Observational constraints on surface B-fields in early type stars

... and their consequences

Dr. Véronique Petit

Phenomena, Physics, and Puzzles Of Massive Stars and their Explosive Outcomes

Magnetic properties of massive stars

10% of massive stars host a strong, large-scale, **surface** magnetic field of **fossil origin**

Main questions

Where do magnetic fields in massive stars come from?

How does surface magnetism influence the structure and evolution of stars.

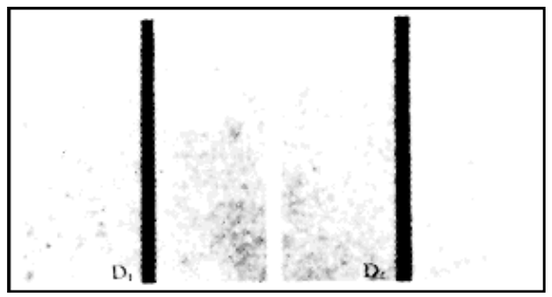
How does the structure and evolution of the star influence surface magnetism.

and **Beyond** the main sequence, how are magnetic stars linked to highly magnetized neutron stars and heavy black holes?

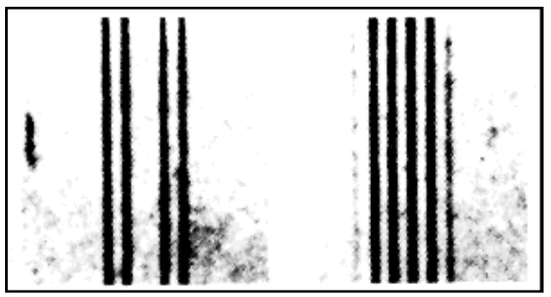
How to measure surface magnetic fields

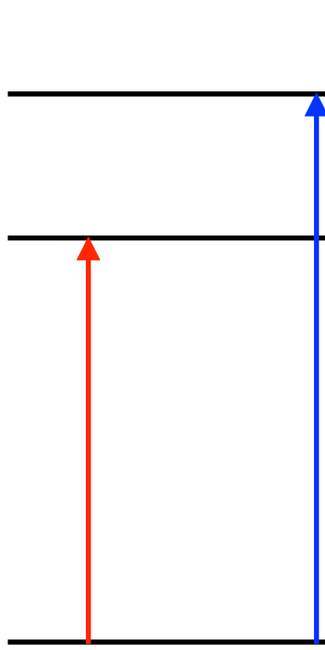
The Zeeman effect changes the electronic energy levels of atoms, and thus the wavelength of photons emitted by these atoms.

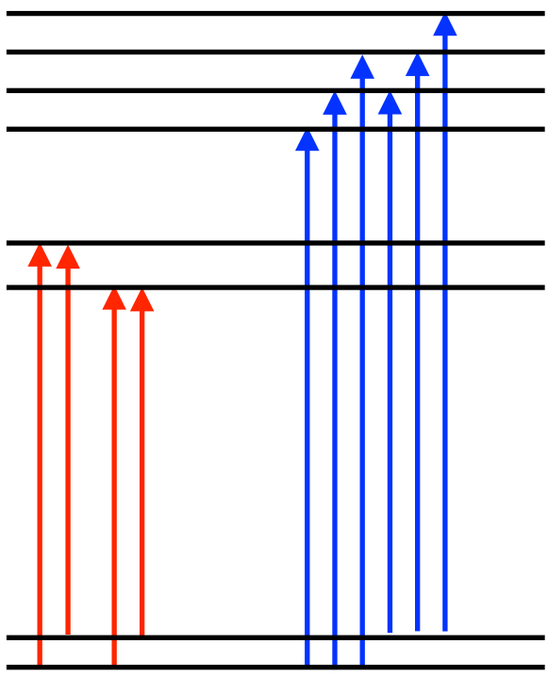
no magnetic field

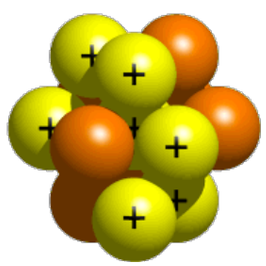


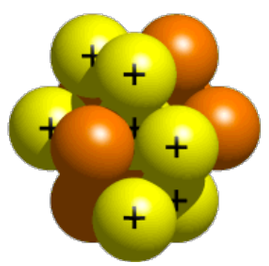
with magnetic field



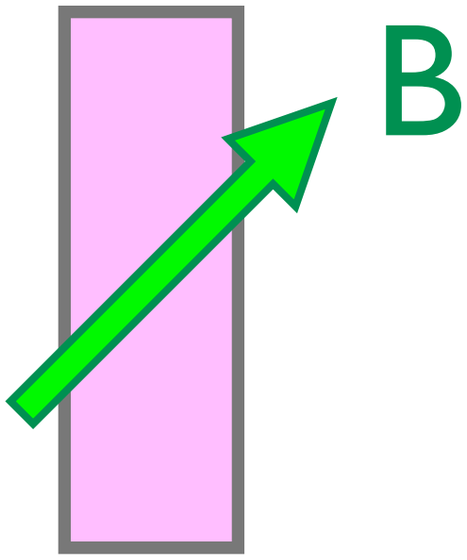


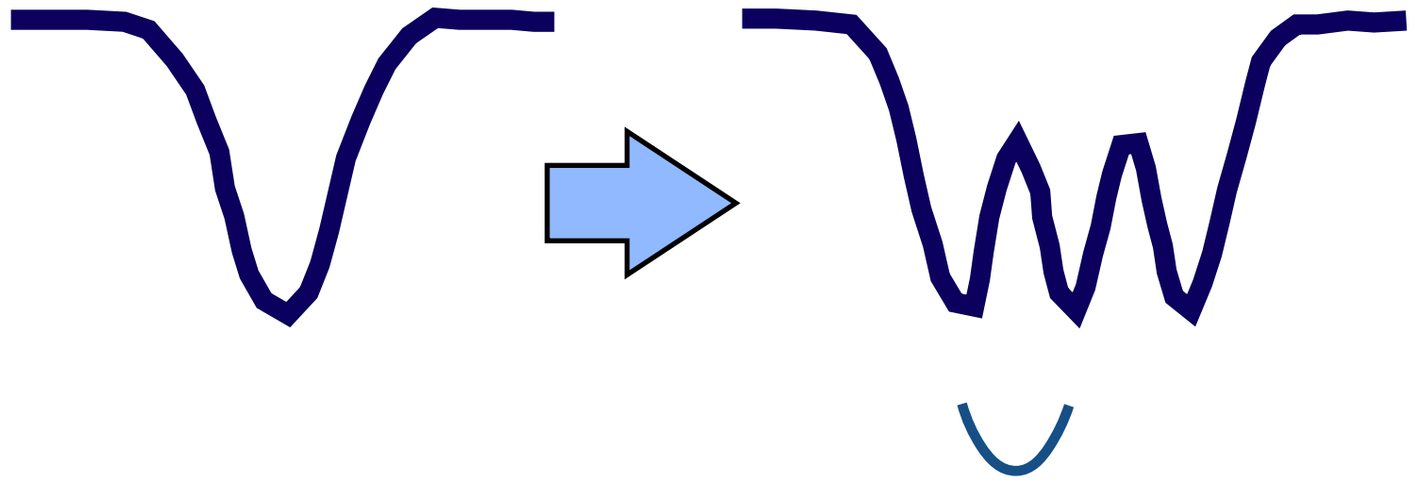


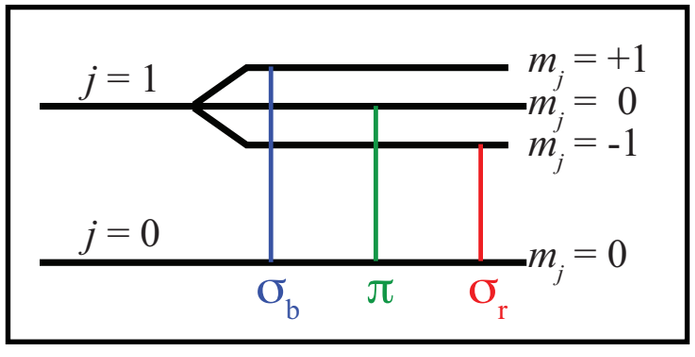




However Zeeman splitting can only be measure if the field is strong, and the spectral lines not broadened by other mechanisms.

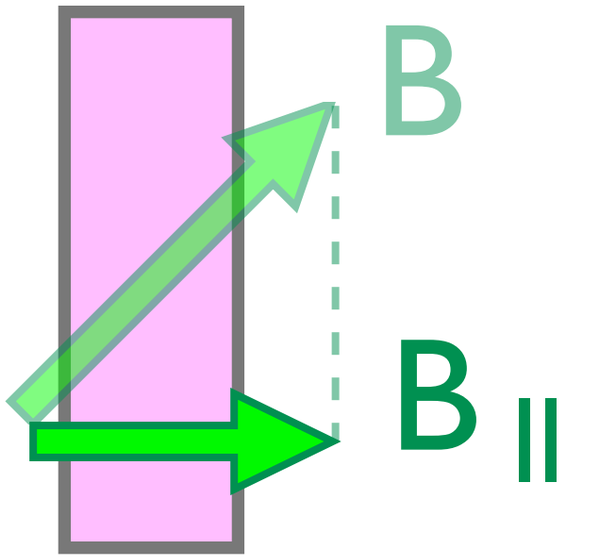


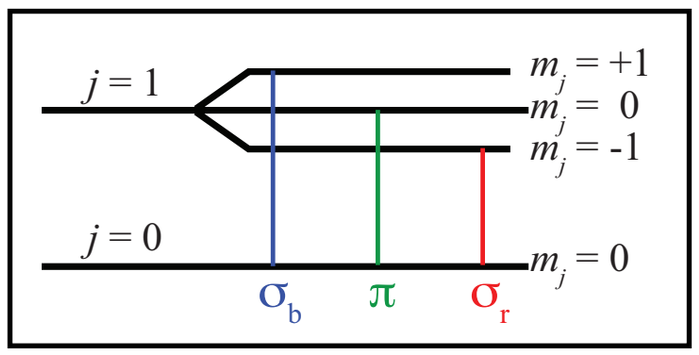


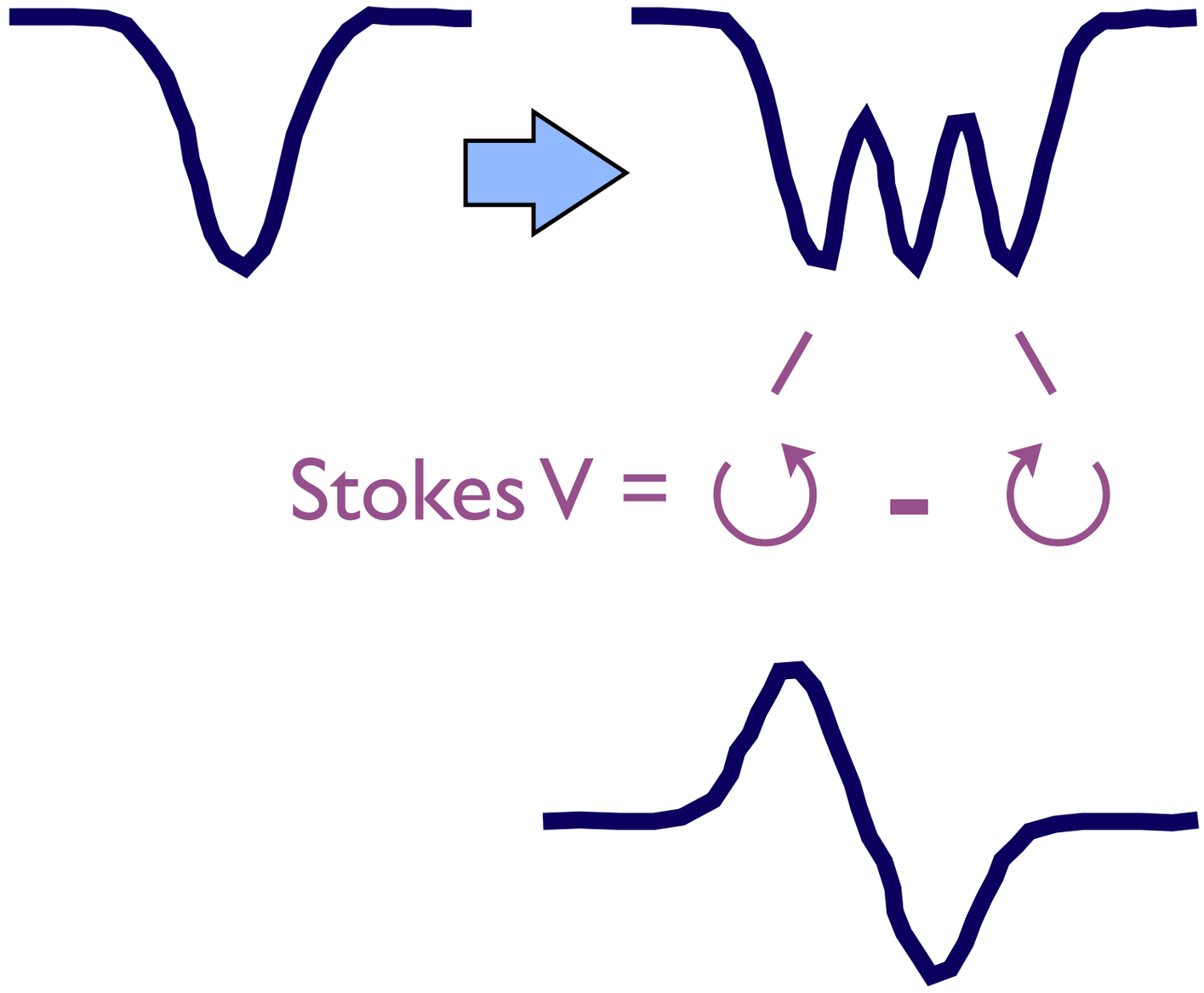


In the optical,
$\Delta v \sim 1$ km/s per kG..

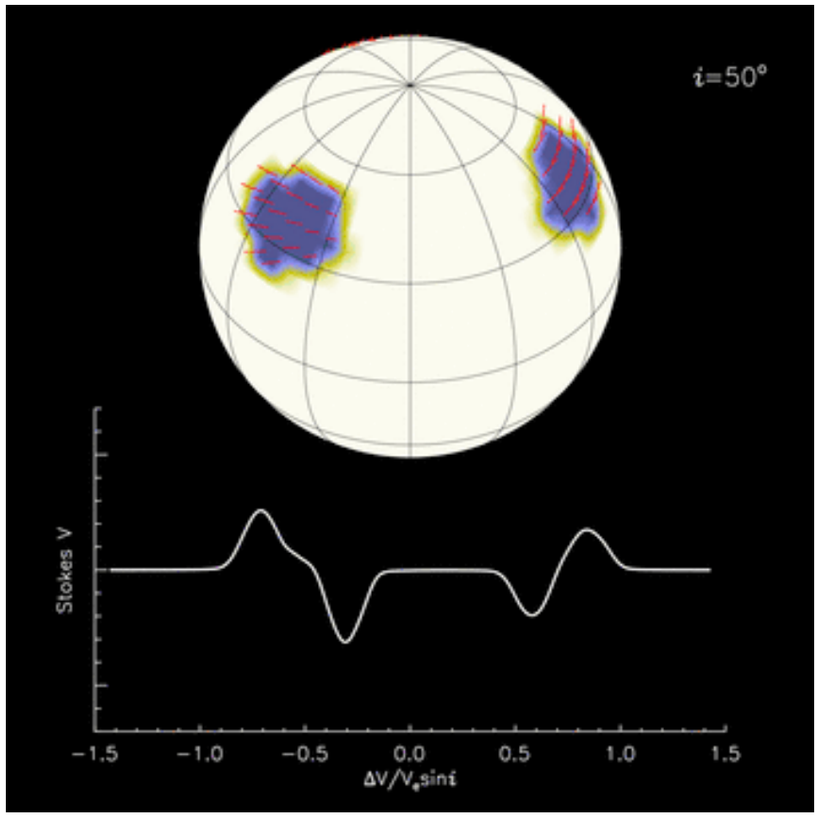
The Zeeman effect also creates circular polarization that we can measure with a spectropolarimeter.

