JOHNS HOPKINS
KRIEGER SCHOOL
of ARTS & SCIENCES

Nuclear burning in Collapsar accretion disks

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AND

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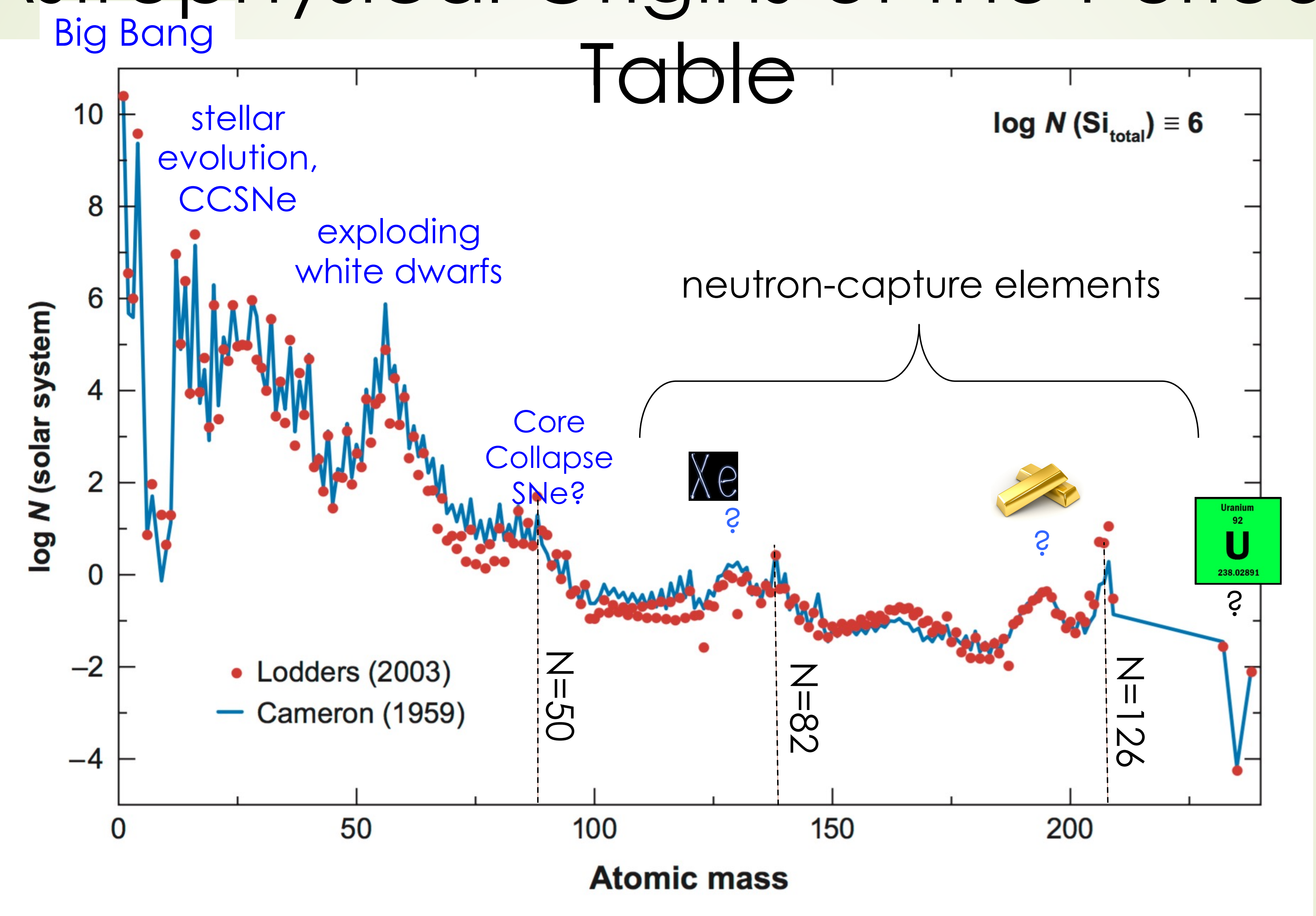
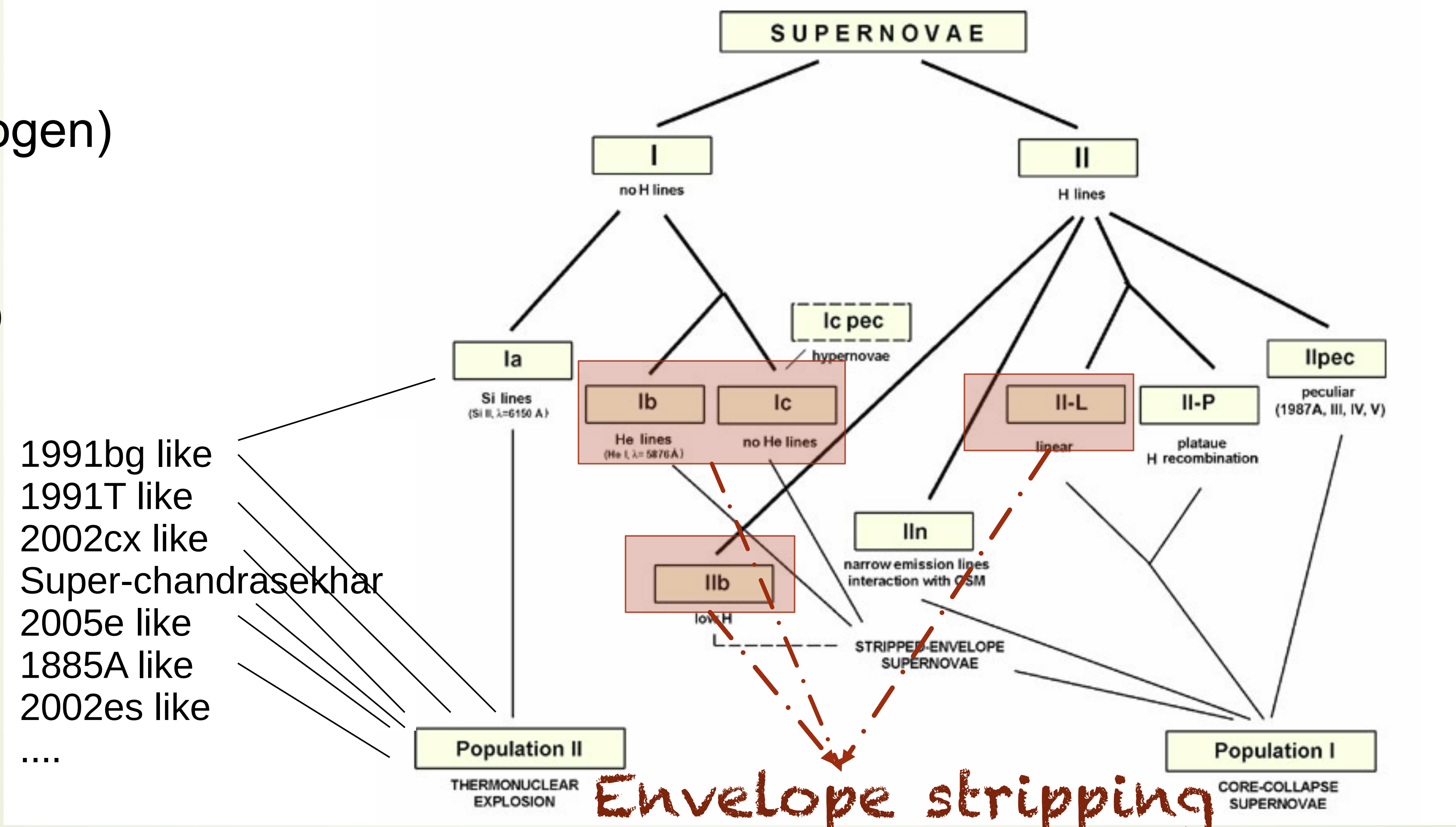
Astrophysical Origins of the Periodic Table



