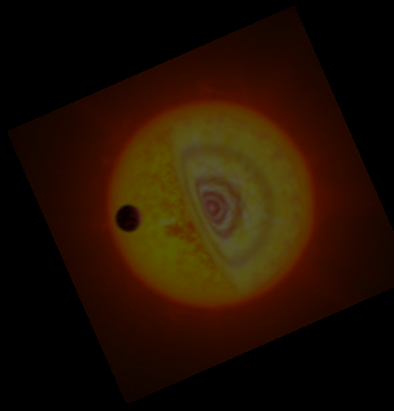
MAGNETIC ACTIVITY & CYCLES

USING SEISMIC OBSERVARTIONS



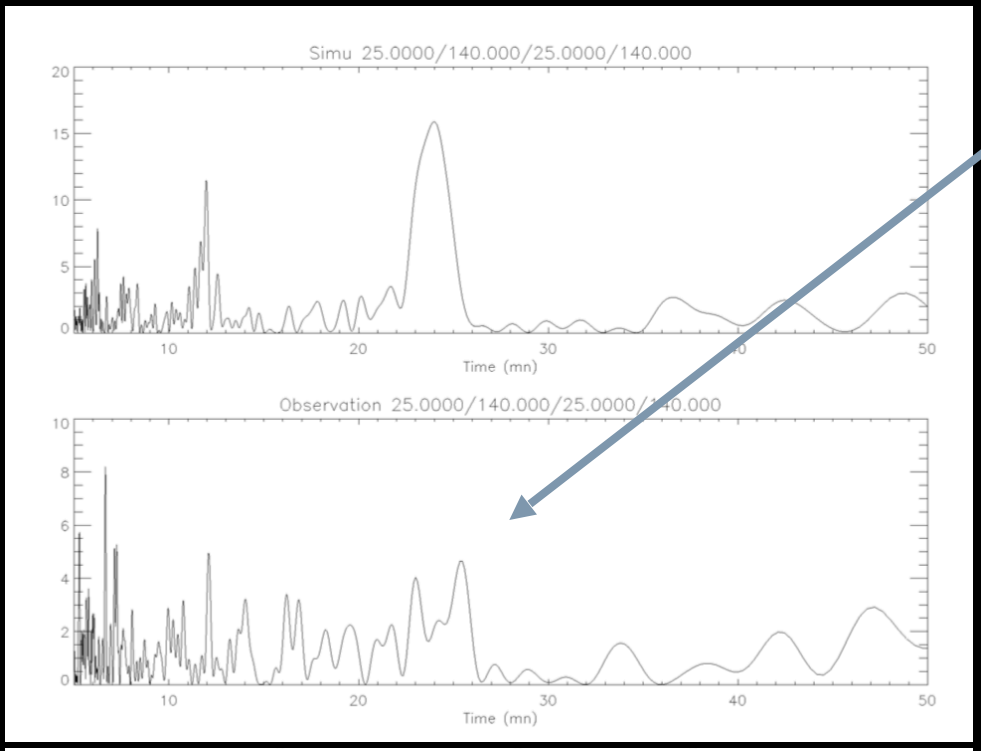
Rafael A. García

Astrophysics Department, CEA-Saclay, France

ON THE G-MODE PATTERN DETECTION IN 2007

THE INTERNAL STRUCTURE OF THE SUN INFERRED FROM G MODES AND LOW-FREQUENCY P MODES

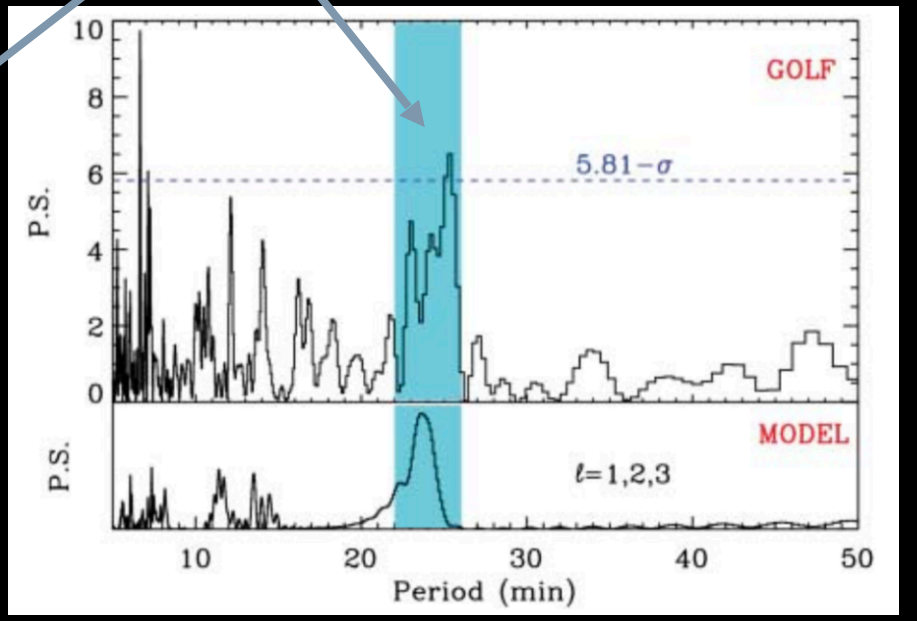
Y. Elsworth[1], F. Baudin[2], W. Chaplin[1], B. Andersen[3], T. Appourchaux[2], P. Boumier[2], A.-M. Broomhall[1], T. Corbard[4], W. Finsterle[5], C. Fröhlich[5], A. Gabriel[2], R.A. García[6], D.O. Gough[7,8], G. Grec[4], A. Jiménez[9], A. Kosovichev[10], J. Provost[4], T. Sekii[11], T. Toutain[1], and S. Turck-Chièze[6]



In the case of the GOLF data, the comb-like structure is much less clear.

Elsworth, Baudin et al. 2006

Really not similar ?



García et al. 2007

GENERAL OUTLINE

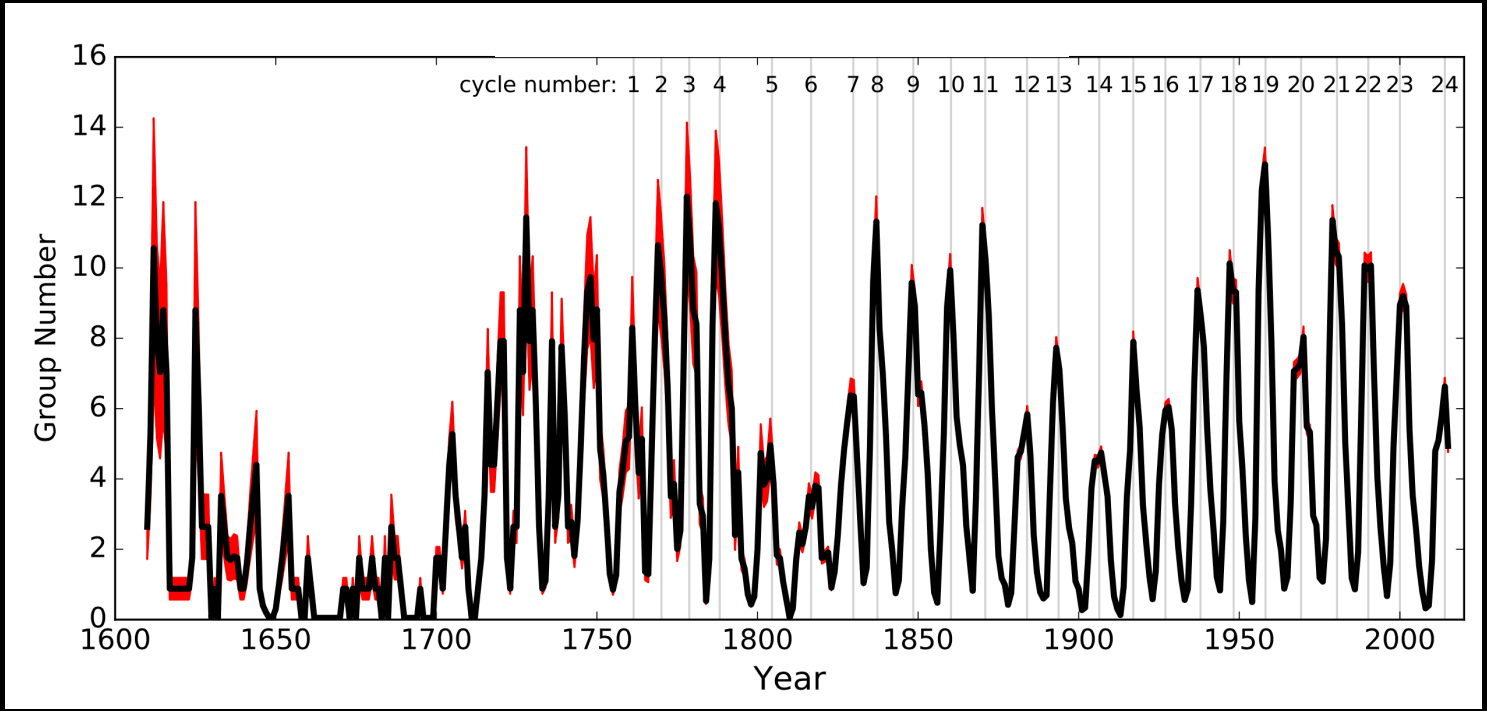
- I- Introduction
  - Magnetic Activity Cycles
    - Generalities
- II- What high precision photometry can offer to the study of
  - magnetic activity
  - And cycles
- III- How magnetic activity cycles affect HPP measurements and seismology?
  - Lessons from the study of the Sun
- IV- Stellar magnetic activity cycles from CoRoT and *Kepler*

I-Introduction:

Magnetic Activity Cycles

I-INTRODUCTION

- Low-mass stars
  - Convective external region
- Rotation + Convection + Magnetic fields
  - Magnetic dynamos and Magnetic activity cycles (11 yr, 87 yr, …)



Data from SILSO, Royal Observatory of Belgium

[Svalgaard & Schatten 2016]

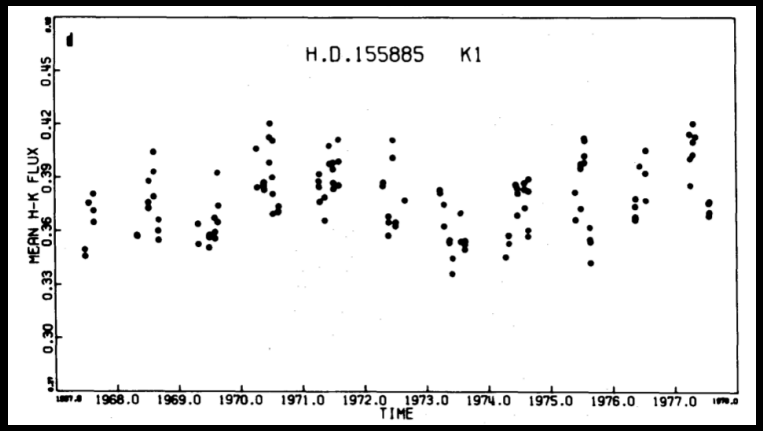
I-INTRODUCTION

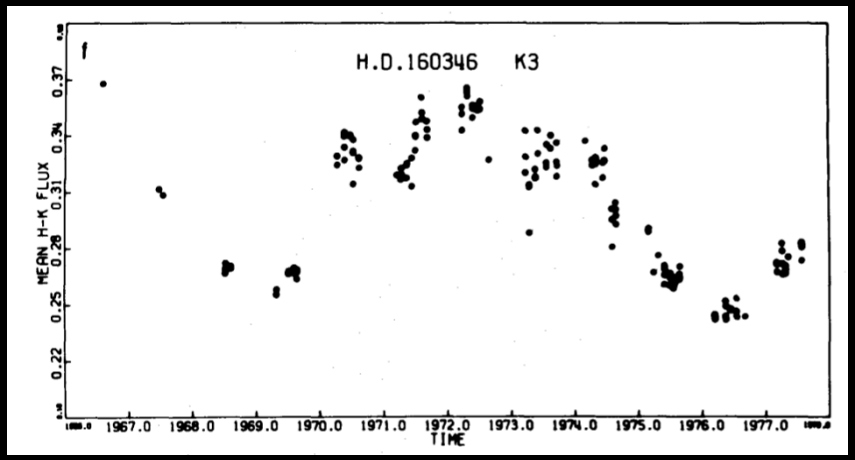
Are other stars with variable magnetic activity and magnetic activity cycles?

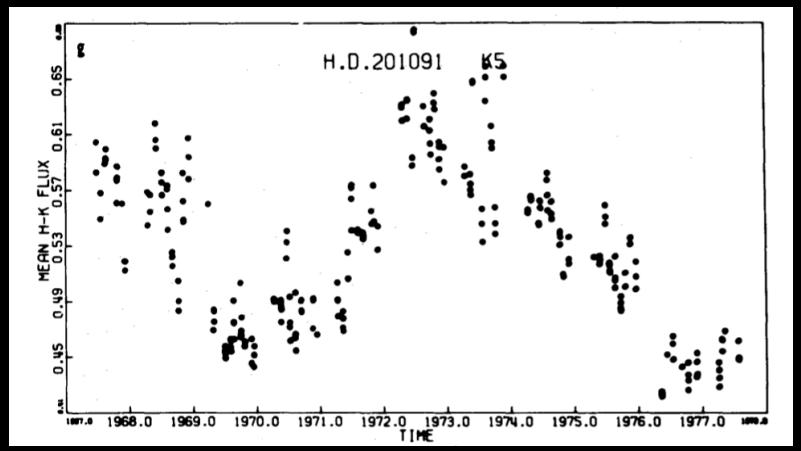
- Thanks to long-term synoptic observations of the Ca II H and K lines at Mount Wilson
  - MWO HK survey measured the emission of plasma in the chromosphere which results from the nonthermal heating that occurs in the presence of strong magnetic fields.
  - "S-index" is the relative measure of Ca II H and K emission with respect to 2 nearby cont. bands
  - R' removes the photospheric contribution to the Ca II HK H and K bands, and is necessary when comparing stars of varied spectral types

[Wilson 1978]

[Noyes 1984]

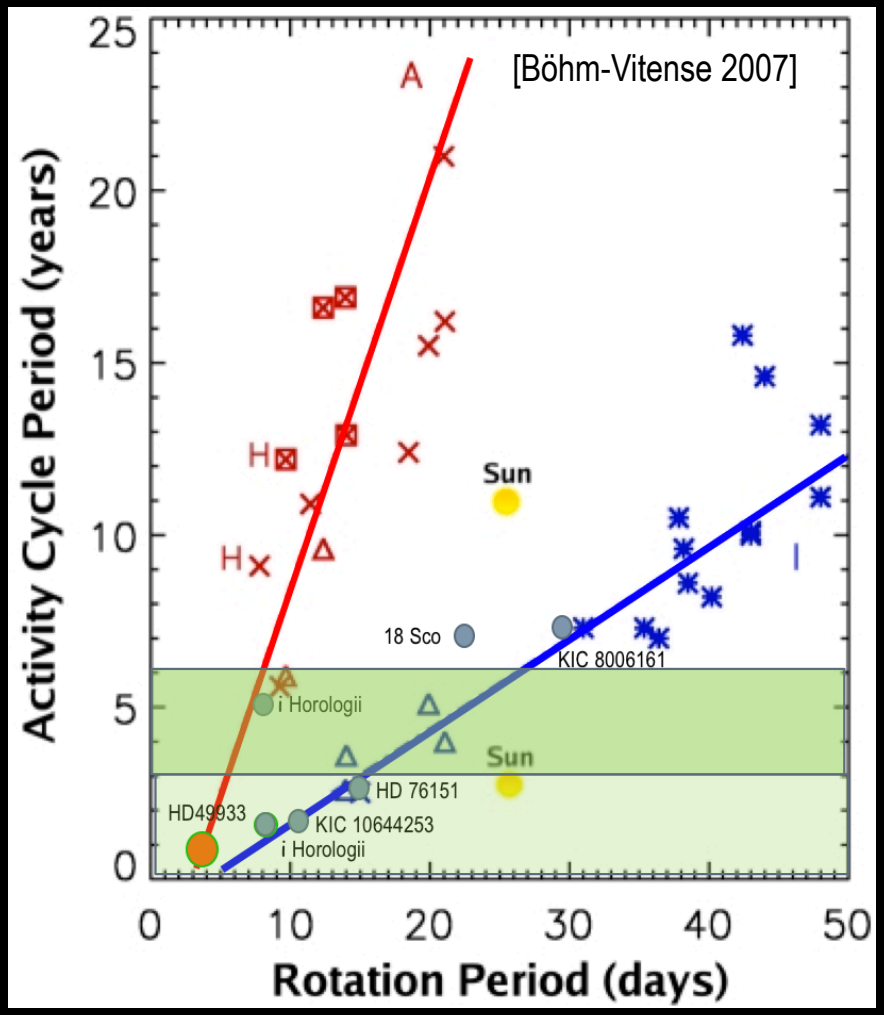






I-INTRODUCTION

- R'_{HK} is approximately proportional to the square root of the mean magnetic field strength at the stellar surface (Schrijver et al. 1989)
- $\langle R'_{HK} \rangle$ is proportional to the inverse Rossby number τ / P_{rot} (Noyes, 1984a)
- And $1/P_{cyc} \alpha (\tau/P_{rot})^n$ (Noyes 1984b)



