Numerical simulations of Long Gamma Ray Bursts from small to large scales

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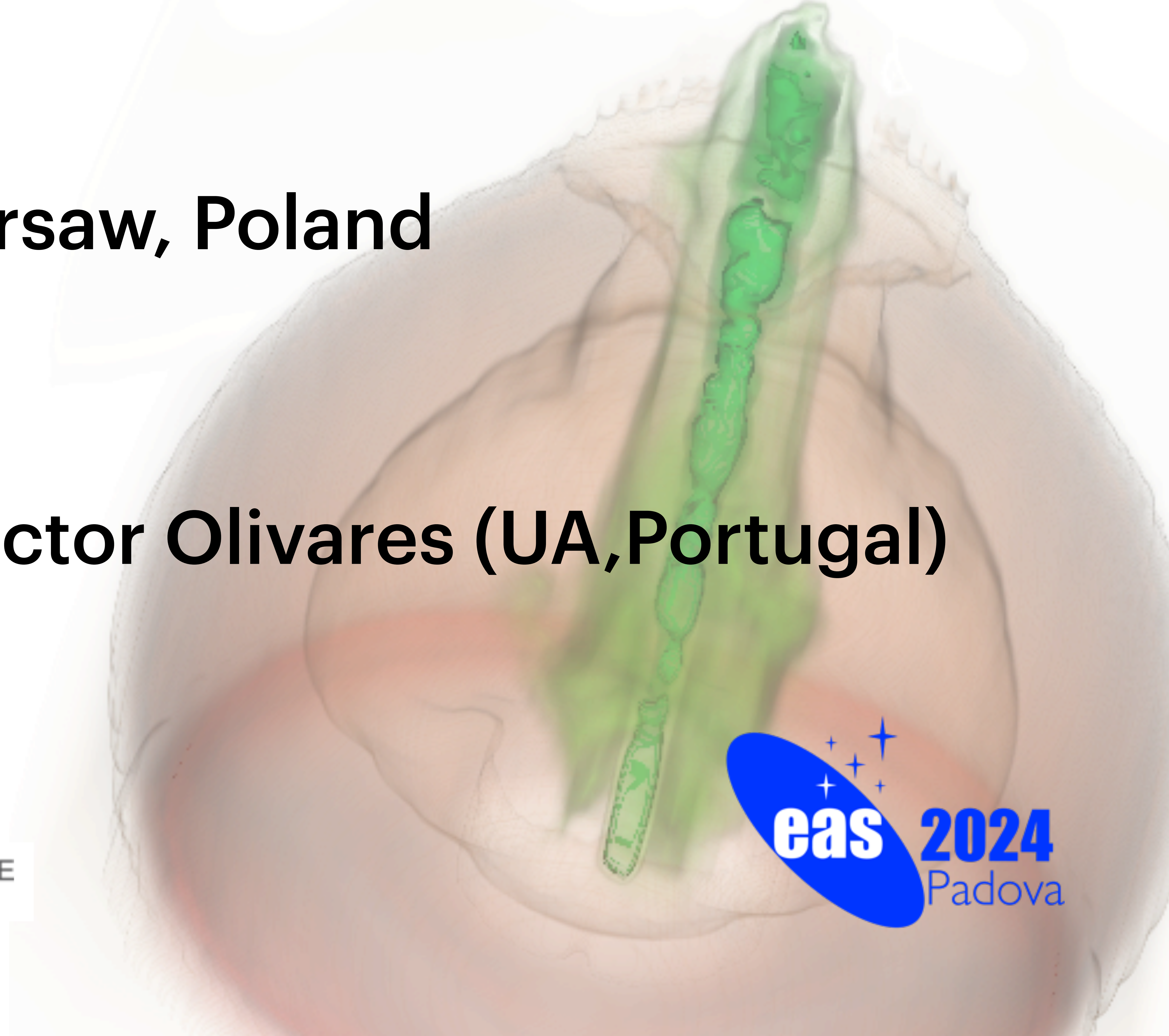

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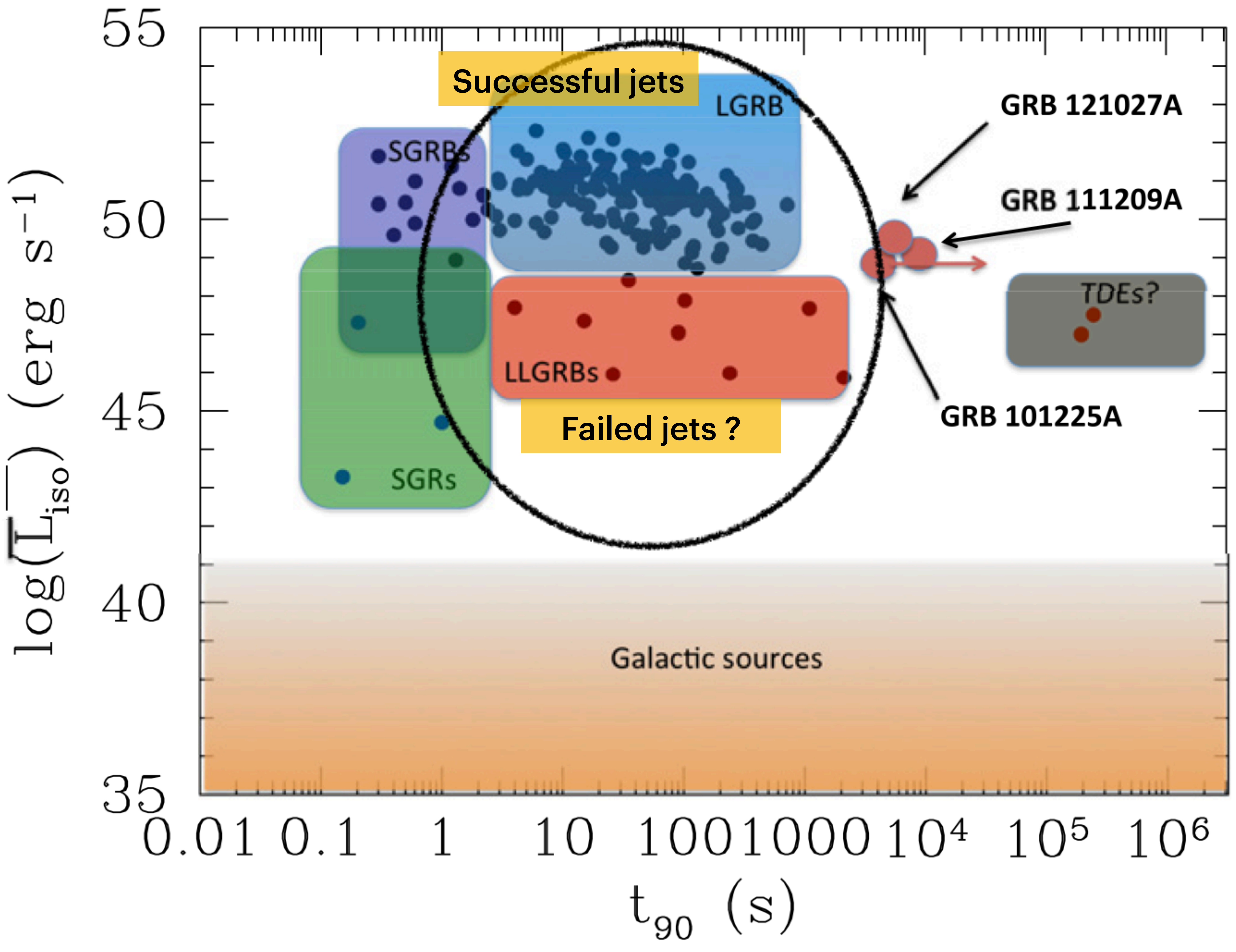
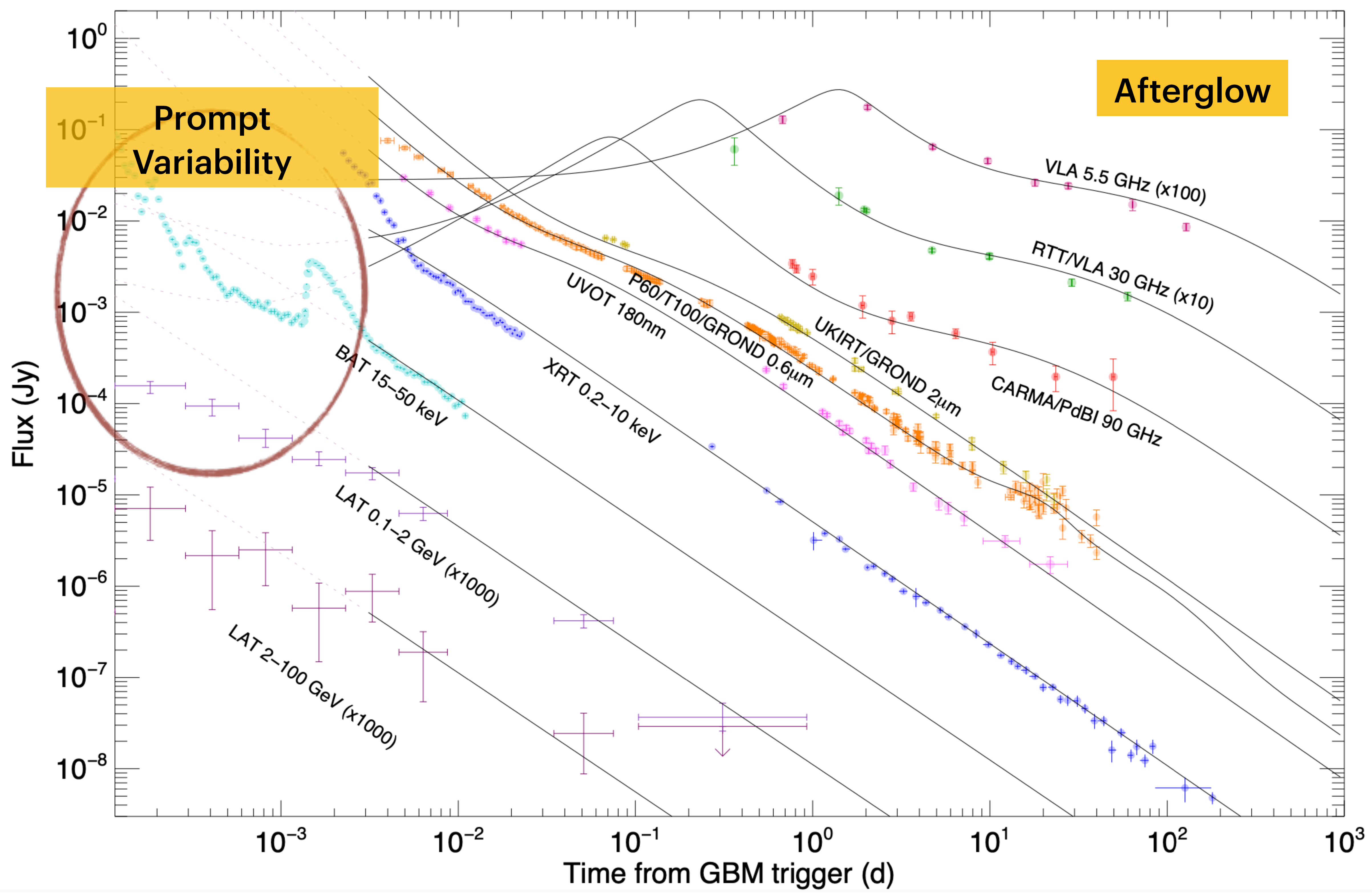
Long GRBs



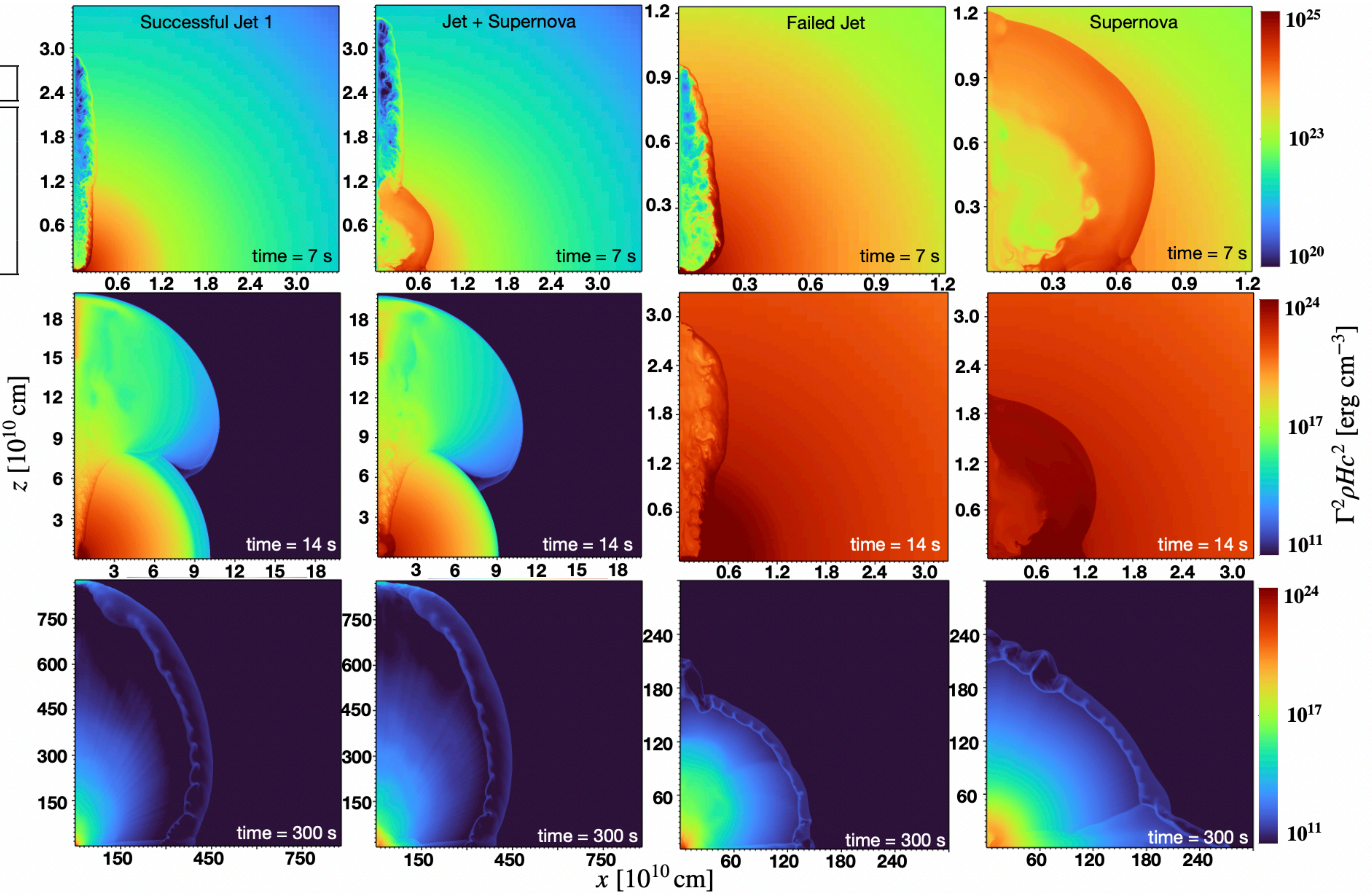
Levan et al. 2014



GRB 130427, Perley et al. 2013

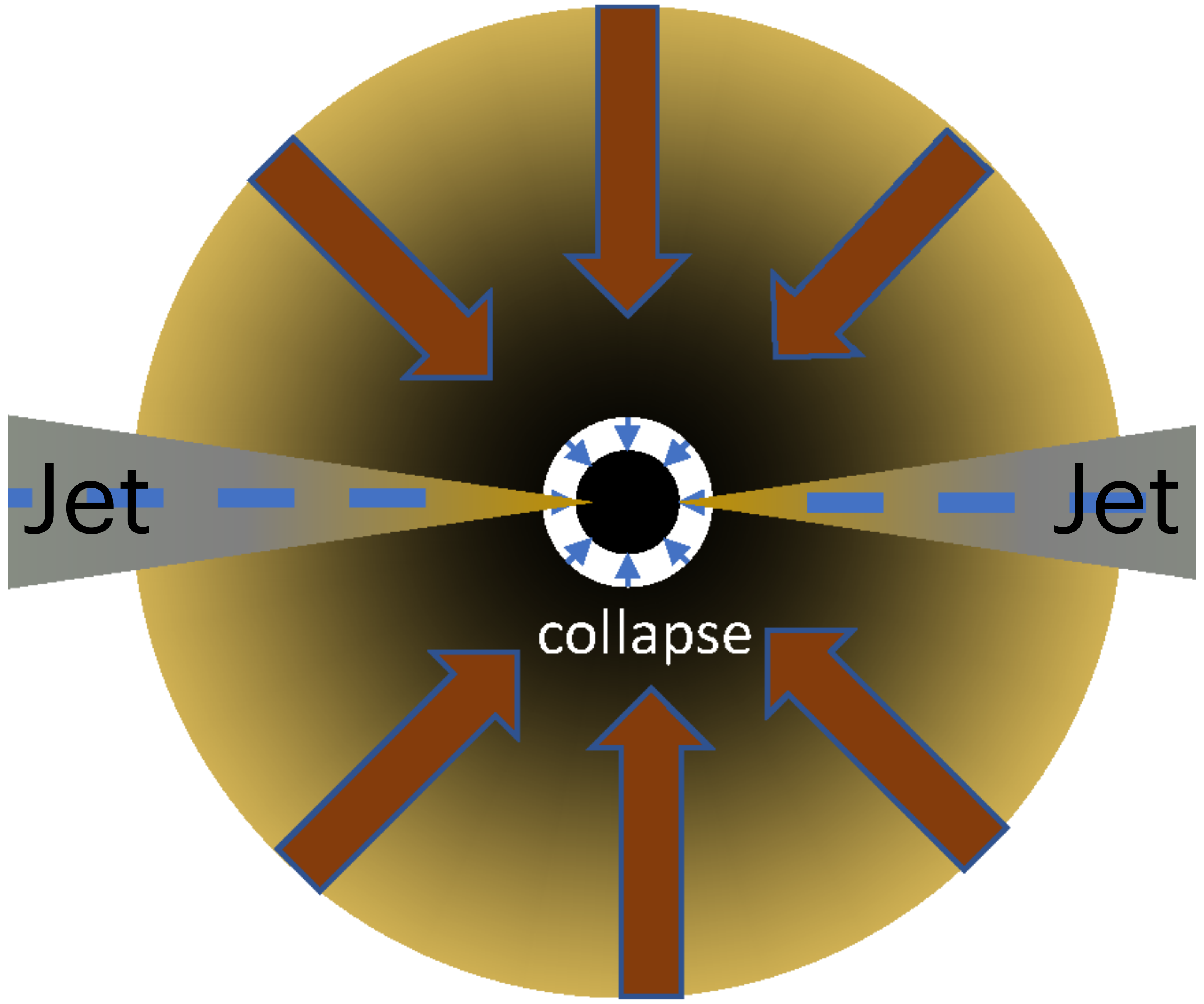
Jet dynamics

Scenario	$t_{\rm inj}$ (s)	Energy (erg)
Successful jet	10	10^{51}
Successful jet	2.5	10^{52}
Failed jet	10	10^{51}
Supernova	1	10^{52}
Jet + Supernova	10	10^{51}



Urrutia et al. 2023

The collapse of massive star produce a Long GRB



- Fast spinning BH (MacFadyen & Woosley 1999)
  - Angular moment distribution
  - Funnel

$$t_{\rm dyn} \sim 10{\rm s} \qquad \dot{M} \sim 0.1 M_\odot {\rm s}^{-1}$$

- Magneto rotational core collapse (Mösta 2014; 2015; Obergaulinger & Aloy 2020; Gottlieb 2022)

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

Figure Credits: Dado et al. 2022

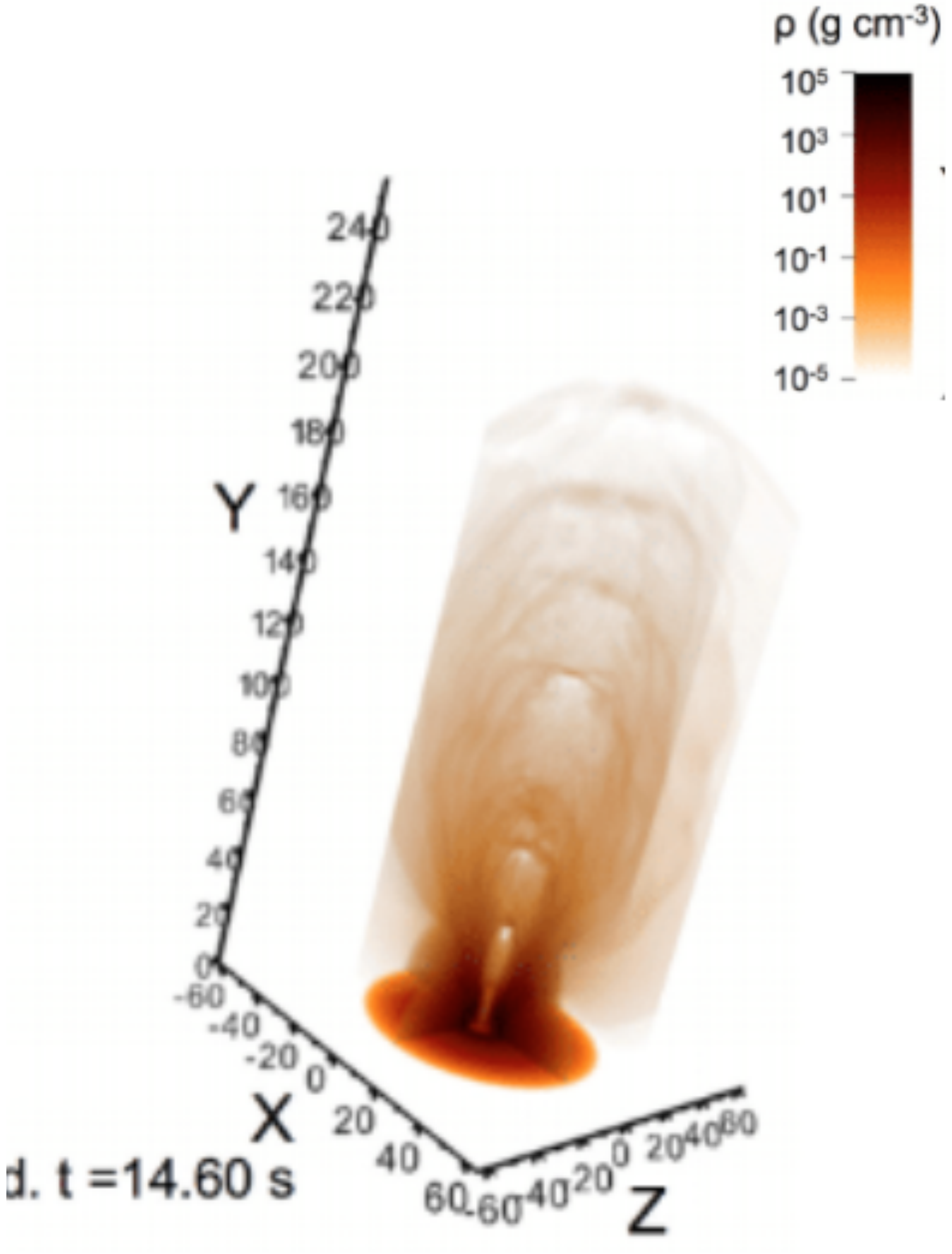
Long GRB Jet is a multi-scale problem

Figure Credits: Dado et al. 2022

Launching point far from the central engine

Launching point far from the central engine

Non symmetric (variable source)



