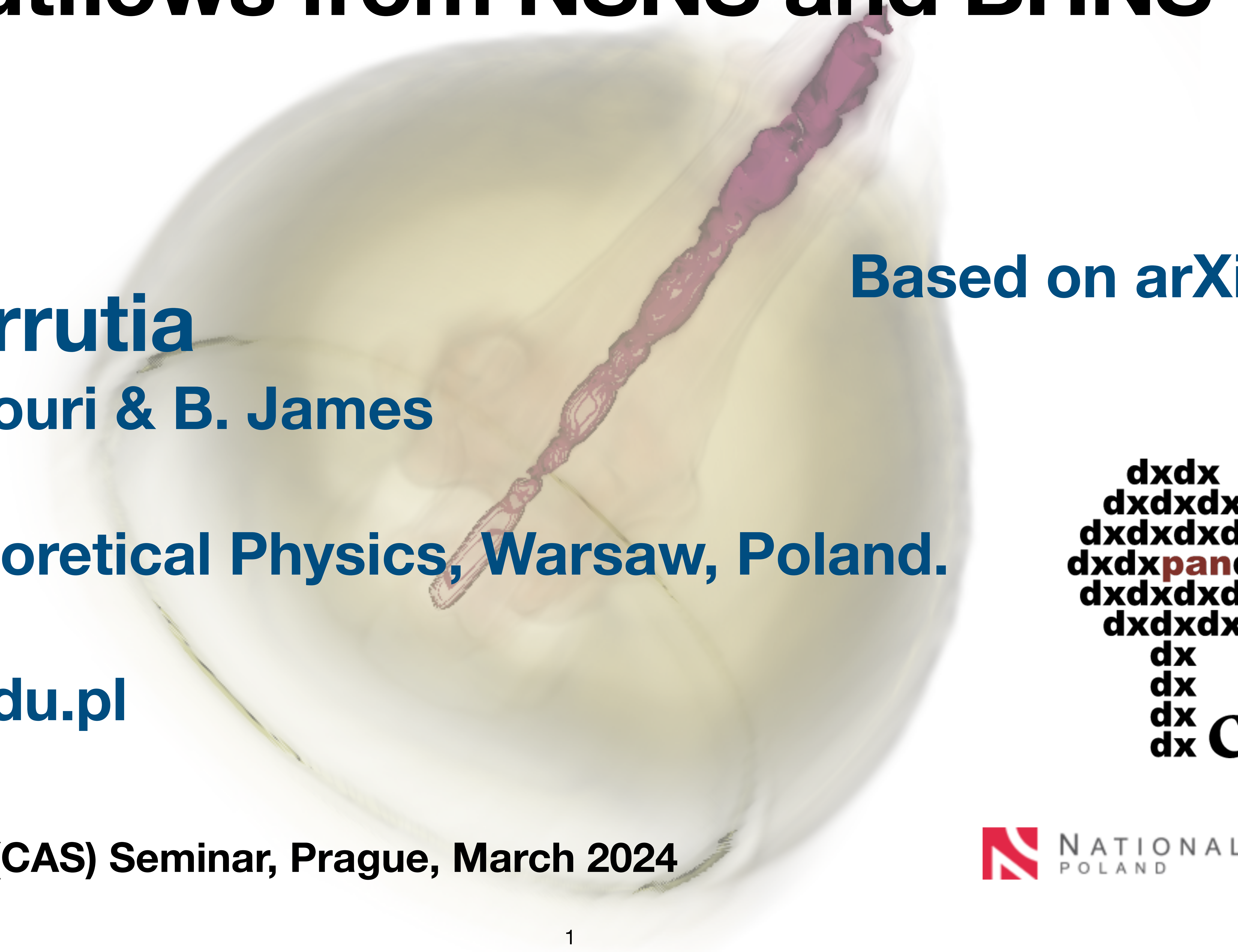
The large-scale interaction between sGRB jets and disk outflows from NSNS and BHNS mergers



