IDENTYFIKACJA MODÓW obserwowanych pulsacji (część 1)

(na podstawie przeglądowego referatu
A.A.P. i J. Daszyńskiej-Daszkiewicz
dla konferencji w Hiszpanii:
„Impact of new instrumentation & new insights
in stellar pulsations", Granada, 5-9 September 2011)

(prezentacja oraz tekst dla Proceedings)

Dostęp do notatek Prof. W. A. Dziembowskiego z astrosejsmologii:

```
ftp  sirius.astrouw.edu.pl
login:  anonymous
password:  anonymous
cd  pub/wd/monograph
ftp> mget mon02.ps (for example)
or  ftp> mget  * (all files)
```

IDENTIFICATION OF PULSATION MODES IN MAIN SEQUENCE STARS: UNCERTAINTIES AND LIMITS

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Stellar Pulsation Conference, September 5-9, 2011, Granada

IDENTIFICATION OF PULSATION MODES

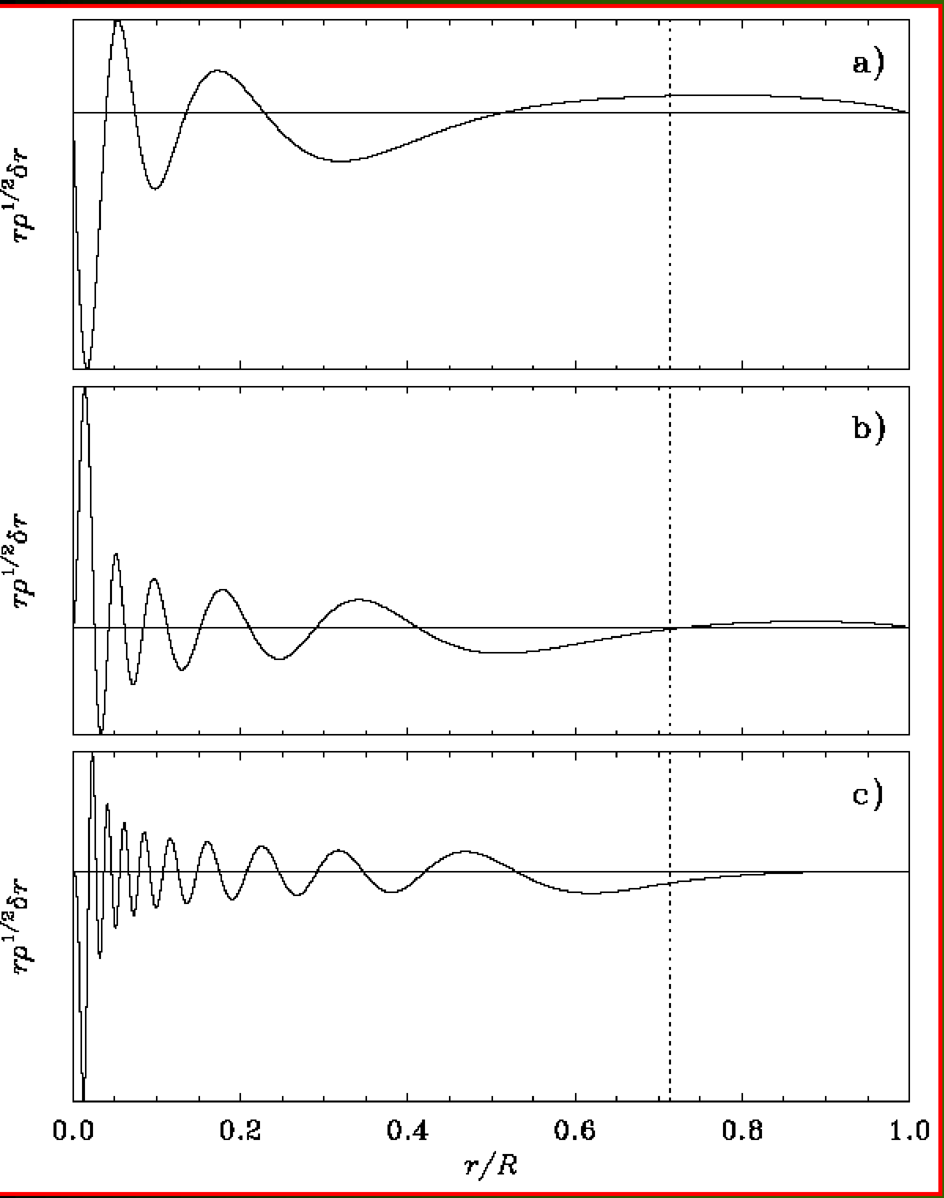
$$\nu = \nu(n, \ell, m)$$

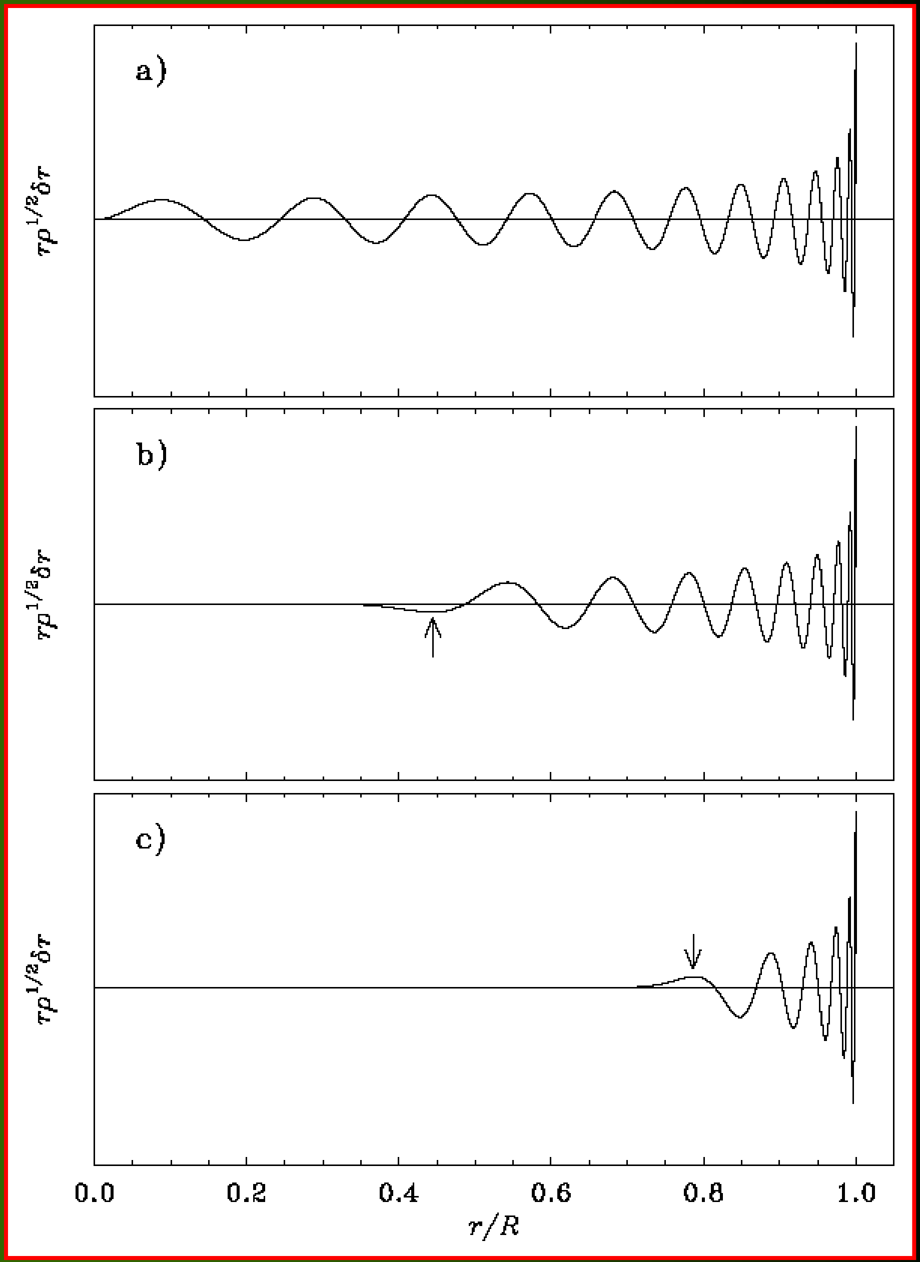
n – radial behaviour of eigenfunction

(ℓ, m) – mode geometry

Mody grawitacyjne

Mody akustyczne (ciśnieniowe)



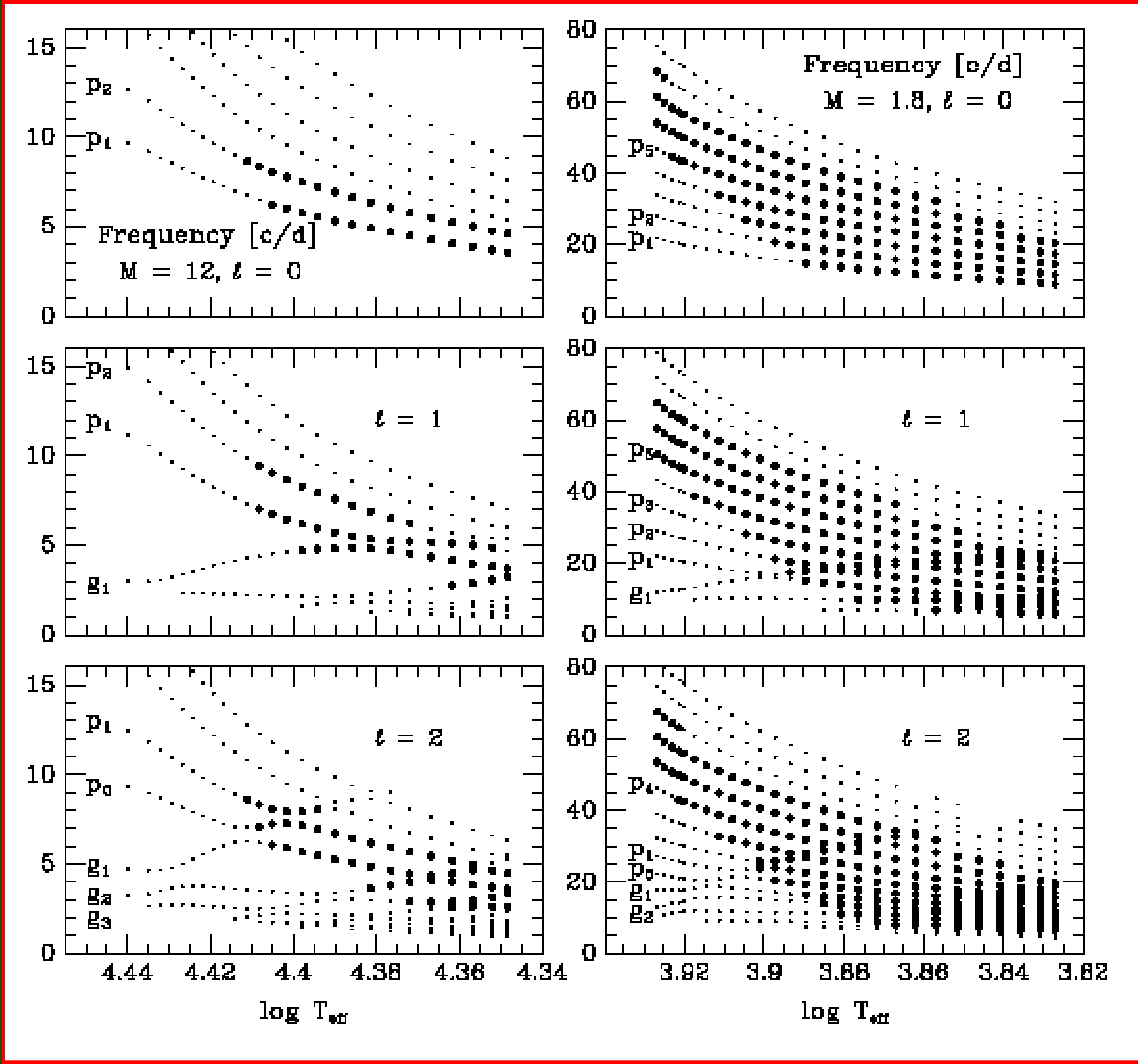


$(l,n)=(1,5), (2,10), (4,19)$, $\nu=100\mu\text{Hz}$

$(l,n)=(0,23), (20,17), (60,10)$, $\nu=3300\mu\text{Hz}$

Oscillation frequencies of typical Beta Cephei and Delta Scuti models on the main sequence

(from the ZAMS to the TAMS)



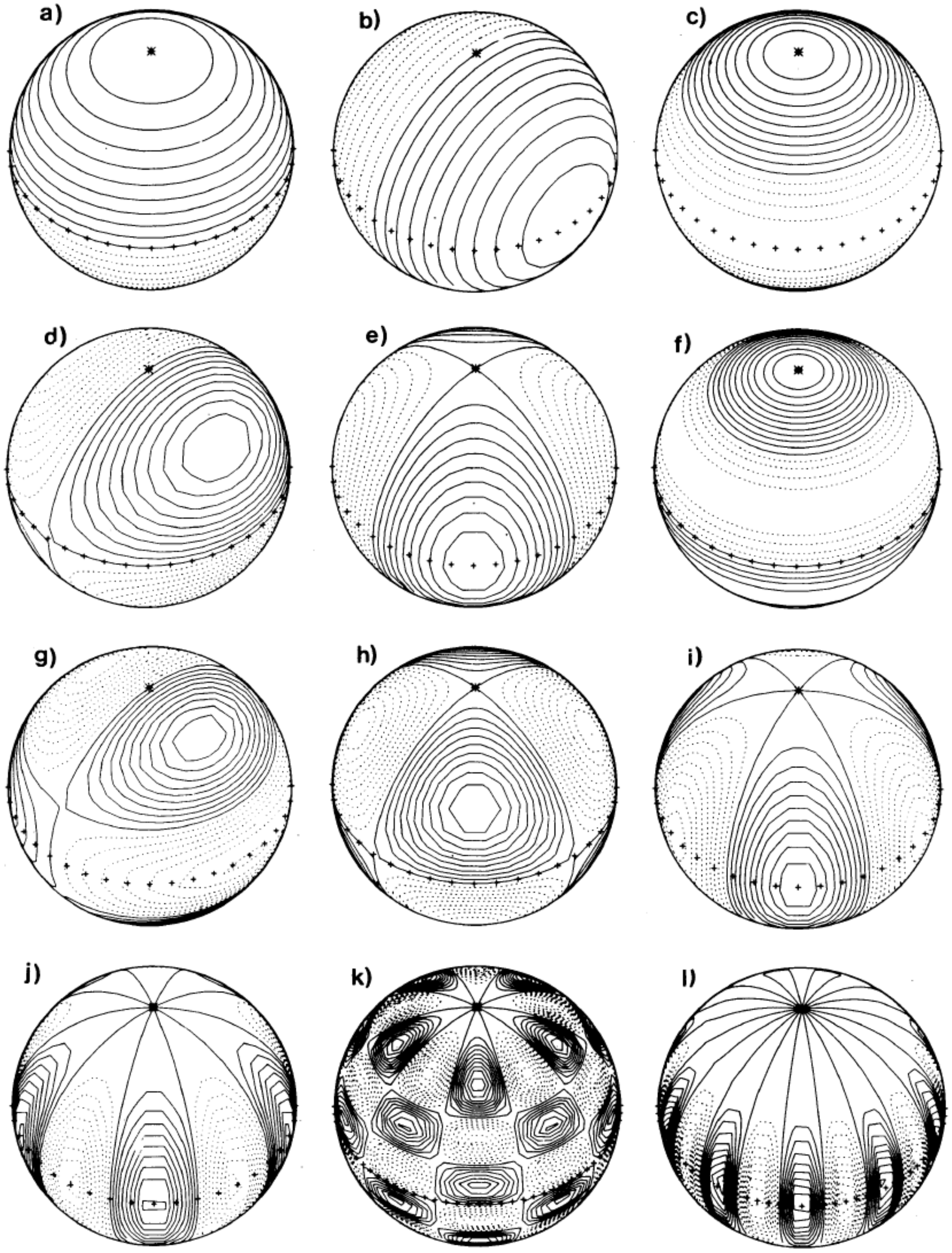
Przykłady geometrii oscylacji nieradialnych:

a) *l*=1, m=0
b) *l*=1, m=1

c) *l*=2, m=0
d) *l*=2, m=1
e) *l*=2, m=2

f) *l*=3, m=0
g) *l*=3, m=1
h) *l*=3, m=2
i) *l*=3, m=3

j) *l*=5, m=5
k) *l*=10, m=5
l) *l*=10, m=10



J. Christensen-Dalsgaard

Plan of the talk

- Mode identification from multicolor photometry.
- Simultaneous determination of mode degree *l* and nonadibatic parameter *f* from observations . Adding the radial velocity.
- Examples:

  δ Sct variables: β Cas, FG Vir, 44 Tau, HD 144277

  β Cep / SPB variables: ν Eri, γ Peg
- Effects of rotation on diagnostic diagrams:
  rotational mode coupling,
  slow (low-frequency) modes.
- Diagnostic diagrams for high *l* oscillations .

MODE IDENTIFICATION FROM MULTICOLOUR PHOTOMETRY

Complex amplitude of monochromatic flux variations

$$A_\lambda(i) = \varepsilon Y_\ell^m(i,0) b_\ell^\lambda (D_{1,\ell}^\lambda + D_{2,\ell} + D_{3,\ell}^\lambda)$$

$$D_{1,\ell}^\lambda = \frac{1}{4} f \frac{\partial \log(\mathcal{F}_\lambda |b_\ell^\lambda|)}{\partial \log T_{\mathrm{eff}}}$$

temperature term

$$D_{2,\ell} = (2+\ell)(1-\ell)$$

geometrical term

$$D_{3,\ell}^\lambda = -\left(2 + \frac{3\omega^2}{4\pi G <\rho>}\right) \frac{\partial \log(\mathcal{F}_\lambda |b_\ell^\lambda|)}{\partial \log g_{\mathrm{eff}}^0}$$

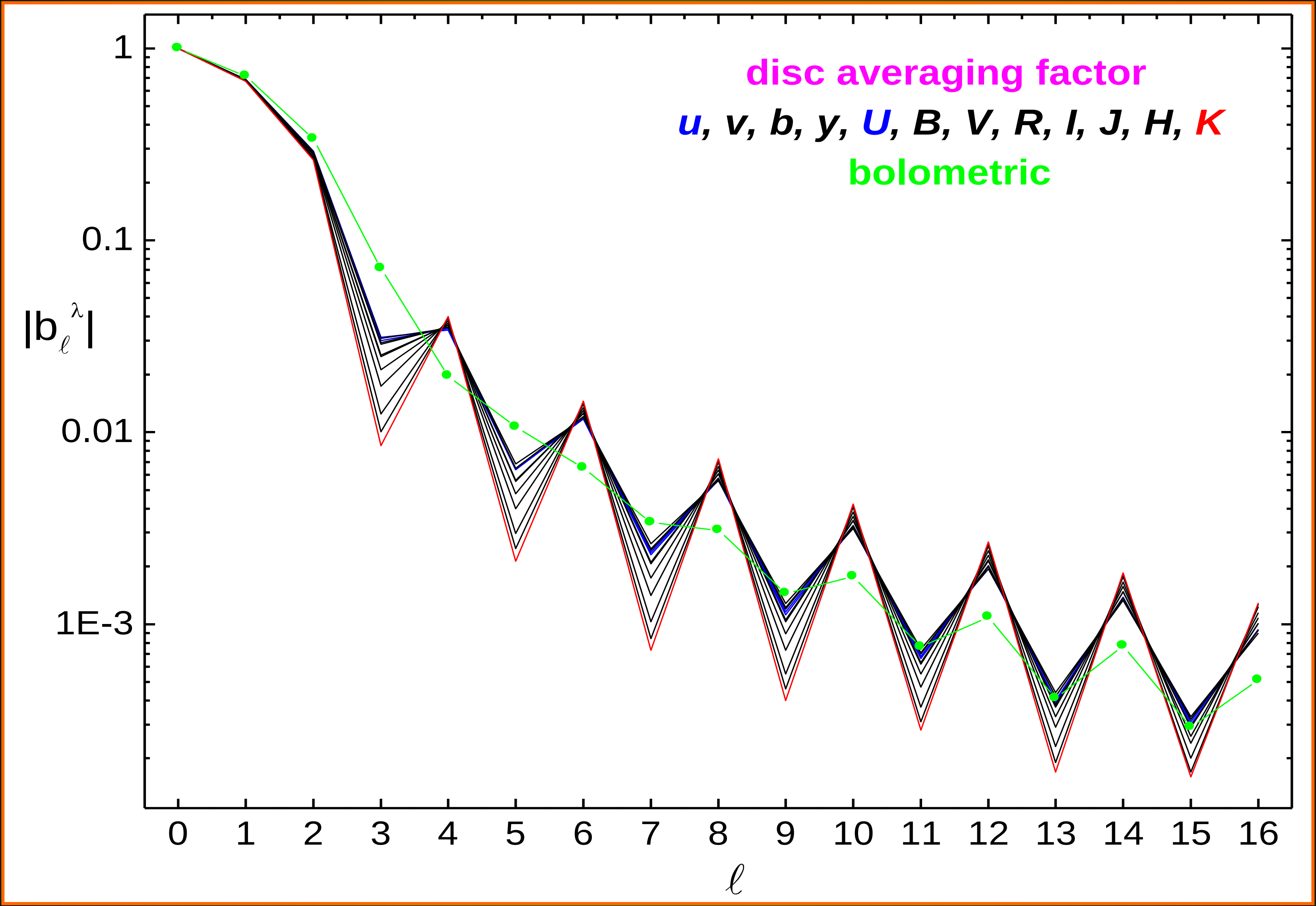
pressure term

$$b_\ell^\lambda = \int_0^1 h_\lambda^0(\mu) \mu P_\ell(\mu) d\mu$$

disc averaging factor

due to Dziembowski 1977, Daszyńska-Daszkiewicz et al. 2002

Disc averaging factor for bolometric flux and for 12 passbands



due to Daszyńska-Daszkiewicz, Dziembowski & Pamyatnykh 2002

INPUT FROM PULSATION CALCULATIONS:

- linear nonadiabatic theory: the *f* parameter

INPUT FROM MODEL ATMOSPHERES:

- derivatives of the monochromatic flux over T_{eff} and g
- limb darkening coefficients: $h_\lambda(T_{eff}, g)$

f - the ratio of the bolometric flux variation to the radial displacement at the photosphere level

$$\frac{\delta \mathcal{F}_{\rm bol}}{\mathcal{F}_{\rm bol}} = \mathrm{Re}\{\varepsilon f Y_\ell^m \mathrm{e}^{-\mathrm{i}\omega t}\},$$

The flux derivatives over log T_{eff} and log g depend on:

- microturbulence velocity, ξ_t
- metallicity, [m/H]
- NLTE effects
- models of stellar atmospheres

The *f* parameter is very sensitive to:

- global stellar parameters
- chemical composition
- opacity
- subphotospheric convection

Two approaches to mode identification from photometry:

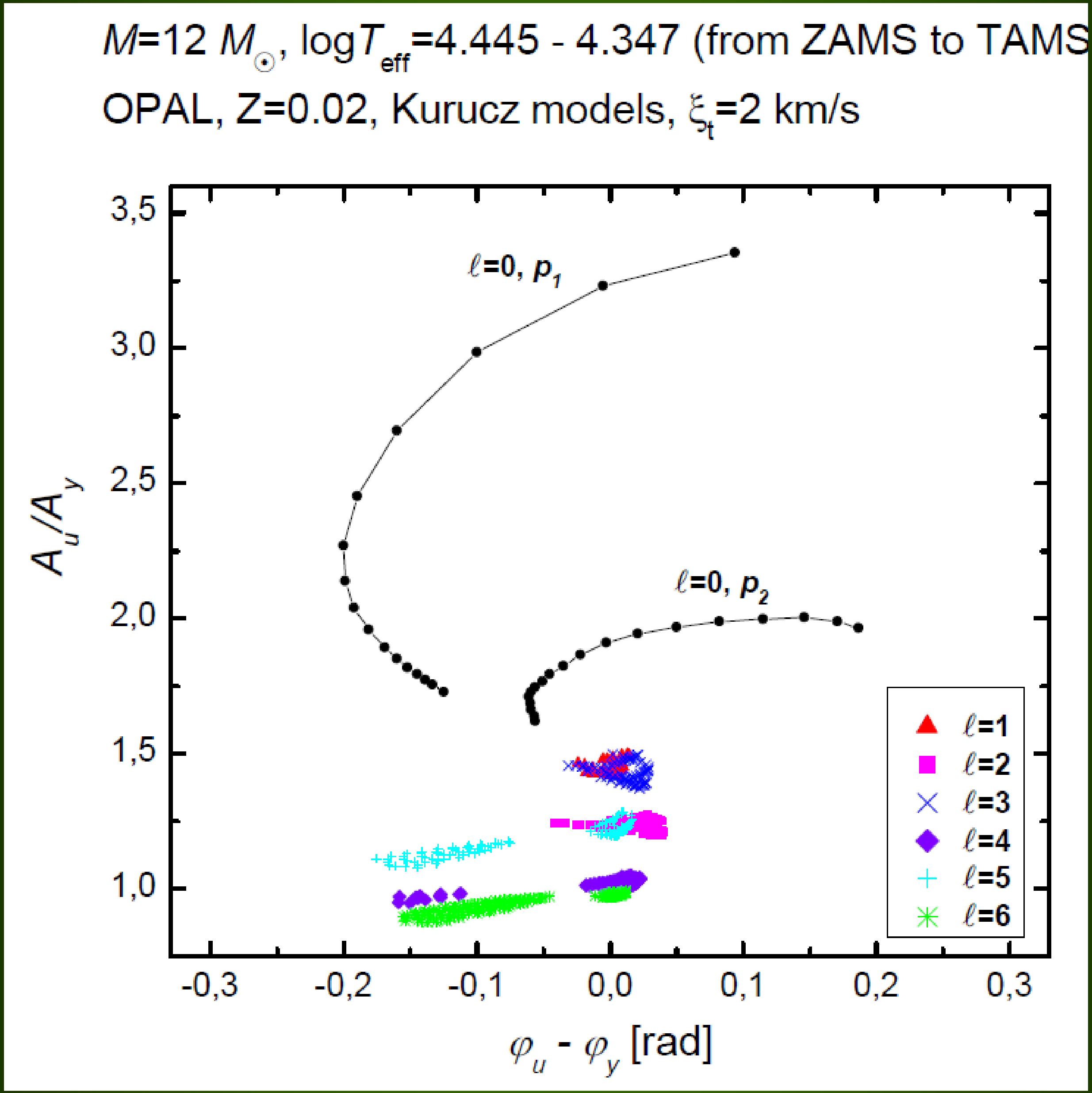
1) Comparing theoretical and observational values of the amplitude ratios and phase differences (f from theory)

2) Making use of the amplitudes and phases themselves (f is determined from observations together with ℓ)

both methods need input from model atmospheres !

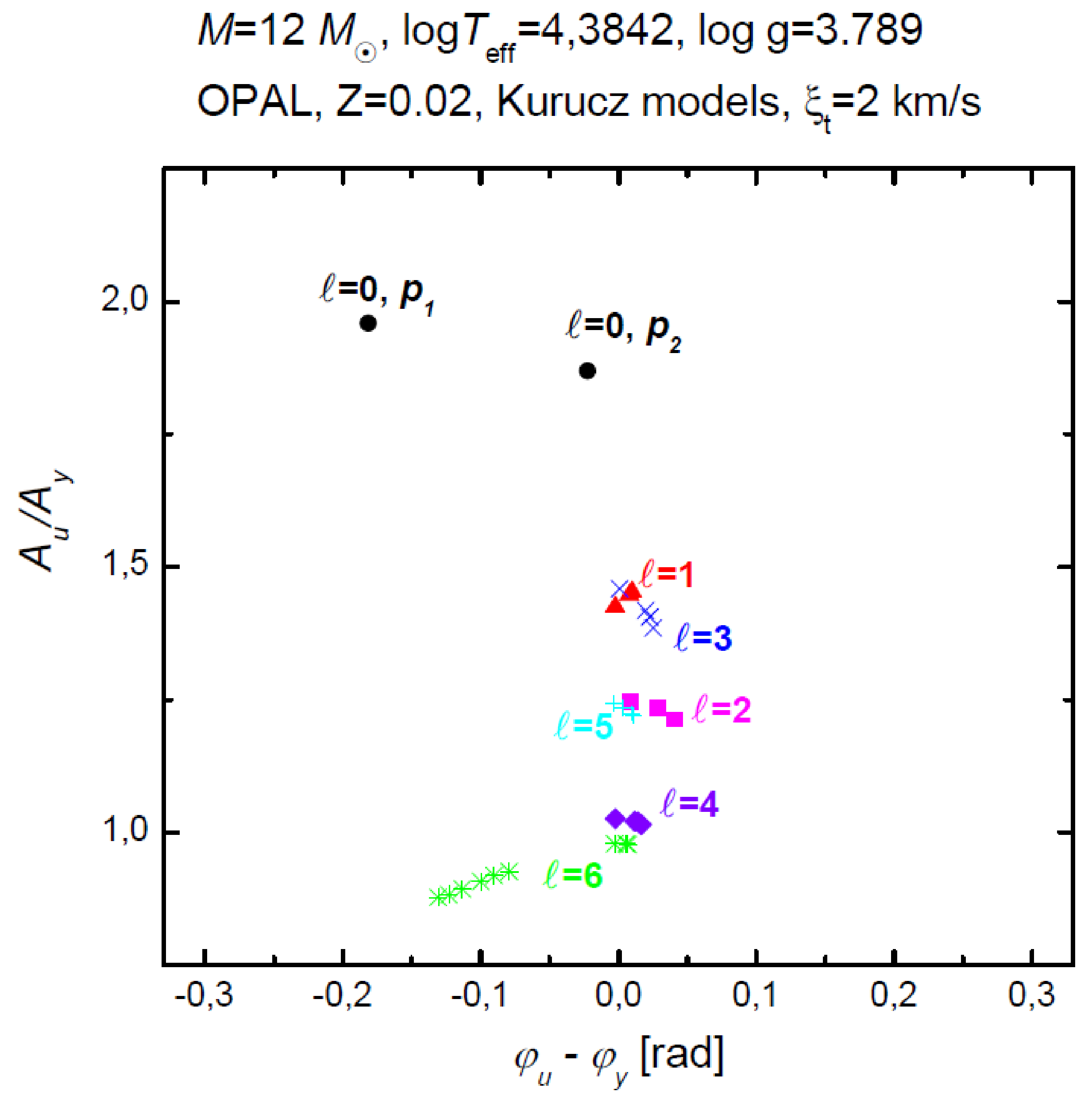
If we ignore rotation,
the amplitude ratios and phase differences
are independent of the inclination angle, i ,
and the azimuthal order, m .

