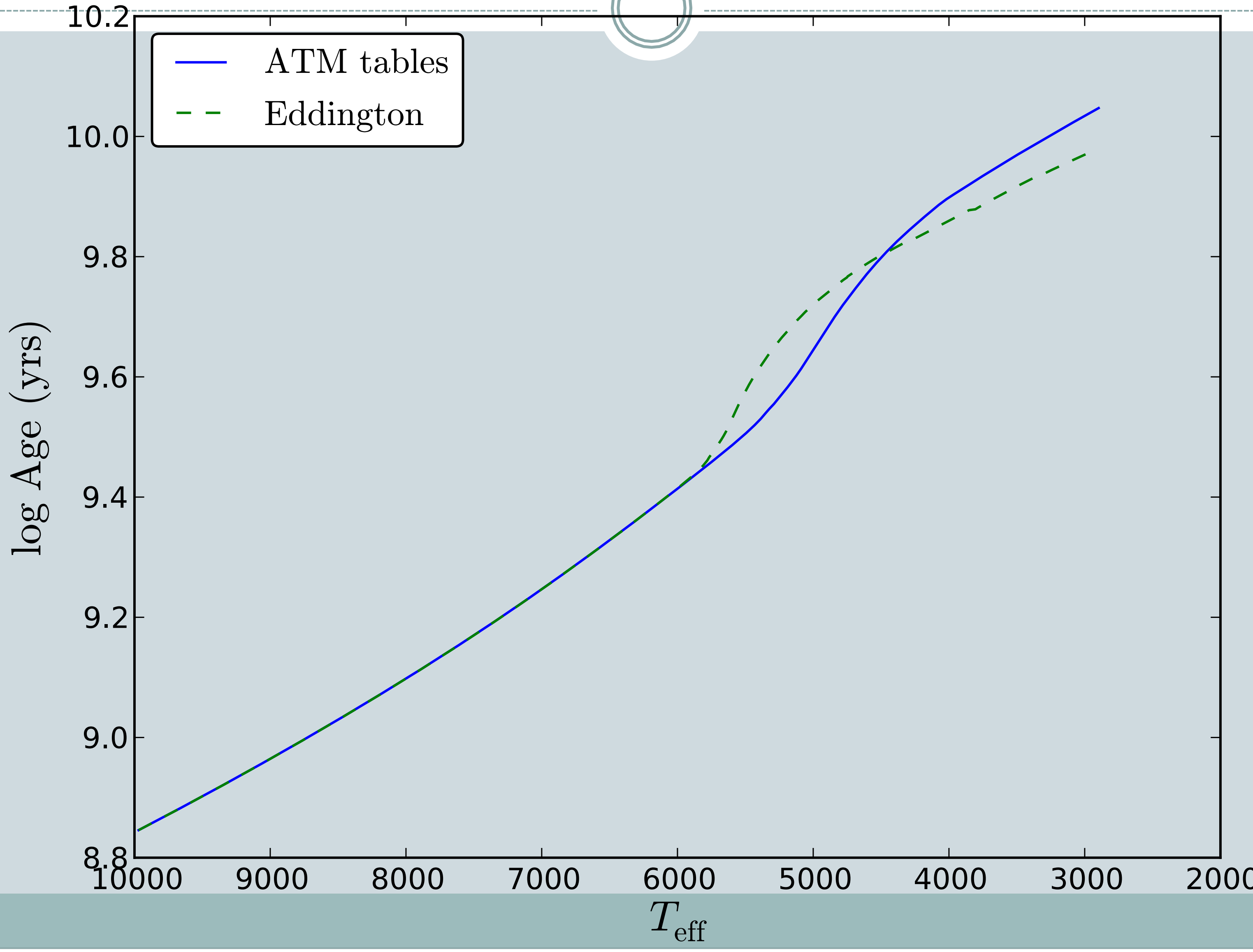
Review of Long Problem Results



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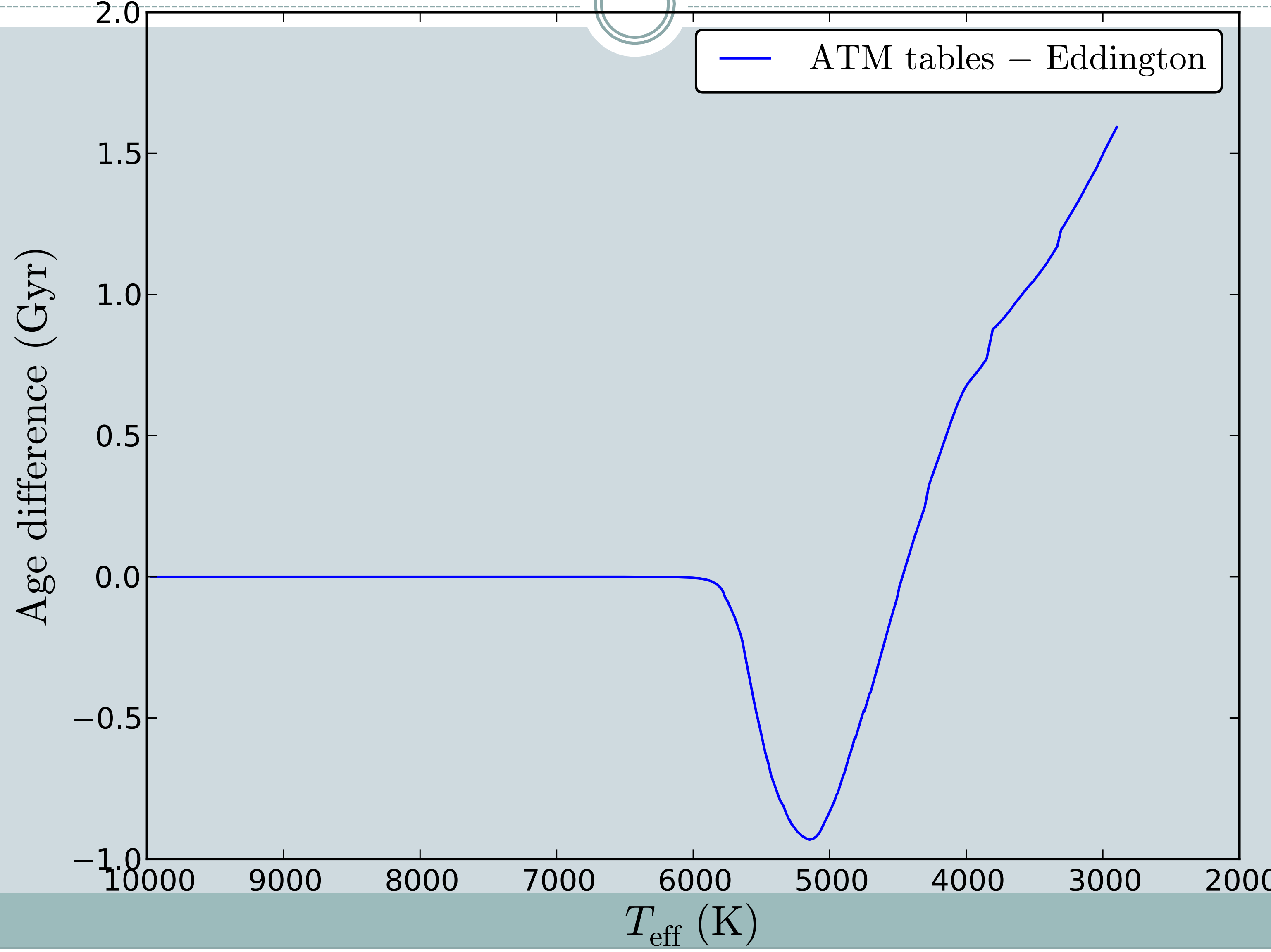

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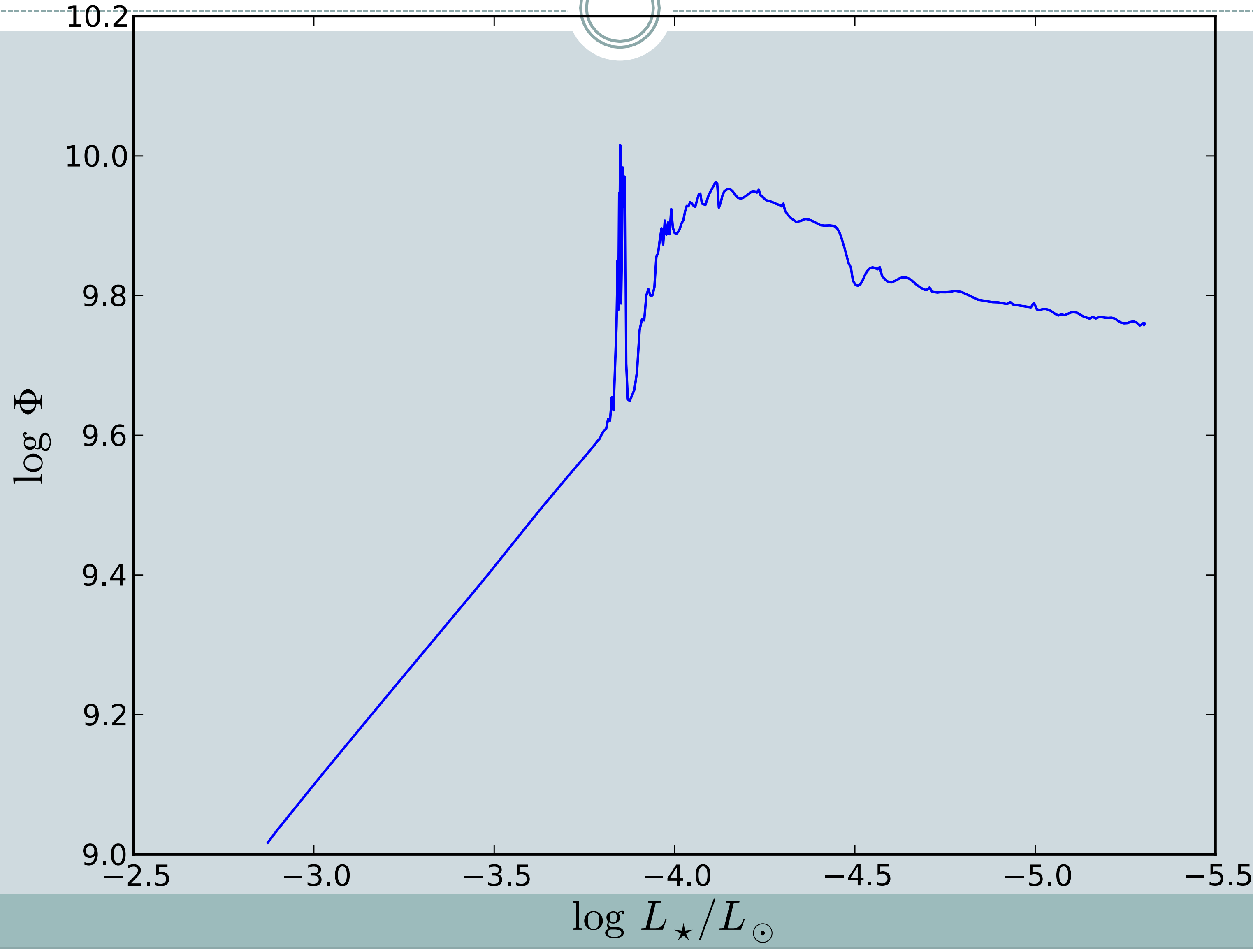

Review of Long Problem Results

- List of additional models people were able to run:

Input Model	Final Teff	Diffusion
0.150_from_1.5_z2m2.mod	0	N
0.200_from_1.5_z2m2.mod	0	N
0.300_from_1.5_z2m2.mod	0	N
0.350_from_1.5_z2m2.mod	0	N
0.400_from_1.5_z2m2.mod	0	N
0.496_from_0.8_z2m2.mod	0	N
0.513_from_0.9_z2m2.mod	0	N
0.522_from_1.0_z2m2.mod	0	N
0.544_from_1.3_z2m2.mod	0	N
0.567_from_2.0_z2m2.mod	0	N
0.604_from_2.3_z2m2.mod	0	N

