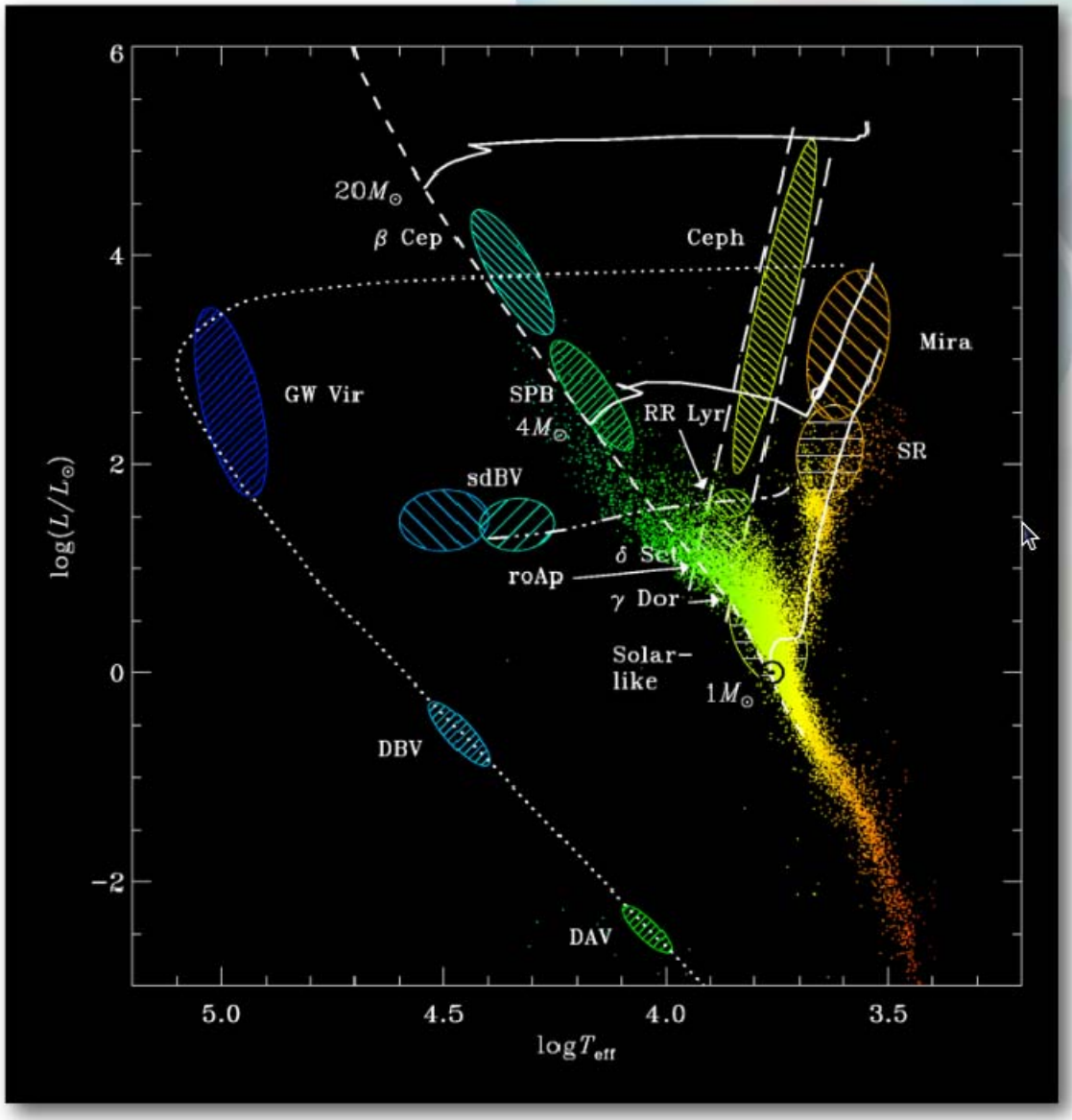
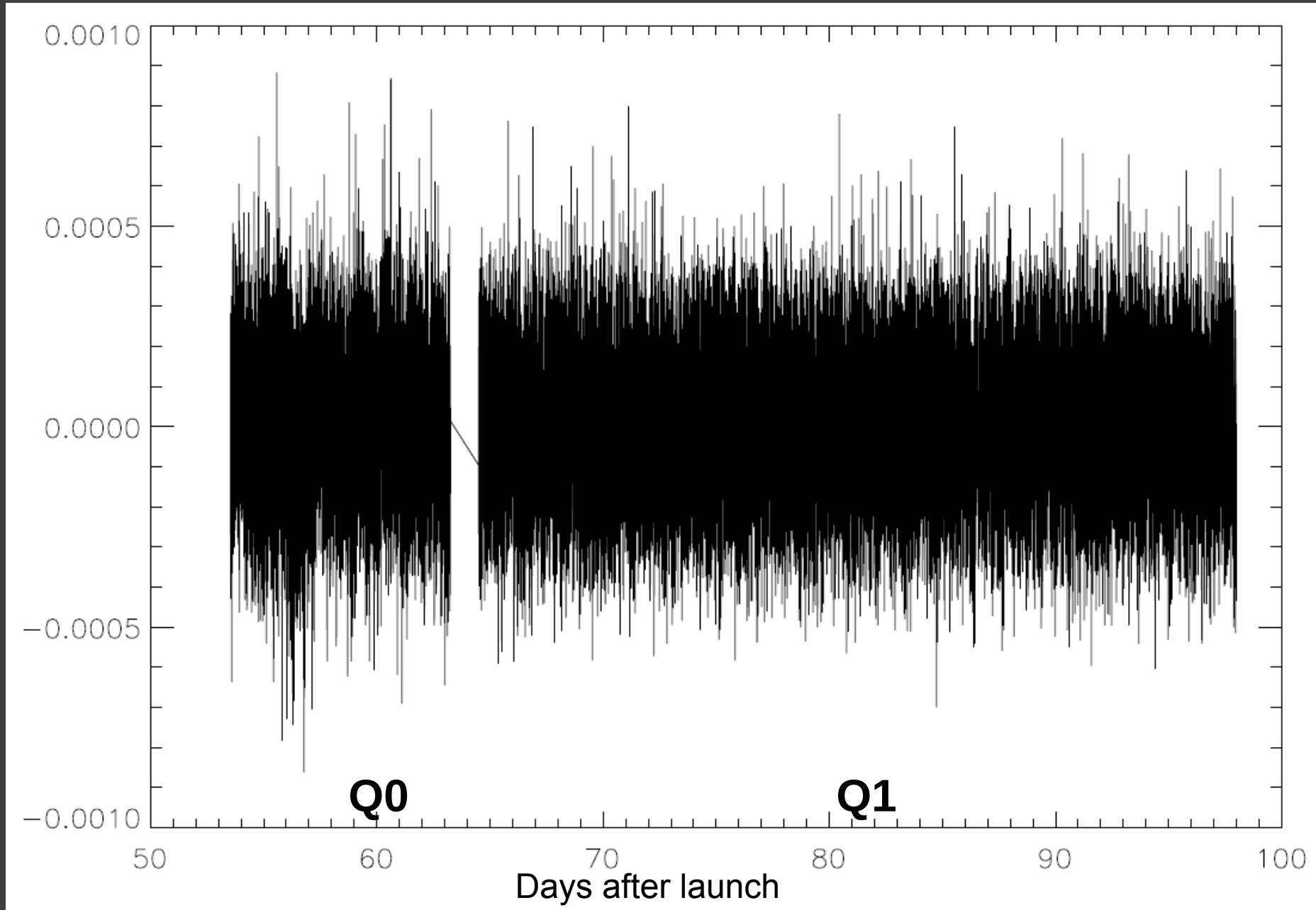
Edades estelares: Astrosismología

