

Observations of magnetic topologies across the fully convective threshold

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University of St Andrews

Cool Stars 16 – 1st September 2010



Stellar dynamo

Solar $\alpha\Omega$ dynamo

- Differential rotation
- Cyclonic convection

➔ Tachocline: crucial role ?

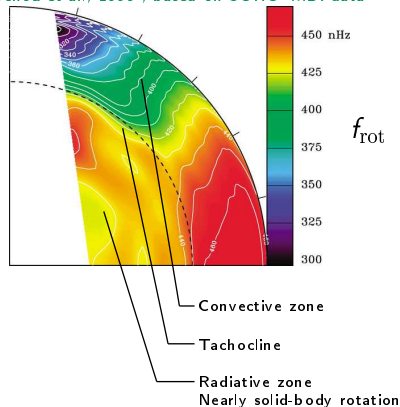
Fully convective: no tachocline

- Very active
- Rotation-activity relation
- Magnetic field

■ Mean field α^2 *Chabrier & Küker (2006)*

■ MHD DNS *Dobler (2006), Browning (2008)*

Schou et al., 1998 ; based on SOHO-MDI data



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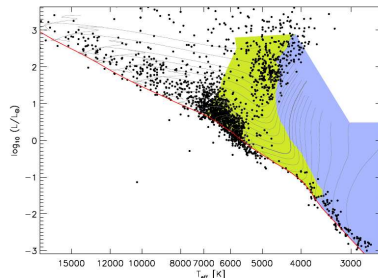
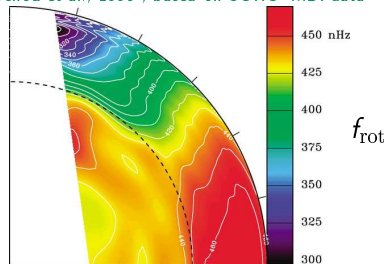
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➔ Generation ?

➔ Properties ?

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Schou et al., 1998 ; based on SOHO-MDI data



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

Spectropolarimetric survey

Techniques

- Spectropolarimetry
- Zeeman-Doppler Imaging
- ESPaDOnS/NARVAL + LSD

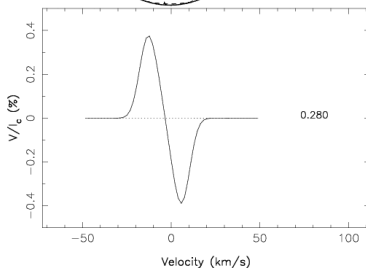
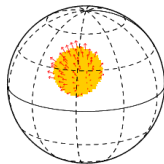
Aims

- Magnetic field
- Stellar parameters
 - Mass / Rotation

Sample

- 23 stars
- $0.08 < M_{\star} < 0.75 M_{\odot}$
- $0.33 < P_{\text{rot}} < 18.6 \text{ d}$
- Active

Vector magnetic field



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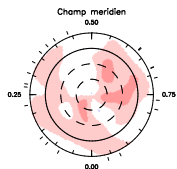
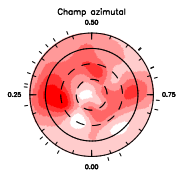
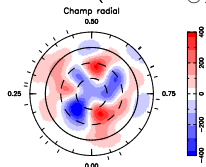
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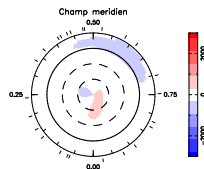
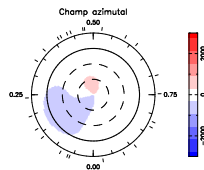
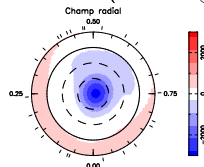
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Results: ZDI reconstructions

DT Vir (0.59 M_⊙)



YZ CMi (0.25 M_⊙)



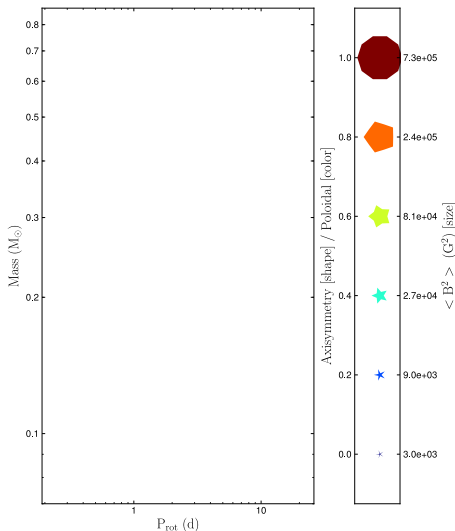
DT Vir

- Partly convective
- Complex B_r
- Azimuthal ring
- $\langle B \rangle = 150$ G
- $B_{\max} = 500$ G
- $d\Omega \gtrsim d\Omega_{\odot}$

