Analysis of Cepheids based on photometric data from the „Pi of the Sky" experiment

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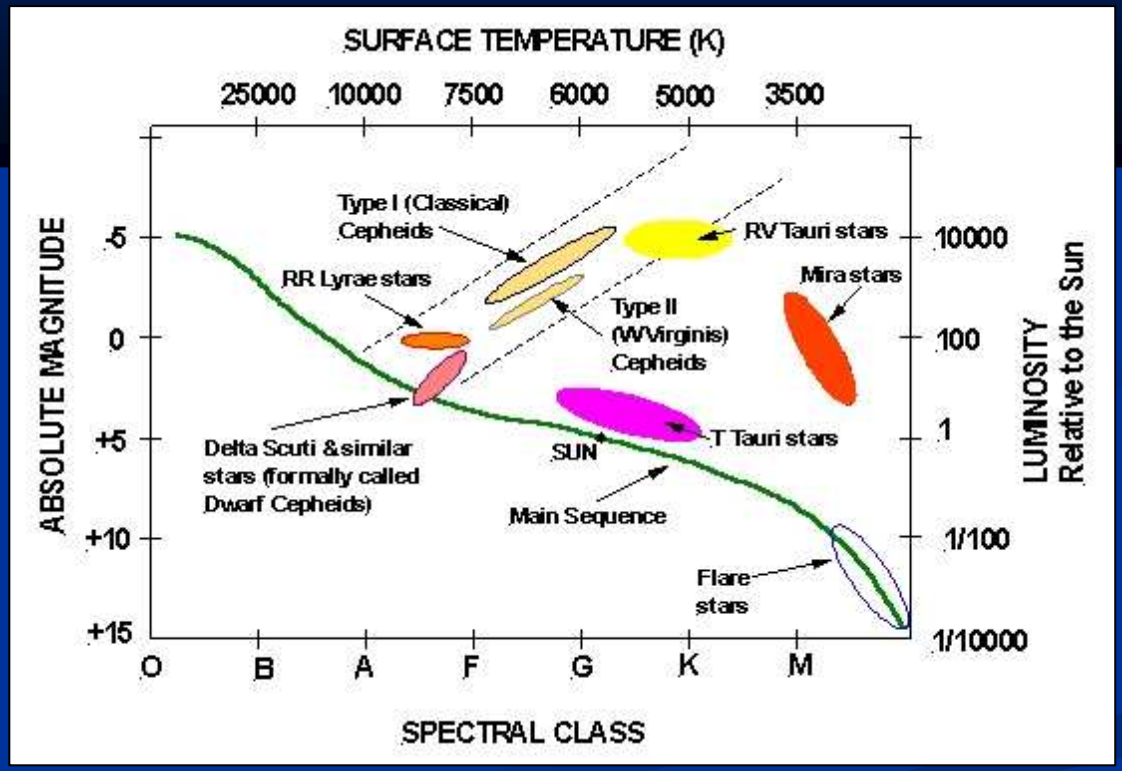
Plan

- Cepheids
- Pulsation mode
- Cepheids as standard candle
- Fourier decomposition techniques
- Cepheids observed by the Pi of the Sky detector
- Summary

Cepheids

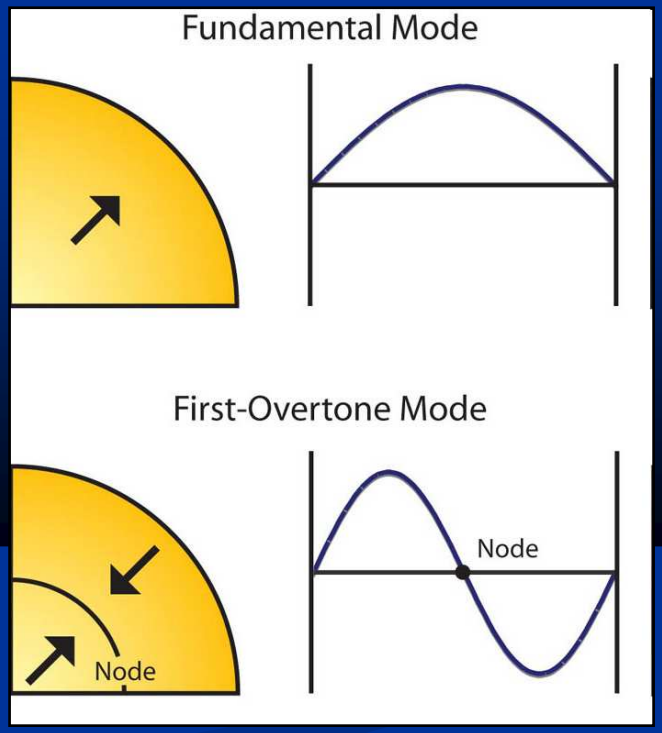
- Pulsating stars
- Period: 1-135 days
- Subclasses:
  - Population I (classical Cepheids)
  - Population II (W Virginis Cepheids)