Review of Long Problem Results

- List of additional models people were able to run:

Input Model	Teff	Diffusion
0.611_from_2.5_z2m2.mod	0	N
0.639_from_3.0_z2m2.mod	0	N
0.734_from_3.5_z2m2.mod	0	N
0.819_from_4.0_z2m2.mod	0	N
0.856_from_5.0_z2m2.mod	0	N
0.927_from_6.0_z2m2.mod	0	N
1.025_from_7.0_z2m2.mod	0	N
1.259_from_8.0_z2m2.mod	0	N
1.316_from_8.5_z2m2.mod	0	N
1.376_from_8.7_z2m2.mod	0	N

The Evolution and Pulsation of White Dwarf Stars II: Extremely Low Mass WD Pulsators

MIKE MONTGOMERY, DON WINGET, **JJ HERMES**,
ROSS FALCON, SAMUEL HARROLD, KEATON BELL

AUGUST 17, 2012

Location of files for talk and problems

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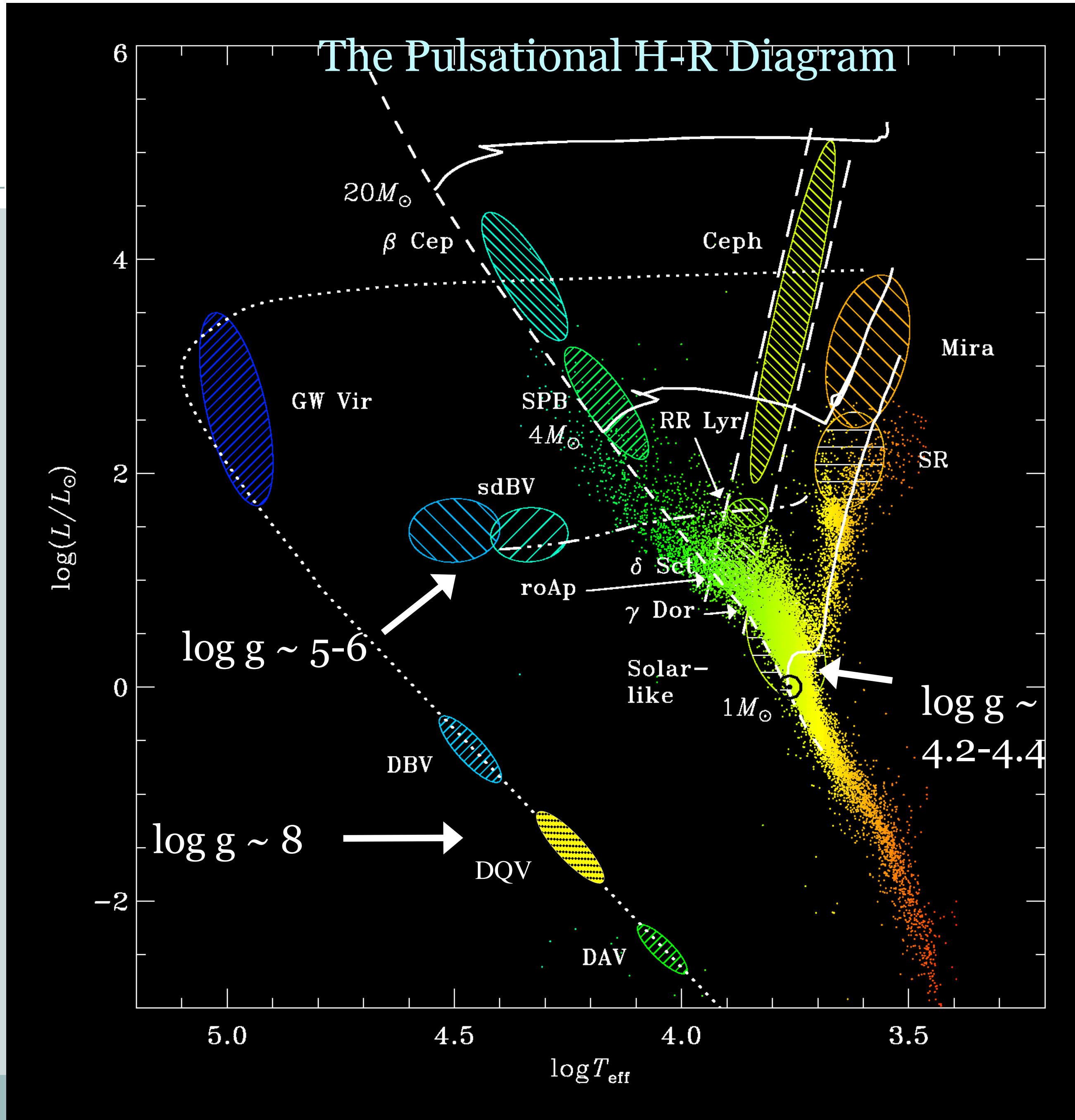
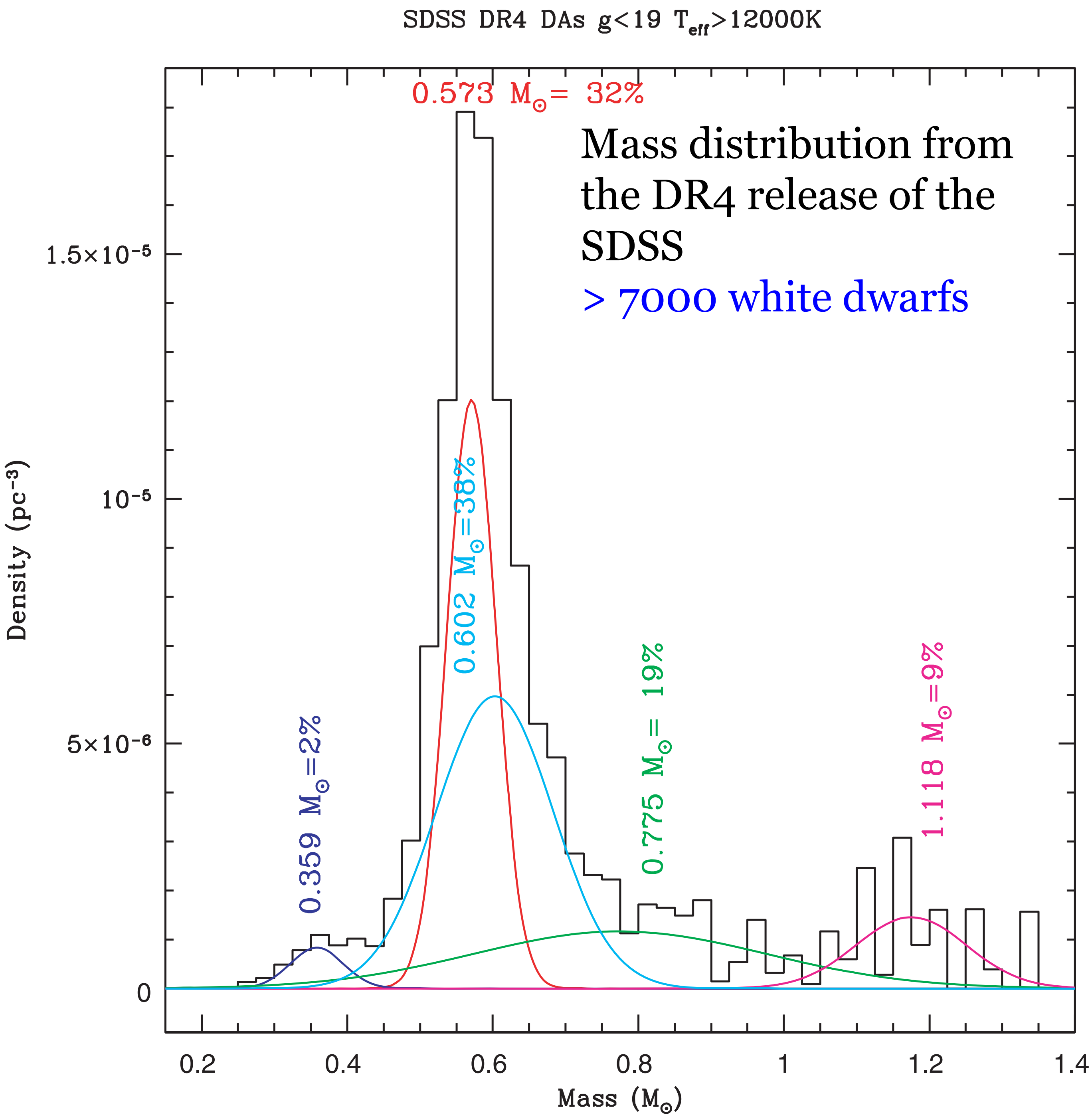
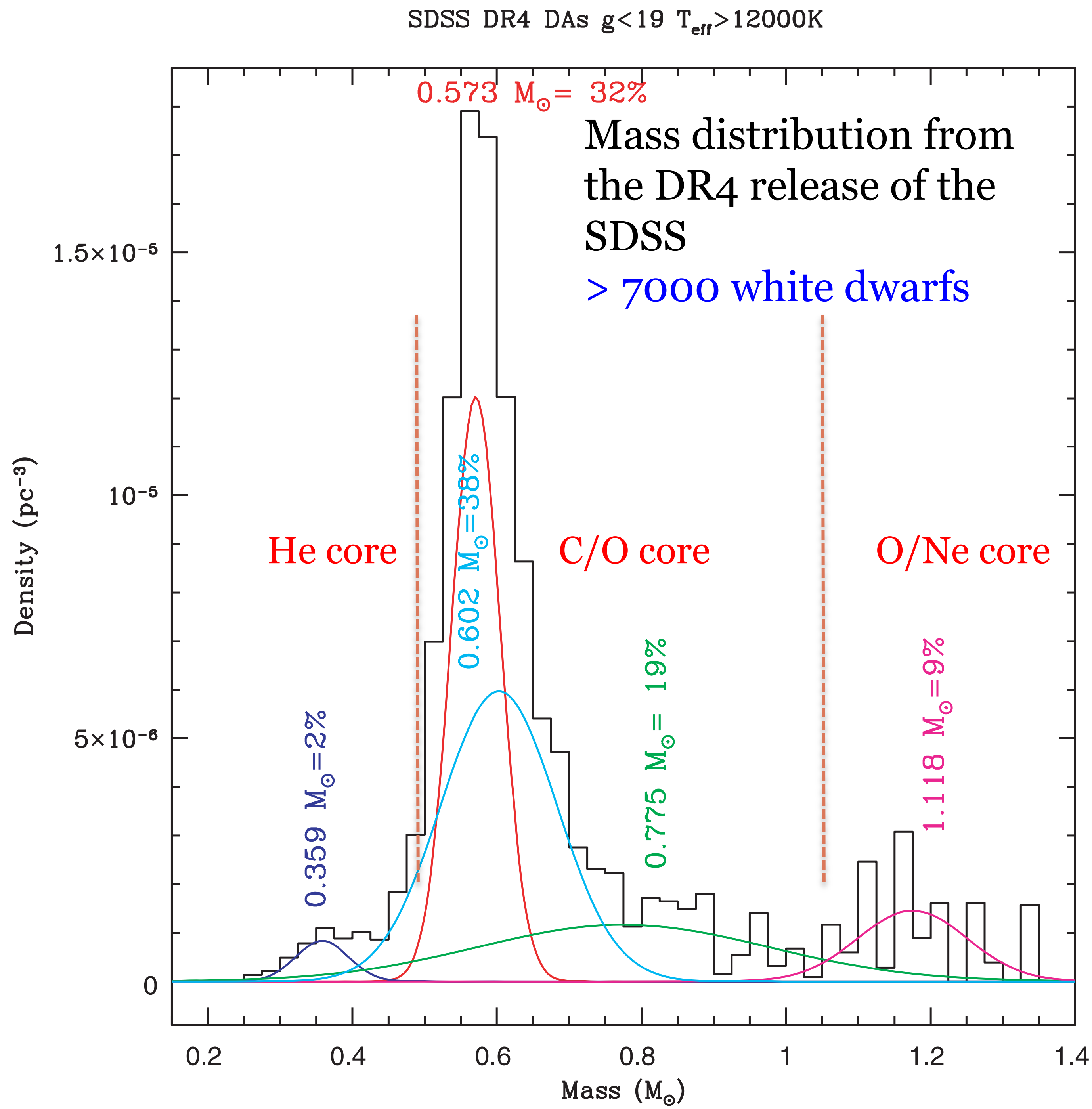

