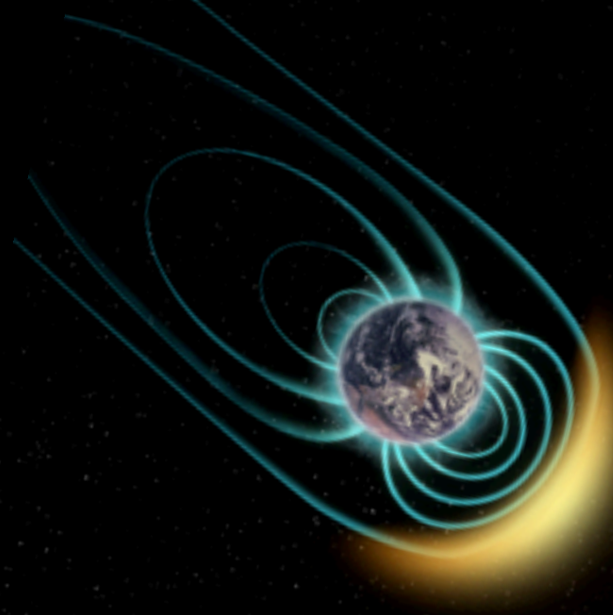
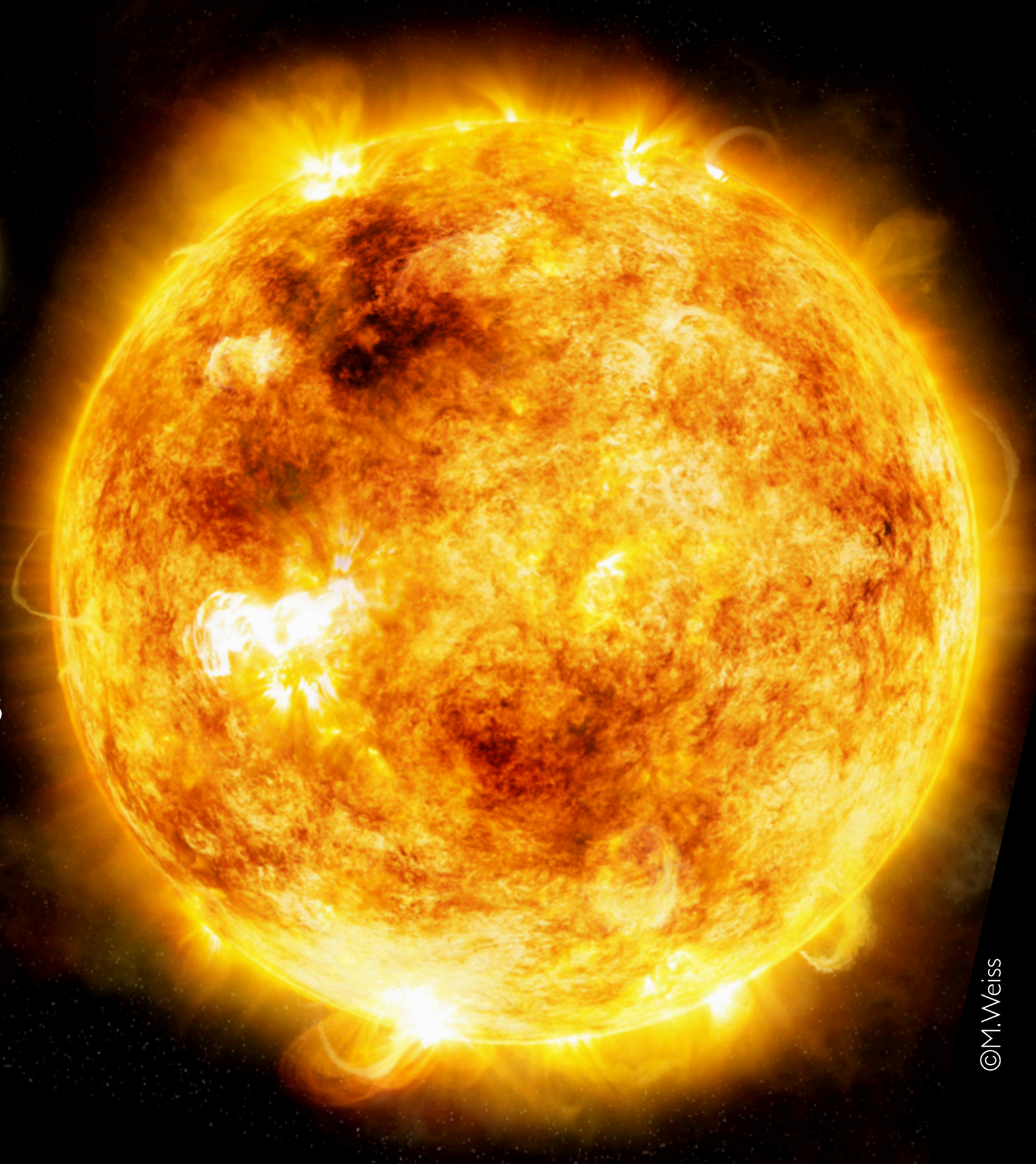
Stellar magnetic activity and their effects on planets

Aline Vidotto

Trinity College Dublin
The University of Dublin





Planets and their effects on stellar magnetic activity

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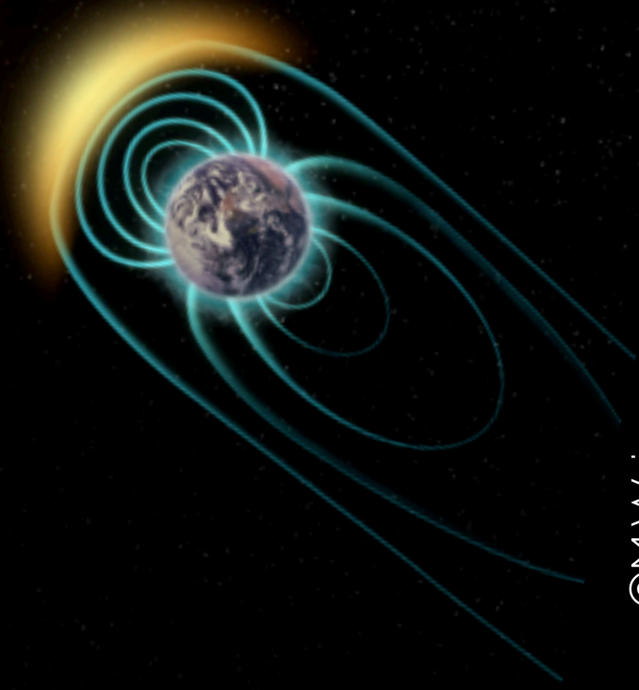
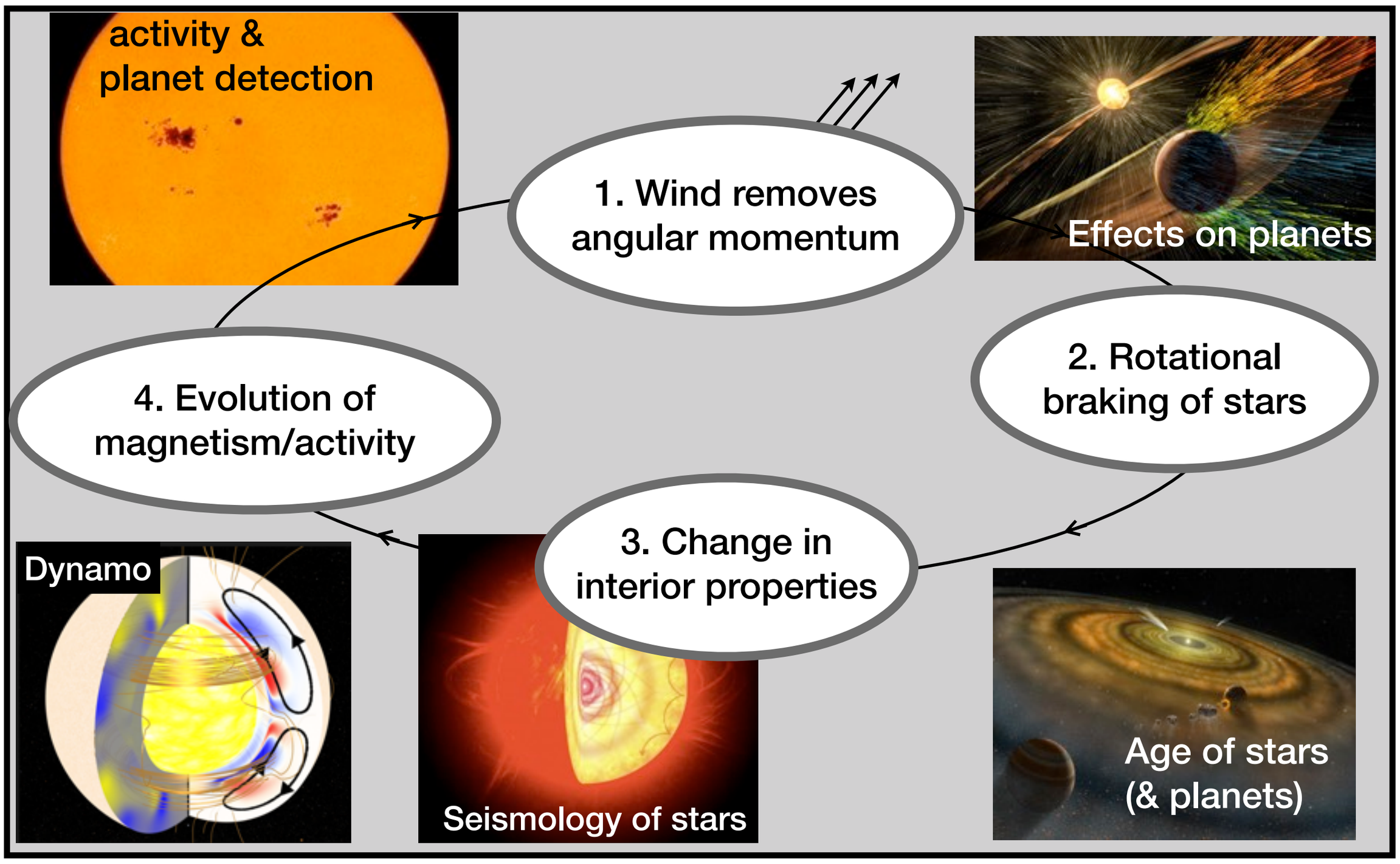
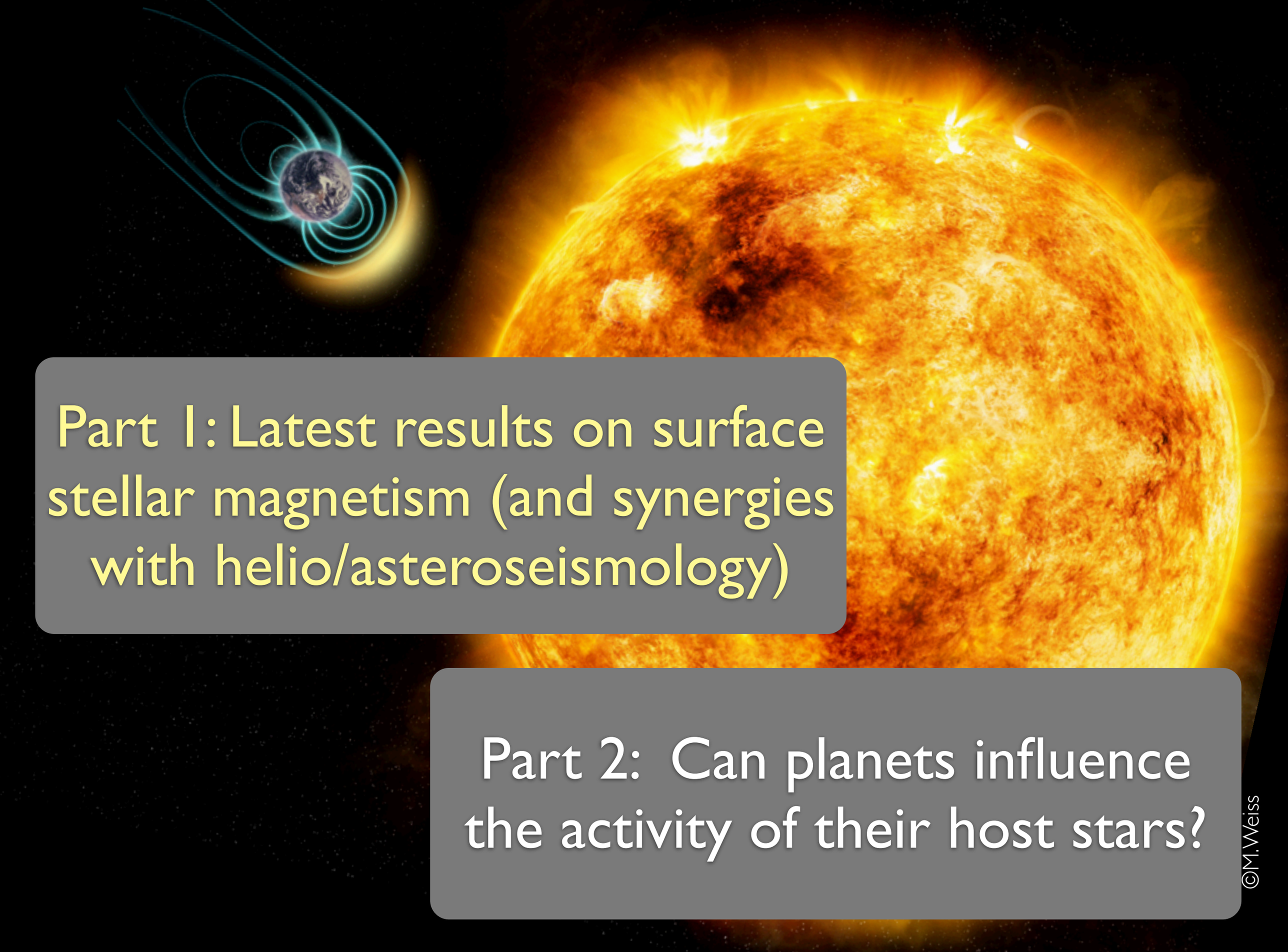


The BIG picture:
evolution of cool dwarf stars



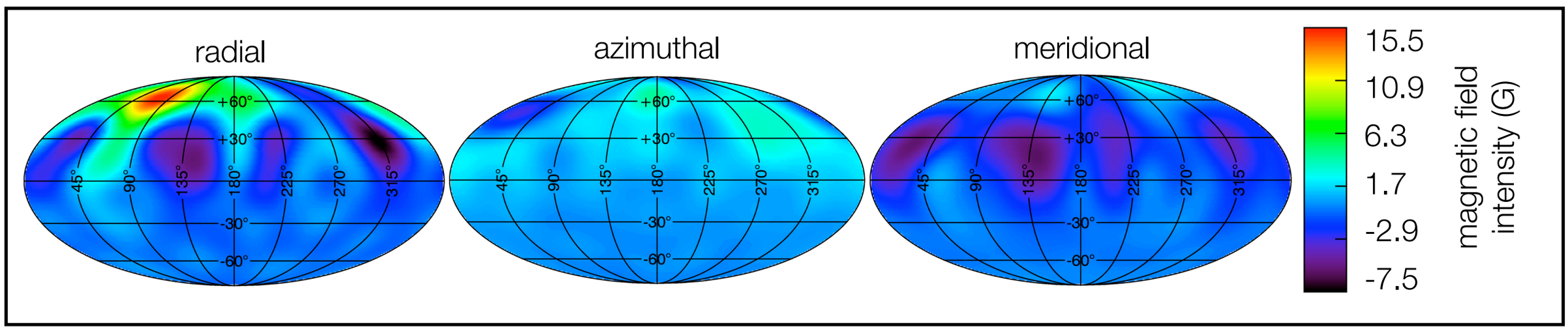


Part 1: Latest results on surface stellar magnetism (and synergies with helio/asteroseismology)

Part 2: Can planets influence the activity of their host stars?

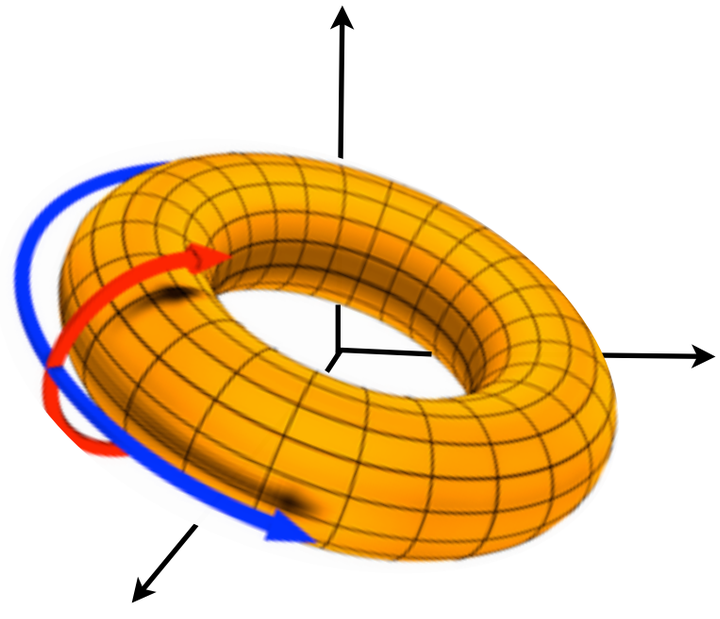
How do we image stellar magnetic fields?