Lopez-Camara et al. 2016

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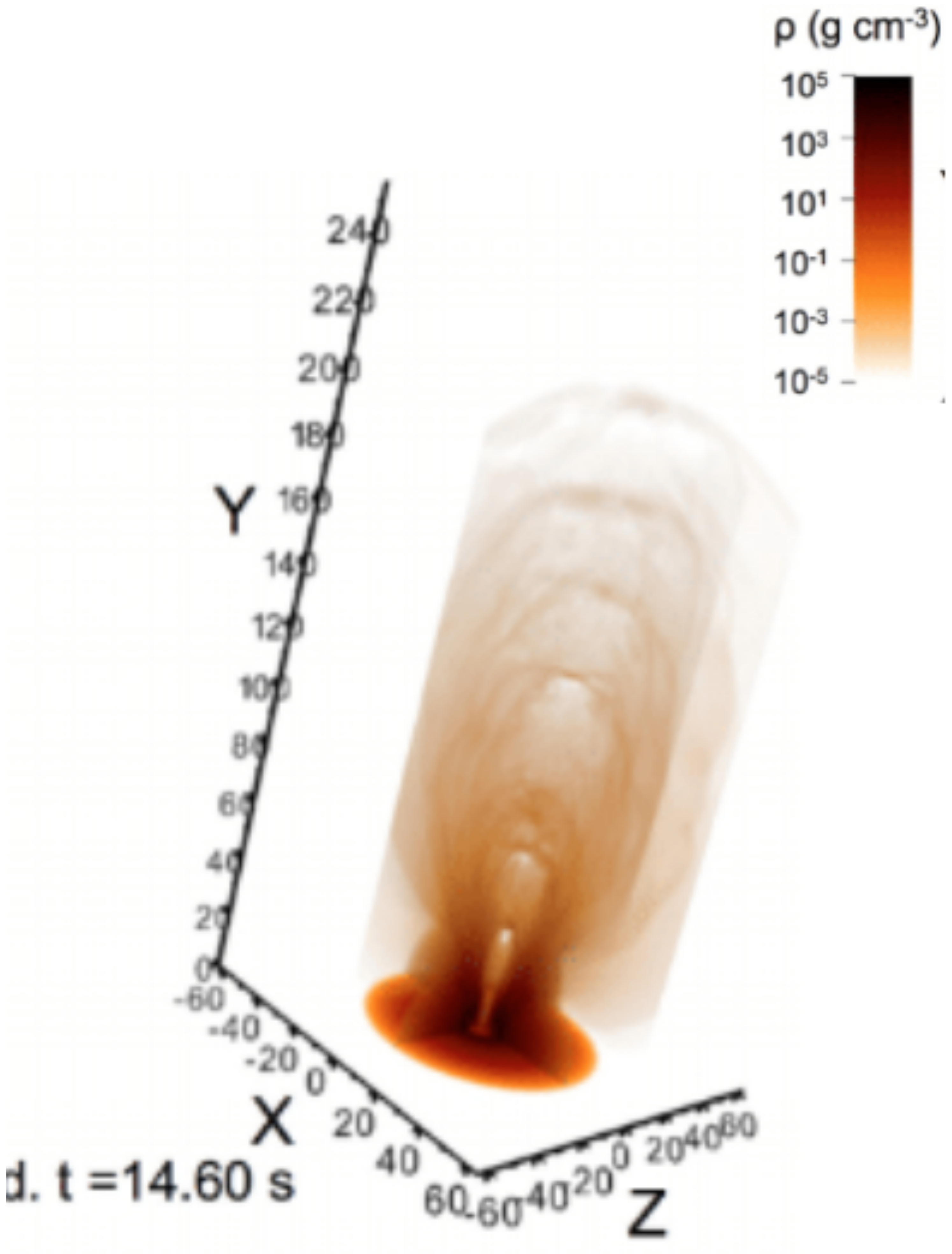
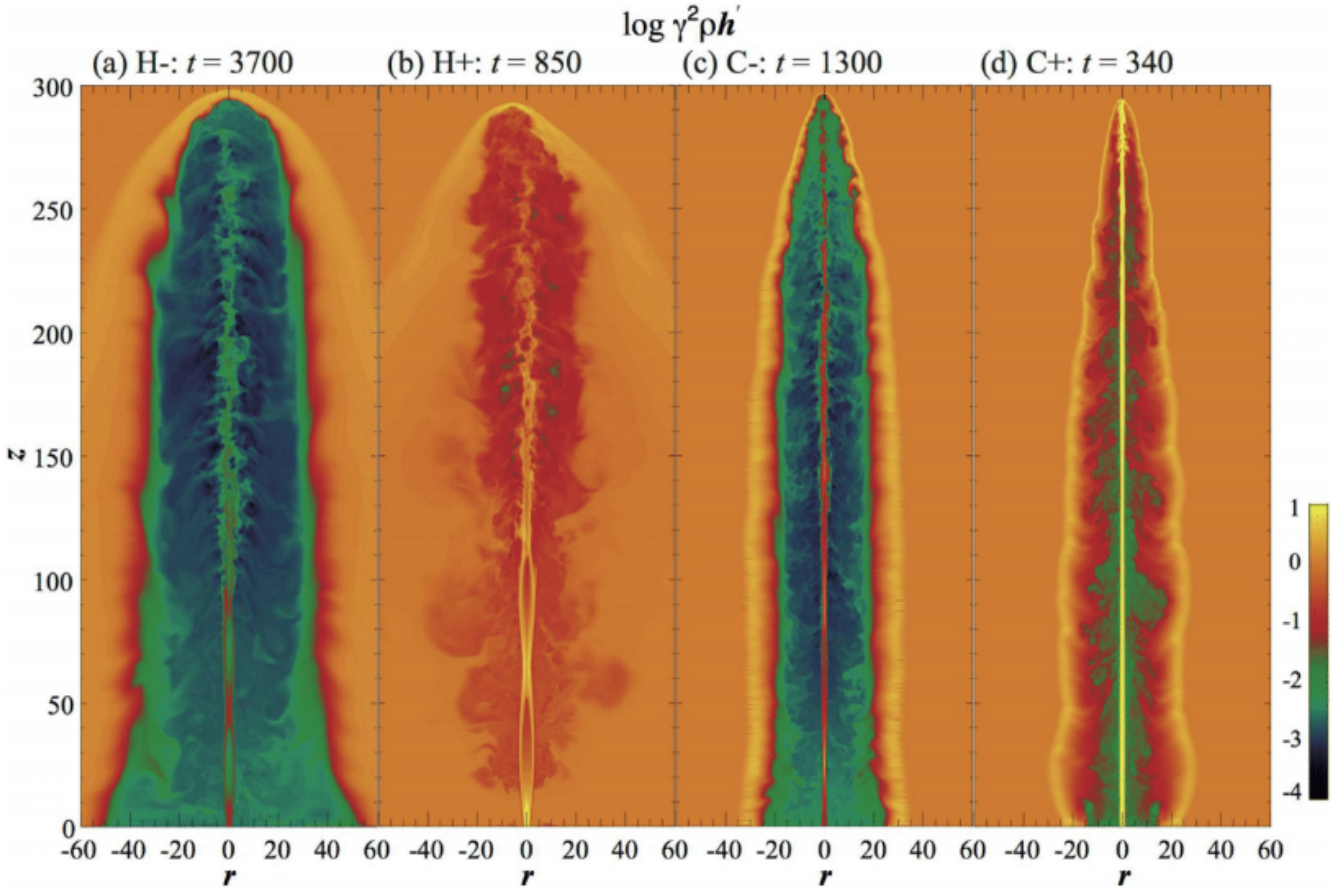


Lopez-Camara et al. 2016

Kinetic or pressure dominated jets



Matsumoto et al. 2019

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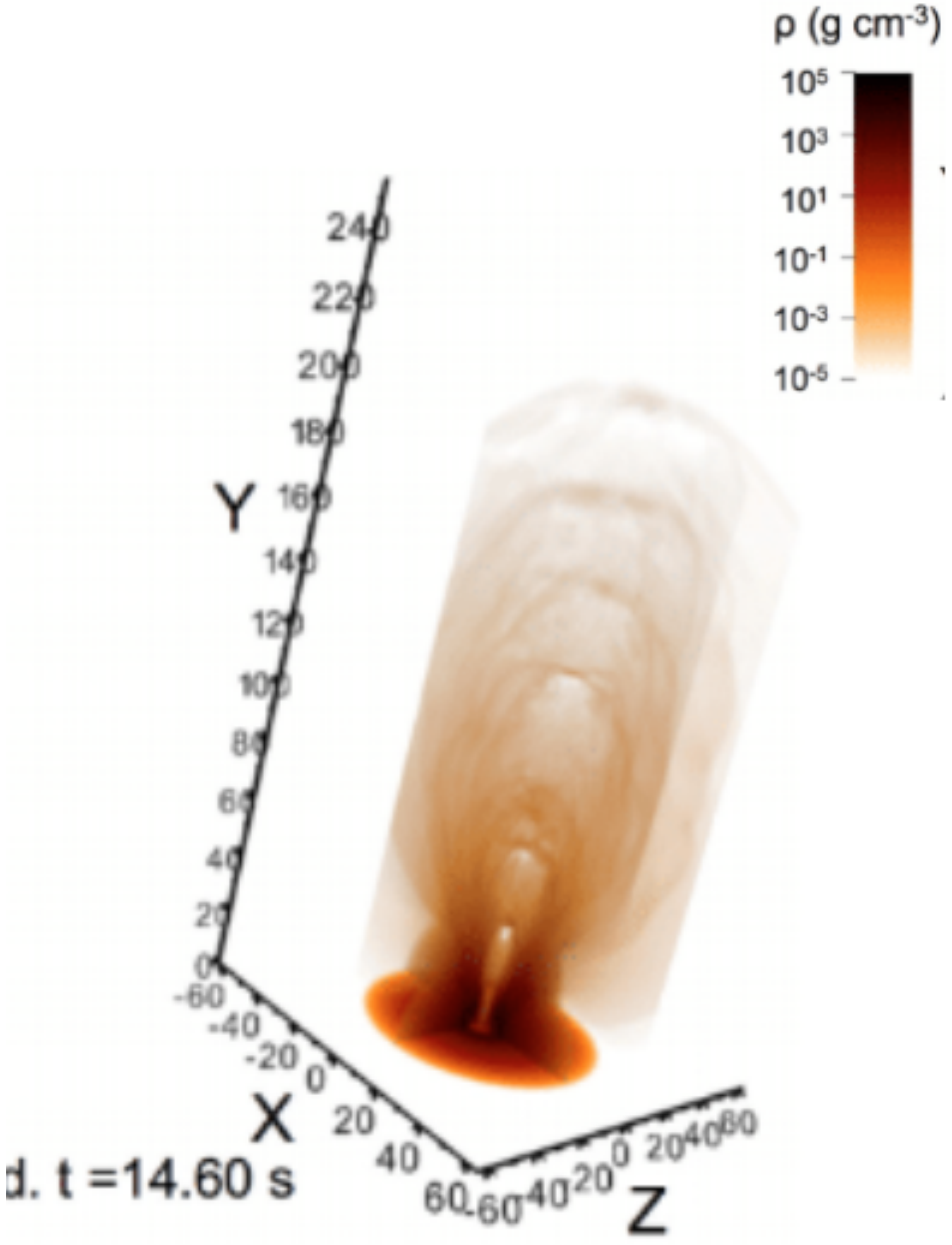

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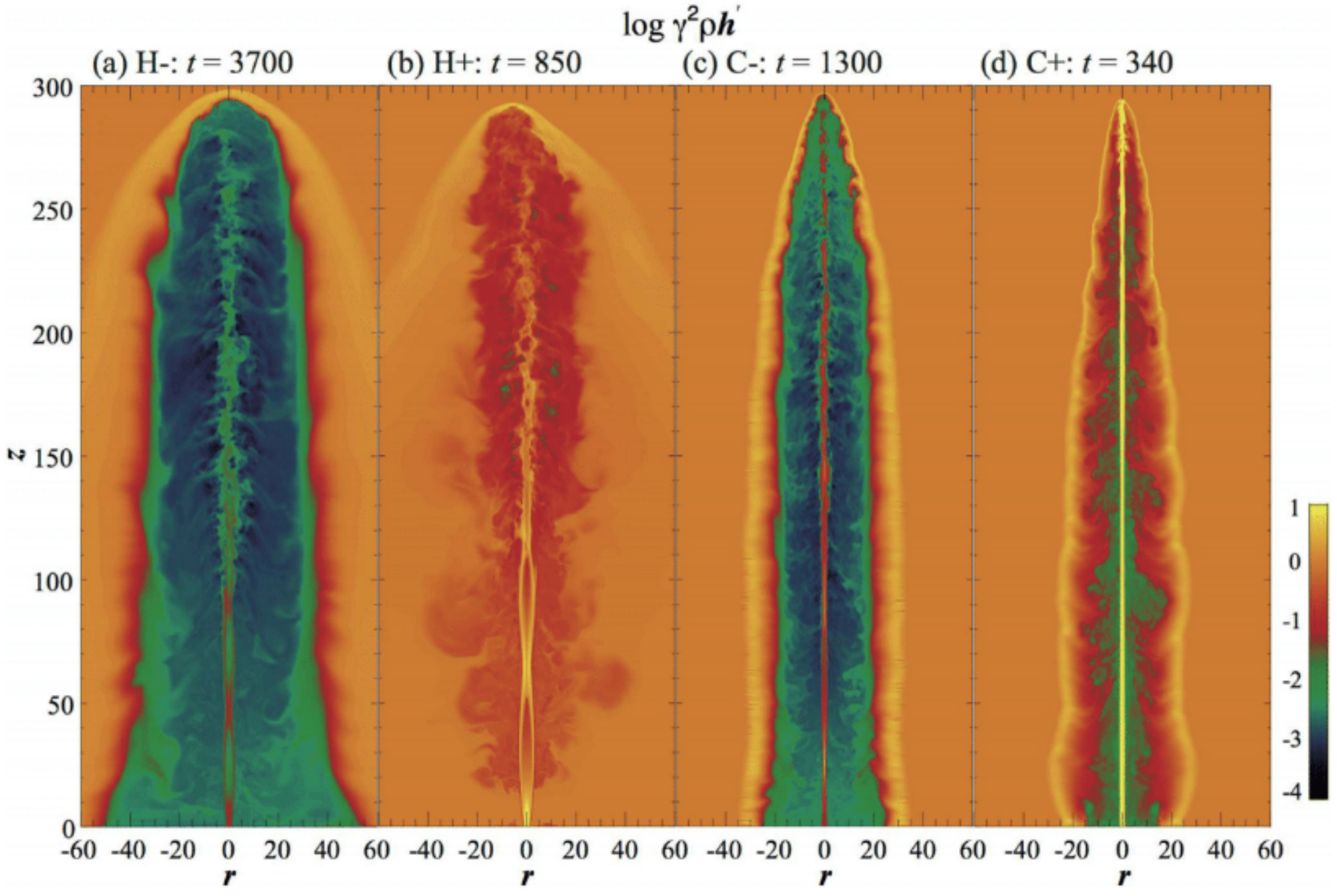
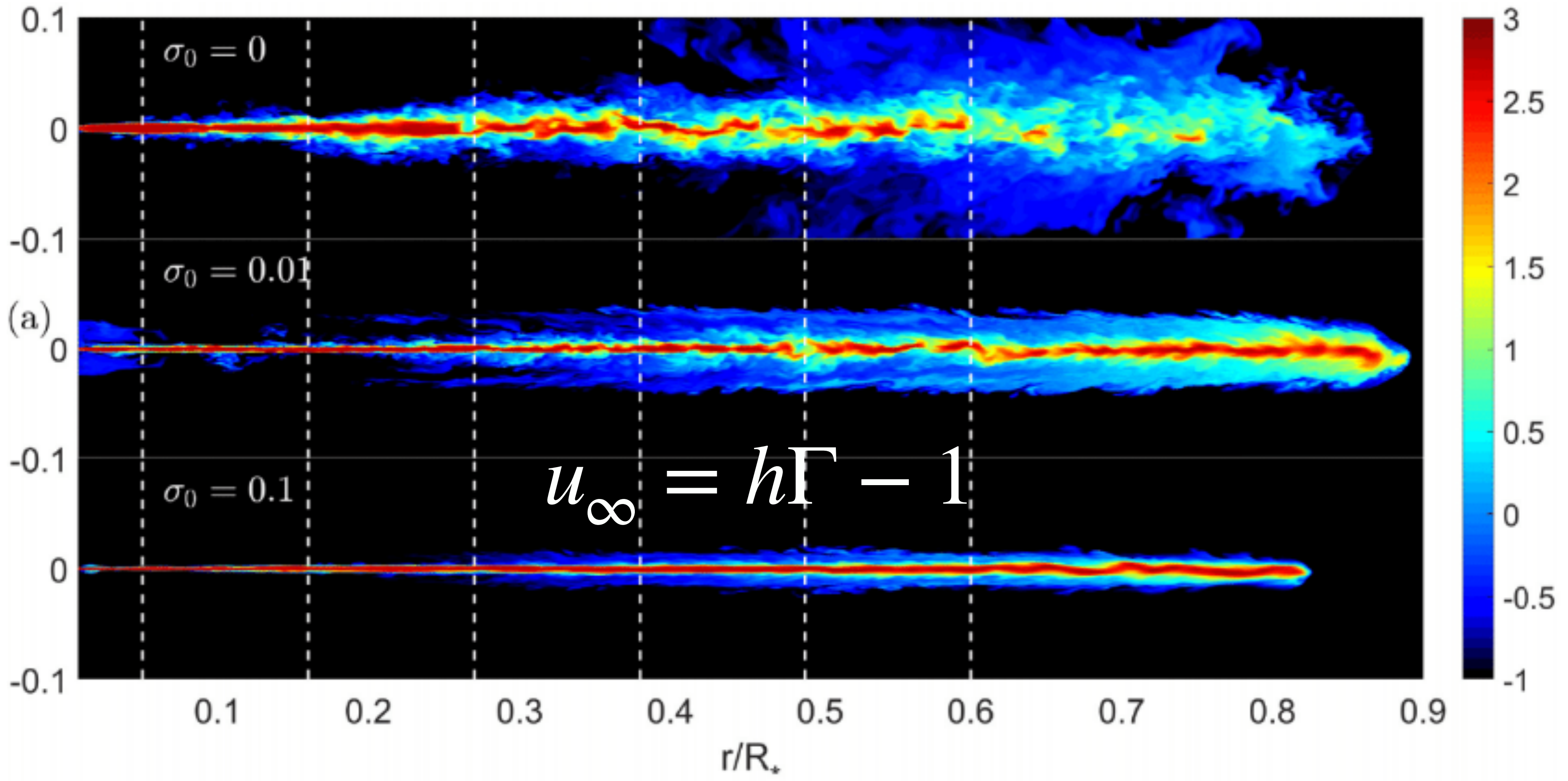


