Magnetism in M dwarfs
observational results and prospects

Julien Morin

Institut für Astrophysik Göttingen

Bcool meeting
IRAP Toulouse 6–8th December 2011

Institut für Astrophysik Göttingen

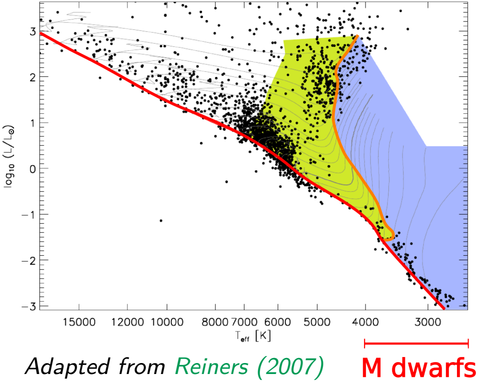
Unterstützt von / Supported by
Alexander von Humboldt Stiftung/Foundation

Outline

1. Studying magnetic fields of M dwarfs
2. Direct methods for magnetic field measurements
3. The first spectropolarimetric survey of M dwarfs
4. What's next for M dwarfs magnetism ?

Outline

Fully-convective vs solar dynamo



Adapted from Reiners (2007)

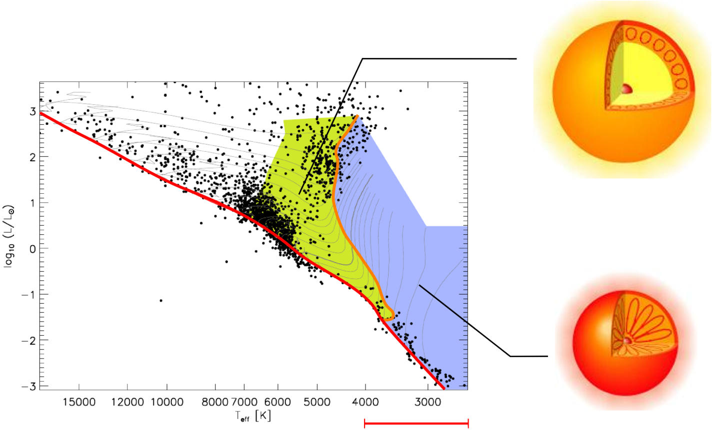
Solar-type dynamo

- $\alpha\Omega$: cyclonic convection + $d\Omega$
- Crucial role of the tachocline ?

M dwarf dynamo

- Importance of aspect ratio ?
- Differential rotation ? α^2 ?

Fully-convective vs solar dynamo



Adapted from Reiners (2007)

M dwarfs

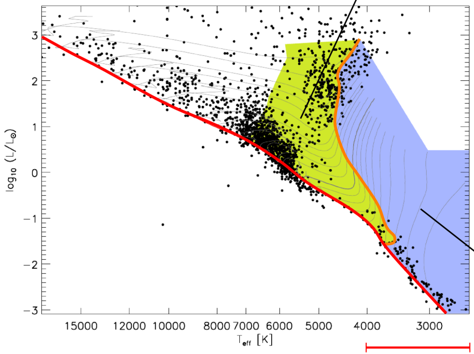
Solar-type dynamo

- $\alpha\Omega$: cyclonic convection + $d\Omega$
- Crucial role of the tachocline ?

M dwarf dynamo

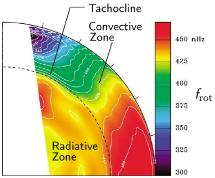
- Importance of aspect ratio ?
- Differential rotation ? α^2 ?

Fully-convective vs solar dynamo



Adapted from *Reiners (2007)*

M dwarfs



Schou et al. (1998)

Solar-type dynamo

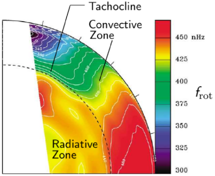
- $\alpha\Omega$: cyclonic convection + $d\Omega$
- Crucial role of the tachocline ?

M dwarf dynamo

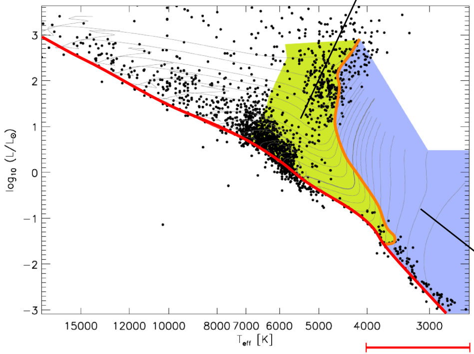
- Importance of aspect ratio ?
- Differential rotation ? α^2 ?

