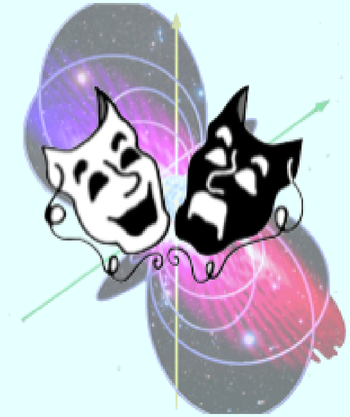


Magnetism in massive stars

Coralie Neiner

LESIA, Paris-Meudon Observatory

and the MiMeS collaboration

3 types of magnetic OB stars:

- Bp stars: extension of Ap stars, strong fields 300 G $<B_{pol} <$ 30000 G
- Massive OB stars (> 16000 K): 50 G $< B_{pol} <$ 1000 G
- Vega-like OB stars?: $B_{pol} <$ 50 G ($B_l <$ 1 G)

MiMeS (Magnetism in Massive Stars)

3 large observing programs (2009-2013)

~500 stars observed, ~4000 measurements

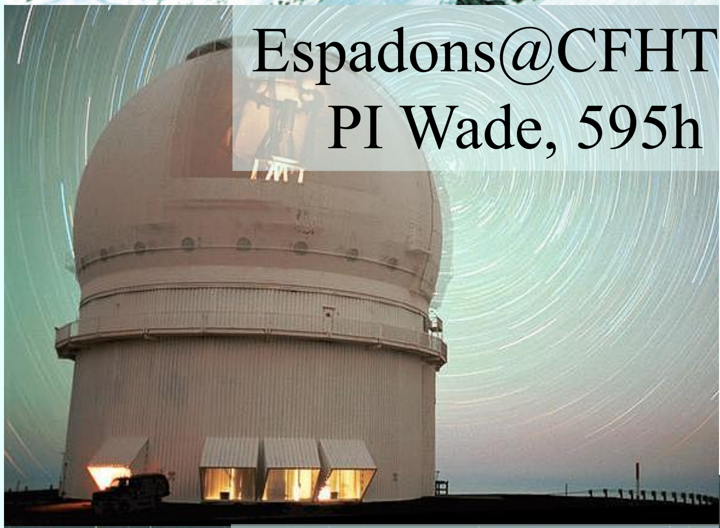
→ Observational constraints

→ Testing of theory

→ Development of new models

Primary science drivers:

- Origin of magnetic fields
- Interaction winds/magnetic fields
- Modification by fields of stellar structure, rotation and evolution



Magnetic massive stars

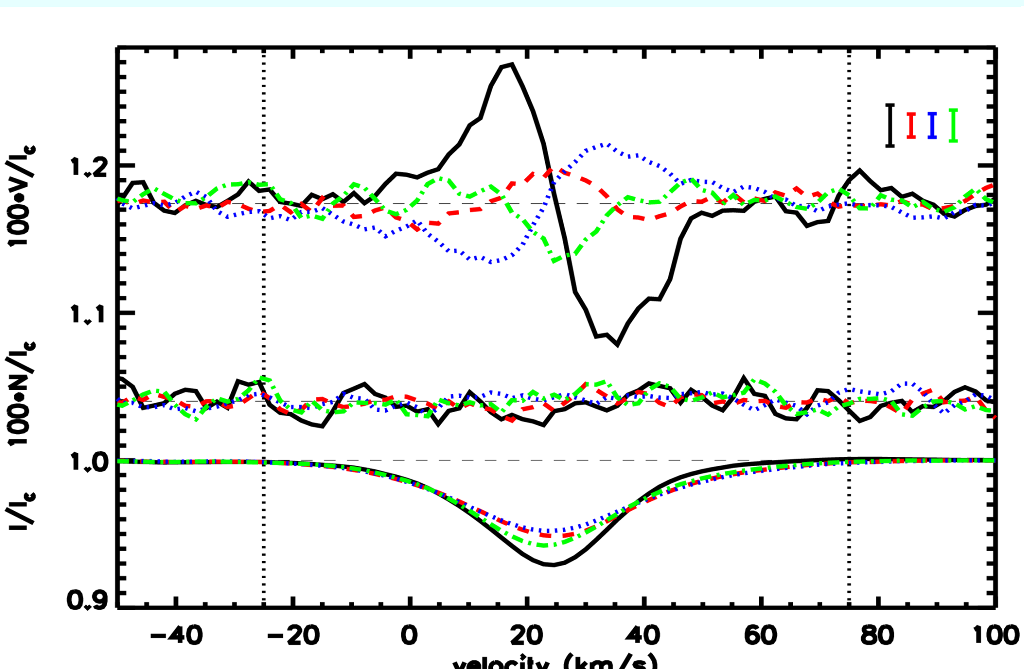
Magnetic stars with T > 16000K: 3 O + 26 B in 2008

10 O + 59 B now thanks mainly to MiMeS

Very diverse magnetic massive stars:

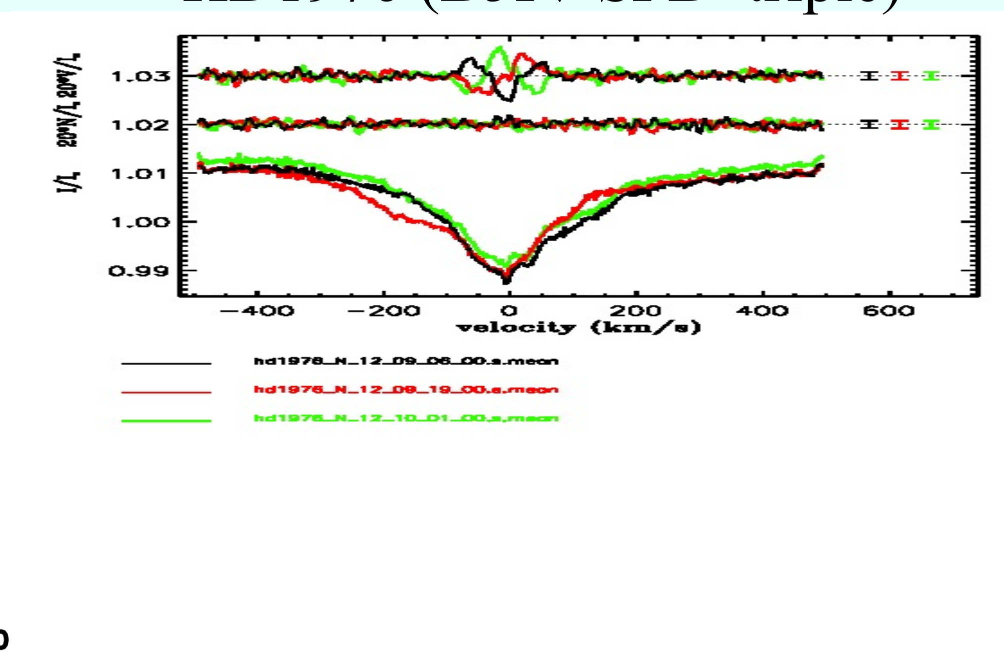
- rapidly and slowly rotating
- weak and stronger fields
- peculiar spectra or not

