JF Donati (CNRS)
& the MagICS collaboration

the Quest for magnetic stars

understanding the magnetic Sun

Larmor 1912 / Cowling 1935 / Parker 1955

dynamo : interplay of convection & rotation > magnetic field

rotation shear @ base of convective zone (CZ) > toroidal field

dynamo action strengthens w/ rotation rate

exploring magnetic stars

theory tailored on one single star : how general?

> explore low-mass stars ≠ Sun (w/ outer convection)

study interface & distributed dynamos separately

find out origin of fields & impact on physics & evolution

fields of low-mass stars

magnetic proxies : activity

eg : emission in optical & UV spectral lines > chromospheres & coronae

eg : regular photometric variability > cool surface spots

detected in all low-mass stars (ie w/ outer CZ)

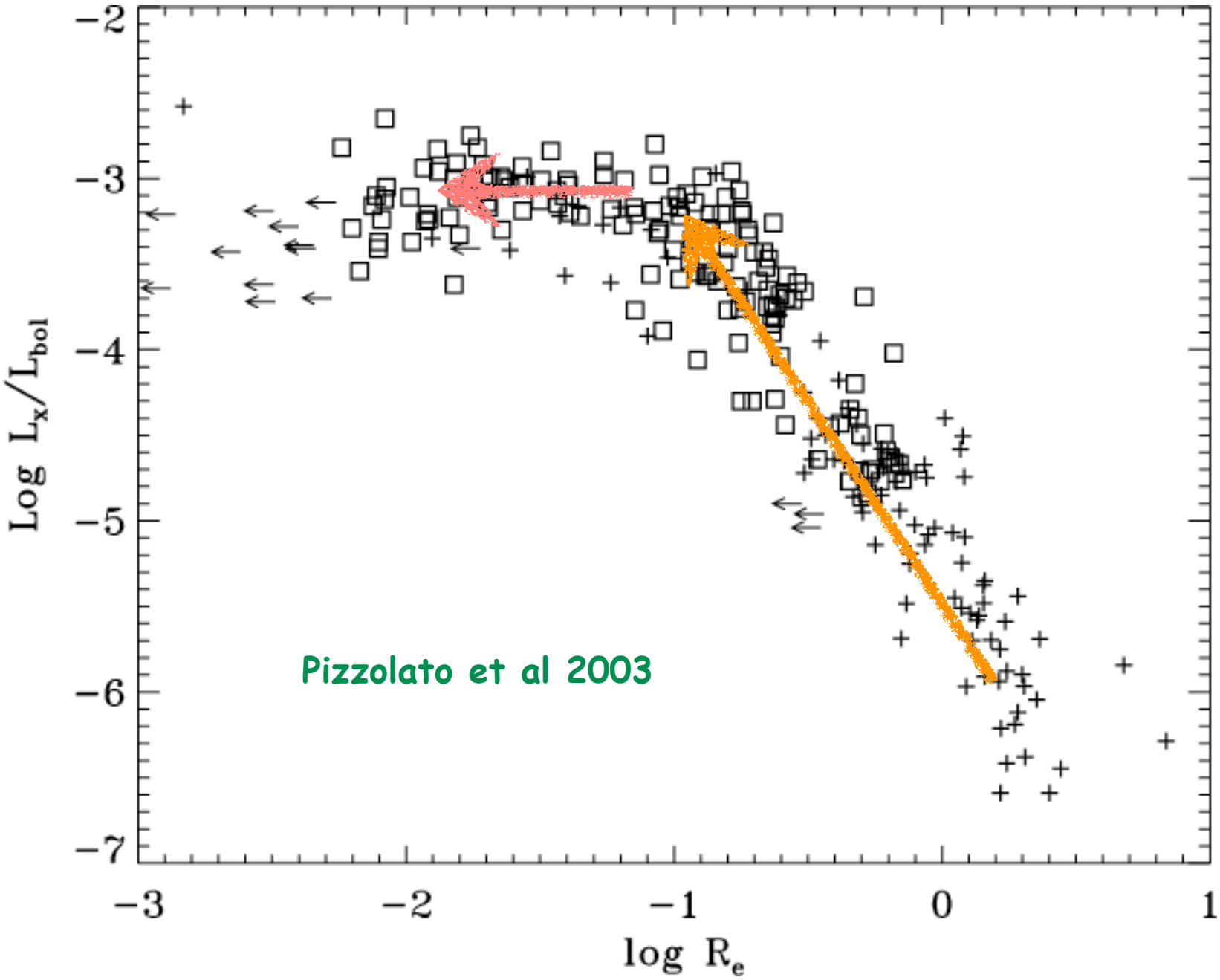
correlates w/ rotation rate > attributed to dynamo fields

magnetic fields

using the Zeeman effect in spectral lines

Robinson 1980 : first solar-type magnetic stars ≠ Sun w/ dynamo fields

magnetic fluxes increasing w/ rotation rates


−2
−3
−4
−5
−6
−7
Log L_x/L_{bol}
−3
−2
−1
0
1
log R_e
Pizzolato et al 2003

detecting stellar fields

spectroscopy vs spectropolarimetry

broadening of spectral lines > magnetic field flux
no information on topology > limited use for dynamo theories
generic high-res spectrograph available @ all telescopes

polarization of spectral lines > topologies of large-scale fields
toroidal & poloidal fields but no information on small-scale fields
dedicated instruments, eg ESPaDOnS@CFHT & NARVAL@TBL


