The PennState-Toruń Planet Search

– project status and recent results

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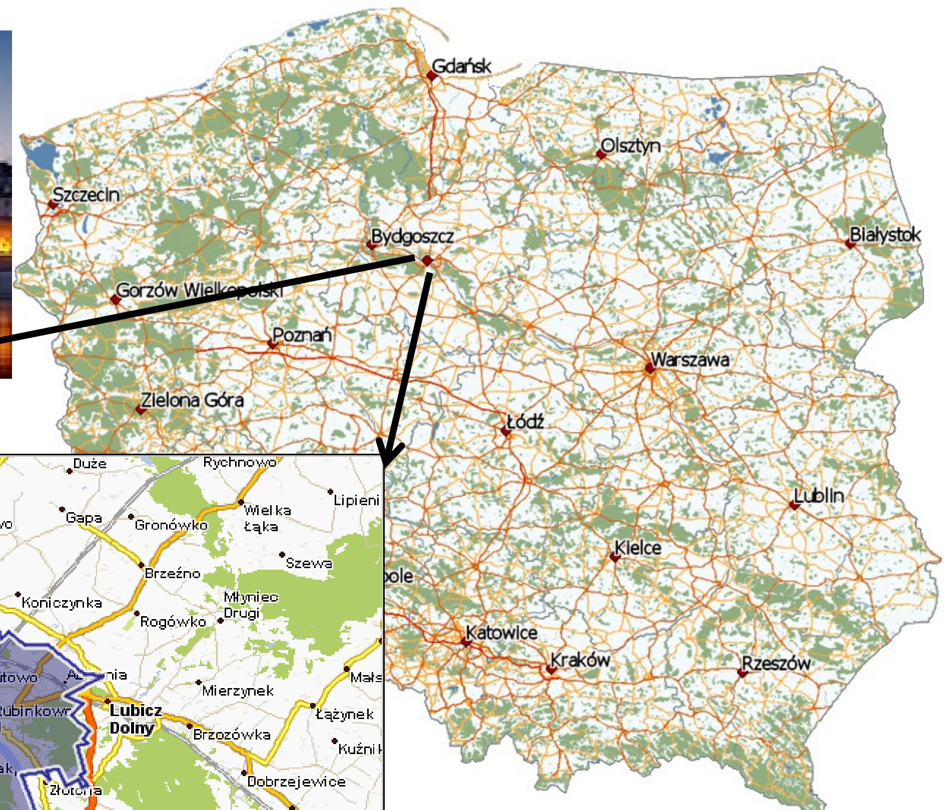
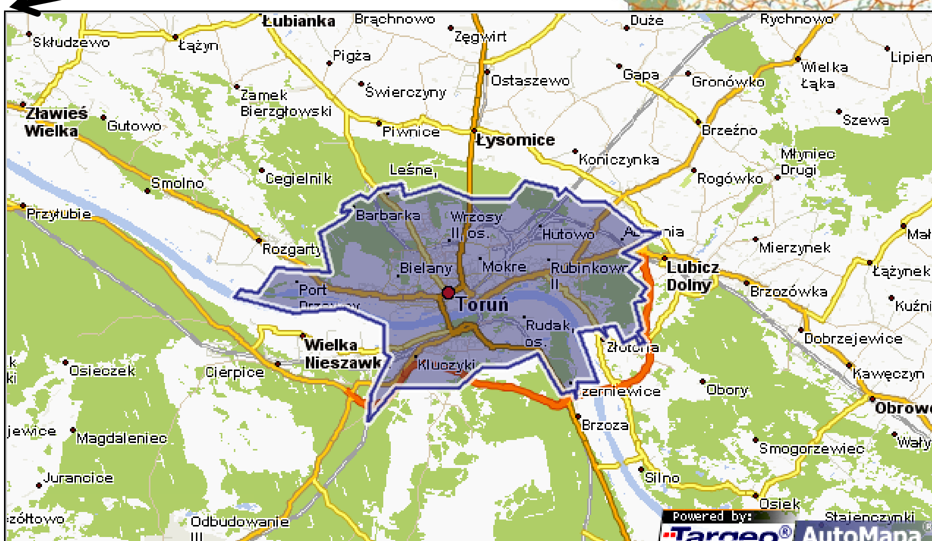


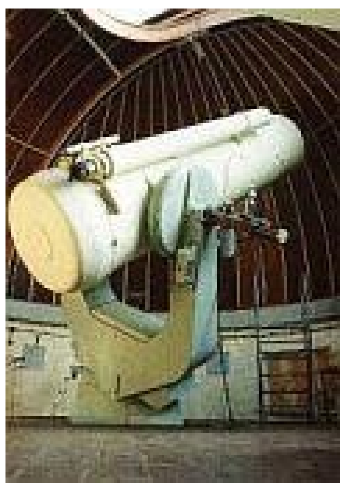


Toruń Centre for Astronomy

- TCfA is divided on two departments:
  - **Astronomy and Astrophysics**

    (variable stars, planetary nebulae, extrasolar planets, ISM, celestial mechanics, MHD)
  - **Radioastronomy**

    (pulsars, masers, AGNs, cosmology)



The PennState–Toruń Planet Search

Pennsylvania State University & Nicolaus Copernicus University

PIs: Andrzej Niedzielski & Aleksander Wolszczan

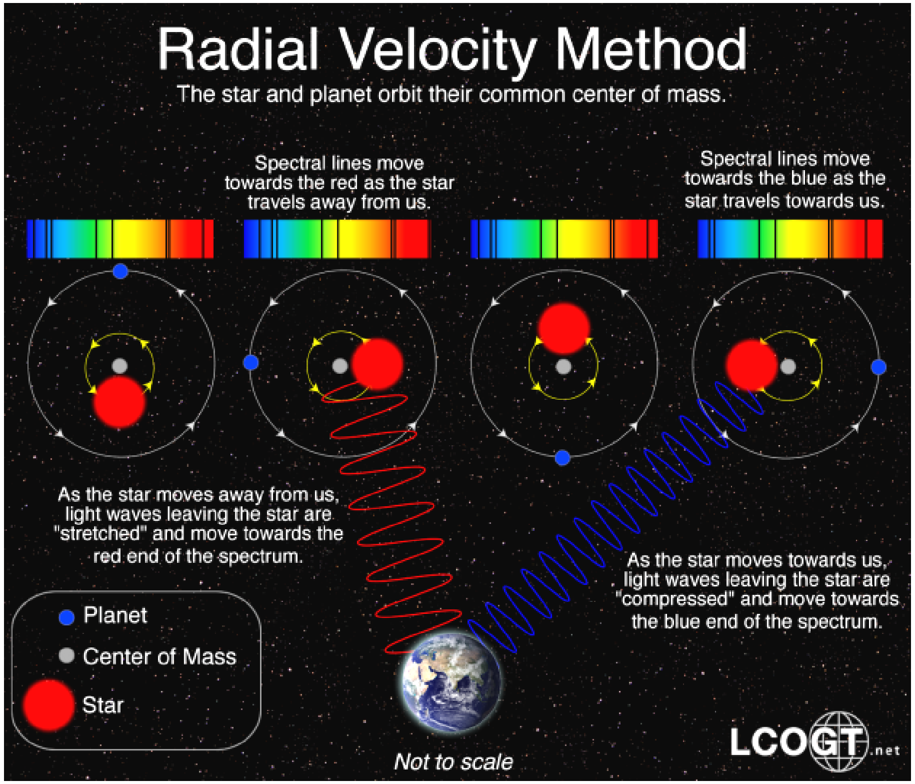
- **Main goals of PTPS:**

a) Search for planets around intermediate-mass, evolved stars by using radial velocity (RV) method

b) Study of star - planet interactions

c) Study of evolution of planetary systems with aging stars

d) **BONUS** – lots of stellar astrophysics: characterization of ~1000 stars (with and without planets)



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- **My research field in PTPS:**

a) Determination and analysis of physical parameters of **~350** stars

b) Confirmation of evolutionary status of **~350** stars

c) Parameters determination for planet-hosting stars **=>** parameters for planets

d) Verification of reality and consistency of parameters determinations for late-type stars

Various methods of parameters estimation

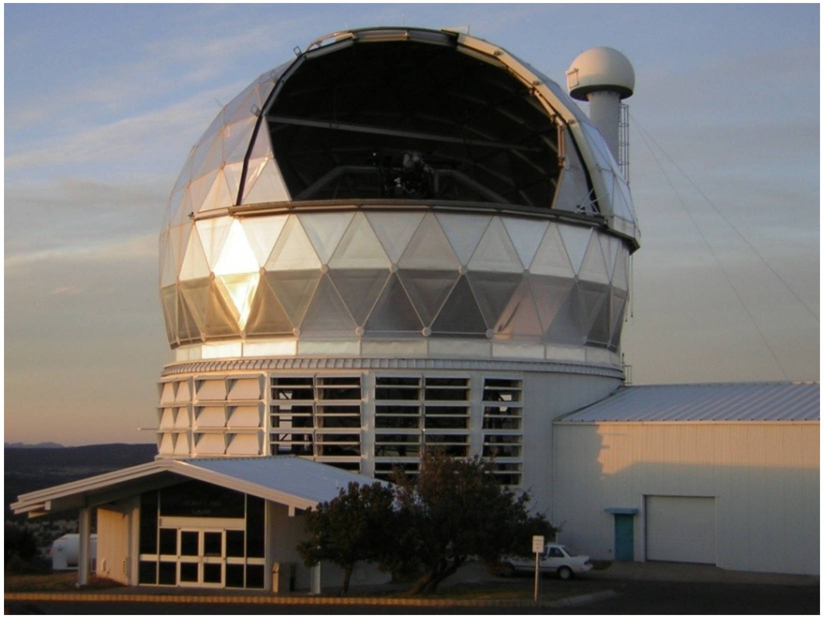
- **Direct methods** (e.g. interferometry, lunar ocultations)
- **Photometric and spectrophotometric methods** (e.g. photometric surveys, empirical calibrations, spectral energy distribution, infrared flux method)
- **Spectroscopic methods** (e.g. analysis of Balmer lines, Balmer jump, depth ratio of metalic lines, equivalenth widths, modelling of synthetic spectrum)
- **Asteroseismic methods** (e.g. analysis of solar-like oscillations)

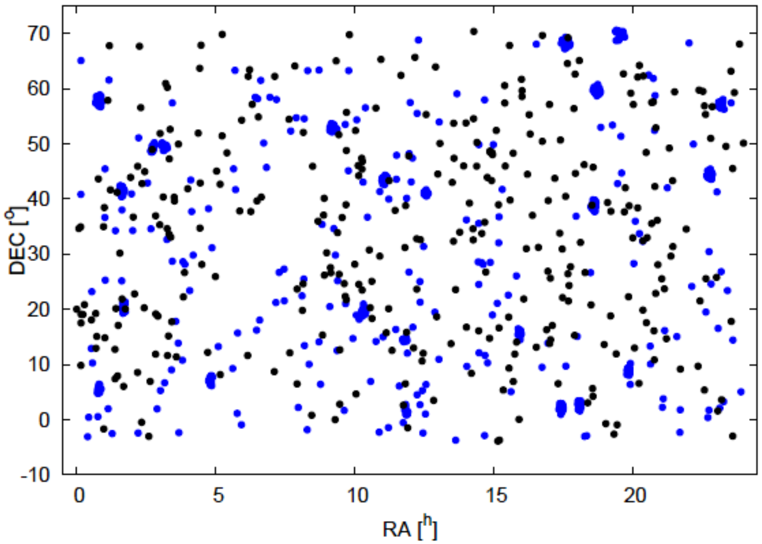
$$L = 4\pi R^2 \sigma T_{\rm eff}^4 \qquad g = \frac{GM}{R^2}$$

