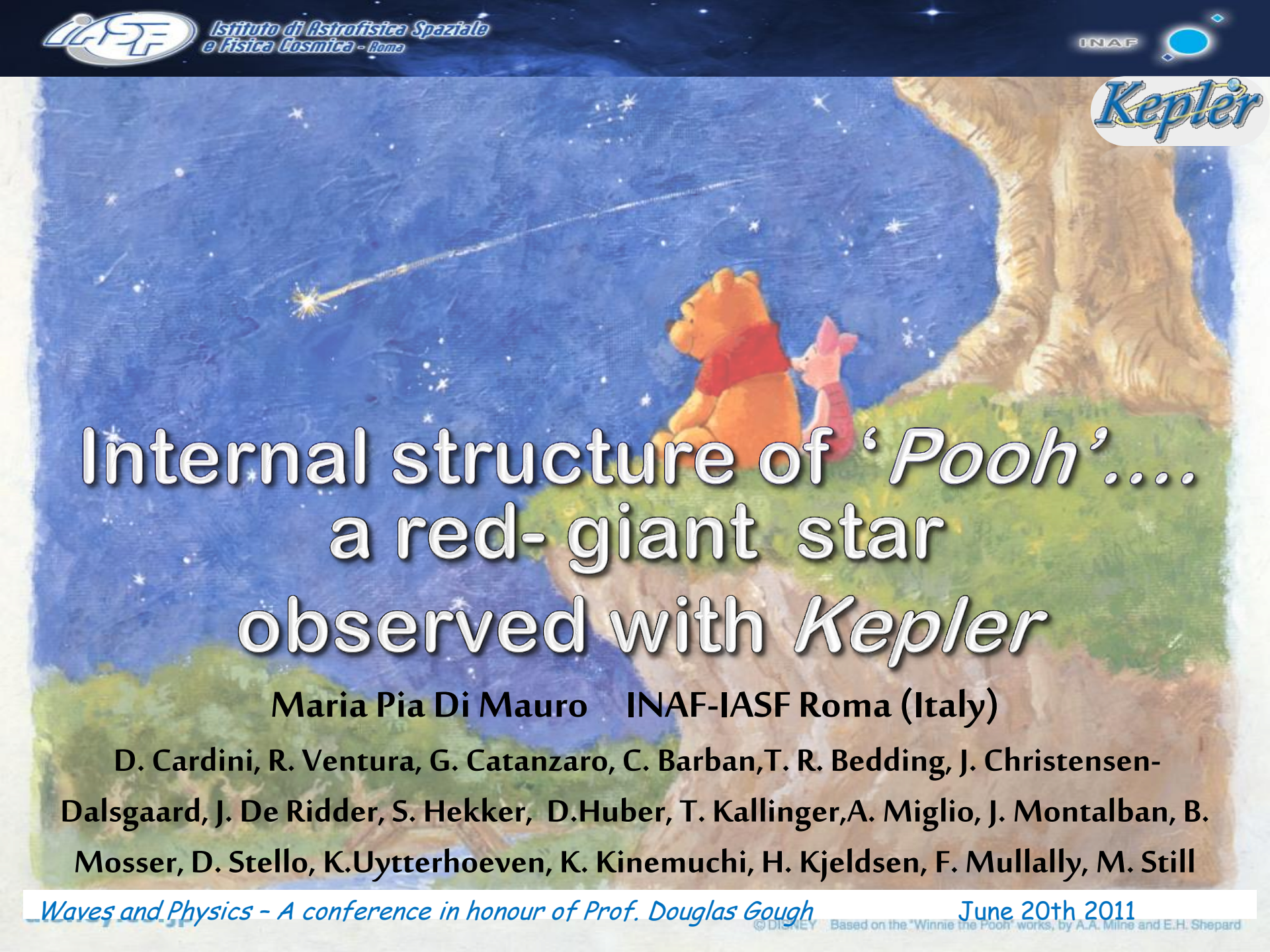


Internal structure of '*Pooh*'.... a red- giant star observed with *Kepler*

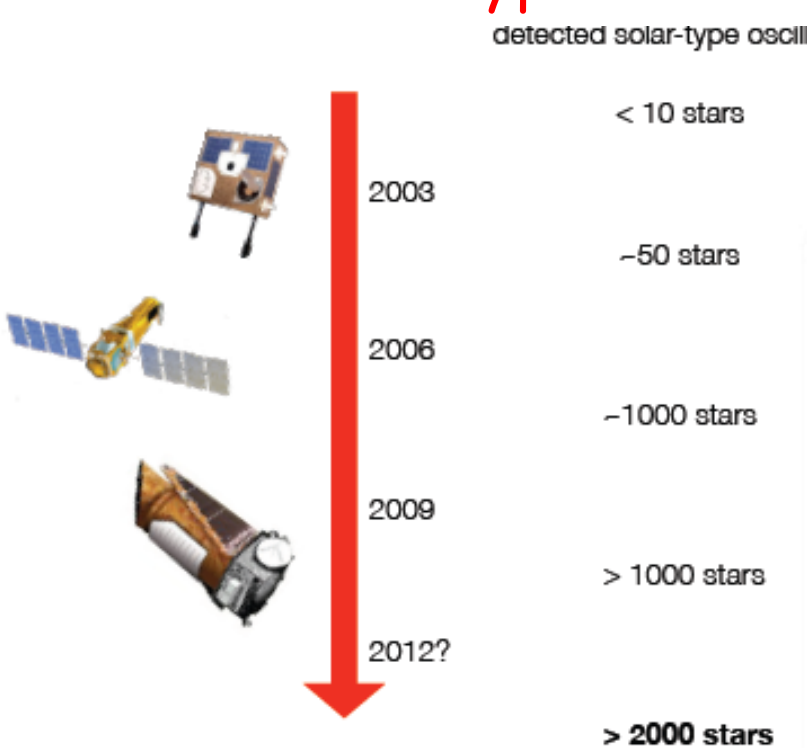
Maria Pia Di Mauro INAF-IASF Roma (Italy)

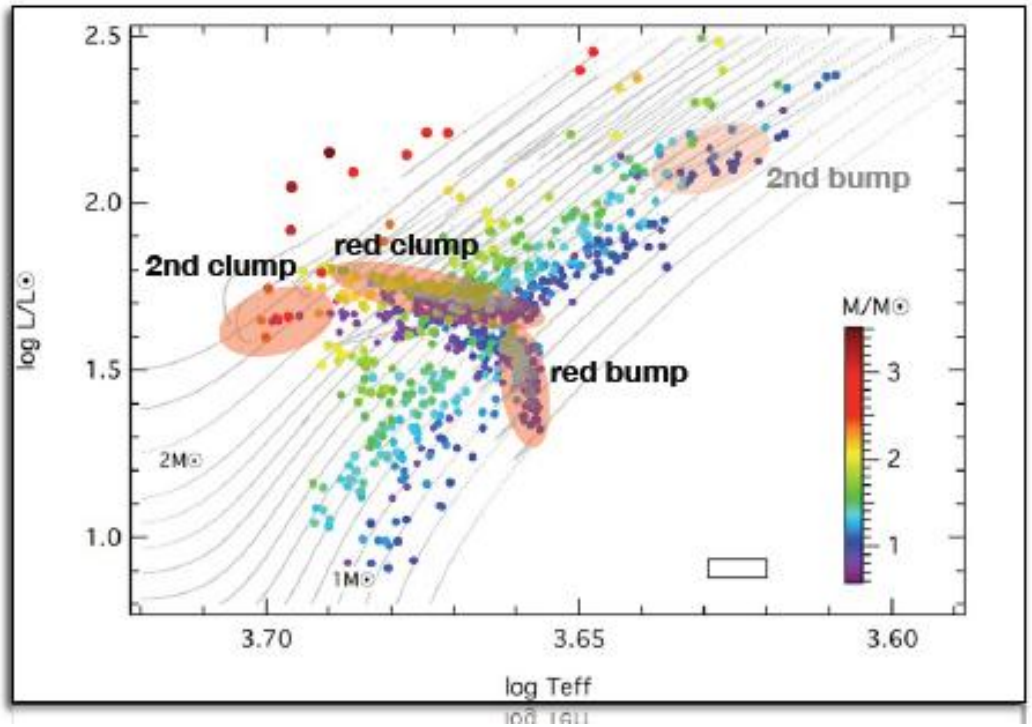
D. Cardini, R. Ventura, G. Catanzaro, C. Barban,T. R. Bedding, J. Christensen-Dalsgaard, J. De Ridder, S. Hekker, D.Huber, T. Kallinger,A. Miglio, J. Montalban, B. Mosser, D. Stello, K.Uytterhoeven, K. Kinemuchi, H. Kjeldsen, F. Mullally, M. Still

