Rotation and activity in low-mass stars

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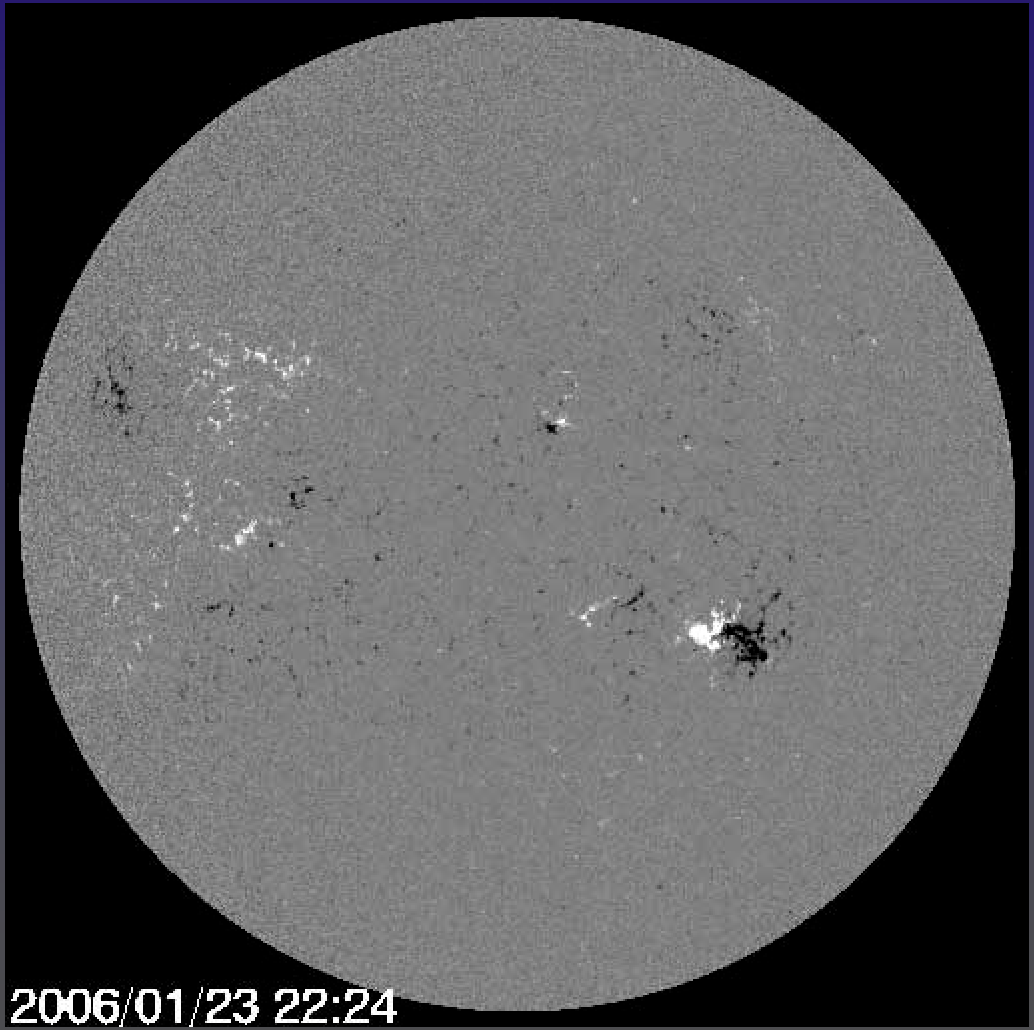
Outline

I. Introduction:
Magnetic activity and why we care about it

II. Spin-up and spin-down:
Rotational evolution of sun-like stars

III. Magnetic field observations:
Explaining rotational evolution at the bottom of the Main Sequence

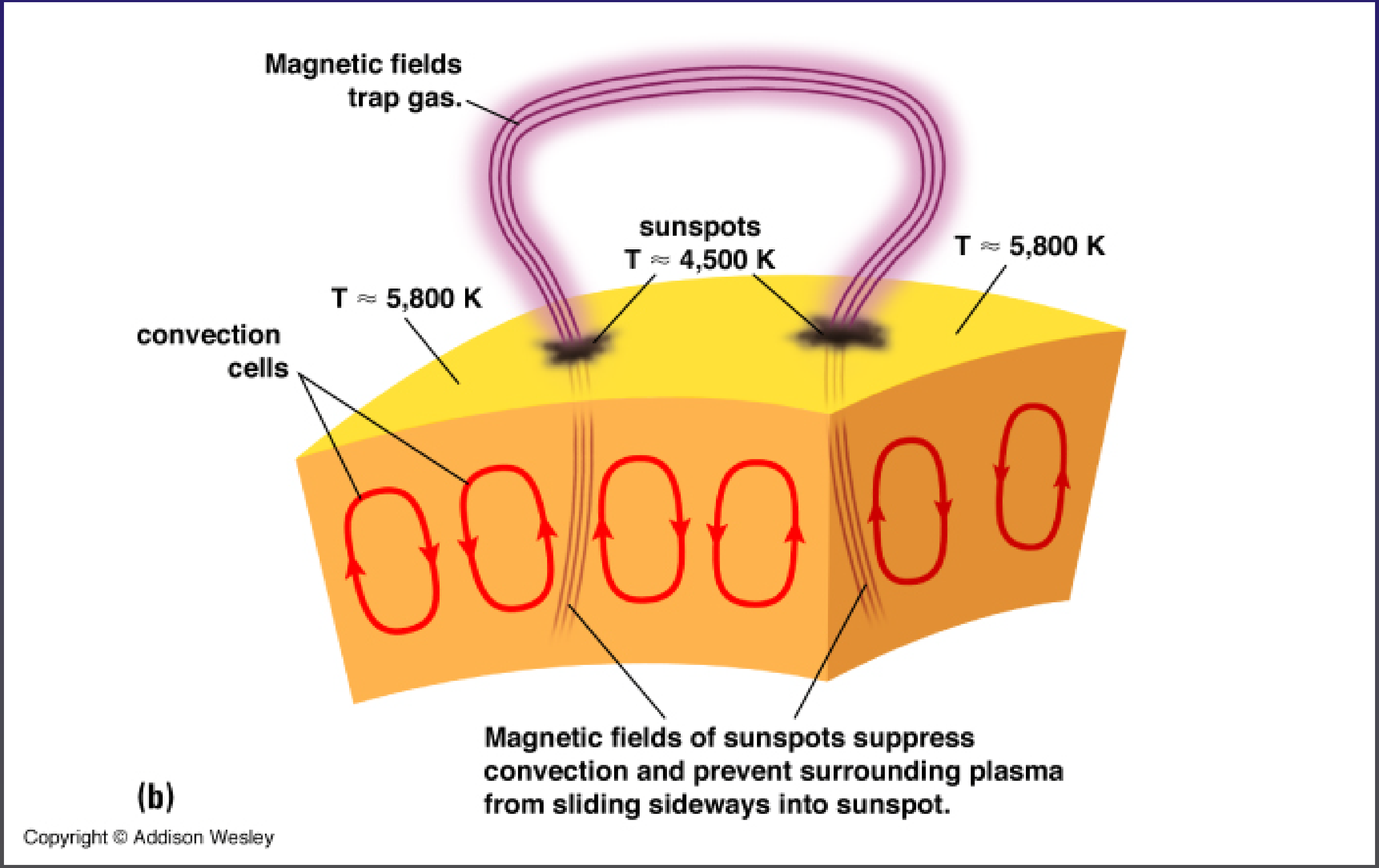
Magnetic activity



SOHO

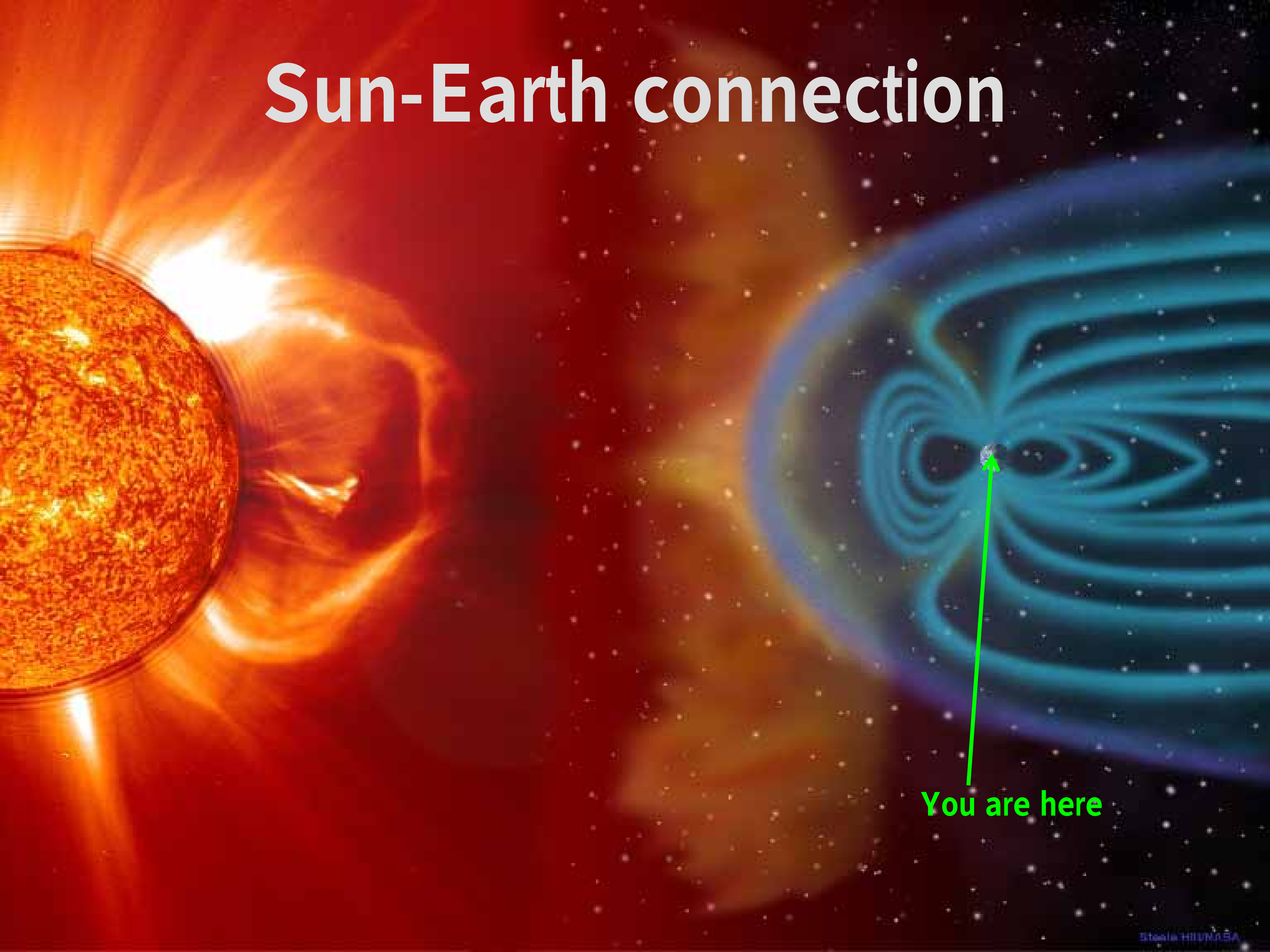
Intensity
Magnetogram

Sunspots



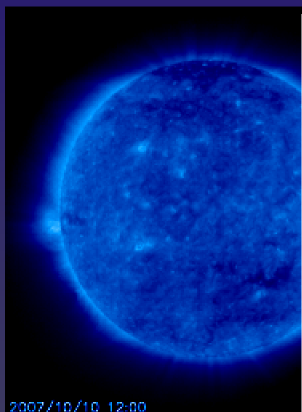
Magnetic fields
trap gas.
sunspots
T ≈ 4,500 K
T ≈ 5,800 K
T ≈ 5,800 K
convection
cells
Magnetic fields of sunspots suppress
convection and prevent surrounding plasma
from sliding sideways into sunspot.
(b)
Copyright © Addison Wesley

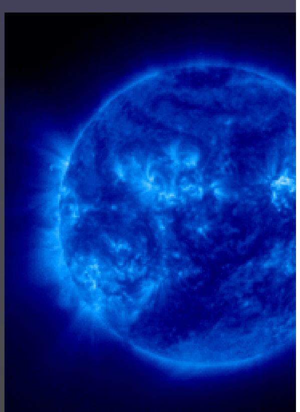
Sun-Earth connection

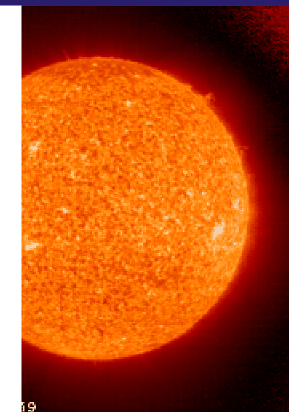


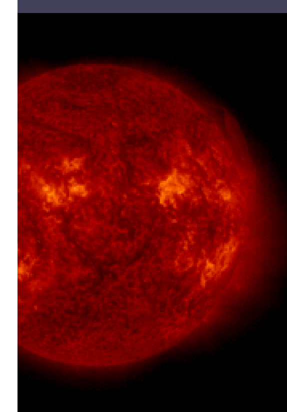
The high-energy Sun and solar variability

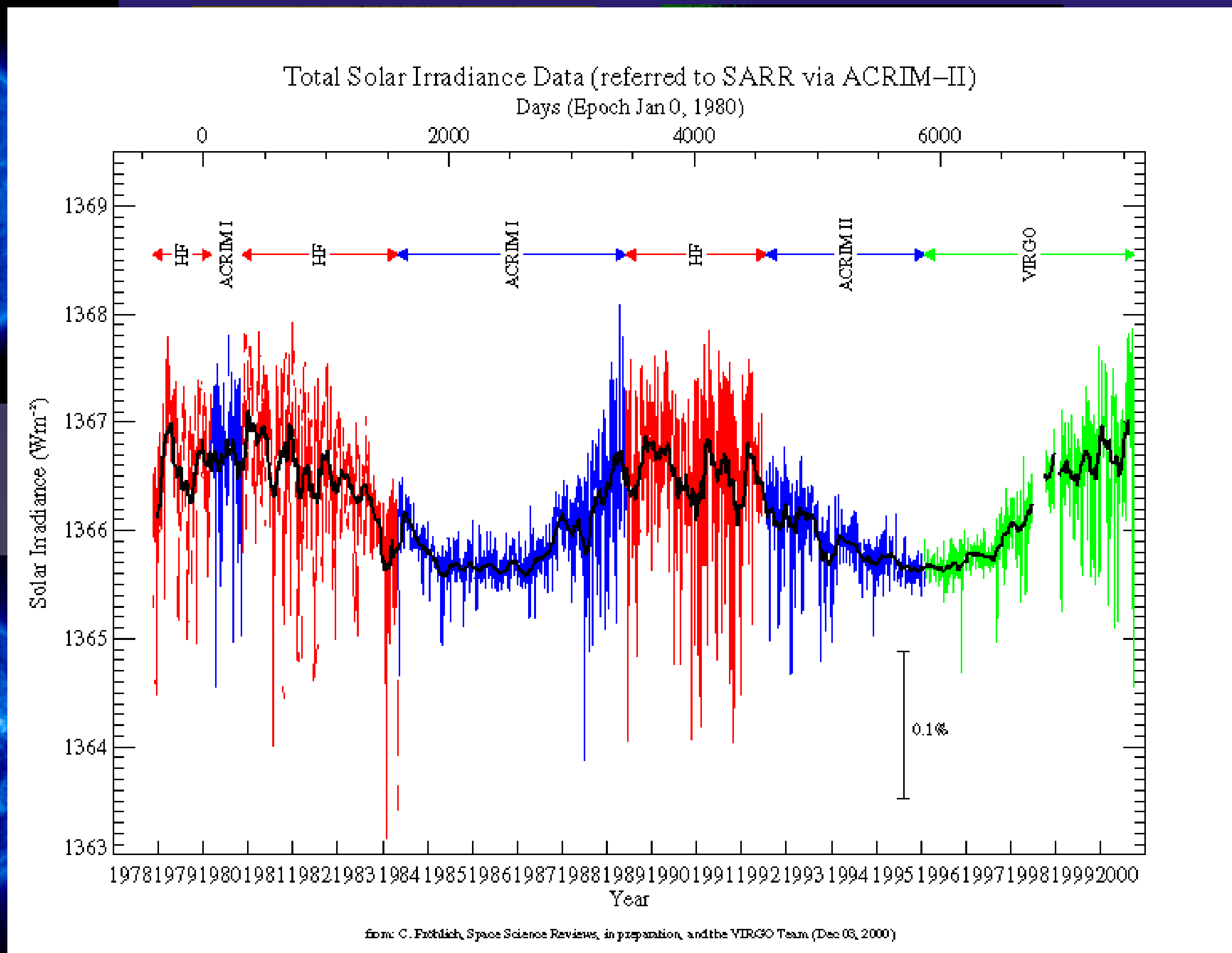
2007











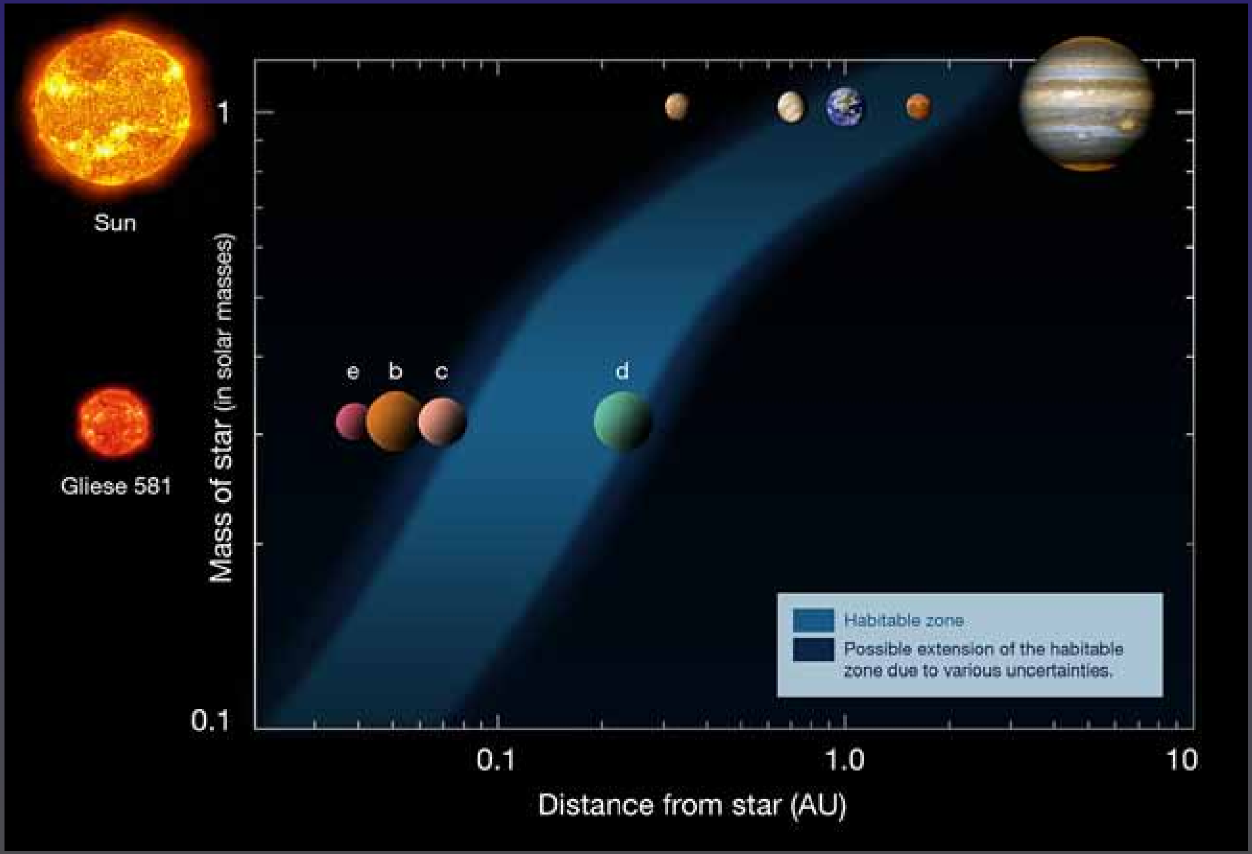
171 Å, T≈1.3MK

284 Å, T≈2.0MK

195 Å, T≈1.6MK

304 Å, T≈1.3MK

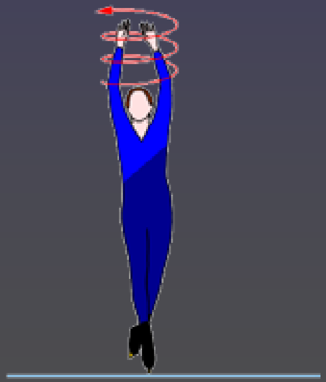
Activity affects the habitability of exo-planets



