XXIII ENAA ENCONTRO NACIONAL DE ASTRONOMIA E ASTROFÍSICA

OPTIMIZATION METHODS FOR DERIVING STELLAR PARAMETERS

Batista, S.[1,2], Sousa, S.[1], Santos, N.[1]

[1] Centro de Astrofísica da Universidade do Porto, Rua das Estrelas, 4150-762, Porto

[2] Departamento de Matemática, Faculdade de Ciências, Universidade do Porto, Rua do Campo Alegre, s/n, 4160-007 Porto

(CAUP2012-04UnF-BI)
(http://www.astro.up.pt/exoearths)

Overview:

- Main goals;
- Motivation;
- Optimization methods and some preliminary results;
- Outlines;

Goals

It is aimed to develop a tool to derive the stellar parameters of FGK type stars, such as:

1. T_{eff};
2. log(g);
3. [Fe/H];
4. ξ (microturbulence);

$$4D \rightarrow (T_{eff}, \log(g), [Fe/H], \xi)$$

T_{eff} of FGK type stars:
F: 6000-7500 K;
G: 5000-6000 K;
K: 3500-5000 K;

Objective function

Objective function:

$$\chi^2 = w_1 c_1^2 + w_2 c_2^2 + w_3 c_3^2 \qquad (1)$$

where:

- $w_i \geq 0, i = 1,2,3 \rightarrow$ values fitted according to the model;
- $c_1 \rightarrow$ slope of the plot Ab(Fe/H) vs $\log_{10}(^{W}/_{\lambda})$;
- $c_2 \rightarrow$ slope of the plot Ab(Fe/H) vs excitation potential (excitation equilibrium);
- $c_3 \rightarrow c_3 = [^{FeI}/_{H}] - [^{FeII}/_{H}]$ (ionization equilibrium);

Stellar parameters are derived assuming LTE conditions.

Optimization methods and some preliminary results

- **Downhill Simplex Method (Amoeba);**
  - Preliminary results;
- **Downhill Simplex with a cooling scheme (Amebsa);**
  - Preliminary results;
- Particle Swarm Optimization (PSO);
- Combination of the Particle Swarm Optimization and deterministic methods;

How was the Downhill Simplex Method adjusted to the problem?

$4D \rightarrow (T_{eff}, \log(g), [Fe/H], \xi)$

$3000K < T_{eff} < 7000K$

$1.0\ cm.s^{-2} < \log(g) < 5\ cm.s^{-2}$

$0\ km.s^{-1} < \xi < 4\ km.s^{-1}$

$-2 < [Fe/H] < 2$

- The objective function is non-differentiable;
- The topology of the function is unknown;

How was the Downhill Simplex Method adjusted to the problem?

1. Initial guess: take the solar parameters as the initial guess. Generate n random points around the initial guess and evaluate the cost function at each point. Define the point with the lowest χ^2-value as the best initial guess;

