What is wrong with our Long GRB Engines/Progenitors?

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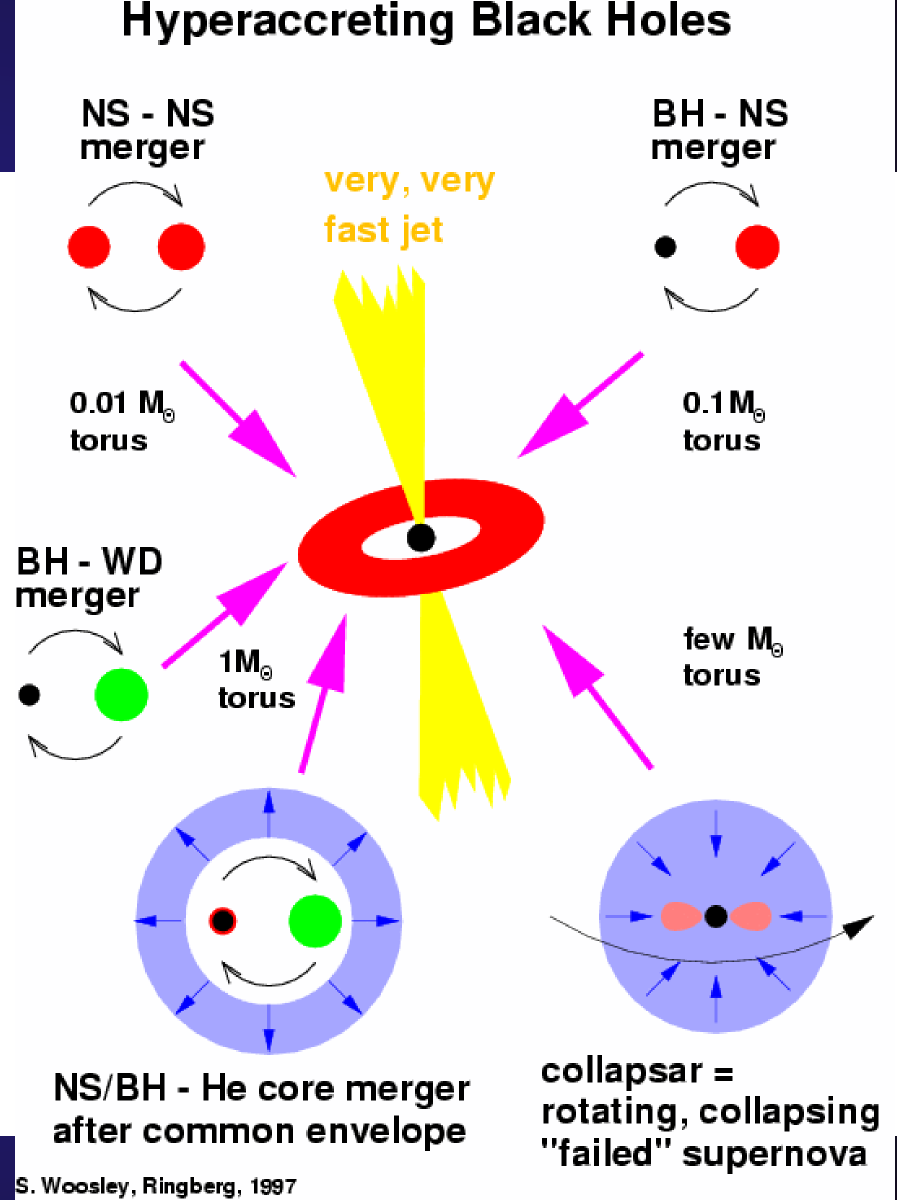
Jet Mechanisms

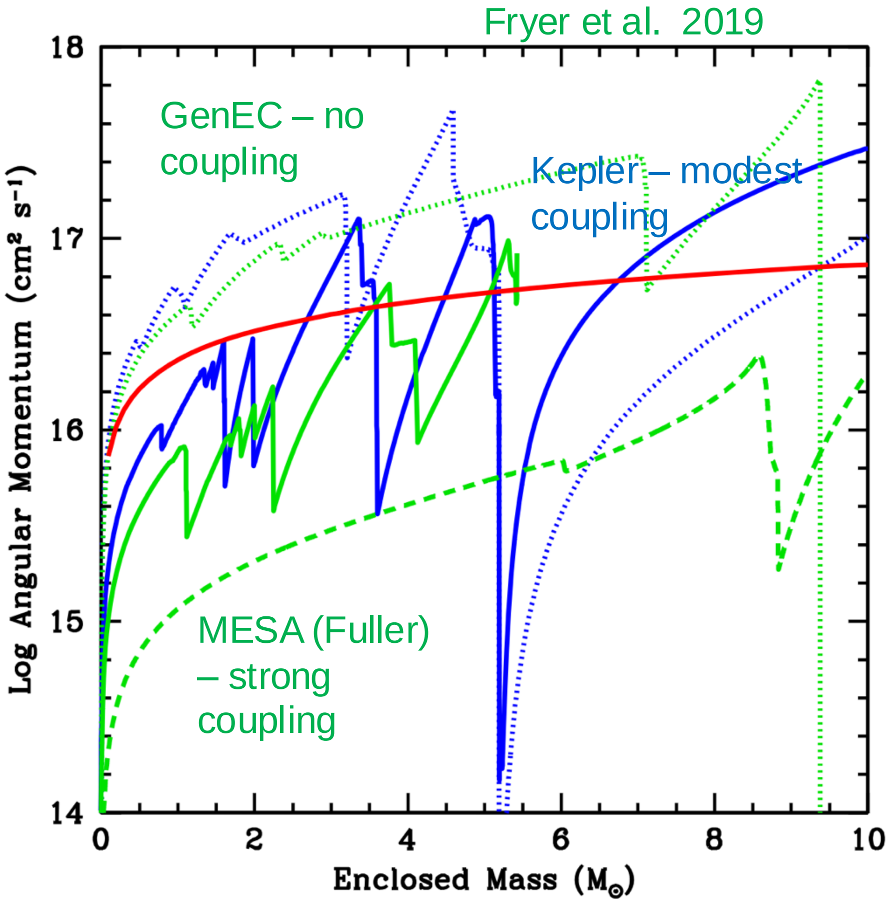
- BHAD models can be formed both through the rotating collapse of a massive star or the merger of 2 compact objects. Different scenarios yield different accretion properties, each arguing for different accretion durations (WD, He mergers and collapsars form long-duration GRBs) and jet powers (Popham et al. 1999)
- The traditional "collapsar" model arises from the collapse of a rotating massive star. A large number of scenarios have been proposed to produce the required high angular momentum (Fryer et al. 1999)
- NSAD and Magnetar channels are similar (we will discuss the differences)



