Stellar magnetic cycles: observational point of view with CoRoT & *Kepler*

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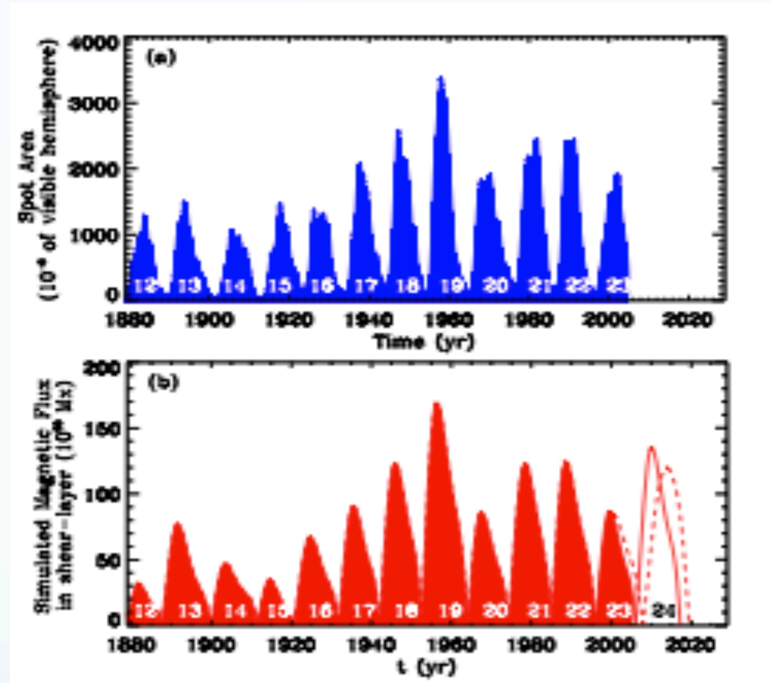
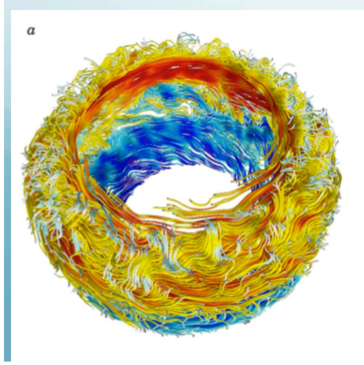
Why study stellar activity cycles?

Solar-Stellar connection: dynamos

- Understand dynamo and the interaction rotation - convection - magnetic field
  - Different physical conditions (rotation rate, depth of CZ)
  - Assuming dynamo operates similarly in solar-type stars compared to the Sun
  - Constraints on solar dynamos
  - Predict solar cycles



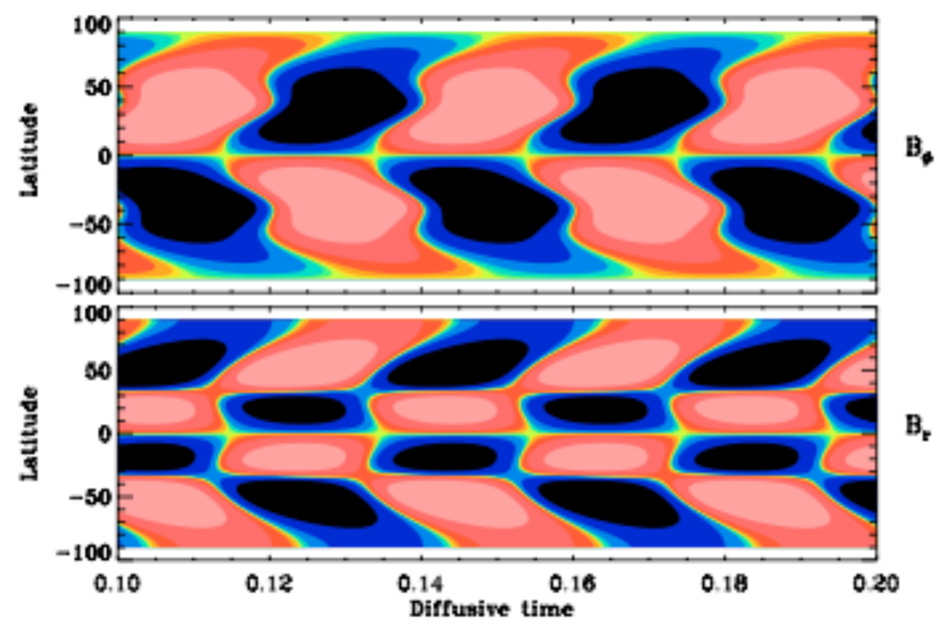
[Dikpati & Gilman, 2008]



[Brown et al. 2011]

Solar-Stellar connection: dynamos

- Variety of dynamo models:
  - Mean field, thin shell, distributed dynamos
    [Mc Gregor & Charbonneau, 1997; Choudhuri et al. 1995;Dikpati 2005]
  - Importance of base of CZ
- Unanswered questions:
  - Contribution of tachocline
  - Role of meridional flow
  - Energy supply



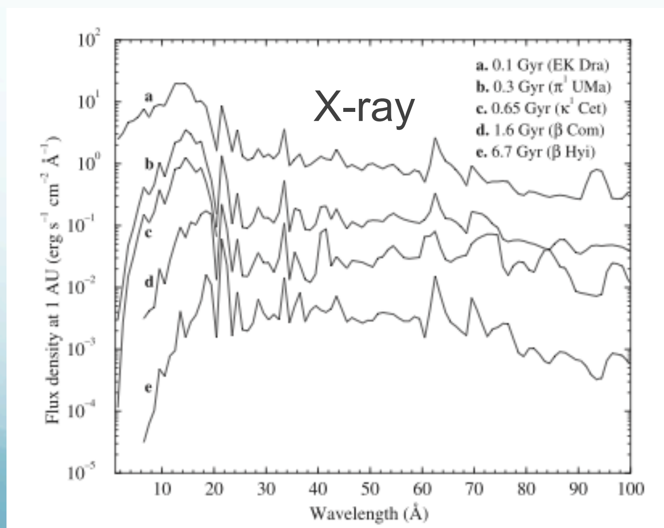
[Jouve et al., 2008]

→ Stars:

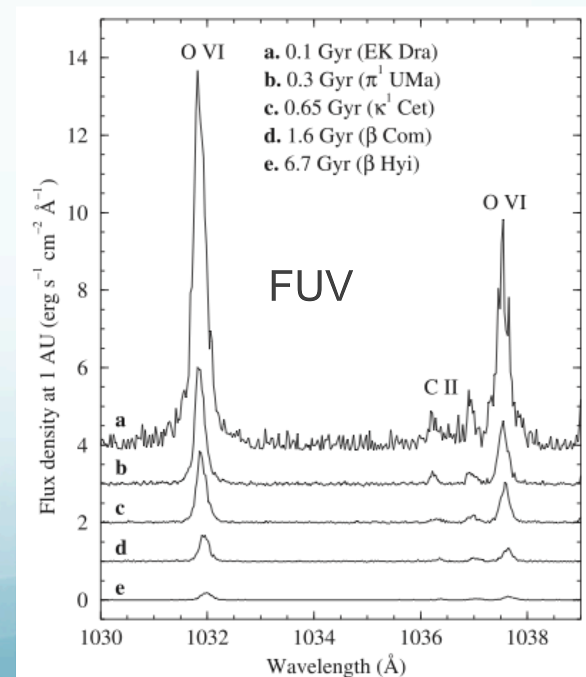
- Explore dynamos at different rotation periods and convective zone depths
- Dynamos periods and activity levels scalings
- Understand relative importance of tachocline and structure of the stars

Star-Planet interaction

- Stars: larger source of energy **[Ribas, 2010]**
  - Emissions (winds) affect composition, thermal properties, existence of planetary atmosphere.
  - Increase of atmospheric temperature, photochemical reactions, erosions… **[Hunten et al. 1991; Bauer & Lammer 2004]**
  - Habitable zone, development of life **[Kasting & Catling 2003]**



[Ribas et al. 2005]