ESPaDOnS@CFHT
NARVAL@TBL

detecting stellar fields

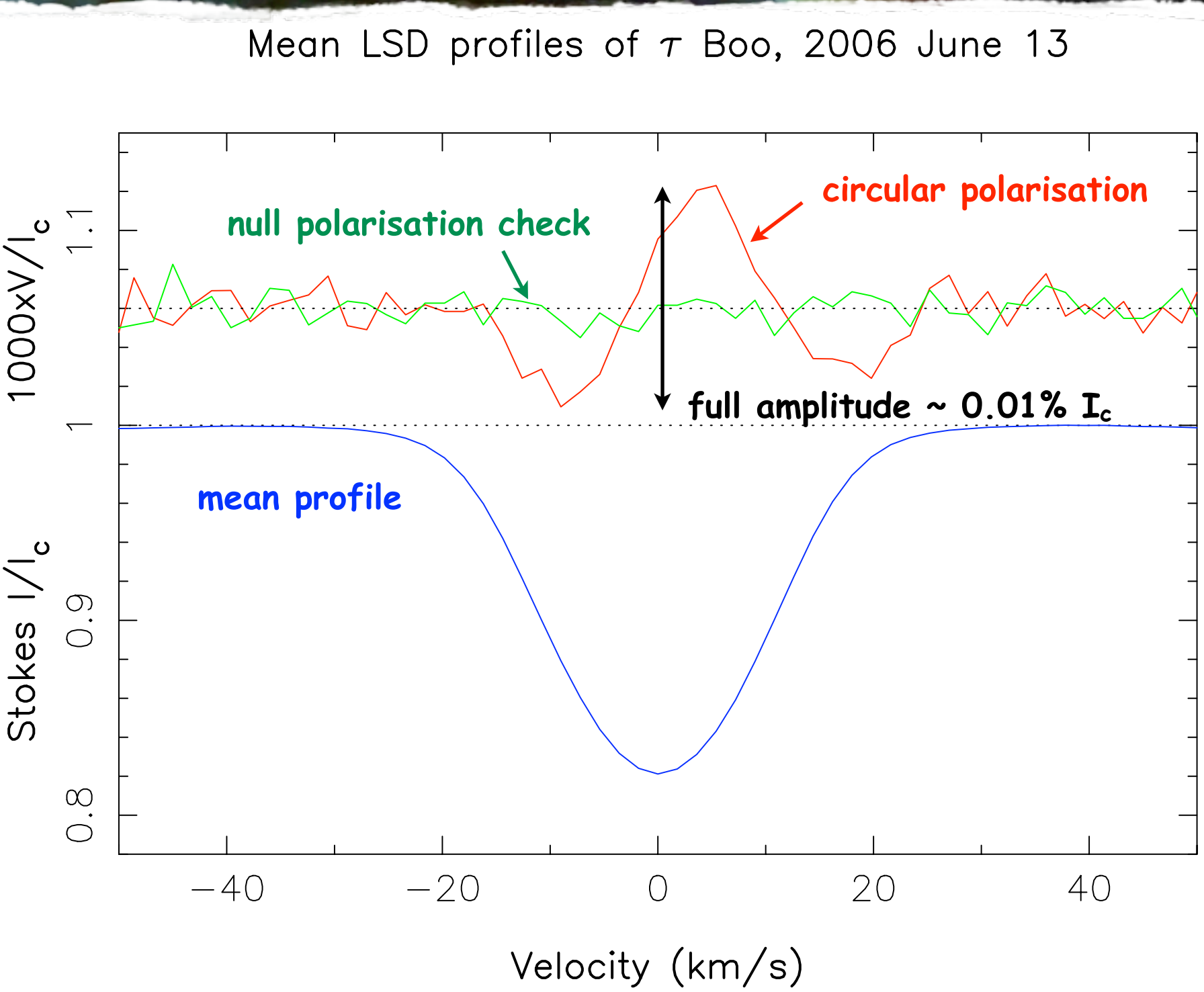
spectroscopy vs spectropolarimetry

broadening of spectral lines > magnetic field flux
no information on topology > limited use for dynamo theories
generic high-res spectrograph available @ all telescopes

polarization of spectral lines > topologies of large-scale fields
toroidal & poloidal fields but no information on small-scale fields
dedicated instruments, eg ESPaDOnS@CFHT & NARVAL@TBL

circular polarisation in line profiles

sensitive to line-of-sight (longitudinal) B component
small Zeeman signatures : fractional size 1%-0.01%
using multiline tools (eg LSD) to improve S/N


Mean LSD profiles of τ Boo, 2006 June 13
null polarisation check
circular polarisation
full amplitude ~ 0.01% Ic
mean profile
1000xV/Ic
Stokes I/Ic
1.1
1
0.9
0.8
−40
−20
0
20
40
Velocity (km/s)

modelling large-scale B's

collect Zeeman signatures throughout rotation cycles...