- **The choice of optimal method for parameters determination depends on:**
  1. accuracy required for stellar parameters
  2. available resources (catalogs or literature data)
  3. type of observational material available for the stars
  4. number of studied targets

Observational material

- 9.2 m **Hobby–Eberly Telescope** (McDonald Observatory)
- High Resolution Spectrograph (R = 60000)
- S/N ~ 200-500 (for spectra without iodine-cell)
- spectral range: **407–592 nm** and **602–784 nm**

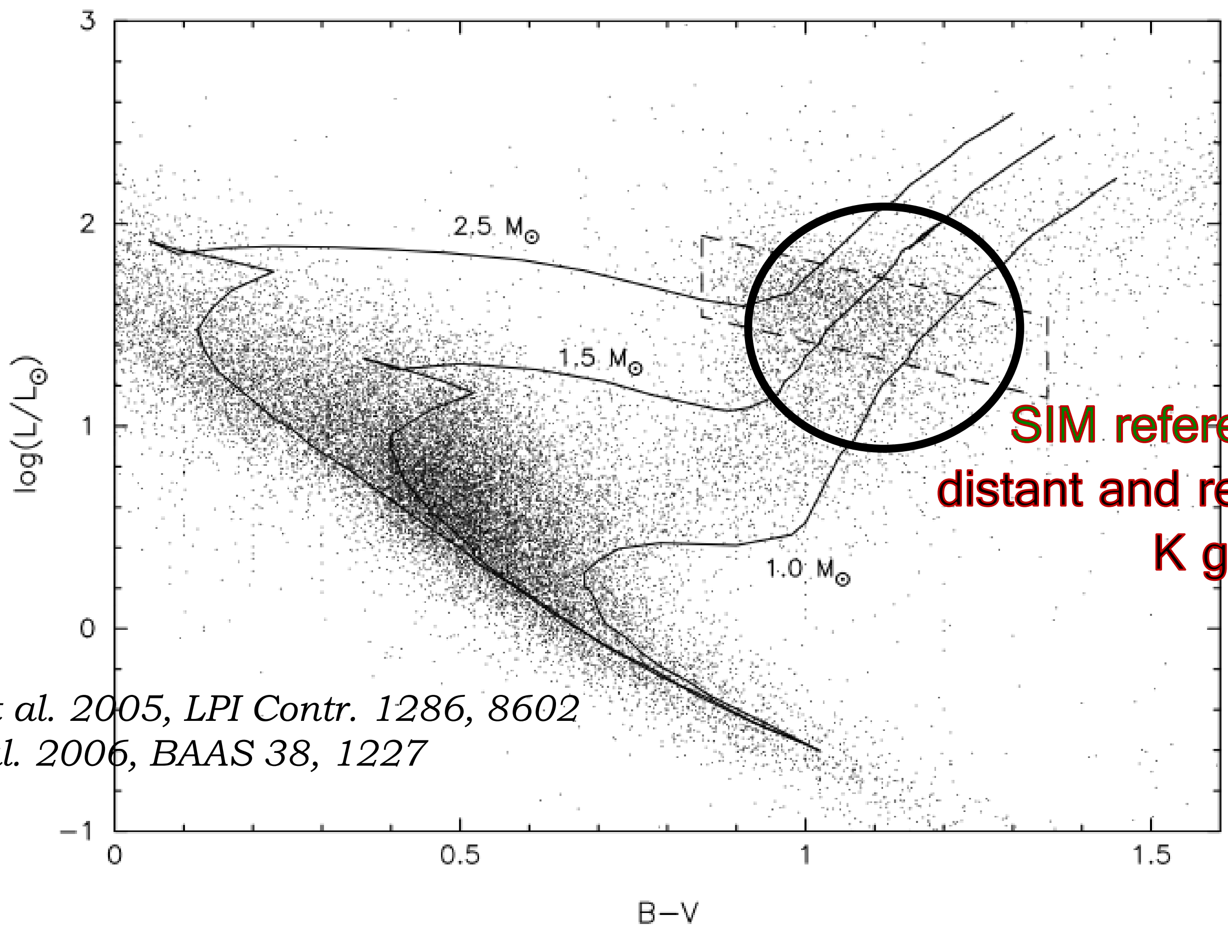




Niedzielski & Wolszczan 2008, IAUS, 249, 43

Selection criteria

PTPS stars: aging dwarfs, subgiants and giants

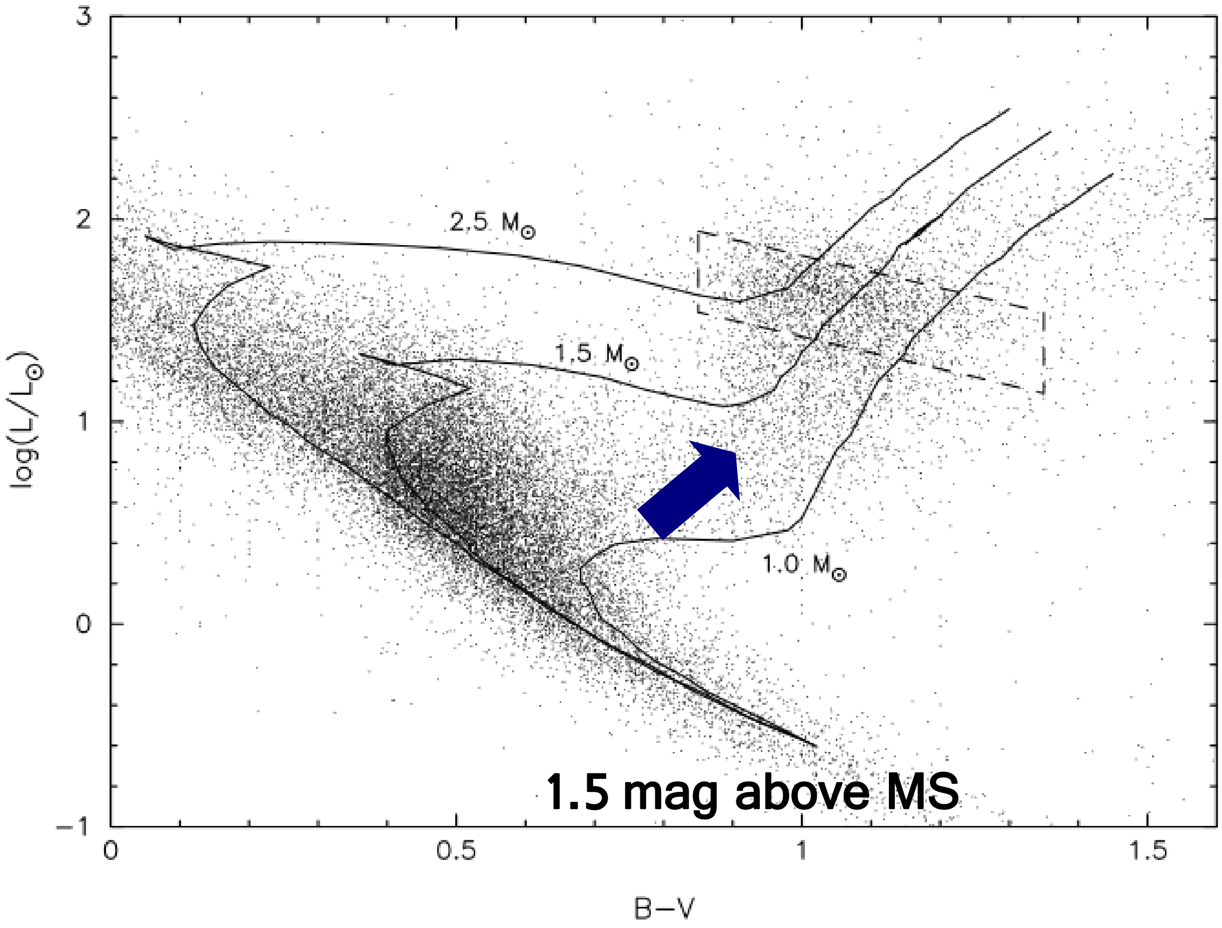


SIM reference stars:
distant and relatively bright
K giants

Gelino et al. 2005, LPI Contr. 1286, 8602
Law et al. 2006, BAAS 38, 1227

Selection criteria

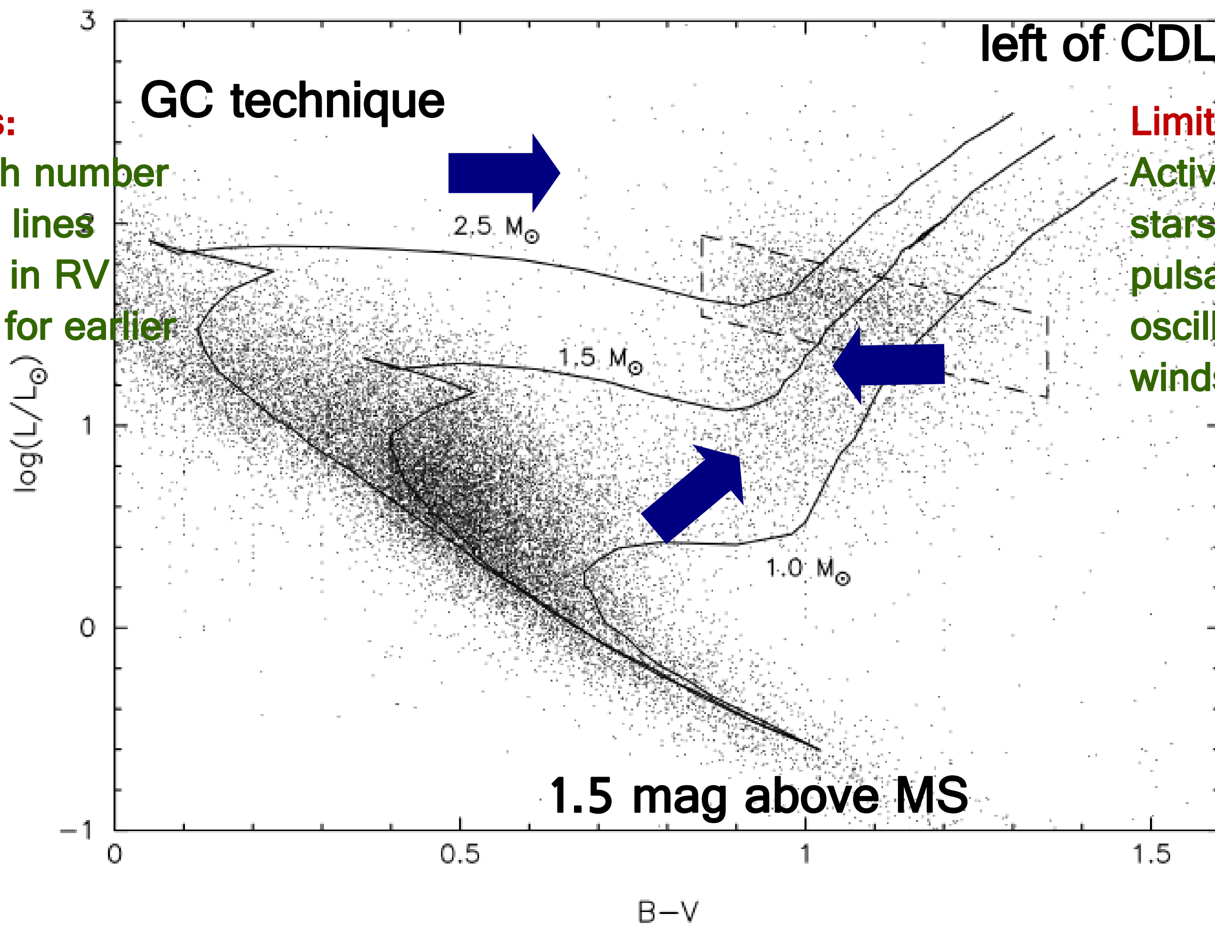
PTPS stars: aging dwarfs, subgiants and giants