Activity/Rotation relation

- Cool star like the Sun with an $\alpha\Omega$ dynamo:
  - Longer rotation period ➔ longer cycle period

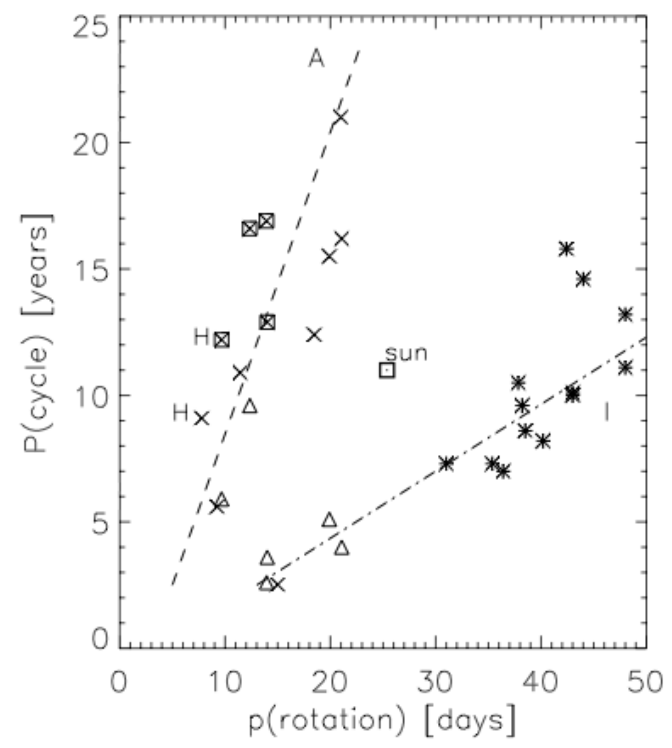
    [Saar & Brandenburg 1999;Thomas & Weiss 2008]

- Empirical law:

  $$P_{cyc}/P_{rot} = \Omega / \Omega_{cyc} = CR_0^q$$

  with $R_o = P_{rot} / \tau_c$, the Rosby number, τ_c the convective turnover time and q changing from 0.25 to 1.

  [e.g. Ossendrijver 1997; Saar 2002; Jouve et al. 2010]



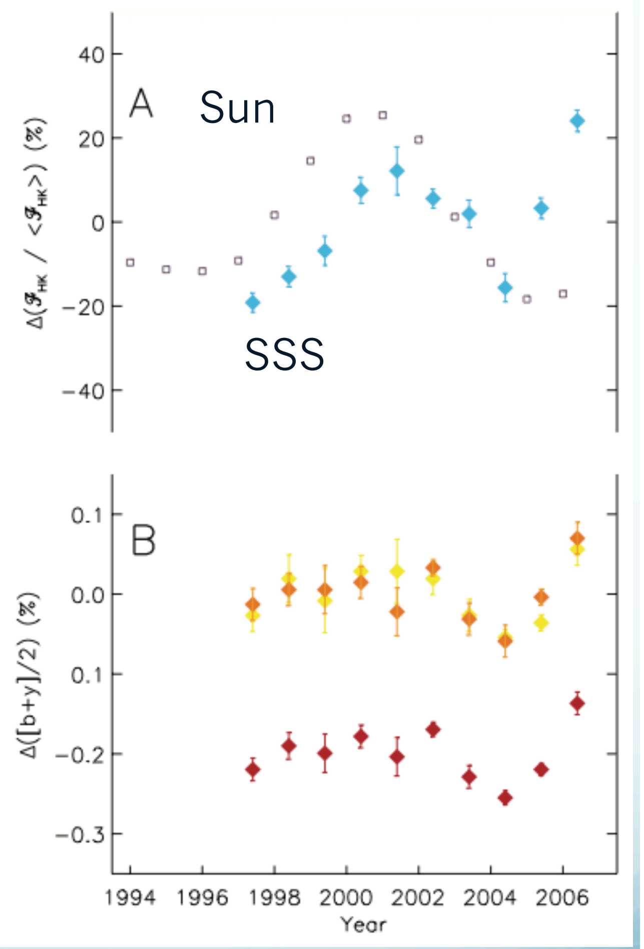
[e.g. Bohm-Vitense 2007]

- Mount Wilson CaHK project study of G and K stars:
  - Active
  - Inactive
  - Sun: special case

Possible explanations: changes in α effect, different locations of the dynamo shell…

Stellar cycles in solar analogs

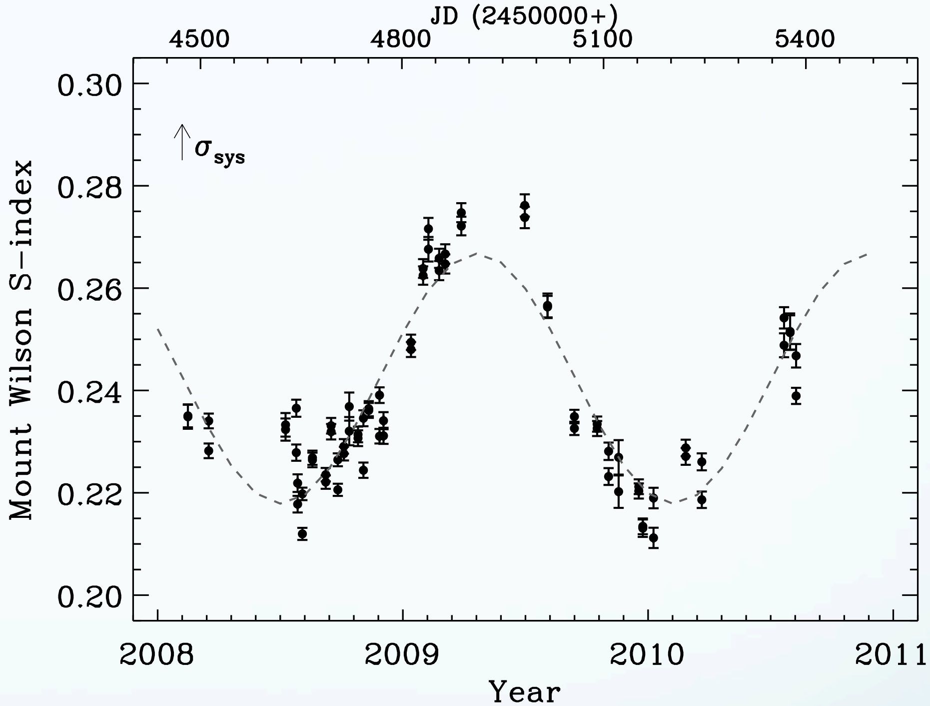
- Example of 18 Sco
  [Hall, Henry & Lockwood 2007]
  - ~10 years of spectroscopic and photometric data from Solar-Stellar Spectrograph+Automatic Photospheric Telescope
    - Measurement of CaHK -> excess flux
    - Simultaneous measurements in b and y passbands
  - Similar variations to the Sun
    - <S>~0.182
    - P_{cyc}~7 yrs ; P_{rot}~22d
    - total brightness variation of 0.09%



[Hall, Henry & Lockwood 2007]

Short cycles not so uncommon?

