Regular gaps in the *Kepler* data: influence on asteroseismic measurements

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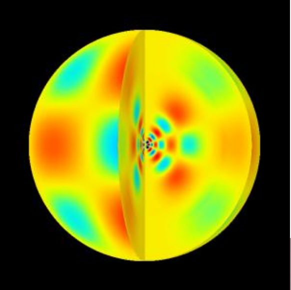
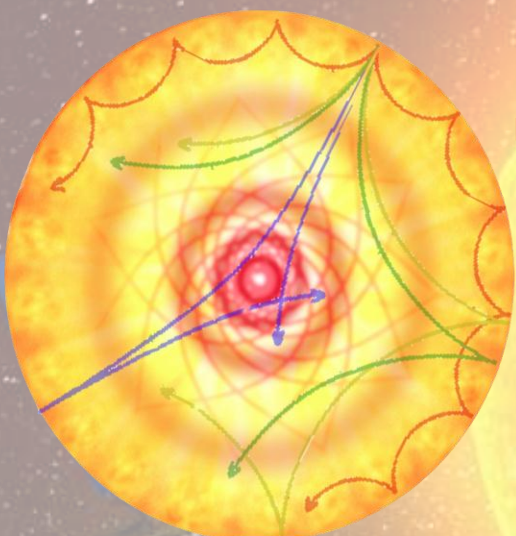
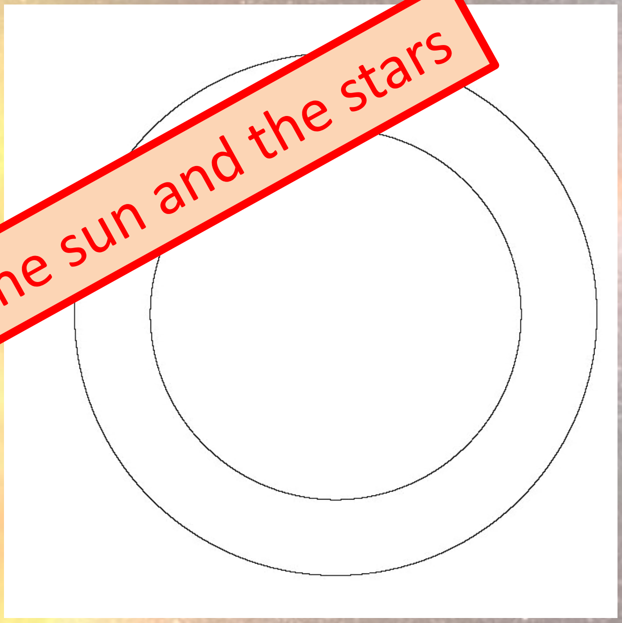


Seismology

- Oscillation eigenmodes characterized by:
  - ℓ : Degree
  - m : Azimuthal order
  - n : Radial Order





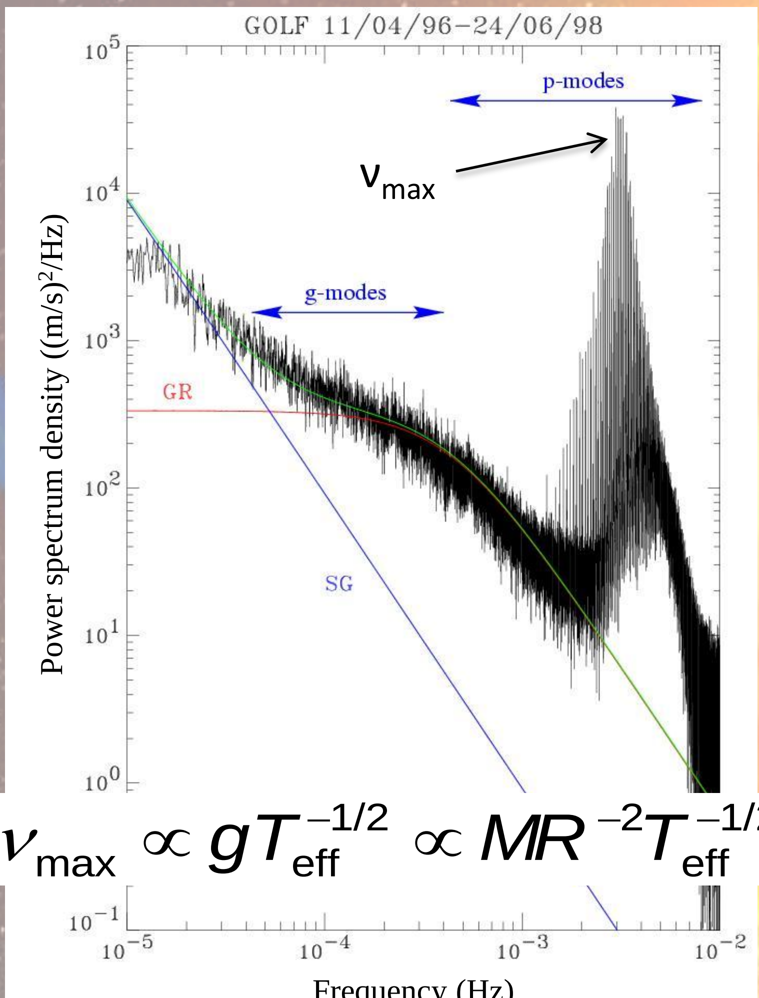
- Acoustic (p) modes:
  - Restoring force:
    - Pressure
    - Equidistant in fr
- Gravity (g)
  - R ce:
    - uoyancy
    - vanescent in the convective zone
    - Equidistant in period