Selection criteria

PTPS stars: aging dwarfs, subgiants and giants

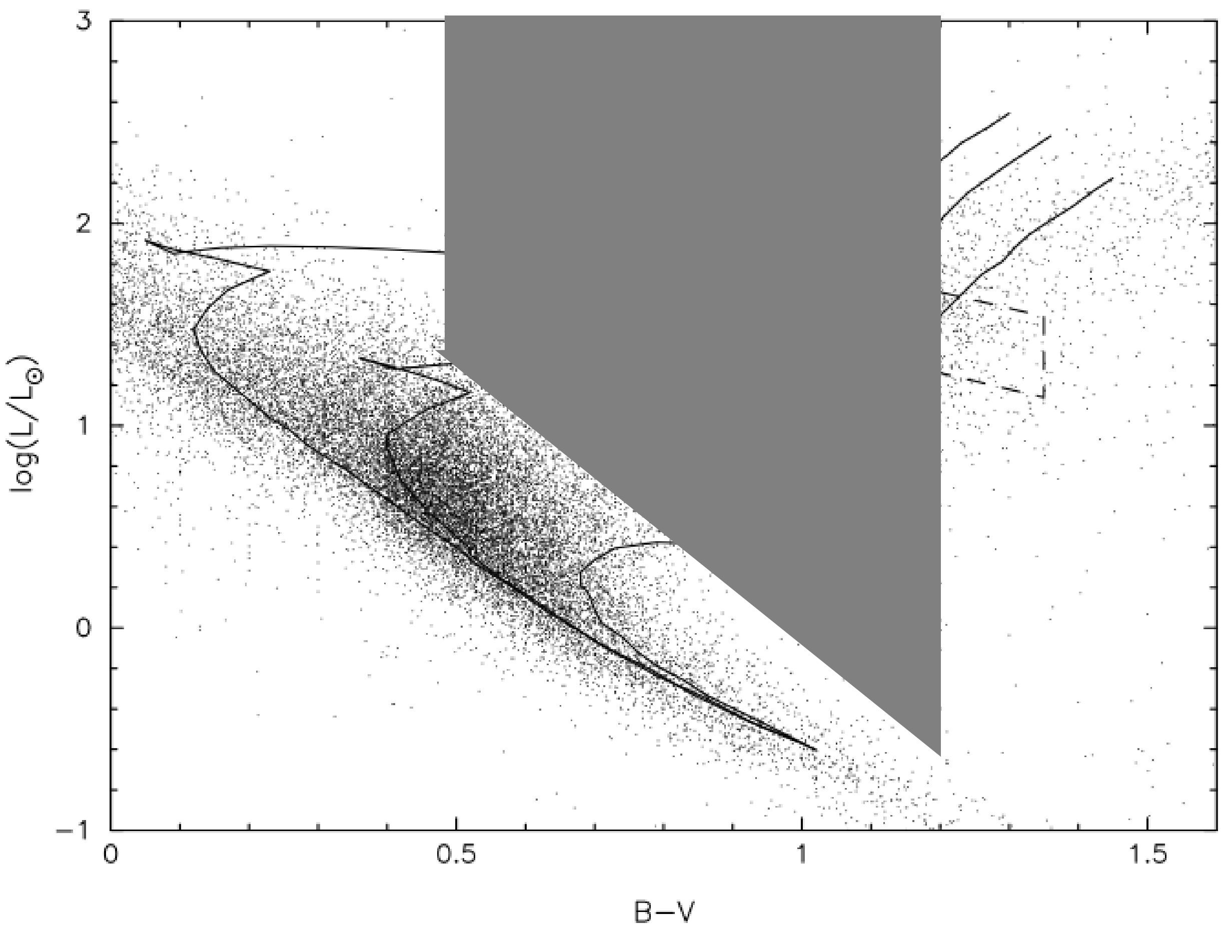
Limitations:
Not enough number of spectral lines (important in RV searches) for earlier type stars



Limitations:
Activity of late type stars (stellar spots, pulsations, oscillations, coronal winds etc.)

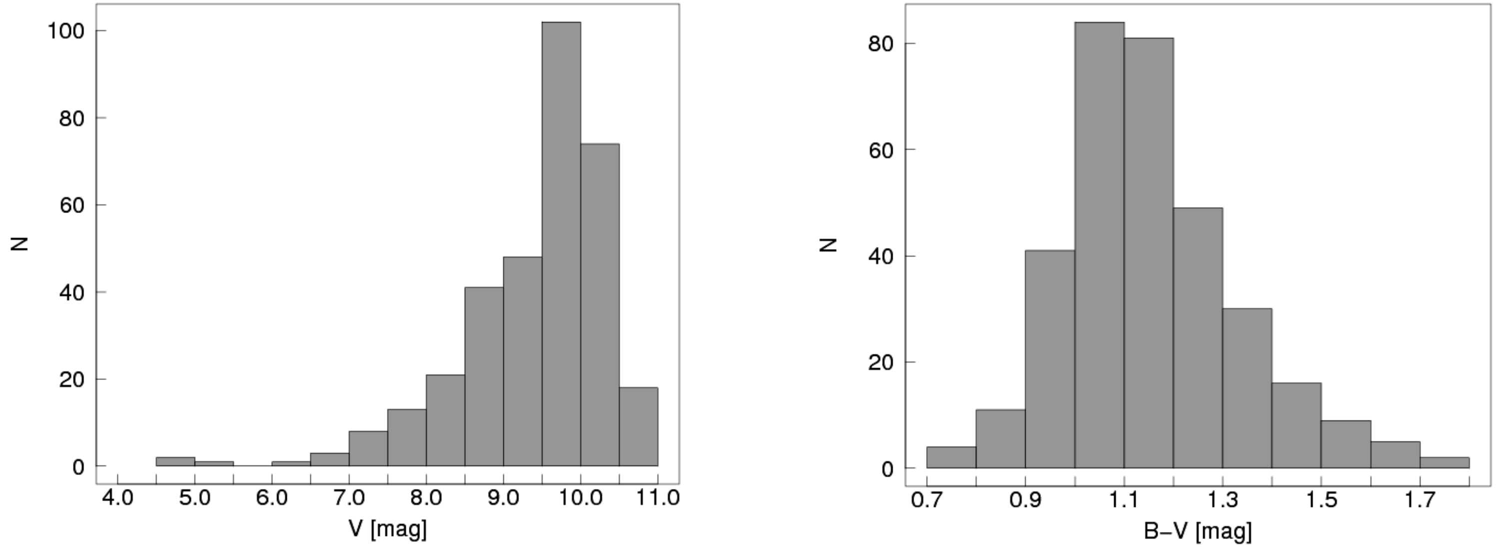
Selection criteria

PTPS stars: aging dwarfs, subgiants and giants



PTPS targets: RGC sample

- **1036** stars of G-K spectral types
- Sample of **348** giants from Red Giant Clump (RGC):
  - V < 11 mag
  - 90% of stars fainter than 8 mag



Equivalenth Widths as input data

•**Measurements of Fe lines:**

→ code **DAOSPEC** (Stetson & Pancino)

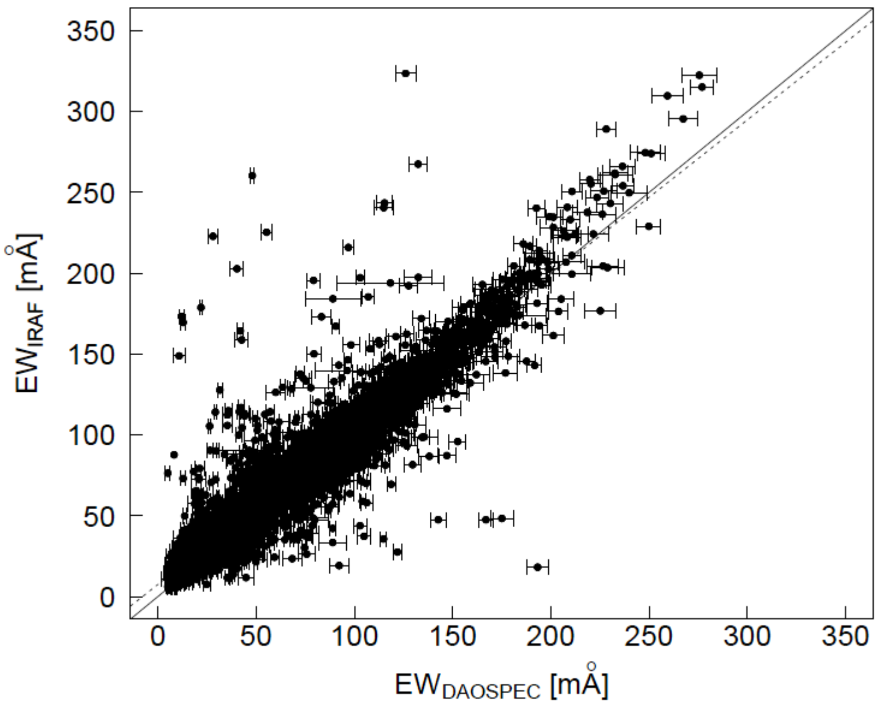
→ **296** neutral (**Fe I**) and ionized (**Fe II**) iron lines

→ selection of iron lines based on well-known compilation of laboratory data lists

Grevesse & Sauval 1999, A&A, 347, 348
Meylan et al. 1993, ApJS, 85, 163
Kurucz et al. 1984, Solar Flux Atlas from 296 to 1300 nm (NSO)

$\Delta EW = 5.3$ mÅ

$\sigma EW_{DAOSPEC} = 2.13$ mÅ



Atmospheric parameters of stars

- **Atmospheric model is characterized by:**
  - effective temperature $\mathbf{T}_{eff}$
  - surface gravity **log *g***
  - microturbulence velocity $\mathbf{v}_t$
  - metallicity **[Fe/H]**

