Typical Scales of Structures in Numerical Models of Betelgeuse

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Abstract

3D radiation hydrodynamics simulations of the envelope and atmosphere of a red supergiant show giant convection cells with sometimes deep-reaching downdrafts. Smaller short-lived cells can appear in the very outer layers. The surface intensity pattern is affected not only by convective motion but also by waves and differs considerably from that of the Sun.

Efforts are going on to disentangle the processes contributing to the complex surface structures seen in the models with the help of 3D visualization tools. The dependence of model properties on input parameters and e.g. the numerical resolution are investigated. With the poster we will try to give an idea about the spatial structure of the convective envelope of the models.

Introduction

The spatial inhomogeneities on the surface of Betelgeuse revealed by interferometric observations are typically modelled as zero to three hot spots on a circular disk. While the surface structure appears to be generally consistent with an explanation (given by Schwarzschild 1975) as large-scale granular intensity fluctuations, the very nature of the spots remains unclear.

Numerical simulations are very successful in modelling solar granulation: they reproduce observations of line profiles with good accuracy (e.g. the talk by Martin Asplund) and provide insight into the detailed structure and dynamics of the surface layers of the Sun (see e.g. the poster by Sven Wedemeyer et al.). Similar 3D radiation hydrodynamics simulations with the newly developed code COBOLD are performed to model an entire red supergiant as "star-in-a-box": Matter in a prescribed spherical potential is heated from the inside. Radiation and convection transport energy to the radiatively cooled surface. The non-local radiation transport uses realistic (but grey) opacities. The equation of state accounts for the ionization of hydrogen and helium (for some more details see the poster of Bernd Freytag & Michelle Mizuno-Wiedner).

In this poster we compare the structure of two models with different numerical resolution and viscosity settings (both: $5\,M_\odot$, $\approx 630\,R_\odot$):

model	grid	reconstruction	viscosity
st35gm04n03 (LOWRES)	127^3	MinMod	1.2
st35gm04n06 (HIRES)	171^3	VanLeer	0.6

The images to the right are rendered with 3D visualization tools written in IDL. These tools are part of Sigurður Finnssons project work for his Master of Science thesis.

Conclusions

- Both LOWRES and HIRES models only have few giant envelope convection cells, see Fig.3 and Fig.7.
- The surface of the giant envelope convection cells can decay into smaller cells with shorter lifetimes, see Fig.6.
- Convection cells are not easily visible in the surface intensity.
- Waves, shocks, and non-radial pulsations play an important role for the structure formation on the surface.
- Extended high-contrast dark spots or bright features occur in the LOWRES as well as in the HIRES model, see Fig.1 and Fig.4.

