The Core-Collapse Supernova Engine and Galactic Chemical Evolution

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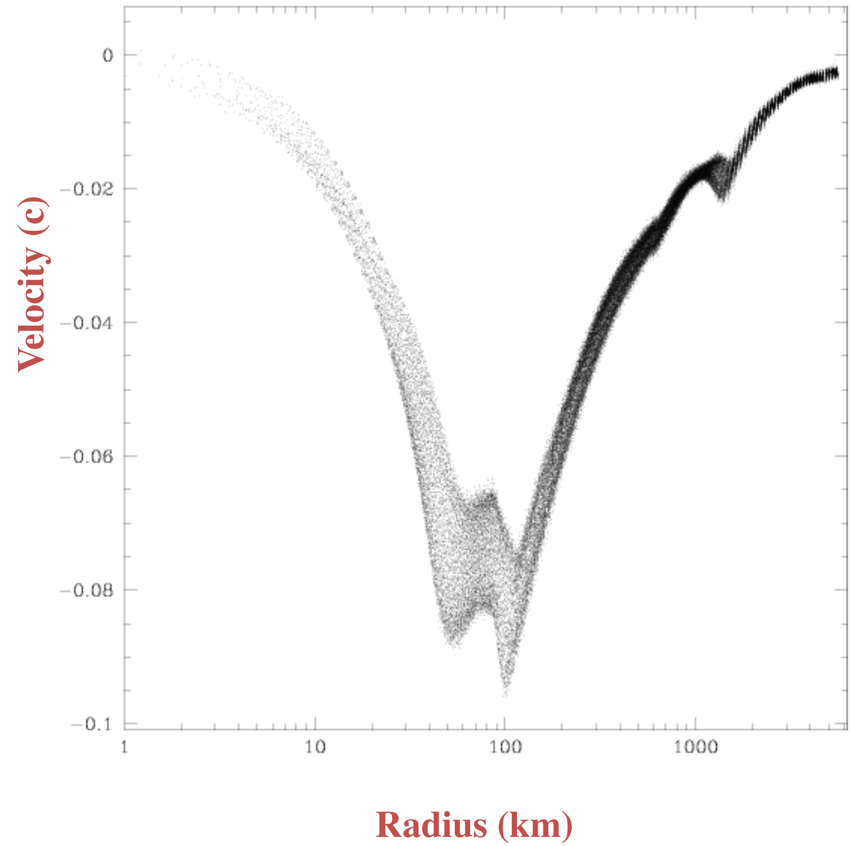
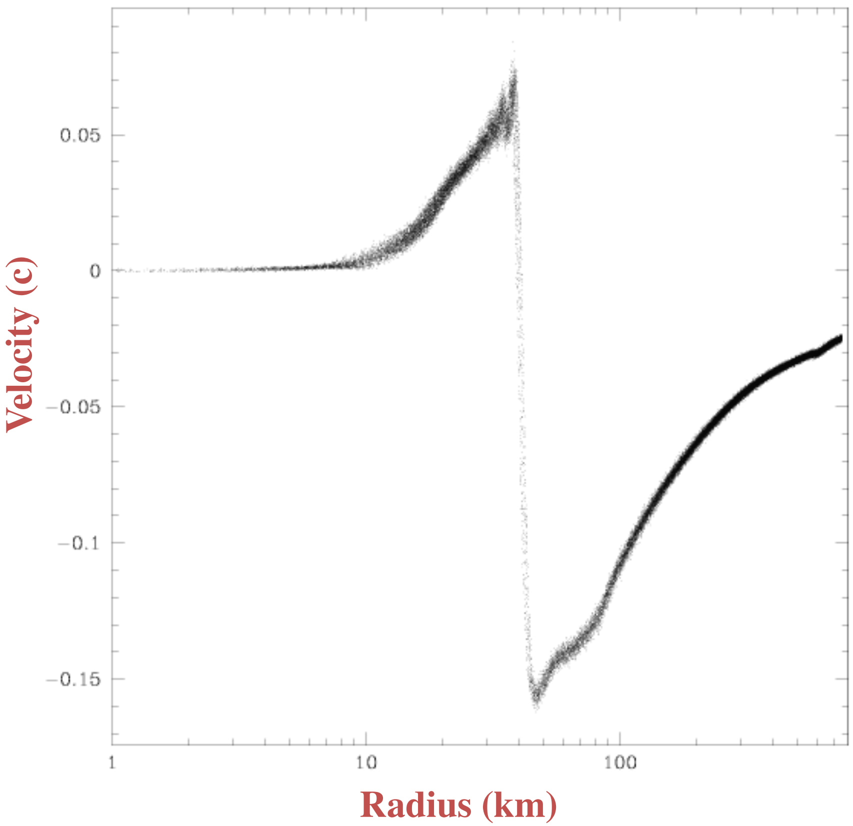
- Building the Case for the Convective Engine
- Yields and their Uncertainties – Engine physics improving yields, GCE constraining engines

Temperature and Density of the Core Becomes so High that:

- Iron dissociates into alpha particles
- Electrons capture onto protons

Core collapses nearly at freefall!



