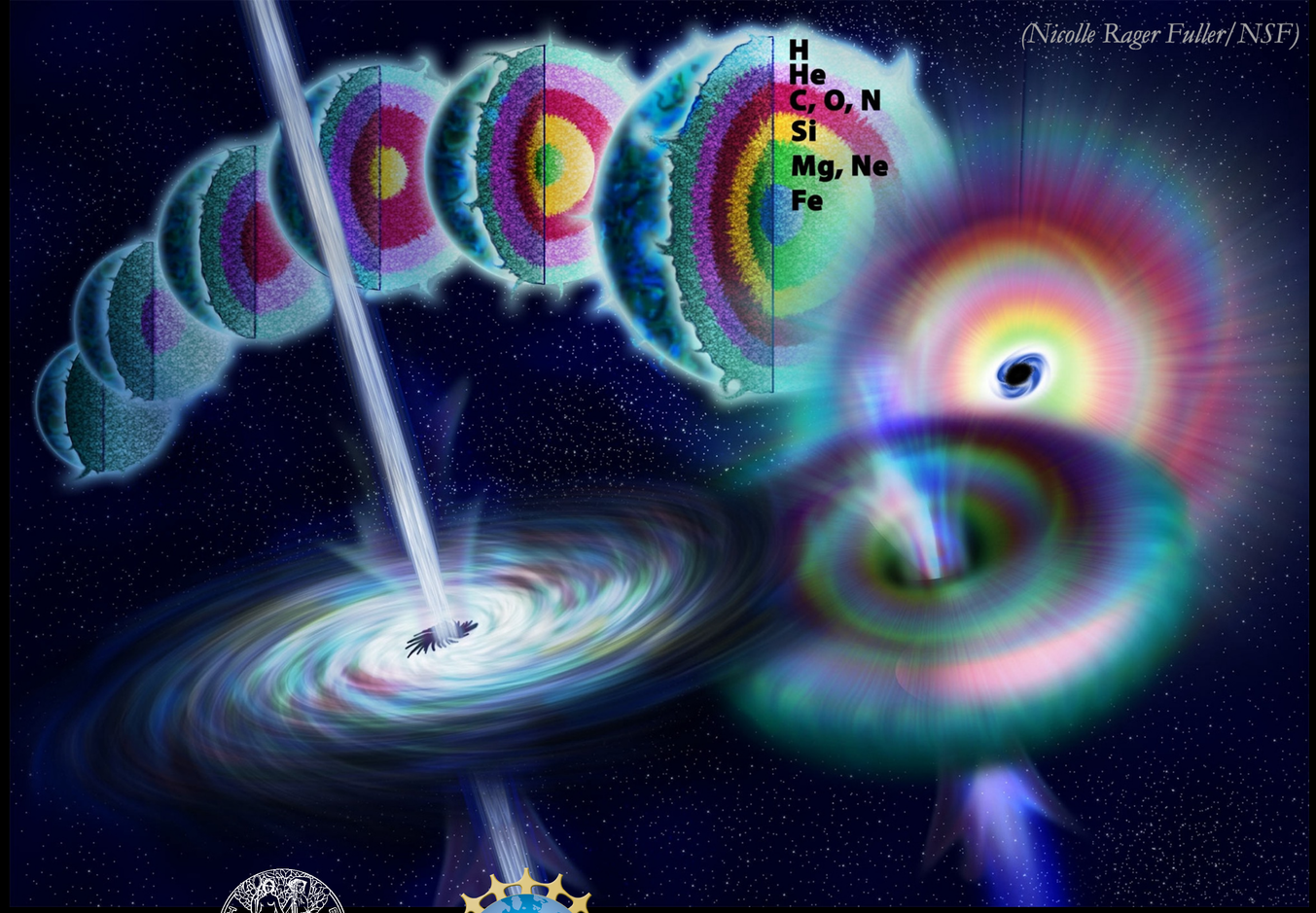
the stellar progenitors of long-duration gamma ray bursts



(Nicolle Rager Fuller/NSF)

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INSTITUTE FOR ADVANCED STUDY

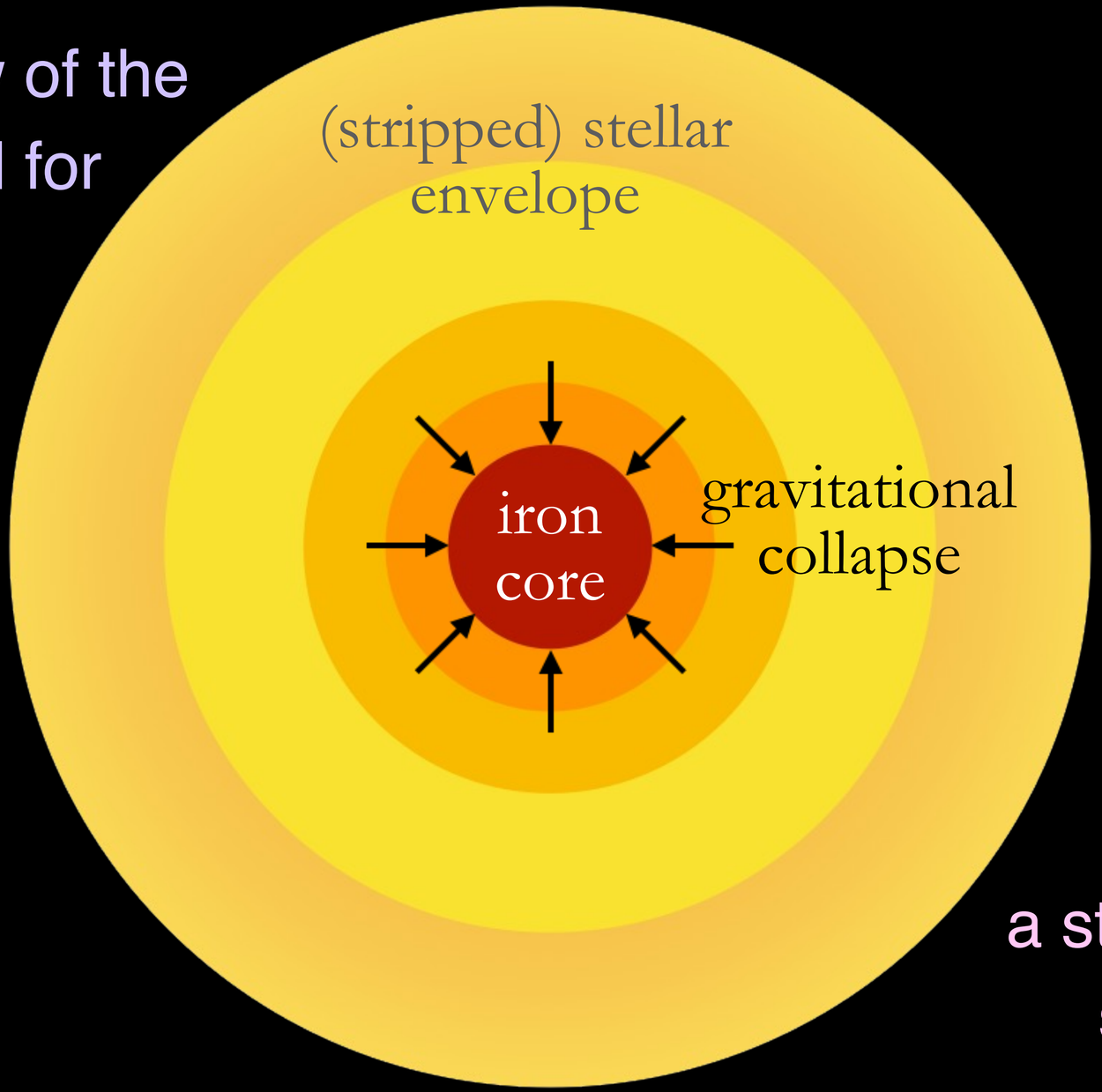
NSF

CIERA

MICRA 2023
ECT*, Trento, IT
september 10, 2023

(G. Halevi)

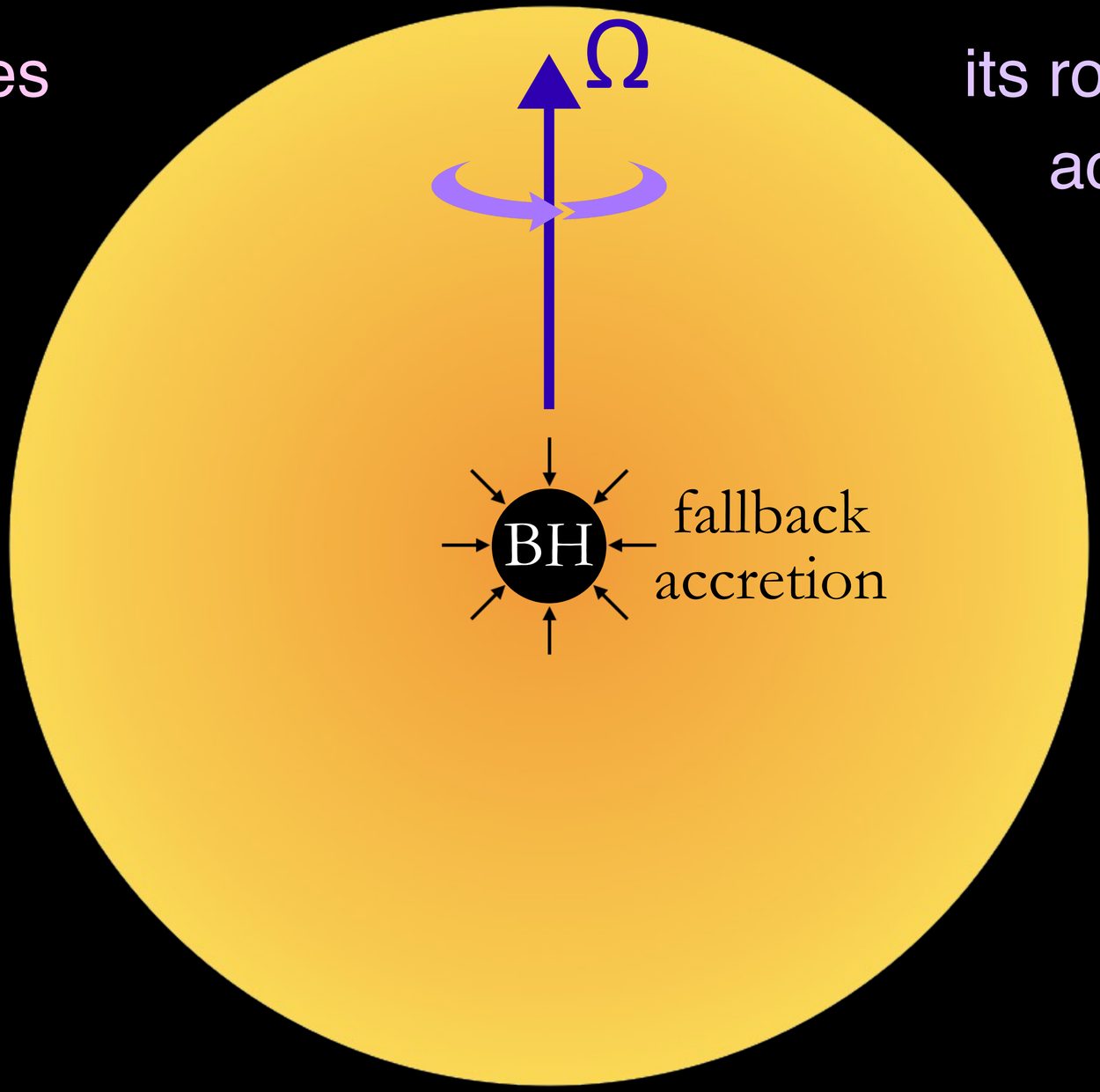
a brief overview of the collapsar model for lGRBs