Rafa Garrido

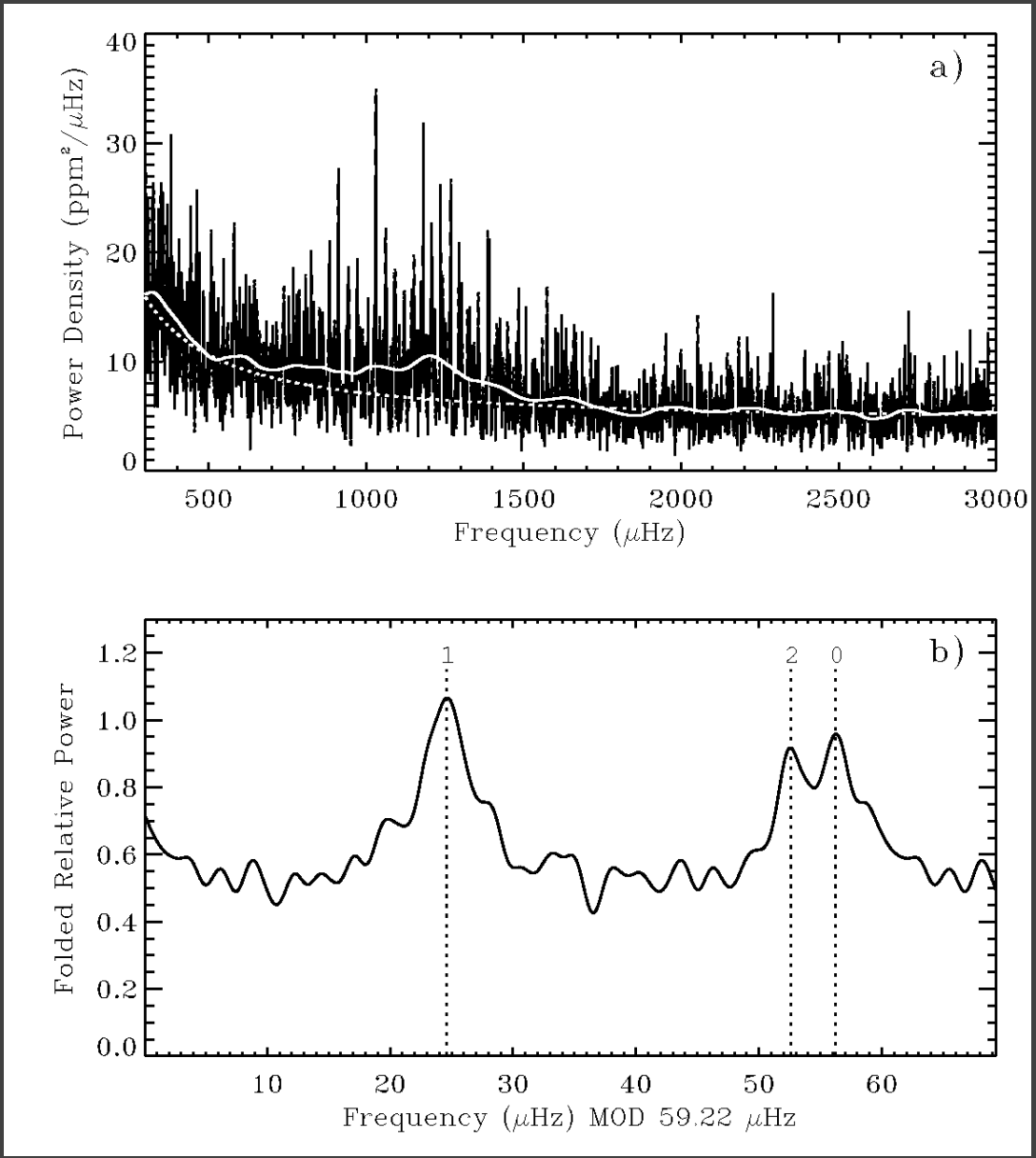
Instituto de Astrofísica de Andalucía (CSIC)

- Nota introductoria
- El papel de la astrosismología
- Limitaciones
- Conclusión

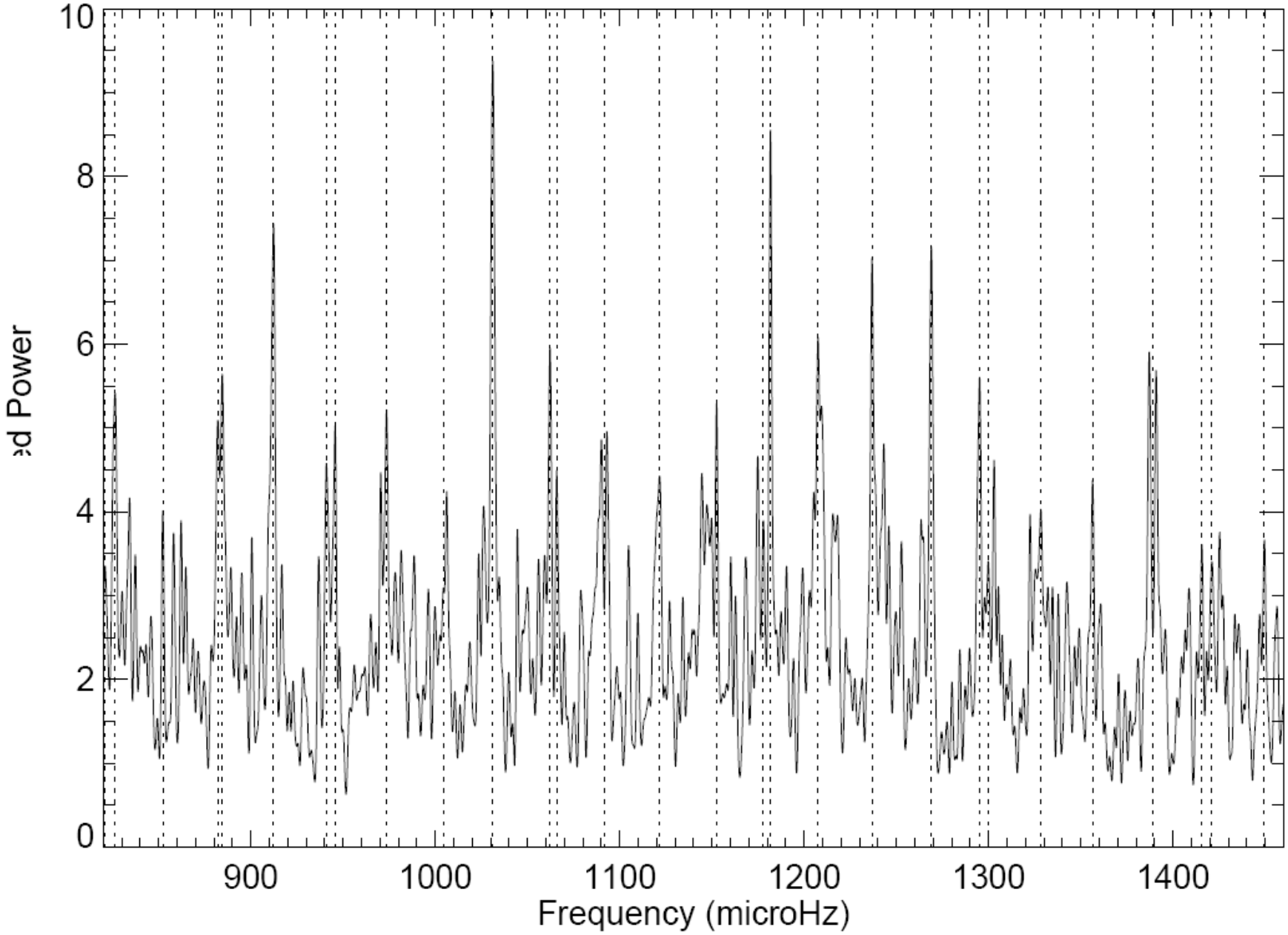

6
4
2
0
−2
log(L/L⊙)
5.0
4.5
4.0
3.5
log T_eff
20M⊙
β Cep
Ceph
Mira
GW Vir
SPB
4M⊙
RR Lyr
SR
sdBV
δ Sct
roAp
γ Dor
Solar-
like
1M⊙
DBV
DAV


