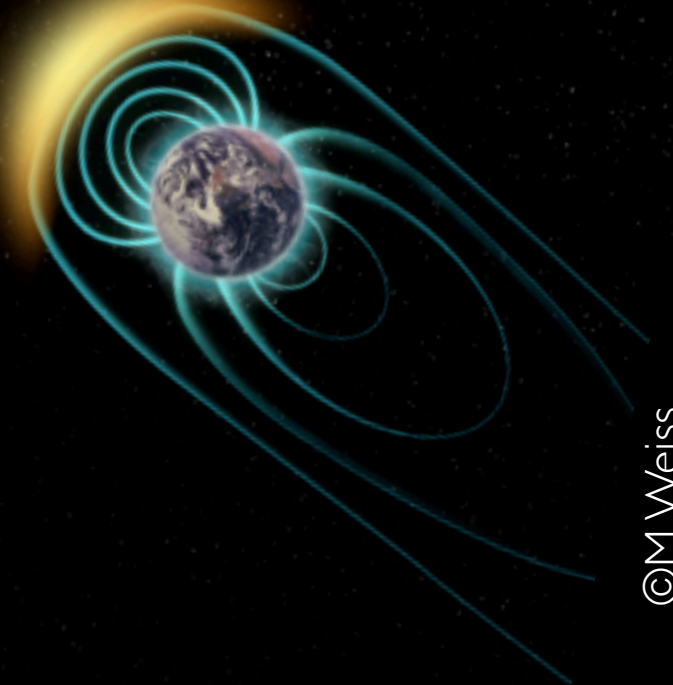


Stellar magnetic activity and their effects on planets

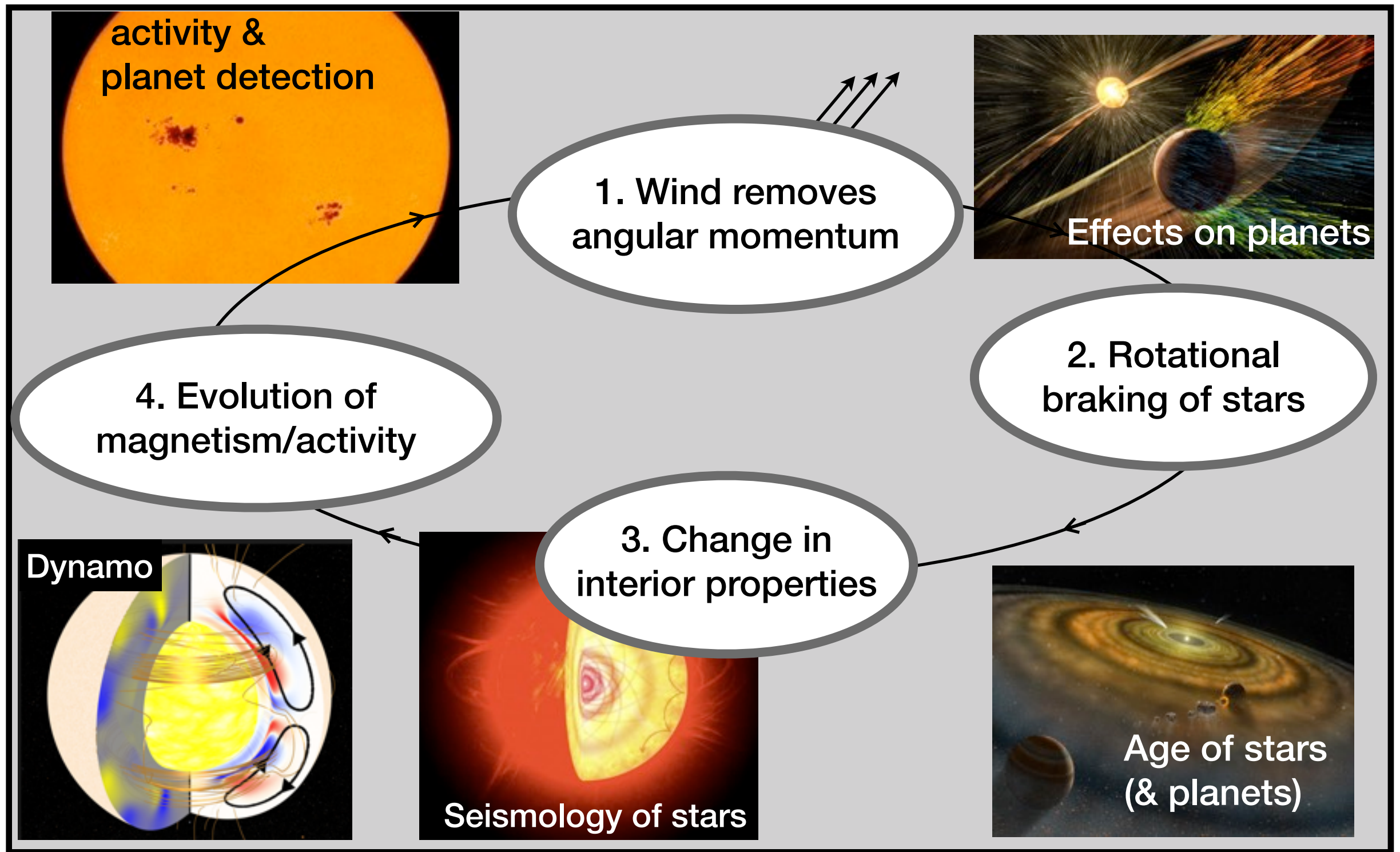
Aline Vidotto

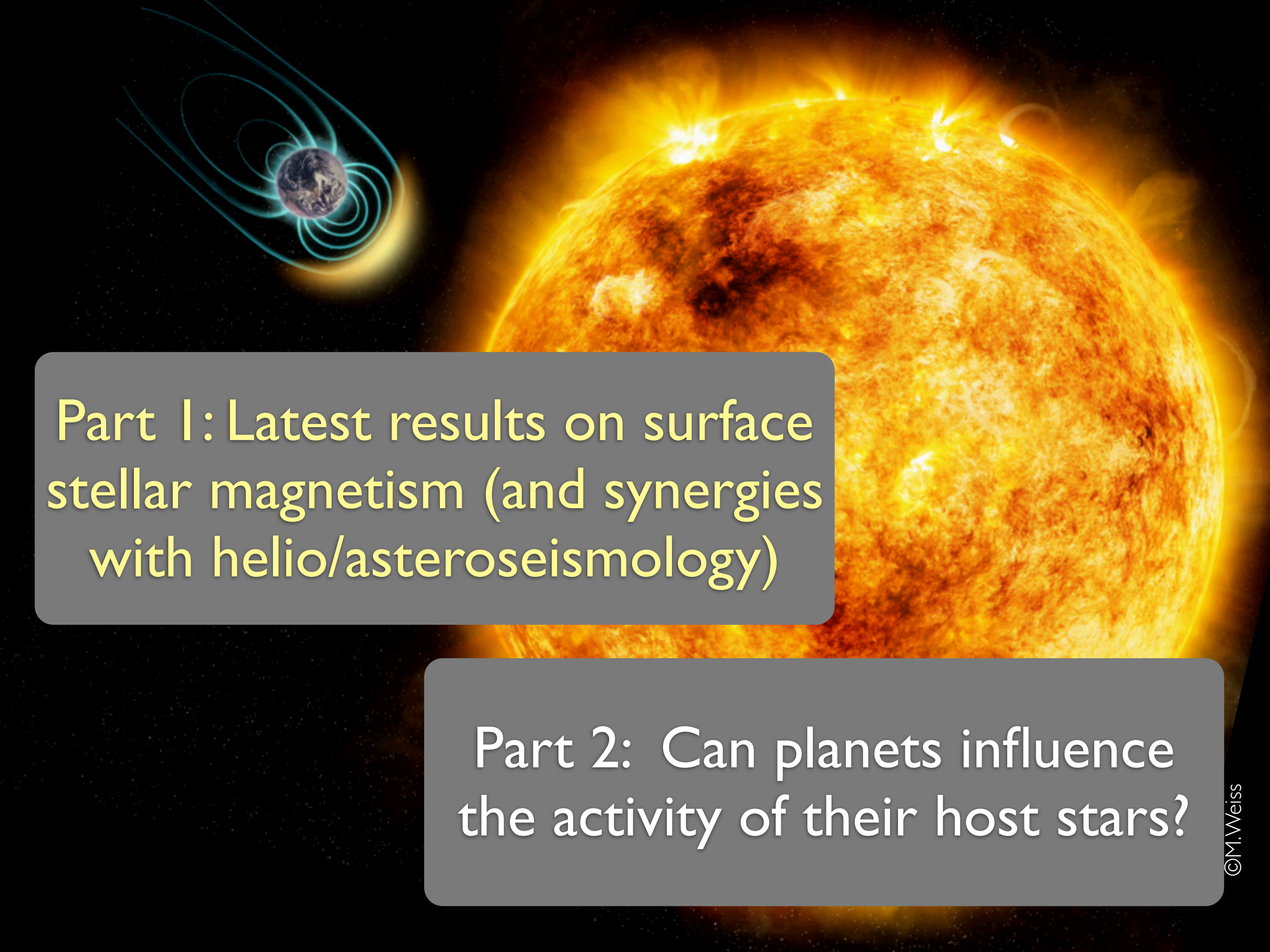
Planets and their effects on stellar magnetic activity

Aline Vidotto



The BIG picture: evolution of cool dwarf stars



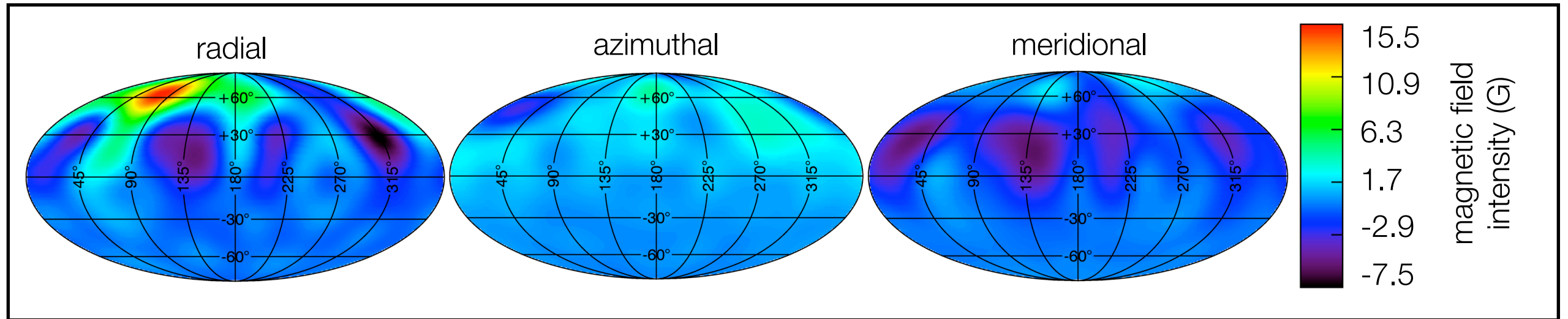


Part 1: Latest results on surface
stellar magnetism (and synergies
with helio/asteroseismology)

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

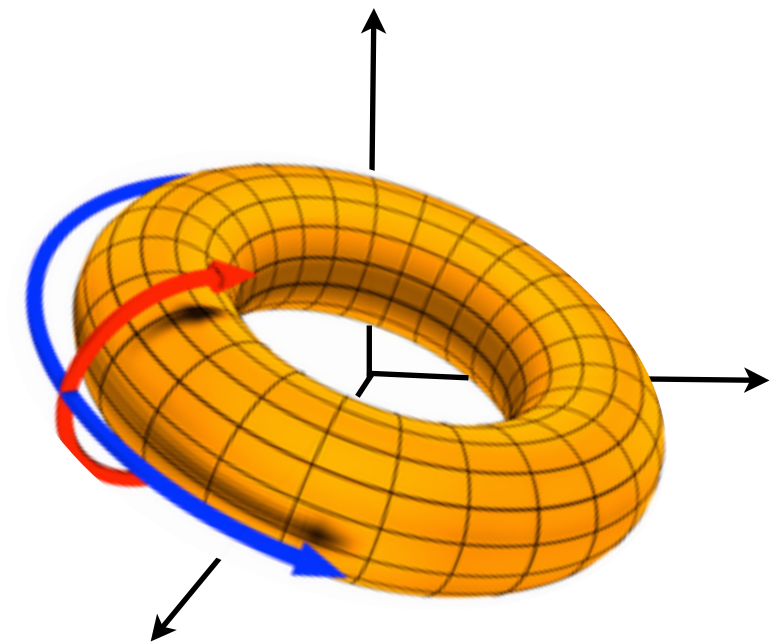
How do we image stellar magnetic fields?