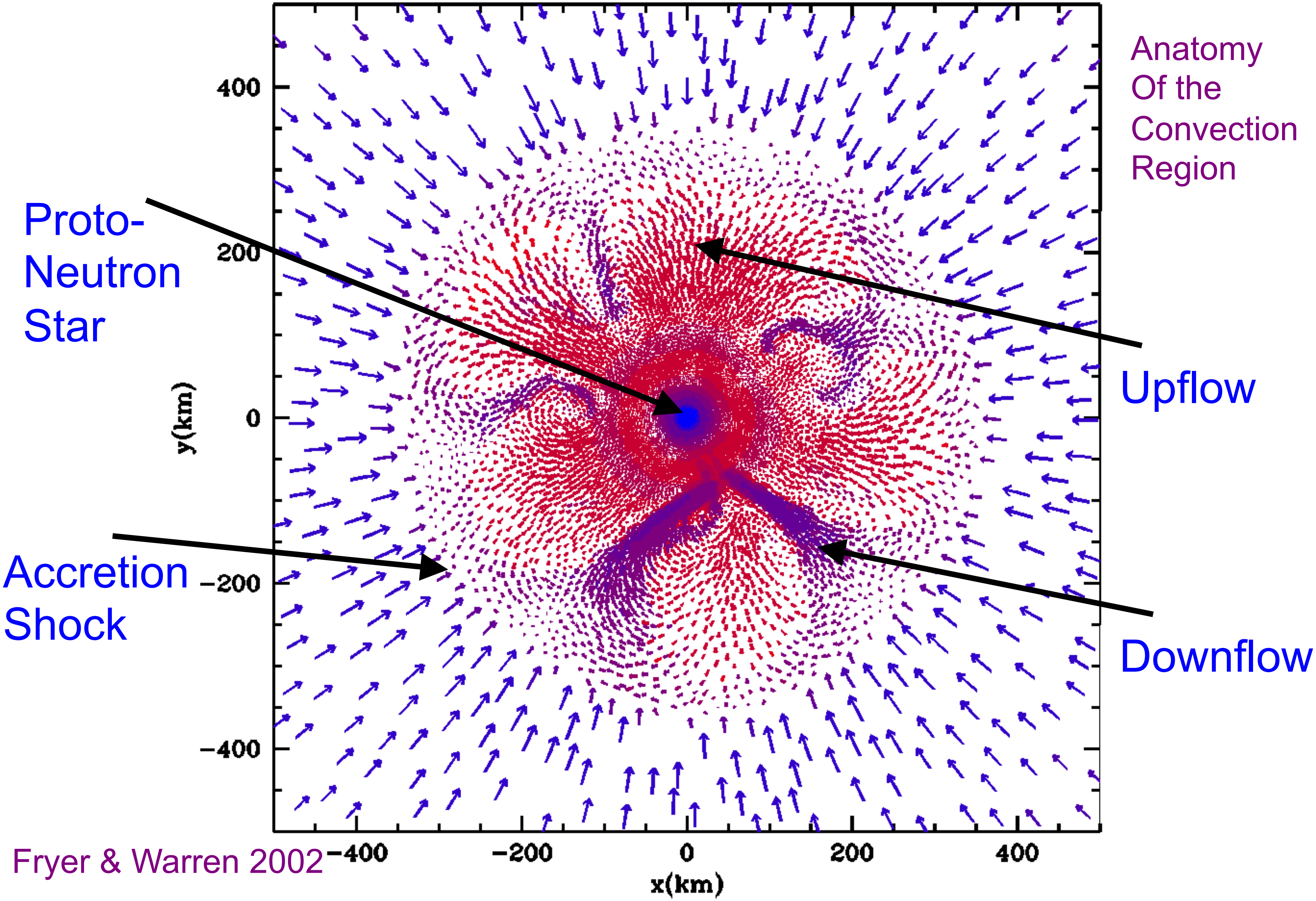


Core reaches nuclear densities

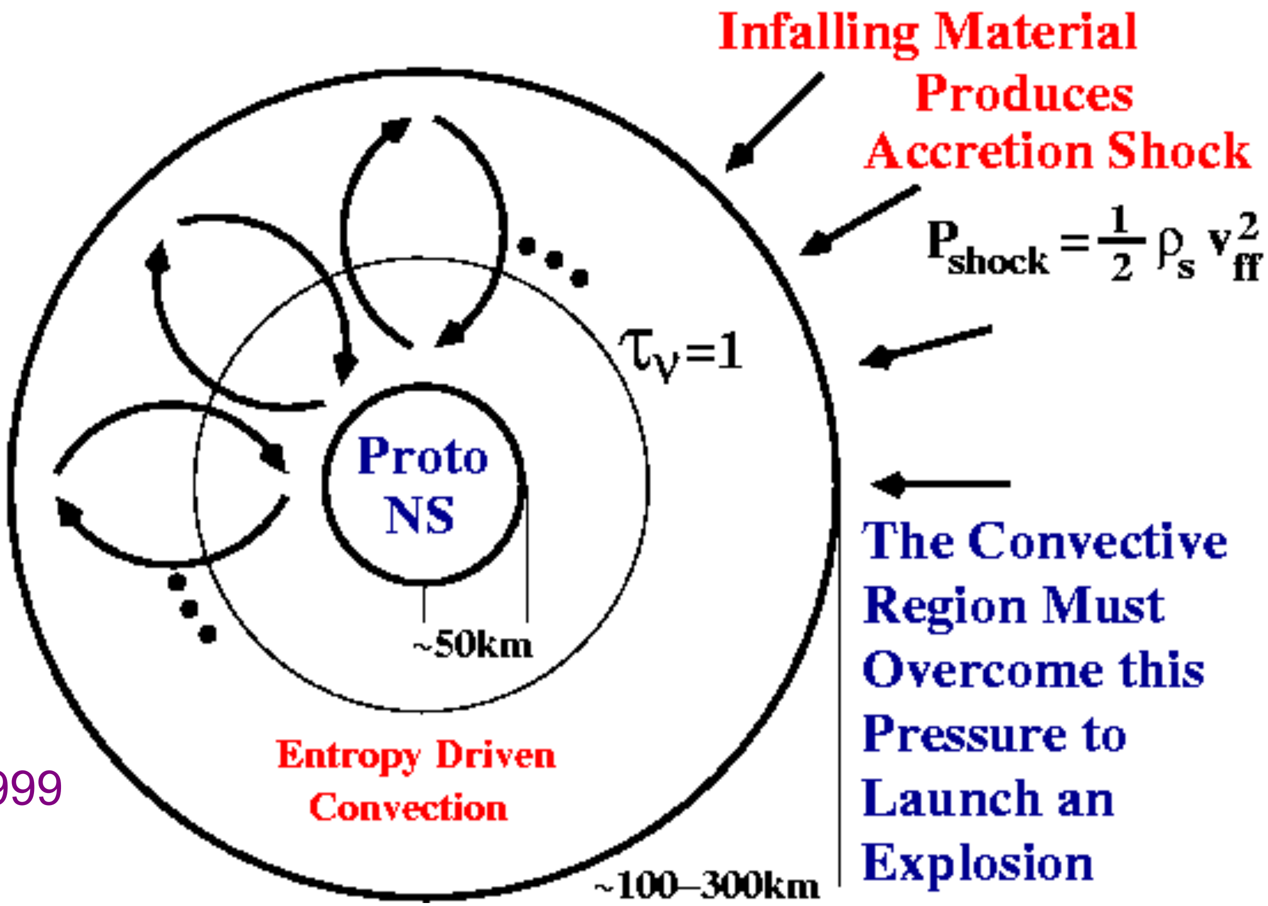
Nuclear forces and neutron degeneracy increase pressure

Bounce!