Part II

I. Introduction: Why care about activity?

II. Spin-up and spin-down:
Rotational evolution of sun-like stars

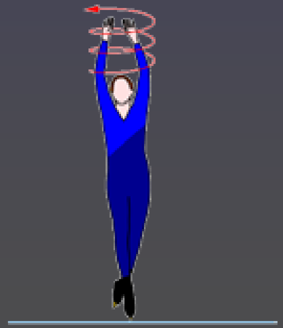


Angular momentum conservation during contraction of the proto- and young star –

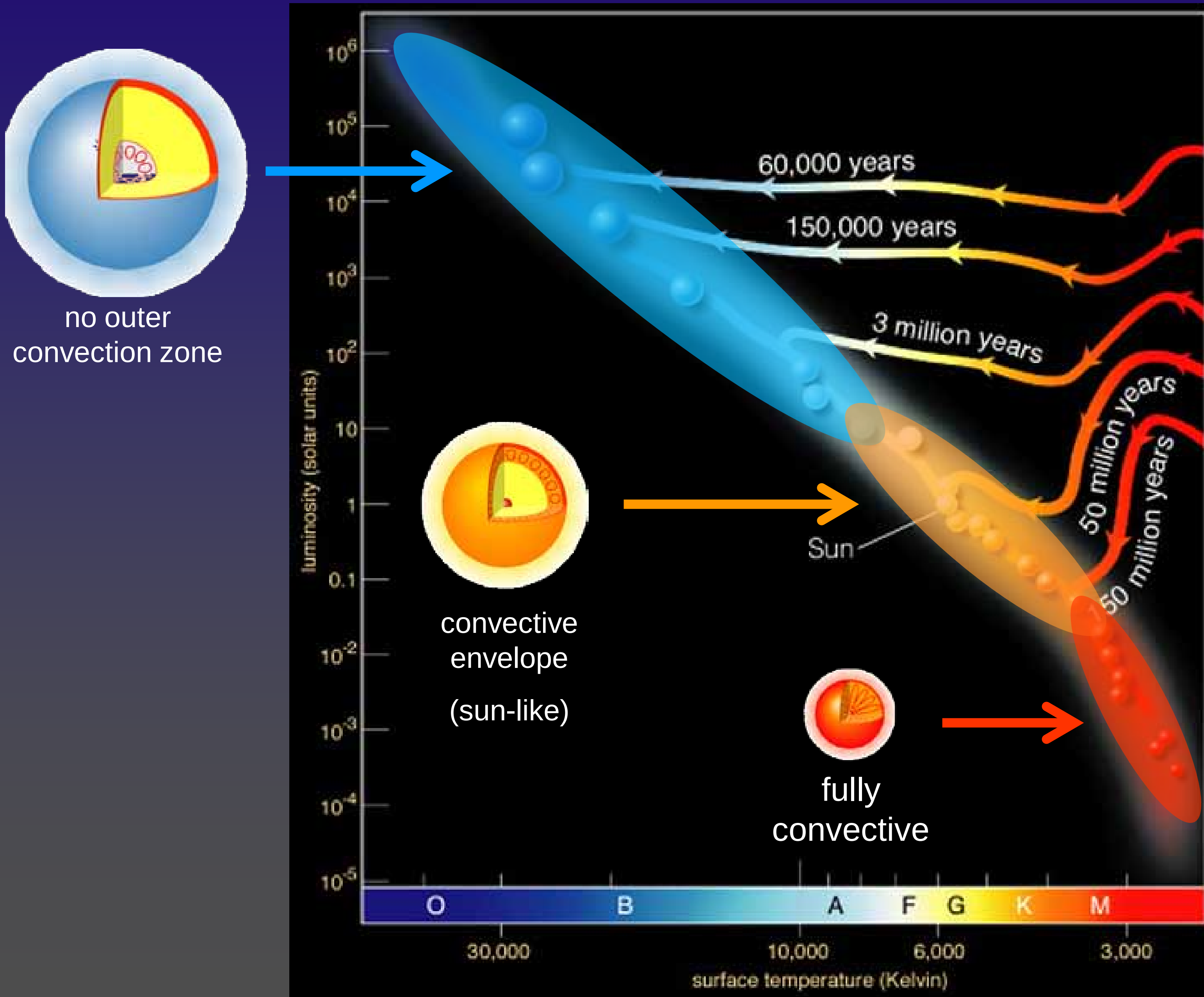
before the Main Sequence

↓

Spin-up

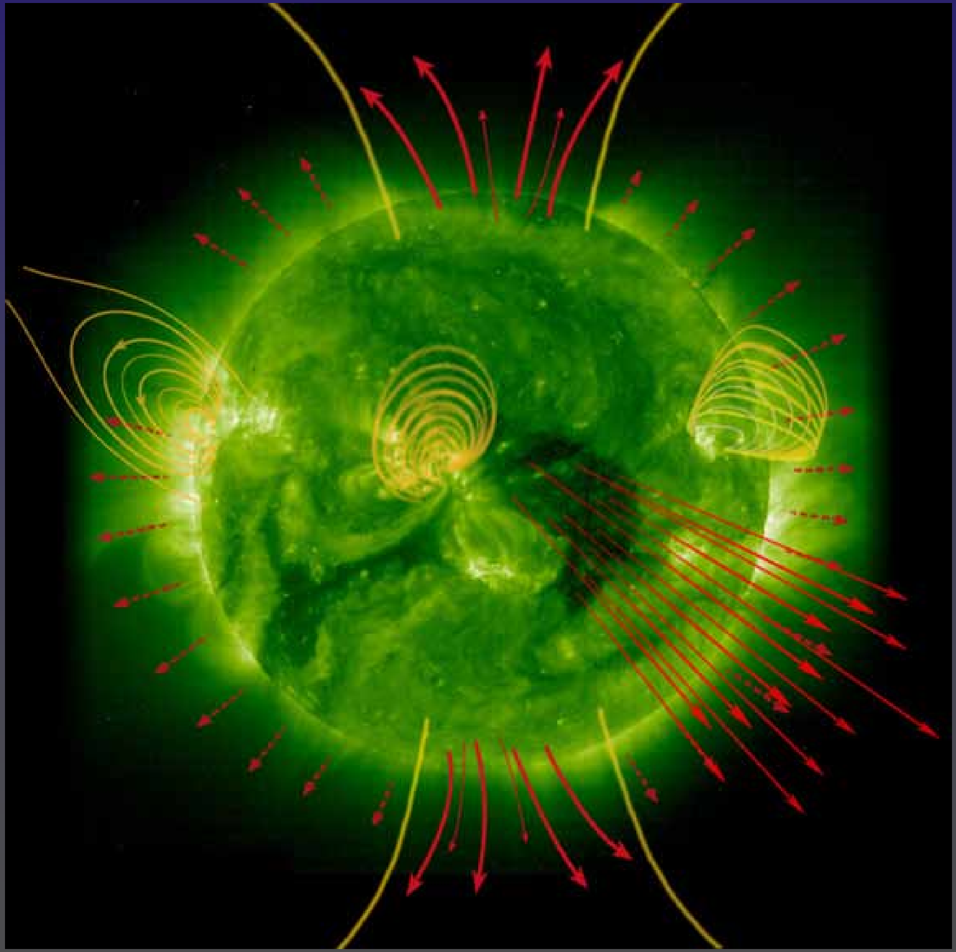


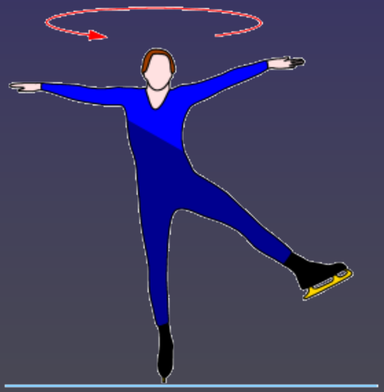
On the Main Sequence



On the Main Sequence

Expanding wind couples to the magnetic field





On the Main Sequence

Spin-down of sun-like stars

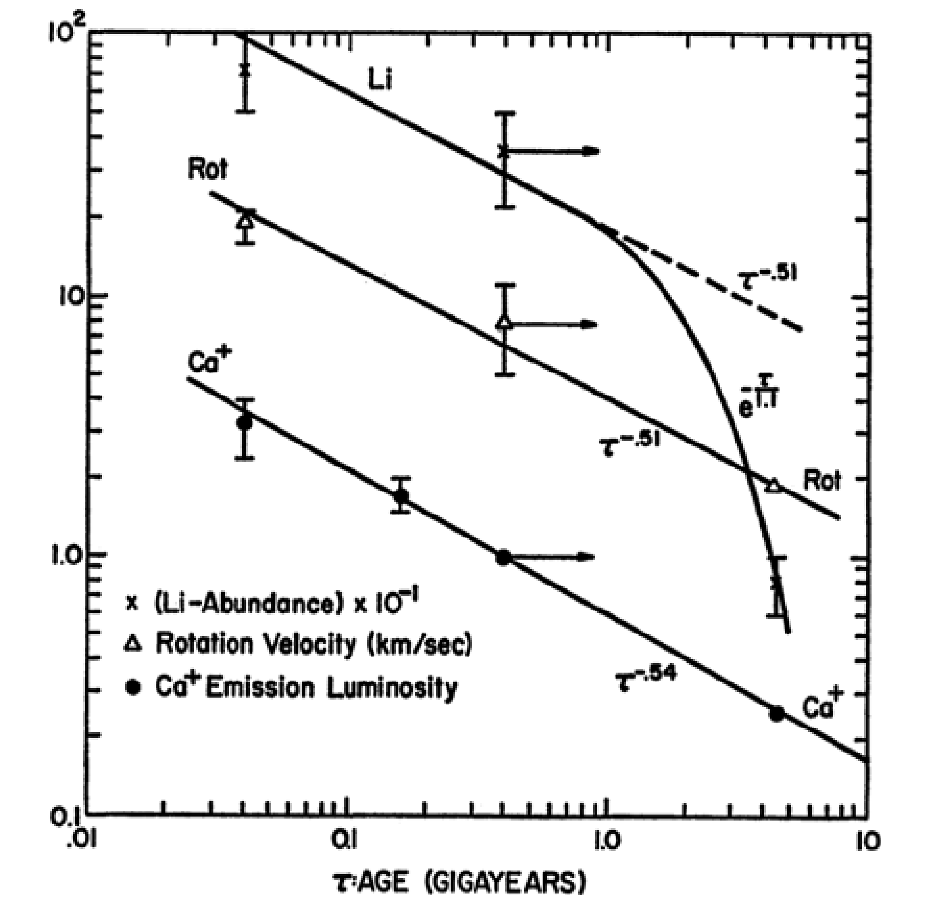
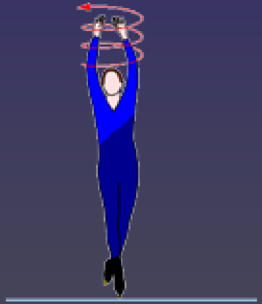
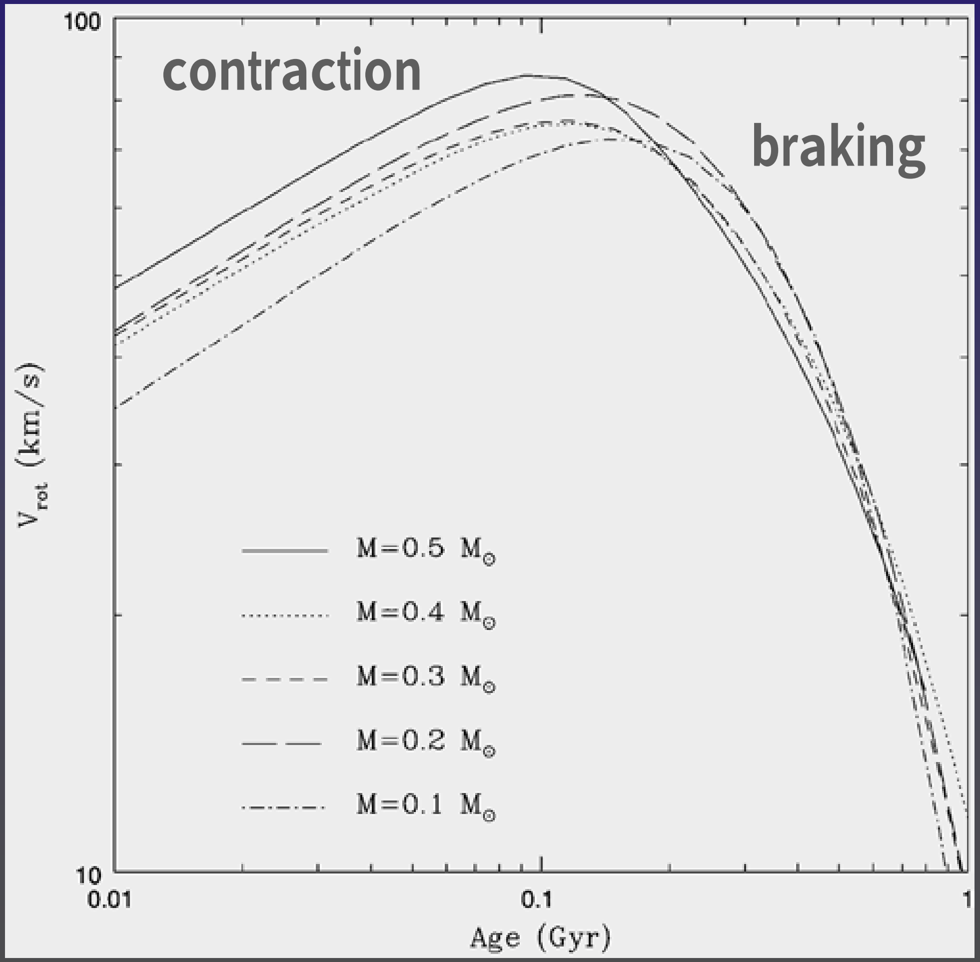


FIG. 1.—Ca^+ emission, rotation, and lithium abundance versus stellar age

Skumanich, 1972

Schematic rotational evolution

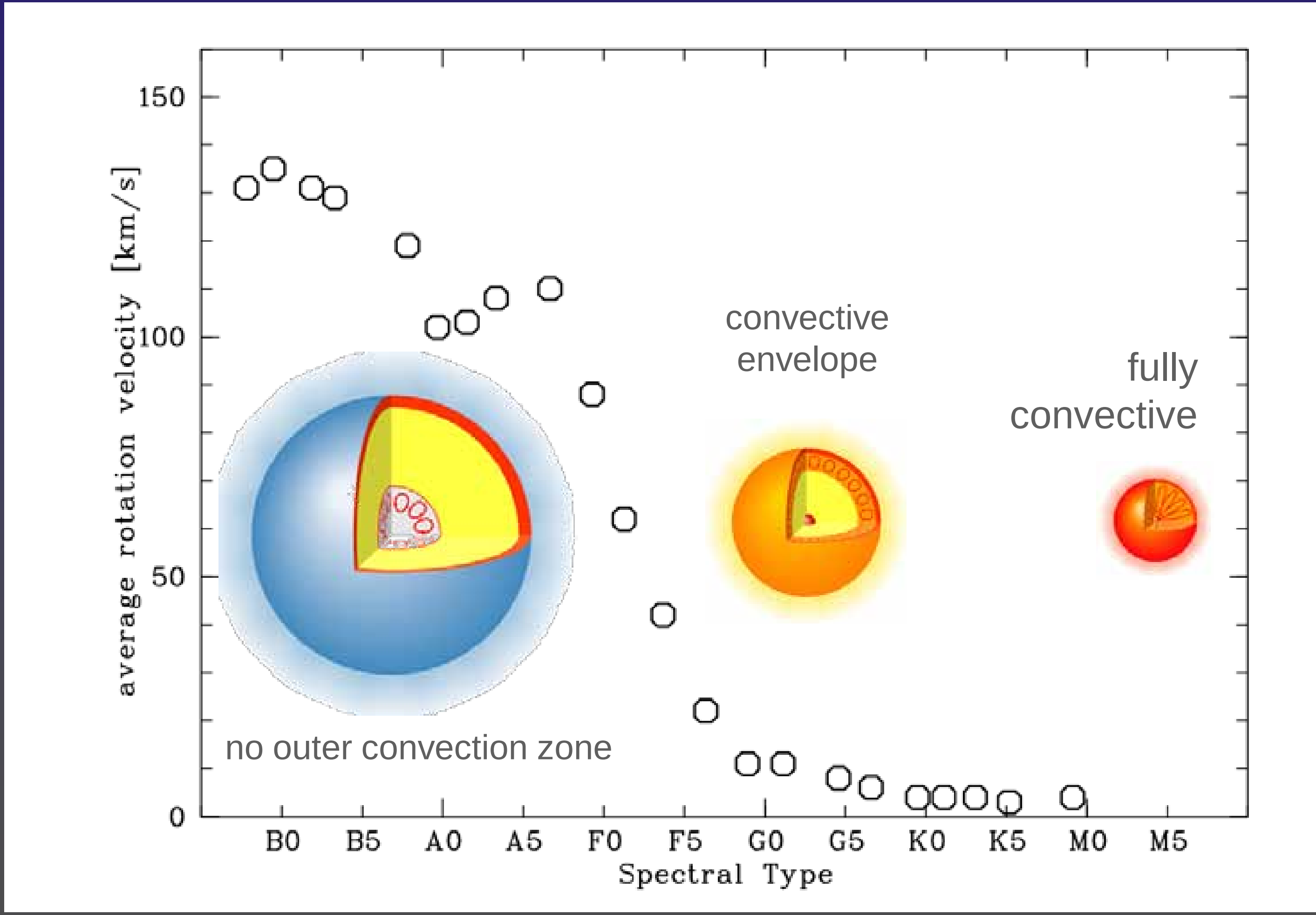




Sills et al., 2000

Mean rotation velocities in field stars

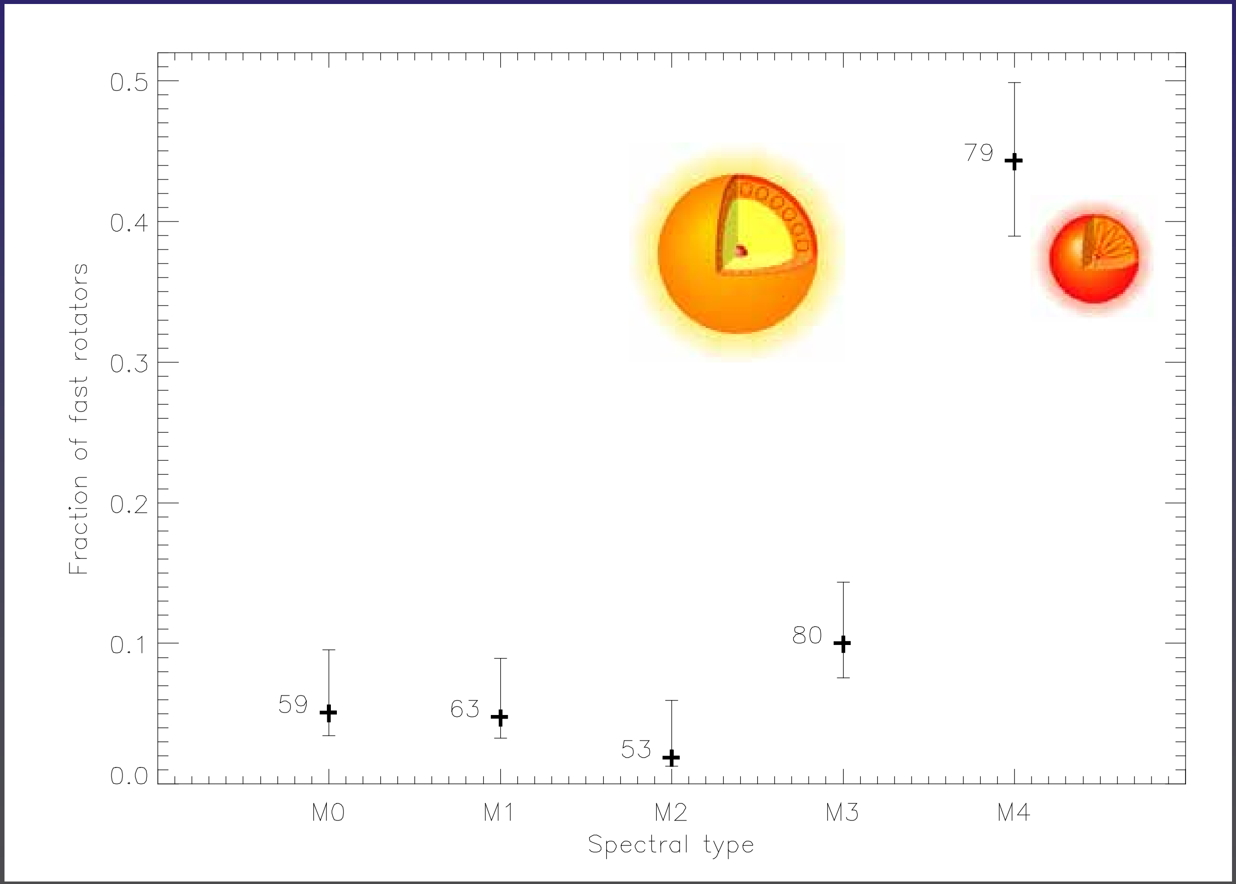
(i.e., after enough time to calm down)



Fraction of "fast" rotators at the boundary to full convection

from more than 300 targets

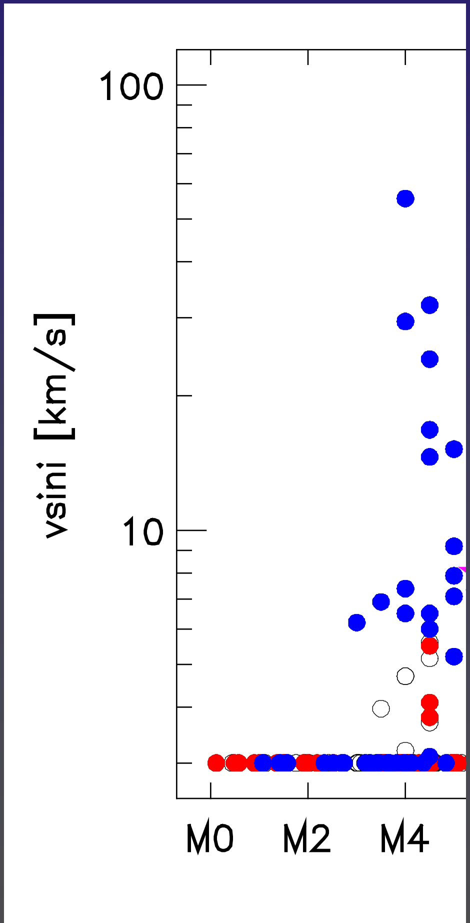
(fast: $v\sin i$ ≳3 km/s)



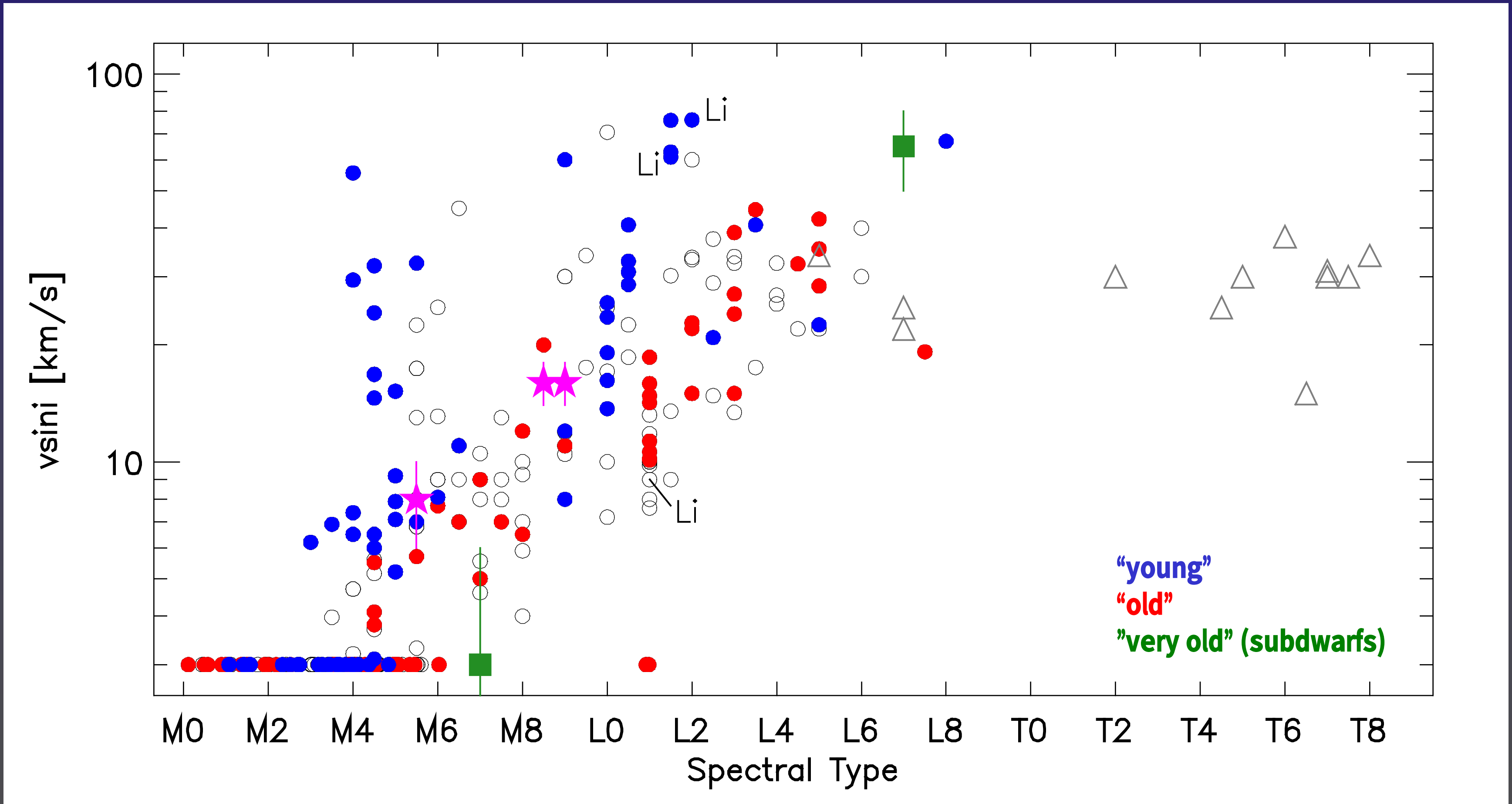
Joshi, Reiners & Goldman

Braking is less efficient in fully convective stars!