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



Poloidal
fields

Toroidal
fields

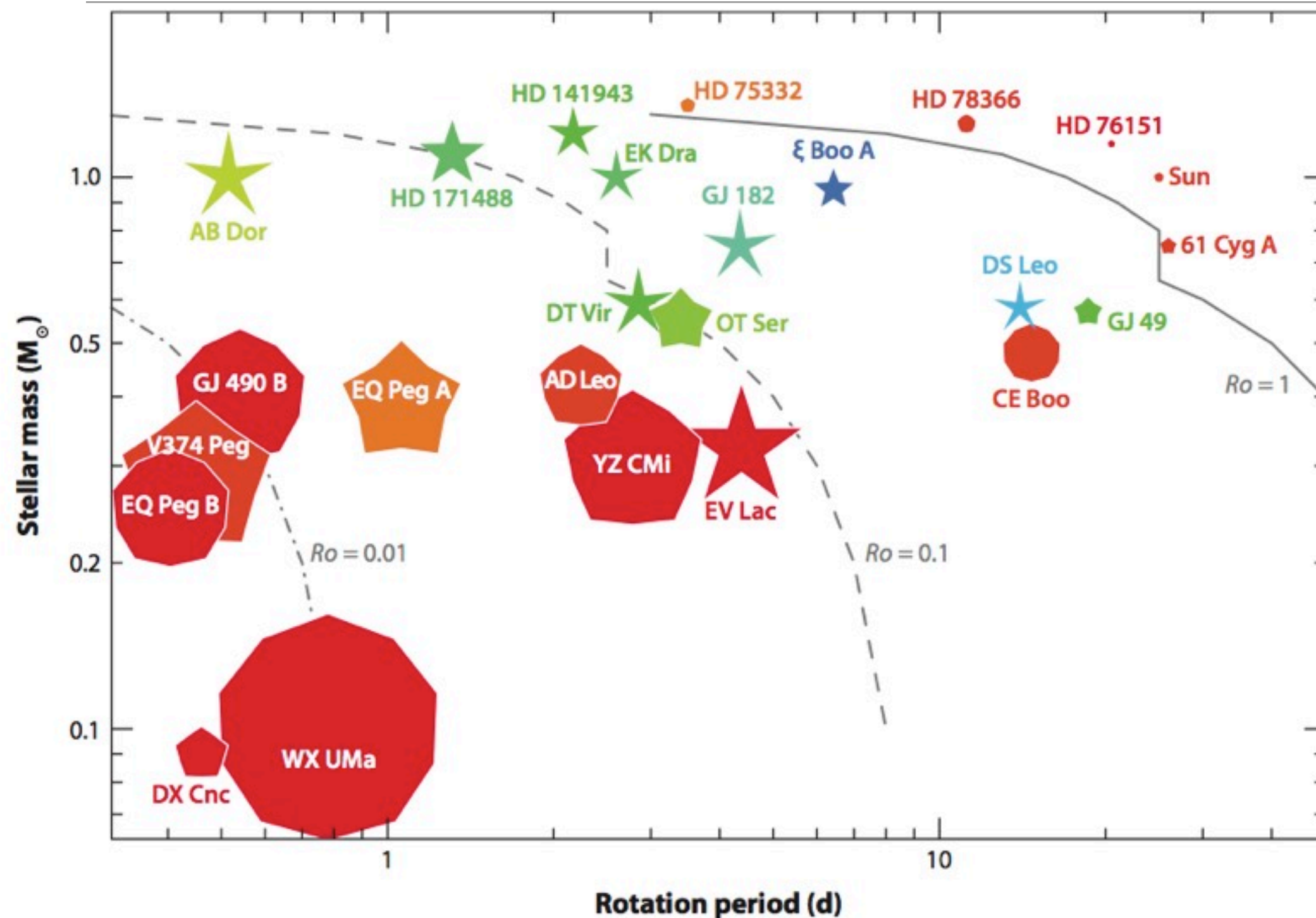


see also: Donati+06, Morin+08, Petit+08, Fares+09,
Marsden+11, Mengel+15, Rosén+16, Folsom+16, etc

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

Surface magnetic topology depends on the internal structure

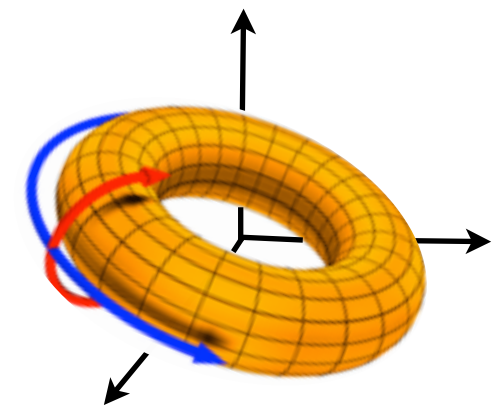
Donati & Landstreet (09)



- Size: intensity

- Colour:

poloidal
toroidal

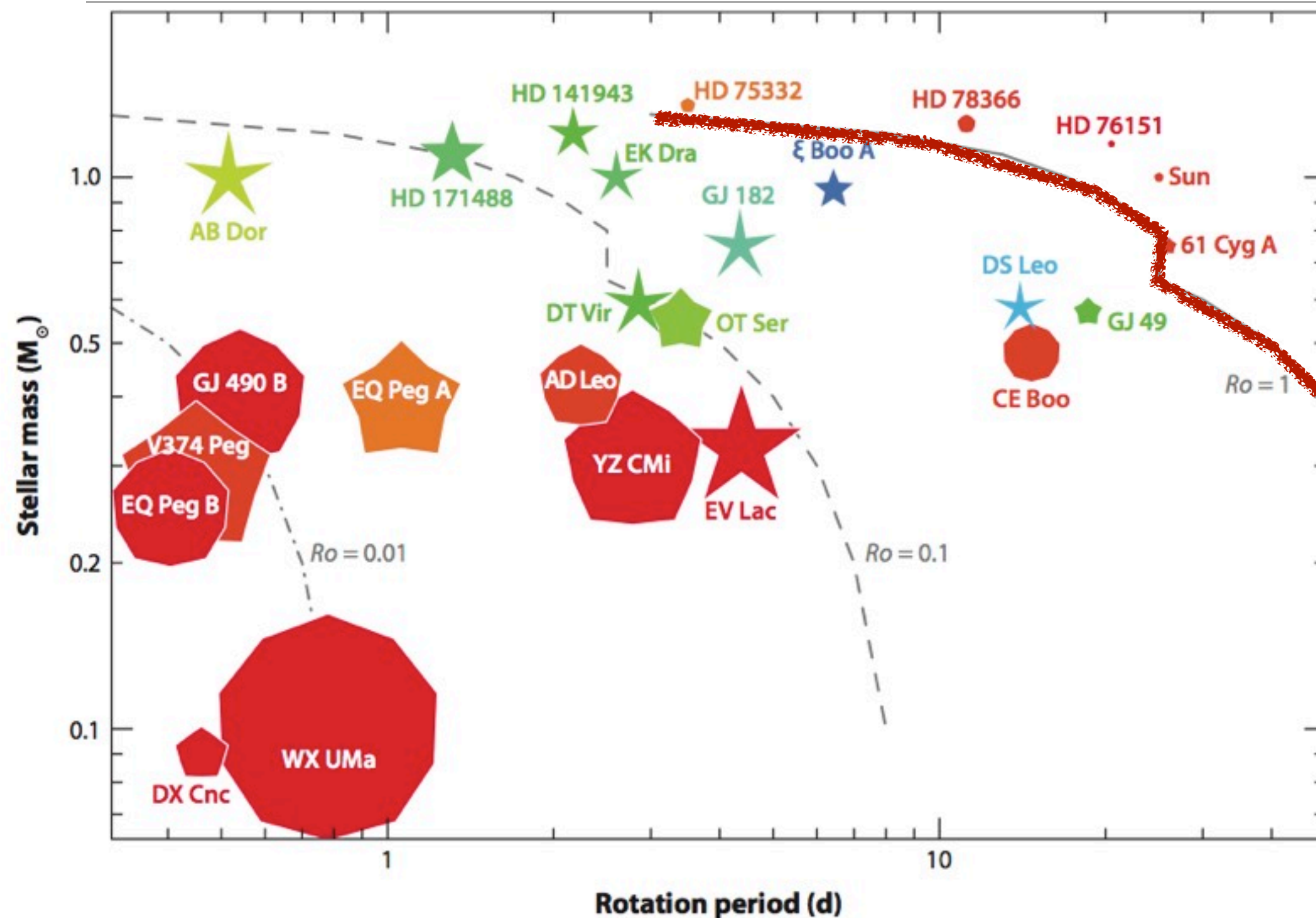


- Shape:

- axisymmetric
- non-axisym.

Surface magnetic topology depends on the internal structure

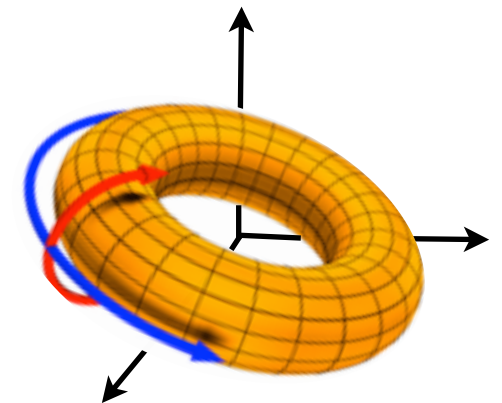
Donati & Landstreet (09)



- Size: intensity

- Colour:

poloidal
toroidal

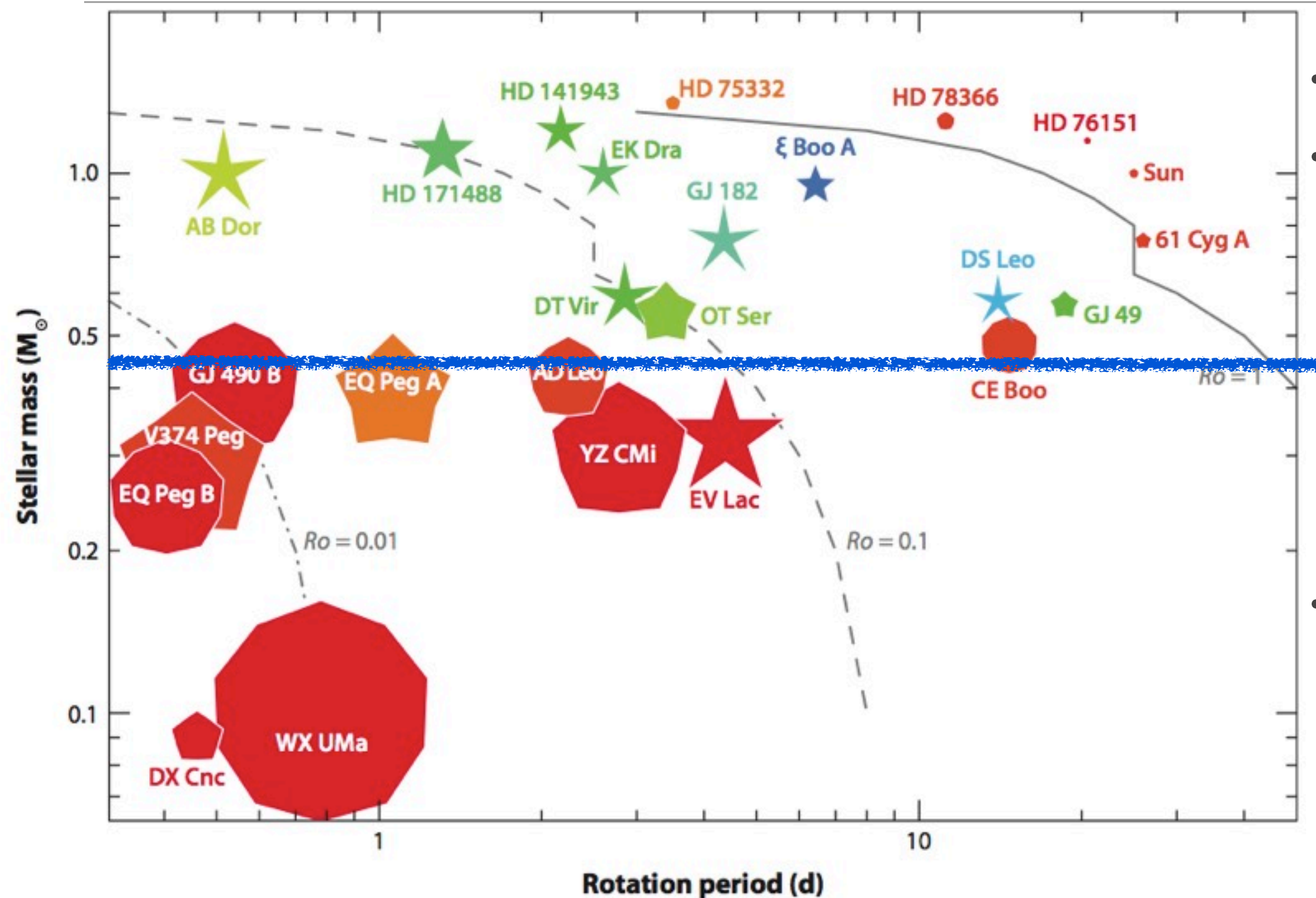


- Shape:

- axisymmetric
- non-axisym.

Surface magnetic topology depends on the internal structure

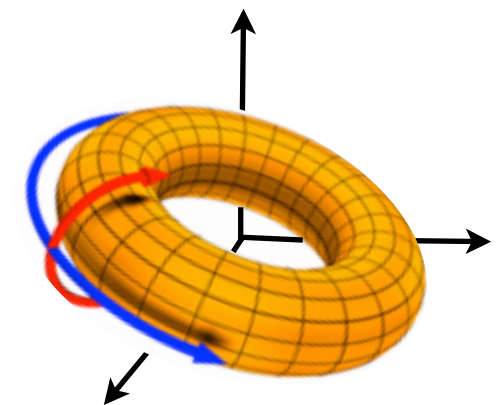
Donati & Landstreet (09)



- Size: intensity

- Colour:

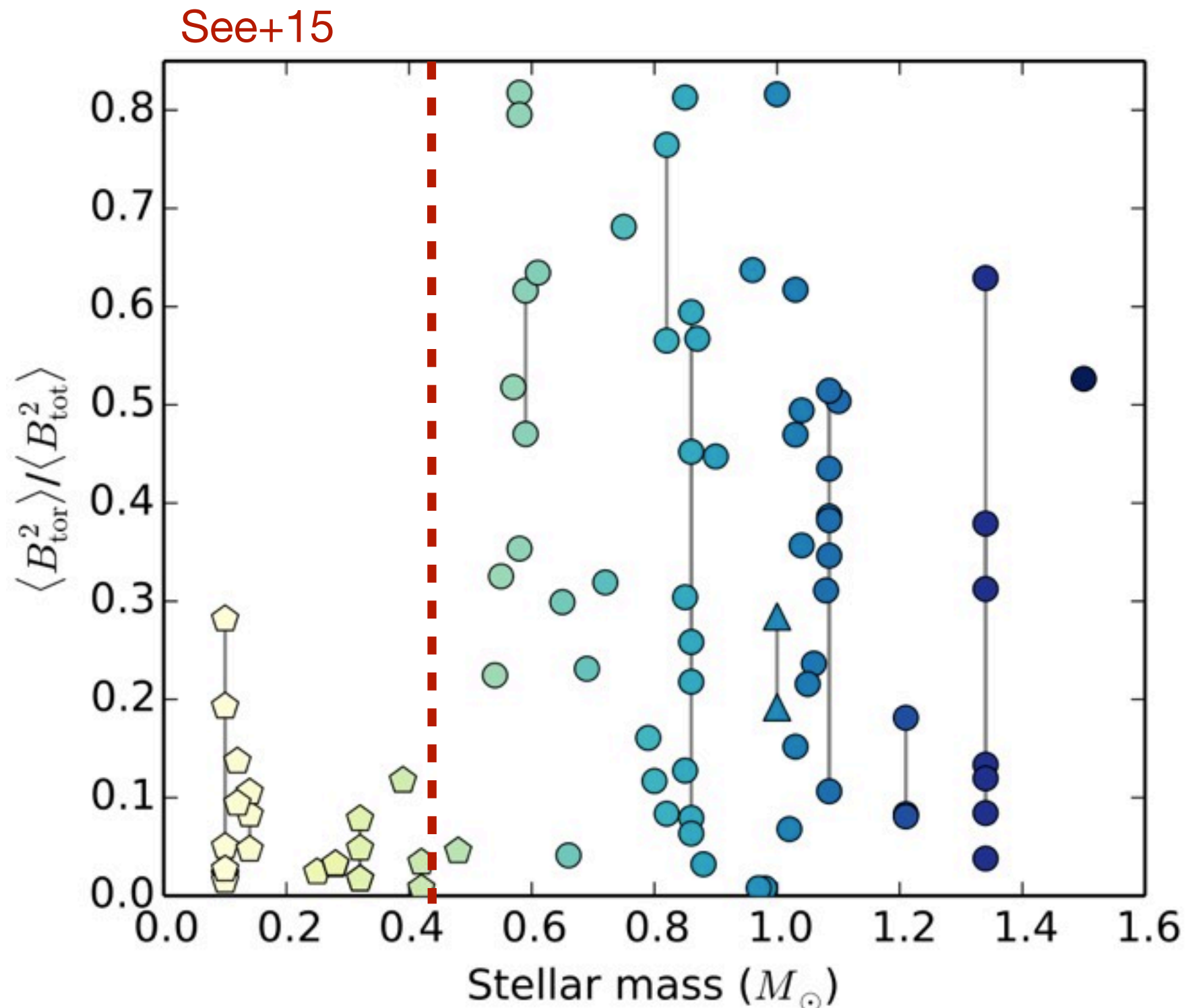
poloidal
toroidal



- Shape:

- axisymmetric
- non-axisym.

