Numerical simulations of GRB jets from the BH horizon to post-breakout in collapsing stars

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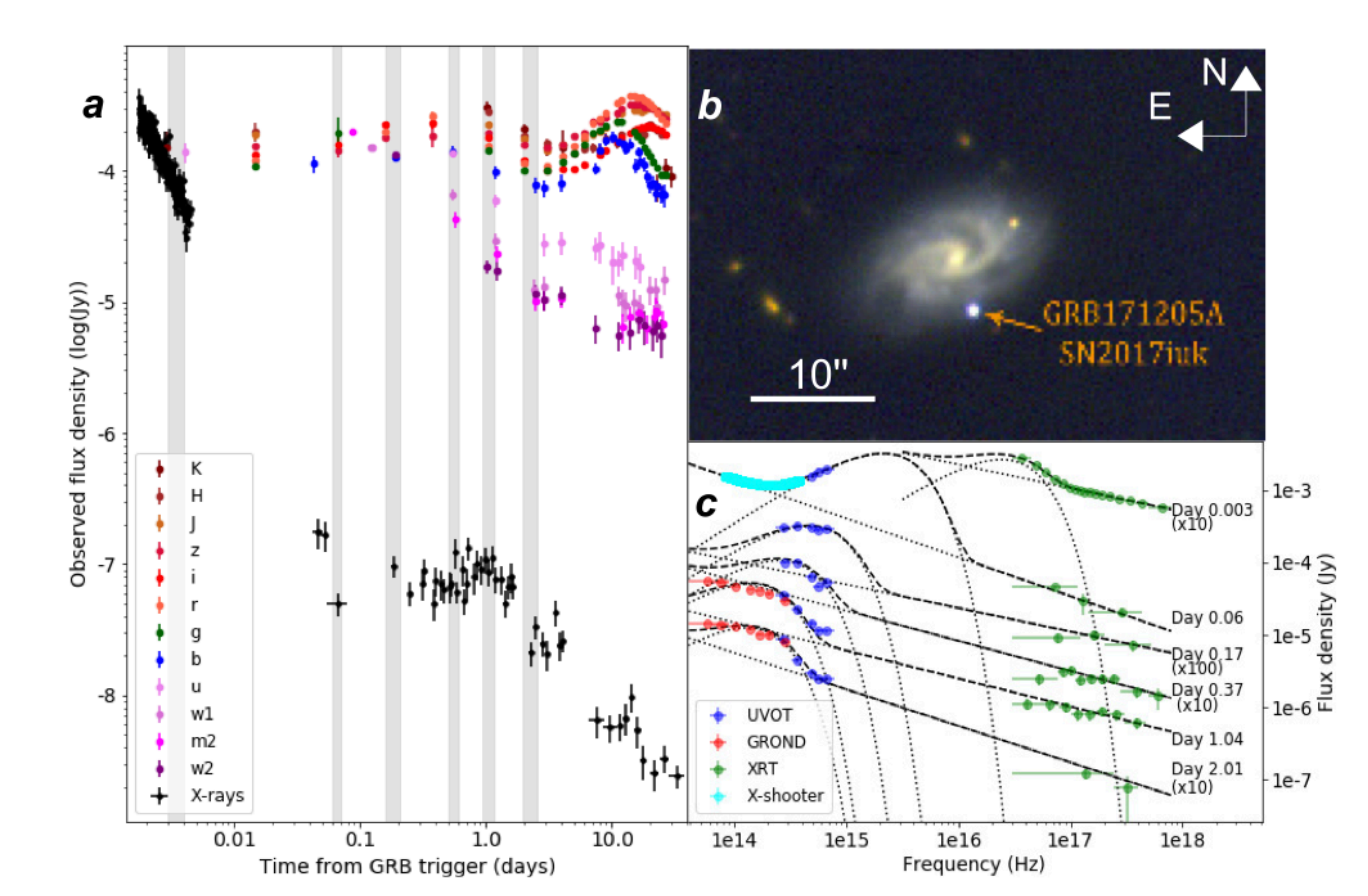
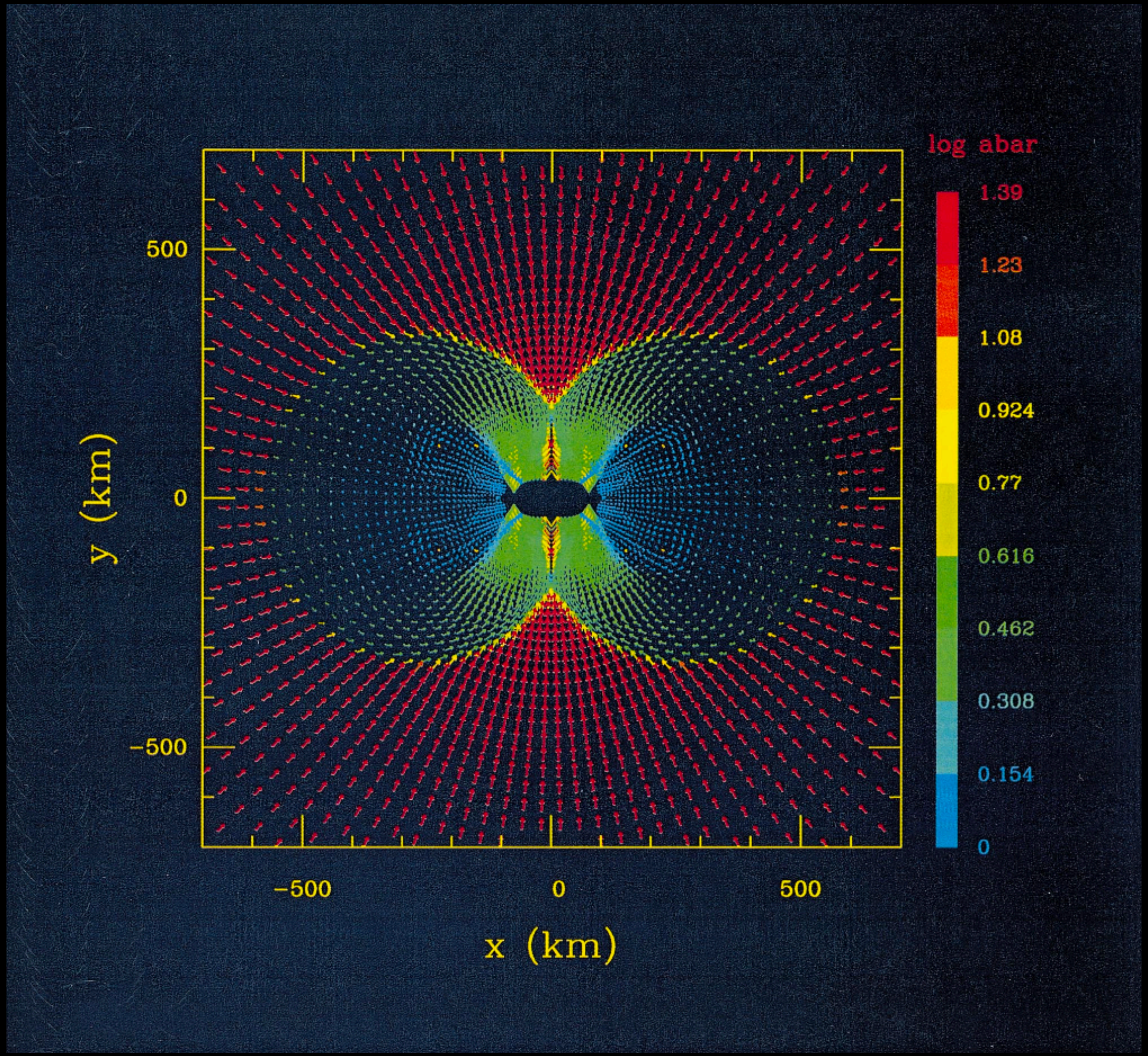
GRBs from collapsars