Fully-convective vs solar dynamo

→ Boris Dintrans' talk



Schou et al. (1998)



Adapted from Reiners (2007)

M dwarfs

Solar-type dynamo

- $\alpha\Omega$: cyclonic convection + $d\Omega$
- Crucial role of the tachocline ?

M dwarf dynamo

- Importance of aspect ratio ?
- Differential rotation ? α^2 ?

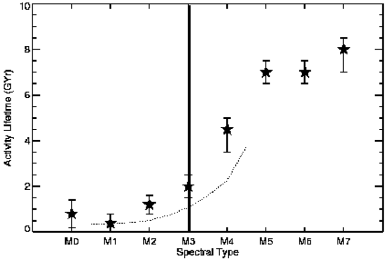
What magnetic fields may help us to understand ?

- Rotation

→ Jerome Bouvier's talk
  - Winds on MS
  - Why mid-late M dwarfs brake less ?
  - *Reiners & Mohanty (2011)* ?

- Activity
  - FC dynamo → activity ?
  - Radio – X-ray correlation down to ∼M7
  - Radio emission of VLMS and BDs

- Planets
  - SPI → Rim Fares' talk
  - Habitability
  - Prevents detection ?



West et al. (2008)

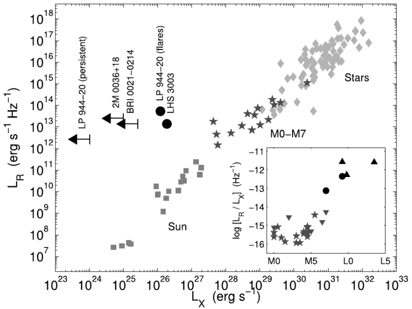
What magnetic fields may help us to understand ?

- Rotation

➔ Jerome Bouvier's talk
  - Winds on MS
  - Why mid-late M dwarfs brake less ?
  - *Reiners & Mohanty (2011)* ?

- Activity
  - FC dynamo ➔ activity ?
  - Radio – X-ray correlation down to ∼M7
  - Radio emission of VLMS and BDs

- Planets
  - SPI ➔ Rim Fares' talk
  - Habitability
  - Prevents detection ?



Berger (2006)

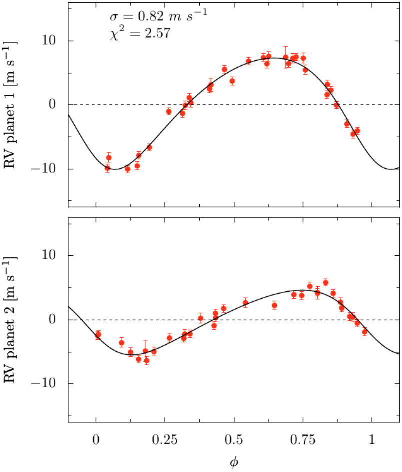
What magnetic fields may help us to understand ?

- Rotation

➔ Jerome Bouvier's talk
  - Winds on MS
  - Why mid-late M dwarfs brake less ?
  - *Reiners & Mohanty (2011)* ?

- Activity
  - FC dynamo ➔ activity ?
  - Radio – X-ray correlation down to ∼M7
  - Radio emission of VLMS and BDs

- Planets
  - SPI ➔ Rim Fares' talk
  - Habitability
  - Prevents detection ?

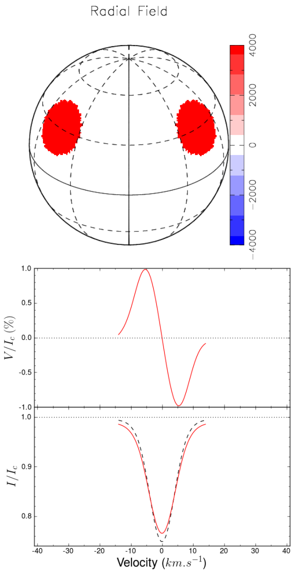


GJ 674 *Bonfils et al. (2007)*

Outline

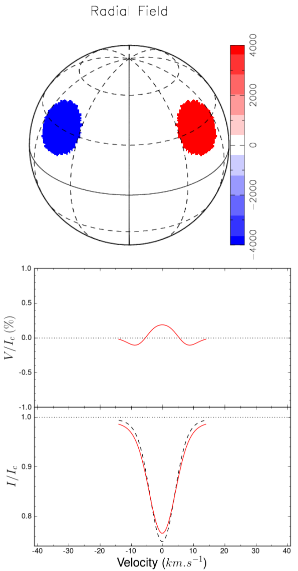
Disk-integrated stellar measurements

- Unpolarised spectrum
  - Total magnetic flux*
  - But almost no information on field geometry
  - ➥ Dynamo energetics
- Polarized spectrum
  - Large-scale component
  - Contains info on **B**
  - ➥ ZDI ➔ topology