Spin Requirements for Different Engines

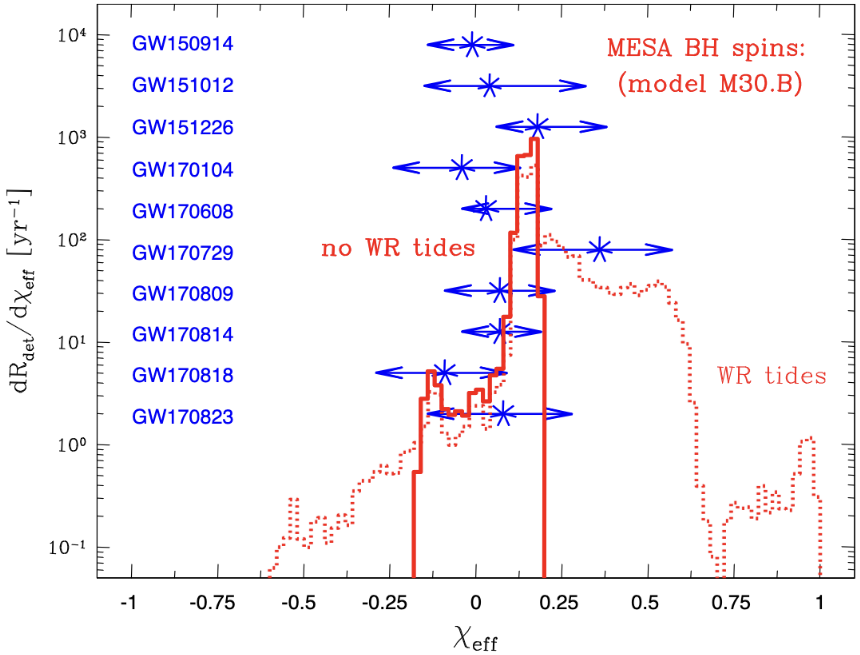
In stars, the angular momentum profile increase with radius (for constant spin, j ~ r^2).

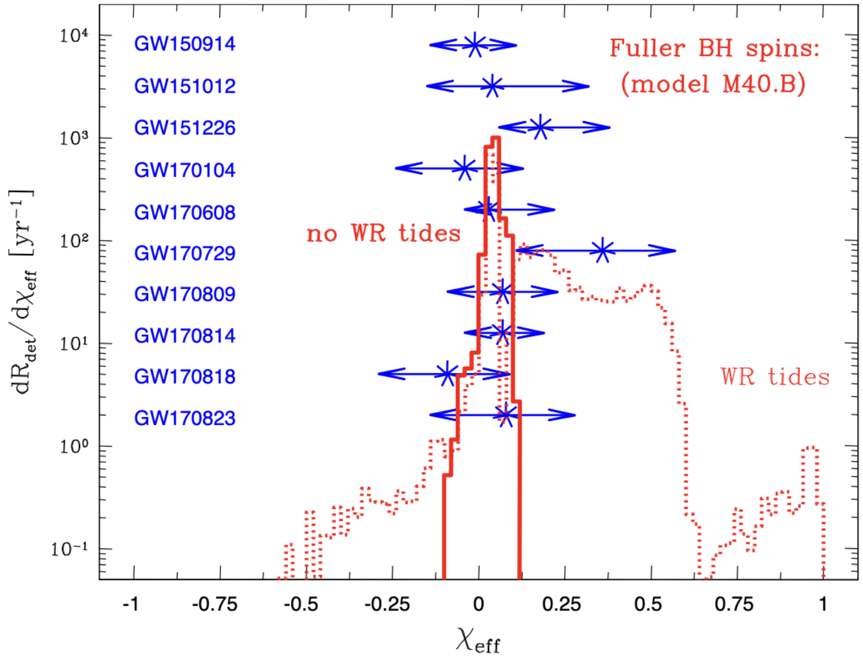
- Single stars (and binaries limited to he-burning and earlier interactions) have trouble producing the angular momenta.
- This claim depends on the coupling being burning layers (right).
- Getting high angular momenta for NS systems is difficult. Most progenitor scenarios (unless we assume no coupling) will not produce the angular momenta needed for NSAD and Magnetar models to work.



