First light emerging from the clouds

M. Jung, R. Banerjee

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

hamburger sternwarte
Fachbereich Physik | Universität Hamburg

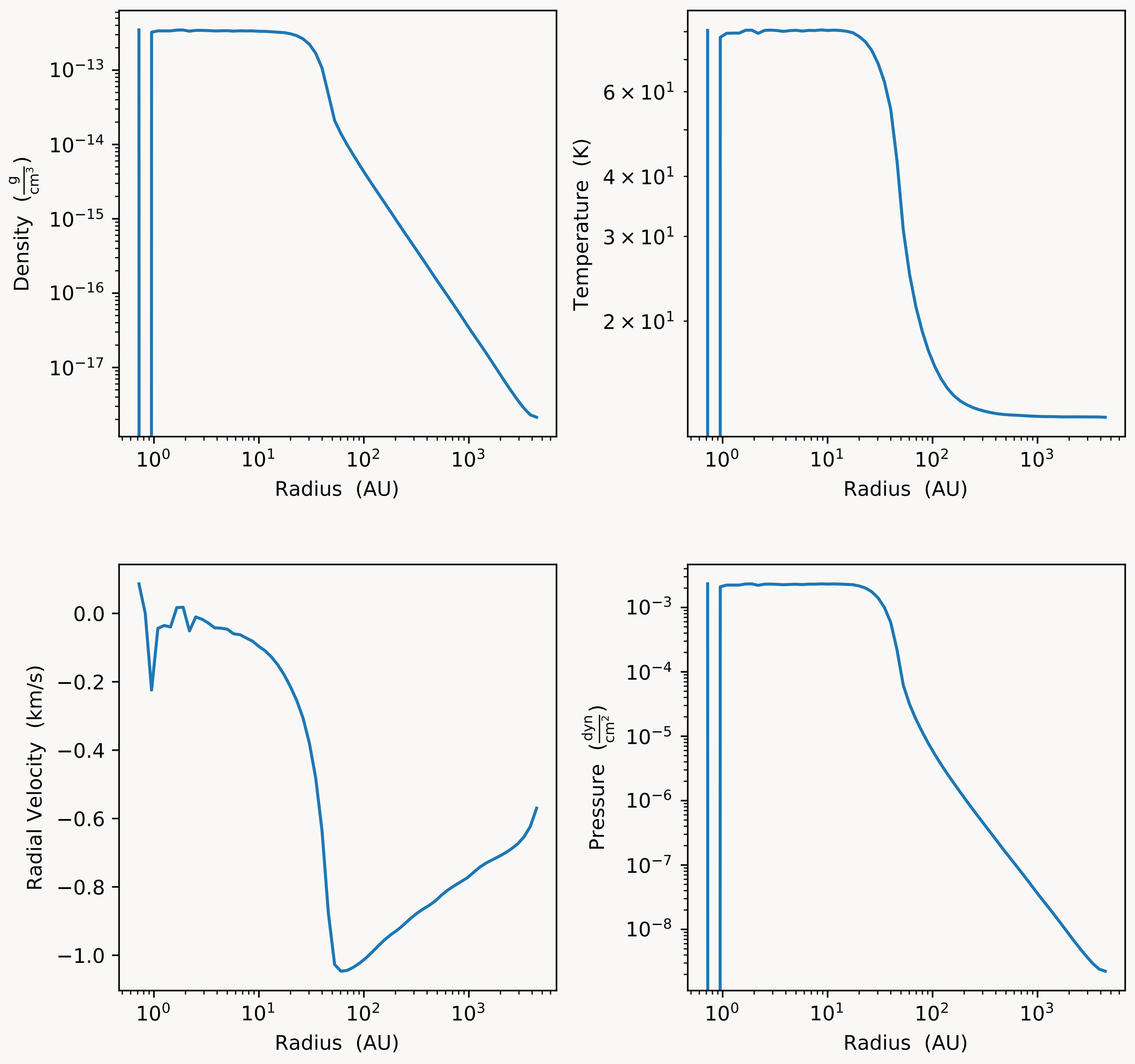
Abstract

We present first 3D cloud collapse simulations employing a hybrid characteristics radiation transfer scheme [1]. The solver is embedded in the magneto-hydrodynamics adaptive mesh refinment code FLASH [3]. We also demonstrate a star formation evolution model [6], which supports the generation of a sink particle [2] at later collapse stages with a suitable sub-grid model.

