Magnetic topologies of M dwarfs

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Toulouse – 16/17 April 2009

Magnetic Fields of M dwarfs

Dynamo in cool stars

- MHD generated field
- Convection + differential rotation
- Tachocline : Crucial role

Low-mass stars

- $M_\star < 0.35\ M_\odot \Rightarrow$ Fully-convective
- Very active : Radio, Hα, X-ray
- Direct detection of magnetic fields

$\longrightarrow$ No solar-type dynamo

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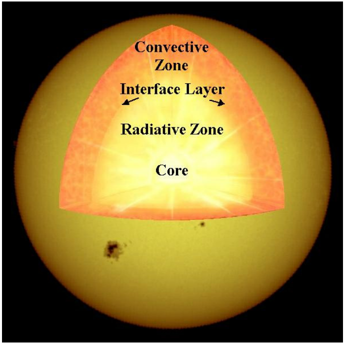

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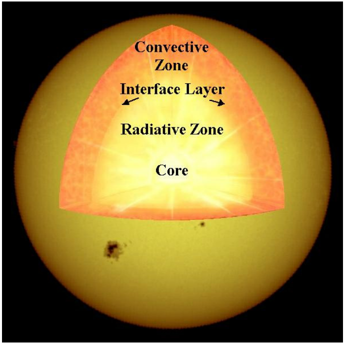

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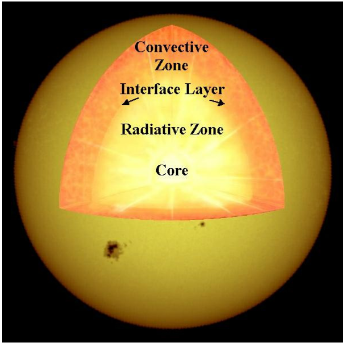

Different techniques

Zeeman effect

- Atom in a magnetic field
  $\longrightarrow$ spectral lines broadening (I)
  $\longrightarrow$ polarised signatures (Q, U, V)

Stellar spectroscopy

- Integration over stellar surface
- Rotation $\Rightarrow$ radial velocity shift
- V : Opposite polarities cancelation
  $\longrightarrow$ large-scale magnetic field
- Tomographic imaging $\Rightarrow$ topology

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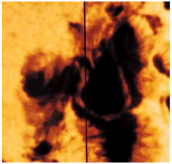

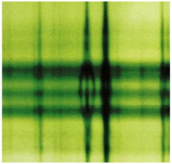

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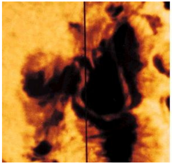

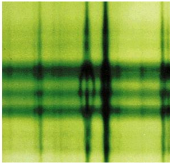

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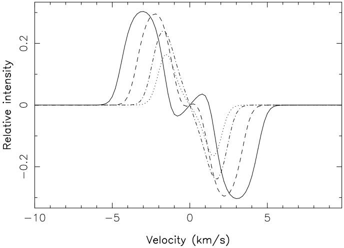

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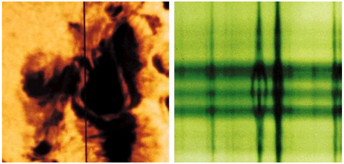

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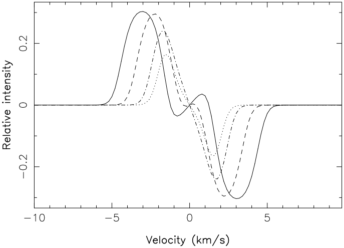

What can we learn ?

Link with numerical simulations

- Field topology / geometry
  - poloidal / toroidal
  - spherical harmonics
  - axisymmetry
- Ability to follow cycles

⇒ directly comparable

Related phenomena

- Coronal heating
- Magnetic braking
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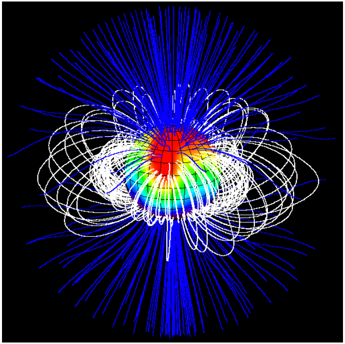

