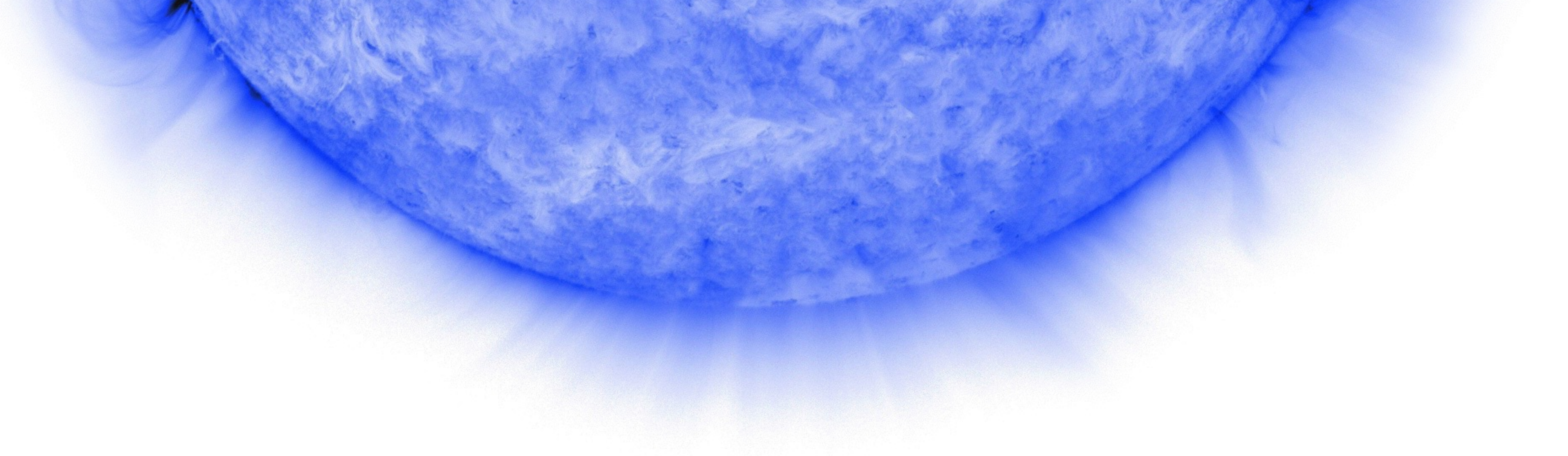


Calibrating the Stellar Structure and Evolution Models of Massive Stars with Asteroseismology

Péter I. Pápics | KU Leuven (Belgium)

The Milky Way and its Stars
KITP@UCSB (USA) - February 3, 2015

KU LEUVEN

fwo Research Foundation Flanders
Opening new horizons

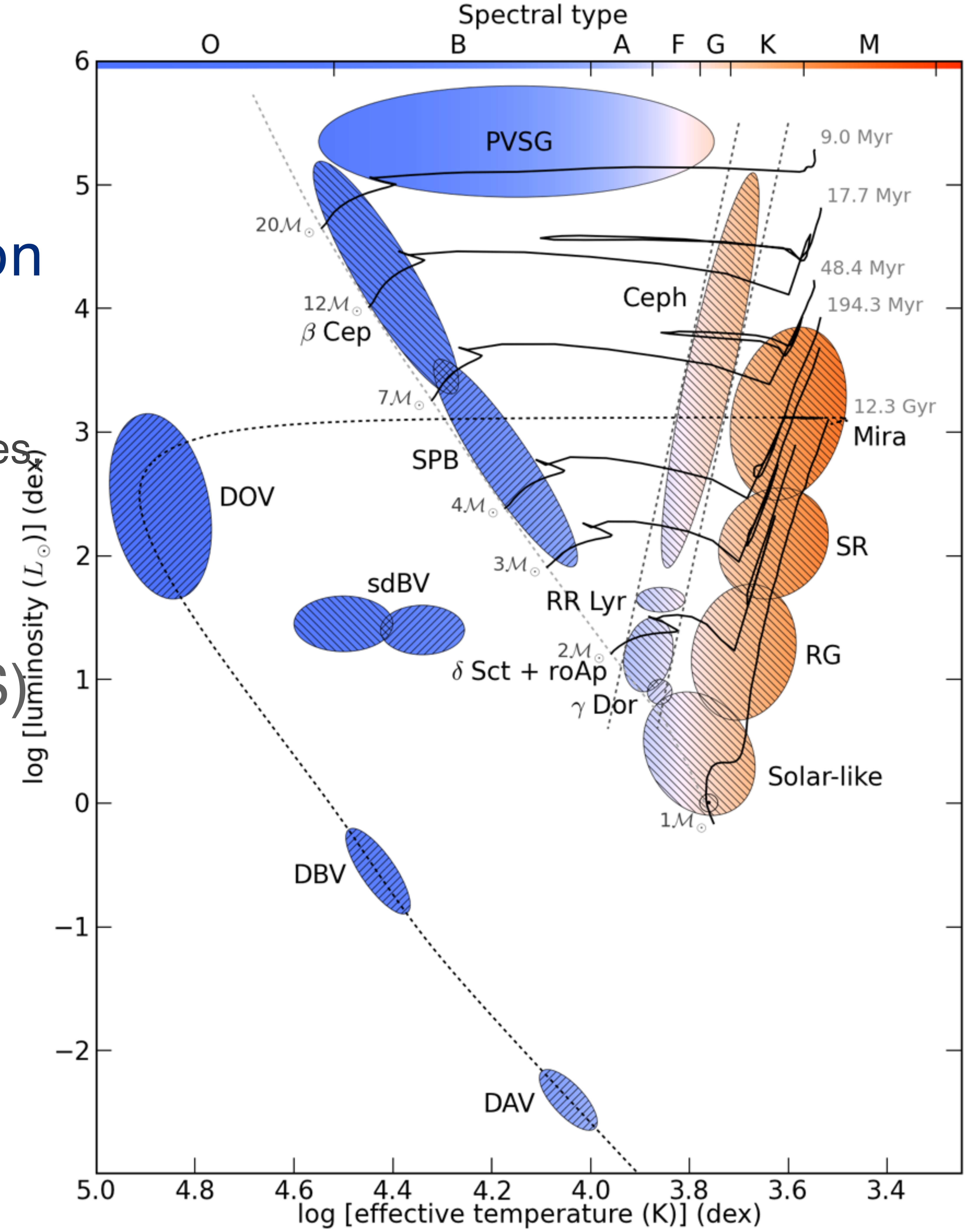
Introduction

GOALS

Calibrate stellar structure and evolution models

Cornerstones in stellar astrophysics

GX chemical enrichment, age of Universe, stellar life cycles, planetary system formation, stellar cluster dynamics, etc.



MASSIVE STARS

Convective core + radiative envelope (on MS)

Important internal **mixing processes**

- **Core overshooting**
- **Internal differential rotation**
- etc.

Many **uncertainties**! -> Effect on **lifetime**!

Only **13 stars with a_{ov}** and **4 with ~$\Omega(r)$** so far

Dependence on *magnetic field*? *Mass*?