Izzo et al 2019

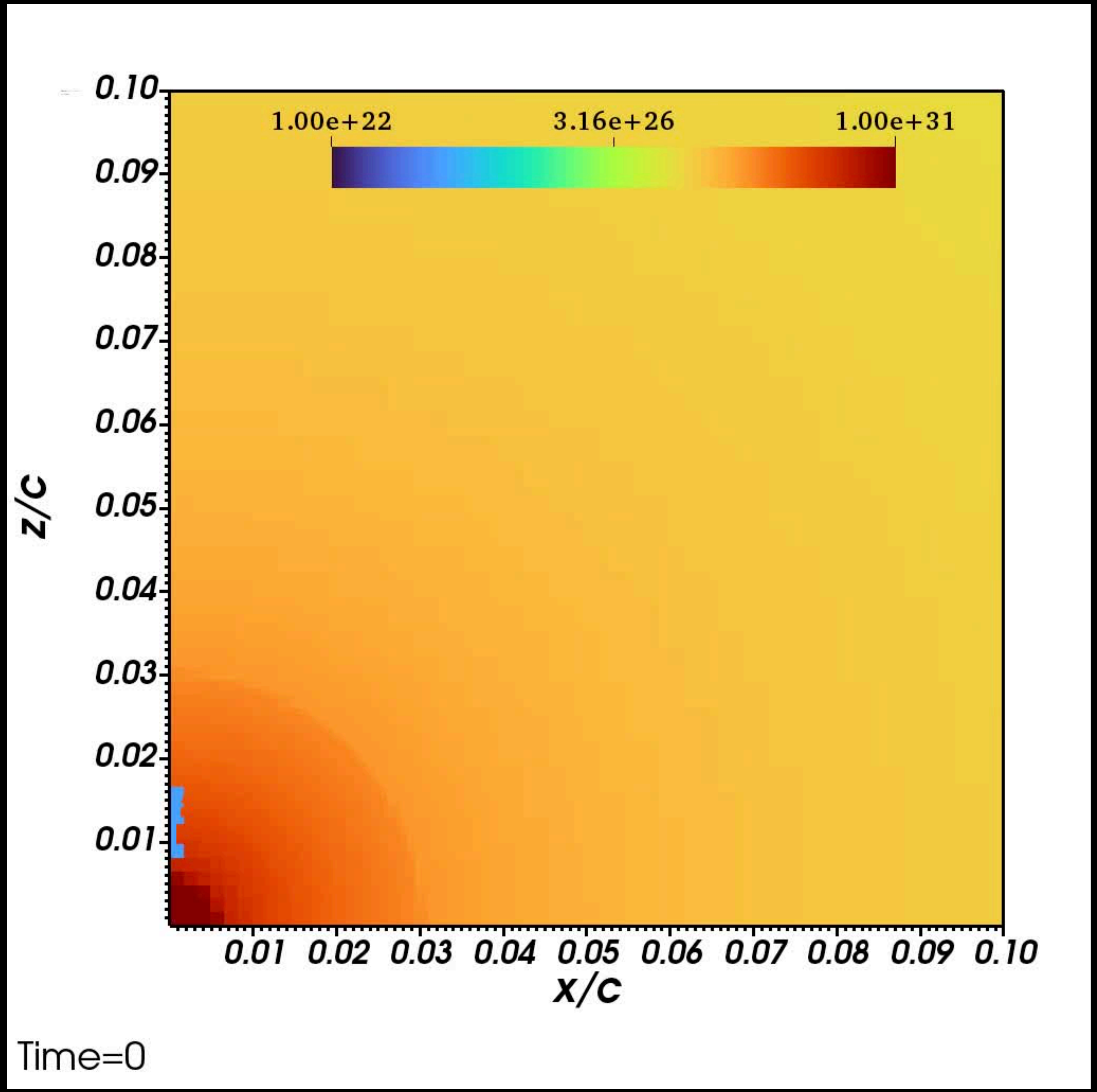
GRBs from collapsars

Small scales, e.g, McFadyen & Woosley 1999



Also see, Shibata + 2025, Aloy & Obergaulinger 2020

e.g., beyond the star surface Urrutia + 2023



Also see, Aloy + 2000, Harrison + 2019, Gottlieb + 2020, …

Long GRB Jet is a multi-scale problem

Figure Credits: Dado et al. 2022

Long GRB Jet is a multi-scale problem

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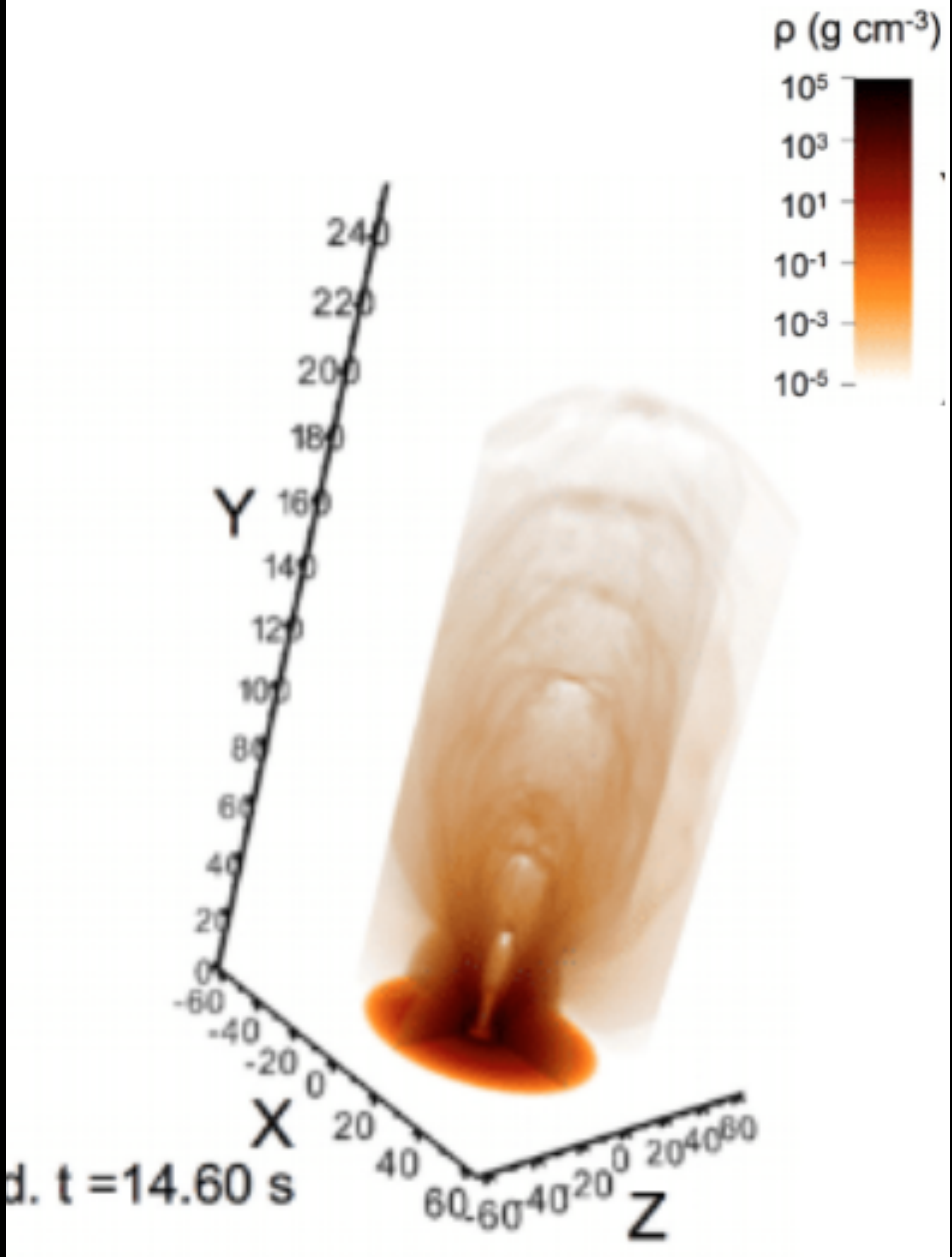
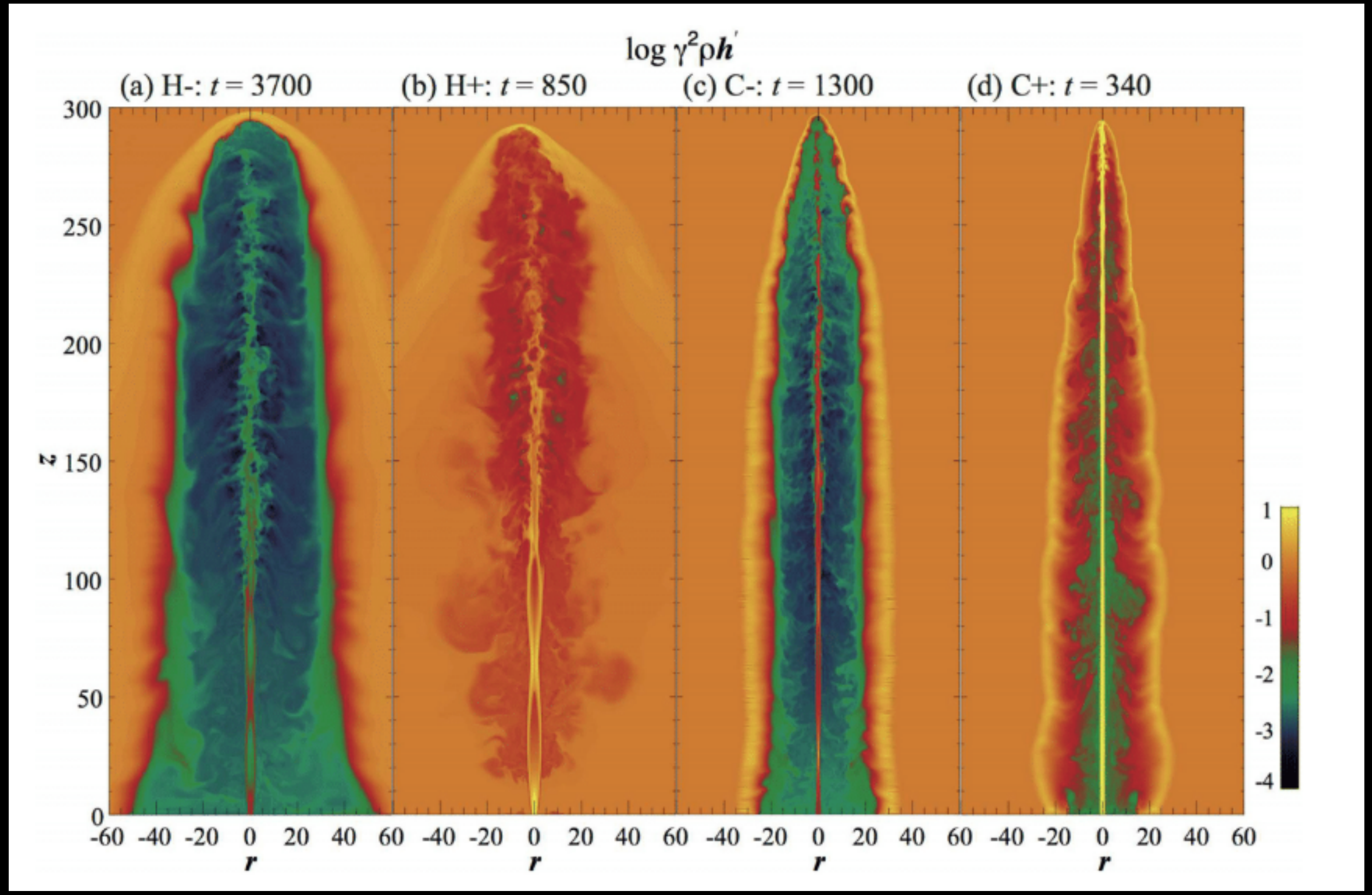
Jets launched beyond the iron core

Non symmetric Top-hat jet (variable source)