Zeeman Doppler imaging: Large-scale magnetic fields of cool stars



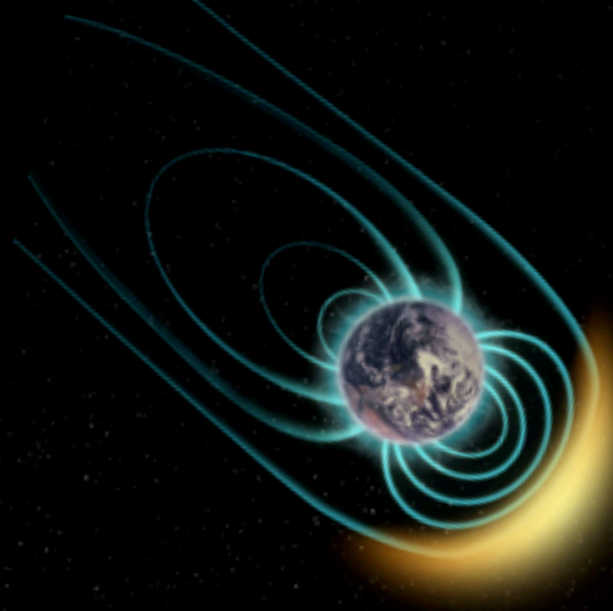
Poloidal fields

Toroidal fields



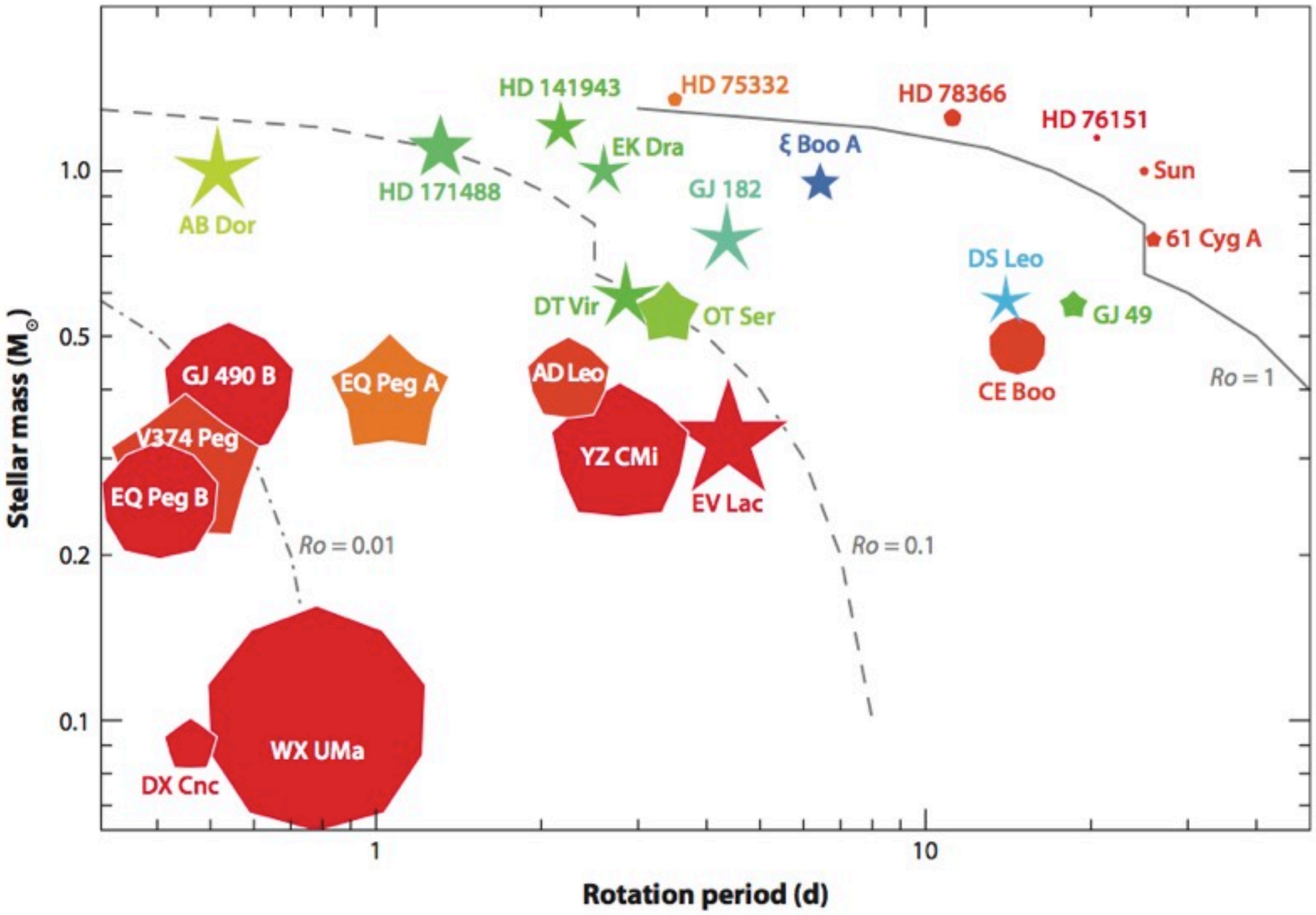
see also: Donati+06, Morin+08, Petit+08, Fares+09, Marsden+11, Mengel+15, Rosén+16, Folsom+16, etc

Part 1: What surveys of stellar magnetic fields have taught us so far?

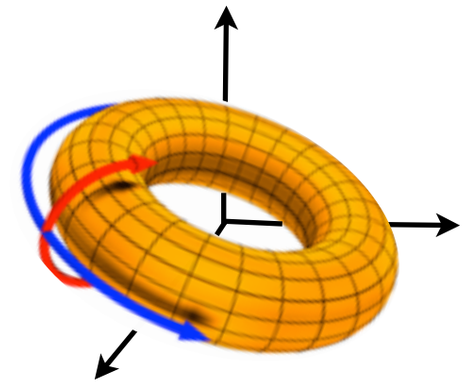


Surface magnetic topology depends on the internal structure

Donati & Landstreet (09)



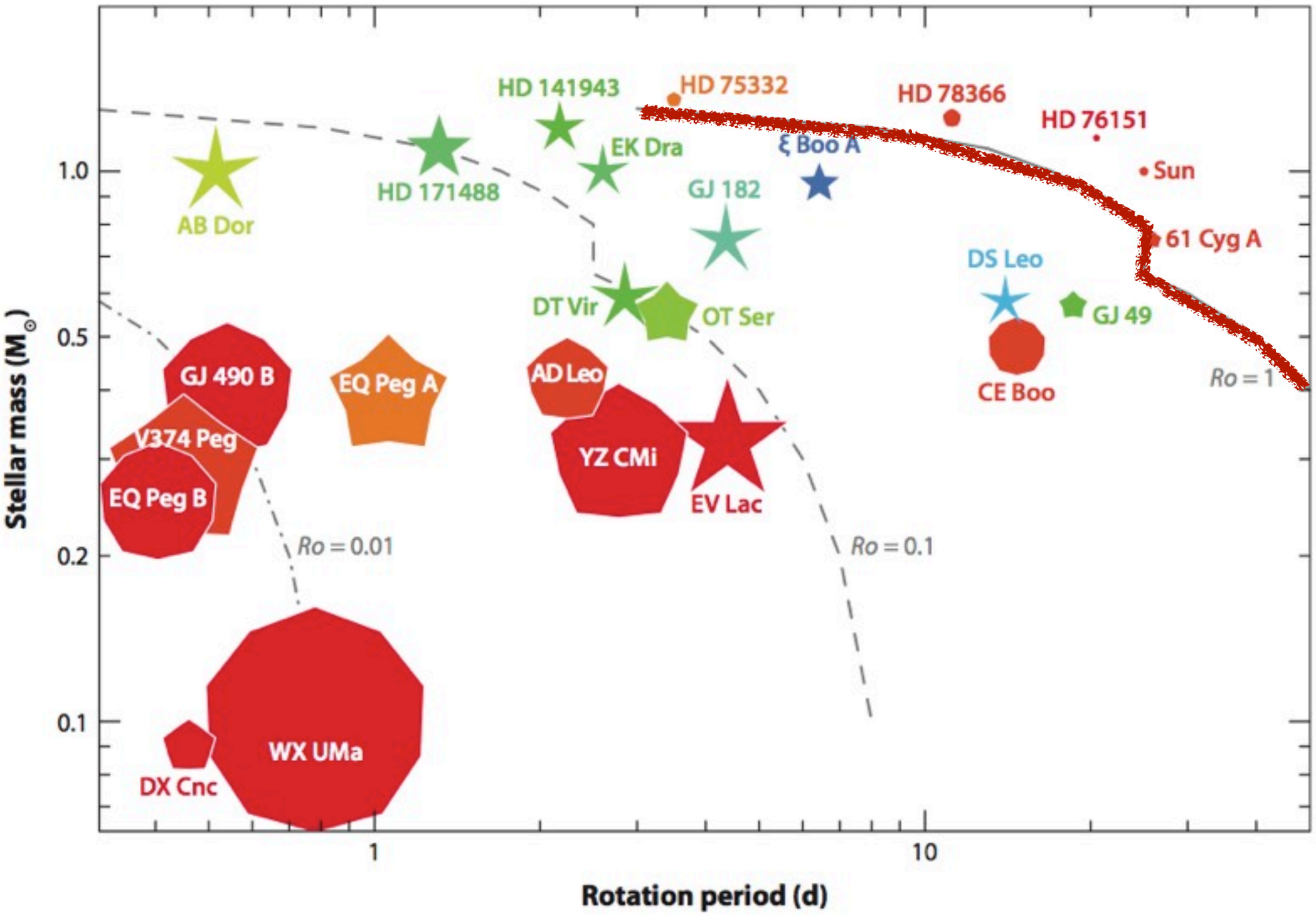
- Size: intensity
- Colour:
  - poloidal
  - toroidal



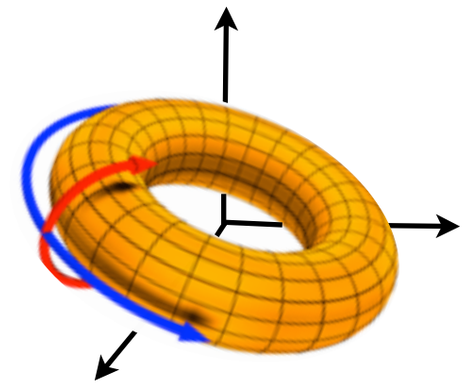
- Shape:
  - ● axisymmetric
  - ★ non-axisym.

Surface magnetic topology depends on the internal structure

Donati & Landstreet (09)



- Size: intensity
- Colour:
  - poloidal
  - toroidal



- Shape:
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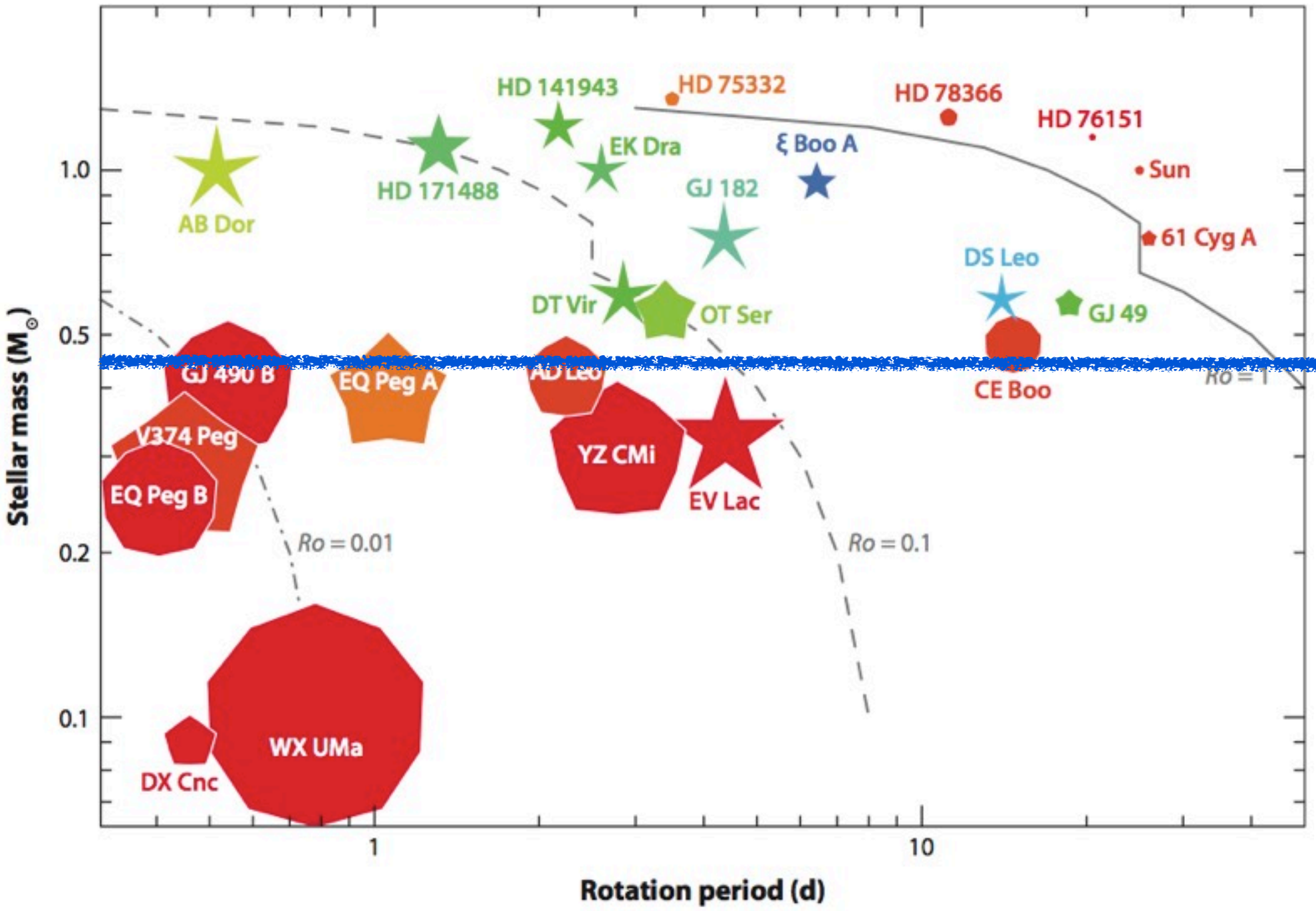
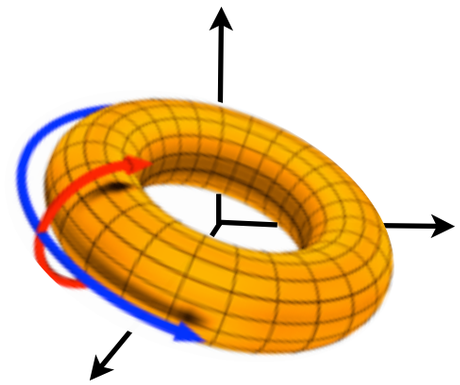
Surface magnetic topology depends on the internal structure

Donati & Landstreet (09)



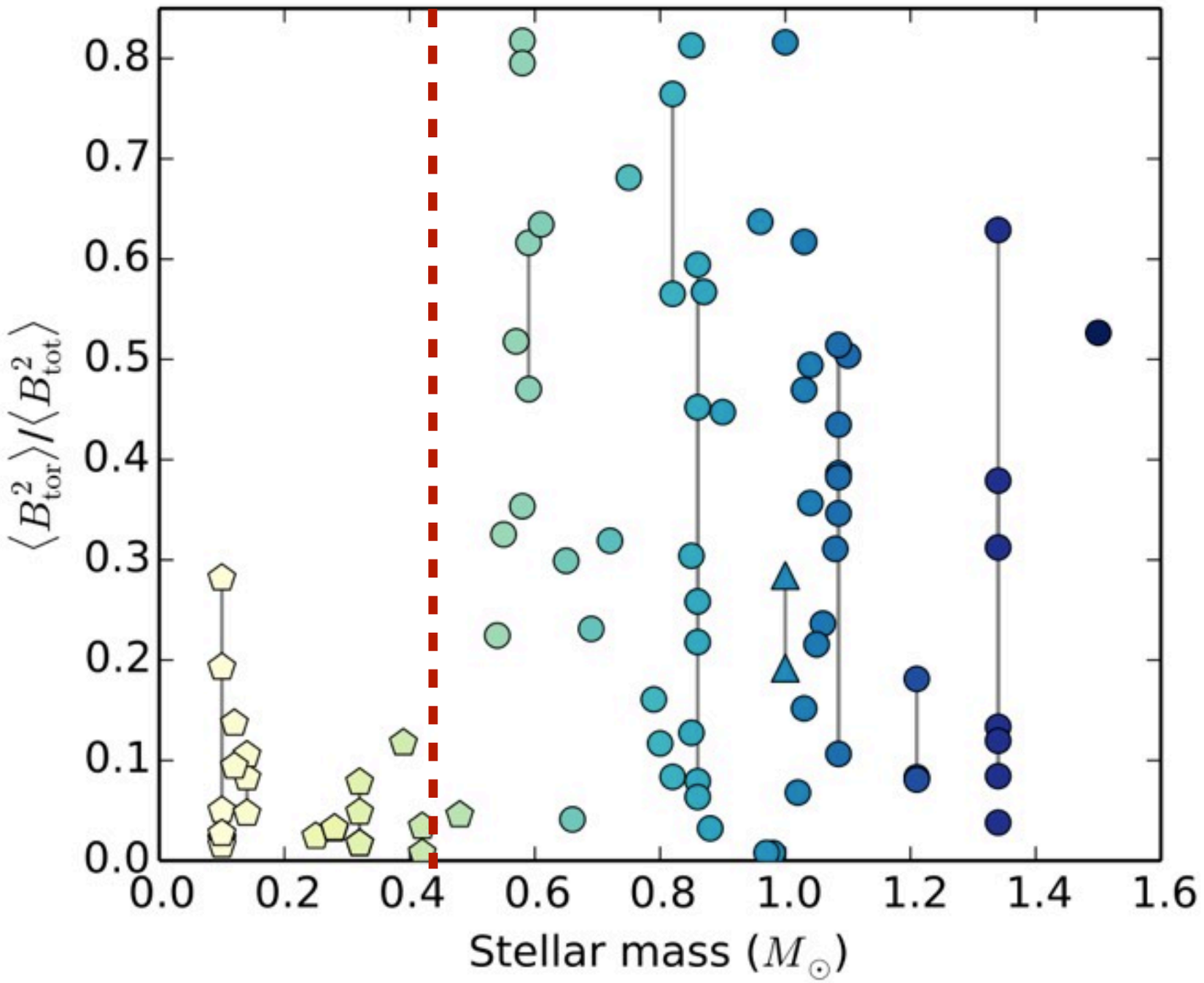
- Size: intensity
- Colour:
  - poloidal
  - toroidal



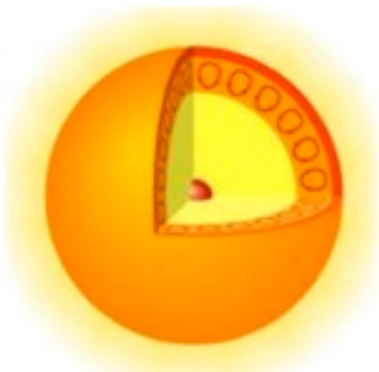
- Shape:
  - ● axisymmetric
  - ★ non-axisym.

