Parameter estimations by optimal projections in a local environment

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1. MOTIVATION: Automated spectral parametrization

In the recent years, the use of spectrographs with multiobject capabilities (FLAMES, 2dF...) and the implementation of extensive surveys (Sloan, RAVE,...) has enormously increased the quantity of available data and, as a result, the efforts needed for their analysis. In the near future, the European Space Agency Gaia mission will collect several millions of stellar spectra, allowing a very complete mapping of the Milky Way. From the Gaia/RVS data i.t will be possible to derive individual chemical element abundances, leading to a huge and precious data base (**Fig. 1**). In this context, these huge sets of data need to be efficiently fitted to astrophysical models in order to summarize the information to a few parameters values. We develop here the mathematical basis and the data analysis framework of MATrix Inversion of Spectral SynthEsis (MATISSE) method to perform this fitting.

2. Mathematical basis of the MATISSE algorithm

The implemented algorithm (see also Recio-Blanco, Bijaoui & de Laverny, 2006) determines a vector *B*θ , allowing the derivation of a particular stellar parameter, θ, by projection of an input spectrum on it. This parameter can be the effective temperature, the gravity, the global metallicity, the [α/Fe] content, individual chemical abundances, stellar rotation, etc. The *B*θ function is derived from an optimal linear combination of theoretical spectra and it relates, in a quantitative way, the variations in the spectrum flux with the, θ variations:

$$\boldsymbol{B}_\theta(\lambda) = \sum_i \alpha_i \boldsymbol{S}_i(\lambda)$$

The parameter θ*i* of an input spectrum *Si* is estimated by its projection into the corresponding *B*θ vector: $\hat{\theta}_i = \sum_\lambda \boldsymbol{B}_\theta(\lambda)\boldsymbol{S}_i(\lambda)$ that is : $\hat{\theta}_i = \sum_j c_{ij}\alpha_j$ where *cij* is the covariance between the spectraSi and Sj. If the spectral values are considered as the realization of random variables (with a variable for each wavelength), the previous equation can be interpreted as a statistical multilinear regression between the parameter to be estimated and the spectra. The αj coefficients are derived from the maximum correlation between θ*i* and the recovered $\hat{\theta}_i$, imposing:

$$\sum_k \left(\sum_i c_{ij} c_{ik} \right) \alpha_k = a \left(\sum_i c_{ij} \theta_i \right)$$

If the covariance matrix is empirically found to be non invertible, this equation can be solved by a least squares linear regresion, using, for instance, a Landweber's algorithm.