a stripped massive star ends its life

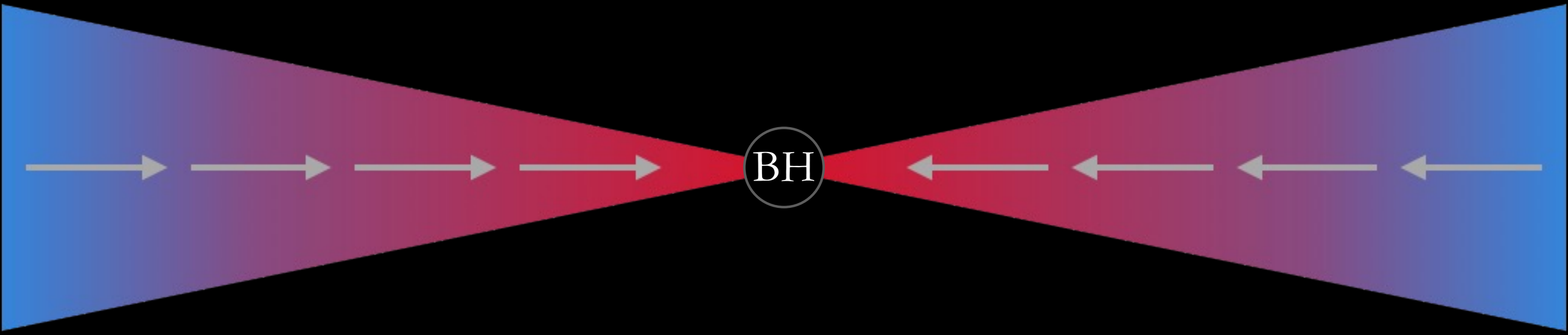
(G. Halevi)

its core collapses
to form a BH



its rotating envelope
accretes onto the
newly born BH

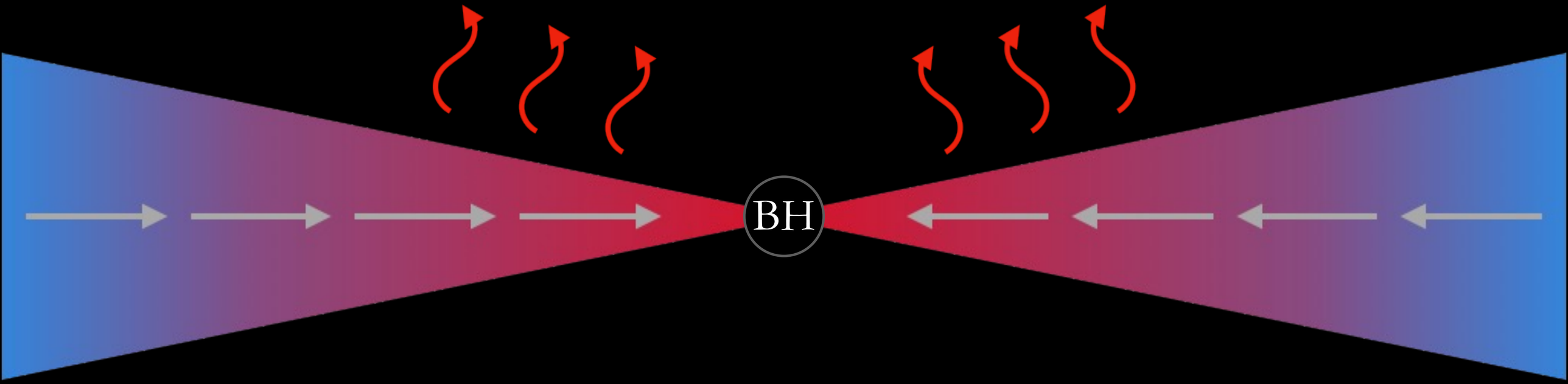
(G. Halevi)

