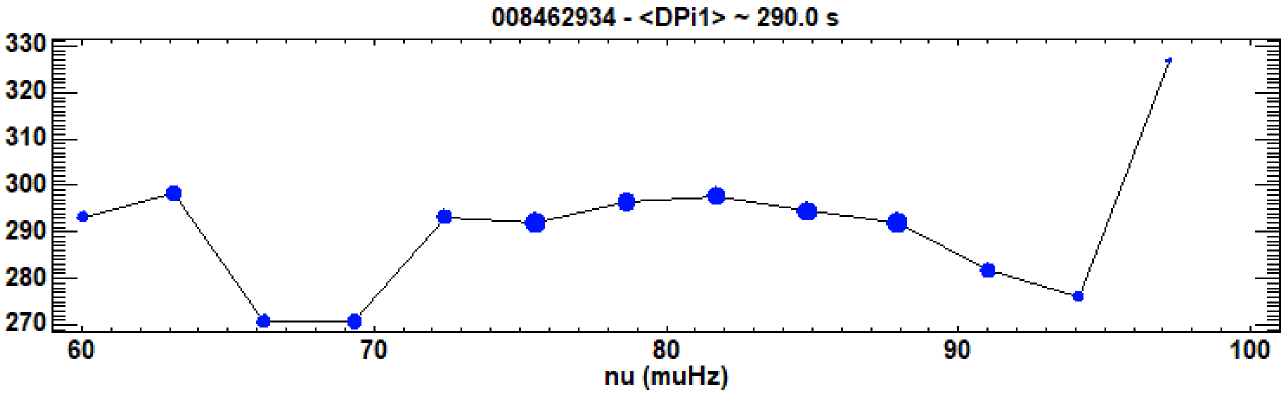
Red giant cores



Benoît Mosser

+ many colleagues

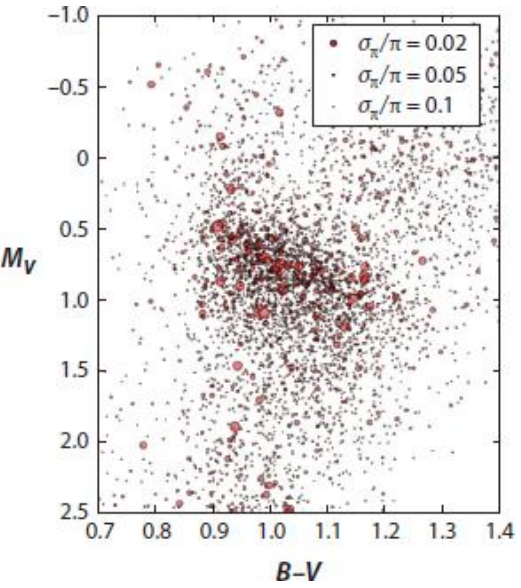
Observatoire de Paris

Red clump stars

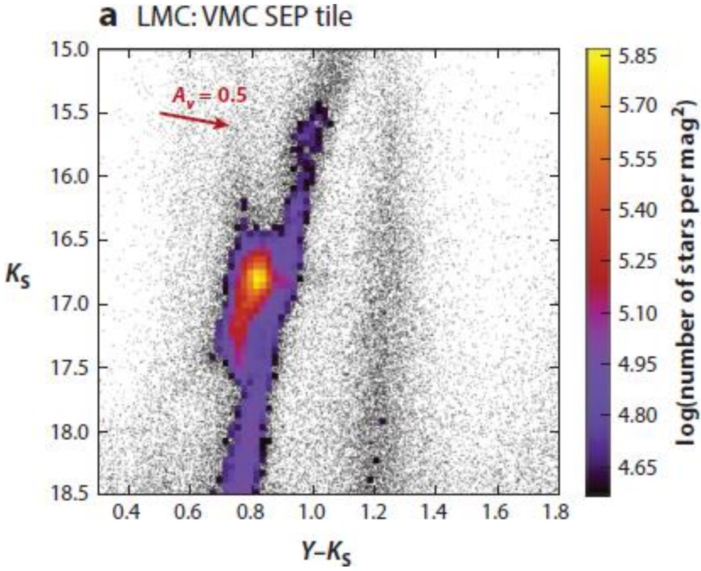
- Standard candles
- Extinction probes
- Density probes
- Kinematical and chemical-evolution probes
- Age probes

(Girardi 2016)