β Cephei star models, the location of unstable modes



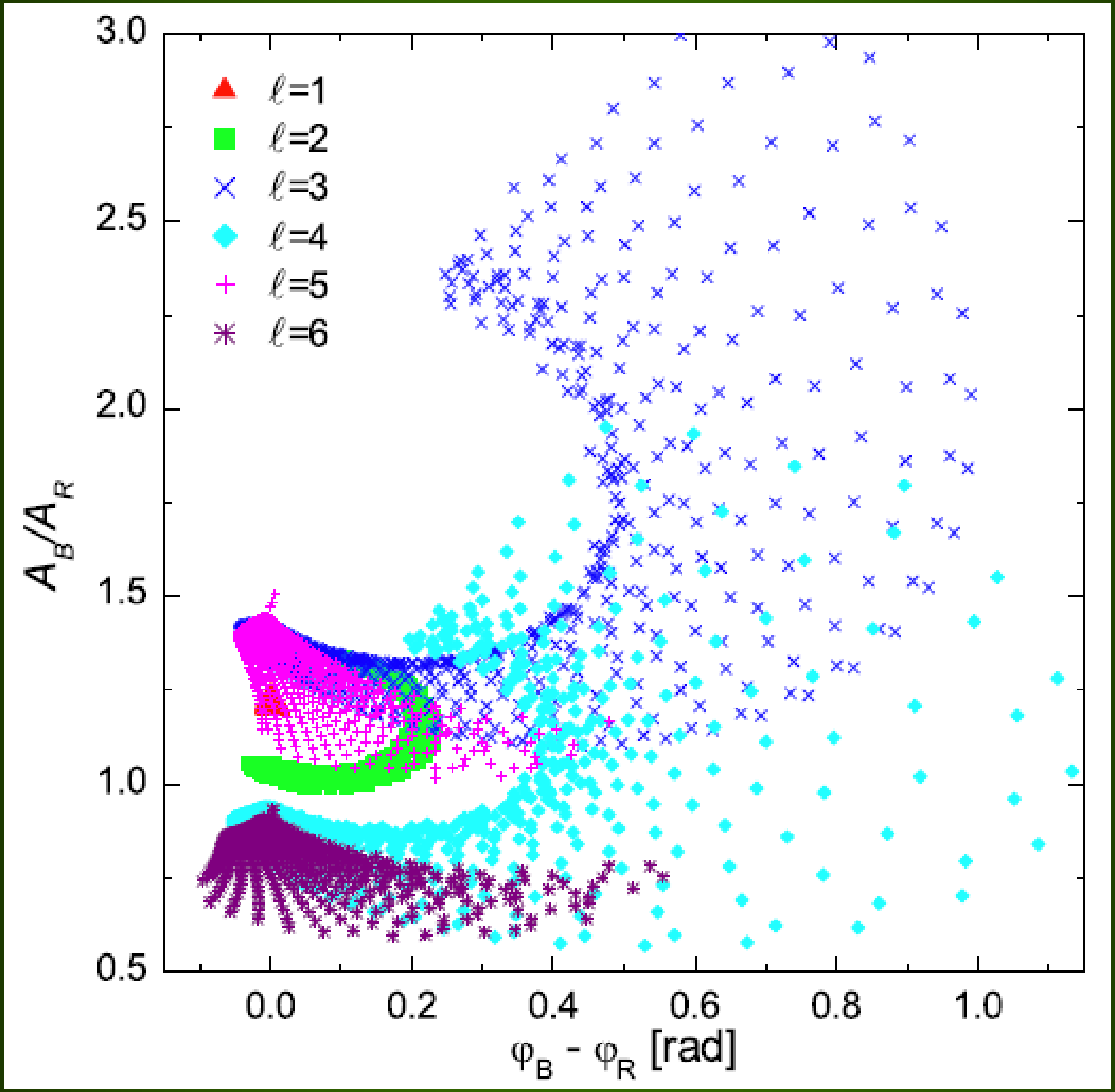
due to Daszyńska-Daszkiewicz 2007

β Cep model: log T_{eff} = 4.400, log g = 3.89



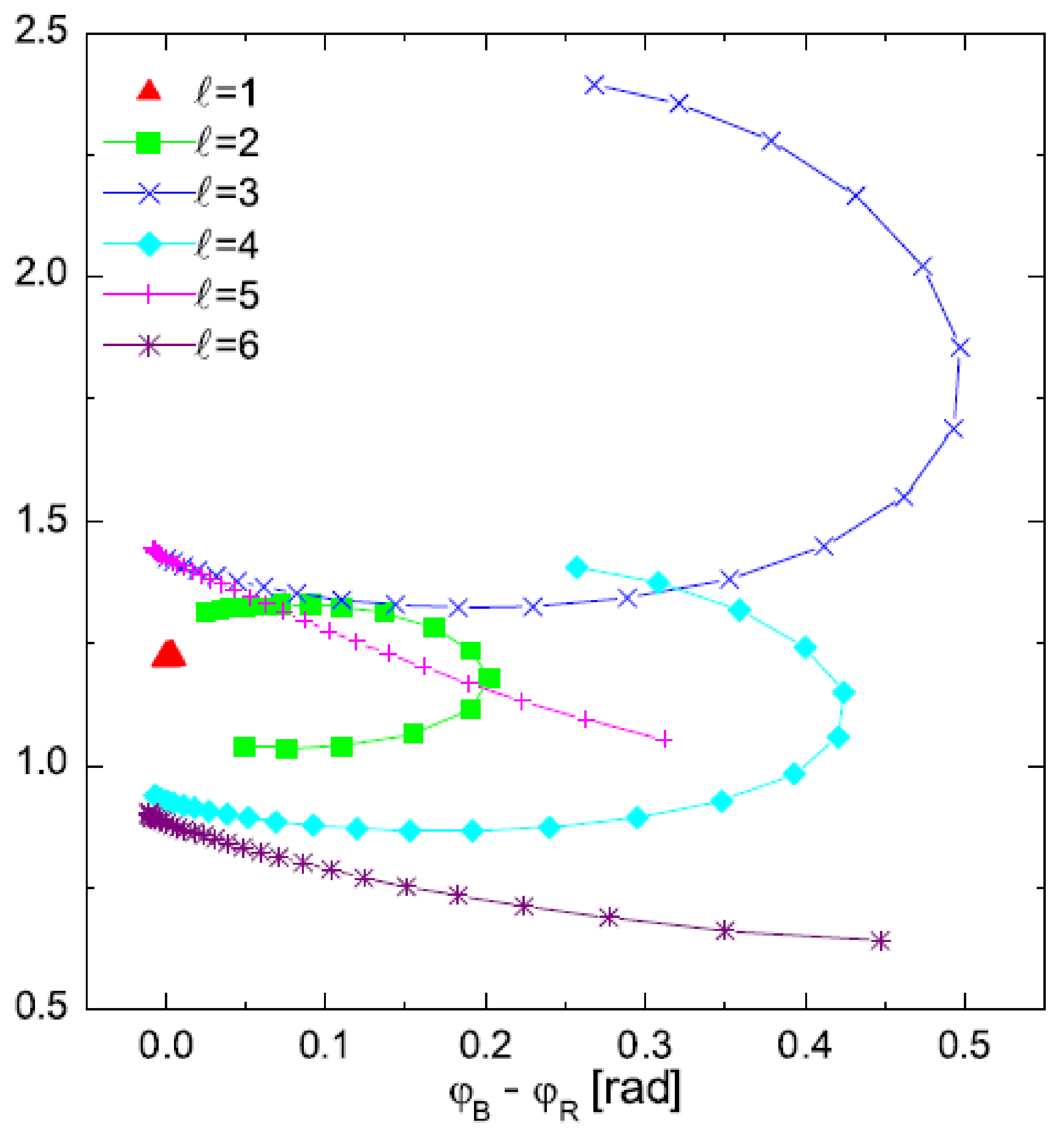
due to Daszyńska-Daszkiewicz 2007

Slowly Pulsating B-type star models of 5 $M_\odot$



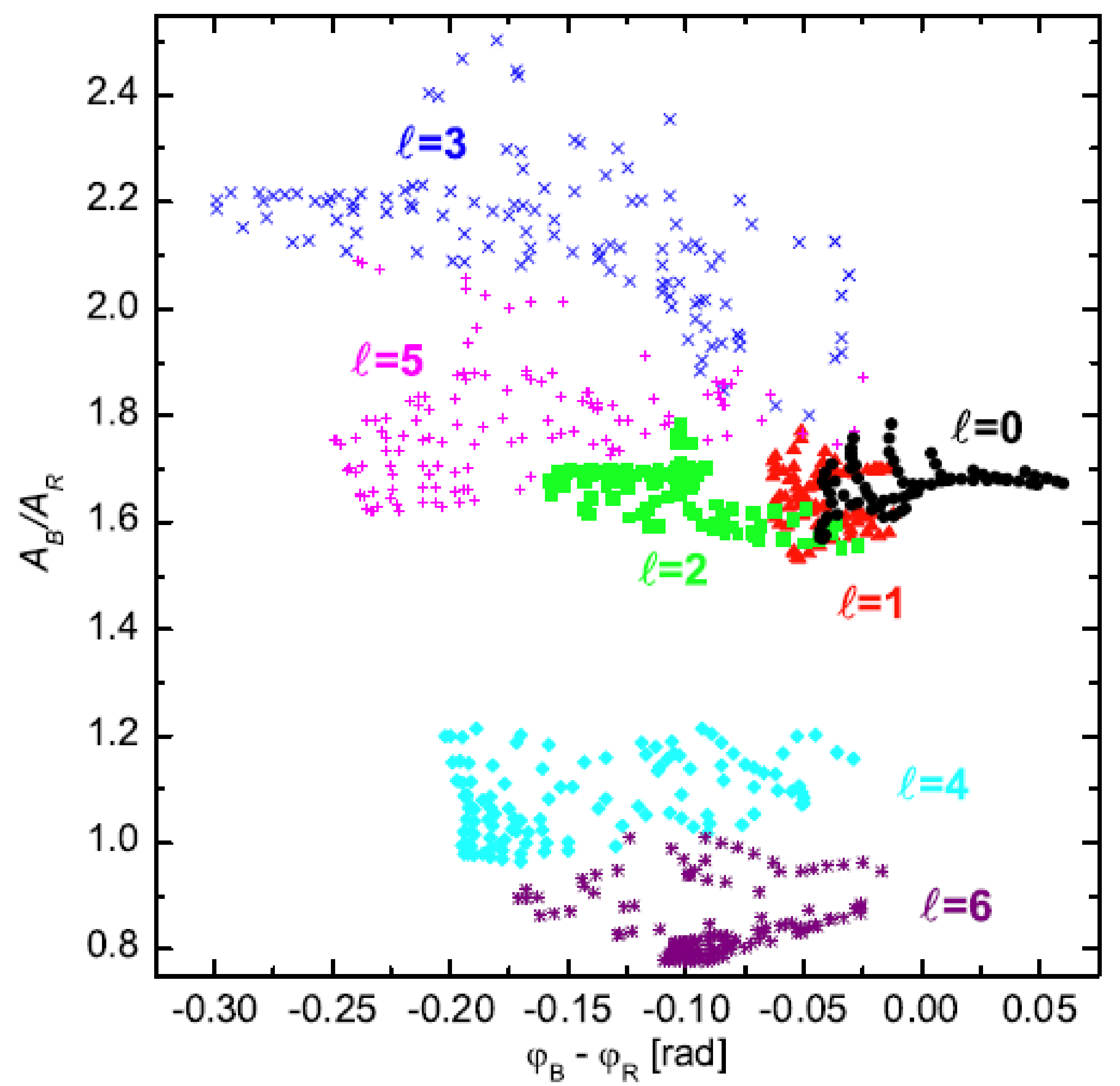
due to Daszyńska-Daszkiewicz 2007

A SPB star model: log T_{eff} = 4.195, log g = 4.02



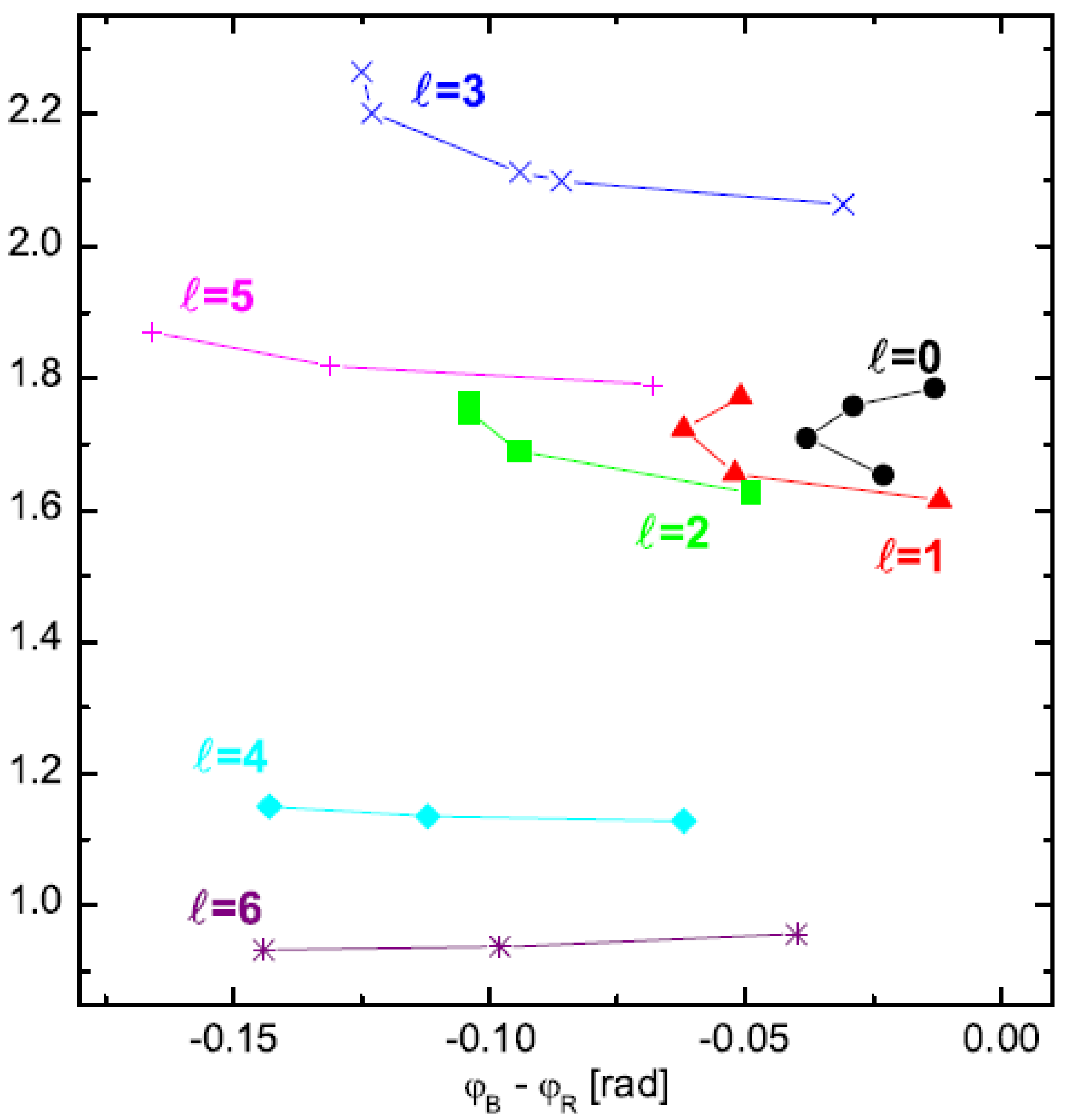
due to Daszyńska-Daszkiewicz 2007

δ Scuti star models of 2 $M_\odot$



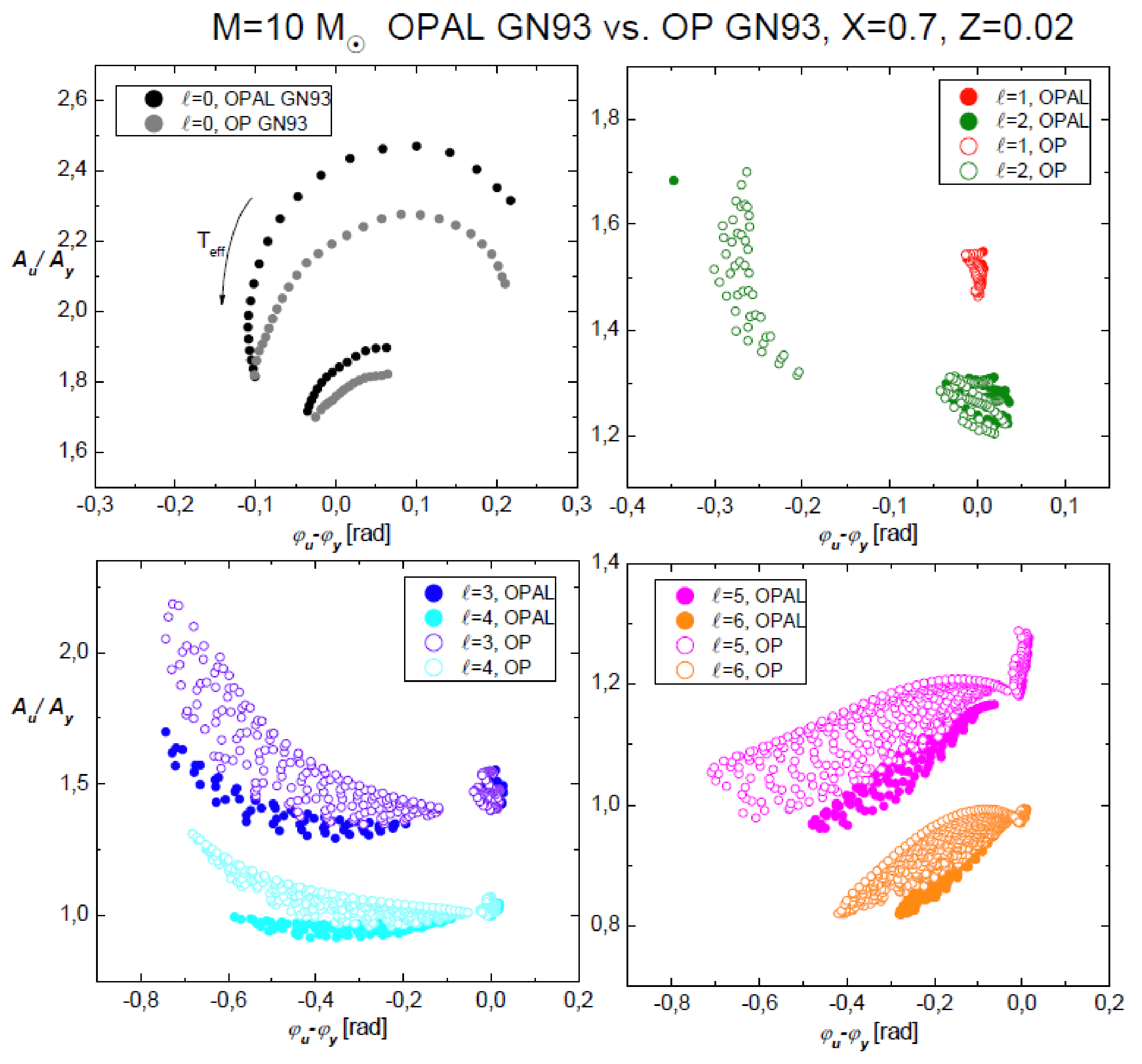
due to Daszyńska-Daszkiewicz 2007

δ Sct star model: log T_{eff} = 3.909, log g = 4.02

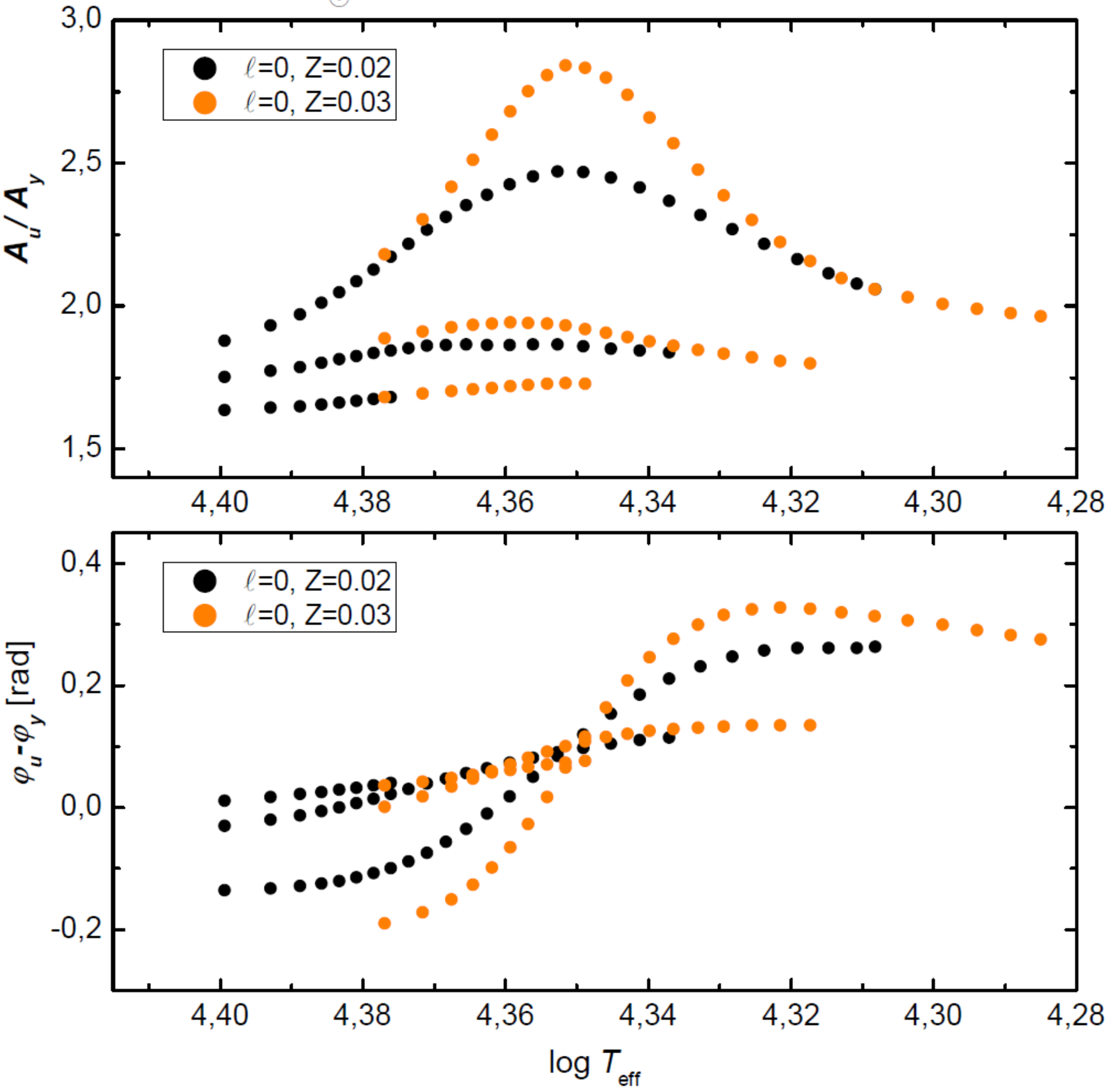


due to Daszyńska-Daszkiewicz 2007

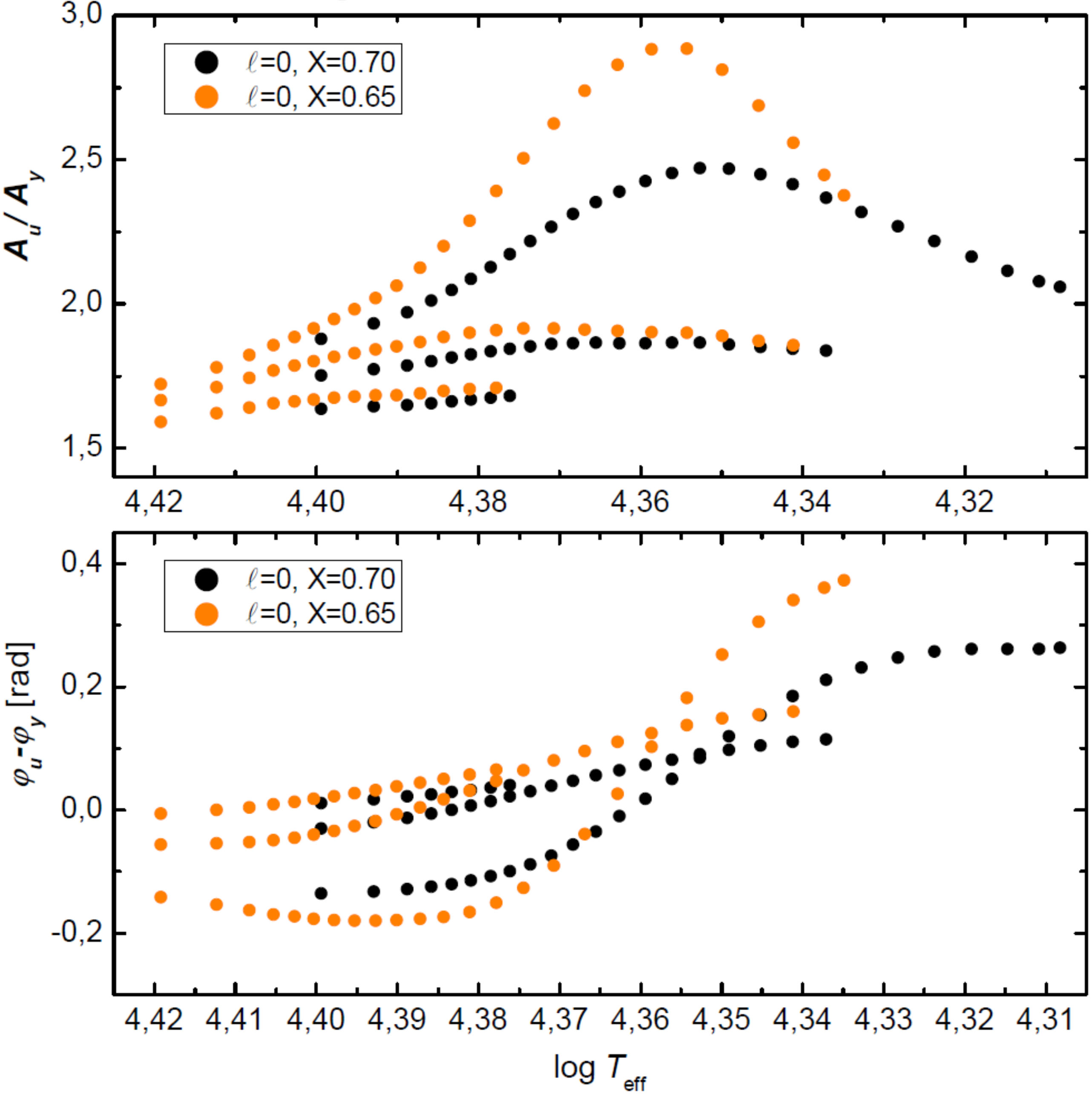
β Cephei star models, effect of opacity choice
$M=10\ M_\odot$ OPAL *versus* OP , X=0.7, Z=0.02



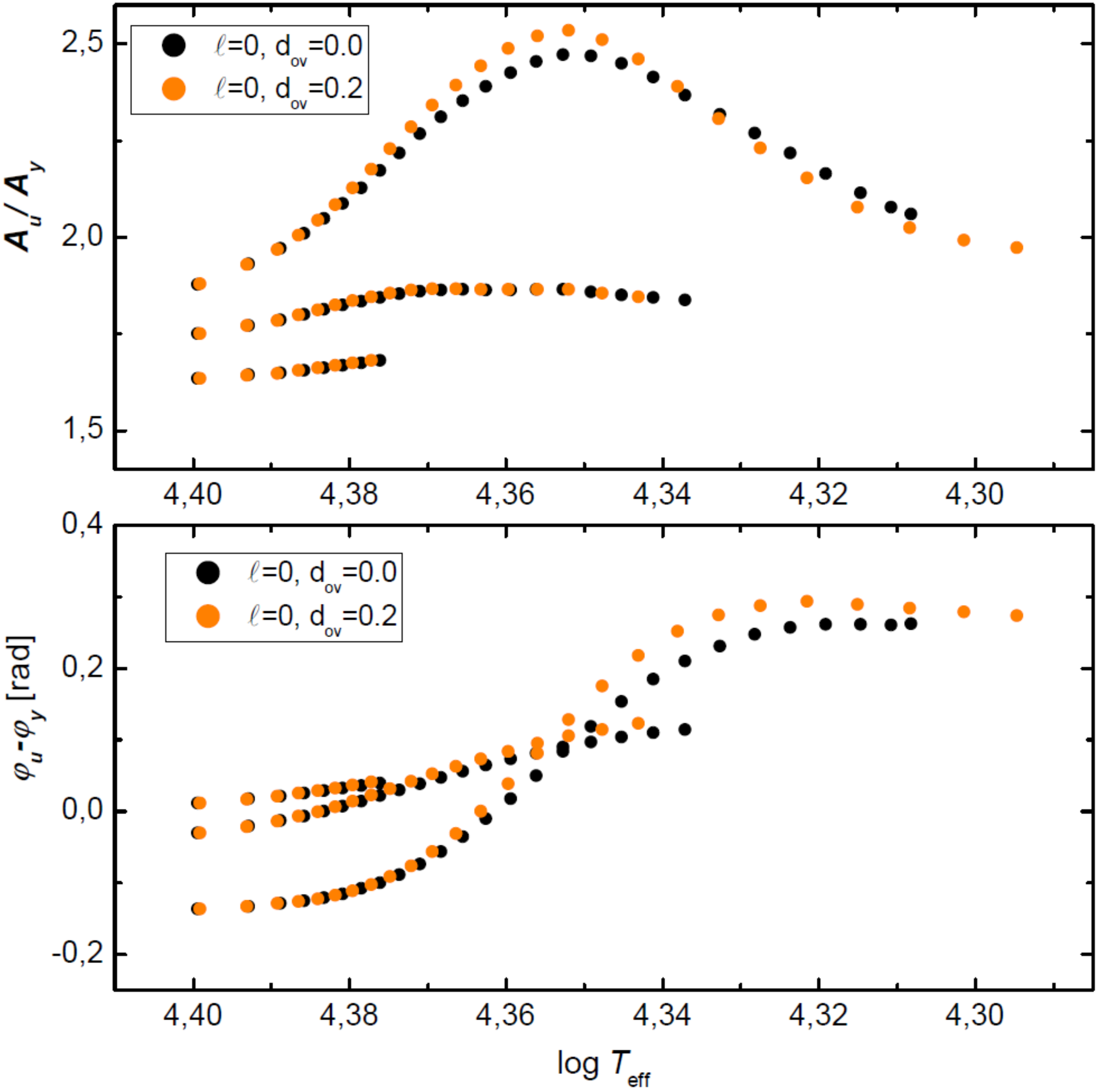
M=10 $M_\odot$ Z=0.02 vs. Z=0.03 OP, A04, X=0.7



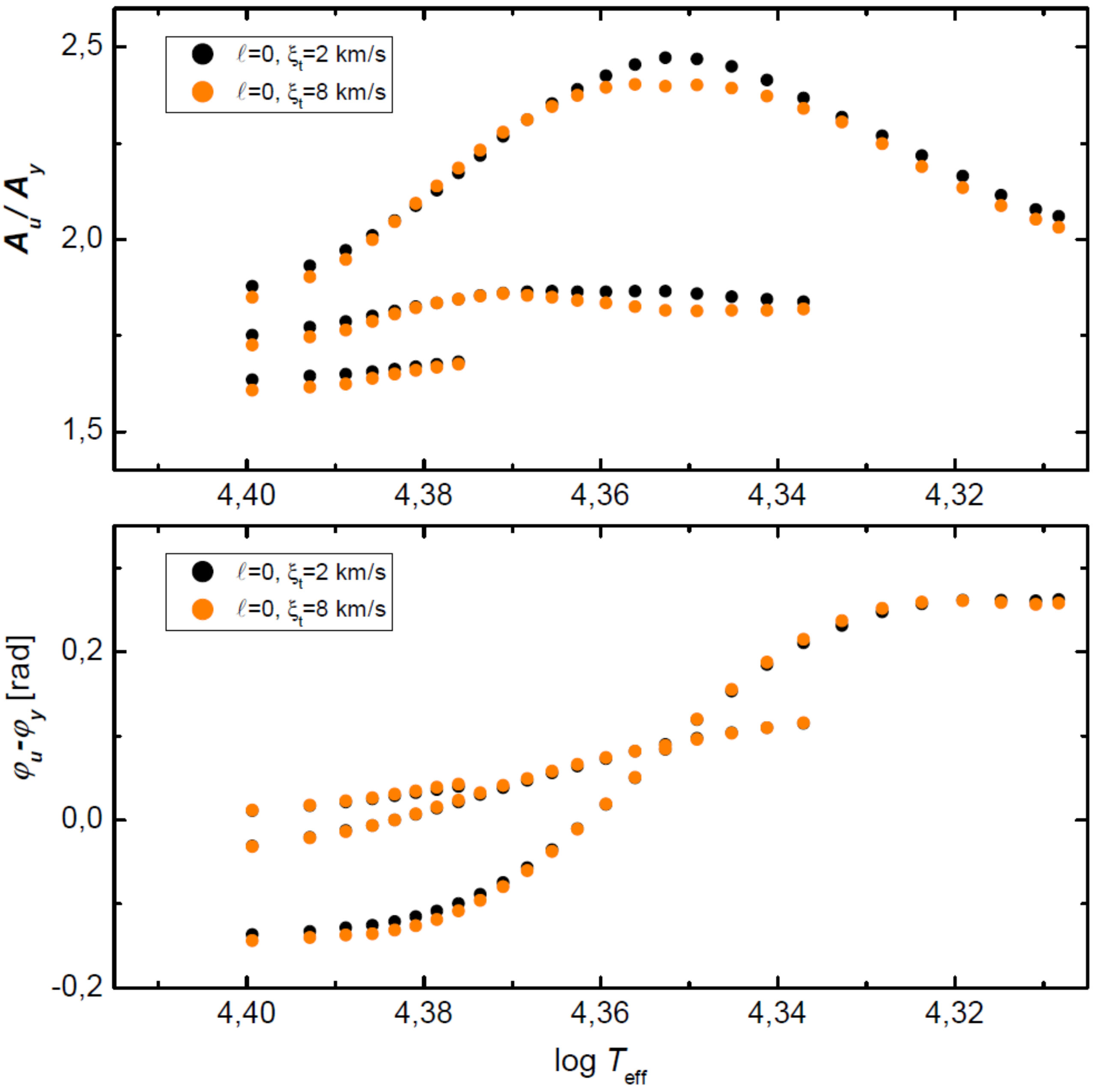
$M=10\,M_\odot$ X=0.70 vs. X=0.65 OP, A04, Z=0.02



