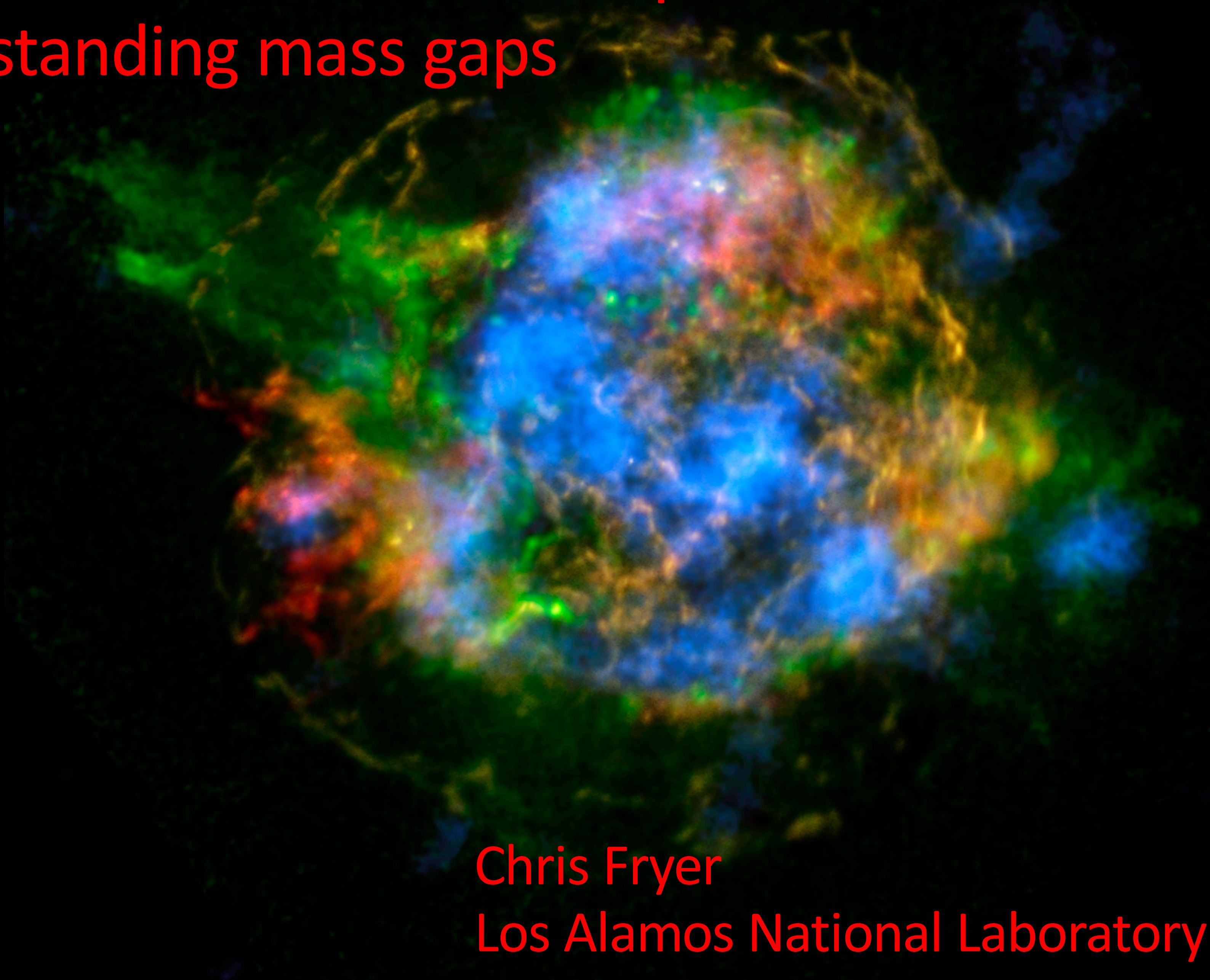
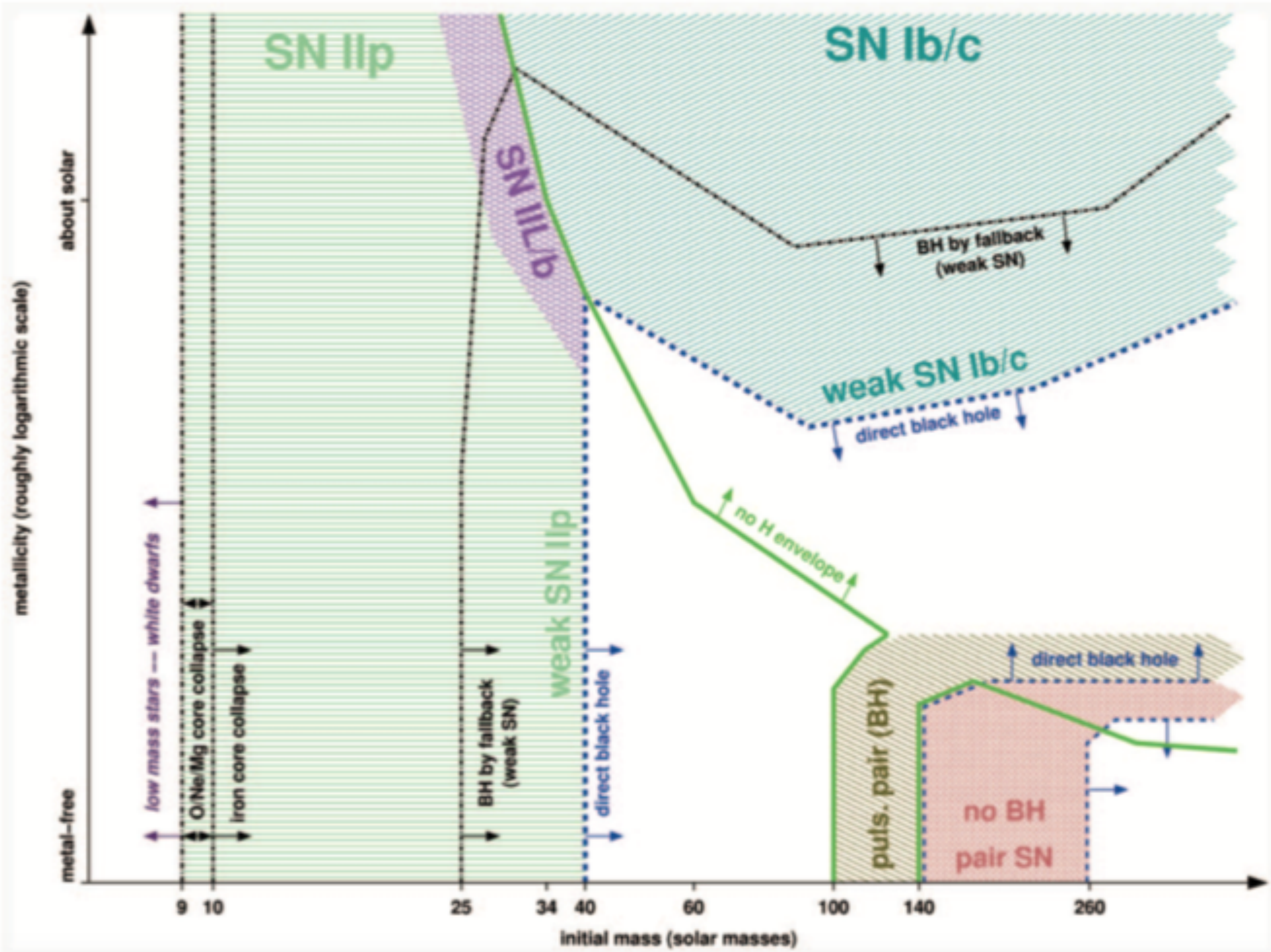
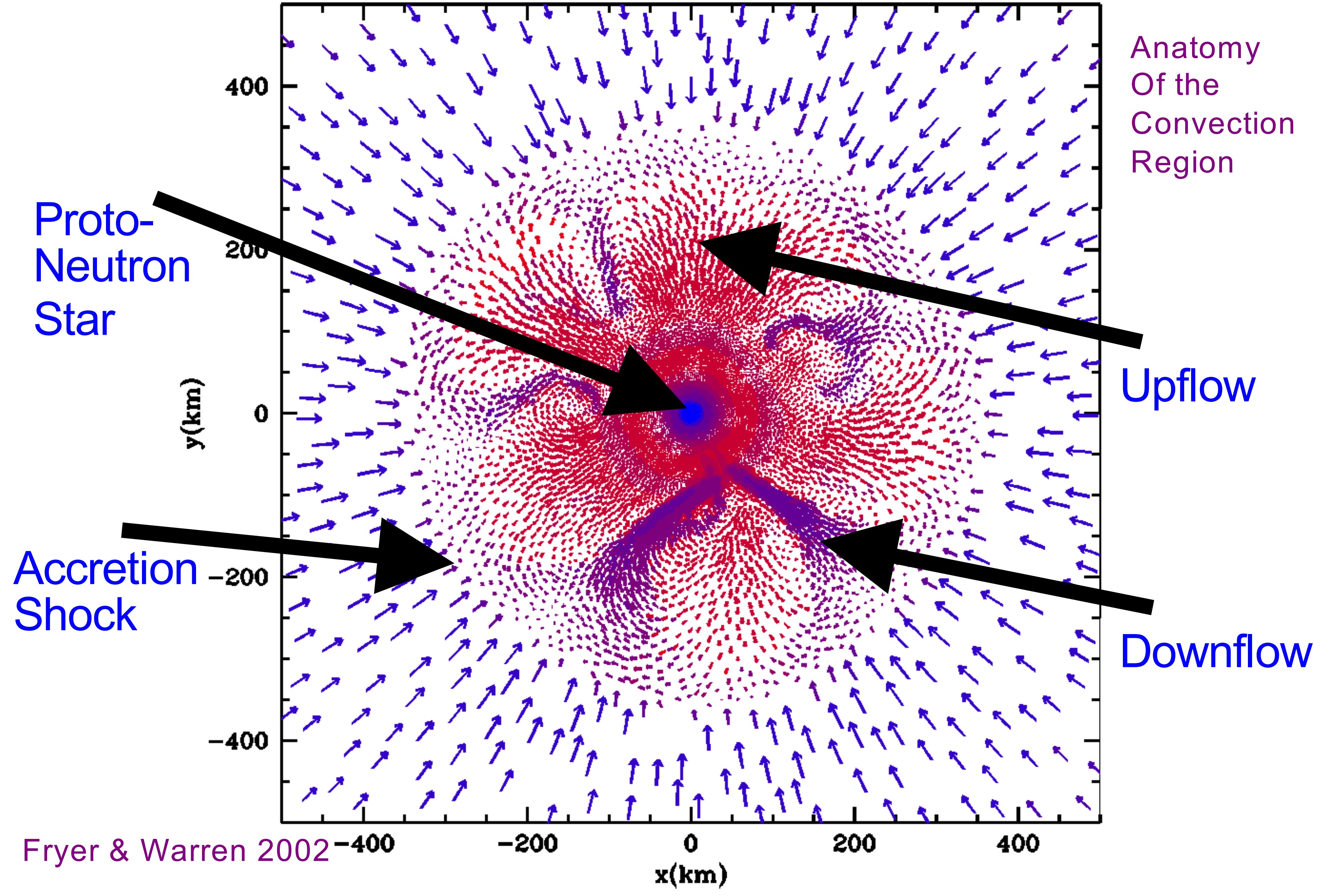
Explosions From Stellar Collapse: Understanding mass gaps