Low Spins confirmed in GW observations

- One of the big uncertainties in stellar evolution is understanding the coupling between burning layers (with implications on BH spins, collapsar GRB models, magnetar explosions, …
- Chris' study showed how gravitational wave data will ultimately be able to provide insight into this problem.





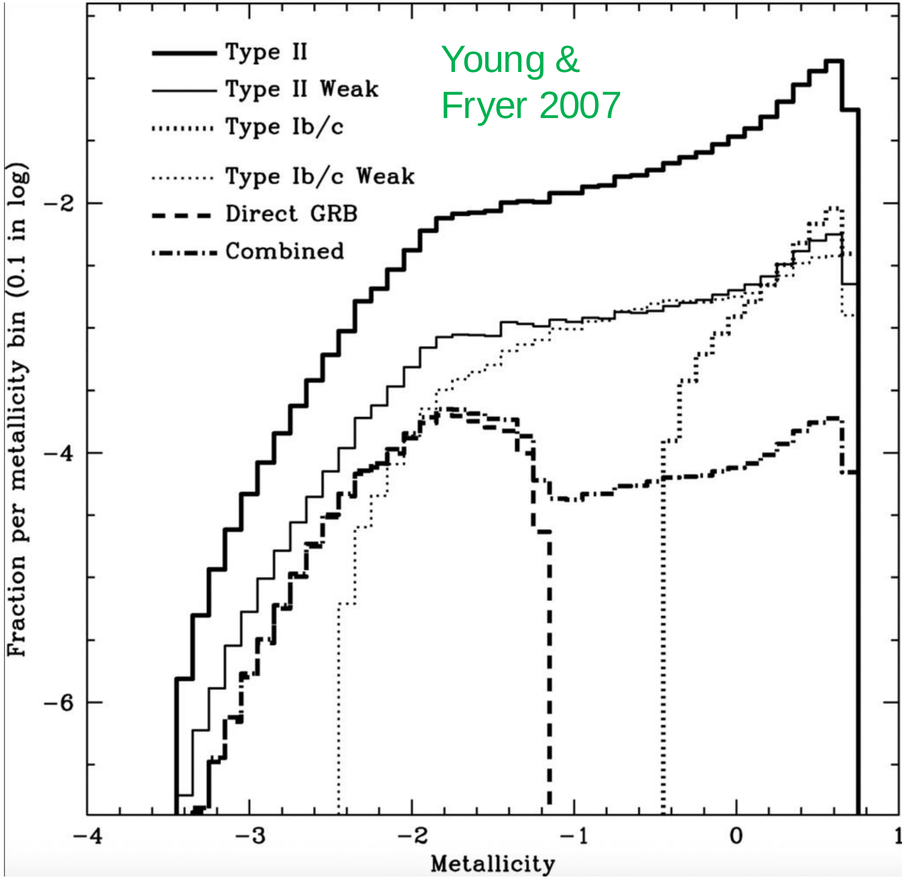
Belczynski et al. 2020

Distribution with Metallicity

BHAD disk models require sufficiently large CO cores to form a BH.
Mass loss prevents many direct-collapse BHs at high metallicities.

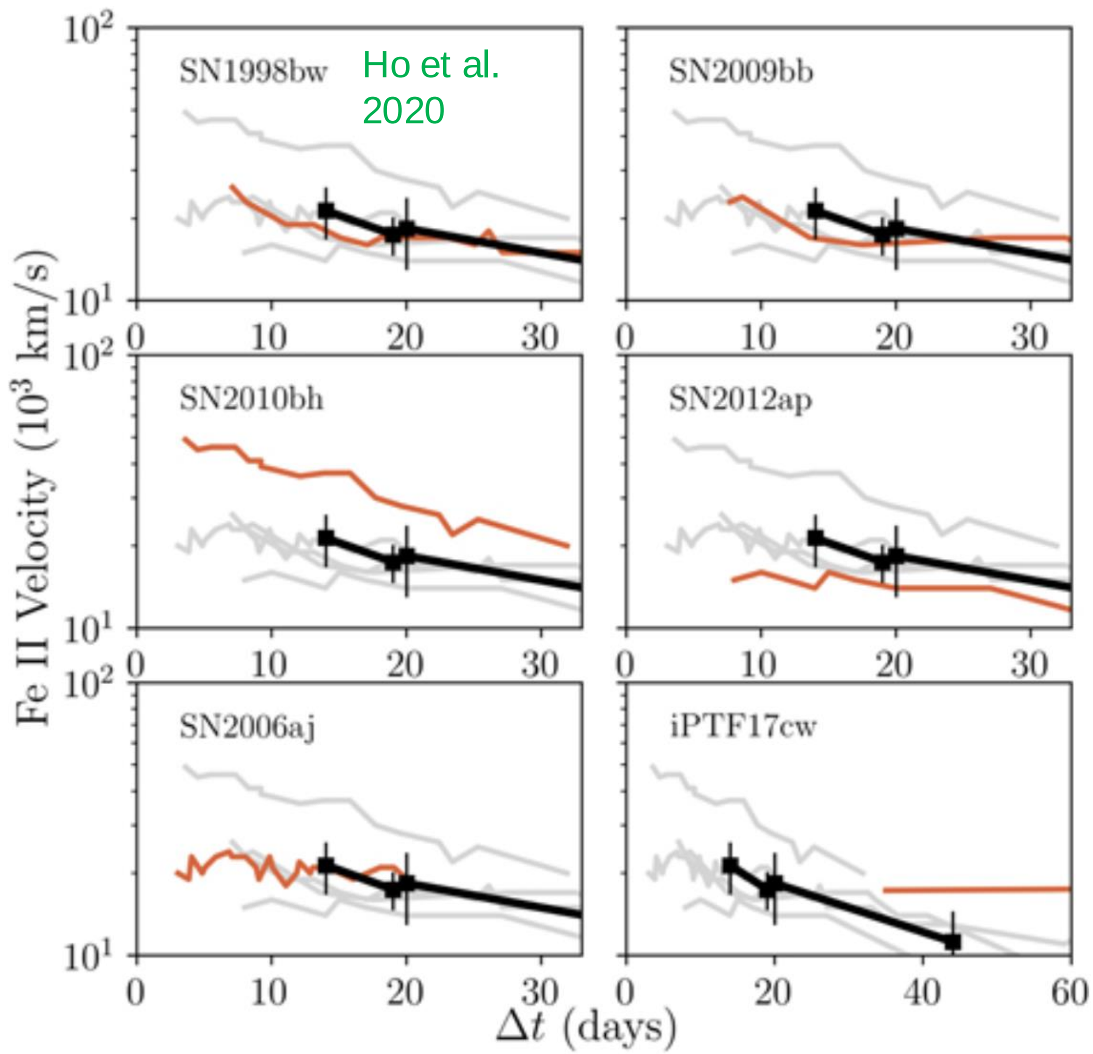
- Strong GRBs from these engines should predominantly be at lower metallicites.
- Weak GRBs (from fallback BHs) should dominant the fraction above ~0.1 solar metallicity.