2. Define the initial simplex around the best initial guess and derive the χ^2-value in each vertex;

3. Usually, the simplex goes to a region where the χ^2-value is maximum;

4. The next steps can be summarized as reflections, contractions and expansions of the 4D space (Fig.1);

5. When the simplex finds a valley, it goes downwards to the minimum;

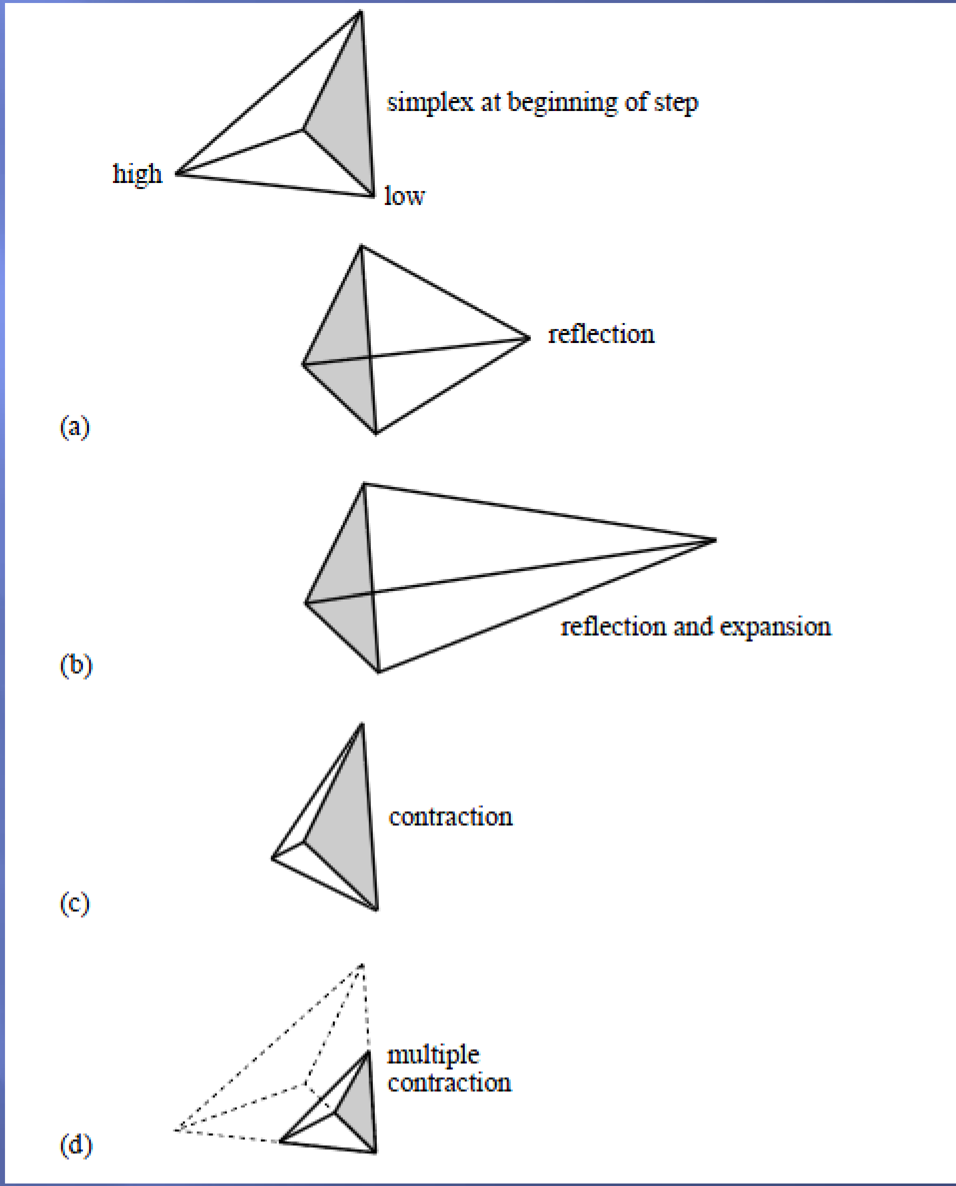

Fig.1 – Possible iterations of the simplex method. *Source:* Press, W. H., Teukolsky, S. A., Vetterling, W. T. And Flannery, B. P. (2002), *Numerical Recipes in C The art of scientific computing,* 2nd Edition, Cambridge Press University

What are the convergence criteria?

χ^2 < Tolerance

Number of iteration > Number of maximum iterations allowed

c_1 < 0.001 (E.P.)

c_2 < 0.002 (EW)

Ab(FeI) - Ab(FeII) (c_3) < 0.005 (ionozation equilibrium)

Amoeba vs Amebsa

Amebsa:

- Based on the downhill simplex method (the allowed moves for the simplex are the same as in Amoeba);
- It has an implemented cooling scheme, similar to the simulated annealing.

How Amebsa works?

1. Initially set an initial temperature (T) sufficiently high and the cooling scheme;

2. The simplex is initially allowed to expand until it reaches an approximately size of the region, which can be reached at this temperature T.

3. The simplex moves in a stochastic tumbling Brownian motion within this region.

4. If the cooling scheme is sufficiently slow, the simplex will converge to a region where the lowest relative minimum is located.

5. When $T \rightarrow 0$, this new implementation reduces to the old simplex method (Amoeba).

Preliminary Results and work still ongoing

	Number of stars that converged to the solution	Number of stars that do not converged to the solution	Total
Amoeba (C-version)	415	36	451
Amebsa (C-version)	422	29	451
PSO (C-version)	390	61	451
PSO + Amoeba (C-version)	?	?	?
PSO + Amebsa (C-version)	426	25	451

Table 1 – Summary of the number of stars that have converged and that have not converged to the solution in a sample of 451 stars. (http://vizier.cfa.harvard.edu/viz-bin/VizieR-3)

Preliminary Results (Amoeba)