0.0010
0.0005
0.0000
−0.0005
−0.0010
Q0
Q1
50
60
70
80
90
100
Days after launch

HAT-P-7 spectrum



J. Christensen Dalsgaard

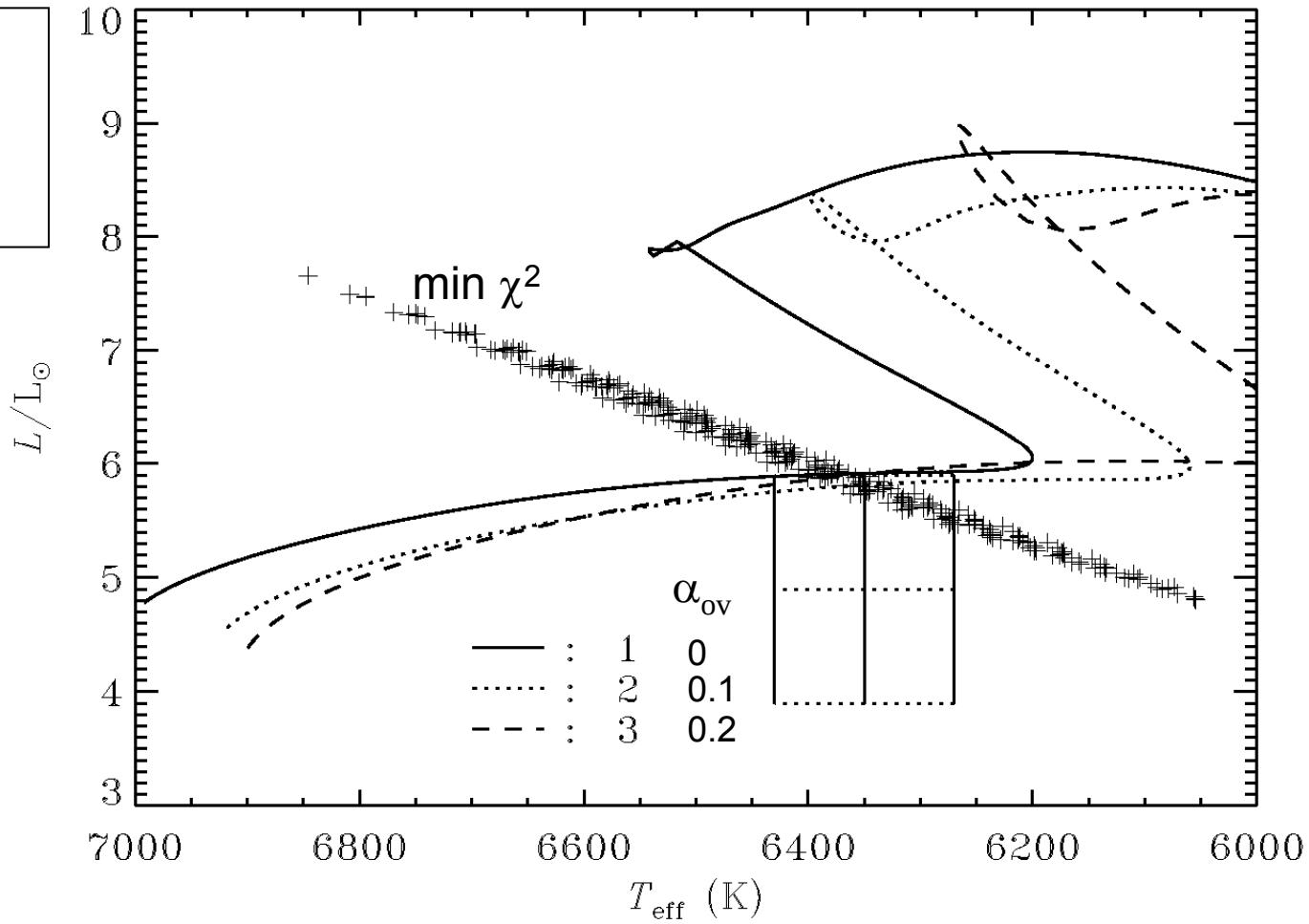

10
8
6
4
2
0
ed Power
900
1000
1100
1200
1300
1400
Frequency (microHz)

Evolution models

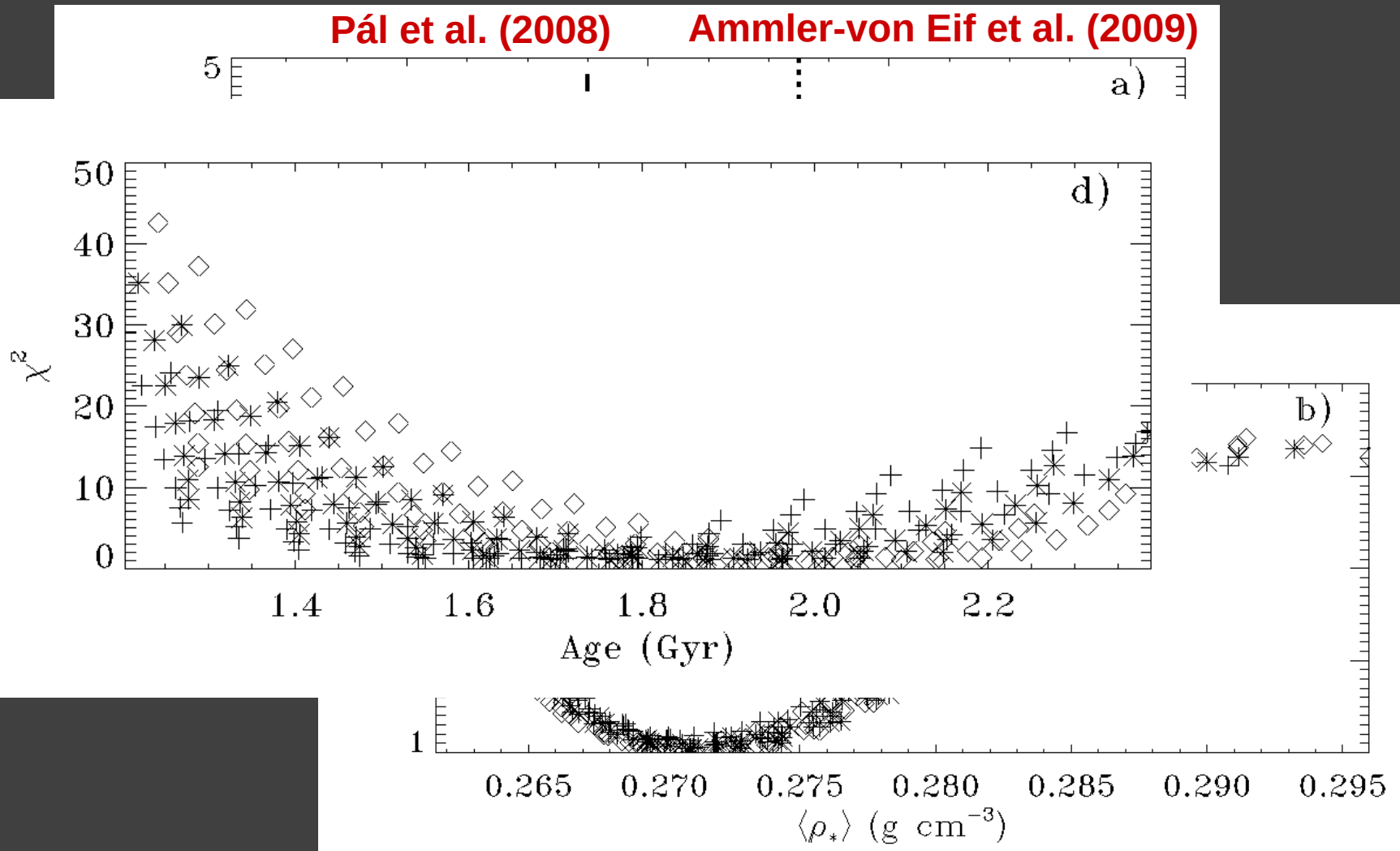
Model grid:

M = 1.41 – 1.61 M_{sol}

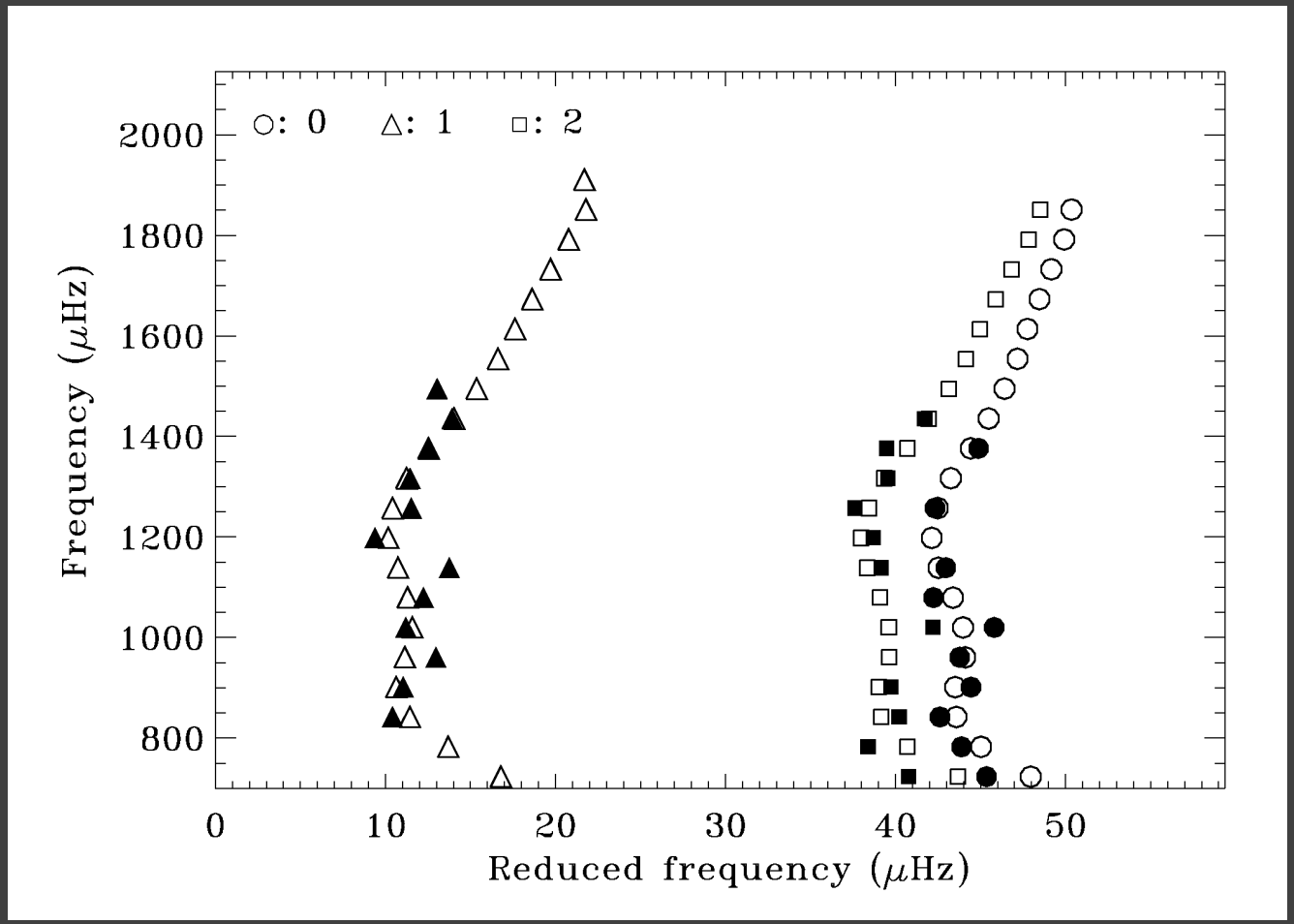
[Fe/H] = 0.17 – 0.38



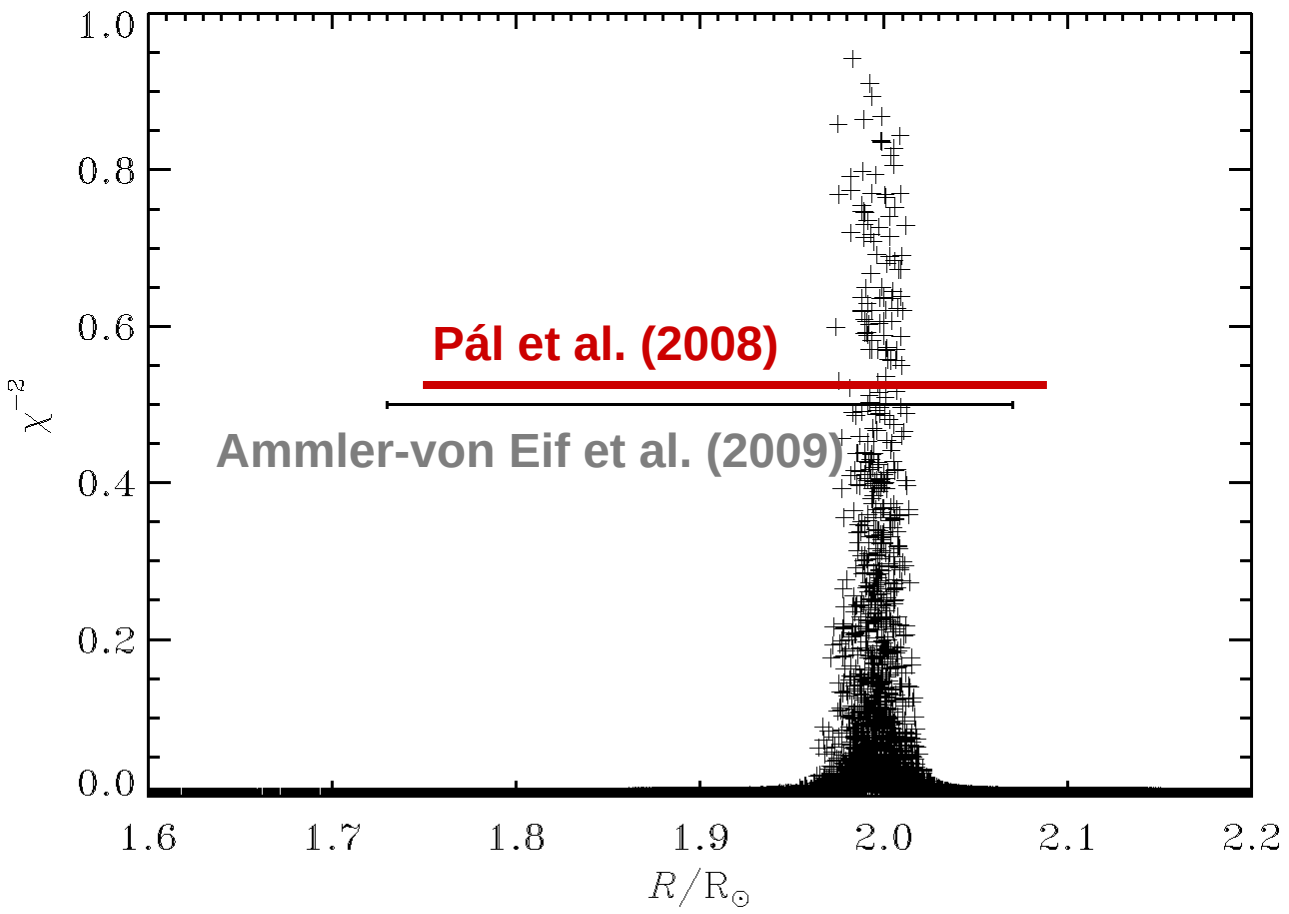
Least-squares fits



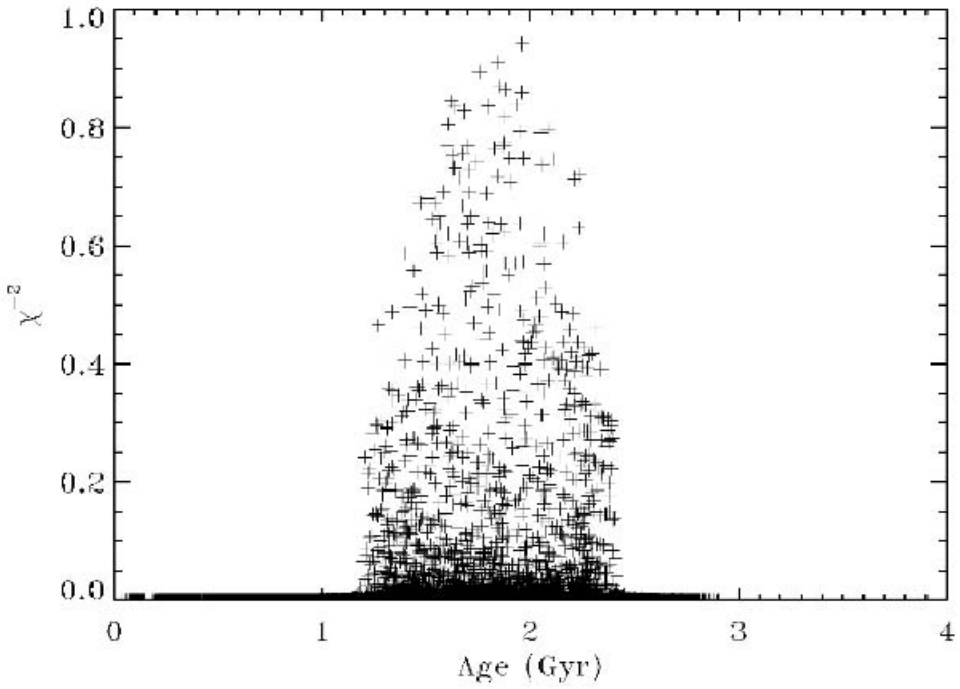
Match of model and observations



Fit for radius



Fit for age



CHARACTERIZING

Without asteroseismology, some examples:

2) Homogeneous studies of transiting extrasolar planets. IV. Thirty systems with space-based light curves

An homogeneous analysis of the public data of 32 transiting planets.