NS engines (magnetars, NSAD) should not see this drop at high metallicity.



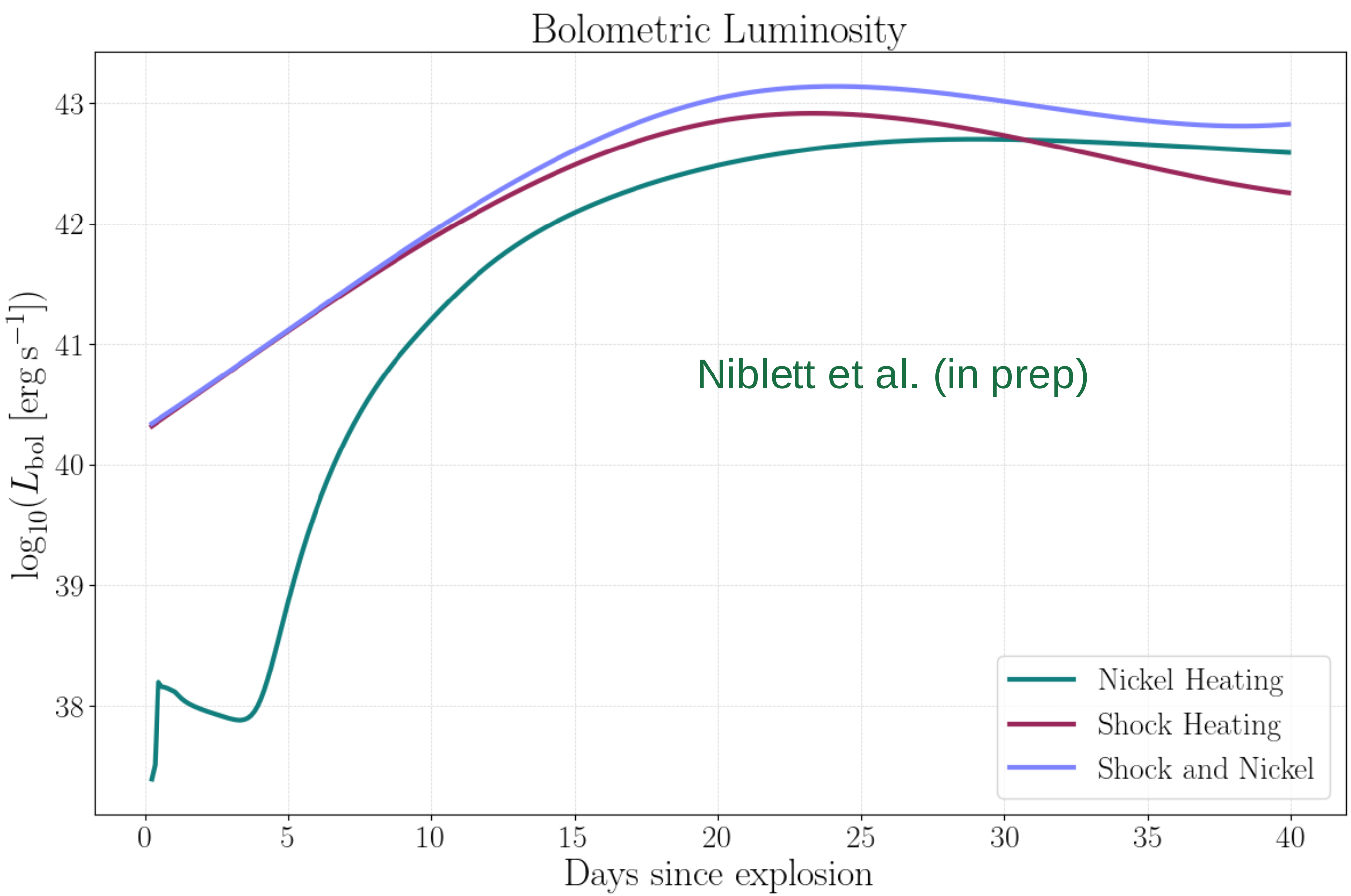
GRB-associated Transients

- Long GRBs have associated energetic supernovae (as predicted by collapsar models). But none of these supernova have strong helium features: all are classified as Ic (not predicted and even difficult to explain by most of our progenitor models).
- The broad iron lines can not be easily explained by normal the Herant et al. (1994) convective-supernova engines. BL SNe are likely all associated with GRB or GRB-like engines.
- Why are broad-line Ib and II SNe rare? Is ejecting the H and He critical?



