Asteroseismology in Action: Probing the interiors of EHB stars

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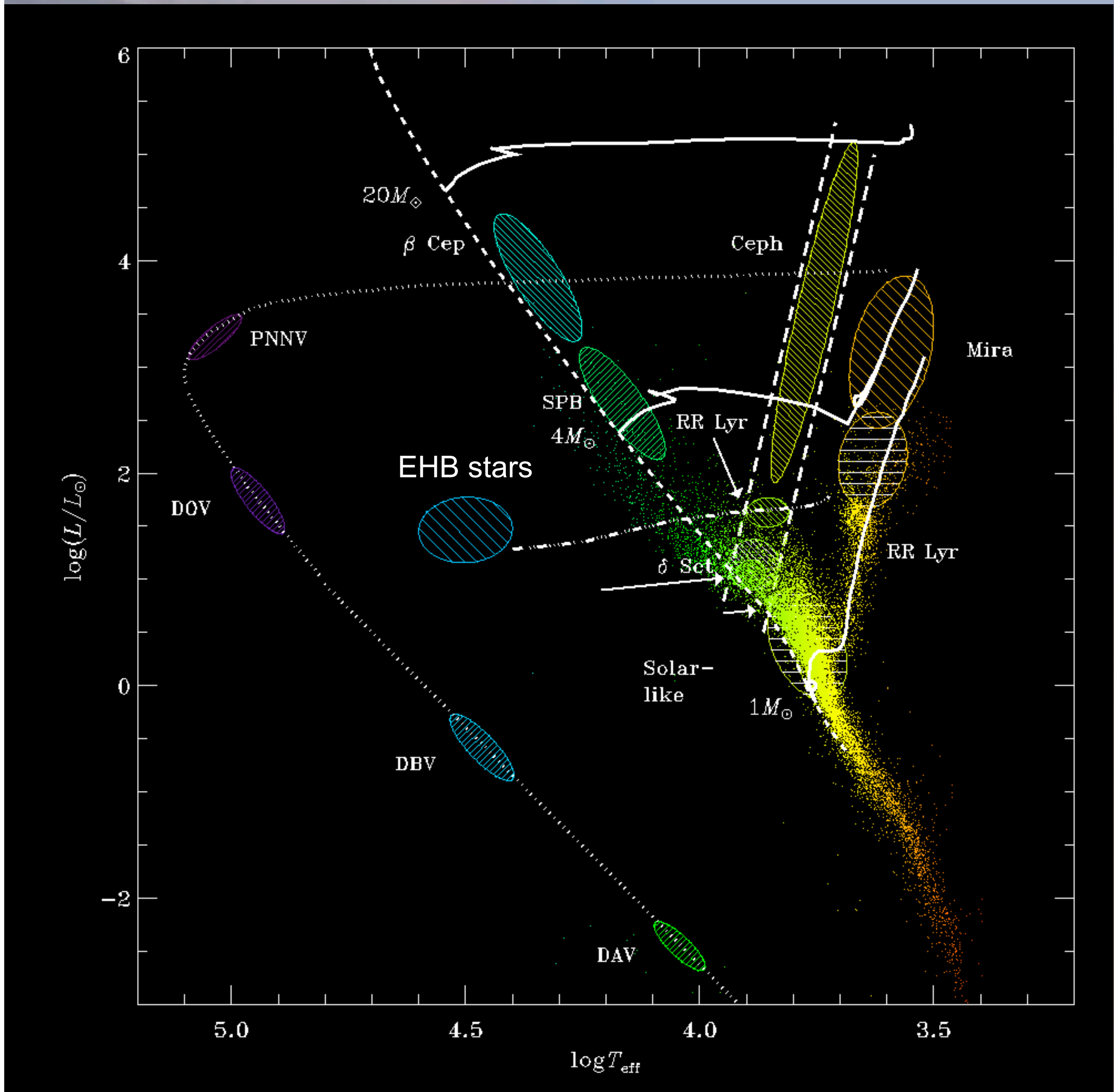
“Asteroseismology is the study of the internal structure of pulsating stars by the interpretation of their frequency spectra. Different oscillation modes penetrate to different depths inside the star. These oscillations provide information about the otherwise unobservable interiors of stars in a manner similar to how seismologists study the interior of Earth and other solid planets through the use of earthquake oscillations.”

- Wikipedia

Pulsating Stars across the H-R diagram



Non-radial pulsators

Radial pulsators

e.g. solar-like oscillators, δ Scuti, β Cepheids, SPB, pulsating white dwarfs and sdB's

e.g. Cepheids, RR Lyrae

Expand and contract radially; spherical symmetry is preserved

Spherical symmetry is not
pre... on;
the... e
pu... t
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-> ... n
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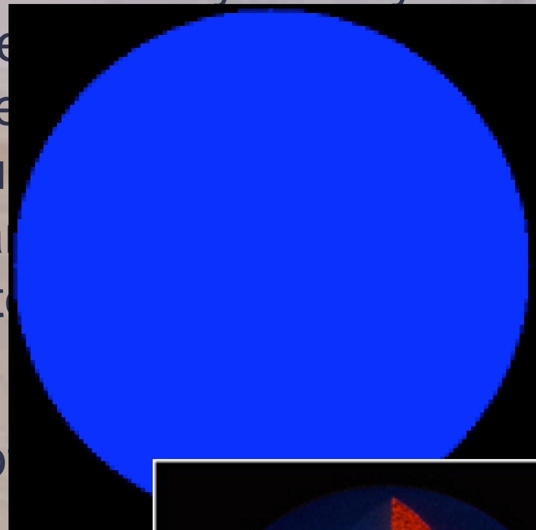
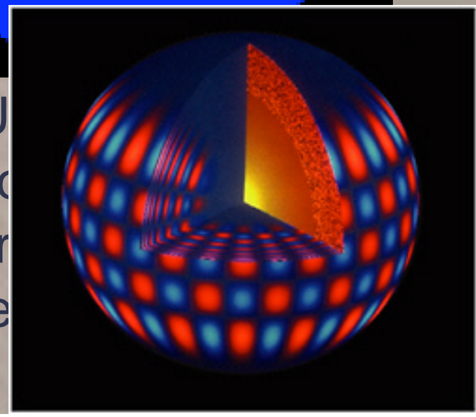


U...
astero...
impor...
candle...

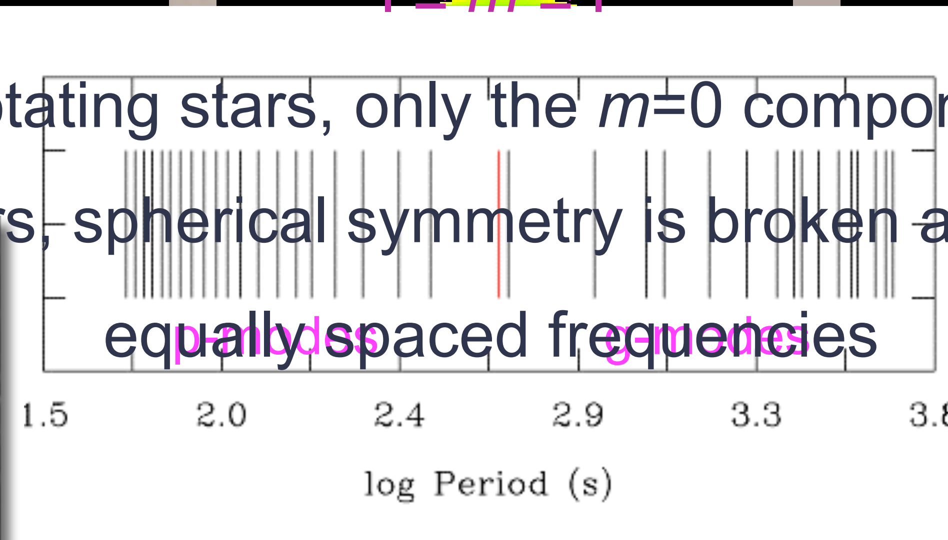


Non-radial pulsations

Non-radial pulsations are described by 3 quantum numbers:

- radial order *n* (or *k*) - number of nodes in the radial direction
- degree index *l* - number of nodal lines across the surface
- azimuthal index *m* - number of nodal lines that cross the stellar equator; spherical models are degenerate in *m*