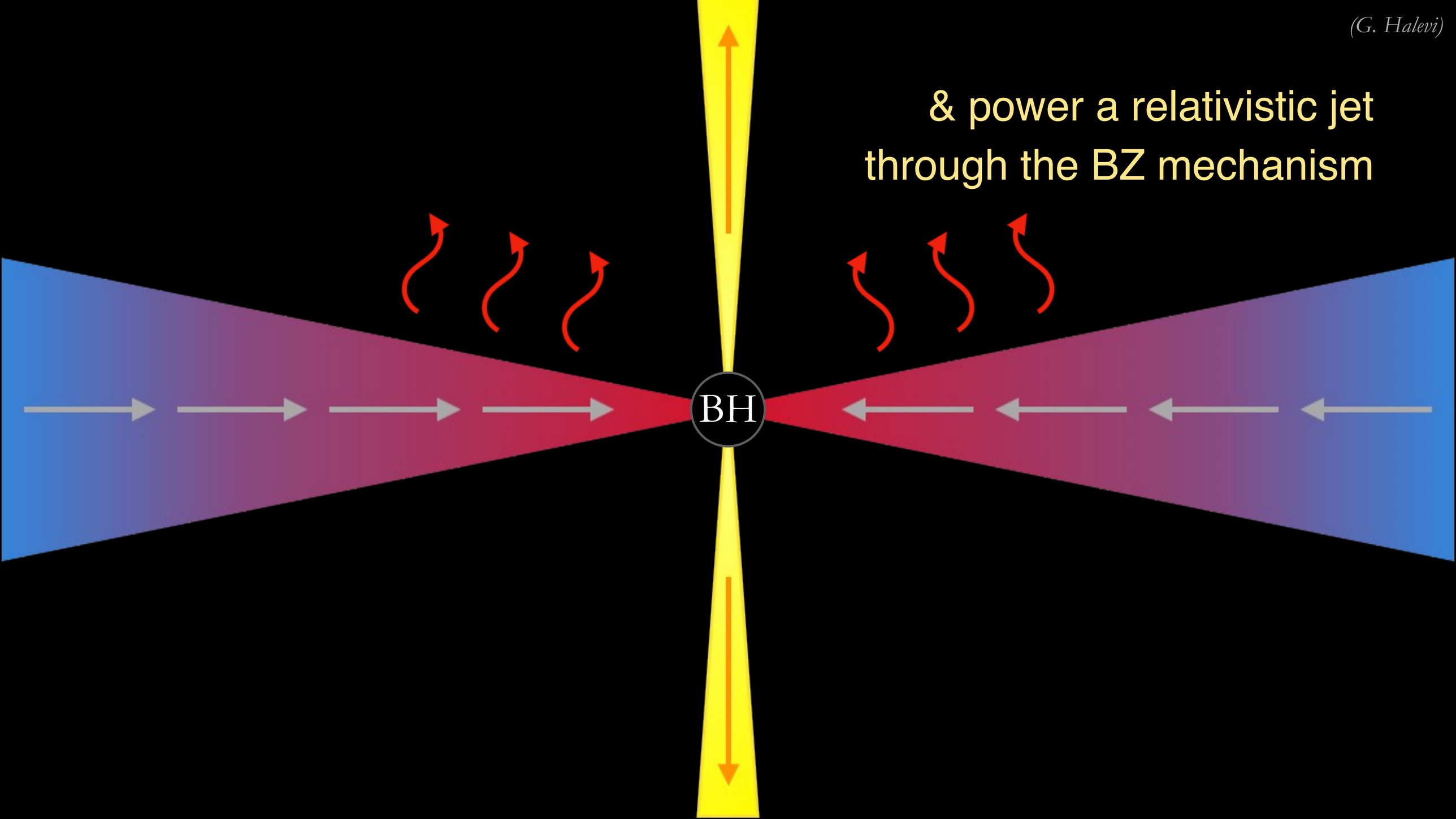


potentially forming an
MRI-driven accretion disk

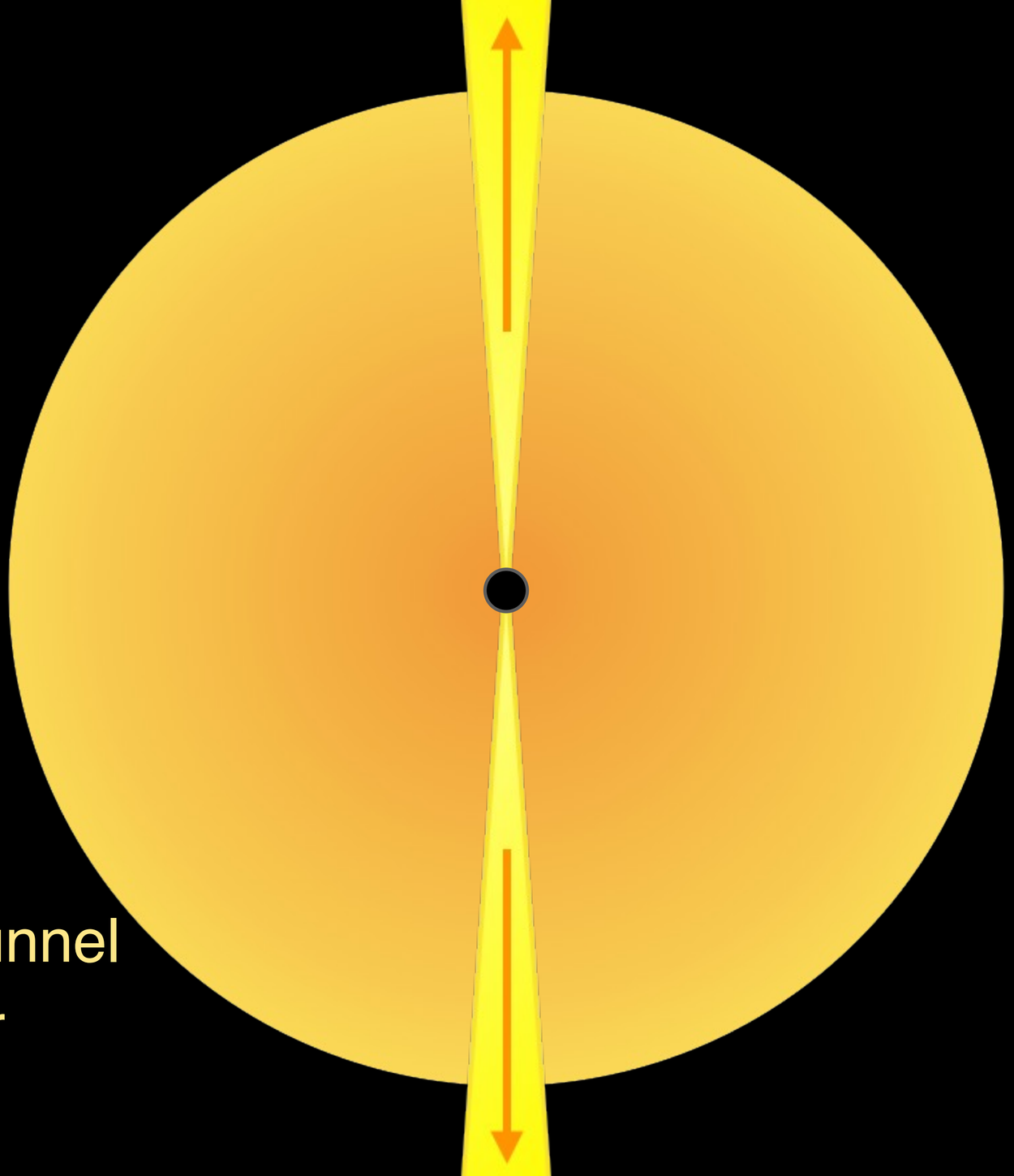
(G. Halevi)

which may launch an outflow enriched with the products of *r*-process nucleosynthesis




(G. Halevi)
& power a relativistic jet
through the BZ mechanism
BH

to be observed as an IGRB…



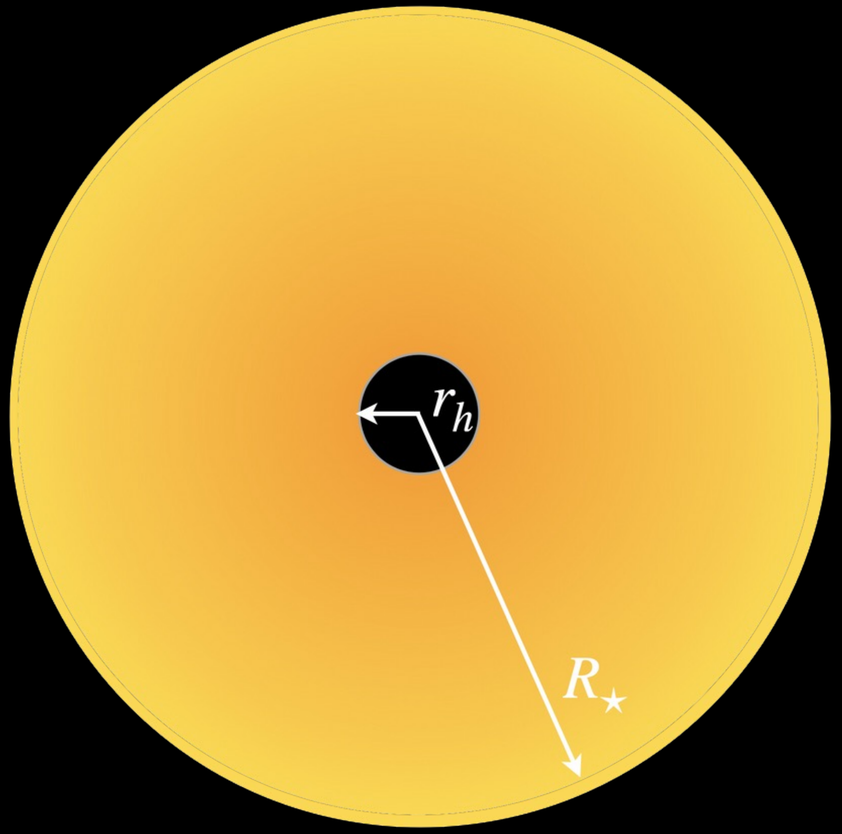
this jet has to tunnel
through the star

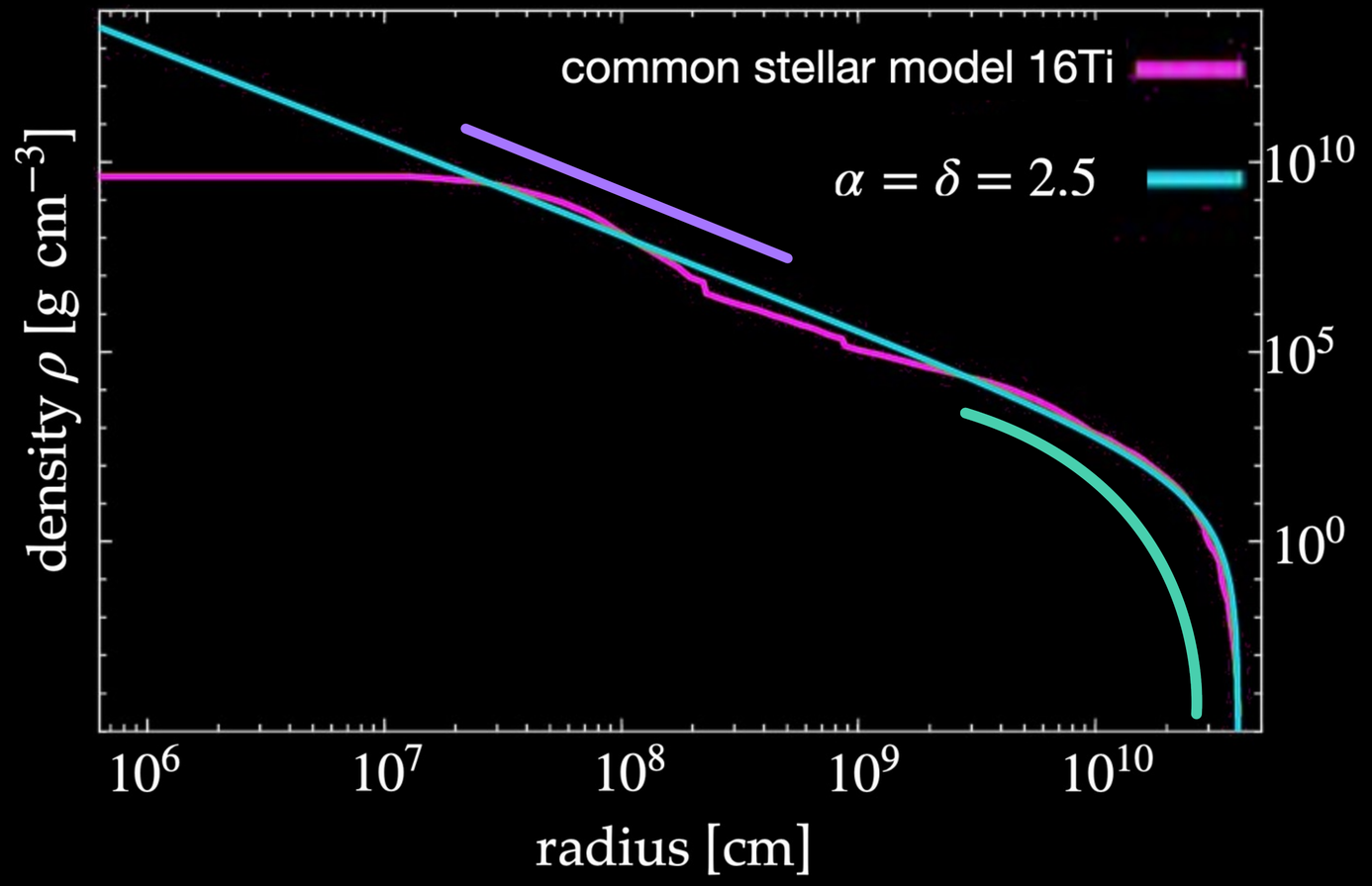
end-to-end simulations of collapsars are challenging

- **scale separation**: must resolve ~6 orders of magnitude in combined spatial+temporal ranges
- need **relativity** and **MHD** to self-consistently launch a jet
- intrinsically **3D** problem (rotation, instabilities)
- to predict nucleosynthetic properties, also need tabulated **EoS**, **neutrino** transport, and **tracer particles**
- poorly constrained **initial conditions** for stellar progenitors

how does the initial stellar density profile affect lGRB properties?

$$\rho(r) = \rho_0 \left(\frac{r}{r_h}\right)^{-\alpha} \left(1 - \frac{r}{R_\star}\right)^{\delta}$$





