Chemical composition of β Cephei and SPB stars

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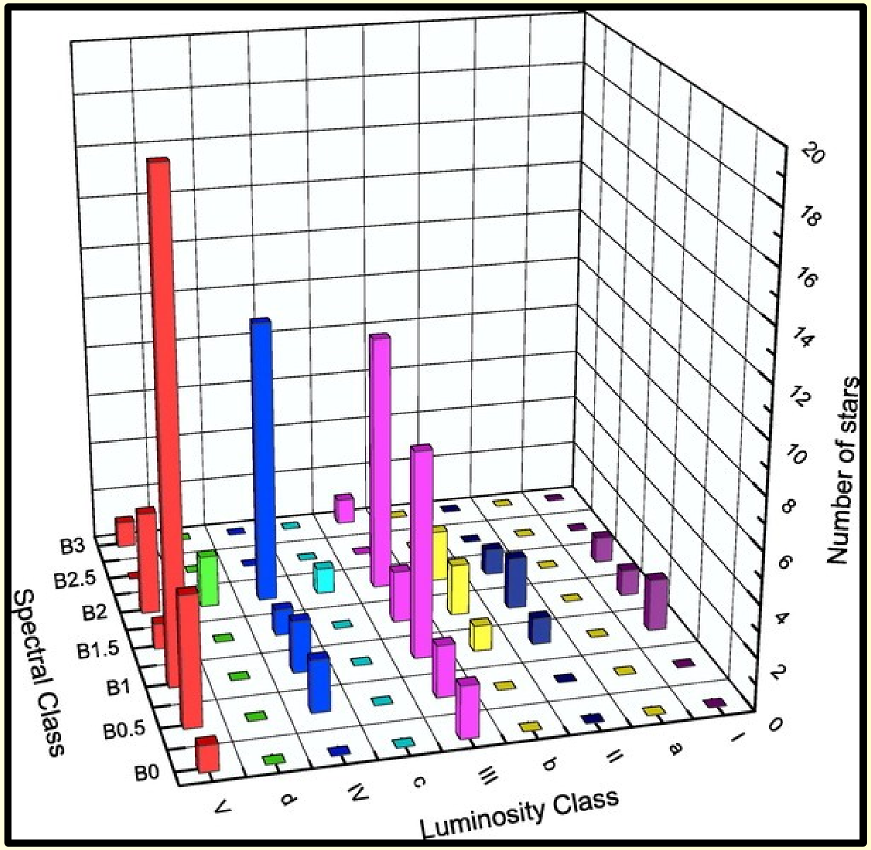
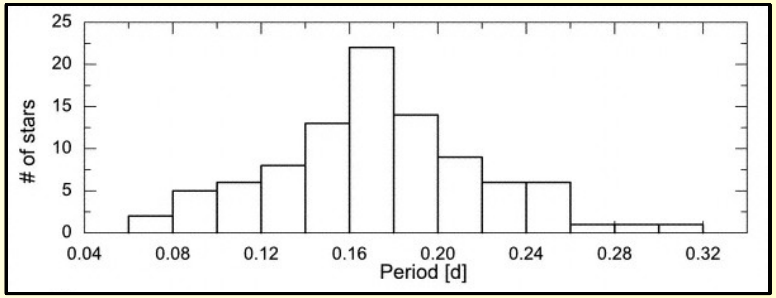
The β Cephei stars – the definition

β Cephei stars are:

- **massive** (M: 7 - 20 solar masses);
- **hot** (T_{eff} : 18000 - 35000 K);
- **early B-type stars** (spectral type: B0.5 - B3) with luminosity classes V – III;
- exhibit **short period variations** of brightness, radial velocity and line profiles;
- are **low radial order p/g-mode pulsators** (pulsation periods: 2 - 12 hours);
- their pulsations are driven by the **classical κ mechanism** operating in the layer of the metal opacity bump at $T \approx 2 \times 10^5$ K.



Stankov & Handler, ApJ, 158, 193, 2005

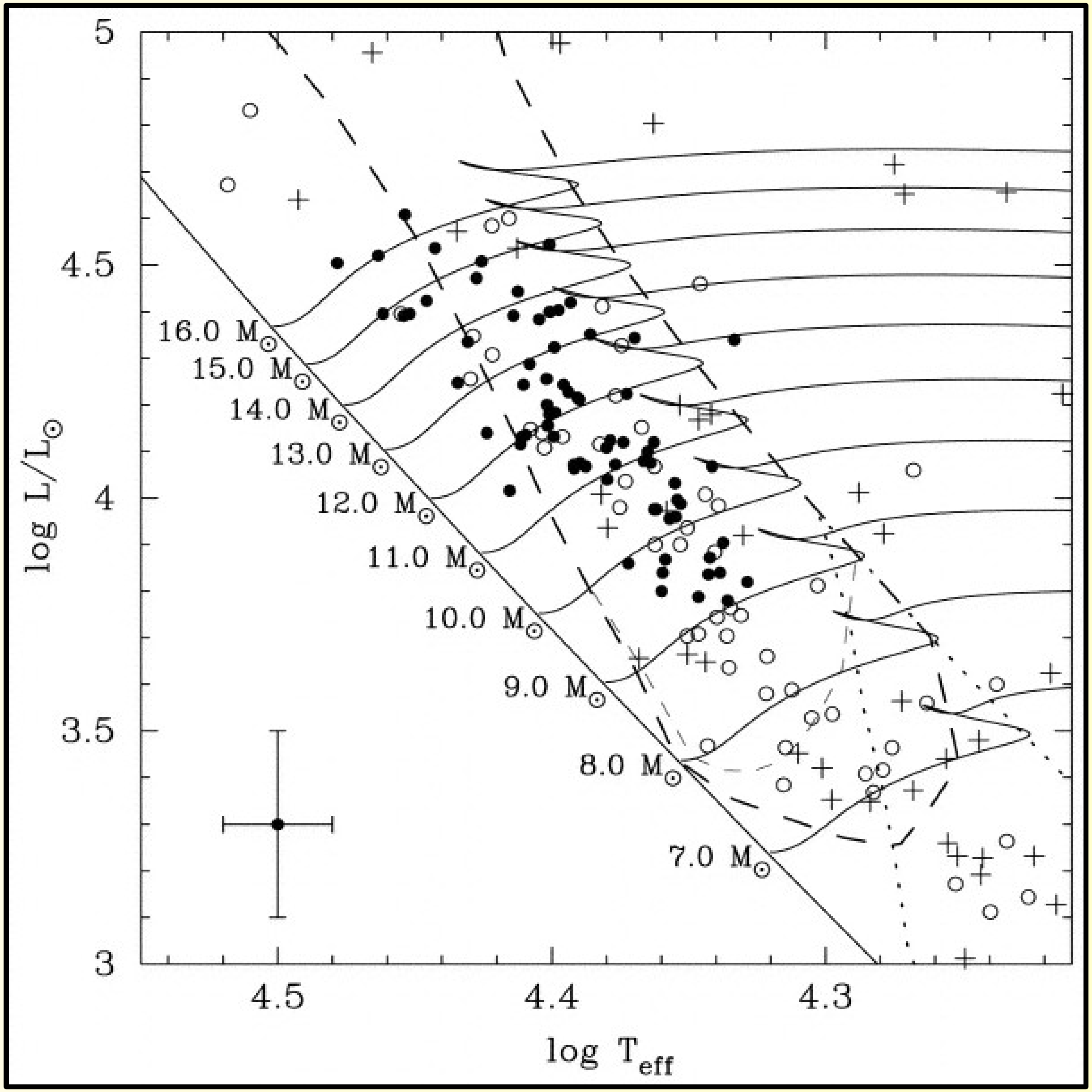


Stankov & Handler, ApJ, 158, 193, 2005

The β Cephei stars – the definition

Theoretical HR diagram:

- confirmed β Cephei (●)
- candidate (○)
- poor or rejected candidates (+)