Low resolution model

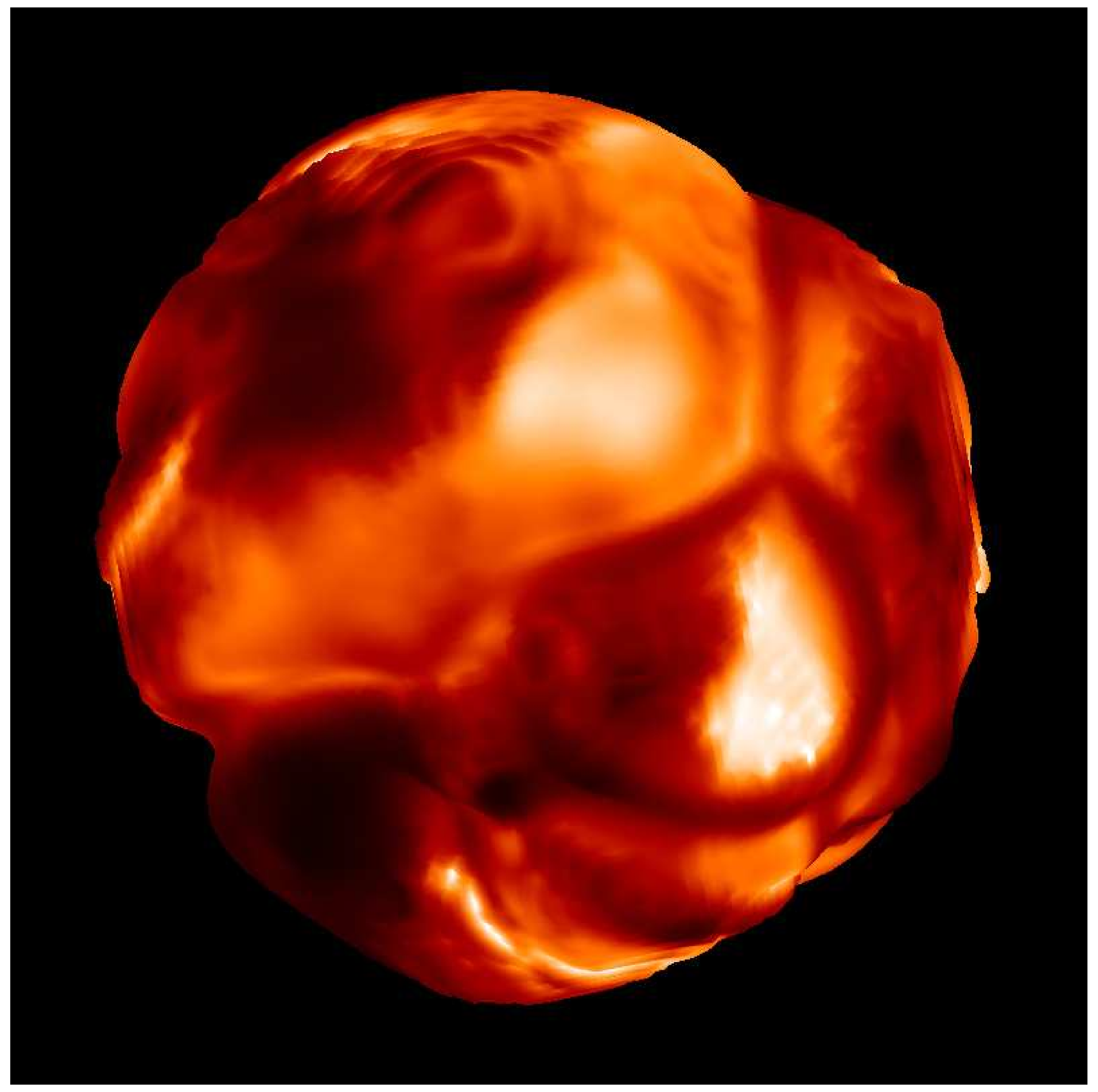

Figure 1: Dataset "st35gm04n03_22.full n=0 (LOWRES)". The temperature (actually T^4) at optical depth unity of a snapshot from the LOWRES run shows dark and bright areas. The outline of the convective cells is only dimly discernible. Compare with a similar image from the HIRES run in Fig. 4.