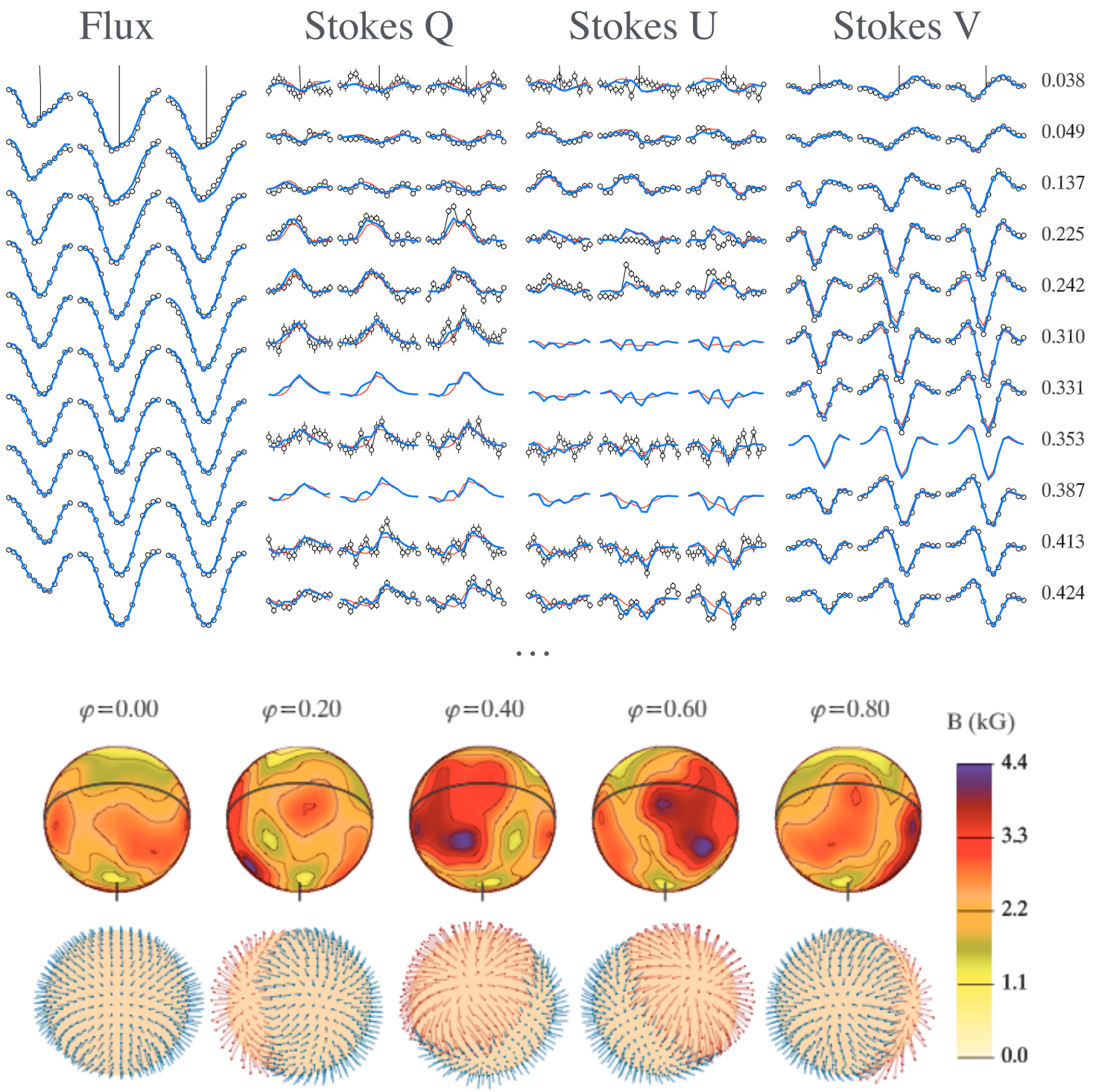






With time-resolved spectropolarimetry observations, we can infer the magnetic topology in great details.





Magnetism is a rare way to unambiguously determine the rotation period of massive stars.

What are the characteristics of magnetic massive stars?

Recent surveys have significantly pushed forward
our understanding of magnetism in massive OB stars

The Magnetism in Massive Stars (MiMeS) survey

Grunhut et al. 2017, Wade et al. 2016

The B-fields in OB stars (BOB) survey

Schöller et al. 2017, Fossati et al. 2015

Binarity and Magnetic Interactions in various classes of Stars

Alecian et al. 2015

The bulk incidence of magnetic star is about 10%, across the OBA mass range.

F stars

A stars

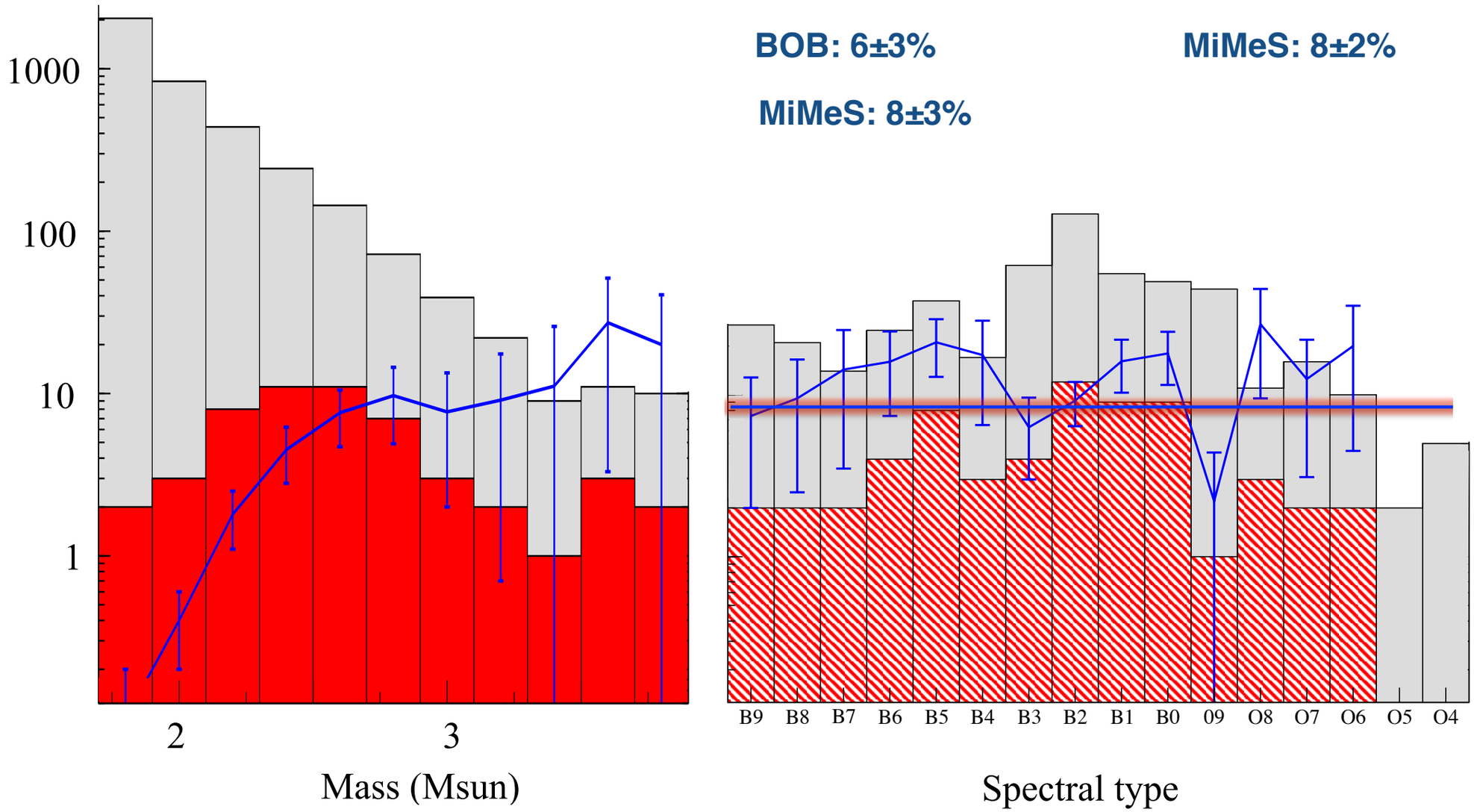
B stars

BOB: 6±3%

MiMeS: 8±3%

O-type stars

MiMeS: 8±2%

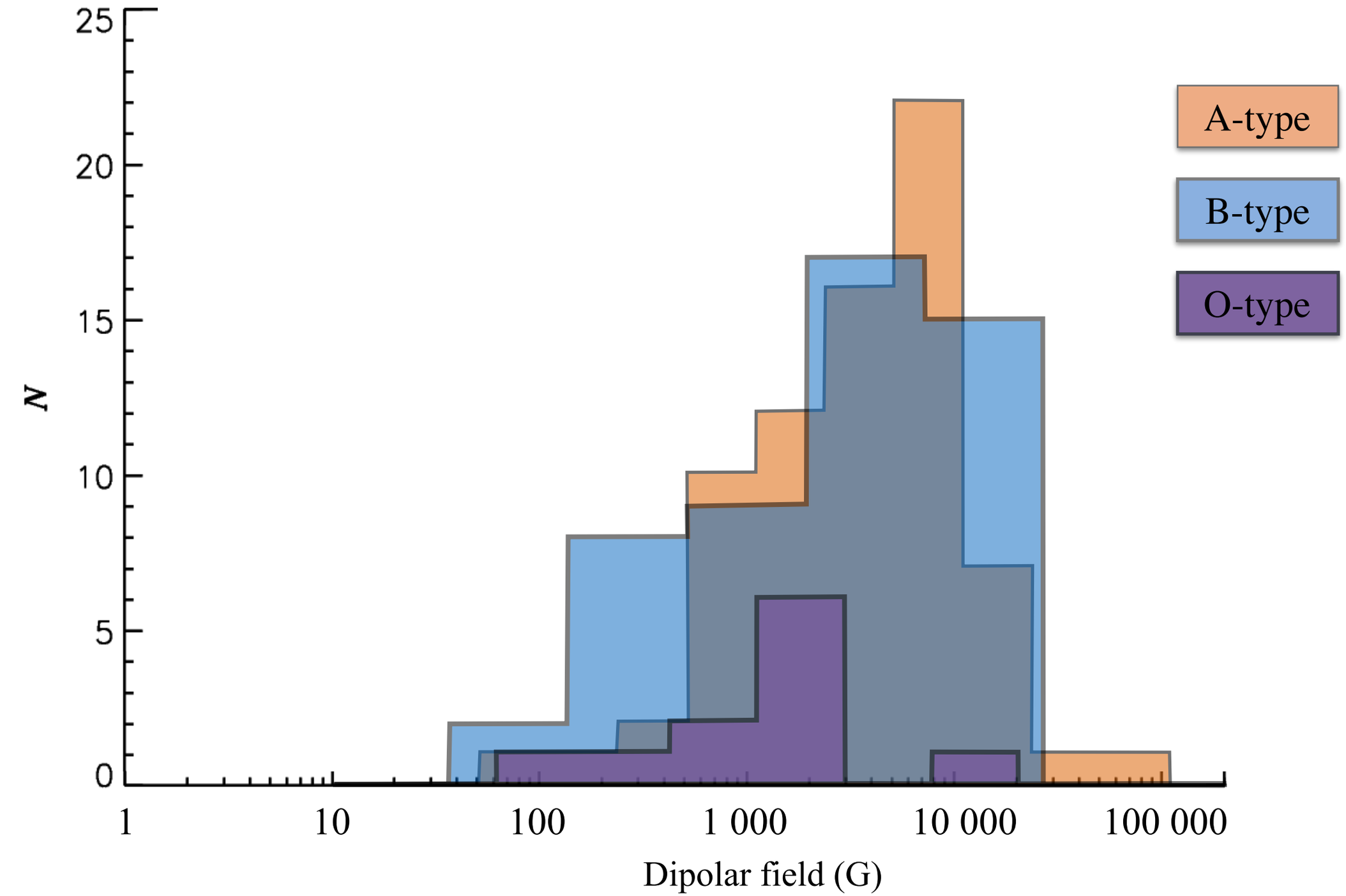


Power et al. 2007

Schöller et al. 2016
Grunhut et al. in prep,

Grunhut et al. 2017,

The distribution of field strength is similar for OBA stars: there are no correlation between field strength and mass



Adapted from Shultz 2016

Magnetic fields of OBA stars are not being currently dynamo-generated

- Strong, simple fields, but rare (10%)
- Strength does not correlate with rotation, mass, etc
- Stable on up to decades timescales
- Magnetic characteristic of Herbig AeBe stars are similar

"Fossil" or "remnant" field

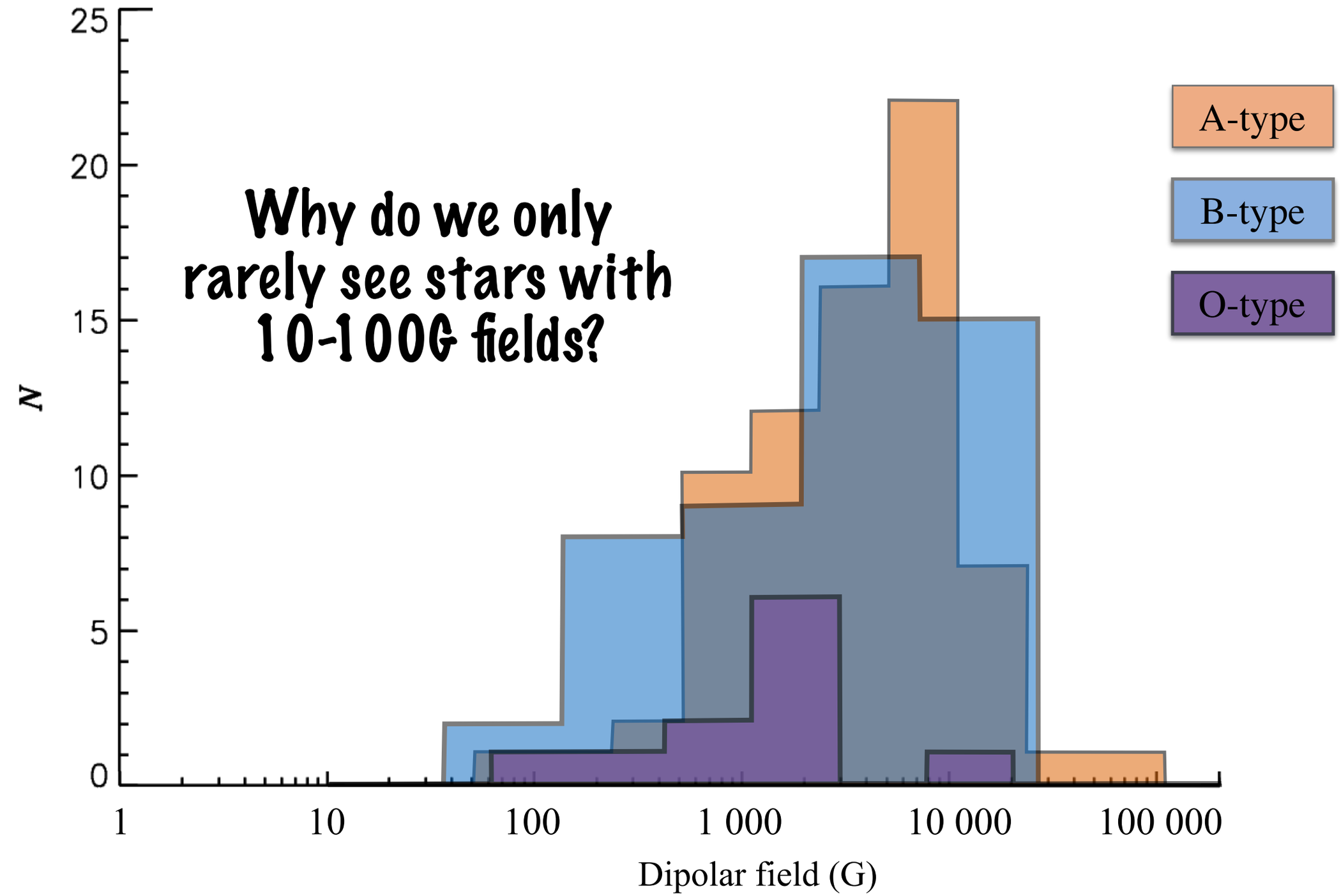
But what was that event or evolutionary phase that set the magnetic characteristics of OBA stars…?

