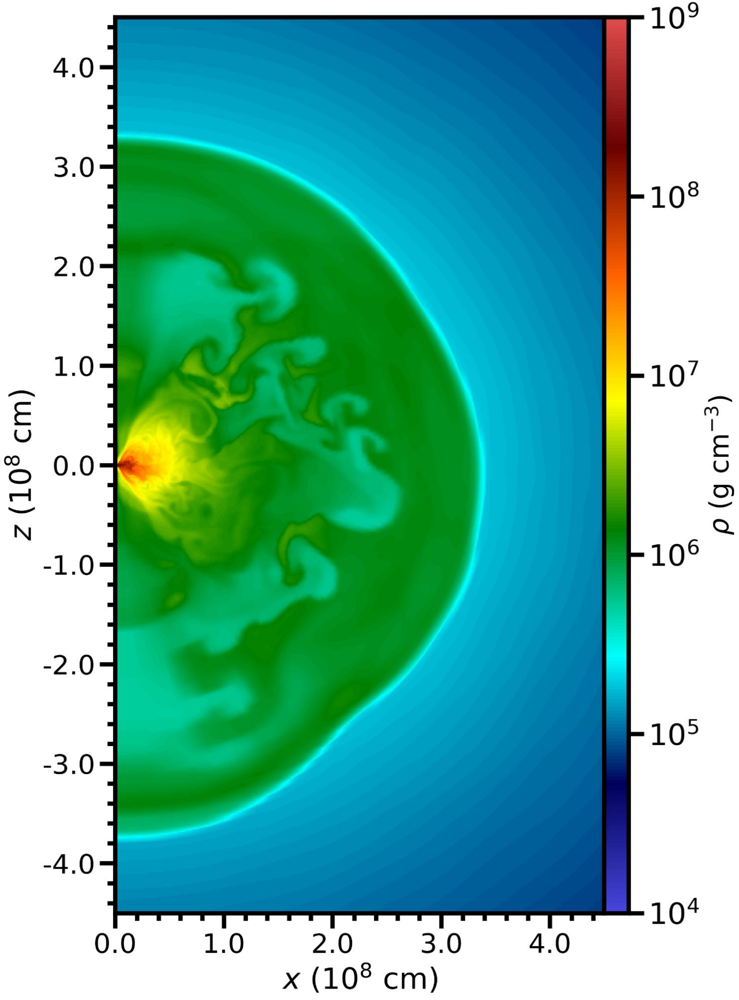
Dynamics of Collapsar Disk Outflows

Coleman Dean and
Rodrigo Fernández

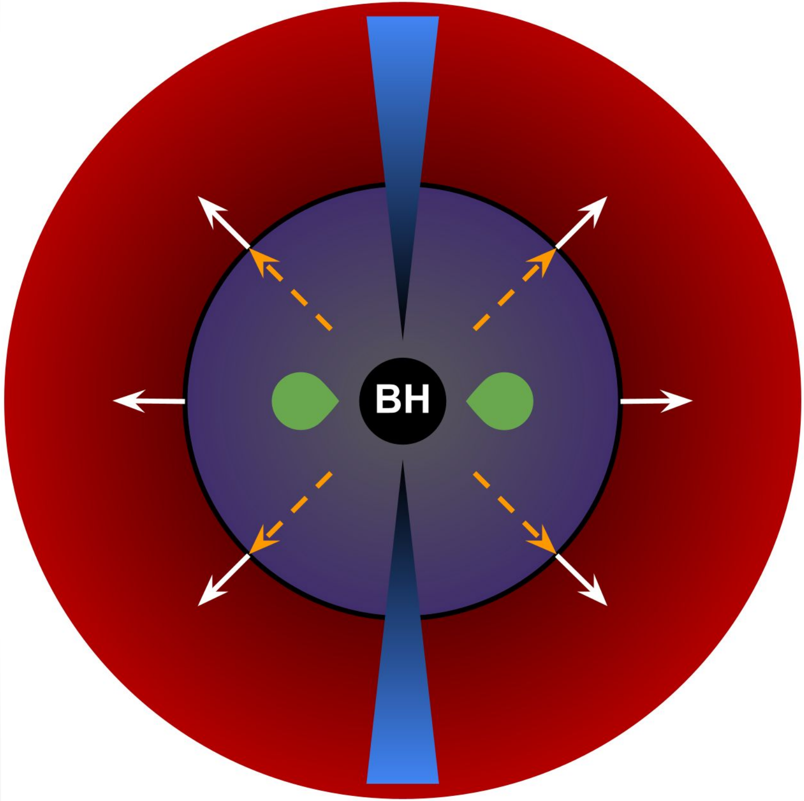


Collapsars: Rotating Core Collapse Supernovae

Wolf-Rayet progenitor
(low metallicity)

Core collapse

Central black hole - accretion disk system



Motivation

Binary neutron star merger: $t_{delay} \sim 100$ Myr

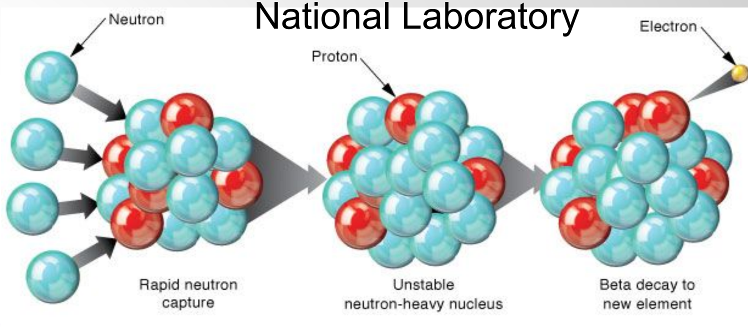
Collapsar: $t_{delay} \sim 1$ Myr

Short timescale heavy element production (Mathews and Cowen 1990)

http://imagine.gsfc.nasa.gov/docs/features/news/10sep08.html

Heavy Element Production

Lawrence Livermore
National Laboratory



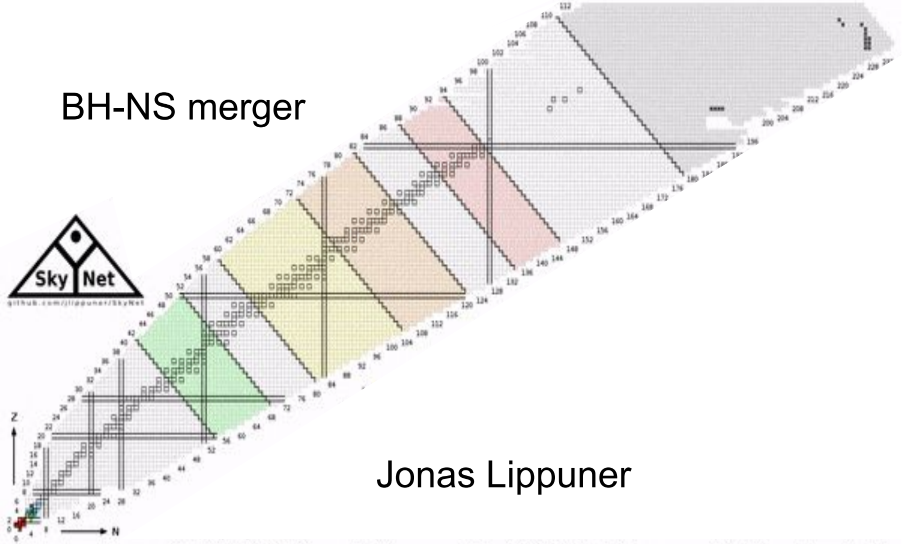
Rapid neutron capture process (r-process)

(~½ of elements heavier than iron)

$Y_e < 0.25$

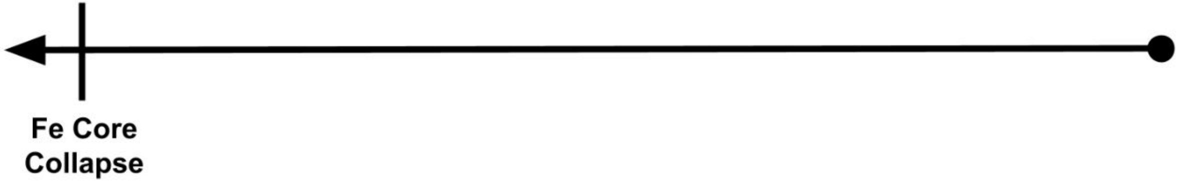
Neutronization

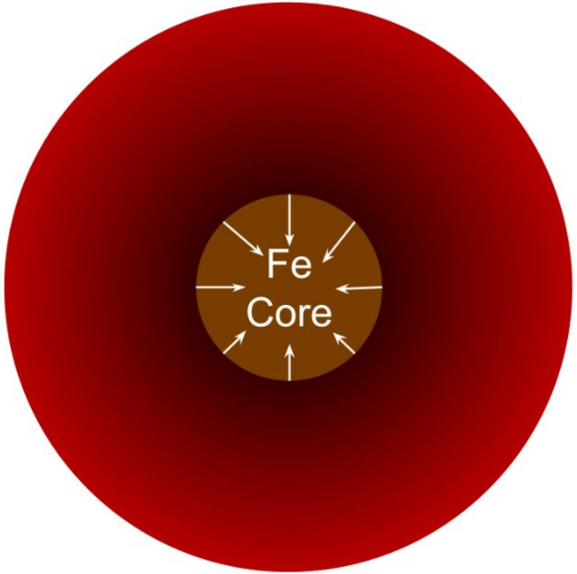
BH-NS merger



Jonas Lippuner

Failed Core Collapse Supernova





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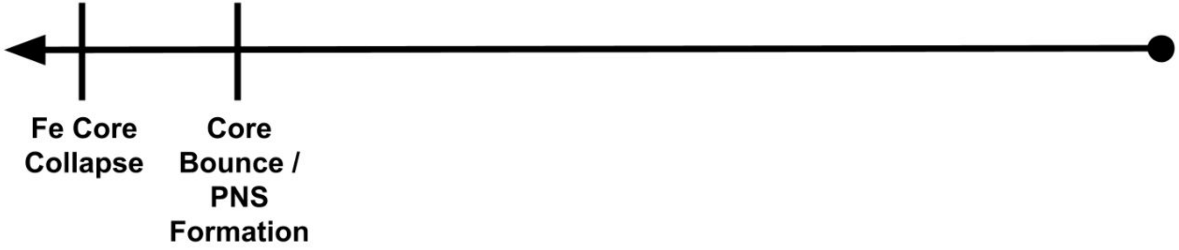