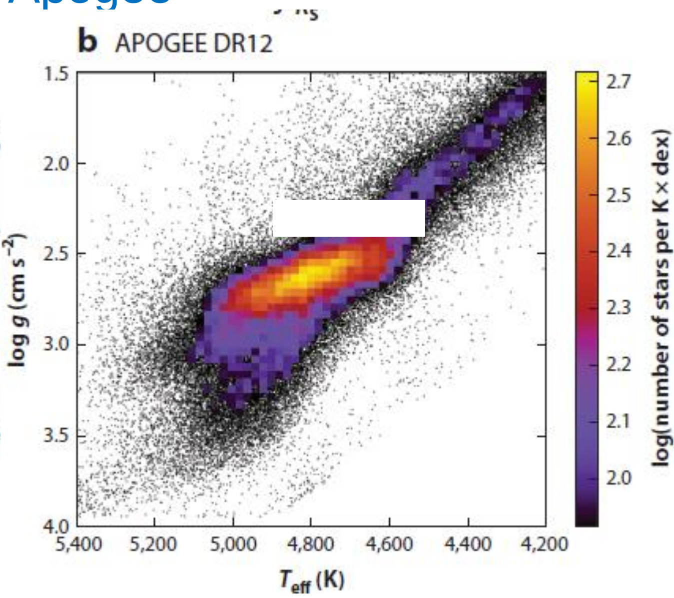
Astrometric surveys; Hipparcos



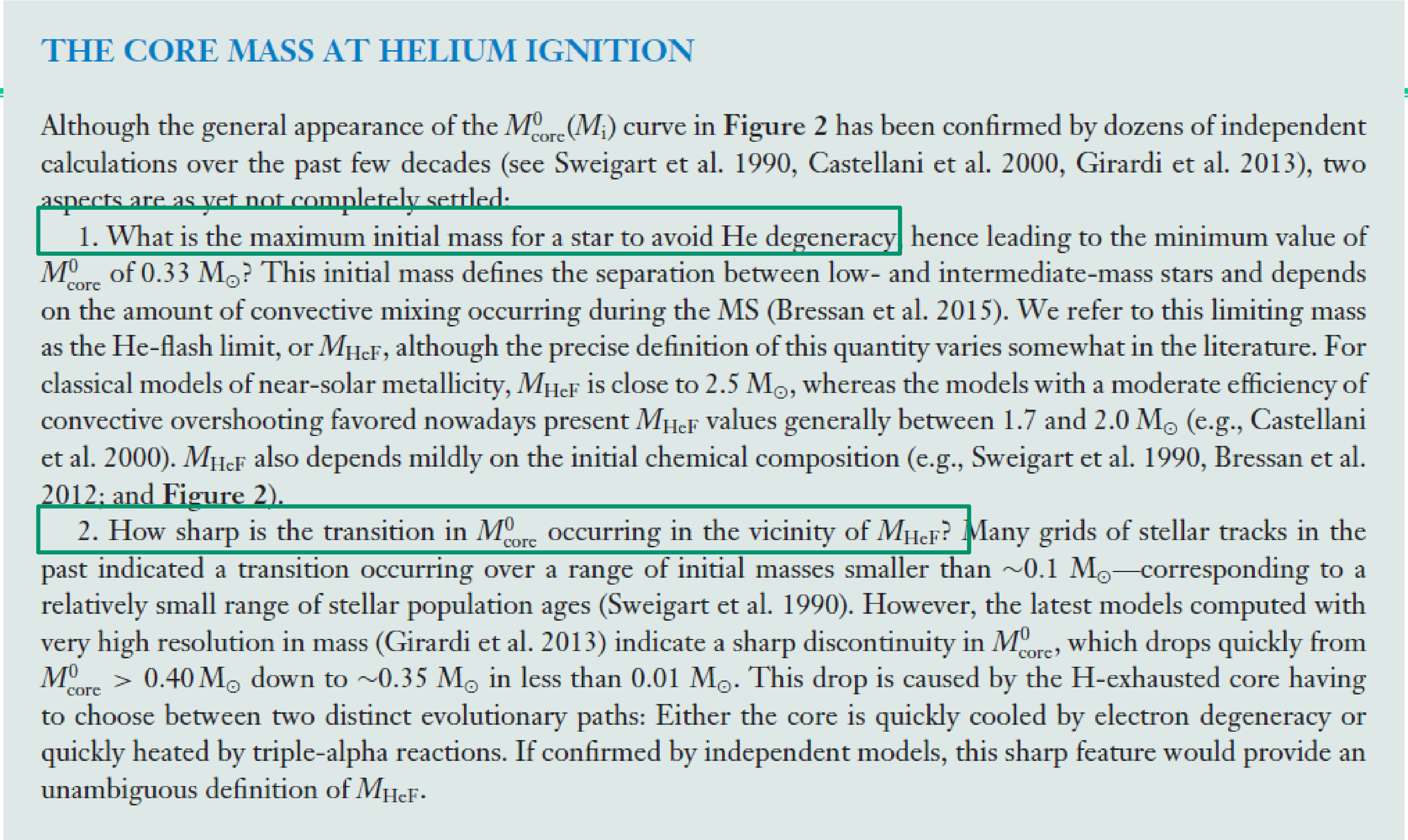
Photometric surveys; Vista



Spectrometric surveys; Apogee



+ Seismic surveys



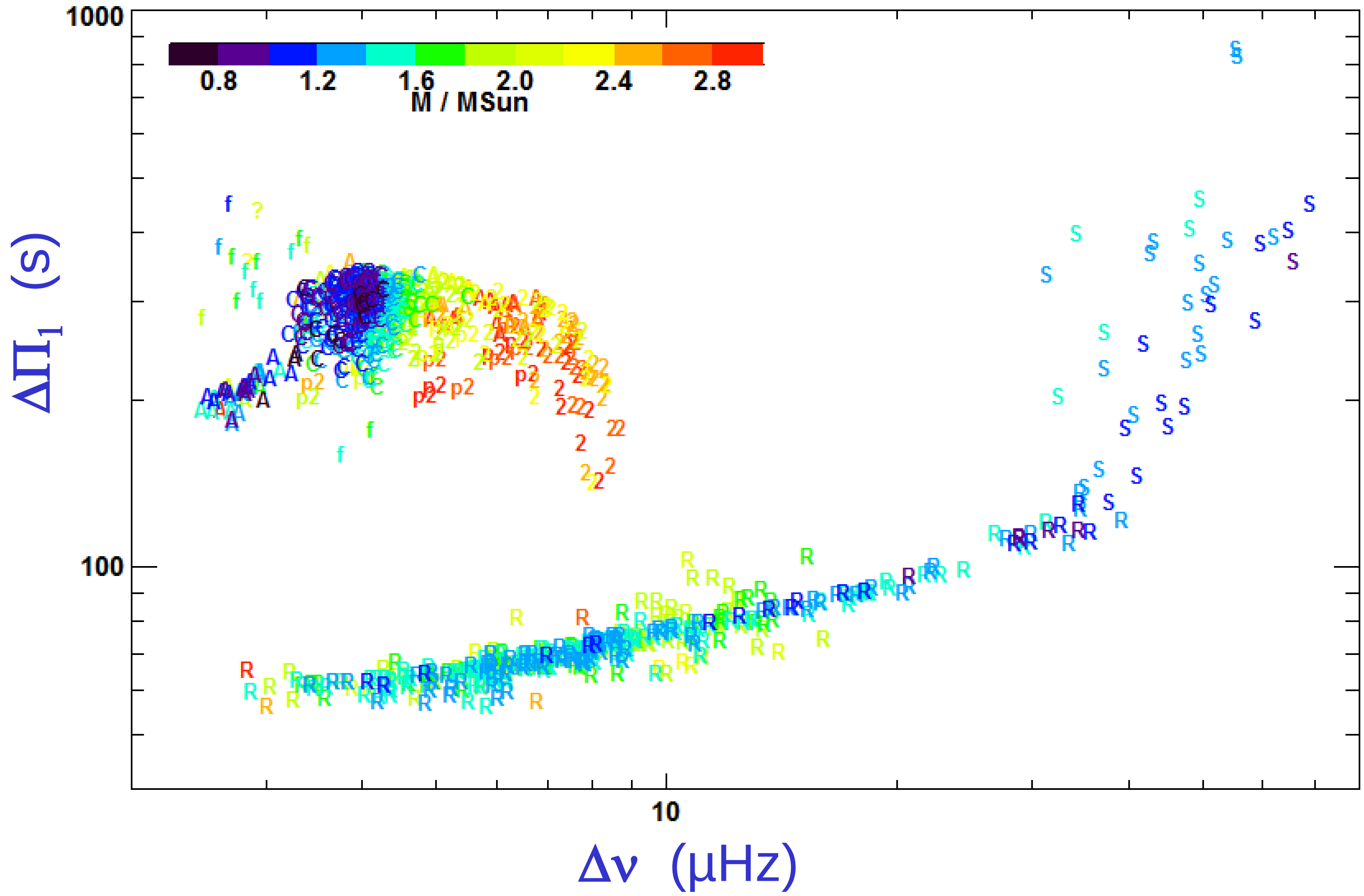
THE CORE MASS AT HELIUM IGNITION

Although the general appearance of the $M^0_{\mathrm{core}}(M_{\mathrm{i}})$ curve in **Figure 2** has been confirmed by dozens of independent calculations over the past few decades (see Sweigart et al. 1990, Castellani et al. 2000, Girardi et al. 2013), two aspects are as yet not completely settled:

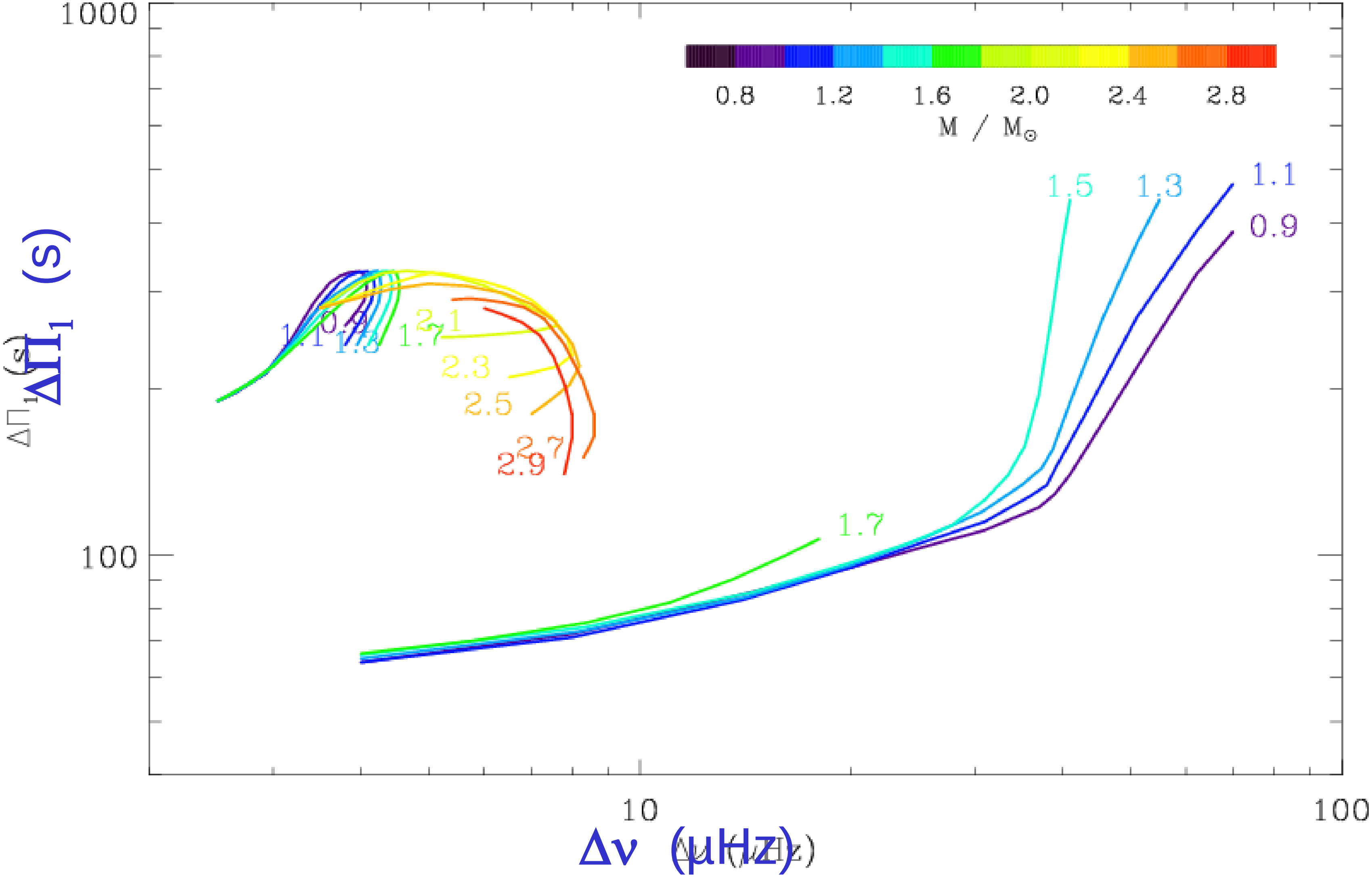
1. What is the maximum initial mass for a star to avoid He degeneracy, hence leading to the minimum value of M^0_{core} of 0.33 $M_\odot$? This initial mass defines the separation between low- and intermediate-mass stars and depends on the amount of convective mixing occurring during the MS (Bressan et al. 2015). We refer to this limiting mass as the He-flash limit, or M_{HeF}, although the precise definition of this quantity varies somewhat in the literature. For classical models of near-solar metallicity, M_{HeF} is close to 2.5 $M_\odot$, whereas the models with a moderate efficiency of convective overshooting favored nowadays present M_{HeF} values generally between 1.7 and 2.0 $M_\odot$ (e.g., Castellani et al. 2000). M_{HeF} also depends mildly on the initial chemical composition (e.g., Sweigart et al. 1990, Bressan et al. 2012; and **Figure 2**).
2. How sharp is the transition in M^0_{core} occurring in the vicinity of M_{HeF}? Many grids of stellar tracks in the past indicated a transition occurring over a range of initial masses smaller than ∼0.1 $M_\odot$—corresponding to a relatively small range of stellar population ages (Sweigart et al. 1990). However, the latest models computed with very high resolution in mass (Girardi et al. 2013) indicate a sharp discontinuity in M^0_{core}, which drops quickly from $M^0_{\mathrm{core}} > 0.40\,M_\odot$ down to $\sim 0.35\ M_\odot$ in less than 0.01 $M_\odot$. This drop is caused by the H-exhausted core having to choose between two distinct evolutionary paths: Either the core is quickly cooled by electron degeneracy or quickly heated by triple-alpha reactions. If confirmed by independent models, this sharp feature would provide an unambiguous definition of M_{HeF}.

