Towards realistic stellar atmosphere models: application to Gaia data processing

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Abstract

This Gaia Technical Note presents the program of the SAM group to test and improve stellar atmosphere models and sythetic spectra, focussing on cool stars ($T_{\rm eff} \lesssim 6500\,$K). We are establishing a consolidated set of benchmark stars – well-known stars, for which we obtain high resolution, high signal-to-noise spectra at 4m-class telescopes. The aim is to assess the systematic errors in abundance analyses due to shortcomings in the theory and input physics of stellar atmosphere models and line formation. We concentrate on the combined effects of hydrodynamic calculations in 3D and departures from local thermodynamic equilibrium, as well as the influence of selecting certain wavelength regions and spectral line data for abundance analysis. This note is directed to both DPAC members and non-members, and therefore includes a general introduction on Gaia and the DPAC.

Contents

1 Introduction

A major task of modern Astrophysics is to determine the origin, structure, and evolutionary history of our Galaxy. Progress in this task depends crucially on our knowledge of the physics of stars as building blocks of the Galaxy, in particular their atmospheres. Low-mass stars play a very important role in this context, because most of them exist for longer than the present age of the Universe. They also display, to a high degree, their original chemical composition at their surfaces.

The ESA cornerstone mission Gaia will provide astronomers with a detailed astrometric and spectrophotometric census of the Galaxy and the local Universe. For one billion stars brighter than an apparent visual magnitude of V≈20, astrometry with an accuracy of down to 20 microarcseconds and optical and near-IR spectrophotometry will be obtained. This will allow a detailed mapping of the content of our Galaxy, both in space and in terms of astrophysical parameters: surface temperature ($T_{\rm eff}$), surface gravity ($\log g$) and metal content ([Fe/H]). For brighter objects, the astrometry and spectrophotometry will be supplemented by near-IR spectroscopic observations, which will allow, besides radial velocities, some individual elemental abundances to be measured.

The scientific goals of Gaia range from understanding the origin and history of our Galaxy (e.g. its star formation history, its chemical and dynamical evolution, and the distribution of dust) to understanding the formation and evolution of stars (e.g. the dynamics of star forming regions, a complete and detailed local census, and a census of multiple stars). Additional scientific products include the detection of extra-solar planetary systems, as well as comprehensive surveys of Solar System and extragalactic objects.

The responsibility for processing and analysing Gaia data lies with the Gaia Data Processing and Analysis Consortium (DPAC). This consortium of over 300 European scientists and software engineers is developing the software system which will convert the raw data recorded by the Gaia satellite into scientifically meaningful data, for immediate use by the Astronomical community.

Within DPAC, the different data processing tasks are carried out by Coordination Units (CUs). CU8, "Astrophysical Parameters", is developing (1) classification algorithms which will determine, for each Gaia source, a probablity of its being a single star, galaxy, quasar, etc., and (2) parametrisation algorithms which will determine astrophysical parameters ($T_{\rm eff}$, $\log g$, metallicity, α element abundance, interstellar extinction) for each single star (or resolved binary). This is the area where the work of the Gaia-SAM collaboration will contribute.

We are aiming to improve synthetic spectra by improving the underlying physical models, to the extent needed to allow Gaia to achieve its science goals based on astrophysical parameters. We focus on the effects of 3D hydrodynamical modelling of convection, non-LTE effects, and improving input data (e.g. atomic data). We concentrate our efforts on F/G/K-type stars, since the effects metioned above are most important in those stars. Furthermore, F/G/K-type stars will be the most numerous among the objects observed by Gaia – 86% of all stars with $V < 20$ according to estimations by Robin (2005). Model validation will be based on a limited number of benchmark stars, with the best known physical properties, and dedicated high-quality observations. In this way we want to make sure that the astrophysical parameters in the Gaia catalogue are based on theoretical grounds beyond the current state of the art of stellar atmosphere modelling. Although Gaia data processing is the main driver for this work, the final goal may not be achieved until after publication of the Gaia catalogue, since our ambition is to eventually include non-LTE effects directly in the 3D stellar atmosphere modelling (for about 10 elements, the most important electron donors).

In the remainder of this section we will briefly review the status of current model grids, following Gustafsson et al. (2007). In Section 2 we motivate this work in more detail and expand upon the specific aims. In Section 3 we review the current status, the methods we are using and what has been achieved up to now. In Section 4 we present our long-term plans, while Section 5 focuses on the short-term schedule, followed by some concluding remarks.

2 Aims and motivation

Calibration of the astrophysical parametrization of Gaia sources.

Improving the models to the extent needed to allow Gaia to achieve its science goals, based on basic parameters (Teff, logg, abundances) - e.g. separation of populations by chemical composition.

To what extent is this possible?

The result of this work should be an estimation of needed improvements in modelling and the achievable parameter accuracies, taking into account the limitations of the Gaia instruments.

What are the limiting factors, concerning models and observations? (Do they lead to a limiting magnitude, e.g. because RVS data are needed?)

Examples for how this estimation will be done and some preliminary results.

e.g. Cycle 4 simulated data with realistic S/N estimates; carry out parametrization using NLTE vs. LTE grids (as training or testing grids); correction of radial velocities for convection effects, tests of flux distributions (correction for continuum flux 1D–>3D for BP/RP).

The result of this work will also form the basis for the calibration of extended parameters (e.g. activity index).

Outlook: Preparation for the era after Gaia and follow-up studies.

This work will be based on observations and models:

Observations (of ”benchmark stars”):

* calibration stars for AP reference stars (in the framework of GBOG=ground-based observations for Gaia)

* constraints for modelling (e.g. radius measurements, high-resolution spectra)

Modelling (development and testing):

* non-LTE for formation of Ca triplet lines (as well as Mg, Ti and Si lines)

* 3D hydrodynamical atmosphere models

* input data for line formation and opacities for models

3 Methods and current status

3.1 Observations

- public archives: list on Gaia Wiki

- new high-res spectra of about 25 stars (candidate benchmark stars)

- radii from interferometry available for 13 stars (8 giants + 5 others, new and literature) ... input from FT, PK needed

3.2 Models

- 3D atmosphere models (Nordlund & Stein)

> snap shots of a number of stars with ”old code”

> new code installed, being tested

- model atoms: Ca for DETAIL, Ca for MULTI under development (input from FT, AK), old one for Mg

- H-collision cross-sections: Mg-H (input from PB, NF)

4 Long-term plans

4.1 Observations

- regular updates of archive list

- reduction and 1D analysis of high-res spectra

- 3D analysis of high-res spectra

- 1D/non-LTE, 3D/non-LTE analysis

- reduction and analysis of interferometric data (FT, KP)

- new observations (photometry, spectrophotometry, polarimetry FT)

4.2 Models

- 3D code: complete transition to and tests of ”new code” (LB, RC)

- snapshots for benchmark stars for 3D analysis (LB, RC)

- Ca atom in DETAIL (AK) vs. in MULTI-1D (FT) - benchmarking with observations

- Mg MULTI-1D with new H-collision data (FT, NF, AK)

- implementation of NLTE Ca triplet in MARCS grid (current atom + improved atom with new H-collision data later) (AK)

- MULTI-3D (FT, RC)

5 Short-term schedule

6 Concluding remarks

7 References

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