Magnetic fields of fully-convective stars: are we observing dynamo bistability?

Julien Morin

Laboratoire Univers et Particules de Montpellier

U. Christensen, X. Delfosse, J.-F. Donati, E. Dormy, L. Duarte, T. Forveille, T. Gastine, M. Jardine, P. Petit, A. Reiners, M. Schrinner, J. Wicht, R. Yadav

Colloque de Prospective du PNPS

Besançon 24–27 février 2014

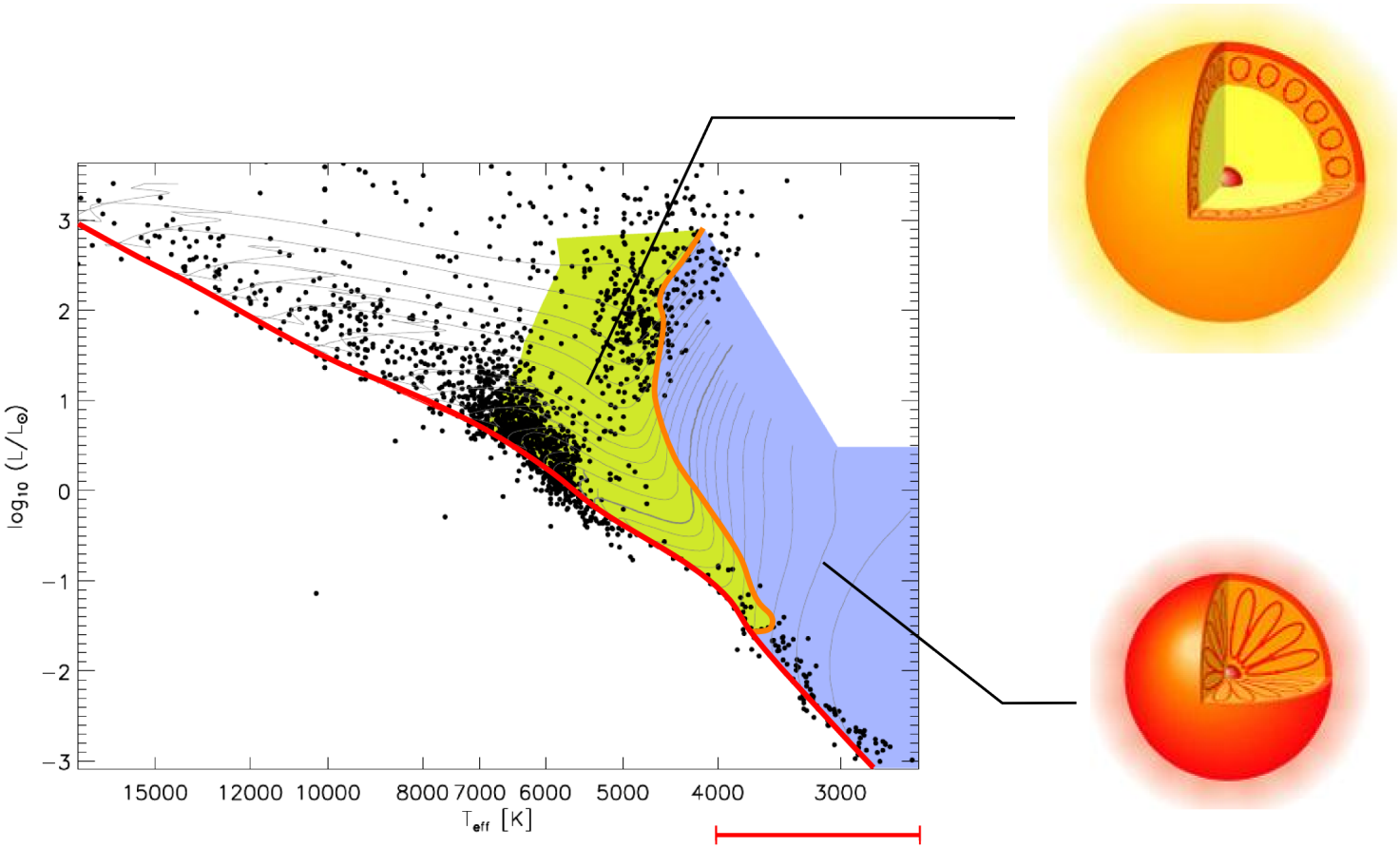
LUPM LABORATOIRE MONTPELLIER UNIVERS & PARTICULES

UM2 UNIVERSITÉ MONTPELLIER 2 SCIENCES ET TECHNIQUES

Outline

Outline

Fully-convective vs solar dynamo



Adapted from Reiners (2007)

M dwarfs

Solar-type dynamo

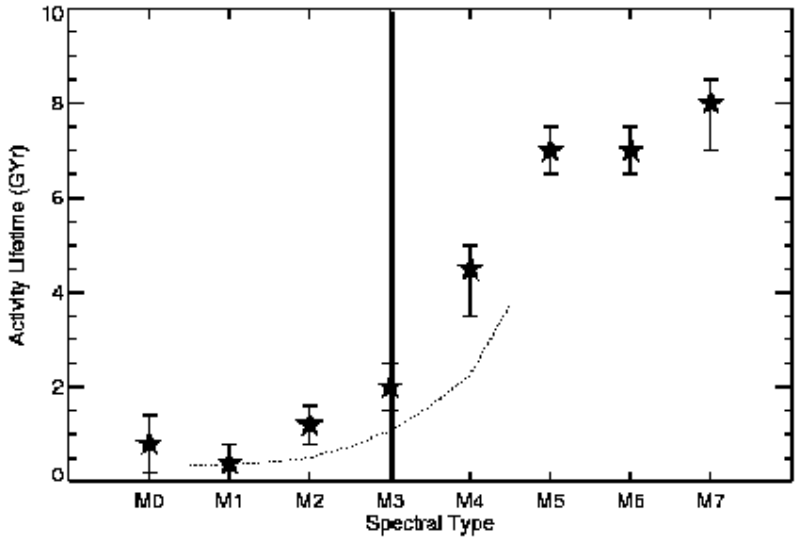
- $\alpha\Omega$: cyclonic convection + $d\Omega$
- Crucial role of the tachocline ?

