Differential rotation in very-low-mass stars: a clue to dynamo bistability?

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MPS

Differential Rotation and Magnetism across the HR Diagram
Nordita, Stockholm
8th April 2013
1. Studying magnetic fields of M dwarfs
2. Magnetic fields of very-low-mass stars
3. Dynamo bistability
Outline

1. Studying magnetic fields of M dwarfs
   - Fully-convective vs solar dynamo
   - Dynamos of stars and planets
   - Magnetic field measurements in unpolarized light
   - Magnetic field measurements with spectropolarimetry

2. Magnetic fields of very-low-mass stars

3. Dynamo bistability
Fully-convective vs solar dynamo

Adapted from Reiners (2007)

M dwarfs
Fully-convective vs solar dynamo

Adapted from Reiners (2007)
Fully-convective vs solar dynamo

Adapted from Reiners (2007)

Schou et al. (1998)

M dwarfs
DYNAMOS OF STARS AND PLANETS

Goudard & Dormy (2008)
Dynamos of stars and planets

Christensen, Holzwarth & Reiners (2009)
Magnetic fields measurements in unpolarized light

- Zeeman effect
- Measure “magnetic flux”
  - Atomic lines
    - *Saar (1988)*
    - *Johns-Krull & Valenti (1996)*
  - Molecular lines
    - *Reiners & Basri (2007+)*
    - *Shulyak et al. (2010)*

→ Single Ro-Bf relation for partly- and fully-convective stars (SpT < M6)
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- Single Ro-Bf relation for partly- and fully-convective stars (SpT<M6)

Reiners, Basri & Browning (2009)
B measurements with spectropolarimetry

- Zeeman effect
- Field orientation + polarity
- Large-scale field only
  - Zeeman-Doppler Imaging
  - Semel (1989)
- Efficient instruments
- Multi-line techniques
  - M dwarfs within reach!

→ Sharp transition large-scale B
  - strong axial dipolar component
  - weak differential rotation

→ $\langle B_V \rangle / \langle B_I \rangle$ increases
  - Reiners & Basri (2009)
  - Morin et al. (2010)
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- \( \nu \sin i = 1 \ km \ s^{-1} \)

\[ \begin{align*}
\text{Julien Morin} & \quad \text{DR and dynamo bistability in very-low-mass stars} \\
08/04/2013 & \quad 7 / 17
\end{align*} \]
B measurements with spectropolarimetry

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$v \sin i = 10 \text{ km s}^{-1}$
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$\nu \sin i = 20 \, \text{km s}^{-1}$

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*Morin, Donati et al. (2008+)*
*Phan-Bao et al. (2009)*

*Reiners & Basri (2009)*
*Morin et al. (2010)*
Outline

1. Studying magnetic fields of M dwarfs

2. Magnetic fields of very-low-mass stars
   - B of VLMS from spectropolarimetry
   - Scenarios for the magnetism of VLMS

3. Dynamo bistability
11 fully-convective stars
- M5-M8 – $M_\star < 0.22\, M_\odot$
- $P_{\text{rot}} < 4.3\, \text{d} – \text{Ro} \sim 10^{-2}$
- Similar stellar parameters
- Two distinct magnetisms
  - Strong aligned dipole, long-lived
  - Weaker multipolar field, evolving

Morin et al. (2010)
B of VLMS from spectropolarimetry

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Only large-scale field affected?

Morin et al. (2010)
Scenarios for the magnetism of VLMS

- Cyclic change SD ↔ WM?
  - up to 3 yr time-series
  - ∃ variability
  - No such change observed

- An effect of age?
  - WM younger
  - SD older
  - Phenomenology?

- Another "hidden" parameter?

- Dynamo bistability
  - Two distinct solutions for one set of parameters
  - Depend on initial conditions
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   - Weak and strong field dynamos
   - Low $R_o\ell$ transition in DNS
Weak and strong field dynamos

Large-scale dynamo bistability
- Similar Bf on both branches

Field strength
- Strong field branch
  - Coriolis–Lorentz force balance
  - \[ \Lambda = \frac{B^2}{\rho \mu \eta \Omega} = \mathcal{O}(1) \]
  - \( B_{sf} \sim 2 - 50 \) kG

Gap between branches
- Lorentz-inertia
  - Lorentz-Coriolis balance
  - \( \frac{B_{sf}}{B_{wf}} = Ro^{-1/2} \sim 10 \)
- Not yet observed in DNS
- V. Morin & Dormy (2009)

Adapted from Roberts (1978)

Morin, Dormy, Schrinner & Donati (2011)
Low $Ro_\ell$ transition in DNS

- **Christensen & Aubert (2006)**
  - Boussinesq simulations
  - Inertia-Coriolis balance:
    \[ Ro_\ell = \frac{Ro_{\hat{\ell} u}}{\pi} \]
  - Low $Ro \Rightarrow$ dipolar

- **Schrinner et al. (2012)**
  - Stress-free boundary conditions

- **Simone & Christensen (2005)**
  - Bistability at low Ro dip vs multipolar depending on IC

- **Gastine et al. (2012)**
  - Similar results in anelastic
  - For moderate stratification

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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
  - $R\ell$ <-> empirical $Ro$ ?
  - Can we find multipolar fields
    - $M_* > 0.15 \, M_\odot$ ?
    - $Ro > 0.02$ ?
  - Outlier

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Gastine, Morin et al. (2013)
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- Larger survey of active M dwarfs
Anelastic simulations vs observations (2/2)

DR plays a key role in dynamo on the multipolar branch

Schrinner, Petitdemange & Dormy (2012)

Clue to assess parallel observations/numerical models?

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Anelastic simulations vs observations (2/2)

V374 Peg

\[ \frac{\Delta \Omega}{\Omega} \approx 0.04\% \]

(a)

(b)

GJ 1245 B

Dipolar branch

Multipolar branch

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Clue to assess parallel observations/numerical models?
Observations of DR in VLMS

- CO band at 2.3 $\mu$m
  - Landé factors $\sim 0$
  - Several 10s deep lines
  - Low spot-to-photosphere contrast

- CRIRES observations
  - $R=10^5$
  - $\sim$ Full CO band
  - Deconvolve rotation profile
  - Use ratio zeros FT

PHOENIX models, S. Wende
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    - $\sim 10$ dMe w/ moderate $v \sin i$
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
  - \( \mathcal{R}_\ell \) drives \( \mathbf{B} \) geometry
  - Bistable domain
  - Interplay DR ↔ \( \mathcal{B} \)

→ More to come!

CFHT 2013 observations
Summary and conclusions

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