# Neutrino-Driven Convection in Stalled Supernova Cores

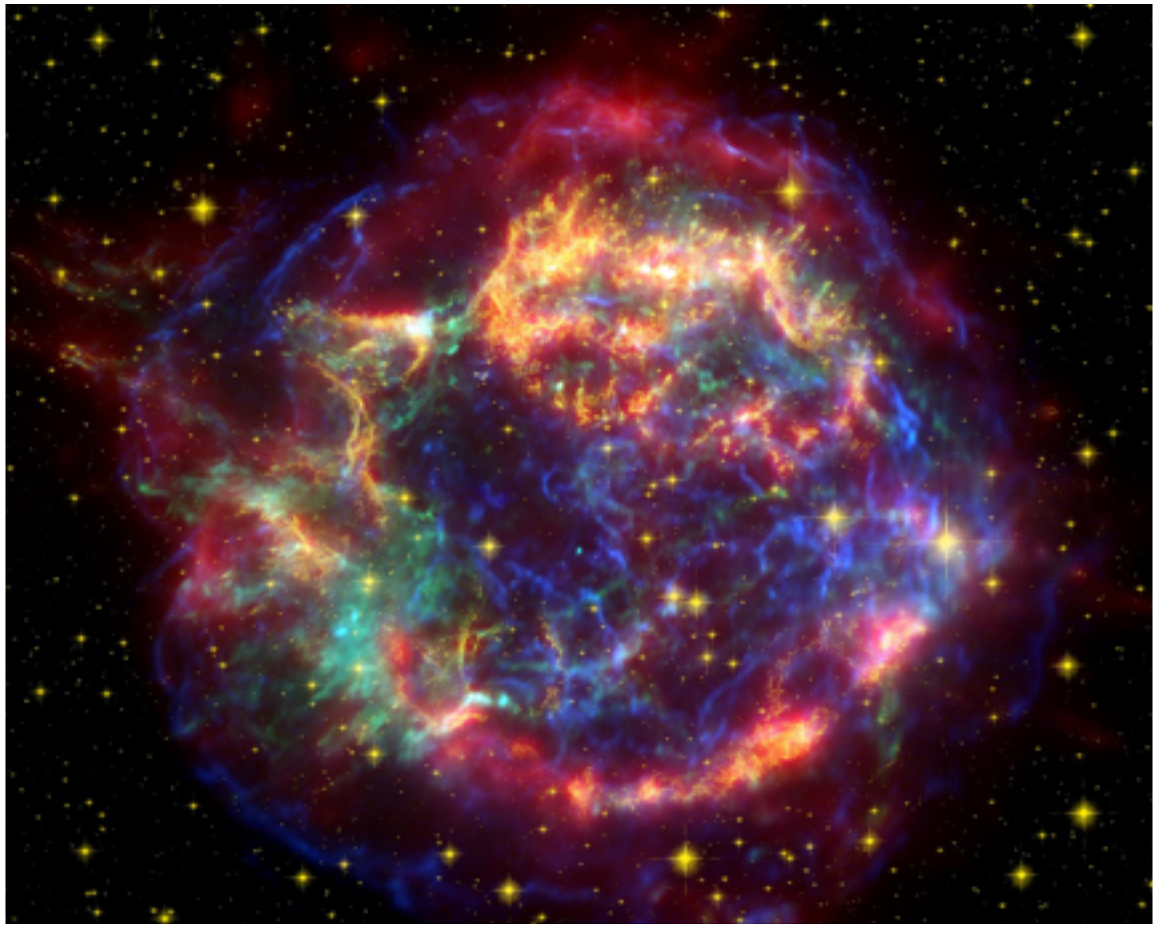
MICRA, Stockholm 2015

David Radice[1]

[1] Walter Burke Fellow, TAPIR, California Institute of Technology

Collaborators: E.Abdikamalov, S.Couch, R.Haas, C.Ott, E.Schnetter

# The Supernova Problem



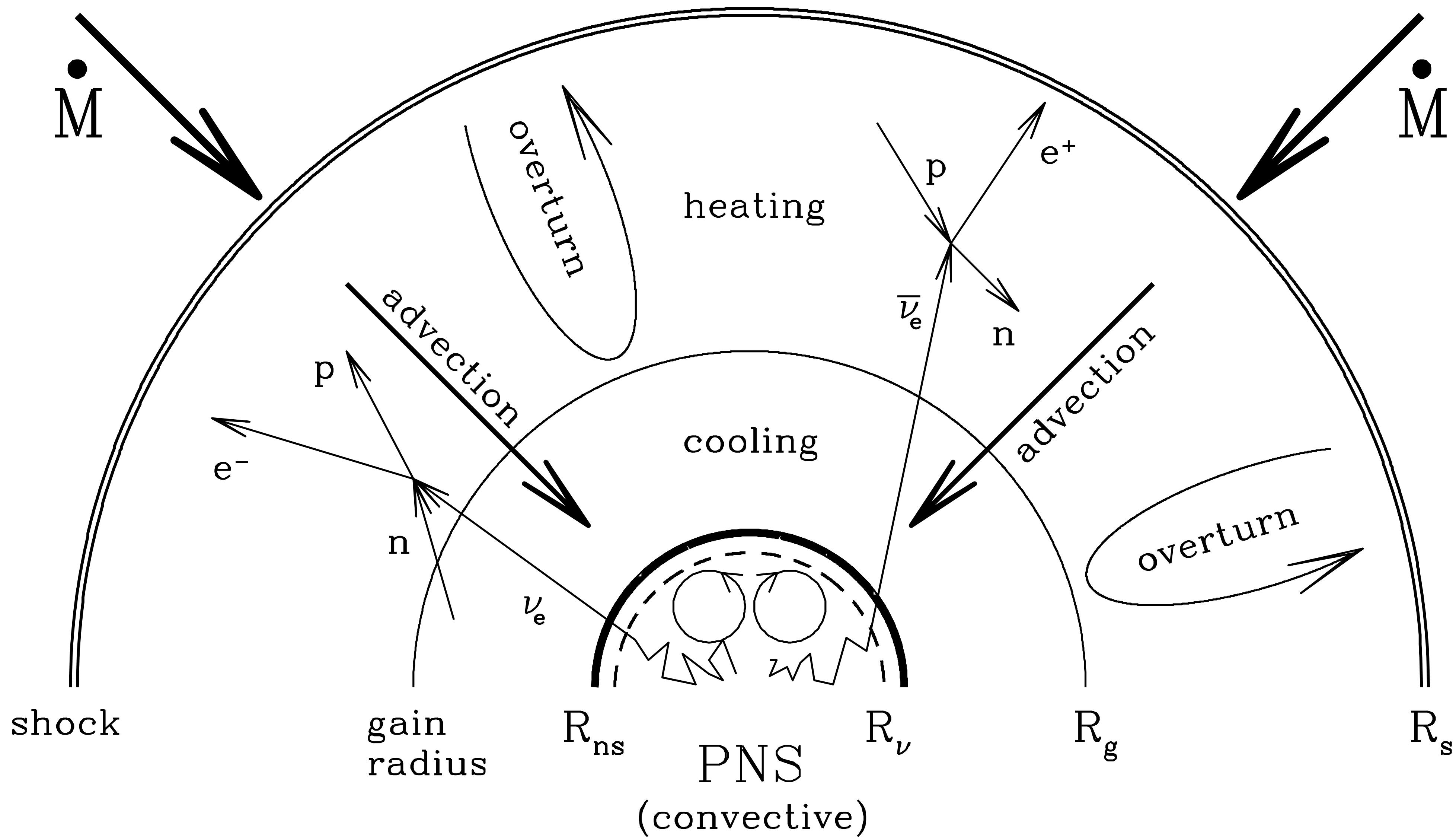
Cassiopeia-A

Core-Collapse Supernovae:

- End of massive stars
- Birthplace of heavy elements, neutron stars, black holes …
- Regulate star formation
- …

