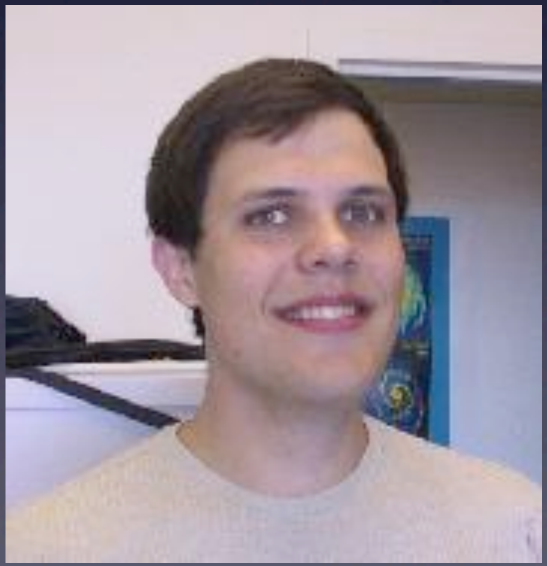
Late-time Activity During Compact Object Mergers (+ a little bit of AIC)

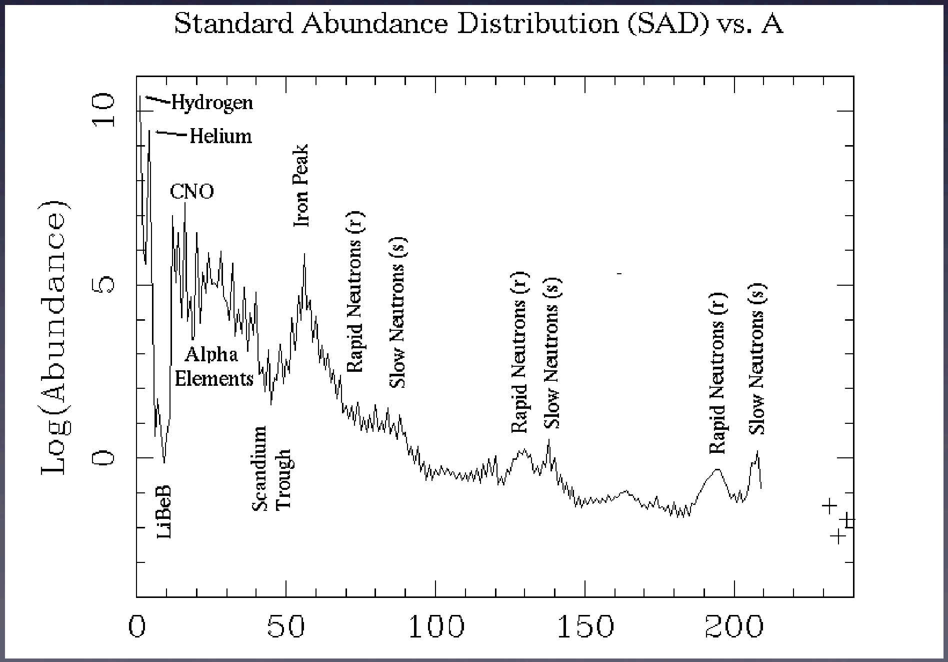
Eliot Quataert (UC Berkeley)

w/ **Brian Metzger,** Tony Piro, Almudena Arcones, Gabriel Martinez-Pinedo



Overview

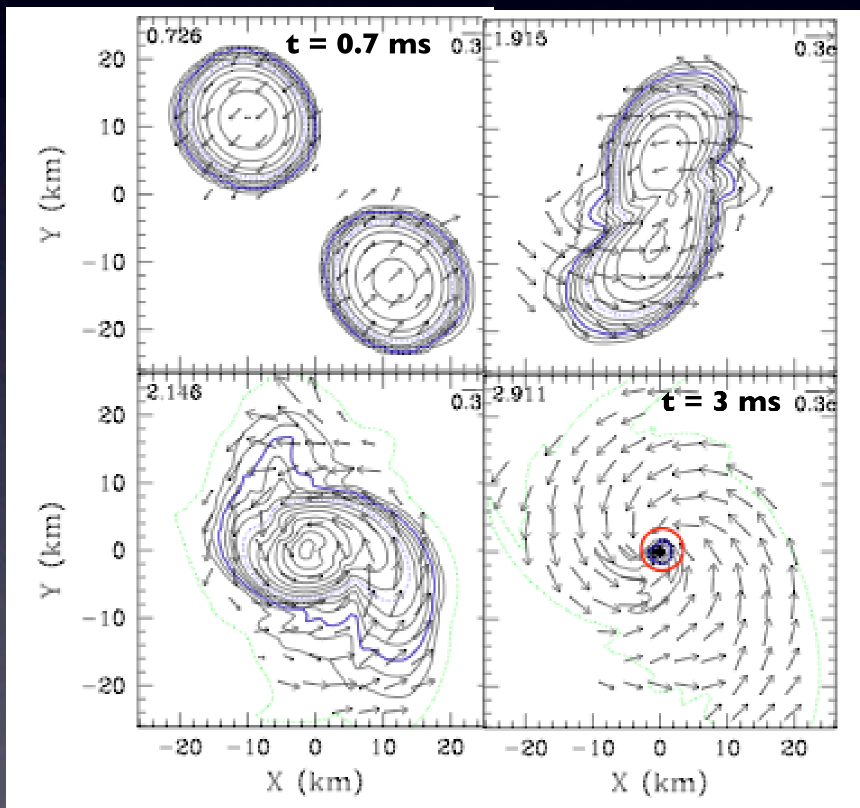
- Compact-Object Mergers & Short-Duration GRBs
  - The Puzzle of ***Late-time Activity*** in Short-Hard GRBs
  - The Disk: Accretion Physics at ~ $M_\odot$ s^{-1}
    - Interlude: Similar Physics in AIC
  - The Tidal Debris: Fallback Accretion & Nucleosynthesis



Compact Object Mergers

(Paczynski 1986; Goodman 1986; Eichler et al. 1989; Narayan et al. 1992 ....)

NS-NS Merger



Shabata & Taniguchi 2006

density contours & velocity vectors

Primary Target for km-scale gravitational wave observatories (e.g., Advanced LIGO)

Leaves Behind Disk ~ 10^{-3}-0.1 $M_\odot$

$$t_{\rm visc} \sim 0.1 \left(\frac{\alpha}{0.1}\right)^{-1} \left(\frac{r}{100\,{\rm km}}\right)^{3/2} \left(\frac{h/r}{0.5}\right)^{-2} sec$$

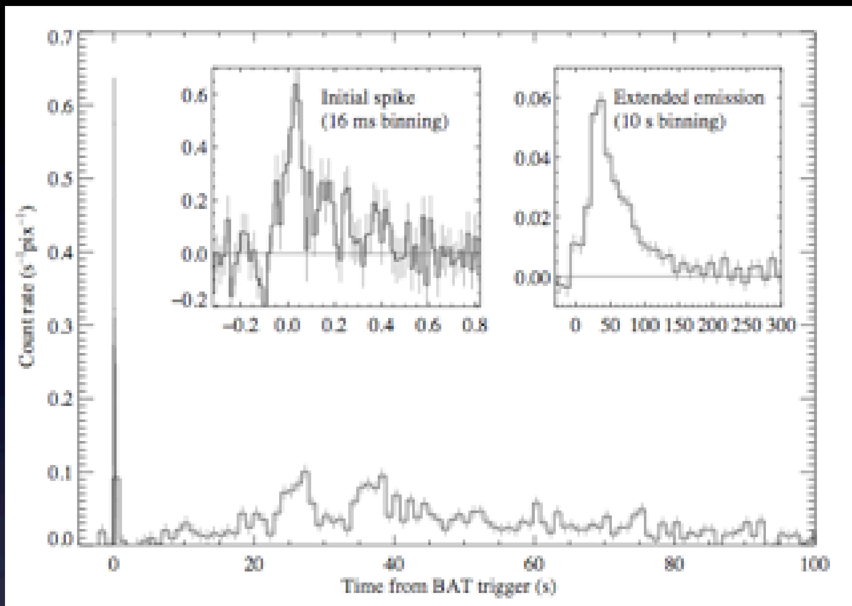
consistent w/ short GRB durations

$$\dot{M} \sim M_\odot\, s^{-1} \quad \tau_{\rm photons} \gg 1;\ \tau_\nu \sim 1$$