- ι Hor or HD170151:
  - Exoplanet host star
  - P_{rot}~8 days
  - 2.5 years of CaHK observations
  - P_{cyc}~1.6yr -> one of the shortest cycles observed



[Metcalfe et al. 2010, ApJ]

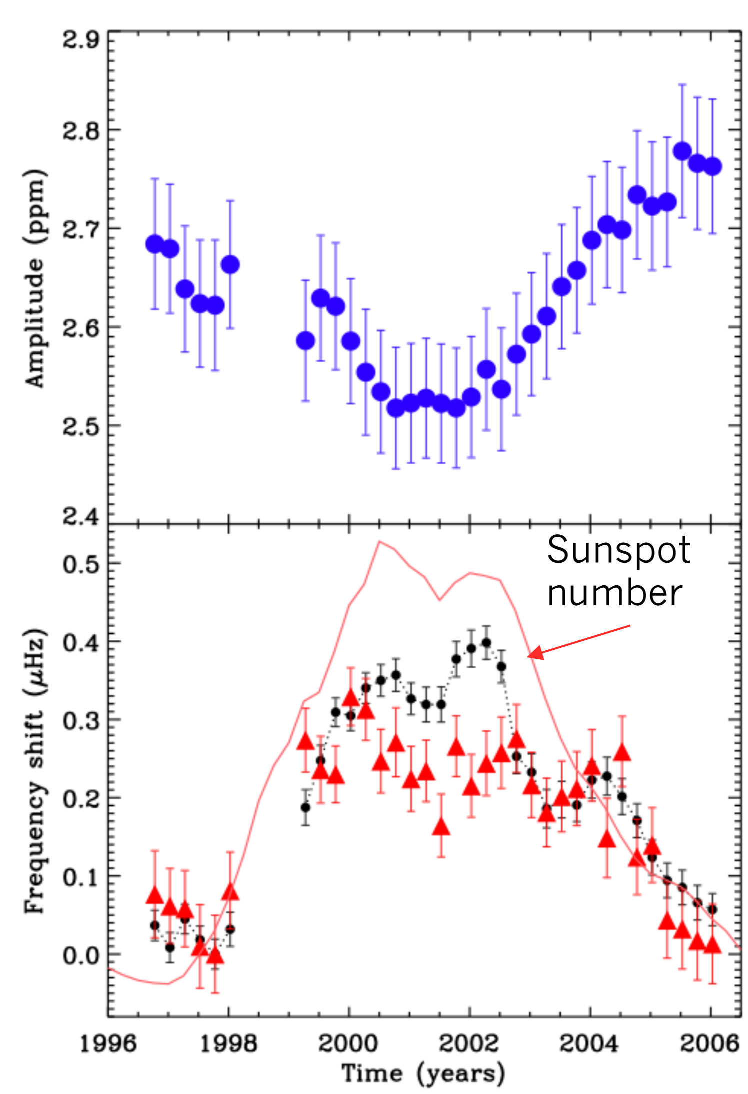
- Not impossible to observe many magnetic activity cycles with the present missions such as CoRoT, *Kepler*…

Using seismology

The Sun

- Magnetic activity affects:
  - Frequency of p modes
    - Increases
  - Amplitude of the p modes
    - Decreases

- Variables affected even when no evidence of surface magnetic activity
  - Maunder minimum (Be) **[Beer et al. A&A, 1998]**
  - Last minimum (p modes) **[Salabert et al. A&A, 2009]**



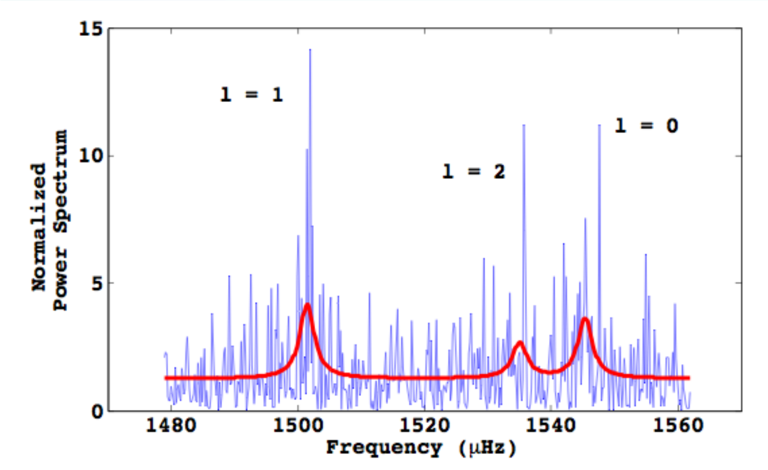
[García et al. Science, 2010]

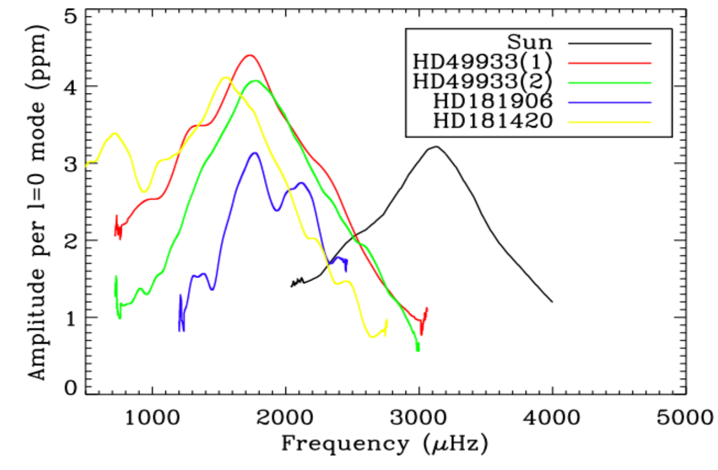
Methodology

- Maximum amplitude per radial mode:
  - Gaussian fit of the p-mode bump with the A2Z pipeline

[Mathur et al. A&A, 2010]

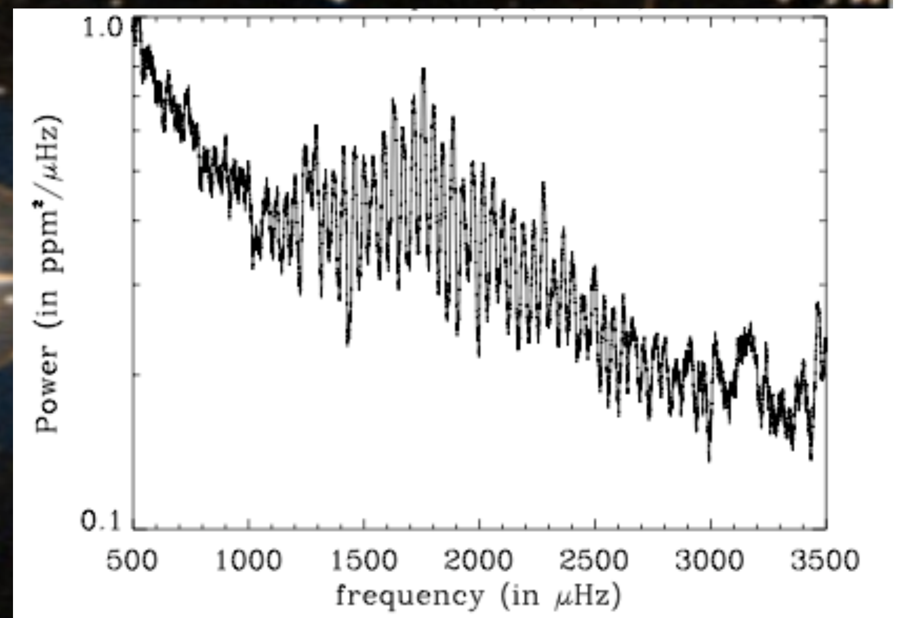
- Frequency shifts
  - Globally: Cross-correlation **[Pallé, Régulo & Roca-Cortés 1989]**
  - Individual modes: local fit of l=0,1 and 2 modes in the PSD