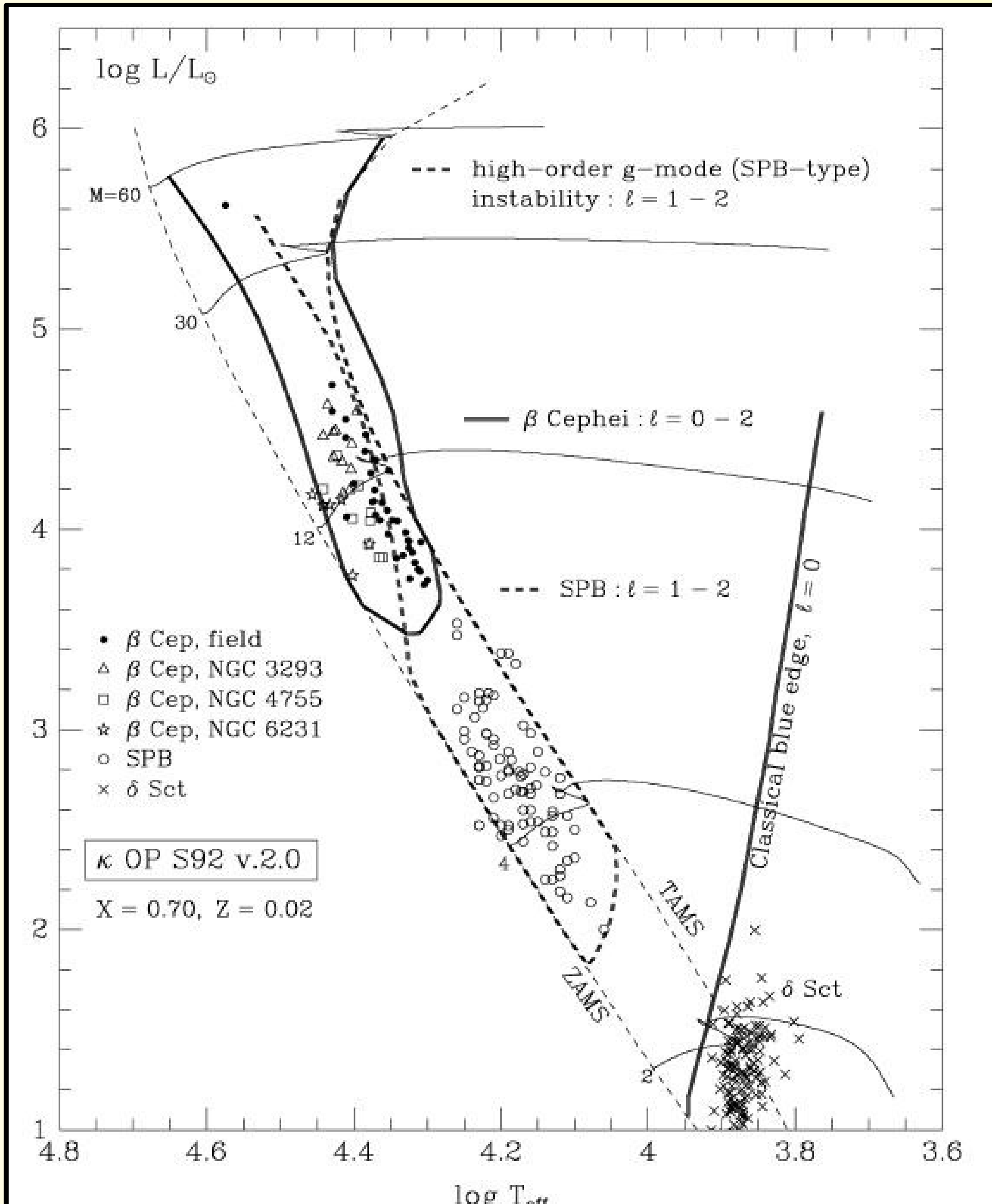
Evolutionary tracks:
Pamyatnykh, Acta Astron., 49, 119, 1999

Stankov & Handler, ApJ, 158, 193, 2005

The SPB stars – the definition

SPB stars are:

- **massive** (M: 3 – 8 solar masses);
- **hot** (Teff: 10000 – 20000 K);
- main sequence **B-type stars** (spectral type: B3 - B8) with luminosity classes V – III;
- exhibit **period variations of brightness, radial velocity and line profiles**;
- are **high-order low-degree g-mode pulsators** (pulsation periods: 1 – 3 days);
- their pulsations are driven by the **classical κ mechanism** operating in the layer of the metal opacity bump at $T \approx 2 \times 10^5$ K.

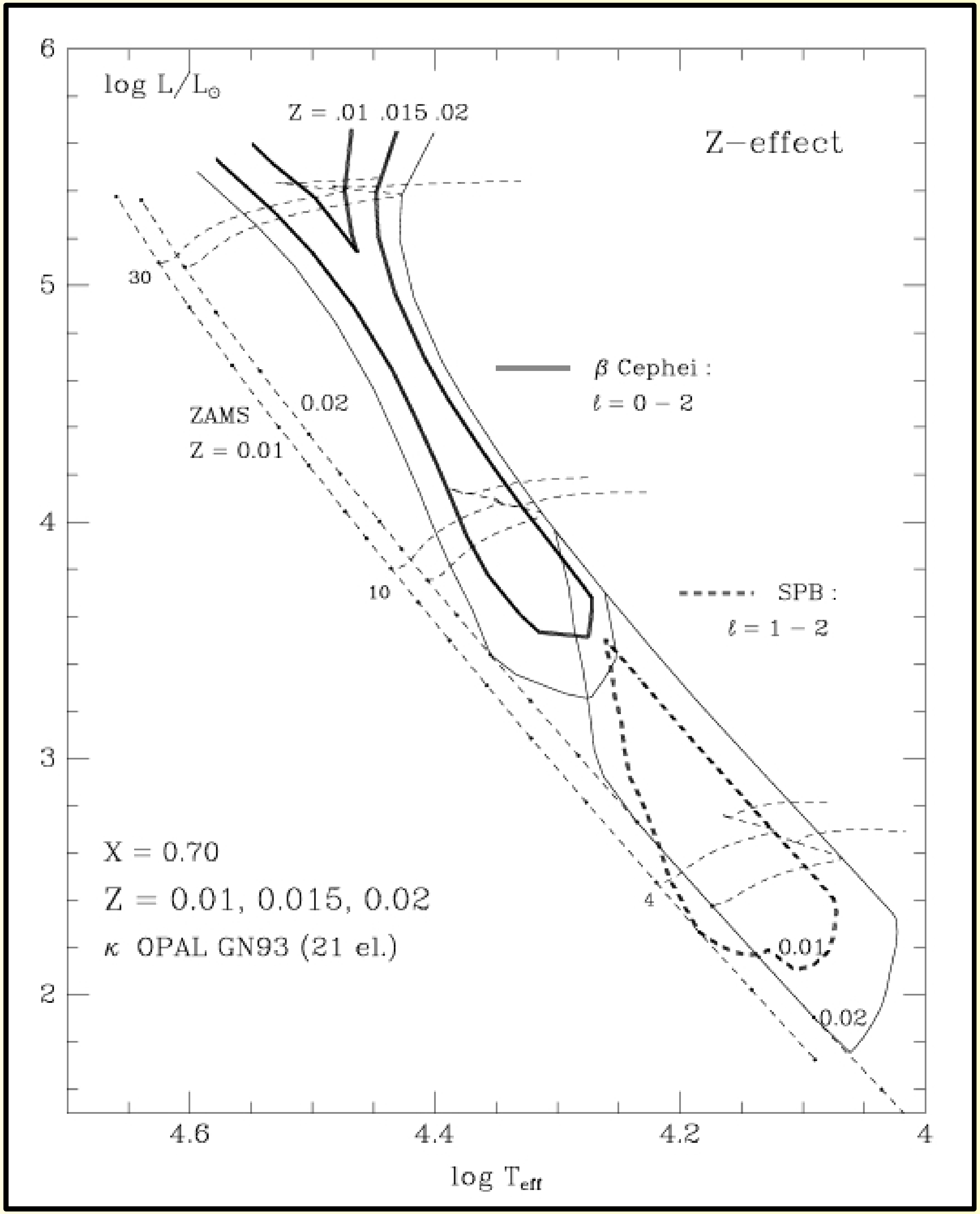


Pamyatnykh, Acta Astr., 49, 119, 1999

The β Cephei and SPB stars - pulsations and metallicity

Theoretical instability domains in the HR diagram for β Cephei and SPB stars.

The effect of changes in the heavy element abundance on the evolution and stability of the upper main sequence stars.



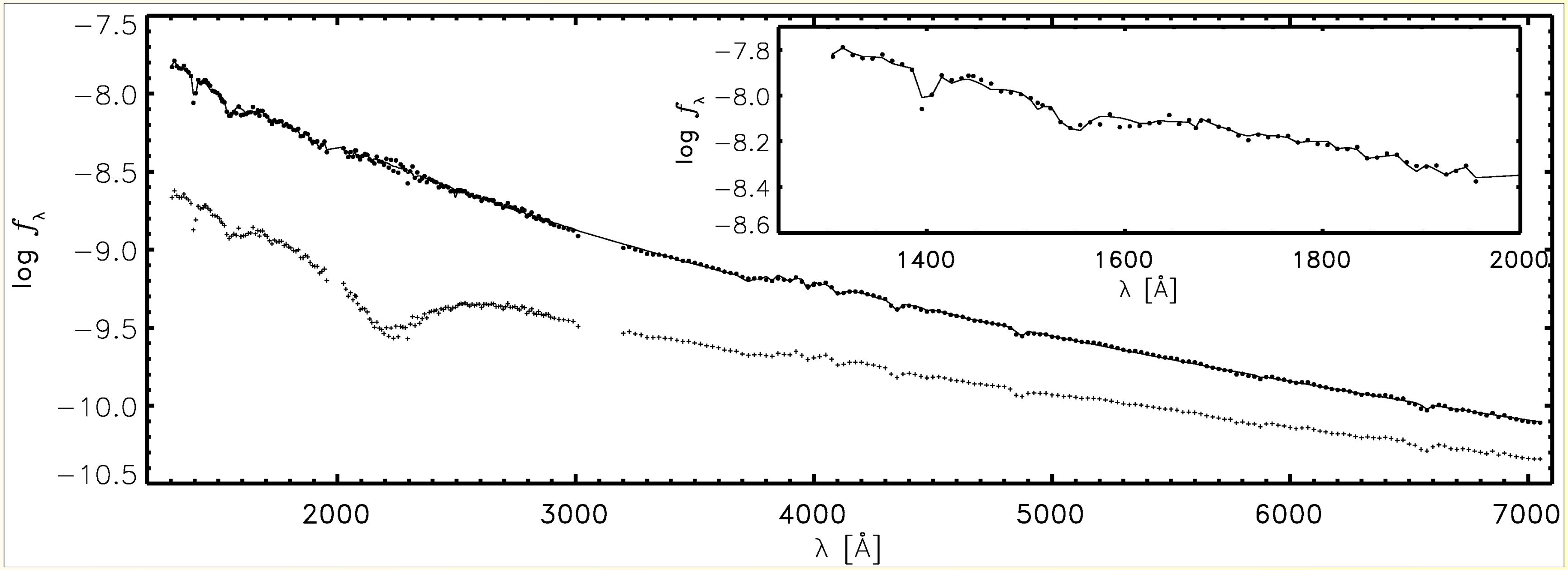
Pamyatnykh, Acta Astr., 49, 119, 1999

Metallicities of the β Cephei and SPB stars from low-resolution ultraviolet spectra