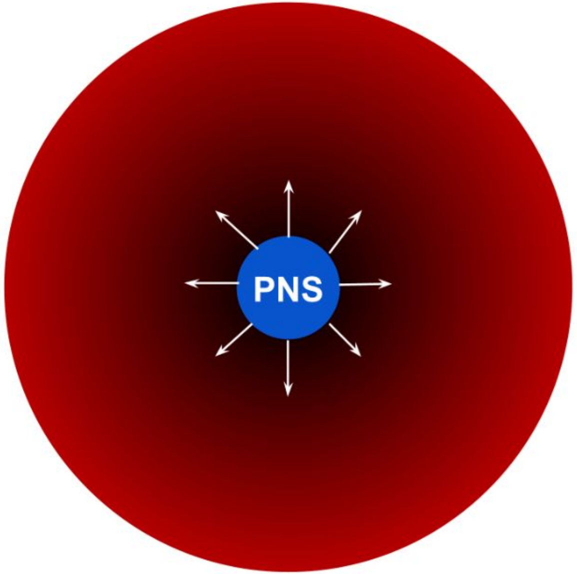

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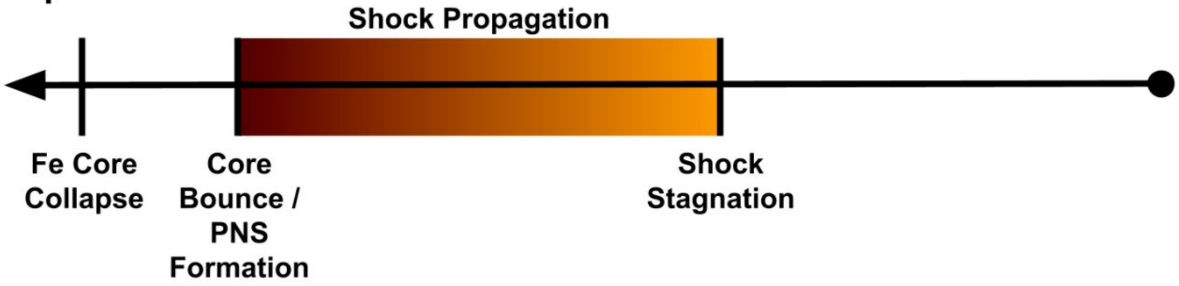

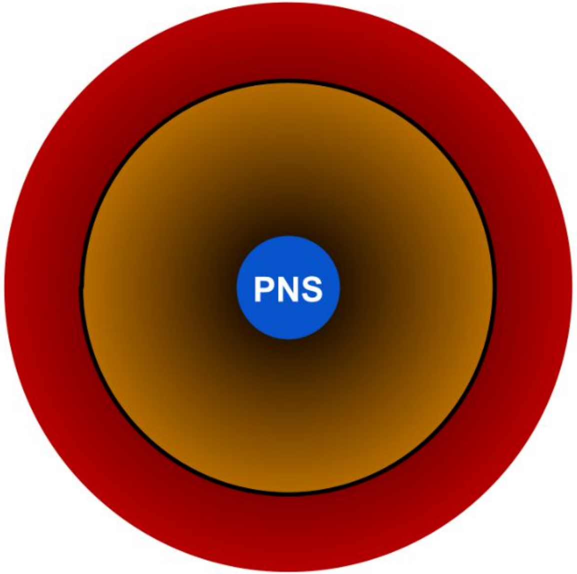

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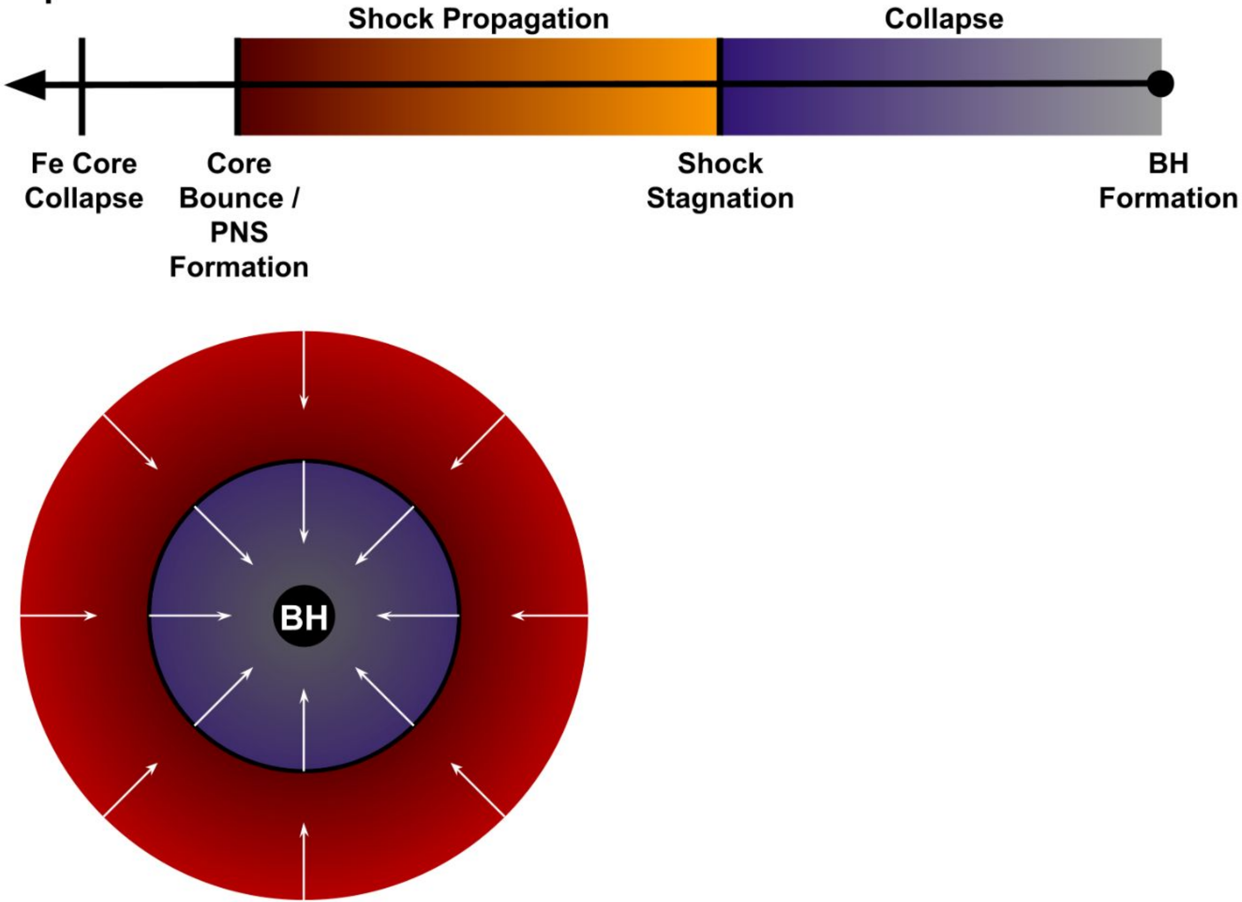
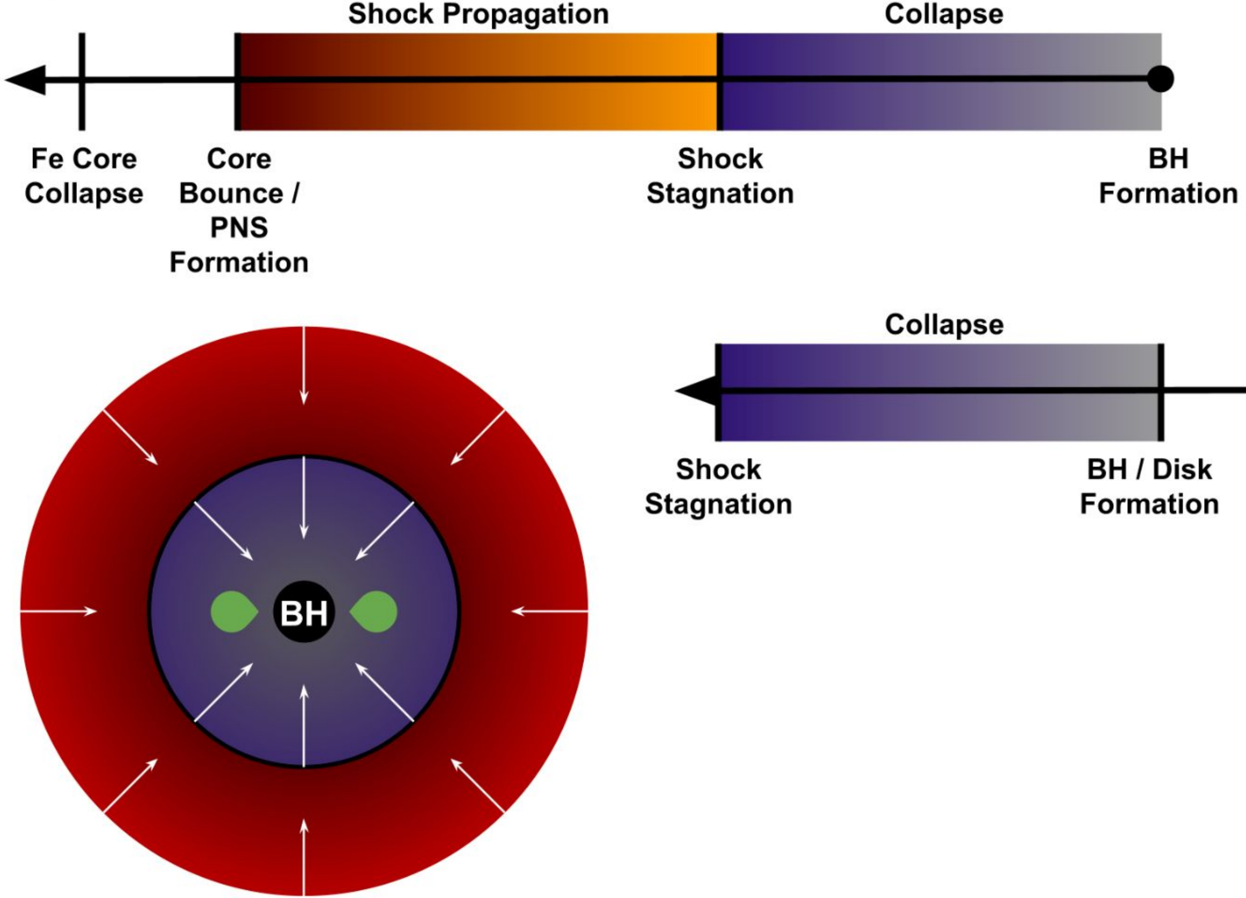