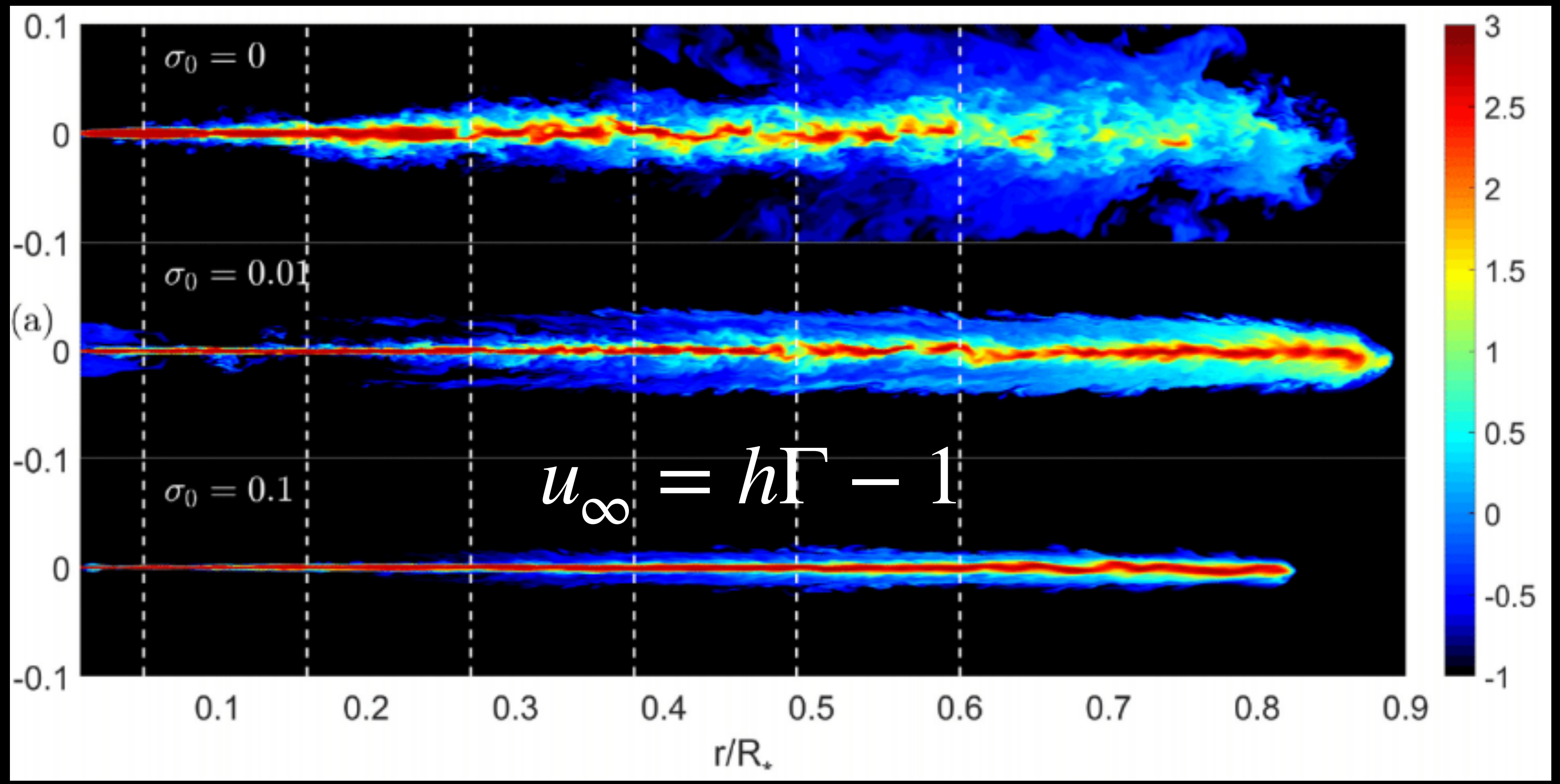
Lopez-Camara et al. 2016

Cold and pressure dominated jets



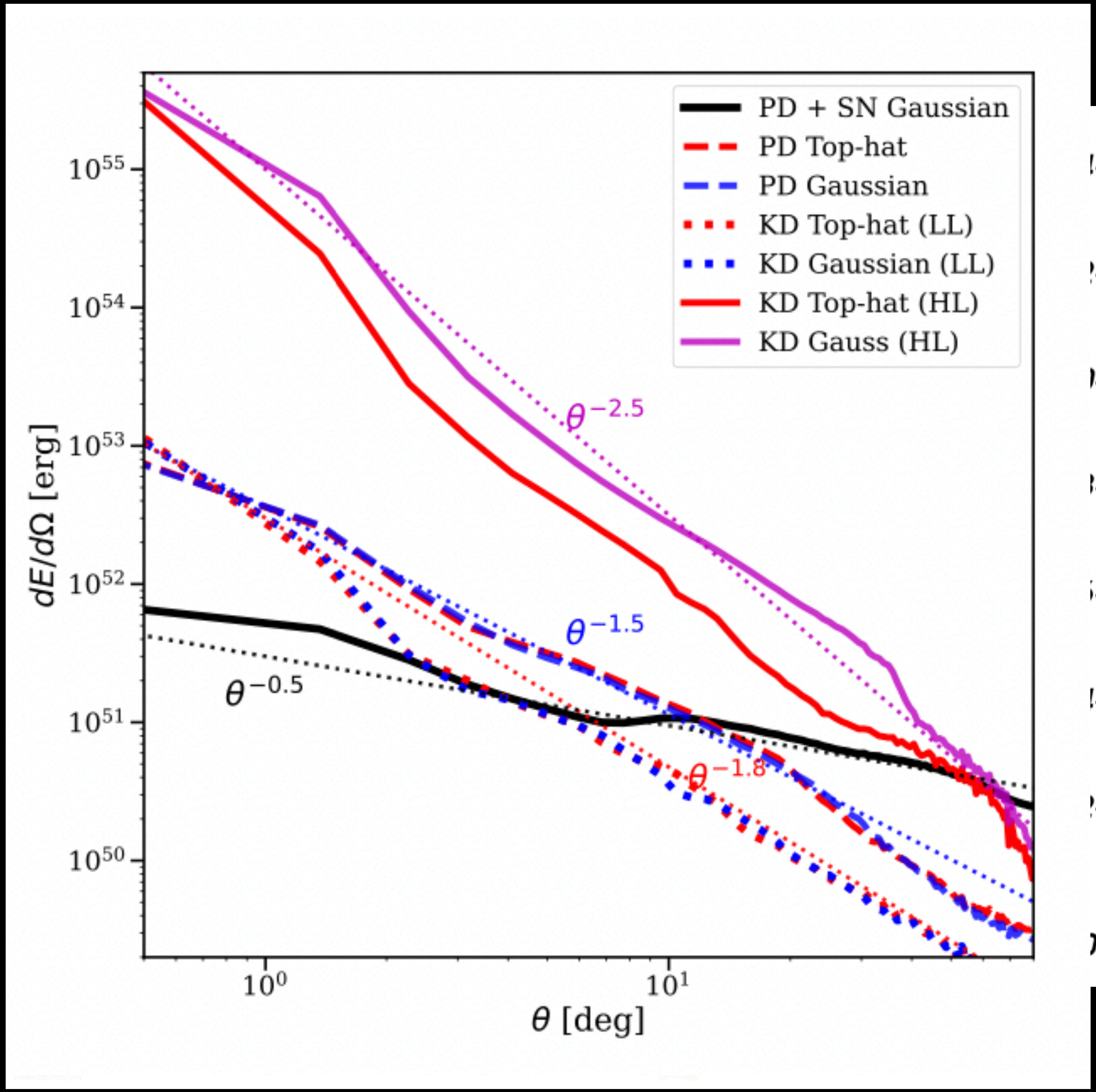
Matsumoto et al. 2019

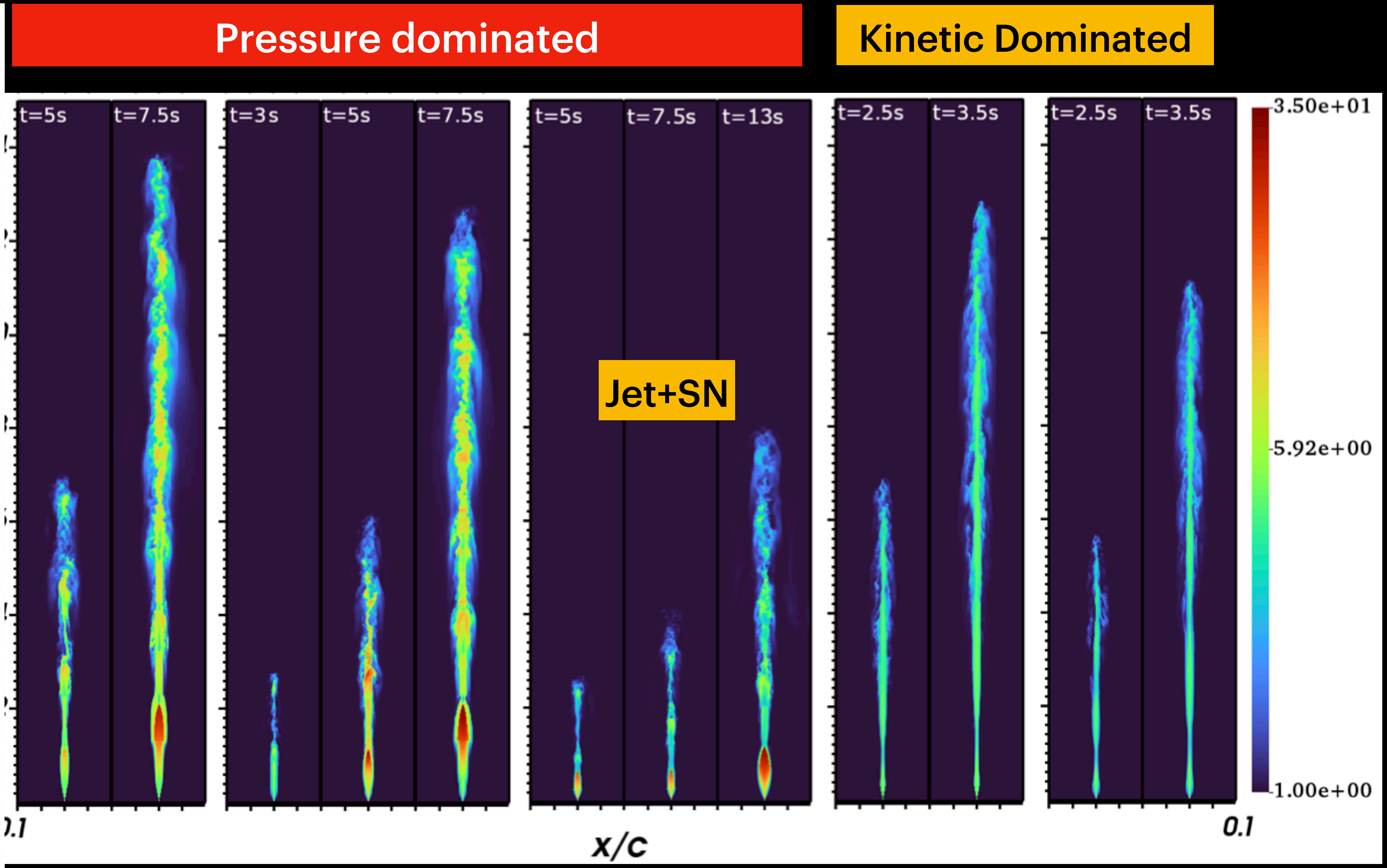
Weakly magnetized jet + variable source



Gottlieb et al. 2020

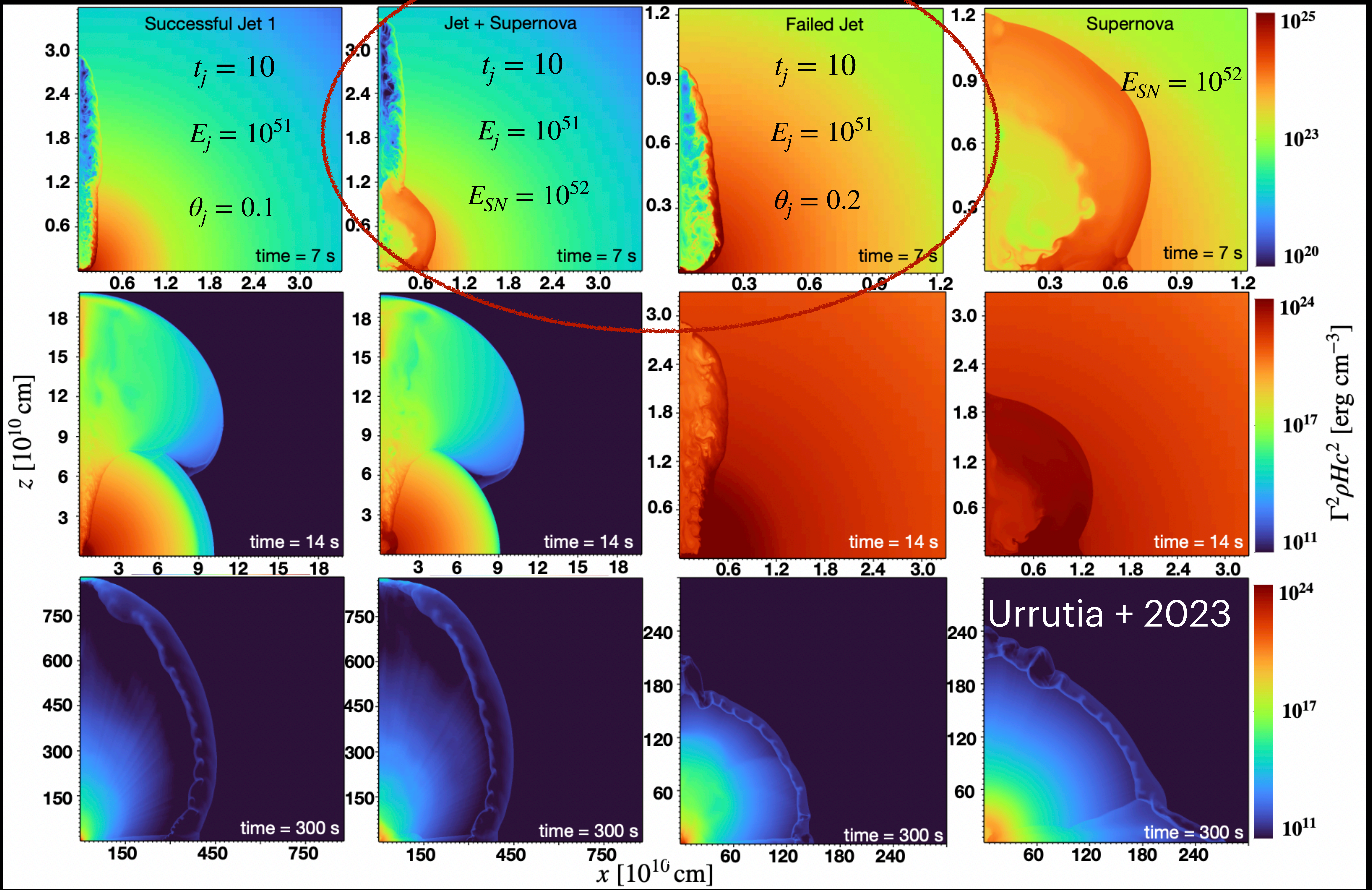
Jets beyond the iron core: jets initially structured