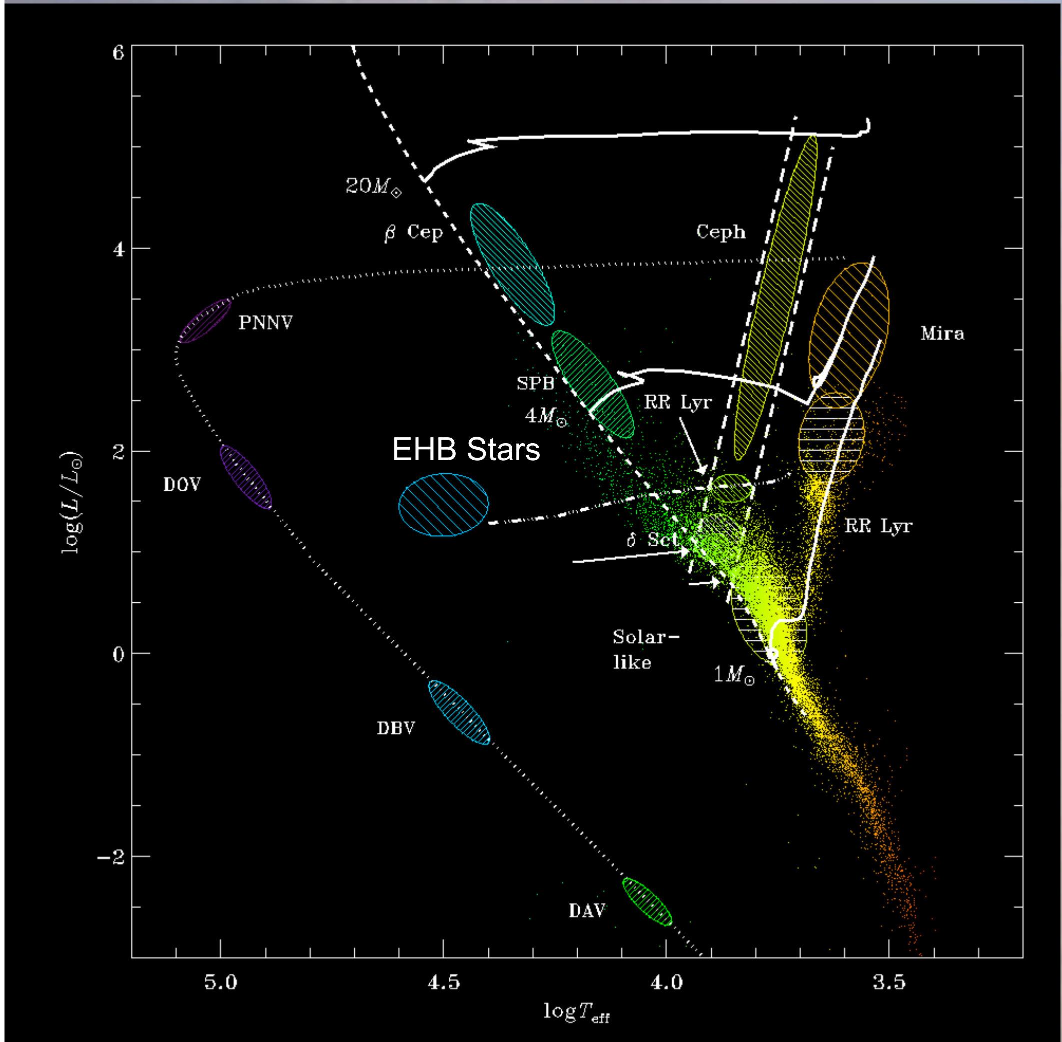
$-l \leq m \leq l$



For non-rotating stars, only the *m*=0 component is seen

For rotating stars, spherical symmetry is broken and we see (2*l*+1) equally spaced frequencies

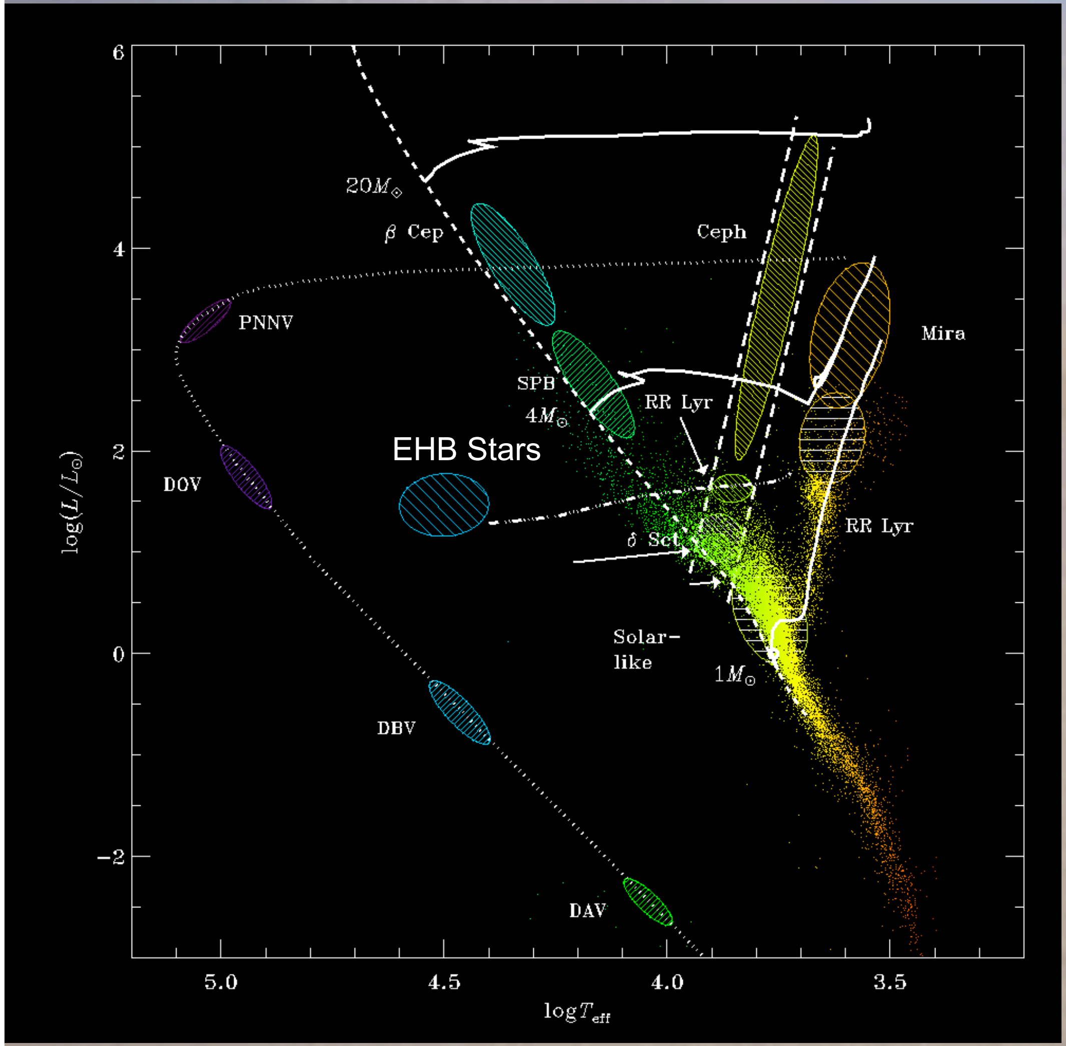
Why do stars pulsate?



1) Stochastic excitation (convective layer):

- the Sun, solar-type oscillators…
- millions of extremely low amplitude acoustic modes with short lifetimes

Why do stars pulsate?



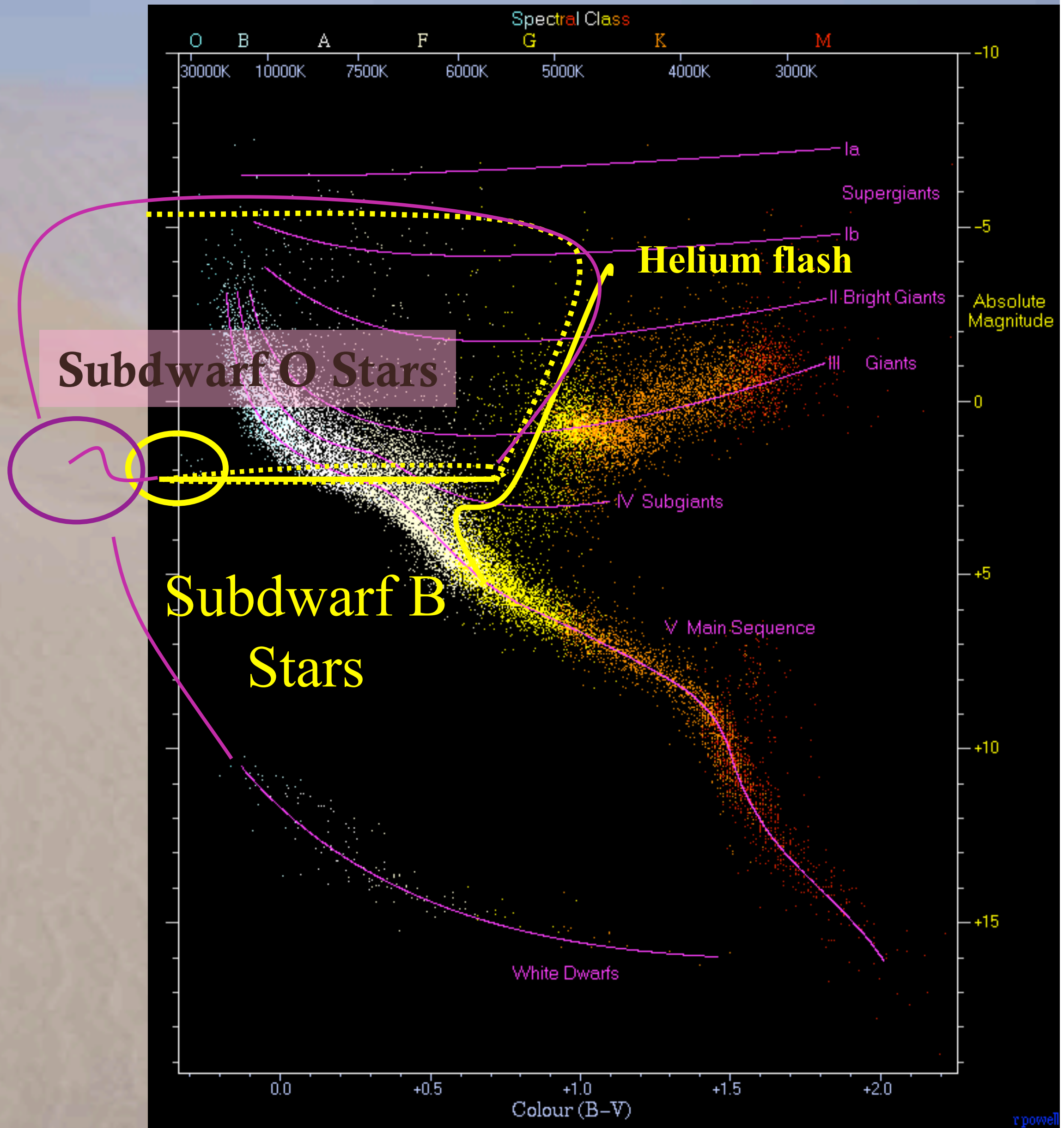
2) Self-excitation (κ-mechanism):