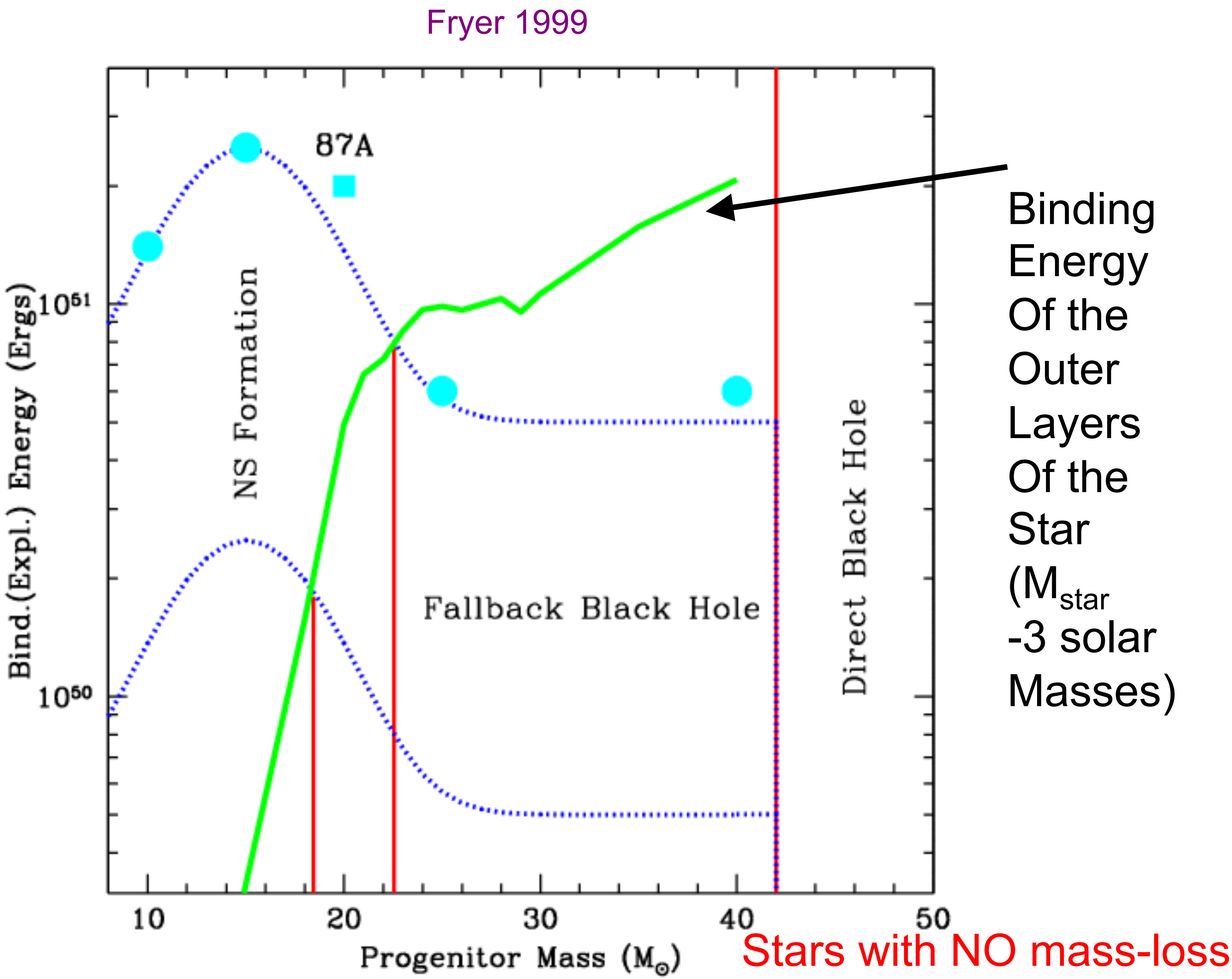
The Herant et al. (1994) Convective Supernova Engine