Hertzsprung -Russell diagram

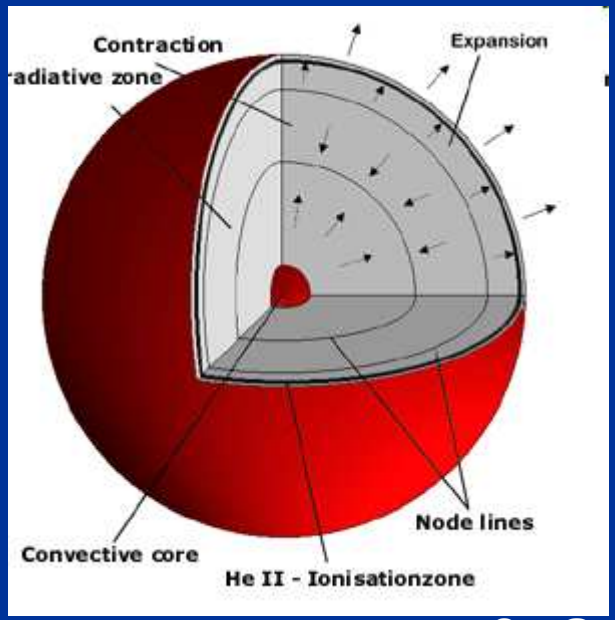


Pulsation

- Two types of pulsations:
  - Radial oscillations- don't change the spherical symmetry of the star
  - Non-radial pulsations
- Radial pulsation:
  - n- the number of nodes



AAVSO Home Page: http://www.aavso.org

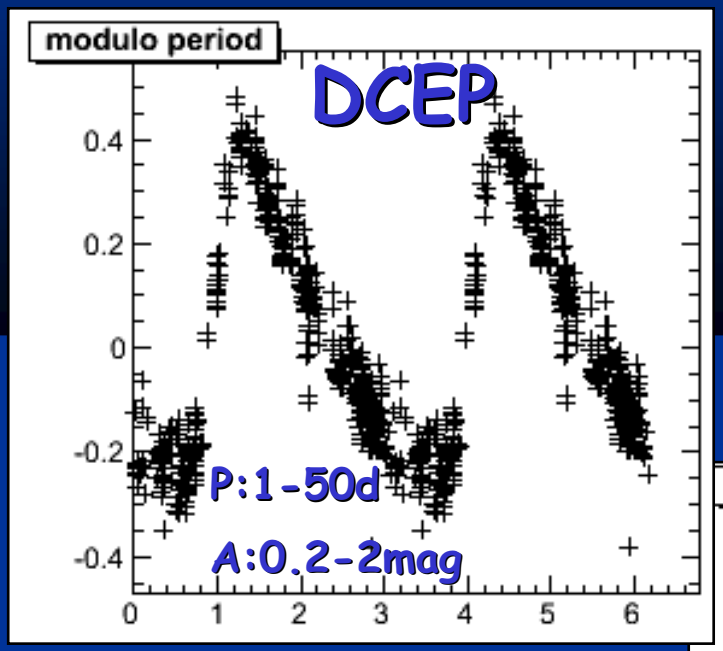


Zima (1999, Master Thesis)

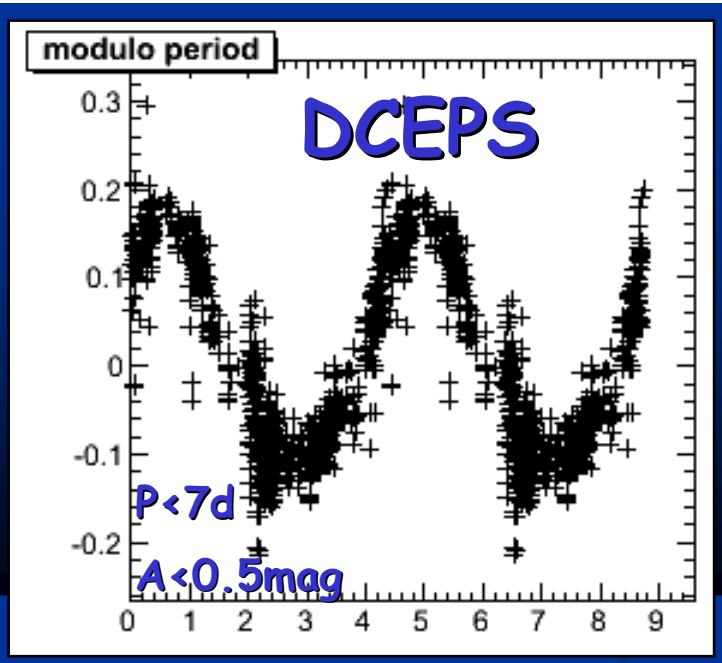
- Radial pulsation:
  - n=1 - Fundamental mode: stars move in and out as a continuous whole
  - n=2 - First- overtone mode (1FO)- part of the star expanding while other parts contract