What we learn from Broad-Line Supernova Observations

- BL Ic light-curves can be powered by ^{56}Ni decay or shocks.
- ^{56}Ni will make broader light-curves unless it is extensively mixed.
- Similar to afterglow models, there are lots of free parameters with shock heating models (we can match light-curves – but then what do we learn).
- We are working to identify observations to distinguish the different shock properties (X-rays, UV?)



Lots of Proposed models

- Many binary models have been proposed to try to obtain the required angular momenta with varying success.
- These are rare – good thing GRBs are rare.
- Most of these models produce both BL Ib and BL Ic.

TABLE 2

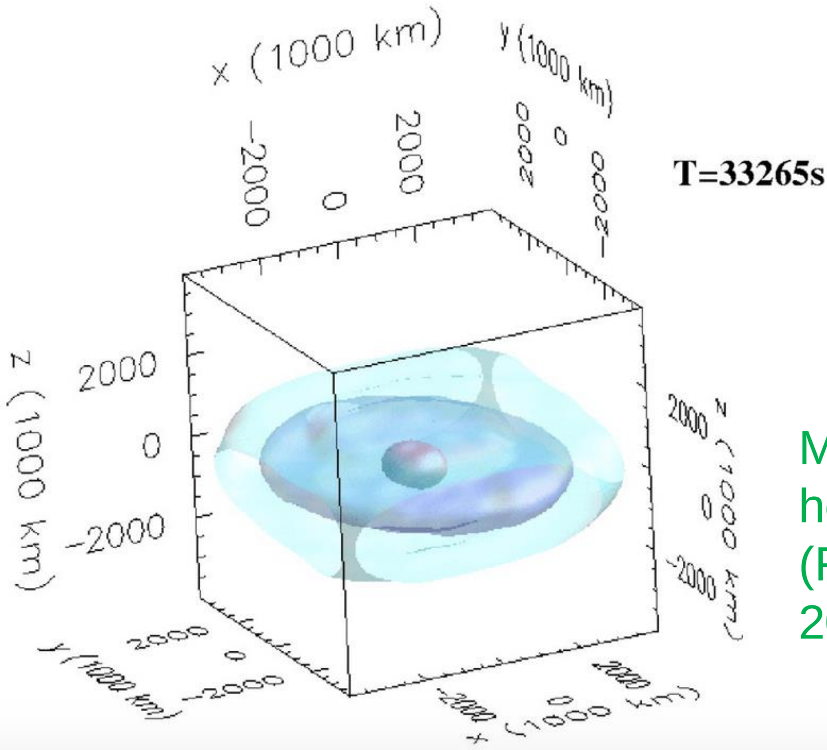
THEORETICAL PREDICTIONS: GRBS

Scenario	Angular Momentum	Metallicity Trend	Surrounding Environment	Associated Supernovae
Classic single	Low?	Rate peaks ~0.1 $Z_\odot$	High wind	H-rich to He-rich
Mixing single	Good	$Z < 0.1\ Z_\odot$	Low wind	All He-rich
Classic binary	Low?	Rate ↑ Z ↓	Tends to low wind	He-rich, He-poor
Tidal binary	Good?	Rate ↑ Z ↓	Tends to low wind	He-rich, He-poor
Brown merger	Good?	Rate ↑ Z ↓	Tends to low wind	He-rich, He-poor
Explosive ejection	Good?	Rate ↑ Z ↓	Shell within 1 pc	He-poor
He merger	High	Rate ↑ Z ↓	Tends to low wind	He-rich, He-poor
He case C	Good?	Rate ↑ Z ↓	Tends to low wind	He-rich, more He-poor
Cluster	Good?	Rate ↑ Z ↓	Tends to low wind?	He-rich?