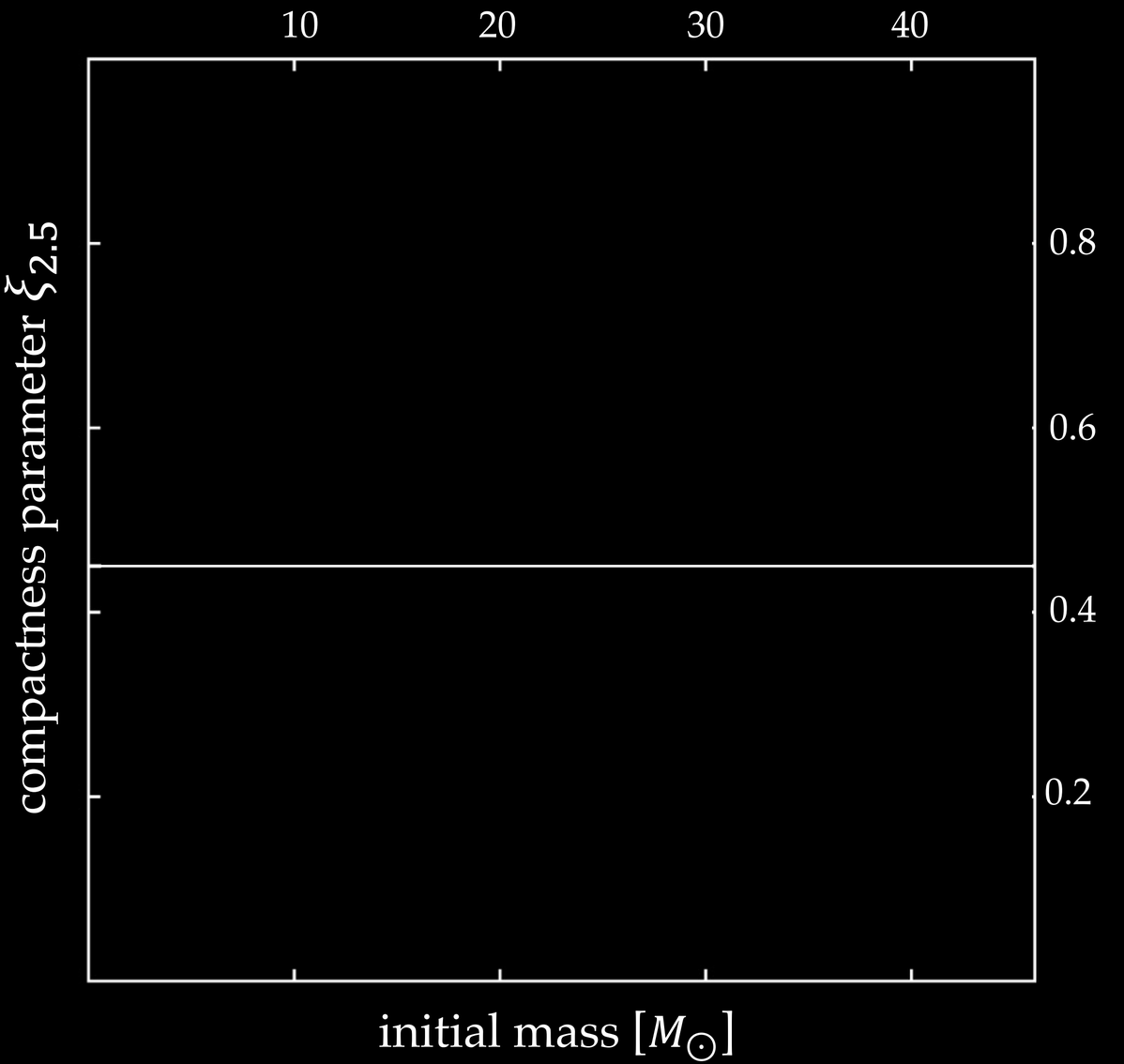
Gottlieb et al. (2021)

	jet power required? [erg/s]	(naïve) light curve evolution?
$\alpha \lesssim 0.5$	$\lesssim 10^{49}$	✗
$0.5 \lesssim \alpha \lesssim 1.5$	$10^{49} - 10^{52}$	—
$\alpha \gtrsim 2$	$\gtrsim 10^{52}$	✗

steepness of density profile (α)

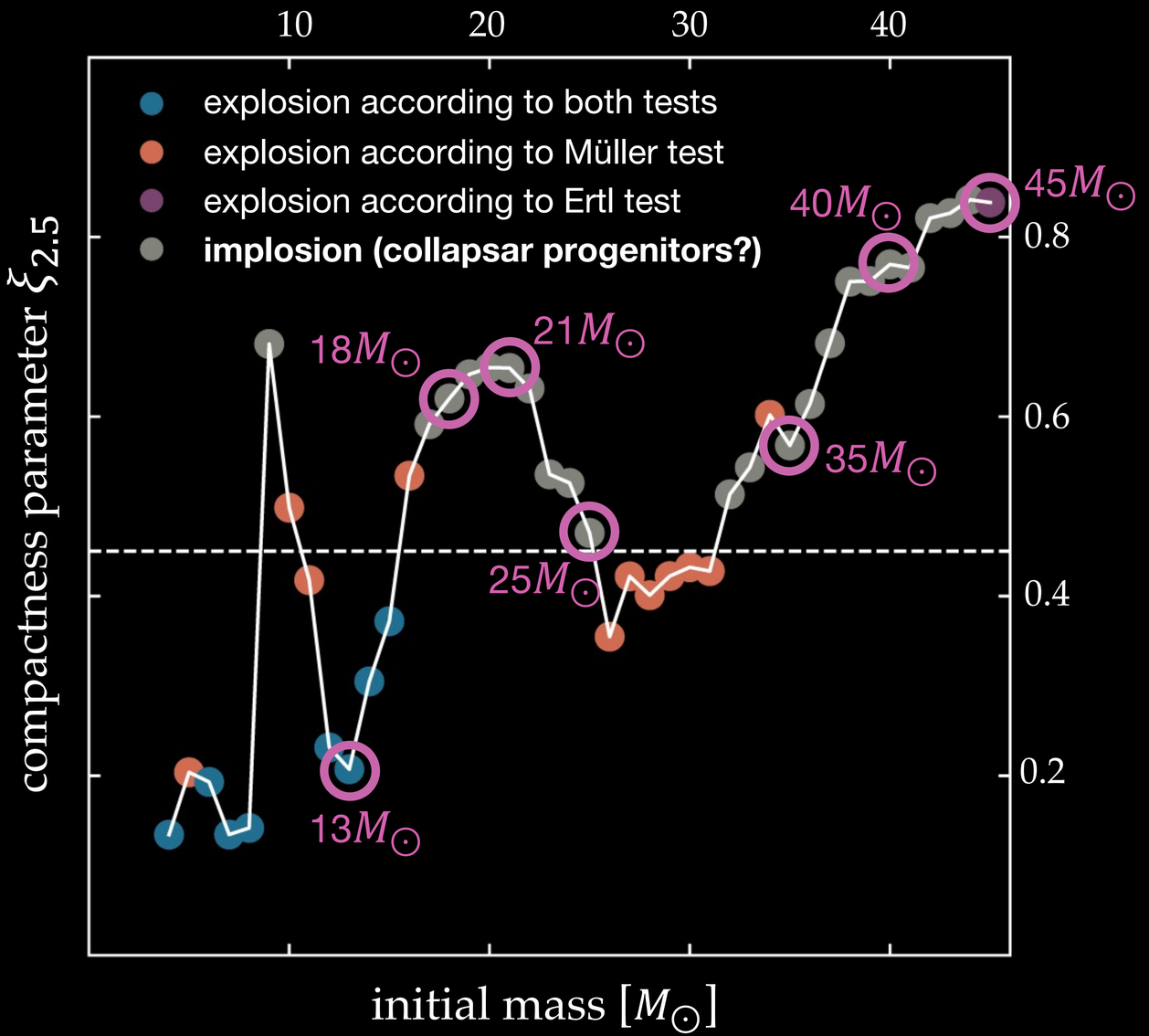
which physical conditions are consistent with observations?

$$\xi_M = \frac{M/M_\odot}{R(M)/(1000\mathrm{km})}$$

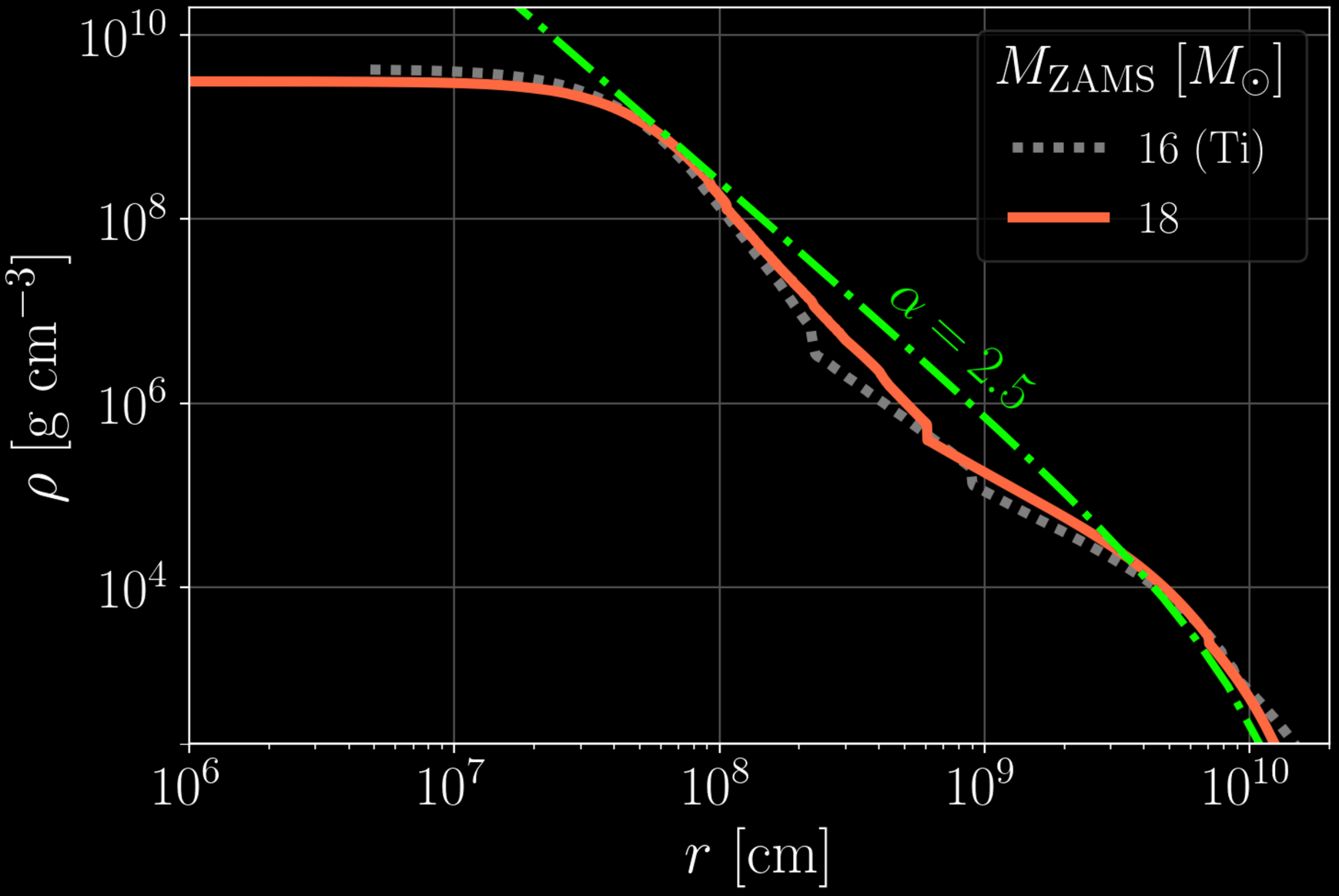


choose realistic updated stellar evolution models for potential long GRB progenitors

