Does inertia determine the magnetic topology of low-mass stars ?

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Outline

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Magnetism of cool stars

$\alpha\Omega$ Dynamo

- Differential rotation
- Cyclonic convection

➔ Tachocline: crucial role ?

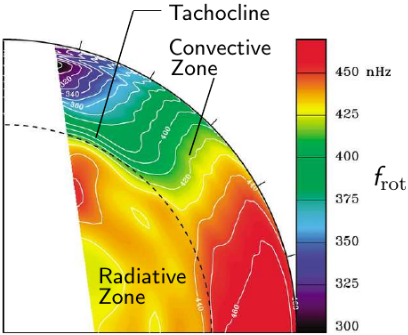
Partly convective

- Rotation-activity, cycles
- Internal structure

➔ Solar-type dynamo

$M_\star < 0.35\ M_\odot$

- ~~Tachocline ➔ no solar dynamo~~
- Activity / magnetic field
- Simple topology



Schou et al. (1998)
from SOHO–MDI data

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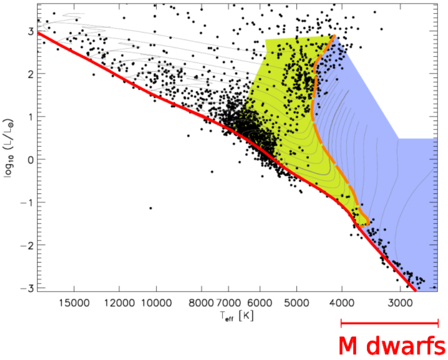

Adapted from Reiners (2007) from Siess et al. (2002) models

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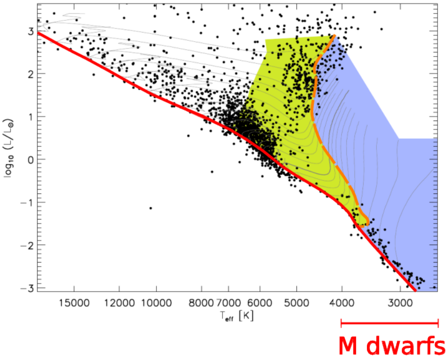

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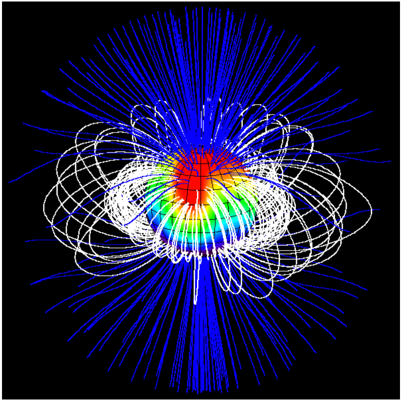


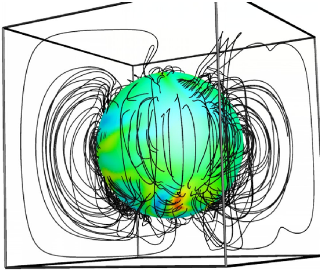
Donati et al. (2006)

Dynamo processes in fully convective stars

- Small-scale dynamo
  - *Durney et al. (1993)*
- Mean-field α^2 and $\alpha^2\Omega$ models
  - *Chabrier & Küker (2006)*
- Global 3D DNS
  - *Dobler et al. (2006)*
    Browning (2008)

Link with geodynamo

- Scaling law $B(E_{\rm conv})$
  - *Christensen, Holzwarth & Reiners (2009)*



Dobler et al.(2006)

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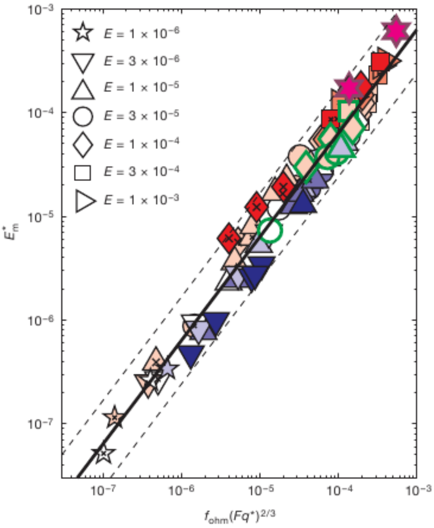

