Evolutionary models for the asteroseismic study of subdwarf B stars

Steven Bloemen – K.U.Leuven
Haili Hu – IoA, Cambridge
Roy Østensen & Conny Aerts – K.U.Leuven
Marc-Antoine Dupret – Université de Liège

PROSPERITY
Probing Stellar Physics and Testing Stellar Evolution Through Asteroseismology

KATHOLIEKE UNIVERSITEIT LEUVEN

Asteroseismology of sdBs

- Gain insight in **internal structure**
- Check modelling of **diffusion processes**
- Accurate determinations of total **mass**, envelope mass, radius
- Constrain **formation channels**

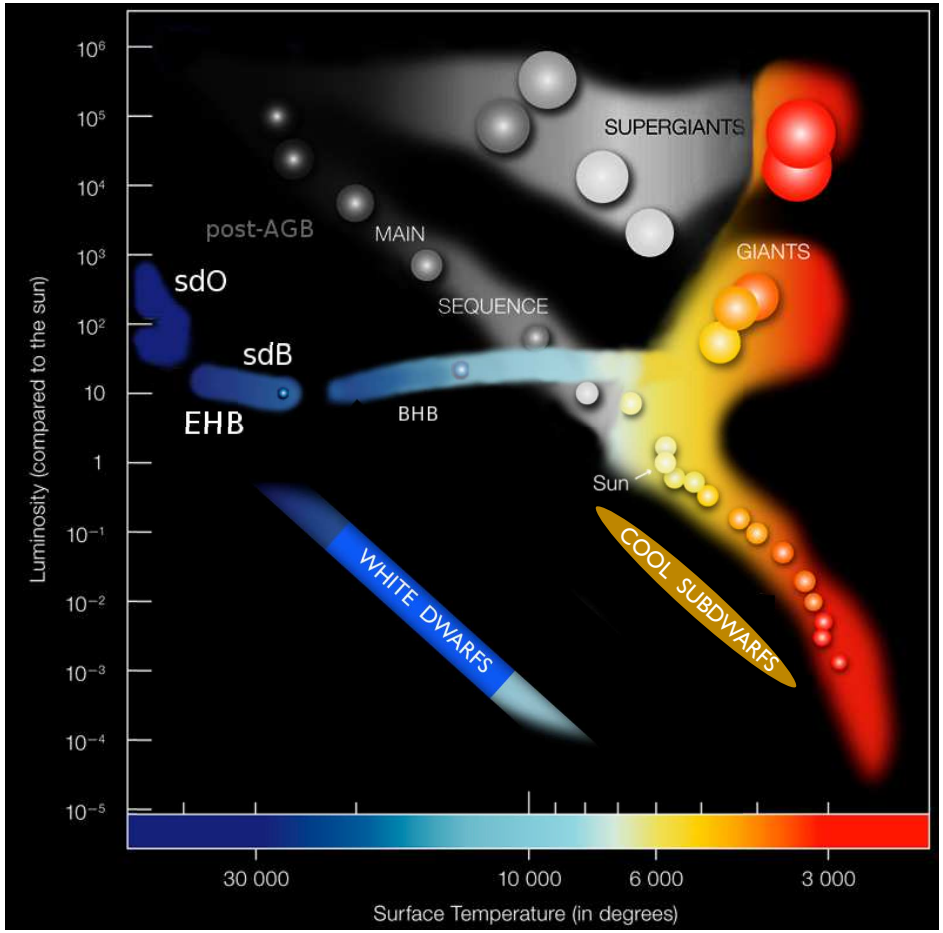


Figure: Heber 2009

Evolutionary models of sdBs

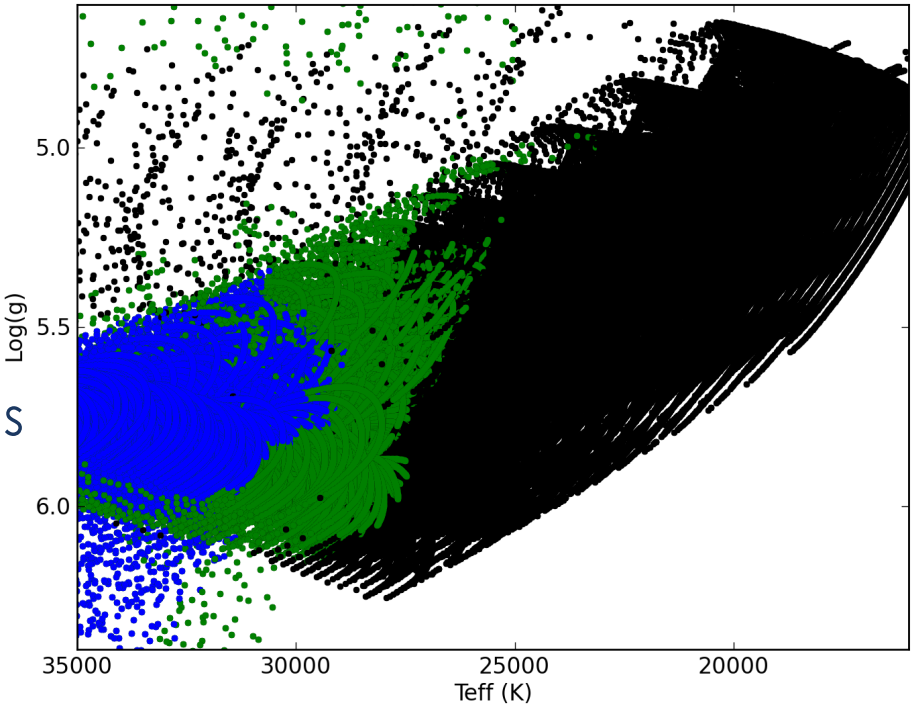
- **Evolutionary** tracks, computed using STARS code (Eggleton 1971 + updates)
- **Non-adiabatic pulsational properties** using MAD (Dupret 2001)
- **Diffusion** processes: gravitational settling, thermal diffusion, concentration diffusion, levitation (Hu et al. 2008, 2009, 2010)
- OP opacities