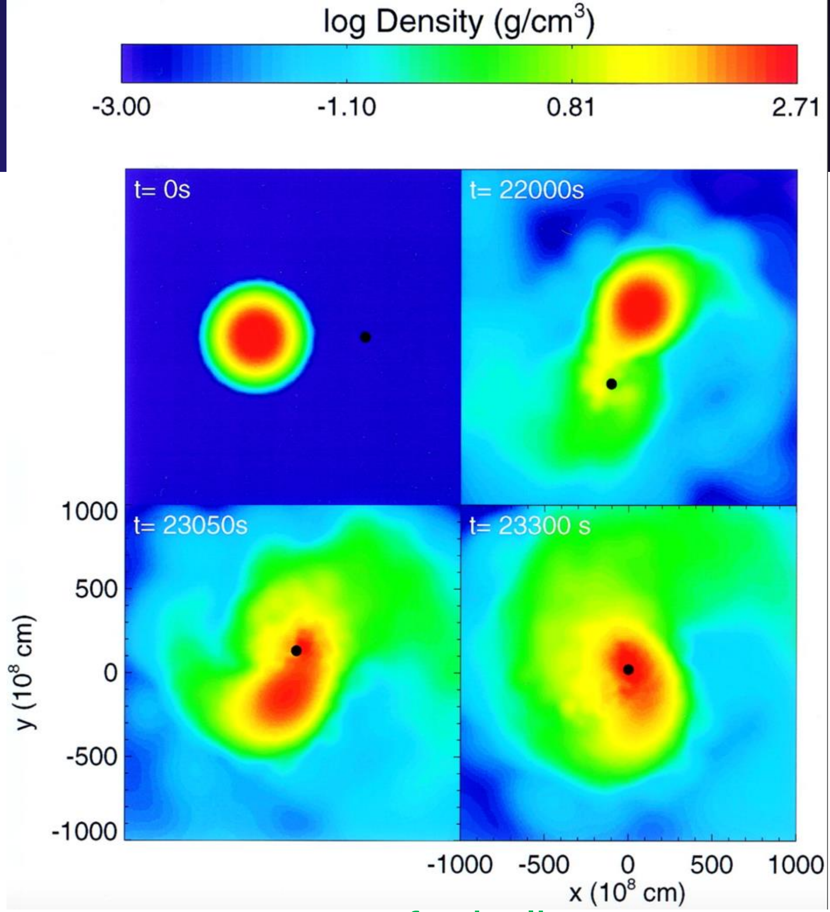
Summary of workshop on the SN/GBR connection: Fryer et al. 2007

Binary Models

Lots of models proposed to produce higher angular momenta.



Merger of 2 helium cores (Fryer & Heger 2005)



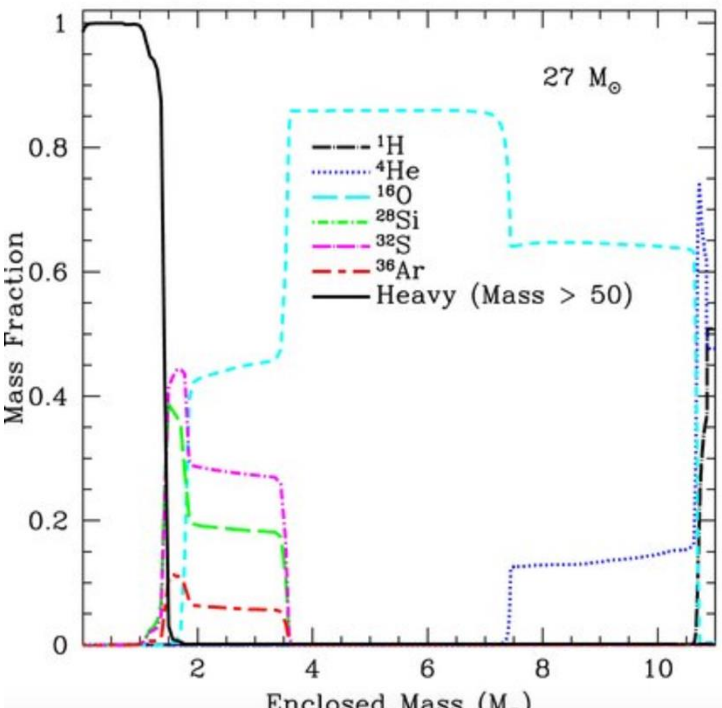
Merger of a helium core with a NS/BH (Zhang & Fryer 2001)

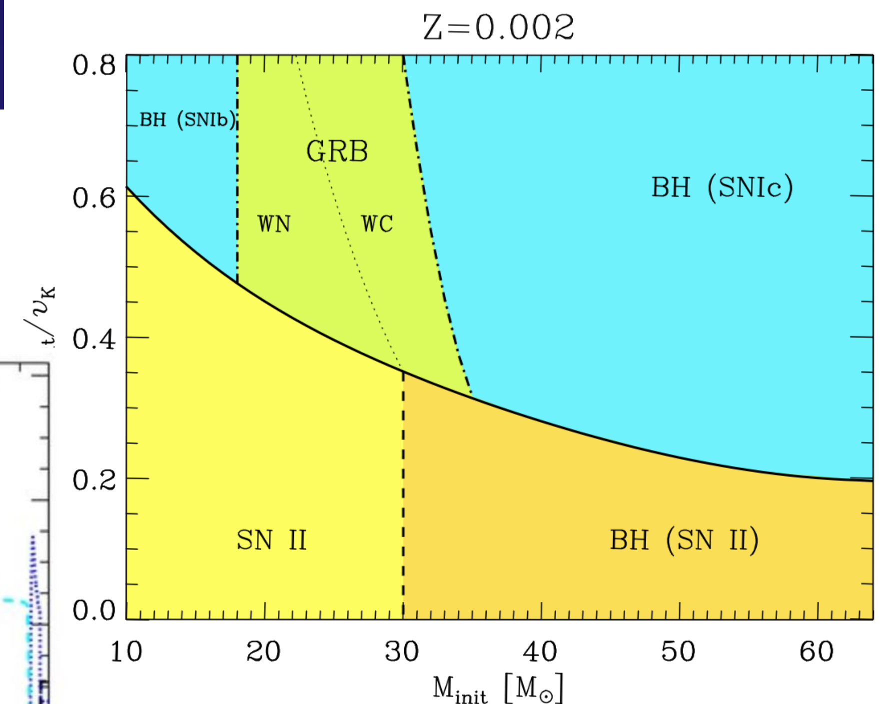
Can we make Single Stars Work?