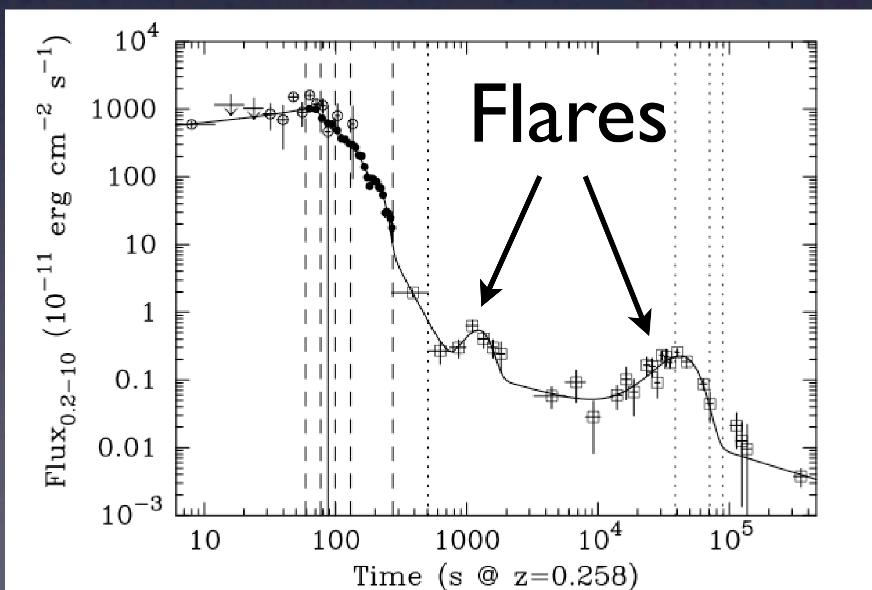
→ disk cooled by neutrinos

New Puzzles

Swift Bursts

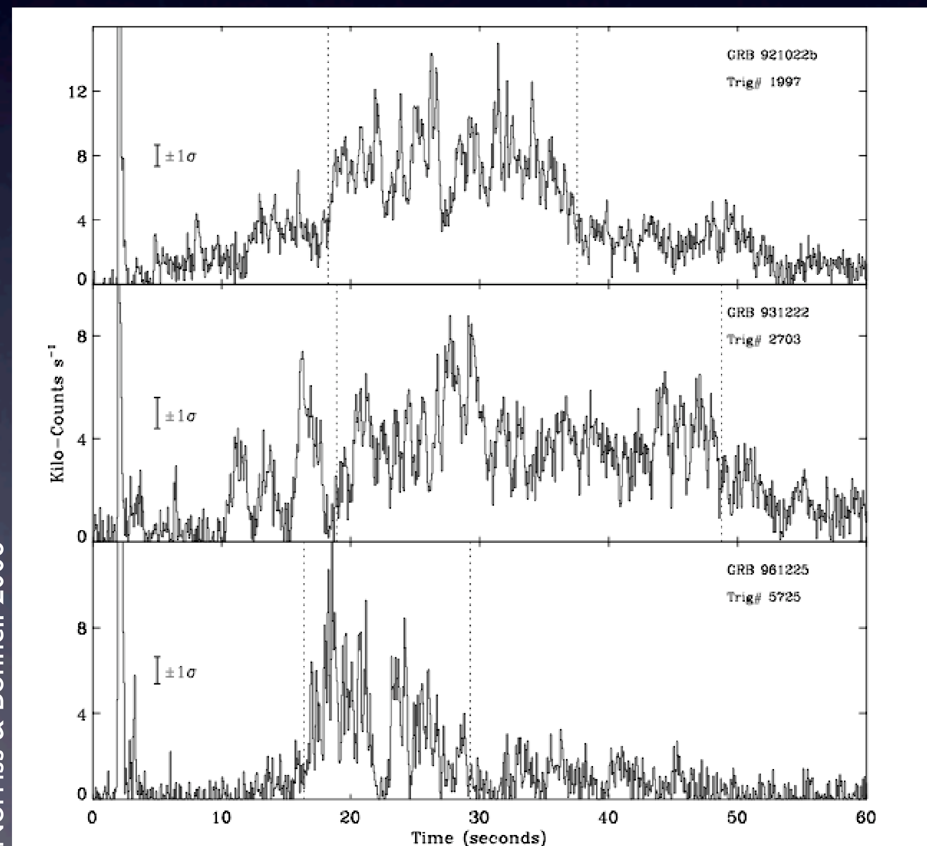


Perley et al. 2009



Campana et al. 2005

In ~ 25% of Swift Bursts
Extended Emission ~ 30-100 sec
Flares on yet longer Timescales
Energy up to ~ 10 x Initial Burst
nontrivial: t_{dyn} ~ ms; t_{visc} ~ 0.1-1 sec

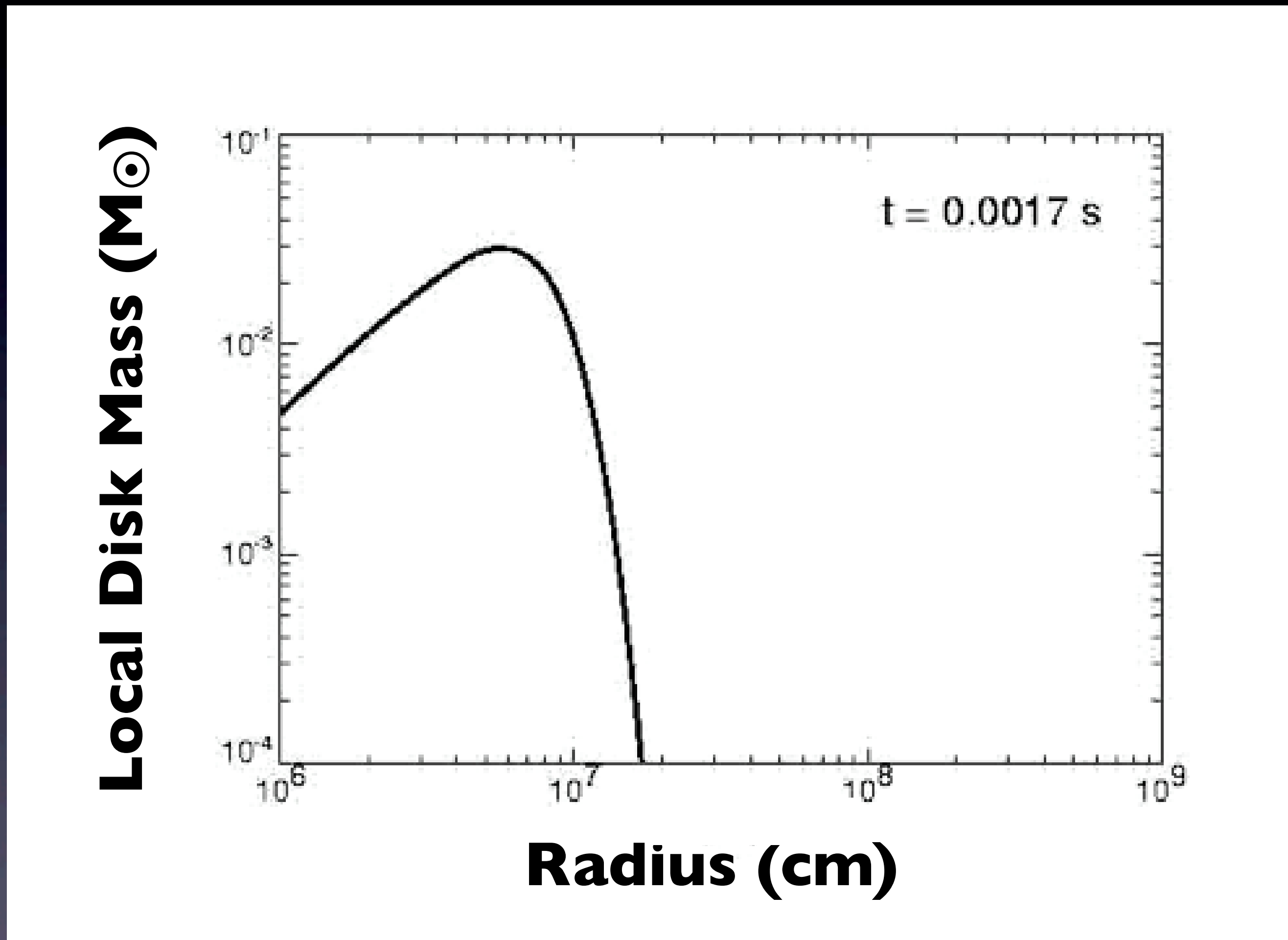


Norriss & Bonnell 2006

BATSE Examples

The Evolution of the Remnant Disk

ang momentum conservation → disk spreads (& cools)

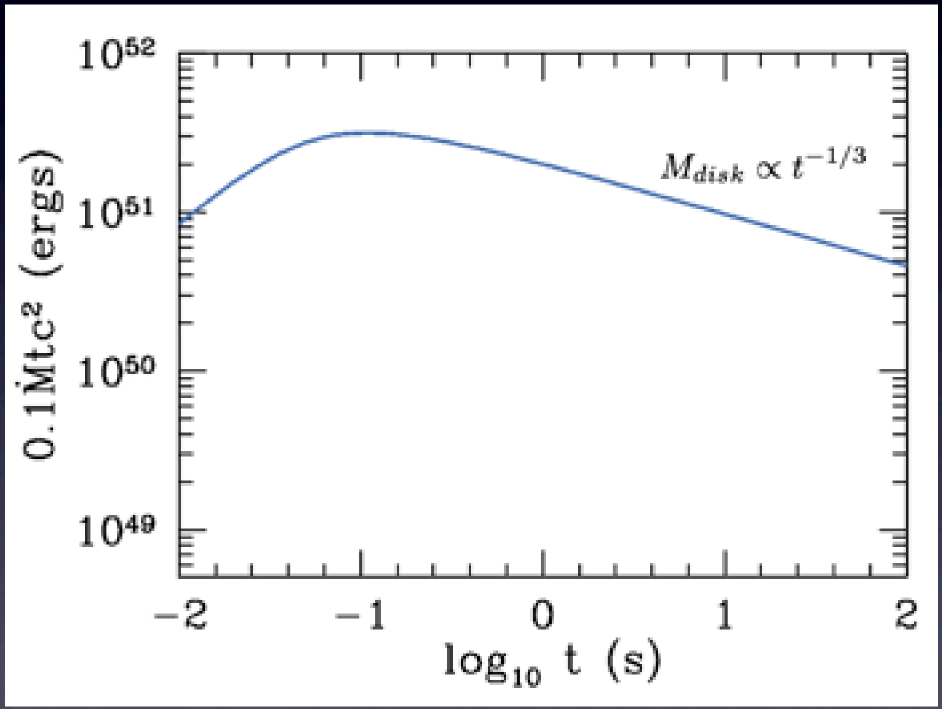


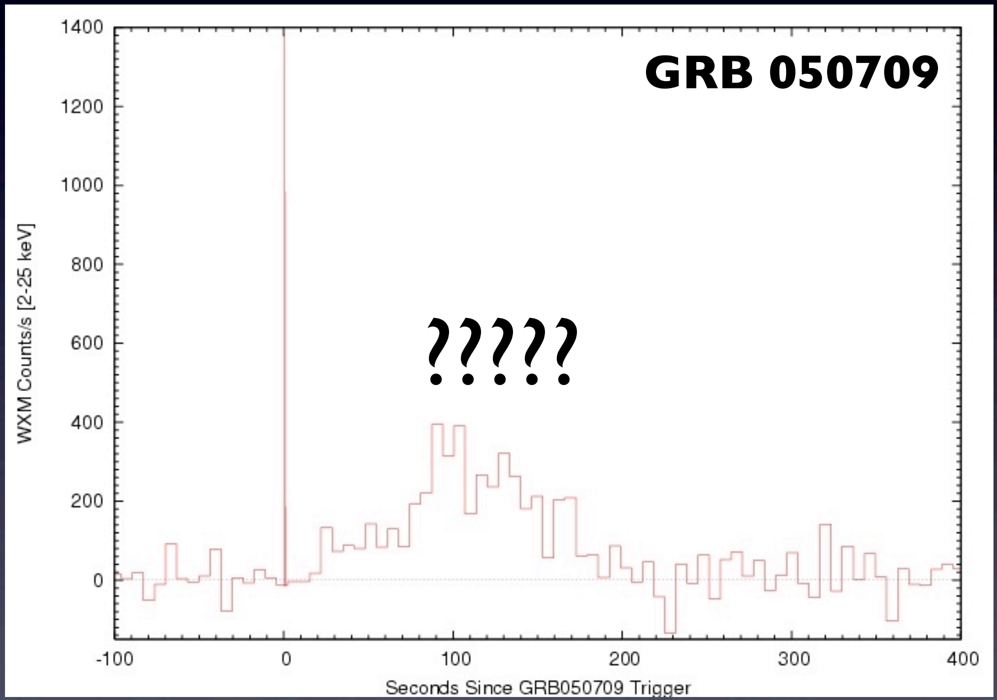
1D time-dependent Models

(α-viscosity; realistic ν-cooling)

Late-time Activity From Late-time Accretion?

