Numerical Simulation of Supernovae and Gamma-Ray Bursts

"When Good Star Goes Bang"
SciDAC Program @ SLAC/KIPAC

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SciDAC

* Scientific Discovery through Advanced Computing
  - Funded via DOE Office of Science
  - Beyond Core Programs (single investigator, small group)
* SciDAC Focuses:
  - Scientific Challenge Codes
  - Computing Systems and Mathematical Software
  - Scientific Computing Hardware/Software Infrastructure
* Science Applications
  - Physics (computational astrophysics, Quantum Chromodynamics, High Energy Physics, & Nuclear Physics)
  - Climate
  - Groundwater
  - Fusion Energy
  - Life Sciences
  - Materials & Chemistry

Participating Oganizations

USA laboratories, universities, and corporations participating in the SciDAC projects announced in 2006

SciDAC CAC Research Project

* Computational Astrophysics Consortium
  - Supernovae, Gamma-ray Bursts, and Nucleosynthesis
* PI: Stan Woosley (UC Santa Cruz)
* Co-PI @ SLAC/KIPAC: Roger Blandford
* SciDAC postdoc fellow @ SLAC/KIPAC: Shizuka Akiyama
* Working Groups
  - Type Ia Supernovae Models
  - Supernova (I,II,GRB) Spectra and Light Curves
  - Supernovae and GRBs Observations
  - Pre-Supernova Evolution of Massive Stars (Pop I, II, & III)
  - Core Collapse Supernova Models, MHD Supernova Models
  - Gamma-ray Burst Models
  - Nuclear Astrophysics, Nuclearsynthesis, X-ray Bursts

Who are we?

- University of California, Santa Cruz
- University of California, Berkeley
- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- Stanford Linear Accelerator Center
- Stanford University
- Los Alamos National Laboratory
- University of Arizona
- State University of New York at Stony Brook
- Princeton University
- New York University
- Lousiana State University

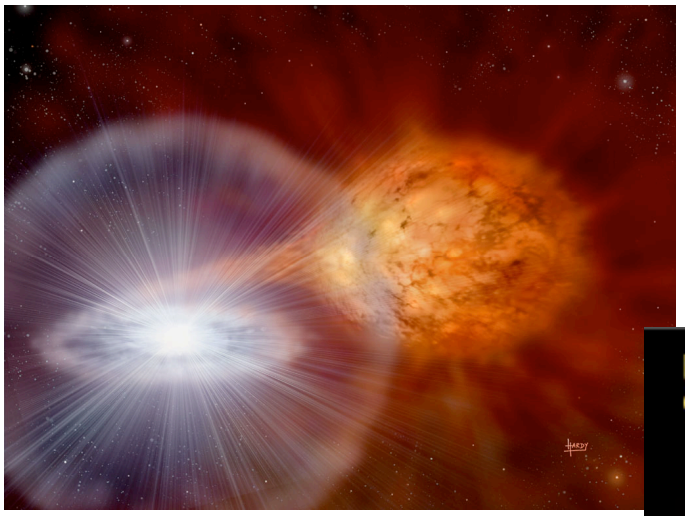
Meetings @ SLAC

* SLAC offers ideal location for collaboration meetings
* Gamma-ray Burst meeting (Sep 21, 2007)
  - ~20 participants from UCSC, Berkeley, Livermore, Stanford, & SLAC
  - 6 talks + discussion
* All-Hands meeting (April 7-9, 2008)
  - ~80 participants from in/out bay area
  - 44 talks + discussion
  - Topics covered
    - Type Ia, Core Collapse, GRB, Nucleosynthesis
    - Observation, Modeling, Simulation, Data Libraries, Code Development
  - Astronomers/Astrophysicists + Computer Scientists