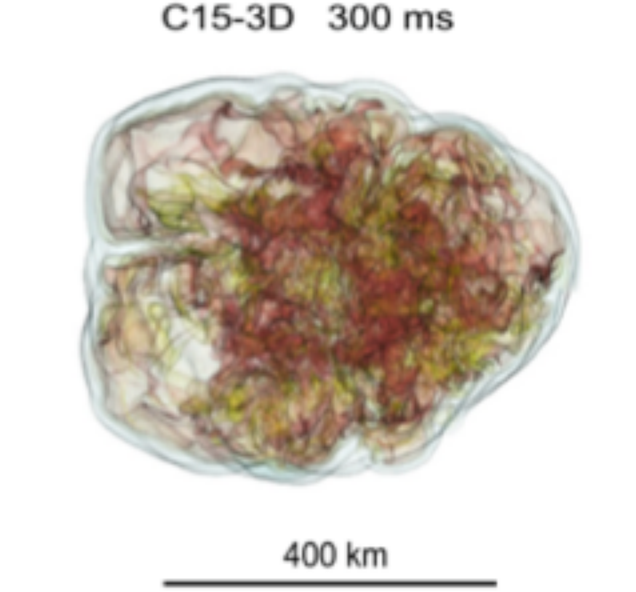
Chris Fryer
Los Alamos National Laboratory