n=3 - Second- overtone

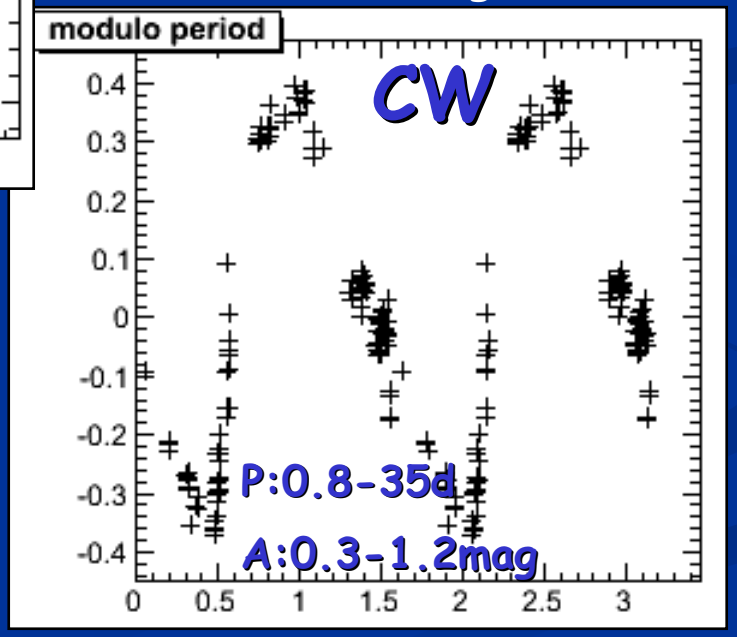
Cepheids Single-Mode



Phased light curve of **RT Mus** star, period= 3.0851 d



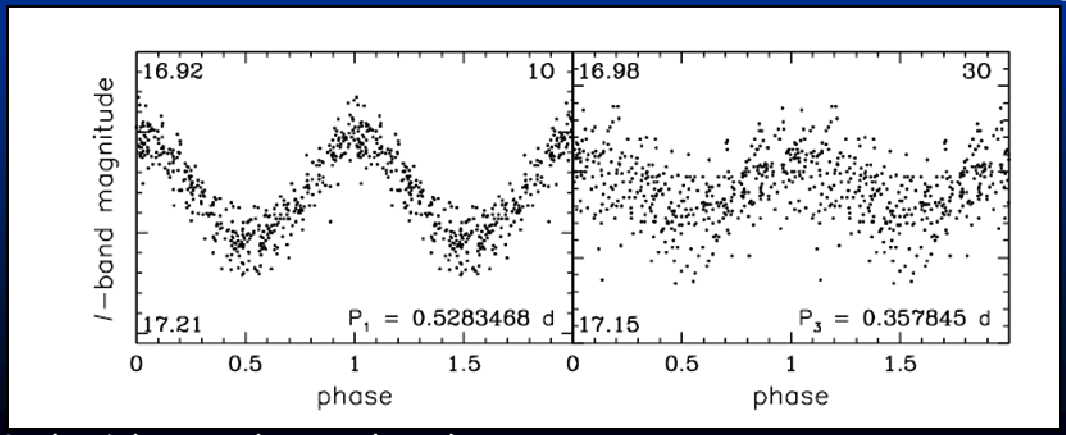
Phased light curve of **V391 Nor** star, period=4.3744 d



