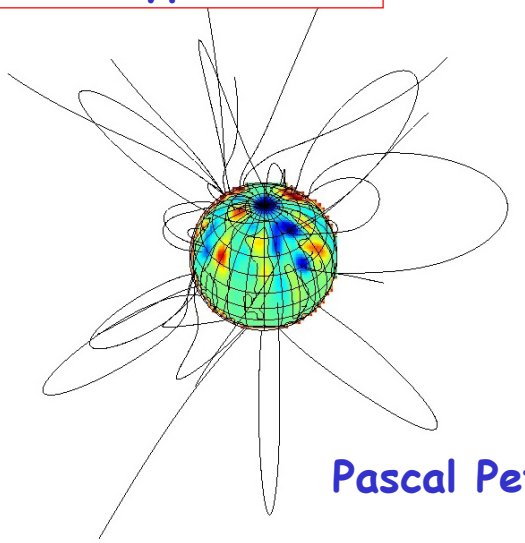
Magnetic mapping of solar-type stars



Pascal Petit

figure: © M. Jardine

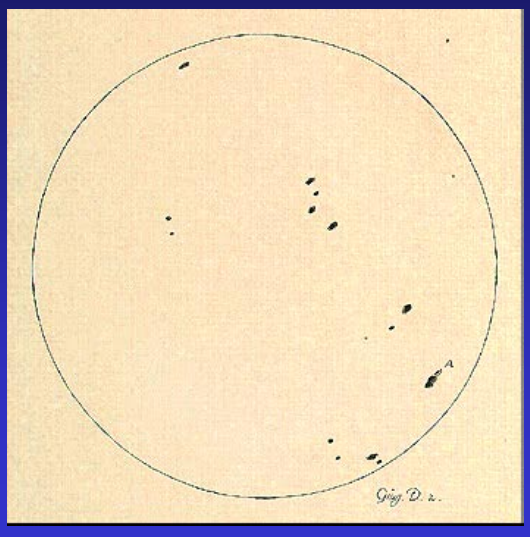
Magnetic mapping of solar-type stars

- introduction: scientific context
- tomographic tools
- magnetic maps of active stars
- stellar differential rotation
- Magnetic geometry of stellar coronae

Introduction

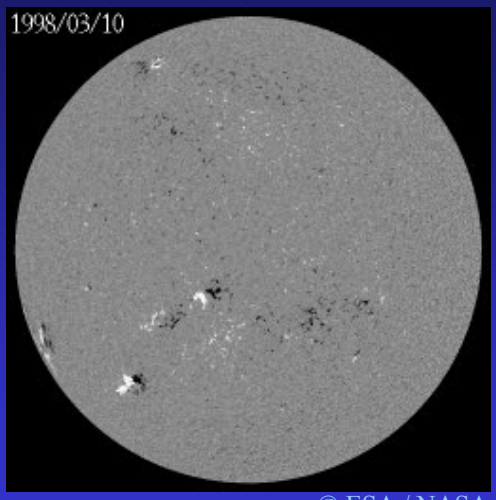
An active star: the Sun

- sunspots (Galileo 1610)
- differential rotation (Scheiner 1630)
- cyclical activity (~11 years) (Schwabe 1843)

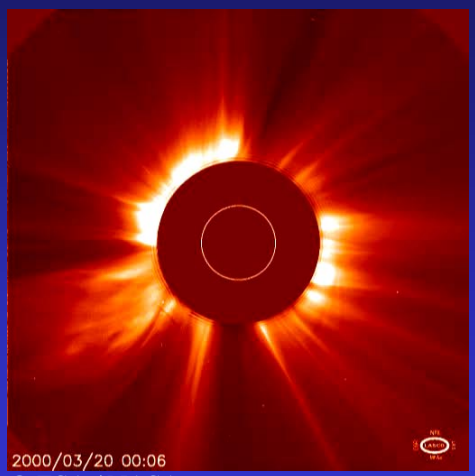


Photospheric magnetic field of the Sun

- inside sunspots (Hale 1908)
- antisymetric about the equator
- cyclical (~22 years)