SN IIp
SN Ib/c
SN IIL/b
BH by fallback
(weak SN)
weak SN Ib/c
direct black hole
no H envelope
weak SN IIp
low mass stars — white dwarfs
O/Ne/Mg core collapse
iron core collapse
BH by fallback
(weak SN)
direct black hole
puls. pair (BH)
direct black hole
no BH
pair SN
metallicity (roughly logarithmic scale)
about solar
metal-free
9
10
25
34
40
60
100
140
260
initial mass (solar masses)

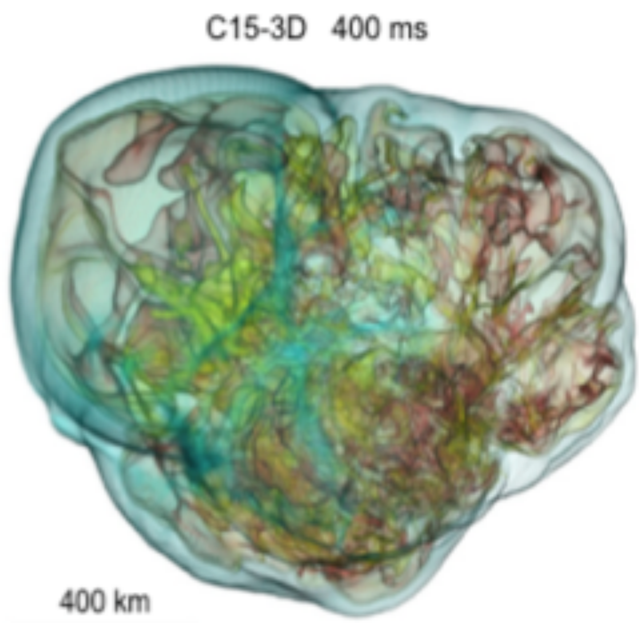
The Herant et al. (1994) Convective Supernova Engine



