# Rotation, Activity, and Convection

## *Issues and Perspectives*

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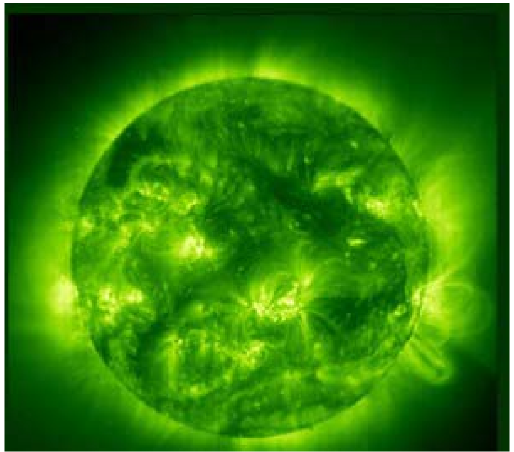


# Relevance

Rotation, convection, B-fields → dynamo

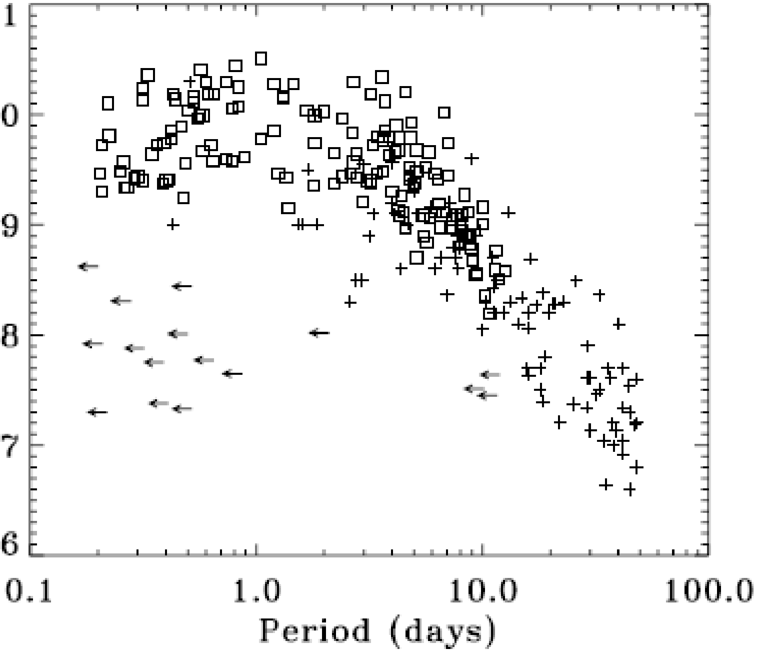
Magnetic fields → activity on all time scales

Irradiance Variability

Variability in energetic particle fluence

Affects ambient radiative and particle environments of extrasolar planetary systems

Interaction of magnetic fields and winds



X-ray luminosity vs. rotation period of field dwarfs (crosses) uster stars (squares). Leftward arrows indicate field stars with s derived from *v* sin *i* data.

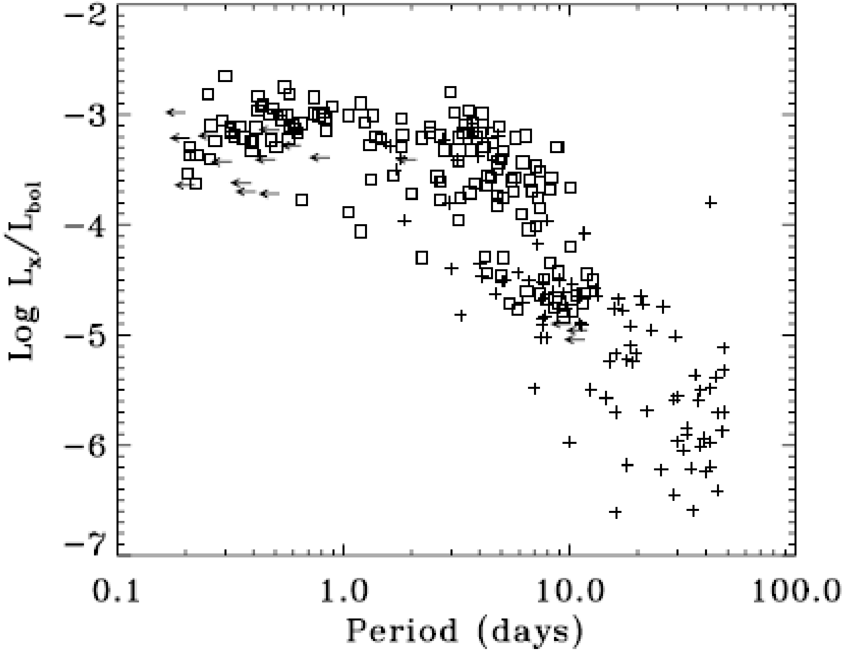
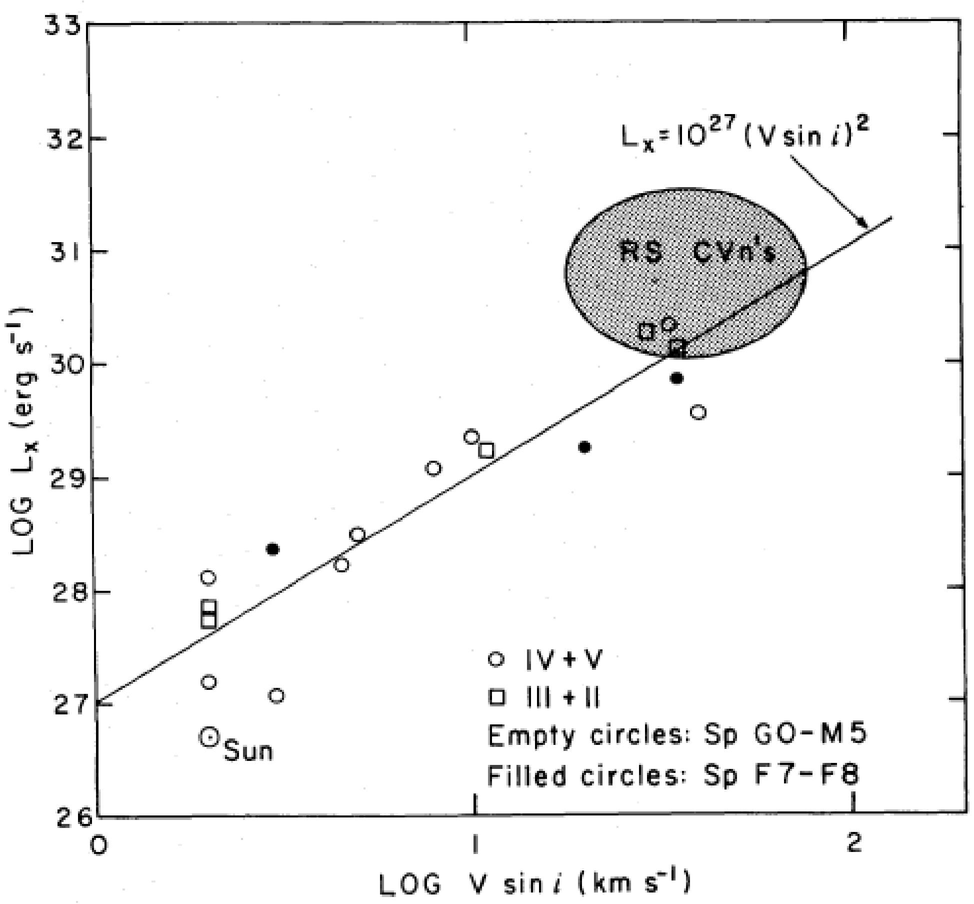


**Fig. 4.** X-ray to bolometric luminosity ratio vs. rotation period for field dwarfs (crosses) and cluster stars (squares). The meaning of the leftward symbols is the same as in Fig. 3.

