Joint Discussion 13: Recent Advances in Convection Theory and Modeling

This one day joint discussion session featured 15 invited speakers and 15 posters.

Evry Schatzman opened the day as a self-confessed “user” of the theory of convection zone structure and highlighted five important issues in convection theory: the stability (Schwarzschild) criterion, effects of radiative energy transport (as formulated by Böhm–Vitense), penetrative convection, numerical simulations, and the role of plumes, especially related to chemical composition constraints. Schatzman also distinguished between astrophysical constraints that could be used to test theories of convection and the physical processes that may rely upon the presence of convection (this includes dynamos, stellar activity, wind production, mass loss, angular momentum transport, penetration, gravity waves, and granular effects on spectral lines).

Kwing Chan introduced a new approach to studying deep convection in a rotating reference frame: the so-called stratified approximation. Chan highlighted the applications to the Sun and the Earth’s middle atmosphere where the Rossby number is of order unity and discussed what effects rotation has on the internal structure of a convective layer. This new technique appears to be more accurate than the conventional anelastic approximation and will be a powerful numerical tool in studying global scale convection problems constrained by rotation.
Peter Fox reviewed the progress in modeling convection in the presence of magnetic fields using two and three dimensional numerical simulations. Fox distinguished between the influence of surface fields, which appear primarily radially with a small filling factor, from subsurface fields, which are likely to be azimuthal, i.e., horizontal but may have a larger filling factor. In the case of vertical fields, it was shown that the statistical properties of the convection, for example the correlation between temperature and velocity, can be altered significantly for strong fibril fields. In the case of a deep seated horizontal field, Fox demonstrated the role of the Poynting flux which showed how storage of magnetic energy within the field can also be used to modulate the local heat transport. In addition, that energy can be transported and released in another form (kinetic or thermal) in a different layer within the Sun when the horizontal field forms into an omega loop (and possibly erupts at the surface).

Pierre Demarque focused on applications to stellar structure and evolution and how convection theory affects both the dynamics and thermodynamics. Convective overshooting, or overmixing as it is often referred to, is important in the evolutionary tracks of giant-branch stars, in particular from a convective core. Demarque suggested that asteroseismology may be able to constrain such effects. In the case of globular cluster stars, convection plays a significant role in the chemical composition variations, especially when element diffusion (primarily helium) is included. Demarque stressed the need for improvements in convection theories and presented some recent results of numerical simulations that test the mixing length theory expressions in shallow photospheric layers. These results indicate that the mixing length to scale height ratio is far from a constant in these layers.

Vittorio Canuto presented the current state of turbulence theory, focusing on full eddy spectrum models, non-locality and RNG models. The full eddy spectrum models use the Reynolds stress method and remove a primary restriction of the conventional mixing length theory, that of a narrow wavenumber range for energy containing eddies. The improved theory allows for a broad range of eddies and has been successfully applied to stellar structure models. The Reynolds stress method has also been applied to non-locality and the problem of overshoot in the Earth’s planetary boundary layer and is now being applied to the stellar case. Finally, Canuto discussed
how RNG theory applied to shear flows is being successfully compared to experimental data but that the next step to include convection is yet to be done.

Sabatino Sofia reported on a parametric approach to convective energy transport using results from large eddy simulations of deep, efficient, compressible convection. These convective flux approximations are used in place of the conventional mixing length theory and do not contain any free parameters, such as the mixing length to scale height ratio. Results for solar structure models using the new approximations were presented, in addition to models for the binary system alpha-Centauri. Sofia highlighted how the new convection approximations exposed the sensitivity of the models to other aspects of the physics, such as the equation of state, opacities, and atmosphere models.

Bob Kurucz then turned the attention to the effects of convection zone theory on the construction of model atmospheres. In particular, for a grid of atmosphere models representing different surface gravities and effective temperatures, there is an abrupt change in the model colors between the presence and absence of a stellar convection zone. Over the years, Kurucz has been improving all aspects of the atomic physics in an attempt to explain the “jump” which is particularly important in population II stars since it affects the lithium abundance which is an important constraint on stellar evolution models. Kurucz also remarked how in some models, the convection zone resides completely within the atmosphere and that the characteristics of convection in that regime are likely to be very different from what the mixing length theory (or even a numerical simulation) would suggest. Finally, Kurucz highlighted the sensitivity of the atmosphere models to the adopted value of the micro-turbulent velocity and stressed the need for convection calculations with full radiative transfer treatments.

Cesare Chiosi discussed the role of semiconvection and overshooting in supergiant stars and presented an empirical model for both under- and overshooting. The two effects accounted for in the formulation are intermittency (where only a fraction of the layer is mixed) and stirring, which are expressed as effective diffusion coefficients. This new formulation has been tested on a twenty solar mass star with metallicity of 0.008, and the mixing during the core helium
burning phase is higher than conventional models predict. The consequences for ages of clusters, etc. is yet to be examined.

Ken Nomoto presented the latest results from a number of groups on the role of convection in supernova explosions. Many of the two and three dimensional simulations have only just begun, but it has been found that convection enhances the neutrino heating and can also trigger shock wave propagation. In addition, two dimensional calculations show the presence of a deformed nuclear burning front associated with the explosion, which has a speed of approximately 4,000 km/sec. Nomoto pointed out that the numerical simulations are still idealized and need many improvements in the microphysics.

David Gray discussed the changing nature of stellar granulation during magnetic activity cycles from an observational perspective. The conventional measure of granulation is the asymmetry in the line bisector of a photospheric spectral line; stars on the cool side of the H-R diagram have C shaped bisectors and stars on the hot side have a reversed C shape. The C shaped bisectors have very similar shapes, whereas the reversed C shaped bisectors show considerable variation. Gray used the velocity span of the asymmetry as a quantitative measure of changes in the character of surface convection over nearly a decade on epsilon Eridiani, sigma Draconis and beta Comae. The velocity span appears to be anti-correlated with both effective temperature and calcium H&K emission, with a phase shift that decreases as the convection zone deepens. Gray admitted that three stars is a small sample but pointed out that the Sun lies exactly on the trend line and suggest that further study of this effect is warranted, since a physical explanation is not yet available.

Aake Nordlund reviewed the current state of solar convection simulations on a wide range of spatial scales, from sub-granular structure up to giant cells. An important small scale feature is the occurrence of concentrated downflow regions with large fluxes of kinetic energy which are found to be inversely proportional to the specific heat at constant pressure. The results suggest that there is not a balance between enthalpy flux and kinetic energy flux in the downflows as previously suggested. Nordlund highlighted the significance of high resolution for the formation of vortex tube structures. Also on small scales, the zone of partial helium ionization is spread over a number of scale heights near the solar surface and thus does not suggest a discrete spatial scale for surface features but