

Exploring the Magnetic topologies of cool stars: a spectropolarimetric study

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University of St Andrews

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Solar dynamo

Magnetic field

- Key ingredient
- Engine of activity phenomena
- Magnetic cycles

$\alpha\Omega$ Dynamo

- Induced field (MHD)
- Differential rotation
- Cyclonic convection

Solar dynamo

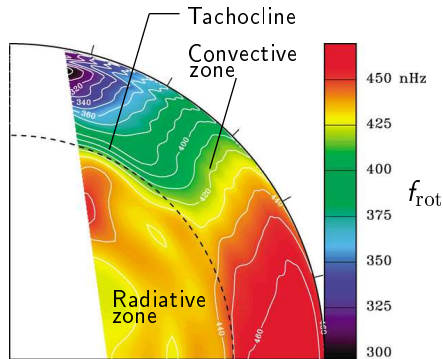
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➔ Tachocline: crucial role ?



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

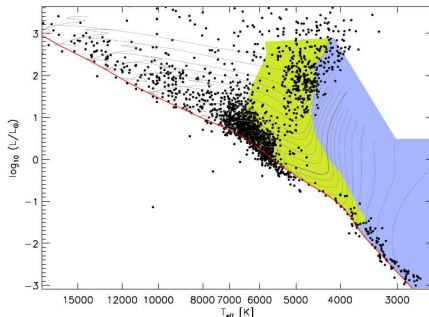
Stellar dynamo

Partly convective: tachocline

- Rotation-activity relation
- Activity cycles
- Internal structure
- ➔ Similar to solar dynamo
- ➔ Differences ?

Fully convective: no tachocline

- Main sequence: $M_{\star} \lesssim 0.35 M_{\odot}$
- Very active
- Rotation-activity relation
- Magnetic field



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

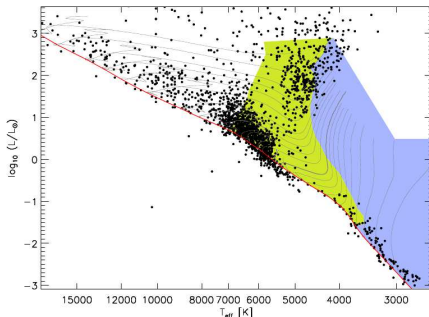
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- ➔ Generation ?
- ➔ Properties ?



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Spectropolarimetry and Zeeman-Doppler Imaging

Zeeman Effect

- Line broadening (I)
- Polarised signatures (Q,U,V)
 - ➔ Geometry/Large-scale component

ZDI principles

- Doppler effect
- Rotational modulation
 - ▶ Surface map of vector **B**

Magnetic field description

- SH + Poloidal/Toroidal
 - ▶ Physically meaningful
 - ▶ Global topologies
- Differential rotation

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Spectropolarimetric Survey

- Multi-line + New generation instruments ESPaDOnS and NARVAL
- ➔ Systematic study of H-R diagram

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

Solar twins

- 4 stars
- $M_{\star} = 1 M_{\odot}$
- $8.8 < P_{\text{rot}} < 22.7 \text{ d}$
- Weakly/moderately active

M dwarfs

- 23 stars
- $0.08 < M_{\star} < 0.75 M_{\odot}$
- $0.33 < P_{\text{rot}} < 18.6 \text{ d}$
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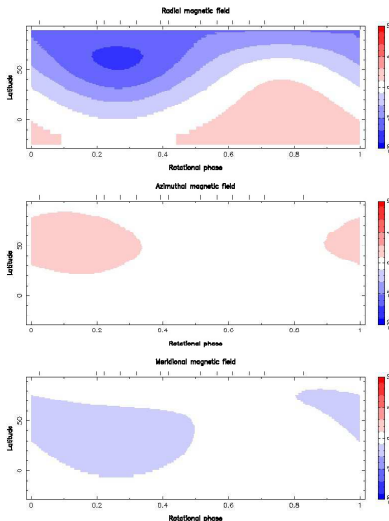
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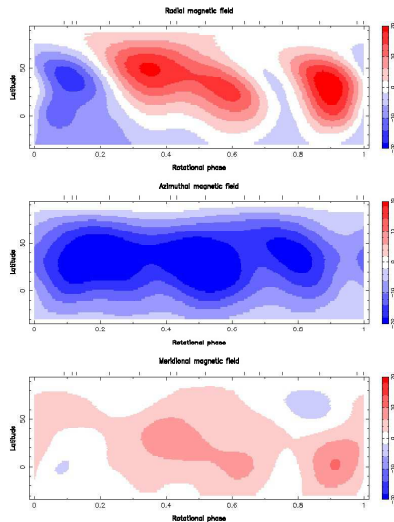
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Solar twins: ZDI reconstructions