- **UV Observations:** low-resolution IUE ultraviolet data (1300 – 3000 Å) processed by NEWSIPS and INES reduction packages;
- **Optical data:** ground-based spectrophotometric observations;
- **Field and cluster SPB and β Cephei stars:** NGC 3293, NGC 4755, NGC 6231;
- **The analysis:**
  - an algorithmic procedure of fitting the theoretical flux distribution to the observations (least squares method);
  - all parameters were determined simultaneously;
  - errors: *bootstrap resampling* method;
  - the theoretical fluxes were calculated by Kurucz (http://kurucz.harvard.edu, 1996);
  - mean interstellar curve was taken from Fitzpatrick (PASP, 111, 63, 1999).
- **Determined parameters:**
  - effective temperature, T_{eff}
  - metallicity, [m/H]
  - angular diameter, Θ
  - color excess, E(B-V)
  - parameters describing the shape of the UV extinction curve,
  - surface gravity, log g
  - microturbulent velocity, V_{turb}

β Cephei: Niemczura, Daszyńska-Daszkiewicz, A&A, 433, 659, 2005
SPB: Niemczura, A&A, 404, 689, 2003

Metallicities of the β Cephei and SPB stars from low-resolution ultraviolet spectra



Dereddened stellar energy distribution of ω^1 Sco (dotted line) in comparison with the best-fit model (solid line).

The original flux of ω^1 Sco is also shown.

In the inset the closer view of the short wavelength part of the spectrum is presented.

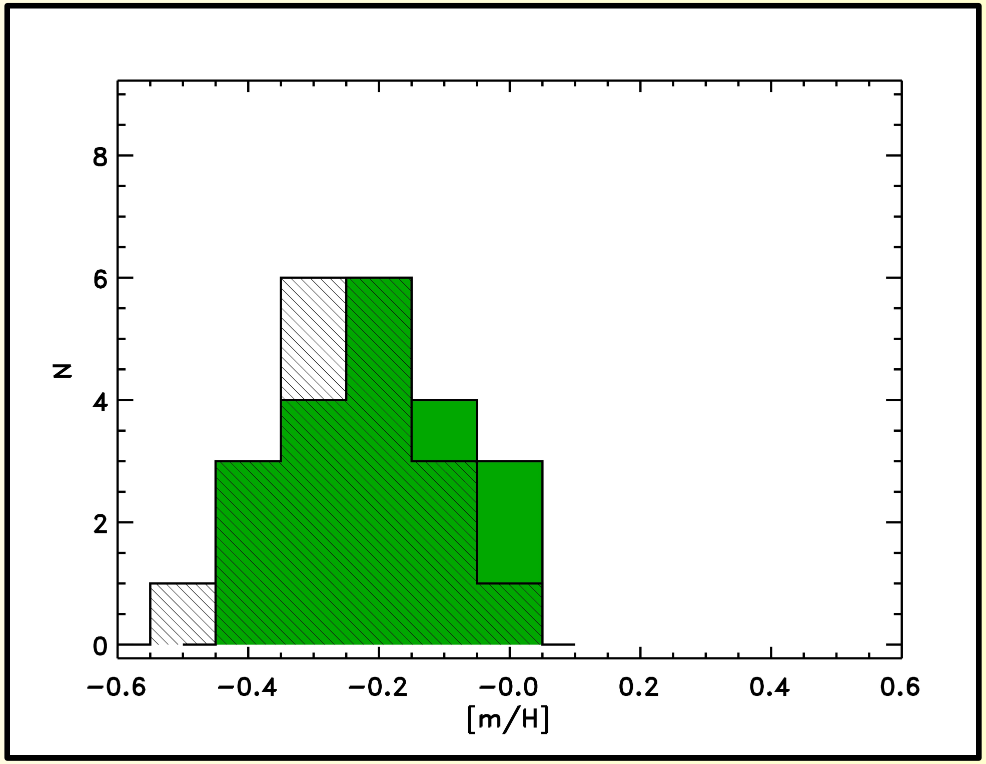
β Cephei: Niemczura, Daszyńska-Daszkiewicz, A&A, 433, 659, 2005
SPB: Niemczura, A&A, 404, 689, 2003

Metallicities of the SPB stars from the low-resolution ultraviolet spectra

Results:	NEWSIPS	INES
→ range of metallicities:	–0.41±0.28 – +0.03±0.02	–0.50±0.12 – –0.04±0.07
→ mean value:	–0.20±0.03	–0.25±0.03
→ mean value for field stars:	–0.18±0.03	–0.25±0.03

The distribution of the SPB stars with the [m/H] parameter.

The hatched histogram shows the results obtained from the IUE/INES spectra, while the green one presents results of the IUE/NEWSIPS data analysis.



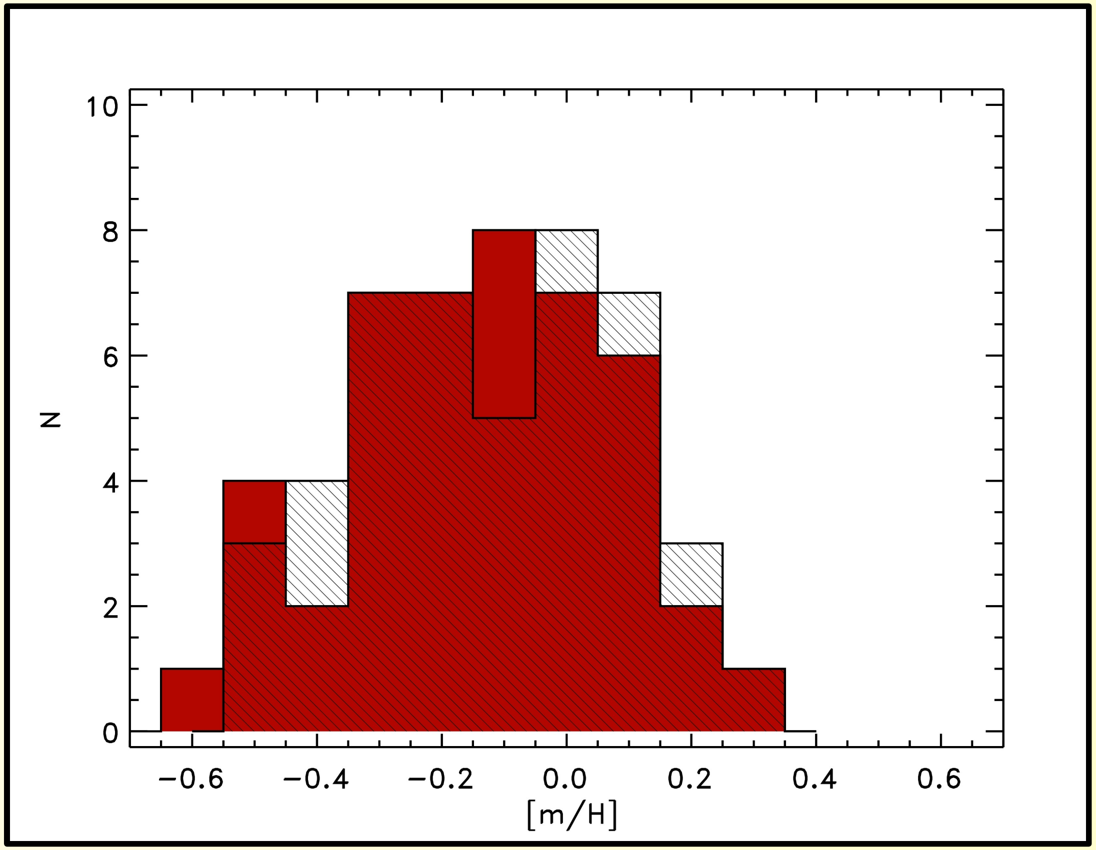
Niemczura, A&A, 404, 689, 2003

Metallicities of the β Cephei stars from low-resolution ultraviolet spectra

Results:	NEWSIPS	INES
range of metallicities:	–0.47±0.18 – +0.21±0.09	–0.42±0.17 – +0.20±0.10
mean value:	–0.15±0.03	–0.13±0.03
mean value for field stars:	–0.14±0.03	–0.13±0.03
mean for NGC 3293:	+0.05±0.06	+0.08±0.07
mean for NGC 4755:	–0.43±0.05	–0.40±0.05
mean for NGC 6231:	–0.12±0.09	–0.05±0.10

The distribution of the β Cephei stars with the [m/H] parameter.

The hatched histogram shows the results obtained from the IUE/INES spectra, while the red one presents results of the IUE/NEWSIPS data analysis.