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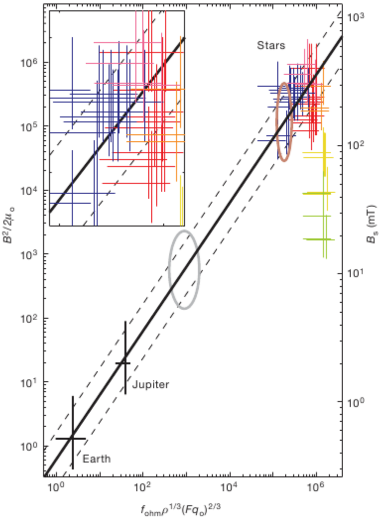


Christensen et al.(2009)

Outline

Measuring magnetic fields: techniques

Zeeman effect

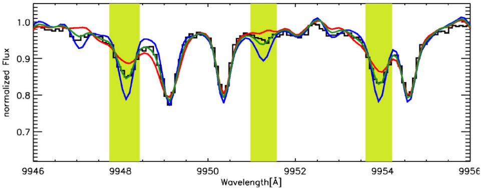
- Line splitting/broadening
  - $\Delta\lambda_B = 4.67 \times 10^{-12}\, \lambda_0^2 g_{eff}\, B$
- Polarization

Unpolarised spectroscopy

- Total field *Bf*
- ~~Geometry~~

Spectropolarimetry

- Field orientation + polarity
- Large-scale component only



GJ 729, FeH Wing-Ford band

Reiners & Basri (2006)

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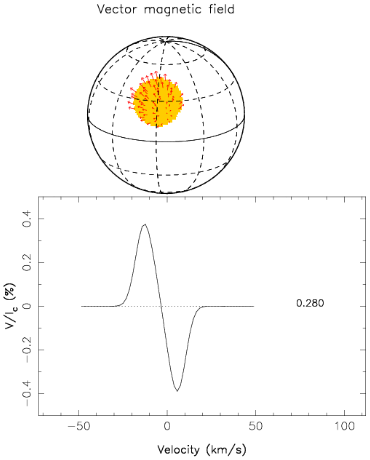

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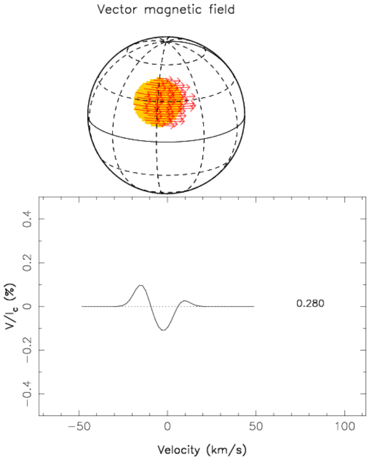
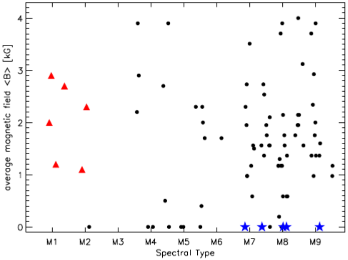


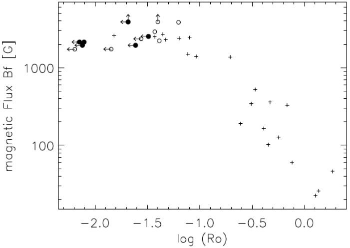
Measuring magnetic fields: M dwarfs results (1/2)

Unpolarised spectroscopy

- Fully-convective transition
  - $0 < Bf < 4\ \mathrm{kG}$
  - On both sides
  - Agreement w/ activity measurements
  - Dispersion due to rotation

