Comparing 3D stellar model atmospheres with solar observations

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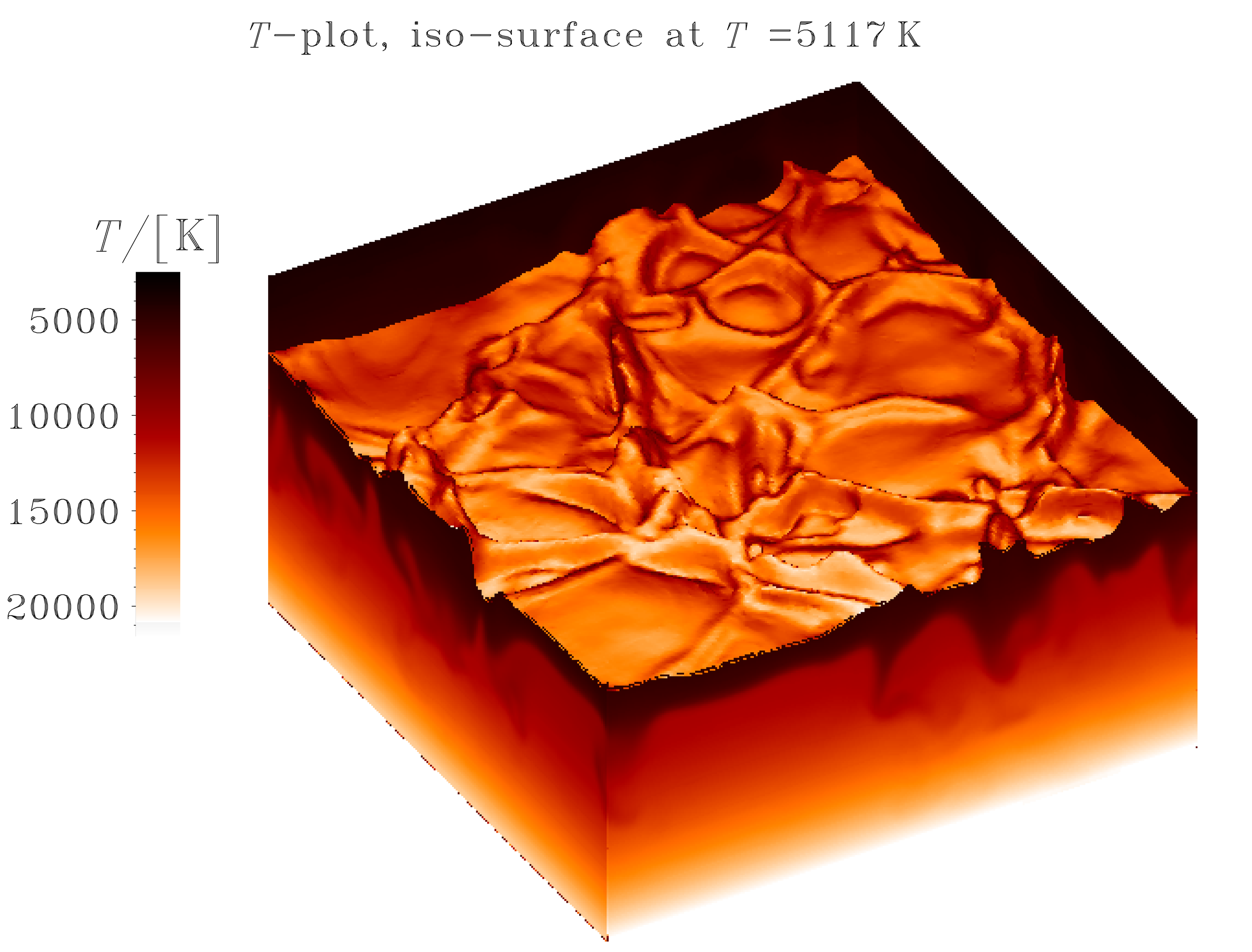
• The 3D Simulations



The temperature−cube of a snapshot of a simulation of the Sun
The box is 6×6×3.5 Mm in size; about 0.9% and 0.5% of $R_{\odot}$.
The hot plasma is rising, forming granules at the surface, and
the cooler (darker), faster downdrafts form between the granules.

The 3D stellar model atmospheres represent a major step forward in stellar astrophysics. Making use of radiative-hydrodynamical convection simulations that contain no adjustable free parameters, the model atmospheres provide a robust and realistic treatment of convection.

These models have been applied by M. Asplund and collaborators to several lines in the Sun and other stars, yielding an excellent agreement with observations.

In some cases the elemental abundances derived with the 3D model atmospheres can be reasonably different from the previous values inferred from 1D models, as in the recent controversy with solar models and Helioseismology.