PALLAVICINI *ET AL.* **1981**



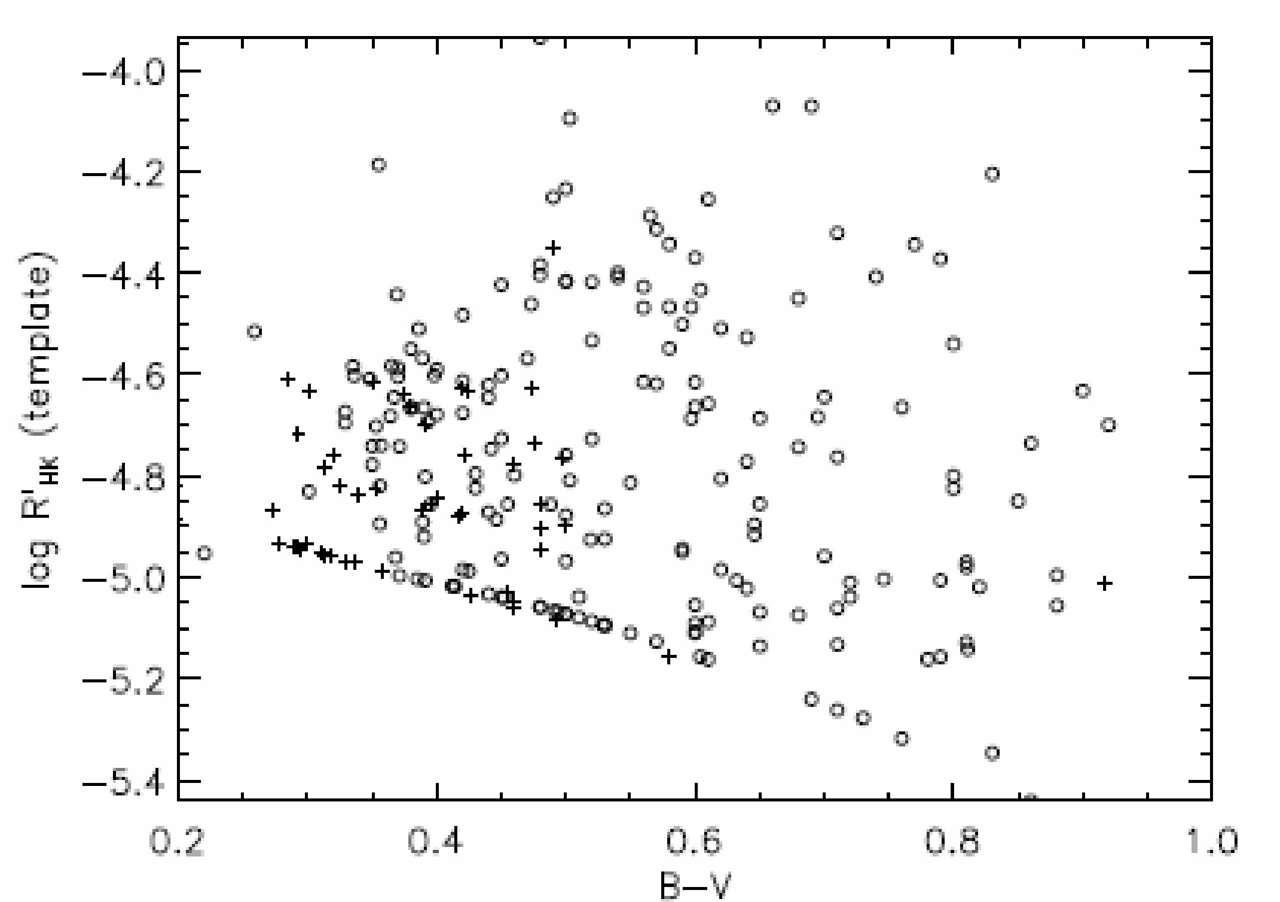


**Fig. 13.** Template $R'_{\mathrm{HK}}$ values plotted over $B-V$. Main-sequence stars are represented by circles, giant stars with "+" symbols. The $B-V$ values range from 0.22 to 0.92. A clear decrease in Ca II H&K activity can be seen in the hottest stars of the sample.

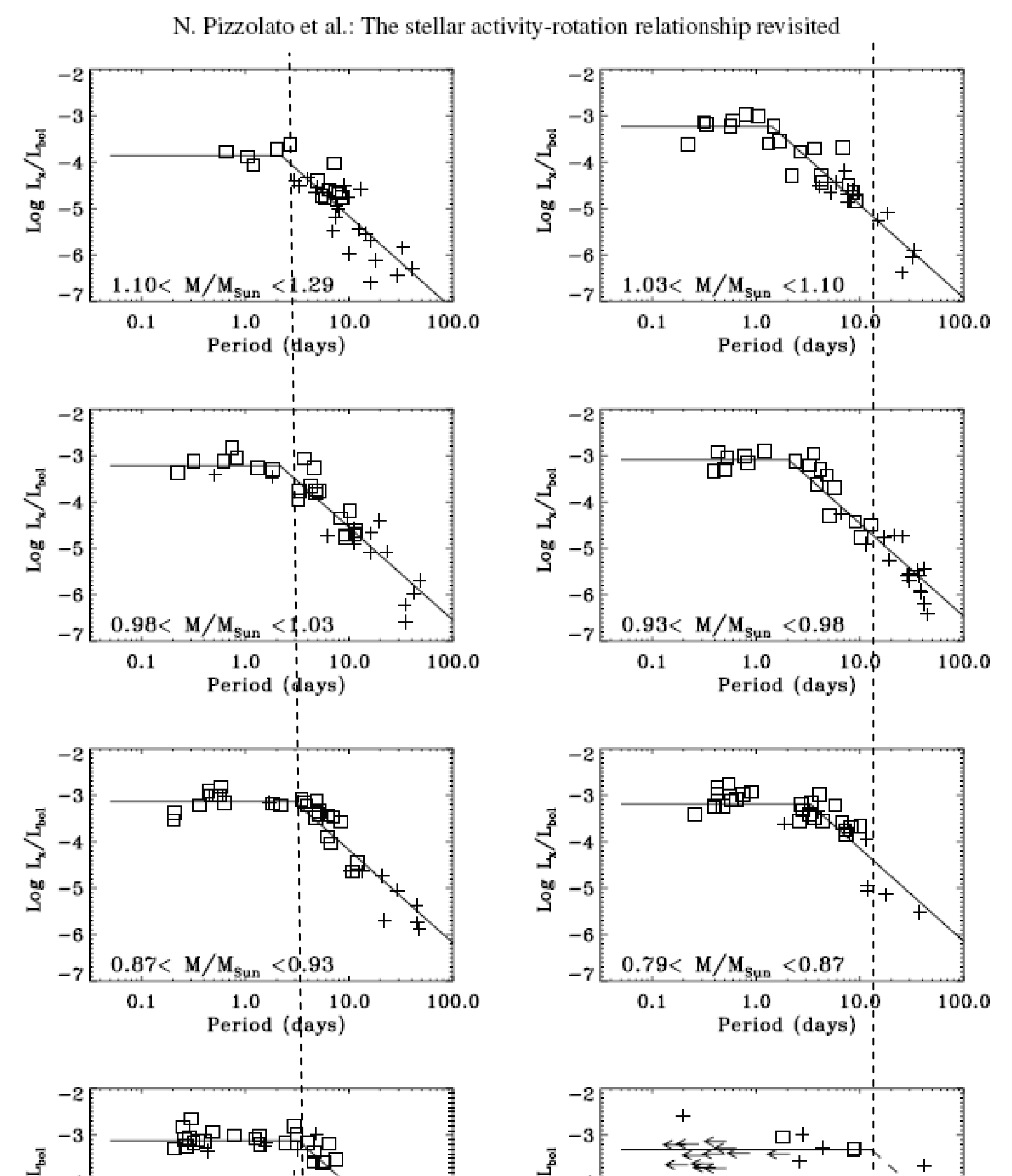
# Onset of solar-dynamo activity

Onset of chromospheric activity in range of $0.1 \leq B\text{-}V \leq 0.2$, or A7-8 V

Increasing magnetic field-related chromospheric and coronal emission with more rapid surface rotation

“Saturation” at $L_x/L_{bol} \sim 10^{-3}$

Decreasing dynamo efficiency in limit of thin convection zones



N. Pizzolato et al.: The stellar activity-rotation relationship revisited

# Activity vs. rotation

Similar linear relation between period and $L_x/L_{bol}$ (or $L_x$) independent of fractional convection zone depth

Increasing efficiency for onset of ‘saturation’ toward greater fractional convection zone depths (i.e., saturation at lower rotation rates)

January 2009|**doi:10.1038/nature07626** nature

LETTERS

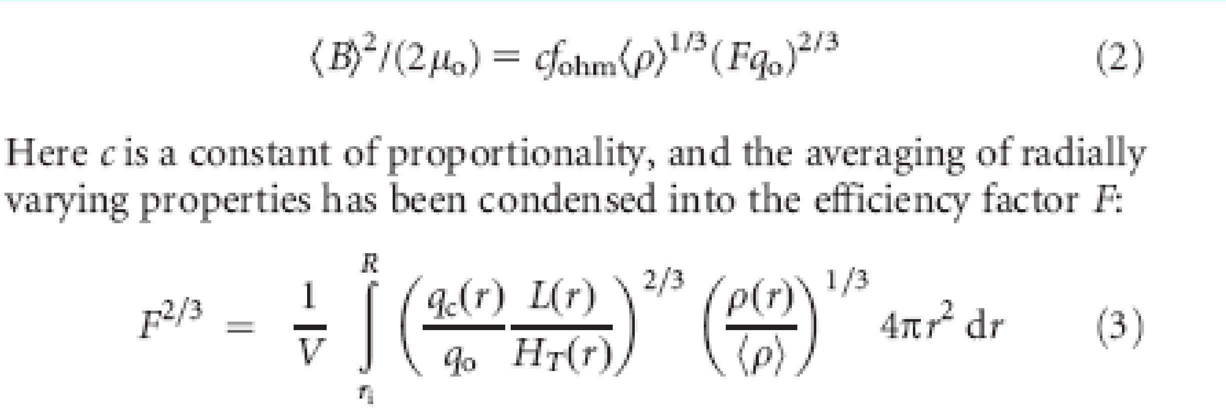
# rgy flux determines magnetic field strength of nets and stars

. Christensen[1], Volkmar Holzwarth[1] & Ansgar Reiners[2]

**The magnetic fields of Earth and Jupiter, along with those of rapidly rotating, low-mass stars, are generated by convection-driven dynamos that may operate similarly[1–4] (the slowly rotating Sun generates its field through a different dynamo mechanism[5]). The field strengths of planets and stars vary over three orders of magnitude, but the critical factor causing that variation has hitherto been unclear[5,6]. Here we report an extension of a scaling law derived from geodynamo models[7] to rapidly rotating stars that have strong density stratification. The unifying principle in the scaling law is that the energy flux available for generating the magnetic field sets the field strength. Our scaling law fits the observed field strengths of Earth, Jupiter, young contracting stars and rapidly rotating low-mass stars, despite vast differences in the physical conditions of the**

