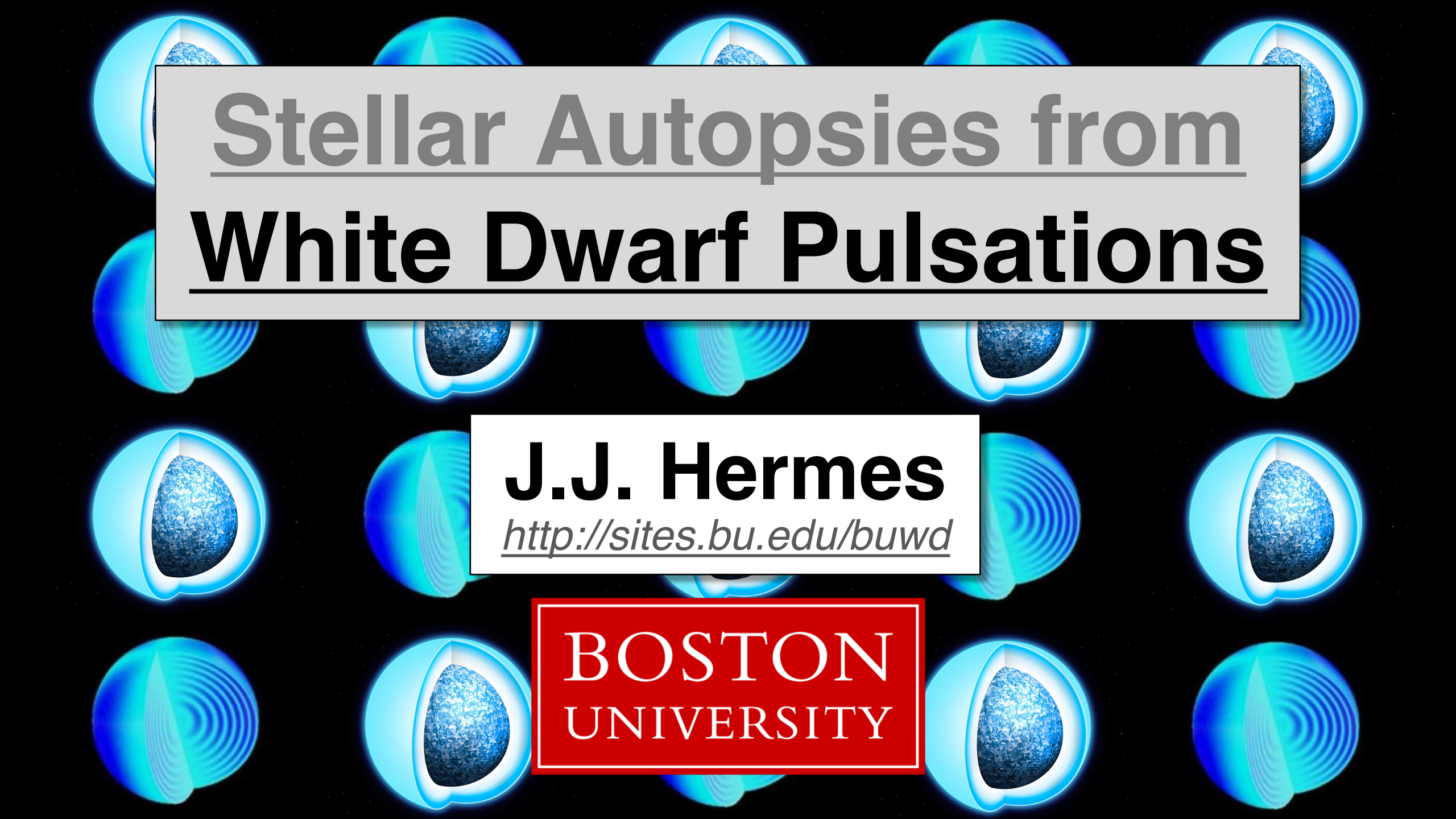
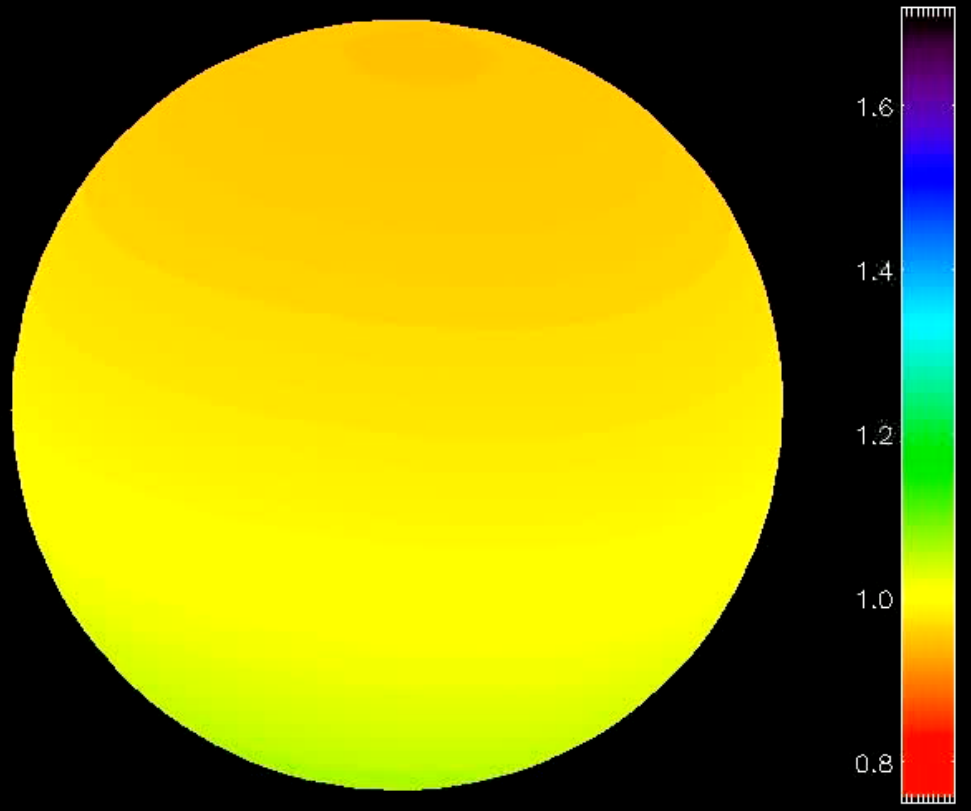


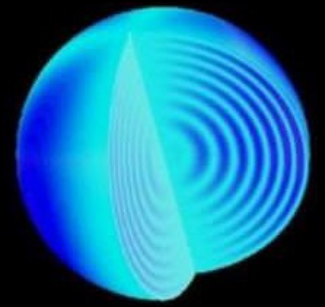
Stellar Autopsies from White Dwarf Pulsations

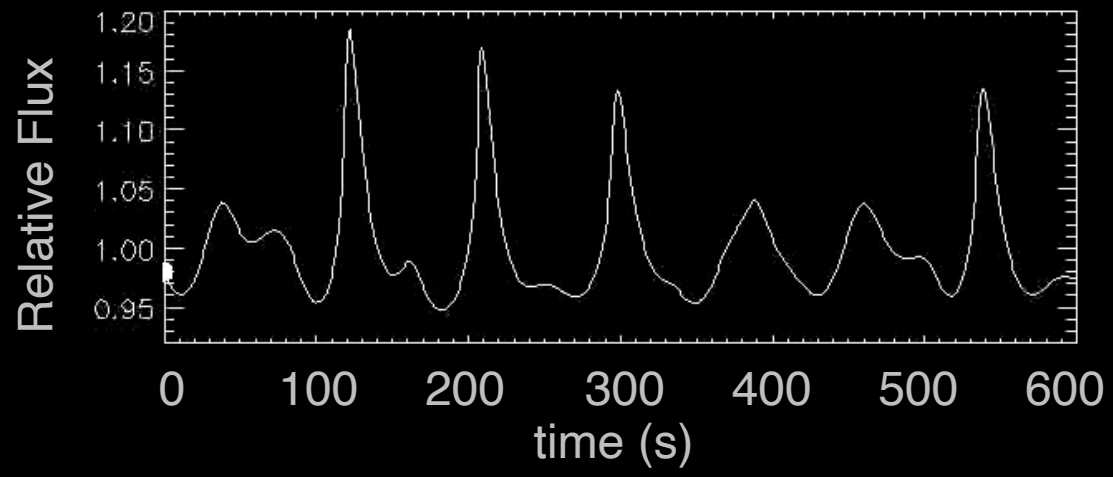
J.J. Hermes

http://sites.bu.edu/buwd

BOSTON UNIVERSITY

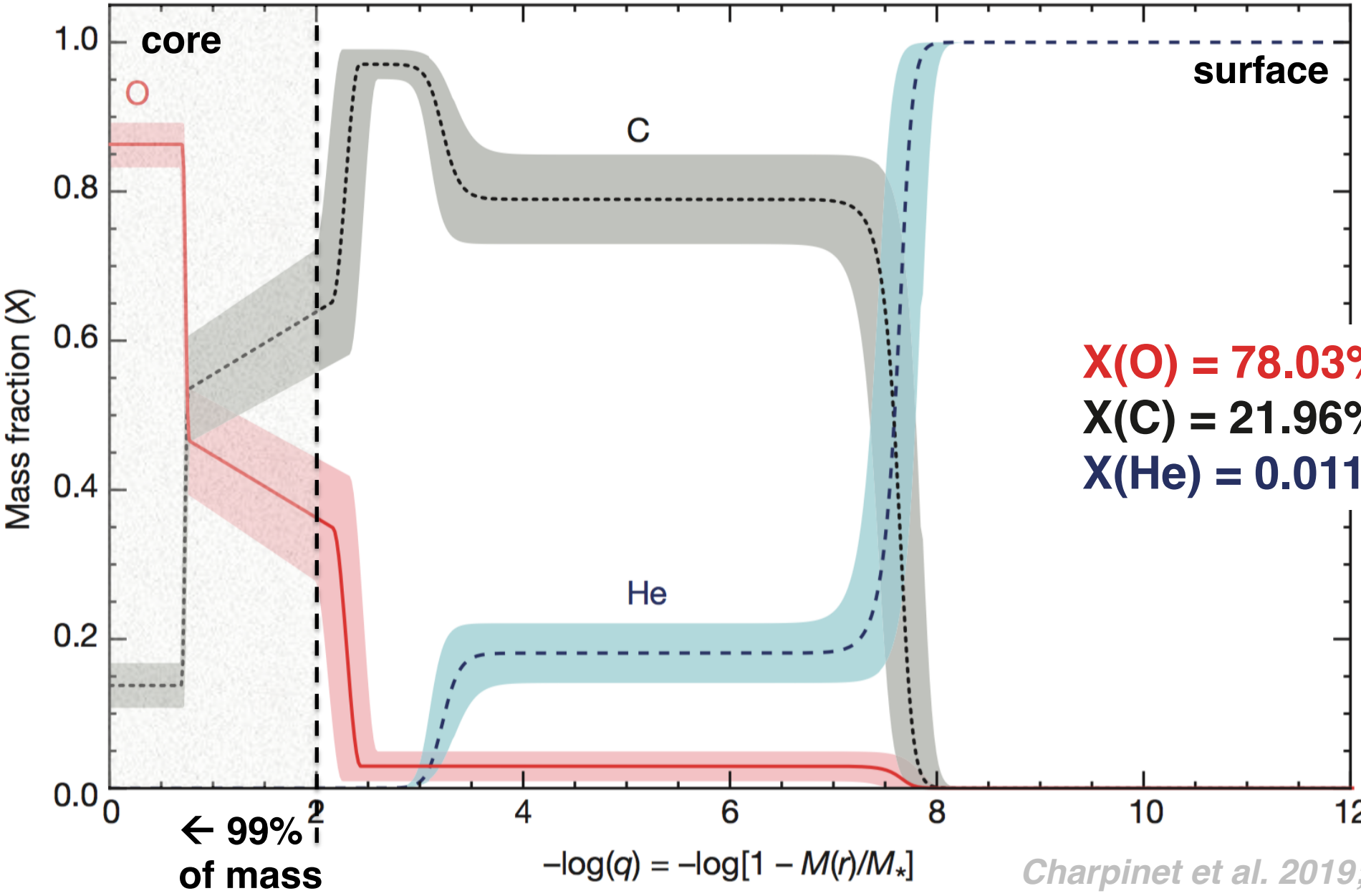






GD 358: Mike Montgomery

End Goal of Asteroseismology: Unique Structural Model



X(O) = 78.03% ± 4.2%

X(C) = 21.96% ± 4.2%

X(He) = 0.0113% ± 0.006%

KIC 08626021:
Giammichele et al. 2018

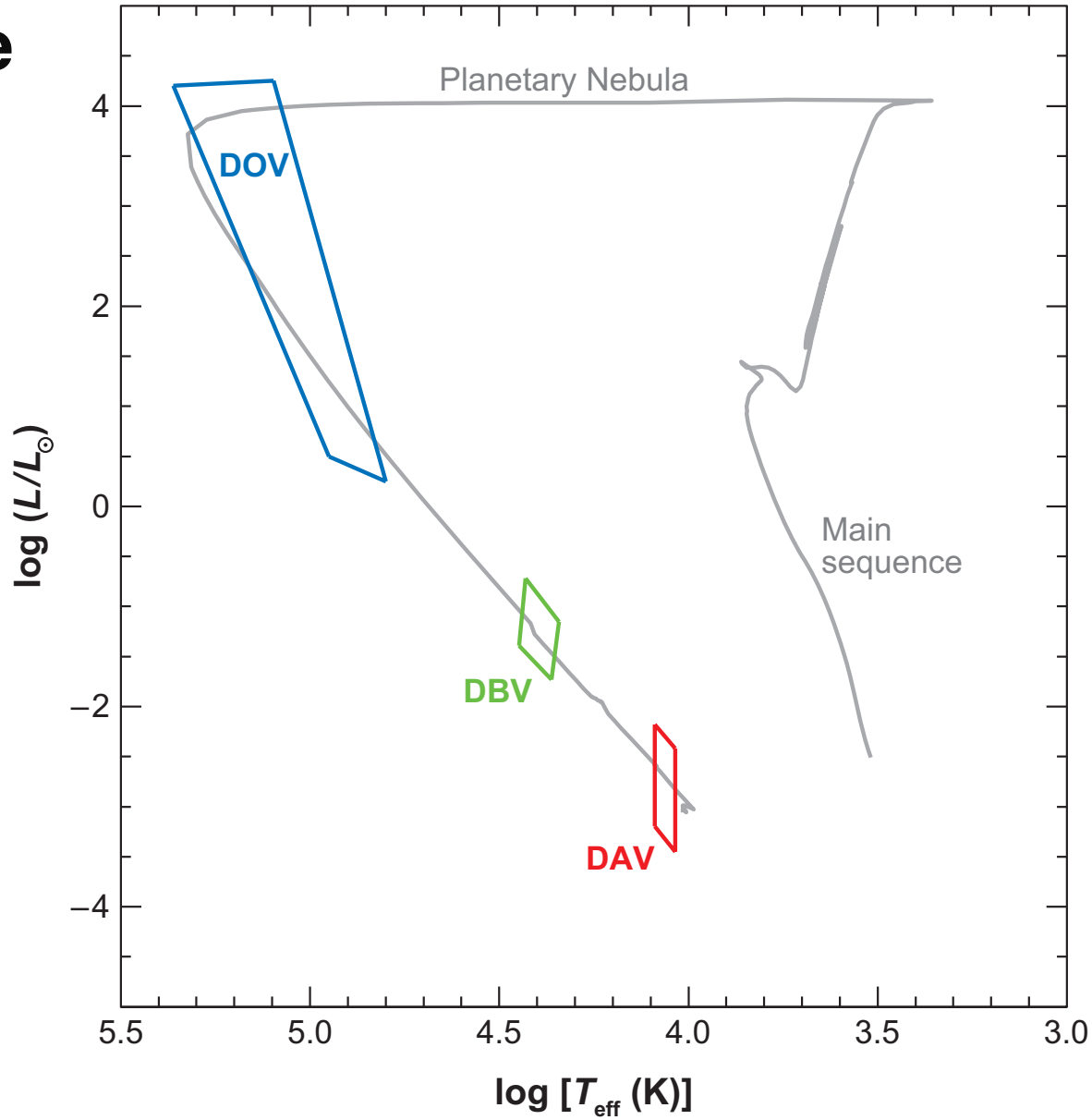
+ Timmes et al. 2018;
Charpinet et al. 2019; De Geronimo et al. 2019