rotational modulation of Zeeman signatures

longer-term evolution

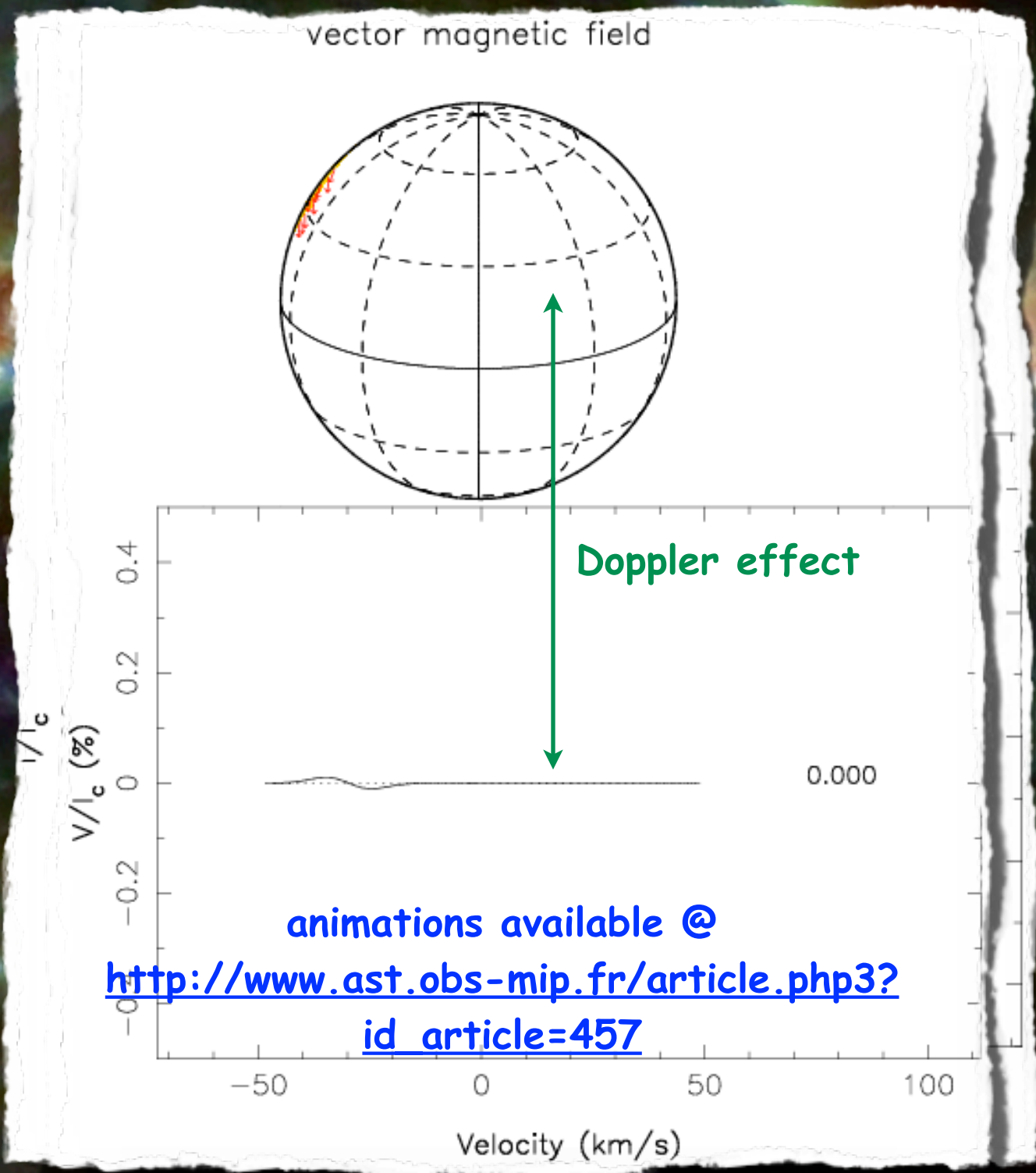
...to reconstruct the large-scale topology...

apply tomographic imaging & use spherical-harmonics expansions

> poloidal & toroidal components of large-scale field

sensitive to location of magnetic spots & orientation of field lines

differential rotation & activity cycles from long-term evolution



animations available @
http://www.ast.obs-mip.fr/article.php3?id_article=457

modelling large-scale B's

collect Zeeman signatures throughout rotation cycles...

rotational modulation of Zeeman signatures

longer-term evolution

...to reconstruct the large-scale topology...