# Application of geodynamo models

- Scaling theory for field strength of (rapidly rotating) planetary dynamos (e.g., Earth, Jupiter, etc.) applied to rapidly rotating, fully convective stars (low mass, T Tauri)
- Thermal flux converted to magnetic energy to sustain it against ohmic dissipation



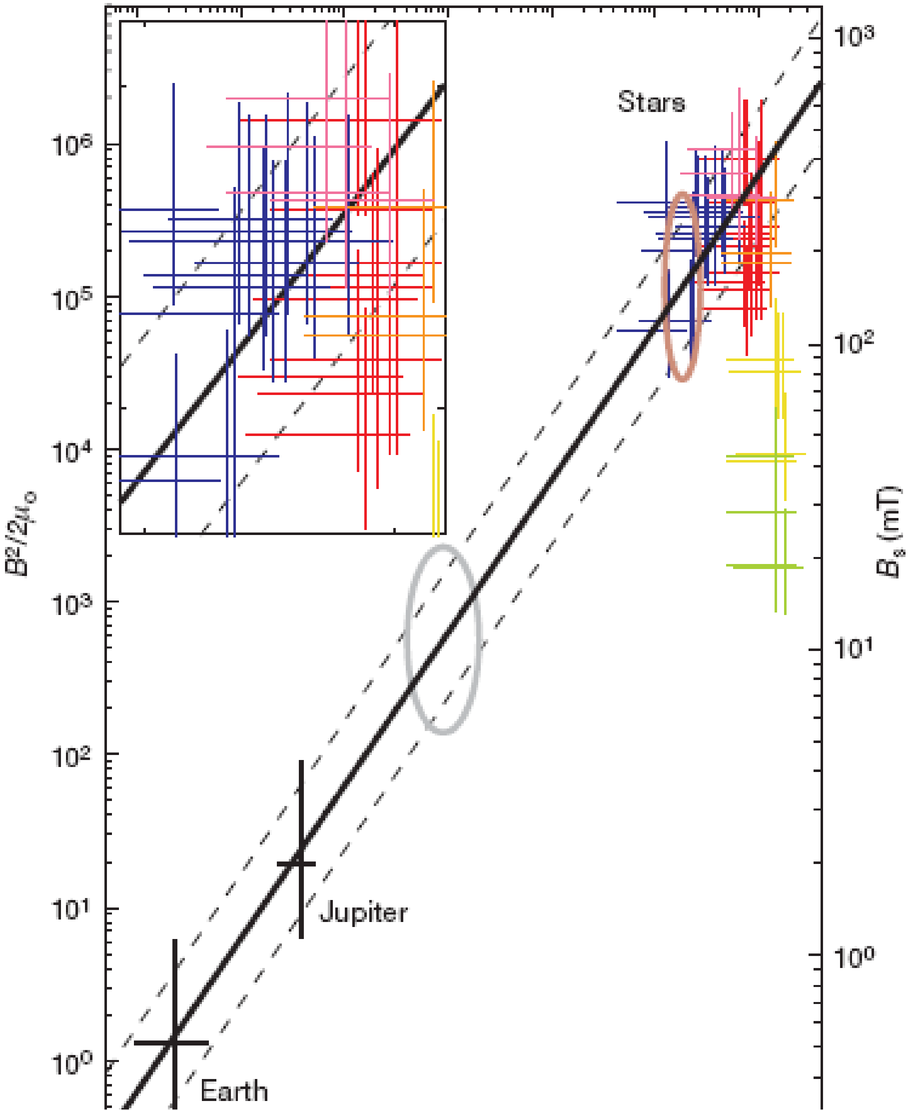
$$\langle B\rangle^2/(2\mu_o) = c f_{\mathrm{ohm}}\langle\rho\rangle^{1/3}(Fq_o)^{2/3} \tag{2}$$

Here $c$ is a constant of proportionality, and the averaging of radially varying properties has been condensed into the efficiency factor $F$:

$$F^{2/3} = \frac{1}{V}\int_{r_i}^{R}\left(\frac{q_c(r)}{q_o}\frac{L(r)}{H_T(r)}\right)^{2/3}\left(\frac{\rho(r)}{\langle\rho\rangle}\right)^{1/3}4\pi r^2\,\mathrm{d}r \tag{3}$$

sen et al. (2009)

$$^2/(2\mu_o) = cf_{\mathrm{ohm}}\langle\rho\rangle^{1/3}(Fq_o)^{2/3}$$



**Scaling law versus magnetic fields of planets and stars.**
nergy density in the dynamo versus a function of density and
flux (both in units of J m$^{-3}$). The scale on the right shows r.m.s.
th at the dynamo surface. The heat flow from Earth's core is
[26] but is in the range 30–100 mW m$^{-2}$. The effective convected
ing compositional convection is about twice as large
ntary Information); we use $q_o = 100$ mW m$^{-2}$, $\langle\rho\rangle = 10^4$ kg m$^{-3}$
35. For Jupiter[27], $q_o = 5.4$ W m$^{-2}$ and $\langle\rho\rangle = 1{,}330$ kg m$^{-3}$. For
ume $F = 1$. For T Tauri stars[15] (in blue) and old M dwarfs (in red
for total field is known[16], and in pink where the large-scale field
ed[2]), $q_o$ is obtained from the effective surface temperatures[15,16,28].
–1.1 solar masses[19] are shown in green for rotation periods
ellow for 4 d $< P <$ 10 d and orange for $P <$ 4 d. Where relevant
are not quoted, we use model-based relationships between
class, mass and luminosity[29,30]. We assume $f_{\mathrm{ohm}} \approx 1$ as a nominal
bar lengths show estimated uncertainty rather than formal error
ntary Information). Black lines show the rescaled fit from Fig. 1
certainties (solid and dashed lines, respectively). The stellar field
in the inset. Brown and grey ellipses indicate predicted locations

# Prediction from planetary dynamo scaling law

- Giant ESPs (5-10 Jupiter masses) should have field strengths 5-12 times Jupiter’s surface
- Possibility of detecting radio emissions from giant Jupiters?
- A lot of variation in magnetic properties of the group of stars considered
- Model with no density stratification not accurate for stars