Girardi 2016 Annu. Rev. Astron. Astrophys. 54:95–133

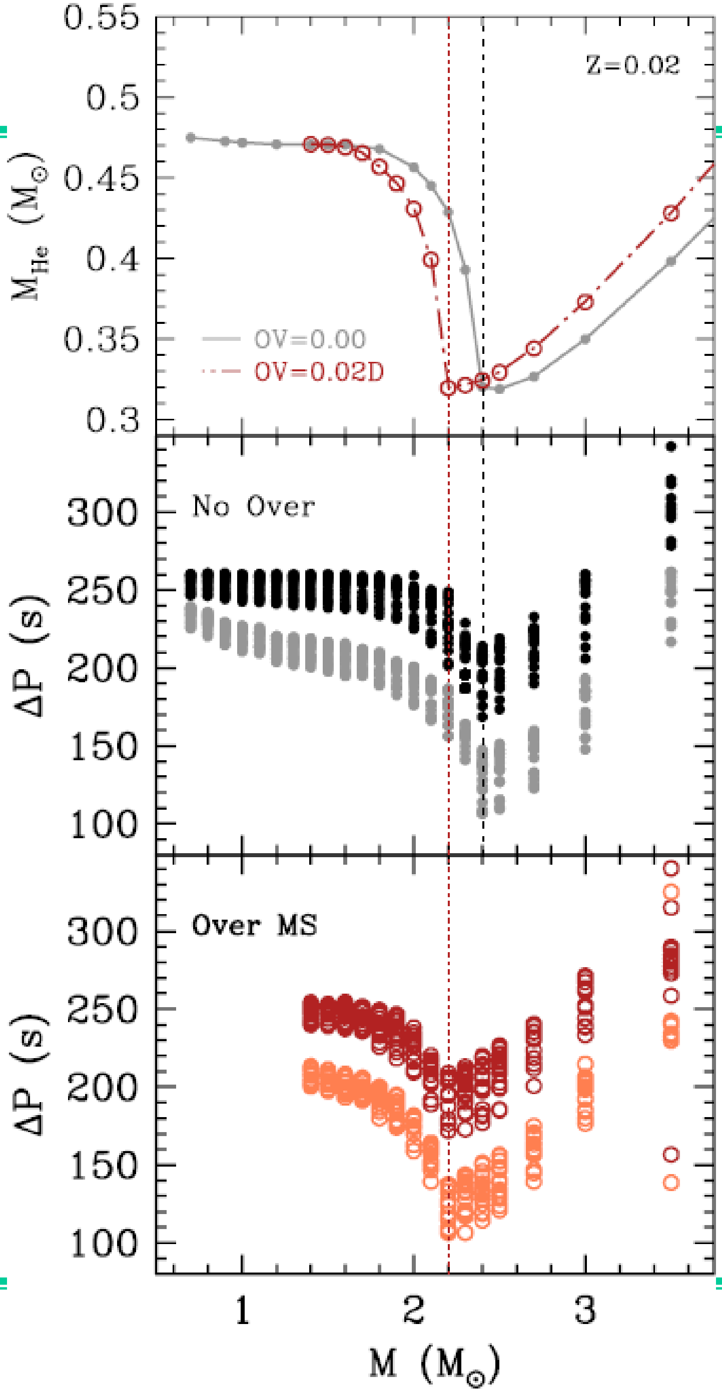
Seismic observable: period spacings



Seismic observable: period spacings



Modelling: core mass



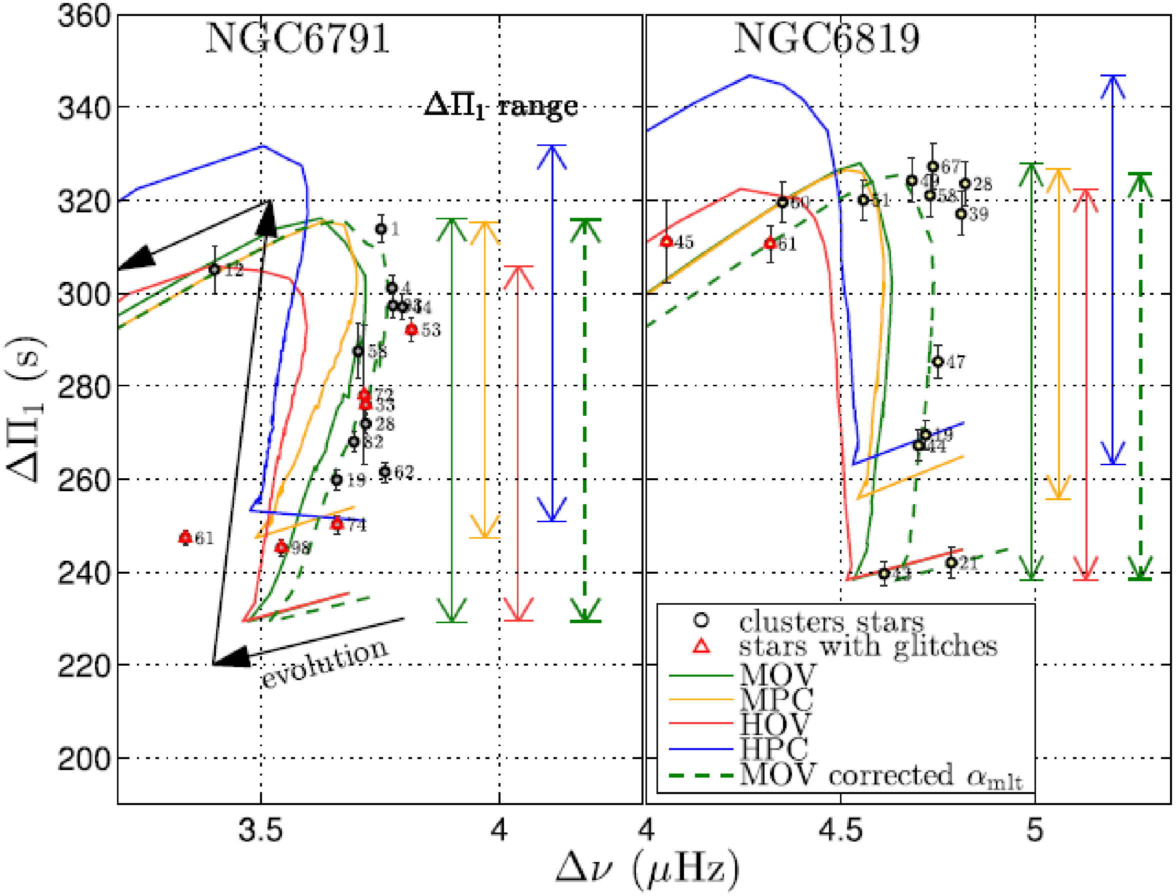
Montalban et al. (2013)