M dwarf dynamo

- Importance of aspect ratio ?
- Differential rotation ? α^2 ?

What magnetic fields may help us to understand ?

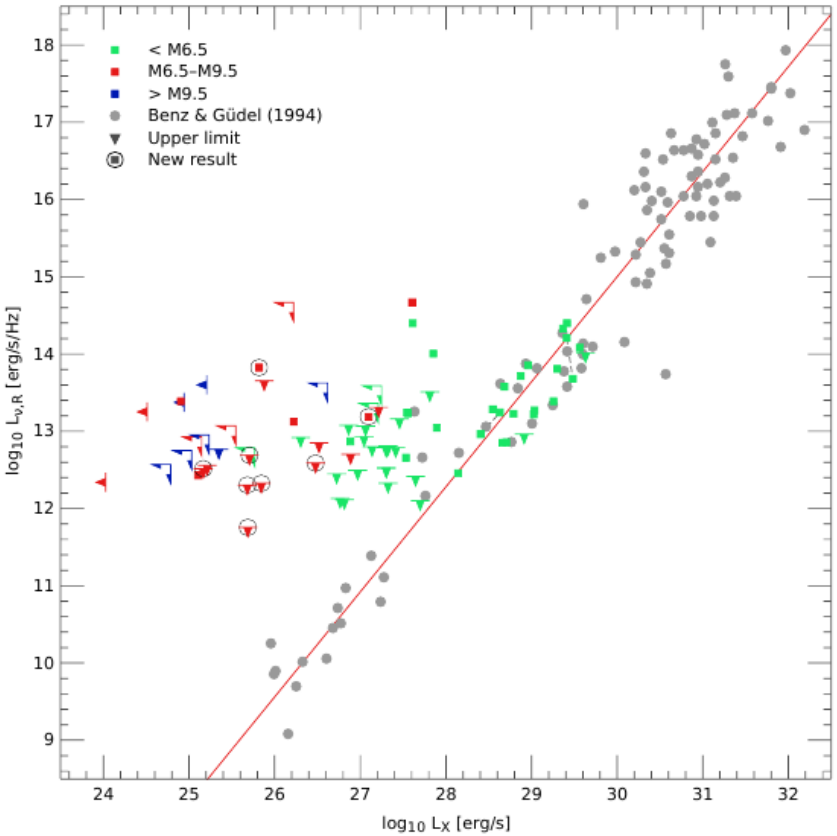
- Rotation
  - Why mid-late M dwarfs brake less?
  - *Reiners & Mohanty (2012)*?
  - *Vidotto et al. (2013)*
- Activity
  - FC dynamo ➔ activity ?
  - Radio – X-ray correlation
  - Radio emission of VLMS and BDs
- Planets
  - SPI
  - Habitability
  - Prevents detection ?



West et al. (2008)

What magnetic fields may help us to understand ?

- Rotation
  - Why mid-late M dwarfs brake less?
  - *Reiners & Mohanty (2012)*?
  - *Vidotto et al. (2013)*
- Activity
  - FC dynamo ➔ activity ?
  - Radio – X-ray correlation
  - Radio emission of VLMS and BDs
- Planets
  - SPI
  - Habitability
  - Prevents detection ?

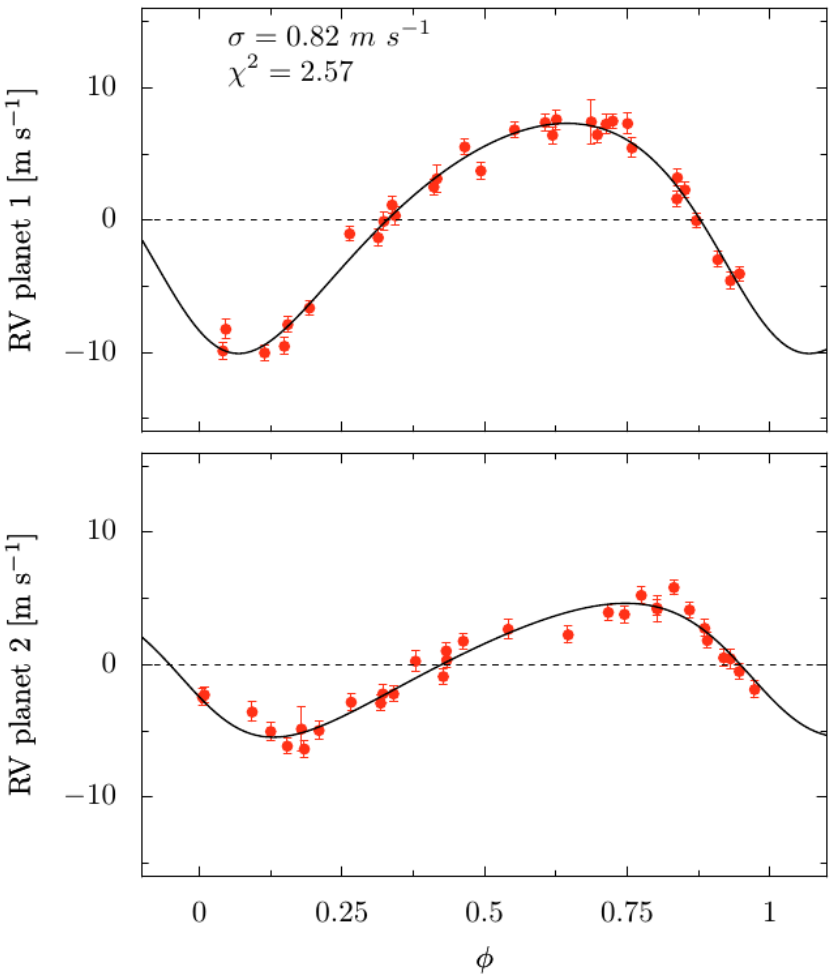


Williams, Cook & Berger (2013)

Berger et al. (2006) +
Hallinan et al. (2008) +

What magnetic fields may help us to understand ?