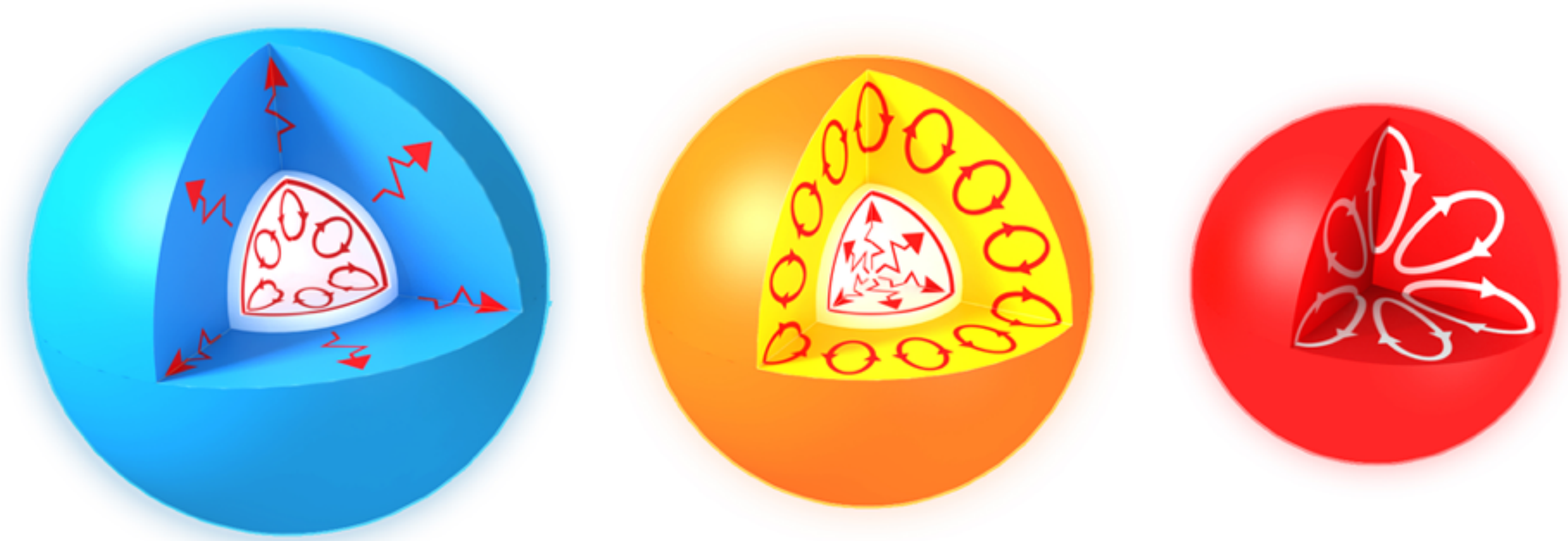
Contribution to *angular momentum transport*?

SPB (SLOWLY PULSATING B STARS)

$M \approx 2.5 - 8\ M_{Sun}$, 11 000 – 22 000 K

High-order gravity modes (P ≈ 0.5 – 3 day)

Characteristic **period spacing** [Tassoul 1980]



Introduction

SEISMIC MODELLING | OVERVIEW

FORWARD MODELLING: from observations to physical constraints

Observations
- Ground-based
  - *multicolour photometry*
  - *high-resolution spectroscopy*
- Space-based
  - *uninterrupted photometry*
  - *no colour information*

Data analysis

Fundamental parameters
- T_{eff}, log g, Z
  - *from SED fitting, spectral synthesis*

Observed pulsation modes
- List of significant frequencies
  - *from frequency analysis techniques*
- Mode ID: Quantum numbers (ℓ,m)
  - *from photometric amplitude ratios*
  - *from line profile variations*

Inside the error box

Model parameters
- M, X_{C}, Z, α_{ov}

**First approach: assuming a fully mixed core overshoot region*

Stellar evolution code (MESA)

Stellar models
- For specified input physics
  - *physical conditions in the star*

Pulsation code (GYRE)

Theoretical pulsation modes
- List of frequencies with (n,l,m)

Comparison (χ^2)

Constraints
- Fundamental parameters / Shortcomings in included physics / Unknown stellar properties (e.g., magnetic field)