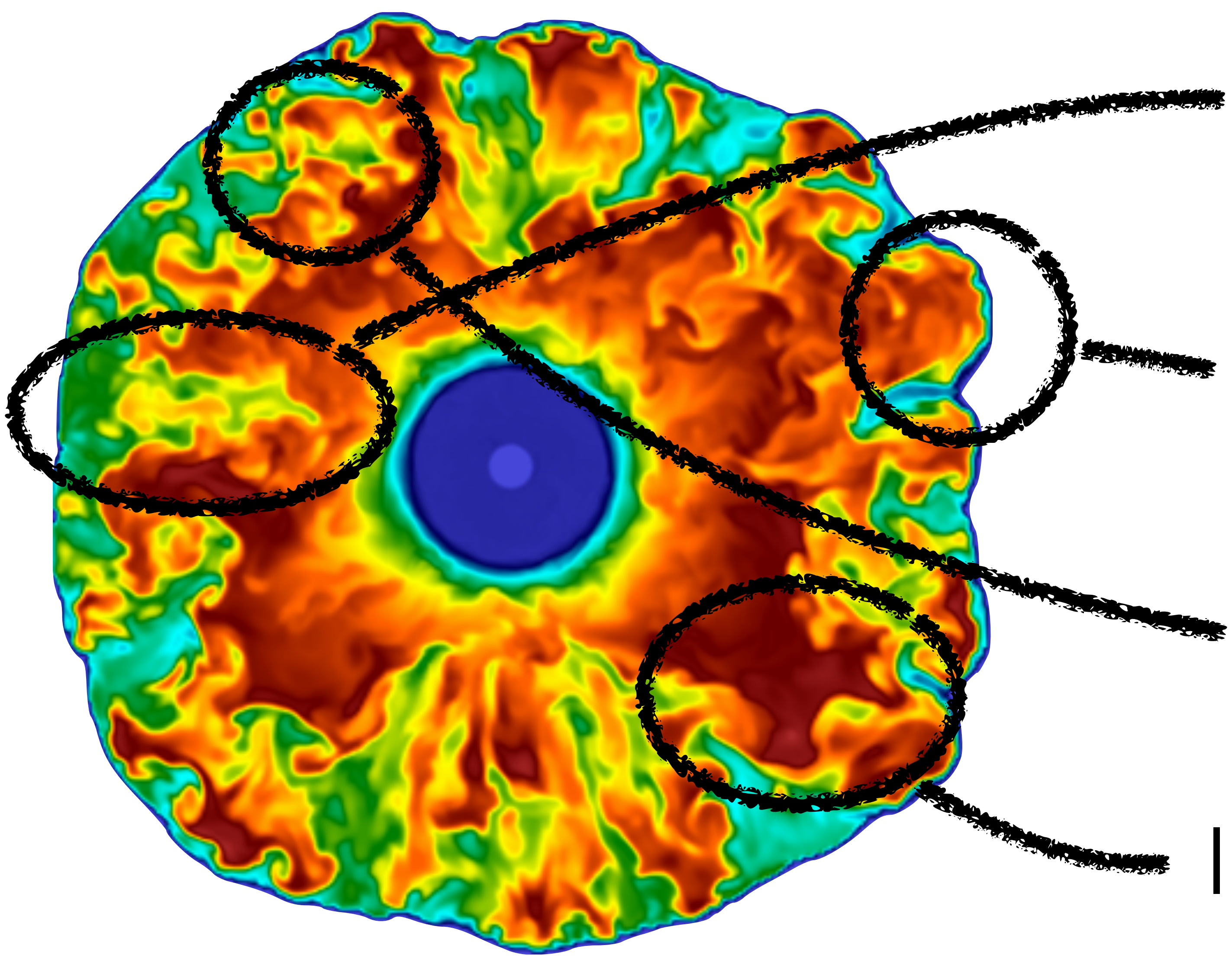
Problem: how do they explode?

# Shock Revival by Neutrinos




From Janka 2001

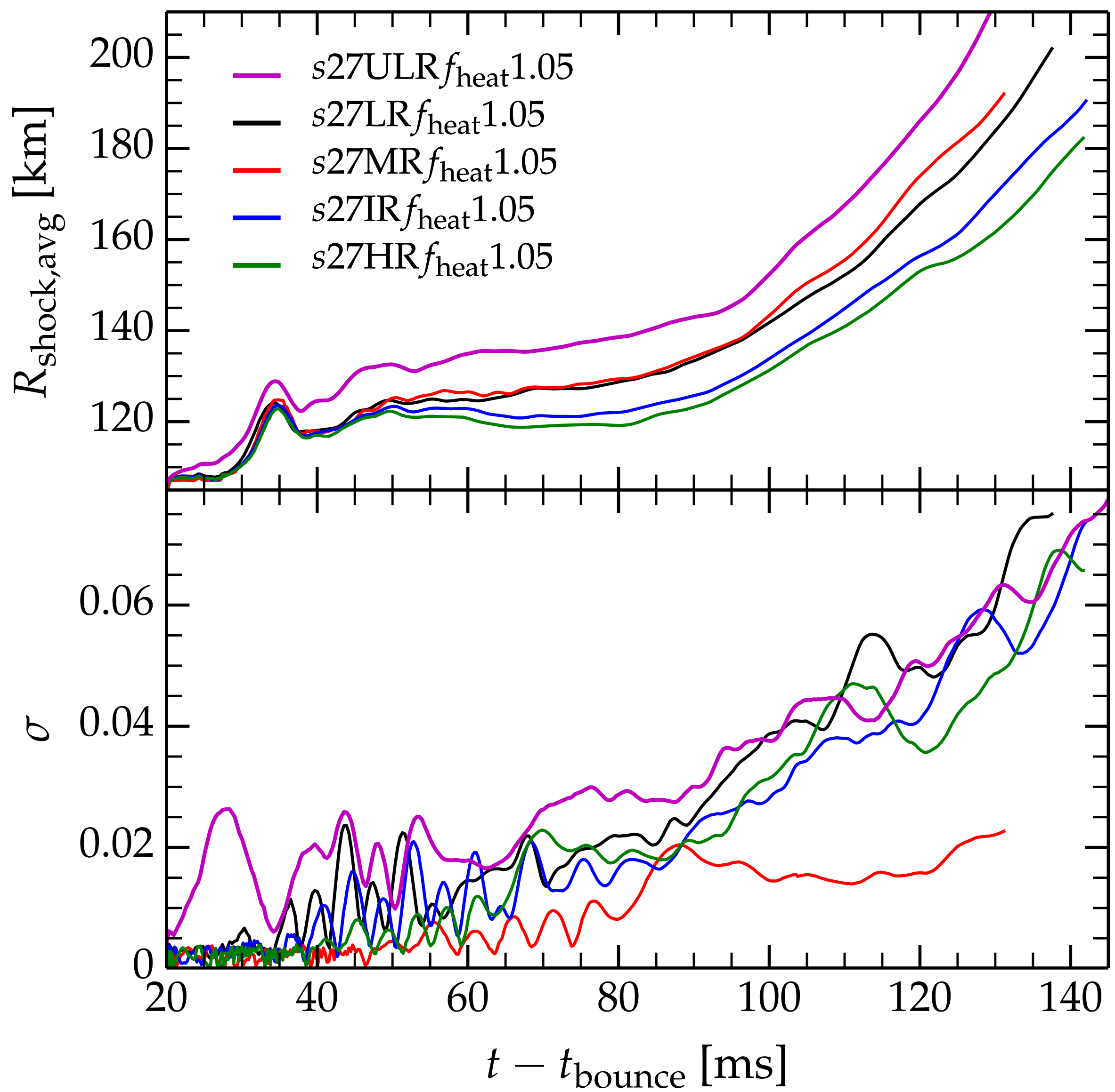
# The Roles of Turbulence




Difficult to simulate!