SNe Zoo

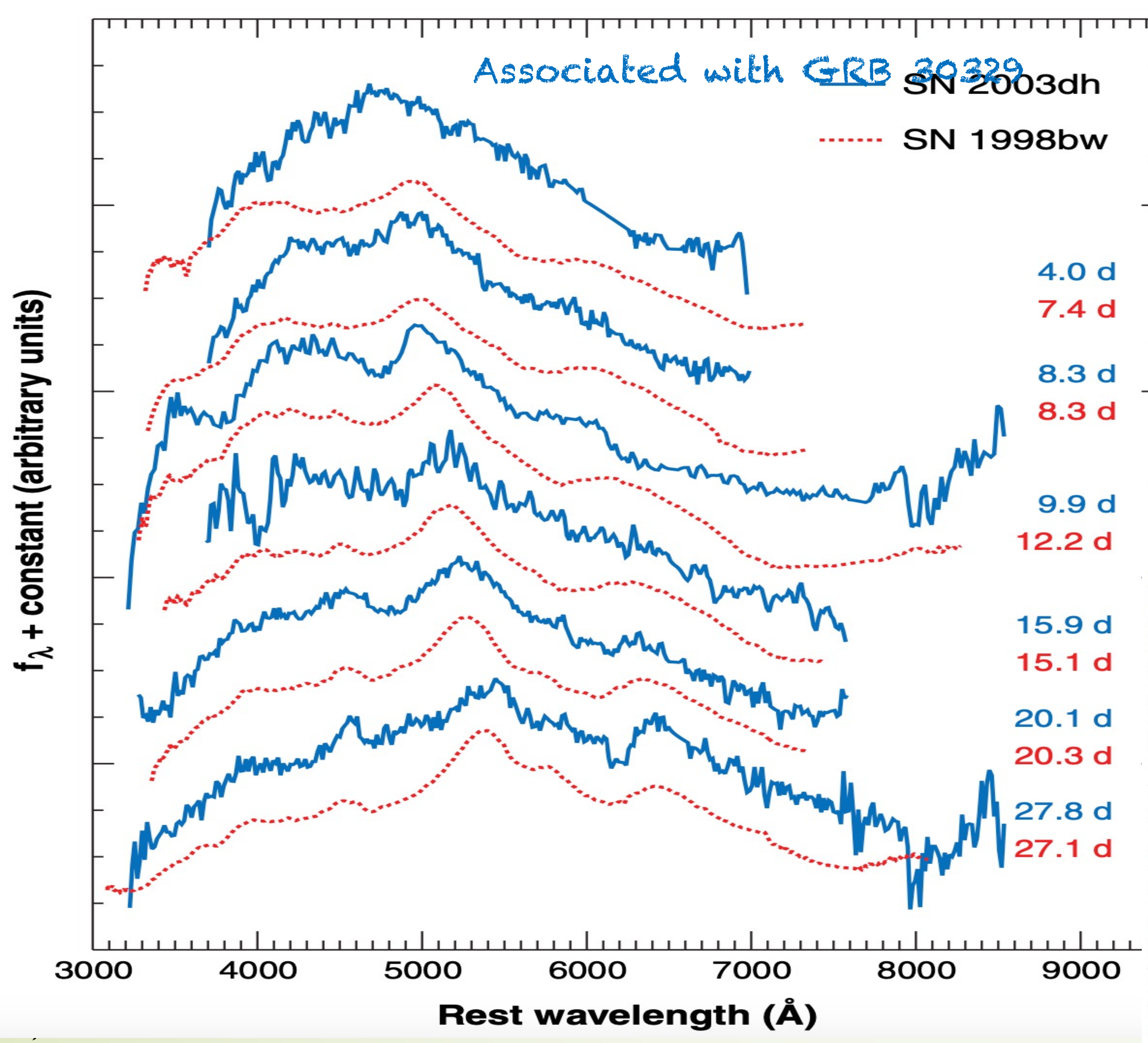
Type I (no hydrogen)

- Ia (Si, no He)
- Ib (He, no Si)
- Ic (no Si; no He)



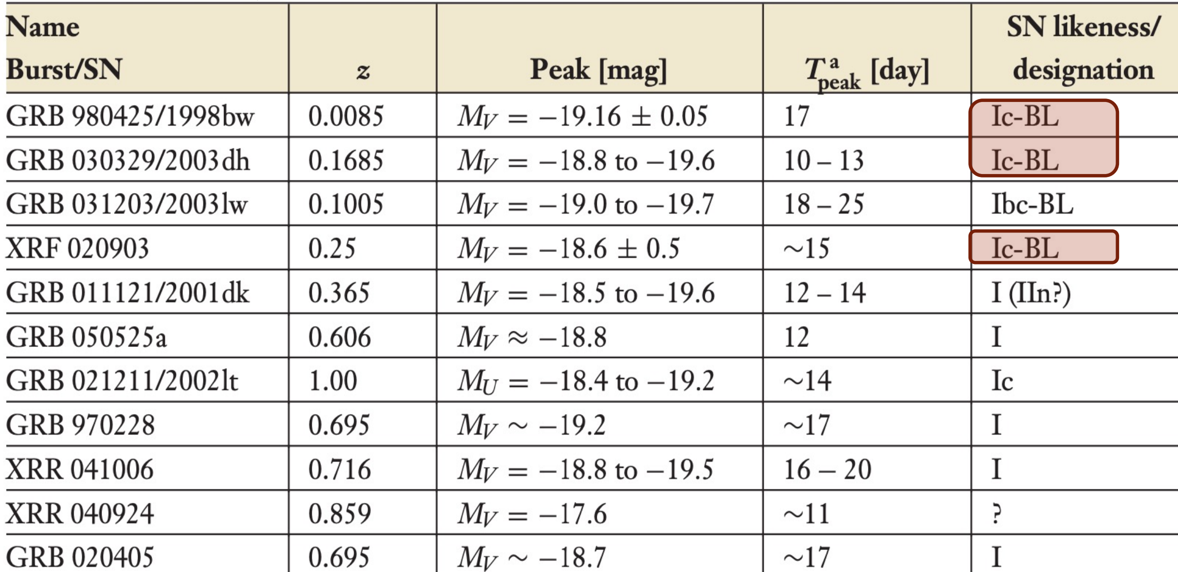
1991bg like
1991T like
2002cx like
Super-chandrasekhar
2005e like
1885A like
2002es like
....