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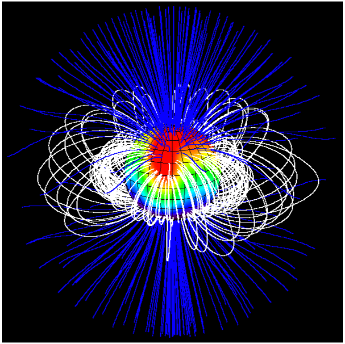

Spectropolarimetric observations

Observations

- ESPaDOnS@CFHT & NARVAL@TBL spectropolarimeters
- High resolution (65k)
- High throughput (up to 20%)
- Complete optical spectrum

Processing

- Data reduction : Libre-ESpRIT
- Least-Squares Deconvolution

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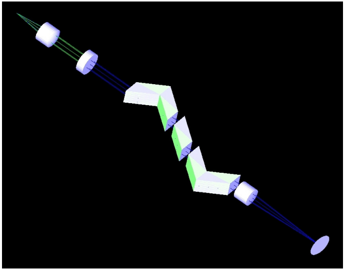

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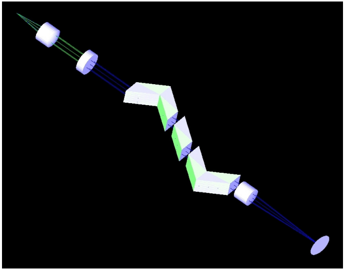

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Zeeman Doppler Imaging

Principles

- Doppler effect
- Rotational modulation
- Field orientation

Required parameters

- vsini
- inclination
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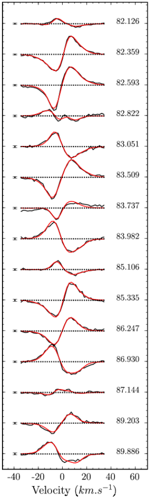

EV Lac

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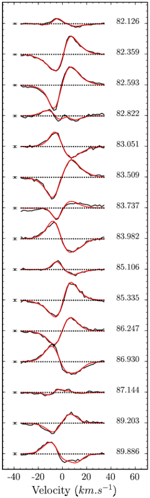
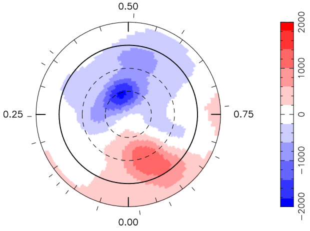
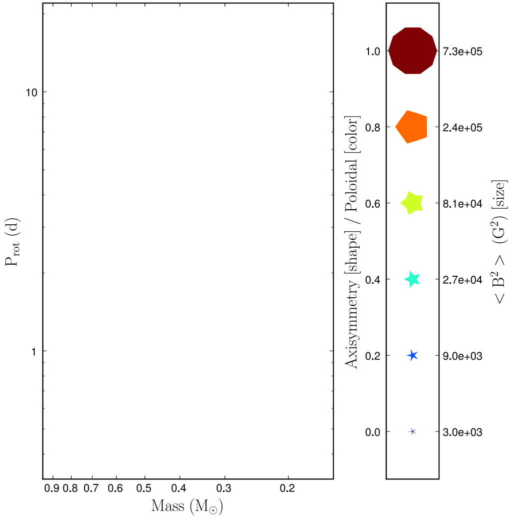




EV Lac

Mass / Rotation period plane



A synthetic view

- Magnetic field properties
- Main stellar parameters

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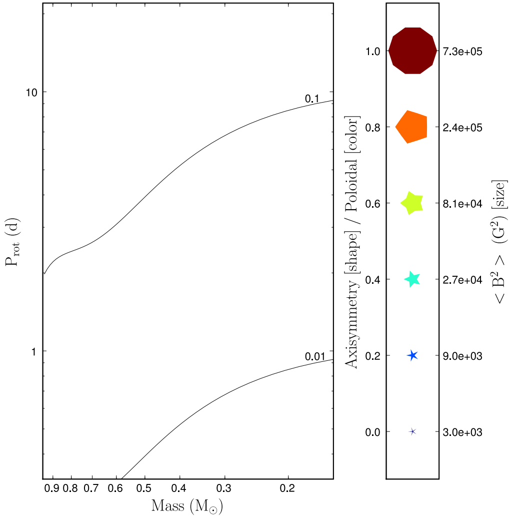

