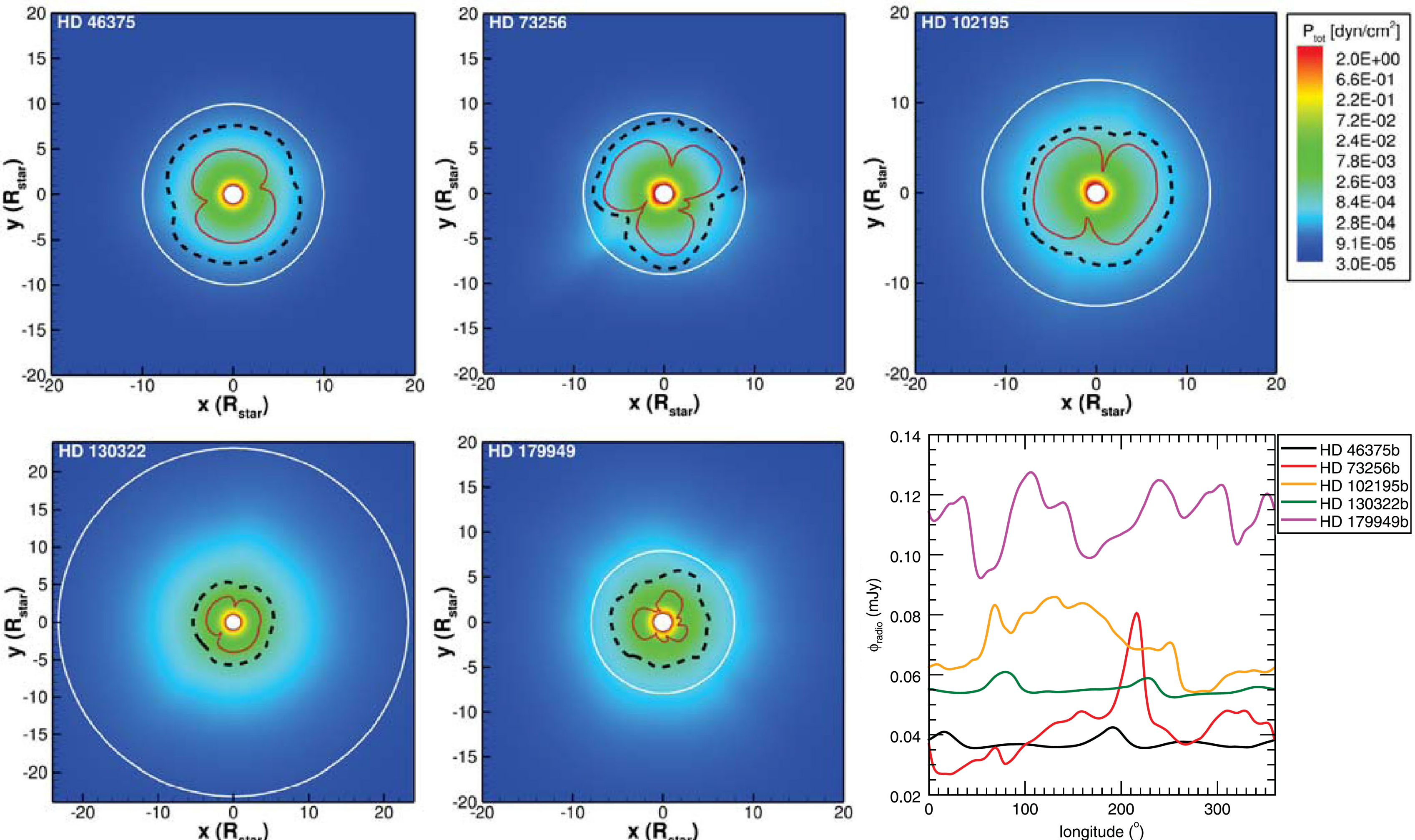
3D MHD wind models



Vidotto+2015

Some exoplanetary orbits are inside the Alfven radius

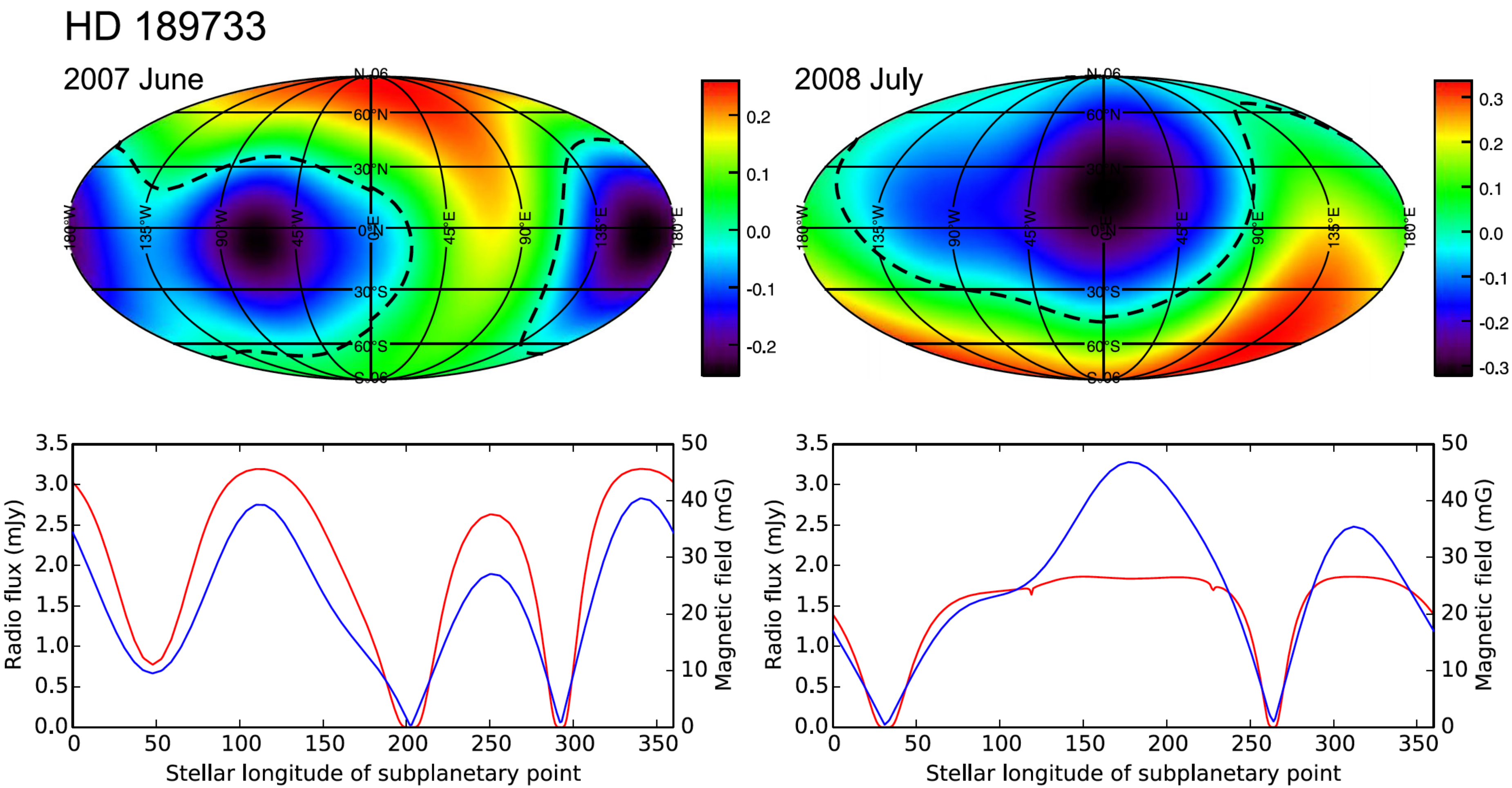
Exoplanets experience varying environments as they orbit



Vidotto+2015

See also: Cohen+10, Strugarek+15, Vernisse+17a,b; Pinto+17

Radio emission modulated on synodic period (and cycle period)