Pulsations Are A Natural Phase for All* White Dwarfs

*non-magnetic

pulsations driven at onset of surface partial ionization (convection) zone

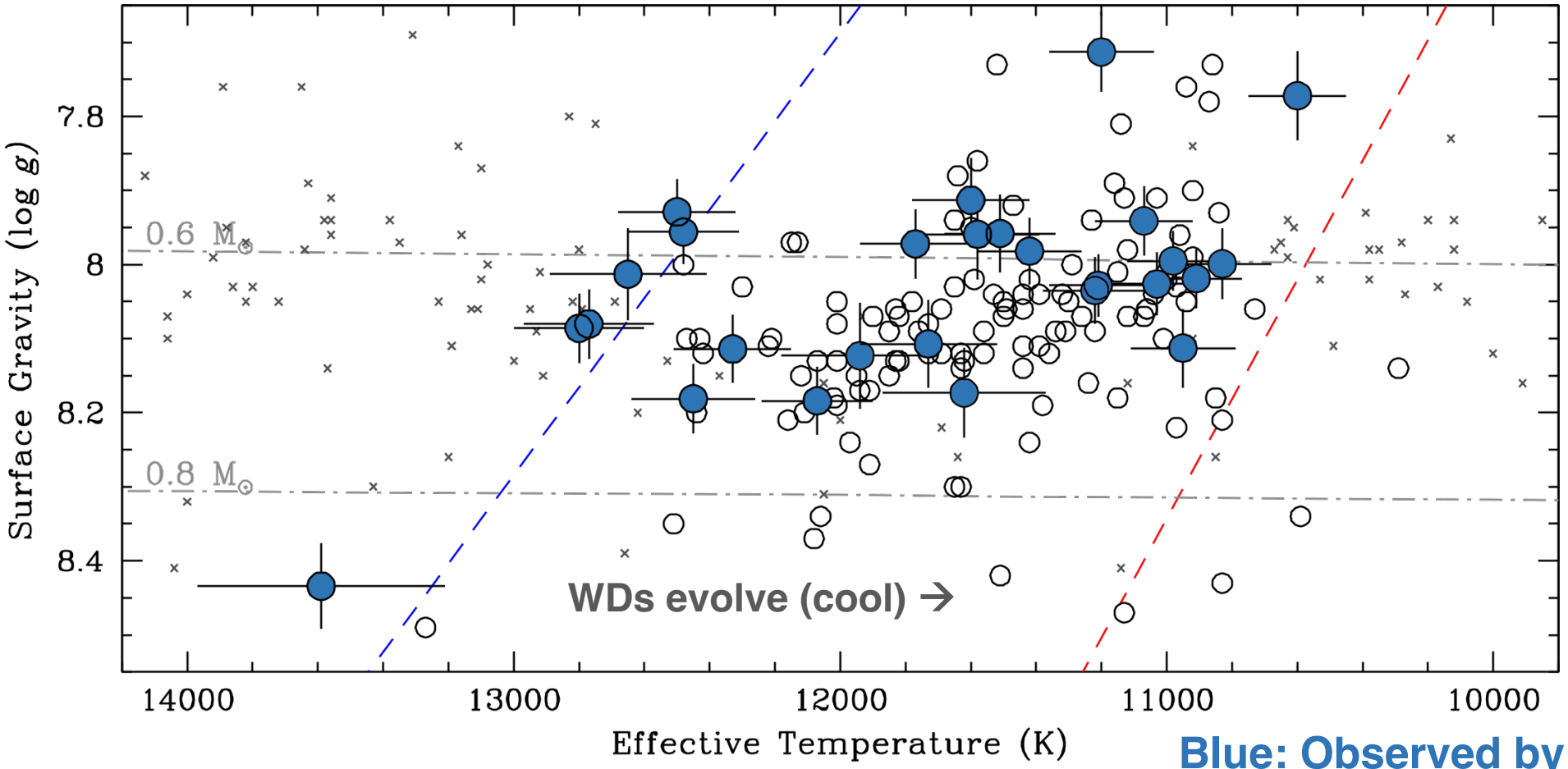
~130,000 K for C/O-atm, DOV
~30,000 K for He-atm, DBV
~12,000 K for H-atm, DAV



See reviews on WD asteroseismology by:

Fontaine & Brassard 2008
Winget & Kepler 2008
Althaus, Córsico, Isern & García-Berro 2010
Córsico, Althaus, Miller Bertolami & Kepler 2019

Most DA Pulsate When They Reach ~13,000 K



Blue: Observed by *Kepler/K2*

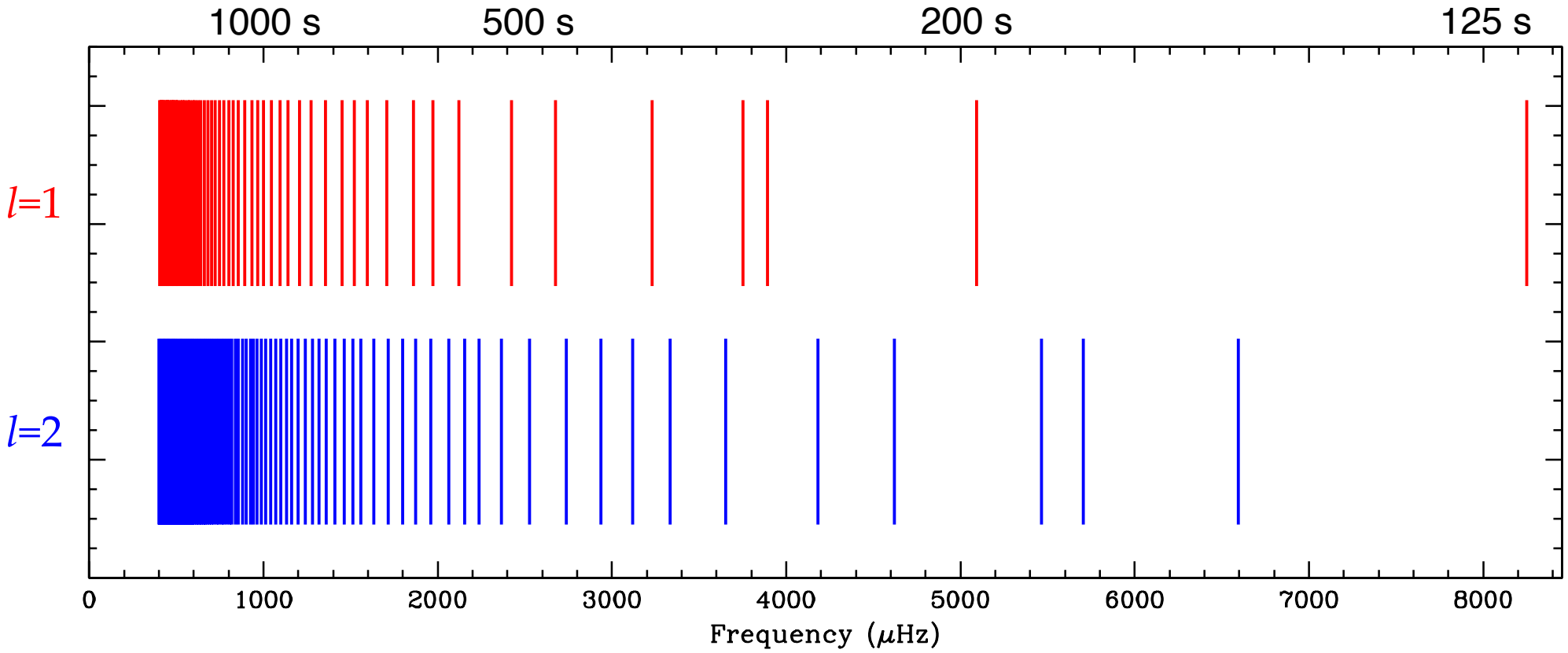
Open circles: Ground-based

small x: Not observed to vary

Hermes et al. 2017, ApJS

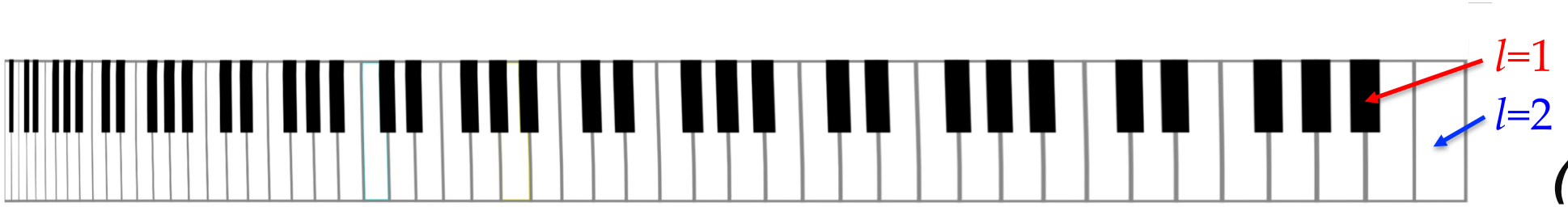
Pulsating WDs Can Ring at a Spectrum of Periods

each white dwarf has a spectrum of *g*-modes:
standing waves that naturally resonate
from 70 s to thousands of s

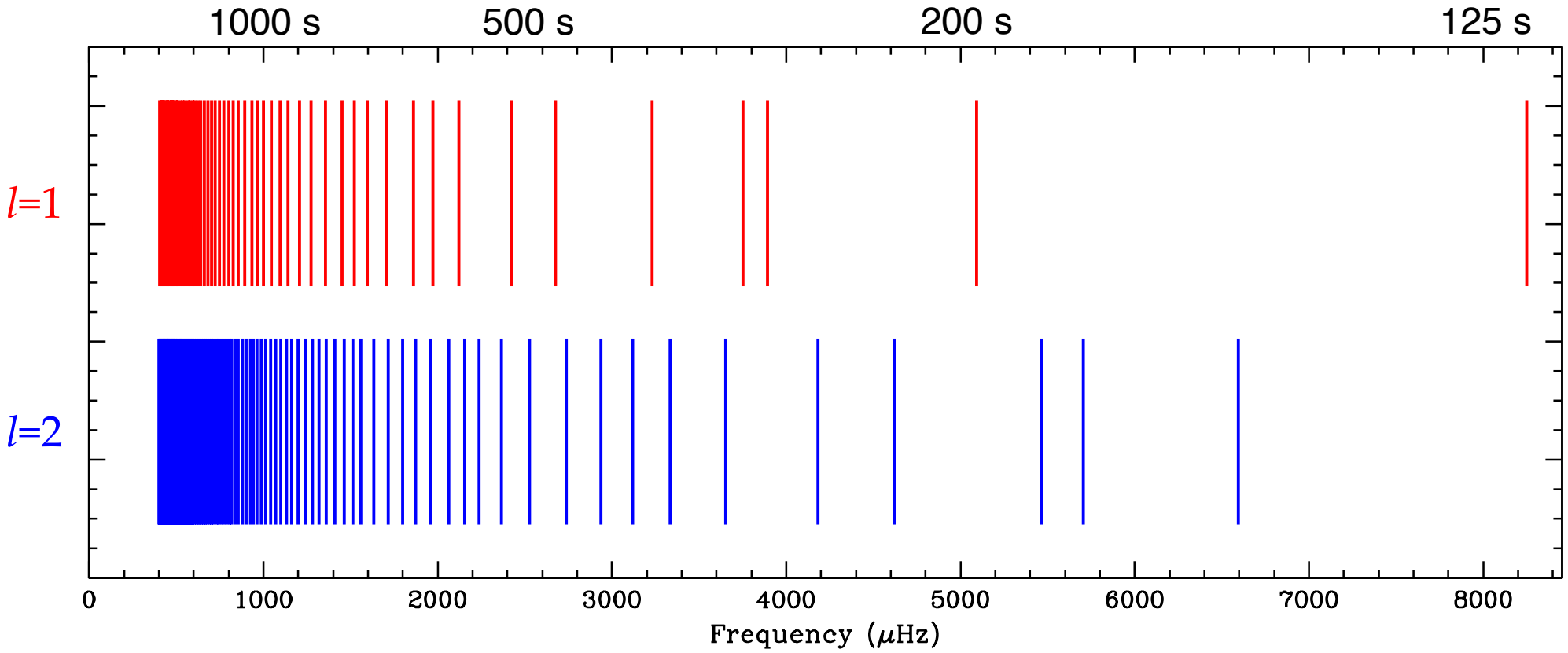


11,245 K, 0.632 $M_\odot$
$10^{-4.12}$ M_H/M_{WD} model
Romero et al. 2012

Pulsating WDs Can Ring at a Spectrum of Periods



(g-modes are ~evenly spaced in period, not frequency)

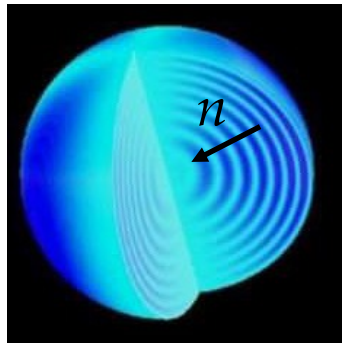


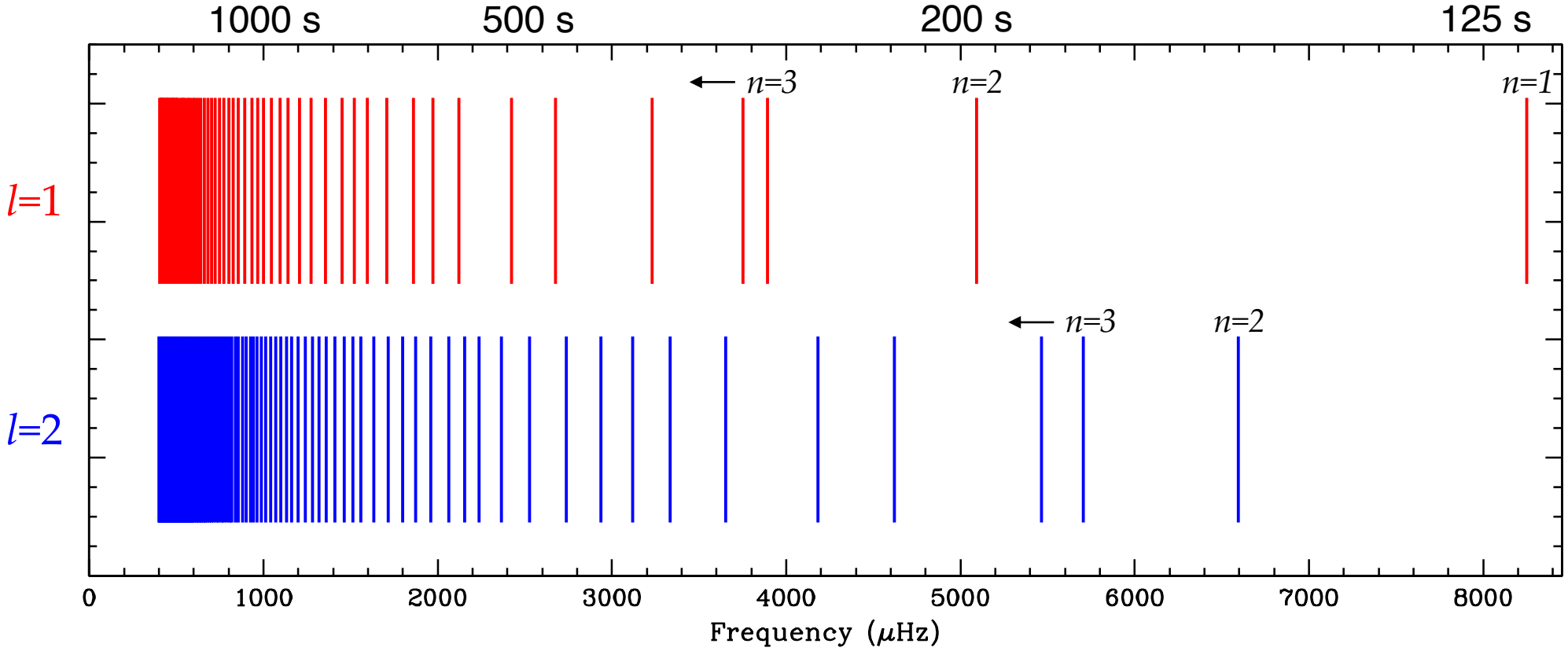
model periods from Romero et al. 2012

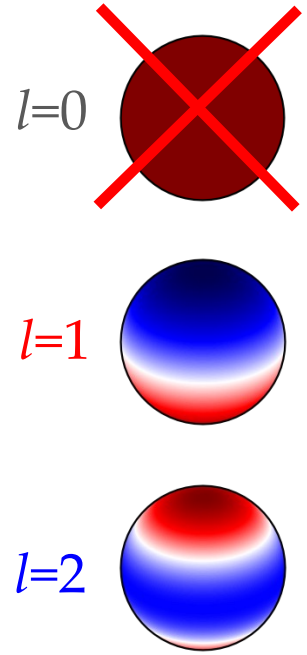
Spherical Harmonics Describe the Pulsations