HD57682 (O9IV)



Grunhut et al. 2012

HD1976 (B5IV SPB+triple)

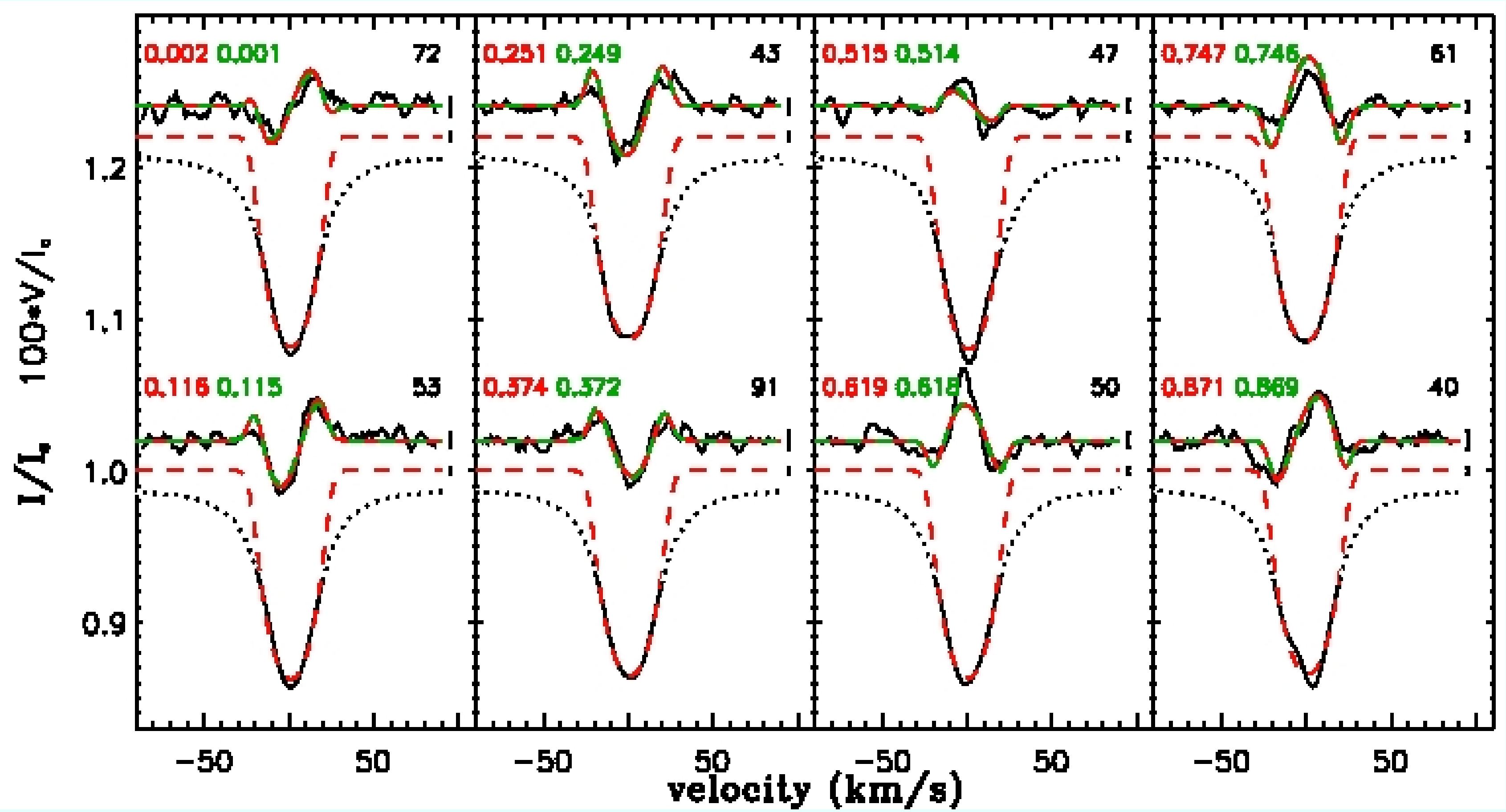


Neiner et al. 2014, in press

Models of Stokes profiles

ζ Cas (B2 SPB)