Fryer & Warren 2002



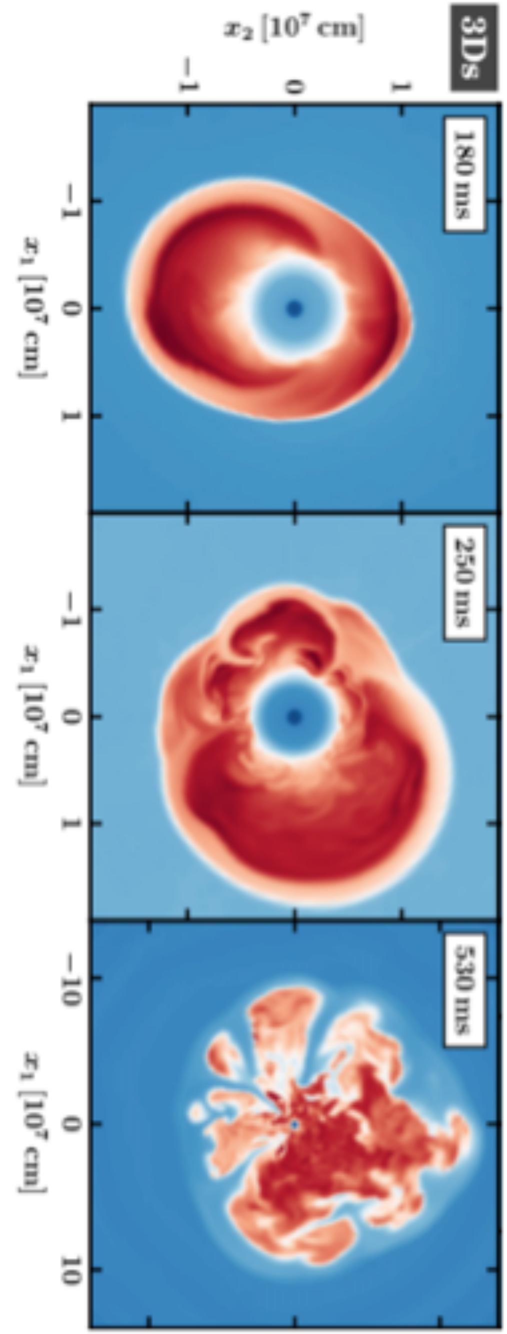
Lentz et al. 2015



Depending on the physics, most groups now produce explosions with this convective engine.

Most arguments focus on the:

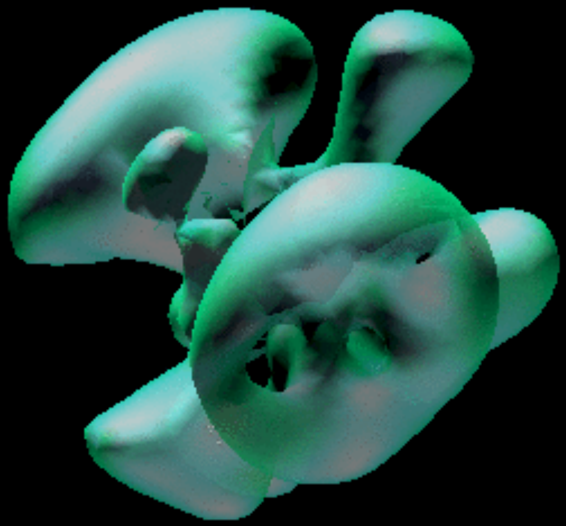
- Most important physics affecting the explosion
- Source of instabilities



