Extraction of Gravitational Wave Signatures from Highly Magnetized Core-Collapse Supernovae

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Caltech LIGO Summer Undergraduate Research Fellowship (SURF)
Presentations

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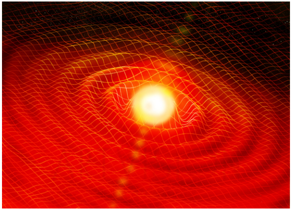
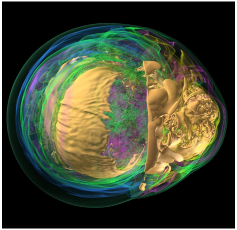


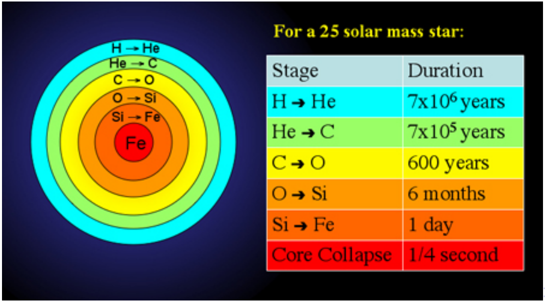
(k) GW from Sne (Artist's Rendering)



(l) Argonne Nat Lab (3D Simulation)

Core-Collapse Basics: Why do We Care?

- CCSNe result from **gravitational collapse** of the core of a massive star ($M >\sim$ 8-10M_{sun}); observed as Type II, Ib, Ic Sne.



For a 25 solar mass star:

Stage	Duration
H → He	$7\text{x}10^6$ years
He → C	$7\text{x}10^5$ years
C → O	600 years
O → Si	6 months
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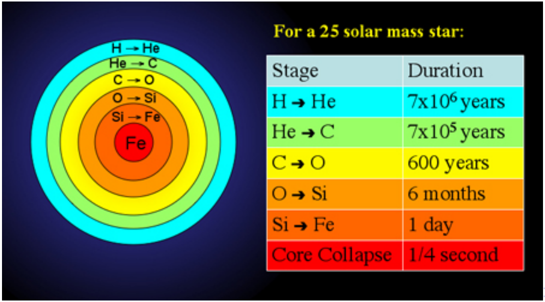

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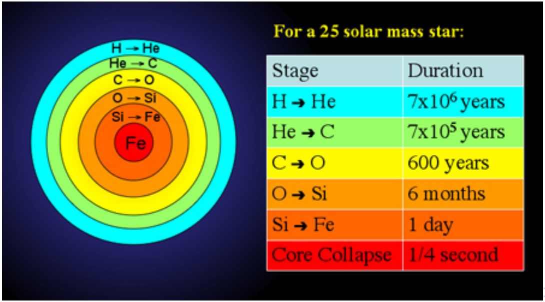

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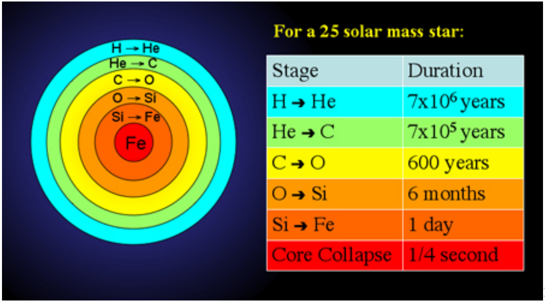
- Rate of 1 to $\sim$ 4 SN per 90 yrs in the Local Group (most events within $\sim$ 100 kpc of Earth.)



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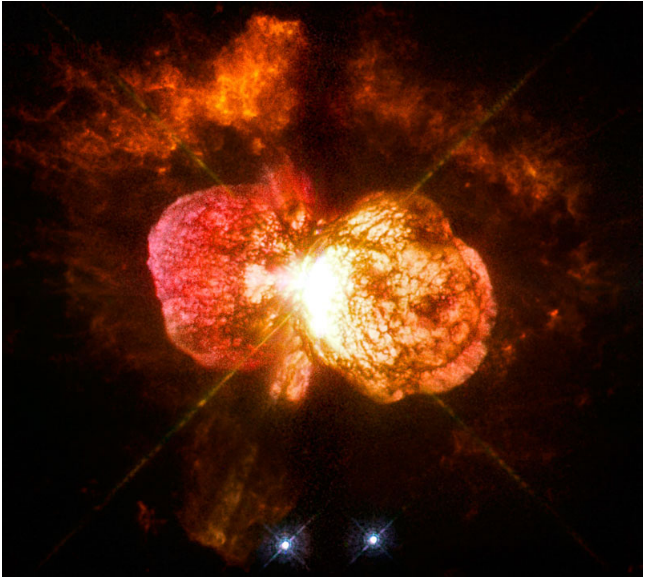
Eta Carinae (NASA WFPC2): likely CCSNe.