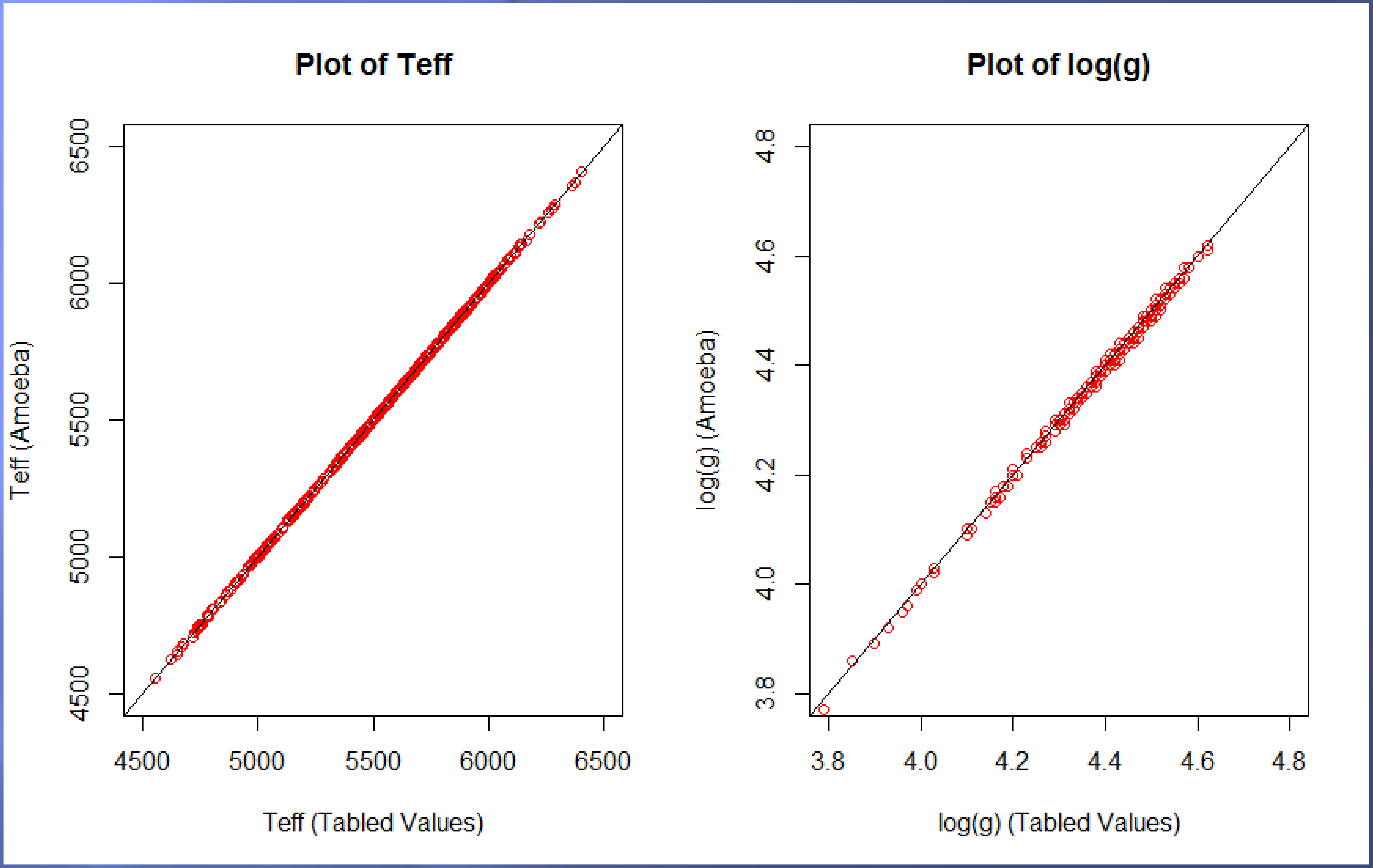

Fig.2 – Right: Plot of the derived Teff versus the tabled values. Left: Plot of the derived surface gravity versus the tabled values. The tabled values were taken from the publically available database: http://vizier.cfa.harvard.edu/viz-bin/VizieR-3.