Enhanced mixing can merge burning layers:

- rotation-induced (homogeneous) mixing (Yoon et al. 2006)

- Improved convection (RANS) models based on 2- and 3-dimensional convection studies (Frey et al. 2013)

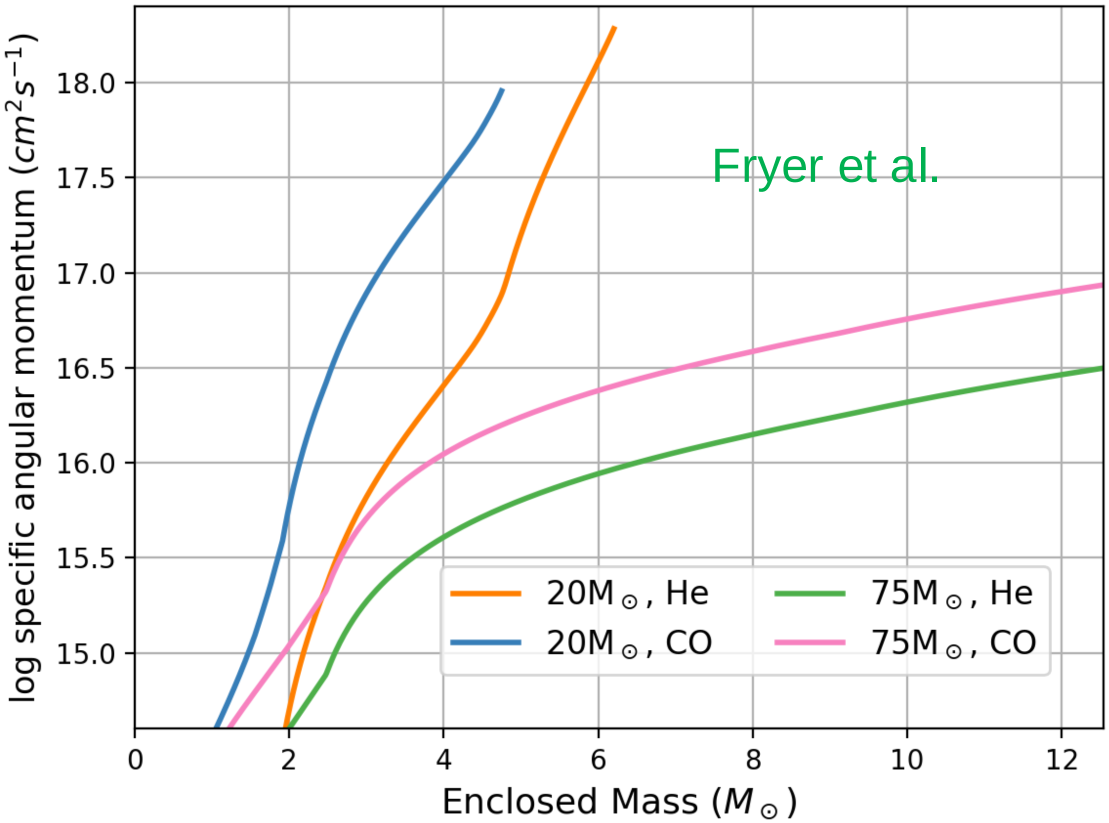




- We can tune the mixing to get the results we need. But we can't ruin other predictions (e.g. GCE, SN remnants, …). Can these effects get the spins needed? We need to understand mixing better.