Mean errors

M_*	R_*	ρ_*	Age	M_p	R_p
9,3%	7%	13.7%	150%	10.6%	7.1%

Southworth, J., 2011, arXiv:1107.1235

CHARACTERIZING: Theoretical studies

Almost all papers focused on solar-like or red giant stars (asymptotic stochastic pulsators)

Stello, Kjeldsen & Bedding, 2007
Kjeldsen, Bedding, Christensen-Dalsgaard, 2008

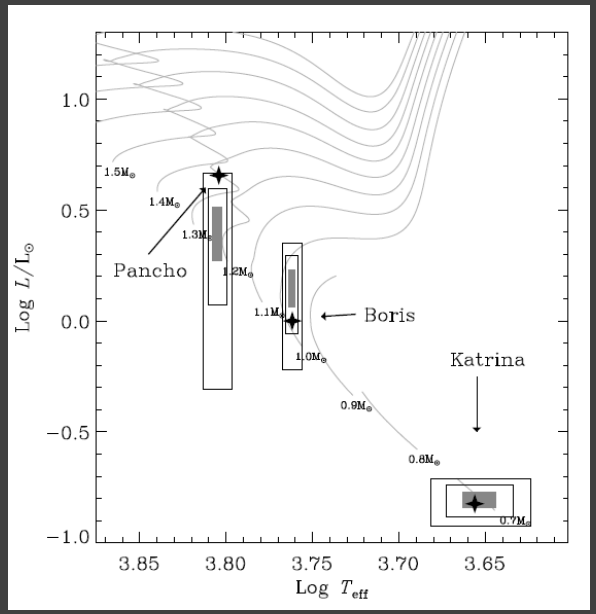
	M_*	R_*	L_*	ρ_*	Age
Without Asterosismology	10%	20%	40%	70% (if coming from M and R)	----------
With Asteroseismology	5%	2-3%	10%	1%	5-10%

CHARACTERIZING: Theoretical studies

Stello et al., 2009

First massive hare-and-hounds exercise. Estimate of radii uncertainties <3%

"The uncertainty in the radius determination is mostly dominated by the uncertainty in the stellar metallicity, which translates to an uncertainty in the stellar mass".



CHARACTERIZING: Real cases, no planets

Metcalfe et al., 2010, KIC 11026764 (off MS)

Chaplin et al., 2010, three Kepler solar-like stars

Table 1. Non-seismic and seismic parameters, and preliminary stellar properties[a]

Star	2MASS ID	$T_{\rm eff}$ [K]	$\log g$ [dex]	[Fe/H] [dex]	$\Delta\nu$ [μHz]	$\delta\nu_{02}$ [μHz]	R [$R_\odot$]	M [$M_\odot$]
KIC 6603624[b]	19241119+4203097	5790±100	4.56±0.10	0.38±0.09	110.2±0.6	4.7±0.2	1.18±0.02	1.05±0.06
KIC 3656476[c]	19364879+3842568	5966±100	4.32±0.06	0.22±0.04	94.1±0.6	4.4±0.2	1.31±0.02	1.04±0.06
KIC 11026764[b]	19212465+4830532	5640±80	3.84±0.10	0.02±0.06	50.8±0.3	4.3±0.5	2.10±0.10	1.10±0.12

CHARACTERIZING: Real cases

μ Arae

- 4 planets (RV)
- HARPS observations
- 43 solar-like modes

Pioneer works:

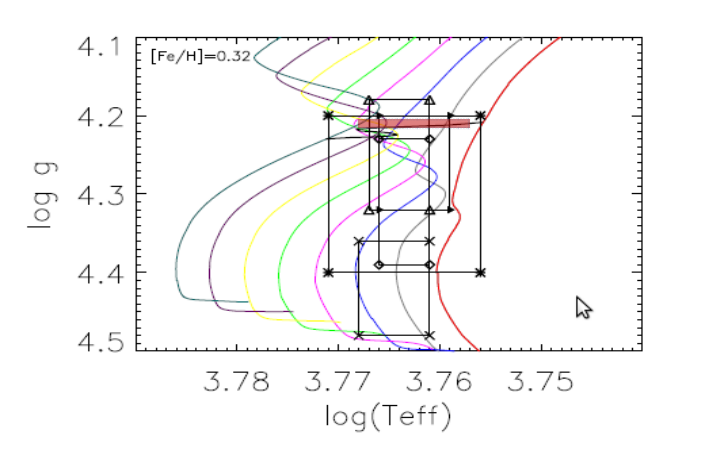
Bazot et al., 2004
Bouchy et al., 2005
Bazot et al., 2005
Soriano & Vauclair, 2008, 2010

Initial aim: disentangling whether the observed over-metallicity is internal or accreted

CHARACTERIZING: Real cases

μ Arae

	M_*	Log g	R_*	[Fe/H]	T_{eff}
Without Asteroseismology	4.6%	2.3%	23%	31%	1.7%
With Asteroseismology	1.8%	0.1%	4.4%	6.3%	0.9%



Very precise determination Y=0.30±0.01, Age=6.3±0.8 Gyr

CHARACTERIZING: Real cases

ι Horologii

- 1 planet (RV)
- HARPS observations
- 25 solar-like modes

Works:

Laymand & Vauclair, 2007
Vauclair et al., 2008
Boisse et al., 2011

Initial aim: is this star an evaporated member of the Hyades cluster?

CHARACTERIZING: Real cases

HR 8799

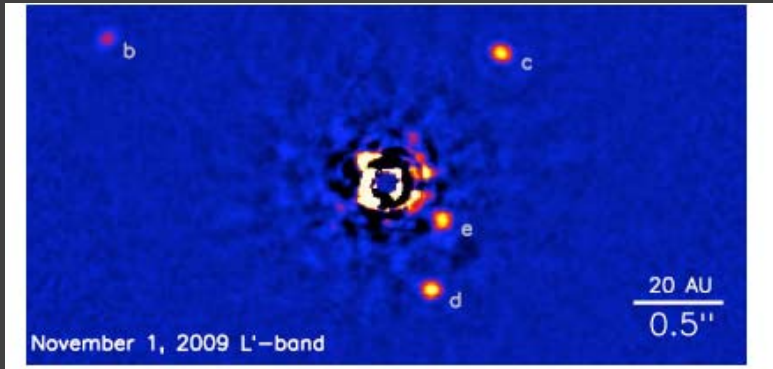
- 4 planets (Imaging)
- Keck observations
- γ Doradus pulsations

Works:

Zerbi et al., 1999
Moya et al., 2010a,b
Wright et al., 2011

Pulsational frequencies (c/d)