Preliminary Results (Amoeba)

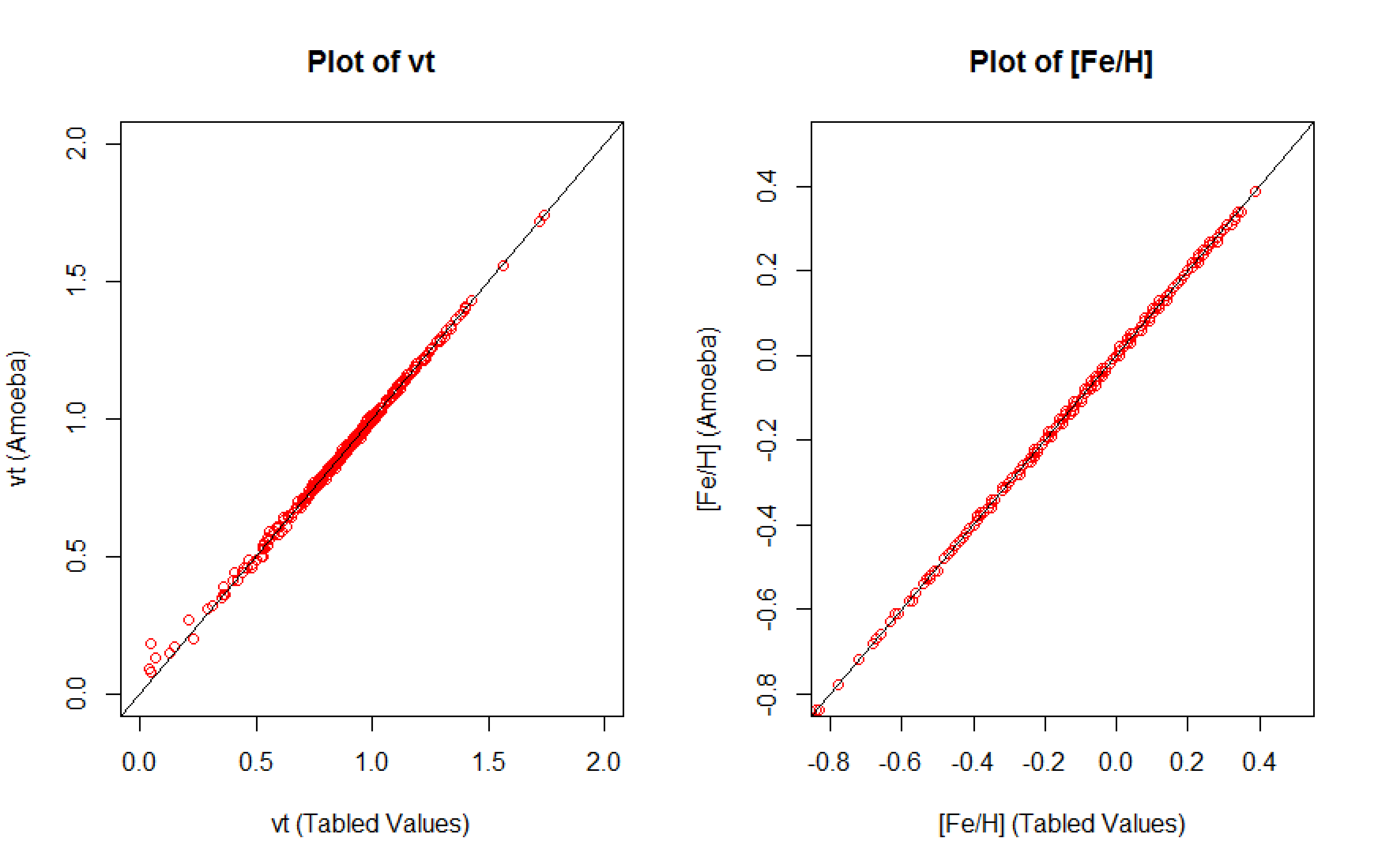

Fig.3 – Right: Plot of the derived microturbulence versus the tabled values. Left: Plot of the derived [Fe/H] values versus the tabled values. The tabled values were taken from the publically available database: http://vizier.cfa.harvard.edu/viz-bin/VizieR-3.

