Observations of stellar dynamos

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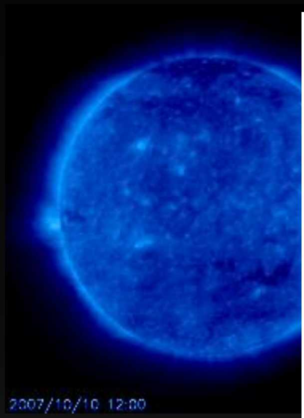
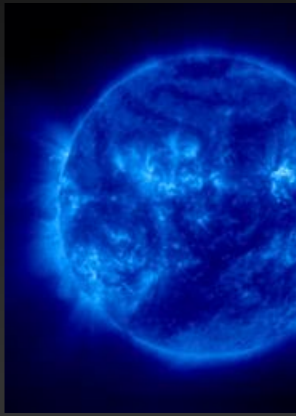
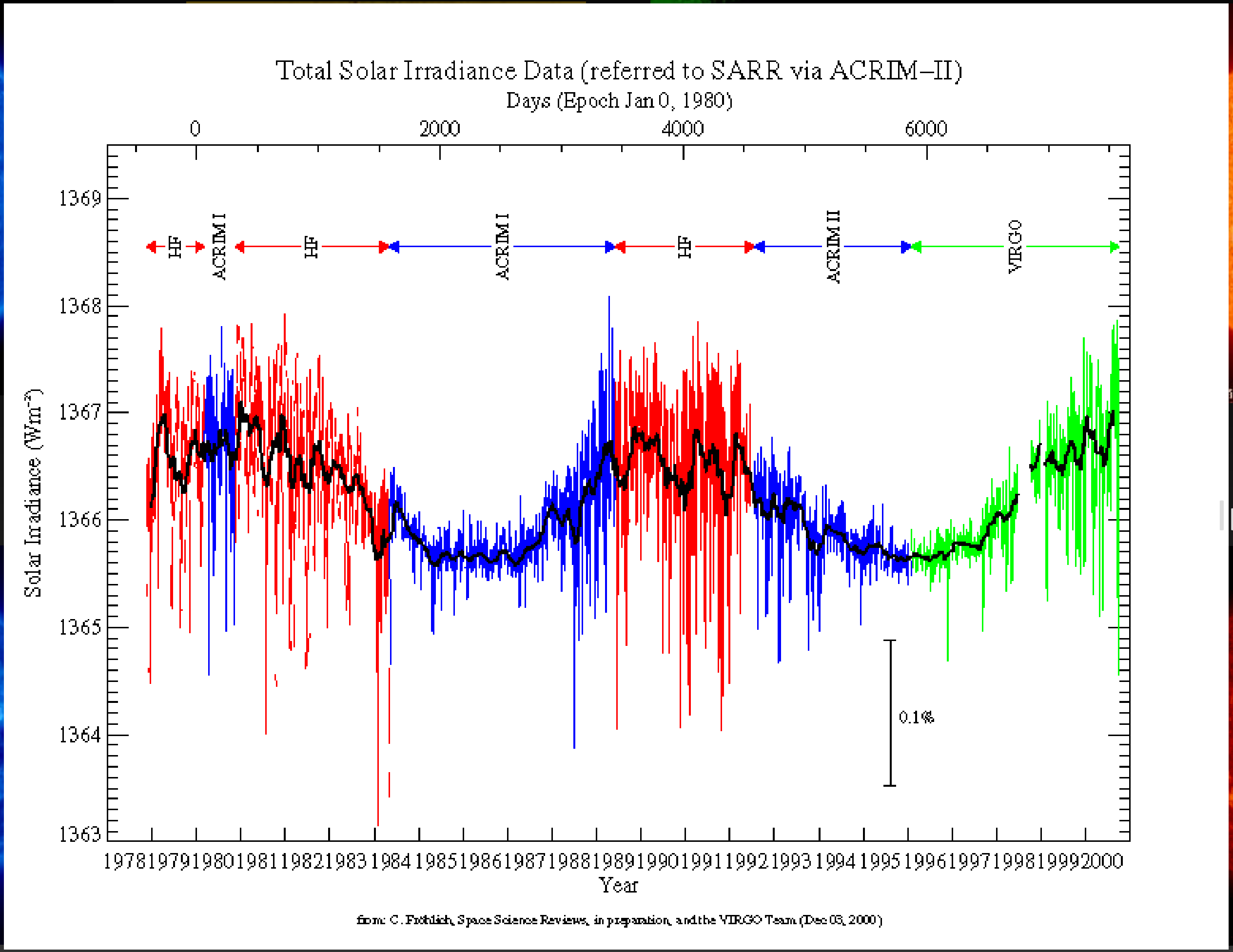
Schrijver & Title, 2011

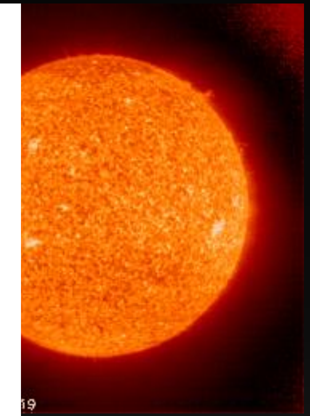
The high-energy Sun and solar variability

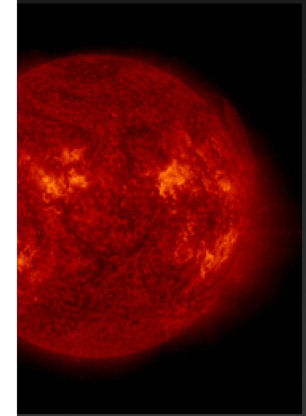
2007











Images: SOHO

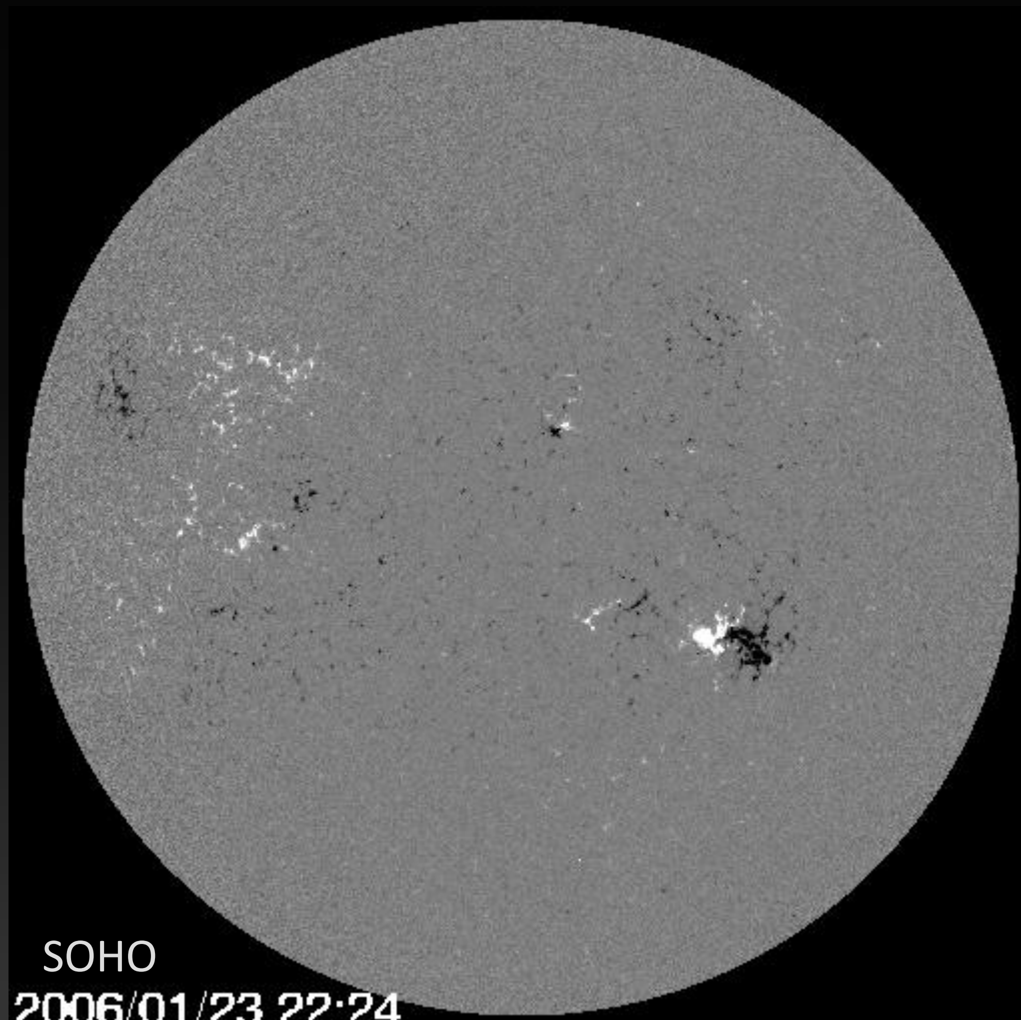
171 Å, T≈1.3MK

284 Å, T≈2.0MK

195 Å, T≈1.6MK

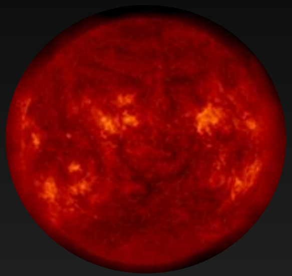
304 Å, T≈1.3MK

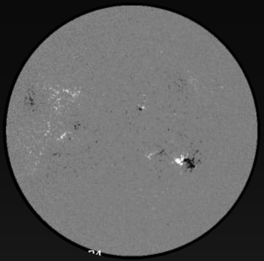
Magnetic Activity



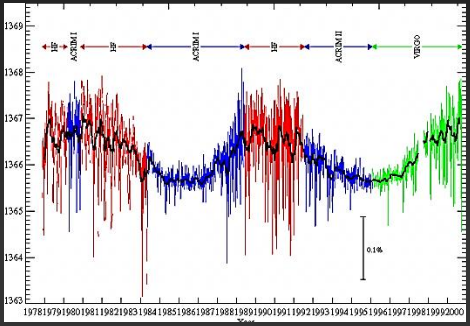
Magnetogram
Intensity

Lesson learned from the Sun:





1. Stars harbour magnetic fields
2. Fields generate “activity”
3. Some field properties are cyclic



Observations of stellar dynamos

1. Introduction to stellar magnetism
2. What can we observe?
3. Observational evidence
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Where do stellar magnetic fields come from?

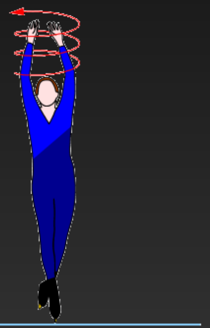
1. Fossil
2. Generated by dynamo

Plasma motion:
Convection, Rotation

Star formation

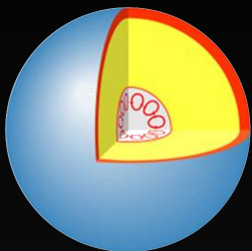
Contraction of the proto- and young star

Spin-up

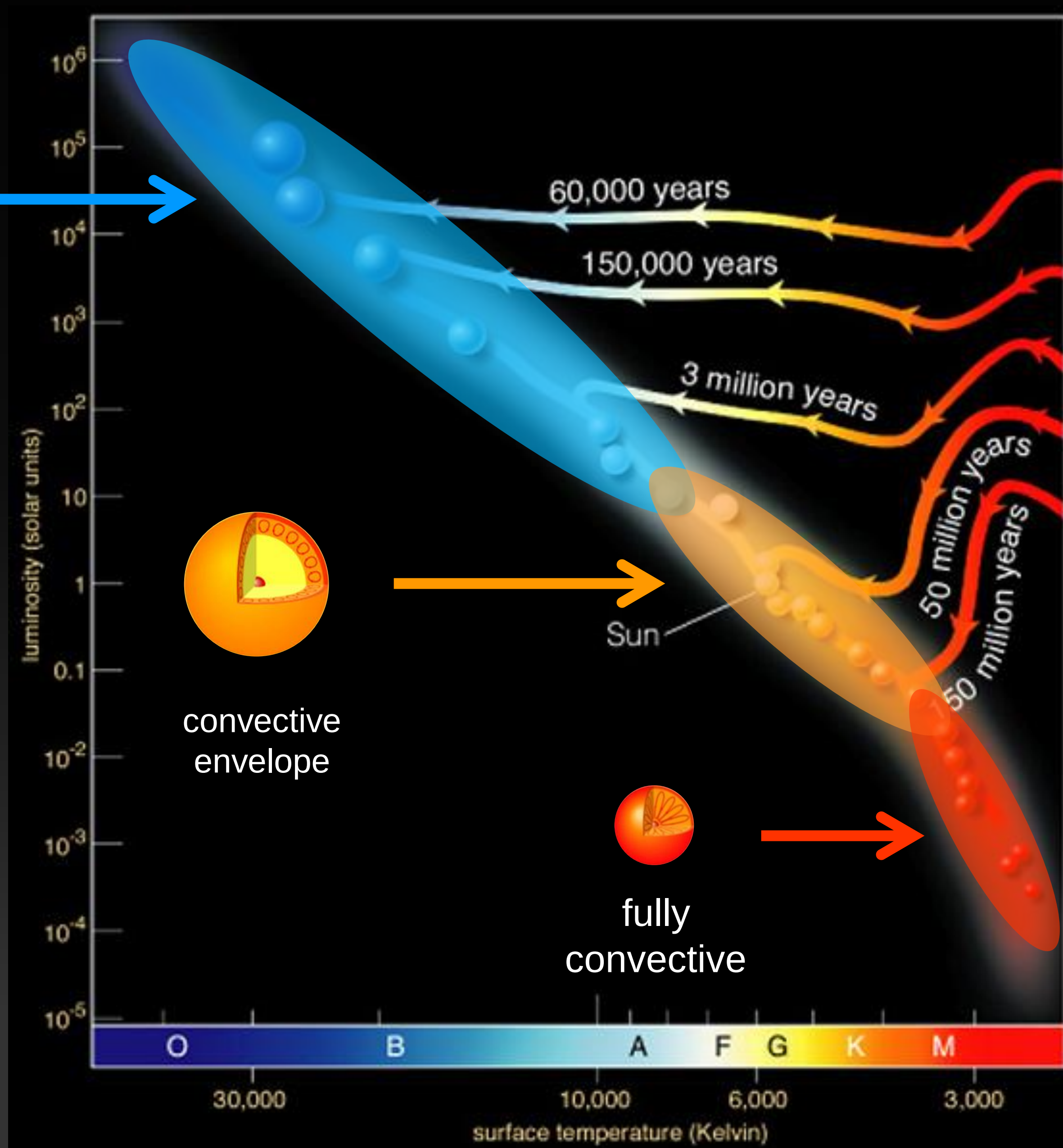


+
field amplification

Before and on the Main Sequence



no outer
convection zone



Fossil field
survival times

Large

< 1000 years

Convective properties of low-mass objects

The (cyclic part of the) solar dynamo may be located at the tachocline – the interface layer between convective envelope and radiative core.