The Pulsational H-R Diagram
log(L/L⊙)
log Teff
20M⊙
β Cep
Ceph
Mira
GW Vir
SPB
4M⊙
RR Lyr
SR
sdBV
δ Sct
roAp
γ Dor
Solar-
like
1M⊙
DBV
DQV
DAV
log g ~ 5-6
log g ~
4.2-4.4
log g ~ 8
6
4
2
0
−2
5.0
4.5
4.0
3.5



SDSS DR4 DAs g<19 T_eff>12000K
0.573 M⊙= 32%
Mass distribution from the DR4 release of the SDSS
> 7000 white dwarfs
0.602 M⊙=38%
0.359 M⊙=2%
0.775 M⊙= 19%
1.118 M⊙=9%
Density (pc⁻³)
1.5×10⁻⁵
10⁻⁵
5×10⁻⁶
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Mass (M⊙)



SDSS DR4 DAs g<19 T_{eff}>12000K
$0.573\ M_\odot = 32\%$
Mass distribution from the DR4 release of the SDSS
> 7000 white dwarfs
He core
C/O core
O/Ne core
$0.602\ M_\odot = 38\%$
$0.359\ M_\odot = 2\%$
$0.775\ M_\odot = 19\%$
$1.118\ M_\odot = 9\%$
Density (pc^{-3})
Mass ($M_\odot$)

This motivated Steinfadt et al. (2010) to examine pulsations in these objects to test whether they have He cores…

PULSATIONS IN HYDROGEN BURNING LOW-MASS HELIUM WHITE DWARFS

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nstitute for Theoretical Physics and Department of Physics, Kohn Hall, University of California, Santa Barbara, CA 93106, USA; bildsten@kitp.u
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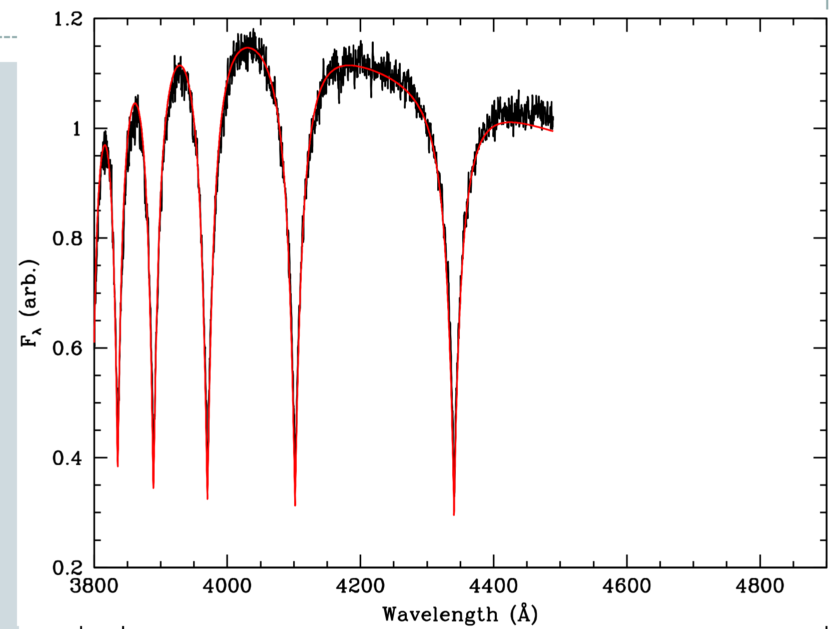
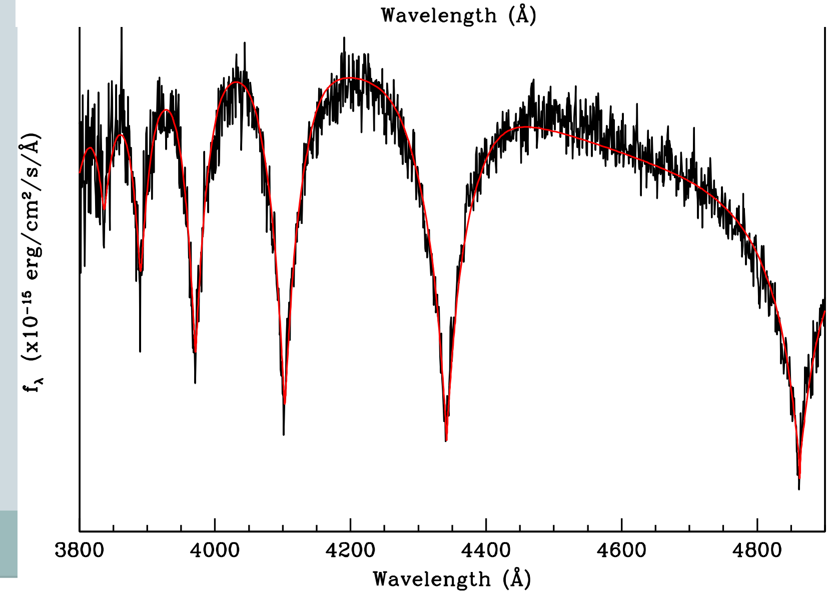
ABSTRACT

Helium core white dwarfs (WDs) with mass $M \lesssim 0.20\,M_\odot$ undergo several Gyr of stable hydrogen burning as they evolve. We show that in a certain range of WD and hydrogen envelope masses, these WDs may exhibit g-mode pulsations similar to their passively cooling, more massive carbon/oxygen core counterparts, the ZZ Cetis. Our models with stably burning hydrogen envelopes on helium cores yield g-mode periods and period spacings longer than the canonical ZZ Cetis by nearly a factor of 2. We show that core composition and structure can be probed using seismology since the g-mode eigenfunctions predominantly reside in the helium core. Though we have not carried out a fully nonadiabatic stability analysis, the scaling of the thermal time in the convective zone with surface gravity highlights several low-mass helium WDs that should be observed in search of pulsations: NLTT 11748, SDSS J0822+2753, and the companion to PSR J1012+5307. Seismological studies of these He core WDs may prove especially fruitful, as their luminosity is related (via stable hydrogen burning) to the hydrogen envelope mass, which eliminates one model parameter.

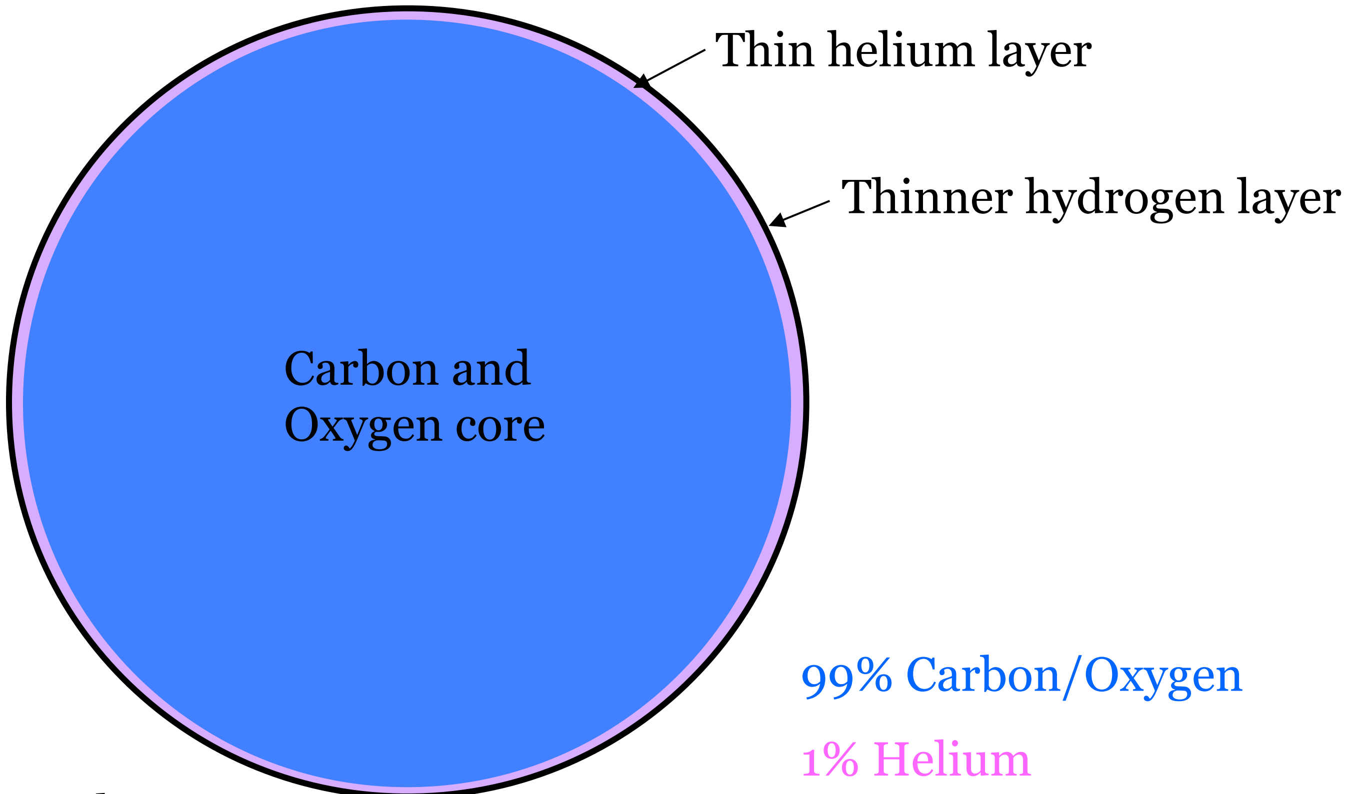
What we (think) we know about Extremely Low-Mass (ELM) WDs…

- $M < 0.25\ M_\odot$
- He-core
  - Stripped of material before much He fusion to C/O can occur
- Identified spectroscopically (hydrogen-atmosphere WDs with narrower lines)
- Must form in binaries
  - Single-star evolution would take too long to form a 0.2 $M_\odot$ WD
  - So far, 18 of 18 WDs with masses < 0.25 $M_\odot$ have detected RV companions (Kilic et al. 2011, ApJ **727** 3)