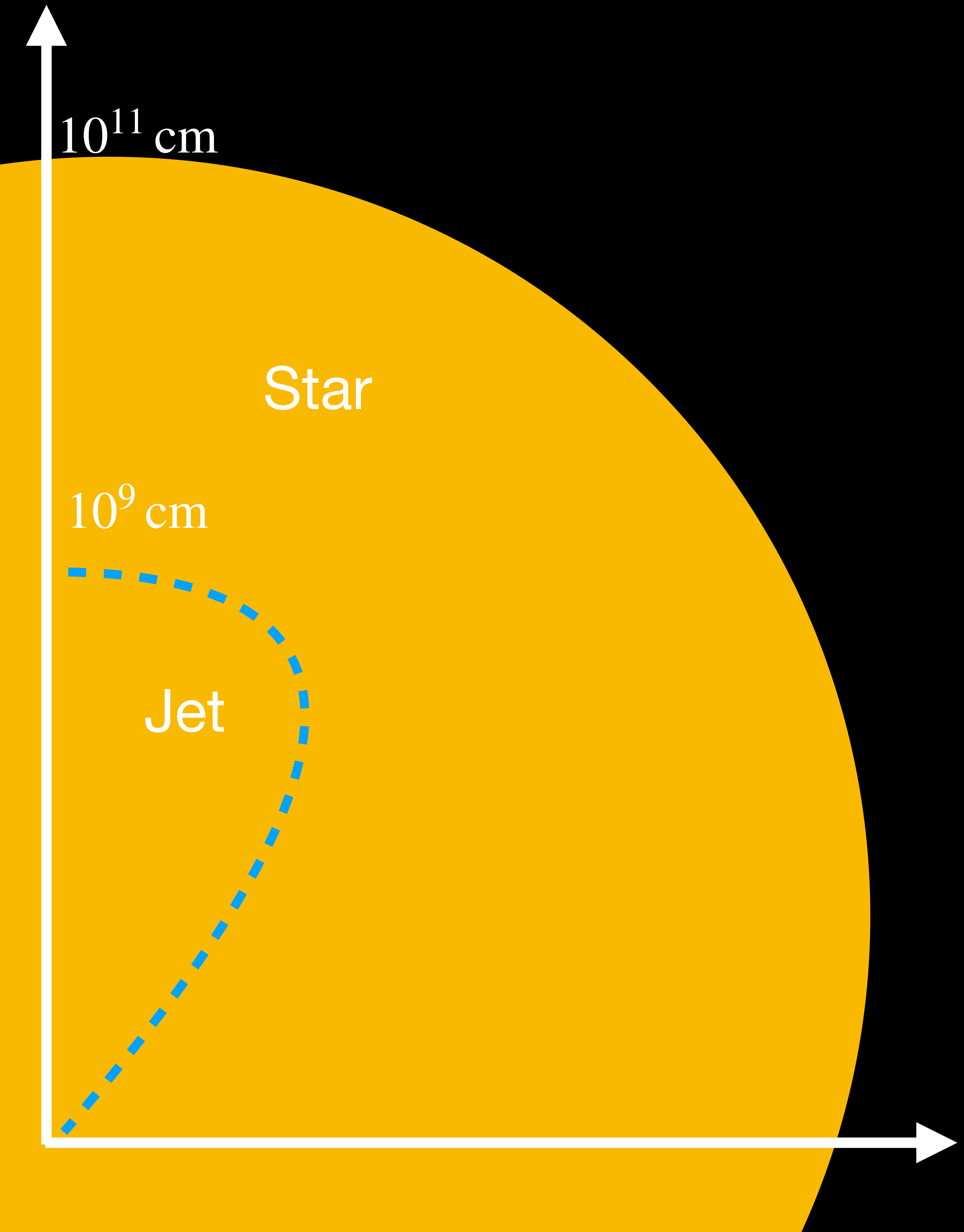


Urrutia, De Colle & Lopez-Camara 2023

Summary: The role of jet/progenitor parameters

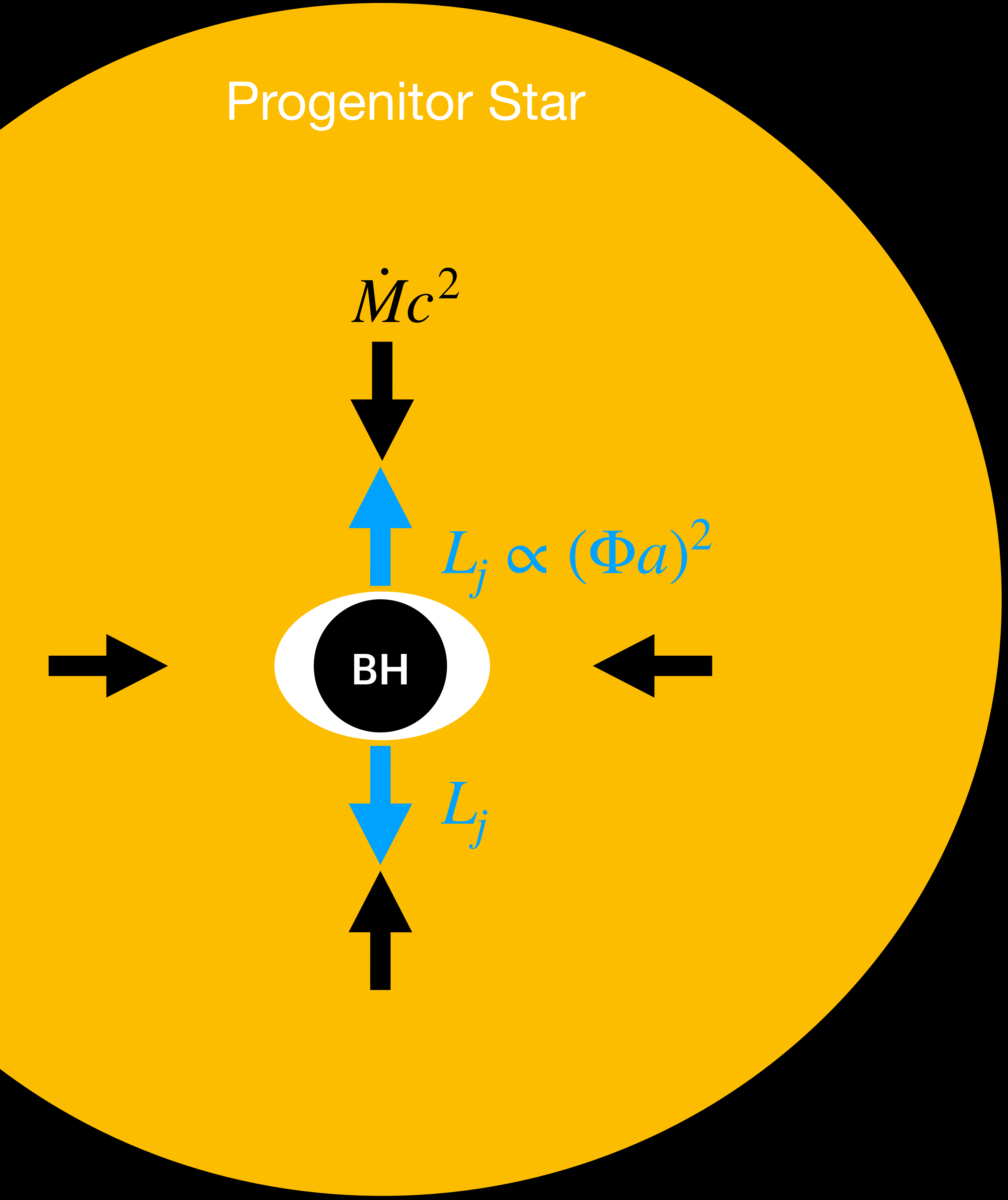


Connection of central engine activity with large scale dynamics?



- Luminosity vs. Time
- Distribution of velocities
- Variability
- Mean life time of the progenitor
- Jet opening angle
- Final estructure of the jet

Jet launching from the center



Fast spinning BH (e.g., MacFadyen & Woosley 1999)

Angular moment distribution $l \propto l_0 \sin^2(\theta)$

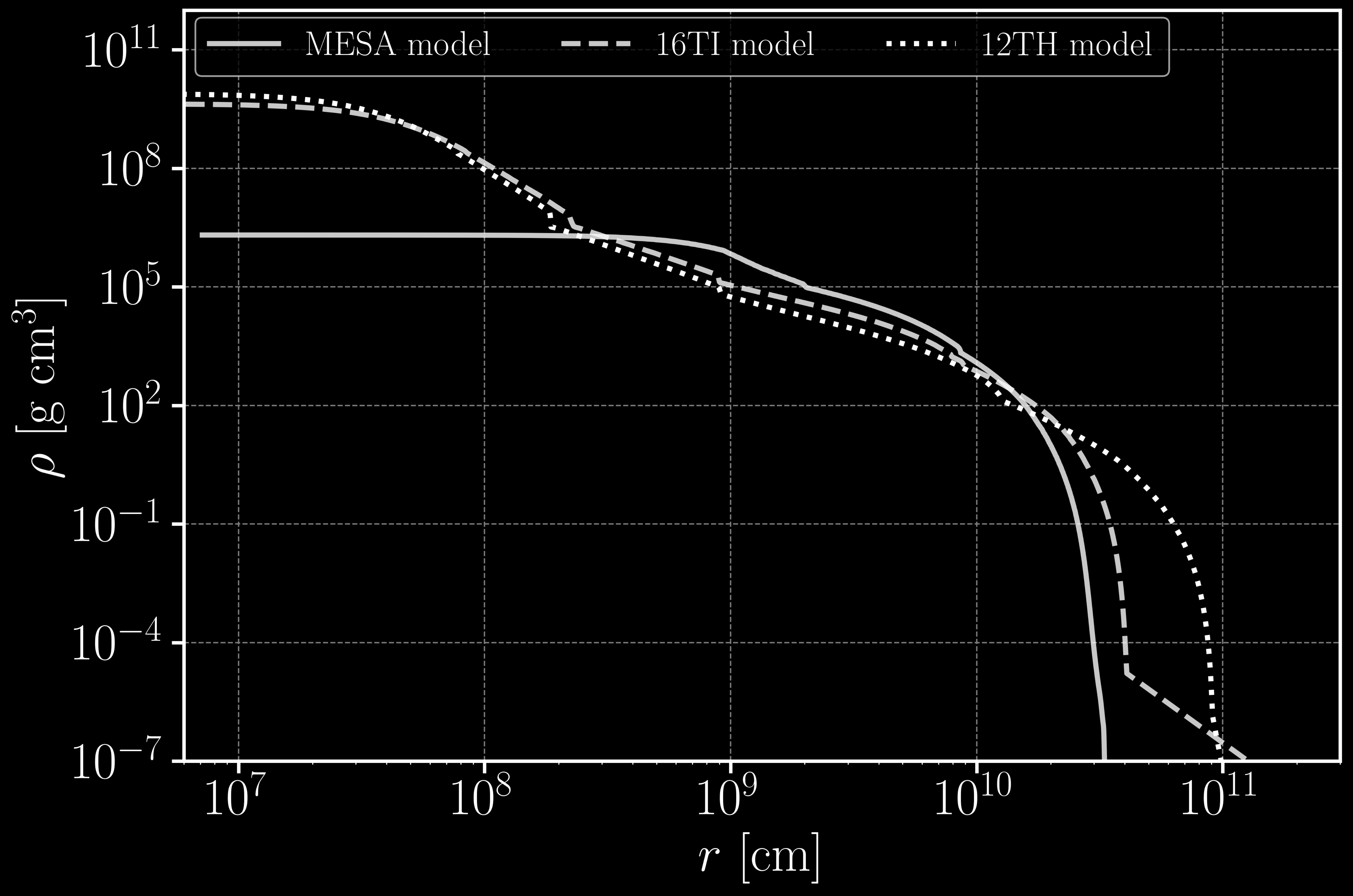
Dynamical time $t_{\rm dyn} \sim 10\,{\rm s}$

Accretion rate $\dot{M} \sim 0.1\,M_{\odot}{\rm s}^{-1}$

Magnetic Field $B_0 \sim 10^{14} - 10^{15}\,{\rm G}$

(e.g., Burrows 2007, Mösta 2014; 2015; Obergaulinger & Aloy 2020; Gottlieb 2022)

Jet launching from the center



Rotation

$$\epsilon_{\rm isco} = -u_{t,\rm isco} = \frac{1 - 2/r_{\rm isco} + a/r_{\rm isco}^{3/2}}{\sqrt{1 - 3/r_{\rm isco} + 2a/r_{\rm isco}^{3/2}}}$$

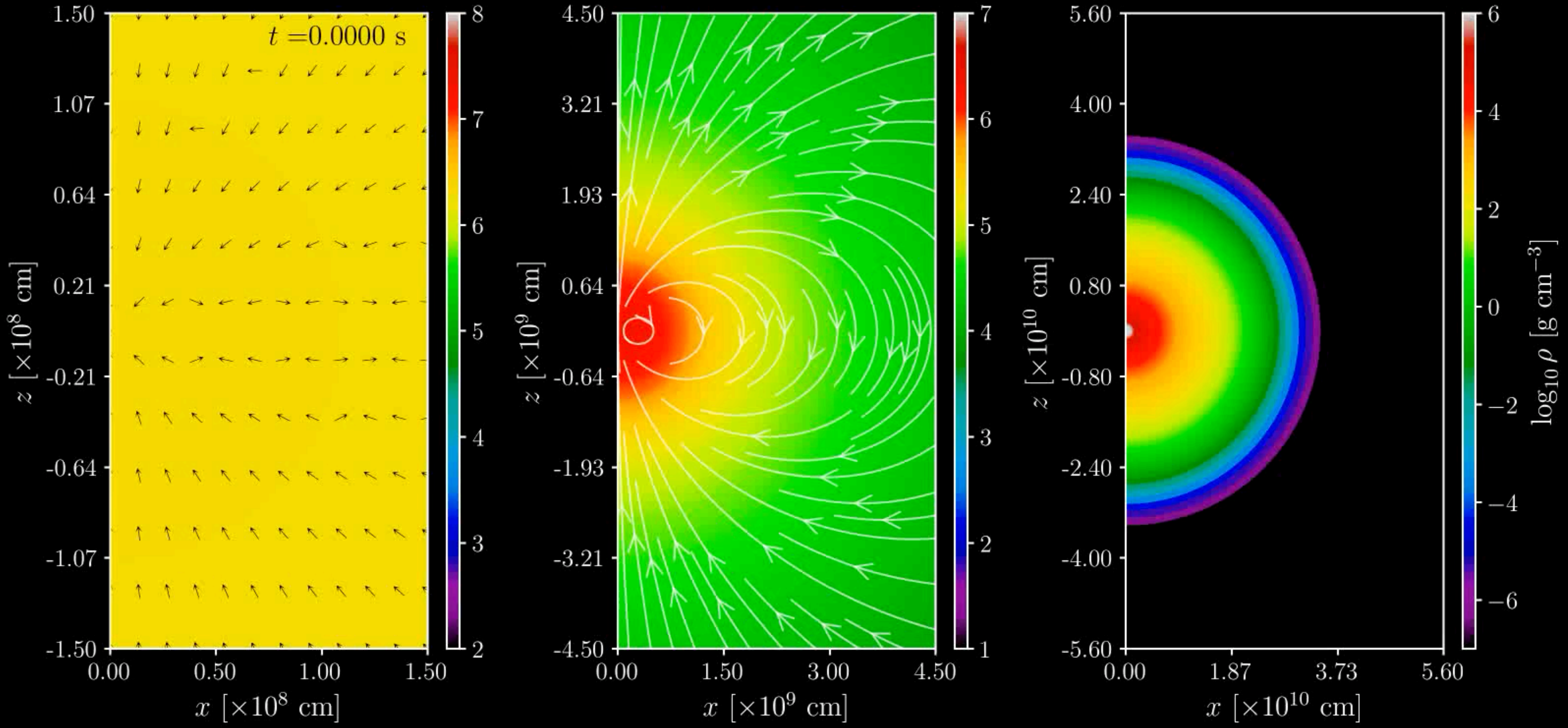
$$l_{\rm isco} = u_{\phi,\rm isco} = \frac{r_{\rm isco}^{1/2} - 2a/r_{\rm isco} + a^2/r_{\rm isco}^{3/2}}{\sqrt{1 - 3/r_{\rm isco} + 2a/r_{\rm isco}^{3/2}}}$$

$$u^{\phi} = C\sin^2\theta\left(-g^{t\phi}\epsilon_{\rm isco} + g^{\phi\phi}l_{\rm isco}\right)$$