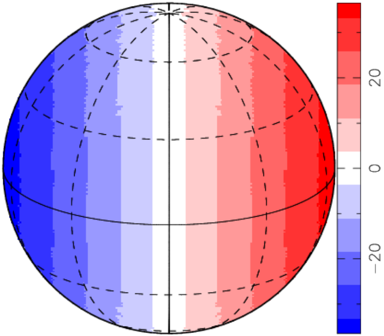
Disk-integrated stellar measurements

- **Unpolarised spectrum**
  - Total magnetic flux*
  - But almost no information on field geometry
  - ➥ Dynamo energetics
- **Polarized spectrum**
  - Large-scale component
  - Contains info on **B**
  - ➥ ZDI ➔ topology



Disk-integrated stellar measurements

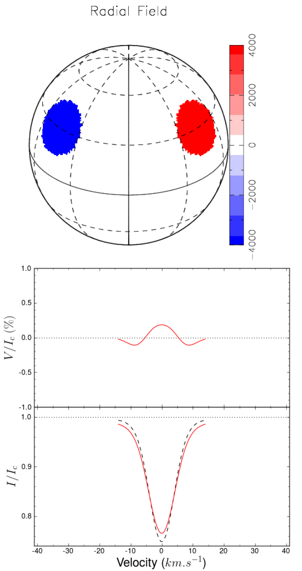
- Unpolarised spectrum
  - Total magnetic flux*
  - But almost no information on field geometry
  - ➥ Dynamo energetics
- Polarized spectrum
  - Large-scale component
  - Contains info on **B**
  - ➥ ZDI ➔ topology



Equal RV stripes

Disk-integrated stellar measurements

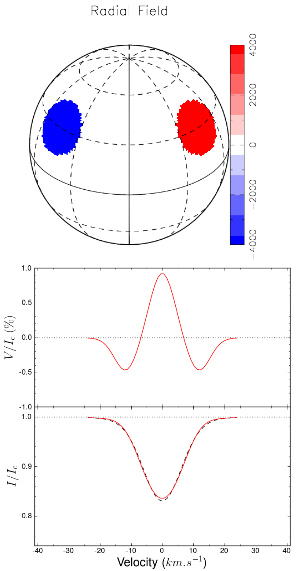
- **Unpolarised spectrum**
  - Total magnetic flux*
  - But almost no information on field geometry
  - ➥ Dynamo energetics
- **Polarized spectrum**
  - Large-scale component
  - Contains info on **B**
  - ➥ ZDI ➔ topology



$v \sin i = 1\ km\,s^{-1}$

Disk-integrated stellar measurements

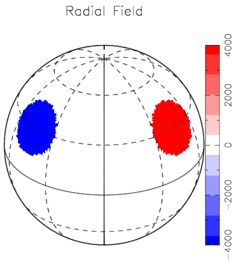
- **Unpolarised spectrum**
  - Total magnetic flux*
  - But almost no information on field geometry
  - ➥ Dynamo energetics
- **Polarized spectrum**
  - Large-scale component
  - Contains info on **B**
  - ➥ ZDI → topology

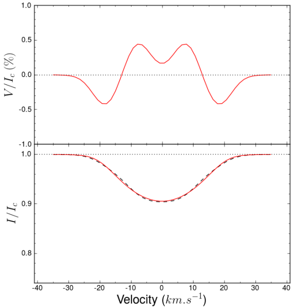


$v \sin i = 10\ km\, s^{-1}$

Disk-integrated stellar measurements

- Unpolarised spectrum
  - Total magnetic flux*
  - But almost no information on field geometry
  - ➥ Dynamo energetics
- Polarized spectrum
  - Large-scale component
  - Contains info on **B**
  - ➥ ZDI ➔ topology





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

Outline

The survey

- Multi-line + New generation instruments ESPaDOnS and NARVAL

➥ Systematic study of H-R diagram including M dwarfs

- 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

- M dwarfs
  - 23 stars
  - $0.08 < M_\star < 0.75\ \mathrm{M}_\odot$
  - $0.33 < P_\mathrm{rot} < 18.6\ \mathrm{d}$
  - Active

Examples of ZDI reconstructions

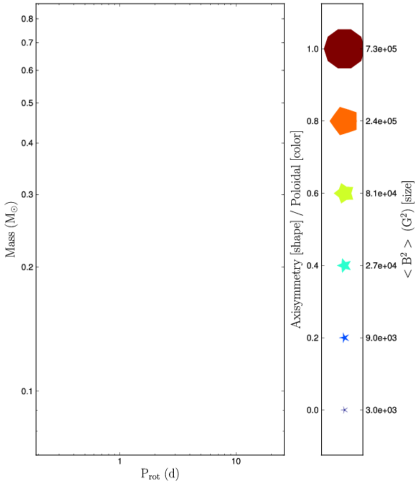
DT Vir (0.59 $M_\odot$)