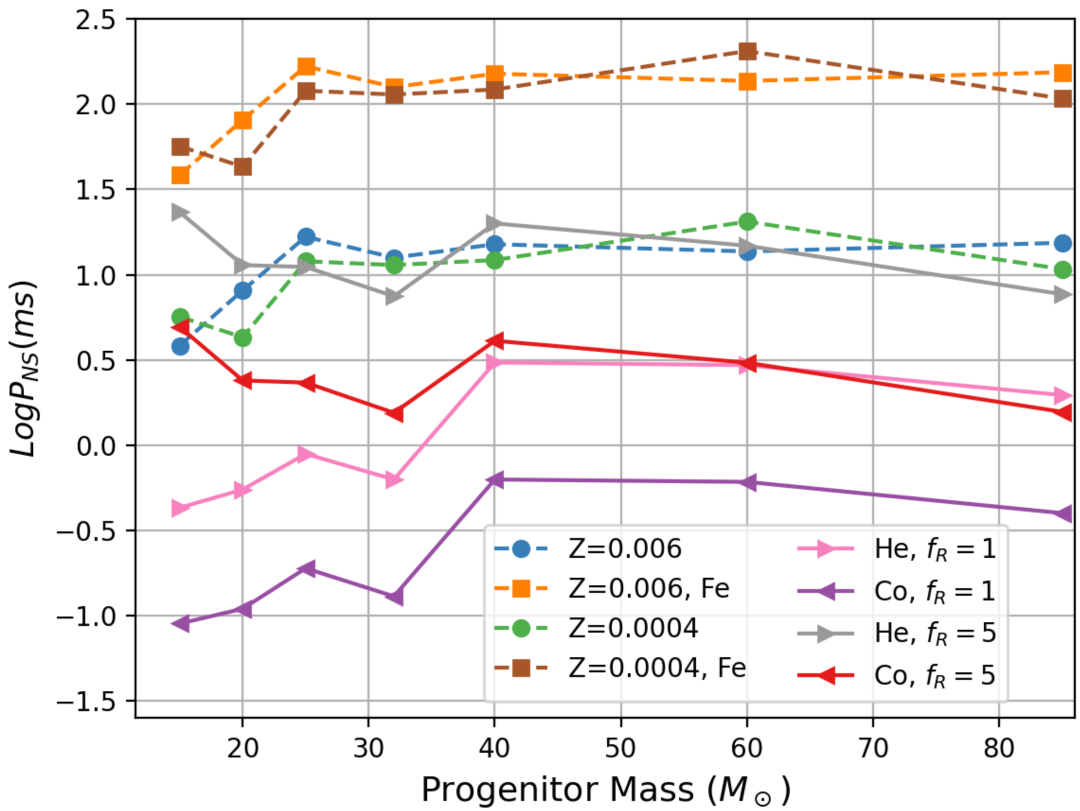
Tidal Locking

- In tight binaries (with a compact object), tides will cause the star to rotate at the binary orbital period.
- The highest angular momenta will be in CO binaries (the CO/NS binary scenario is the same as the IGC progenitor)
- However, we don’t really know how to eject the helium layer.



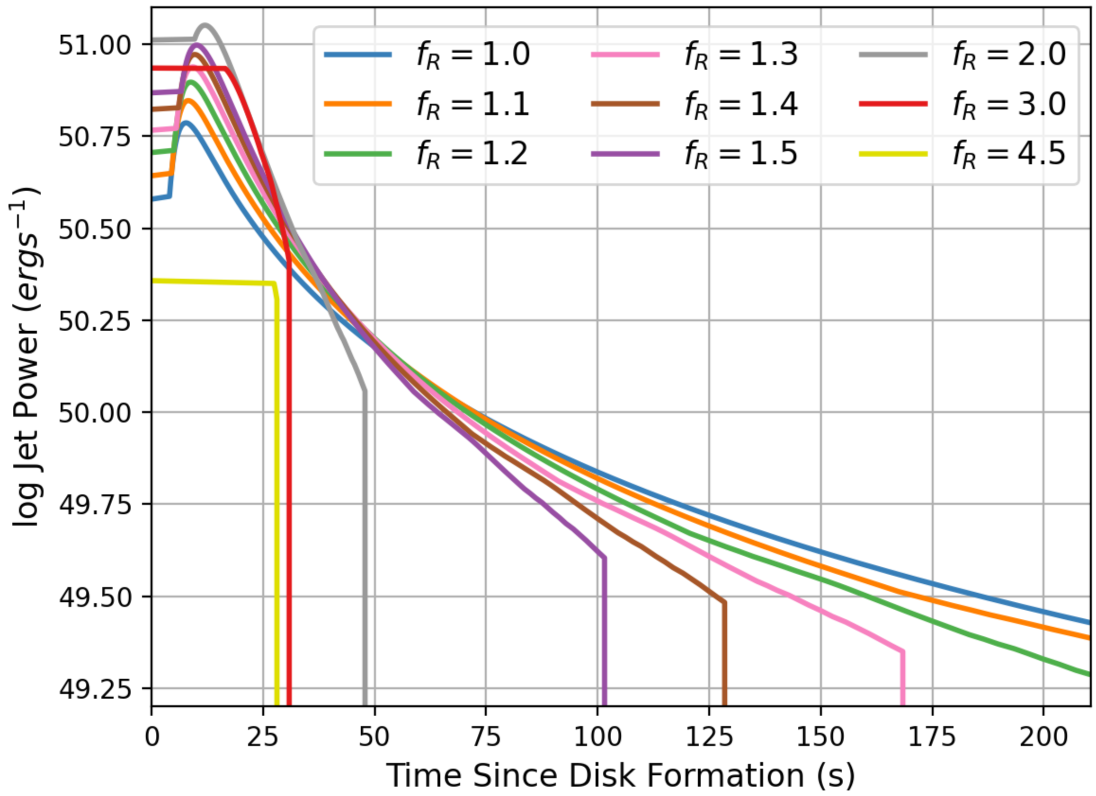
Magnetar and NSAD engines

- For close binaries, we can get the sub ms spins so that magnetar or NS accretion disk engines.
- But these engines will be strongest for low-mass progenitors. They should be common at high metallicities.



Can these progenitors explain durations?

The duration of the burst depends on the binary separation (distance behond Roche radius): tighter binaries have more angular momentum, form a bigger disk and, hence, have longer durations.



Where are we at?

- Multiple engine models exist: BHAD, NSAD, Magnetar, IGC.
- Many binary progenitors proposed and many of these progenitors can work for multiple engines. More than one progenitor is needed to explain GRBs (e.g. short vs. long vs ultralong)
- Many binary progenitors would produce Ib as well as Ic SN associated with long burst (either we have to change our understanding of stellar mixing or we will be pushed to only a few progenitor candidates). Proving most/all broad-line SNe are Ic is an important clue!
- Angular momentum is a problem and it is worse for the NS engines (BHAD, NSAD). Tight (CO) binaries might work - can produce LGRBs and ultra-long GRBs.
- NS engines (Magnetar, NSAD) should produce explosions at all metallicities. Why don’t they form BL-Ics and GRBs?
- Lots more questions: Where are the he-merger explosions?