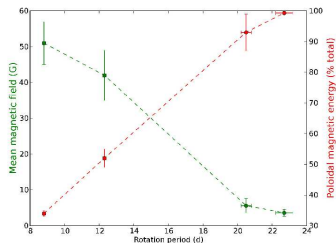
HD 76151 ($P_{\text{rot}}=20.5$ d)



HD 190771 ($P_{\text{rot}}=8.8$ d)



Solar twins: rotation influence $P_{\text{rot}}=23 \Rightarrow 9 \text{ d}$

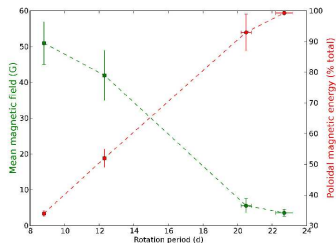


- **B** growth: factor 120
 - ▶ poloidal: factor 40
 - ▶ toroidal: factor 10^4
- Transition between $P_{\text{rot}}=20 \text{ d}$ and 12 d
- Toroidal belts, similar to:
 - ▶ Obs of very active stars *Donati (1992)*
 - ▶ Numerical simulations *Brown (2010)*

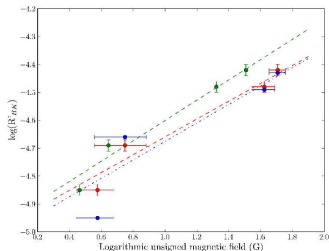
- Power-law $R'_{HK}(B_V)$
 - ▶ discrepancy w/ solar relation
- $B_V \leftrightarrow$ large-scale magnetic flux
- Solar relation \leftrightarrow overall flux
 - ▶ Rapid rotators \rightarrow larger-scale field

Petit et al.(2008)

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Solar twins: long-term magnetic variability

■ Cycles identified in Ca II

Baliunas et al.(1995)

► Topology evolution ?

➡ B_ϕ polarity reversal of HD 190771

■ τ Boo:

F7, $M_\star = 1.3 M_\odot$, $P_{\text{rot}} = 3.3$ d

➡ 2 reversals in 2 years

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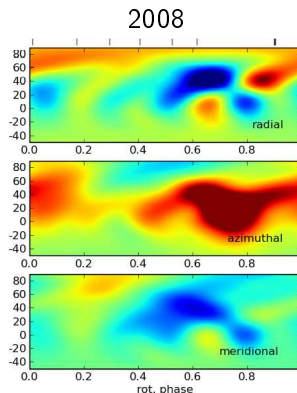
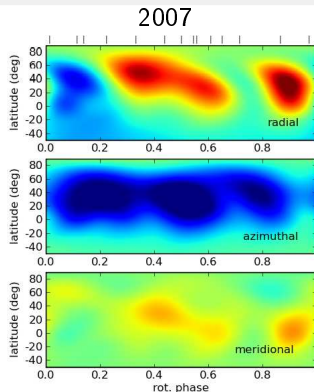
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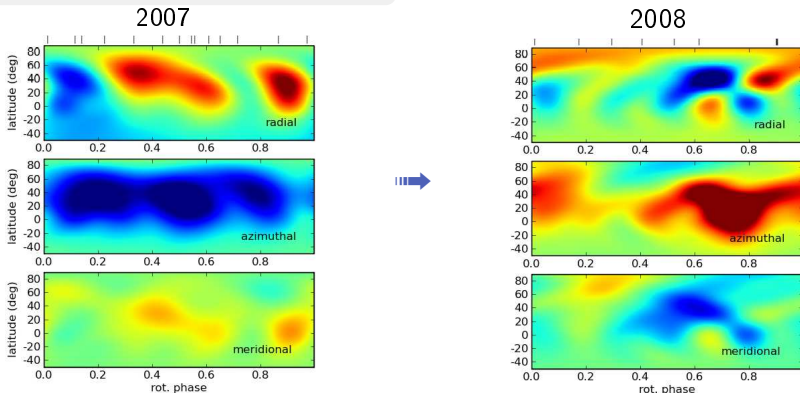
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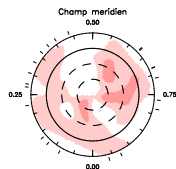
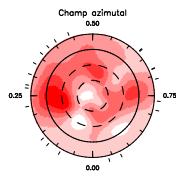
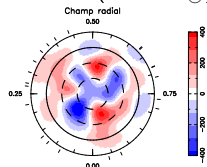
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Fares et al. (2009)