f_1	1.9791
f_2	1.7268
f_3	1.6498

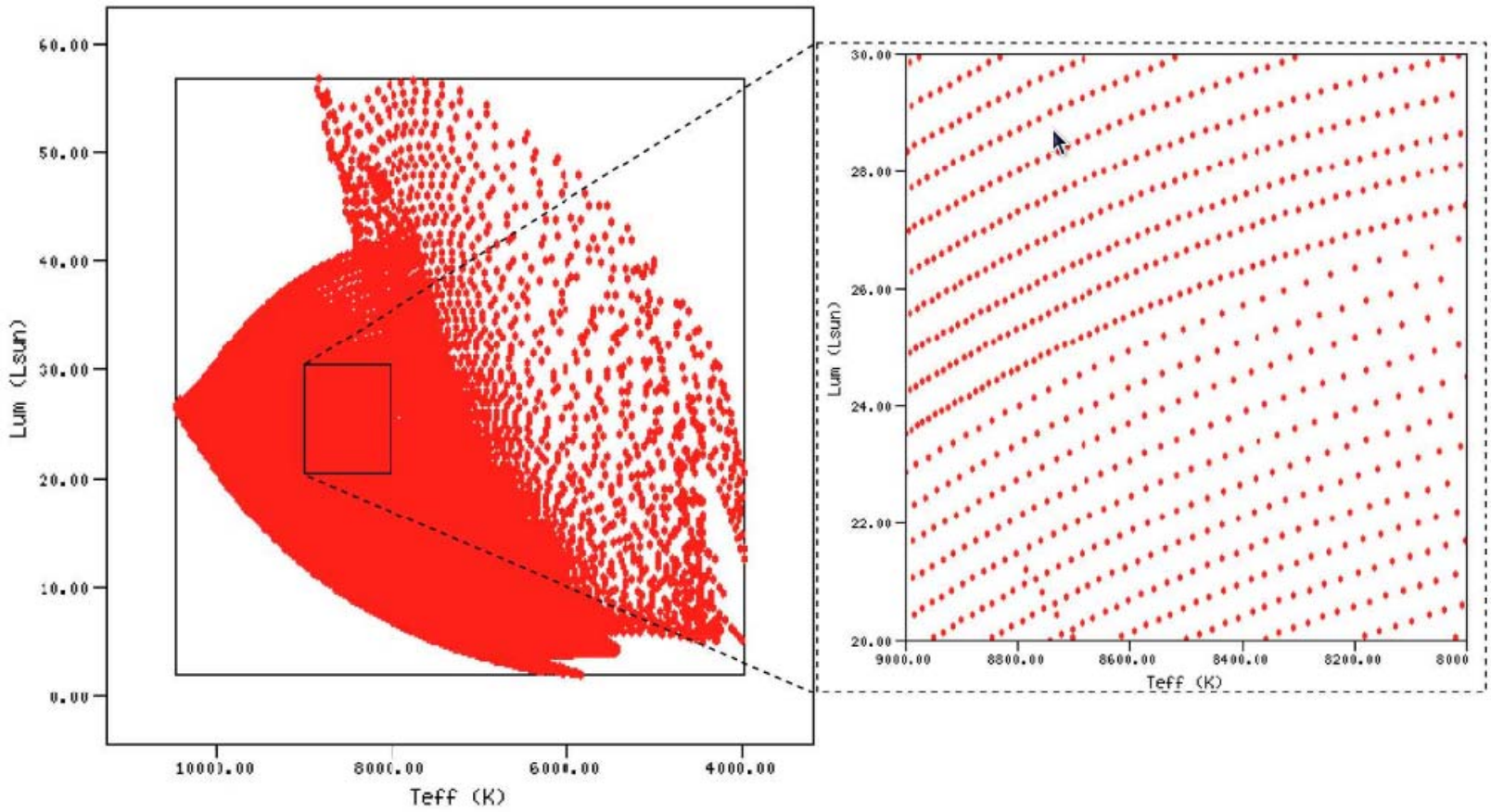


T_{eff} (K)	7430±75
Log g (cm s^{-2})	4.35±0.05
M_V	2.98±0.08
R ($R_\odot$)	1.34±0.05
v sin i (km s^{-1})	37.5±2

VOTA-GRID

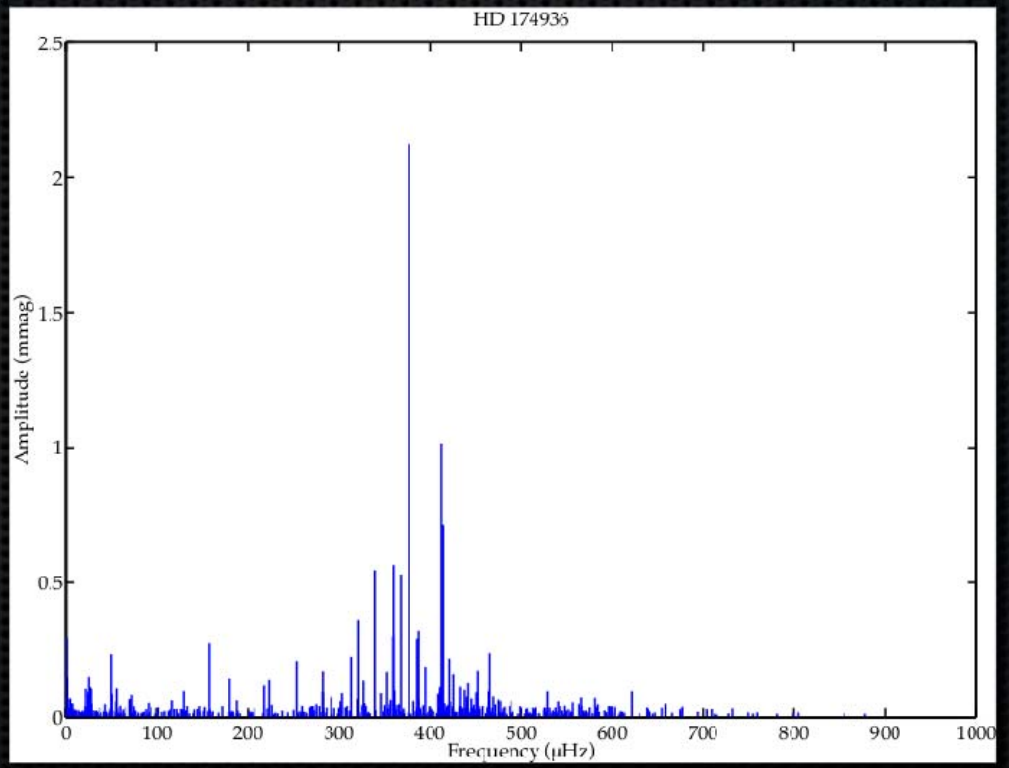
(Virtural Observatory Tool for Asteroseismology-GRID)

Antonio García Hernández
Susana Sánchez Expósito
Juan Carlos Suárez Yanes
Instituto de Astrofísica de Andalucía-CSIC, Granada


60.00
50.00
40.00
30.00
20.00
10.00
0.00
Lum (Lsun)
10000.00
8000.00
6000.00
4000.00
Teff (K)
30.00
28.00
26.00
24.00
22.00
20.00
Lum (Lsun)
9000.00
8800.00
8600.00
8400.00
8200.00
8000
Teff (K)

Past results: HD 174936

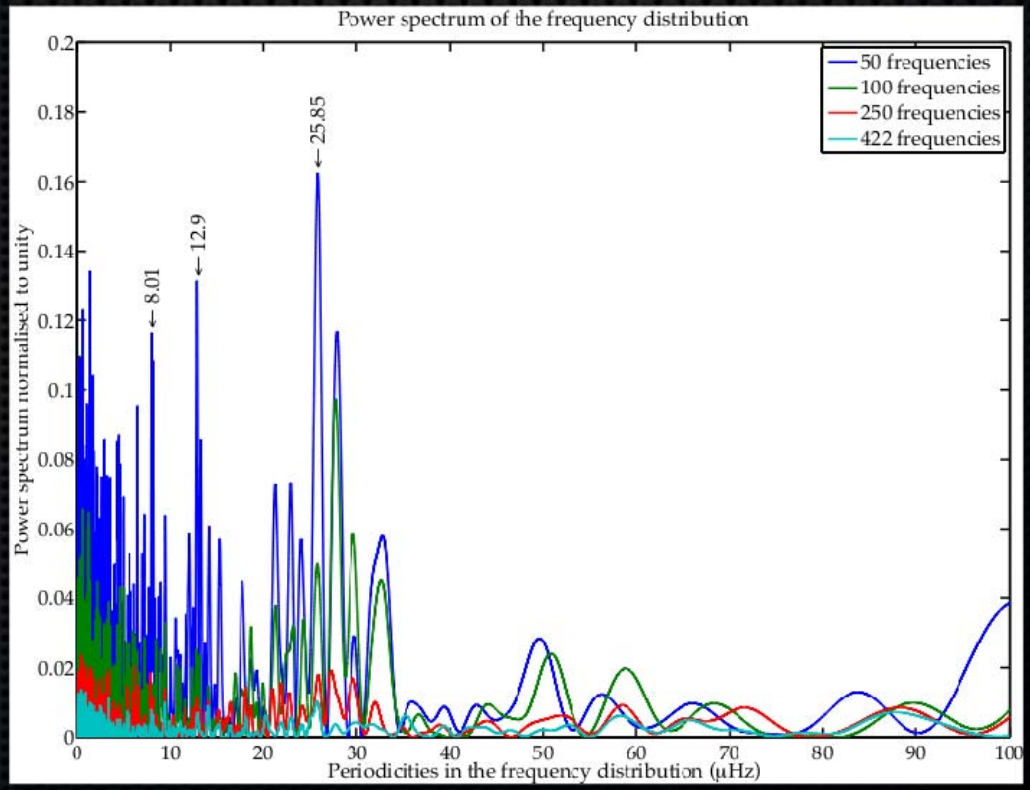
- A2, m_v = 8.58:
  - T_{eff} = 8000 ± 200 K
  - log g = 4.08 ± 0.2 deg
  - [Fe/H] = -0.32 ± 0.2 deg
- 422 frequencies (sig=10)
- ~26 μHz pattern
- Large separation ($\Delta\nu = \nu_{n+1,\ell} - \nu_{n,\ell}$)?