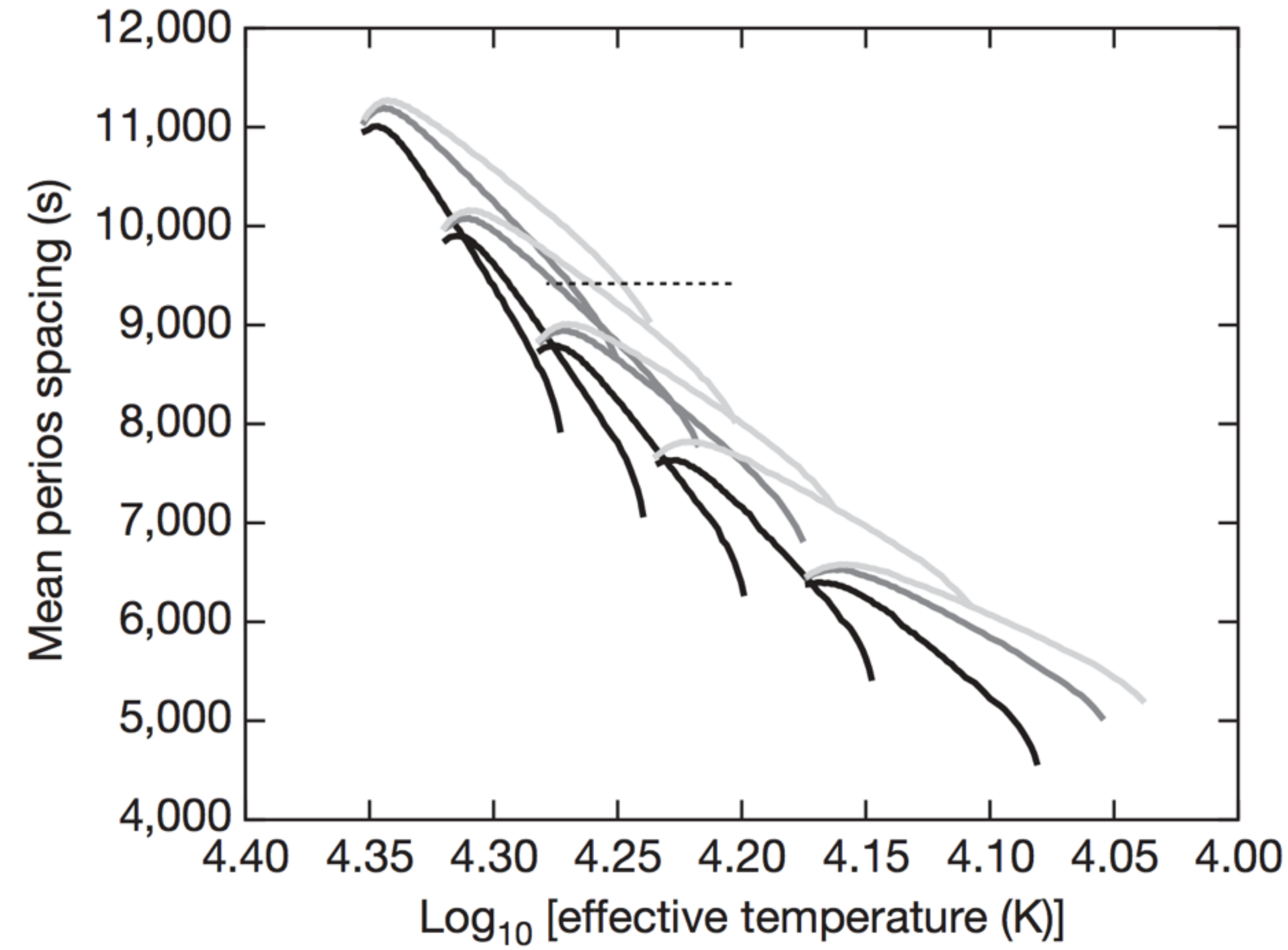
The Seismic Fingerprint

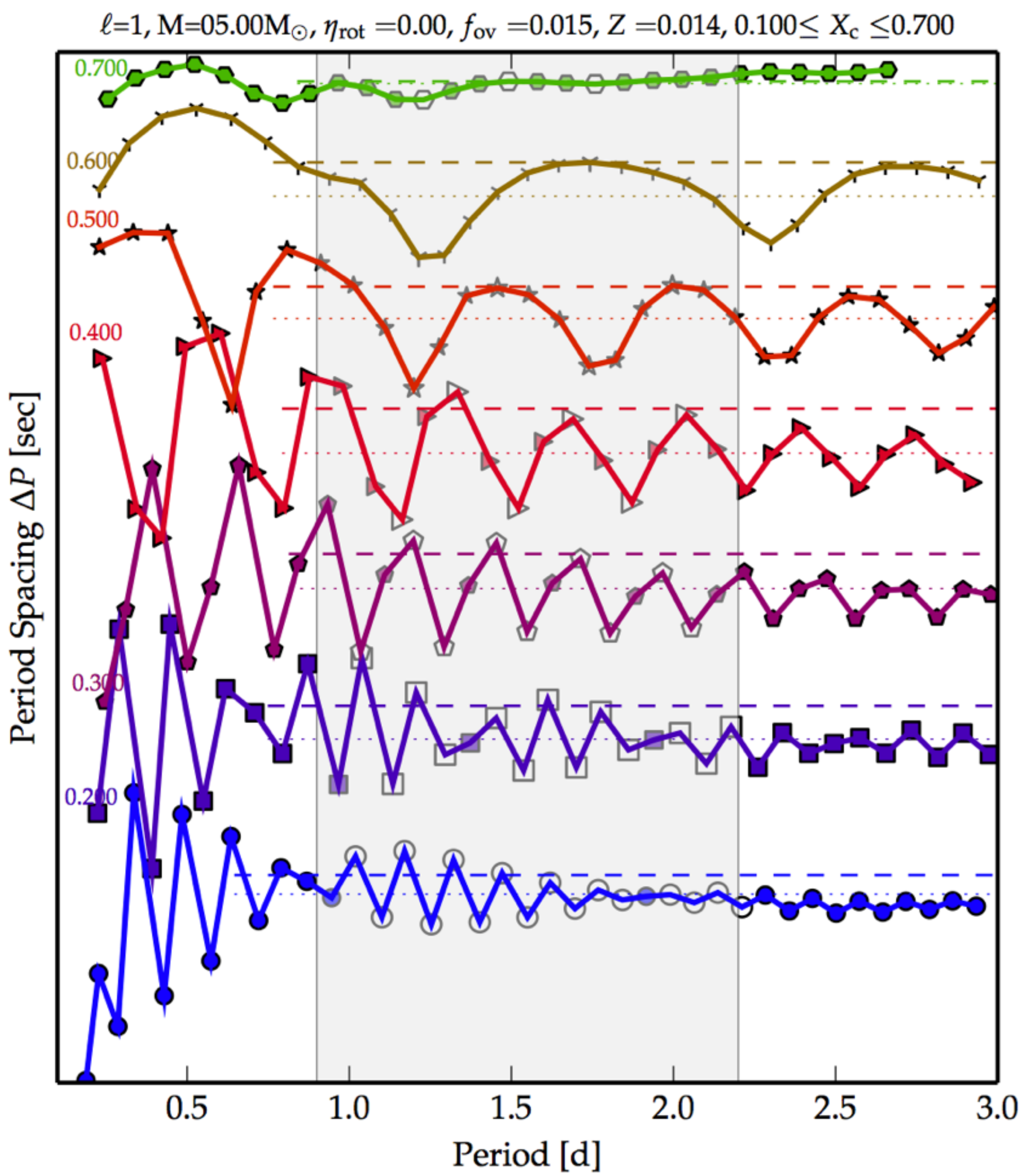
PERIOD SPACING

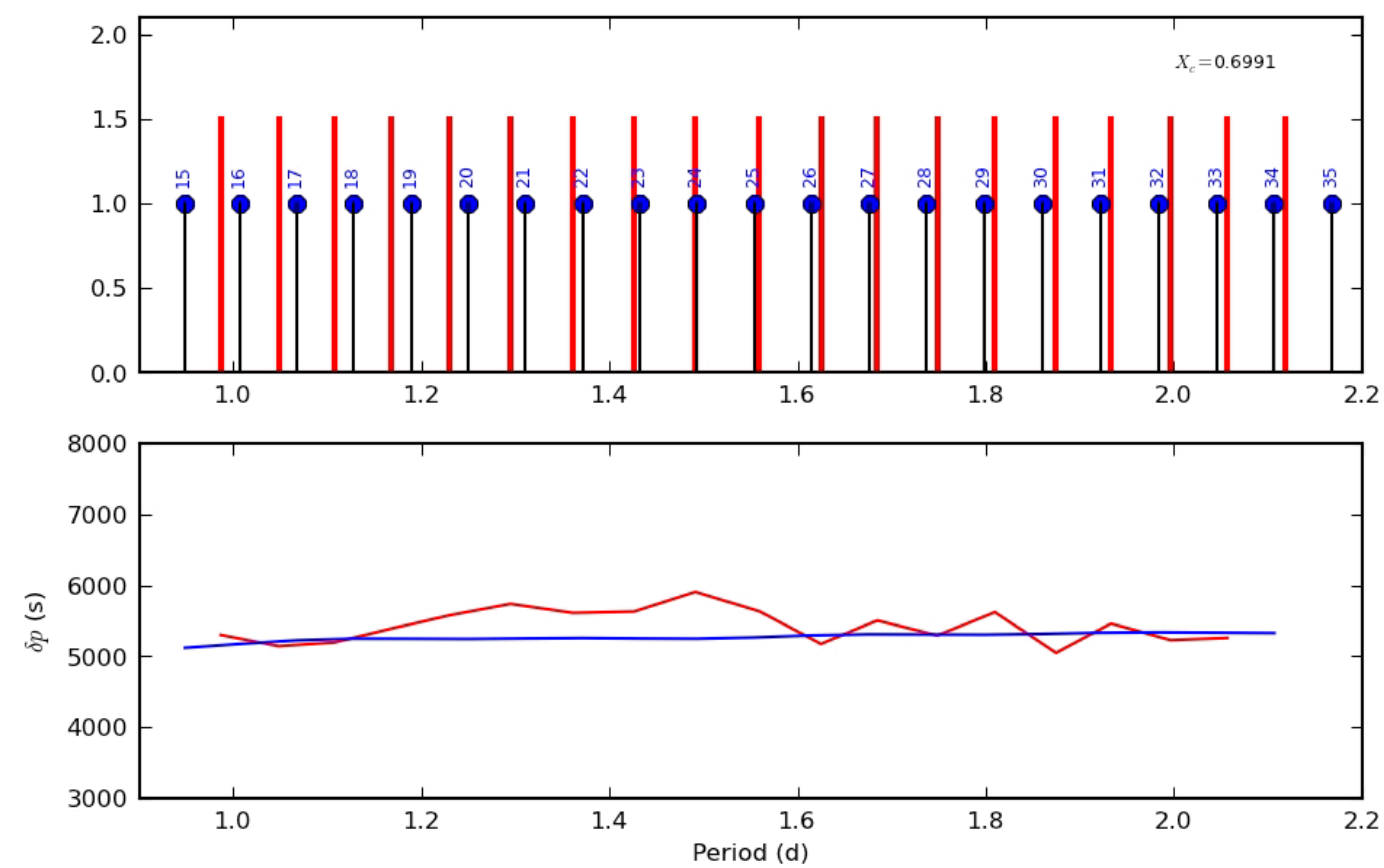
Average spacing

Shape of the period spacing 'function'