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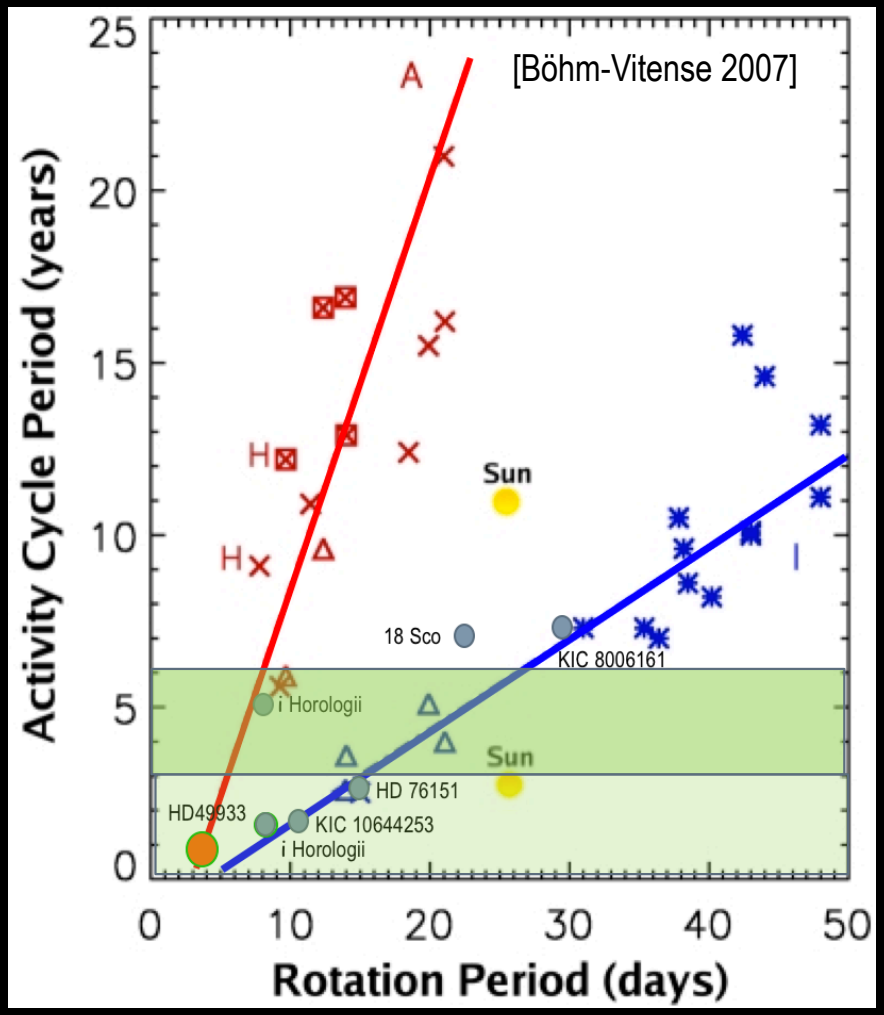
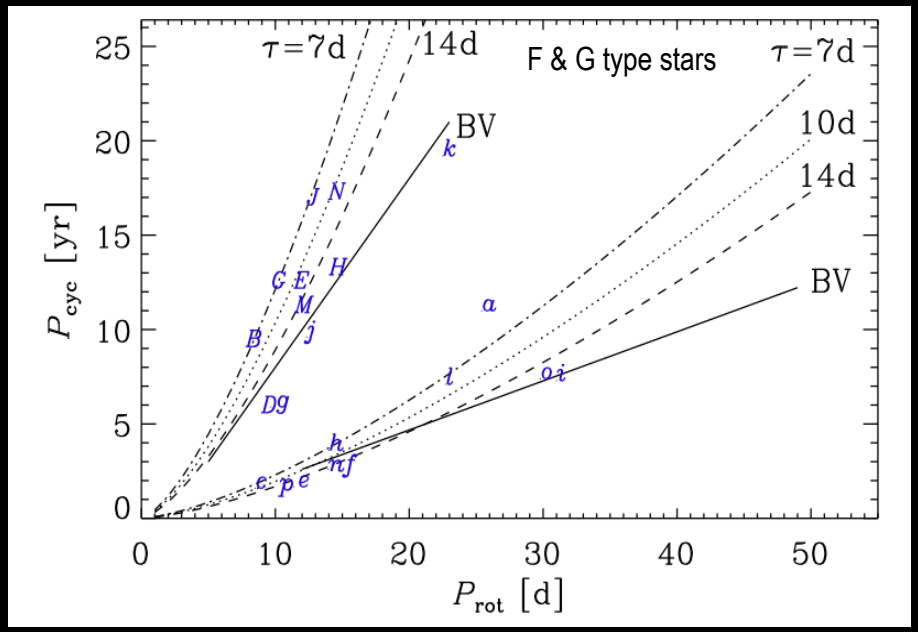
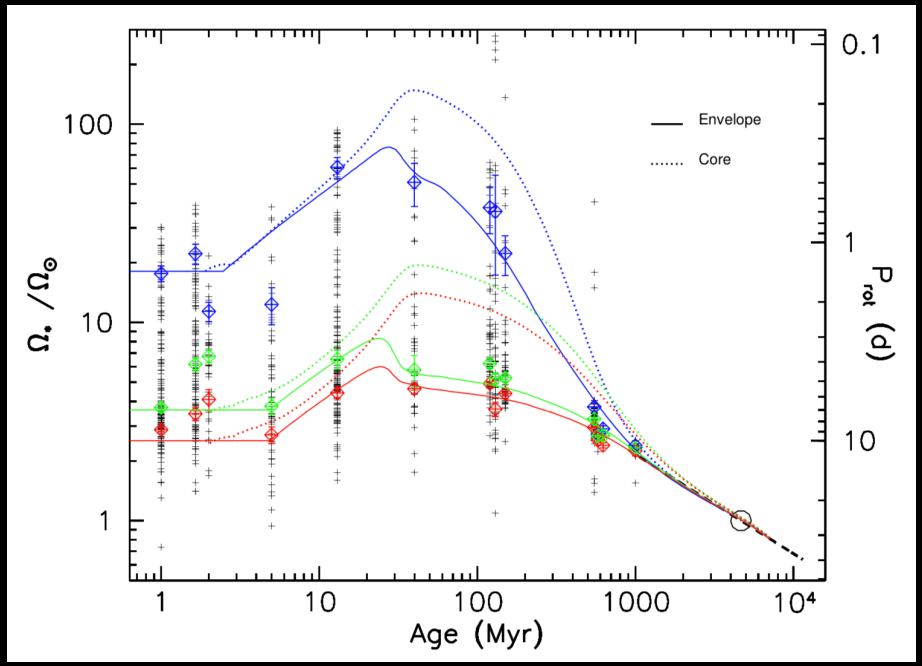


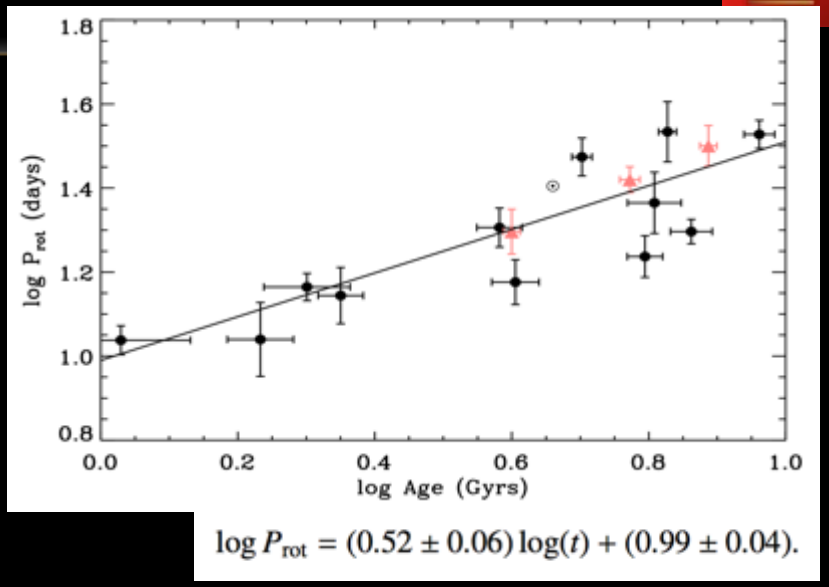


[Brandenburg, Mathur & Metcalfe 2017]

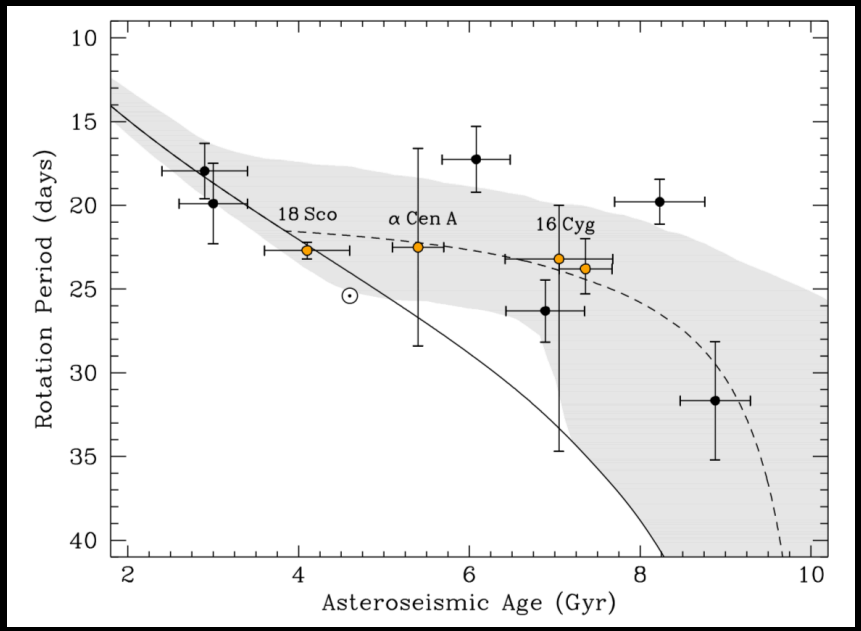
I-INTRODUCTION.



[e.g. Bouvier 2013]



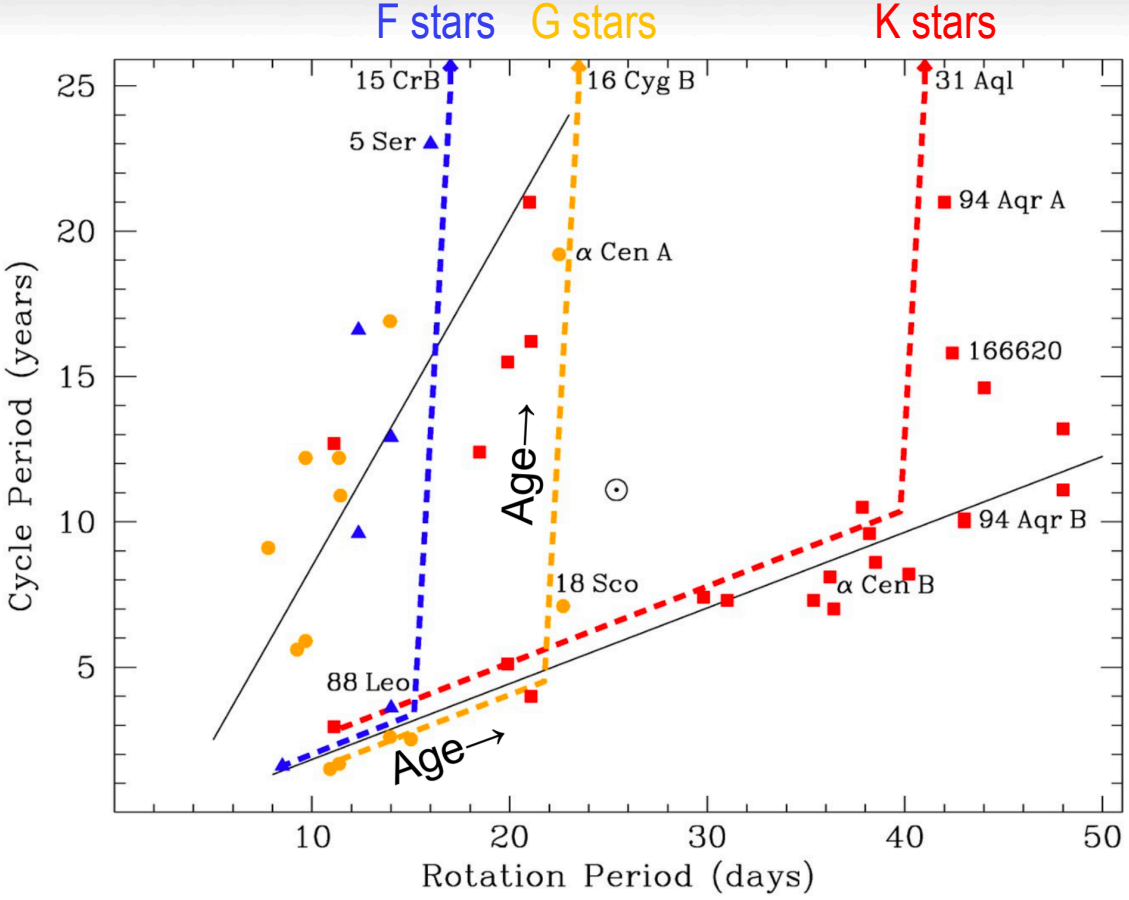
[e.g. Skumanich 1972; Garcia et al. 2014…]



[Van Saders et al. 2016; Metcalfe & van Saders 2017]

- Gyrochronology
  - Stars brakes during most of the main sequence
  - BUT it seems that at a given moment they stop braking

Transition in the interior



- Drop in activity coincides with gradual lengthening of the stellar cycle
- Old stars eventually reach a constant activity state, or cycle is undetectable
- Observed in hotter and cooler stars at faster and slower rotation (Ro ~ 2)

Metcalfe & van Saders (2017)

II-What can offer seismic time series to better understand

solar magnetic activity

& cycles

II- WHAT SEISMIC OBS. CAN OFFER?

- Long (continuous) sesismic observations can potentially give access to:
  - Surface (differential?) rotation of hundred to thousand stars
  - Internal (differential?) rotation through seismology

[e.g. McQuillan et al. 2013, 2014; Nielsen et al. 2013, 2017; Reinhold & Reiners 2013, 2015; García et al. 2014]

- Convection properties
  - Characteristic time scale of convection (granulation)
    - other scales:
      - e.g. Faculae in active stars

[e.g. Beck et al. 2012; Deheuvels et al. 2012,2014,2015; Mosser et al. 2012, Nielsen et al. 2014, Benomar et al. 2016, Pia di Mauro et al. 2016]

[e.g. Mathur et al. 2011; Kallinger et al. 2014, 2016]

- Internal structure (through seismology)
  - Size of the convective envelope (through seismology (+ modelling))
  - Constraining deep internal magnetic fields & convective core dynamos?

[e.g. Karoff et al. 2013]

- Activity cycles & surface magnetism
  - Through the analysis of long time series (activity proxies) & p-mode variability
    - Or asteroseismology

[e.g. Mathur et al. 2012; Mazumdar et al. 2014; Metcalfe et al. 2014,…]

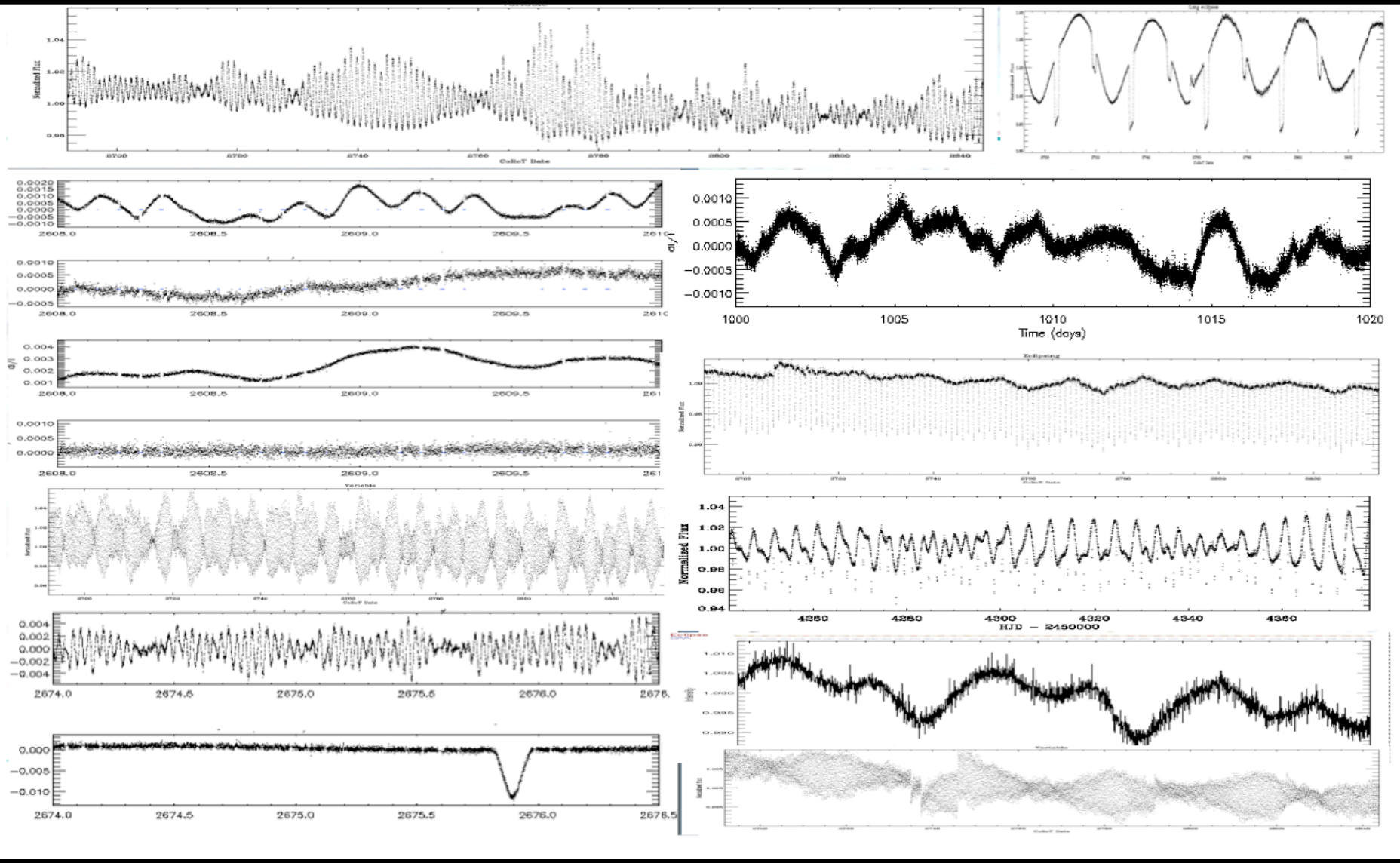
[Fuller et al. 2015.; Stello et al. 2016a,b]

[e.g. García et al. 2010; Mathur et al. 2013, 2014, Salabert et al. 2016, Kiefer et al. 2017, Santos et al. 2018]

[e.g. García et al. 2010; Salabert et al. 2018]