Based on arXiv:2401.10094

Gerardo Urrutia

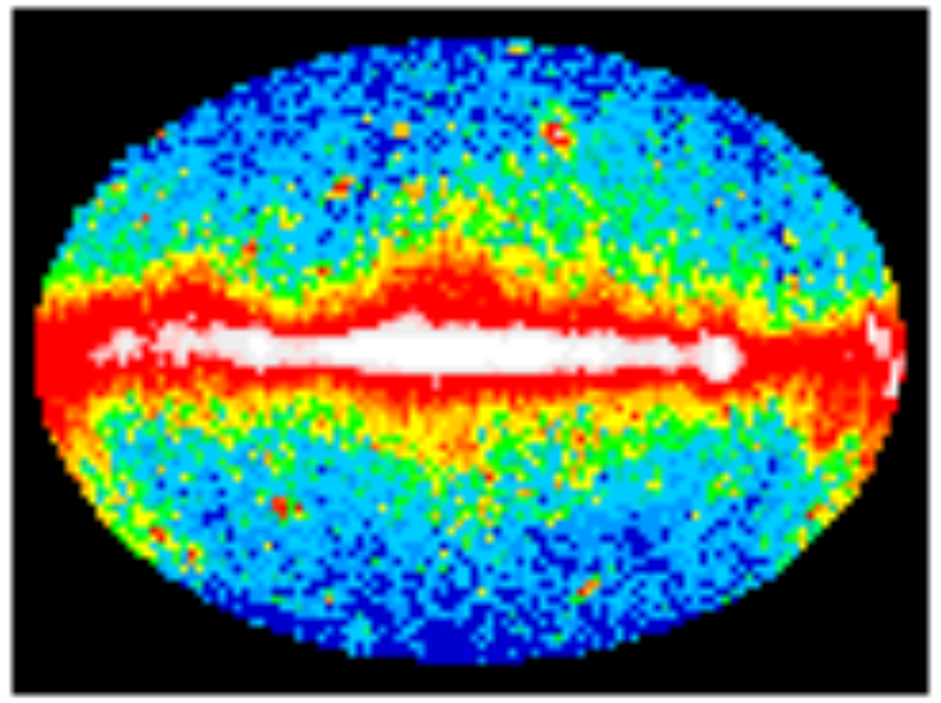
A. Janiuk, F. Nouri & B. James

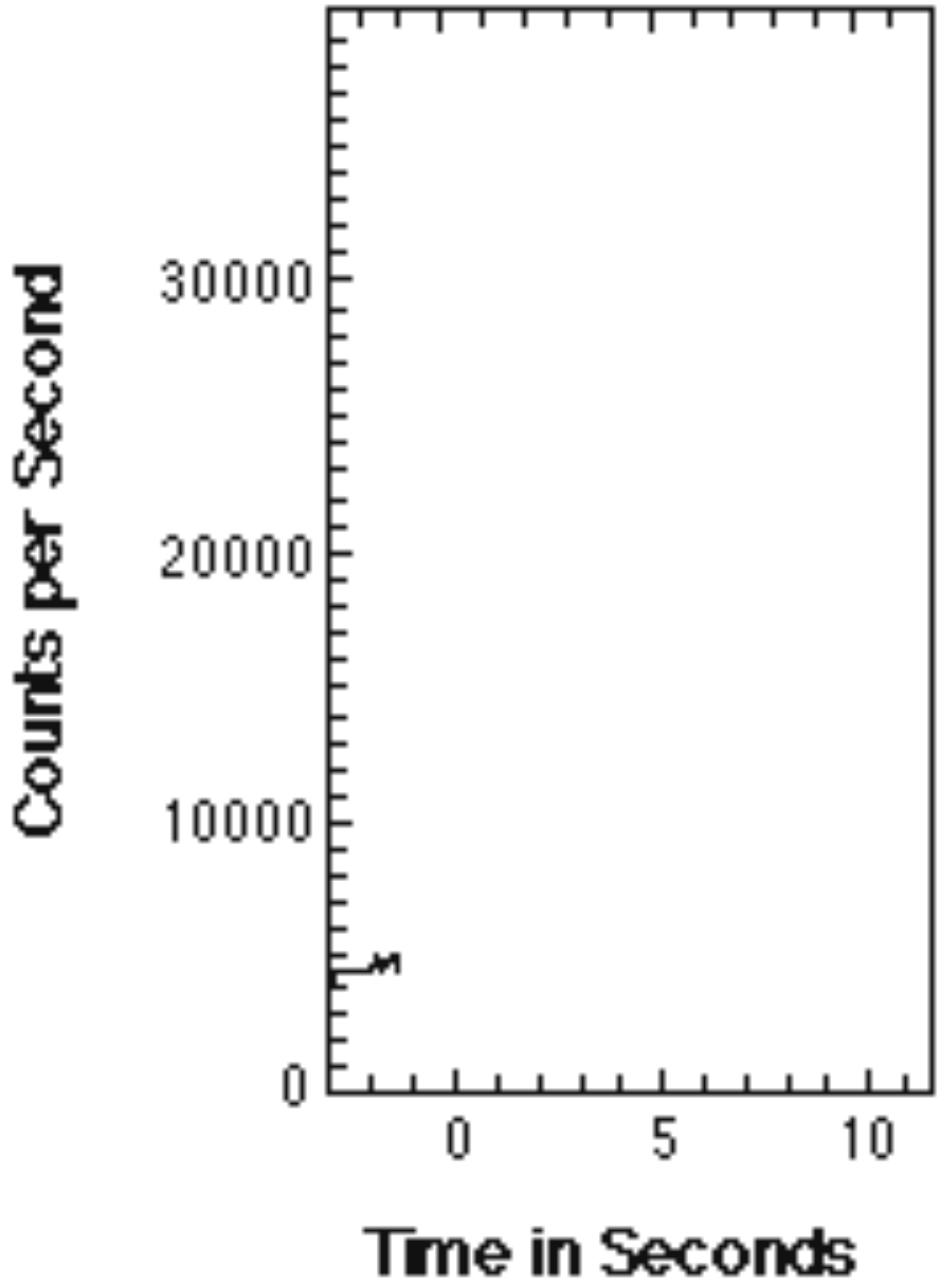
Centre for Theoretical Physics, Warsaw, Poland.

gurrutia@cft.edu.pl

Astronomy Institute (CAS) Seminar, Prague, March 2024

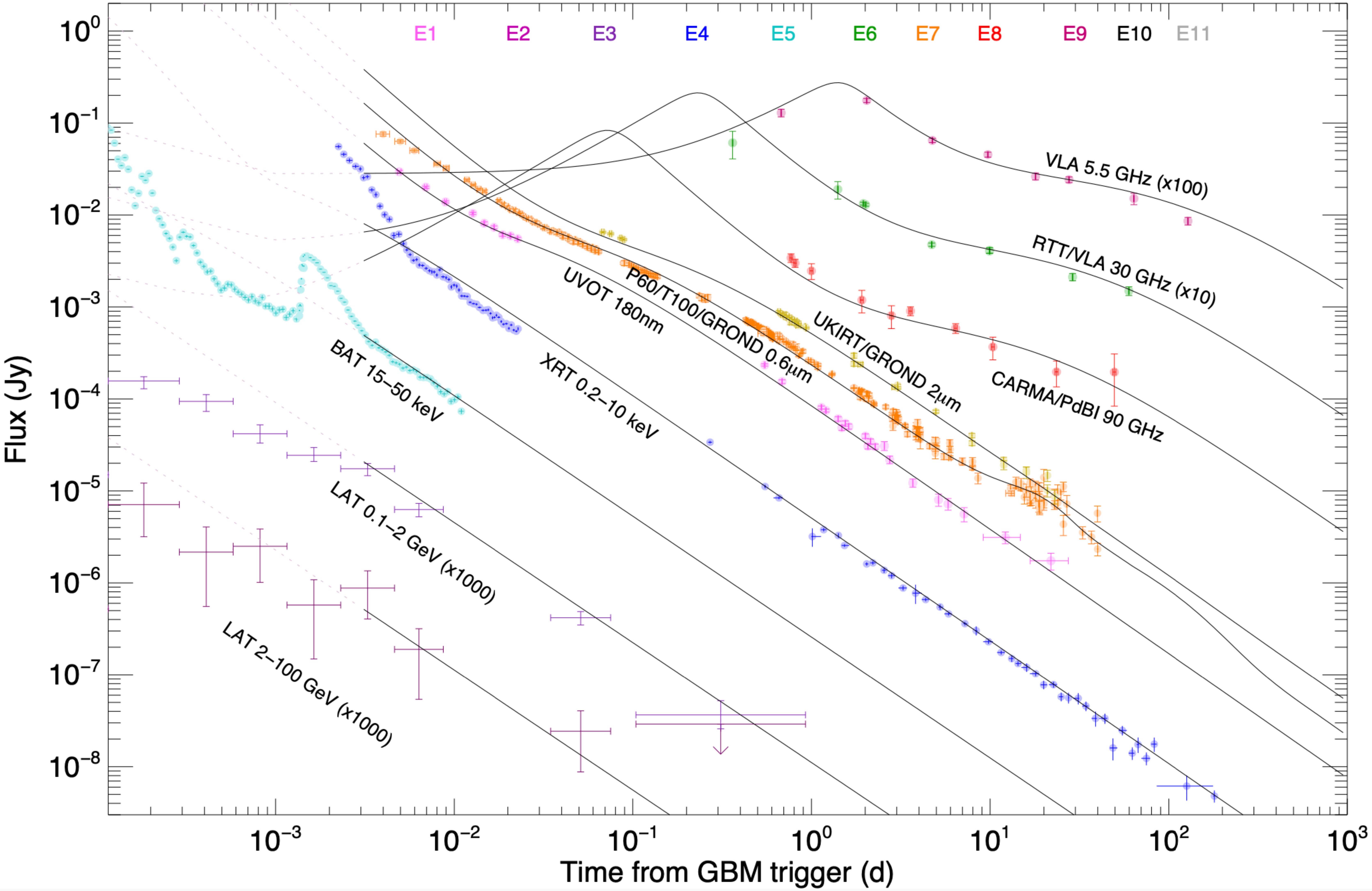
Gamma-Ray Bursts (prompt emission)