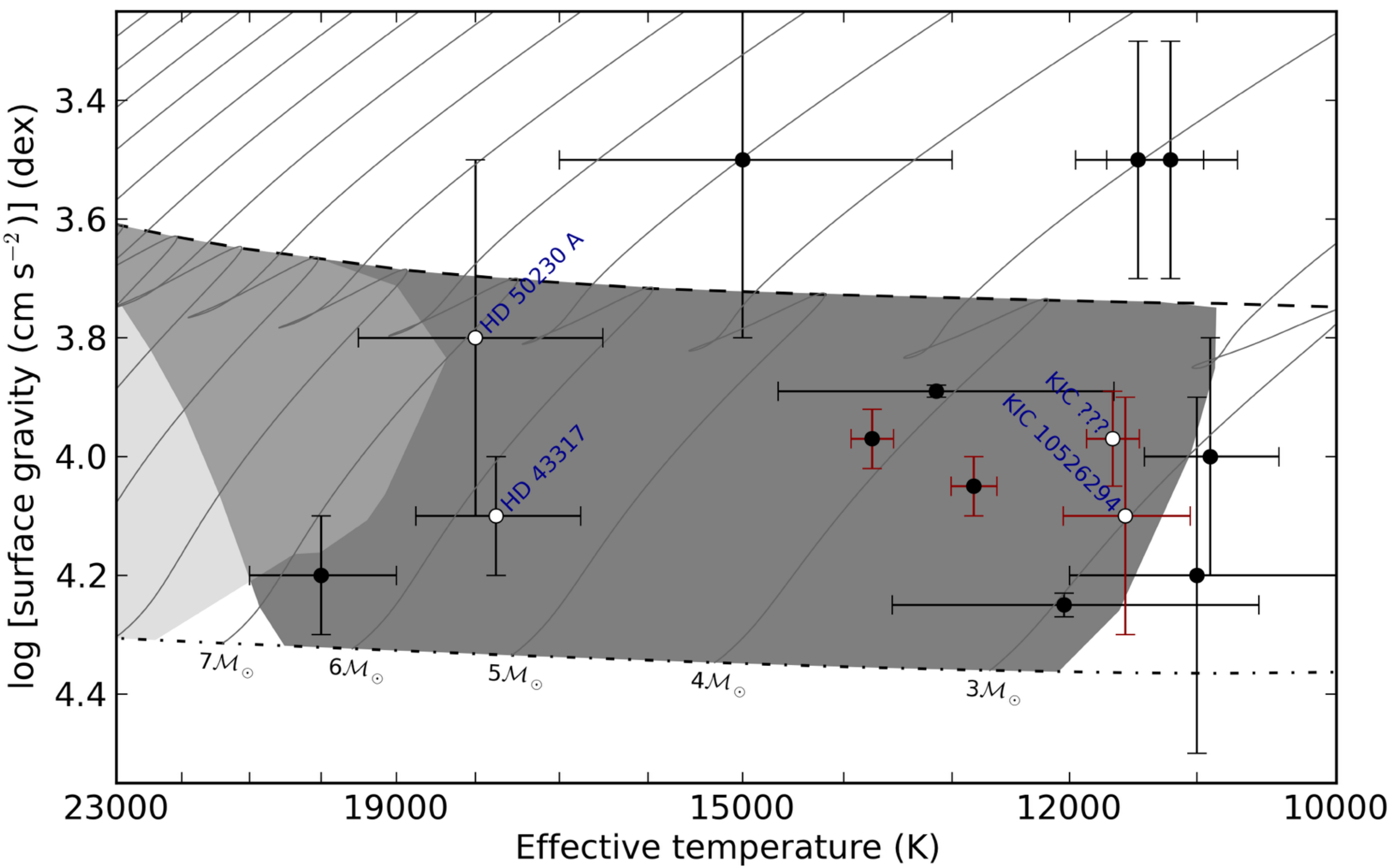
Periodic deviations







The Scene



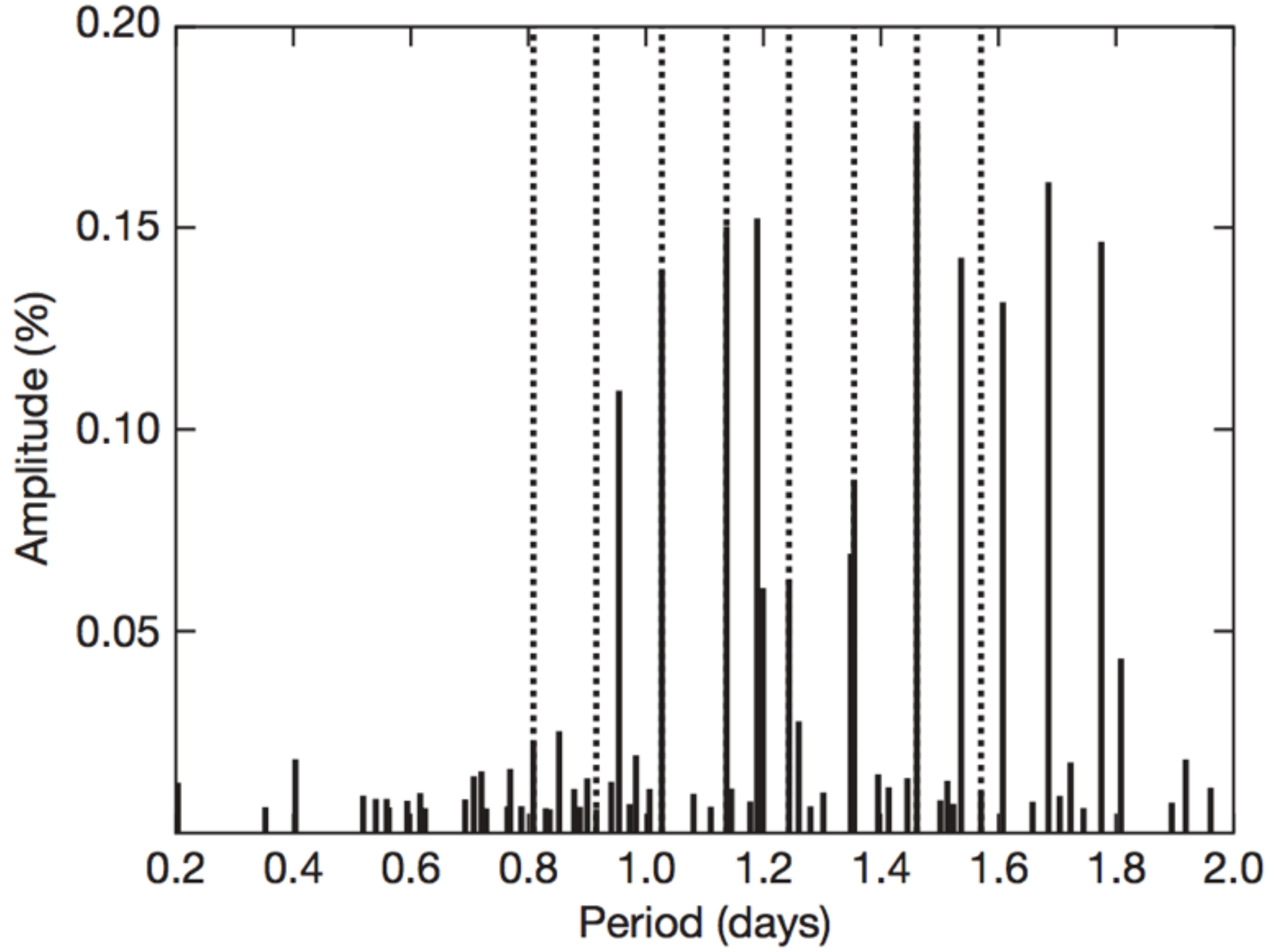
HD 50230 A
HD 43317
KIC ???
KIC 10526294
7$\mathcal{M}_\odot$
6$\mathcal{M}_\odot$
5$\mathcal{M}_\odot$
4$\mathcal{M}_\odot$
3$\mathcal{M}_\odot$
3.4
3.6
3.8
4.0
4.2
4.4
23000
19000
15000
12000
10000
Effective temperature (K)
log [surface gravity (cm s^{-2})] (dex)