- **Computational method:**

→ numerical code **TGVIT** (Takeda et al. 2002, 2005)

→ Kurucz models of stellar atmospheres (1-D, plane-parallel)
(*Kurucz, R.L. 1993, CD-ROM 13, ATLAS9 stellar atmosphere program and 2 km/s grid*)

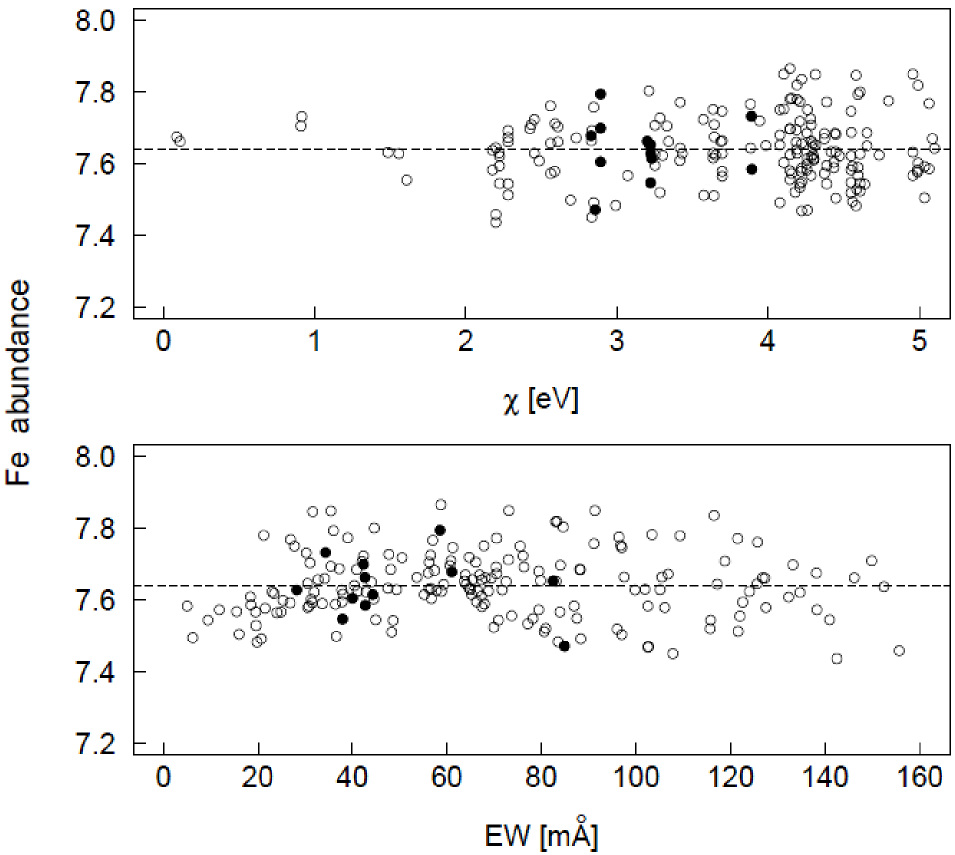
→ LTE assumptions:

excitation equilibrium	A(Fe) vs. χ
ionization equlibrium	A(Fe I) = A(Fe II)
matching the curve of growth	A(Fe) vs. EWs

Takeda et al. 2005a, PASJ, 57, 27
Takeda et al. 2005b, PASJ, 57, 109

Atmospheric parameters of stars

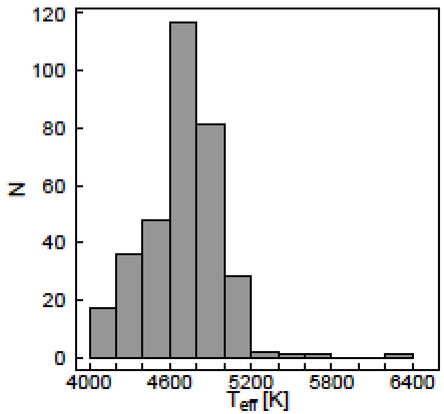
→ number of lines taken to the analysis is on average **190** (**Fe I**) and **15** (**Fe II**)