Initial Disk: 0.1 M☉ & 100 km

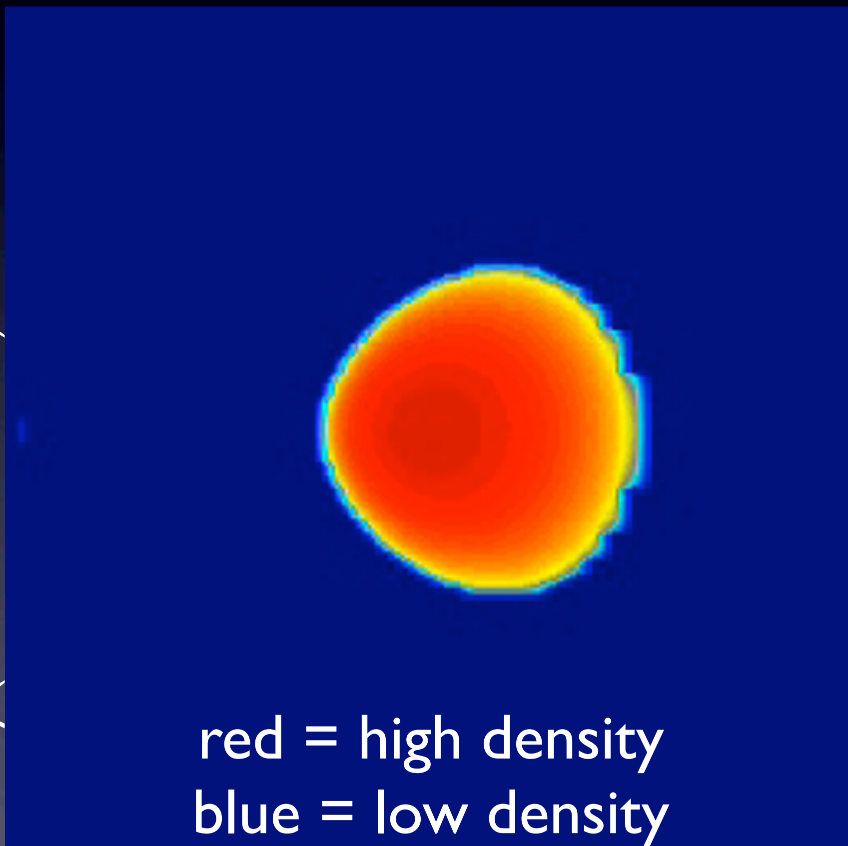




Appears to be Ample Accretion
Energy Available at Late Times ...

Late-time Disk Winds

The Late-time Advective Disk Unbinds Most of the Remaining Mass; aided by fusion to He once T $\lesssim$ 0.5 MeV



Hawley (MHD Simulations)

Ejected Mass ~ $10^{-2}\, M_\odot$

Neutron-rich: Y_e ~ 0.35

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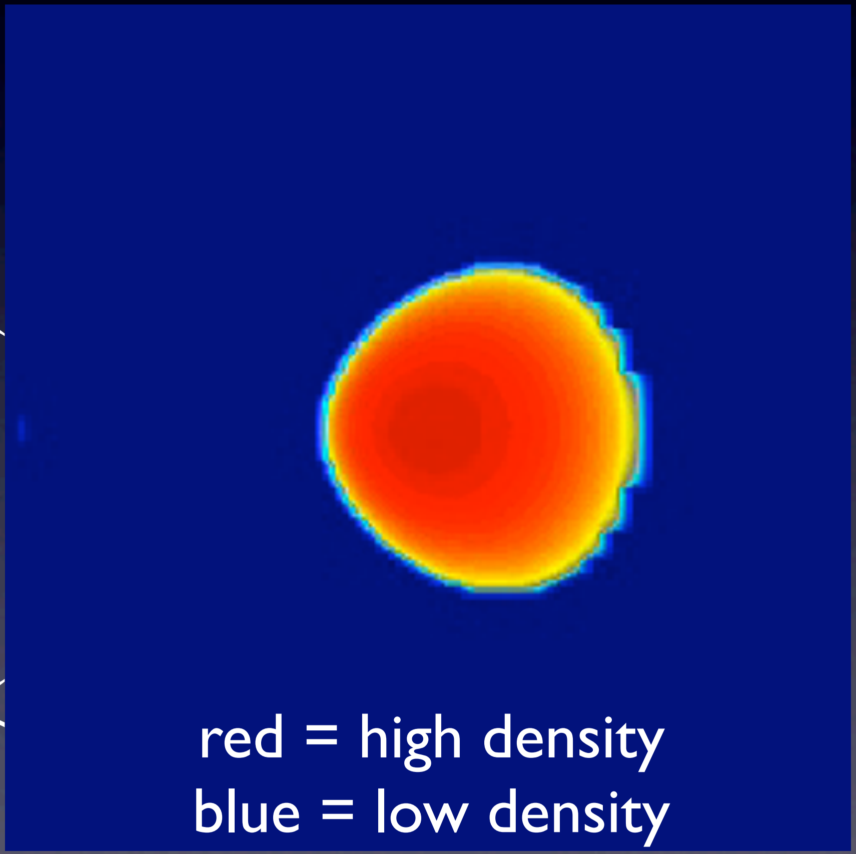

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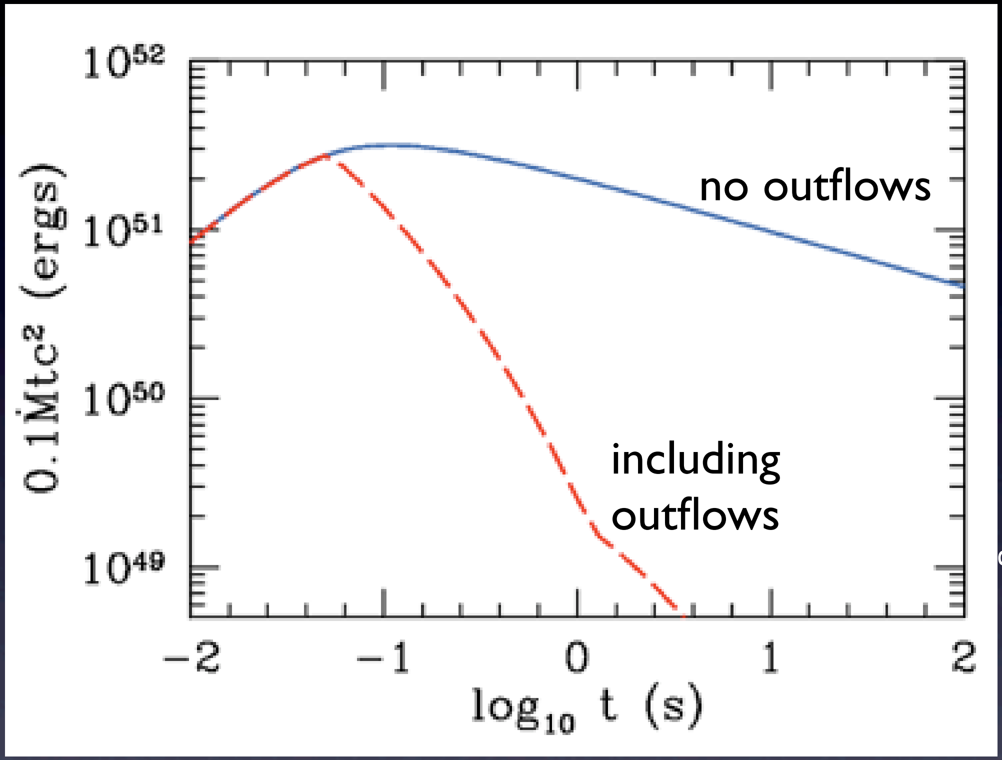

Metzger et al. 2008

Accretion of the Initial Disk Cannot Power Late Time Activity in SGRBs

(unless α ~ 10^{-3})