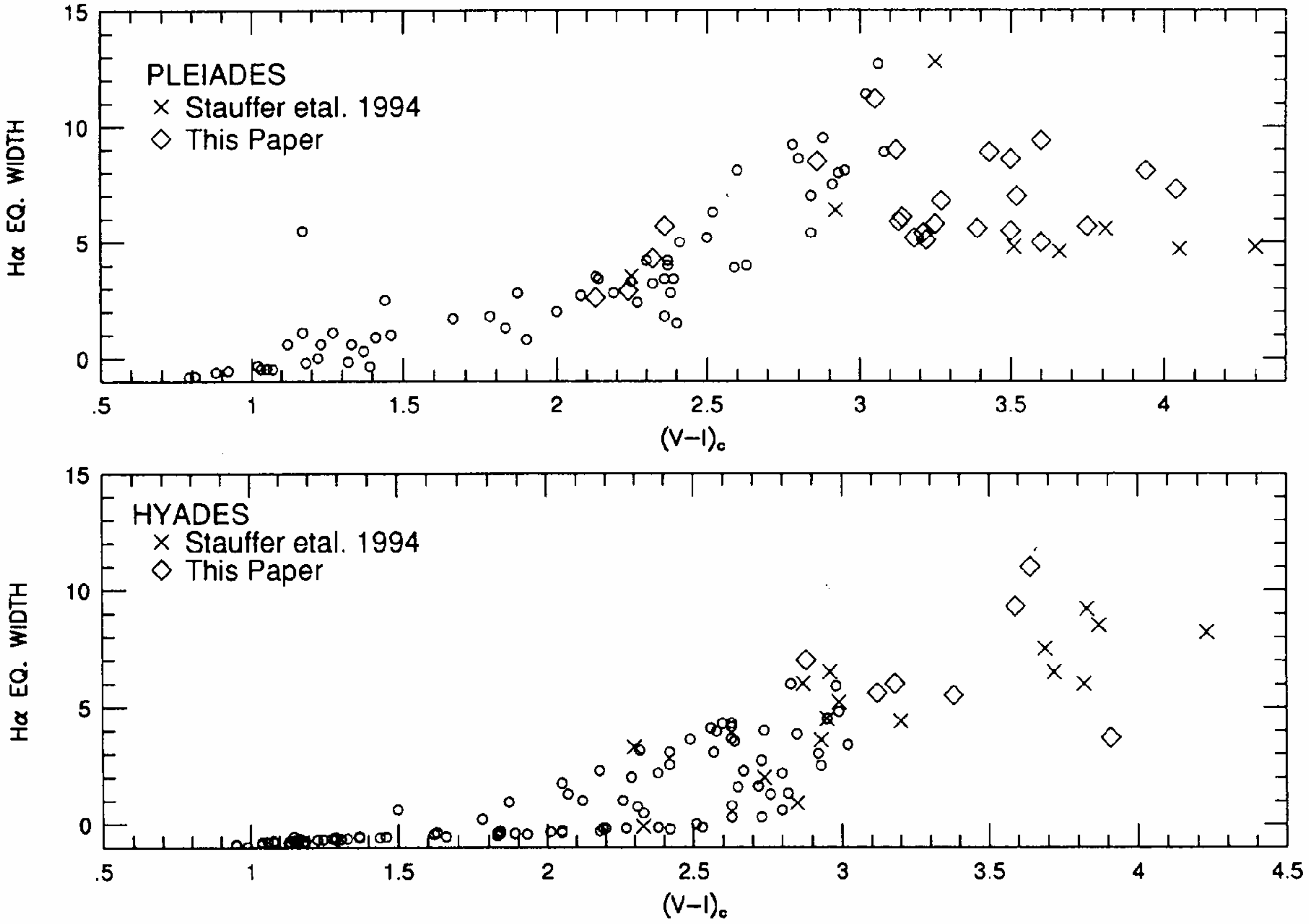
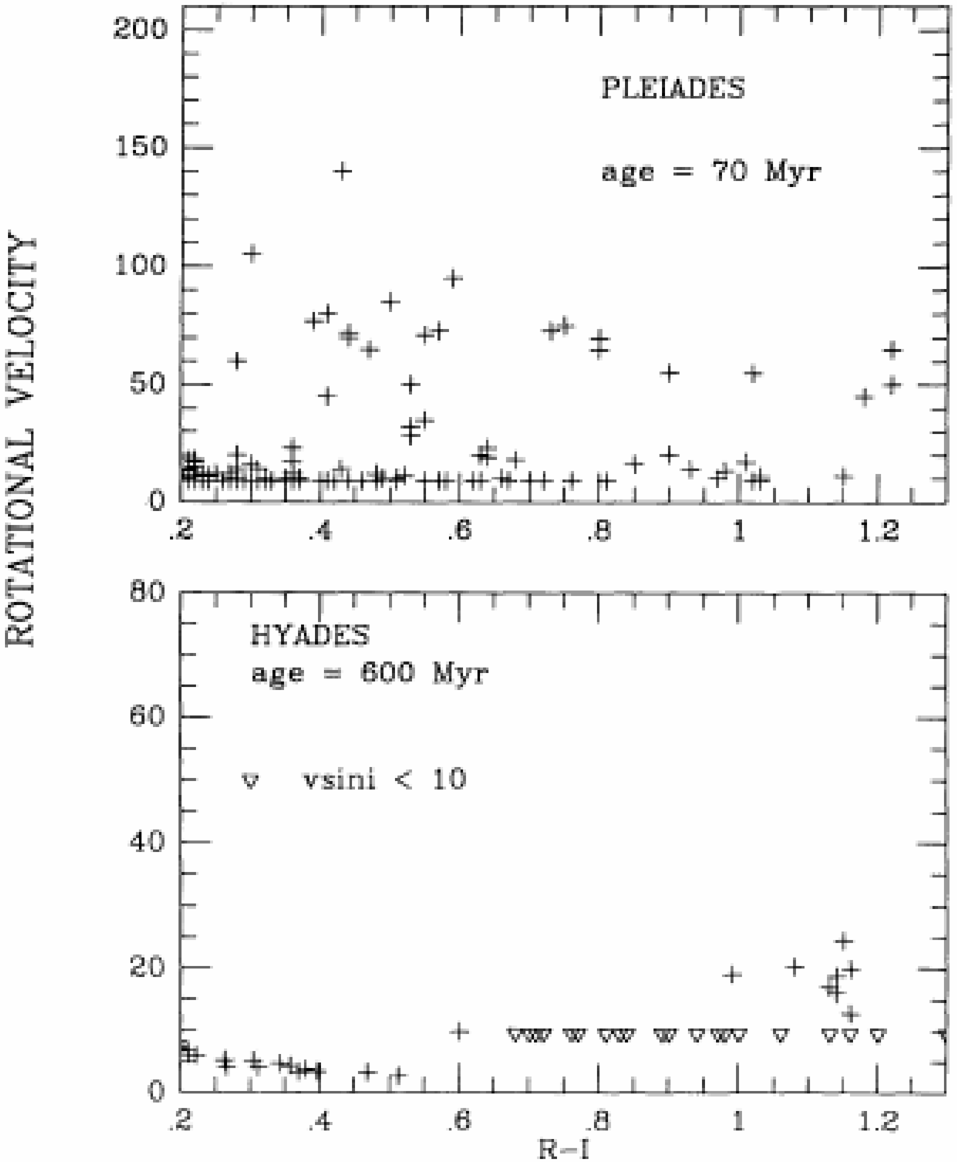
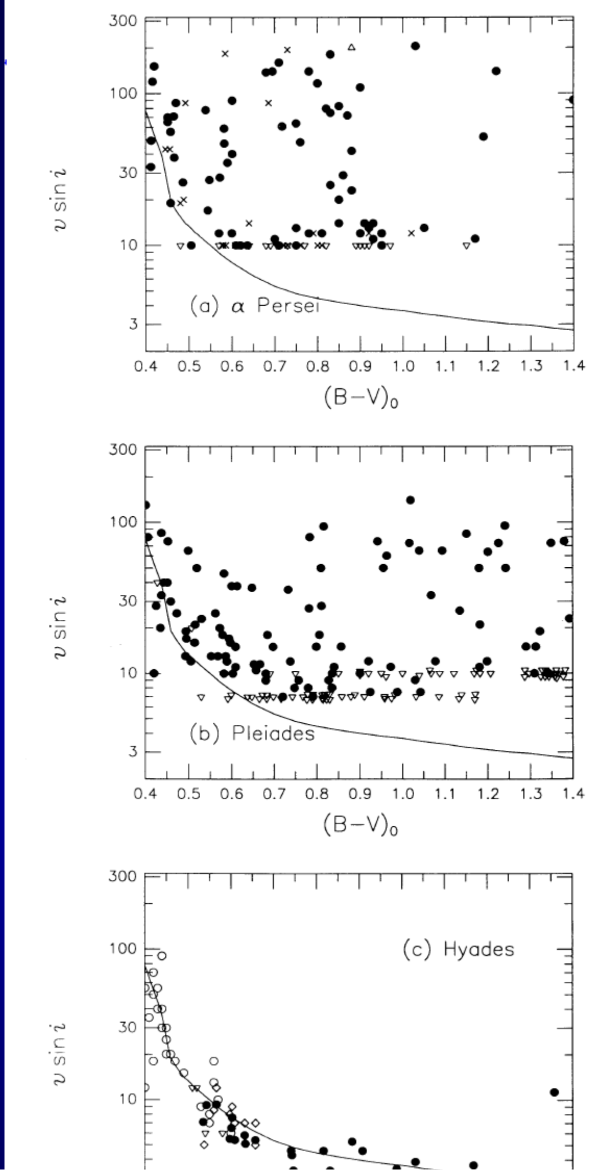


FIG. 13. Hα equivalent width for Pleiades and Hyades low mass stars as a


ROTATIONAL VELOCITY
PLEIADES
age = 70 Myr
200
150
100
50
0
.2
.4
.6
.8
1
1.2
HYADES
age = 600 Myr
▽ vsini < 10
80
60
40
20
0
.2
.4
.6
.8
1
1.2
R−I


(a) α Persei
(b) Pleiades
(c) Hyades
v sin i
(B−V)0
300
100
30
10
3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4

$$\frac{J}{t} = \frac{2}{3}\,\frac{dM}{dt}\;R^2\,\Omega\,\left(\frac{r_A}{R}\right)^m$$

**following Mestel (1984); Kawaler (1988); Durney (1993)**

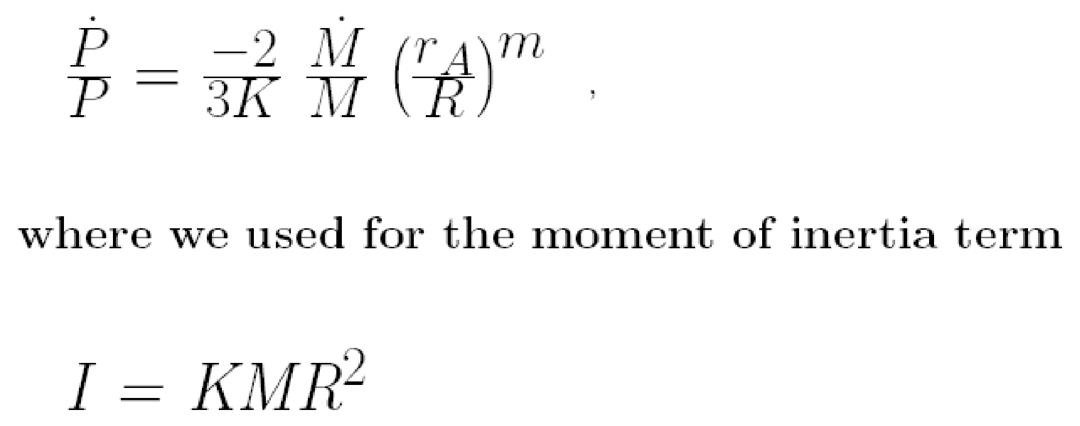
**= 2 for a radial field**

**= 1 for a dipole field**

$$\frac{dJ}{dt} = \Omega\,\frac{dI}{dt} + I\,\frac{d\Omega}{dt}$$

**Stellar Evolution**

Rewriting above in terms of **relative change** in **rotation period** and the moment of inertia



$$\frac{\dot{P}}{P} = \frac{-2}{3K}\,\frac{\dot{M}}{M}\,\left(\frac{r_A}{R}\right)^m \quad ,$$

where we used for the moment of inertia term

$$I = KMR^2$$

**Relevant quantities:**

- **mass loss rate**
- **stellar mass**
- **“K”– what is spinning down?**
- **magnetic field strength & geometry**

# n terms of surface magnetic field strength

$$\frac{\dot{P}}{P} \sim \rho^{1/2} \, \frac{B_s R^2}{KM} \left(\frac{r_A}{R}\right)^{m'}$$

Used that Alfven speed = wind speed at the Alfven surface;

mass continuity;

scaling of the decline of the surface magnetic field strength with distance out to the co-rotation radius

