The large-scale interaction between sGRB jets and disk outflows from NSNS and BHNS mergers

Gerardo Urrutia

A. Janiuk, F. Nouri & B. James

Centre for Theoretical Physics, Warsaw, Poland.

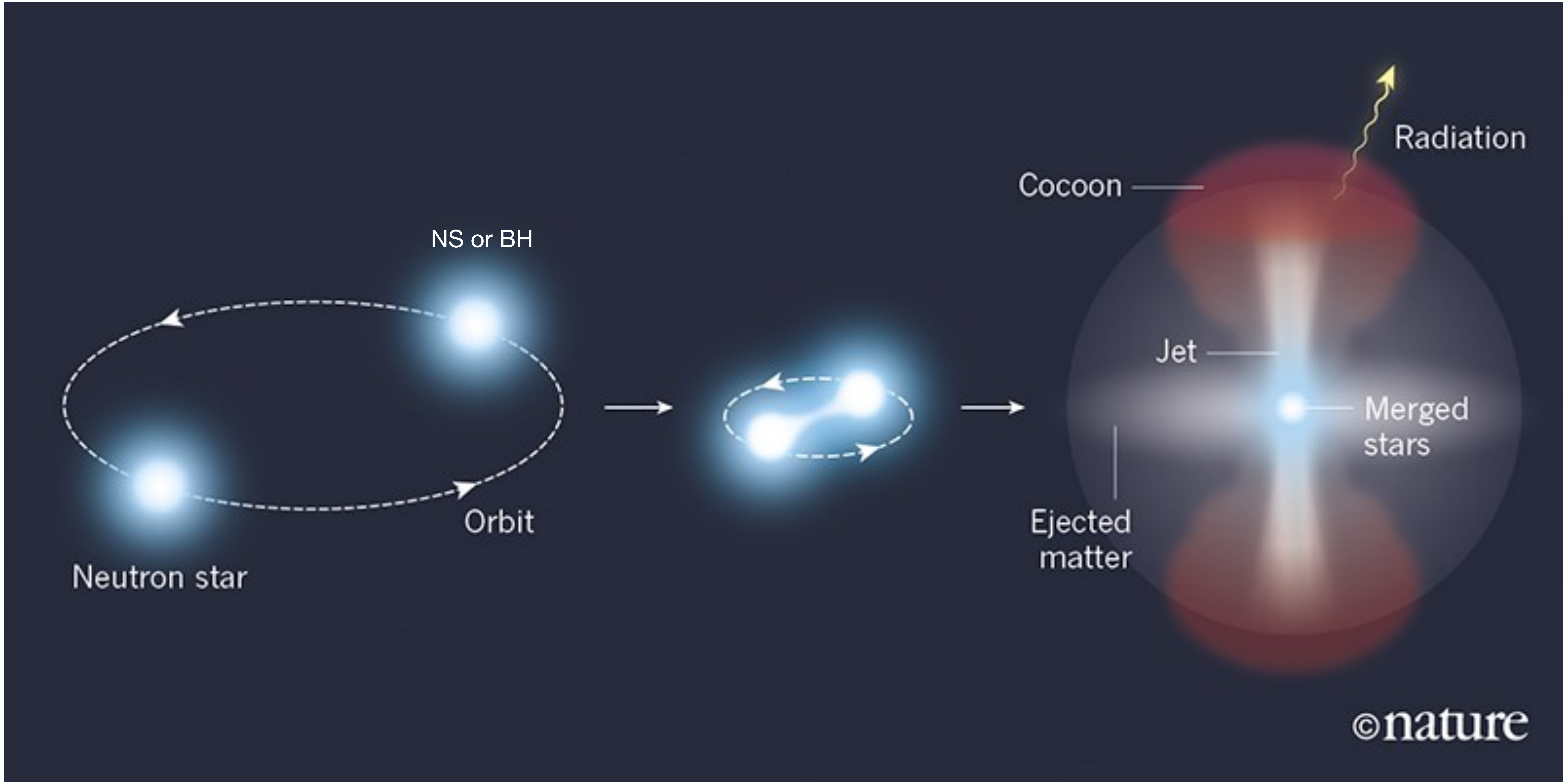
gurrutia@cft.edu.pl

Based on arXiv:2401.10094

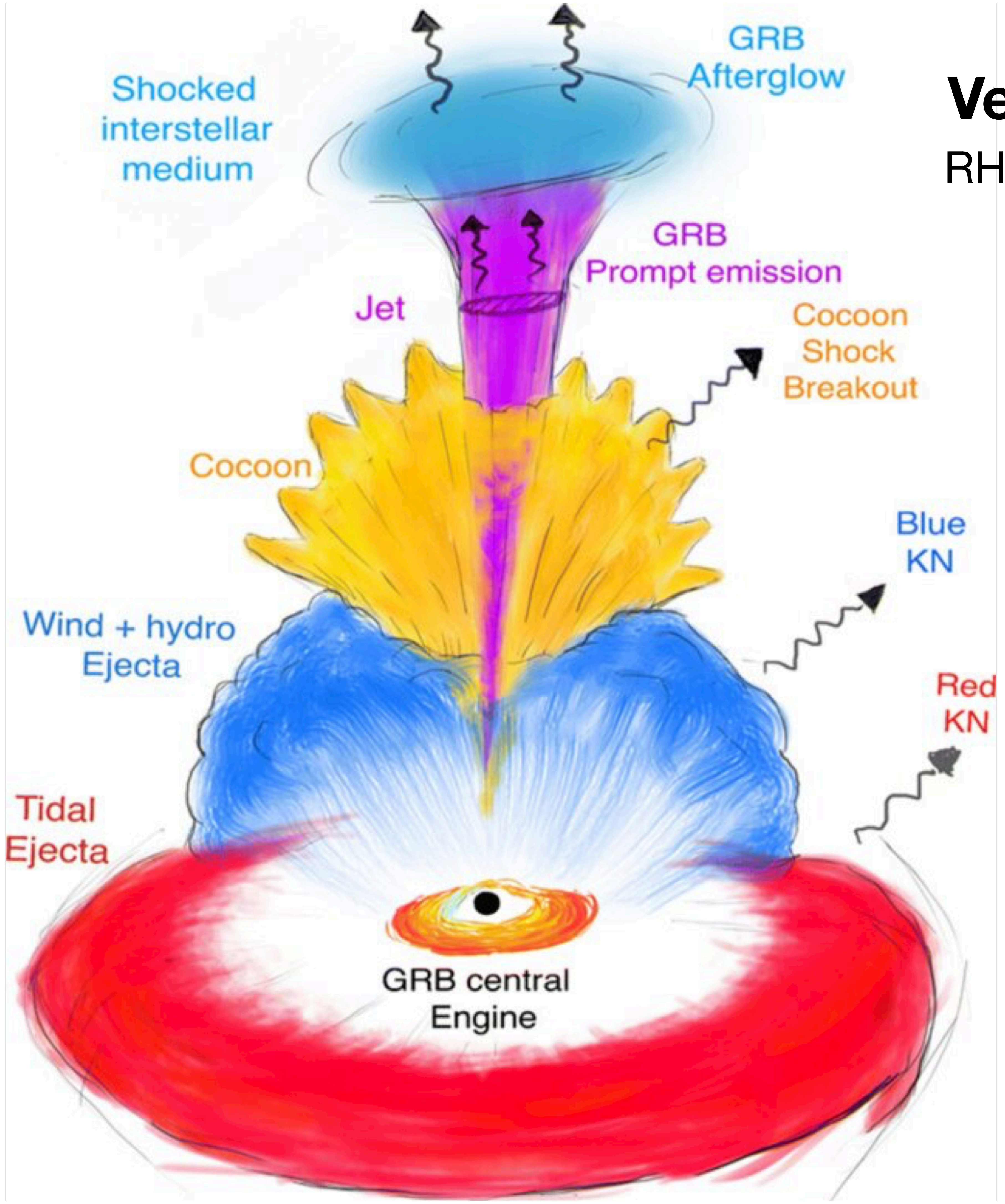
Looking AHEAD to soft gamma-ray Astrophysics, Ferrara - Italy, February 2024

NATIONAL SCIENCE CENTRE POLAND

The origin of Short Gamma Ray Bursts



Post-merger evolution of the jet



Cartoon of GRB evolution (Stefano Ascenzi)

Very Large Scales $r \gtrsim 10^{16}\,\mathrm{cm}$

RHD simulations or Analytical extrapolations

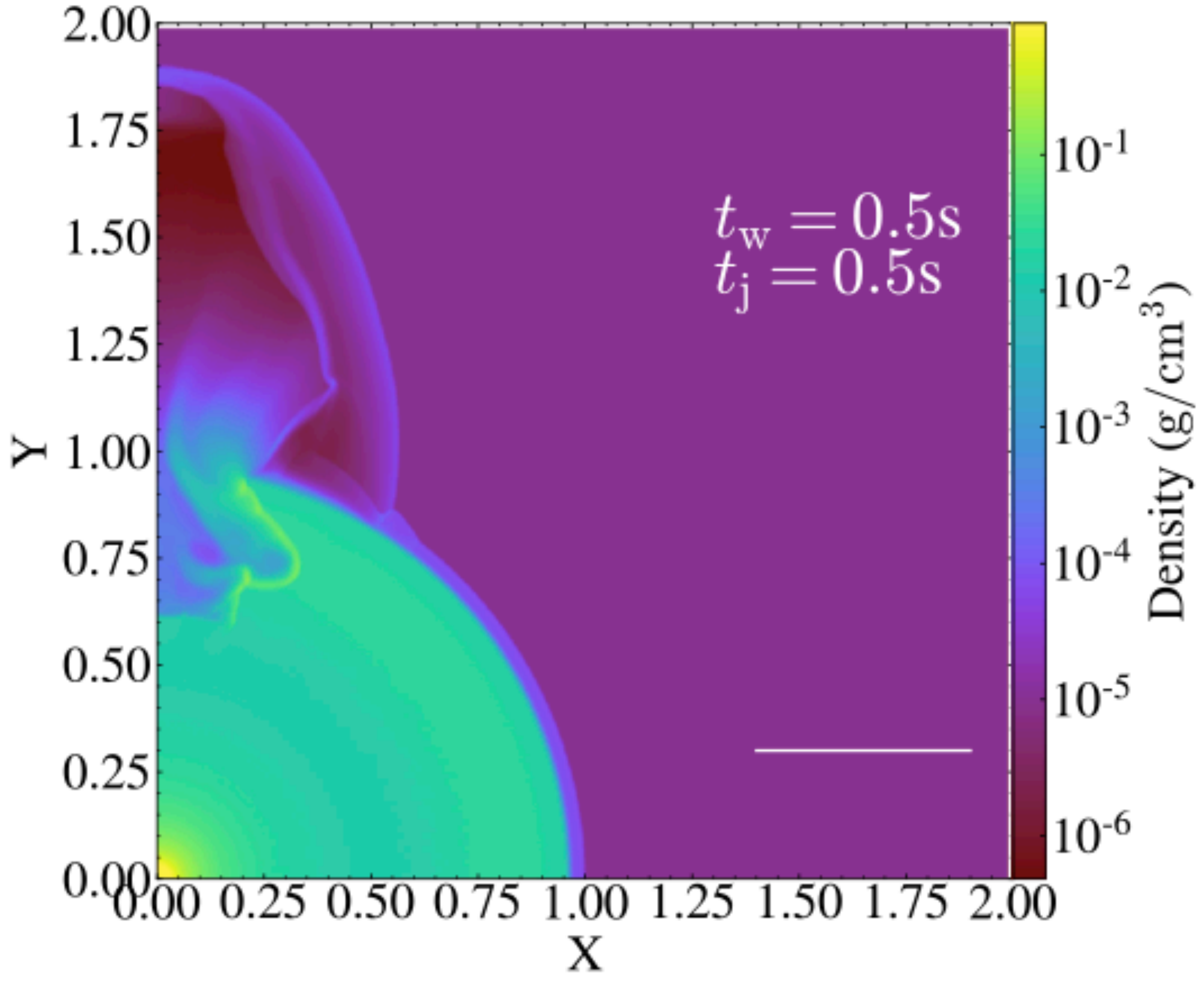
Large Scales $r \gtrsim 10^{11}\,\mathrm{cm}$

