Multi-Messenger Astronomy: Understanding Supernovae

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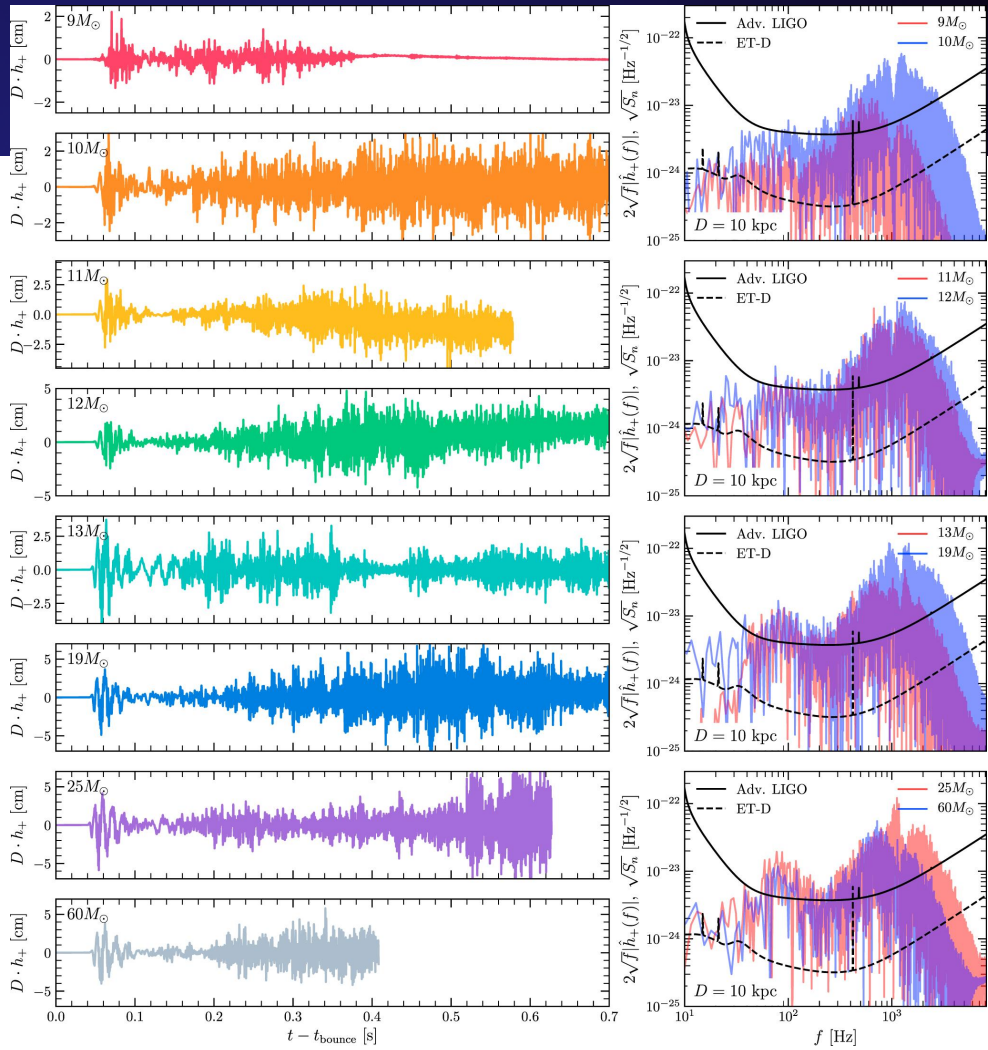
Understanding the Engine

- Gravitational Waves probe rotation and convection in the engine.
- Neutrinos also probe the engine but, coupled with gravitational waves, can be used to probe the neutron star and dense nuclear physics.

Both these constraints require nearby events.