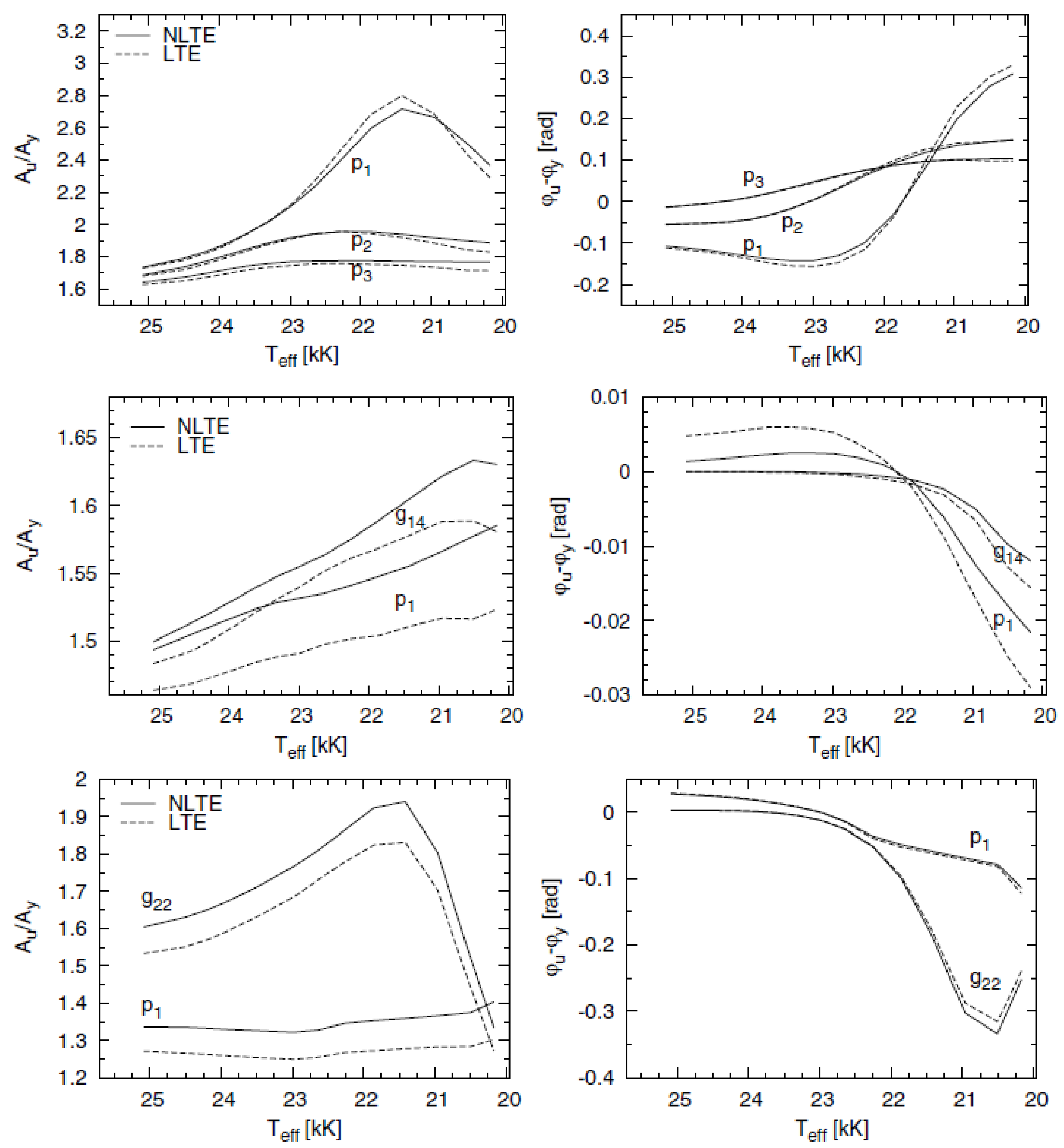
$M=10\ M_\odot$ $d_{ov}=0.0$ vs. $d_{ov}=0.2$, OP, A04, X=0.70, Z=0.02



$M=10\ M_\odot$ $\xi_t=2$ vs. $\xi_t=8$ km/s, OP, A04, X=0.70, Z=0.02



The NLTE and LTE values of the amplitude ratios and phase differences for 10 $M_\odot$ main-sequence models as a function of $T_{\rm eff}$



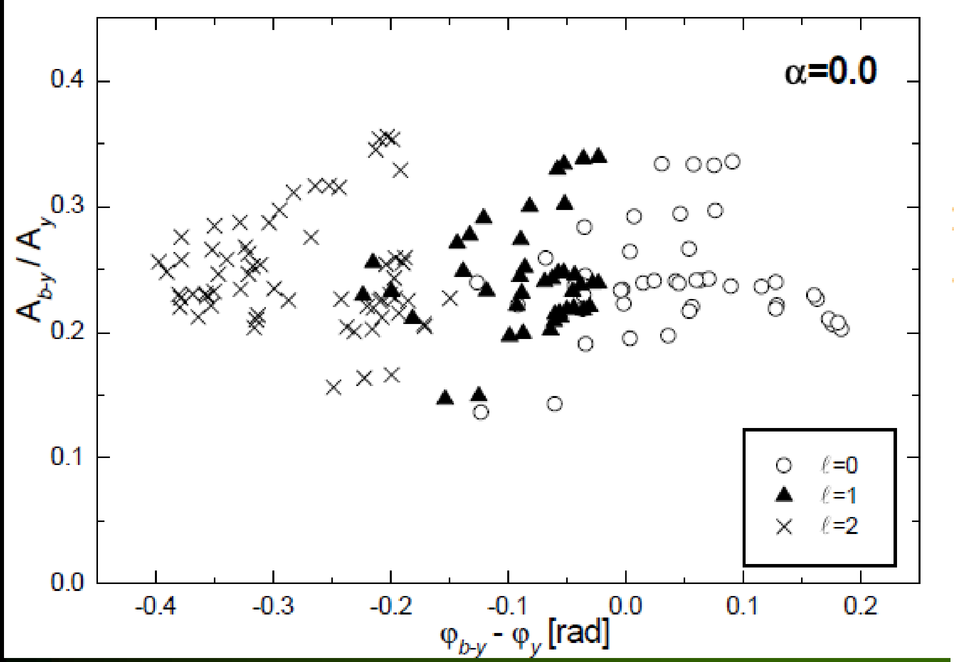
ℓ=0

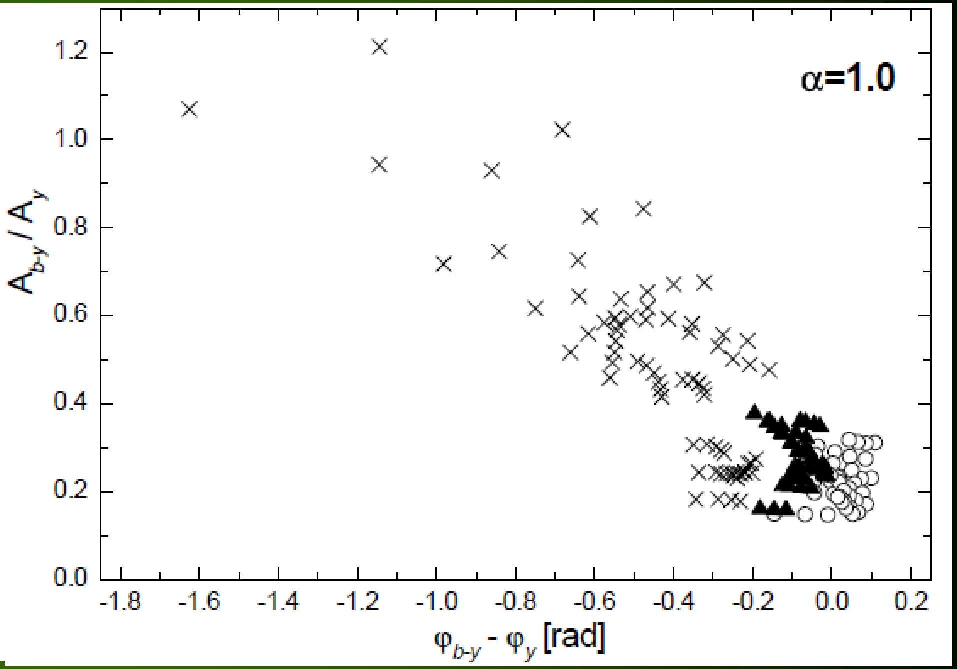
ℓ=1

ℓ=2

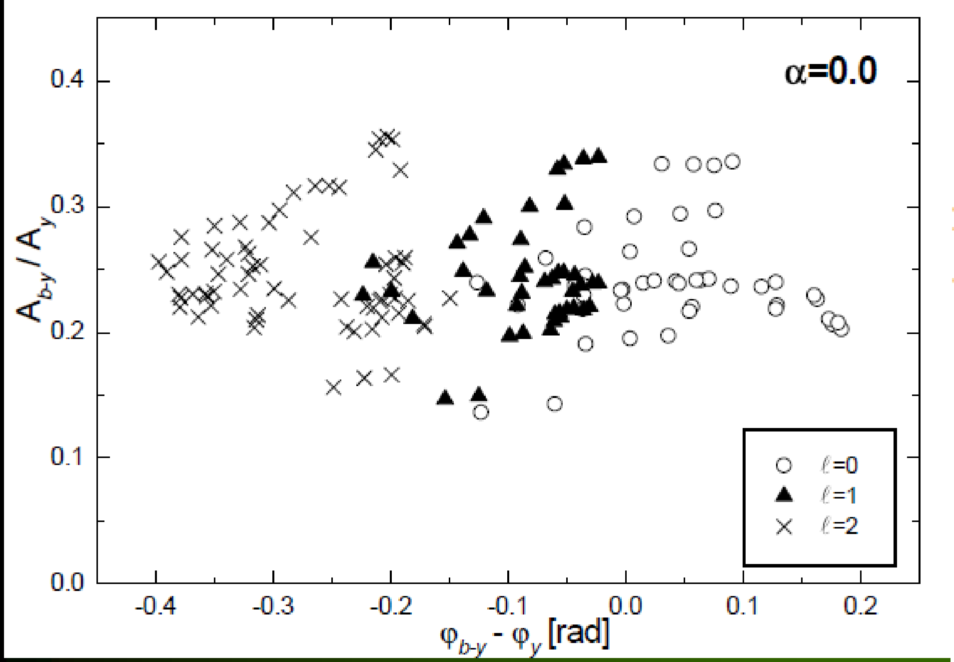
Daszyńska-Daszkiewicz, Szewczuk, 2010, ApJ 728, 17

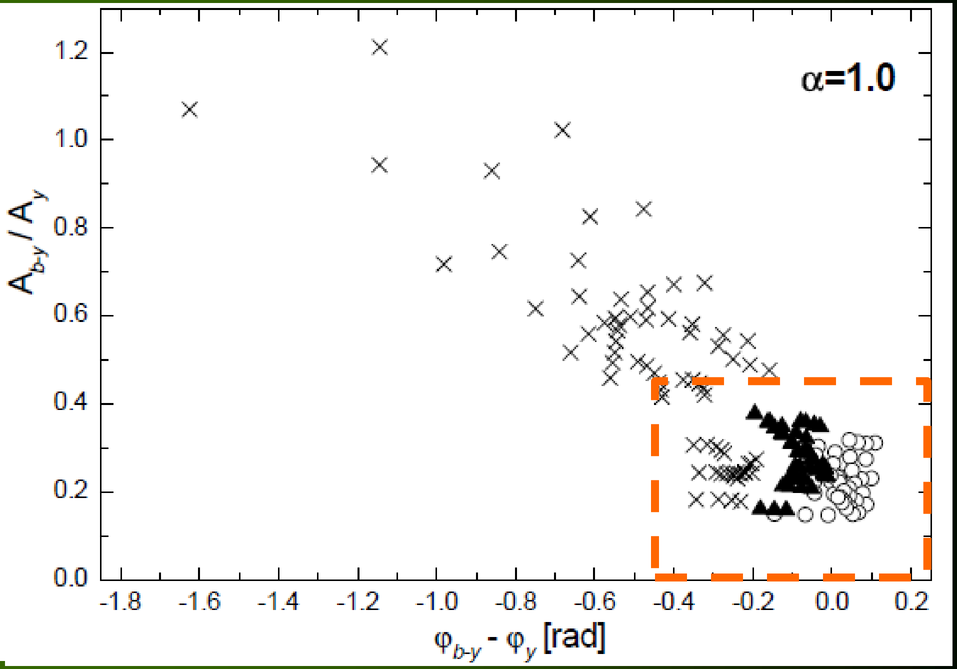
Effect of the MLT parameter, α, δ Scuti models with 1.9 $M_\odot$



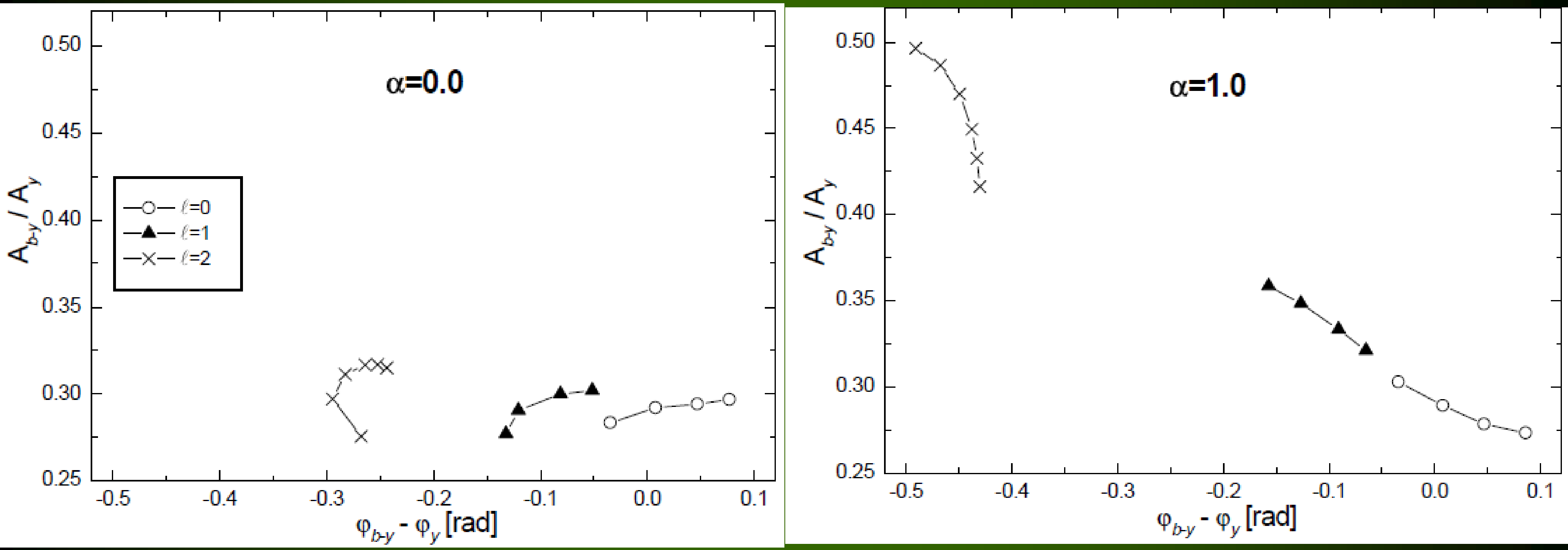


Effect of the MLT parameter, α, δ Scuti models with 1.9 $M_\odot$

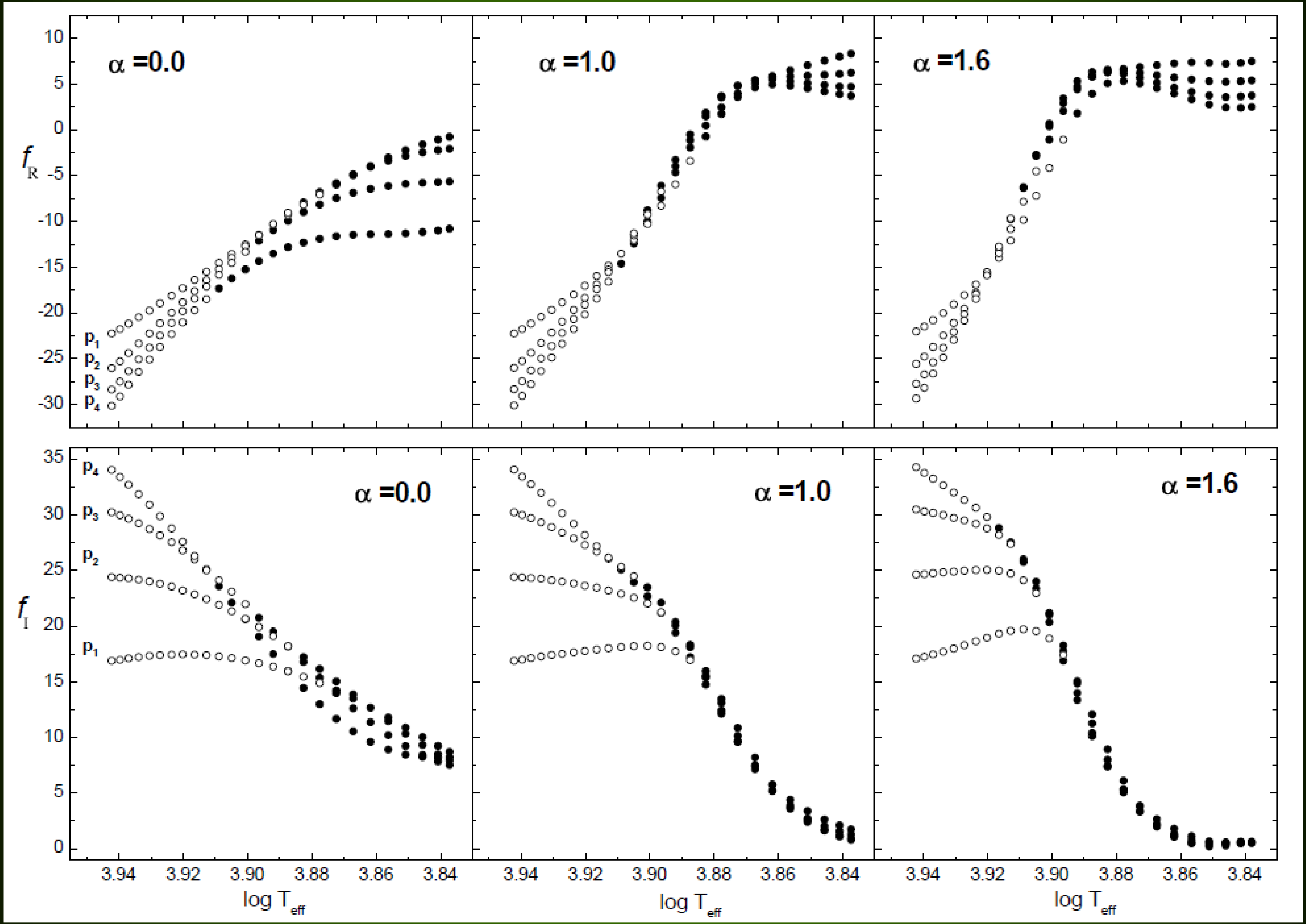




Effect of α for a fixed model $\log T_{\rm eff}=3.867$



Real and imaginary part of the f parameter for radial oscillation of a 1.9 $M_\odot$ star in the main sequence evolutionary stage, for three values of the MLT parameter, α. Filled circles - the unstable modes, open circles - the stable ones.



Daszyńska-Daszkiewicz, Dziembowski & Pamyatnykh 2003

SIMULTANEOUS DETERMINATION OF ℓ AND f FROM OBSERVATIONS

A SYSTEM OF EQUATIONS

$$\mathcal{D}_\ell^\lambda(\tilde{\varepsilon} f) + \mathcal{E}_\ell^\lambda \tilde{\varepsilon} = A^\lambda,$$

$$\tilde{\varepsilon} = \varepsilon Y_\ell^m(i, 0),$$

$$\mathcal{D}_\ell^\lambda = \frac{1}{4} b_\ell^\lambda \frac{\partial \log(\mathcal{F}_\lambda |b_\ell^\lambda|)}{\partial \log T_{\mathrm{eff}}},$$

$$\mathcal{E}_\ell^\lambda = b_\ell^\lambda \left[(2+\ell)(1-\ell) - \left(\frac{\omega^2 R^3}{GM} + 2 \right) \frac{\partial \log(\mathcal{F}_\lambda |b_\ell^\lambda|)}{\partial \log g} \right].$$

Daszyńska-Daszkiewicz, Dziembowski & Pamyatnykh 2003

METHOD

Two complex unknown quantities

$$(\tilde{\varepsilon} f), \ \tilde{\varepsilon}.$$

For a given degree, ℓ, the system is solved by the least-square method to find the minimum of χ^2.