The Connection between GRB - SNe



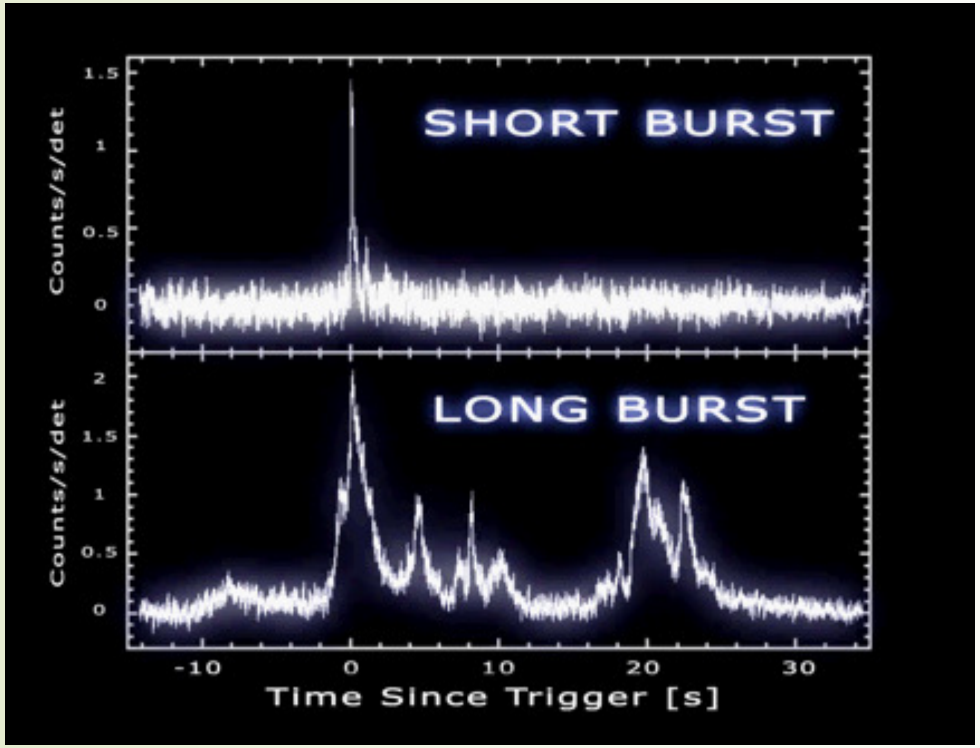
Associated with GRB 30329

Woosley +06

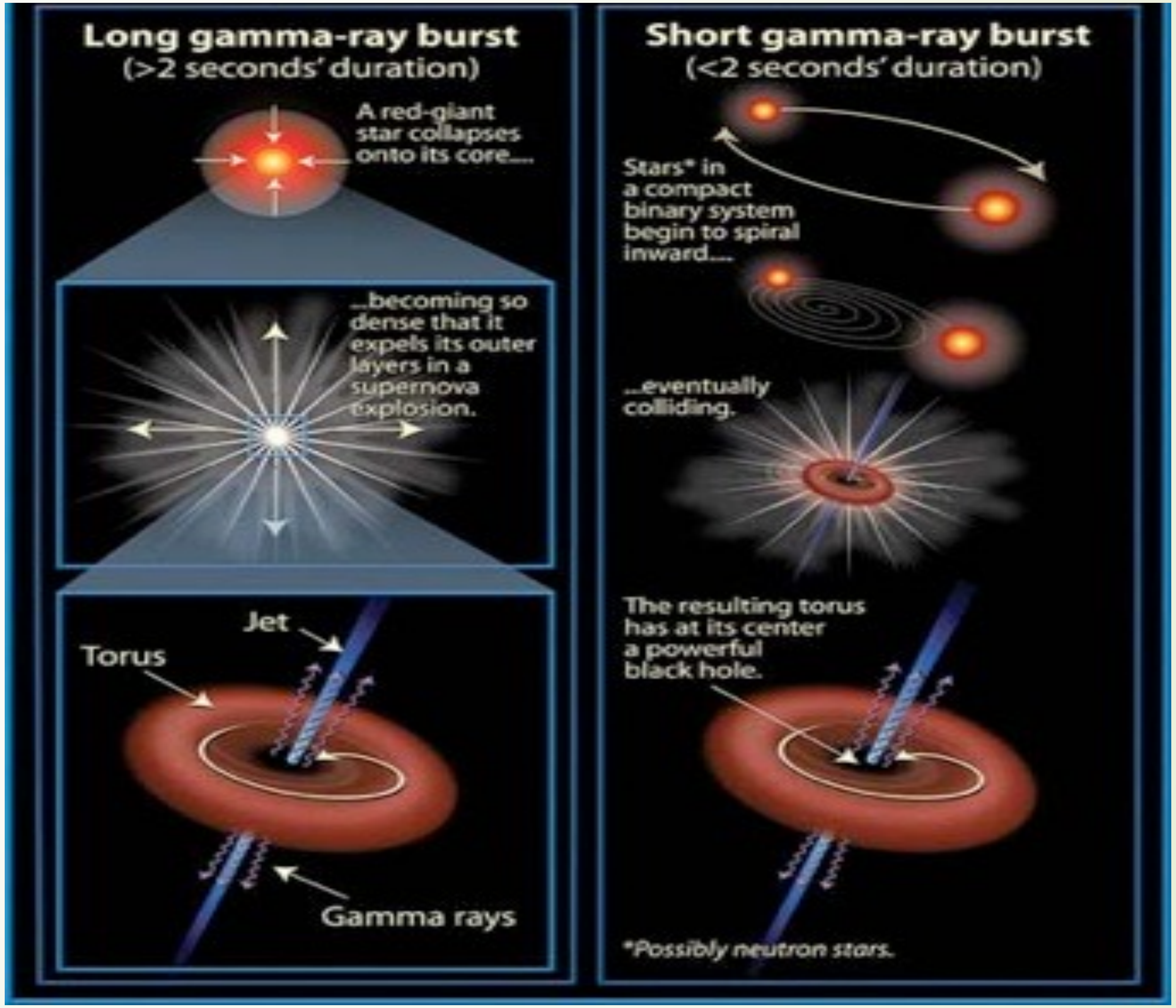


Name Burst/SN	z	Peak [mag]	$T^{\rm a}_{\rm peak}$ [day]	SN likeness/ designation
GRB 980425/1998bw	0.0085	$M_V = -19.16 \pm 0.05$	17	Ic-BL
GRB 030329/2003dh	0.1685	$M_V = -18.8$ to -19.6	10 – 13	Ic-BL
GRB 031203/2003lw	0.1005	$M_V = -19.0$ to -19.7	18 – 25	Ibc-BL
XRF 020903	0.25	$M_V = -18.6 \pm 0.5$	~15	Ic-BL
GRB 011121/2001dk	0.365	$M_V = -18.5$ to -19.6	12 – 14	I (IIn?)
GRB 050525a	0.606	$M_V \approx -18.8$	12	I
GRB 021211/2002lt	1.00	$M_U = -18.4$ to -19.2	~14	Ic
GRB 970228	0.695	$M_V \sim -19.2$	~17	I
XRR 041006	0.716	$M_V = -18.8$ to -19.5	16 – 20	I
XRR 040924	0.859	$M_V = -17.6$	~11	?
GRB 020405	0.695	$M_V \sim -18.7$	~17	I

The central engine powering the GRBs jets (ultra re.) could be different Progenitors



NASA, SWIFT



Long GRBs (duration > 2sec) Short GRBs (duration < 1sec)

Single Star as Progenitors- Collapsar

- Core collapse of rapidly-rotating stars, which are stripped of their outer hydrogen (also helium) envelopes
- Long GRBs associated with CC of massive WR stars.
- Collapse yields SBH or rapidly spinning, highly magnetized NS
- Infalling material form a tours around the CCO.
- Accretion in the torus fuel gamma-ray jet. $\geq 0.01 M_\odot \quad sec^{-1}$
- Internal shocks (gamma ray jet) external shocks with residual wind – result in GRBs and the afterglows

Woosley & Bloom 2006; Nagataki 2018, Anderson 2019

Single Star as Progenitors- Collapsar

- Bursts last for 2 sec, the longest known has 2000 sec.
- Total energy $\geq 10^{51} erg$
- Similar to the X-ray flash (XRF) which they fainter and softer.
- Hosts are late type (dwarf galaxies) and connected with center of star formation in host galaxies.
- They are bright and detected at all redshits
- GRB 980326, 011121,030329

Bloom +99, 02; Stanek +03

SNe Ic-bl show a unique properties

- High ejecta expansion velocities $\sim 15000 - 30000 km\ sec^{-1}$.
- energy released $\geq 10^{52} erg\ sec^{-1}$
- The Ni56 amount $\sim 0.1 - 0.5 M_{\odot}$
- While all bona-fide long GRBs have been associated with SNe Ic-bl.
- According to the high luminosity, LGRBs can be detected at very high redshit.
- Unsuccessful direct imaging the progenitors of SNeIc-bl.
- Many SNe Ic-bl comes without observed GRBs.

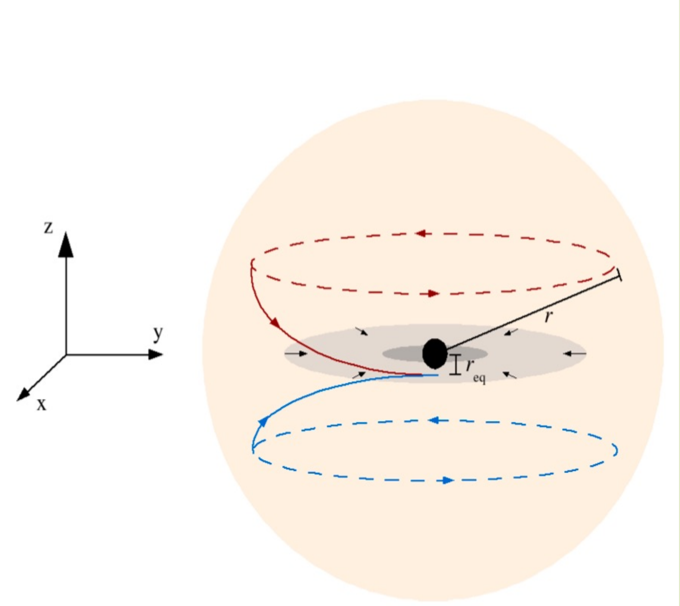
Two phases of accretion rates

- Hyper-accreting BH- neutron-rich through weak interactions < tens of gravitational radii → High T and ρ → heavy nuclei ($A \gtrsim 130, Y_e \ll 0.5$).

$t_{visc} \ll t_{ff}$

- In large radii the midplane temperature ~ $10^8 K$ → X_i retain → accretes onto the central BH → high T in small radii → ignite nuclear burning in the midplane.
- The "viscously-evolving isolated torus" → unexpected behavior of some GRB X-ray afterglows.

$t_{visc} > t_{ff}$



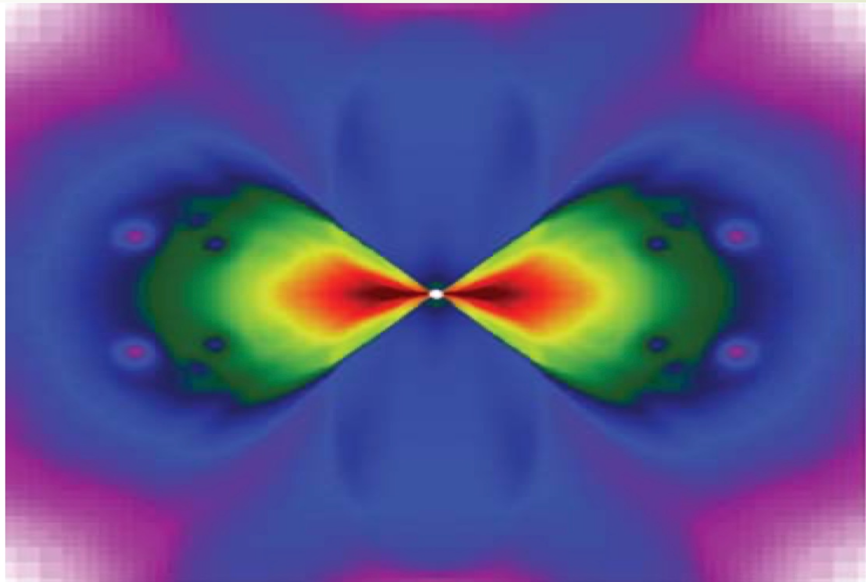
Macfadyen & Woosley 99; Beloborodov 03; Metzger 08; Kumer +08; Cannizzo et al 11; Siegel +19; YZ +20