Coronal magnetic field



- Prominences trapped in closed magnetic loops
- Coronal plasma ejected if reconnexion of magnetic lines
- solar wind controlled by open field lines

Angular momentum exchange between the Sun and its close environment

Study of stellar activity

Replace the Sun in a more general context:
influence of various stellar parameters (age, mass, rotation, binarity) on stellar activity

- distribution and evolution of starspots and surface magnetic field
- surface differential rotation
- geometry and dynamics of stellar coronal plasma

Evaluate the impact of magnetic fields on stellar evolution

- magnetospheric accretion in young solar analogues
- magnetic rotational braking of active stars

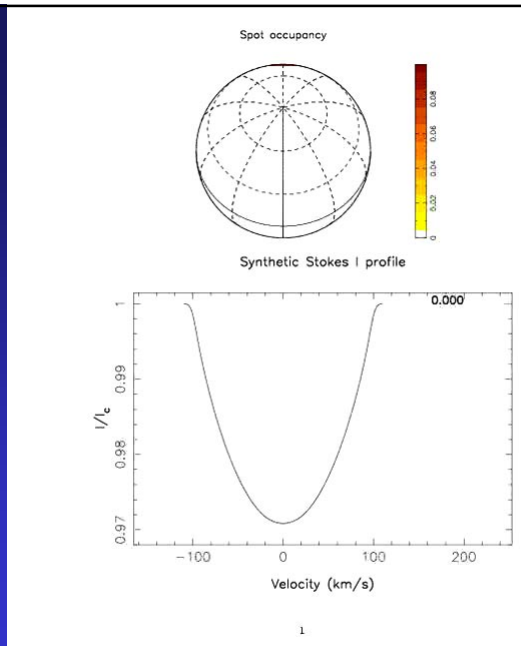
→ necessity to spatially resolve stellar photospheres and coronae