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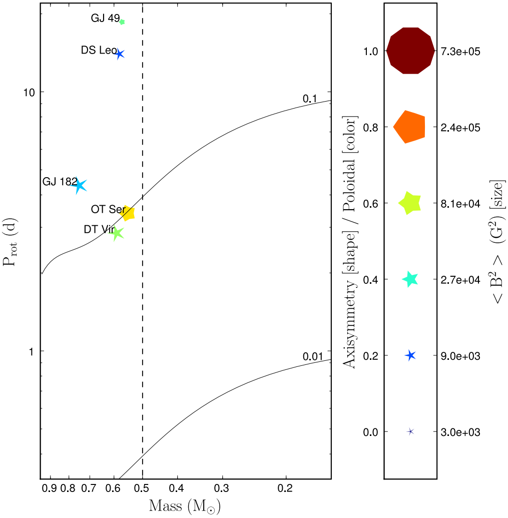
$M_\star > 0.5\ M_\odot$



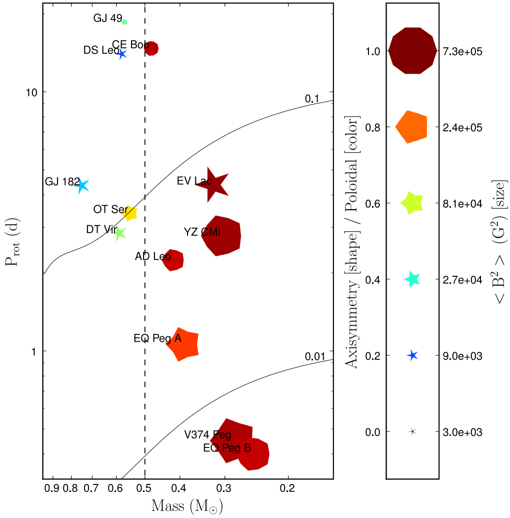
Properties

- Toroidal
- Non-axisymmetric

Differential rotation

- $d\Omega \gtrsim d\Omega_\odot$
- Short-lived structures

$M_\star < 0.5\ M_\odot$



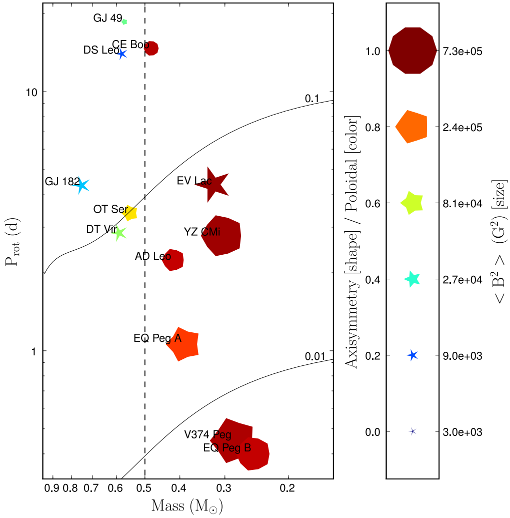
Properties

- Poloidal
- Axisymmetric
- ∼ dipolar
- Stronger

Differential rotation

- $d\Omega \simeq \frac{d\Omega_\odot}{10}$
- Long-lived structures

First Results



Regions

- 2 regions
- Very different properties
- No dependance on rotation rate ?

Work in progress

- Completing the survey
  - Saturated partly-convective ★
  - Non-saturated fully-convective ★
  - Very low mass ★

Evidence for a different dynamo regime

Rossby number

- $P_{\mathrm{rot}} \;\longrightarrow\; Ro = \frac{P_{\mathrm{rot}}}{\tau_c}$
- Compare activity in stars of different masses

Rossby number

- Discontinuity
- Generation of large-scale field more efficient below $0.4\mathrm{M}_\odot$

$\longrightarrow$ Different spatial scales
Same magnetic energy

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Noyes et al 1984

Kiraga & Stepien 2007

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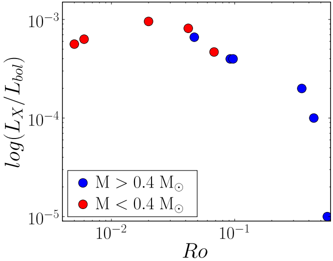

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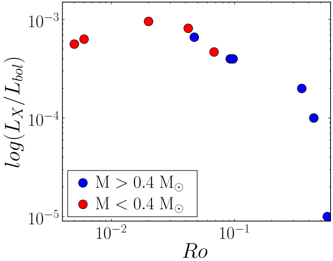