Toroidal fields appear when tachocline develops



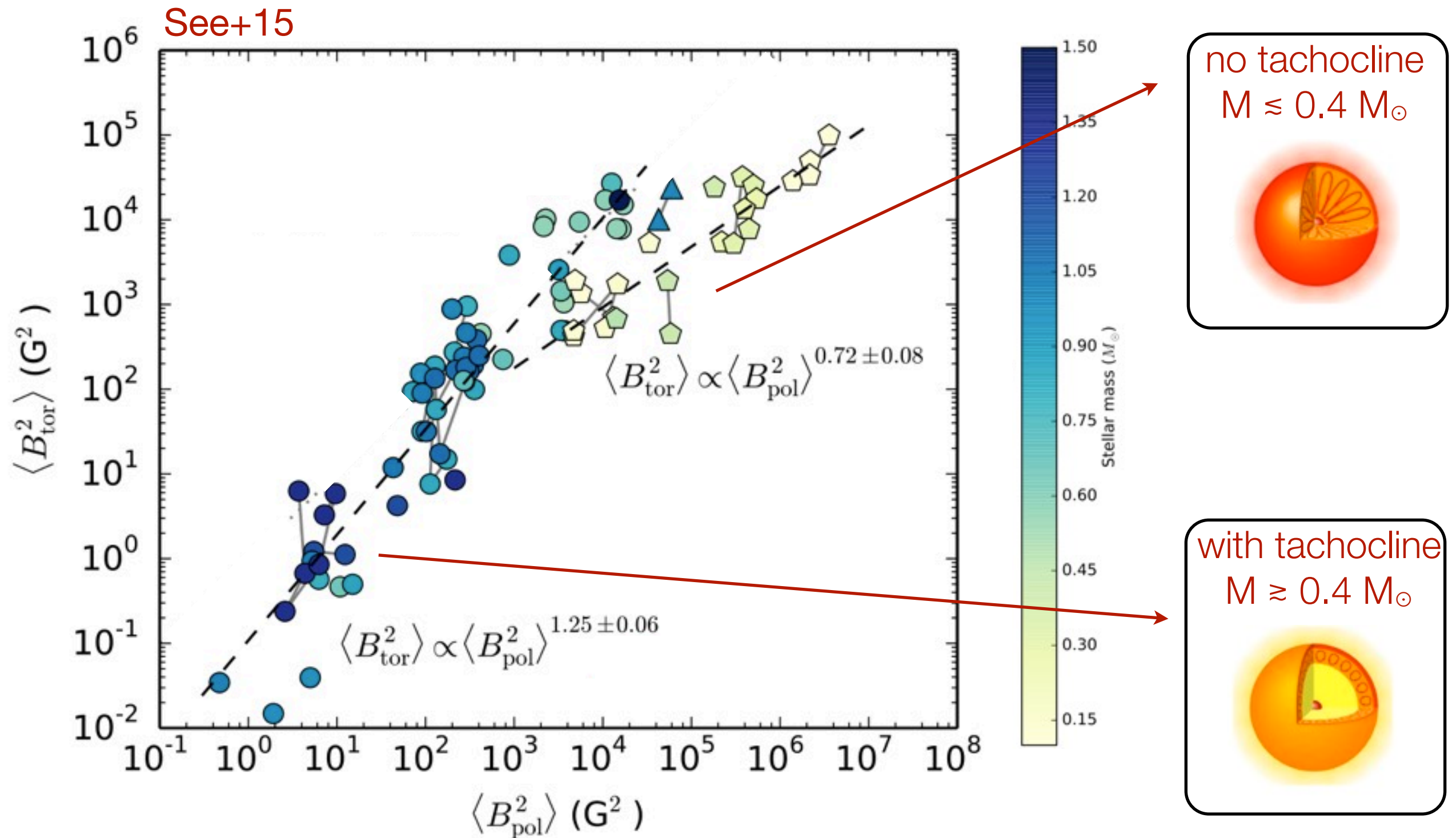
no tachocline
 $M \lesssim 0.4 M_{\odot}$



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



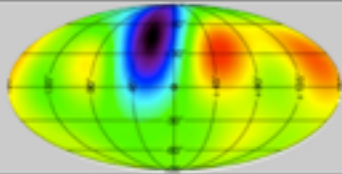
Toroidal & poloidal fields grow together: the **stellar** case



Magnetism evolves in time: “magnetochronology”