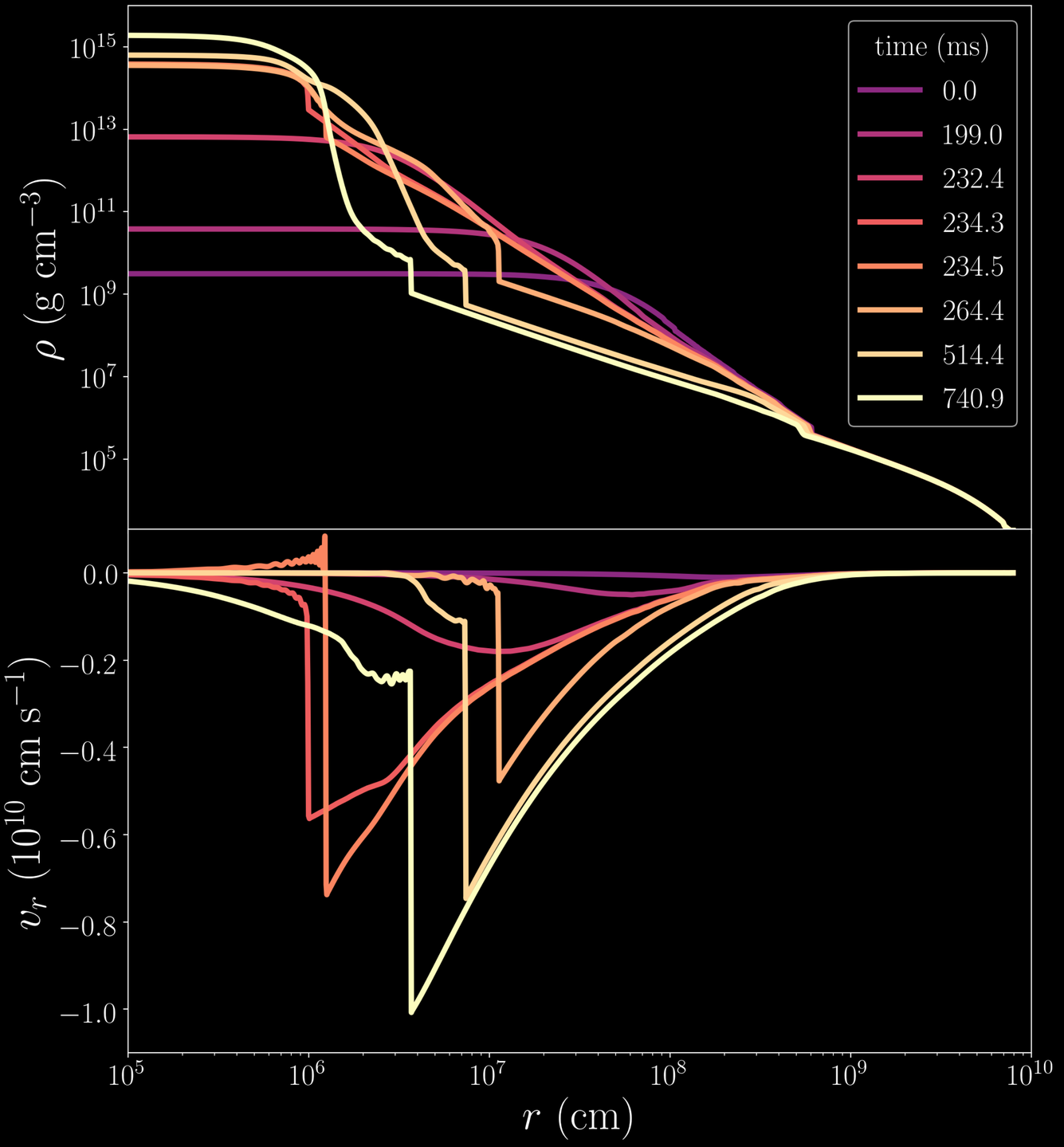
Aguilera-Dena et al. (2021)



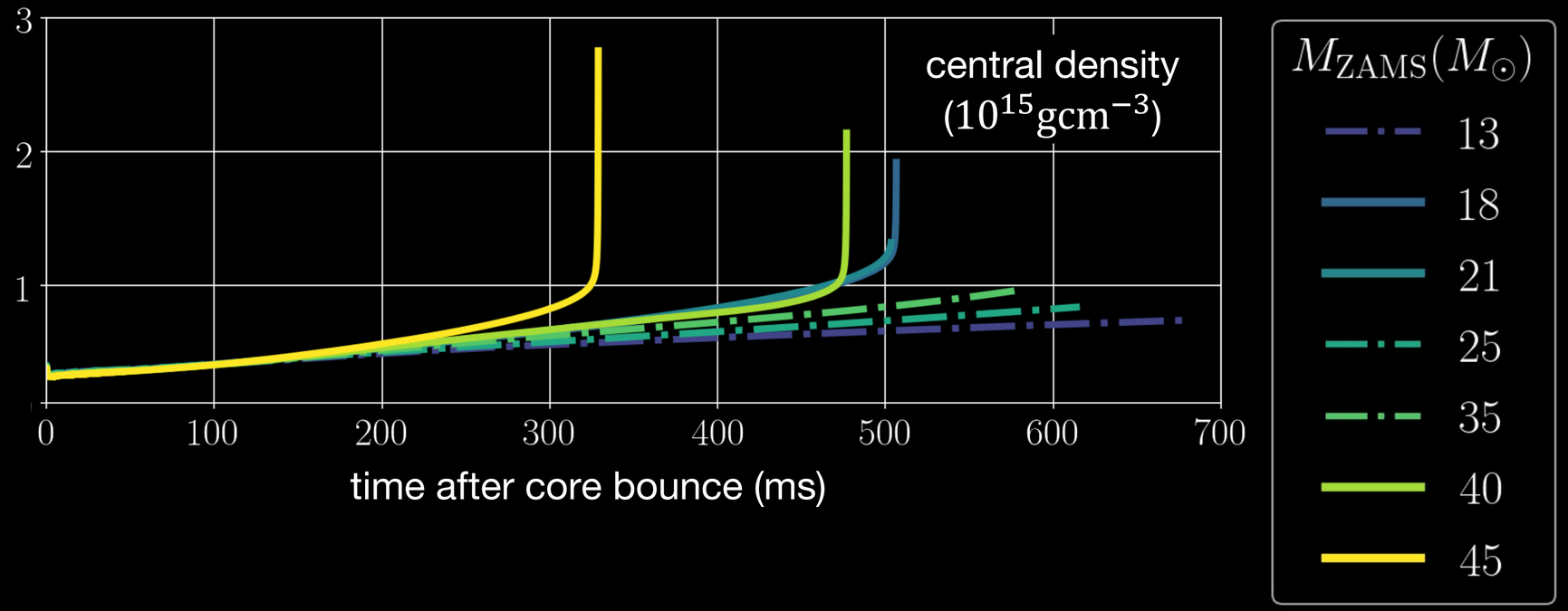
choose realistic updated stellar evolution models for potential long GRB progenitors

