# After the Shock: Magnetic Fields and Fallback on Newly Formed Neutron Stars

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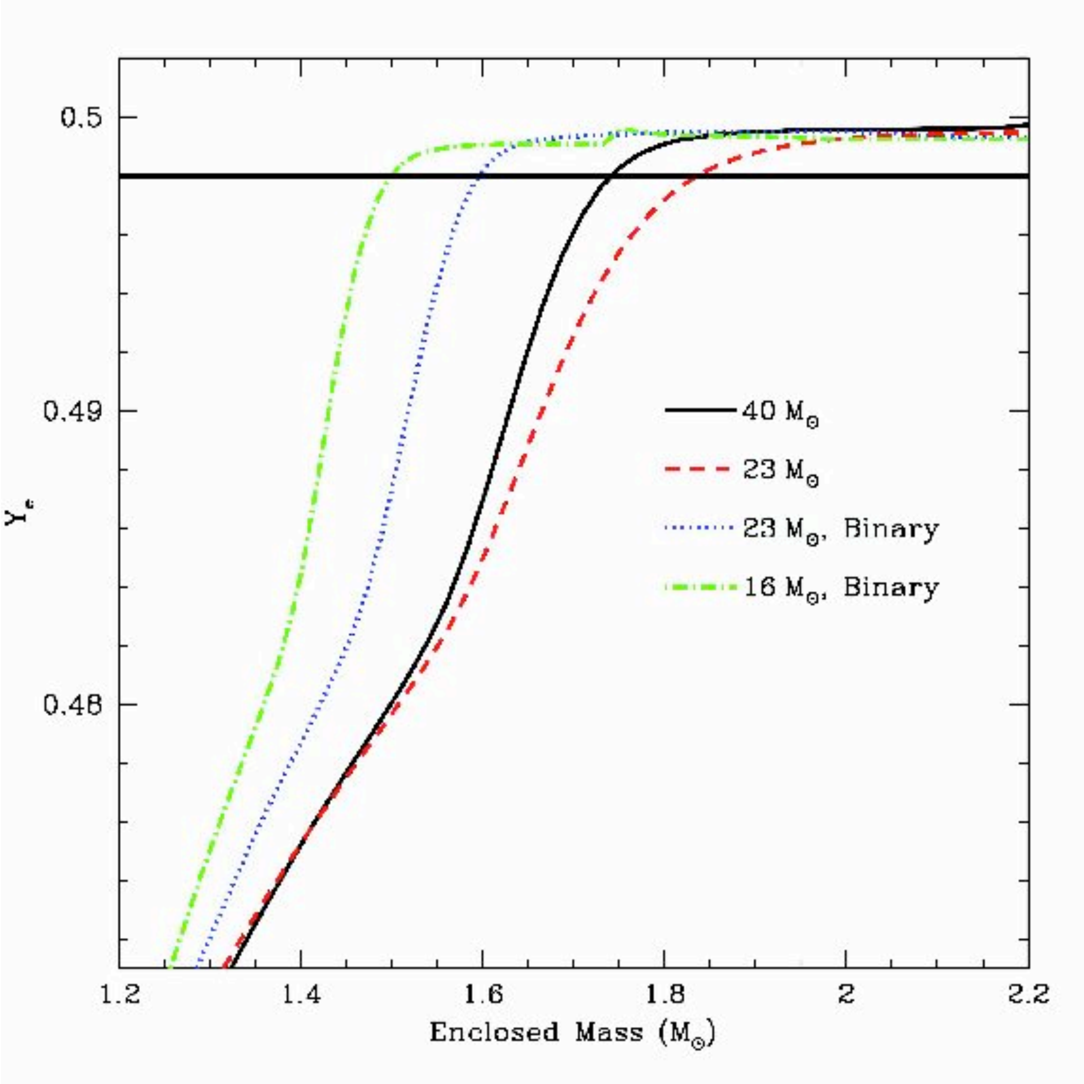
- After the Supernova Explosion (What we know about Magnetars and Fallback)
- Modeling Fallback - Nucleosynthesis and Neutrinos
- Preparing for the Future

# Fallback Invoked Since Early 1970s

- Colgate vs. Arnett (1971). Arnett argued that core-collapse explosions would eject low $Y_e$ material - bad for nucleosynthesis. Colgate responded - this stuff will fall back.



