3D Hydrodynamical simulations of substellar objects' atmospheres

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Description and motivation

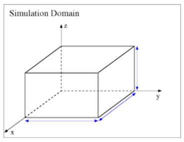
With surface temperatures below 2000K, convection is the dominant energy transport mechanism and plays a key role in the thermal structure and chemical mixing of the atmospheres of Sub-stellar Objects (SSO). Nevertheless, the mixing length theory (MLT) is still widely used as an approximation for convection.

The main aim of this work is to simulate convection in a more realistic way.

We use the FLASH Code (Fryxell, 2000) to perform 3D hydrodynamical simulations in order to study the various effects of convection in the SSO atmospheres. Since molecules form at such low temperatures and chemical processes can energetically play an important role for the onset of convection, the choice of the equation of state (EOS) is crucial.

Simulation setup

Simulation domain

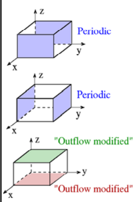


The simulation domain is a box in the upper part of the atmosphere´s convective layer.

ACES equation of state:

We have coupled to the FLASH code a realistic and detailed Equation of state (EOS), which is a module of the PHOENIX code (Hauschildt, 2010). This EOS can handle the low temperatures encountered in the sub-stellar objects' atmospheres through a detailed treatment of the physical and chemical phenomena.

Boundary conditions:



•Periodic in x and y

•Upper and lower outflow boundary conditions with fixed values for the density, energy, temperature and pressure. The values used are the results of PHOENIX/1D models (provided by Soeren Witte, private communication).

FLASH code:

For the 3D hydrodynamical simulations we are using the FLASH code (Fryxell, 2000). This code was partly developed by the DOE-supported ASC/Alliance Center for Astrophysical Thermonuclear flashes at the University of Chicago. It solves the 3D Euler equations and has been tested successfully for a wide range of hydrodynamical cases.

Preliminary results

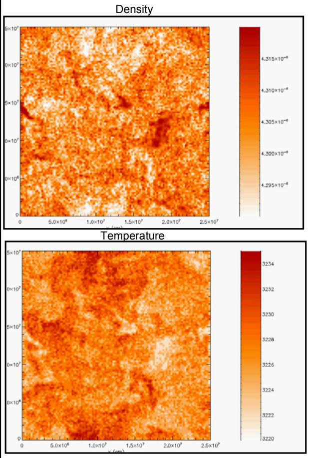


Figure 1: Horizontal slices for the density and temperature.

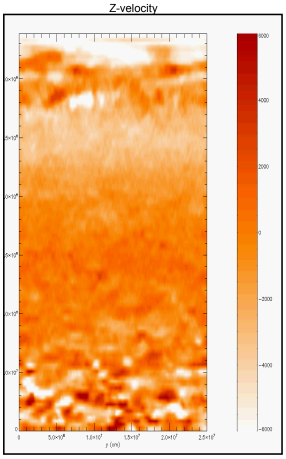


Figure 2: Vertical slice for the z-velocity

These results correspond to the simulation of an object with effective temperature of 2100 K and surface gravity of 10^3 g*cm/s^2.

In figures 1 and 2 hot and cold regions coexist at the same altitude z. Comparing the density, temperature and velocity slices it is clear that warmer and less dense regions rise while cooler and denser regions sink, a clear sign of convection. The resolution of the simulations is currently limited by the resolution of the EOS table.

Comparison with 1D PHOENIX models

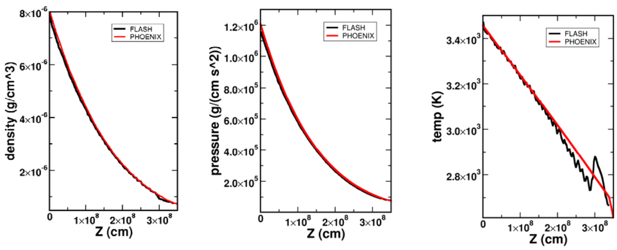


Figure 3: We plotted 1D slices of the density, pressure and temperature structures of an object with effective temperature of 2100 K and surface gravity of 10^3 g*cm/s^2 simulated with FLASH coupled with the ACES-EOS and compared them with PHOENIX/1D models (provided by Soeren Witte (private communication)).

More preliminary results

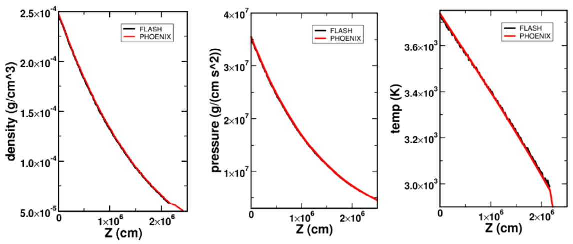


Figure 4: We plotted again 1D slices of the density, pressure and temperature structures of an object with effective temperature of 2100 K and surface gravity of 10^5g*cm/s^2 simulated with FLASH coupled with the ACES-EOS and compared them with PHOENIX/1D models.
The profiles obtained in our preliminary simulations are again consistent with the PHOENIX/1D models. The reasonable agreement between these two results is encouraging and can be interpreted as a first validation of our simulations.

Conclusions and Outlook

• We have obtained convection for a 3D hydrodynamical simulation of a substellar object's atmosphere using the FLASH code coupled with a realistic equation of state (ACES-EOS).

•Simulations with FLASH coupled with the ACES-EOS have consistent temperature, density and pressure profiles with 1D-PHOENIX models.

•The resolution of the EOS table has to be improved

•Next, we will perform simulations for a wider range of effective temperatures and surface gravities.

•We will also test and include a new FLASH radiation module (Rijkhorst, 2006).

•We will use the 3D Hydrodynamical simulations as an input for the PHOENIX/3D code to compute spectra and compare it with observations.

References

•Fryxell, B., Olson, K., Ricker, P., Timmes, F., Zingale, M., Lamb, D., MacNiece, P., Rosner, R, Truran, J. And Tufo, H., 2000: Flash: An adaptive mesh hydrodynamics code for modeling astrophysical thermonuclear flashes, *The Astrophysical Journal Supplement Series* **131**.
•Hauschildt, P. H. And Baron, E. , 2010: A 3D radiative transfer framework. VI. PHOENIX/3D example applications. *Astronomy and Astrophysics*, **509**, doi:10.1051/0004-6361/200913064
•Rijkhorst, E.J., Plewa, T., Dubey, A. And Mellema, G., 2006: Hybrid characteristics: 3D radiative transfer for parallel adaptive mesh refinement hydrodynamics. *Astronomy and Astrophysics*, **452.**

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