There is no tachocline in low-mass stars!

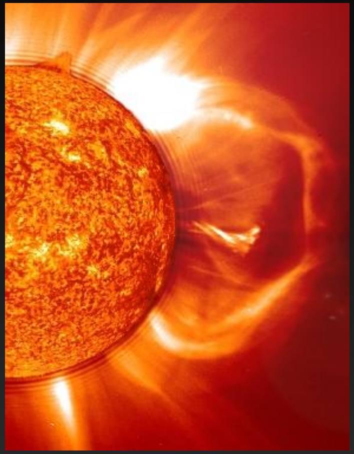
Sun-like star

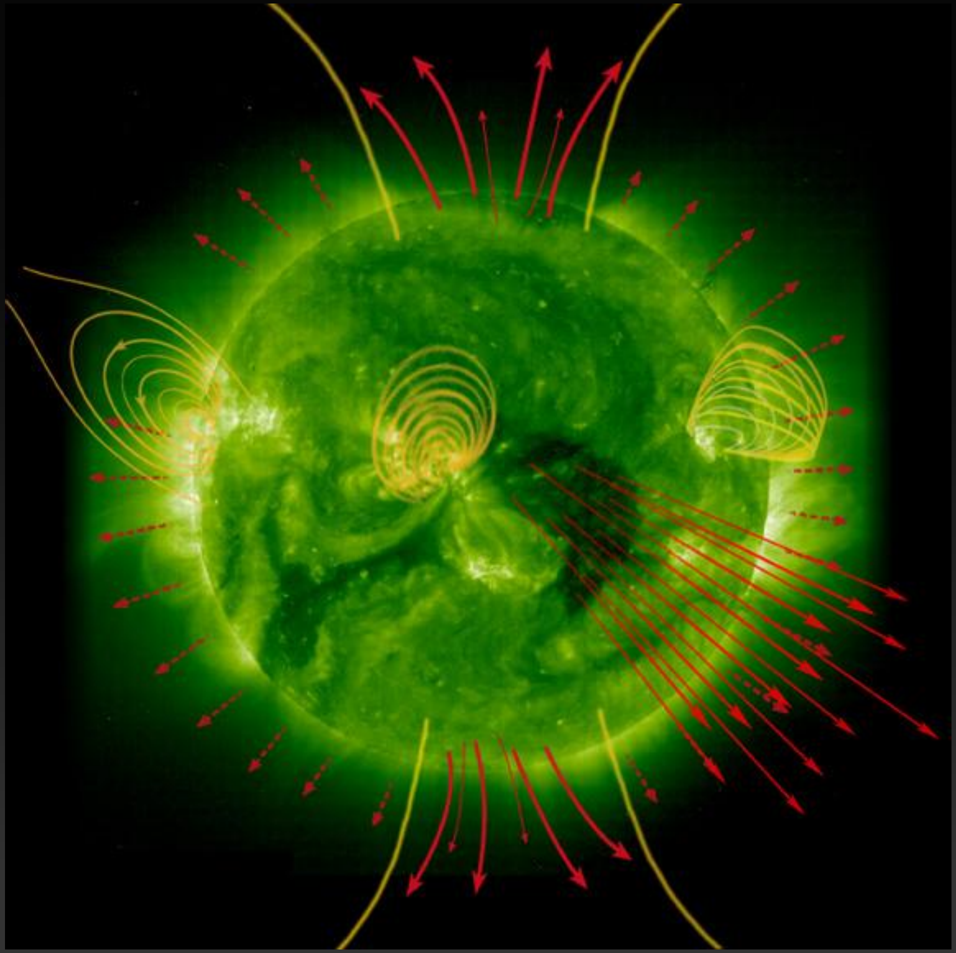
Low-mass star, brown dwarf

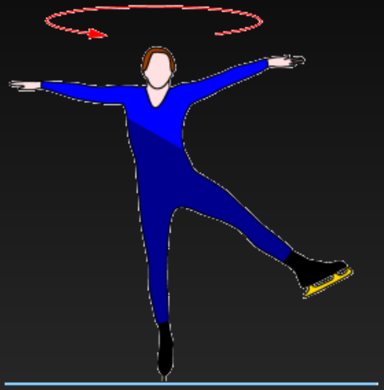
Planet

Spin Down after star has formed

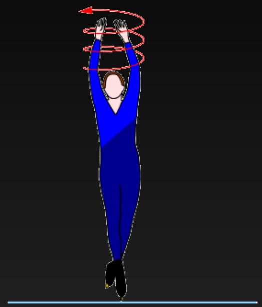
Expanding, ionized wind couples to magnetic field