- δ Scuti stars, SPBs, β Cepheids, EHB stars, white dwarfs
- show *p* and/or *g* modes with a variety of degree and radial indices
- are found in “instability strips” in the H-R diagram

3) Forced oscillations through tidal excitation in close binary systems

Extreme Horizontal Branch (EHB) stars

- Subdwarf B stars have $20{,}000 < T_{\mathrm{eff}} < 40{,}000$ K and $5.0 < \log g < 6.2$
- $M \approx 0.5\, M_{\odot}$
- Helium-burning core surrounded by a thin hydrogen envelope
- Chemically peculiar, with He typically underabundant by a factor of 10
- Subdwarf O stars are hotter, with $40{,}000 < T_{\mathrm{eff}} < 100{,}000$ K
- They have an inert C/O core surrounded by a He/H envelope
- Link sdB and post-AGB stars to the white dwarfs



Why study EHB stars???

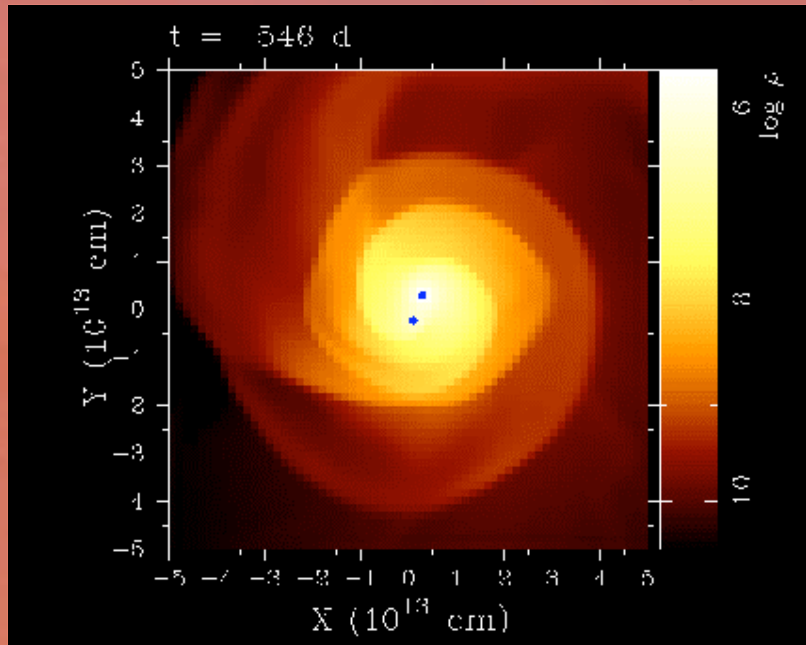
1) Their formation is a mystery

<u>Proposed formation channels</u>

- Common-envelope ejection channel
- Stable Roche lobe overflow channel
- Double helium White Dwarf merger channel

CE ejection

© Eric Sandquist



-> short period (*P*~0.1-10 d) binary systems

-> very thin hydrogen-rich envelopes

-> masses sharply peaked at ~0.46 M_{Sun}

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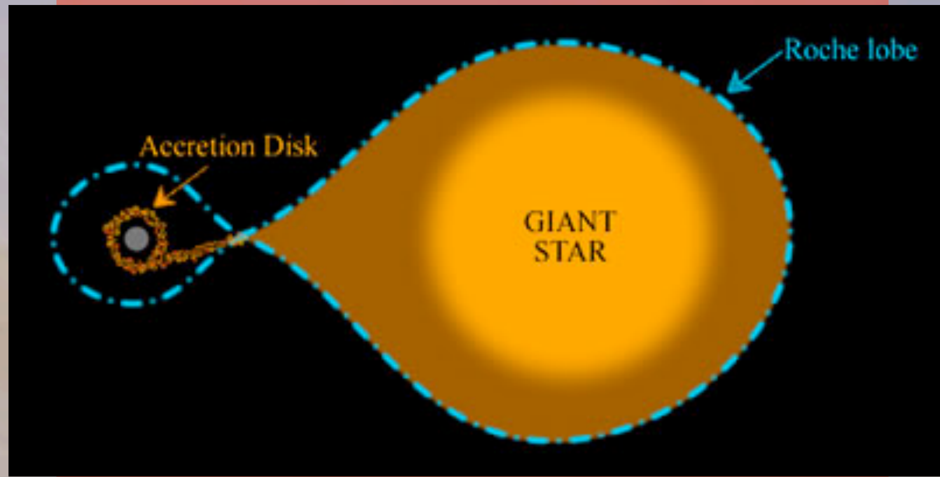
Stable Roche Lobe Overflow



-> long period (P~400-1500 d) binary systems

-> rather thick hydrogen-rich envelopes

-> similar mass distribution as for CE ejection

Why study EHB stars???

1) Their formation is a mystery

Proposed formation channels

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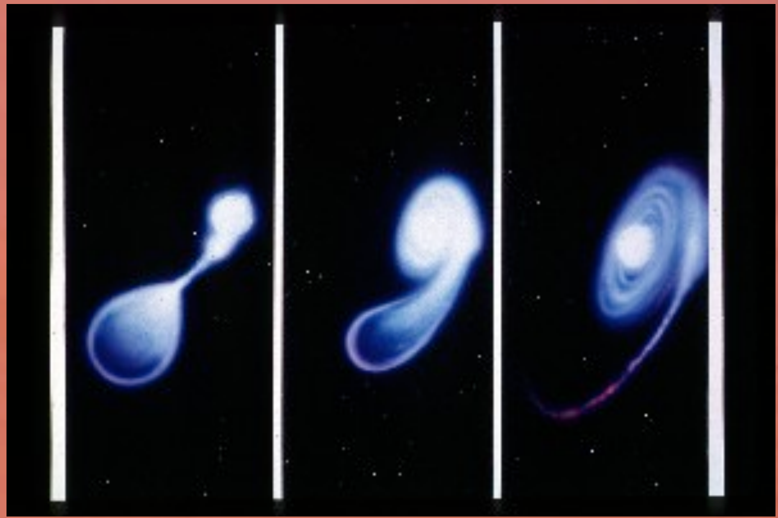
- Stable Roche lobe overflow channel
- Double helium White Dwarf merger channel

He-White Dwarf merger



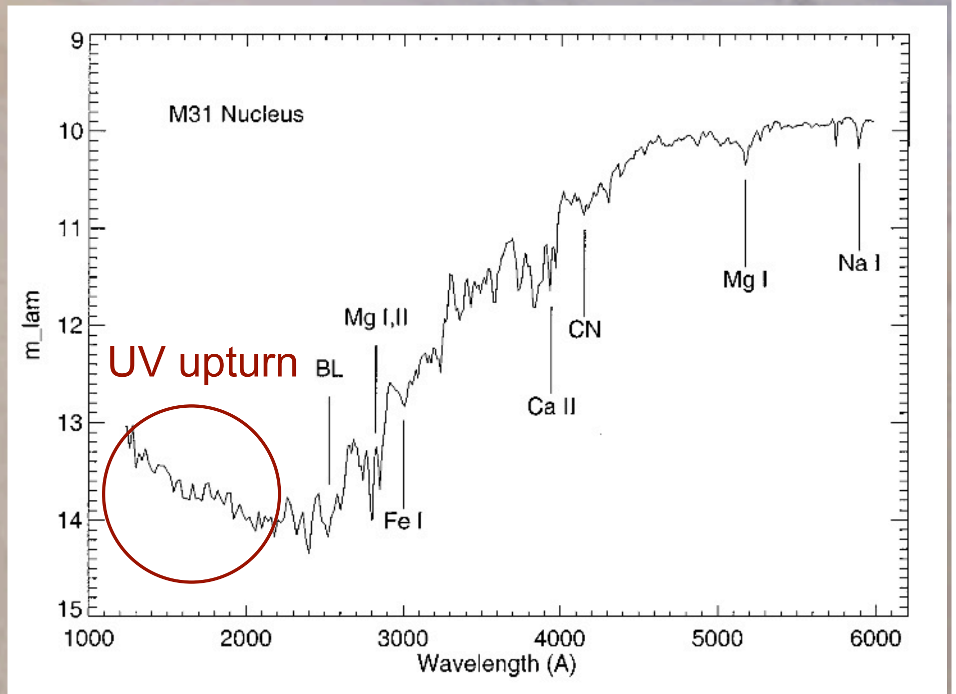
-> single sdB stars

-> extremely thin hydrogen-rich envelopes

-> wide distribution of masses (0.4-0.65 M_{sun})

Why study EHB stars???