Neutrino-Driven Supernova Mechanism: Convection

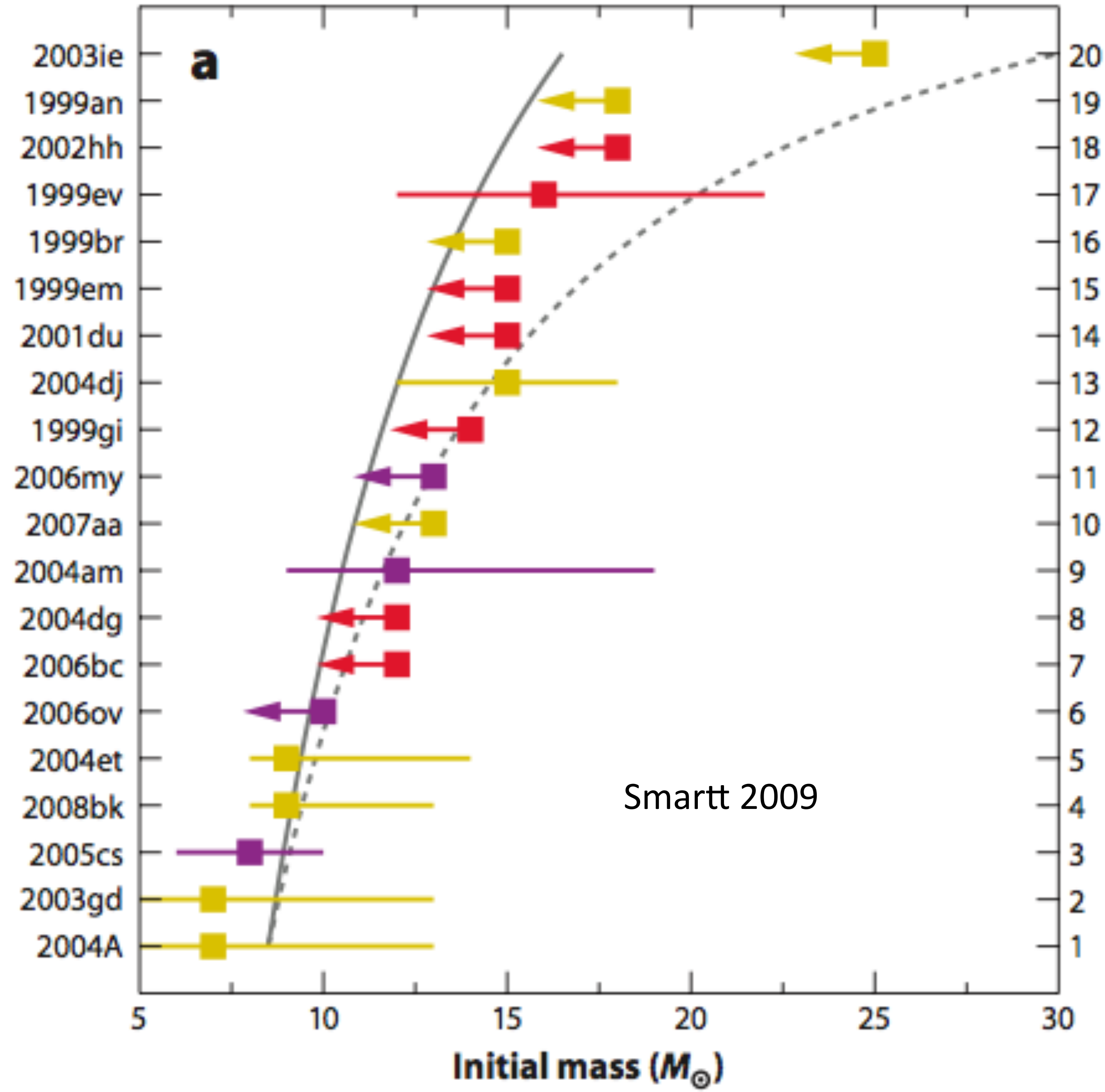


Fryer 1999

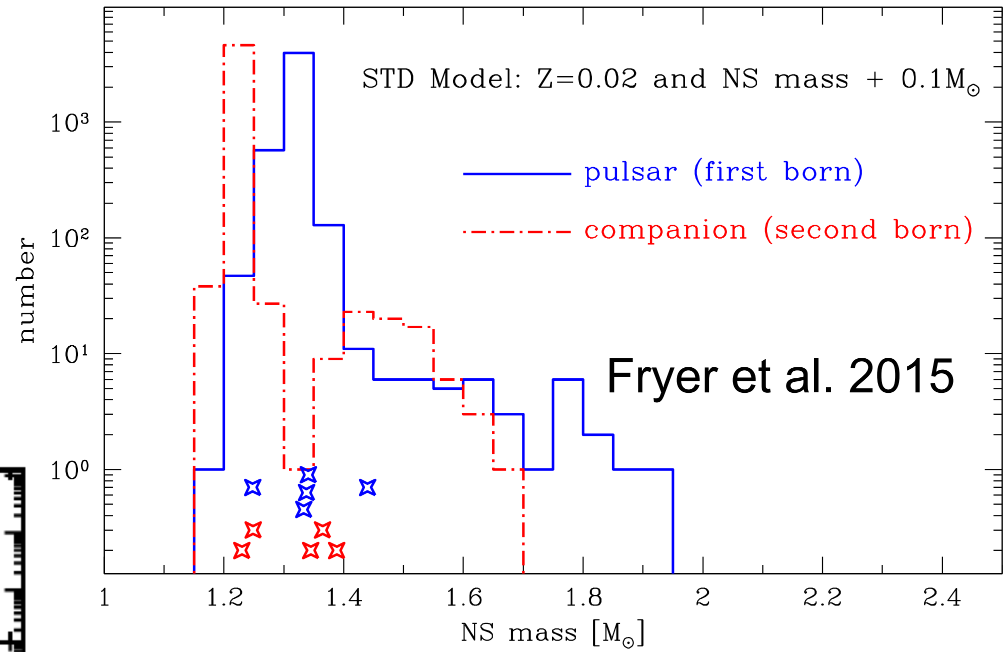

Fryer 1999
87A
NS Formation
Fallback Black Hole
Direct Black Hole
Binding Energy Of the Outer Layers Of the Star (M_{star} -3 solar Masses)
Bind.(Expl.) Energy (Ergs)
10^{51}
10^{50}
10
20
30
40
50
Progenitor Mass ($M_{\odot}$)
Stars with NO mass-loss

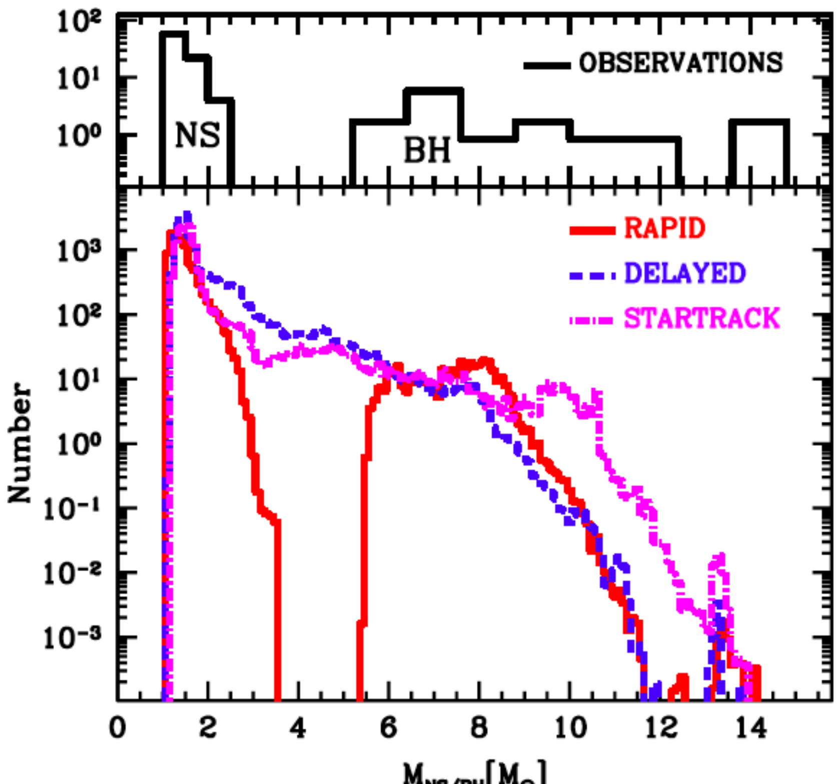
With HST, astronomers now have a slowly growing set of progenitors observed pre-collapse.

These observed progenitors confirm the theory predictions.



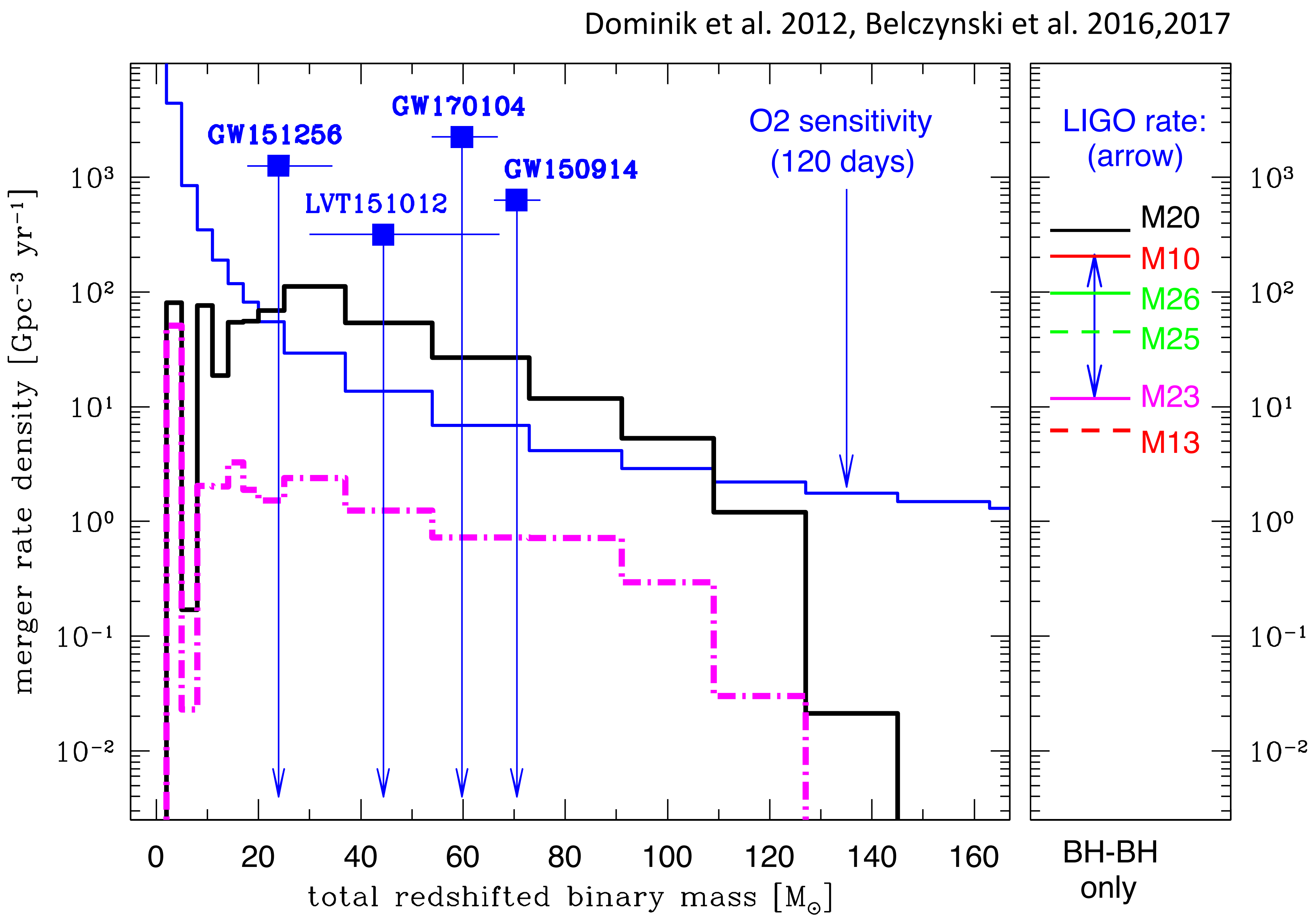
Distribution of Neutron and Black Hole Masses