See talk by Takiwaki

# Resolution Dependance



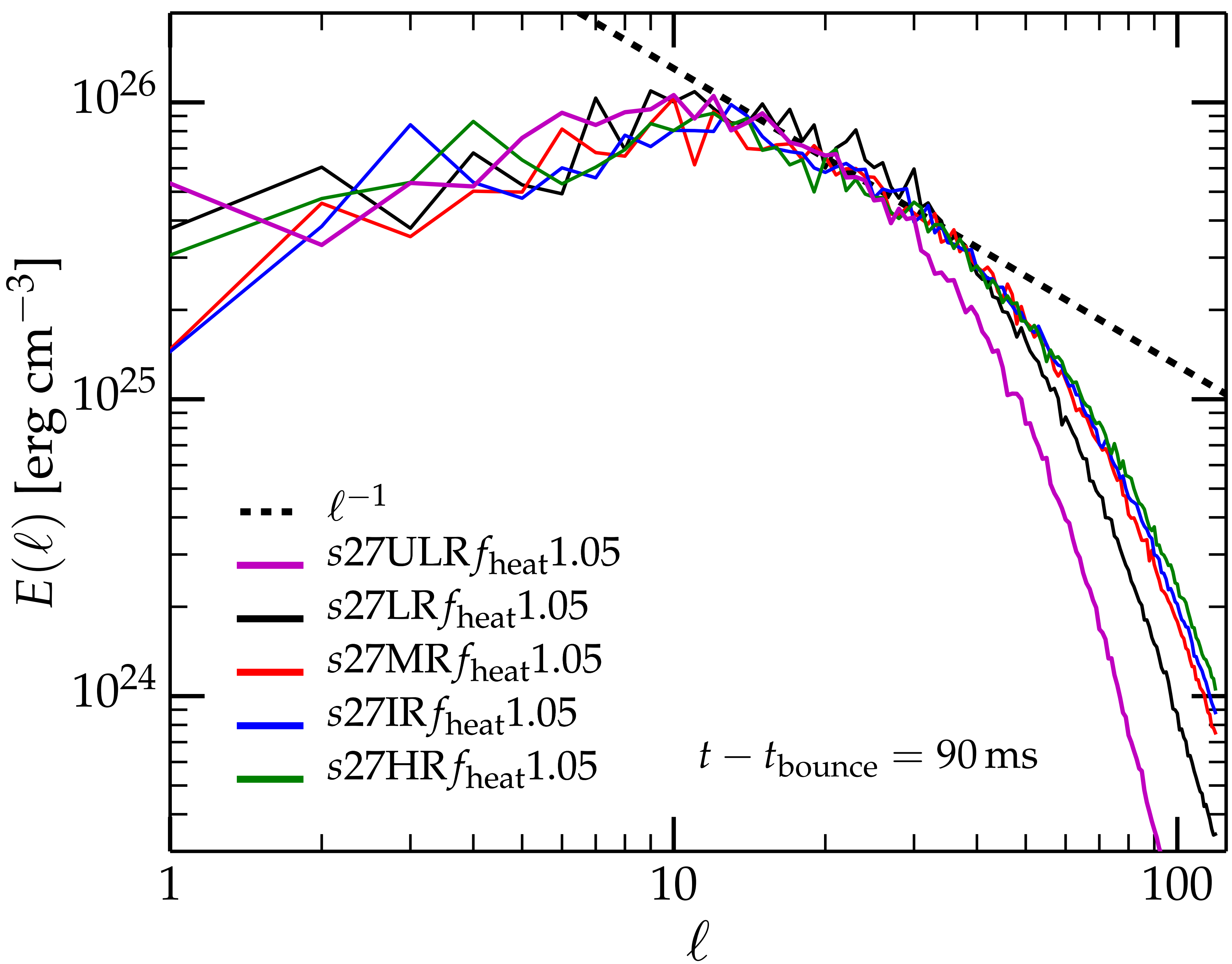

From Abdikamalov et al. 2015

| | |
|---|---|
| ULR | 3.78 km |
| LR | 1.89 km |
| MR | 1.42 km |
| IR | 1.24 km |
| HR | 1.06 km |

Resolutions

Explosion more difficult at higher resolution!

# Turbulent Energy Spectrum

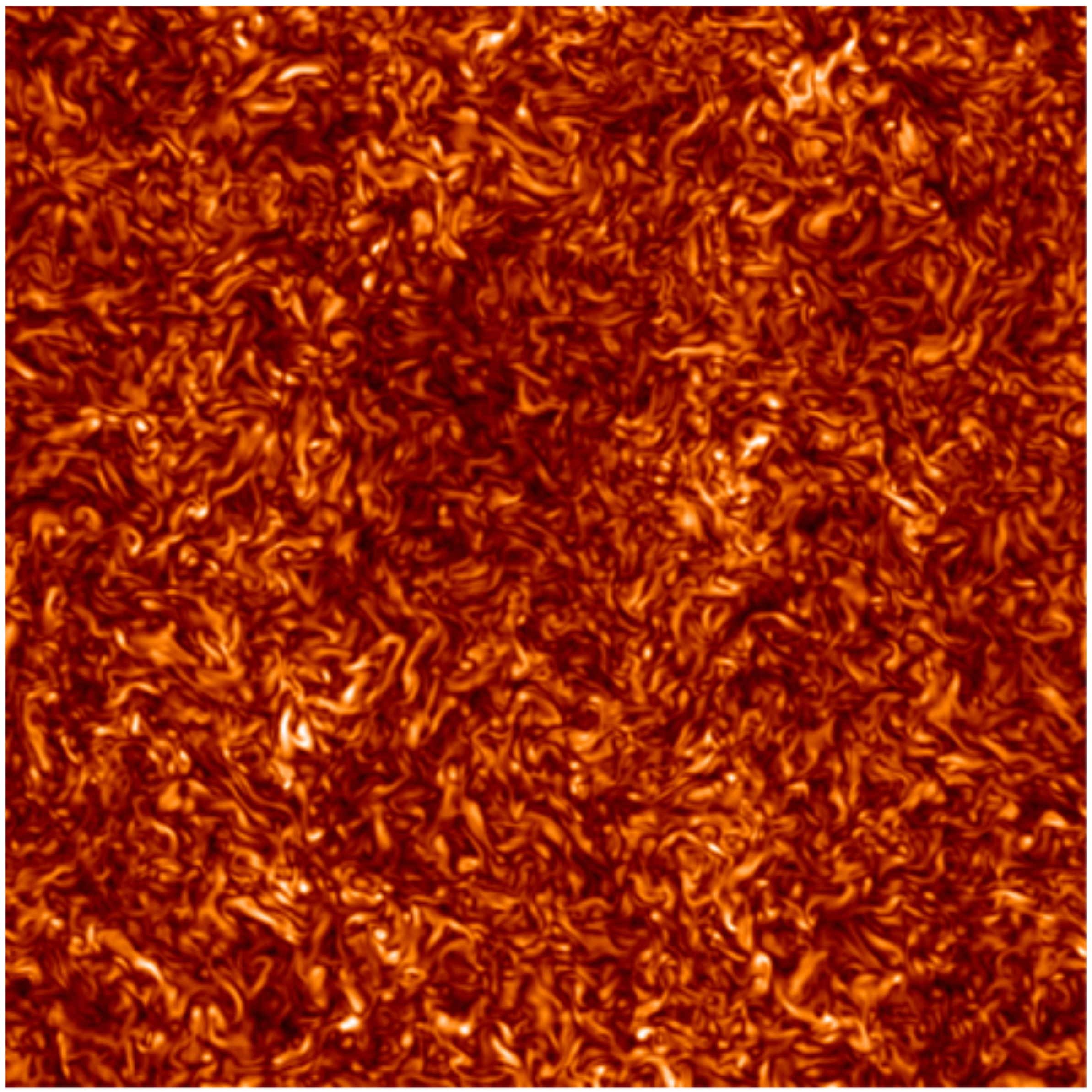


# Open Questions

- When is the resolution good enough?
- How does neutrino-driven convection work?
- What is the main role of turbulence?