“Normal” White Dwarfs…



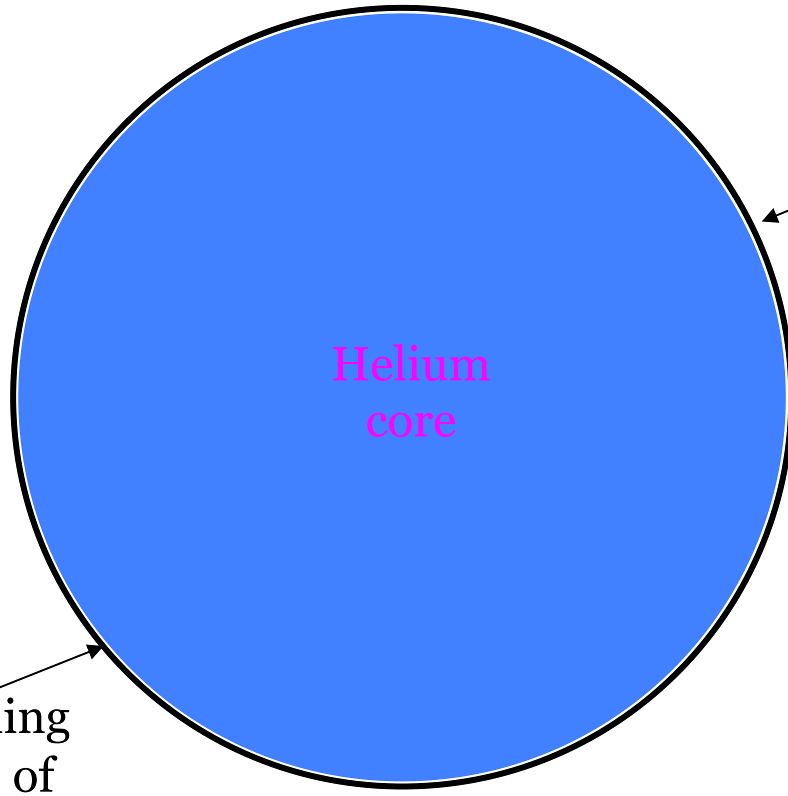
99% Carbon/Oxygen

1% Helium

0.01% Hydrogen

DA= hydrogen atmosphere
DB= helium atmosphere

Extremely Low Mass White Dwarfs



Thin hydrogen layer

For M < 0.2 Msun, residual nuclear burning still occurring at base of H envelope

"Mostly" Helium

0.1-1% Hydrogen

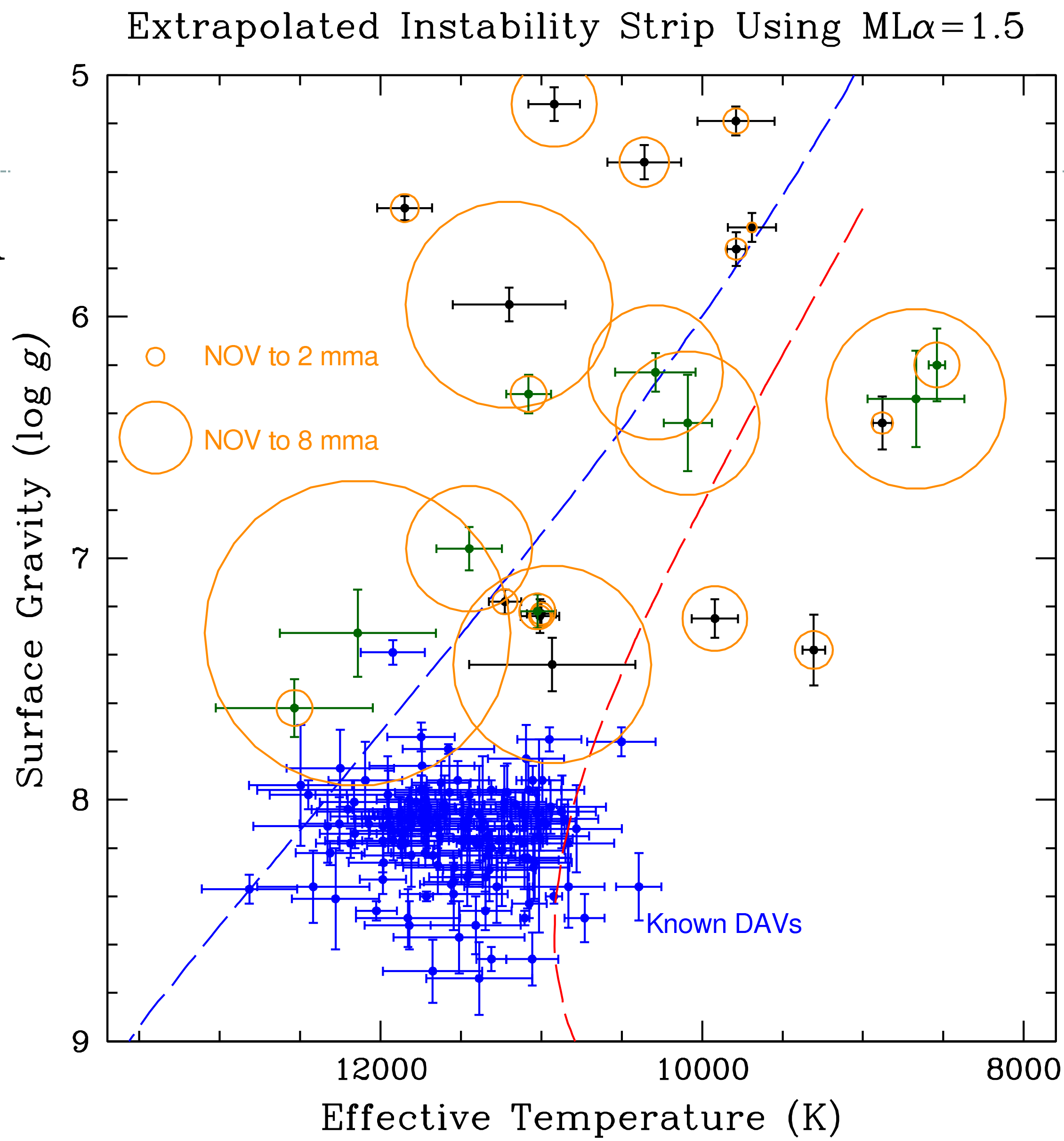
(Panei et al. 2007 , Steinfadt et al. 2010)

The SDSS

It's good to be faint and blue!

In the last 9 years the number of known pulsators has gone from ~35 to ~160

(e.g., Mukadam et al. 2004, ApJ, 607, 982; Gianninas, Bergeron, & Fontaine 2006, AJ, 132, 831; Castanheira et al. 2006, A&A, 450, 227; Mullally et al. 2005, ApJ, 625, 966; Nitta et al. 2009, ApJ, 690, 560)



THE FIRST PULSATING EXTREMELY LOW MASS WHITE DWARF : SDSS J184037.78+642312.3

SDSS J184037.78+642312.3: THE FIRST PULSATING EXTREMELY LOW MASS WHITE DWARF

J. J. Hermes[1,2], M. H. Montgomery[1,2], D. E. Winget[1,2], Warren R. Brown[3], Mukremin Kilic[4], and Scott J. Kenyon[3]

[1] Department of Astronomy, University of Texas at Austin, Austin, TX 78712, USA; jjhermes@astro.as.utexas.edu

[2] McDonald Observatory, Fort Davis, TX 79734, USA

[3] Smithsonian Astrophysical Observatory, 60 Garden St, Cambridge, MA 02138, USA

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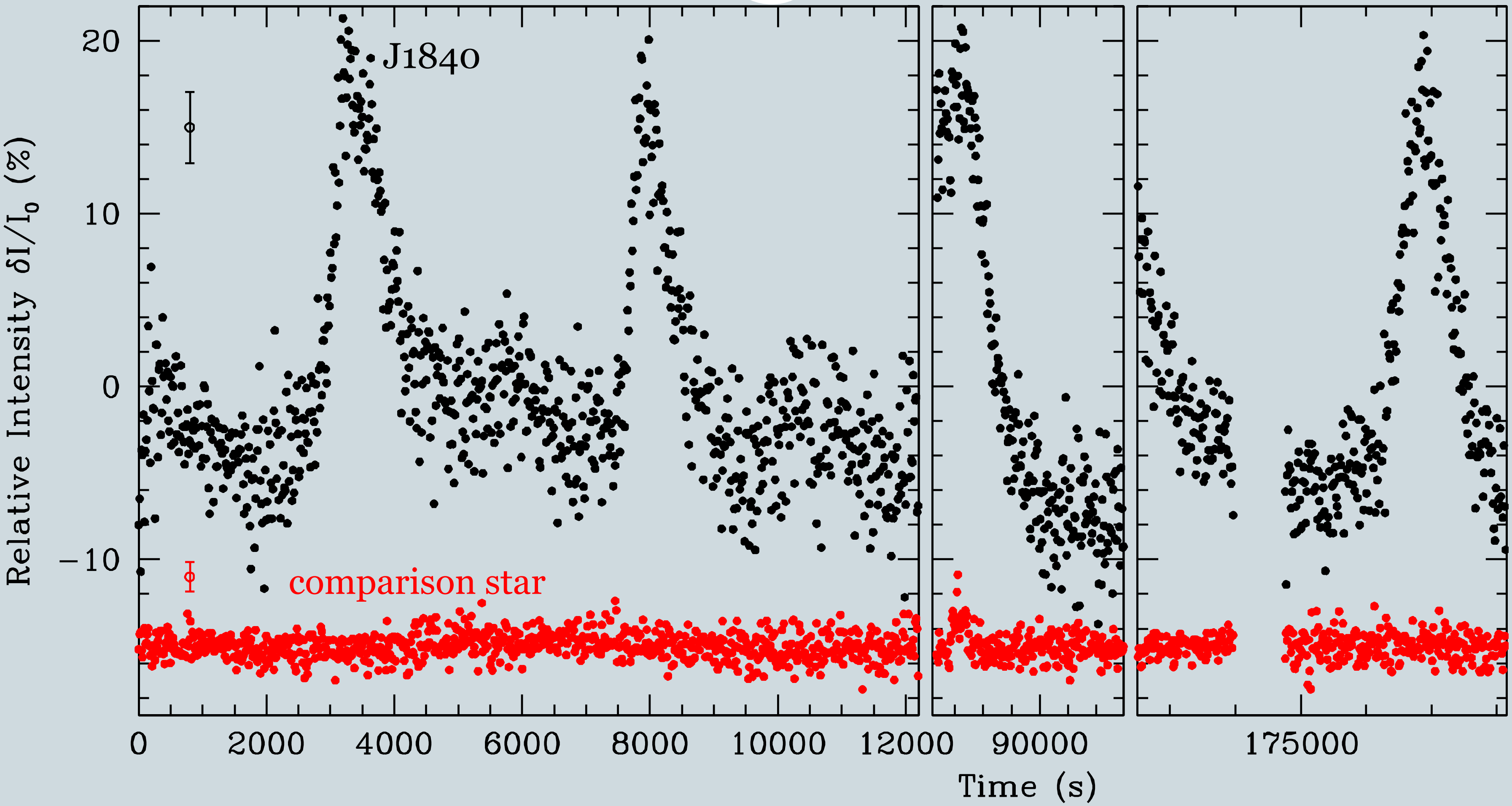
ABSTRACT

We report the discovery of the first pulsating extremely low mass (ELM) white dwarf (WD), SDSS J184037.78+642312.3 (hereafter J1840). This DA (hydrogen-atmosphere) WD is by far the coolest and the lowest-mass pulsating WD, with $T_{\rm eff} = 9100 \pm 170$ K and $\log g = 6.22 \pm 0.06$, which corresponds to a mass of $\sim$0.17 $M_{\odot}$. This low-mass pulsating WD greatly extends the DAV (or ZZ Ceti) instability strip, effectively bridging the $\log g$ gap between WDs and main-sequence stars. We detect high-amplitude variability in J1840 on timescales exceeding 4000 s, with a non-sinusoidal pulse shape. Our observations also suggest that the variability is multi-periodic. The star is in a 4.6 hr binary with another compact object, most likely another WD. Future, more extensive time-series photometry of this ELM WD offers the first opportunity to probe the interior of a low-mass, presumably He-core WD using the tools of asteroseismology.