- Rotation
  - Why mid-late M dwarfs brake less?
  - *Reiners & Mohanty (2012)*?
  - *Vidotto et al. (2013)*
- Activity
  - FC dynamo ➔ activity ?
  - Radio – X-ray correlation
  - Radio emission of VLMS and BDs
- Planets
  - SPI
  - Habitability
  - Prevents detection ?



GJ 674 *Bonfils et al. (2007)*

Outline

Disk-integrated stellar measurements

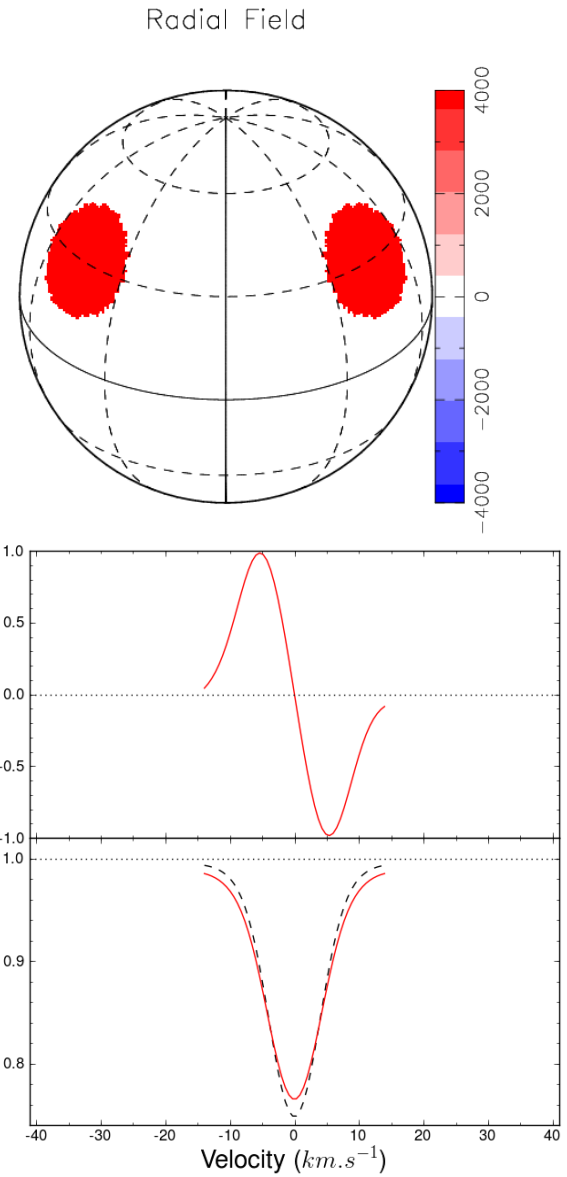
- Zeeman effect
  - Zeeman splitting
  - $\Delta\lambda_B = \propto \lambda_0^2 g_{eff} B$
  - Polarization : vector props of **B**

- Unpolarised spectrum
  - Total magnetic flux*
  - But almost no information on field geometry

➥ Dynamo energetics

- Polarized spectrum
  - Large-scale component
  - Contains info on **B**

➥ ZDI ➔ topology



Disk-integrated stellar measurements

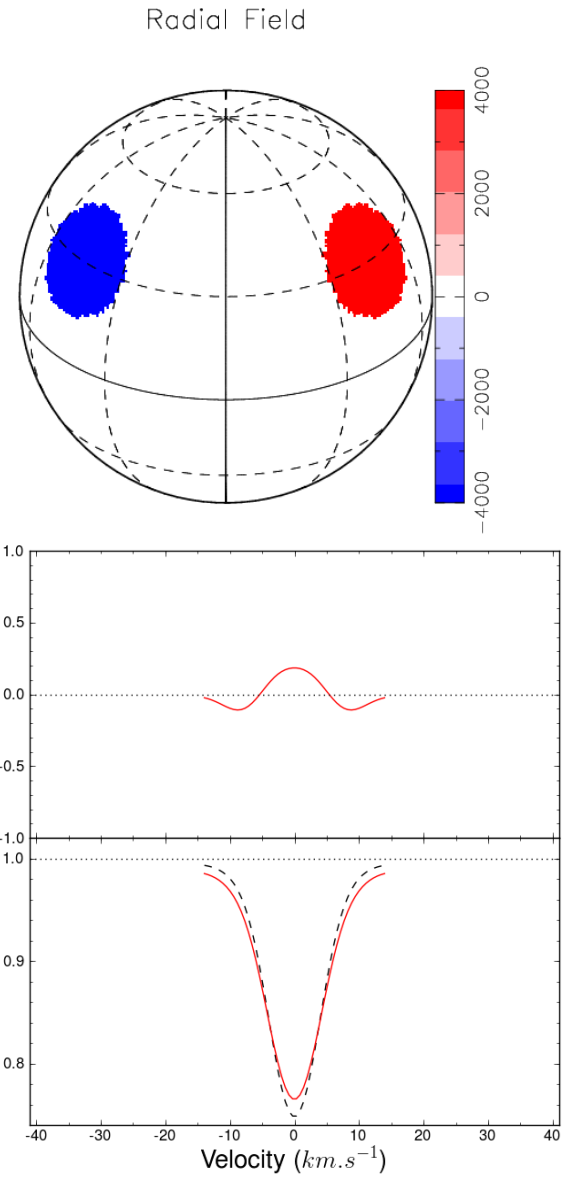
- Zeeman effect
  - Zeeman splitting
  - $\Delta\lambda_B = \propto \lambda_0^2 g_{eff} B$
  - Polarization : vector props of **B**

- Unpolarised spectrum
  - Total magnetic flux*
  - But almost no information on field geometry