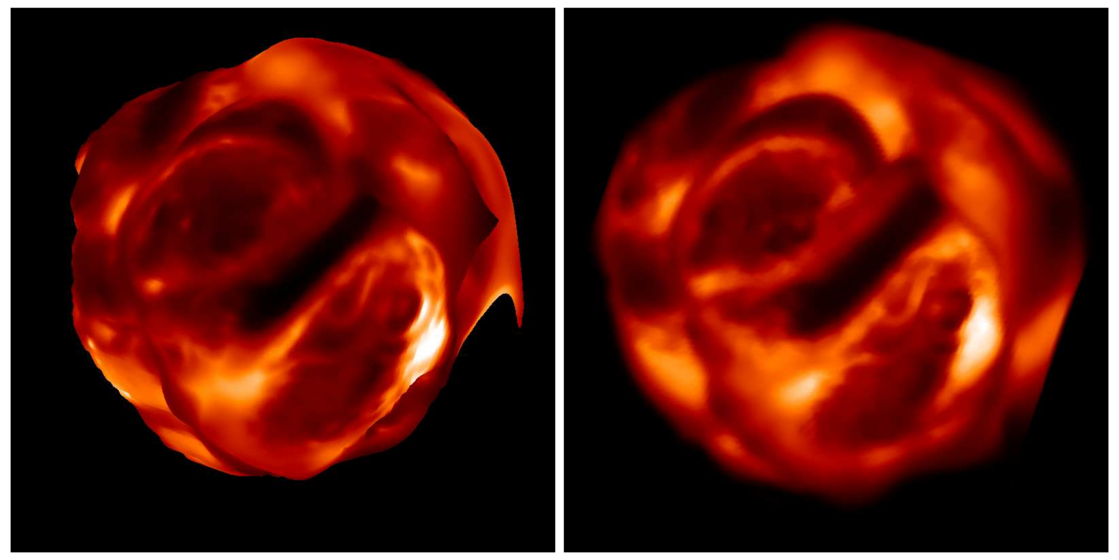

Figure 2: Dataset "st35gm04n03_20.full n=0 (LOWRES)". This pair of images compares T^4 at τ=1 (left) with the intensity computed from the radiation transport module within COBOLD (note that some edges are slightly cut off compared to the left image). The same view is shown in Fig. 3 (right) where the position of the convective cells become clearer.

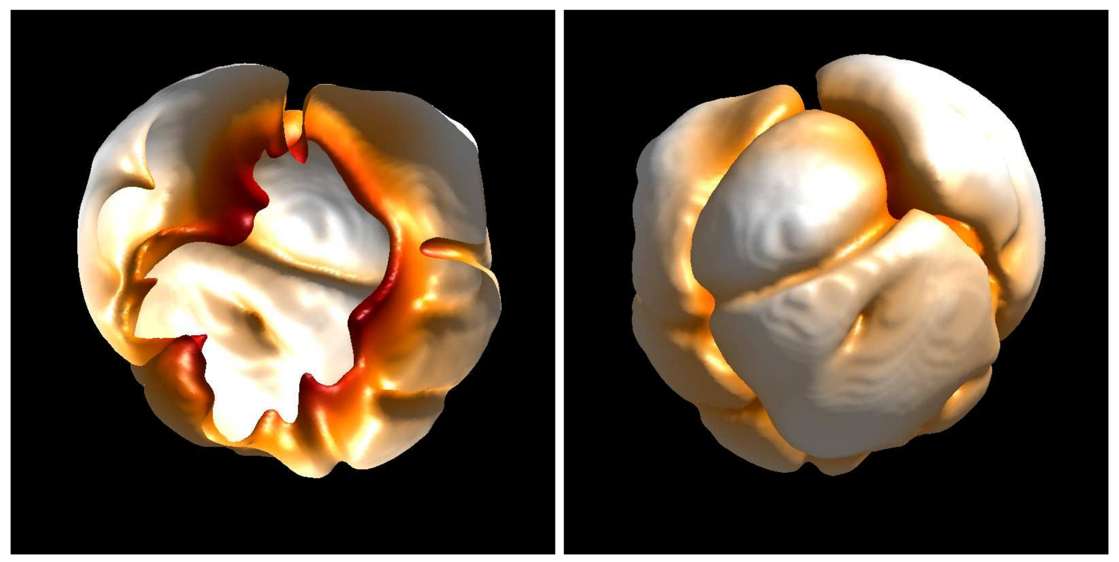

Figure 3: Dataset "st35gm04n03_20.full n=0 (LOWRES)". The left image shows an isosurface of the entropy seen "from the inside". The radius is used for color coding and the star is cut in half. The right image shows the same data seen properly from the outside (same view as in Fig. 2.)