Initial grid

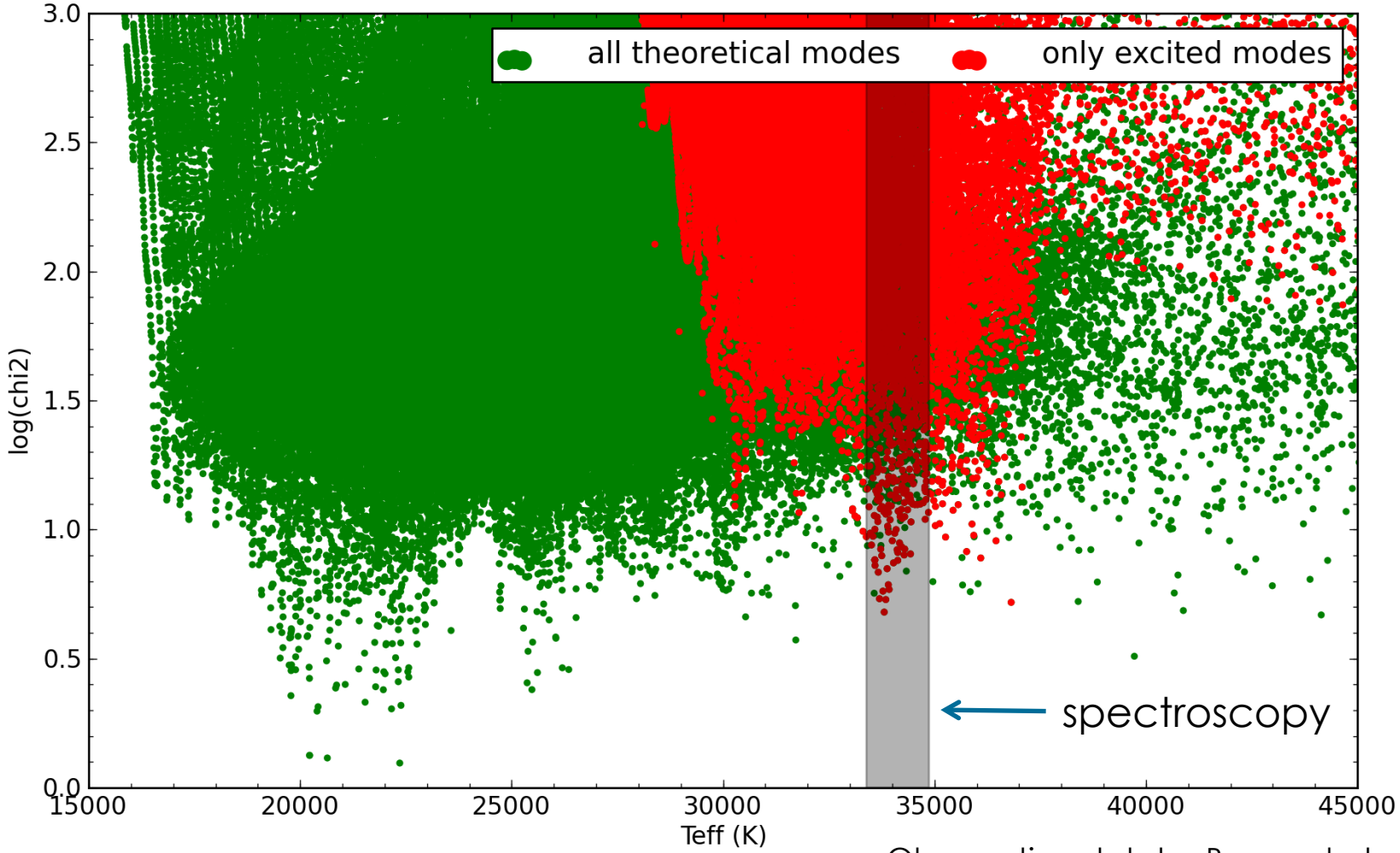
- >1000 evolutionary tracks, > 200 000 models
- Total mass: 0.35 – 0.55 $M_\odot$ in 50 steps
- 25 envelope masses per total mass
- Metallicity at ZAEHB: Z=0.02
- ***Artificial* Fe enhancement** in envelope, driving pulsations

→ Find best model, minimising

$$\chi^2 = \sum_{i=1}^{N_{\rm obs}} \left(P^i_{\rm obs} - P^i_{\rm th} \right)^2$$