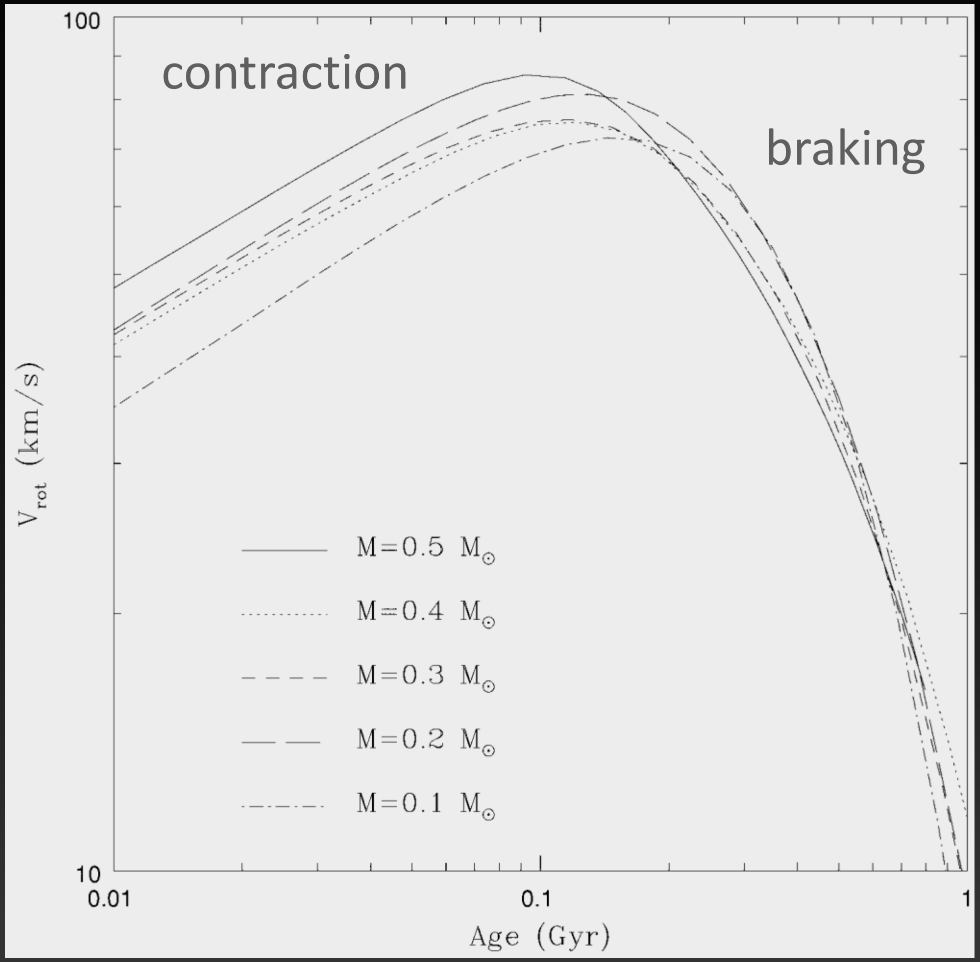


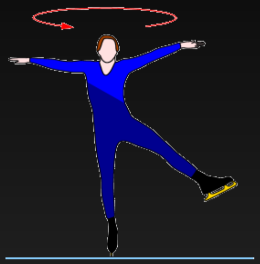




Schematic rotational evolution

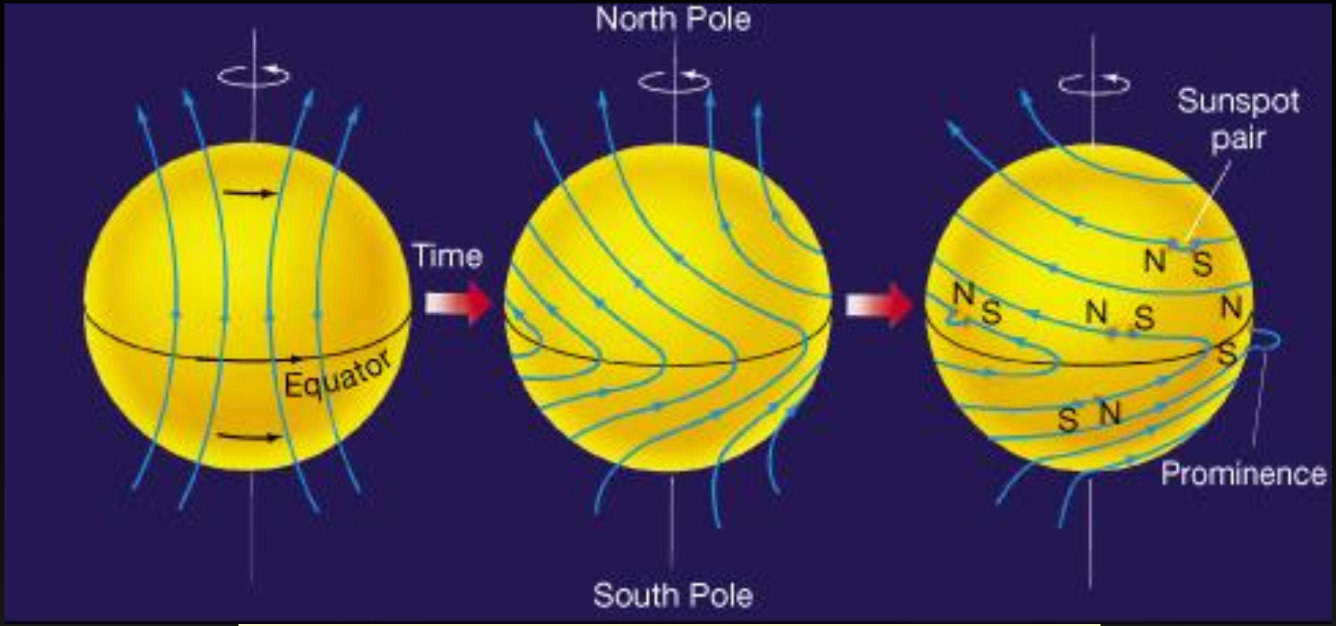


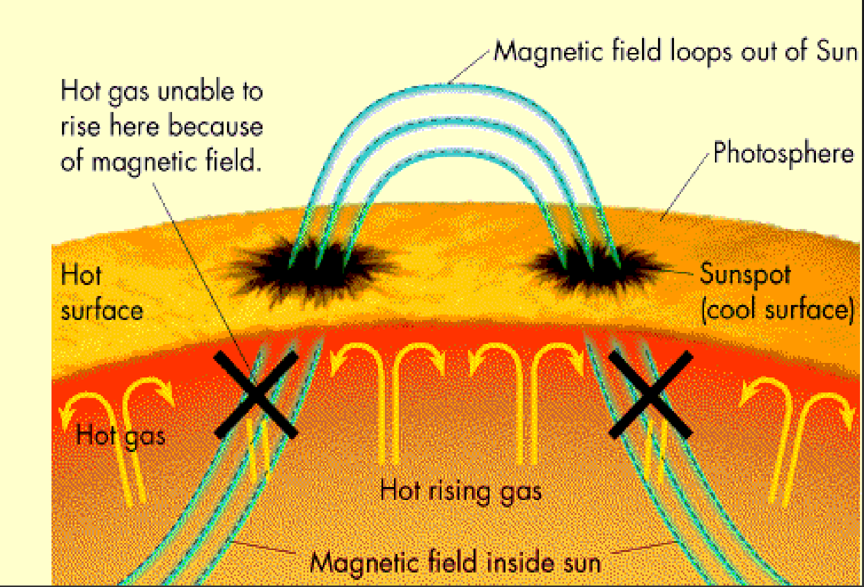




Sills et al., 2000

Sunspots and differential rotation





Observations of stellar dynamos

1. Introduction to stellar magnetism
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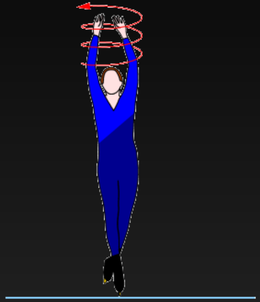
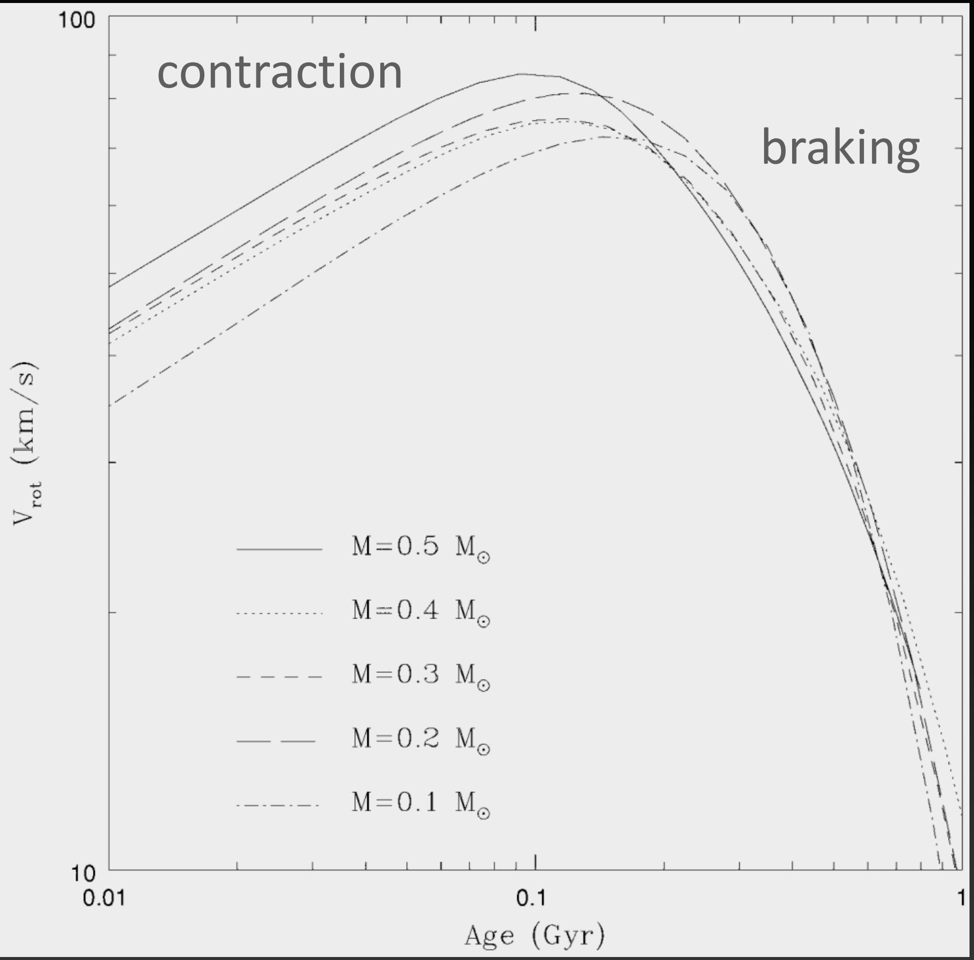
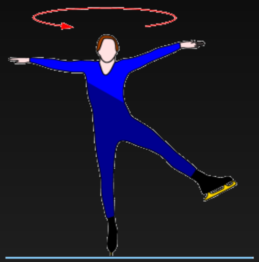
Observations I: Rotation



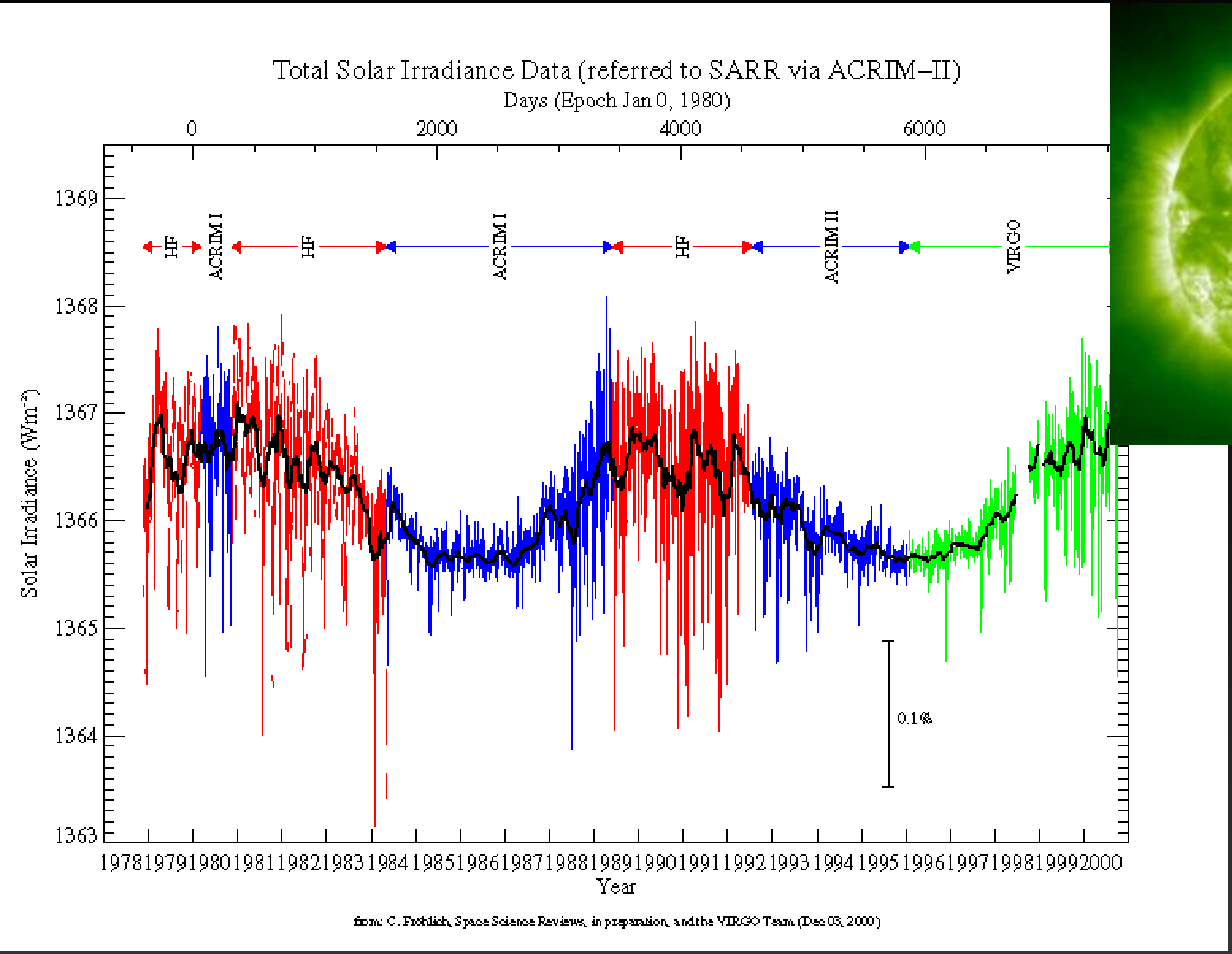


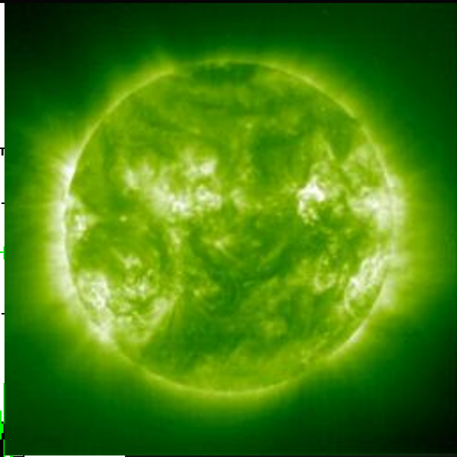


Sills et al., 2000

Observations II: non-thermal emission

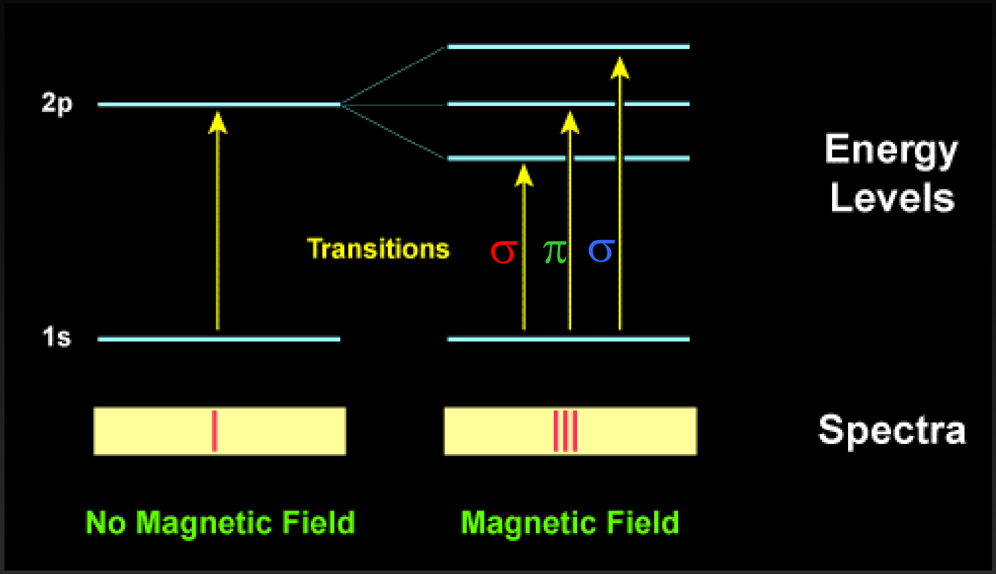
(activity)



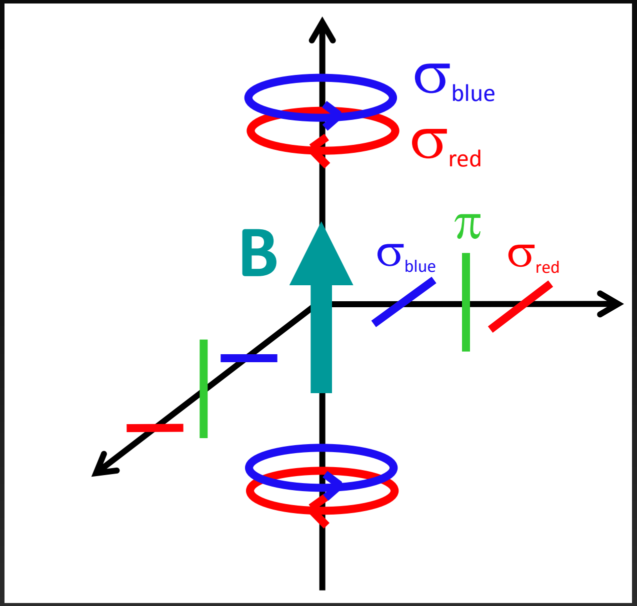


Observations III: Presence of magnetic field
(Zeeman effect)

Line-splitting in the presence of a magnetic field



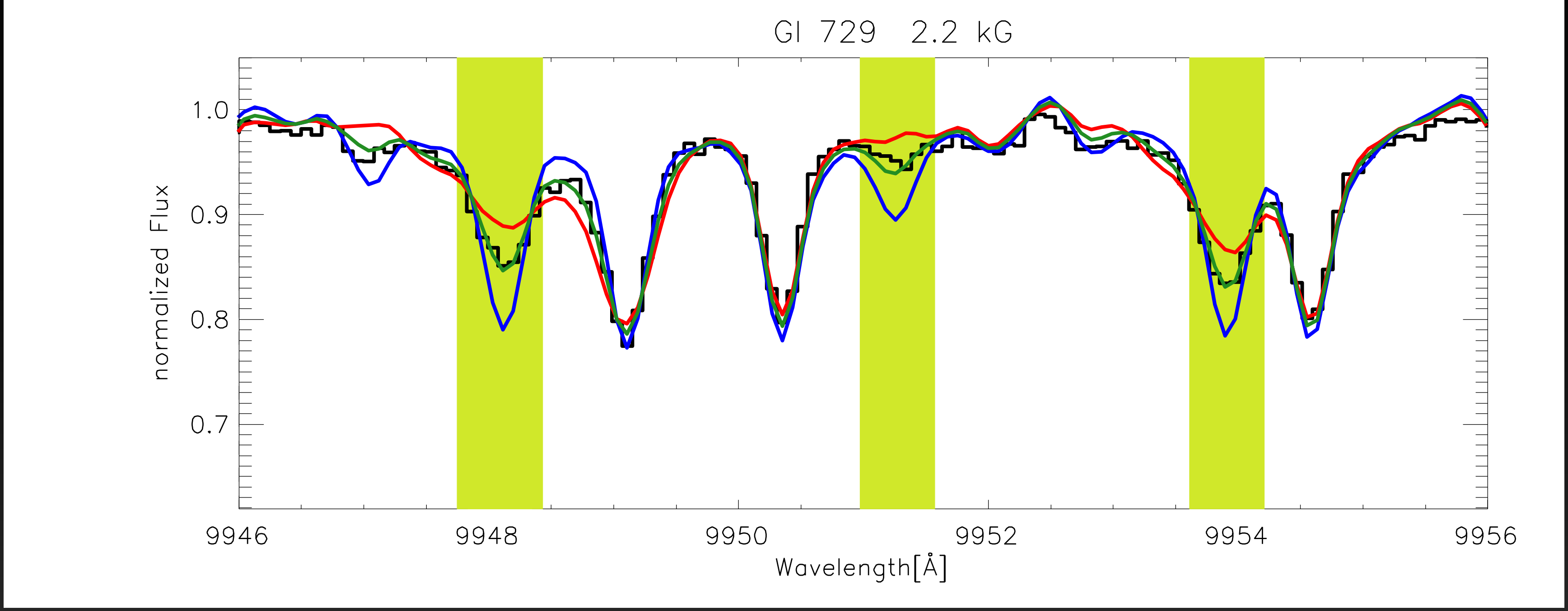
Polarization of components depends on the viewing angle



Integrated light: Stokes I

Polarization: Stokes V, Q, U

Examples of magnetic field measurements in integrated light
(Stokes I)