Toroidal fields appear when tachocline develops

See+15

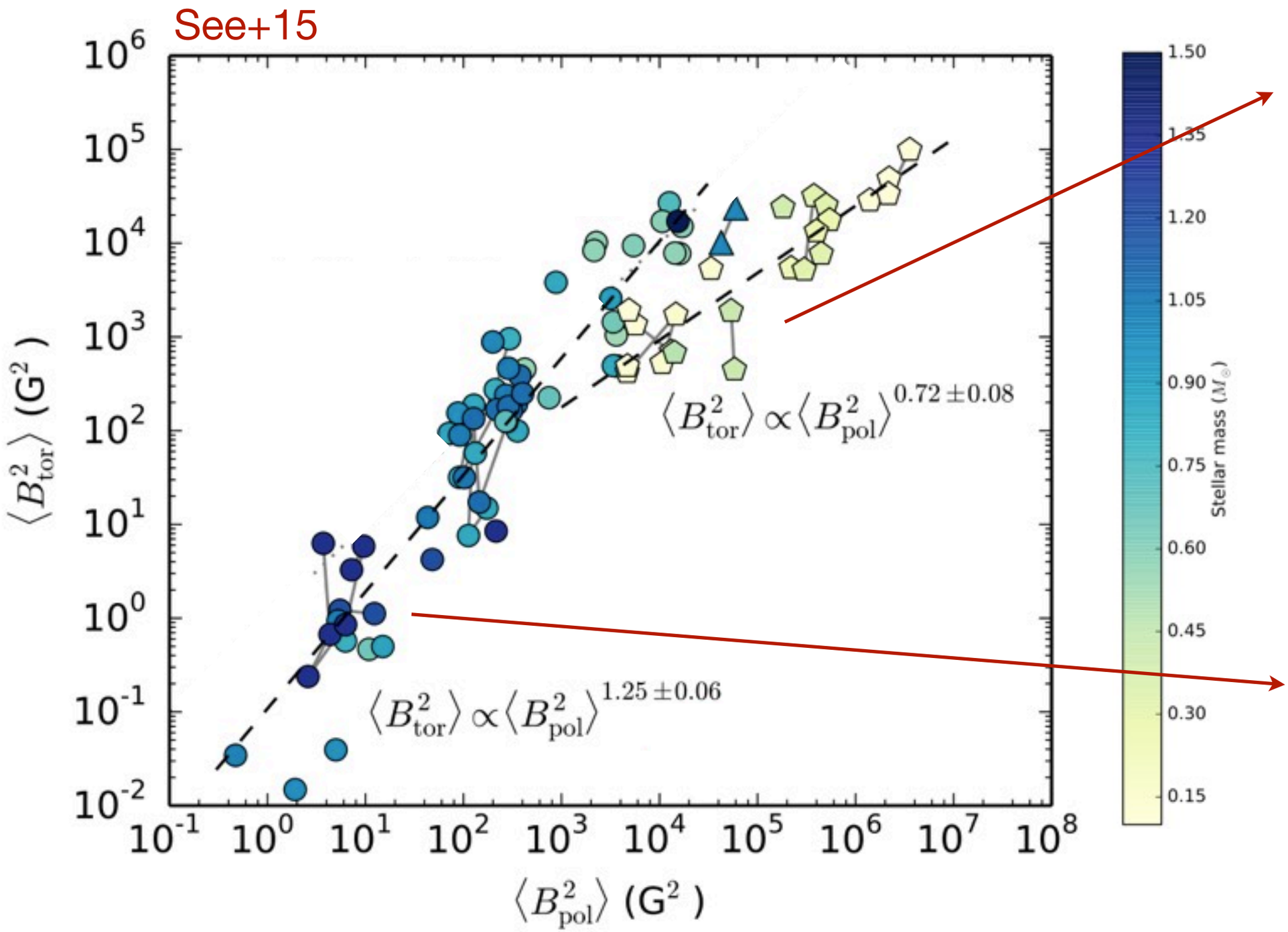


no tachocline
$M \lesssim 0.4\ M_\odot$



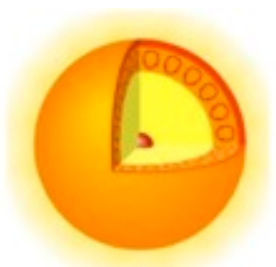
with tachocline
$M \gtrsim 0.4\ M_\odot$

Toroidal & poloidal fields grow together: the stellar case



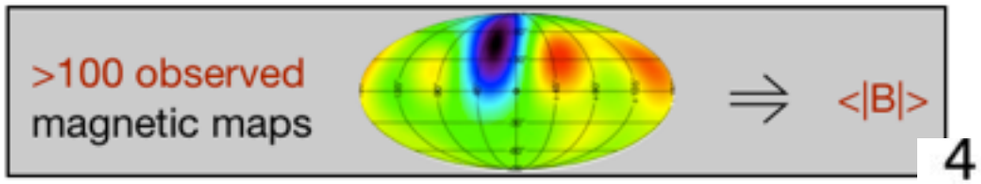
no tachocline
$M \lesssim 0.4\ M_\odot$

with tachocline
$M \gtrsim 0.4\ M_\odot$

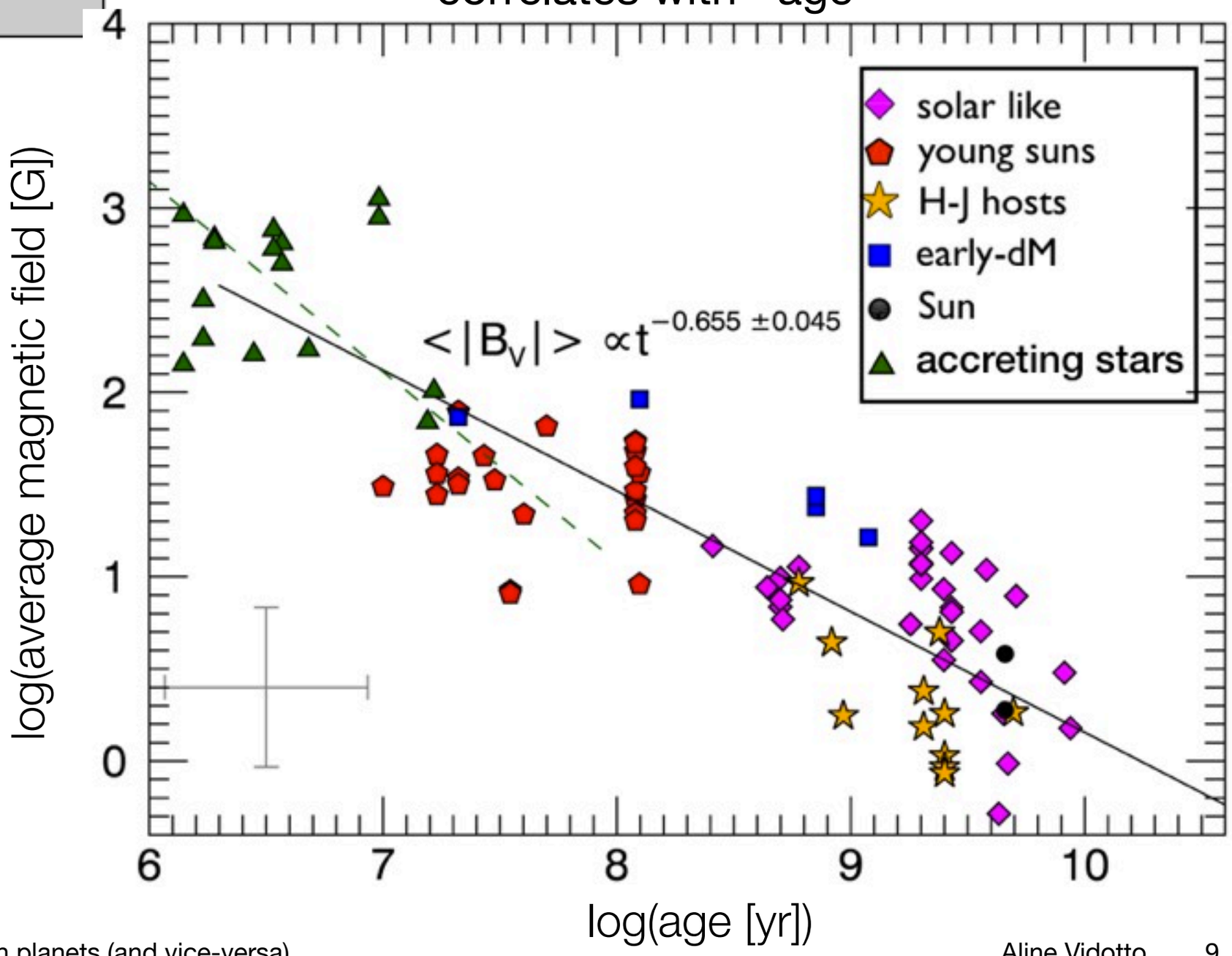


Magnetism evolves in time: "magnetochronology"

Vidotto+14b

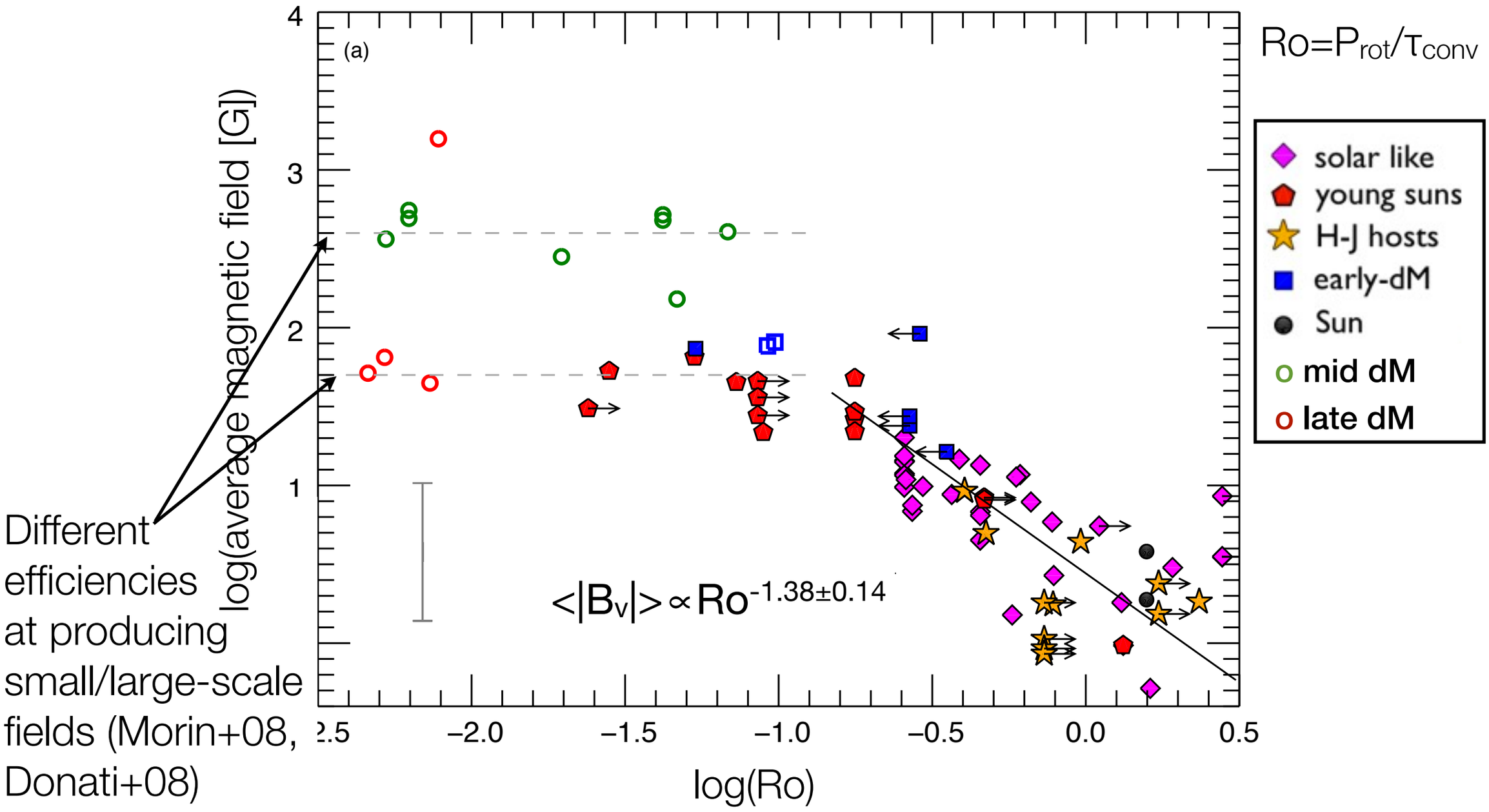


Large-scale magnetic field
correlates with ~age$^{-0.6}$



Fast rotators have more intense magnetic fields

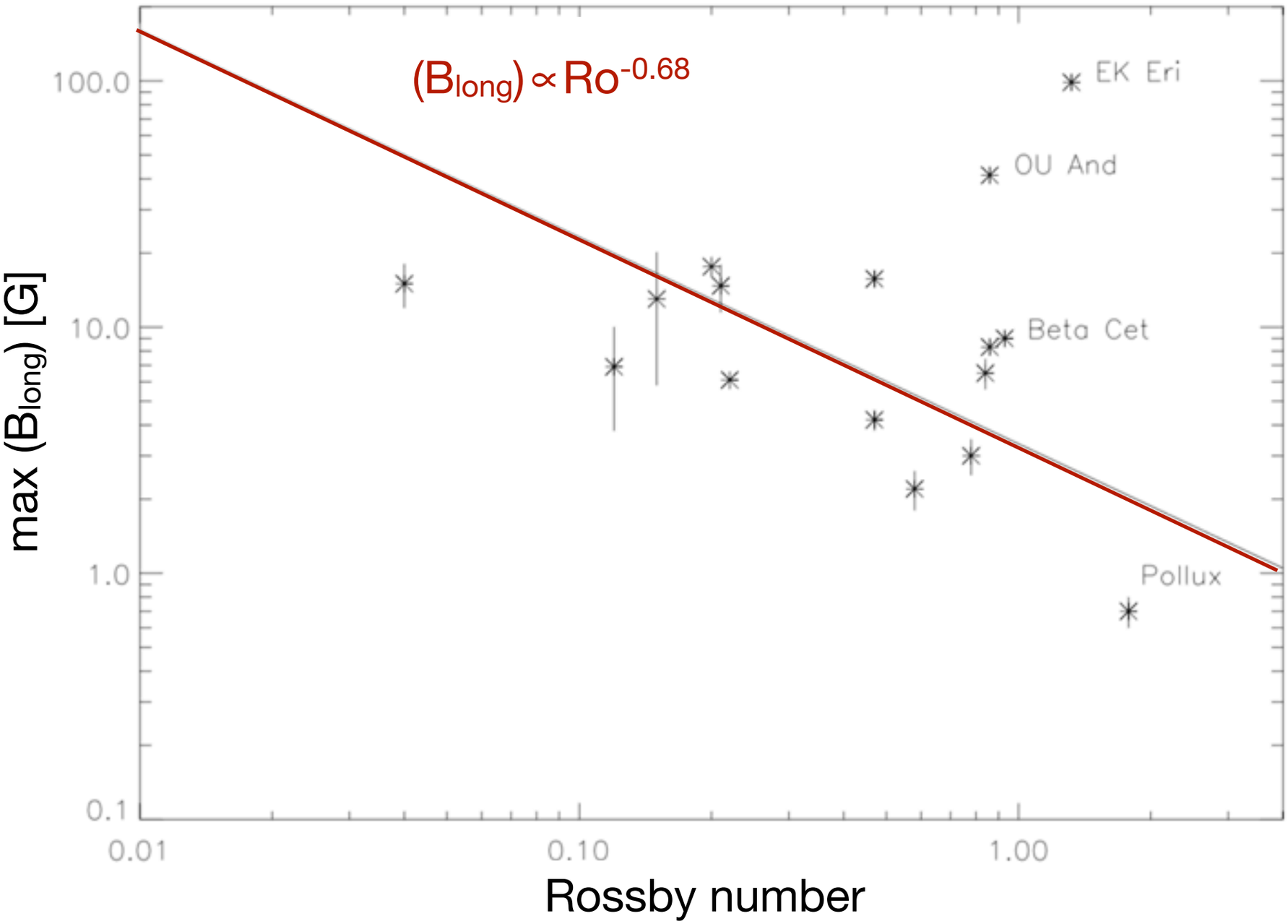
Vidotto+14b



Different efficiencies at producing small/large-scale fields (Morin+08, Donati+08)