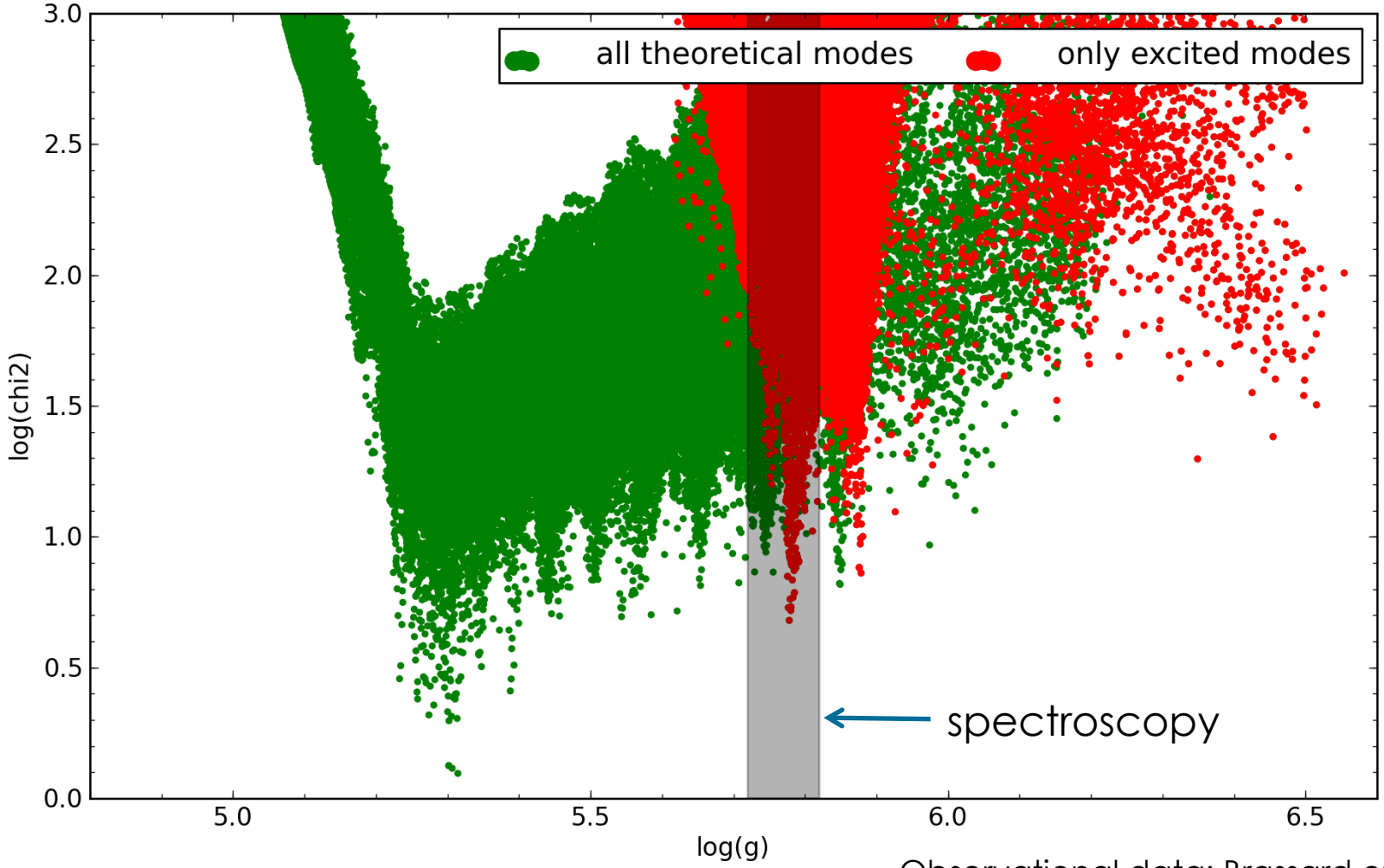


Example 1: **p-mode** pulsator PG0014+067



Observational data: Brassard et al. 2009

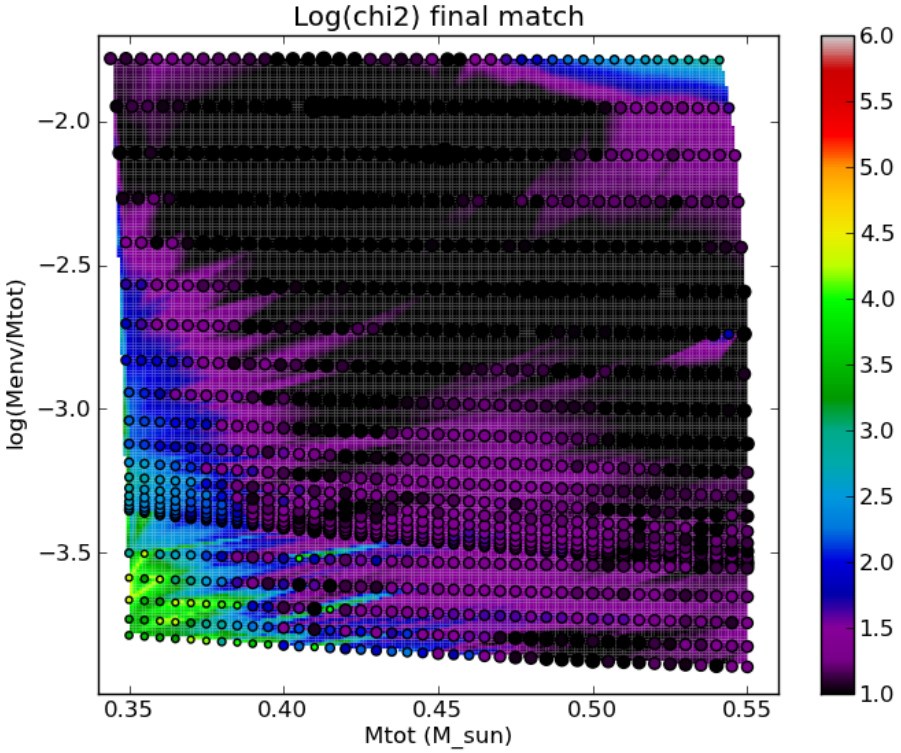
Example 1: **p-mode** pulsator PG0014+067



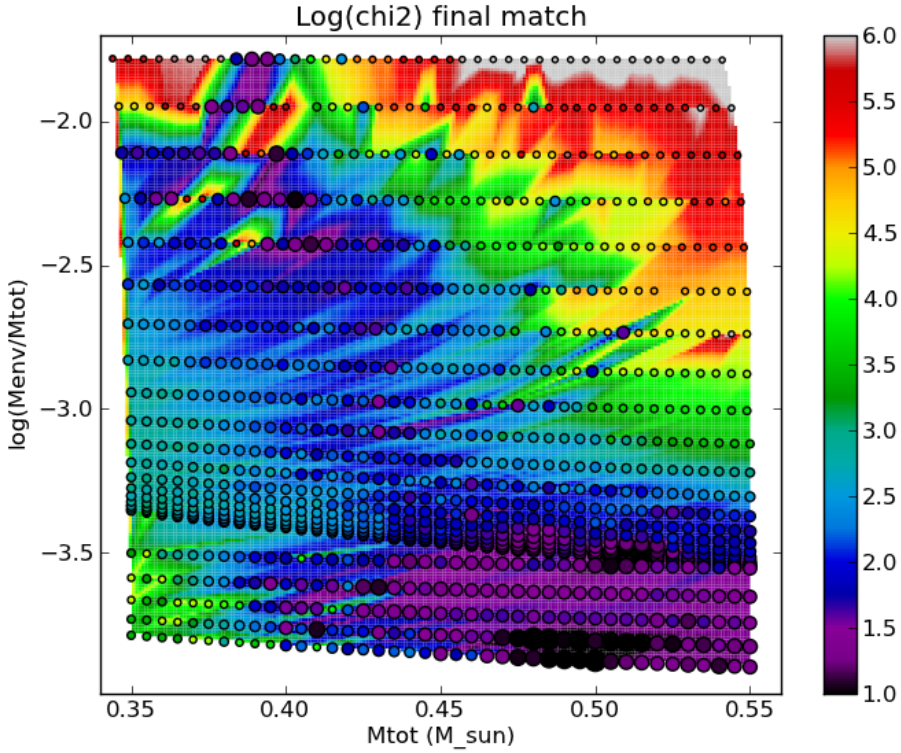
Observational data: Brassard et al. 2009