Cloud collapse

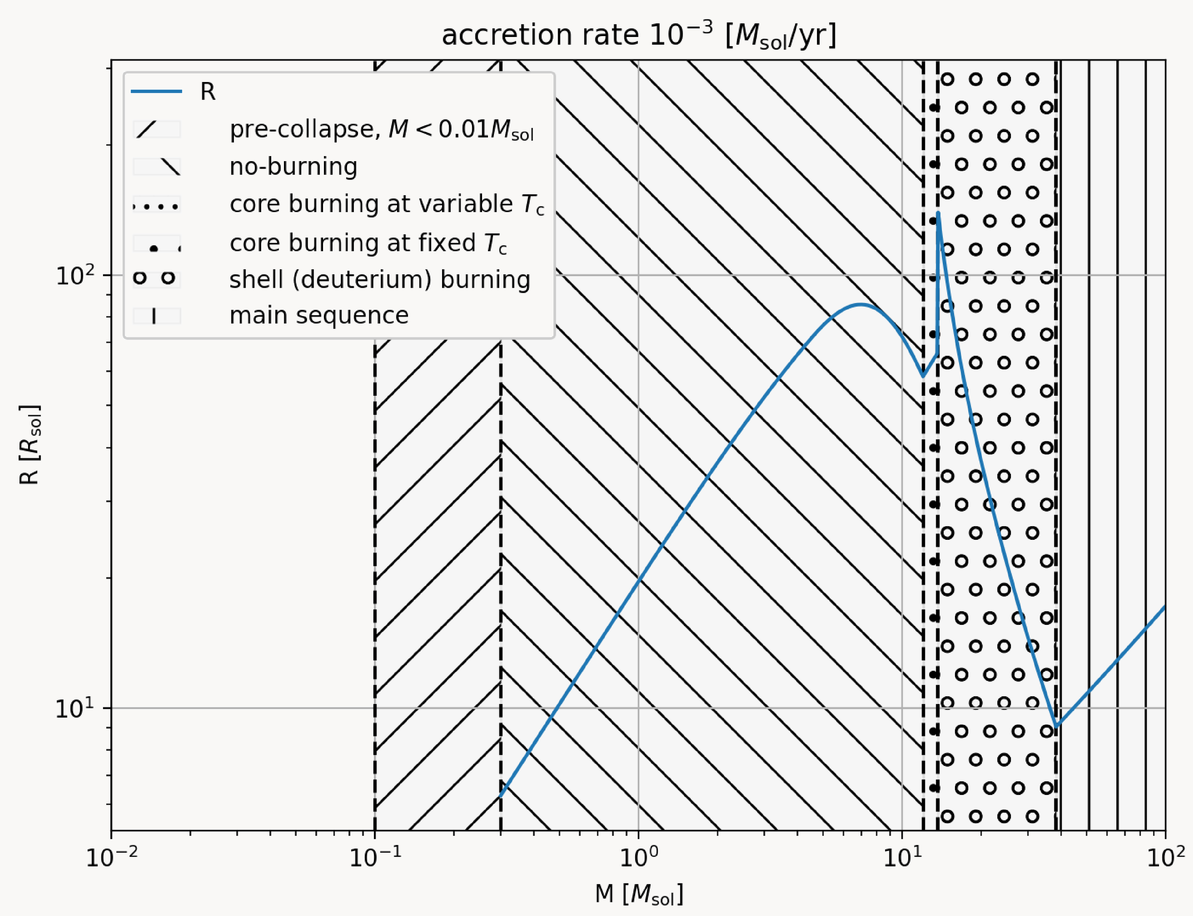
In this simulation we follow the collapse of a low mass cloud until the first hydrostatic core forms. We use a tree based self-gravity solver and the 3D radiation transfer scheme. Since the 3D setup is spherical symmetric, the figure shows the 1D profiles of charateristic quantities.

- simulation box $9450^3\,\mathrm{AU}^3$
- homogeneous density, $M_{\mathrm{total}} = 1.96\,\mathrm{M}_{\mathrm{sol}}$
- outflow boundary conditions
- 10 K background radiation
- angular velocity $\Omega = 0\,\mathrm{rad/s}$
- free fall time $\tau_{\mathrm{ff}} = 56.67\,\mathrm{kyr}$



Protostellar evolution model

At some point in a adaptive mesh refinement collapse simulation, the resolution has to be limited. To follow the star formation further typically [4, 7, 6] a sink particle is created. If we couple the accretion rate onto the sink particle with a protostellar evolution model [6, 5], we are able to assign a radius and luminosity to the sink particle, which now models a young stellar object. Here we show the stellar radius evolution for a constant accretion rate in our protosteller evolution model implementation.