The CoRoT target: HD49933

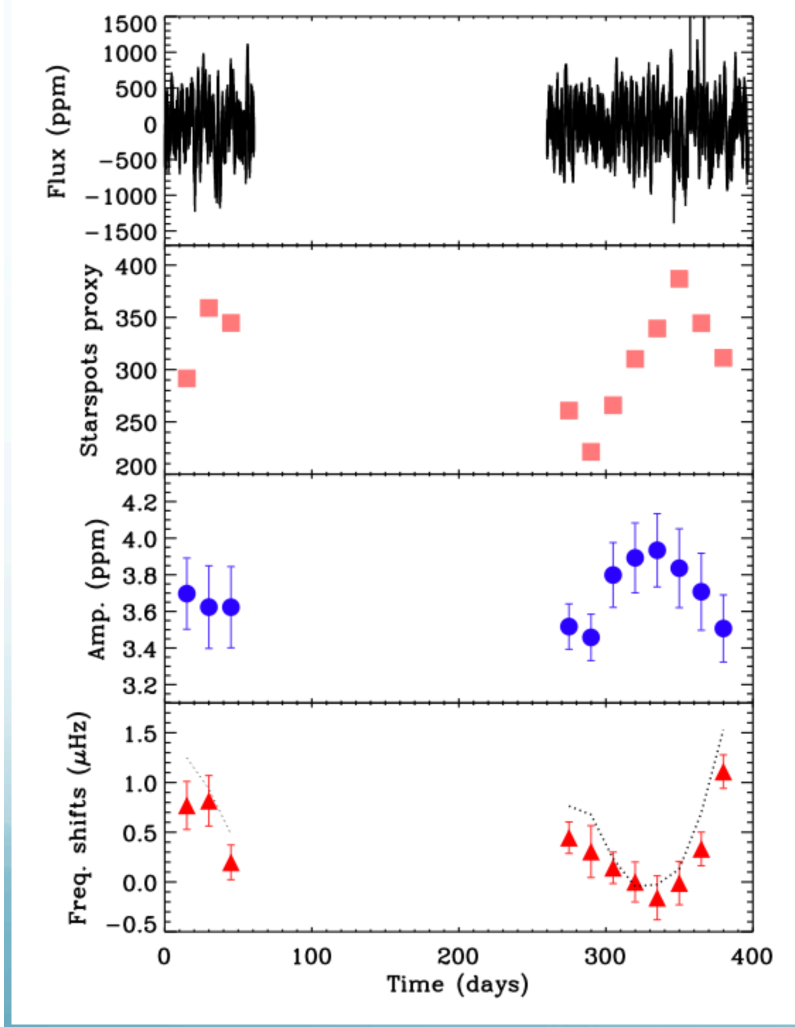
- Stellar parameters:
  - F5V dwarf
    - 1.2 $M_{\odot}$; 1.3 $R_{\odot}$
  - P_{rot} = 3.4 days
  - Observed by CoRoT during 60 + 137 days
    - 50 oscillation modes measured



[Appourchaux et al. 2008; Benomar et al. 2009]

Stellar activity:
HD49933

1st detection of magnetic cycle with seismology



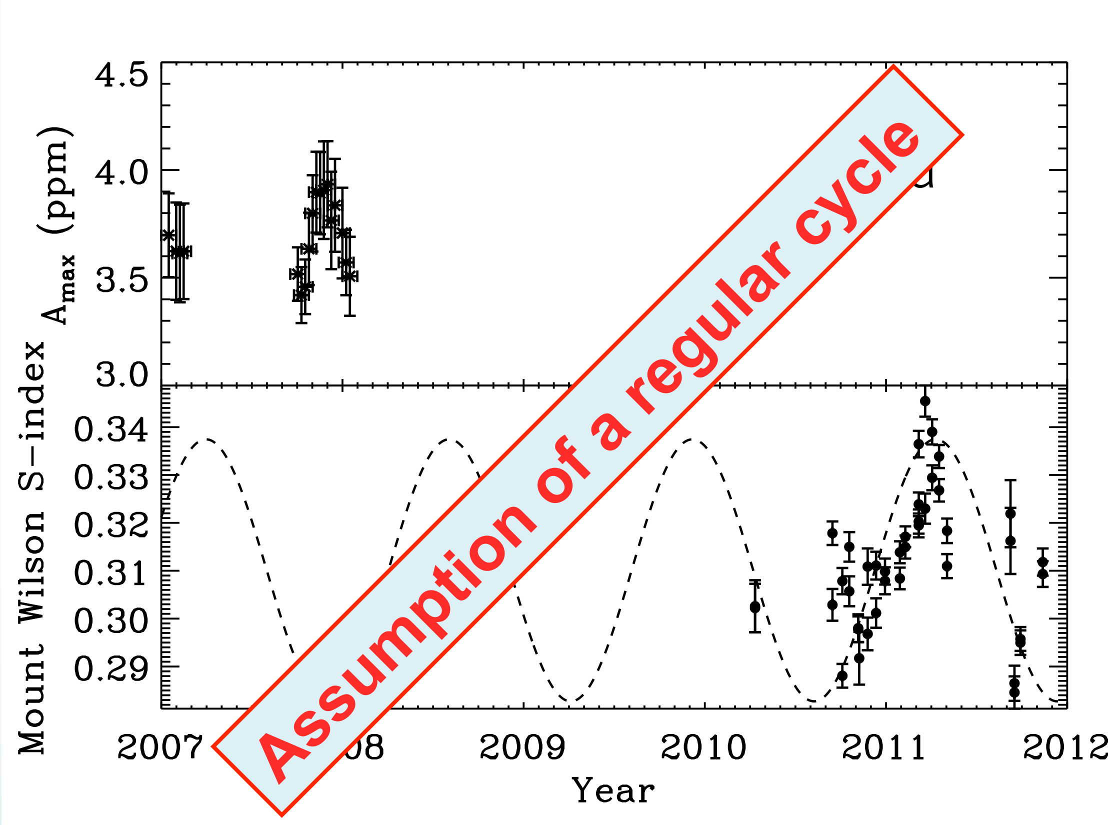
[García et al. Science, 2010]

→ **Anticorrelation between amplitude variation and frequency shifts evolution**
P_{cyc}>120days

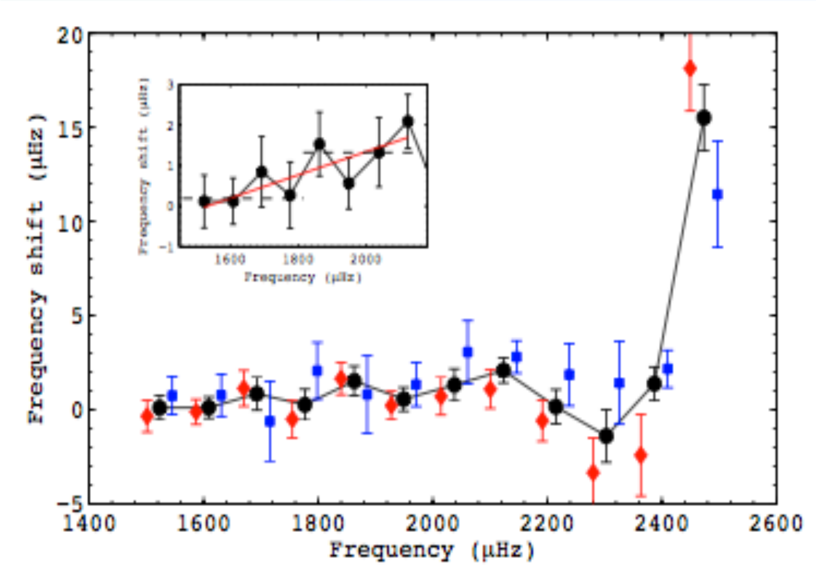
- Stellar cycles measured:
  - Hundreds of stars
  - Empirical relation: P_{cyc}/P_{rot}
  - Need to know convective turnover time
- With seismology:
  - Precise determinations of cycle
  - Precise determination of:
    - Base of convective zone (acoustic glitches or models)
    - Internal conditions of the star
- Strong constraints for dynamo simulations

Follow up in CaHK

- Observations at Cerro Tololo started in April 2010 + 8 months (09/2010-04/2011)
  - Ca HK: Mount Wilson S index of 0.3
    - Active star
  - See a hint of minimum
  - Definitely a maximum
  - Suggests a P_{cyc}>210d