n = no. of radial nodes

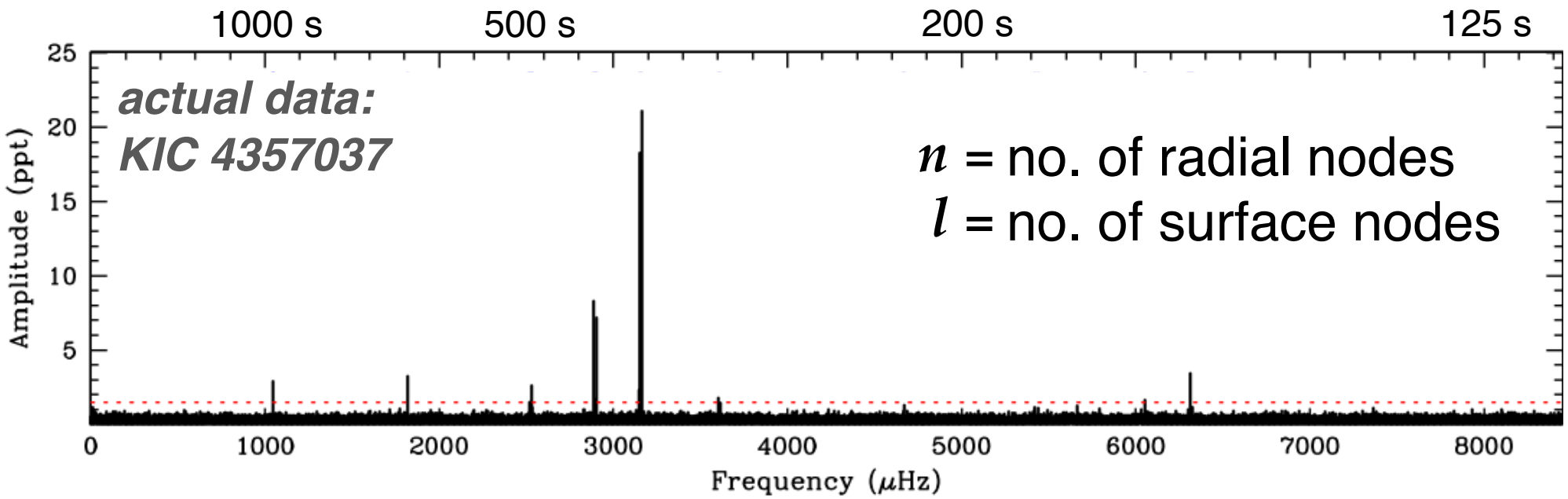
l = no. of surface nodes





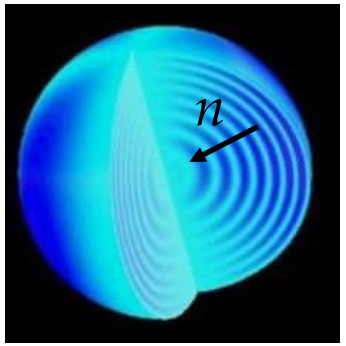


model periods from Romero et al. 2012

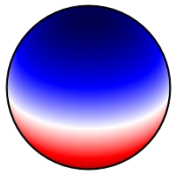


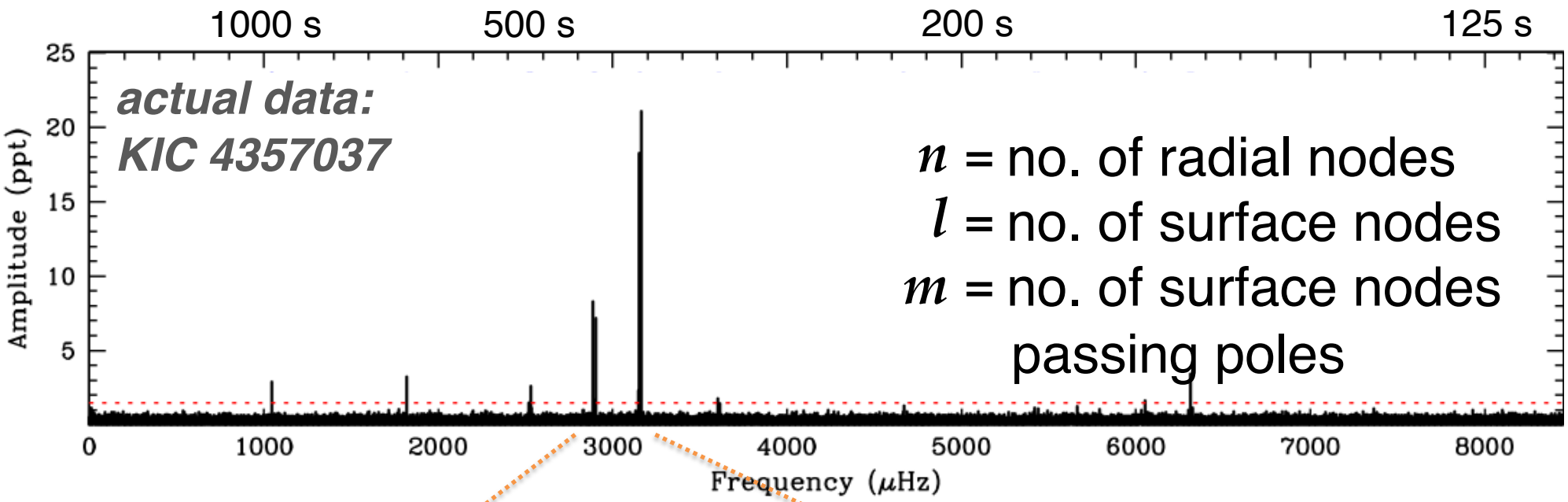
n = no. of radial nodes

l = no. of surface nodes

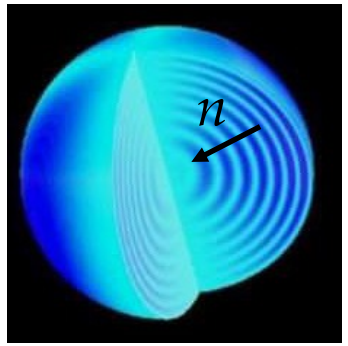


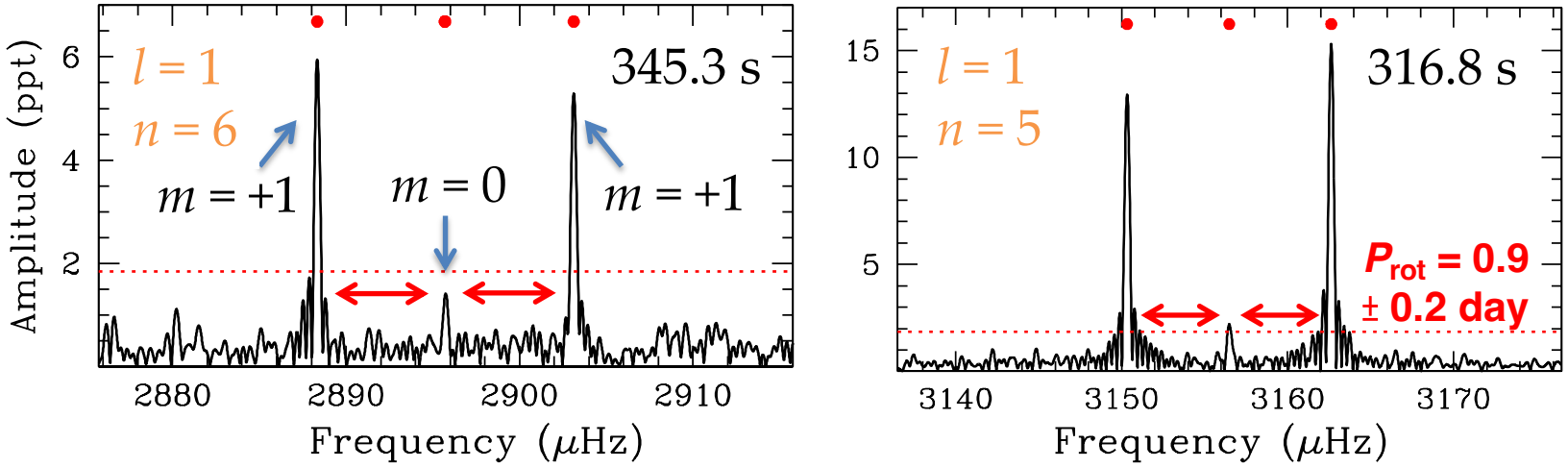
l=1

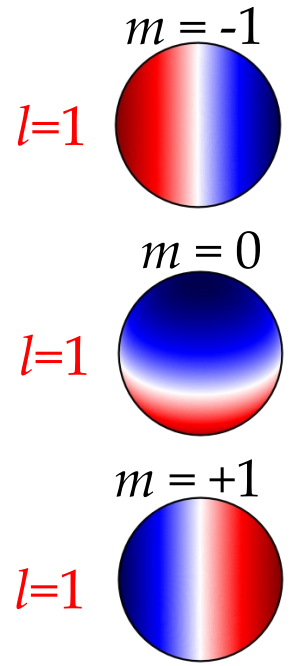




n = no. of radial nodes
l = no. of surface nodes
m = no. of surface nodes passing poles

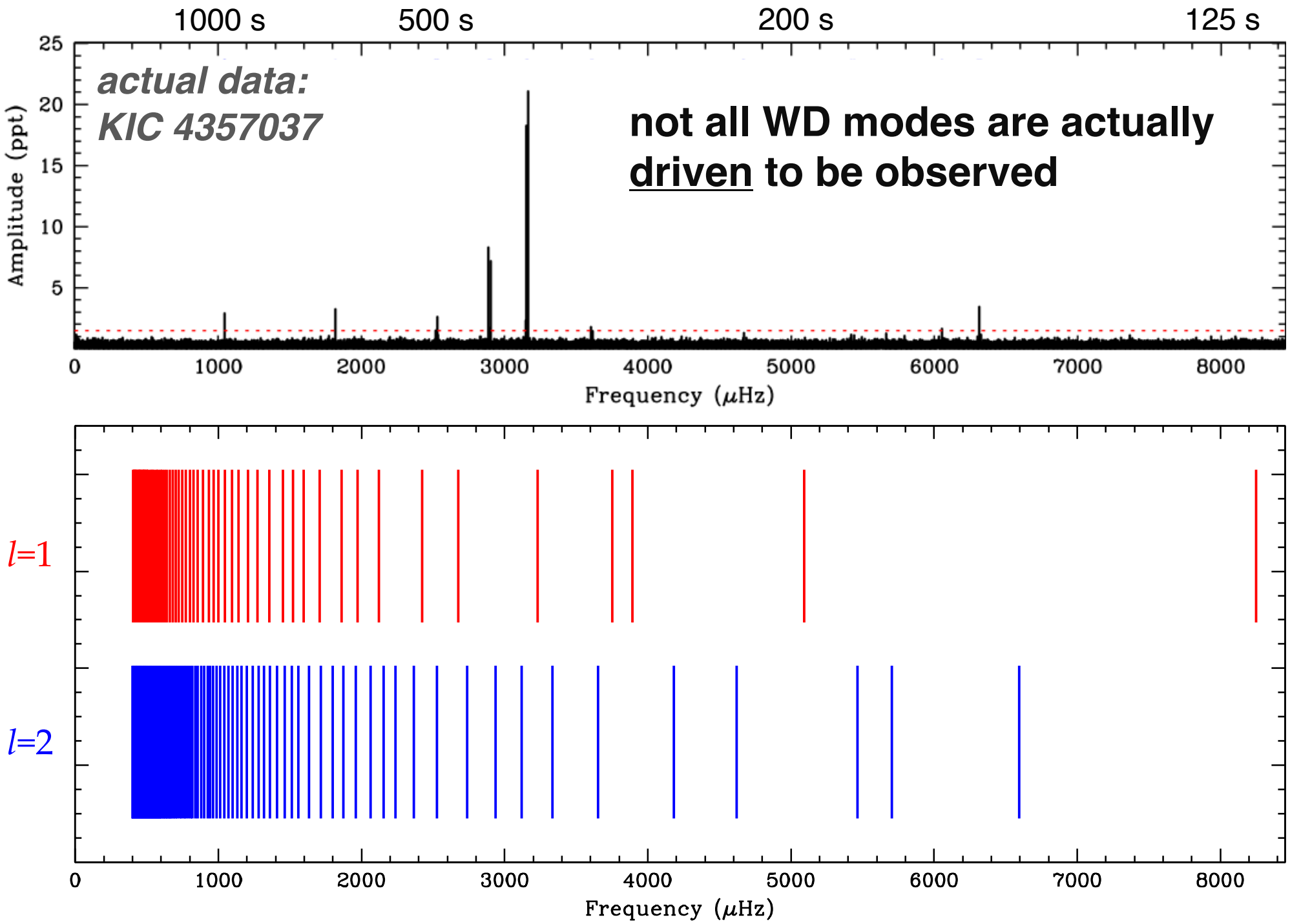






<u>rotation</u> causes splitting of a mode of given l,m

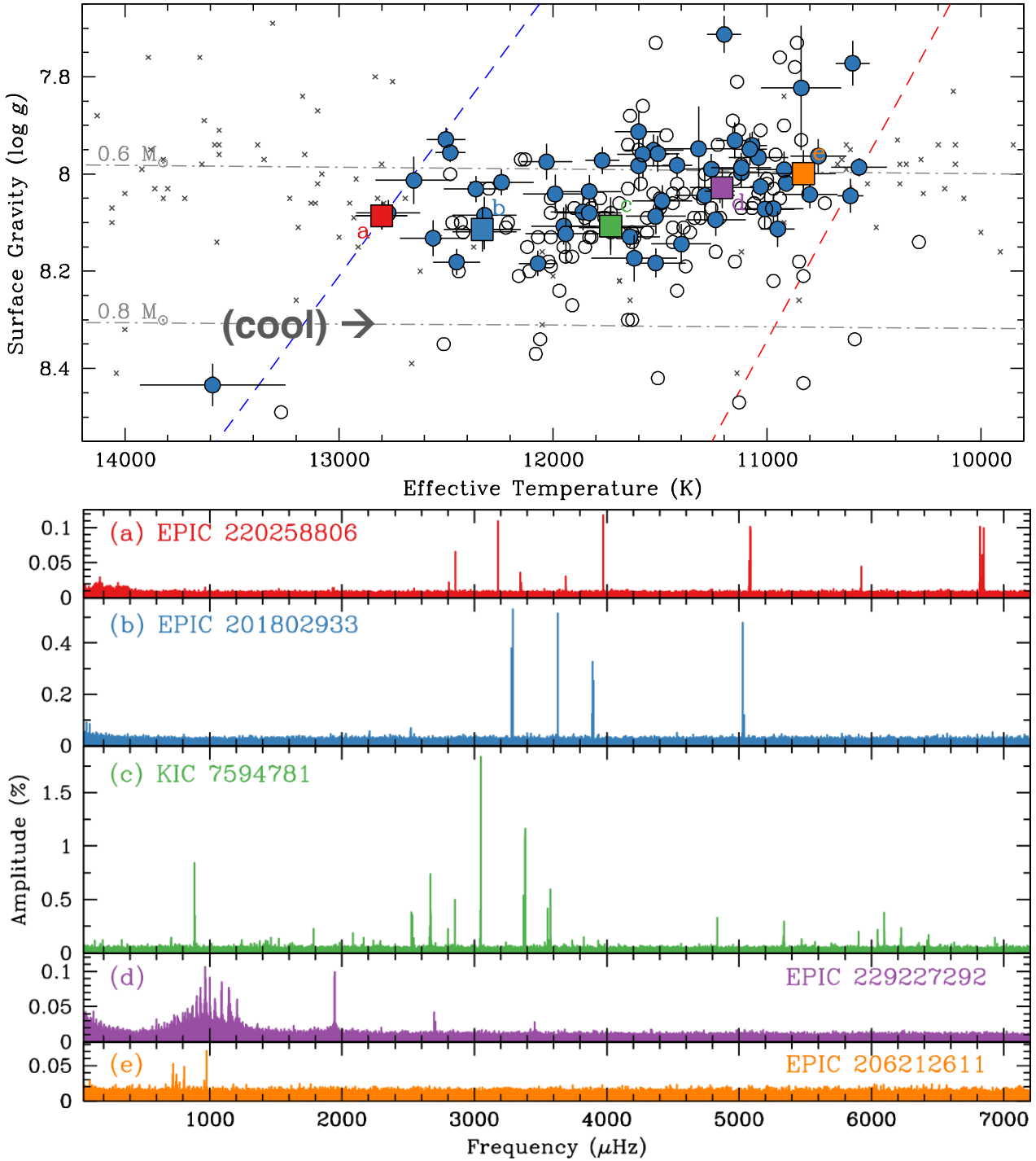
https://github.com/keatonb/sphericalharmonics