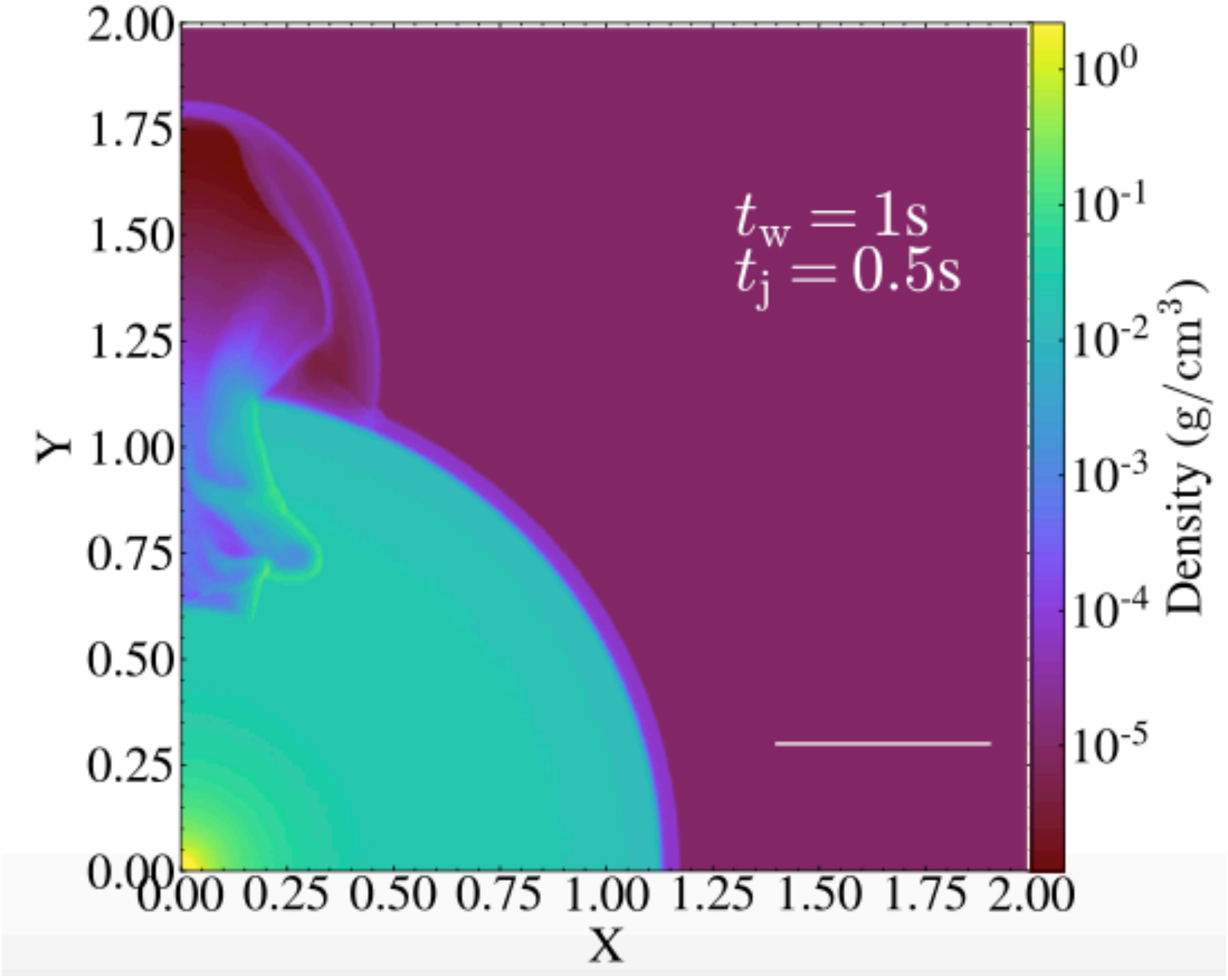
RMHD or RHD simulations

Small Scales $r \lesssim 10^{8}\,\mathrm{cm}$

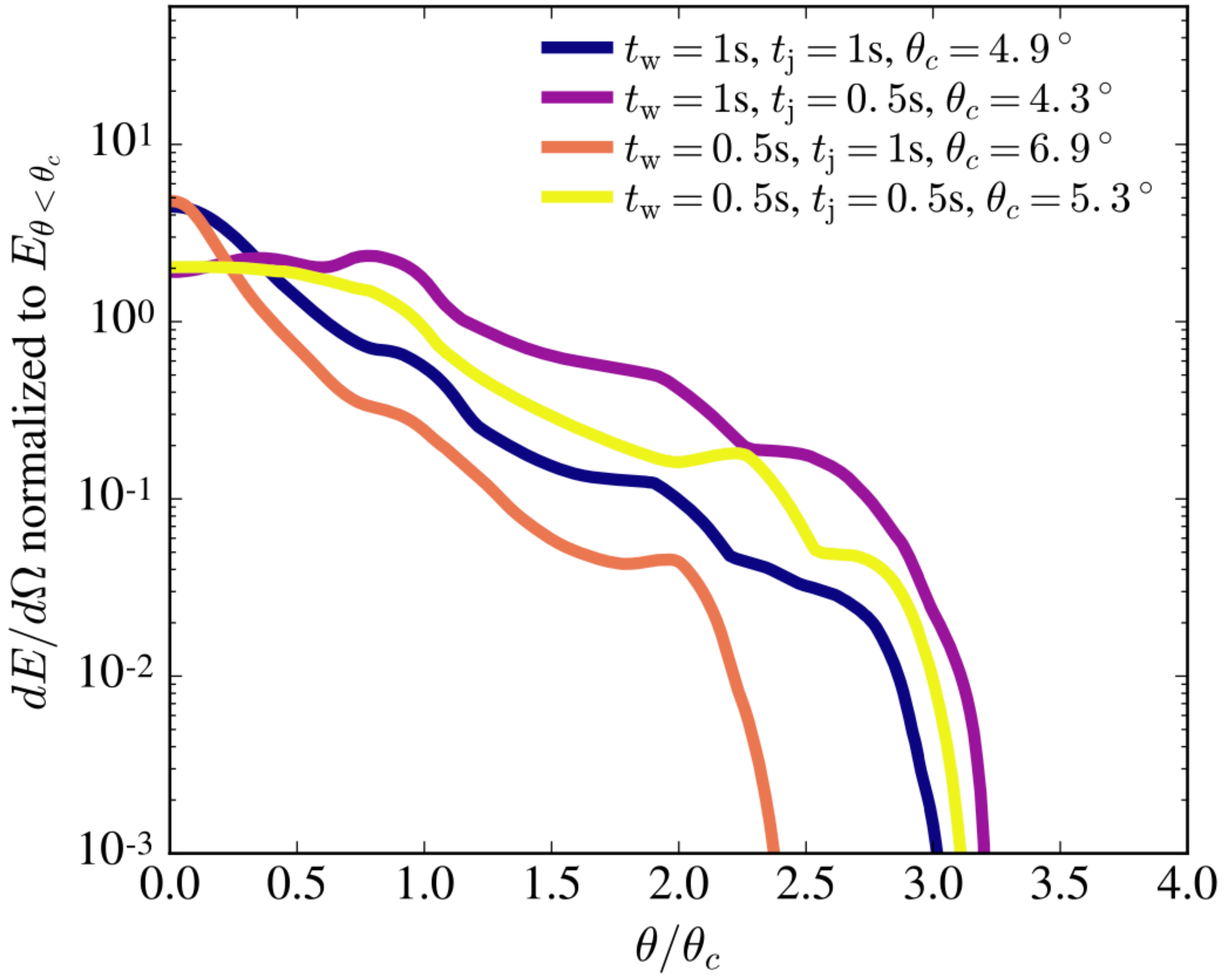
GRMHD simulations

The Jet structure is modified by the interaction with post-merger winds



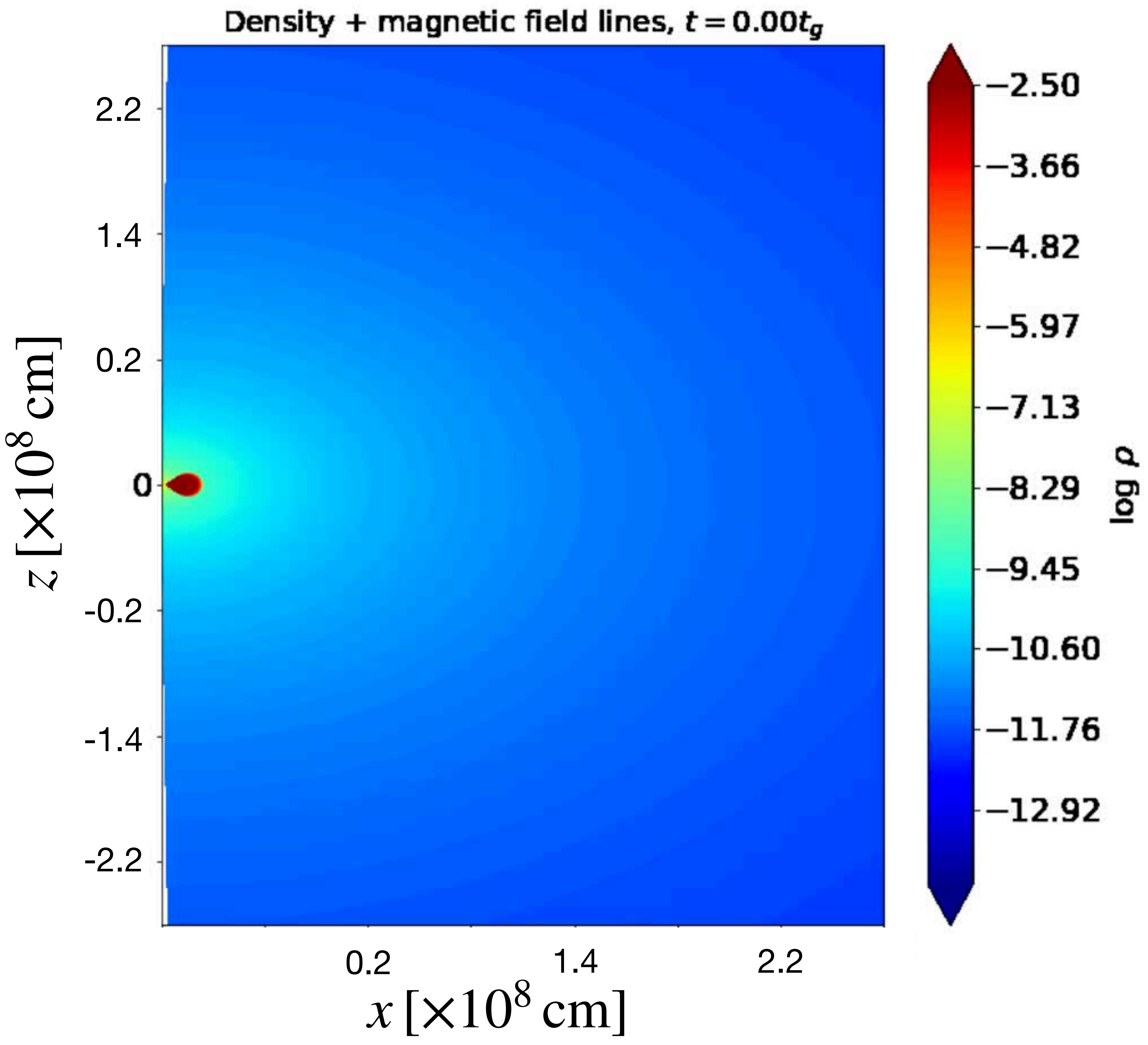


Energy distribution (jet structure)

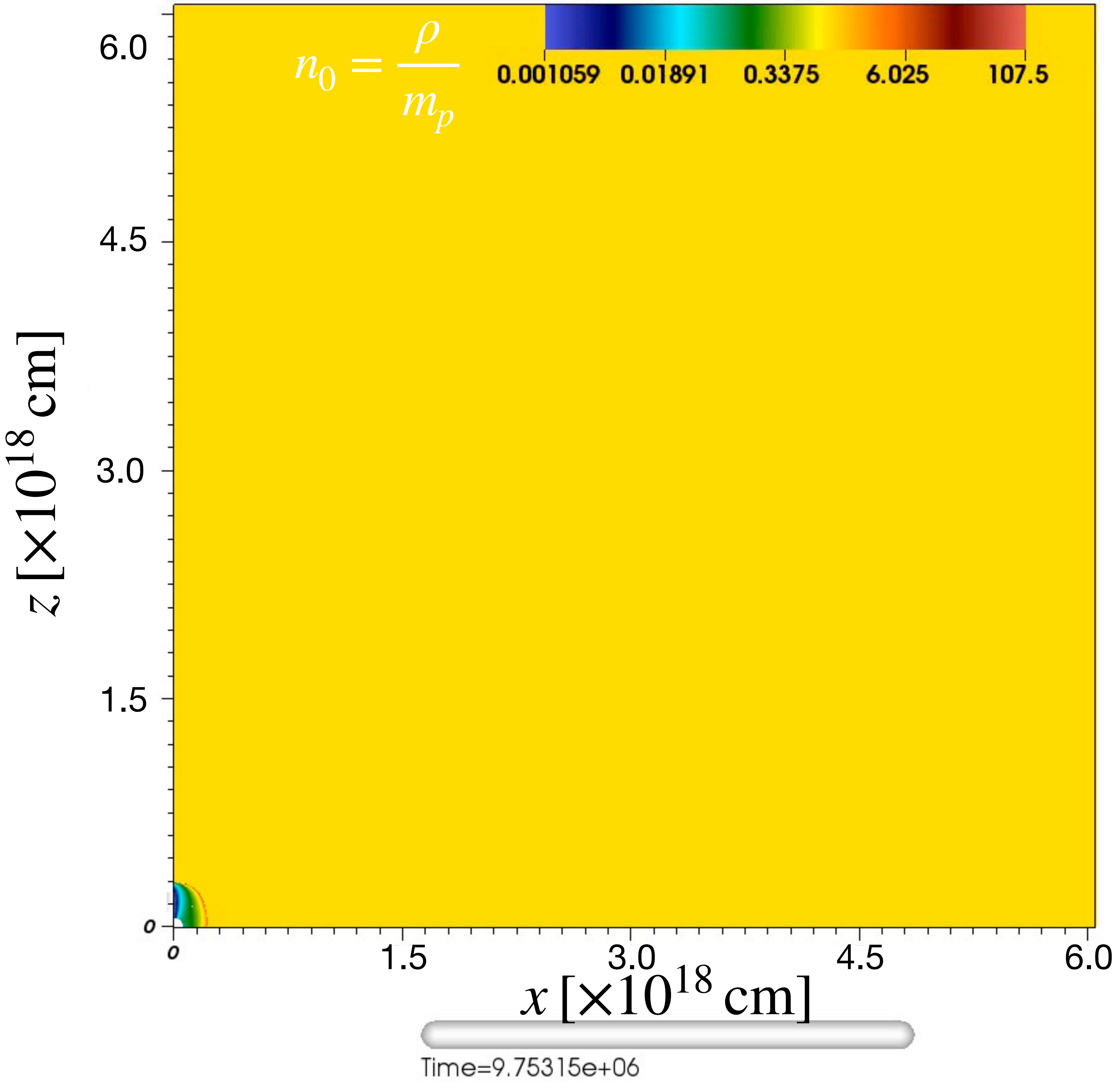


Murguia-Berthier et al., 2021

Example: Solving the jet dynamics at different scales



Astrophysics group CFT-Poland



HEAP group, UNAM-Mexico

Our Connection between small and large scales

Small scales $r < 3 \times 10^8\,\mathrm{cm}$

General Relativistic MHD simulation

$$(\rho u_\mu)_{;\nu} = 0$$

$$T^\mu_{\nu;\mu} = 0$$

$$T^{\mu\nu} = T^{\mu\nu}_{\mathrm{m}} + T^{\mu\nu}_{\mathrm{em}}$$

-HARM CODE (Gammie 2003)
-HLL solver
-Kerr-schild metric

Neutrino treatment (Janiuk et al. 2013)
The neutrino optical depth

$$\tau_{\mathrm{a},\nu_i} = \frac{H}{4\frac{7}{8}\sigma T^4} q_{\mathrm{a},\nu_i},$$

Species:

$$p + e^- \rightarrow n + \nu_e$$
$$n + e^+ \rightarrow p + \bar{\nu}_e$$
$$e^+ + e^- \rightarrow \nu_i \bar{\nu}_i$$

Importing data

Methods:

- **The disc wind outflow was performed by Nouri et al. 2023 by GRMHD simulation.**
- **We constrain the jet parameters from GRMHD simulation.**
- **We import outflow data as an initial condition for a large-scale simulation.**