Our approach: local and semi-global simulations

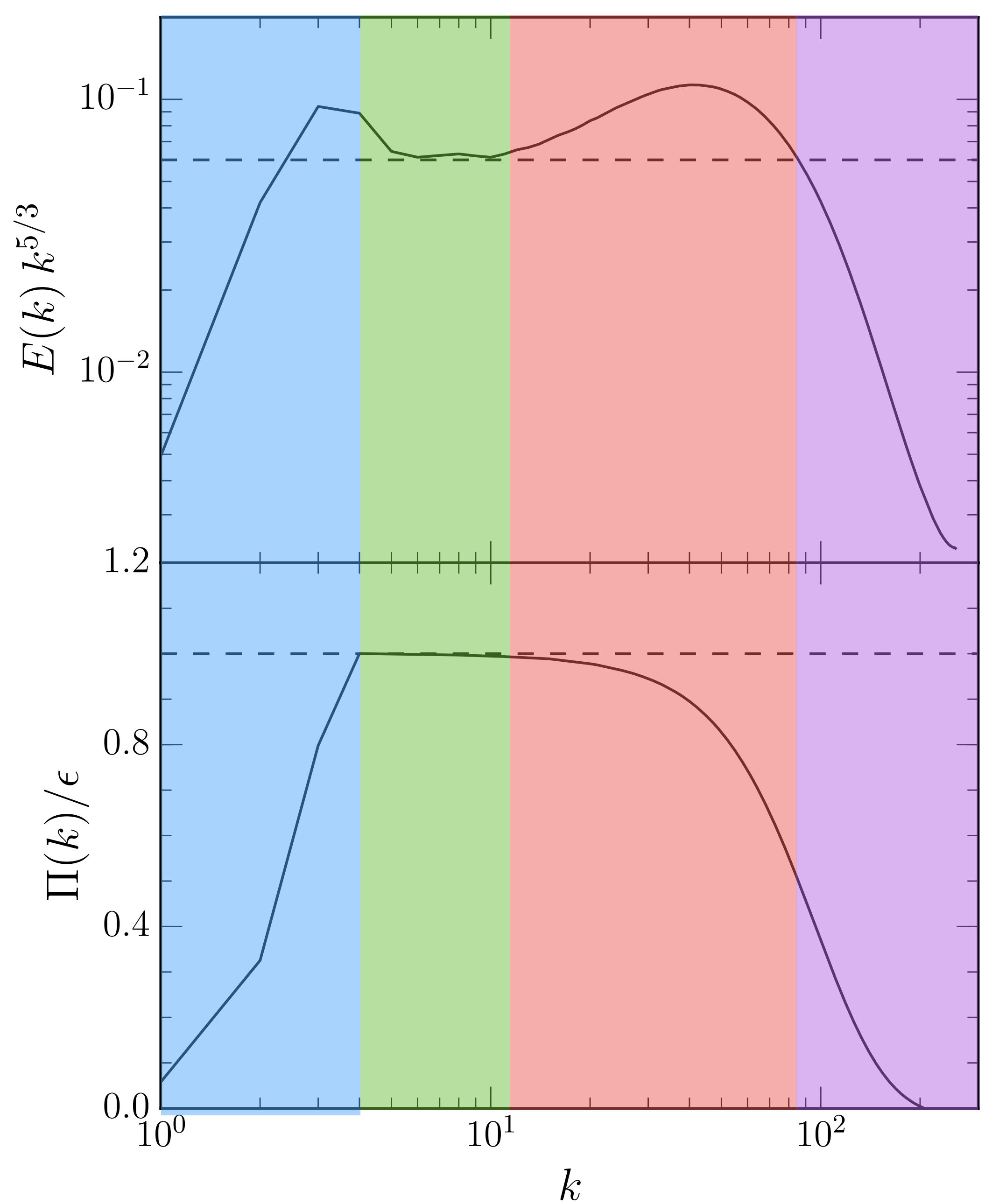
# Local Simulations



PPM+HLLC, $N=512^3$, Vorticity

- Periodic box
- Anisotropic
- Mildly compressible
- Compare different methods

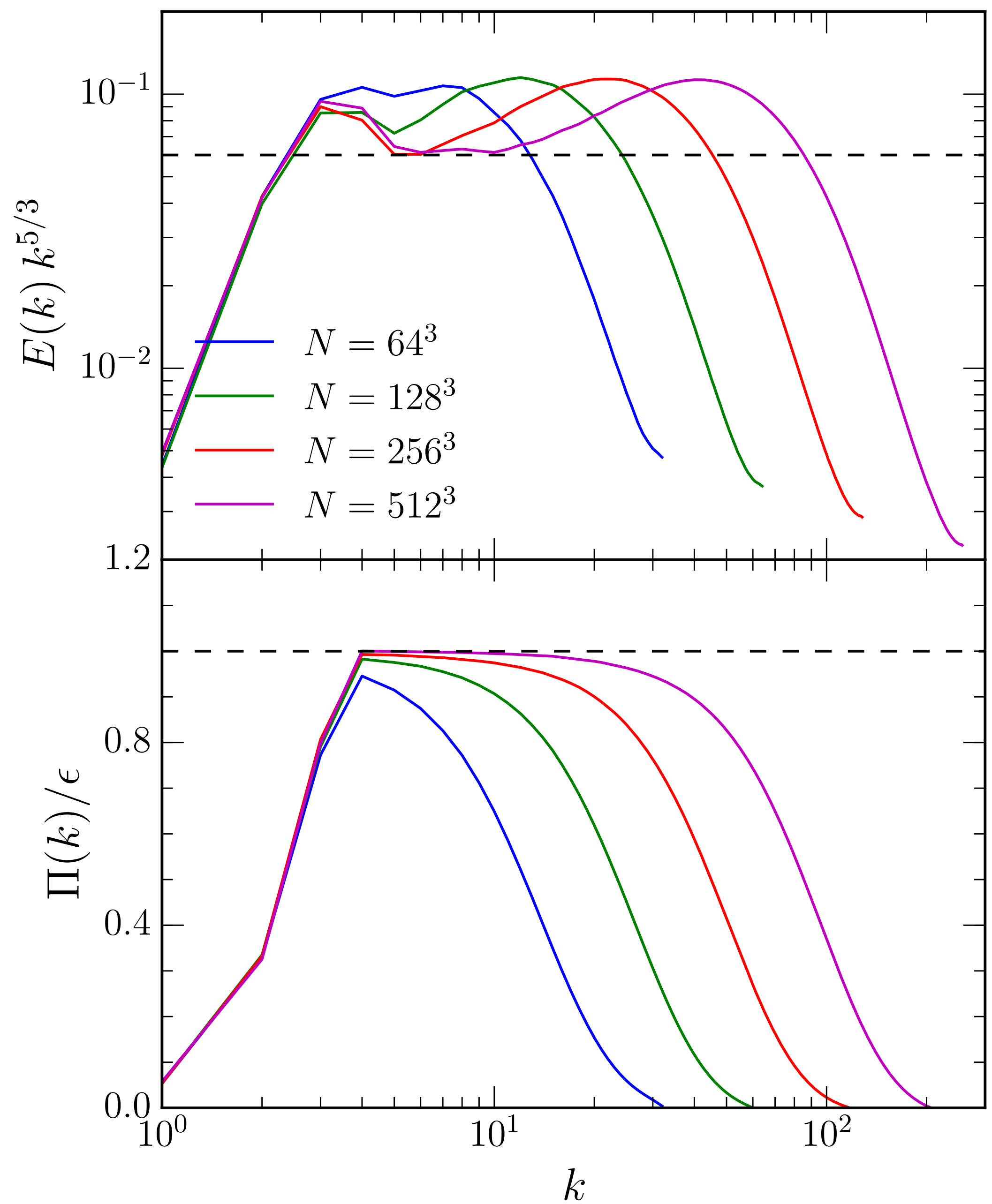
# Energy Cascade (I)




PPM+HLLC, N = $512^3$

- Energy injection scale
- Inertial range
- Bottleneck
- Dissipation range

# Energy Cascade (II)

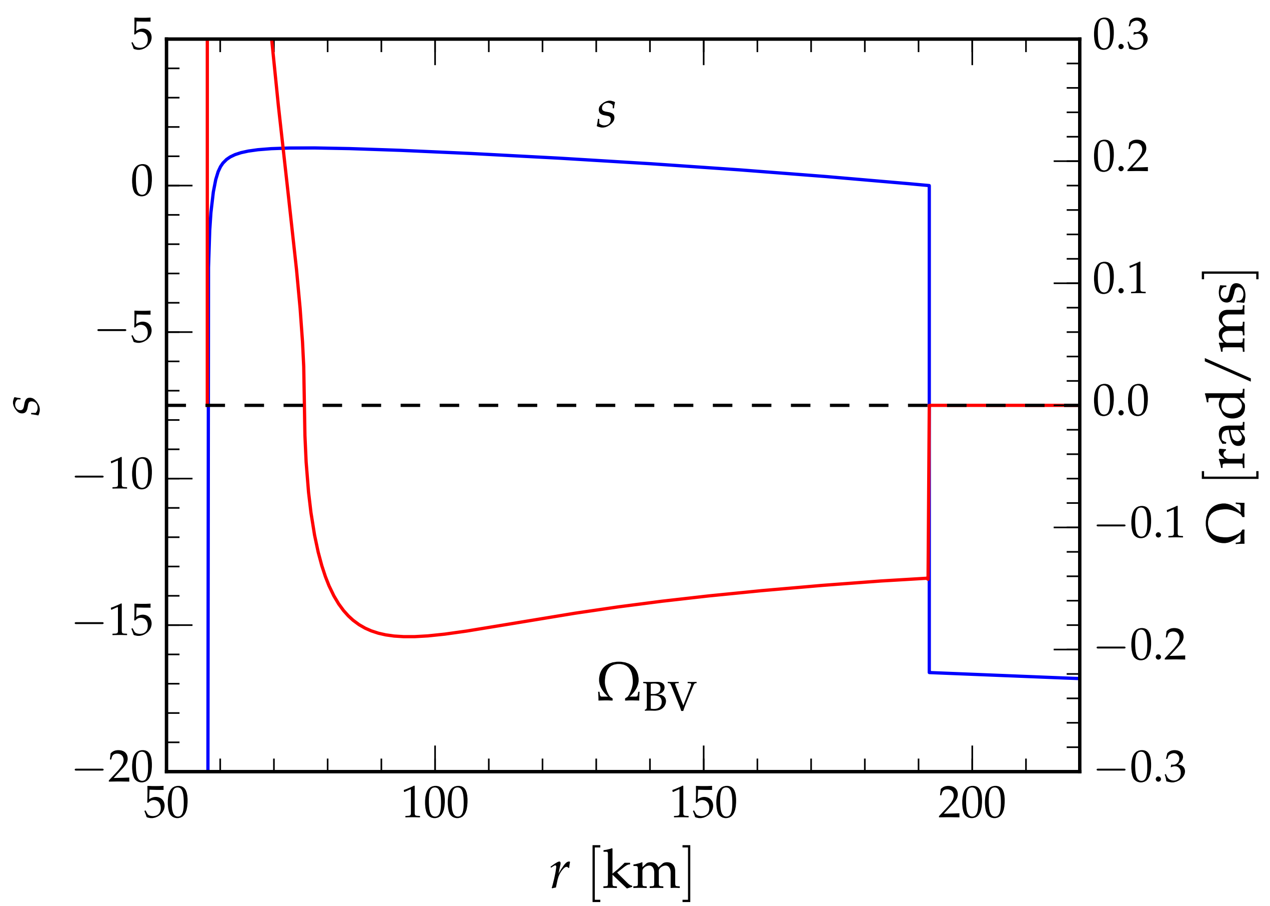



PPM+HLLC

- Global simulations ~ $64^3$
  bottleneck dominated!
- 2x: start to converge
- 8x: inertial range