Individual rotation velocities in low-mass stars

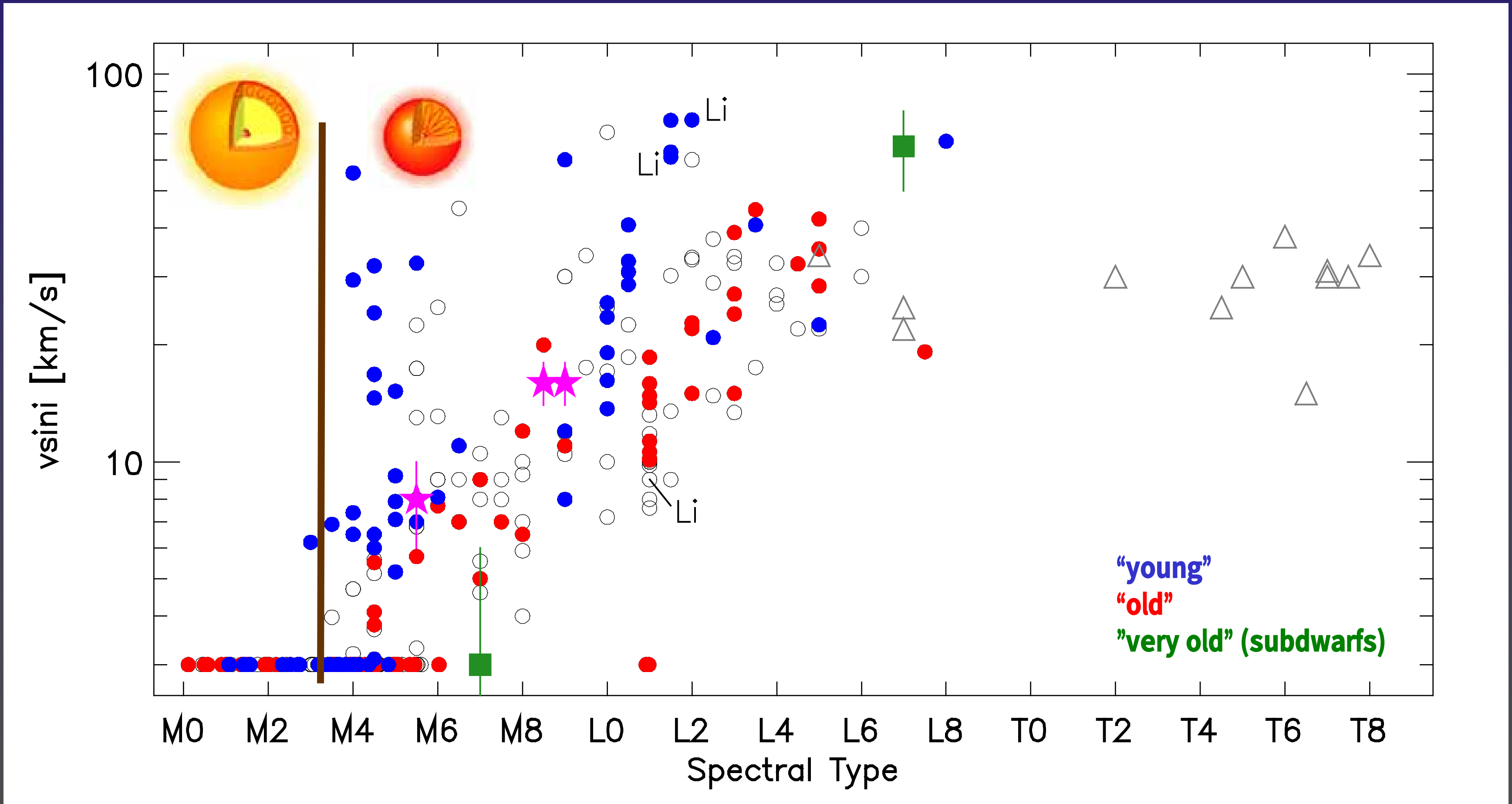


Individual rotation velocities in low-mass stars



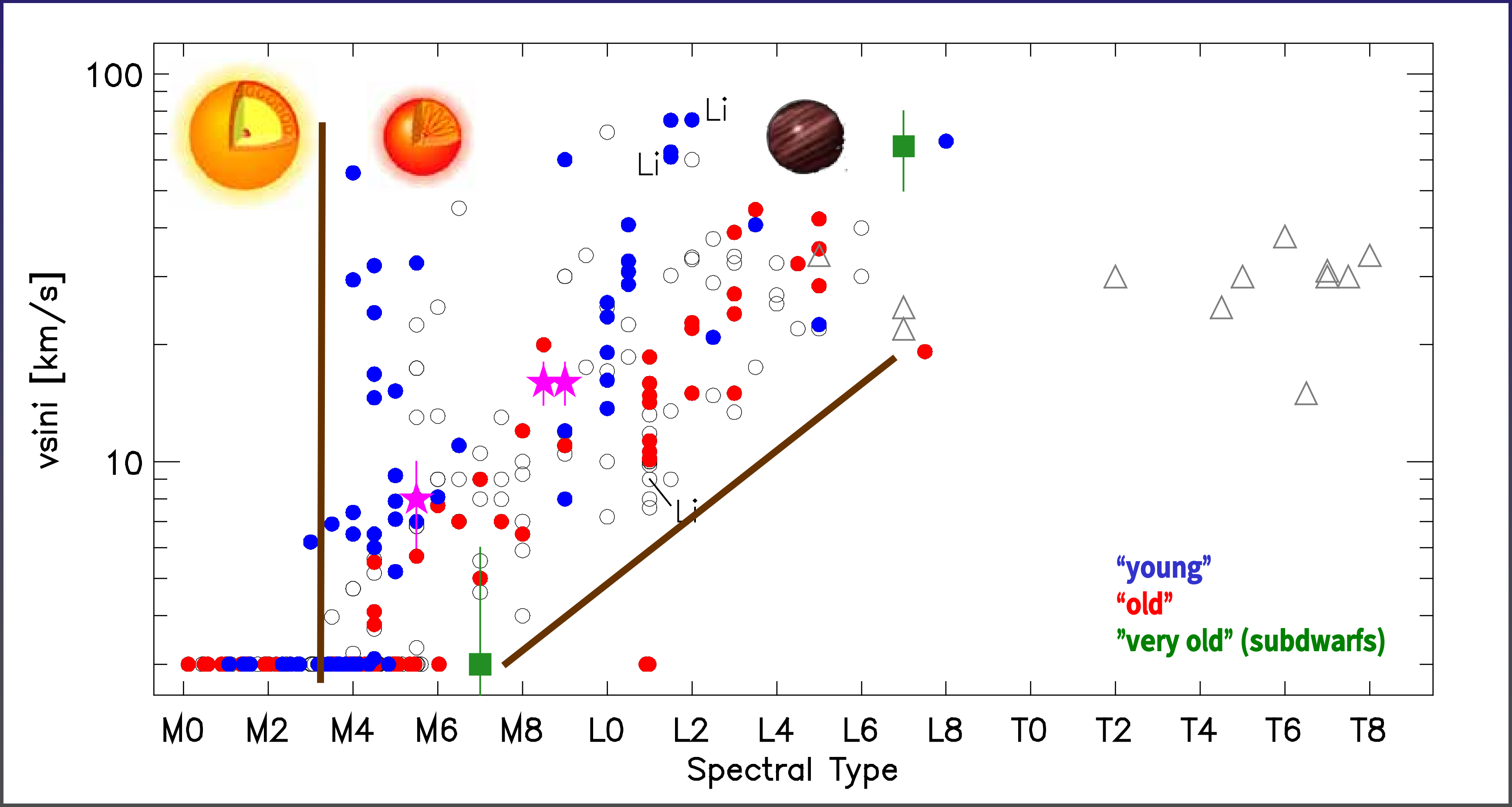
Reiners & Basri, 2008

1. Weaker or selective braking at the threshold to full convection



Reiners & Basri, 2008

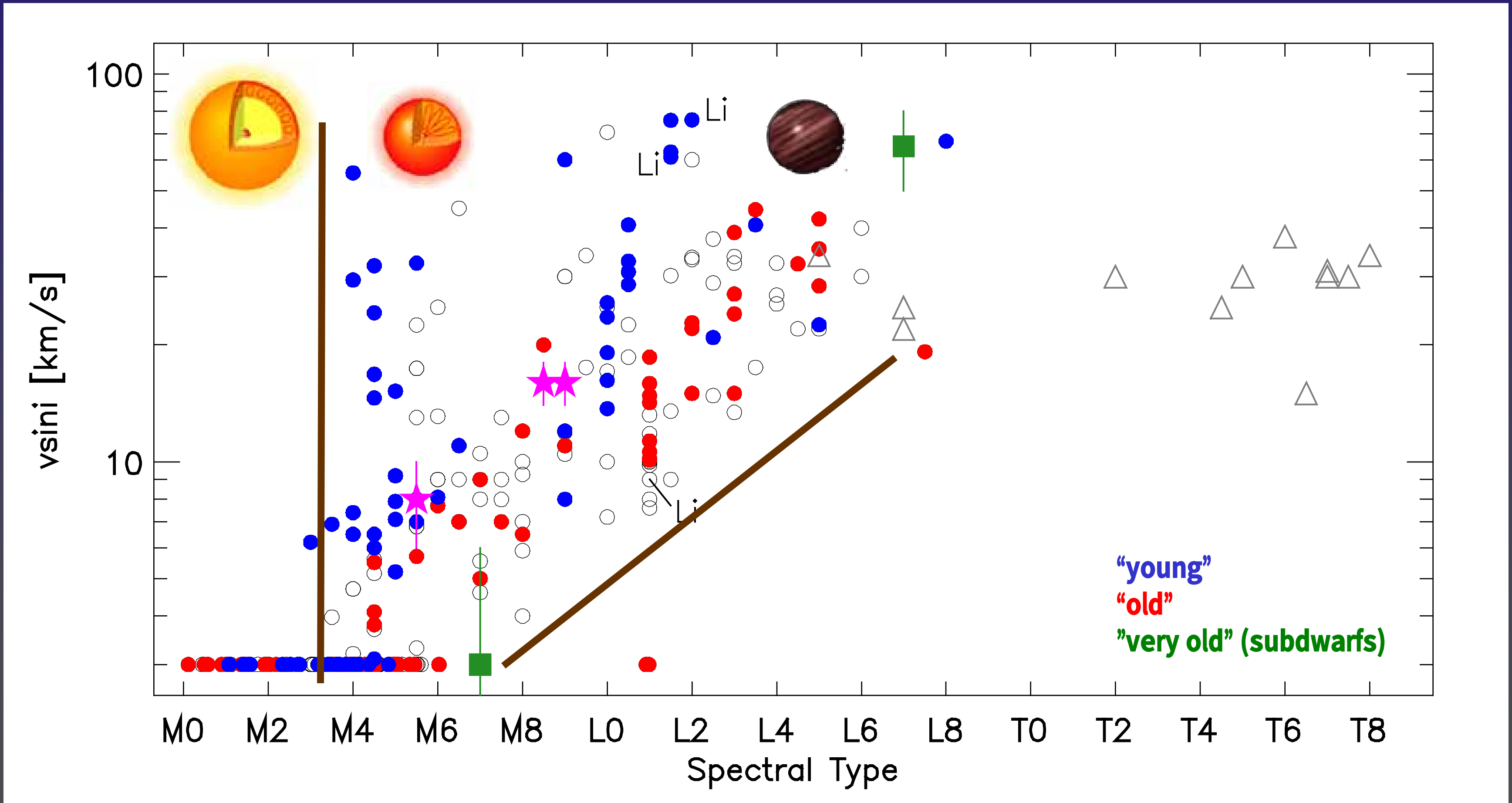
2. Braking is gradually disappearing towards the brown dwarf regime



Reiners & Basri, 2008

Hypothesis:

Fully convective M dwarfs cannot generate magnetic fields



Reiners & Basri, 2008

→ search for magnetic fields in mid- and late-M dwarfs!

Part III

I. Introduction: Why care about activity?

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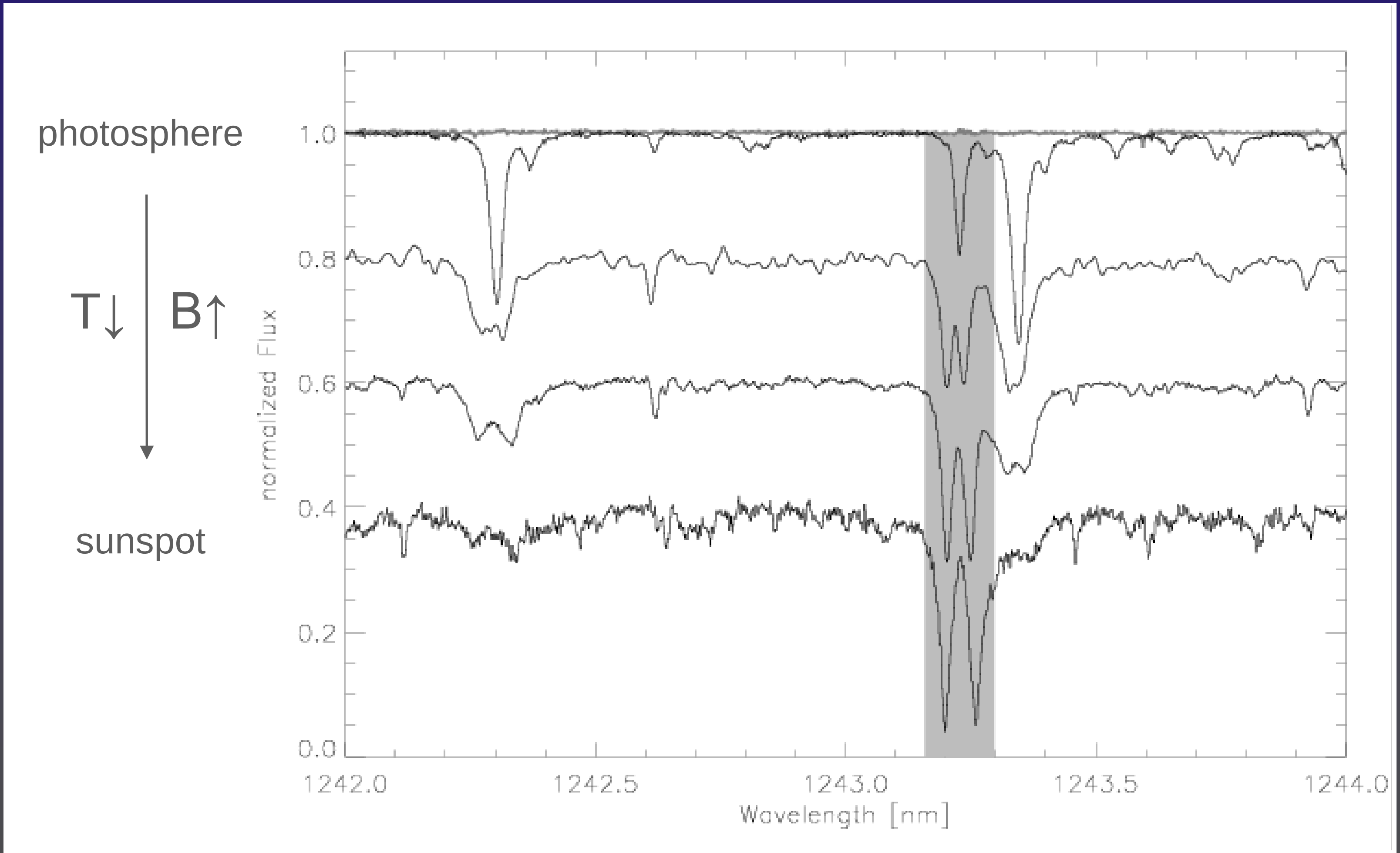
Explaining rotational evolution at the bottom of the Main Sequence

How to find stellar magnetic fields

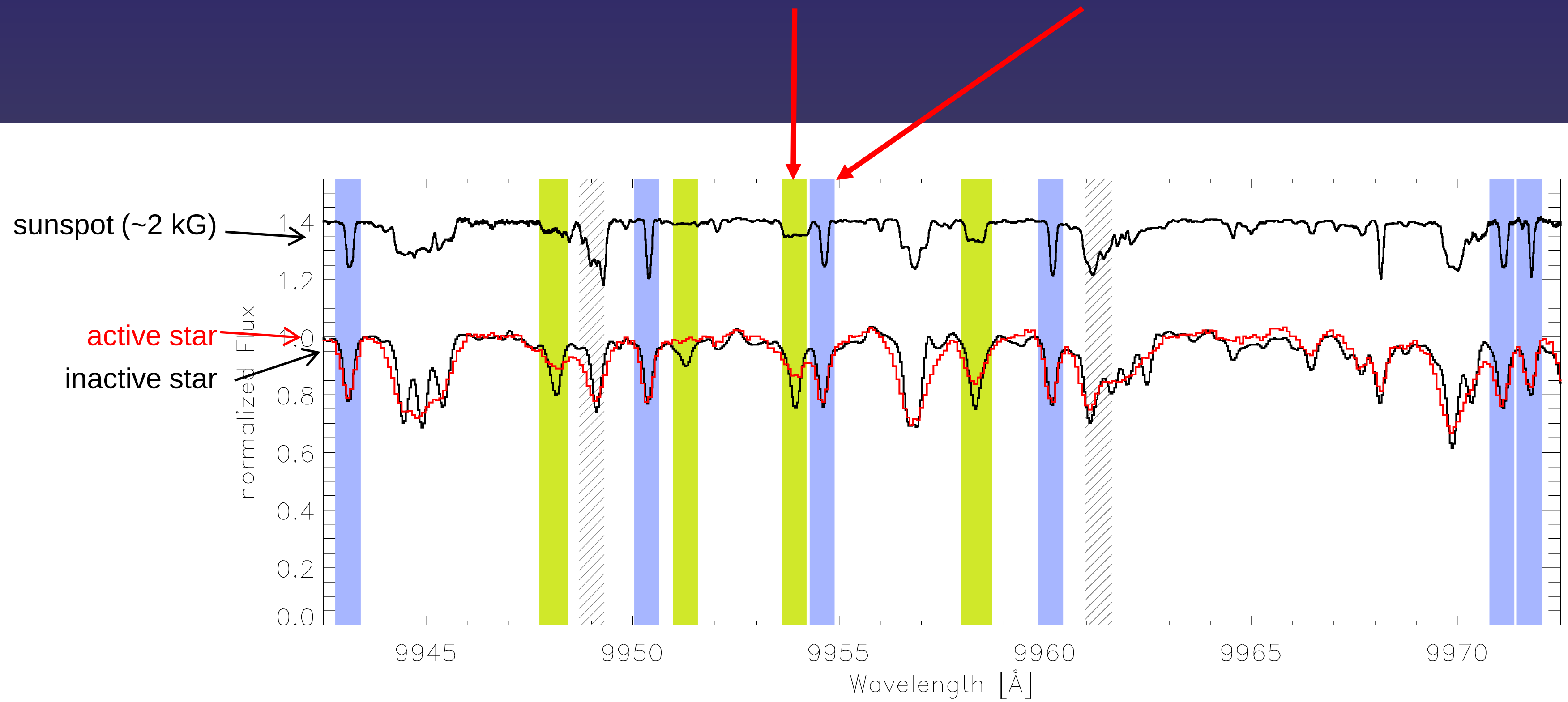
Example: Zeeman effect in Sunspots



Magnetic flux observations in *very-low mass* stars

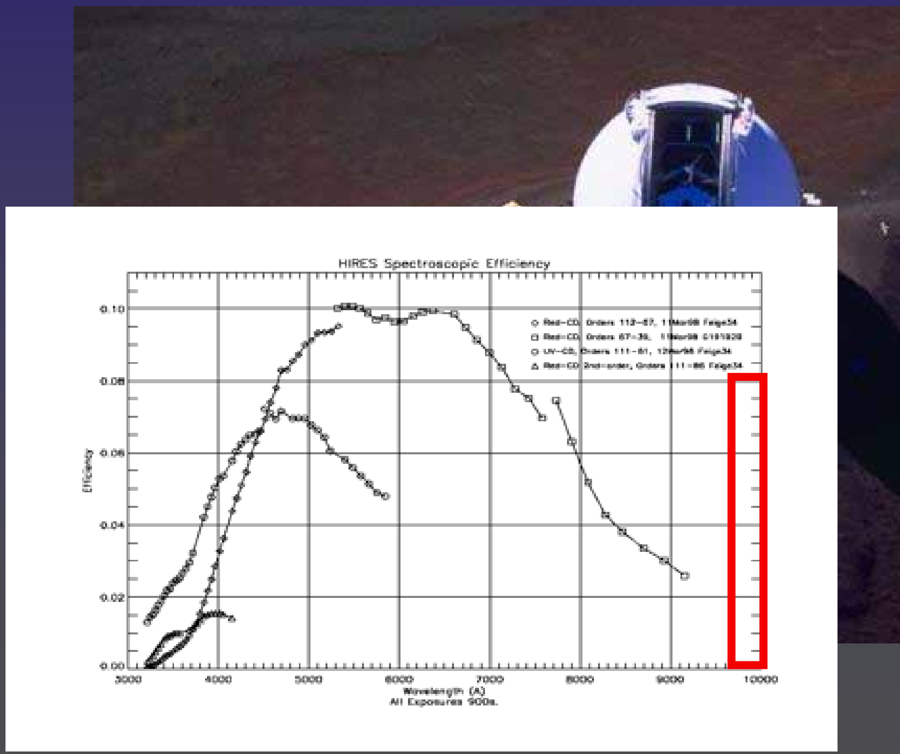
At low temperature, atomic lines vanish, and molecules dominate the spectra