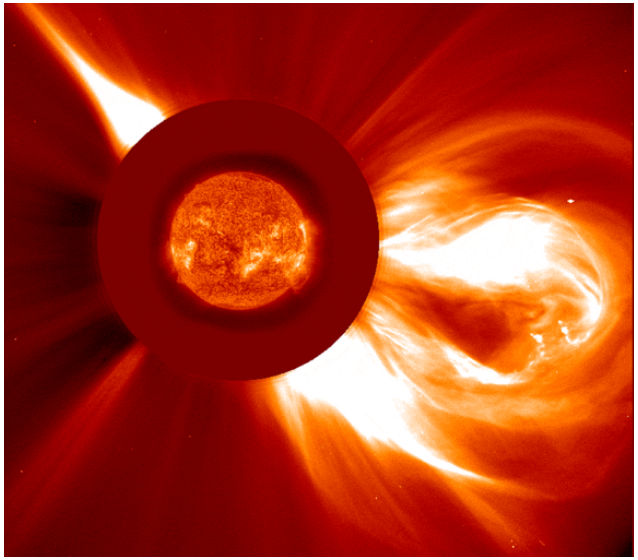


See+2015

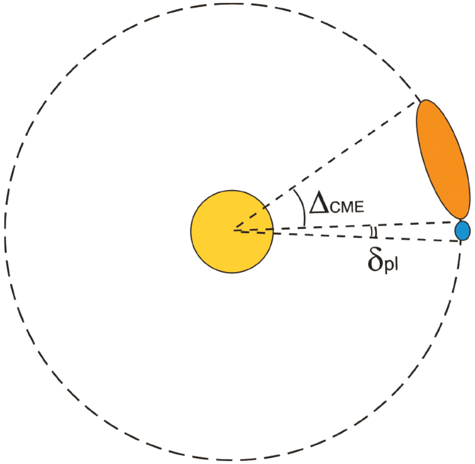
Intermittent mass ejections in stellar winds

<u>M dwarfs exoplanets in close orbits:</u>

Continuous impact with stellar mass ejections if ejection rate ~ 6 solar (Khodachenko+07).