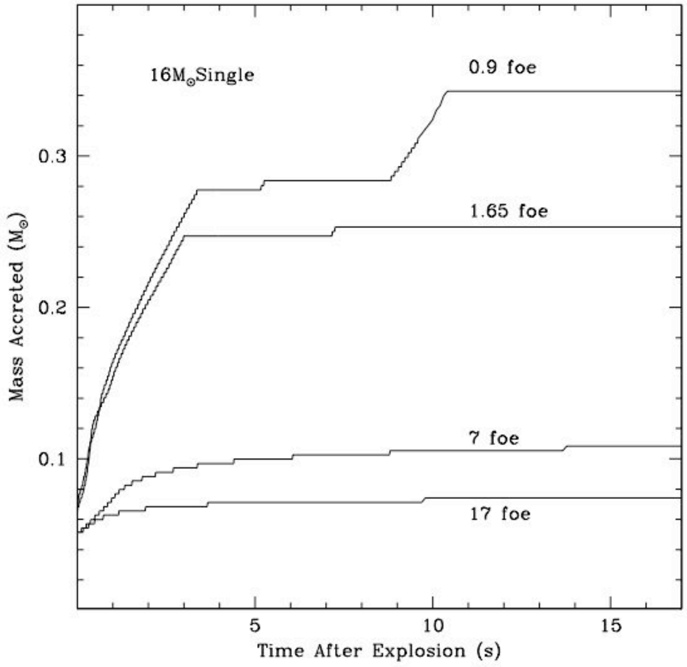
# Fallback Understood

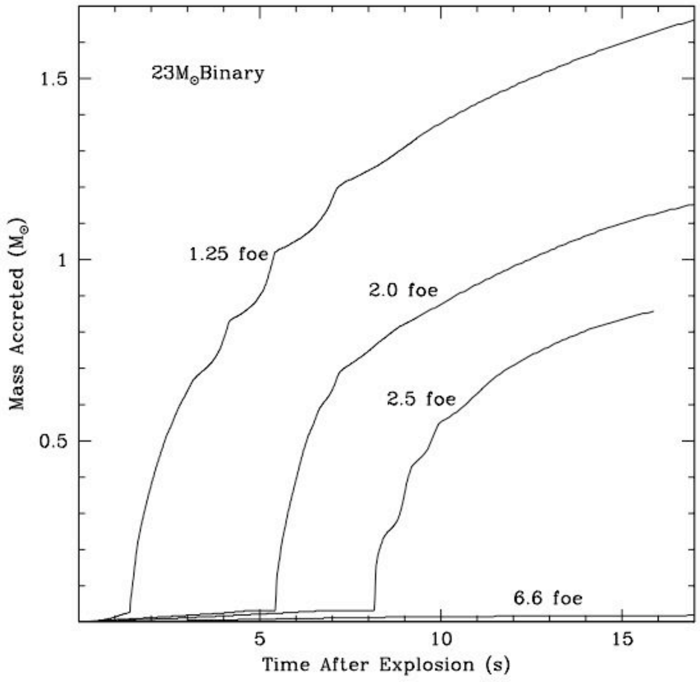
Two explanations for Fallback exist:

- material pushing against outer layers slows until its velocity falls below the escape velocity (Colgate 1971) - early time fallback
- As the shock decelerates as it moves through the shallow density gradients of the star, its velocity drops below the escape velocity - late time fallback

# Modern Simulations of Fallback

- Fallback seen in nearly all modern (energy injection rather than piston-driven explosion models) explosion simulations
- For 1-2 foe explosions, the accretion rate for stars more massive than 15 solar masses is: 0.1-1.5 solar masses in the first few seconds.
- Luminosities in the first few seconds of $10^{52}$-$10^{53}$ erg/s
- Colgate fallback scenario correct - occurs in both II and Ib/c supernovae.