Matsumoto et al. 2019

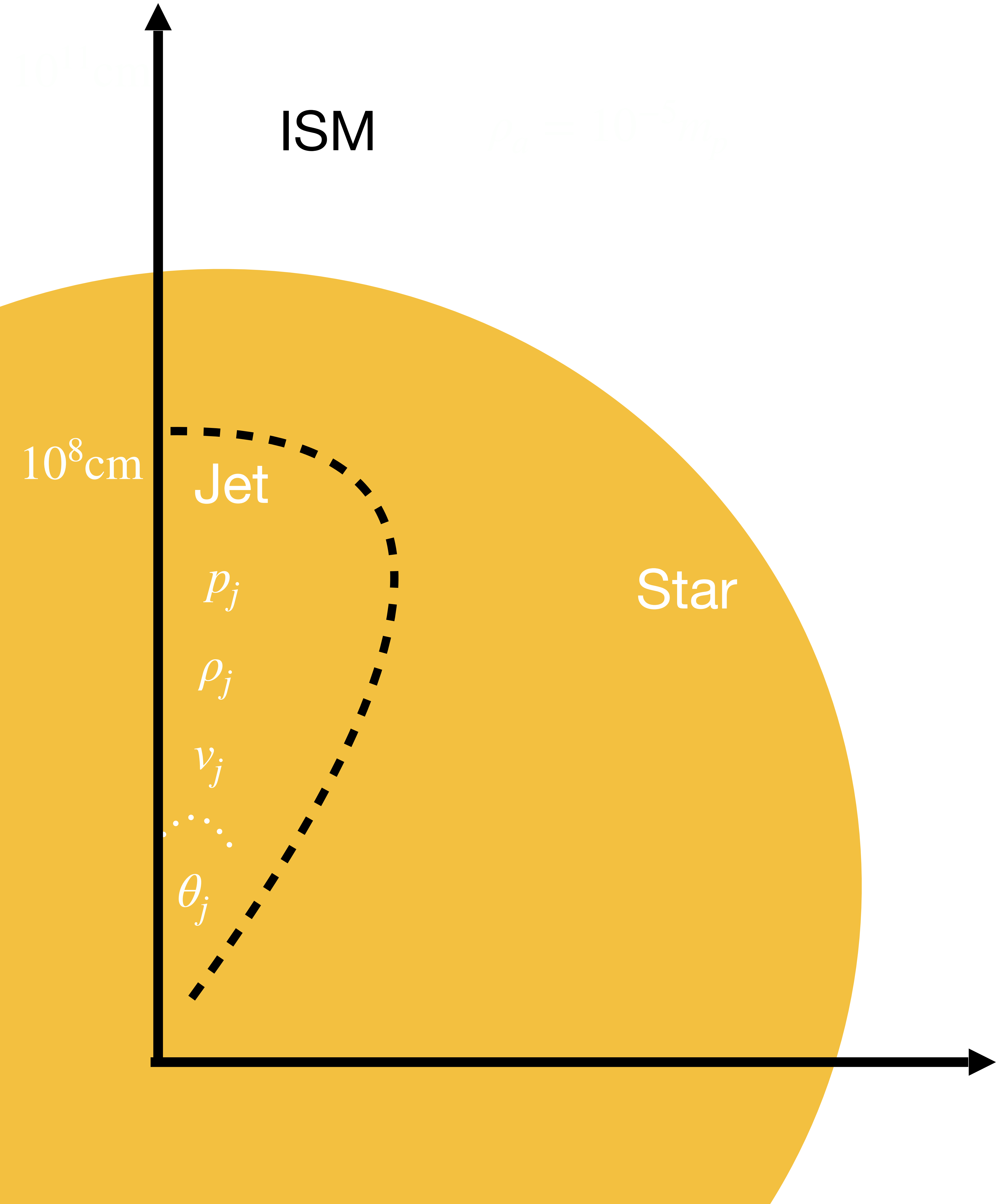
Weakly magnetized jet + variable source



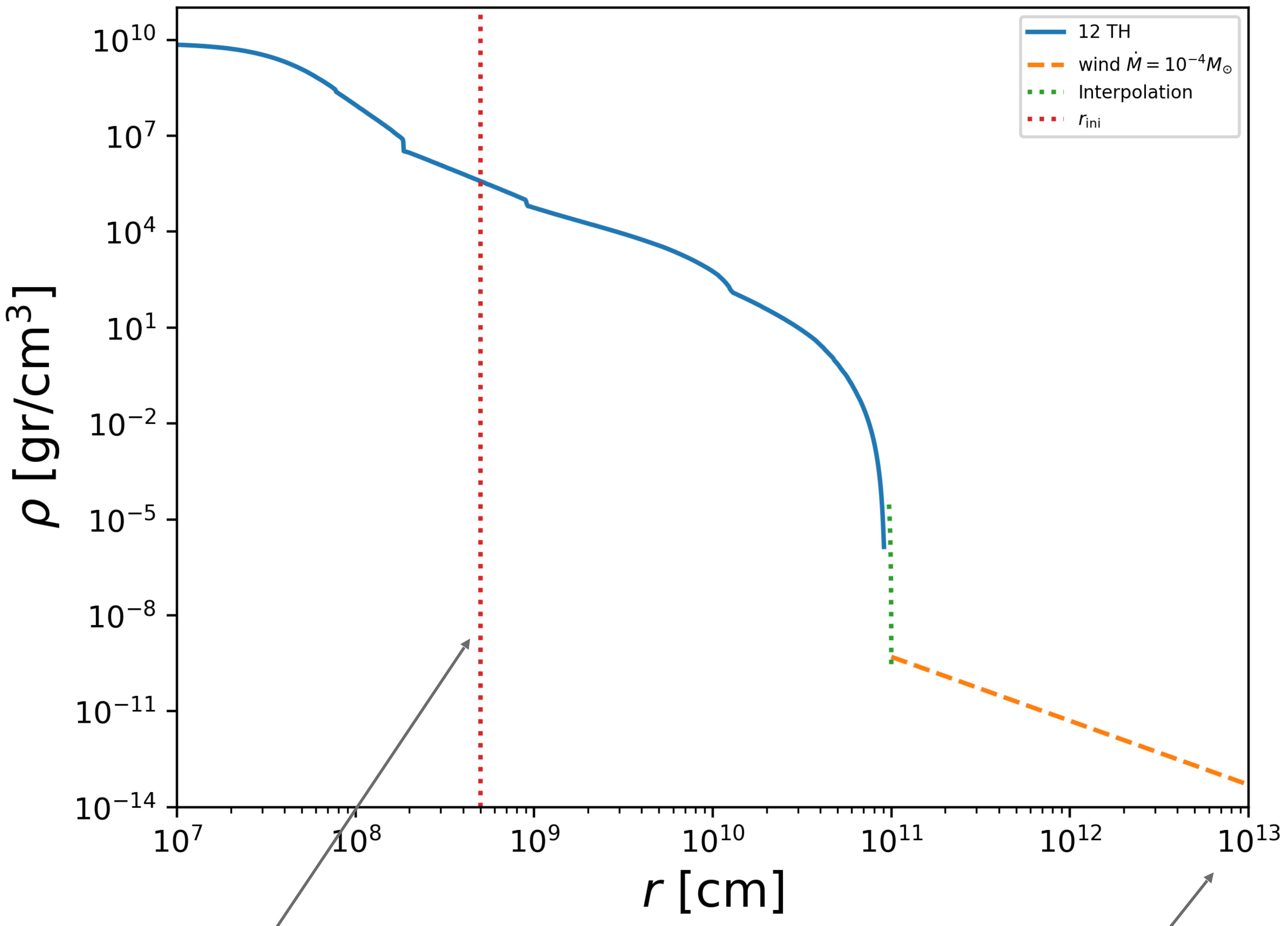
Gottlieb et al. 2020

Intermediate scales

The jet is imposed as a strong shock condition



- Stellar striped envelope WR (Woosley & Heger 2006)