# Semi-Global Simulations

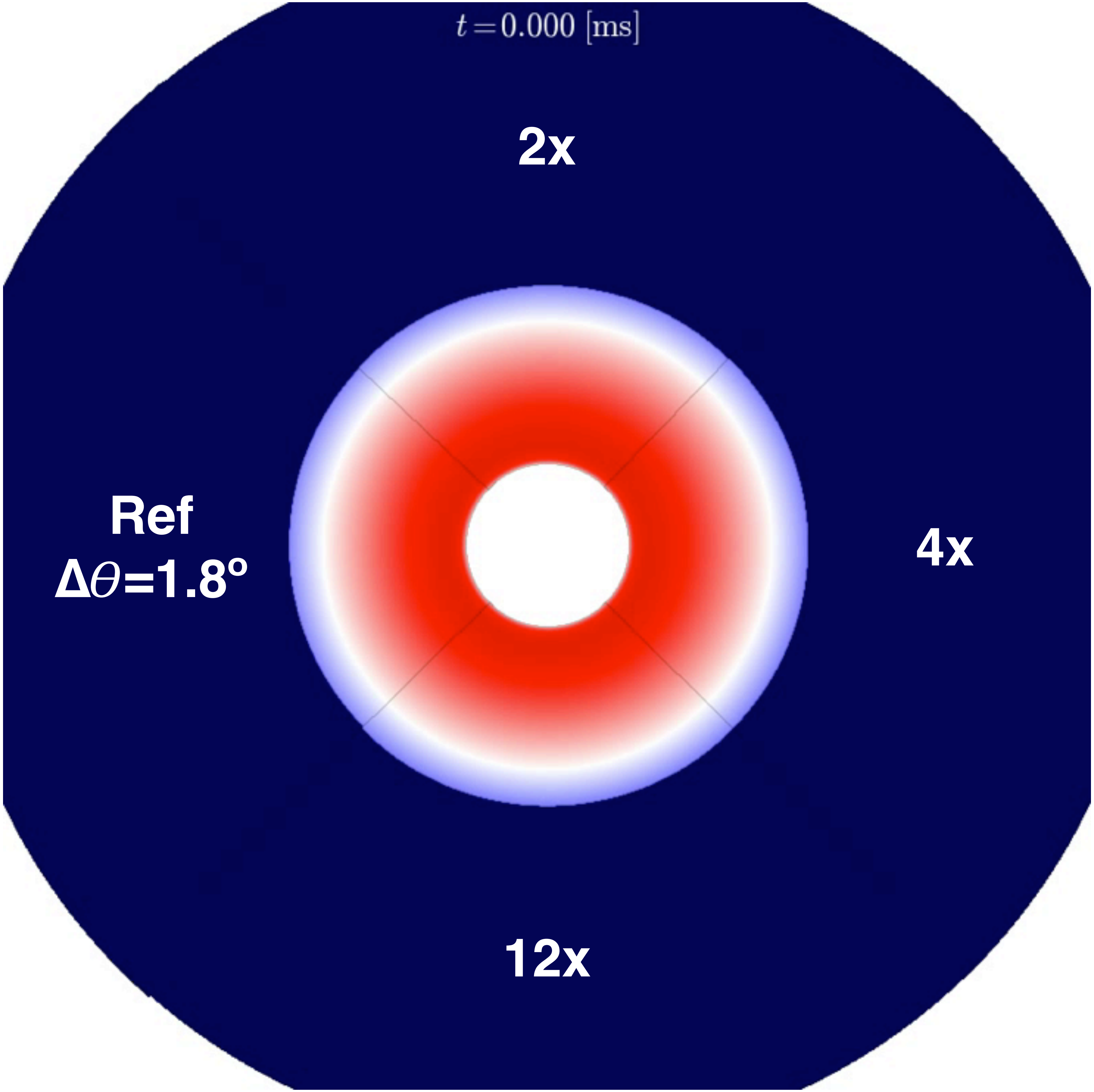
- Local simulations: instructive, but very simplified
- Global simulations: expensive, more difficult to interpret




Semi-global simulations: initial data

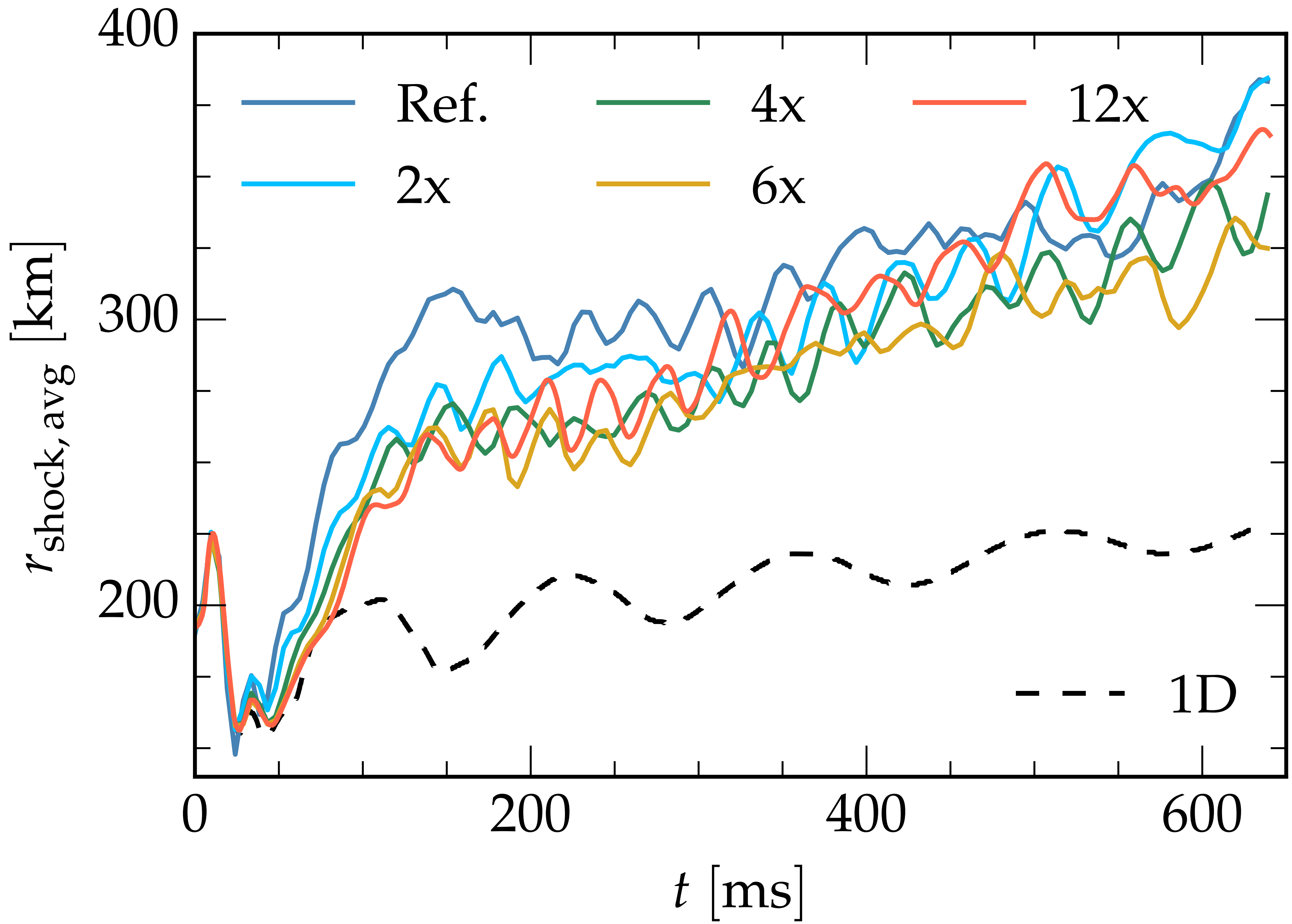
### Semi-global simulations

- Stationary initial conditions
- $90^{\circ}$ 3D wedge domain
- Simplified neutrino cooling/ heating
- Simplified nuclear dissociation treatment