Waves and Physics – A conference in honour of Prof. Douglas Gough June 20th 2011

Red giants and oscillations

Number of red giants with detected solar-type oscillations

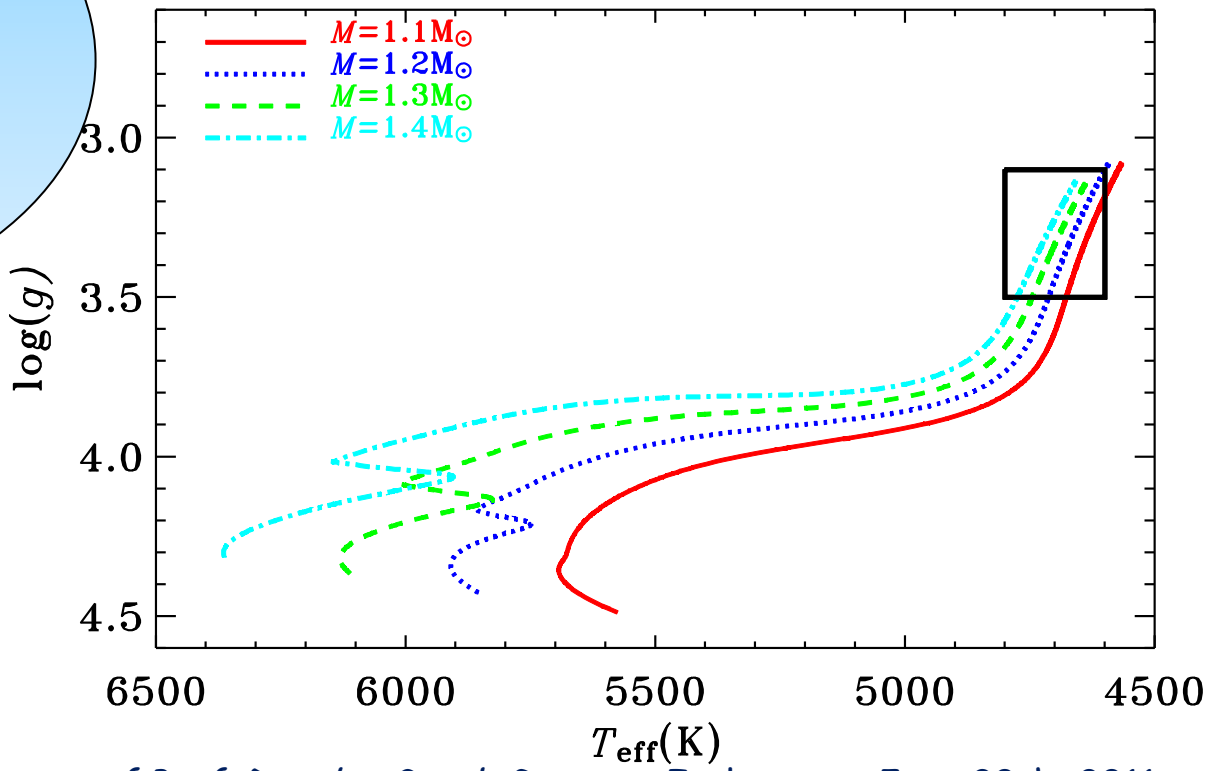




KIC 4351319, 'Pooh'

Spectroscopic observations at the 2.7m McDonald Observatory (V=10.19)

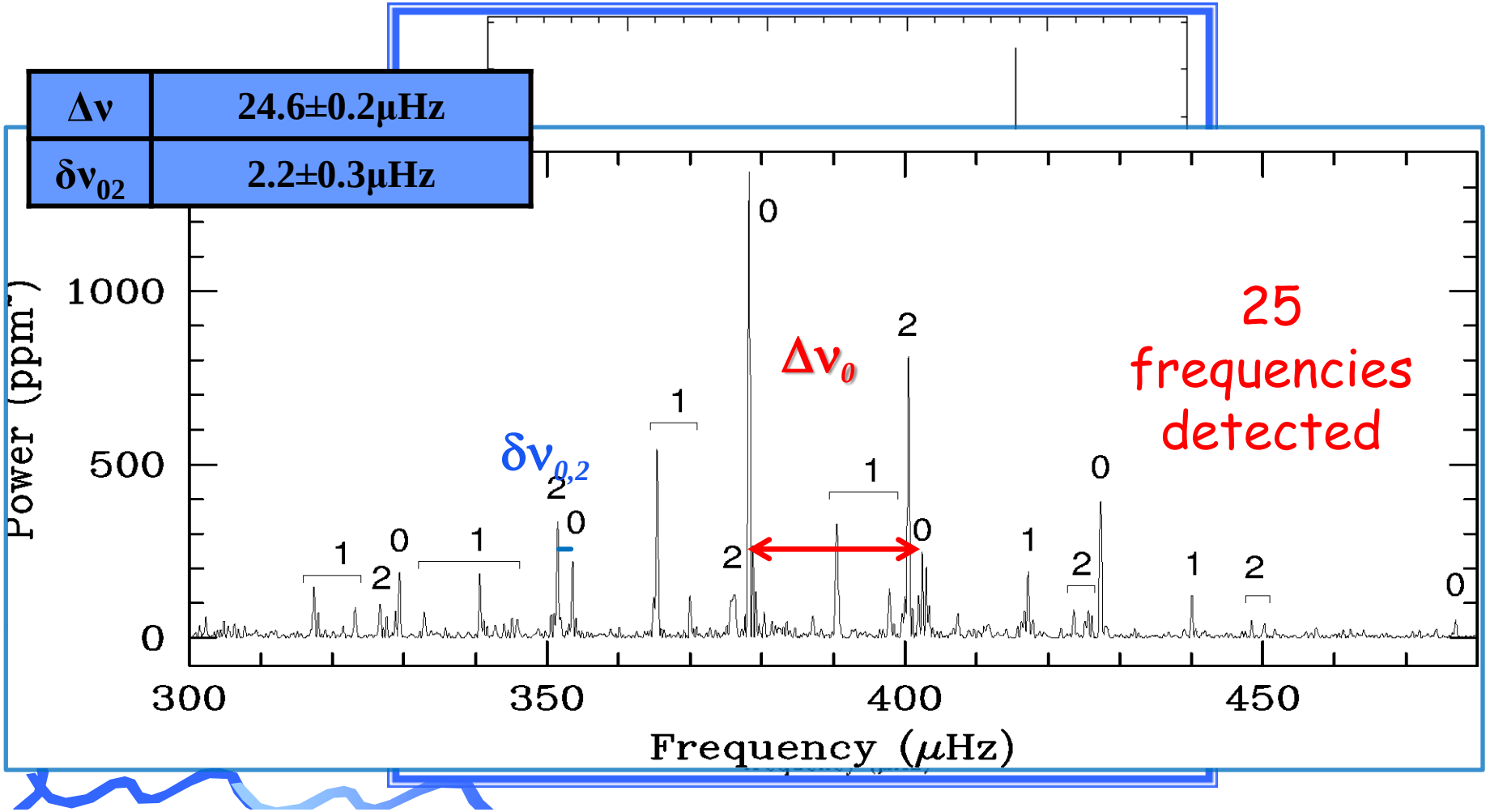
T_{eff} (K)	4700 ±50 K
log g	3.3 ± 0.1 dex
[Fe/H]	0.23 ± 0.15 dex
vsin*i*	6± 1 km/s