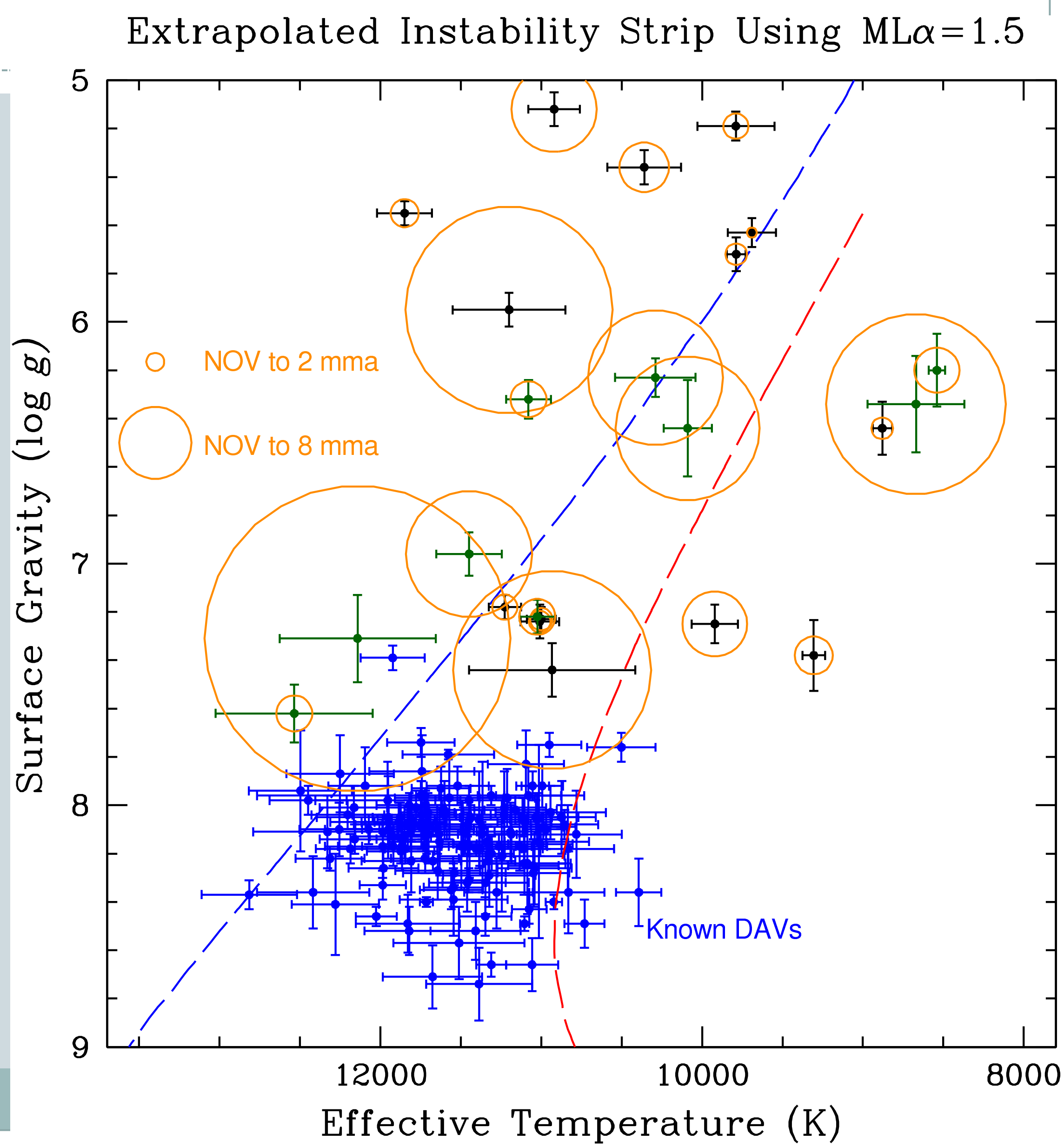
Hermes et al. (2012)

THE FIRST PULSATING EXTREMELY LOW MASS WHITE DWARF : SDSS J184037.78+642312.3

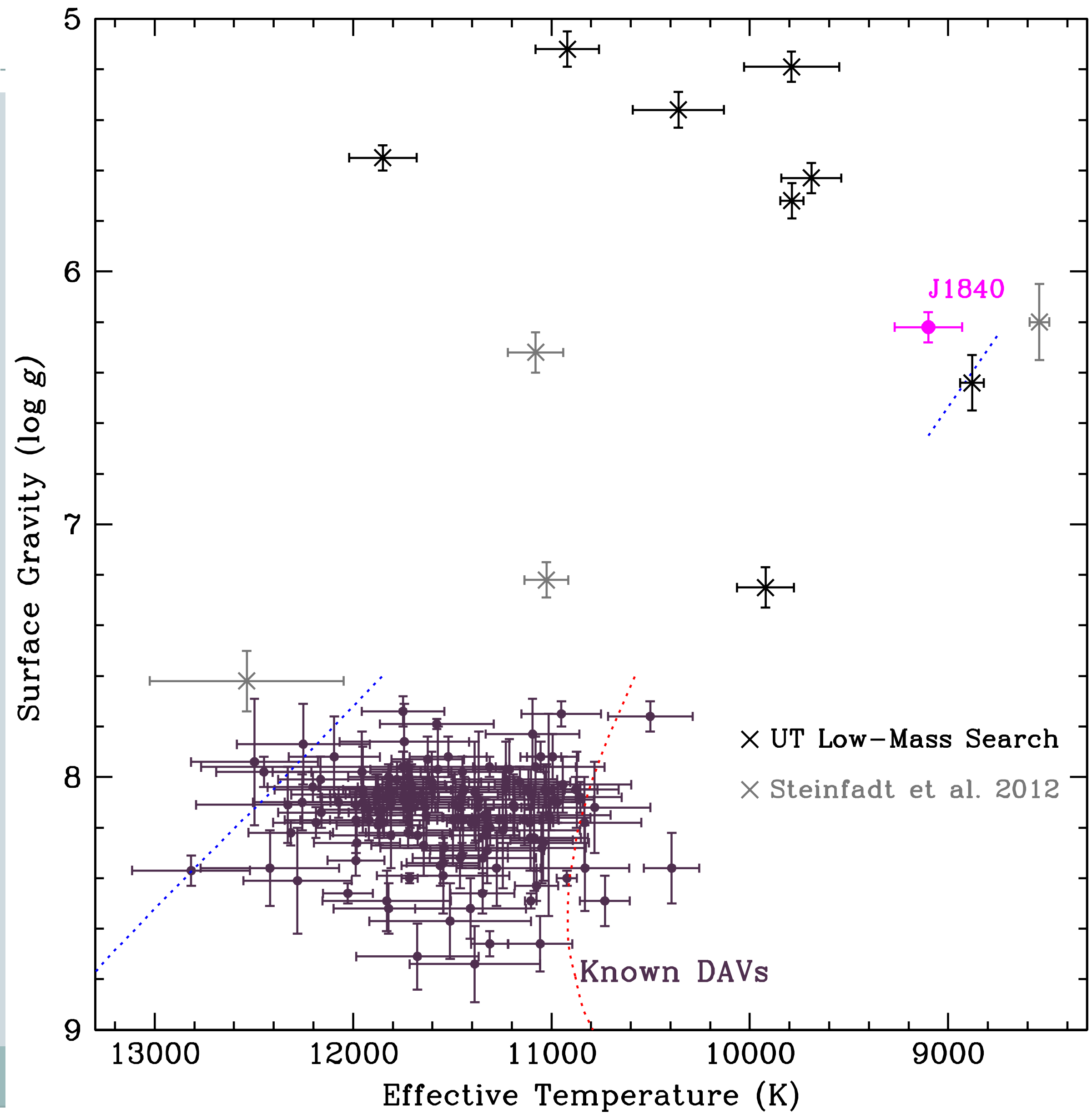


Hermes et al. (2012)

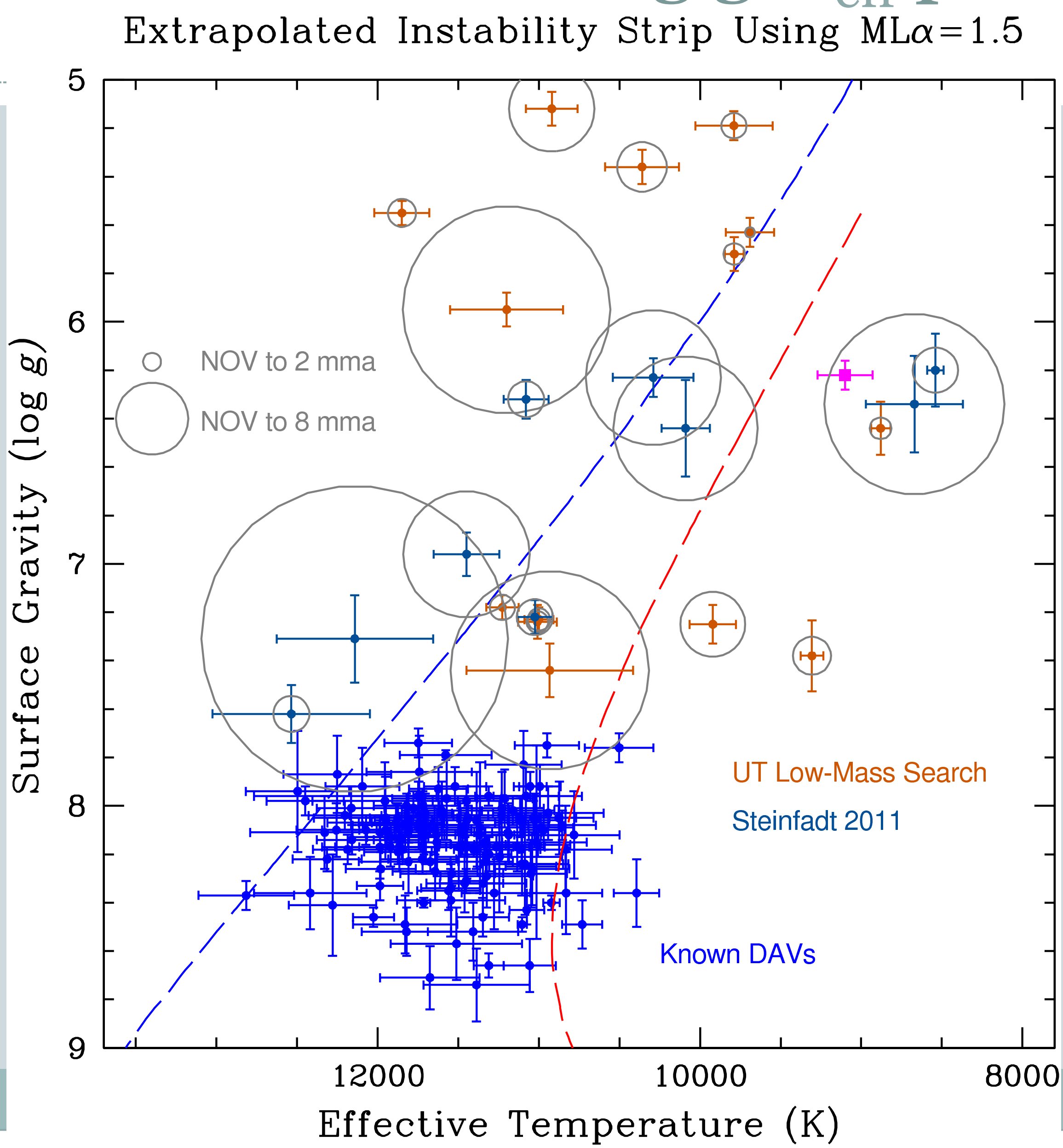
The search for pulsating ELM WDs



The search for pulsating ELM WDs



Its location in the log g-T_{eff} plane



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What to know about WD pulsations

- White dwarfs have been observed to pulsate in non-radial g-modes
  - g-modes are asymptotically evenly spaced in period, not frequency

$$P_n = n\,\langle \Delta P \rangle_\ell + \epsilon,\ \ n = 1, 2, 3...$$

$$\langle \Delta P \rangle_\ell \sim \frac{2\pi^2}{\sqrt{\ell(\ell+1)}} \left(\int_{r1}^{r2} dr N/r \right)^{-1}$$