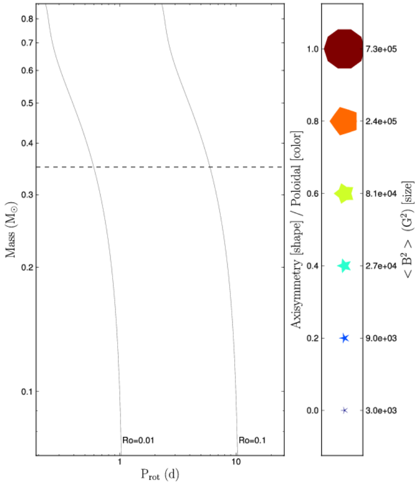


Reiners (2010)



Reiners (2012)

Measuring magnetic fields: M dwarfs results (2/2)

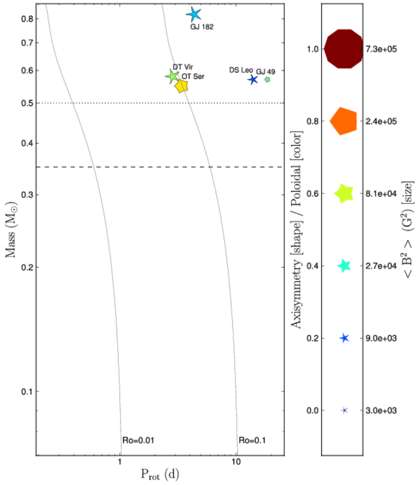


Spectropolarimetry

- Fully-convective transition
  - Partly convective stars
    - Toroidal, non-axisymmetric
    - Variable
  - Fully convective stars
    - Almost dipolar, stronger
    - Steady
- Very low mass stars
  - Similar stellar parameters
  - Two distinct magnetisms
    - strong dipole
    - weak non-axisymmetric

Morin, Donati et al. (2008–2010)

Measuring magnetic fields: M dwarfs results (2/2)



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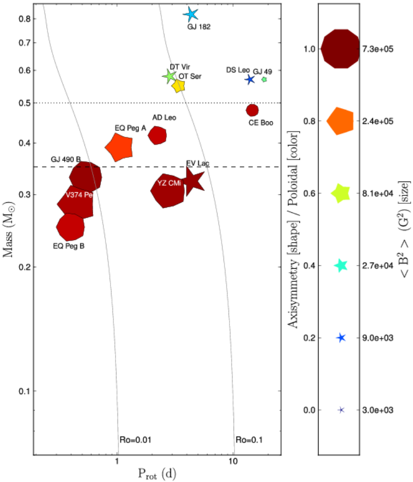

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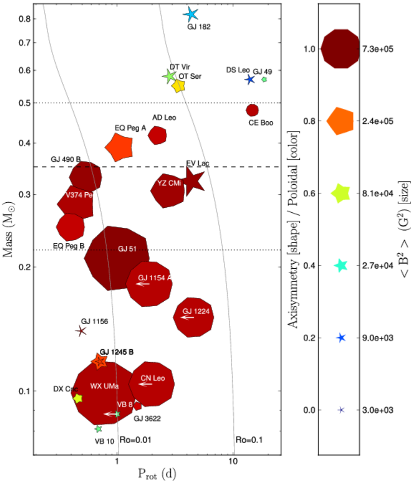

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Outline

Weak and strong field dynamos

Large-scale dynamo bistability

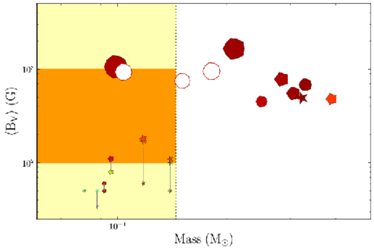
- Similar Bf on both branches

Field strength

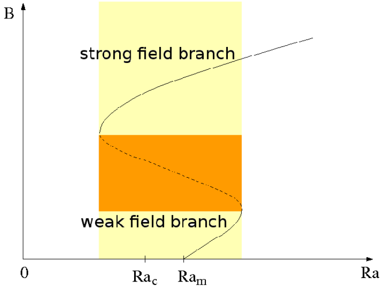
- Strong field branch
  - Coriolis–Lorentz force balance
  - $\Lambda = \dfrac{B^2}{\rho\mu\eta\Omega} = \mathcal{O}(1)$
- $B_{sf} \sim 2 - 50\ \mathrm{kG}$