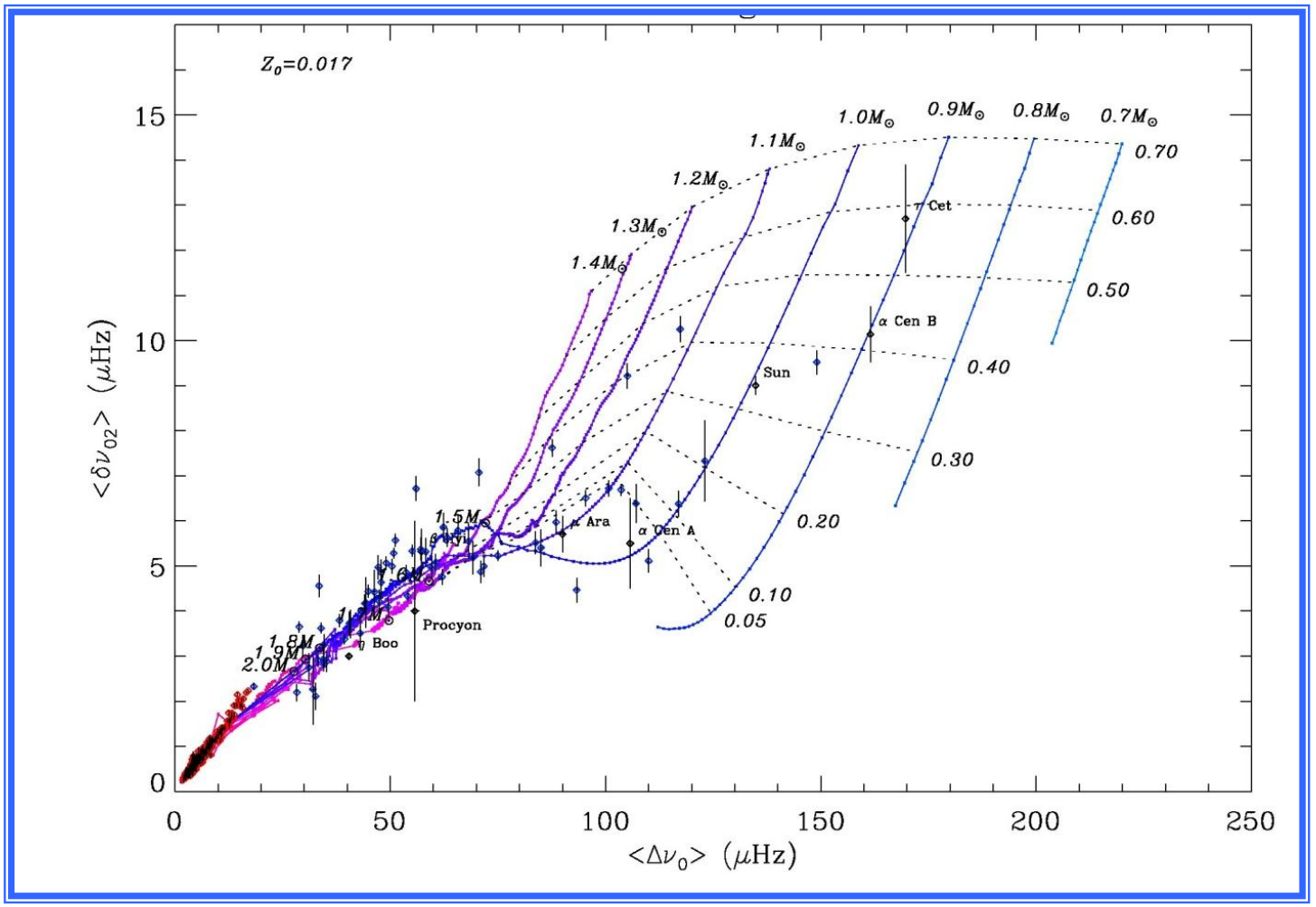
Pooh: a solar-type star

Observed by *Kepler* during the Q3 season for 30 days in short cadence mode (temporal sampling ~1 min).

$\Delta\nu$	24.6±0.2μHz
$\delta\nu_{02}$	2.2±0.3μHz



CD diagram

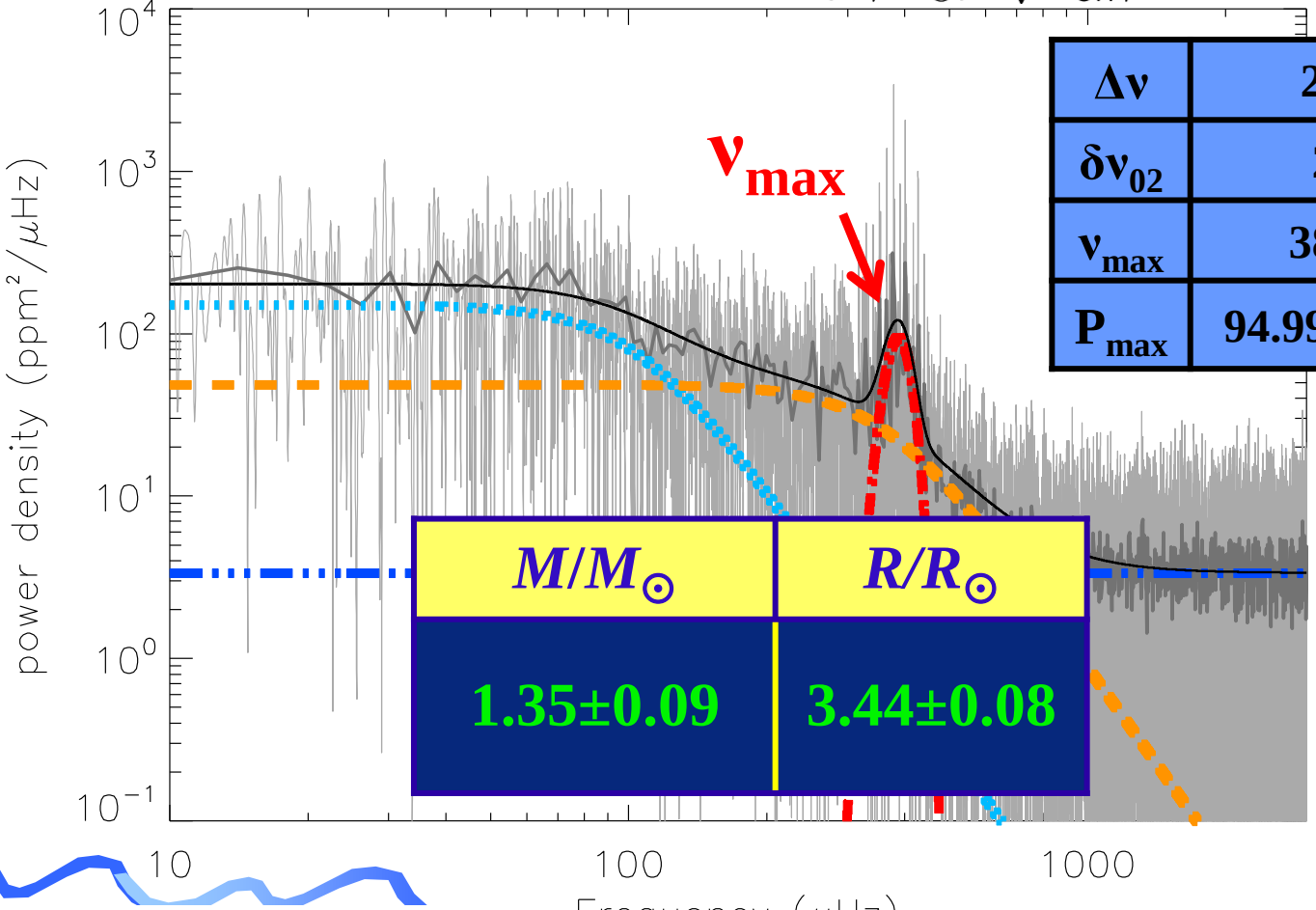


Bedding et al. 2010, ApJL
Montalban et al. 2010, ApJ

Global parameters of Pooh

Brown et al. 1991 **Kjeldsen & Bedding 1995**

$$\Delta\nu = \sqrt{\frac{M/M_\odot}{(R/R_\odot)^3}}\,134.9\mu\text{Hz} \qquad \nu\text{max} = \frac{M/M_\odot}{(R/R_\odot)^2\sqrt{T_{\text{eff}}/5777K}}\,3.05\ \text{mHz}$$



$\Delta\nu$	24.6±0.2μHz
$\delta\nu_{02}$	2.2±0.3μHz
ν_{max}	386.5±4.0μHz
P_{max}	94.99±0.3 ppm²/μHz

Theoretical Models

- ASTEC (Christensen-Dalsgaard 2008)
- ADIPLS (Christensen-Dalsgaard 2008)

★ EOS OPAL 2005 (Rogers & Nayvonov 2002)
★ OPACITY OPAL (Iglesias & Rogers 1996)
★ Nuclear Cross sections NACRE (Angulo et al 1999)
★ Metallicity Z/X=0.04±0.01
★ Mixing-length MLT (Bohm-Vitense 1958)
★ Extra mixing effect: Diffusion and overshooting