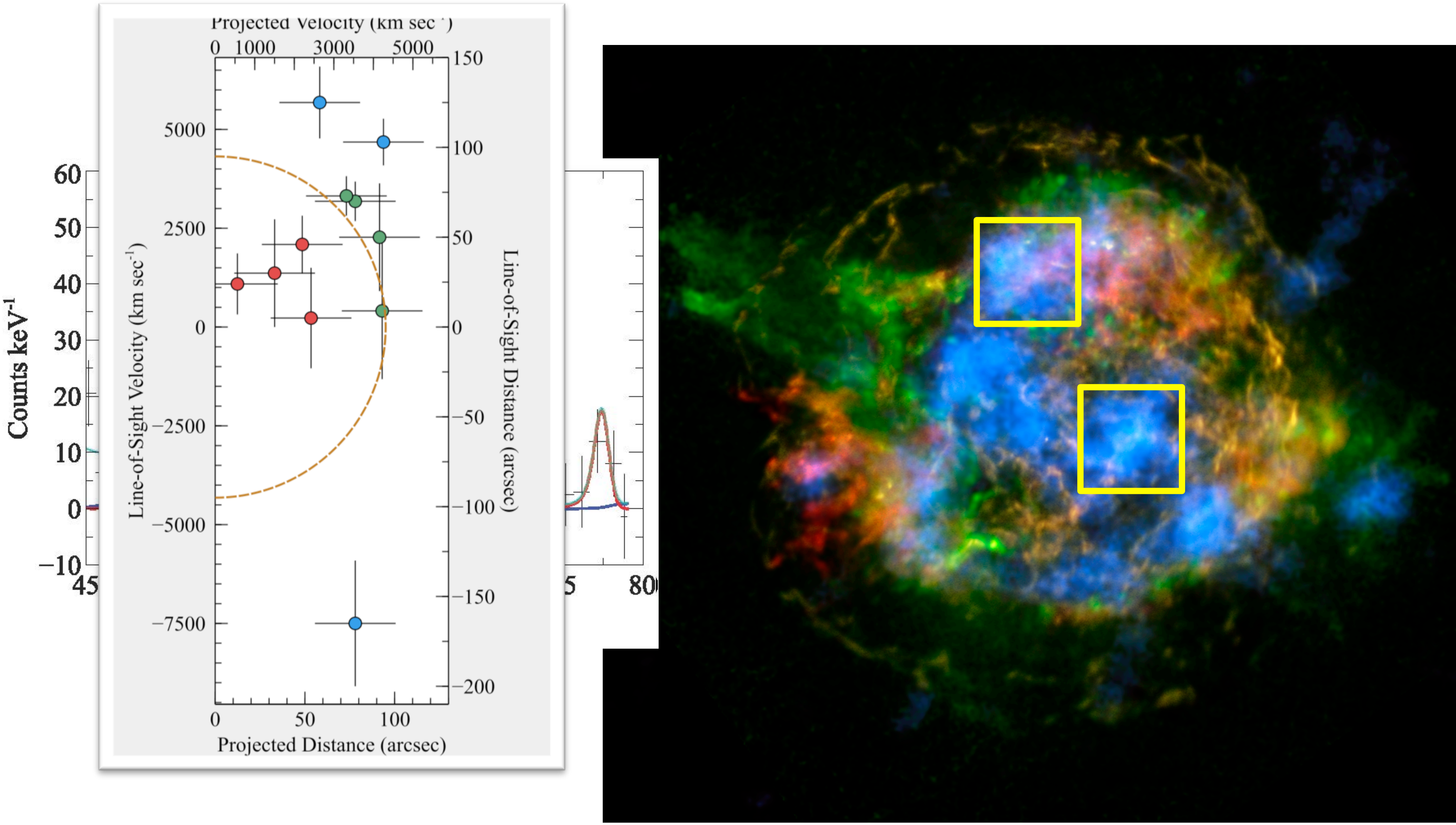
Belczynski 2012

The range of remnant masses was predicted by models (in 2000, observations argued for delta function mass distributions). But the mass gap places constraints on the engine.