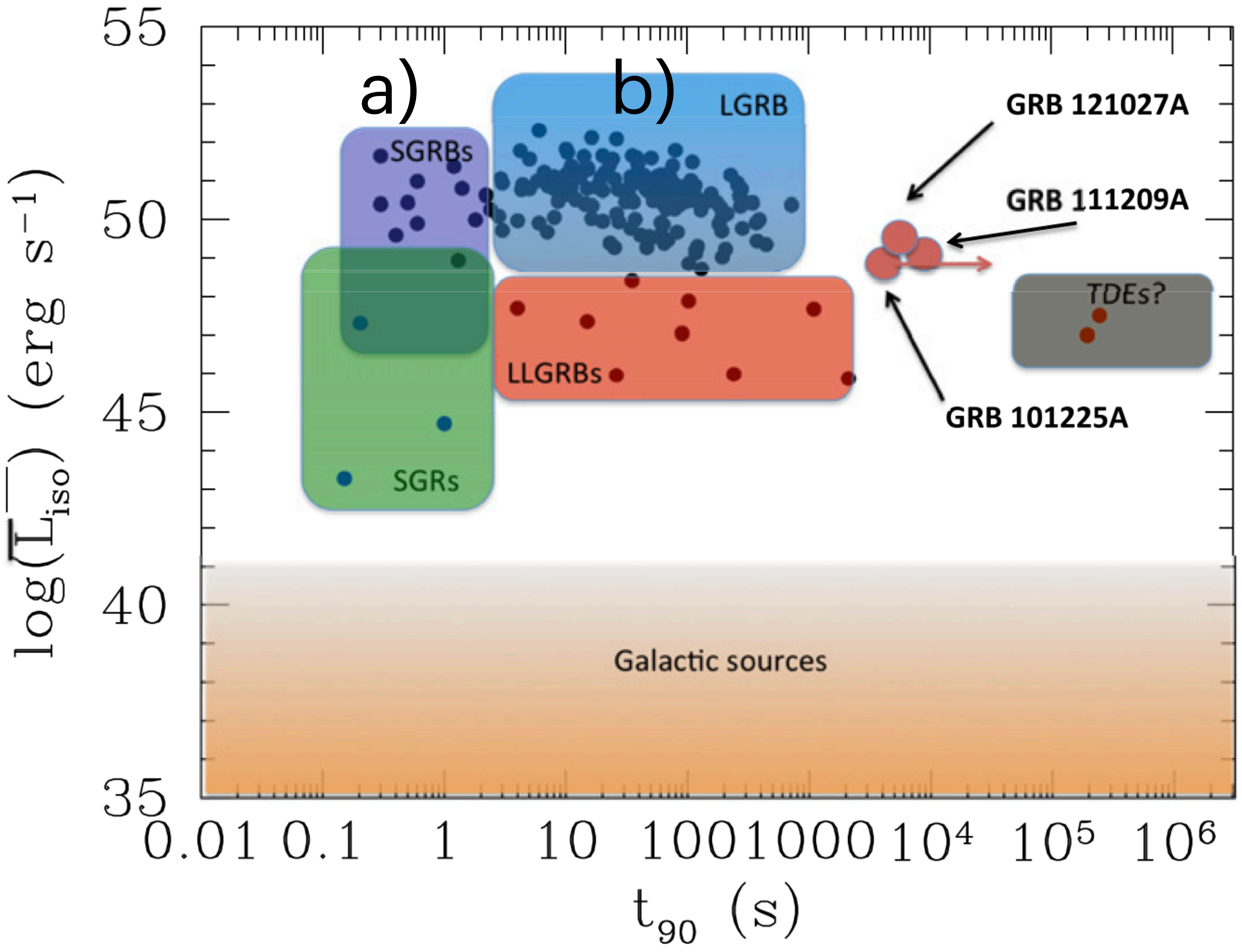
Credits: NASA

Gamma-Ray Bursts (afterglow emission)

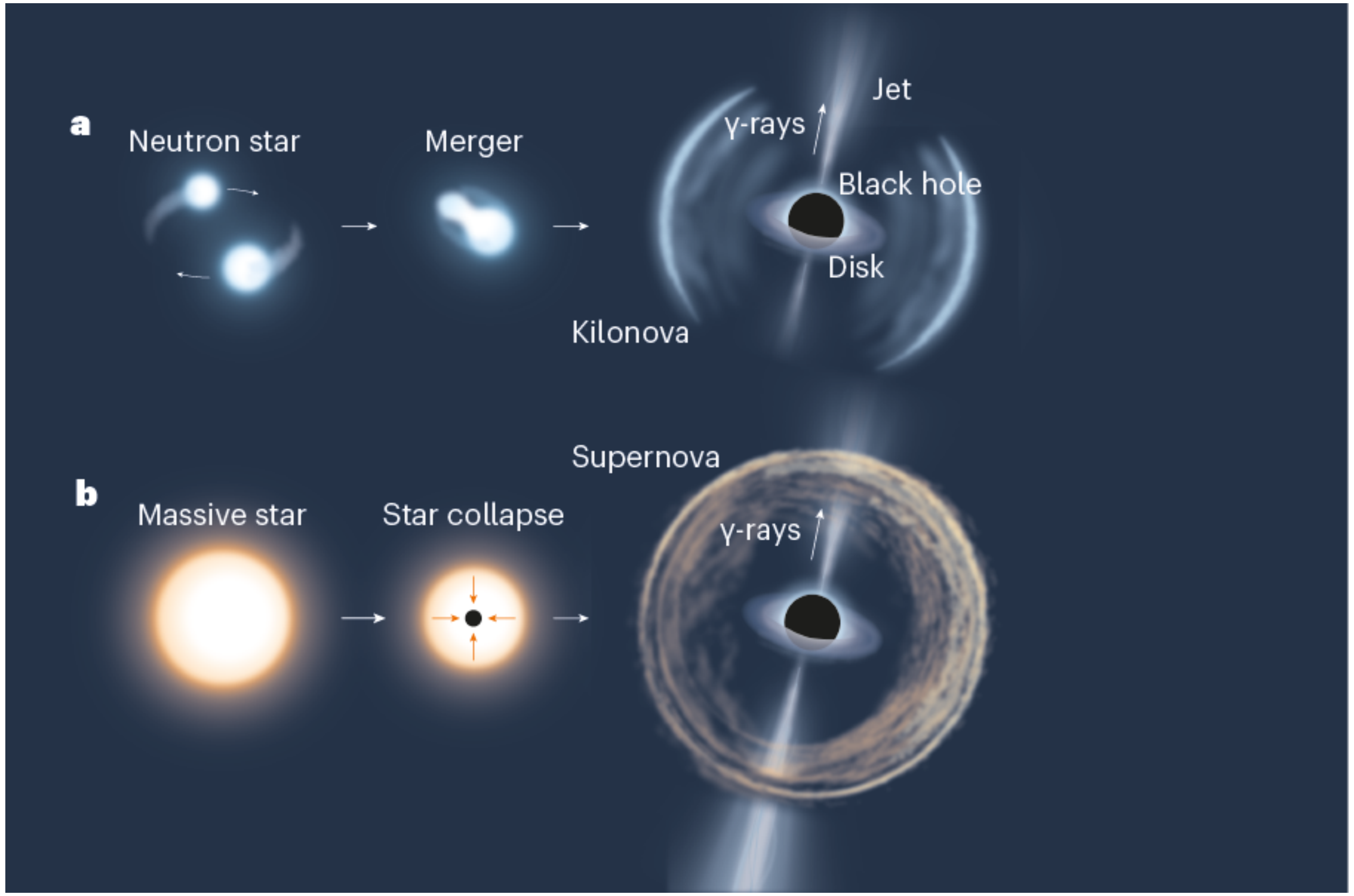


GRB 130427, Perley et al. 2013

Gamma-Ray Bursts (progenitors)