2)They are useful for constraining the age of giant elliptical galaxies, tracing galaxy dynamics, and studying He core burning



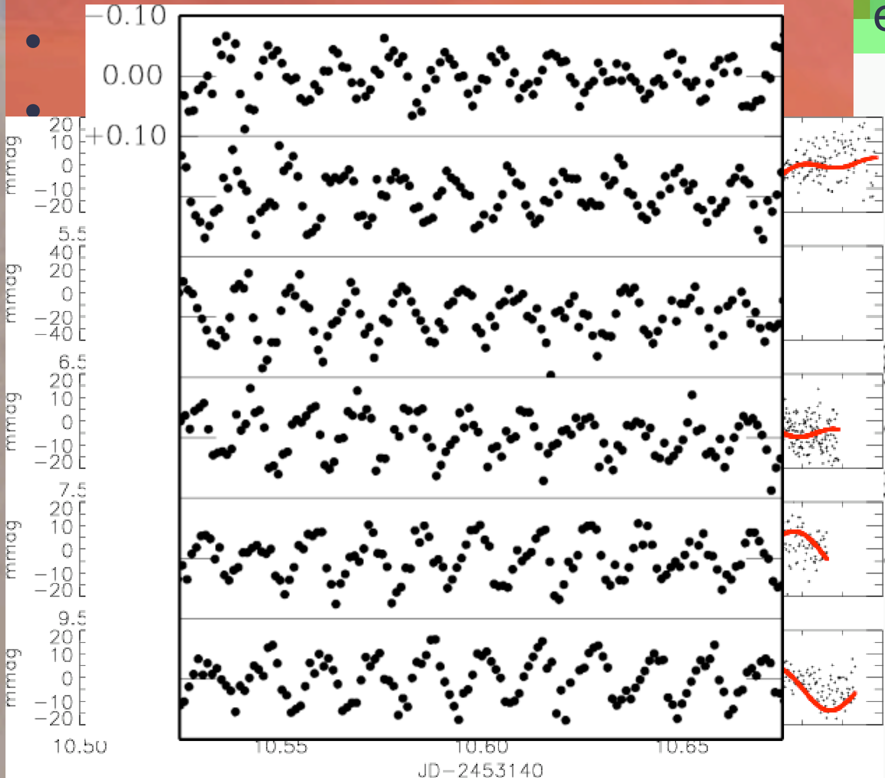
Why study EHB stars???

3) Asteroseismology seems to be feasible - at least for some sdB stars…

Extreme Horizontal Branch Pulsators

1) EC 14026 stars (34)

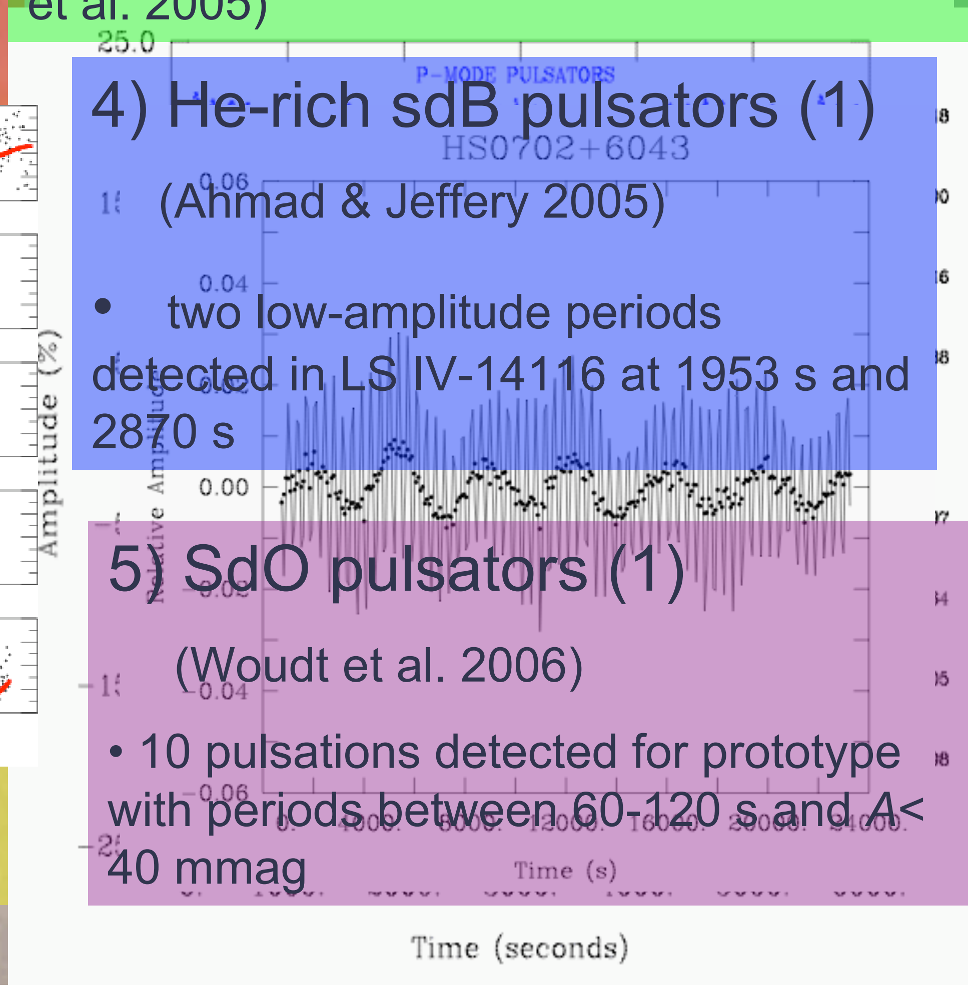
(Kilkenny et al. 1997)



- *g* modes with high radial orders

3) Fast/slow pulsating hybrids (3)

(Schuh et al. 2005; Oreiro et al. 2005; Baran et al. 2005)



4) He-rich sdB pulsators (1)

(Ahmad & Jeffery 2005)

- two low-amplitude periods detected in LS IV-14116 at 1953 s and 2870 s

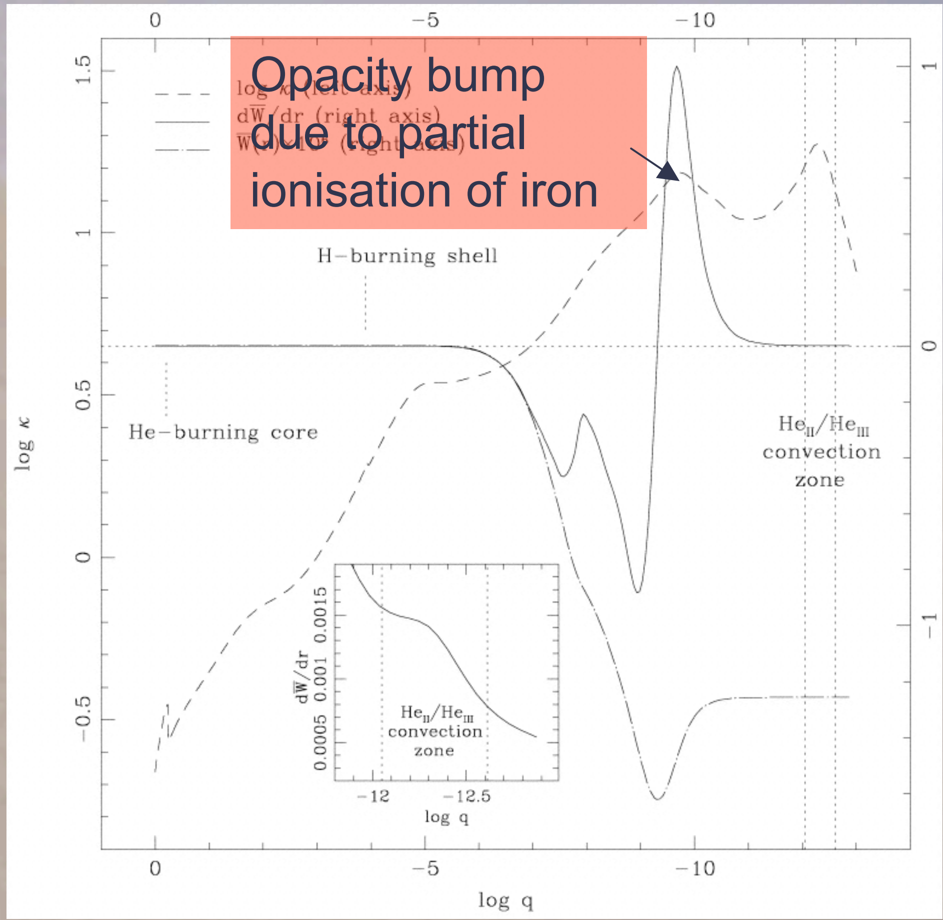
5) SdO pulsators (1)