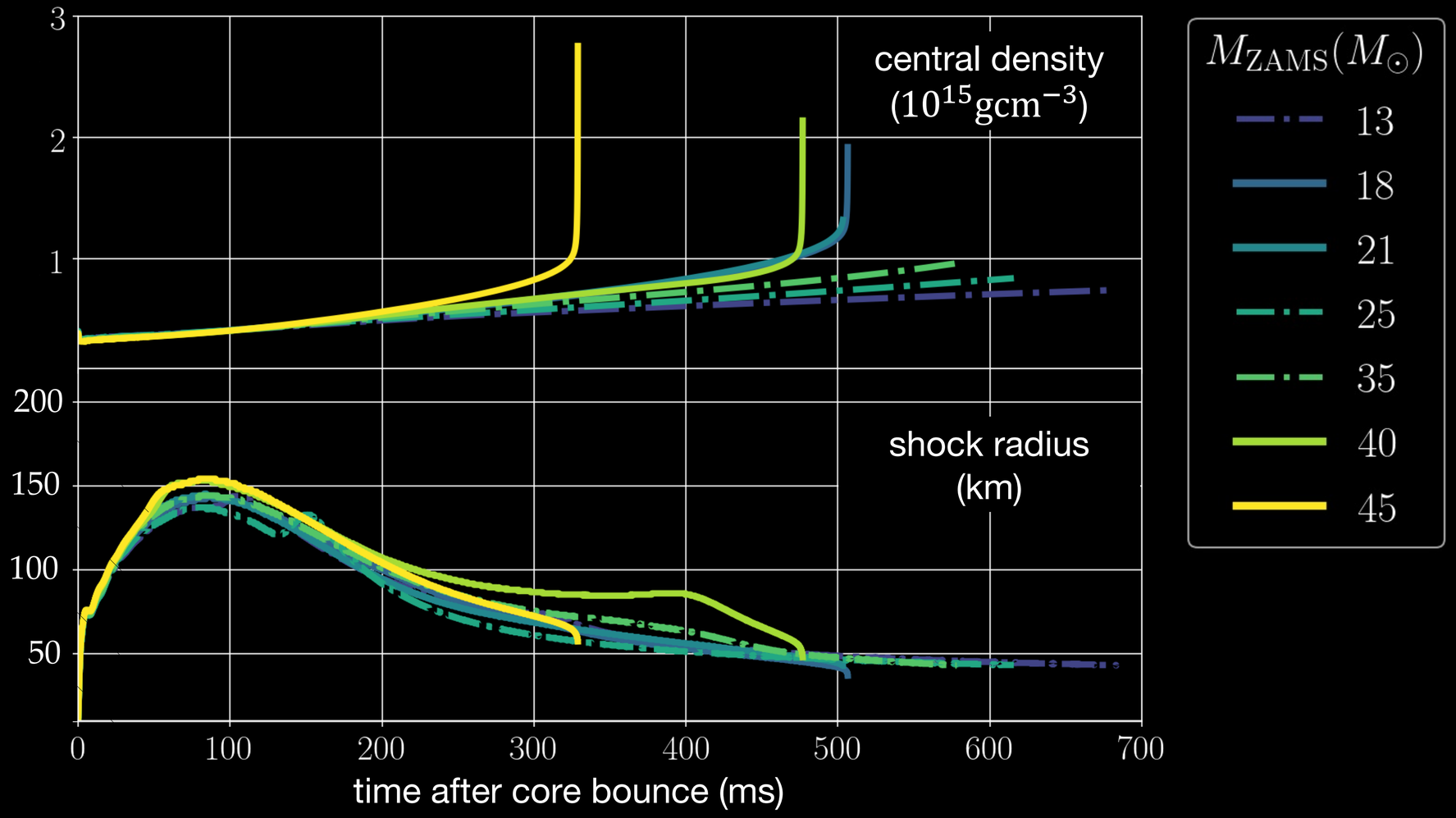


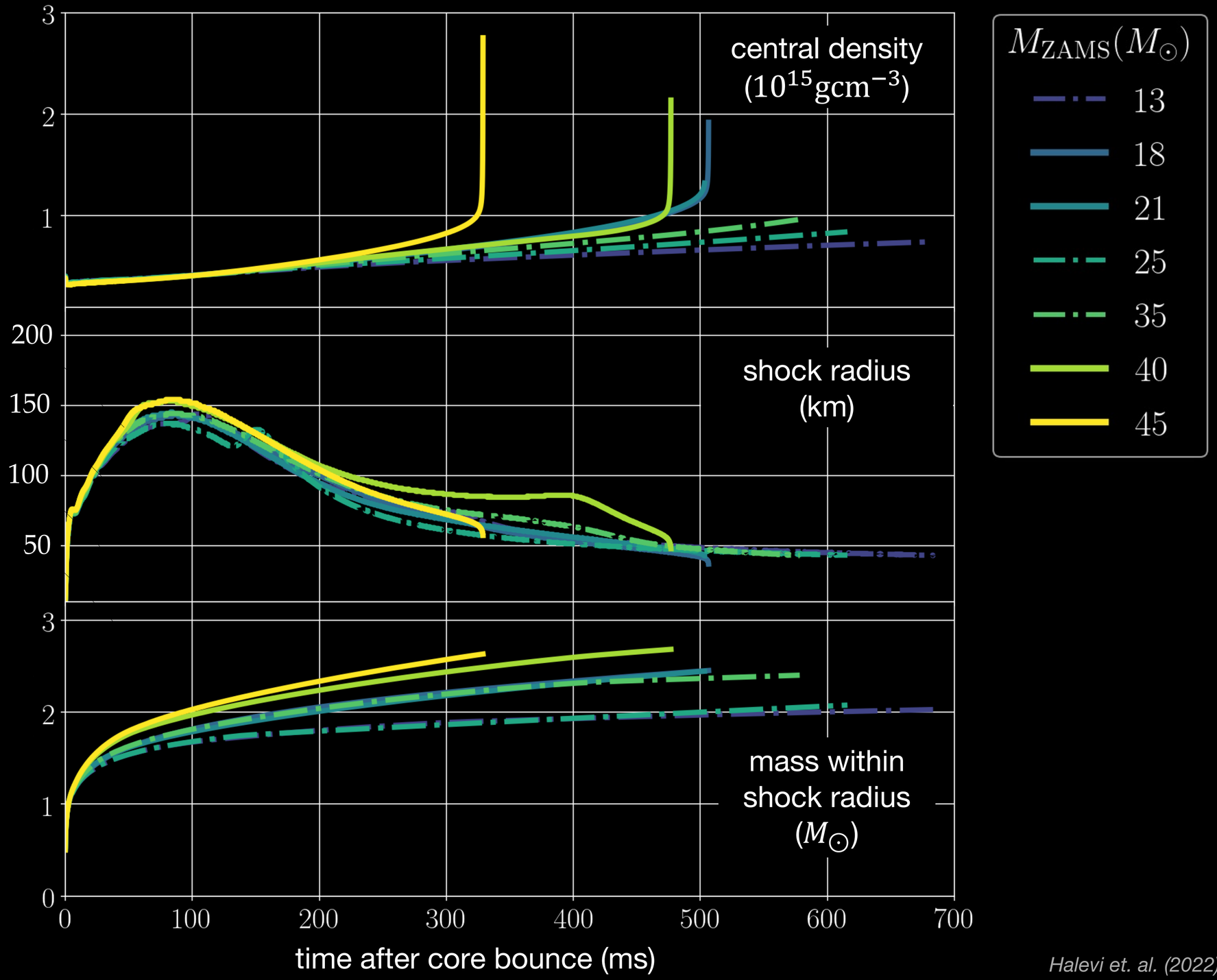
evolve each model with GR1D: relativistic hydro in 1.5D
with M1 neutrino transport and a tabulated EoS



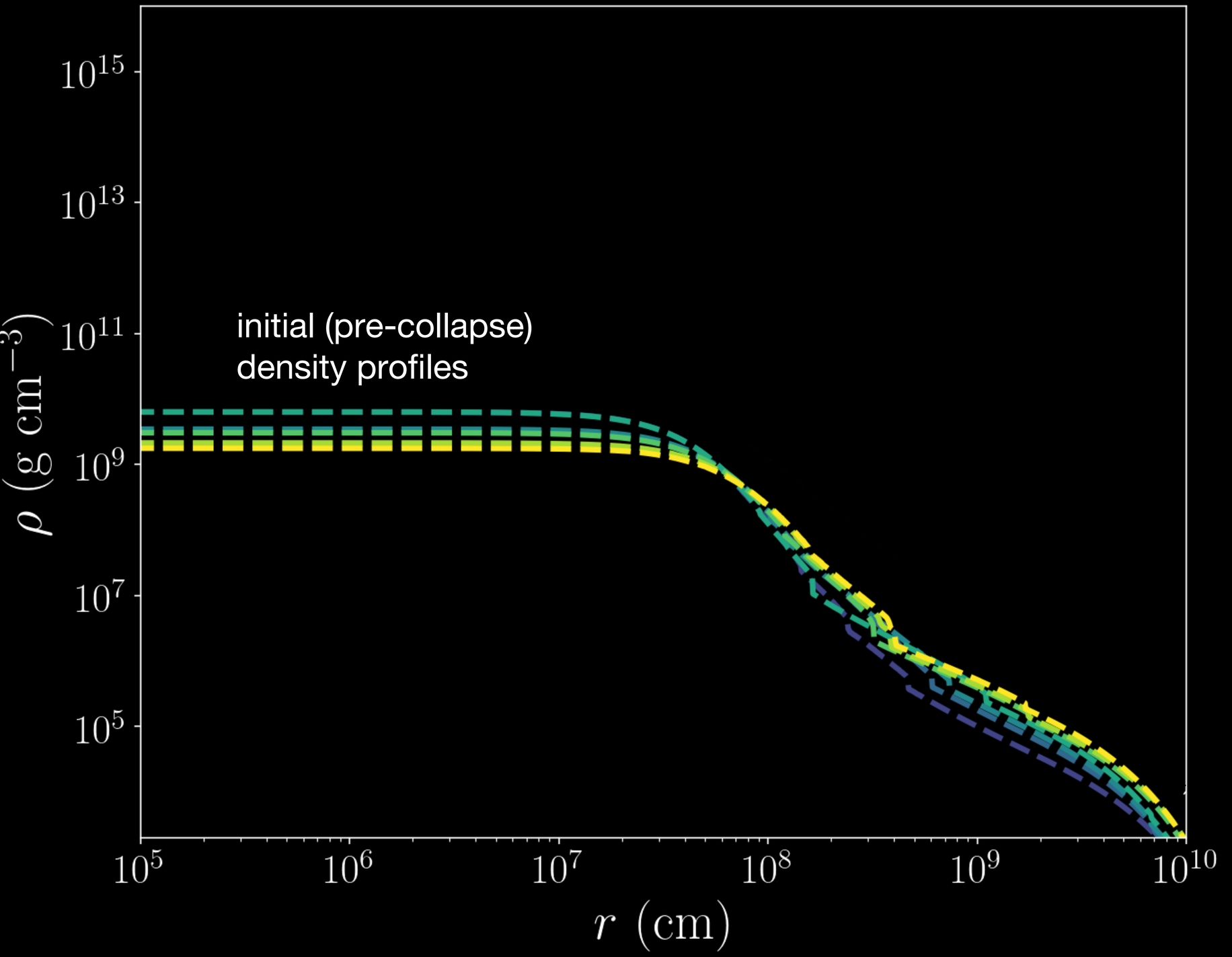
Halevi et. al. (2022)


central density
$(10^{15}\mathrm{gcm}^{-3})$
3
2
1
0
100
200
300
400
500
600
700
time after core bounce (ms)
$M_{\mathrm{ZAMS}}(M_\odot)$
13
18
21
25
35
40
45

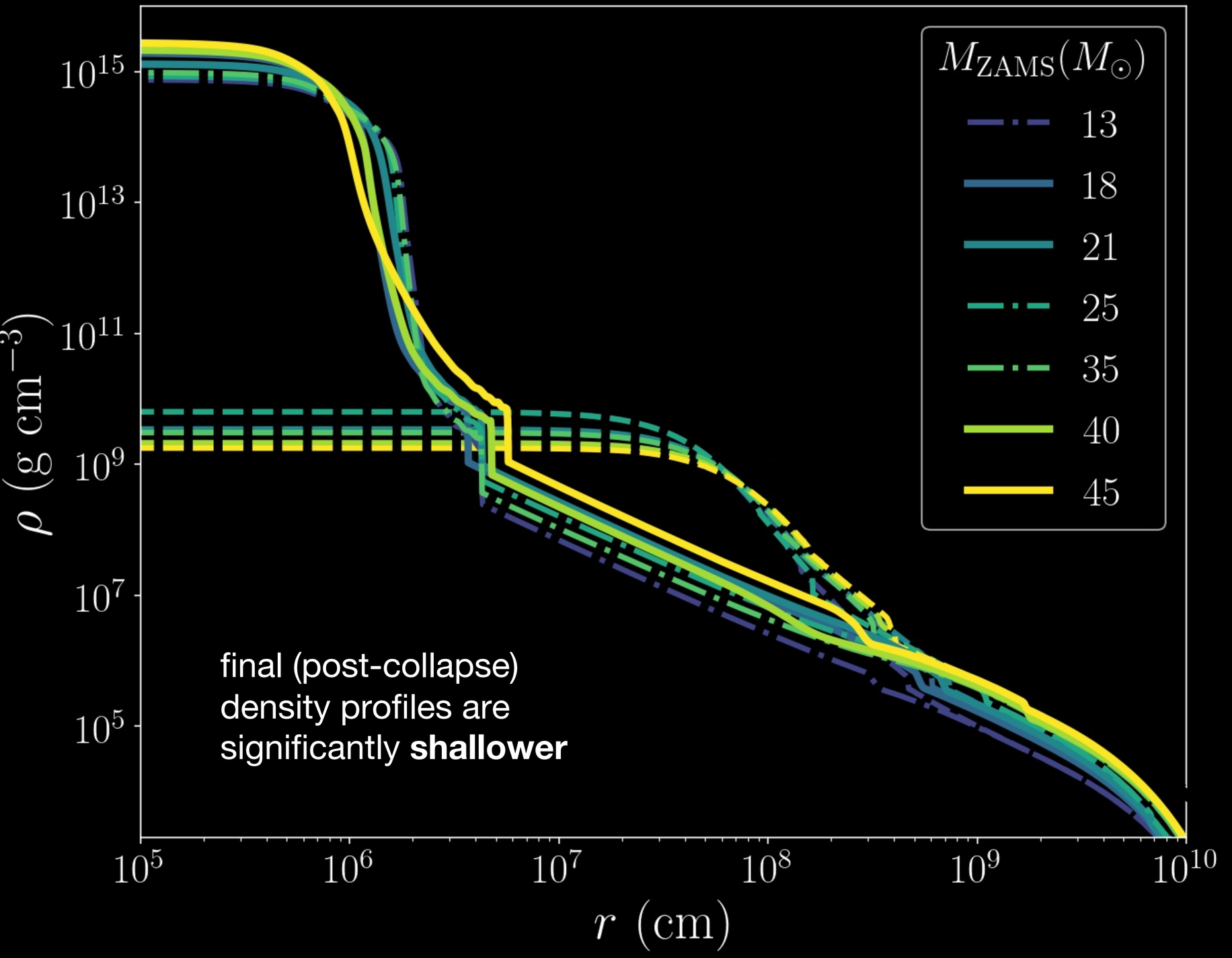

central density
(10^{15}gcm^{-3})
shock radius
(km)
3
2
1
200
150
100
50
0
100
200
300
400
500
600
700
time after core bounce (ms)
$M_{\rm ZAMS}(M_\odot)$
13
18
21
25
35
40
45