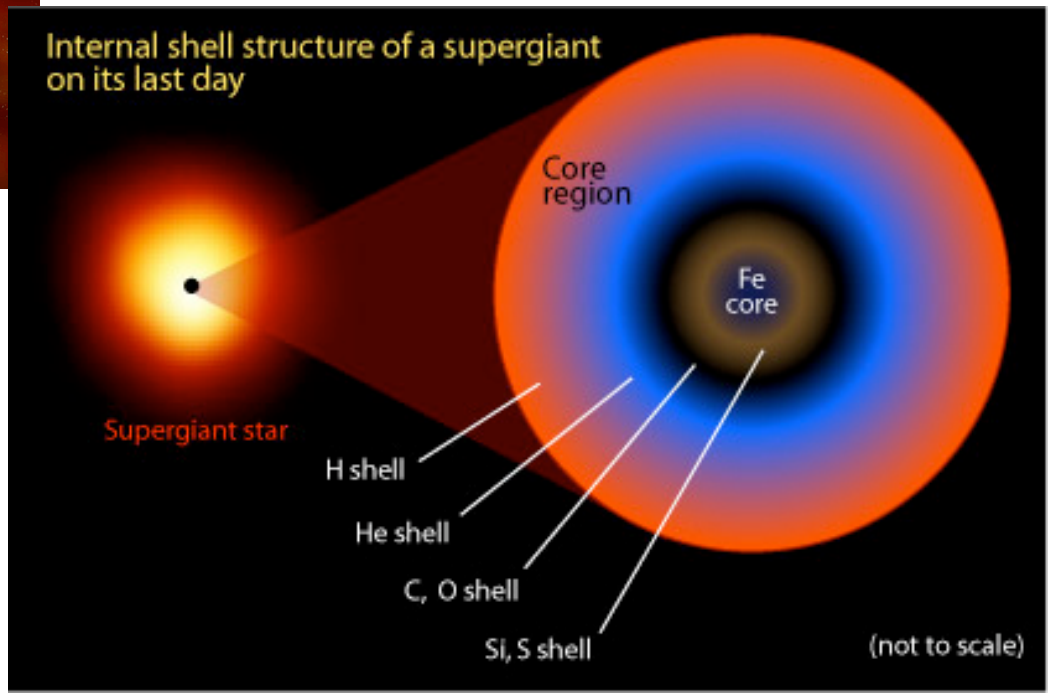
@ SLAC

* Co-PI: Roger Blandrod
* Personel:
  - Tom Abel (Professor)
  - Shizuka Akiyama (SciDAC postdoc fellow)
  - Jonathan McKinney (Chandra postdoc fellow)
  - Peng Wang (grad. Student)
* Numerical Simulation of Supernovae and GRBS
* TeraGrid MRAC grant awarded
  - “Direct Numerical Simulations of Magnetically-Driven Gamma-Ray Bursts and Supernovae”
  - Peer-reviewed allocation
  - 500,000 SUs on Lonestar cluster
    - 5840 processors
    - 11.6 TB total memory
    - 62 TFLOPS peak performance