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

EQ Peg B (0.25 $M_\odot$)

- Fully convective
- Strong B_r polar spot
- Axisymmetric
  - $\langle B \rangle = 450$ G
  - $B_{\max} = 1200$ G
- no hint of DR

Mass–period diagram



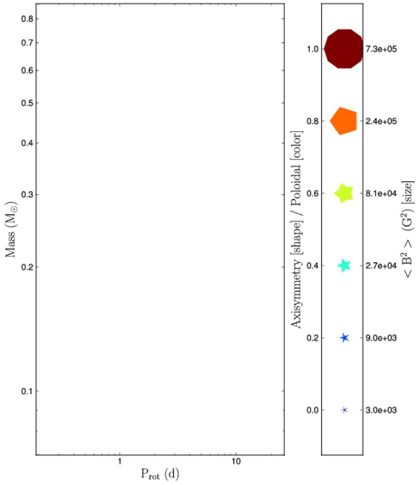
Stellar parameters

- Mass
- Rotation period

Magnetic topologies

- Magnetic energy
- Poloidal/toroidal
- Axisymmetry

Mass–period diagram



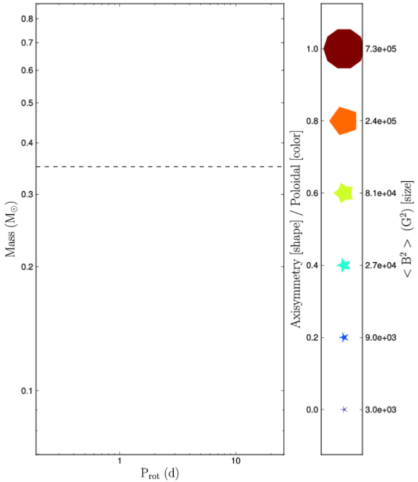
Stellar parameters

- Mass
- Rotation period

Magnetic topologies

- Magnetic energy
- Poloidal/toroidal
- Axisymmetry

Mass–period diagram



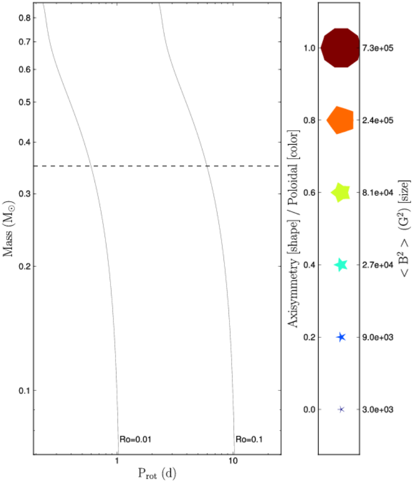
Stellar parameters

- Mass
- Rotation period

Magnetic topologies

- Magnetic energy
- Poloidal/toroidal
- Axisymmetry

Mass–period diagram



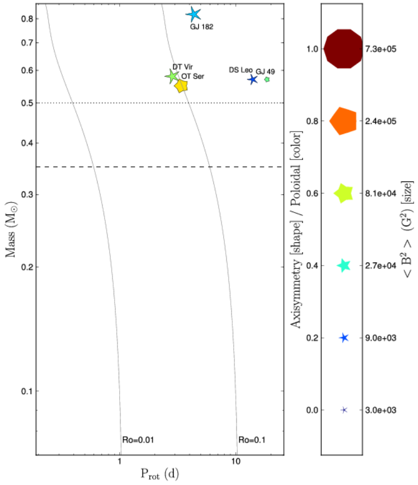
Stellar parameters

- Mass
- Rotation period

Magnetic topologies

- Magnetic energy
- Poloidal/toroidal
- Axisymmetry

Mass-period diagram: $M_\star > 0.5\ \mathrm{M}_\odot$



Magnetic field

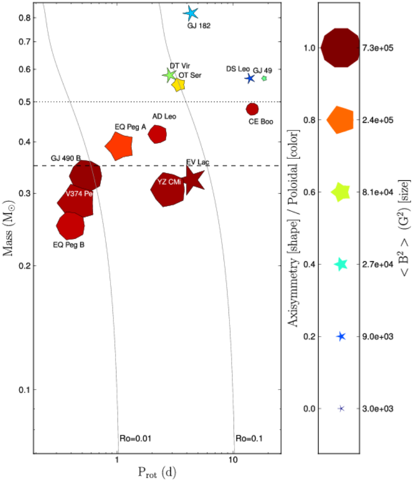
- Toroidal component
  - Significant or even predominant
- Poloidal component
  - Non-axisymmetric