apply tomographic imaging & use spherical-harmonics expansions

> poloidal & toroidal components of large-scale field

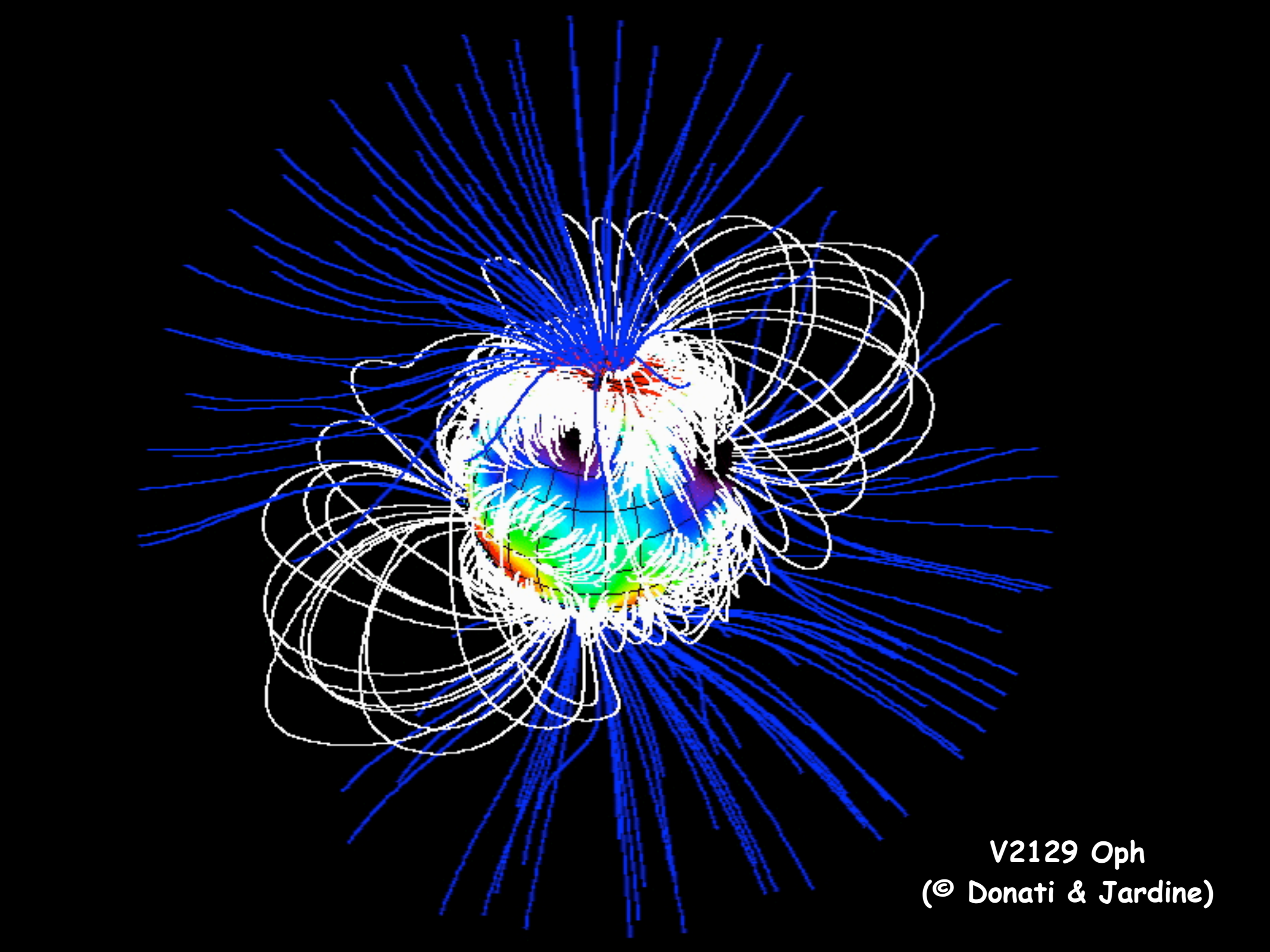
sensitive to location of magnetic spots & orientation of field lines

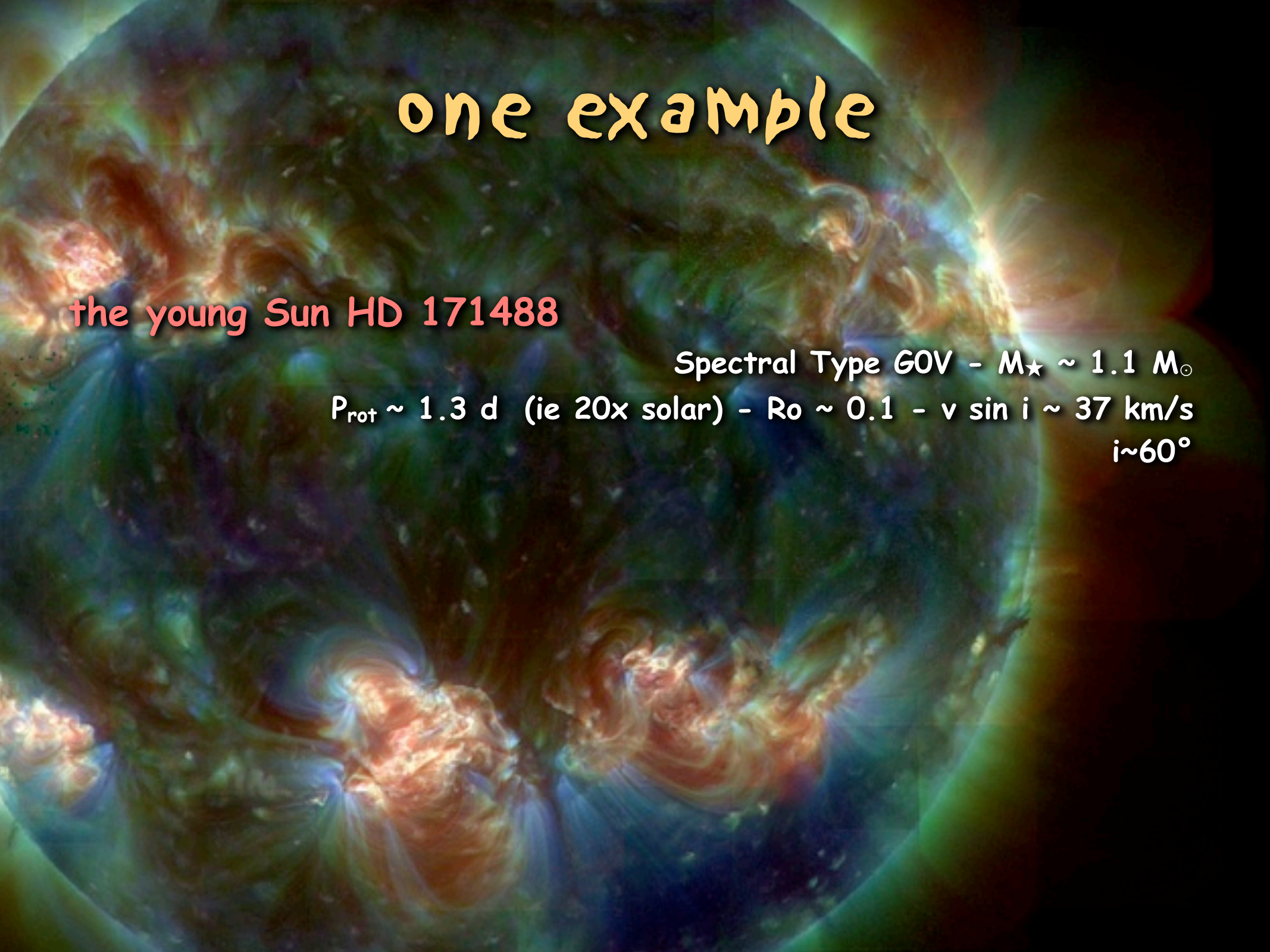
differential rotation & activity cycles from long-term evolution