Snapshot magnetic field observations of active single G-K giants

Aurière+15



See poster by J. Ballot

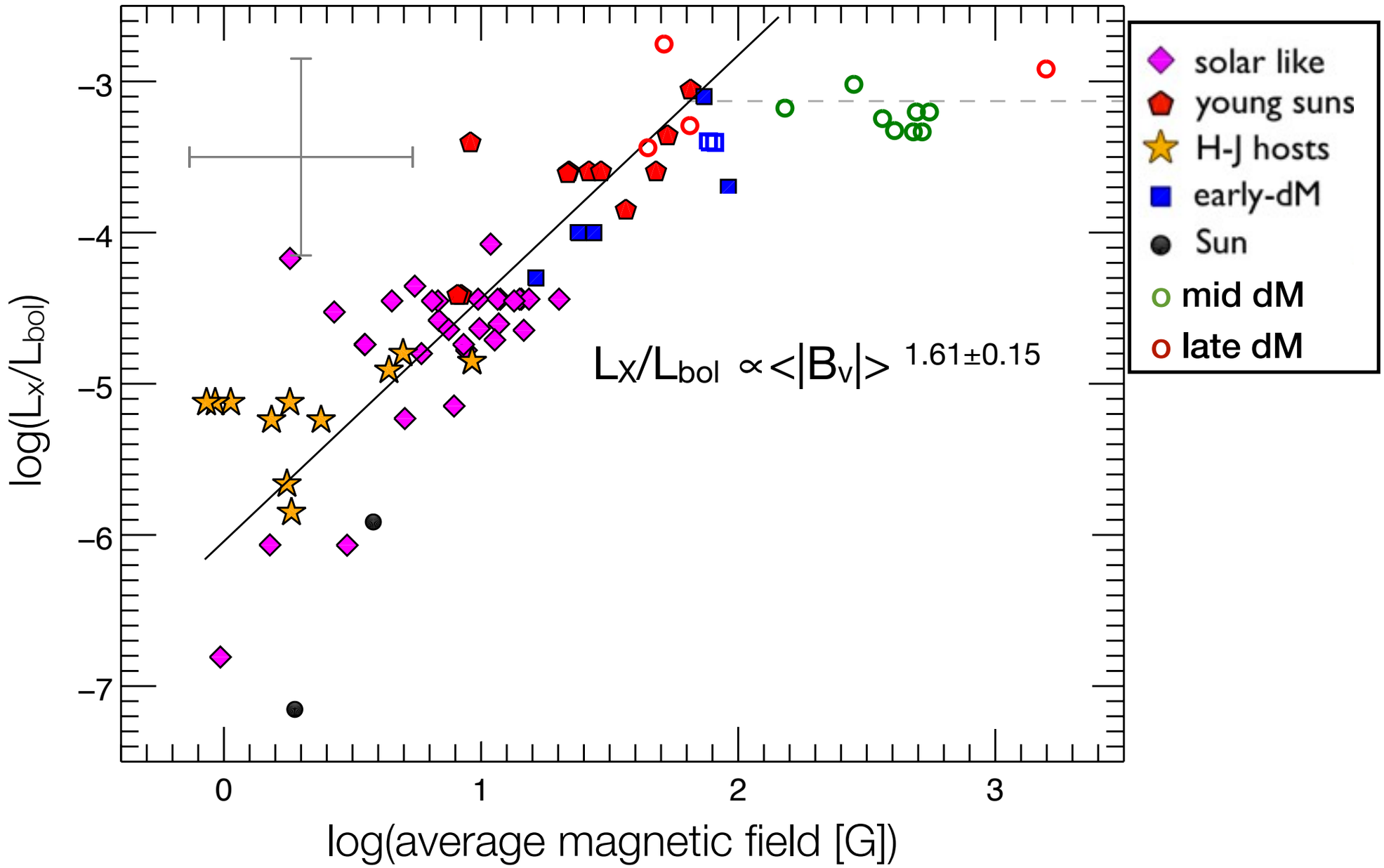
cf: for dwarfs

$\langle|B_V|\rangle \propto Ro^{-1.38\pm0.04}$

(Vidotto+14b)

X-ray luminosity can indeed be used as a proxy for stellar magnetism

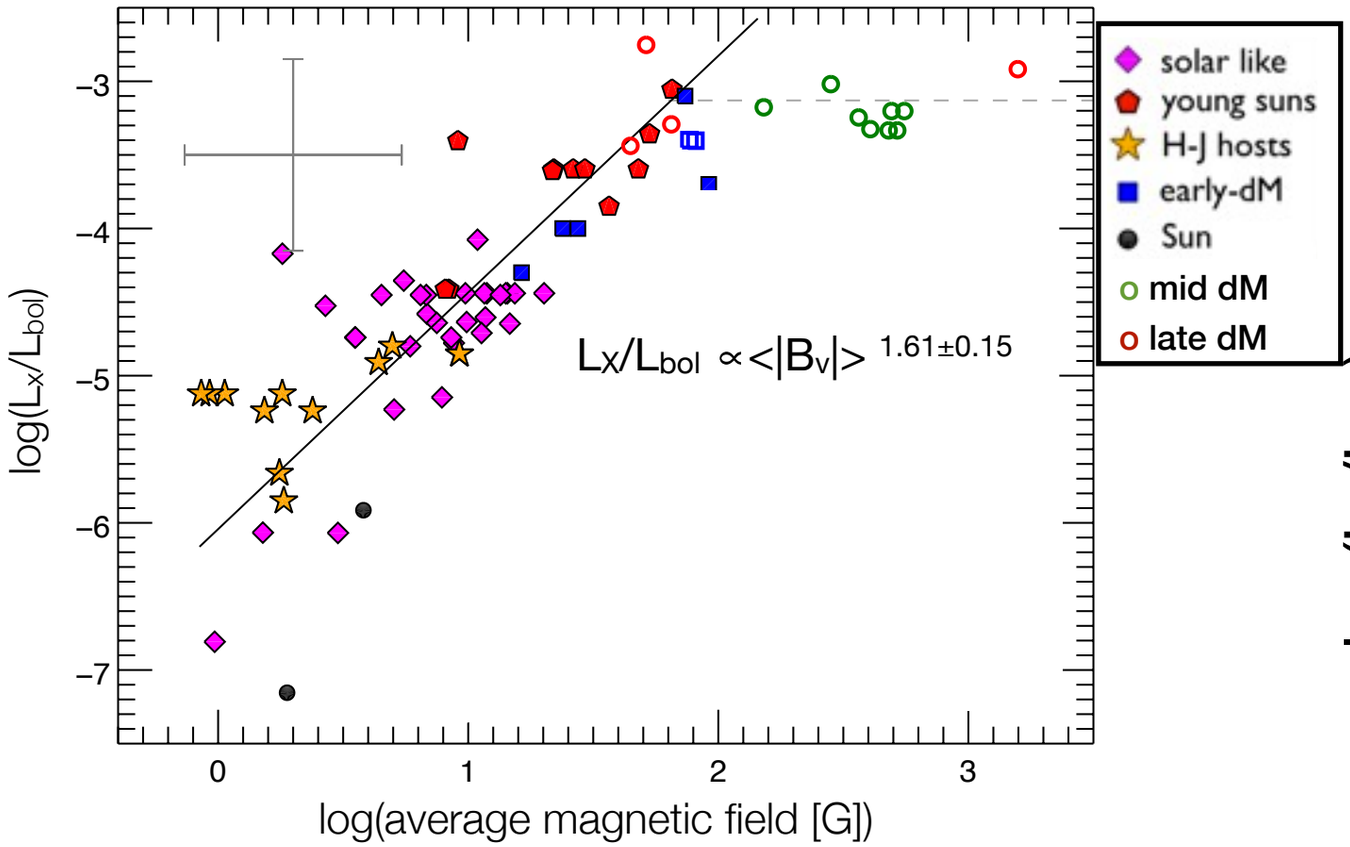
Vidotto+14b

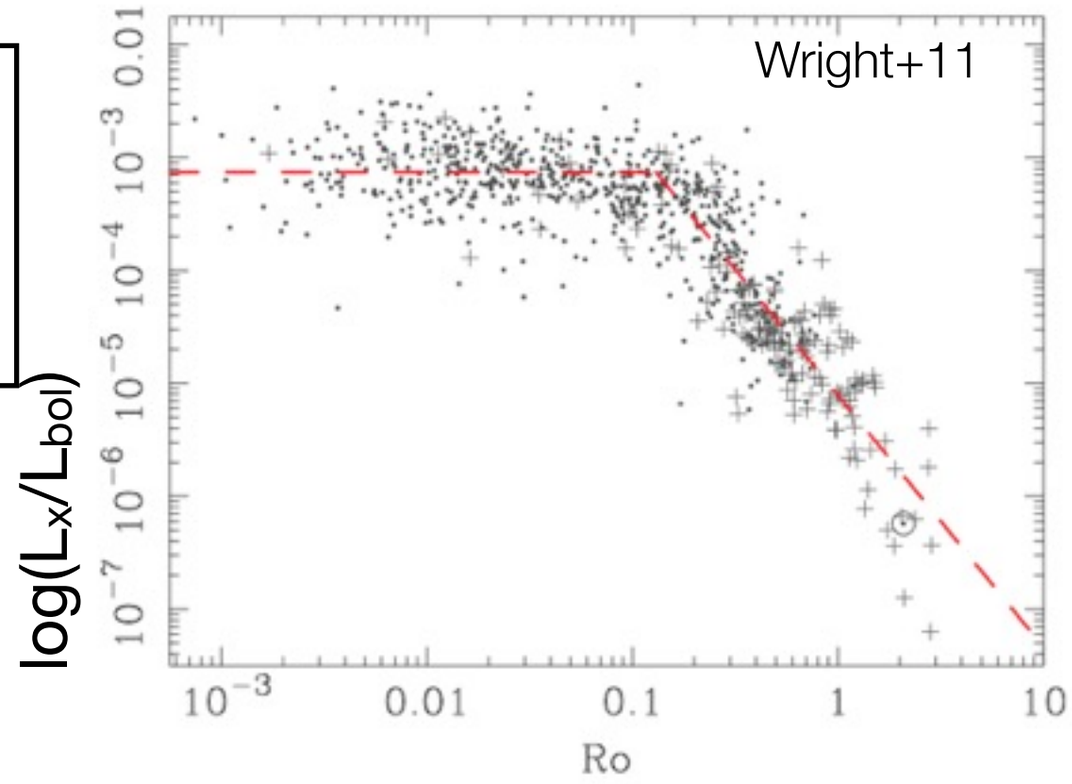


Saturation at $\log(L_X/L_{bol}) \approx -3.1 \rightarrow \langle|B_V|\rangle \gtrsim 80$ G

X-ray luminosity can indeed be used as a proxy for stellar magnetism

Vidotto+14b



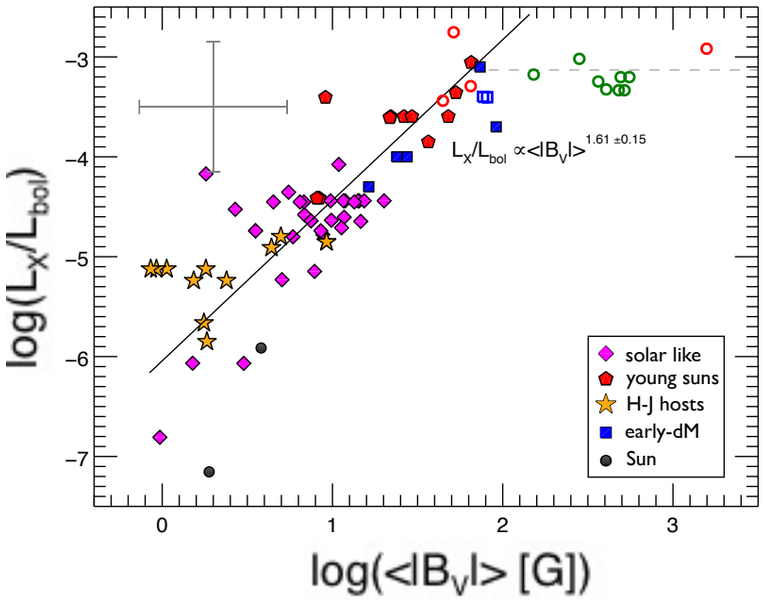


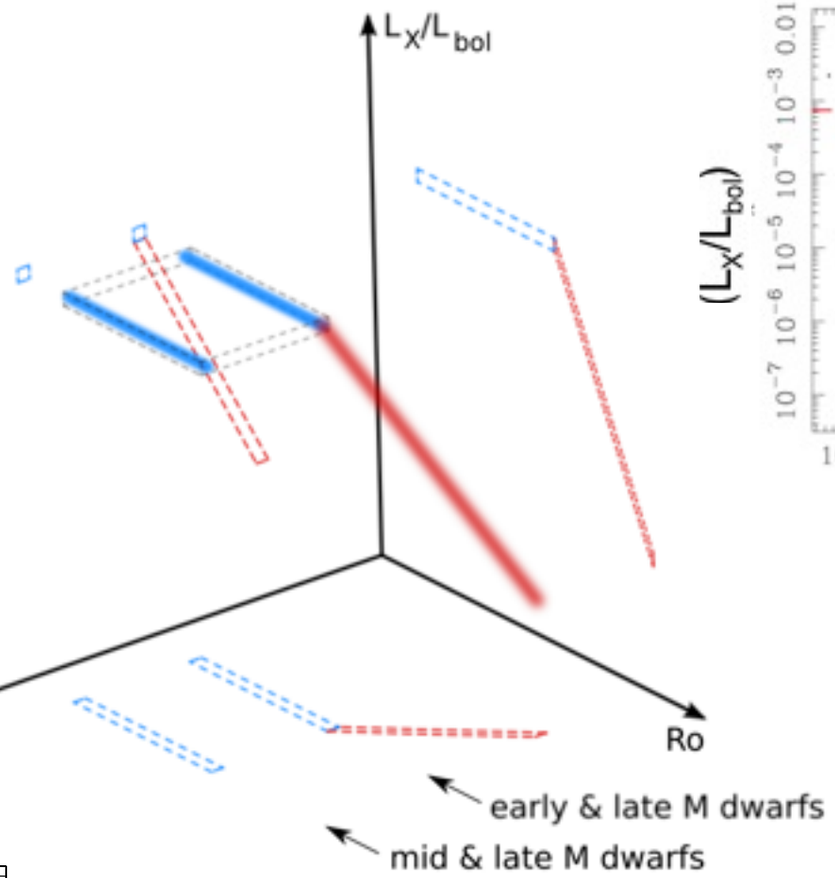
Saturation at
$\log(L_x/L_{bol})\approx -3.1 \rightarrow Ro \approx 0.1$

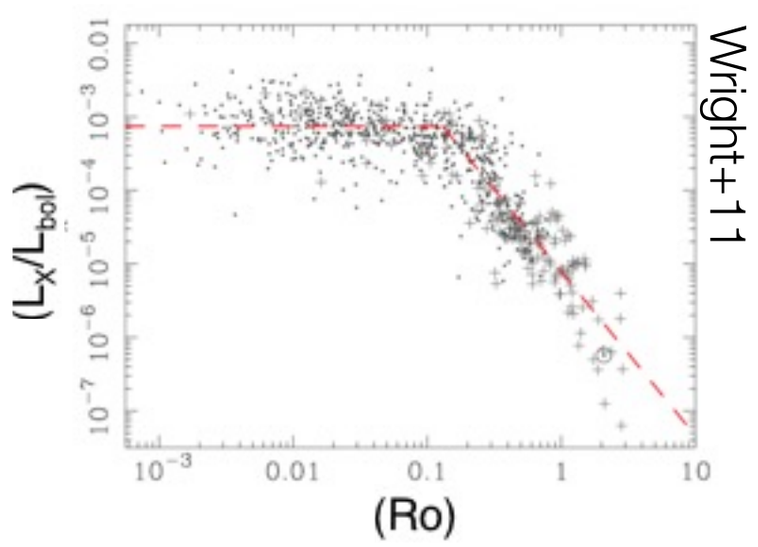
Saturation at $\log(L_x/L_{bol})\approx -3.1 \rightarrow \langle|B_V|\rangle \gtrsim 80$ G

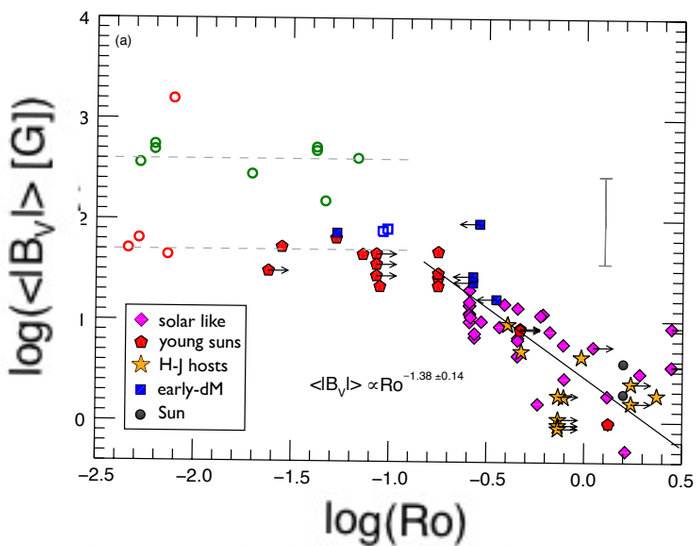
Unified interpretation: trying to make sense of all these empirical relations

Vidotto+14b









The activity relation is a complex function of many variables: age, mass, rotation, magnetism...