Phased light curve of **SW Tau** star, period= 1.8339 d

Cepheids Double-Mode

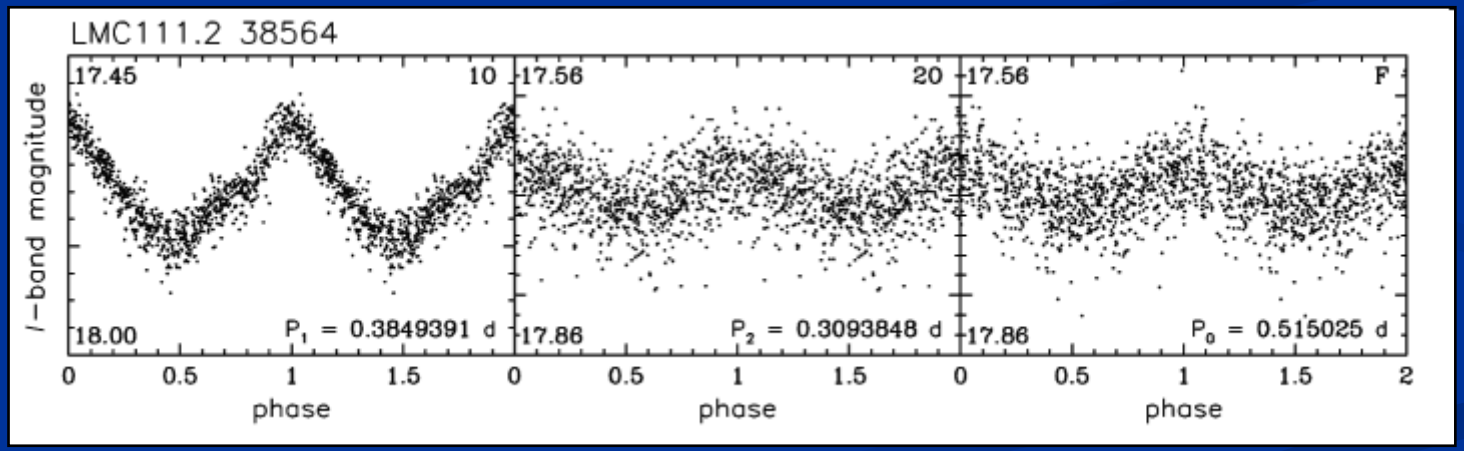
265 in the LMC



10/30 double-mode Cepheid

Cepheids Triple-Mode

5 in the LMC



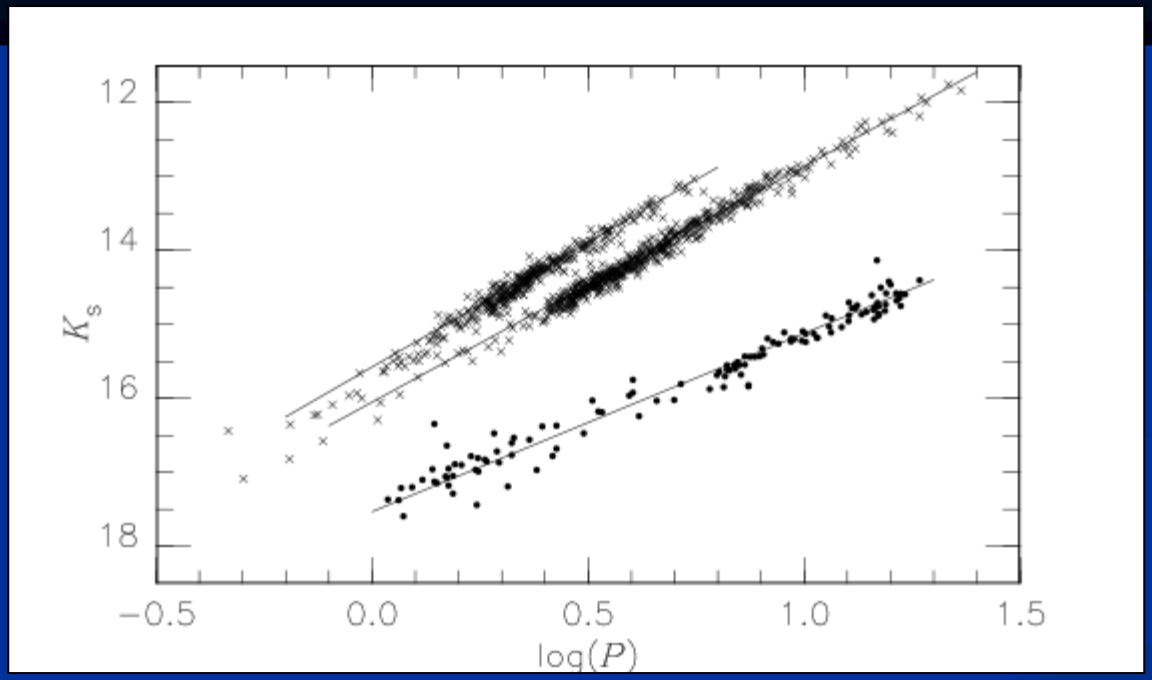
F/10/20 triple-mode Cepheid

Soszynski *et al.*, 2008, Acta Astron., 58, 153

Cepheids- the cosmic candles

- One of the most valuable methods for distance determination
- Period- luminosity relationship

$$D=10^{0.2\cdot(m+5-M-A)}$$



- Points- Population II
- Crosses- Population I

Noriyuki Matsunaga at al, *Period-Luminosity Relation for Type II Cepheids*, Journal of Physics: Conference Series, vol. 144 012011, 2009.