Supernova Types



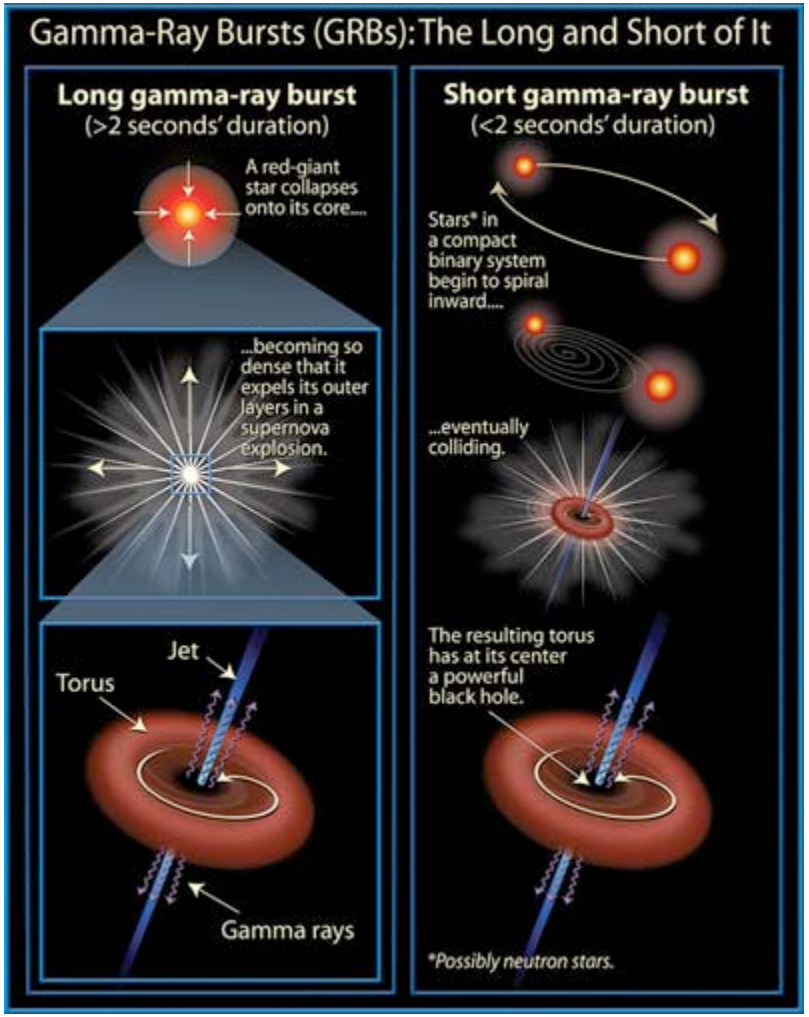
* Type Ia
  - Thermonuclear Explosion



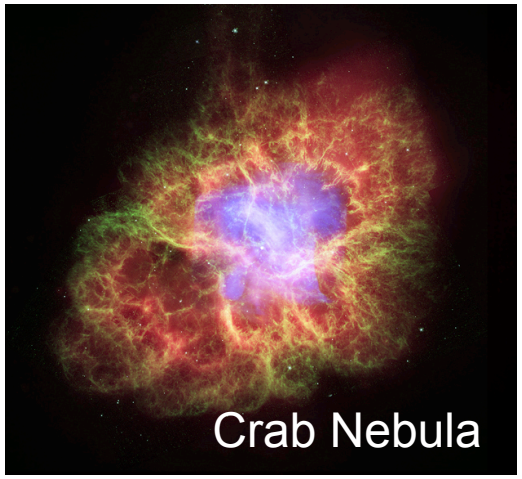
* Core Collapse
  - Fe Core implosion
  - Explosion mechanism??
  - Neutron star/black hole formation
  - SN-GRB connection

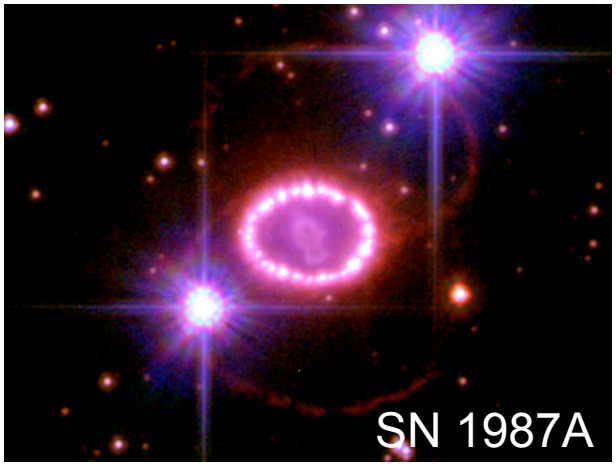
Gamma-Ray Bursts

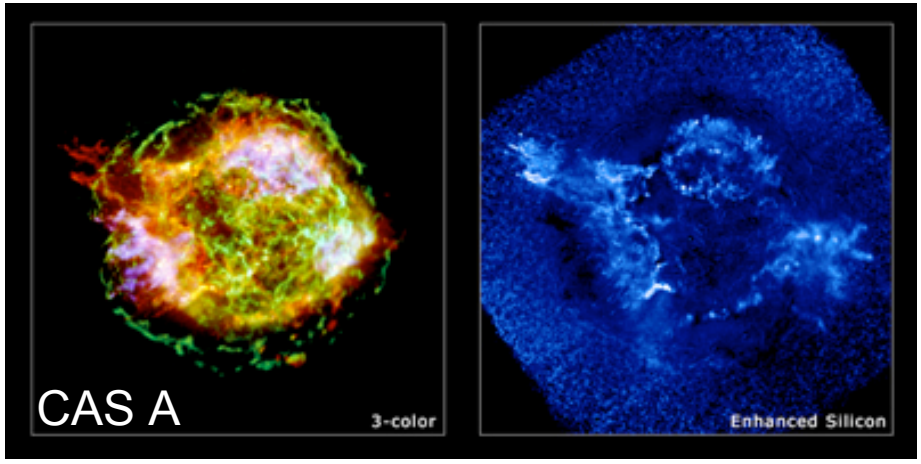
* Long bursts
  - Associated with death event of massive stars
  - Supernova - GRB connection
* Collapsar model
  - Core Collapse
  - Black hole formation
  - BH/disk
  - Relativistic jets
* GRB powered via
  - Neutrino annihilation?
  - MHD processes?