Frequency shifts variation



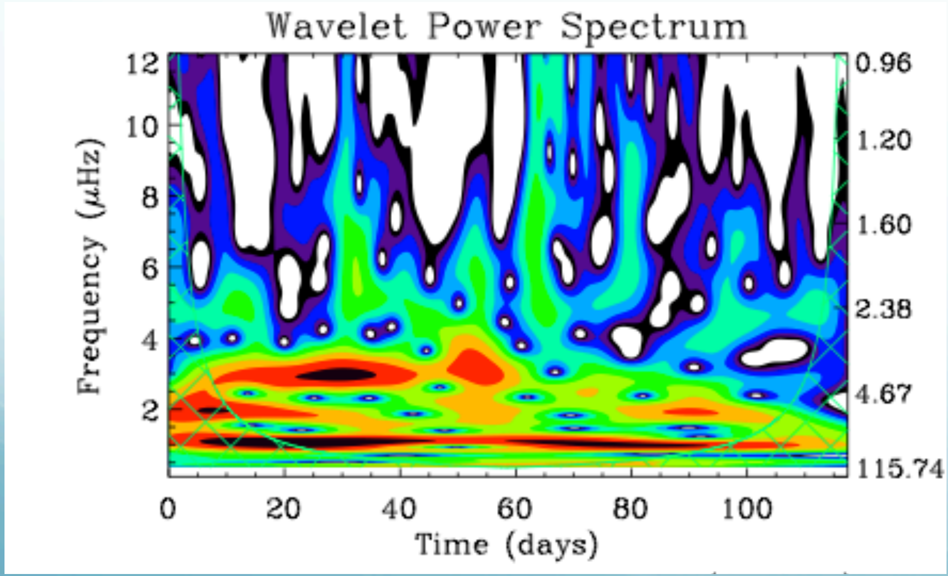
[Salabert et al., A&A 2011]

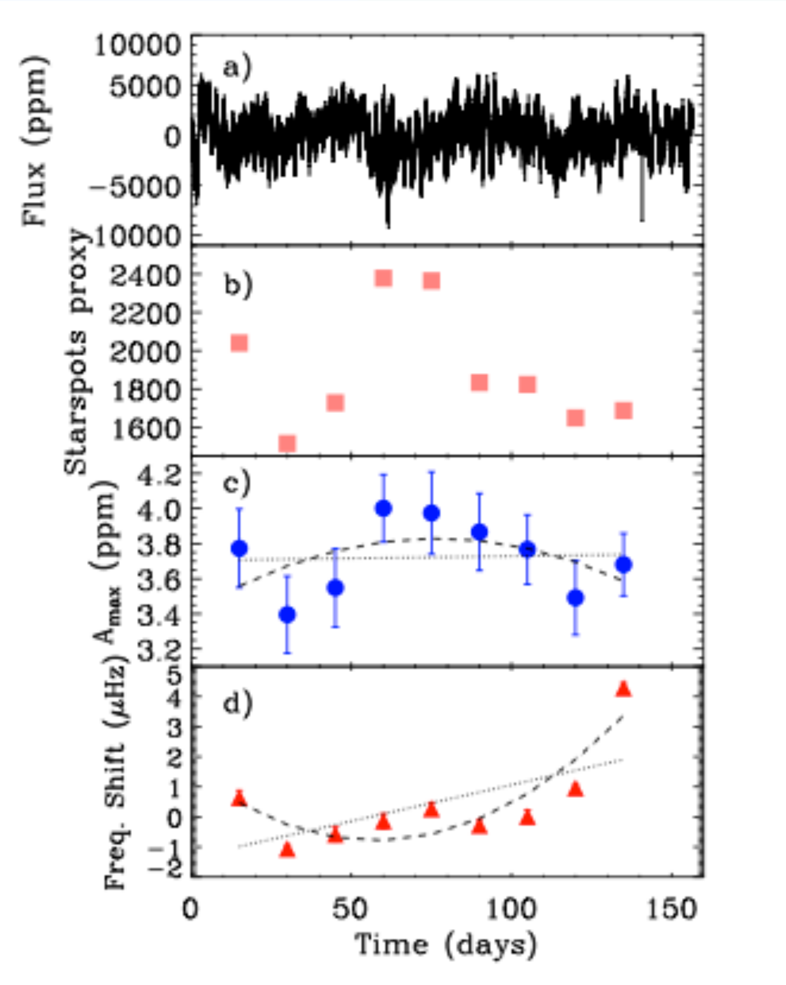
- Asteroseismology
  - Study of frequency shifts as a function of frequency
  - Closer to surface or deeper in the CZ?
- *Analysis of HD49933*
  - increased frequency shifts at high frequency
  - similar to the Sun

→ **Possible explanation: changes in outer layers due to magnetic activity. Work in progress: see the contribution of magnetic field in the surface effects**

The exoplanet host star HD52265

- Star observed during 117 d:
  - G0-type metal rich star **[Ballot et al. 2011]**
  - P_{rot}=11-12 days
- Decrease of A_{max} and increase of freq. shift
- Starspot proxy different from wavelet analysis



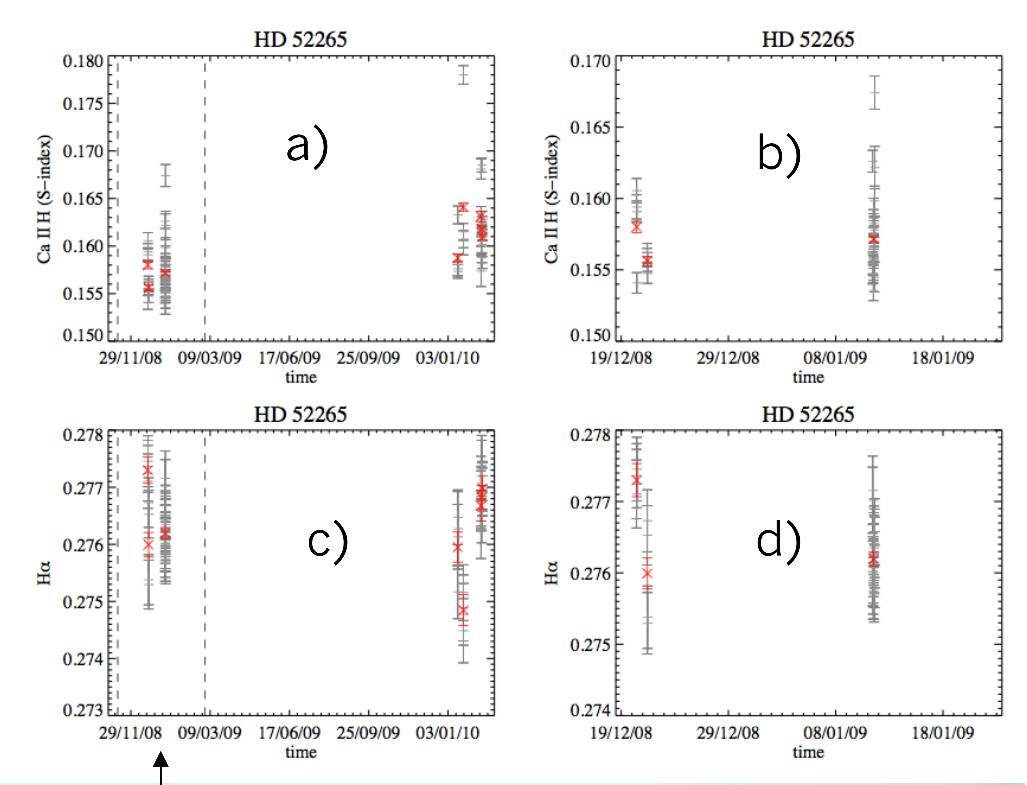


[Mathur et al. submitted]