Fit of Stokes V profiles

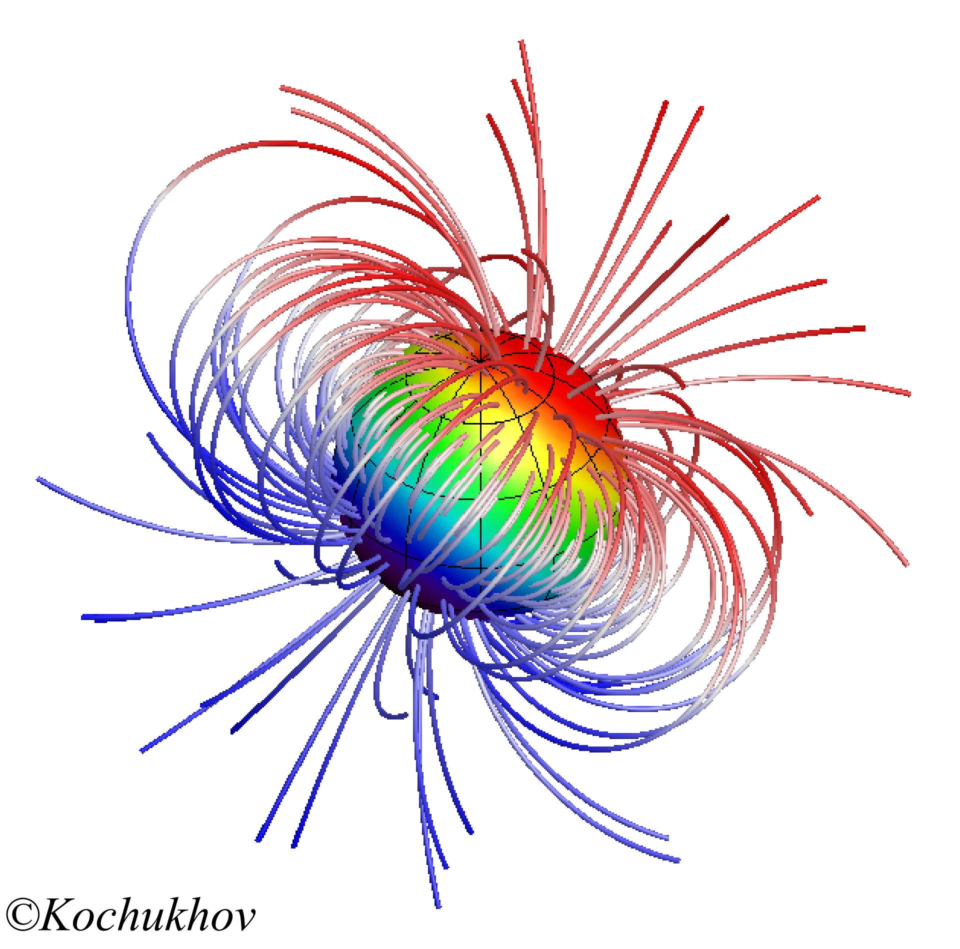


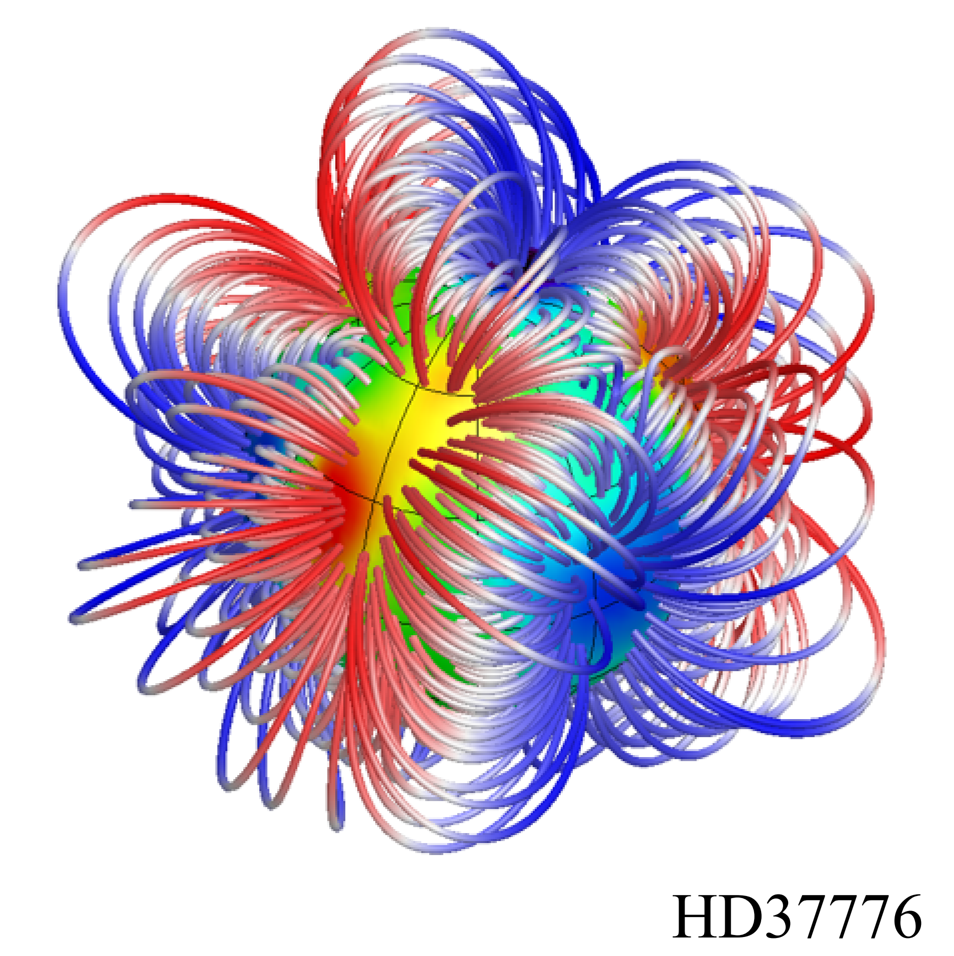
Dipole model:
$i = 35°$
$\beta = 108°$
$B_{pol} \sim 55$ G

Briquet et al. in prep.

Magnetic topologies in massive stars

- Usually simply structured → oblique dipole, but some exceptions
- Weak at the surface (but strong inside the star)
- Stable over years/decades