• 3D Line Formation

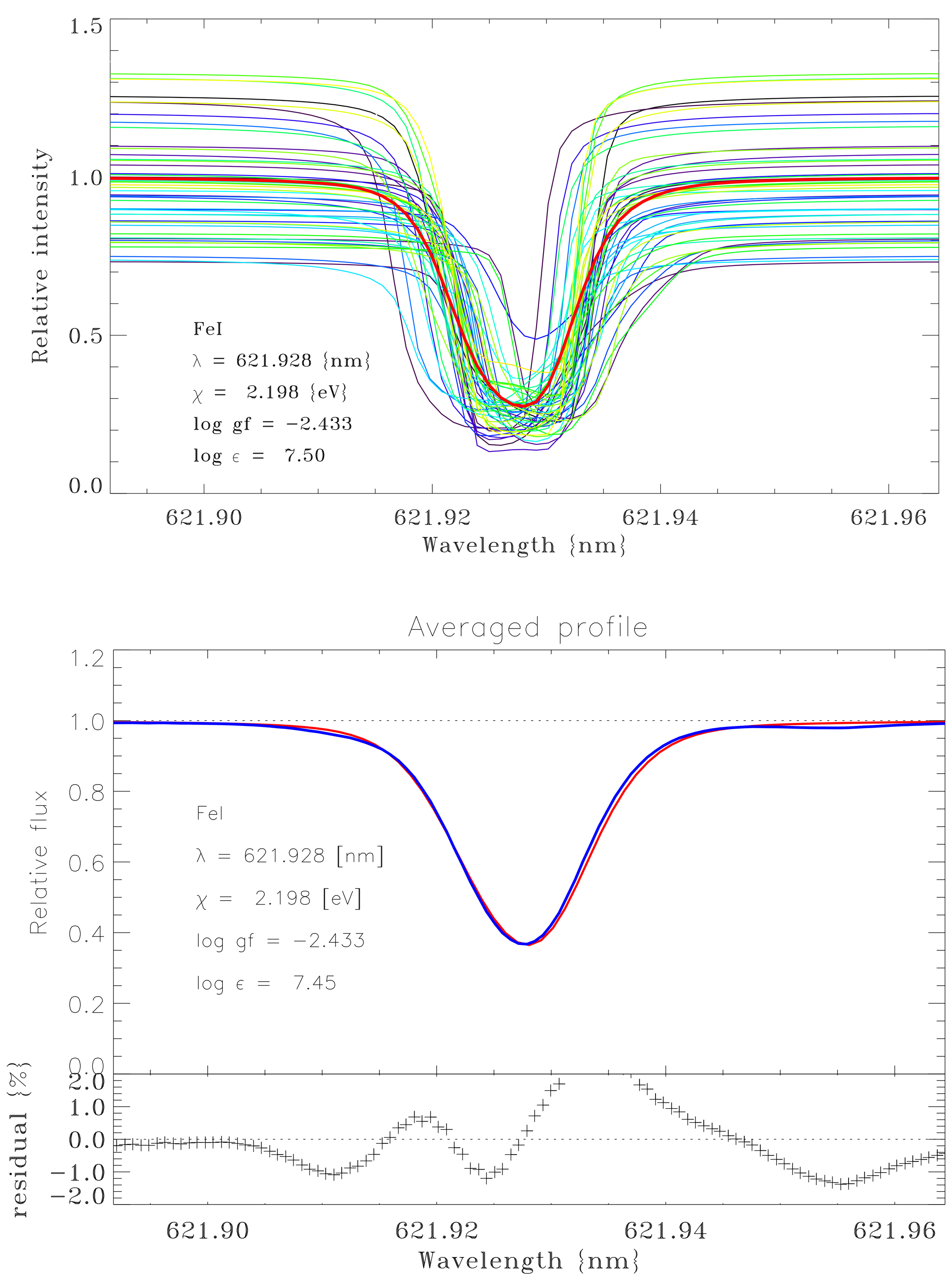


Fig. 1. How 3D line formation is computed, using the flux profile of a strong Fe line as an example. Physical conditions in the atmosphere are extracted from the 3D convection simulation (see "The 3D Simulations"), of which a temporal average is made. For each point in the "surface" xy grid, a line profile is computed (top panel: different profiles are computed for different surface points, red thicker line represents the mean profile). These profiles are then averaged and the spacial average profile is obtained (bottom panel: red profile represents the model, blue line the solar flux atlas of Kurucz et al. 1984).

The present work aims to provide additional observational tests to the 3D solar model atmospheres.