$t = 0.000$ [ms]
2x
Ref
$\Delta\theta$=1.8°
4x
12x

# Global Dynamics (I)



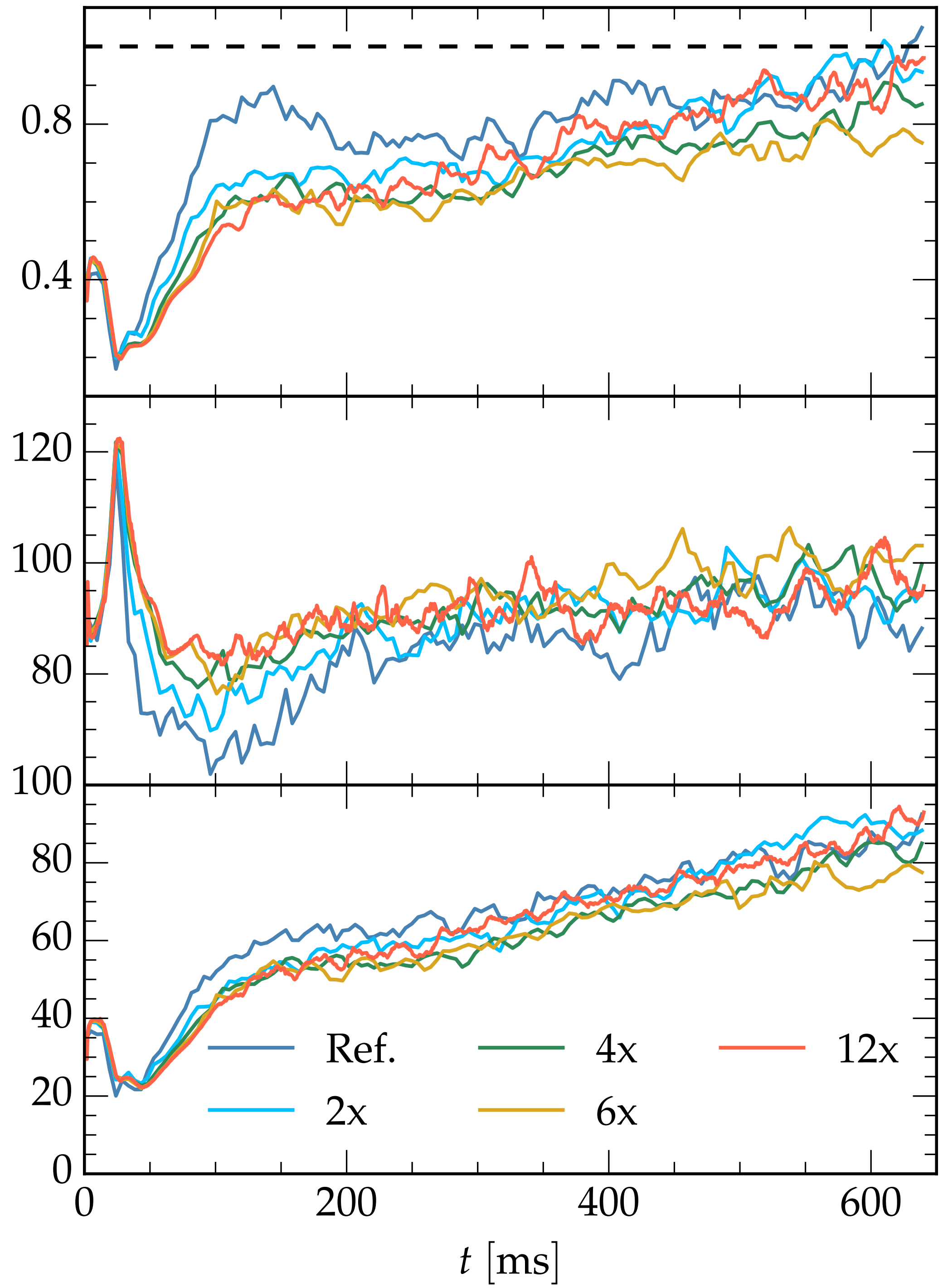

Shock radius

# Global Dynamics (II)

$$\frac{\tau_{\mathrm{adv}}}{\tau_{\mathrm{heat}}}$$

$$\tau_{\mathrm{adv}} = \frac{M_{\mathrm{gain}}}{\dot{M}}\ [\mathrm{ms}]$$

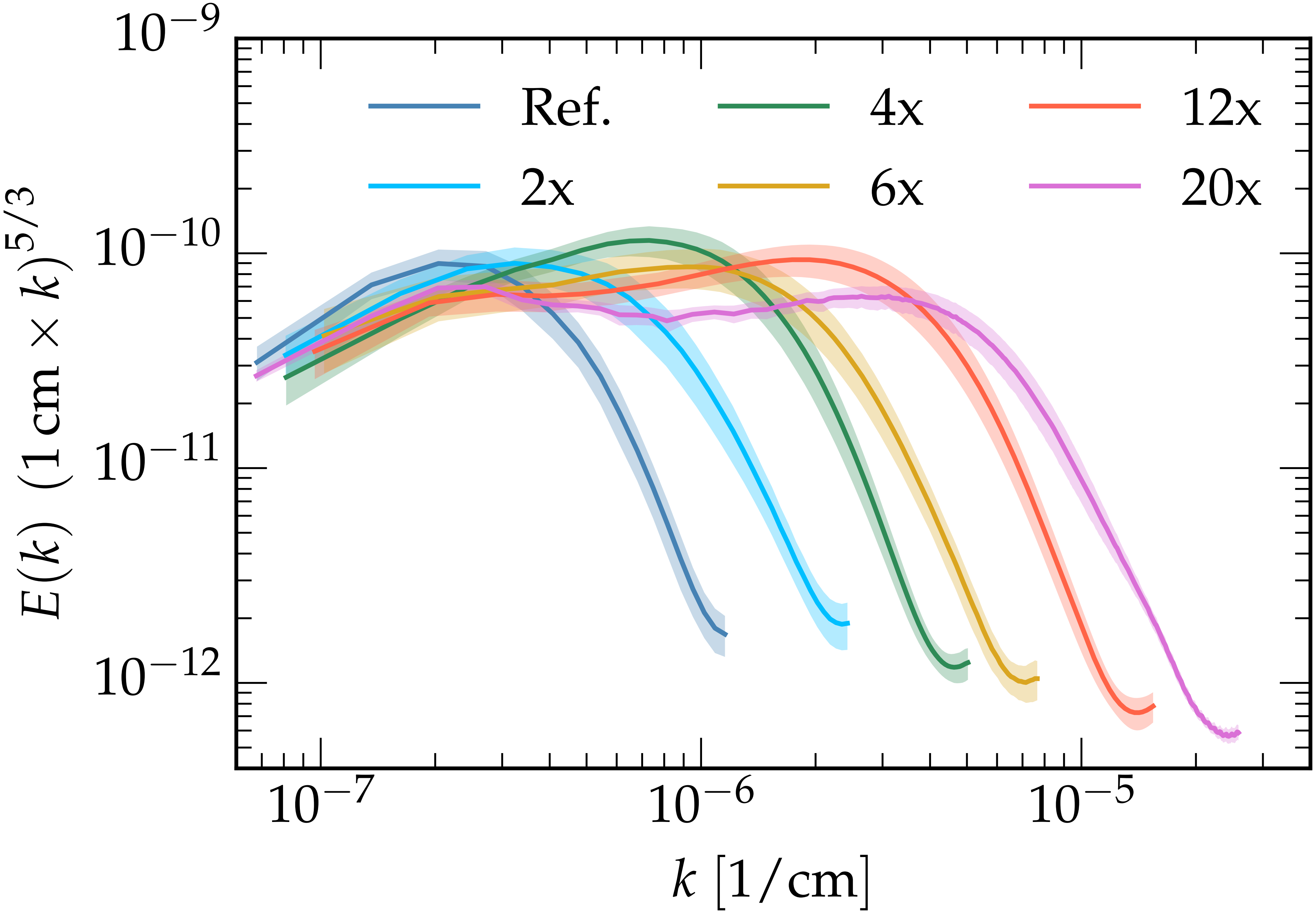
$$\tau_{\mathrm{heat}} = \frac{E_{\mathrm{bind}}}{\dot{Q}}\ [\mathrm{ms}]$$