ADDING THE RADIAL VELOCITY

$$\mathrm{i}\omega R\left(u_\ell^\lambda + \frac{GM}{R^3\omega^2}v_\ell^\lambda\right)\tilde{\varepsilon} = V_{rad}(i)$$

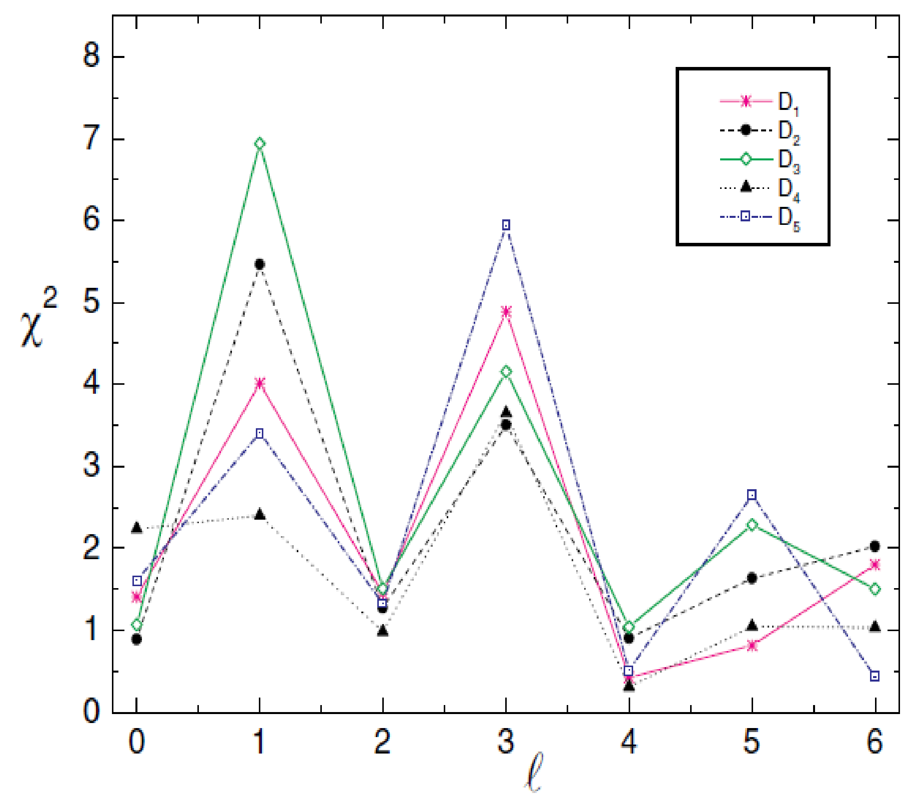
$$u_\ell = \int_0^1 h\mu^2 P_\ell(\mu)d\mu,$$

$$v_\ell = \ell\int_0^1 h(P_{\ell-1} - \mu P_\ell)\mu d\mu,$$

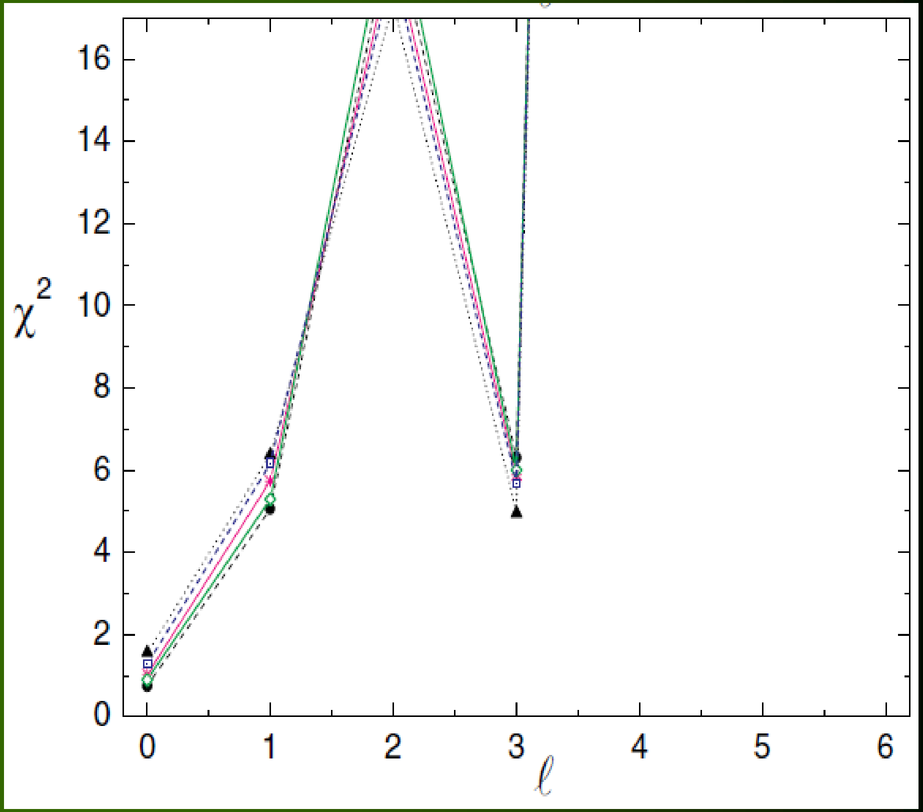
Dziembowski , 1977, Acta Astr. 27, 203

Effect of adding Vrad data.
δ Ceti – monoperiodic β Cephei star

photometry



photometry + spectroscopy



Daszyńska-Daszkiewicz, Dziembowski & Pamyatnykh 2005

Examples: δ SCUTI STARS

β Cas, FG Vir, 44 Tau

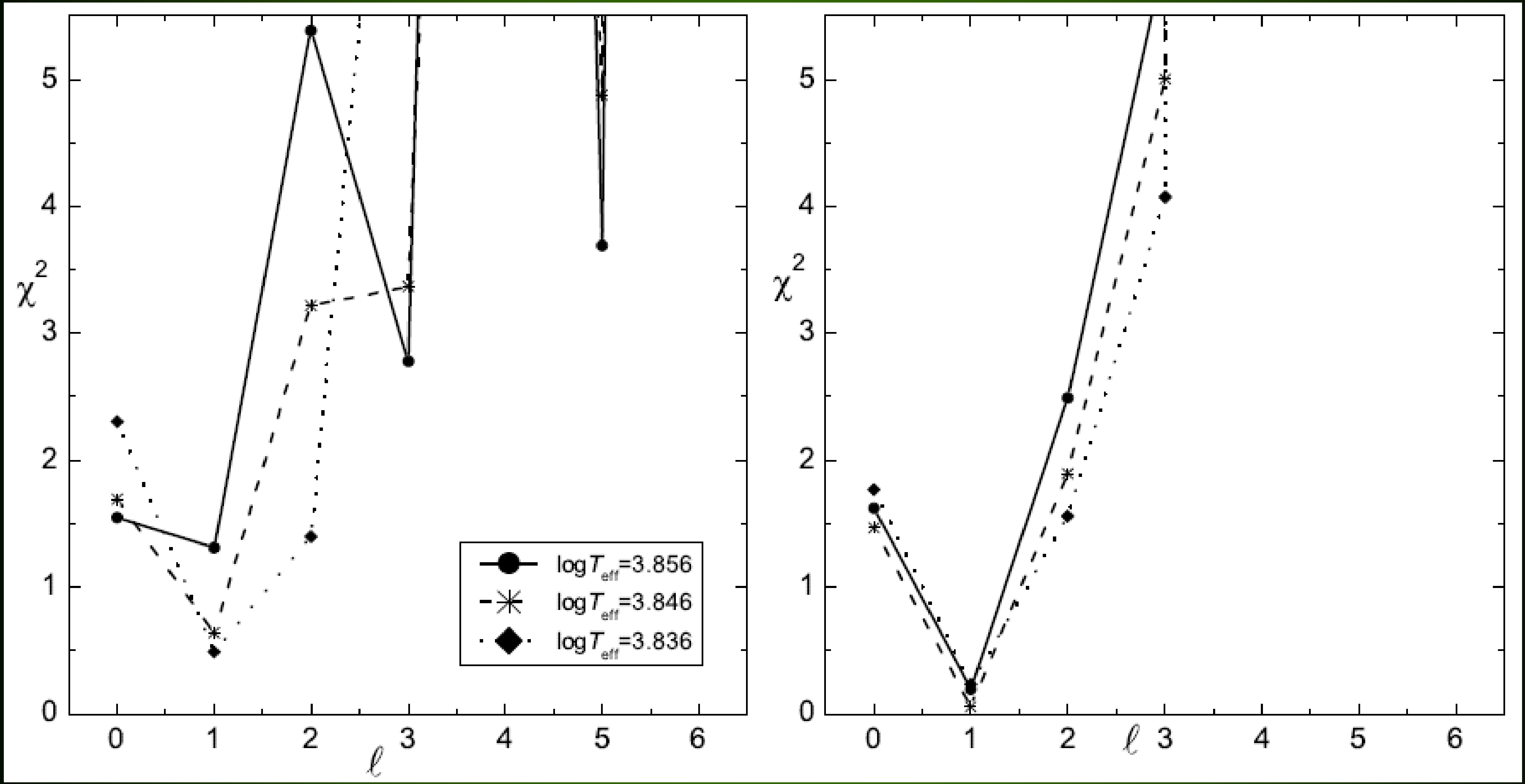
Daszyńska-Daszkiewicz, Dziembowski & Pamyatnykh, 2003, A&A 407, 999
Daszynska-Daszkiewicz, Dziembowski, Pamyatnykh et al., 2005, A&A 438, 653
Lenz, Pamyatnykh, Breger & Antoci, 2008, A&A 478, 855
Lenz, Pamyatnykh, Zdravkov & Breger, 2010, A&A 509, A90

β Cassiopeiae

Period of about 0.1 days, A_V = 0.03
Sp F2 IV,
mV = 2.27,
p = 59.58 +- 0.38 mas,
Vsin i = 70 km/s,
[m/H] = approx 0.0,
Teff = 7000 +- 150 K

β Cas – monoperiodic (?) δ Scuti star

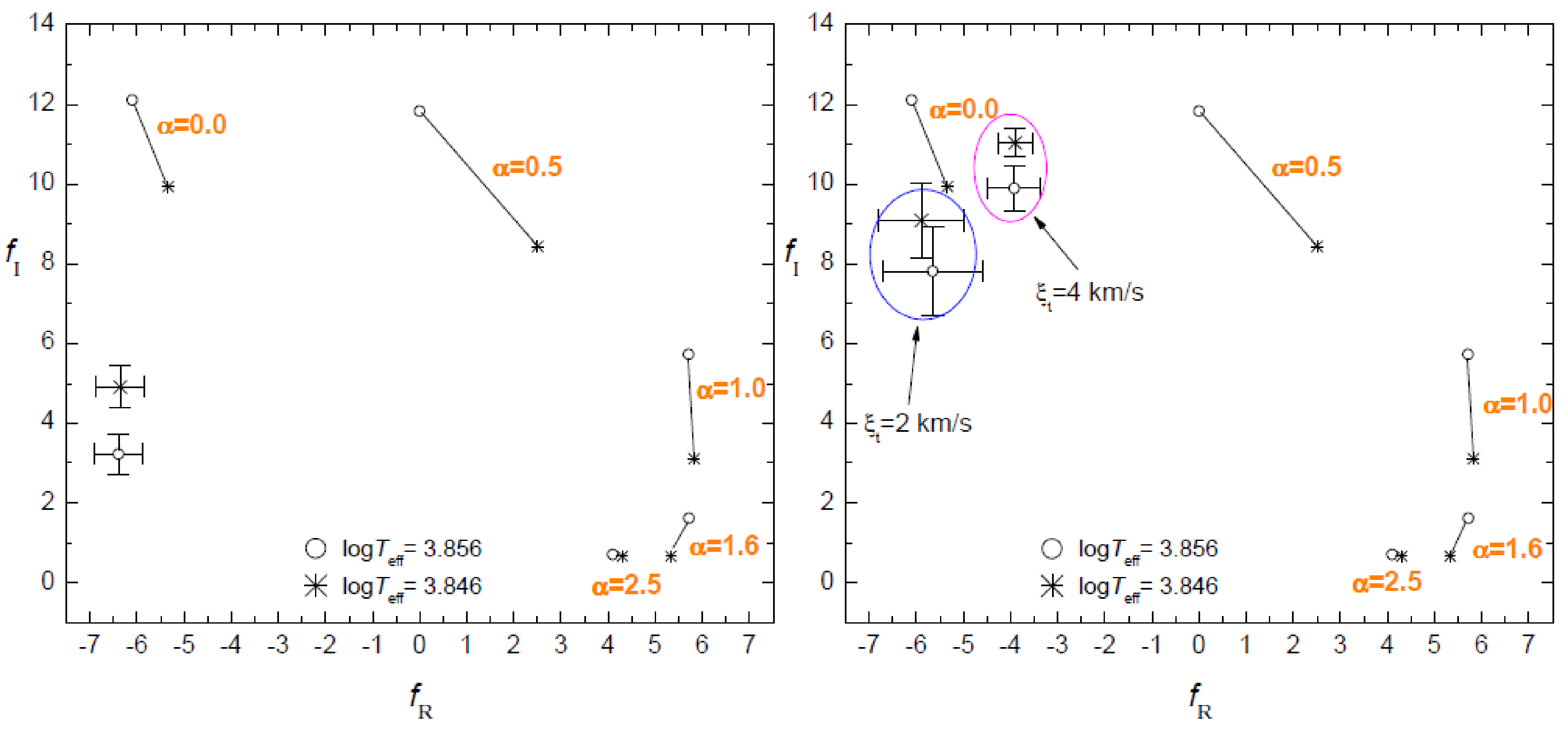
Kurucz models **NEMO2003 models**



Daszyńska-Daszkiewicz 2006, CoAst 148

β Cas. M = 1.95, log Teff = 3.856 (7180 K), 3.846 (7000 K), [m/H] = 0.0

Kurucz models | NEMO2003 models



Daszyńska-Daszkiewicz 2006, CoAst 148

FG Virginis

67 frequencies (degree *l* is identified for 12 of them),
Sp A5 V,
mV = 6.56,
p = 12.81 +- 0.50 mas,
Vsin i = 21 +- 1 km/s,
[m/H] = approx 0.0,
Teff = 7500 +- 100 K,
log g = 3.95 +- 0.1

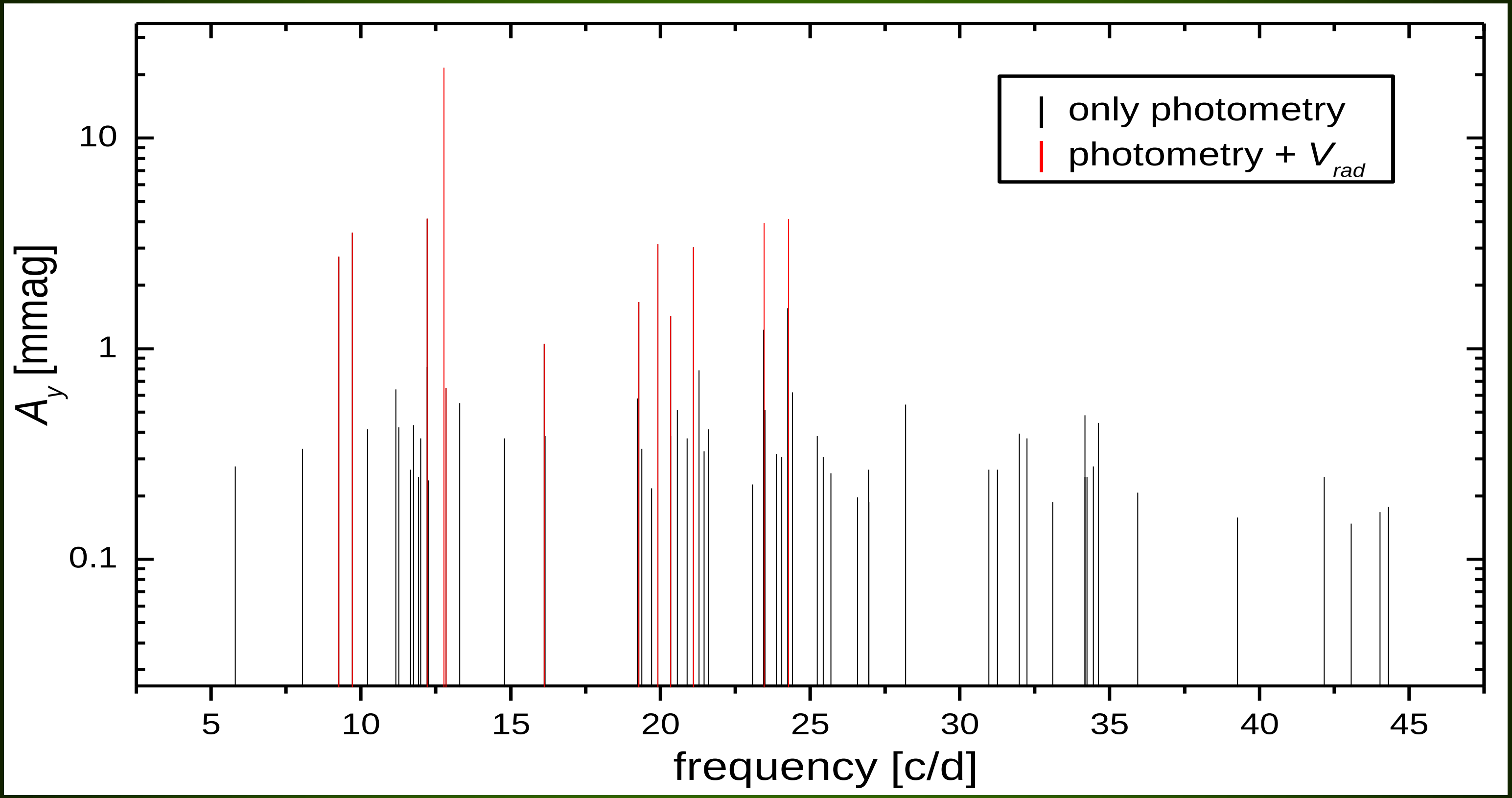
The most multiperiodic δ Scuti variable

(from the ground-based observations).

Photometric campaigns: 2002, 2003 and 2004.

Spectroscopic campaign: 2002.