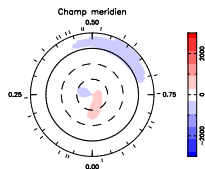
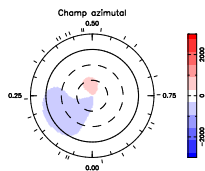
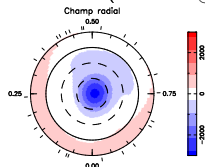


M dwarfs: ZDI reconstructions

DT Vir (0.59 M_{\odot})



YZ CMi (0.25 M_{\odot})



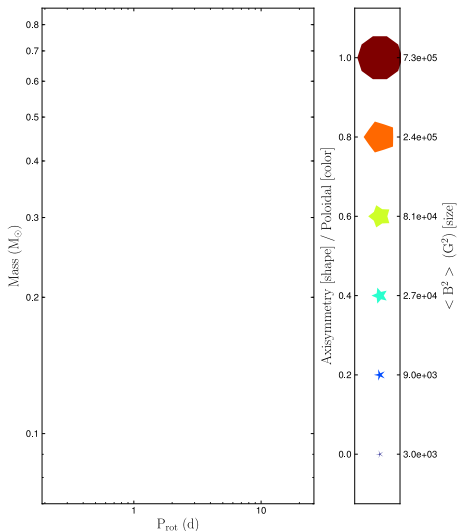
DT Vir

- 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
- $d\Omega < \frac{d\Omega_{\odot}}{10}$

M dwarfs: mass–period diagram



Stellar parameters

- Mass
- Rotation period

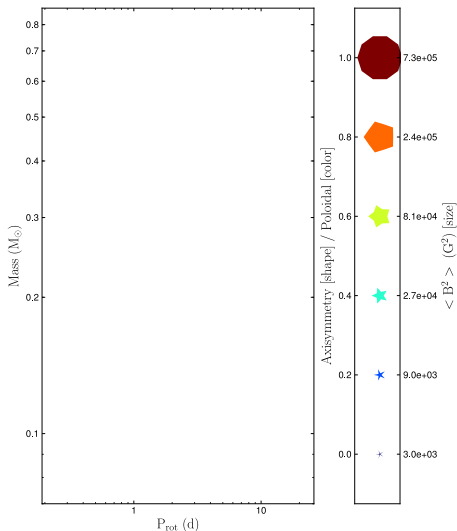
Magnetic topologies

- Magnetic energy
- Poloidal/toroidal
- Axisymmetry

Rossby number

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

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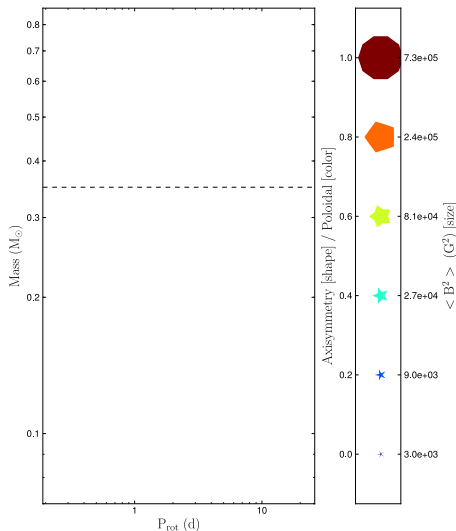
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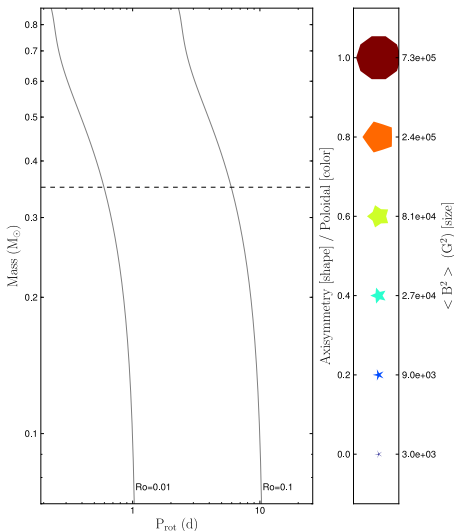
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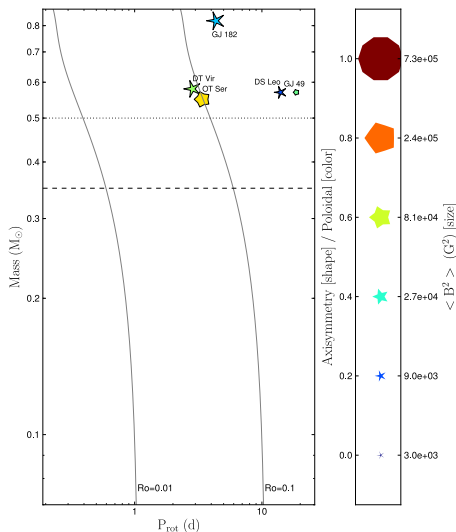
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M dwarfs: $M_{\star} > 0.5 M_{\odot}$