(not intended to be representative) model periods from Romero et al. 2012

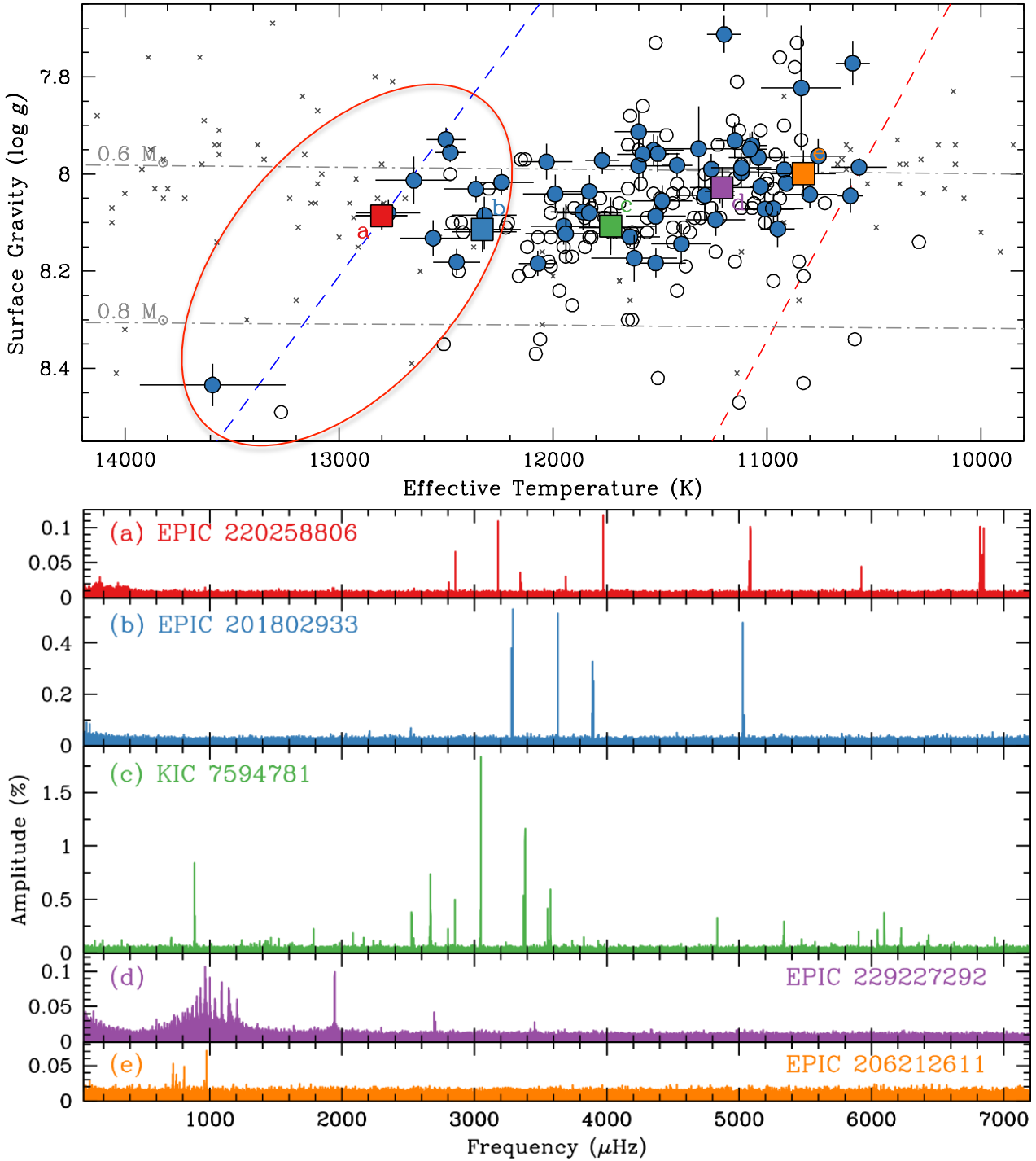
cooler WDs have longer-period pulsations

τ_{thermal} **at base of convection zone ~sets periods**



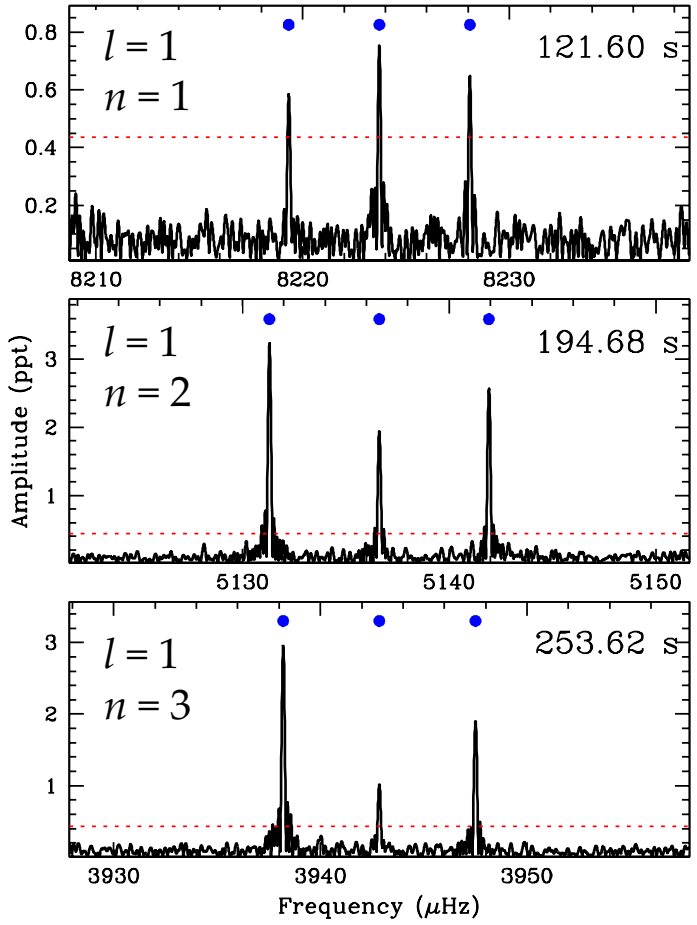
A Few Stops Along the DAV Instability Strip

1. **shortest-period modes show structural similarities (M_H)**

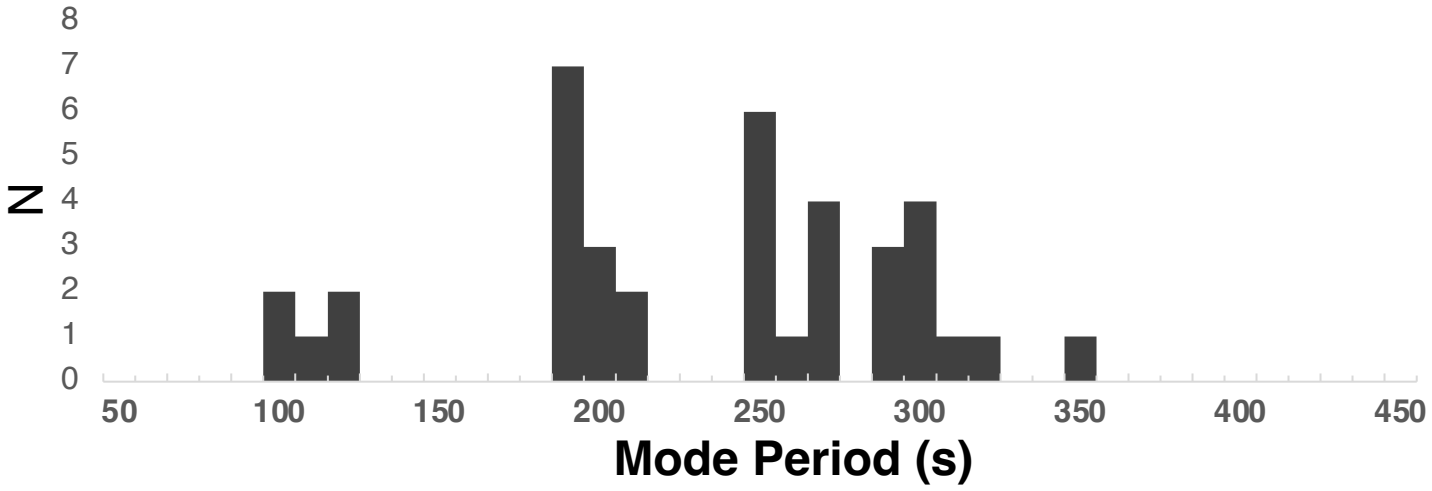


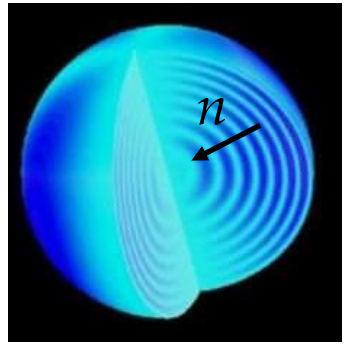
Low-Radial-Order Modes Reveal Structural Similarities

rotational splittings allow for mode identification

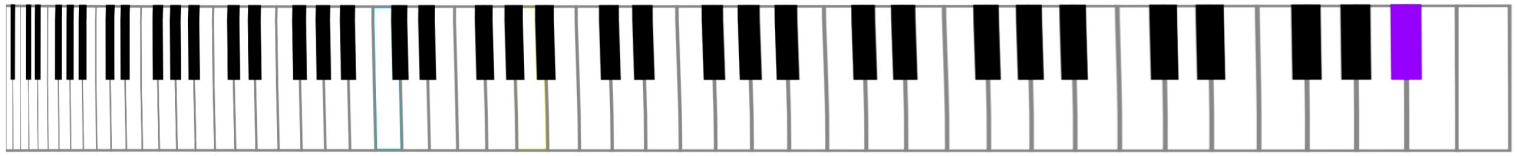


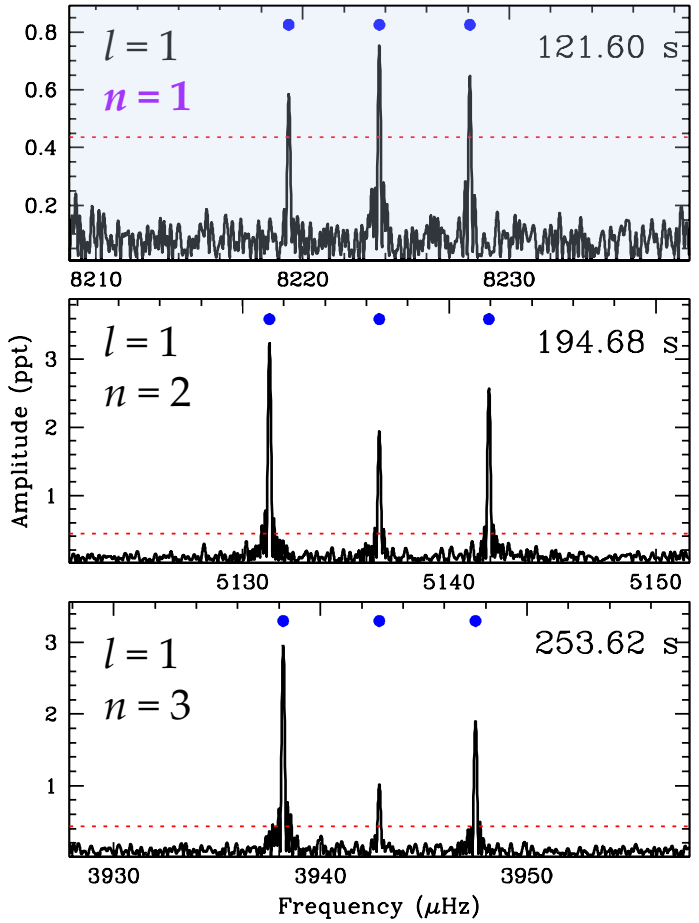
if we only plot identified l=1 modes:





Low-Radial-Order Modes Reveal Structural Similarities





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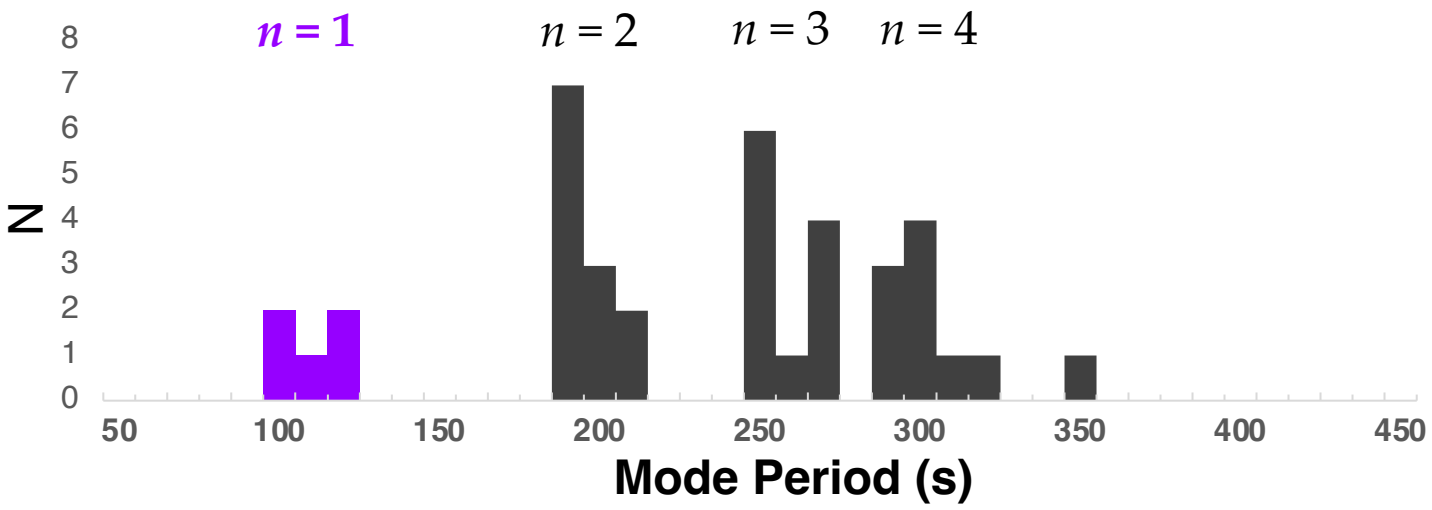
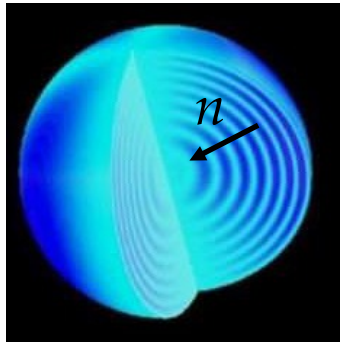
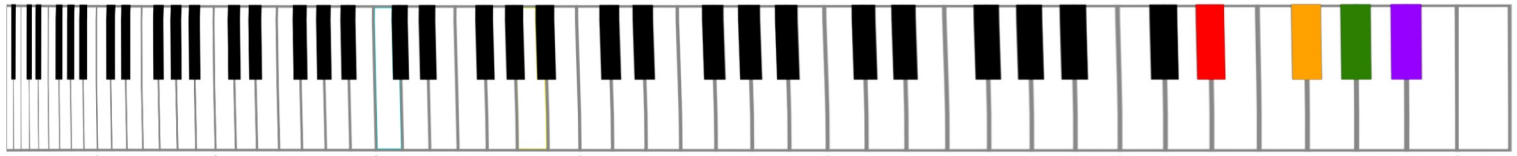
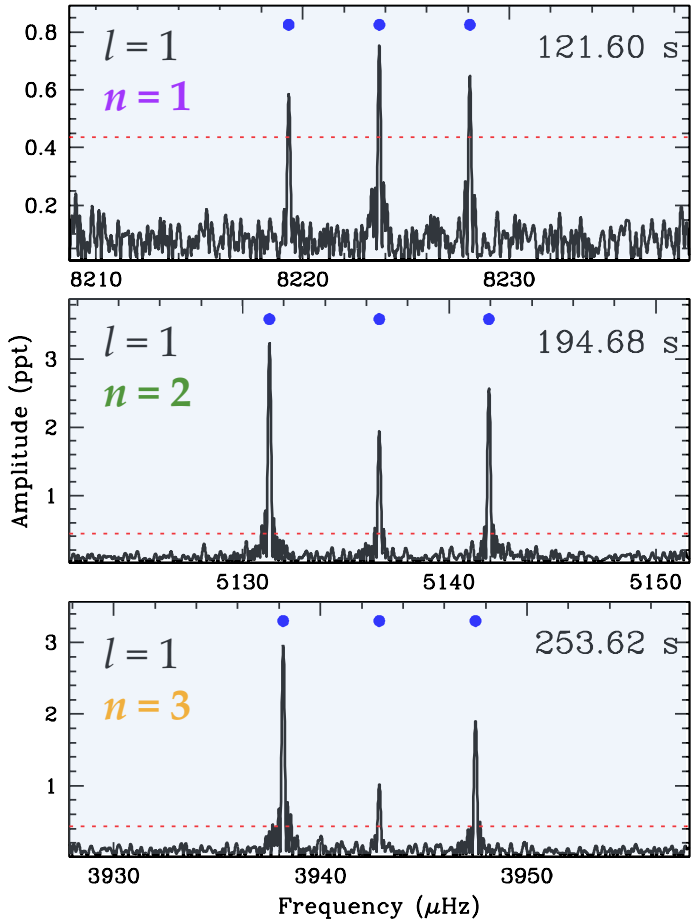