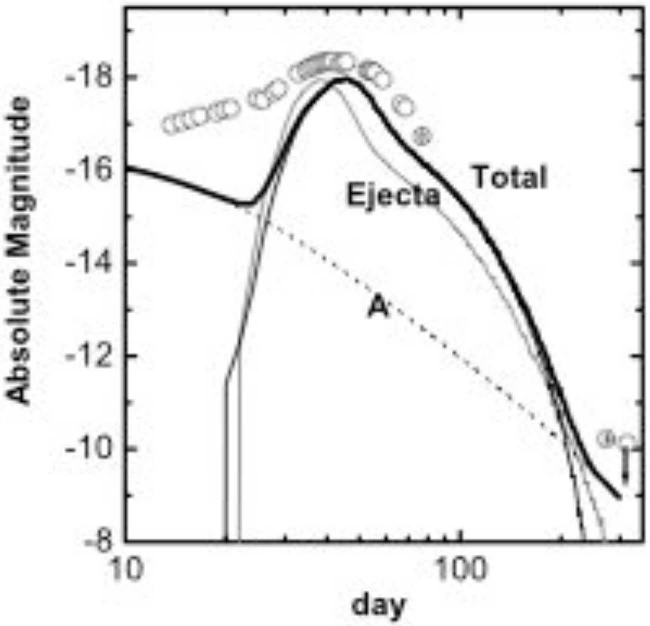


# SN 2005bf

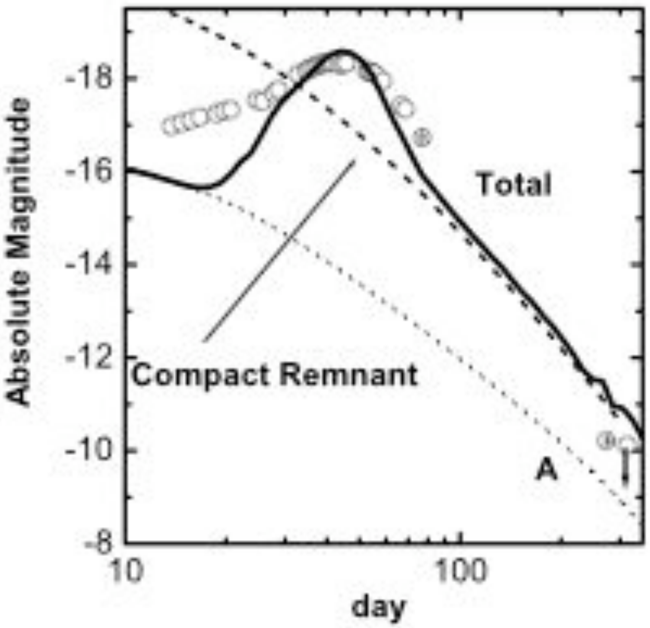
- Maeda et al. (2007) found that SN 2005bf's high peak luminosity predicted a much higher $^{56}$Ni yield than predicted by the late-time light curve in the simple explosion model.

They studied 2 solutions:

- Fallback removes $^{56}$Ni at late times
- There is further engine activity after the explosion (they assume Magnetar activity).