The limb-darkening profile (center-to-limb variations) is a useful tool to probe the atmospheres as a function of depth. By changing the viewpoint (μ=cosθ), one effectively sees light that was generated in different layers. By comparing the model with the solar observations, one has a good test on how realistic are the model's physical conditions (as a function of depth).

The Hydrogen lines Hα and Hβ, on the other hand are a very sensitive temperature indicator (in the wings). These wings are believed to be formed in deep layers, where LTE prevails. Changes in gravity and in the Hydrogen and metal abundances produce a negligible efect in the line's strenght. As Hydrogen influences the main source of opacity, the lines are very temperature sensitive and temperature. This makes Hα and Hβ a very good probe for the temperature of the models.

• Hydrogen Lines

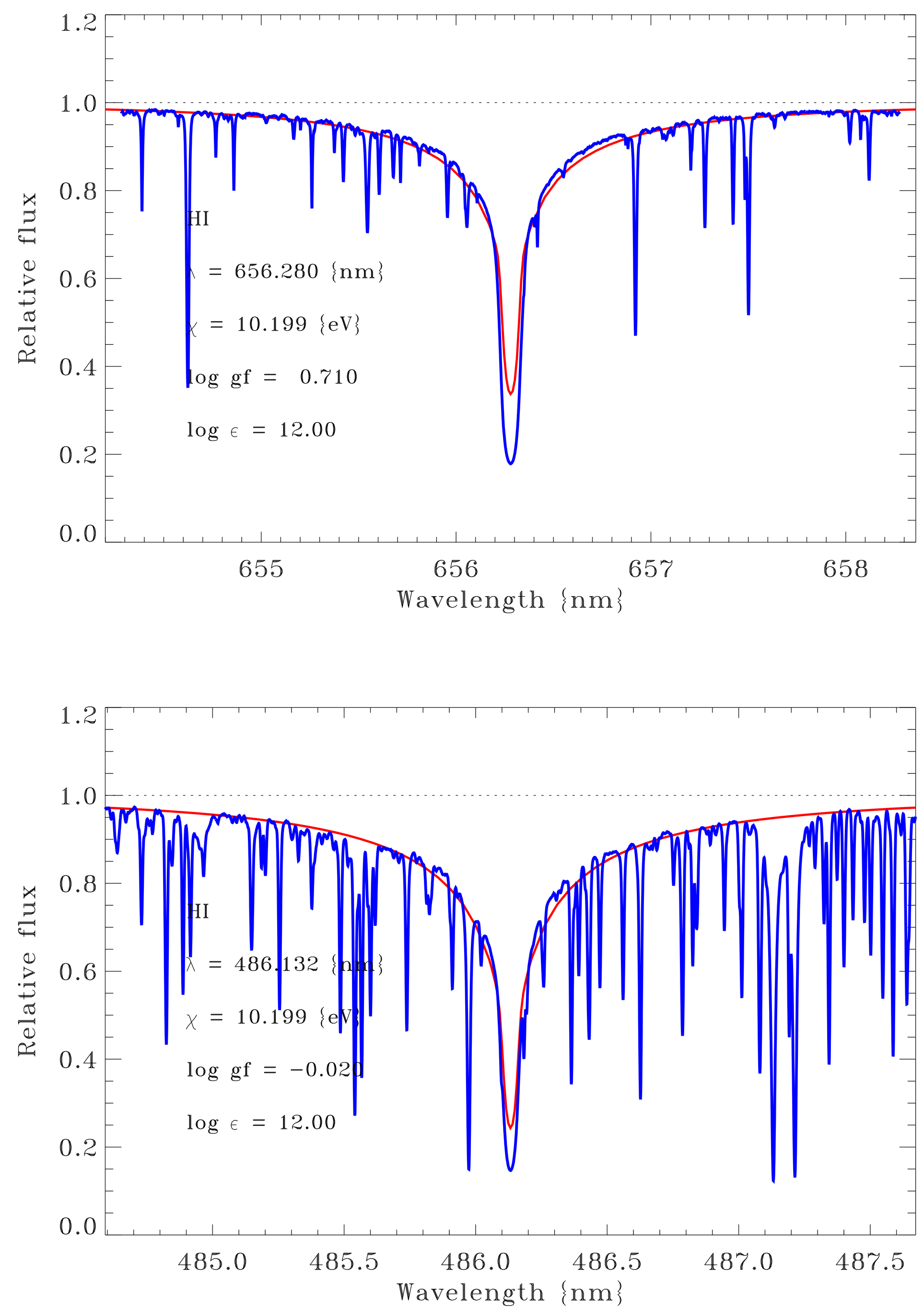


Fig. 2. The predicted spatially and temporally averaged flux profiles of the Hα and Hβ lines (top and bottom panel, respectively). Red lines: model, blue lines: solar flux atlas. The lines were computed using a sequence of snapshots covering 50 min of solar time, from the full solar convection simulation (covering 2 hr of solar time, with a numerical resolution of 200x200x82 gridpoints). A reasonable agreement can be found in the wings but not at the core (which is believed to be formed at higher layers, in non-LTE conditions).