Directly probes the deeper layers of the sun and the stars

- Mixed modes
  - Coupling between p- and g-mode cavities

Power Spectrum

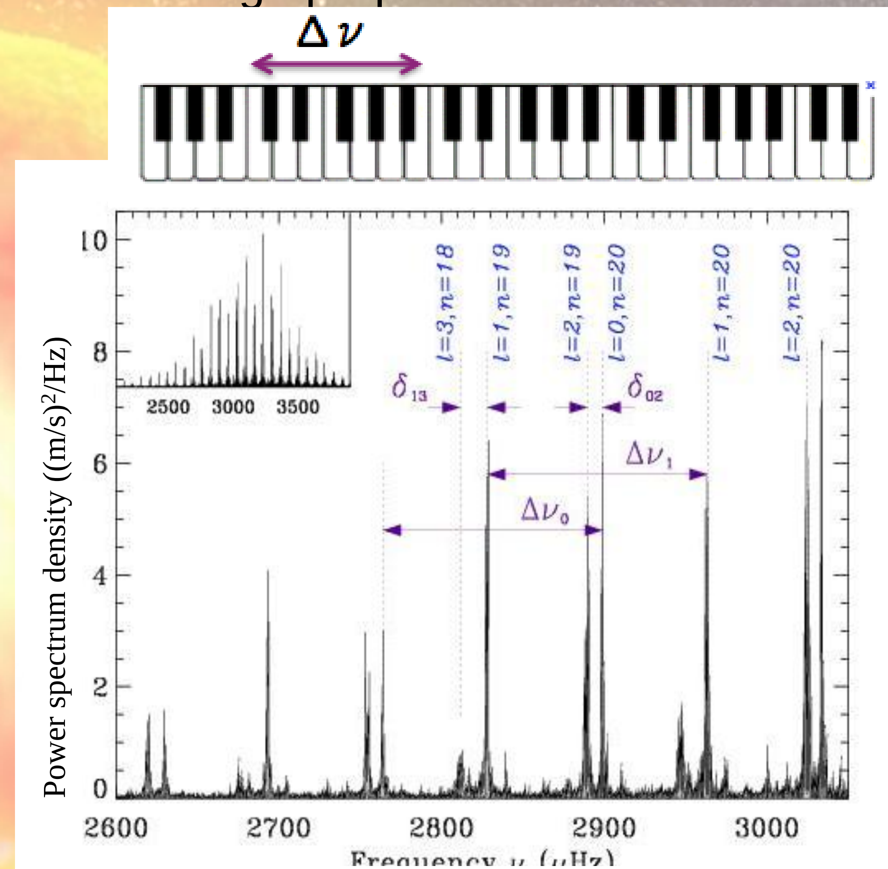
- Frequency at maximum power



$$\nu_{max} \propto g T_{eff}^{-1/2} \propto M R^{-2} T_{eff}^{-1/2}$$

[Brown et al. 1991; Belkacem et al. 2011]

- Large separation: $\Delta\nu = \nu_{n,\ell} - \nu_{n-1,\ell}$
  - Average properties of the star:



$$\langle \Delta\nu \rangle \propto \langle \rho \rangle^{1/2} \propto M^{1/2} R^{-3/2}$$

Stellar properties: direct methods

Use of scaling relations

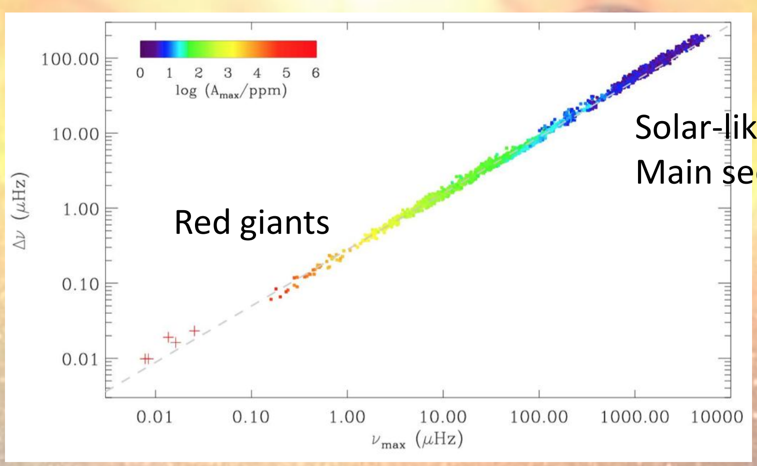
From global asteroseismic parameters and a good estimation of T_{eff}

$$R \propto \nu_{\max} \langle \Delta\nu \rangle^{-2} T_{\text{eff}}^{0.5} \quad (\sim5\%)$$

$$M \propto \nu_{\max}^{3} \langle \Delta\nu \rangle^{-4} T_{\text{eff}}^{1.5} \quad (\sim10\%)$$

Tested both theoretically and observationally

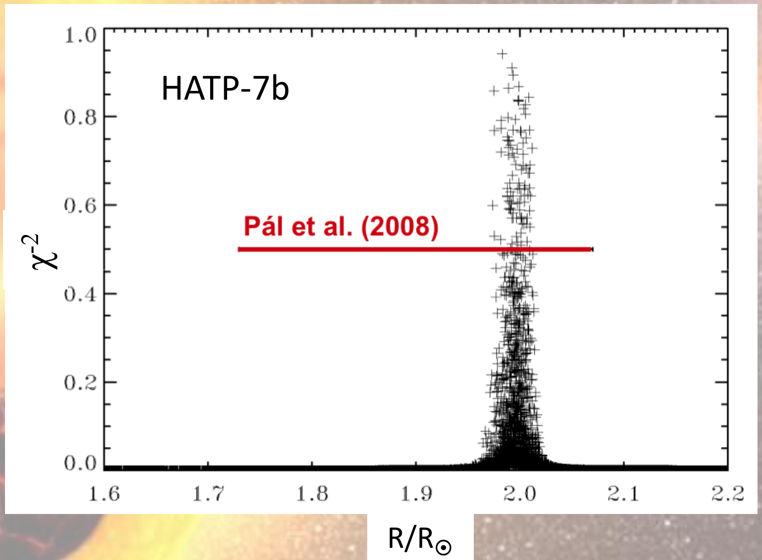
[Kjeldsen & Bedding 1995; Huber et al. 2012; Mathur et al. 2012; Silva Aguirre et al. 2012]



[Mosser et al., 2013 SF2A]

Stellar modeling

- Best-fit model to spectroscopic and seismic constraints
  - Grid-based models [Chaplin et al. 2014]
  - E.g. Asteroseismic Modeling Portal [Metcalfe et al. 2009]