Large scales $10^8\,\mathrm{cm} < r < 10^{10}\,\mathrm{cm}$

Special Relativistic HD simulation

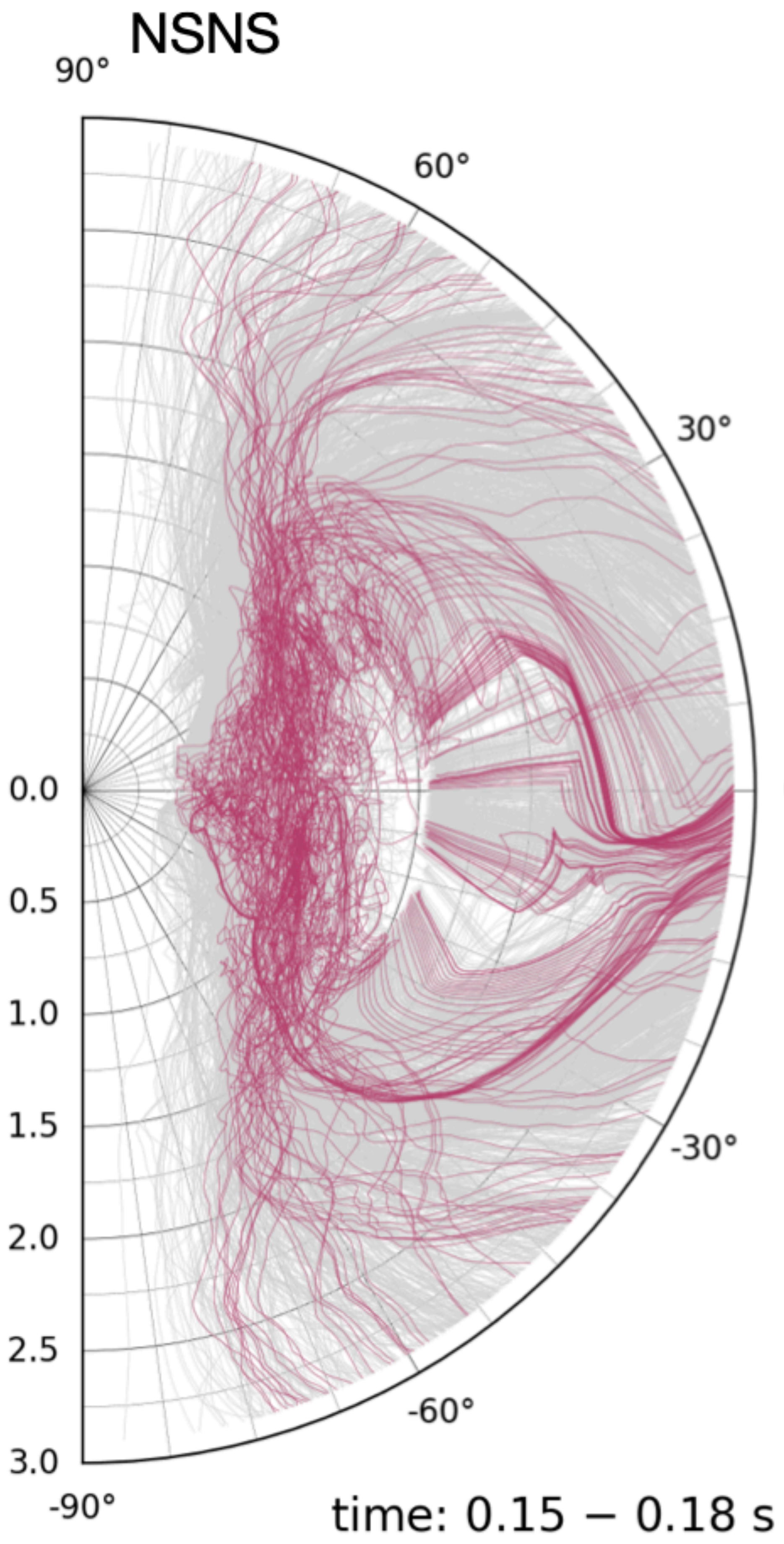
$$(\rho u_\mu)_{;\nu} = 0$$

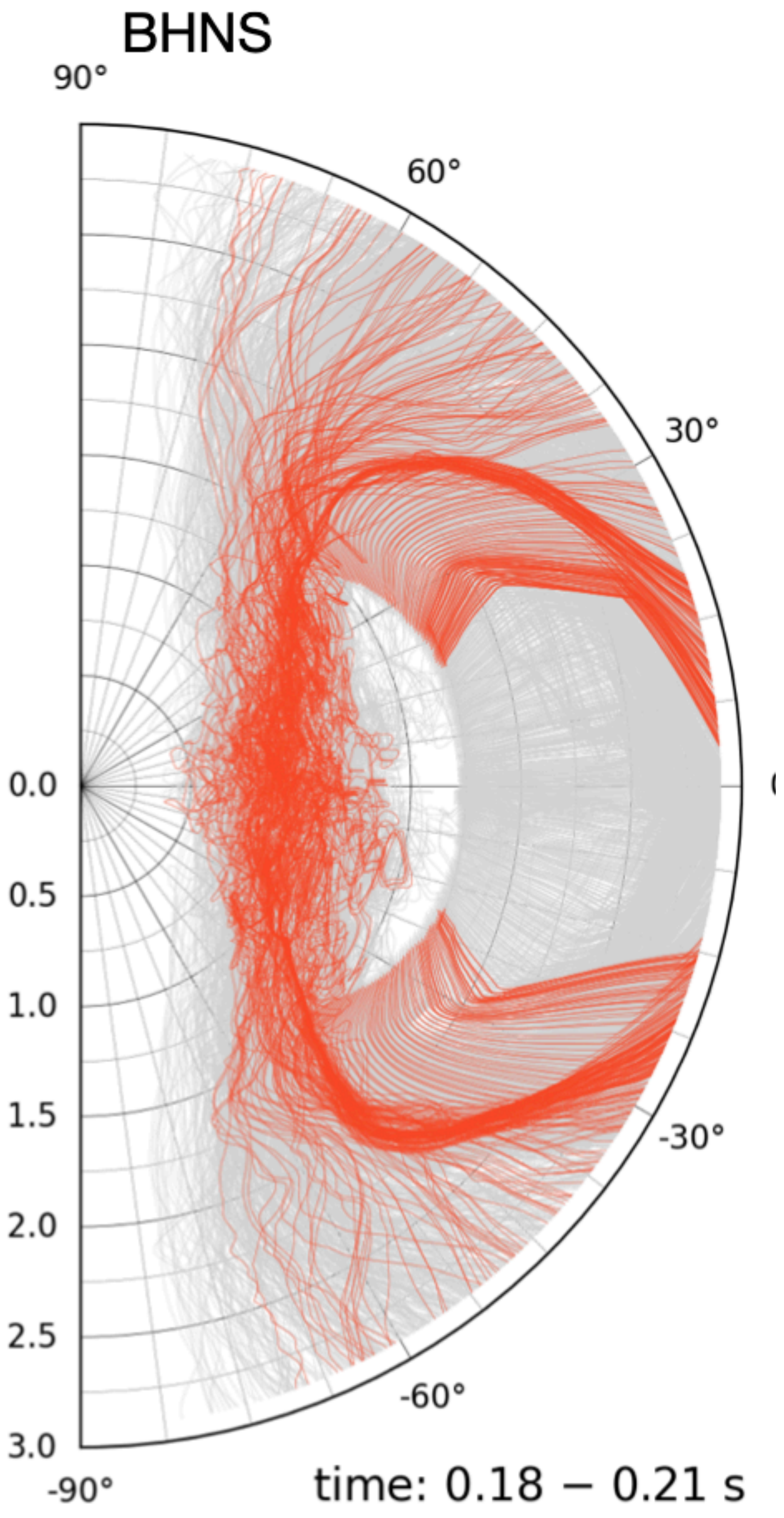
$$T^\mu_{\nu;\mu} = 0$$

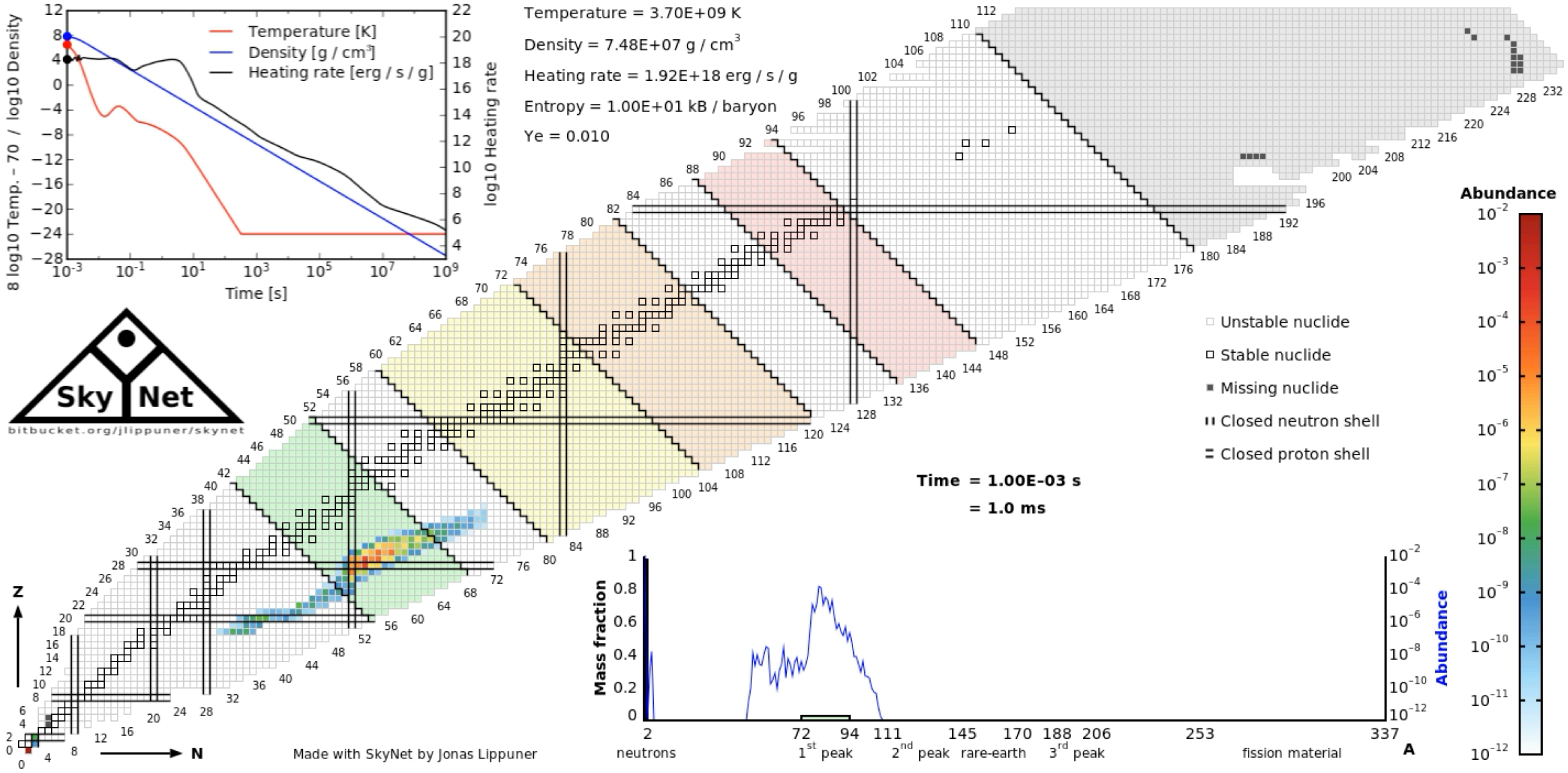
$$T^{\mu\nu} = T^{\mu\nu}_{\mathrm{m}}$$

- Mezcal Code (De Colle 2012)
- Adaptive Mesh Refinement
- HLLC solver
- GR effects not considered

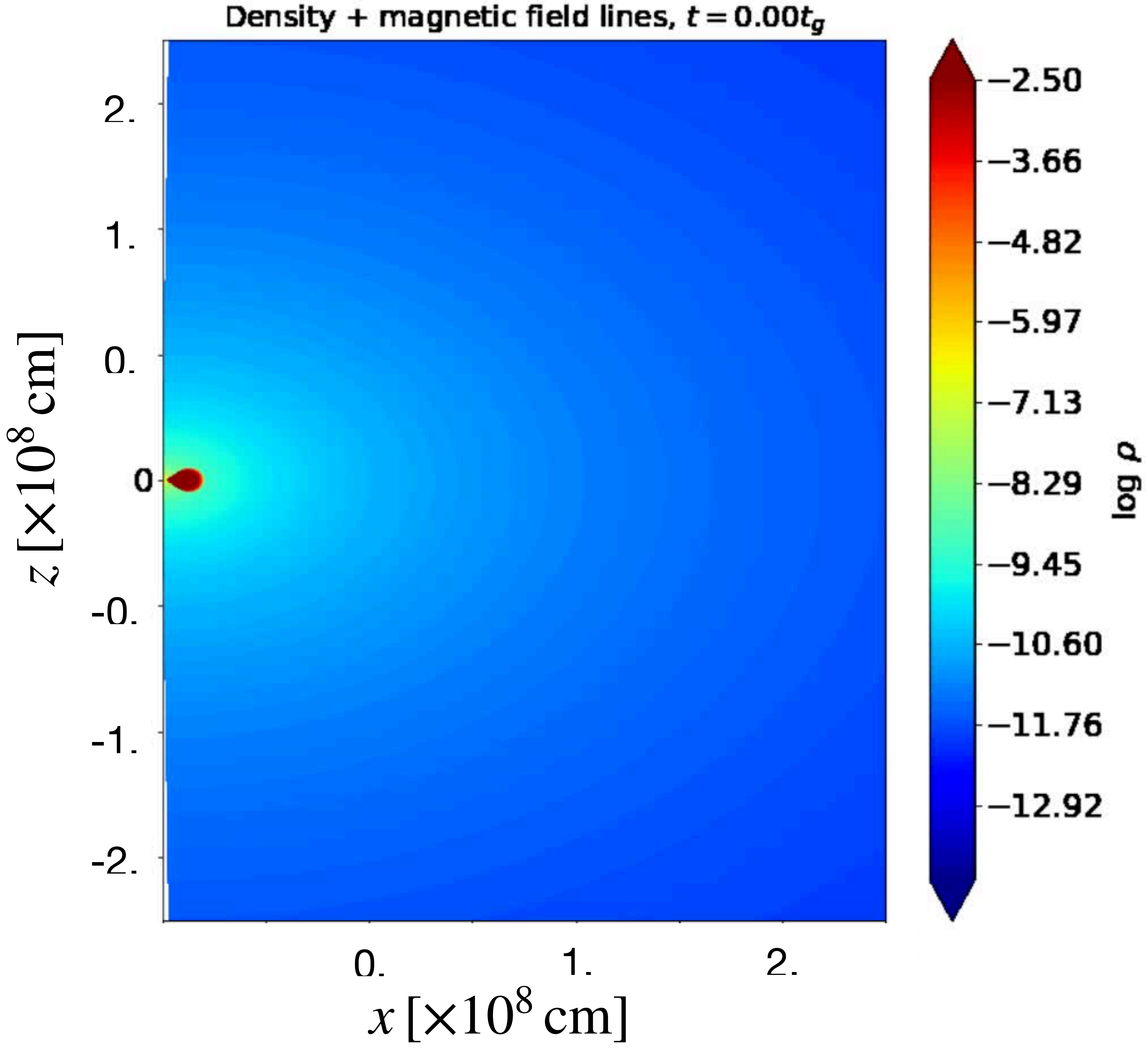
Outflow tracers proceed to follow r-process and get the gas pressure