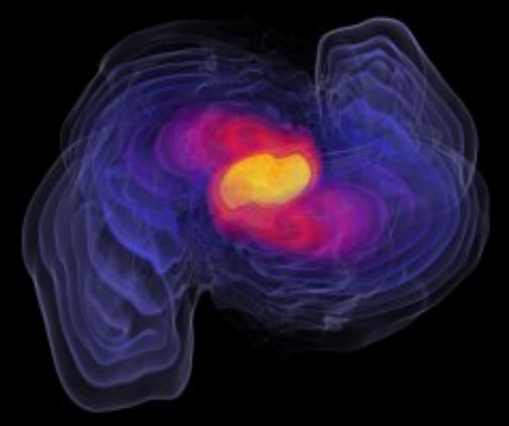


Levan et al. 2014



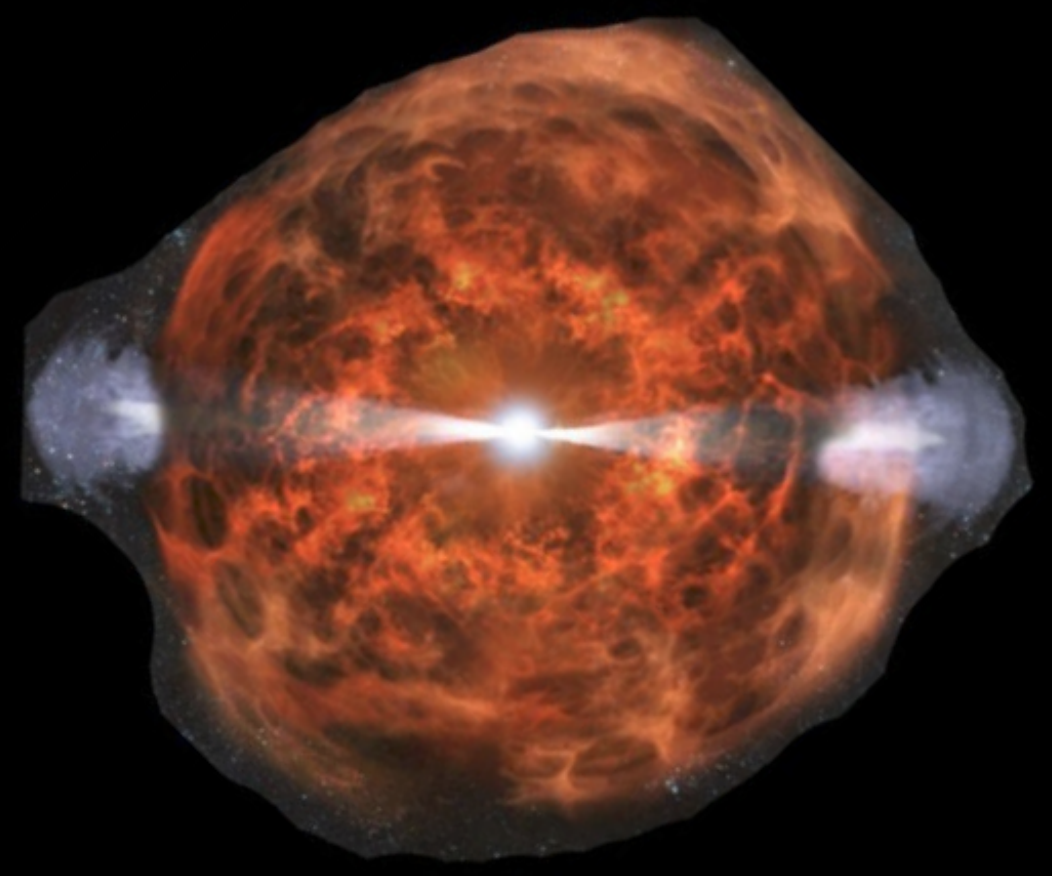
The origin and evolution of Short GRBs

NS-NS merger
Or
BH-NS merger



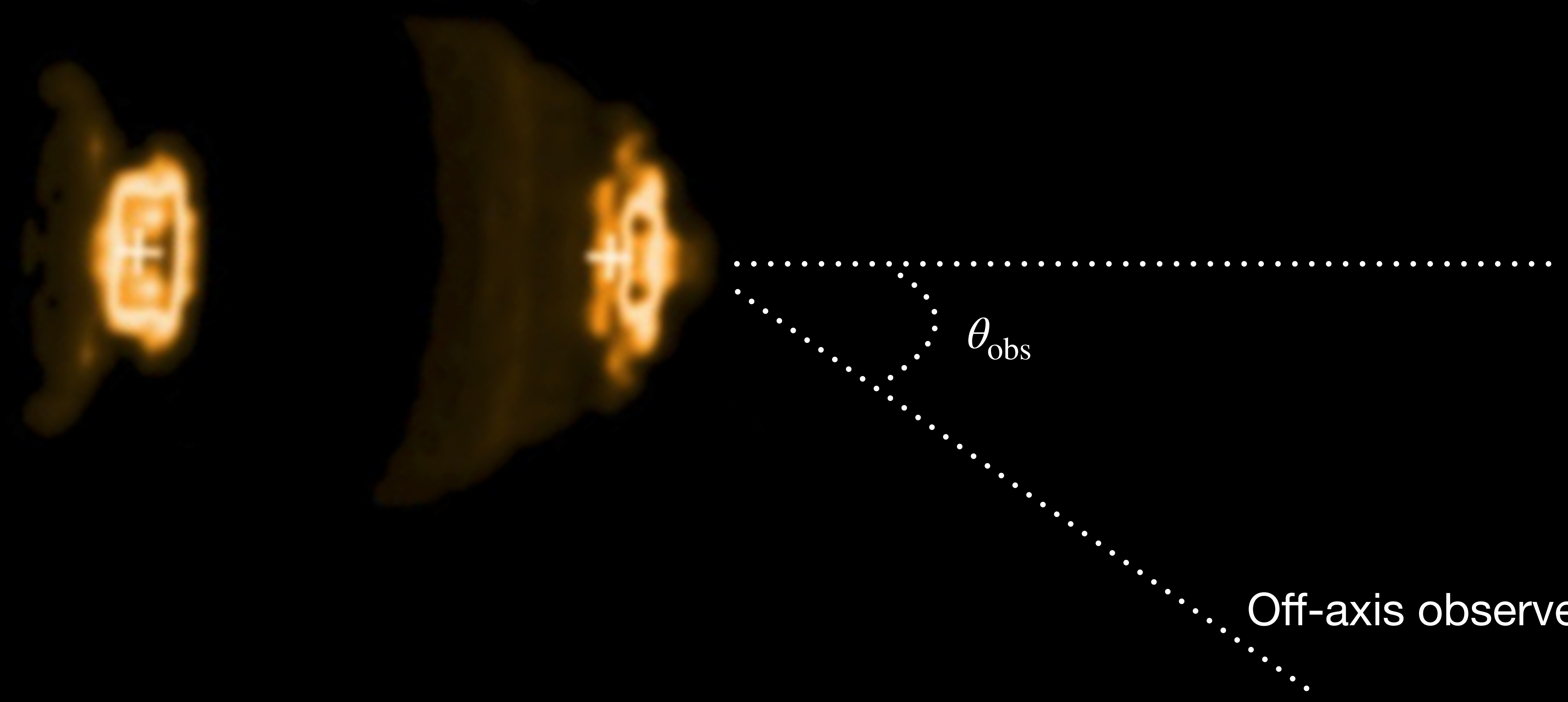
Central Engine

Jet Propagation within Post-merger outflows