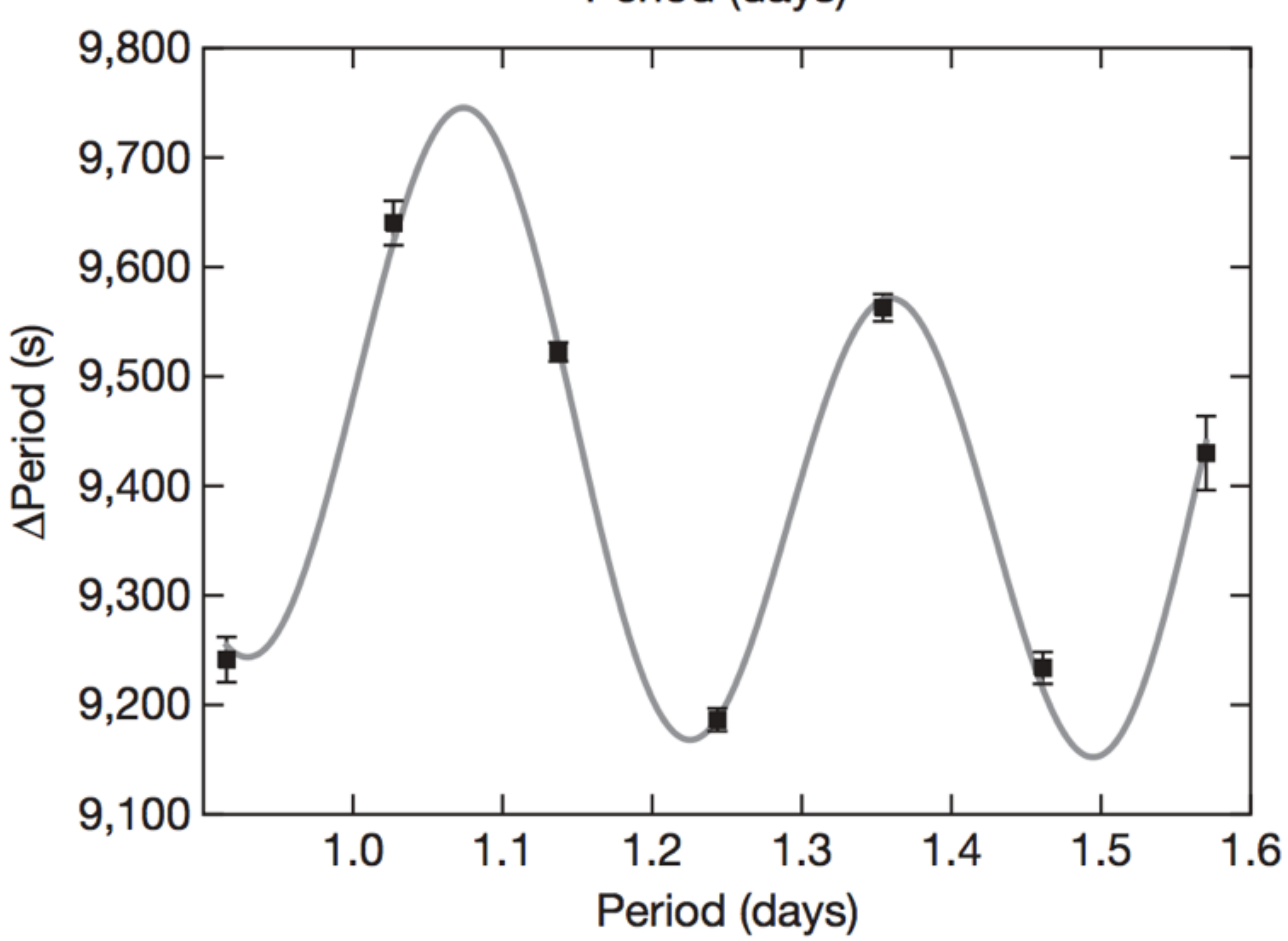
The Start of the Space Revolution with

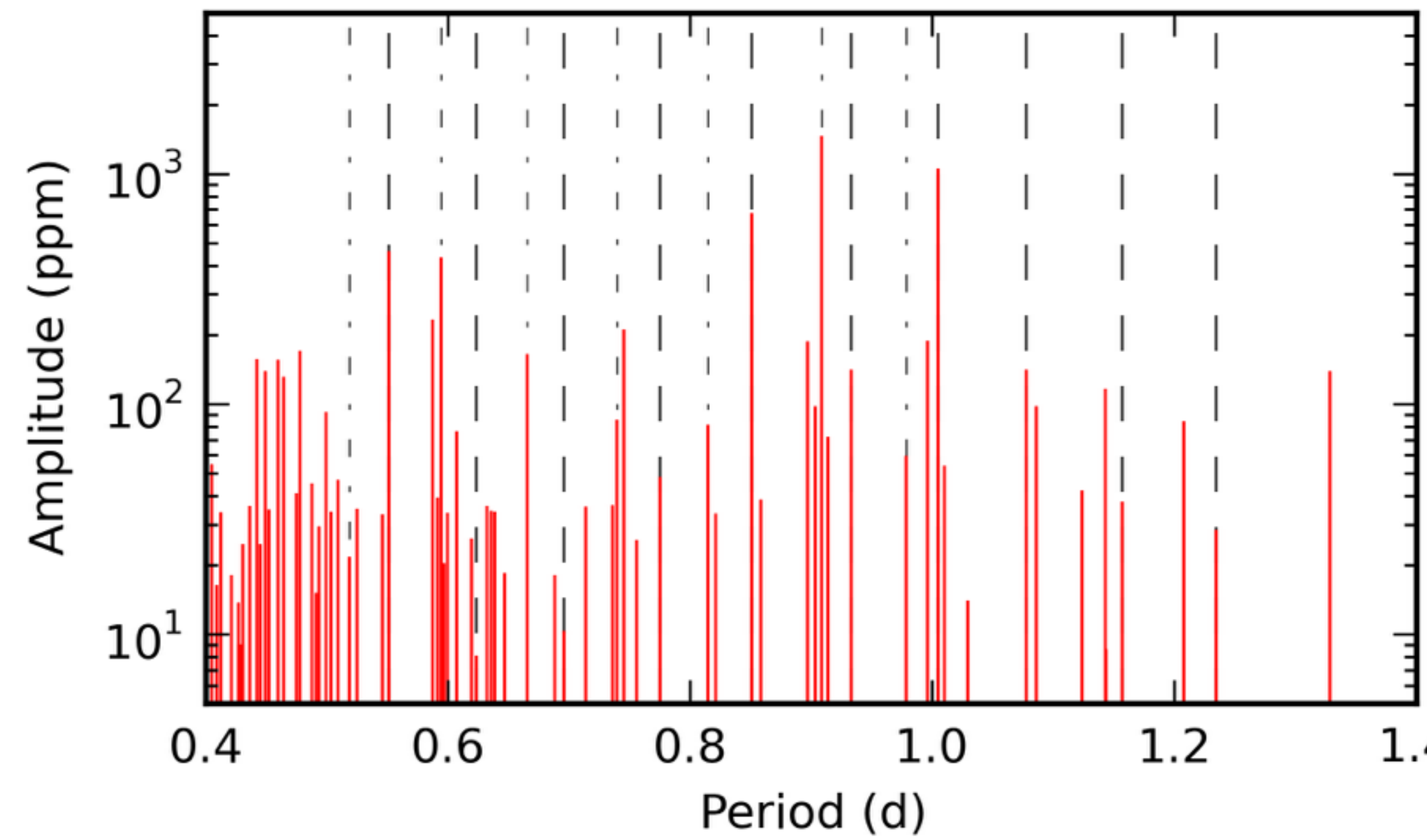
THE FIRST DETECTIONS OF PERIOD SPACINGS

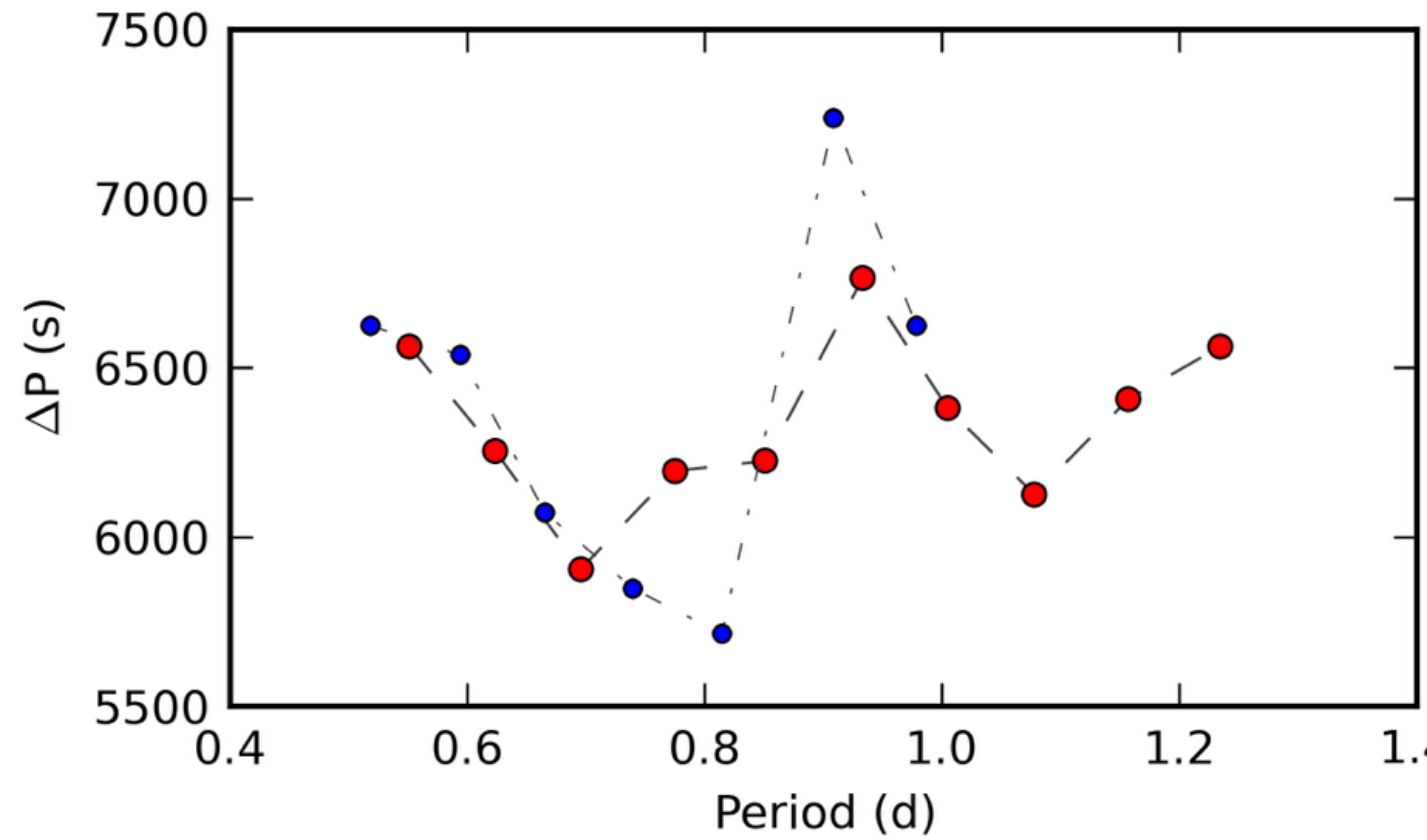
HD 50230 [**Degroote et al. 2010**, Nature]

Average g mode spacing 9418 sec









HD 43317 [**Pápics et al. 2012**]