# Illustration……

$$\frac{\dot{P}}{P} \sim \rho^{1/2}\ \frac{B_s R^2}{KM}\ \left(\frac{r_A}{R}\right)^{m'}$$

ume similar wind densities and magnetic topologies.  In solar units:

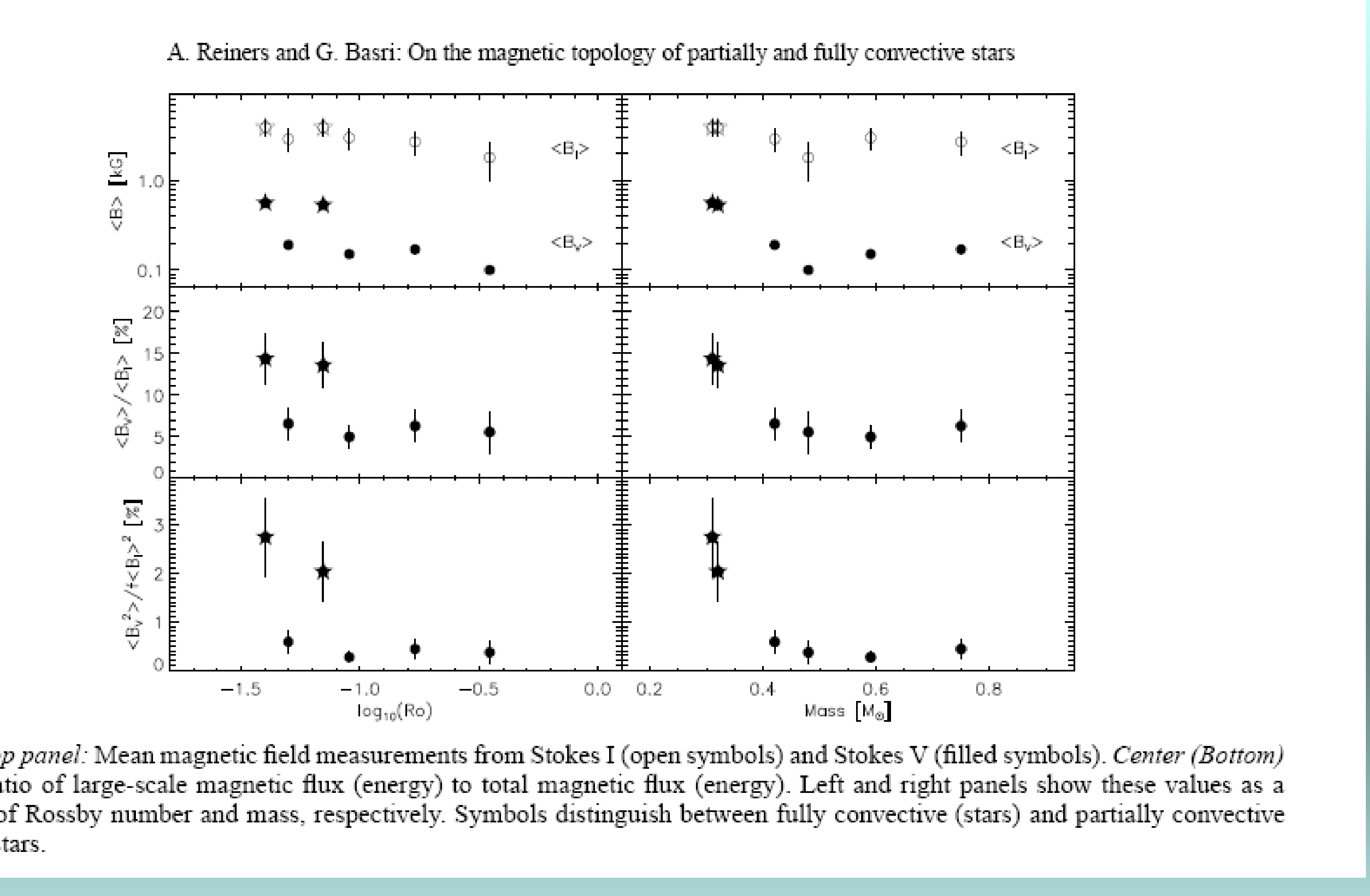
**3 V:  $BR^2/M \sim 0.3$,  with $B \sim 3000$ G, $R \sim 0.1$, $M \sim 0.1$**

**r very low mass (small) dwarfs, the total surface magnetic x is relatively low, suggesting slower spin-down**

**5 V: $BR^2/M \sim 0.6$, with $B \sim 2000$ G, $R \sim 0.3$, $M \sim 0.2$**

# Magnetic topologies in low mass stars

- Donati (2008): Abrupt change in large-scale magnetic topologies at ~ M3
- Early M—large-scale toroidal and non-axisymmetric poloidal configurations
- Later M—large-scale axisymmetric poloidal fields
- Rapid change in size of radiative core, e.g., $0.5R_*$ at $0.5\ M_{Sun}$ to negligible at



A. Reiners and G. Basri: On the magnetic topology of partially and fully convective stars

p panel: Mean magnetic field measurements from Stokes I (open symbols) and Stokes V (filled symbols). *Center (Bottom)* atio of large-scale magnetic flux (energy) to total magnetic flux (energy). Left and right panels show these values as a of Rossby number and mass, respectively. Symbols distinguish between fully convective (stars) and partially convective tars.

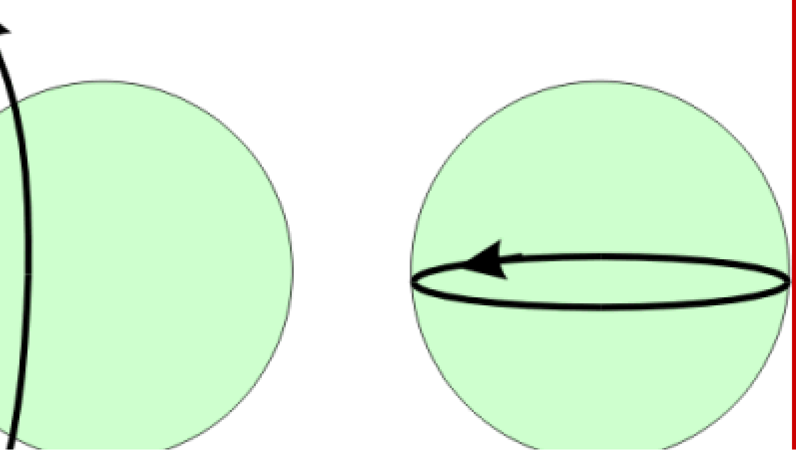
kes V – large scale field

arly M-dwarfs: 6% of total magnetic flux large-scale configurations

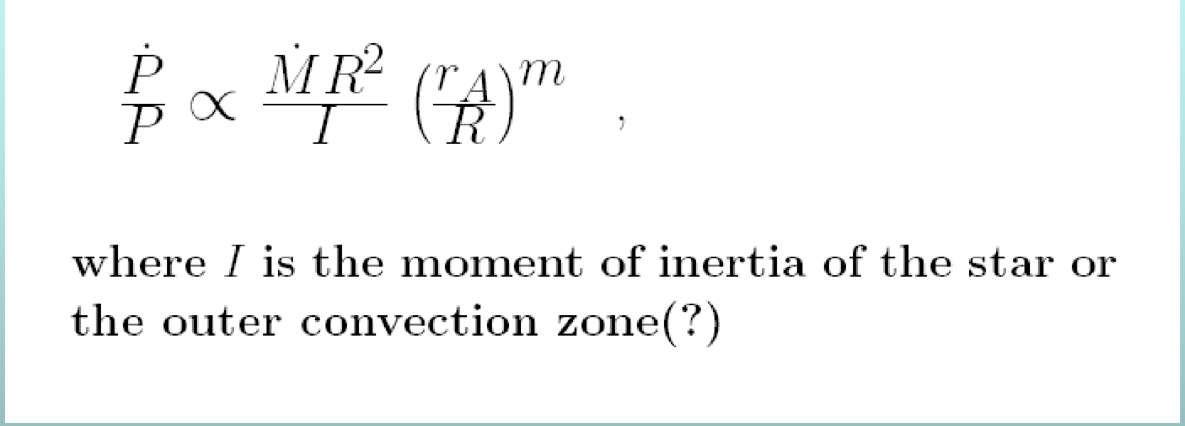
ully convective, mid-M dwarfs: 14%

***ulk of magnetic flux in small-scale omponents***

Reiners & Basri (2009)

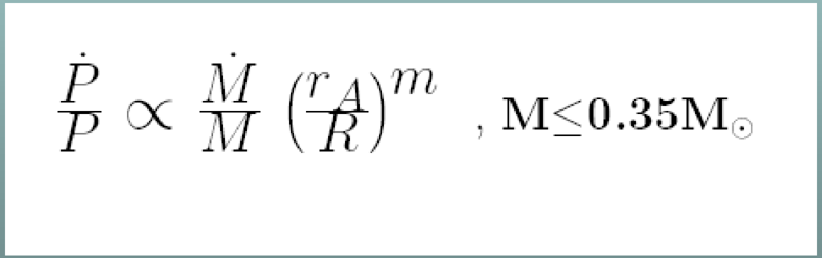


# Stellar ‘moment of inertia’



$$\frac{\dot{P}}{P} \propto \frac{\dot{M} R^2}{I} \left(\frac{r_A}{R}\right)^m \quad ,$$