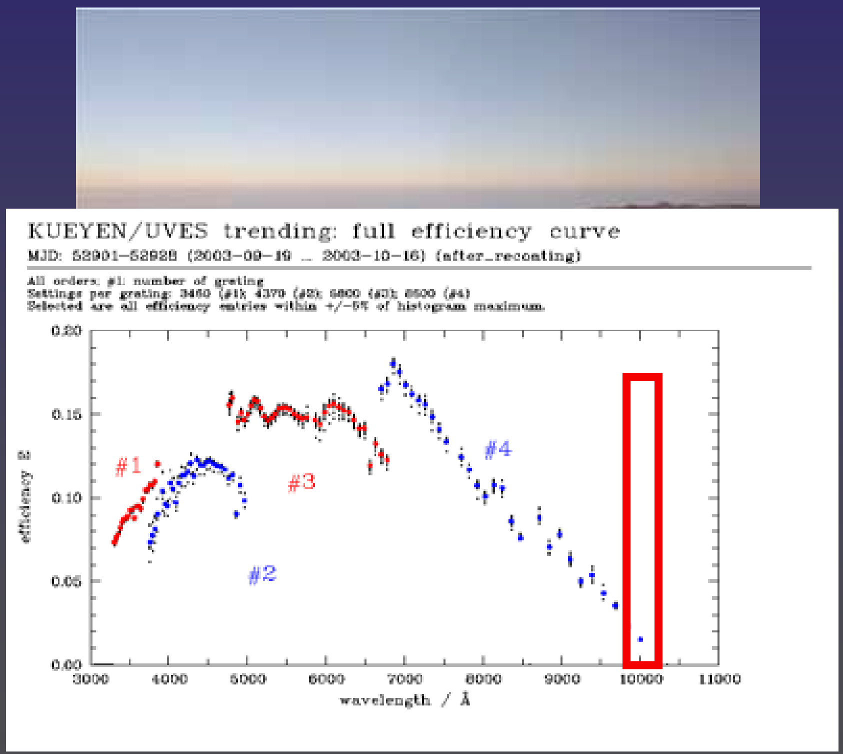
Identification of magnetically sensitive and insensitive lines of FeH



Observations of the FeH band

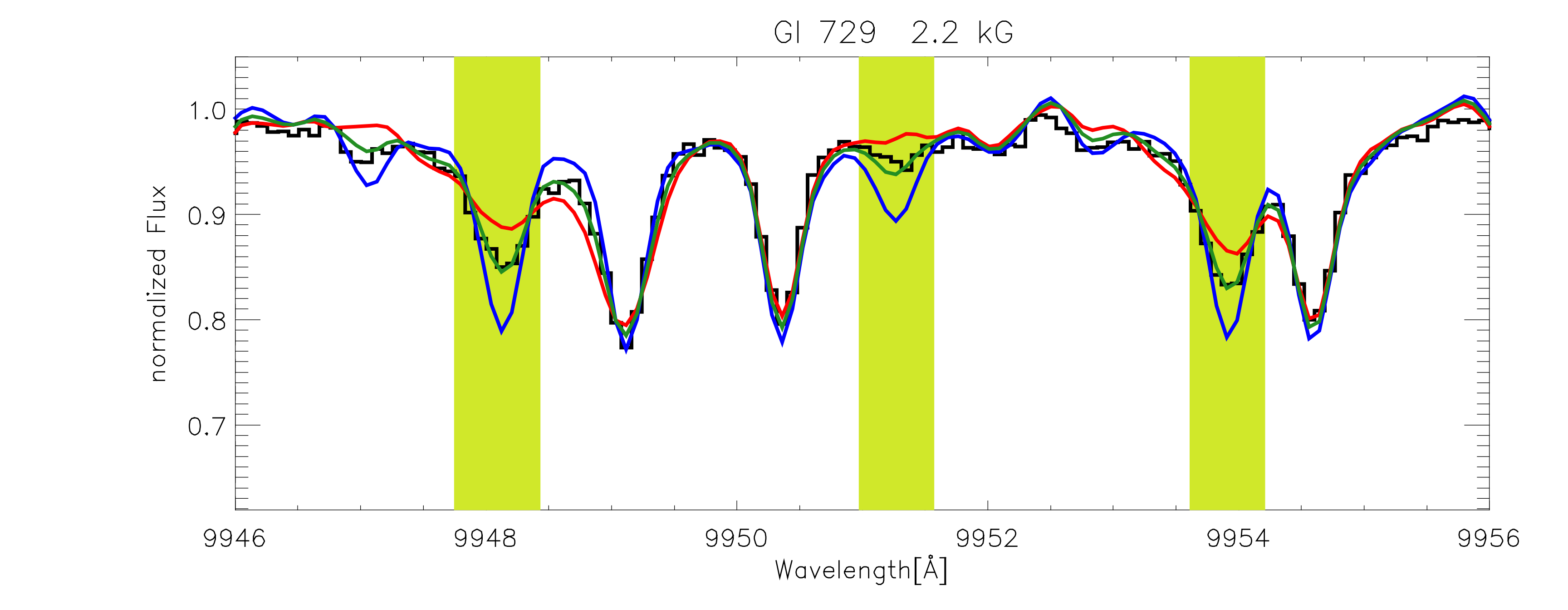
with HIRES/Keck and UVES/VLT





Not exactly optimal efficiency, but it's the only game in town···

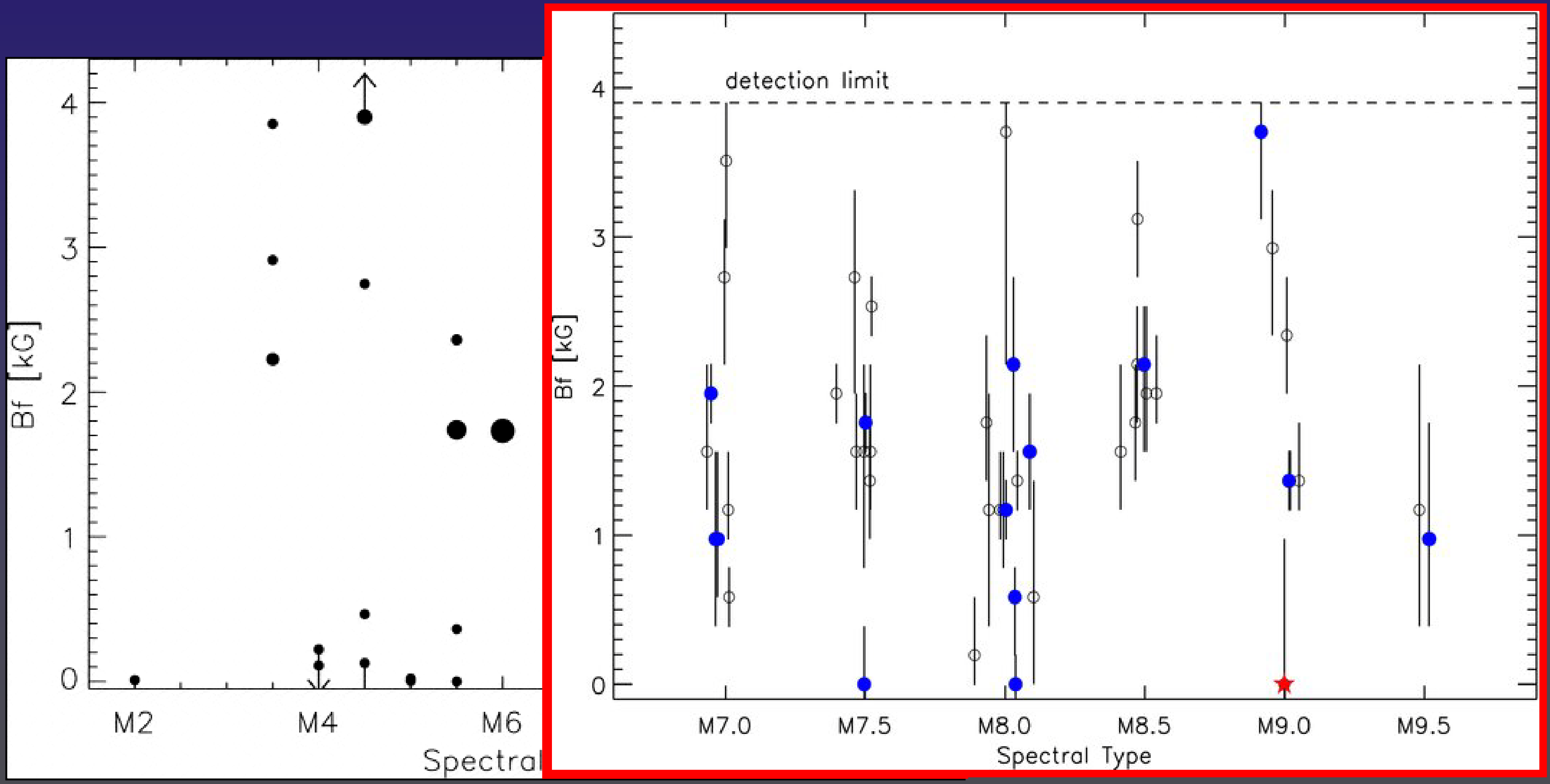
Magnetic flux observations in *very-low mass stars*



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

Result:



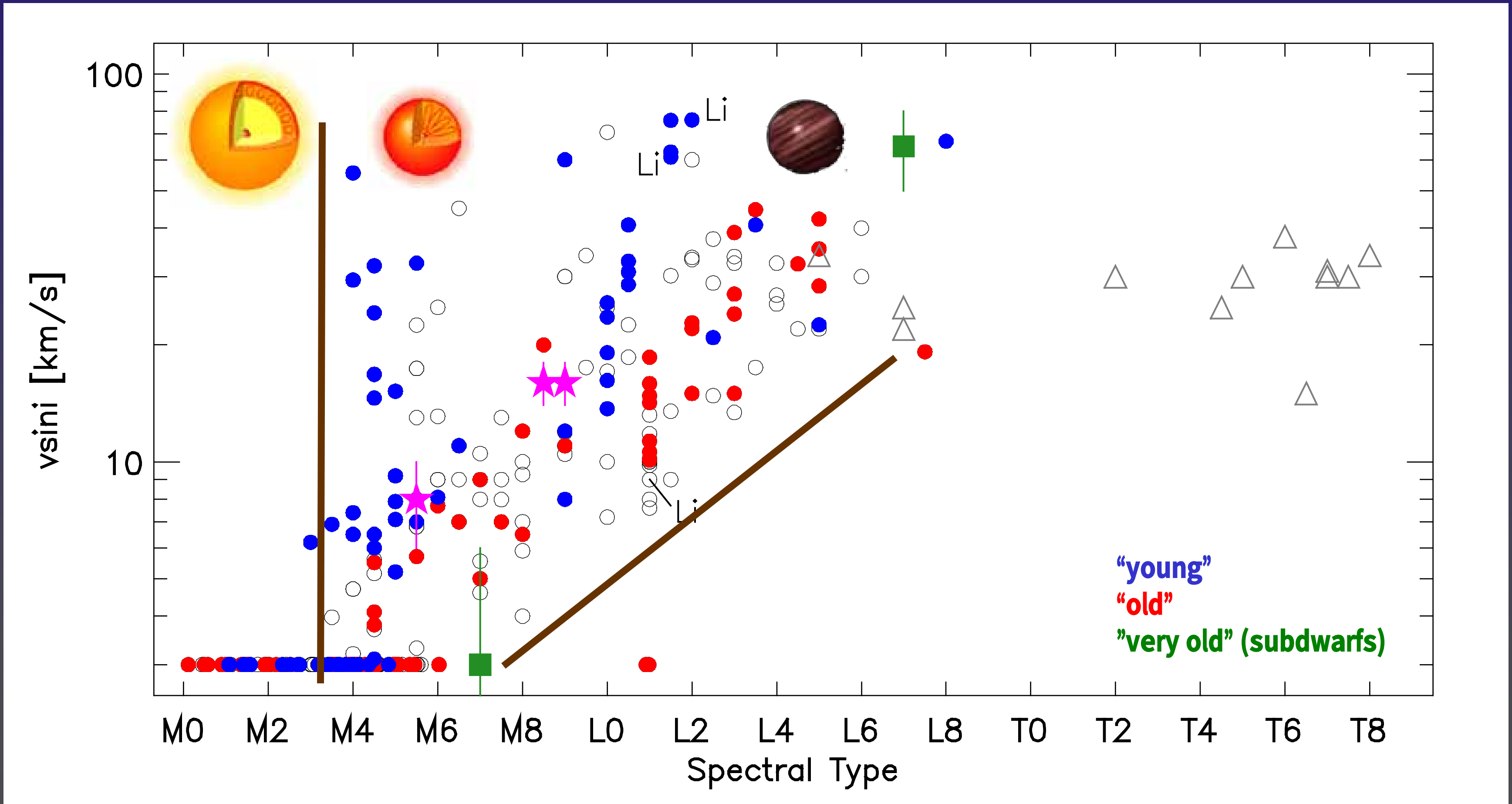
Reiners & Basri, 2007

Reiners & Basri, 2010

Magnetic fields in very-low mass stars exist!

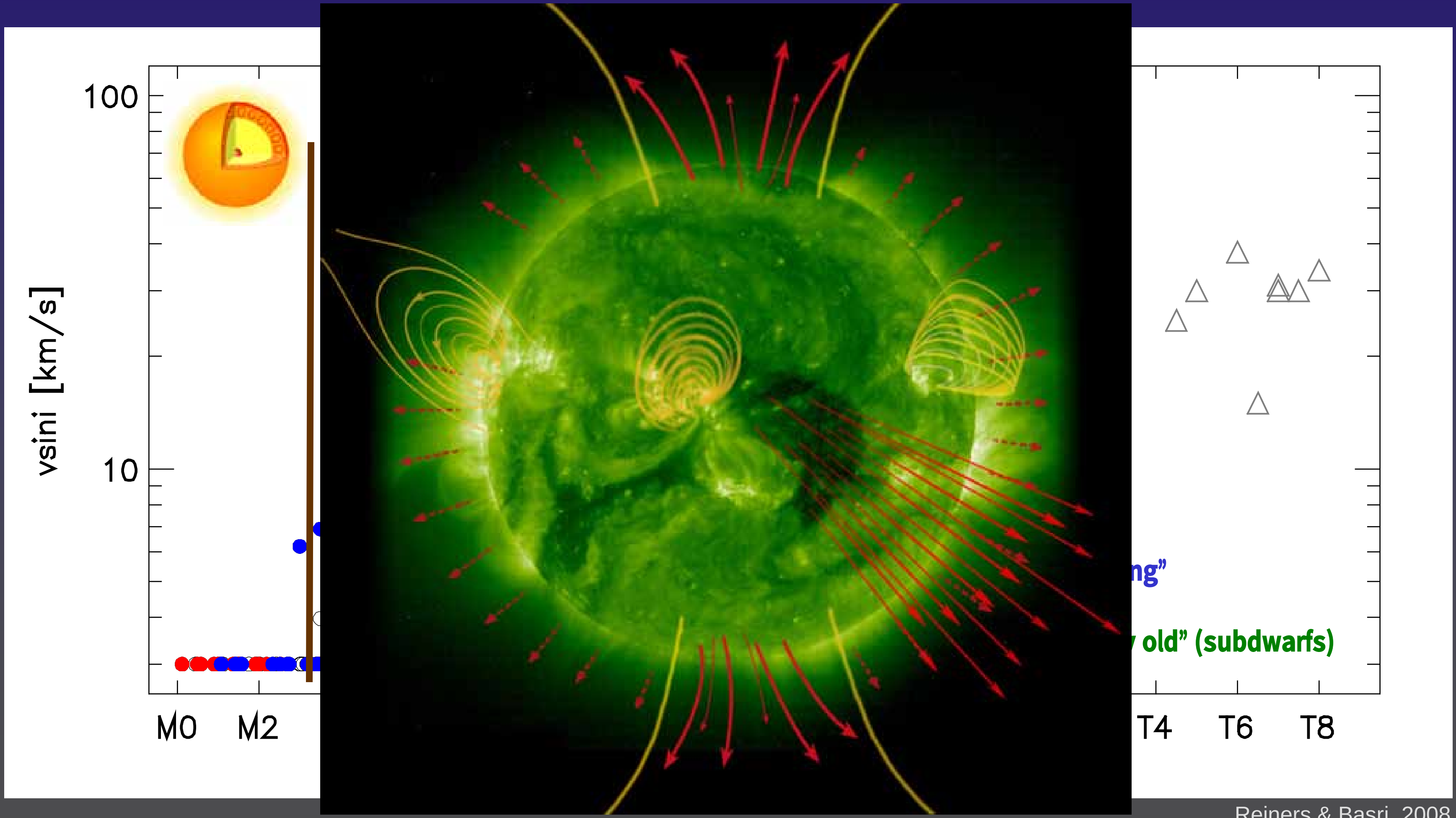
Hypothesis:

Fully convective M dwarfs ~~cannot~~ generate magnetic fields



Reiners & Basri, 2008

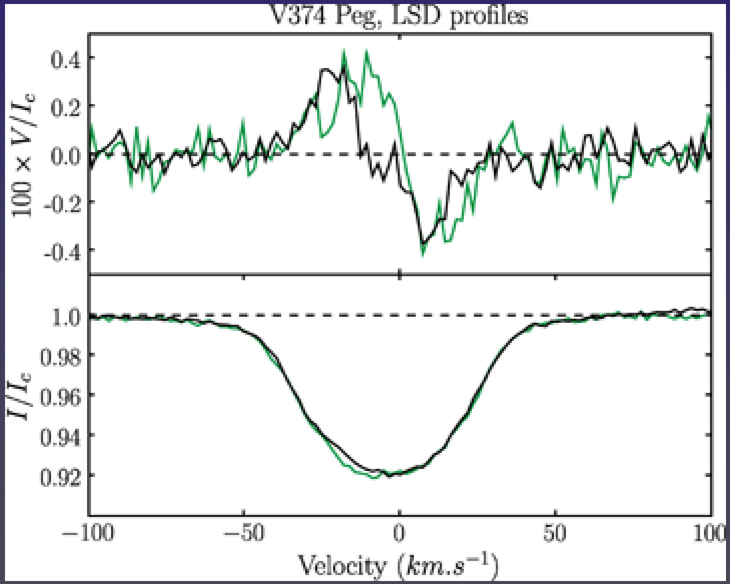
What else could be happening at the boundary to full convection?



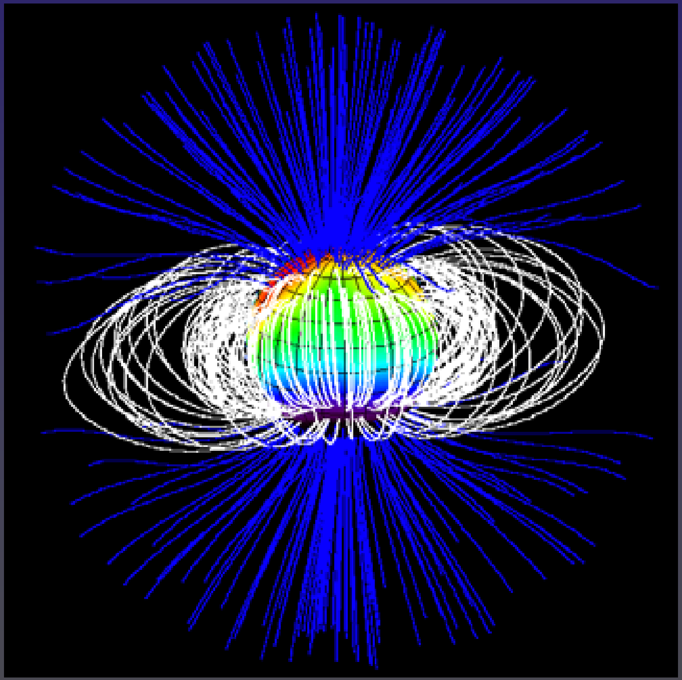
Reiners & Basri, 2008

the field geometry may change - only "small-scale"?

Doppler-maps in polarized light measure the uncancelled flux (Stokes V)



Morin et al., 2008



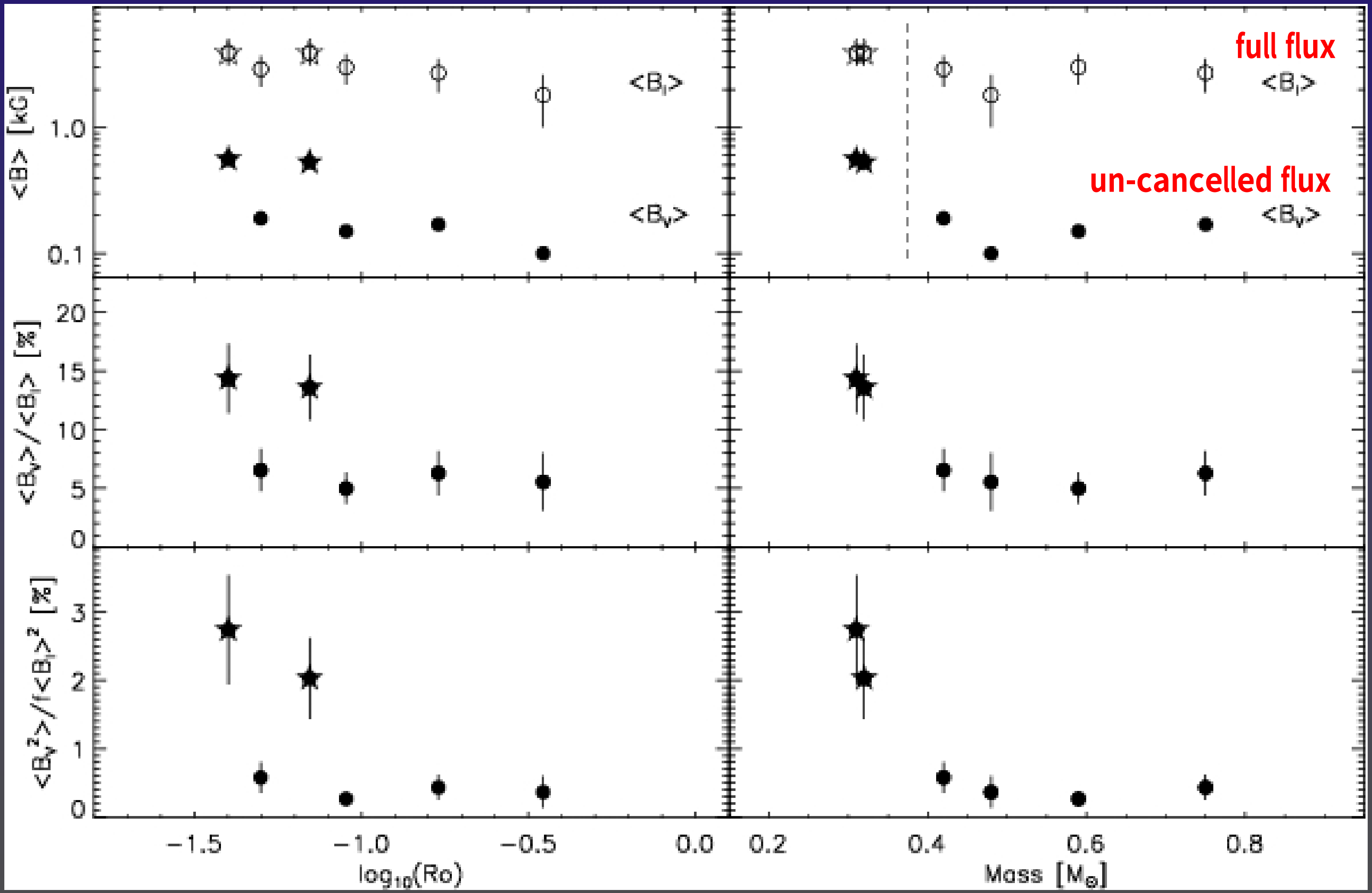
© MM Jardine & JF Donati

… and find mid-M dwarfs that do have large-scale fields.