~~Failed Core Collapse Supernova~~ Collapsar



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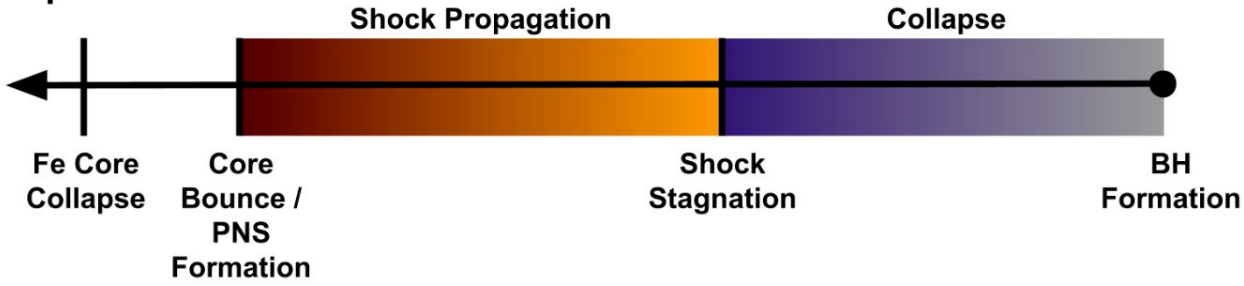

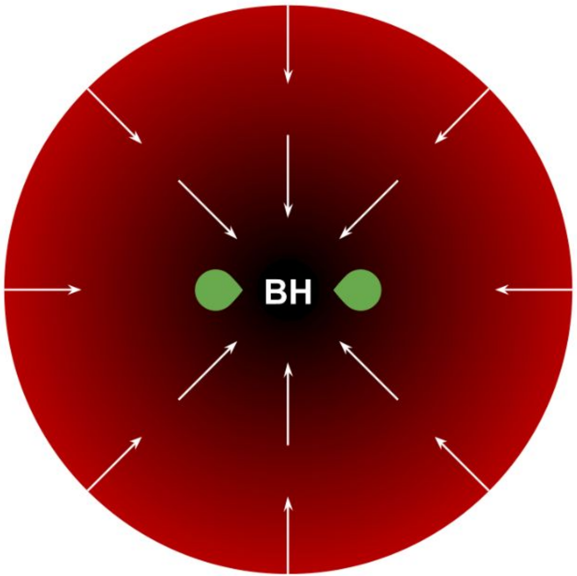

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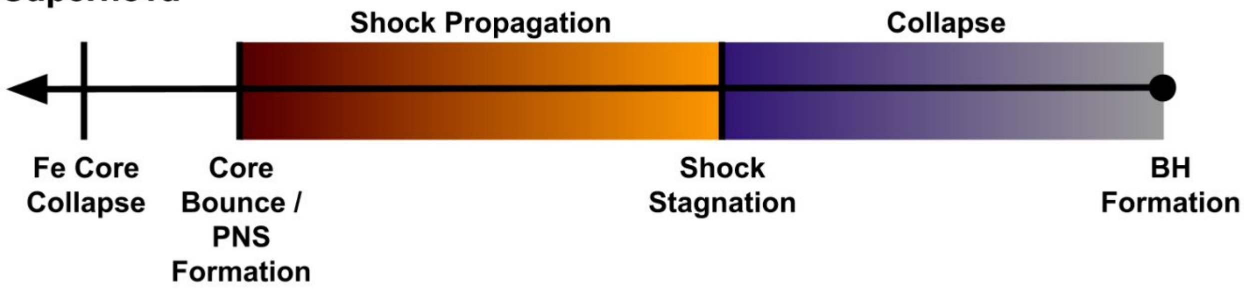
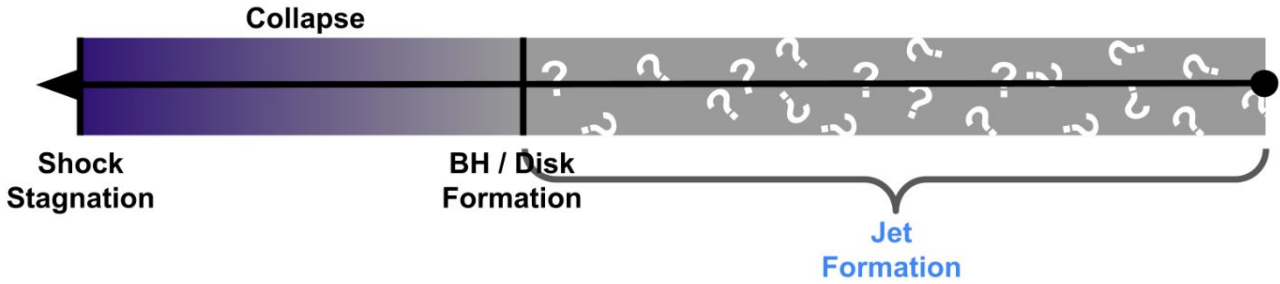
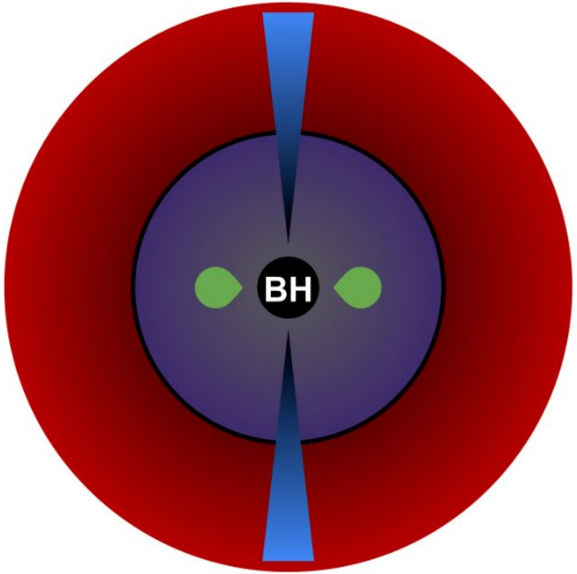
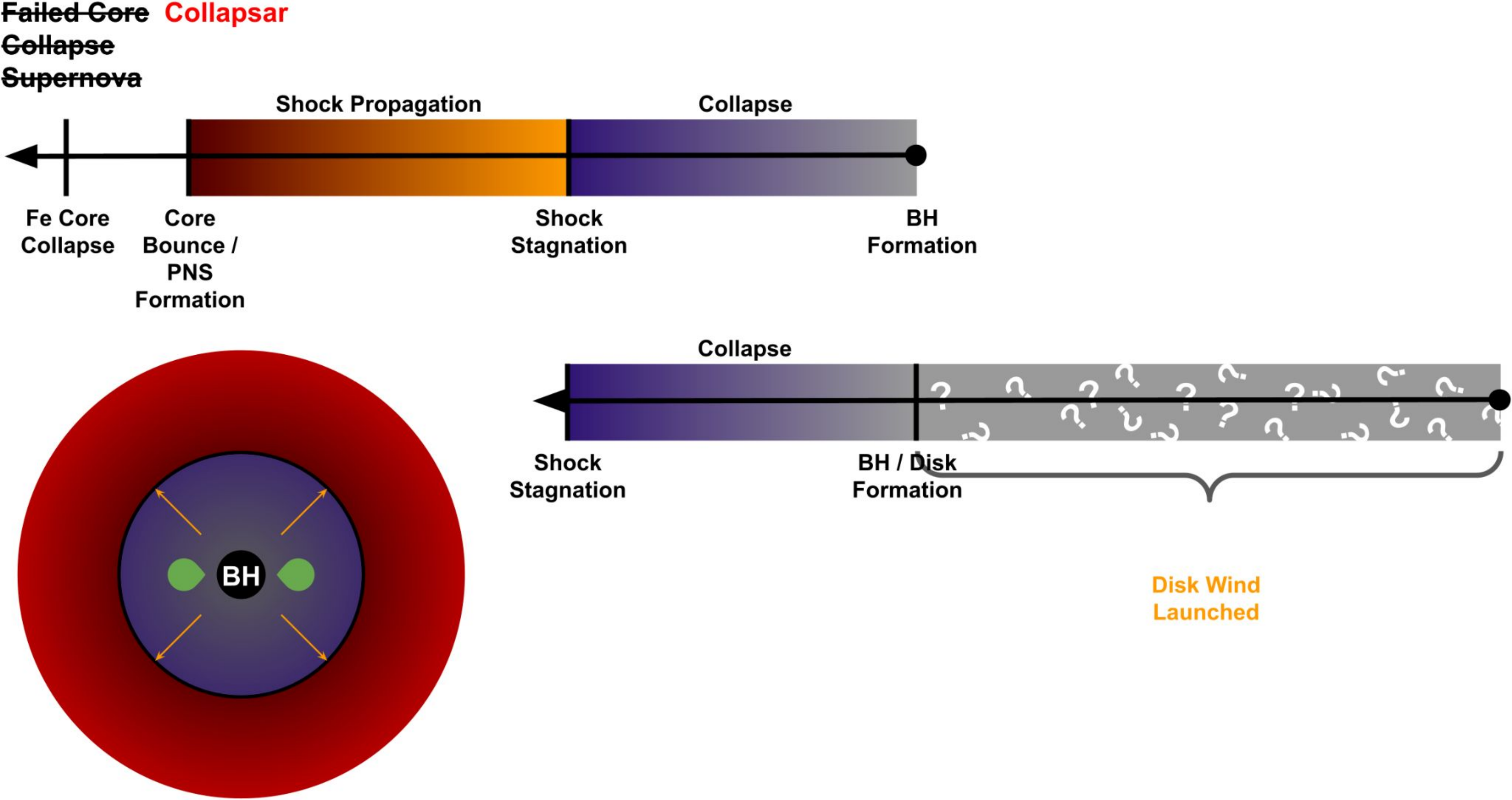


