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A new grid of 3D non-LTE Barium abundance corrections*

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Purpose and methods

The purpose of this project is to provide the community with a simple tool to improve the accuracy of standard 1D LTE barium abundance determinations. Based on a grid of about 100 CO5BOLD 3-dimensional (3D) hydrodynamic stellar atmosphere models, we performed statistical equilibrium calculations for an updated barium model atom (Gallagher 2020) using the state-of-the-art 1D non-LTE code MULTI (Carlsson 1986) combined with our MPI wrapper NLTE15D. Post-processing the results with the spectrum synthesis code Linfor3D, we derived so-called 3D non-LTE abundance corrections (Δ_{3D}) for five commonly used Ba II lines. The corrections describe the impact of deviations of the atomic level populations from local thermodynamic equilibrium (LTE) in a 3D stellar atmosphere on the Ba II spectral lines.

Coverage of stellar parameters

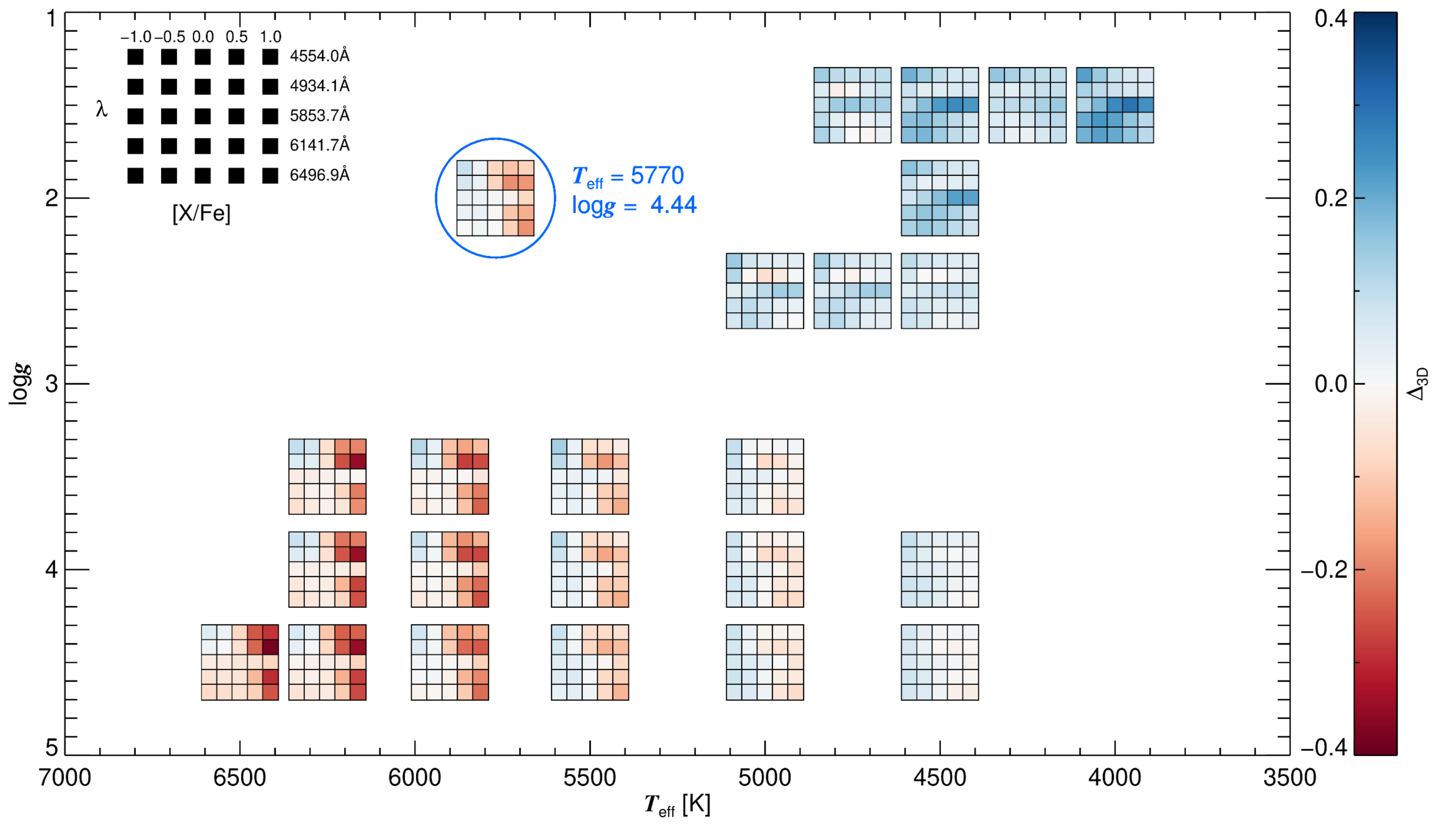

Fig. 1. *Raw grid of the (logarithmic) 3D non-LTE Ba abundance corrections (Δ_{3D}) in the T_{eff} - log g plane at metallicity* [M/H]=–2.0. *For each stellar parameter combination, the color code of the 5x5 square indicates the magnitude of the corrections for 5 different Ba II lines obtained at 5 different Ba abundances [Ba/Fe] (legend at upper left).The exact same grids are available for* [M/H]=0.0, –1.0, – 2.0, *and* –3.0. *In addition, we have computed the corresponding 1D non-LTE Ba abundance corrections (Δ_{1D}) using 1D MARCS model atmospheres for exactly the same stellar parameters.*

Corrections across the HRD

Direction and magnitude of the corrections depend the stellar parameters T_{eff}, log g, [M/H], on the barium abundance, and on the atomic transition of the spectral line under consideration. As illustrated in Figs. 2 and 3, 1D and 3D non-LTE corrections show little similarity, they may even have different sign.