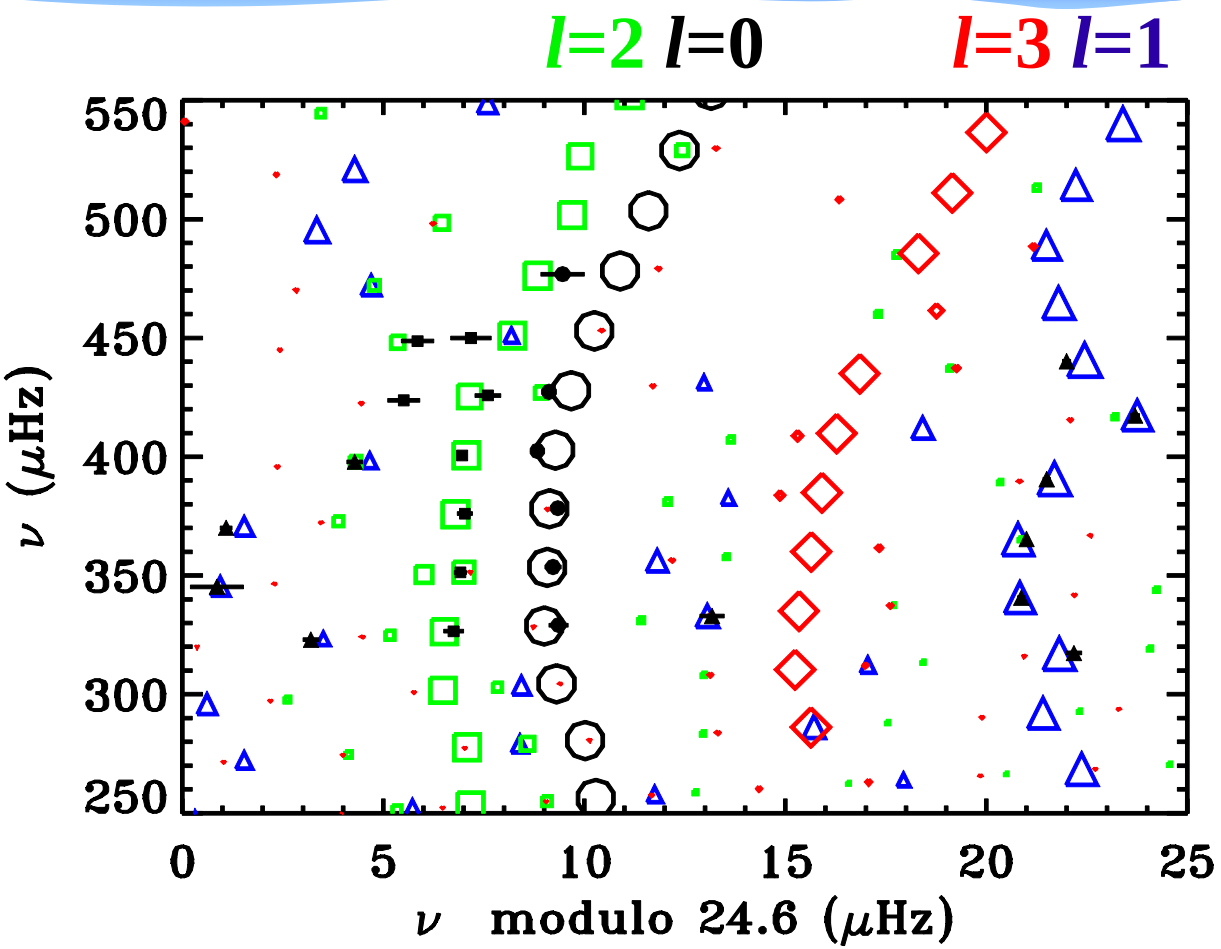
Age =5.6±0.4 Gyr

M =1.30±0.03$M_\odot$ ☛**1.35±0.09**

R =3.37±0.03 $R_\odot$ ☛**3.44±0.08**

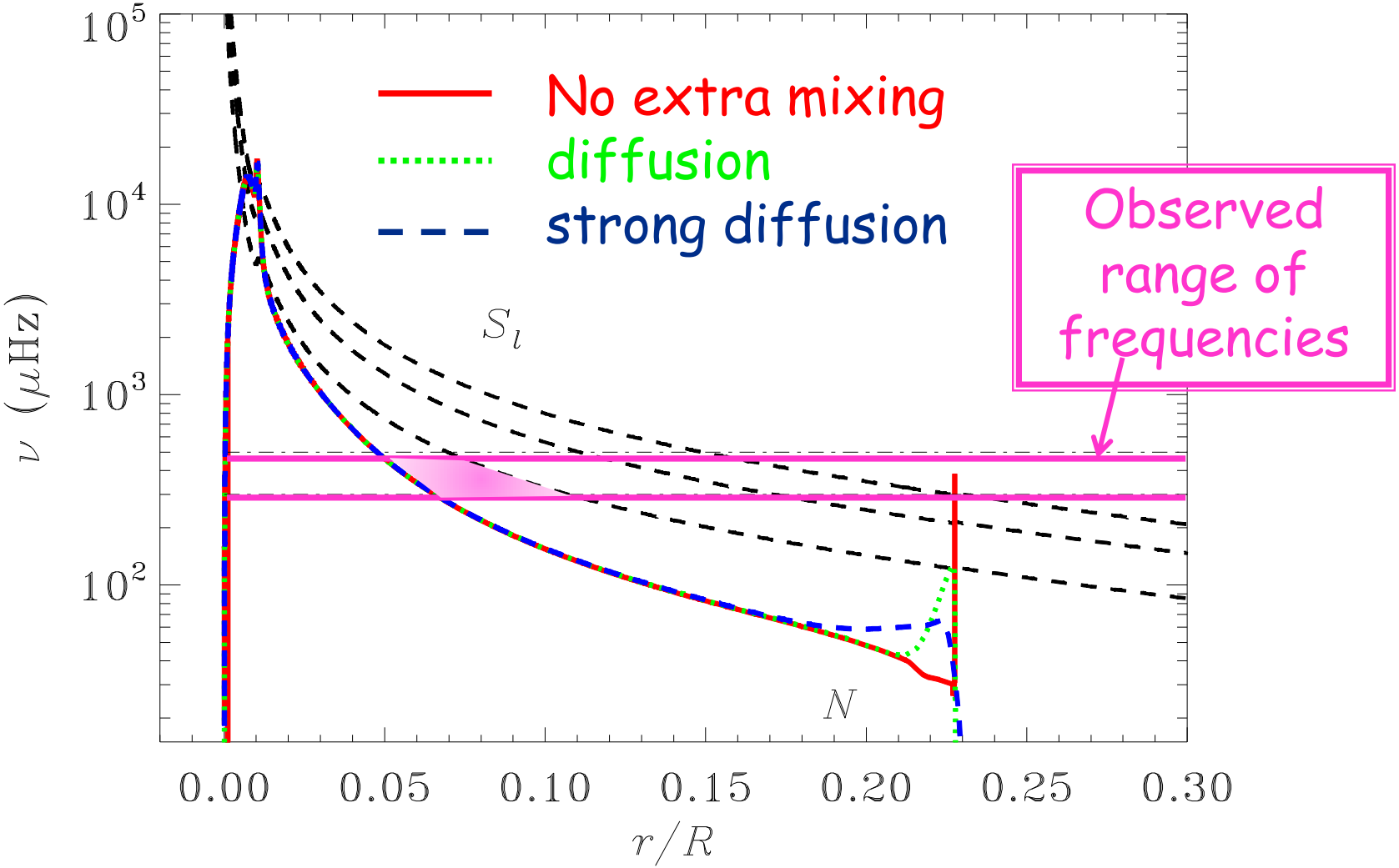
L =5.1±0.2$L_\odot$

Solar-type behaviour



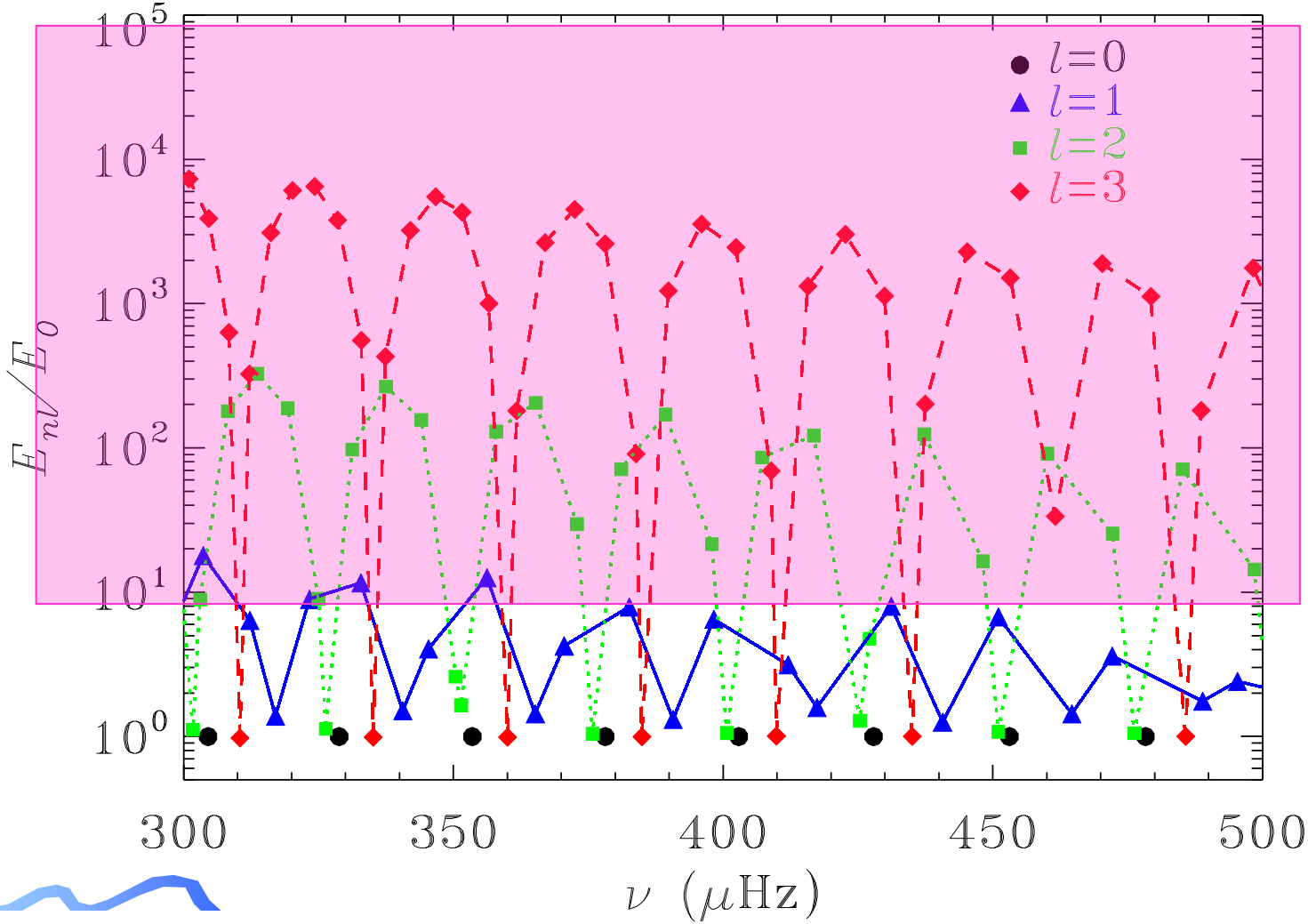
$M/M_\odot$	Age (Gyr)	Z	$L/L_\odot$	T_{eff} (K)	$R/R_\odot$
1.32	5.29	0.03	5.25	4752	3.39