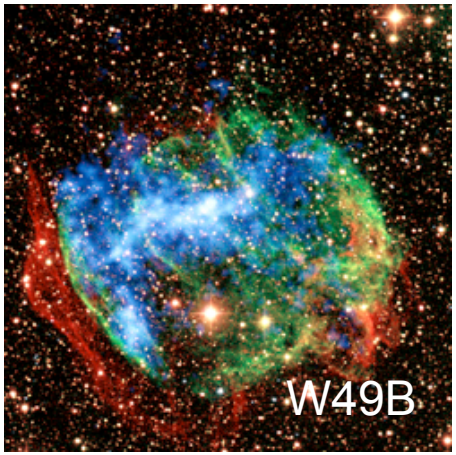


Aspherical Explosion of SNe









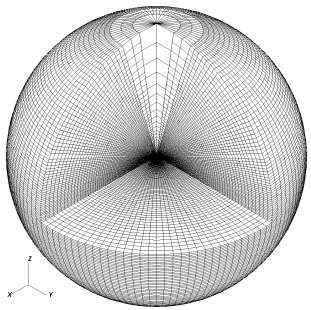
* (MHD) Jet- induced explosion??

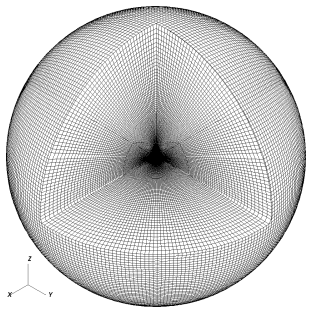
Issues on MHD Explosions

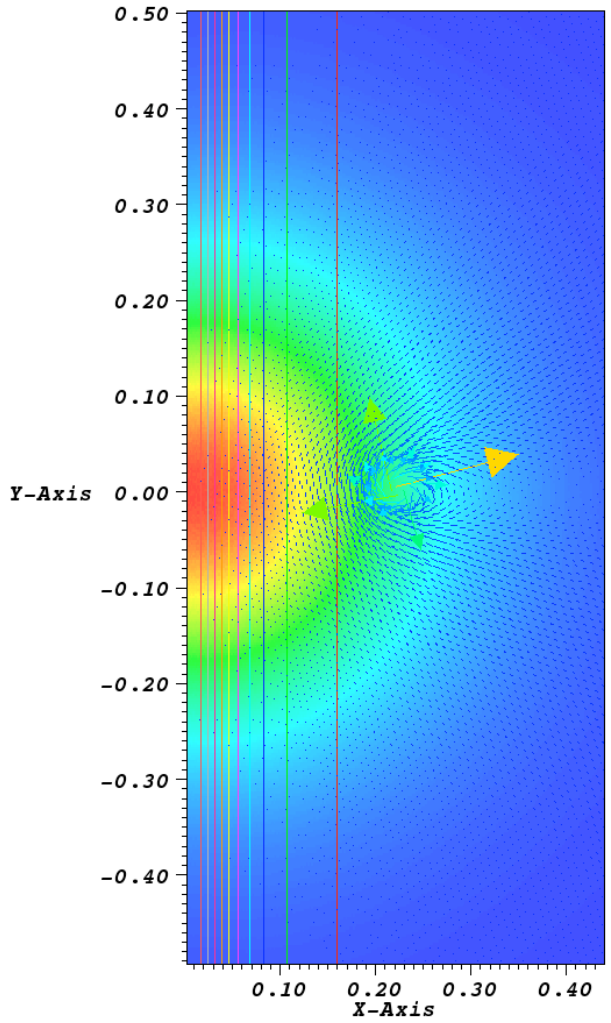
* Initial condition unknown
  - Angular momentum & magnetic fields in iron core
* How does magnetic fields amplified
  - Differential rotation
  - Linear wrapping
  - Magnetorotational instability
    - Moderate initial condition
    - $10^{15\text{ - }17}$ G within ~few 10 msec
* Too rapid rotation required??
  - Neutron star spin & magnetic fields
* SN and GRB shares the same progenitor profiles?

