Multidimensional Multiscale Dynamics of High-Energy Astrophysical Flows

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Core-Collapse SNe
Core-Collapse SNe
SN 1987A

Hubble
Cas A

Hubble, Chandra, Spitzer

Monday, July 26, 2010
Cas A

Hubble, Chandra, Spitzer

Chandra

Fe K
Core-Collapse SNe

- 2D effects such as neutrino convection, SASI, and perhaps advective-acoustic effects, make explosions marginally successful.

- Results from different groups don’t always agree.

- Explosions may be robust in 3D, but too early to tell.
Core-Collapse SNe

Hammer et al. 2009

5 x 10^{11} cm

350 s

9000 s

7.5 x 10^{12} cm

Burrows & Nordhaus 2010
Core-Collapse SNe

Moo
Core-Collapse SNe

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Core-Collapse SNe

Moo

Cows are aspherical and magnetic, and so are supernovae!

Magnetorotational SNe

Figure 5 clearly shows the liftoff of the corkscrewing Lagrangian parcels as rotation transitions into spiraling ejection, and then, at larger radii, into a directed jet. In addition, in model M15B11UP2A1H the radius of the shock in the equatorial regions is larger. This is because the equatorial magnetic pressures achieved there at a given time are larger than in model M15B11DP2A1H. This, in turn, is due to the fact that in model M15B11UP2A1H the uniform (''U'') initial poloidal field results in larger accreted fields at later times than in model M15B11DP2A1H, for which the late-time accretion is of matter from the outer core where the initial field decays in the $1/r^3$ dipolar manner ($x^3$). In fact, for model M15B11UP2A1H the equatorial regions join the explosion at later times. This outcome is expected eventually for all models, but due to the different magnetic field structures and magnitudes for the models listed in Table 1, the times to equatorial explosion will vary greatly from model to model.

The particle trajectories implied by Figure 5 and magnetic flux freezing indicate that the ejected material stretches toroidal field into poloidal field, in a reverse of what happens during rotational winding in the inner $10^{15} \text{km}$. So, in the jet column at large radii the field has a significant poloidal component.

Figure 6 shows radial slices along the poles (solid lines) and along the equator (dashed lines) of both the poloidal (red) and toroidal (black) fields for models M15B11DP2A1H (left panel) and M15B11UP2A1H (right panel) at 635 and 585 ms, respectively, after bounce. Since there is no appreciable rotational shear interior to $10^{15} \text{km}$, the magnetic fields there have little dynamical effect. It is the fields in the region between $10^{15}$ and $150 \text{km}$ that are of consequence, since it is here that the magnetic tower is launched and maintained. Figure 6 and $x^{2.3}$ indicate that the fields achieved in this region in these models are comparable to what is expected at saturation for a $P_0$ of $2 \text{s}$ ($10^{15}$ $15\ G$). This justifies our focus on these models when assuming $P_0 = 2 \text{s}$, despite the fact that we underresolve the MRI.

Figure 7 depicts color maps of the poloidal (left panel) and toroidal (right panel) field distribution for model M15B11UP2A1H, 585 ms after bounce. In both panels, the lines are isopoloidal field lines and the inner 200 km on a side is shown. The relative extents of the red and yellow regions demonstrate the dominance of the toroidal component in the inner zones at these late times well into the explosion, but the presence of a column of yellow/red (high field) along the axis in the poloidal plot attests to the conversion due to stretching by ejected matter of toroidal into poloidal field (see also Fig. 5). Figure 7 also demonstrates the columnar structure of this inner region due to both equatorial accretion (and, hence, pinching) and rotation about the (vertical) axis. However, it should be made clear that the actual field distributions after saturation are likely to be different, and what they are in detail when the MRI is fully enabled remains to be determined.

Figure 8 compares maps of the gas pressures ($P_{\text{gas}}$; left panels) with the magnetic pressures ($P_{\text{mag}}$; right panels) for models M15B11DP2A1H (top panels) and M15B11UP2A1H (bottom panels), at various times after their respective explosions.
What do Jet-driven SNe Look Like?

Need simulations of the late-time dynamics

Need resolution to study instabilities

Need means of directly comparing to observations

Khokhlov et al. 1999
The FLASH Code

- Block-structured Adaptive-Mesh Refinement
- Piecewise-Parabolic Method, explicit Eulerian hydro
- Tabular EoS
- Poisson self-gravity
- HDF5 output

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Viz & Analysis Tools

- Primarily VisIt through Python interface
- Parallel viz hardware (primarily at TACC)
- Also, some IDL...
Dynamic range

- 2D cylindrical geom.
- Radius, time-dependent max. refinement level
- Modified FLASH to excise central hole
- Hole radius expands with time
- Start with 25 refinement levels
Density

Kinetic  Thermal
Density

Kinetic

Thermal
X-ray emission modeling

- Optical depths integrated along lines of sight
- Accurate opacities from LANL
- Multiple photon energy groups
- Composition: helium with 0.5 solar metallicity
- Black body emission with color temperature = gas temperature at therm. depth

\[ \tau_{\text{tot}} = \tau_{\text{scat}} + \tau_{\text{abs}} \approx \frac{2}{3} \]
\[ \tau_{\text{eff}} = \sqrt{3\tau_{\text{abs}}\tau_{\text{tot}}} \approx \frac{2}{3} \]
Would like to get away from IDL...

Need parallel resources capable of handling 3D AMR data

Lagrangian particle analysis

Vector field viz

Minimize data movement

Fast viz important, flexible data manipulation also needed