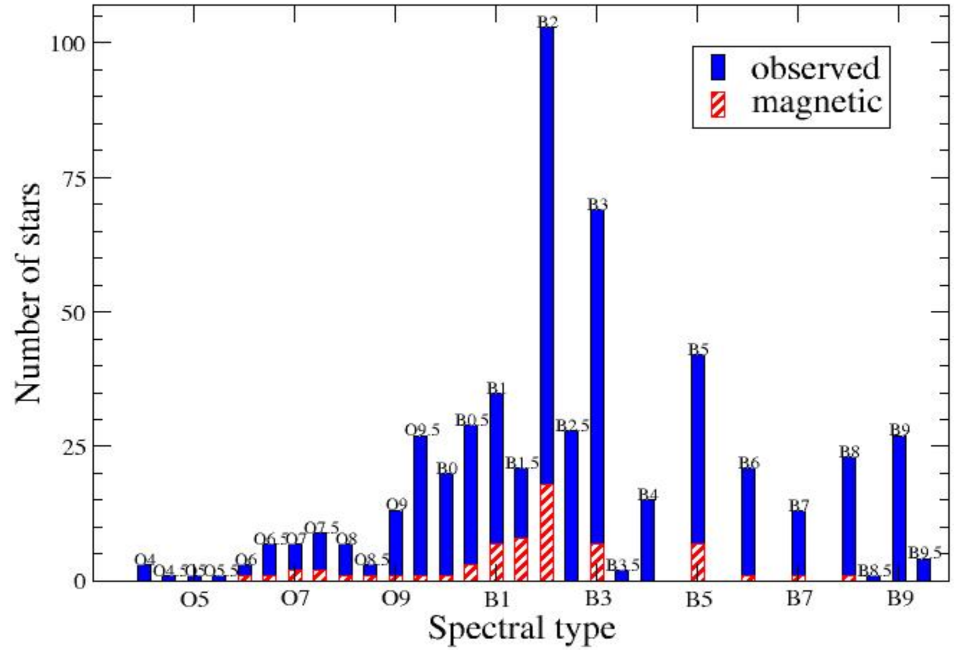




MiMeS statistical results

- 7% of all massive stars are magnetic (B_{pol} > ~50 G)
- Pulsating stars are not more or less magnetic than non-pulsating stars
  (e.g. Shultz et al. 2012, Neiner et al. in prep.)
- Same occurrence of field in O and B stars *(Grunhut et al. in prep.)*, except:
  - 100% of Of?p are magnetic *(e.g. Wade et al. 2012)*
  - <1% of Be stars are magnetic ? (rapid rotation or observational bias?)

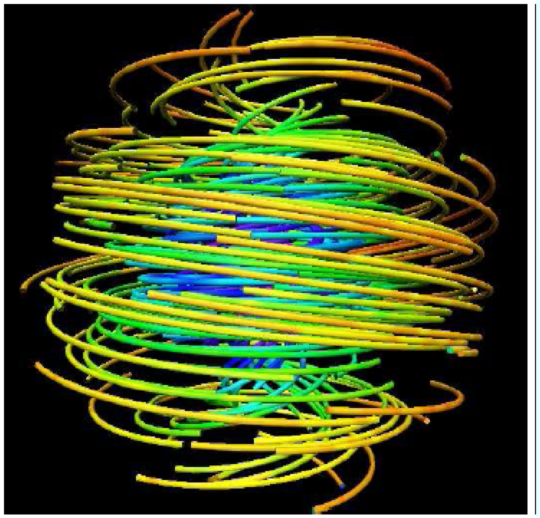
→ no correlation between field occurrence/strength/ obliquity vs stellar type/rotation/...



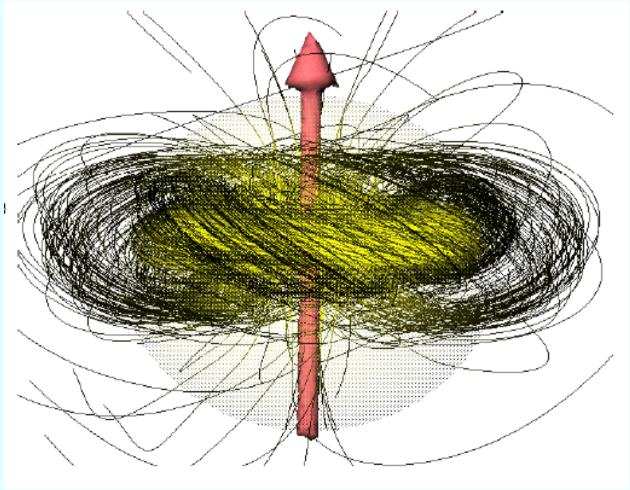
Origin of the fields of massive stars

- stable field
- most often simple oblique dipole
- similar occurrence and configuration on MS *(MiMeS)* and PMS *(Alecian et al. 2013)*

- predicted by stable analytical configuration of fossil fields
- reproduced by simulations of fossil fields
- dynamo models do not work (e.g. Tayler-Spruit dynamo)



Duez & Mathis 2010



Braithwaite & Nordlund 2006

The magnetic field of massive stars is of fossil origin!

Fossil field scenarios

Fossil field scenarios: some stars have a “strong” fossil field and all others should have a very weak Vega-like field *(Aurière et al. 2007, Braithwaite & Cantiello 2013)*

We observe “strong” fields in 7% of OB stars
→ We should find very weak fields in the remaining 93%...

- The B2 star γ Peg: no field detected with $B_l = -0.1 \pm 0.4$ G *(Neiner et al. 2014)*
- The B3 star iota Her: no field detected either *(Wade et al. in prep)*

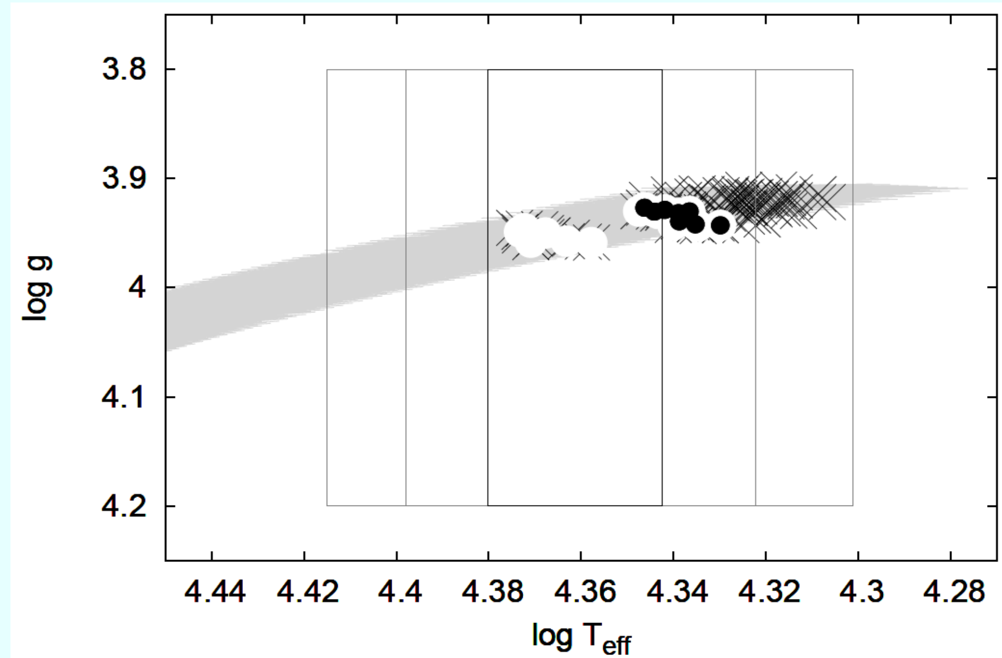
→ There are no Vega-like fields observed in OB stars so far
→ The strong field limit seems lower in OB stars than in A stars
→ The fossil field scenarios should be revised...