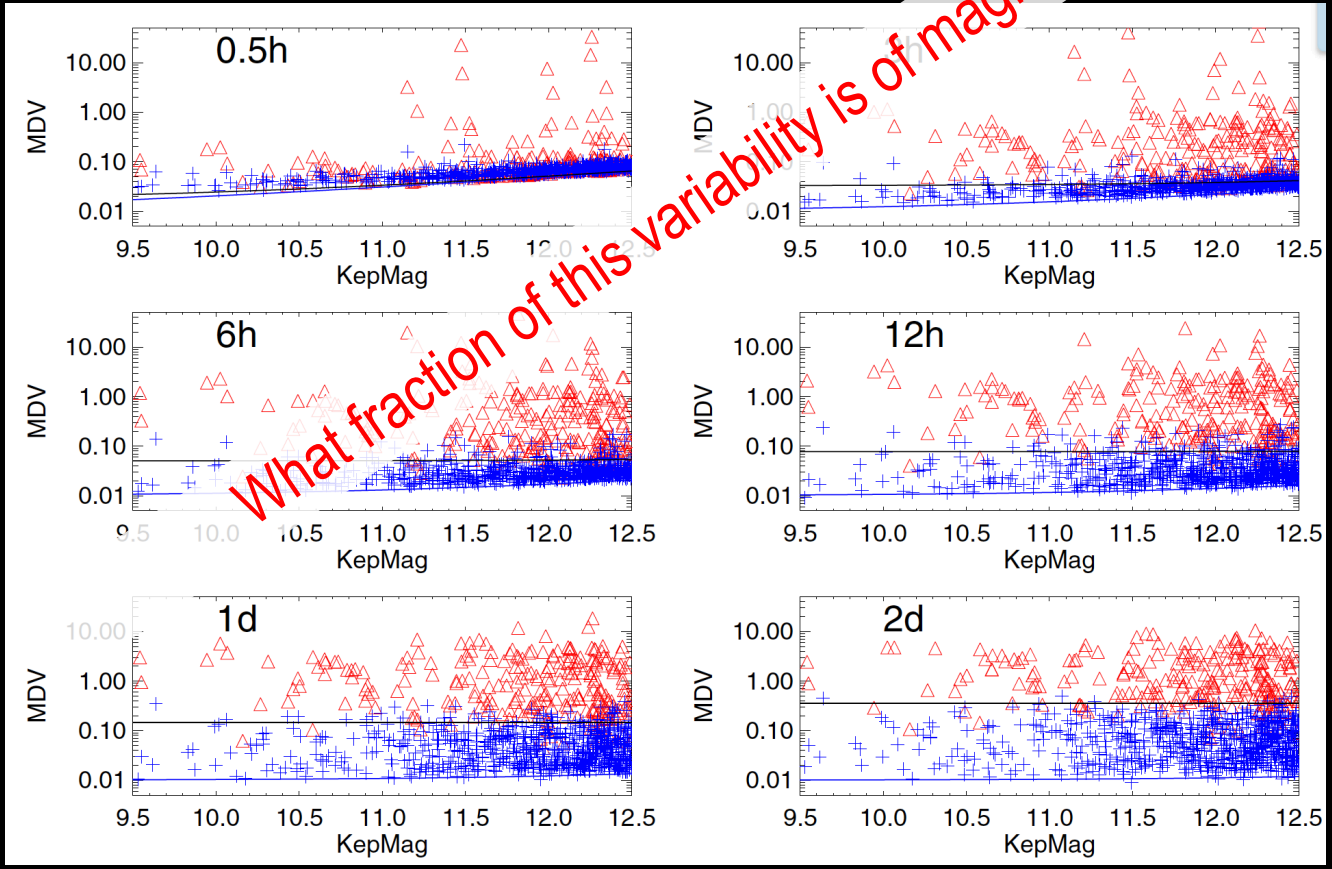
III-Photospheric magnetic activity proxies

III-STELLAR VARIABILITY



III-STELLAR VARIABILITY

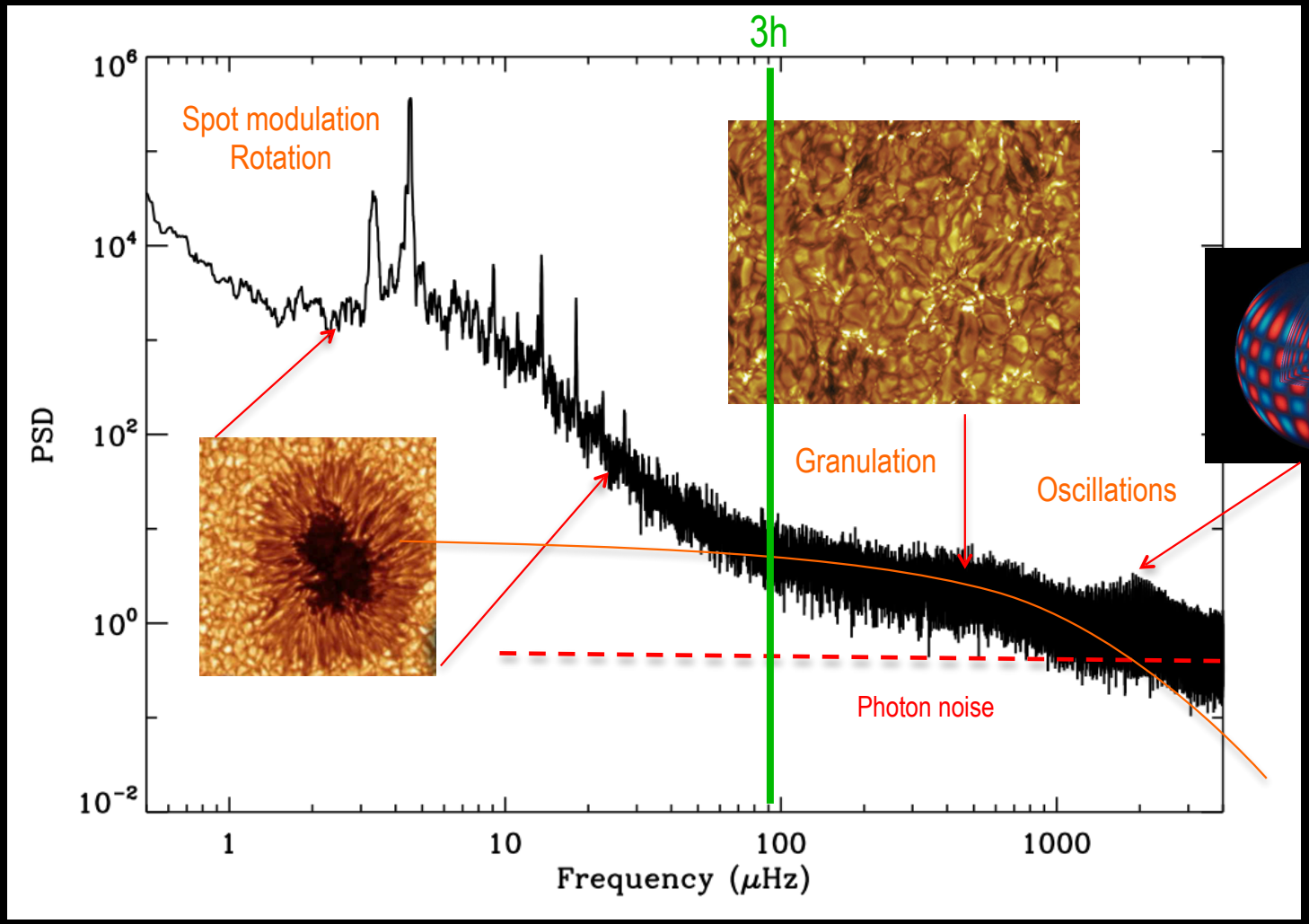
- To study the photometric variability of a star:
  - It is common to parameterize it at a given time
    - E.g. MDV (t_{bin}) (Median Differential Variability), Range, etc
      - Median of the bin-to-bin variability for bins of a given timescale t
    - This methodology is good to compare variability of stars at different timescales



[Basri et al. 2013]

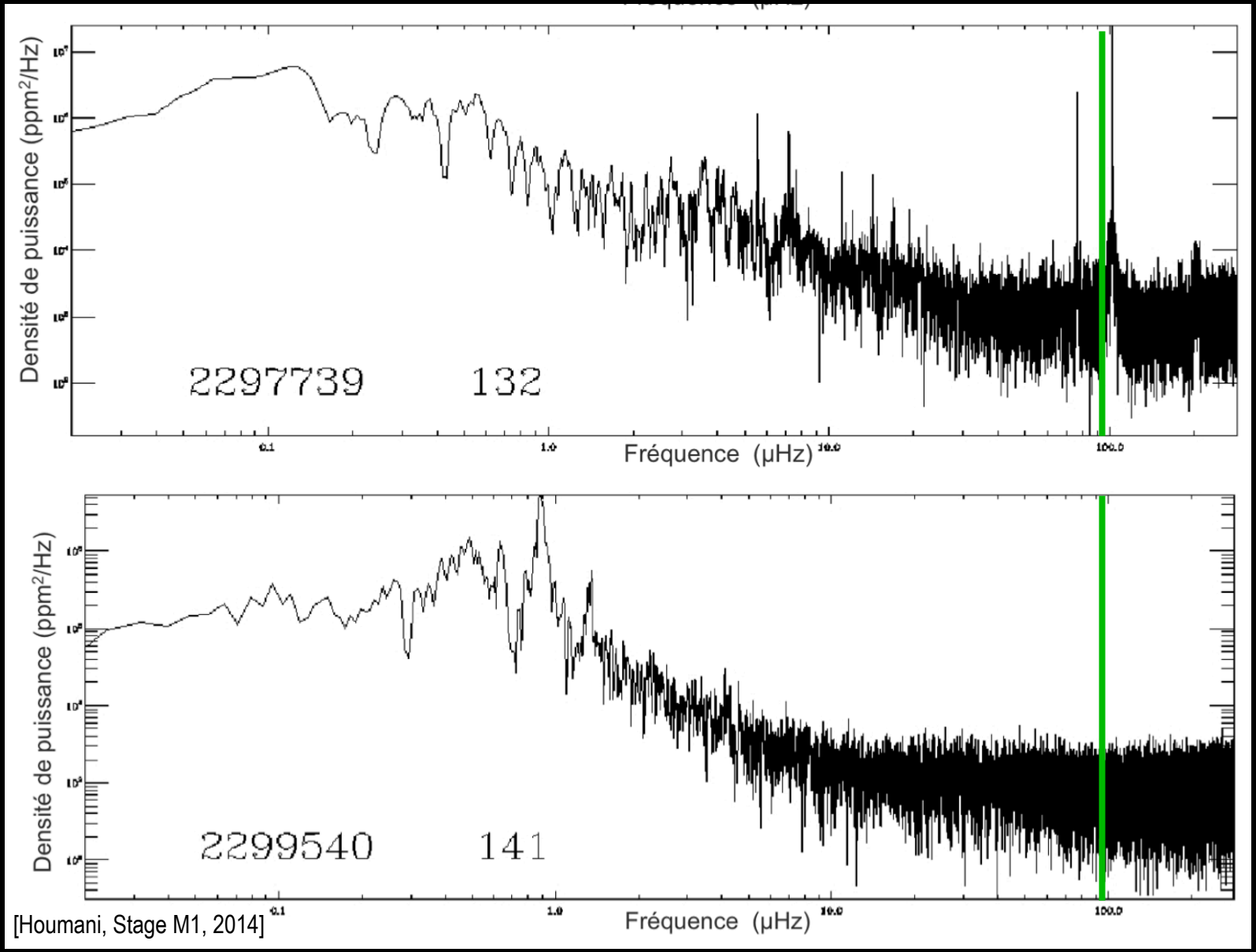
III-STELLAR VARIABILITY

➢ Example of the PSD of a Solar-Like star



III-STELLAR VARIABILITY

➢ Example of other type of pulsators (F, M)

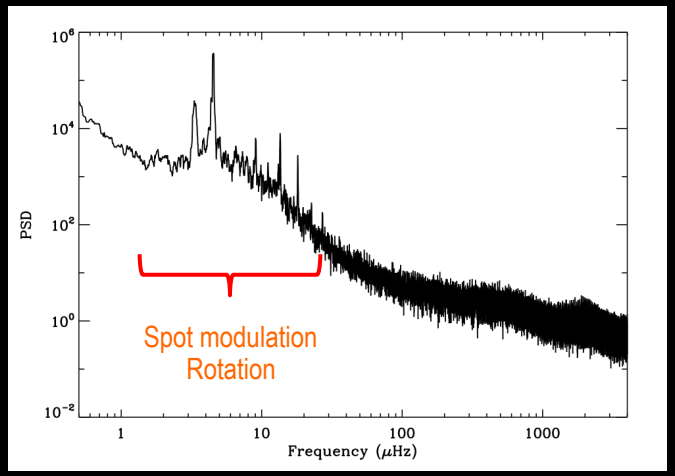


[Houmani, Stage M1, 2014]

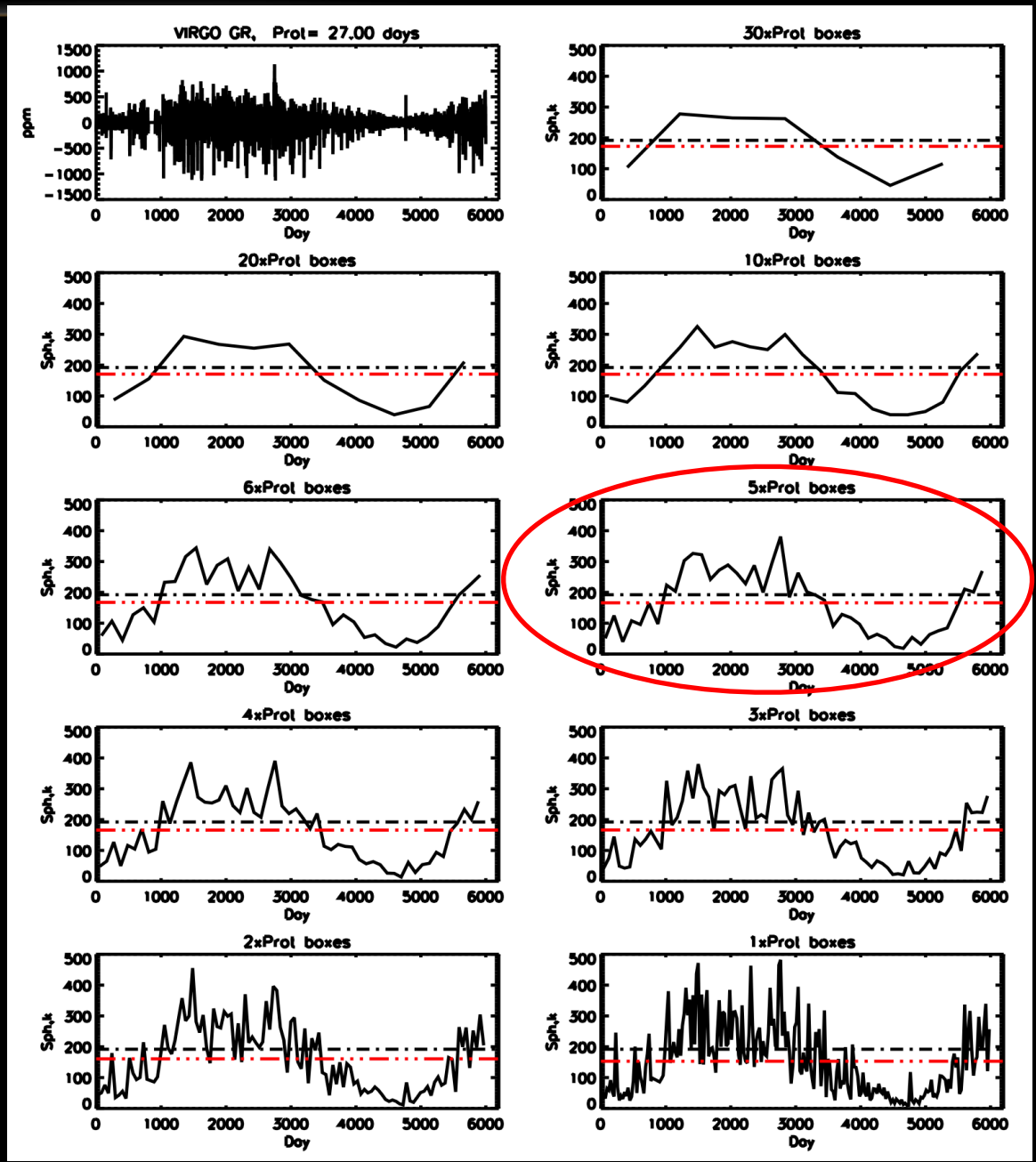
III-PHOTOSPHERE MAGNETIC ACTIVITY PROXY

- S_{ph}
  - Standard deviation of the light curve

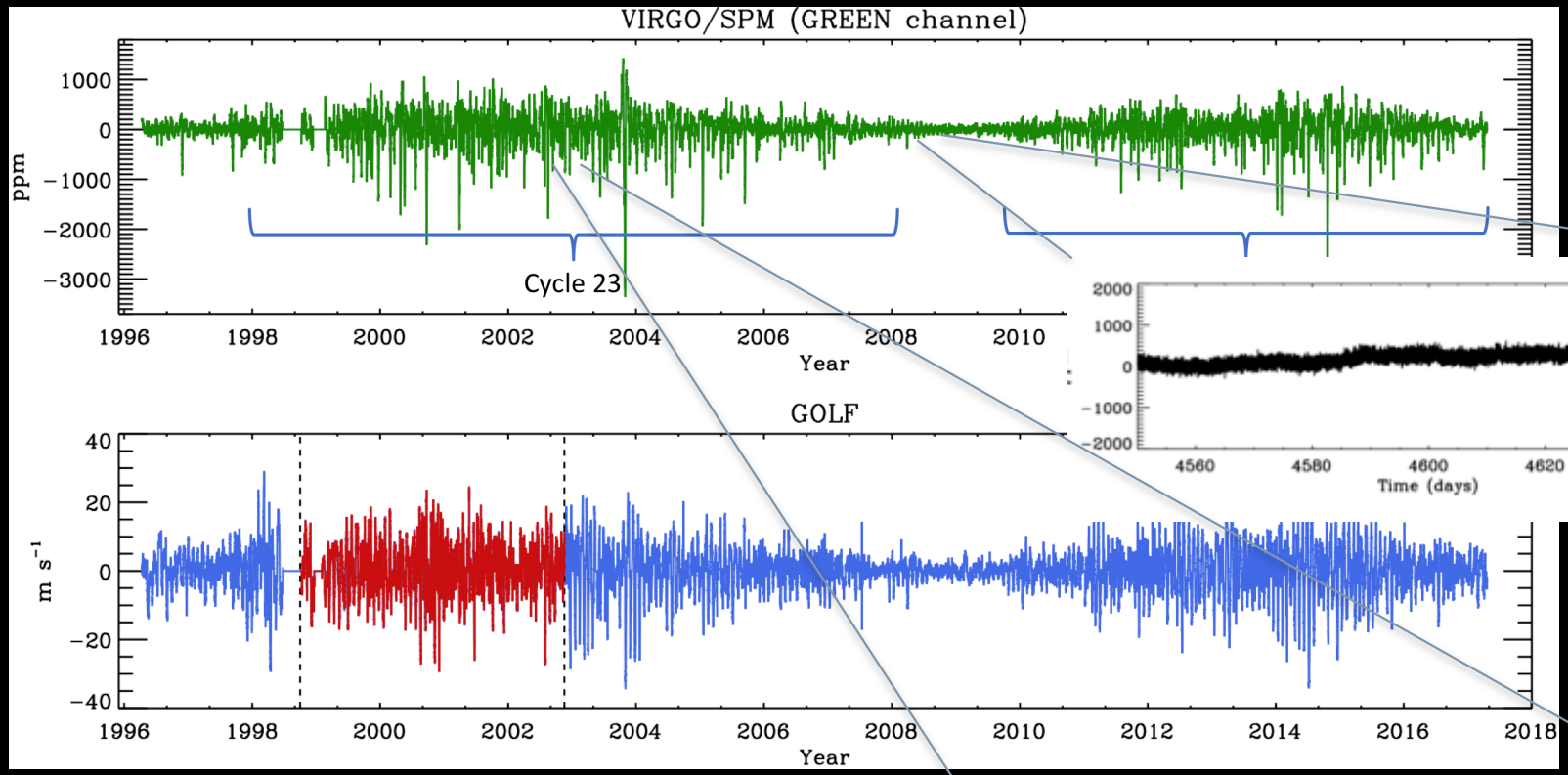
    [García et al. 2010; Chaplin et al. 2011; Campante et al. 2013]
  - $K \times P_{rot}$
    - In general k=5