But: Only a part of the field is visible to Stokes V.

Field measurements in Stokes I and V

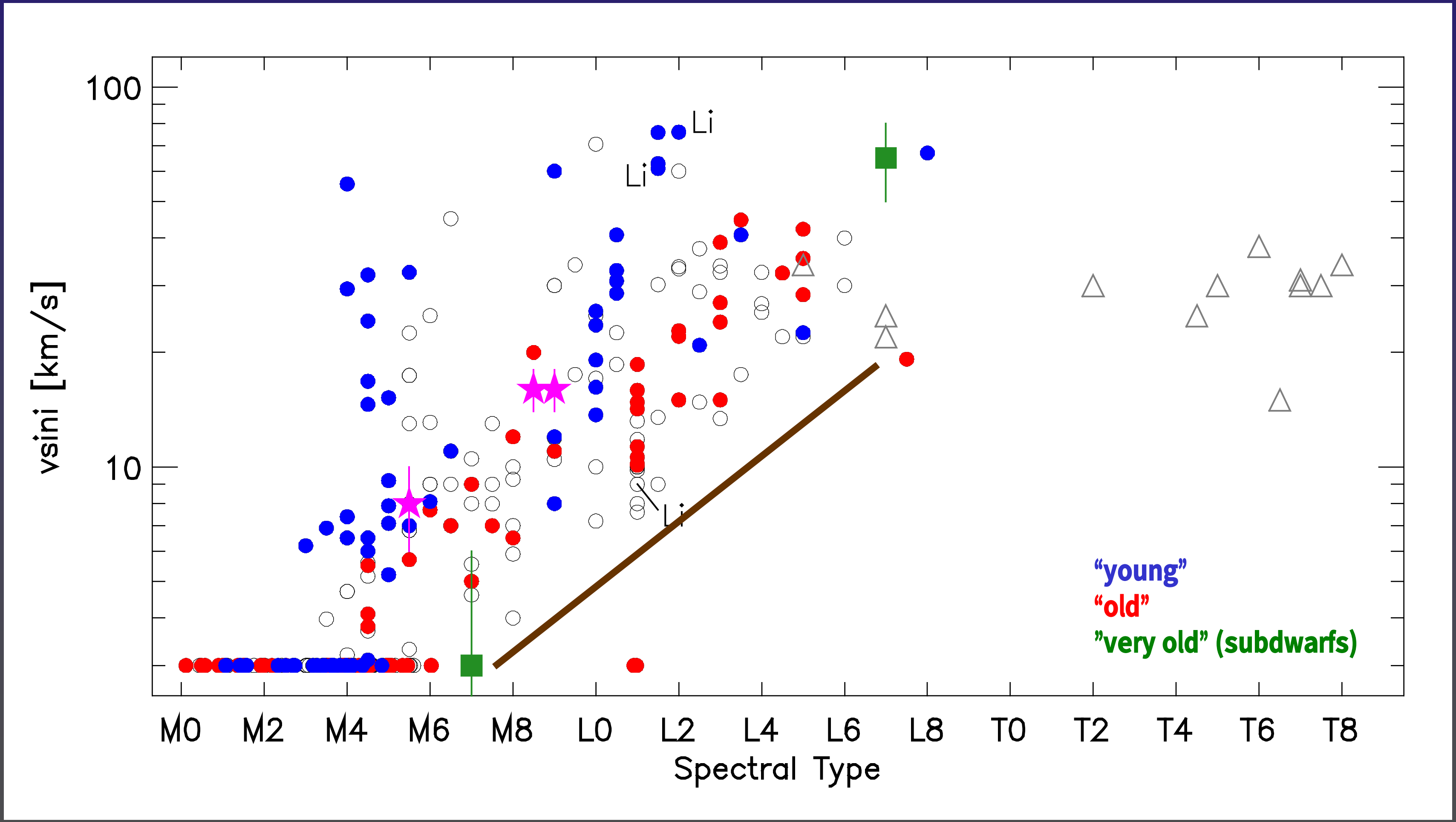
So far, no full field geometry measurement achieved…



Reiners & Basri, 2009

Its probably the field geometry that changes at the boundary to full convection.

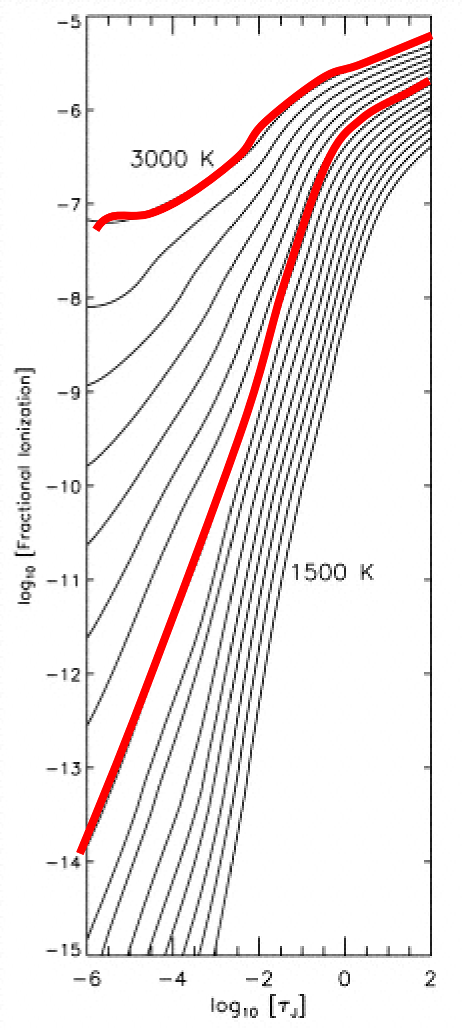
2. Why is the braking gradually disappearing towards the brown dwarf regime?



Reiners & Basri, 2008

Answer: Reduced coupling between magnetic fields and atmosphere because of lower fractional ionization

3000K ~ M5
2300K ~ L0

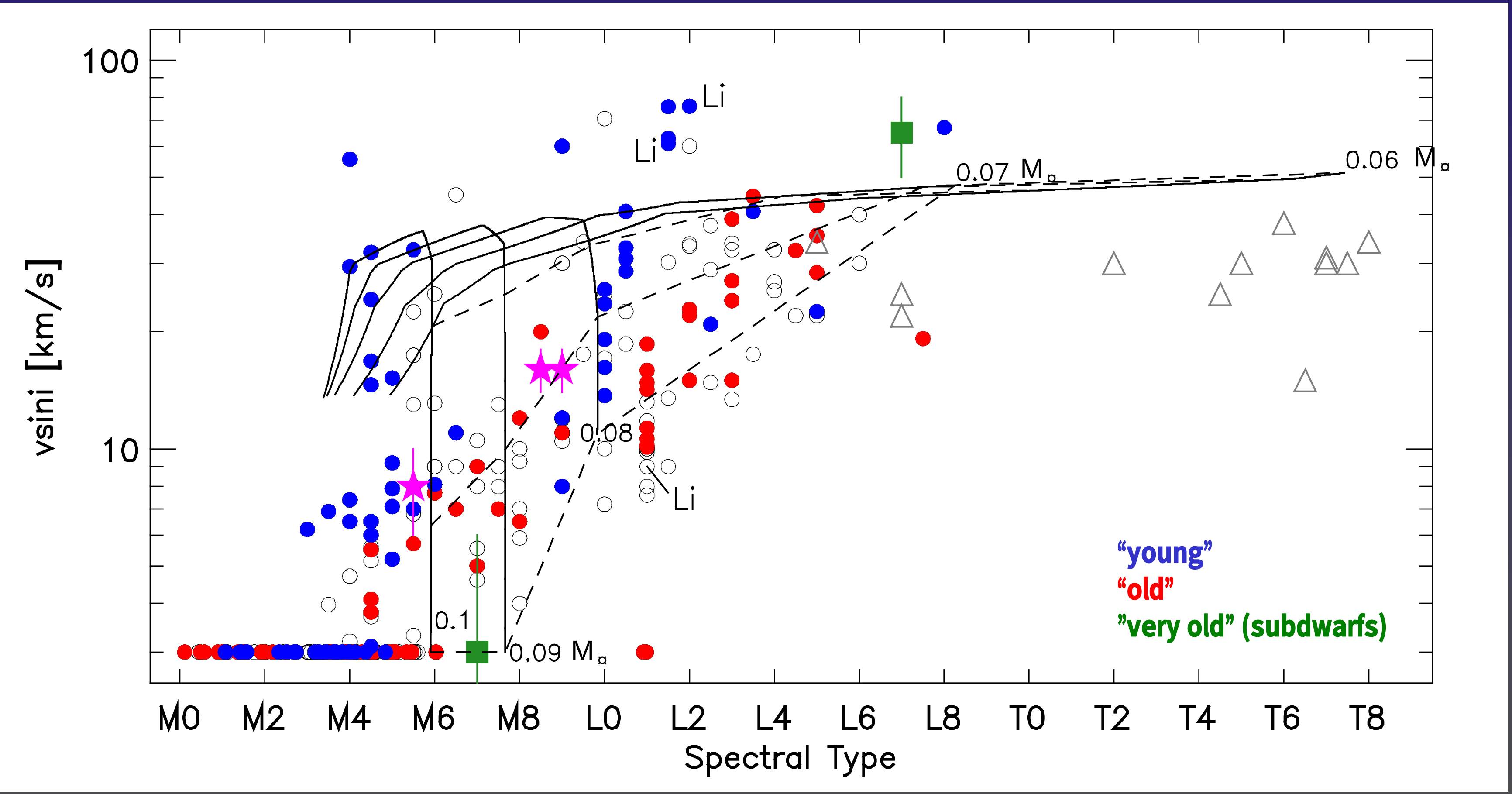


(COND Model)

Mohanty et al., 2002

Rotation in low mass objects

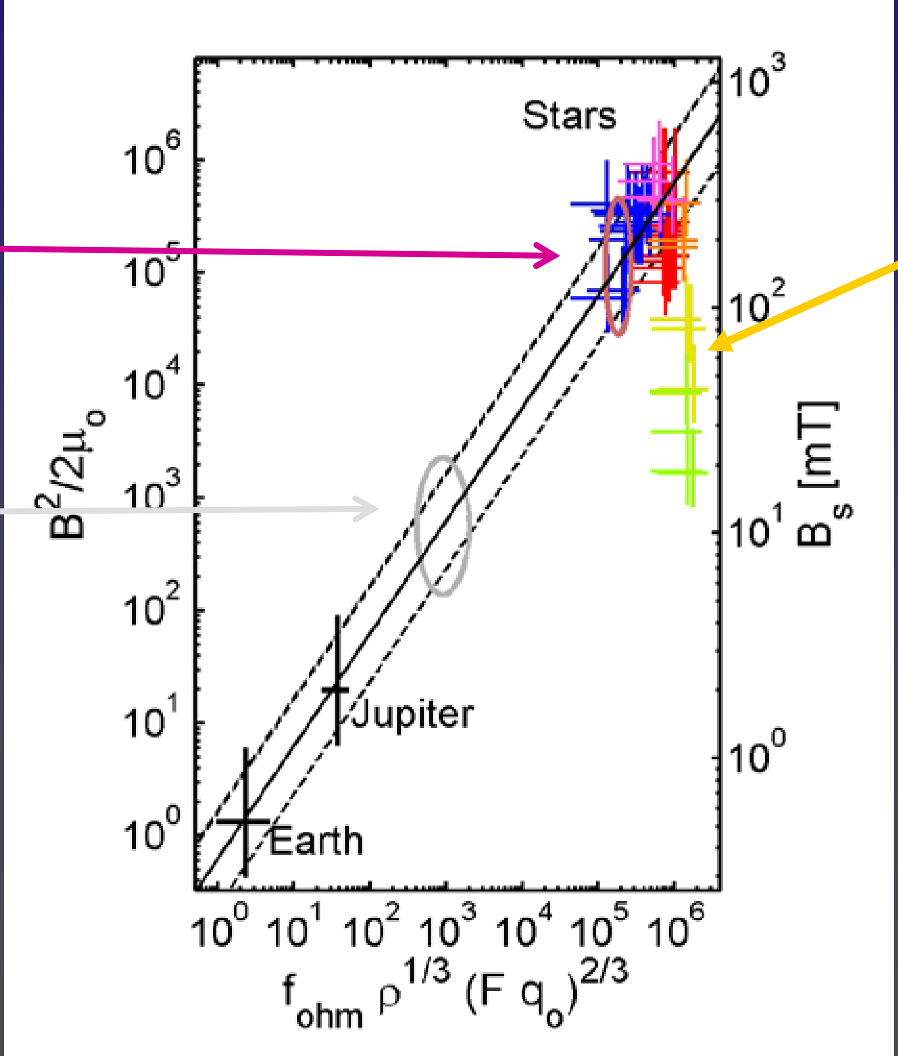
assuming temperature-dependent wind braking



Reiners & Basri, 2008

Thus: Magnetic fields can probably occur in low-mass stars, brown dwarfs, and planets!

Magnetic field strength may follow a general rule



Christensen, Holzwarth & Reiners, 2009, Nature, 457, 169

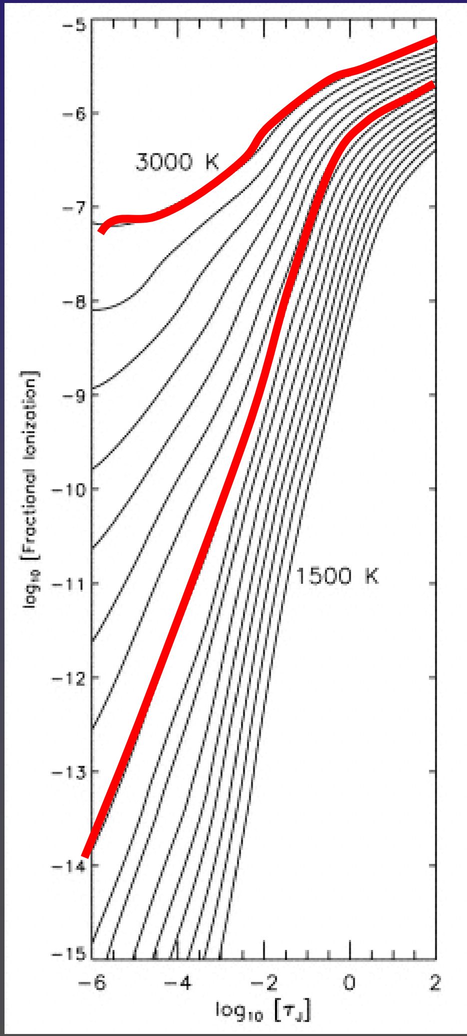
… there's still some work left

Summary

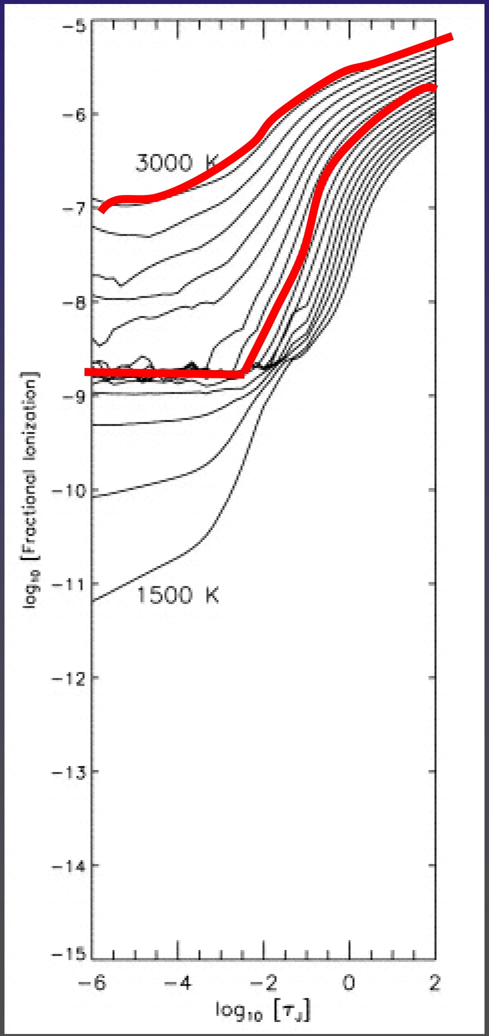
1. Stars can spin up and down
2. Magnetic fields are measured down to spectral type M9
3. Braking is different in fully convective stars, the reason is probably a difference in field topology
   (distributed dynamo vs. interface dynamo)
4. Brown dwarf atmospheres are much less ionized and show weak coupling to magnetic fields – low activity and negligible braking but possibly high fields
5. Potentially unified scaling of magnetic fields in planets and stars

Answer: Reduced coupling between magnetic fields and atmosphere because of lower fractional ionization

(3000K ~ M5,
2300K ~ L0)



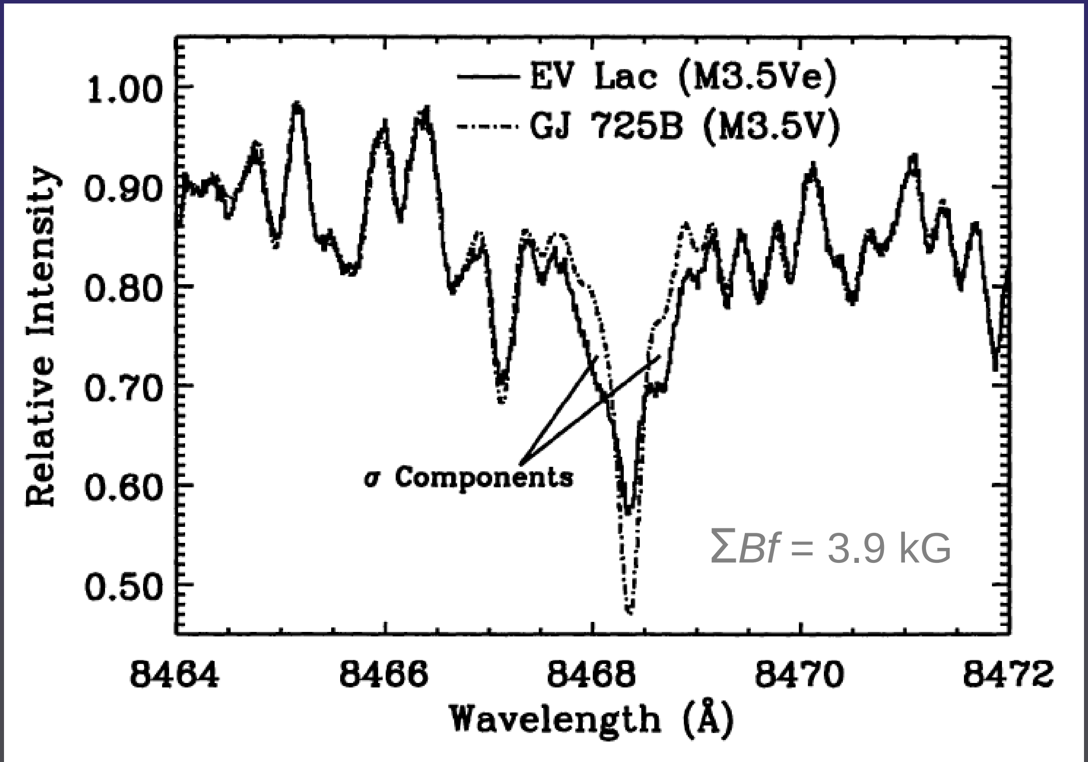
(COND Model)



(DUSTY Model)

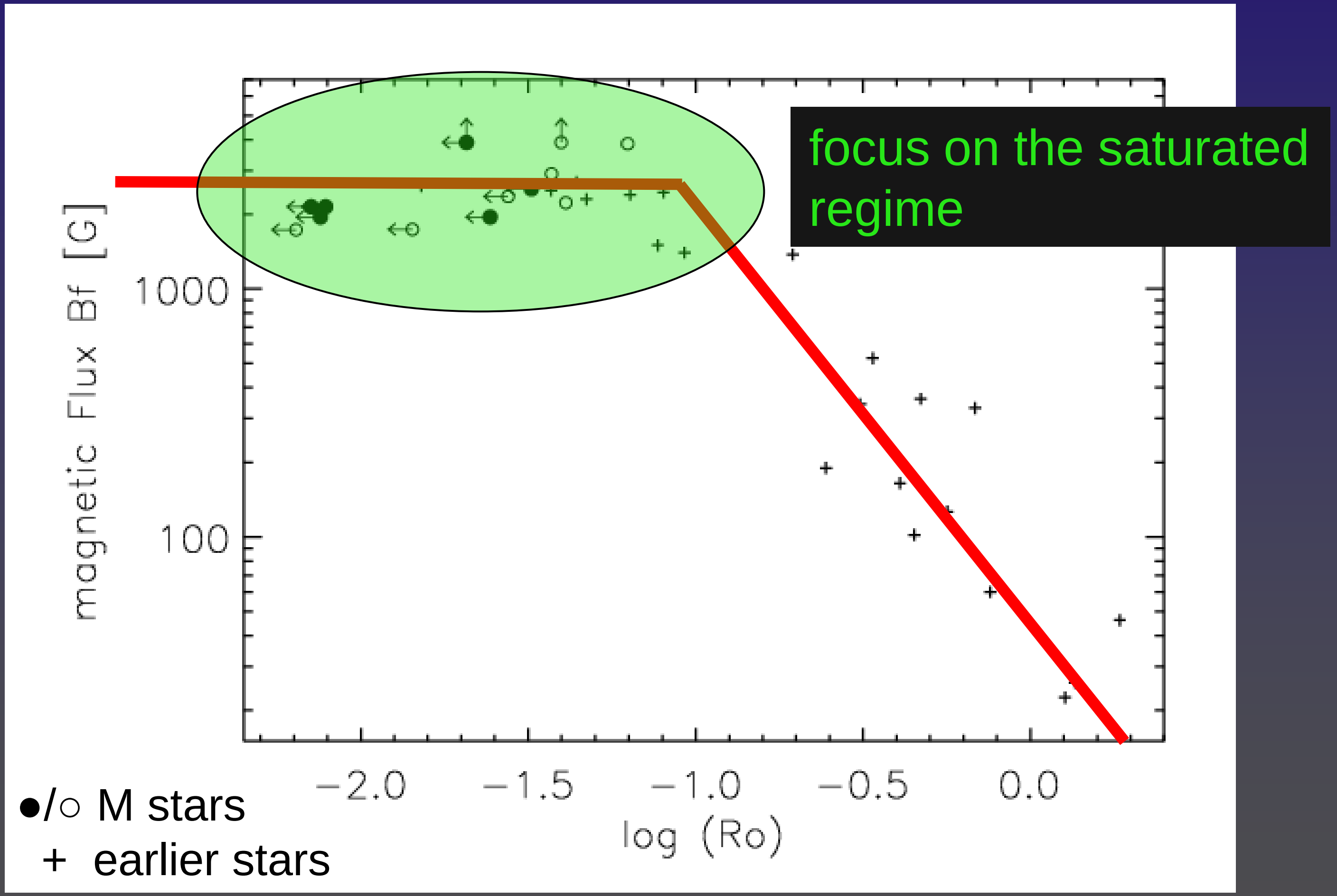
Mohanty et al., 2002

Measuring the fields is very difficult!