Tomographic imaging of solar-type stars: basic principle

Doppler Imaging

Spectral signatures of starspots

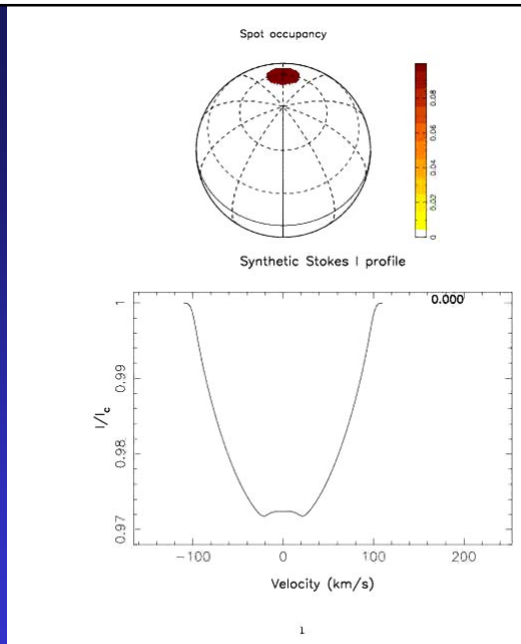
1. low-latitude spot



Doppler Imaging

Spectral signatures of starspots

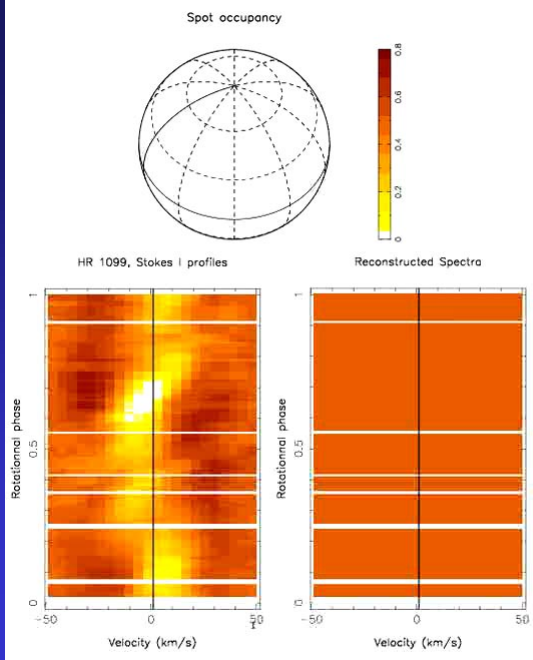
2. high-latitude spot



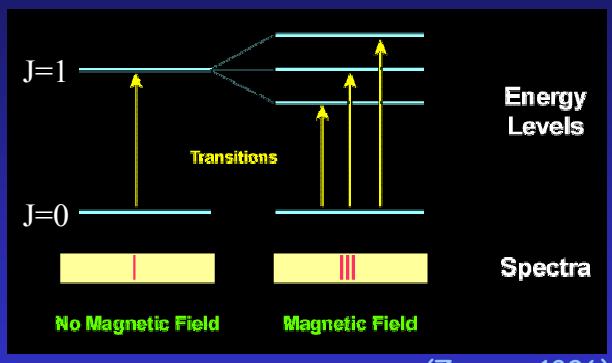
Time series
of intensity spectra

iterative
maximum entropy
algorithm
(Vogt & Penrod 1983)

Reconstructed
cool spot map



Measurement of stellar magnetic fields: Zeeman effect



(Zeeman 1896)

broadening (or splitting) of spectral lines: field strength
Polarization of spectral lines: field strength and orientation

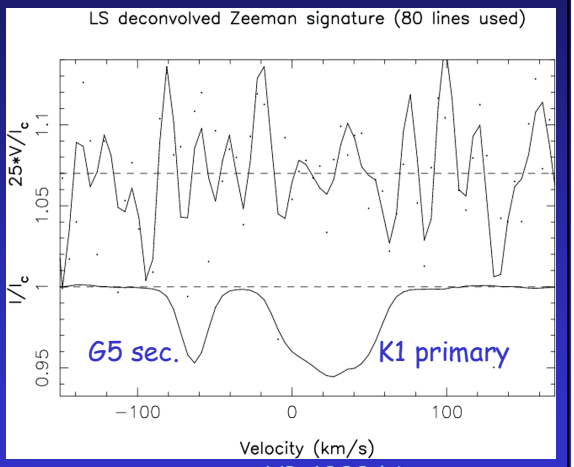
extraction of Zeeman signatures: Multi-line techniques

Raw spectrum

3200 lines deconvolved

S/N x 30

Mean line profile

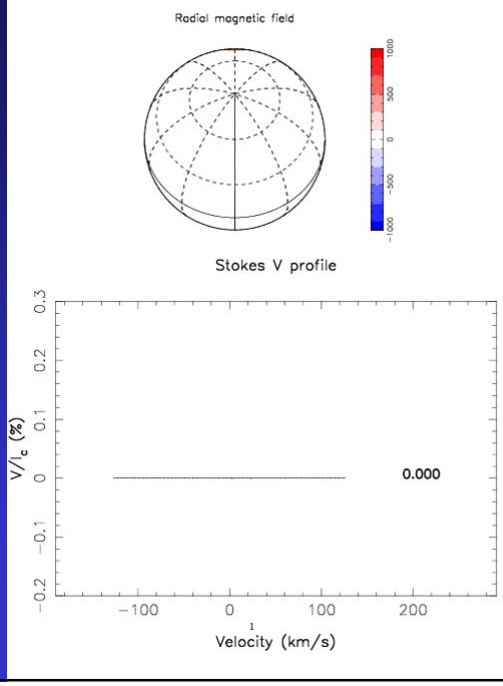


HR 1099 binary system

Zeeman-Doppler Imaging

How to reconstruct a stellar vectorial magnetogram?