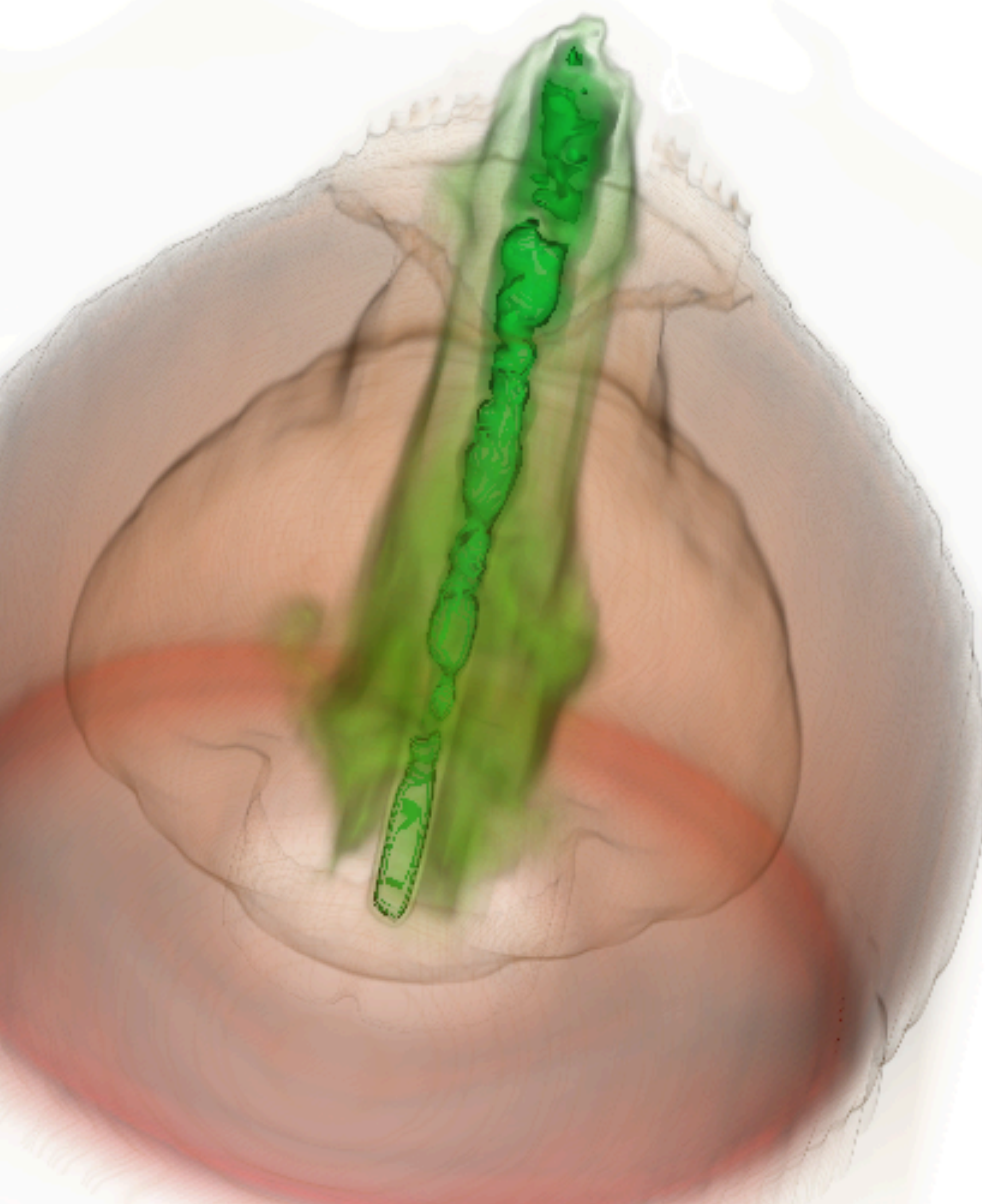


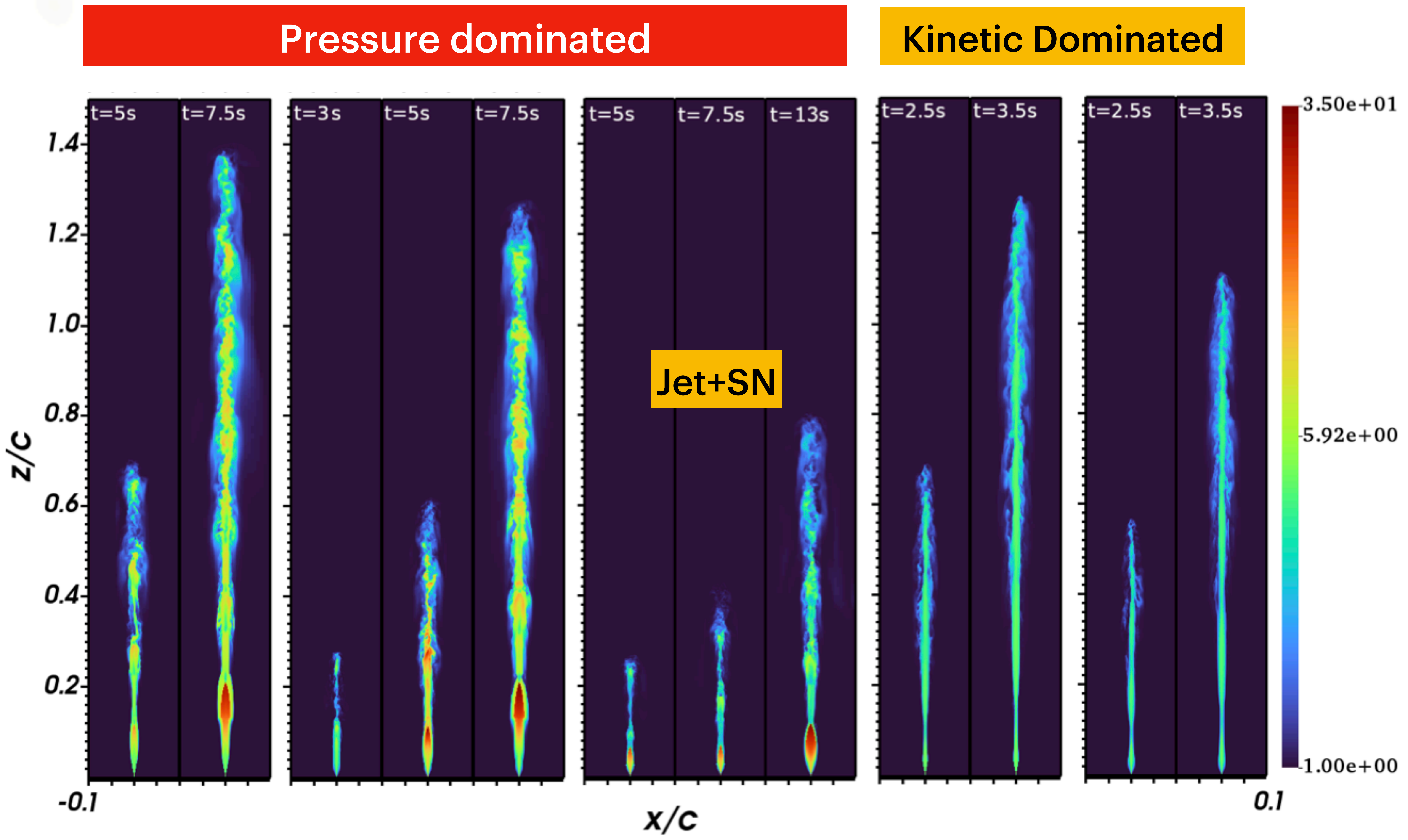
Initial Conditions

Size of AMR computational box

Jets initially structured

Gaussian jet + Supernova

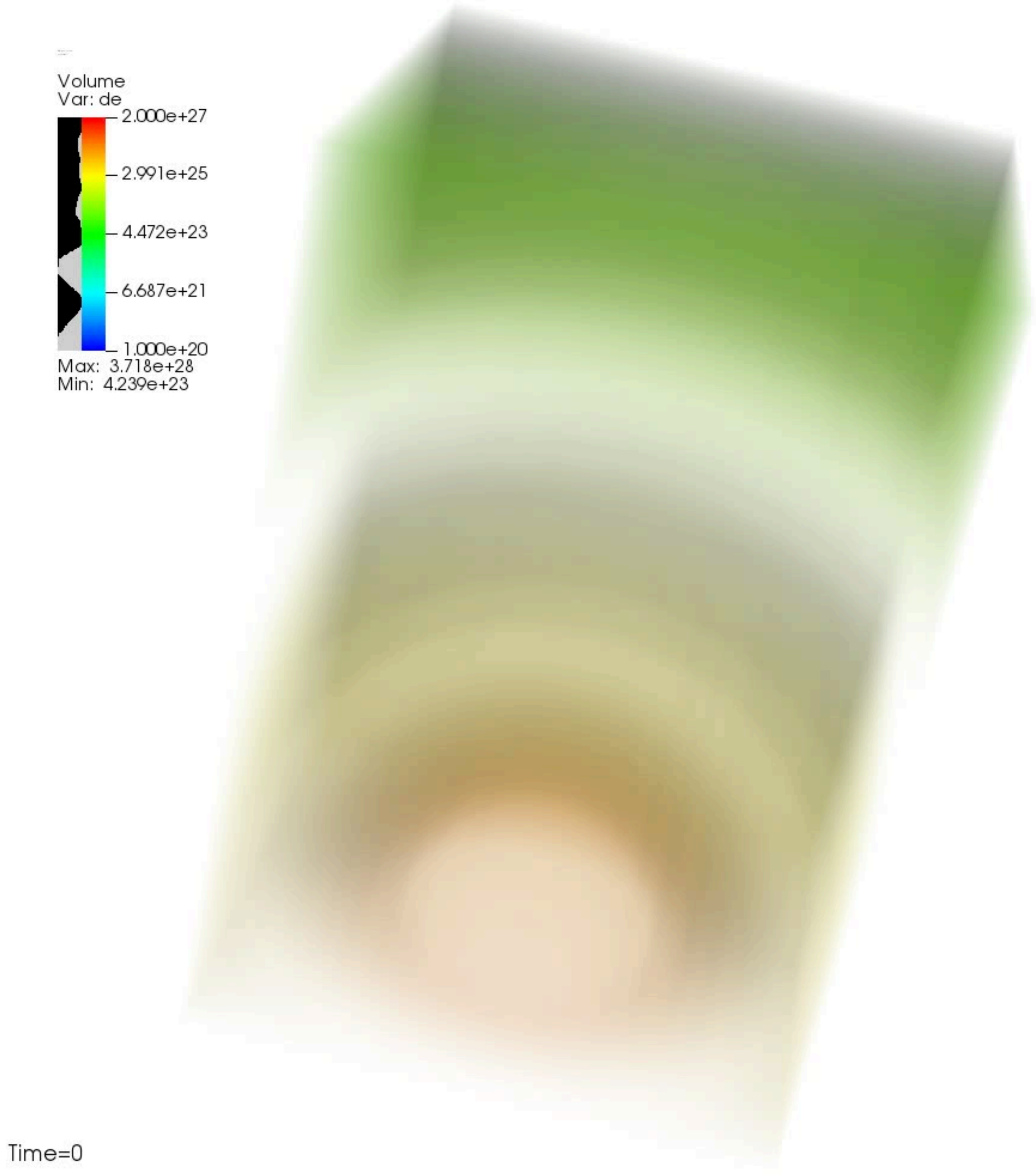


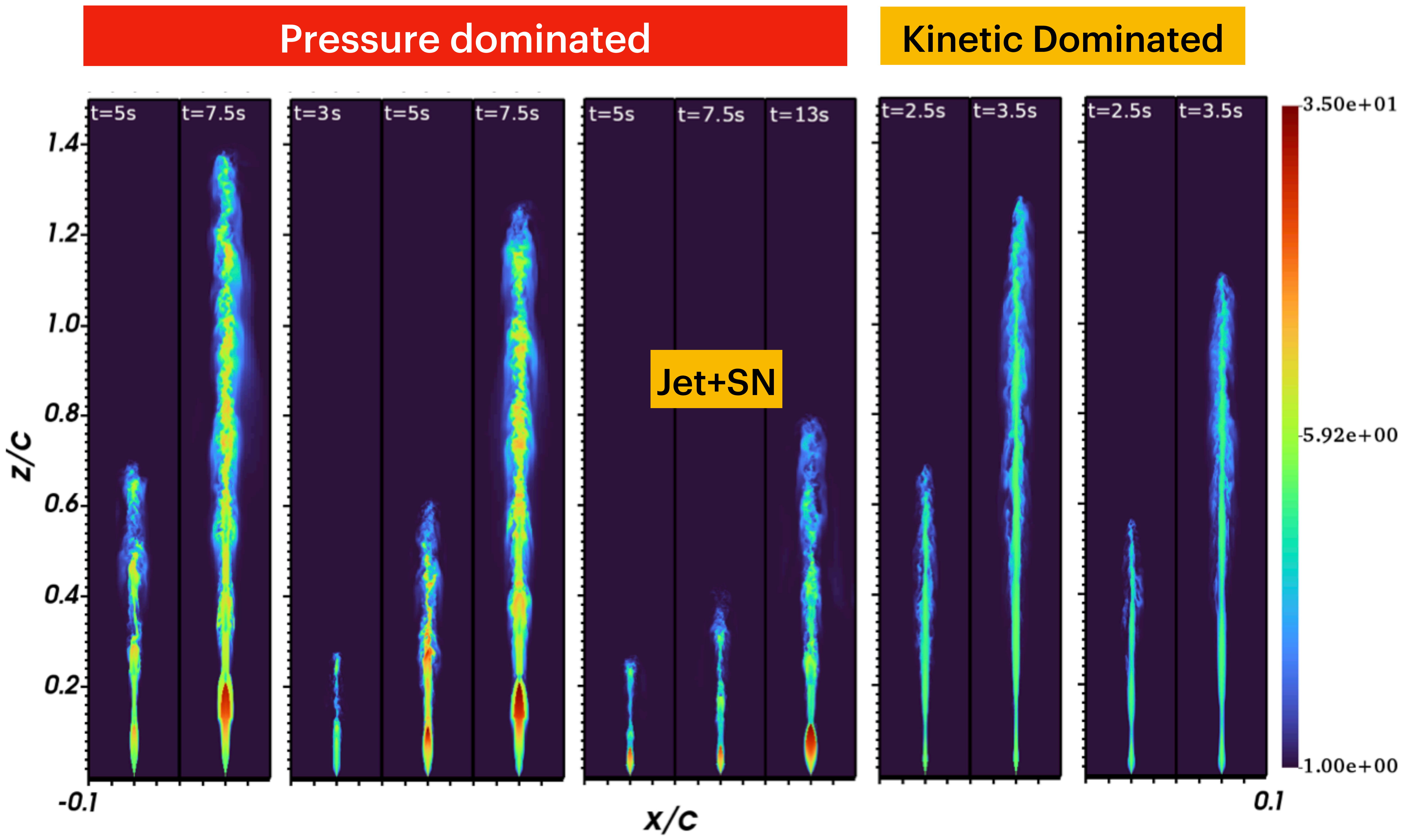


Urrutia, De Colle & Lopez-Camara 2023

Jets initially structured

Gaussian jet + Supernova





Urrutia, De Colle & Lopez-Camara 2023

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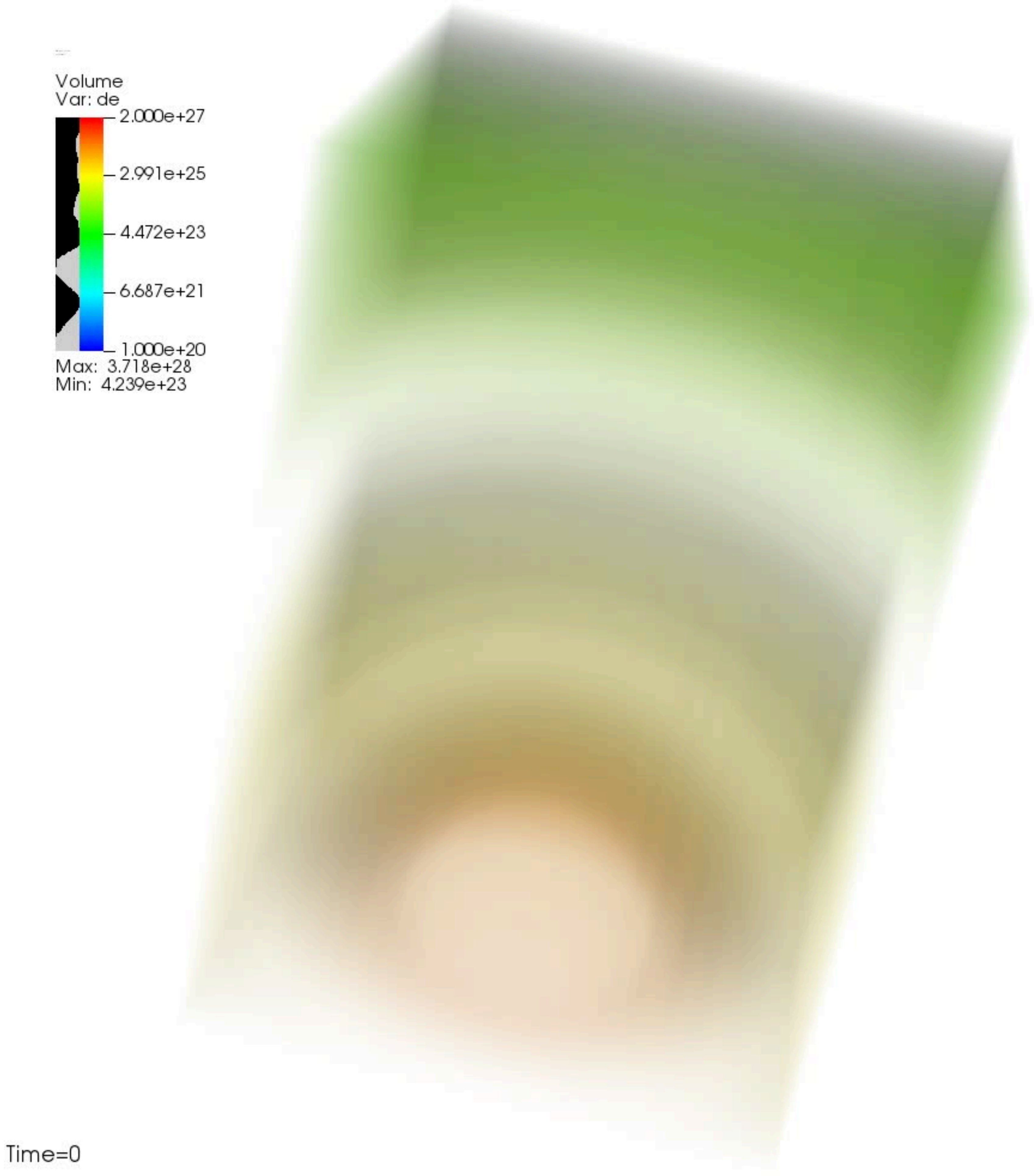

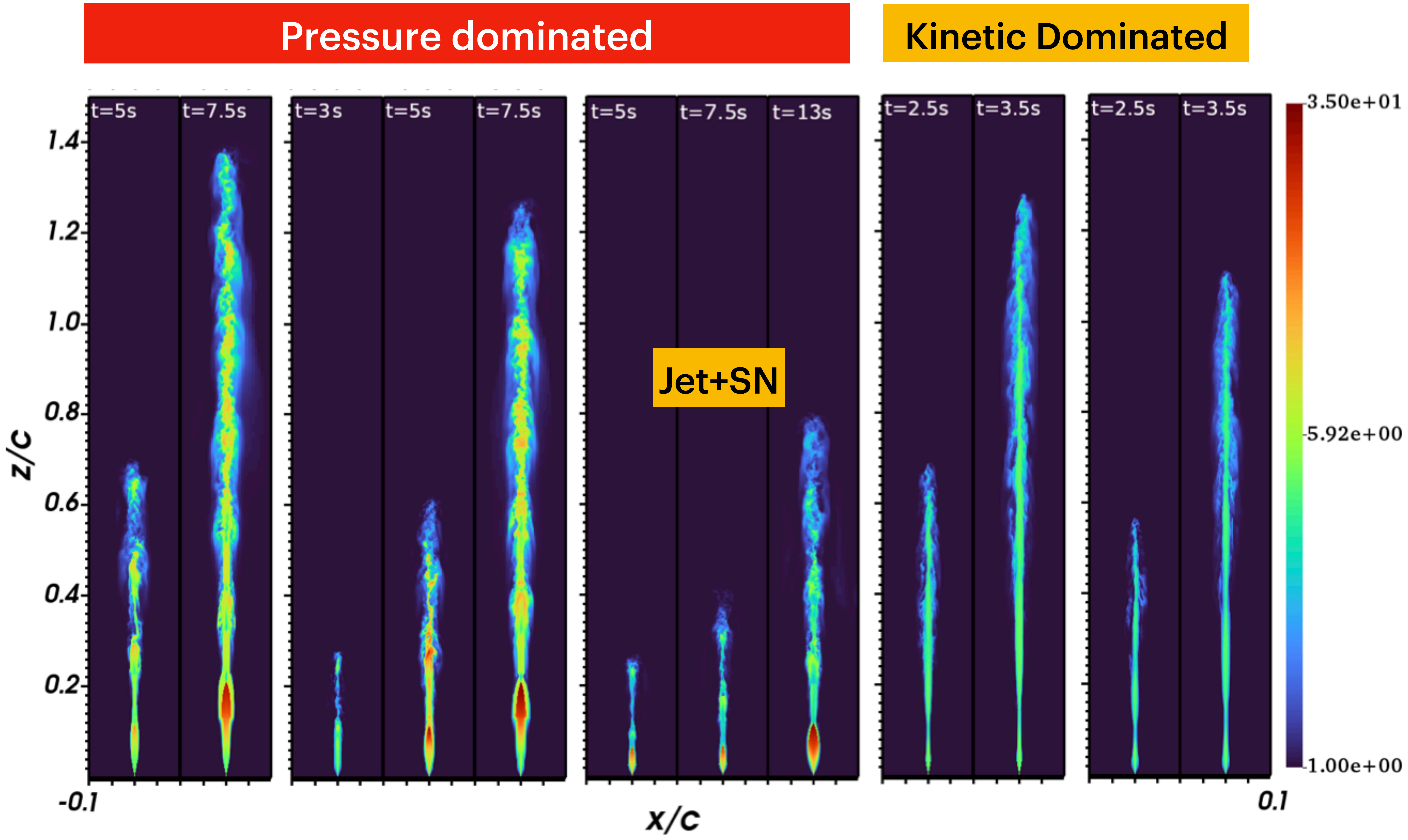

Urrutia, De Colle & Lopez-Camara 2023

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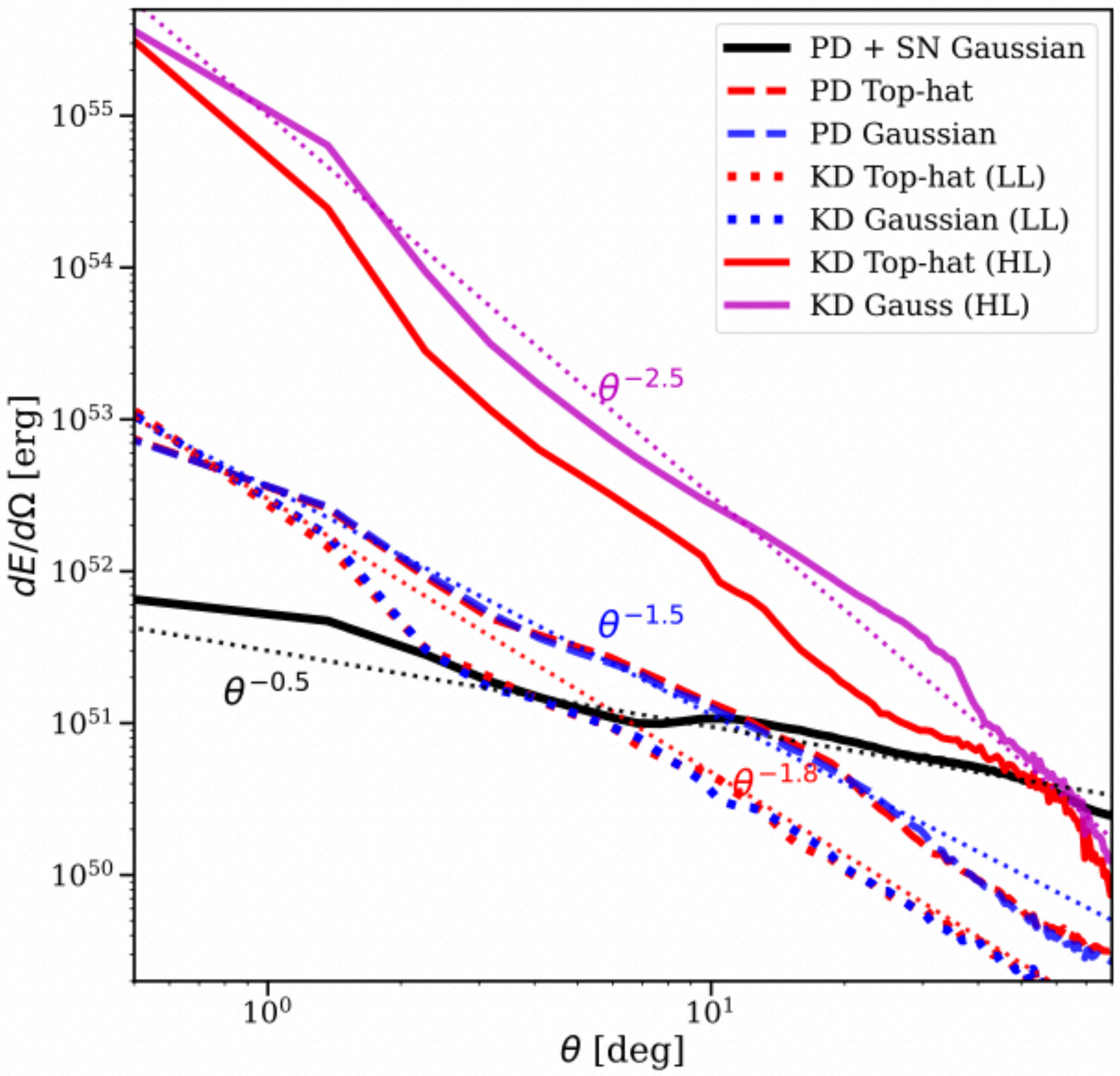

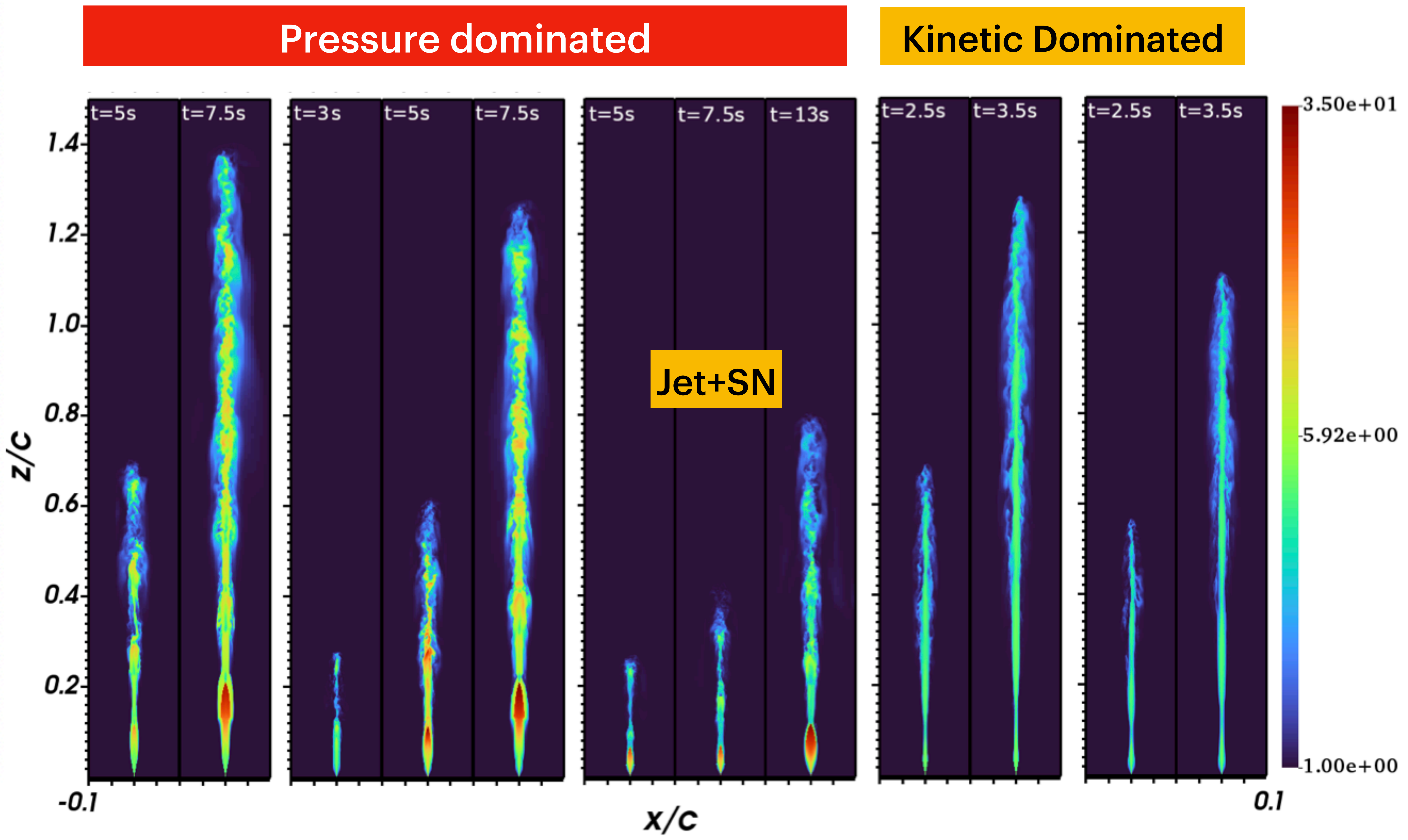

Time=0

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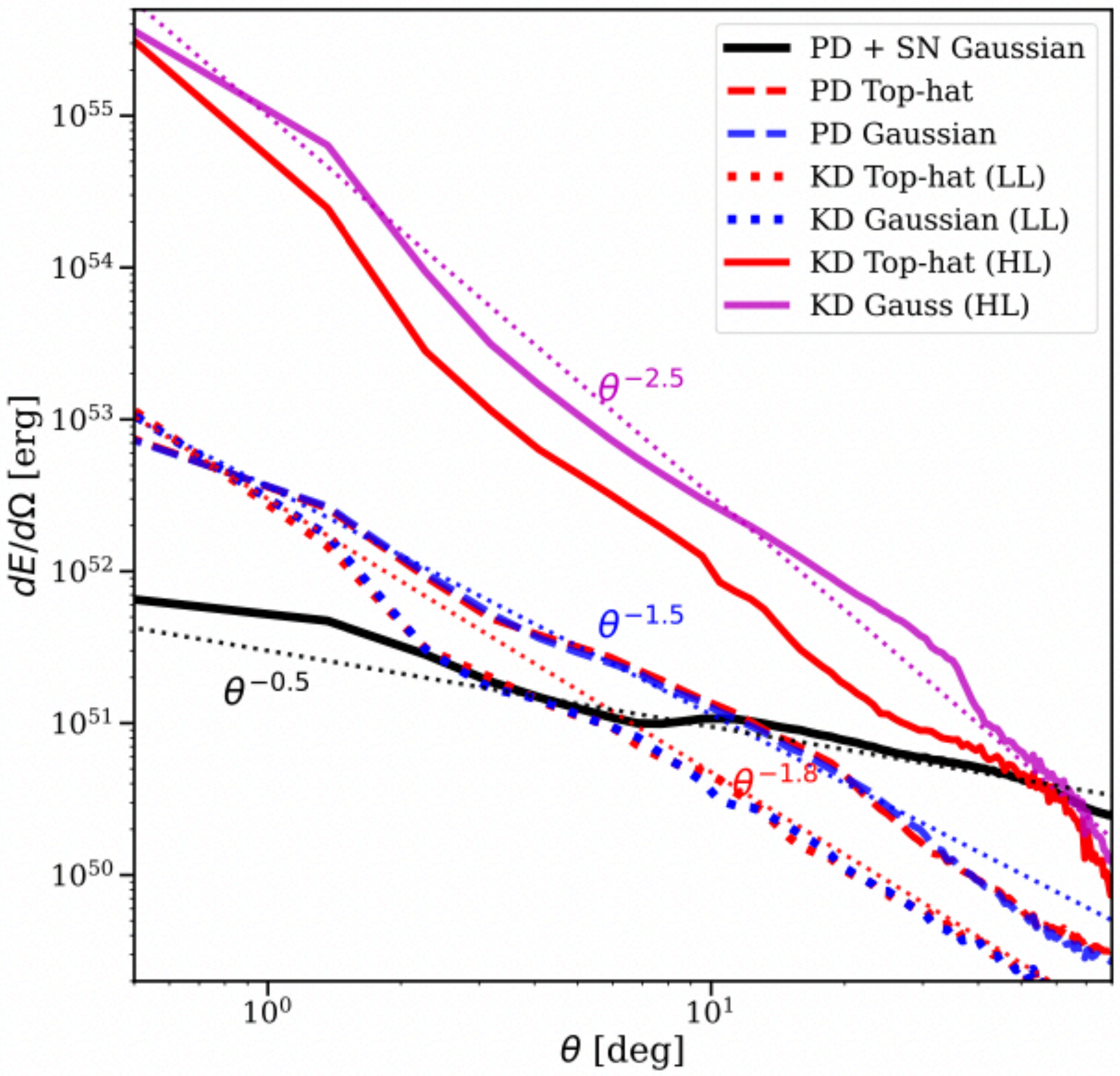