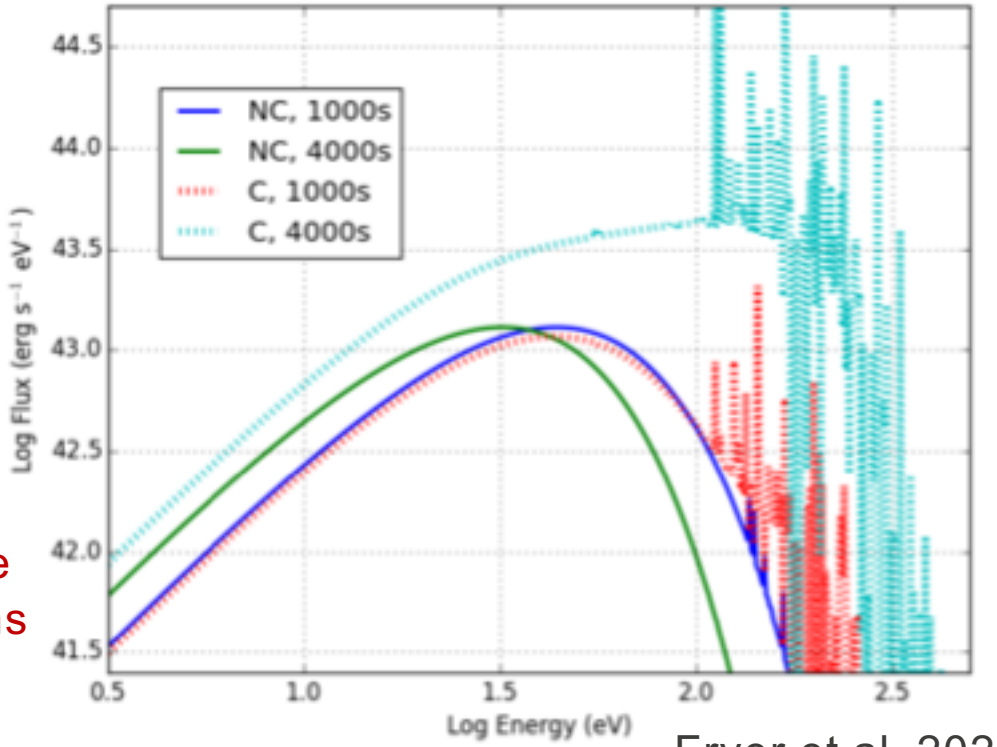


Radice et al. 2019

Probing Supernova Progenitors and their Environs

- Shock Breakout: Breakout probes the stellar photosphere, supernova shocks and the inner circumstellar material.
- Supernova Light-Curves probe the star, the explosion, and the circumstellar material.

We have a large set of SN light-curve data and shock breakout observations are growing, especially with next generation detectors.