➥ Dynamo energetics

- Polarized spectrum
  - Large-scale component
  - Contains info on **B**

➥ ZDI ➔ topology



Disk-integrated stellar measurements

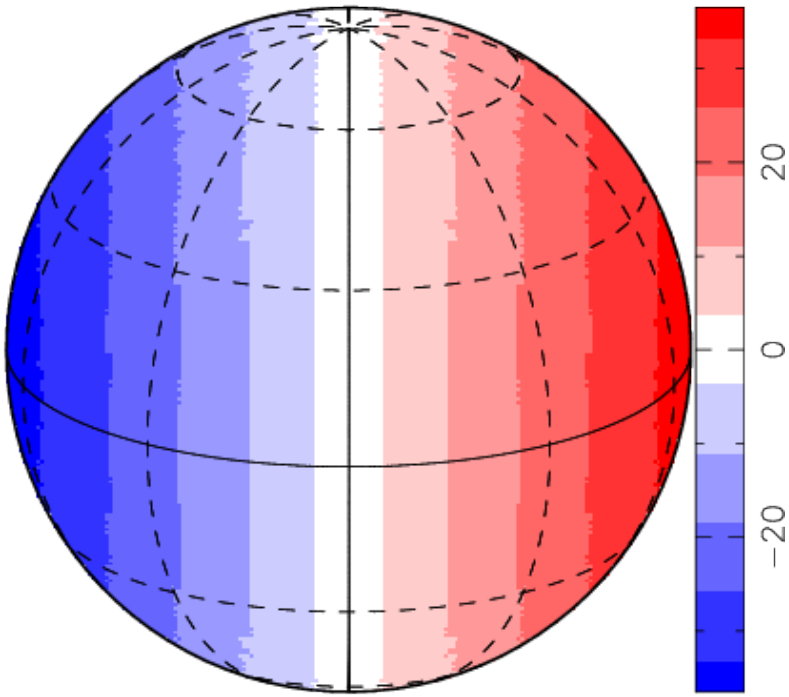
- Zeeman effect
  - Zeeman splitting
  - $\Delta\lambda_B = \propto \lambda_0^2 g_{eff} B$
  - Polarization : vector props of **B**

- Unpolarised spectrum
  - Total magnetic flux*
  - But almost no information on field geometry

➥ Dynamo energetics

- Polarized spectrum
  - Large-scale component
  - Contains info on **B**

➥ ZDI ➔ topology



Equal RV stripes

Disk-integrated stellar measurements

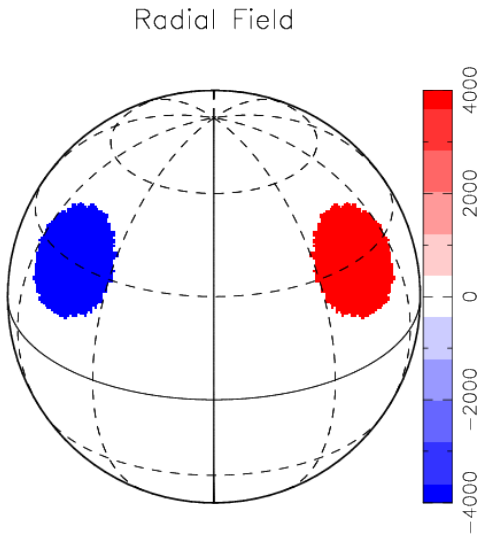
- Zeeman effect
  - Zeeman splitting
  - $\Delta\lambda_B = \propto \lambda_0^2 g_{eff} B$
  - Polarization : vector props of **B**

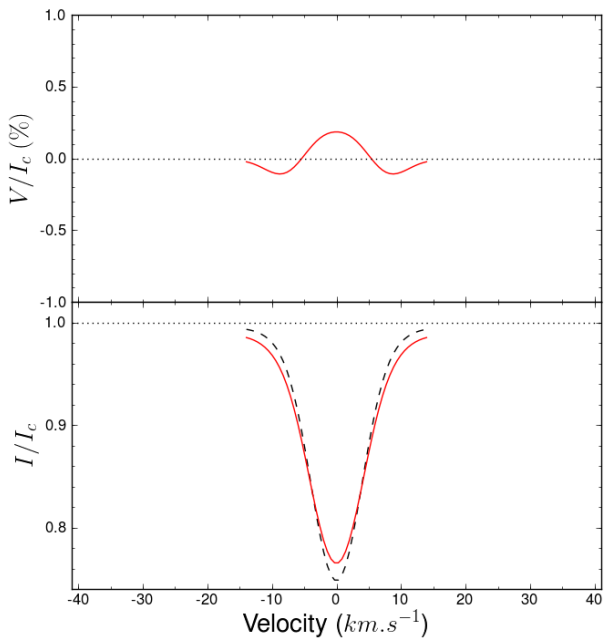
- Unpolarised spectrum
  - Total magnetic flux*
  - But almost no information on field geometry

➥ Dynamo energetics

- Polarized spectrum
  - Large-scale component
  - Contains info on **B**

➥ ZDI ➔ topology





$v \sin i = 1\ km\,s^{-1}$

Disk-integrated stellar measurements

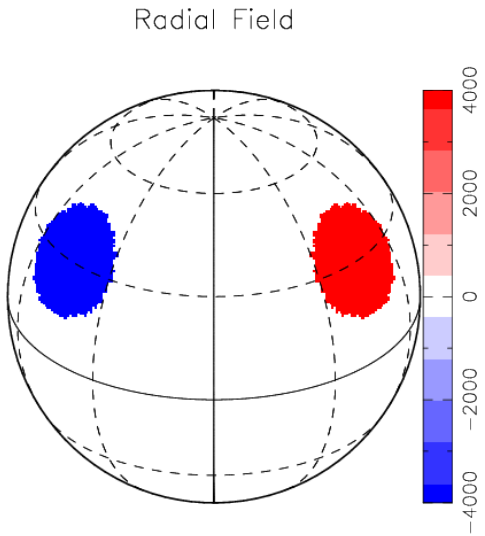
- Zeeman effect
  - Zeeman splitting
  - $\Delta\lambda_B = \propto \lambda_0^2 g_{eff} B$
  - Polarization : vector props of **B**