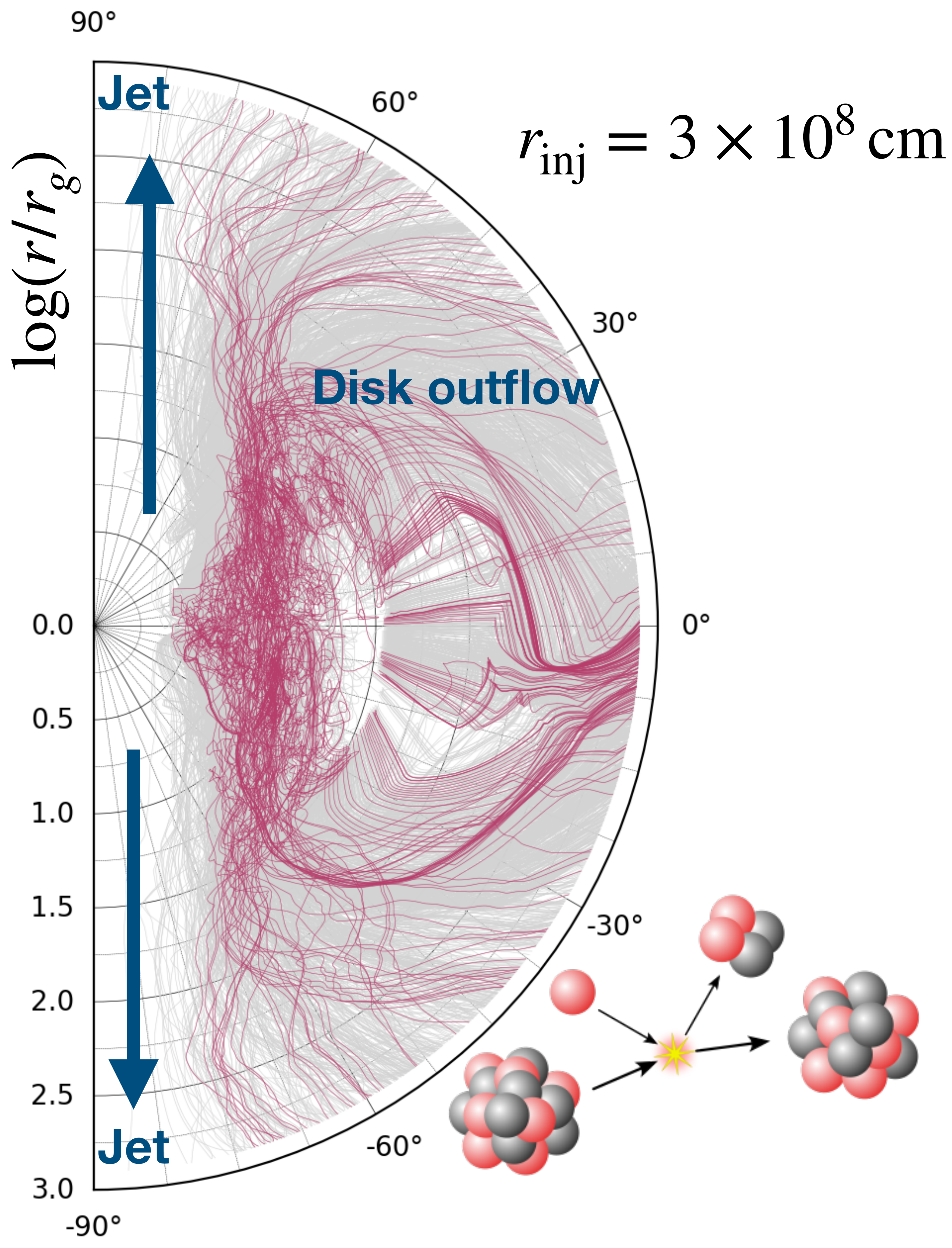


Step 1



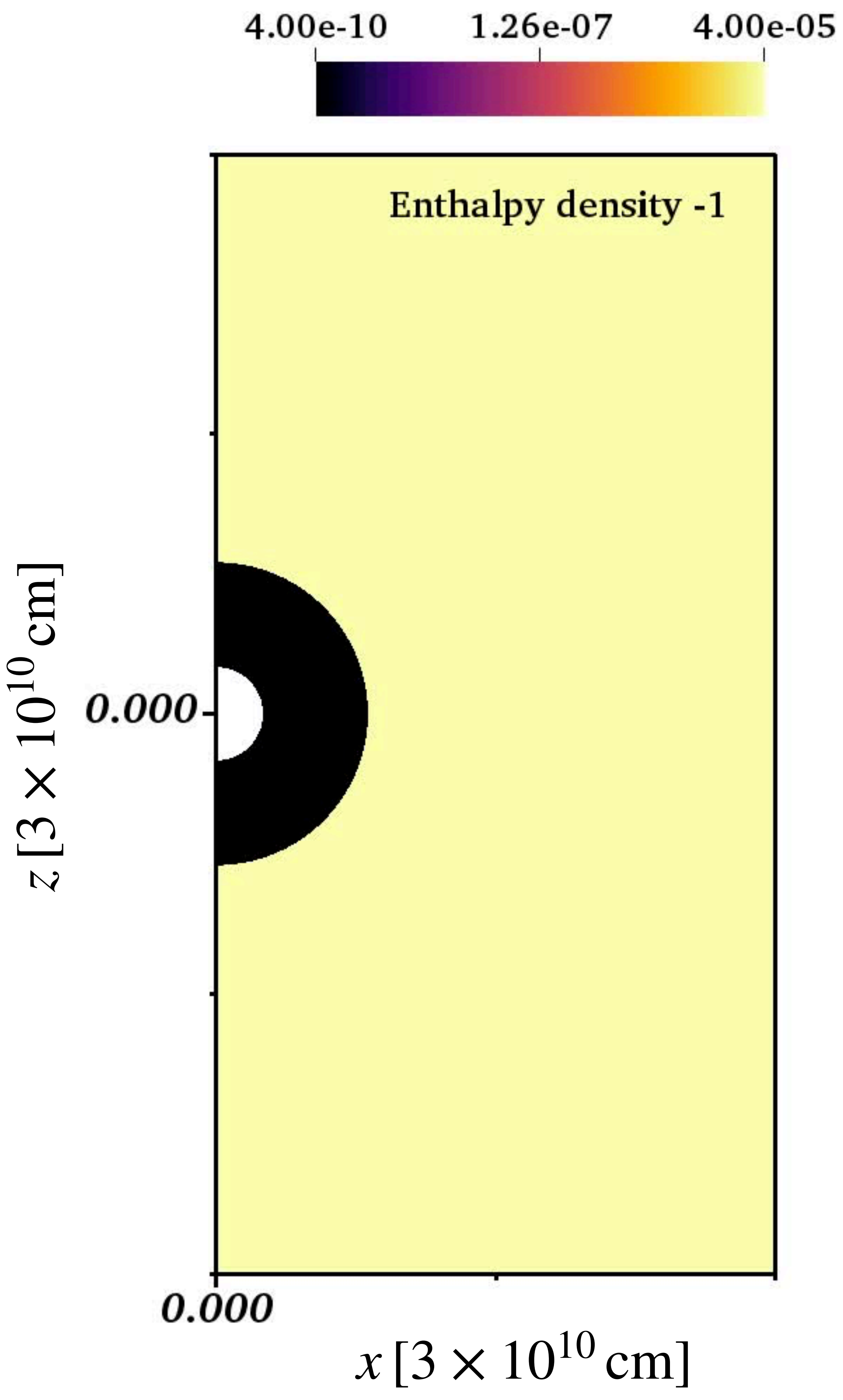
Astrophysics group CFT-

Step 2



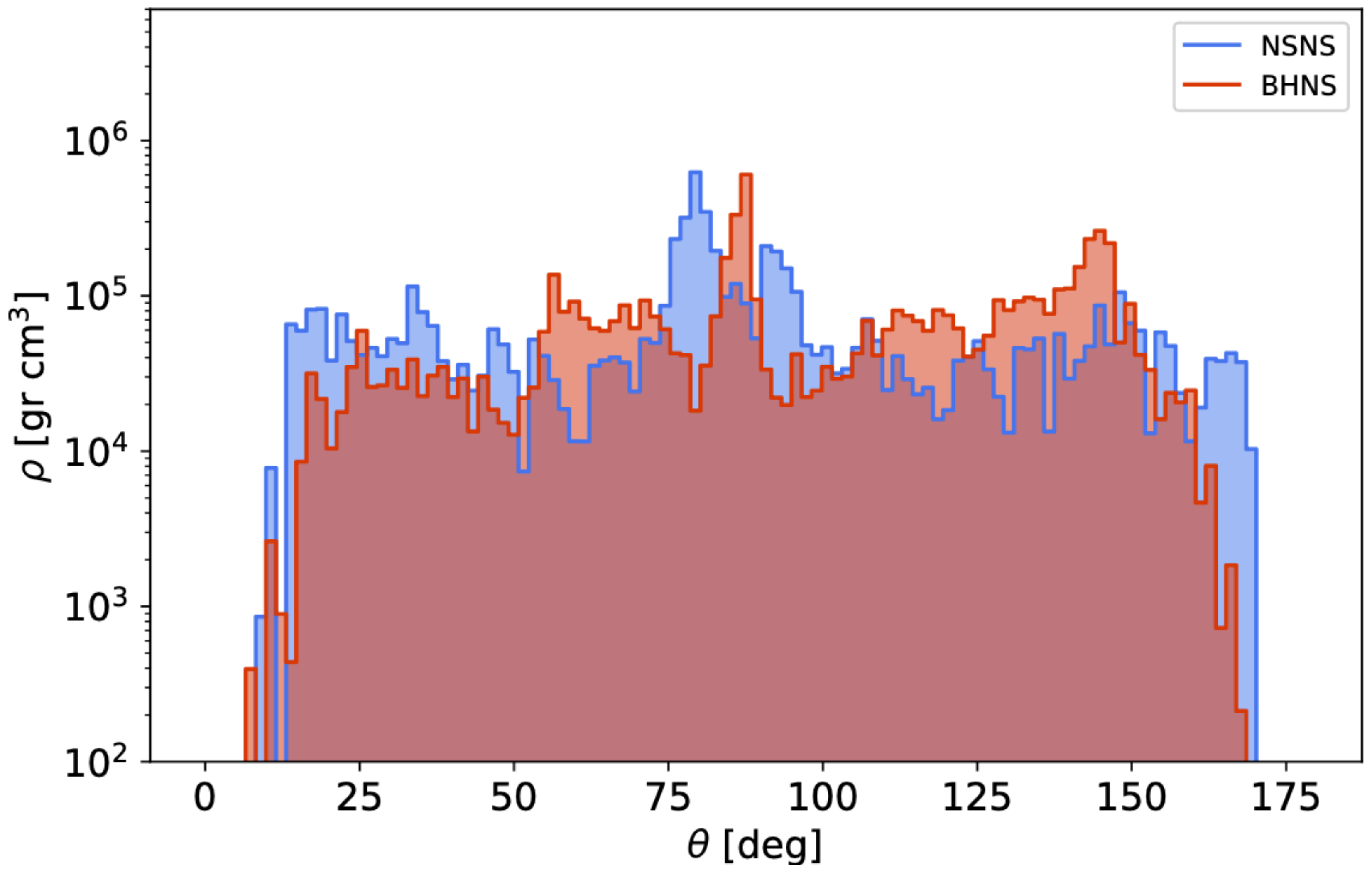
Time=0

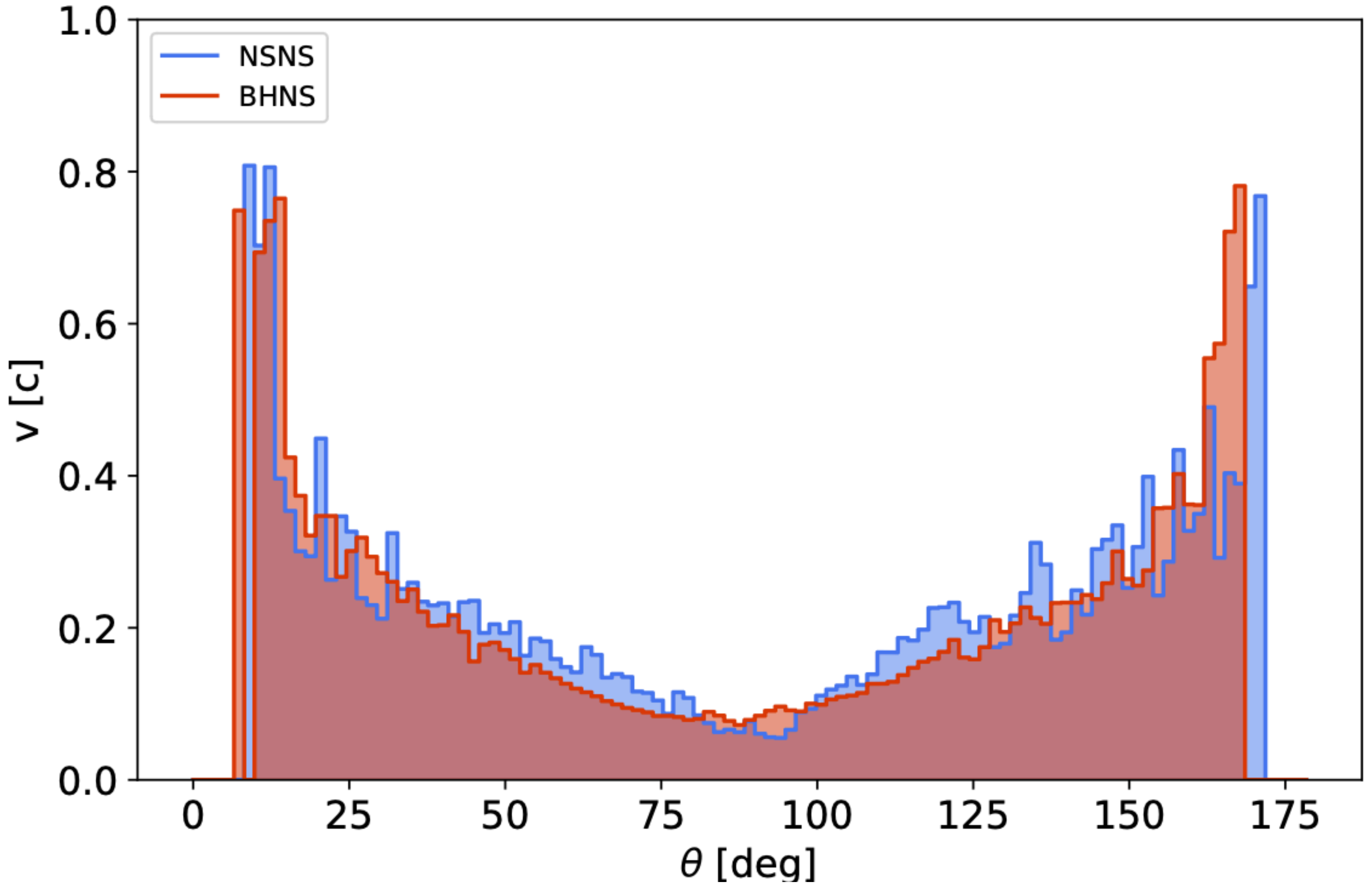
Step 3

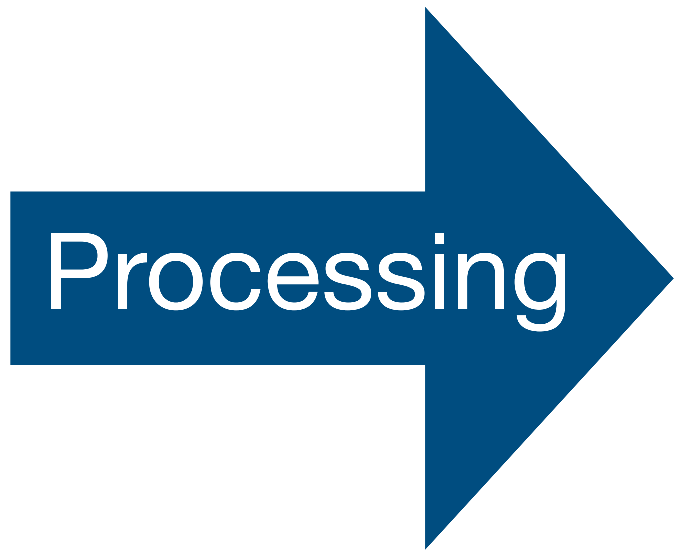


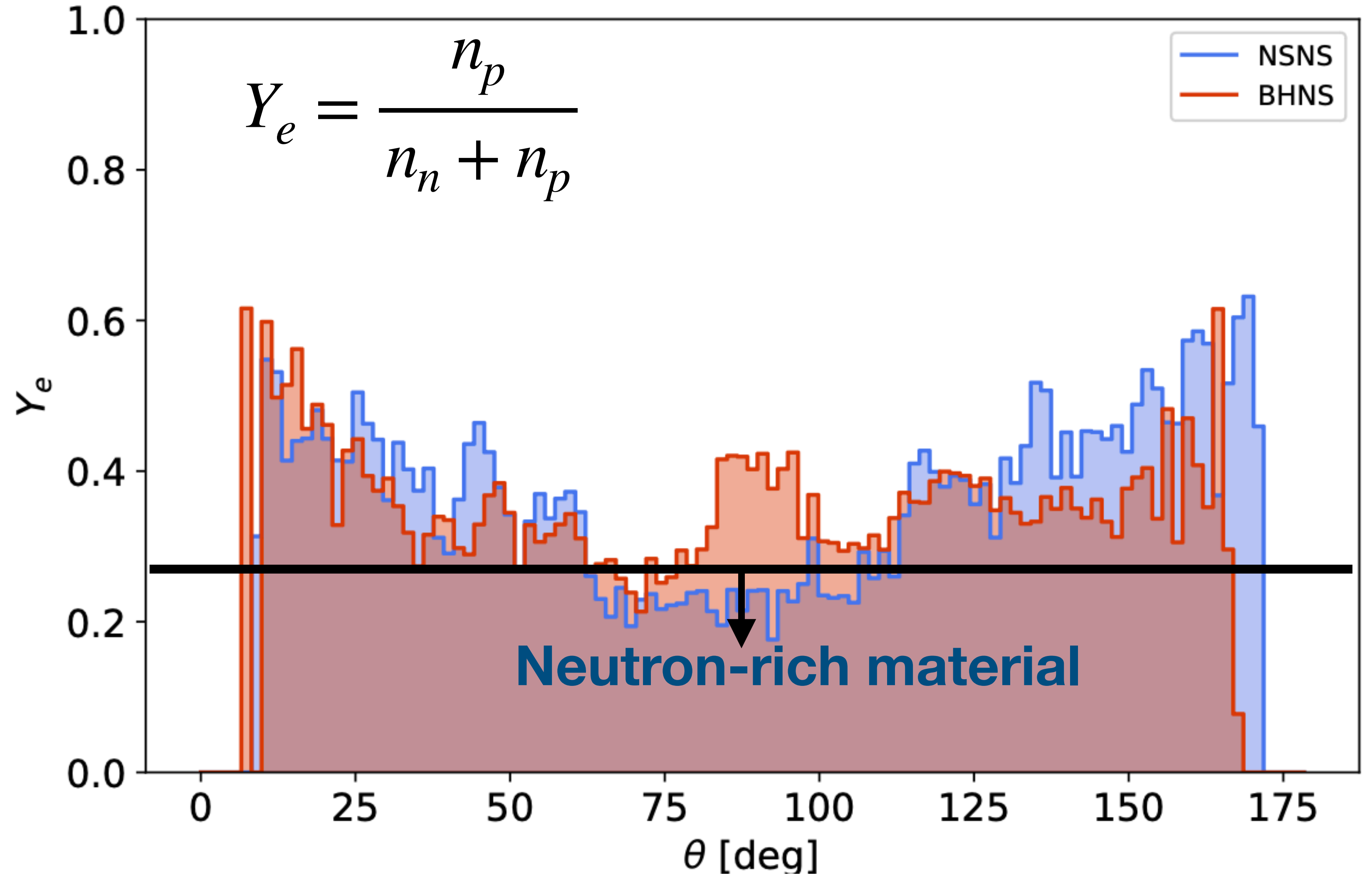
Urrutia, Janiuk 2024

Wind distributions at $r_{\rm inj} \sim 2 \times 10^8$ [cm]