Magnetic field

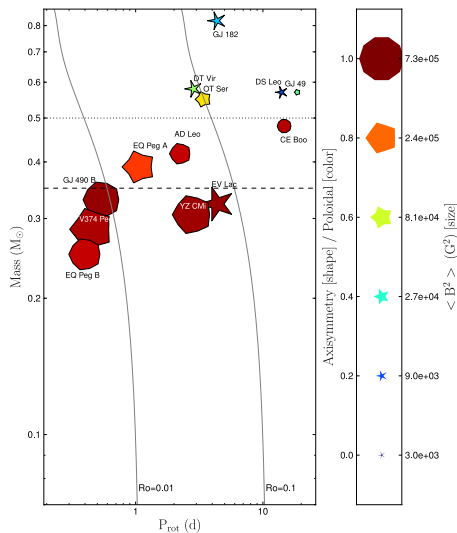
- Toroidal component
 - ▶ Significant or even predominant
- Poloidal component
 - ▶ Non-axisymmetric

Differential rotation

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

Donati et al. (2008)

M dwarfs: $0.2 < M_{\star} < 0.5 M_{\odot}$



Magnetic field

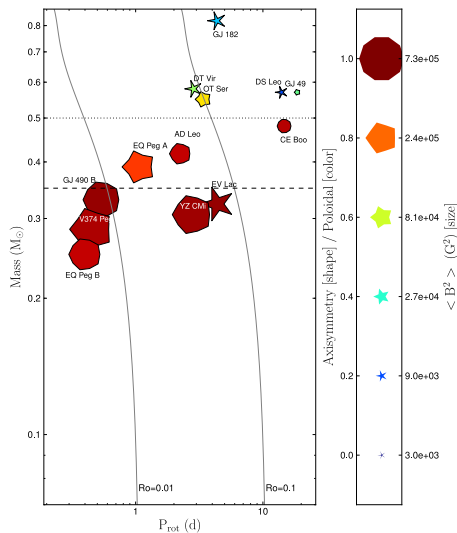
- Poloidal
- Axisymmetric
- Stronger
- \sim Dipole

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
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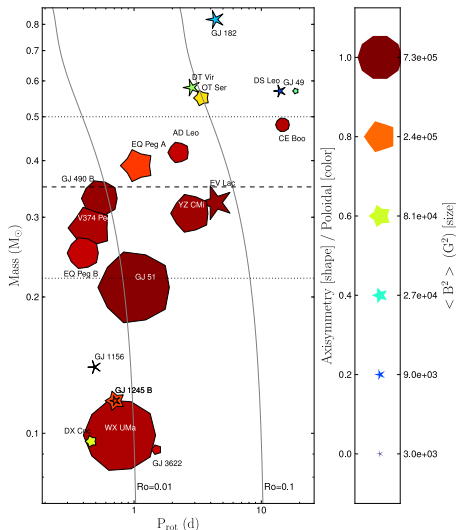
Differential rotation