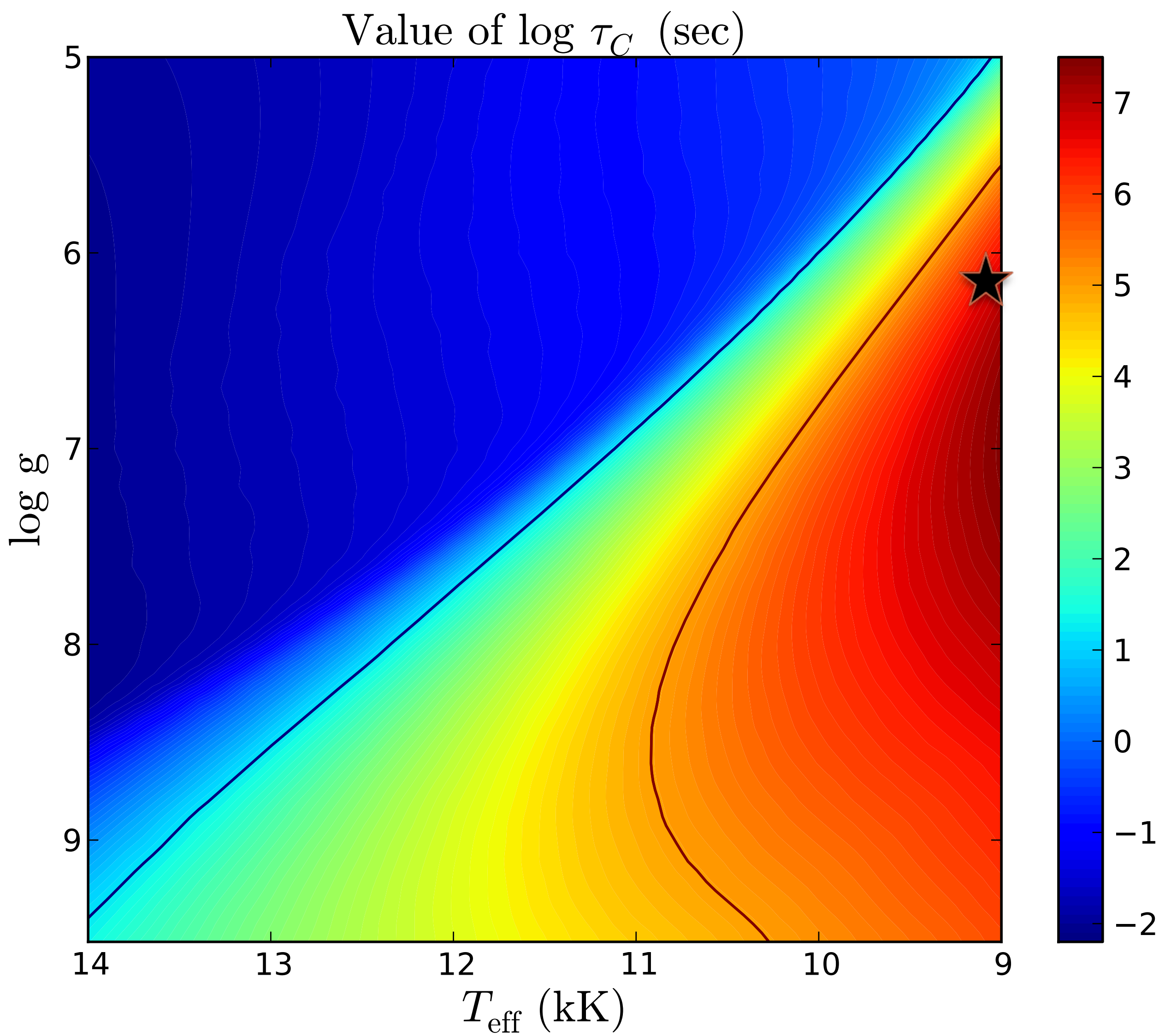
DBV and DAV driving

Due to convective driving – the “Brickhill effect”
(Brickhill 1992, Wu & Goldreich)

- convection zone is associated with the partial ionization of either H or He
- predictions of instability are similar to those of κ mechanism driving in white dwarfs:

“Blue” (hot) edge occurs when the n=1, l=1 mode satisfies $\omega\tau_C \approx 1$, where $\tau_C \approx 4\,\tau_{\mathrm{thermal}}$ at the base of the convection zone (Wu & Goldreich, late 1990’s)

Extension of ZZ instability strip to lower log g's



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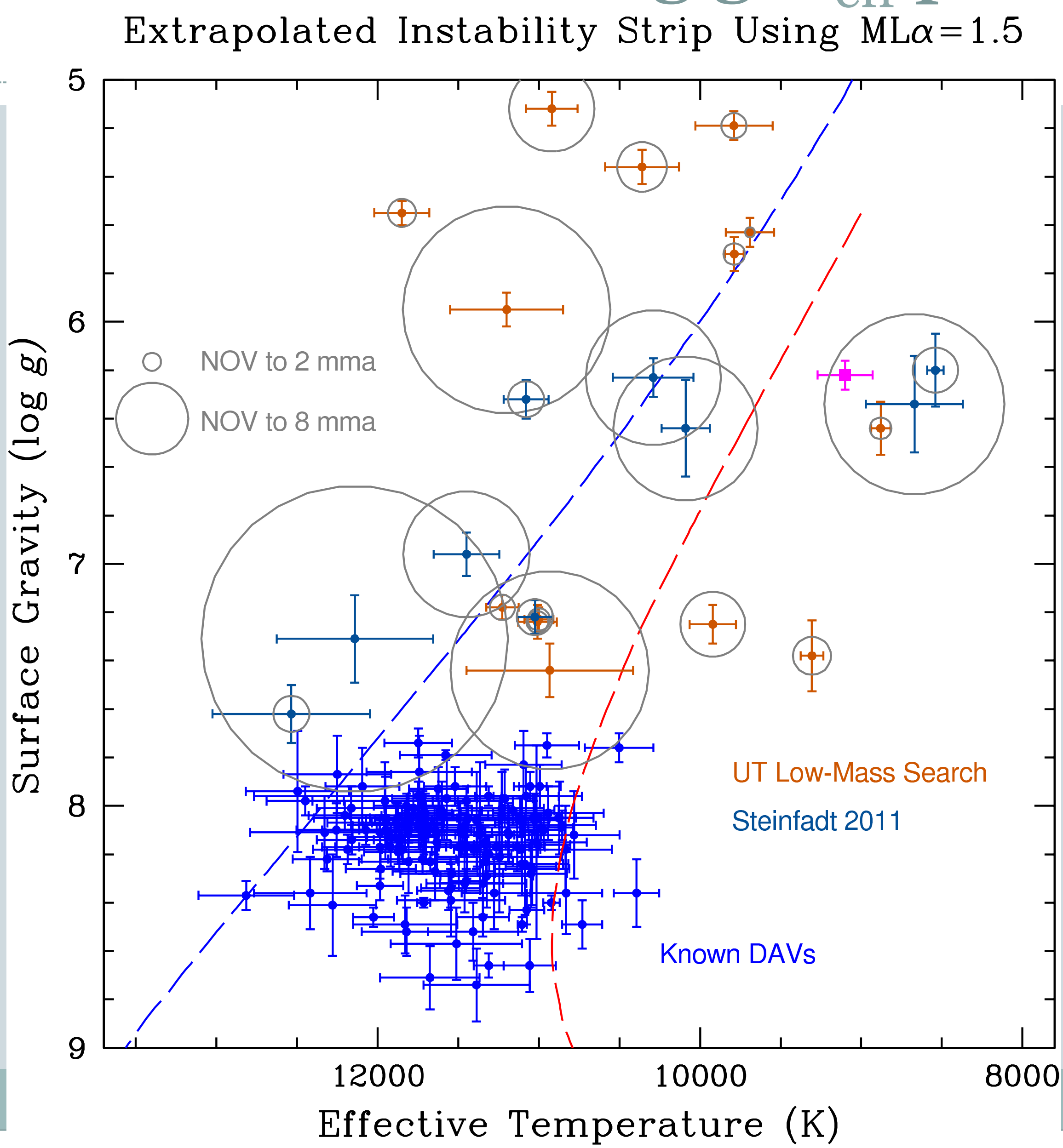
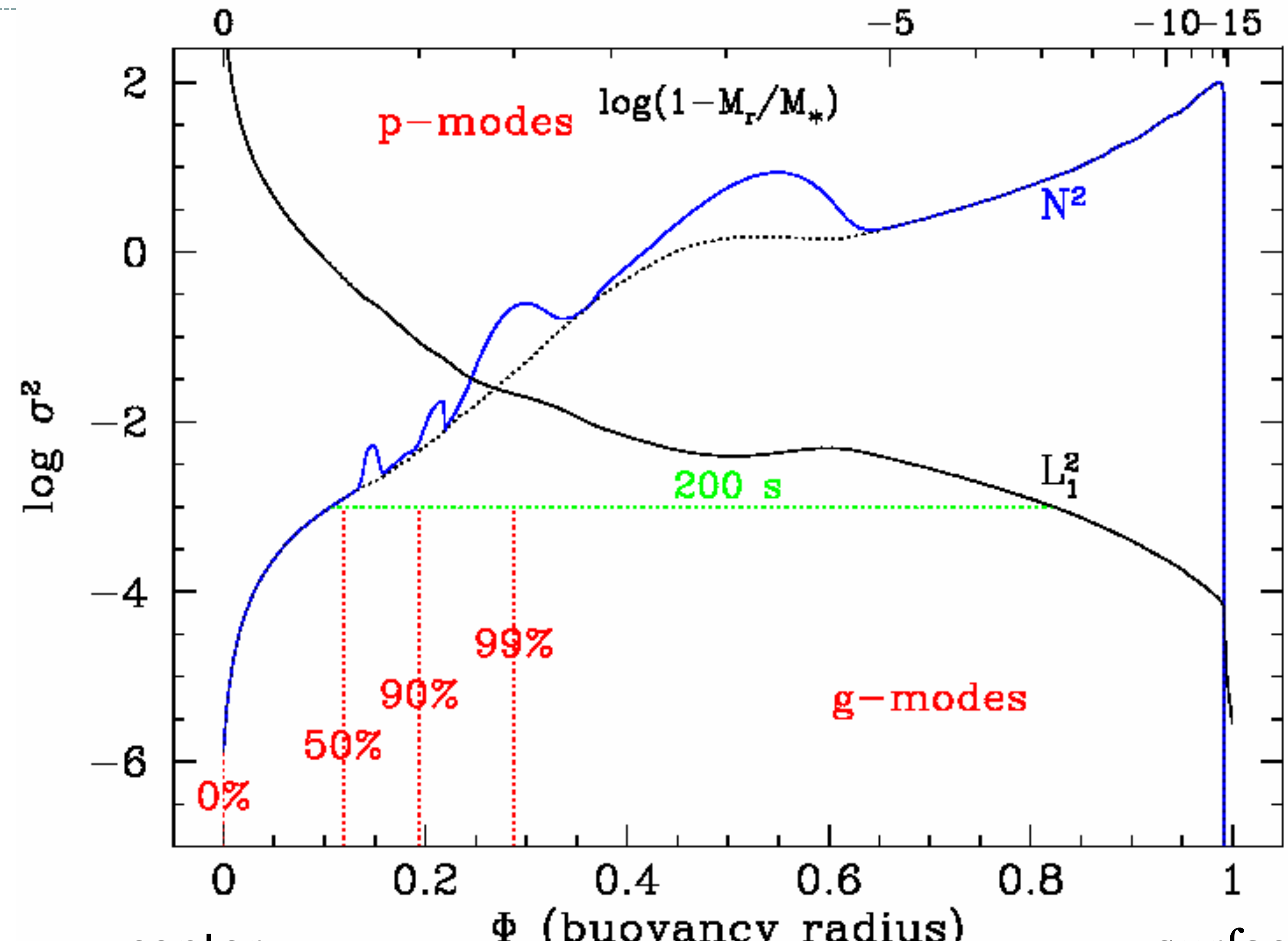