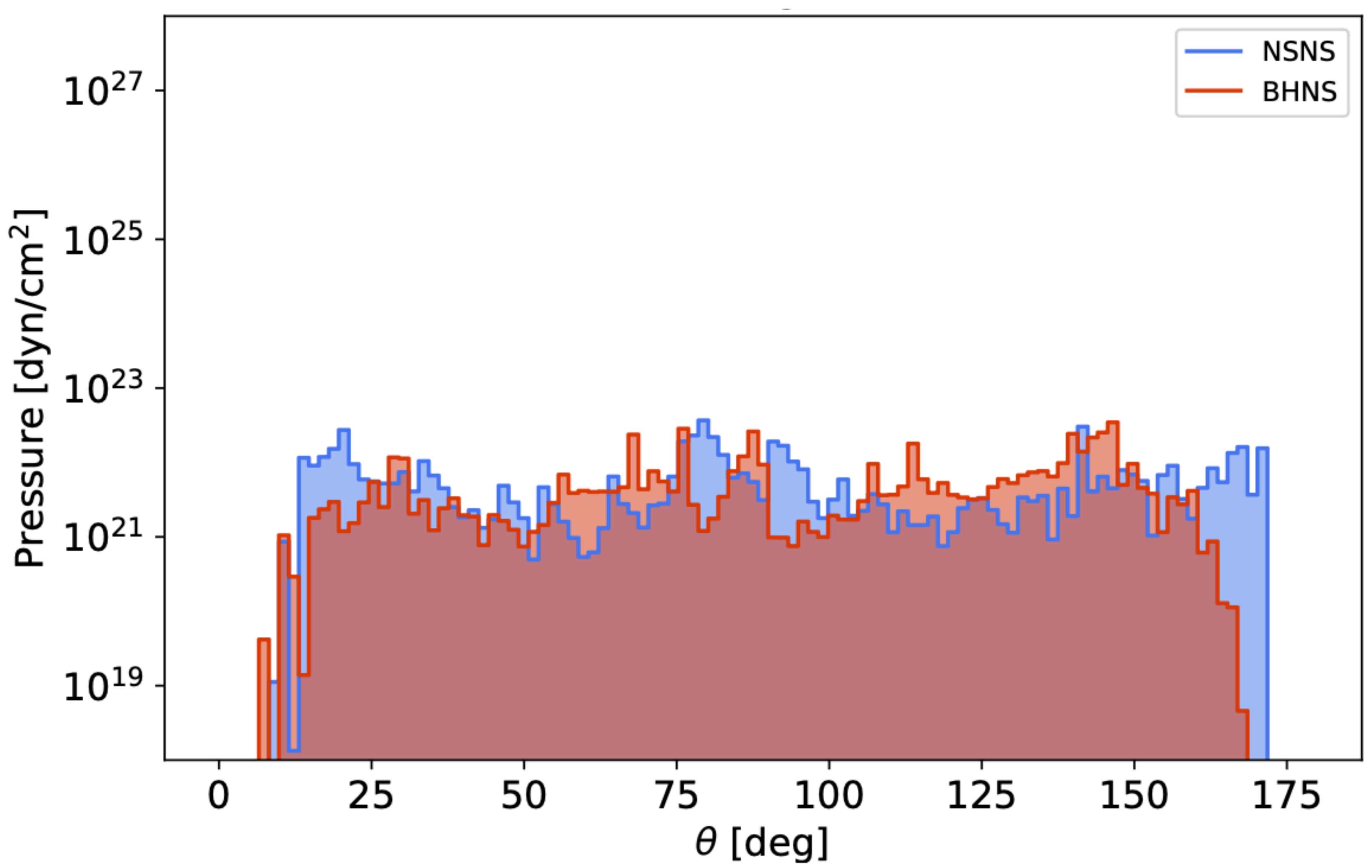




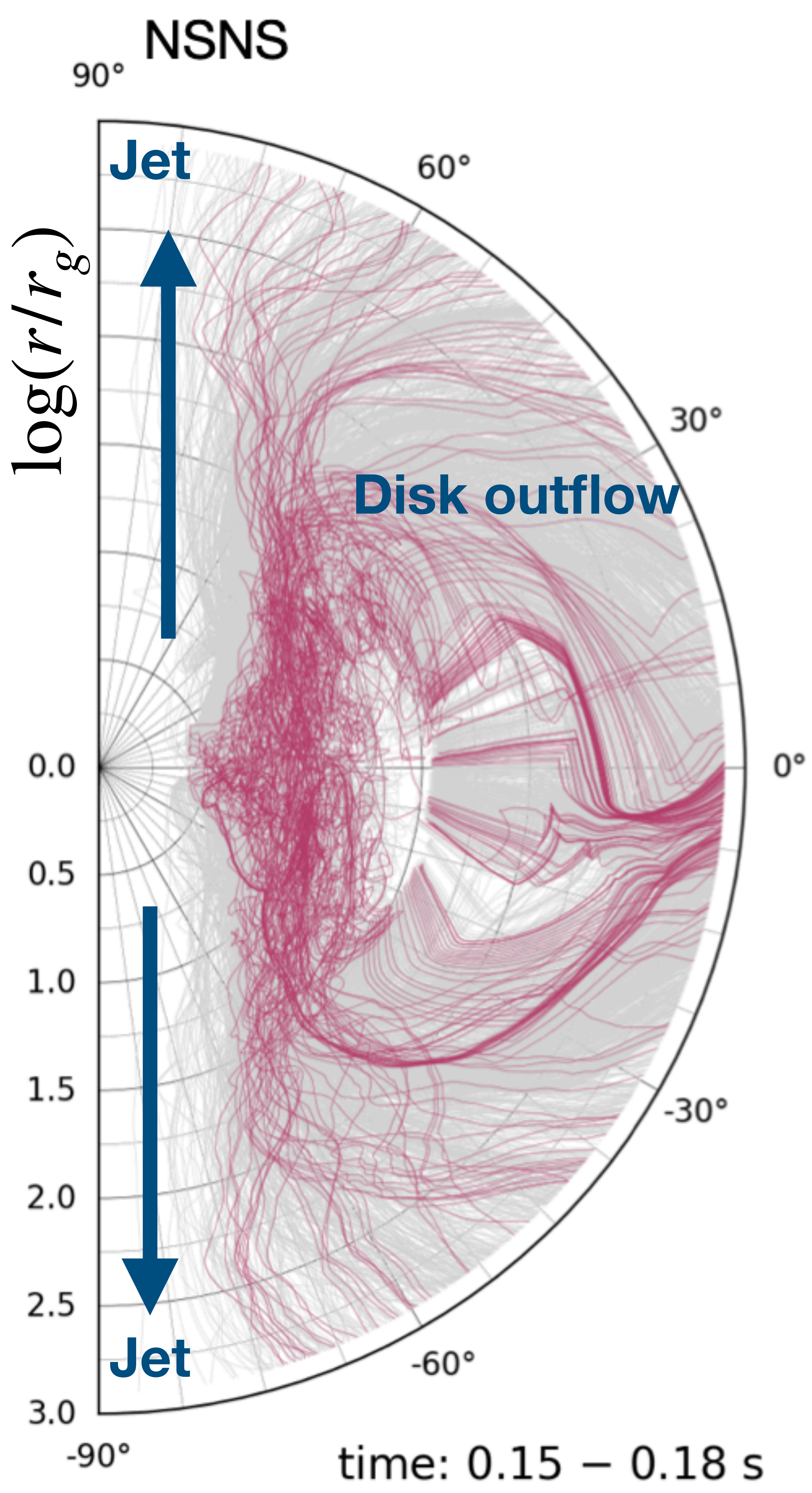
SkyNet nuclear reaction network (Lippuner & Roberts 2017)

Inversion of Helmholtz equation (Timmes & Arnet 1999)

Note: Abundances of these models are discussed in Nouri et al., 2023



Outflow characteristics



$M_{\rm BH} = 2.65 M_\odot$

$M_{\rm disc} = 0.10276\, M_\odot$

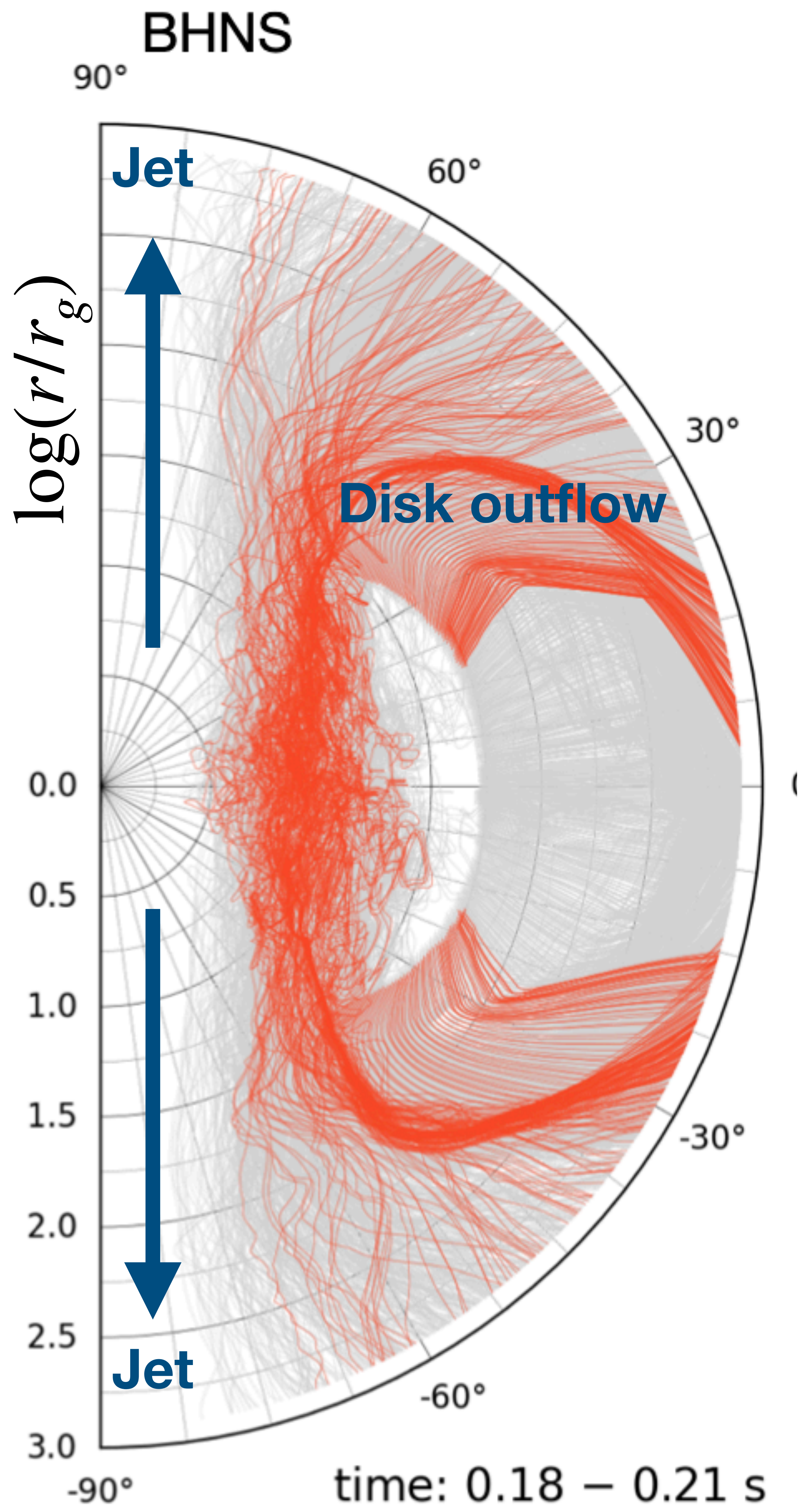
$\dot{M}_{\rm out} = 3.27 \times 10^{-2}\, M_\odot\ {\rm s}^{-1}$

$\Gamma_j = 7.2$

$t_{\rm j} \propto M_{\rm disk}/\dot{M} \sim 1.57\,{\rm s}$

$\theta_j = 15^\circ$

$L_j \approx 1.7 \times 10^{50}\,{\rm erg/s}$



$M_{\rm BH} = 5.0 M_\odot$

$M_{\rm disc} = 0.3120\, M_\odot$

$\dot{M}_{\rm out} = 1.49 \times 10^{-1}\, M_\odot\ {\rm s}^{-1}$

$\Gamma_j = 12$

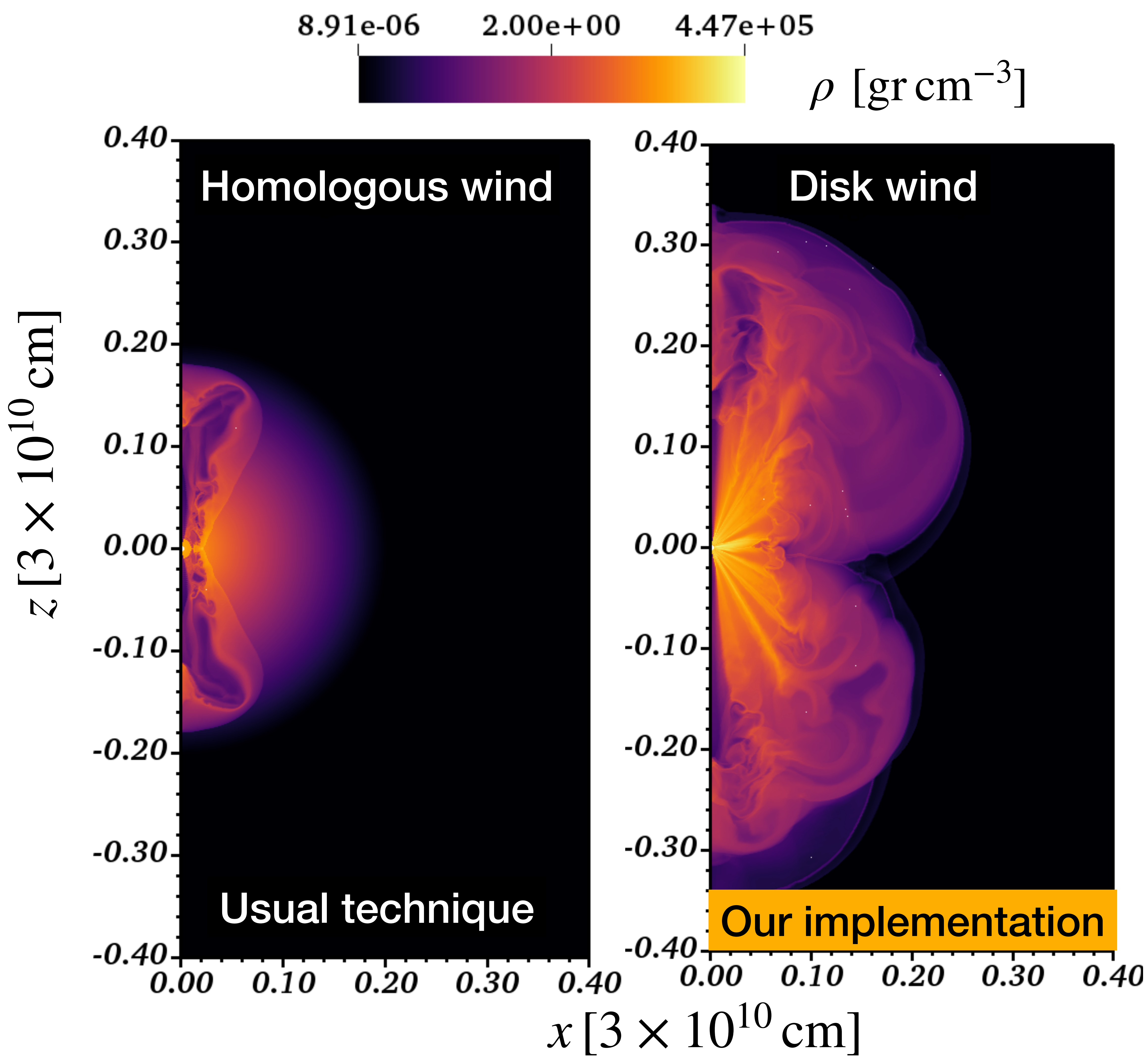
$t_{\rm j} \propto M_{\rm disk}/\dot{M} \sim 1.07\,{\rm s}$