- **Primordial ISM magnetic field**
- **Protostellar dynamo**
- **Stellar Merger**

Need a common mechanism working over a large range of initial masses

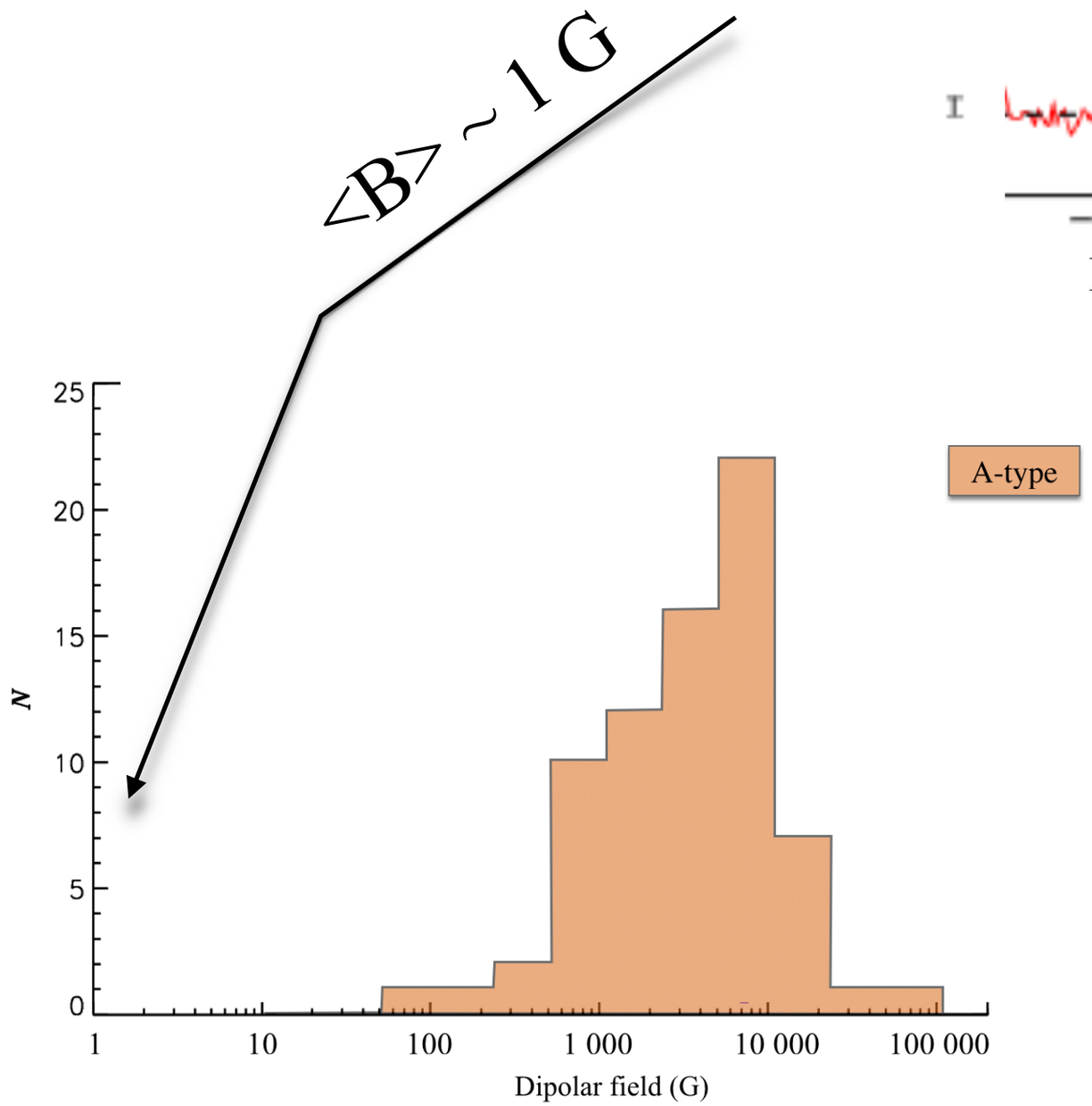
Two interesting characteristics of magnetic stars that could tell us more about their origins

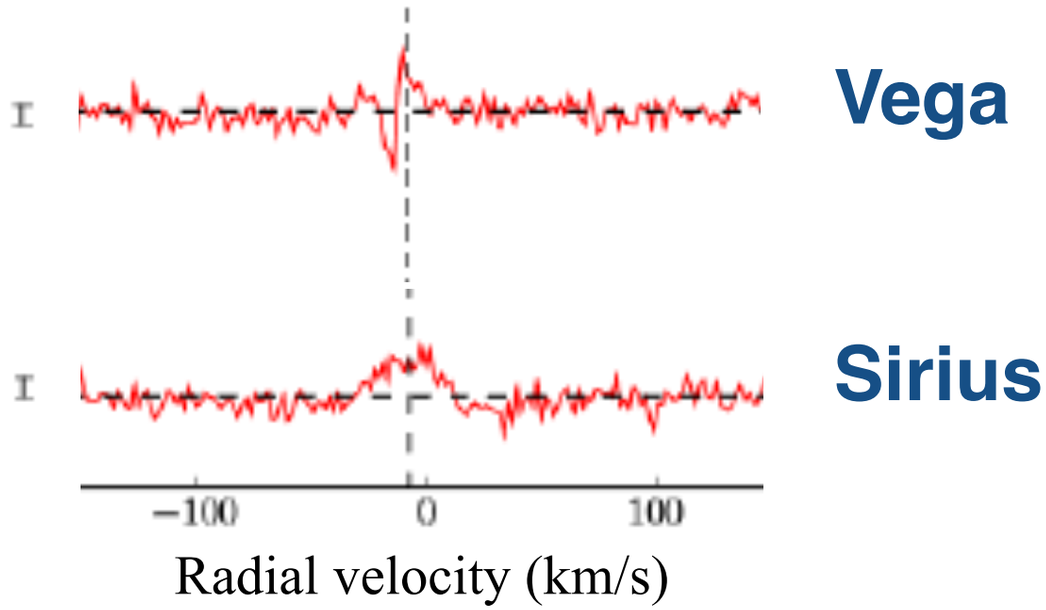
The so-called "magnetic desert"



Adapted from Shultz 2016

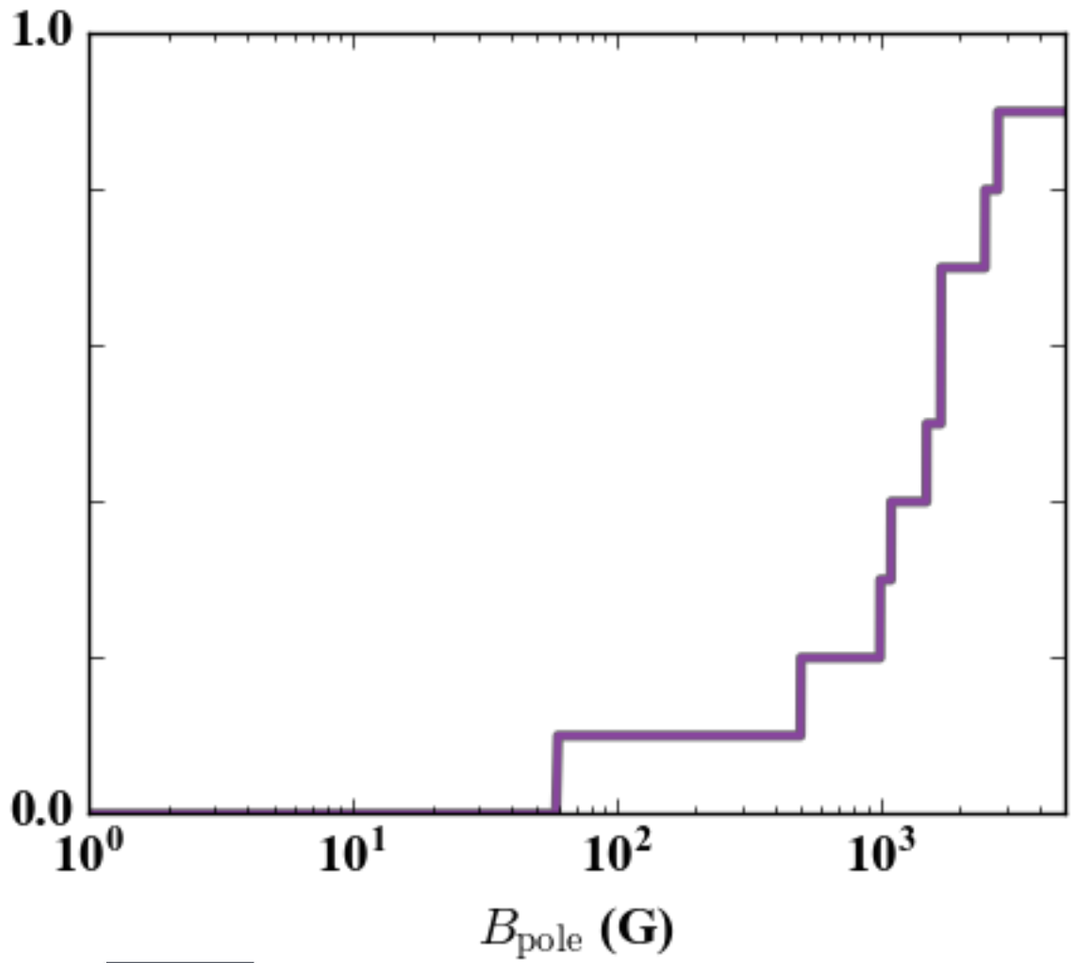
Evidence for ultra-weak magnetic fields at the surface of bright, A-type stars.

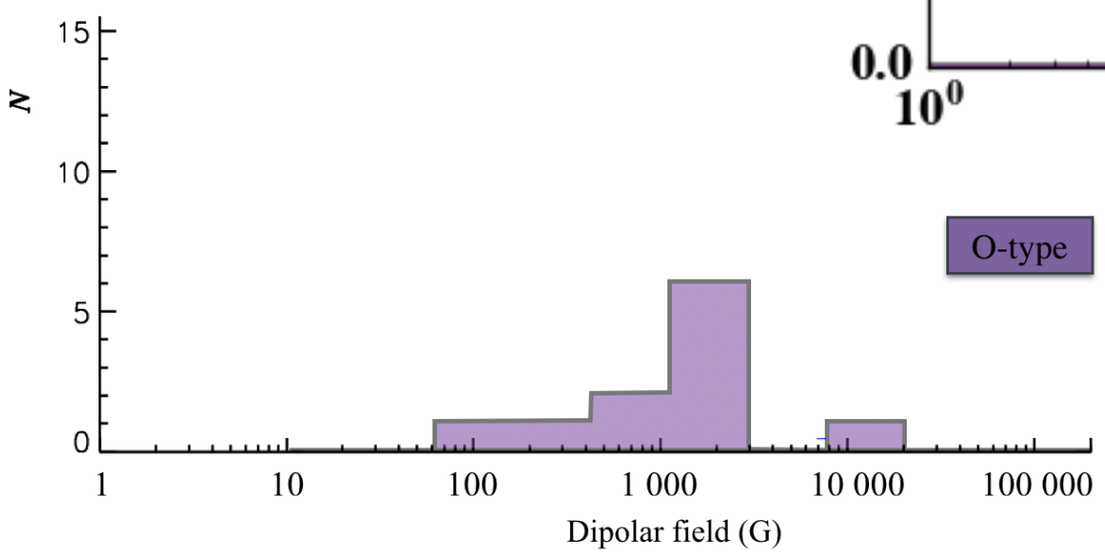




Adapted from Petit, P. et al. 2011
Blazere et al. 2016

There seem to be a similar shortage of O-type stars with ~100 G magnetic fields





MiMeS O-star sample
Petit et al. in prep.