Example 1: **p-mode** pulsator PG0014+067

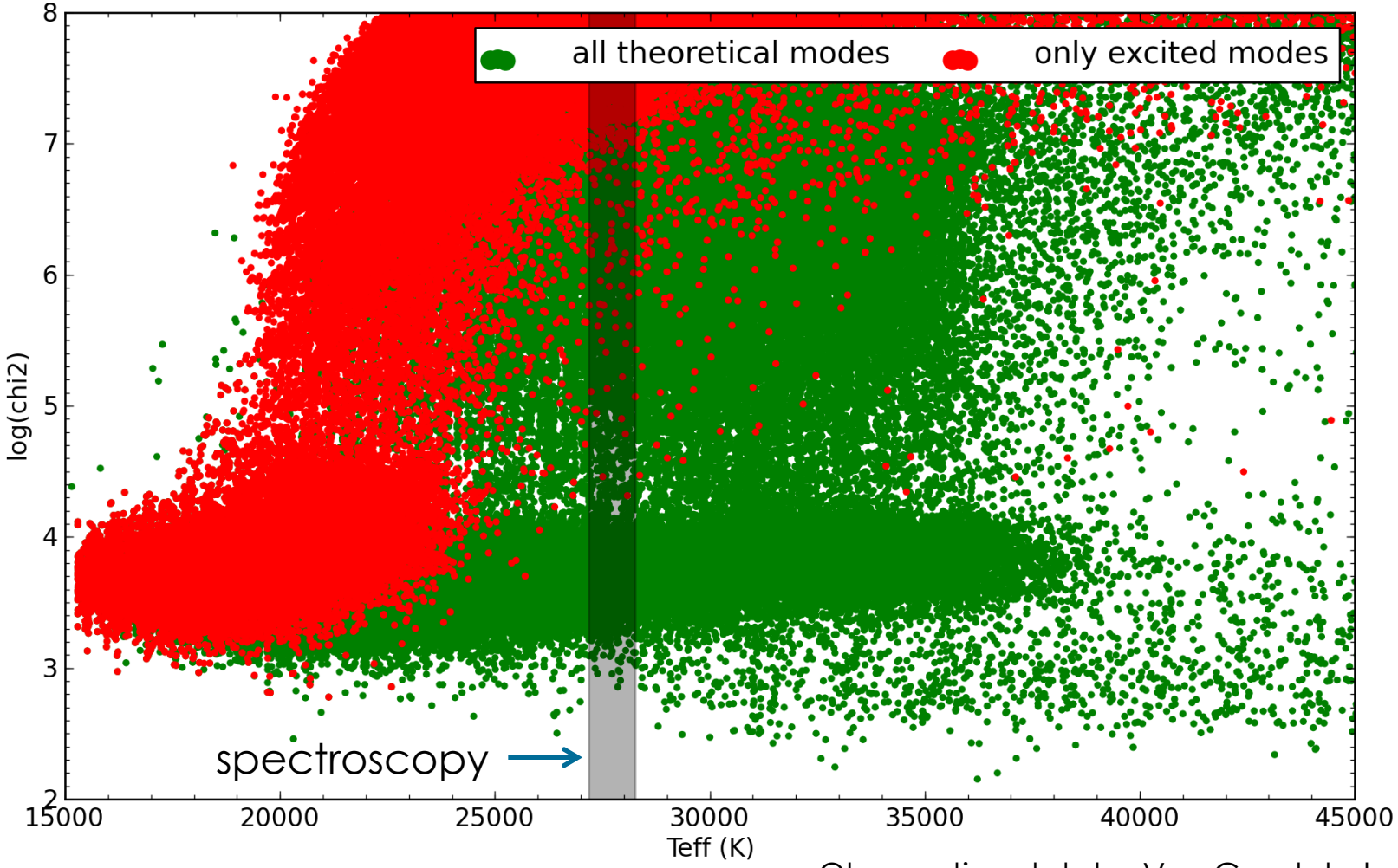
Using all theoretical modes



Using only driven modes

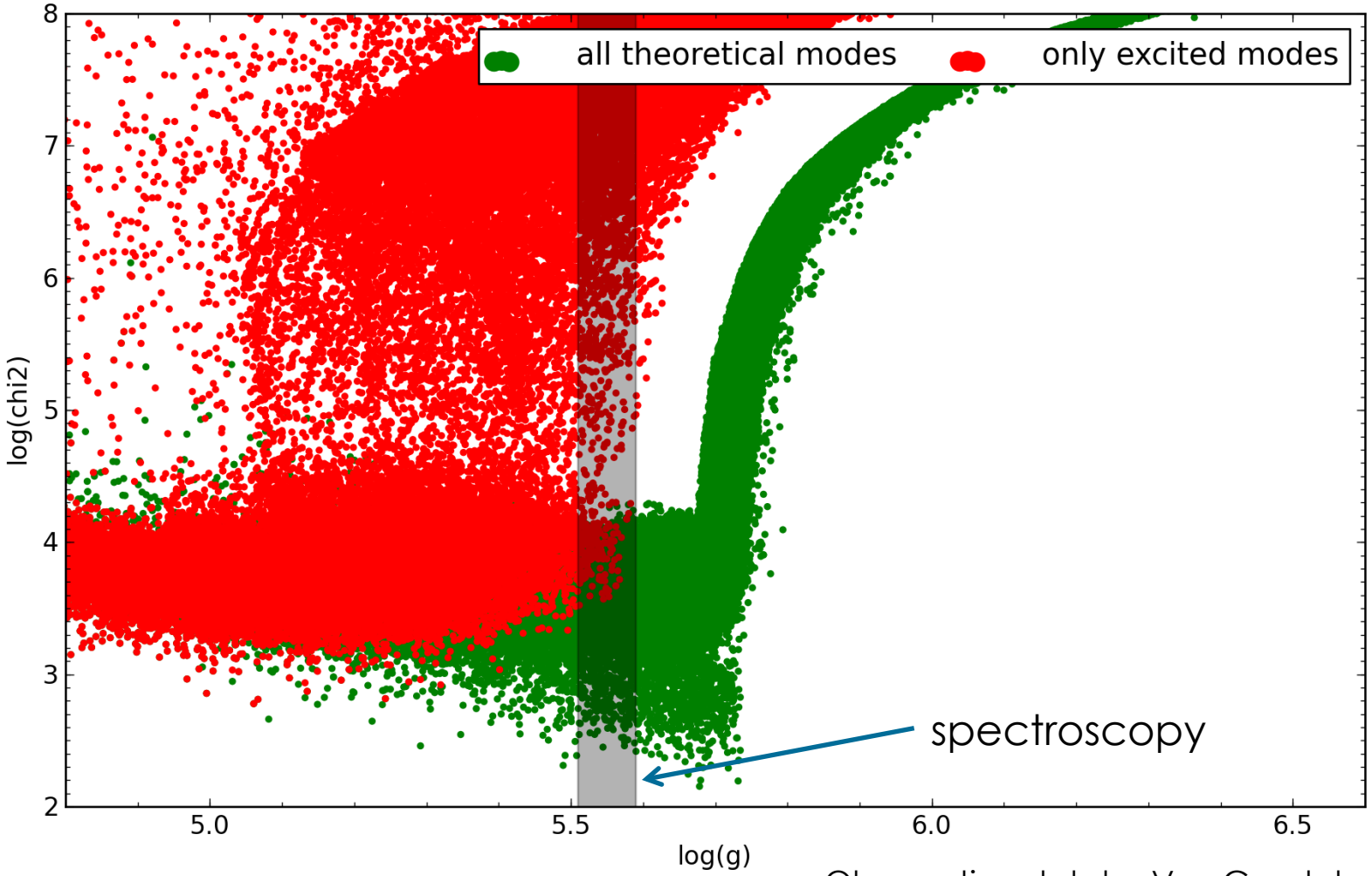