High resolution model

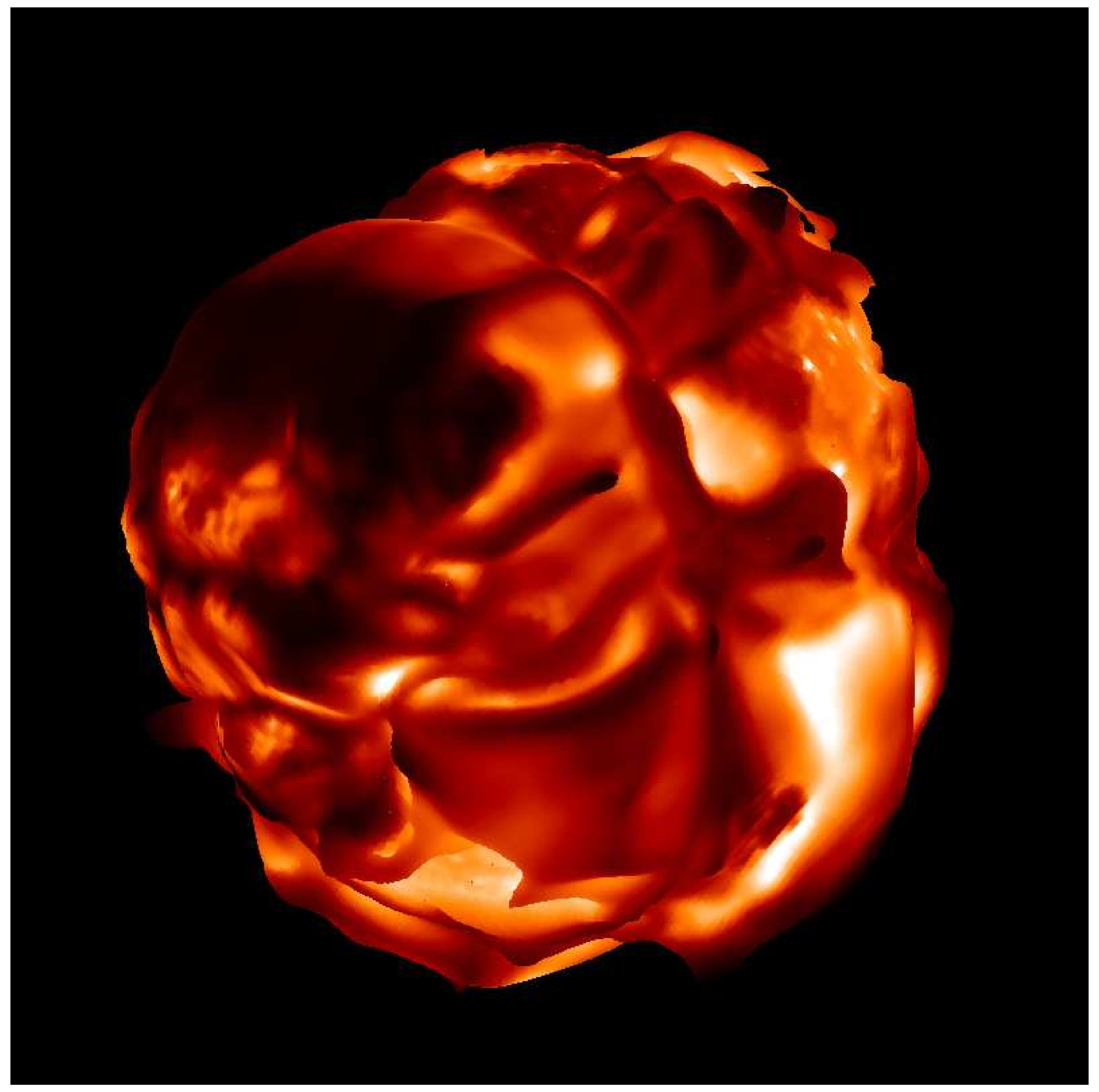

Figure 4: Dataset "st35gm04n06_14.full n=3" T^4 at τ=1 of a snapshot from the HIRES run shows structures on a finer scale than a similar image from the LOWRES run in Fig. 1. Still, dark and bright features can extend over a significant fraction of the surface.