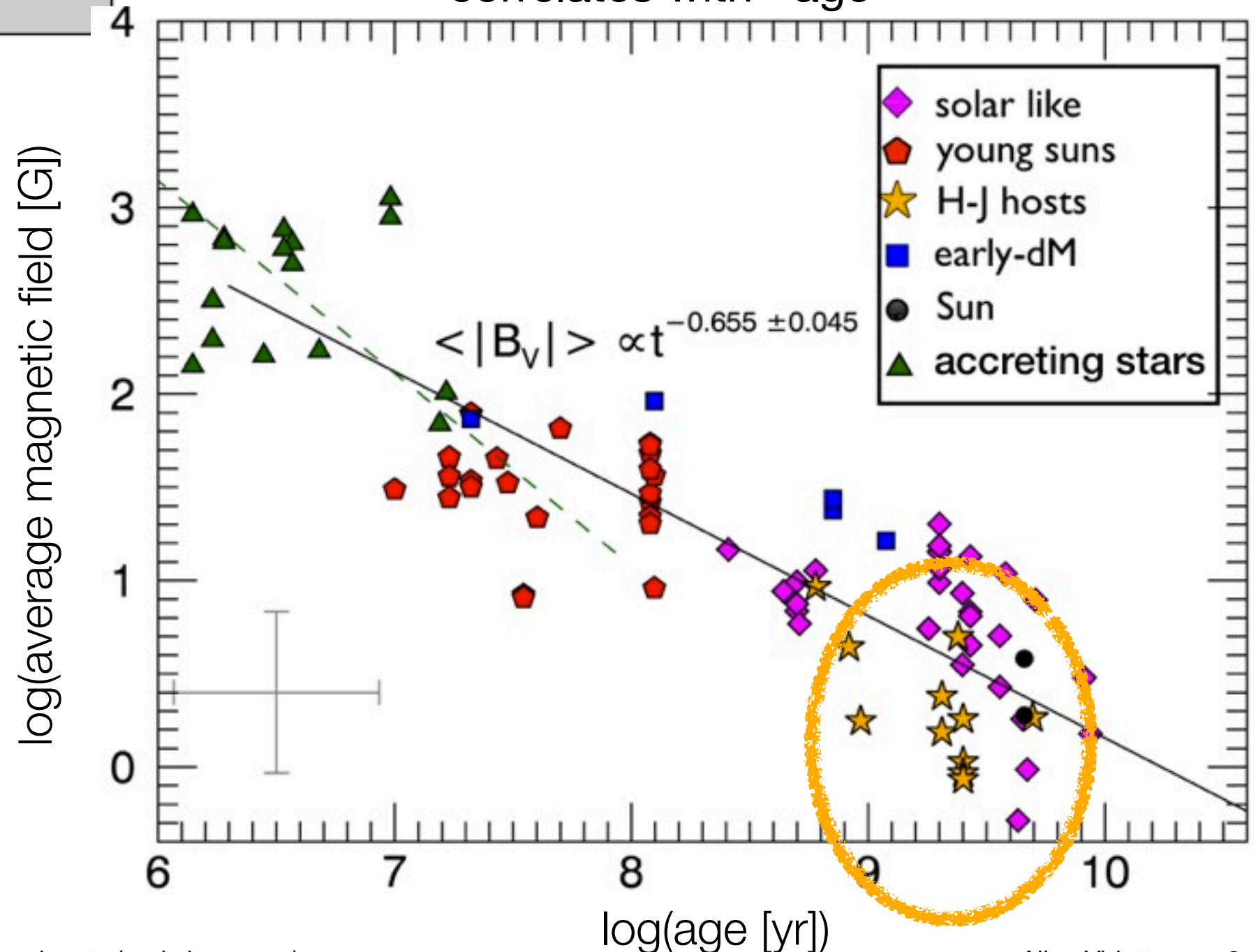
Vidotto+14b

>100 observed
magnetic maps



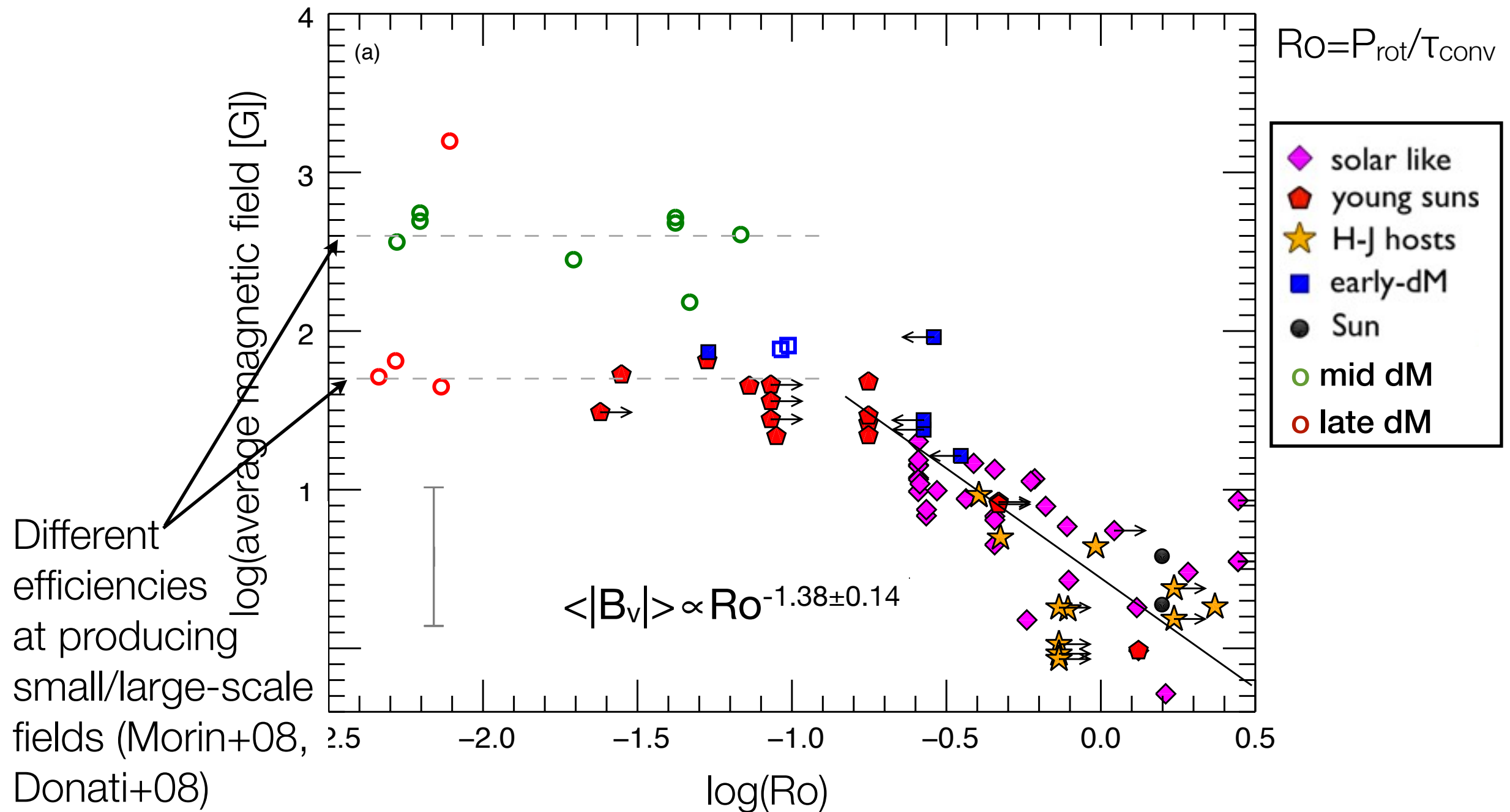
$\Rightarrow \langle |B| \rangle$

Large-scale magnetic field
correlates with $\sim \text{age}^{-0.6}$



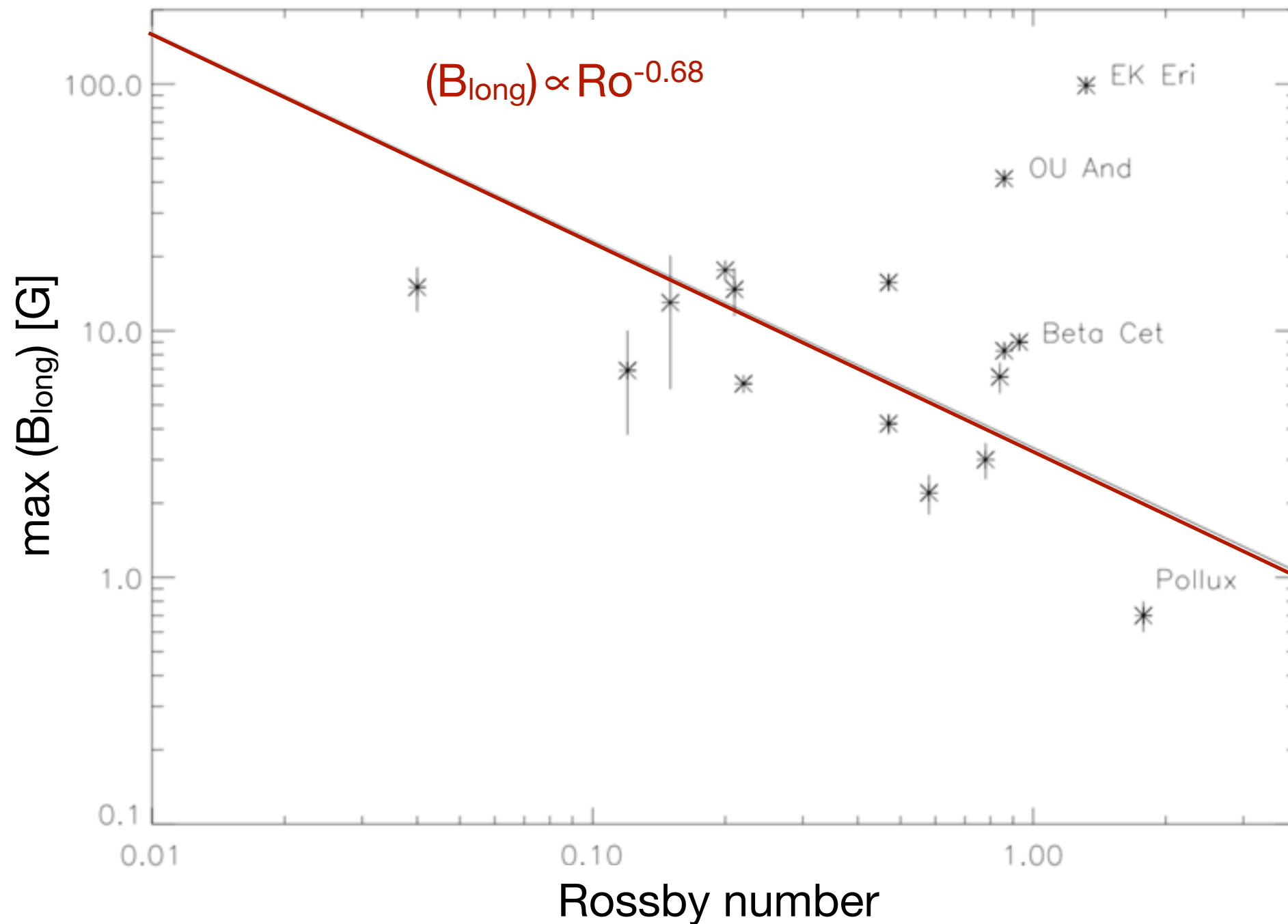
Fast rotators have more intense magnetic fields

Vidotto+14b



Snapshot magnetic field observations of active single G-K giants

Aurière+15



See poster by
J. Ballot

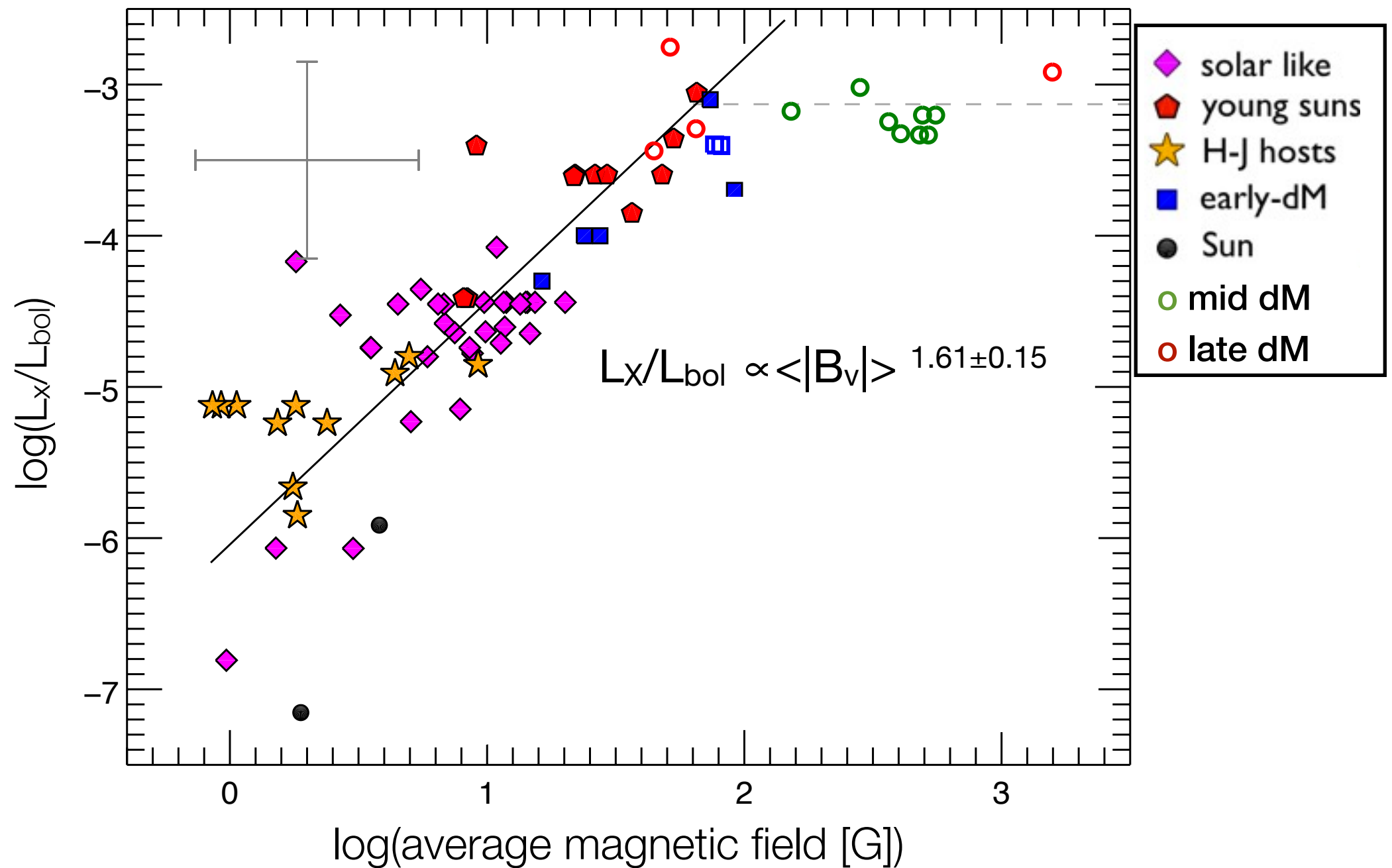
cf: for dwarfs

$$\langle |B_V| \rangle \propto Ro^{-1.38 \pm 0.04}$$

(Vidotto+14b)

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

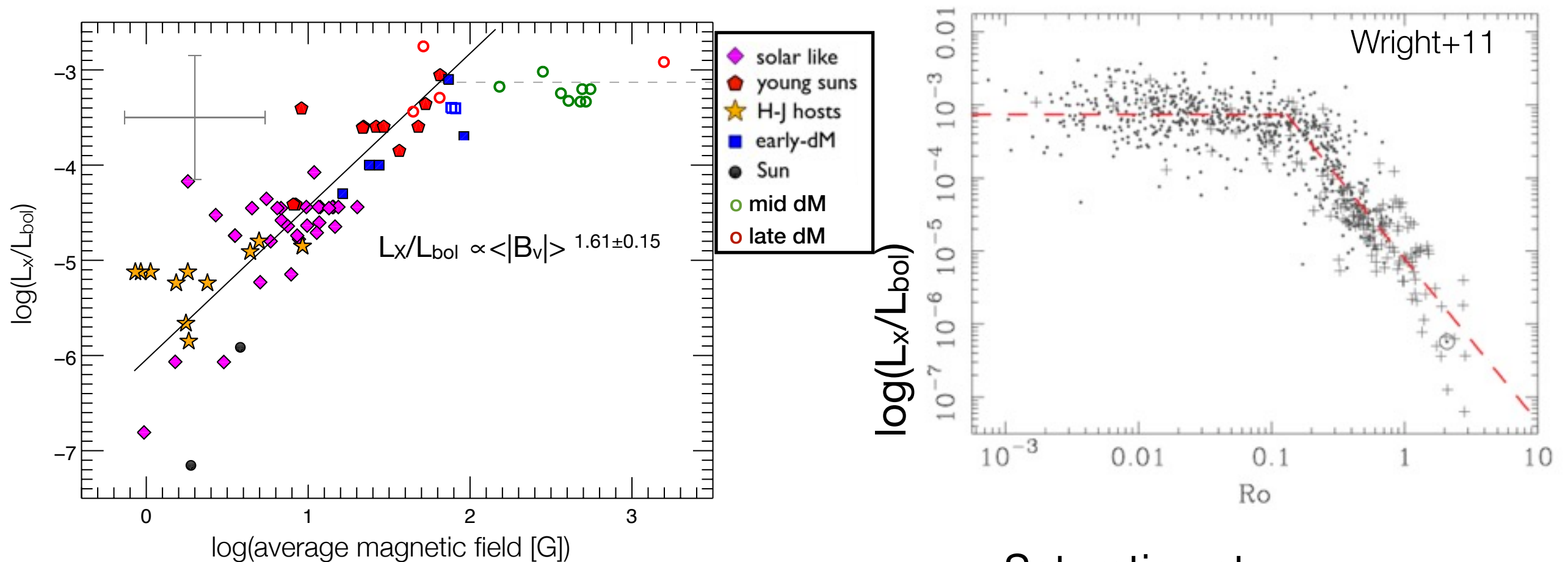
Vidotto+14b



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

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

Vidotto+14b

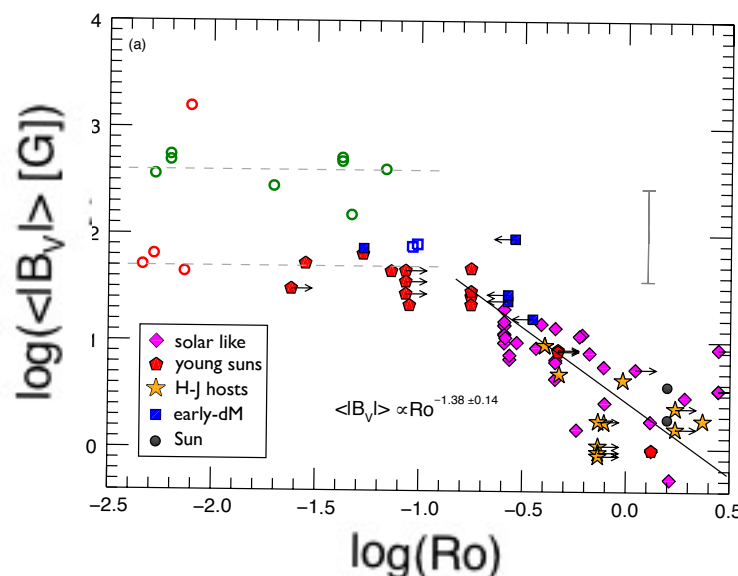
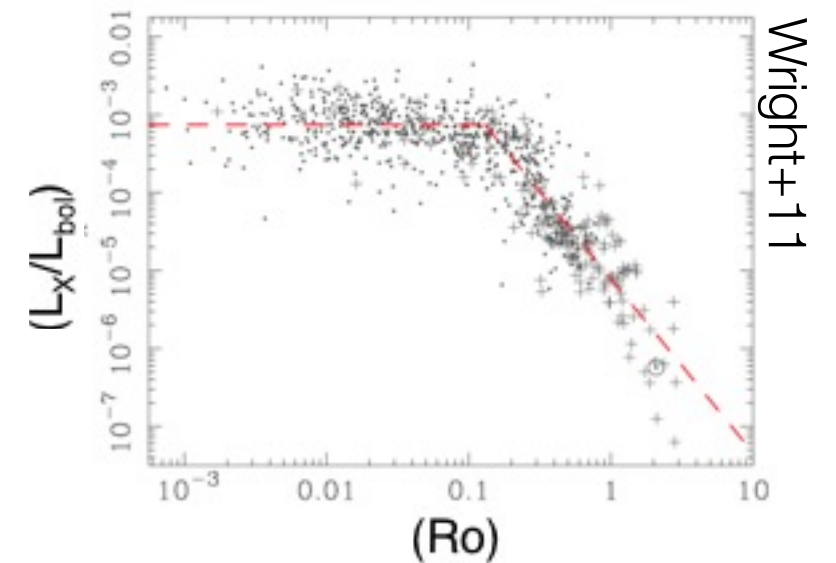
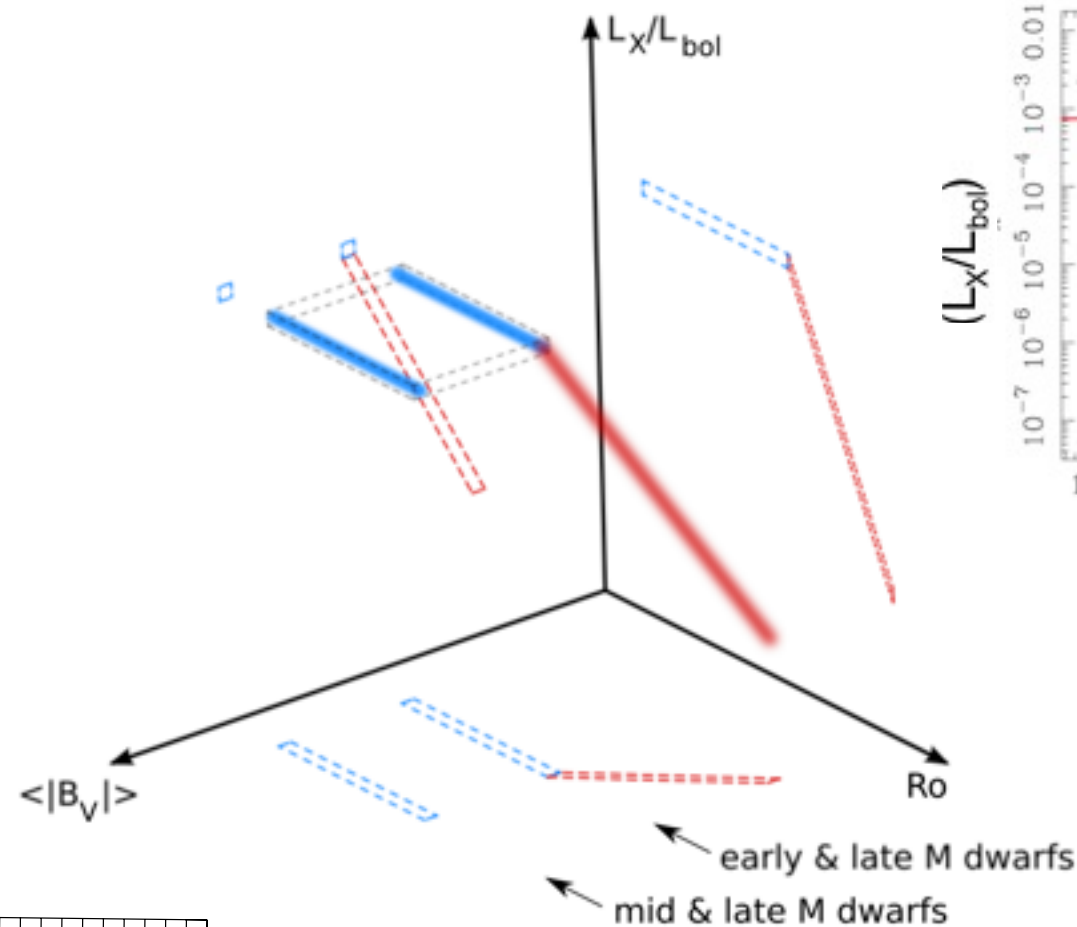
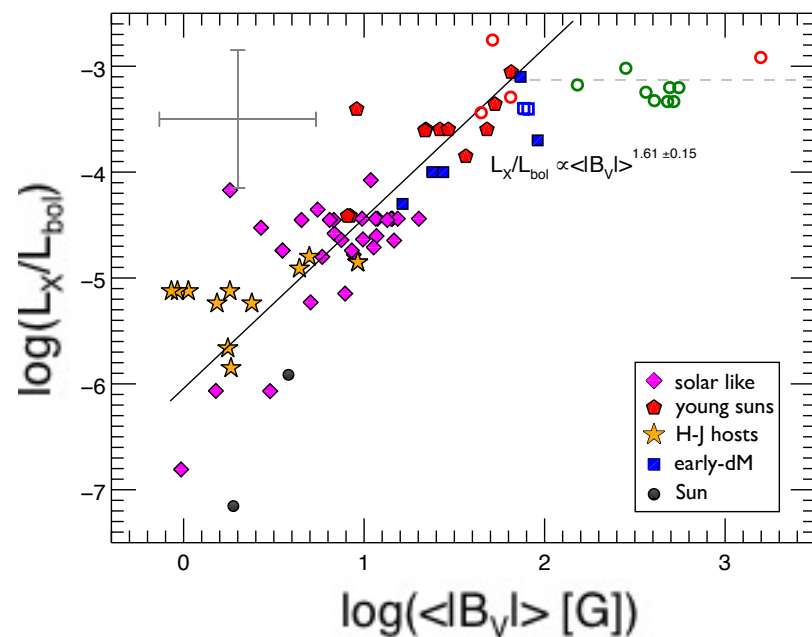