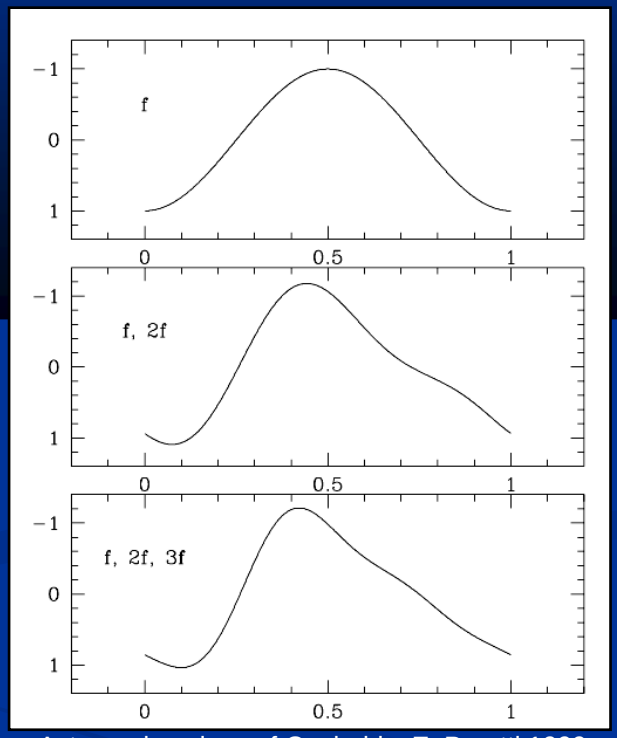
Fourier analysis

- Classification of pulsation mode
- Fourier decomposition techniques

$$V_r(t) = A_0 + \sum_{i=1}^{N} A_k \sin[2\pi k f (t - t_0) + \phi_i]$$

$$f = \frac{1}{P}$$

V- magnitude observed at time t, A_0 - the mean magnitude, A - the amplitudes of each compponent, f- frequency, P- pulsation period, ϕ_i- the i-th phase at i=T_0.



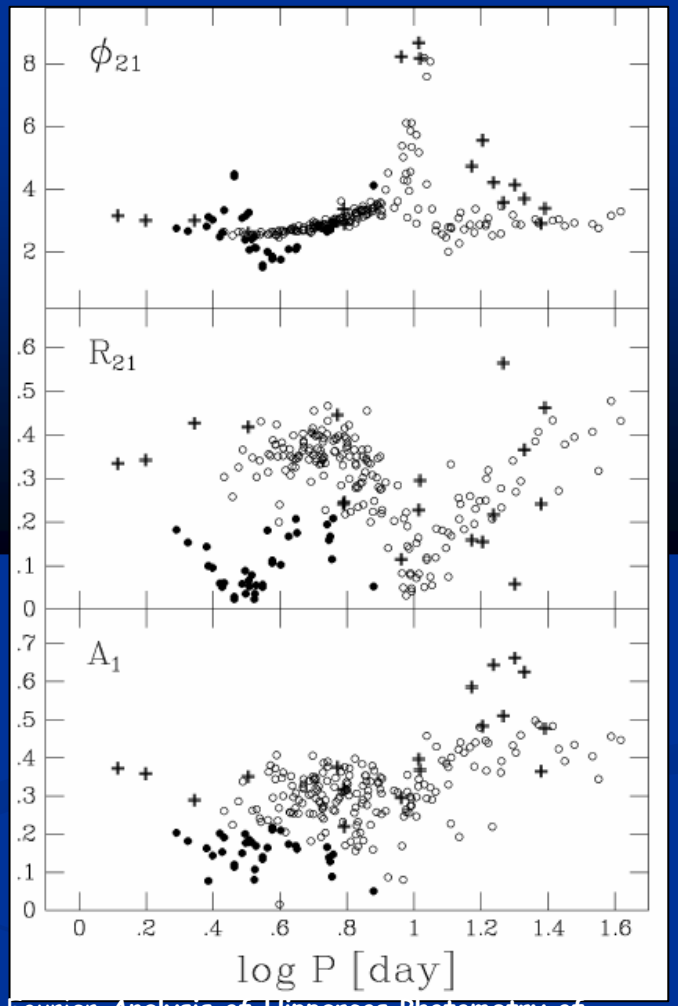
Asteroseismology of Cepheids, E. Poretti 1999