Interlude: Accretion-Induced Collapse of a WD to a NS

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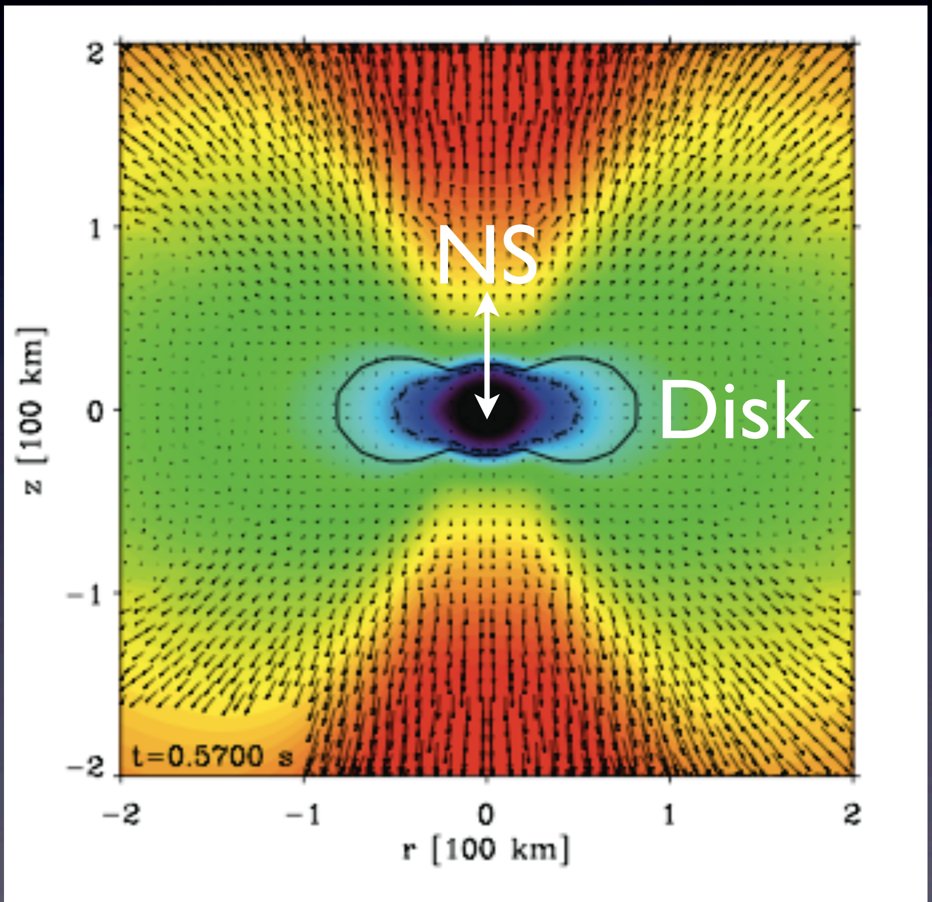
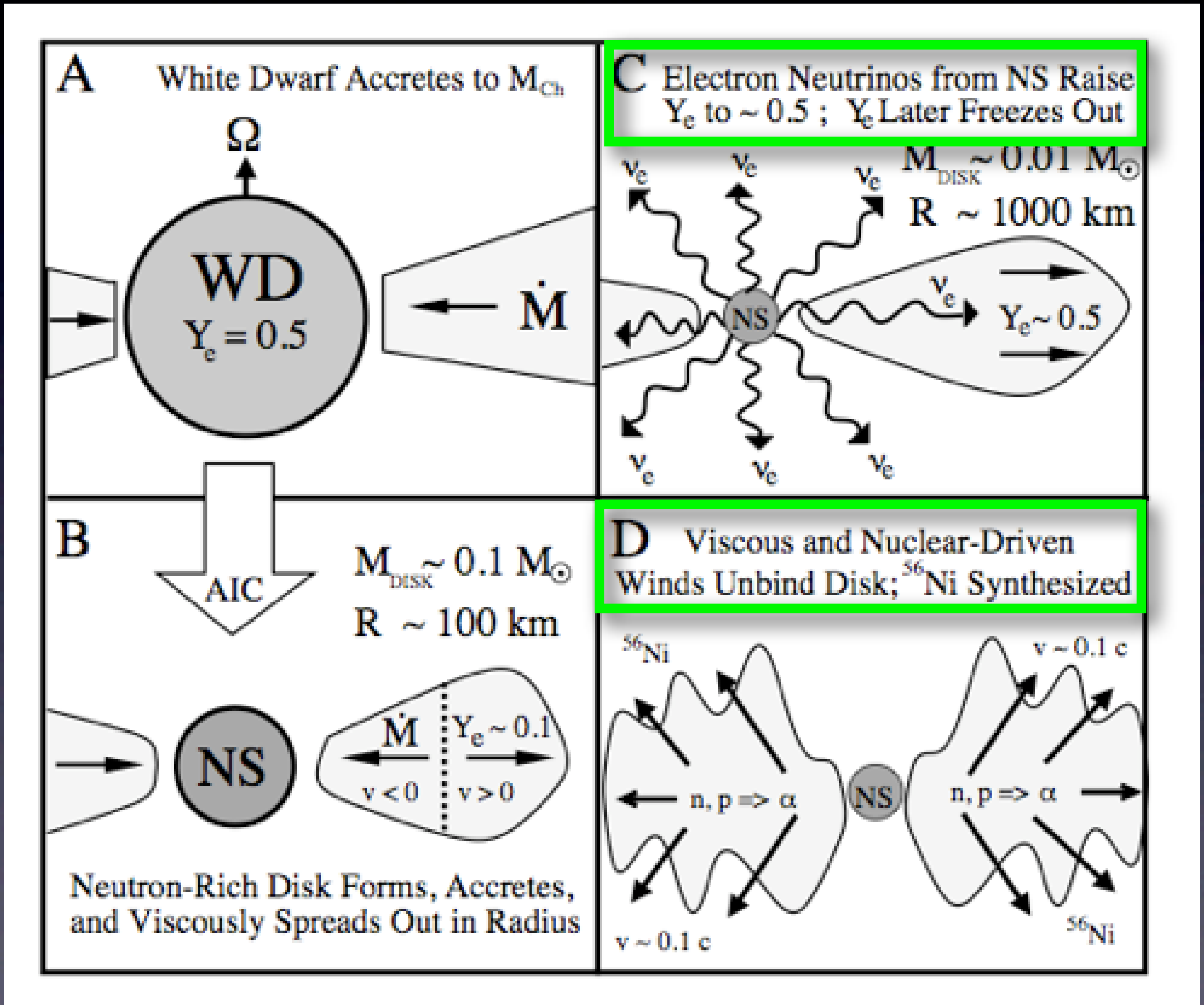


Dessart et al. 2006

color=density

- AIC rate uncertain; perhaps ~ 10^{-2} Ia?
- weak explosion:~3×10^{49} ergs; <10^{-3} $M_\odot$ Ni
  Dessart et al. 2006
- collapse of rapidly rotating WD → disk around PNS: M_{disk} ~ 0.01-0.3 $M_\odot$
- evolution similar to that of SGRB disks
  - ~ 1/2 of the disk material ejected

SNe from Disk Ejecta in AIC



Metzger et al. 2009

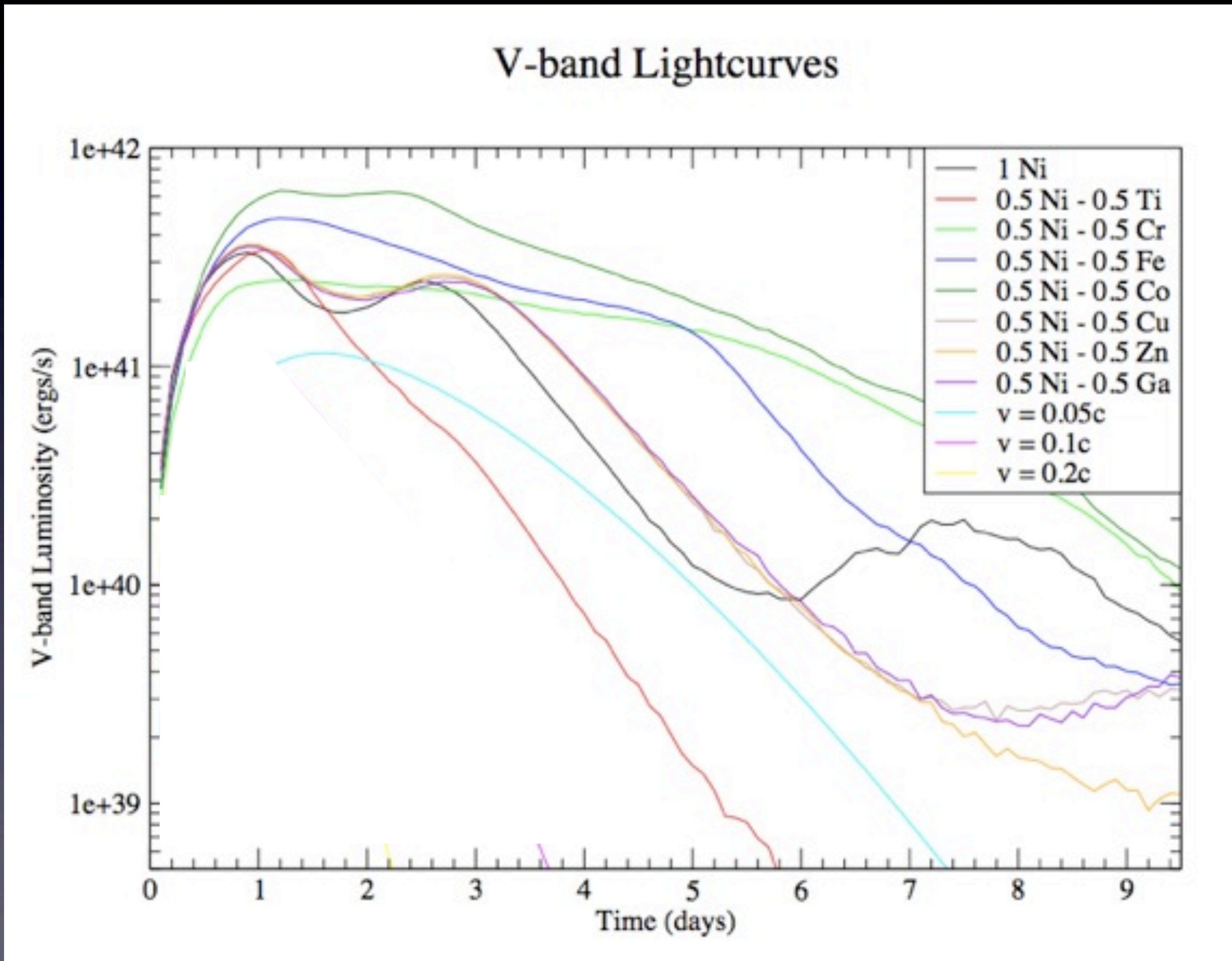
~ 10^{-3}-0.02 $M_\odot$ Ni synthesized

unusual n-rich elements:

Se, Br, Zn, Kr, Cr, Rb, Ti, Sr, Ga, ...