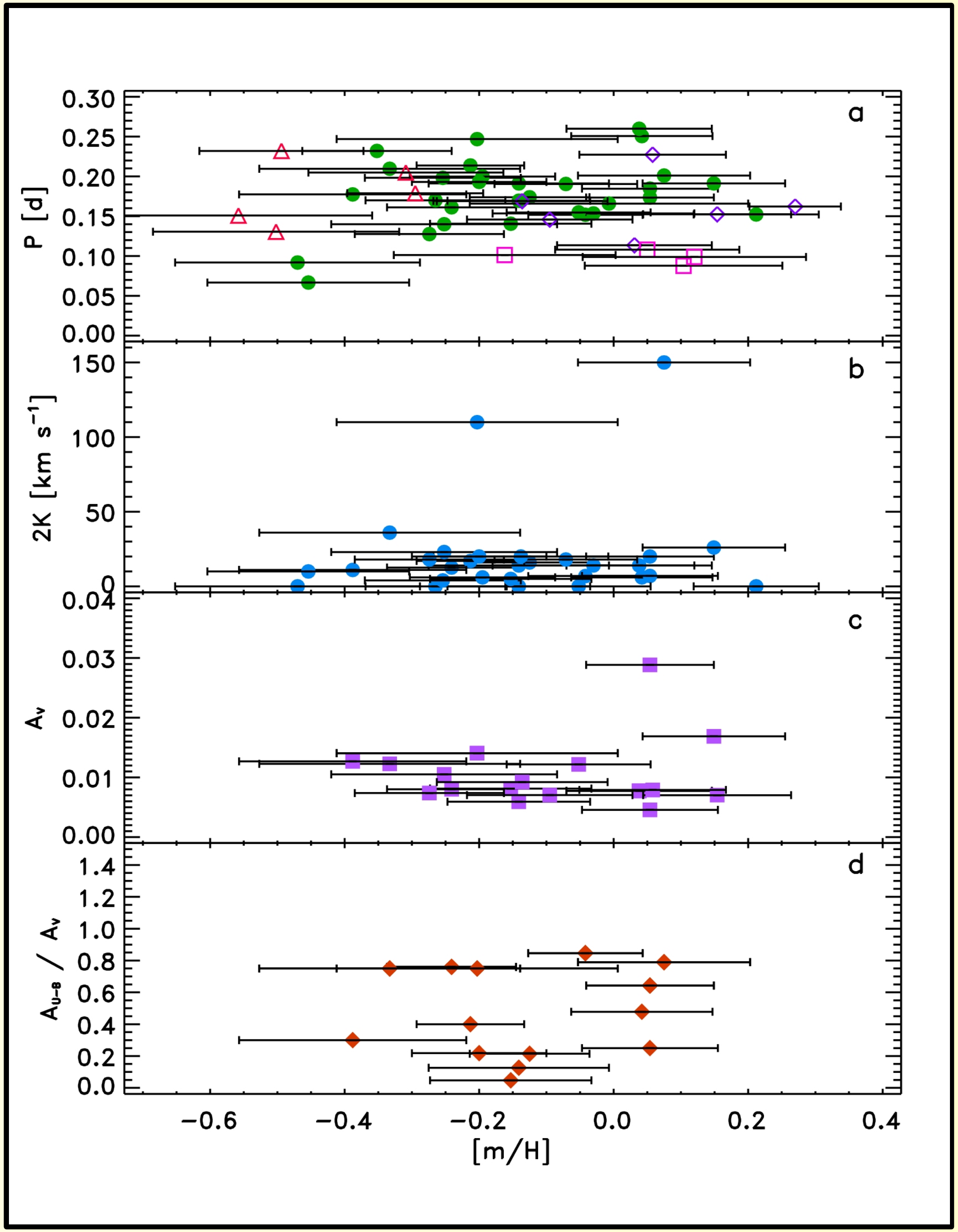
Niemczura, Daszyńska-Daszkiewicz, A&A, 433, 659, 2005

Metallicities of the β Cephei stars from low-resolution ultraviolet spectra

Which pulsational parameters are sensitive to the metallicity in β Cephei stars?

We checked:

- **Period of the dominant mode P**
- **Radial velocity amplitude 2K**
- **Light amplitude in the V filter, A_V**
- **Ratio of photometric amplitudes, A_{U-B}/A_V**

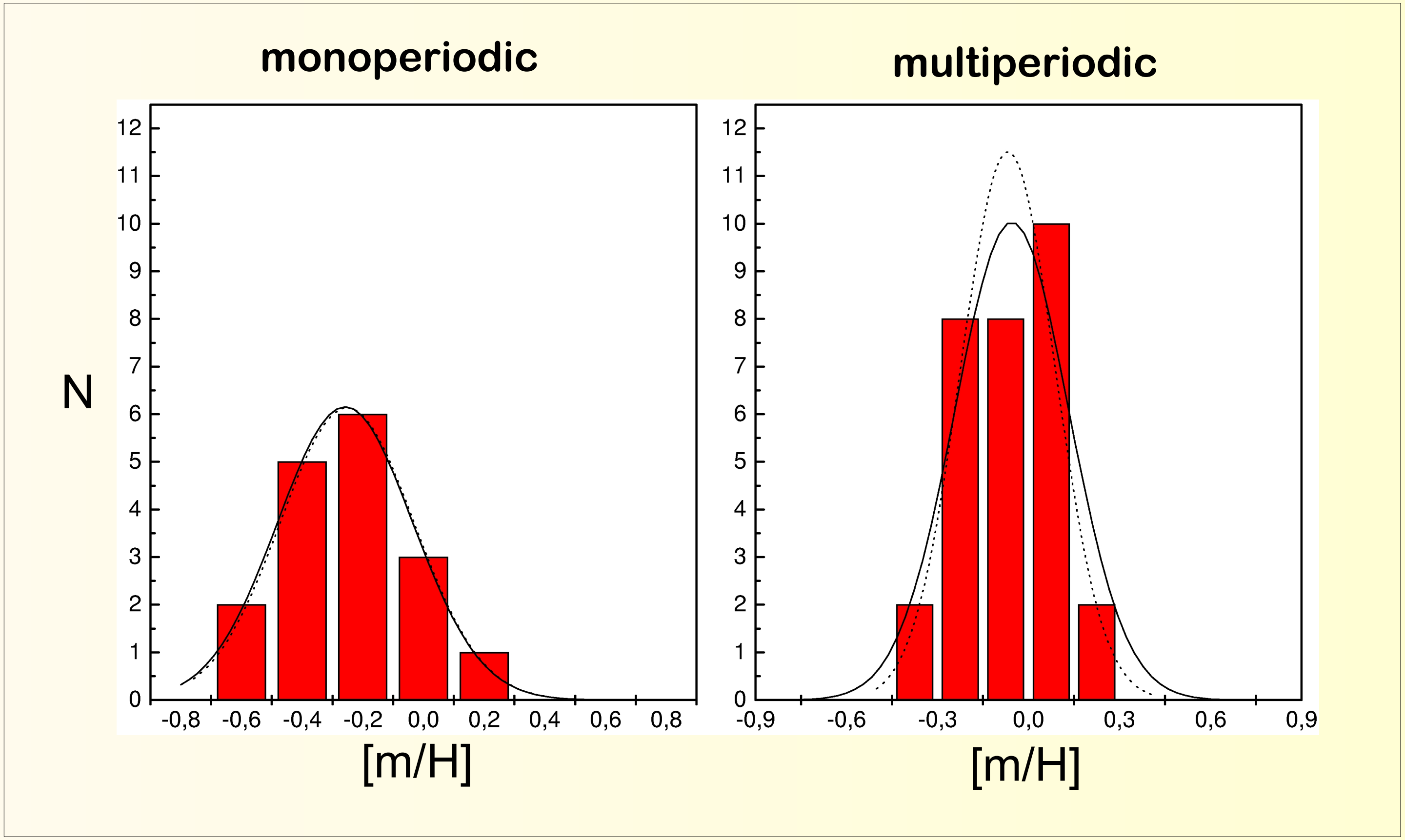


Niemczura, Daszyńska-Daszkiewicz, A&A, 433, 659, 2005

Metallicity of mono- and multiperiodic β Cephei stars

Dichotomy of β Cephei stars with regard to the value of metallicity:

	mean	standard deviation	standard error
▪ monoperiodic pulsators:	-0.252	0.221	0.054
▪ multiperiodic pulsators:	-0.068	0.156	0.029