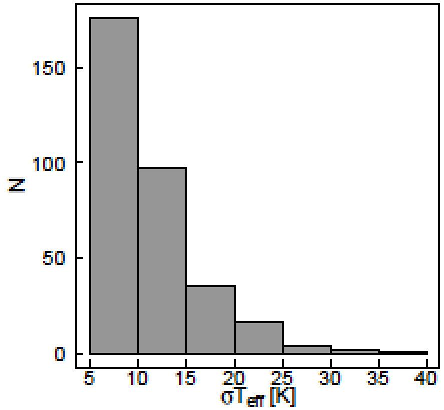


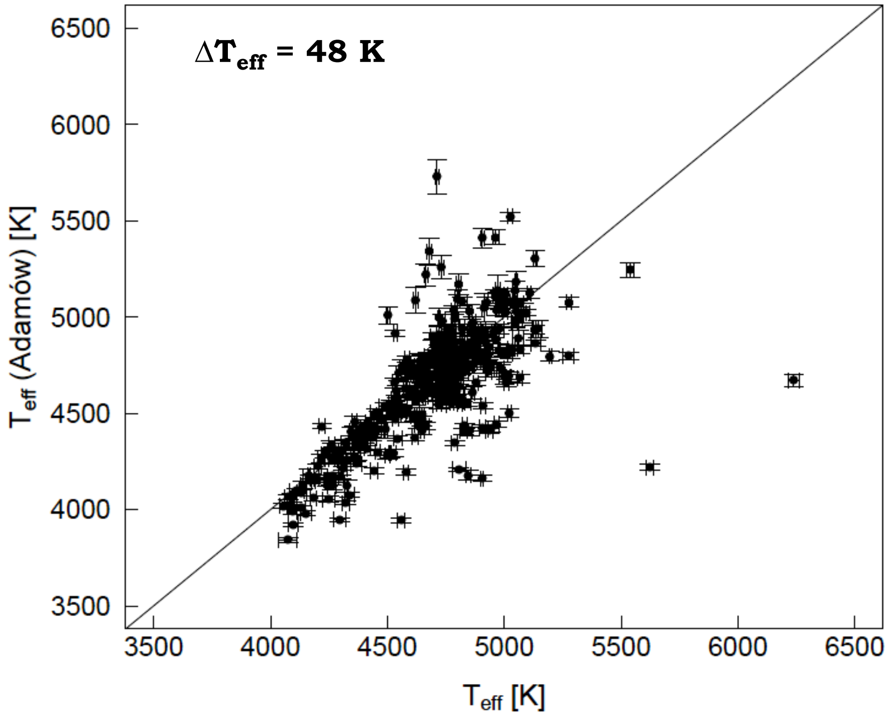
Atmospheric parameters - results

Effective temperature: σT_{eff} = 13 K

Zieliński et al. 2012, A&A, 547, A91



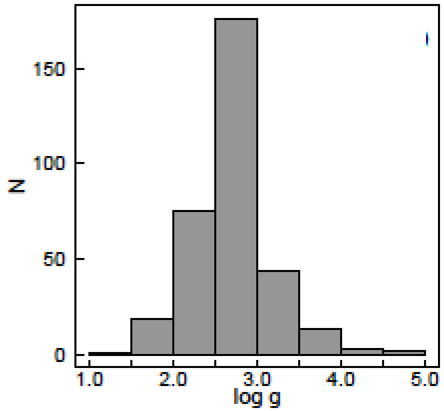


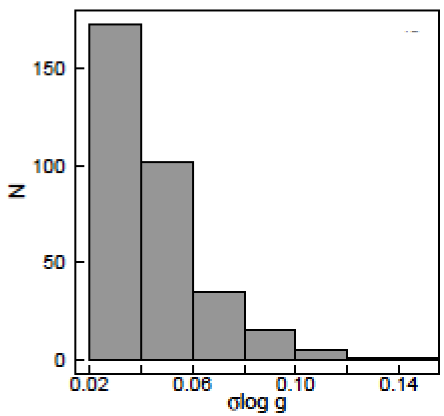


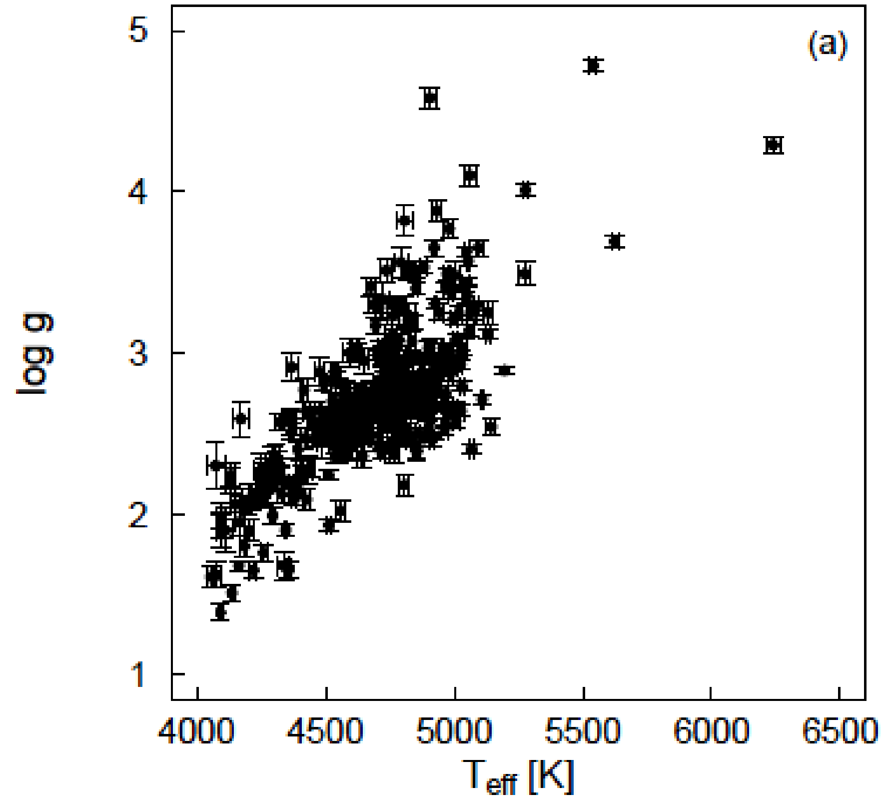
Atmospheric parameters - results

Surface gravity: σlog *g* = 0.05

Zieliński et al. 2012, A&A, 547, A91

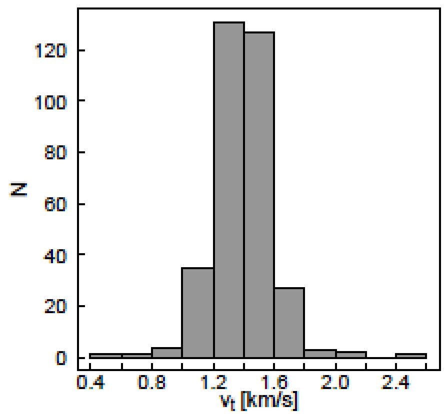


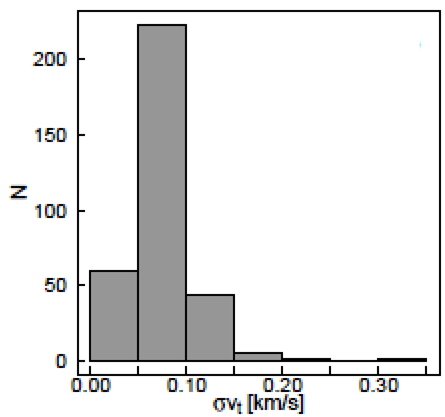


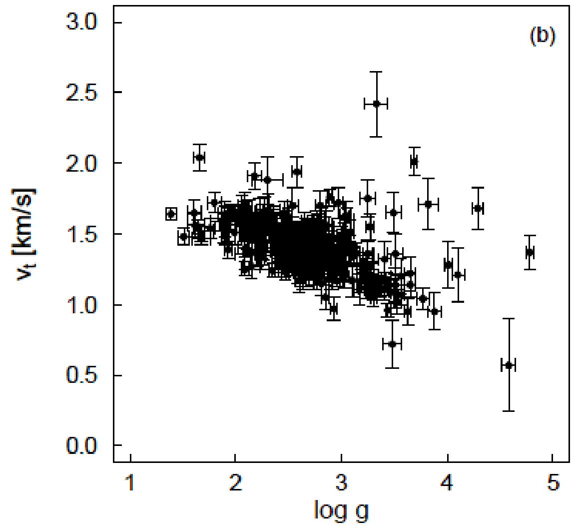


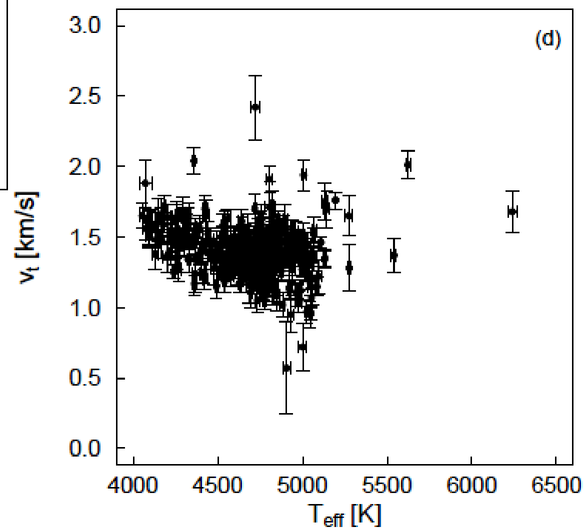
Atmospheric parameters - results

Microturbulence velocity: $\sigma v_t = 0.08\ \mathrm{kms}^{-1}$ *Zieliński et al. 2012, A&A, 547, A91*





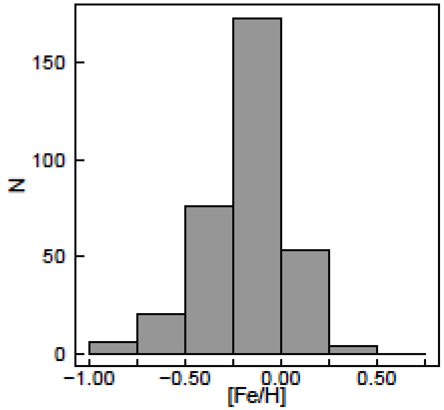


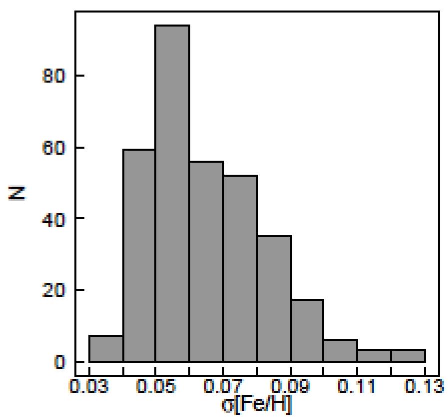


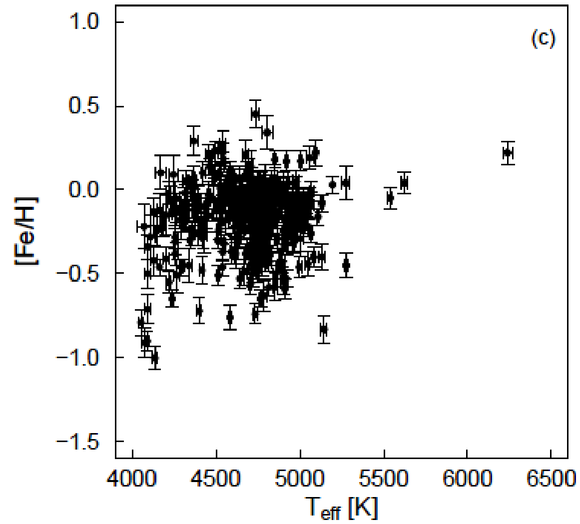
Atmospheric parameters - results

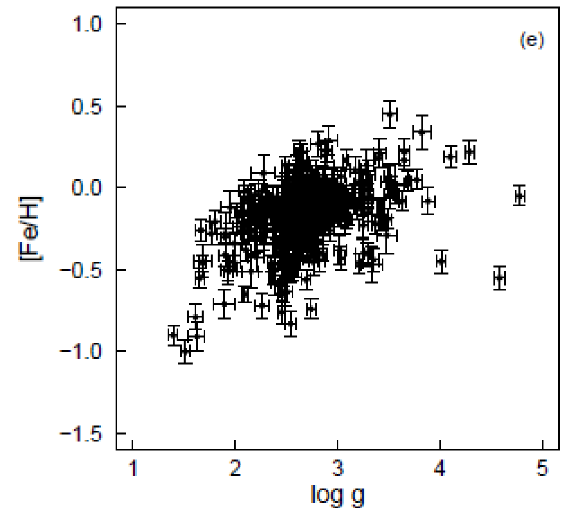
Metallicity: σ[Fe/H] = 0.07

Zieliński et al. 2012, A&A, 547, A91









Integral parameters of stars

- Based on Hipparcos / Tycho parallaxes and V, B-V
- Luminosity derived directly from parallaxes for 57 stars, preliminary estimations for the rest
- Comparing the position of each star on HR diagram with evolutionary tracks
  (Girardi, L., et al. 2000, A&AS, 141,37; Salasnich, B., et al. 2000, A&A, 361, 1023)

→ determination of stellar mass, final luminosity, radius and age

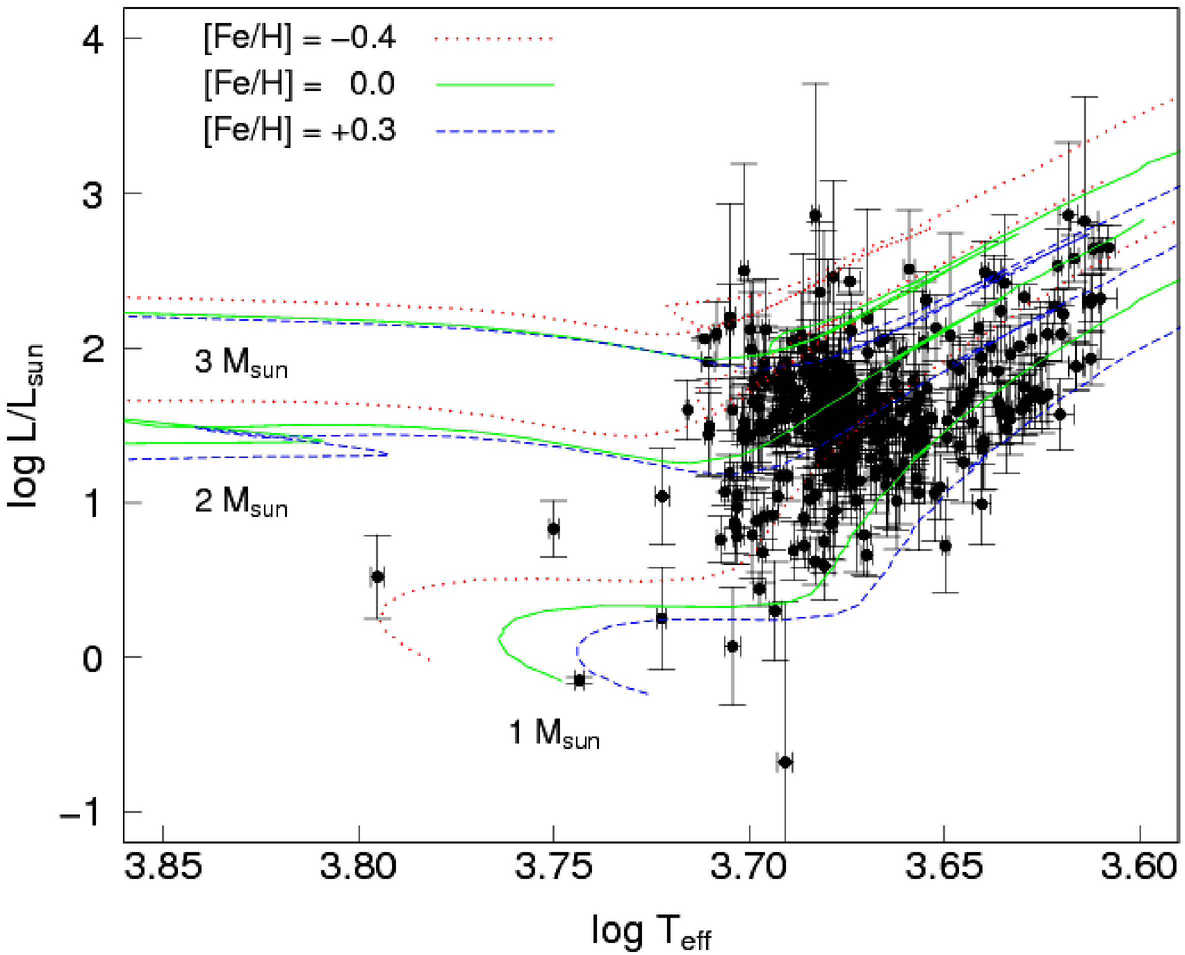
$$\chi^2 = \sum_{i=1}^{n} \left(\frac{q_i^{obs} - q_i^{mod}}{\sigma_i} \right)^2$$

for n = 3, i.e. [log L/L_{sun}, T_{eff}, log g]

↓

final fit of log L/L_{sun},
estimation of M/M_{sun}, *Age*
calculation (from the formula) of R/R_{sun}