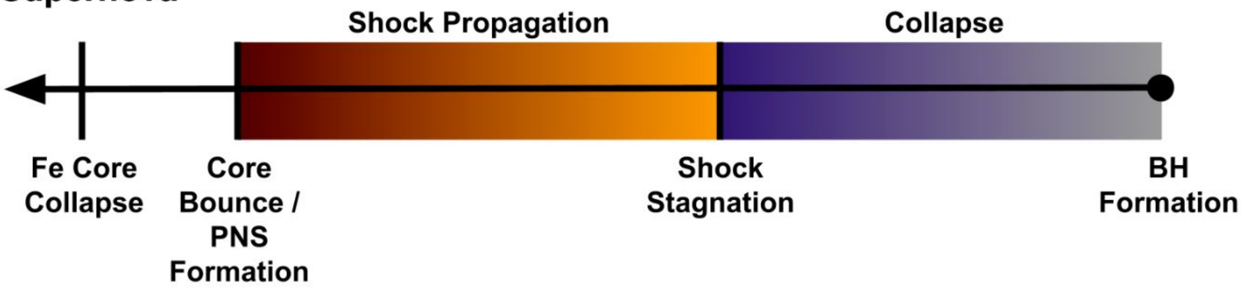


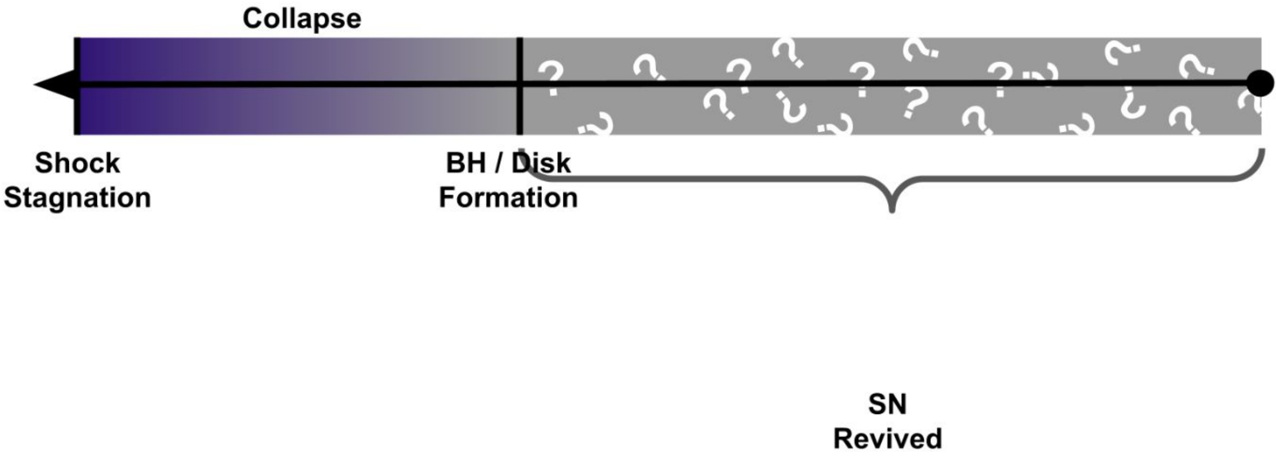


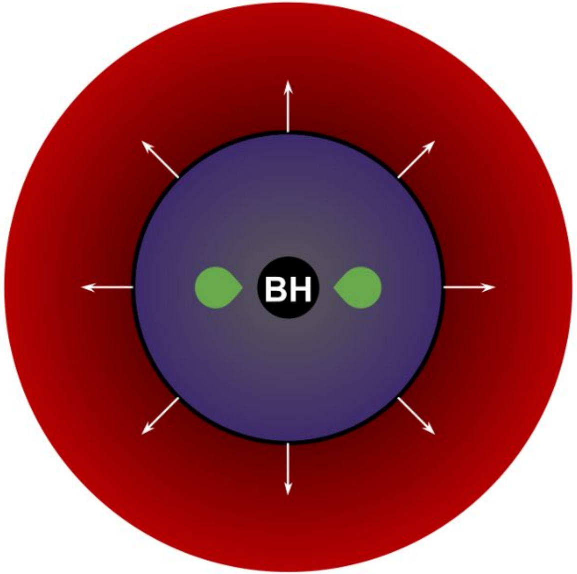


Failed Core Collapse Supernova
Collapsar
Shock Propagation
Collapse
Fe Core Collapse
Core Bounce / PNS Formation
Shock Stagnation
BH Formation
Collapse
Shock Stagnation
BH / Disk Formation
Disk Wind Launched
BH

~~Failed Core Collapse Supernova~~ Collapsar







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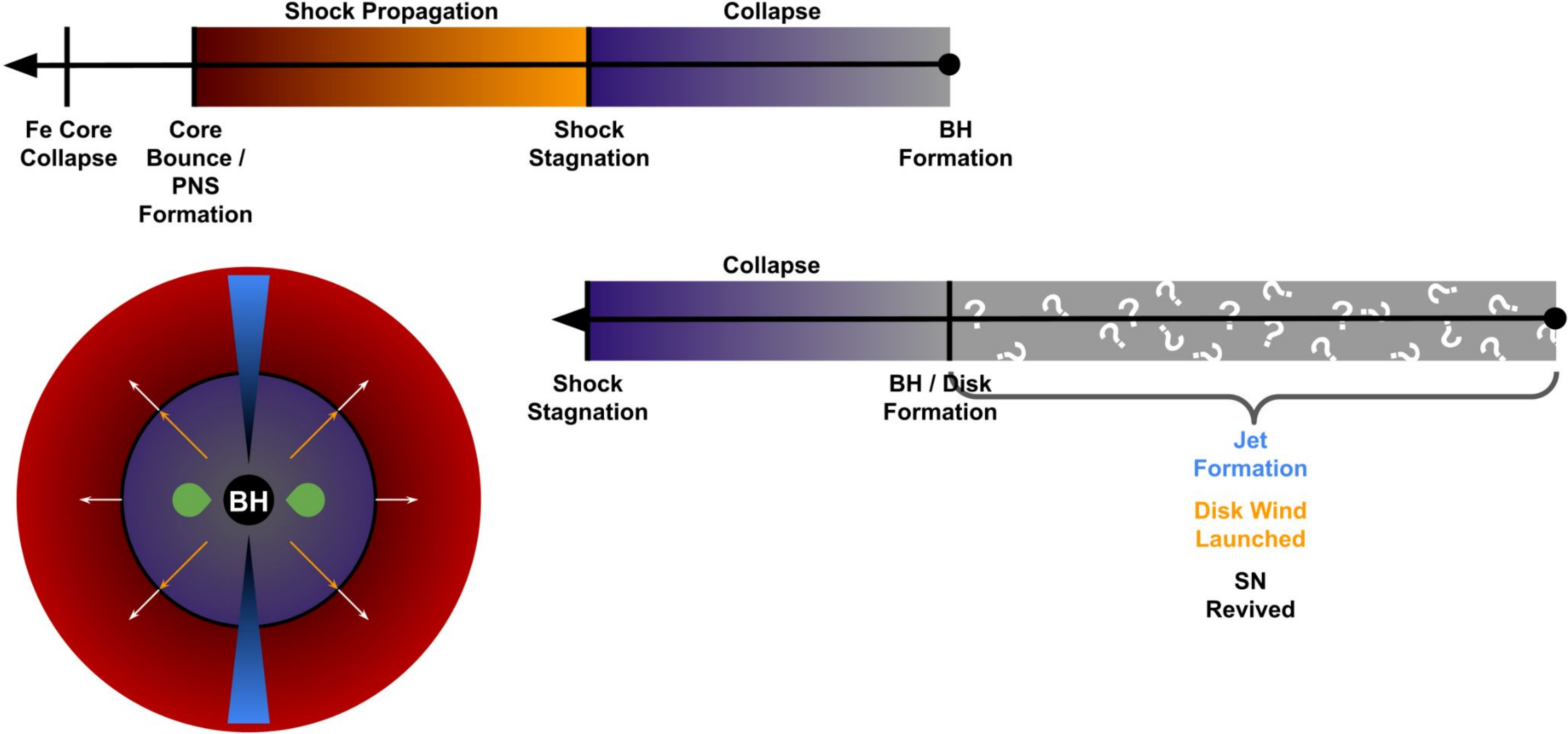


Computational Challenge

Large range of spatial and temporal scales

Magnetic effects

(turbulence, heating of disk)

Neutrino effects

(neutronization, r-process)

General relativistic effects

(potential around BH)

$t_{orb,isco}$	~10 ms
$t_{shock\ breakout}$	~100 s
r_{ISCO}	~10^6 cm
$R_{progenitor}$	~10^{11} cm

Our Model

Long term disk outflow simulations (no relativistic jet)

Low computational cost

Explore:

- progenitor stars
- r-process viability
- disk wind as a means of driving a shock
- Angular momentum distribution

Model	M_{ZAMS} ($M_\odot$)	M_{CC} ($M_\odot$)	Z ($Z_\odot$)
16TI	16	13.95	0.01
35OC	35	28.07	0.1

Our Model

Two-dimensional Hydrodynamics (Helmholtz EOS)

Log radial grid - cos θ grid

Newtonian multipole self-gravity + Artemova (L = 0)