Impact of the magnetic field inside the star

V2052 Oph (B2, β Cep)

High rotation rate
→ mixing should be high

Seismic model → no mixing
(0.07 ± 0.08 Hp)

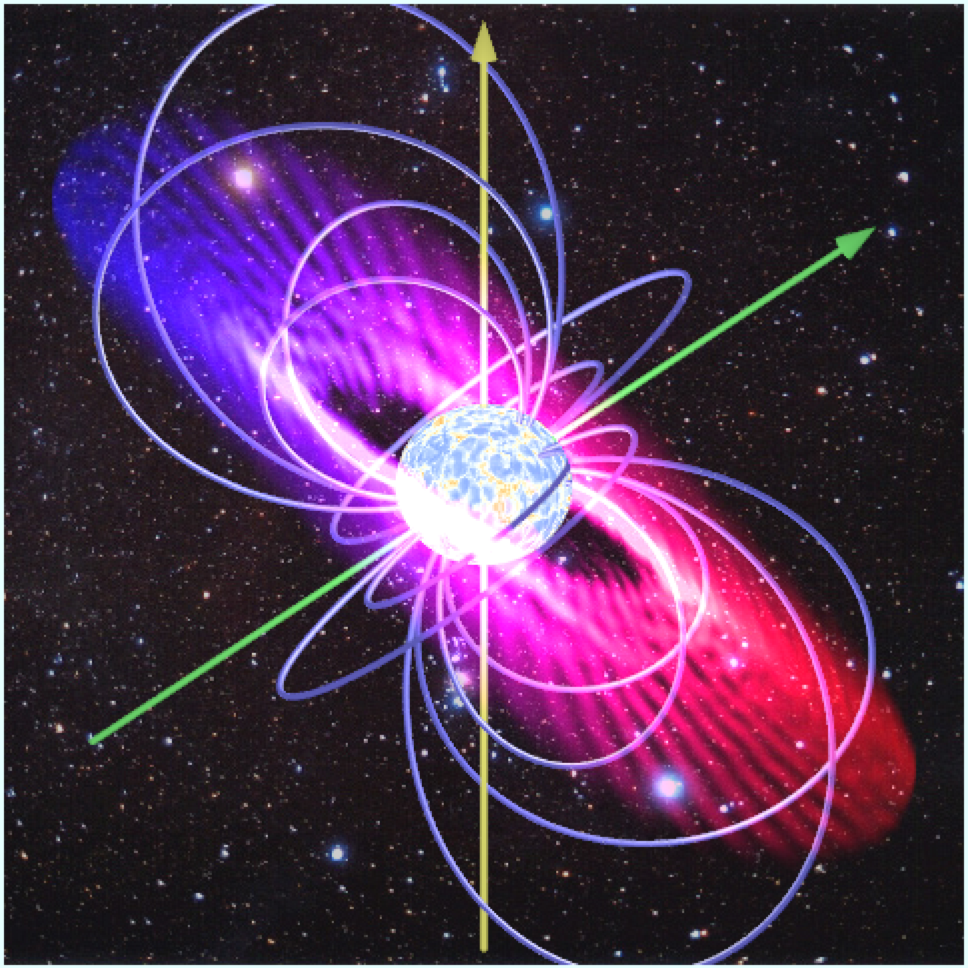


(Briquet et al. 2012)

Theory:
Zahn criterium: $B_{crit}^2 = 4\pi\rho\ R^2\Omega\ /\ t_{AM}$ *(Zahn 2011, Mathis & Zahn 2005)*
For V2052 Oph: $B_{crit} \sim 70$ G
→ if $B_{pol} > 70$ G, neither differential rotation nor rotational mixing

Observations:
$B_{pol} \sim 400$ G → inhibition of mixing by the magnetic field

Impact on the environment: magnetospheres



©*Townsend*

Oblique dipole field

→ Rotational modulation of:
- Longitudinal field
- Photospheric lines if spots

Confined wind in the magnetosphere

→ Rotational modulation of:
- UV wind lines
- Hα emission
- X-ray emission
- Photometric light curve