...and extrapolate it outwards

assume potential field topology

> get 3D image of stellar magnetosphere


V2129 Oph
(© Donati & Jardine)



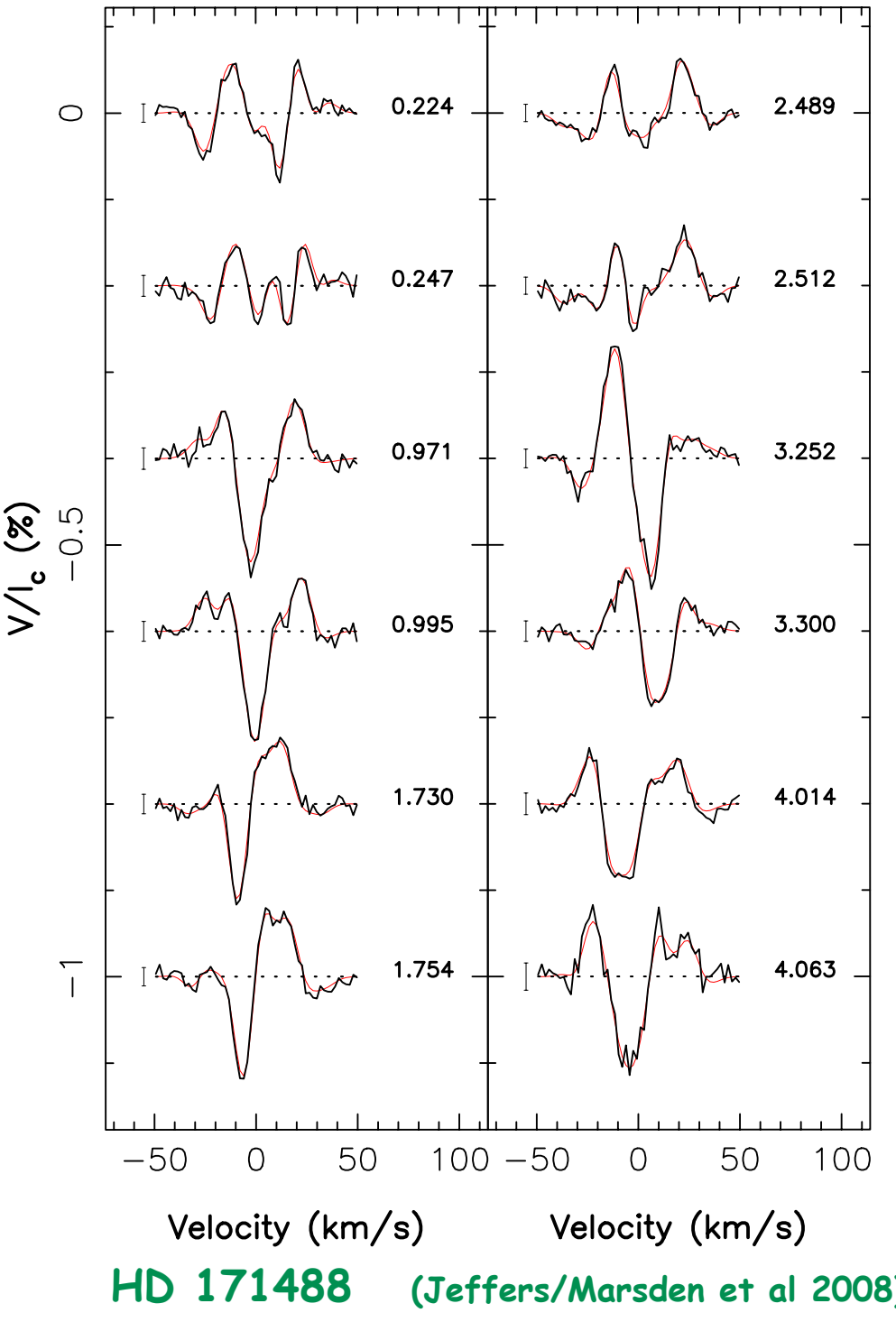
one example

the young Sun HD 171488

Spectral Type G0V - $M_\star \sim 1.1\ M_\odot$

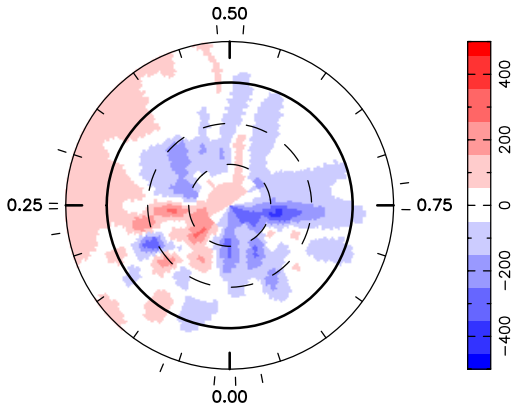
$P_{rot} \sim 1.3$ d (ie 20x solar) - Ro ~ 0.1 - v sin i ~ 37 km/s