Saturation at
 $\log(L_x/L_{bol}) \approx -3.1 \rightarrow Ro \approx 0.1$

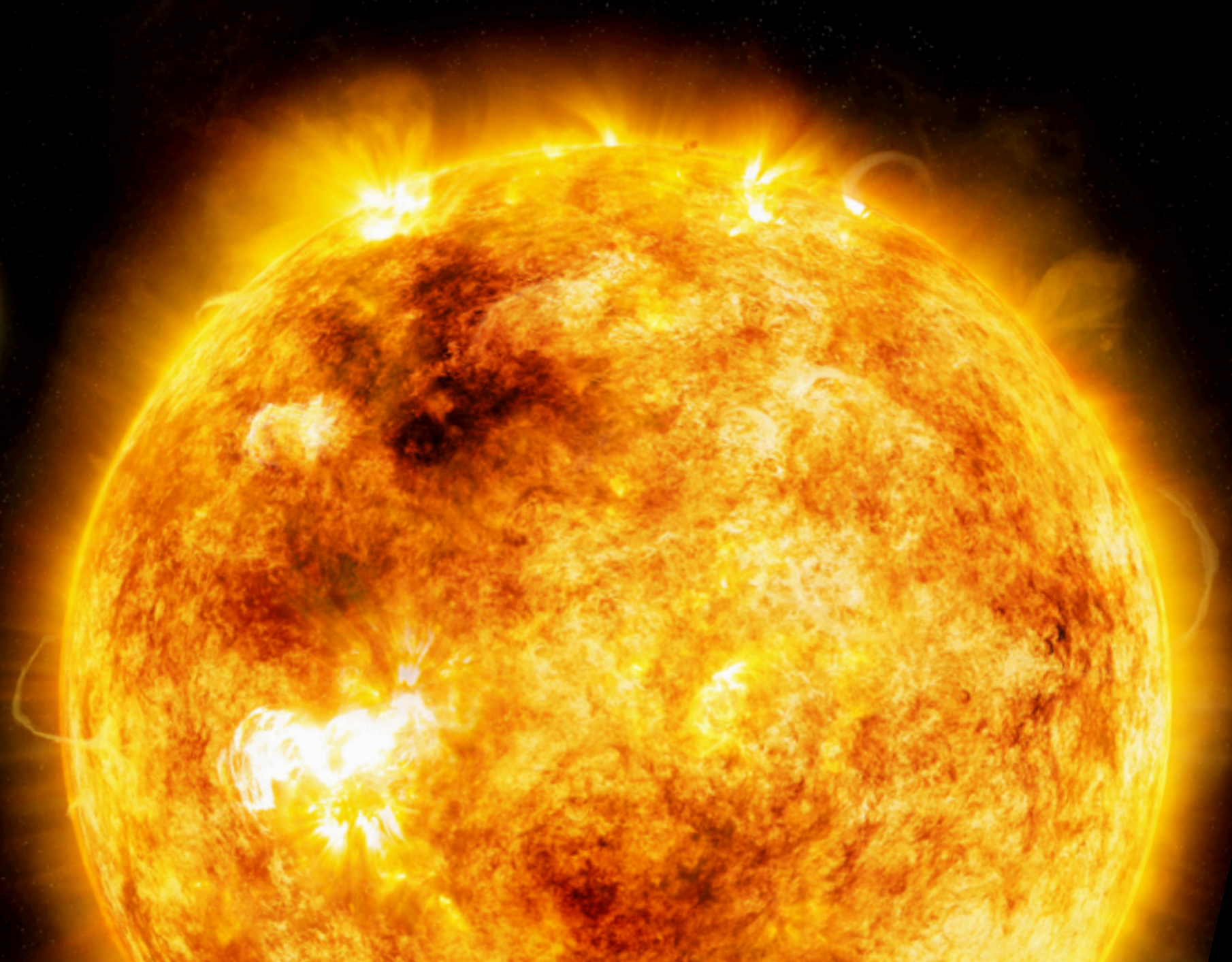
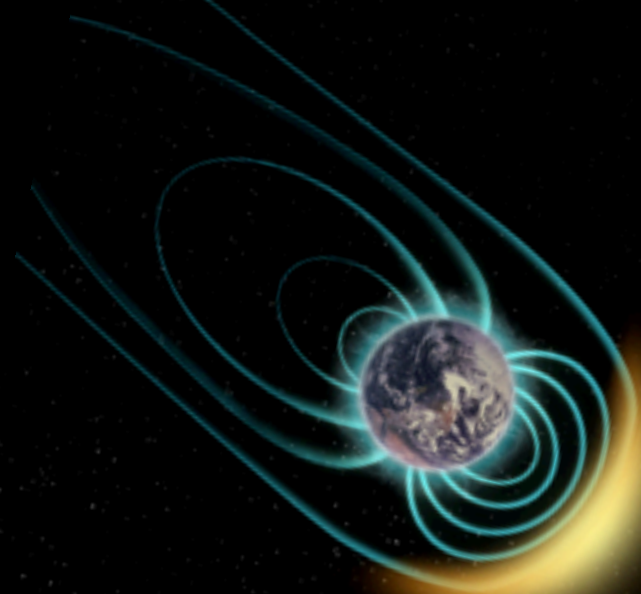
Saturation at $\log(L_x/L_{bol}) \approx -3.1 \rightarrow \langle |B_v| \rangle \gtrsim 80 \text{ G}$

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
- $1.34 M_{\odot}$, $1.46 R_{\odot}$
- $v \sin i = 15.0 \pm 0.5$ km/s
(Valenti & Fischer 2005)
- $P_{\text{rot}} \sim 3.3$ days
- $d\Omega = 0.46$ rad/day

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

planet

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

**‘only’ star with confirmed
full magnetic cycle**



τ Boo: the cyclic planet-hosting star

June/06
(Catala+07)

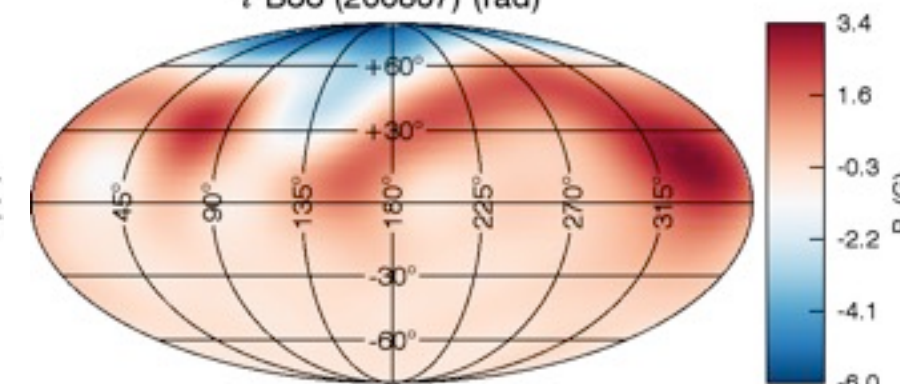
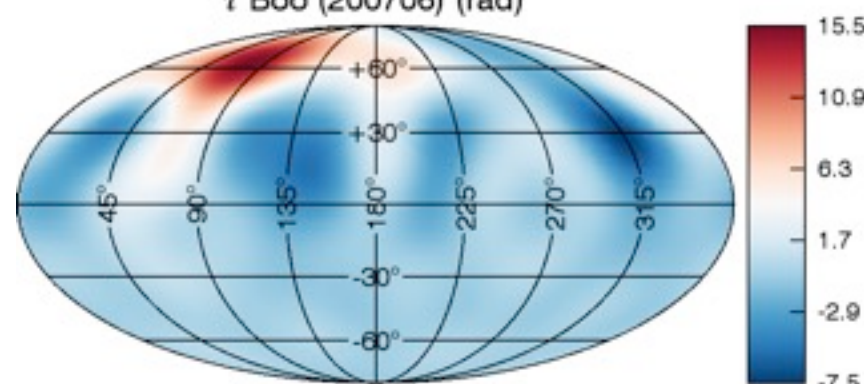
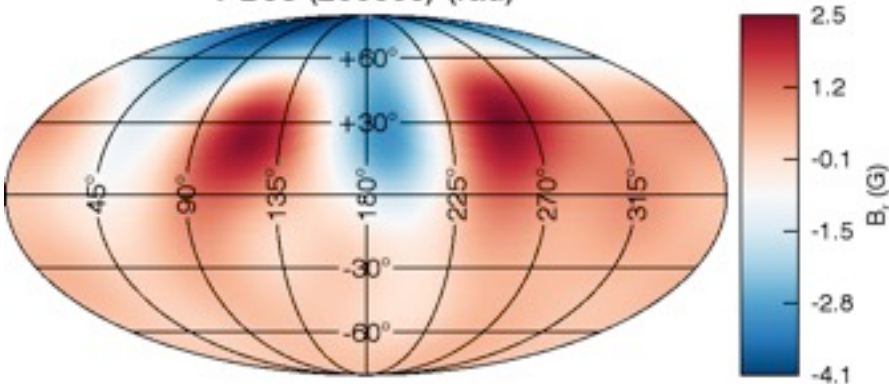
June/07
(Donati+08)

July/08
(Fares+09)

τ Boo (200606) (rad)

τ Boo (200706) (rad)

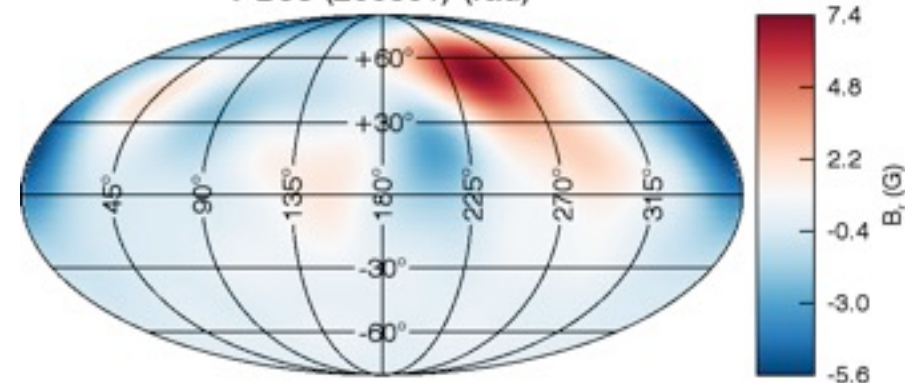
τ Boo (200807) (rad)



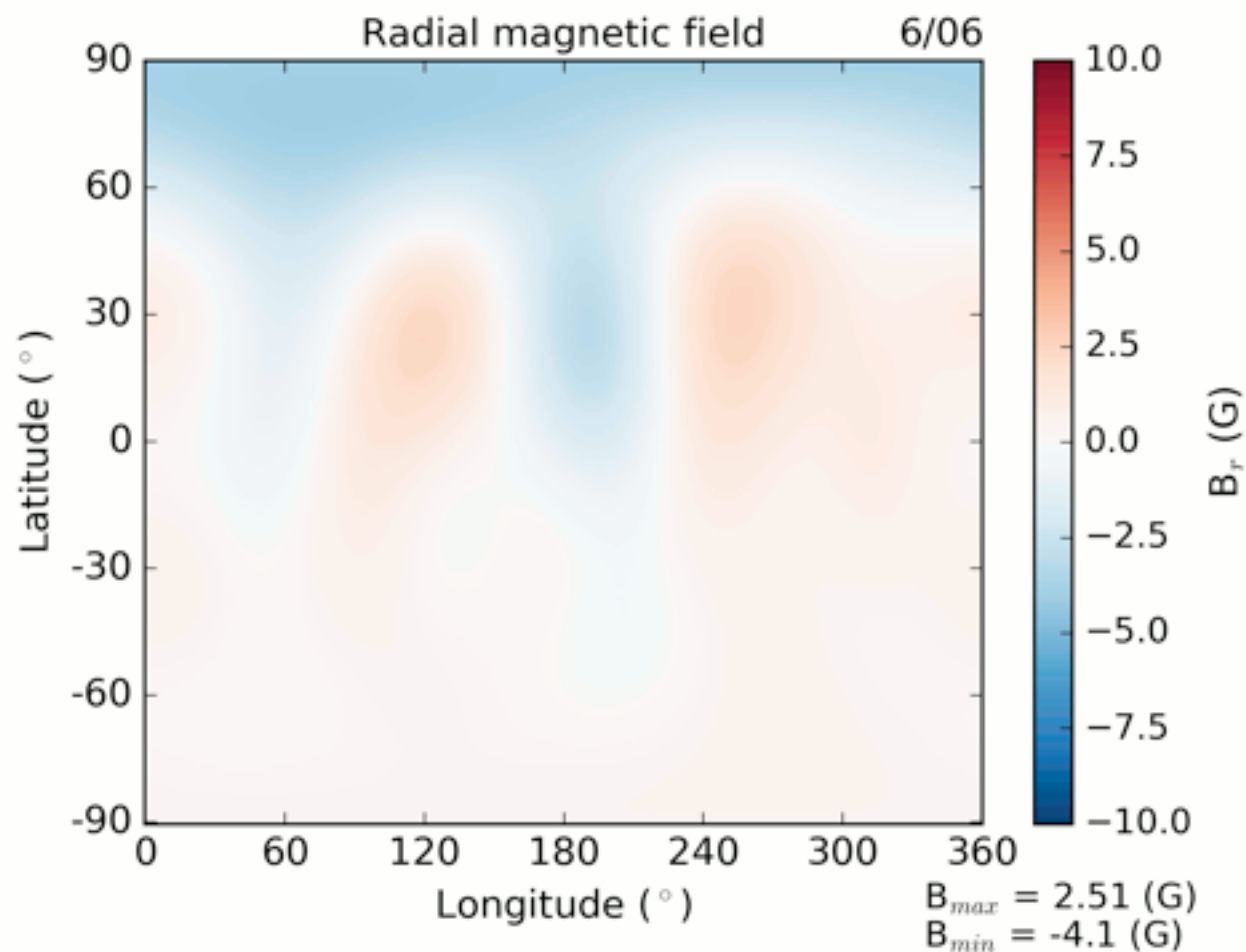
January/08
(Fares+09)