(Woudt et al. 2006)

- 10 pulsations detected for prototype with periods between 60-120 s and *A*< 40 mmag

The EC 14026 stars - fast sdB pulsators

- Driving mechanism well-understood
- Quantitative interpretations of period spectra (asteroseismology) achieved for 9 targets
- Remaining problem: the co-existence of pulsators and non-pulsators in the same part of the H-R diagram



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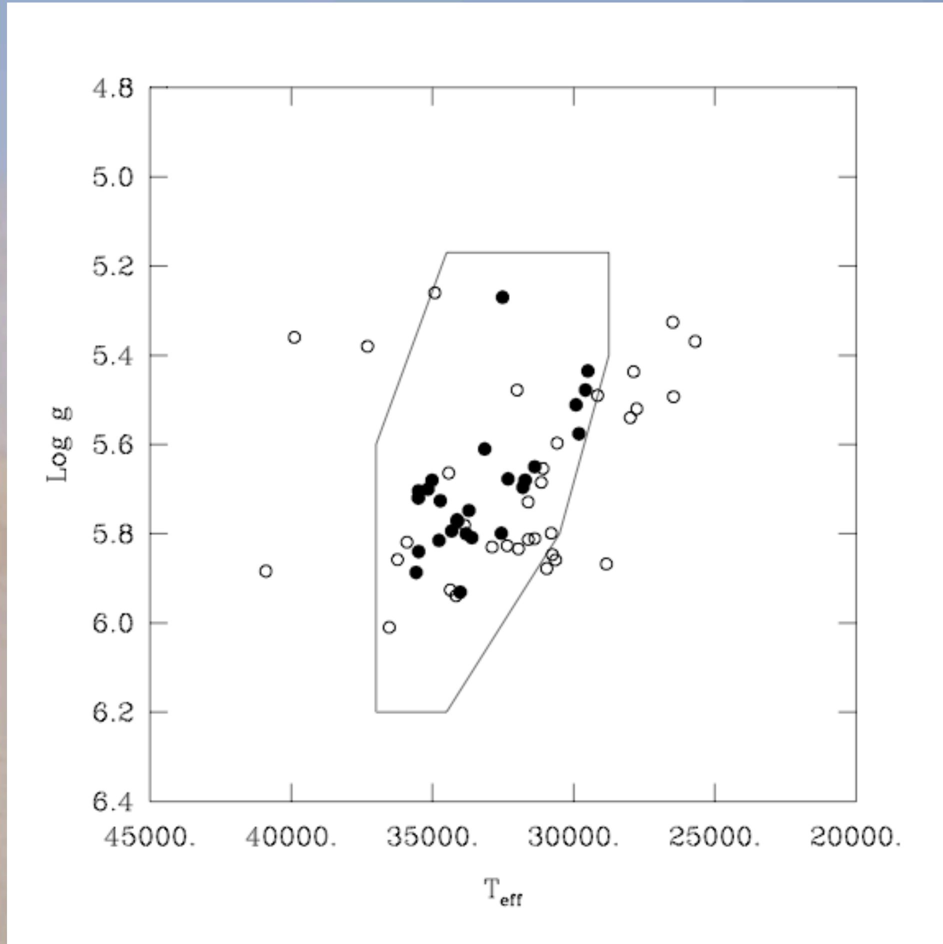
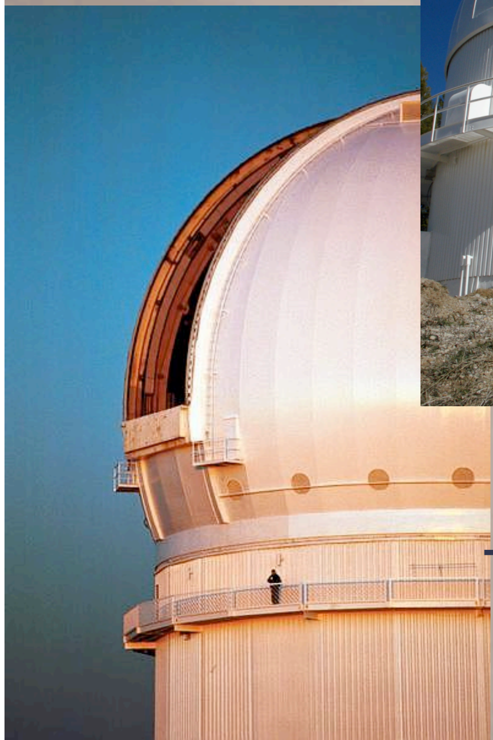
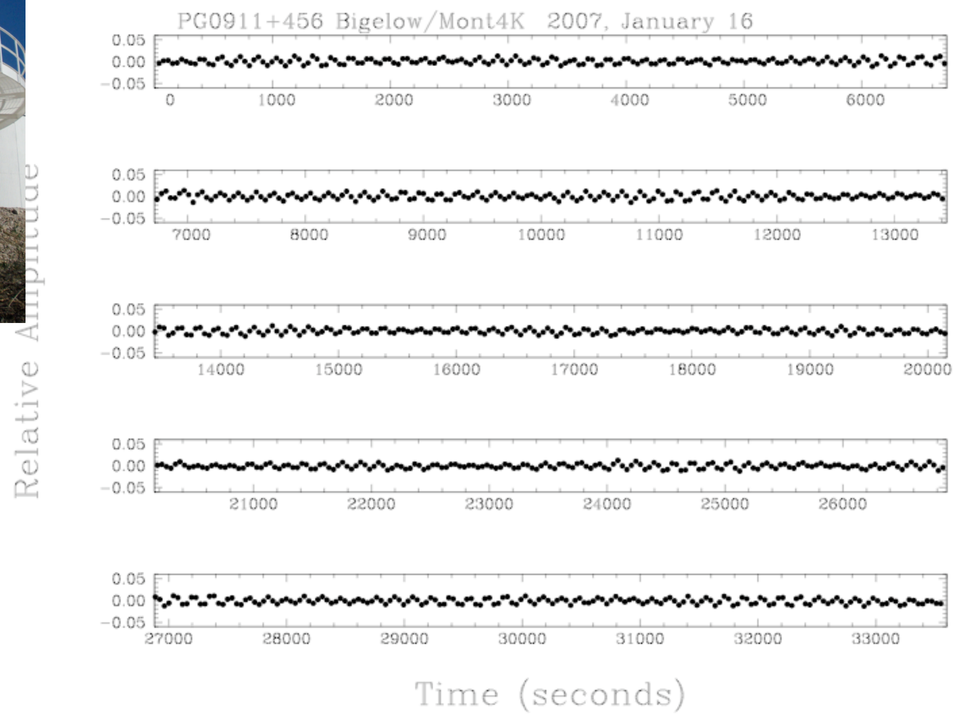


- FUSE spectra show no difference in atmospheric metal abundance between pulsators and non-pulsators…(Blanchette et al. 2006)