Collapsar disk as a defferent mechanism

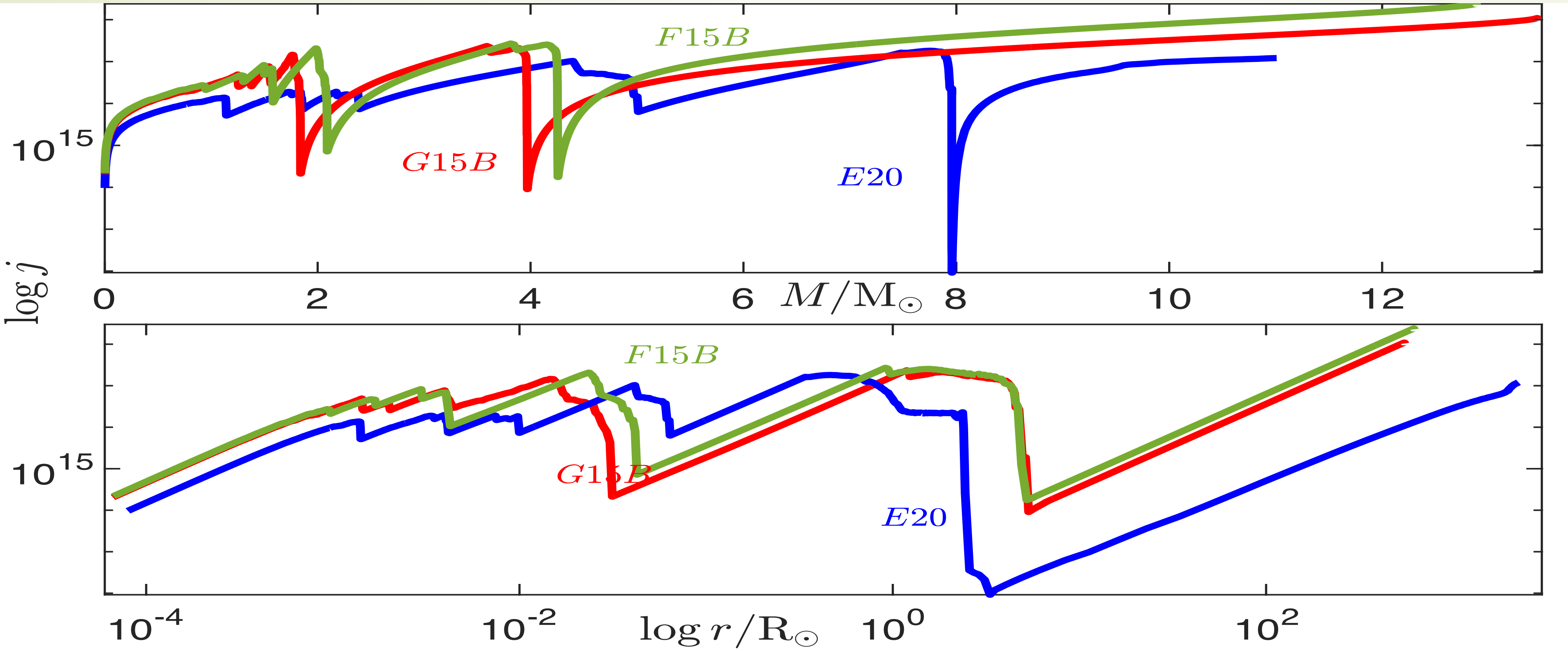
- the effects of nuclear burning on the late-time accretion flows generated by collapsar.
- The accretion flow starting from an equilibrium torus.
- Modified the angular momentum profile.
- We do not follow the actual collapse and the formation of the disk.

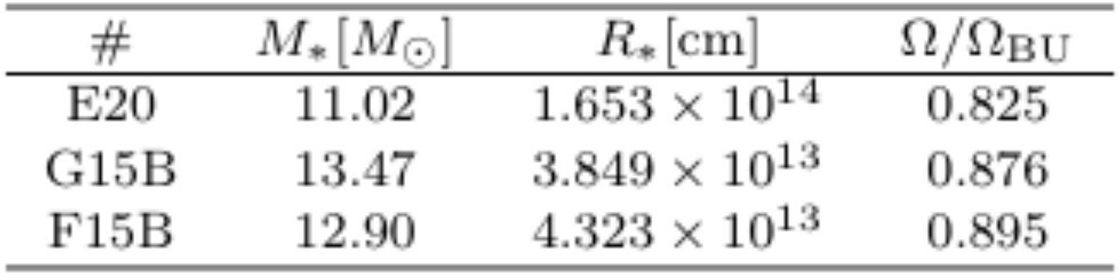
$$e_{\mathrm{tot}} = \frac{1}{2}\left[v_{\bar{\rho}}^2 + \frac{l_z^2}{\bar{\rho}^2}\right] - \frac{GM_{\mathrm{BH}}}{r} - E_{\mathrm{grav,d}} + e_{\mathrm{int}},$$

$$t_{visc} > t_{ff}$$



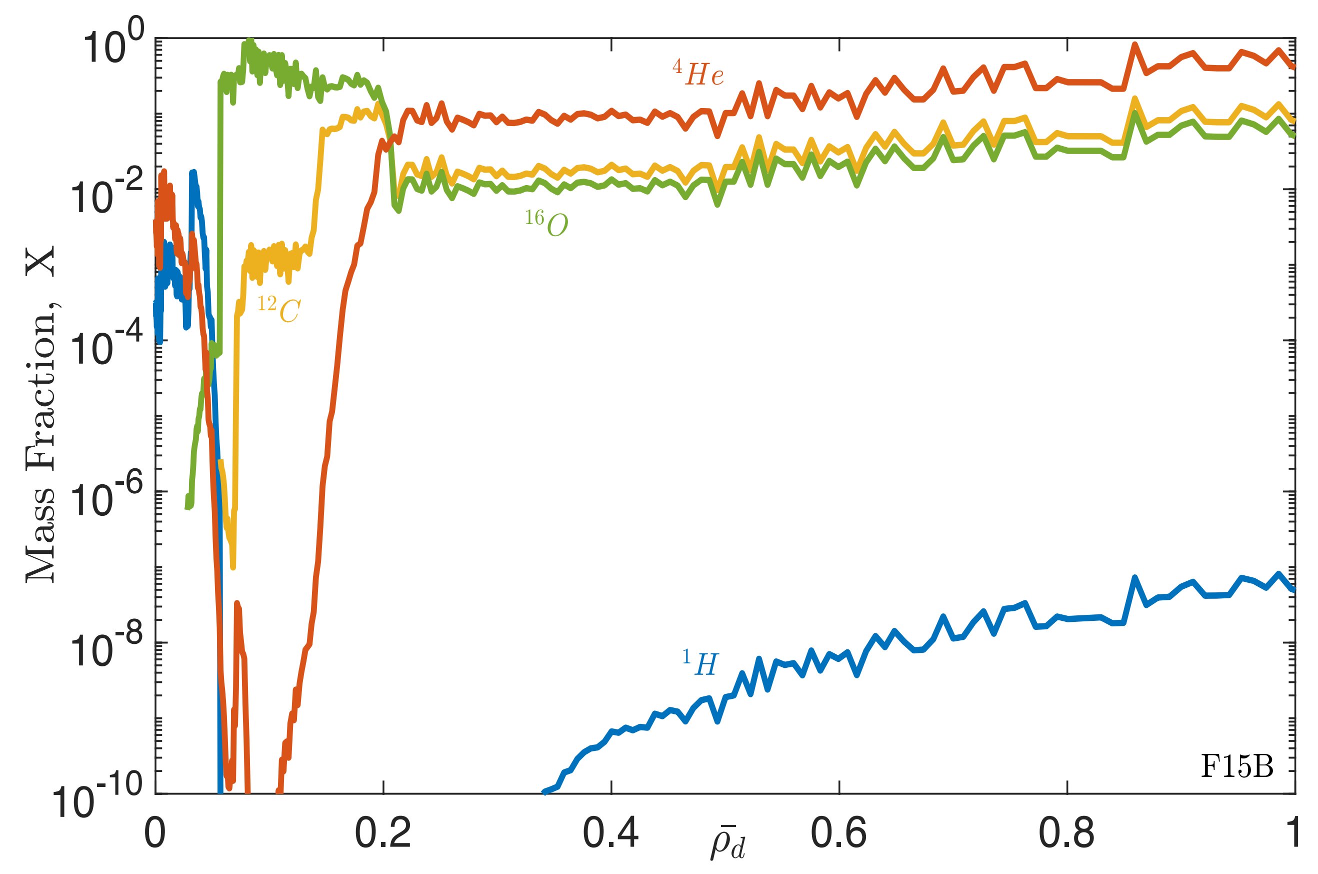
Specific angular momentum profiles of the progenitor models