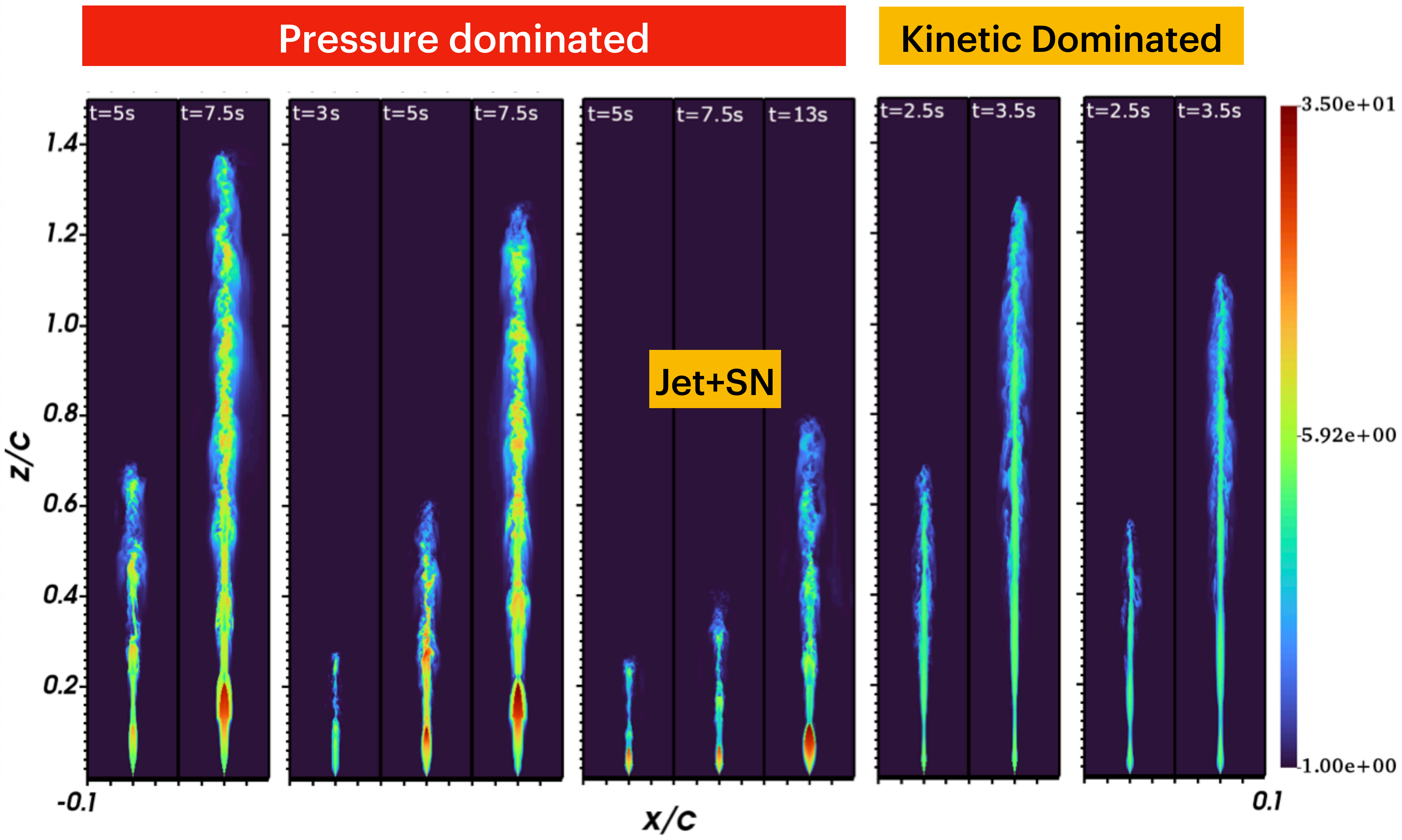

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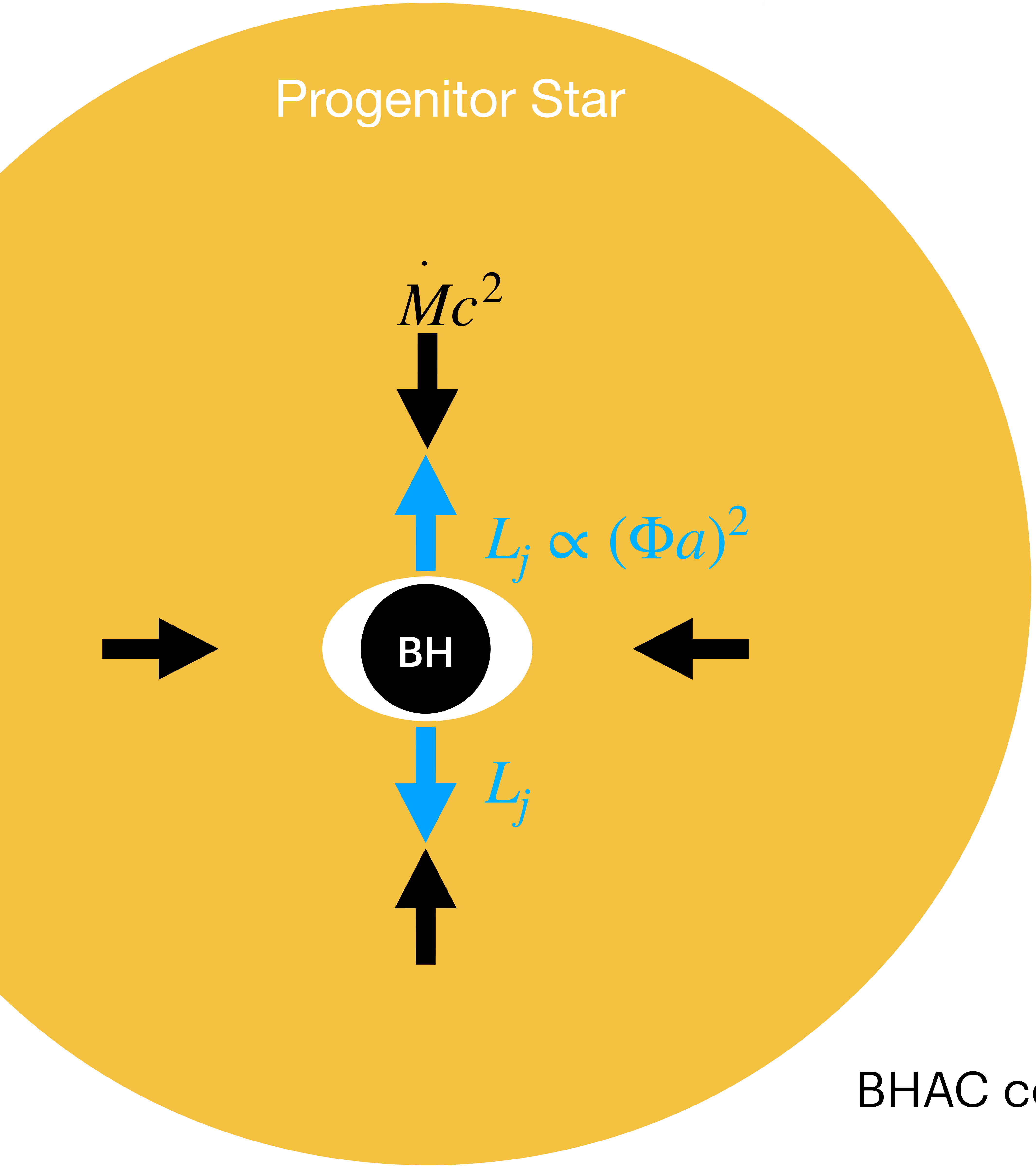
Simulations from small scales



Rotation

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

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

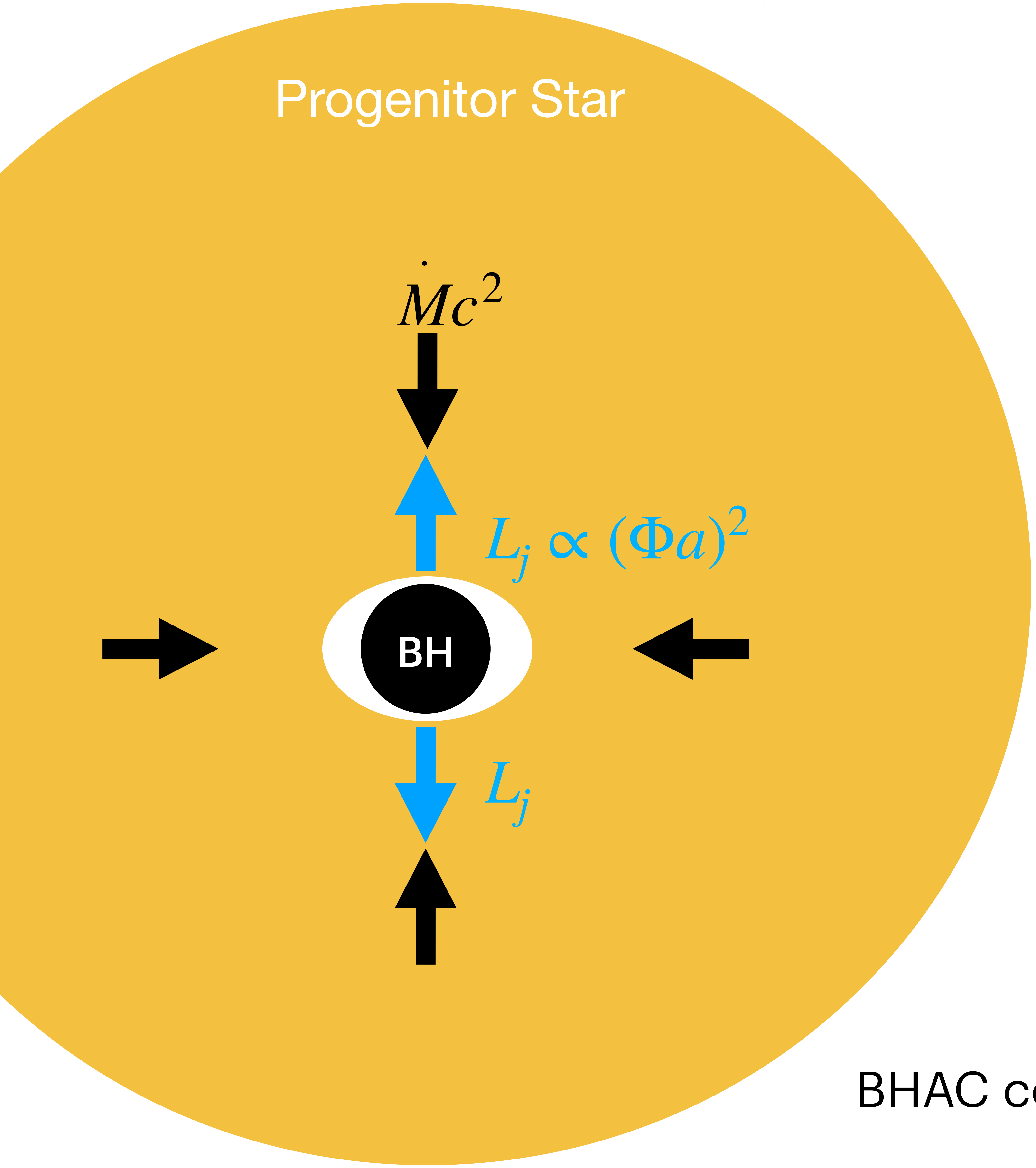
$$u^{\phi} = C\sin^2\theta\left(-g^{t\phi}\epsilon_{\rm isco} + g^{\phi\phi}l_{\rm isco}\right)$$

Magnetic Field Potential

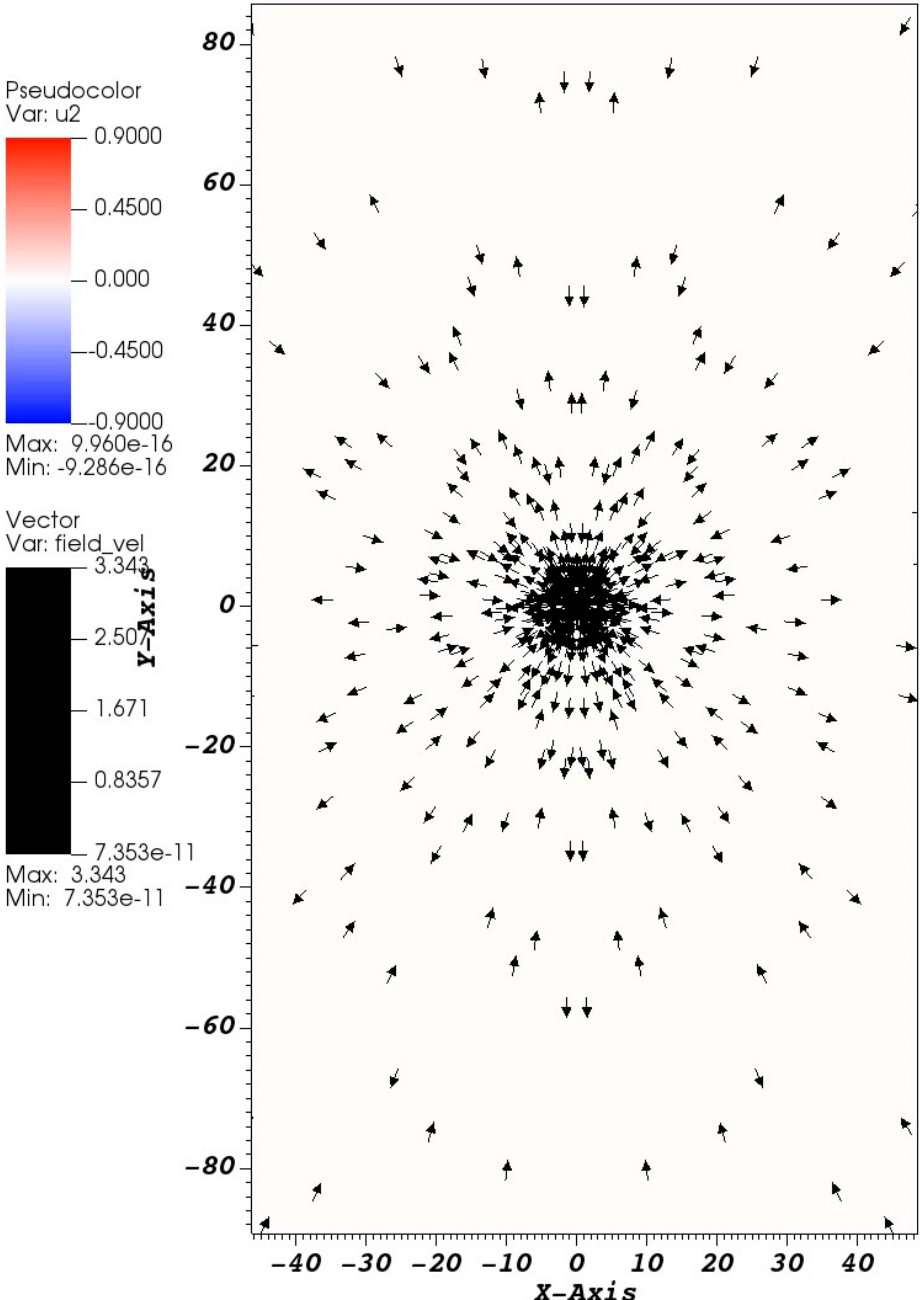
$$A_{\phi} = \frac{B_0 r_c^3}{r^3 + r_0^3}\sin\theta \qquad B_0 = 10^{14}$$

BHAC code AMR (Port, Olivares et al. 2017; Olivares, Port, et al. 2019)

Simulations from small scales



BHAC code /



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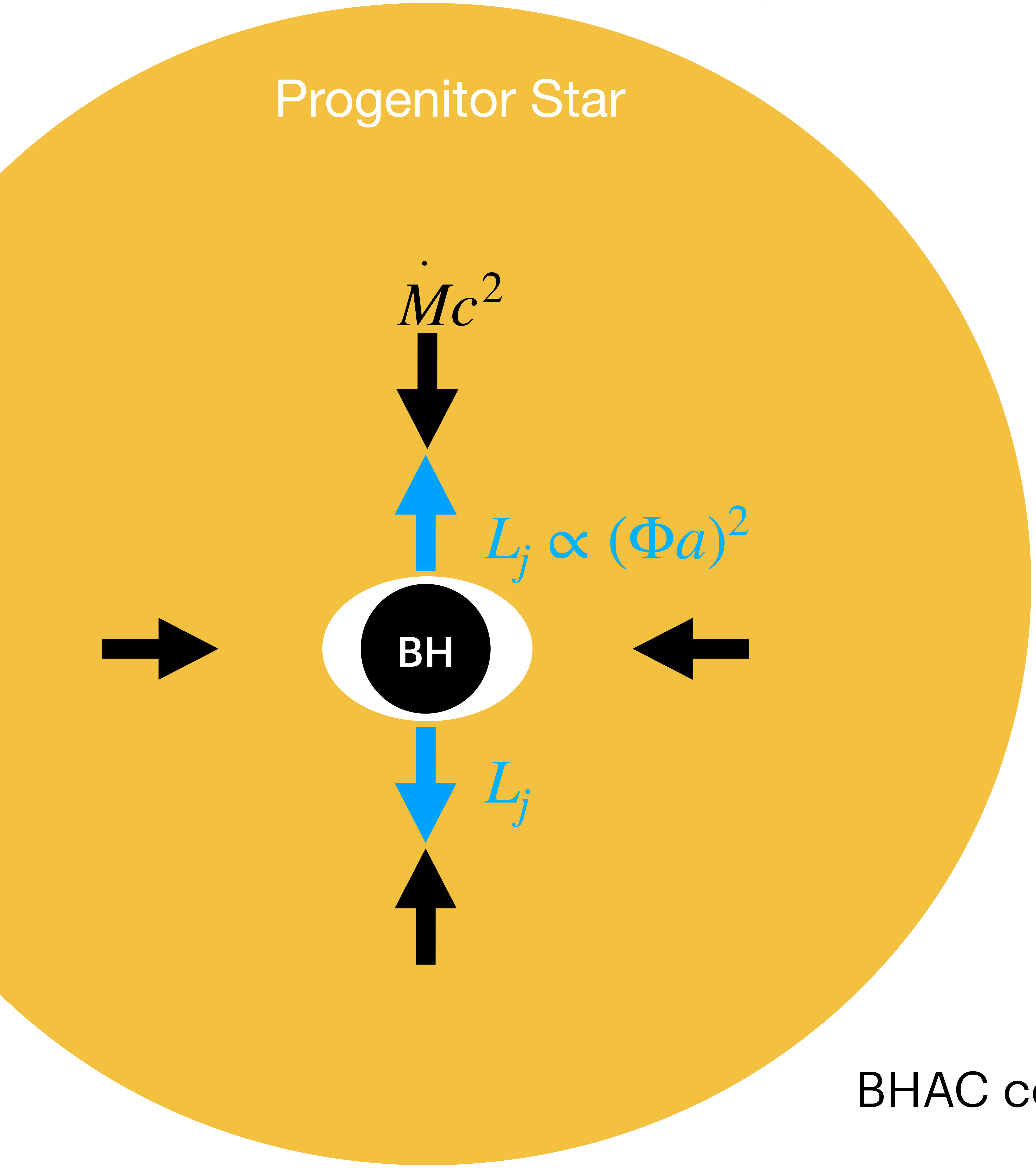

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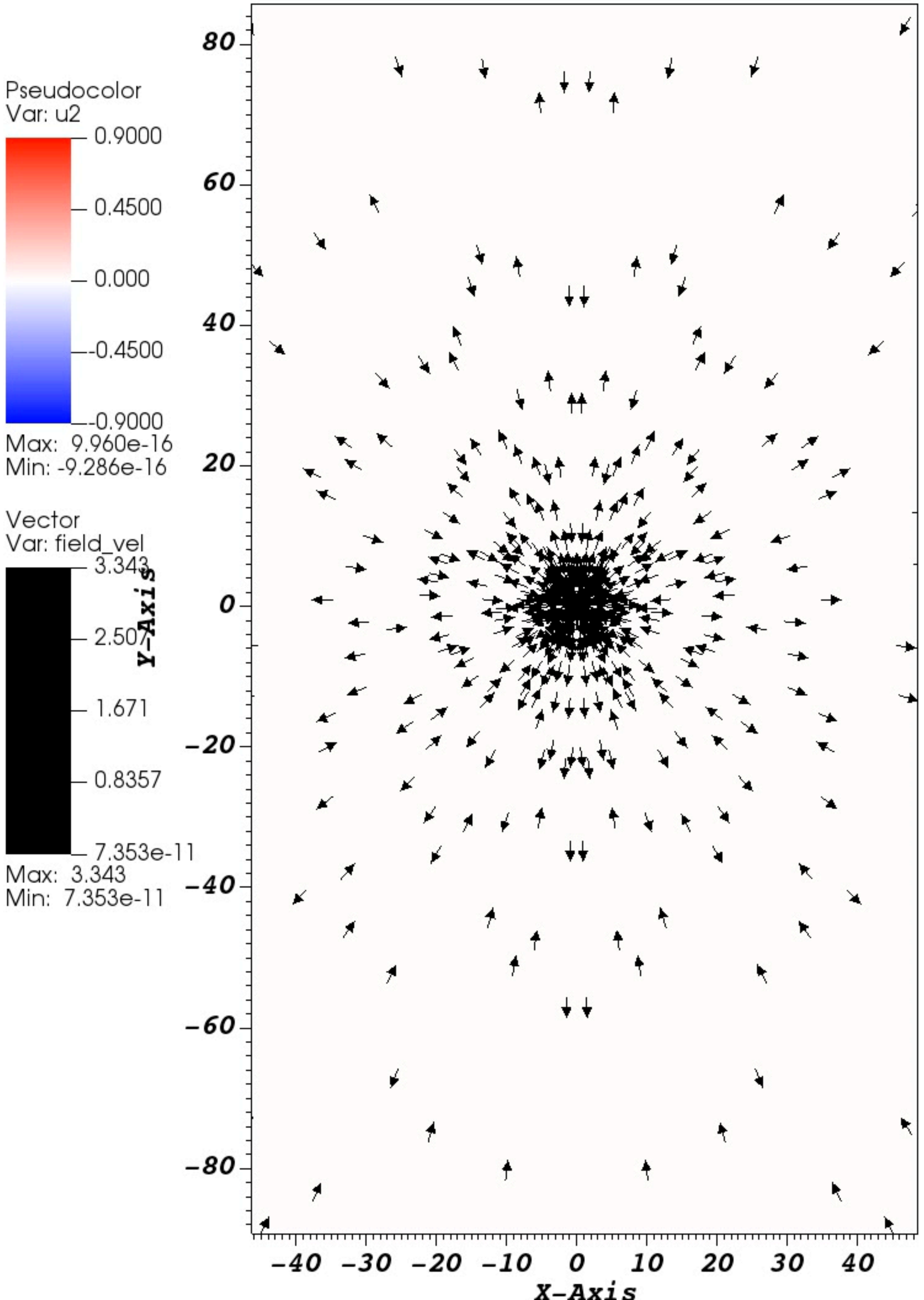

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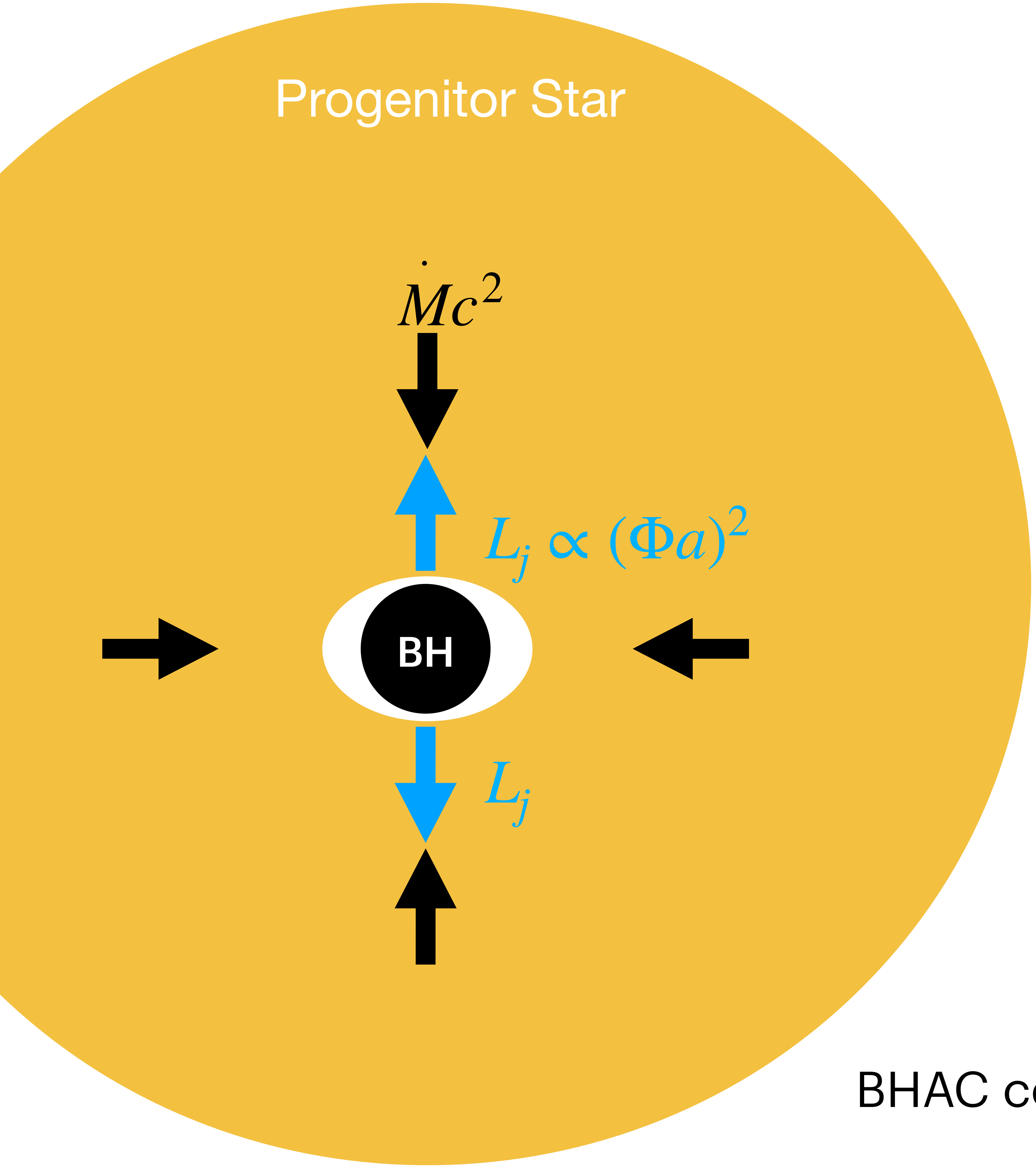