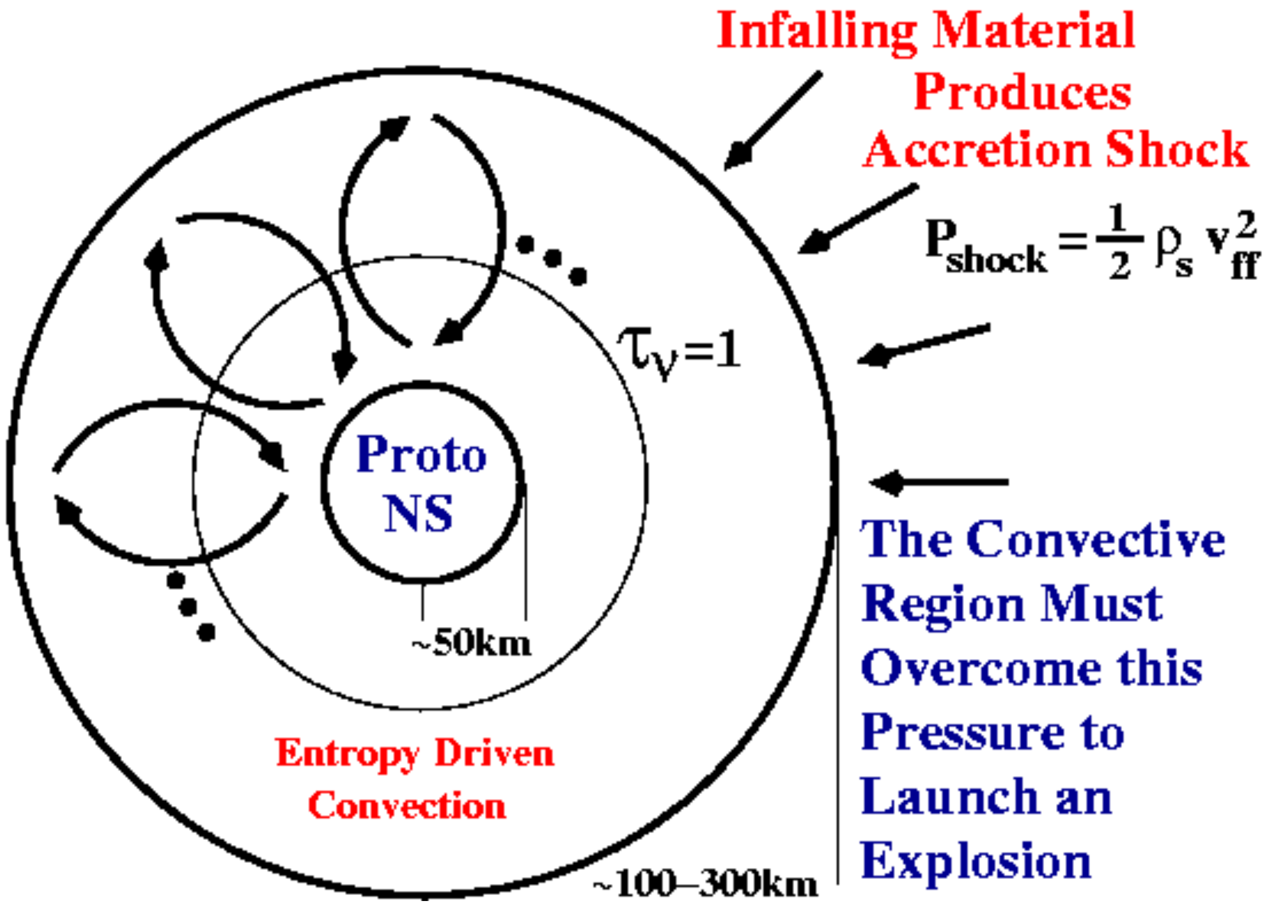
Melson et al. 2015

Ejecta Remnants – Probing Low Mode Convection

- In most simulations, low mode convection driven by Rayleigh-Taylor or advective-acoustic instabilities seem to dominate the flows.
- Although this has dominated the focus of theorists for nearly 20 years, the evidence was indirect until the NuStar observations of Cas A.