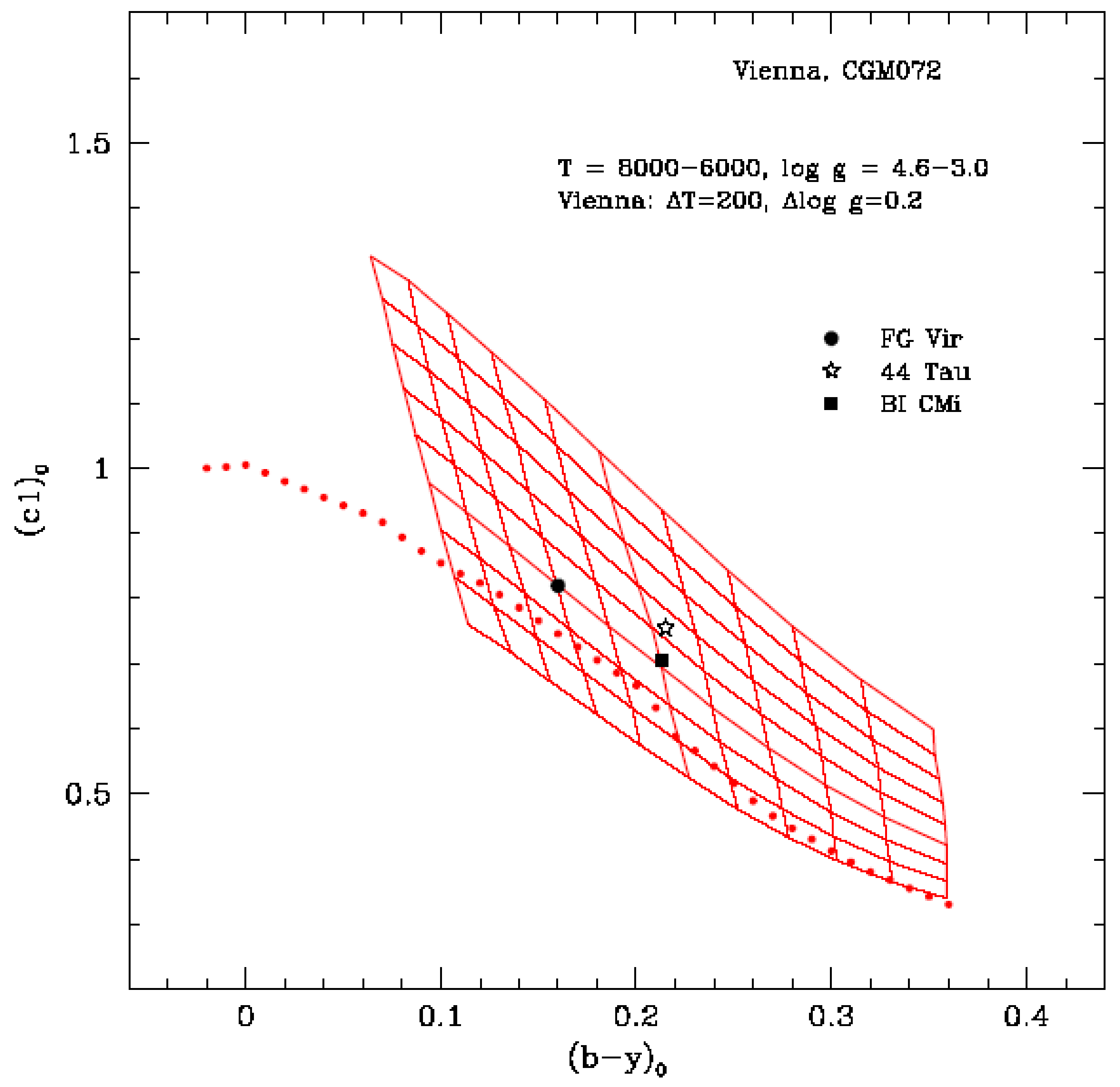
The oscillation spectrum of FG Vir



67 independent frequencies

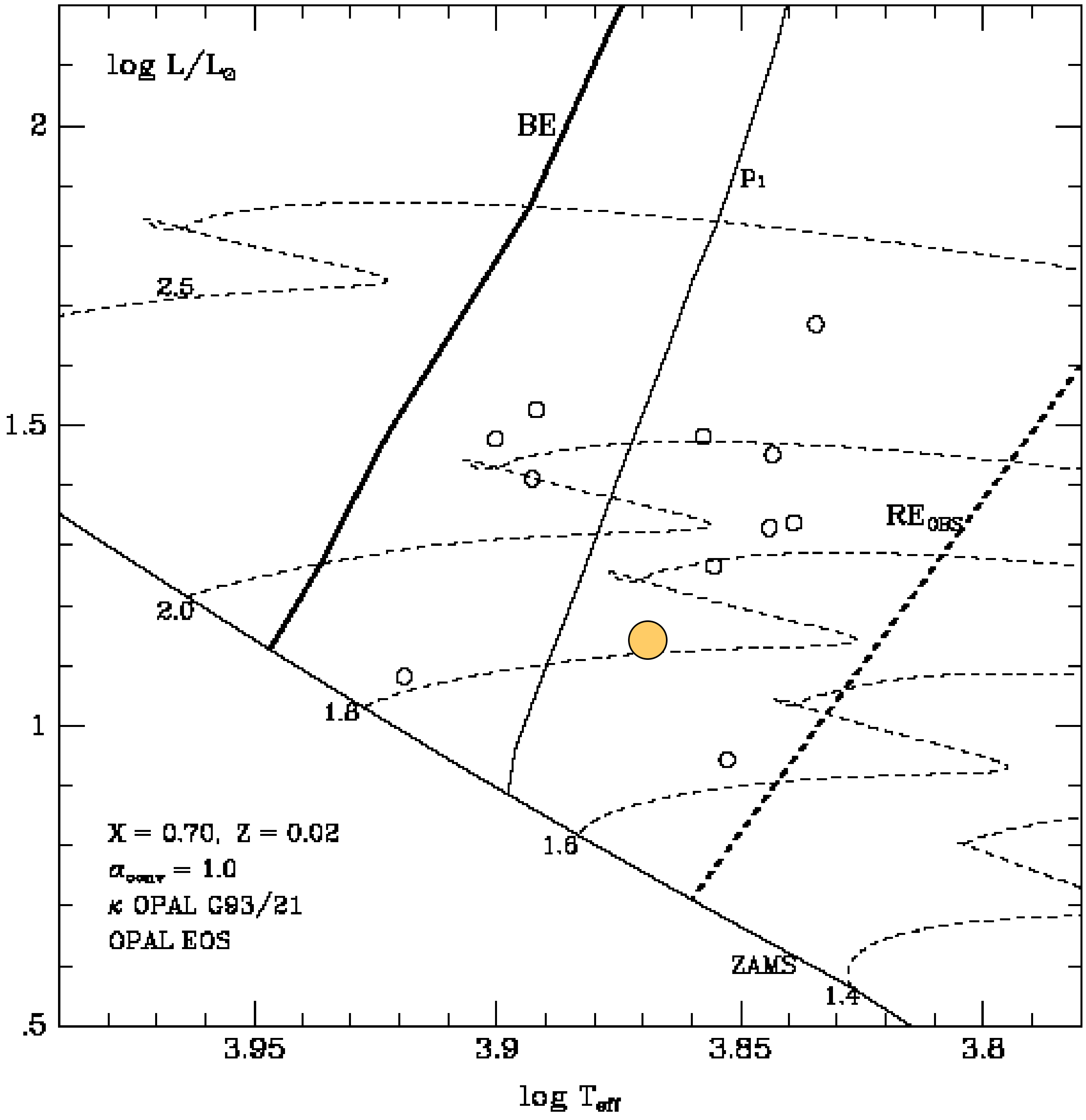
12 frequencies detected both in photometry and V_{rad}

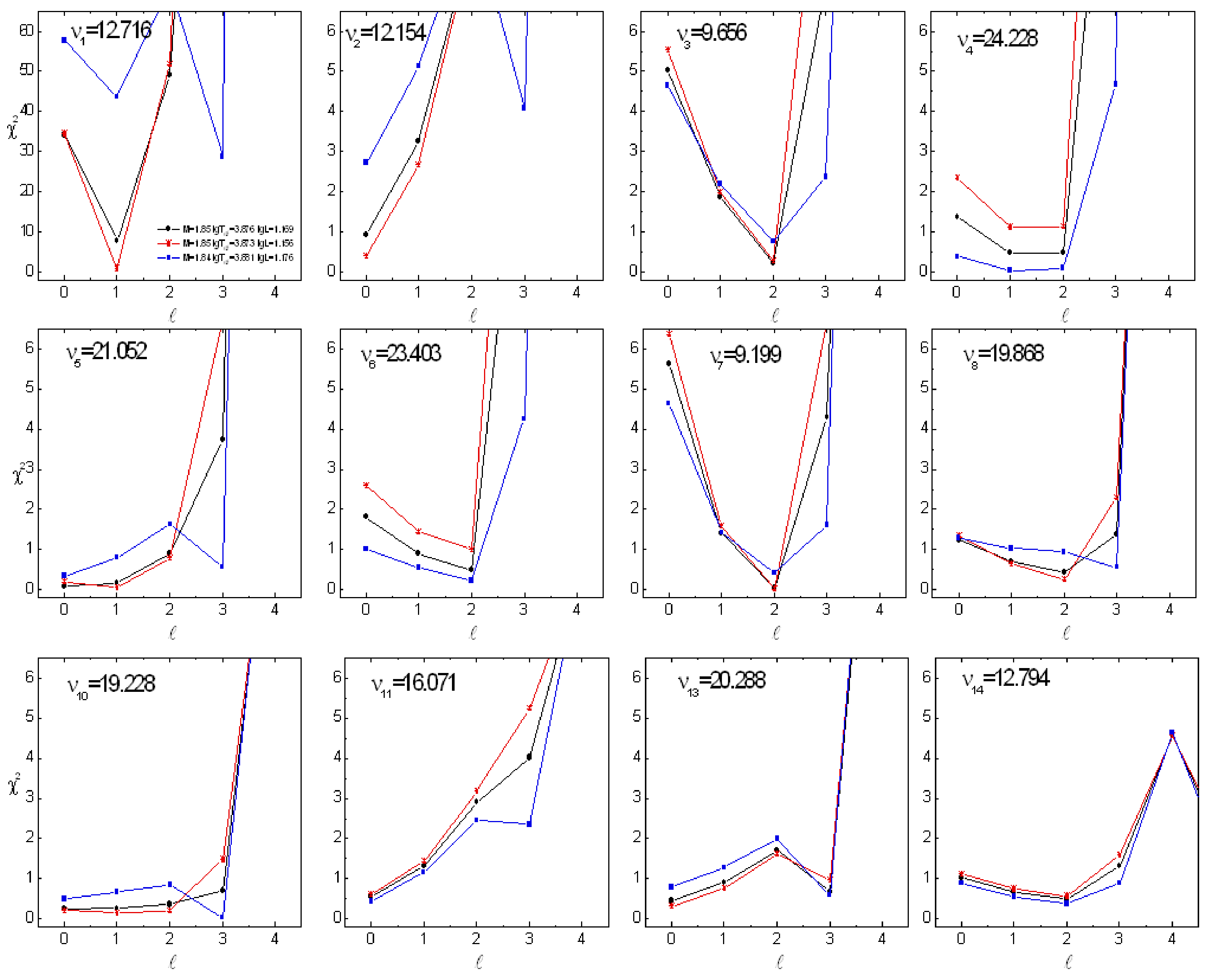
Breger et al. 2005, A&A


Vienna, CGM072
T = 8000–6000, log g = 4.6–3.0
Vienna: ΔT=200, Δlog g=0.2
● FG Vir
☆ 44 Tau
■ BI CMi
1.5
1
0.5
(c1)₀
0
0.1
0.2
0.3
0.4
(b−y)₀

FG Vir

in the δ Scuti instability domain

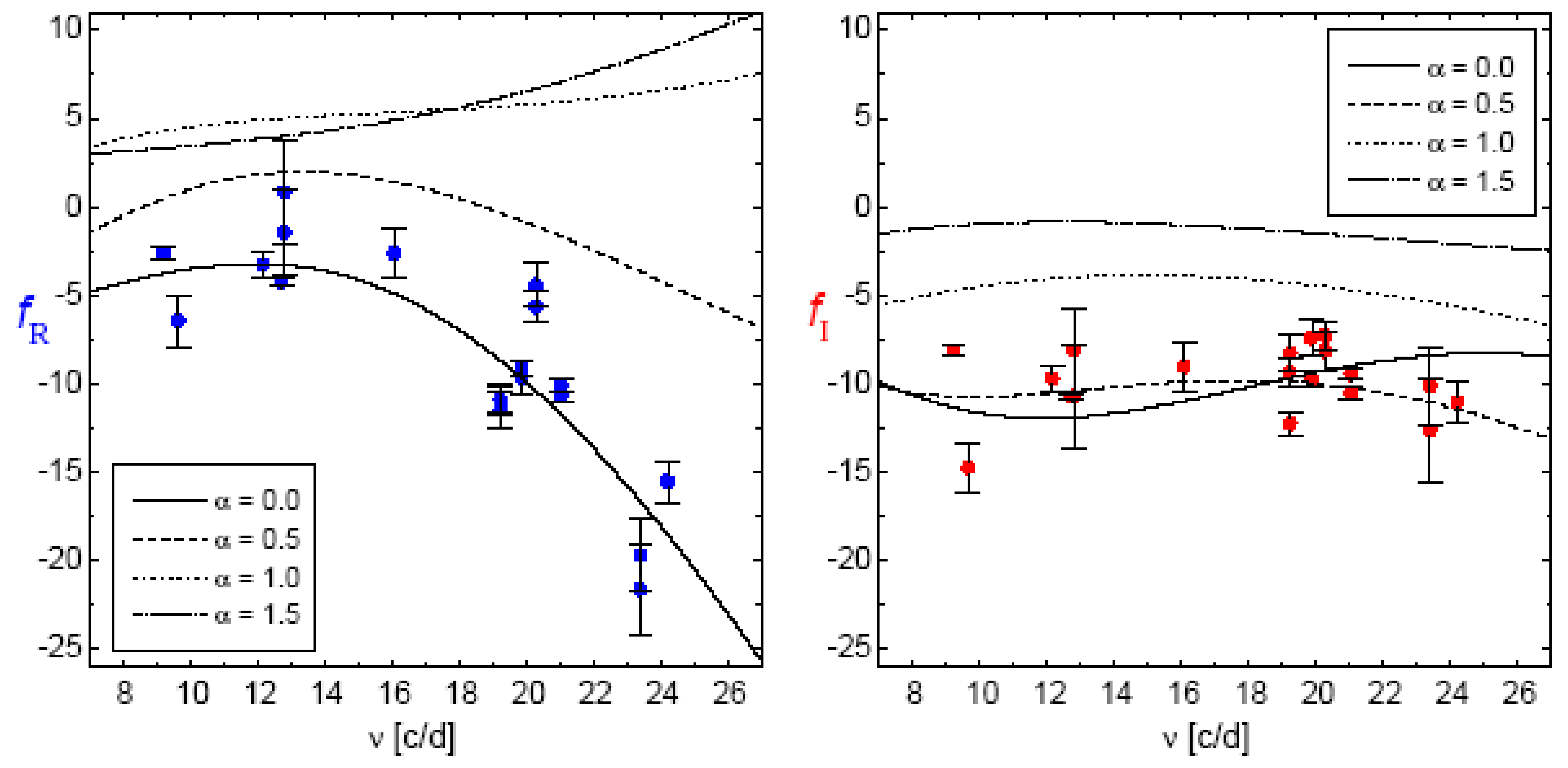




Daszyńska-Daszkiewicz et al. 2005

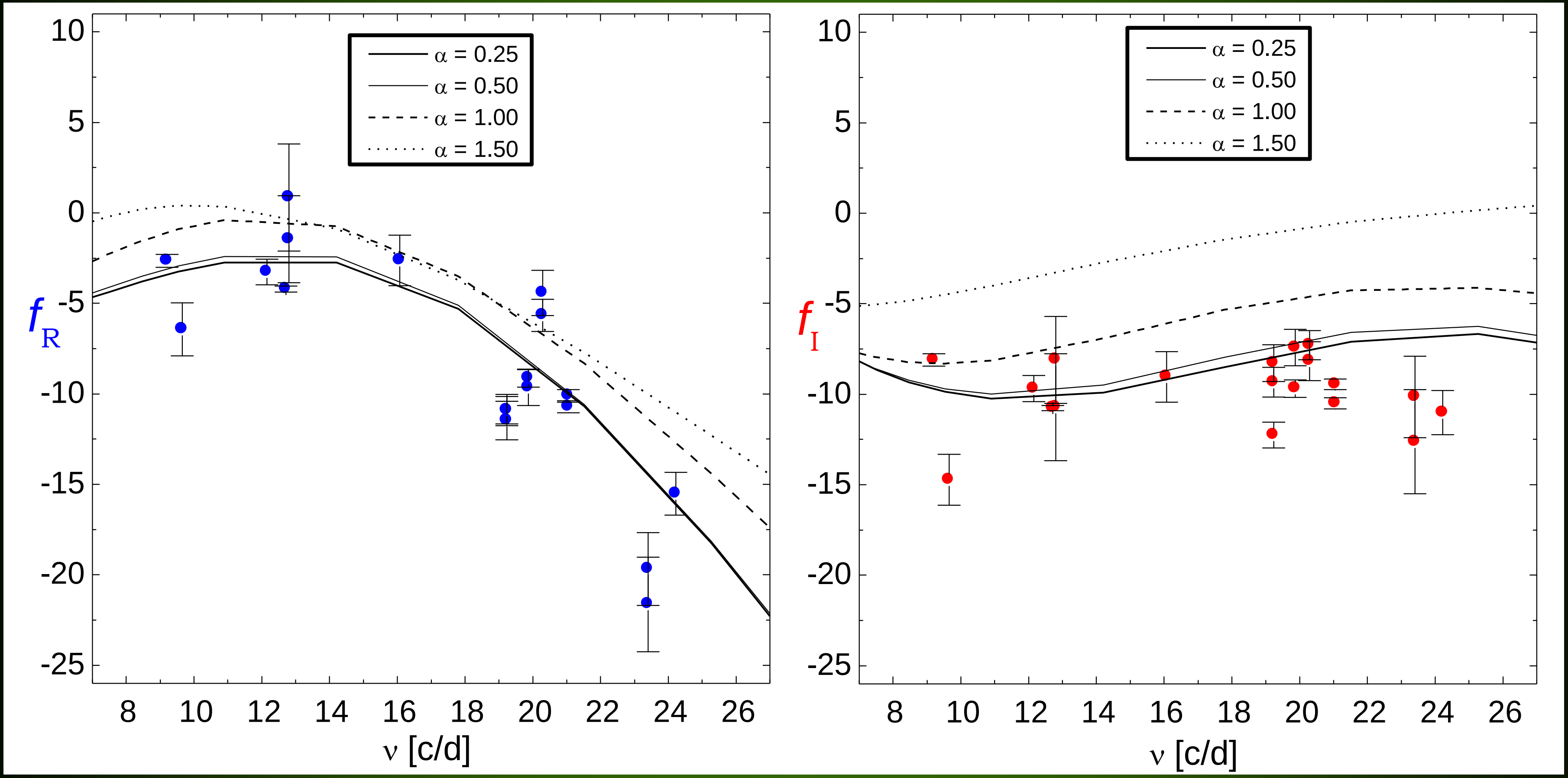
FG Vir

Comparison of the empirical values of f with the theoretical ones calculated for four values of the mixing-length parameter α



Daszyńska-Daszkiewicz et al.(2005)

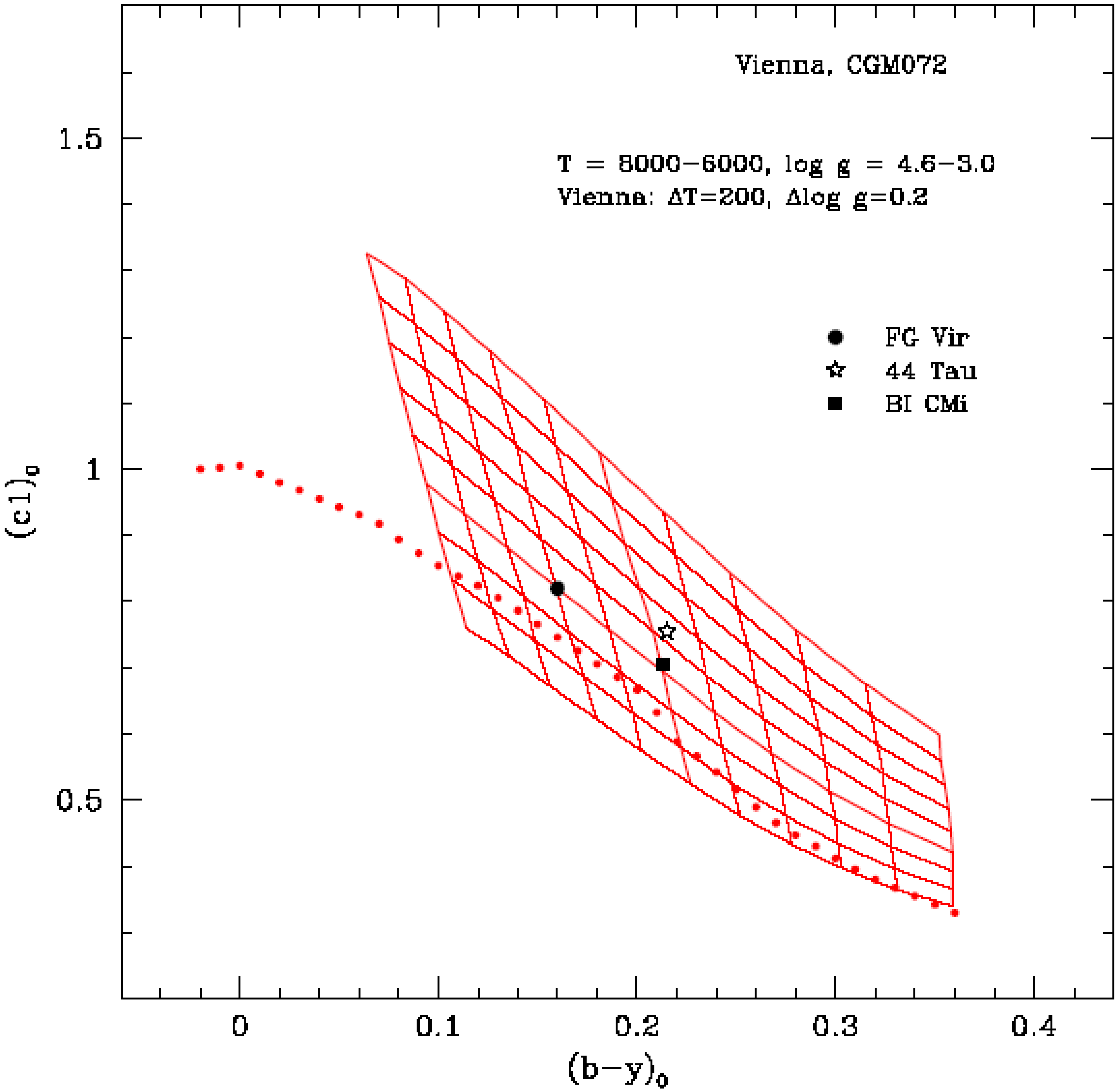
Empirical and theoretical *f* values.
Model: non-local, time-dependent formulation of MLT



due to Guenter Houdek
Daszyńska-Daszkiewicz et al. 2005, A&A 438, 653

44 Tauri

15 frequencies (degree *l* is identified for 10 of them),
Sp F2 IV-V,
mV = 5.399,
p = 16.72 +- 0.93 mas,
Vrot = 3 +- 2 km/s,
[m/H] = approx 0.0,
Teff = 6900 +- 100 K,
log g = 3.6 +- 0.1