$r \lesssim 10^{10}\,\mathrm{cm}$

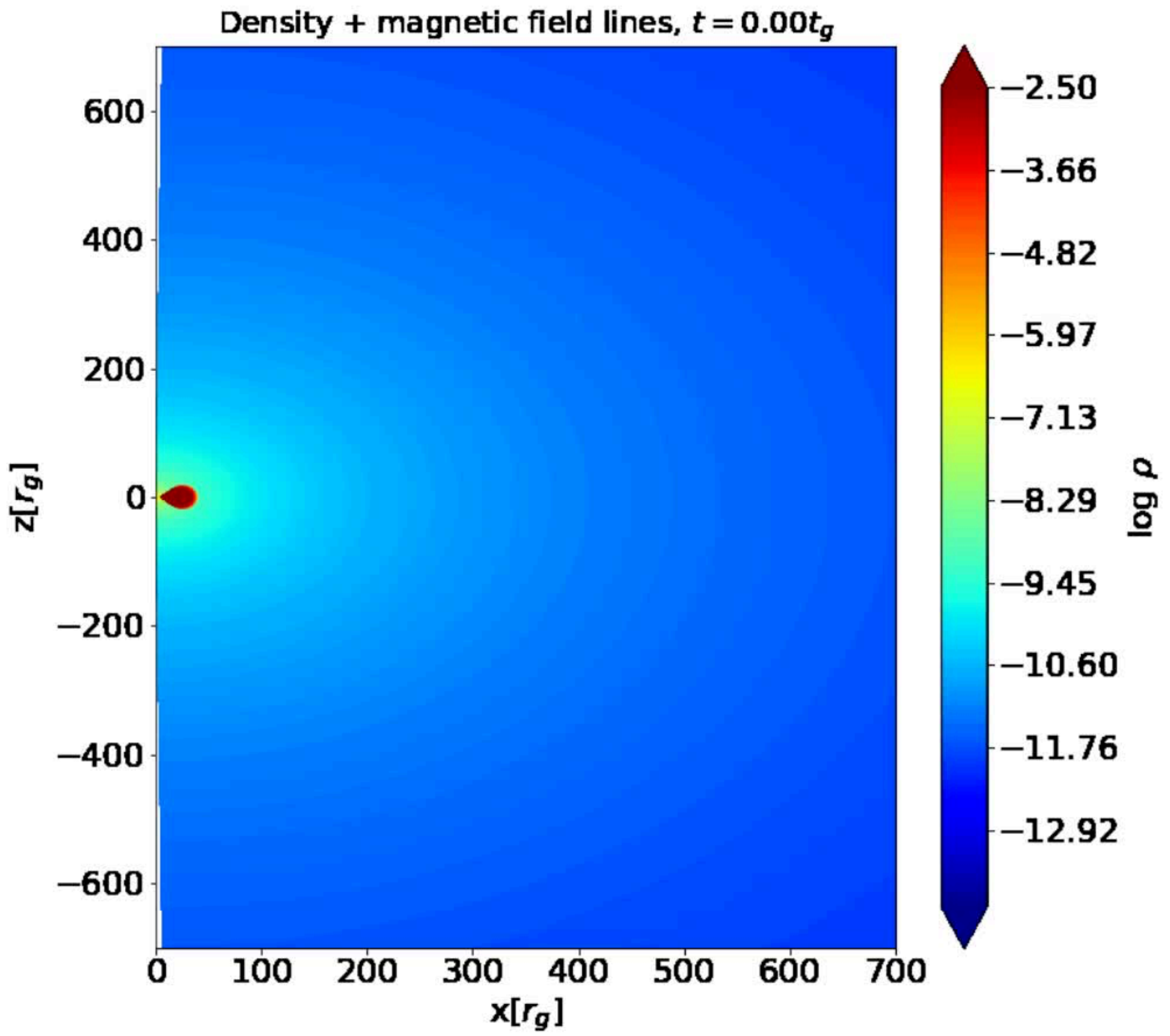
Shell propagation in External ISM



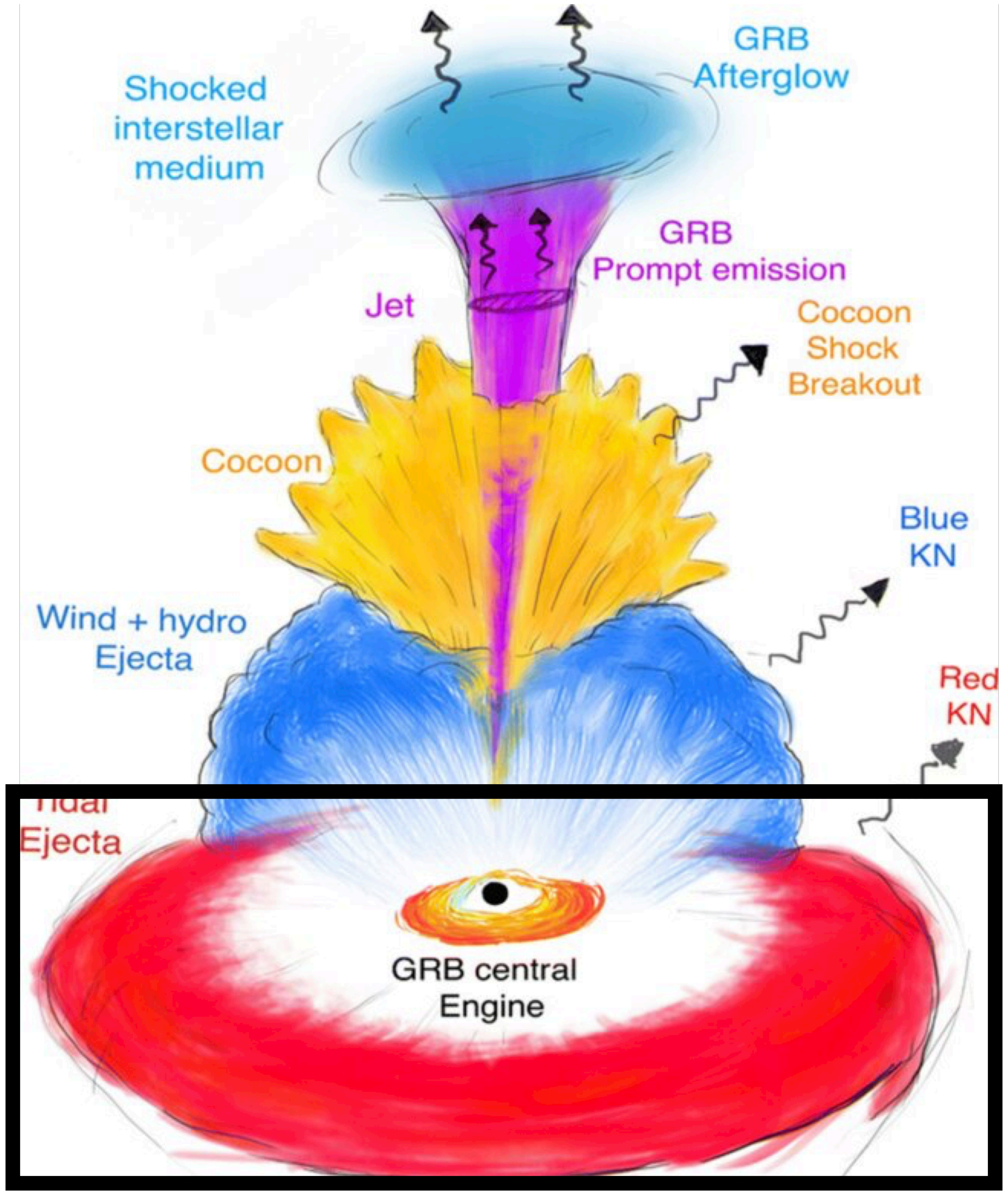
$r \sim 10^{16}\,\mathrm{cm}$

Afterglow Emission

Post-merger evolution of the jet



e.g., Nouri et al. 2023