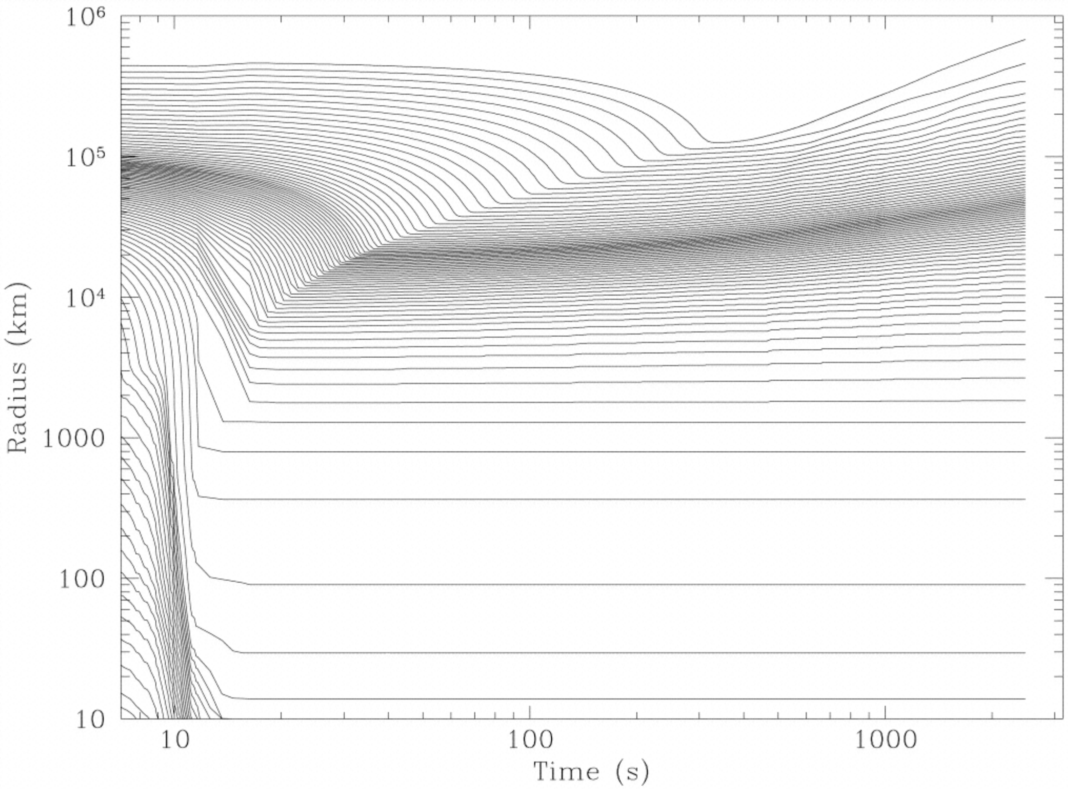
Fallback



Magnetar

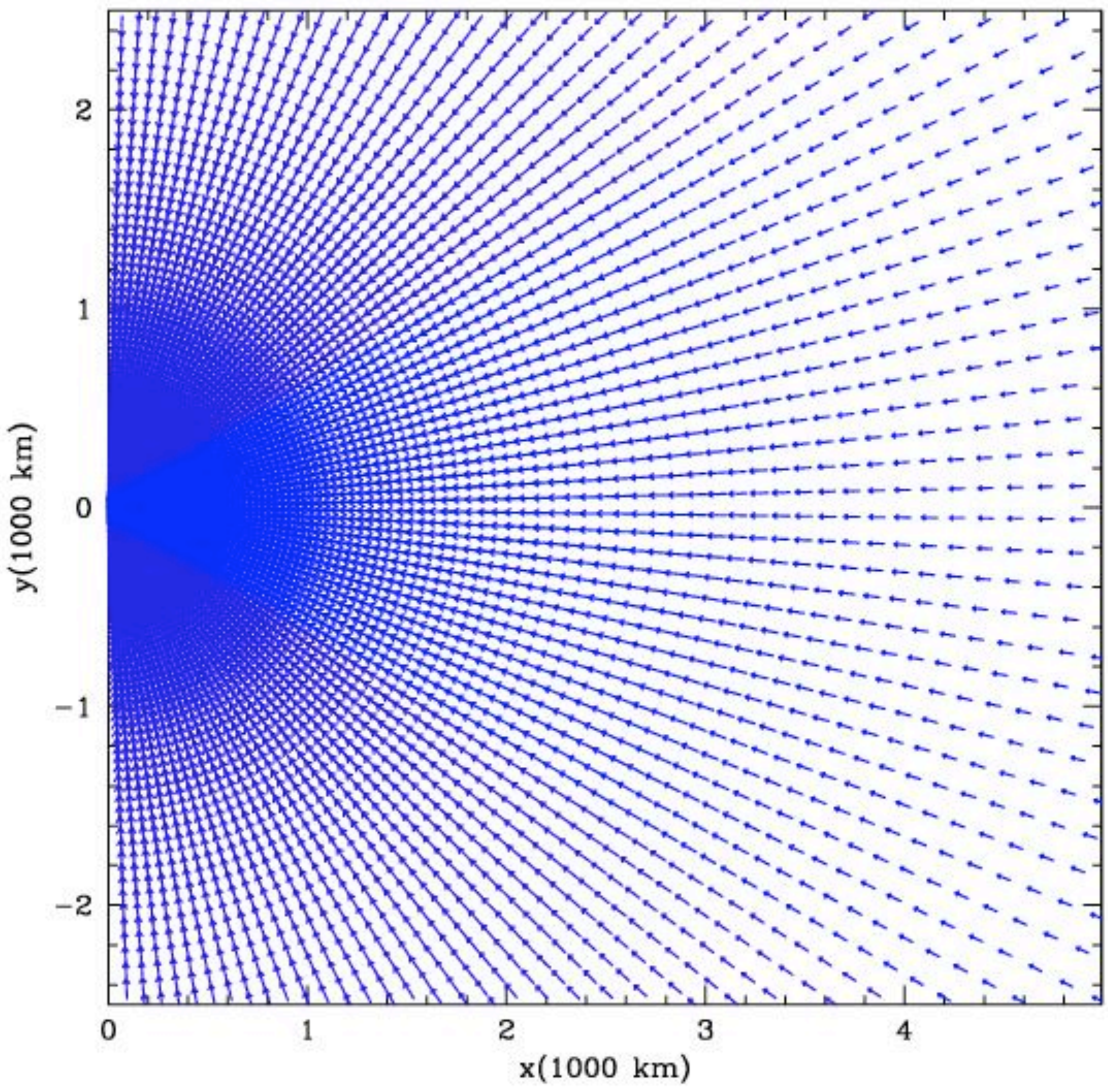
# Explosions From Fallback Predicted in late1990s

- Fryer et al. (1999) found that the super-Eddington radiation flow could drive explosion, preventing further accretion.
- Genevieve et al. (2005) invoke such a model to explain the lack of late-time emission in SN 1987A