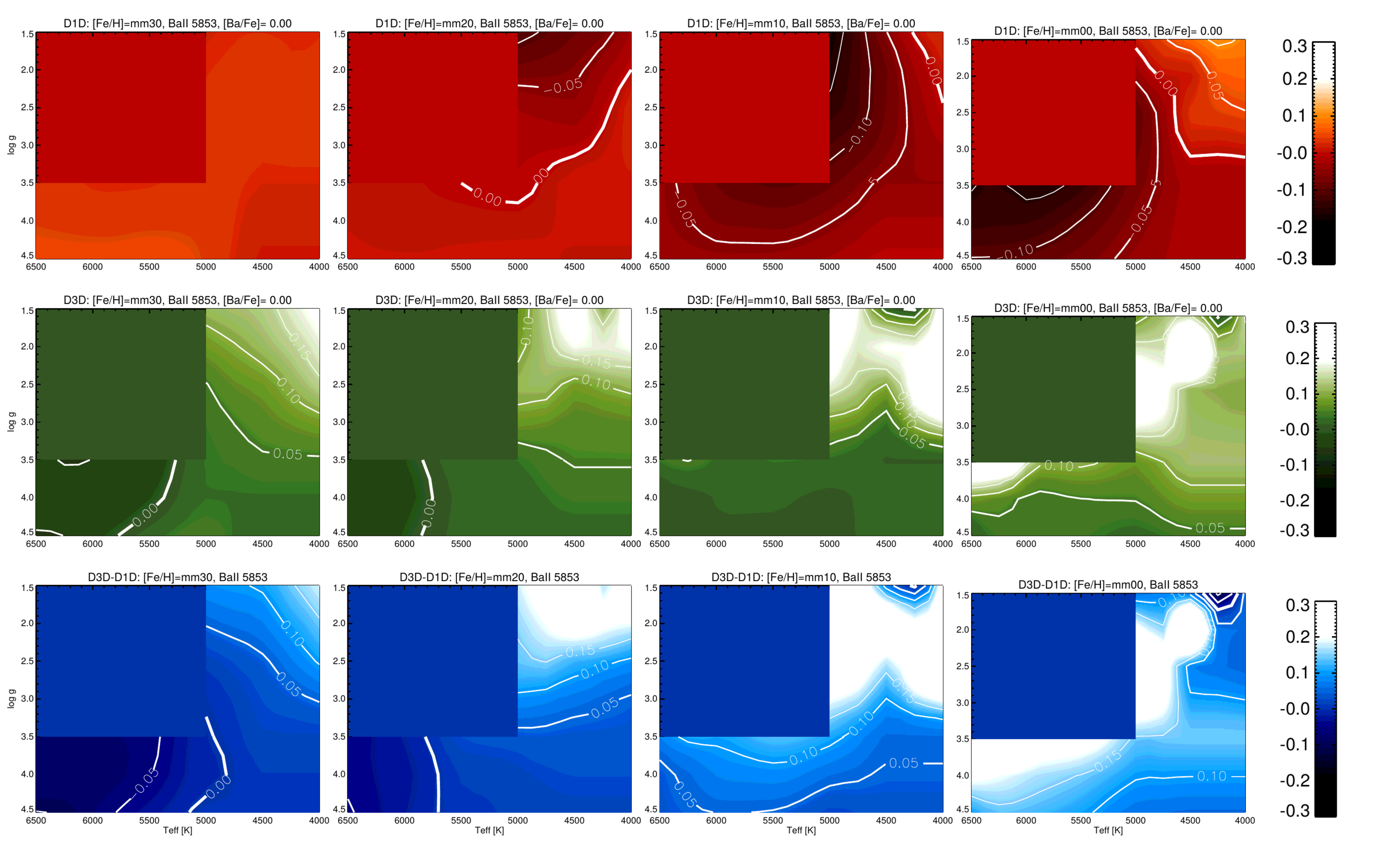

Fig. 2. *For given* [Ba/Fe] $_{LTE}$=0.0, the *contour plots show the 1D non-LTE corrections (red), 3D non-LTE corrections (green) and their difference (blue) in the T_{eff} - log g plane for the Ba II subordinate line at λ 5853* Å. *[M/H] increases from left to right from -3.0 to 0.0 in steps of 1.0. Contour lines indicate values from* –0.2 *to* +0.2 *in steps of* 0.05. *The largest corrections are found for giants at* [M/H]=–1, *where* –0.15 ≤ Δ_{1D} ≤ 0.0 *and* +0.15 ≤ Δ_{3D} ≤ +0.30, *hence* +0.25 ≤ ($\Delta_{3D} - \Delta_{1D}$) ≤ +0.40.