Preliminary Results (Amebsa)

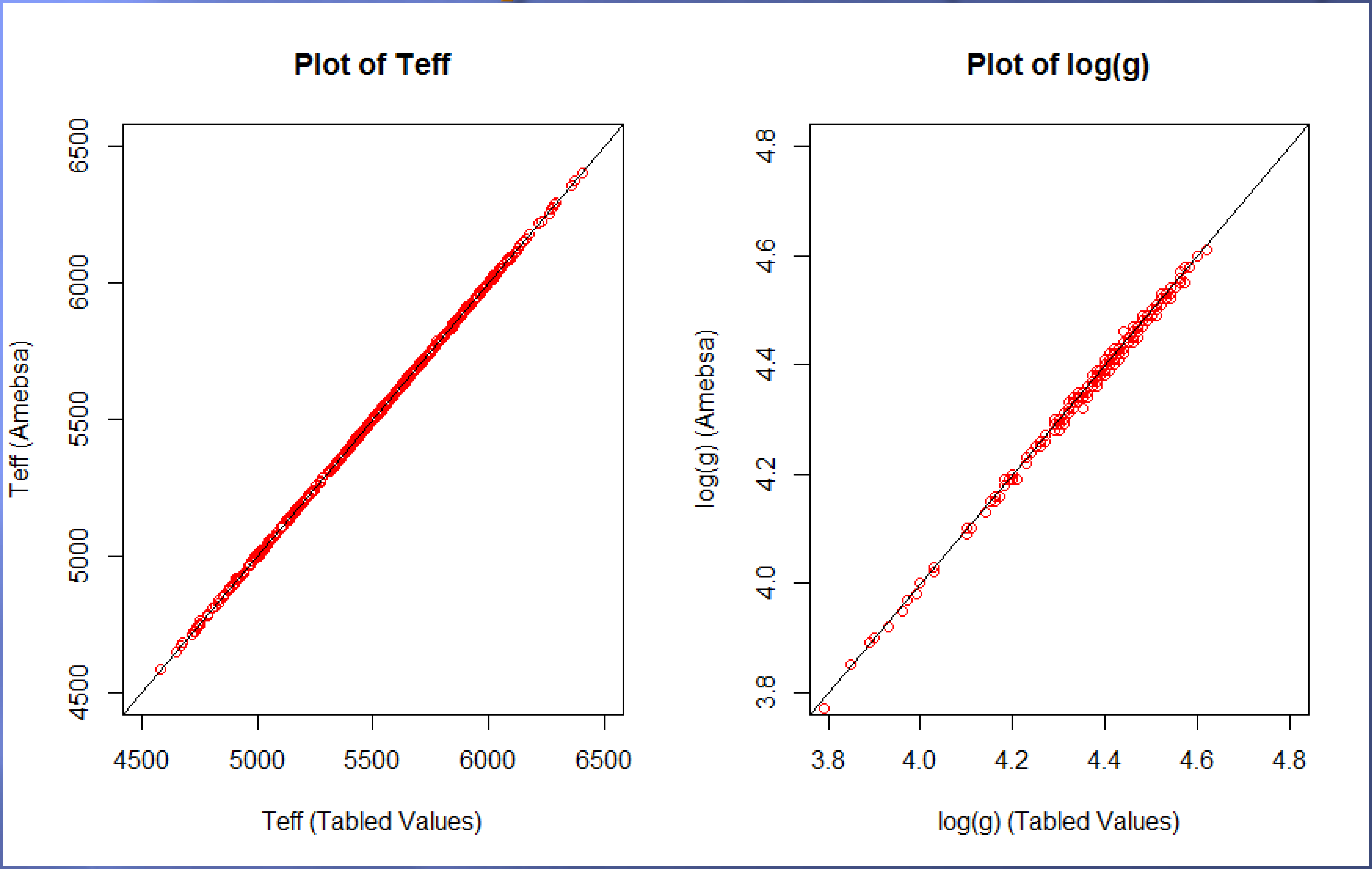

Fig.4 - Right: Plot of the derived Teff versus the tabled values. Left: Plot of the derived surface gravity versus the tabled values. The tabled values were taken from the publically available database: http://vizier.cfa.harvard.edu/viz-bin/VizieR-3.

