Evidence for dynamo bistability among very low mass stars

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Magnetism of cool stars

$\alpha\Omega$ Dynamo

- Differential rotation
- Cyclonic convection

➔ Tachocline: crucial role ?

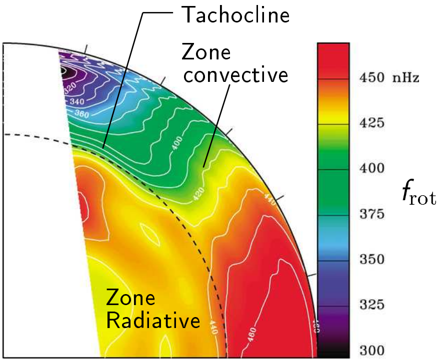
Partly convective

- 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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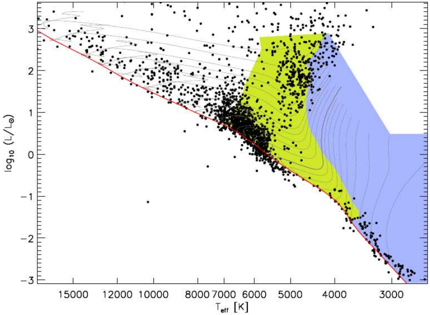

Reiners (2007), from Siess et al. (2002) models

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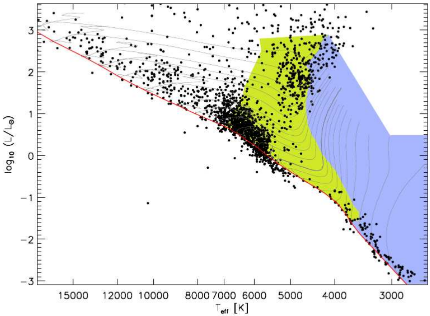

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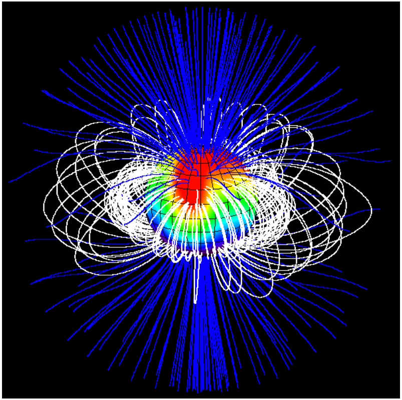


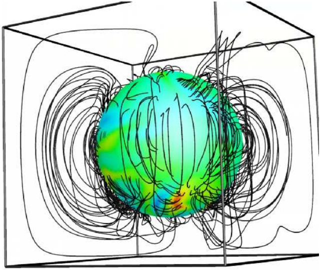
Donati et al. (2006)

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

- Influence of aspect ratio
  - *Goudard & Dormy (2008)*
- Scaling law $B(E_{\rm conv})$
  - *Christensen, Holzwarth & Reiners (2009)*



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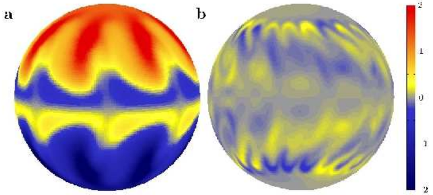

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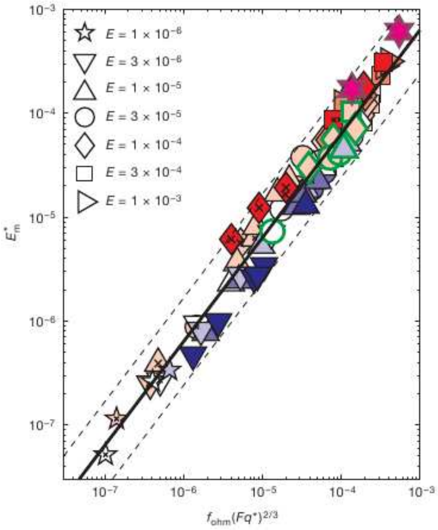