Example 2: **g-mode** pulsator KPD1943+4058



Observational data: Van Grootel et al. 2010

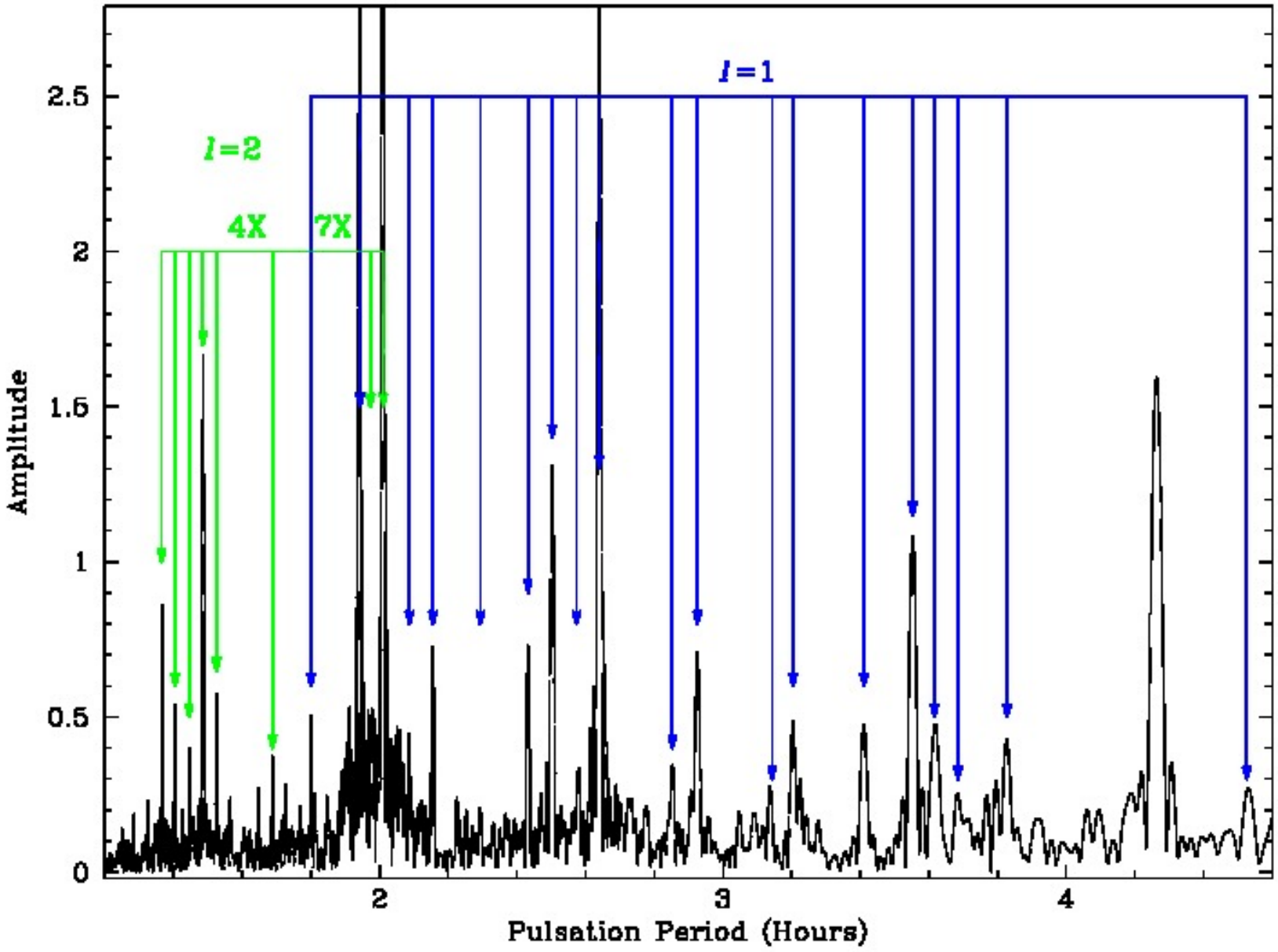
Example 2: **g-mode** pulsator KPD1943+4058