i~60°

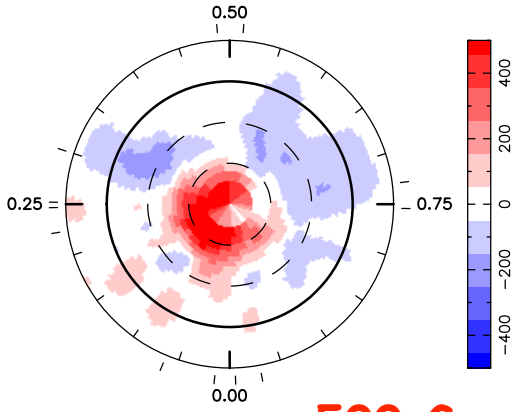


HD 171488 (Jeffers/Marsden et al 2008)

radial field

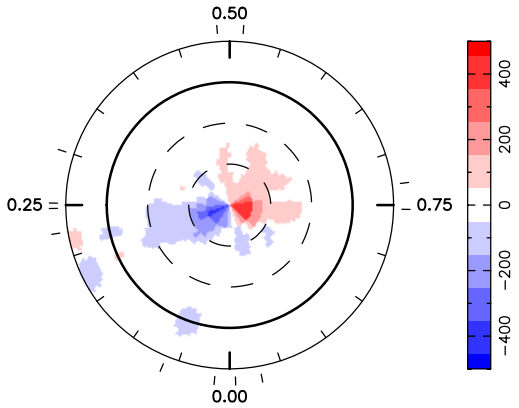


azimuthal field



~500 G max

meridional field



one example

the young Sun HD 171488

Spectral Type G0V - $M_\star \sim 1.1\ M_\odot$

$P_{rot} \sim 1.3$ d (ie 20x solar) - Ro ~ 0.1 - v sin i ~ 37 km/s

i~60°

complex Zeeman signatures & rapid temporal modulation

> reconstruct SH modes up to l~30

> dominant toroidal field & non-axisymmetric poloidal field

> works w/ slow rotators as well

(though some loss in spatial resolution)

the many faces of dynamo

explore $M_\star$ vs P_{rot} diagram

detect Zeeman signatures & map large-scale field

$M_\star$: from 0.1 to 1.5 $M_\odot$ - P_{rot} : from 0.4 to 30 d

> (i) magnetic energy, (ii) fractional energy of poloidal component & (iii) degree of axisymmetry of poloidal component

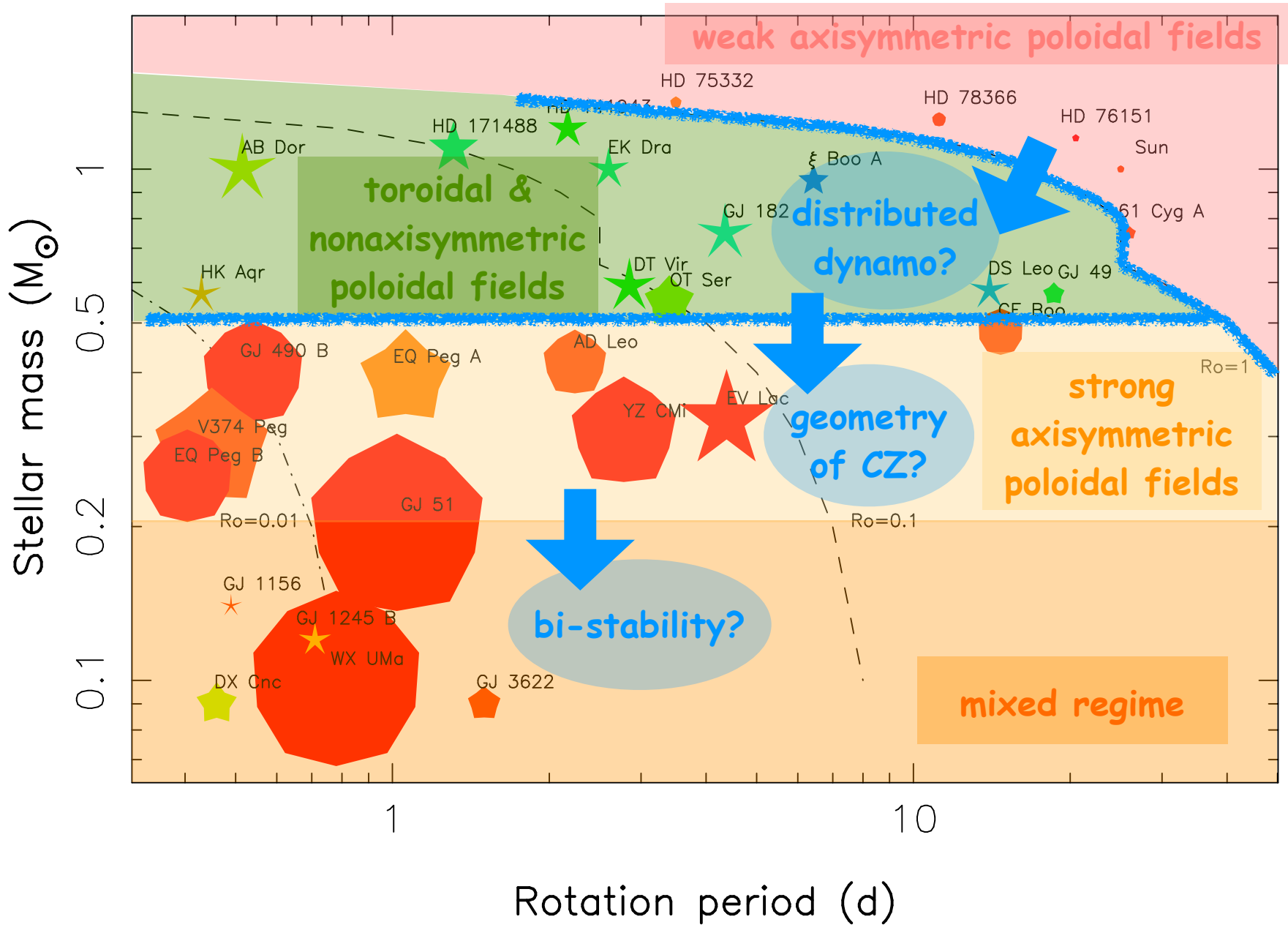
magnetic energy of large-scale field = symbol size