Magnetic confinement

$\eta_* = B^2 R^2 / \dot{M} V_\infty$

$\eta_* > 1 \rightarrow$ confinement

Alfven radius

$R_A / R_* = \eta_*^{1/2n} \rightarrow$ confinement only below R_A

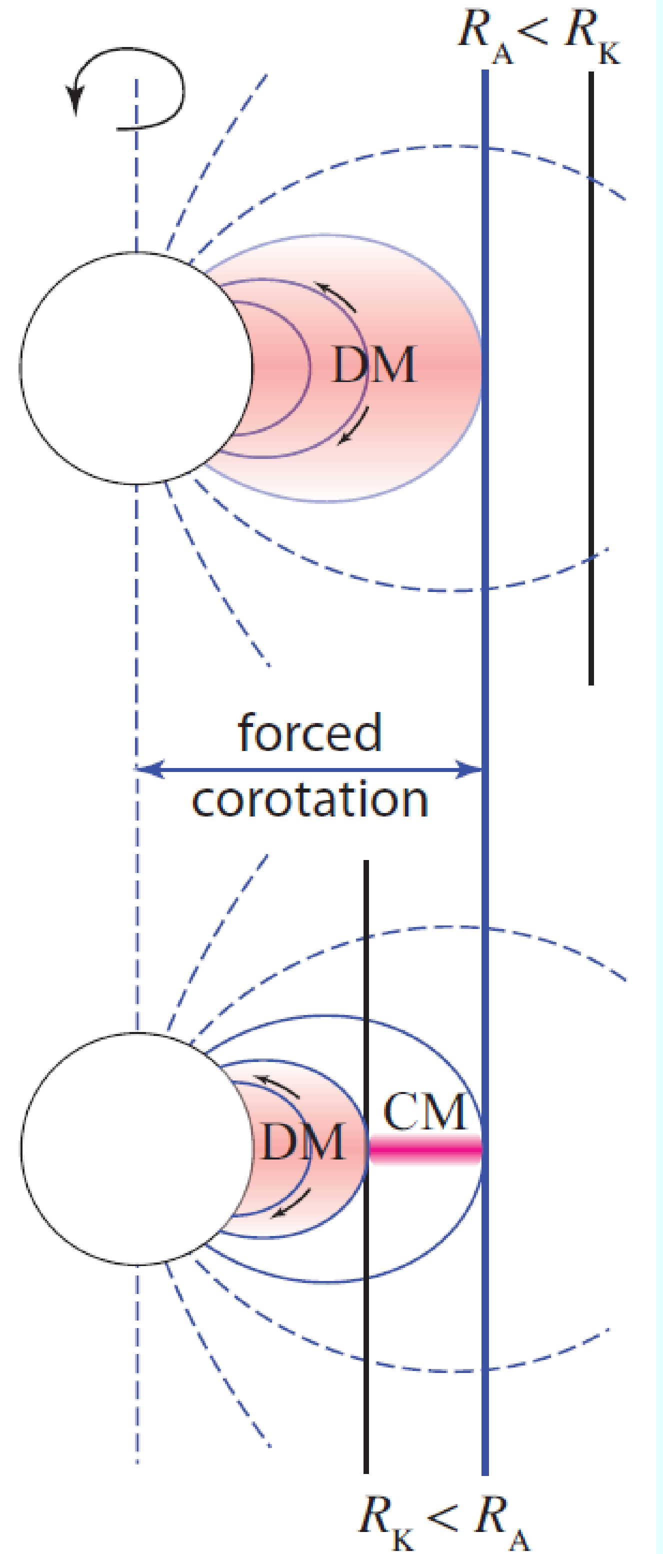
Kepler corotating radius (g force = centrifugal force)

$R_K / R_* = V_{rot} / V_{crit} \rightarrow$ centrifugal support only above R_K

$r < R_A$ and $\eta_* > 1 \rightarrow$ Magnetosphere

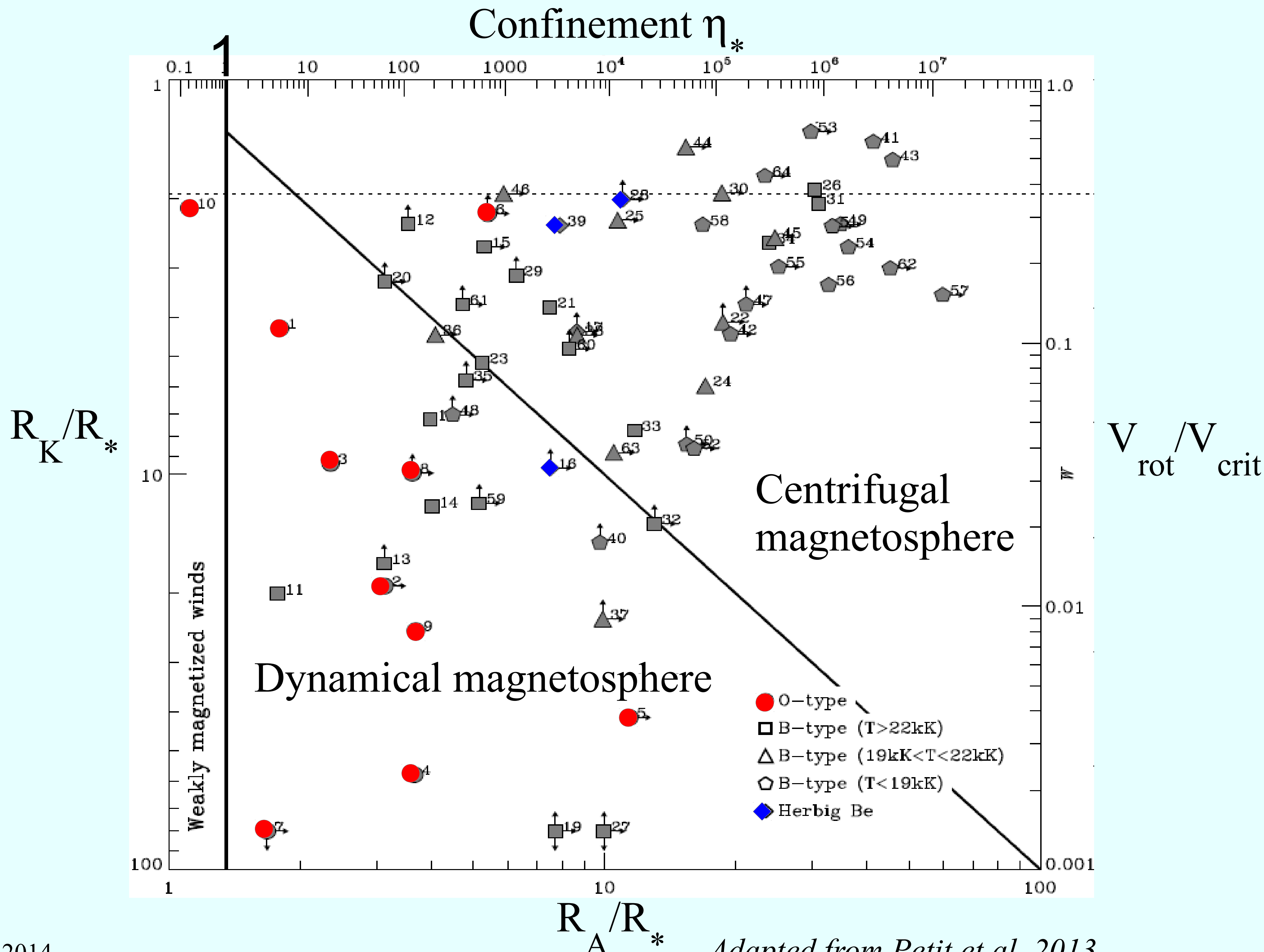
$r < R_K \rightarrow$ Dynamical magnetosphere