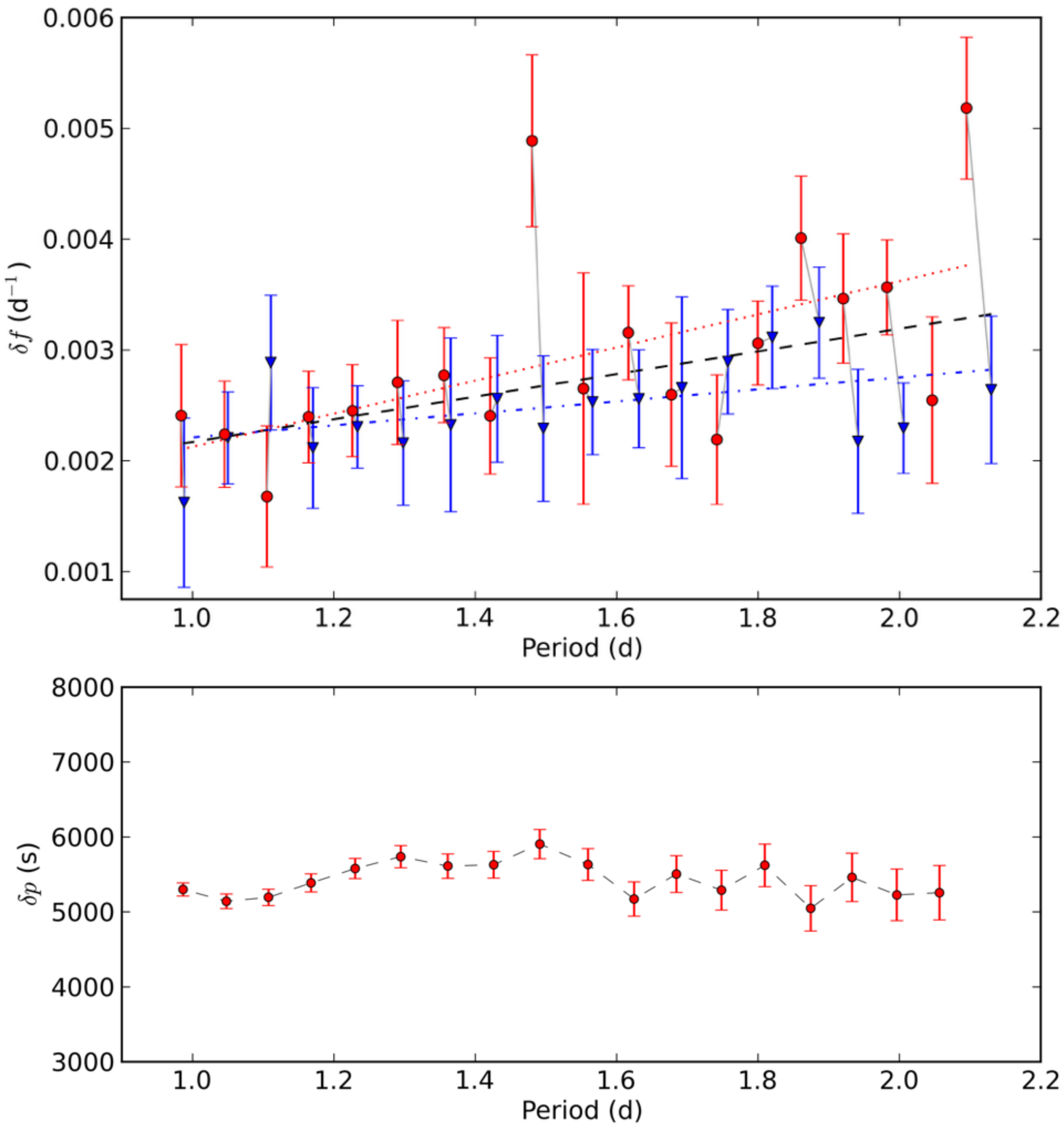
average spacing 6339 & 6380 sec

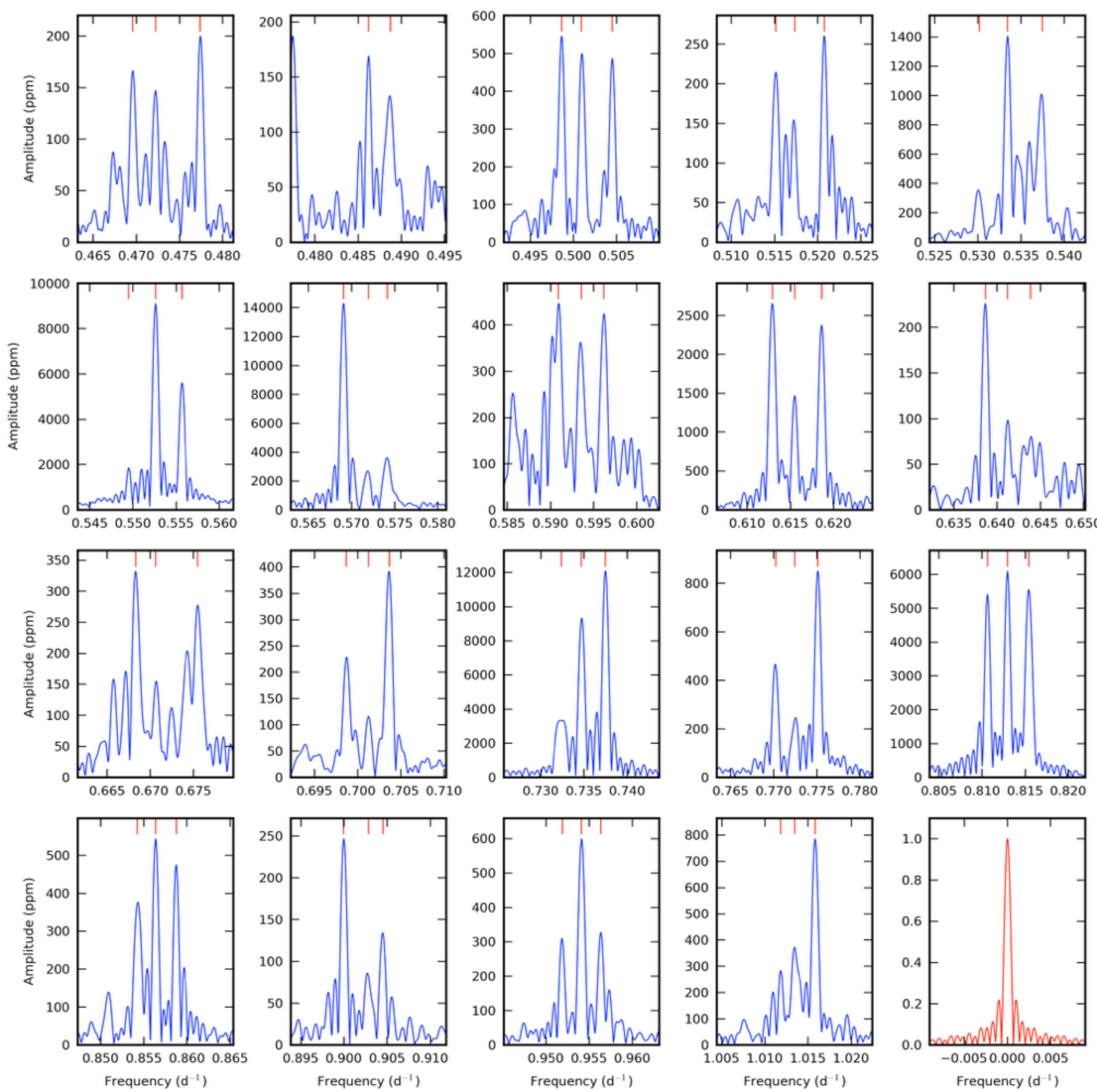
Extending the Timebase with *Kepler*

THE ROSETTA STONE OF SLOWLY ROTATING SPB STARS

KIC 10526294 [Pápics et al. 2014, Moravveji et al. in prep., Triana et al. in prep.]

19 rotationally split gravity modes with nearly equal period spacing (5428 sec)





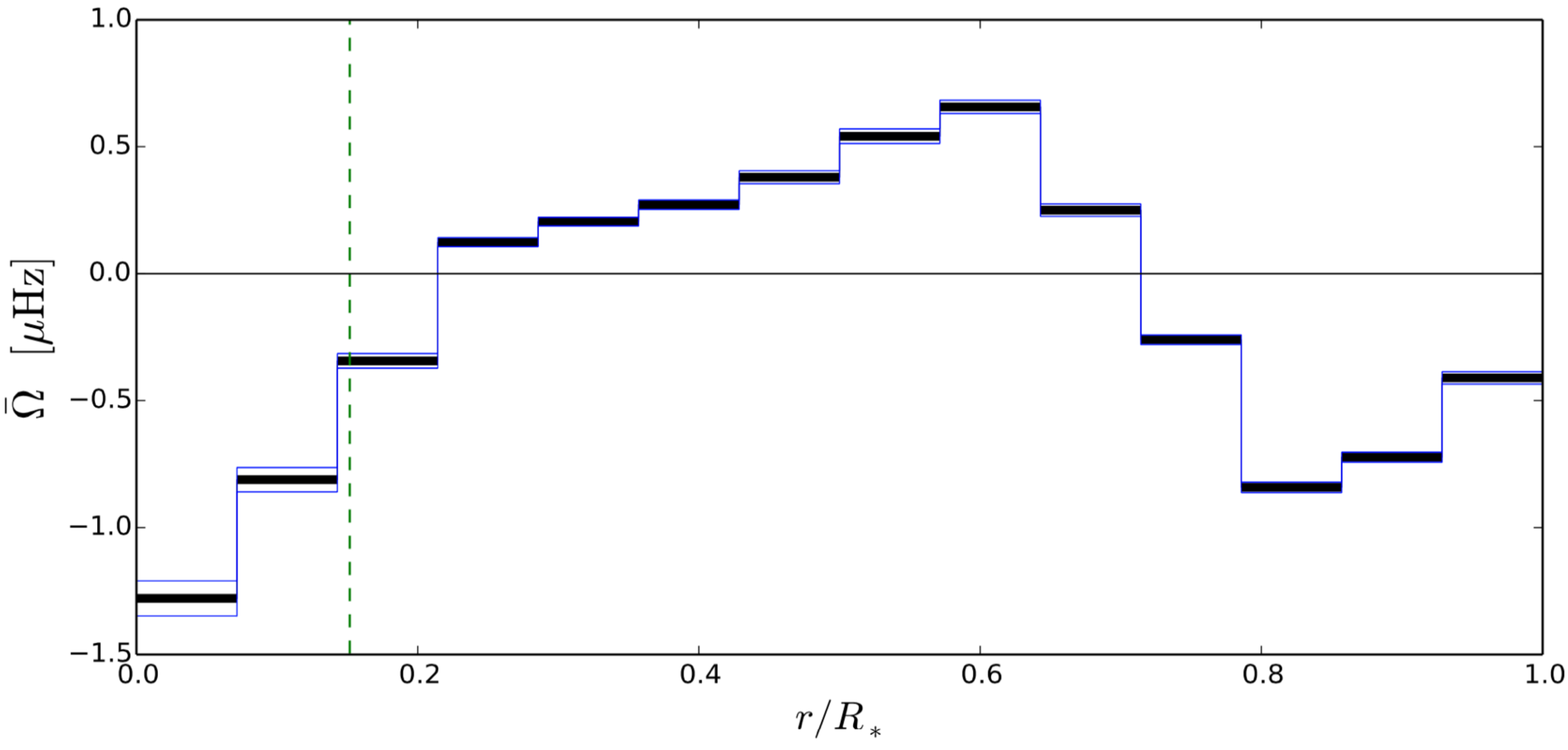
Extending the Timebase with *Kepler*

THE ROSETTA STONE OF SLOWLY ROTATING SPB STARS

KIC 10526294 [**Pápics et al. 2014, Moravveji et al. in prep., Triana et al. in prep.**]

The first actual **seismic modelling** of an SPB star

- Model with extra **diffusive mixing** gives better fit
- Strong constraints on mass, age ($X_c \approx 0.63$), overshooting ($\alpha_{ov} \approx 0.17$), etc.