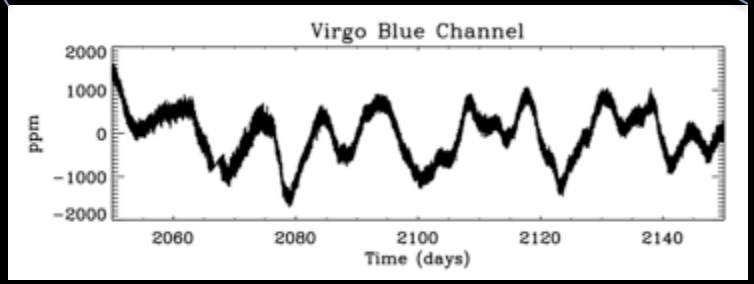


[Mathur, Salabert, García, et al. 2014]



III-MAGNETIC ACTIVITY



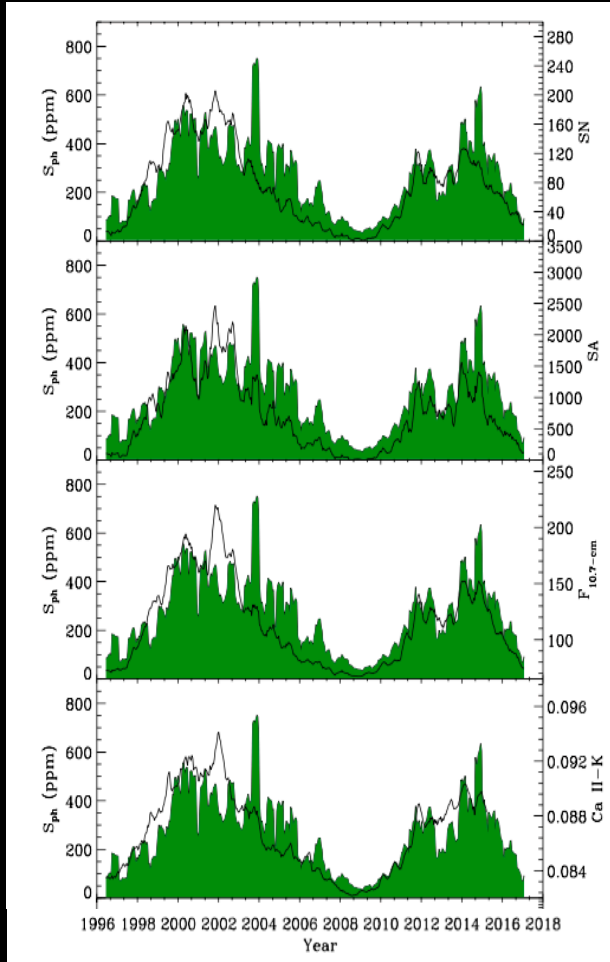


http://www.spaceinn.eu/data-access/photospheric-solar-activity-index-virgospm-sph/

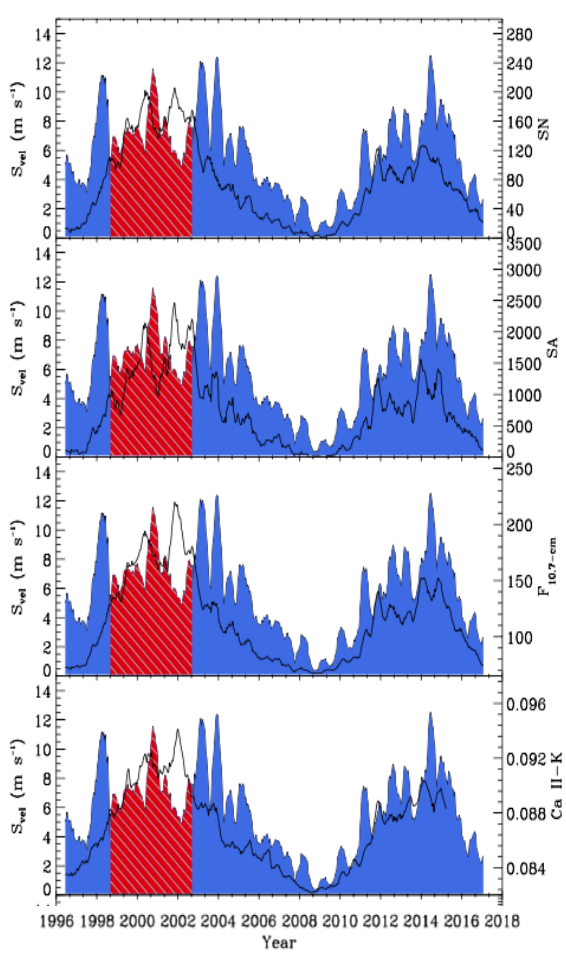
[Salabert, Garcia et al. 2018]

III-MAGNETIC ACTIVITY & HPP

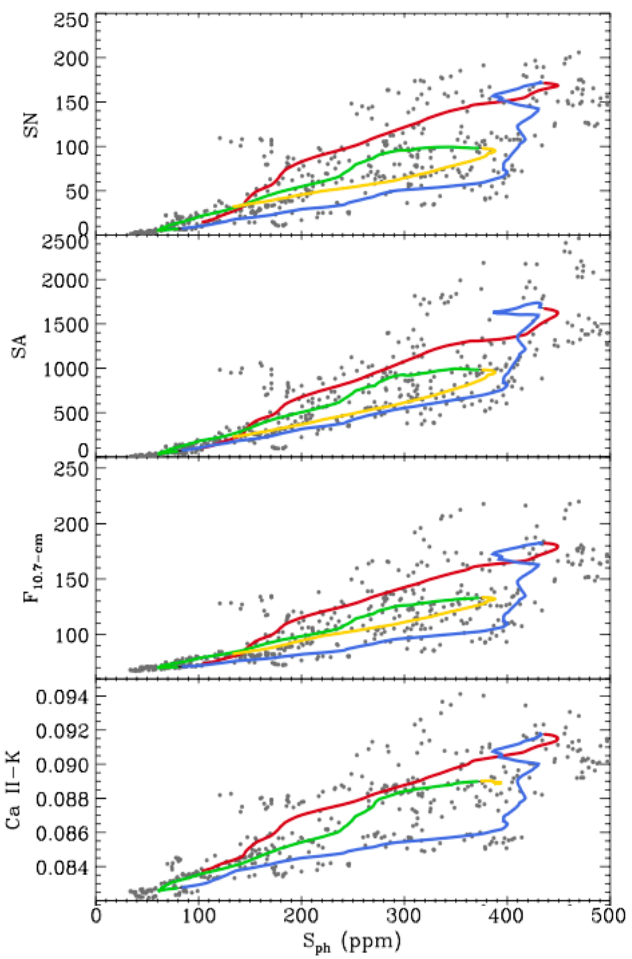
➢ Comparison of S_{ph} and S_{vel} with other solar magnetic activity proxies



VIRGO/SPM



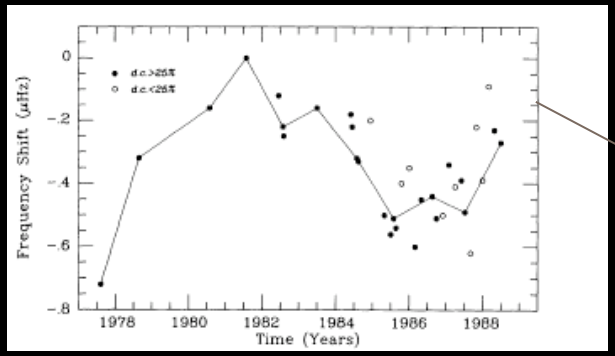
GOLF



[Salabert, Garcia et al. 2018]

III-EFFECT ON HELIOSEISMOLOGY

- Seismic frequencies respond to changes in the surface activity
  - Reported first by Woodard & Noyes (1985, Nature):
- "*The frequencies of l = 0 and l = 1 acoustic modes in the 5-min band have decreased from 1980 (near solar maximum) to 1984 (near solar minimum), by ~0.42 μHz (…).*"

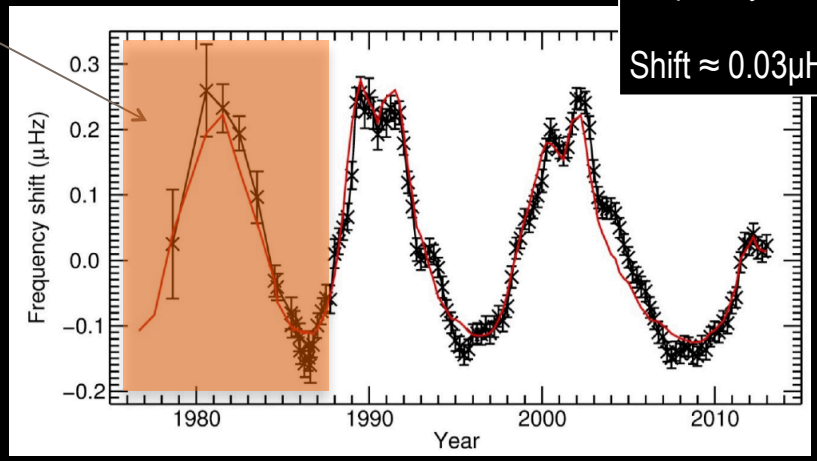


30 years ago

Solar cycle 21, Mark-I data, Observatorio del Teide, Pallé et al. 1989

Shift ≈ 0.01% of mode frequency

Shift ≈ 0.03μHz G^{-1}

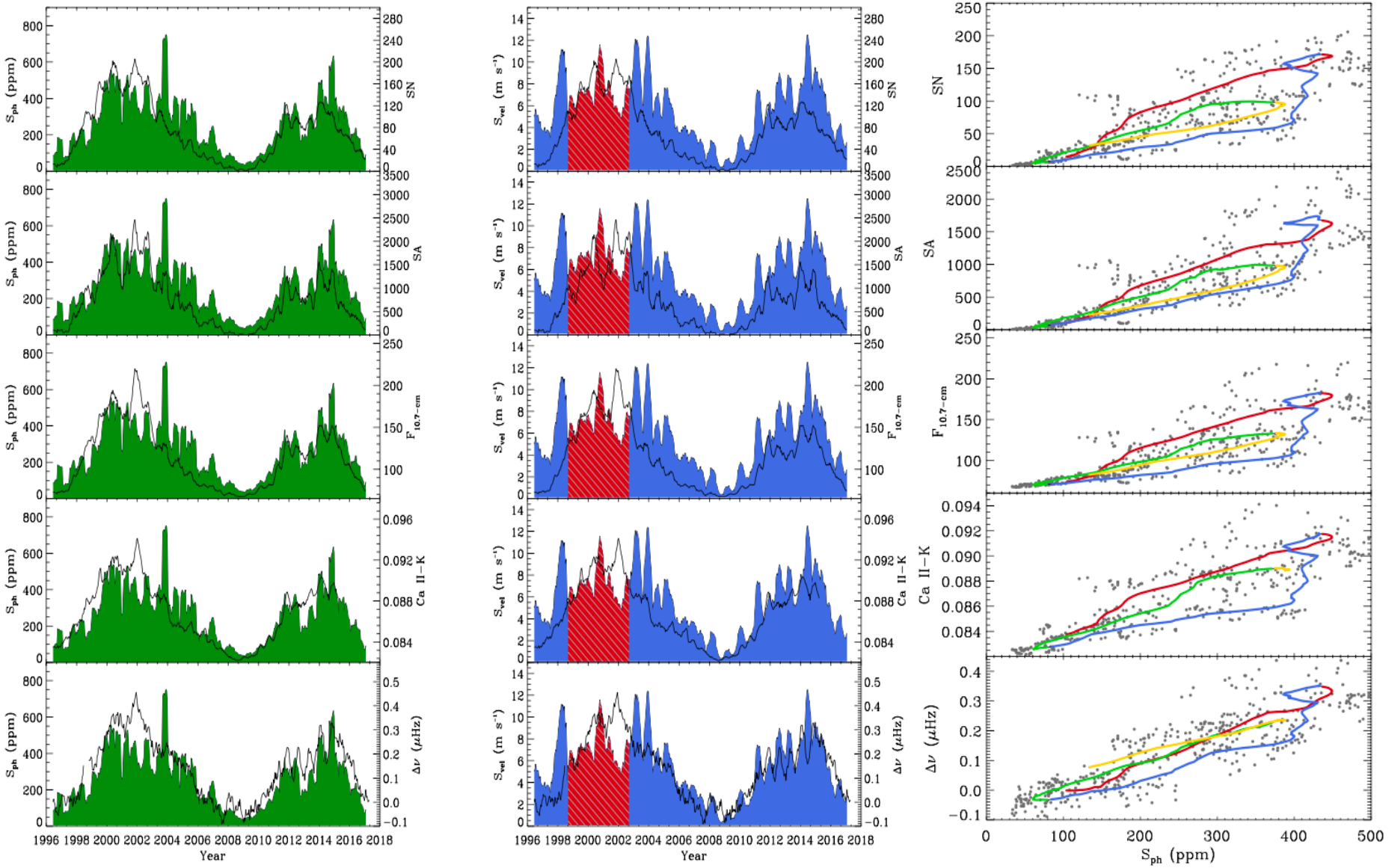


Today

Solar cycles 21, 22, 23,
Ground-based BiSON observations, Chaplin et al.

Scaled 10.7cm flux
= predicted frequency shift

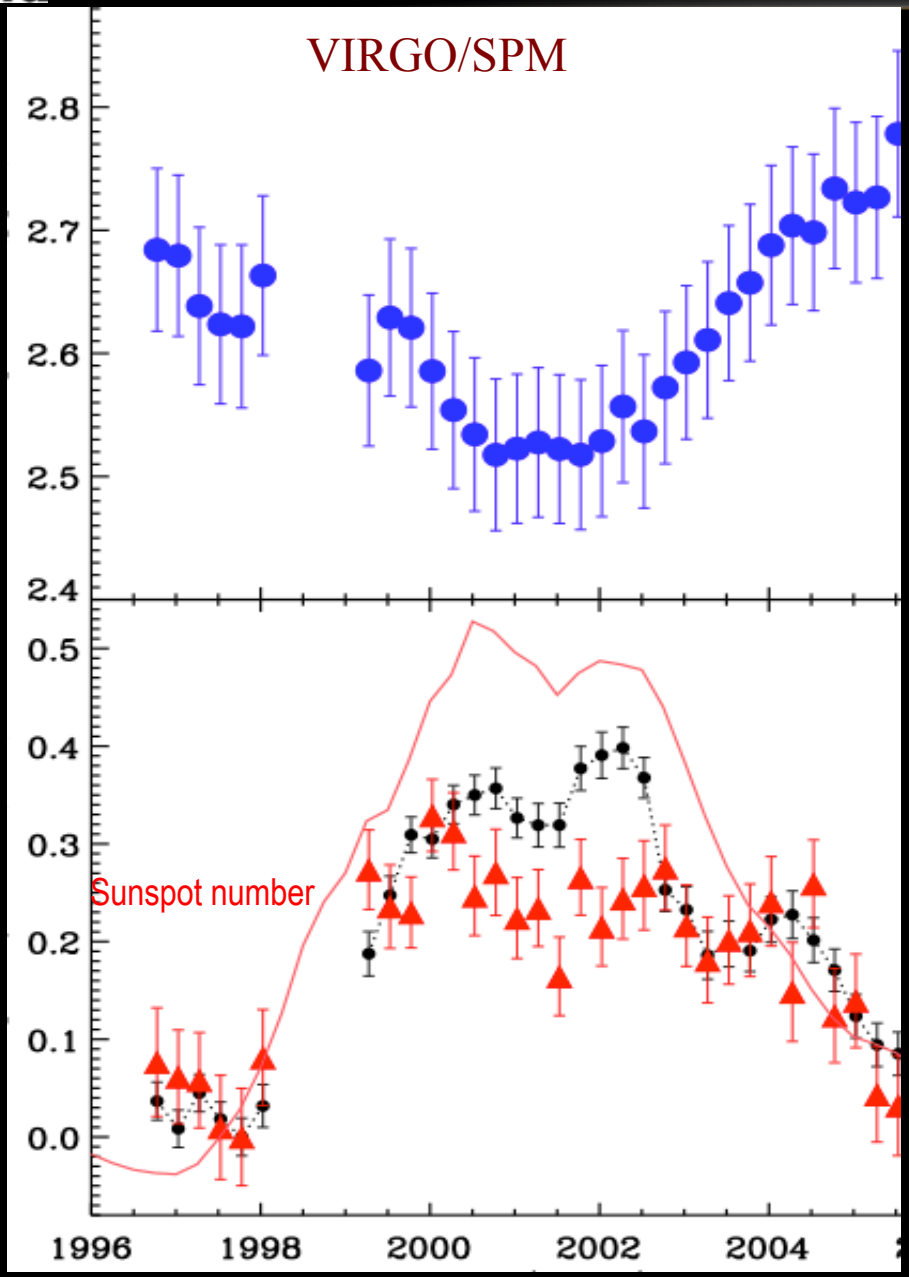
III-MAGNETIC ACTIVITY & HPP



➢ Frequency shifts highly correlated (> 0.9) with all other usual magnetic activity proxies