Part 2: Can planets influence the activity of their host stars?

τ Boo: the cyclic planet-hosting star

star

- sp. type: F7V
- 1.34 $M_\odot$, 1.46 $R_\odot$
- v sini = 15.0±0.5 km/s
  (Valenti &Fischer 2005)
- P_{rot} ~ 3.3 days
- dΩ = 0.46 rad/day

14 epochs of observations (ZDI maps): Catala+06, Donati+07, Fares+09,13, Mengel+16

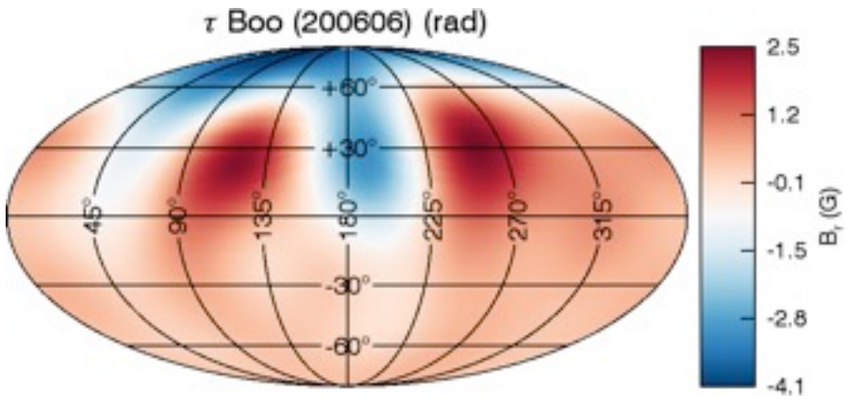
planet

- Mass ~ 6 M_{Jup}
- P_{orb} = 3.31 days
- orbital radius:
  0.0462 au = 6.8 R_*

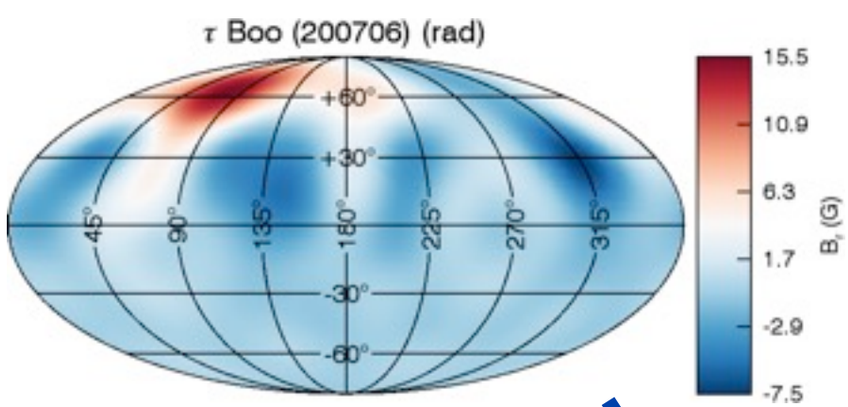
'only' star with confirmed full magnetic cycle

τ Boo: the cyclic planet-hosting star

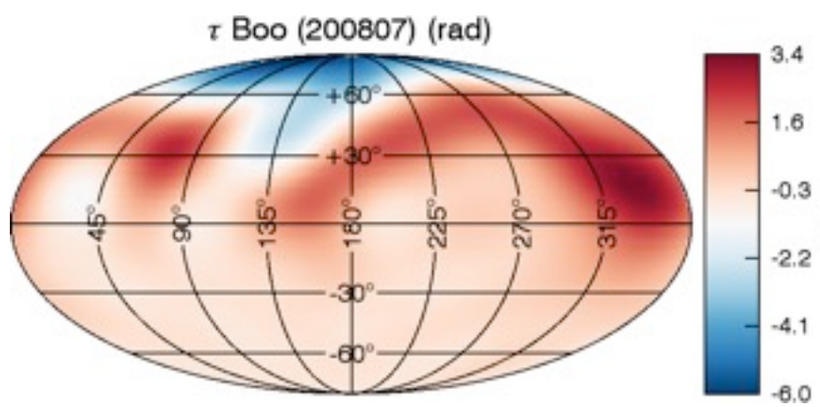
June/06
(Catala+07)



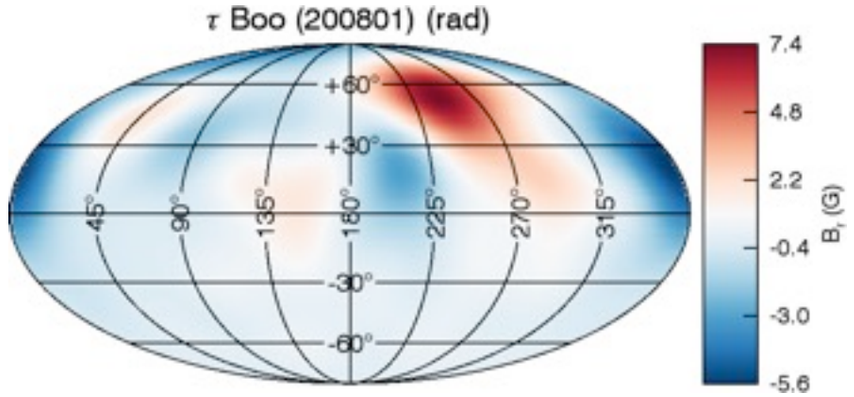
June/07
(Donati+08)



July/08
(Fares+09)

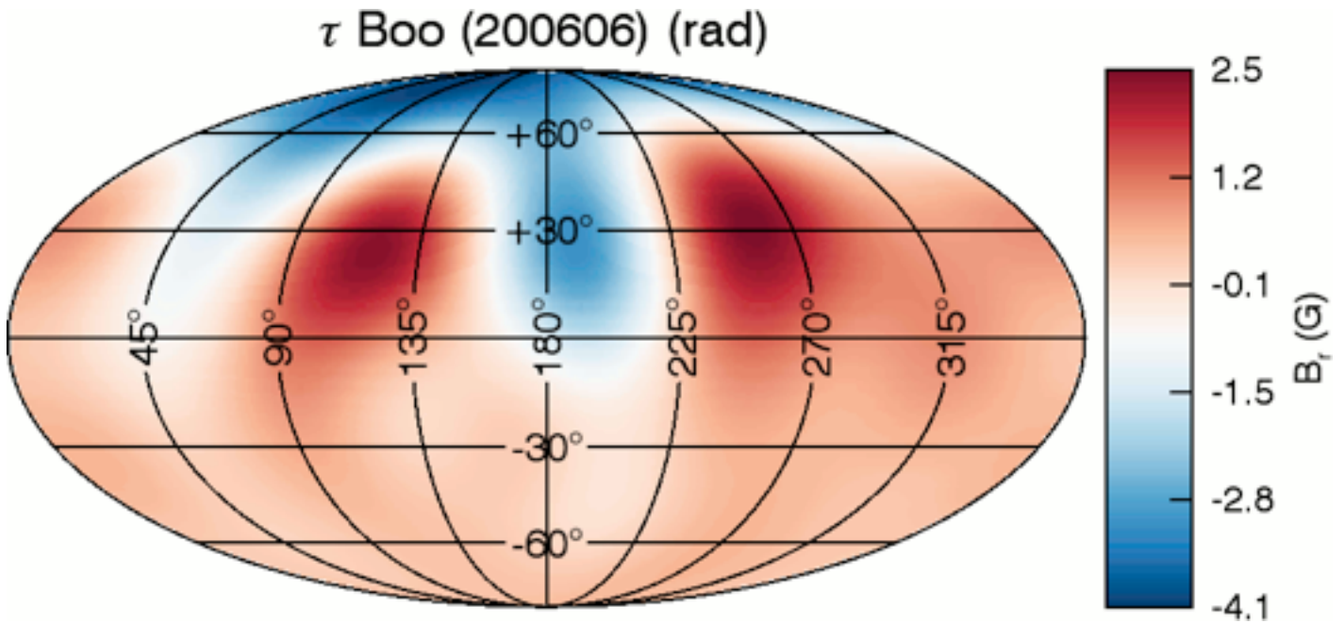


January/08
(Fares+09)



P_{cycle} = 2 years
(Fares+09)

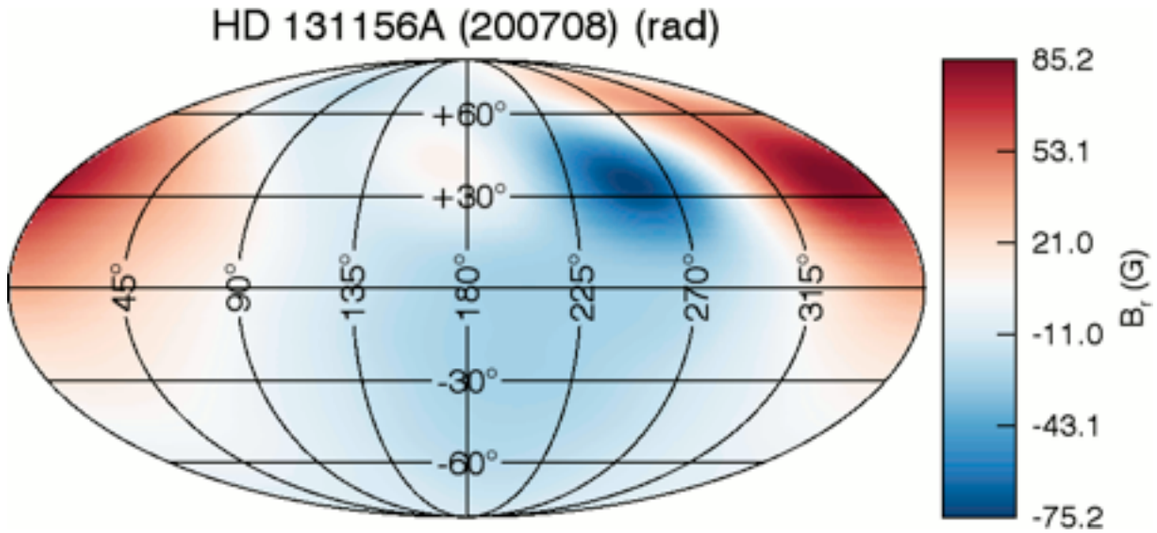
τ Boo: the cyclic planet-hosting star



Radial

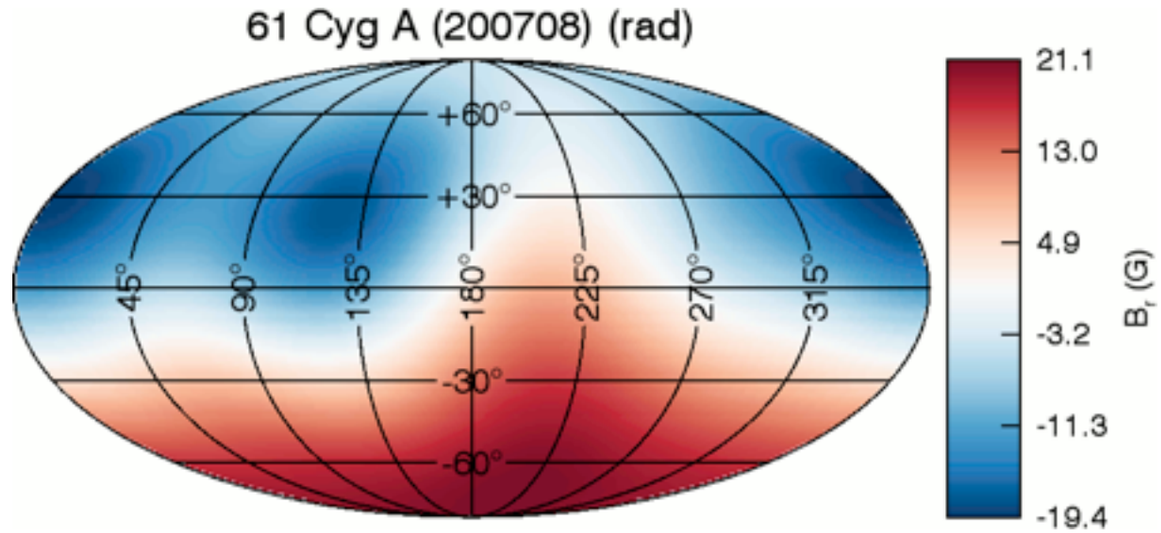
- Why such a short cycle?
  - high dΩ=0.46 rad/day?
  - sync the shallow convective envelope (tides) due to a close-in planet?

Other (quasi) magnetic cyclic stars



- sp. type: G8V
- 0.93 $M_\odot$, 0.84 $R_\odot$
- P_{rot} ~ 5.56 days

Morgenthaler +12
7 epochs of observations
(Aug07 - Jan11)

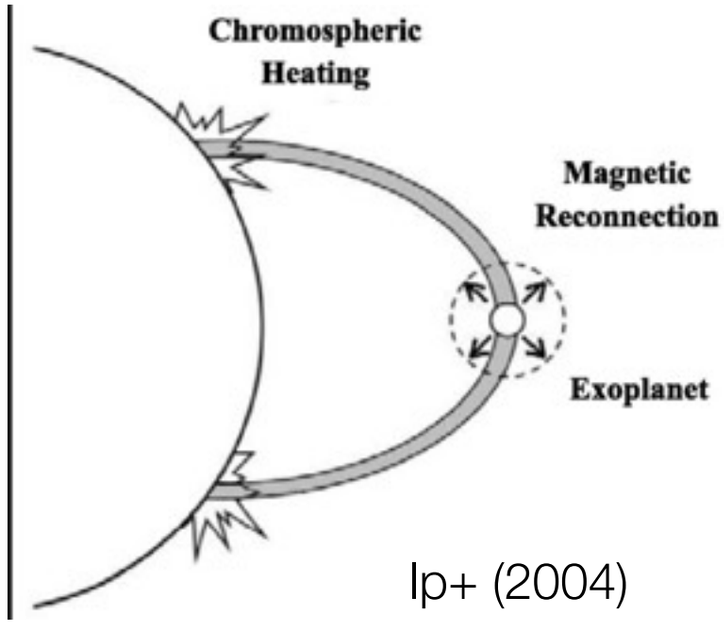


- sp. type: K5V
- 0.66 $M_\odot$, 0.665 $R_\odot$
- P_{rot} ~ 35.7 days

Boro-Saikia +16
6 epochs of observations
(Aug07 - Aug15)

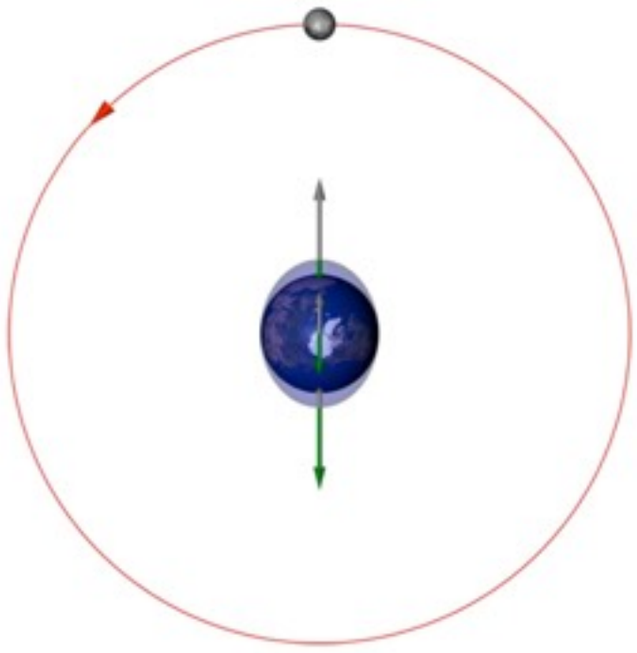
Stellar-planet interactions: Planet-induced (anomalous) stellar activity

- Magnetospheric interactions
  - enhanced heating, stellar activity
  - activity modulated by P_{orb}