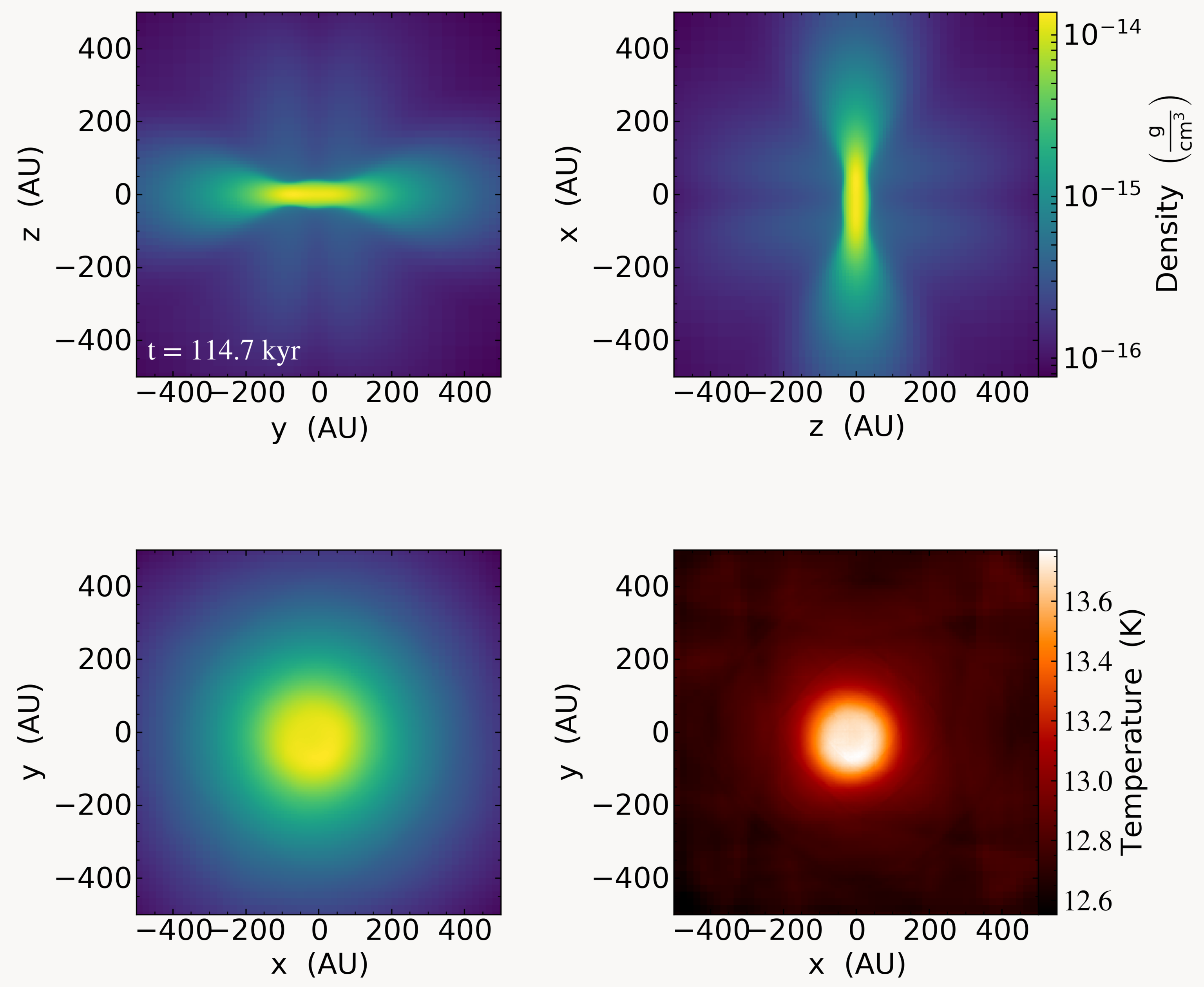
Conclusion

- A cloud collapse evolution can be followed successfully until the first hydrostatic core is formed
- A protostellar evolution model has been implemented and tested

As the next step we will follow the collapse further until the second hydrostatic core is formed and a protostar is ignited.