YZ CMi

- Fully convective
- Strong B_r polar spot
- Axisymmetric
 - ▶ $\langle B \rangle = 560$ G
 - ▶ $B_{\max} = 2900$ G
- $d\Omega < \frac{d\Omega_{\odot}}{10}$

Results: mass–period diagram



Stellar parameters

- Mass
- Rotation period

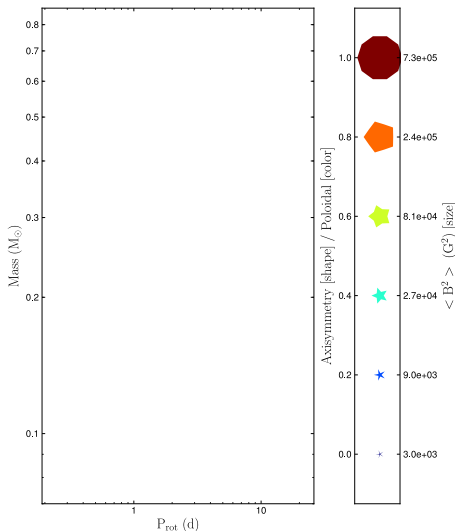
Magnetic topologies

- Magnetic energy
- Poloidal/toroidal
- Axisymmetry

Rossby number

$$Ro = \frac{P_{\text{rot}}}{\tau_{\text{conv}}} = \frac{\text{Inertial forces}}{\text{Coriolis force}}$$

Results: mass–period diagram



Stellar parameters

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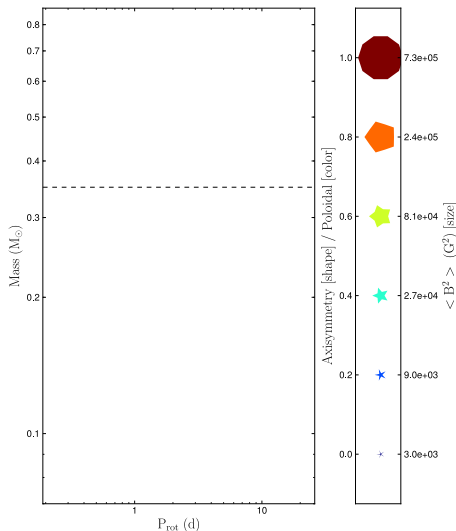
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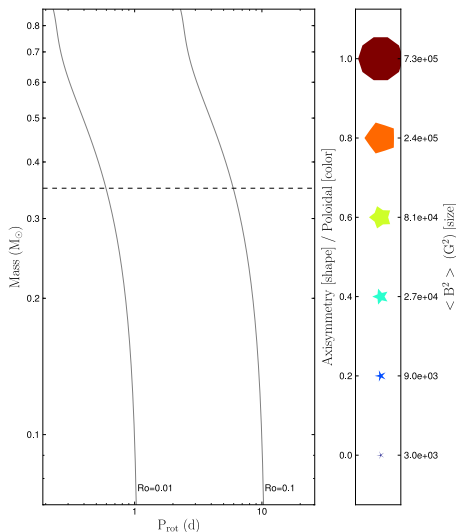
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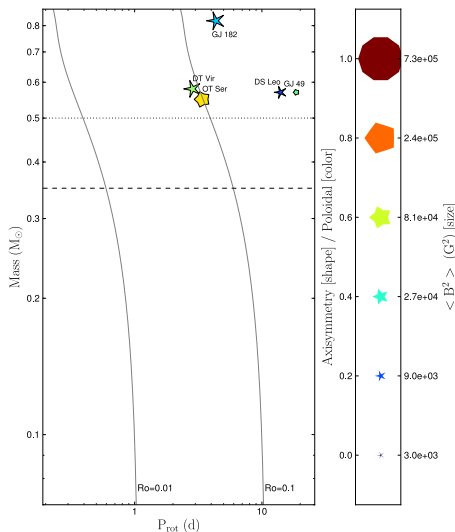
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Results: $M_{\star} > 0.5 M_{\odot}$