Period spacing ≡ core mass

Influence of the overshooting during the MS phase

-

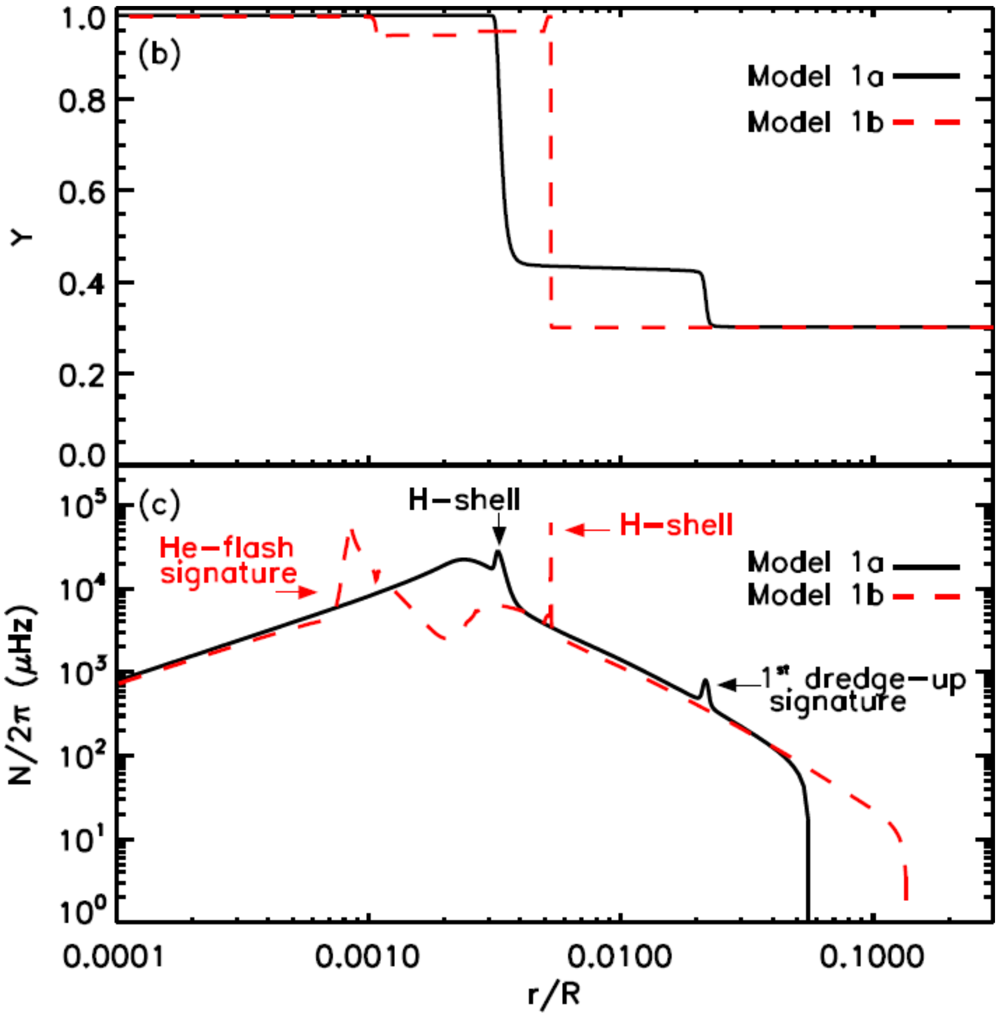
Red giants in open clusters



Bossini et al. (2017)
→ Constraints on core mixing

“We find that models with moderate overshooting successfully reproduce the range observed of ΔΠ in clusters….
In particular, we show that there is no evidence for the need to extend the size of the adiabatically stratified core, at least at the beginning of the HeCB phase”

Buoyancy glitches



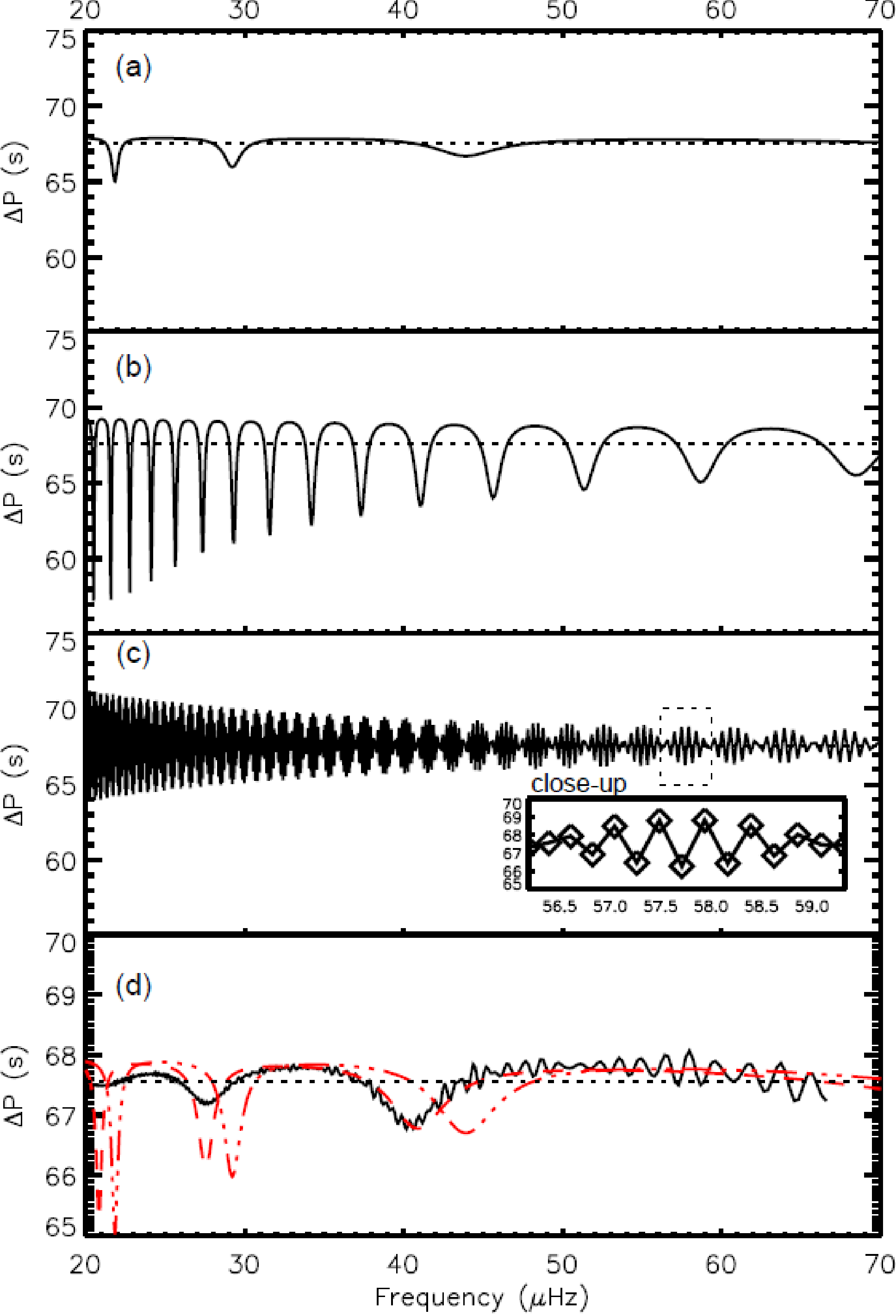
”STRUCTURAL GLITCHES NEAR THE CORES OF RED GIANTS REVEALED BY OSCILLATIONS IN G-MODE PERIOD SPACINGS FROM STELLAR MODELS”