Propagation of the modes

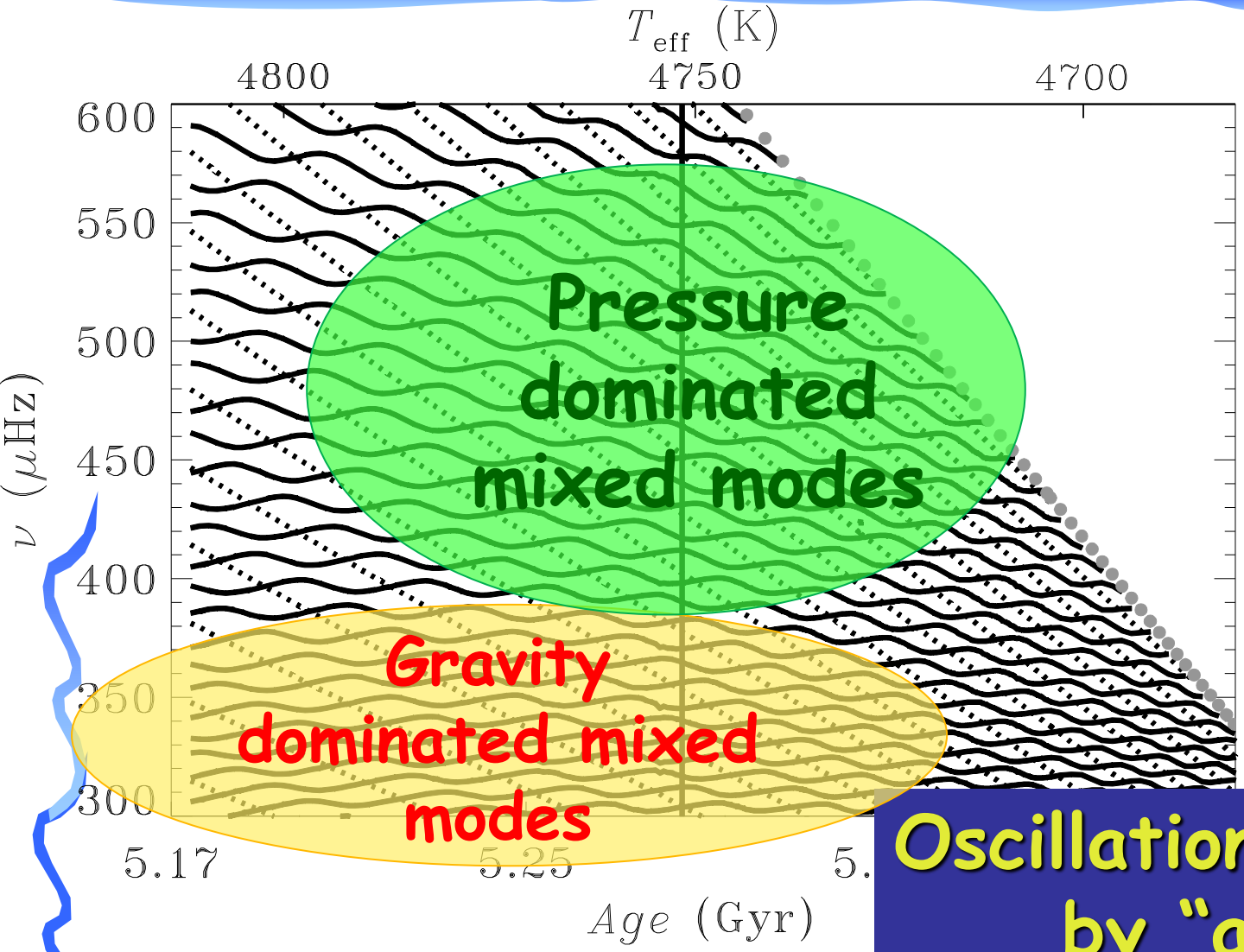


Inertia of the modes

$$\frac{A_{n,l}}{A_0} = \frac{E_0}{E_{n,l}}$$



Evolution of oscillation frequencies



M=1.32 $M_\odot$

Z=0.03

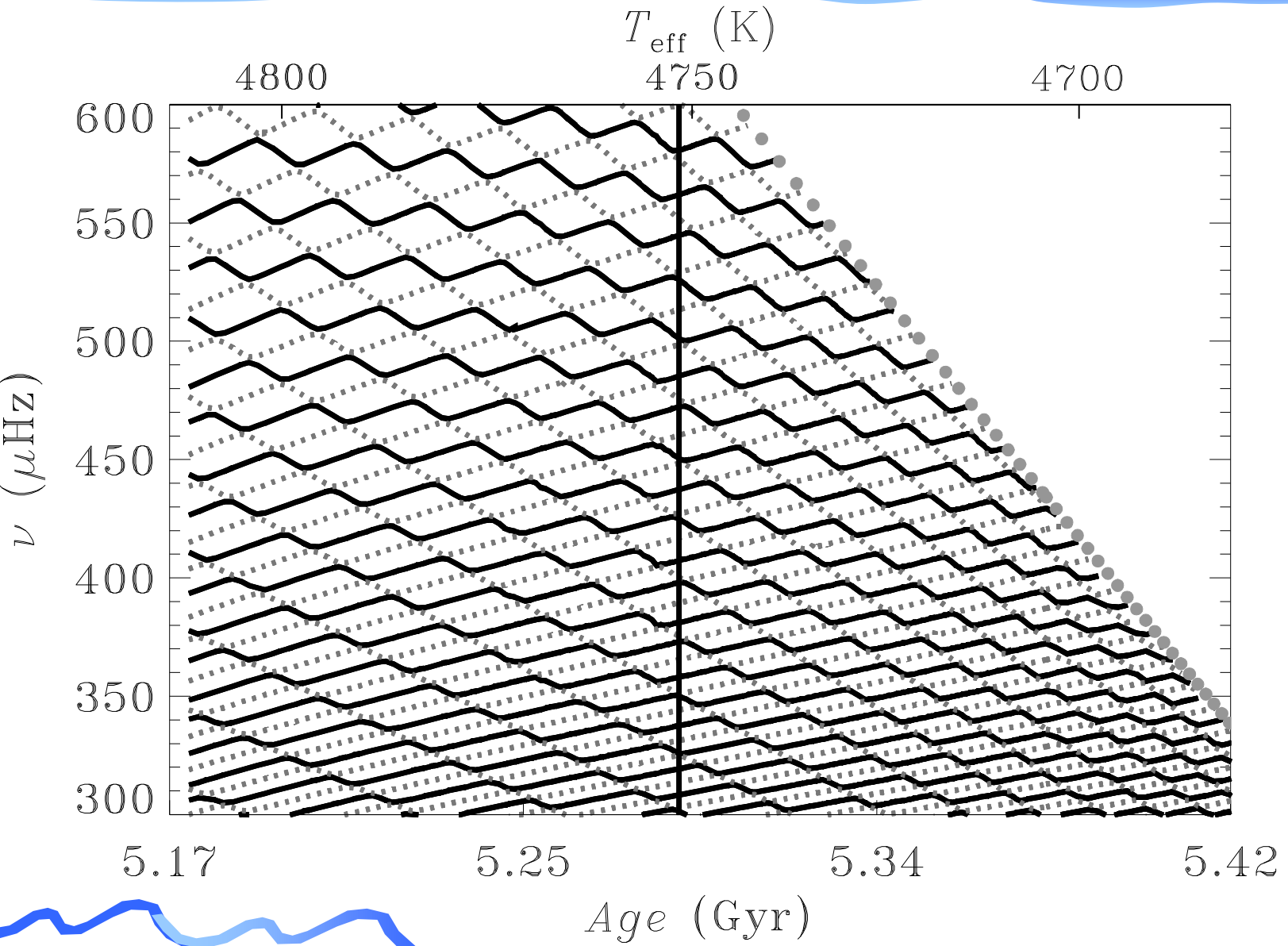
X_0=0.7

—— l=1

····· l=0

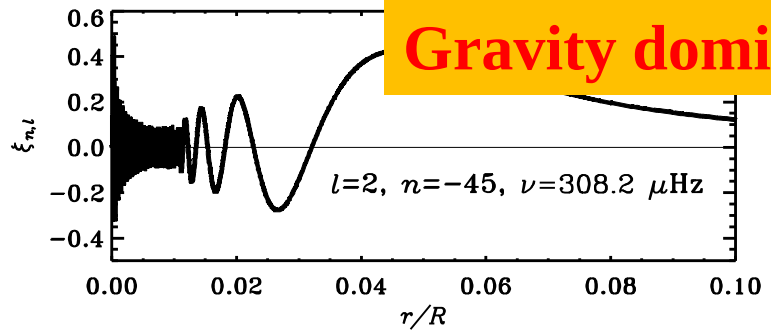
Oscillations affected by "avoided crossing"