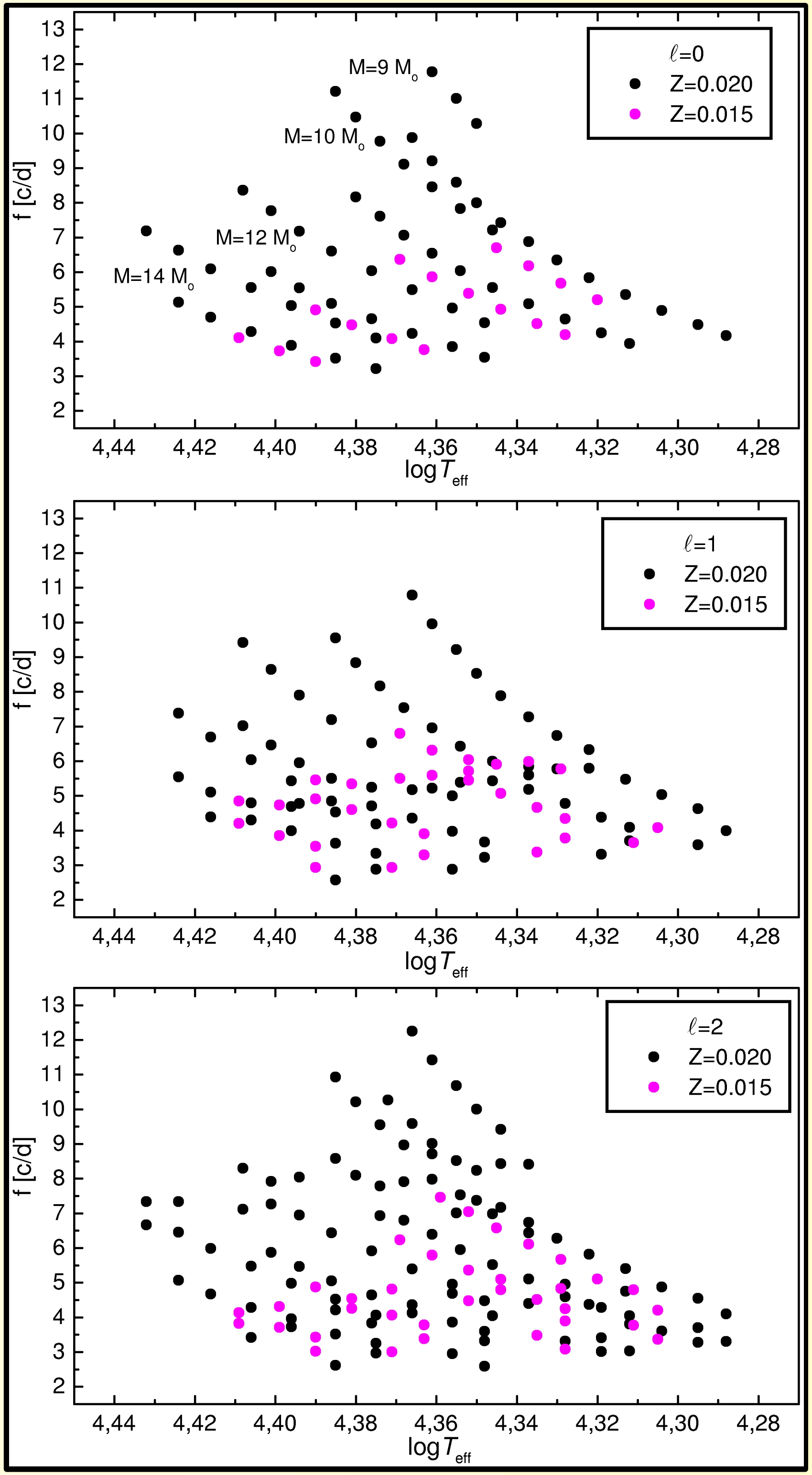


Daszyńska-Daszkiewicz & Niemczura, A&A, 433, 1031, 2005

Metallicity of mono- and multiperiodic β Cephei stars

For greater metal abundance we get more unstable modes (Dziembowski & Pamyatnykh MNRAS, 262, 204, 1993).

For the higher Z value we get a wider range of unstable frequencies.



The evolution of oscillation frequencies in the main-sequence phase for four indicated masses and two values of the heavy element abundance Z. We considered low degree modes with *l* = 0,1,2.

In these computations the Warsaw-New Jersey stellar evolution code and the non-adiabatic pulsation code of Dziembowski (AcA, 27, 303, 1977) were used. We took OPAL opacities and did not include effects of rotation and convective core overshooting.

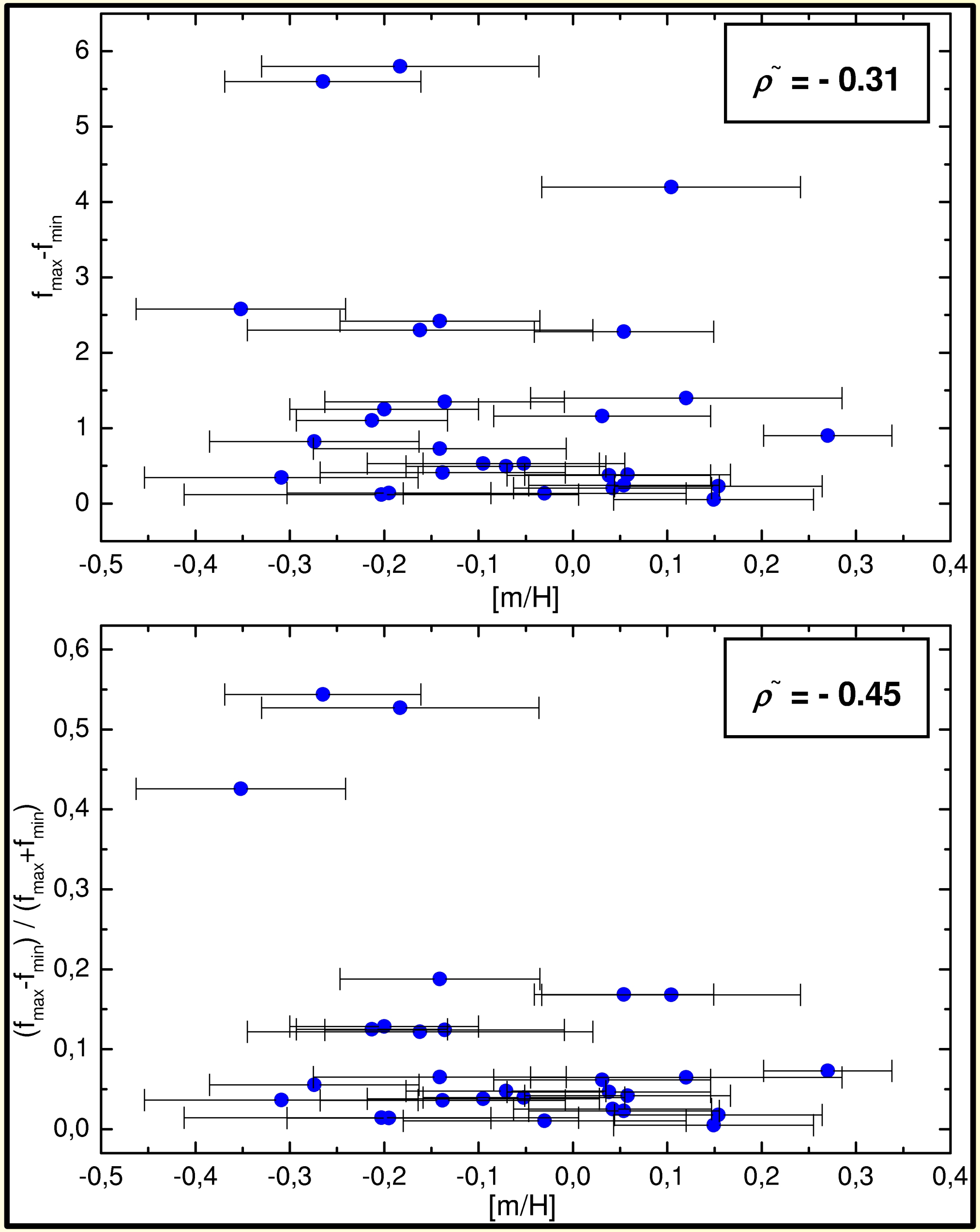
Daszyńska-Daszkiewicz & Niemczura, A&A, 433, 1031, 2005

Metallicity of mono- and multiperiodic β Cephei stars

The range of observed frequencies in β Cephei stars as a function of [m/H].

The frequency range normalized by the sum of the lowest and highest frequency as a function of [m/H].

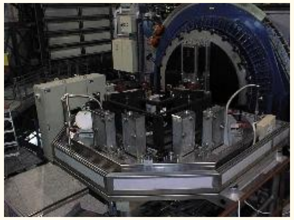
The values of weighted correlation coefficient are given in the right-upper corners.



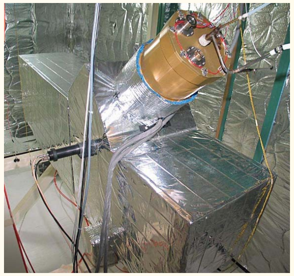
Daszyńska-Daszkiewicz & Niemczura, A&A, 433, 1031, 2005

Chemical composition of the pulsating β Cephei star γ Peg

UVES

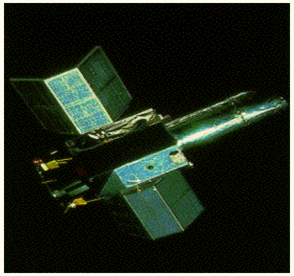


ELODIE



HST

IUE



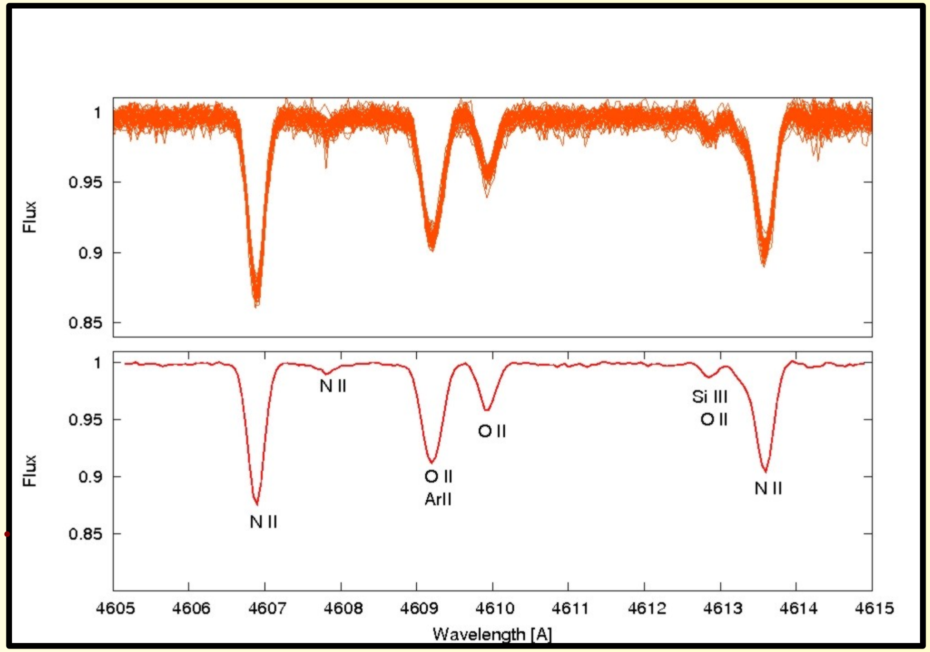
We perform the detailed spectral line identification and an abundance analysis of the pulsating β Cephei star γ Peg (HD886, B2 IV).