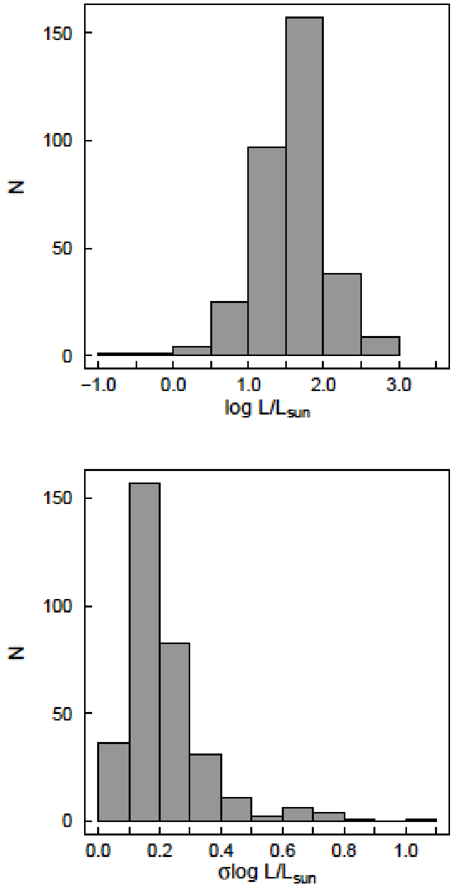
HR diagram for RGC sample

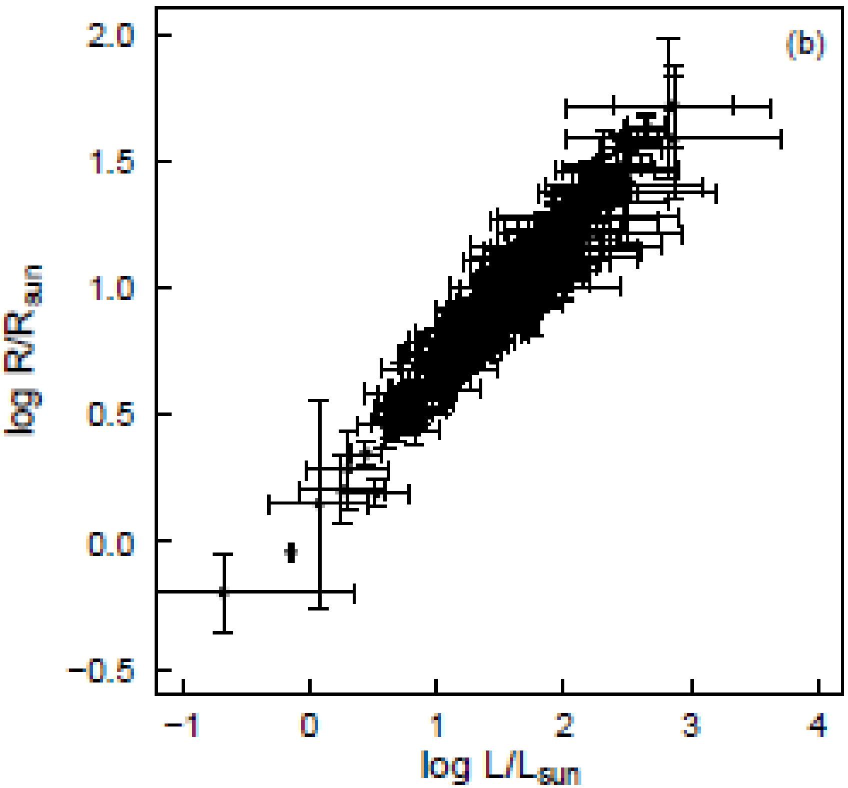


Integral parameters - results

Luminosity: $\sigma \log L/L_{sun} = 0.23$

Zieliński et al. 2012, A&A, 547, A91

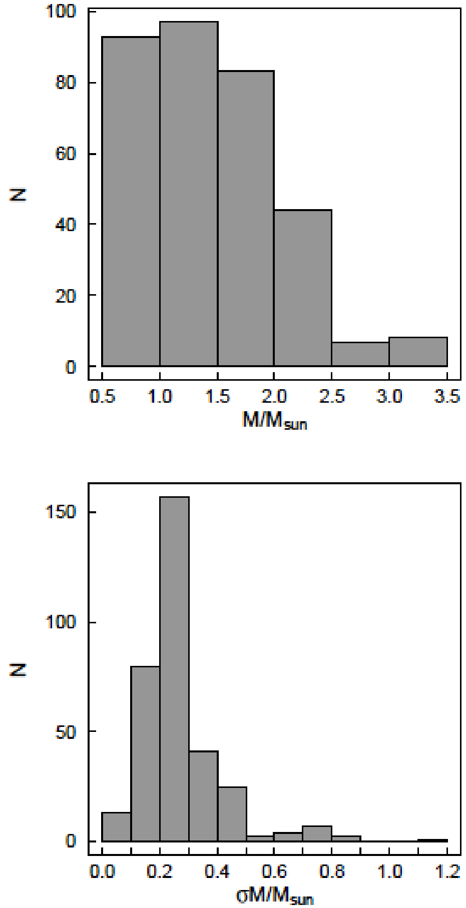


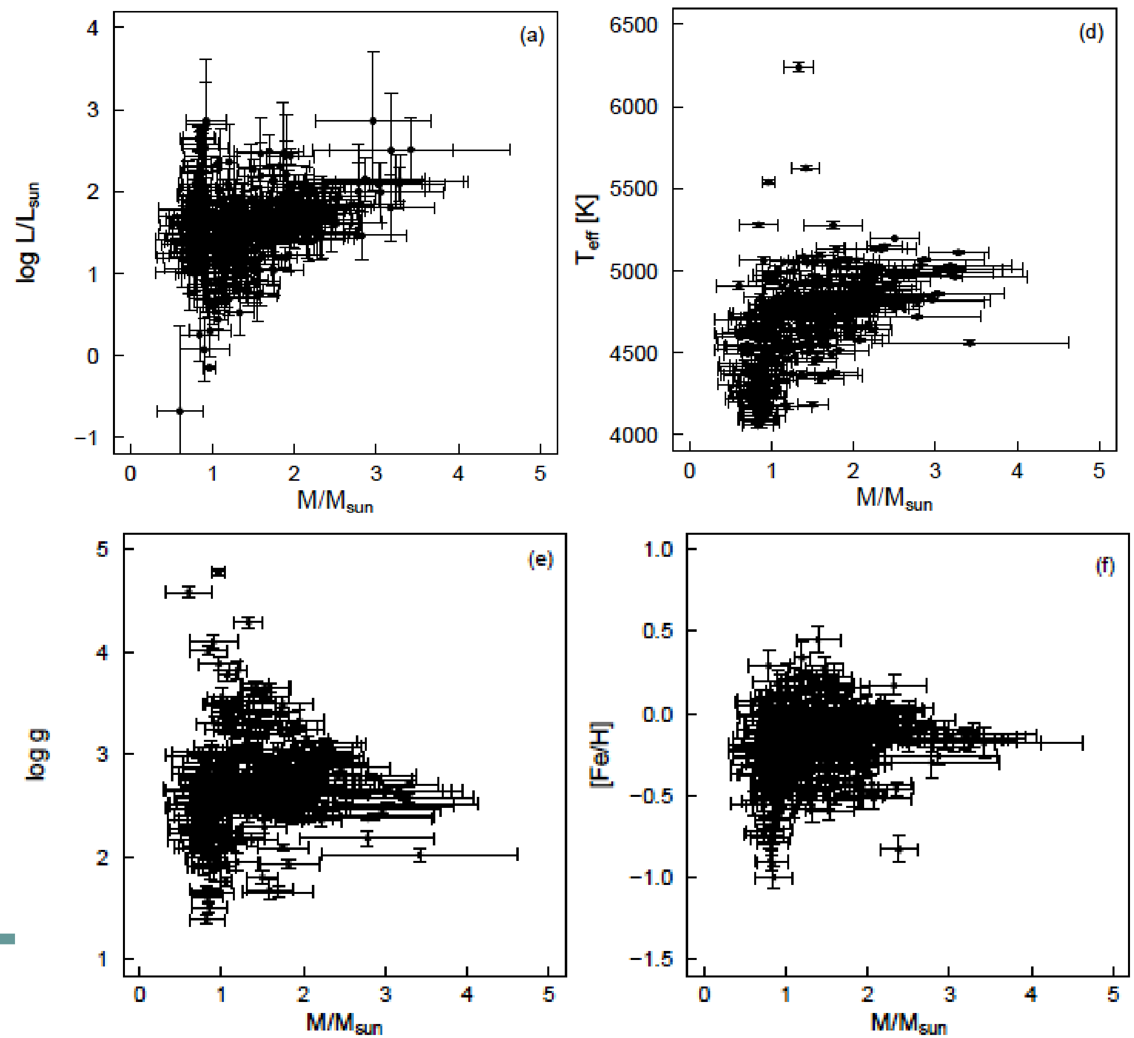


Integral parameters - results

Mass: $\sigma M/M_{sun} = 0.3$

Zieliński et al. 2012, A&A, 547, A91





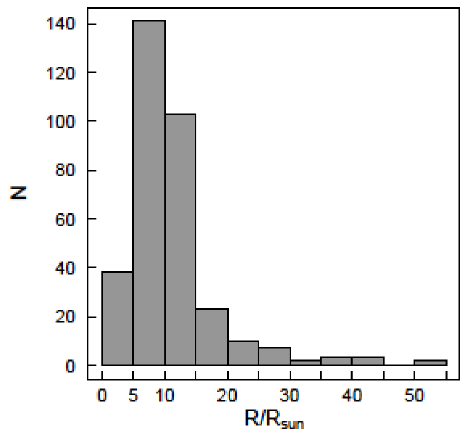
Integral parameters - results

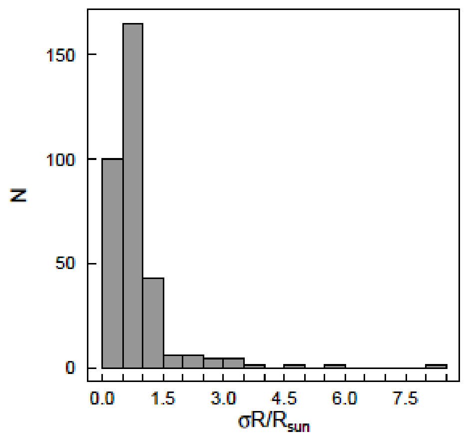
Radius: $\sigma R/R_{sun} = 0.8$

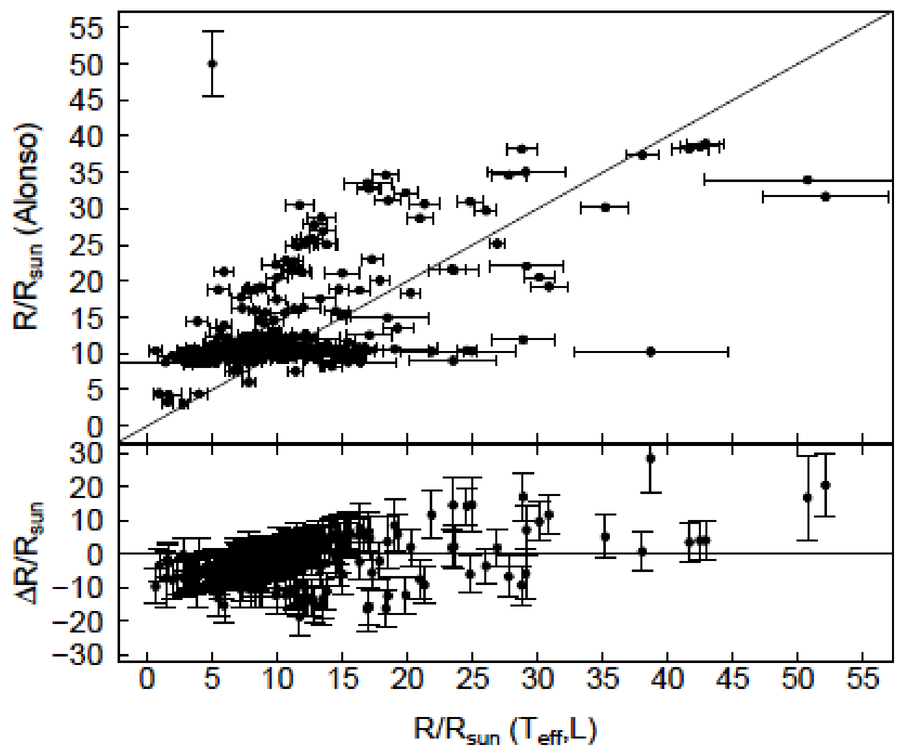
Zieliński et al. 2012, A&A, 547, A91

$$R/R_{\odot}(T_{\mathrm{eff}}, L) = \sqrt{\frac{L}{L_{\odot}}}\left(\frac{T_{\mathrm{eff}\odot}}{T_{\mathrm{eff}}}\right)^2$$