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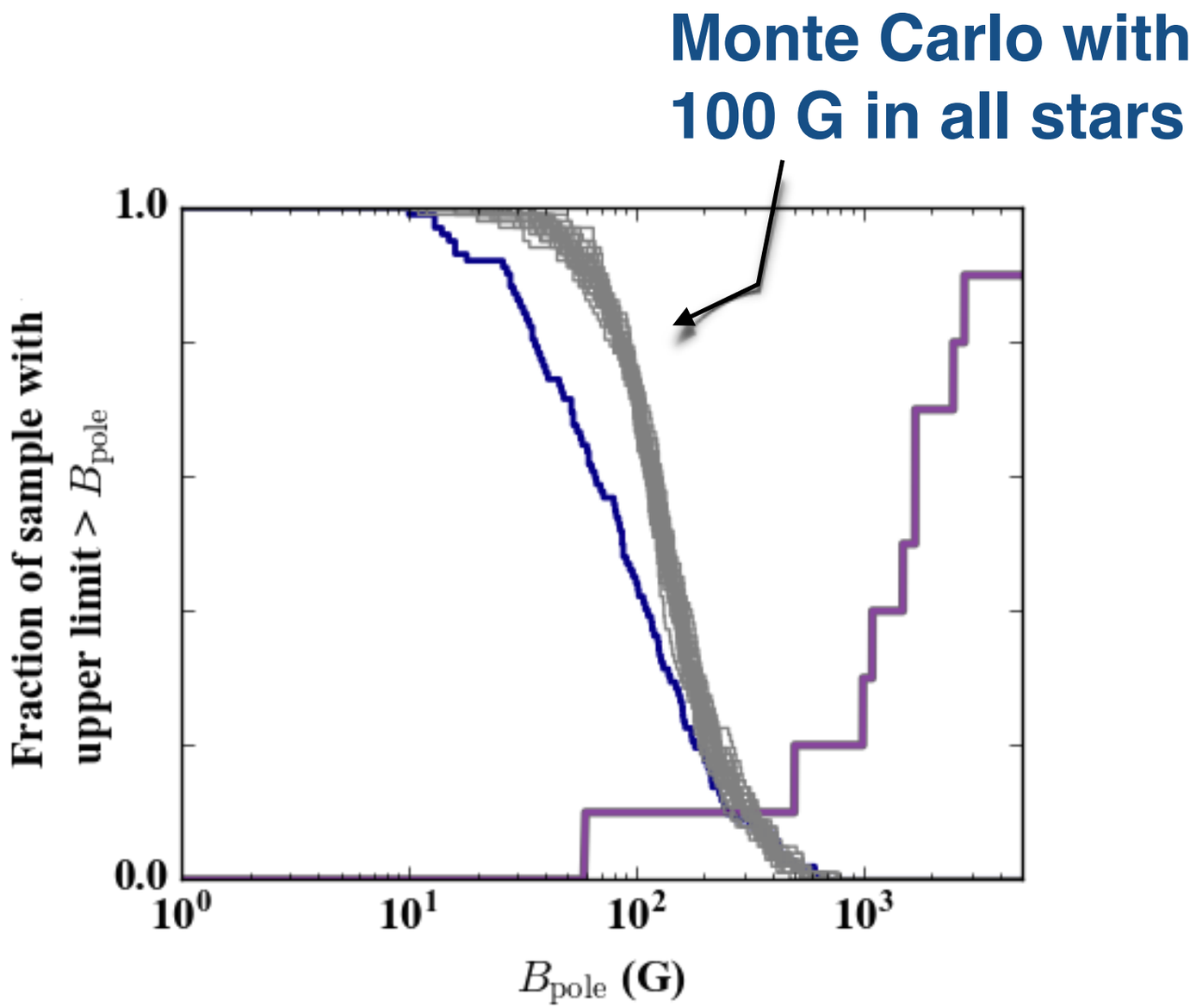

MiMeS O-star sample
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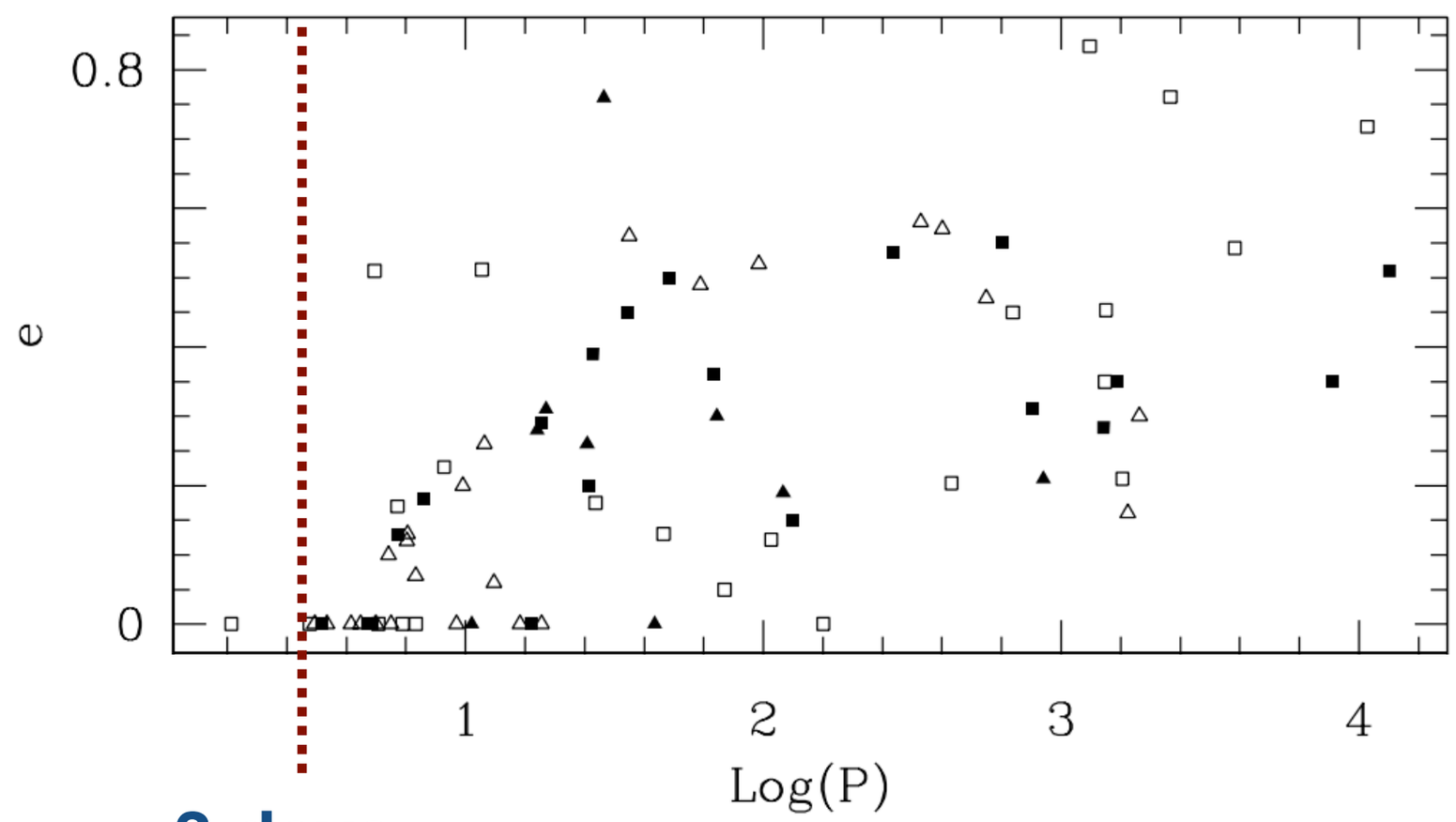
There are evidences for a “shortage” of close magnetic binaries

Sample of 78 Ap stars in a binary system



3 days

Carrier et al. 2002

There are evidences for a “shortage” of close magnetic binaries

Binarity and **M**agnetic **I**nteractions in various classes of **S**tars

200 close OBA binary systems → **400 stars**

10%

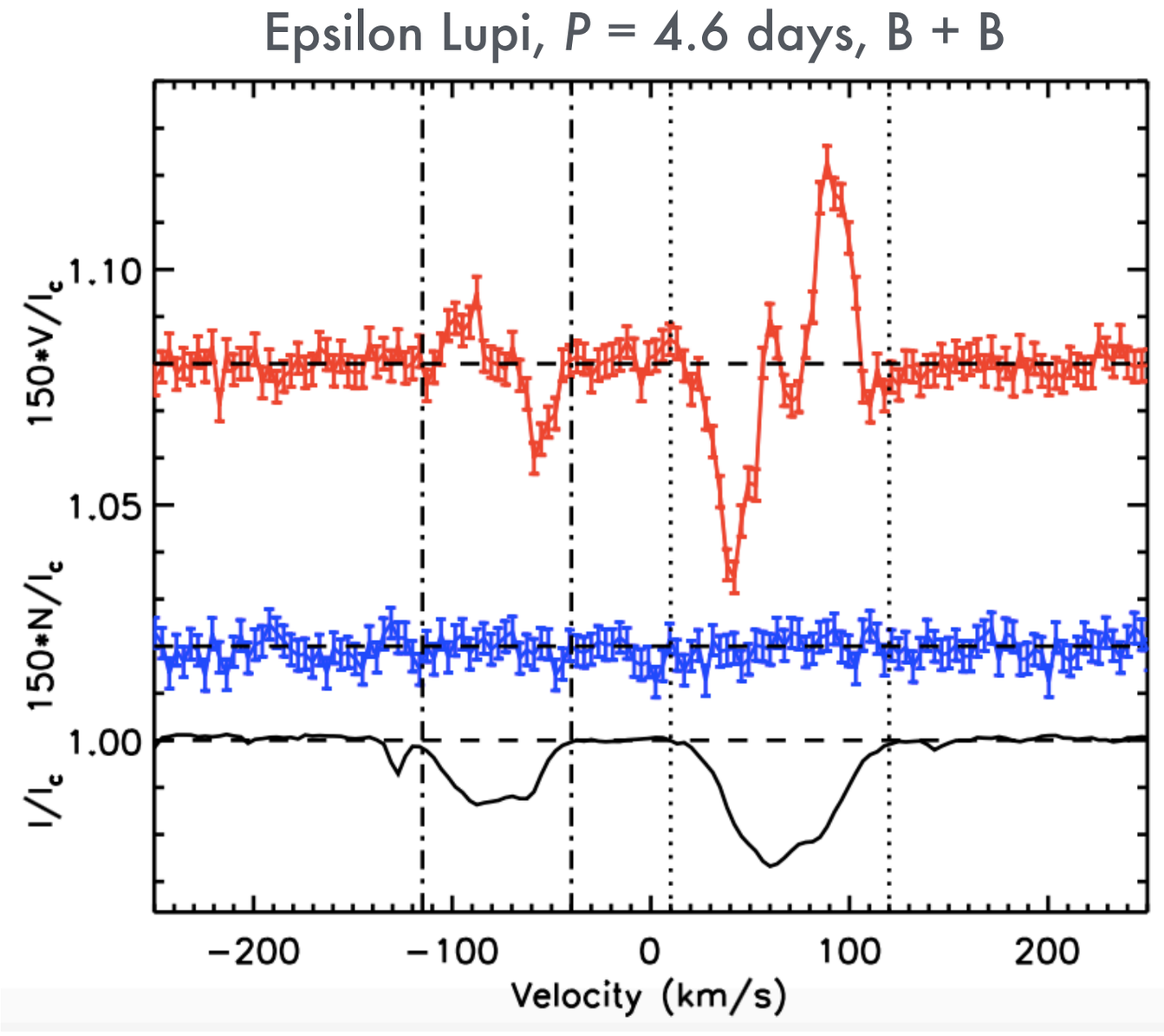
There should be ~ 40 new magnetic OBA stars

Only two were found..

Alecian et al. in prep

There are evidences for a “shortage” of close magnetic binaries

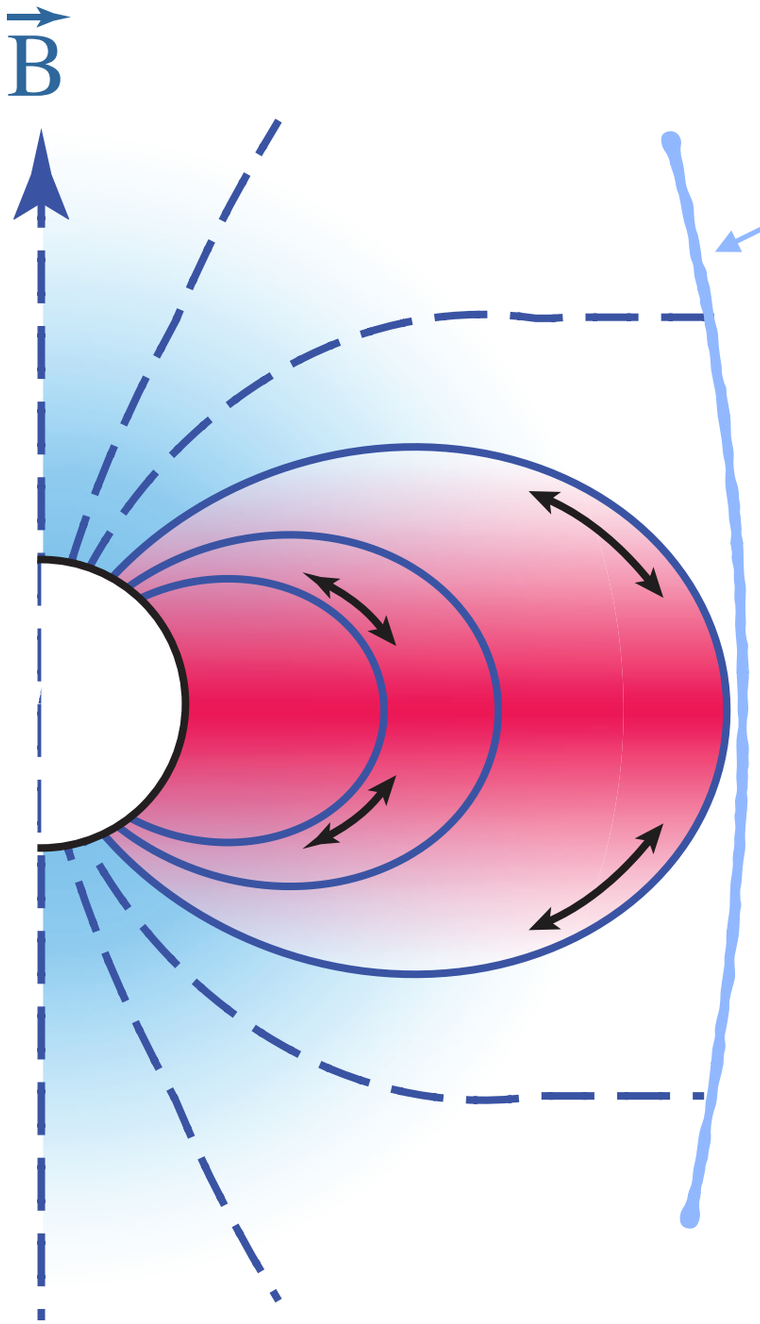
However it does not mean they do not exist



Shultz et al. 2015

How does surface magnetism influence the structure and evolution of stars?