Preliminary Results (Amebsa)

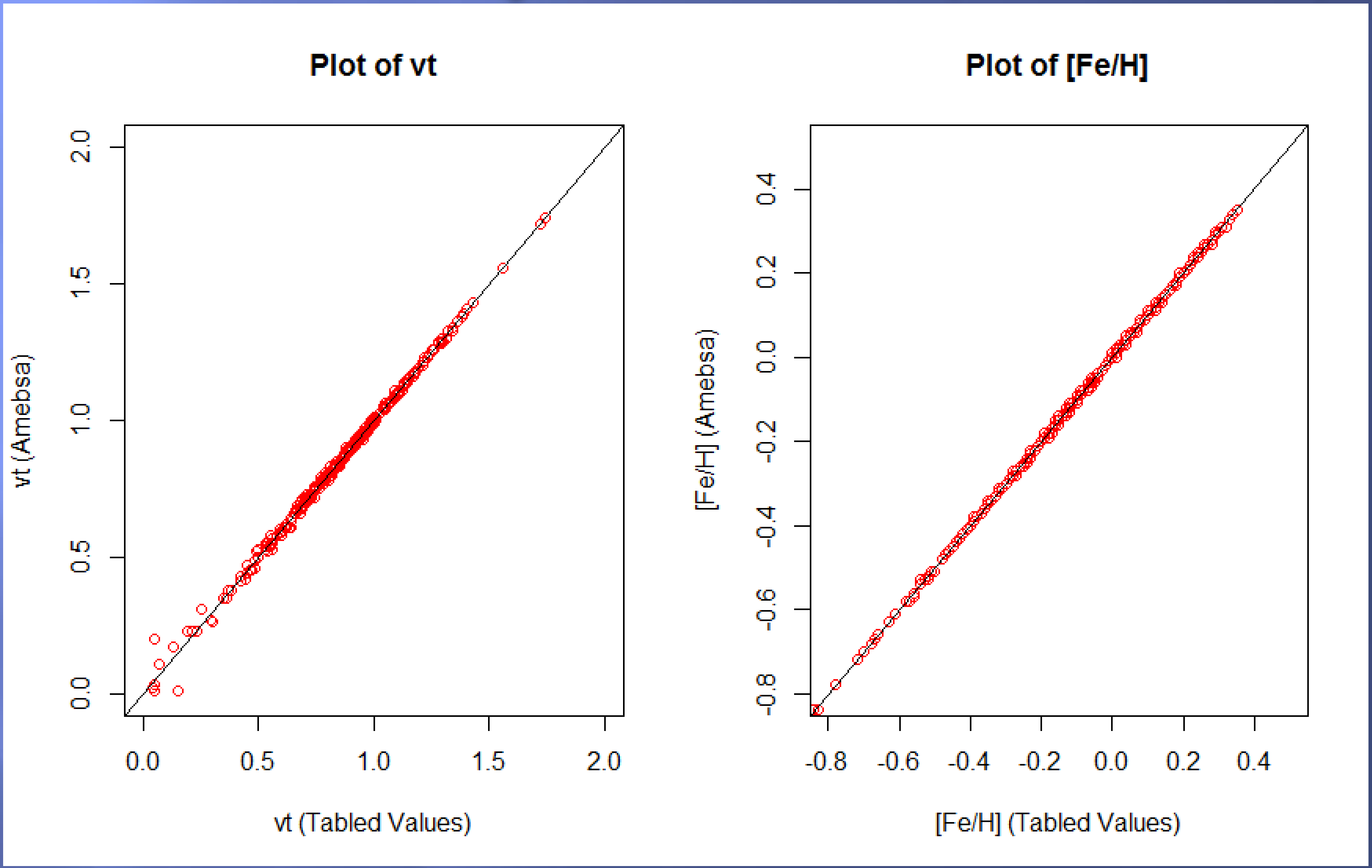

Fig.5 - Right: Plot of the derived microturbulence versus the tabled values. Left: Plot of the derived [Fe/H] values versus the tabled values. The tabled values were taken from the publically available database: http://vizier.cfa.harvard.edu/viz-bin/VizieR-3.

Brief summary of the mean convergence times

	Amoeba (Fortran)	Amoeba (C-version)
K-type stars	27.60	23.16
G-type stars	17.19	9.70
F-type stars	5.60	13.09

Table 2 – Summary of the mean convergence times for the FGK type stars, using the Amoeba and Amebsa optimization methods. The convergence times are listed in minutes.

Brief summary of the mean convergence times

	K-type stars	G-type stars	F-type stars
Amoeba (C-version)	39.07	17.18	18.18
Amebsa (C-version)	34.13	12.37	8.93
PSO (C-version)	117.43	65.53	44.03
PSO + Amoeba (C-version)	?	?	?
PSO + Amebsa (C-version)	44.34	21.37	16.14

Table 3 – Summary of the mean convergence times for the FGK type stars, using the Amoeba and Amebsa optimization methods. The convergence times are listed in minutes.