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

τ Boo (200801) (rad)



τ Boo: the cyclic planet-hosting star

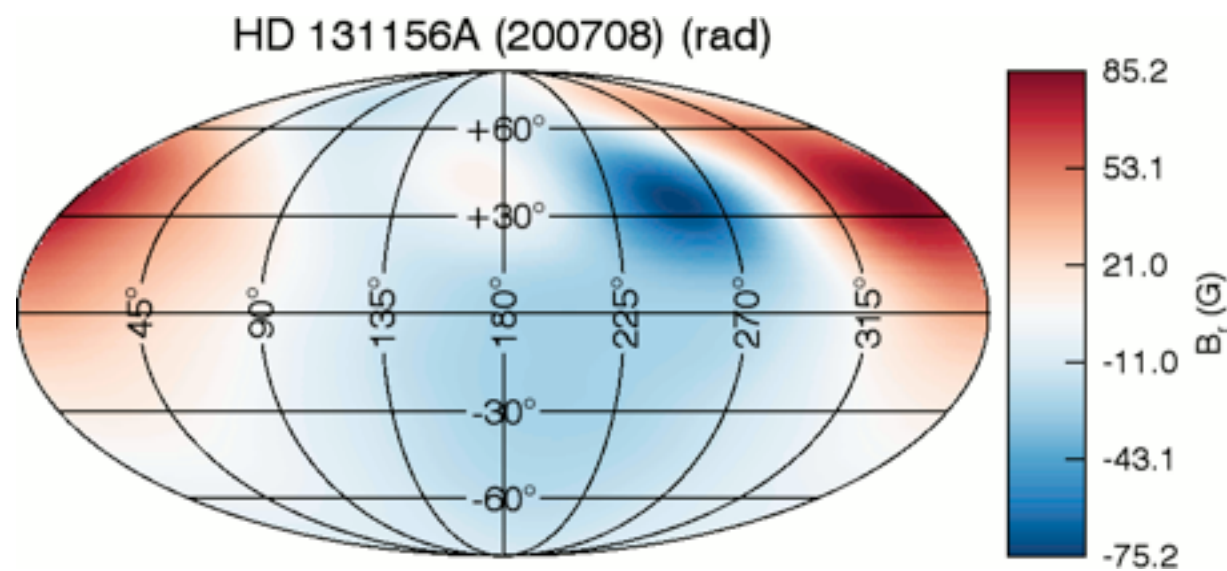


Movie Credit: Robert Kavanagh

Data from: Catala+06, Donati+07, Fares+09,13, Mengel+16

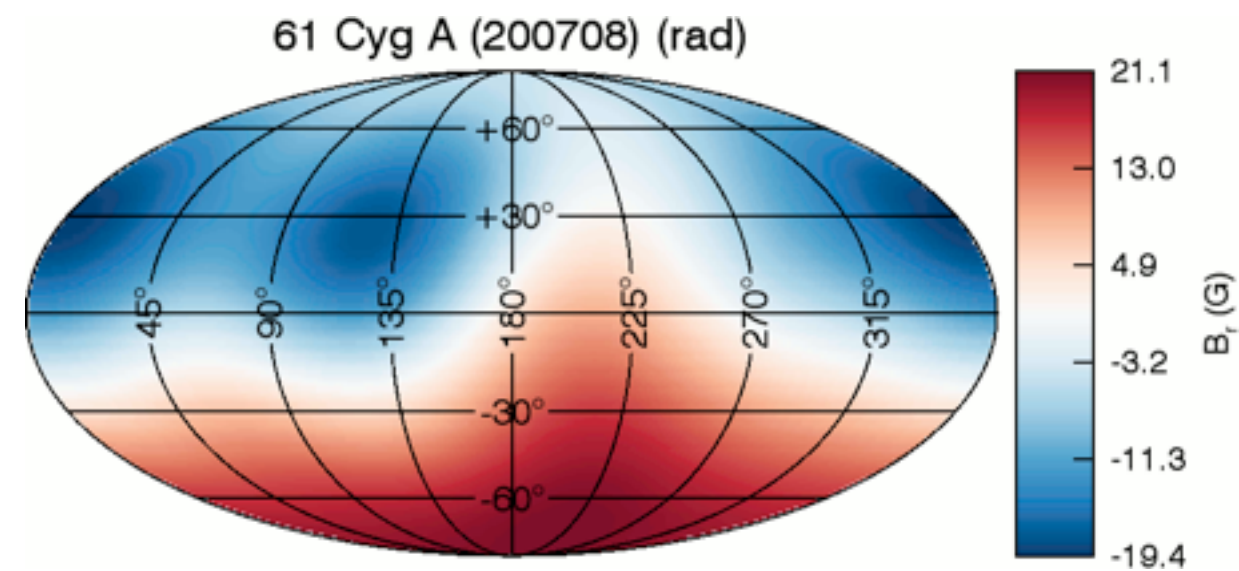
- **Why** such a short cycle?
 - ▶ high $d\Omega=0.46$ rad/day?
 - ▶ sync the shallow convective envelope (tides) due to a close-in planet?

Other (quasi) magnetic cyclic stars



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

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

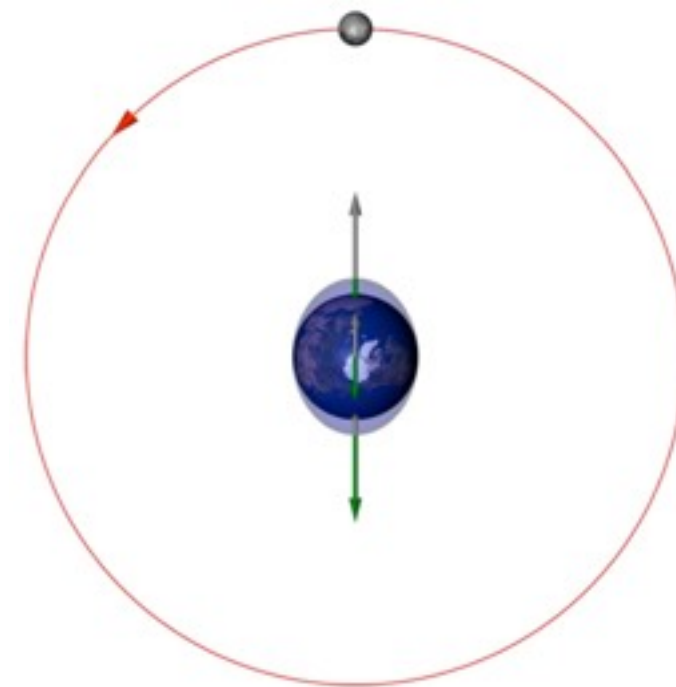
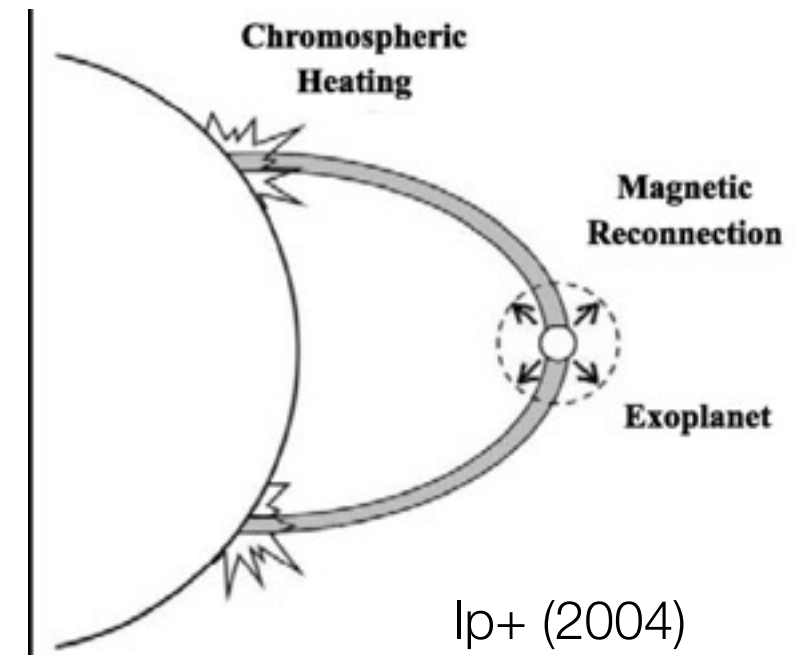


- sp. type: K5V
- $0.66 M_{\odot}$, $0.665 R_{\odot}$
- $P_{\text{rot}} \sim 35.7$ days

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

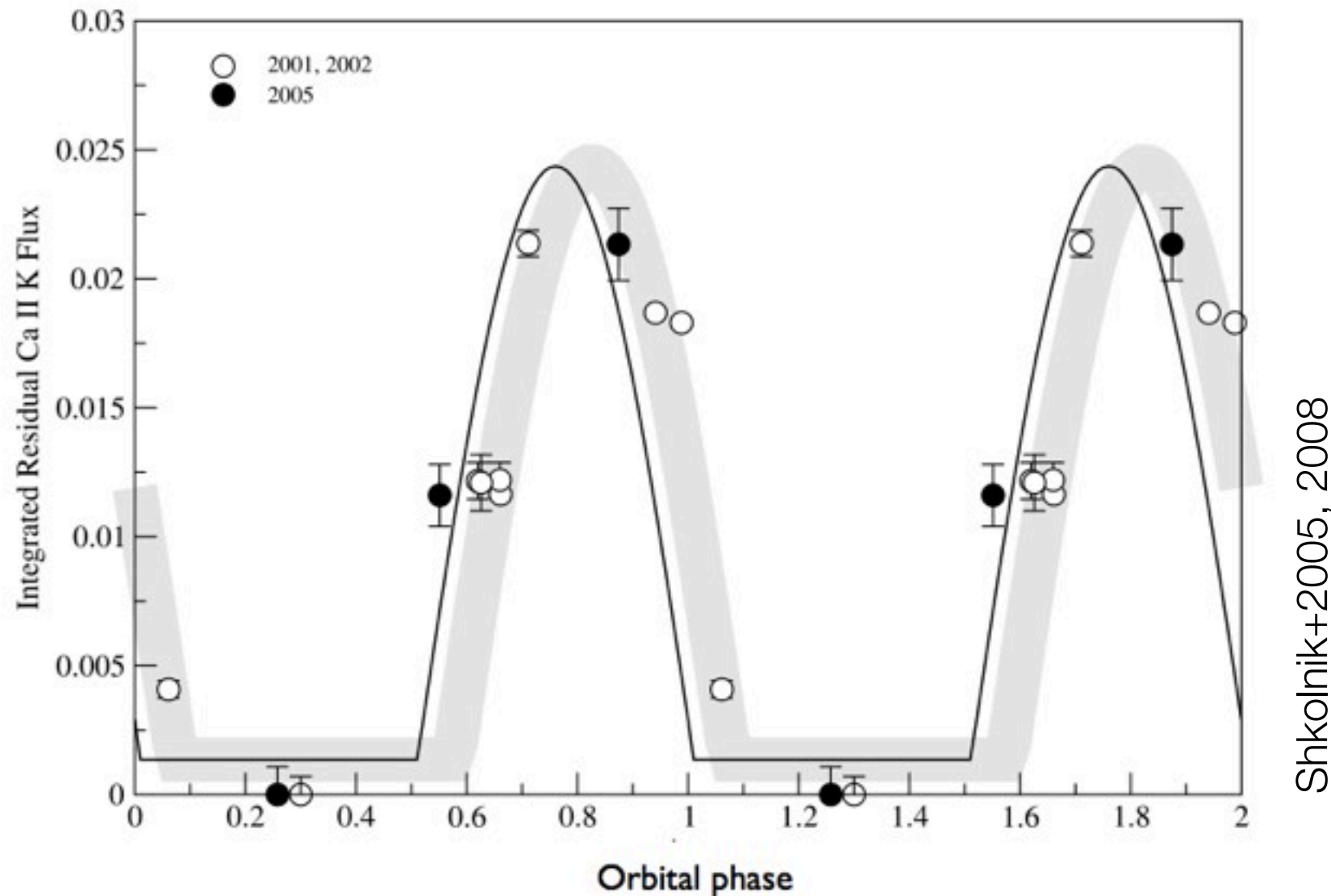
Stellar-planet interactions: Planet-induced (anomalous) stellar activity

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



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

HD179949



- At some epochs:
 - ▶ Activity modulated by P_{orb} : **anomalous**
 - ▶ phase lag: activity & subplanetary phase ($\phi=0$)