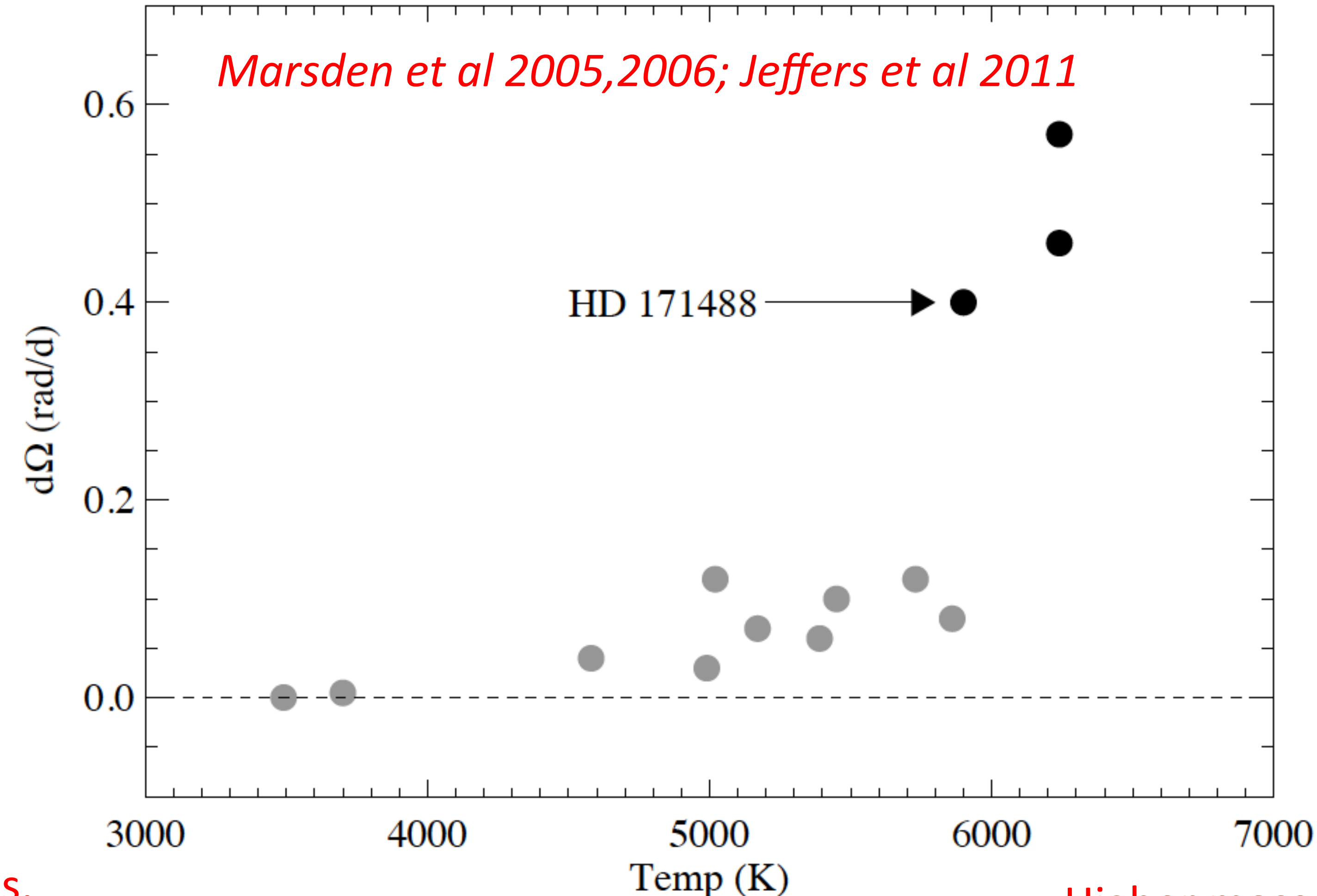


NASA: STEREO



- *What determines the ejection rate?*
- Flux emergence rate
- Differential rotation (rate of shear)