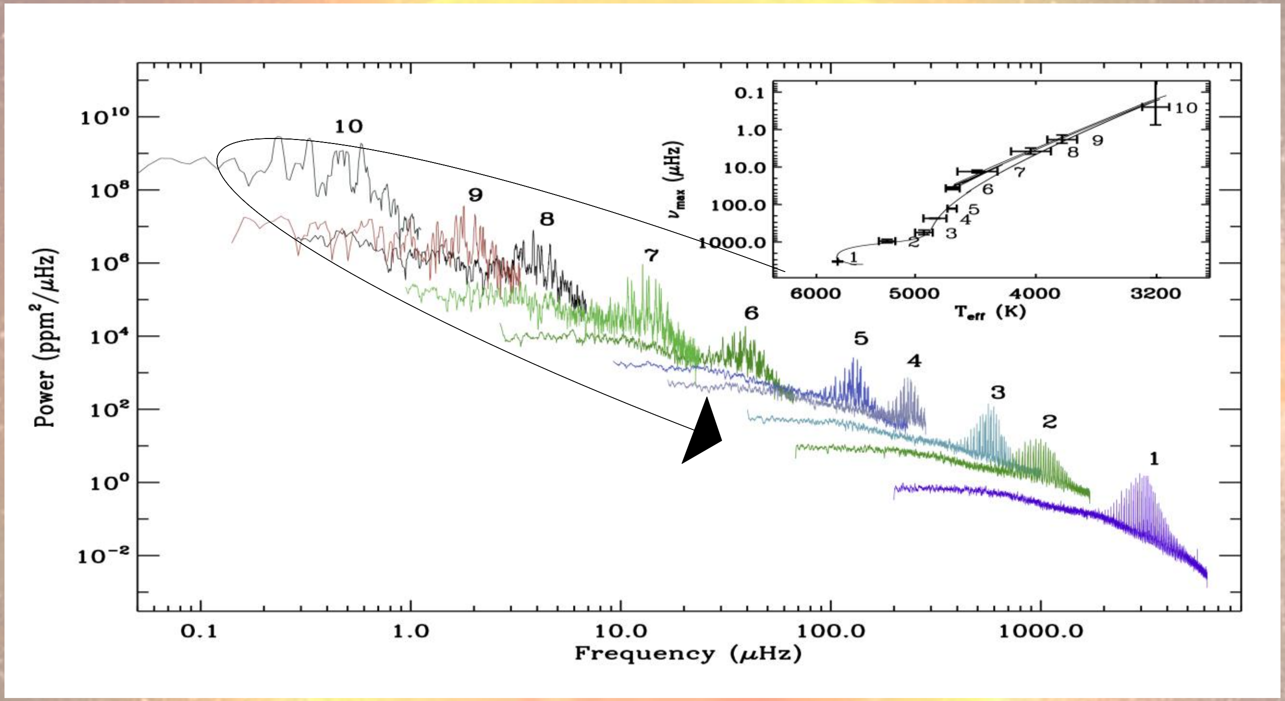


[Christensen-Dalsgaard et al. 2010]

- Large sample of stars [Mathur et al., 2012; Metcalfe et al. 2014]
  - Improve precision on M, R, age
  - Structure:
    - base of convection zone

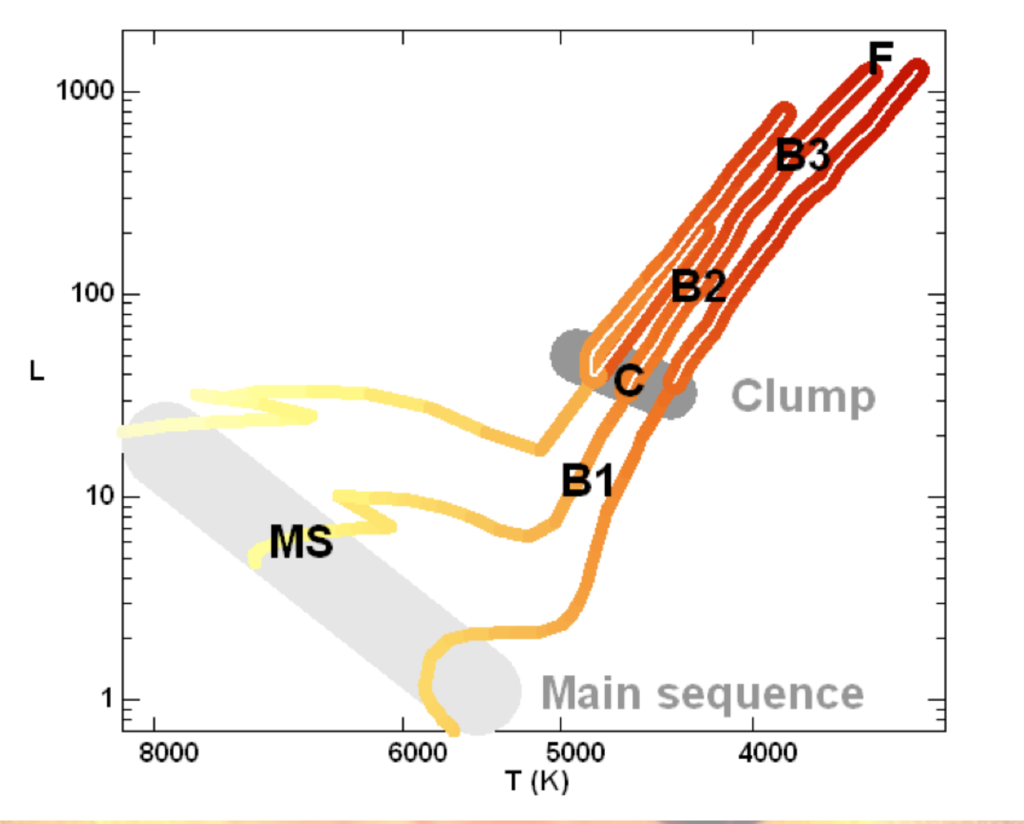
Model-dependent…

Stellar evolution



[García & Stello in Extraterrestrial seismology, CUP, 2015]