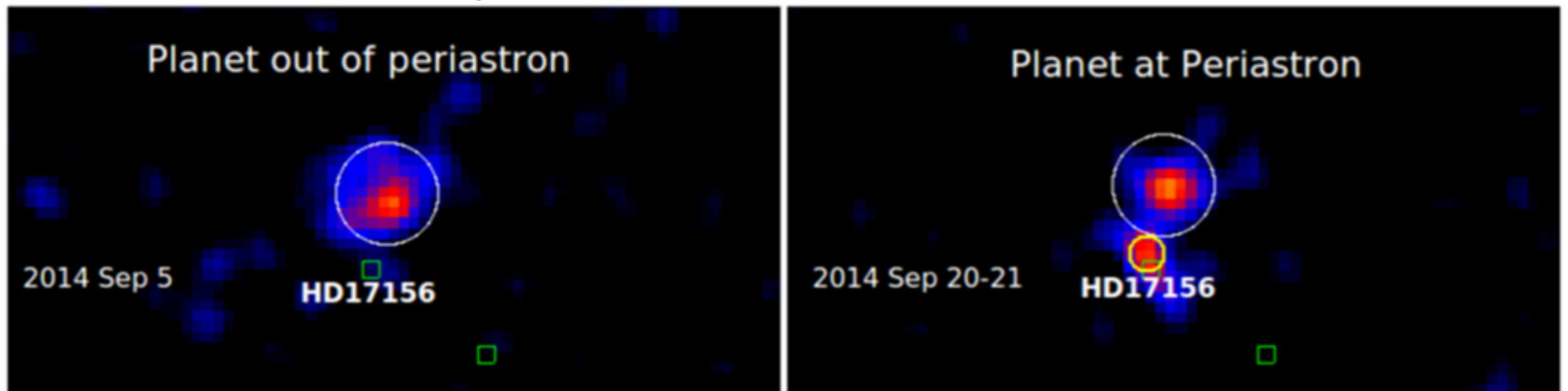
- However: at other epochs:
 - ▶ activity modulated by stellar P_{rot} : **normal stellar activity**

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

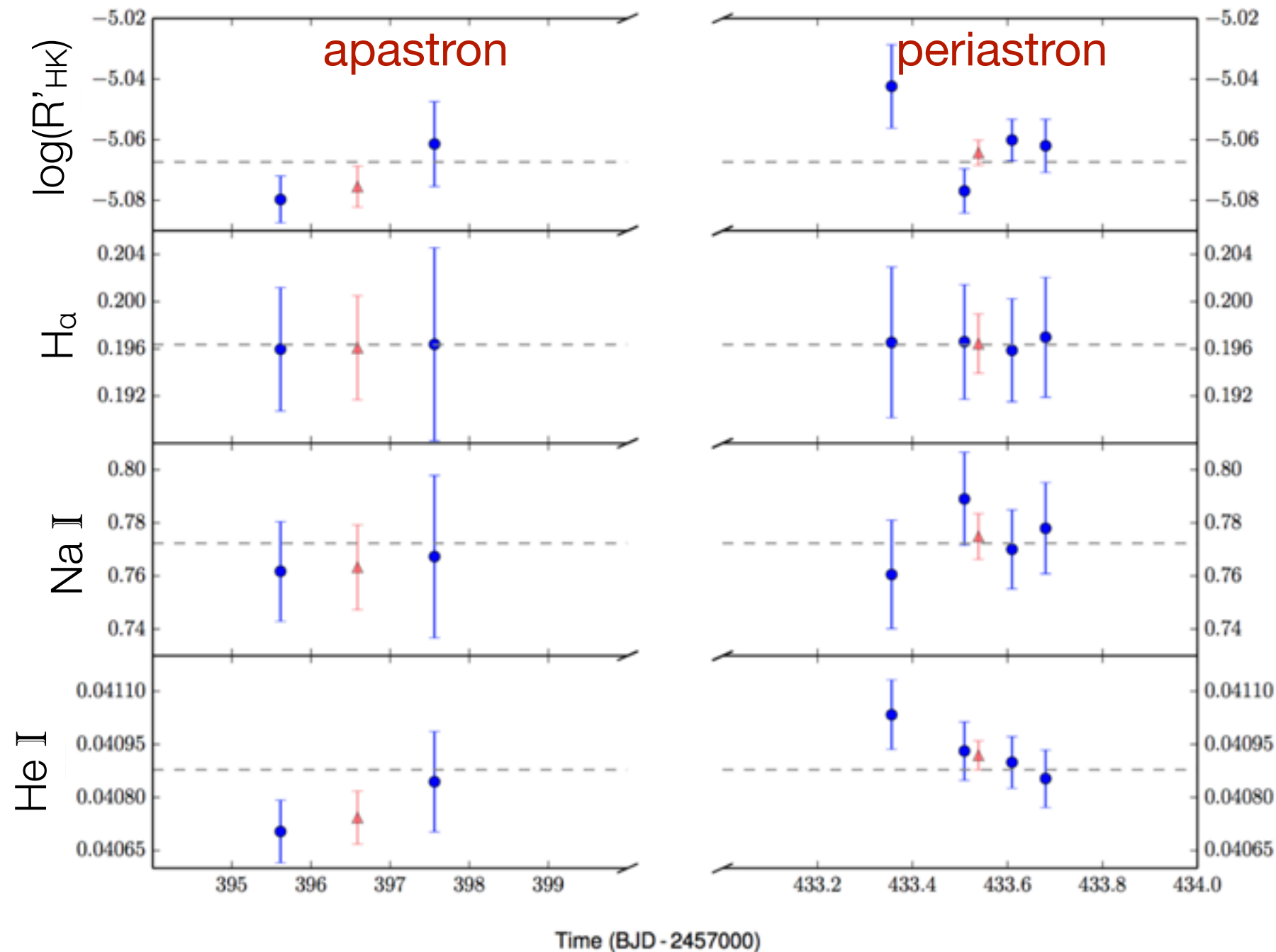
- Magnetic reconnection?
- Accretion of planetary material towards the star?

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

Influence of the planet on the stellar (magnetic) activity

Figueira+16

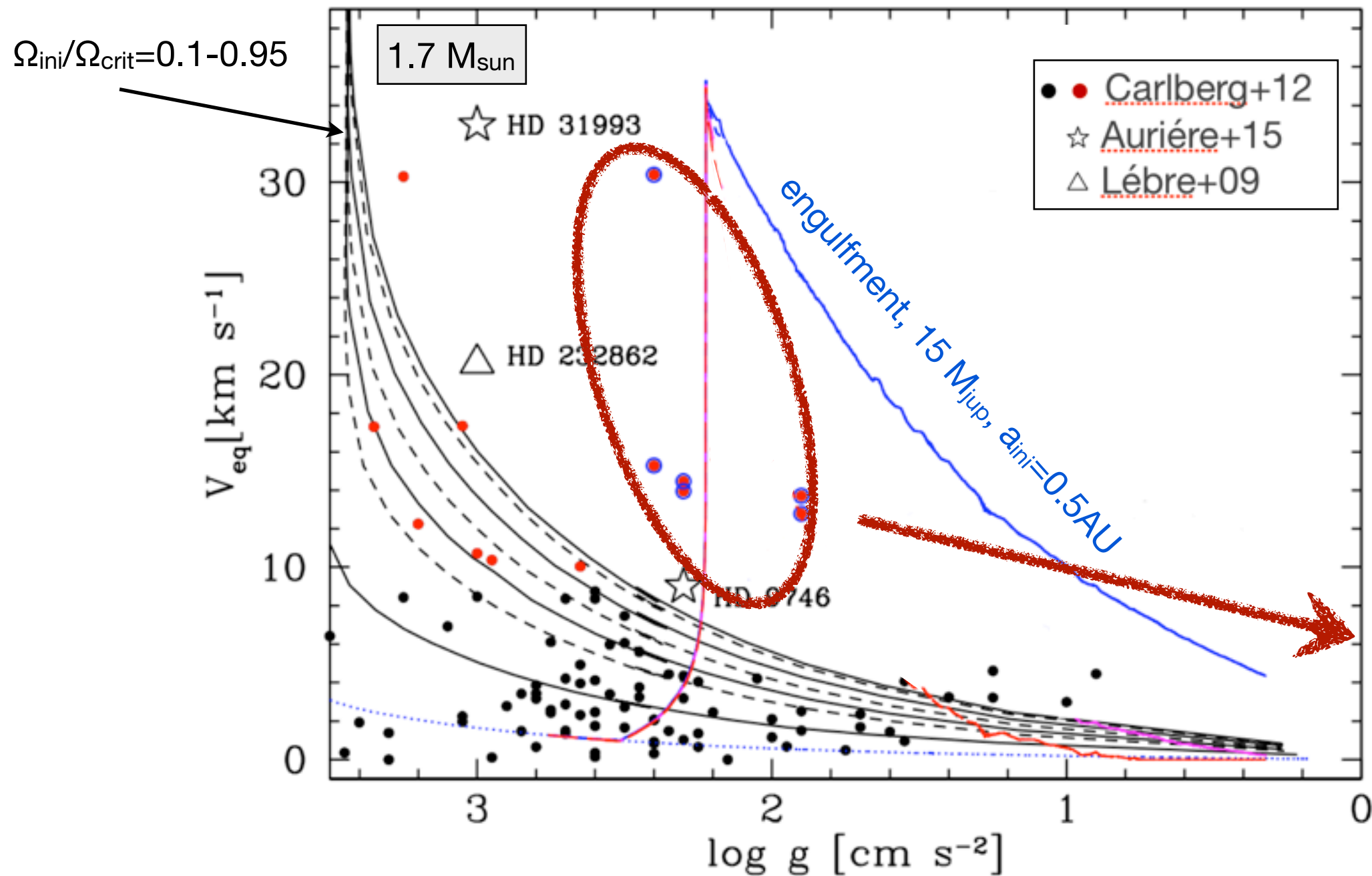
Activity proxies of HD 80606 (eccentric planet $e=0.93$)



No evidence of planet triggering SPI

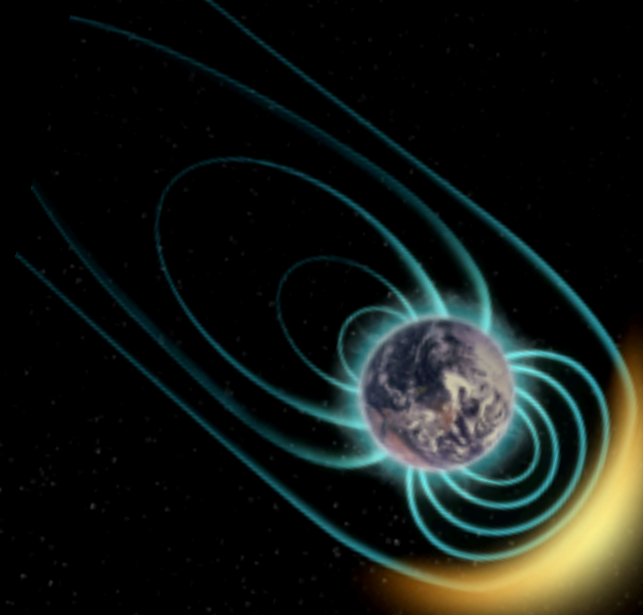
Could planet engulfment trigger stellar magnetic fields at the red giant branch phase?

Privitera+16c, subm.



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

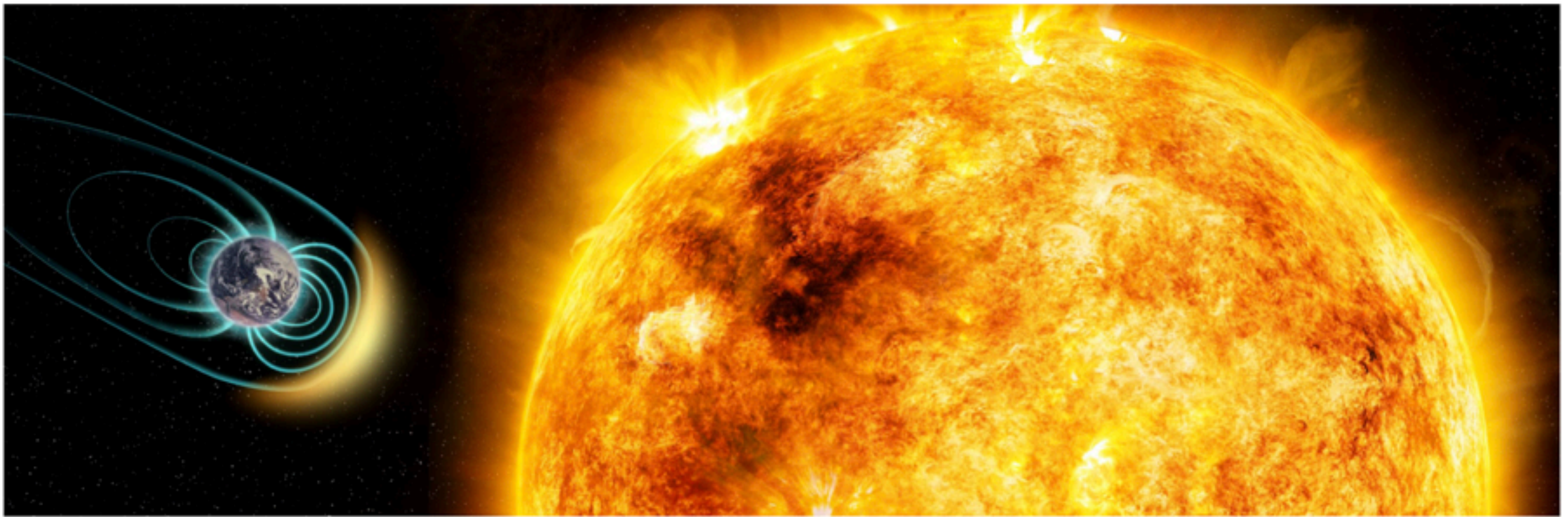
Empirically: $|B| \propto \text{Ro}^{-0.68}$ (Aurière+15)



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

Summary

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



© M. Weiss/CfA

International Astronomical Union Symposium 328:

Living around active stars

October 17 - 21, 2016

Maresias, SP, Brazil

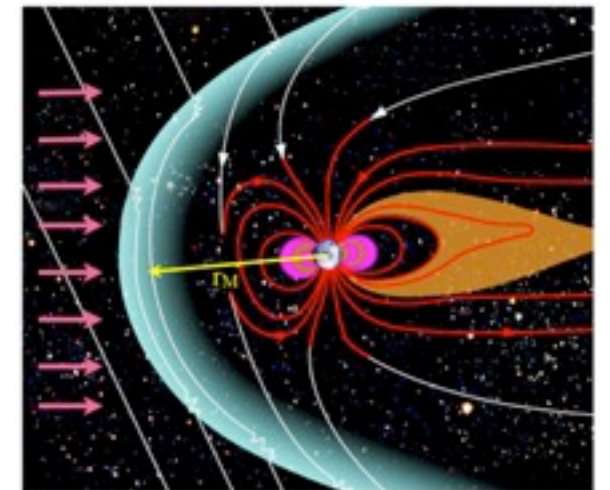
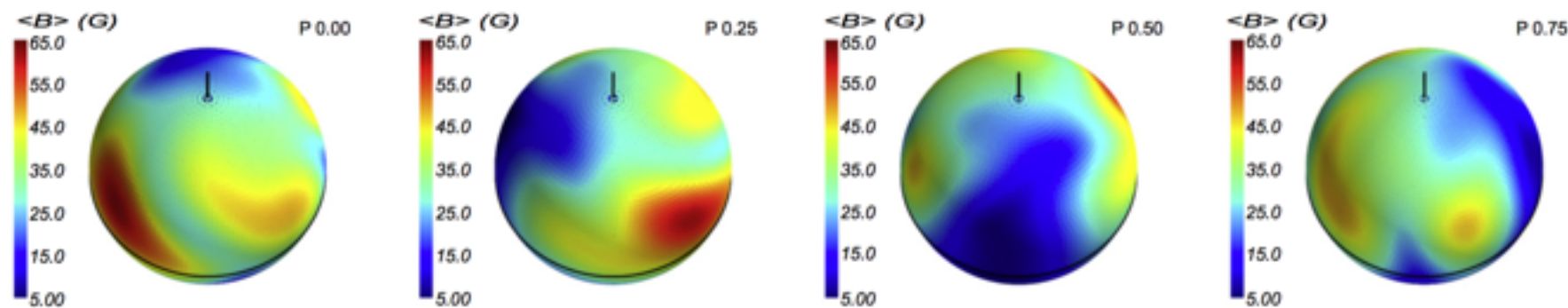
<http://www.sab-astro.org.br/IAUS328>

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



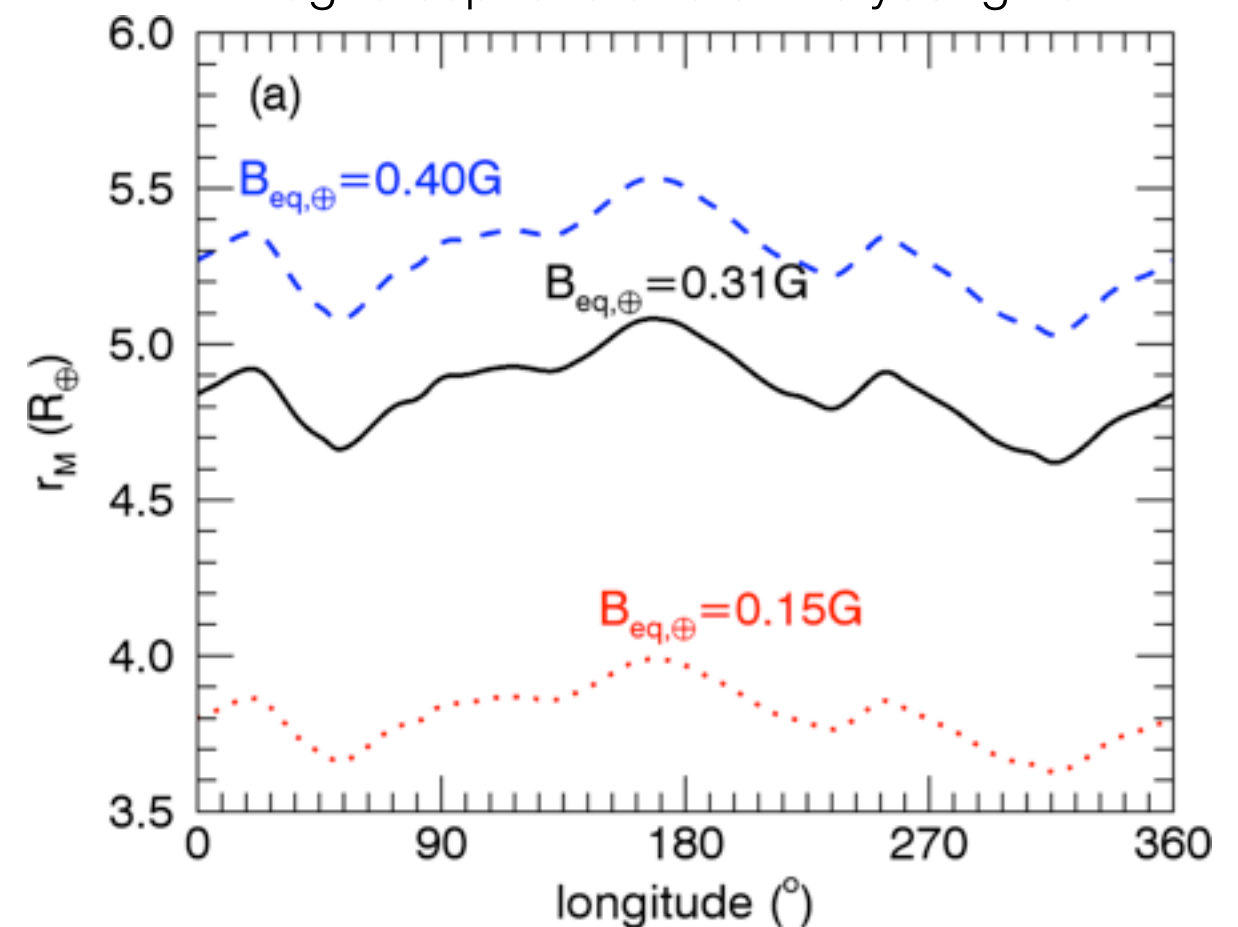
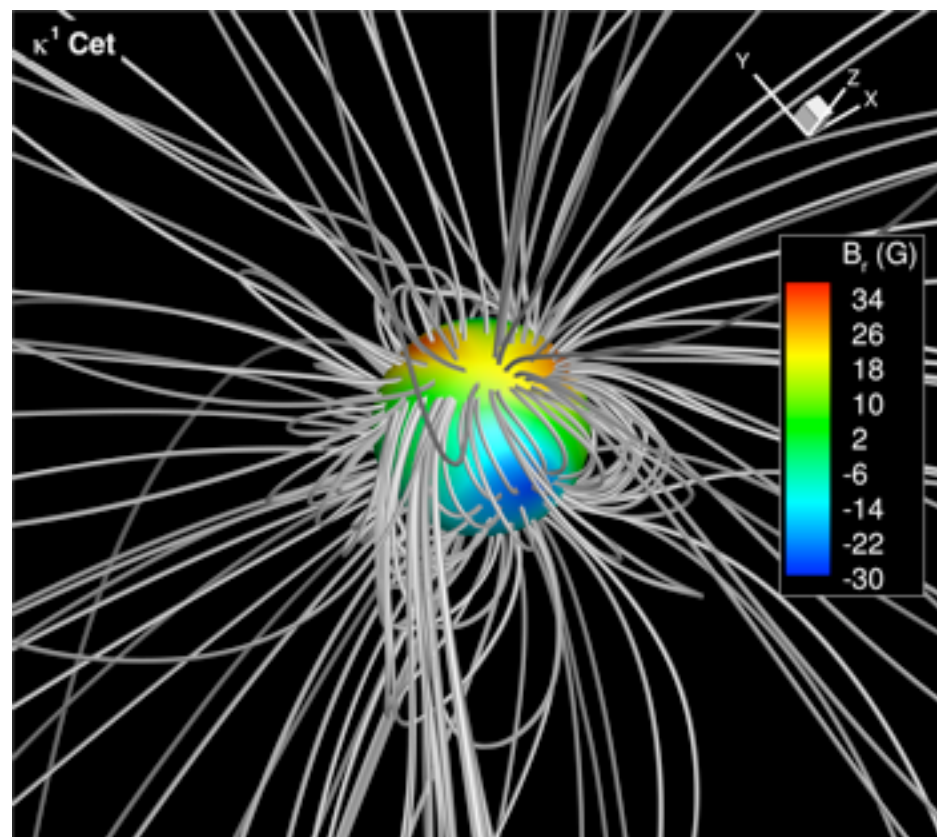
κ^1 Cet: a proxy of the young Sun when life arose on Earth

do Nascimento +16



3D stellar wind simulations

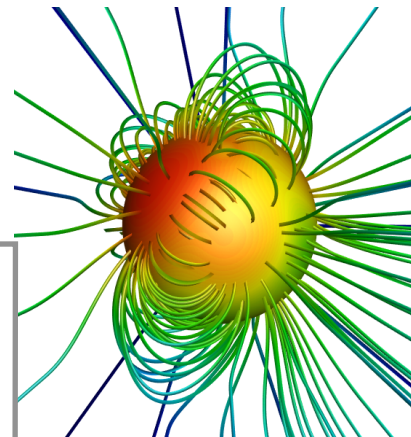
magnetospheric size of the young Earth



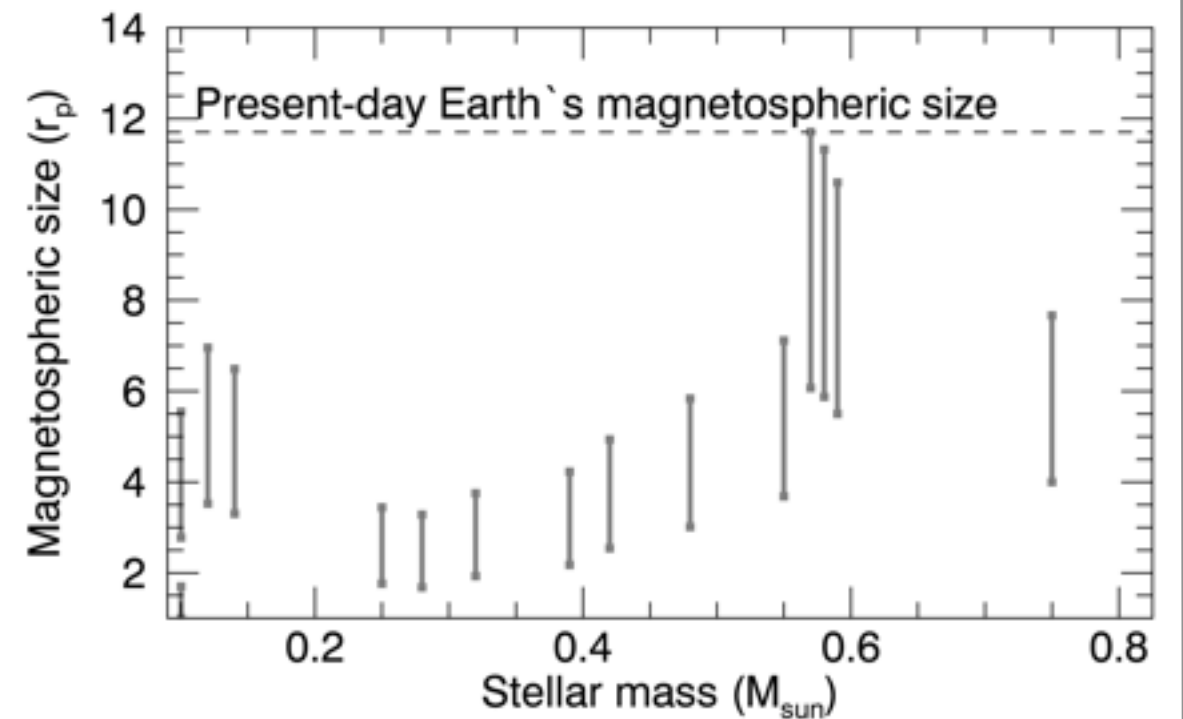
Small planetary magnetic fields can expose planet's atmosphere to erosion: **habitability**

Earth-analog at Habitable zones of M dwarfs:

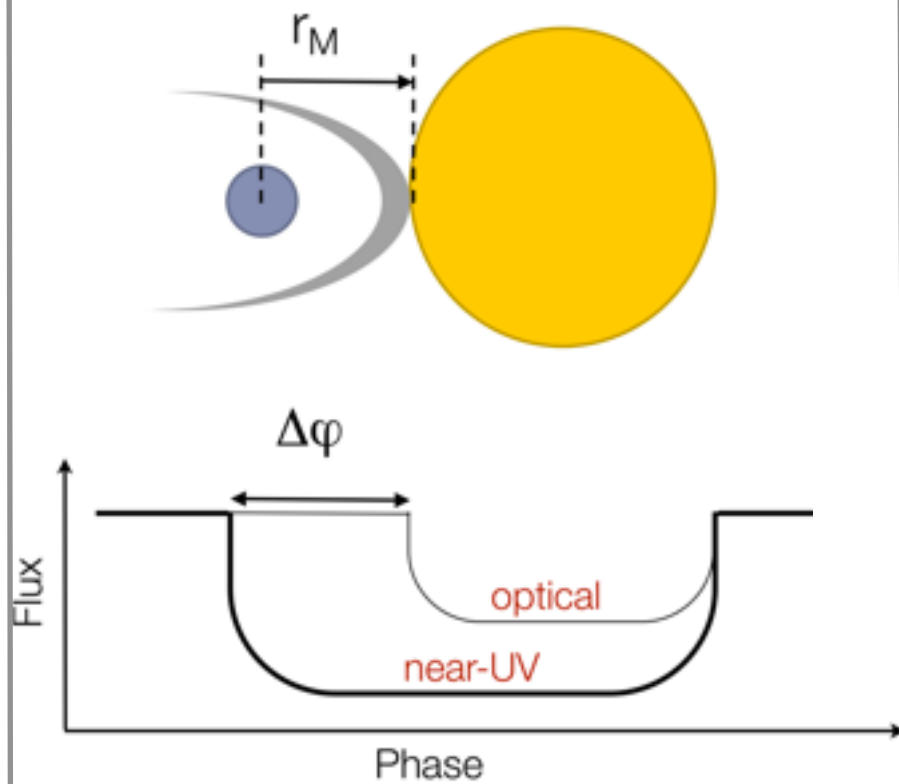
Intense stellar magnetism can reduce the extent of planetary magnetospheres



Vidotto+13



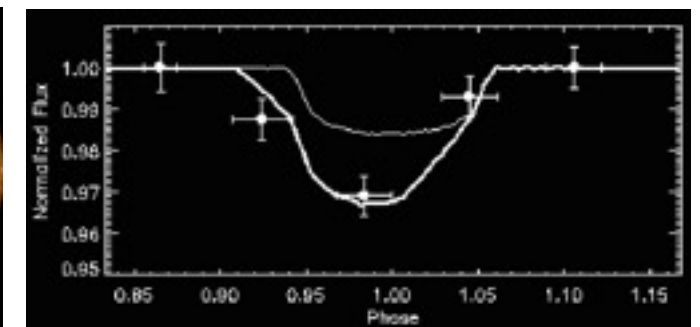
model: Vidotto+10a,b,11a,b,c



- Observations of bow shocks surrounding exoplanets:

estimate B_{planet} .

- For WASP-12b:
 $B_{\text{planet}} < 24\text{G}$



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