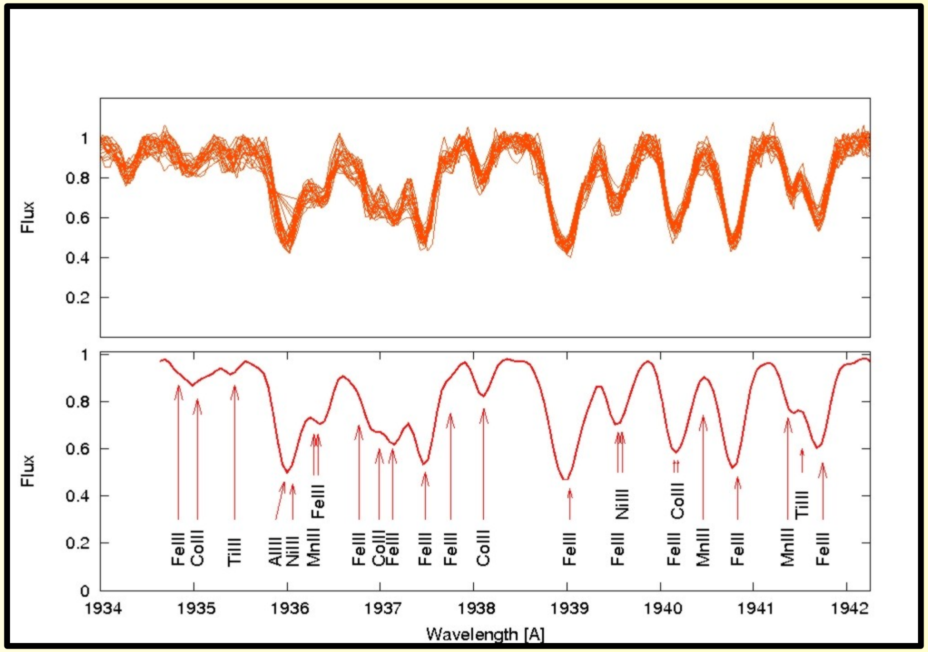
For this purpose we collected all currently available spectroscopic data and performed analysis by means of spectrum synthesis method.

The majority of lines for hot B type stars are located in the ultraviolet part of the spectra.

The high-resolution IUE and HST/GHRS observations have been used to determine abundances of the iron group elements.

The visual high-resolution, high S/N ratio spectra from UVES/VLT and ELODIE were used to find the abundances of the light elements.





Niemczura & Połubek, soho, 18, 120, 2006

Chemical composition of the pulsating β Cephei star γ Peg

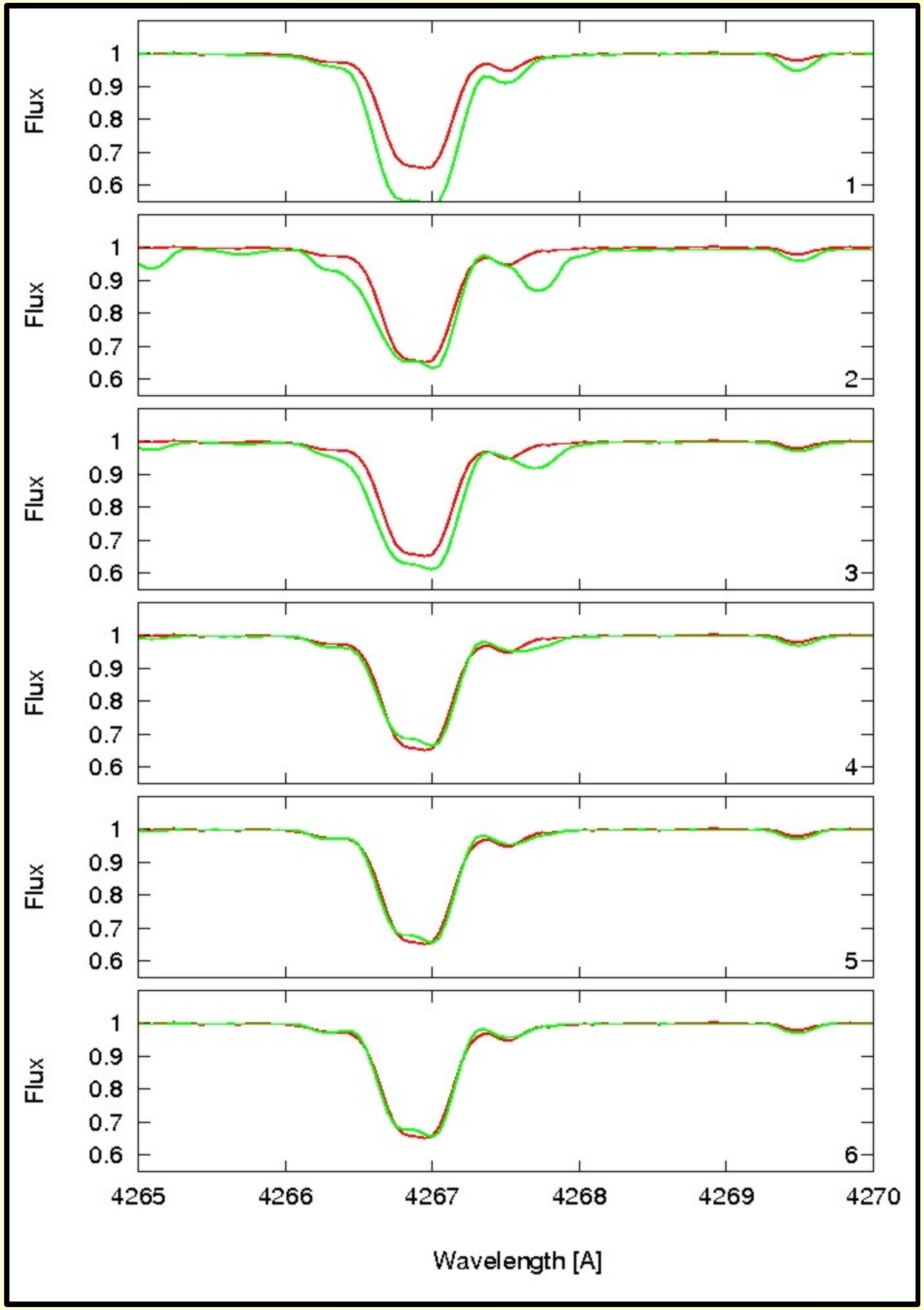
The synthetic spectra were computed with the SYNTHE code (Kurucz 1993, CD-ROM, No. 18). All the Kurucz atmospheric models were computed with the line-blanketed LTE ATLAS9 code.

To the analysis of the data an efficient spectral synthesis method was utilized, useful for simultaneous determinations of various parameters involved with stellar spectra.

The synthetic spectrum depends on the stellar parameters like **effective temperature T_{eff}, surface gravity log g, rotational velocity $V_e \sin i$, microturbulence V_{turb}, radial velocity V_r and relative abundances of the elements e_i.**