3. Application to experimental sets

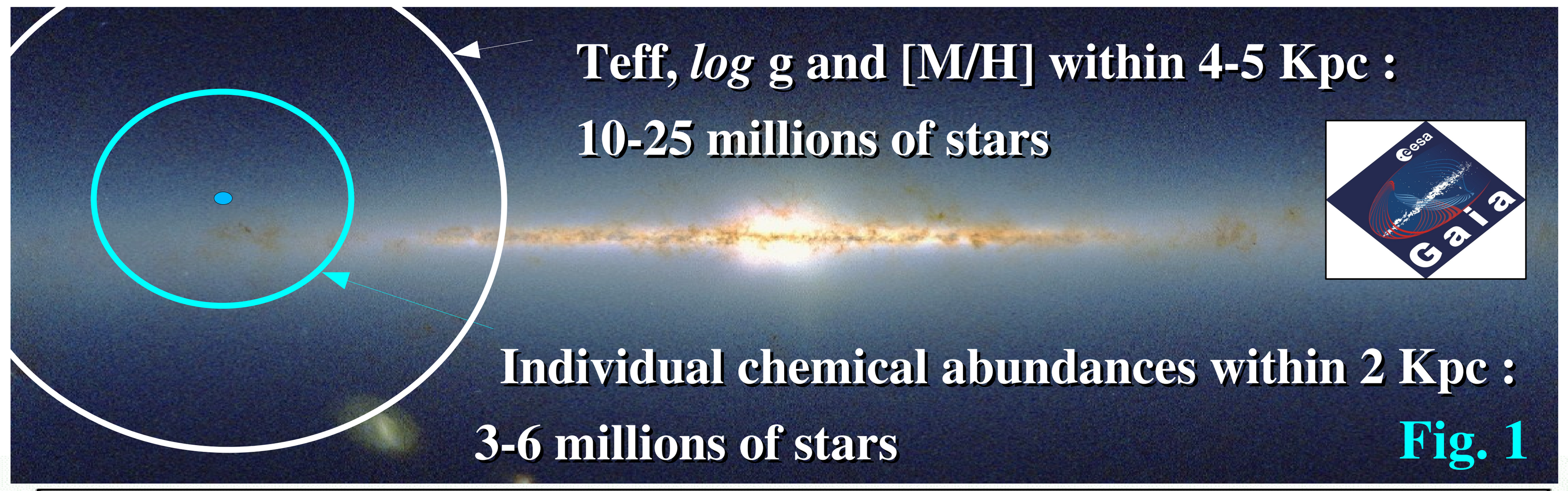

Fig. 1

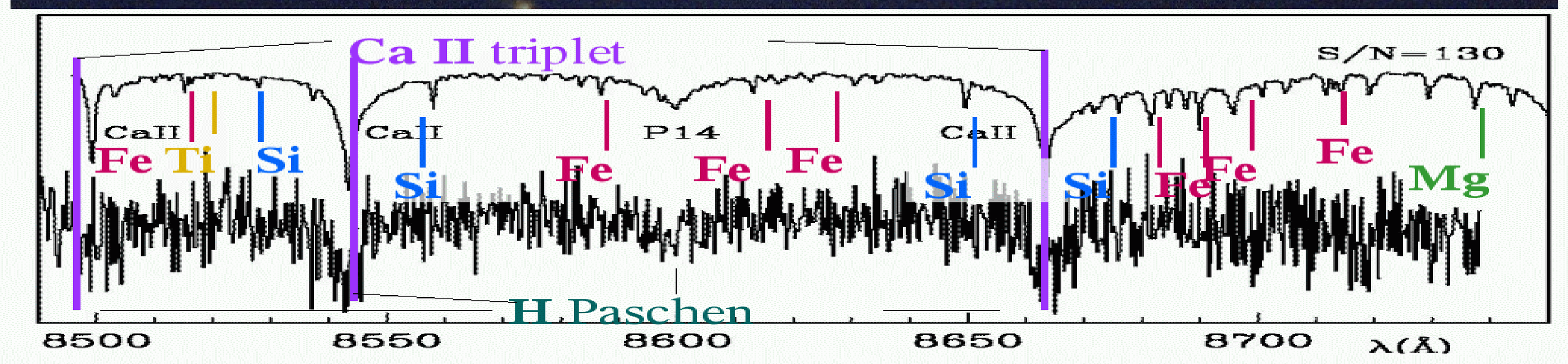

Fig. 2 Main features for the RVS spectral range and resolution.

The projection vectors are first computed for all the points of the model grid. This preliminary task can be understood as the learning step. of an ANN algorithm. Similarly to the Principal Component Analysis (PCA), this task starts with the computation of the variance covariance matrix, instead of learning element by element as for an ANN algorithm.

The application of MATISSE is illustrated in the following to the determination of stellar parameters from the Gaia/RVS spectra (c.f. **Fig. 2**).

RULE FOR ESTIMATION

The MATISSE method has a **two-layer structure**: initial $B^o\theta$ functions are used to converge to a subregion of the spectra grid where final $B^f\theta$ functions are applied.