Brief summary ot the convergence times

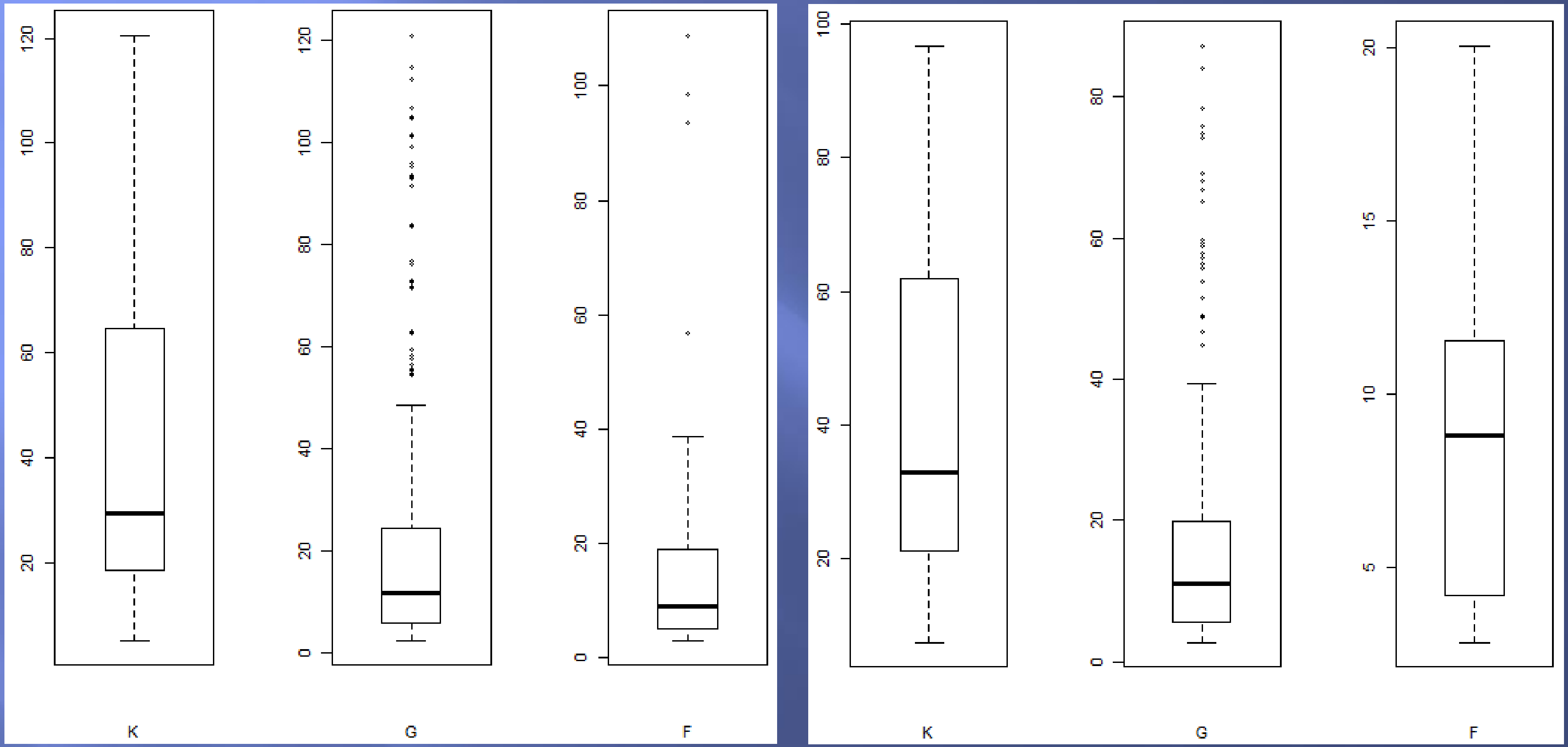

Fig.6 – Left: Boxplots of the convergence times for the K-, G- and F-type stars, respectively, using the Amoeba optimization method. Right: Boxplots of the convergence times for the K-, G- and F-type stars, respectively, using the Amebsa optimization method.

Outlines

- The convergence times ae better for the C-version of Amoeba, comparing with Fortran (for K. And G-type stars);
- Amebsa and Amoeba are well adapted to the described problem and both give the correct optimal solution;
- The convergence rate is higher in the Amebsa implementation;
- The convergence to the optimal solution is faster in the Amebsa implementation (for G- and F-type stars);

Thank you