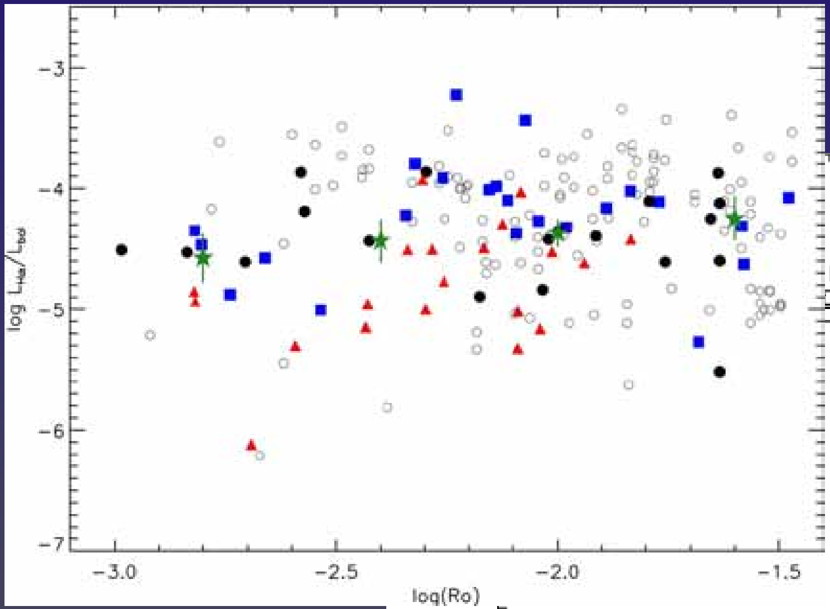
Johns-Krull & Valenti, 2000

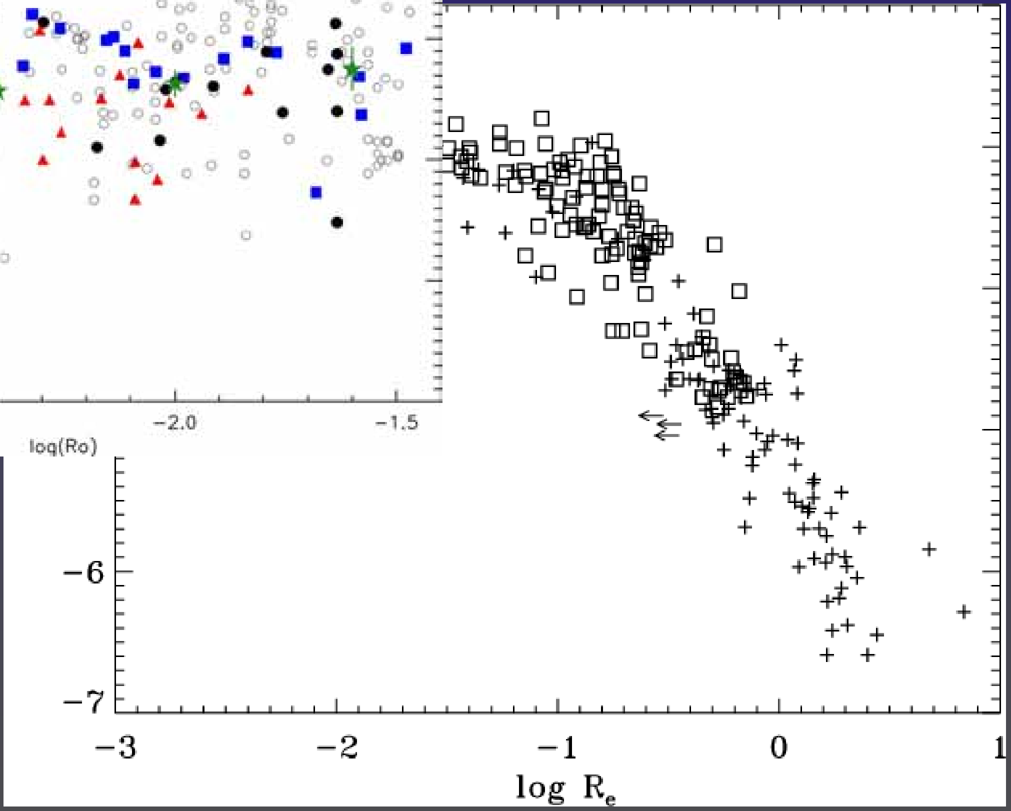
Saturation of the total magnetic flux in stars at rapid rotation



Reiners et al., 2009, ApJ, 692, 538

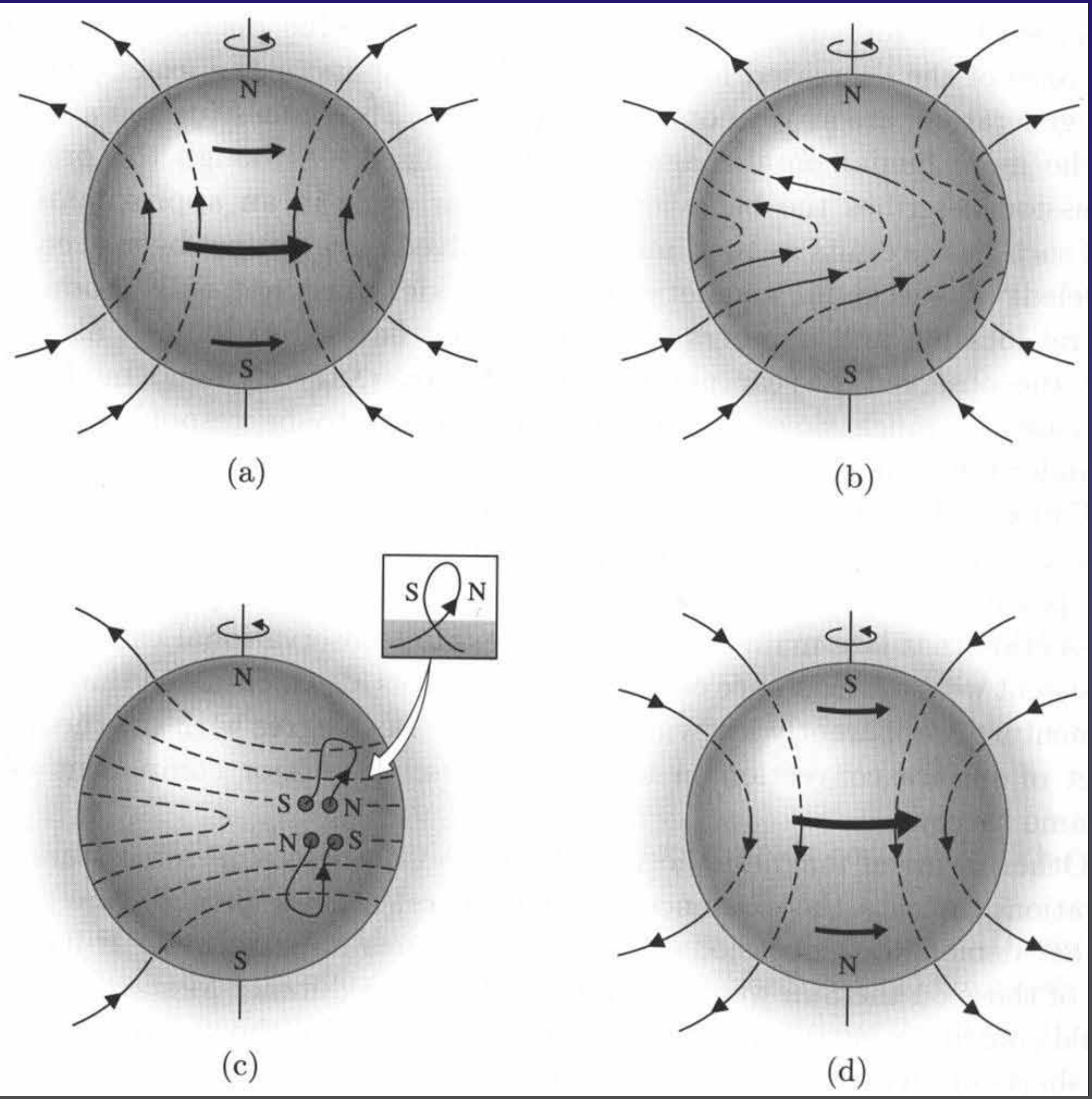
…back to the Rossby number

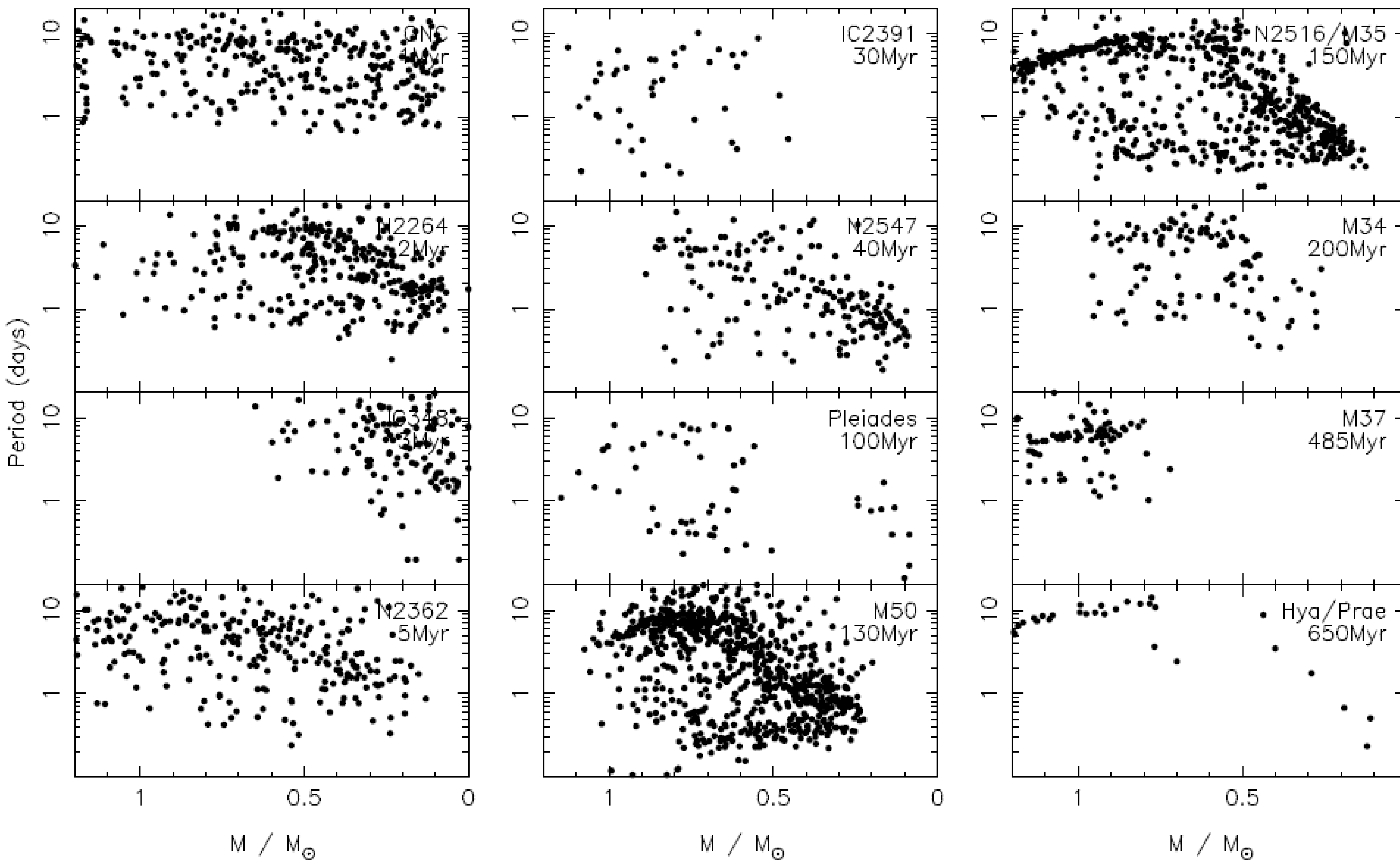




most low-mass stars are in the rapid-rotation regime (saturated)

The solar cycle

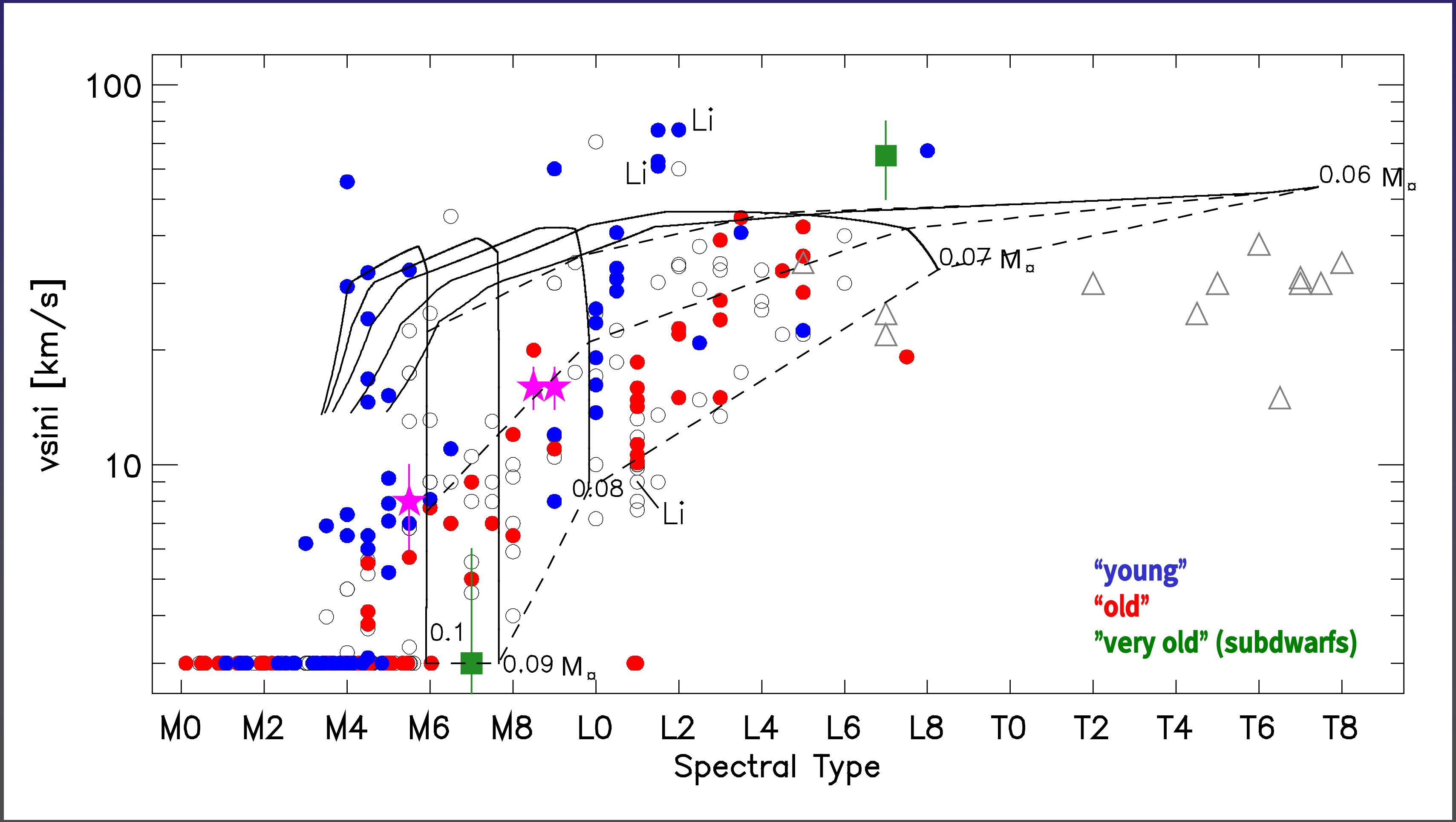



ONC
1Myr
IC2391
30Myr
N2516/M35
150Myr
N2264
2Myr
N2547
40Myr
M34
200Myr
IC348
3Myr
Pleiades
100Myr
M37
485Myr
N2362
5Myr
M50
130Myr
Hya/Prae
650Myr
Period (days)
M / M⊙

Rotation in low mass objects

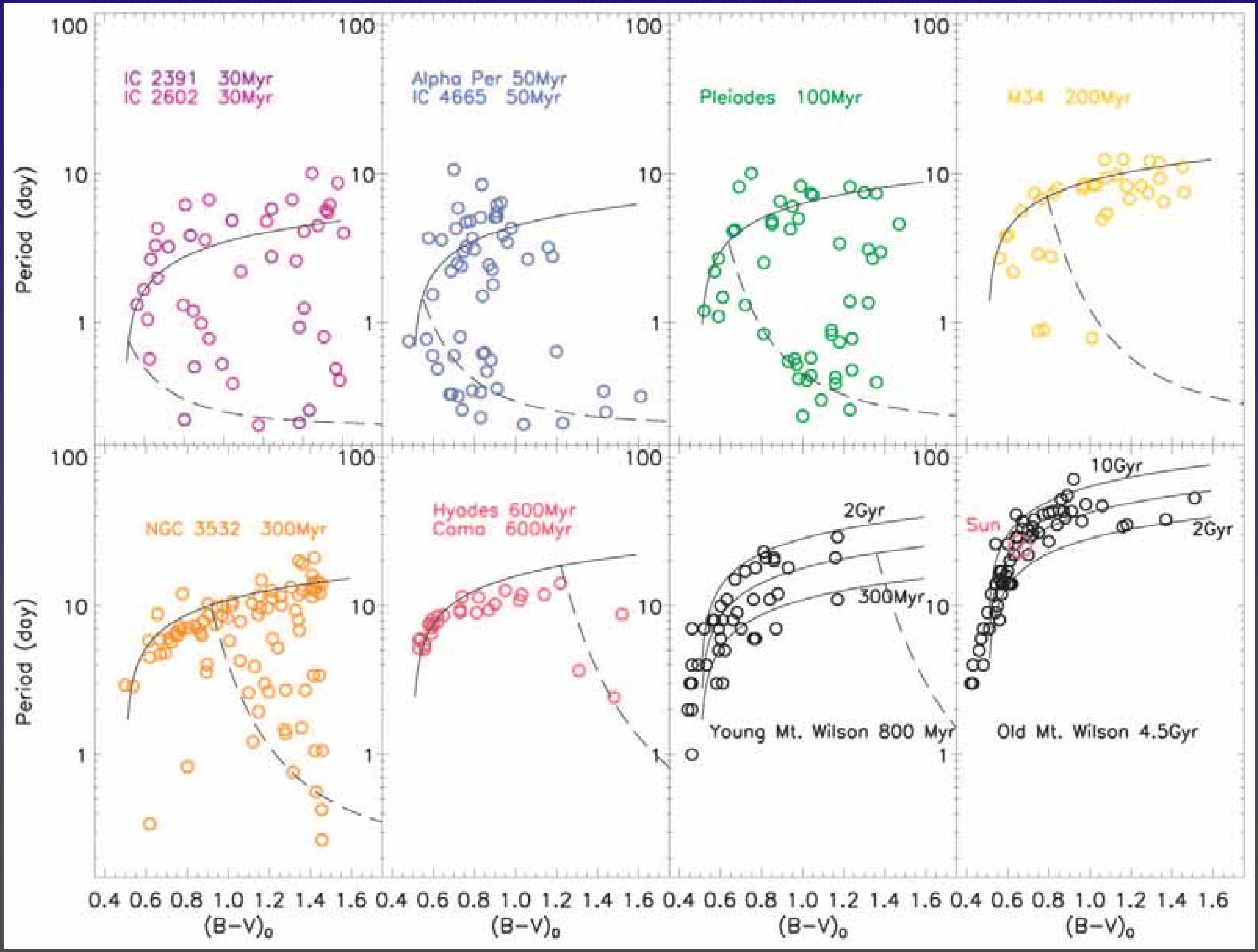
Wind braking law:

Mass dependent



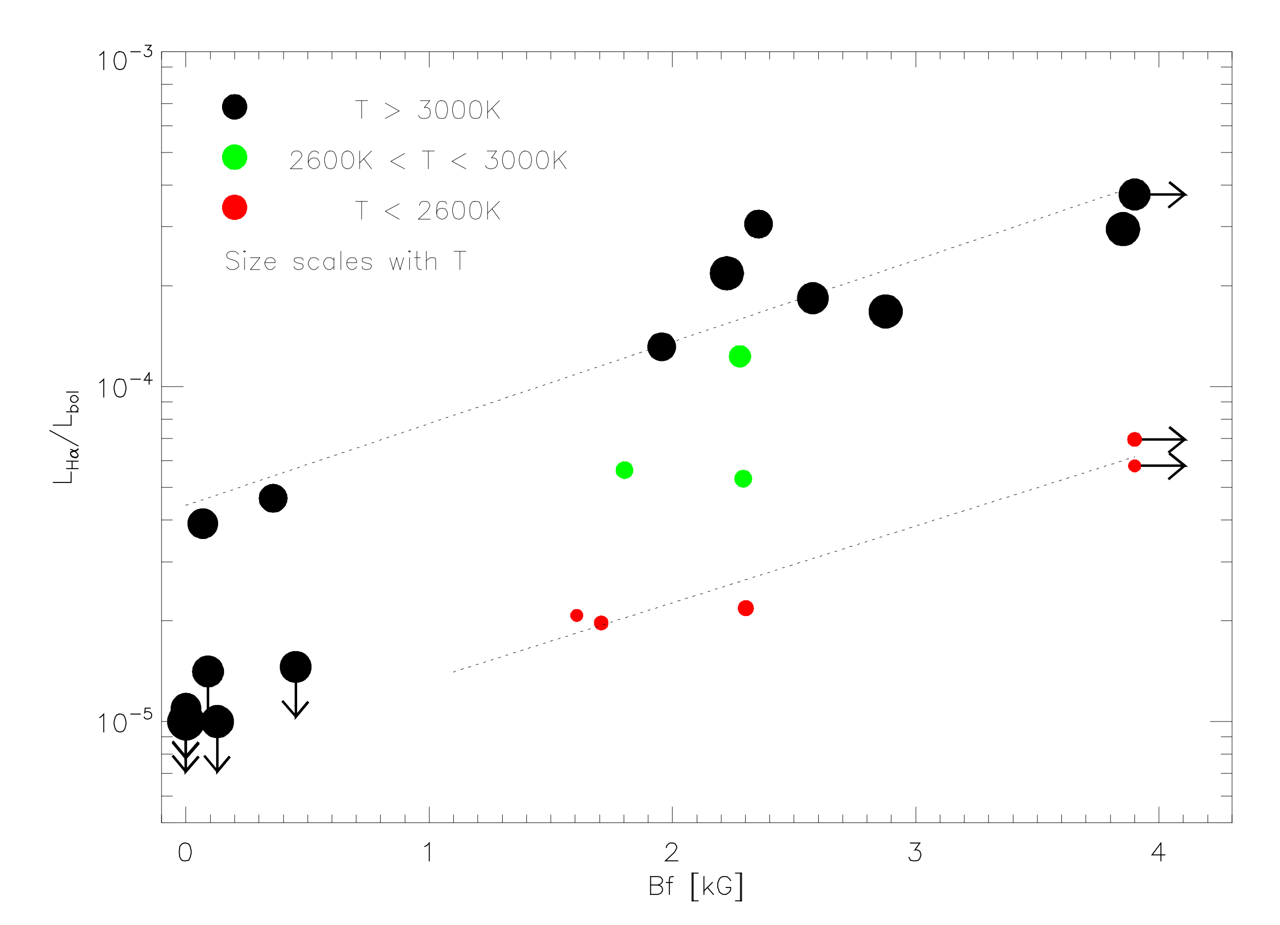
Reiners & Basri, 2008

Observations of clusters (young) and field (old) stars



Barnes, 2003

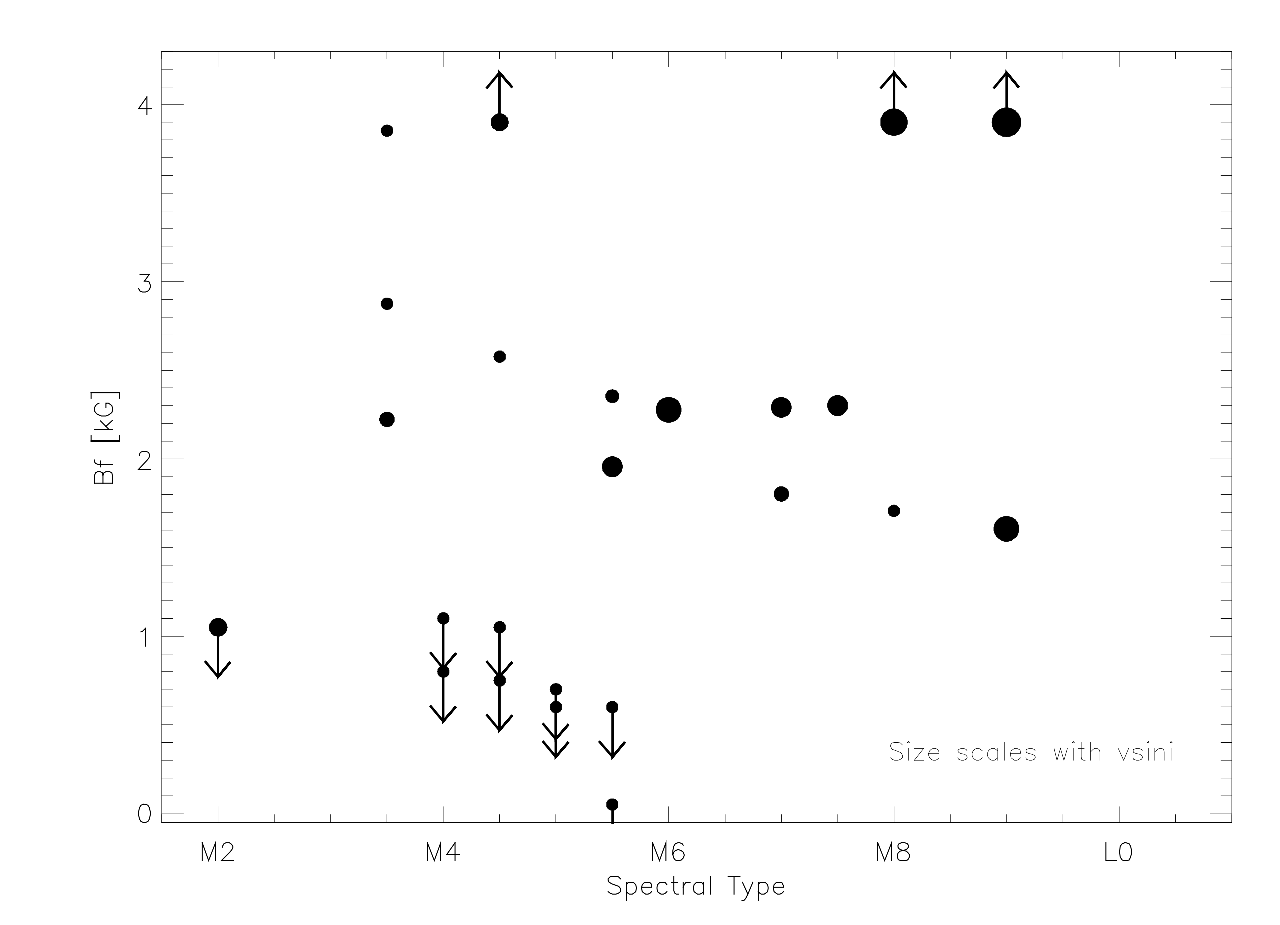
Activity and magnetic flux with temperature



Reiners & Basri, 2007

At fixed temperature, Ha-activity scales with magnetic flux!
The overall level of activity is decreasing.

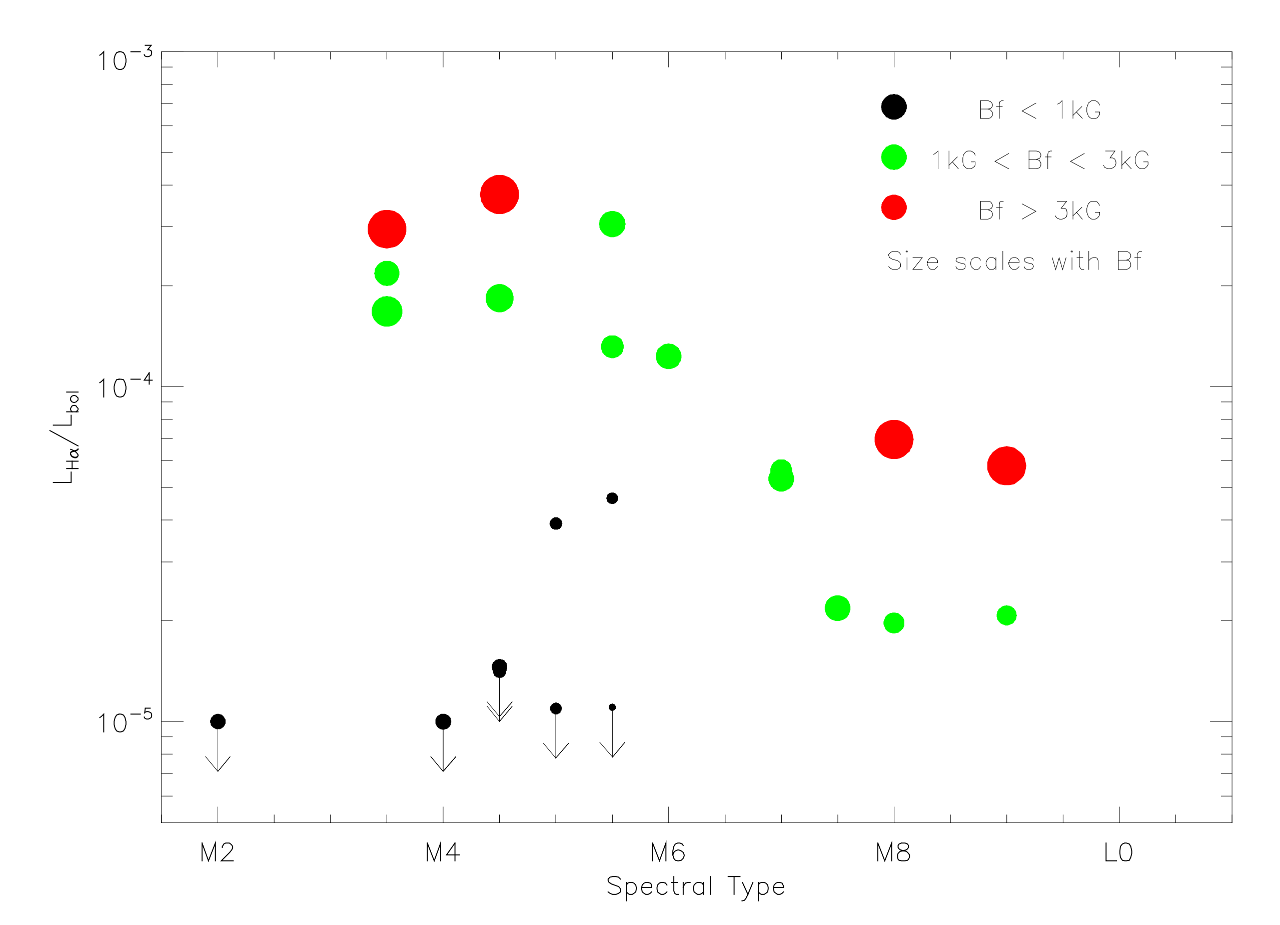
Magnetic flux and spectral type



Reiners & Basri, 2007

Magnetic flux ubiquitous in late M-type objects!

Activity and spectral type with magnetic flux

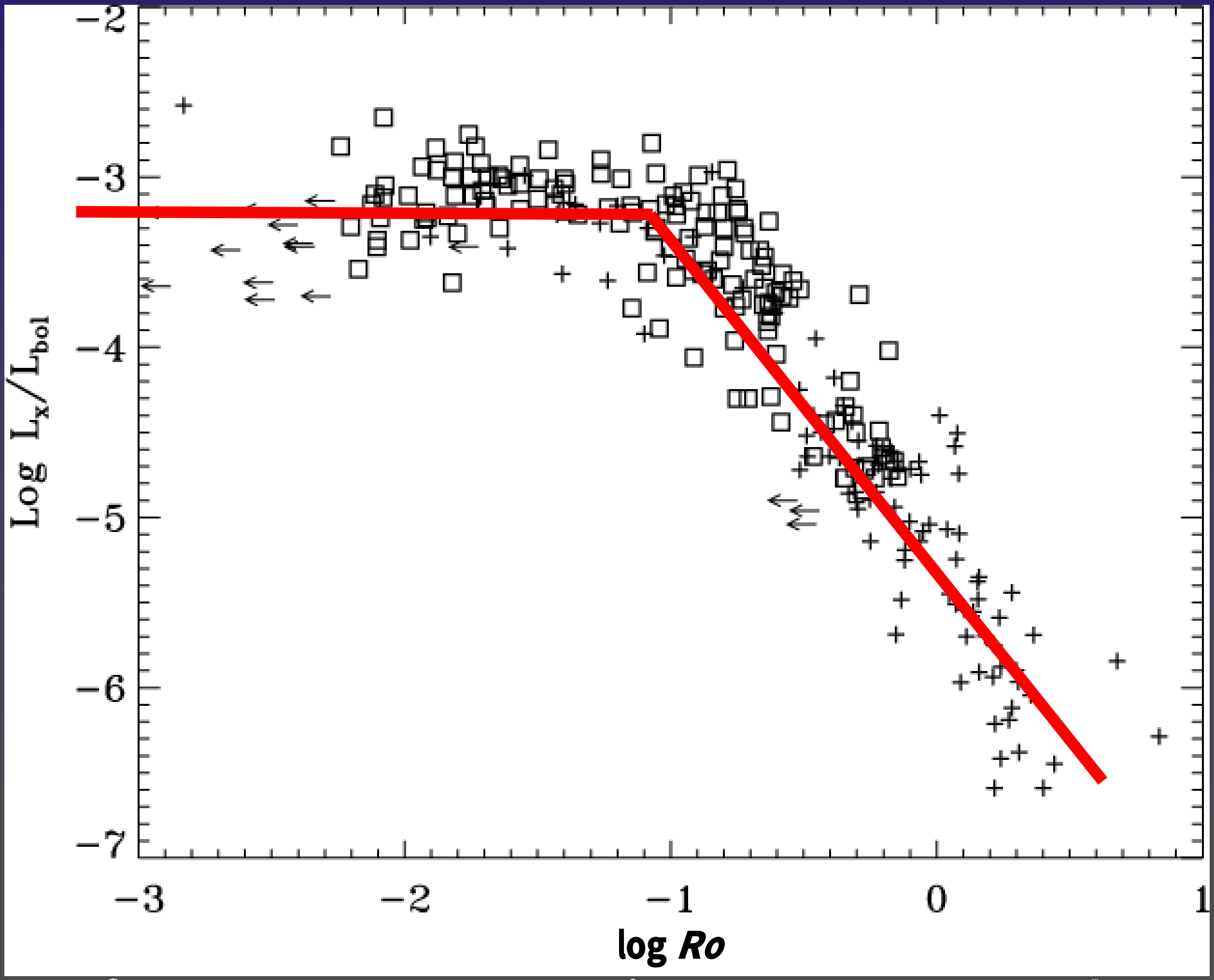


Reiners & Basri, 2007

Yes, there are magnetic fields!
At fixed temperature, Ha-activity scales with magnetic flux.

Stars: Rotation-Activity Connection

(F5-M5, different age)



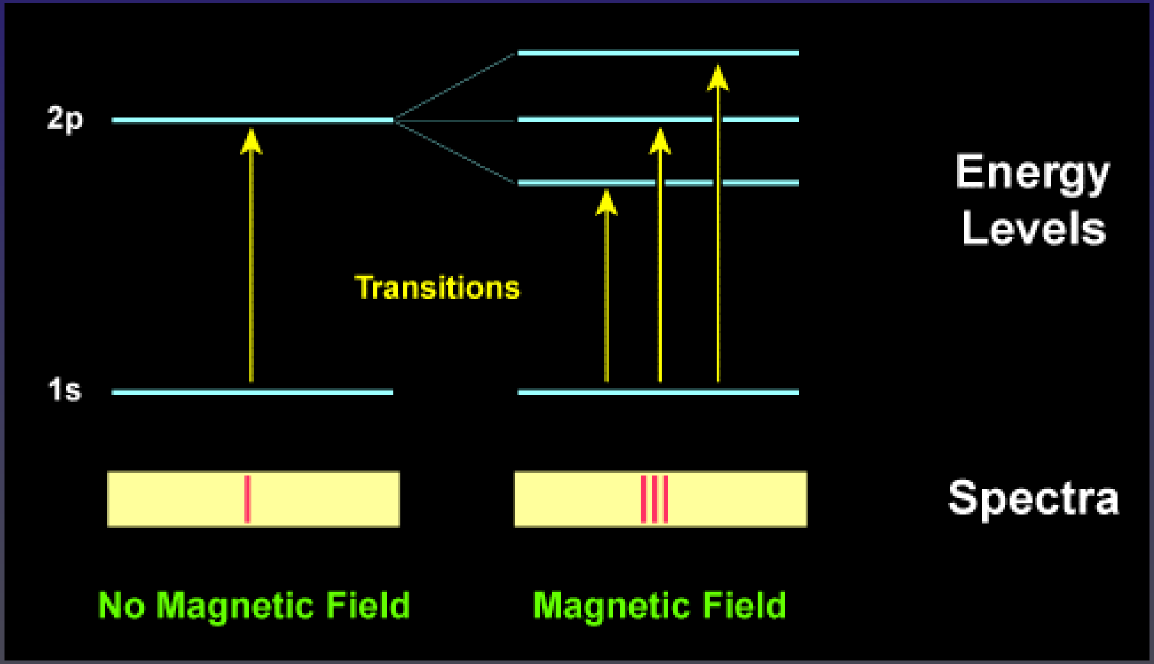
fast rotation slow

Rossby Number

$$Ro = \frac{P}{t_{conv}}$$

Pizzolato et al., 2003

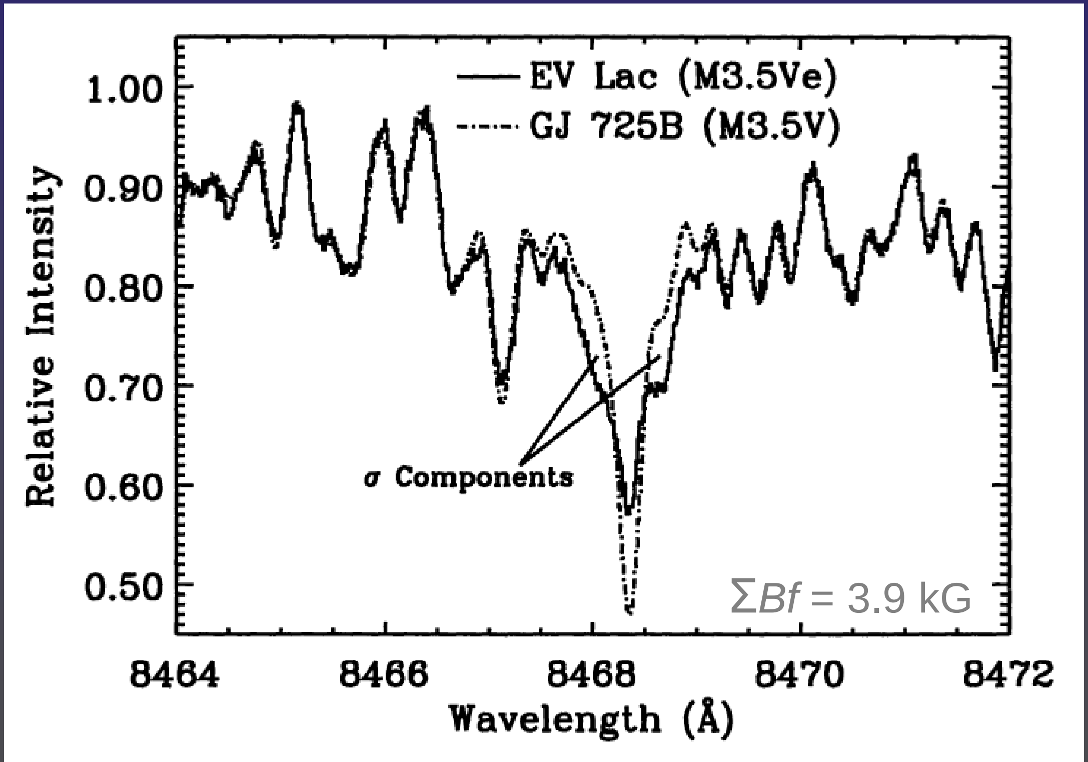
IIIb. Magnetic fields in ultra-cool stars



Need isolated magnetically sensitive and some insensitive lines

Magnetic flux observations in *very-low mass* stars

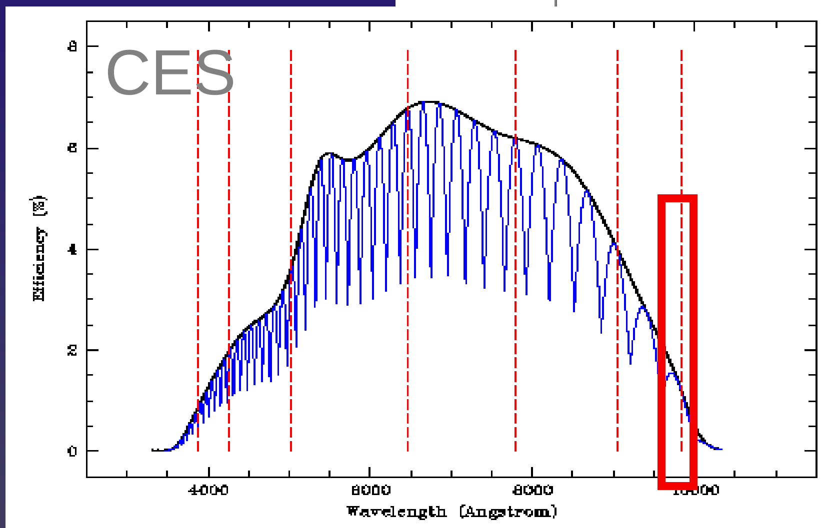
Trouble: atomic features vanish or get buried in the molecular haze

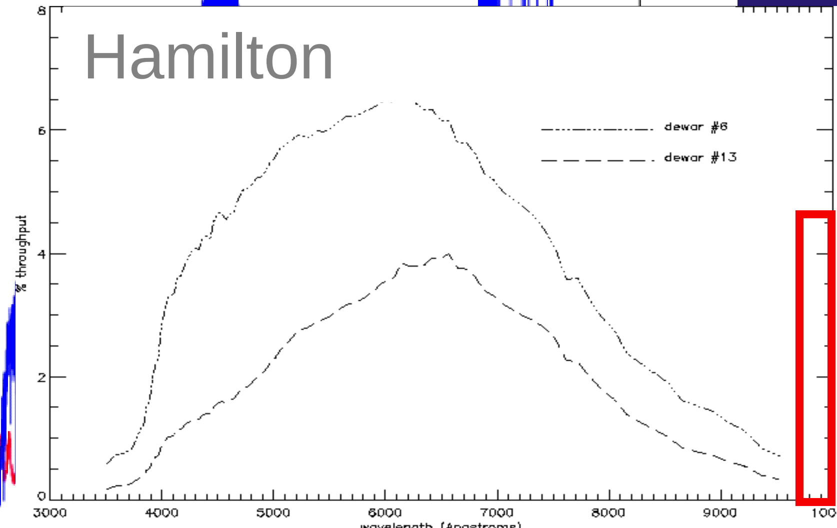


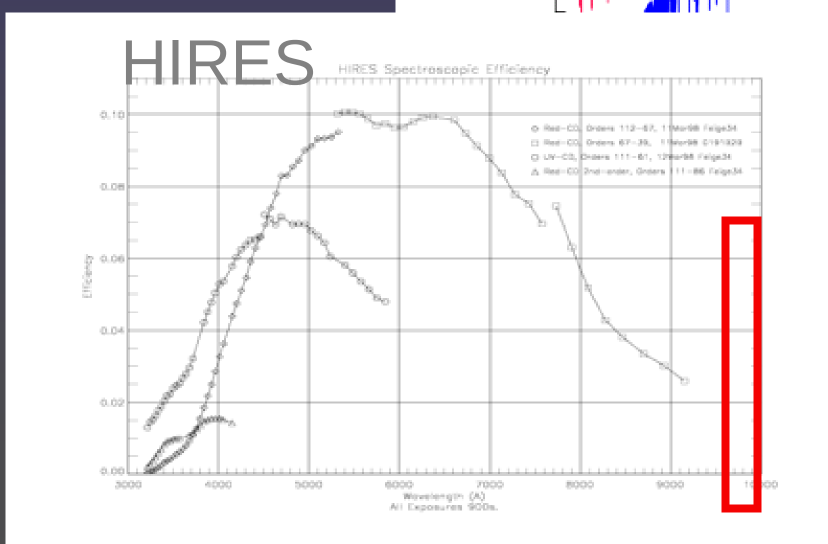
Johns-Krull & Valenti, 2000

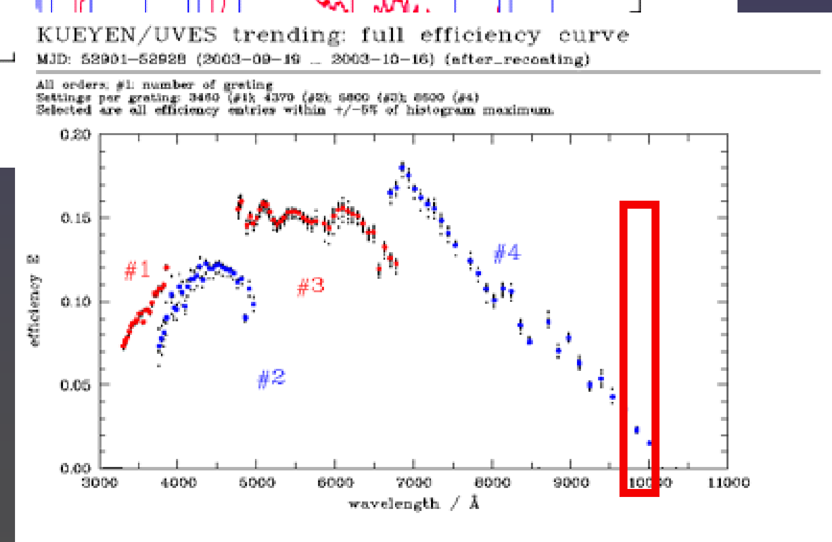
Although observations are still a challenge