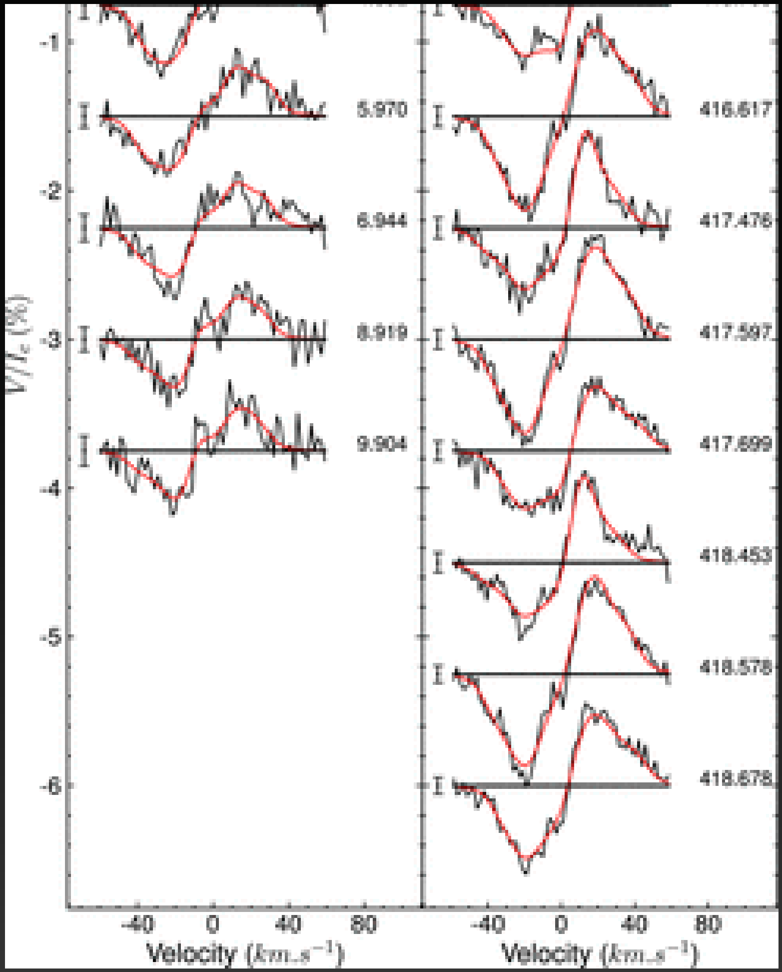


Reiners & Basri, 2007

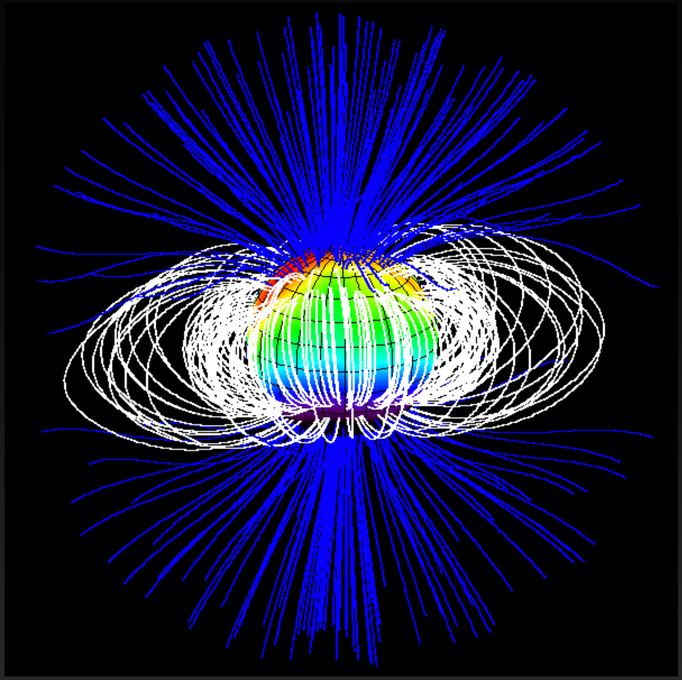
Star	Spectral Type	log (L_X/L_{bol})	log ($L_{H\alpha}/L_{bol}$)	*Bf* [kG]
GJ 1227	M4.5	< -3.85	< -5.0	
Gl 729	M3.5e	-3.50		2.0*
Gl 873	M3.5e	-3.07	-3.70	3.9*

*Johns-Krull & Valenti, 2000
(from atomic lines)

Examples of magnetic field measurements in polarized light
(Stokes V)



Morin et al., 2010



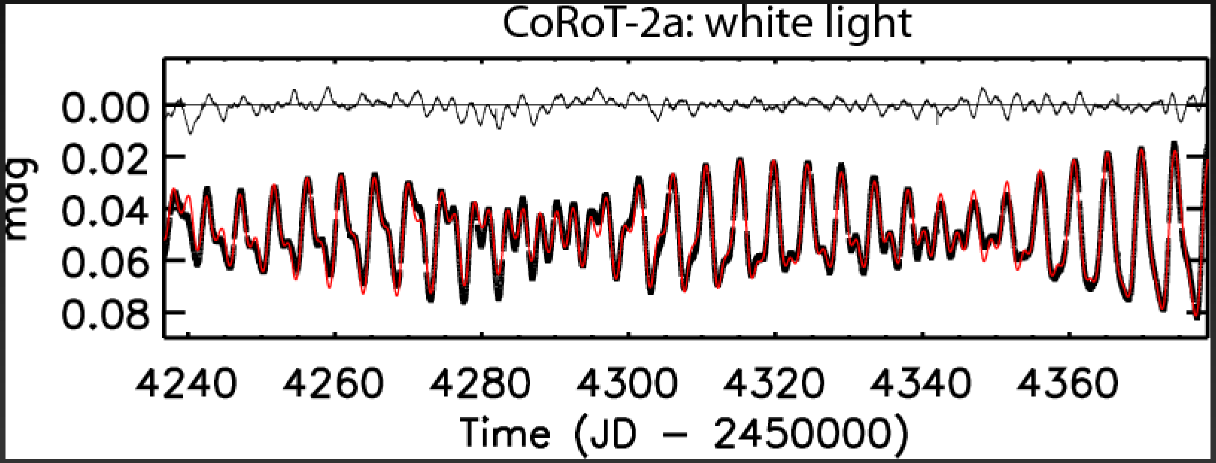
© MM Jardine & JF Donati

important:
observation of uncancelled flux only!