The surface field interacts with the magnetic field to create a circumstellar magnetosphere



Alfvén radius

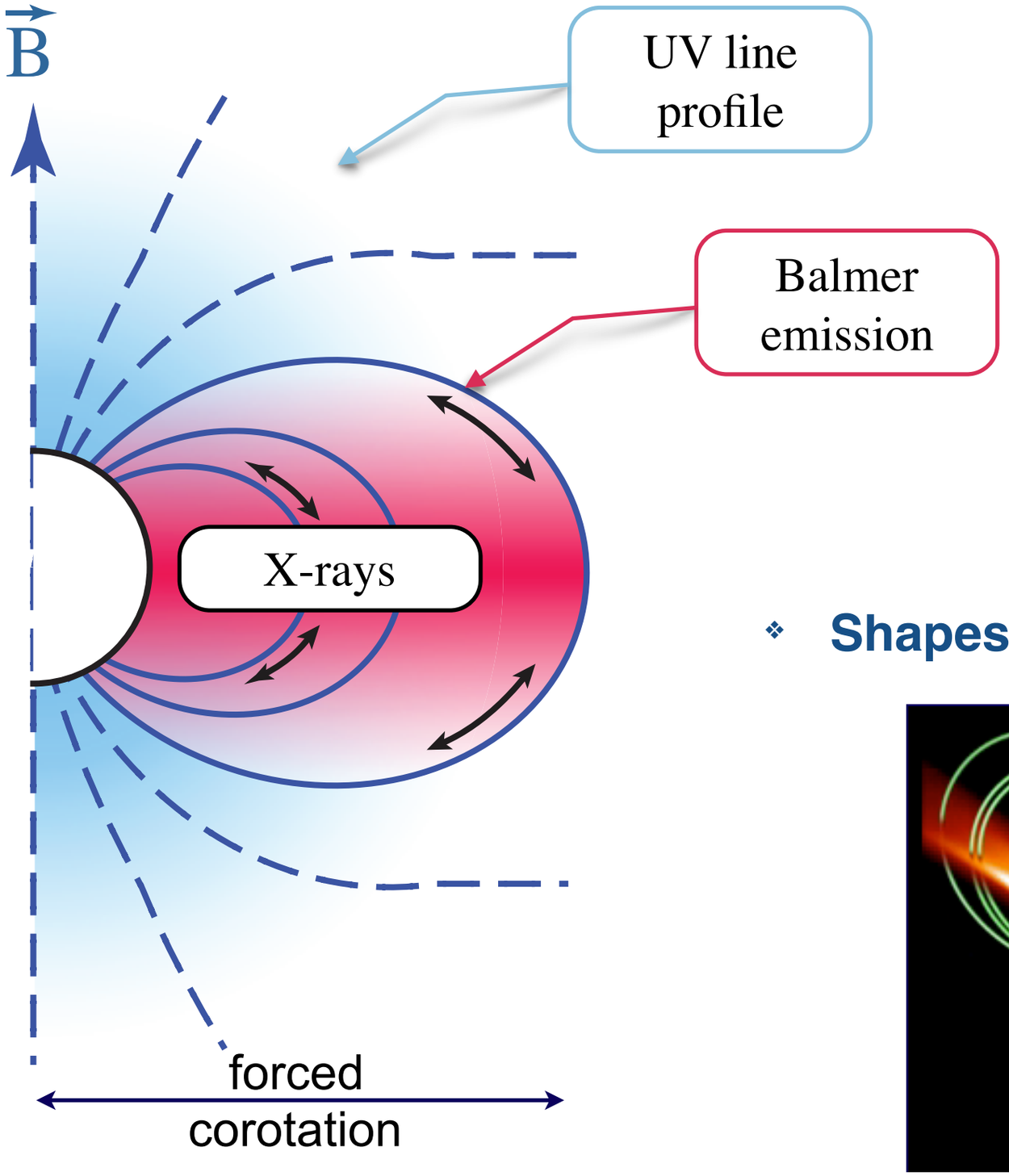
$$R_{\rm A} = \left(\frac{B_{\rm eq}^2 R_\star^2}{(\dot{M} V_\infty)} \right)^{1/4}$$

would have with B=0

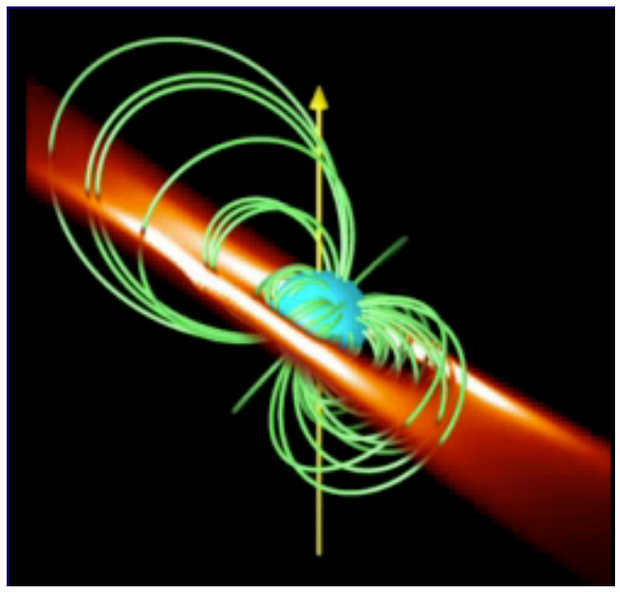
- Shapes the wind outflow
- Changes angular momentum loss
- Quenches mass-loss

ud-Doula et al. (2008) Fig. from Petit et al (2015)

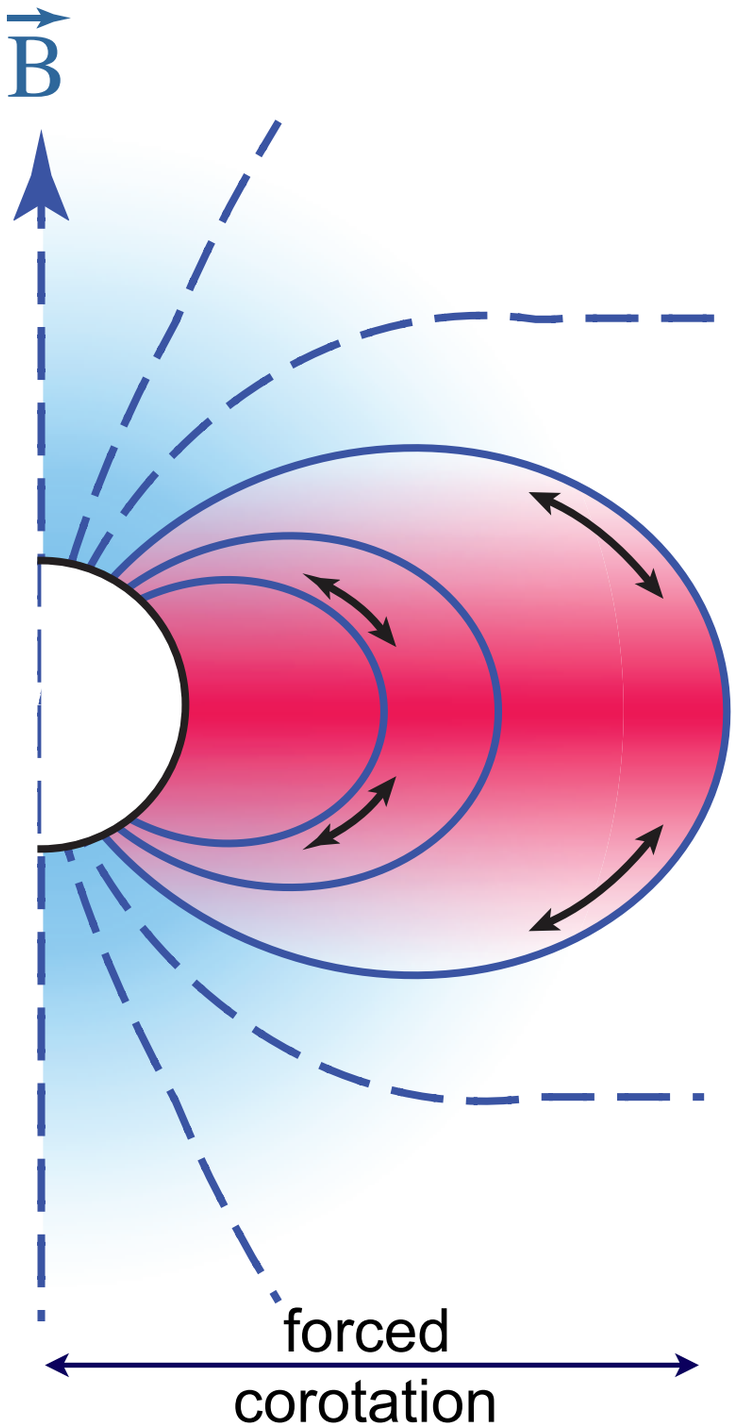
Rotationally modulated emission from magnetosphere can be seen across the electromagnetic spectrum



- **Shapes the wind outflow**



Courtesy of R. Townsend



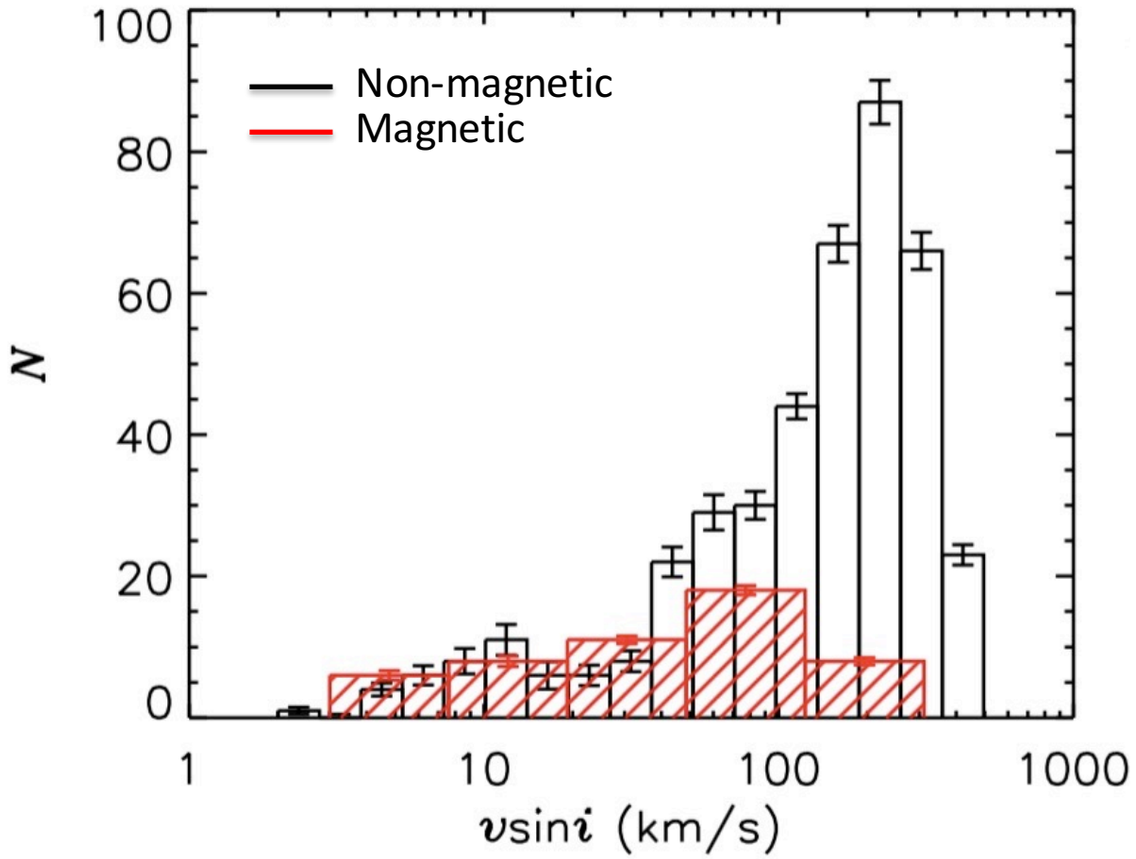
- **Changes angular momentum loss**

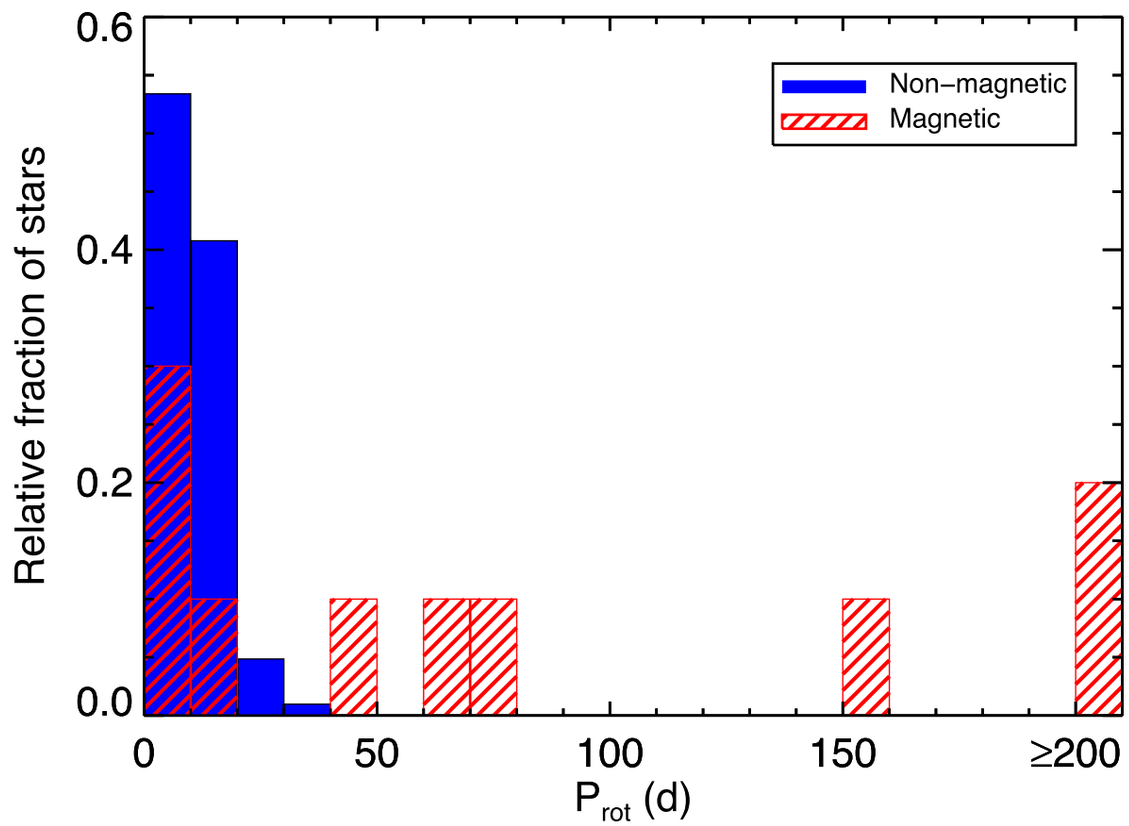
Magnetic braking timescale

$$\tau_J = \frac{3}{2}\, f\, \tau_{\rm M} \left(\frac{R_\star}{R_{\rm A}}\right)^2$$

ud-Doula et al. 2009

As a population, magnetic OB-type stars rotate slower than their non-magnetic counterparts





Shultz 2016, Grunhut et al. 2017

Magnetic O-stars are slow rotators, whereas magnetic B-stars are generally faster rotators.