Differential rotation

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

Donati et al.(2008)

Mass-period diagram: $0.2 < M_\star < 0.5\ \mathrm{M}_\odot$



Magnetic field

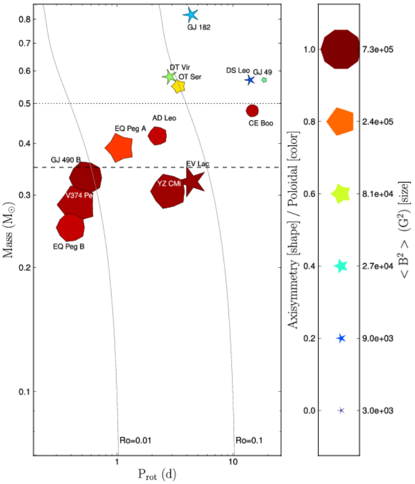
- Poloidal
- Axisymmetric
- Stronger
- ➥ ∼ Dipole

Differential rotation

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

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

Mass-period diagram: $0.2 < M_\star < 0.5\ \mathrm{M}_\odot$



Magnetic field

- Poloidal
- Axisymmetric
- Stronger
- ➥ ∼ Dipole

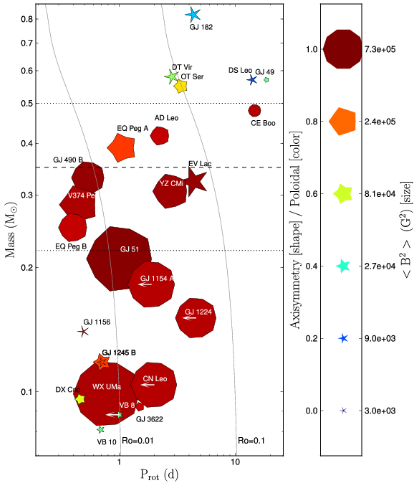
Differential rotation

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

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

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

Mass-period diagram: $M_\star < 0.2\ \mathrm{M}_\odot$



Two distinct groups of stars
Similar stellar parameters

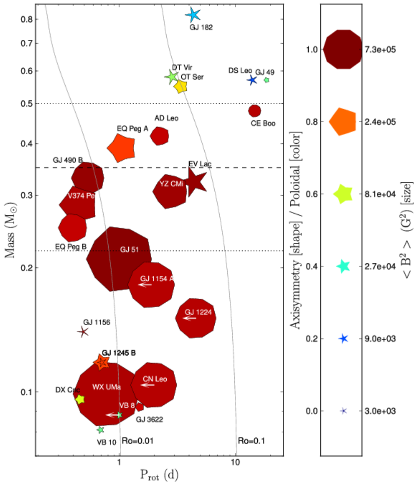
- Field similar to stars

  $0.2 < M_\star < 0.5\ \mathrm{M}_\odot$
- $\sim$ strong dipole

- Weak field
- Non-axisymmetric

Morin et al.(2010)

Mass-period diagram: $M_\star < 0.2\ \mathrm{M}_\odot$



Two distinct groups of stars
Similar stellar parameters

- Field similar to stars

  $0.2 < M_\star < 0.5\ \mathrm{M}_\odot$

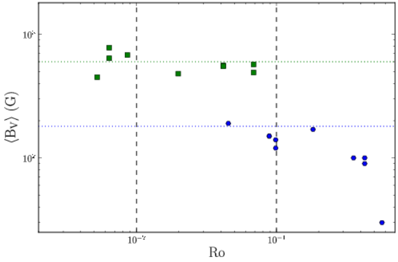
- $\sim$ strong dipole

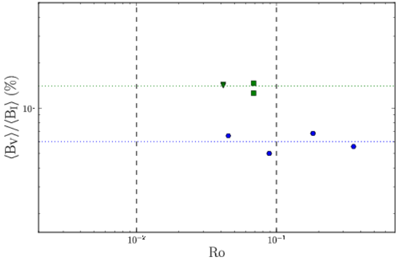
- Weak field
- Non-axisymmetric

➔ Two possible dynamo modes ?
➔ Switch between two states ?
➔ Influence of age ?