$\theta_j = 15^\circ$

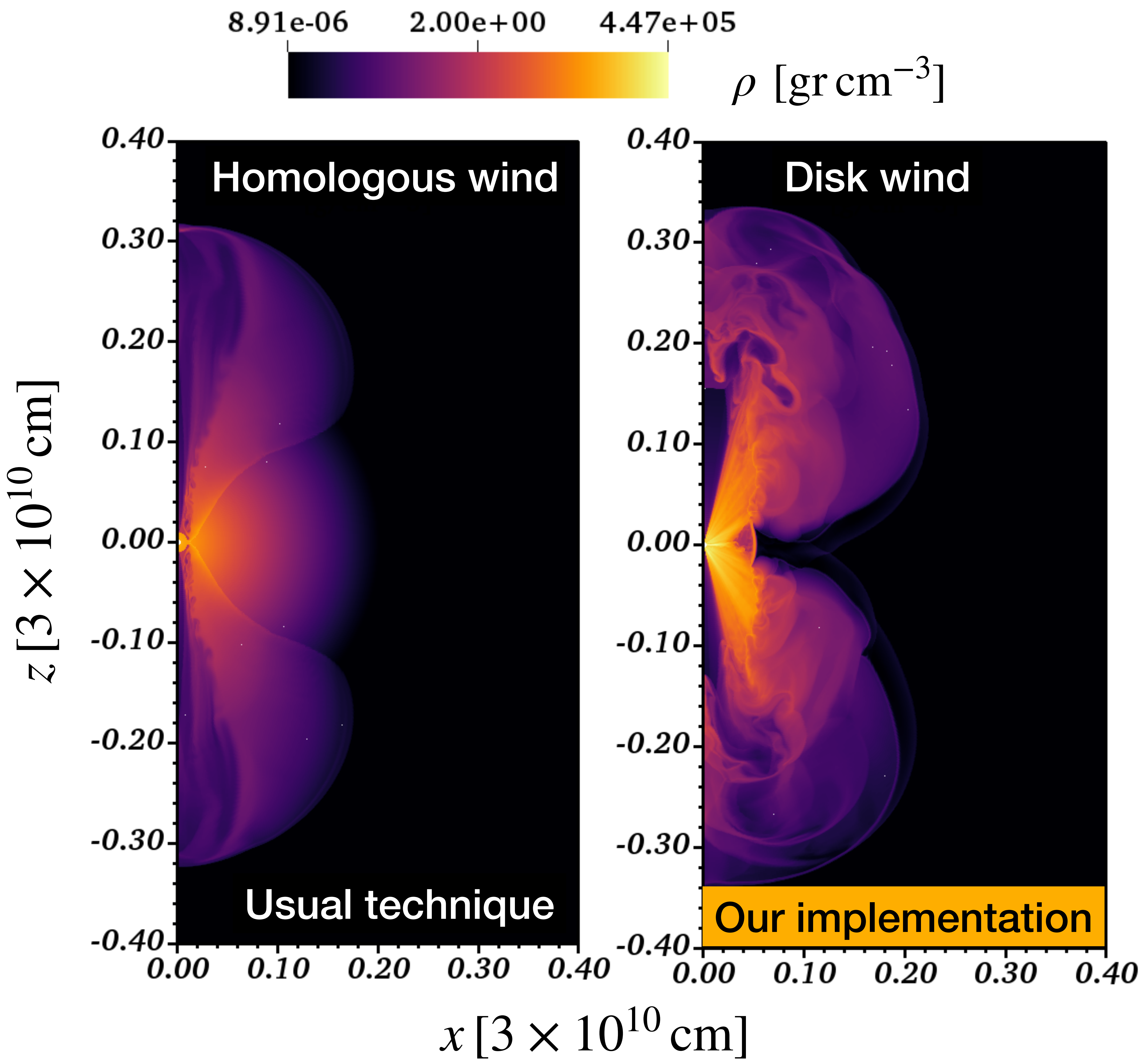
$L_j \approx 2.2 \times 10^{50}\,{\rm erg/s}$

Results of jet interaction

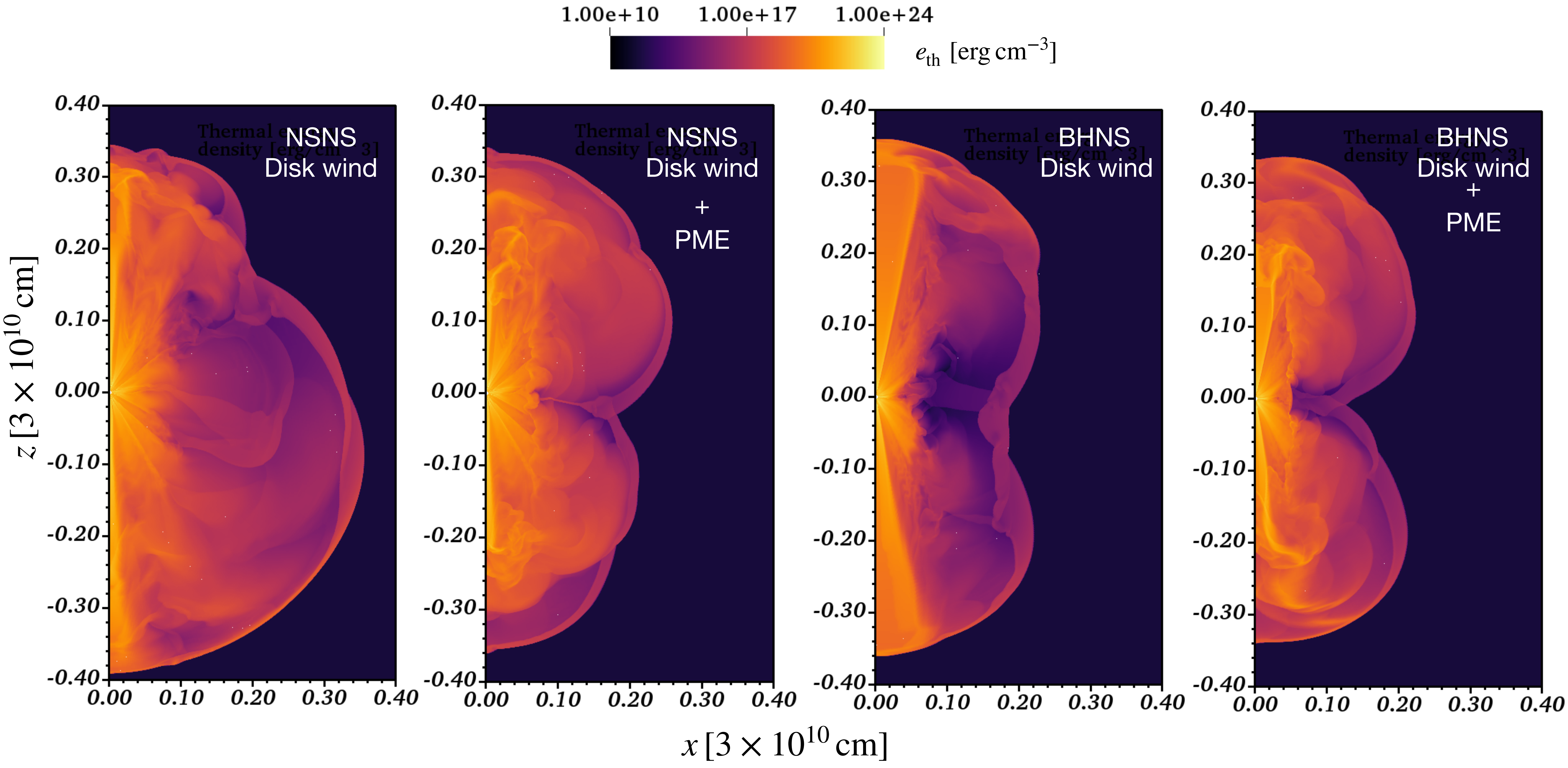
Jet from NSNS merger



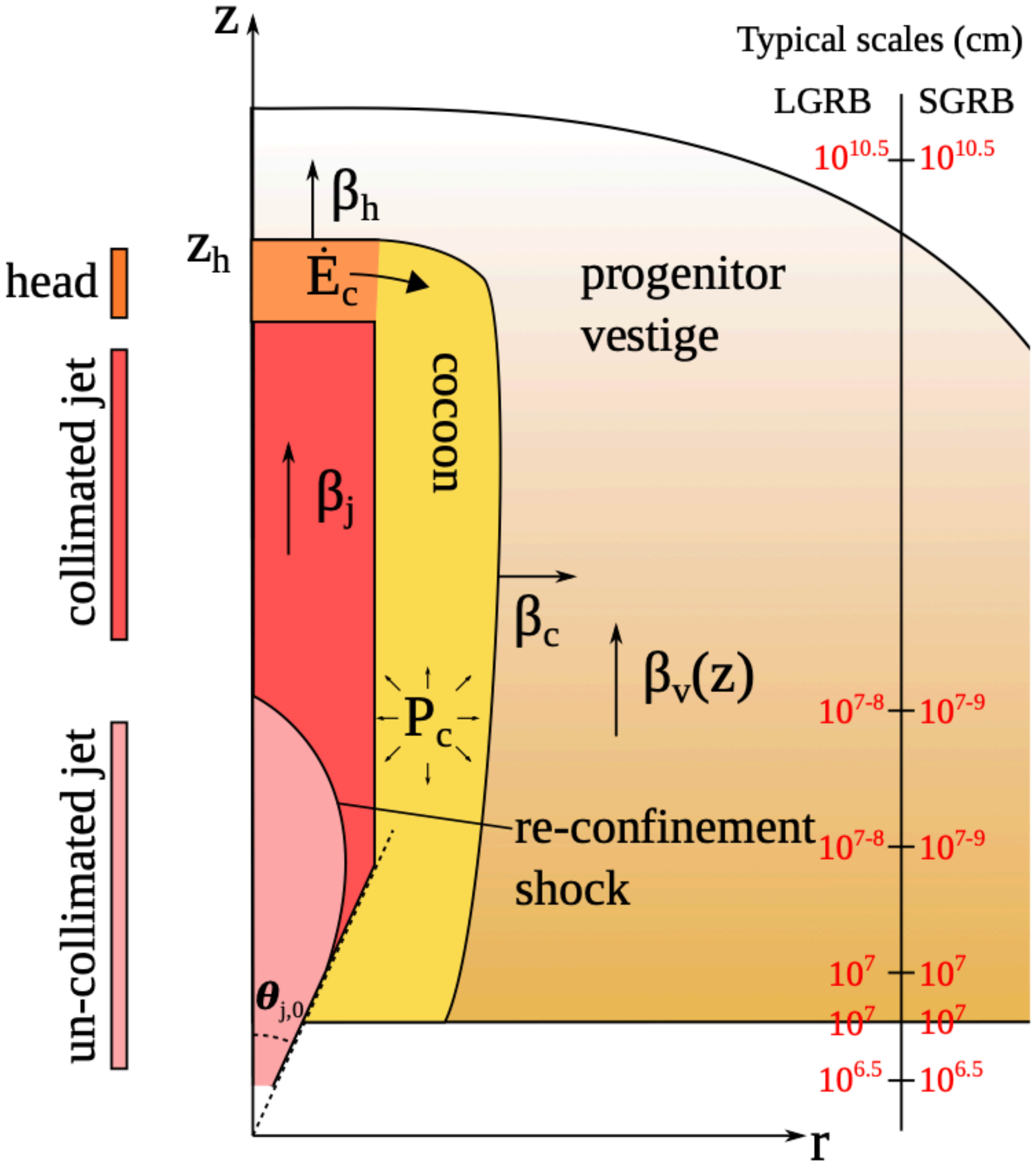
Jet from BHNS merger



Results of jet interaction



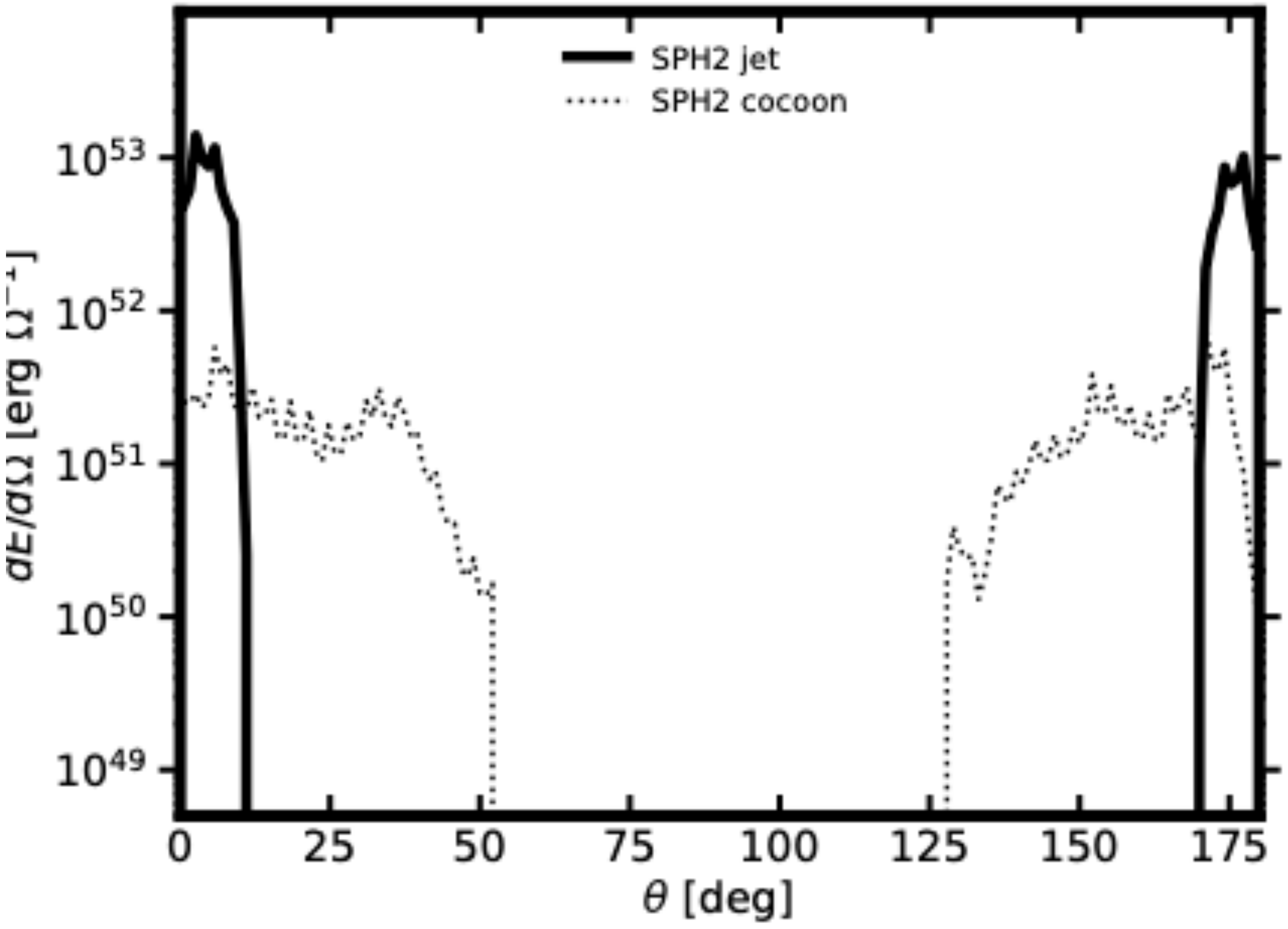
Jet anatomy: each component is distinguished by the velocity