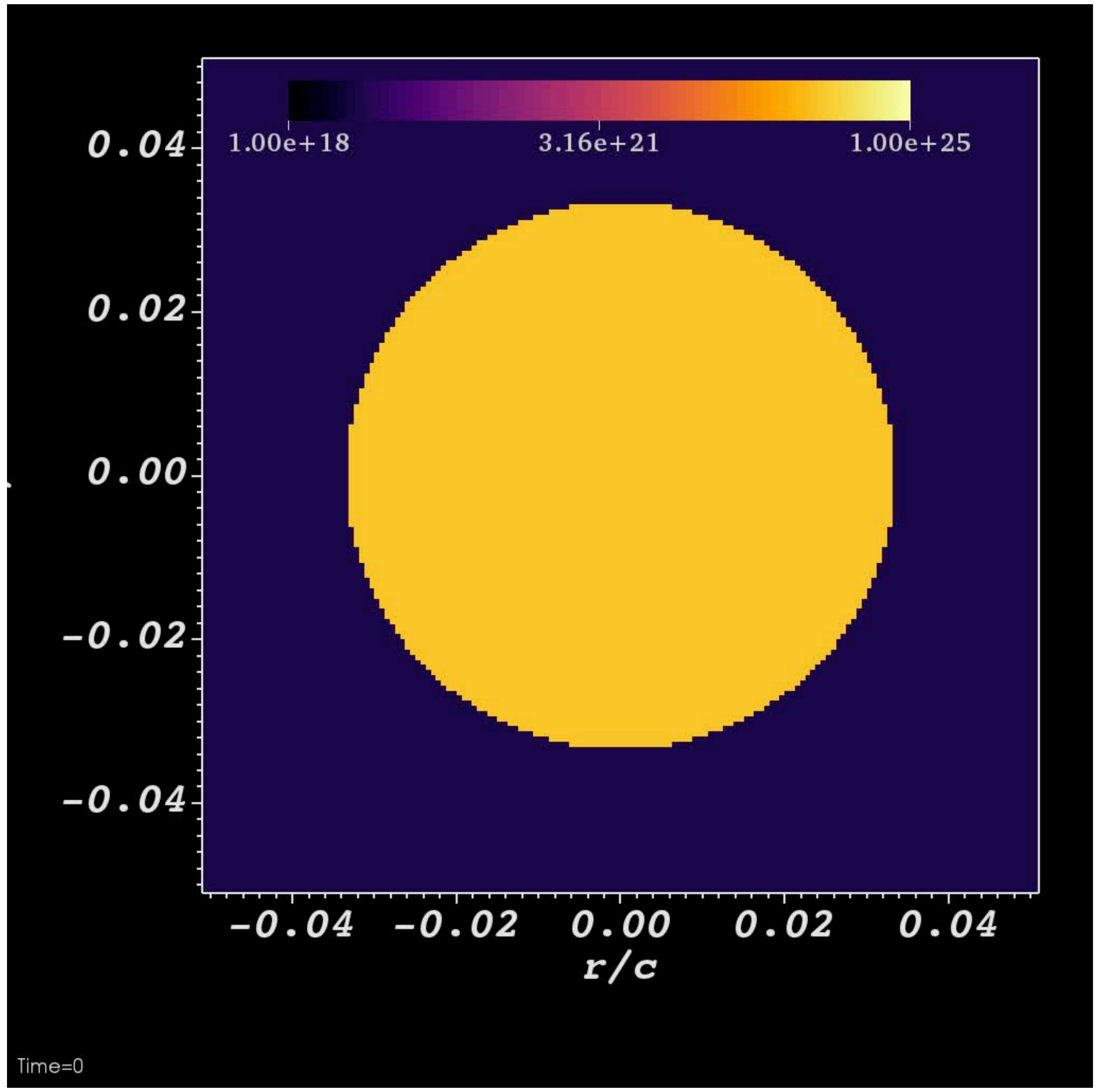


Cartoon of GRB evolution (Stefano Ascenzi)

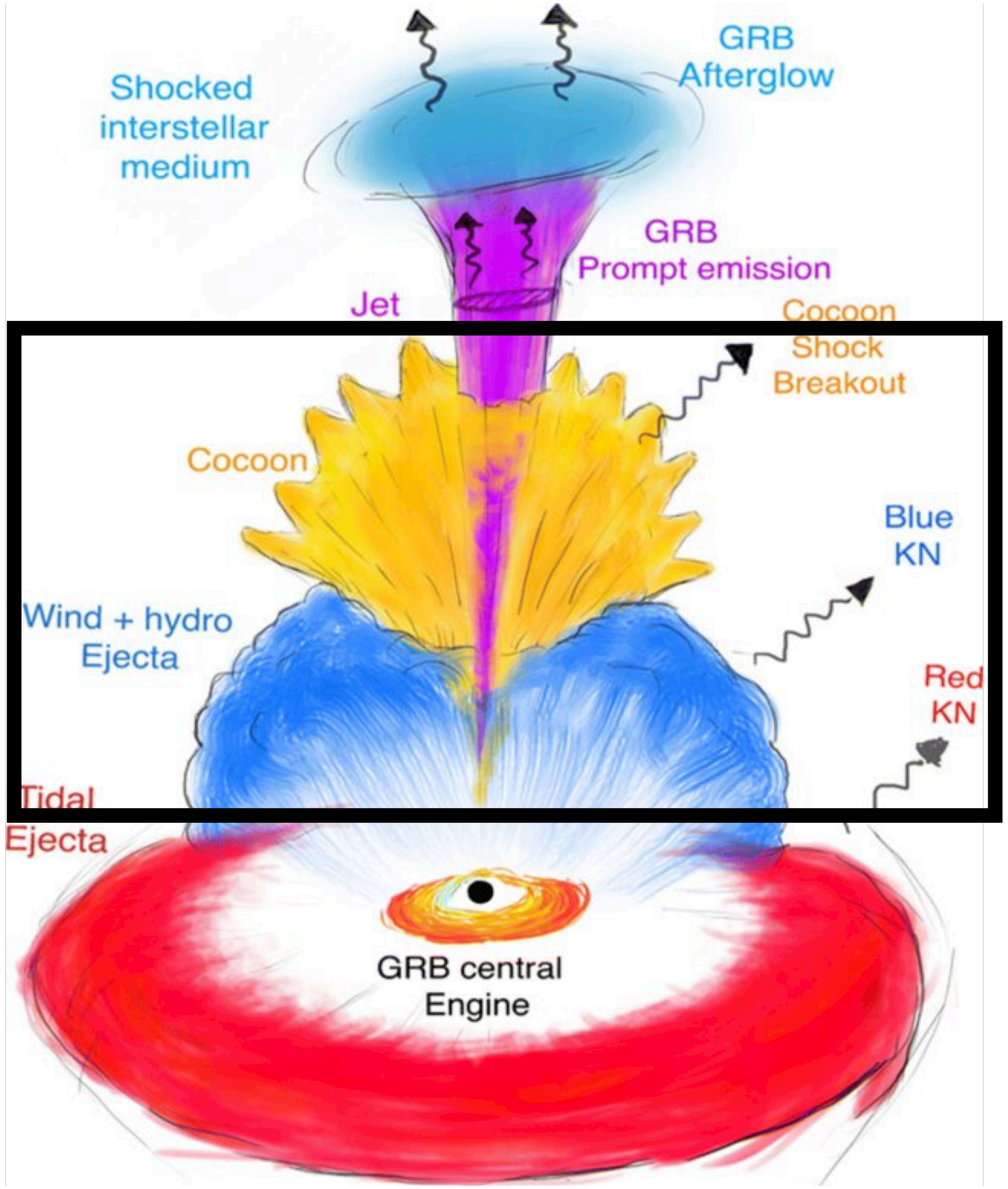
Small Scales $r \lesssim 10^8\,\mathrm{cm}$

GRMHD simulations

Post-merger evolution of the jet



e.g., Urrutia et al. 2021



Cartoon of GRB evolution (Stefano Ascenzi)