Frequency spectrum

Past results: HD 174936

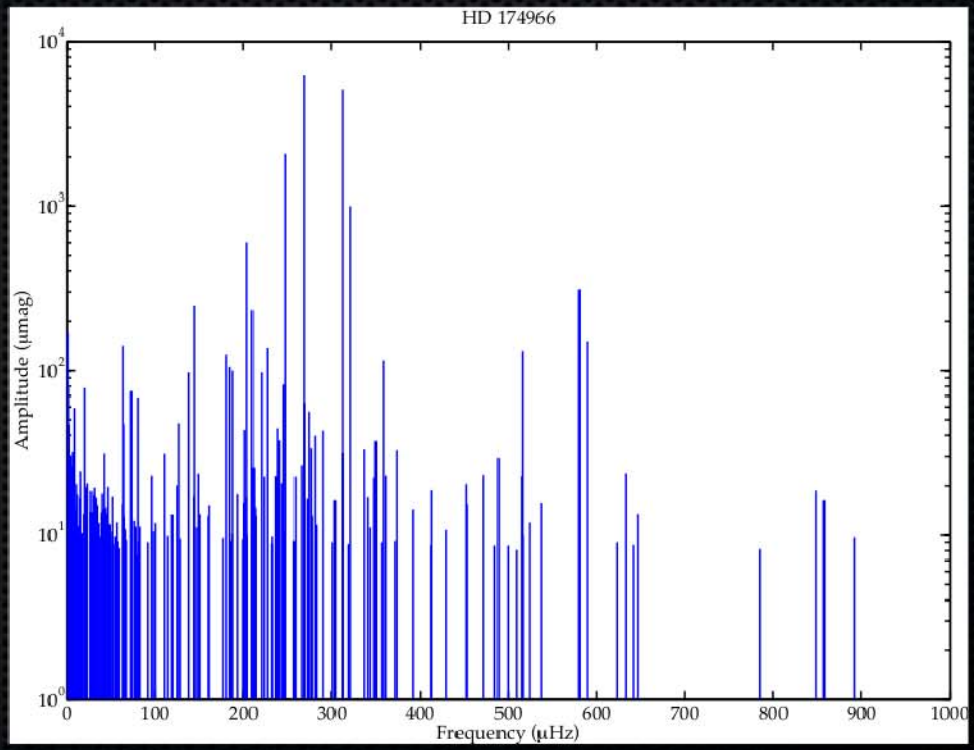
- A2, m_v = 8.58:
  - T_{eff} = 8000 ± 200 K
  - log *g* = 4.08 ± 0.2 deg
  - [Fe/H] = -0.32 ± 0.2 deg
- 422 frequencies (sig=10)
- ~26 μHz pattern
- Large separation ($\Delta\nu = \nu_{n+1,\ell} - \nu_{n,\ell}$)?



FT of the frequency spectrum

HD 174966 with CoRoT

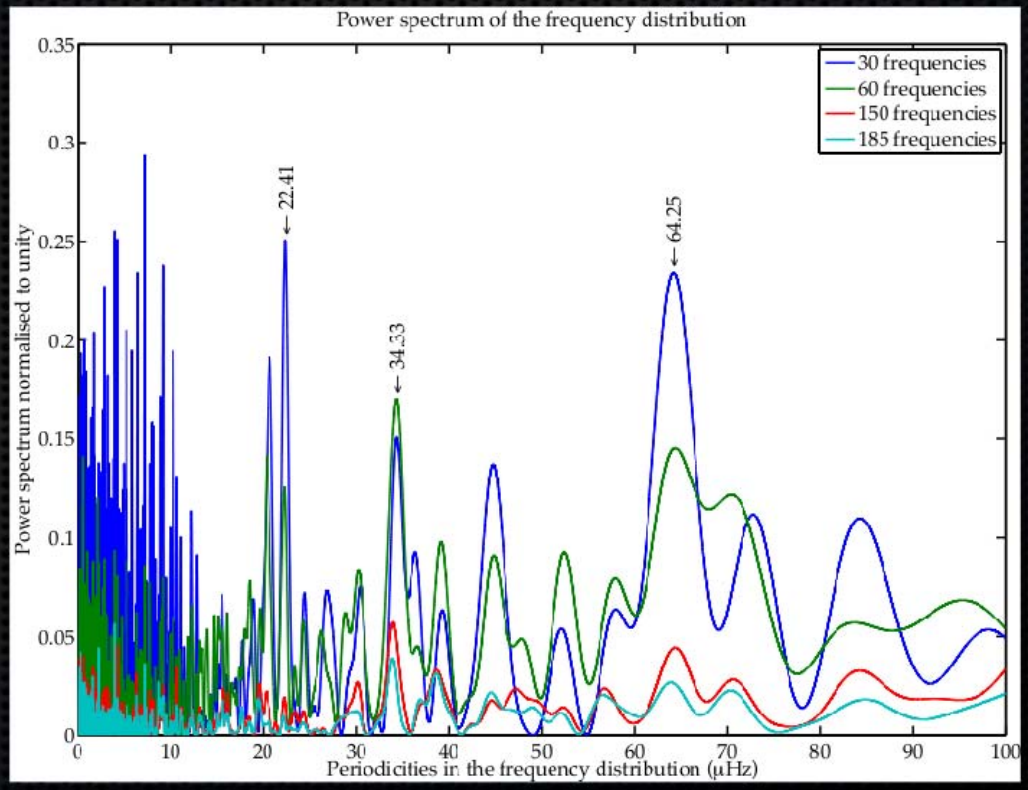
- A3, m_v = 7.72, Strömgren param.:
  - T_{eff} = 7637 ± 200 K
  - log *g* = 4.03 ± 0.2 deg
  - [Fe/H] = -0.11 ± 0.2 deg
- 185 frequencies (sig=10)
- **Δν** = [60,80] **μ**Hz



Frequency spectrum

HD 174966 with CoRoT

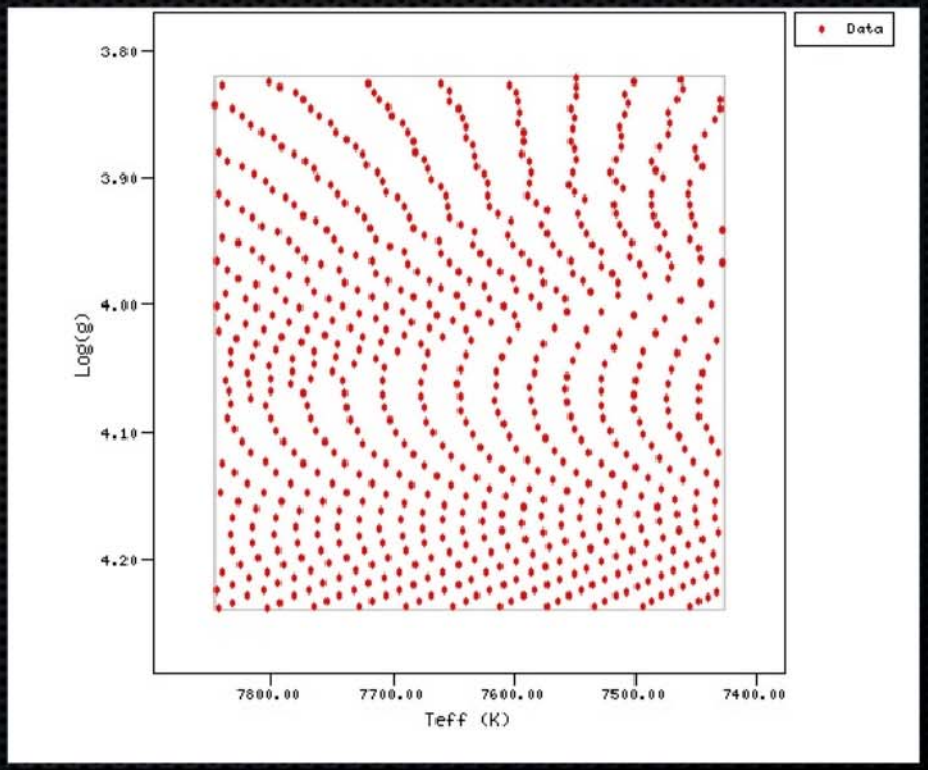
- A3, m_v = 7.72, Strömgren param.:
  - T_{eff} = 7637 ± 200 K
  - log *g* = 4.03 ± 0.2 deg
  - [Fe/H] = -0.11 ± 0.2 deg
- 185 frequencies (sig=10)
- Δν = [60,80] μHz