Emission likely dominated by disk ejecta, not WD explosion

Preliminary AIC Lightcurves



Siva Darbha w/ Nugent, EQ

$M_{Ni} \sim 0.01\ M_\odot$

$M_{tot} \sim 0.02\ M_\odot$

$v \sim 0.1\ c$

(can slow down due to interaction w/ SNe/debris)

$L \sim 3 \times 10^{41}$ erg/s

rise time ~ day

duration ~ 3 days

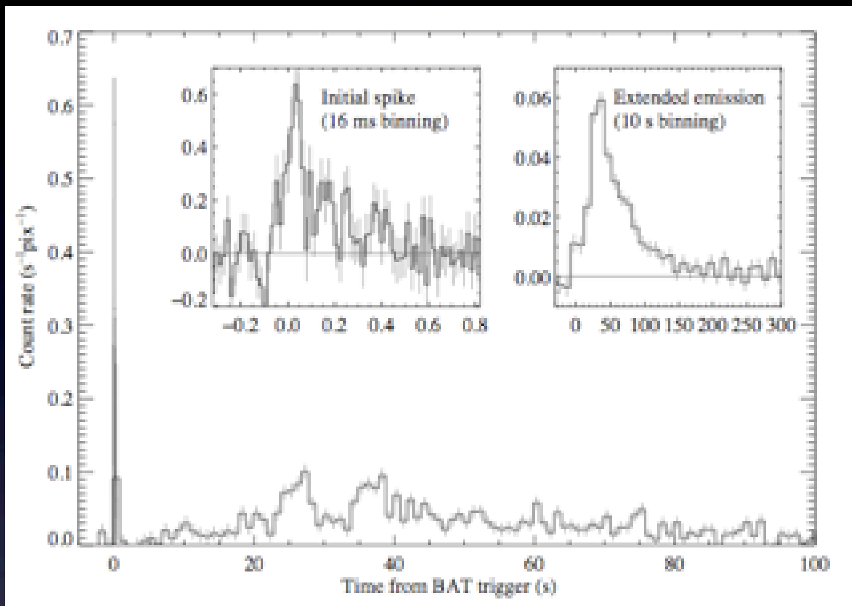
perhaps relevant to 'peculiar' SNe such as 2005e (Gal-Yam talk)

Interlude Over ...

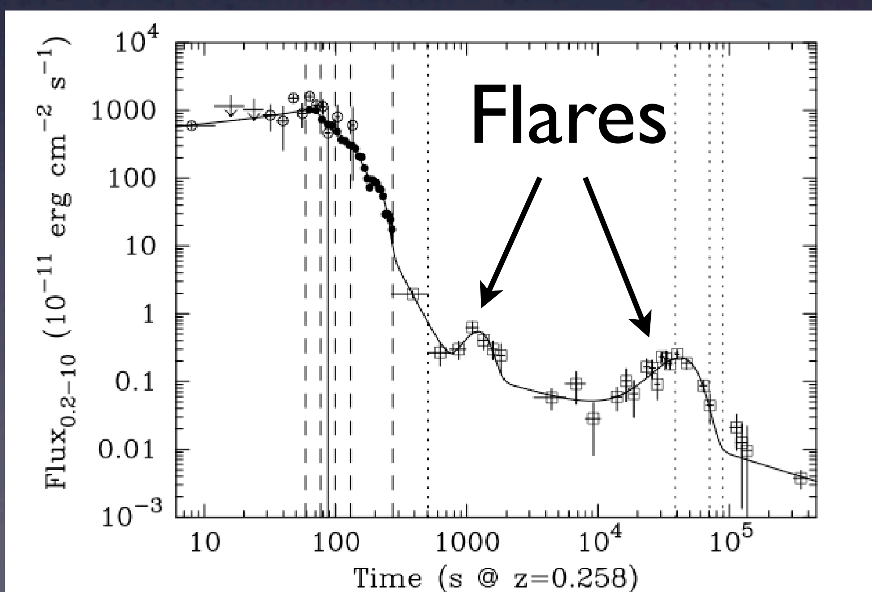
Back to Compact Object Mergers

New Puzzles in SGRBs

Swift Bursts



Perley et al. 2009



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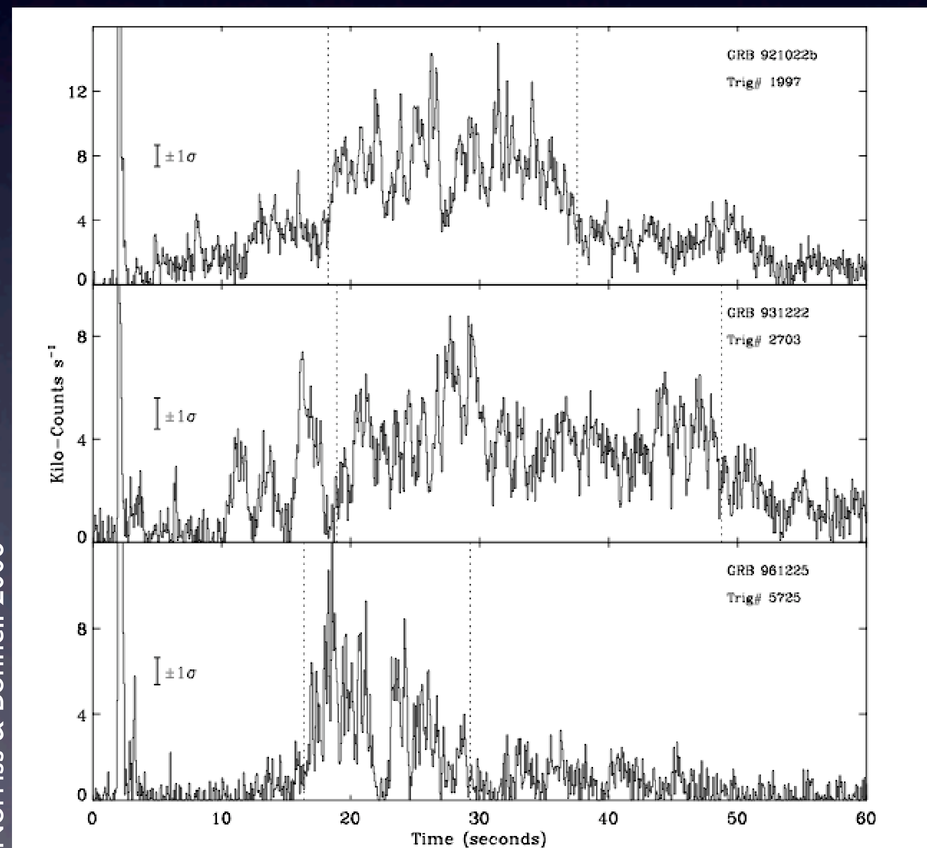

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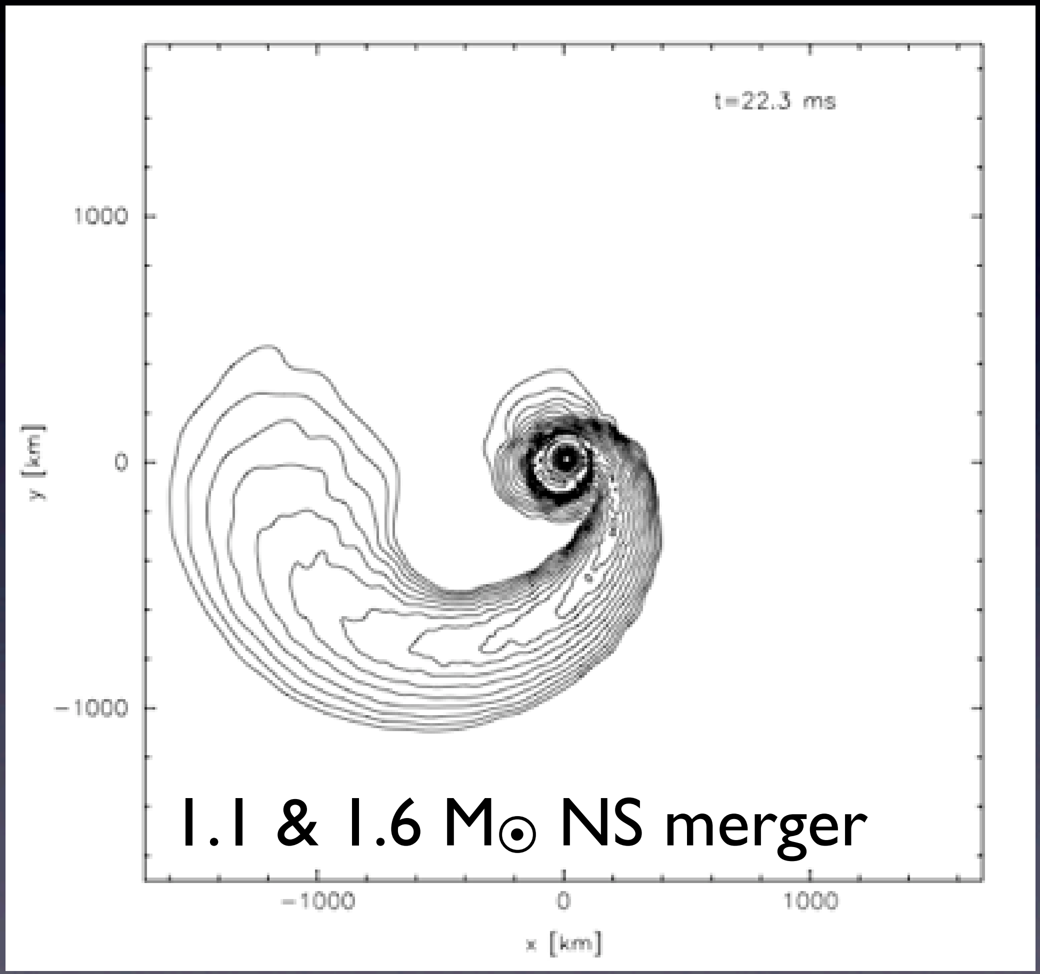