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

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

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

M dwarfs: $M_{\star} < 0.2 M_{\odot}$

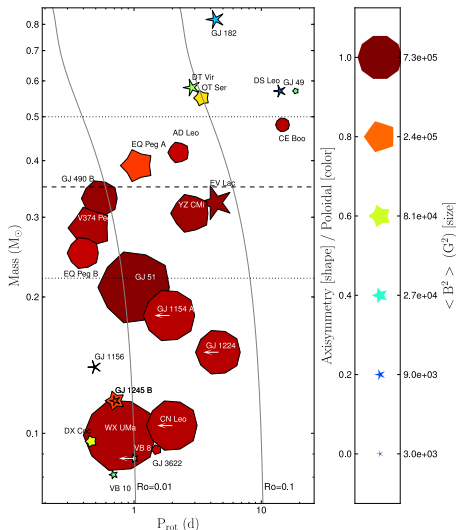


Two distinct groups of stars
Similar stellar parameters

- Field similar to stars
 $0.2 < M_{\star} < 0.5 M_{\odot}$
- \sim strong dipole

- Weak field
- Non-axisymmetric

M dwarfs: $M_{\star} < 0.2 M_{\odot}$



Two distinct groups of stars
Similar stellar parameters

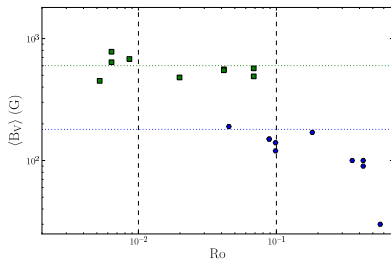
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- Weak field
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- Two possible dynamo modes ?
- Switch between two states ?

Morin et al. (2010)

M dwarfs: rotation influence



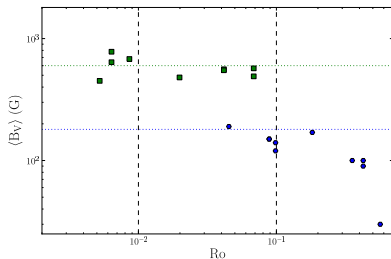
Large-scale magnetic flux

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

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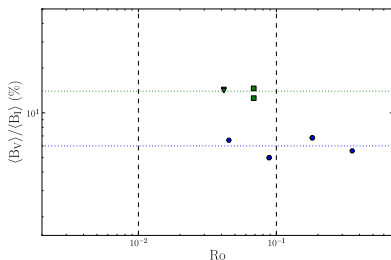


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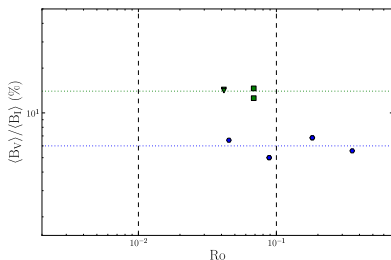
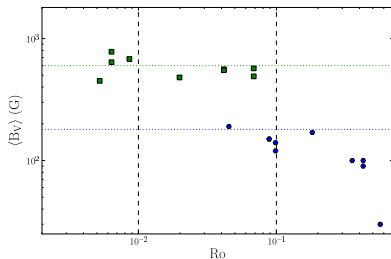
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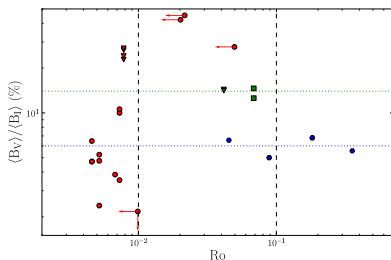
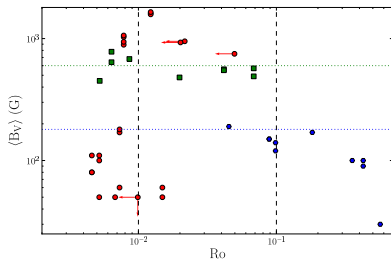
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More efficient at generating
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Donati et al. (2008)

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

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- ➔ Systematic study of H-R diagram

Solar twins

- Dipole ➔ azimuthal ring
 - ➔ Rotation threshold
- B_ϕ polarity reversal

M dwarfs

- Sharp transition close to FC boundary
 - ➔ Large-scale topology
 - ➔ Magnetic energy spectrum
- 2 groups of late M dwarfs

Other projects

- Star-planet interaction
- Young stars ➔ cTTS
- Giant stars

Ongoing and future work

- Long-term monitoring of 17 F to M ★
- Extend surveys
- Spectropolarimetric database
- HARPSpol: southern hemisphere
- SPIRou@CFHT: nIR (2015)

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