The RG revolution



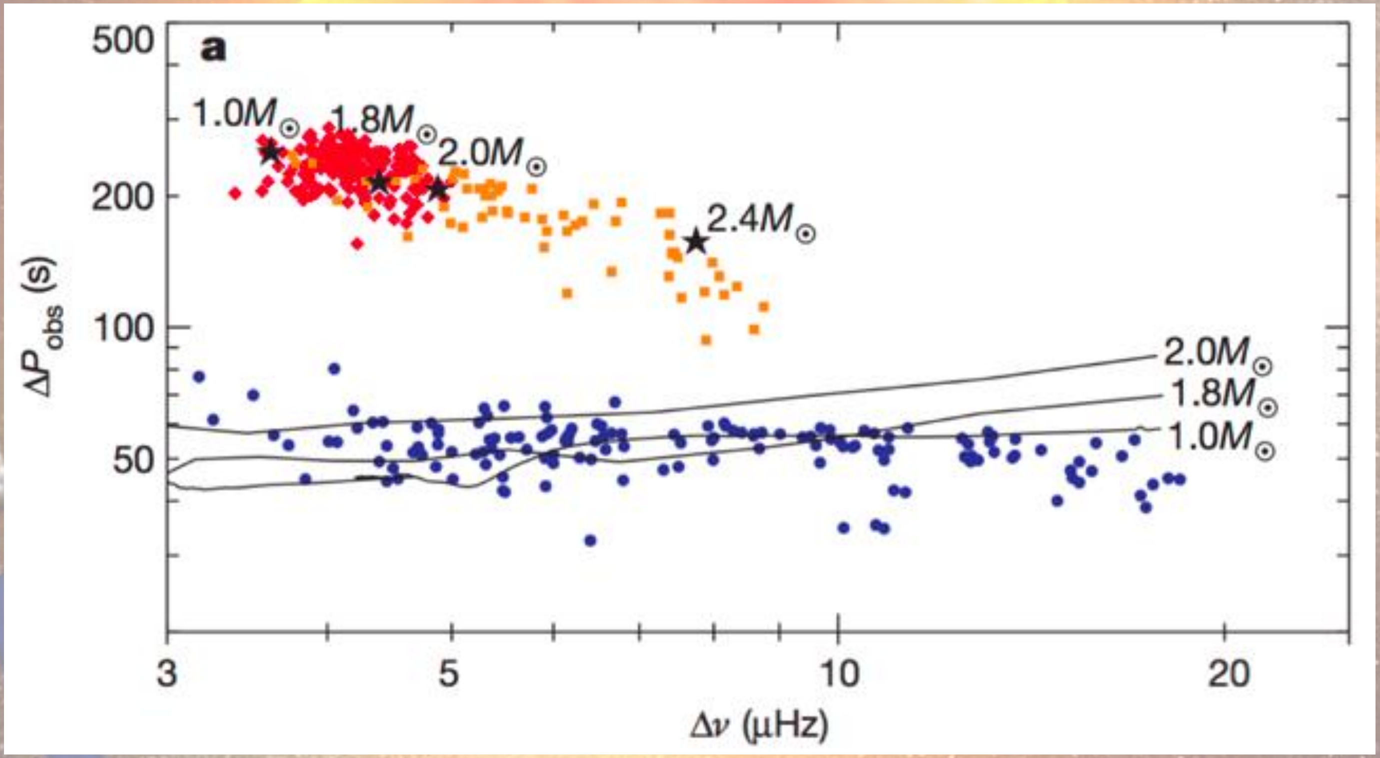
Confusion in the HR diagram:

– From their global properties a RGB star and a Red Clump giant are the same
– Same HR position, same envelopes, same large frequency spacings…
– "Just as in Hollywood, the age of a star is not always obvious if you look at the surface"

[Metcalfe, 2011]

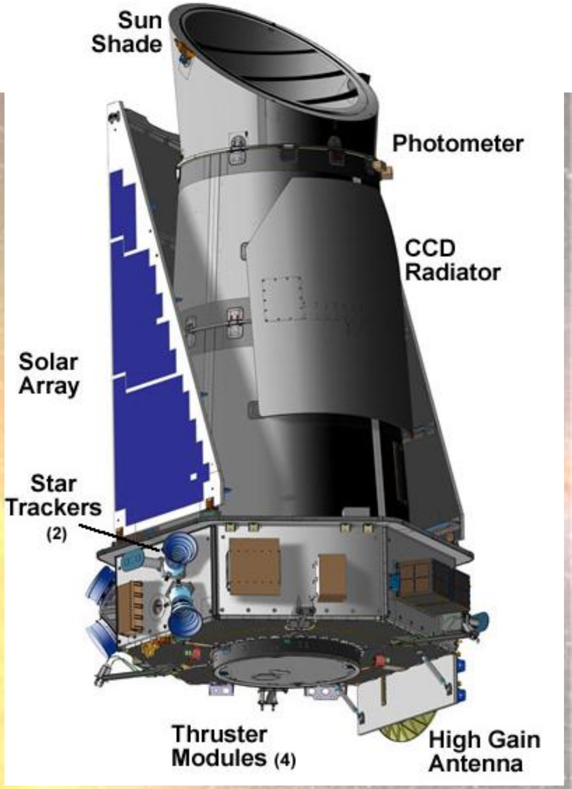
Probing interiors of red giants

- Determination of period spacing of mixed modes ΔP
- Two regimes:
  - Large values of ΔP : burning He in their core
  - small values of ΔP : burning H in a shell



[Bedding et al. 2011, Mosser et al. 2011]

Kepler mission



Transit Photometry

- 0.95 meter aperture
- 100 square degrees
- Heliocentric orbit (Earth trailing)
- Monitor stars continuously
- Observed for ~4 years