Rosswog 2007

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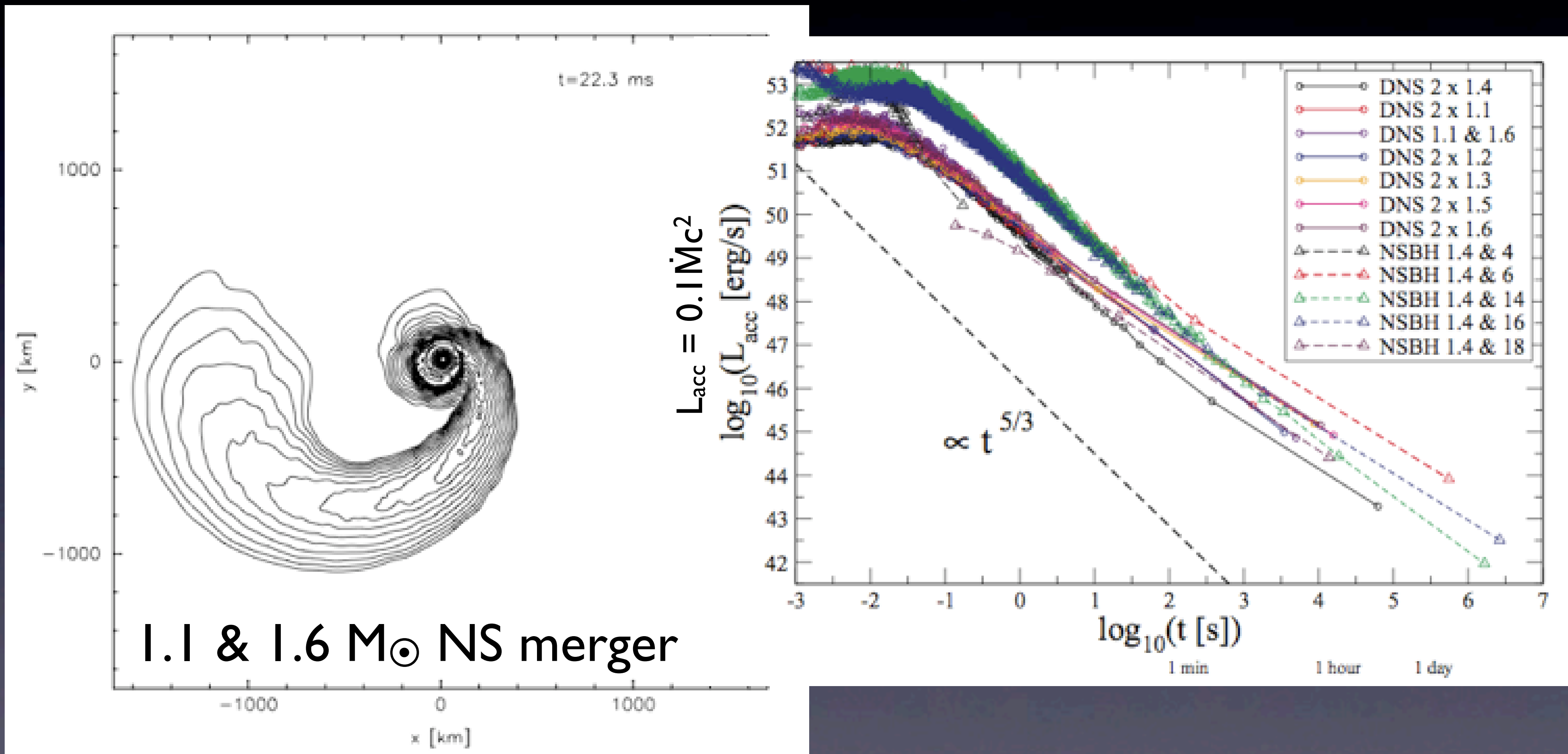
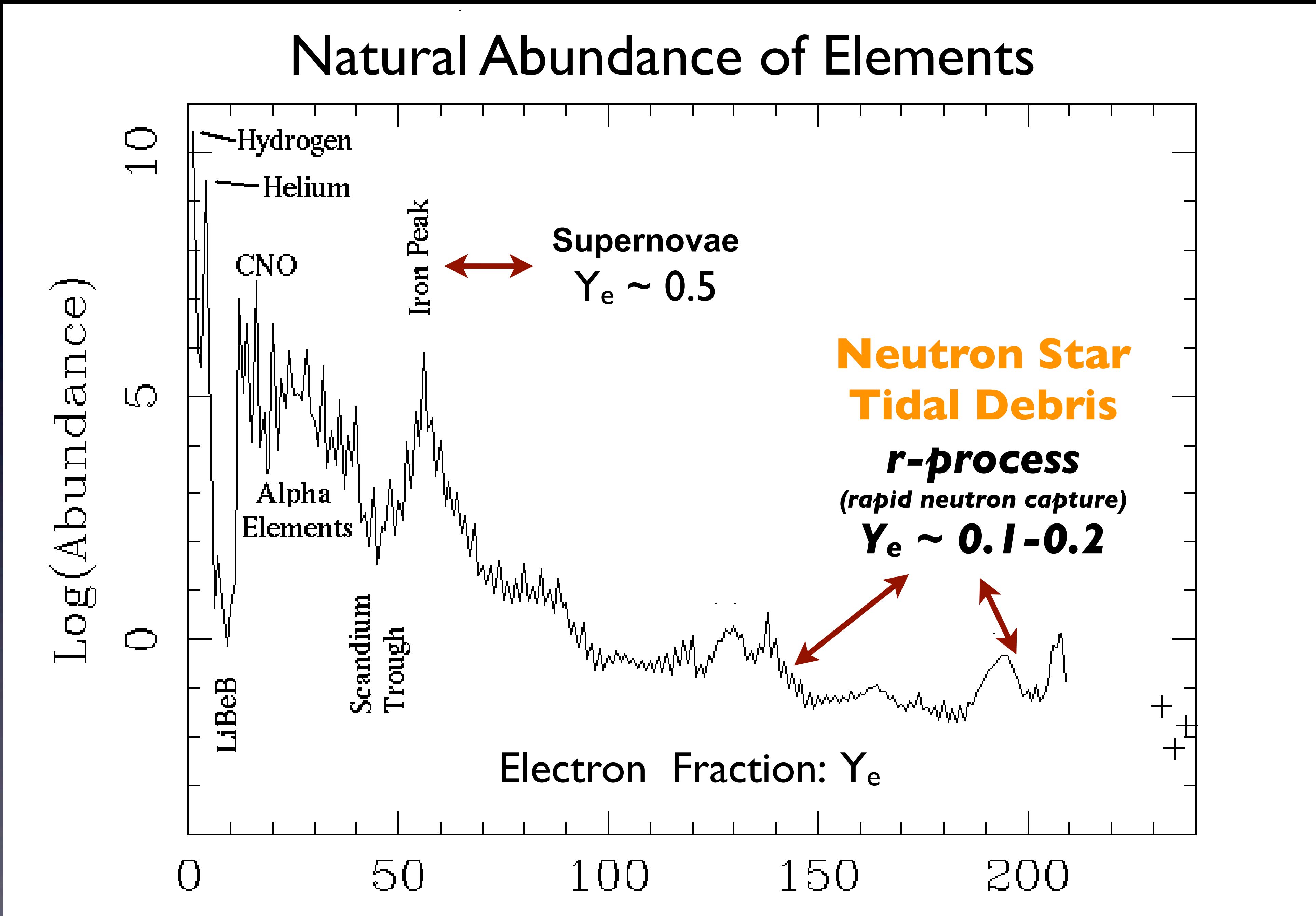


Rosswog 2007

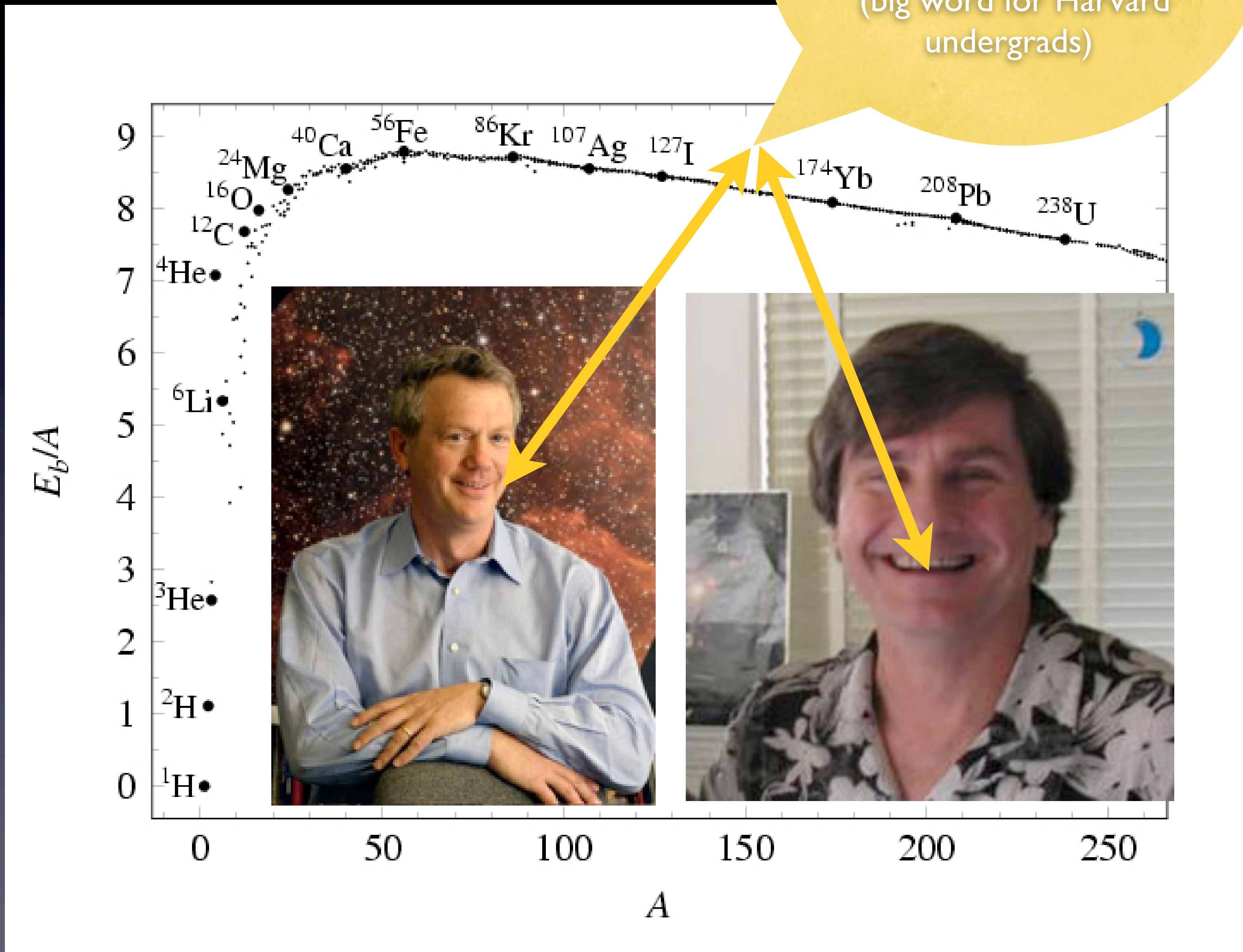
Dynamical Consequences of Nucleosynthesis in Bound Ejecta