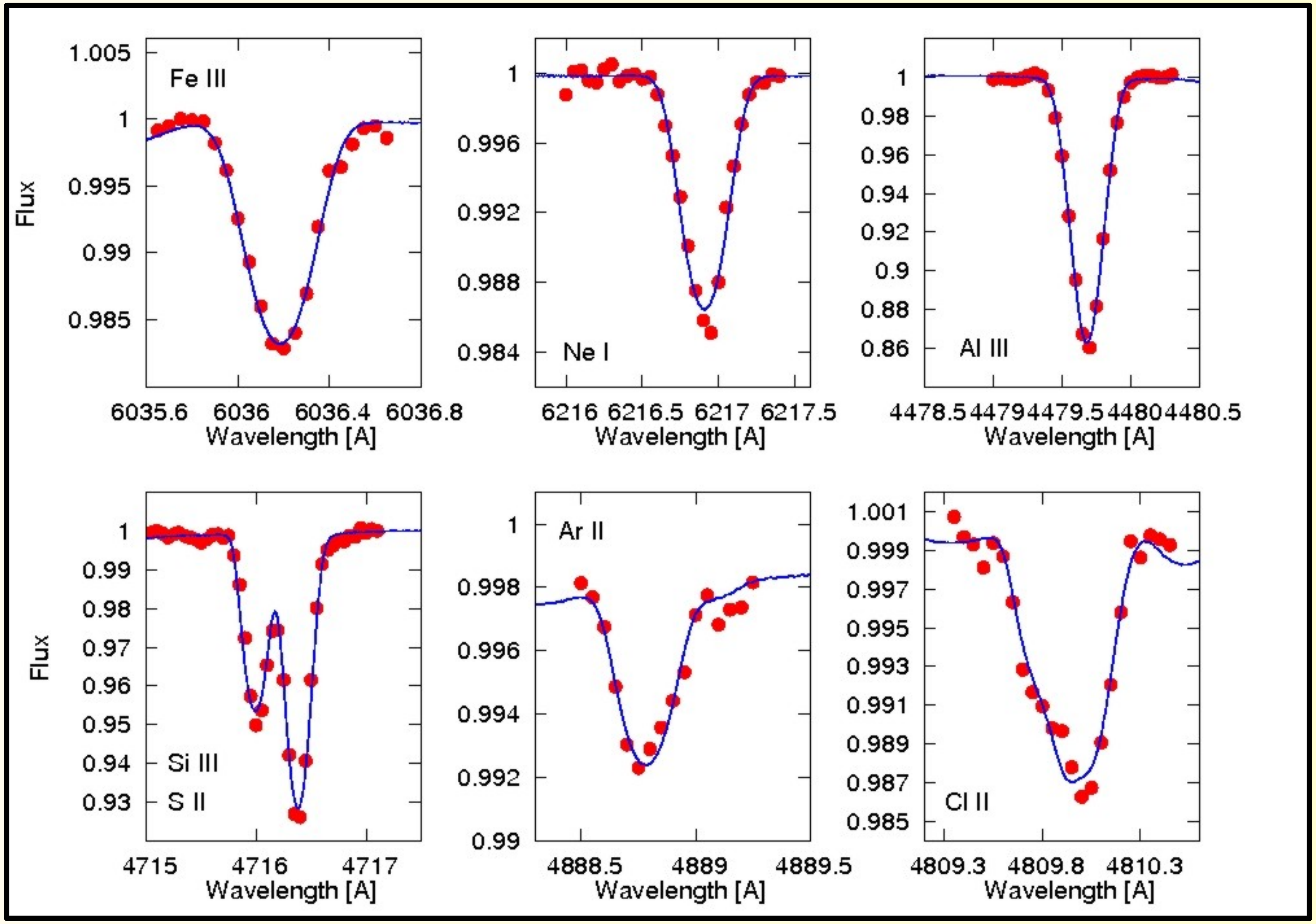
In the Figure part of the observed flux (red line) together with synthetic flux (green line) at each of the iteration steps is plotted. In this example abundances of S, Ar, Fe and C as well as radial velocity and microturbulence were determined.

We adopted the atmospheric parameters: T_{eff} = 22,000 K, and log g = 4.0 from the literature (Niemczura & Daszyńska-Daszkiewicz, 2005, A&A, 433, 659). The rotation velocity was determined as equal to ≈ 11 km s^{-1}.



Niemczura & Połubek, soho, 18, 120, 2006

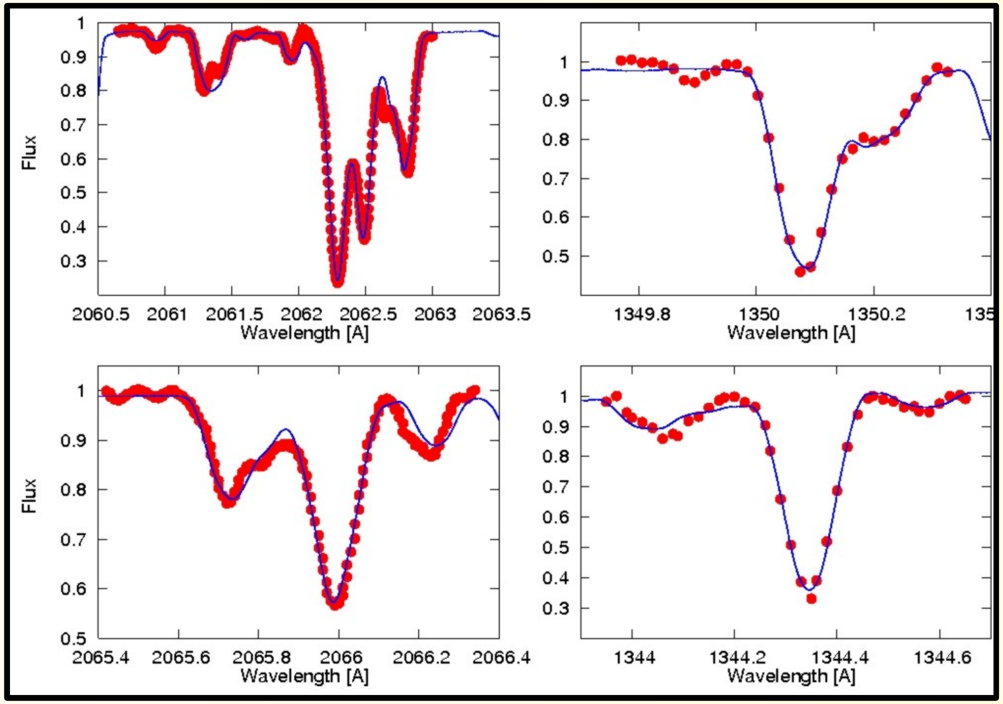
Chemical composition of the pulsating β Cephei star γ Peg

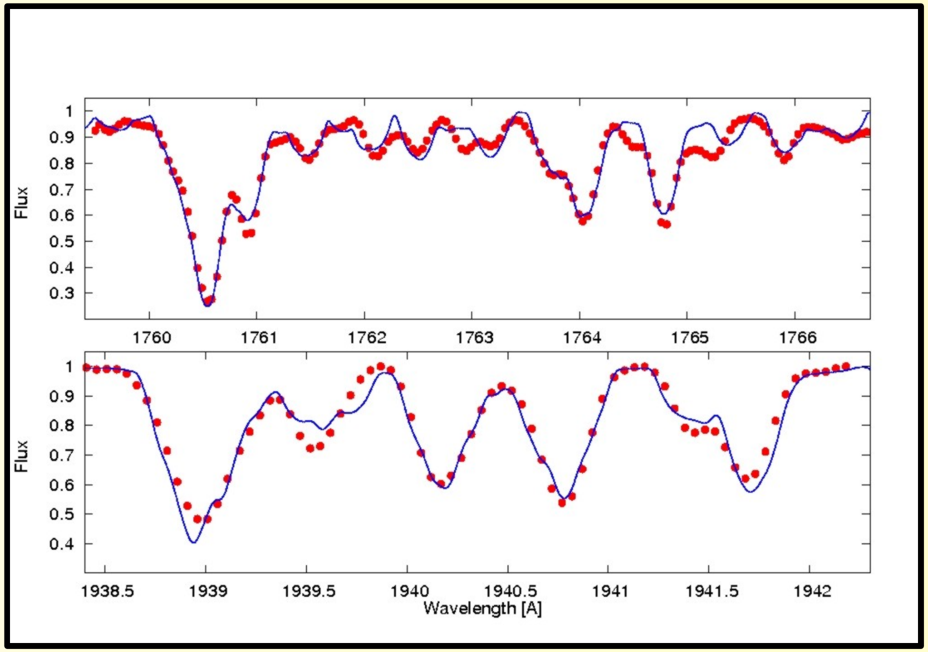


Comparison of the observed co-added ELODIE spectra and synthesized spectra of a few elements. The blue line represents the synthesized spectrum and the red points represent the observed one. In the visual part of the spectrum, the analysis of unblended lines were possible. Even for a very weak lines agreement between the observed and synthesized spectrum can be very good.

Niemczura & Połubek, soho, 18, 120, 2006

Chemical composition of the pulsating β Cephei star γ Peg





Comparison of the observed, co-added IUE spectra (right Figure) and GHRS spectra (left Figure) with the result of the spectrum synthesis method.
The blue line represents the synthesized spectra and the red points represent the observed one.

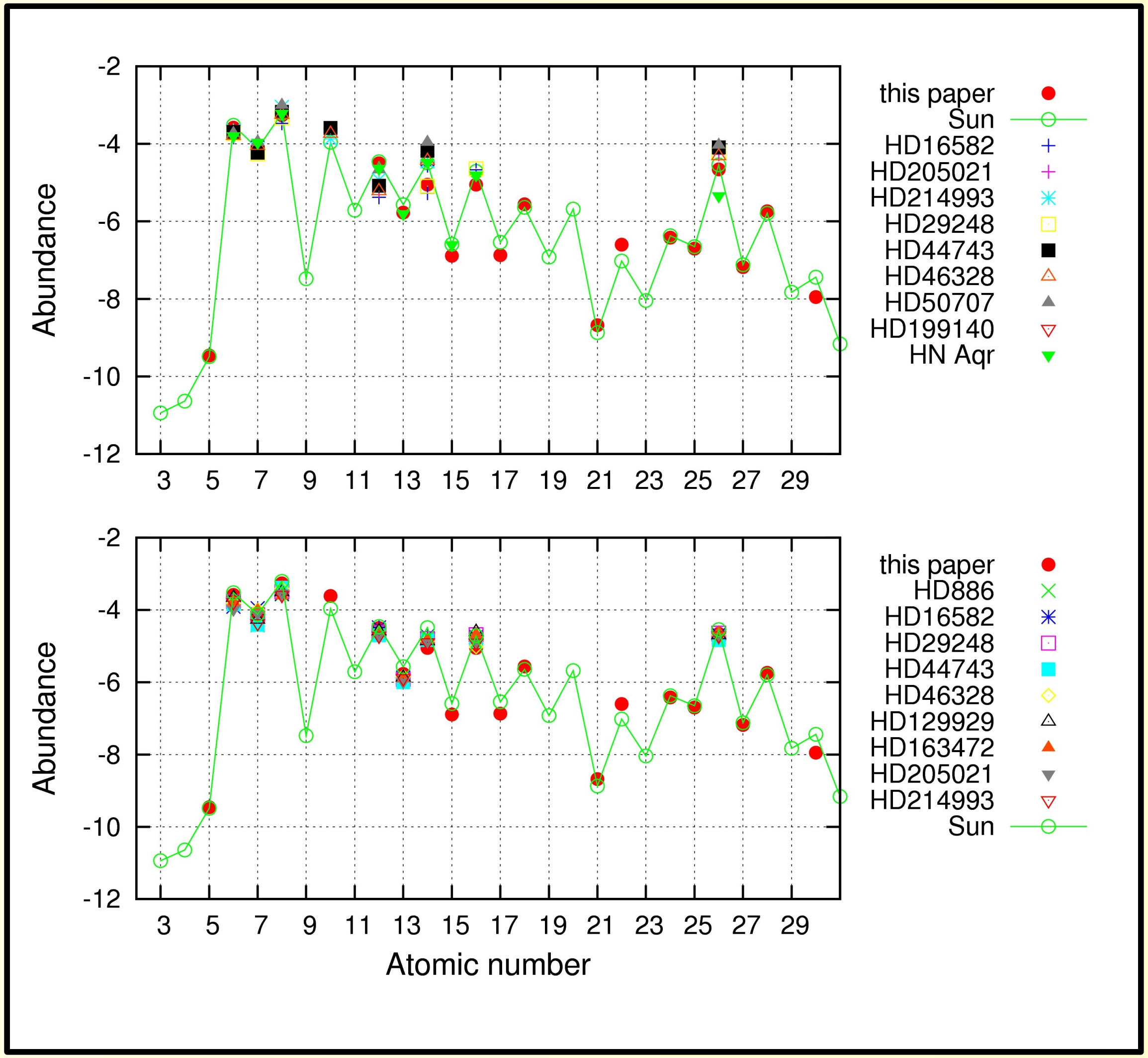
Niemczura & Połubek, soho, 18, 120, 2006