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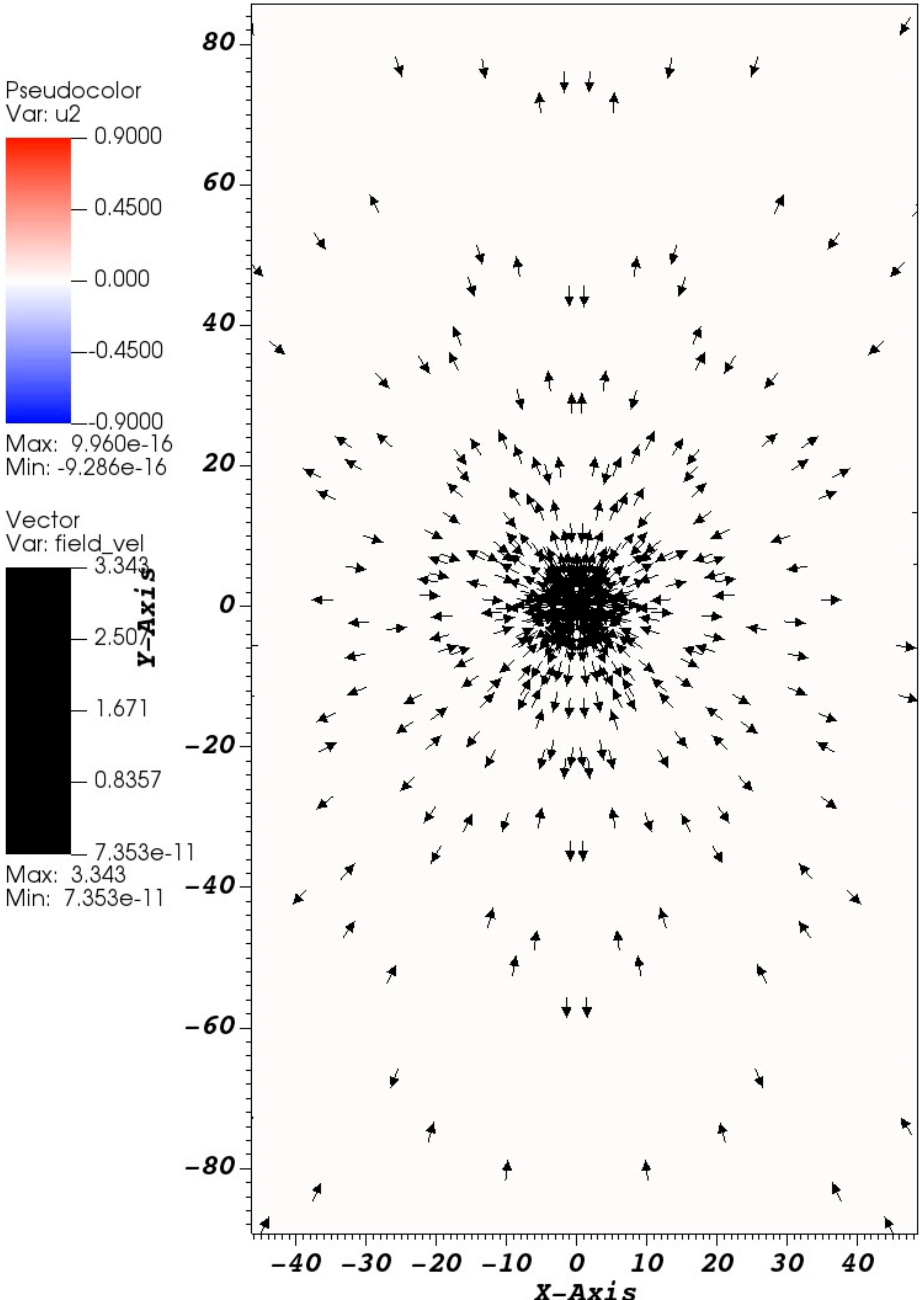
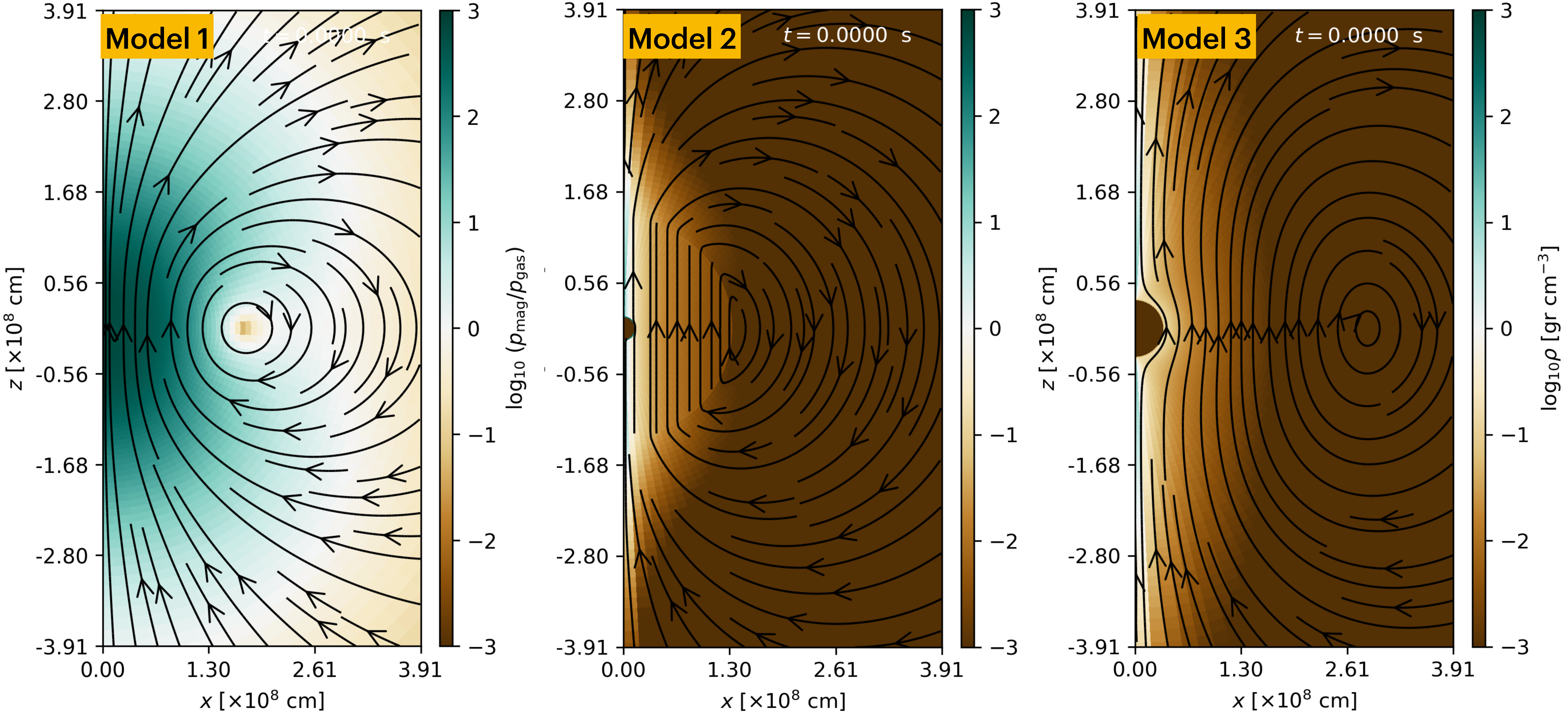
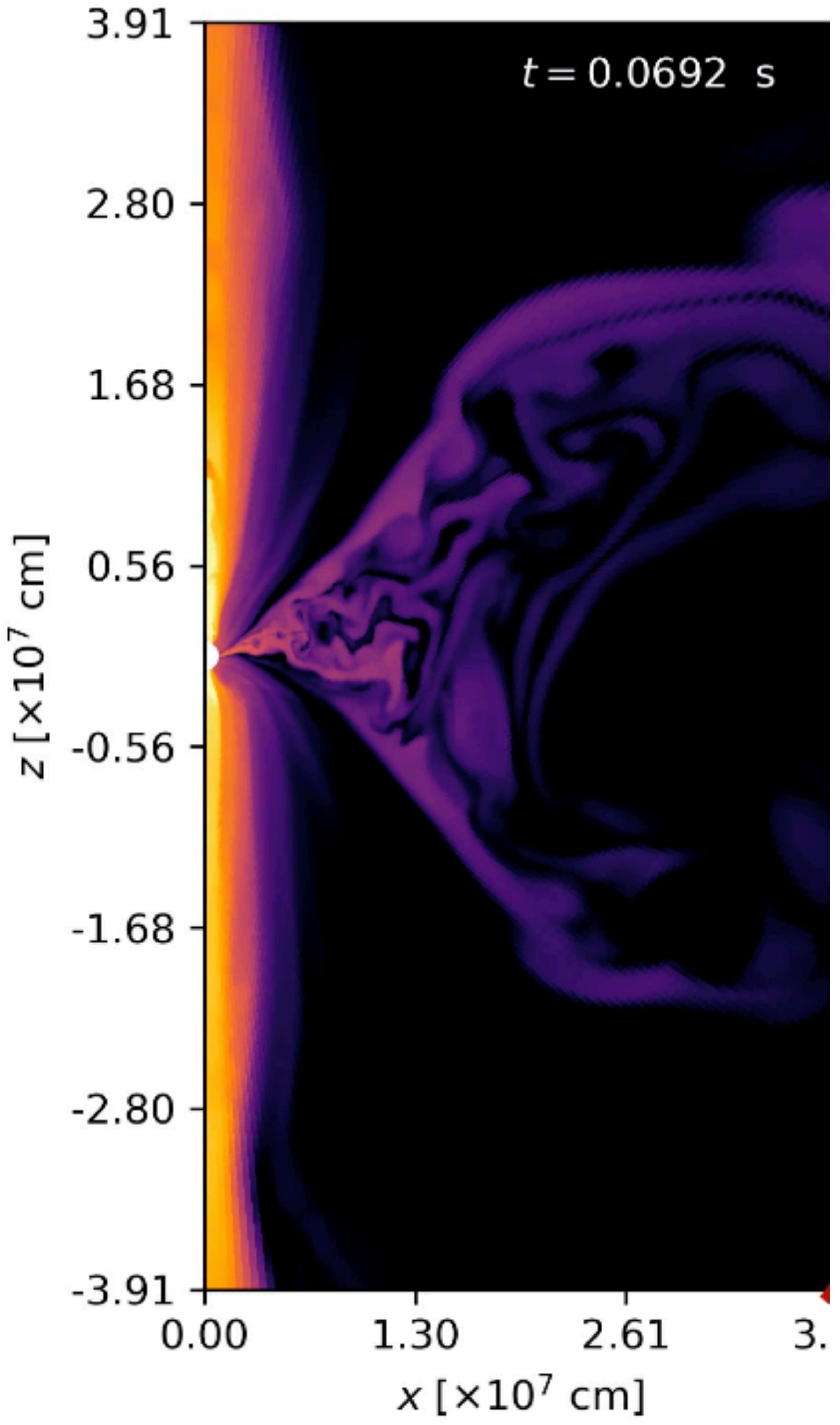


Initial magnetic field configuration



Jet launching and evolution



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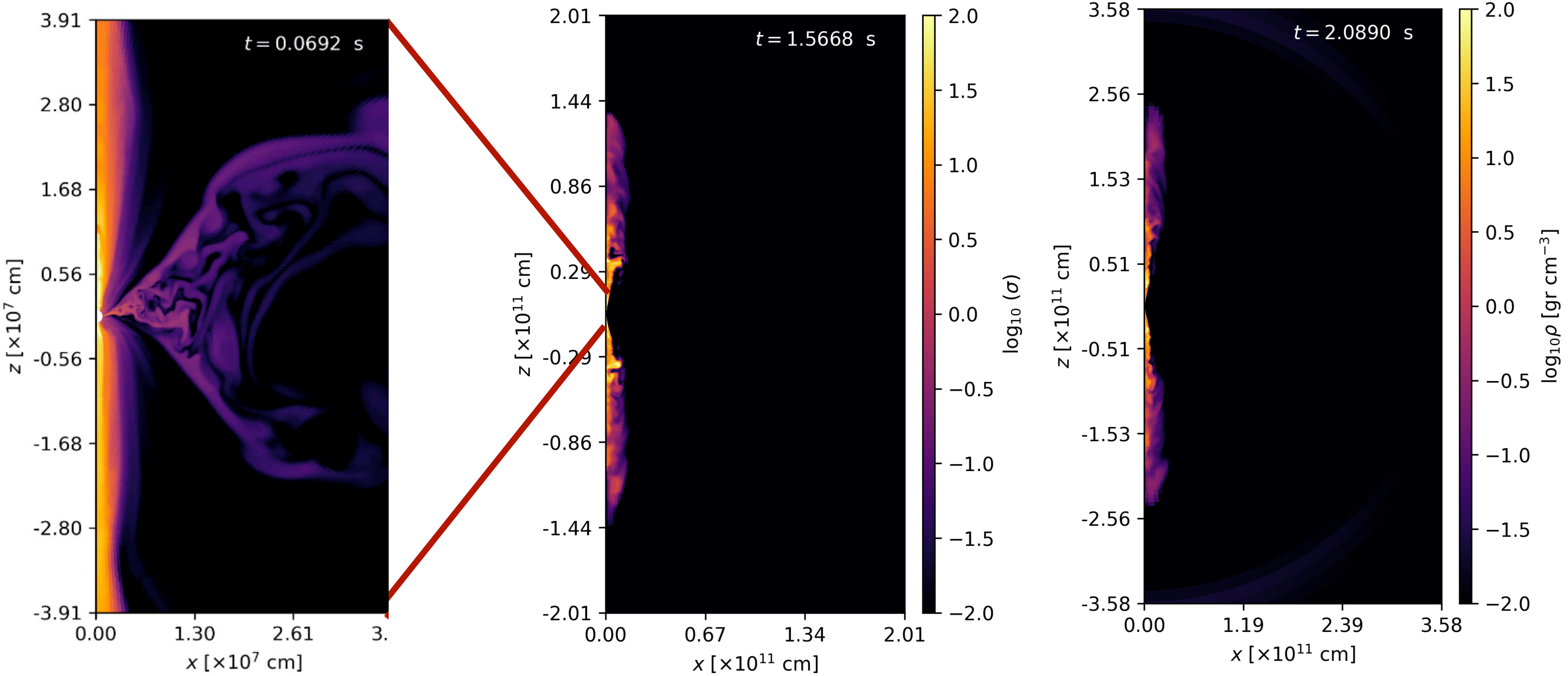
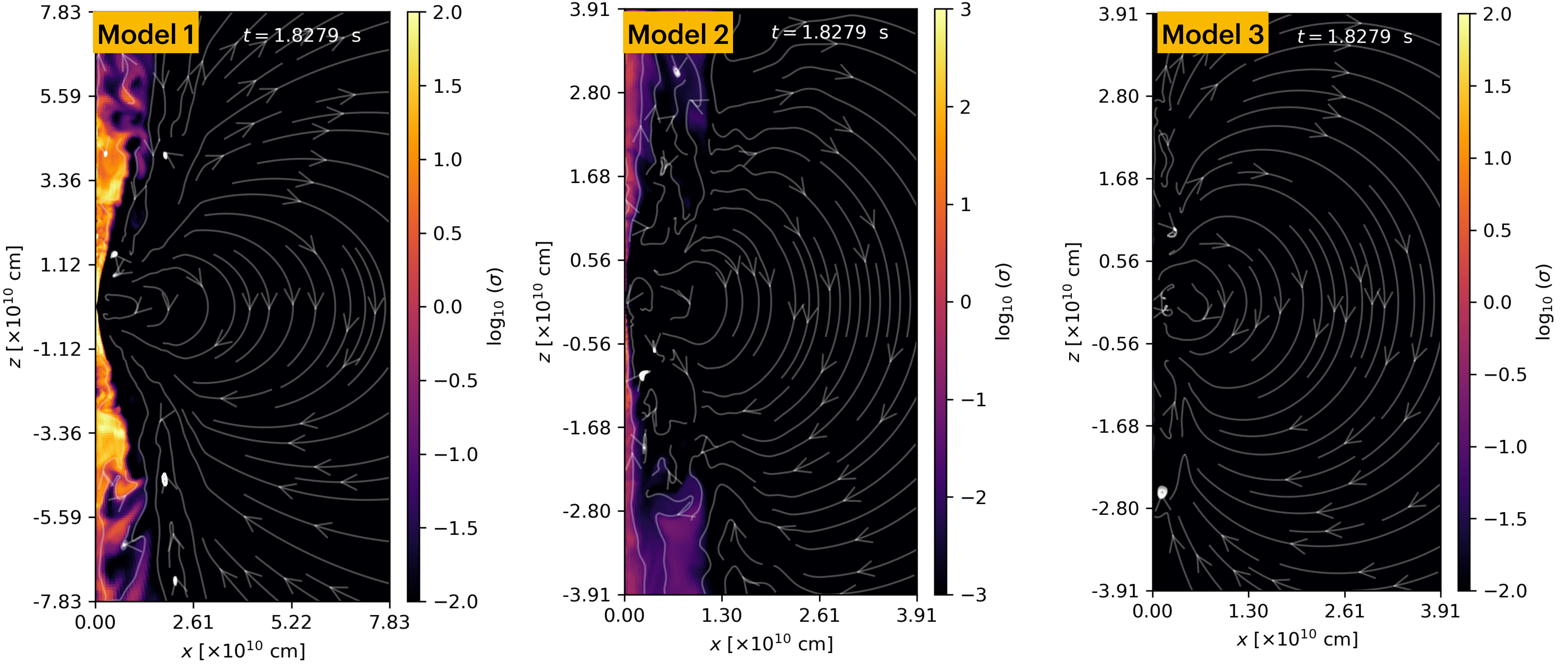
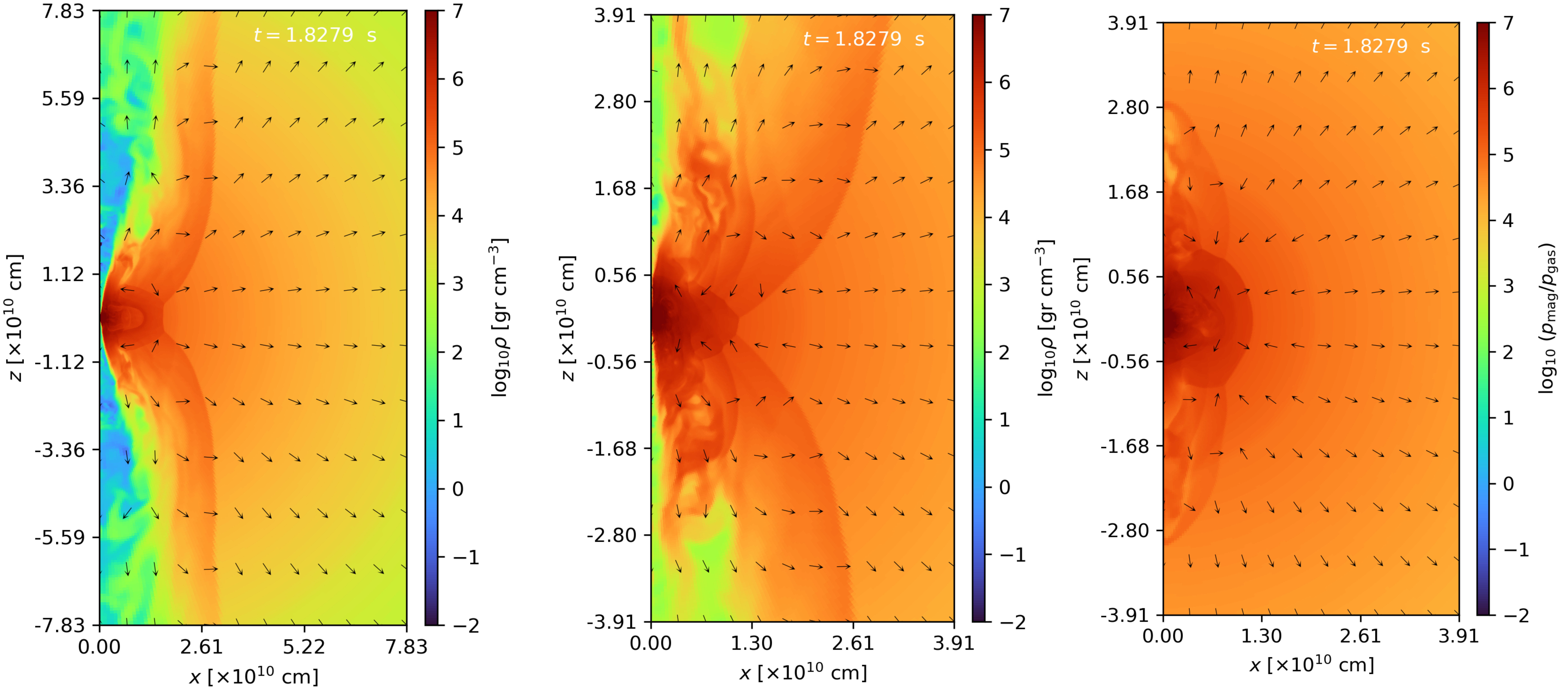