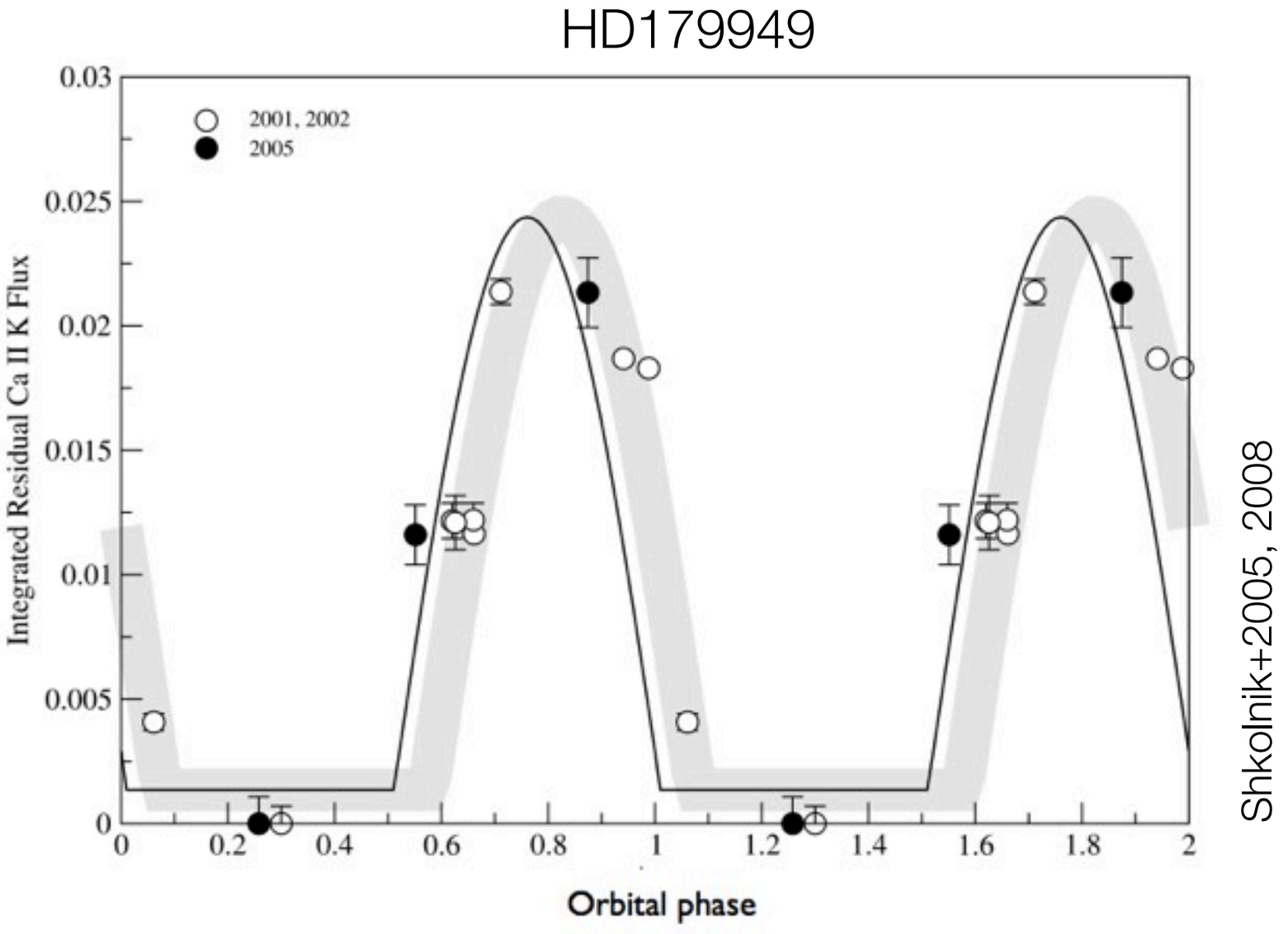


Ip+ (2004)

- Activity enhancement could also be of tidal origin:
  - expansion/contraction bulges → waves → non-radiative energy → enhanced heating, stellar activity
  - activity modulated by $P_{orb}/2$



Stellar-planet interactions: Planet-induced (anomalous) stellar activity



Shkolnik+2005, 2008

- At some epochs:
  - Activity modulated by P_{orb}: anomalous
  - phase lag: activity & subplanetary phase (ϕ=0)

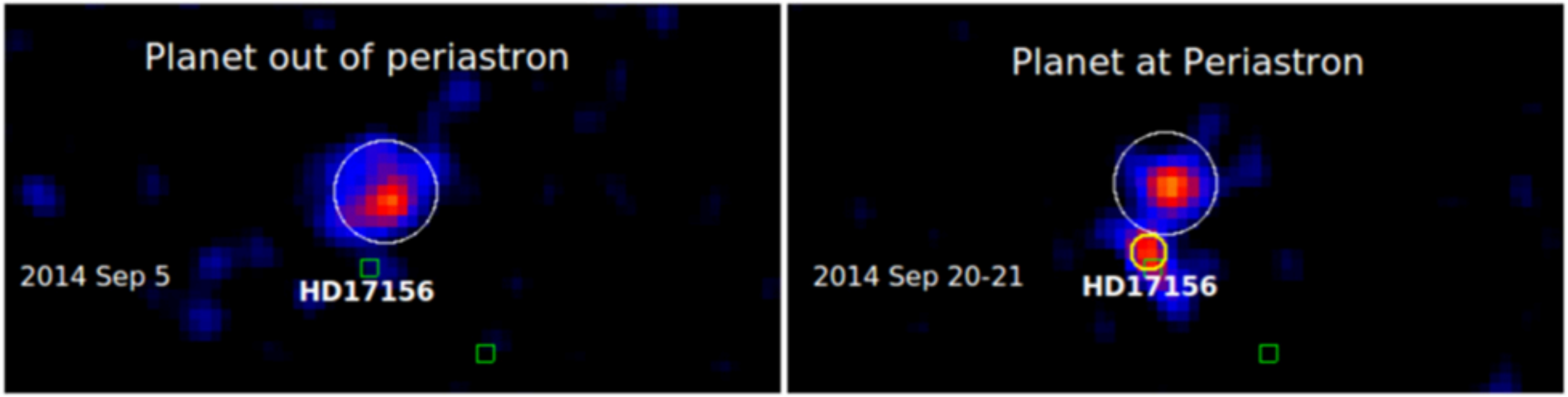
- **However**: at other epochs:
  - activity modulated by stellar P_{rot}: *normal* stellar activity

Excess activity occurred only once per orbit → observations consistent to magnetic interactions

Influence of the planet on the stellar (magnetic) activity

Maggio+16

X-ray images of HD 17156 (eccentric planet e=0.68)



Enhanced stellar emission a few hours after the passage of the planet at the periastron

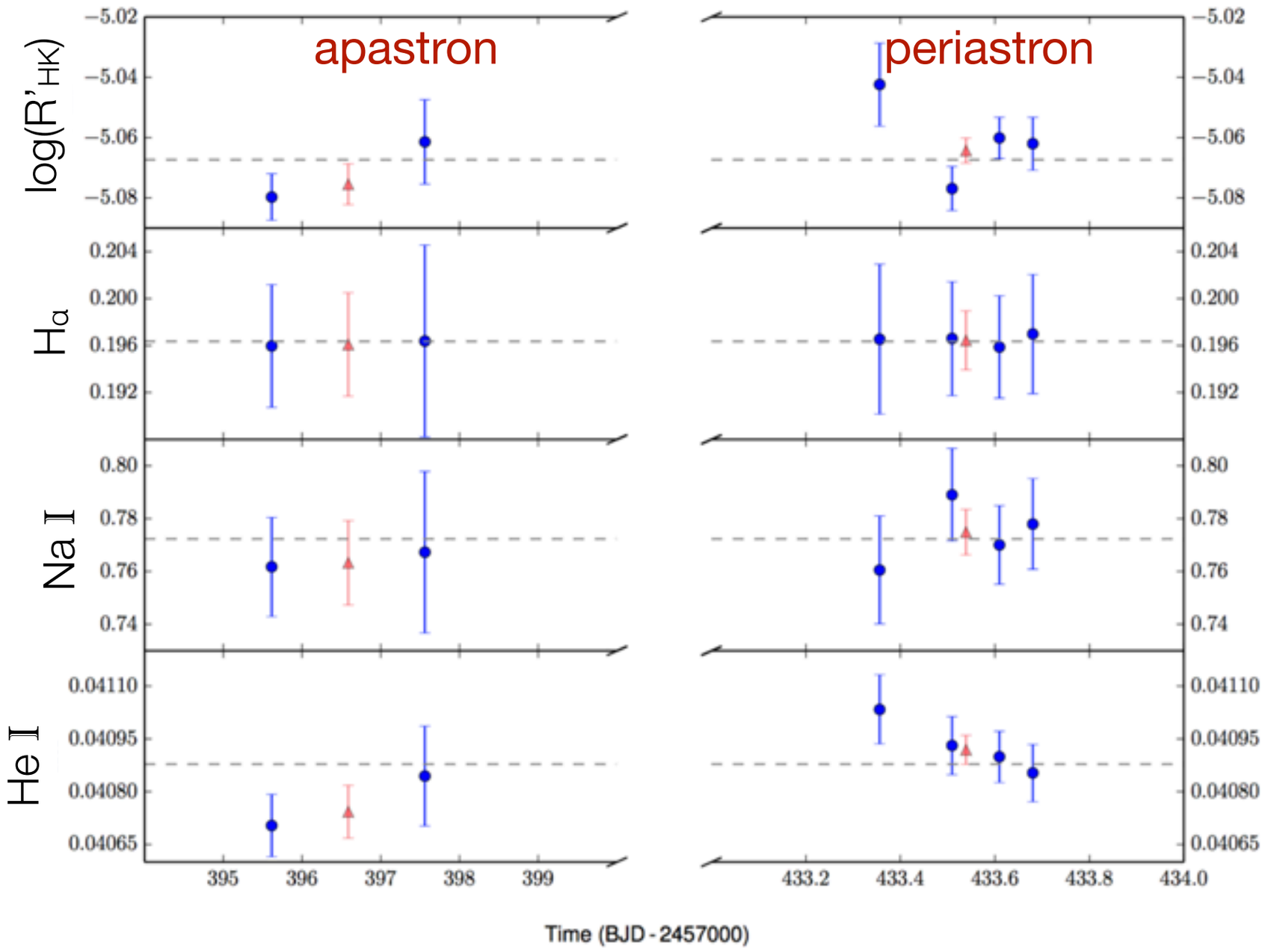
- Magnetic reconnection?
- Accretion of planetary material towards the star?

Star-planet interaction events are occasional (see also Shkolnik+08)

Influence of the planet on the stellar (magnetic) activity

Figueira+16

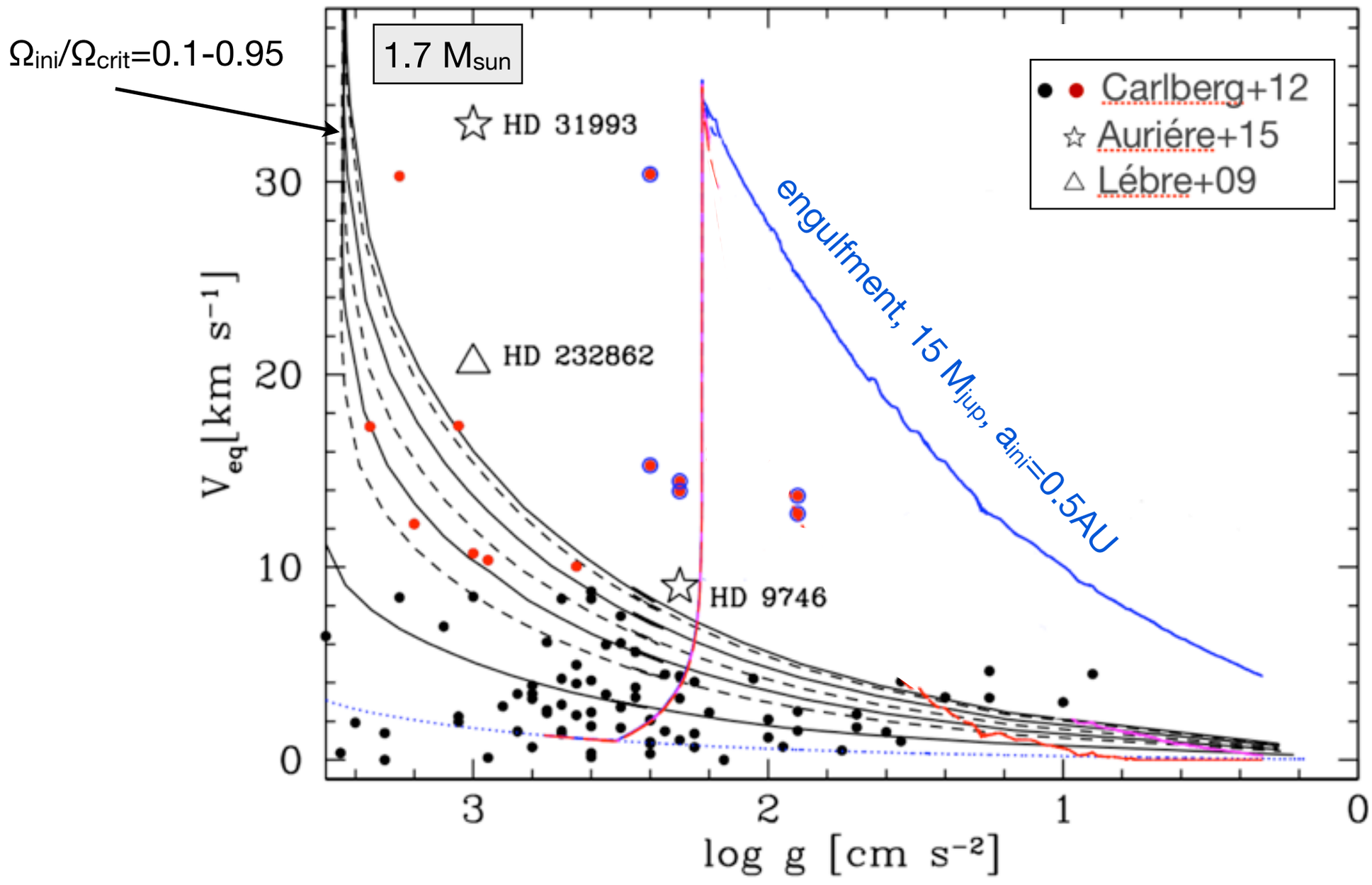
Activity proxies of HD 80606 (eccentric planet e=0.93)



No evidence of planet triggering SPI

Could planet engulfment trigger stellar magnetic fields at the red giant branch phase?

Privitera+16c, subm.



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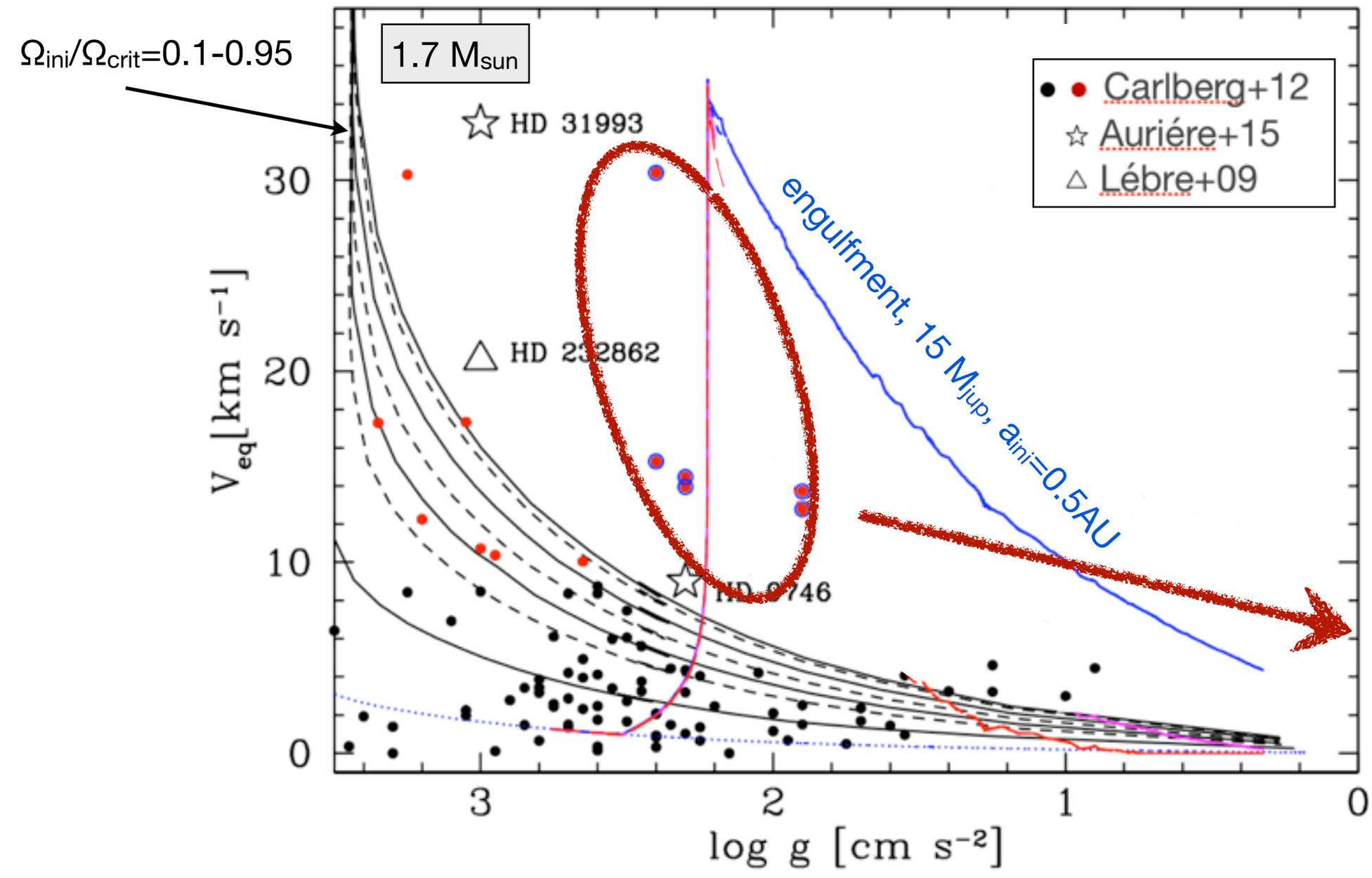