Differential rotation

Rotation period can change with time

or

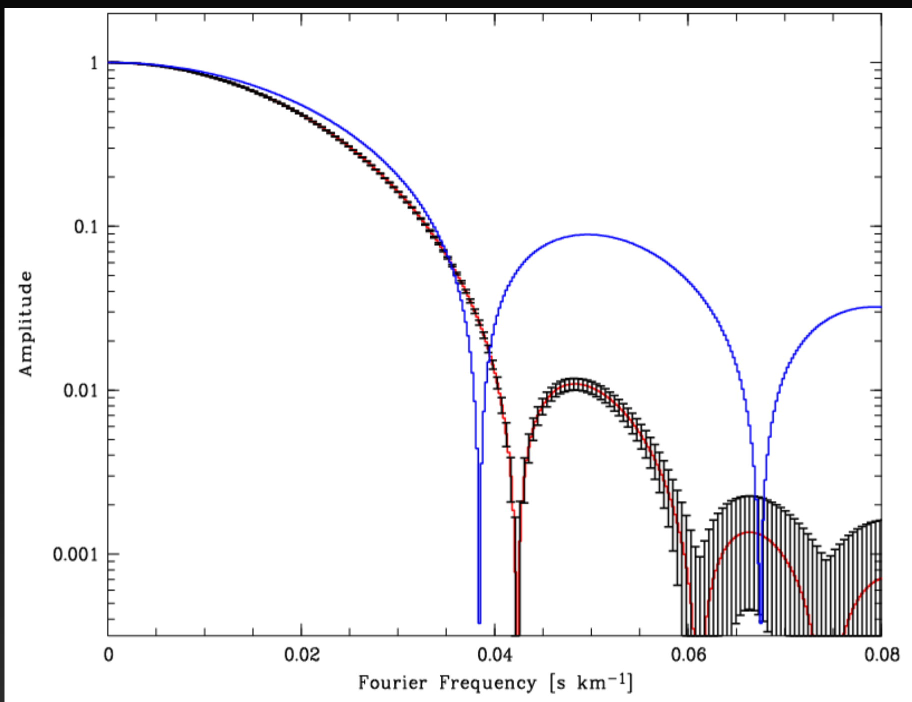


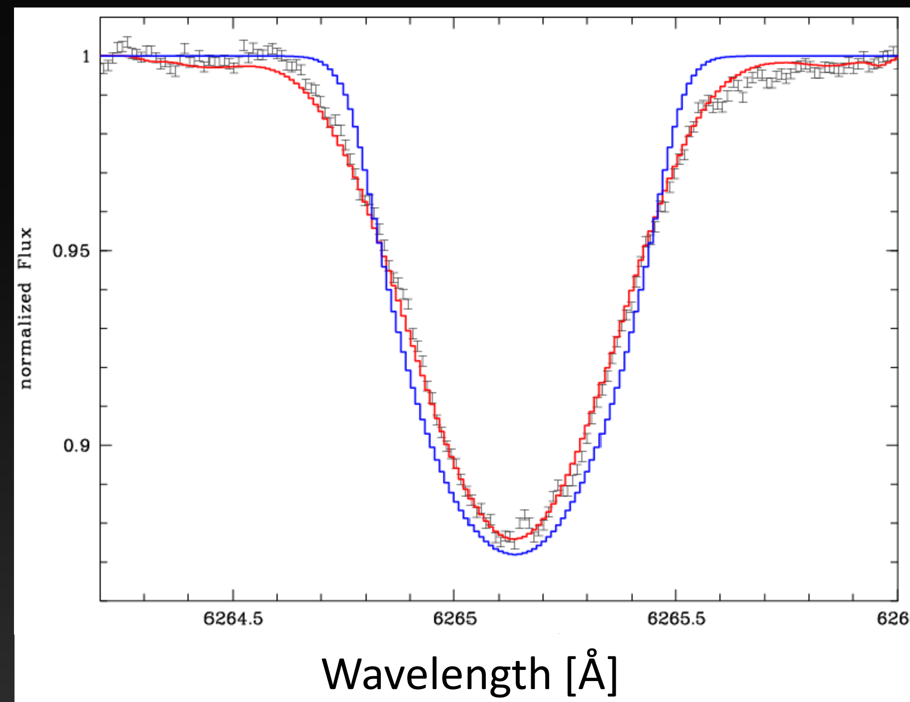
Beat pattern

Differential rotation

Example: HD 121370

$\alpha/\sqrt{\sin i} = 0.37 \pm 0.1$





red: observed profile

blue: profile of rigid rotator

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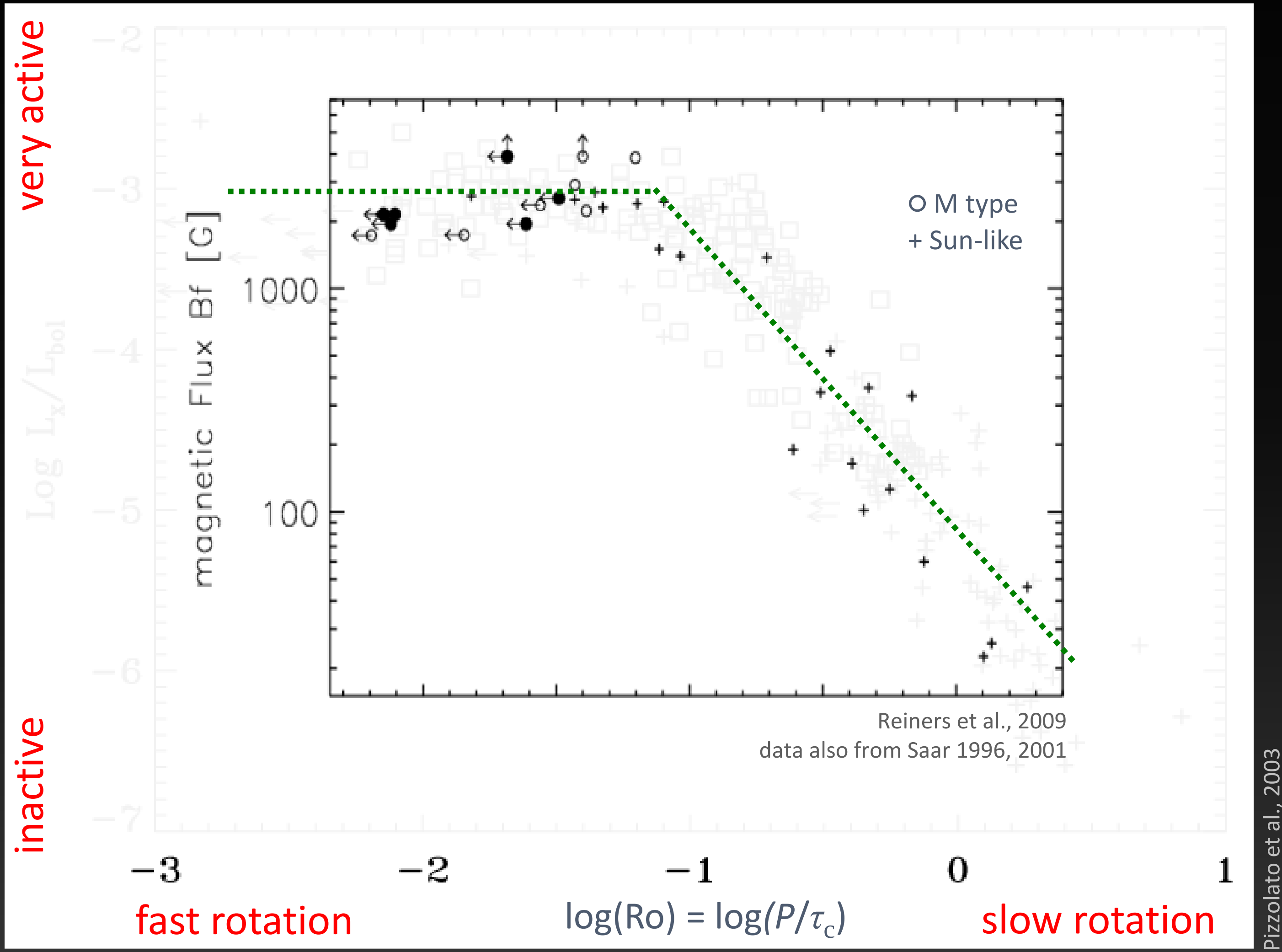
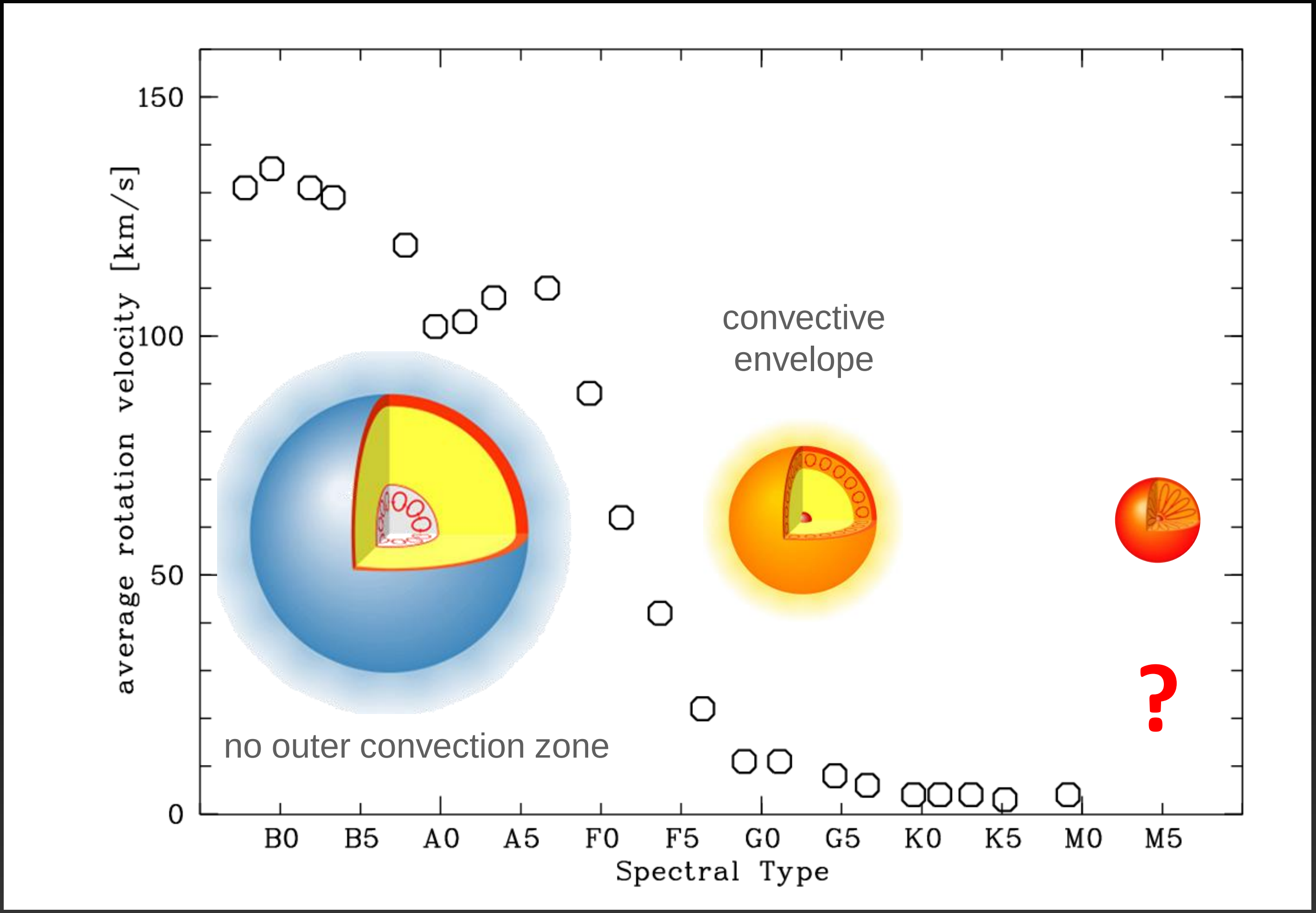
The rotation-magnetic activity relation



Activity saturation is due to magnetic field saturation

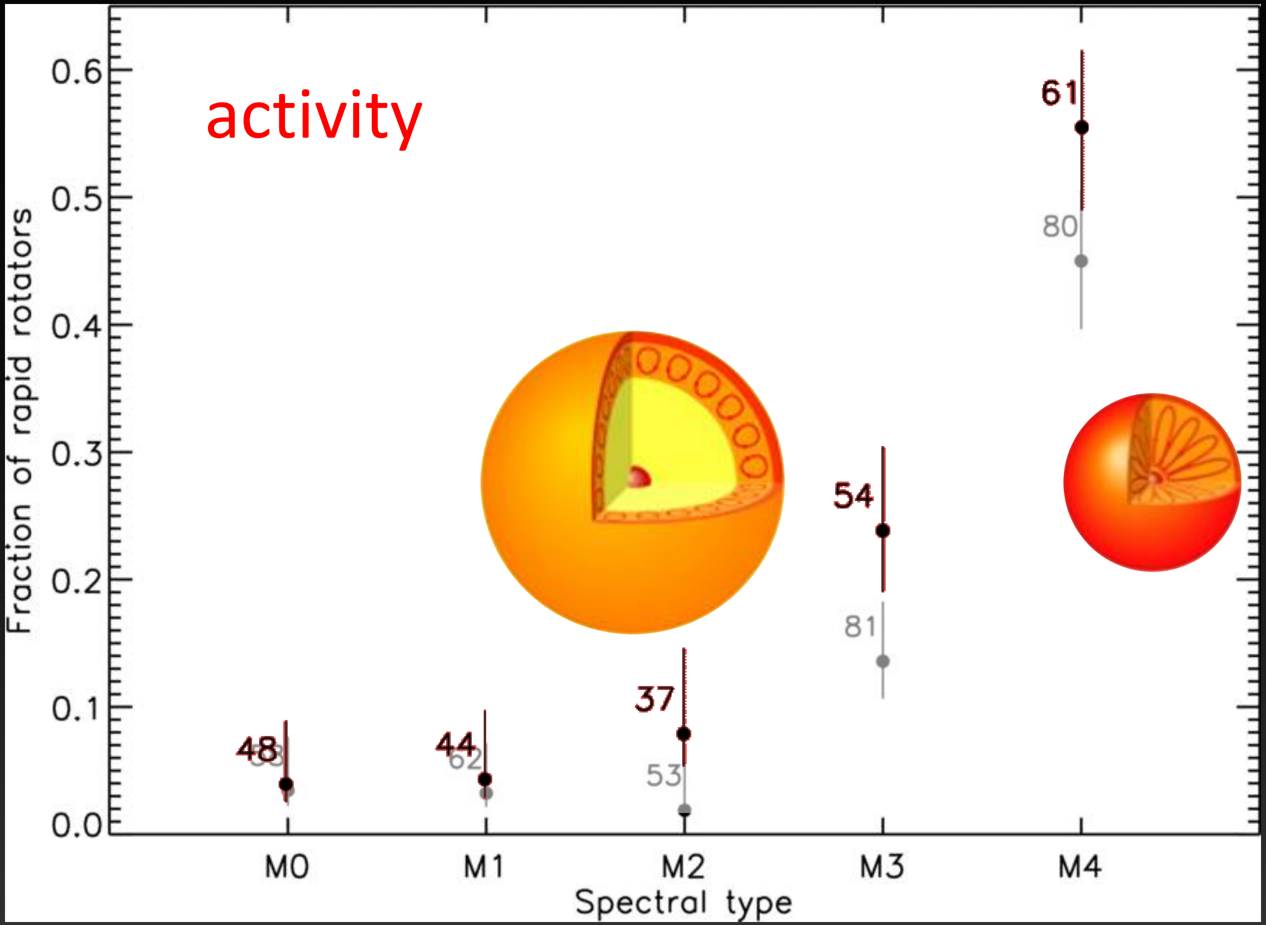
Mean rotation velocities in field stars

(i.e., after enough time to calm down but before later phases of evolution)