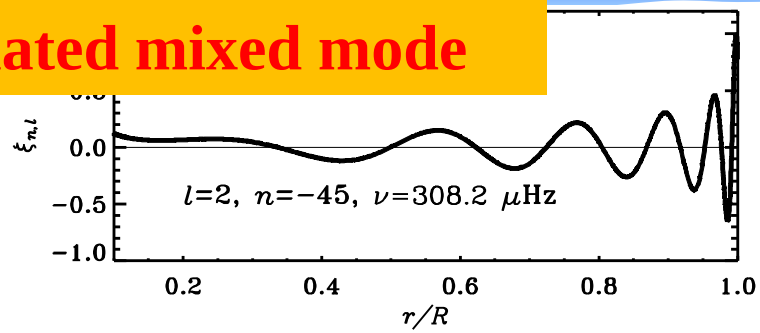
Evolution of *l*=2 modes



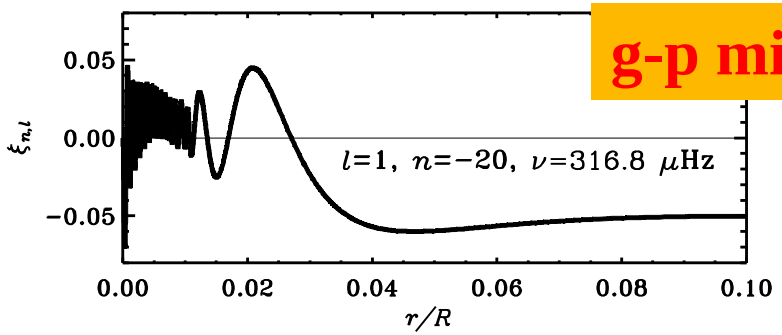
Modes in red giants

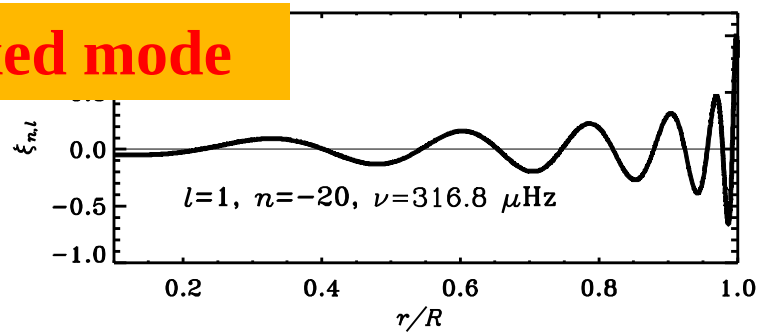
Gravity dominated mixed mode



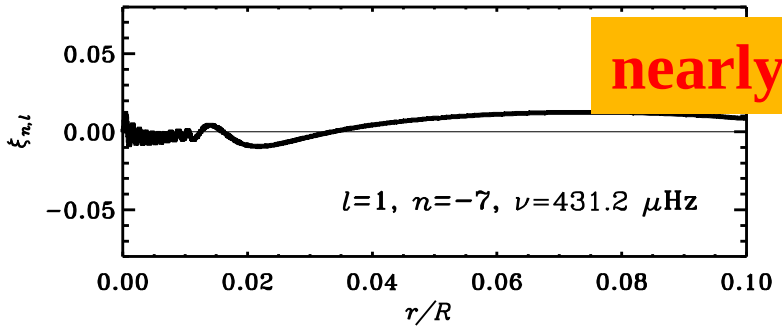


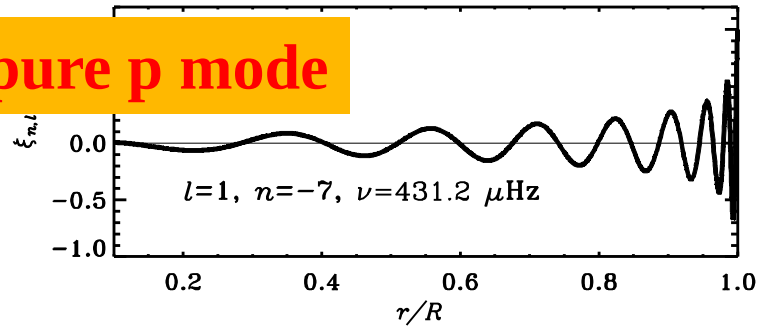
g-p mixed mode





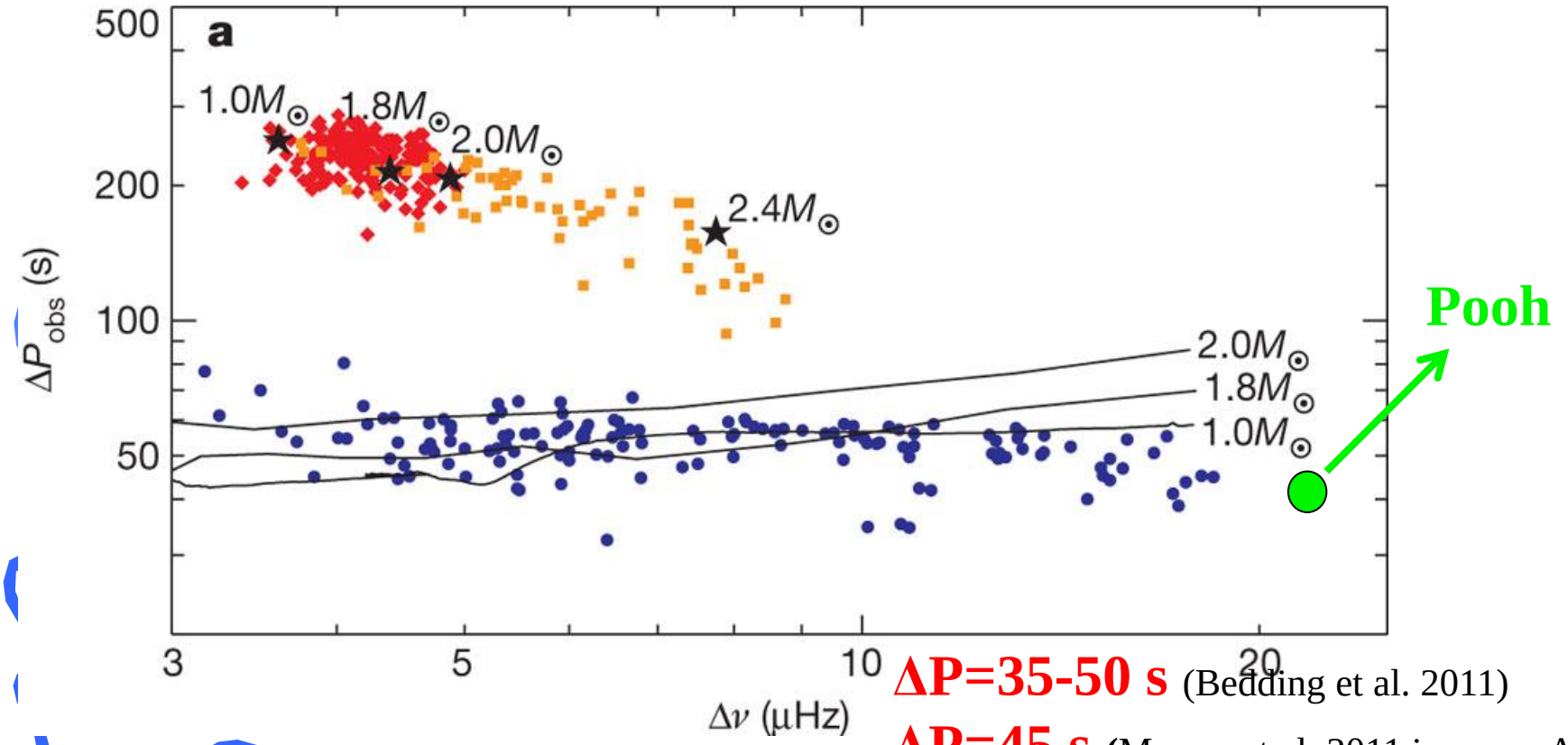
nearly pure p mode





Period spacings

It is possible to distinguish the evolutive phase of the red giants by measuring the period spacing of the g-dominated mixed modes (Beck et al. 2011, Bedding et al. 2011)