Chemical composition of the pulsating β Cephei star γ Peg

Determined abundances for γ Peg compared with the results for several β Cephei stars and the solar values from Greevese & Sauval (1998, Space Sci. Rev., 85, 16, 1998).

In the upper panel the chemical compositions from Gies & Lambert (1992, ApJ, 387, 673), Stankov et al. (2003, A&A, 408, 1077) and Ryans et al. (1996, MNRAS, 278, 132) are shown.

In the lower panel the abundances determined by Morel et al. (A&A, 457, 651, 2006) are presented.



The abundances of C, N, O are consistent for all stars and are close to the solar values. The most important discrepancies can be seen for Mg and Si. This effect is probably connected with the nonLTE effects, which can be strong for these elements.

Niemczura & Połubek, soho, 18, 120, 2006

Abundance analysis of prime B-type targets for asteroseismology

Morel et al., A&A, 457, 651, 2006

Field β Cephei stars: γ Peg, δ Cet, ν Eri, β CMa, ξ^1 CMa, V836 Cen, V2052 Oph, β Cep, DD Lac;

Observations: high-resolution optical data (ELODIE, CORALIE, FEROS and CS2 spectrograph at McDonald observatory);

Analysis: NLTE analysis, codes: DETAIL and SURFACE; line-blanketed LTE Kurucz atmospheric models; the line atomic data from NIST and VALD databases; the abundances were derived by comparison of the measured EWs and the values measured in the synthetic spectra;

Considered chemical elements: He, C, N, O, Mg, Al, Si, S, Fe;

Results:

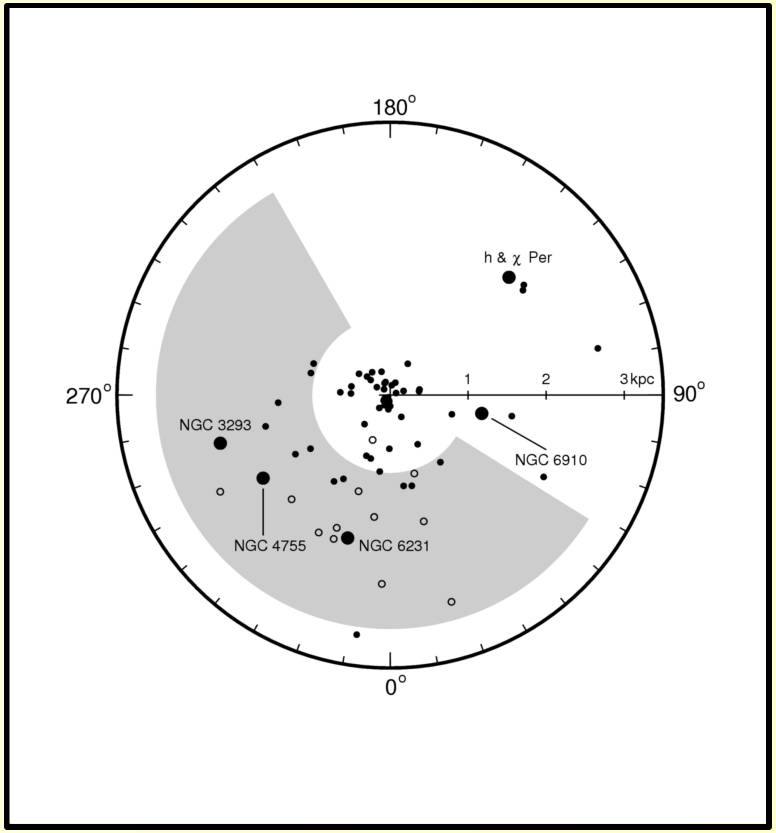
- Ni is enhanced by up to 0.6 dex in four stars (β Cep, V2052 Oph, δ Cet, ξ^1 CMa)
- the other elements are the same as for OB dwarfs in the solar neighbourhood

The Galactic β Cephei stars:

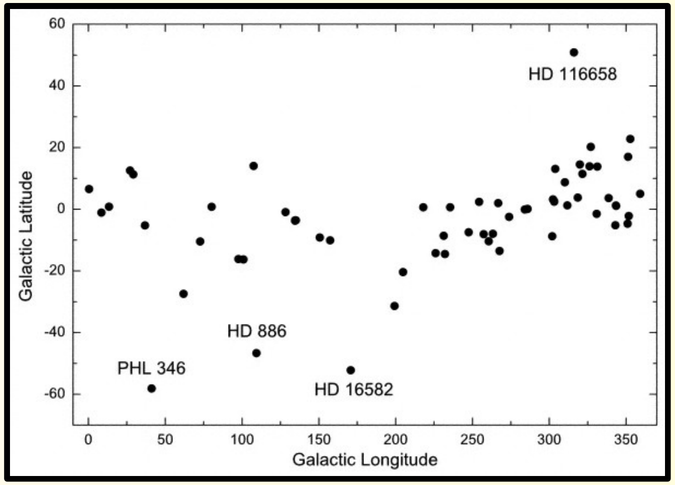
The distribution of the Galactic β Cephei stars in the sky:

➔ Large asymmetry in the distribution: about 80% of them are located in the southern sky. This is partly due to the observational selection effects, but *the dependence of the driving mechanism on metallicity, combined with decreasing metallicity at larger galactocentric distances, may also play an important role.*

➔ An apparent strip of bright β Cephei stars between Galactic longitudes *l* = 200° and 360°, inclined with respect to the Galactic plane (Pigulski, Comm. in Asteroseismology, 144,2003).



Pigulski, Comm. in Asteroseismology, 144, 2003



Stankov & Handler, ApJ, 158, 193, 2005)

Galactic open clusters with β Cephei stars:

- NGC 3293 – Handler et al. (Comm. In Asteroseismology, vol. 150, 2007);
- NGC 4755 – Stankov et al. (MNRAS, 336, 189, 2002);
- NGC 6231 – Arentoft et al. (A&A, 380, 599, 2001);
- NGC 1502 – Stęślicki (ASP Conf. Series, 349, 335, 2006);
- NGC 6910 – www.astro.uni.wroc.pl/ngc6910.html;
- NGC 884 – Krzesiński & Pigulski (ASPC, 203, 496, 2000);
- NGC 869 – Krzesiński et al. (A&A, 345, 505, 1999);
- NGC 7235 – Pigulski et al. (AcA, 47, 365, 1997);
- NGC 663 – Pigulski et al. (AcA, 51, 159, 2001);
- NGC 2169 – Jerzykiewicz et al. (AcA, 53, 151, 2003) ;
- Cygnus OB2 – Pigulski & Kołaczkowski (MNRAS, 298, 753, 1998).

Chemical composition of β Cephei and SPB stars in open clusters

The β Cephei and SPB stars in open clusters are of special interest. Observations of oscillation frequencies in many stars in the same environment with nearly the same age and chemical abundances has many advantages. For the well-studied open clusters: NGC3293, NGC6231, NGC4755, NGC6910 and NGC884 the spectroscopic observations are planned, which allow us to determine:

- ✔ Chemical compostion (He, C, N, O, Ne, Mg Al, Si, S, Ar, Ca, Fe) for individual β Cephei and SPB stars (needed for asteroseismology);
- ✔ Which pulsational parameters (e.g. period of the dominant mode, number of frequencies, radial velocity mode, light amplitudes in different filters, ratio of photometric amplitudes) are correlated with abundances of individual elements and metallicity;
- ✔ The differences between chemical abundances of β Cephei, SPB and stars not classified as pulsators;
- ✔ Evidences of diffusion in β Cephei and SPB stars;
- ✔ Evolutionary status of pulsating stars in open clusters.