Low-Radial-Order Modes Reveal Structural Similarities





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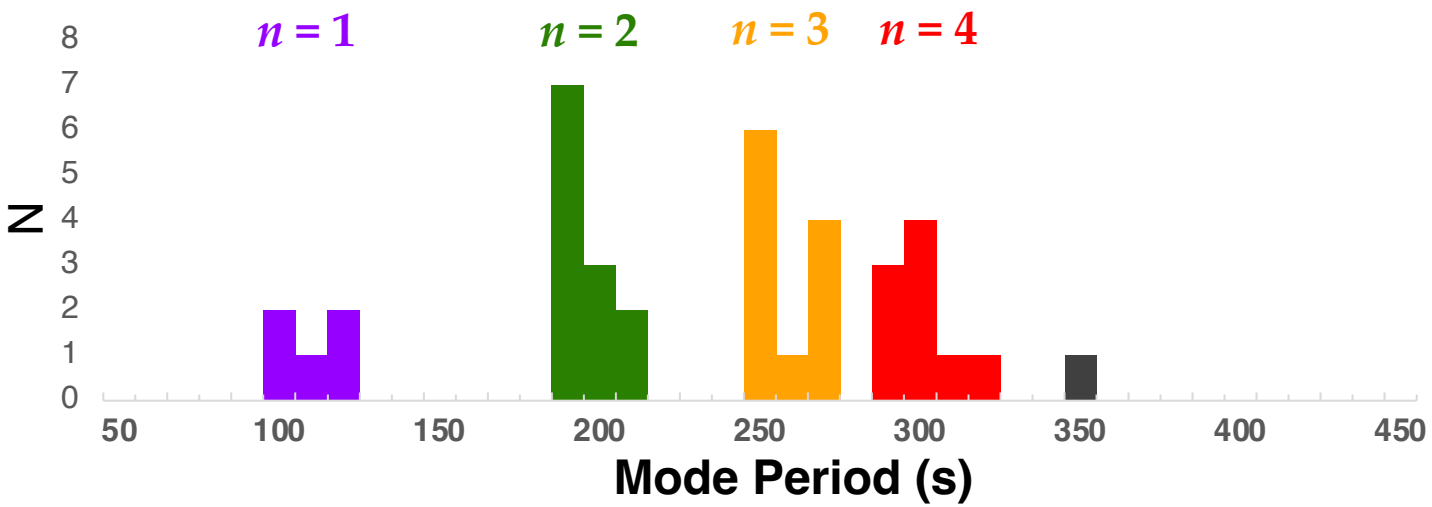
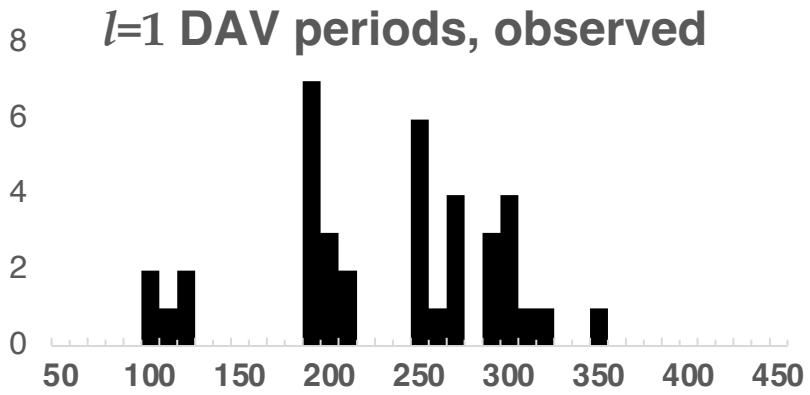
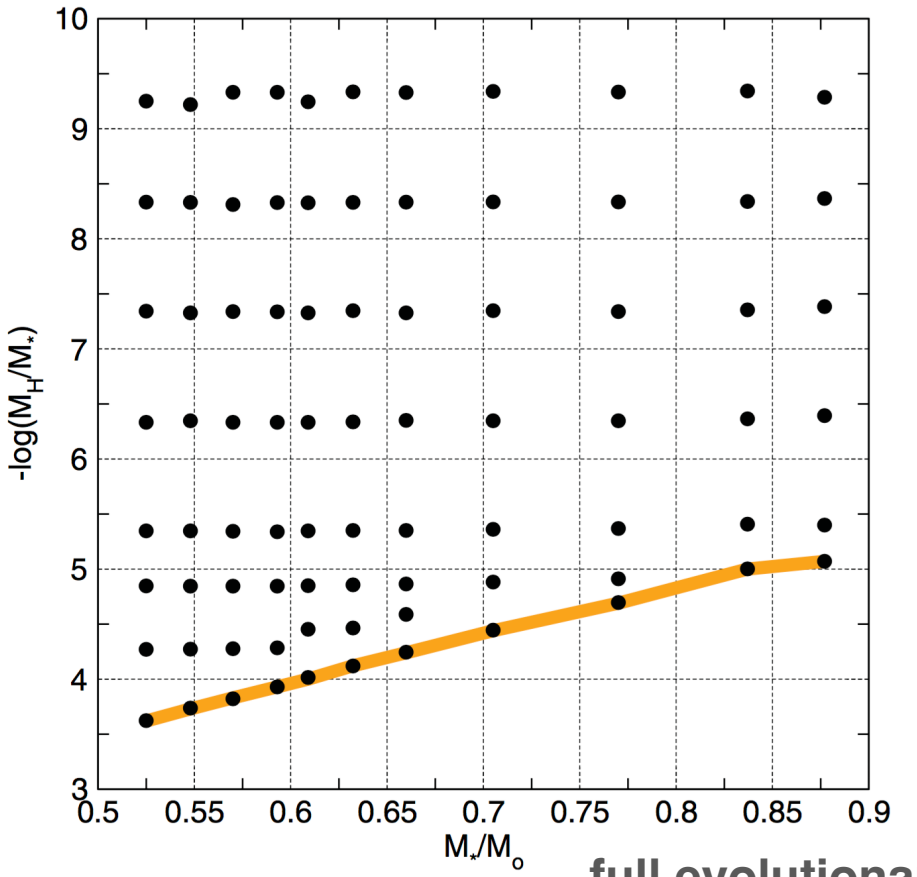


following Clemens, O'Brien, Dunlap & Hermes 2017, 20th EuroWD

Low-Radial-Order Modes Reveal Structural Similarities

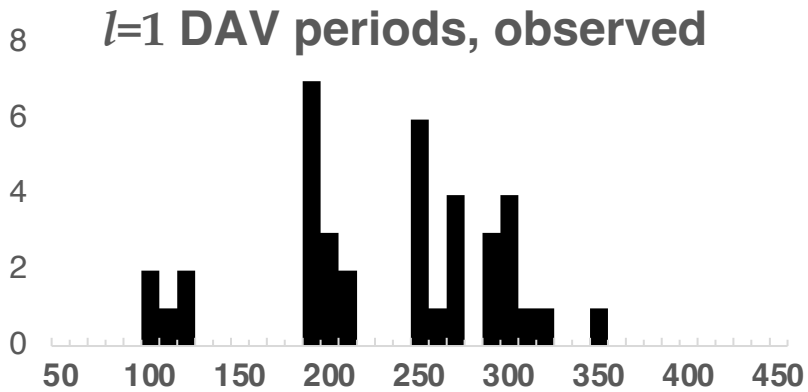


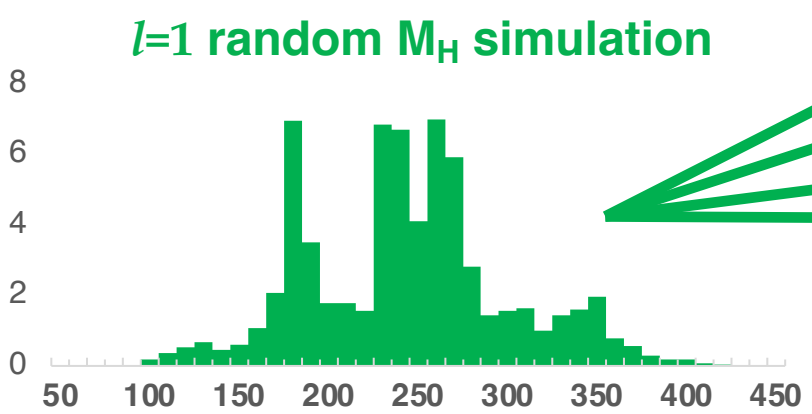


full evolutionary models computed by *Romero et al. 2012*

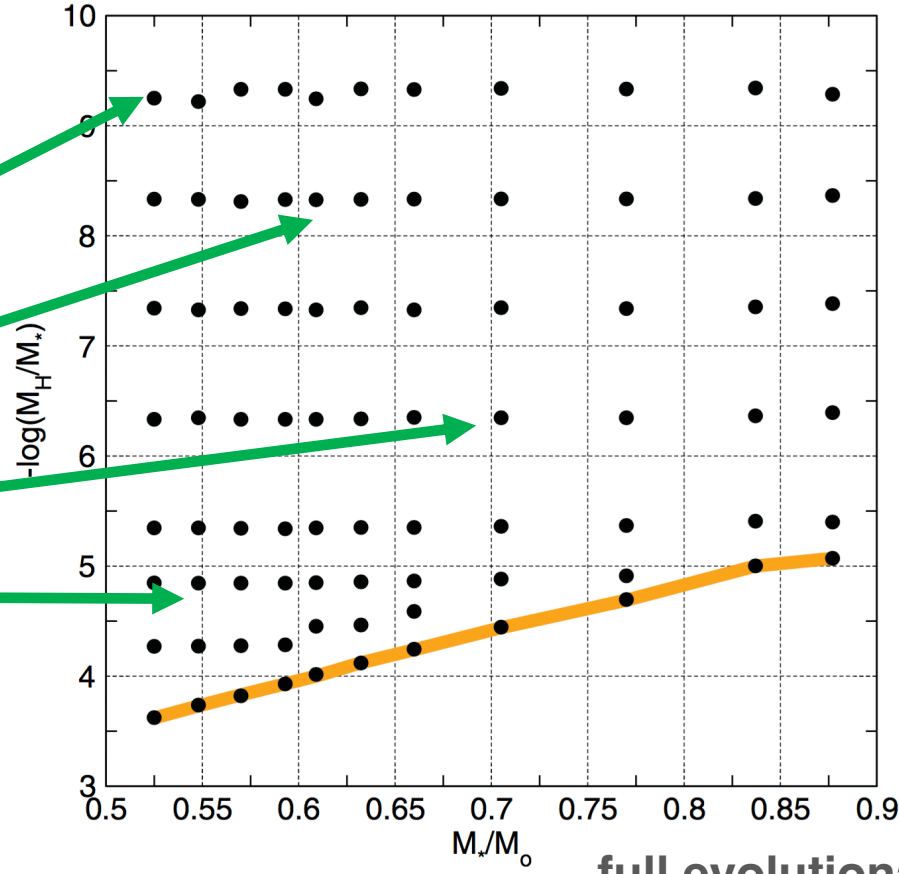
following Clemens, O'Brien, Dunlap & Hermes 2017, 20th EuroWD

Low-Radial-Order Modes Reveal Structural Similarities





drawing from a random distribution of all hydrogen layer masses



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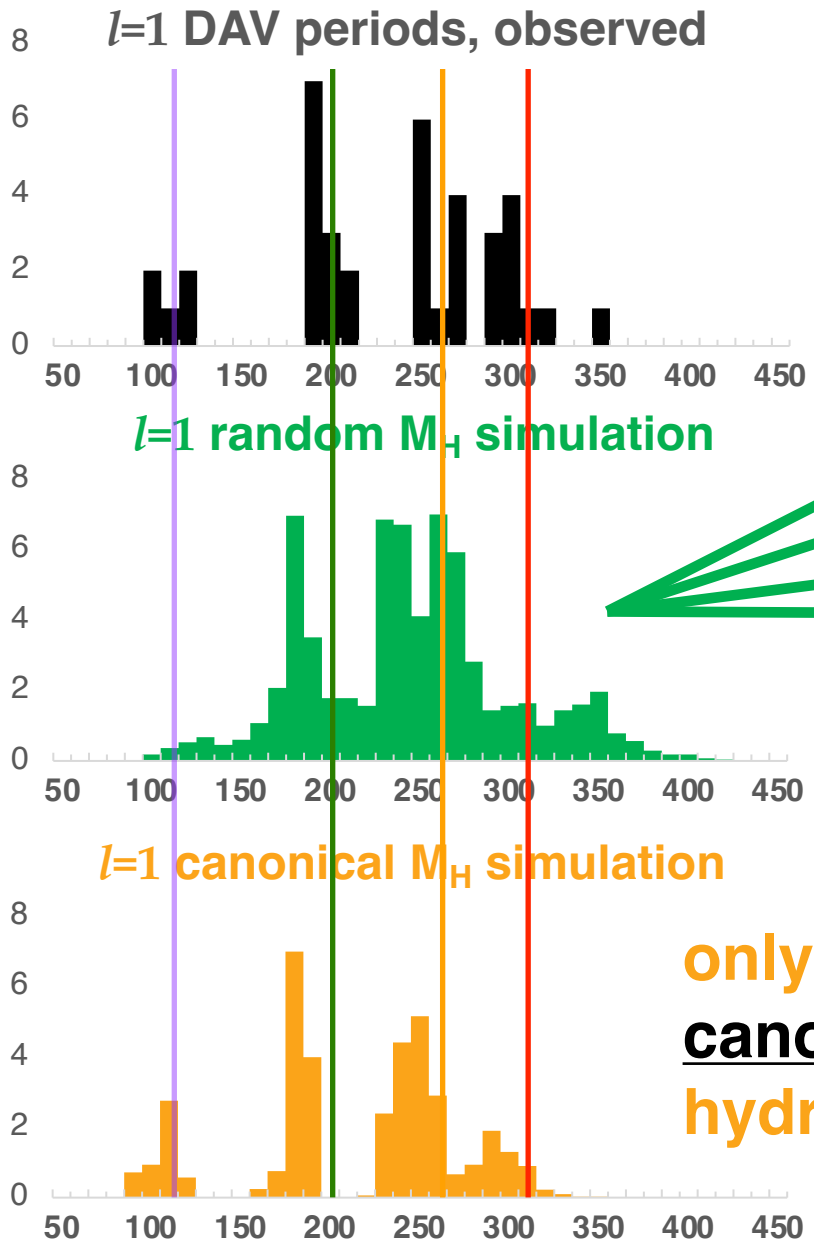
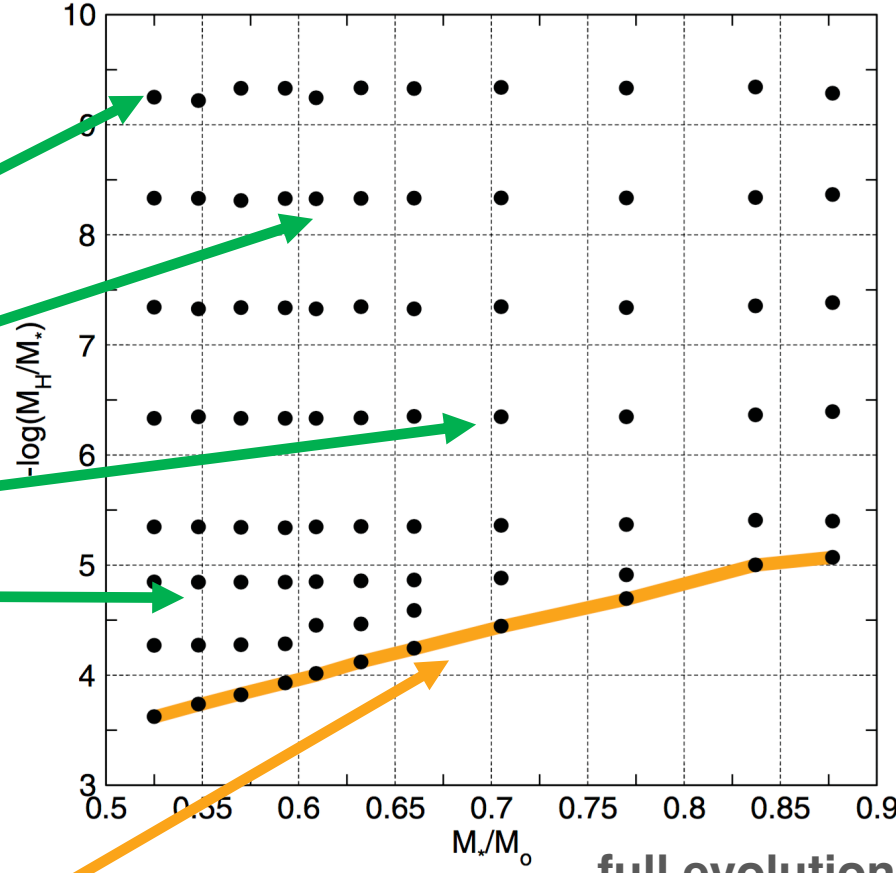
Low-Radial-Order Modes Reveal Structural Similarities