Asteroseismology from A to Z: PG 0911+456

1) Obtain a high-quality / long light curve





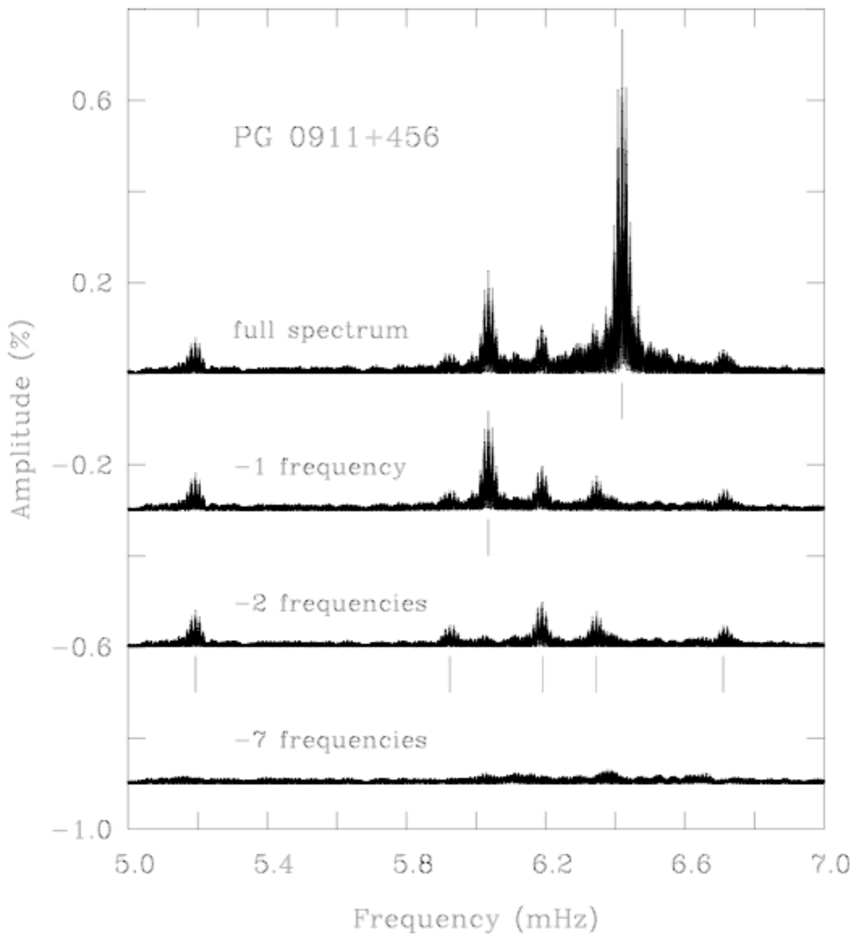
Mt. Bigelow

+Mont4kccd

CFHT + LaPoune

Asteroseismology from A to Z: Feige 48

2) Extract of order 5-10 pulsation frequencies

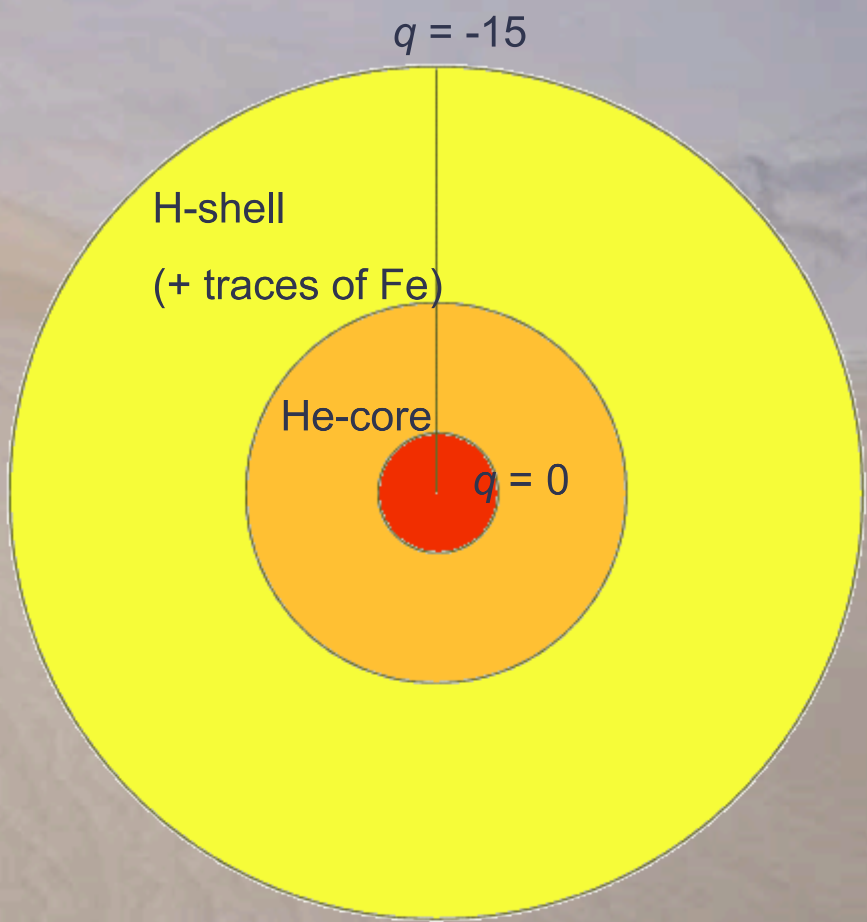


Rank	P (s)	A (%)
4	192.6	0.08
6	168.8	0.05
2	165.7	0.22
3	161.6	0.10
5	157.6	0.08
1	155.8	0.76
7	149.0	0.05

- 7 independent harmonic oscillations to be used in the asteroseismological analysis

Asteroseismology from A to Z: Feige 48

3) Search for the "optimal" model in 4-d parameter space



4 stellar parameters:

- effective temperature T_{eff}
- surface gravity log *g*
- total mass *M*
- depth of the H transition zone log *q*(H) = log [*M(H)/M]*

Asteroseismology from A to Z: Feige 48

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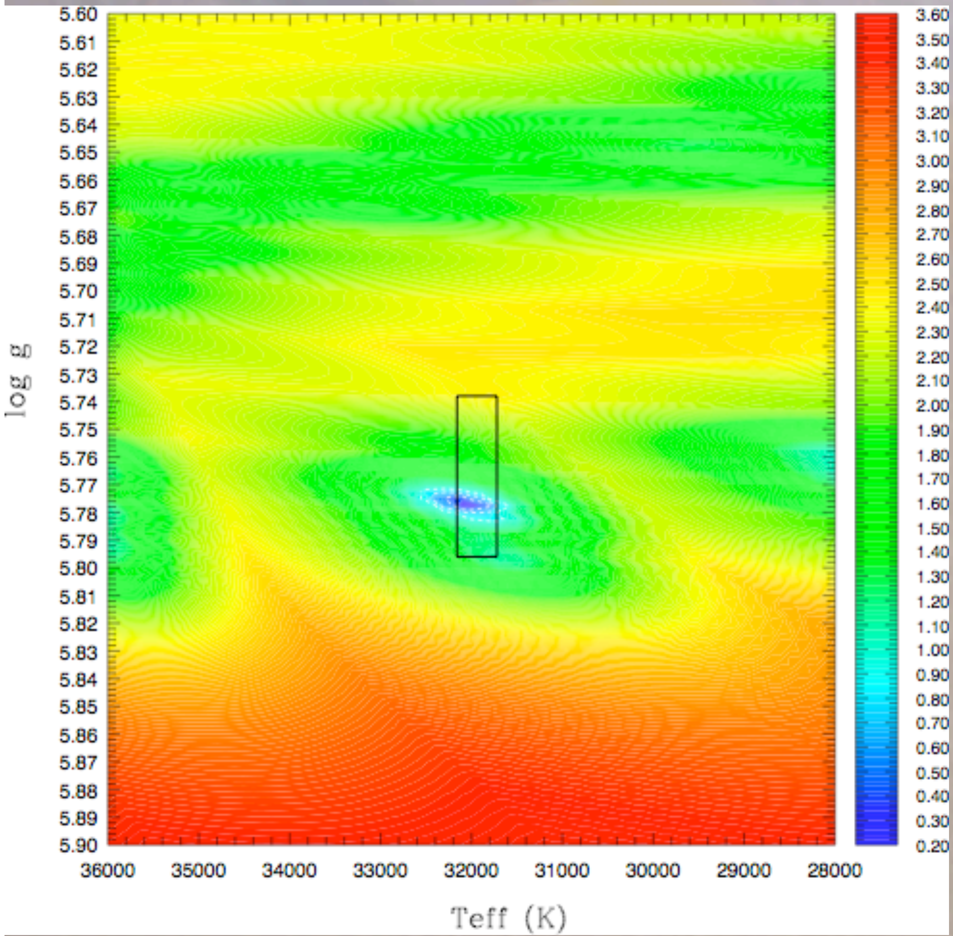
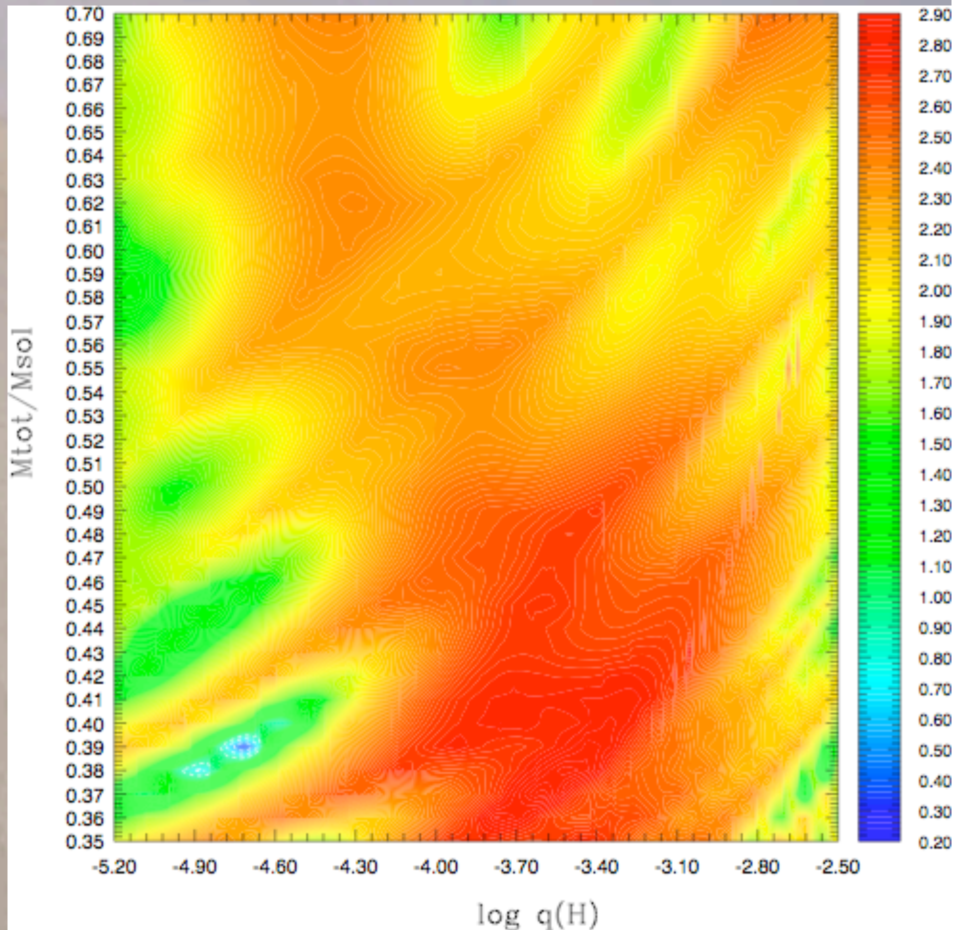
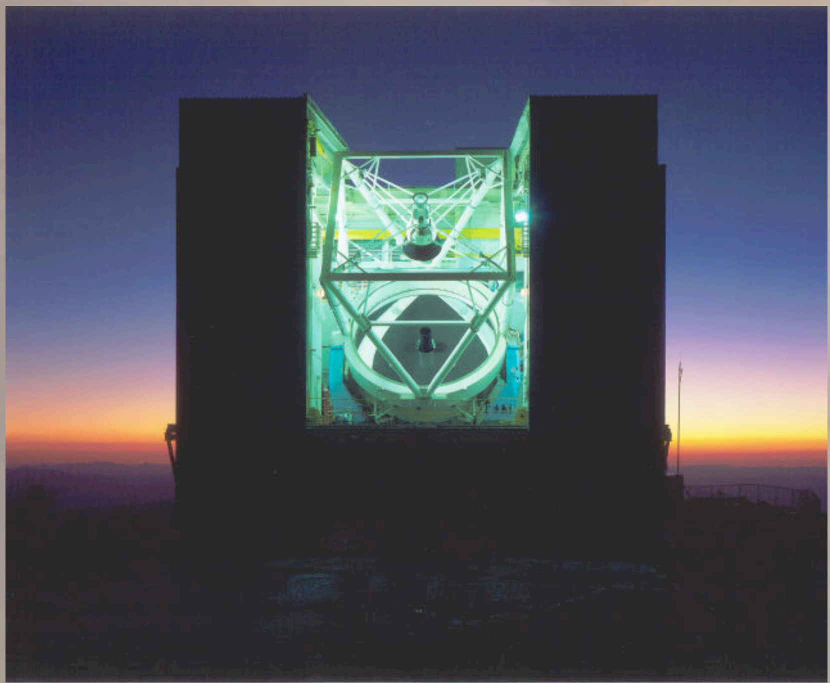