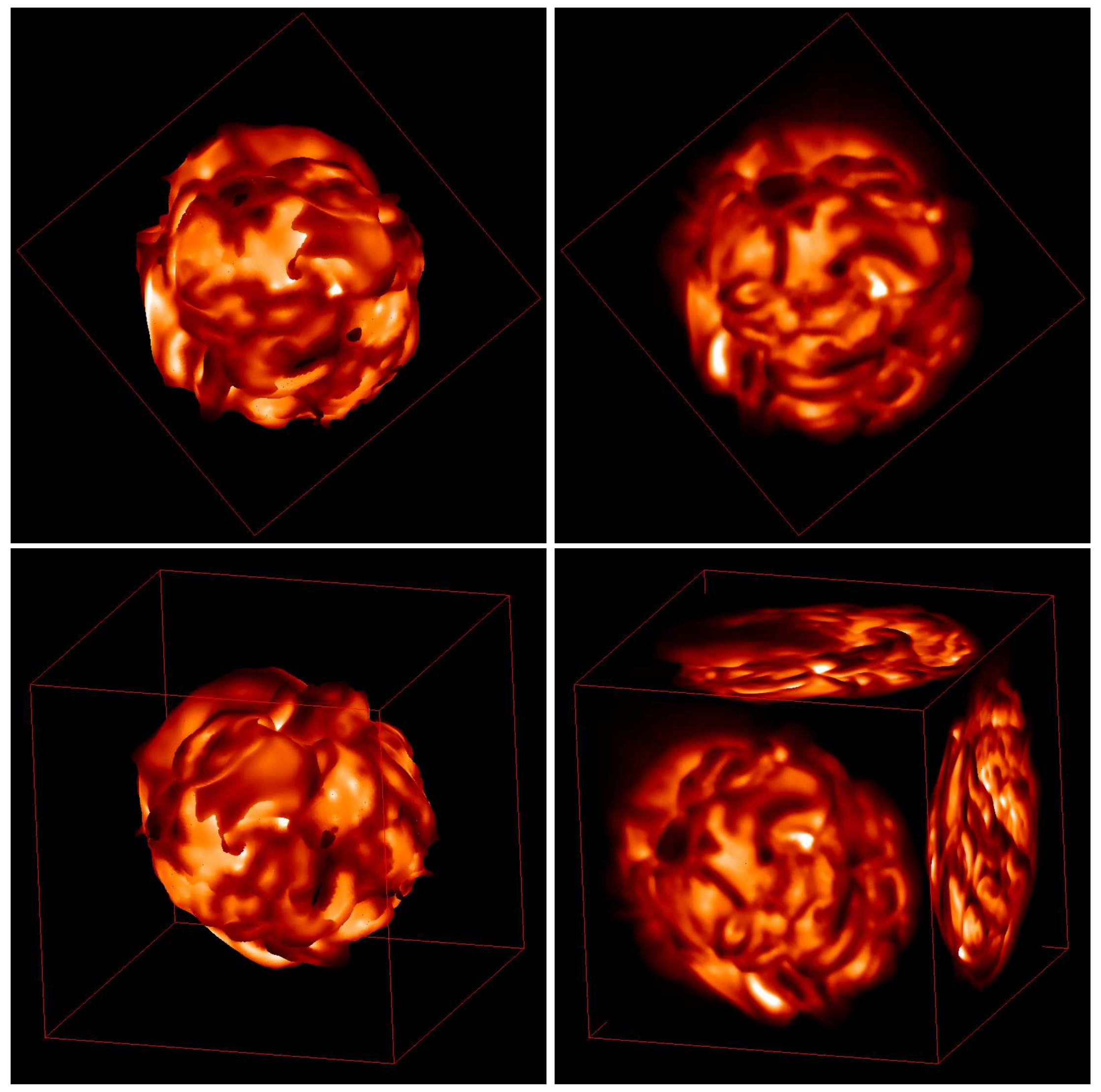

Figure 5: Dataset "st35gm04n06_14.full n=3 (HIRES)". These images compare T^4 at τ=1 (left) with the intensity (right) computed from the radiation transport module within COBOLD as in Fig. 2 for the LOWRES model. The radiation transport module calculates the intensity as seen from six directions, here these six views are mapped on each side of a box for comparison with the isosurface. The images in the bottom panel show the box slightly rotated. The top view corresponds to the view in figures 6 to 8.