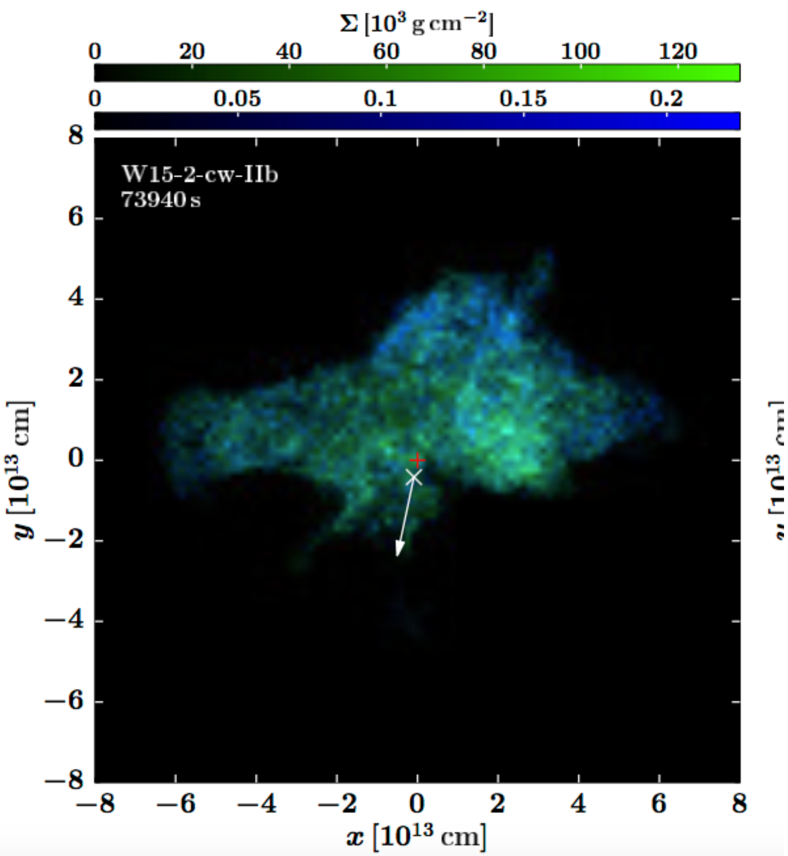
Dominik et al. 2012, Belczynski et al. 2016,2017
GW151256
GW170104
LVT151012
GW150914
O2 sensitivity
(120 days)
LIGO rate:
(arrow)
M20
M10
M26
M25
M23
M13
merger rate density [Gpc⁻³ yr⁻¹]
total redshifted binary mass [M⊙]
BH-BH
only

Cassiopeia A



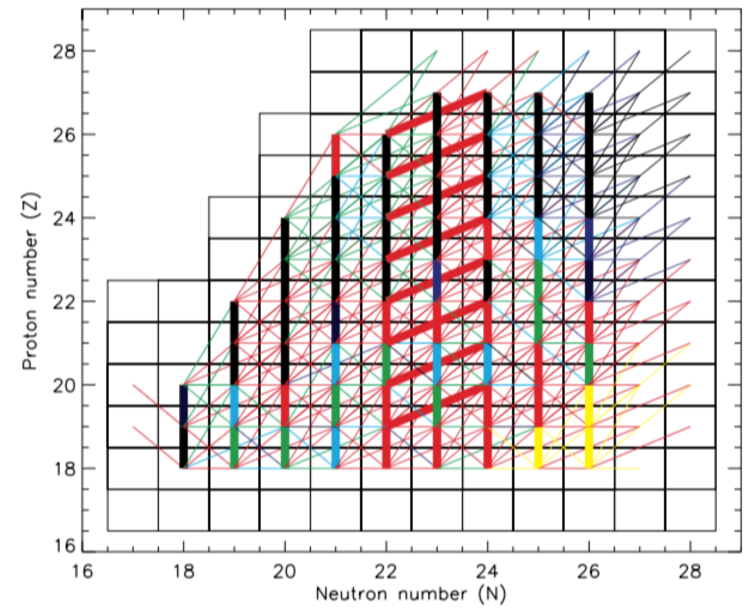
Grefenstette et al., ApJ (2017)

Wongwathanarat et al. (2017) and Young et al. (2017) both found that simple models based on the convective engine could match the structure of Cas A.

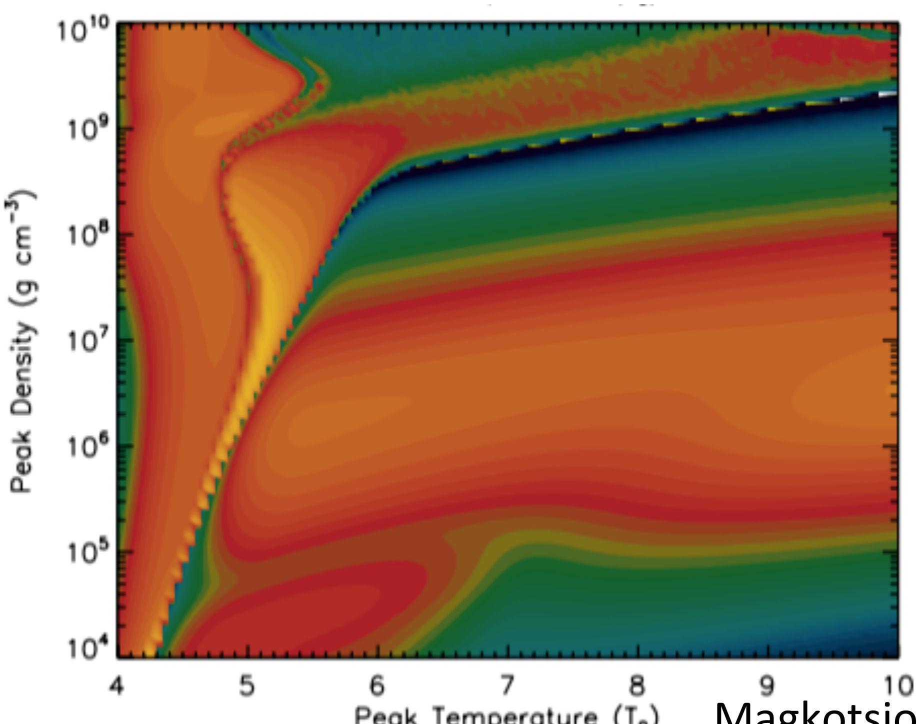


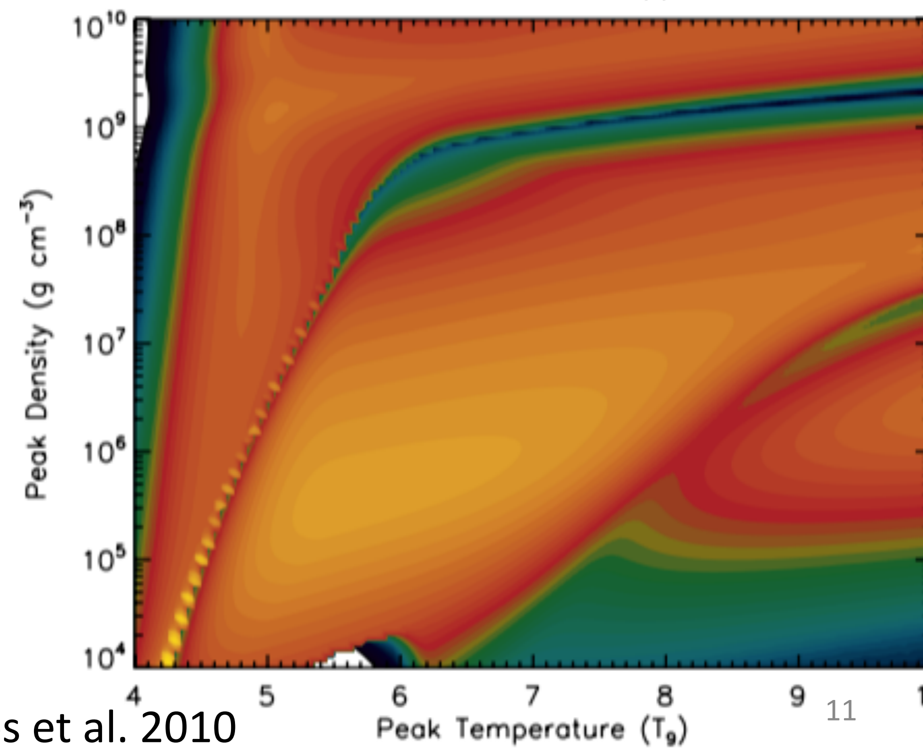
Y_e dependence

The yields depend sensitively on the electron fraction. Near the proto-neutron star, this can be set by the neutrino spectra (transport, neutrino physics – e.g. oscillations, …)