Magnetization

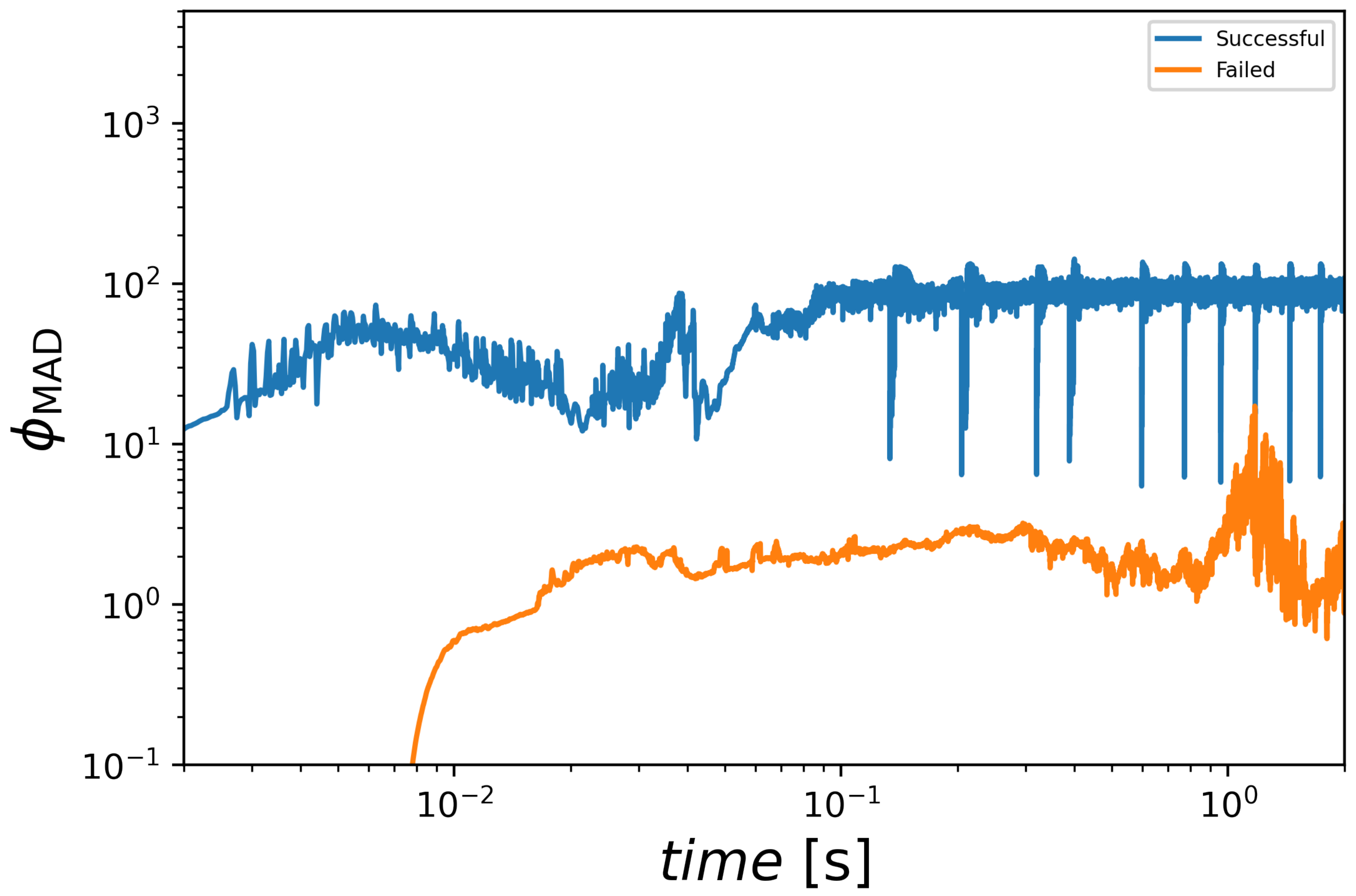


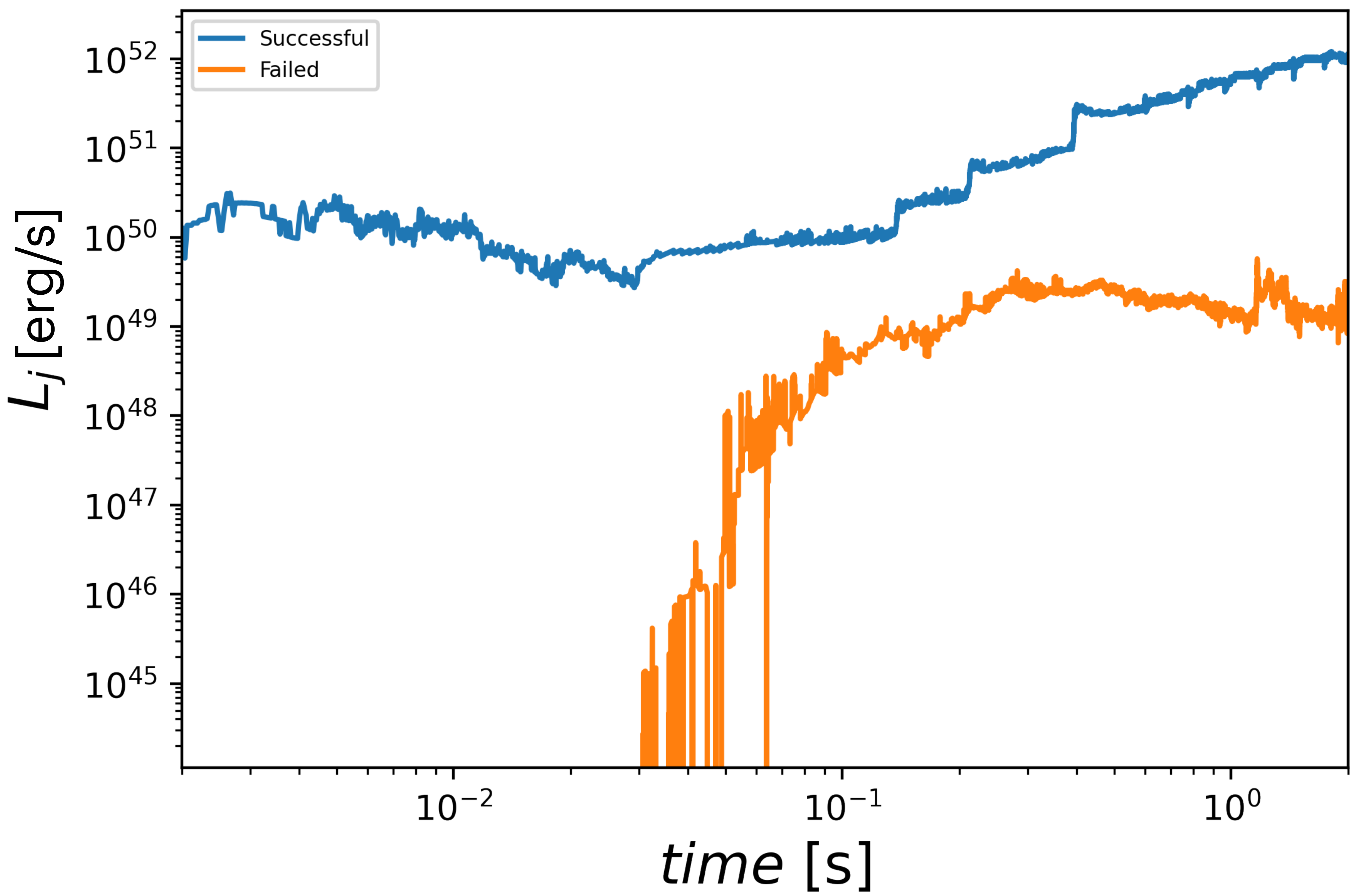
Density



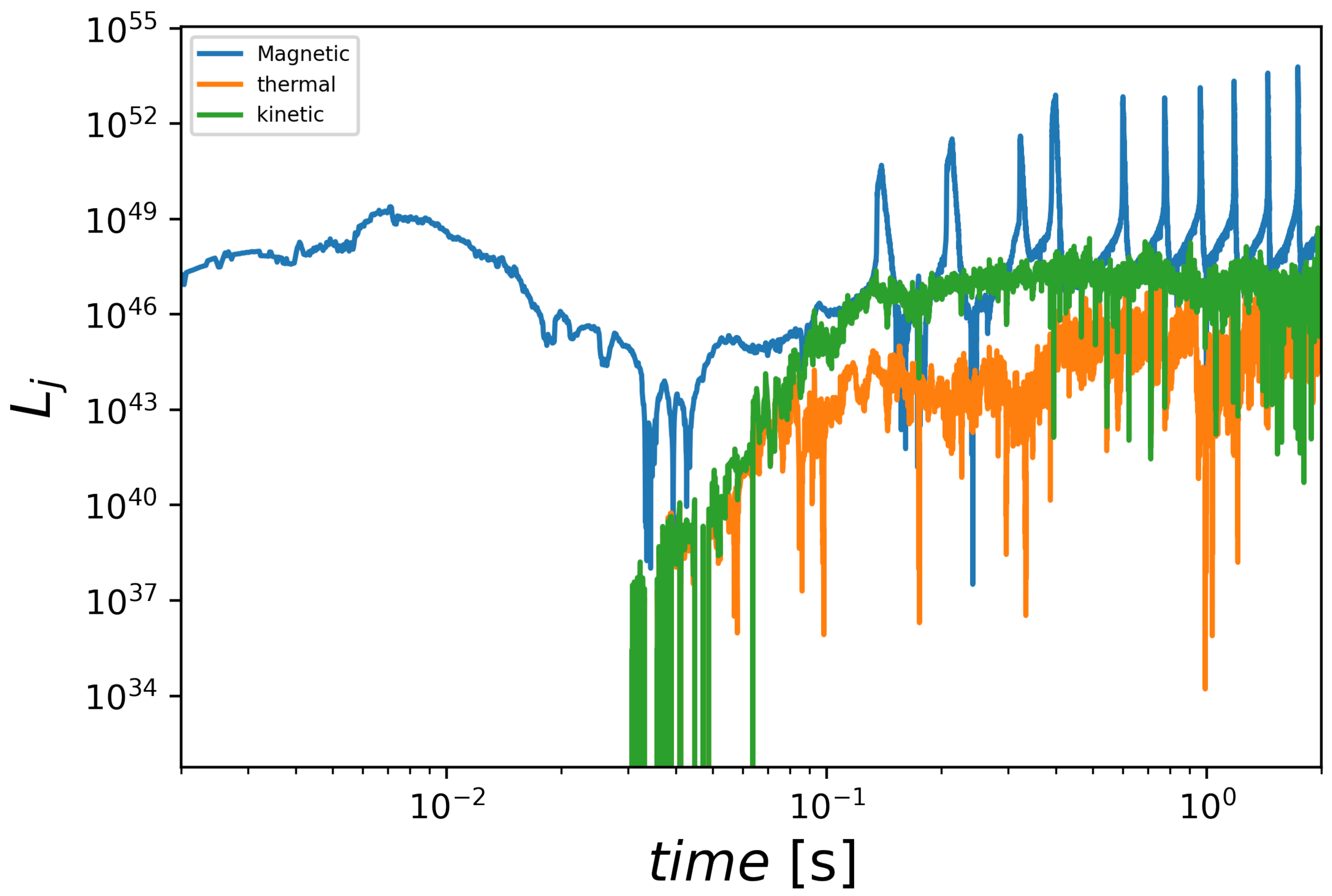
$t = 1.8279$ s
z [$\times 10^{10}$ cm]
x [$\times 10^{10}$ cm]
$\log_{10}\rho$ [gr cm^{-3}]
$\log_{10}$ ($p_{\mathrm{mag}}/p_{\mathrm{gas}}$)
7.83
5.59
3.36
1.12
-1.12
-3.36
-5.59
-7.83
0.00
2.61
5.22
3.91
2.80
1.68
0.56
-0.56
-1.68
-2.80
-3.91
1.30
7
6
5
4
3
2
1
0
−1
−2

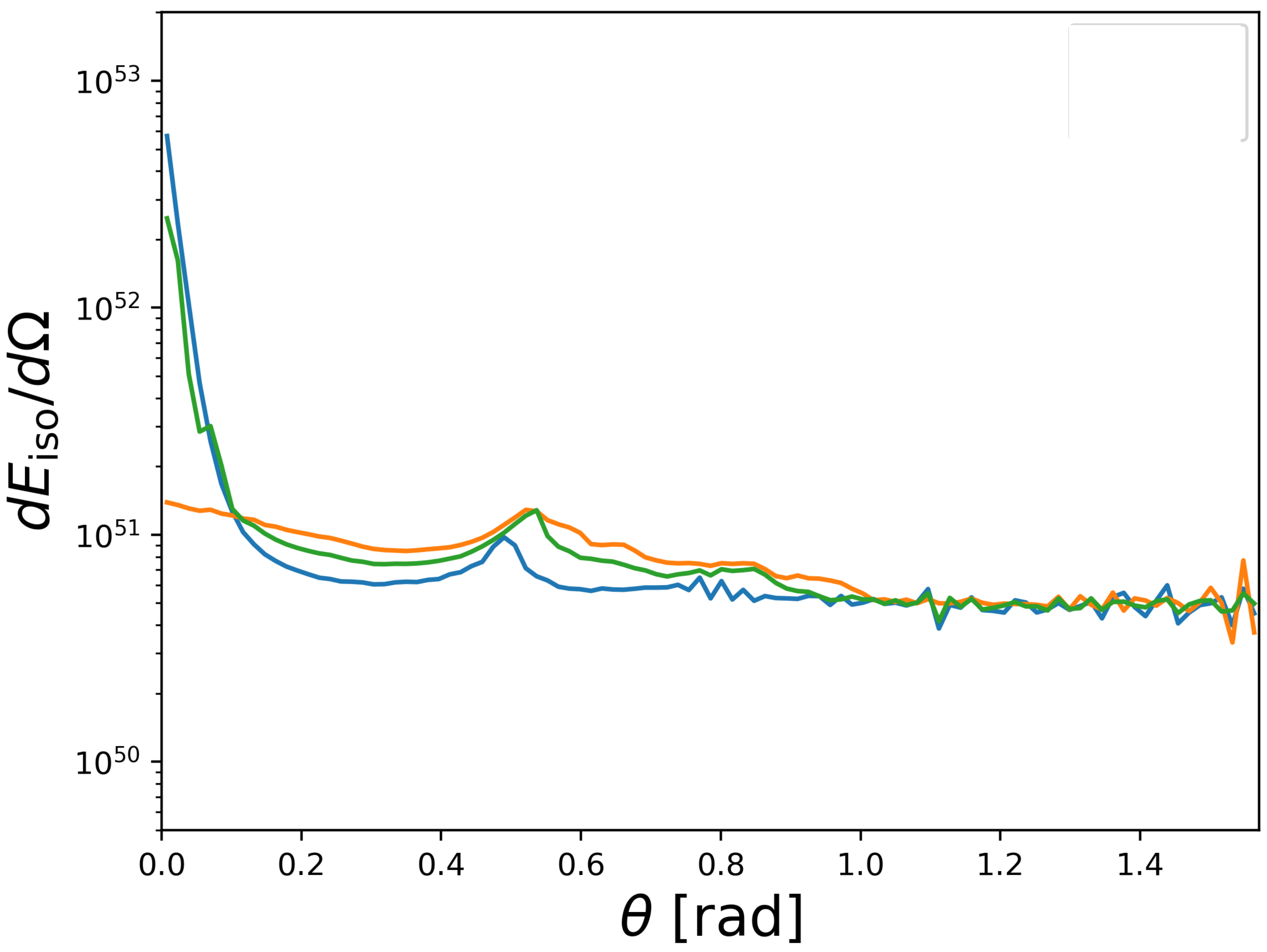
Flux evolution

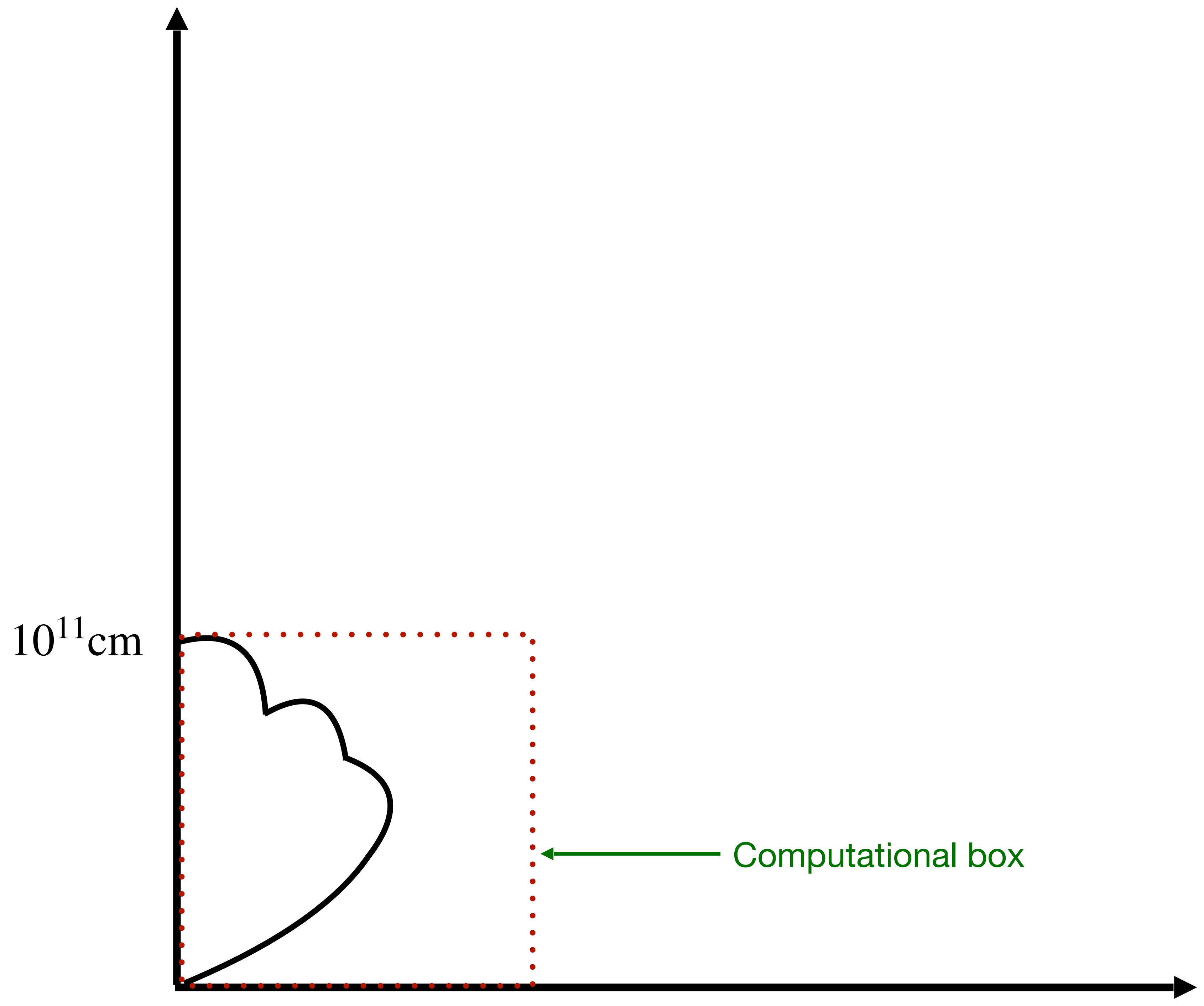




Energy components and structure



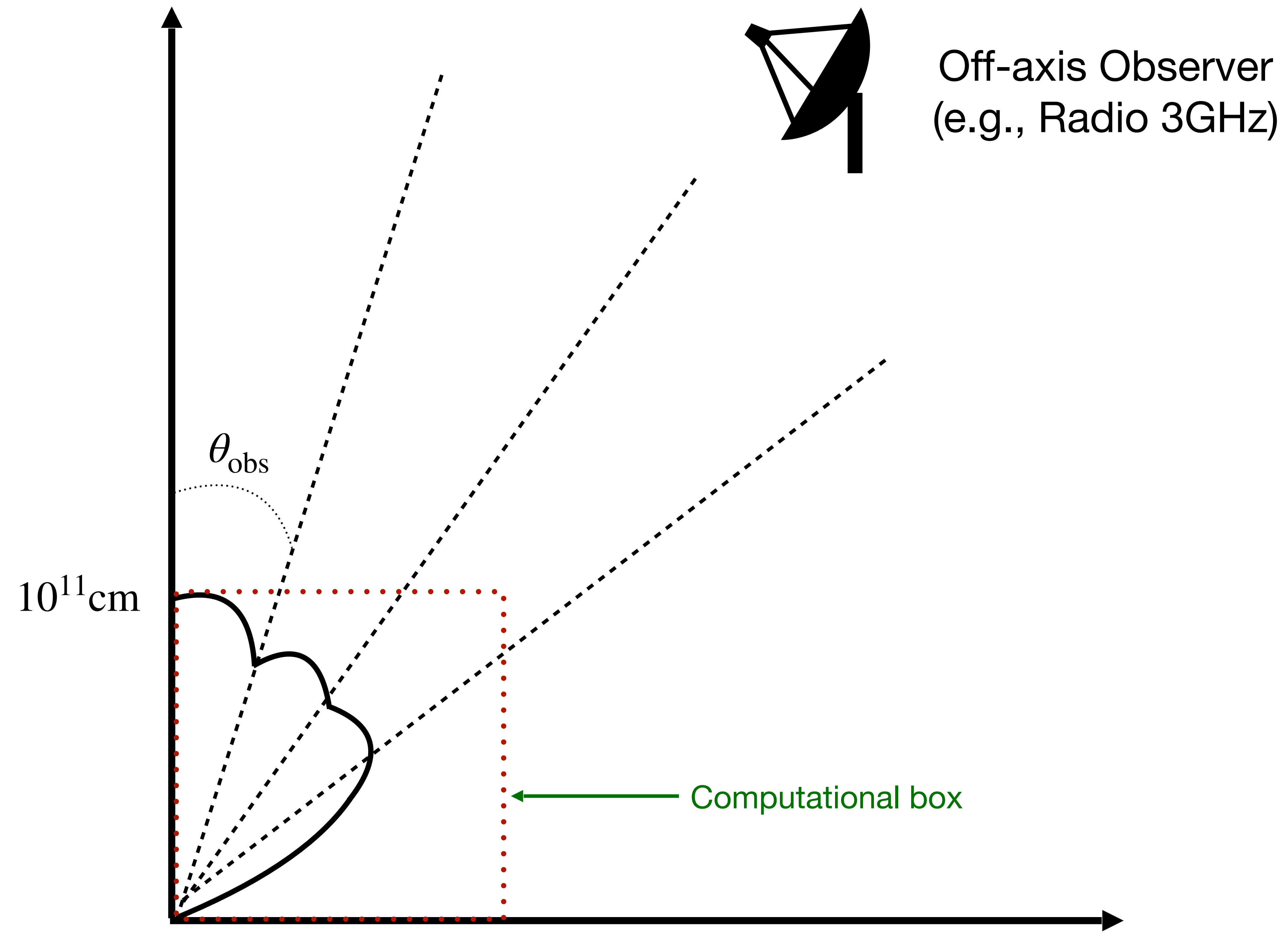




We follow the standard afterglow estimation
(Sari, Piran & Narayan 1990; Granot & Sari 2002)

- Blandford & Mckee 1976 model
- Synchrotron emission. Magnetic field amplified in the shock front.