Magnetic field

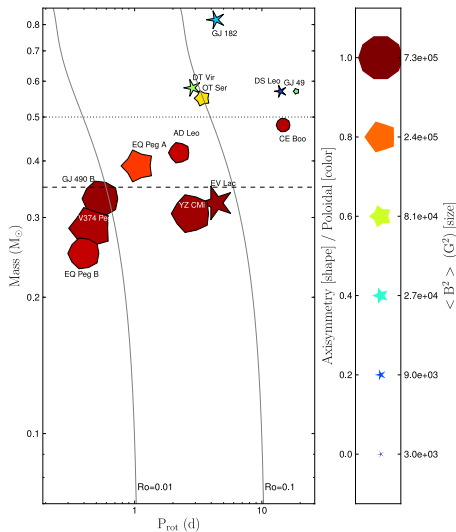
- Toroidal component
 - ▶ Significant or even predominant
- Poloidal component
 - ▶ Non-axisymmetric

Differential rotation

- $d\Omega \gtrsim d\Omega_{\odot}$
- Short-lived magnetic features

Donati et al. (2008)

Results: $0.2 < M_{\star} < 0.5 M_{\odot}$



Magnetic field

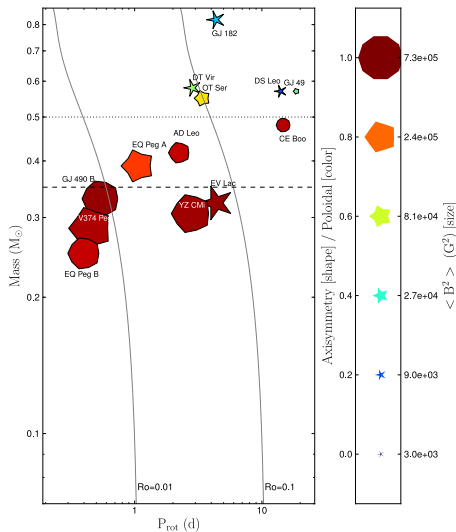
- Poloidal
- Axisymmetric
- Stronger
- \sim Dipole

Differential rotation

- $d\Omega \simeq \frac{d\Omega_{\odot}}{10}$
- Stable magnetic features

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

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Magnetic field

- Poloidal
- Axisymmetric
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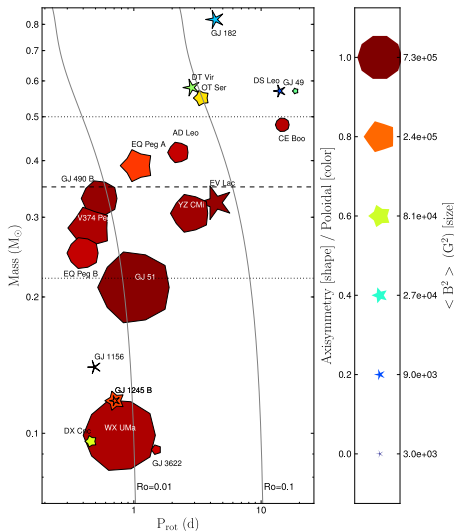
Differential rotation

- $d\Omega \simeq \frac{d\Omega_{\odot}}{10}$
- Stable magnetic features

- ➔ Sharp transition
- ➔ Full-convection boundary
- ➔ Agreement w/ DNS
Browning (2008)

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

Results: $M_{\star} < 0.2 M_{\odot}$



Two distinct groups of stars
Similar stellar parameters

Field similar to stars

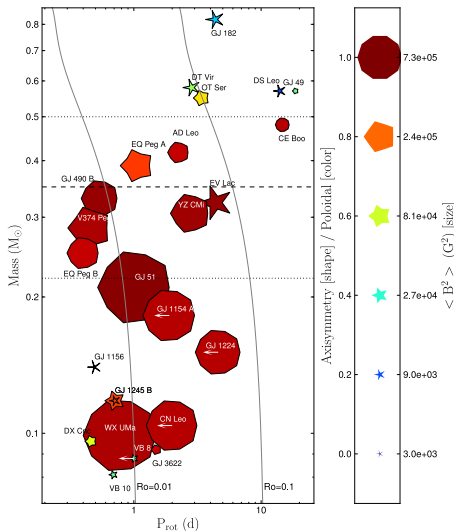
$$0.2 < M_{\star} < 0.5 M_{\odot}$$

\sim strong dipole

Weak field

Non-axisymmetric

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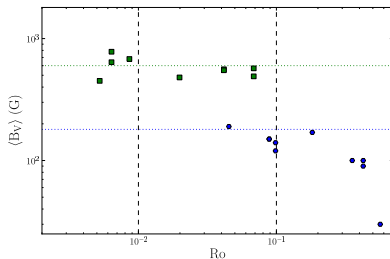
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Weak field
Non-axisymmetric