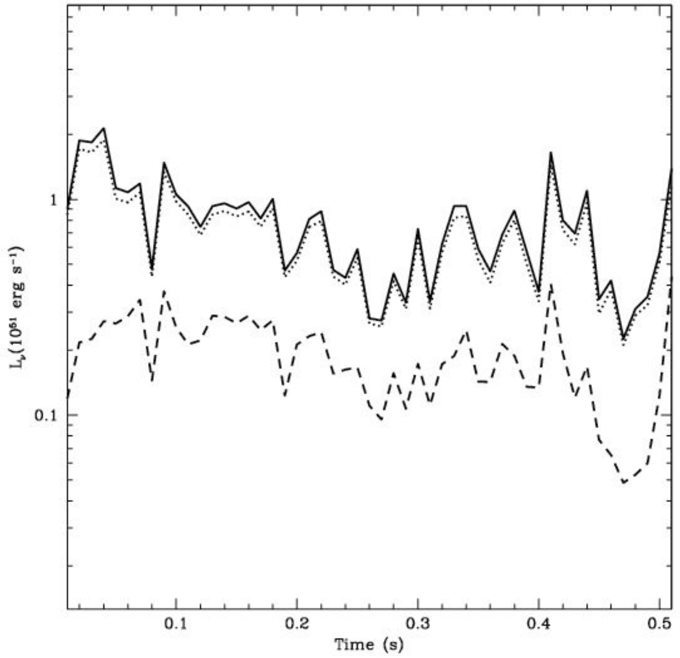
CLF et al. 2007

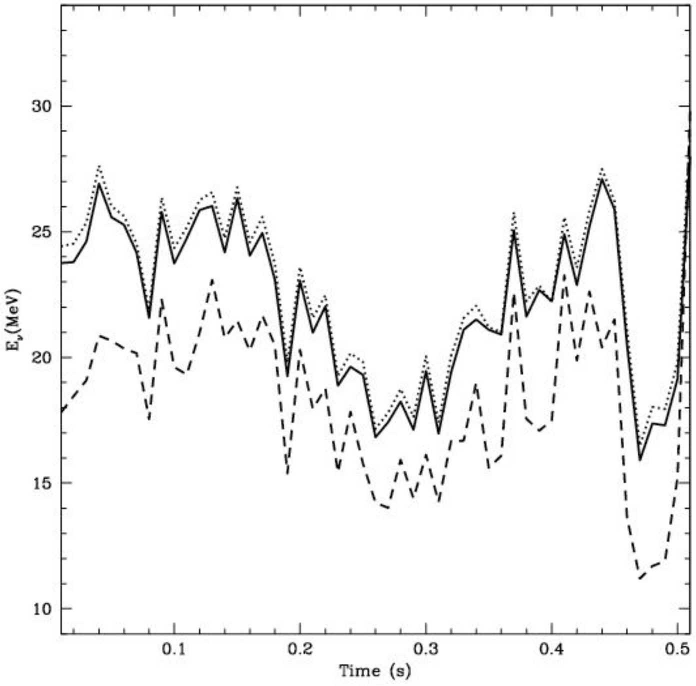
- When Fallback happens, turbulent convection with outflows will also occur.
- This fallback could dominate the neutrino yields and will almost certainly affect estimates of r-process yields



# Neutrinos From Fallback

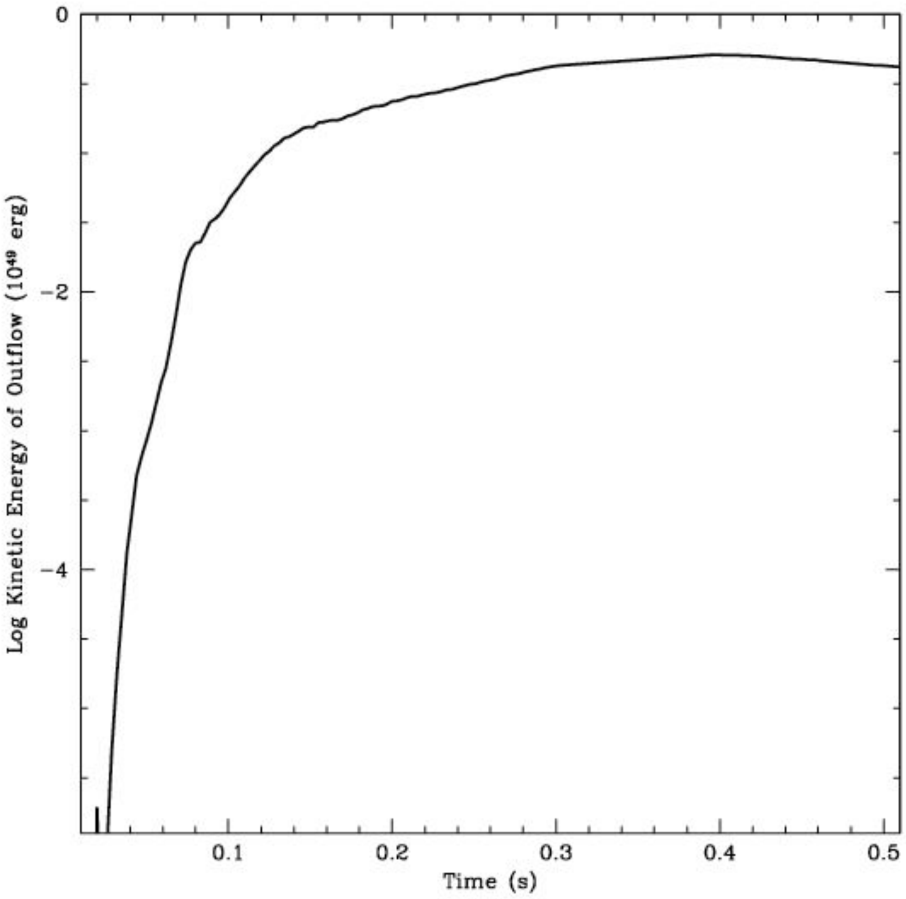
- Because of outlfows, it is not just a simple matter of calculating the amount of fallback.
- Neutrino Luminosities fluctuate with the convection - making a phase that is nearly as messy as the explosion itself.