$\Delta R/R_{sun}$ = **-2.2**



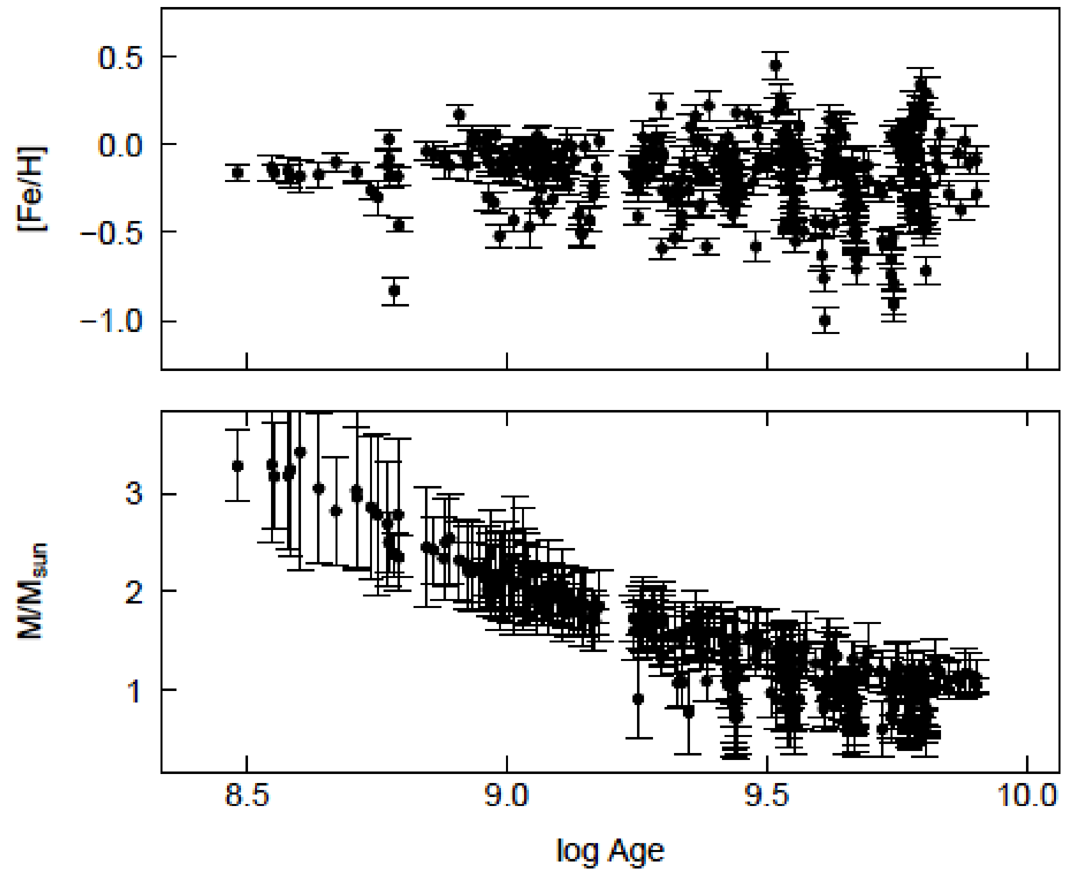




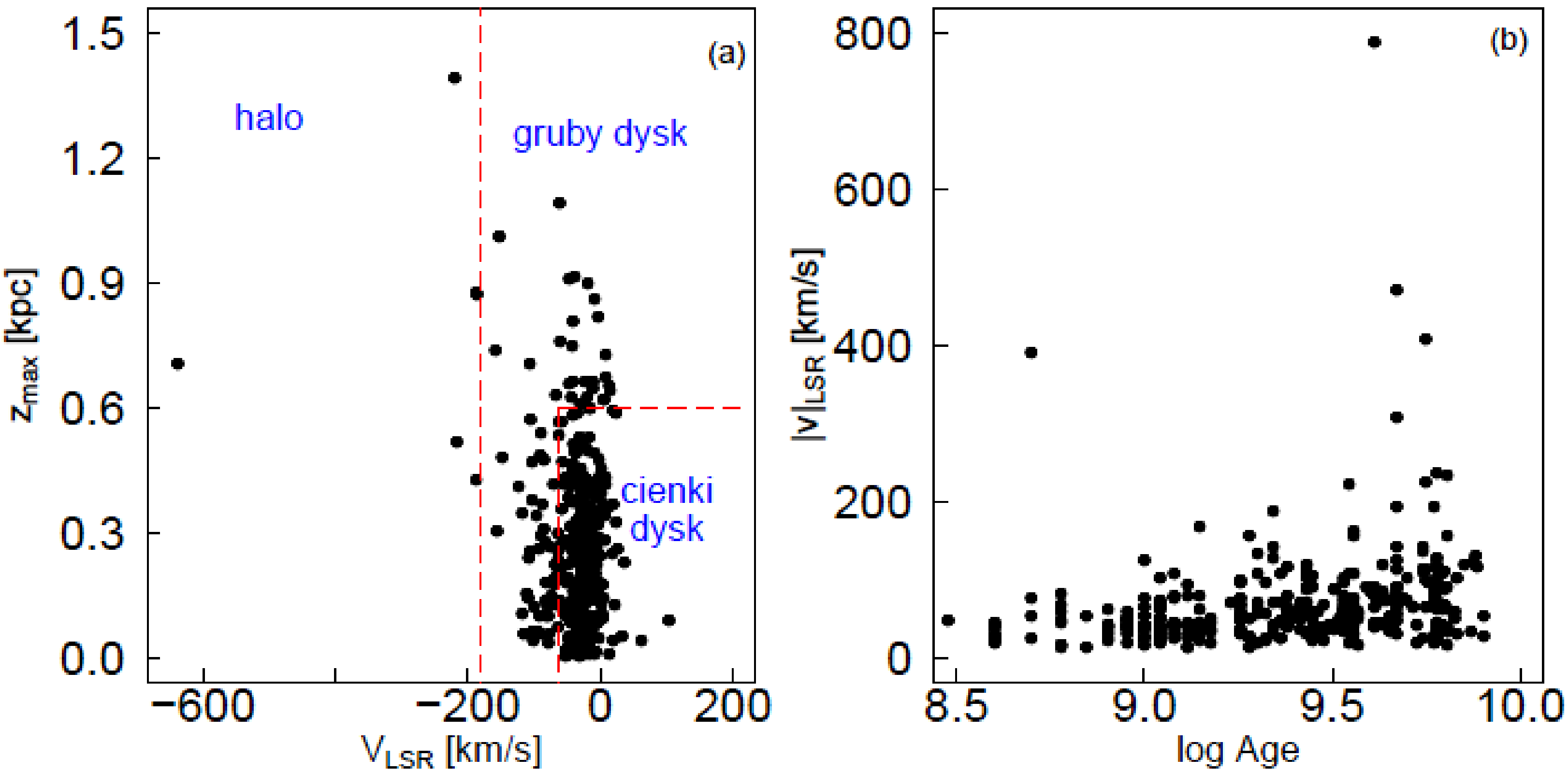
Integral parameters - results

Age: $\sigma Age/Age = 0.4$

Zieliński et al. 2012, A&A, 547, A91



Kinematics and Galactic distribution

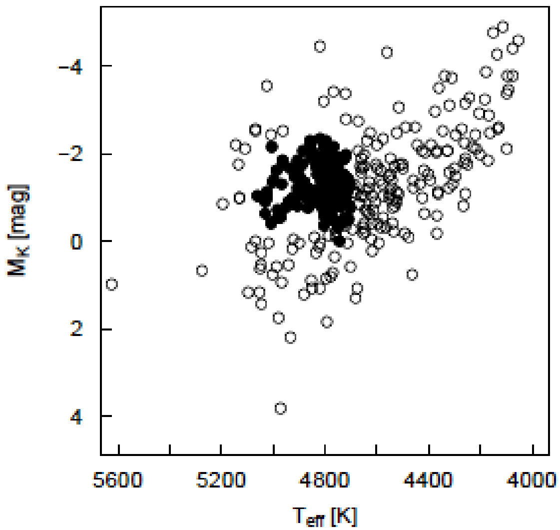


Distribution criteria: *Ibukiyama & Arimoto 2002, A&A, 394, 927*

Clump giants

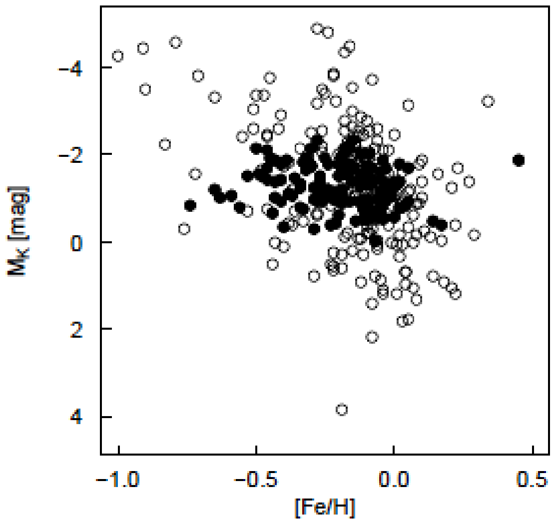
Criteria of clump giants selection:
4700 K ≤ $\mathbf{T}_{eff}$ ≤ 5100 K
1,25 ≤ **log** L/L_{sun} ≤ 2,10

Tautvaisiene & Puzeras 2009, IAUS 254, 75
Jimenez et al. 1998, MNRAS 299, 515



- 126 stars (38%) fulfill the criteria

- But high dispersion in absolute magnitudes!
- To confirm the clump giants membership chemical analysis is necessary