Core Collapse Simulation

* COSMOS++ (GRMHD + AMR)
* Rotating Polytrope
* Parametric EOS
* No neutrino included
* Moving Mesh, remapping option
* Cubed-Sphere option
  - Nearly uniform zone sizing
  - No coord. Singularities, except origin

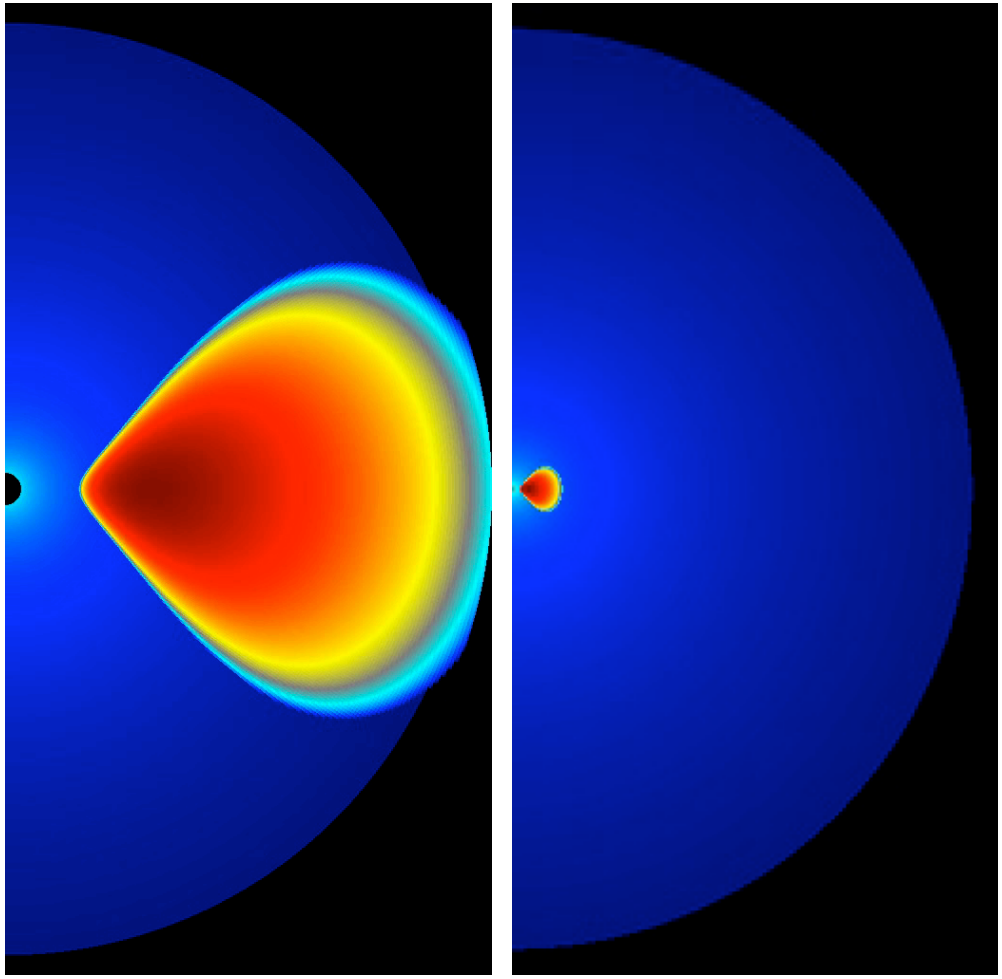




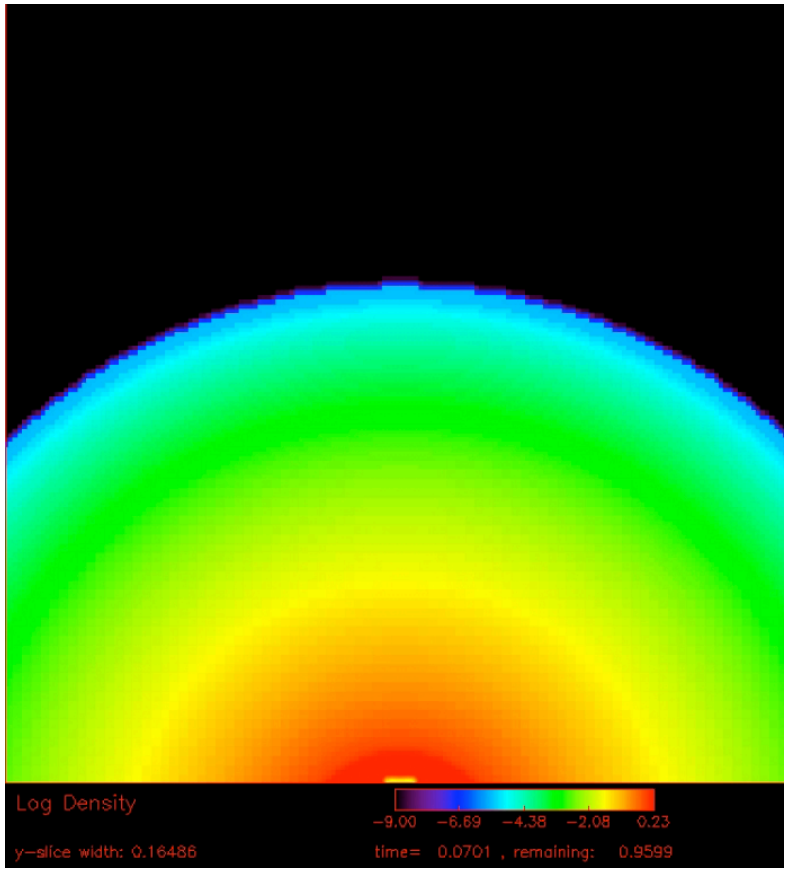


P. Fragile

GRB Sims.



Sim. By Jonathan McKinney (HARM)



Sim. By Peng Wang (RENZO)
Ref. Talk given in this session

GLAST!

Mission Objectives

- Explore the most extreme environments in the Universe, where nature harnesses energies far beyond anything possible on Earth.
- Search for signs of new laws of physics and what composes the mysterious Dark Matter.
- Explain how black holes accelerate immense jets of material to nearly light speed.
- Help crack the mysteries of the stupendously powerful explosions known as gamma-ray bursts.
- Answer long-standing questions across a broad range of topics, including solar flares, pulsars and the origin of cosmic rays.

* Talk given earlier by E. do Couto e Silva in NAP session
* LAT (Large Area Telescope)
  - 20 MeV - 300 GeV
  - Will see high energy component
* GBM (GLAST burst monitor)
  - 8 KeV - 25 MeV