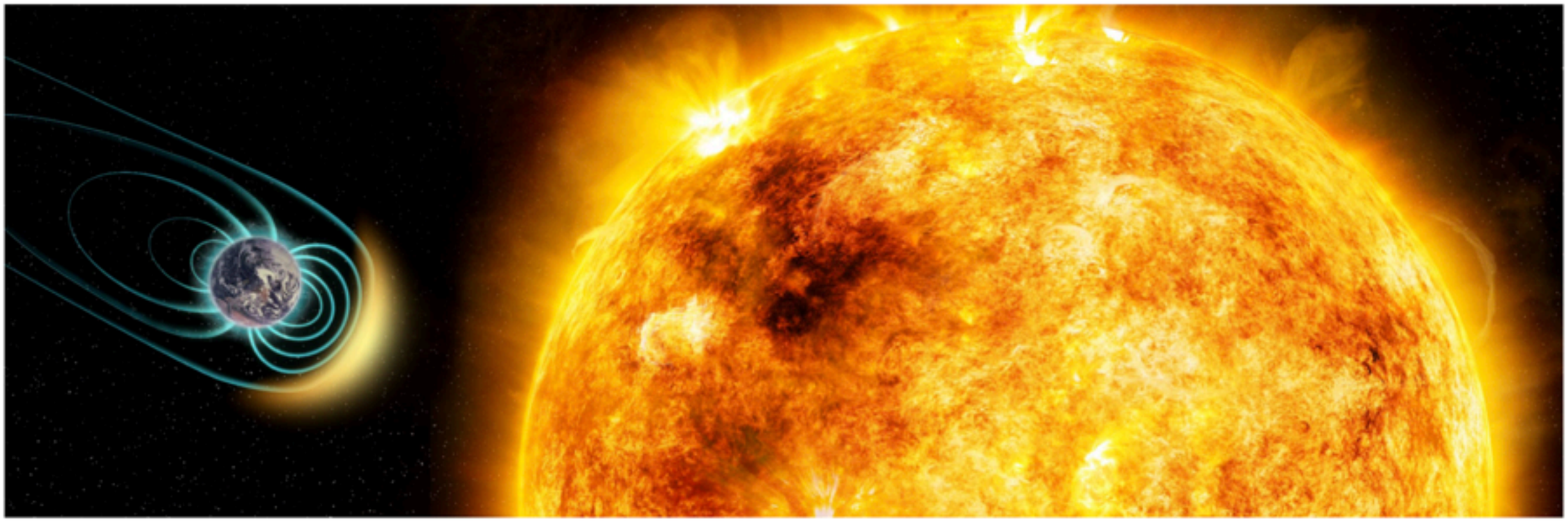
cannot be explained by any reasonable model for single star evolution (Privitera+16a,b)

Empirically: $|B| \propto Ro^{-0.68}$ (Aurière+15)

Summary

Global properties of stellar magnetic fields are becoming more evident as more data are become available; internal structure playing an important role there

Planets might (or not) enhance stellar magnetic activity.
Is there a way that asteroseismology could settle this debate?



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International Astronomical Union Symposium 328:

Living around active stars

October 17 - 21, 2016

Maresias, SP, Brazil

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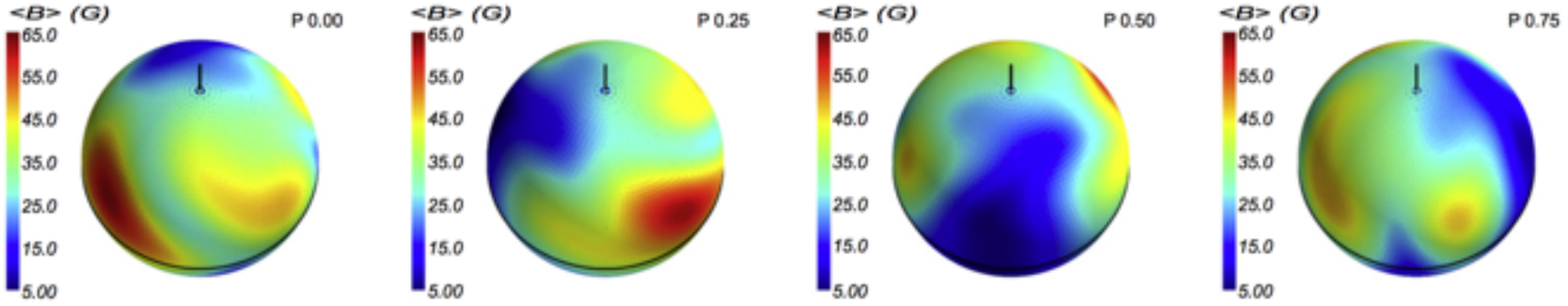
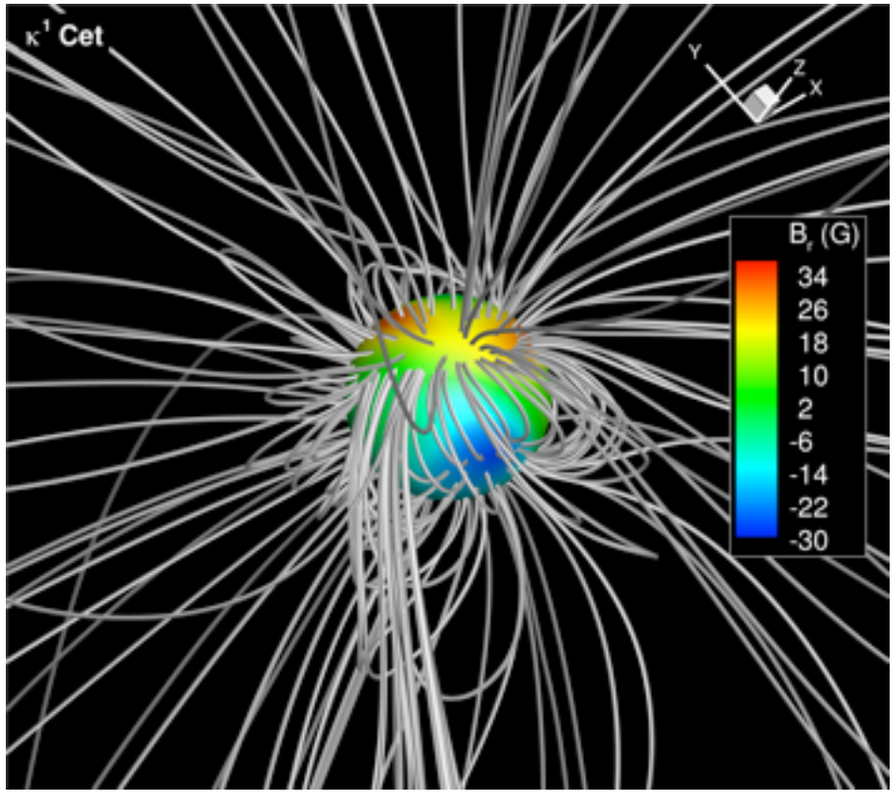
- Divisions E (Sun and Heliosphere)
- Division F (Planetary systems & Bioastronomy)
- Division G (Stars & Stellar Physics)

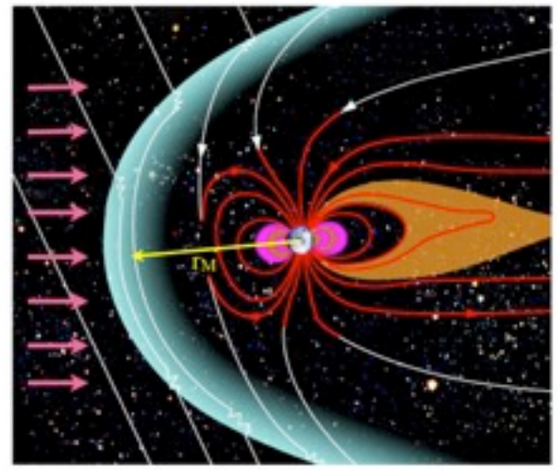
κ^1 Cet: a proxy of the young Sun when life arose on Earth

do Nascimento +16

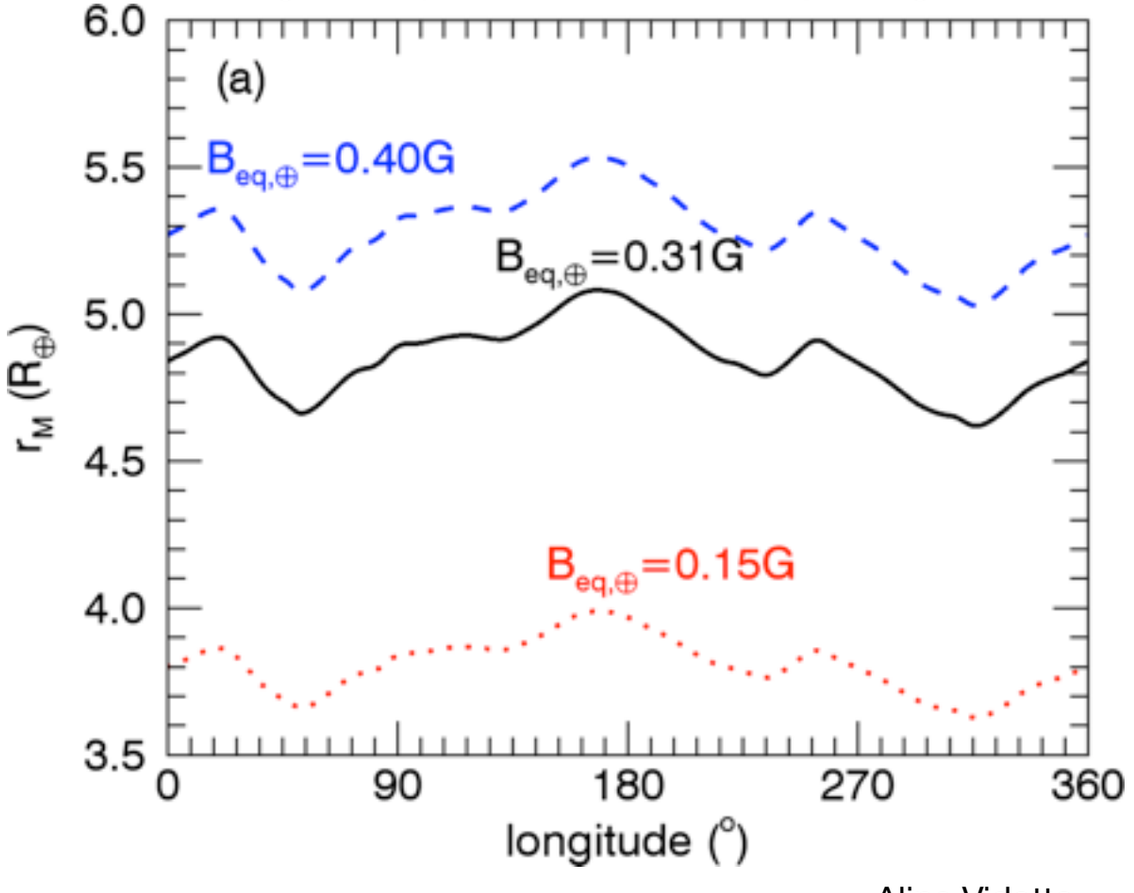


3D stellar wind simulations



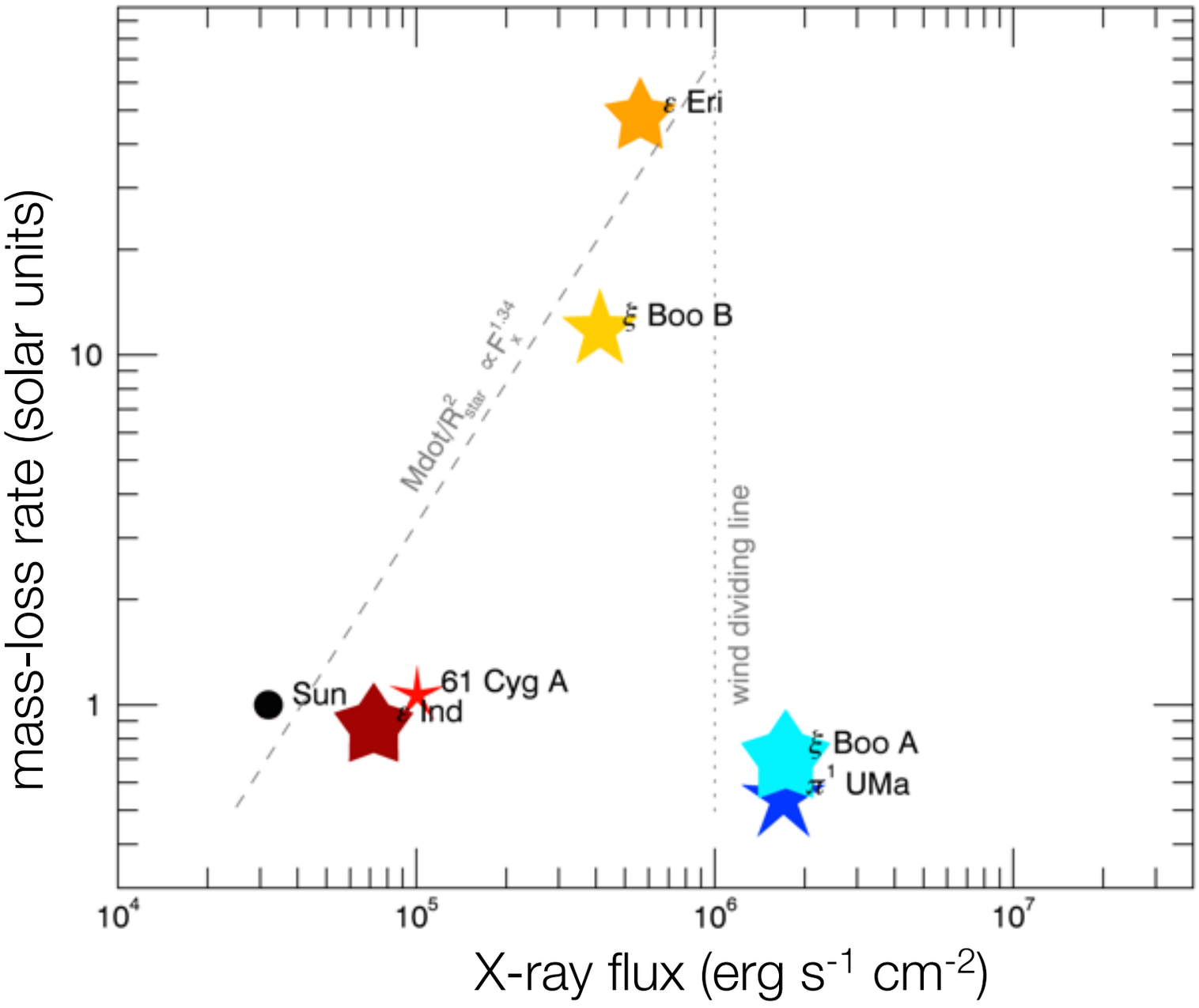


magnetospheric size of the young Earth

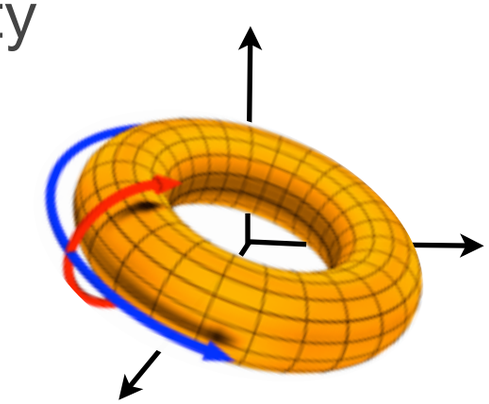


Is the wind-activity break related to magnetic field topology?