Gap between branches

- Lorentz-inertia
  ➔ Lorentz-Coriolis balance
  - $\frac{B_{sf}}{B_{wf}} = Ro^{-1/2} \sim 10$



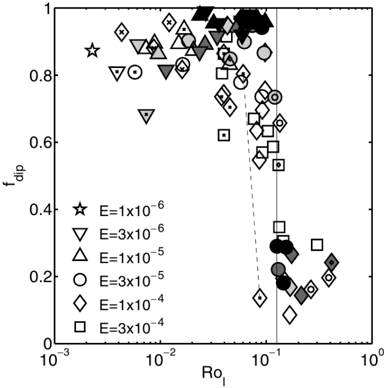
Morin, Dormy, Schrinner & Donati (2011)



Adapted from Roberts (1978)

The role of inertia in Boussinesq simulations

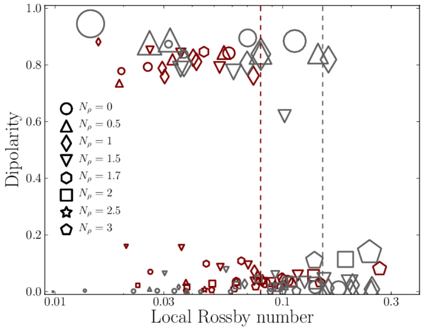
- *Christensen & Aubert (2006)*
  - Boussinesq simulations
  - Inertia-Coriolis balance: $Ro_\ell = Ro\frac{\bar{\ell}_u}{\pi}$
  - Low Ro ➔ dipolar
- *Schrinner et al. (2012)*
  - Stress-free boundary conditions
    - *Simitev & Busse (2009)*
  - Bistability at low Ro
    - dip *vs* multipolar depending on IC



Christensen & Aubert (2006)

The role of inertia in anelastic simulations

- *Gastine et al., submitted*
  - Still recovers in anelastic:
    - Transition to dipole at low Ro_ℓ
    - Dipole/multipole bistability



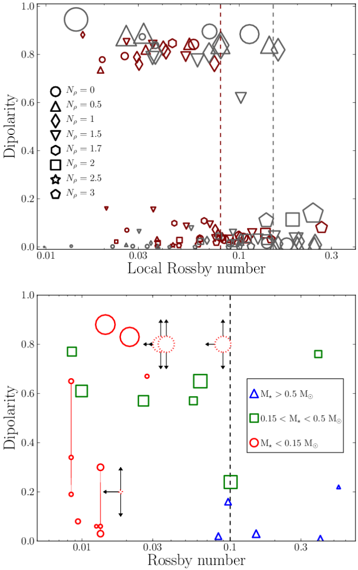
Gastine et al., submitted

Anelastic simulations *vs* observations (1/2)

- Compare simulations w/ spectropolarimetric measurements
  - large-scale component of **B**
  - "scale separation" assumption

➥ similar transition to bistable regime

- Caveats and questions
  - $Ro_\ell \leftrightarrow$ empirical Ro ?
  - Can we find multipolar fields
    - $M_\star > 0.15\ \mathrm{M}_\odot$?
    - $Ro > 0.02$?
  - Outliers



Gastine, Morin et al., in prep.

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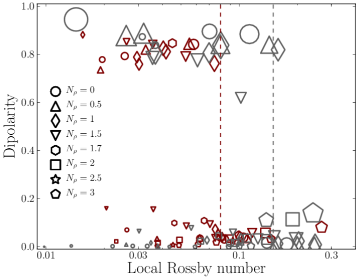
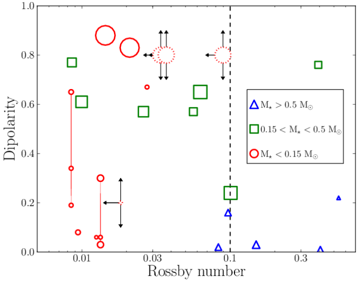
➥ Larger survey of active M dwarfs