Cunha et al 2015, ApJ 805, 127

1a model = RGB

1b model = clump

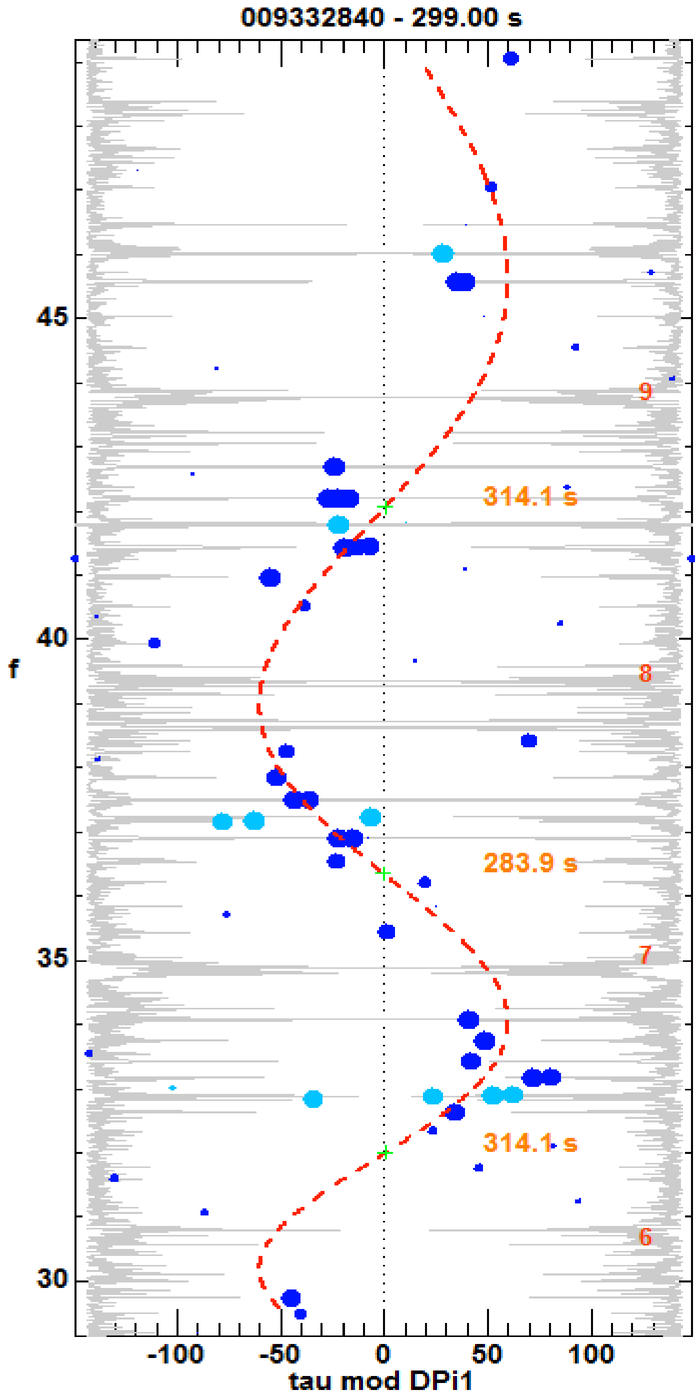
Buoyancy glitches



Period spacings for **pure gravity modes** in model 1A

From shallow to deep glitch

Observed buoyancy glitches



KIC 9332840

- At low frequency: 298 s

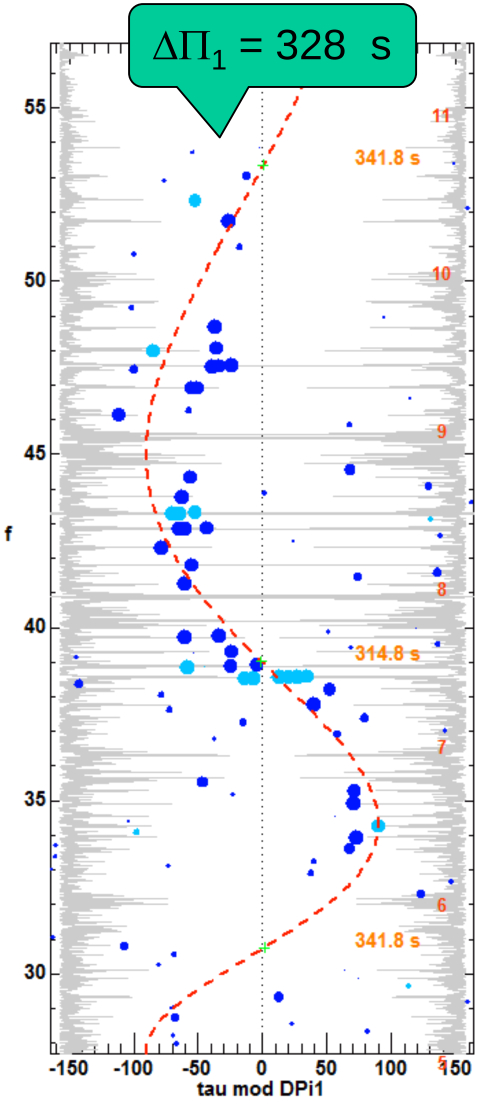
- At high frequency: 306 s

Mosser et al 2012, A&A 540

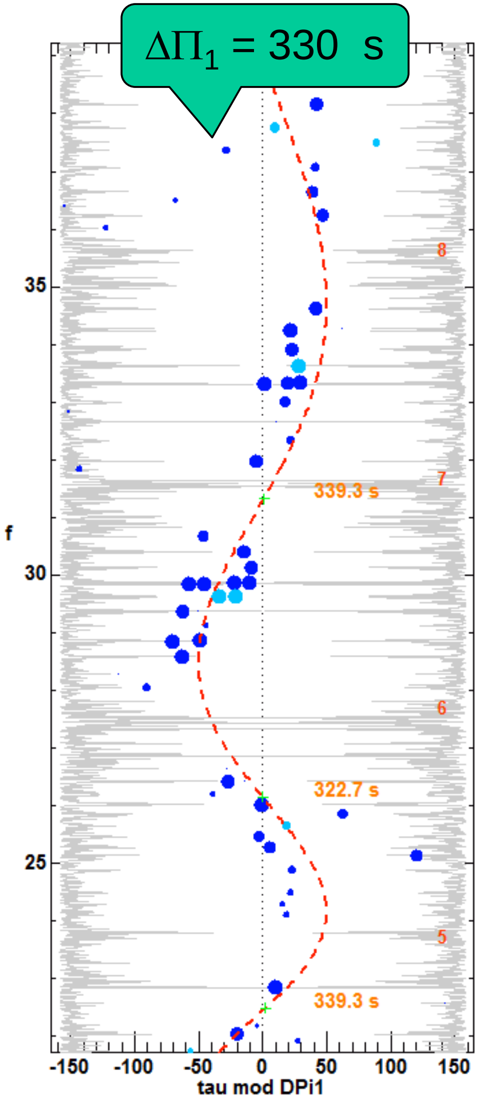
Here: deep glitch?

Cunha et al. 2015, ApJ 805, 127

Large modulation in the red clump



$\Delta\Pi_1$ = 328 s



$\Delta\Pi_1$ = 330 s

→ Glitches are very often present in red clump spectra

→ They most often show a periodic modulation

→ In a vast majority of cases, glitches are not an issue for measuring $\langle \Delta\Pi_1 \rangle$