$r > R_K \rightarrow$ Centrifugally supported magnetosphere



Petit et al. 2013

Rotation vs Magnetic confinement diagram

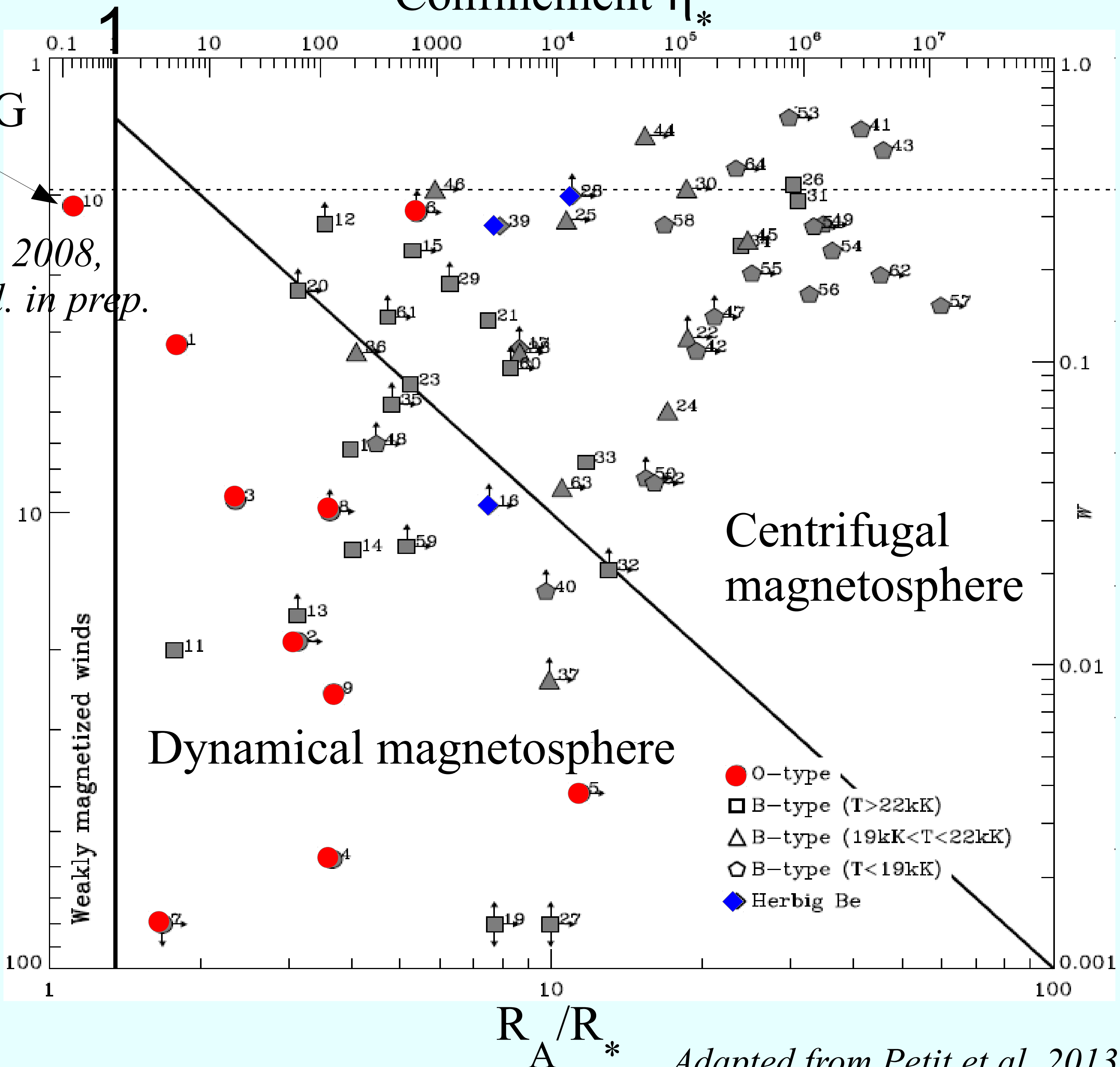


Adapted from Petit et al. 2013

Rotation vs Magnetic confinement diagram

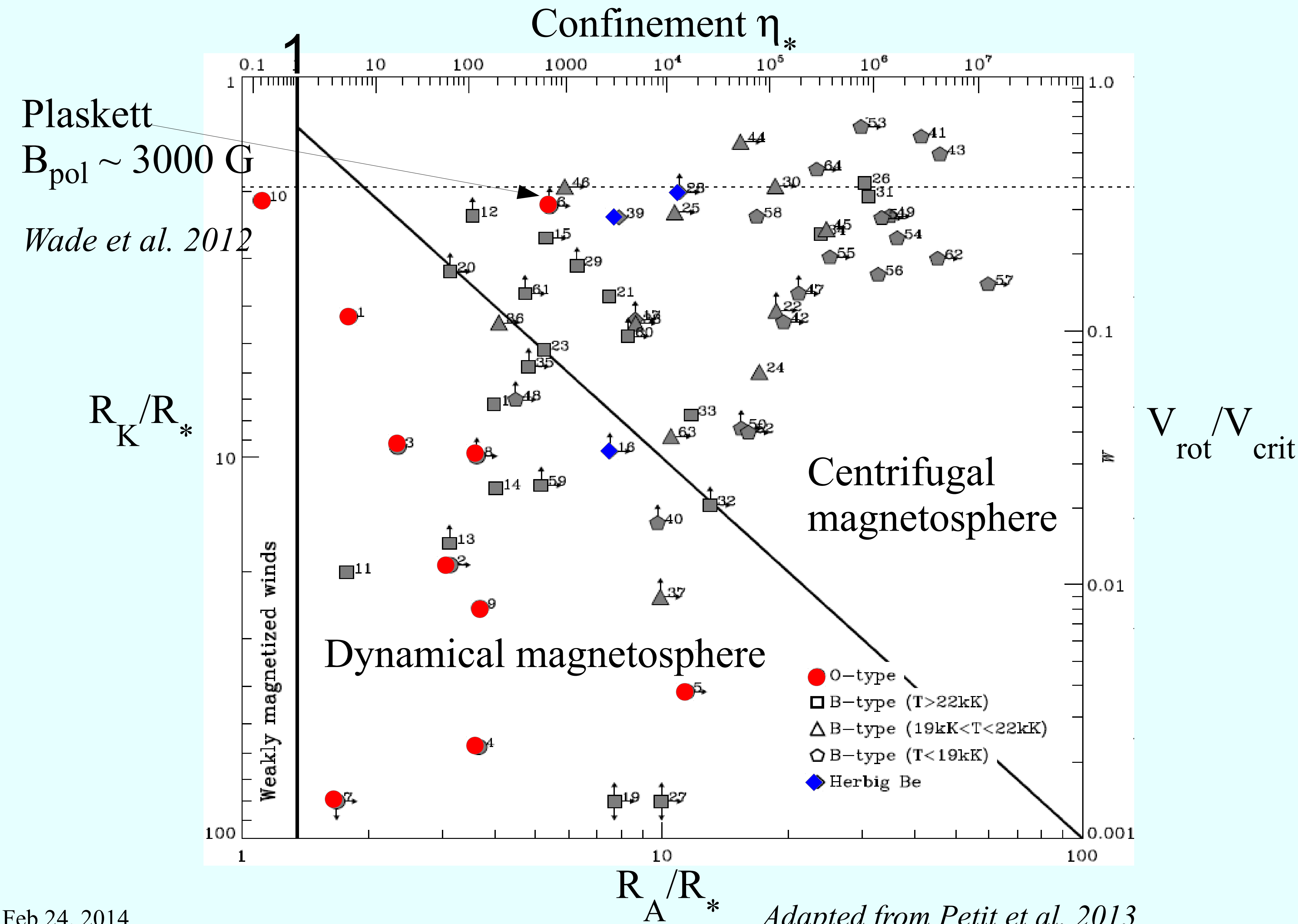
ζ Ori A
$B_{pol} \sim 40$ G

Bouret et al. 2008,
Blazere et al. in prep.



Adapted from Petit et al. 2013

Rotation vs Magnetic confinement diagram



Adapted from Petit et al. 2013

Summary

- The field of massive stars are simple (oblique dipole) and stable, as predicted by the fossil field theory → the fields are of fossil origin

- 7% of massive (O or B, pulsating or not) stars are magnetic, with two exceptions:

  100% of Of?p stars are magnetic → f?p nature comes from field
  <1% of Be stars are magnetic → related to rapid rotation ?
  or observational bias ?

- We did not detect Vega-like fields in OB stars (so far)

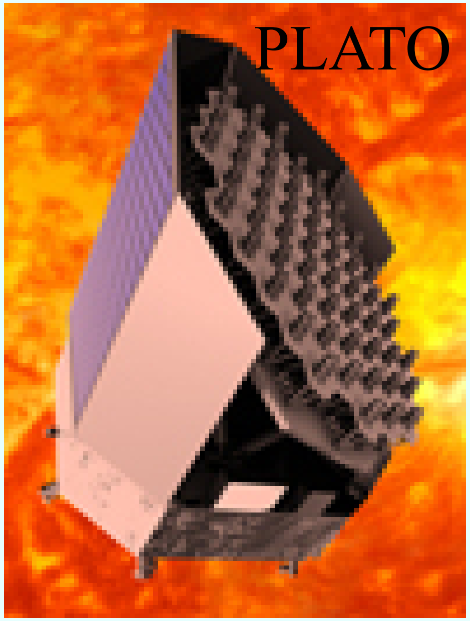
- Magnetic field inhibits mixing inside the stars and produces surface spots

- Two kinds of magnetospheres can exist: centrifugal and dynamical magnetospheres, depending on the strength of the field, the speed of the wind and the rotation rate

Short-term perspectives

- Improve statistics on fossil fields

→ complete, unbiased and deep (wrt field detection limit) census of magnetism in all bright stars from O to F5
