Numerical simulations of stellar surface convection

Bernd Freytag, Matthias Steffen
Institut für Astronomie und Astrophysik der Universität Kiel, D-24098 Kiel, F.R.G. [Freytag@astrophysik.uni-kiel.de], [Steffen@astrophysik.uni-kiel.de]

Based on detailed 2D numerical radiation hydrodynamics calculations of time-dependent compressible convection, we have studied the dynamics and thermal structure of the convective surface layers of a number of stars of different type.

Our sample includes stars on or near the main-sequence with effective temperatures between 4300 K and 9000 K (K1 V to A0 V), gravities between log \( g = 2.54 \) and 4.74, and metallicities from [M/H] = 0 to -2. Additionally we produced models of several cool DA white dwarfs with effective temperatures between 11400 and 14200 K, log \( g = 8.0 \).

In contrast to the picture of mixing-length theory (MLT), fast narrow downdrafts are the dominant feature in the hydrodynamical simulations. We find that merging of downdrafts produces deep-reaching plumes, causing convective motions to extend well beyond the unstable layers. This so called overshoot leads to diffusive mixing in the stable layers below.

As example results of these simulations we display and analyze a number of models along the main-sequence from A-type stars to K dwarfs. In A-type stars radiation dominates the energy transport. Convection is weak with shallow convection zones, small velocities, and tiny fluxes. Towards F-type stars convection becomes more and more violent with high flow velocities, carrying a significant part of the energy and extending to increasingly deeper regions. In G- and K-type stars convection is very efficient and carries easily (with comparably small velocities) all the energy flux in very extended convection zones.

The transonic convective motions are accompanied by the emission of sound waves. The resulting photospheric acoustic energy flux depends strongly on the convective velocities.

Within the G- and K-type stars, the characteristic size of the granules is closely proportional to the subphotospheric pressure scale height. Only radiatively dominated convection zones in A-type stars show relatively larger granules.

The models of F- to K-type stars cover only the uppermost layers of the total convection zone. Nevertheless, it is within these layers that the jump in entropy between the photosphere and the deep adiabat takes place. This jump can be determined from the numerical simulations and enables the calibration of the free parameter in the mixing-length theory.