Atomic Mass

(mis)Leading Generations of Undergraduates

"Nucleosynthesis above the Iron Peak is Endothermic"
(big word for Harvard undergrads)



r-process: free n's + seed nuclei → n-rich elements

ΔE_r ~ 1-3 MeV/nucl: beta-decays (+ some fission)

[not in current merger or fallback sims]

$$E_{bind} \simeq 1 \left(\frac{t_{orb}}{1\,\mathrm{sec}} \right)^{-2/3} \mathrm{MeV/nucl}$$

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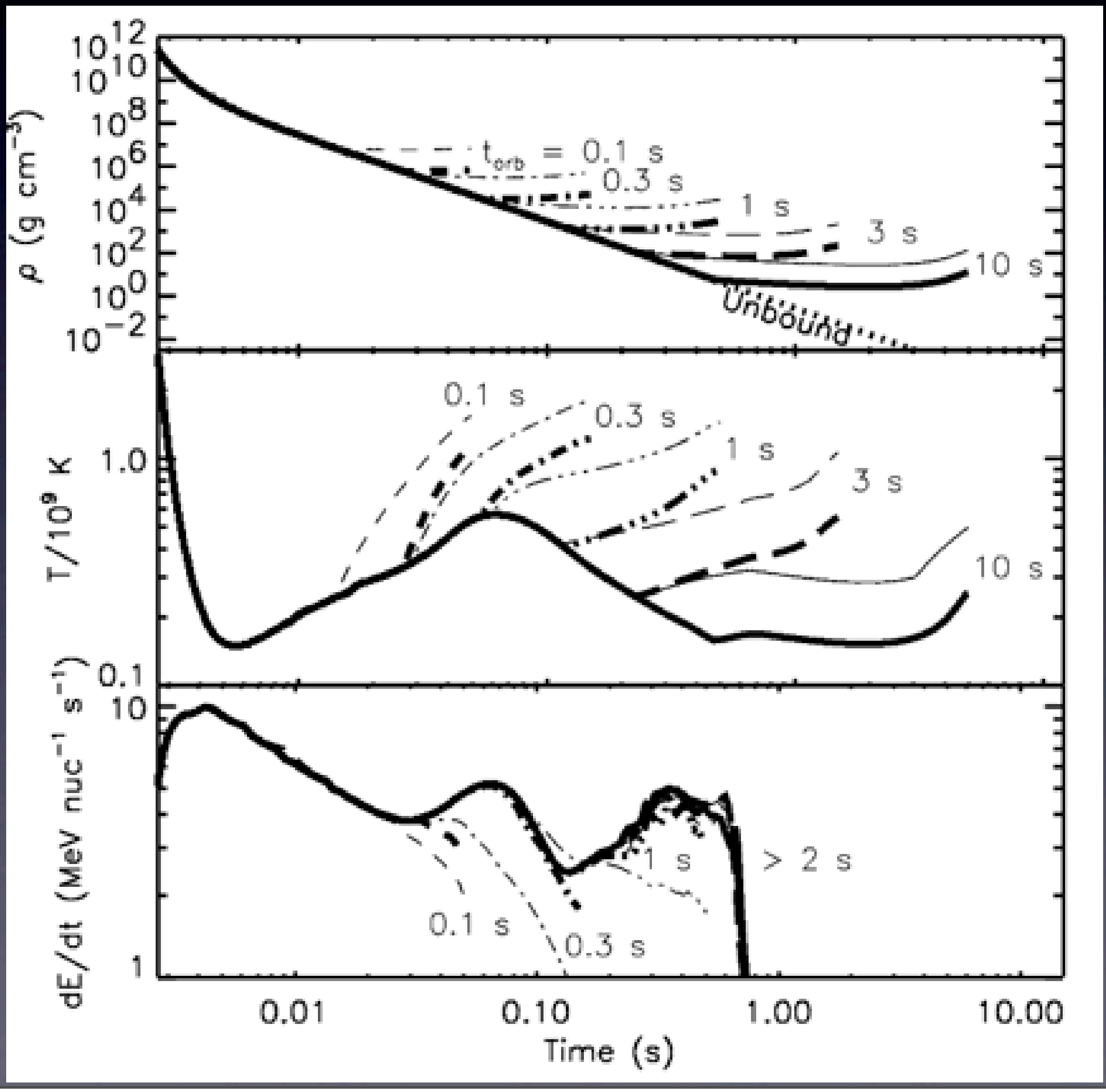
Density

Temperature

R-process Ė



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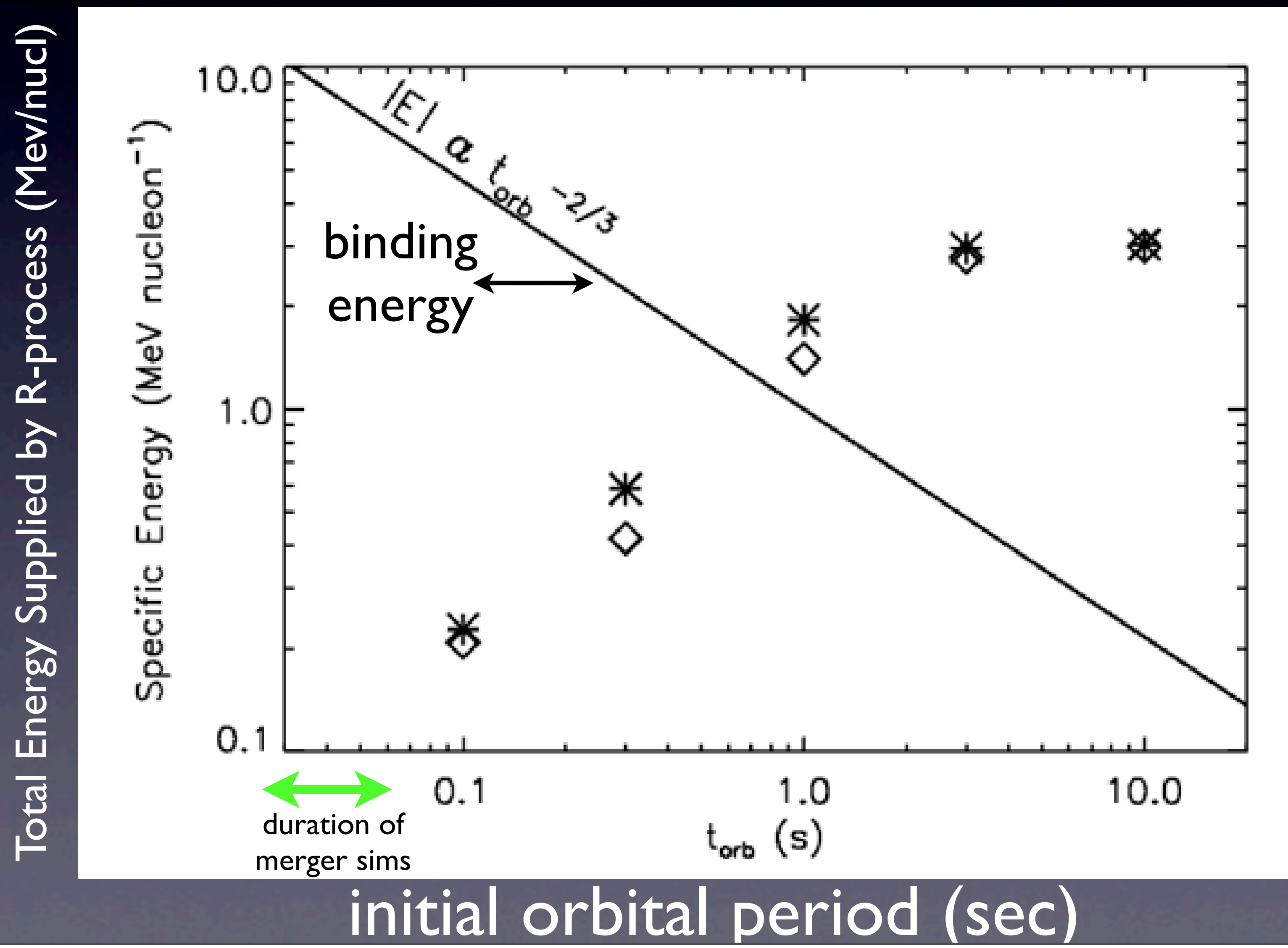
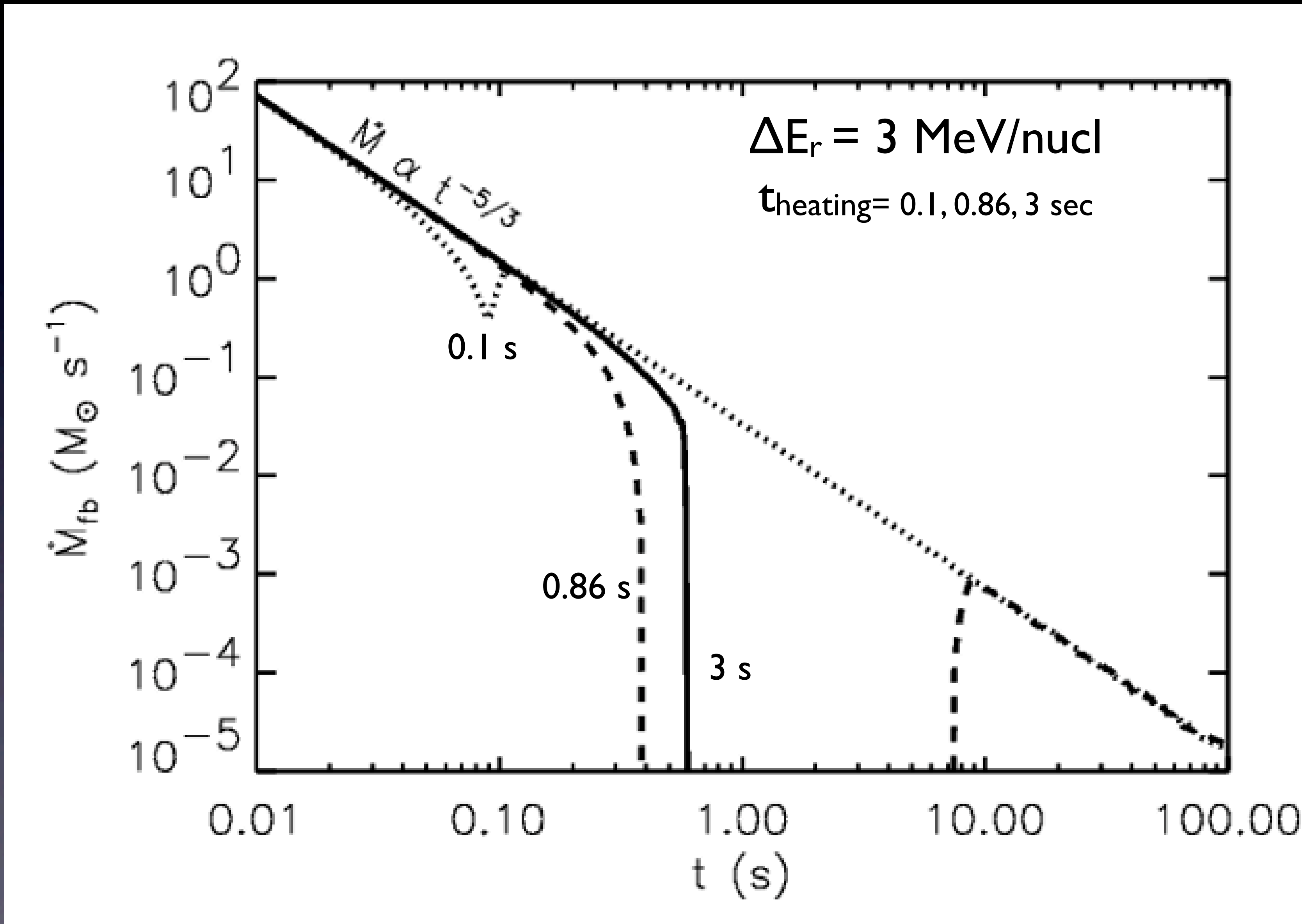