Morin et al.(2010)

Rotation–magnetic field relation





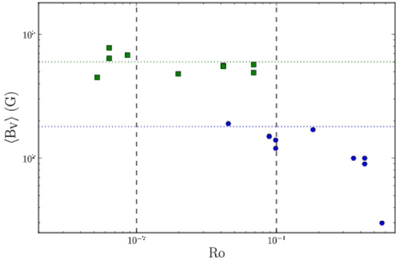
Large-scale magnetic flux

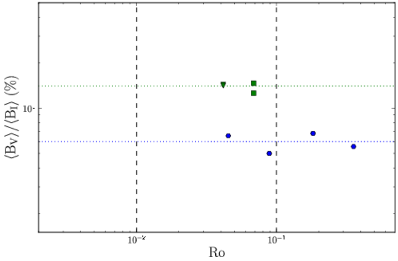
- Boundary at 0.4 $\mathrm{M}_\odot$
  - $M_\star > 0.4\ \mathrm{M}_\odot$: $B_{\mathrm{sat}} \simeq 180$ G
  - $M_\star < 0.4\ \mathrm{M}_\odot$: $B_{\mathrm{sat}} \simeq 600$ G

Ratio of total and large-scale magnetic fluxes

- Unpolarized / molecular lines FeH
- $M_\star > 0.4\ \mathrm{M}_\odot$: $\simeq 6\%$
- $0.2 < M_\star < 0.4\ \mathrm{M}_\odot$: $\simeq 14\%$

Rotation–magnetic field relation





Large-scale magnetic flux

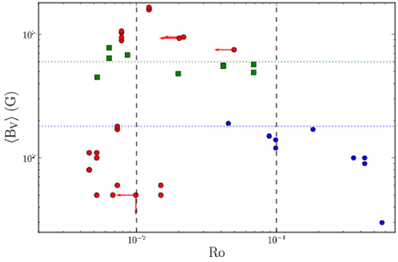
- Boundary at 0.4 $\mathrm{M}_\odot$
  - $M_\star > 0.4\ \mathrm{M}_\odot$: $B_{\rm sat} \simeq 180$ G
  - $M_\star < 0.4\ \mathrm{M}_\odot$: $B_{\rm sat} \simeq 600$ G

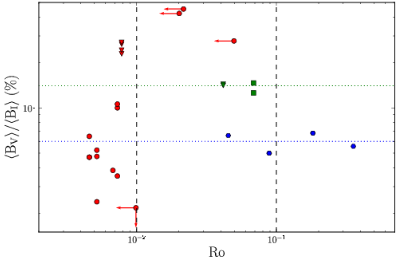
Ratio of total and large-scale magnetic fluxes

- Unpolarized / molecular lines FeH
- $M_\star > 0.4\ \mathrm{M}_\odot$: $\simeq 6\%$
- $0.2 < M_\star < 0.4\ \mathrm{M}_\odot$: $\simeq 14\%$

More efficient at generating large-scale magnetic field

Rotation–magnetic field relation





Large-scale magnetic flux

- Boundary at 0.4 $\mathrm{M}_\odot$
  - $M_\star > 0.4\ \mathrm{M}_\odot\ :\ B_{\mathrm{sat}} \simeq 180\ \mathrm{G}$
  - $M_\star < 0.4\ \mathrm{M}_\odot\ :\ B_{\mathrm{sat}} \simeq 600\ \mathrm{G}$

Ratio of total and large-scale magnetic fluxes

- Unpolarized / molecular lines FeH
- $M_\star > 0.4\ \mathrm{M}_\odot\ :\ \simeq 6\%$
- $0.2 < M_\star < 0.4\ \mathrm{M}_\odot\ :\ \simeq 14\%$

Weak vs strong field dynamo bistability ?

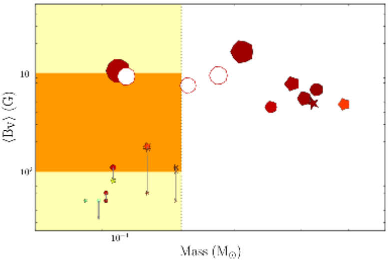
Morin, Dormy, Schrinner & Donati (2011)

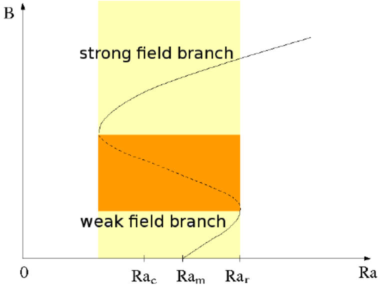
The idea

- Simultenous Ω and **B**
- Reduced inhibition of convection
- SF $\Leftrightarrow$ Magnetostrophic regime

Application to VLMS

- Strong field branch
  - Coriolis–Lorentz force balance
  - $B_{sf} \sim 2 - 50\ \mathrm{kG}$
- Gap between branches
  - $\frac{B_{sf}}{B_{wf}} = Ro^{-1/2} \sim 10$