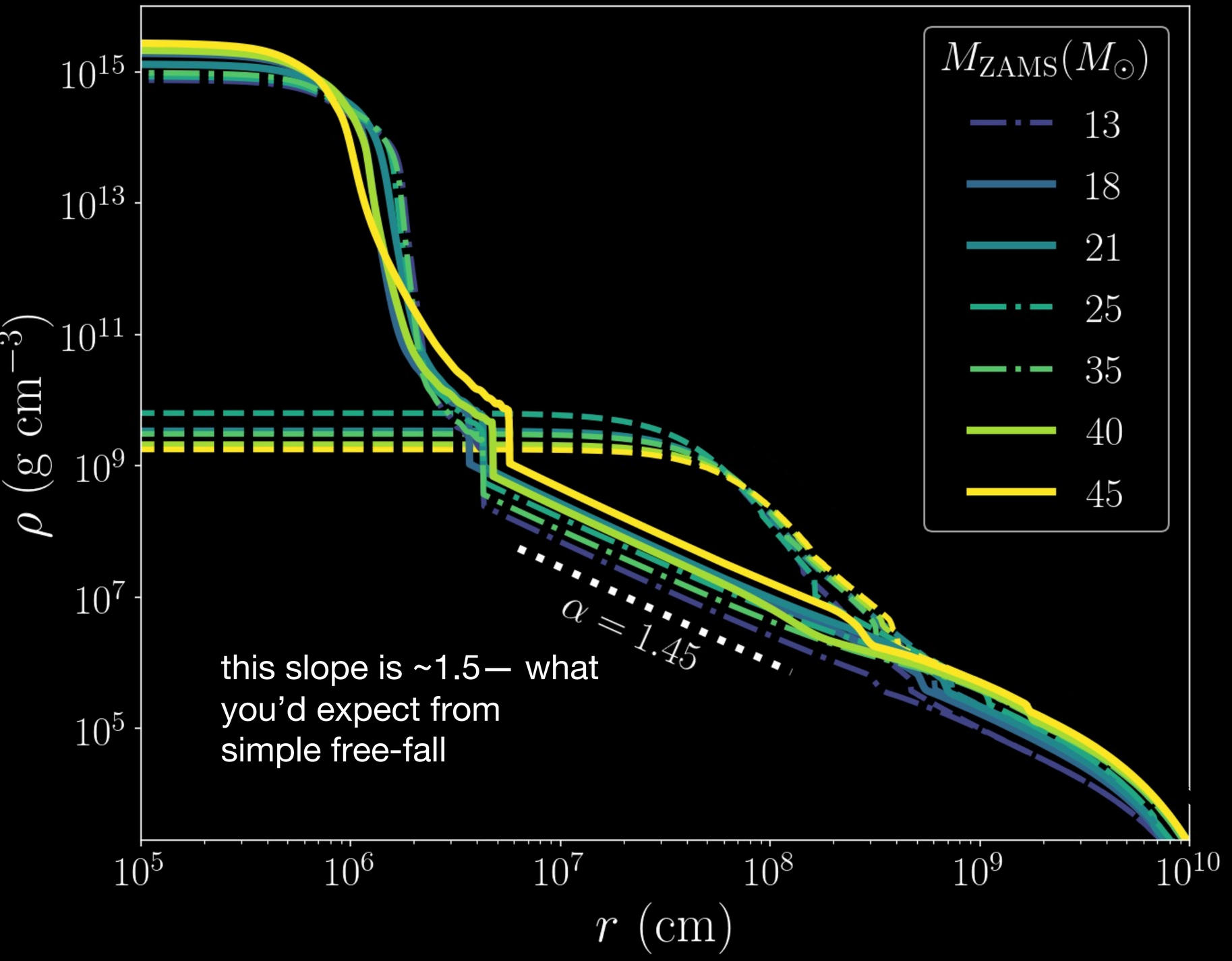
Halevi et. al. (2022)



Halevi et. al. (2022)

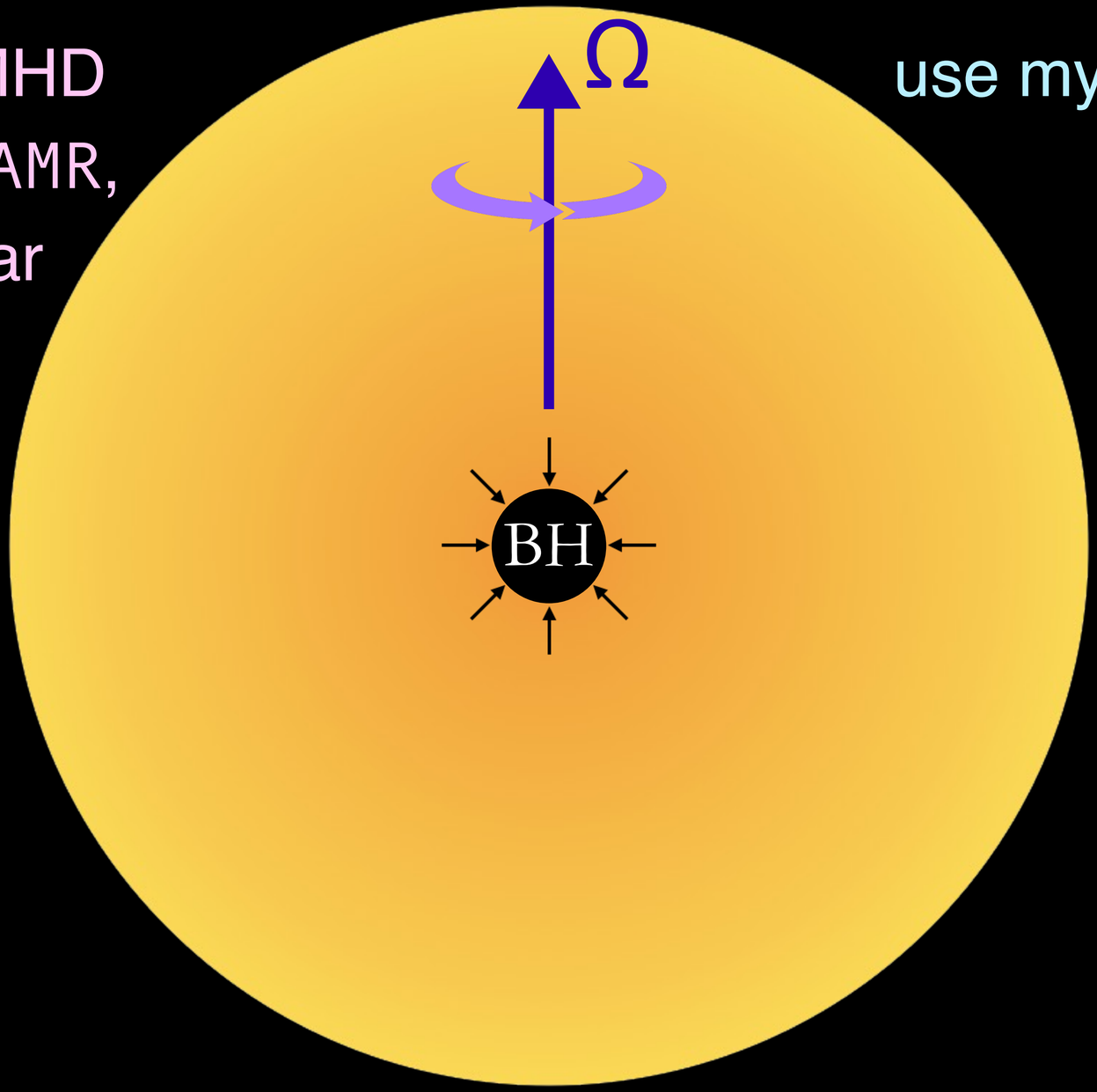


Halevi et. al. (2022)



