Outline

- Evidence for asymmetries
- Expected magnitude of global asymmetry
- Impact of asymmetry on Cobalt decay emission
- Future directions

LA-UR-02-6114
The Guitar Nebula (5-m Hale Telescope at Palomar Observatory, August 1995.)

The body of the guitar is the SN remnant where the neutron star was born, however, the neck of the guitar is formed by this neutron star which is moving at ~1000 km/s. This suggests neutron stars are given “kicks” at birth.
Optical polarization of SN 1999em (Leonard et al. 2001)

The % polarization increases with time as we look deeper into the ejecta. This suggests that the asymmetry which gives rise to the polarization was imprinted by the explosion mechanism.
Spherically symmetric models for $\gamma$-ray emission in SN 1987A (Pinto & Woosley 1988). Top panel is for an explosion of the progenitor model 10H with no mixing. Bottom panel is for the explosion of the same progenitor, but includes artificial outward mixing of the $^{56}$Ni. Including the effects of mixing greatly improves the theoretical fit to observed data.
Line profiles of FeII (1.26\(\mu\)m and 18\(\mu\)m) at \(\sim 400\) days (Spyromilio, Meikle & Allen 1990.)

The line wings can be seen out to \(\sim 3500\) km/s.

For a homologous expansion of the SN 1987A ejecta, this implies that Fe has been mixed into the hydrogen layer.
Left panel is an image of Cas-A supernova remnant as seen by Chandra Observatory (Hughes et al. 2000.)

The red material on the left outer edge is enriched in iron and the greenish material is enriched in silicon. Mixing can explain why these element that are made in the middle of star, show up in the outer parts of the ejecta.

Right panel shows a 2-D simulation of the mixing that occurs during the explosion of a massive star (Kifonidis et al. 2001.)
3-D plot of the Jet2 density distribution with $^{56}\text{Co}$ number density isosurface plotted in yellow.

The density profile is basically spherical, but the heavy element distribution (e.g. $^{56}\text{Co}$) retains the asymmetry of the initial explosion.

Isosurface is for $^{56}\text{Co}$ number density of $1. \times 10^5 \text{cm}^{-3}$
3-D plot of the Symmetric density distribution with $^{56}$Co number density isosurface plotted in yellow.

The density profile and $^{56}$Co are both roughly spherical, as would be expected for a spherical initial explosion.

Isosurface is for $^{56}$Co number density of $1 \times 10^5 \text{cm}^{-3}$
Distribution in enclosed mass of Nickel synthesized in the explosion for various initial explosion models.

Note that the Symmetric + Decay model (in which all the nickel/cobalt decay energy is deposited into the nickel ejecta) produces almost as much mixing as the Jet2 model. More than 10% of the nickel produced is ejected beyond the helium core.
High energy spectrum of SN Ia model DD202c as calculated by several different research groups using a Monte Carlo technique. (from P. Milne, private communication)

This comparison effort is currently under way. There are variations in the spectra that still need to be understood, but that understanding seems near. This collaboration has been an invaluable code validation step during the development phase of Maverick.
Jet2 explosion is brighter regardless of viewing angle.

Hard X-rays can be seen much earlier for the asymmetric explosion, as in the artificially mixed 1-D simulations.

This assumes the distance to the supernova is 60 kpc.
Plot of the optical depth from various positions along the edge of the emission region, to the edge of the SN ejecta.

Emission into the equatorial direction for the Jet2 model arises predominantly from the ends of the $^{56}$Co distribution.

Optical depths are for an assumed energy of 1 MeV.
847 keV line profiles as a function of viewing angle and time for the Symmetric (left panel) and Jet2 (right panel) models.

The redward shift of the line centroid with time results from seeing deeper into the ejecta as it expands. Symmetric model shows similar profiles regardless of viewing angle. Jet2 model profiles are dominated by emission from the polar ends of the $^{56}$Co distribution. From the equator view, this emission has a low line of sight velocity. This explains the redward shift of the line centroid with viewing angle.
Derived line profile for Jet2 model at \( t = 250 \) days assuming no optical depth in the SN ejecta.

Red line is for equator view; Black line is for polar view. These are examples of the irregular line profile shape which should emerge as the SN expands. Infrared line profiles may differ from these predictions as the IR emission is affected by excitation conditions in the ejecta. A natural next step is to calculate ionization states in the ejecta in order to get at the IR profiles themselves.