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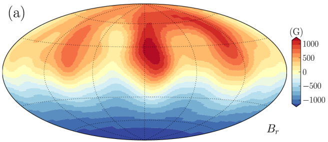
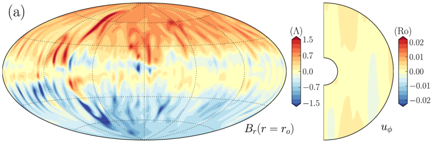
Anelastic simulations *vs* observations (2/2)

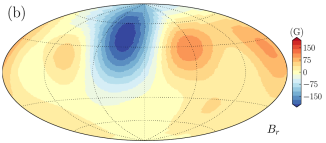


$$\frac{\Delta\Omega}{\Omega} \simeq 0.04\,\%$$

V374 Peg

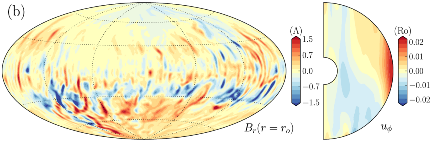


Dipolar branch



$$\frac{\Delta\Omega}{\Omega} \quad ?$$

GJ 1245 B



Multipolar branch

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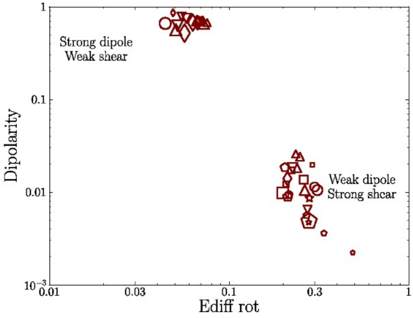

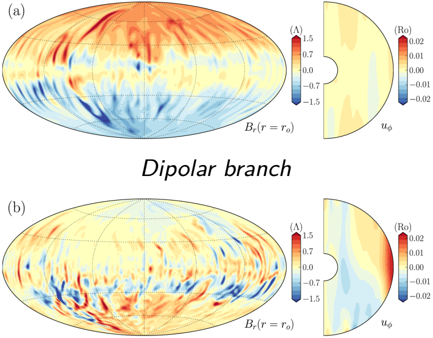

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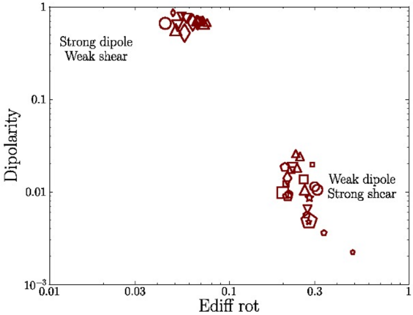

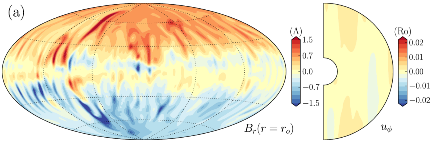

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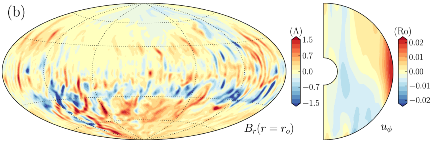


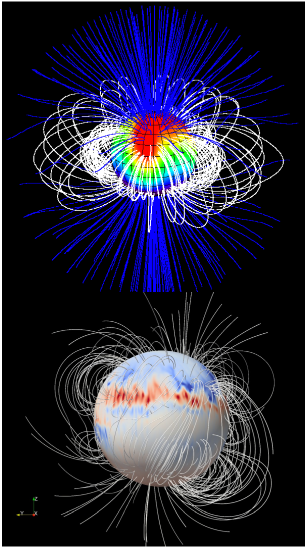
Multipolar branch

➥ Differential rotation measurement in both subsamples

Summary and conclusions

- M dwarfs: prime interest for dynamos
  - non-solar dynamo
  - fast-rotation
- Observations
  - Unpolarized spectroscopy
  - Spectropolarimetry
    - Bistable domain VLMS/fast rotation
- Theory/Simulations
  - Continuum planets/BDs/stars
  - Inertia ➔ drives LS topology
  - Bistable domain

➔ More to come !



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