Efficiencies of high resolution facilities



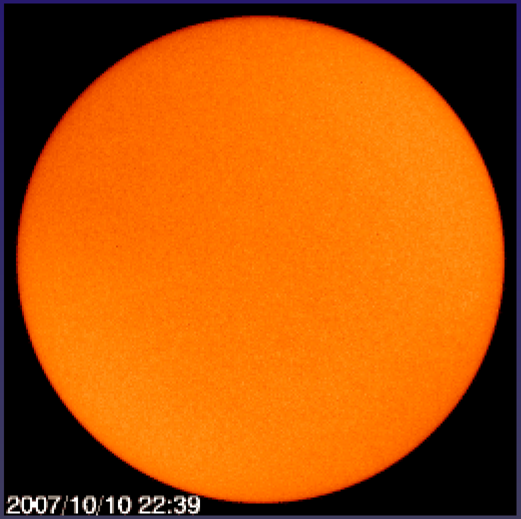


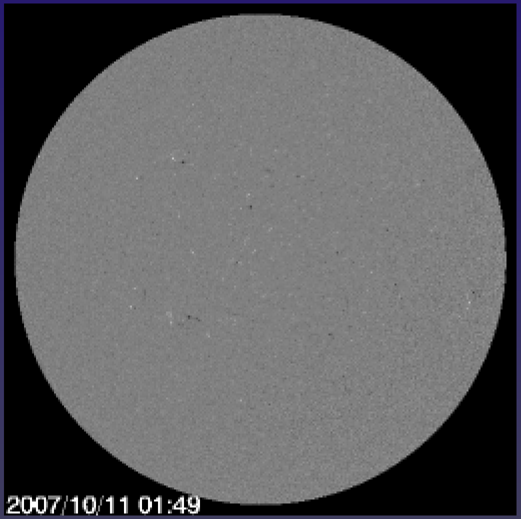




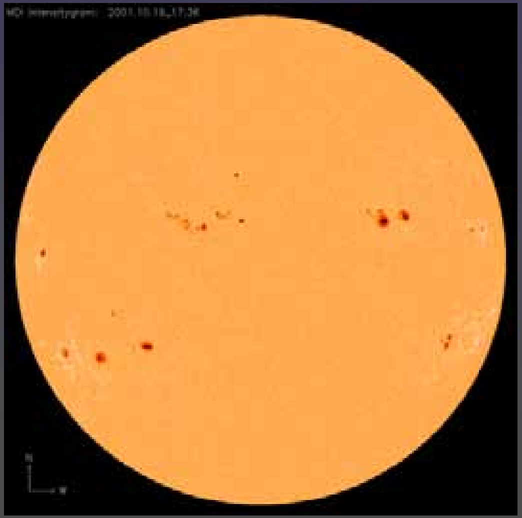
The Sun

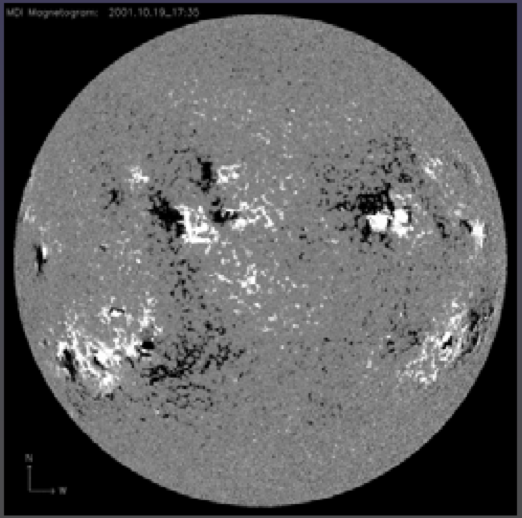
2007





2001

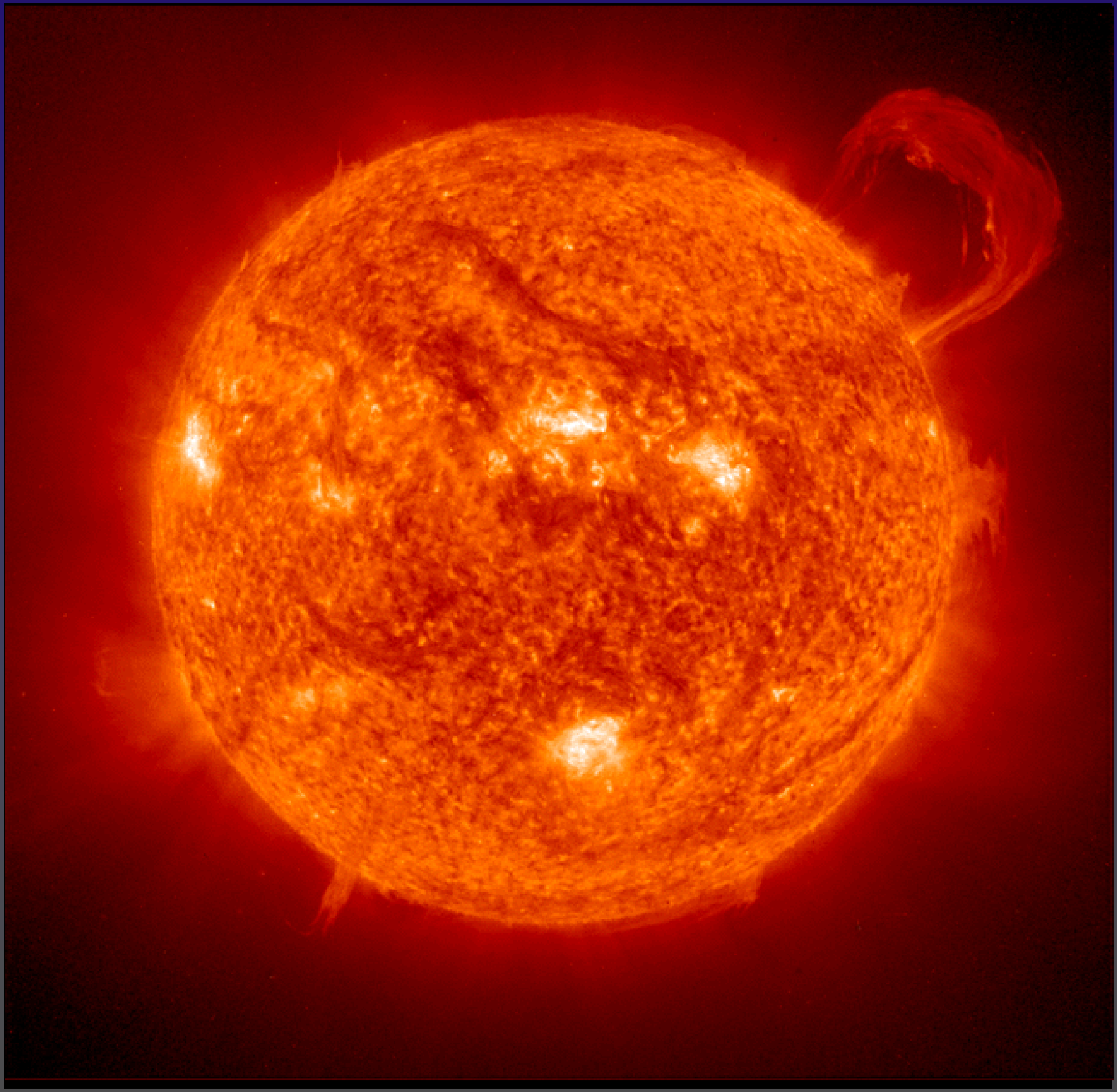




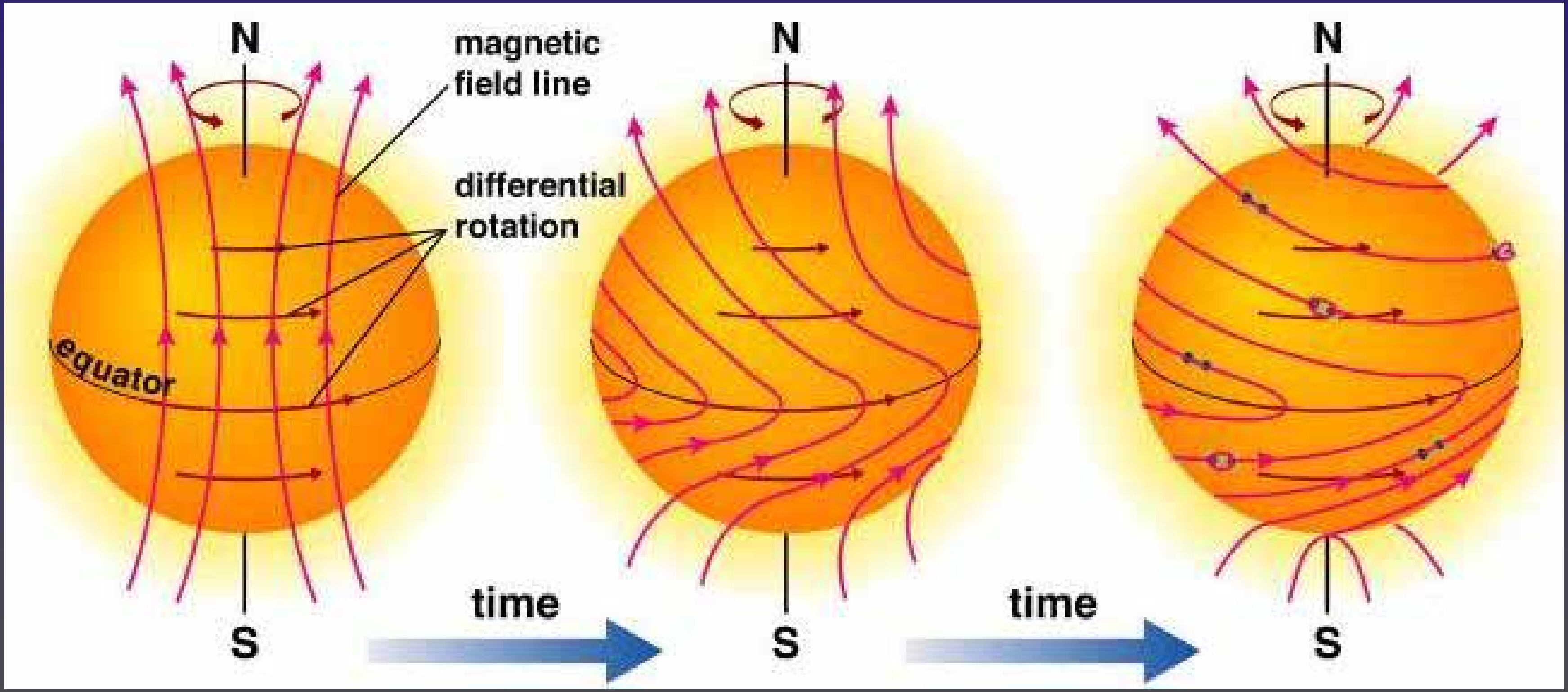
optical

magnetogram

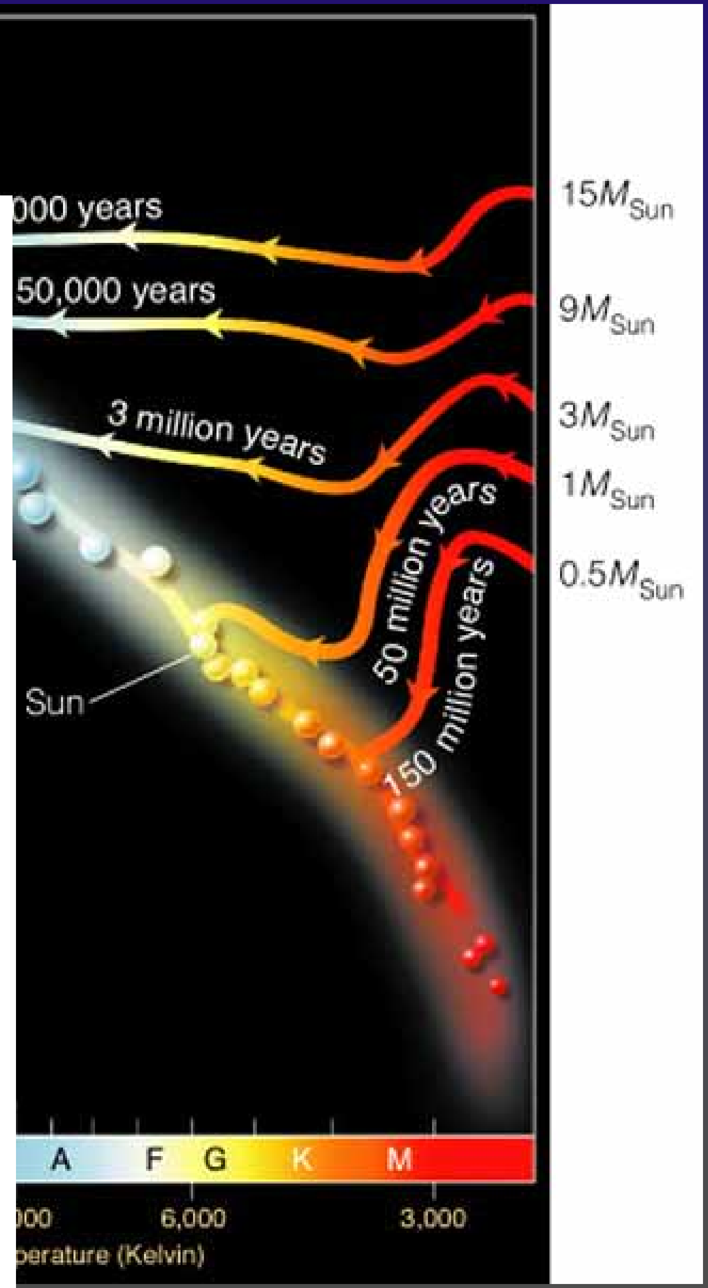
The Sun

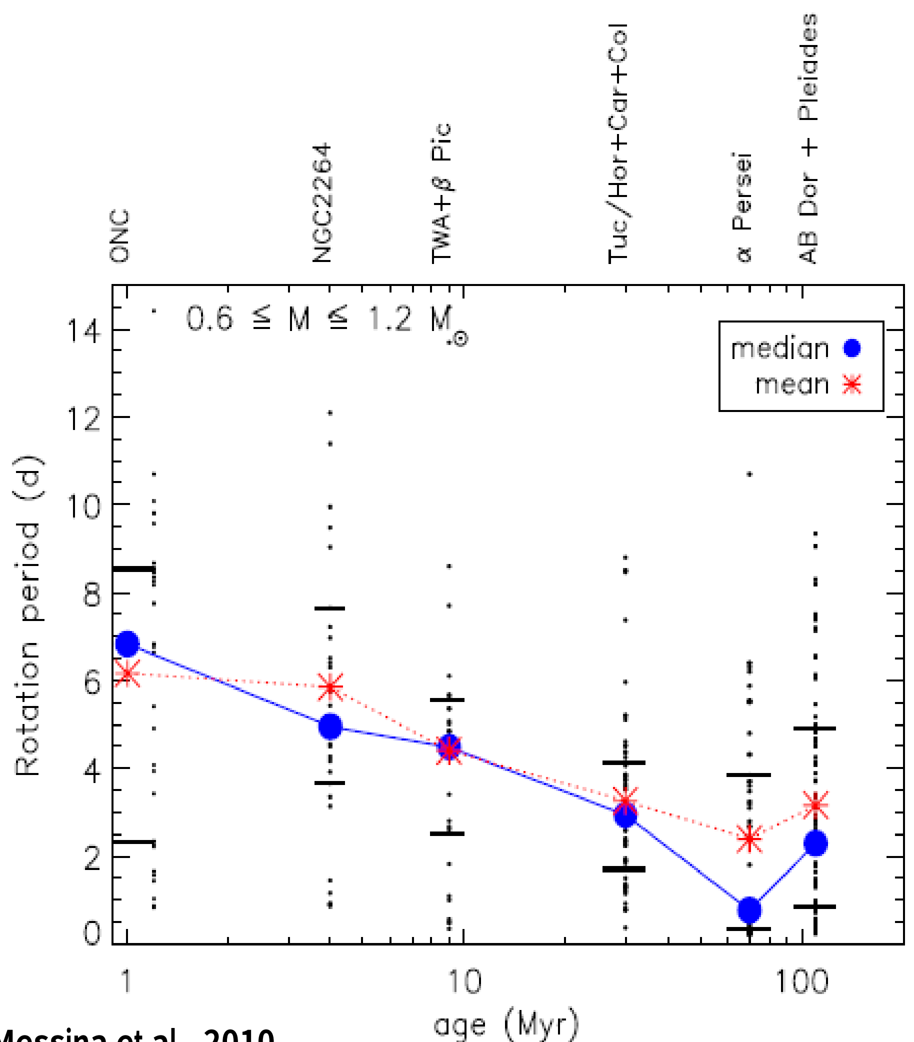


Differential rotation in the Sun



Evolution of young stars

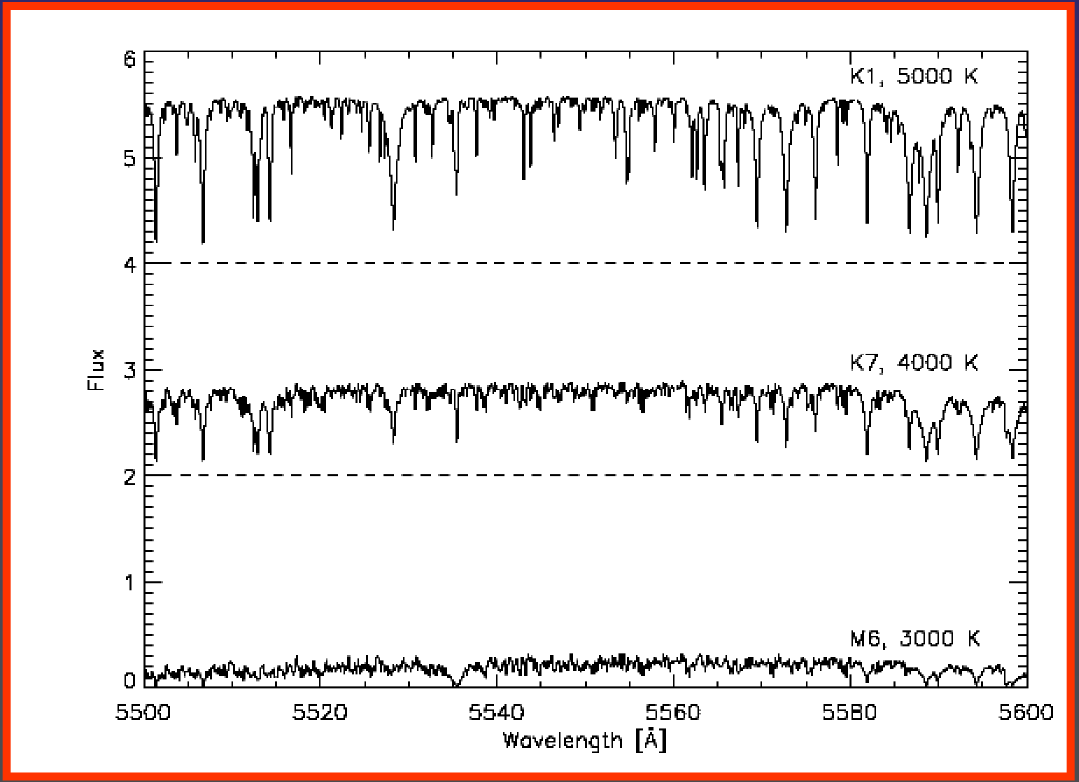




Messina et al., 2010

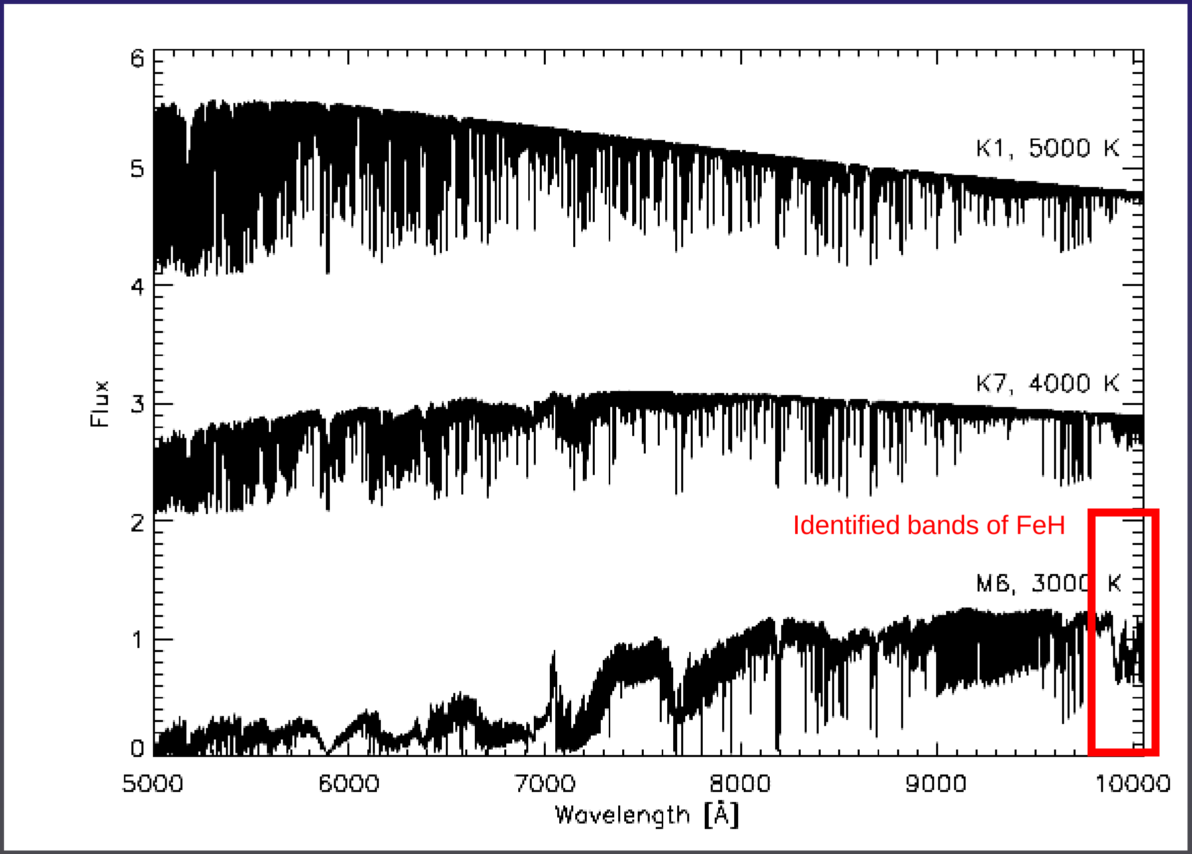
How to find stellar magnetic fields

At low temperature, atomic lines vanish, and molecules dominate the spectra



How to find stellar magnetic fields

Promising tool: molecular FeH absorption



FeH lines are narrow, isolated (!), embedded in a clear continuum, and at the peak of SEDs in ultra-cool objects!