Typical timescales

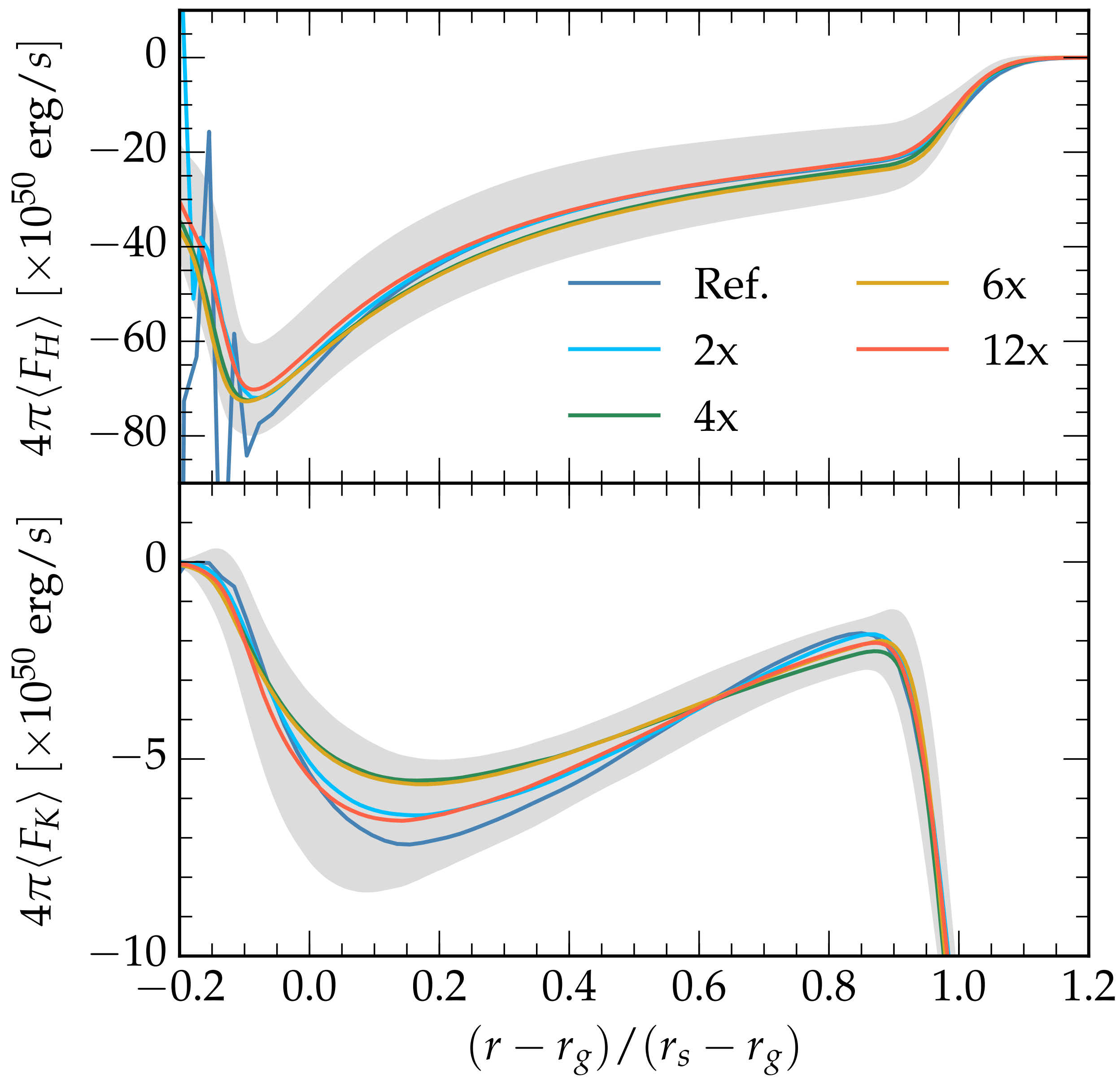
- Low resolution simulations easier to explode
- Good convergence of large scale quantities
- Caveat: convergence is going to be worse for nearly-critical models