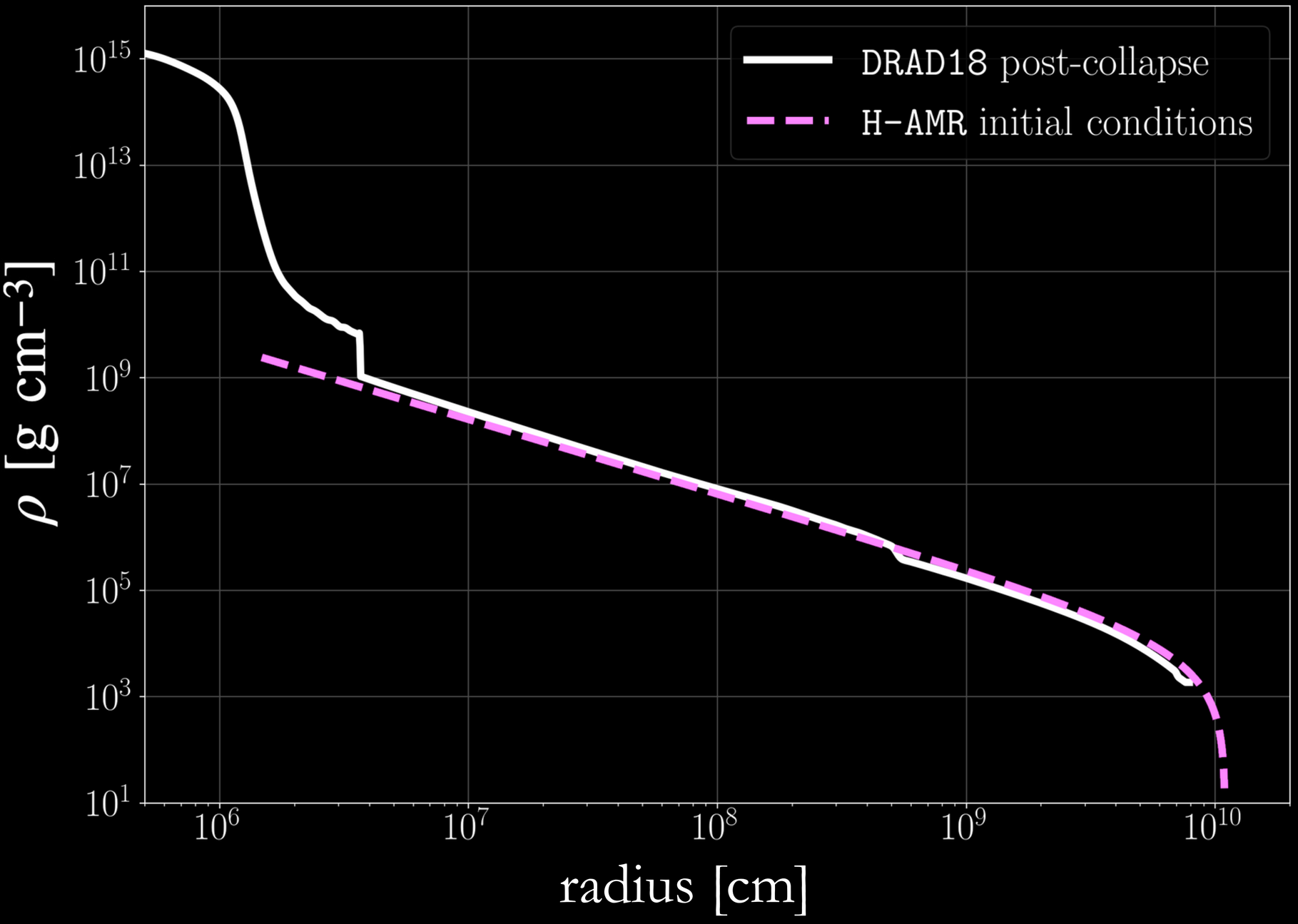
Halevi et. al. (2022)

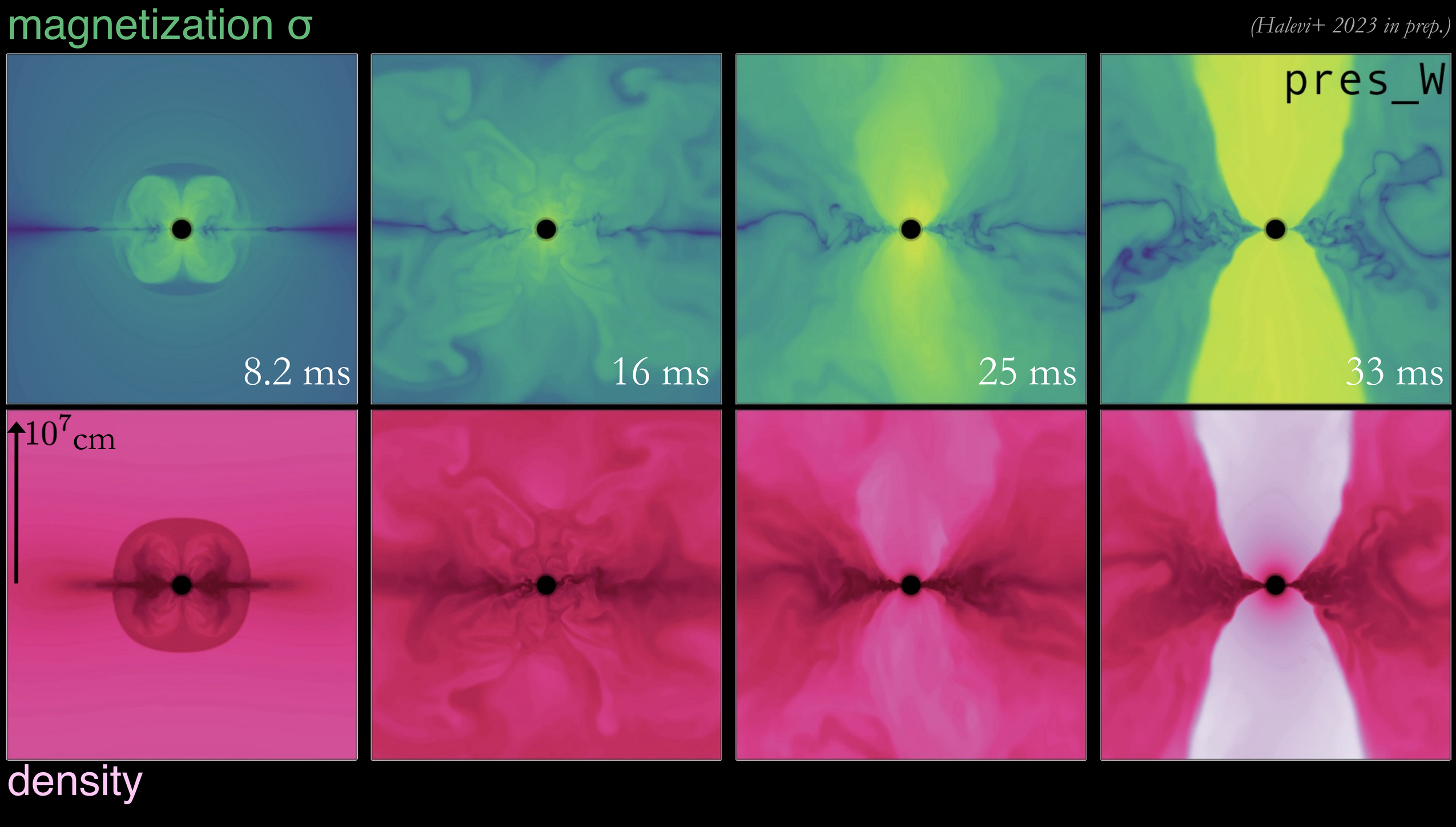
initialize 3D GRMHD simulation, in H-AMR, of a rotating stellar envelope with a central BH



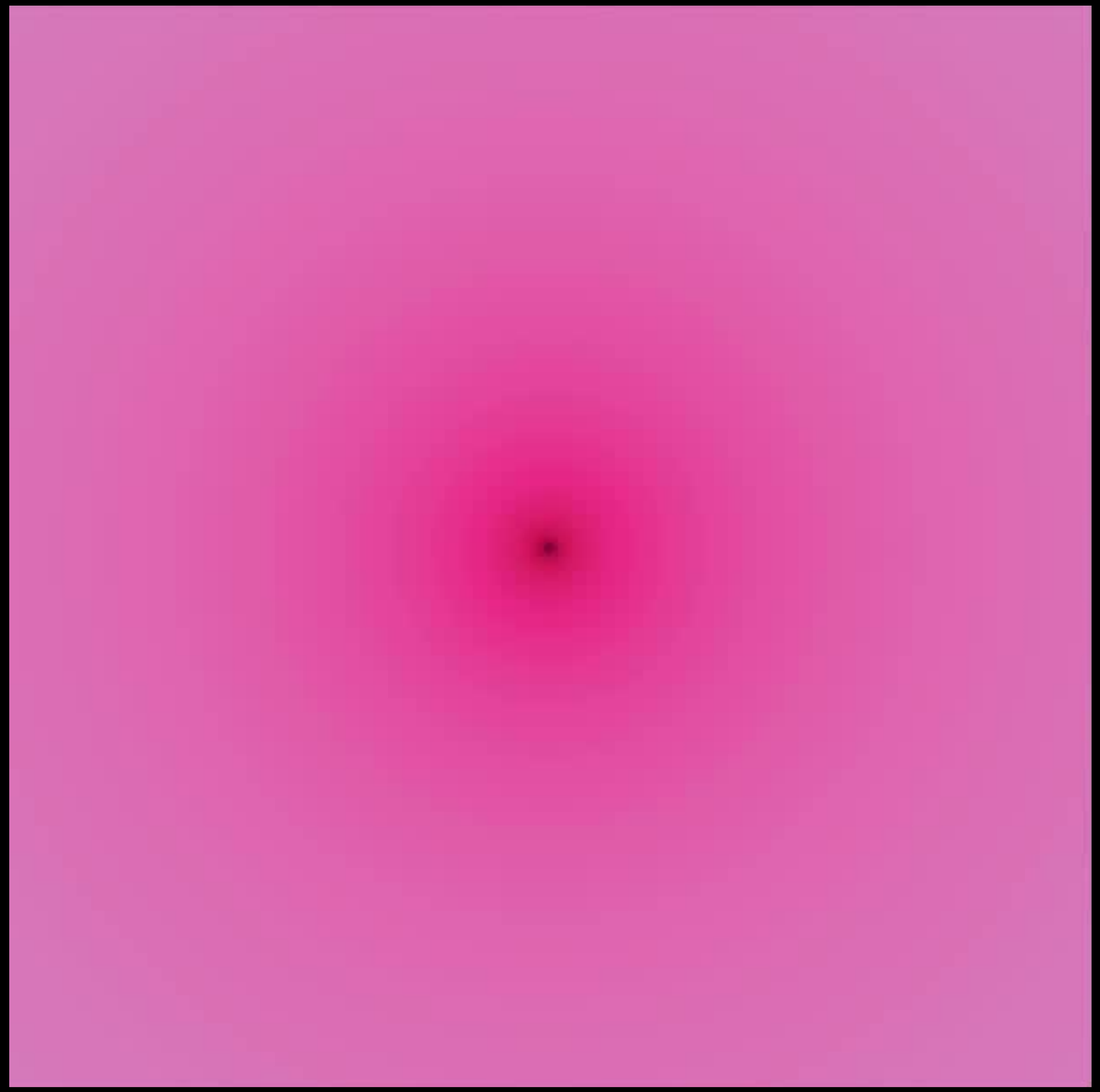
use my core-collapsed stellar model to motivate initial conditions

(Halevi+ 2023 in prep.)




magnetization σ
(Halevi+ 2023 in prep.)
8.2 ms
16 ms
25 ms
pres_W
33 ms
10^7 cm
density

(Halevi+ 2023 in prep.)



density evolution

end-to-end simulations of collapsars are within reach

- **scale separation** is tractable with GPUs and AMR
- we can self-consistently launch jets in **3D GRMHD**
- an M1 **neutrino** transport scheme has recently been developed– we can soon perform detailed nucleosynthesis calculations
- we can better constrain **initial conditions** for stellar progenitors
- magnetic field configurations? rotation profiles?