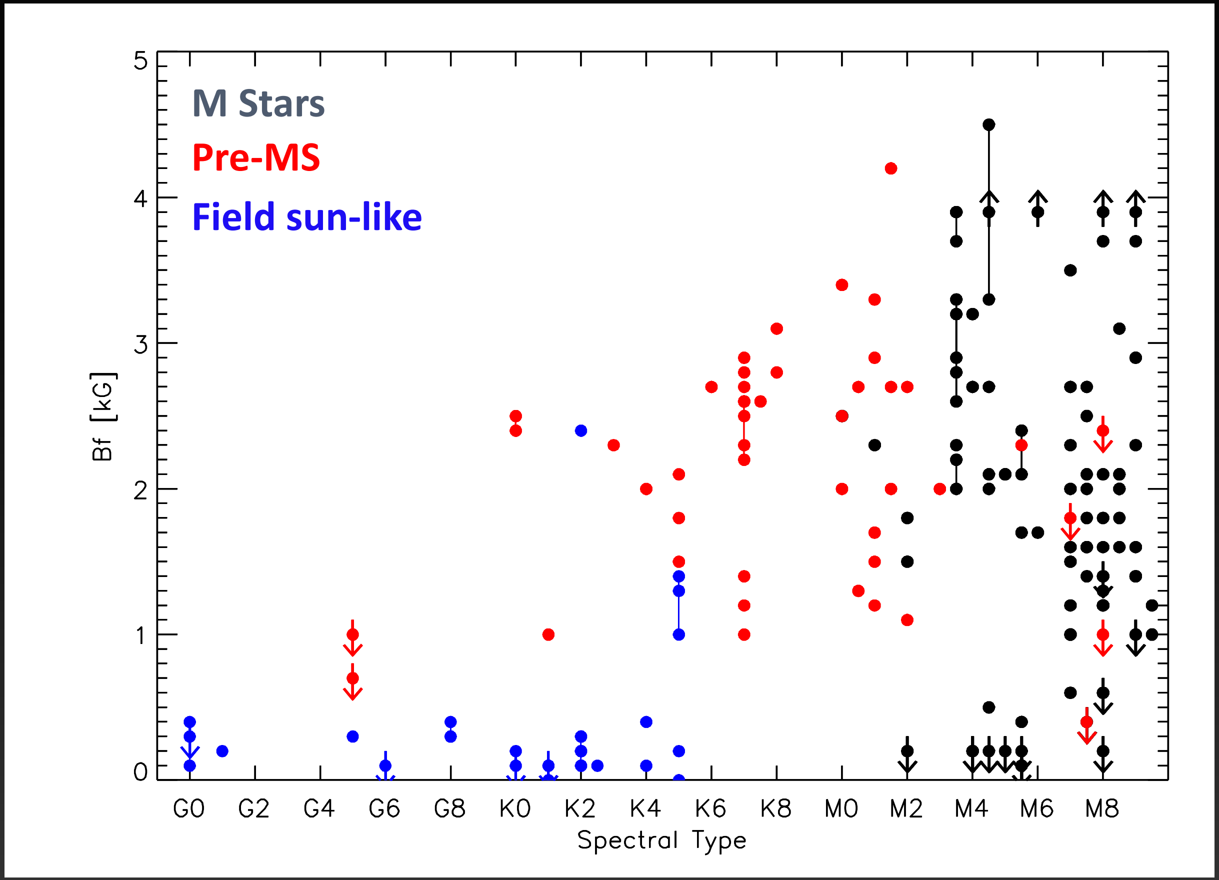
Braking depends on convective structure

Rotation of low-mass stars

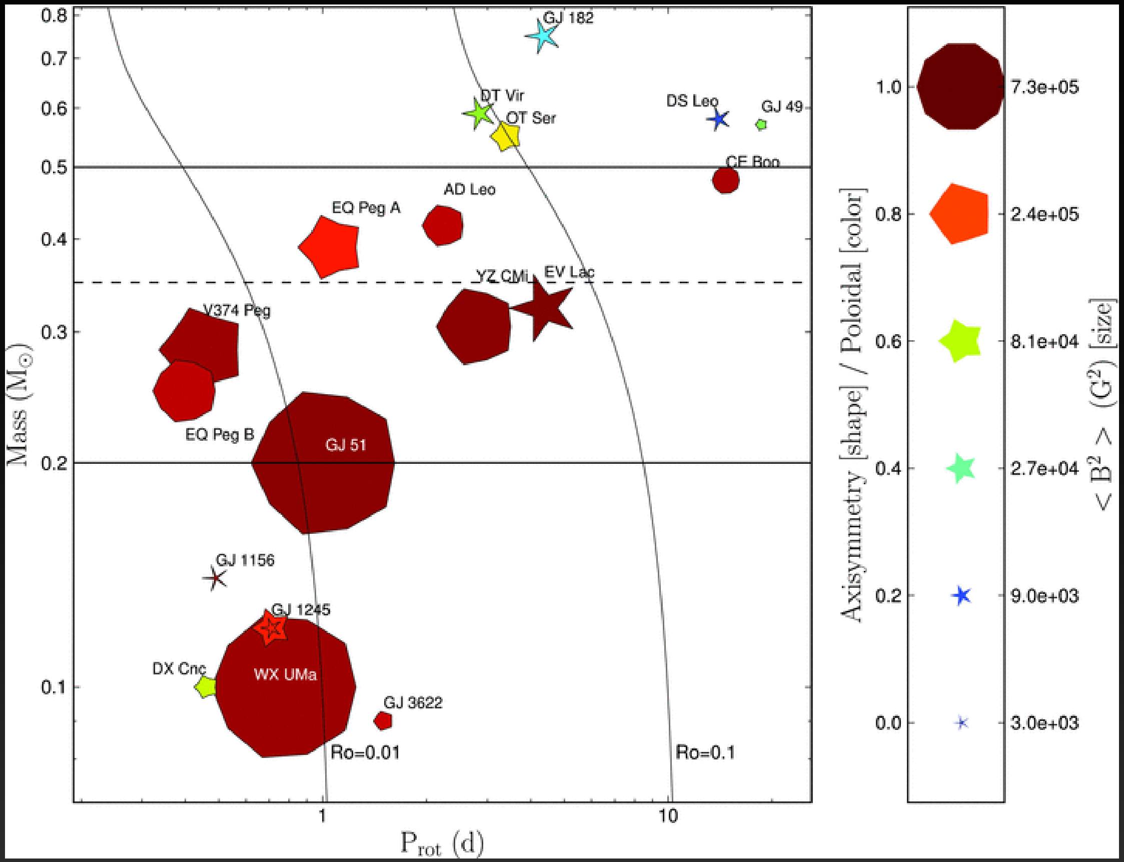


Reiners et al., 2012

Observations of average surface magnetic fields



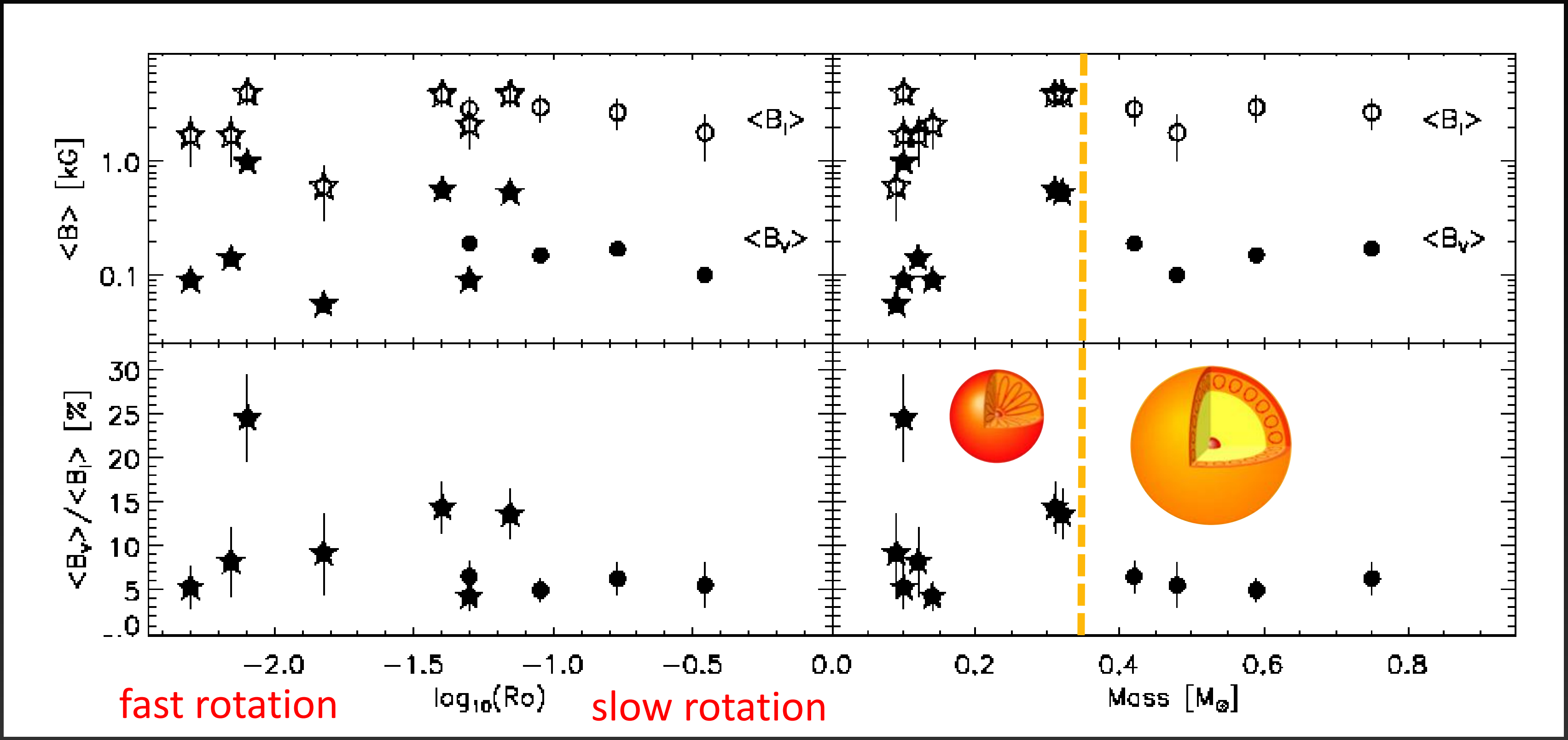
Large-scale geometries from Stokes V



Morin et al., 2010

- More flux detected at lower masses (and Rossby numbers)
- Different geometries found
- Large-scale field only (un-cancelled flux)

Comparison between flux detected in Stokes I and V across the boundary to complete convection

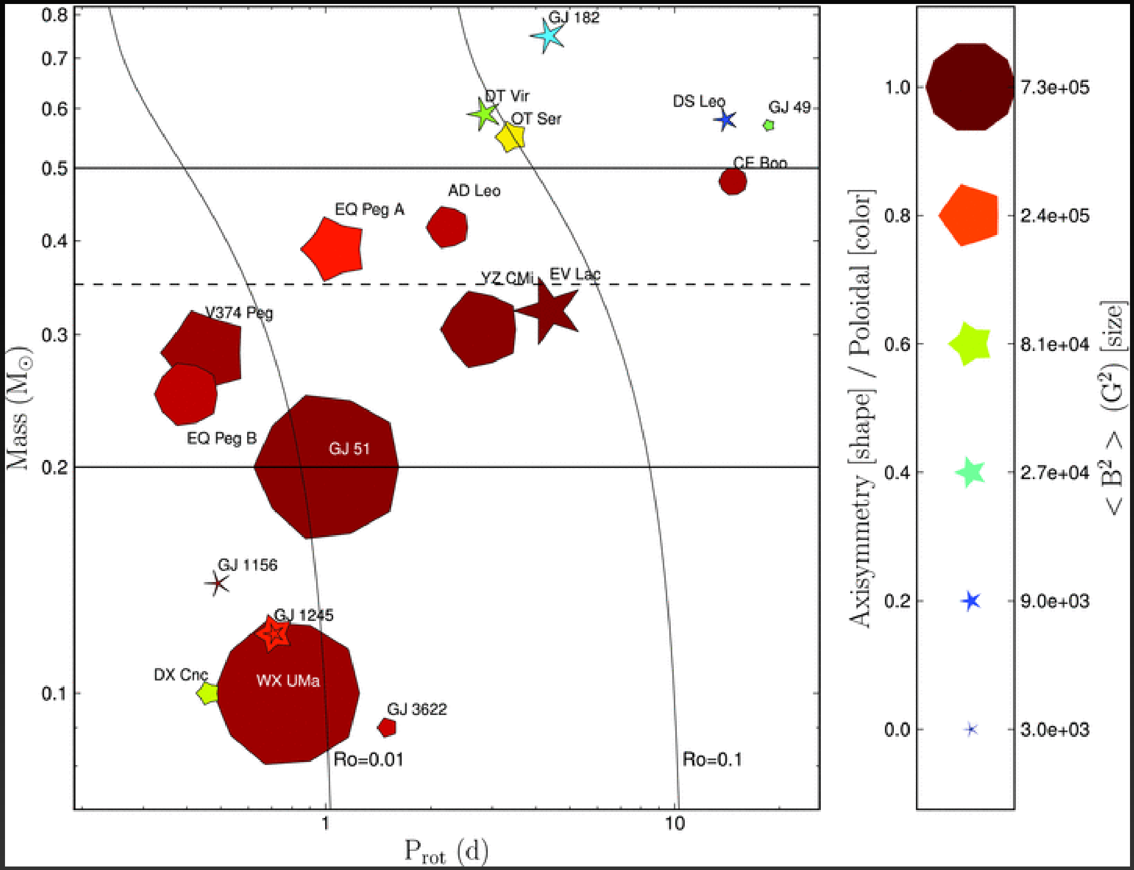


full field

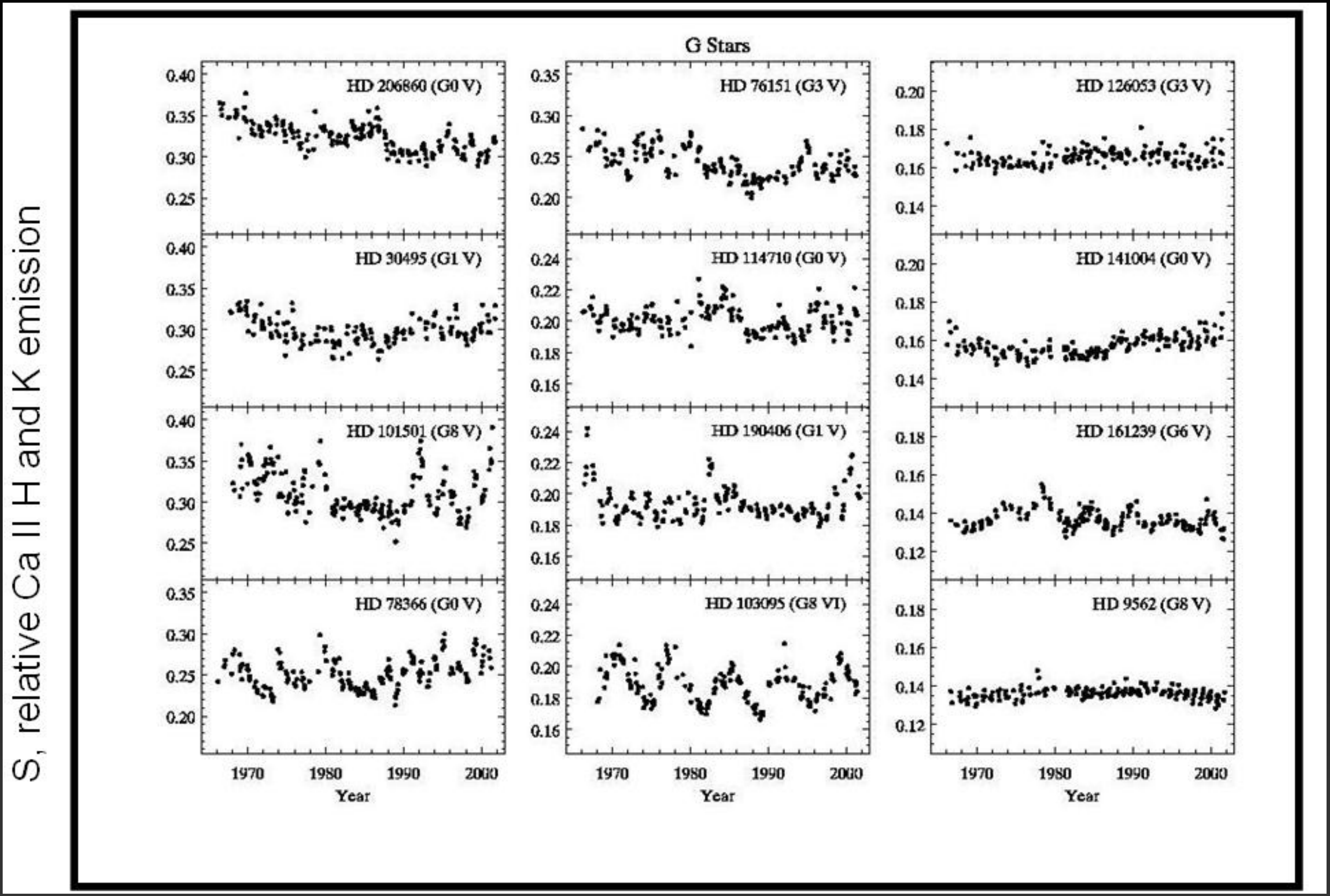
"large-scale"

Large-scale geometries from Stokes V

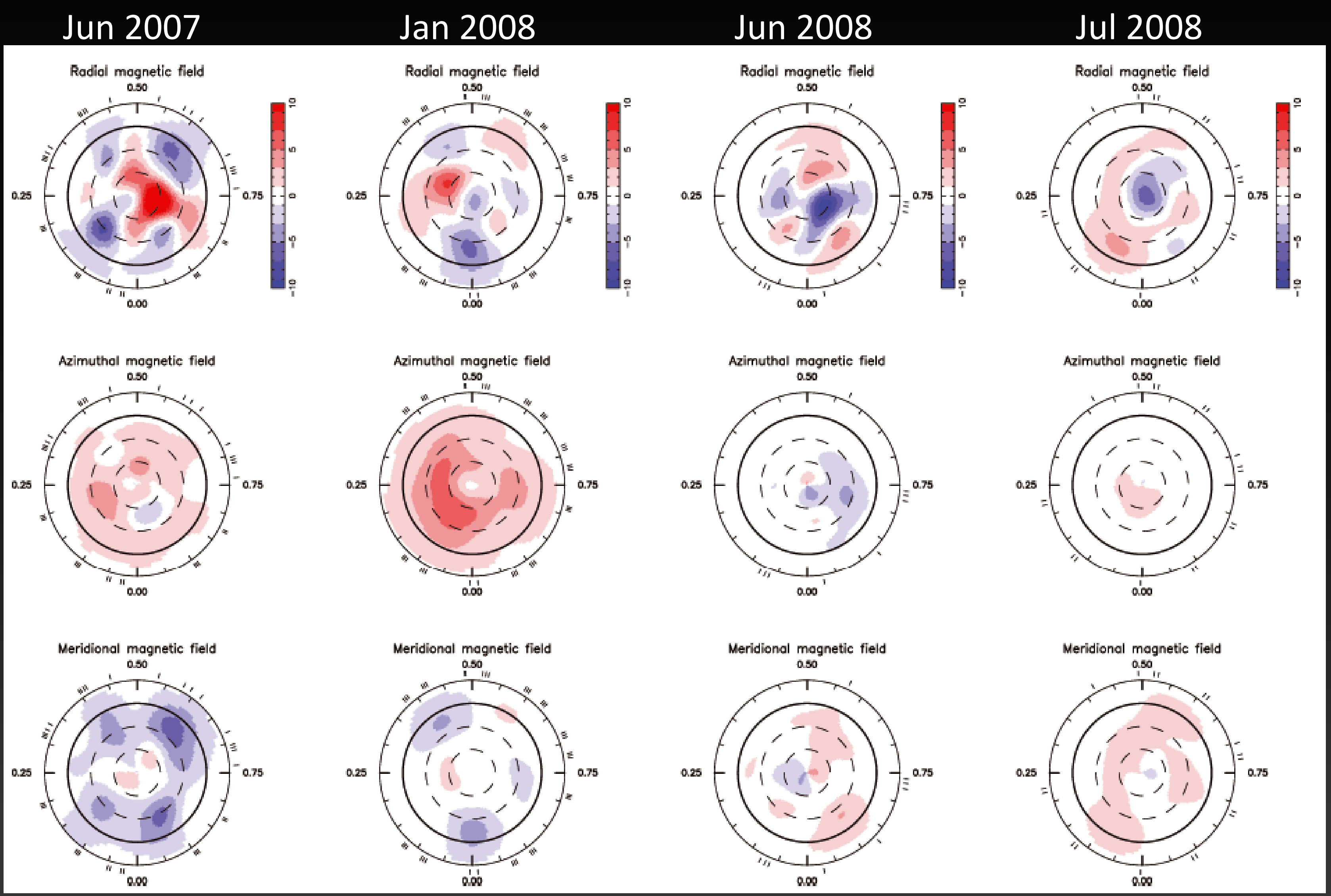
What about the missing 75 – 95% of the magnetic field?