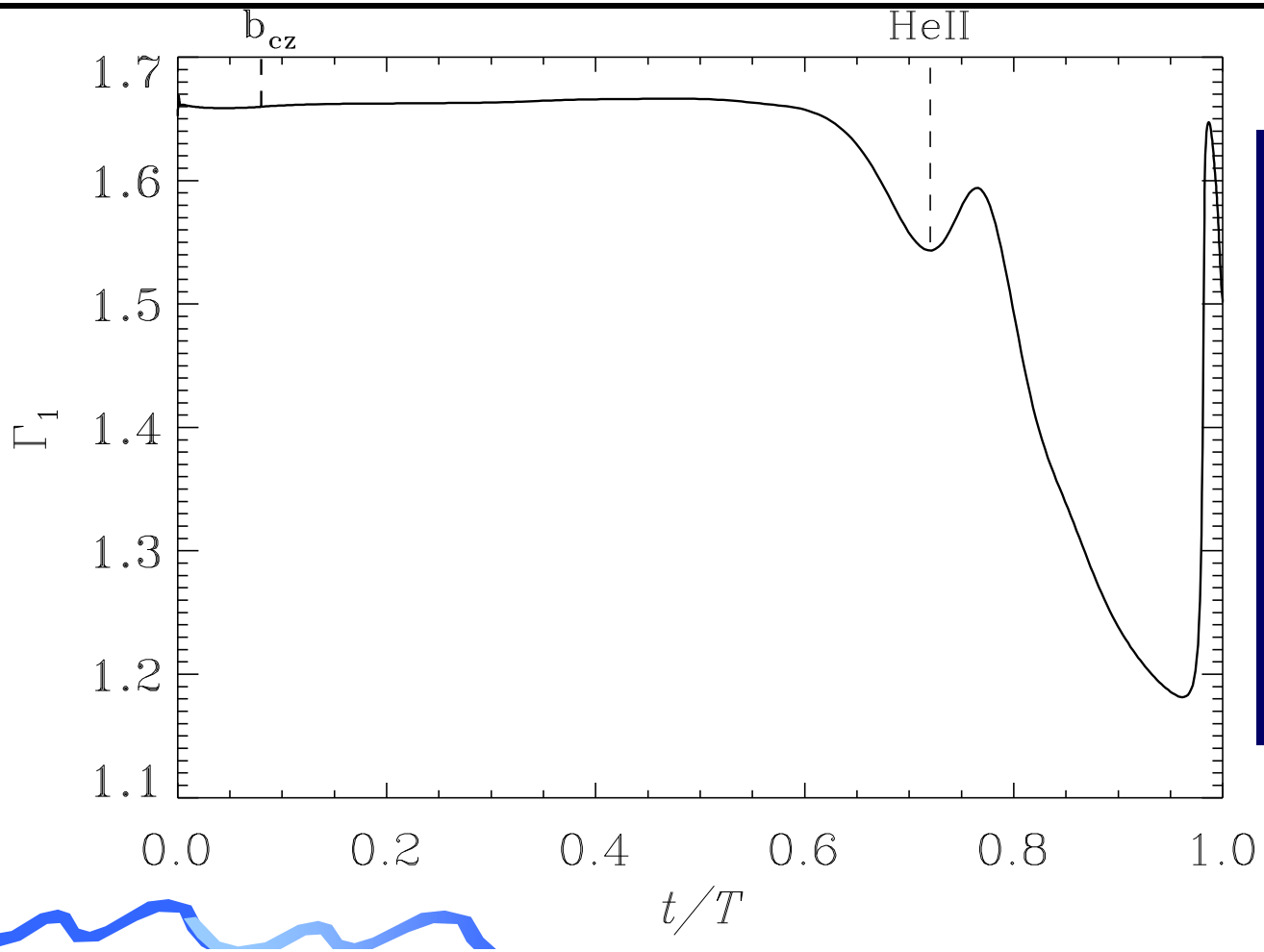
Pooh

ΔP=35-50 s (Bedding et al. 2011)

ΔP=45 s (Mosser et al. 2011 in press A&A)

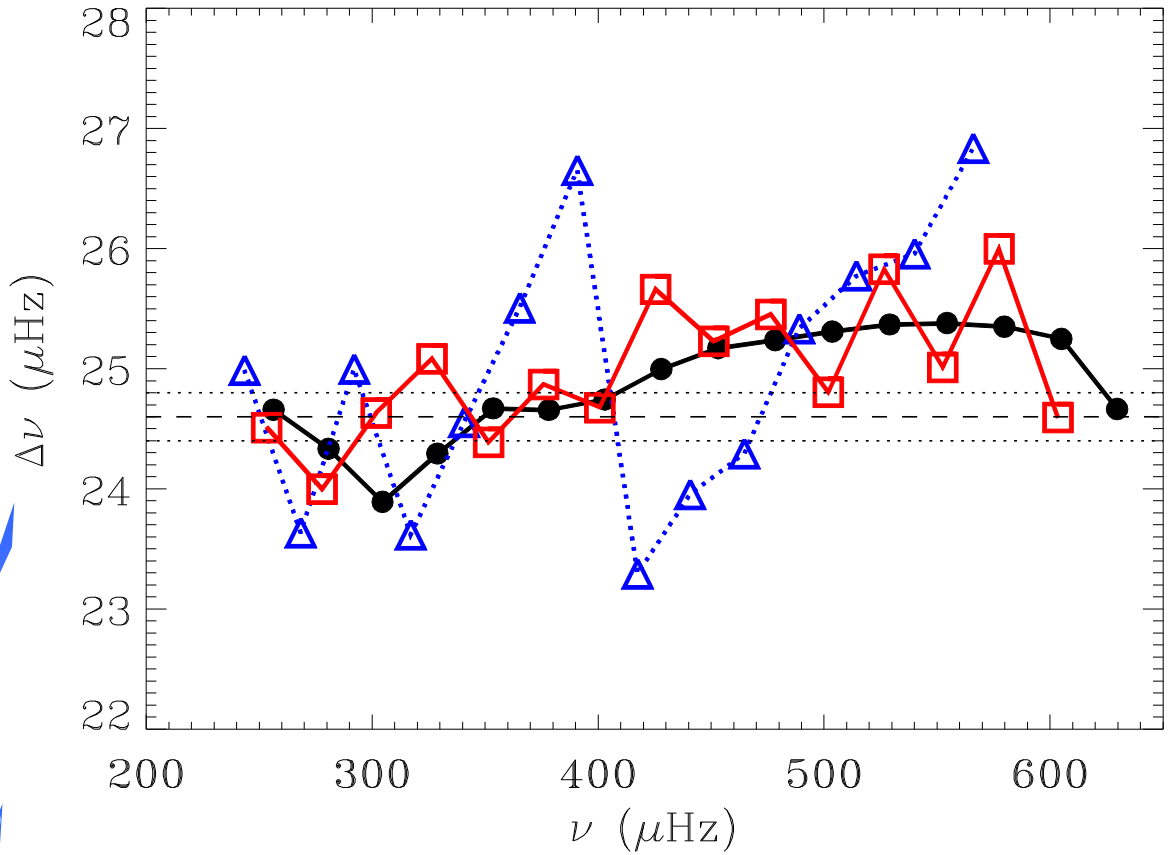
Effects of sharp features

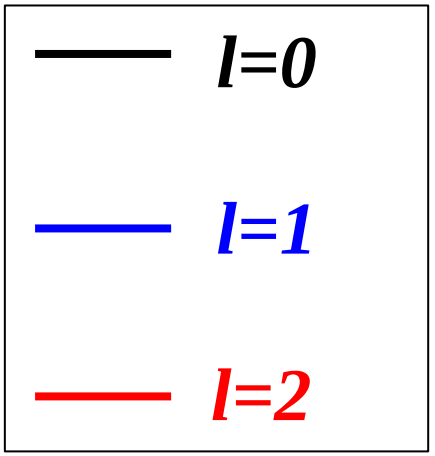
Sharp localized variations at an acoustic radius *t* produce quasi-periodic signals in the oscillations frequencies



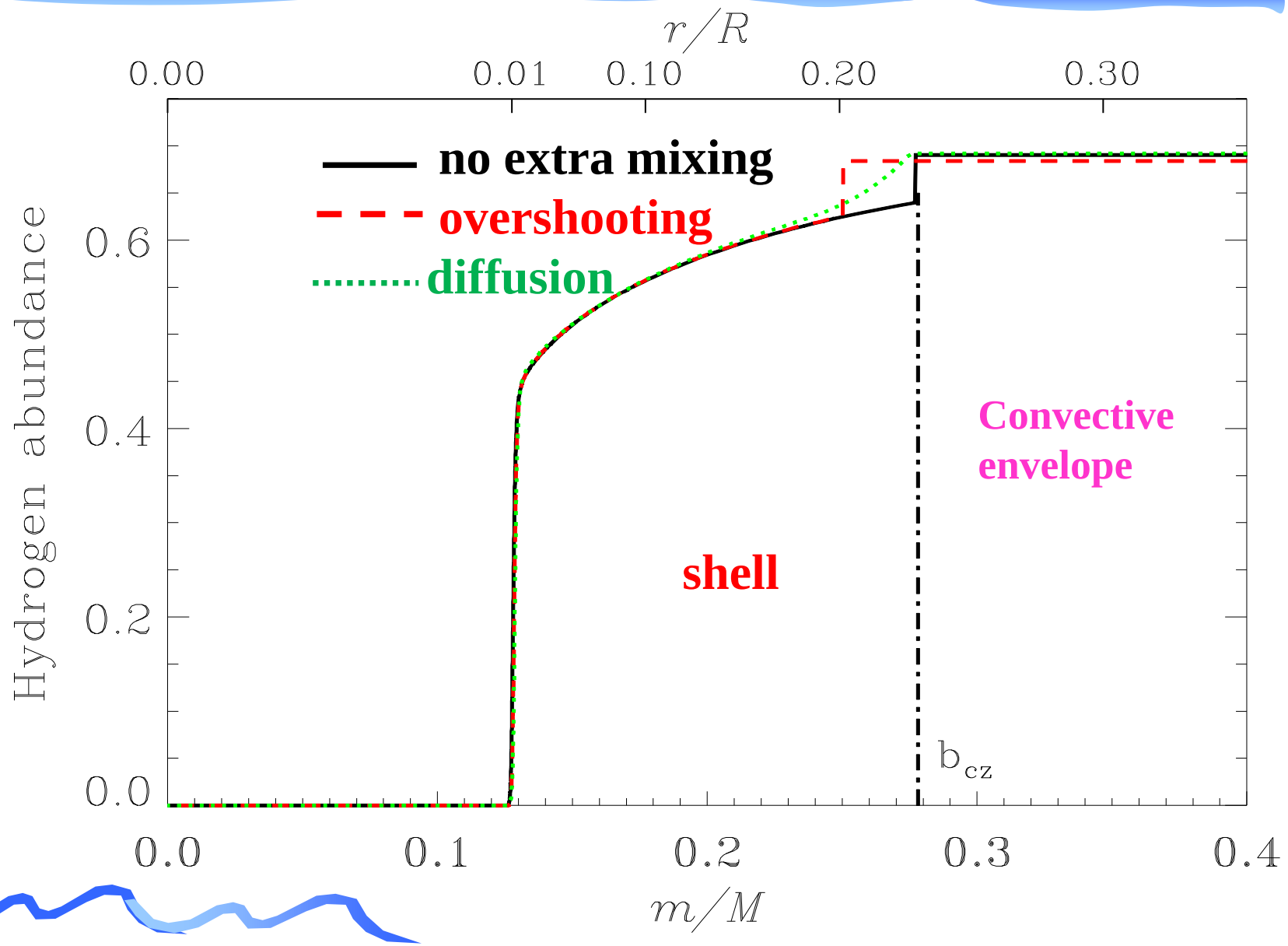
Oscillatory signal rising from the sharp variation of Γ_1 in the second helium ionization zone