Magnetic Field Potential

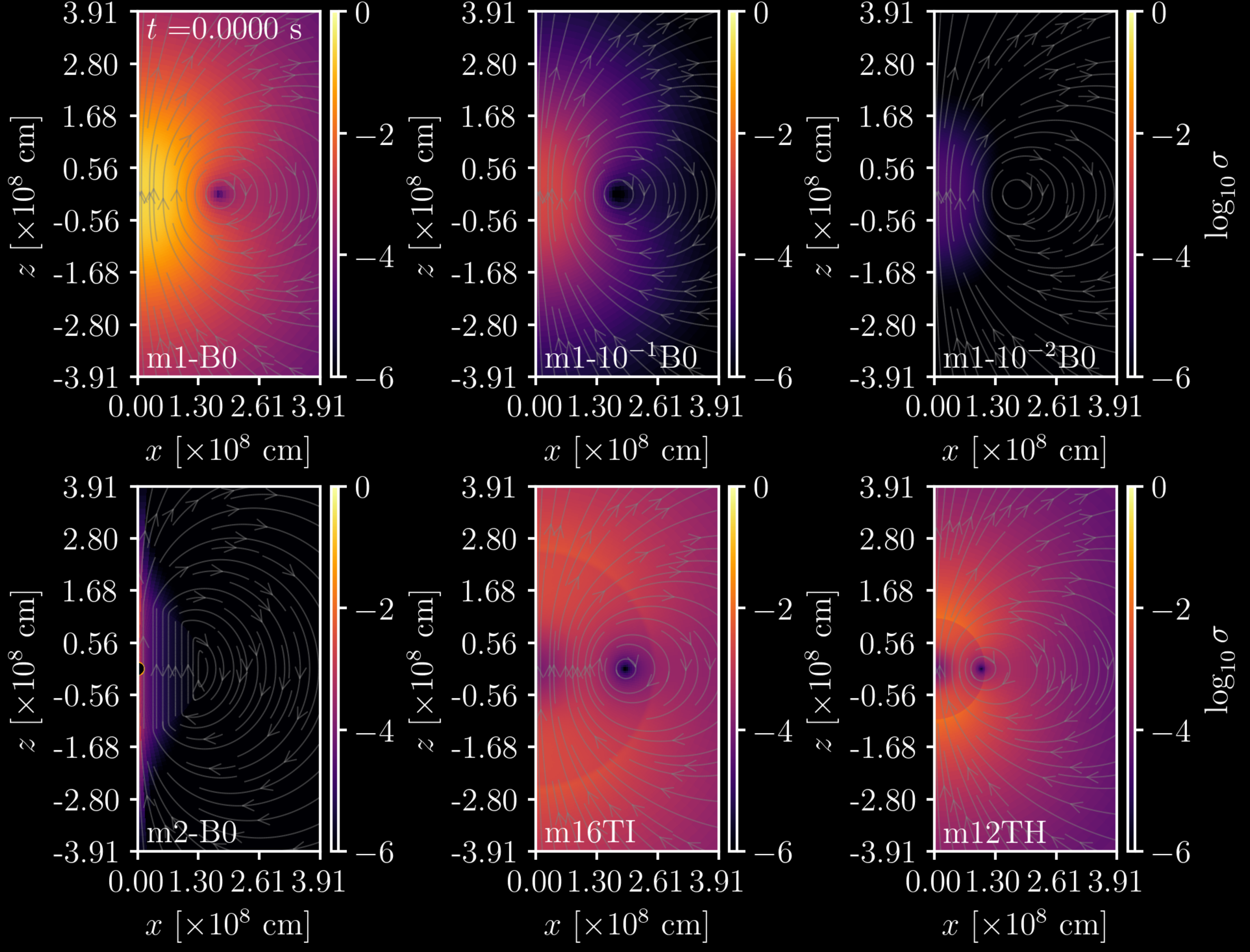
$$A_{\phi} = \frac{B_0 r_c^3}{r^3 + r_0^3}\sin\theta$$

We are remapping the stelar profile in BHAC code (Porth + 2017; Olivares + 2019)

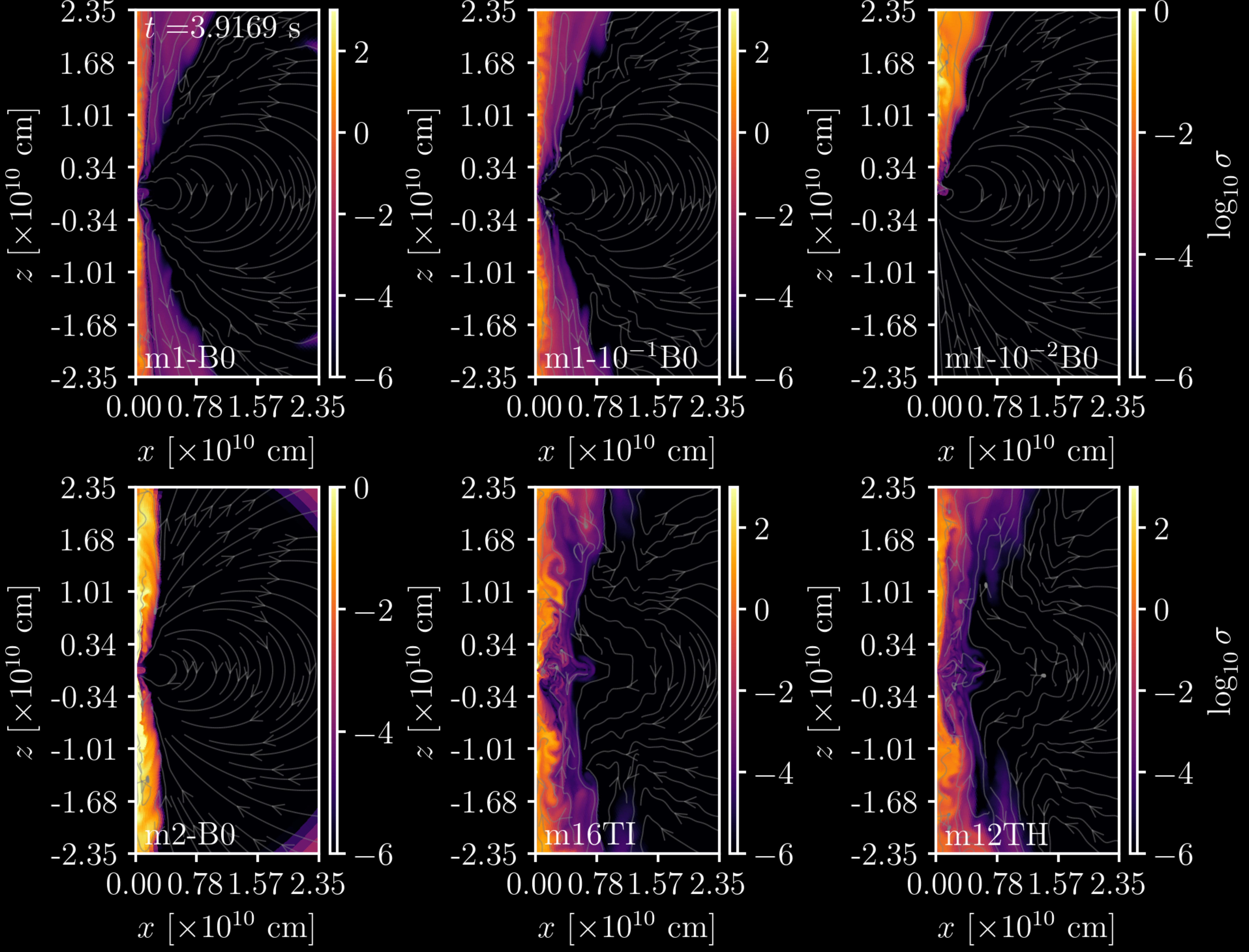


$t = 0.0000$ s
x [$\times 10^8$ cm]
z [$\times 10^8$ cm]
x [$\times 10^9$ cm]
z [$\times 10^9$ cm]
x [$\times 10^{10}$ cm]
z [$\times 10^{10}$ cm]
$\log_{10} \rho$ [g cm^{-3}]