- 2f, 3f, 4f…- First, second, third … harmonic of the main frequency
- N- order of fit-increased until adding another harmonic doesn't decrease σ significantly

Fourier parameters

- Define the shape of he light curves
- Two groups:
  - The amplitude ratios $$R_{ij} = \frac{A_i}{A_j}$$
  - The phase shifts $$\phi_{ij} = i\phi_j - j\phi_i$$
- Rising time- the phases of maximum and of minimum brightness

In plots of Fourier parameters against period is clear separation between classes of Cepheids

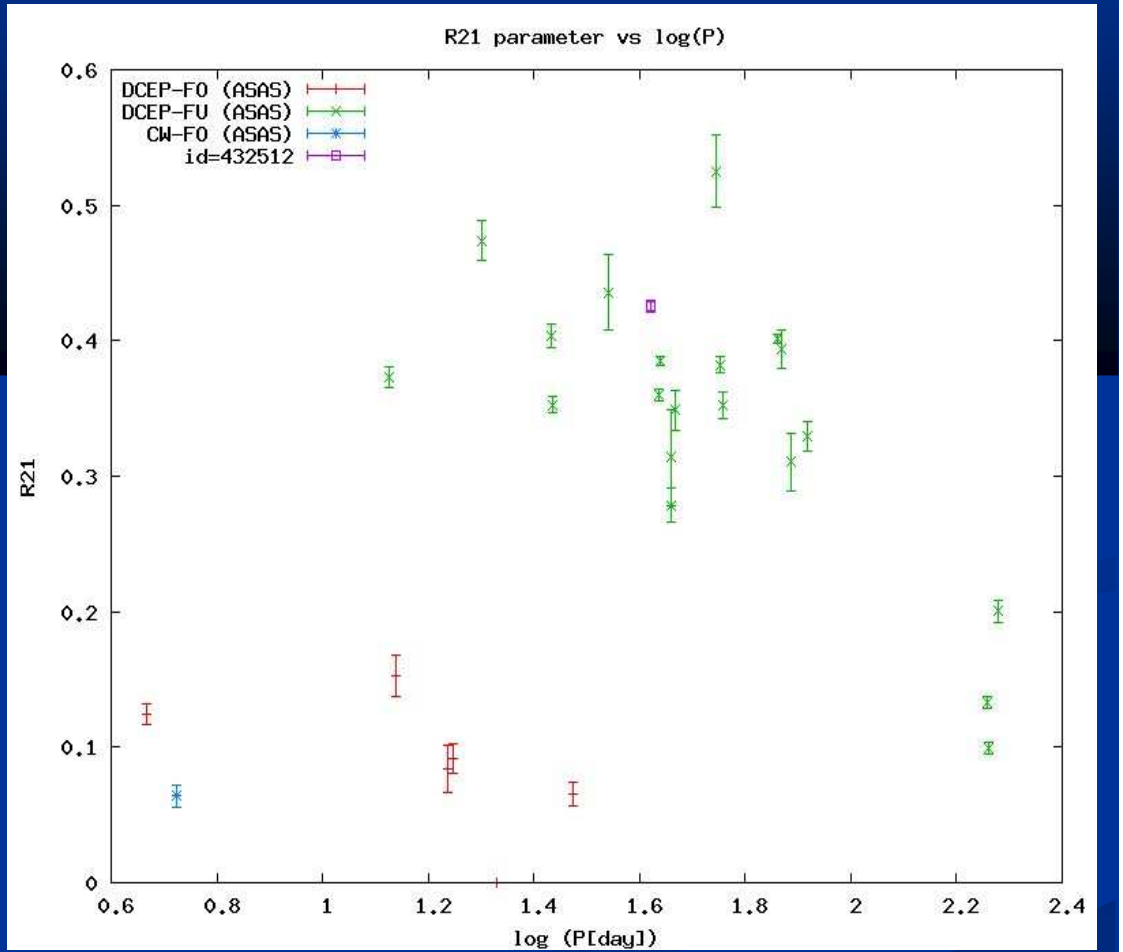


Fourier Analysis of Hipparcos Photometry of Cepheid Variables, B. Zakrzeski, Acta Astronomica 2000