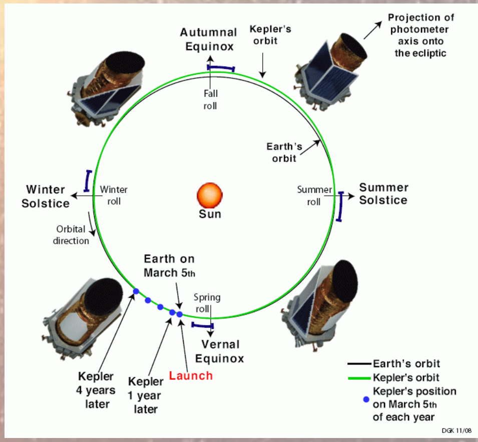
Statistically valid results

- 200,000 stars
- Array of 21 modules of CCD detectors

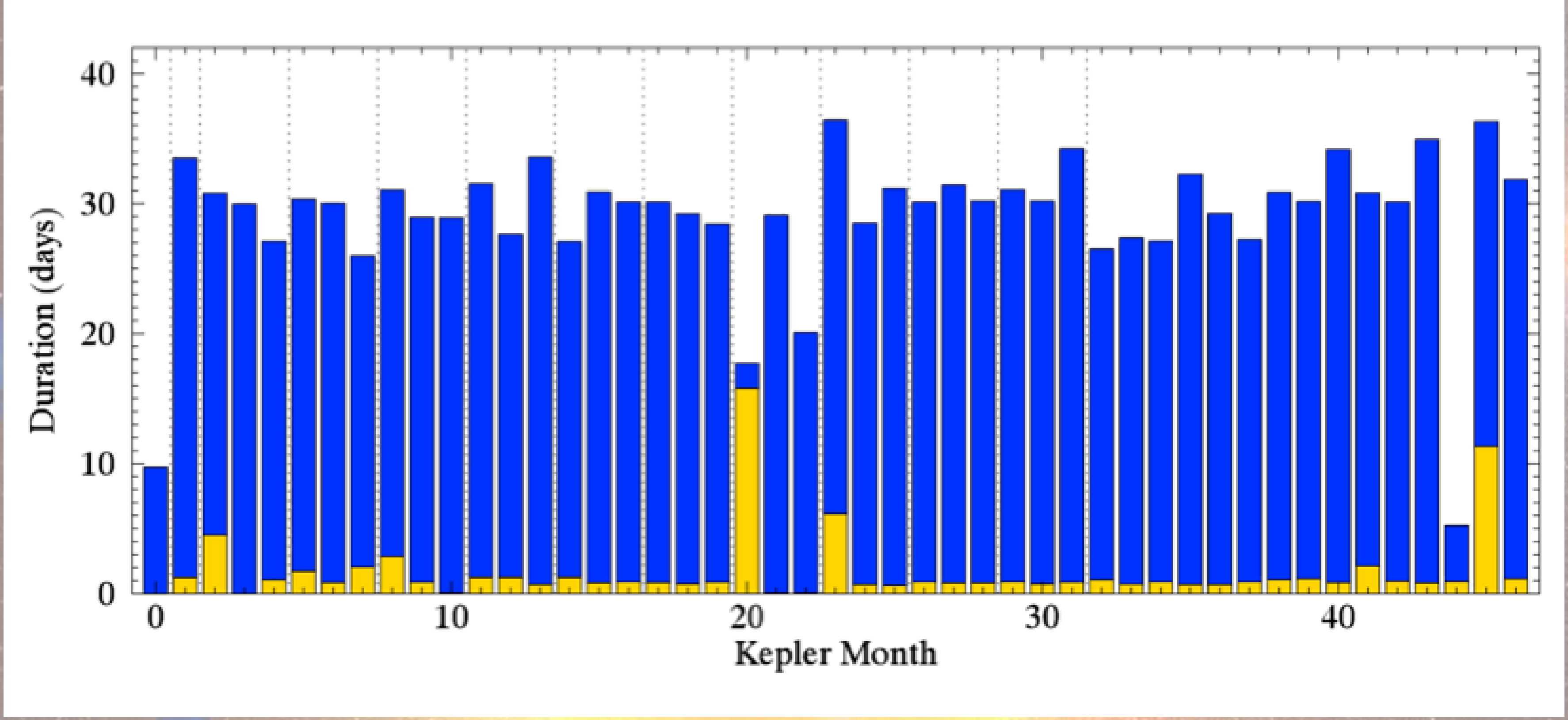
Main goal: Look for exoplanets from transits
Additional goal: characterize stars (planet host stars)

Kepler operation features

- Two cadences of observations: 30 min and 1 min
- Operations leading to regular gaps:
  - Angular Momentum Dump: reaction wheels are desaturated
  - Download Earth Pointing every 30 days -> ~0.9 day gap
  - Rotates every 3 months (mostly during the DEP but a few times longer gaps)
- Other irregular events: losses of spacecraft fine pointing, and sudden pixel sensitivity drop-outs…

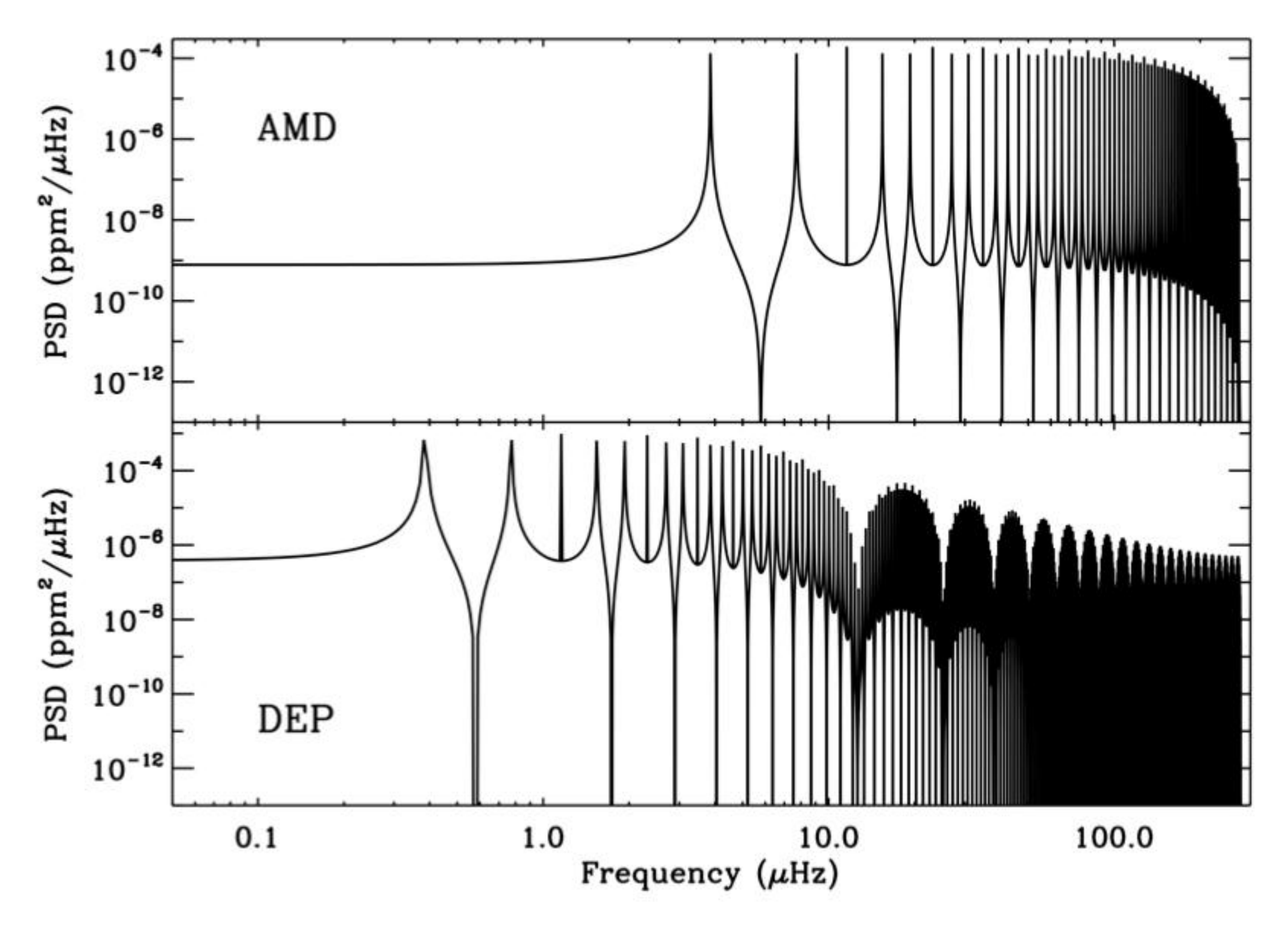


Kepler gaps



[García et al. 2014, A&A, 568, 10]

Spectral windows of the gaps



[García et al. 2014, A&A, 568, 10]