→ Two possible dynamo modes ?
→ Switch between two states ?

Morin et al.(2010)

Results: rotation influence



Large-scale magnetic flux

■ Boundary at $0.4 M_\odot$

- ▶ $M_\star > 0.4 M_\odot : B_{\text{sat}} \simeq 180 \text{ G}$
- ▶ $M_\star < 0.4 M_\odot : B_{\text{sat}} \simeq 600 \text{ G}$

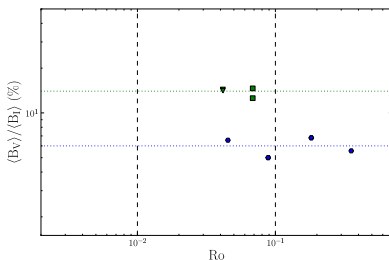
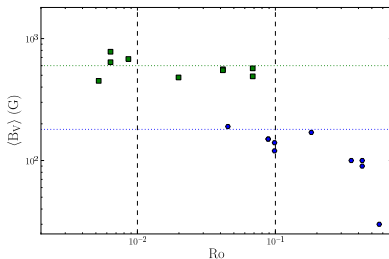
Ratio of total and large-scale magnetic fluxes

■ Unpolarized / molecular lines FeH

▶ *Reiners & Basri, 2007*

- $M_\star > 0.4 M_\odot : \simeq 6\%$
- $0.2 < M_\star < 0.4 M_\odot : \simeq 14\%$

Results: rotation influence



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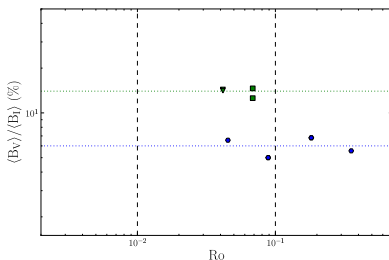
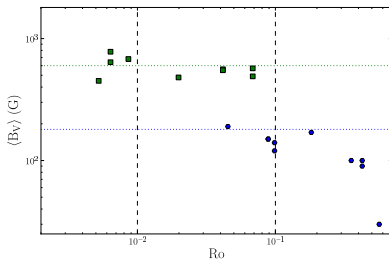
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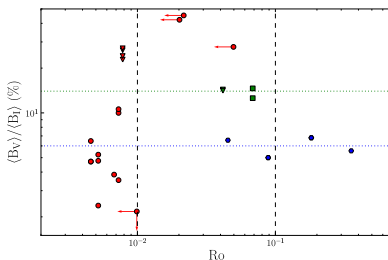
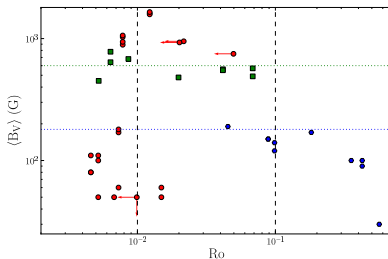
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More efficient at generating
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Donati et al. (2008)

Results: rotation influence



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Donati et al.(2008) Morin et al.(2010)

Summary and conclusions

- Multi-line + New generation instruments ESPaDOnS and NARVAL
- ➔ Study of a sample of M dwarfs on both sides of FCL

Fully convective limit

- Sharp transition
 - Large-scale topology
 - Magnetic energy spectrum
- Partial agreement with DNS

Late M dwarfs

- 2 groups of stars
 - Very different magnetic fields
 - Similar stellar parameters
- Unexpected/unexplained

Connected topics

- Interpret radio observations
- Magnetic fields in cTTS
- Angular momentum evolution

Ongoing and future work

- Long-term monitoring
- Extend survey
- HARPSpol: southern hemisphere
- SPIRou@CFHT: nIR (2015)

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