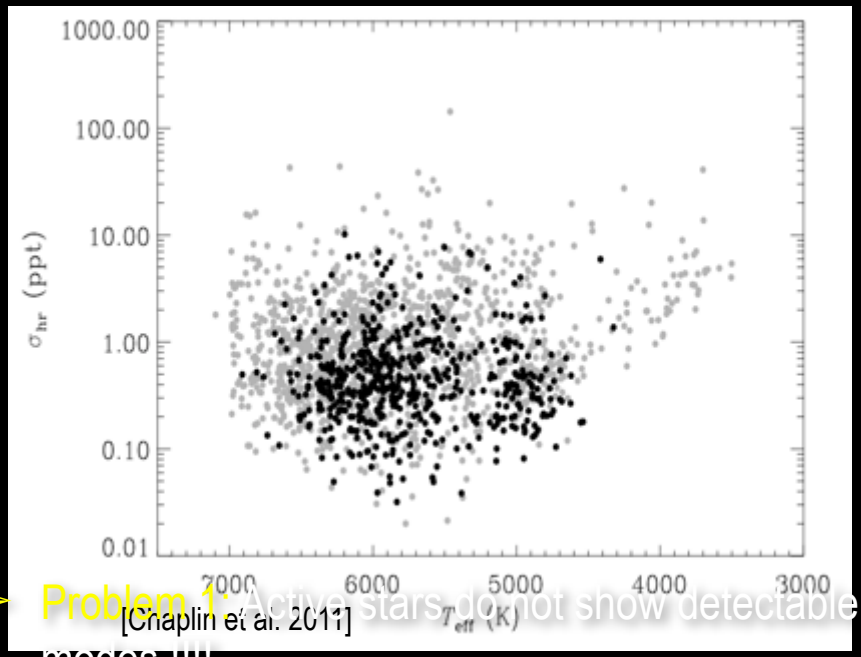
[e.g. Chaplin et al. 2007, Salabert, Garcia et al. 2018]

III-EFFECTS ON HELIOSEISMOLOGY



[García et al. 2010]

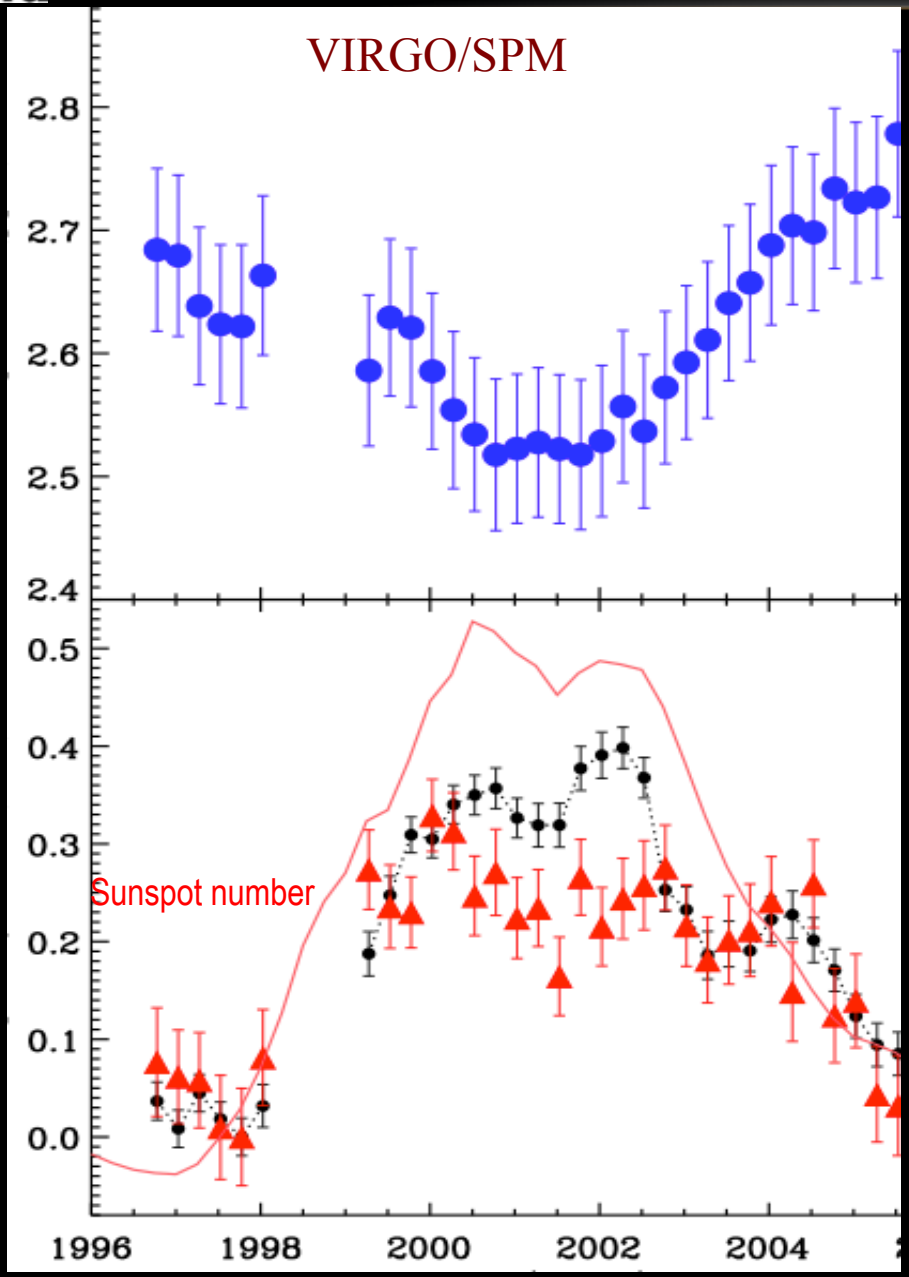
- Amplitudes, linewidths and asymmetries also change with magnetic activity.



[Chaplin et al. 2011]

- Problem 1: Active stars do not show detectable modes !!!!

III-EFFECTS ON HELIOSEISMOLOGY



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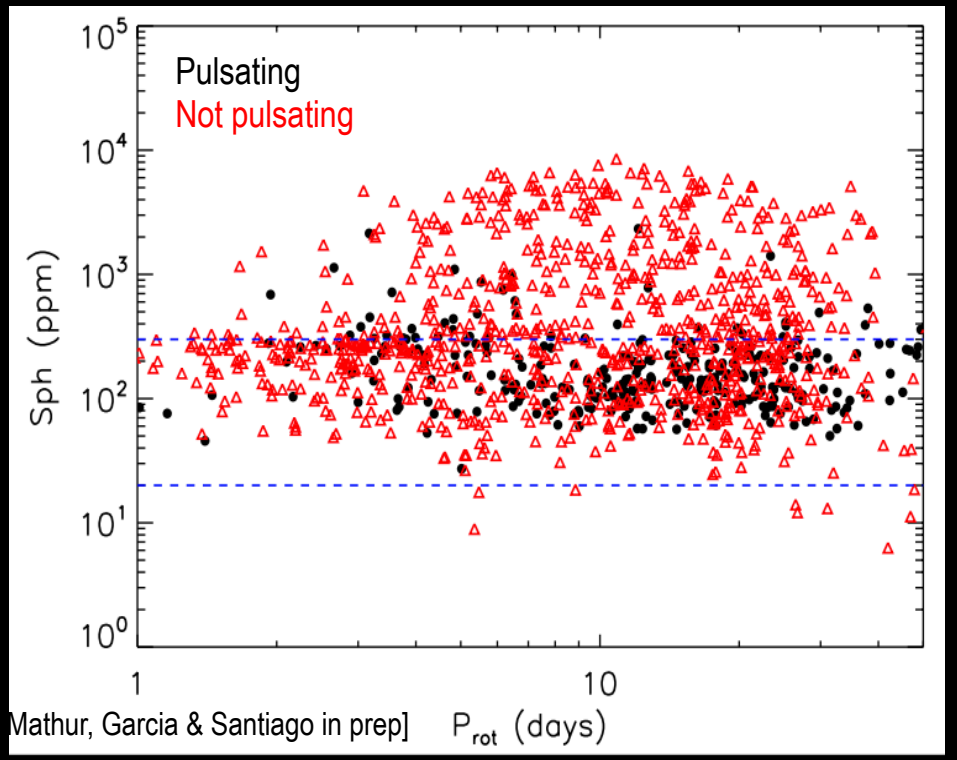


show pulsations in 1 month datasets

[García et al. 2010]

IV-Stellar magnetic activity cycles

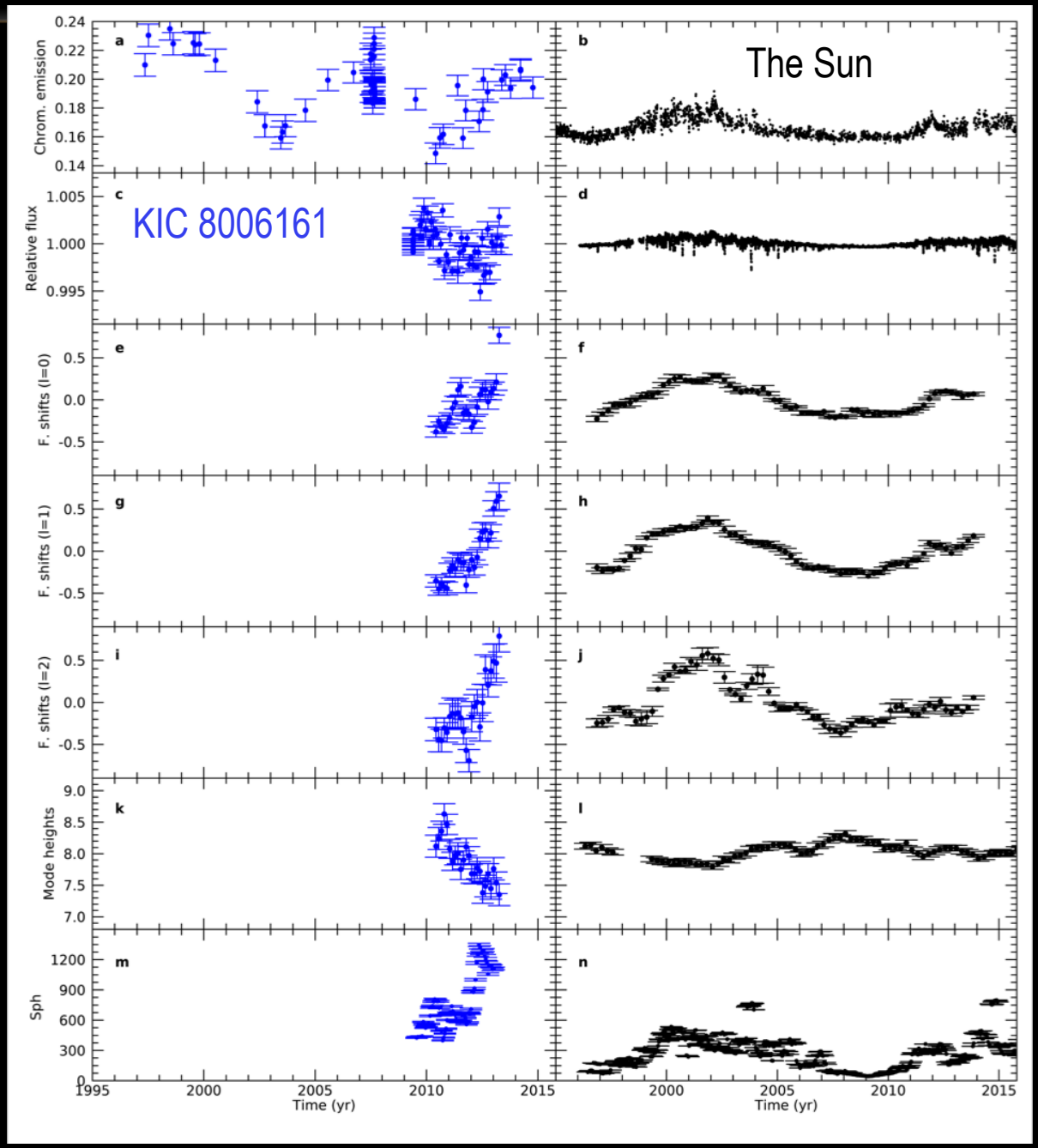
IV-STELLAR MAGNETIC CYCLES

KIC 8006161

Radius*	$0.930 \pm 0.009\ R_\odot$
Mass*	$1.00 \pm 0.03\ M_\odot$
Log g*	4.498 ± 0.003
Age*	4.57 ± 0.36 Gyr
Effective temperature**	5488 ± 77 K
Metallicity**	0.3 ± 0.1
Rotation period	21^{+2}_{-2} days
Inclination	38^{+3}_{-4} degrees
Cycle period	7.41 ± 1.16 years

- Stronger chromospheric emission than the Sun
- Shorter cycle period than the Sun

→ Effect of metallicity



[Karoff et al. 2018]

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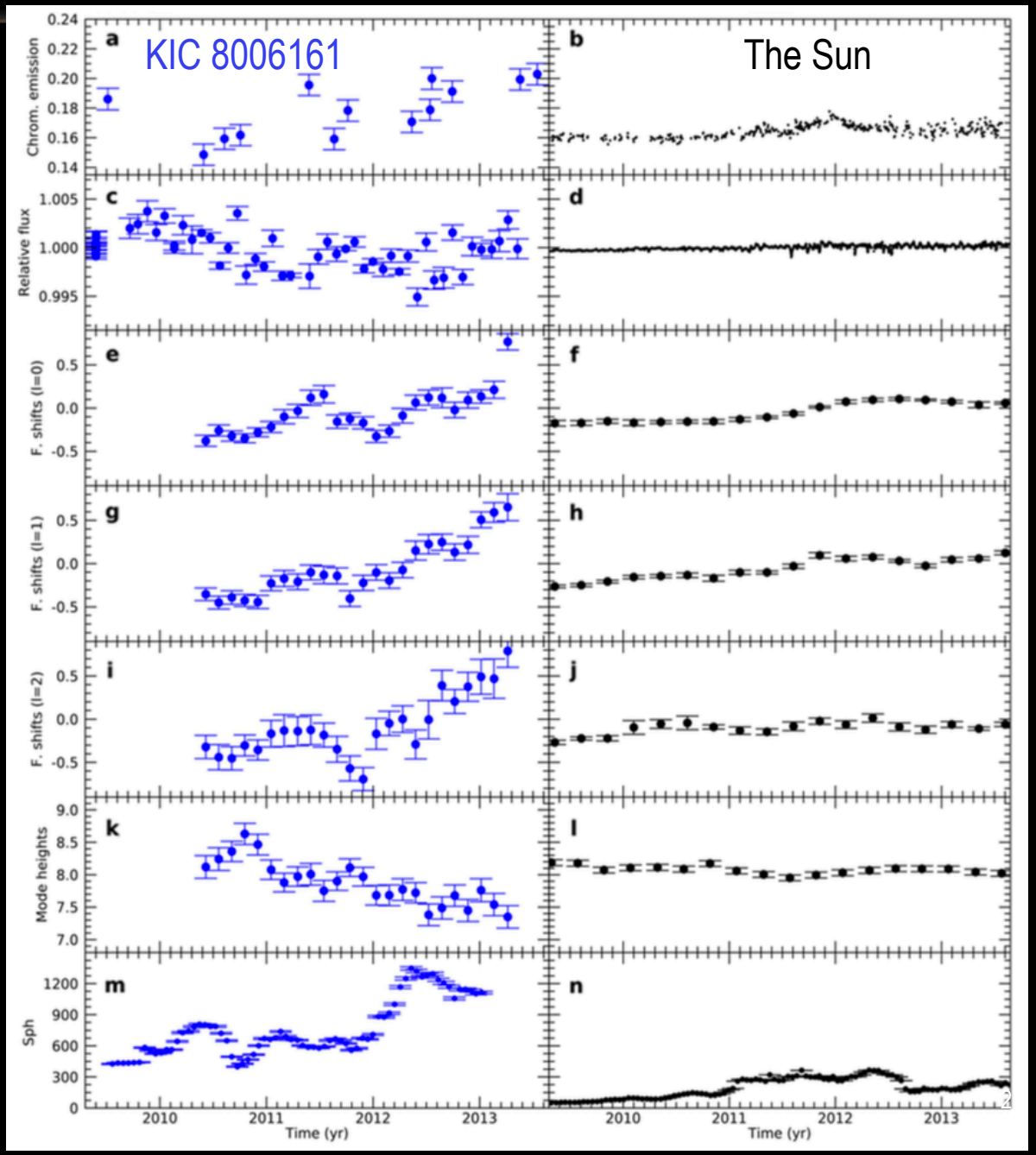
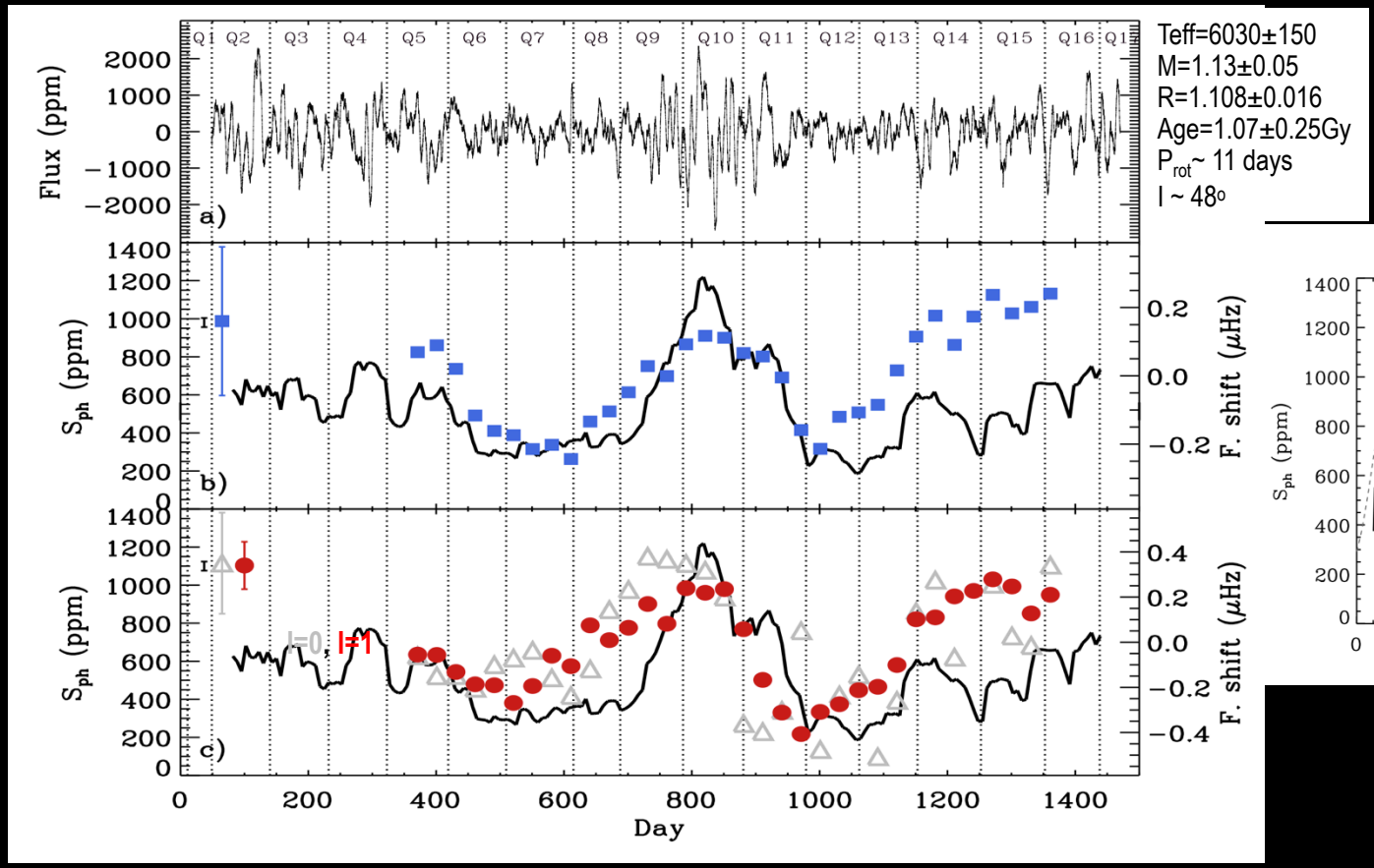
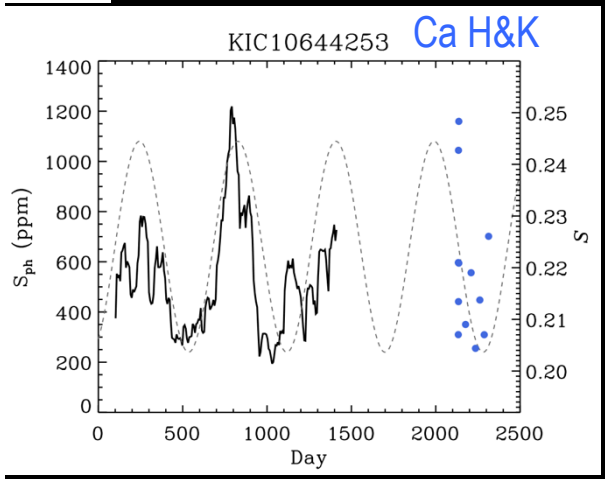