complete suppression of fallback accretion?

Effect of R-process Htg on $\dot{M}_{fb}$ (Toy Model)



Qualitative diff. btw. effects of short (0.1 s) and long (1-3 s) duration heating → must capture temporally extended htg

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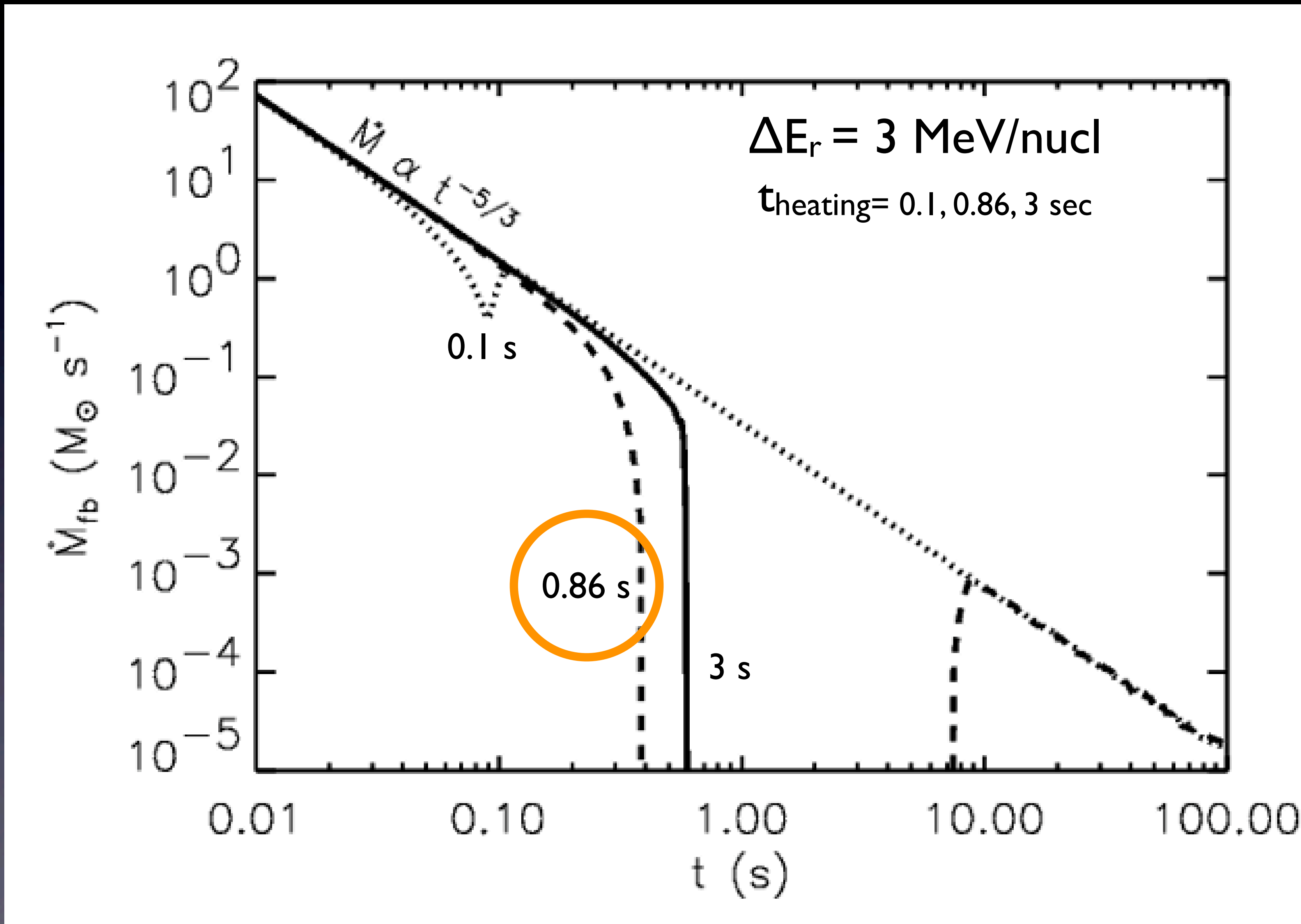


Qualitative diff. btw. effects of short (0.1 s) and long (1-3 s) duration heating → must capture temporally extended htg

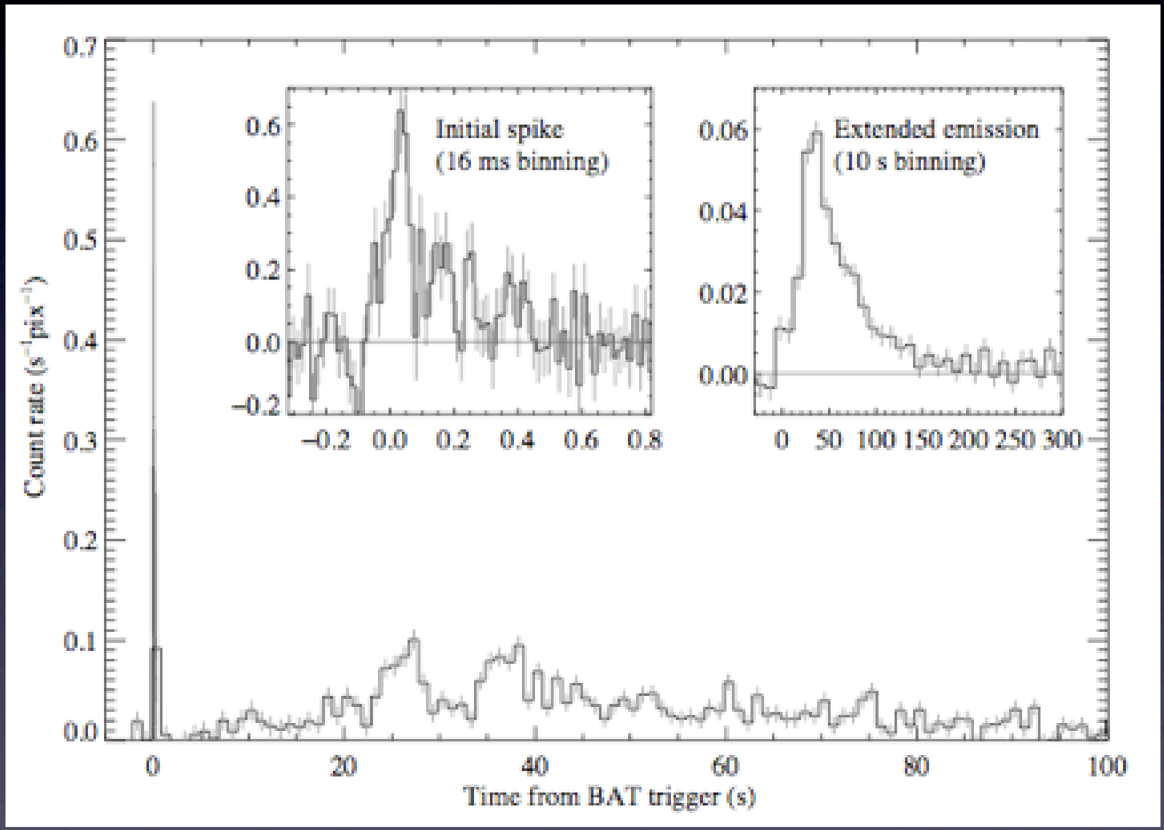
✔ timescale reasonable

Can this help explain the "Extended Emission"?

× fine-tuning (but see ✔)

× extended power > prompt hard to explain

(but ∃ HUGE uncertainties in beaming, jet production, emission physics, ... & large dispersion in observed prompt/extended)



Perley et al. 2009

hydro calcs of fallback w/ r-process htg required

Alternatives:

$\alpha < 10^{-3}$

difft. progenitor

????

Summary

- At least 25% (& perhaps the majority) of short GRBs show energetically significant emission on timescales ~100 sec
    - Origin in Compact Object Mergers?

      X Initial Disk: blown apart after ~ 1 sec (neutron rich ejecta)

      ?? Fallback: severely disrupted by r-process heating

      (may account for 'gap' btw prompt & extended emission; more detailed calcs reqd)

- AIC: Rapidly rotating WD → 0.01-0.3 $M_\odot$ disk around the NS
    - evolution similar to compact object merger disks
    - NS irradiation → 10^{-3}-10^{-2} $M_\odot$ Ni ejected
        - L ~ few 10^{41} ergs/s; rise time ~ day; duration ~ 3+ days
        - accompanied by unusual n-rich ejecta