fractional energy of poloidal component = symbol color

poloidal - mixed - toroidal

axisymmetry of poloidal component = symbol shape

(● axisymmetric - ★ non-axisymmetric)


weak axisymmetric poloidal fields
HD 75332
HD 78366
HD 76151
Sun
HD 171488
AB Dor
EK Dra
ξ Boo A
GJ 182
61 Cyg A
toroidal &
nonaxisymmetric
poloidal fields
distributed
dynamo?
HK Aqr
DT Vir
OT Ser
DS Leo
GJ 49
CE Boo
GJ 490 B
EQ Peg A
AD Leo
Ro=1
strong
axisymmetric
poloidal fields
YZ CMi
EV Lac
geometry
of CZ?
V374 Peg
EQ Peg B
Ro=0.01
GJ 51
Ro=0.1
GJ 1156
GJ 1245 B
WX UMa
bi-stability?
DX Cnc
GJ 3622
mixed regime
Stellar mass (M⊙)
0.1
0.2
0.5
1
1
10
Rotation period (d)

other faces of dynamo

surface differential rotation

estimate rotation shear dΩ between successive magnetic images

Sun-like shears (sign & strength) in solar-type (GK) stars

supersolar shears (x5) in F stars w/ very shallow convection

subsolar shears (÷5) in fully-convective M stars

activity cycles

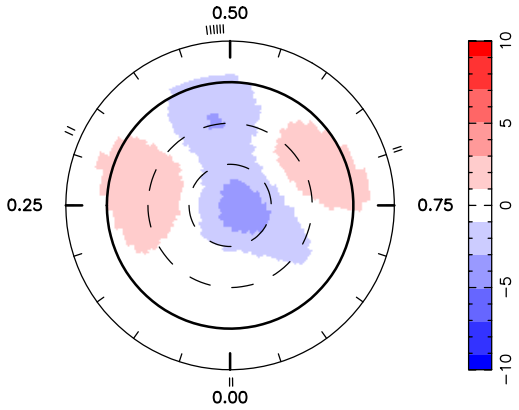
magnetic cycles from long-term evolution

tau Boo (F7) : first magnetic cycle detected in star ≠ Sun

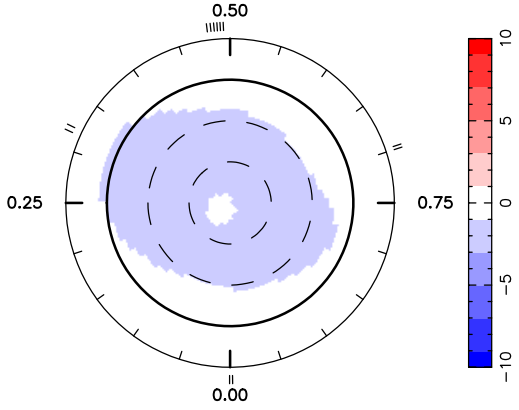
poloidal & toroidal fields flipping sign every 1.1yr

shallow CZ? strong differential rotation? close-in giant-planet?