Magnetic braking timescale

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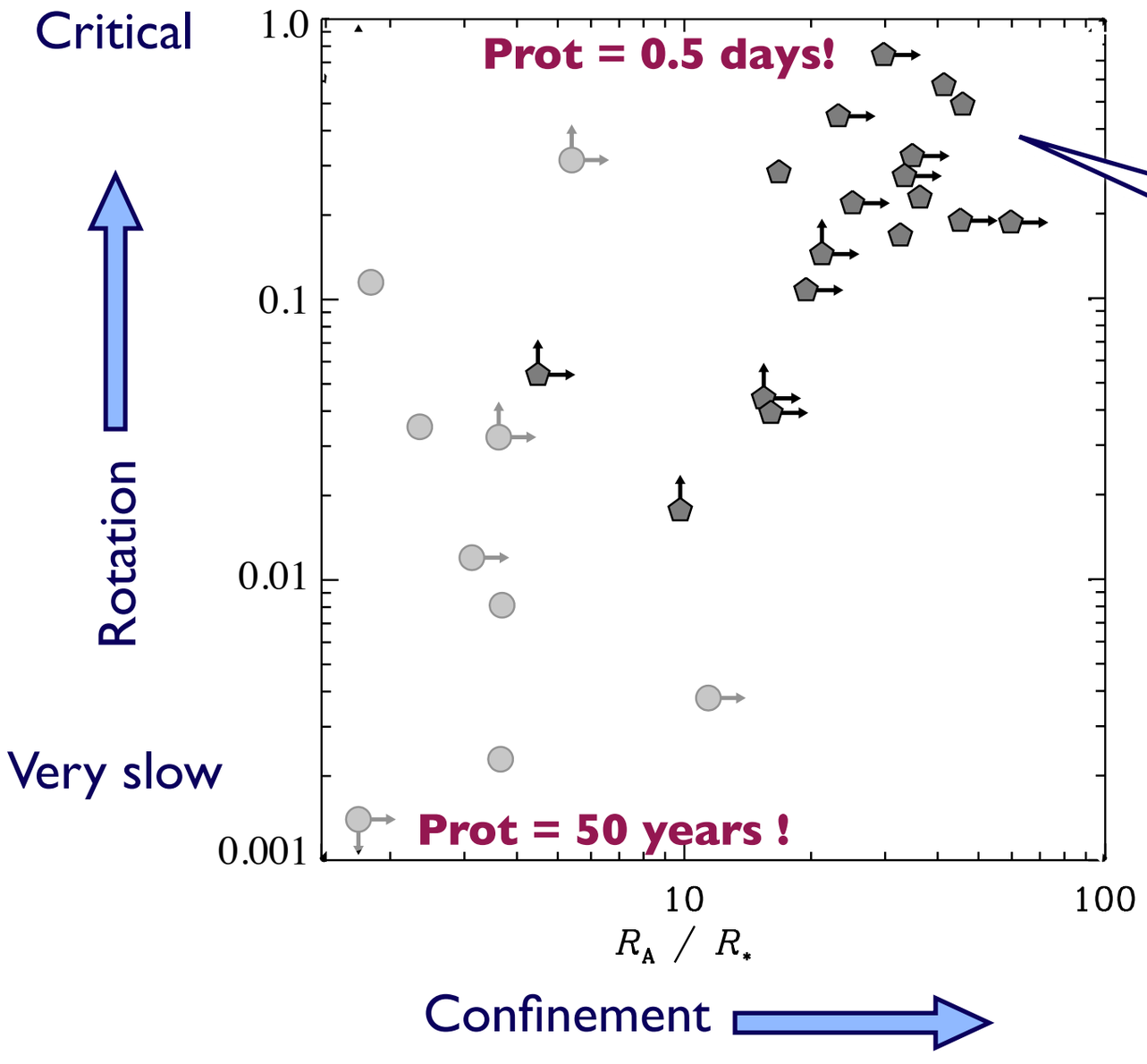
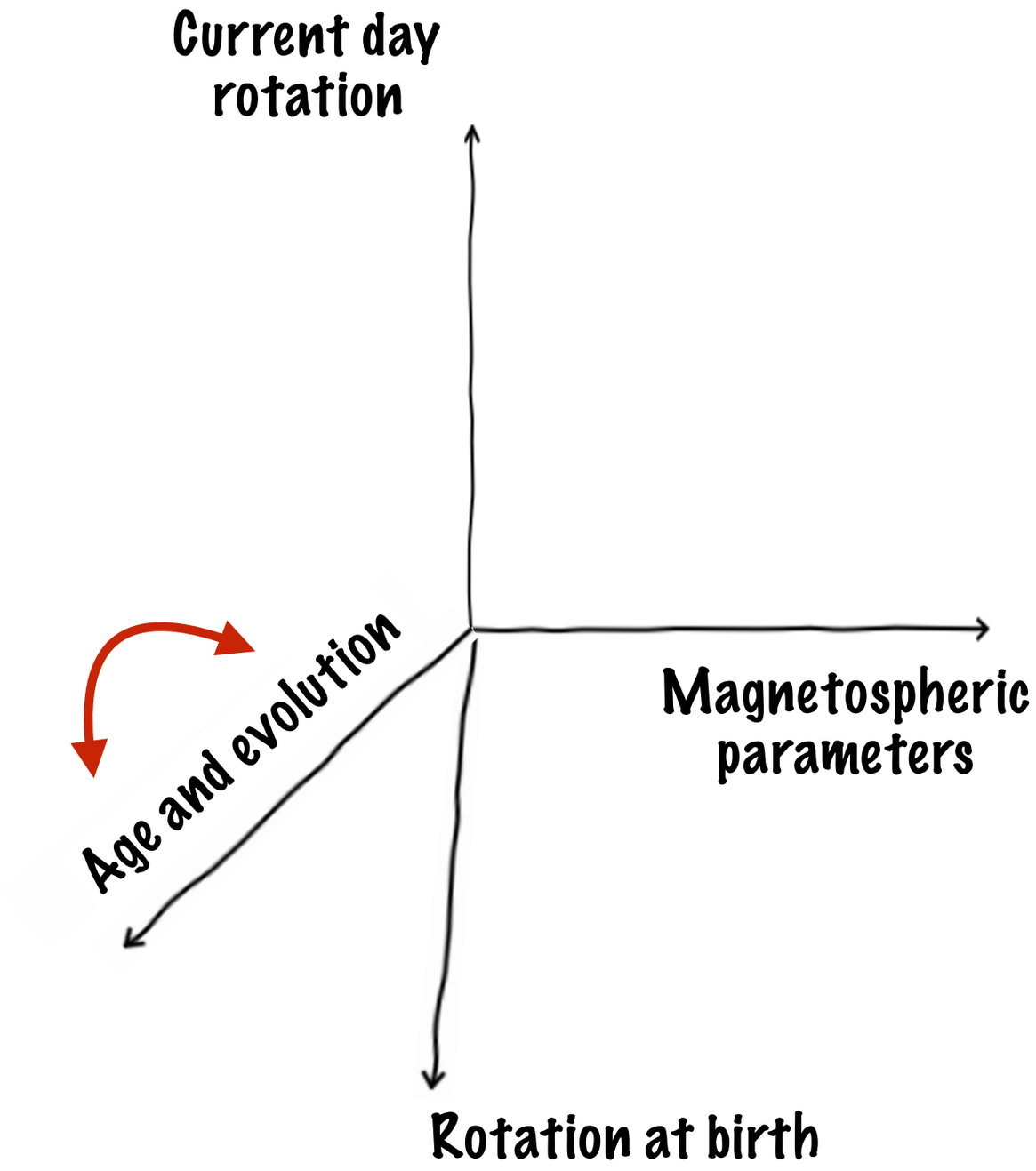


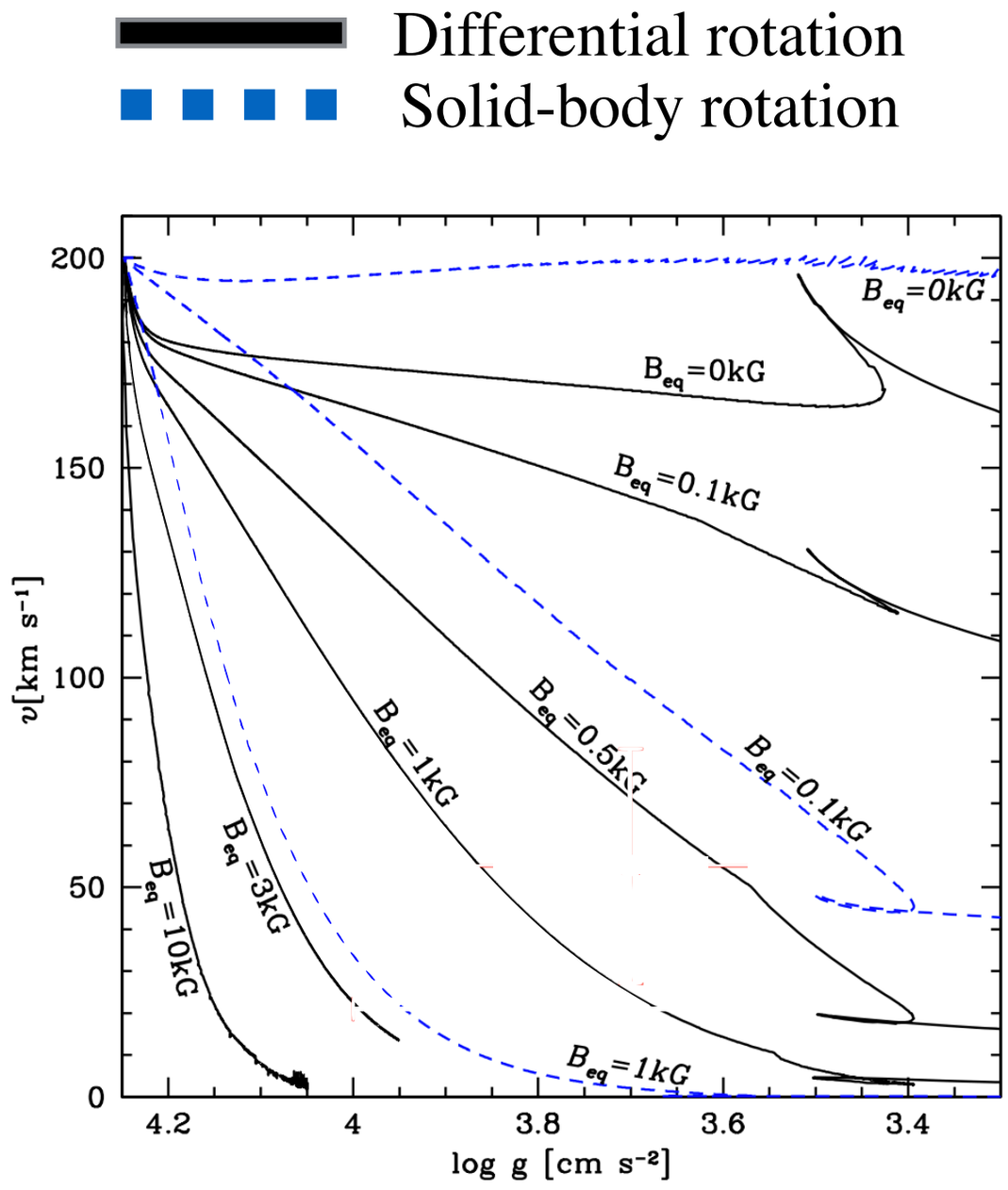
Spin-down measured on two magnetic B-type stars

Mikulášek et al. 2009
Townsend et al. 2010

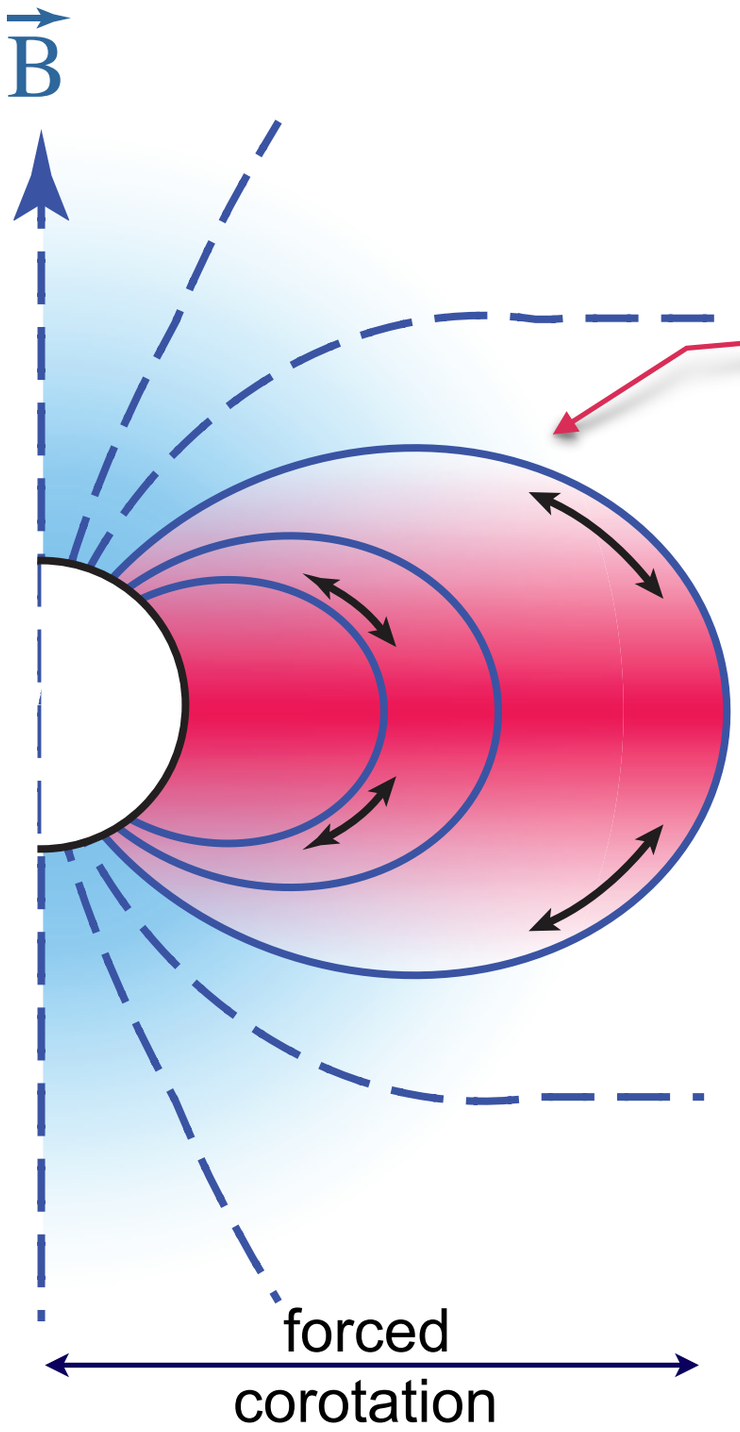
Petit et al. 2013

We need to learn more about the angular momentum transport in stars with strong surface fields





Meynet et al. 2011



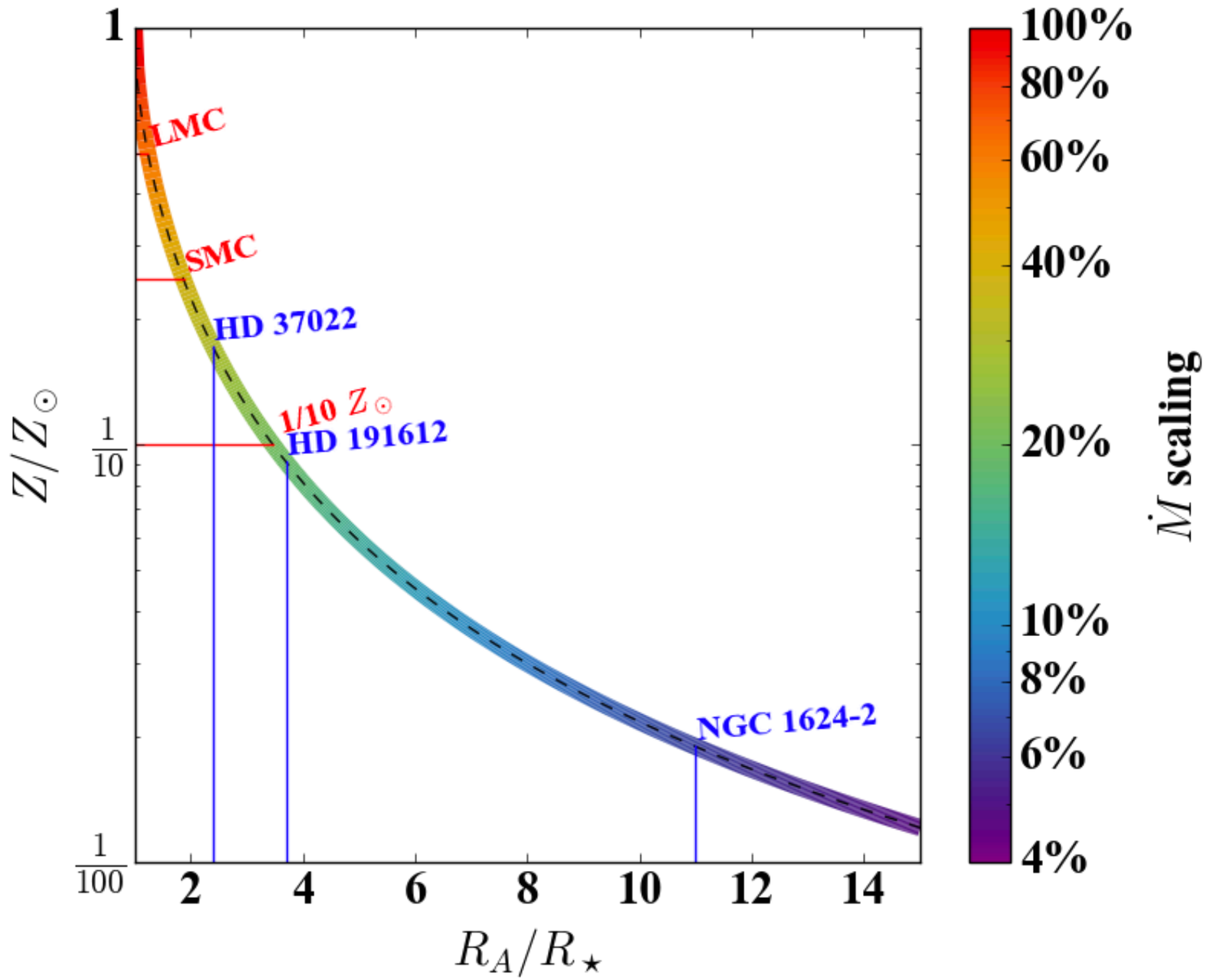
- **Quenches mass-loss**

Current day "escaping fraction"