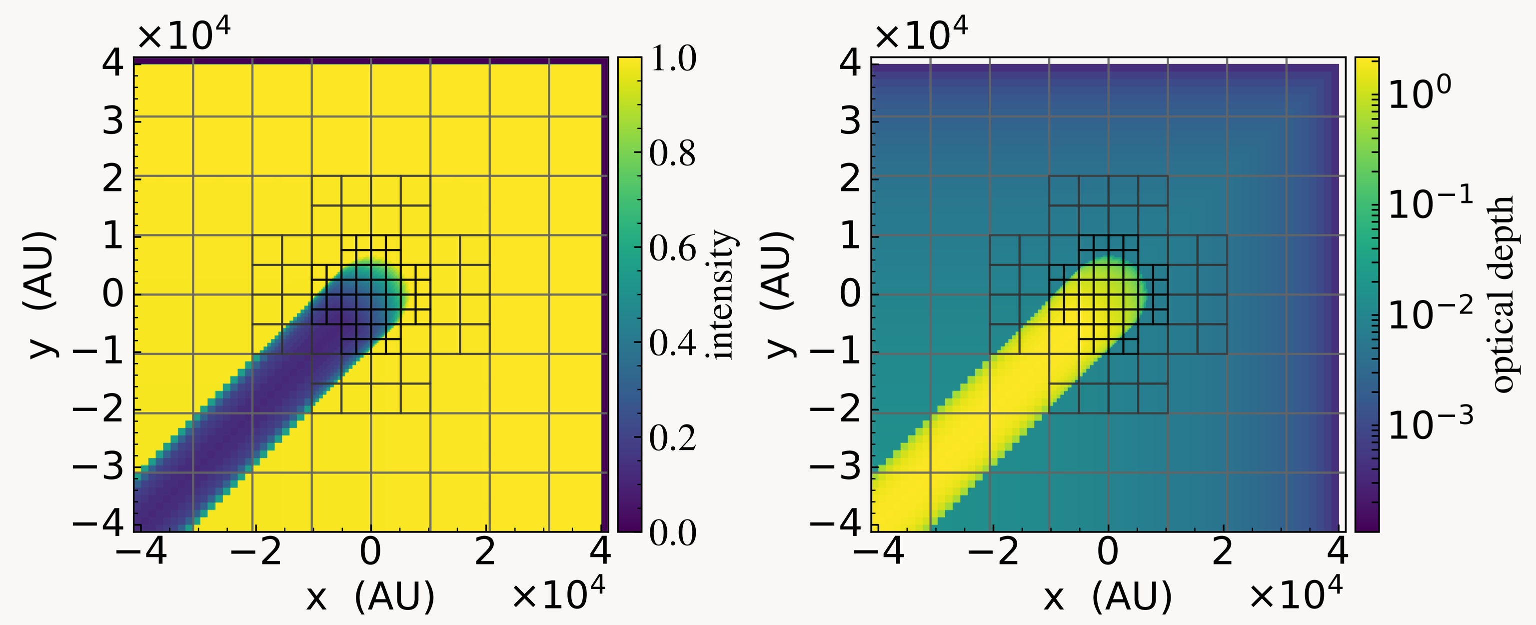
Cloud collapse with rotation

If an angular velocity of $\Omega = 1.886 \cdot 10^{-13}$ rad/s is added to the initial gas distribution, early disk formation can be observed.