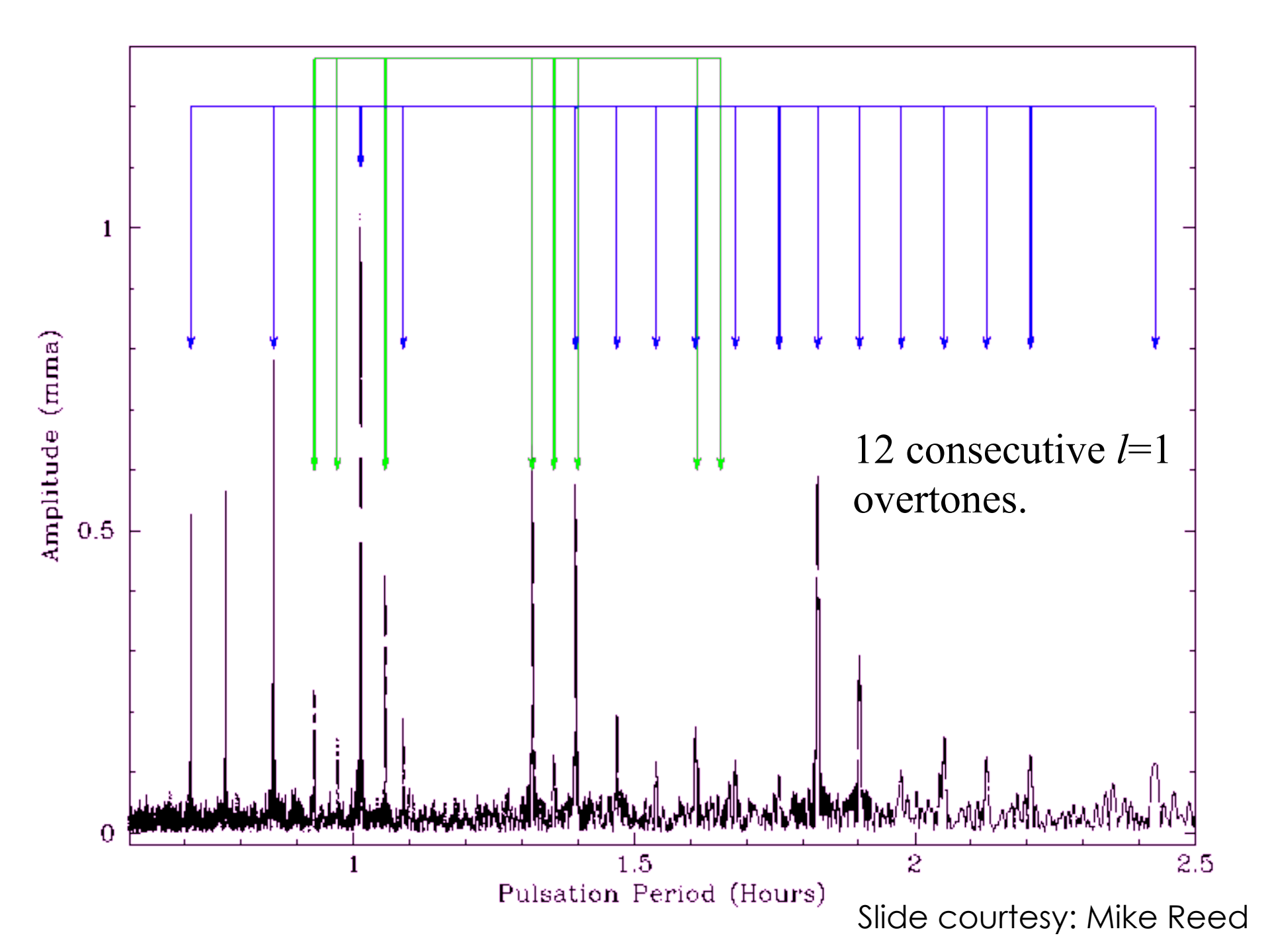
Observational data: Van Grootel et al. 2010

Extra constraints

- **Spectroscopic** T_{eff} and log(g)
- **Mode identification**
  - Spectroscopy: hard…
  - Rotational multiplets: efforts underway (Pablo et al.)
  - Ratios of amplitudes in different passbands
  - Asymptotic period spacing relations
    Reed et al. 2011: 70% of modes in 13 Kepler g-mode pulsators fit l=1 or 2 series



Slide courtesy: Mike Reed



Slide courtesy: Mike Reed

Extra constraints

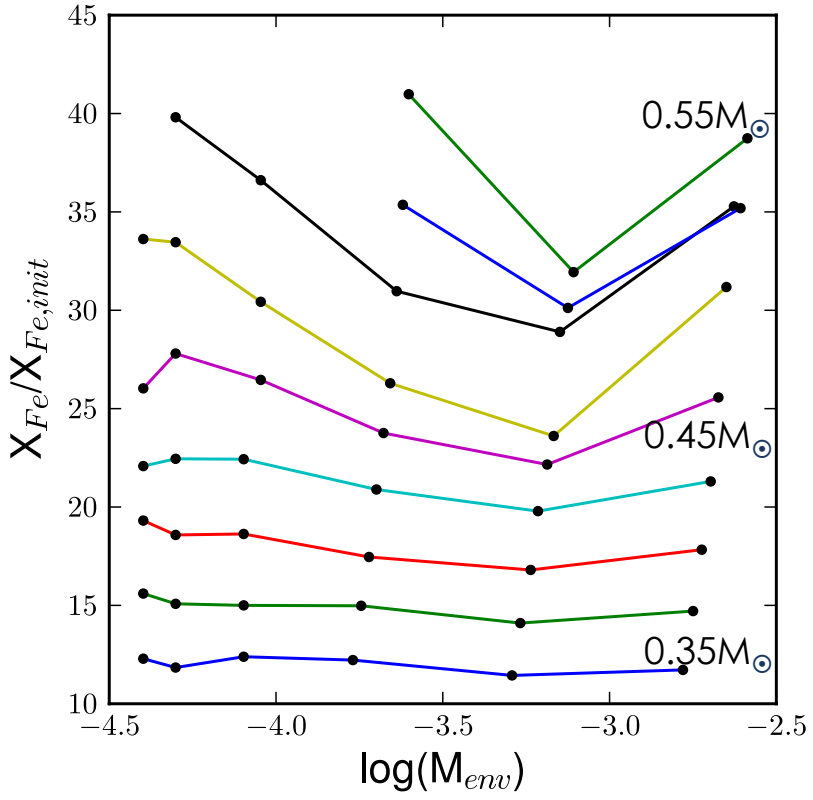
- **Spectroscopic** T_{eff} and log(g)
- **Mode identification**
  - Spectroscopy: hard…
  - Rotational multiplets: efforts underway (Pablo et al.)
  - Ratios of amplitudes in different passbands
  - Asymptotic period spacing relations
    Reed et al. 2011: 70% of modes in 13 Kepler g-mode pulsators fit l=1 or 2 series
- Theoretical **mode instability** from non-adiabatic pulsation code MAD → accurate modelling of Fe/Ni build-up needed