Star	%f
HD 148937	33.3
CPD -282561	17.7
HD 37022	23.6
HD 191612	14.6
NGC 1624-2	4.6
HD 47129	9.7
HD 108	35.8
ALS 15218	15.0
HD 57682	14.6
HD 37742	69.8

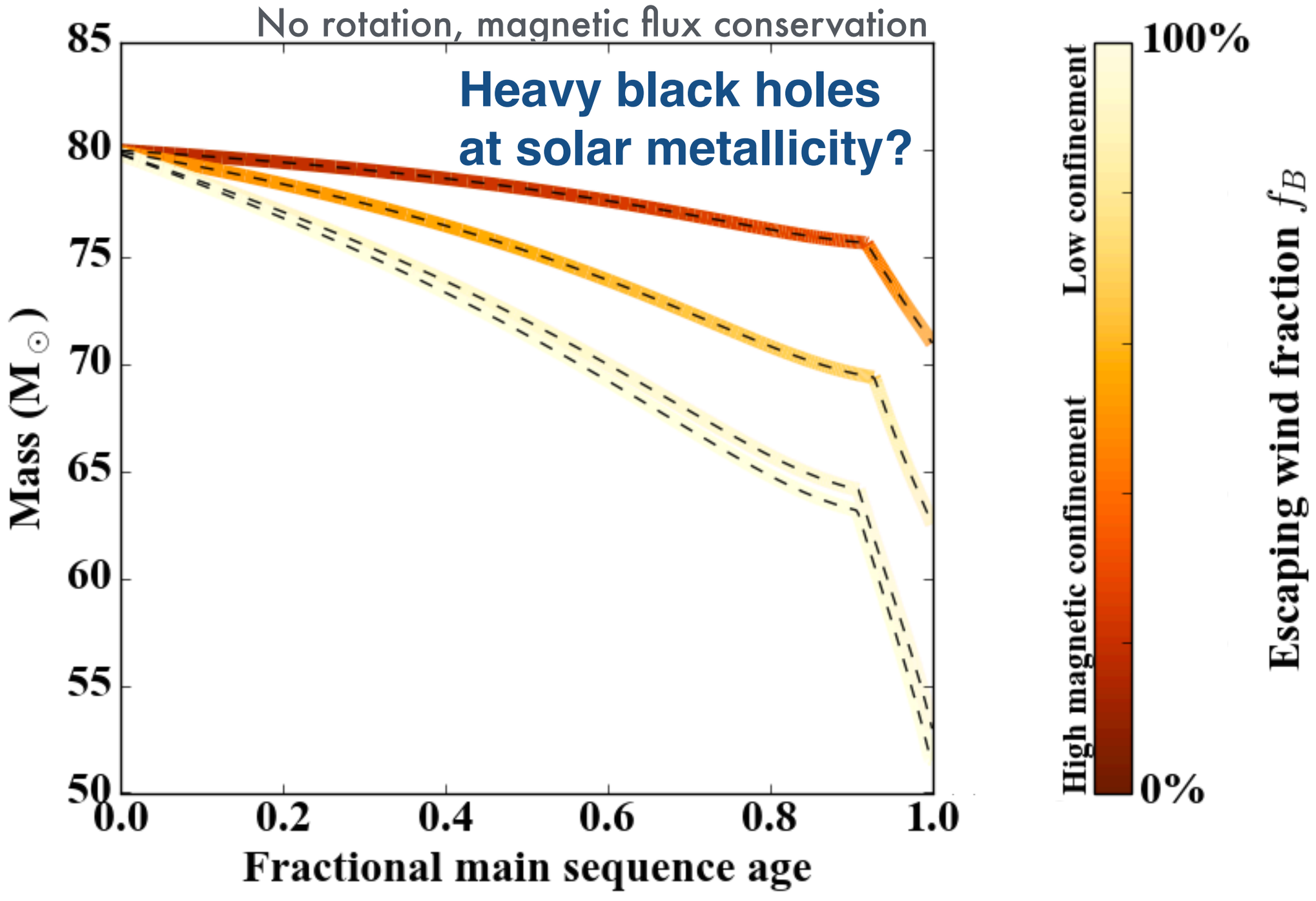
Petit et al. 2017

Magnetic mass-loss quenching rivals with the effect of metallicity



Petit et al. 2017

Magnetic massive stars will be more massive at the TAMS than their non-magnetic counterparts

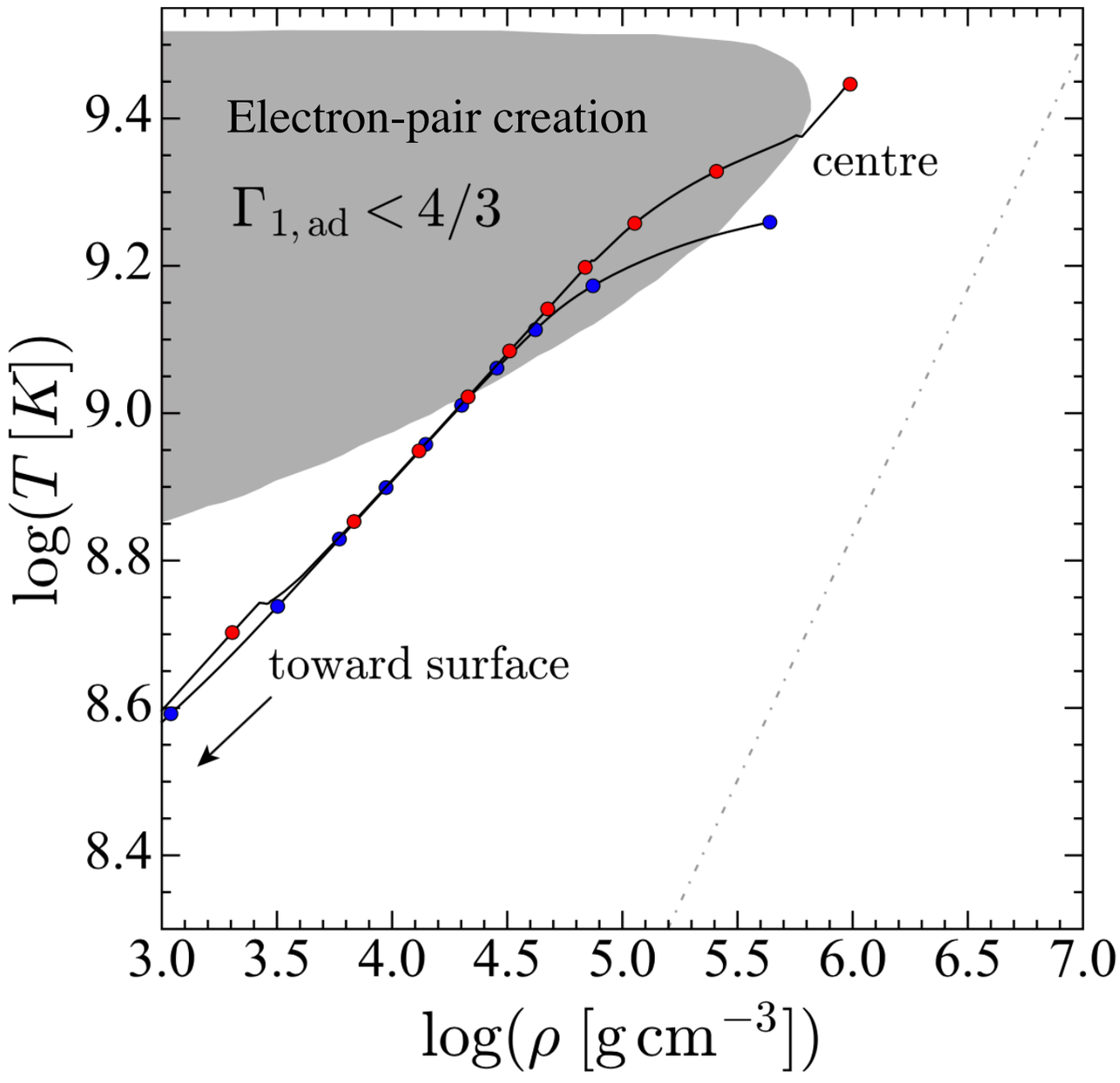


Petit et al. 2017

Magnetic VMS could produce pair-instability supernovae at solar metallicity

ZAMS:

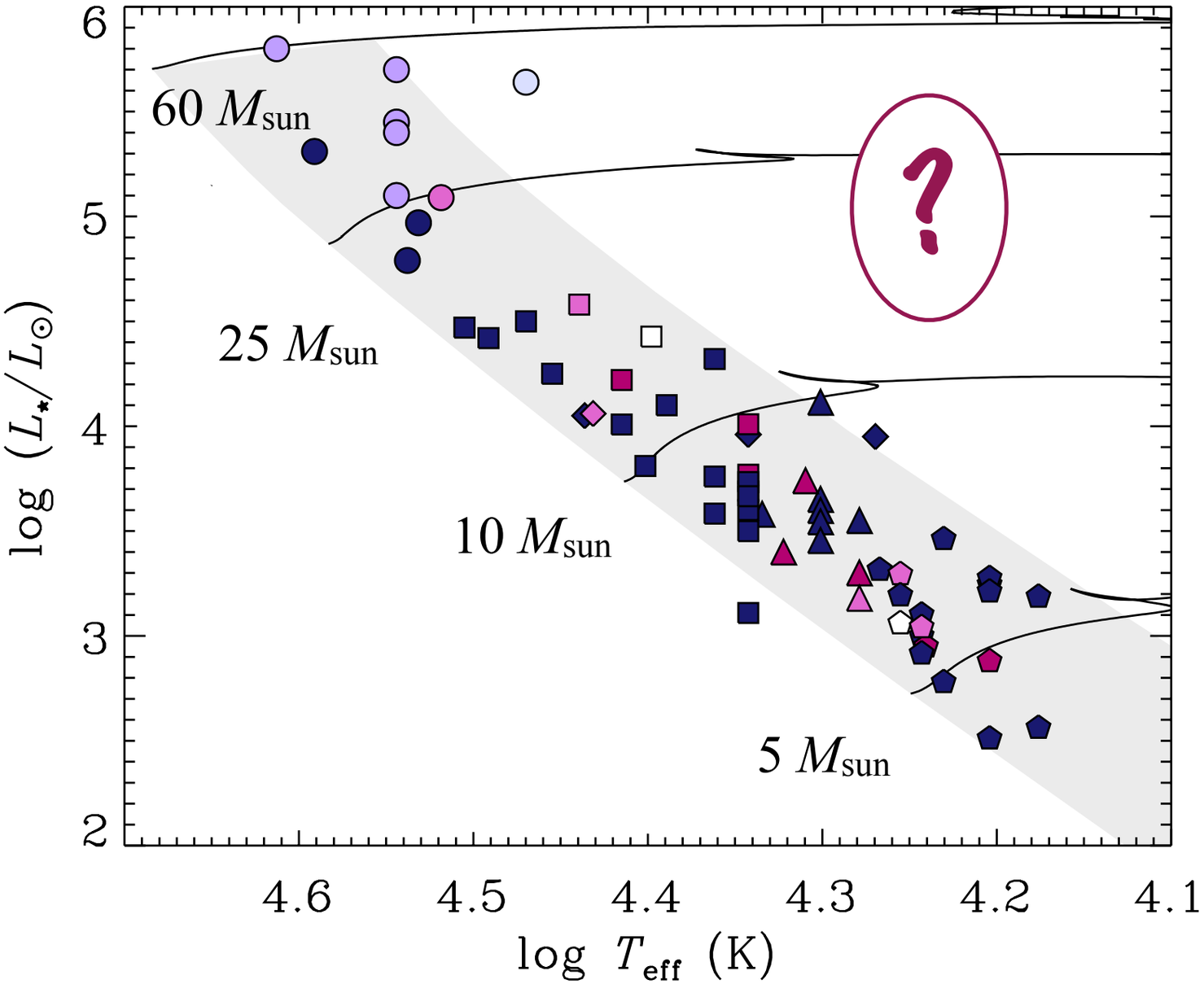
200 Msun
1 kG



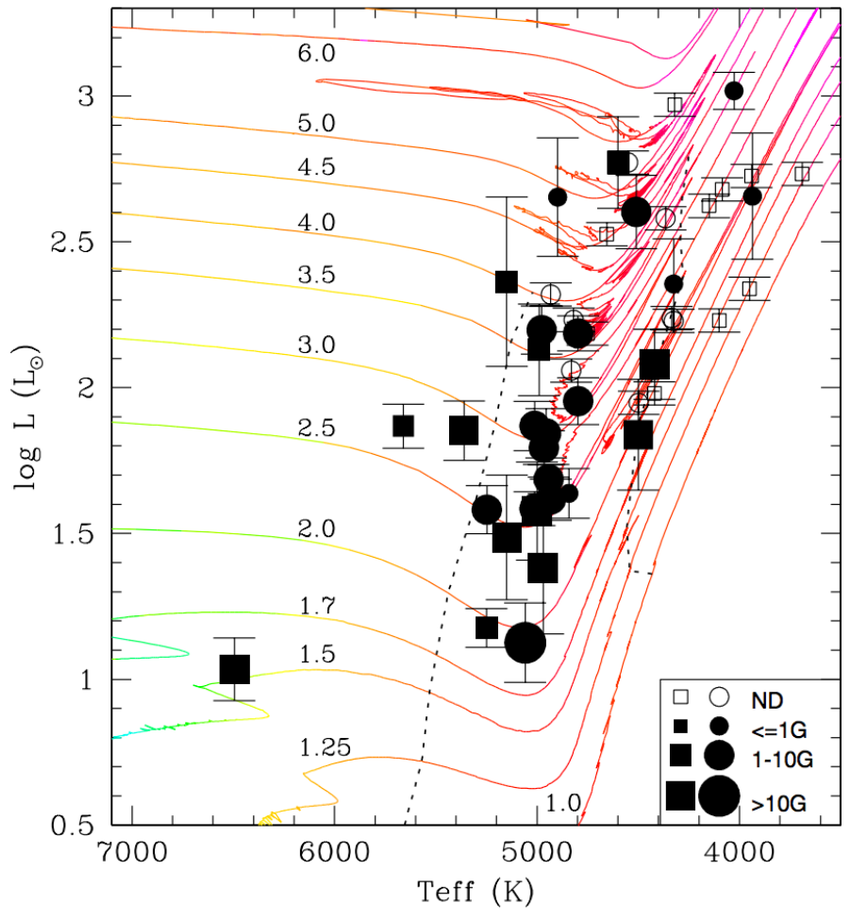
Georgy et al. 2017

How does the structure and evolution of the star influence surface magnetism?