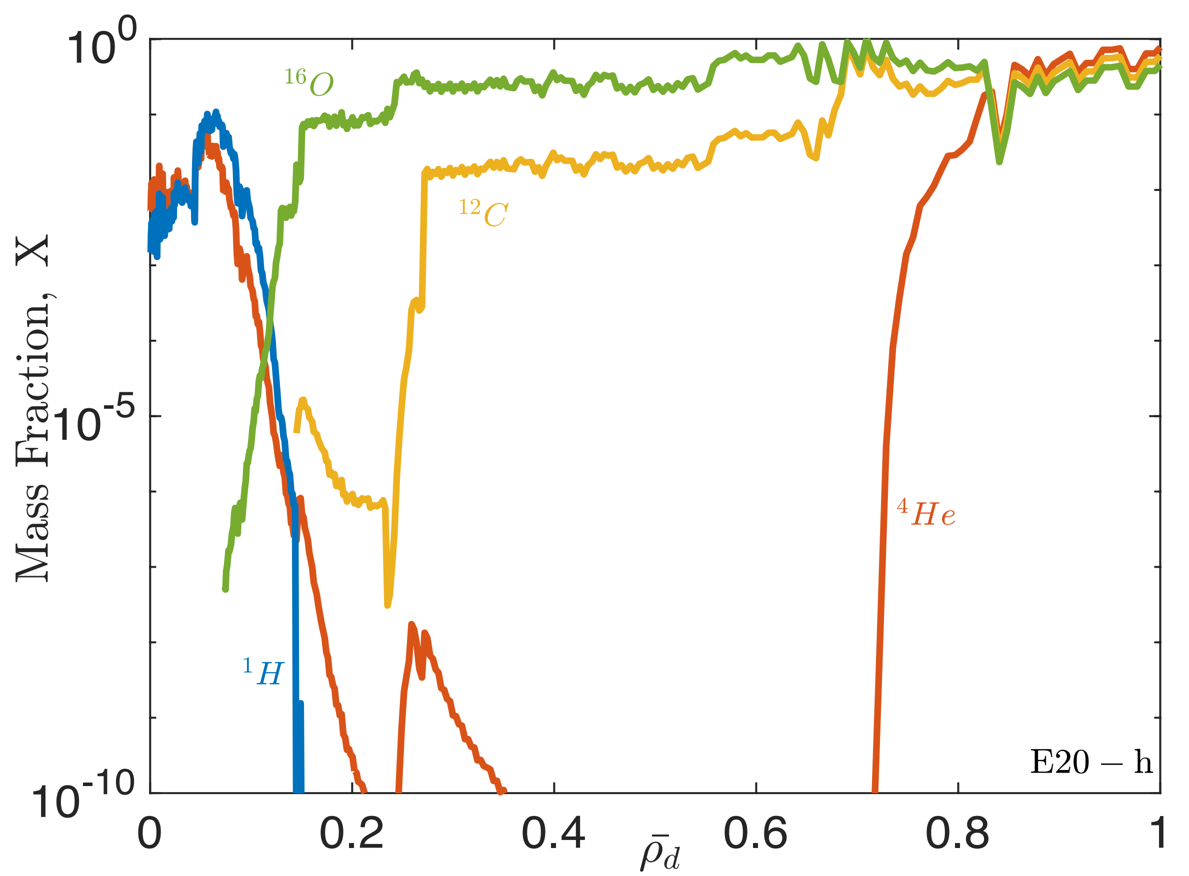




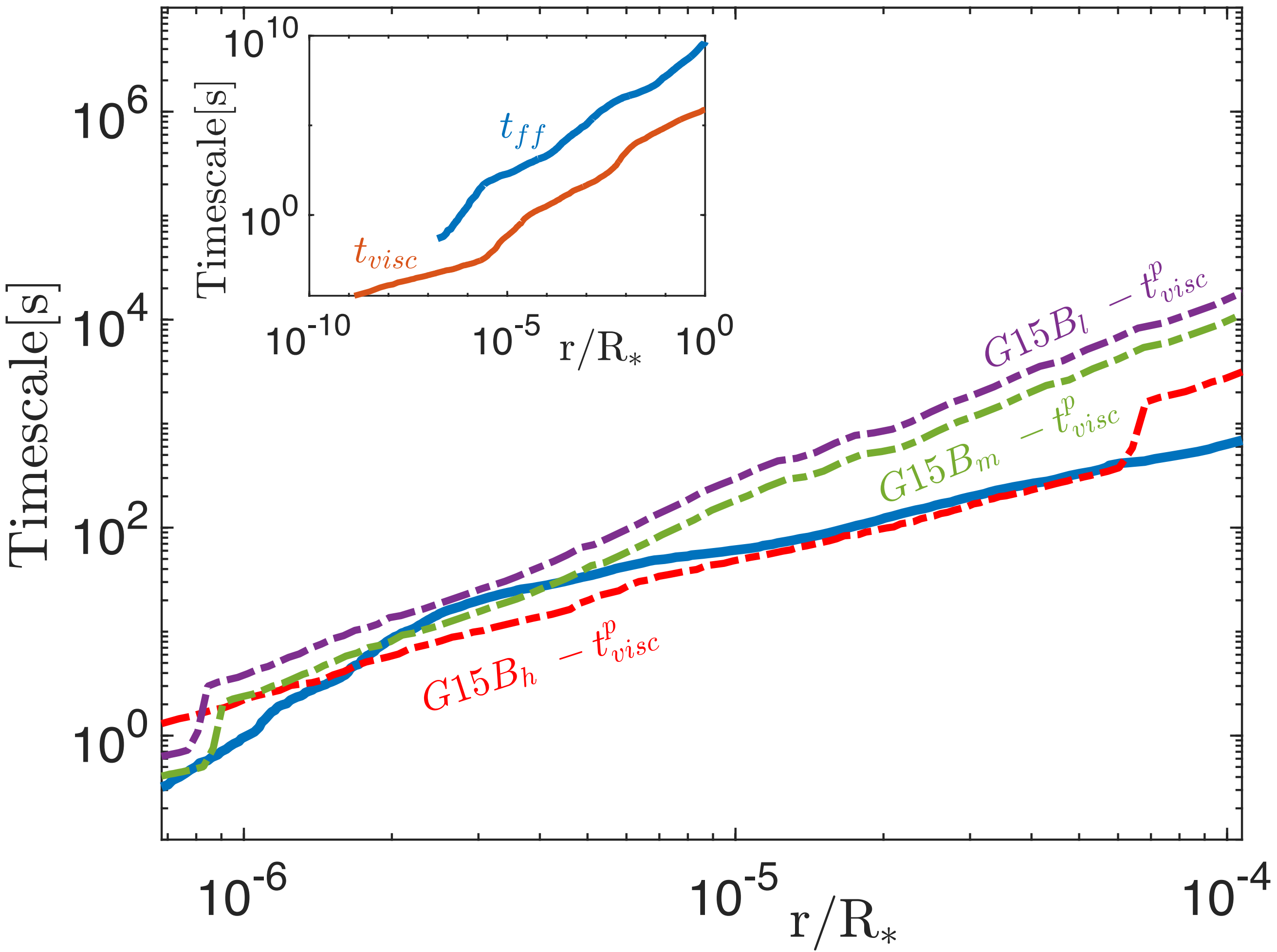
#	$M_*[M_\odot]$	R_*[cm]	$\Omega/\Omega_{\rm BU}$
E20	11.02	1.653×10^{14}	0.825
G15B	13.47	3.849×10^{13}	0.876
F15B	12.90	4.323×10^{13}	0.895

Initial compositions of the collapsar accretion disks



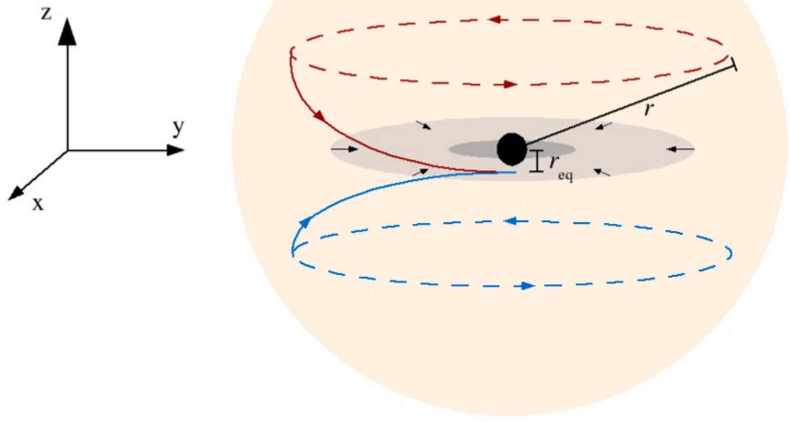


Timescales as a key of the disc formation



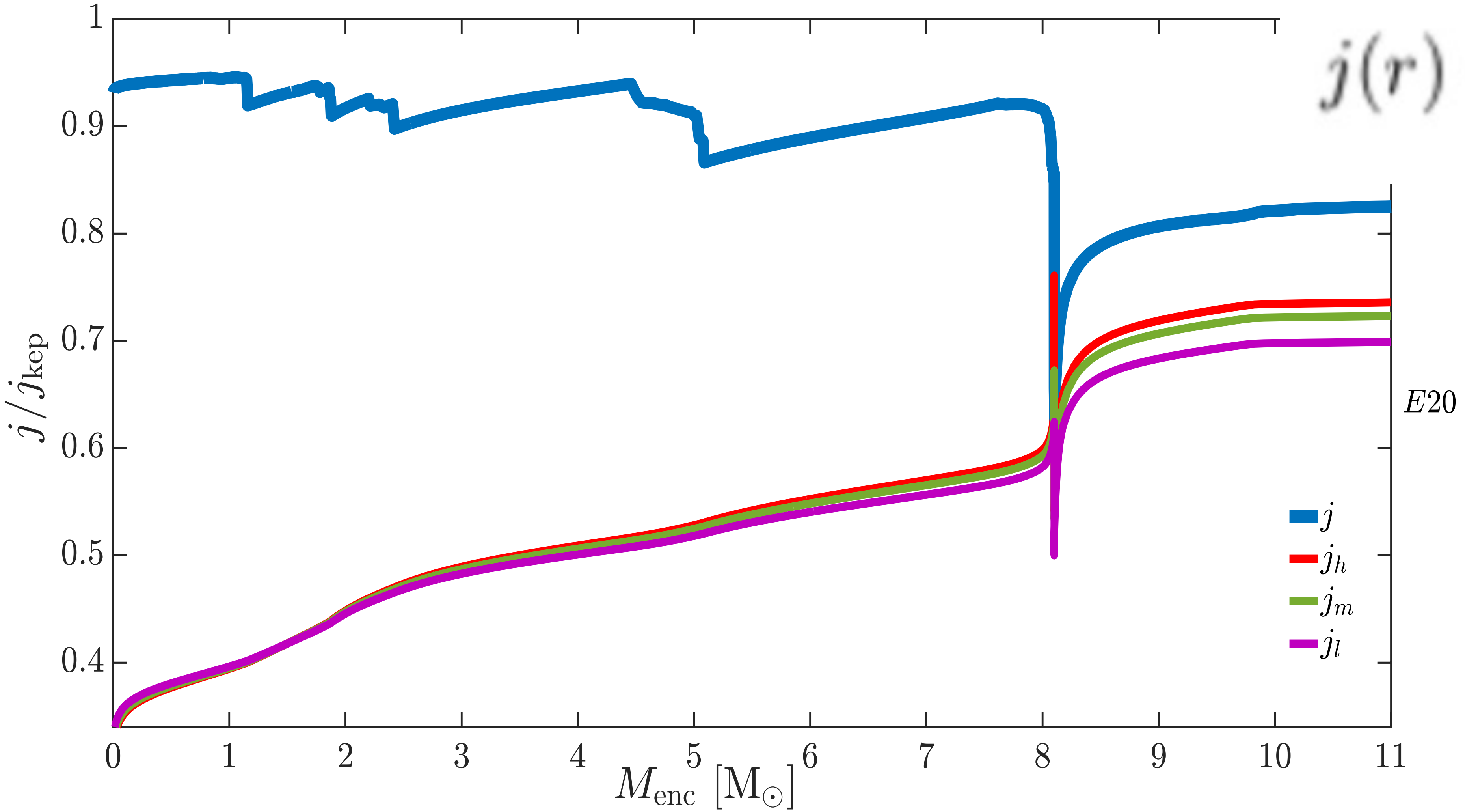
$$t_{\rm visc}(r) = \frac{r_{\rm circ}^2(r)}{\nu_\alpha} \approx \frac{1}{\alpha}\left(\frac{r_{\rm circ}^3}{GM_{\rm enc}}\right)^{1/2}\left(\frac{H_0}{r_{\rm circ}}\right)^{-2}$$