[Karoff et al. 2018]

HINTS OF A MAGNETIC-ACTIVITY CYCLE

➢ **KIC 10644253**: a young Solar analogue





[Bruntt et al. 2012; Metcalfe et al. 2014; García et al. 2014,Salabert et al. 2016]

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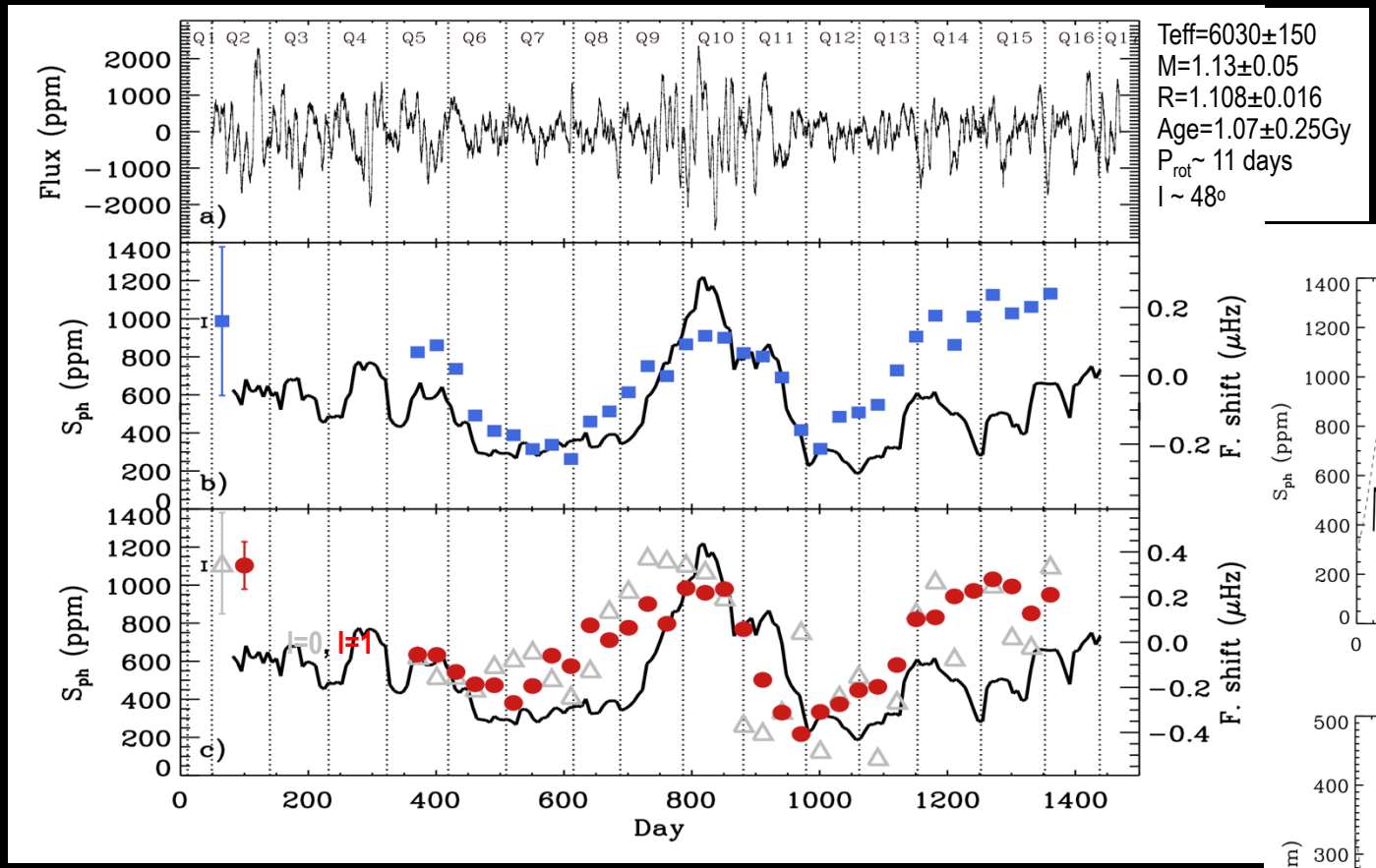
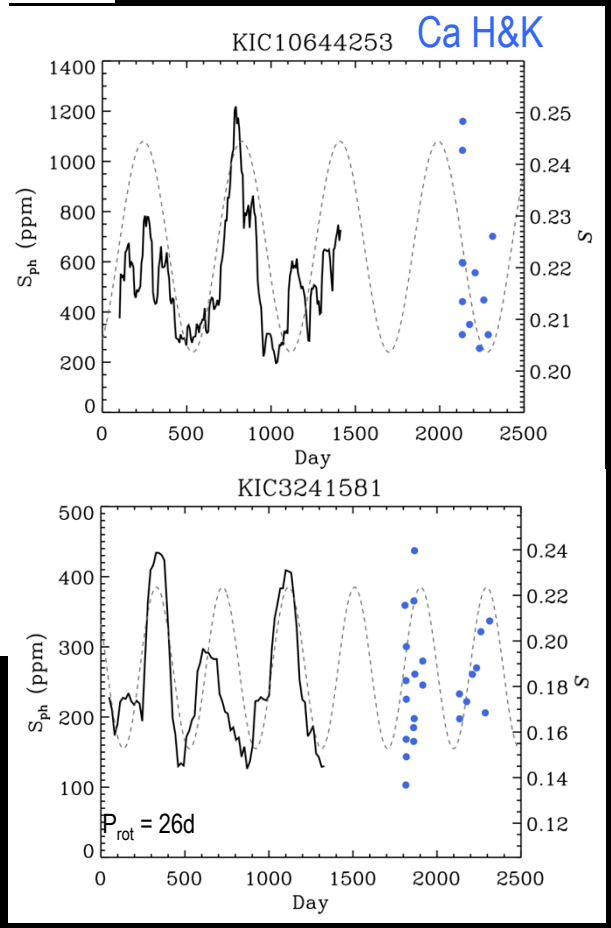
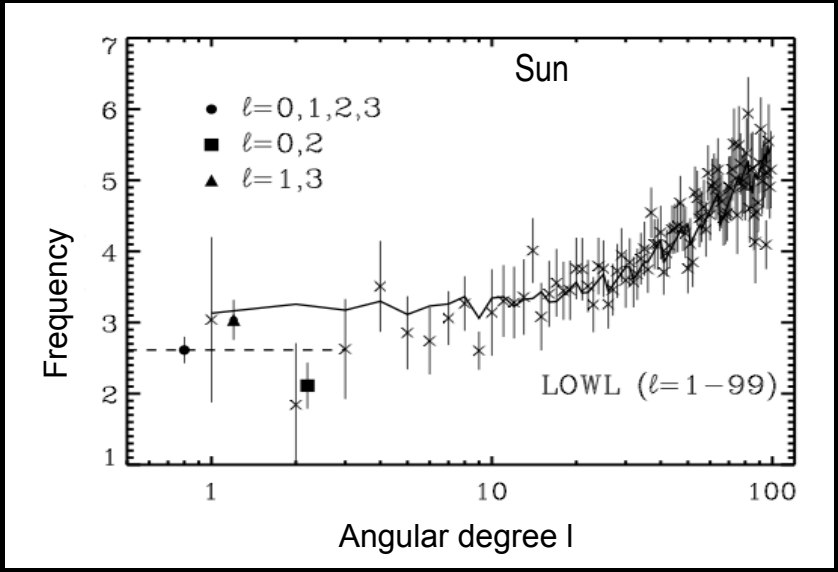




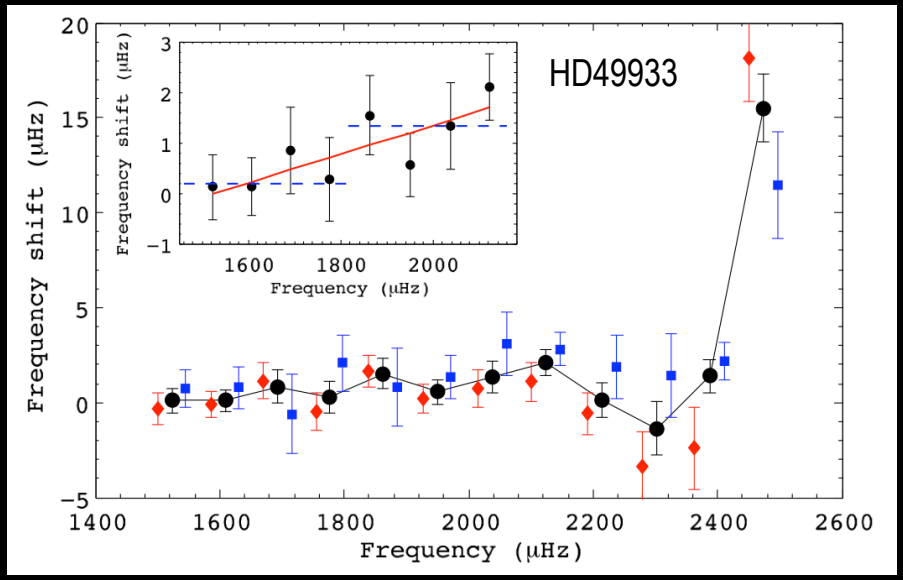
[Bruntt et al. 2012; Metcalfe et al. 2014; García et al. 2014,Salabert et al. 2016]

[Salabert et al., 2016; García et al. in prep]

FREQUENCY SHIFT WITH FREQUENCY



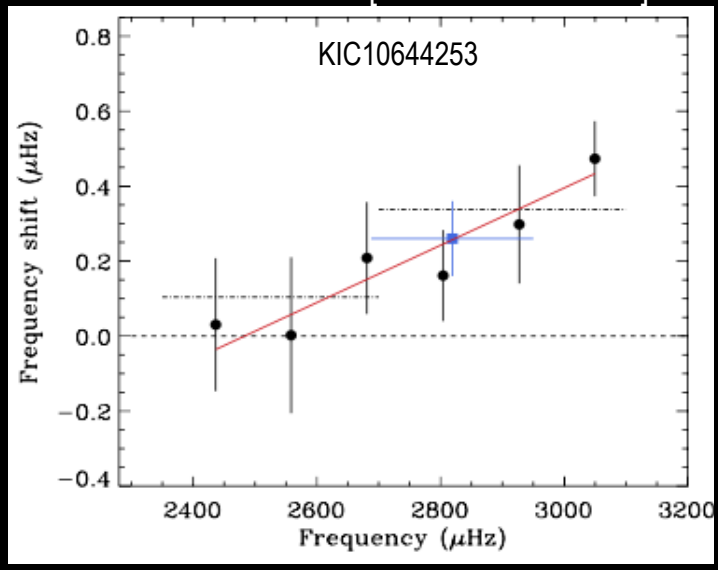
[Jiménez-Reyes et al., 2001]



[Salabert et al. 2011]

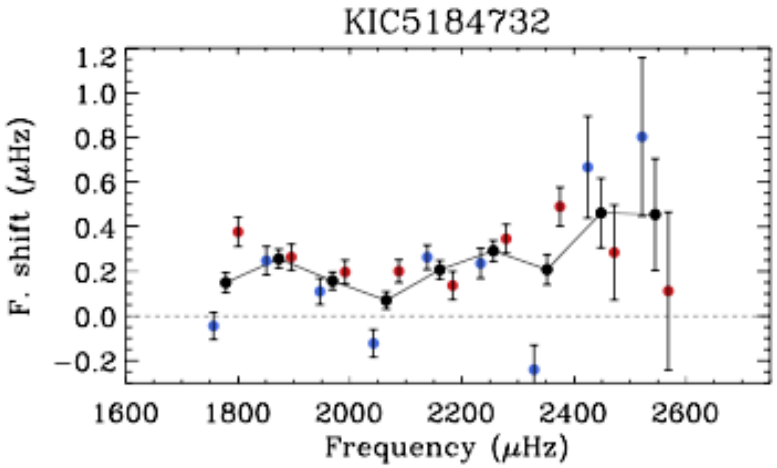
- Mechanisms responsible for the frequency shifts
  - Far to be understood
  - From angular degree dependence
    - Near-surface phenomenon, outside the cavity in the Sun
- Arise from structural changes in the sub-surface layers
  - Indirect effect of temperature changes
  - Effect of a change in acoustic cavity size [Kuhn 1988]

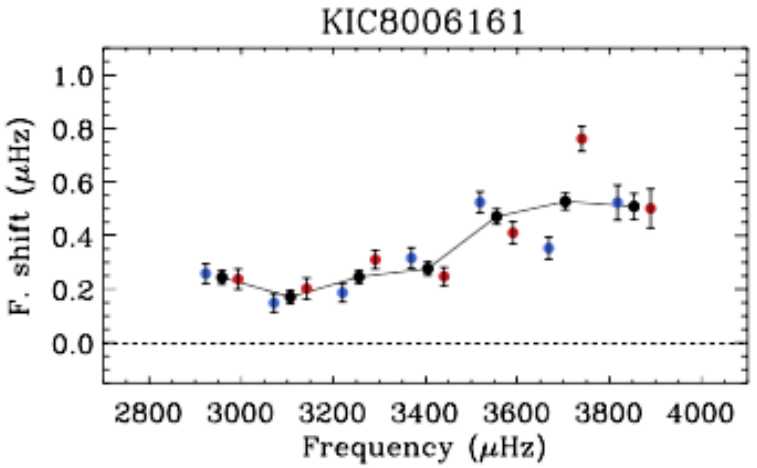
[Dziembowski & Goode 2005]