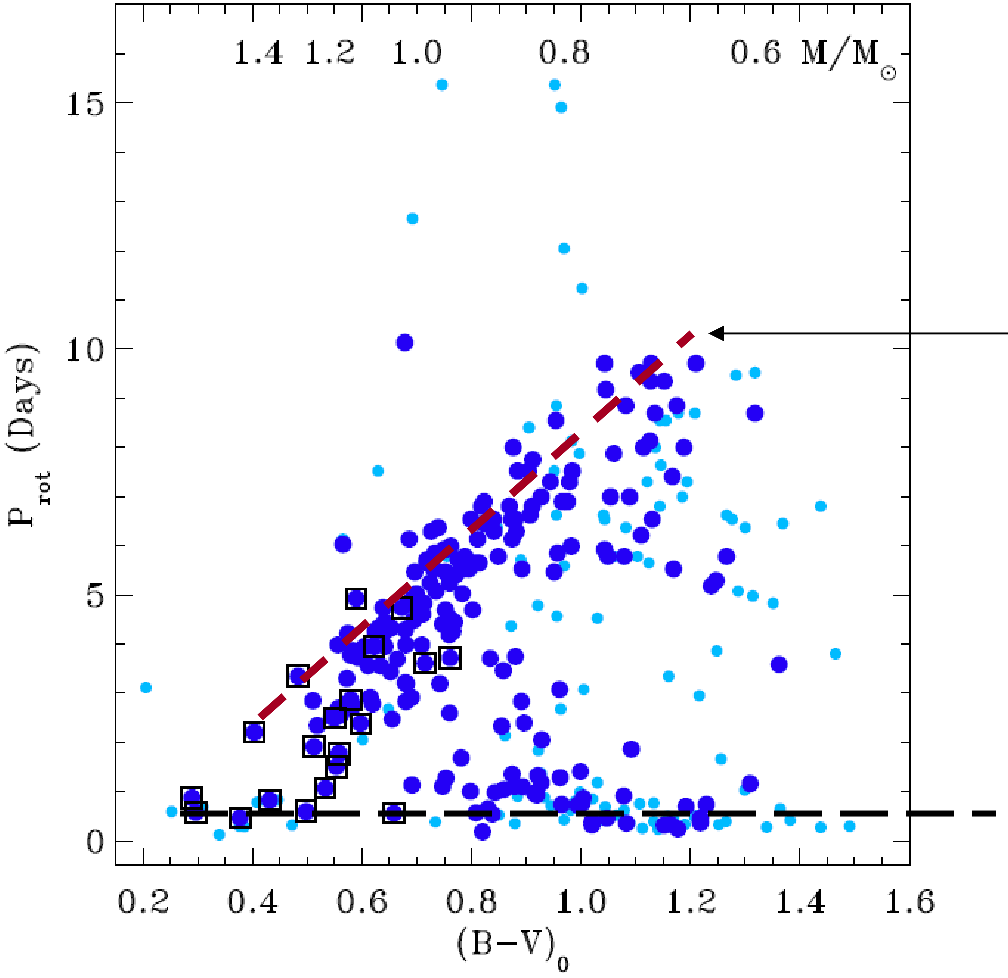
where $I$ is the moment of inertia of the star or the outer convection zone(?)



$$\frac{\dot{P}}{P} \propto \frac{\dot{M}}{M} \left(\frac{r_A}{R}\right)^m \quad , \mathrm{M} \leq 0.35 \mathrm{M}_\odot$$

**Fully convective stars**

## M35 (150 Myr)

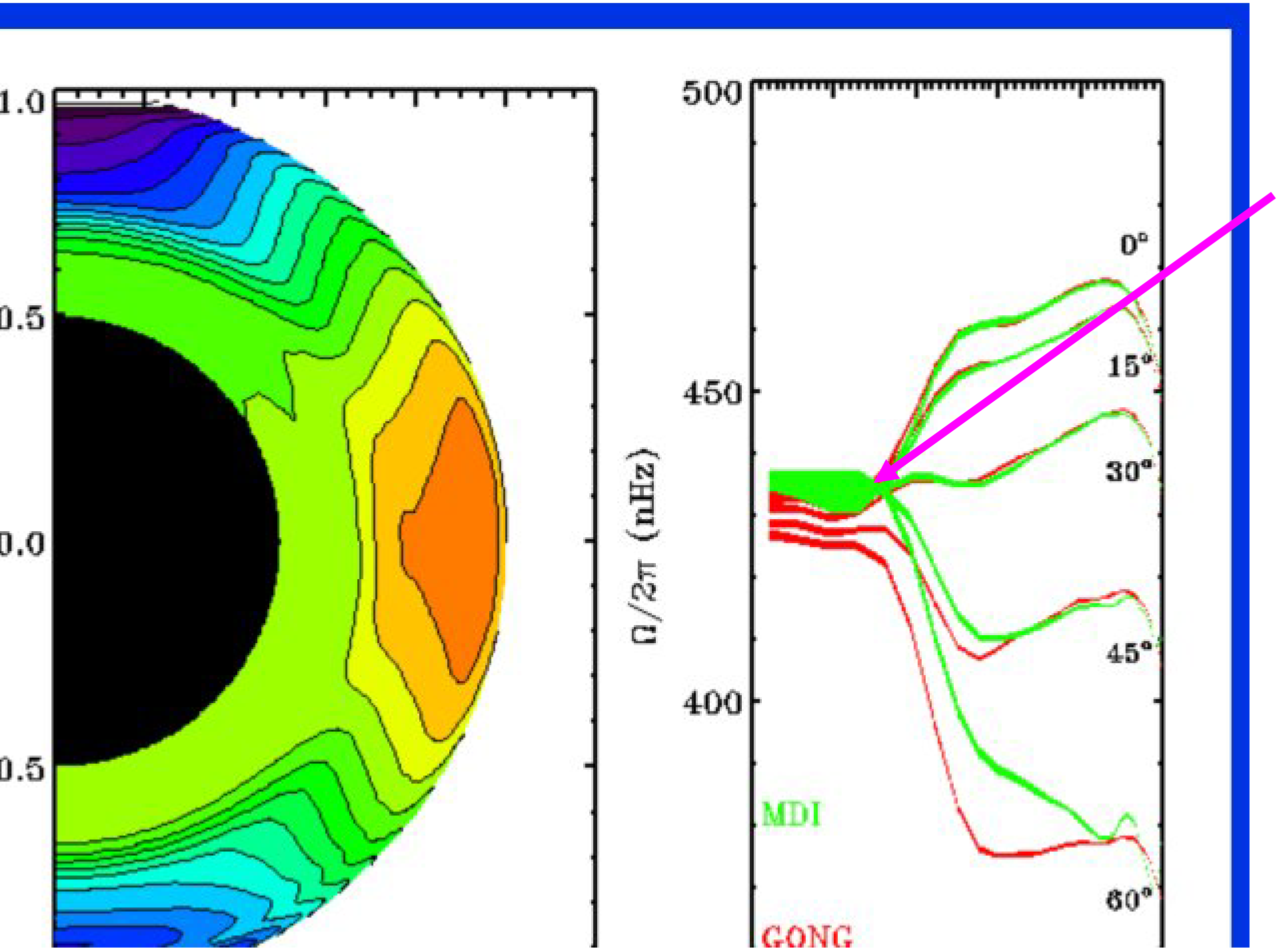


“I (interface) Sequence”—core and envelope coupled

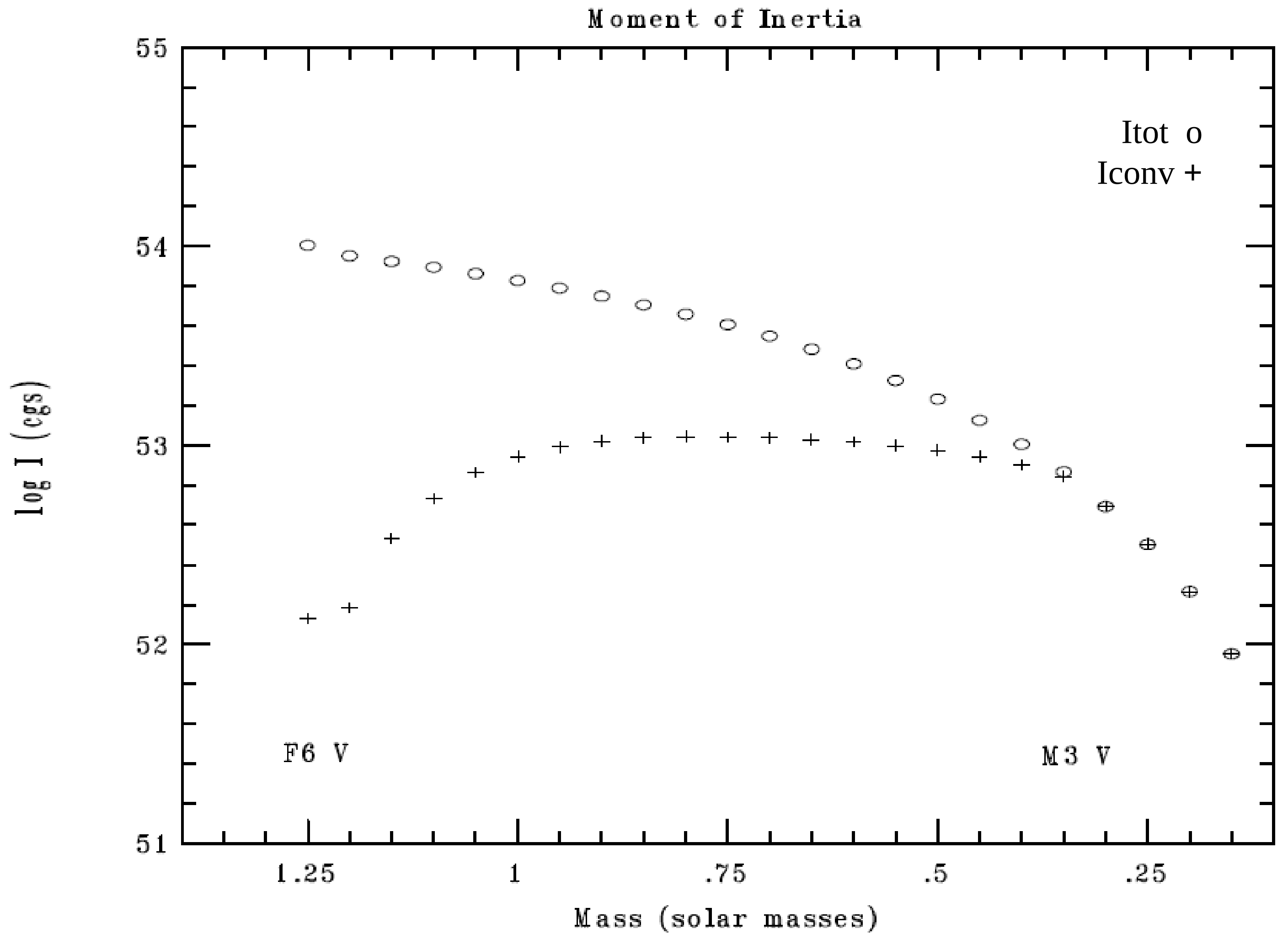
“C (Convective) Sequence”—decoupled radiative and convective cores