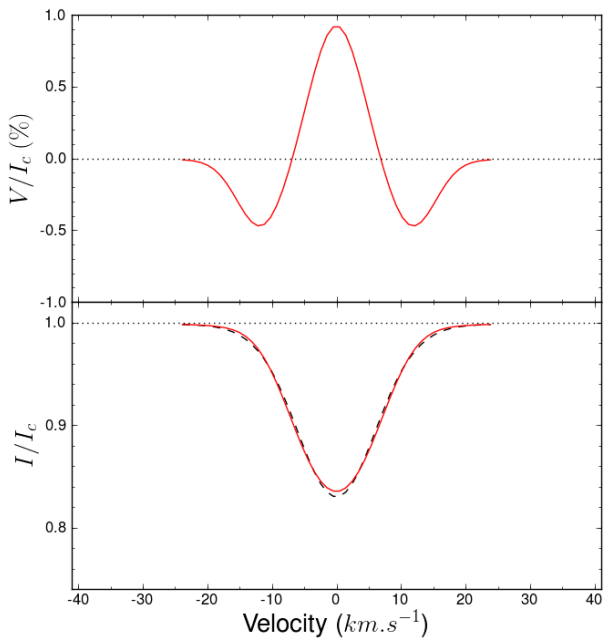
- Unpolarised spectrum
  - Total magnetic flux*
  - But almost no information on field geometry

➥ Dynamo energetics

- Polarized spectrum
  - Large-scale component
  - Contains info on **B**

➥ ZDI ➔ topology





$v \sin i = 10\ km\,s^{-1}$

Disk-integrated stellar measurements

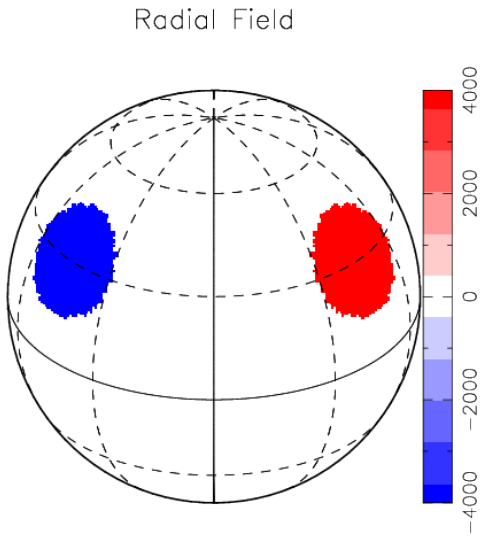
- Zeeman effect
  - Zeeman splitting
  - $\Delta\lambda_B = \propto \lambda_0^2 g_{eff} B$
  - Polarization : vector props of **B**

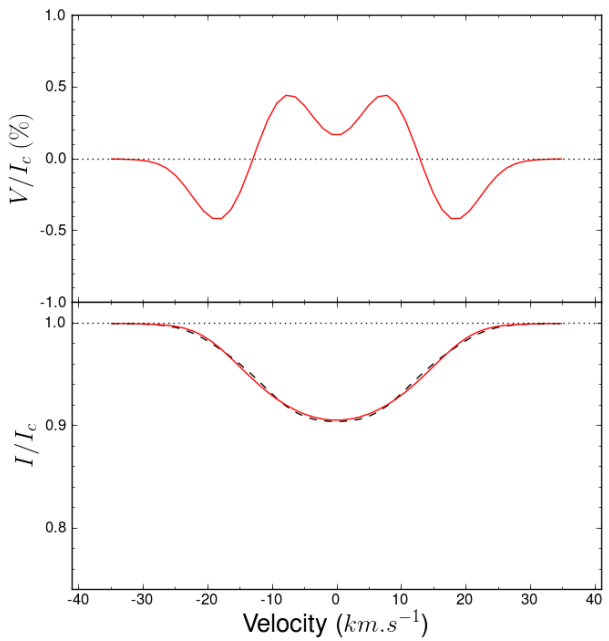
- Unpolarised spectrum
  - Total magnetic flux*
  - But almost no information on field geometry

➥ Dynamo energetics

- Polarized spectrum
  - Large-scale component
  - Contains info on **B**

➥ ZDI ➔ topology





$v \sin i = 20\ km\,s^{-1}$

Outline

The survey

- Multi-line + New generation instruments ESPaDOnS and NARVAL

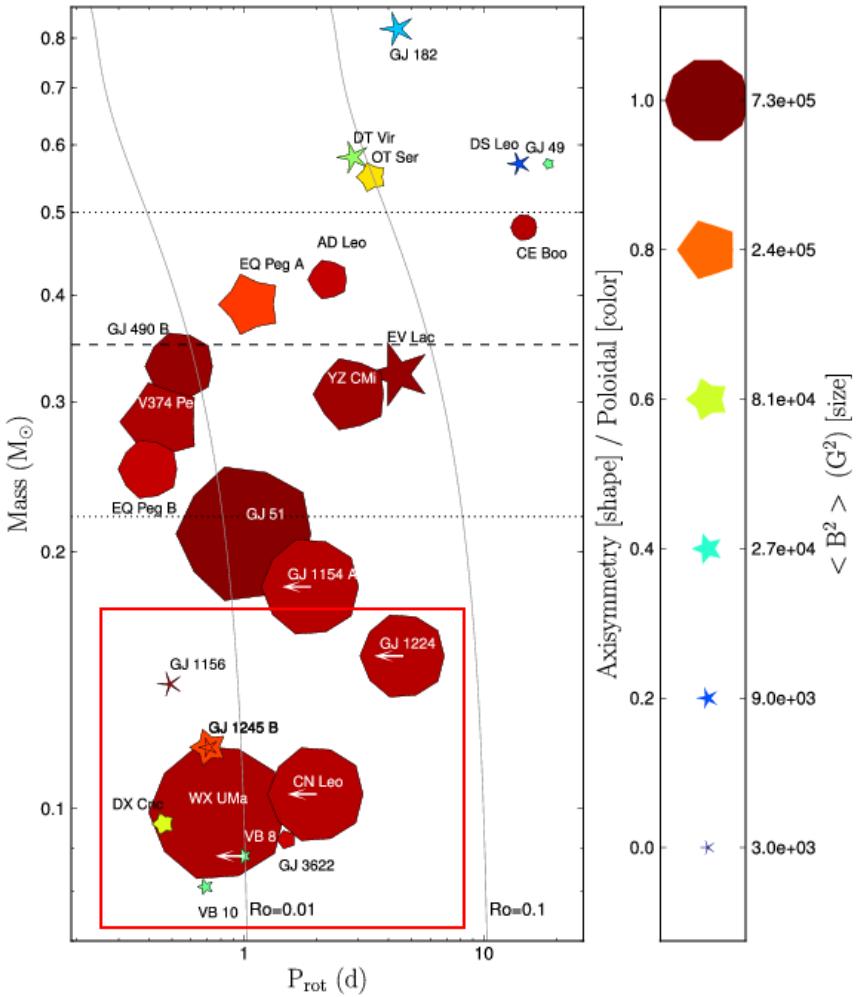
➥ Systematic study of H-R diagram including M dwarfs