Summary of my PhD results

- Fundamental parameters and kinematical properties for 348 stars
- Spectroscopic analysis reveals that:
  - ✓ 5 stars from RGC sample classified as giants are in fact dwarfs (log g ≥ 4)
  - ✓ 4 stars classified as dwarfs are in fact K giants
  - ✓ 126 stars from the sample are most likely clump giants
- Kinematical analysis reveals that:
  - ✓ 76% of stars are members of thin Galactic disk
  - ✓ 22% of stars are members of thick disk
  - ✓ 2% of stars are members of halo population

T_{eff} ~ 4055 – 6239 K (mean value 4736 K)

log g ~ 1.39 – 4.78 (mean value 2.66)

log L/L_{sun} ~ -0.68 – 2.86 (mean value 1.6)

M ~ 0.6 – 3.4 M_{sun} (> 2 M_{sun} for 63 stars)

R ~ 0.6 – 52.1 R_{sun} (mostly 9-11 R_{sun})

[Fe/H] ~ -1.0 – +0.45 (mean value -0.15)

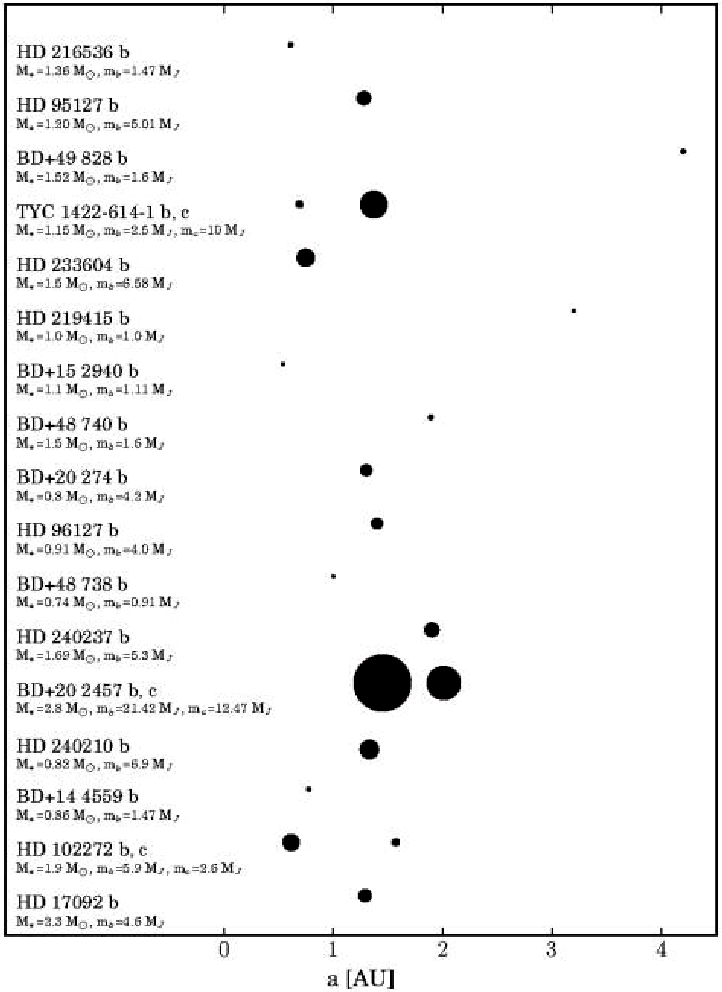
Age ~ 3 – 5 Gyr

→ **first spectroscopic study of red giants, such faint and distant from the Sun!**

Summary of my PhD results

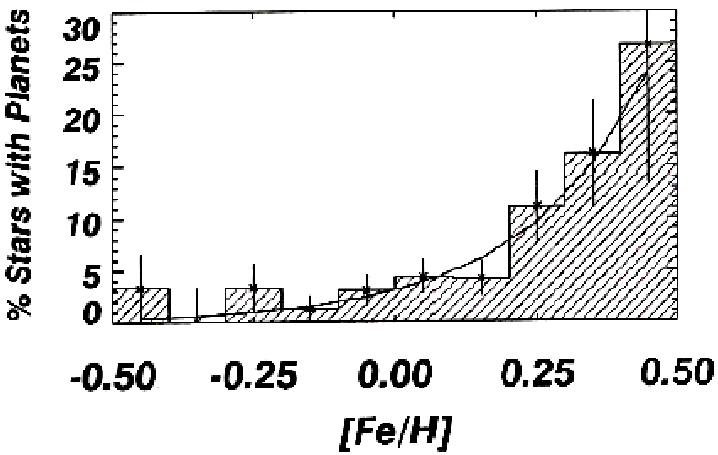
- Physical parameters of stars are crucial for masses and orbital parameters of their companions
  => until today there are **17 stars** from PTPS with planetary or brown dwarf candidates

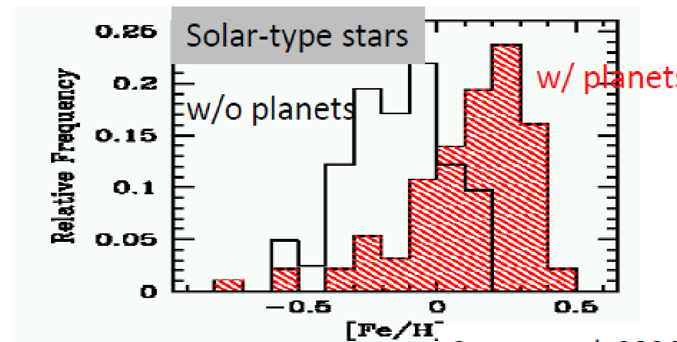
- RV survey reveals that **~30 %** of PTPS stars are suspected to host planetary-mass companions



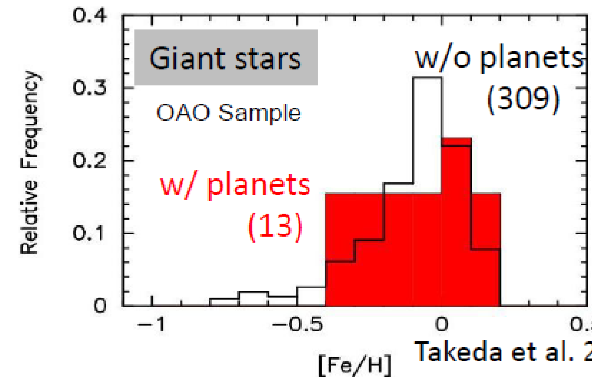
More PTPS results

- Promising results of statistical correlations studies => planet occurrence vs. stellar metallicity (*Zieliński et al. 2010, EAS Publ. Series 42, 201*)





Santos et al. 2004

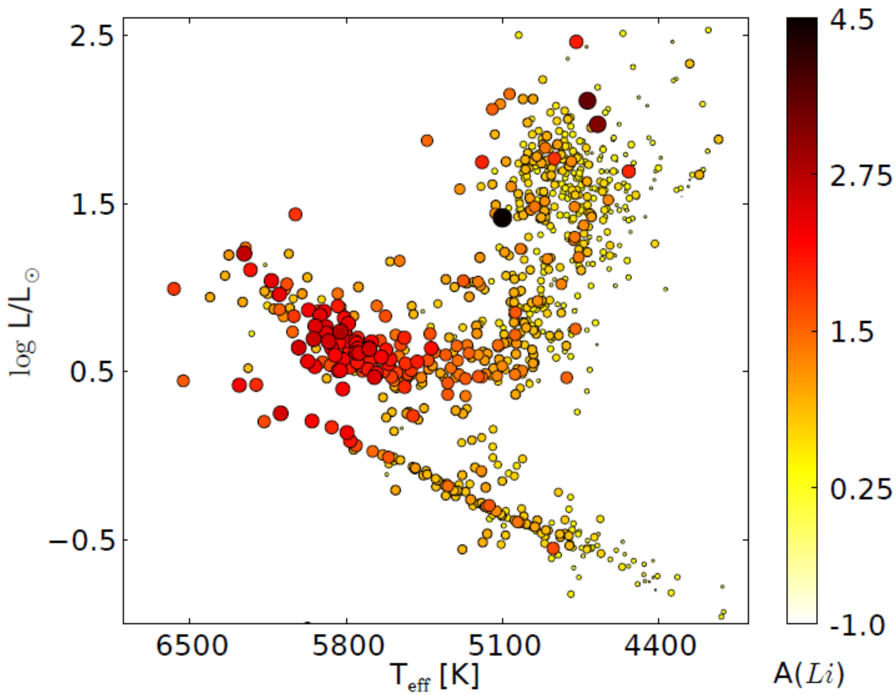


Takeda et al. 2008

Metallicity of main-sequence stars:
Dwarfs with planets tend to be more metal abundant than those without planets
(*Santos et al. 2001, 2004, Fischer & Valenti 2005)*

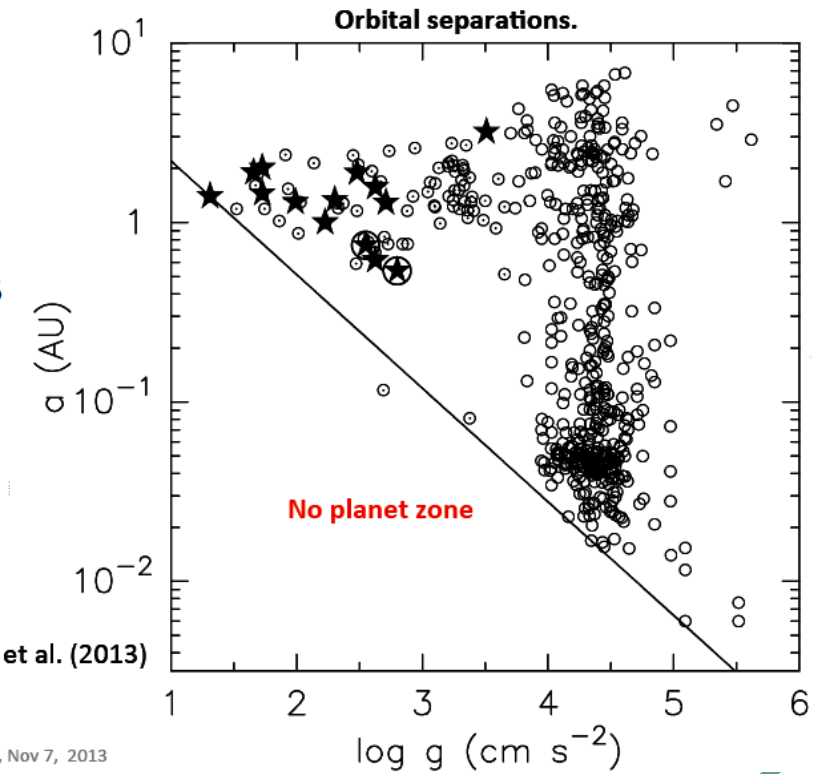
$|\Delta[Fe/H]| = 0.13$

More PTPS results



Adamów et al. 2014, A&A 569, A55

Stellar parameters are valuable for detailed spectroscopic analysis



Nowak et al. (2013)

Cancun, Nov 7, 2013


Thank you for attention!