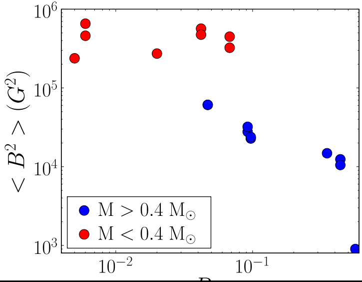

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New sample

Gl 51

- $\mathrm{M}_\star = 0.20\ \mathrm{M}_\odot$
- $v \sin i = 12\ \mathrm{km\,s^{-1}}$
- $P_{\mathrm{rot}} = 1.02\ \mathrm{d}$
- '06 '07 '08

GJ 1245b

- $\mathrm{M}_\star = 0.12\ \mathrm{M}_\odot$
- $v \sin i = 7\ \mathrm{km\,s^{-1}}$
- $P_{\mathrm{rot}} = 0.70\ \mathrm{d}$
- '06 '07 '08

GJ 1111

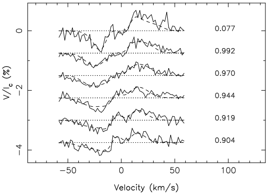
- $\mathrm{M}_\star = 0.10\ \mathrm{M}_\odot$
- $v \sin i = 13\ \mathrm{km\,s^{-1}}$
- $P_{\mathrm{rot}} = 0.46\ \mathrm{d}$
- '07 '08 '09

Gl 412b

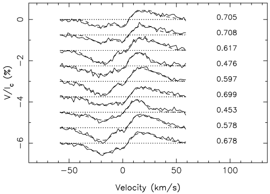
- $\mathrm{M}_\star = 0.10\ \mathrm{M}_\odot$
- $v \sin i = 5\ \mathrm{km\,s^{-1}}$
- $P_{\mathrm{rot}} = 0.78\ \mathrm{d}$
- '06 '07 '08 '09

gl 51

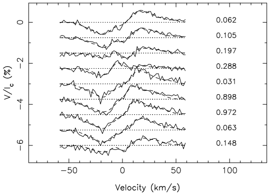
06


0
−2
−4
V/I$_c$ (%)
0.077
0.992
0.970
0.944
0.919
0.904
−50
0
50
100
Velocity (km/s)

07


0
−2
−4
−6
V/I$_c$ (%)
0.705
0.708
0.617
0.476
0.597
0.699
0.453
0.578
0.678
−50
0
50
100
Velocity (km/s)

08


0
−2
−4
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V/I$_c$ (%)
0.062
0.105
0.197
0.288
0.031
0.898
0.972
0.063
0.148
−50
0
50
100
Velocity (km/s)

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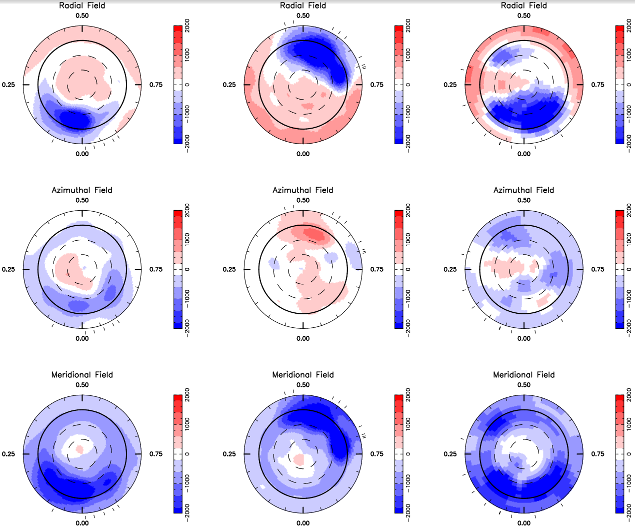