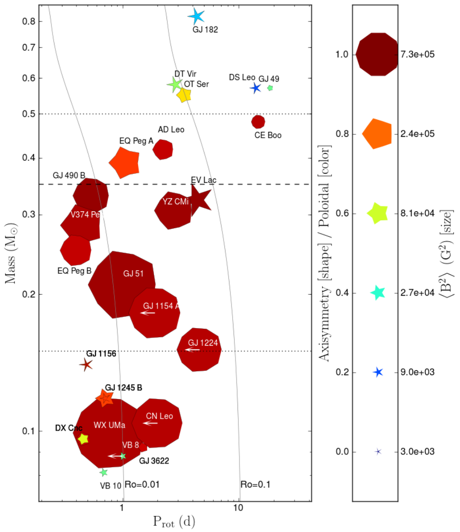




Outline

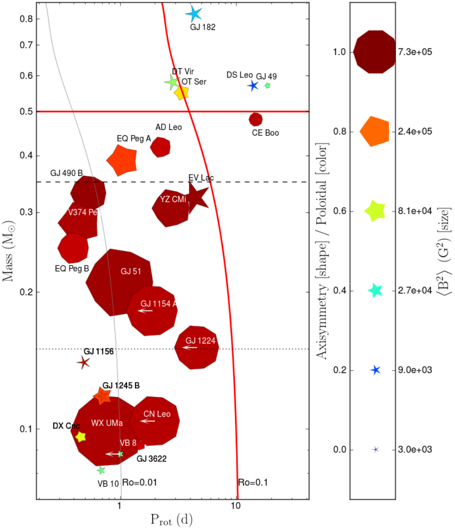
What is missing in the present data ?

- Disentangling Mass–$P_{\rm rot}$
  - Extend to weakly-active stars
- Very low mass regime
- Long-tem evolution ➔ cycles ?
- Relation w/ other mesurements
  - Total magnetic field *Bf*
  - Activity indices
- Effect of binarity ?



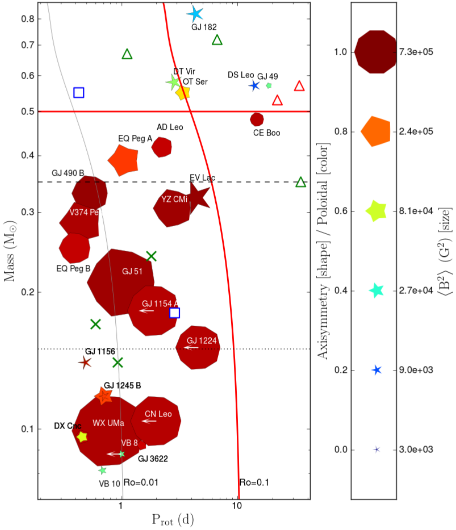
What is missing in the present data ?

- Disentangling Mass–$P_{\rm rot}$
  - Extend to weakly-active stars
- Very low mass regime
- Long-tem evolution ➔ cycles ?
- Relation w/ other mesurements
  - Total magnetic field *Bf*
  - Activity indices
- Effect of binarity ?



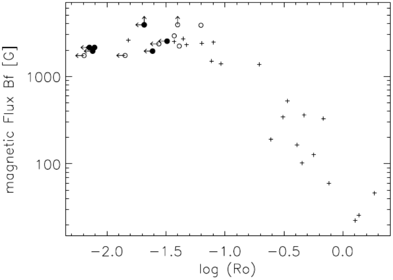
What is missing in the present data ?

- Disentangling Mass–P_{rot}
  - Extend to weakly-active stars
- Very low mass regime
- Long-tem evolution ➔ cycles ?
- Relation w/ other mesurements
  - Total magnetic field *Bf*
  - Activity indices
- Effect of binarity ?

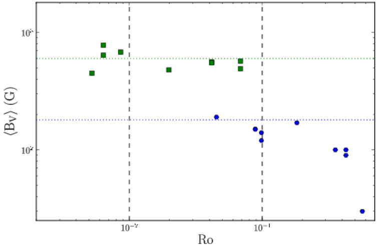


Bf measurements from unpolarised spectroscopy

- Spectroscopy + spectropolarimetry
  - Ratio of large-scale to total field
    - Increase at FC boundary
- Low number of objects
- Non-simultaenous measurements
  - Rotational modulation ?
  - Long-term variations ?
- Very low mass domain

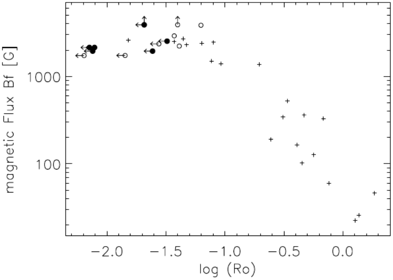


Reiners, Basri & Browning (2009)