FT of the frequency spectrum

Model discrimination

- 24520 non-rotating models (CESAM+GraCo, α_{ML}=[0.5, 1.5], d_{ov}=[0.1, 0.3])
- $\Delta\nu$ = [60,80] μHz



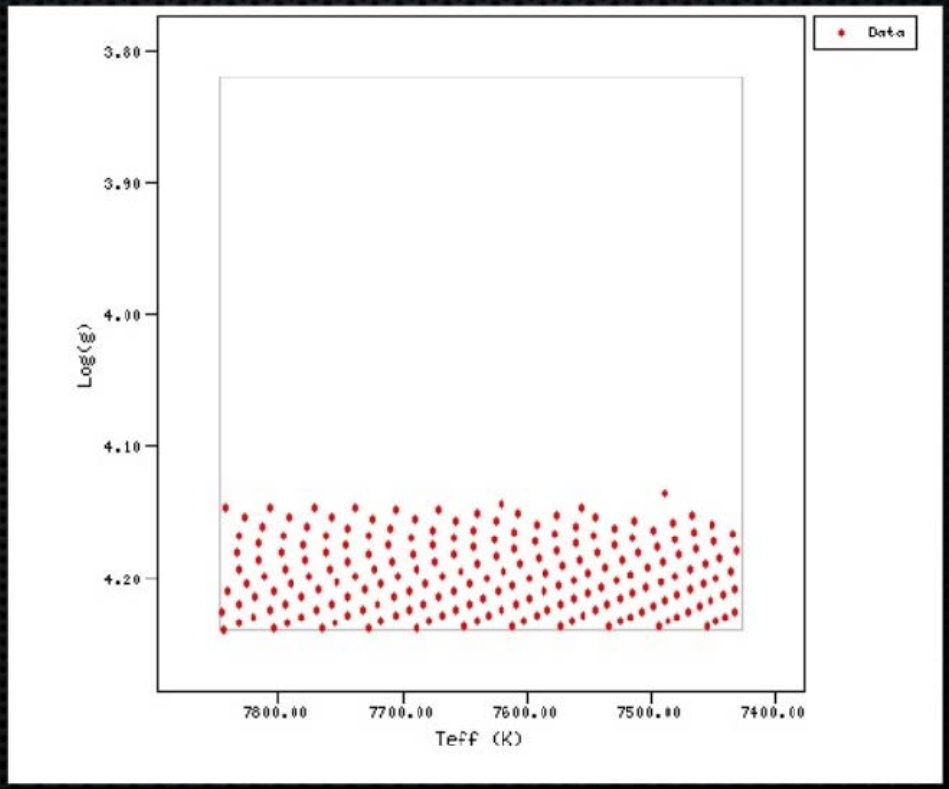
Uncertainty box (1σ, α_{ML}=0.5, d_{ov}=0.2)

Model discrimination

- 24520 non-rotating models (CESAM+GraCo, α_{ML}=[0.5, 1.5], d_{ov}=[0.1, 0.3])
- $\Delta\nu$ = [60,80] μHz

  ⇒ 5838 models

76 % of reduction in the number of models



Uncertainty box (1σ, α_{ML}=0.5, d_{ov}=0.2)

Model discrimination

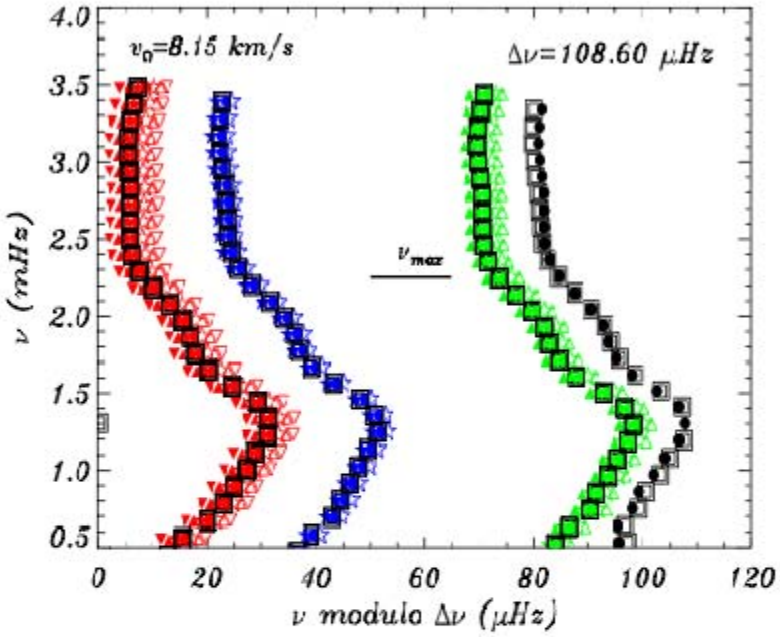
M ($M_\odot$)	R ($R_\odot$)	L ($L_\odot$)	$\overline{\rho}$ ($g \cdot cm^{-3}$)	Age (Myr)	H_c
[1.35, 2.20]	[1.46, 3.02]	[5.87, 30.94]	[0.113, 0.61]	[434, 2244]	[0, 0.7373]
[1.35, 1.78]	[1.46, 1.85]	[5.87, 11.36]	[0.39, 0.61]	[434, 1913]	[0.3099, 0.7373]

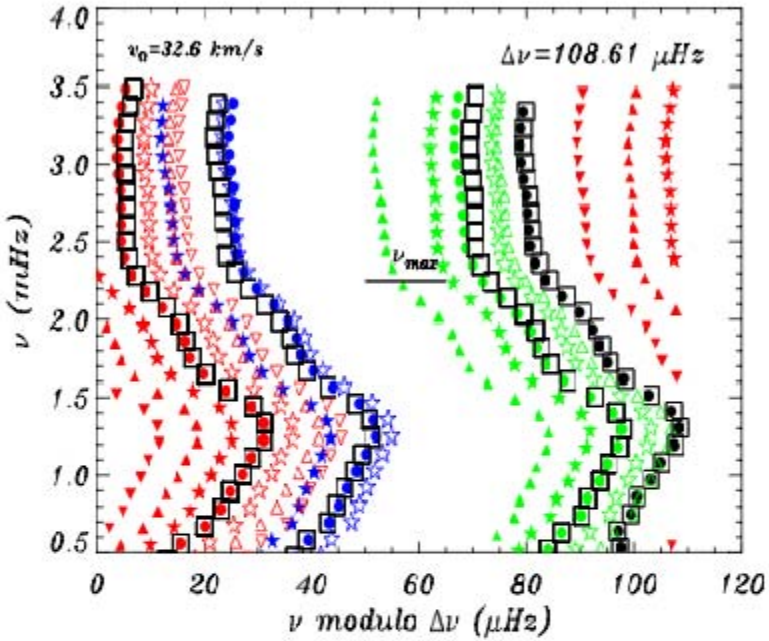
Photometric uncertainty box (upper) and reduced by $\Delta\nu$ (lower)

Model discrimination

M ($M_\odot$)	R ($R_\odot$)	L ($L_\odot$)	$\overline{\rho}$ ($g \cdot cm^{-3}$)	Age (Myr)	H_c
[1.35, 2.20]	[1.46, 3.02]	[5.87, 30.94]	[0.113, 0.61]	[434, 2244]	[0, 0.7373]
51%	[1.46, 1.85]	[5.87, 11.36]	56%	18%	[0.3099, 0.7373]

Photometric uncertainty box (upper) and reduced by $\Delta\nu$ (lower)





Suárez et al. (2010)

Asteroseismic models:
Equilibrium: ~1.3 $M_\odot$, global conservation of J, uniform rotation
Oscillations: P ÷ NPT

Conclusión

- Actualmente la astrosismología mejora en 1-2 órdenes de magnitud los valores de los parámetros fundamentales de las estrellas
- Pero, atención, nadie se explica el por qué de esa enorme cantidad de frecuencias observadas en los objetos de la MS !!!

Stay tuned…