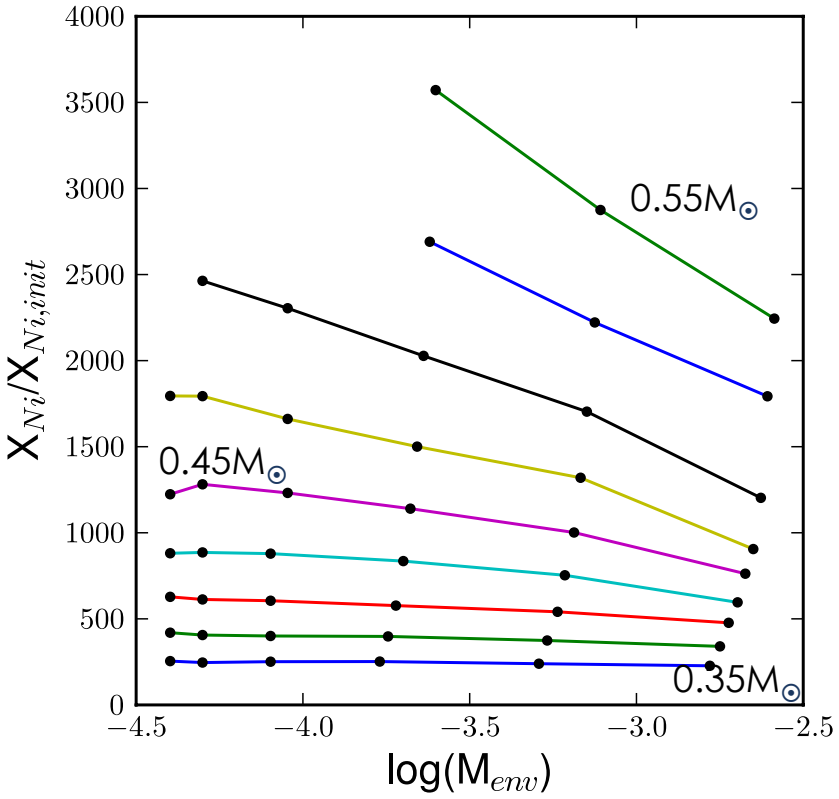
Next generation models

- **Radiative levitation** included
- Fe and Ni enhancements built up by levitation instead of artificially
- Ni abundance as large as Fe,
  equal enhancements were assumed (e.g. Jeffery & Saio 2007)
  → better driving of g-modes
- Computationally intensive…

→ Haili Hu et al. (2011)