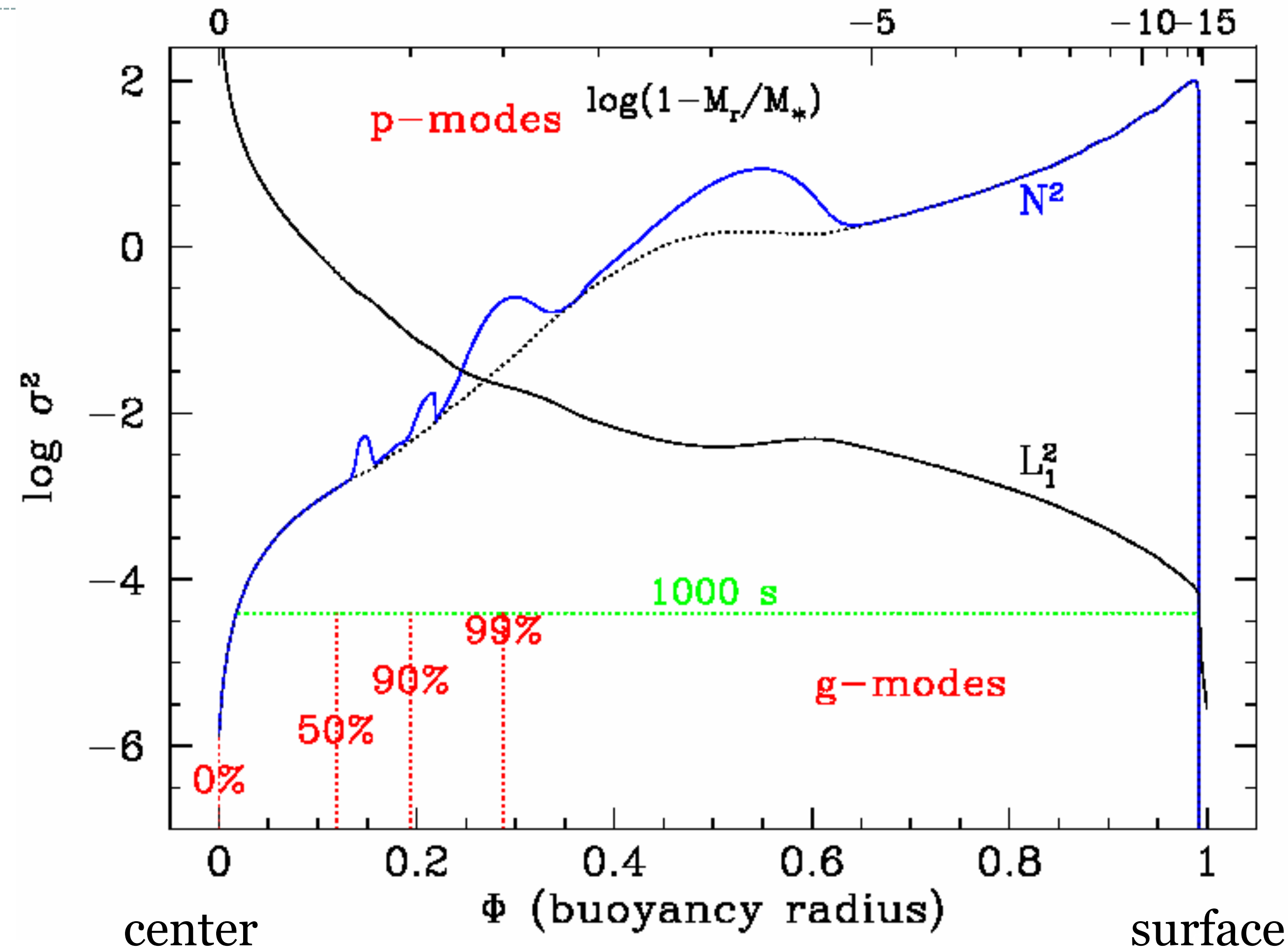
White Dwarf Seismology: a propagaton diagram



center

surface

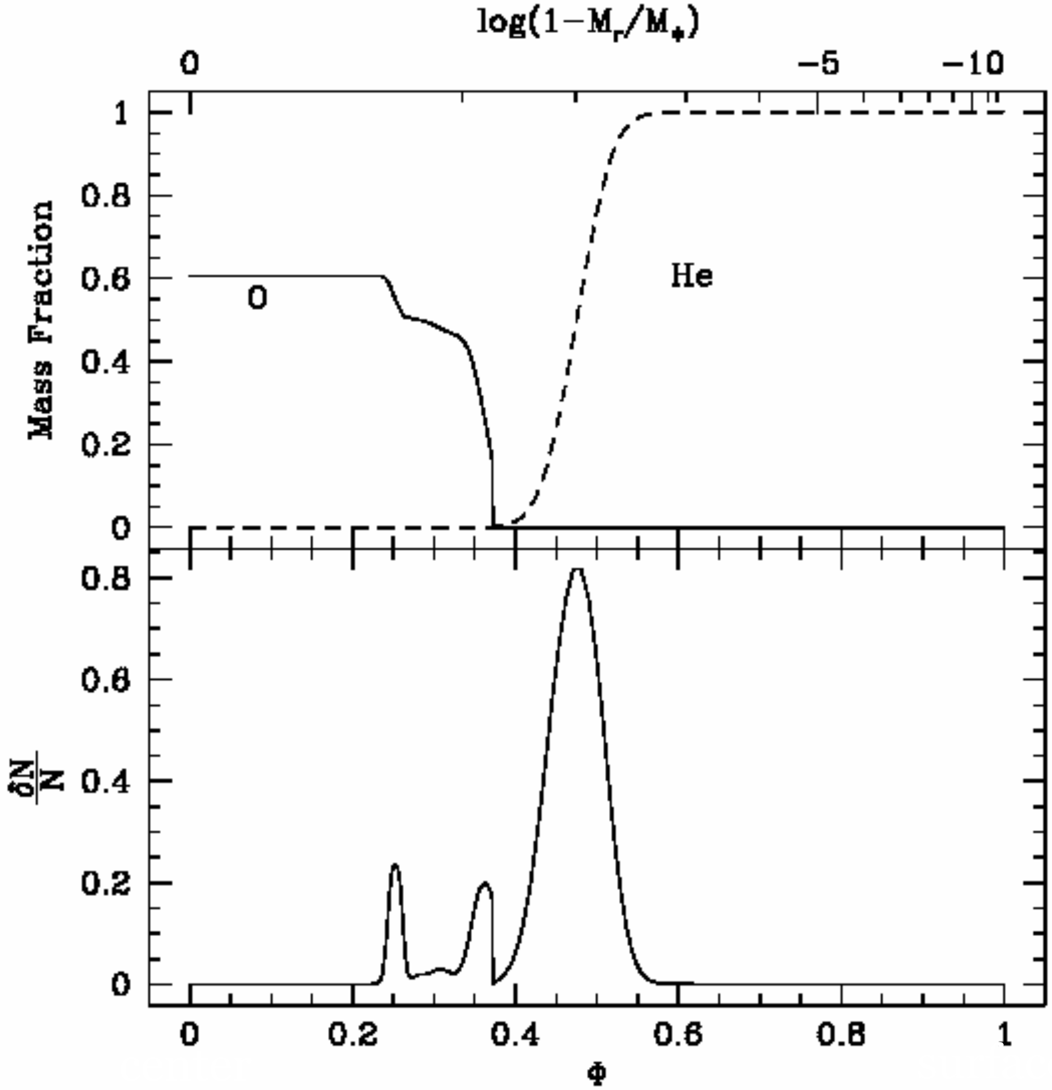
White Dwarf Seismology: a propagation diagram



Chemical Profiles produce bumps in N

The composition transition zones produce bumps in *N*

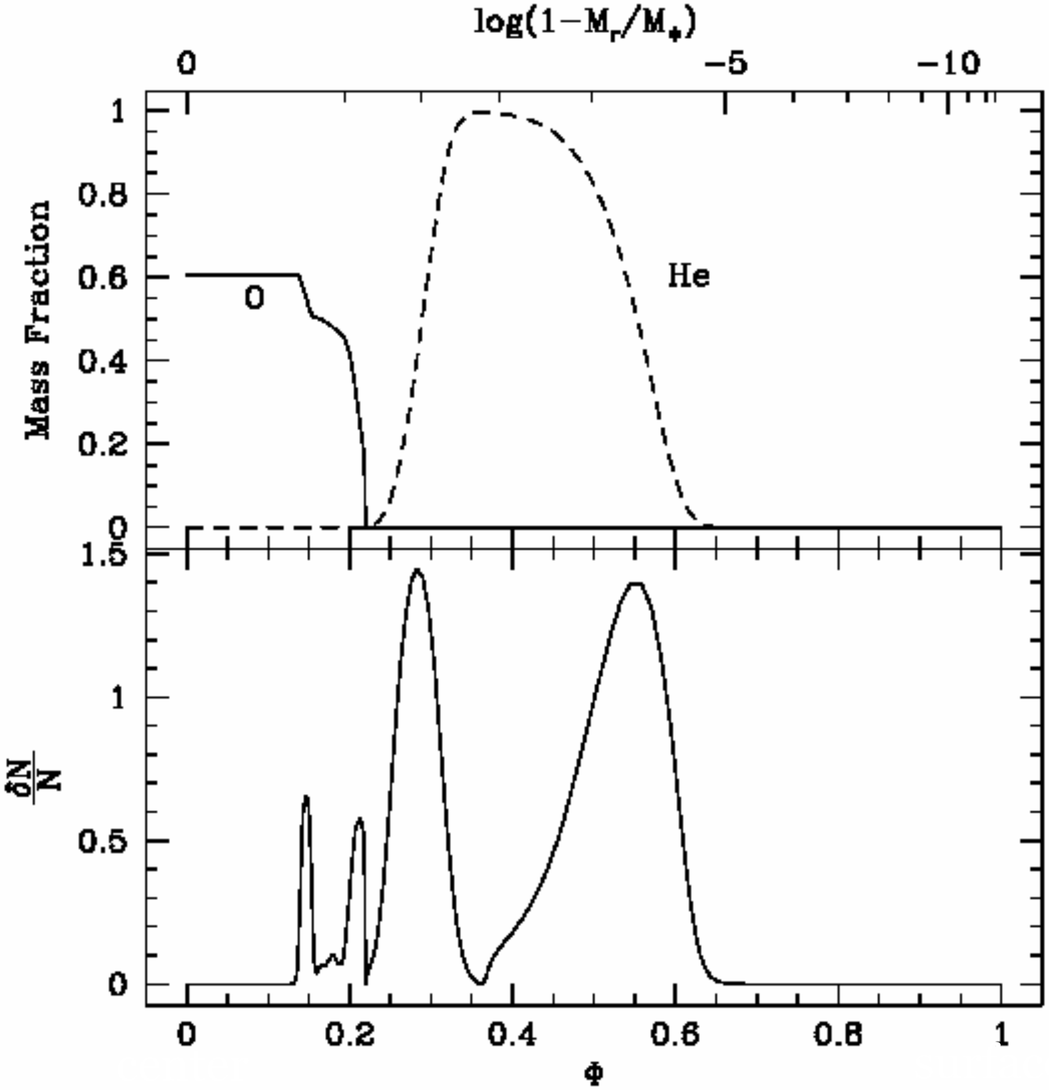
DBV model
$M = 0.6\ M_{\odot}$
$T_{eff} = 25000$ K



Chemical Profiles produce bumps in N

The composition transition zones produce bumps in *N*

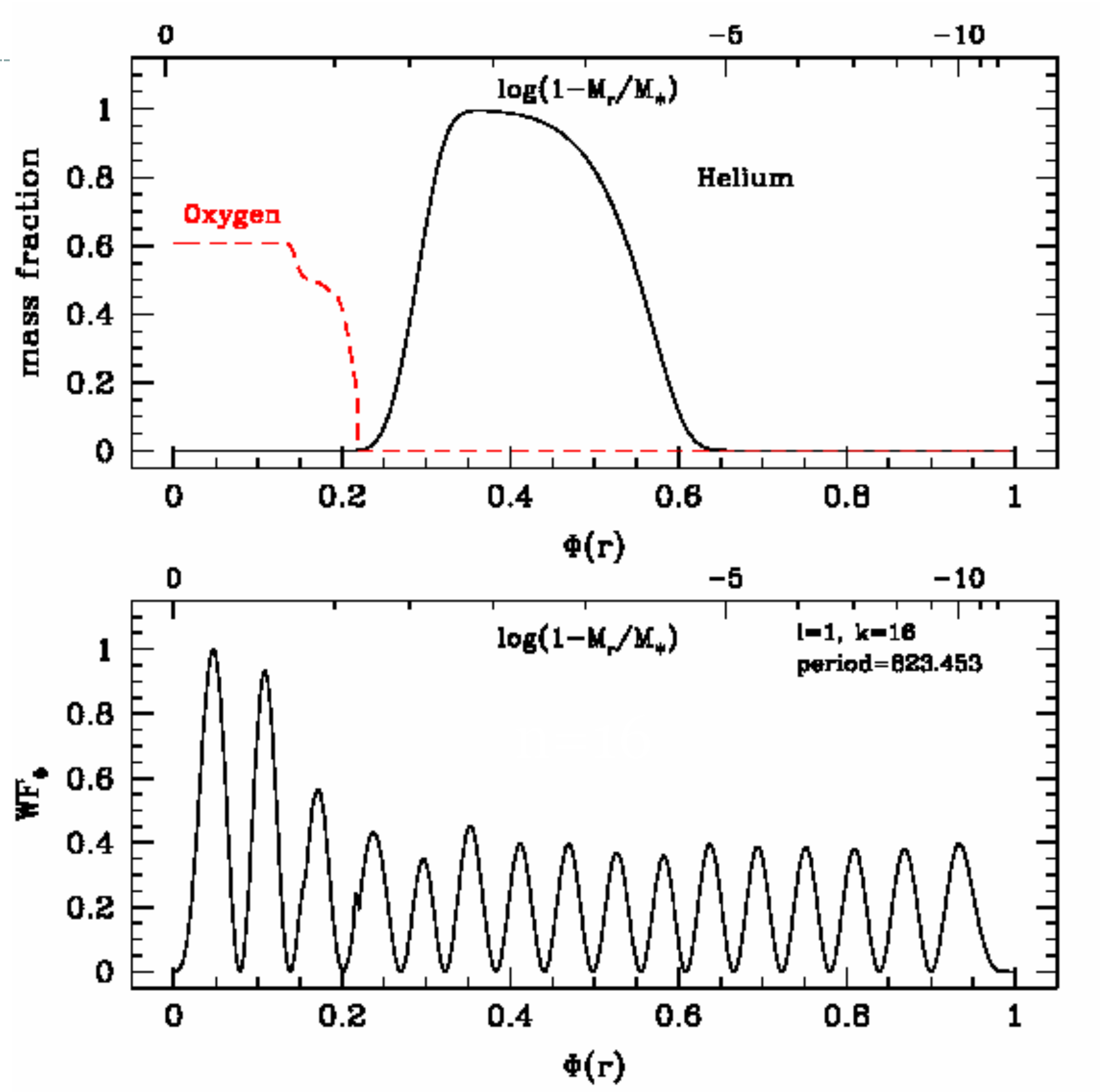
DAV model
$M = 0.6\ M_\odot$
$T_{eff} = 12000$ K