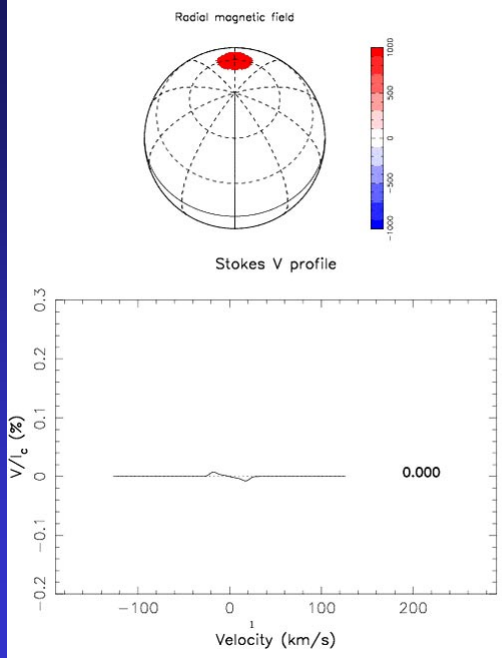
1. longitude of magnetic regions



Zeeman-Doppler Imaging

How to reconstruct a stellar vectorial magnetogram?

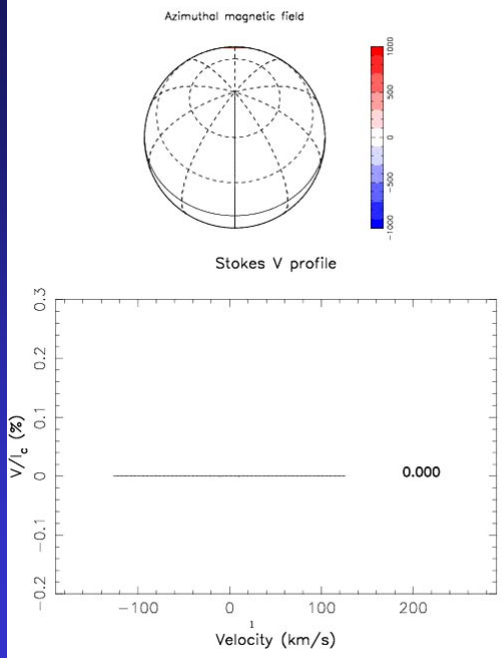
2. latitude of magnetic regions



Zeeman-Doppler Imaging

How to reconstruct a stellar vectorial magnetogram?

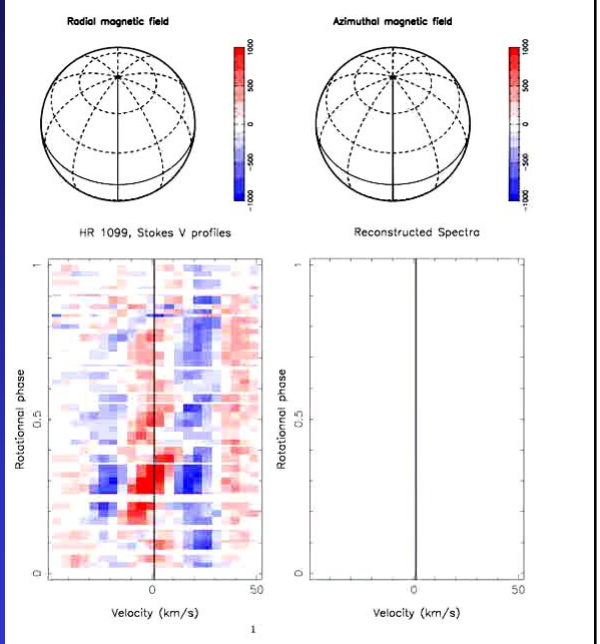
3. orientation of field lines



Time series
of polarised spectra

iterative
maximum entropy
algorithm
(Donati & Brown 1997)