7.— The distribution of stellar rotation periods with (B-V) color index for 310 members
I35. Dark blue symbols represent stars that are both photometric and radial-velocity
bers of M35. Light blue symbols are used for stars that are photometric members only.
per-motion members are marked with additional squares. The upper x-axis gives a stellar

# Sun’s Internal Rotation



Tachocline



$$\dot{P} \quad \dot{M} R^2 \ (r_A)^m$$

# Perspectives and Issues….

- In low mass stars, evidence for compact field topologies **and** large-scale fields
- How do we reconcile slow spin-down with extended field structures at low stellar mass?
- “Seamless” transition in chromospheric/coronal emission properties from partial to fully convective interior
- Transition from partial to full convection manifested in changing magnetic field topologies
- Fractional convection zone depths may be most relevant to magnetic cycle properties

Are relative mass-loss rates similar from F to M?

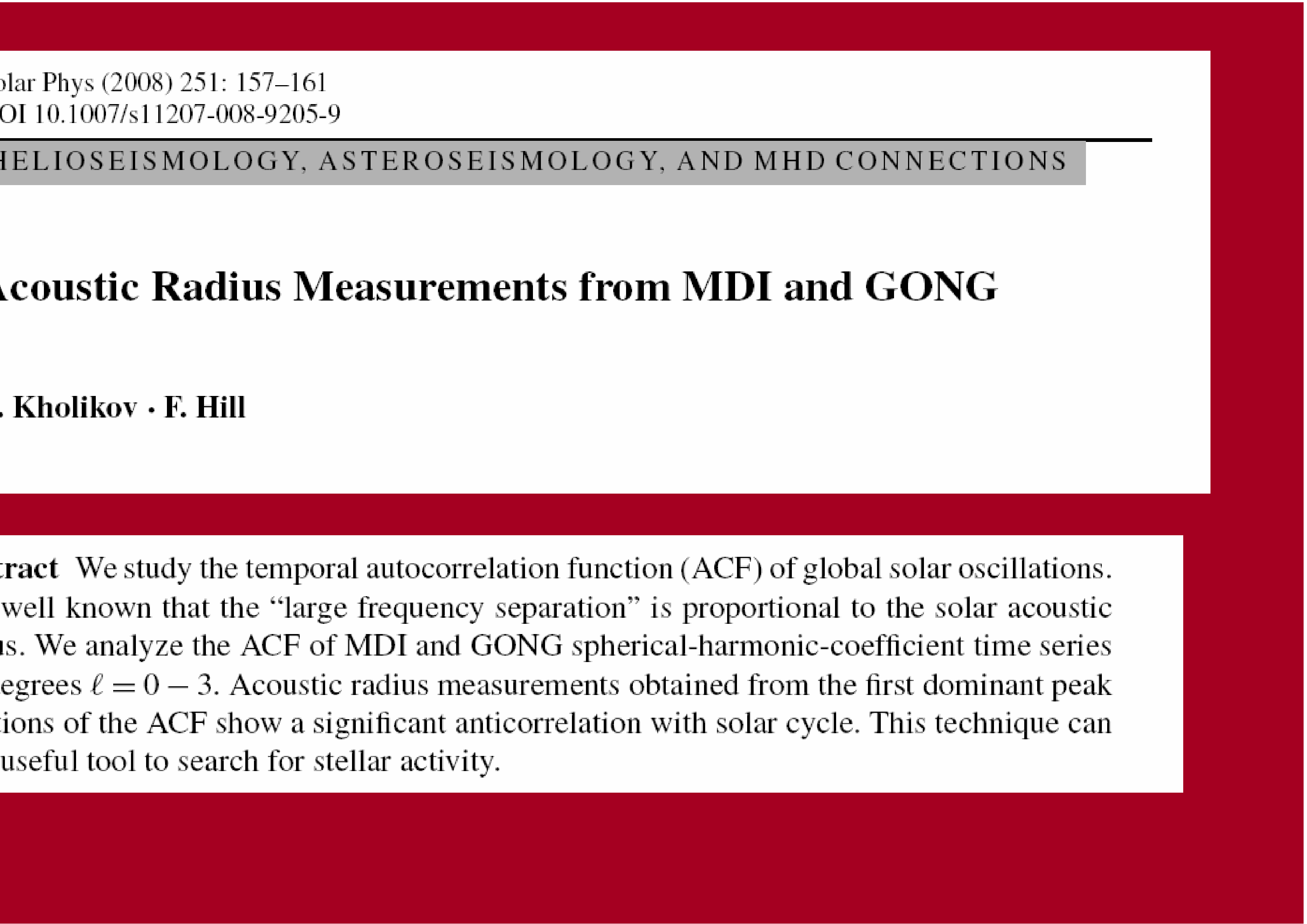
What is spinning down?

- — Is it the whole star?
- — Is it just the outer layers?

Can the outer convection zone and radiative interior “decouple” and “recouple”?

Is stellar spin-down a smooth function of time?

Can we detect solar-like cycles at the limits of thin and thick convection zones?



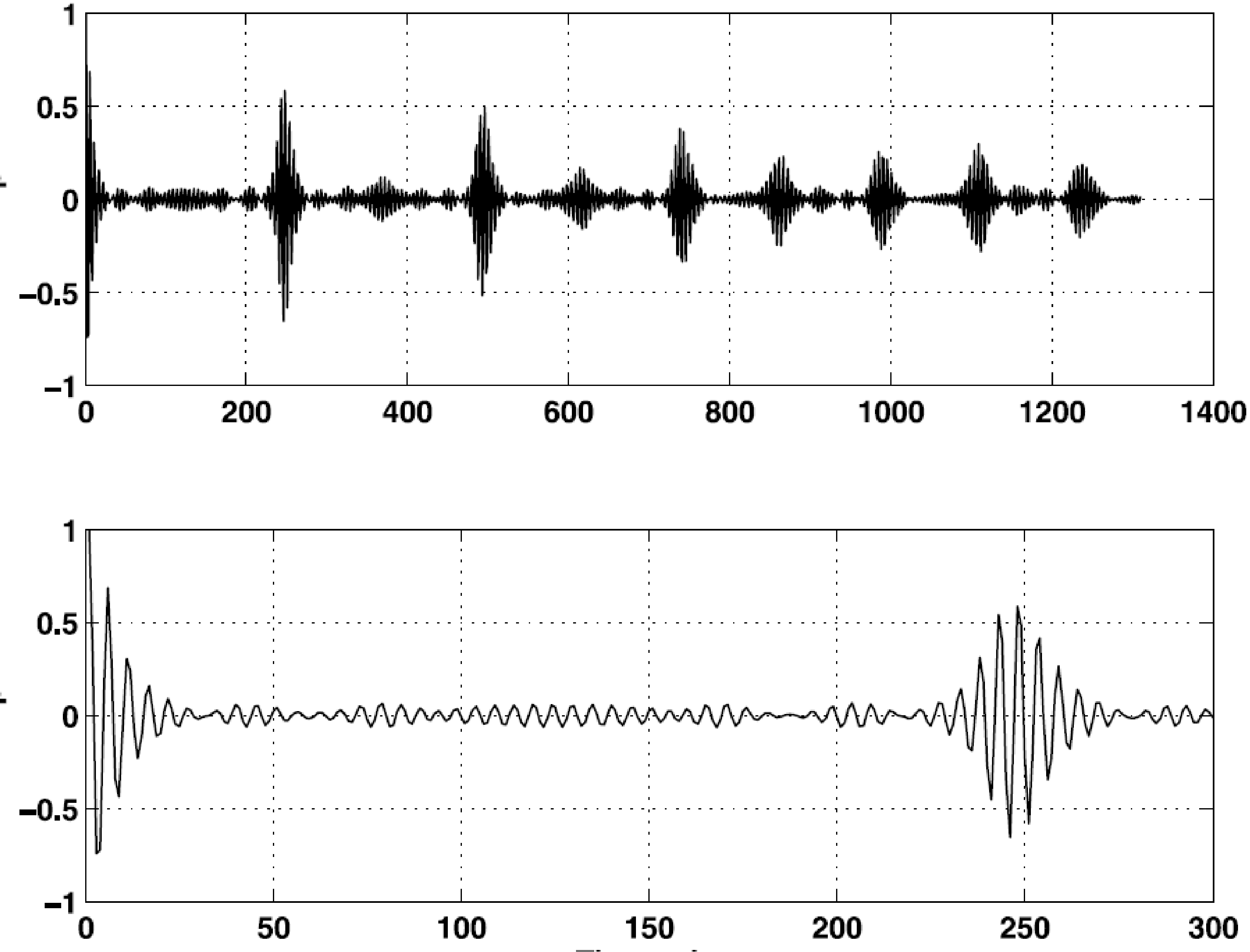
olar Phys (2008) 251: 157–161
OI 10.1007/s11207-008-9205-9