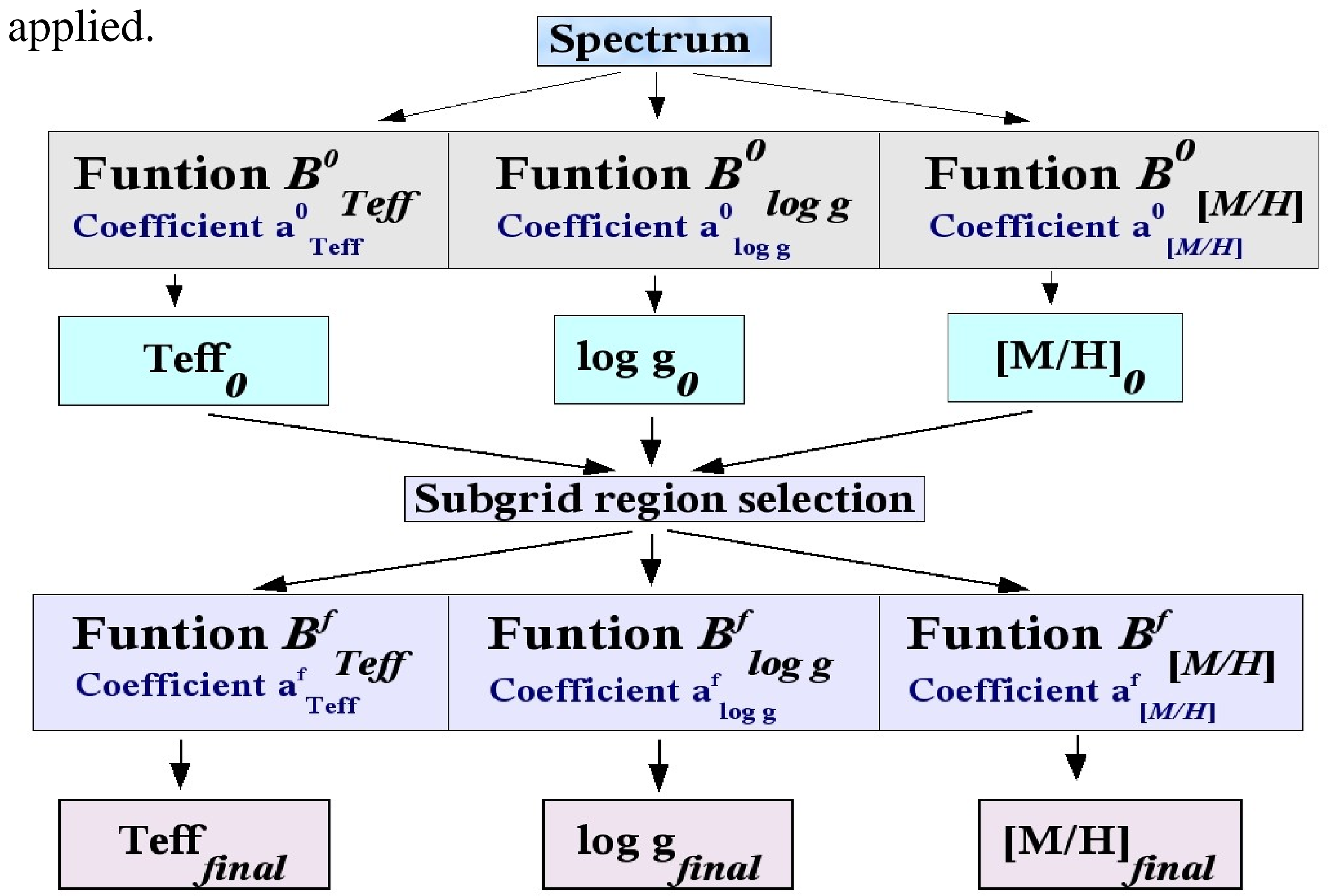

Fig. 3 Scheme of the MATISSE algorithm for estimation of atmospheric parameters form stellar spectra