Magnetization

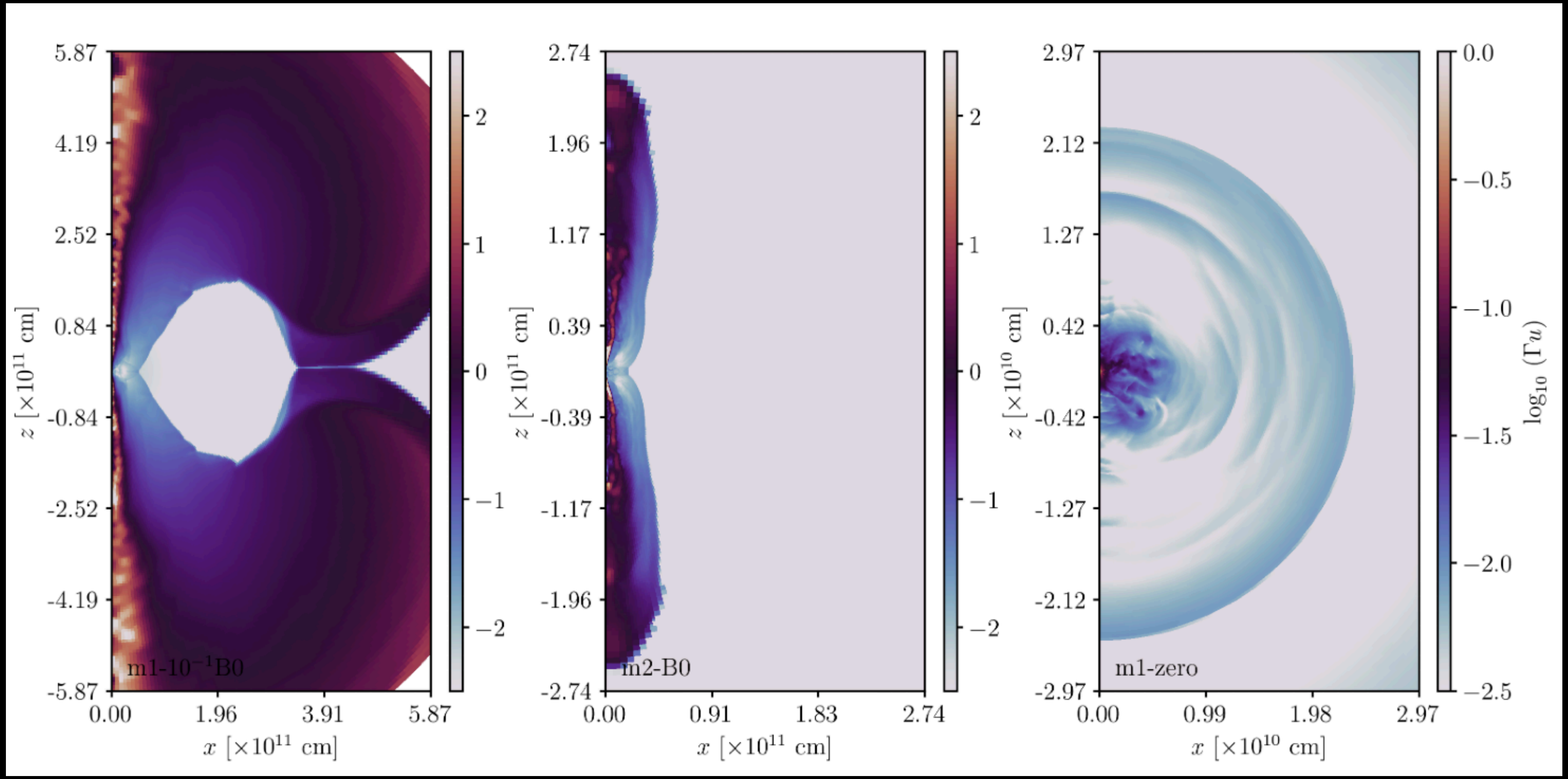


Magnetization

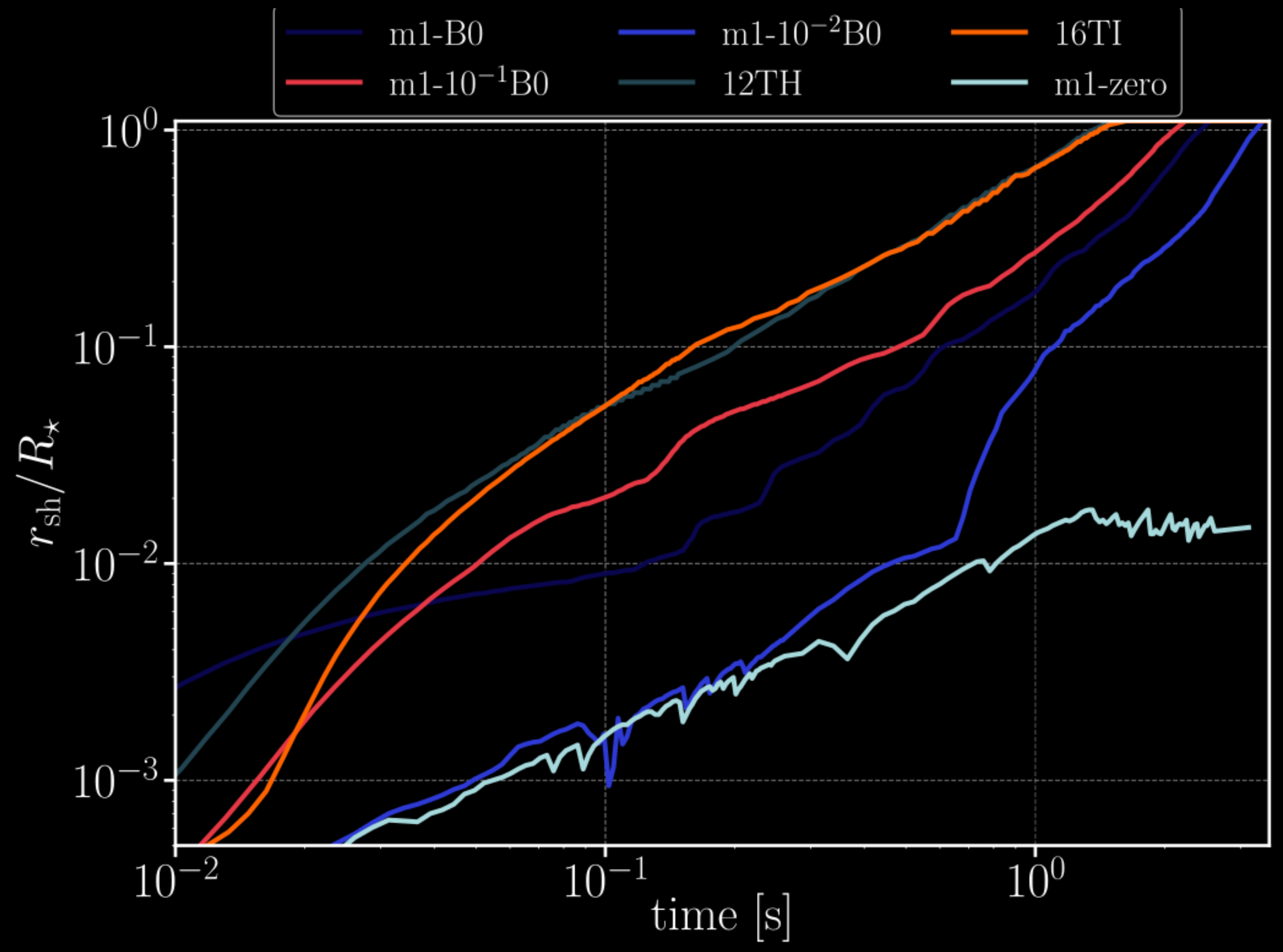


Jet propagation

High magnetized | Weakly magnetized | Non magnetized

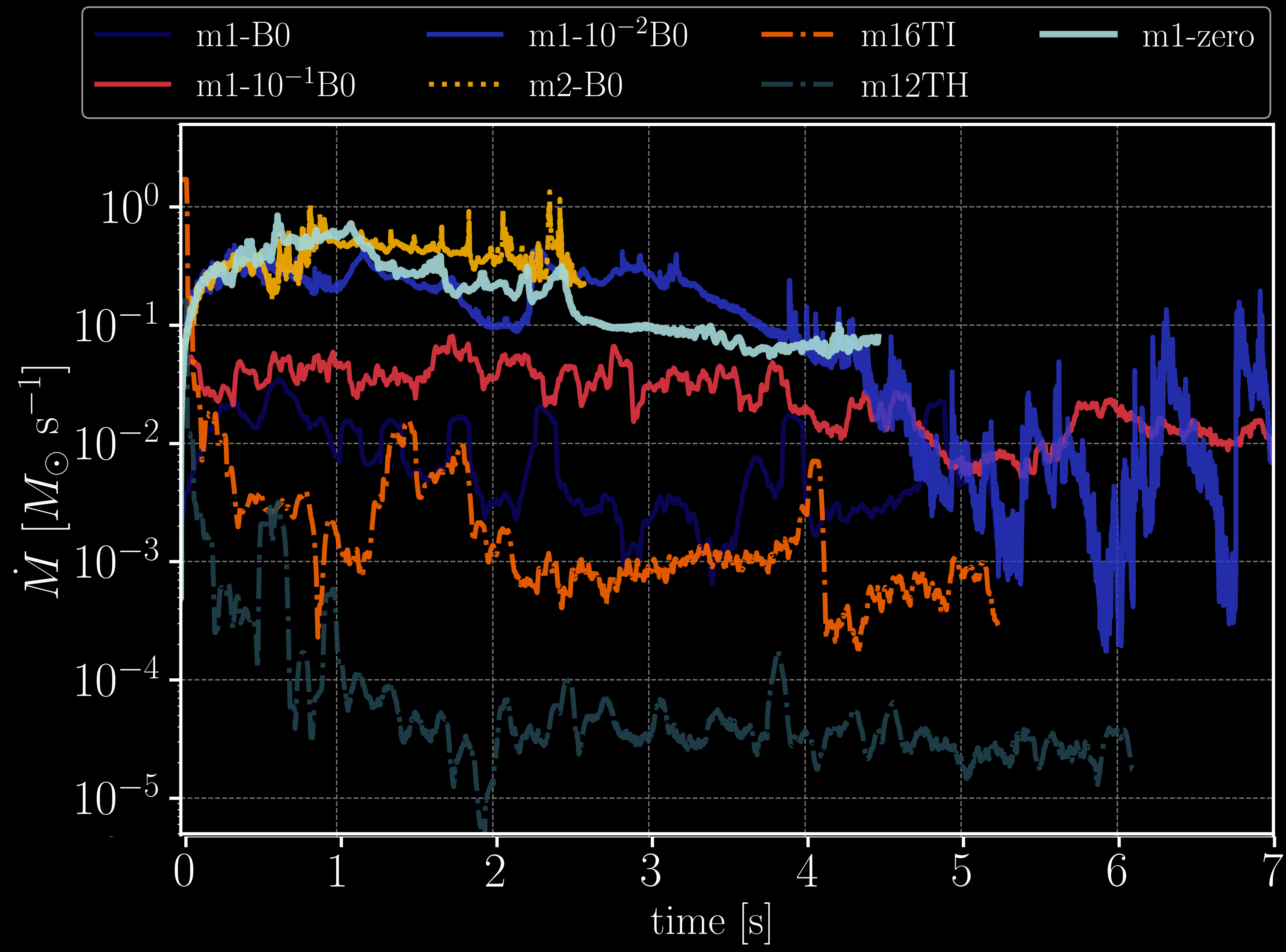


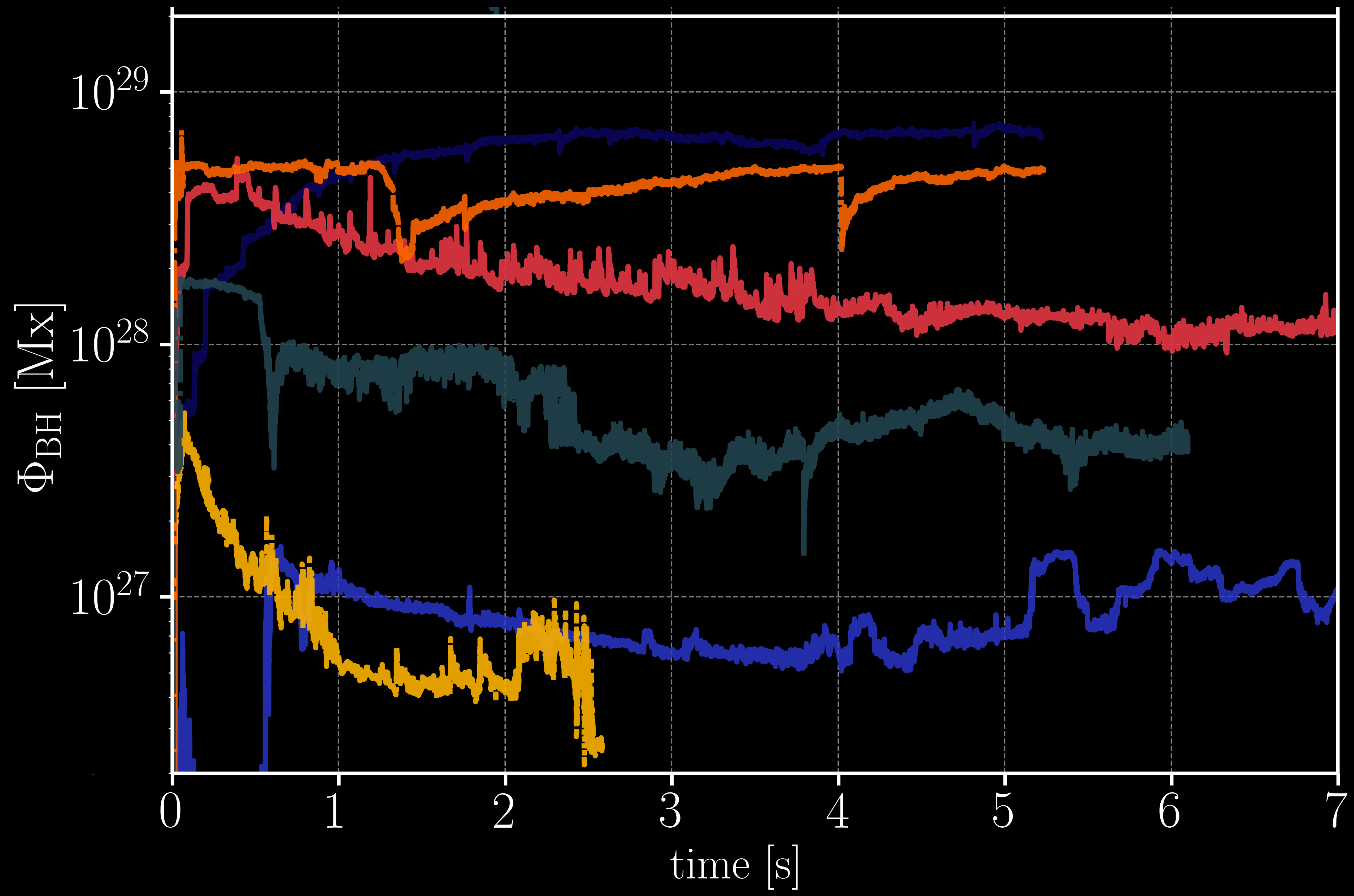
Shock front



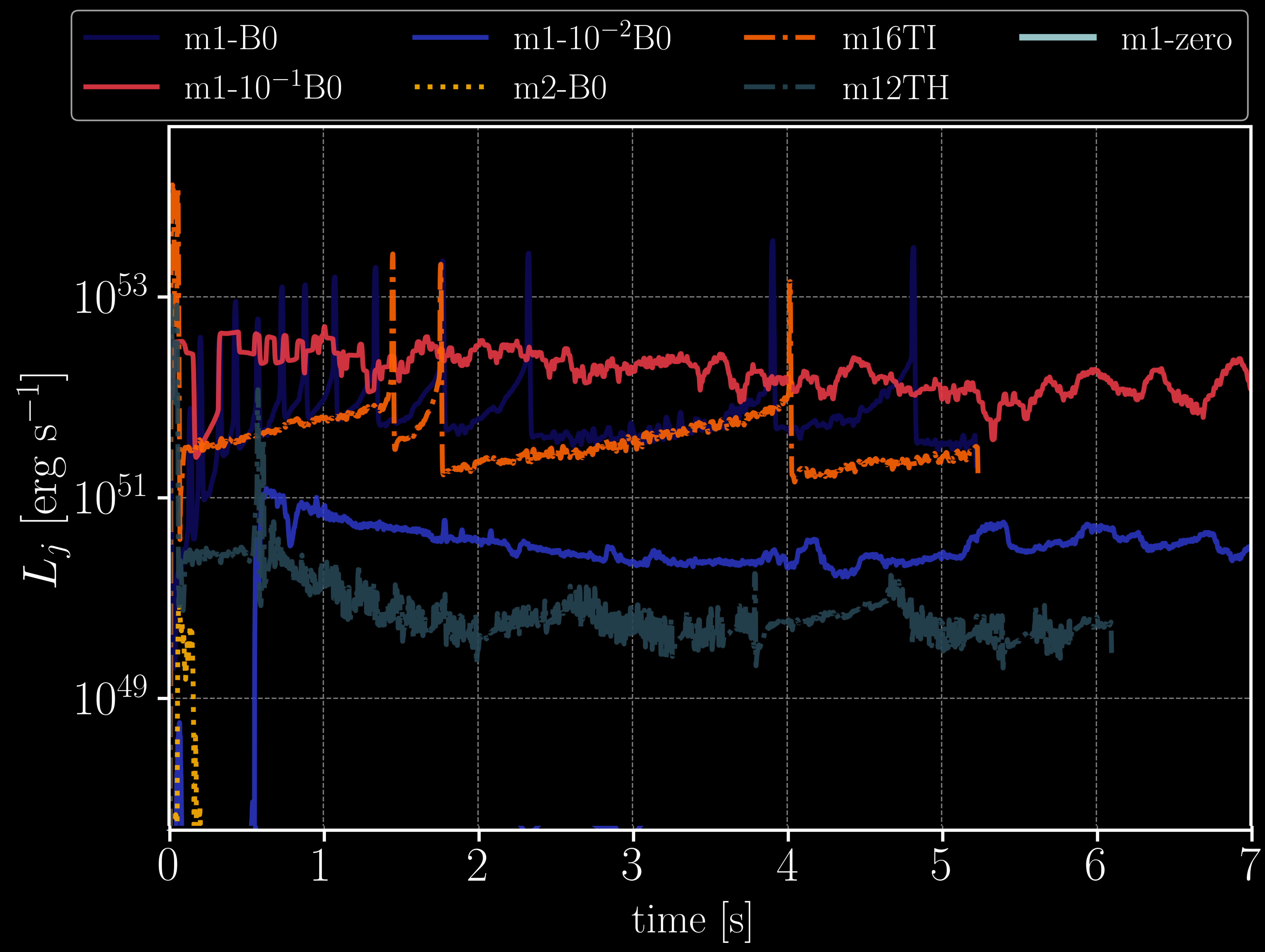
Model	$\theta_{j,50}$ [°] $\sigma > 1$	$\theta_{j,R_\star}$ [°] $\sigma > 1$	$\Gamma u > 2$
m1-B0	8.6	4.5	8.4
m1-10^{-1}B0	6.4	6.6	8.7
m1-10^{-2}B0	6.7	2.6	5.2
16TI	4.9	8.4	10.6
12TH	5.8	4.6	7.5