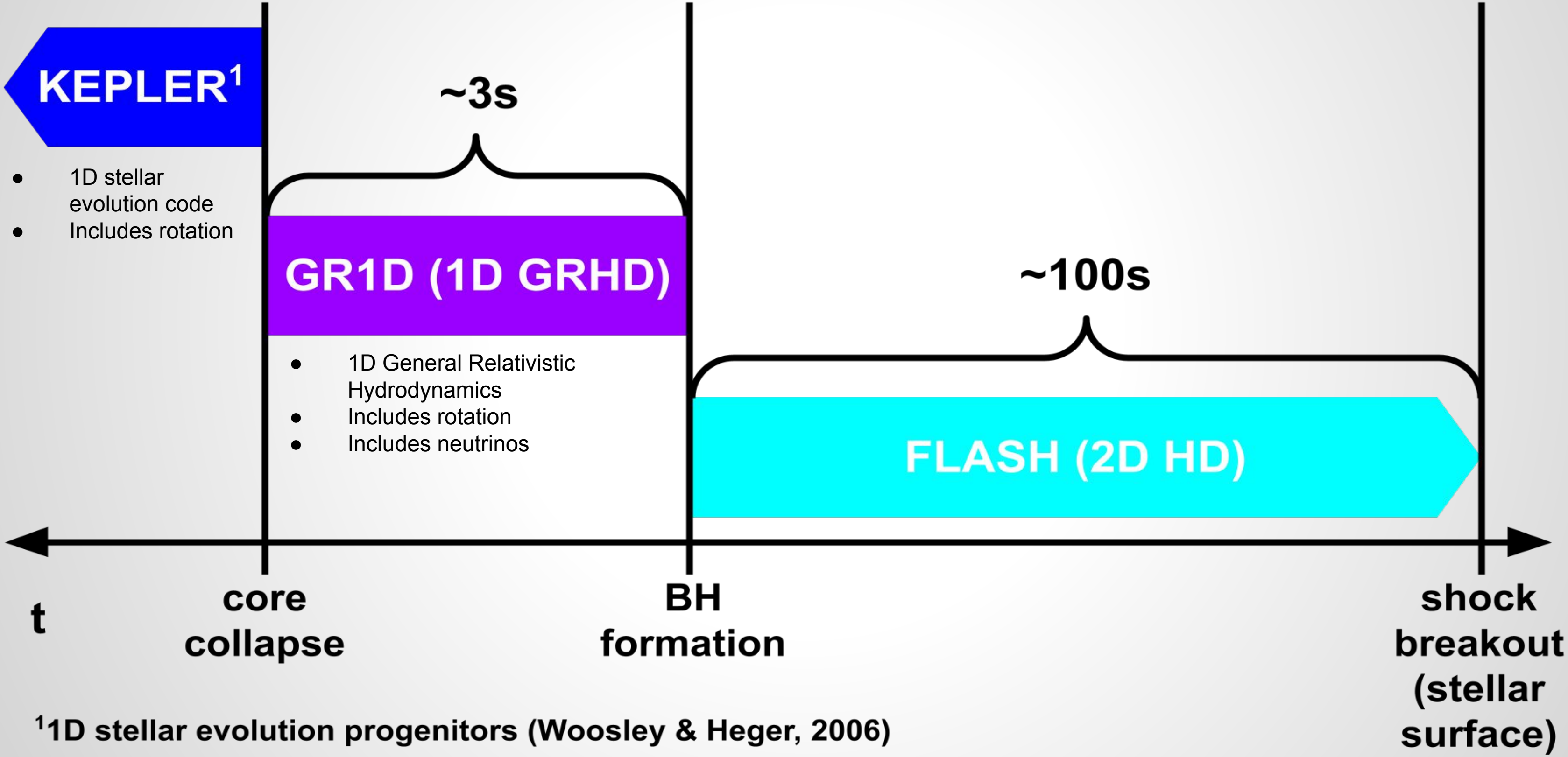
∝-viscosity (turbulence → heating in the disk)

(Shakura & Sunyaev 1973)

3 species neutrino leakage (annular lightbulb) + absorption

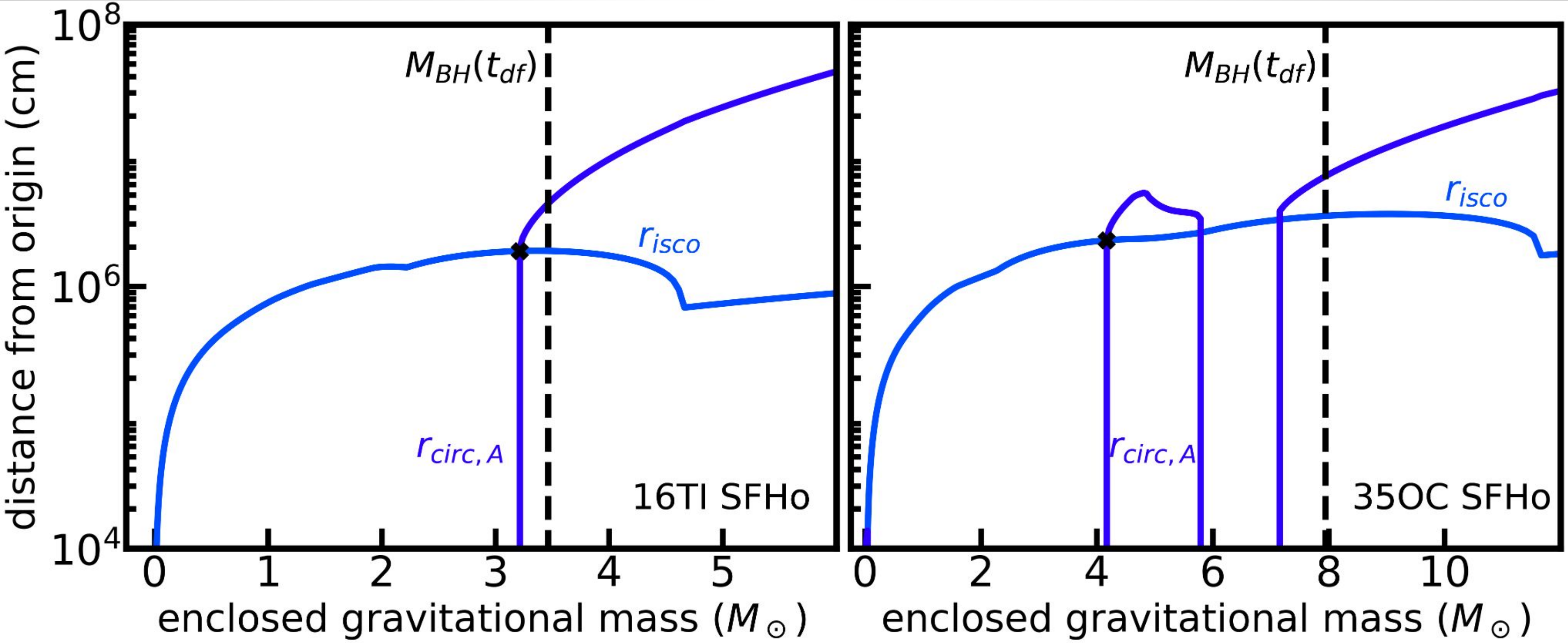
19 isotope nuclear network + Nuclear Statistical Equilibrium solver

Our Model



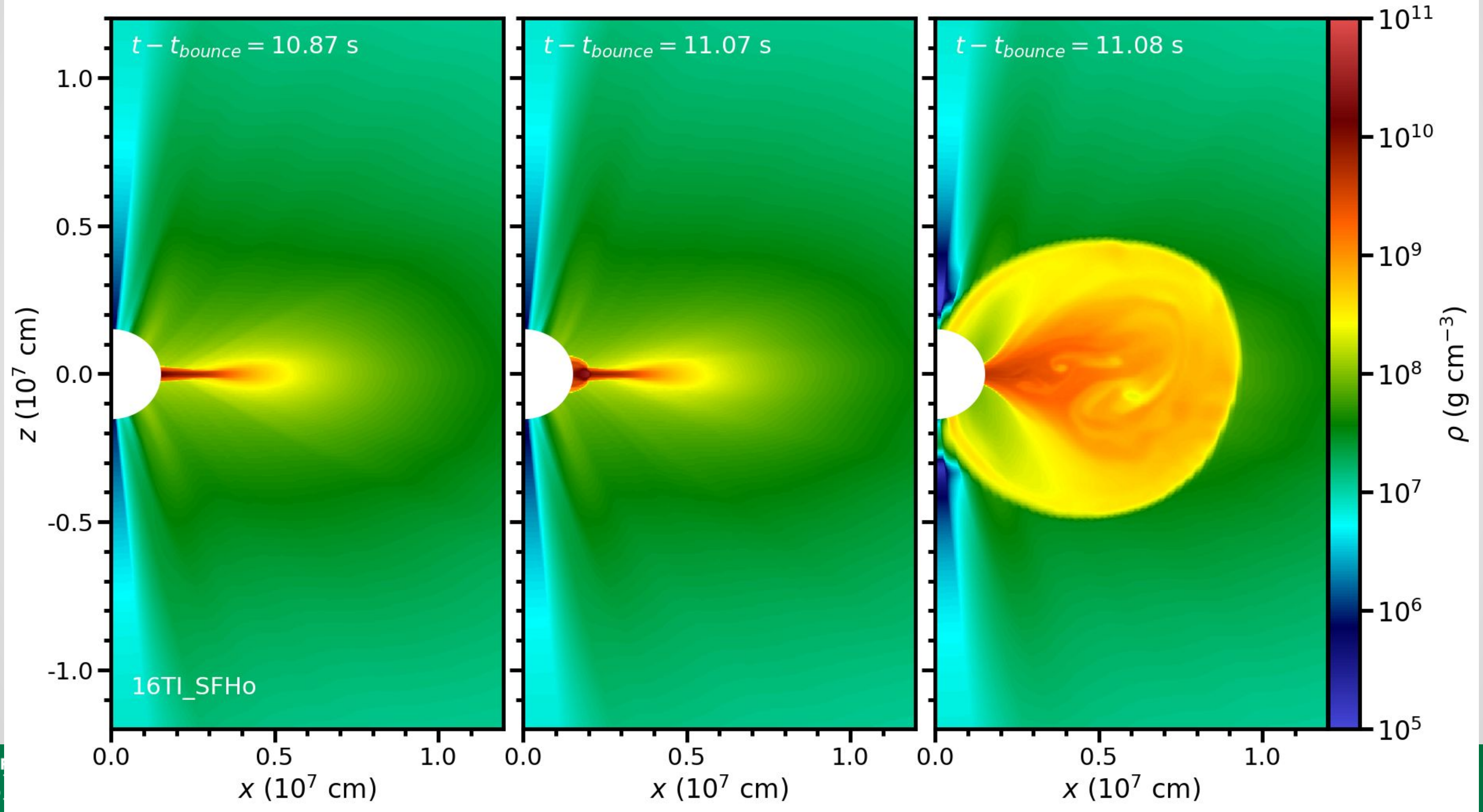
[1]1D stellar evolution progenitors (Woosley & Heger, 2006)