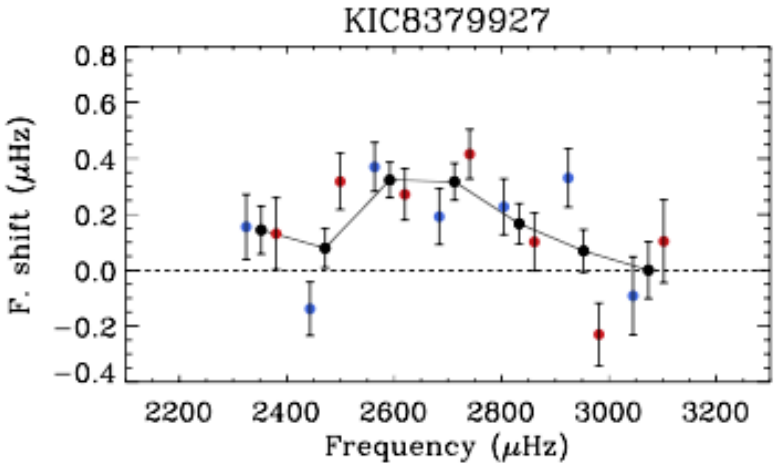


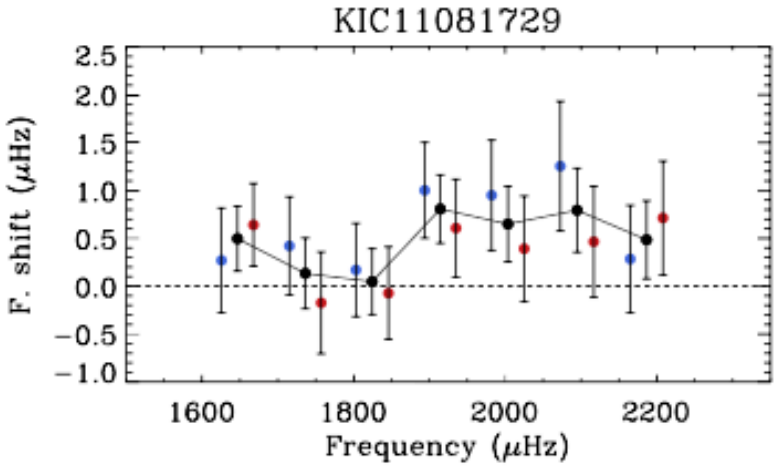
[Salabert et al. 2016]

FREQUENCY SHIFT WITH FREQUENCY





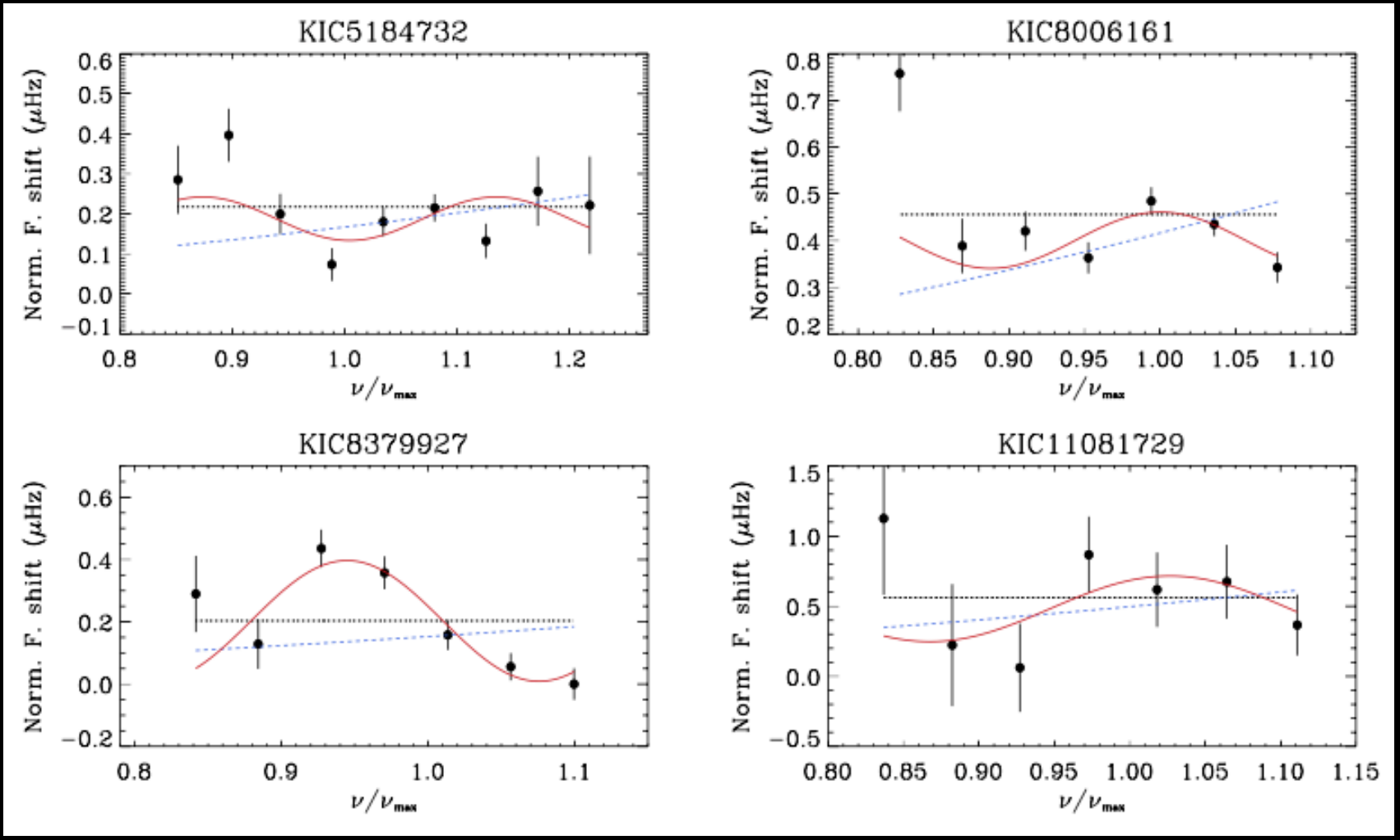




[Salabert et al. 2018]

➢ Other 4 Kepler stars

FREQUENCY SHIFT WITH FREQUENCY

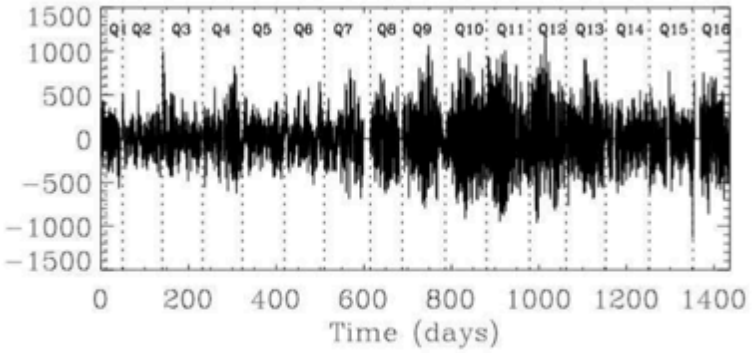


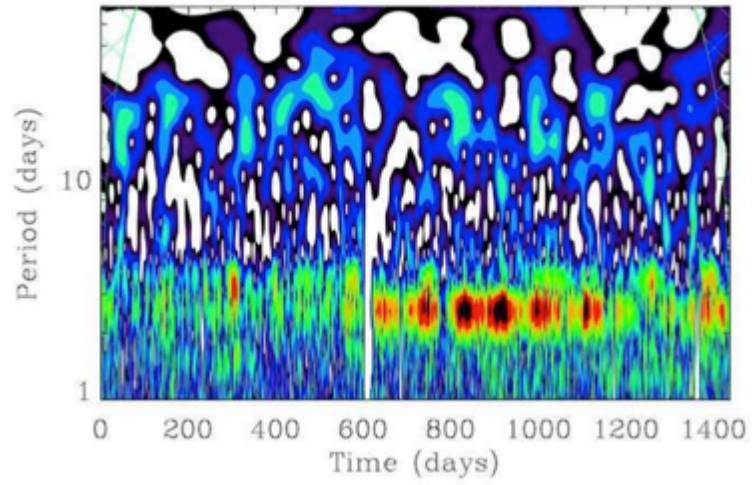
- Normalized frequency shifts by mode inertia [Salabert et al. 2018]
- Sinusoidal behavior as it would be if the perturbation is inside the p-mode cavities

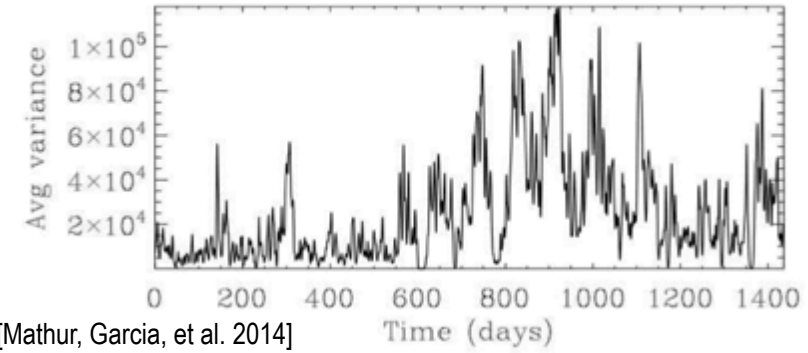
[Dziembowski & Goode 2001, 2005]

Thanks

IV-STELLAR MAGNETIC CYCLES







[Mathur, Garcia, et al. 2014]

P_{rot}=2.

<S_{ph}>

i ~30°

Astero

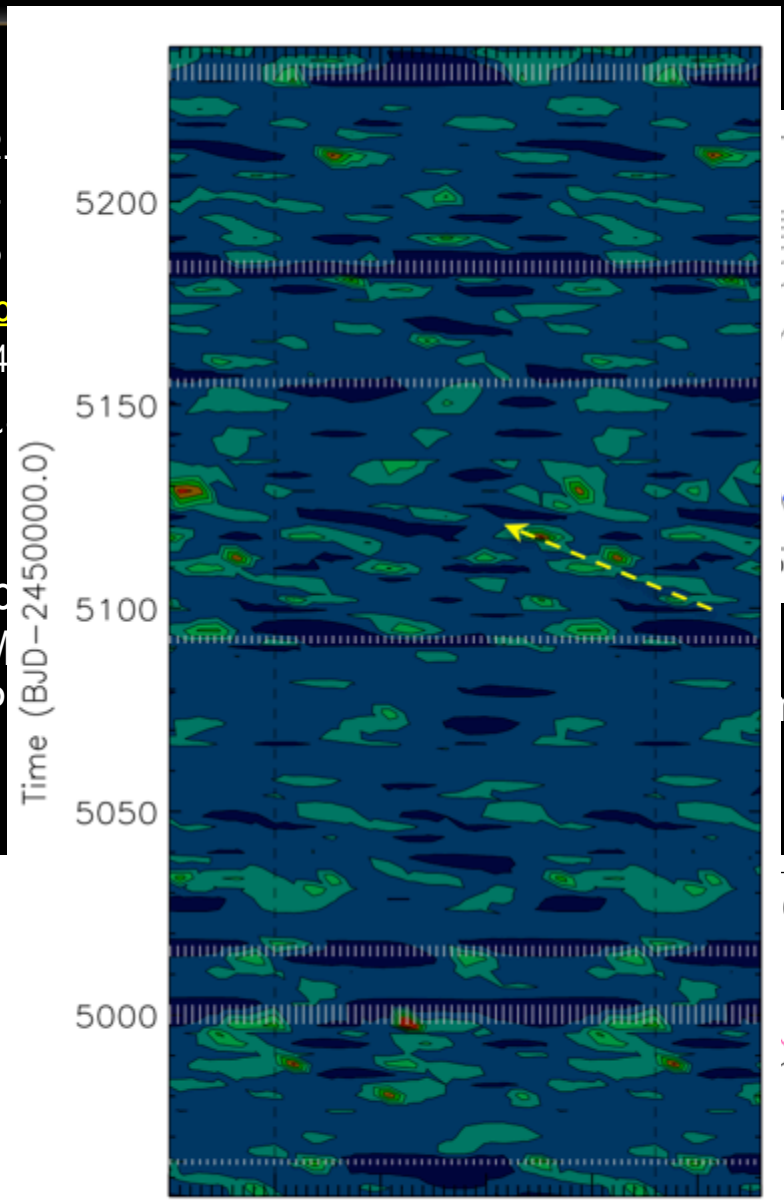
M~1.4

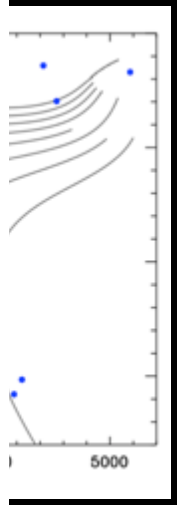
DCZ~

We c

- M
- P

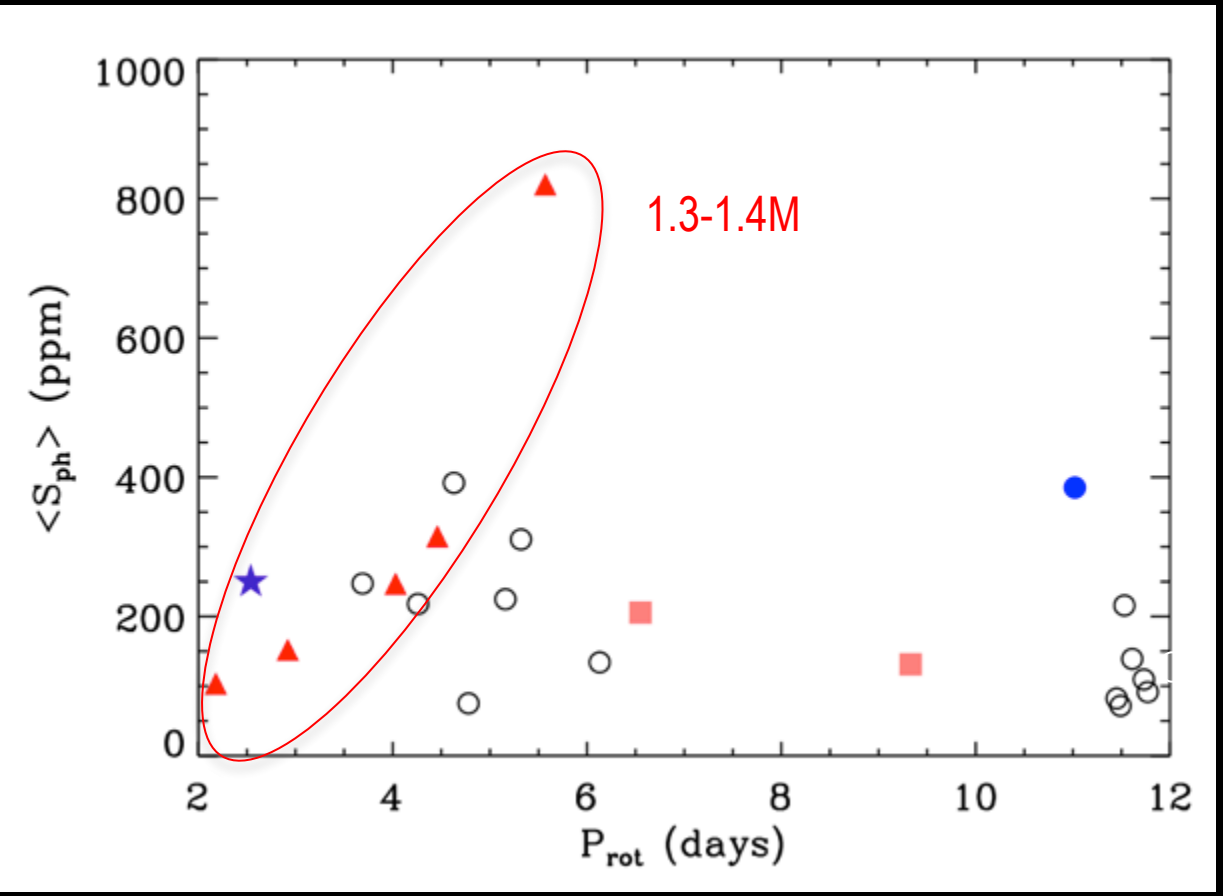
n activity





[Lanza priv. Comm]

IV-STELLAR MAGNETIC CYCLES

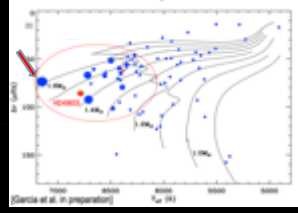


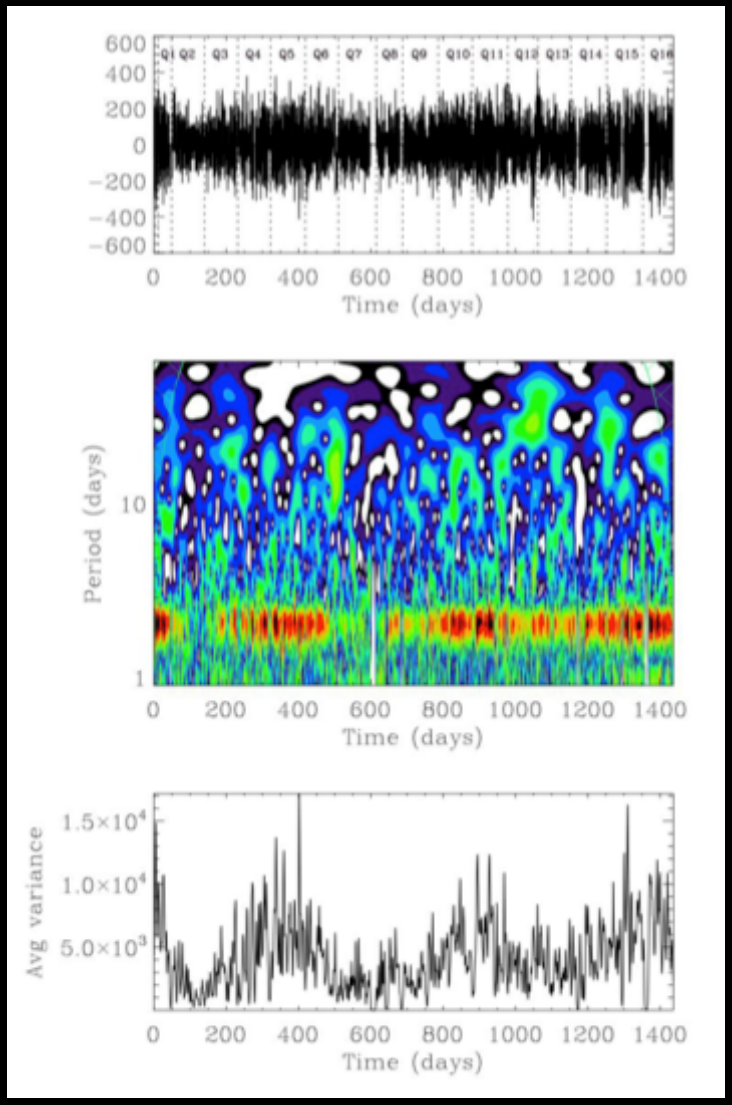
Long-lived active longitudes
Trends
Cycle

[Mathur, Garcia, et al., 2014]

- Fast rotating F stars.
  - Do not see regular cycles in most of them.