Neutrino-Driven Supernova Mechanism: Convection

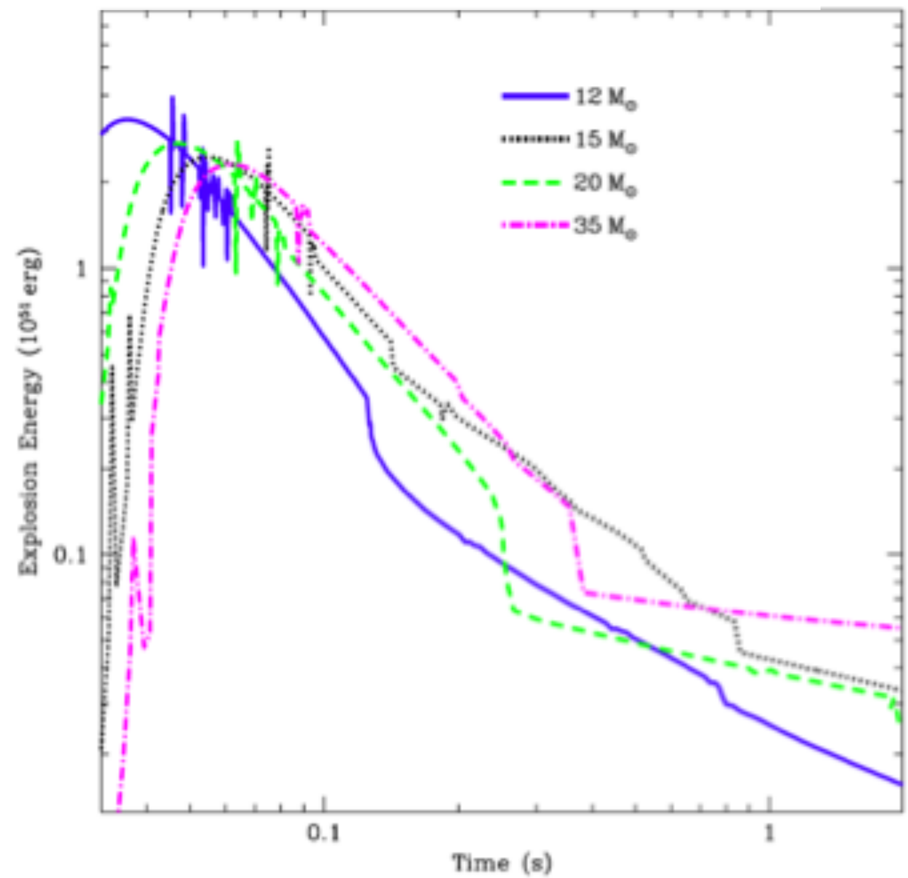


Fryer 1999

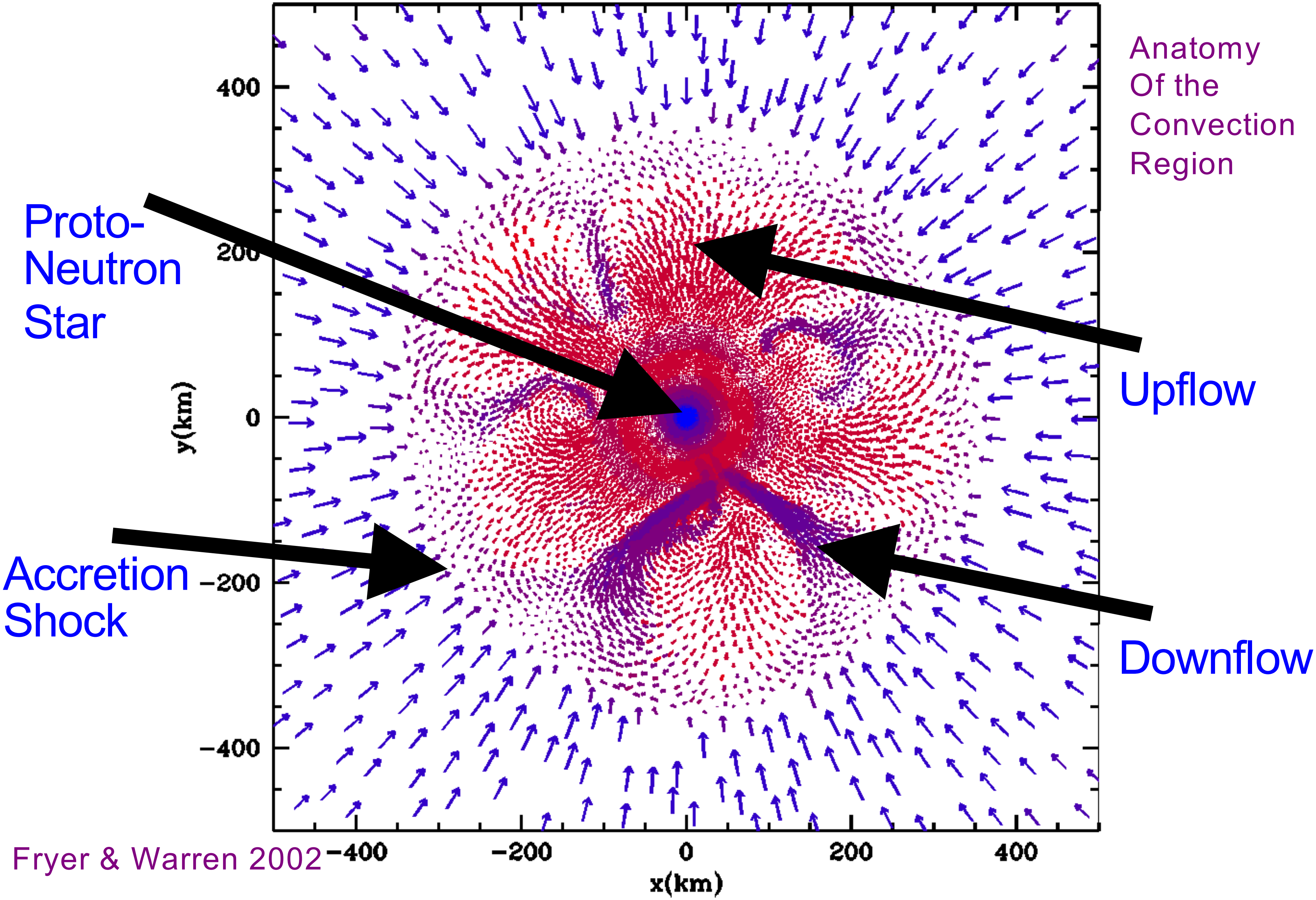
$$P_{\rm shock}(r) = 1/2\rho_{\rm shock}v_{\rm free-fall} = (2GM_{\rm NS})^{0.5}\dot{M}_{\rm acc}/(8\pi r_{\rm shock}^{2.5})$$

$$u_{\rm convection}(r) = 3\left[4.7\times10^{8}\frac{M_{\rm NS}}{M_\odot}\frac{10k_{\rm B}{\rm nucleon}^{-1}}{S_{\rm rad}}\left(\frac{10^6{\rm cm}}{r}-\frac{10^6{\rm cm}}{r_{\rm shock}}\right)+1.2\times10^6\left(\frac{M_{\rm NS}}{M_\odot}\frac{\dot{M}_{\rm acc}}{M_\odot{\rm s}^{-1}}\right)^{1/4}\left(\frac{2\times10^7{\rm cm}}{r_{\rm shock}}\right)^{5/8}\right]^4 {\rm erg\,cm^{-3}}.$$

- For most stars, the maximum energy is a few times 10^{51} erg. Fallback can increase this value, but not by much.
- This is a natural explanation for the energy, but it means that this engine can not explain hypernovae.