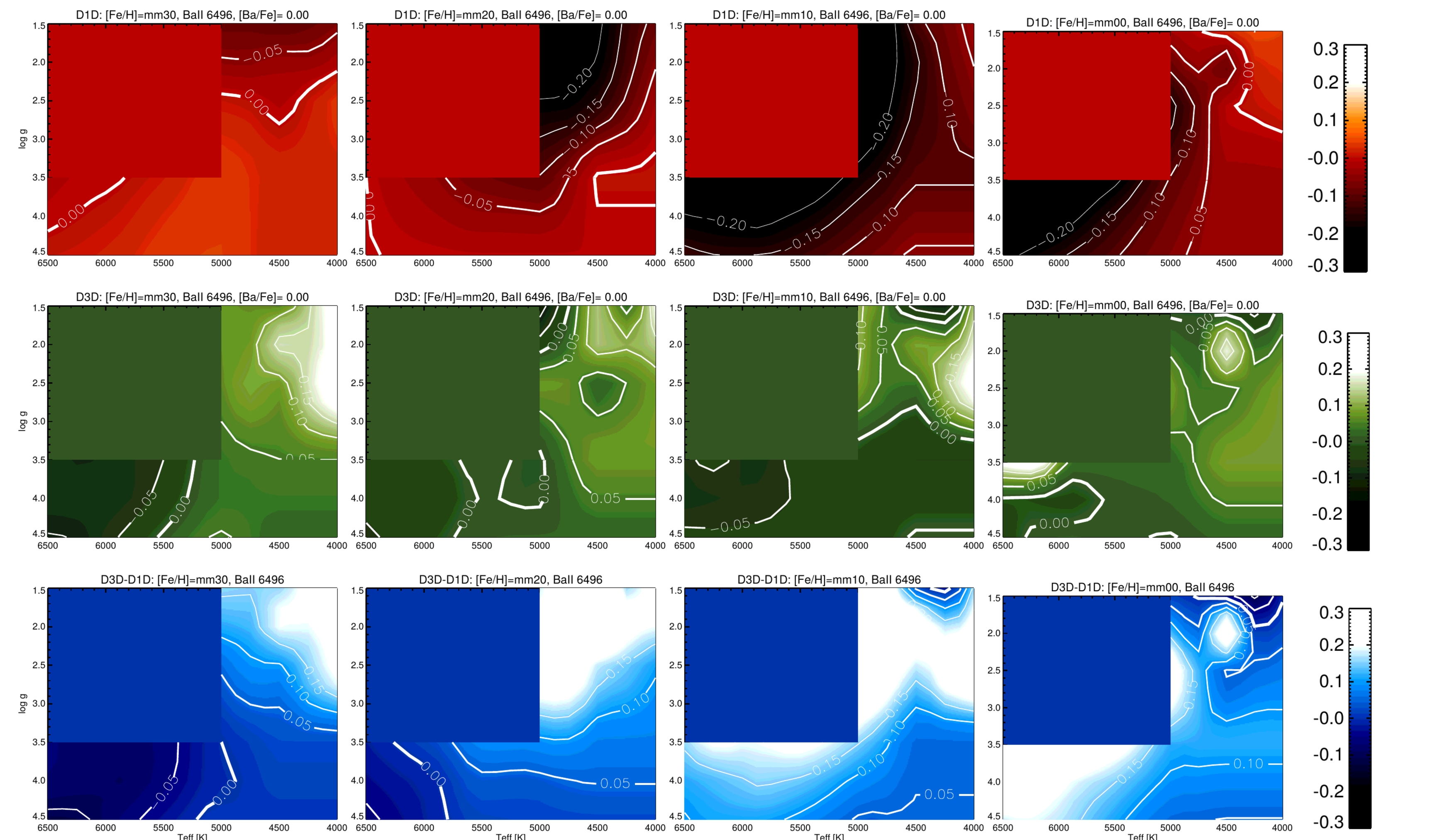

Fig. 3. *As Fig. 2, but for the Ba II subordinate line at λ 6496* Å. *Again, Δ_{1D} is mostly negative, while Δ_{3D} tends to be positive. Δ_{1D} is negligible at* [M/H]=-3, *but can reach values of* –0.25 dex *at solar metallicity (giants and dwarfs).* ($\Delta_{3D} - \Delta_{1D}$) *is as large as* +0.40 dex *for giants at* [M/H]=–1.0.

Example application

We demonstrate in Fig. 4 how the barium abundance derived from a sample of red giant stars depends on the analysis method. This example indicates that the more commonly used 1D non-LTE corrections may be misleading.