- Explore dynamo response to
  - Mass
    - Depth of convective zone
  - Rotation period

- Measurements
  - Stokes V time-series
  - **B**: pol., tor., axi.
  - Differential rotation
  - Long-term evolution

- M dwarfs
  - 23 stars
  - $0.08 < M_\star < 0.75\ \mathrm{M}_\odot$
  - $0.33 < P_{\mathrm{rot}} < 18.6\ \mathrm{d}$
  - Active

Results : the mass–period diagram



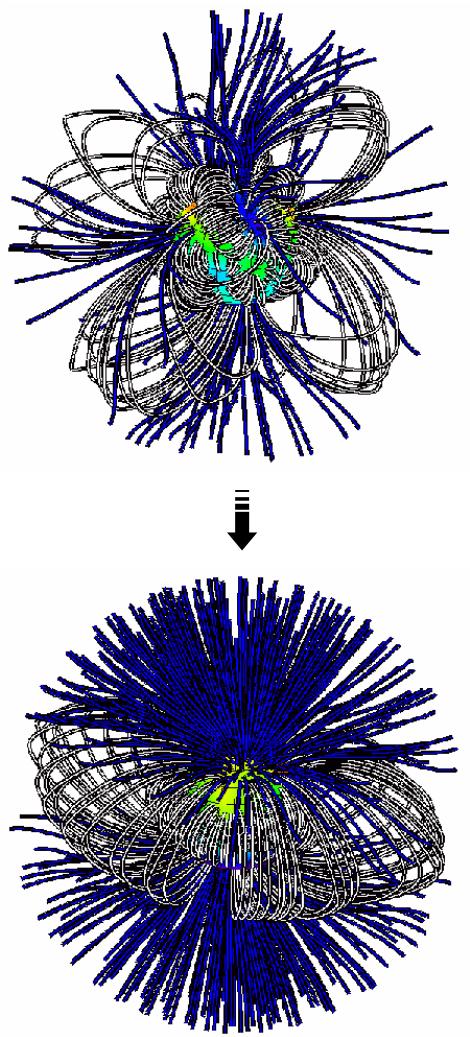
- Sharp transition $\sim 0.5\ \mathrm{M}_\odot$
  - Magnetic topologies
  - Differential rotation

Morin et al.(2008a,b), Donati et al. 2008, Phan-Bao et al.(2009)

- $M_\star < 0.2\ \mathrm{M}_\odot$; $P_{\mathrm{rot}} \sim$ d
  - 2 types of **B**
  - Similar stellar parameters

Morin et al.(2010)

Results : the mass–period diagram



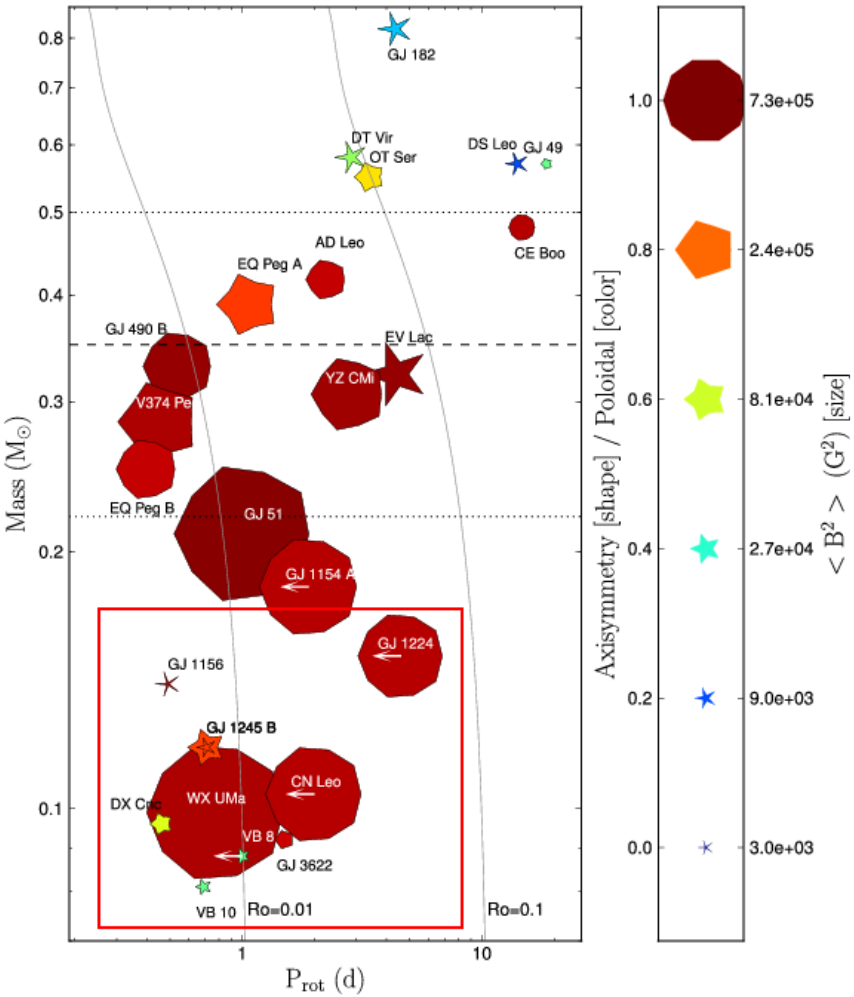
- Sharp transition $\sim 0.5\ \mathrm{M}_\odot$
  - Magnetic topologies
  - Differential rotation