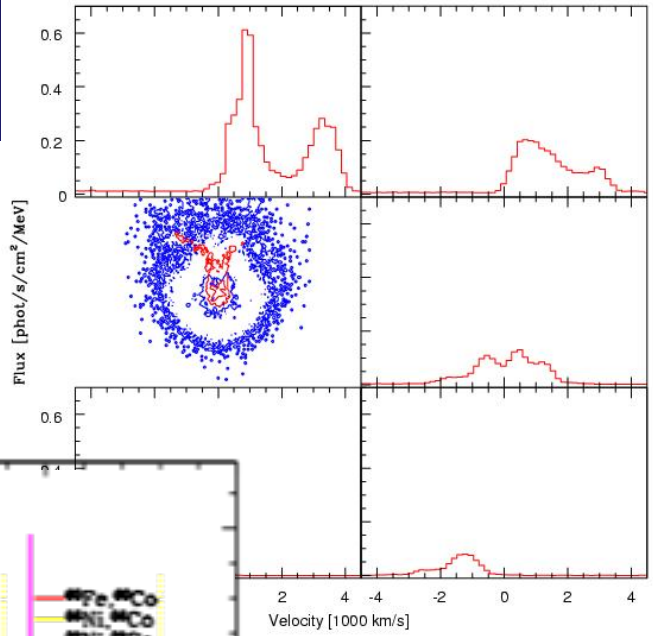


Fryer et al. 2020

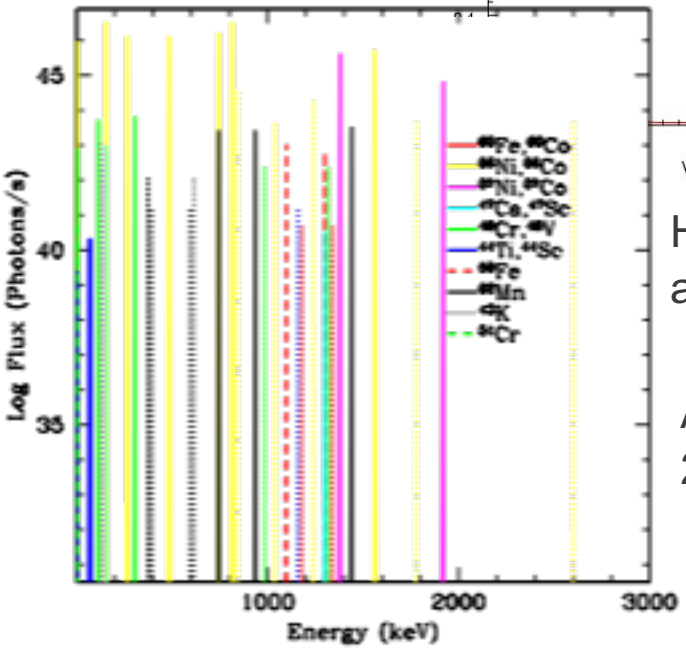
Nucleosynthetic Yields

Nucleosynthetic yields teach us a lot about the progenitor star and its explosion

- Stellar Abundances: easy to observe (probes populations)
- Gamma-Rays: ideal probe of single-explosion yields (only nearby events)
- Dust grains probe isotopic yields: Draine 2003 (probes populations)



Hungerford et al. 2003

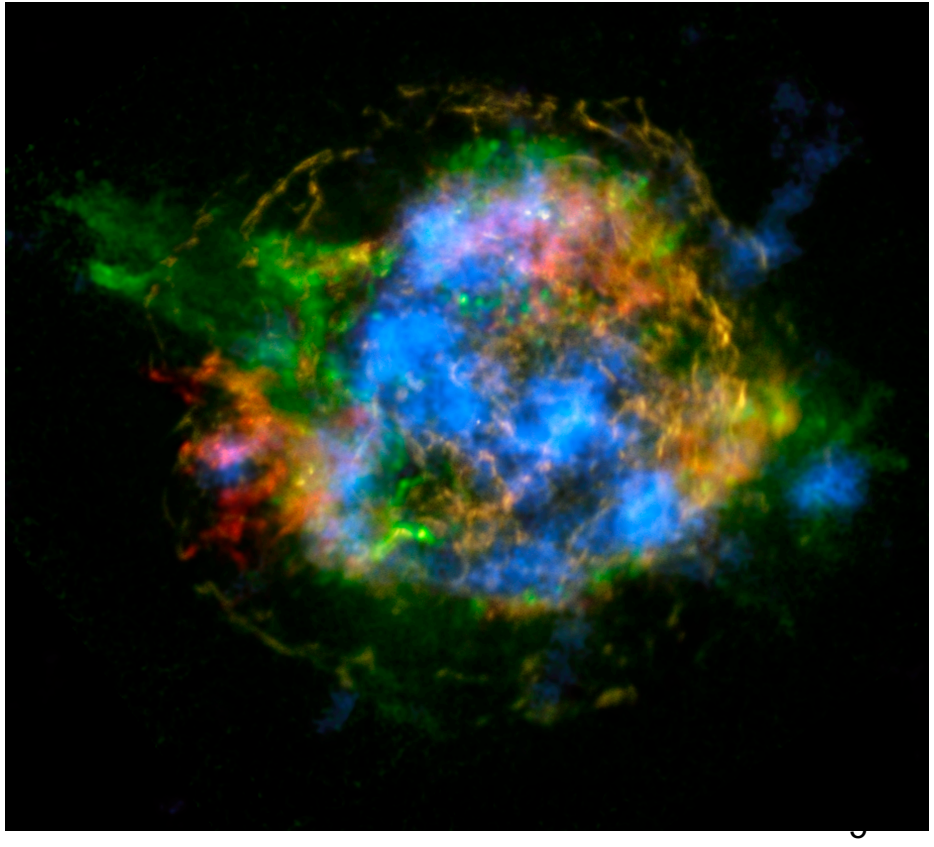


Andrews et al. 2020

Supernova Remnants

- Supernova remnants probe explosion energies, ejecta masses, yields.
- Coupling our understanding of of the explosions, compact remnant constraints (masses, spins, magnetic fields from GWs, pulsars, X-ray binaries, magnetars, …) allow us to understand both the explosion and the physics behind it.
- Cosmic rays produced in the remnant can probe the shock.

Hard X-ray observations of ^{44}Ti in Cassiopeia A provided indisputable evidence of the convective engine.



Grefenstette et al. 2017

Needs for Multi-Messenger Supernovae Studies

- To understand supernovae, we need to combine the information we gain from many fields in astrophysics.
- Multi-messenger is not enough. We need to incorporate data from a wide range of observations of different phenomena (and at different times) with a broad range of energies from each messenger.
- Putting this all together requires theory and multi-physics modeling. We need to work with the physics communities more tightly.