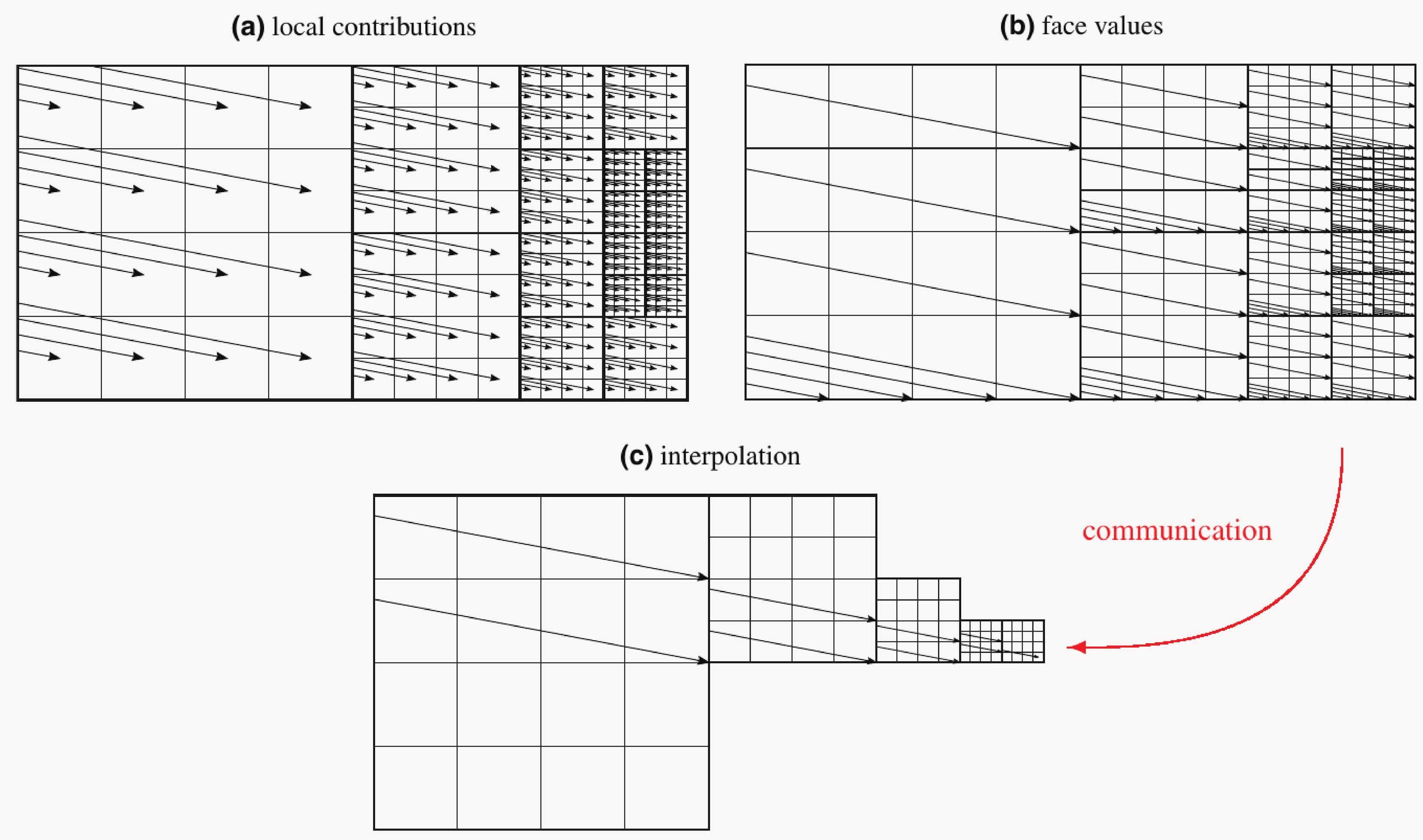
Shadow test

The shadow test shows the illumination of a dense clump by two elongated light sources along the lower x- and y-boundaries. Only rays in the $(-1, -1, 0)$ direction are calculated.

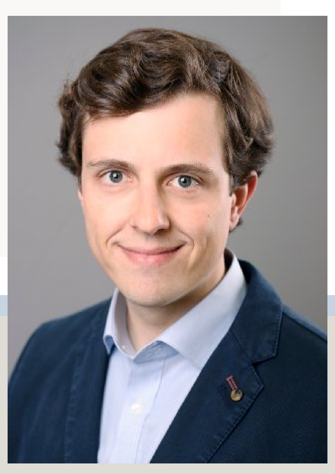


Hybrid characteristics

The basic functionality of the hybrid characteristics method [8, 1] in an AMR environment. The local contributions (a) are calculated along long characteristics for the cell centers. Face values (b) are calculated for communication with other blocks. At refinement boundaries (c) linear interpolation is used.



[1] Buntemeyer, L., Banerjee, R., Peters, T., Klassen, M., and Pudritz, R. E.: 2016, *New Astronomy* 43, 49
[2] Federrath, C., Banerjee, R., Clark, P. C., and Klessen, R. S.: 2010, *The Astrophysical Journal* 713, 269
[3] Fryxell, B., Olson, K., Ricker, P., Timmes, F. X., Zingale, M., Lamb, D. Q., MacNeice, P., Rosner, R., Truran, J. W., and Tufo, H.: 2000, *The Astrophysical Journal Supplement Series* 131, 273
[4] Klassen, M., Pudritz, R. E., Kuiper, R., Peters, T., and Banerjee, R.: 2016, *The Astrophysical Journal* 823, 28
[5] Klassen, M., Pudritz, R. E., and Peters, T.: 2012, *Monthly Notices of the Royal Astronomical Society* 421, 2861
[6] Offner, S. S. R., Klein, R. I., McKee, C. F., and Krumholz, M. R.: 2009, *The Astrophysical Journal* 703, 131
[7] Raskutti, S., Ostriker, E. C., and Skinner, M. A.: 2016, *The Astrophysical Journal* 829, 130
[8] Rijkhorst, E.-J., Plewa, T., Dubey, A., and Mellema, G.: 2006, *Astronomy and Astrophysics* 452, 907



Manuel Jung
manuel.jung@hs.uni-hamburg.de
Hamburg Observatory