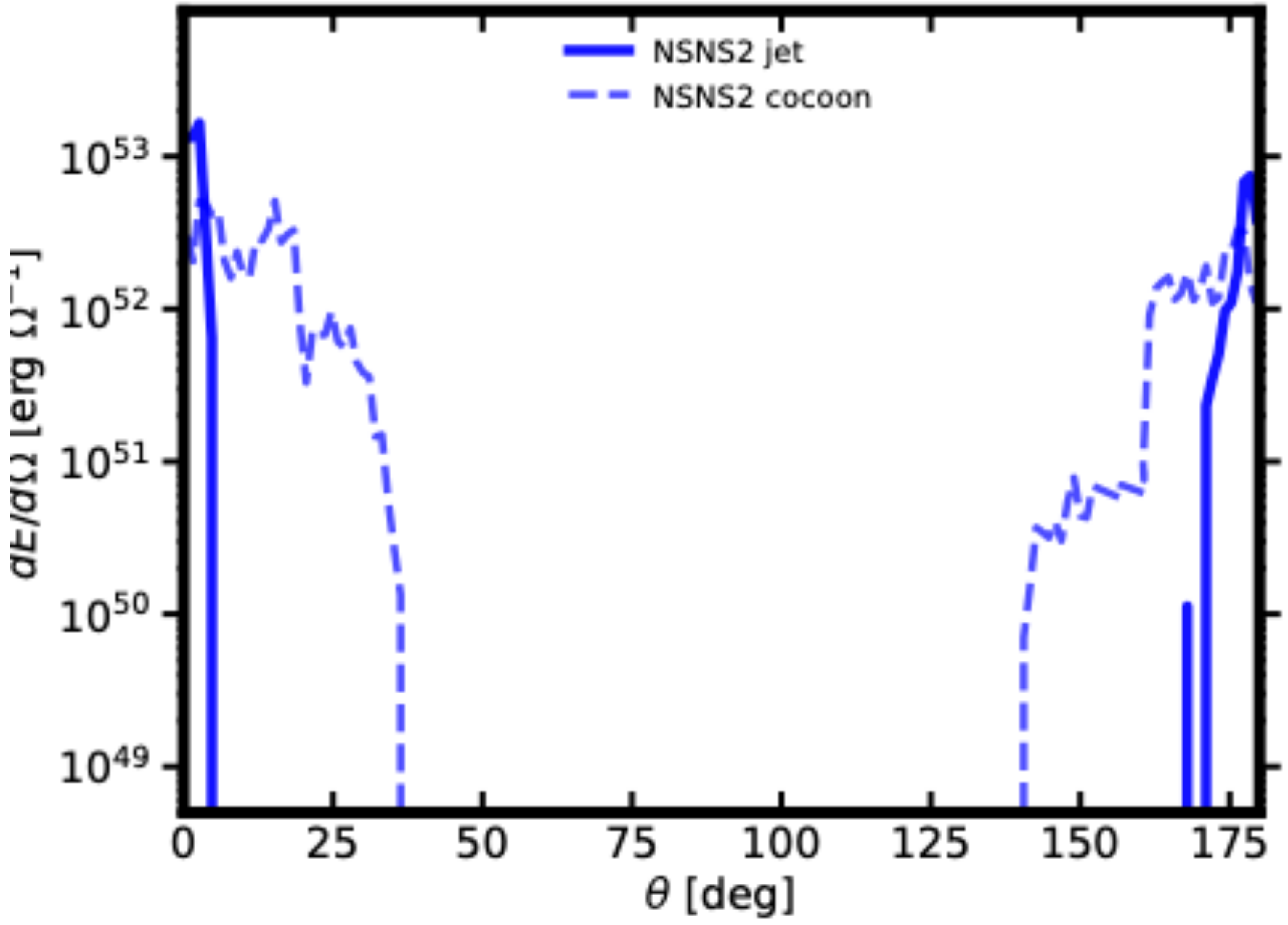
Credits: Salafia & Ghirlanda 2022

Disk wind changes the jet collimation and cocoon lateral expansion

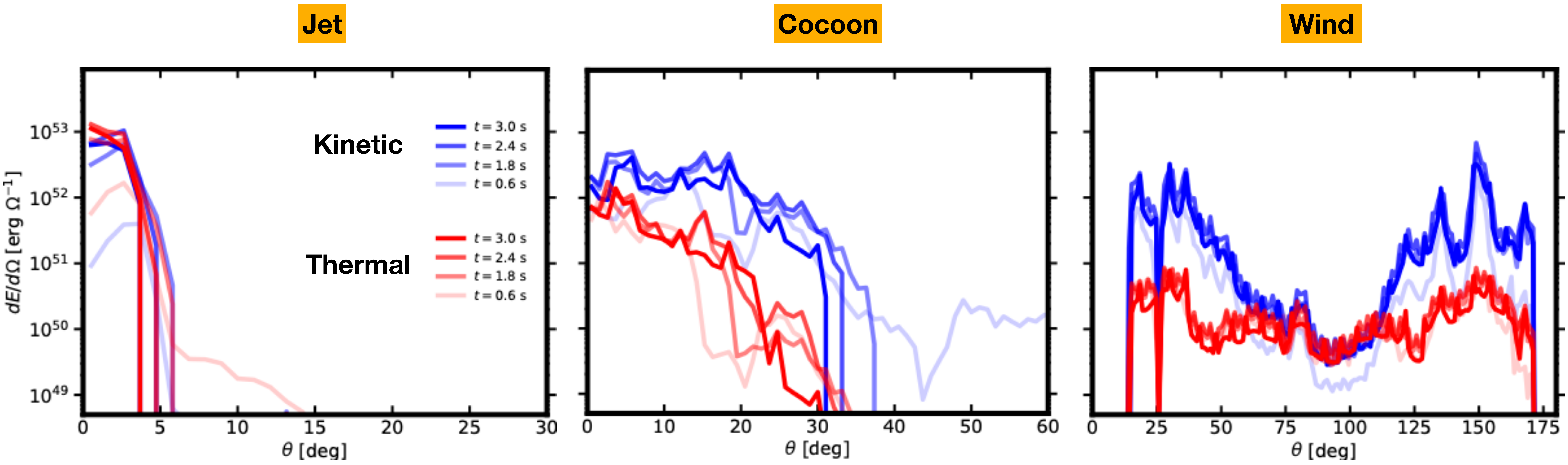
Homologous wind

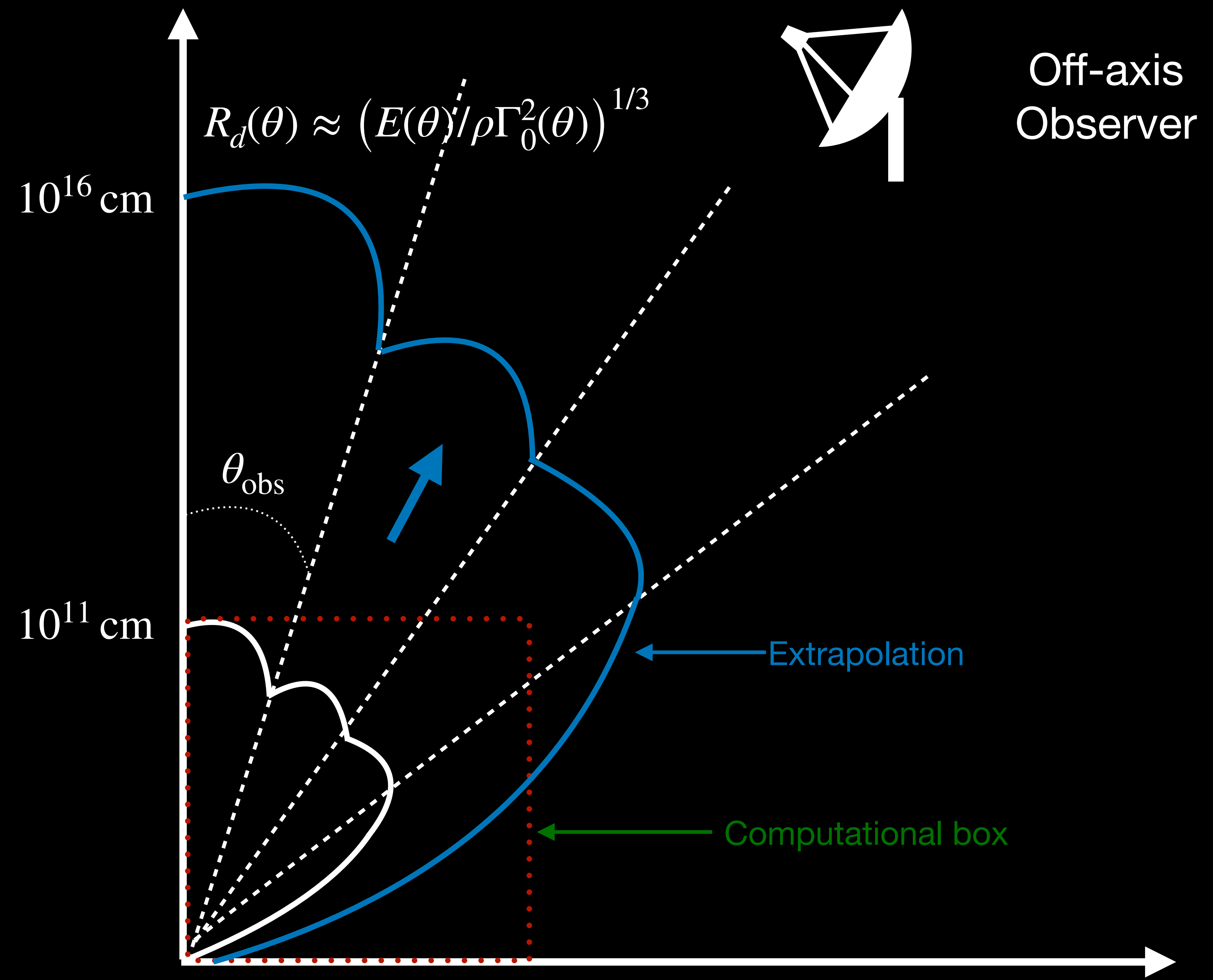


Disk wind

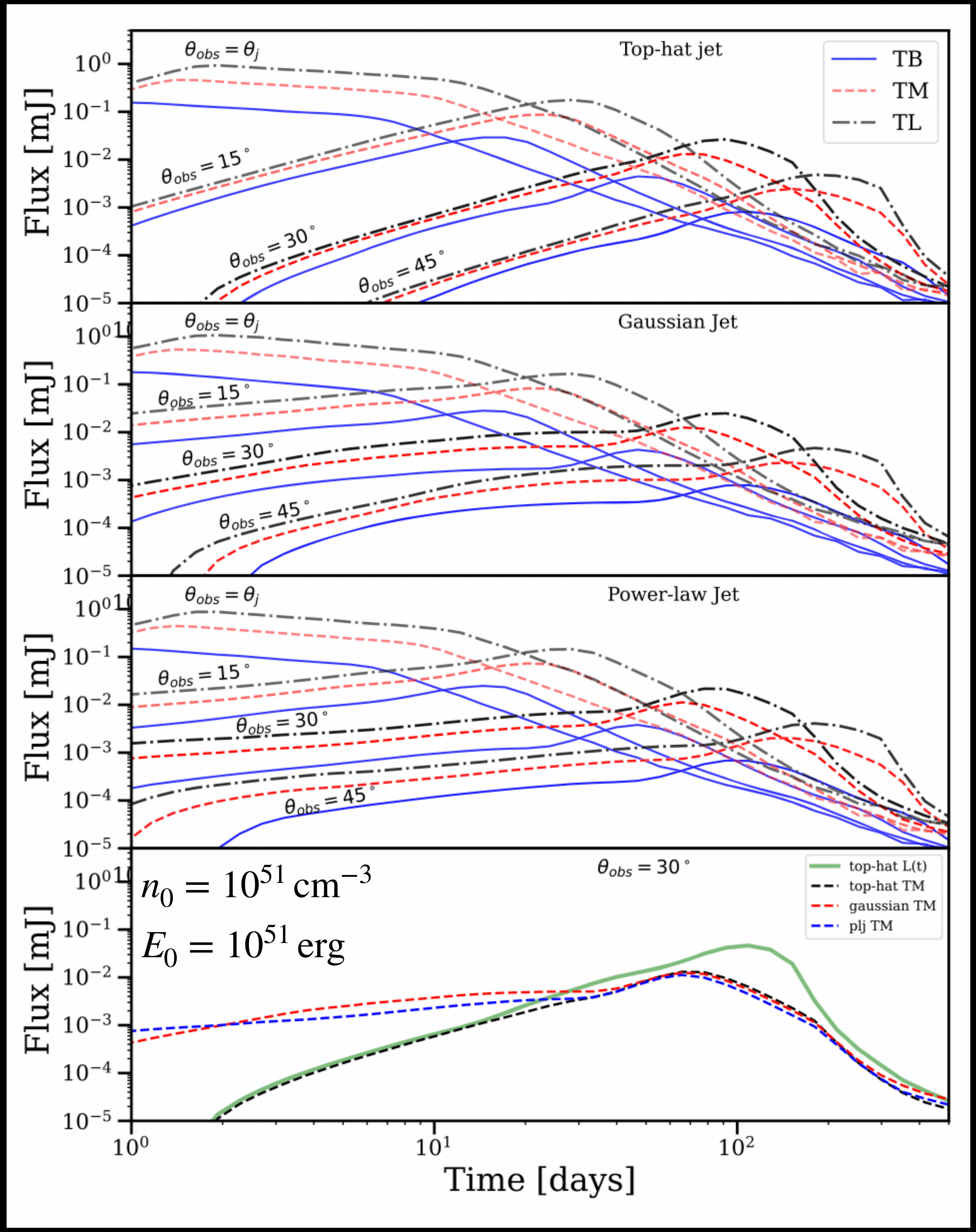


Energy evolution (jet from NSNS)



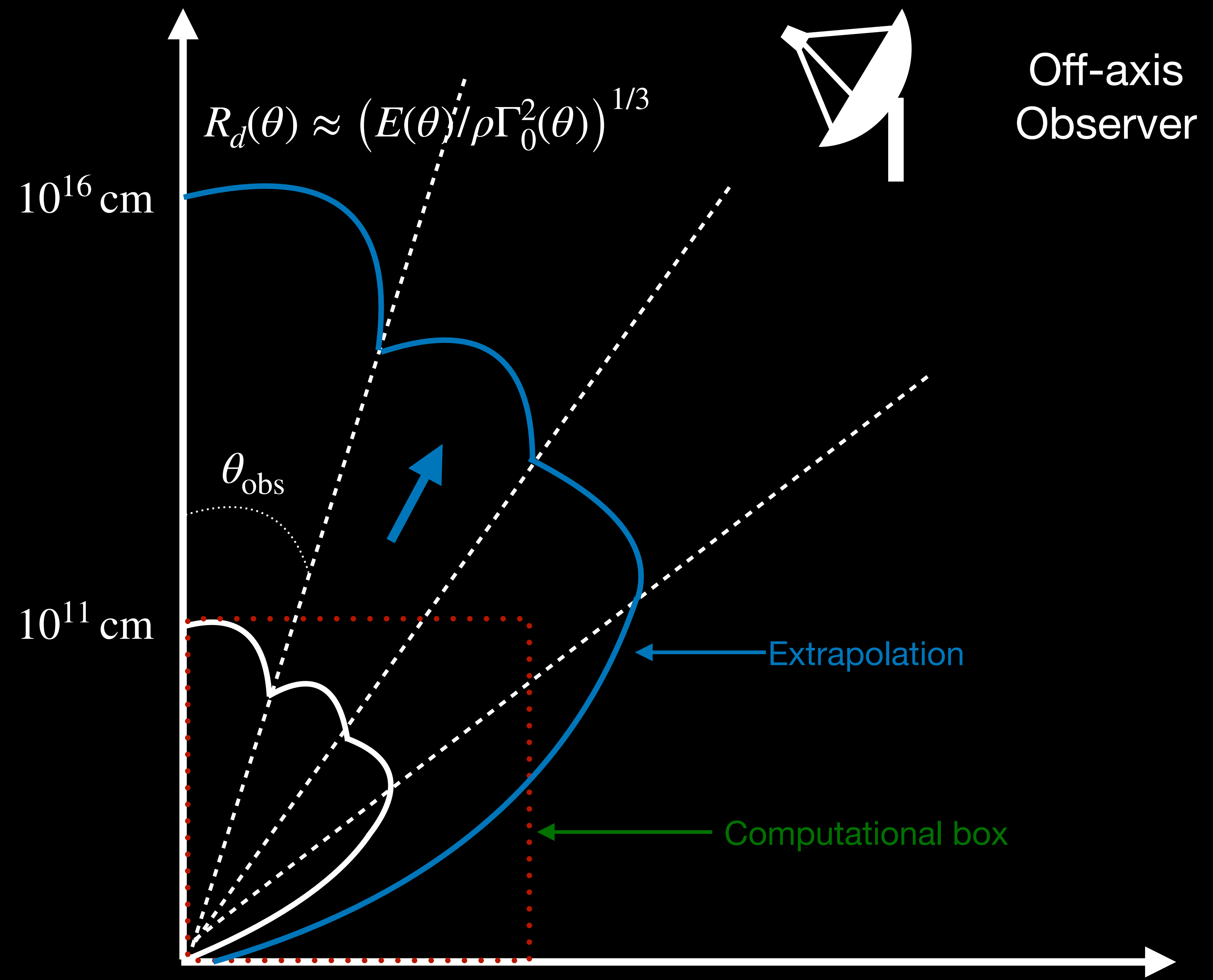


Radio Light Curves (3 GHz)



Urrutia, De Colle, Murguia-Berthier & Ramirez-Ruiz (2021)