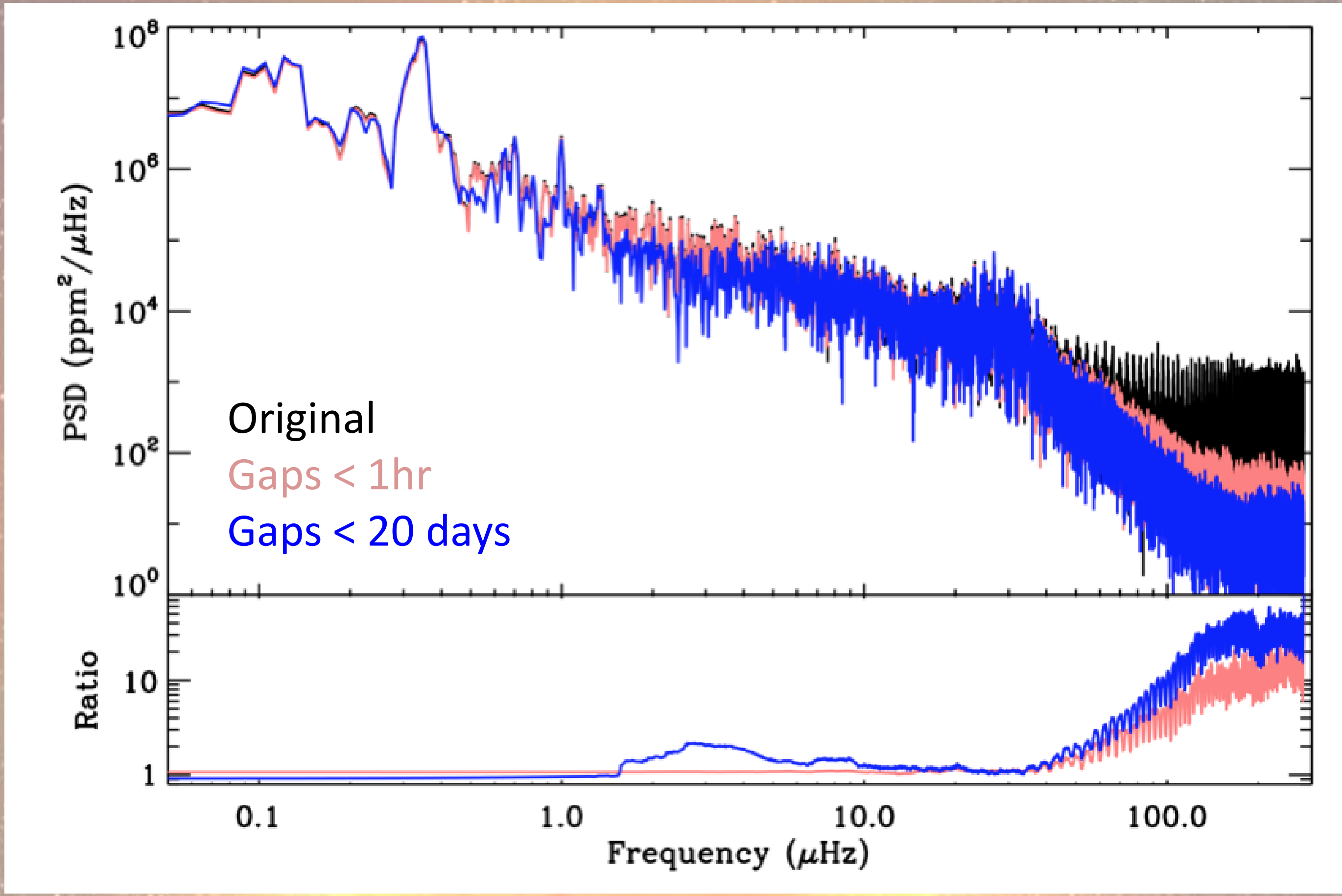
Filling the gaps

- Method used: linear interpolation but works only for a few points gaps

- Implemented inpainting based on Multi-scale Discrete Cosine Transform

[Pires et al. 2015, A&A, 574, 18]

Changes in the background



[García et al. 2014, A&A, 568, 10]

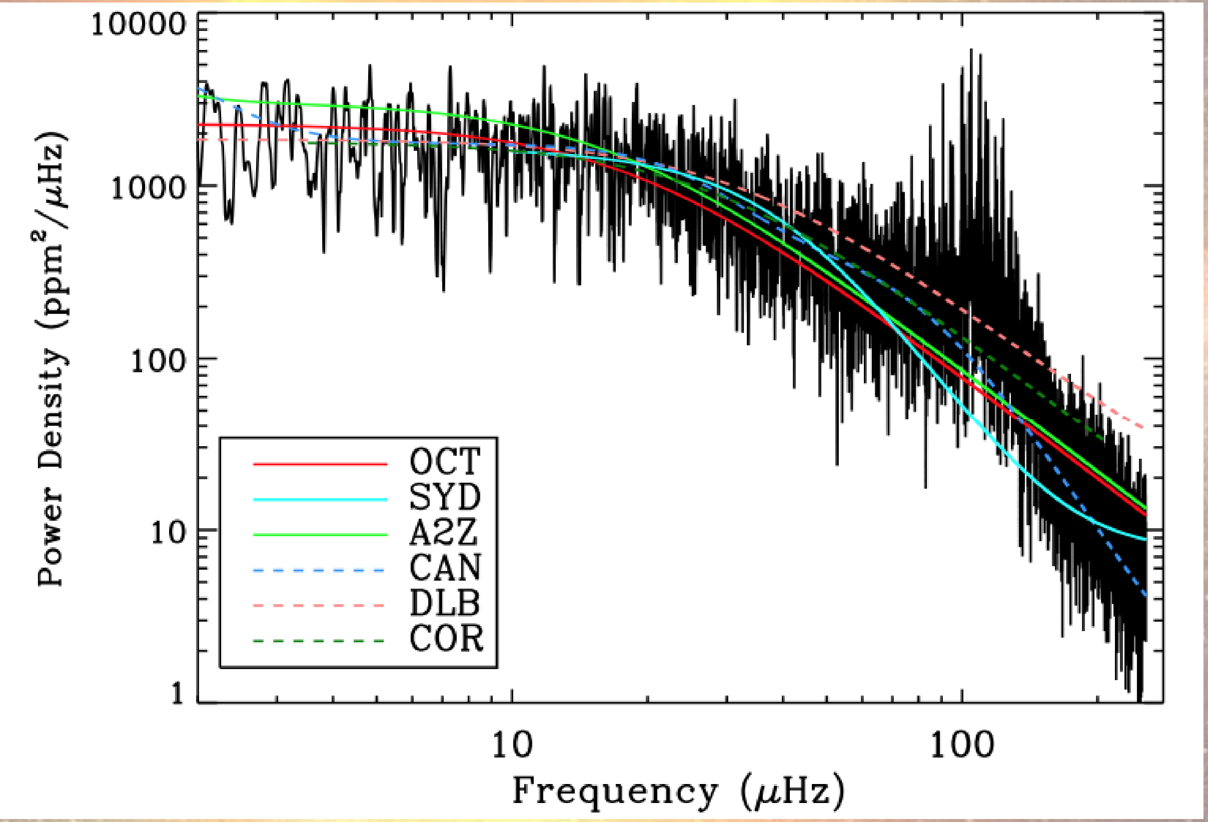
- Decrease of the photon noise
- In some cases: change of the shape