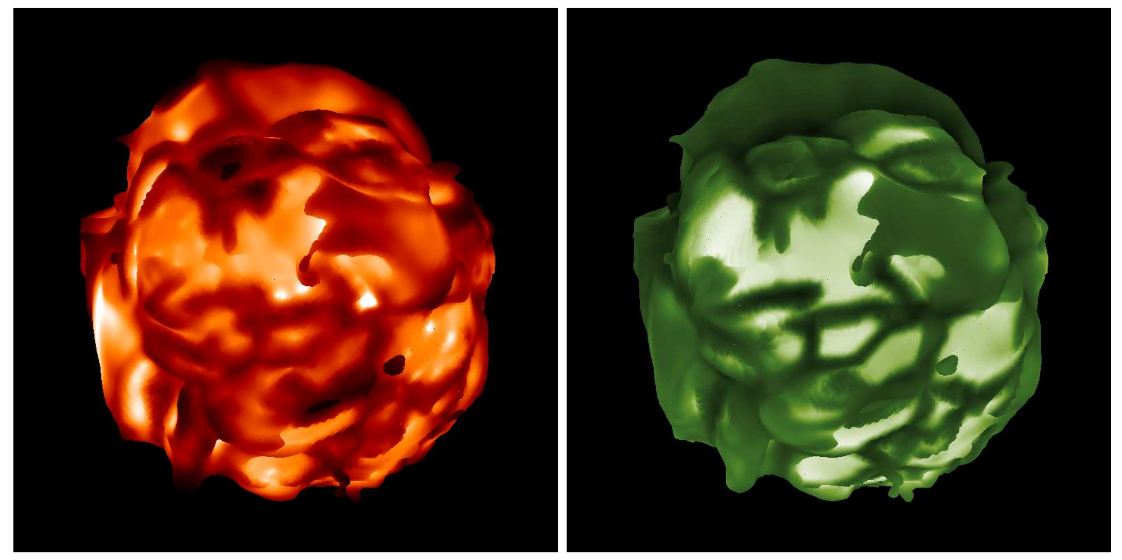

Figure 6: Dataset "st35gm04n06_14.full n=3 (HIRES)". This pair of images compares T^4 at τ=1 (left) with the radial velocity at τ=1 (right, light green means outward flow). On parts of the surface the correlation between intensity and velocity is obvious. Small cells do not brighten individually but in groups with relatively short lifetimes. Sometimes wave-like bright features travel over the surface. The intensity pattern reflects the convective cells to a much lower degree than on the Sun.

