Multidimensional Hydrodynamics of Core-Collapse Supernovae

Josh Dolence, Princeton

with
Adam Burrows
&
Jeremiah Murphy
A Multidimensional History

1979  Lepton-gradient-driven convection (e.g. Epstein)

1985  Neutron fingers (e.g. Wilson)

1987  Prompt convection (e.g. Burrows)

1990  Neutrino-driven convection (e.g. Bethe)

2003  Standing Accretion Shock Instability (Blondin et al.)

Now   Neutrino-driven convection & the SASI
Multi-D hydrodynamics is \textbf{a} key ingredient...

But of course we should worry about

- Neutrino transport
- Microphysics (EOS)
- General relativity
- Progenitors
Numerical Setup

- CASTRO: AMR Godunov
- Monopole gravity

\[ H = H_0 \frac{L_{\nu e}}{r^2} (x_n + x_p)e^{-\tau} \]

\[ C = C_0 T^6 (x_n + x_p)e^{-\tau} \]

- Shen et al. (1998) EOS
- 15 \text{ } M_{\odot} \text{ Woosley & Weaver ('95)}
- Liebendörfer’s \text{ } Y_e \text{ scheme}
Results

2D is not 3D.
Pop quiz: How many dimensions am I?

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Flows are different, even by eye.
Does it matter?  Yes

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Structure of multi-D models

1. The shock
\[ a_l^m = \frac{(-1)^{|m|}}{\sqrt{4\pi (2l + 1)}} \int R_s(\theta, \phi) Y_l^m(\theta, \phi) d\Omega \]
Where’s the “sloshing” in 3D?

Burrows et al. 2012
Where’s the “sloshing” in 3D?

Multi-D Hydrodynamics of Core Collapse Supernovae
Evolution of the shock surface in 3D L=2.2 model
Evolution of the shock surface in 3D L=2.3 model
Structure of multi-D models

2. Turbulence
2D and 3D nonlinear turbulence are different.
Power distributed differently. Inverse vs. forward energy cascades?
See Hanke et al. 2012 for similar plots.
2D has longer mean dwell time but 3D has long tail
Which is more important?
Conclusions

- 2D & 3D shock structure and evolution are different
- 2D & 3D power spectra of turbulence are different
- 2D & 3D dwell time distributions are different
- Yet explosions occur earlier in 3D. Why?