Measuring the background

Fit a function:

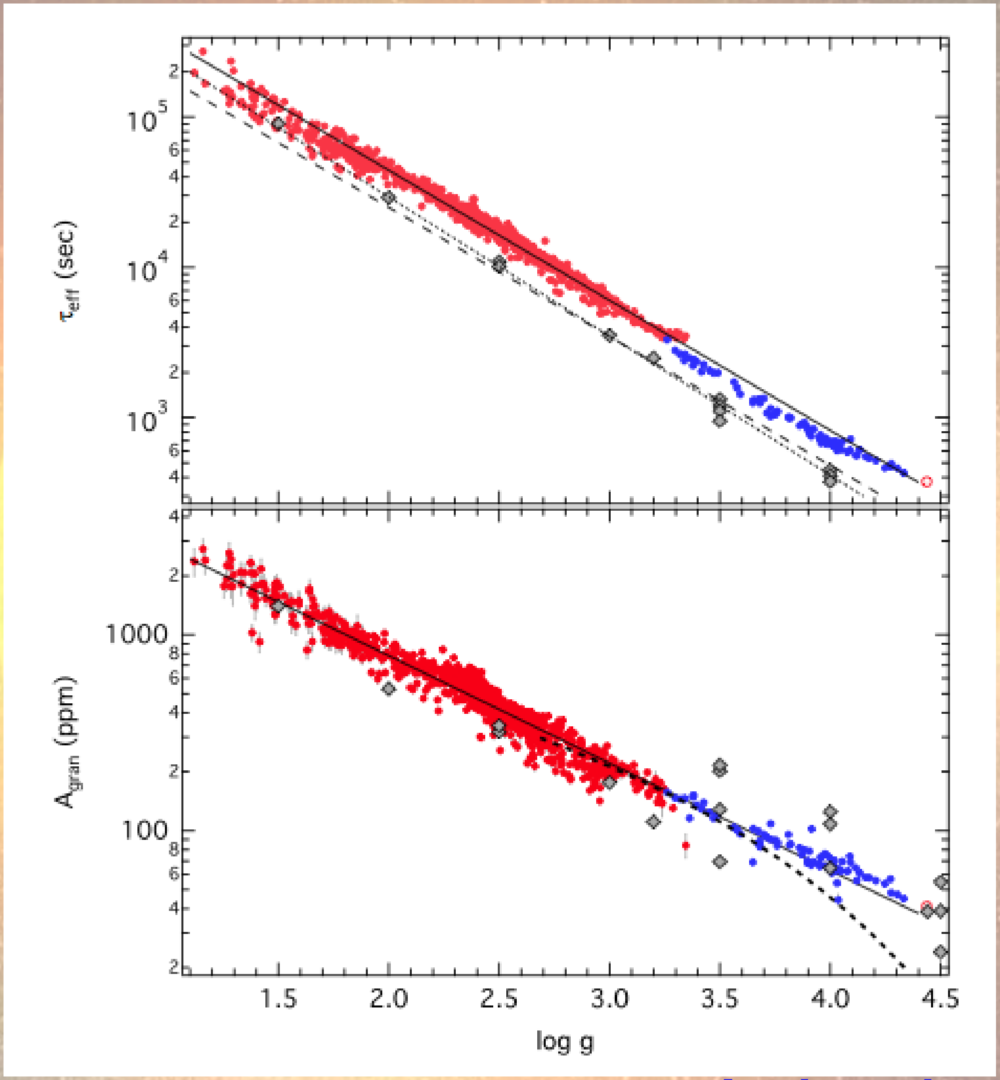
$$W + \frac{4\sigma^2 \tau_{gran}}{1 + (2\pi \nu \tau_{gran})^{\alpha}}$$

[Harvey 1985]



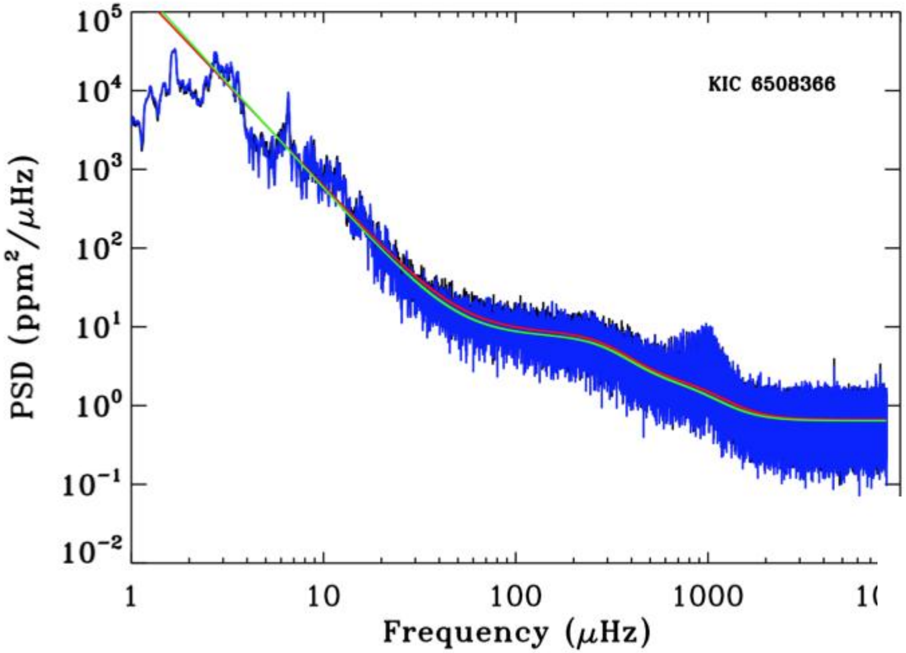
[Mathur et al. 2011, ApJ]