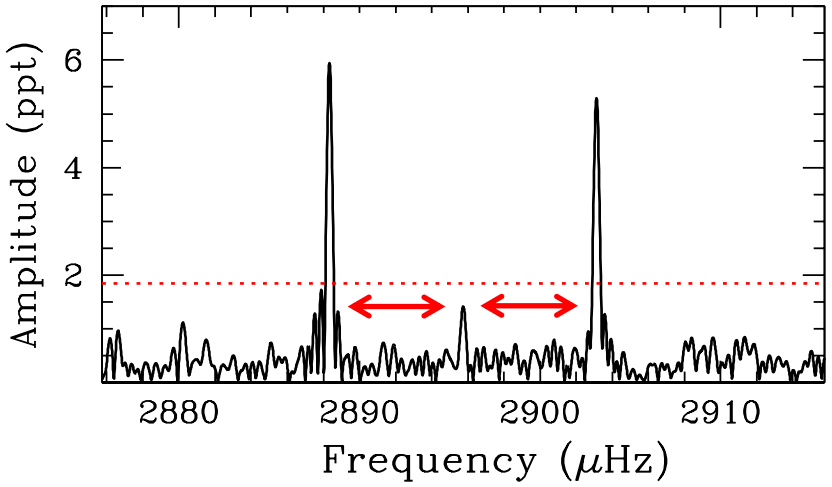
full evolutionary models computed by *Romero et al. 2012*

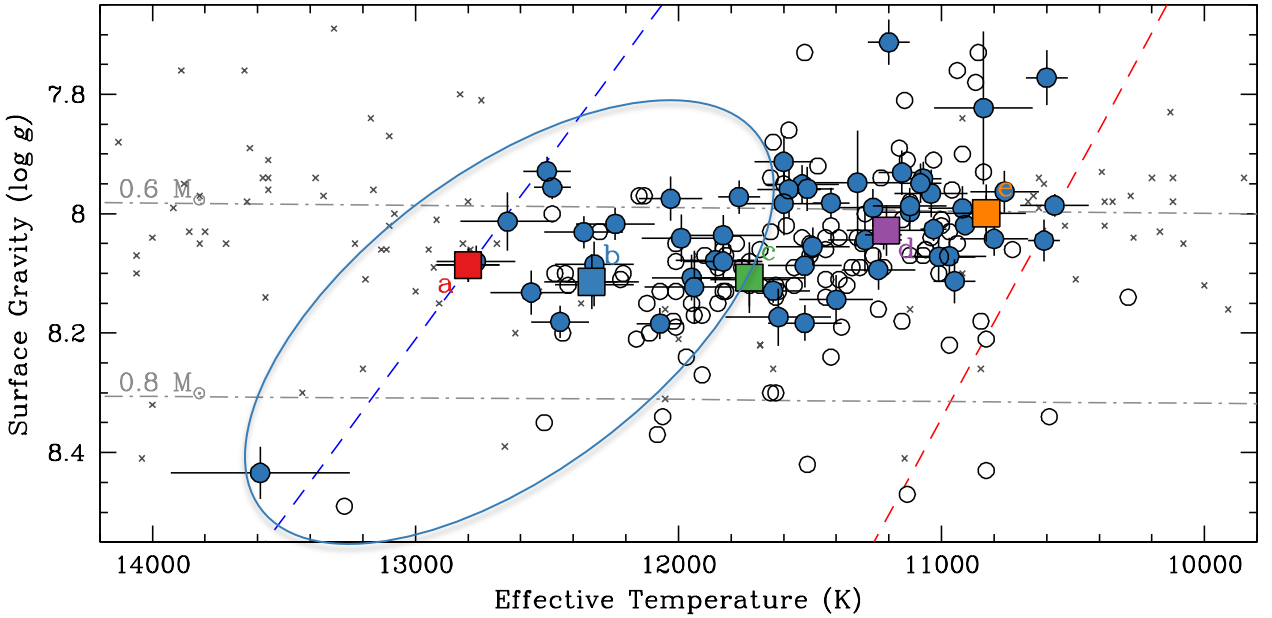
only drawing from the models with **canonically thick** (10^{-4} $M_H/M_\star$) hydrogen layers

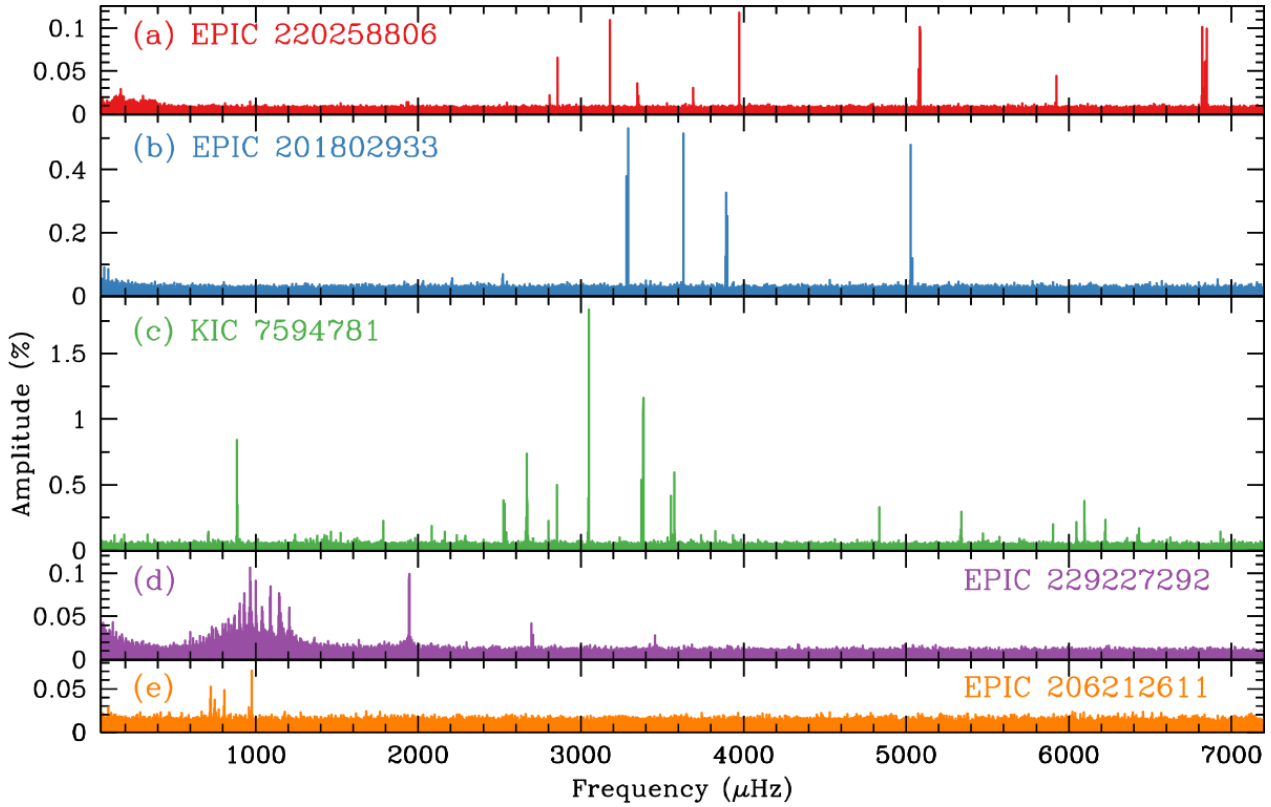
following Clemens, O'Brien, Dunlap & Hermes 2017, 20th EuroWD

A Few Stops Along the DAV Instability Strip

1. **shortest-period modes show structural similarities (M_H)**
2. **stable modes reveal 1-2 day rotation rates**