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- High-energy shockwave is created as the proto-neutron star at the CCSNe center and inner core **supersonically collide**.
  - evolves into a standing accretion shock, immediately losing most of its kinetic energy via photodissociation.
  - Shock can be revived via neutrino heating, SASI, and magnetorotational effects, causing a **massive detonation** which releases $\sim \mathbf{10^{51}}$ **ergs** of energy!

2D Simulation Example

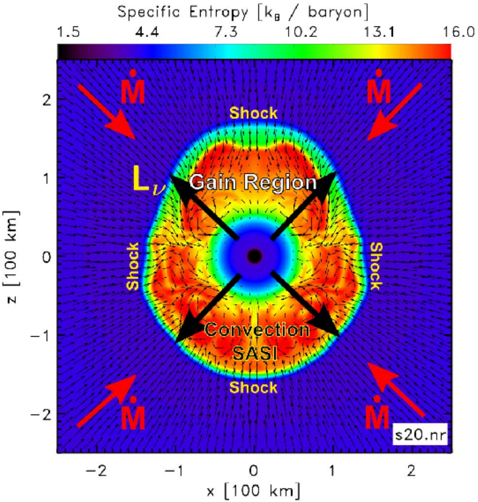

Figure: Shortly after first bounce ($\sim$ 20-50 ms evolution).

Getting GWs

- Typically use the quadrupole formula:

$$h_{ij}^{TT}(t,\mathbf{x}) = \left[\frac{2}{c^4}\frac{G}{|\mathbf{X}|}\ddot{I}_{ij}\left(t-\frac{|\mathbf{X}|}{c}\right)\right]^{TT} \tag{1}$$

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- implementation boils down to finding the second-time derivative of the quadrupole tensor, $\ddot{I}_{ij}$.

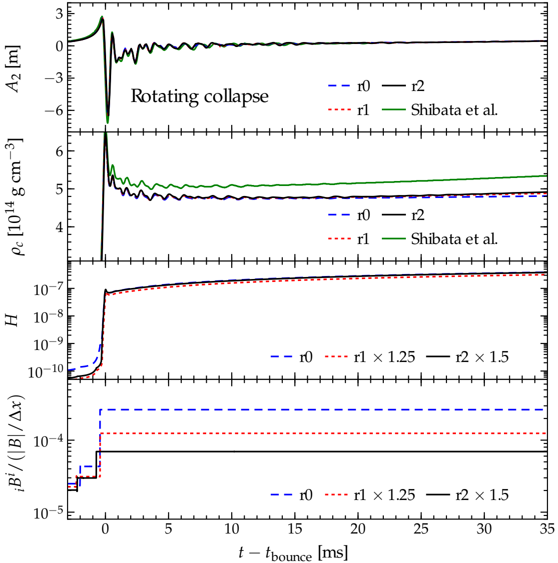

Figure: Mösta et al. (2013) [MHD in simulation, not extraction.]

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Early Result II:

b^2 contributions **don't affect signature** in early simulation $\Rightarrow$ initially $\mathcal{O}$(rotational effects) $\ll \mathcal{O}$(hydrodynamical effects).

Simulation Progress

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- effects appear to be at 5-10% level, as expected.

Future Directions

- Extraction Specific: Implement higher-order magnetic effects in other hydrodynamics, off-diagonal terms ($b_i b_j$).

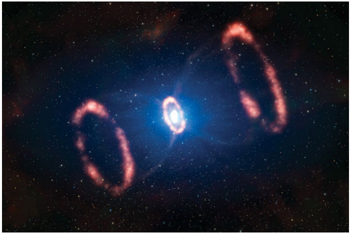

Figure: CCSNe 87A (European Southern Observatory)

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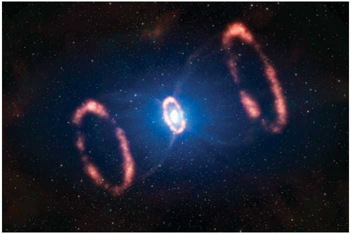

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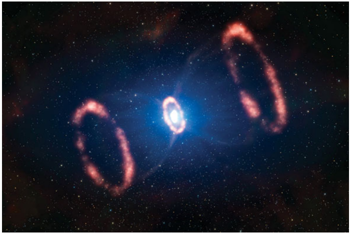

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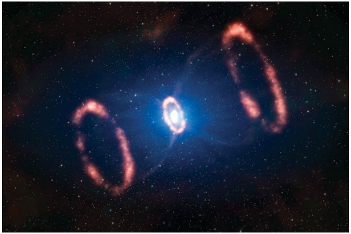
  - author will implement tracer particles to track nucleosynthesis (started).



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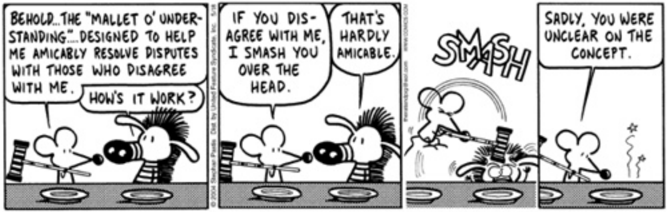
Questions?



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