Reconstructed
magnetic map



**Tomographic imaging:
application to active stars**

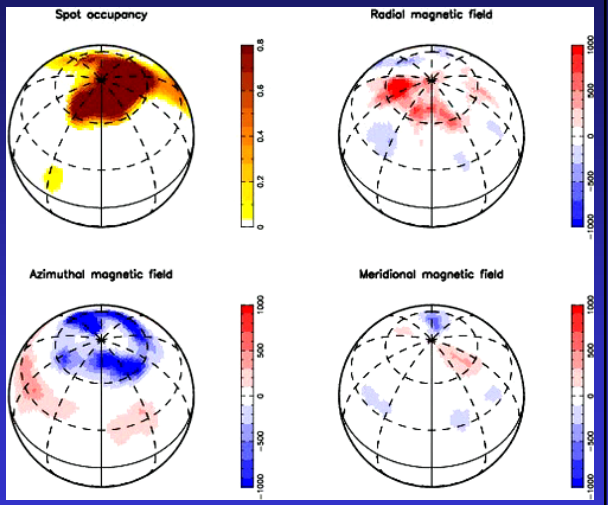
ZDI targets: fast rotating late-type stars

- Young stars (P_{rot} = 0.3 – 8 days)
- Components of close binary systems (P_{rot} of a few days)
- FK Com giants (P_{rot} of a few days)

Stellar vectorial magnetograms

HR 1099
Close binary
K1 subgiant (+ G5 sec.)
P_{rot} = 2.83 days
M ~ 1.0 M_{sun}
R ~ 3.7 R_{sun}
T ~ 4700 K

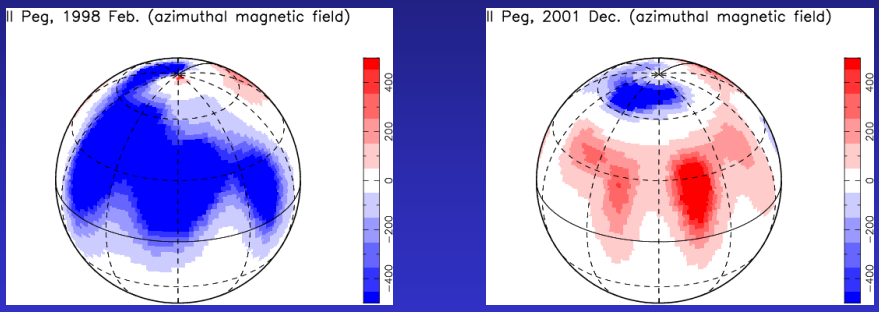
- giant starspots at high latitude
- azimuthal (toroidal) component of the surface field



(Petit et al. 2004a)

Stellar magnetic cycles

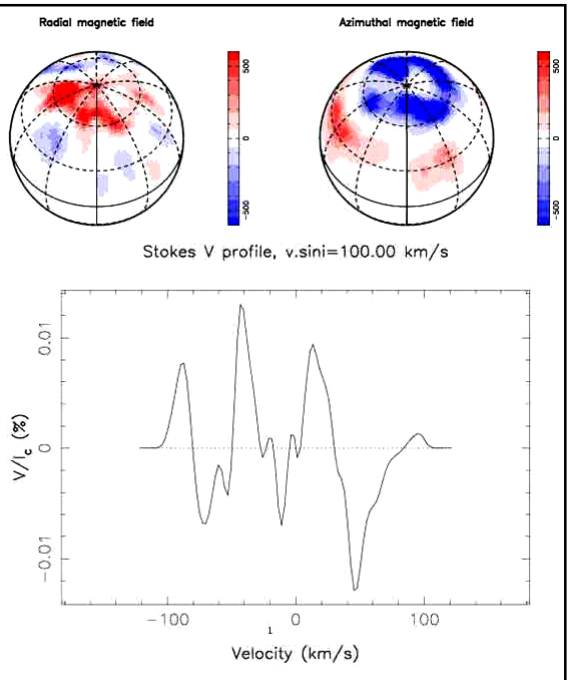
Sign reversal of the large-scale toroidal field



II Peg, Petit et al., in prep.