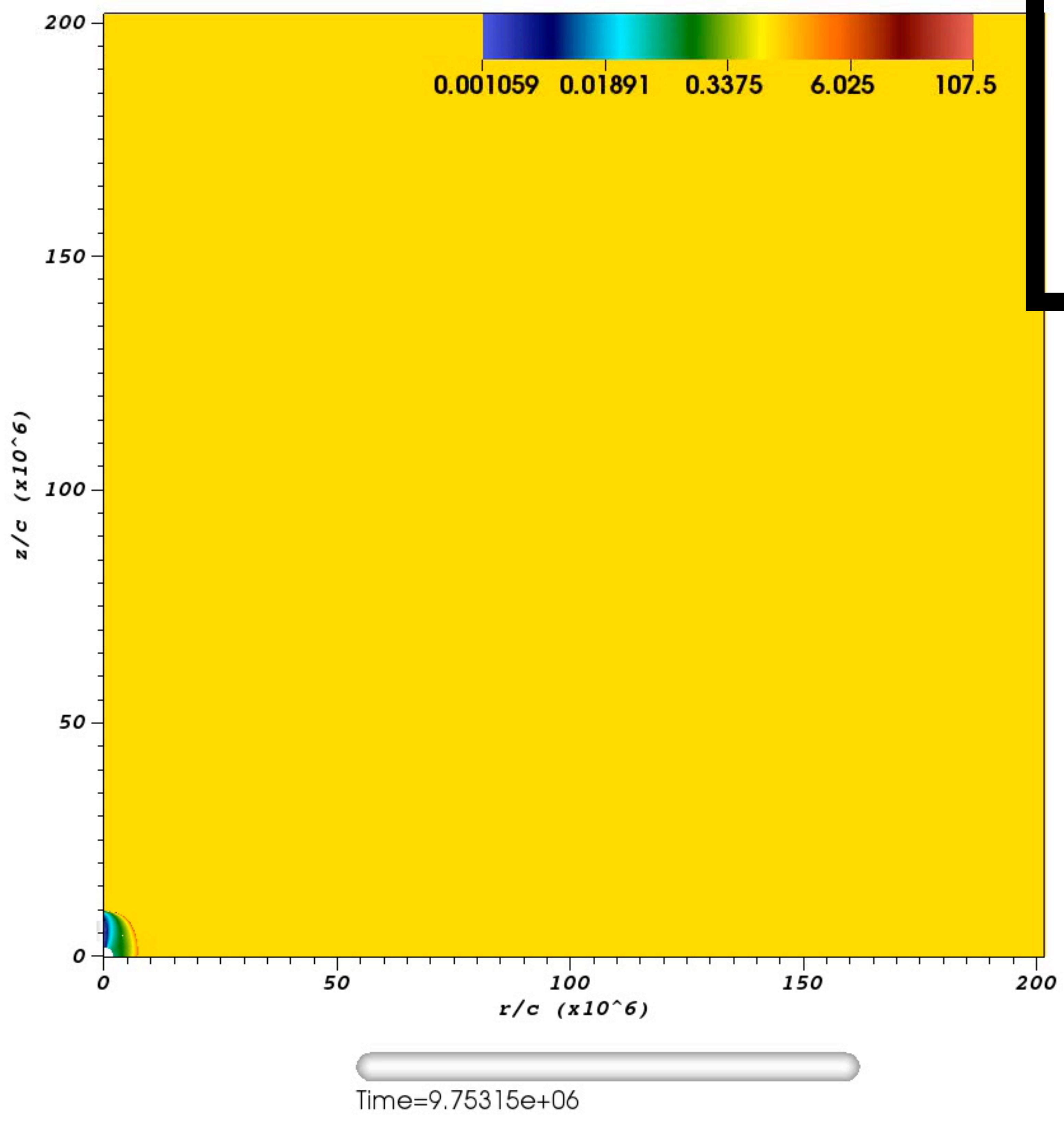
Intermediate Scales $10^8 \lesssim r \lesssim 10^{11}\,\mathrm{cm}$