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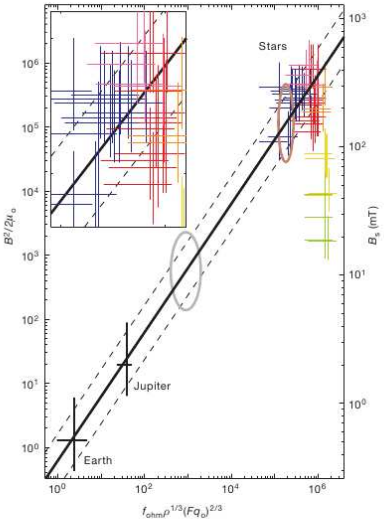


Christensen et al.(2009)

Measuring magnetic fields: techniques

Zeeman effect

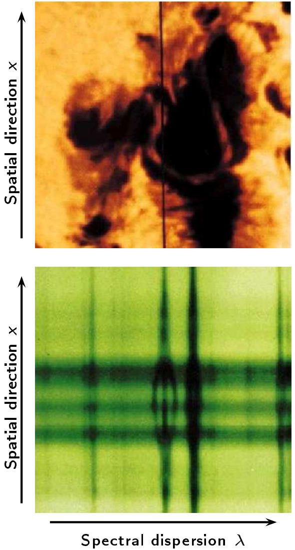
- Line splitting/broadening
  - $\Delta\lambda_B = 4.67 \times 10^{-12}\, \lambda_0^2 g_{eff} B$
- Polarization

Unpolarised spectroscopy

- Total field Bf
- ~~Geometry~~

Spectropolarimetry

- Field orientation + polarity
- Large-scale component only



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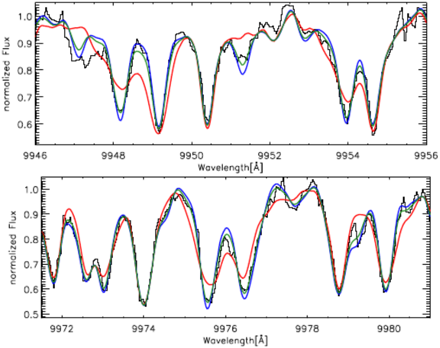

M7, FeH Wing-Ford band
Reiners & Basri (2010)

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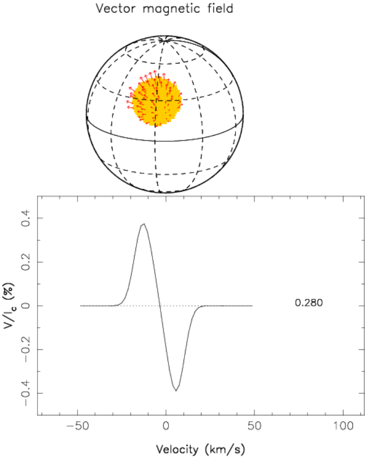

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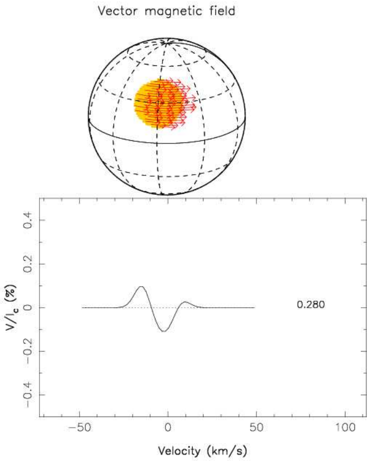
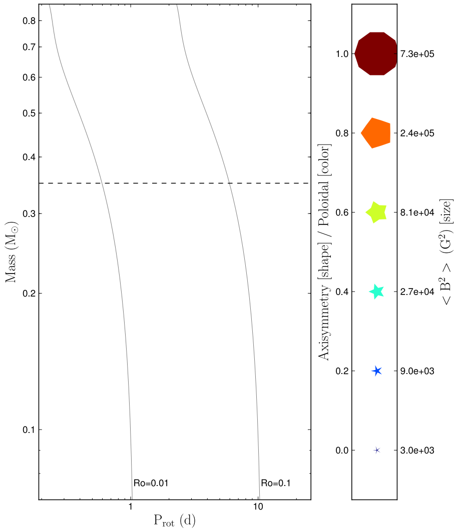


Measuring magnetic fields: M dwarfs results (1/2)



Fully convective transition

- Partly convective stars
  - Toroidal, non-axisymmetric
  - Variable
- Fully convective stars
  - Almost dipolar, stronger
  - Steady