Evidence for cycles in sun-like stars

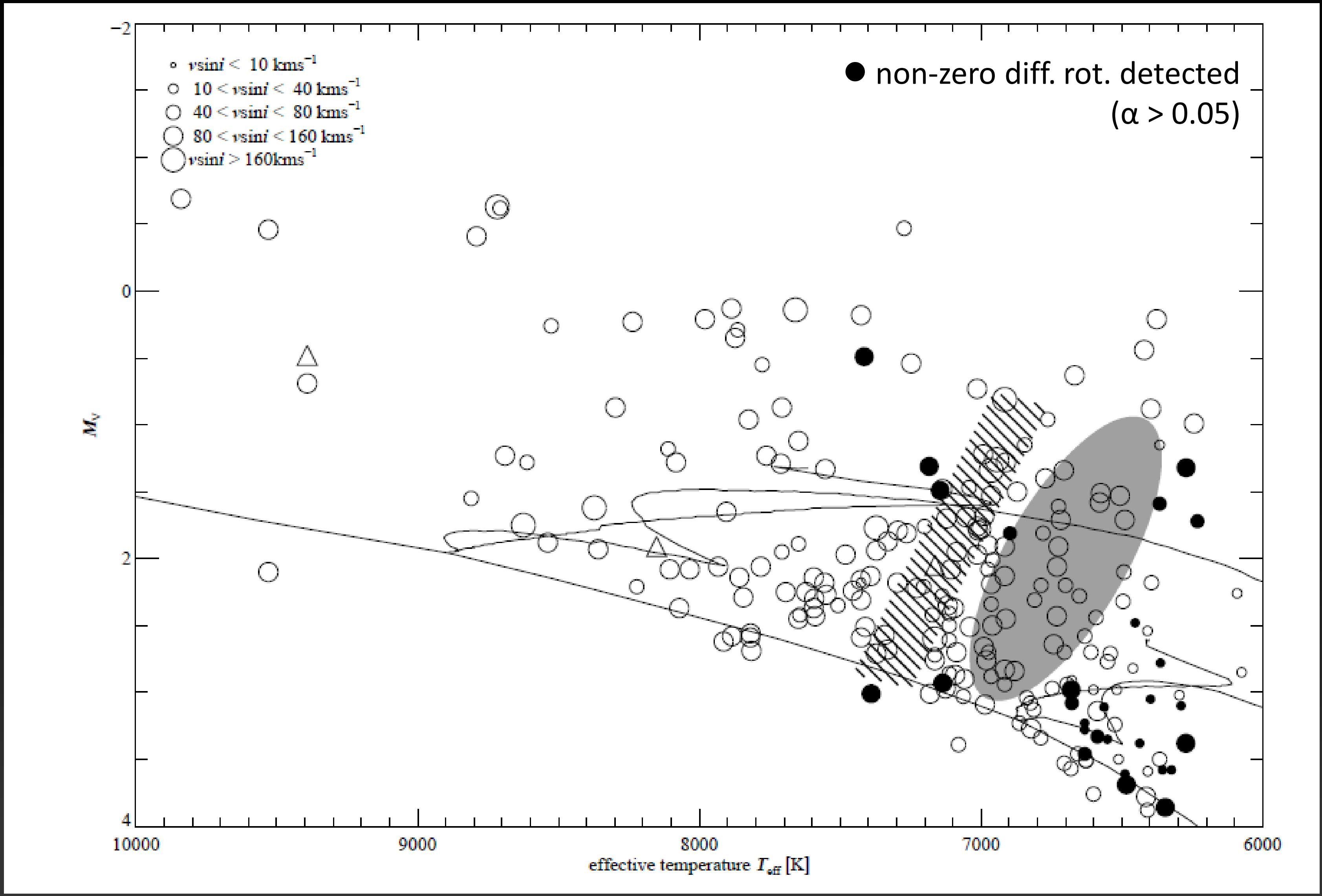


Polarity reversal in Doppler maps (?)



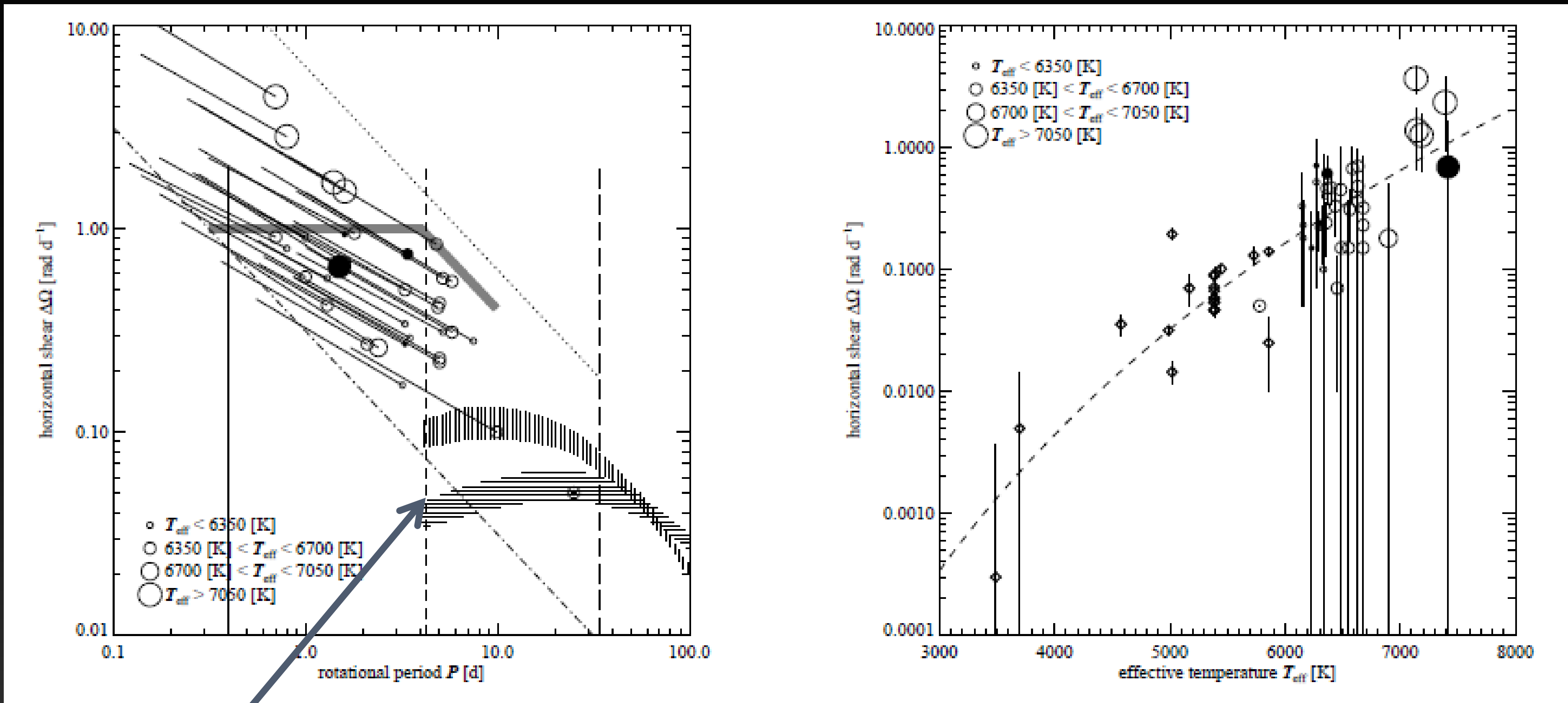
Fares et al., 2009

Differential rotation



Ammler-von Eiff & Reiners, 2012

Differential rotation



Theoretical predictions for F8 and G2 stars (Küker & Rüdiger, 2005)

Ammler-von Eiff & Reiners, 2012

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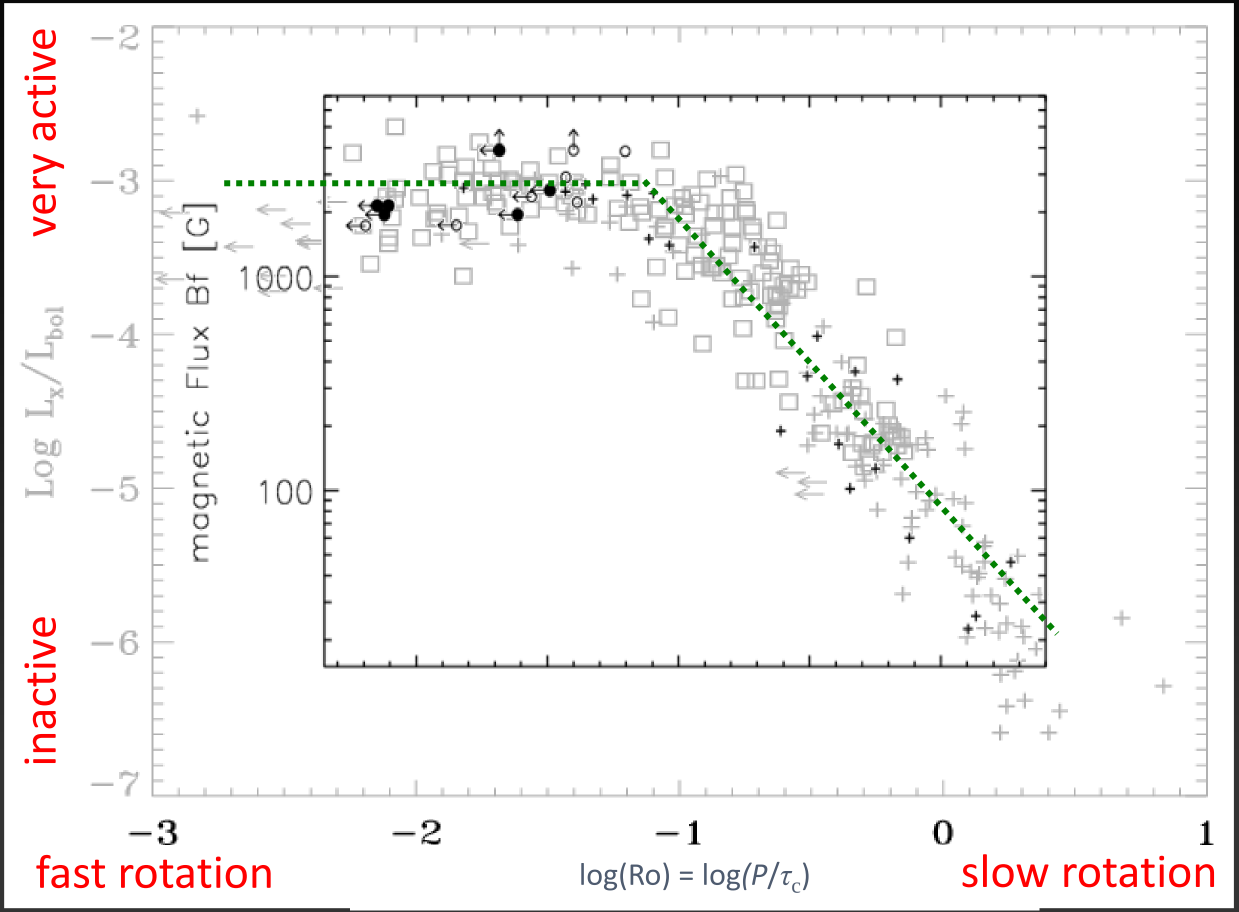
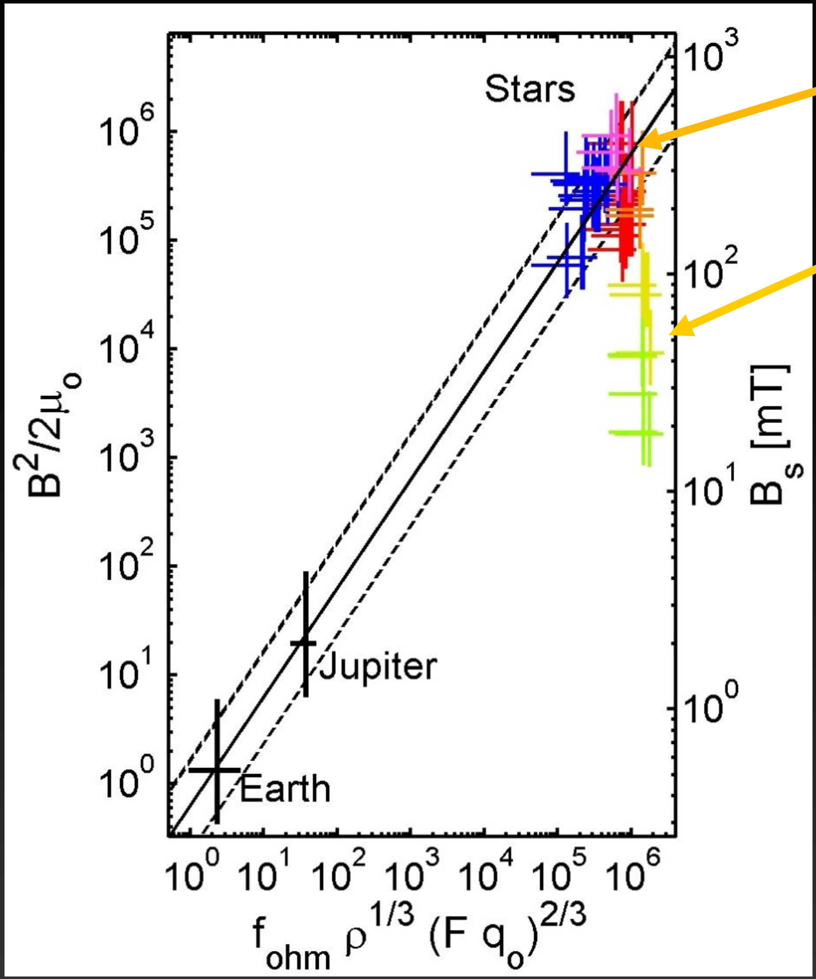
The picture

1. Rotation = magnetic field = activity
2. Field density saturates at a few kG



Convective flux-scaling from geo-dynamo models



Christensen, Holzwarth & Reiners, Nature, 2009

saturation level

slow rotation
(less efficient
dynamo)

In the model, flux is generated in the entire convection zone.