Most known magnetic OB stars are not very evolved



Aurière et al. 2015
see also Oksala et al. 2017



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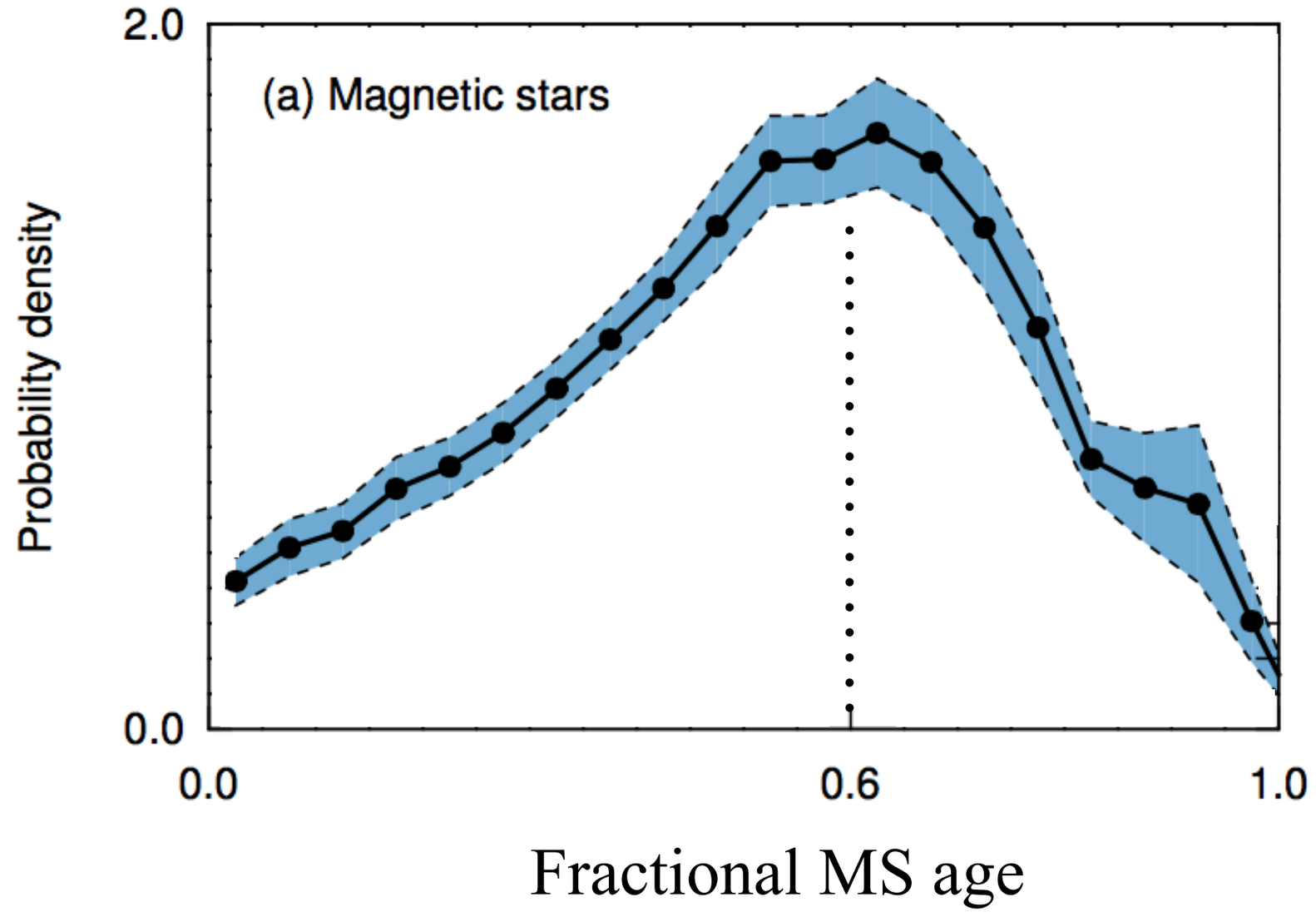

Fossati et al. 2016

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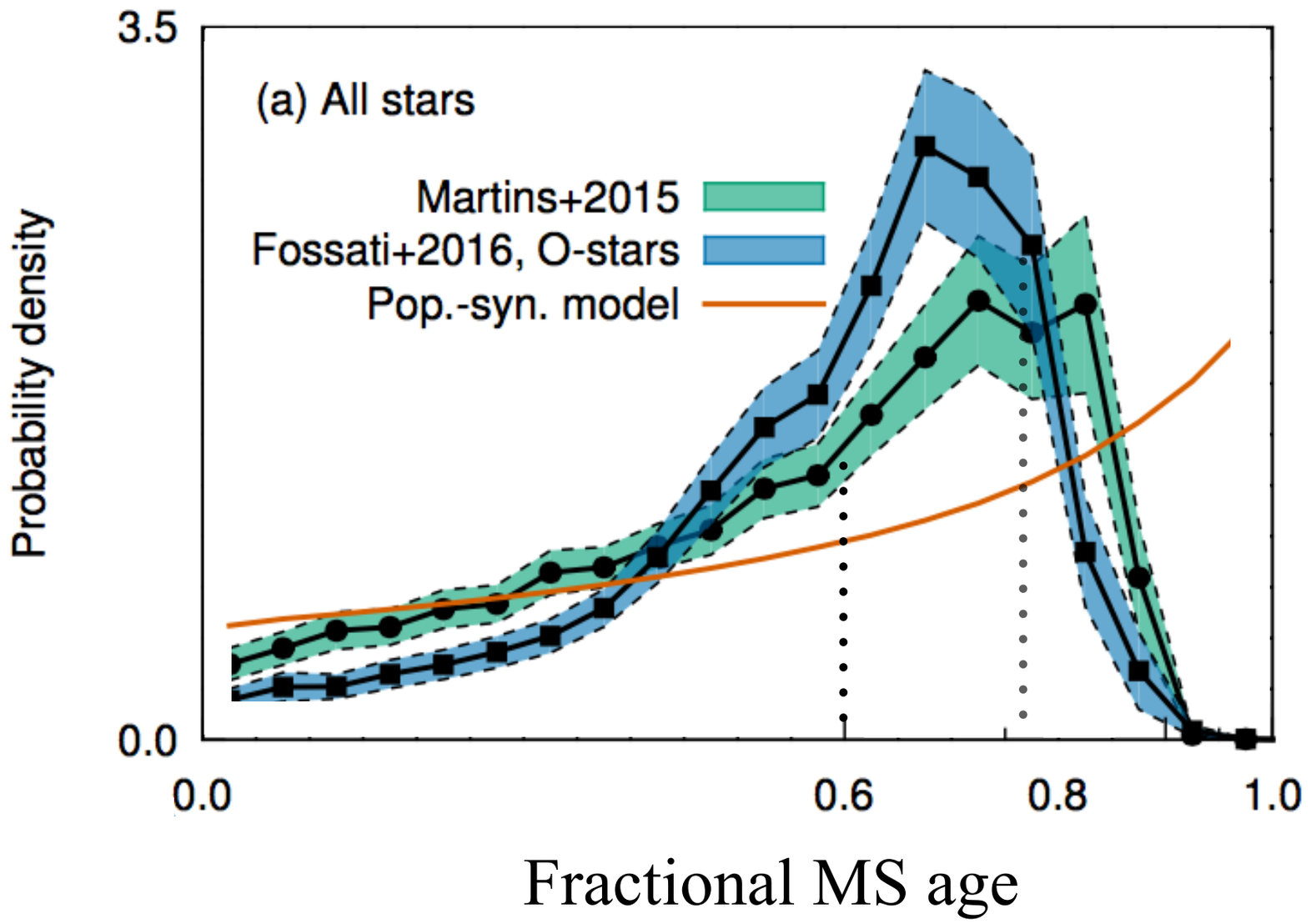
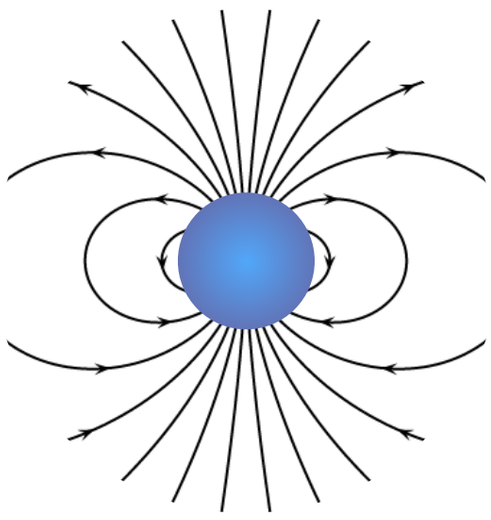
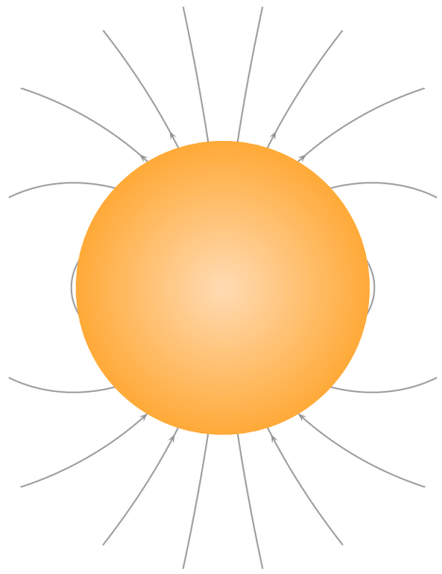


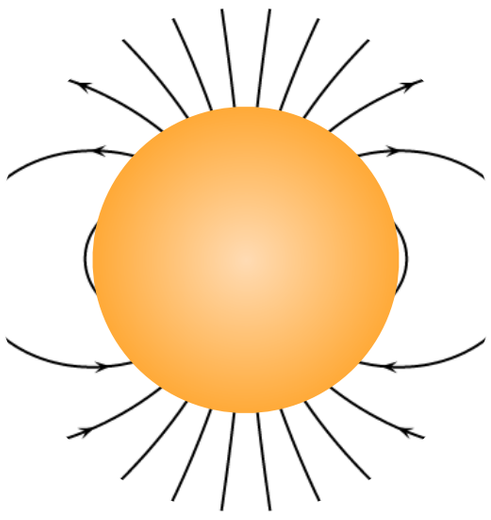
MiMeS O-star sample, Petit et al. in prep



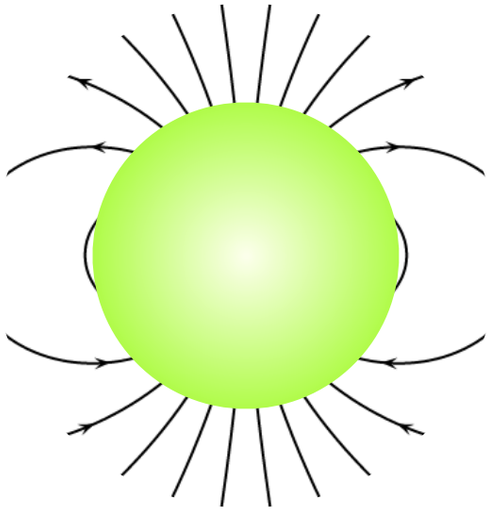
Magnetic flux decay?
(Fossati et al. 2016)



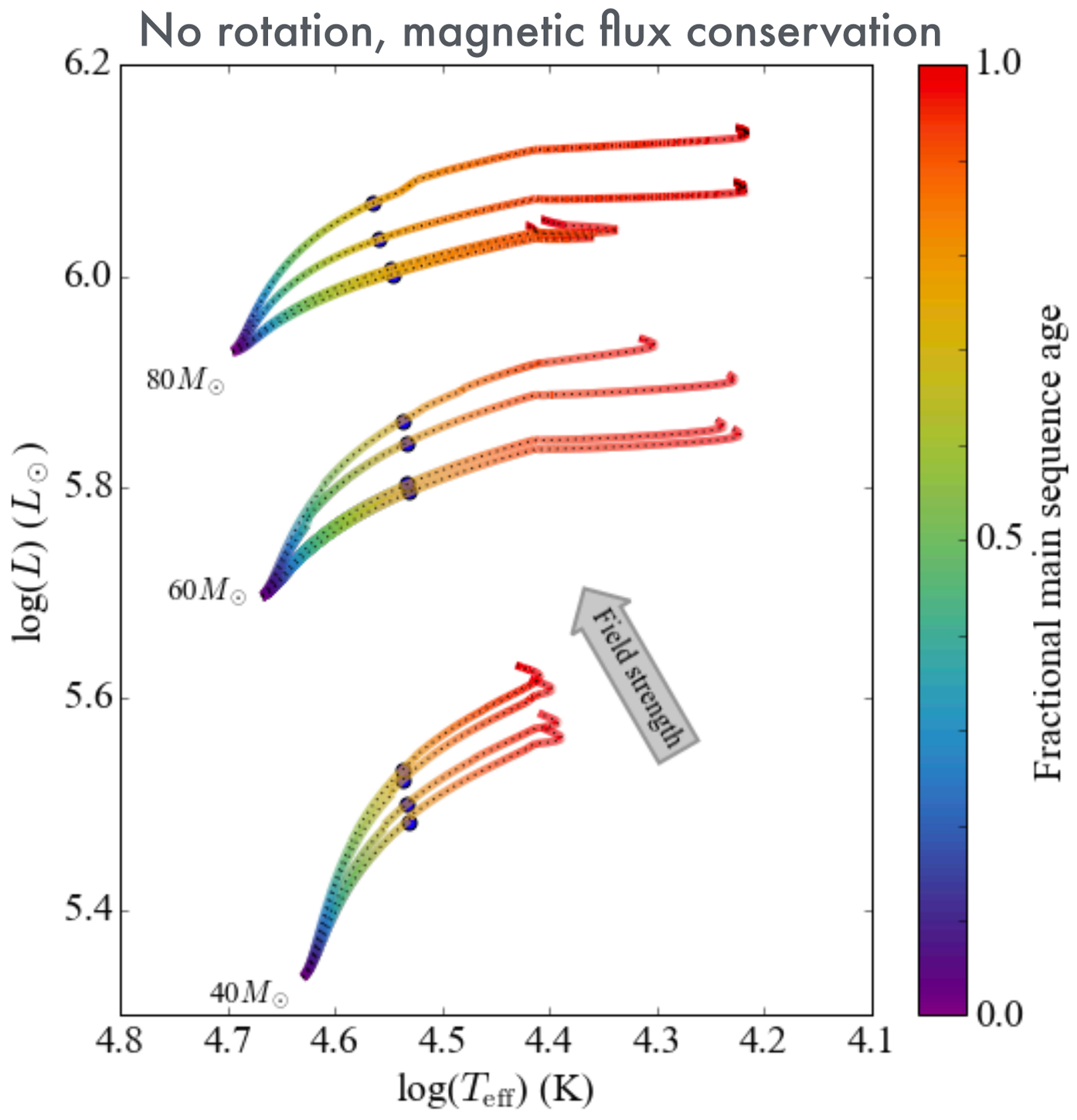
Magnetic flux conservation



"Magnetic botox"?
Petit et al. 2017



Magnetic massive stars evolve at higher luminosity during the MS



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