Yesterday, Talk by Emma Dreas: The kinetic component dominate at scales > 10^11 cm



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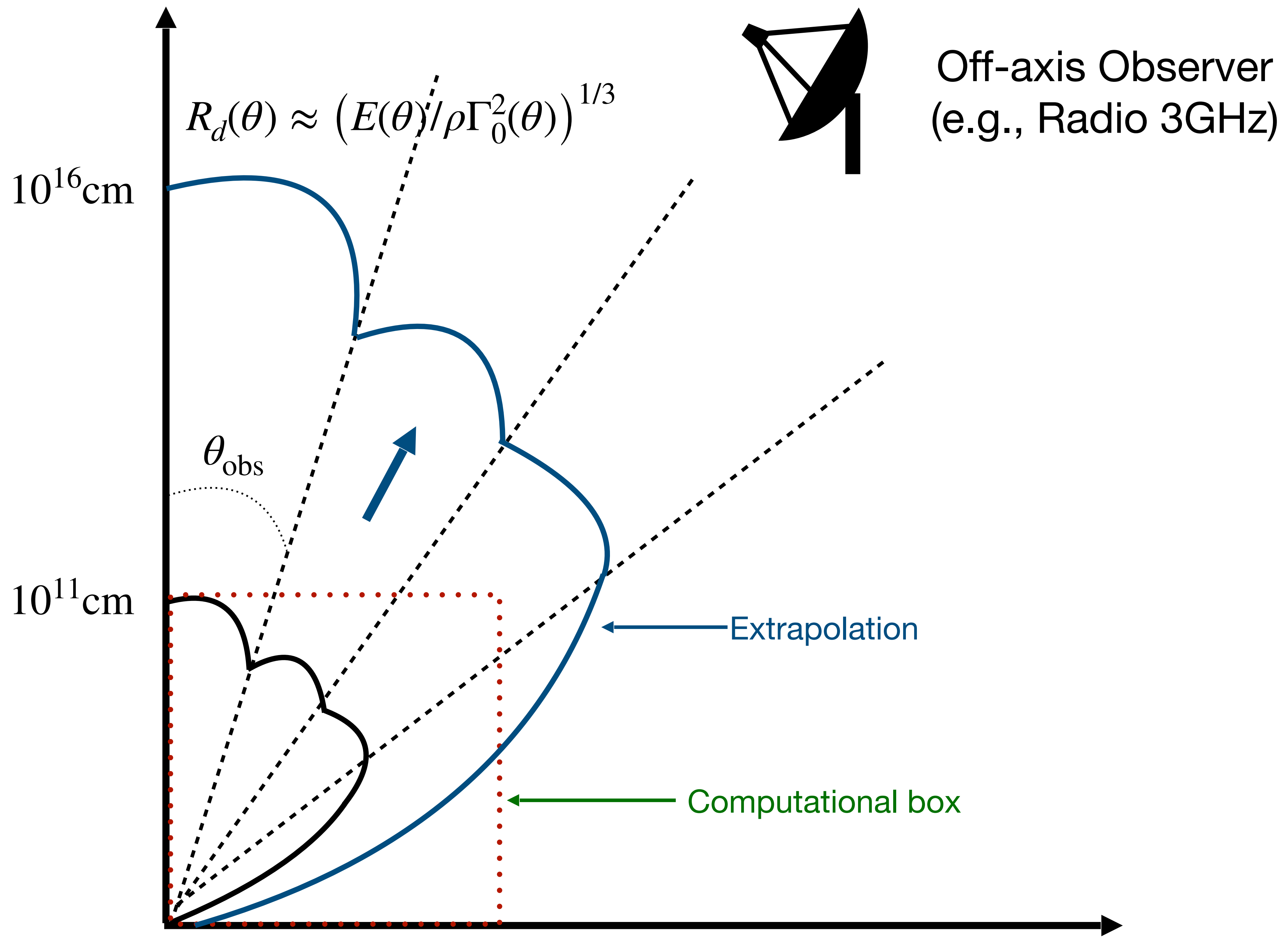

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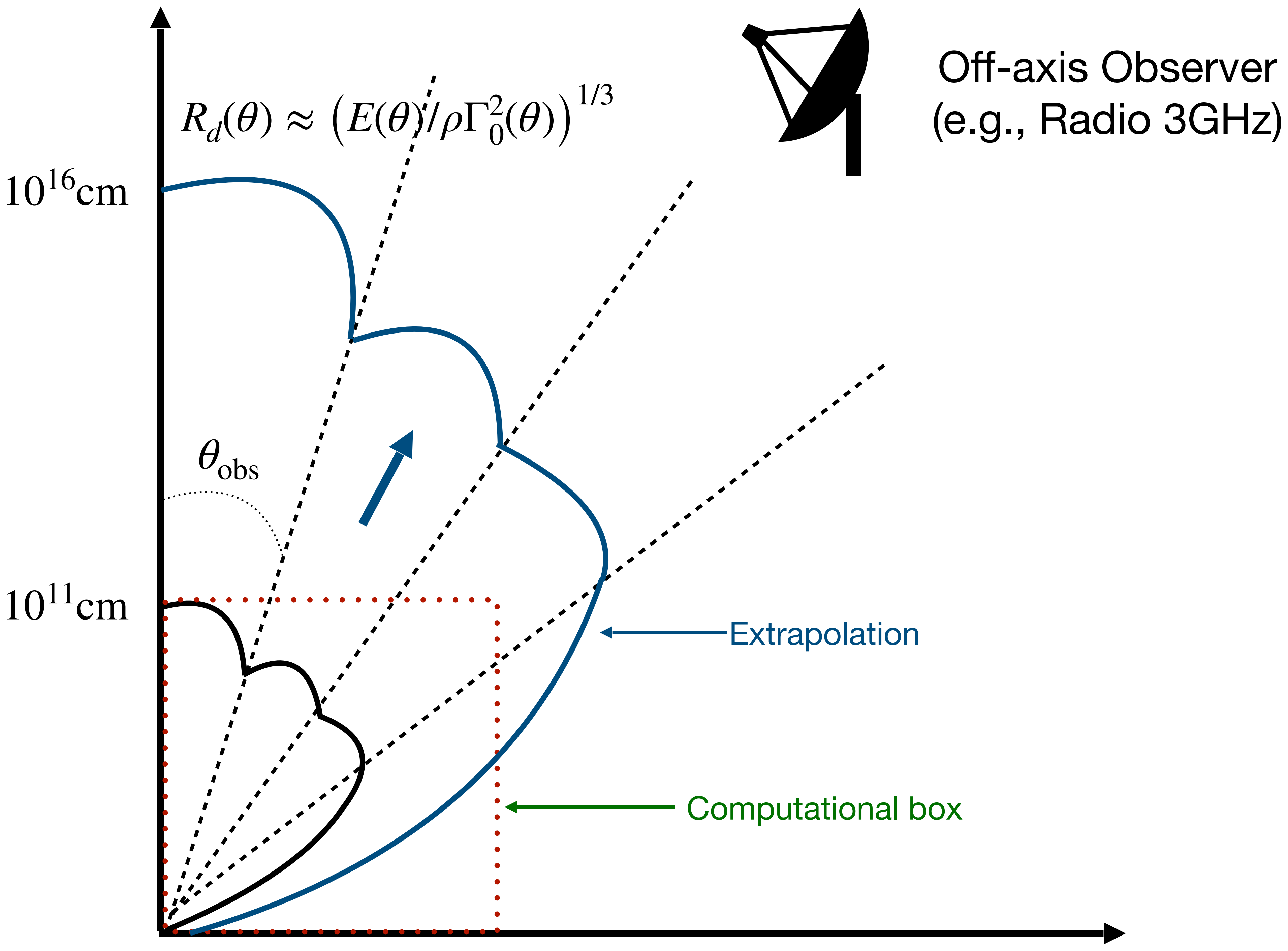

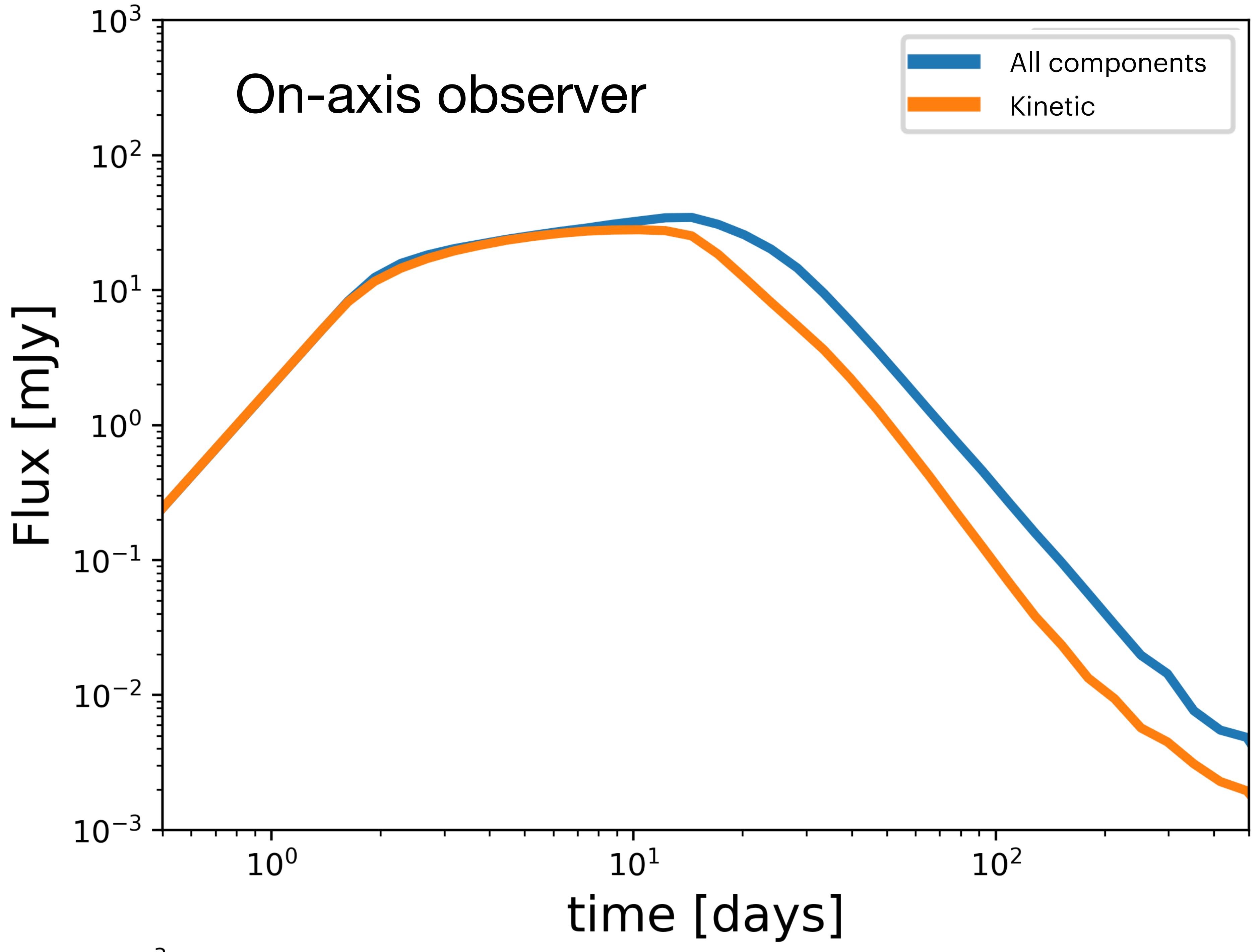

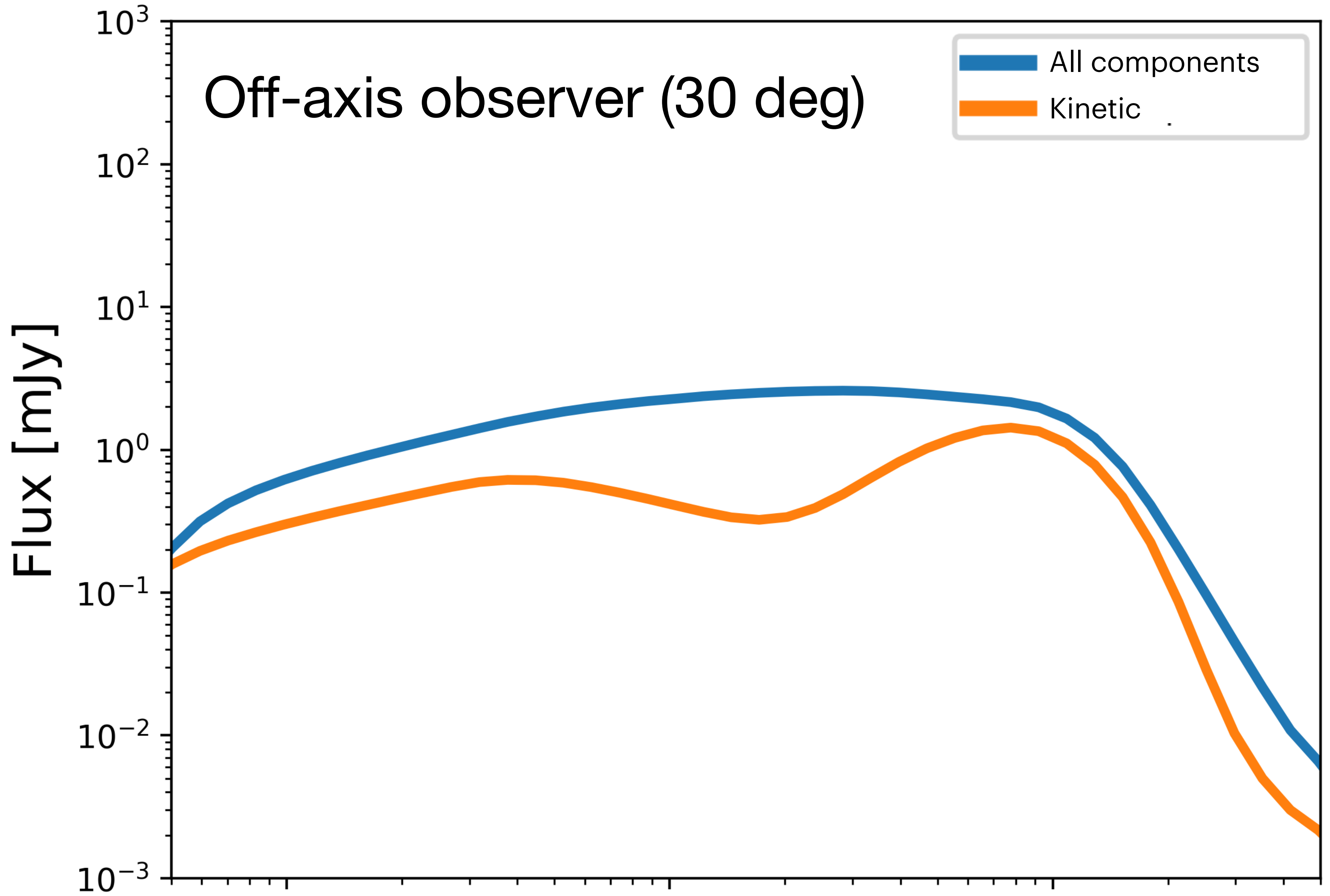

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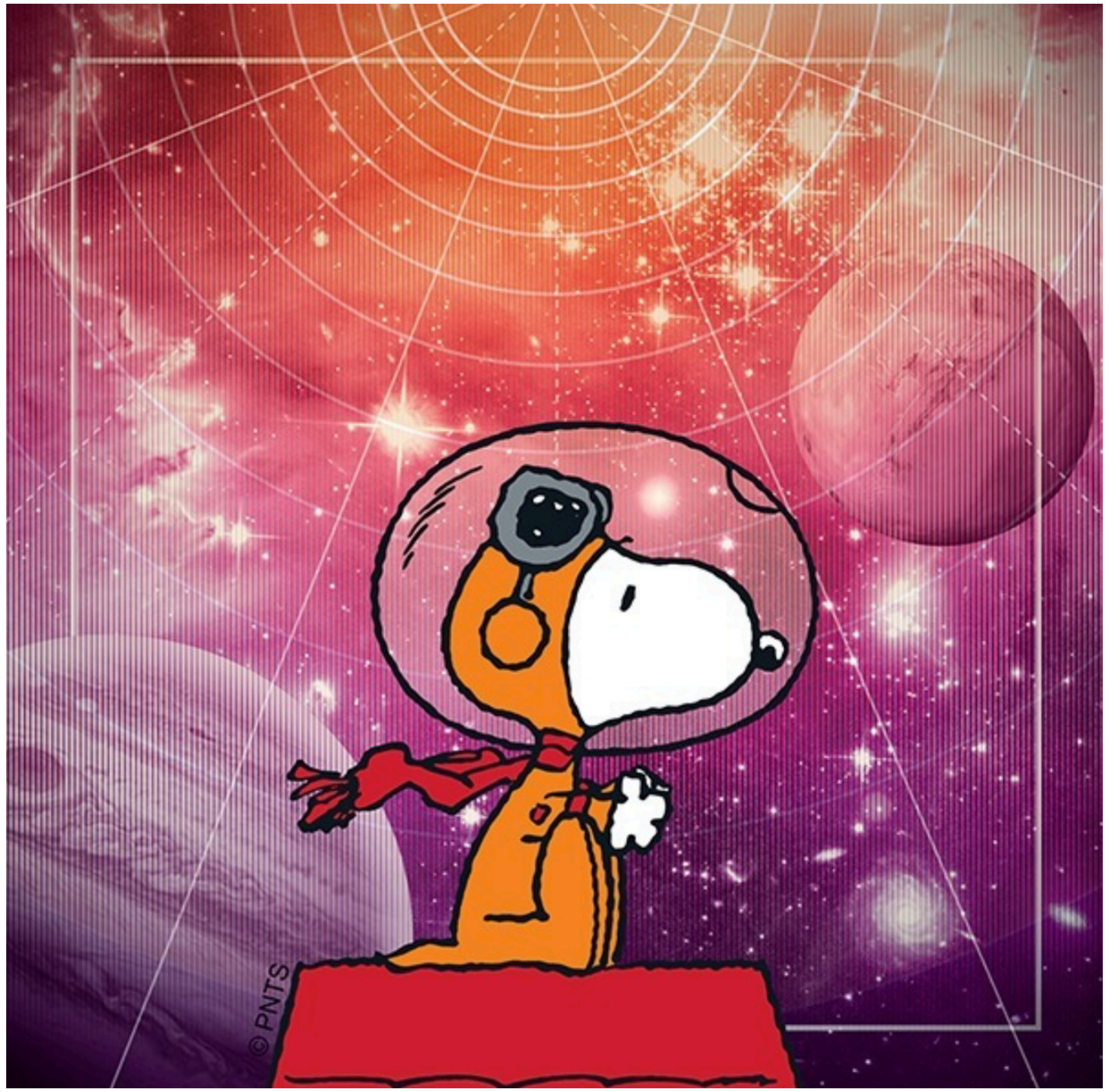
Conclusions

- At scales $r \sim 10^8\mathrm{cm}$ and $t \sim 2\mathrm{s}$, the jet is still magnetized. In this scenario, strong shock conditions imposed far from the black hole could be not consistent with the central engine activity.
- At intermediate scales, the kinetic energy is still not dominant, therefore, an analytical expansion for estimates of afterglow radiation could not represent a correct interpretation.
- Failed jets are produced in a low-magnetized scenario. It happens when the BZ mechanism is not activated. It is more related to the previous evolution of the progenitor star (special configuration of the magnetic field) and not to the dynamics of the jet.

Thank you! - Grazie! - ¡Gracias!



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