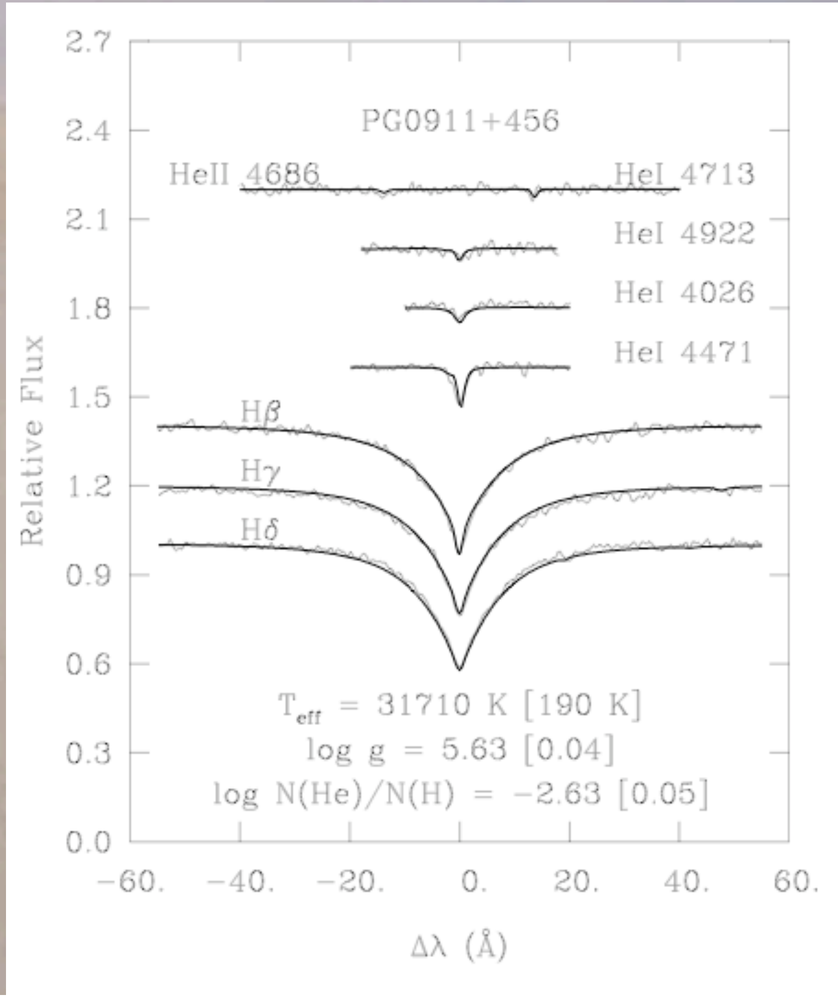


Asteroseismology from A to Z: Feige 48

4) Use spectroscopic log *g* and T_{eff} to discriminate / constrain families of optimal models



MMT



Asteroseismology from A to Z: Feige 48

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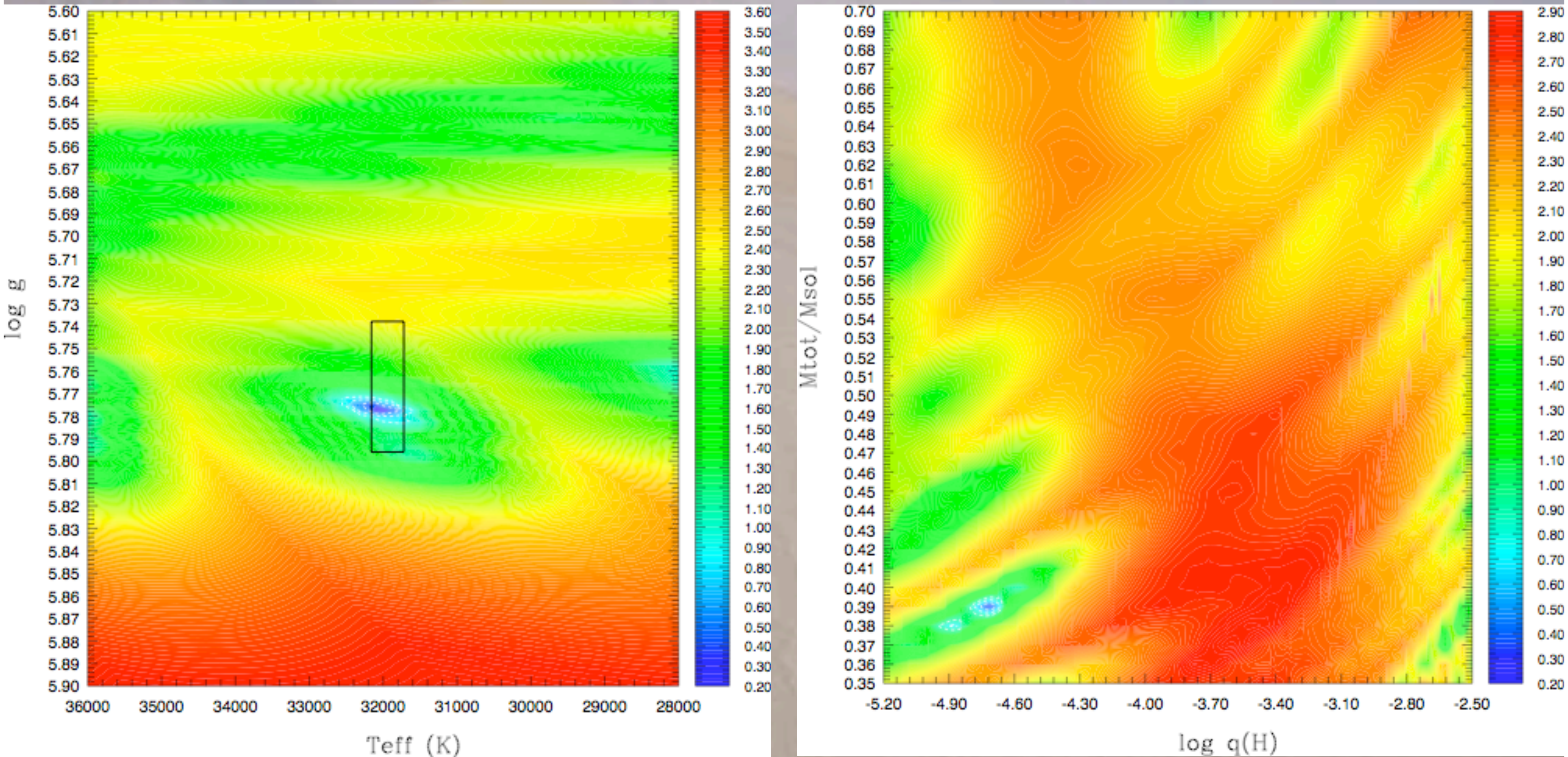
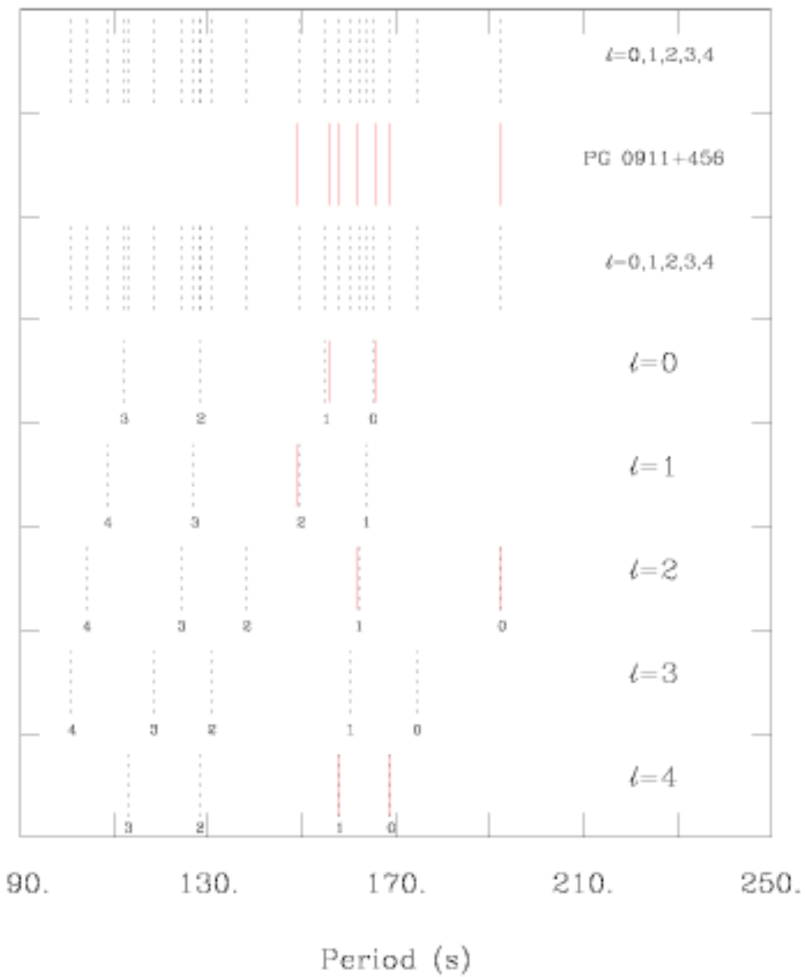