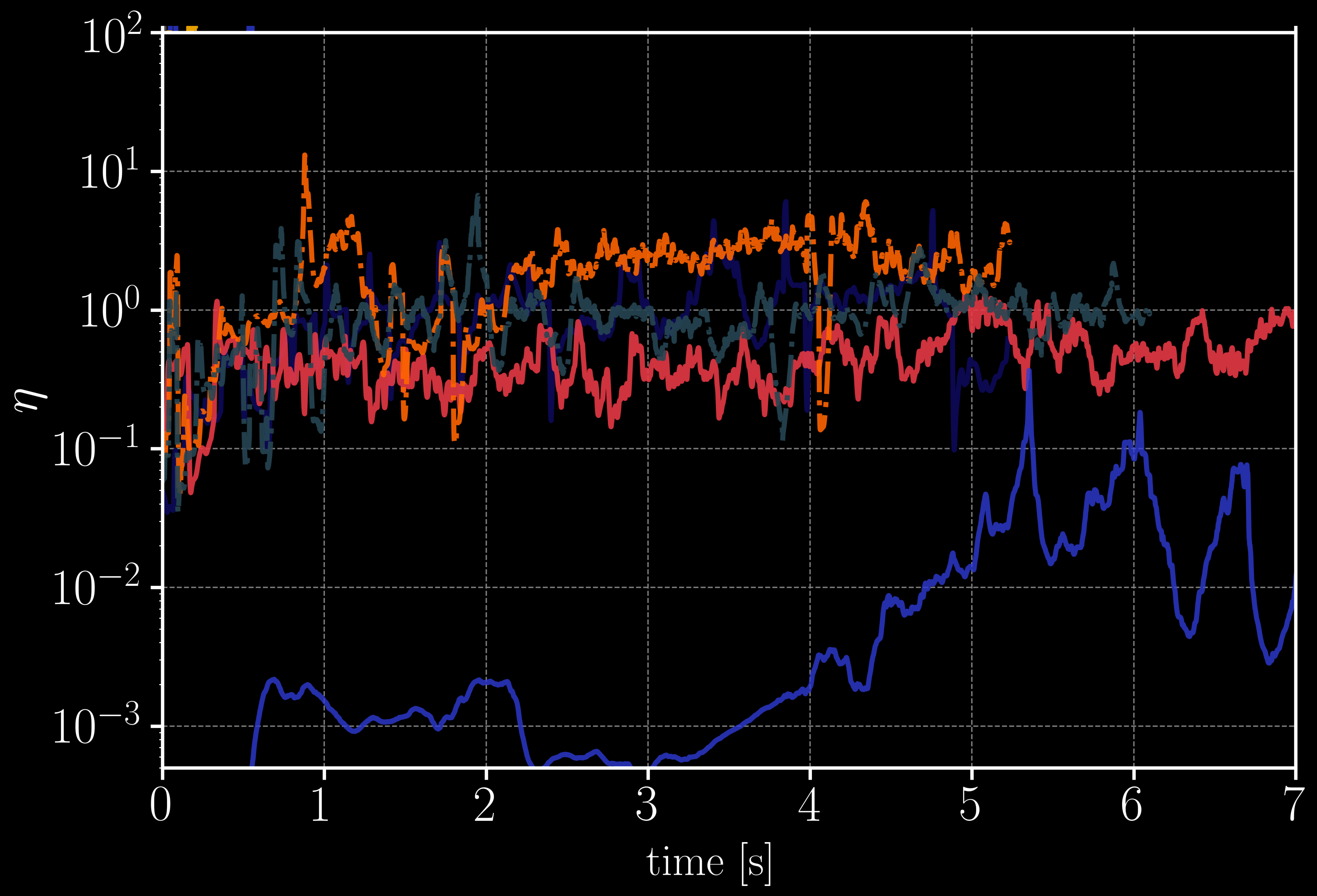
Central engine activity



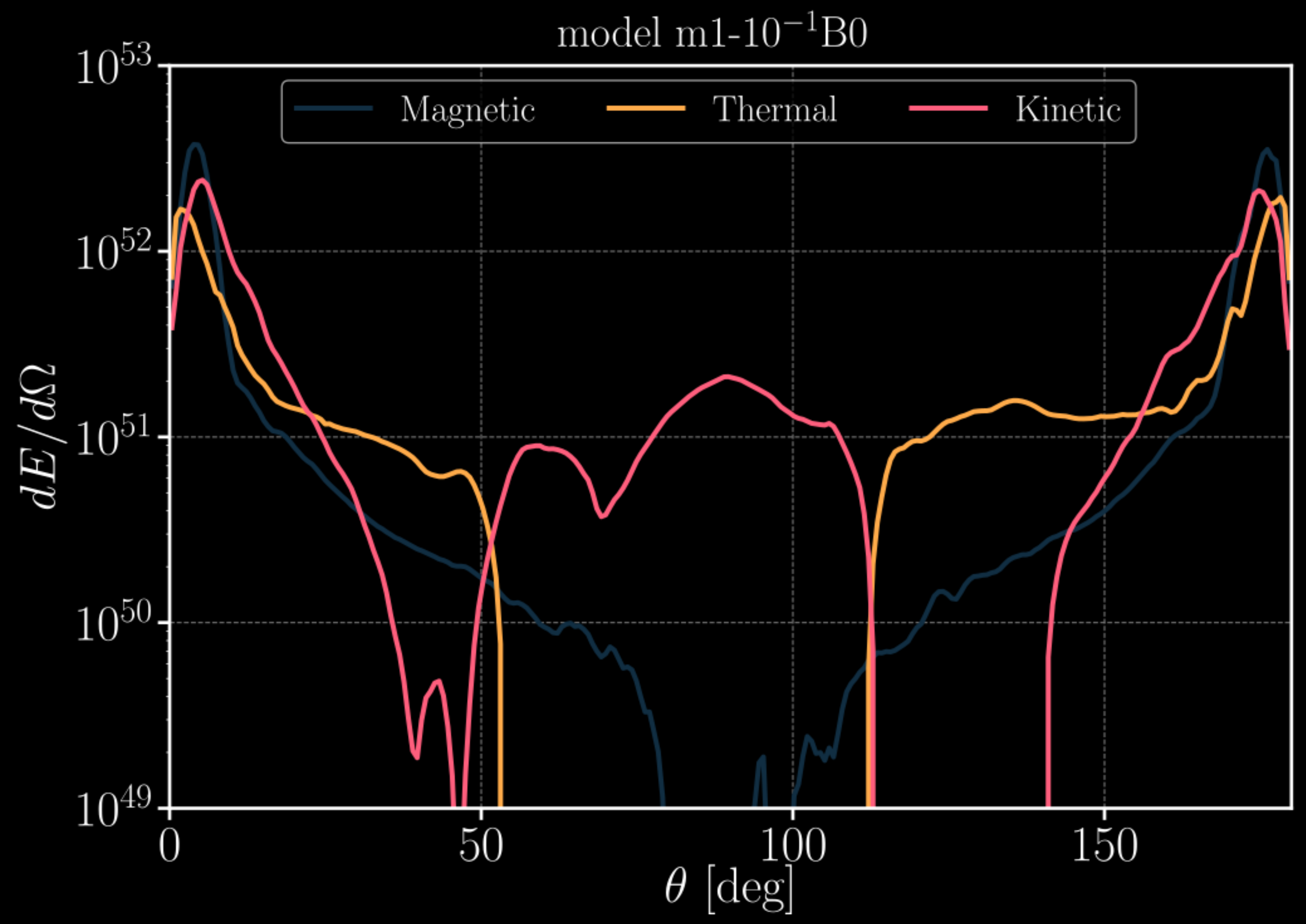


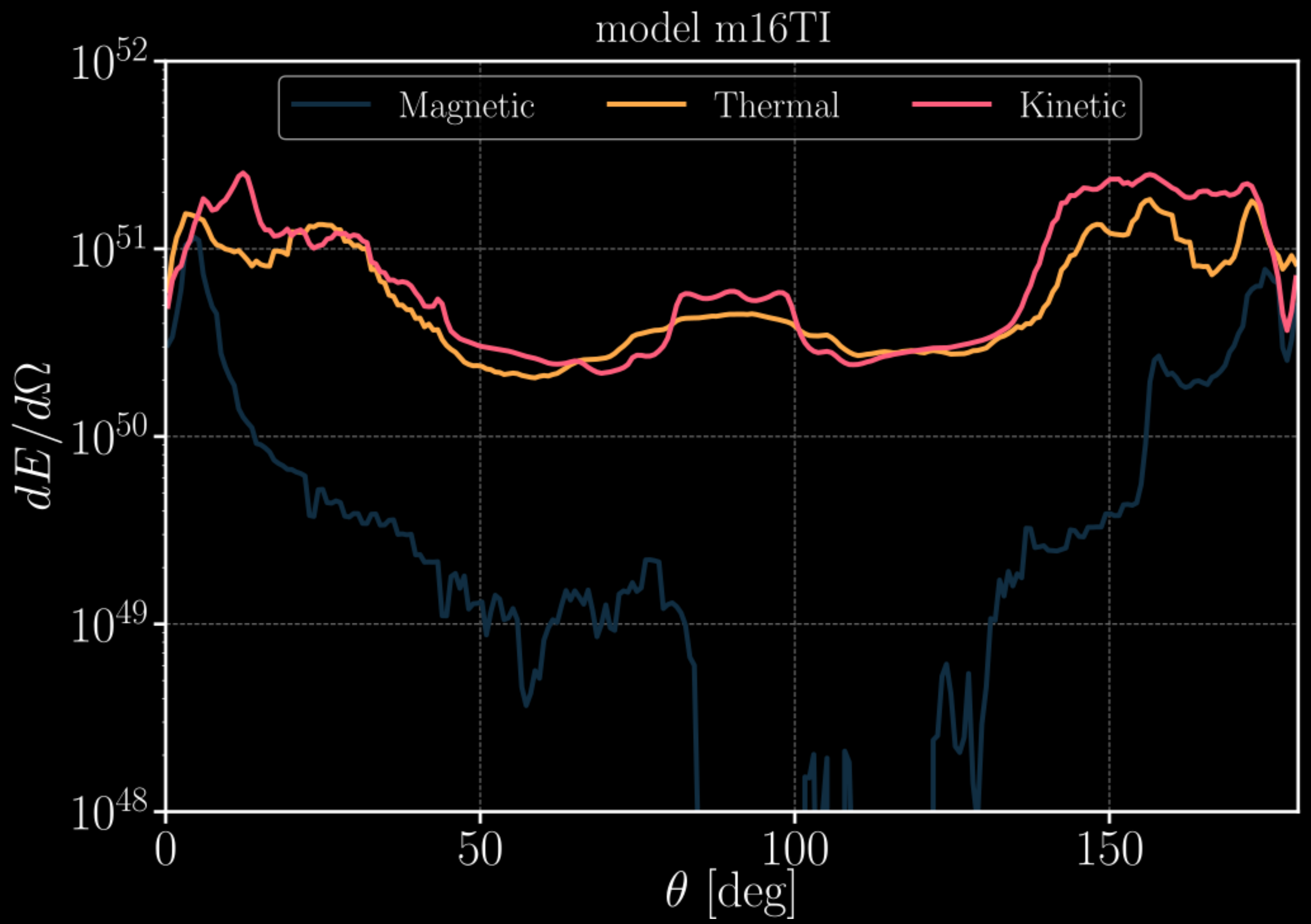
Jet luminosity and efficiency



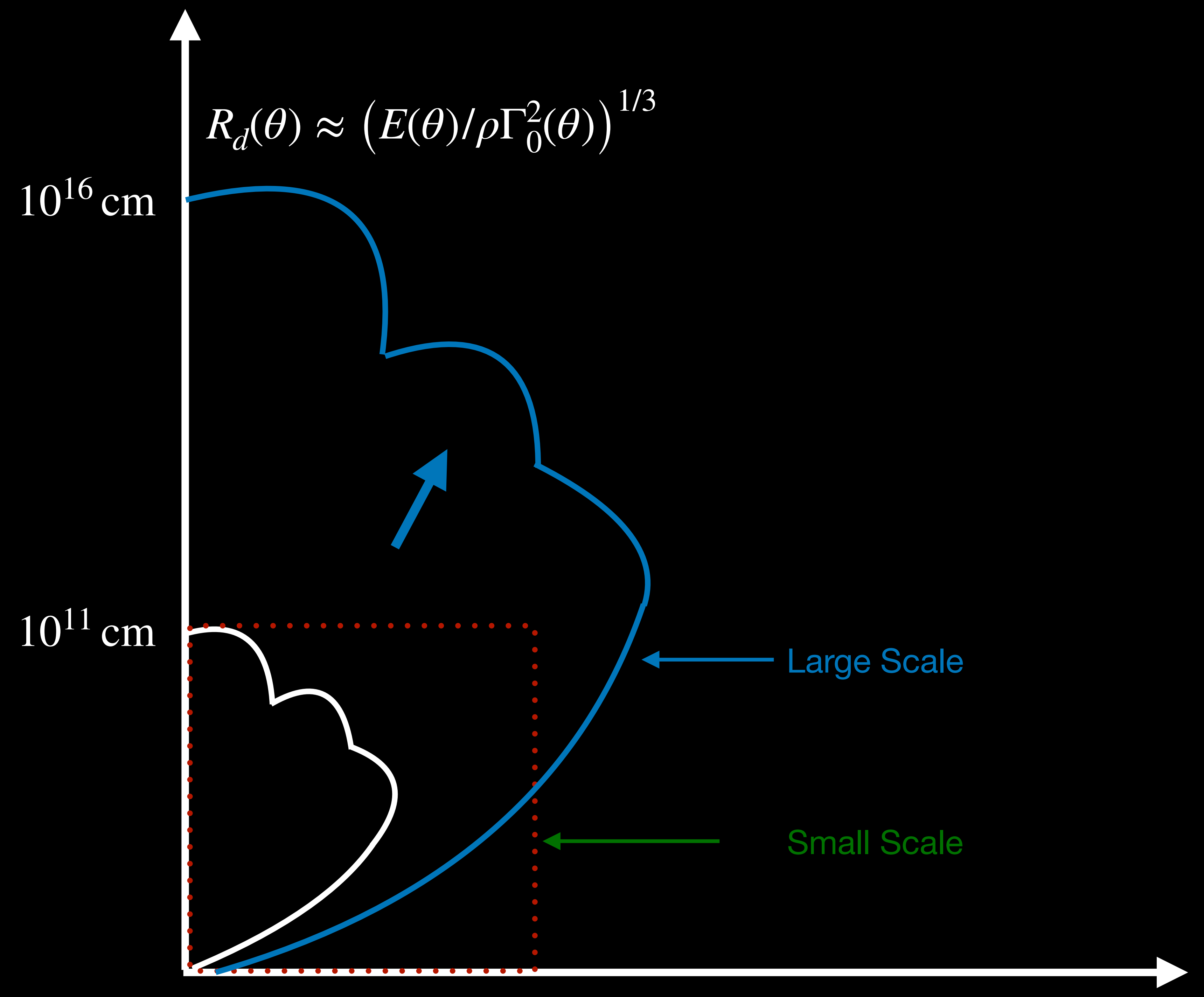


Jet structure

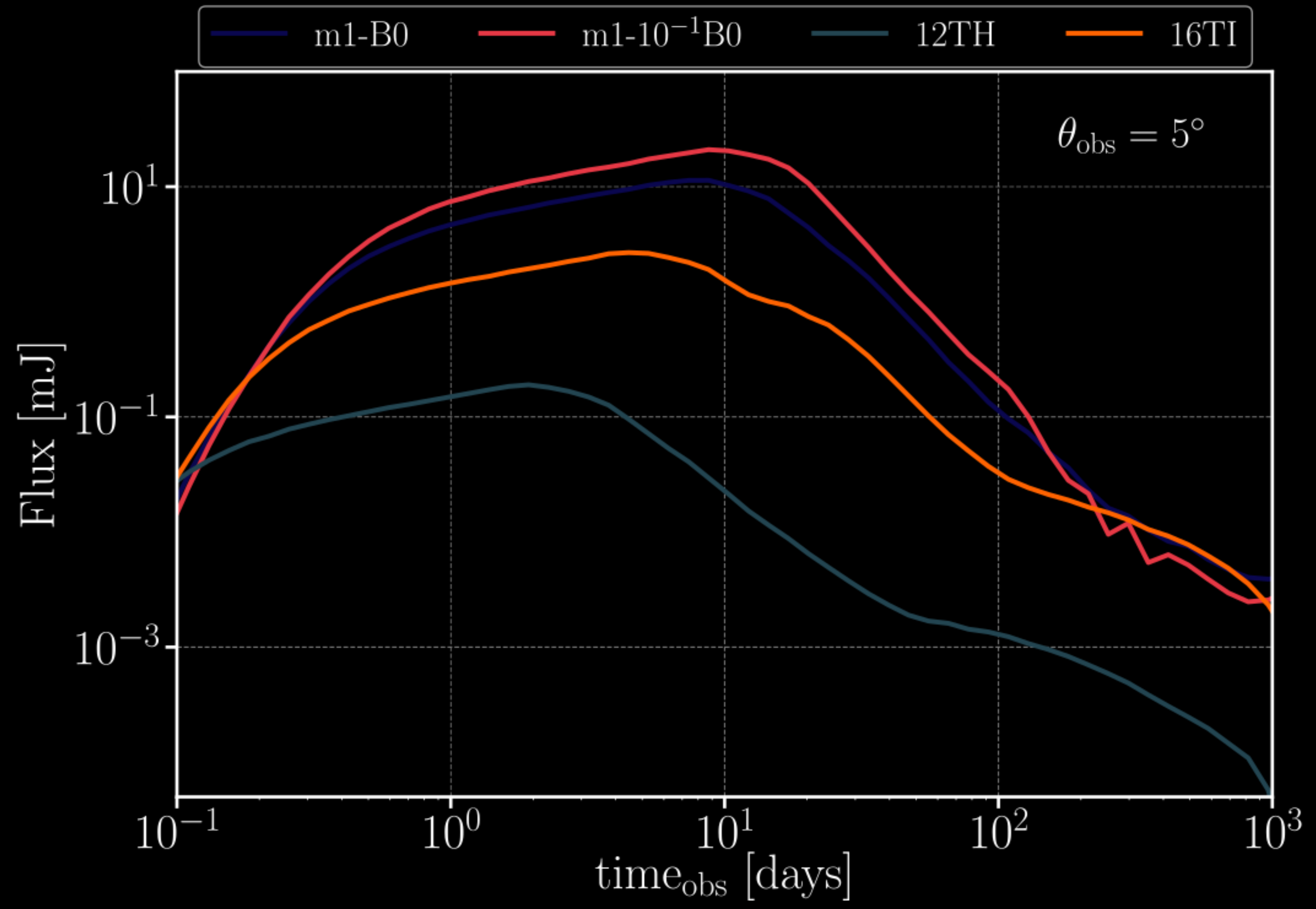




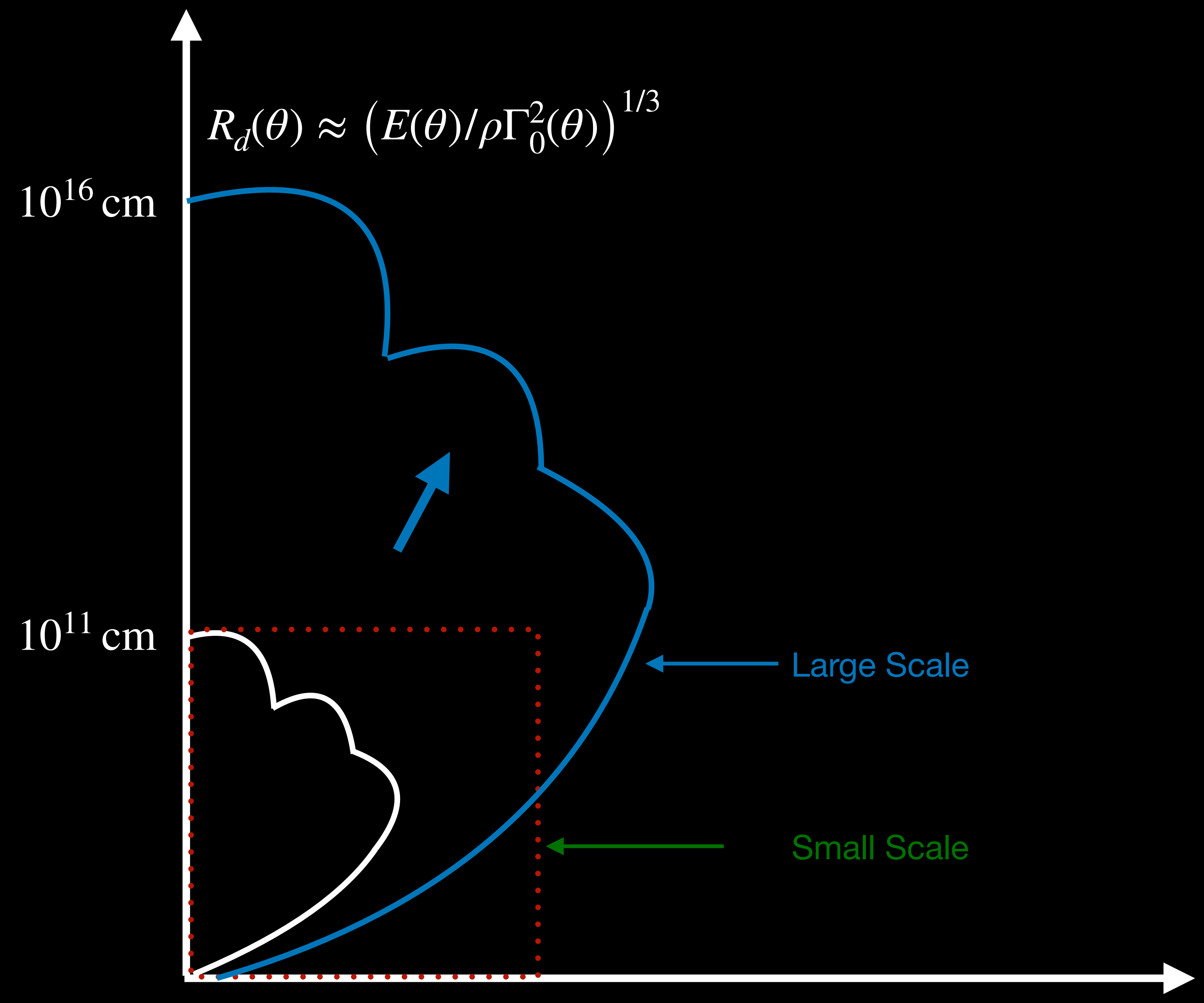
Afterglow estimation from jet structure



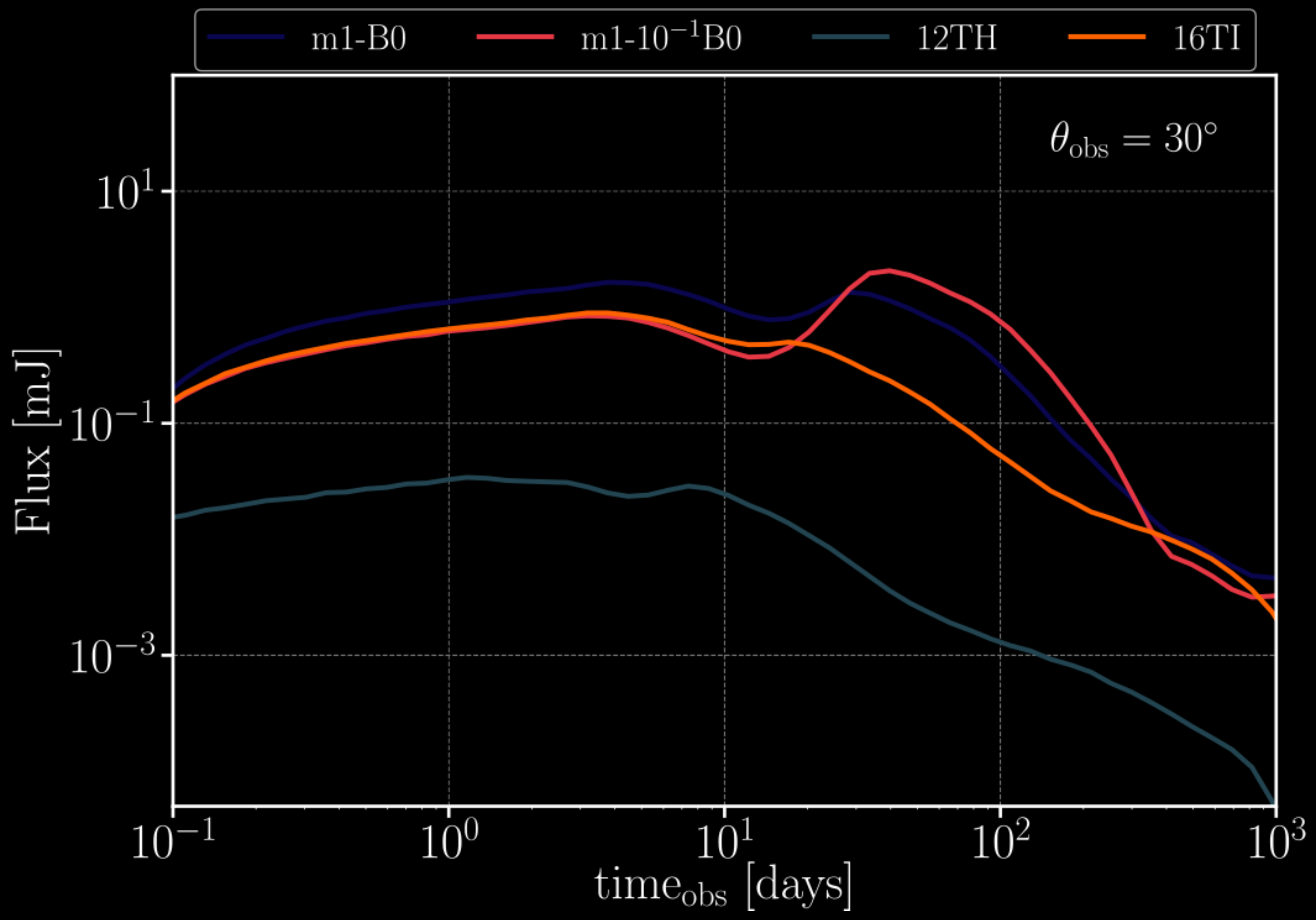
$\theta_{\rm obs} = 5°$



Jet structure



$\theta_{obs} = 30°$



Summary

- Jets are launched only when a dipolar field with peak strength B0 >1e12 G. It produces a magnetic flux > 1e25 Mx.

- We obtained jet luminosities: 1e50-1e53.

- Strongly magnetized models develop a narrow, highly magnetized core surrounded by moderately magnetized wings.

- Hybrid field geometries yield a quasi-cylindrical outflow described as a failed jet.

- At jet’s breakout the magnetization drops and kinetic energy dominates.

- For identical magnetic setups, the Wolf–Rayet models 12TH and 16TI, whose envelopes fall more steeply than the MESA star, allow faster head propagation. They also produce stronger core–wing mixing and larger terminal opening angles.

- A purely hydrodynamic accretion flow amplifies the central density but never excavates a low–density funnel, therefore, disk winds alone can not break the progenitor star.

¡Gracias! - Thank you!

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dxdxpandx cft

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