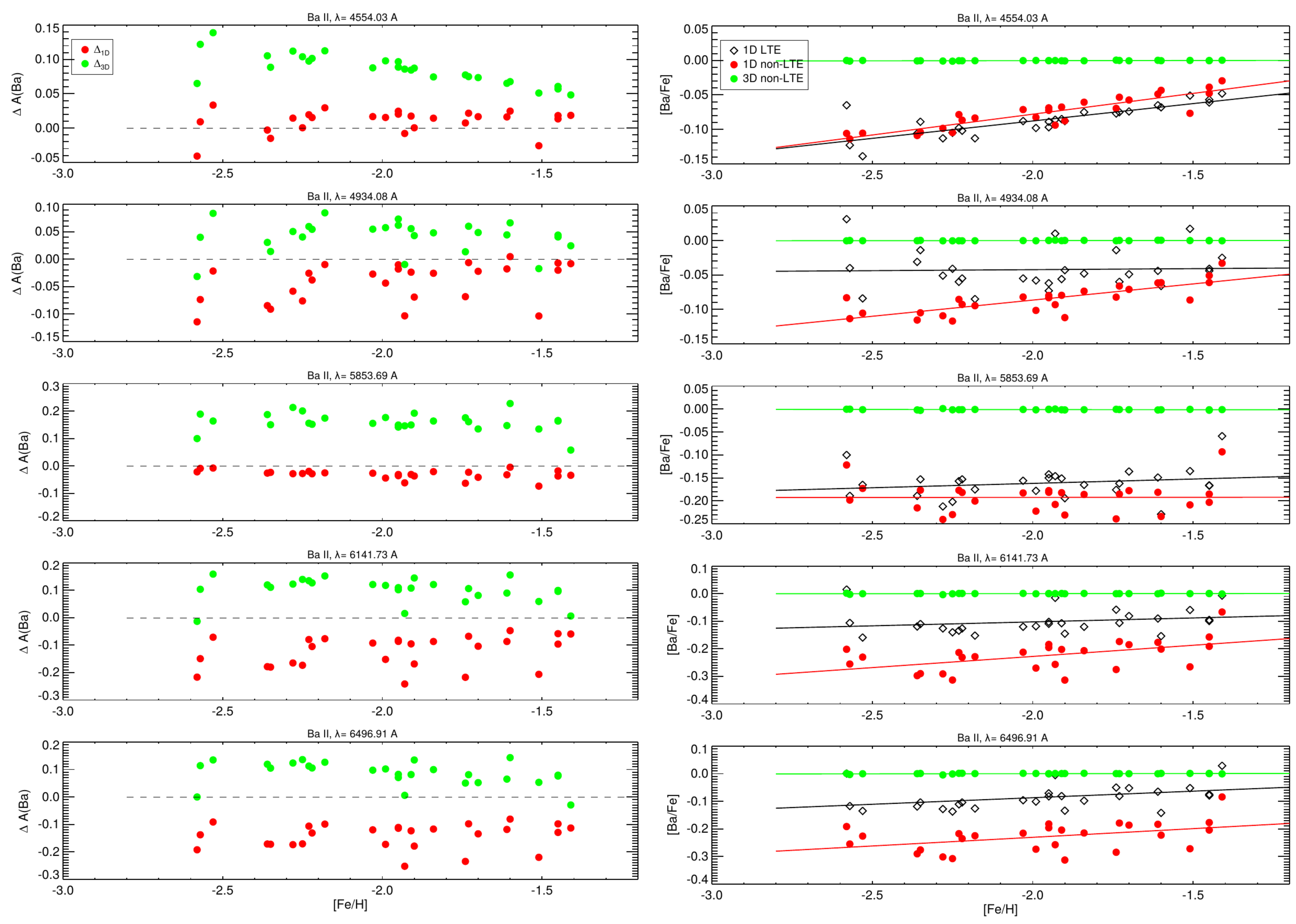

Fig. 4. Left: *Corrections Δ_{1D} (red) and Δ_{3D} (green) as a function of* [Fe/H] *for a sample of 27 red giants with* 4000 K ≤ T_{eff} ≤ 5000 K, 1.4 ≤ log *g* ≤ 2.2. **Right:** *Barium abundance* [Ba/Fe] *that would be obtained in 1D LTE (black) and 1D non-LTE (red) assuming that the true abundance, as derived by a 3D non-NLTE analysis, is* [Ba/Fe]=0 *for all stars (green). Ignoring non-LTE effects leads to an underestimation of* [Ba/Fe] *by* -0.05 to -0.20 dex, *depending on the considered spectral line. For the* 4554 Å *line,* 1D LTE *and* 1D non-LTE *results are very similar, both showing a spurious trend of* [Ba/Fe] *with* [Fe/H]. *In general, the 1D non-LTE corrections exacerbate the LTE results.*

Summary

We provide a grid of 1D and 3D non-LTE corrections for five commonly used Ba II lines, covering dwarfs and (sub)giants of spectral type FGK at different metallicity. The complex physics of non-LTE line formation can thus be accounted for by simply adding these (logarithmic) corrections to the 1D LTE Ba abundance. The corrections depend on stellar parameters, spectral line and line strength. We find that 1D and 3D corrections behave rather differently and often have opposite sign, for reasons yet to be understood.

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*) https://www.chetec-infra.eu/3dnlte