The bumps can "trap" modes…

Unequal sampling produces unequal period spacings

DAV model
$M = 0.6\ M_\odot$
$T_{eff} = 12000$ K



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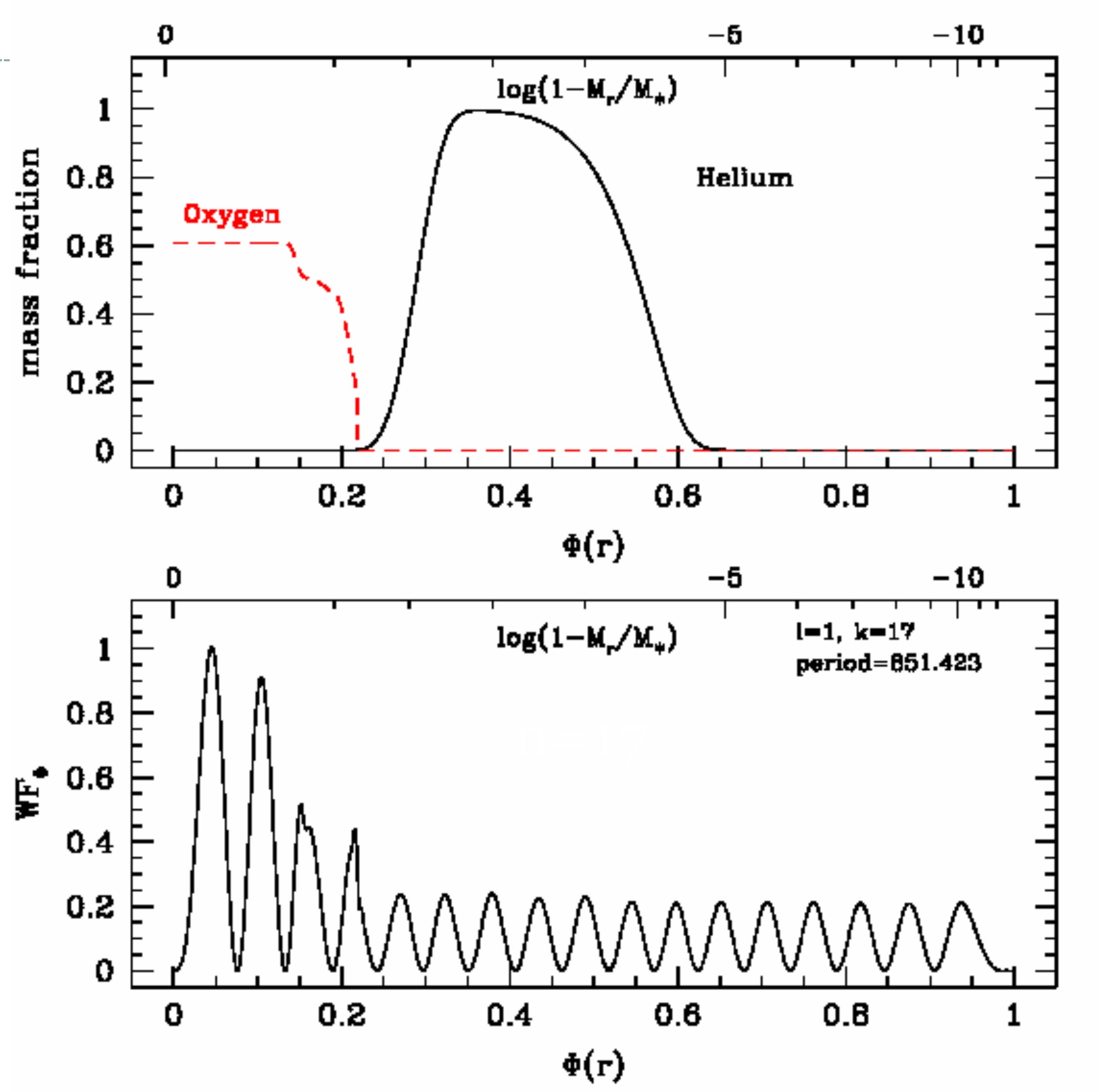

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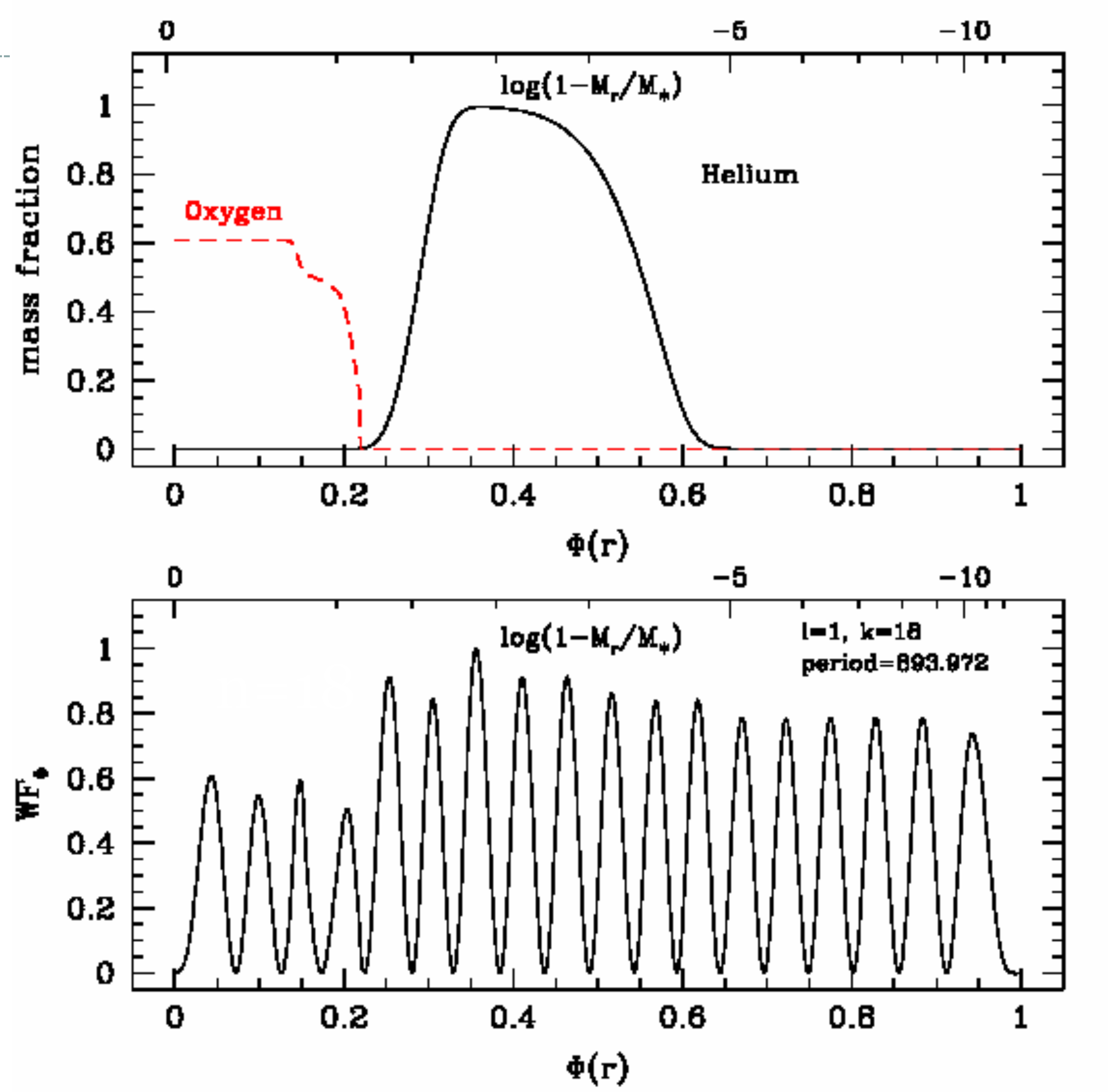
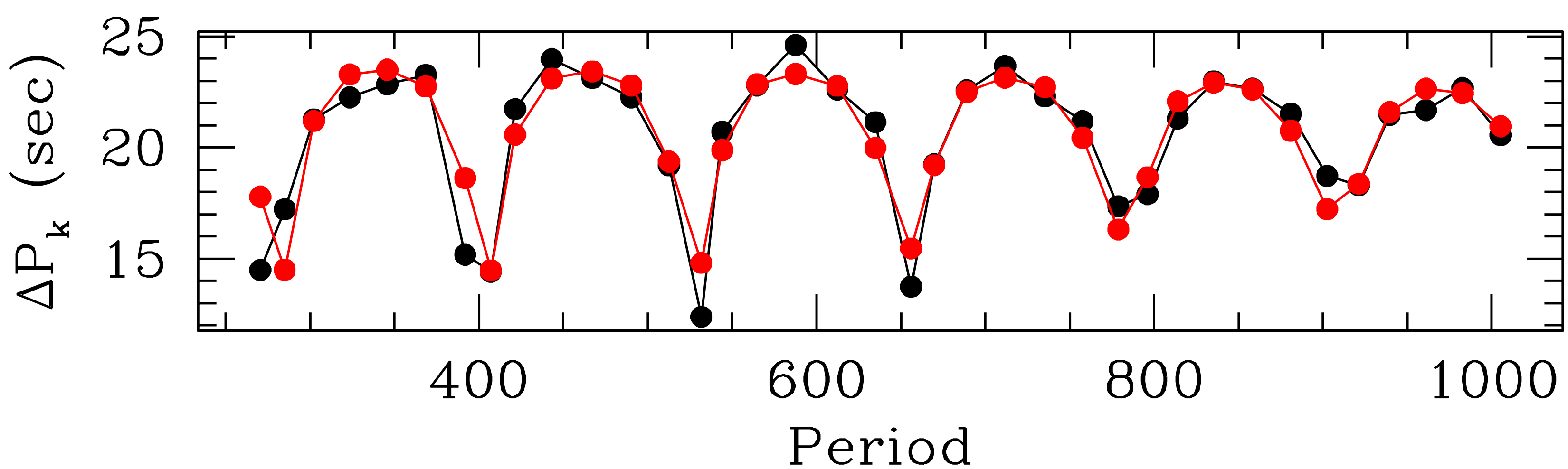


This information is encoded in the periods…

Variations in the period spacing ΔP_n contain information about the structure of the model

$$\Delta P_n \equiv P_{n+1} - P_n$$



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