Differential rotation decreases with mass



Low mass,
deep convective zone

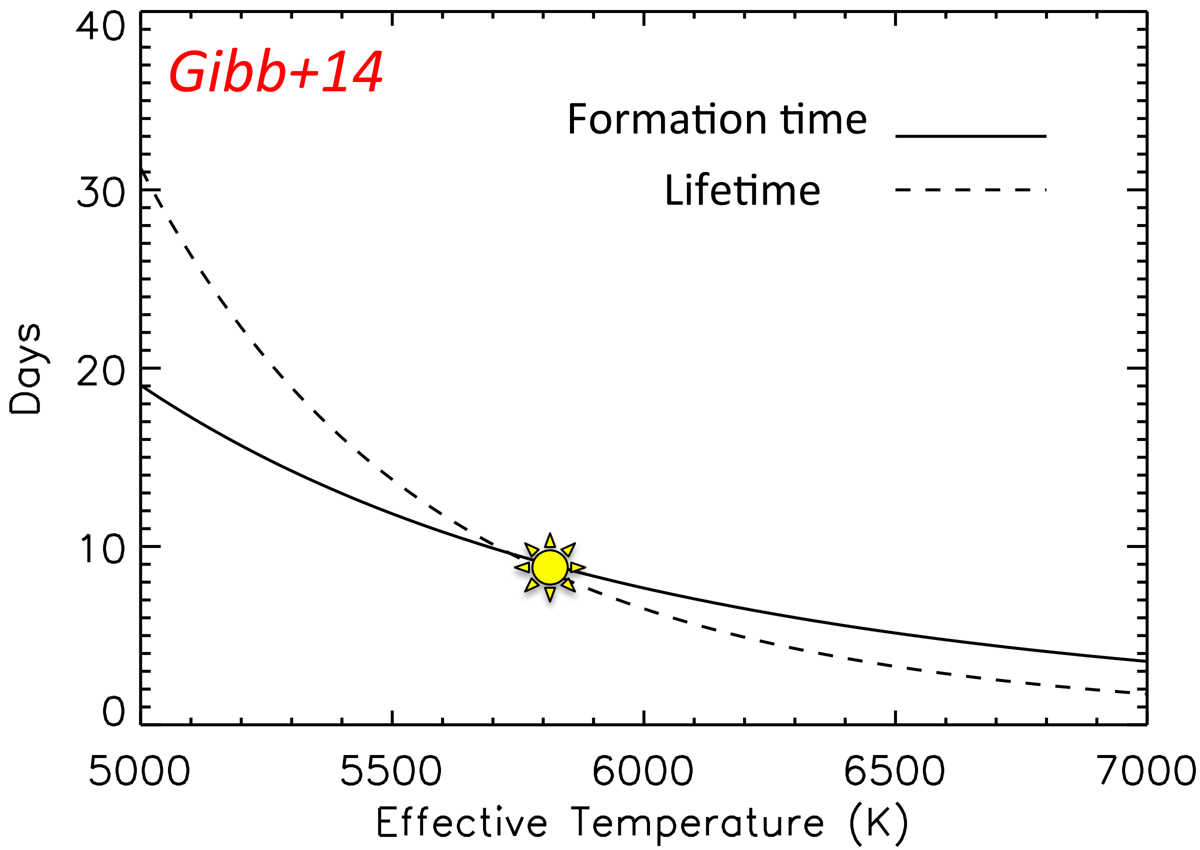
Higher mass,
shallow convective zone

Is the ejection rate a function of stellar mass?

Pilot study (*Gibb+14*):

- Emerge a simple bipole through stellar surface
- Evolve coronal magnetic field with magnetofrictional approach (Yang 86)
- Track formation and evolution of flux ropes (blue) that are precursors to coronal mass ejections.

Lower mass -> lower surface shear -> slowly-evolving coronae

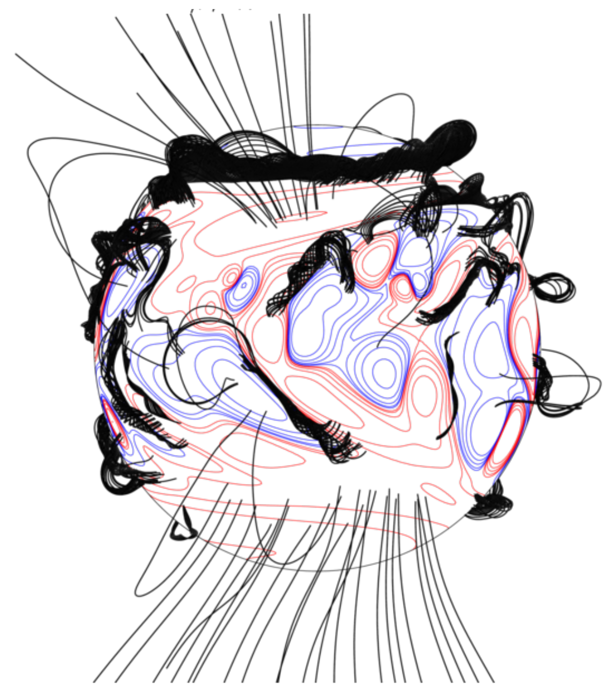


$d\Omega = 3.03[T_{eff}/5130\ K]^{8.6}$ deg/day (Collier Cameron 07)

Full-star, long term evolution

25 models, each evolved for 1 year:

- (1-5) x solar flux emergence rate
- (1-5) x solar differential rotation



Resolution:

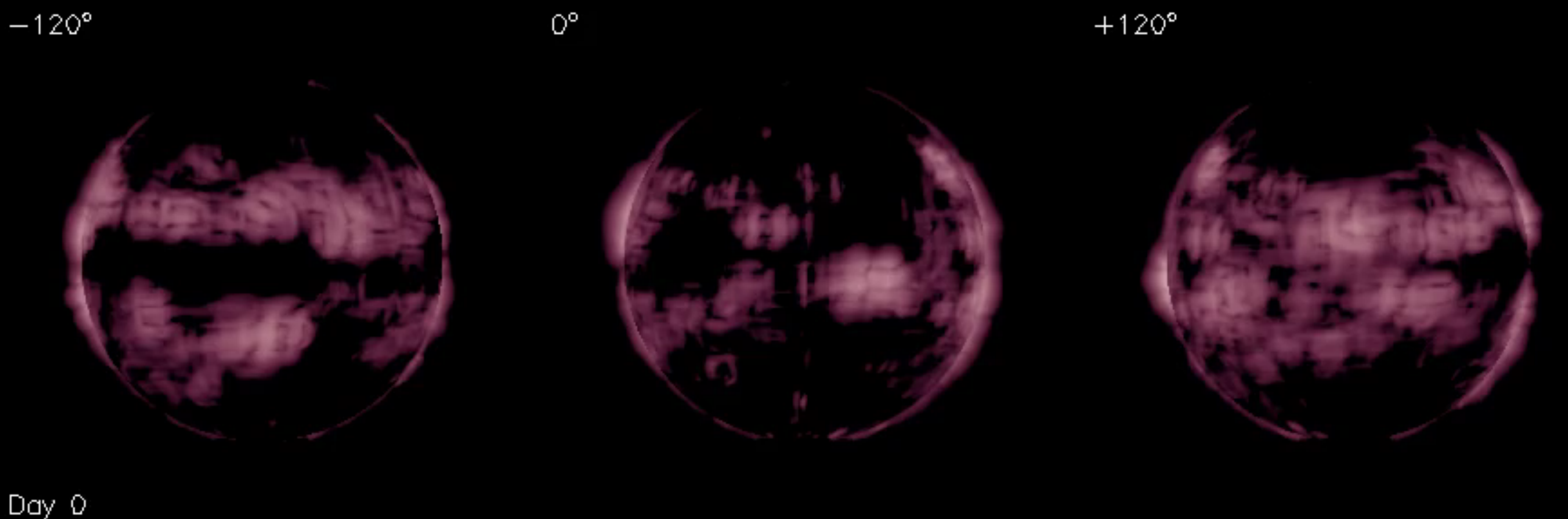
- Spatial: 1^{o} at equator, less at poles
- Temporal: 1 day

Boundary conditions:

- open at 2.5R_*, B_r at surface

Gibb+16

The Sun on steroids…

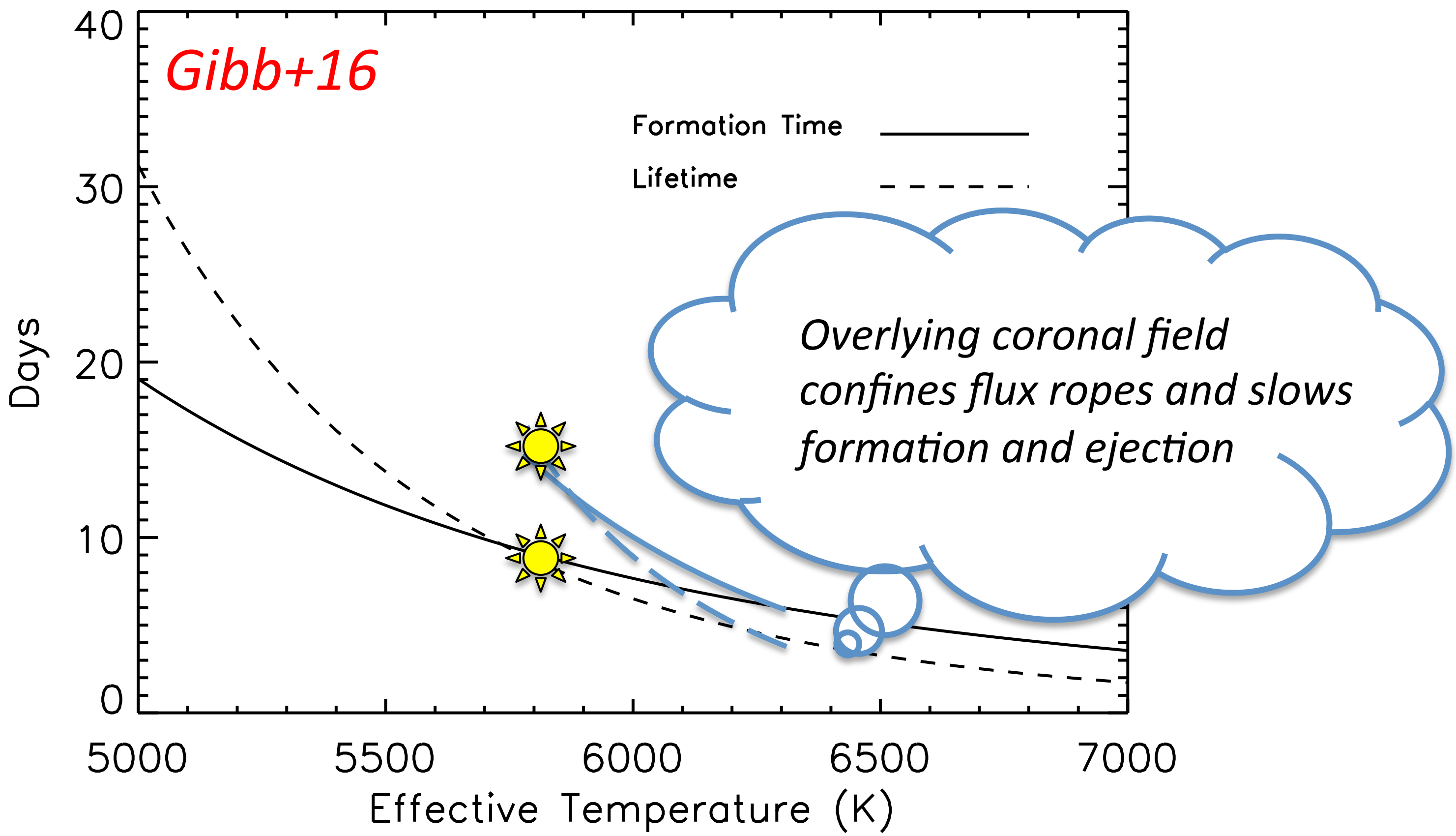


(*Gibb+14,16*)

Frequency and location of coronal ejections depends on:

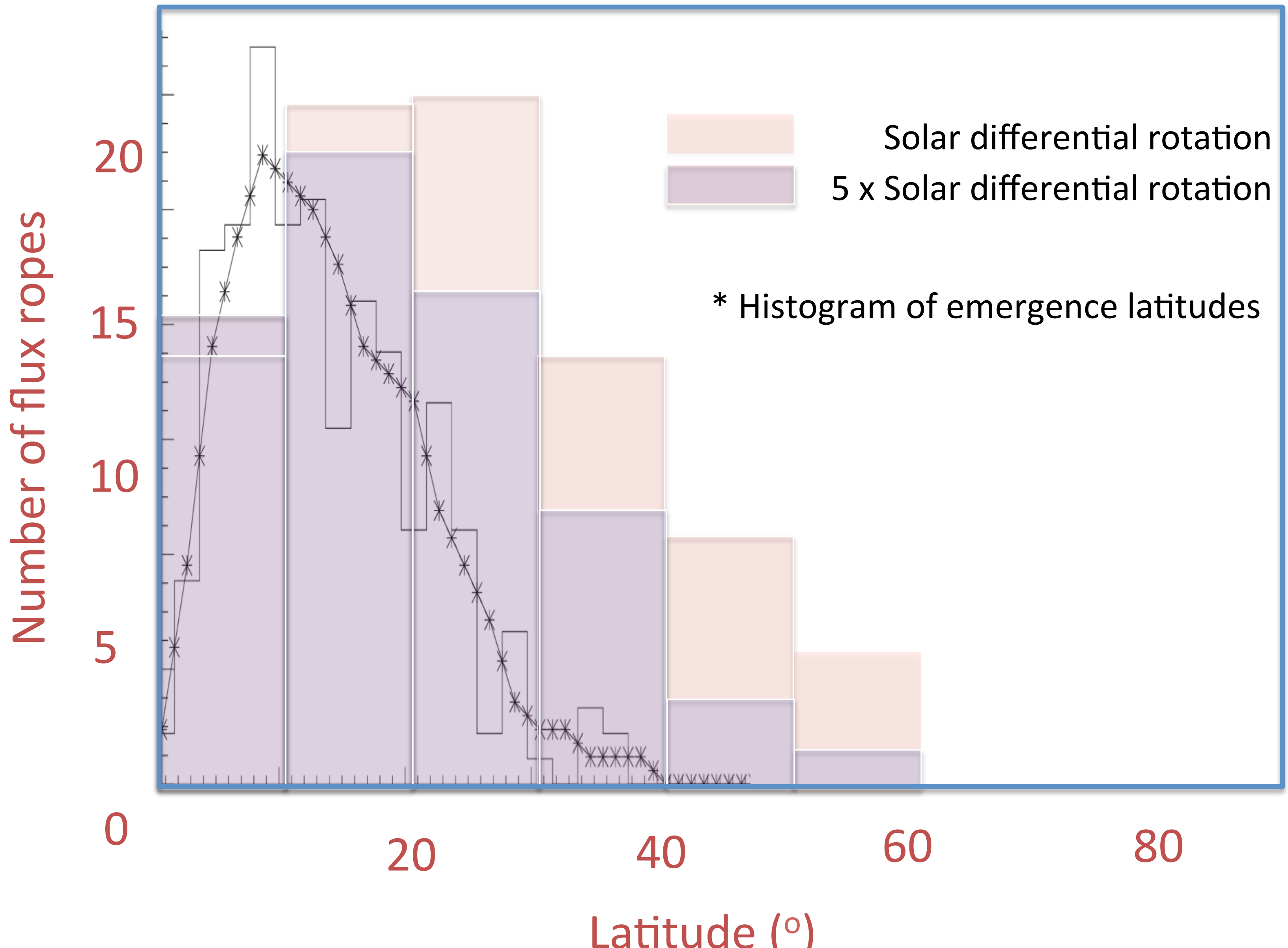
- stellar rotation rate (magnetic flux emergence rate) and
- stellar mass (surface differential rotation)