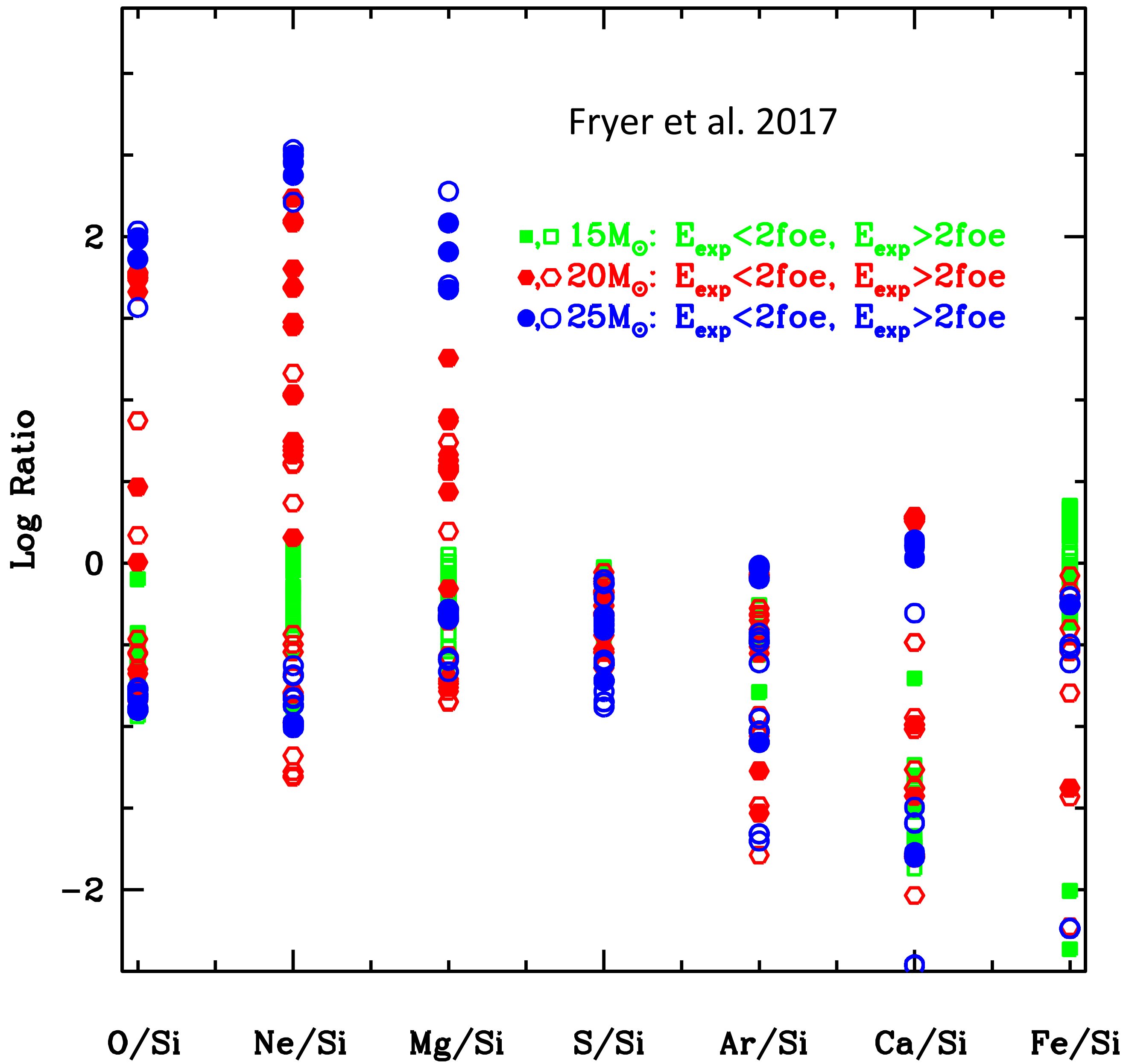
Y_e=0.0506





Magkotsios et al. 2010

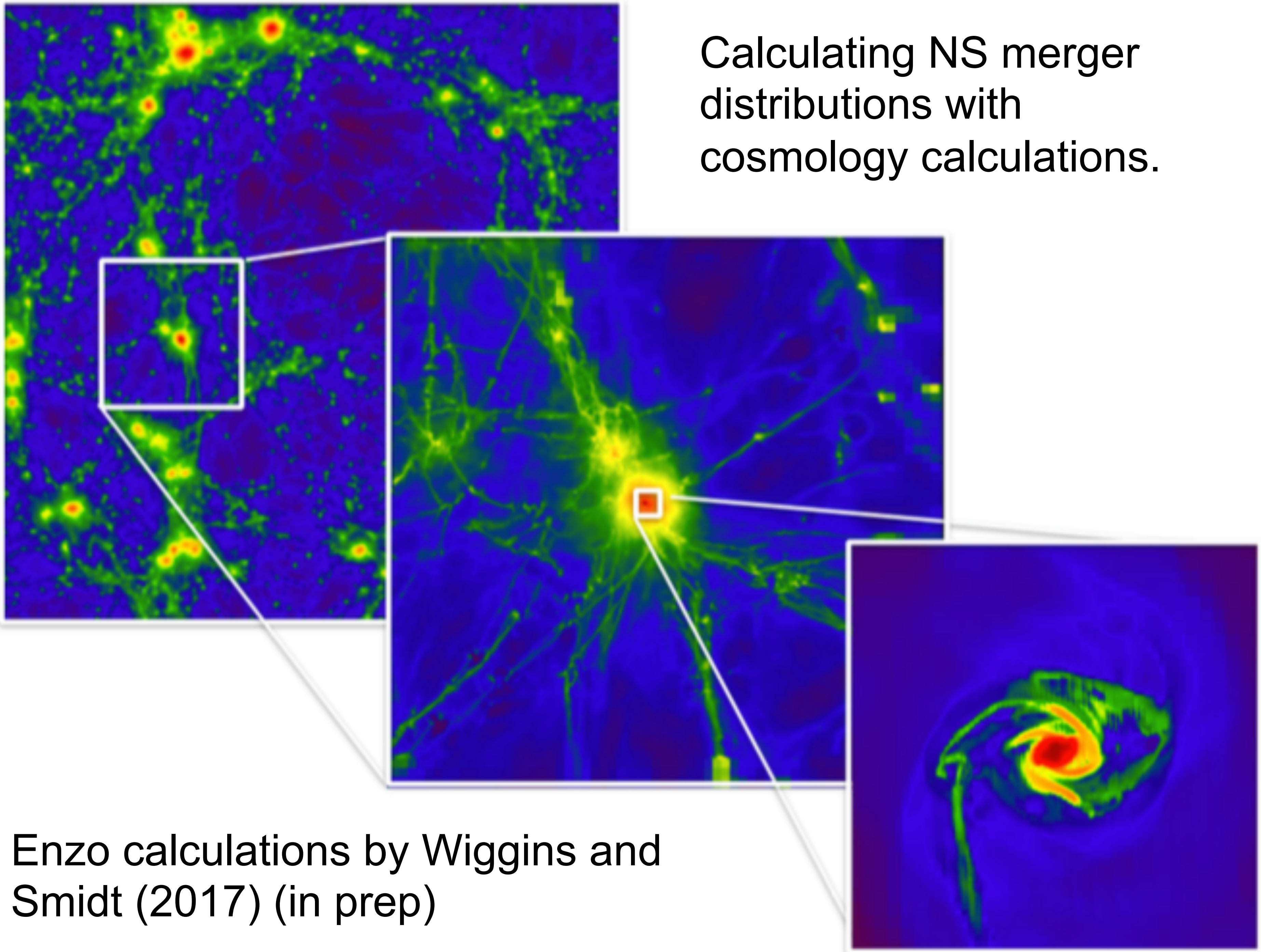
- We can compare to a broader set of remnant yields.
- The difficulty with these broader yields is that most remnants don't have the diverse set of data like Cas A. We can get a wide range of yields just on explosions alone.
- We need to understand the progenitor uncertainties as well.