IV-STELLAR MAGNETIC CYCLES





[Mathur, Garcia, et al. ApJ, 2014]

KIC9226926

P_{rot}=2.2d

$\langle S_{ph} \rangle$ = 104 ppm

Asteroseismology:

M~1.4M$_\odot$

DCZ~1%

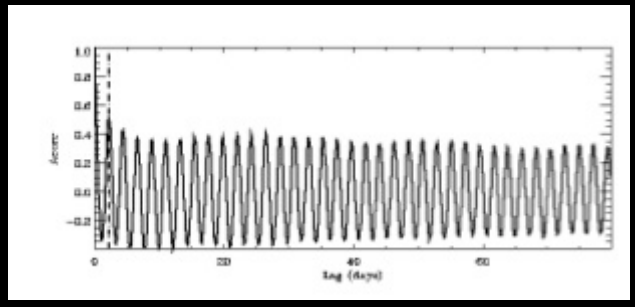
Power Spectrum

Two close frequencies (5.223 and 5.259 μHz)

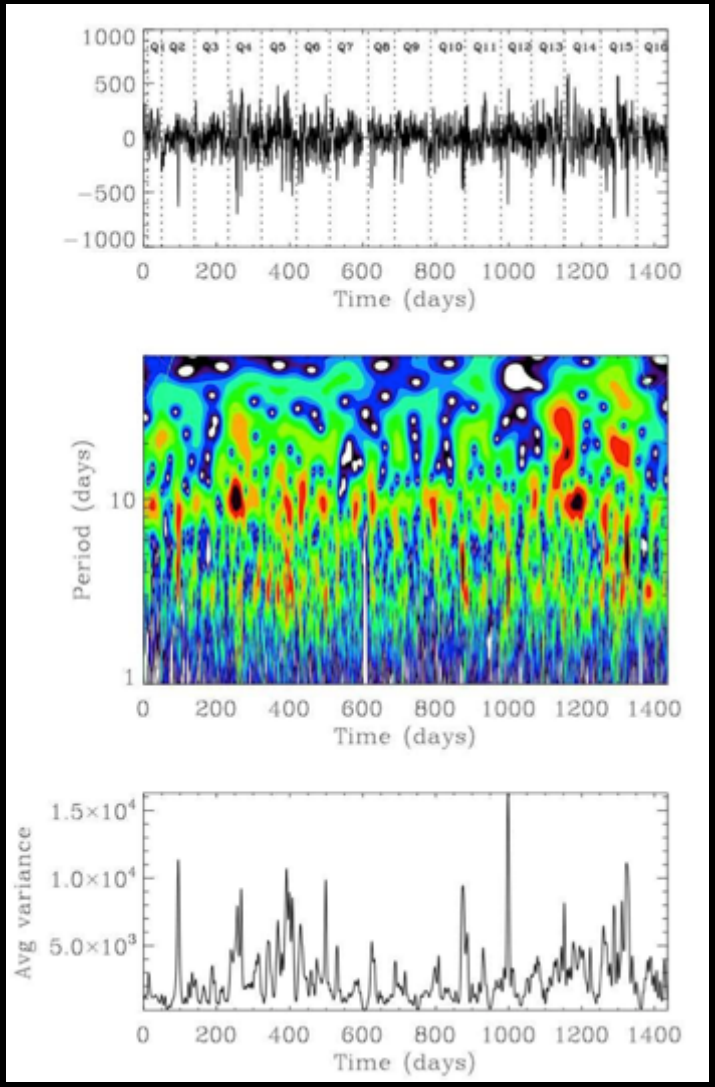
Beating effect with a period of ~540 days

Not a cycle but signature of long lived magnetic structures:

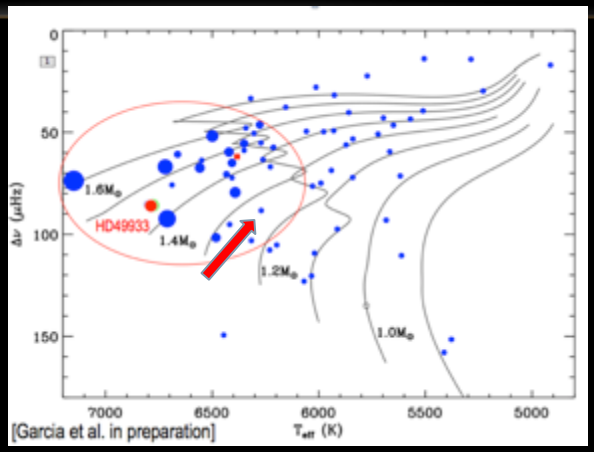
→ Very long lived active regions



IV-STELLAR MAGNETIC CYCLES

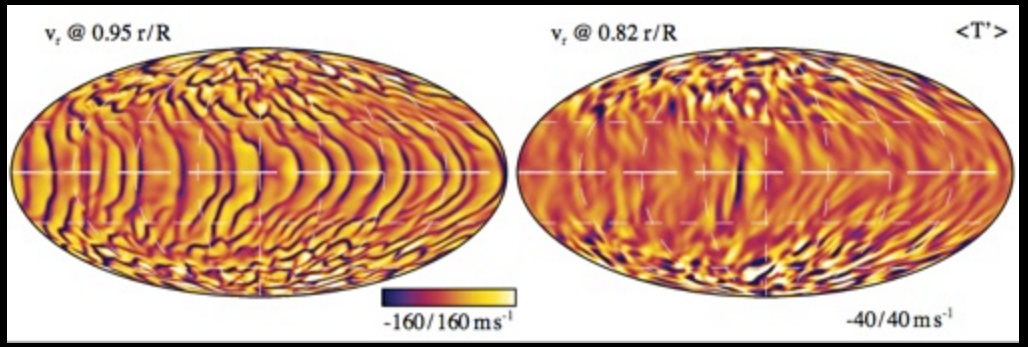


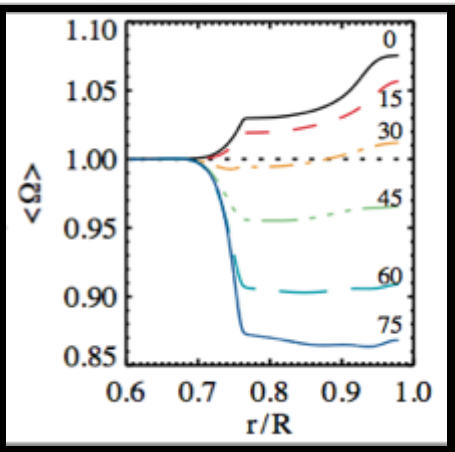
[Mathur, Garcia, et al. ApJ, 2014]



- KIC12009504
- 1D Seismic model
- 3D Model by ASH

Hydrodynamic models





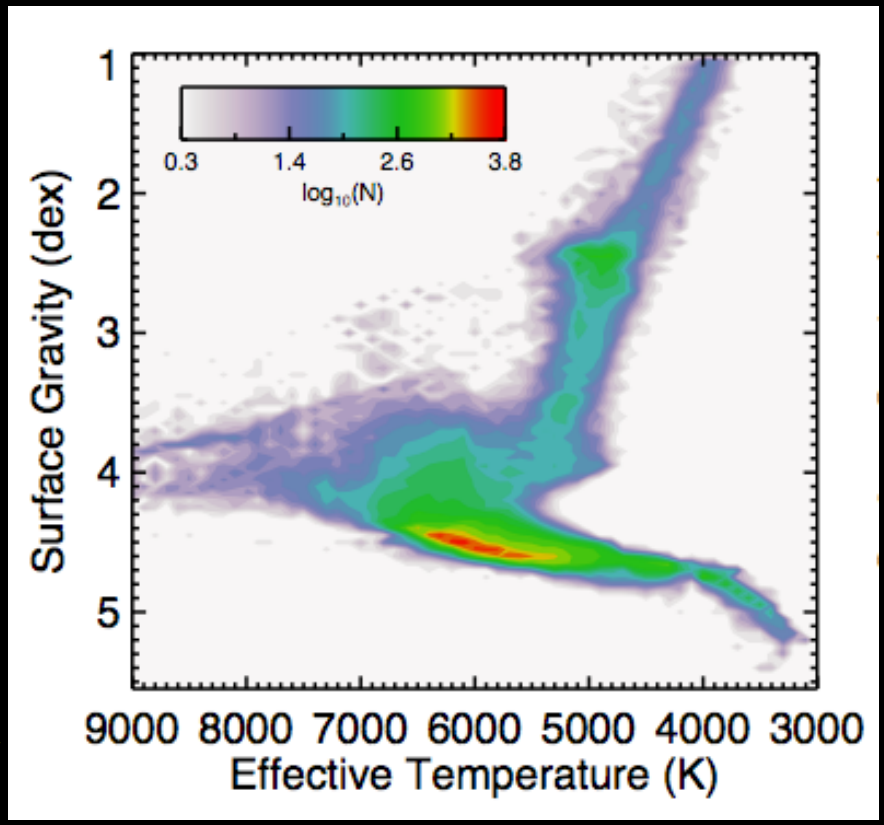
[Augustson, Mathur, Brun et al. in prep.]

P_{rot}=9.5d; M~1.12$M_\odot$; $<S_{ph}>$ = 167.1 ppm; DCZ 0.8 R

I-INTRODUCTION

- Detailed mechanisms of solar dynamo not completely understood
- No prediction available for solar magnetic activity
- Answer the questions :
  - Is the Sun a peculiar star?
  - Is its cycle normal?

[Mathur et al. 2017]



- A better understanding of magnetic activity

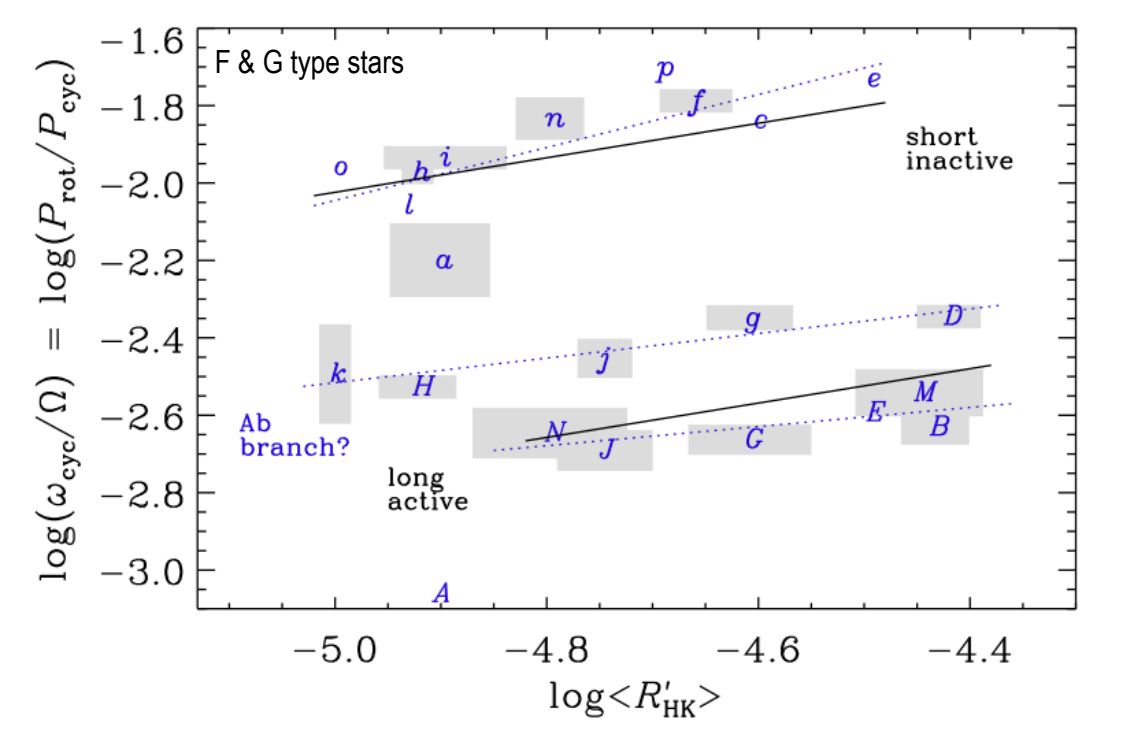
IIb-Stellar Dynamics:

Internal Rotation

(Main Sequence stars)

I-INTRODUCTION

- R'_{HK} is approximately proportional to the square root of the mean magnetic field strength at the stellar surface (Schrijver et al. 1989)
- $\langle R'_{HK} \rangle$ is proportional to the inverse Rossby number τ / P_{rot} (Noyes, 1984a)
- And $1/P_{cyc} \propto (\tau/P_{rot})^n$ (Noyes 1984b)

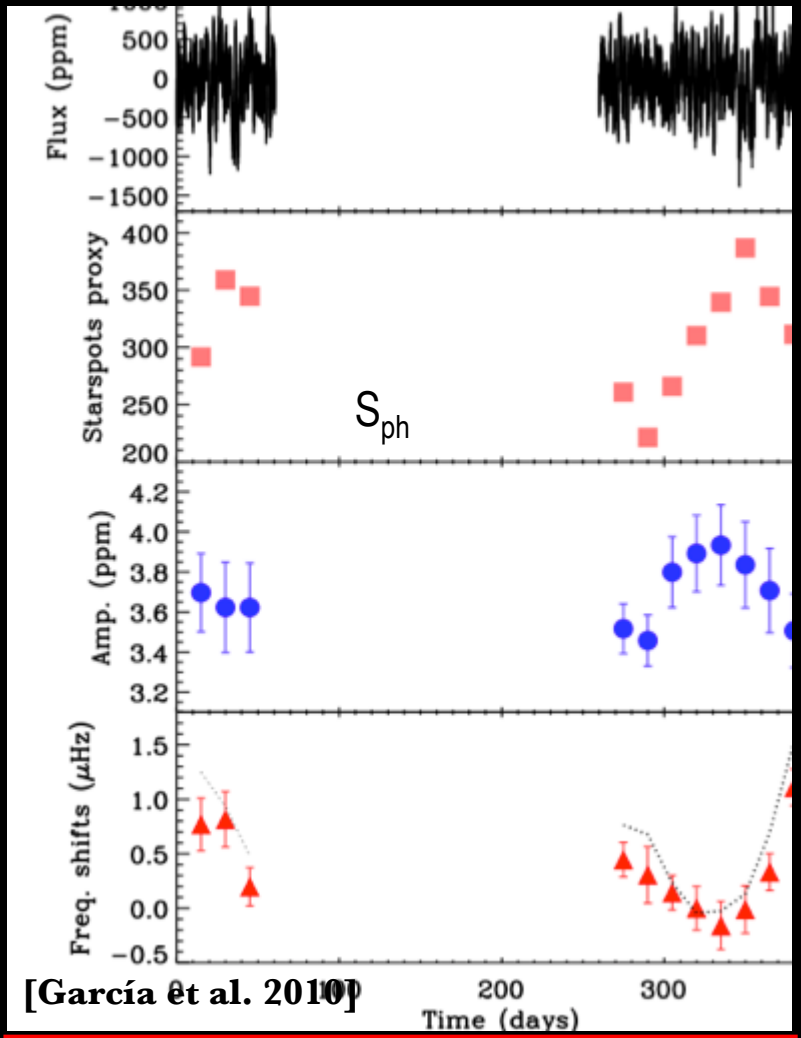


[Brandenburg et al. 1998]
[Brandenburg, Mathur & Metcalfe 2017]

HINTS OF A MAGNETIC-ACTIVITY CYCLE

Seismology

CoRoT

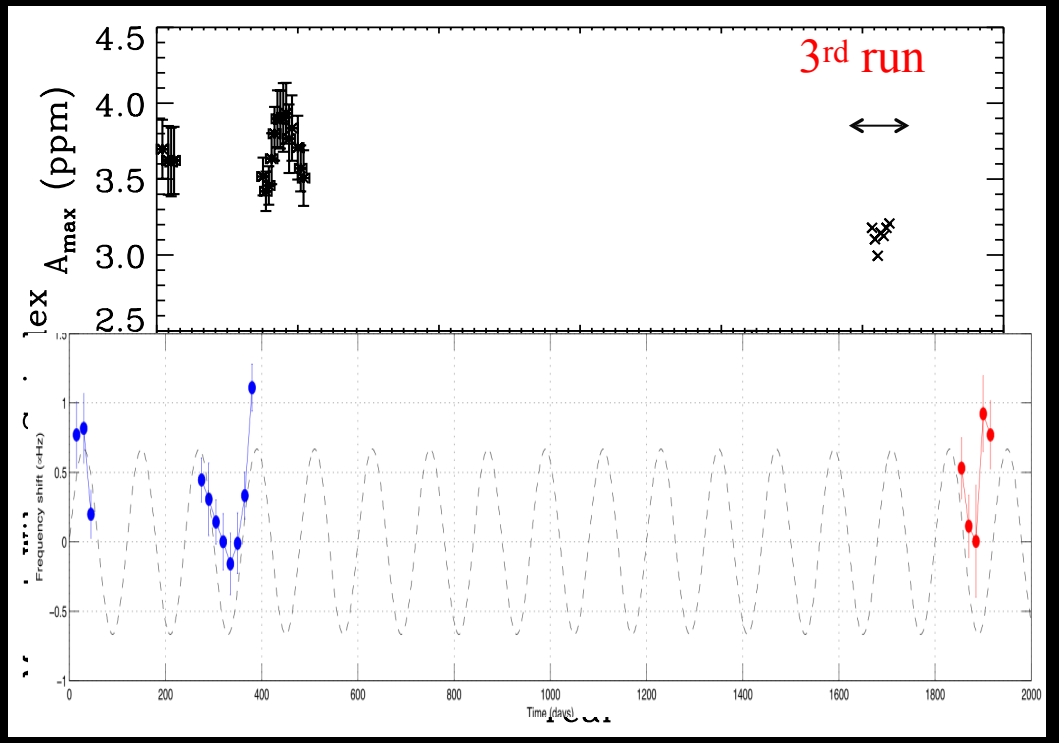


[García et al. 2010]

Anticorrelation between amplitude variation and frequency shifts

P_{cyc}>120days

HD49933



- Complementary observations
  - ✓ Ca HK: Mount Wilson index of 0.31 Active star

Modified S_{ph} also used by Chaplin et al. 2011 Campante et al. 2014