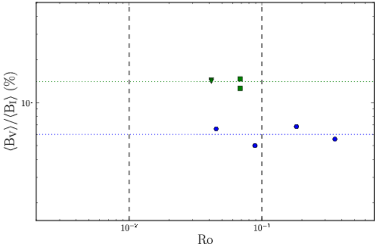


Bf measurements from unpolarised spectroscopy

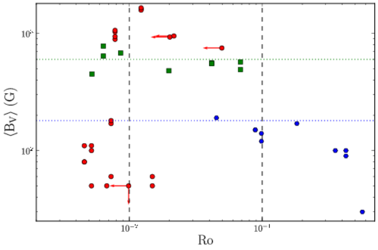
- Spectroscopy + spectropolarimetry
  - Ratio of large-scale to total field
    - Increase at FC boundary
- Low number of objects
- Non-simultaenous measurements
  - Rotational modulation ?
  - Long-term variations ?
- Very low mass domain

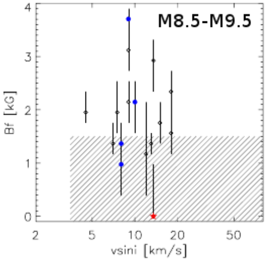


Reiners, Basri & Browning (2009)



Bf measurements from unpolarised spectroscopy

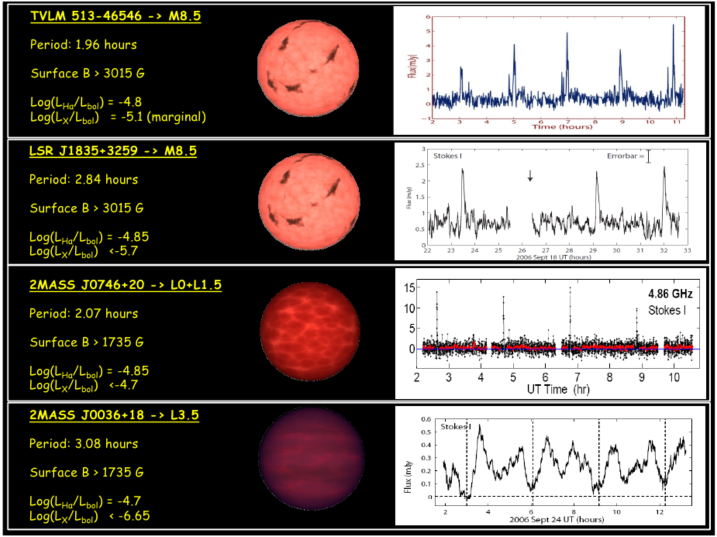




Reiners & Basri (2010)

- Spectroscopy + spectropolarimetry
  - Ratio of large-scale to total field
    - Increase at FC boundary
- Low number of objects
- Non-simultaenous measurements
  - Rotational modulation ?
  - Long-term variations ?
- Very low mass domain

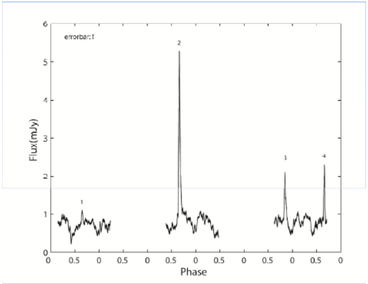
Radio observations brown and red dwarfs

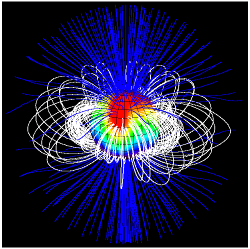


Credit: Gregg Hallinan (NRAO/UC Berkeley)

Radio observations brown and red dwarfs

- Polarized pulses
  - ➥ ECMI emission
  - ➥ Similar giant planets, AKR
- Also observed on M dwarfs



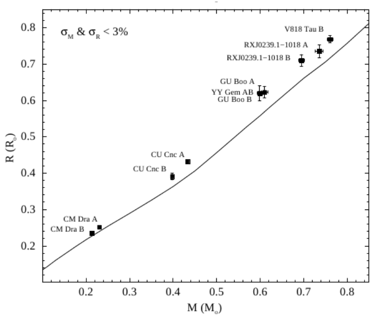


Hallinan et al. (2009)

Effect of binarity on magnetism

- Close eclipsing binaries
  - Strong tidal interaction
  - ➥ Effect on dynamo ?
  - ➥ Related to SPI

- Stellar models: Mass-Radius relationship
  - Large discrepancy for EBs
  - Accurate for inactive objects



Ribas (2006)

Results and prospects on M dwarfs magnetism

- 1st spectropol. survey of M dwarfs
  - Topology change ∼ FCL
  - Bistability among VLMS
- Disentangle Mass–P_{rot}
- Long-term evolution
- Mutli-technique approach
- Close binaries
- Link w/ **B** of TTS
- Detection of extrasolar planets
- . . .