• Limb darkening profile

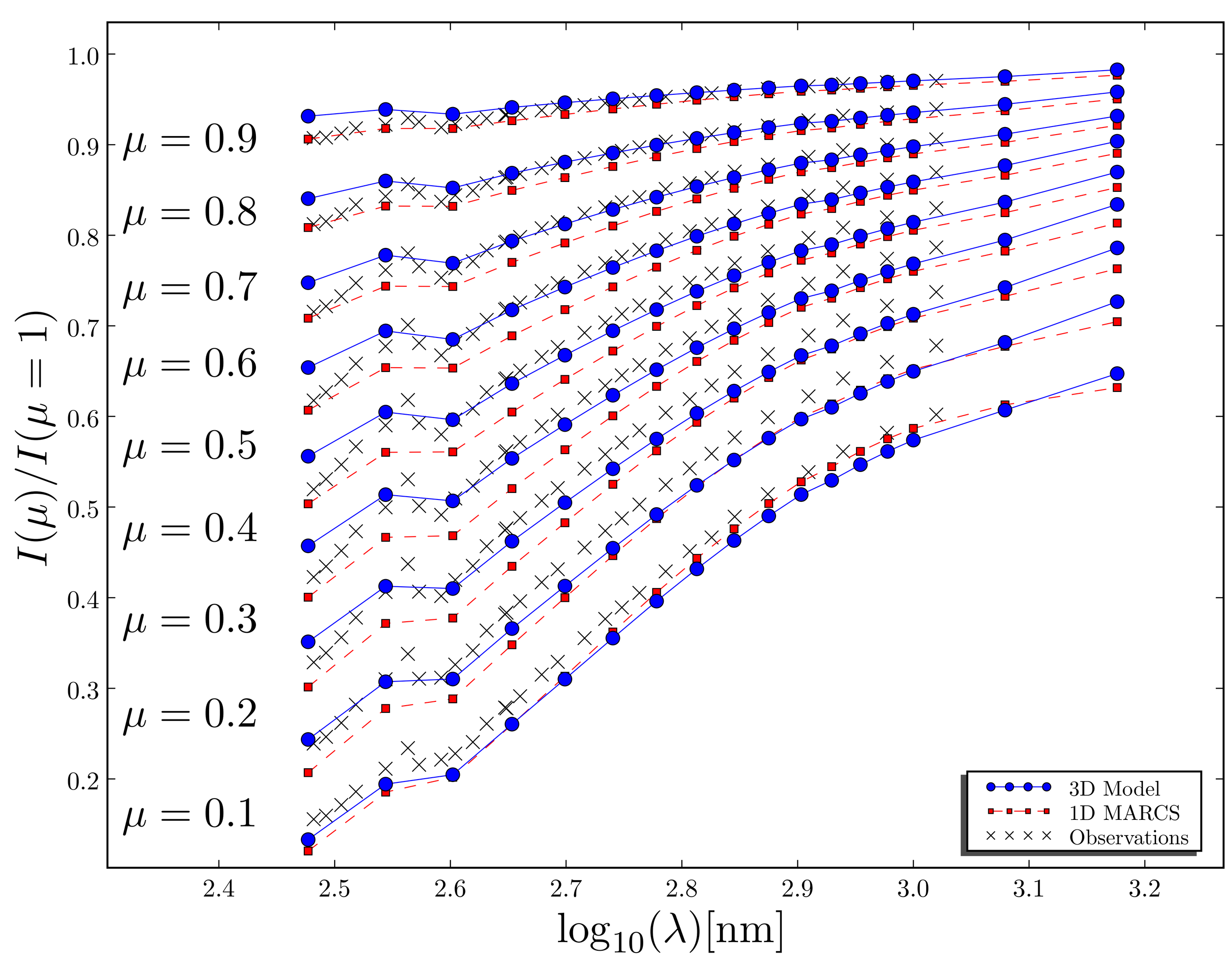


Fig. 3. The limb-darkening profile for the 3D solar simulation, in the range of 3000-20000 Å, computed for the continuum intensity. The μ parameter defines the angle of the viewpoint (μ=cosθ), μ=1 corresponding to disk center. A comparison with the solar observations of Neckel & Labs (1994) and the 1D MARCS model is done. While generally there is a good agreement (in some cases better than the MARCS model), it is clear that there are a few locations where the agreement with observations can still be improved.