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# New Theory of Stellar Convection without the mixing-length parameter: new stellar atmosphere models

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**Abstract.** Stellar convection is customarily described by the mixing-length theory, which makes use of the mixing-length scale to express the convective flux, velocity, and temperature gradients of the convective elements and stellar medium. The mixing-length scale is taken to be proportional to the local pressure scale height, and the proportionality factor (the mixing-length parameter) must be determined by comparing the stellar models to some calibrator, usually the Sun. No strong arguments exist to suggest that the mixing-length parameter is the same in all stars and all evolutionary phases. Because of this, all stellar models in the literature are hampered by this basic uncertainty.

In a recent paper (Pasetto *et al.* 2014) we presented a new theory that does not require the mixing length parameter. Our self-consistent analytical formulation of stellar convection determines all the properties of stellar convection as a function of the physical behavior of the convective elements themselves and the surrounding medium. The new theory of stellar convection is formulated starting from a conventional solution of the Navier-Stokes/Euler equations, i.e. the Bernoulli equation for a perfect fluid, but expressed in a non-inertial reference frame co-moving with the convective elements. In our formalism, the motion of stellar convective cells inside convective-unstable layers is fully determined by a new system of equations for convection in a non-local and time-dependent formalism.

We obtained an analytical, non-local, time-dependent solution for the convective energy transport that does not depend on any free parameter. The predictions of the new theory are compared with those from the standard mixing-length paradigm with positive results for atmosphere models of the Sun and all the stars in the Hertzsprung-Russell diagram.

**Keywords.** Sun: fundamental parameters Sun: interior stars: evolution stars: fundamental parameters

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## 1. Introduction

The transfer of energy by convection is of paramount importance in all the stars. High-mass stars, roughly for masses $m > 1.3m_{\odot}$ contain fully convective cores, all stars $m \in [0.1, 100[\, m_{\odot}$ have outer convective envelopes, and finally stars smaller in mass than $m < 0.3m_{\odot}$ are fully convective. Despite its great importance, a satisfactory treatment of stellar convection in stars is still open to debate and a self-consistent treatment of the physics of convective energy transfer is still missing.

In a recent paper Pasetto *et al.* (2014) developed the first theory of stellar convection in which the solar properties are reproduced without making use of free parameters.



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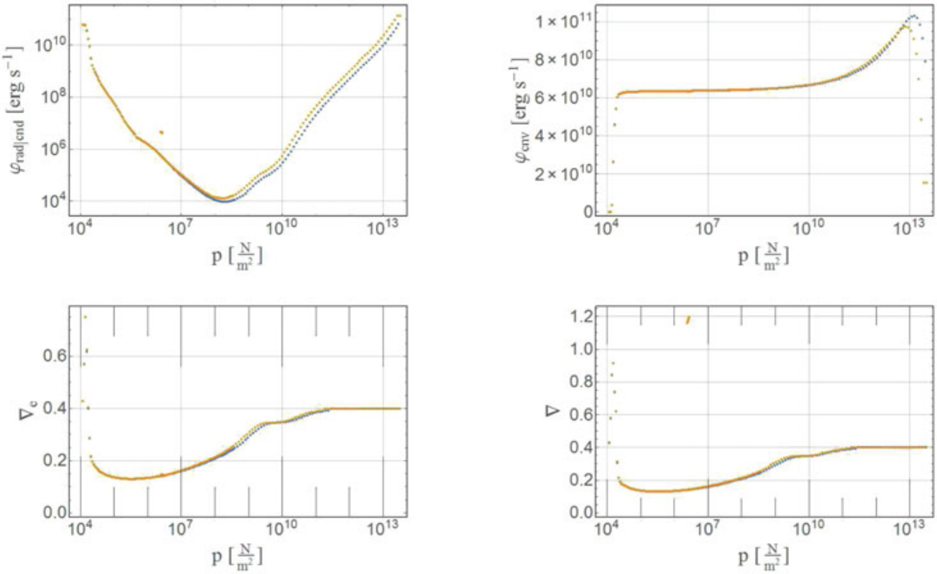


**Figure 1.** Solar fluxes and temperature gradient profiles for the internal pressure stratification of the star. The upper panels show the expectation for $\varphi_{\mathrm{rad|cnd}}$ on the left and $\varphi_{\mathrm{cnv}}$ on the right. Yellow refers to our theory, blue to the MLT.

## 2. Results: The model matching the Sun

We present here a comparison between the standard MLT and the SFC theory. We consider the stellar track of Bertelli *et al.* (2008) best fitting the present position of the Sun on the HRD e.g., $\log_{10}\{L/L_\odot, T_{\mathrm{eff}}\} \cong \{0.000, 3.762\}$ with standard chemical composition $\{X, Y\} = \{0.71, 0.27\}$. The results are shown in Fig.1. In the same plot we show also the predictions of the MLT with $\Lambda_m = 1.65$ (the MLT is according to the version presented in Kippenhahn *et al.* (2012)), so that comparison between SFC theory and MLT is possible. Both the temperature gradients $\nabla$ and $\nabla_e$ and fluxes $\varphi_{\mathrm{rad|cnd}}$ and $\varphi_{\mathrm{cnv}}$ predicted by SFC theory and MLT are in mutual agreement over an impressive range in pressure of almost ten orders of magnitude.

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