$$t_{\rm ff}(r) = \left(\frac{r^3}{GM_{\rm enc}}\right)^{1/2}$$



The viscos time intersect the free fall time

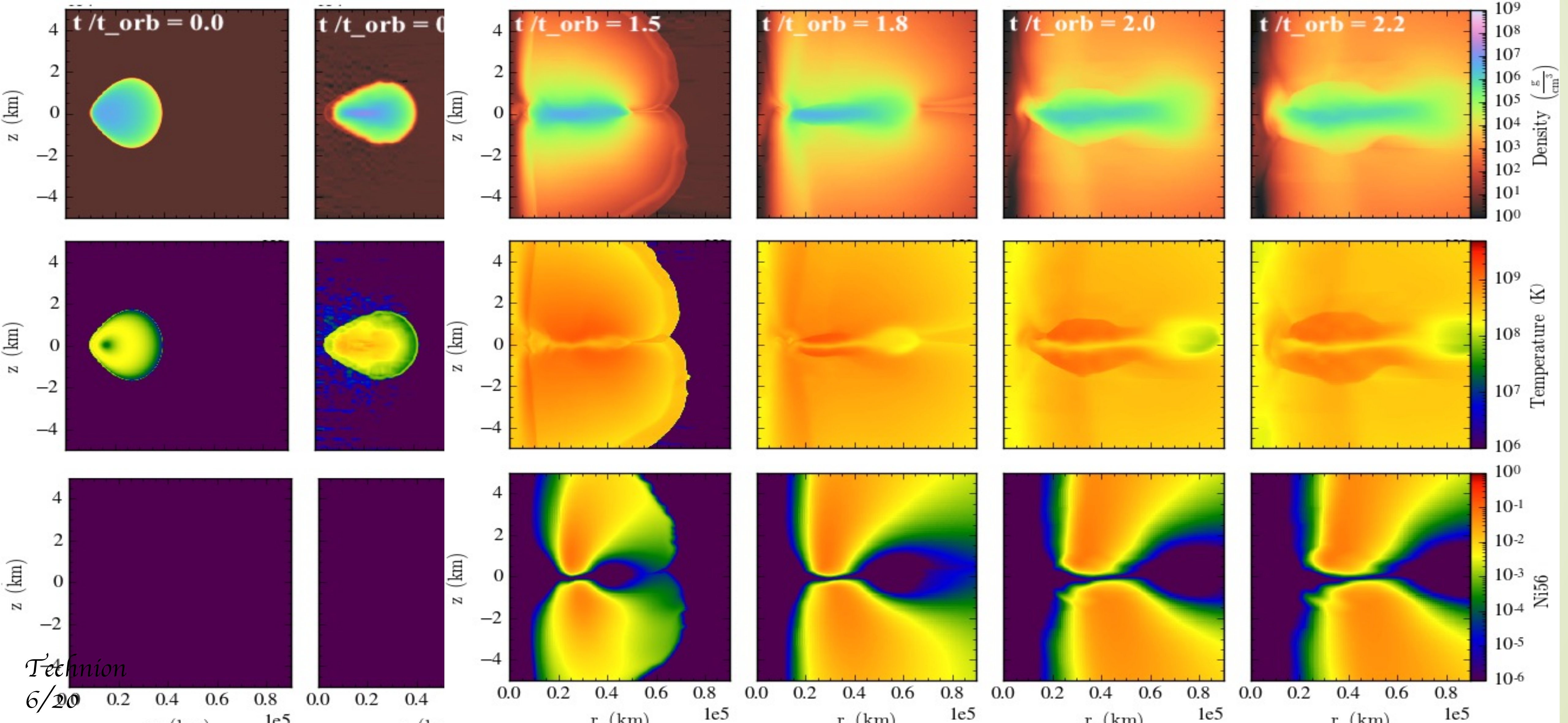
$$j(r) = j(R_\star)\left(\frac{r}{R_\star}\right)^p$$



Simulation should include both hydrodynamics and thermonuclear reaction

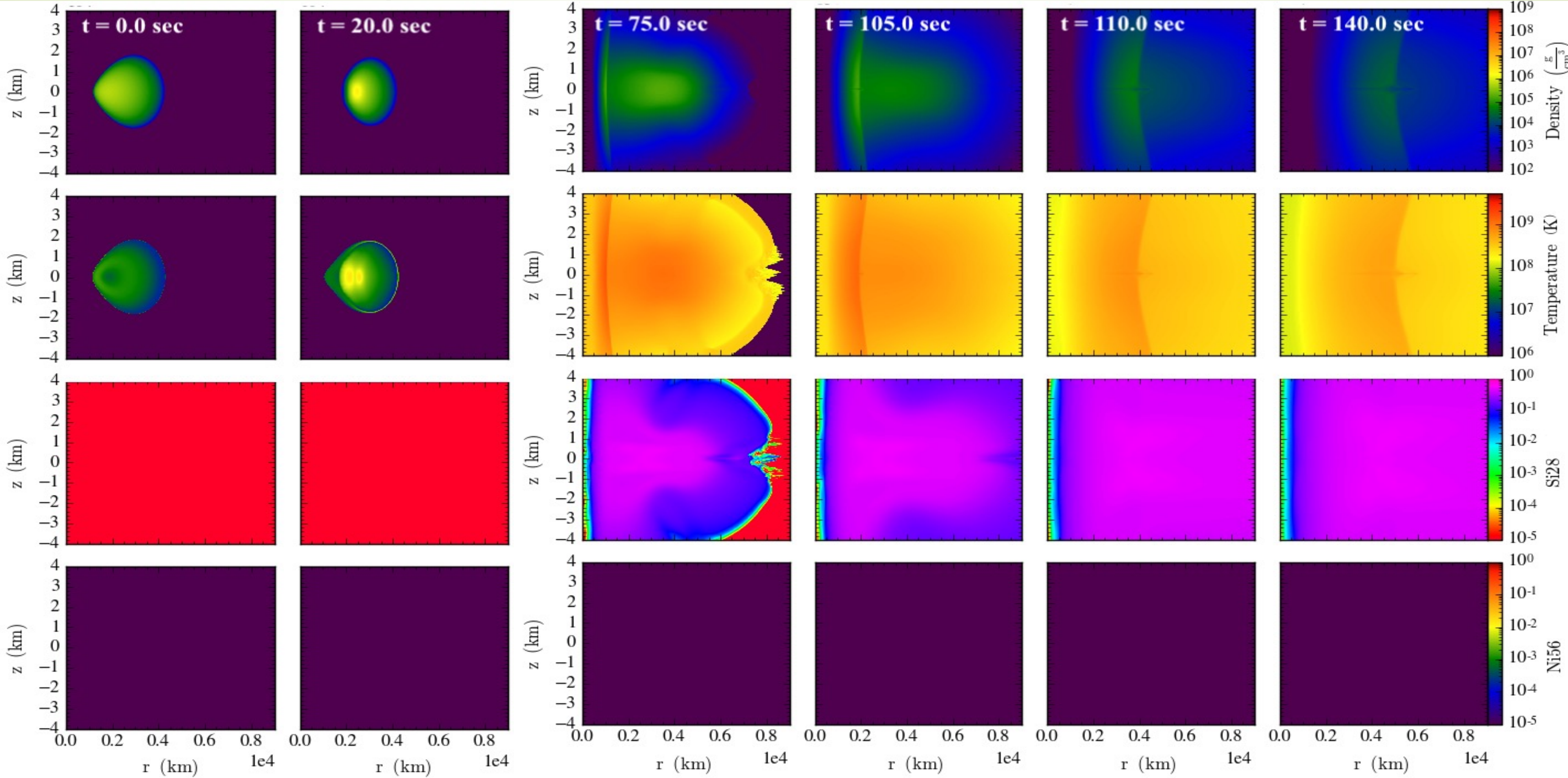
- BH-WD merger –during the merger, the WD is tidally disrupted and sheared into accretion disk. (Papaloizou et al 83,Fryer et al 1998 and Metzger 2012).
- Also Paschalidis et al. (2011) & Bobrick et al. (2017) has been explored the disruption and the disk formation process by with time-dependent simulations.
- Thermonuclear process can play an important role also on the dynamics of accretion following the TD of WD. (Metzger 11+12,FM13, Zenati et al 2018).
- NS-WD mergers could be modeled in 2D using accretion disk. (FM13, Bobrick et al 2016 and Zenati et al 2018, FMM19).