Morin et al.(2008a,b) Donati et al.(2008)

Phan-Bao et al.(2009)

VLMS

- Similar stellar parameters
- Two distinct magnetisms
  - strong dipole
  - weak non-axisymmetric

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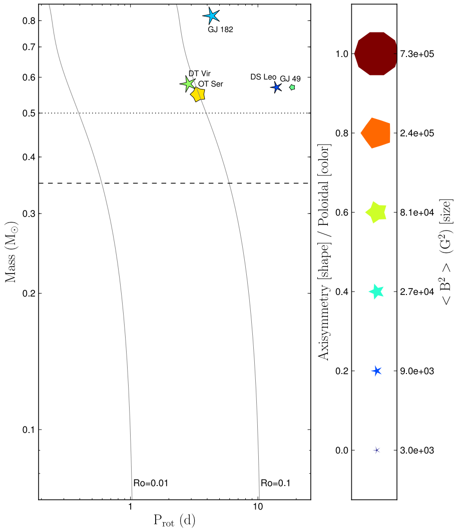

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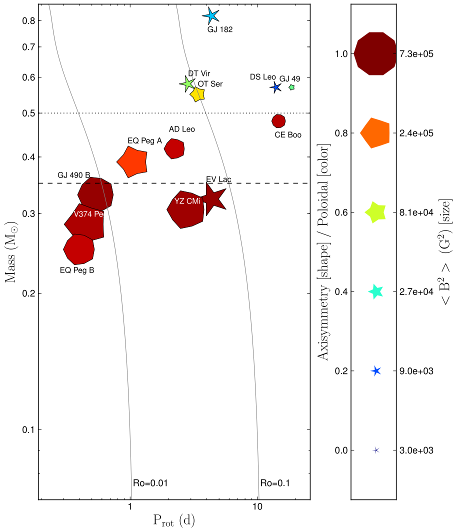

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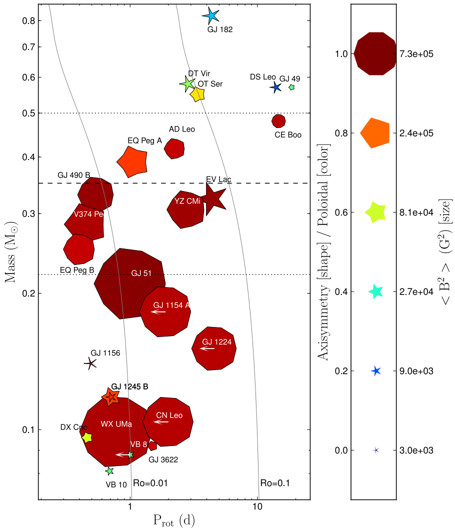

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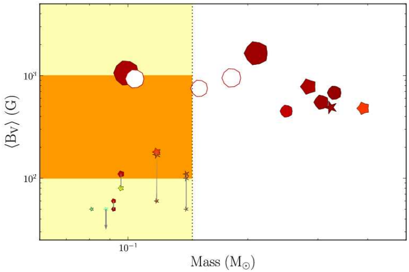

Bimodal domain

- "Saturated" dynamo
- $M_\star < 0.15\ M_\odot$
- $P_{rot} < 1.5$ d
  - Not well defined
  - Larger sample needed

Unpolarised spectroscopy

- $Bf \sim 1 - 4$ kG
  - Dominated by small-scale
- No correlation w/ spectropolarimetry

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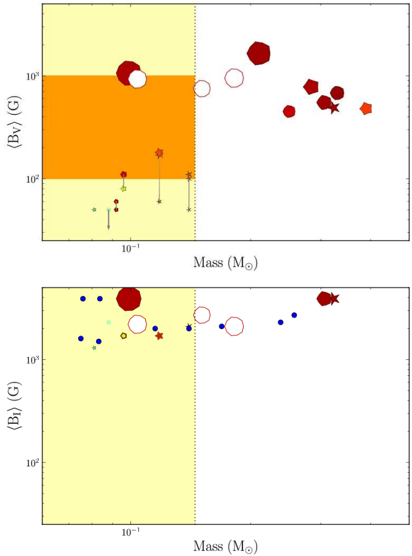