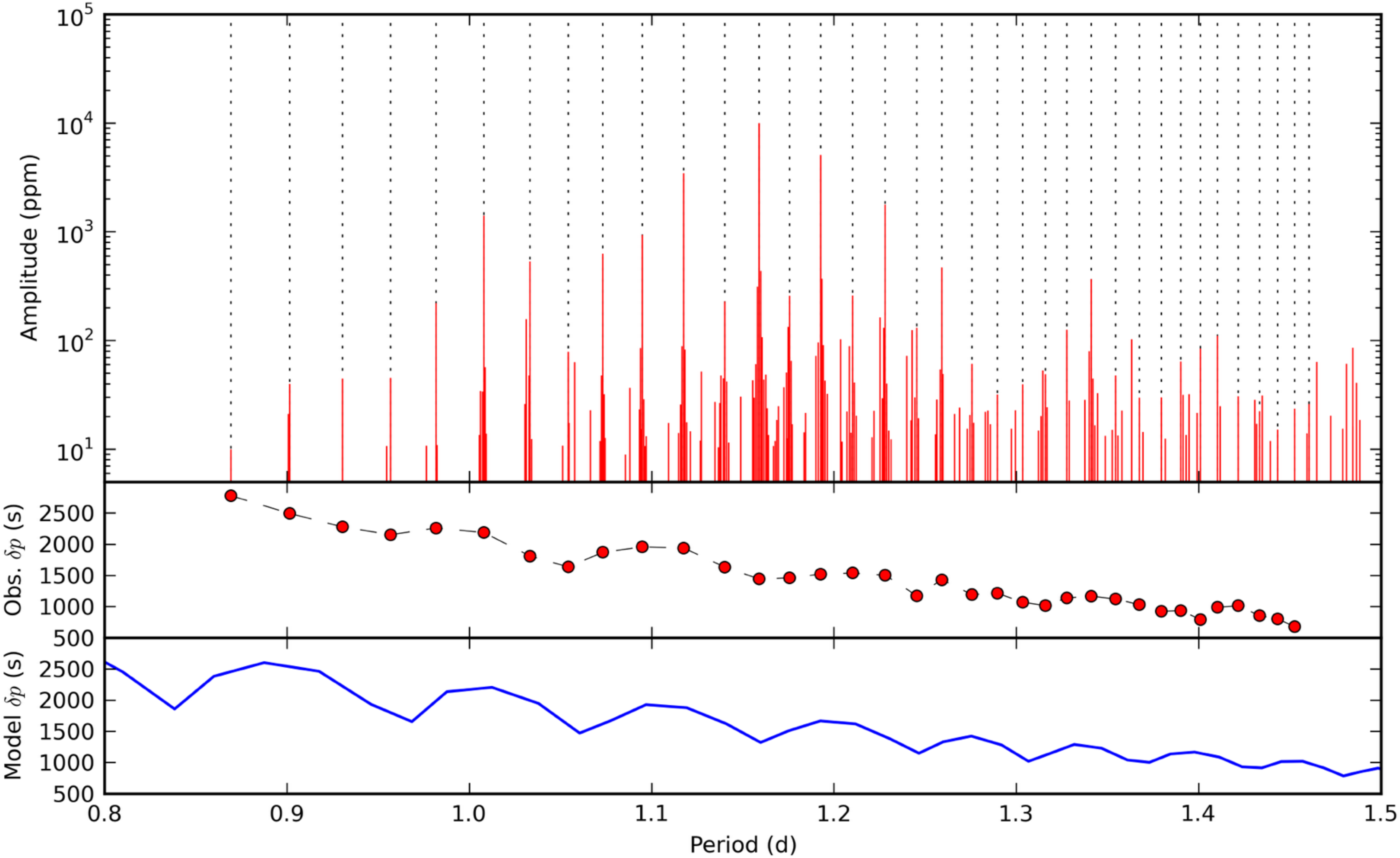


And yet it Moves

THE EFFECTS OF (FAST) ROTATION

KIC ??? [**Pápics et al. in preparation**]

36 gravity modes (ℓ=1, m=1), period series tilted by rotation: $f' = f_0 + m\beta_{nl}\Omega$



Not in Kansas anymore…

CONCLUSIONS / DISCUSSION POINTS

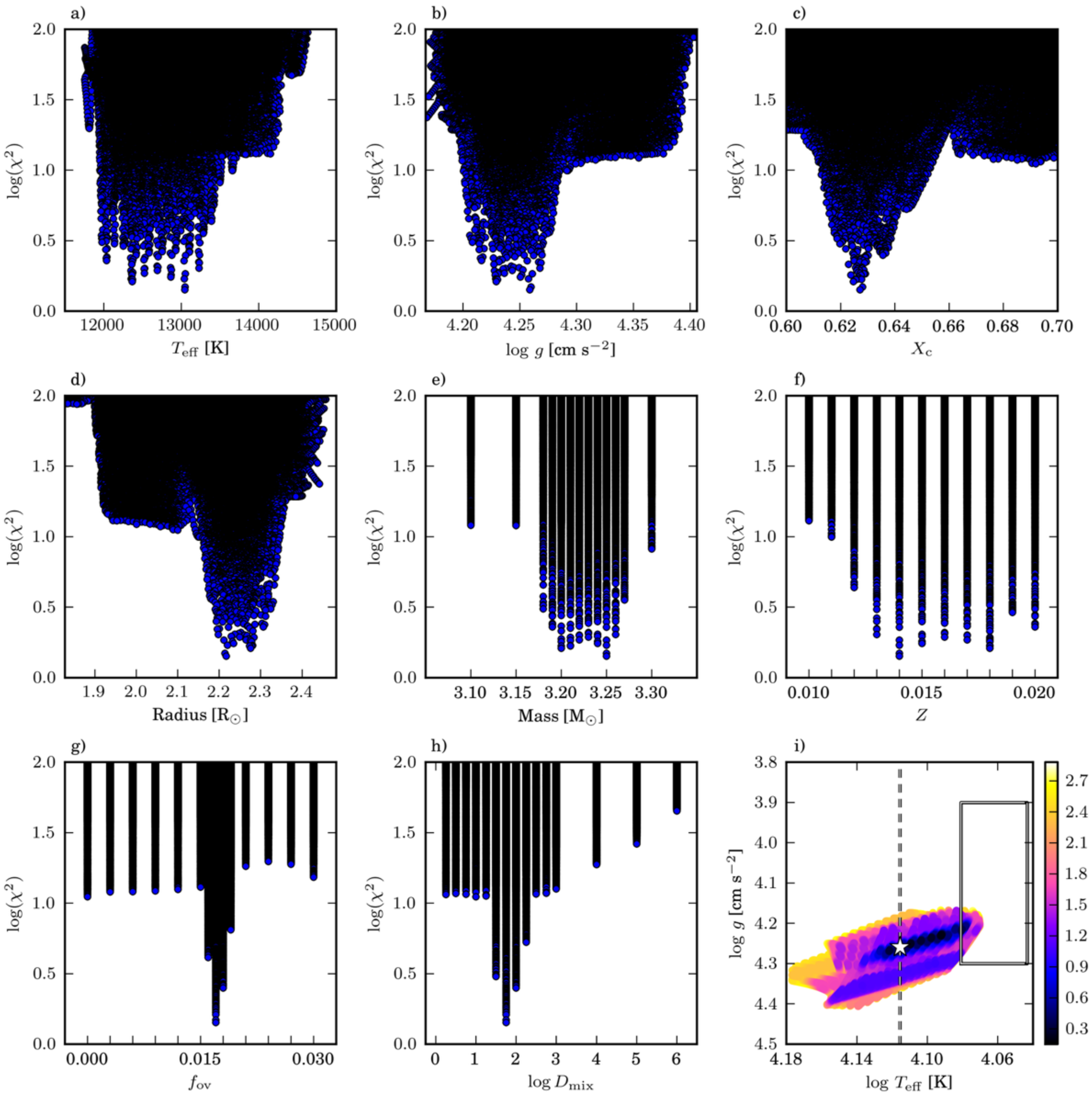
- We observe the theoretically predicted period series, although **finding them is not trivial**, as it is currently more-or-less manual
- Advantage of using **period series**: instantaneous mode identification!
- We are able to model the pulsation spectrum of an SPB star, but…
- …we are missing a lot from the models, as the fine details are not reproduced
  - What about **rotation**? -> The first faster rotator SPB with clear period series identified!
  - What about these **asymmetric rotational splitting**s? -> Ideas?
  - What is the **rotation profile** inside massive stars? -> From a proper model, inversion is possible! Would be nice to find hybrid B-type pulsators in *Kepler* data…
  - Does the **overshoot** depend on fundamental parameters? -> We need a larger sample!
  - How to **improve our models**? What is missing? -> I need help/input from modellers/theoreticians! (Excitation calculations? Don't even ask…)

Asteroseismic studies of SPB stars can provide information on the mixing processes inside massive stars on the main sequence.

THANK YOU!

Extra Material

KIC 10526294



Extra Material

KIC 10526294