→ Overshoot in the core to be included in the modelling

Bossini et al (2015), MNRAS 453, 2290
Lagarde et al (2015), A&A 590, A141

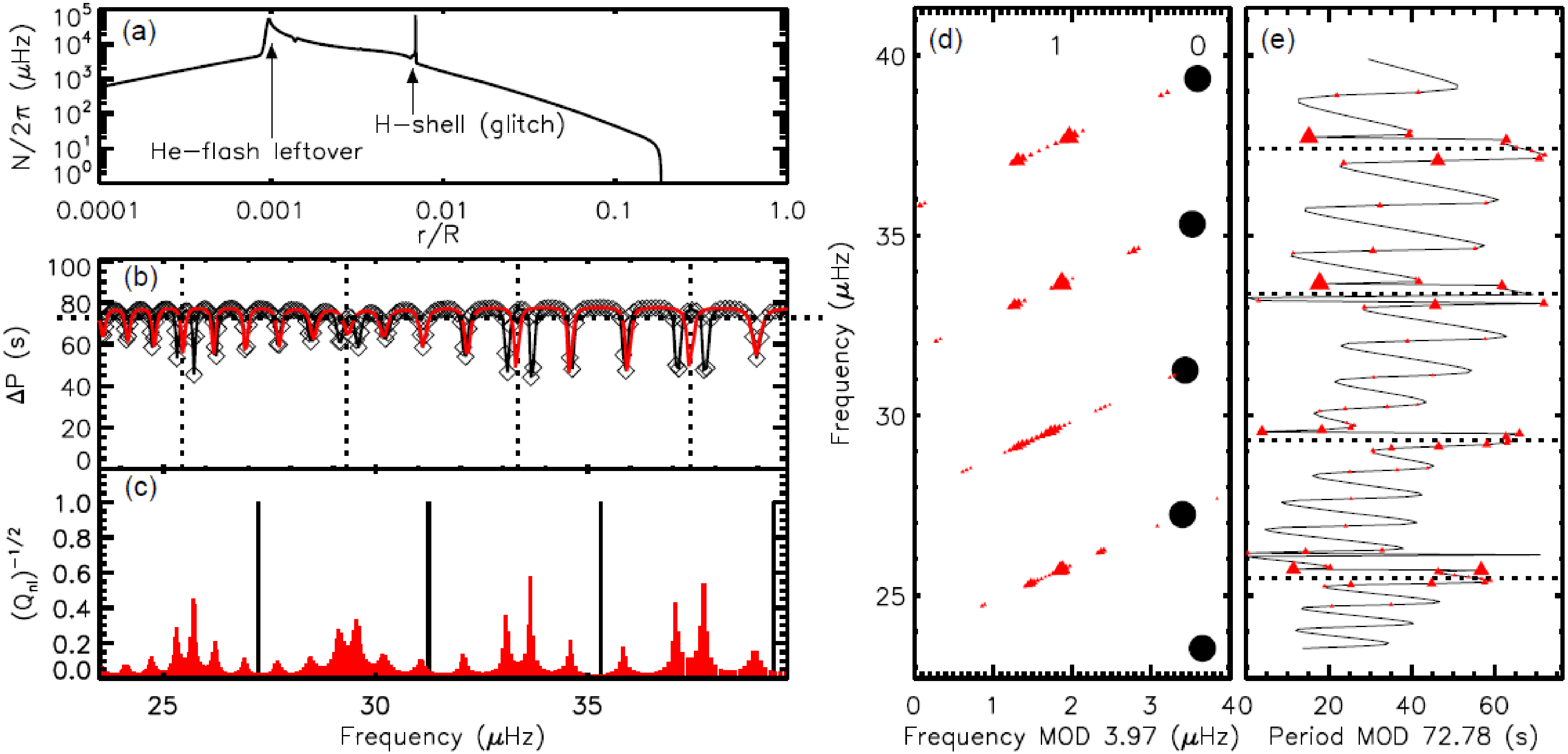
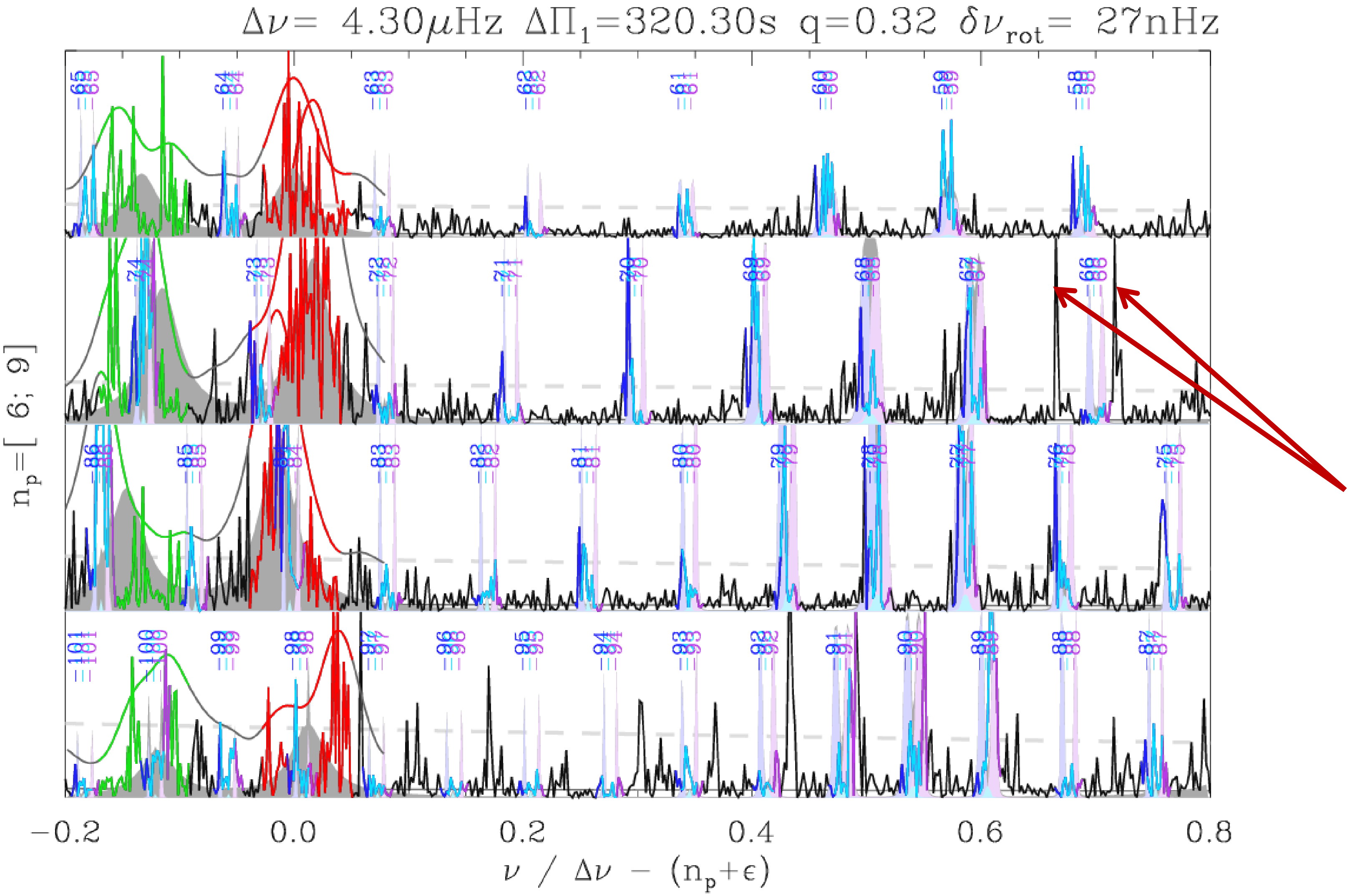


FIG. 11.— Model 2 (M = 1.0 $M_\odot$; $\nu_{\max}$= 31 μHz) - (a) Buoyancy frequency with key features indicated. (b) Period spacing of pure g modes (as in section 3.2.2) (red) and full numerical solution using GYRE (black). The vertical dotted lines indicate the approximate position of the dipole acoustic modes. They have been positioned relative to the nearest radial mode in agreement with Stello et al. (2014) (see also Huber et al. (2010); Montalbán et al. (2010)). Horizontal dotted line marks $\Delta P_{\rm as}$. (c) Pseudo amplitude spectrum based purely on mode inertia, normalized to the radial modes. Dipole modes are shown in red and radial modes in black. (d) Échelle diagram. The abscissa is the frequency modulo $\Delta\nu$. Symbol size follows the peak heights in panel (c). (e) Period échelle diagram. Symbol sizes as in panel (d). The