Predicting accretion disk formation



As discussed in Beloborodov & Illarionov 2001

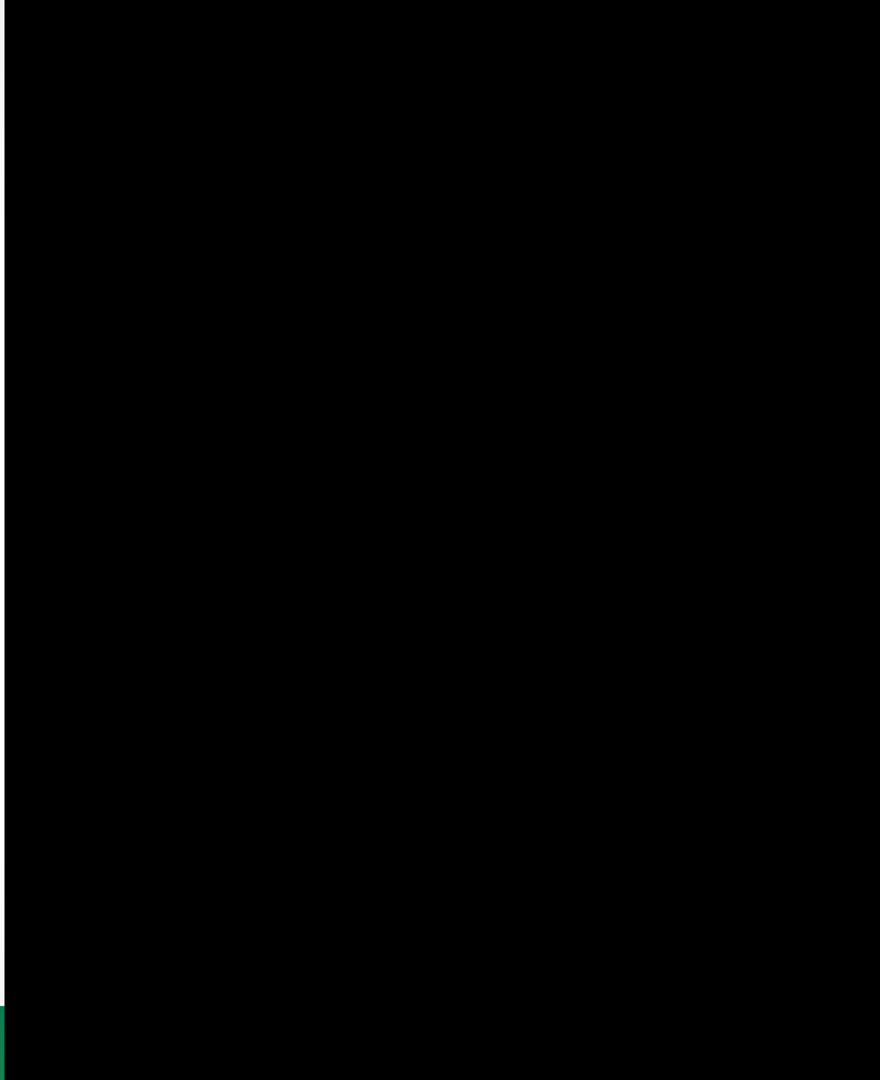
“Dwarf Disk” Formation



Density colour-plot

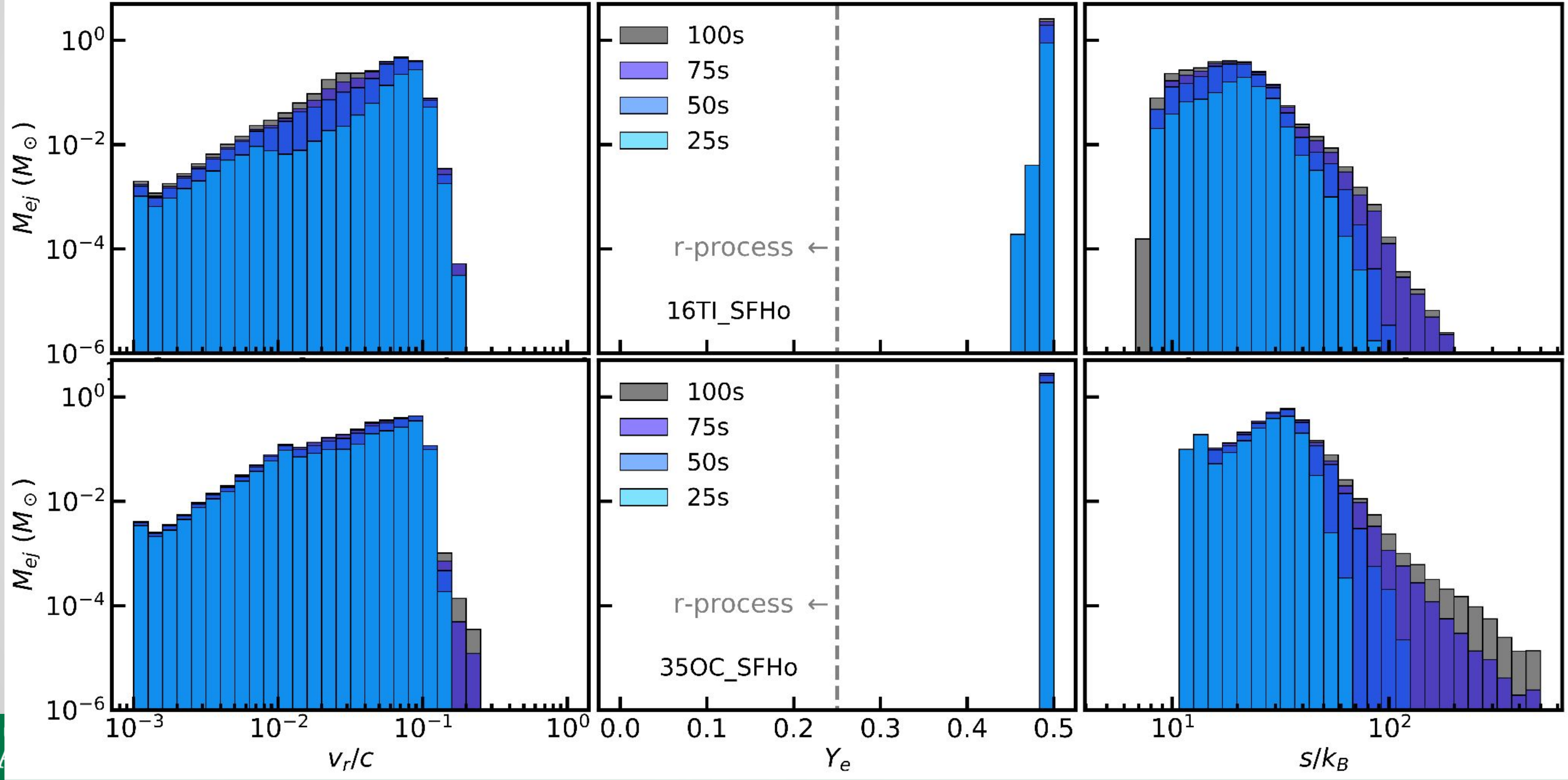
16TI progenitor star (Woosley & Heger 2006)