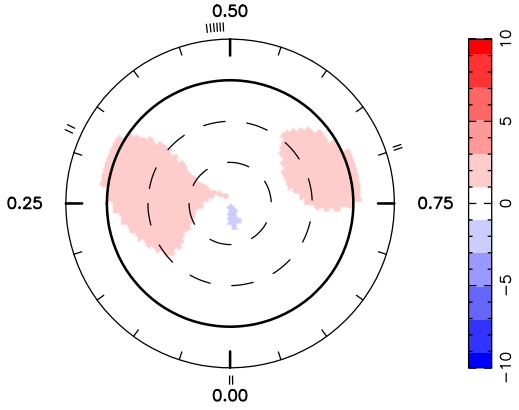
radial field



azimuthal field

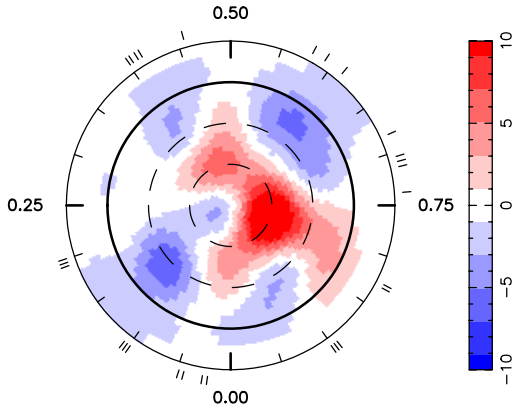


meridional field

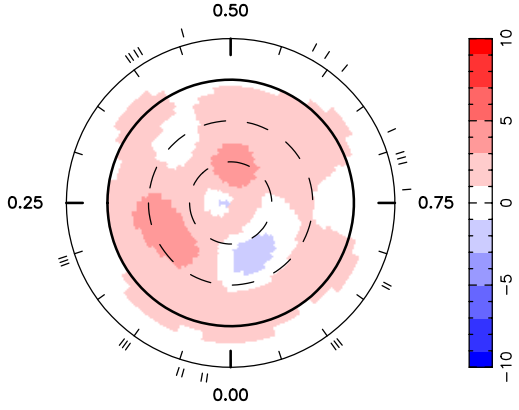


June '06 (Catala et al 2006)

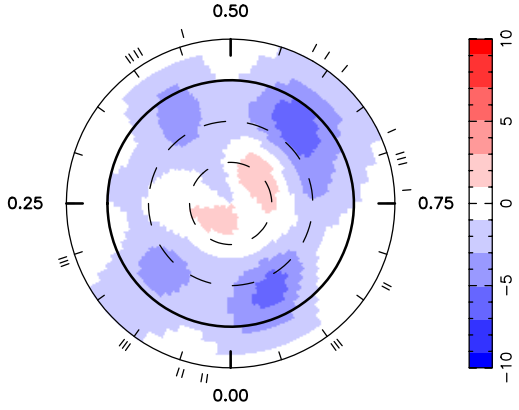
radial field



azimuthal field

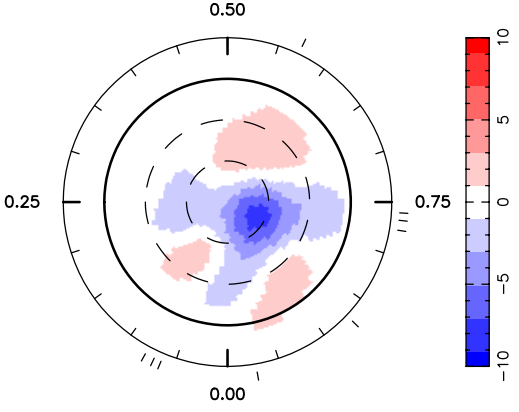


meridional field

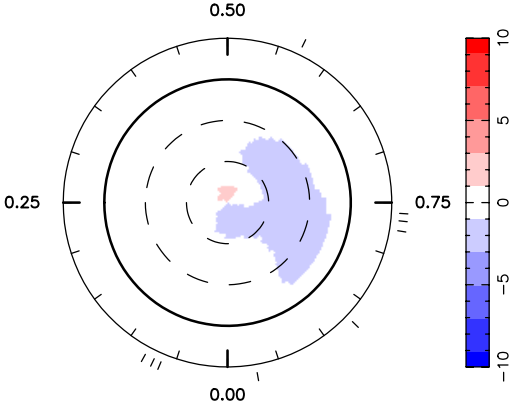


June '07 (Donati et al 2008)

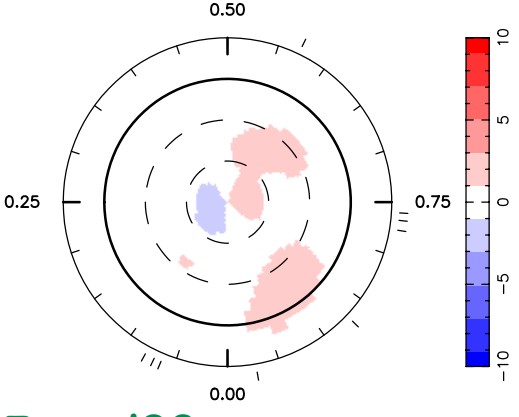
radial field



azimuthal field



meridional field



June '08 (Farès et al 2009)

other faces of dynamo

surface differential rotation

estimate rotation shear dΩ between successive magnetic images

Sun-like shears (sign & strength) in solar-type (GK) stars

supersolar shears (x5) in F stars w/ very shallow convection

subsolar shears (÷5) in fully-convective M stars

activity cycles

magnetic cycles from long-term evolution

tau Boo (F7) : first magnetic cycle detected in star ≠ Sun

poloidal & toroidal fields flipping sign every 1.1yr

shallow CZ? strong differential rotation? close-in giant-planet?

& many others

local dynamos of RGB stars

> field detected on Betelgeuse (Aurière et al 2010)

dynamos of young protostars

accretion discs dynamos & planet formation

prospects

coordinated observations & simulations : MagIcS

worldwide program w/ ESPaDOnS@CFHT & NARVAL@TBL

coordinated multi-wavelength campaigns (Xray, UV, nIR, radio)

> explore HR diagram & the many faces of dynamo

theoretical predictions from numerical simulations

toroidal/poloidal, axymmetry, large/small scales, differential rotation

SPIRou @ CFHT?

nIR cryogenic spectropolarimeter/velocimeter (1-2.4 μm)

> magnetic topologies of low-mass dwarfs & young Suns

> habitable exo-Earths around M dwarfs