* GRB rates:
  - GBM: ~ 200 GRBs/year
  - LAT: ~70 GRB/year (> 10 photons & E > 30 MeV)
* Simulations & Modeling

END

MRI Sim. In Core Collapse Supernovae

* MRI is a weak-field instability
* Resolving unstable modes challenging
  - Start with fairly strong initial magnetic field

$$\lambda_{max} \sim 0.56 - 2.1\mathrm{Km}\left(\frac{\Omega}{10^3\mathrm{rads}^{-1}}^{-1}\right) \times \left(\frac{\mathrm{B}}{10^{14}\mathrm{G}}\right) \times \left(\frac{\rho}{10^{13}\mathrm{gcm}^{-3}}\right)$$

  - Requires grid size ~ 0.1 max wavelength
* Simplify microphysics
  - Parametric EOS

$$\begin{aligned} \mathrm{P}(\rho,\epsilon) &= P_p(\rho) + P_{th}(\rho,\epsilon) \\ \mathrm{P_p}(\rho) &= K_1\rho^{\Gamma_1}, \rho \leq \rho_{nuc} \\ &= K_2\rho^{\Gamma_2}, \rho \leq \rho_{nuc} \\ \mathrm{P_{th}} &= (\Gamma_{th}-1)\rho\epsilon_{th} \end{aligned}$$

  - Polytropic initial condition with various rotational and magnetic profiles
  - No neutrino transport
* Obergaulinger et al. (2006) & Shibata et al. (2006)

Explosion Mechanisms

* Neutrino heating
* Acoustic power
* MHD processes (MHD jets)
  - Aspherical explosion
  - Magnetar formation from massive stars
  - GRB connection??