Shock breaks out at $t_{sb} \sim 116$ s



Mass Tracking

$$r_{\rm ej} = 10^9\ {\rm cm}$$



Electron Fraction

Orange represents $Y_e < 0.25$

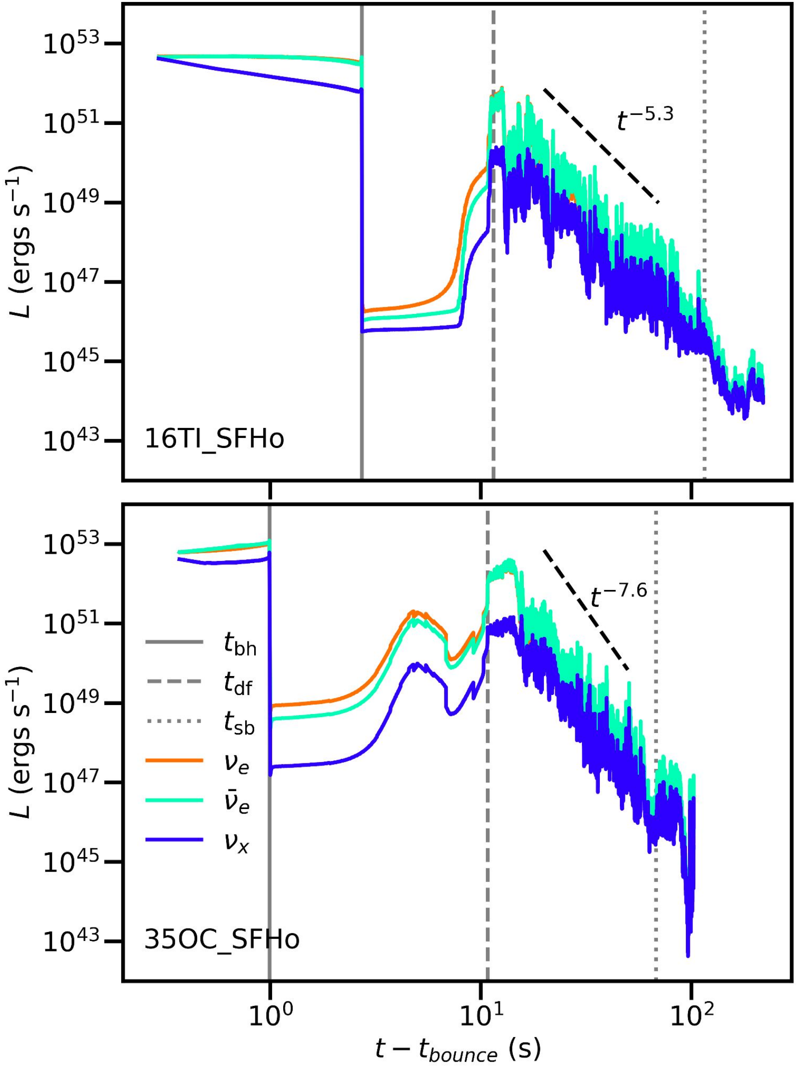
Fed by $Y_e = 0.5$ material

Density contours

Neutrino Luminosity

Delay time measures angular momentum distribution

Height of second peak depends on M/R, accretion rate

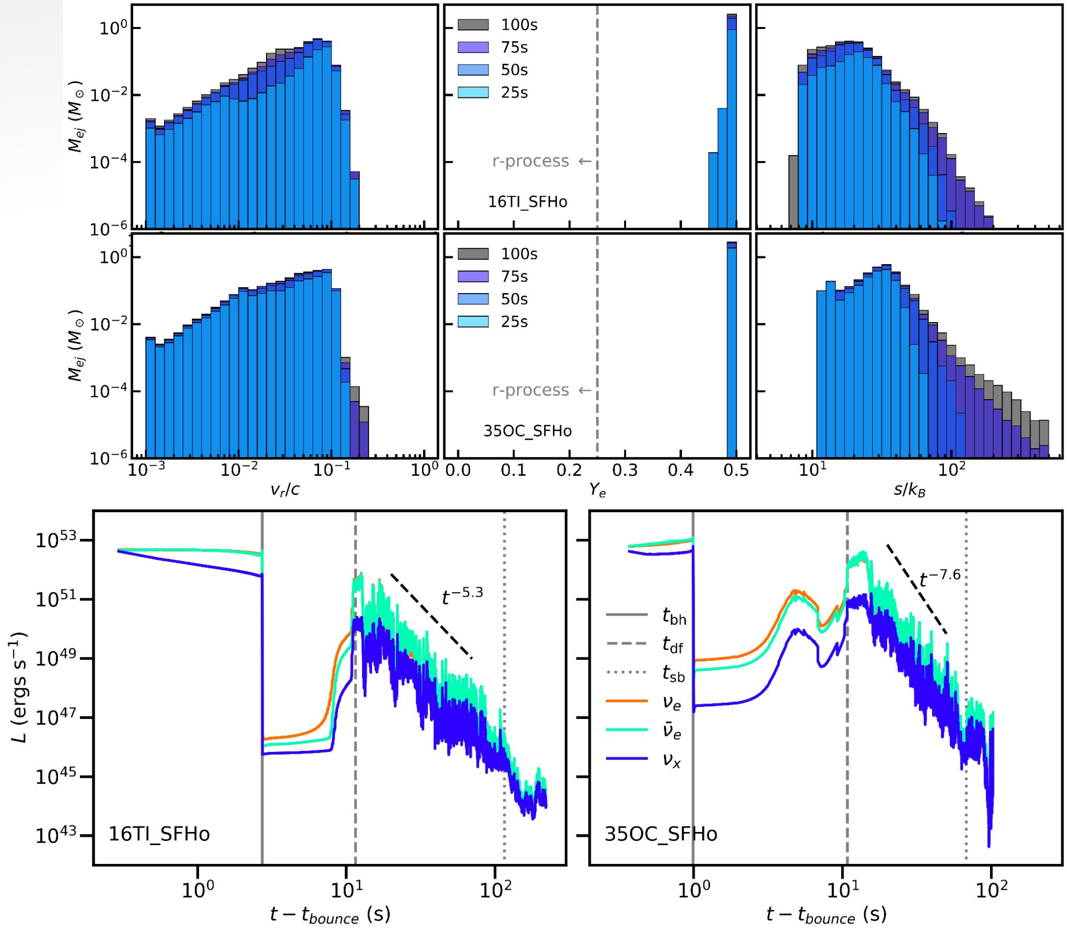


Conclusion

Insufficient neutronization in the disk wind

Neutrino Luminosity delay time diagnostic of angular momentum profile

Disk wind leads to shock breakout from the star



Extra Slides

CCSNe as r-process source

Early GCE simulations of Eu suggest CCSNe necessary to explain low metallicity halo stars Eu abundance (i.e. Mathews and Cowen 1990)

Significant scatter in Eu abundances (i.e. McWilliam et al. 1995)

Hierarchical galaxy merger / low star formation efficiency might explain Eu abundances on BNS timescales (i.e. Ishimaru et al. 2015)

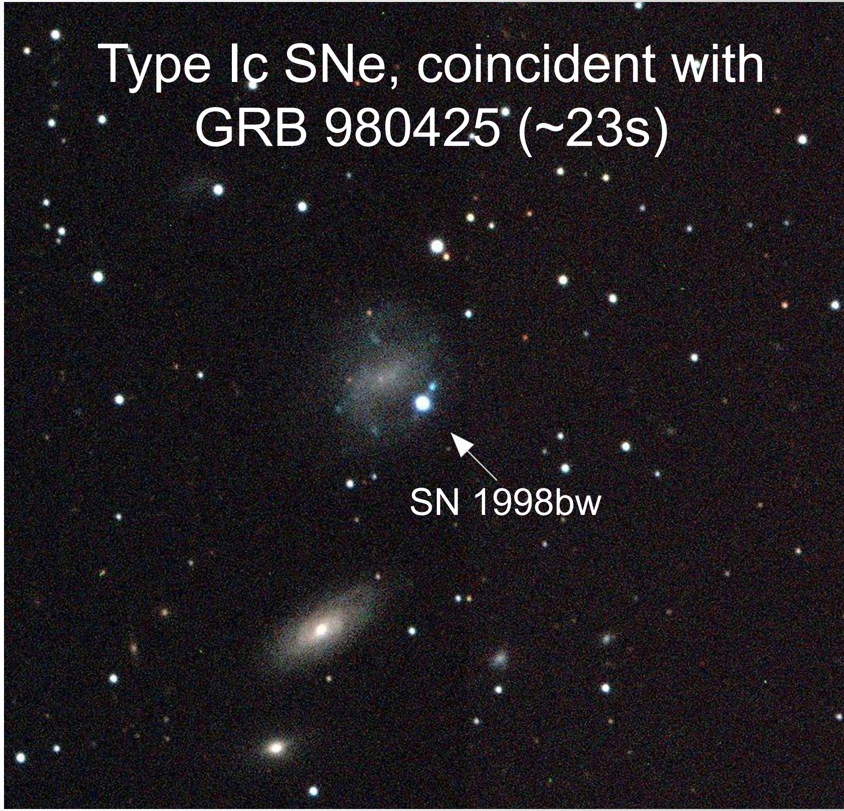
Type Ic SNe

No hydrogen lines

Weak/no helium lines

Core collapse of a stripped star such as a wolf-rayet star

Some coincident with long GRBs



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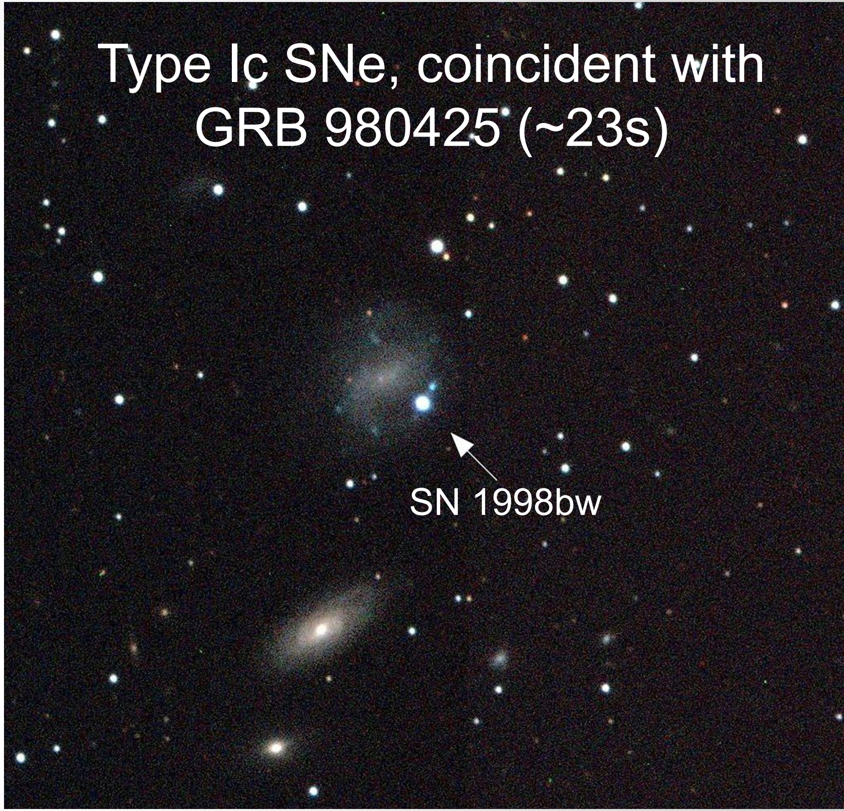
GRB Progenitors

lGRB's ($\gtrsim$ 2s)

- Near Star Formation
- Death of massive stars
- Long duration GRB "engine"

Collapsars as a progenitor?