Collapsar disks with nuclear burning



Technion

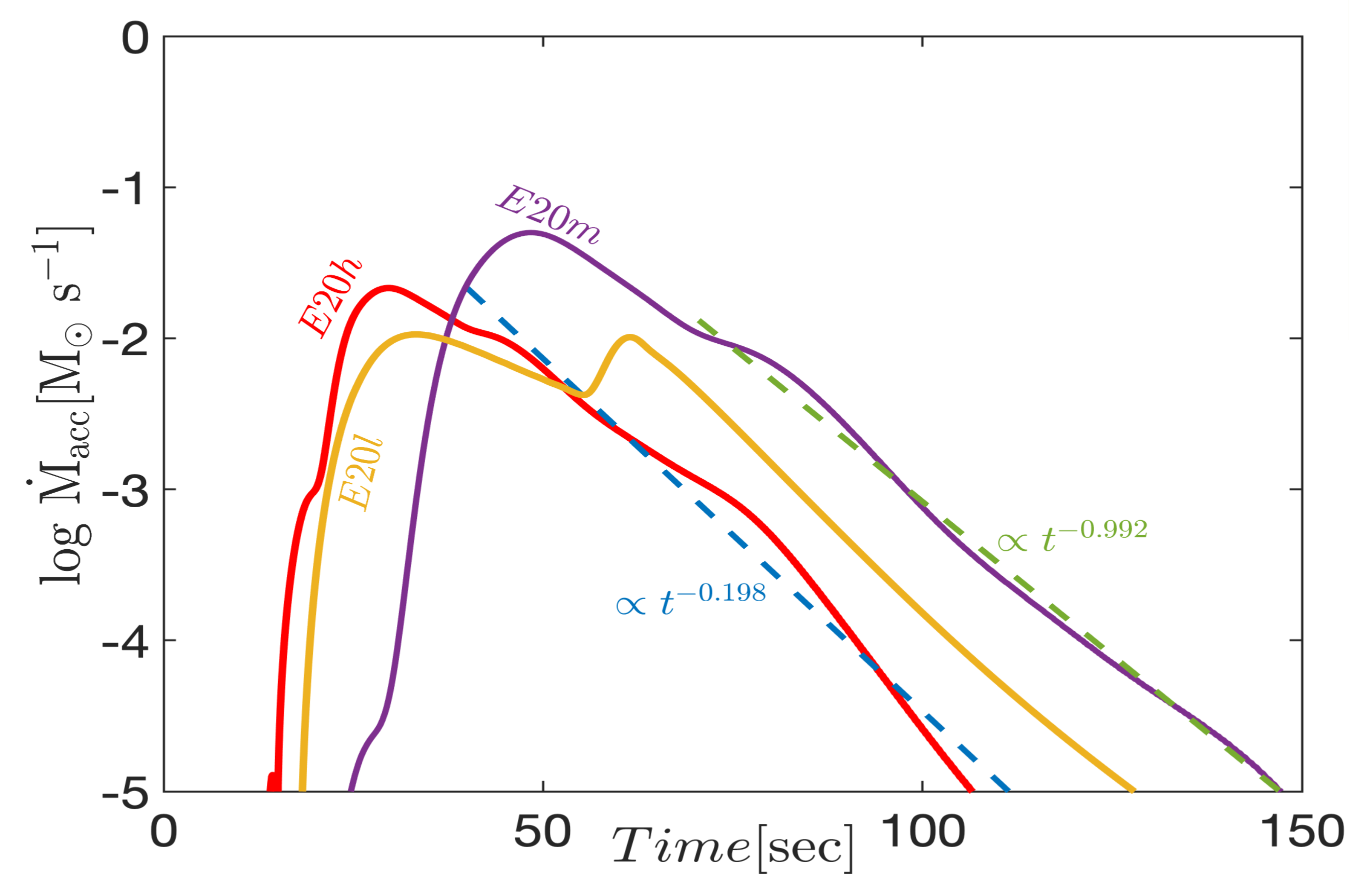
Collapsar disks with nuclear burning

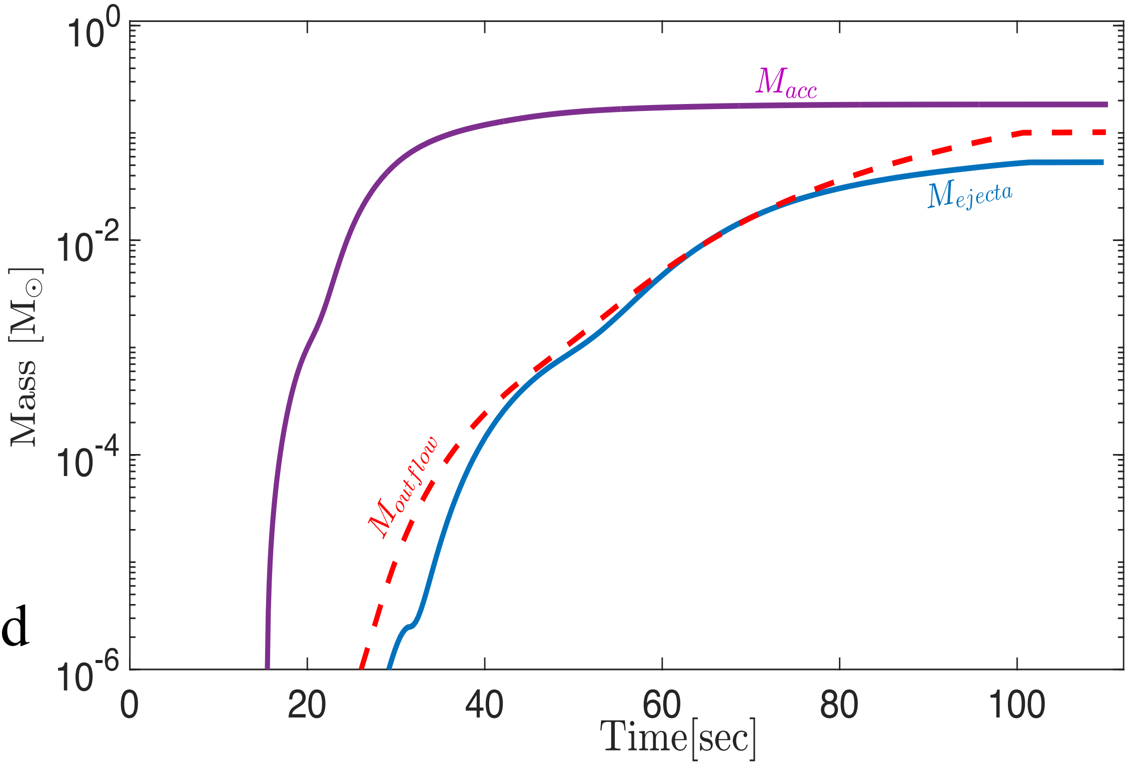


Three classes of collapsar accretion disks

- ‘Prompt’ detonation $\Leftrightarrow \lesssim t_{visc} \sim 100\ t_{orb}.$
- ‘delayed’ detonation $\Leftrightarrow \gtrsim (1 - few) t_{visc}.$
- ‘Non’ detonating disk $\Leftrightarrow$ *No detonation*