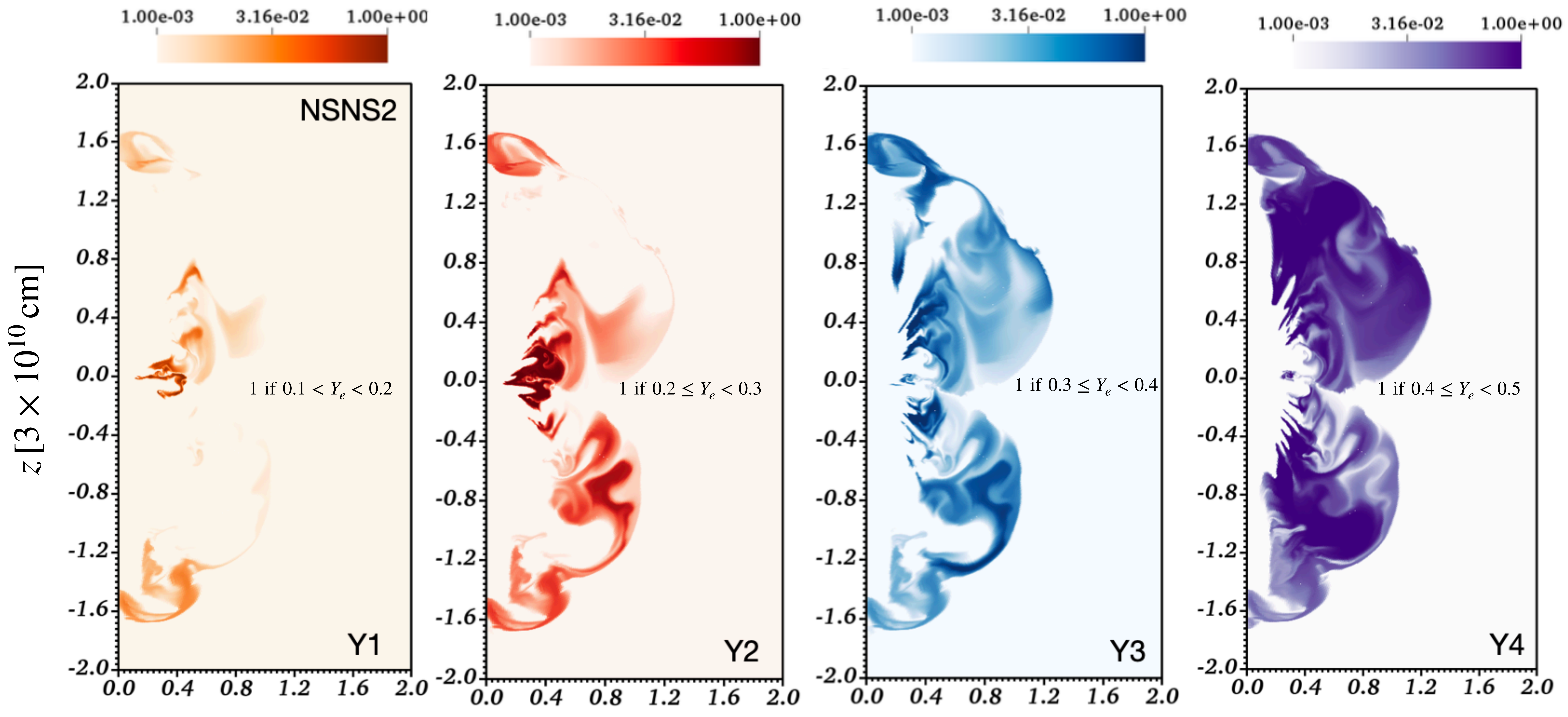
Large-scale implications (observations)



Implications of the current work for the jet emission at large scales, under construction…

But we can follow a geometrical distribution of the ejected material, Kilonova, on the next slide…

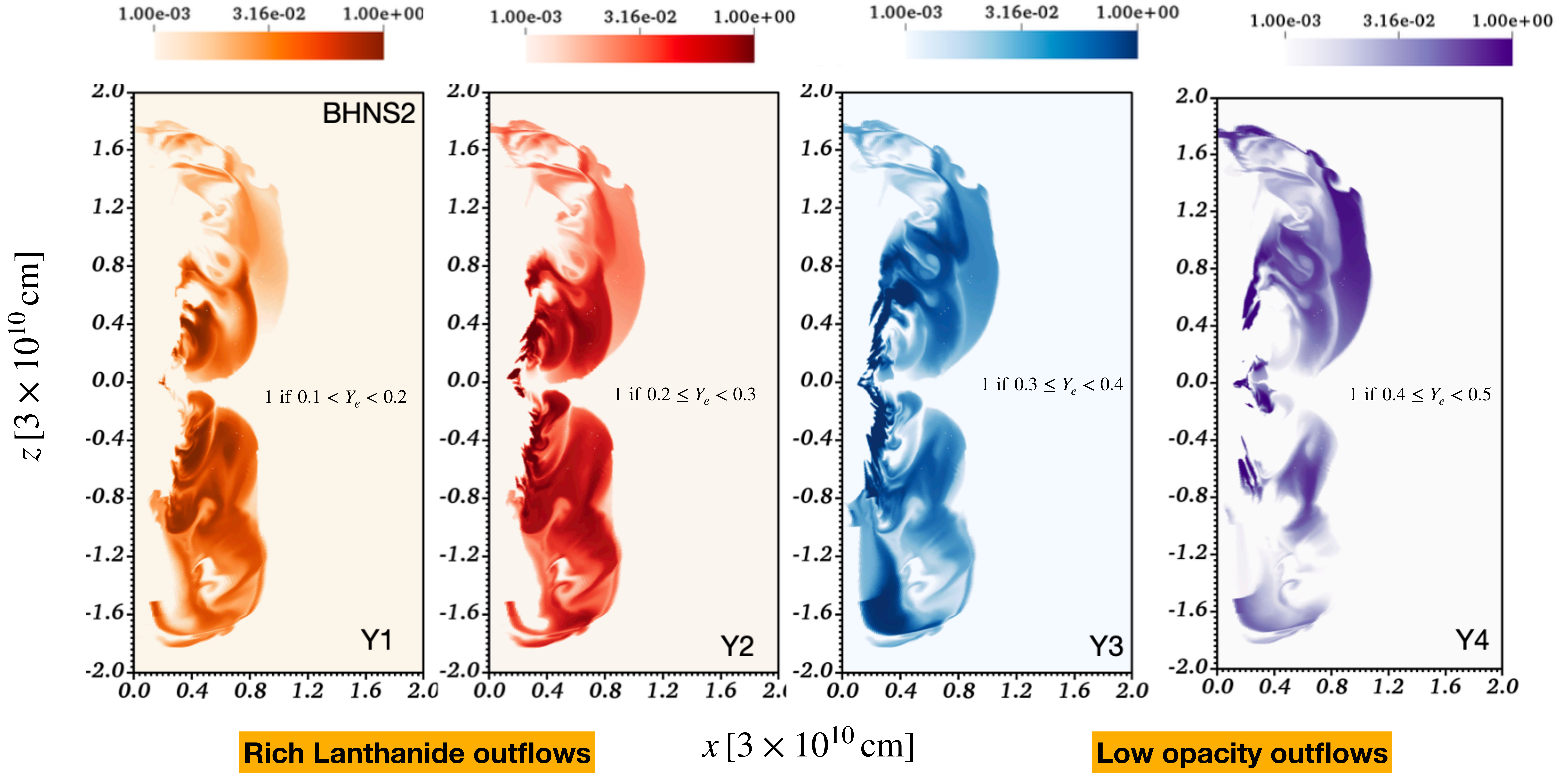
Future distribution of the kilonova



Rich Lanthanide outflows

Low opacity outflows

Future distribution of the kilonova



Rich Lanthanide outflows

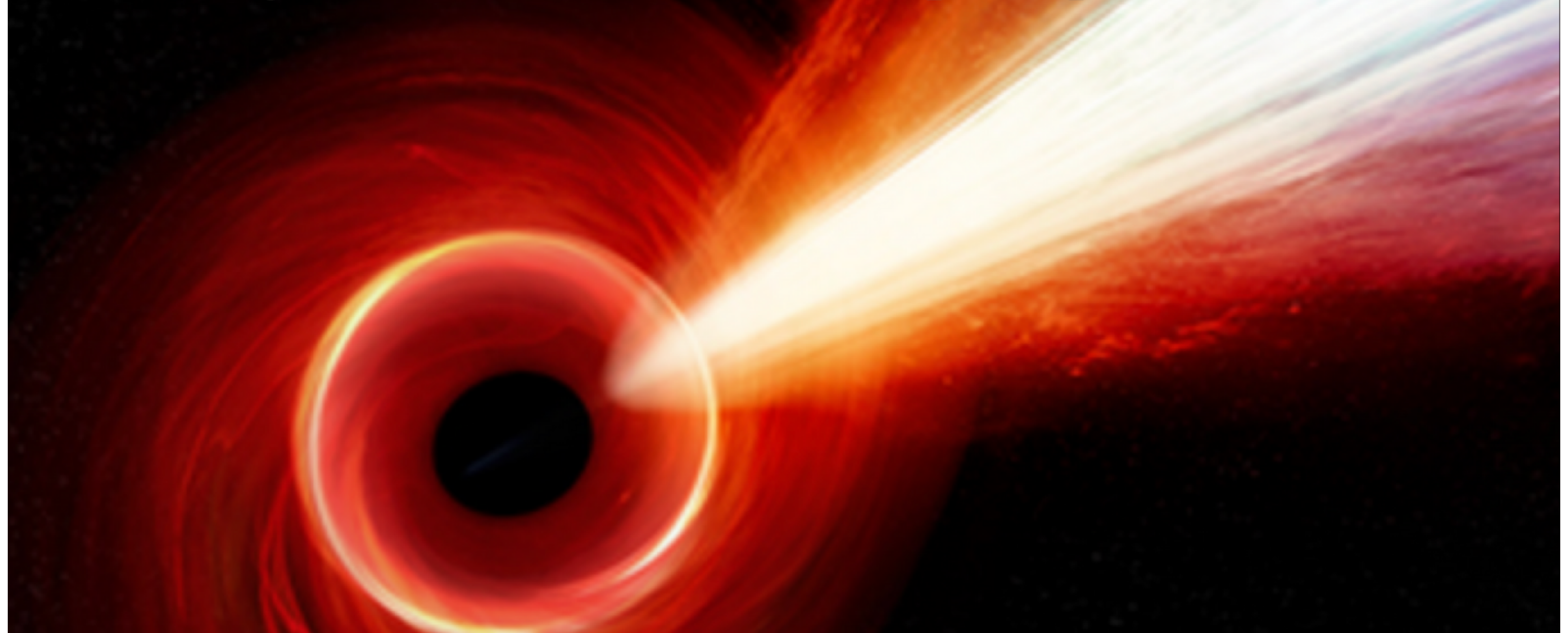
Low opacity outflows

Summary and Conclusions

- The r-process effects was considered to recover the gas pressure of the wind.
- We found that the wind produces a jet collimation (pressure effect).
- The interaction of the jet with a spherical atmosphere results in a spread distribution of material and energy.
- The disc outflow modifies substantially the dynamics of the jet, making it an essential component in Short GRB dynamics.

Galactic and Extragalactic X-ray Transients

Theory and observational perspectives



Key topics:
1. Quasi periodic eruptions in accreting black holes
2.Tidal disruption events
3. Changing activity of supermassive black holes
4. Fast variability of Galactic X-ray sources
5. Accretion instabilities and gravitational waves from black hole and neutron star binaries
6. Testing General Relativity with supermassive black holes

Warsaw, Poland, September 9 - 11, 2024

---

https://cl-agn.cft.edu.pl

Abstract submision deadline: May 1 st

SOC

Bozena Czerny (CFT PAN) - Co-Chair
Agnieszka Janiuk. (CFT PAN) - Co-Chair
Szymon Kozłowski (University of Warsaw)
Vladimir Karas (Astronomical Institute, Prague)
Mikołaj Korzyński (CFT PAN)
Alex Markowitz (CAMK PAN, Warsaw)
Benny Trakhtenbrot (Tel Aviv University)
Michal Zajacek (Masaryk University, Brno)

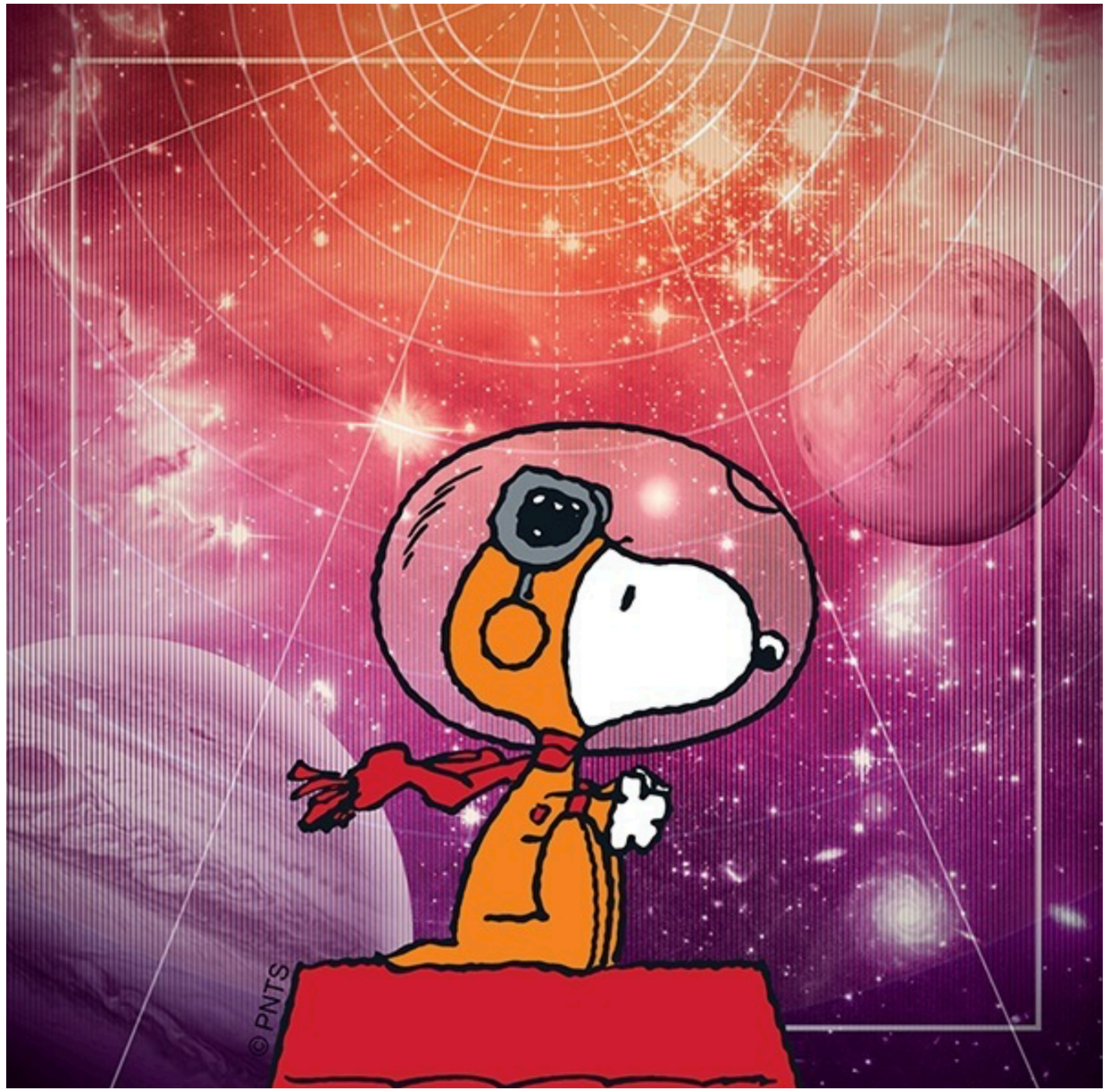
LOC

Gerardo Urrutia (CFT PAN)
Ashwani Pandey (CFT PAN)
Raj Prince (CFT PAN)

National Science Centre Poland

dxdx dxdxdx dxdxdxdx dxdxpandx dxdxdxdx dxdxdx dx dx dx dx cft

Thank you, Dziękuję, Grazie, ¡Gracias!



Gerardo Urrutia
gurrutia@cft.edu.pl

dxdx
dxdxdx
dxdxdxdx
dxdxpandx
dxdxdxdx
dxdxdx
dx
dx
dx
dx cft

PL GRID

NATIONAL SCIENCE CENTRE
POLAND