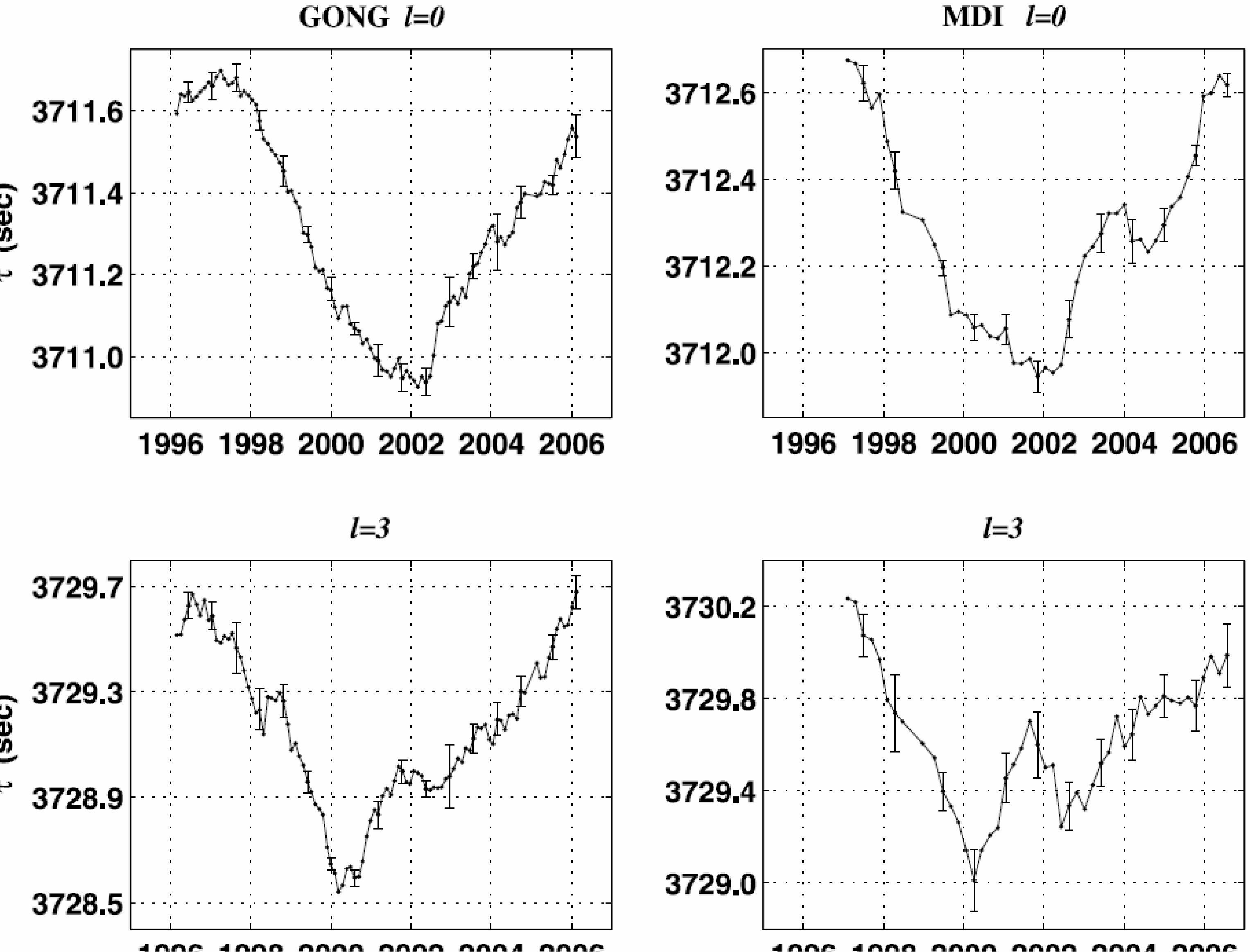
HELIOSEISMOLOGY, ASTEROSEISMOLOGY, AND MHD CONNECTIONS

# coustic Radius Measurements from MDI and GONG

. Kholikov · F. Hill

**tract** We study the temporal autocorrelation function (ACF) of global solar oscillations. well known that the "large frequency separation" is proportional to the solar acoustic us. We analyze the ACF of MDI and GONG spherical-harmonic-coefficient time series egrees $\ell = 0 - 3$. Acoustic radius measurements obtained from the first dominant peak tions of the ACF show a significant anticorrelation with solar cycle. This technique can useful tool to search for stellar activity.


1
0.5
0
−0.5
−1
0
200
400
600
800
1000
1200
1400
1
0.5
0
−0.5
−1
0
50
100
150
200
250
300


**GONG** *l=0*

**MDI** *l=0*

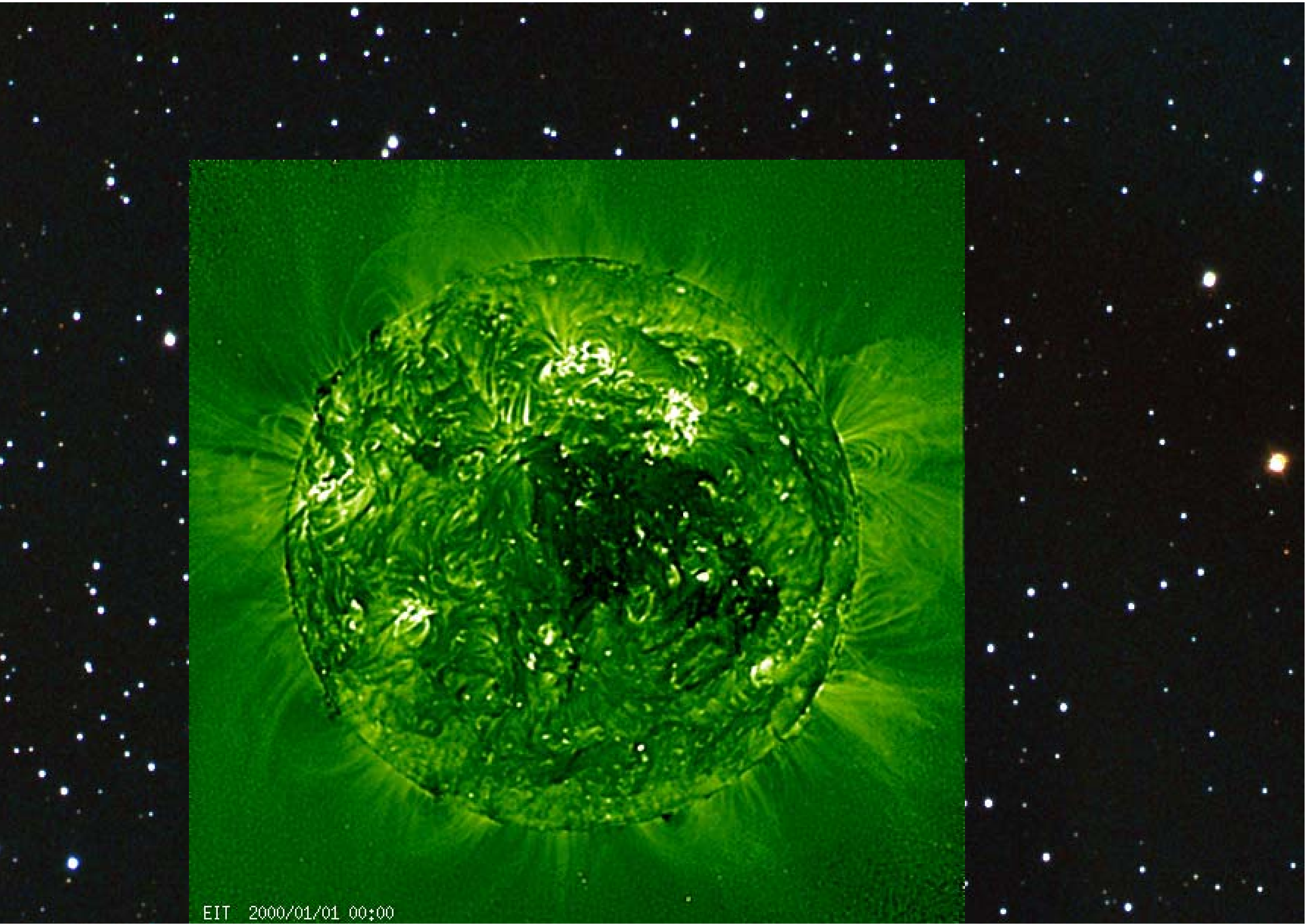
*l=3*

*l=3*

From stars to habitable planets

# ....applications

- Acoustic radius variations as diagnostic of surface magnetic structure
- High sensitivity measurements of low-amplitude rotational modulation for slow (Sun-like) rotators


EIT 2000/01/01 00:00