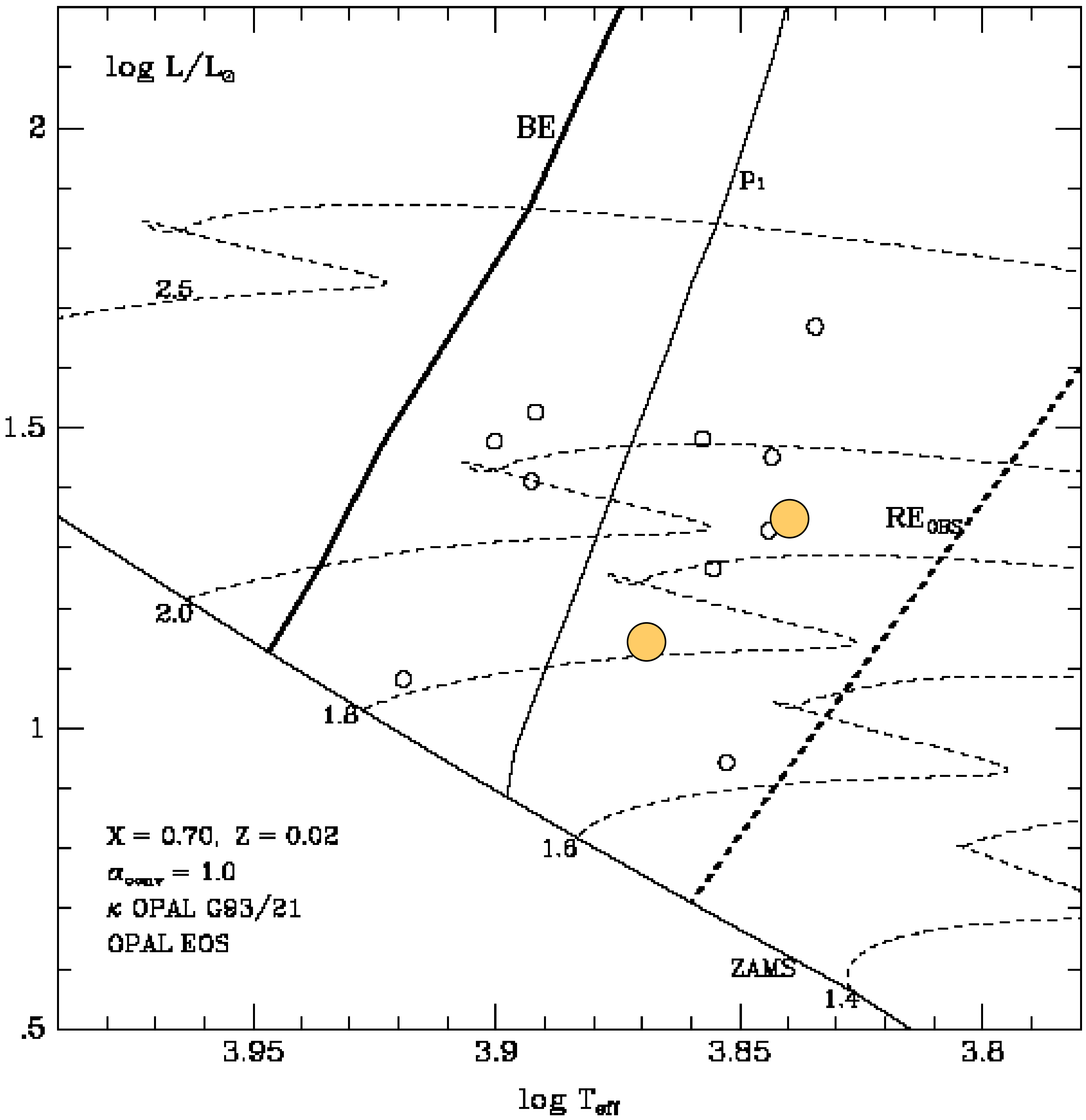

Vienna, CGM072
T = 8000−6000, log g = 4.6−3.0
Vienna: ΔT=200, Δlog g=0.2
● FG Vir
☆ 44 Tau
■ BI CMi
1.5
1
0.5
$(c1)_0$
0
0.1
0.2
0.3
0.4
$(b-y)_0$

FG Vir (MS)