CaH and Hα observations

Zoom of 1st period

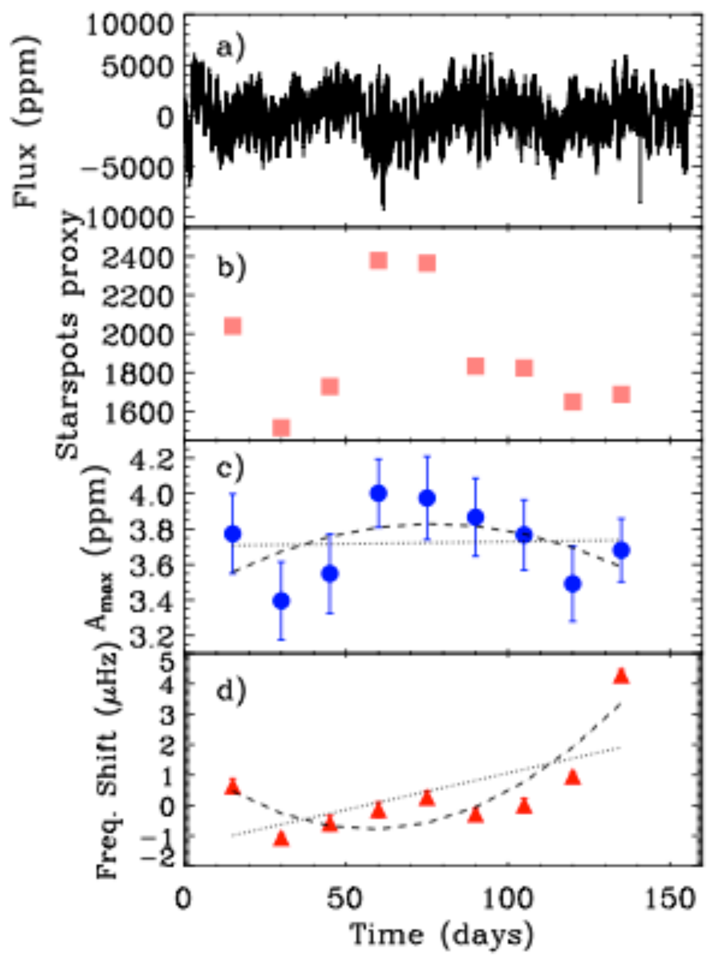
- Observations from Narval
  - Several nights simultaneously with CoRoT observations
  - Observations 1 year later
  - Average: slight increase
- Not an obvious increase
- But a tendency in agreement with seismic observations
- Suggests long cycle
- $P_{cyc} > 1$ yr



CoRoT observation period

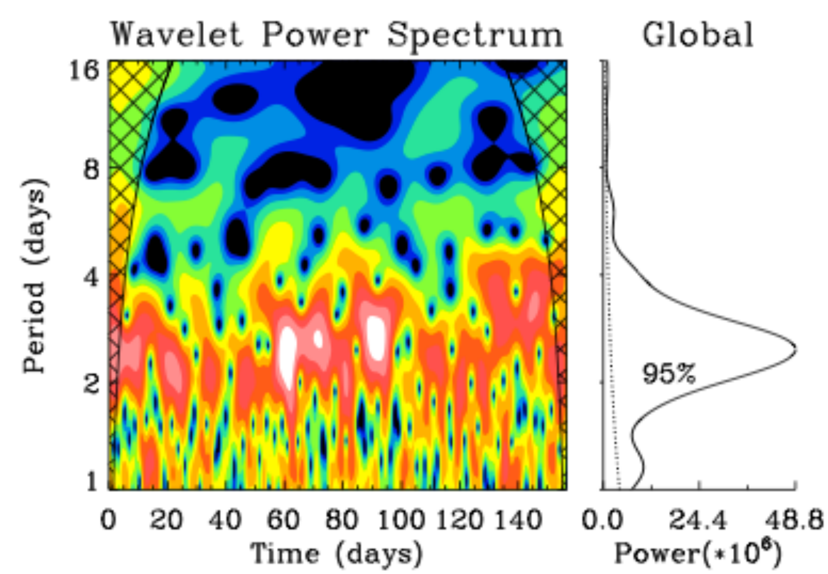
[Mathur et al. , submitted]

Case of HD181420



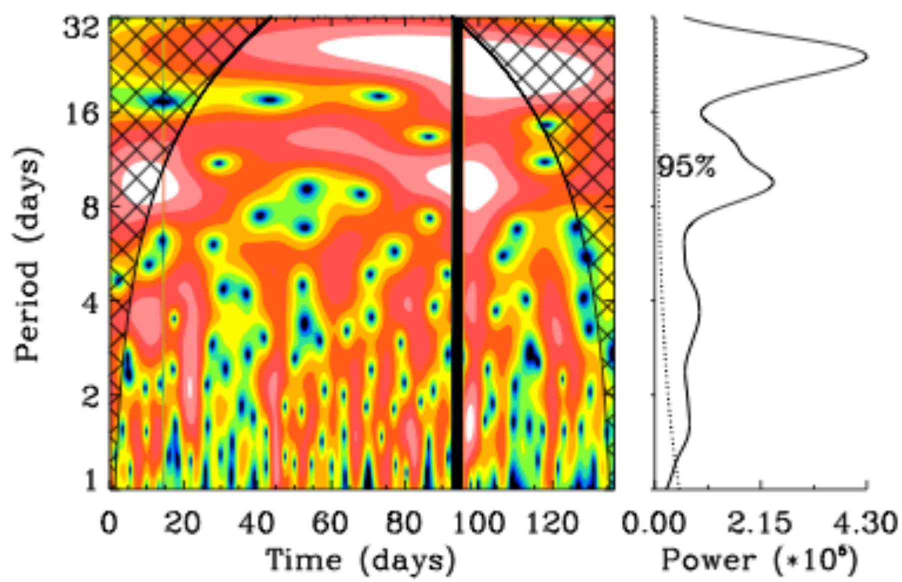
[Mathur et al. , submitted]

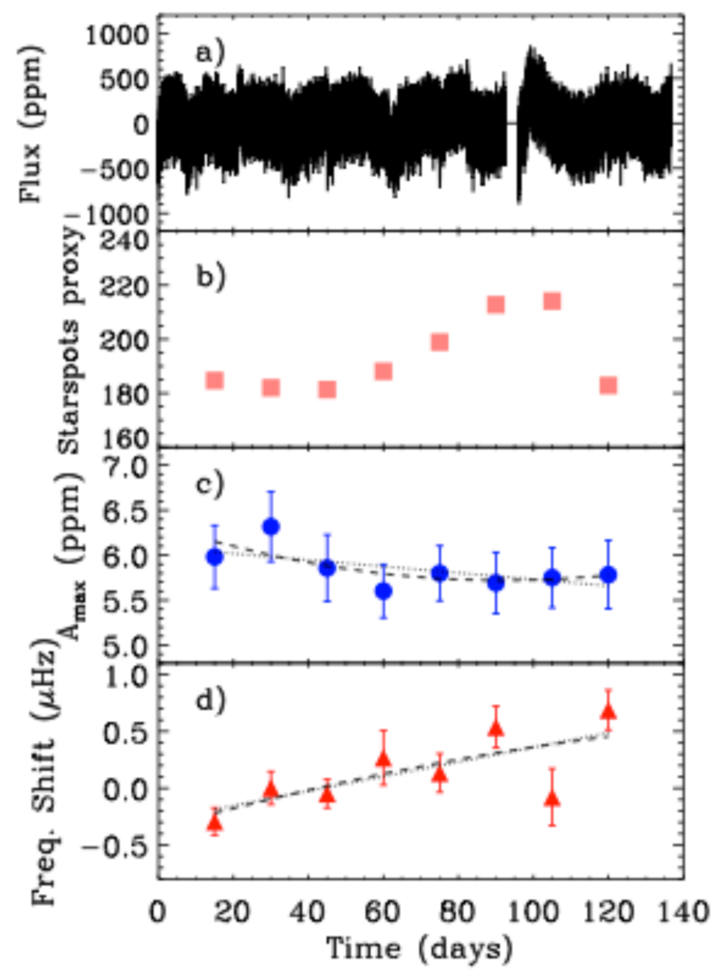
- Star observed during 156.6 d:
  - F2 star
  - $\Delta\nu \sim 75\mu$Hz ; 1.3 $M_\odot$
  - P_{rot}=2.5 days [Barban et al. 2009]
  - Inclination: 40.2-50.1 degrees
- Study in the range 1300-2000 μHz
- Faint hint of anticorrelation
- But correlation of A_{max} with starspot proxy and wavelet analysis