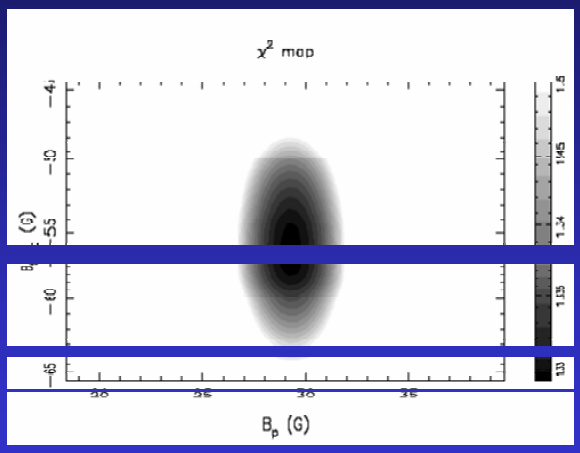
The case of slow rotators

- less information in line profiles
- global field still observable



Large-scale field of slow rotators

- individual active regions unresolved
- large-scale inclined dipole and toroidal field still observed



ξ Bootis A (young G8 dwarf, v.sini=3 km/s)
(Petit et al., submitted)

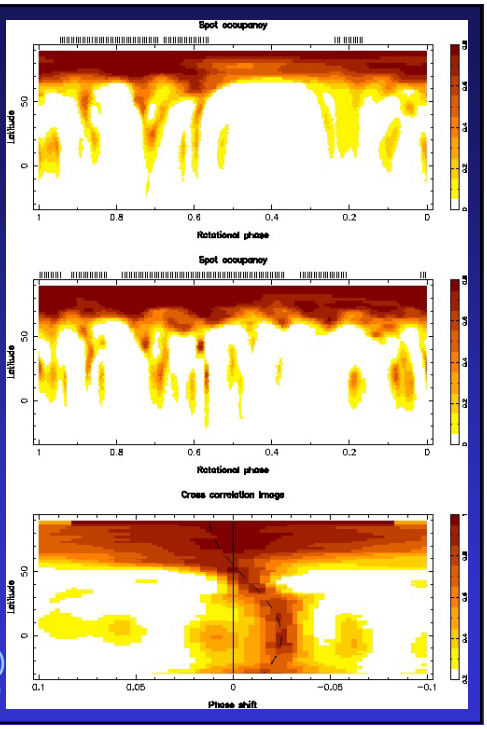
Stellar differential rotation

Differential rotation

Measurement of surface shear:

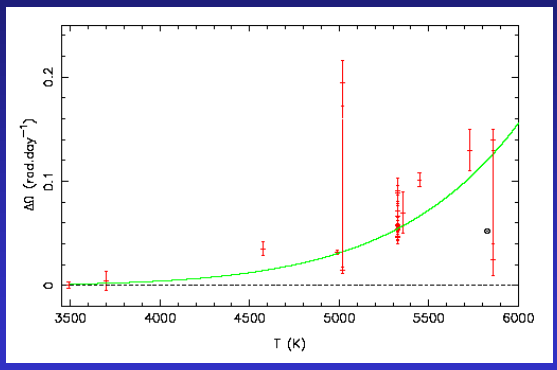
Track the relative motion of cool spots / magnetic regions

Surface shear:
- of solar-type
- not correlated to rotation period
- weaker in close binary systems (Petit et al. 2004a,b)



(AB Dor, ZAMS dwarf)
Donati et al. 1999

Temperature dependence of differential rotation



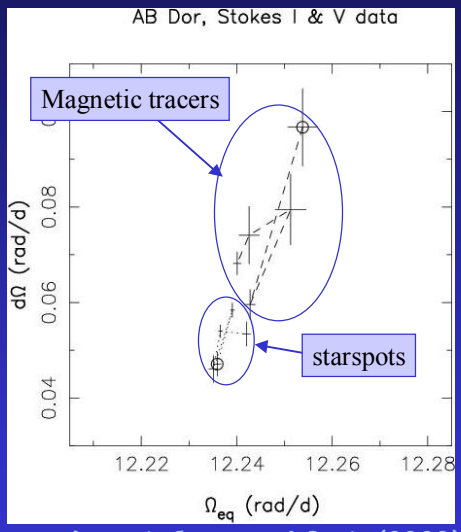
ZAMS single dwarfs: shear intensity increasing with T_{eff}

Barnes et al. 2005

fluctuations of the surface shear

- Stronger shear for magnetic tracers
- Secular fluctuations of the shear.