- open and filled circles- fundamental mode and overtone Population I Cepheids,
- crosses Population II Cepheids

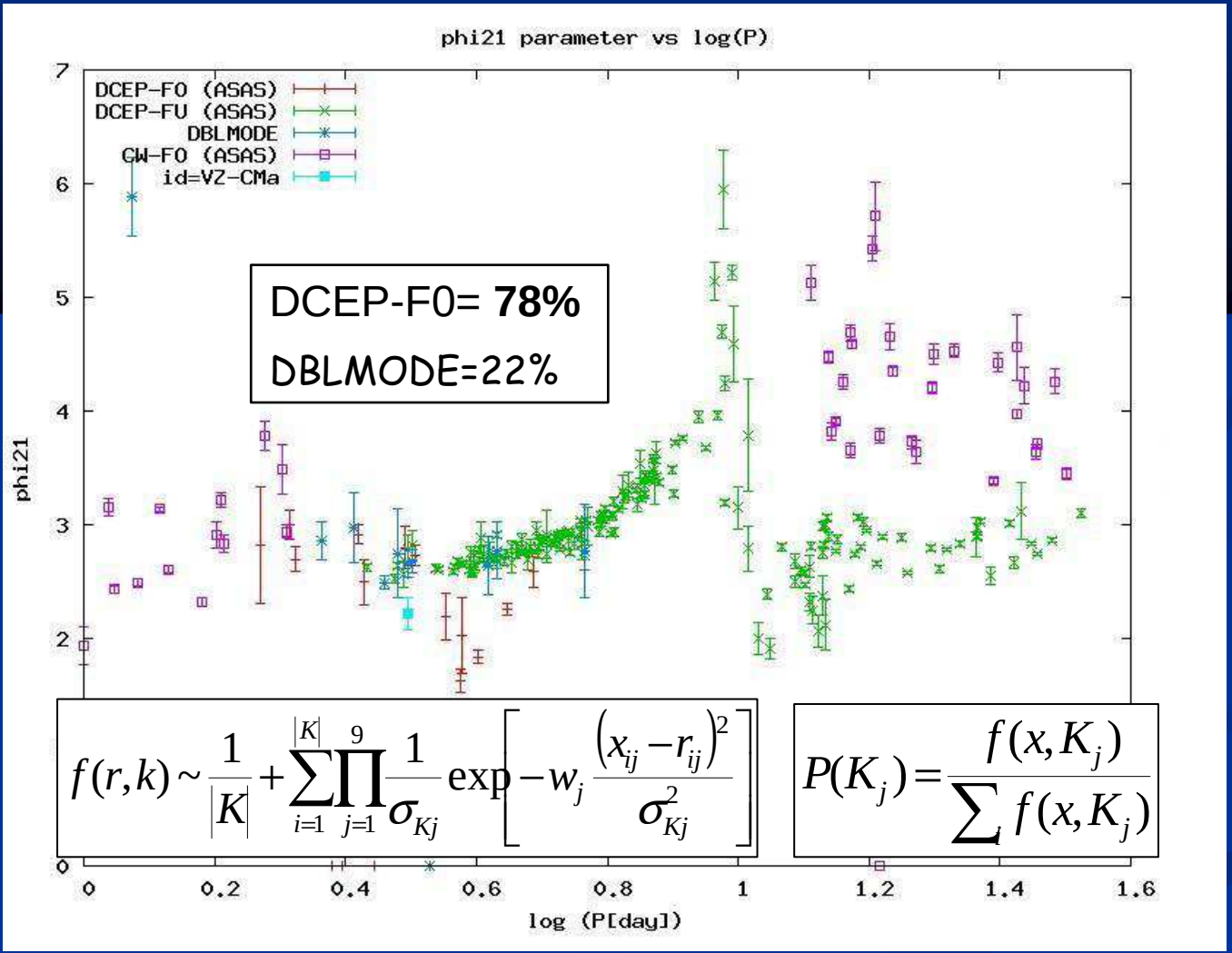
Cepheids observed by Pi of the Sky

- Cepheids found in Pi of the Sky data from season 2006_2007
- Not enough stars
- From May 2009 we have filter R



- Fourier parameters from ASAS data for:
  - Population I Cepheids:
    - Fundamental mode: 178
    - First- overtone mode: 18
    - Double mode: 12
  - Population II Cepheids: 42