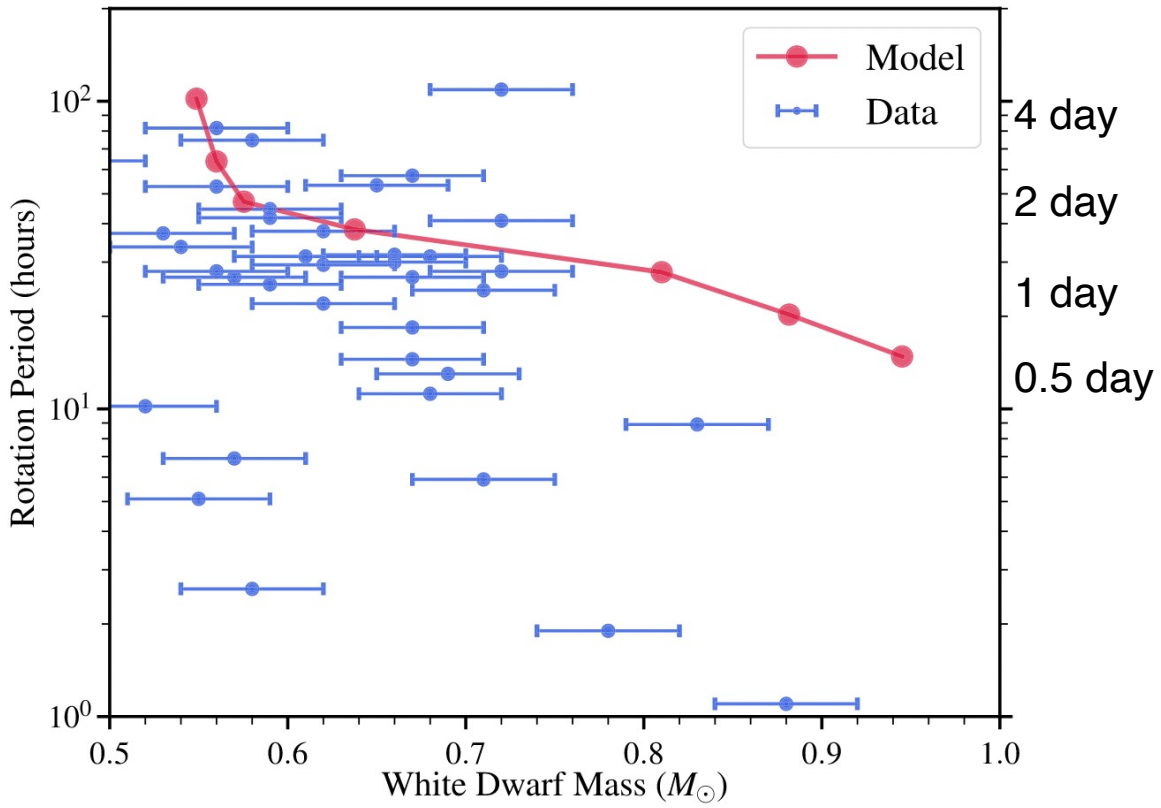


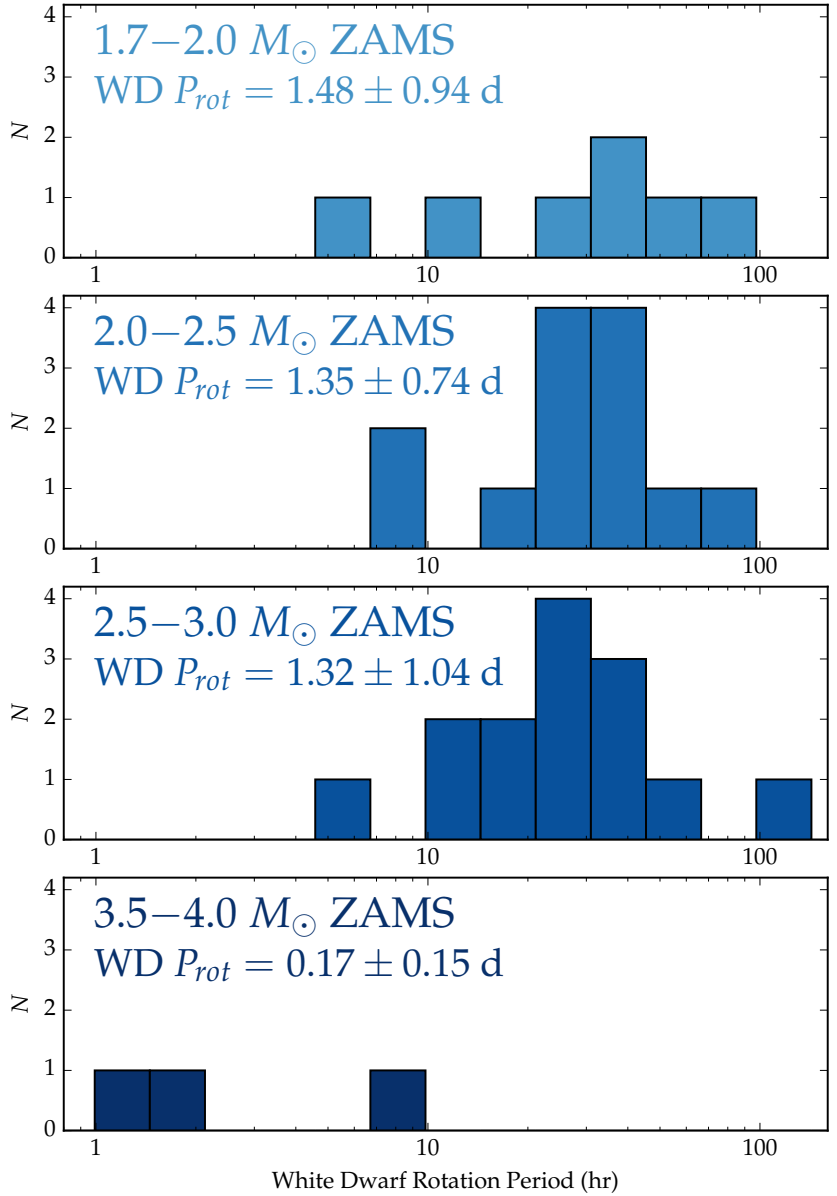




Most WDs Rotate Between 0.5-2.2 Days

WDs rotate slowly, having lost most internal angular momentum as red giants



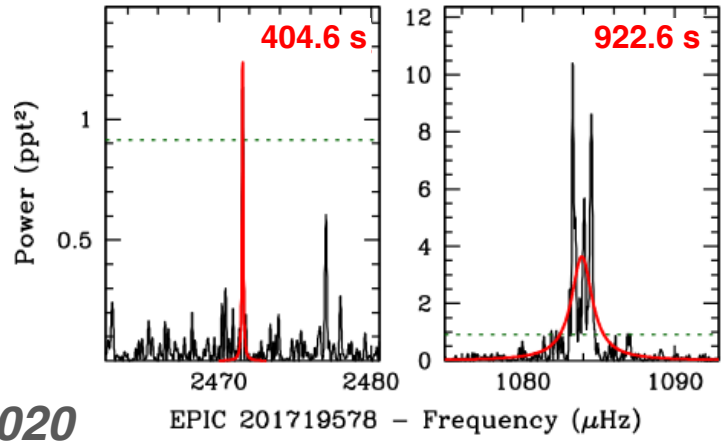


Fuller, Piro & Jermyn 2019: modified Tayler-Spruit dynamo

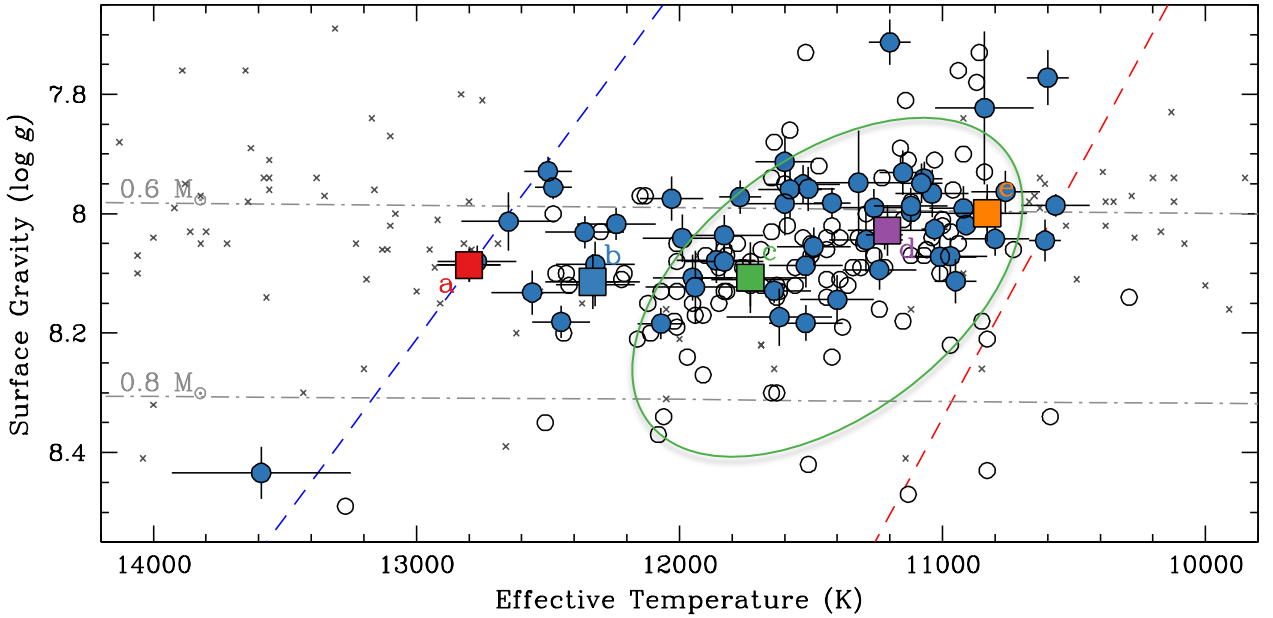
Hermes et al. 2017, ApJS

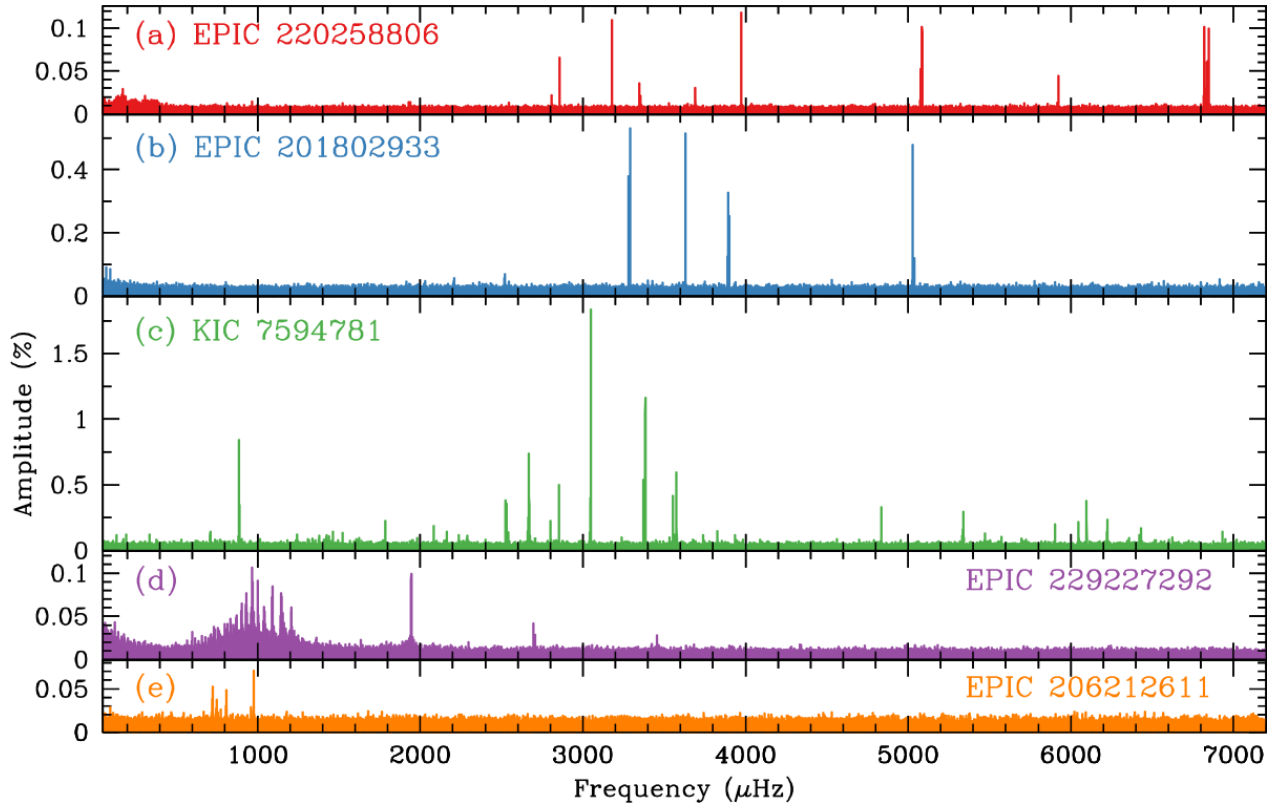
A Few Stops Along the DAV Instability Strip

1. **shortest-period modes show structural similarities (M_H)**
2. **stable modes reveal 1-2 day rotation rates**
3. **modes > 800 s feel effects of changing convection zone**



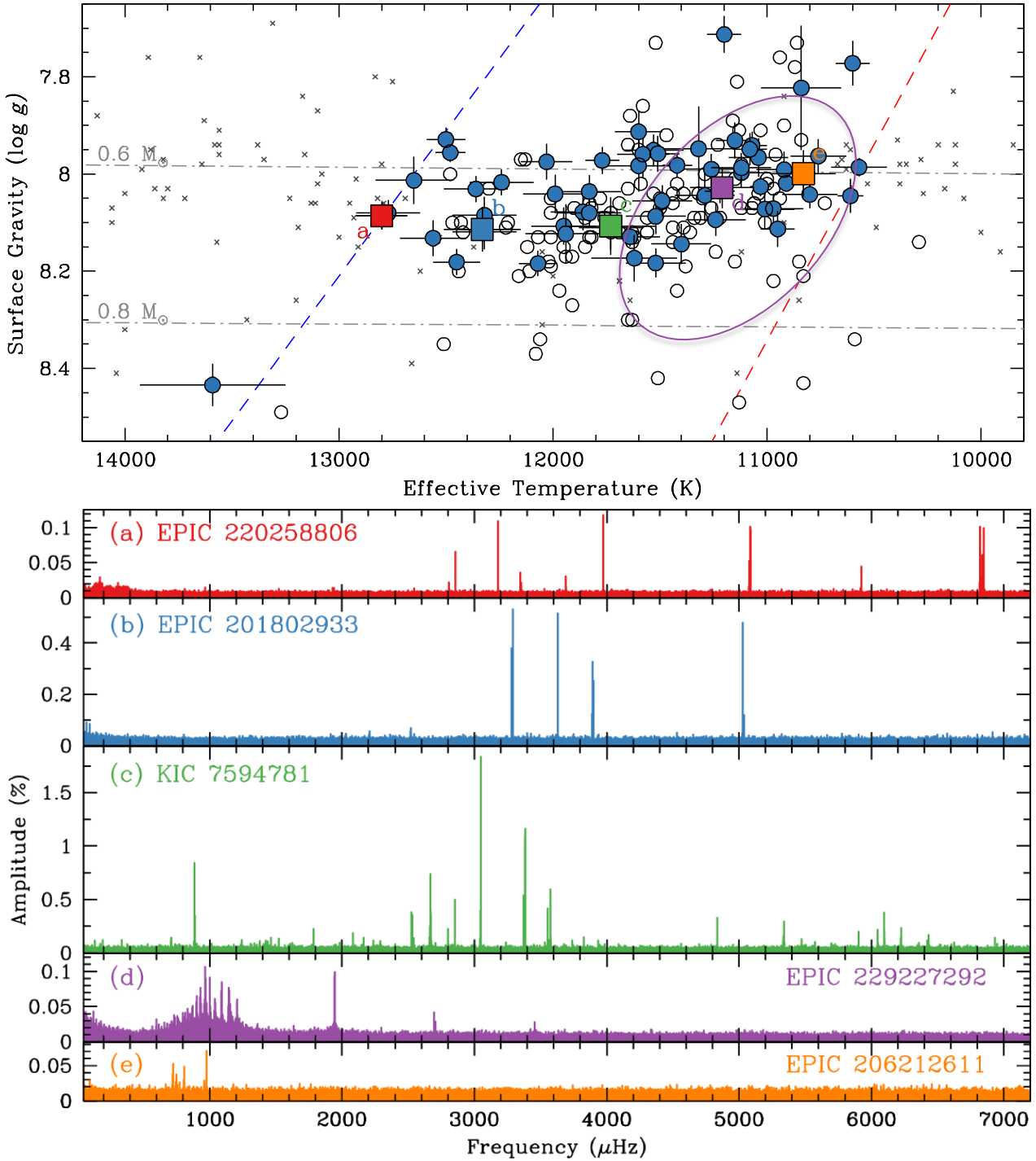
see Montgomery et al. 2020



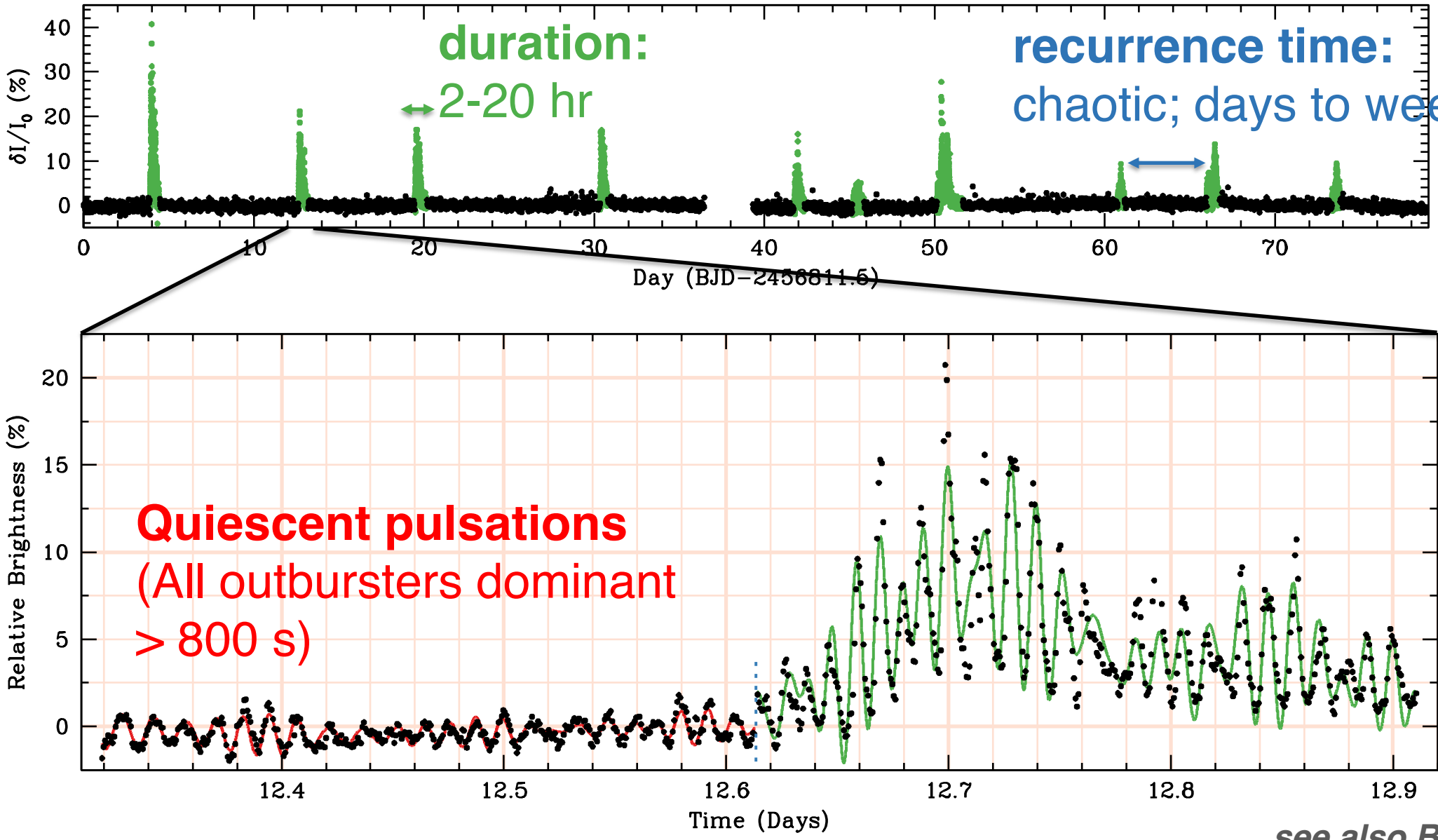


A Few Stops Along the DAV Instability Strip

1. **shortest-period modes show structural similarities (M_H)**
2. **stable modes reveal 1-2 day rotation rates**
3. **modes > 800 s feel effects of changing convection zone**
4. **mode coupling leads to dramatic outbursts**



The Coolest Pulsating WDs Show Stochastic Outbursts

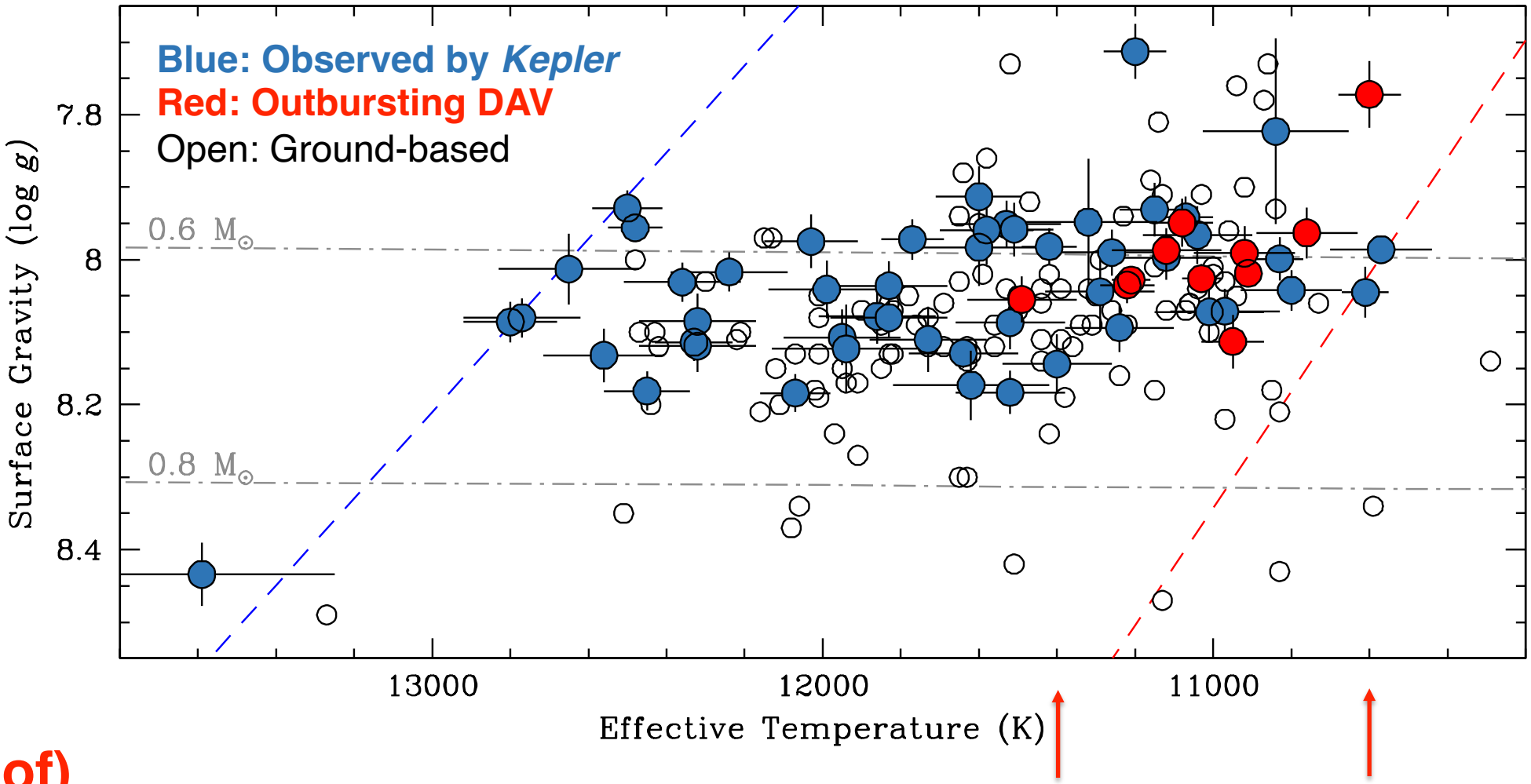


excess energy: $10^{33\text{-}34}$ erg

15% flux increase: 700 K T_{eff} increase

PG 1149+057: Hermes et al. 2015
see also Bell et al. 2015, 2016

The Coolest Pulsating WDs Show Stochastic Outbursts



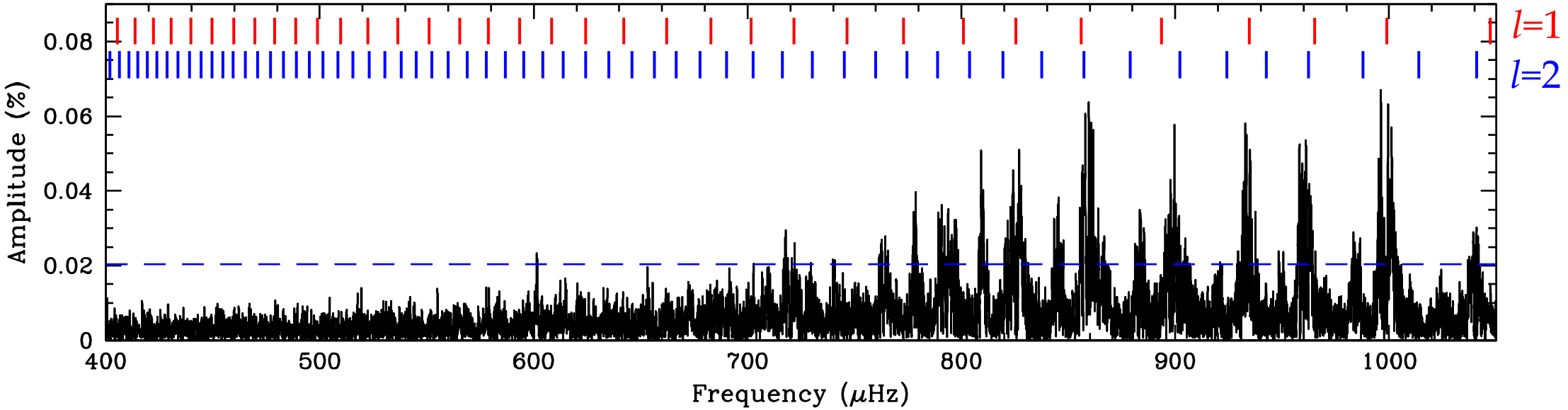
16/71 (>20% of) DAVs with Kepler data show outbursts

more than 50% of DAVs from 11,200-10,600 K show **outbursts** in ~70 days of *K2* monitoring