Morin et al.(2008a,b), Donati et al. 2008, Phan-Bao et al.(2009)

- $M_\star < 0.2\ \mathrm{M}_\odot$; $P_{\mathrm{rot}} \sim$ d
  - 2 types of **B**
  - Similar stellar parameters

Morin et al.(2010)

Results : the mass–period diagram



- Sharp transition $\sim 0.5\ \mathrm{M}_\odot$
  - Magnetic topologies
  - Differential rotation

Morin et al.(2008a,b), Donati et al. 2008, Phan-Bao et al.(2009)

- $M_\star < 0.2\ \mathrm{M}_\odot$; $P_{\mathrm{rot}} \sim$ d
  - 2 types of **B**
  - Similar stellar parameters

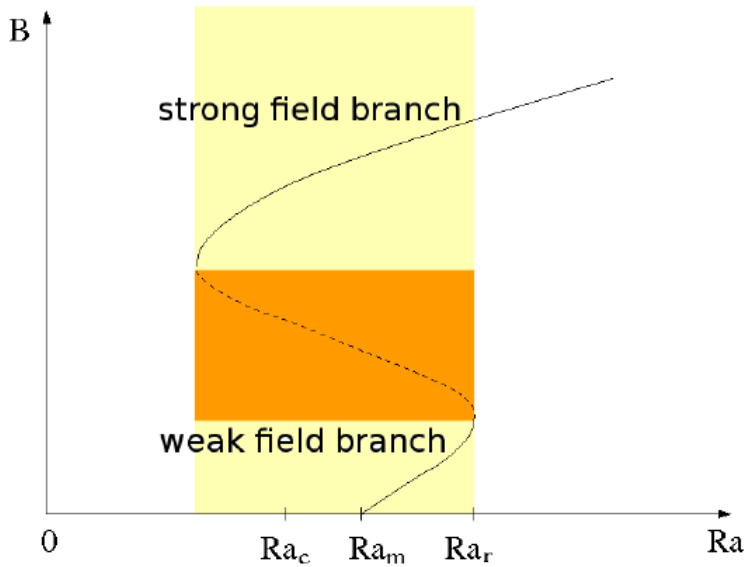
➔ Two possible dynamo modes ?
➔ Switch between two states ?
➔ Influence of age ?

Morin et al.(2010)

Outline

Dynamo bistability: the idea

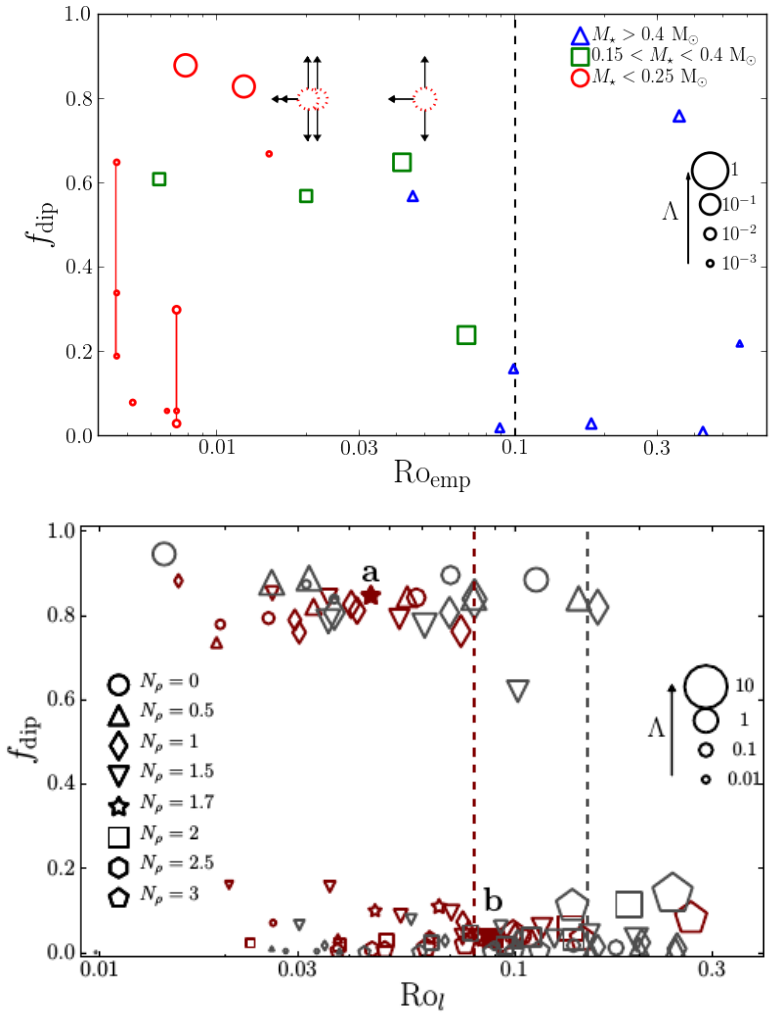
- Dynamo bistability
  - cf *Simitev & Busse (2009)*
  - 2 $\neq$ dynamo types
  - Depend on initial conditions/history
  - *Morin et al. (2011), Gastine et al. (2013)*
- Comparison w/ DNS
  - Similar phenomenology
  - Predictions
    - Extent of bistable domain
    - Differential rotation



Morin et al. (2011),
adapted from Roberts (1988)