# Turbulent Cascade

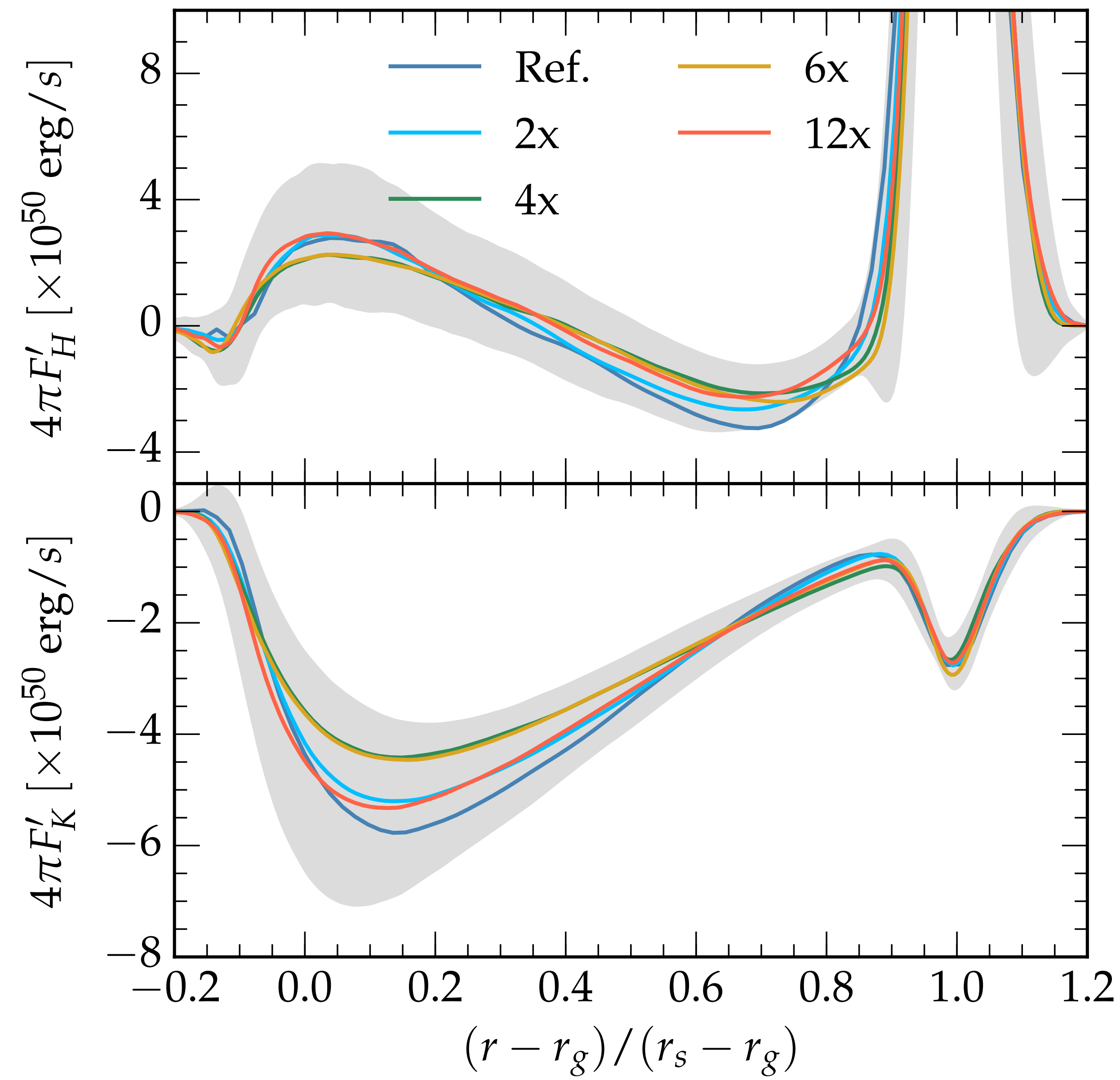



Turbulent energy spectra

# Turbulent Convection

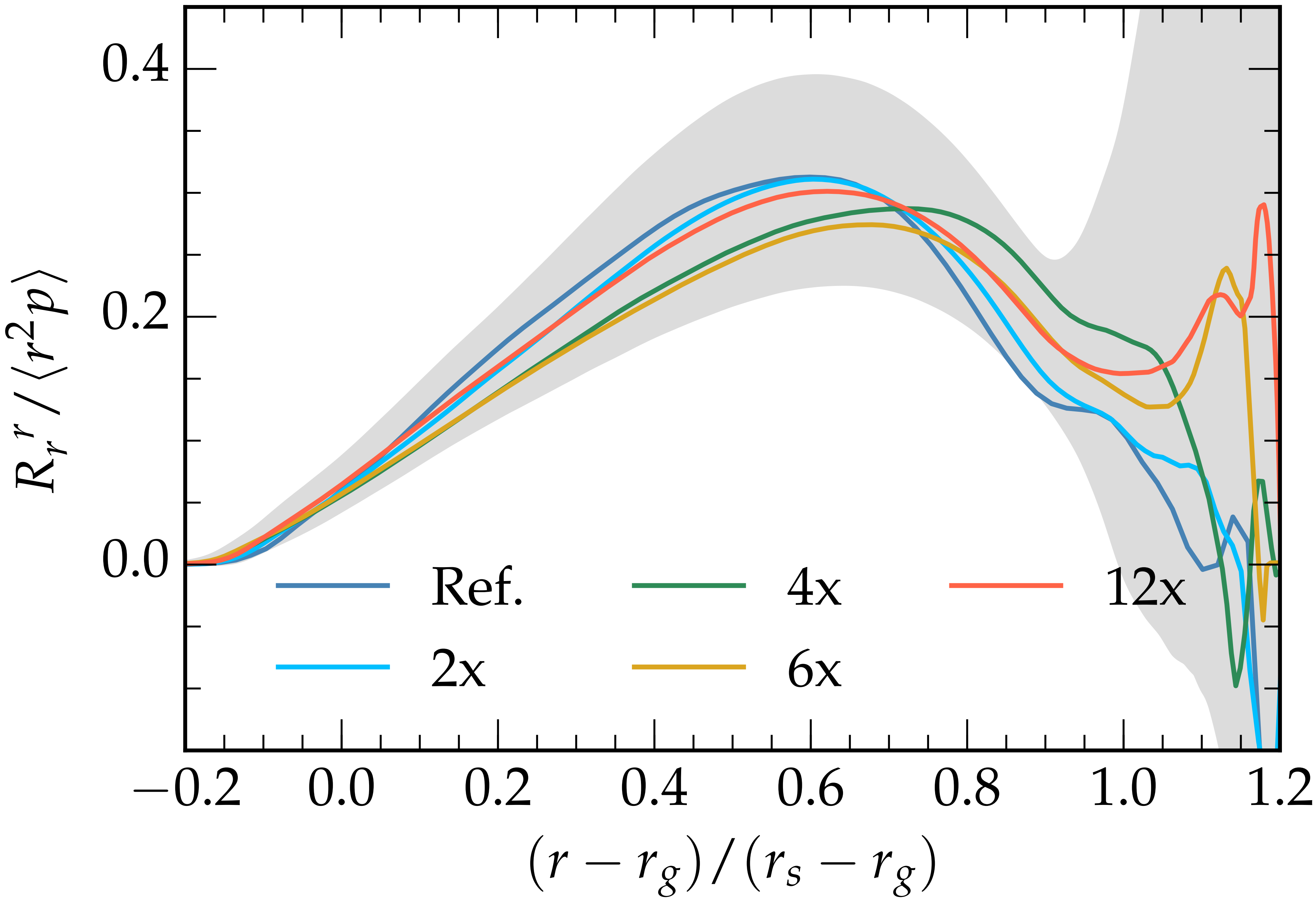



Total energy fluxes




Turbulent energy fluxes

# Turbulent Pressure

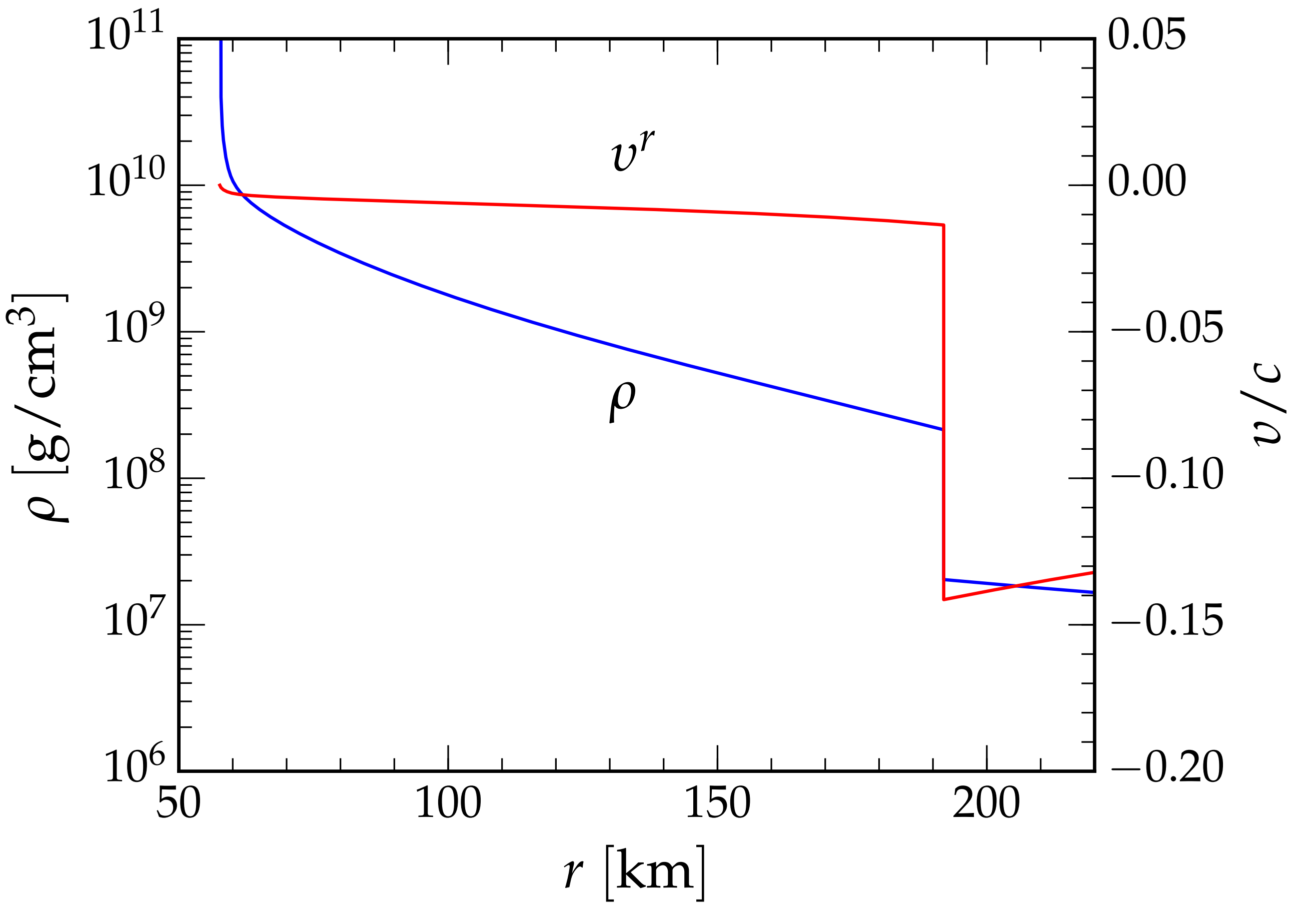


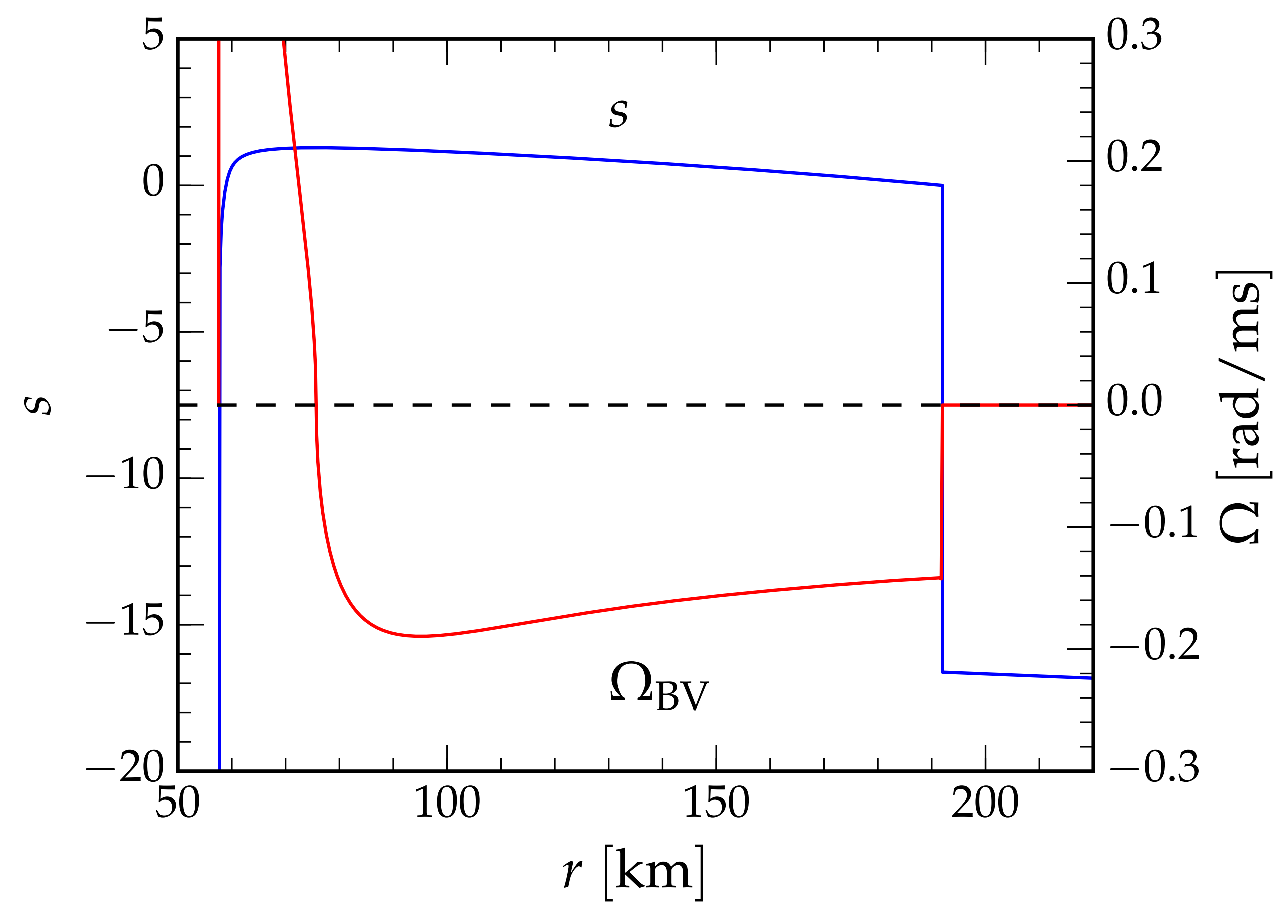

Turbulent pressure

# Conclusions

- Convergence: large scales converge even at moderate resolution ($\Delta\vartheta \lesssim 2^\circ$)
- Turbulence is only resolved at very high resolutions ($\Delta\vartheta \lesssim 0.1^\circ$)
- Kolmogorov spectrum
- Turbulence pressure dominates over energy transfer

# Initial Data




Stationary initial data