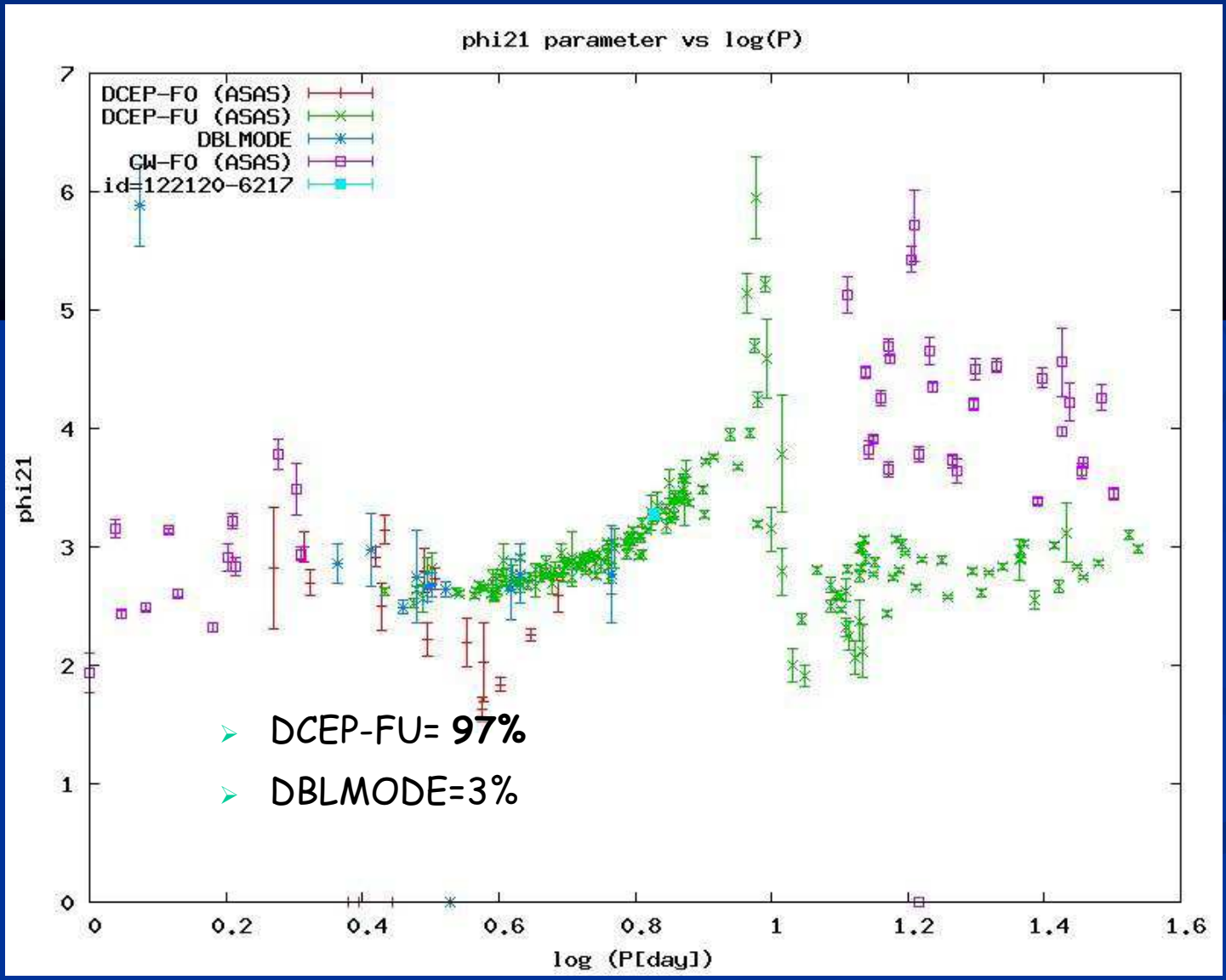
Observation of Cepheids with filter by Pi of the Sky



$$f(r,k) \sim \frac{1}{|K|} + \sum_{i=1}^{|K|} \prod_{j=1}^{9} \frac{1}{\sigma_{Kj}} \exp\left[-w_j \frac{(x_{ij} - r_{ij})^2}{\sigma_{Kj}^2} \right]$$

$$P(K_j) = \frac{f(x,K_j)}{\sum f(x,K_j)}$$

T Cru – Fundamental mode Population I Cepheid



- DCEP-FU= **97%**
- DBLMODE=3%

Conclusions:

- The importance of Cepheids is well known in many fields of astronomy
- Fourier decomposition techniques are powerful tools
- In plots of Fourier parameters against period is clear separation between classes of Cepheids

The end!!!

http://grb.fuw.edu.pl/