The G-type star HD49385

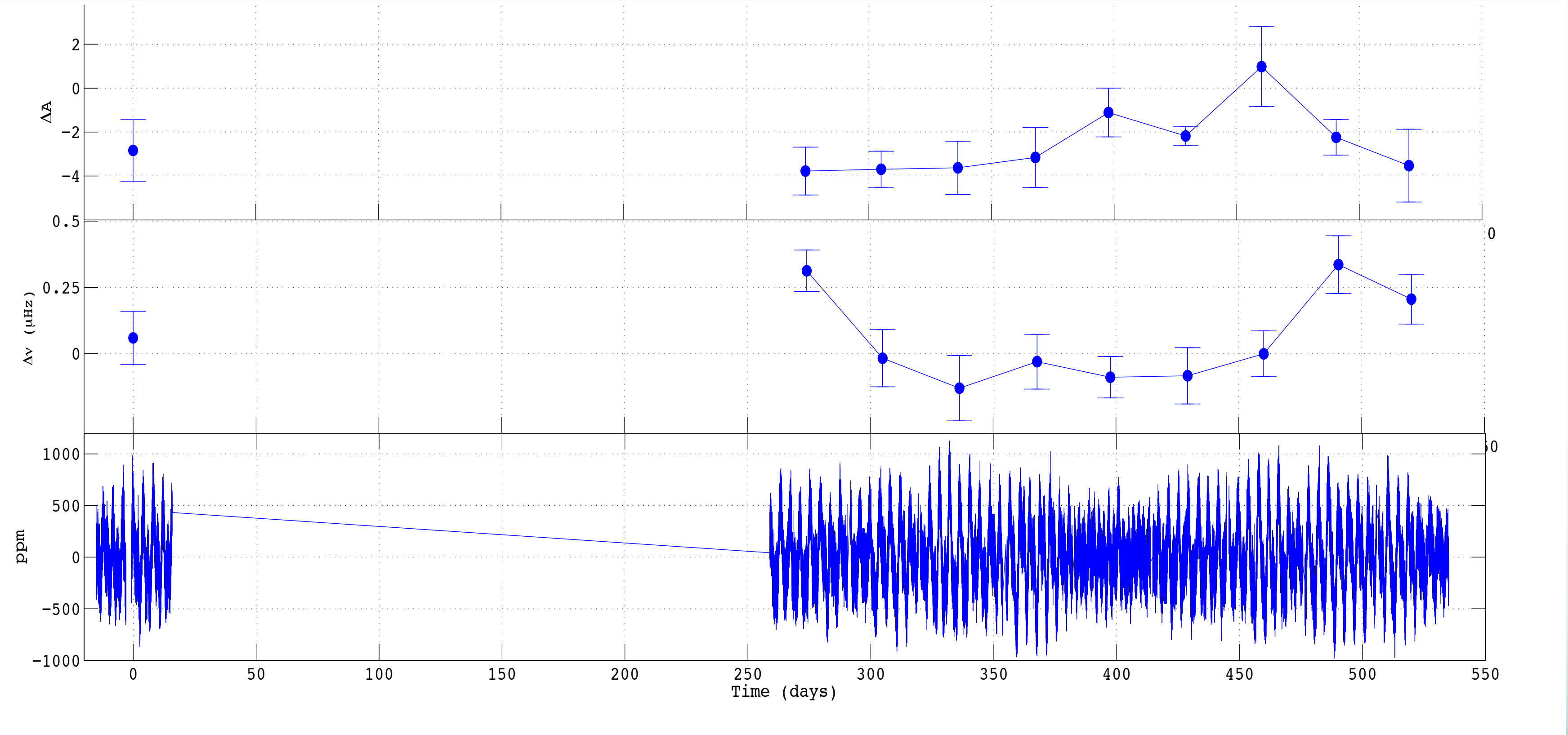
- Star observed during 156.6 d with following parameters:
  - G- type star **[Deheuvels et al. 2009]**
  - $\Delta\nu$~56μHz; 1.9 $R_\odot$
  - P_{rot}=29 days (?); no clear signature
  - Inclination: 20.5±0.5 degrees
- Study in the range 1300-2000 μHz





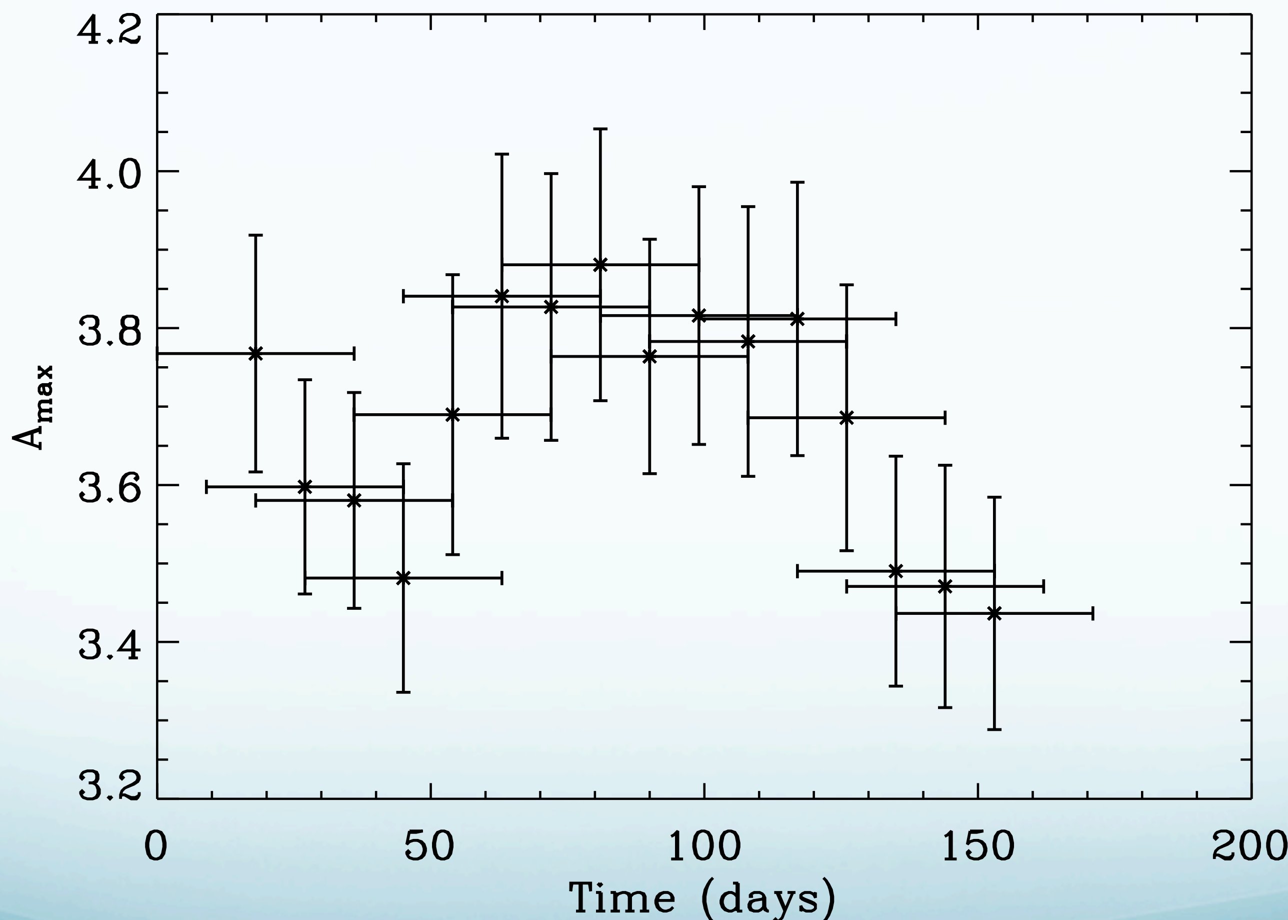
[Mathur et al. , submitted]

Kepler target showing activity?



