The Long Term Project
(6D Core-collapse Models)

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Results ca. 3000 A.D.!
Some key ingredients are

**Neutrino transport/interactions,**
- Spatial dimensionality;
- Dependence on energy and angles;
- Relativity;
- Comprehensiveness of interactions;

**(Magneto)Hydrodynamics/gravitation,**
- Dimensionality;
- Relativity;

**Equation of state/composition,**
- Dense matter treatments;
- Number and evolution of nuclear species;

**Diagnostics,**
- Accounting of lepton number;
- Accounting of energy;
- Accounting of momentum.
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Open Issues…Core-collapse Supernovae, Seattle, 22-24 June 2004

$E_{\text{explosion}} \sim 10^{51}$ erg
$E_{\text{neutrinos}} \sim 10^{53}$ erg
A code under development: 
*GenASiS*
General Astrophysical Simulation System
Modularity via Fortran 90 function overloading
Coordinate system, spacetime theory, fluid dynamics
flux methods, radiation solver methods…
Some key ingredients are

**Neutrino transport/interactions**

**(Magneto)Hydrodynamics/gravitation**

**Equation of state/composition**

**Diagnostics**

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**Progress in GenASiS**

- Distributed 1/2/3D solver working for unigrid
- No velocity corrections yet
- “Realistic” emission/absorption now included
- Distributed interaction tables
- Conservative Newtonian hydrodynamics
- Adaptive, but parallelization not complete
- Upwind (second order)
- Riemann solver
- Distributed Poisson solver, adaptive
- This fall: Postdoc for MHD
- Mean heavy nucleus/bulk nuclear matter (Lattimer-Swesty)
- Conservation tracking for hydrodynamics
- Conservative differencing of neutrino transport
Neutrino transport and transfer
Non-conservative formulation of radiative transfer

Scalar distribution function

\[ dN = f \left[ t, \vec{x}, \vec{p} \right] (-p \cdot u) \, dV \, dP \]

Boltzmann equation

\[ \hat{p}^\mu \mathcal{L}^\mu \hat{\mu} \frac{\partial f}{\partial x^\mu} - \mathcal{R}^i \hat{\rho} \hat{\mu} \hat{p}^\rho \hat{p}^\mu \frac{\partial u^j}{\partial p^i} \frac{\partial f}{\partial u^j} = c \left[ f \right] \]
Properties of the conservative formulations

**Spacetime coordinates**
- Global, Eulerian ("lab frame")

**Momentum coordinates**
- Convenient (e.g. energy/angles), taken from orthonormal momentum components measured by an observer comoving with the fluid

"Conservative" in spacetime and momentum space
- Transparent connection to particle number and 4-momentum balance
Particle number vector and conservation law

\[
\frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \left( \sqrt{-g} \, N^\mu \right) = \int c \, [f] \, dP
\]

\[
N^\mu = \int f \, p^\mu \, dP = \int f \, L^\mu_\mu \, p^\mu \, dP
\]

Boltzmann equation, integrated over momentum

\[
\int \left( p^\mu \, L^\mu_\mu \frac{\partial f}{\partial x^\mu} - \Gamma^\lambda_\rho \, \hat{\mu} \, p^\rho \, p^\lambda \, \frac{\partial u^j}{\partial p^i} \frac{\partial f}{\partial u^j} \right) \, dP = \int c \, [f] \, dP
\]