Full-star, long term evolution also shows that hotter stars have more dynamic coronae.



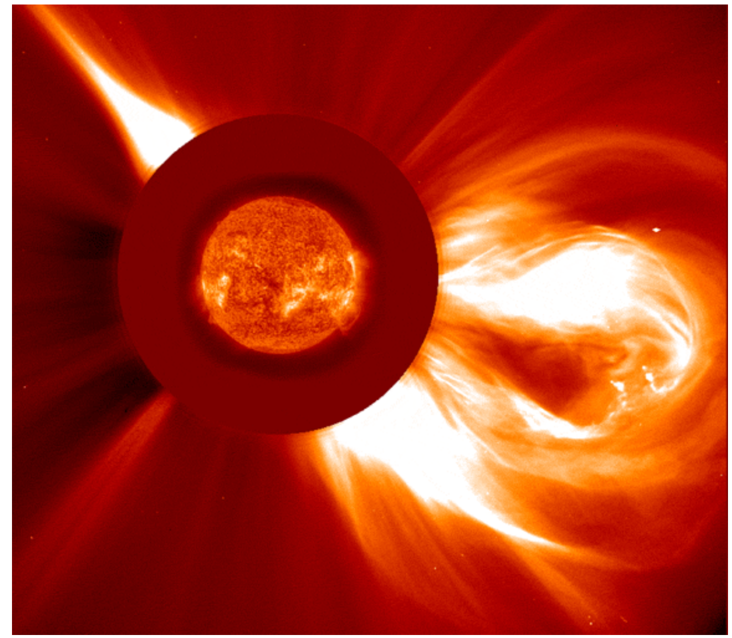
$d\Omega = 3.03[T_{eff}/5130\ K]^{8.6}$ deg/day (Collier Cameron 07)

Increased shear confines flux ropes to active belts



Exoplanet environments vary with stellar mass and rotation rate (age)

- Low mass stars:
  - remain magnetically very active over long timescales
  - have low differential rotation (and slowly-evolving coronae?)
  - Implications for mass ejection rates?



NASA: STEREO

- Exoplanet environments vary on synodic and stellar cycle timescales