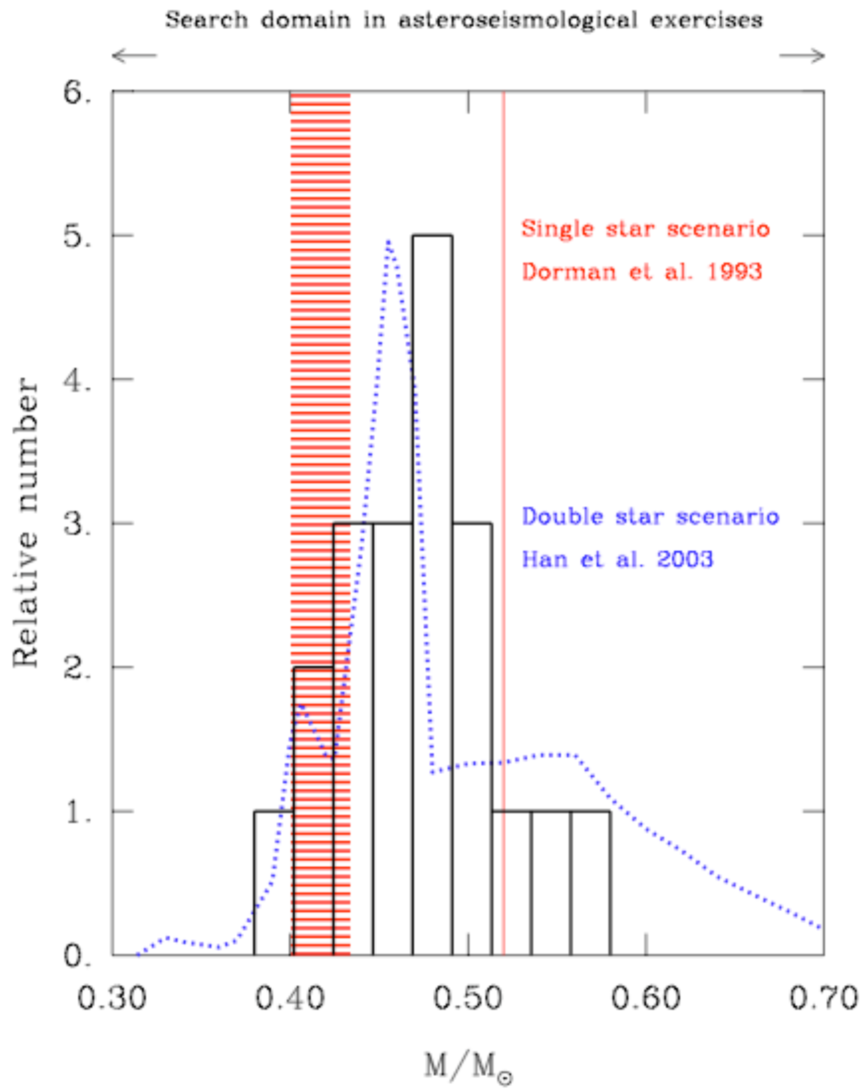
Asteroseismology from A to Z: Feige 48

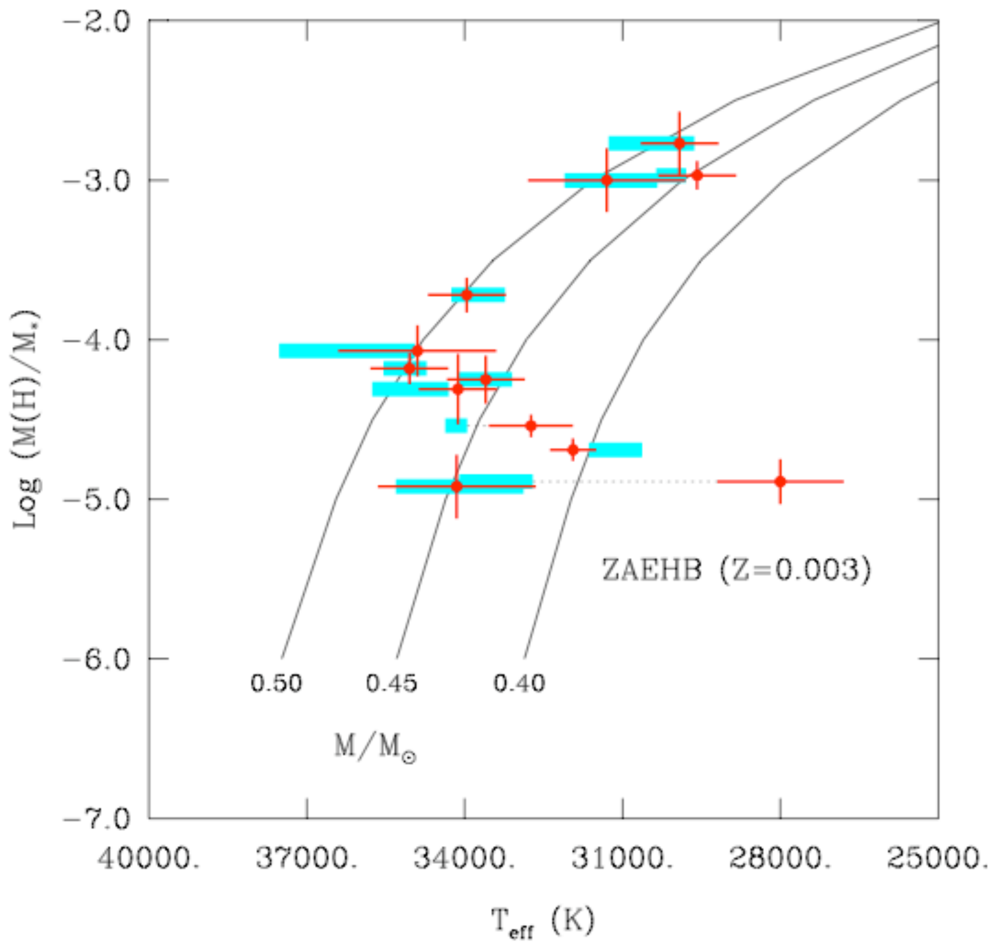
5) Determine best values for model parameters and uncertainties



Quantity	Estimated value
T_{eff} (K) (spec)	31,940 ± 220
log g	5.777 ± 0.002
M/M☉	0.39 ± 0.01
log(Menv/M)	-4.69 ± 0.07
R/R☉	0.134 ± 0.002
L/L☉	16.8 ± 1.0
MV	4.82 ± 0.04
d (parsec)	948 ± 106

Results from asteroseismological analyses to date





Conclusion

- EC 14026 stars are very willing collaborators for asteroseismology -> we estimate that we need around 20 asteroseismic targets to start discriminating between different evolutionary scenarios (currently have 12)
- Verify the mode identification inferred from asteroseismology using independent means, e.g. multi-colour photometry, time-series spectroscopy
- Other types of EHB pulsators are more elusive - need significant developments on both the observational and theory front
- Techniques developed for the asteroseismological analysis of sdB stars can be applied to other pulsating stars, e.g. white dwarfs