abscissa is the period modulo $\Delta P_{\rm as}$. Dotted lines indicate the approximate position of the dipole acoustic modes. Black curve connects all dipole modes.


Δν= 4.30μHz ΔΠ1=320.30s q=0.32 δνrot= 27nHz
-65 -64 -63 -62 -61 -60 -59 -58
-74 -73 -72 -71 -70 -69 -68 -67 -66
-86 -85 -84 -83 -82 -81 -80 -79 -78 -77 -76 -75
-101 -100 -99 -98 -97 -96 -95 -94 -93 -92 -91 -90 -89 -88 -87
n_p=[6; 9]
−0.2
0.0
0.2
0.4
0.6
0.8
ν / Δν − (n_p+ϵ)

(Temporary) conclusion

Physics in the core

Moderate overshoot

Period spacings

Identification of buoyancy glitches
→ Accurate measurement of $\langle \Delta\Pi_1 \rangle$
(~ 0.07 % relative accuracy)

Red-clump stars as:
standard candles, kinematical and chemical-evolution probes, extinction probes, age probes, density probes

Probing the stellar core

Don Diègue	Rodrigue, as-tu du **cœur** ?	*Rodrigue, are you brave?*
Don Rodrigue	Tout autre que mon père L’éprouverait sur l’heure	*Any but my father* *Might test it at this moment*
	Pierre Corneille	**Stone Crow**
	le Cid, Acte I scène 5	*Cider, Act I Scene 5*