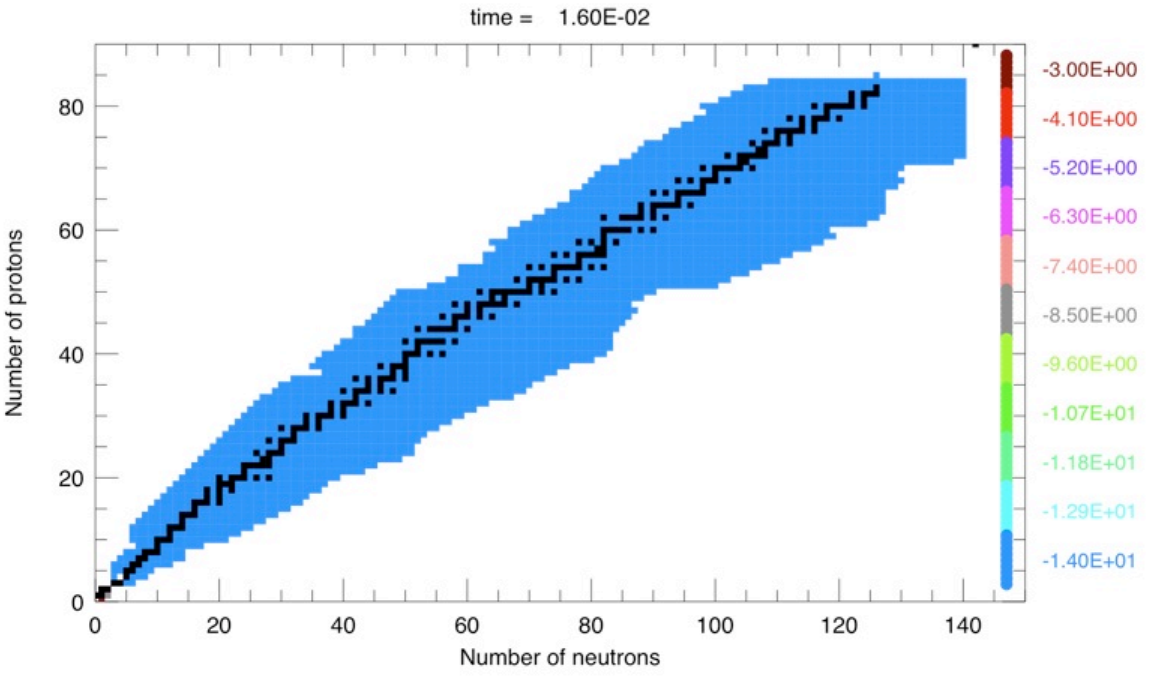
# Outflows Inject Explosion Energy

The kinetic energy of the out-flowing matter in the simulation domain quickly rises to a few times $10^{48}$ erg $s^{-1}$.



# A New Nucleosynthetic Path - rapid n + p capture “rp process”

- At Ye ~ 0.5 with appropriate (non-uniform) expansion, proton capture can allow material to overcome waiting points and produce very heavy elements (mass ~ 195): Meyer (2002), Fryer et al. (2006)
- But the devil is in the details - slight differences in the trajectory of the matter lead to very different yields.



# Conclusions

- Fallback happens in nearly all supernova explosions. For low mass stars, its effect on the observations may be manageable.
- Fallback accretion is at least as turbulent as the explosion mechanism itself. The neutrinos emitted will depend sensitively on this turbulence (perhaps not a good time to study neutrino cross-sections, but then when is a good time?)
- We can possibly probe this fallback using nucleosynthetic yields and explosion effects.
- Expect much more work on this in the near future!!!