Outbursts Arise from Nonlinear Resonances in the Star

rapid transfer of energy via parametric resonance to damped modes that break near the surface of the star

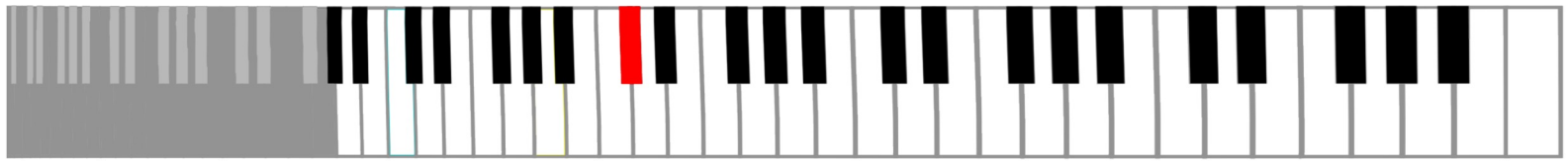
see Luan & Goldreich 2018



model: 11,245 K, 0.632 $M_\odot$, $10^{-4.12}$ M_H/M_{WD} *(Romero et al. 2012)*
observed: 11,060(170) K, 0.64(0.03) $M_\odot$ *(Gianninas et al. 2011)*

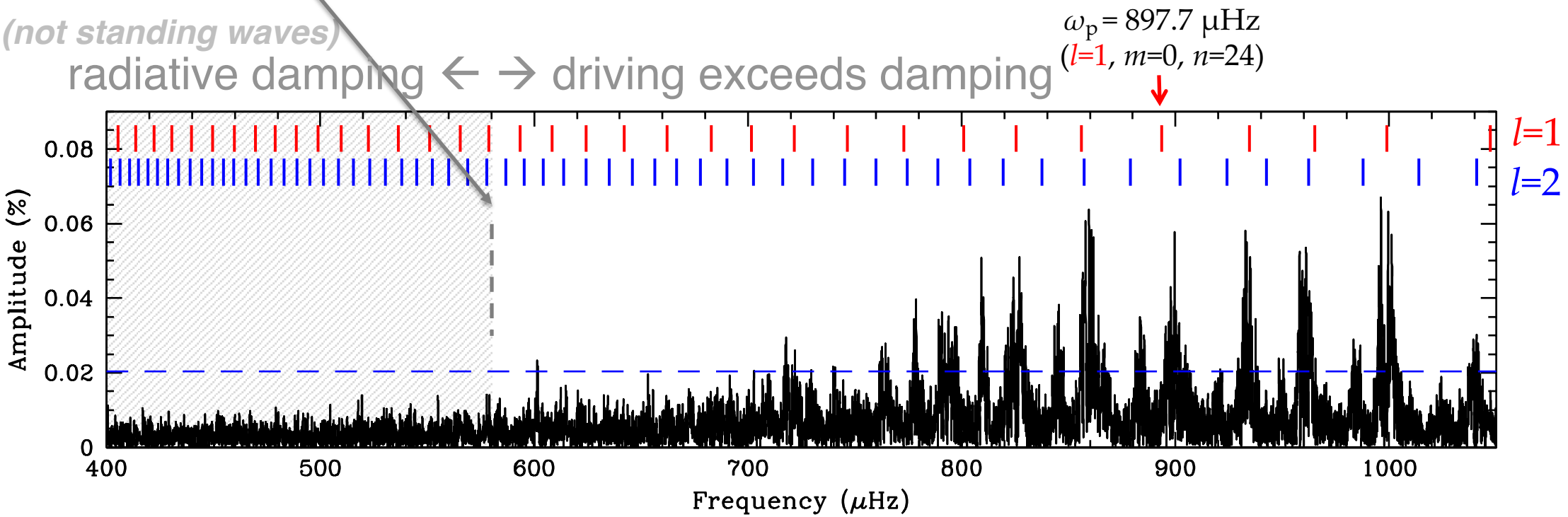
as a representative example: PG 1149+057

Outbursts Arise from Nonlinear Resonances in the Star



(not standing waves)

radiative damping ← → driving exceeds damping



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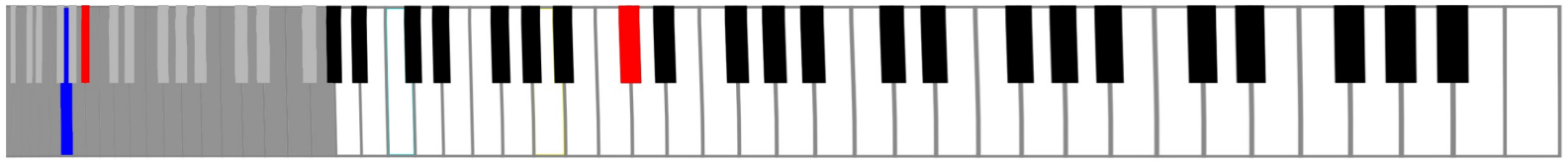


$$\omega_{d1} + \omega_{d2} = \omega_p + \delta\omega$$

limit cycle if: $\delta\omega < \gamma_d$

(typical $1/\gamma_d$ **< 1 day)**

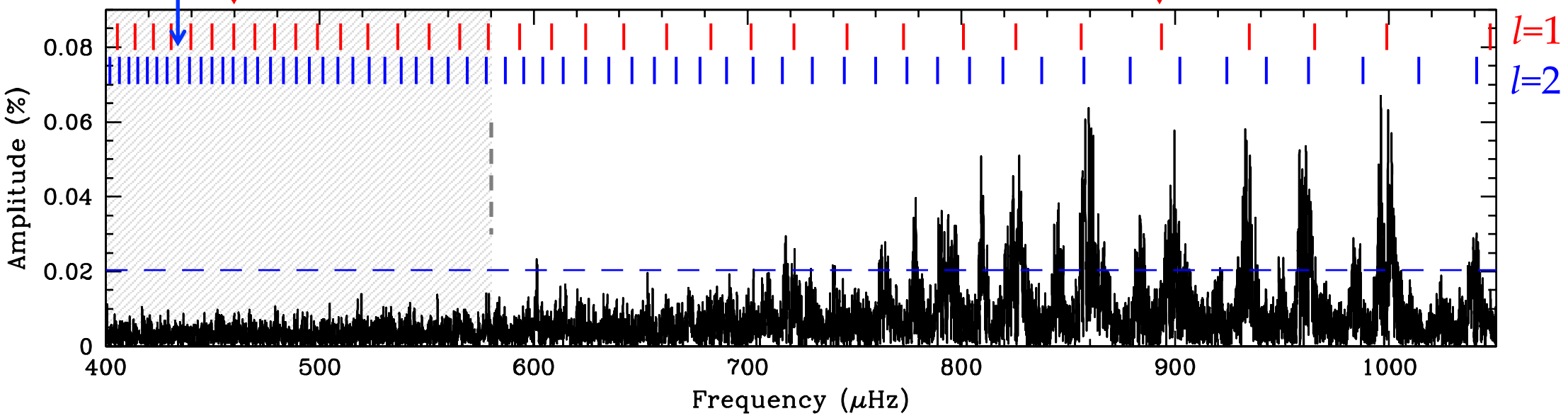
Wu & Goldreich 2001

ω_{d1} = 435.9 μHz (l=2, m=0, n=88)

ω_{d2} = 461.9 μHz (l=1, m=0, n=48)

[435.9 + 461.9 = 897.7 + 0.1 μHz]

ω_p = 897.7 μHz (l=1, m=0, n=24)



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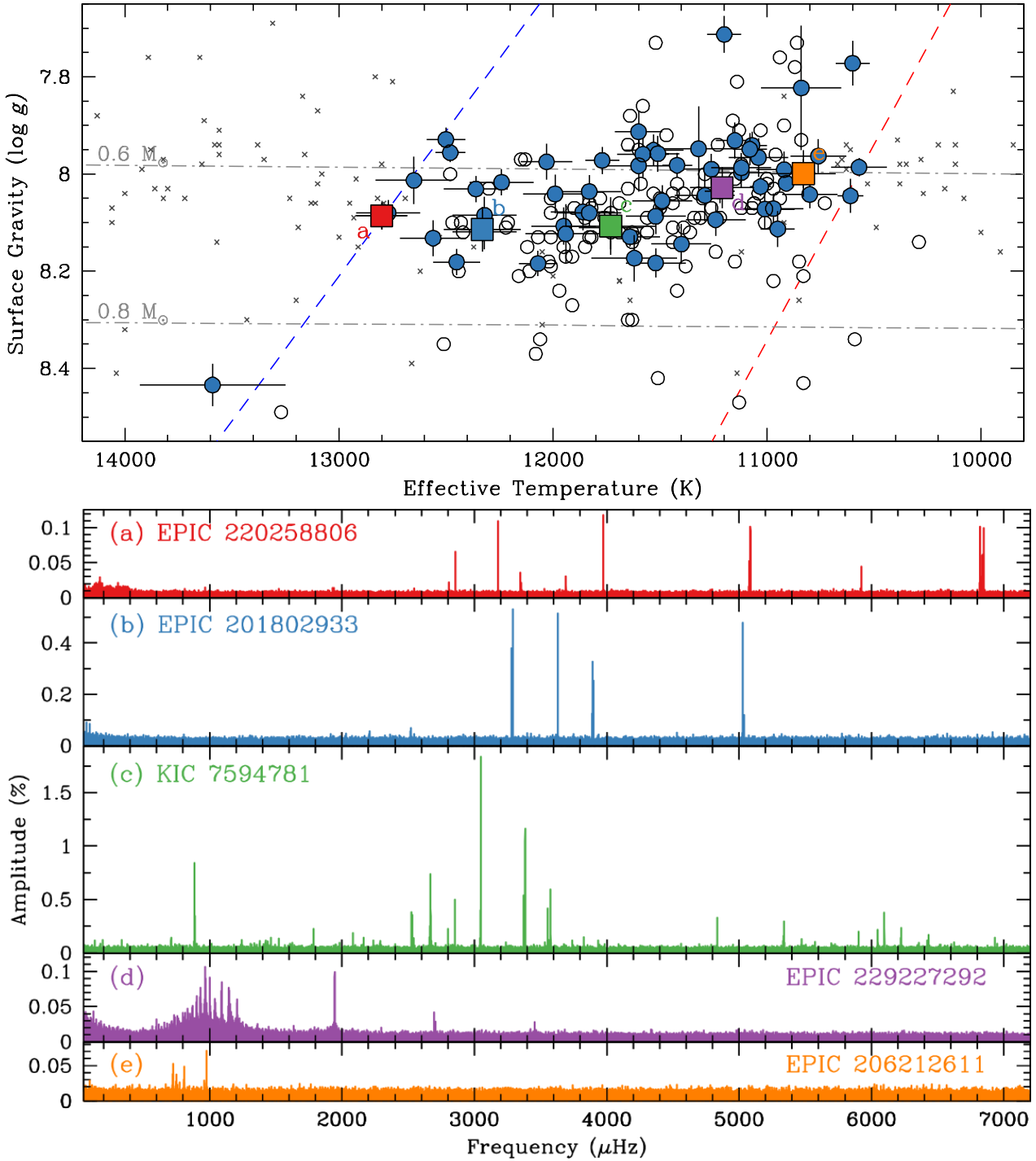
as a representative example: PG 1149+057

Conclusions from a Quick Tour of the DAVs

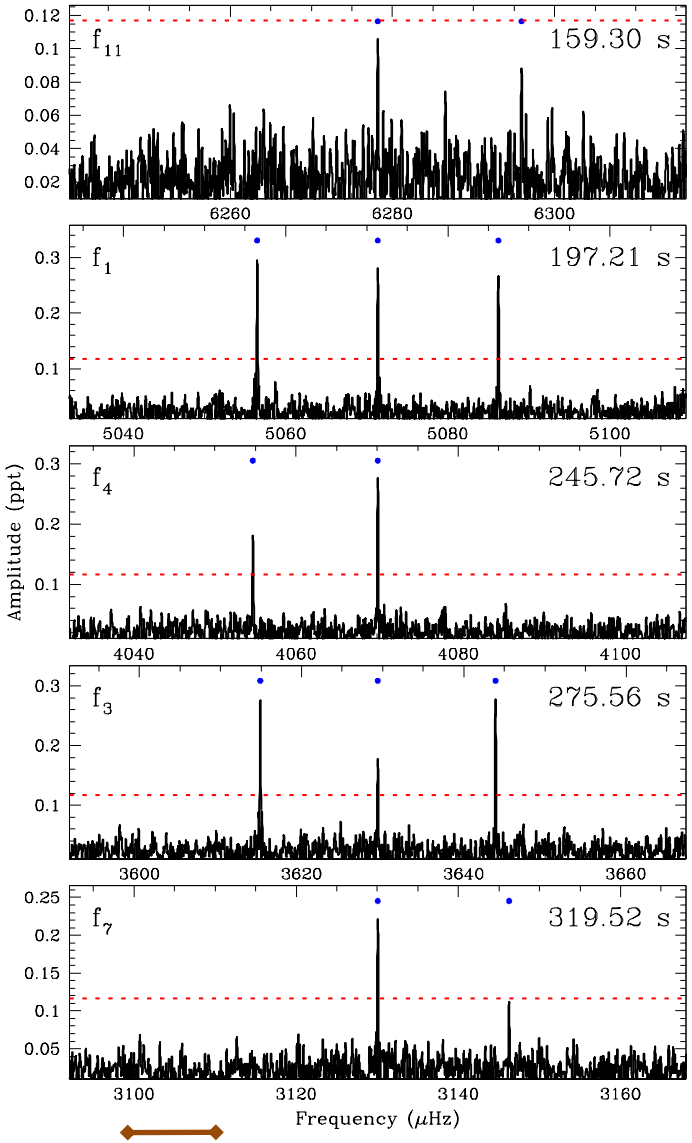
1. **shortest-period modes show structural similarities (M_H)**
2. **stable modes reveal 1-2 day rotation rates**
3. **modes > 800 s feel effects of changing convection zone**
4. **mode coupling leads to dramatic outbursts**
5. **amplitudes die off strongly at 10,500 K**

Hermes et al. 2017, ApJS



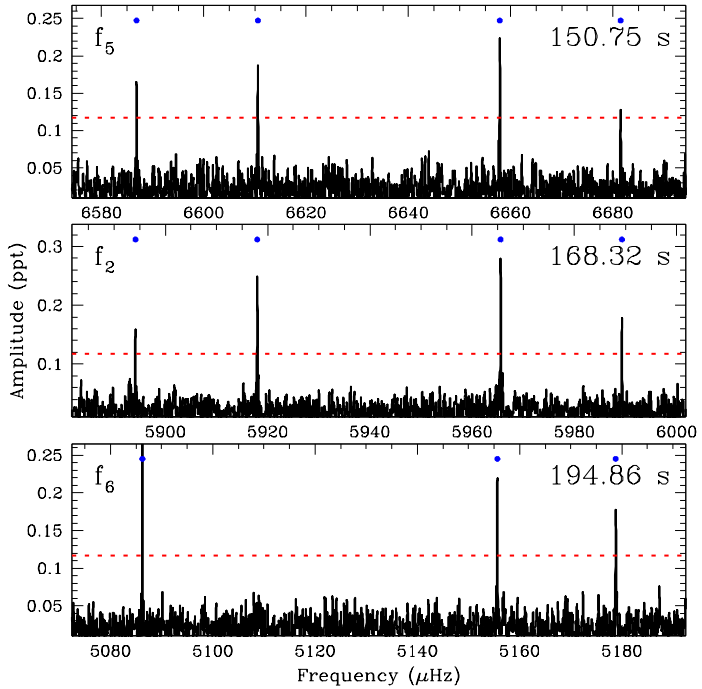
Extra Slides

l=1 modes



Size of 1 day alias

l=2 modes



Both *l=1* and *l=2* modes suggest a model-independent **rotation period** of 10.1±0.9 hr

PG 0112+104: *Hermes et al. 2017, MNRAS*

The Coolest Pulsating WDs Show Stochastic Outbursts