Oscillatory signal



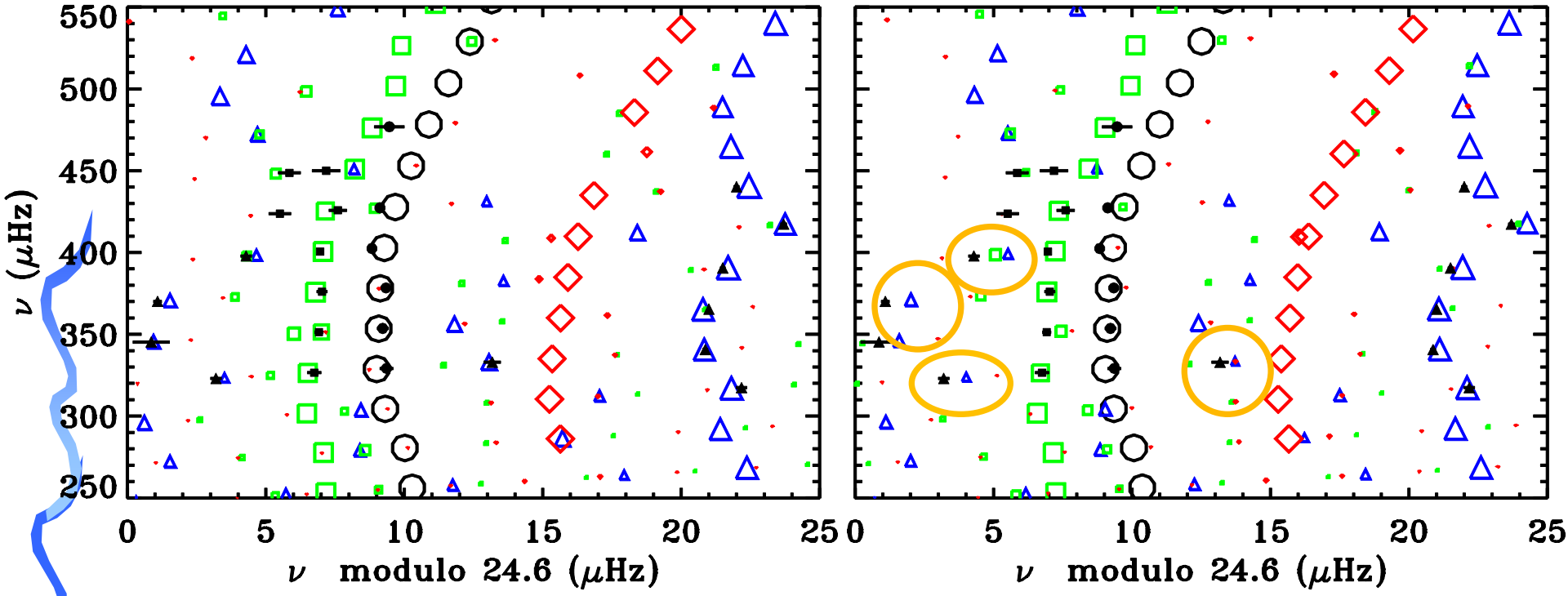


Base of the CZ



Base of the convective envelope

We can use g dominated mixed modes to probe the inner part of the star



with diffusion from con. env.

Conclusions for Pooh

Di Mauro et al. MNRS in press

★Red giant in the shell-H-burning phase

★It shows solar-type pulsations due to nearly pure p modes

★It shows some gravity dominated mixed modes

Age =5.6±0.4 Gyr

M =1.30±0.03$M_\odot$

R =3.37±0.03 $R_\odot$

L =5.1±0.2$L_\odot$

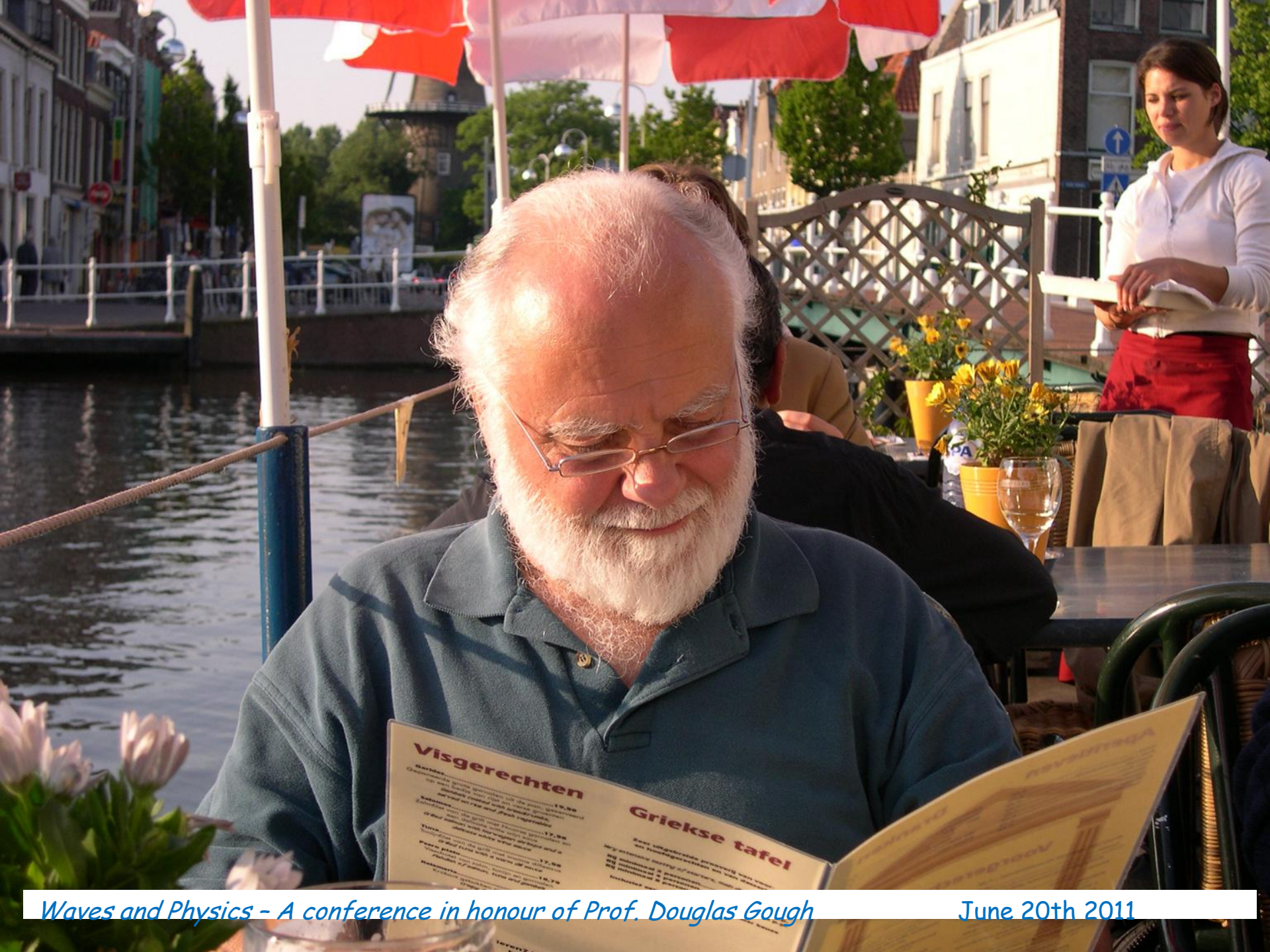
It has been scheduled for long term observations!!!

Conclusions

Method	Scaling laws	Individual frequencies
Mass	7%	2%
Age	--	7%
Radius	2%	1%
Luminosity	--	4%

With many accurate frequencies we are able to characterize details of observed red giants!

- Condition of the core ⇨ gravity dominated mixed modes
- Condition in the envelope ⇨ pressure dominated mixed modes


Visgerechten
Griekse tafel


Happy birthday!