Vidotto+16a



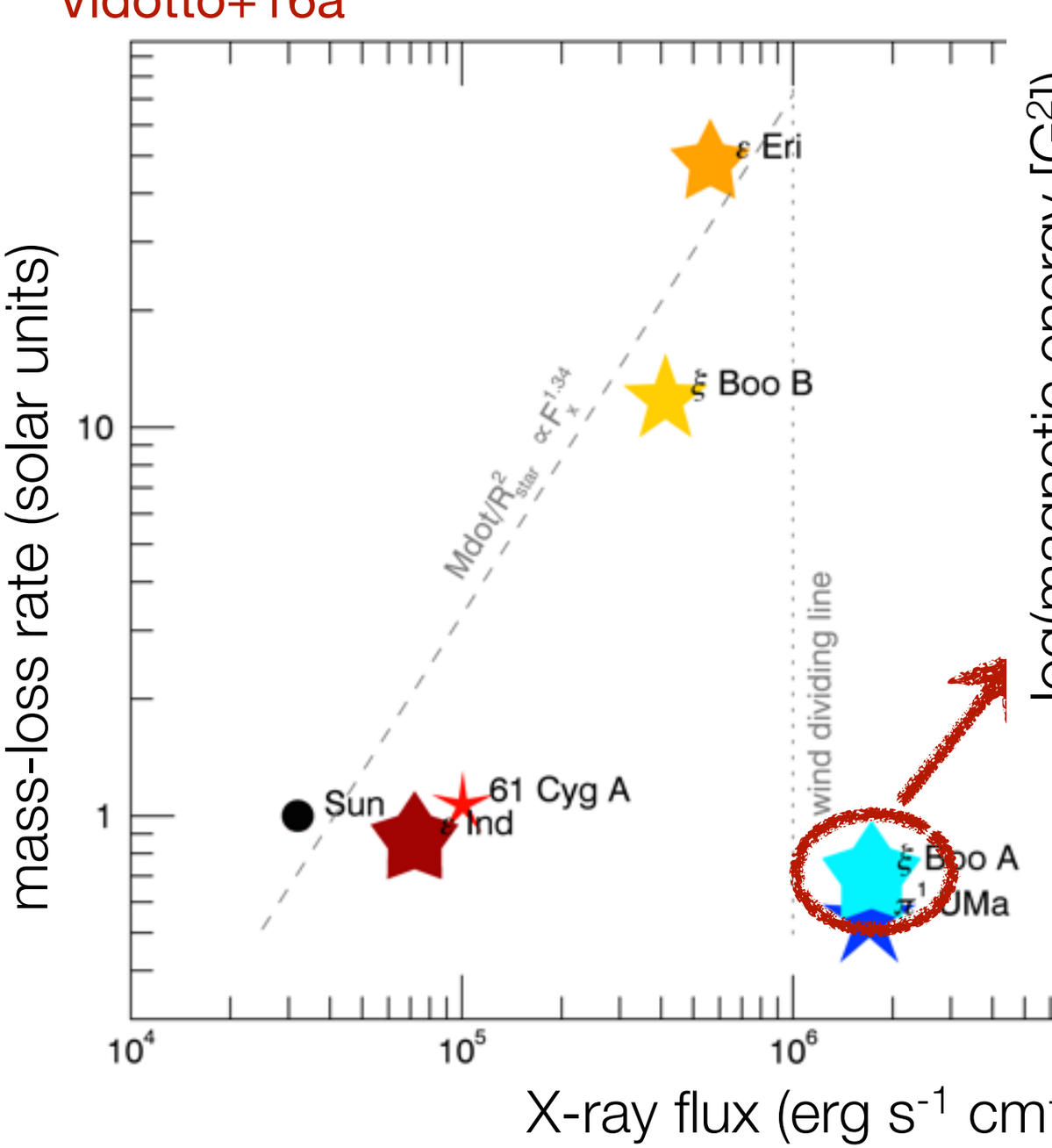
- Size: intensity
- Colour:
  - poloidal
  - toroidal

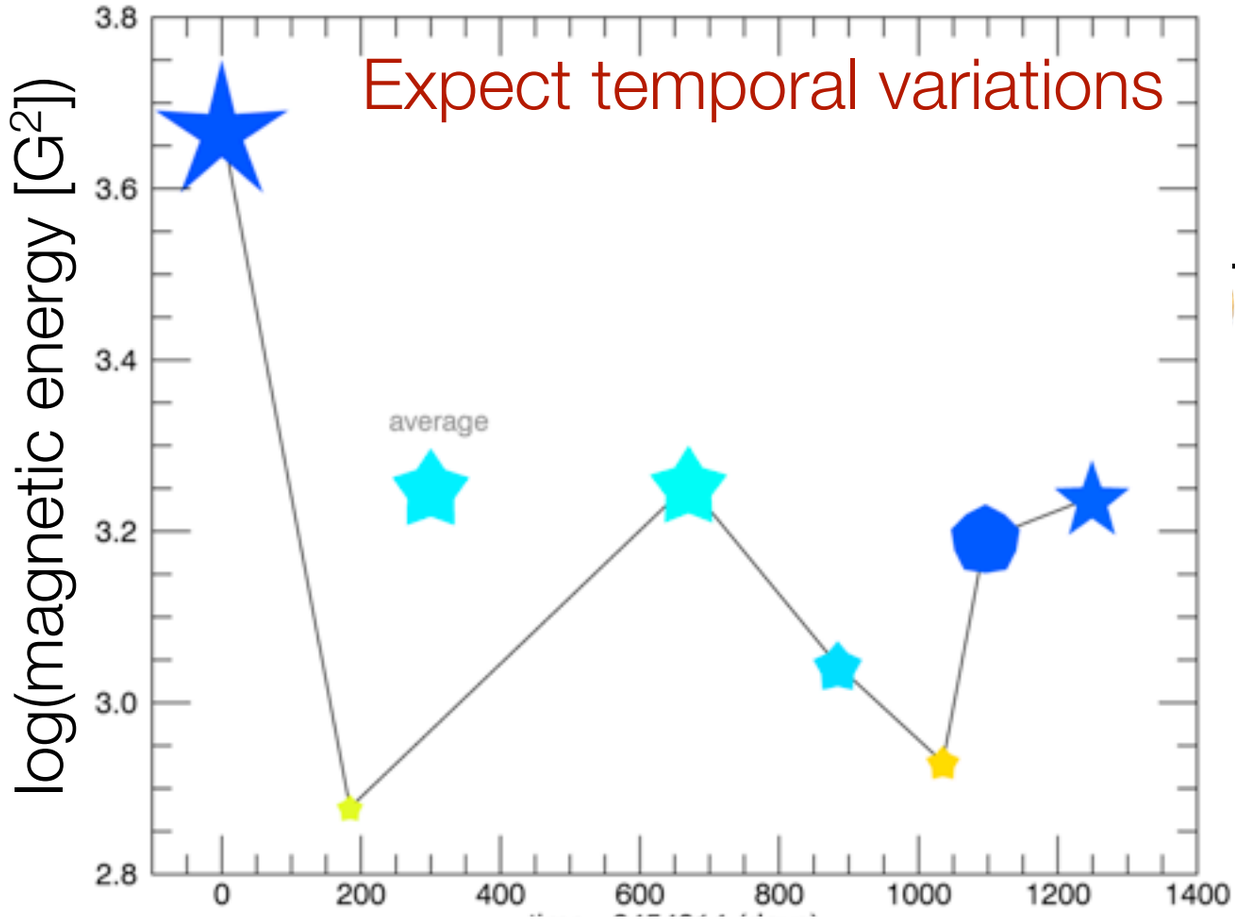


- Shape:
  - ● axisymmetric
  - ★ non-axisym.

Is the wind-activity break related to magnetic field topology?

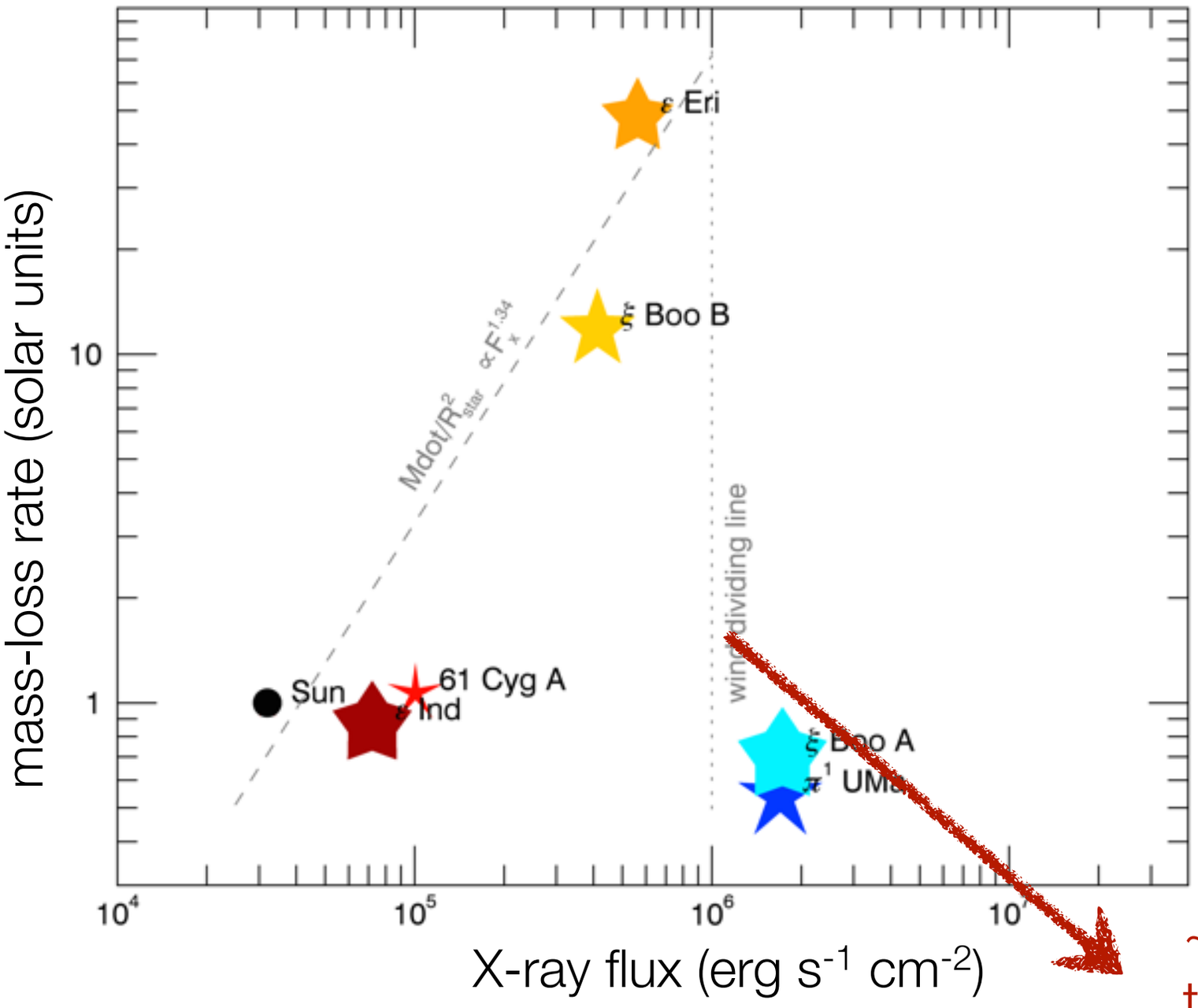
Vidotto+16a



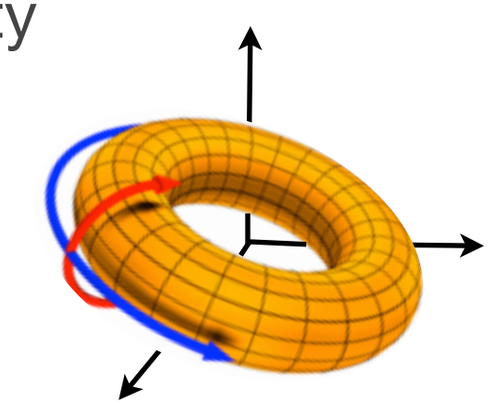


Is the wind-activity break related to magnetic field topology?

Vidotto+16a



- Size: intensity
- Colour:
  - poloidal
  - toroidal



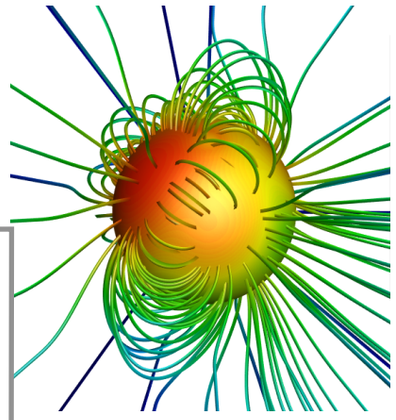
- Shape:
  - ● axisymmetric
  - ★ non-axisym.

~600 Myr: no sudden transition in topology

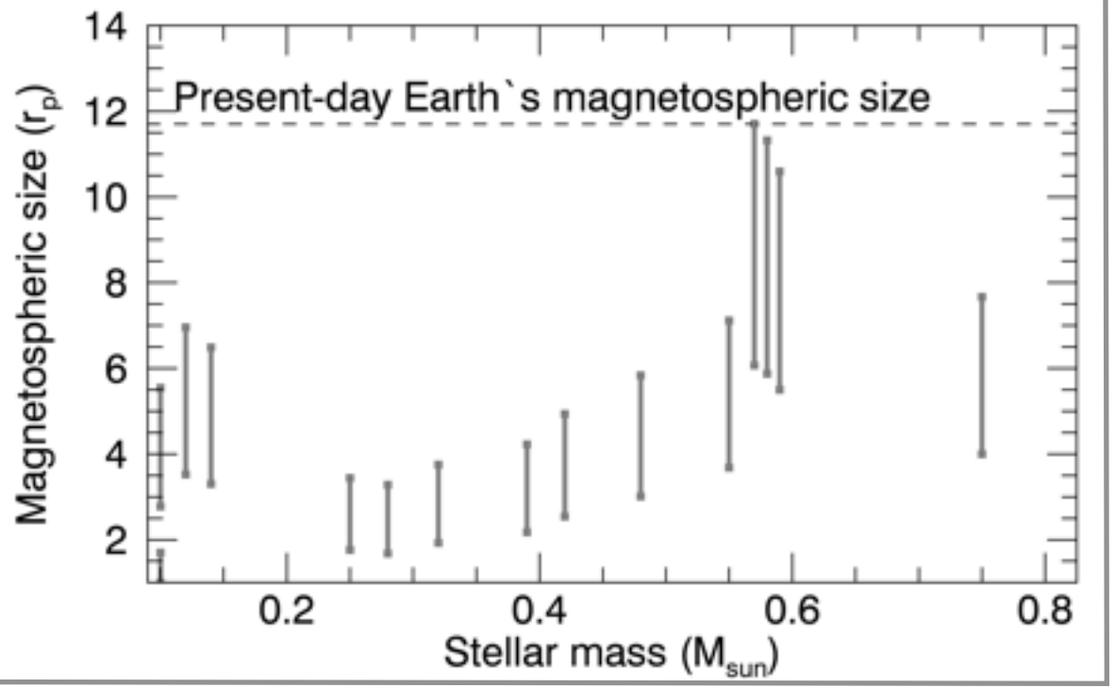
Small planetary magnetic fields can expose planet's atmosphere to erosion: habitability

Earth-analog at Habitable zones of M dwarfs:

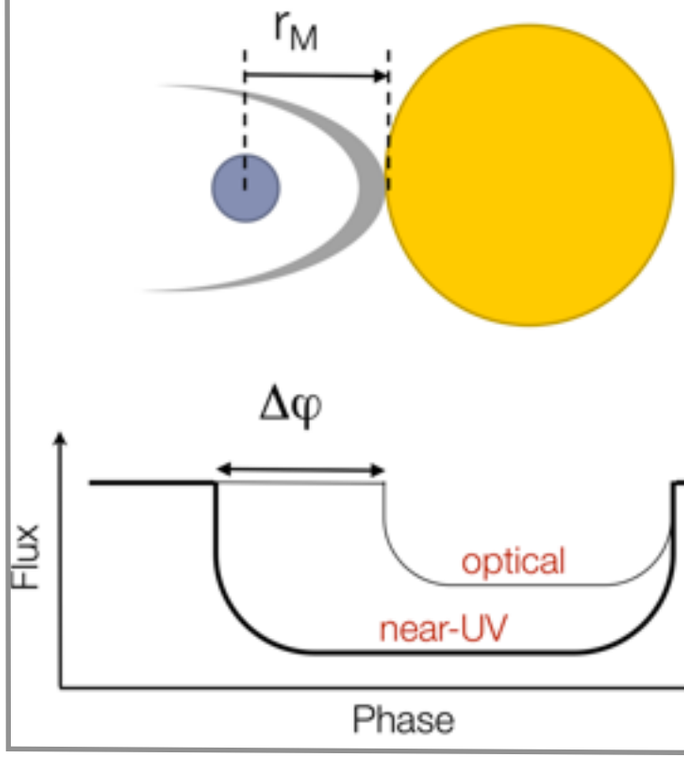
Intense stellar magnetism can reduce the extent of planetary magnetospheres



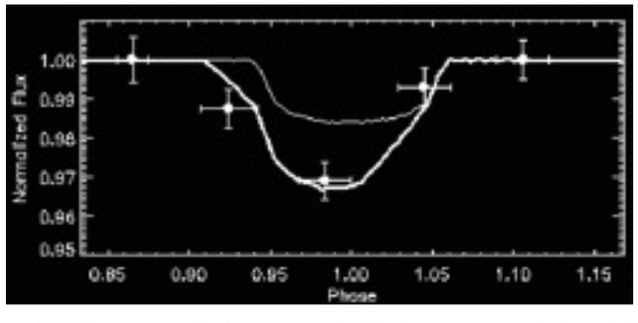
Vidotto+13



model: Vidotto+10a,b,11a,b,c



- Observations of bow shocks surrounding exoplanets: estimate B_{planet}.
- For WASP-12b: B_{planet}<24G



Monte Carlo simulations (Llama,Vidotto+11,13)