Enhancement of Fe and Ni abundance in driving region

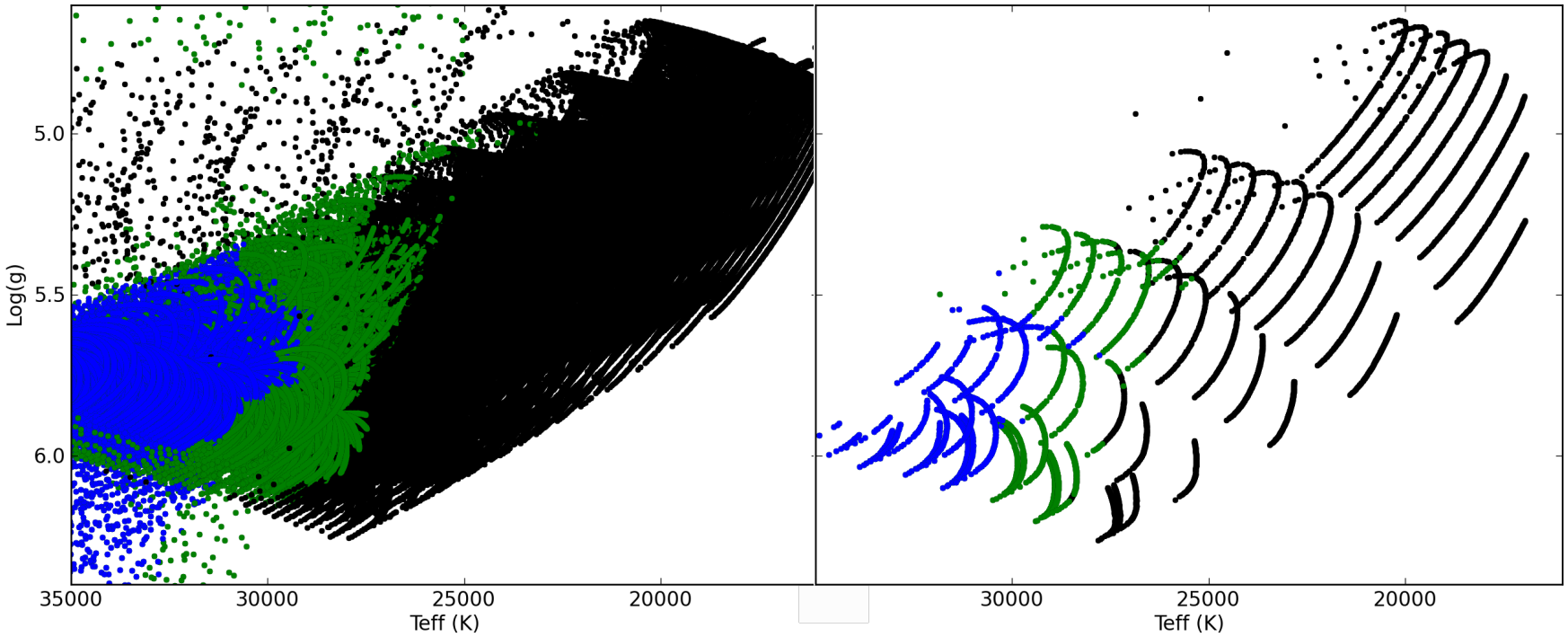




Unstable p-modes

Artificial Fe-profile

Radiative levitation of Fe and Ni

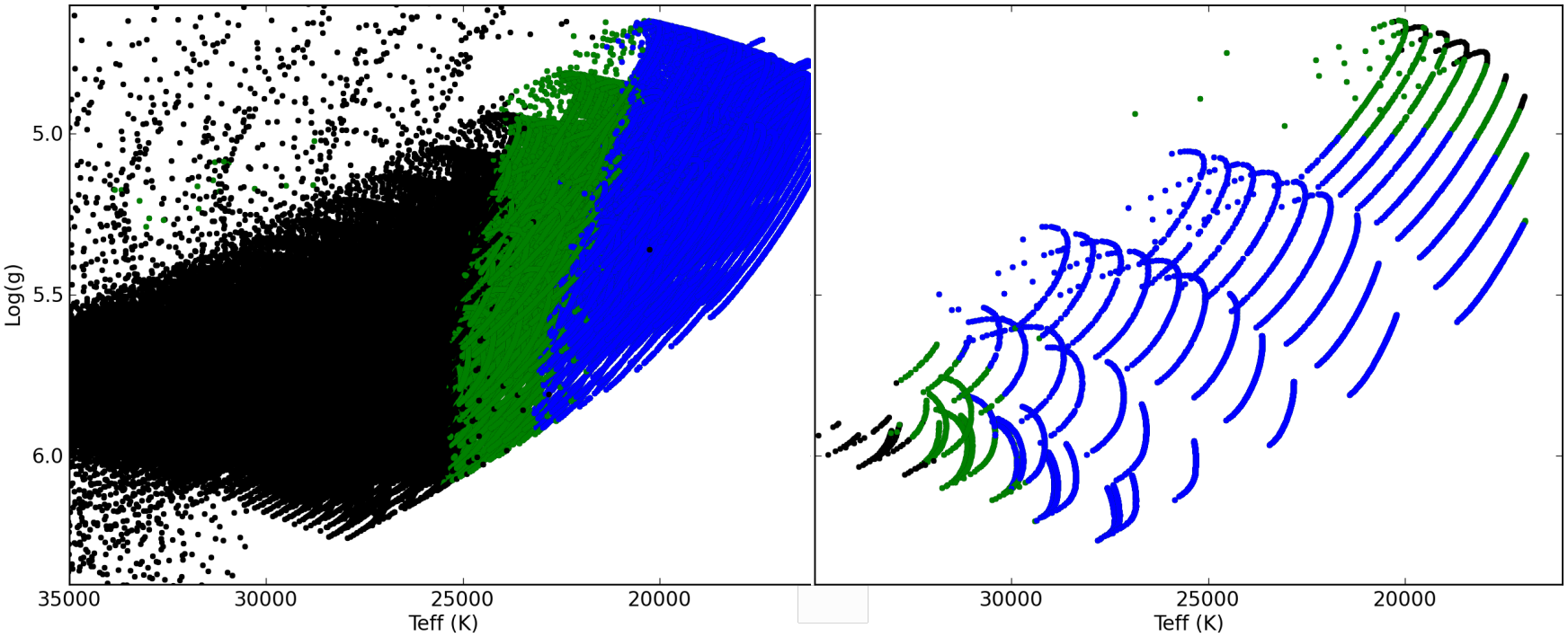


black = 0-5%, **green** = 5-20%, **blue** = >20% of modes unstable

Unstable g-modes

Artificial Fe-profile

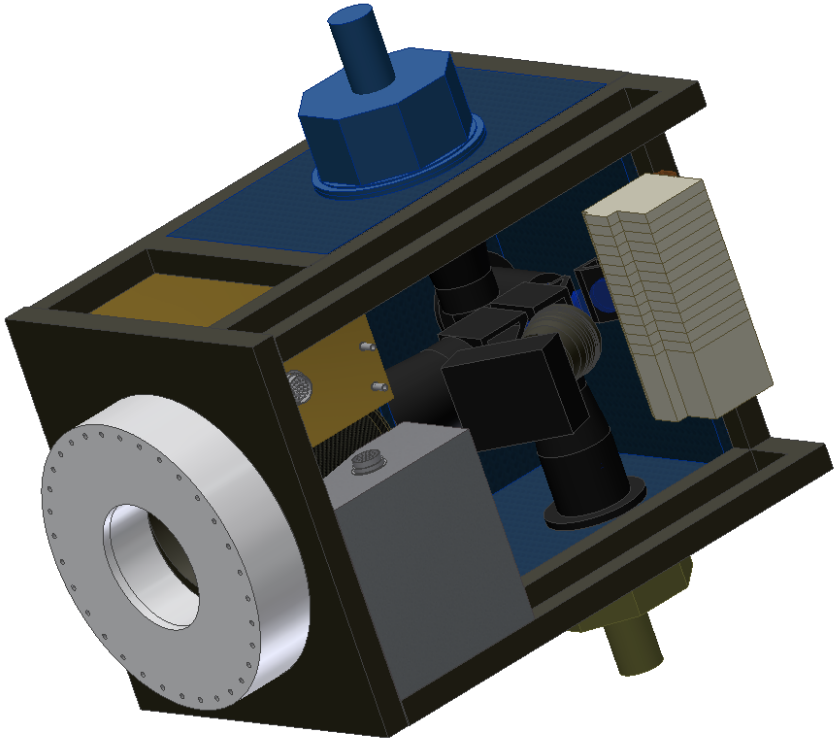
Radiative levitation of Fe and Ni



black = 0-5%, **green** = 5-20%, **blue** = >20% of modes unstable

Dedicated camera for multi-colour photometry

ultrafast Mercator Advanced Imager for Asteroseismology, MAIA
3 color bands simultaneously, 2k x 6k frame transfer CCDs



Pictures: Jeroen Vandersteen (MAIA) and Peter Papics (Mercator)

Summary

- Using asteroseismology to constrain sdB formation
- Grid of evolutionary models + pulsation properties
  - Initial grid works for p-mode pulsators
  - Radiative levitation (next grid) required to predict stability of g-modes
- Further degeneracy can be broken by mode identification
  - Multi-colour photometry from dedicated MAIA camera
  - Period spacings (?)