→ BRITE targets
→ just starting with Narval (PI Neiner)



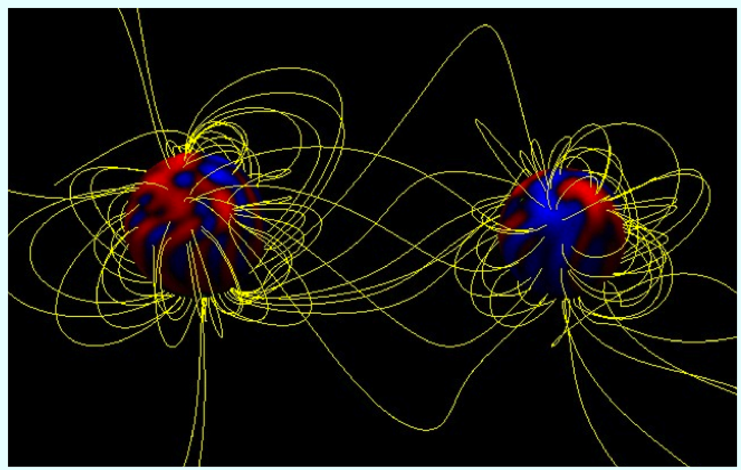
- Study the impact of magnetism on stellar structure

→ seismology of magnetic massive stars
→ BRITE (2014-2022), Kepler2 (2014-2017), PLATO (>2024) combined with spectropolarimetry

Short-term perspectives

- Study magnetic field in binary massive stars

→ information on fossil field and fragmentation during stellar formation
→ interactions between magnetospheres
→ BinaMIcS: LP Espadons (2013-2017, PI Alecian) + LP Narval (2013-2015, PI Neiner) + study of colliding wind binaries



- Check for the existence of Vega-like fields in massive stars

→ very deep spectropolarimetry of very bright OB stars
→ only a few targets, but very telescope time consuming

Long-term perspectives

- Try to measure magnetic fields in disks (YSO, Herbig and Be stars)

→ IR spectropolarimetry with SPIRou (> 2017)

- Study the magnetospheres by coupling wind and magnetic field studies

→ simultaneous UV + visible spectropolarimetry

→ UVMag space mission (will study all types of stars)

UVMag R&T study ongoing (LESIA+IRAP)

UVMag will be proposed as the ESA M4 mission in September 2014 (for a launch in 2027)

UVMag Phase 0 will start in October 2014

→ http://lesia.obspm.fr/UVMag

→ if you wish to participate, contact me!