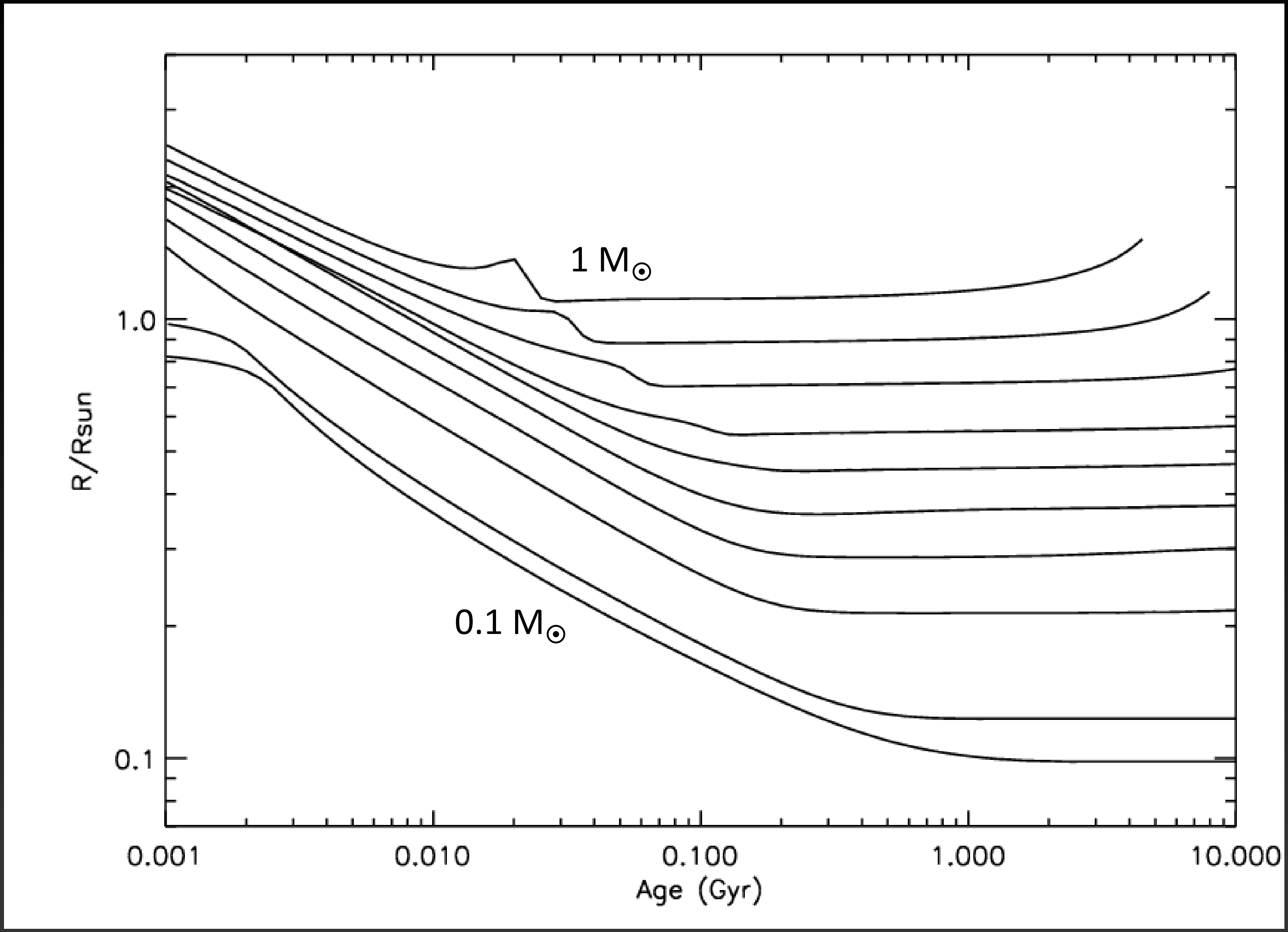
The picture

1. Rotation = magnetic field = activity
2. Field density saturates at a few kG
3. Maximum magnetic energy scales with convective energy

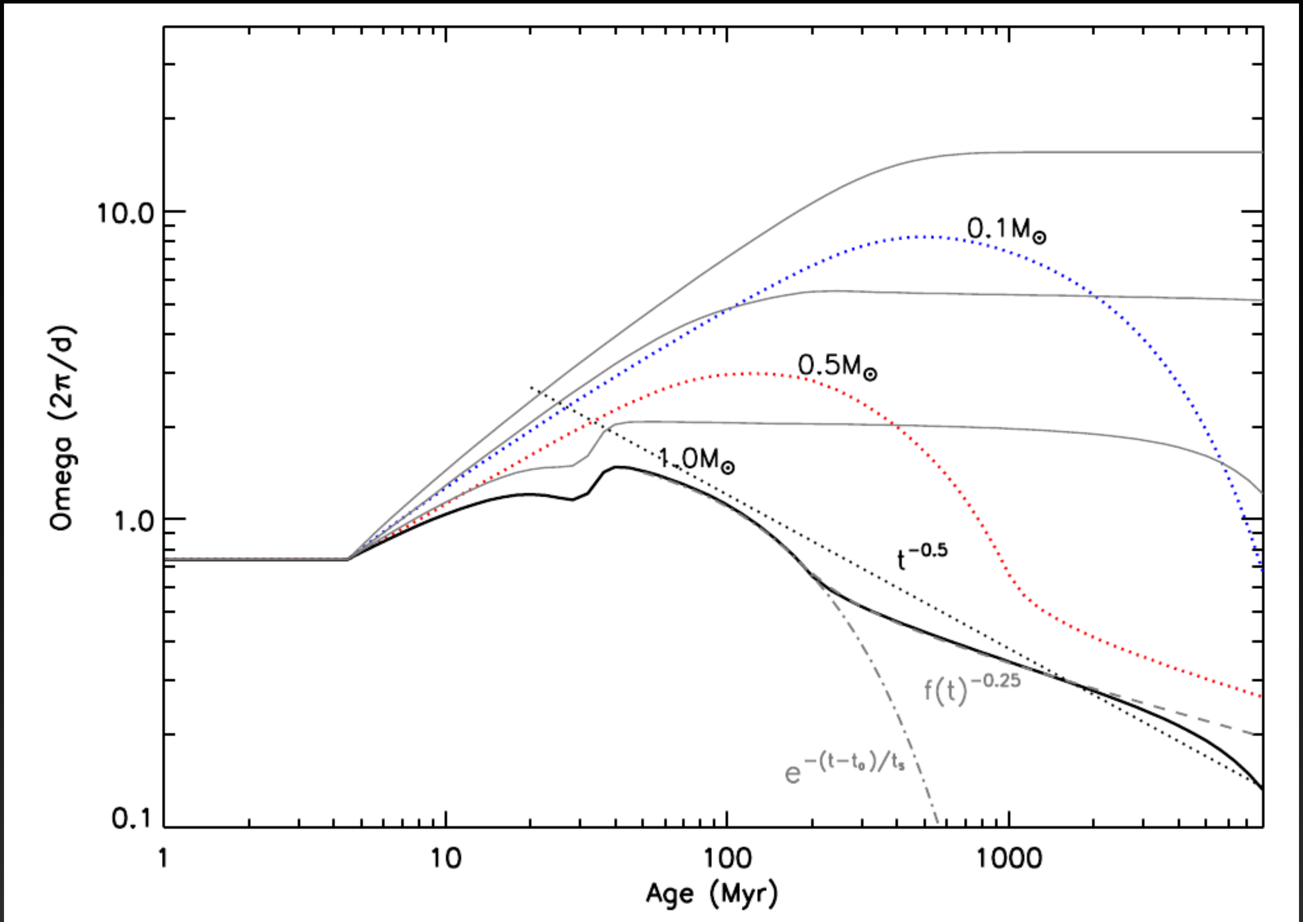
What about the transition to fully convective stars?

Why are fully convective stars faster and more active?
Less braking due to different field geometry?

Radii are very different



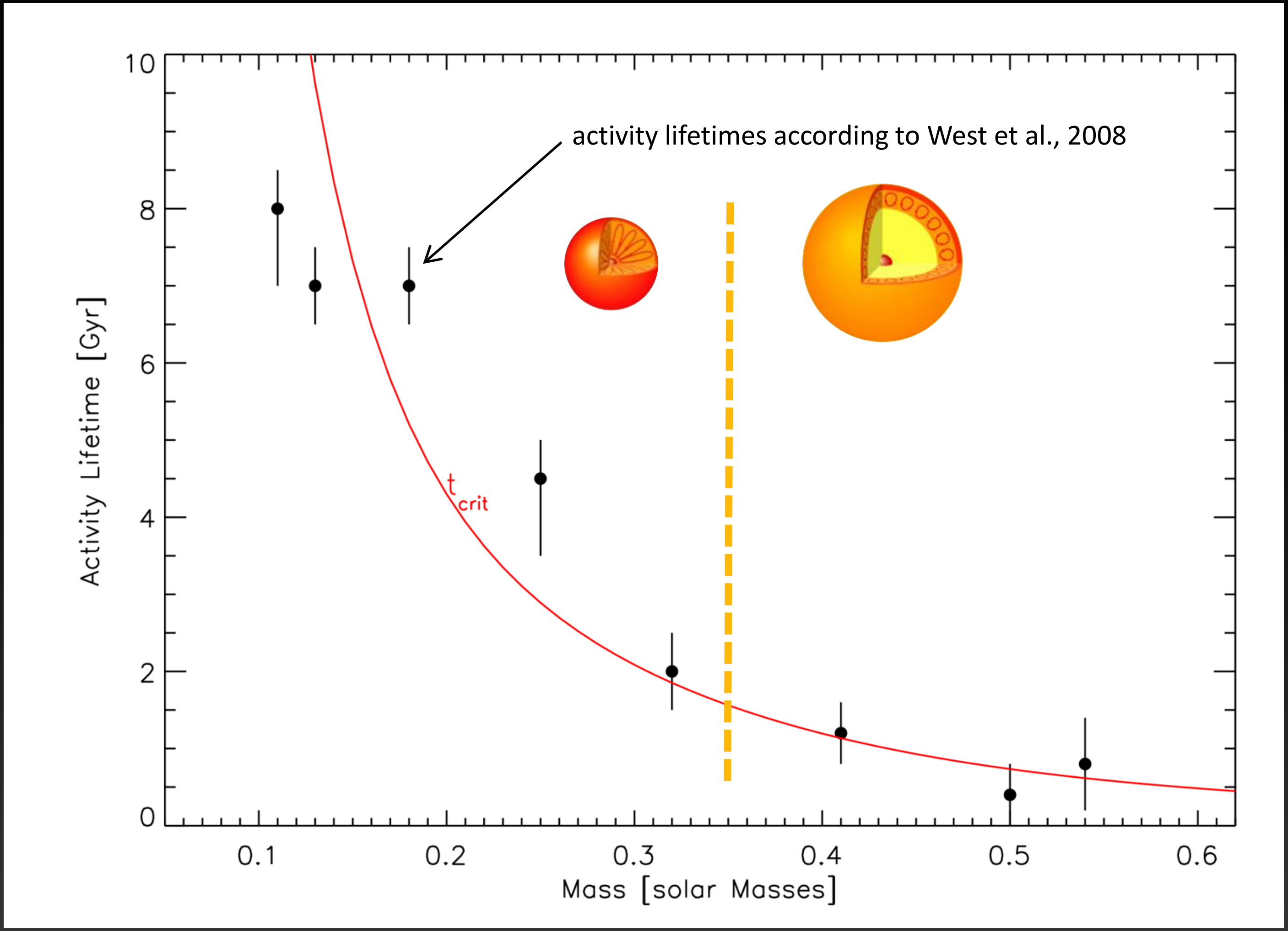
Evolution of angular velocity



Reiners & Mohanty, 2012

Low-mass stars spin-down slower;
fully convective stars are smaller than stars with radiative cores

Picture can explain activity lifetimes



The picture

1. Rotation = magnetic field = activity
2. Field density saturates at a few kG
3. Maximum magnetic energy scales with convective energy
4. No fundamental difference between partial and full convection

Open questions:

- Where is the small-scale field?
- Are there different dynamo modes?
- On what timescale do fields vary?
  Cycles, field reversals, etc.
- How good of an example is the Sun for other stars?

- etc., etc., etc., …