Results

- Strong field
- Tilted dipole
- Long-lived
- Gl 412b

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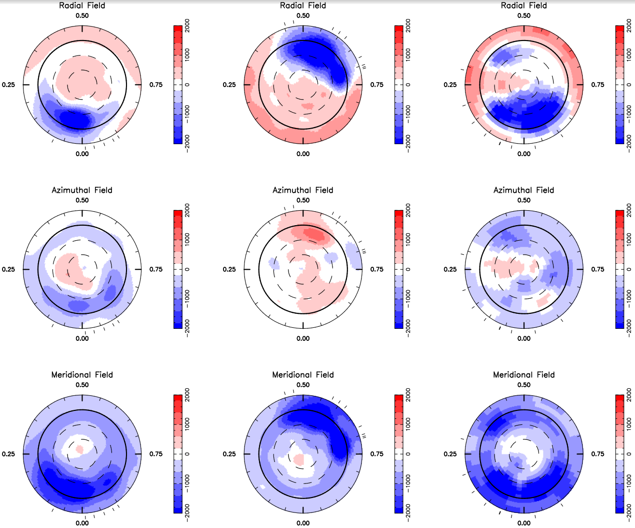

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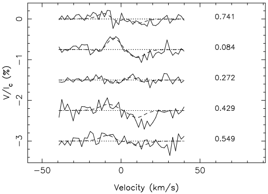

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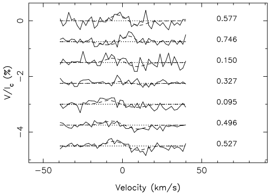

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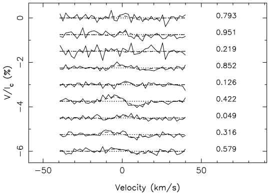

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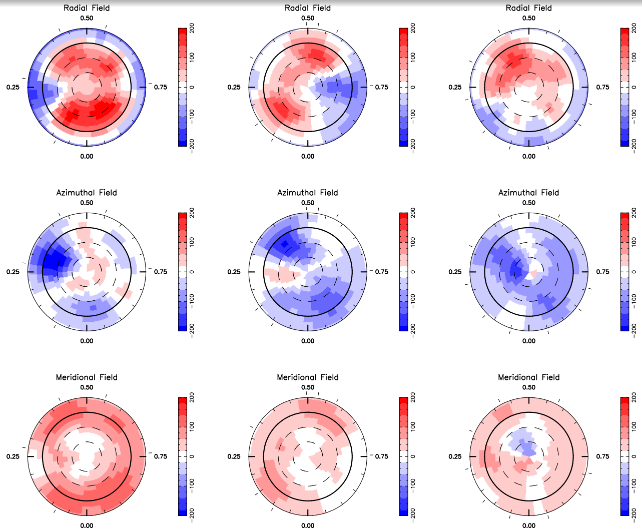

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- Evolution
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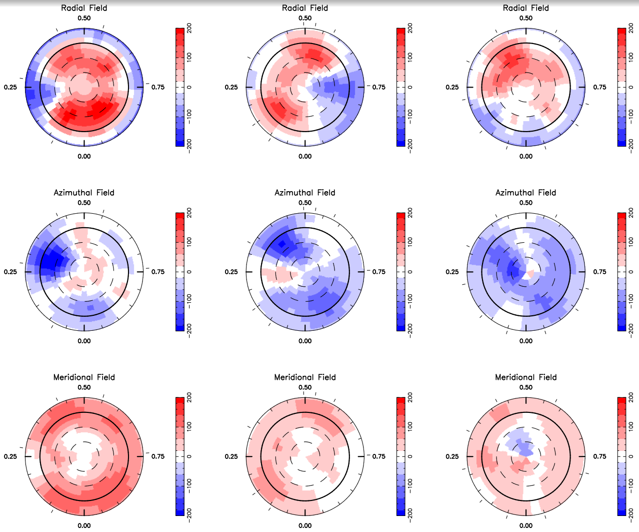

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Late M dwarfs : a new puzzle

Puzzle

- $M_\star < 0.20 M_\odot$
- 2 different type of fields observed
- very similar stellar parameters

$\longrightarrow$ evolution between 2 states ?

$\longrightarrow$ stellar structure ?

Conclusions

Large-scale topology

- Spectropolarimetry
- Tomographic imaging techniques
- Importance

Study

- Spectropolarimetric survey
- A few active stars
- $0.1 < \mathrm{M}_\star < 0.8\ \mathrm{M}_\odot$
- $0.4 < P_{\mathrm{rot}} < 20\ \mathrm{d}$
- Tomographic imaging

First results

- Transition at $\sim 0.5\mathrm{M}_\odot$
  - Topology
  - Caracteristic scales
- Change in dynamo processes
  - Onset of full-convection ?

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