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Weak and strong field dynamos

Linear stability analysis

- Ω or $\mathbf{B}$ inhibit convection
  - Higher Ra_c, smaller spatial scales
- $\Omega + \mathbf{B}$ ➔ counteraction
  - Most efficient if Coriolis $\sim$ Lorentz
  - Magnetostrophic regime

Dynamo-generated **B** w/ rotation

- Roberts' conjecture
  - Runaway growth of B
  - Bistable domain
- Theoretical support

  Childress & Soward (1978)
- Numerical simulations

  V. Morin & Dormy, in prep.

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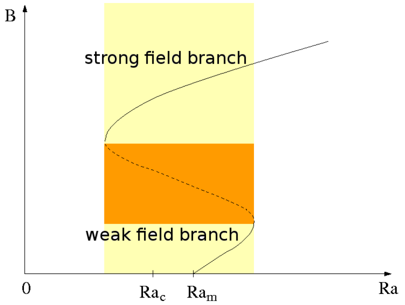


Adapted from Roberts (1978)

Weak and strong field dynamos: fully-convective stars

Large-scale dynamo bistability

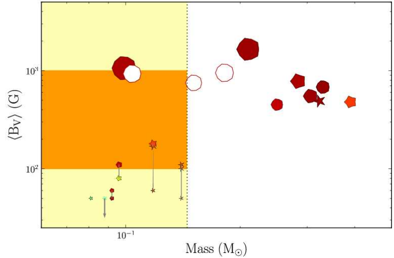
- Similar FC boundary
- Small fraction of *Bf*

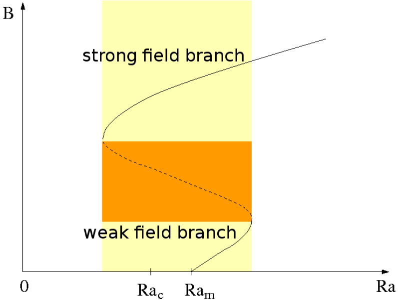
Field strength

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

$$B_{sf} \sim 6 \left(\frac{M_\star}{\mathrm{M}_\odot}\right)^{1/2} \left(\frac{R_\star}{\mathrm{R}_\odot}\right)^{-1} \left(\frac{L_\star}{L_\odot}\right)^{1/6} \left(\frac{\eta_\odot}{10^{11}\ \mathrm{cm^2\,s^{-1}}}\right)^{1/2} \left(\frac{P_{\mathrm{rot}}}{1\ \mathrm{d}}\right)^{-1/2} kG$$

- $B_{sf} \sim 2 - 50$ kG





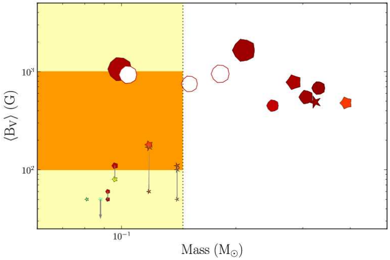
Weak and strong field dynamos: fully-convective stars

Gap between branches

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

Dependence on rotation

- $B_{sf} \propto \Omega^{1/2}$
  - No evidence in our limited sample
  - L_X / B_{bol} weakly affected
  - no relation with super-saturation



Summary and Conclusions

- 2 groups of stars
  - Same stellar parameters
  - Different magnetic topologies
- No distinction in *Bf* measurements

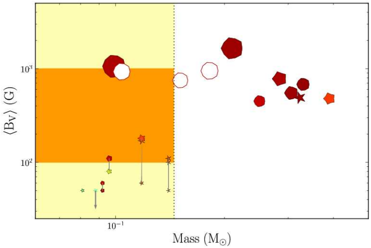
→ Several hypothesis

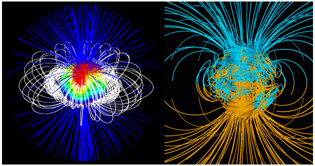
→ WF/SF dynamo bistability

- Field strength: $\Lambda = \mathcal{O}(1)$
- Gap between branches: $Ro^{-1/2}$

- Hysteretic behaviour
- Present **B** depend on history

→ Impact on stellar formation/evolution





Morin, Dormy, Schrinner & Donati
arXiv:1106.4263