4. Main applications of MATISSE

- ***Gaia/RVS stellar spectra*** *(Nice):*
  8470-8740A, R=11500 and grid of MARCS spectra
- ***Gaia BP/RP non resolved galaxies*** *(Nice & Univ. of Athens):*
  Spectro-photometry in the optical domain and grid of PEGASE spectra
- ***Automated parametrization for the Espadons/Narval spectrographs*** *(Nice, Toulouse & Montpellier):*
  3695-10485A, Δv=1.8 km/s and grid of MARCS spectra
- ***Characterisation of Corot targets :*** *(Nice and Marseille)*
  Flames/Giraffe 5130-5370A, R~26000 and grid of MARCS spectra (Thesis of J.-C. Gazzano)
- ***Parametrization of O Stars*** *(Nice and Marseille):*
  Elodie/FEROS 3950-6750A and grid of TLUSTY spectra
- ***Milky Way populations: gradients in the Thick Disc?*** *(Nice)*
  Flames HR21 ~8500A, R~16000 and grid of MARCS spectra

5. Performances for Gaia/RVS spectra.

A total of 500 000 different normalized synthetic spectra, with randomly selected parameters, have been analysed to check the performances of MATISSE in the Gaia spectra analysis. A programme to introduce Gaussian white noise, at desirable values of S/N ratio, was implemented. Atmospheric parameters and [α/Fe] abundance are derived. **Fig. 4** shows the maximum errors (bias + standard deviation) in the recoved parameters, as a function of S/N for metal-rich dwarf stars. The needed scientific precision in the stellar physical and chemical properties for the study of the history of our Galaxy. is satisfied.

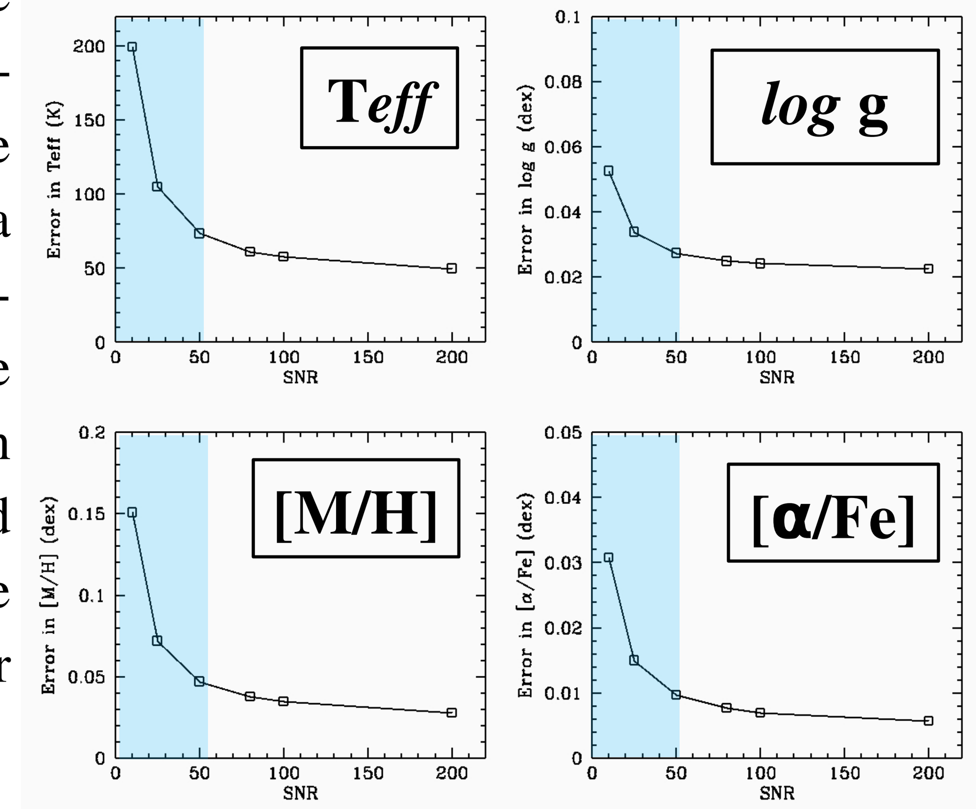

Fig.4

6. Conclusions

The illustrated results corroborate the efficiency of the automated MATISSE algorithm as an analysis and classification tool, particularly adapted to large surveys, such as the Gaia mission. Regarding the computational time needed, the MATISSE method is extremely fast (10^8 spectra analysed in a few hours) thanks to its low complexity.

Bibliography:

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