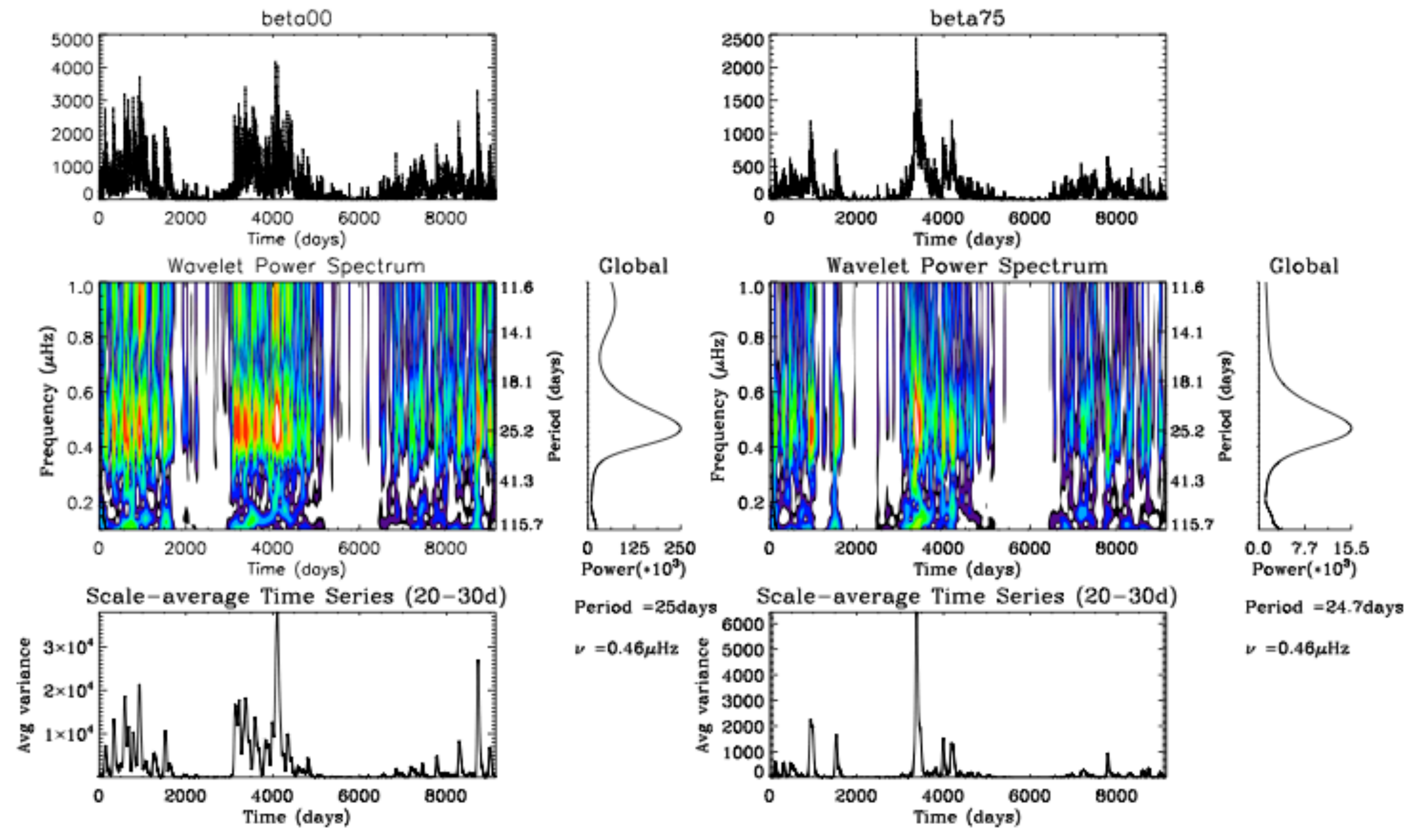
Work in progress...

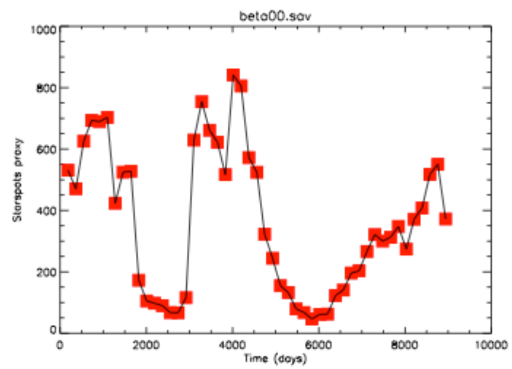
Another *Kepler* target

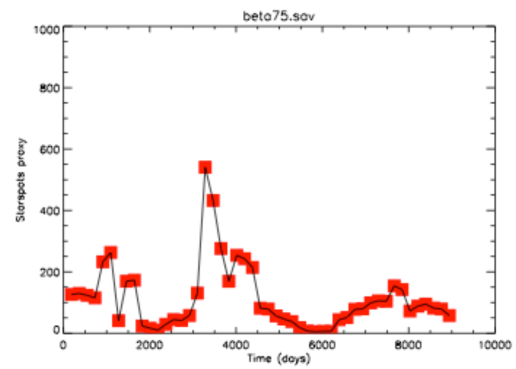


Work in progress...

Inclination angle







[Ramio Vasquez et al., 2011]

Conclusions

- Mount Wilson HK project:
  - Relation P_{rot}/P_{cyc}
  - Active and inactive branches
- *HD49933: first detection* of a *magnetic activity cycle* with *asteroseismic* methods

- Asteroseismology:
  - structure of star (base of CZ)
  - rotation
  - magnetic activity

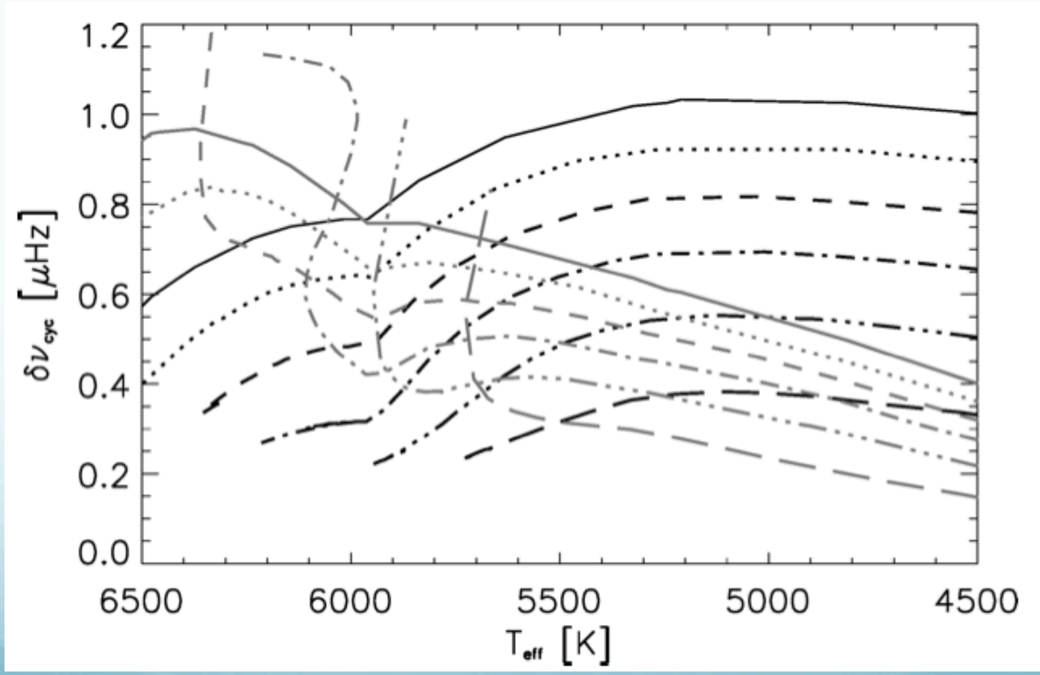
→ Solar-Stellar connection (dynamo…)
Star-Planet Interaction

- Scalings between classical proxies (CaHK) and p-mode parameters variation
- Inclination angle impact
- Active latitudes

Thank you

What to expect with seismology for solar-type stars?

- Prediction of the amplitude of frequency shifts using 2 different scalings between δν and $\Delta R'_{HK}$
  - Higher amplitudes for G stars **[Chaplin et al. 2007, A&A]**
  - Higher amplitudes for F stars **[Metcalfe et al. 2007, MNRAS]**



[Karoff et al. 2009, MNRAS]