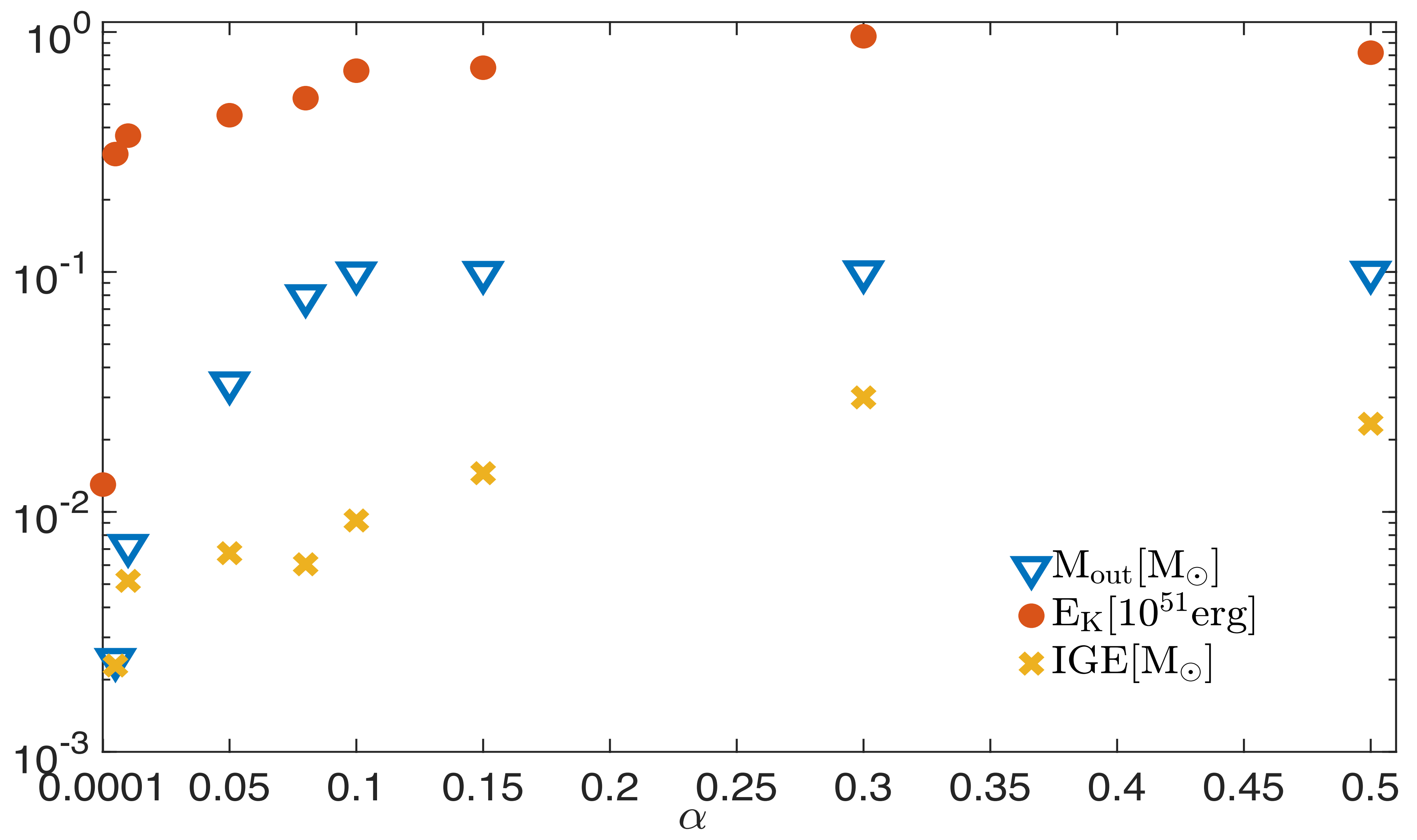
Accretion rate onto the black hole



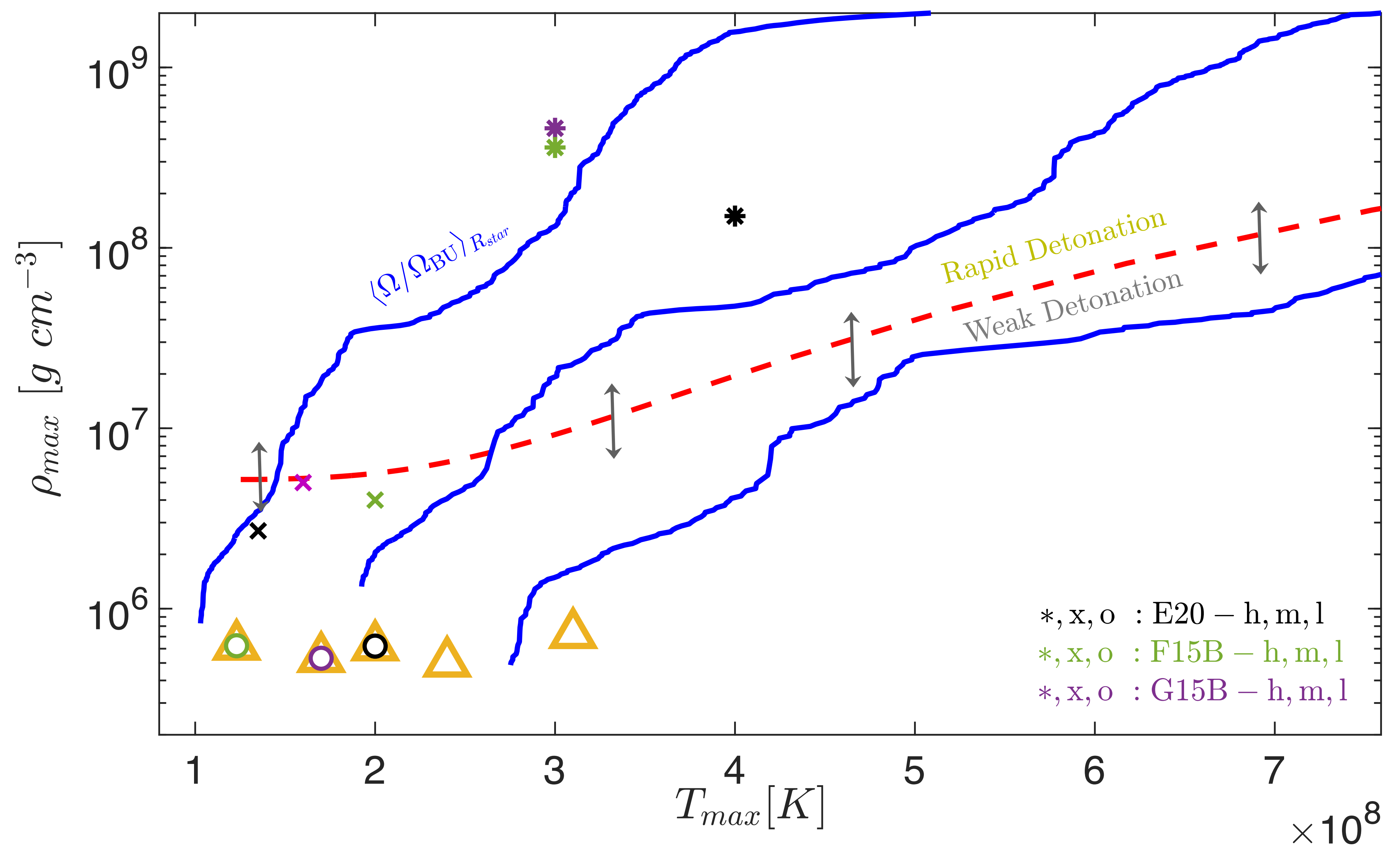


“Mout” -total mass in outflows , bound and unbound

Viscosity dependence

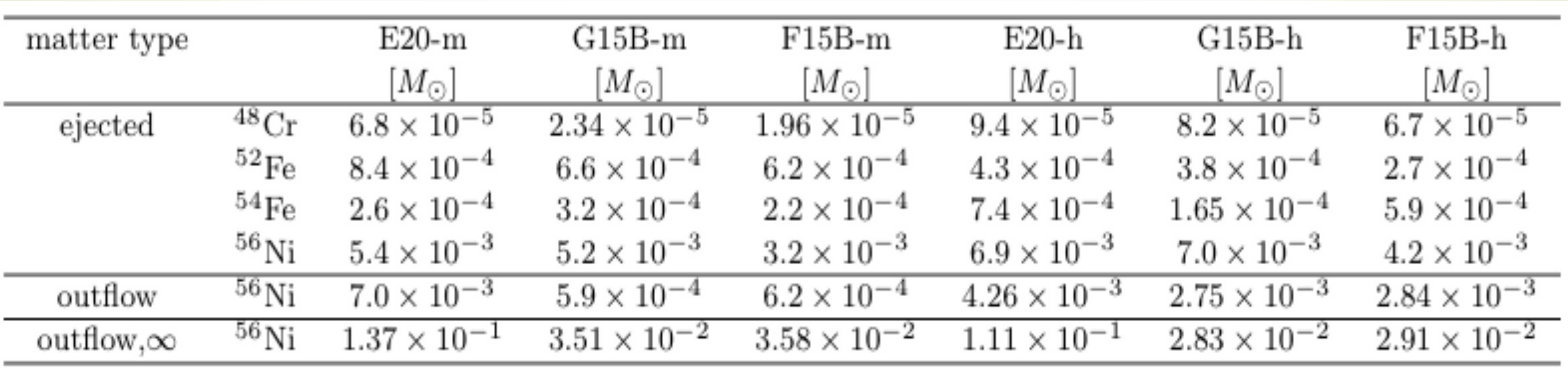


Universal detonation collapsar disk or not?



Nuc 2021

The Iron group ejecta from all the detonating accretion disk



matter type		E20-m $[M_\odot]$	G15B-m $[M_\odot]$	F15B-m $[M_\odot]$	E20-h $[M_\odot]$	G15B-h $[M_\odot]$	F15B-h $[M_\odot]$
ejected	^{48}Cr	6.8×10^{-5}	2.34×10^{-5}	1.96×10^{-5}	9.4×10^{-5}	8.2×10^{-5}	6.7×10^{-5}
	^{52}Fe	8.4×10^{-4}	6.6×10^{-4}	6.2×10^{-4}	4.3×10^{-4}	3.8×10^{-4}	2.7×10^{-4}
	^{54}Fe	2.6×10^{-4}	3.2×10^{-4}	2.2×10^{-4}	7.4×10^{-4}	1.65×10^{-4}	5.9×10^{-4}
	^{56}Ni	5.4×10^{-3}	5.2×10^{-3}	3.2×10^{-3}	6.9×10^{-3}	7.0×10^{-3}	4.2×10^{-3}
outflow	^{56}Ni	7.0×10^{-3}	5.9×10^{-4}	6.2×10^{-4}	4.26×10^{-3}	2.75×10^{-3}	2.84×10^{-3}
outflow,∞	^{56}Ni	1.37×10^{-1}	3.51×10^{-2}	3.58×10^{-2}	1.11×10^{-1}	2.83×10^{-2}	2.91×10^{-2}

"outflow,∞" - corrected for future accretion onto the BH

Summary

- The generation of 56_{Ni} in disk outflows, which may contribute to powering GRB supernovae.
- That's could provide the radioactive heating source necessary to make the spectral signatures of *r-process* elements visible in late-time GRB-SNe spectra.
- The "viscously-evolving isolated torus" proposed to explain unexpected behavior of some GRB X-ray afterglows.