Convection and log g



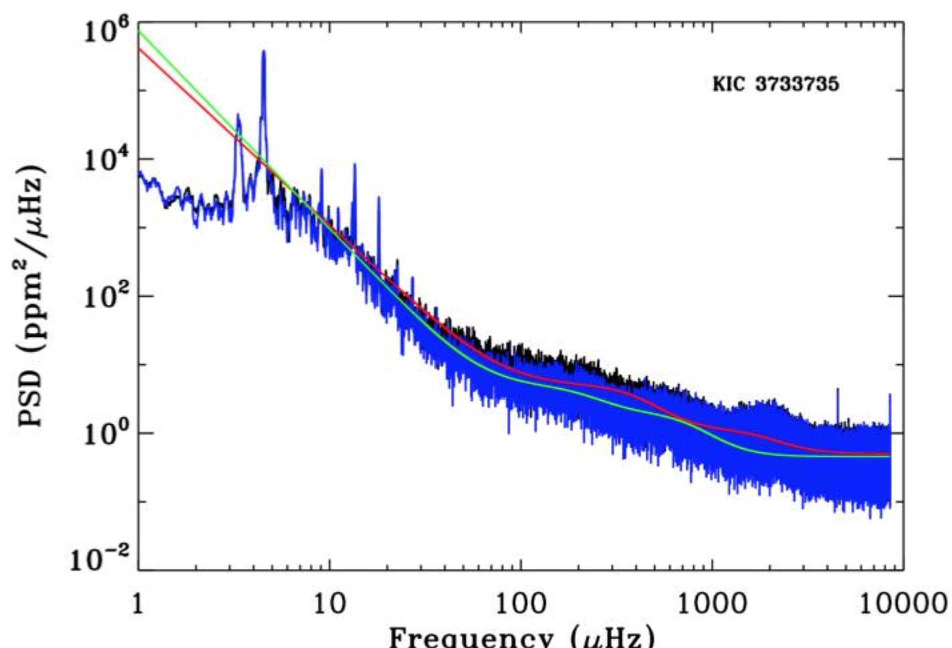
[Mathur et al. 2011, ApJ;
Kallinger et al., 2014 A&A]

Background parameters



Fit for data with gaps

Fit for data without gaps



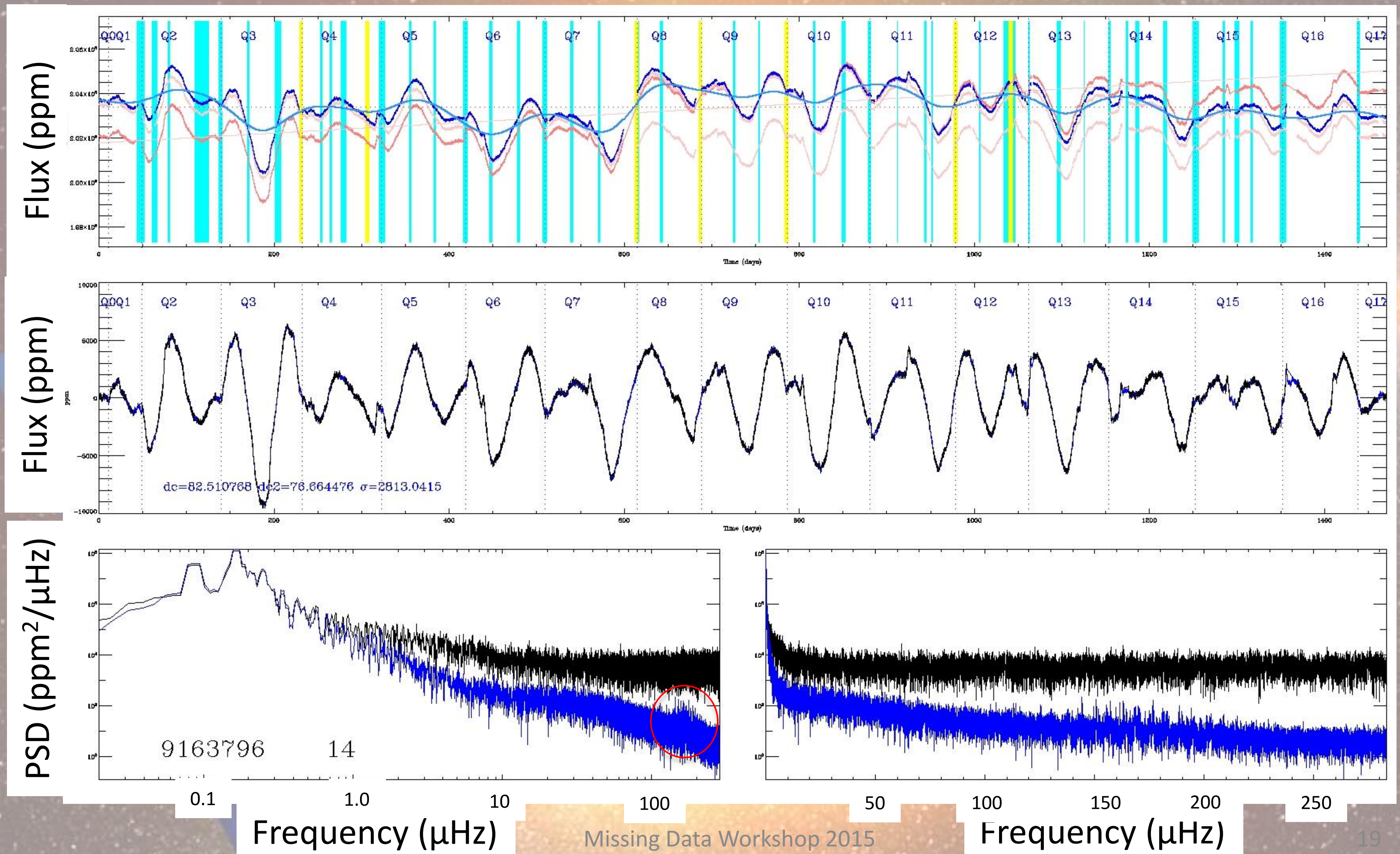
- Clearly see a difference
- Stars with high peak at low frequency (rotation)

[García et al. 2014, A&A, 568, 10]

Impact on seismic parameters

- Red giants (long cadence)
  - Photon noise decreases in average by 90%
  - Granulation time scale can change from 10 to 40%
- Solar-like stars (short cadence)
  - Photon noise decreases by 2 to 18%
  - Granulation time scale can change by up to 90%.
- Impact on ν_{max} can lead to change in logg by 0.05 dex

Unveiling modes



Summary

- Asteroseismology is a powerful tool: M, R, age, evolutionary stage

- Impacted by the window function from regular gaps
  - Specially in cases where very low frequency modulation (due to rotation)
  - Changes background and amplitude of the modes

- Use of inpainting leads to improvements in the seismic parameters and the SNR allowing the detection of modes.

- Implemented in the *Kepler* calibration and in CoRoT final version of the pipeline.

Thank you