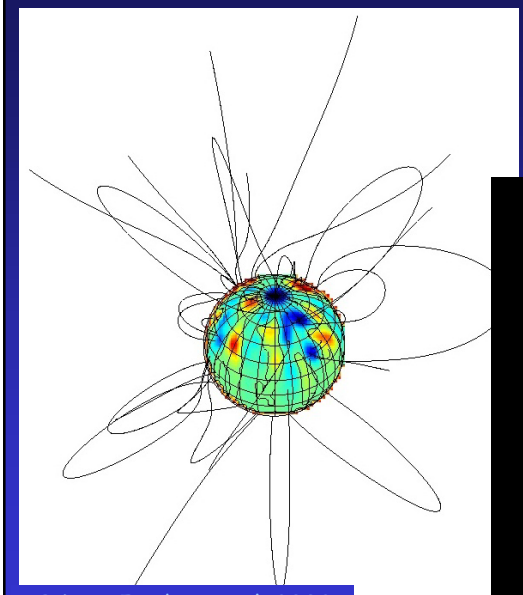
(AB Dor, ZAMS dwarf)



Donati, Cameron & Petit (2003)

Magnetic geometry of active coronae

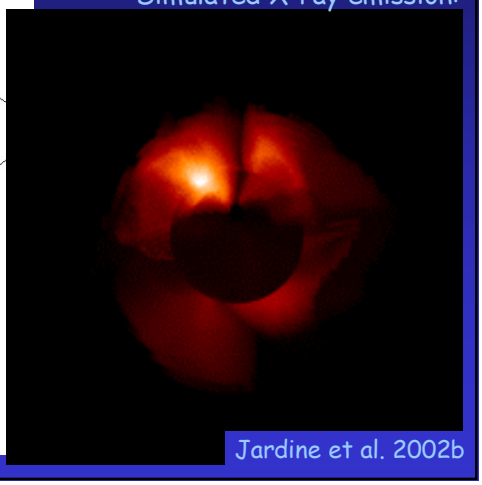
From photosphere to corona



AB Dor, Jardine et al. 2002a

Field extrapolation using ZDI map as boundary conditions (potential field)

Simulated X-ray emission:

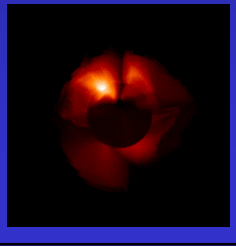


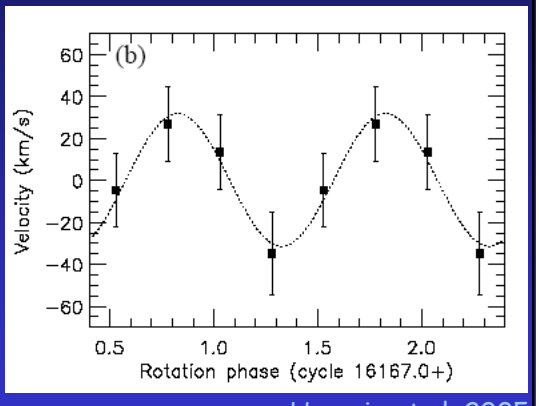
Jardine et al. 2002b

X-Ray tomography of stellar coronal plasma

AB Dor:
OVIII 18.97Å spectral line
(Chandra observations)

velocity shifts compatible with single, high-latitude (60°), compact emitting cloud