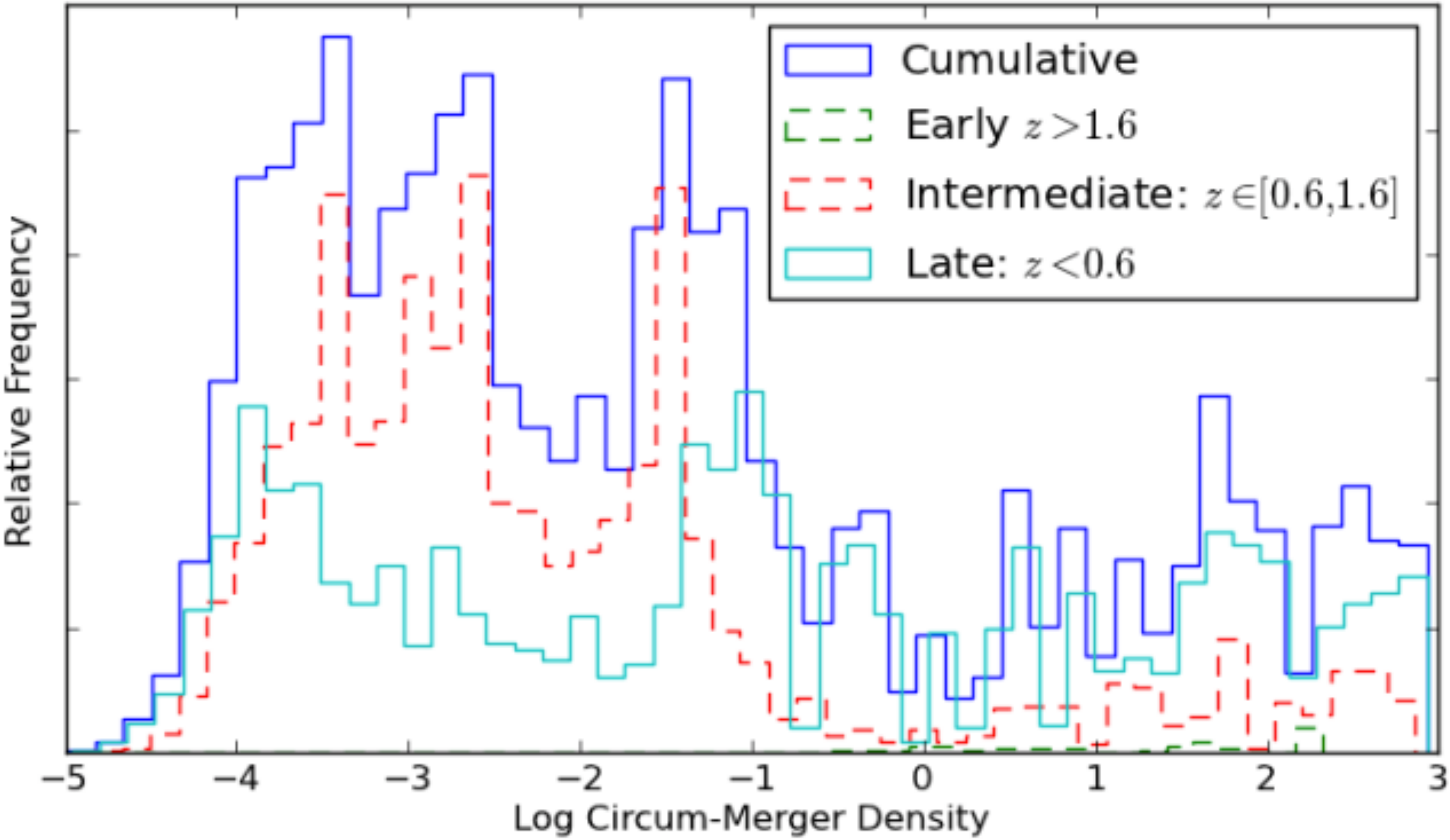
Conclusions

- The convective engine has been the leading theory model for 2 decades. Observations from SN energies, remnant masses, and remnant structure support this engine (no other proposed model matches these constraints without extreme tuning).
- Other engines exist – pair-instability supernovae, MHD jets to explain hypernovae/GRBs (and perhaps some SLSNe). For some yields, these will be important.
- We can use individual supernova remnants to probe nucleosynthesis (and the engine). Stay tuned for new results here.
- Currently there are still large yield uncertainties. Within the uncertainties, more than one solution can be found to match GCE. Determining all solutions and eliminating solutions should be high on our “to-do” list.

Calculating NS merger distributions with cosmology calculations.



Enzo calculations by Wiggins and Smidt (2017) (in prep)



Cumulative
Early $z > 1.6$
Intermediate: $z \in [0.6, 1.6]$
Late: $z < 0.6$
Relative Frequency
−5
−4
−3
−2
−1
0
1
2
3
Log Circum-Merger Density