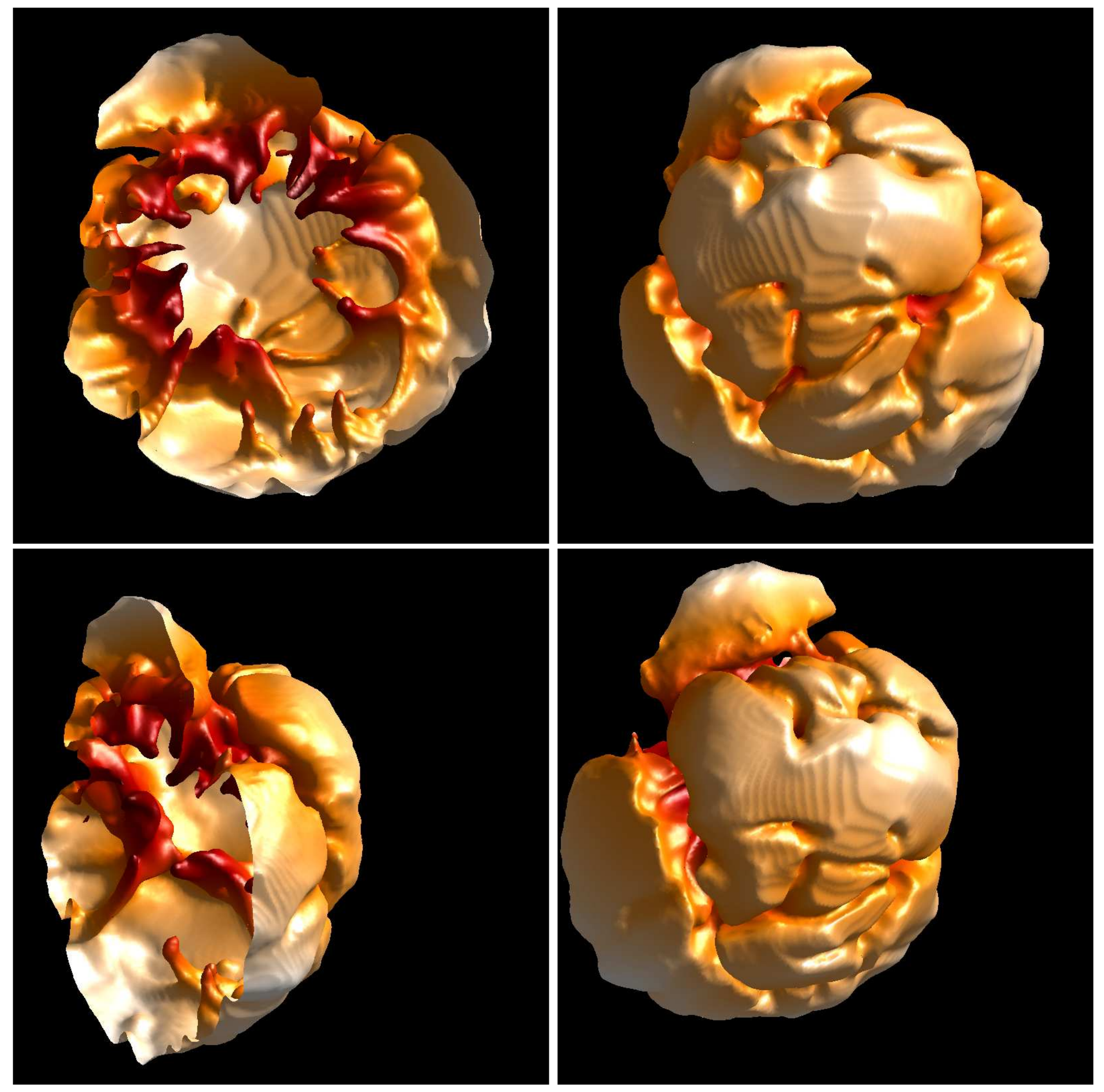

Figure 7: Dataset "st35gm04n06_14.full n=3 (HIRES)". Top left image shows an isosurface of the entropy seen "from the inside". The radius is used for color coding and the star is cut in half. Top right image shows the same data seen properly from the outside. Bottom images show intermediate angles. There are more and smaller cells than in the LOWRES model (compare Fig. 3). Still, the interior downdrafts seem to form groups with much larger scales than those in Fig. 3 even if they have finer structures.

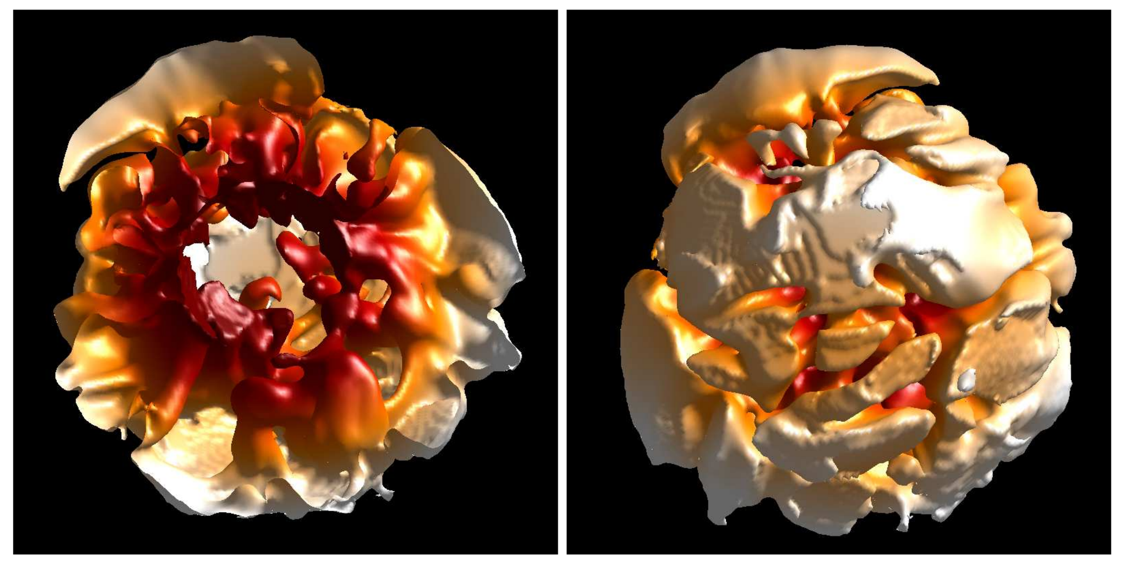

Figure 8: Dataset "st35gm04n06_14.full n=3 (HIRES)". These images show an isosurface of the outward radial velocity (at 1 km/s) seen from the inside (left, core is cut away) and from the outside (right). The radius is used for the color palette. Data above isosurface of τ=1 has been cut away. As in the same view of the isosurface of the entropy (Fig. 7 top) small surface cells and the ring of downdrafts in the interior are clearly visible.