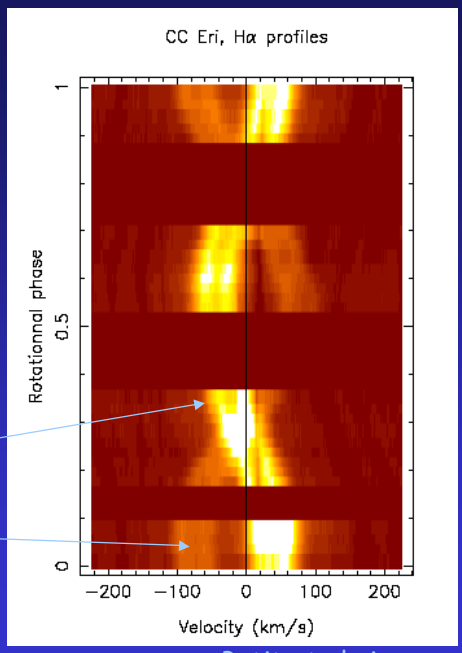


Hussain et al. 2005

Ha tomography of stellar prominence systems

primary component (M0 dwarf)

secondary component (M4 dwarf)



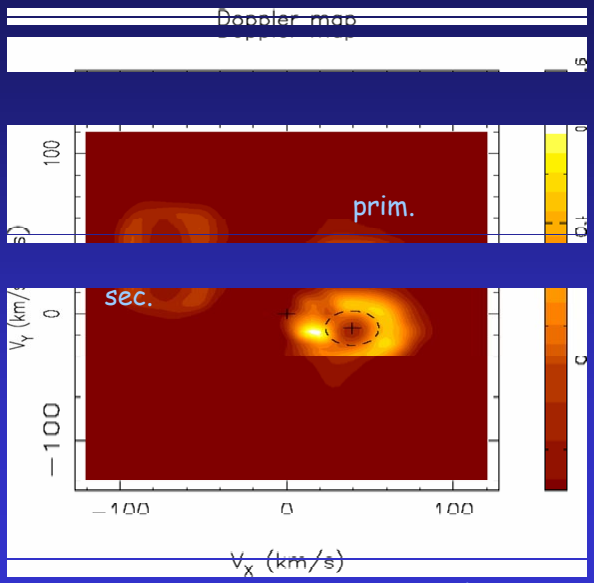
Petit et al., in prep.

Ha tomography of stellar prominence systems

Location & evolution of coronal condensations

Mass-loss rate due to coronal mass ejections

Braking timescale



Petit et al., in prep.

Perspectives

Perspectives

- Magnetospheric accretion in young solar analogues
- Surface imaging using molecular Zeeman effect: magnetic structure of starspots
- Multi-wavelength observations: optical/X-ray

Hα tomography of stellar prominence systems

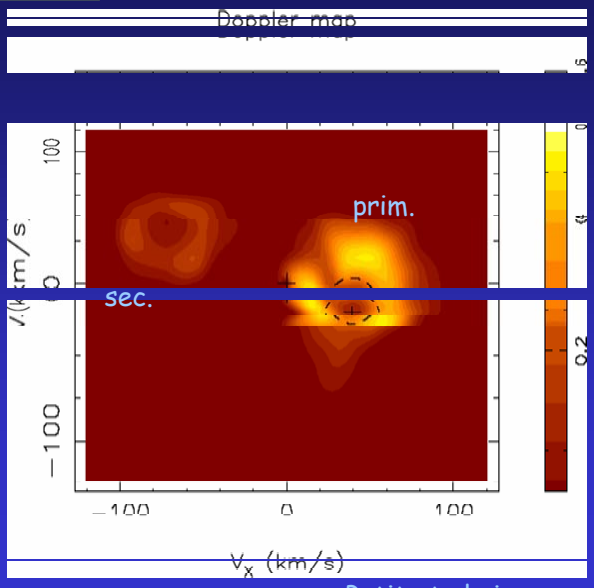
Location & evolution of coronal condensations

↓

Mass-loss rate due to coronal mass ejections

↓

Braking timescale



Petit et al., in prep.