- 11 GRB-SNe (Modjaz et al. 2016)



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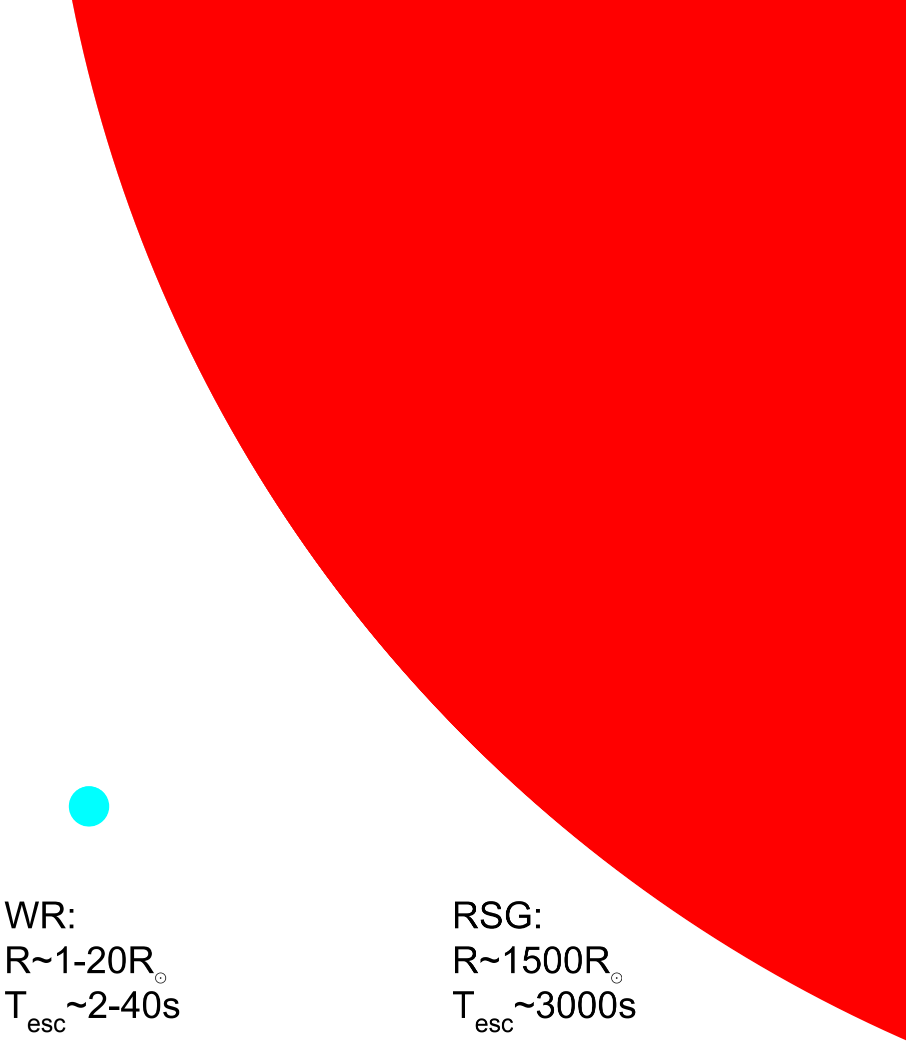
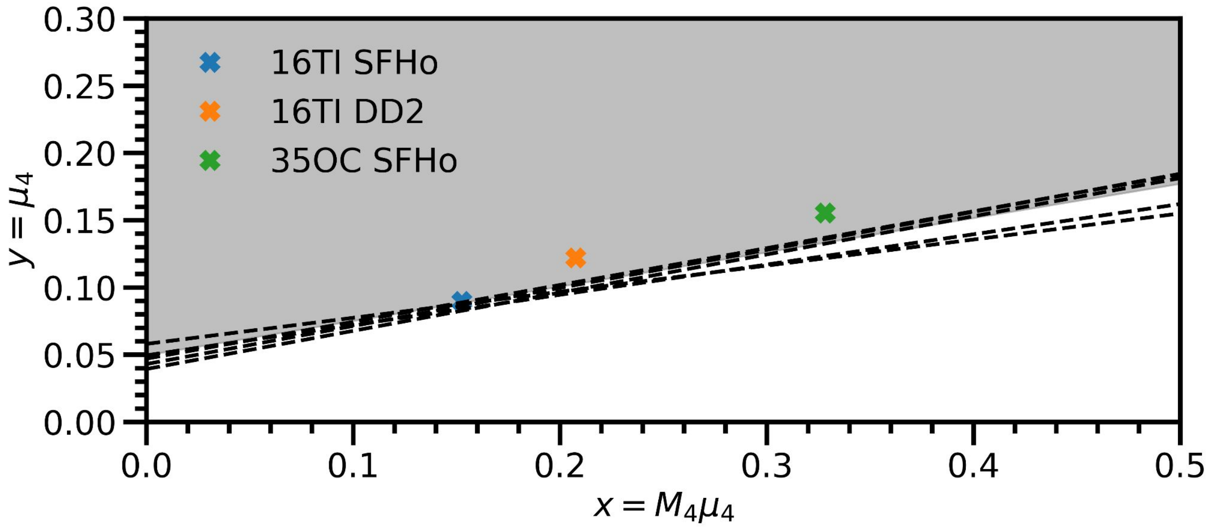
Progenitor Length Scale



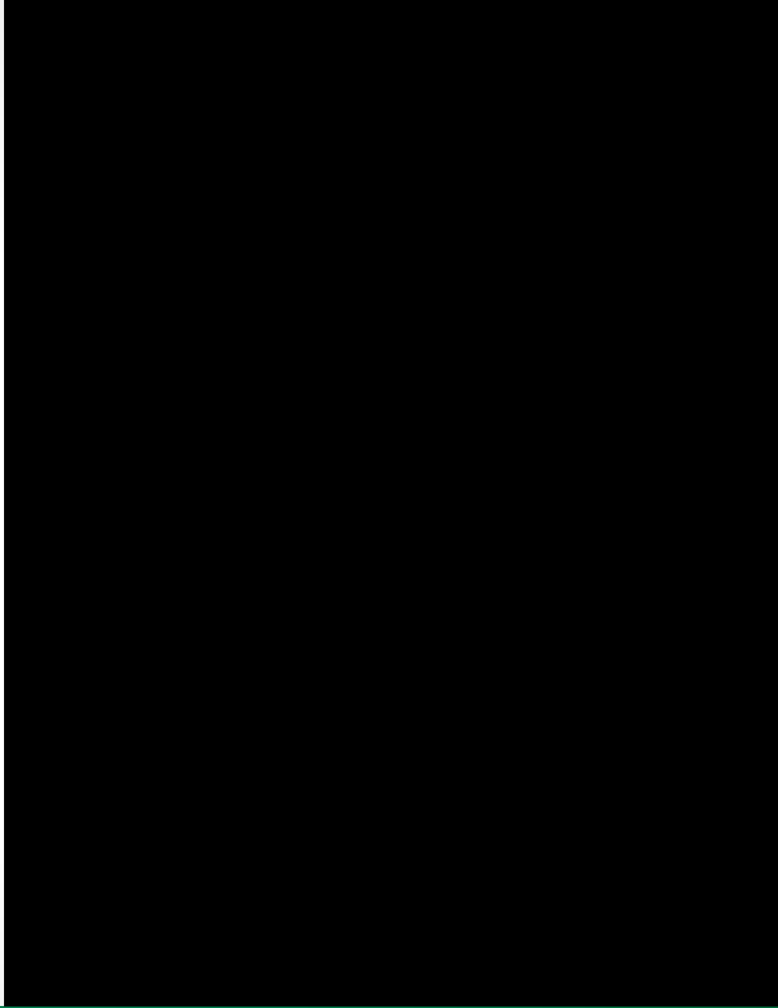
Two parameter explosion criteria

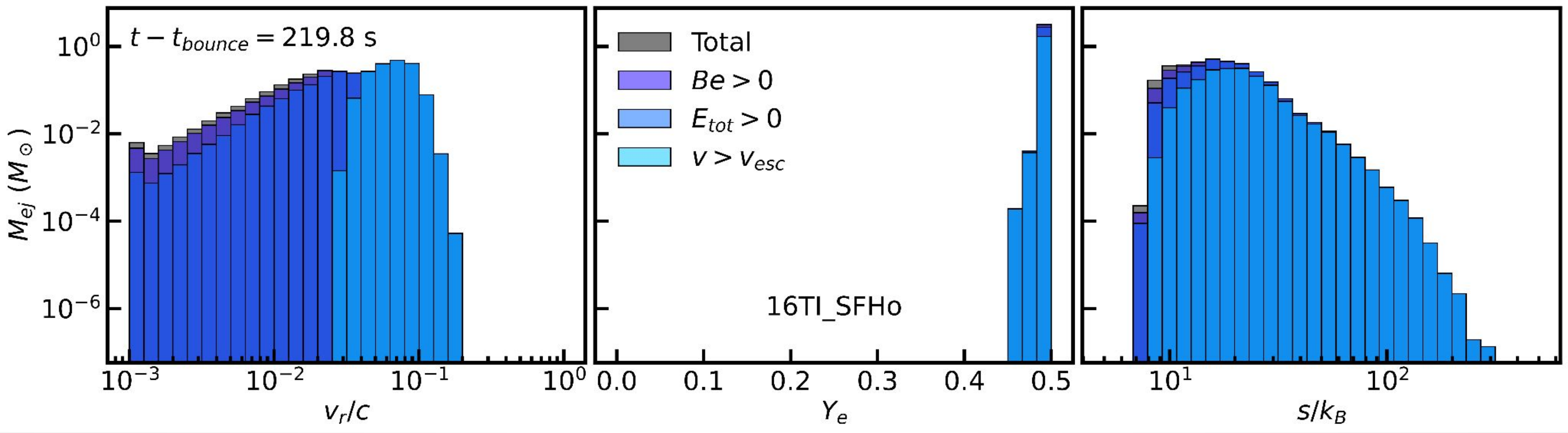
Ertl et al. 2016



35OC_SFHo

Density colour-plot





$t - t_{bounce} = 219.8$ s
10^0
10^{-2}
10^{-4}
10^{-6}
M_{ej} ($M_\odot$)
10^{-3}
10^{-2}
10^{-1}
10^0
v_r/c
Total
$Be > 0$
$E_{tot} > 0$
$v > v_{esc}$
16TI_SFHo
0.0
0.1
0.2
0.3
0.4
0.5
Y_e
10^1
10^2
s/k_B