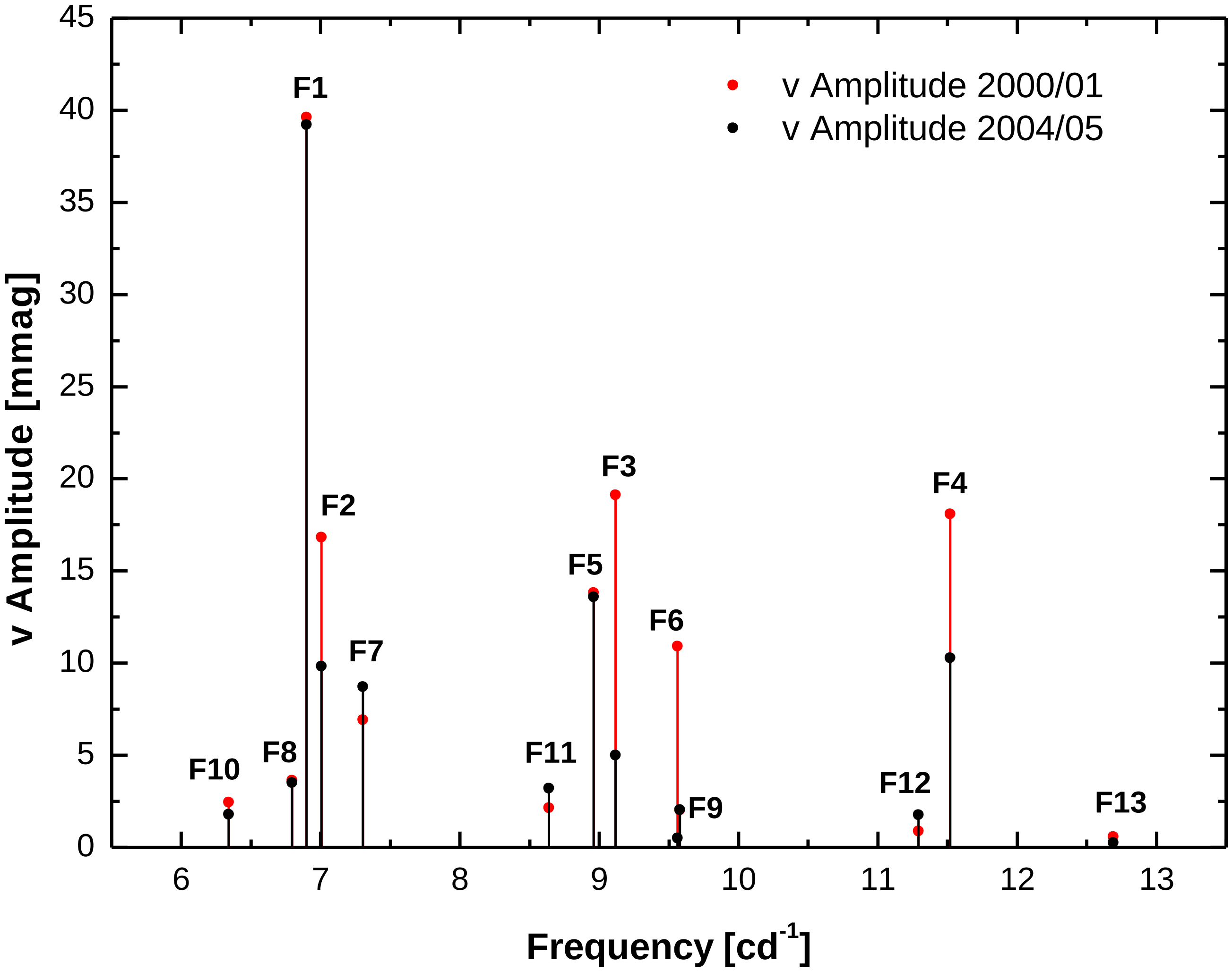
and

44 Tau
(post-MS)

in the δ Scuti
instability
domain

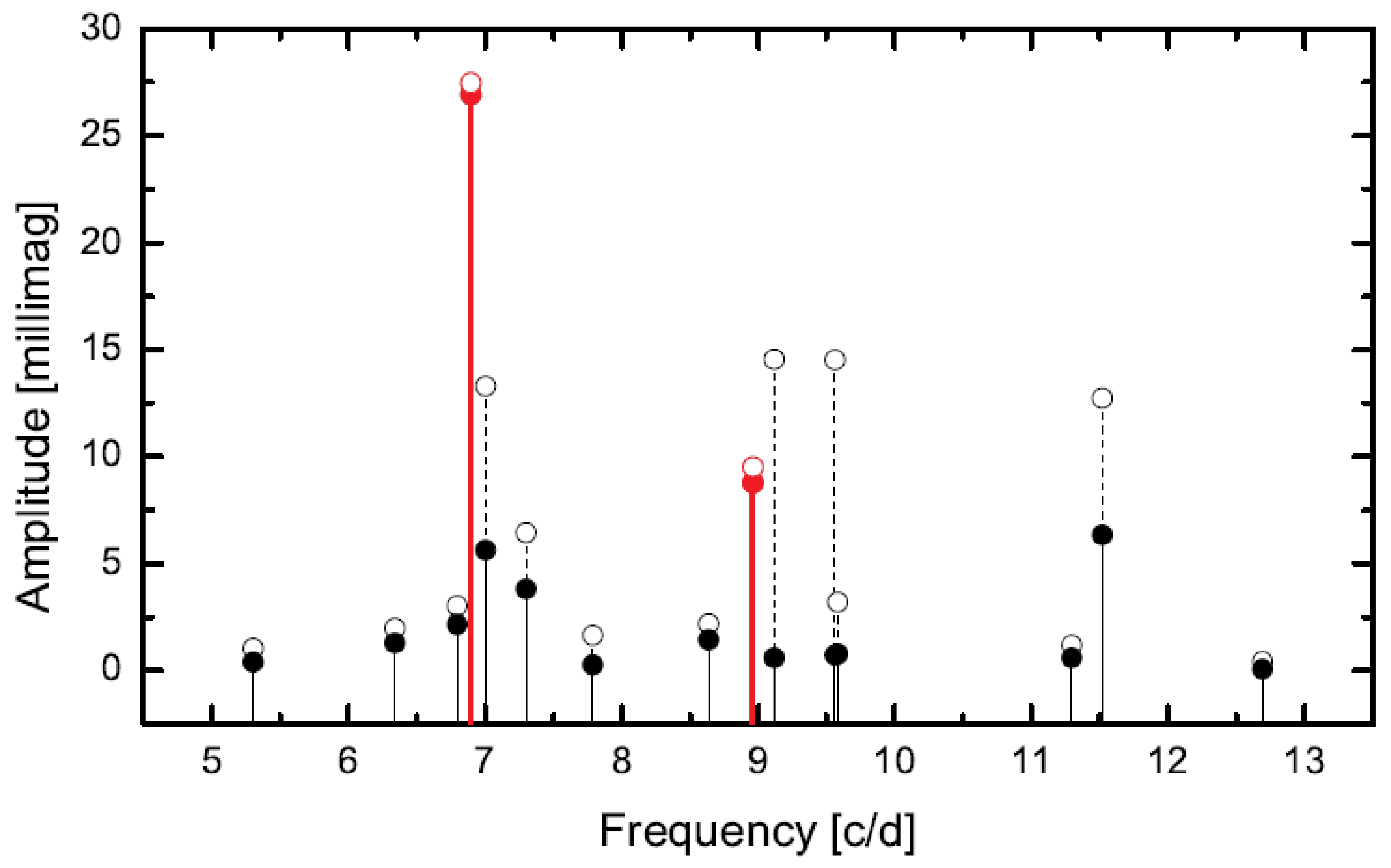


44 Tau

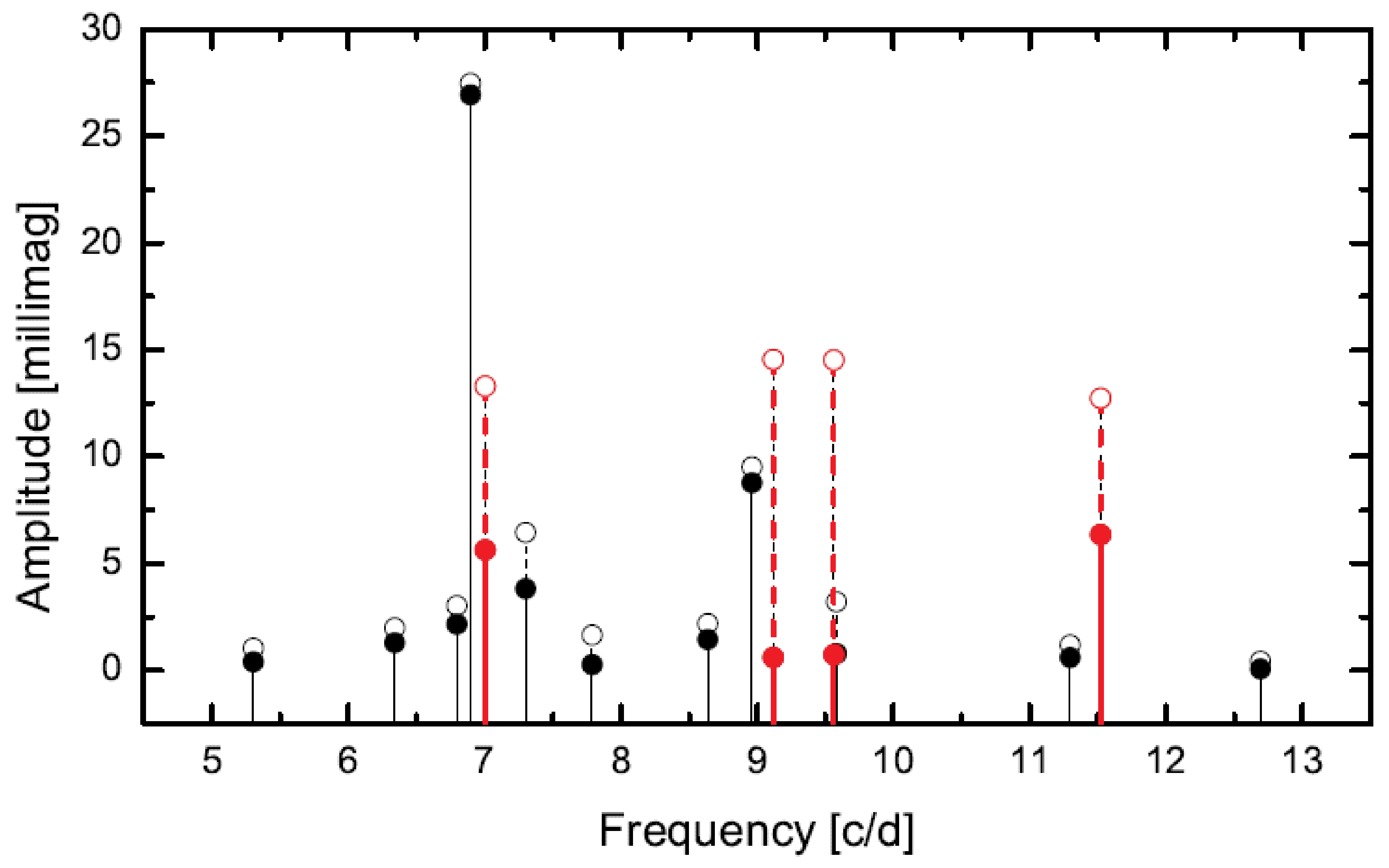


Lenz et al. 2008

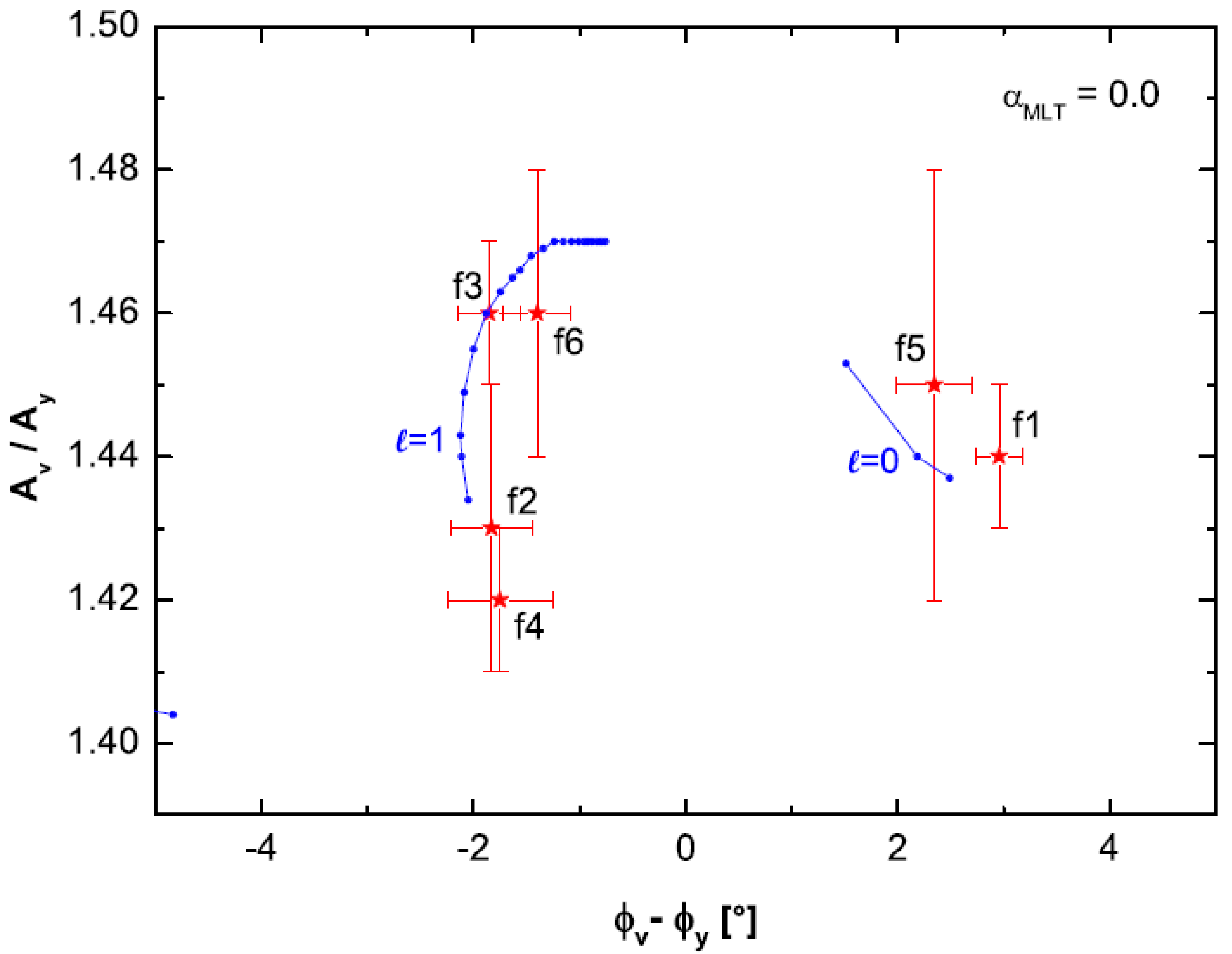
44 Tau, photometry, radial



44 Tau, photometry, dipole

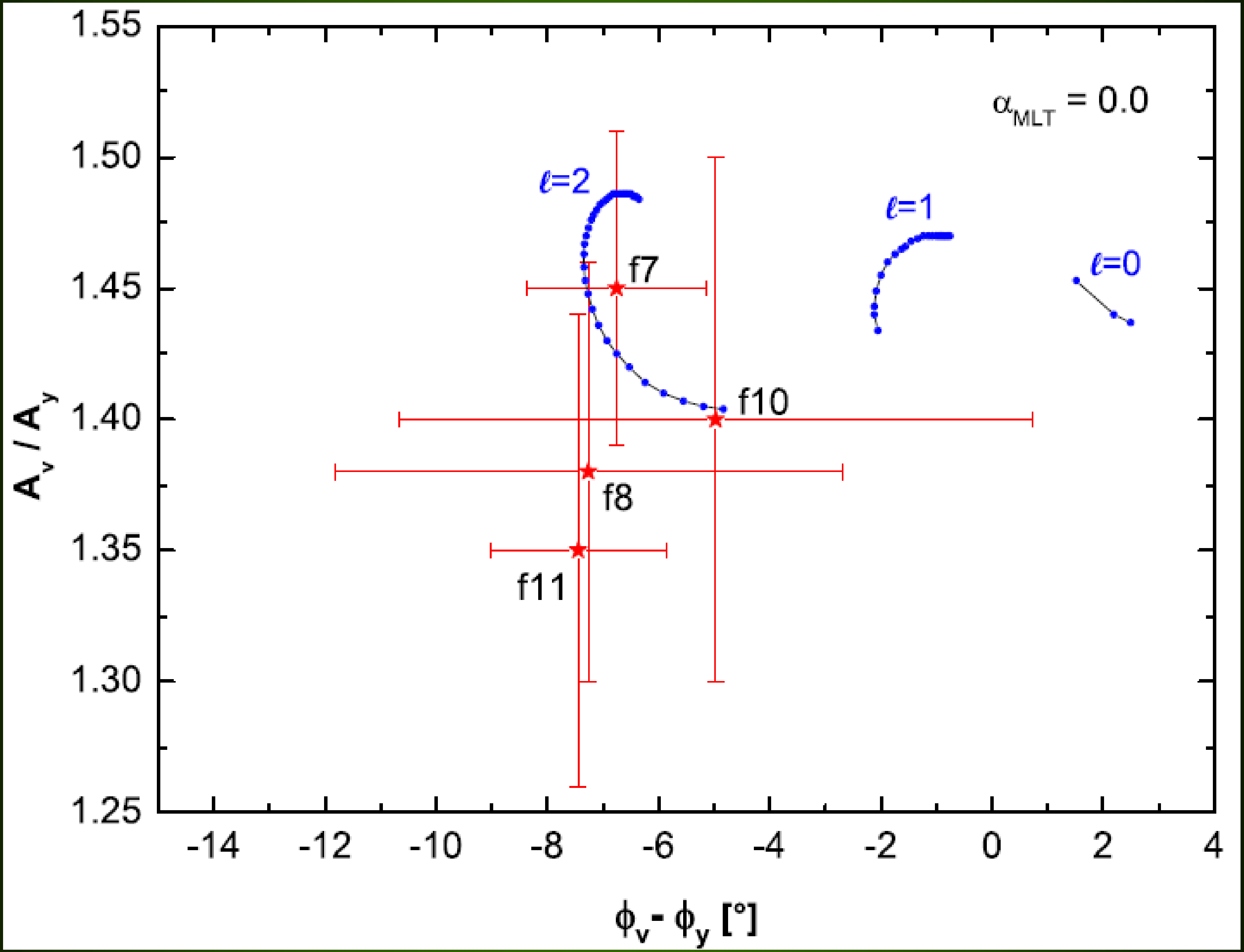


44 Tau, mode identification



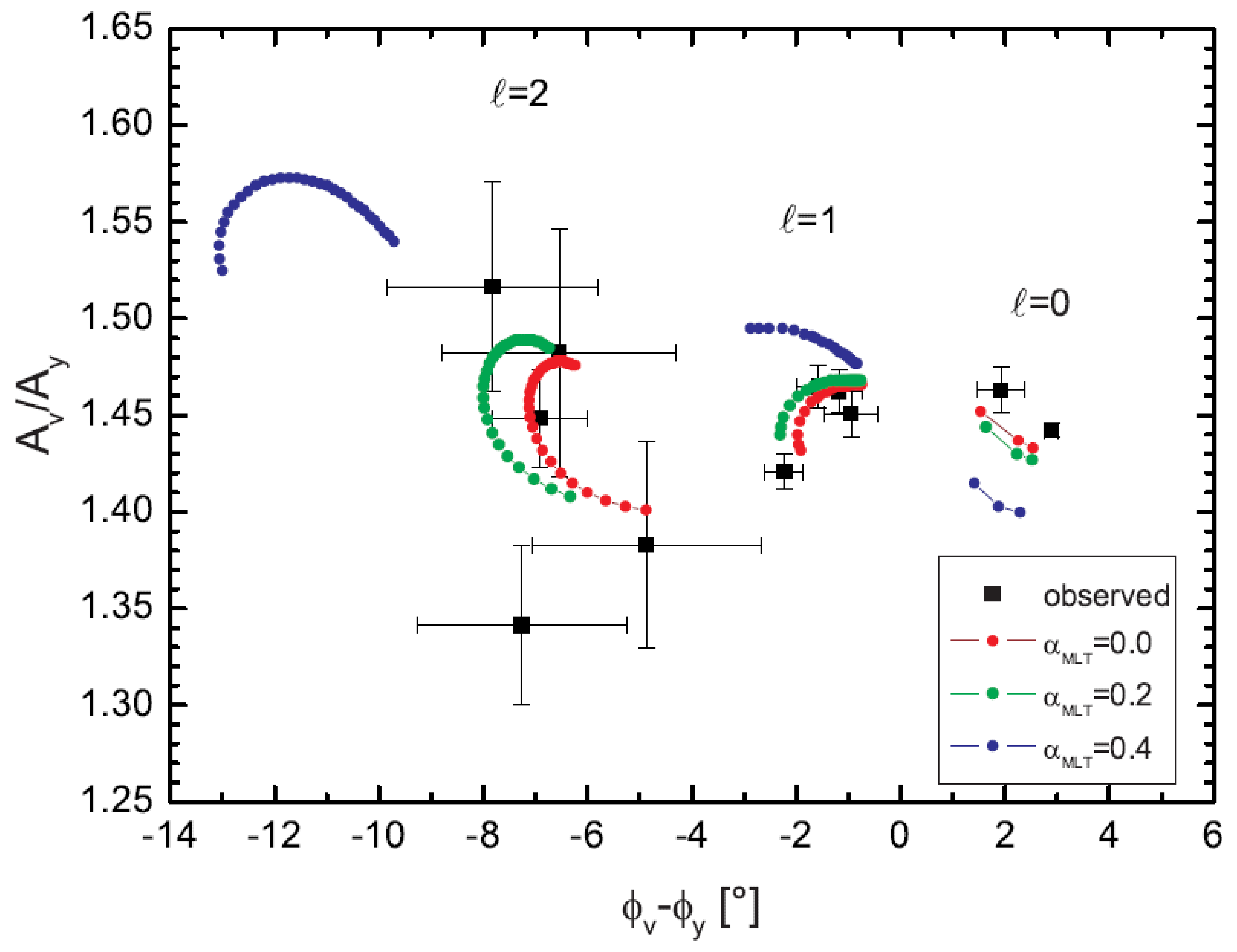
Lenz et al. 2008

44 Tau, mode identification



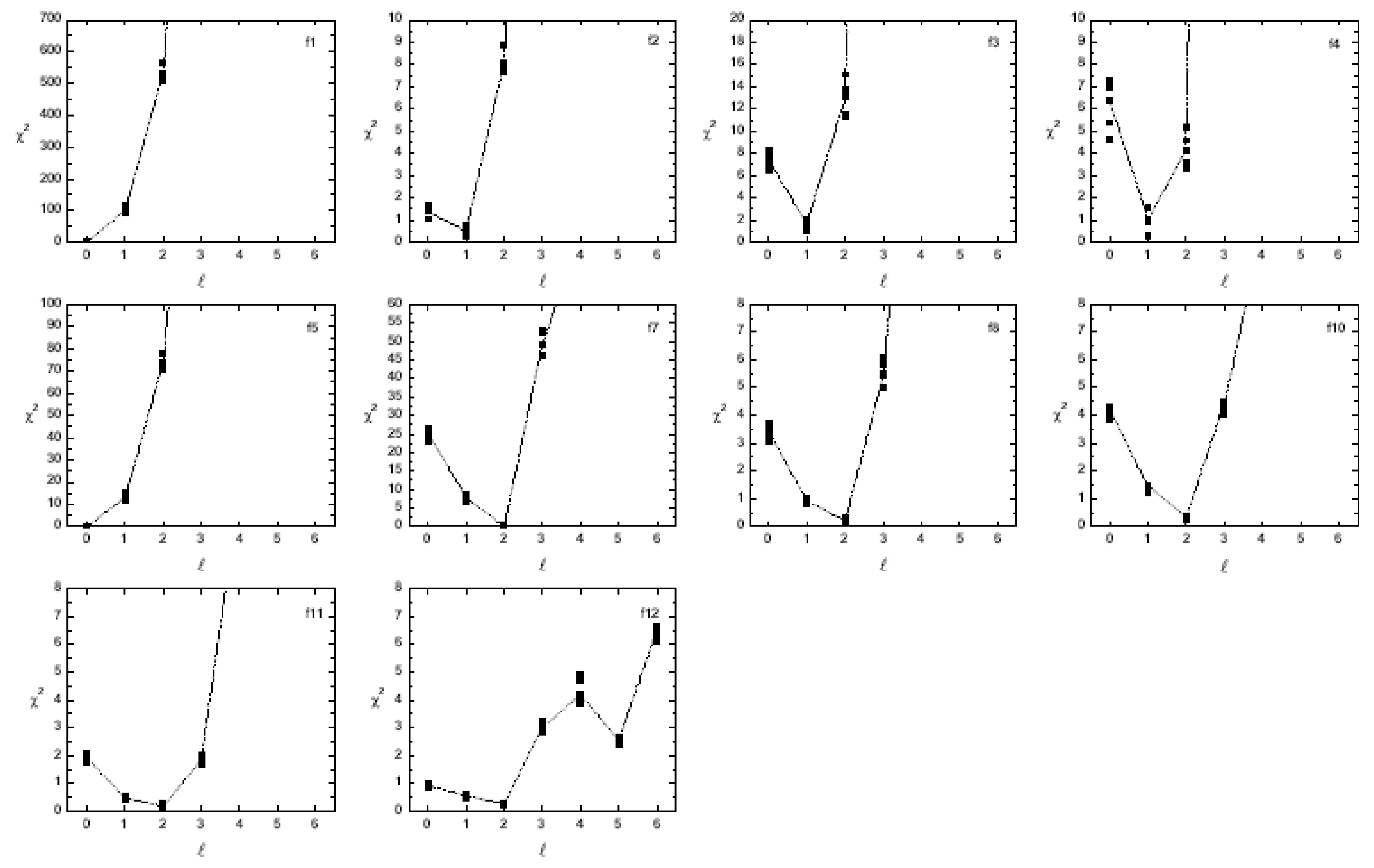
Lenz et al. 2008

44 Tau, mode identification



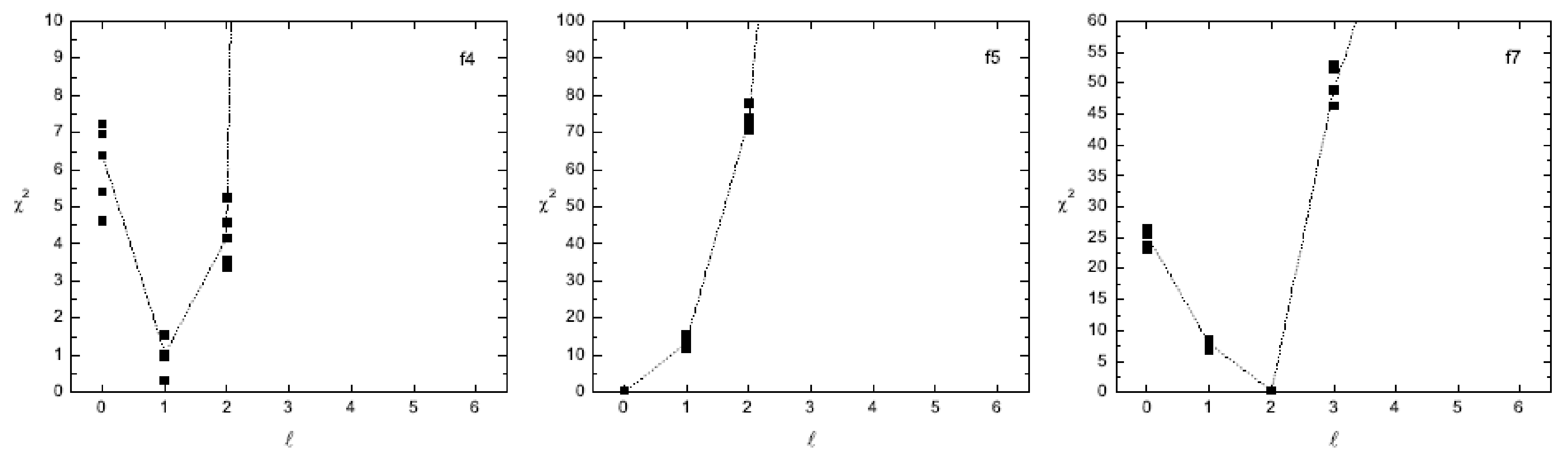
due to Lenz et al. 2008, 2010

44 Tau, mode identification for 10 frequenies.



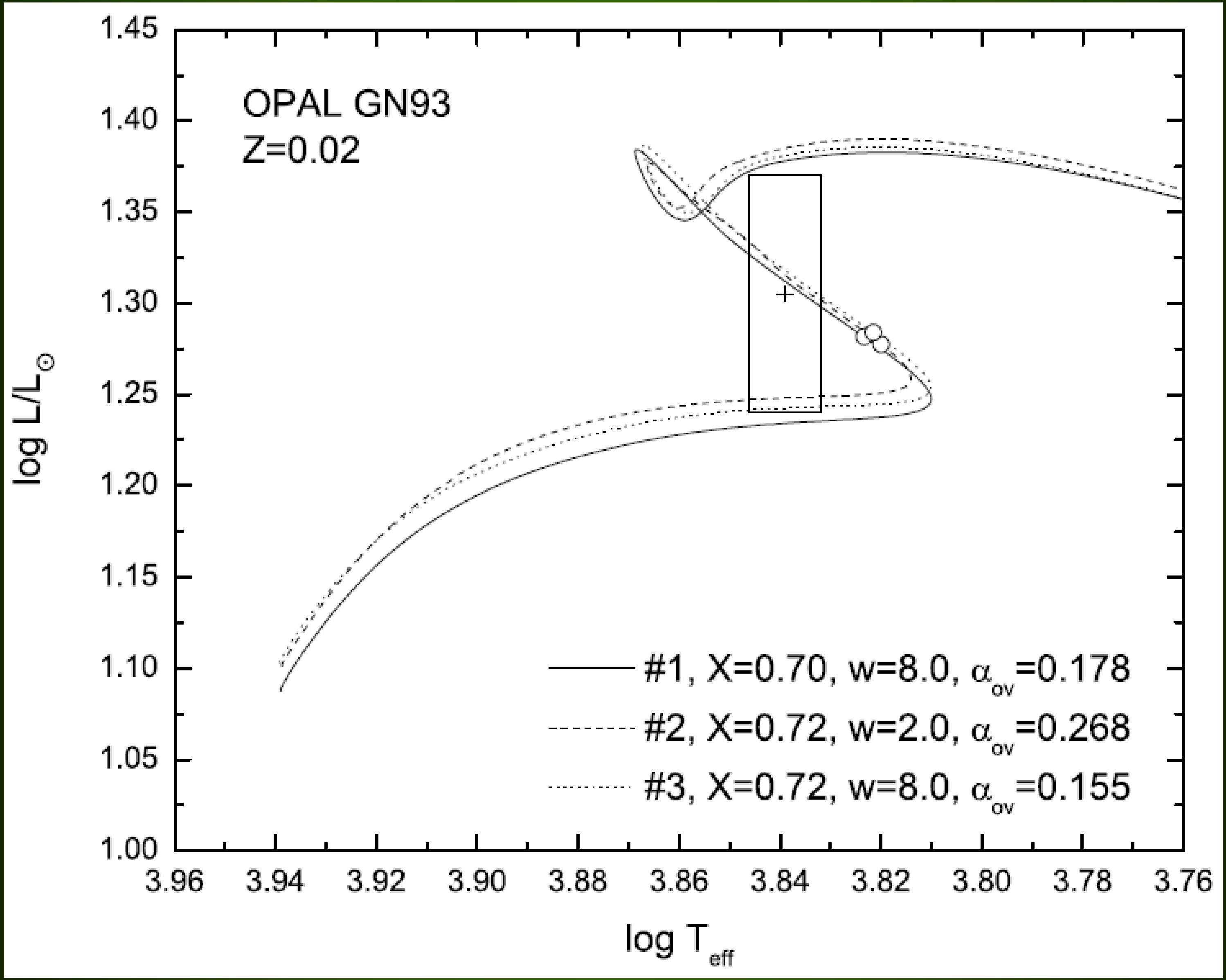
Lenz 2009, PhD Thesis

44 Tau, examples of the mode identification



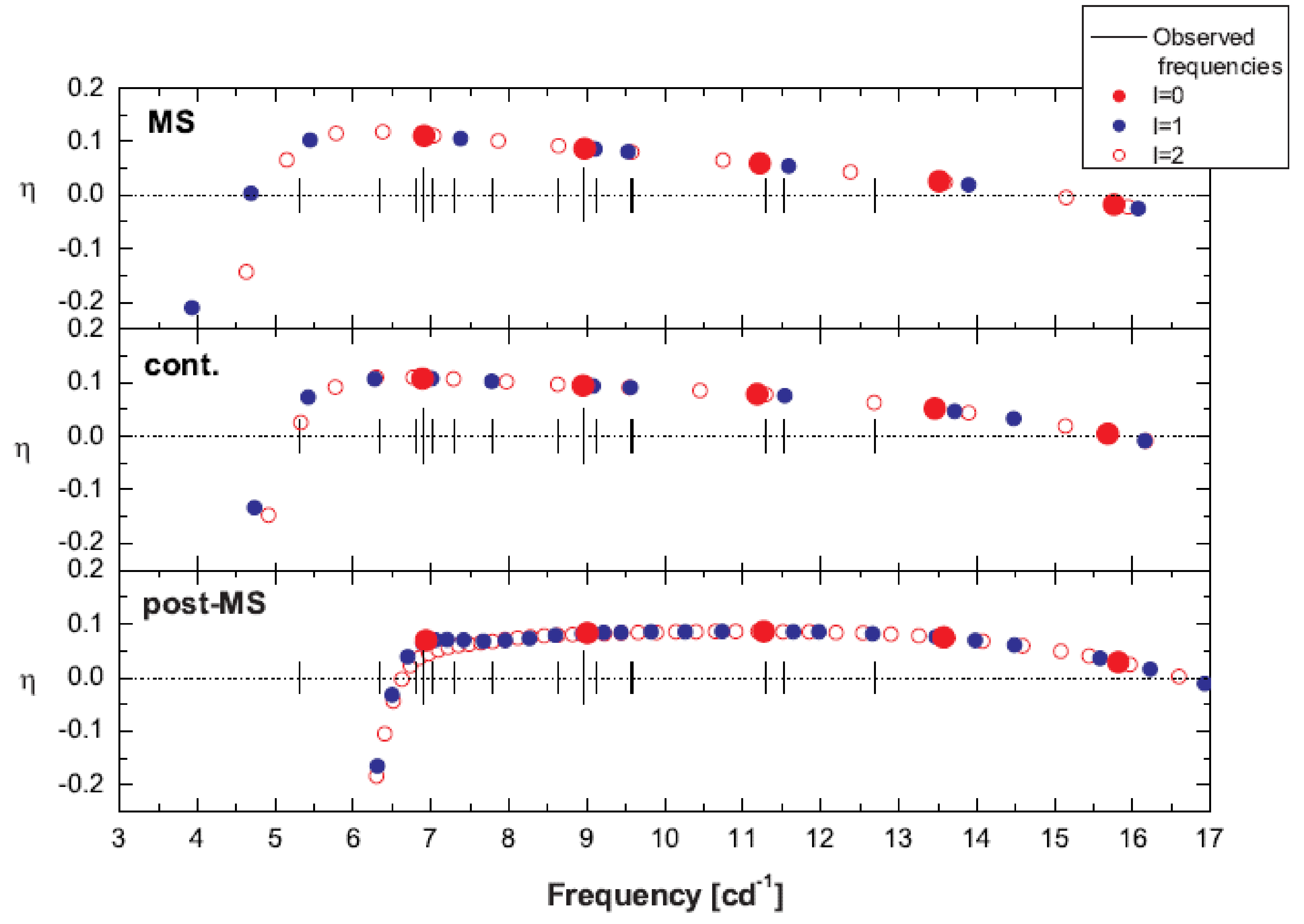
due to Lenz 2009, PhD Thesis

44 Tau. Evolutionary tracks for best models.



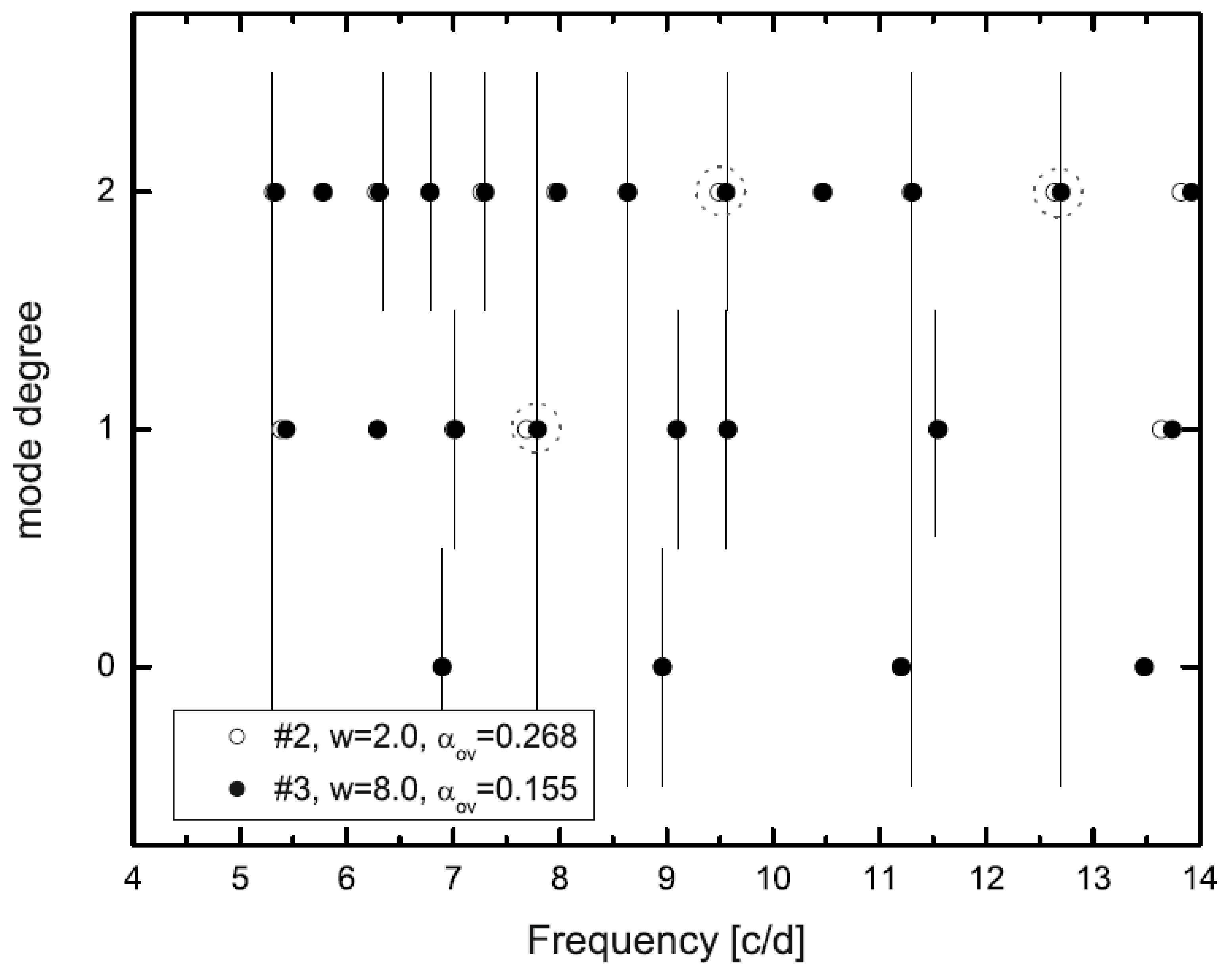
Lenz, Pamyatnykh, Zdravkov & Breger, 2010, A&A 509, A90

44 Tau, pulsational instability range



due to Lenz 2009, PhD Thesis

44 Tau. Frequency fitting for best models.



Lenz, Pamyatnykh, Zdravkov & Breger, 2010, A&A 509, A90