Dynamo bistability: the idea

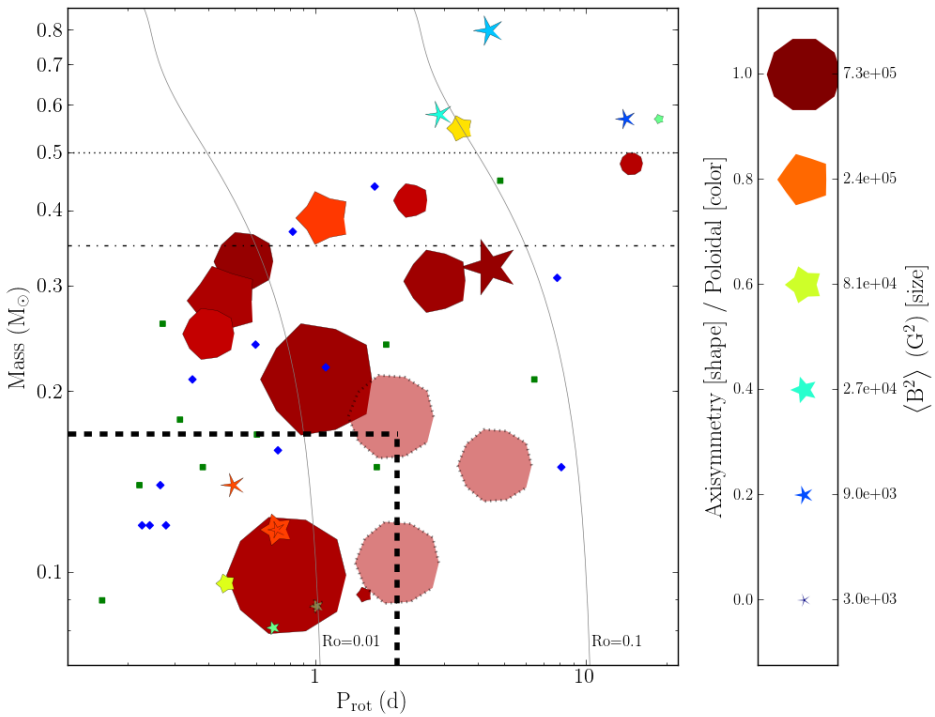
- Dynamo bistability
  - cf *Simitev & Busse (2009)*
  - 2 $\neq$ dynamo types
  - Depend on initial conditions/history
  - *Morin et al. (2011), Gastine et al. (2013)*
- Comparison w/ DNS
  - Similar phenomenology
  - Predictions
    - Extent of bistable domain
    - Differential rotation



Gastine et al. (2013)

Dynamo bistability: observational tests

- Ongoing studies
- ESPaDOnS snapshot program 2013AB
  - Disentangle w/ age hyp
  - 1st results : more multipolar stars!
- Differential rotation
  - Systematic relation Topology $\Longleftrightarrow$ DR?



CFHT 13AB

Outline

Summary

Dynamo bistability?

- ➥ Obs tests ongoing
- Alternative explanations?
  - Stellar age / kinematic pop.
  - Cyclic dynamo ➔ *Kitchatinov+(2014)*
  - Binaries : Binamics CFHT/TBL LP
- Implications
  - Origin of $\neq$ fields?
  - Ω evolution? Activity BDs?

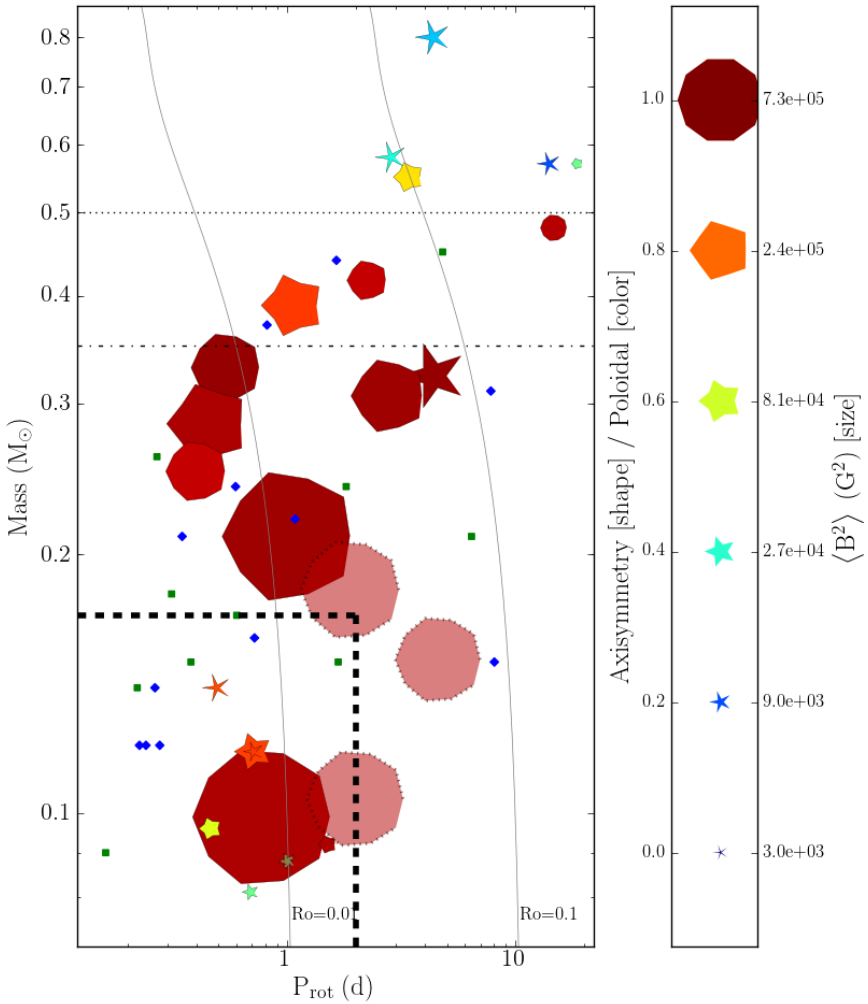
➔ *Williams+ (2013); Cook+ (2013)*

  - bistability in DR?

➔ *Gastine+ (2014); Kapyla+ (2014)*

SPIRou

- Ideal for M dwarfs magnetism
  - Next big step forward
  - Synergy w/ planet search



Summary

Dynamo bistability?

- ➥ Obs tests ongoing
- Alternative explanations?
  - Stellar age / kinematic pop.
  - Cyclic dynamo ➔ *Kitchatinov+(2014)*
  - Binaries : Binamics CFHT/TBL LP
- Implications
  - Origin of $\neq$ fields?
  - Ω evolution? Activity BDs?

➔ *Williams+ (2013); Cook+ (2013)*

  - bistability in DR?

➔ *Gastine+ (2014); Kapyla+ (2014)*

SPIRou

- Ideal for M dwarfs magnetism
  - Next big step forward
  - Synergy w/ planet search