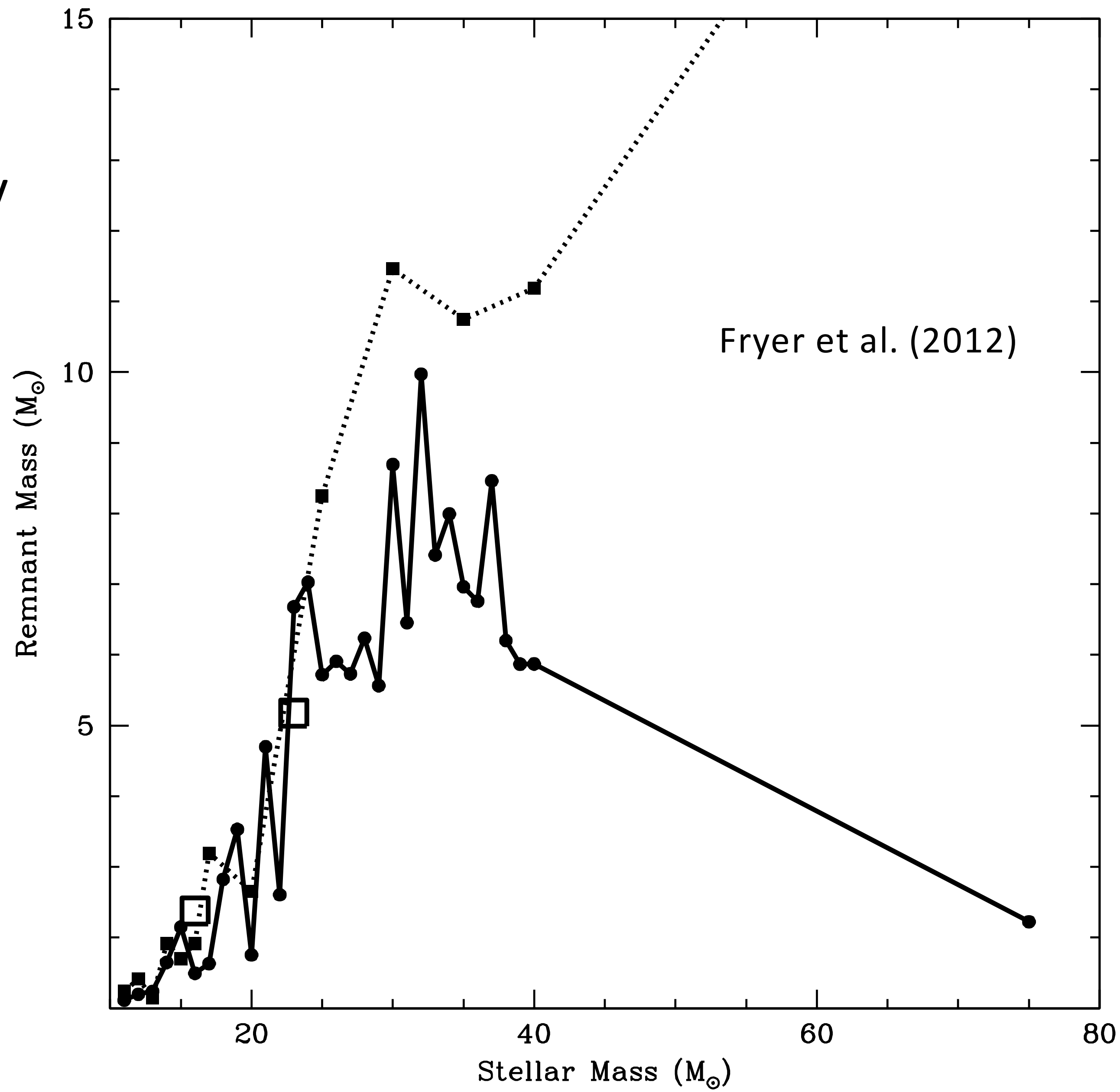


The Herant et al. (1994) Convective Supernova Engine

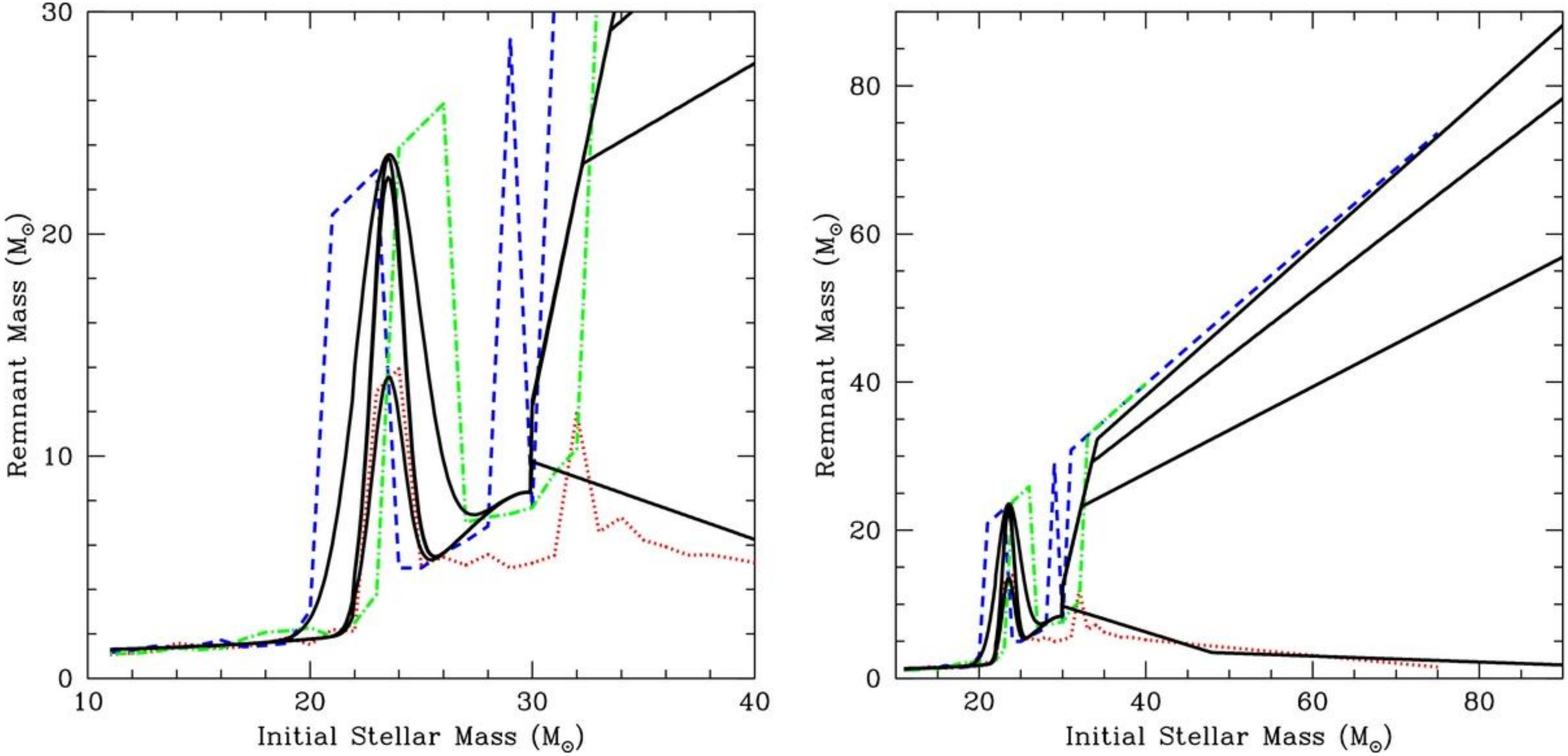


Fryer & Warren 2002

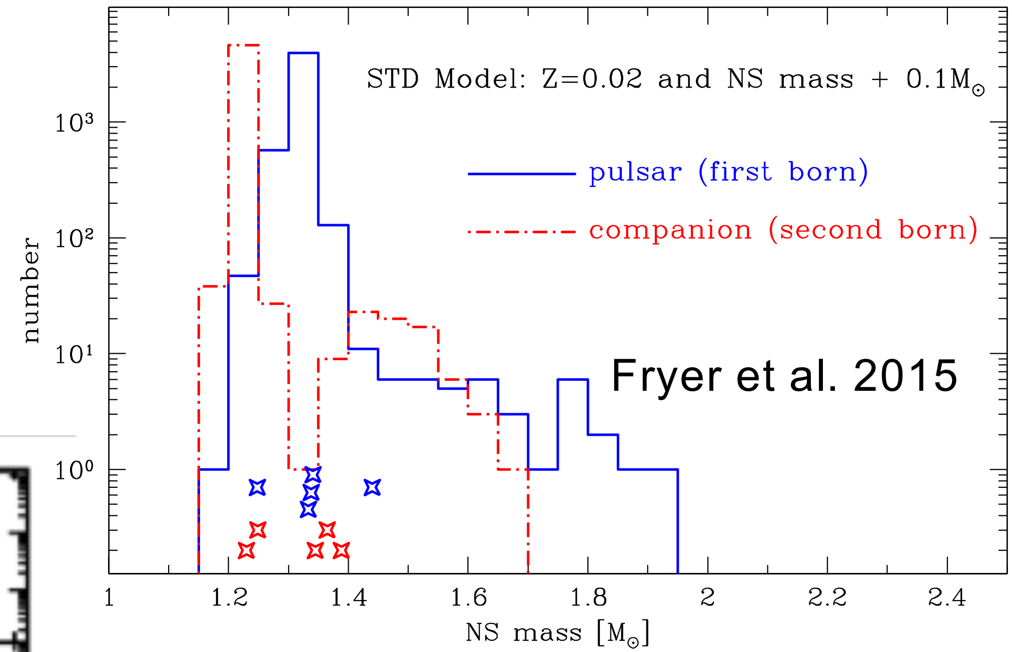
The remnant mass depends sensitively on the progenitor. Whereas the remnant mass decreases above ~30 solar masses for the Woosley et al. 2002 models at solar metallicity, it continues to increase for the Limongi and Chieffi (2006) models.

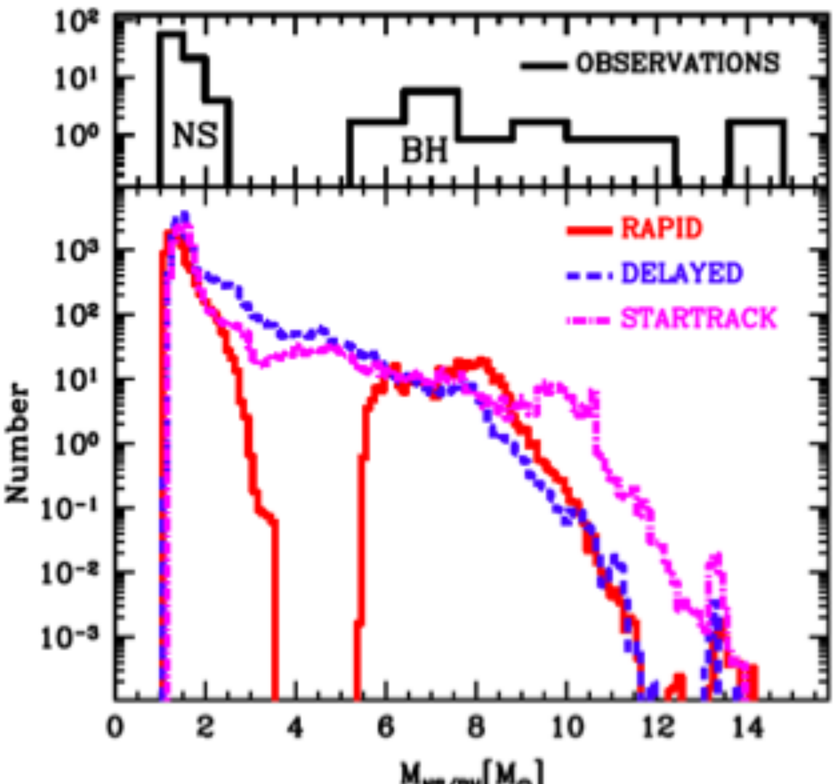


Fitting the data (Fryer et al. 2012). I applied these concepts to different stellar grids and then fit to these results. I assumed the fates were smooth. More thought should be done here.



Distribution of Neutron and Black Hole Masses





Belczynski 2012

Both the NS-BH mass gap and the distribution of NSs must be fit by any explosion model. Since these masses have all evolved from close binaries, we must also include binary effects.

Spins and the explosion

High spin systems can have different engines:

- If the stellar angular momentum is high, you can form a disk. Given that spin-coupling tends to make flat spins, the angular momentum in the core is typically low (why the long-duration GRB model invoked black holes for disks).
- To get SN-like energies from a highly-spinning NS, we need near ms pulsars (faster than what is produced with spin coupling models)

These explosions should be very rare!