RMHD or RHD simulations

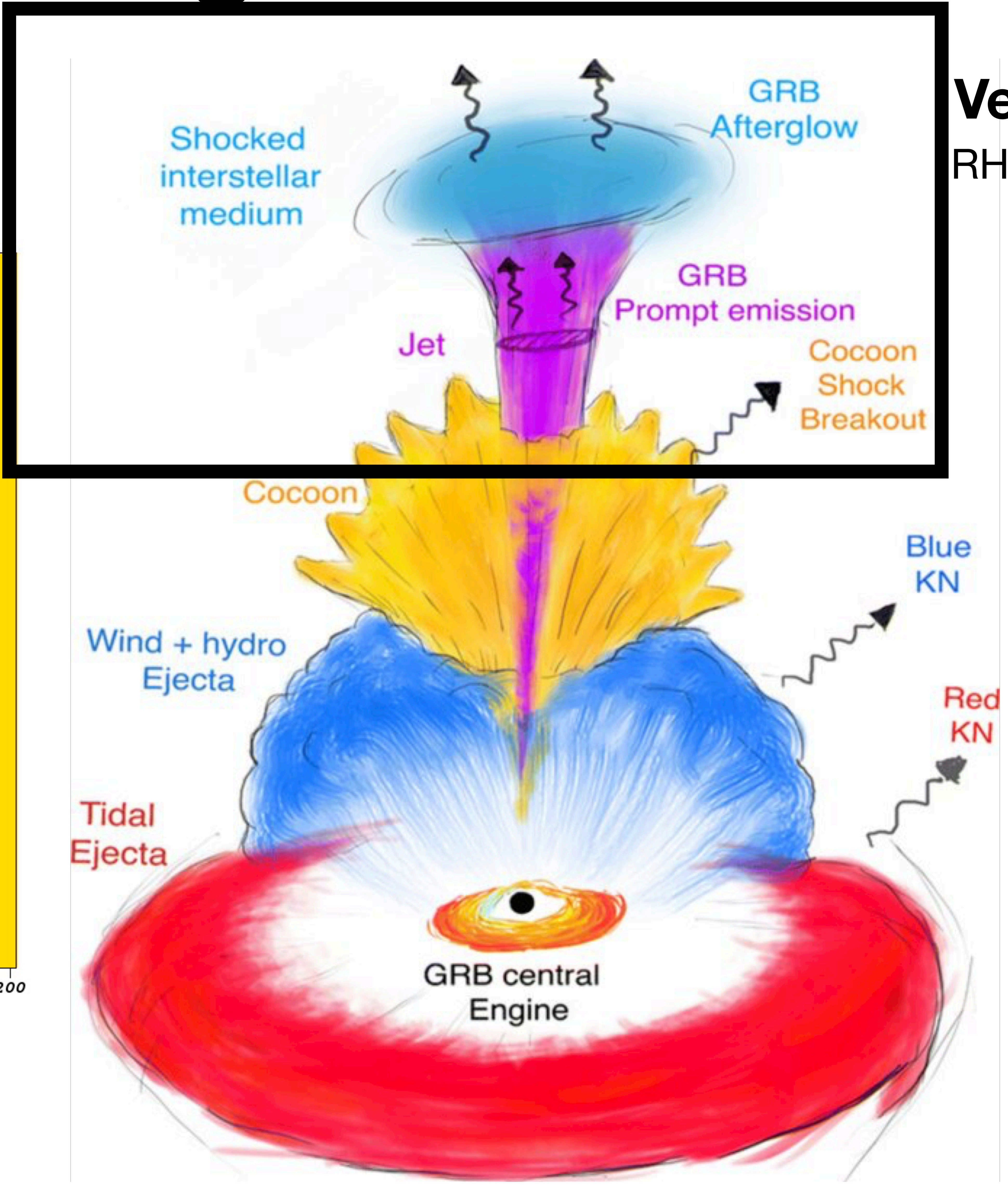
Post-merger evolution of the jet

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

RHD simulations or Analytical extrapolations

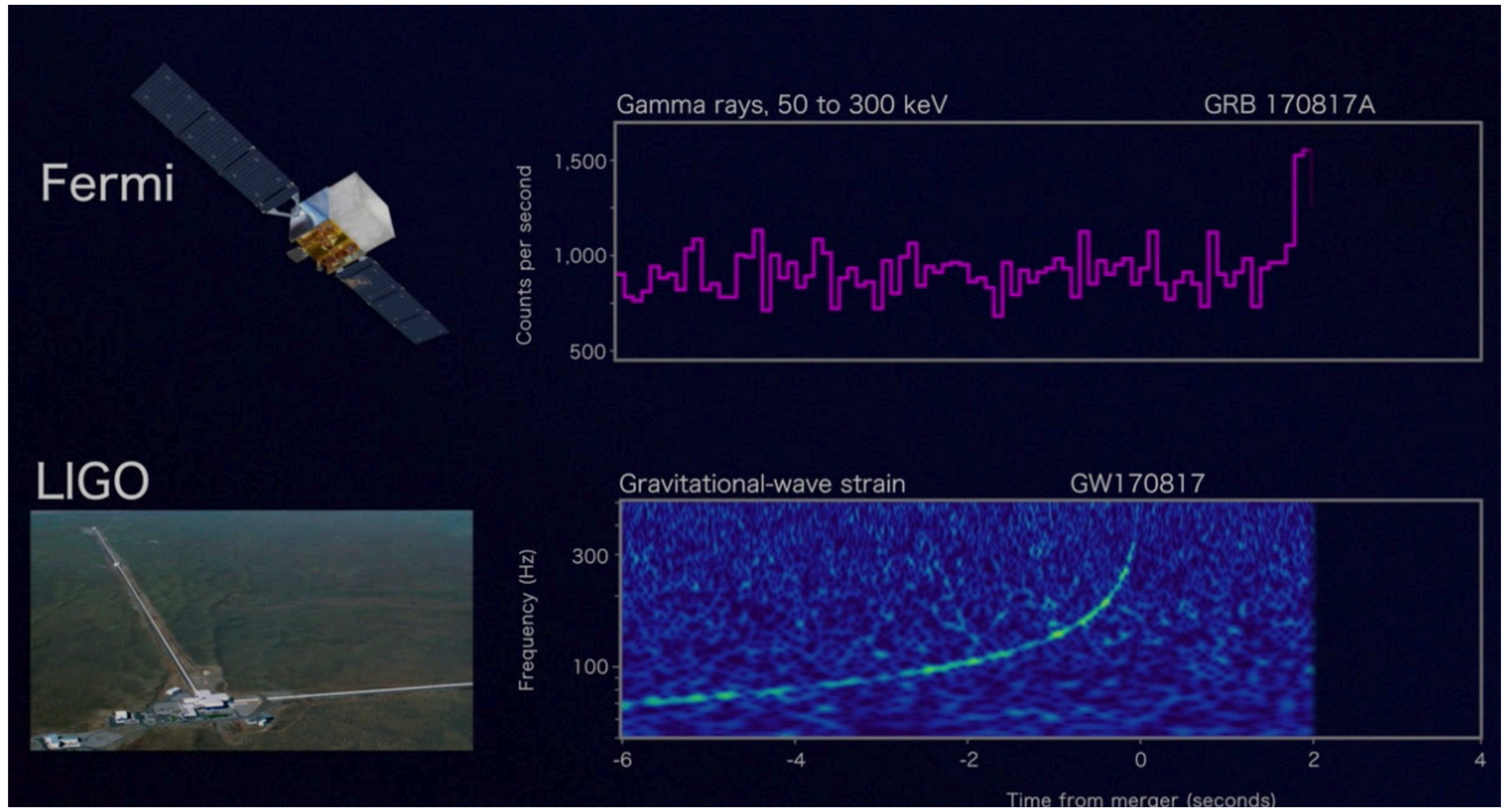


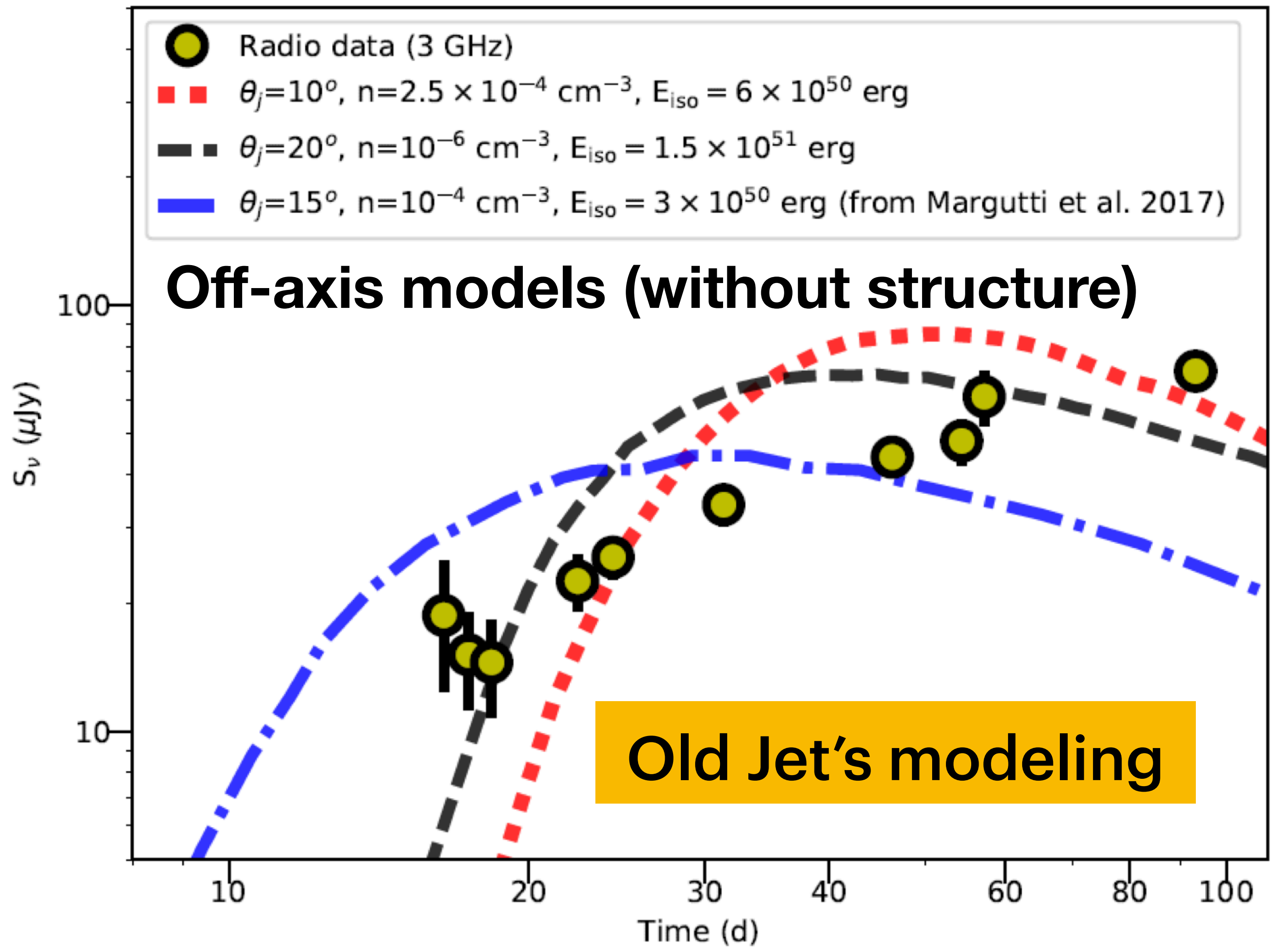
Urrutia in prep

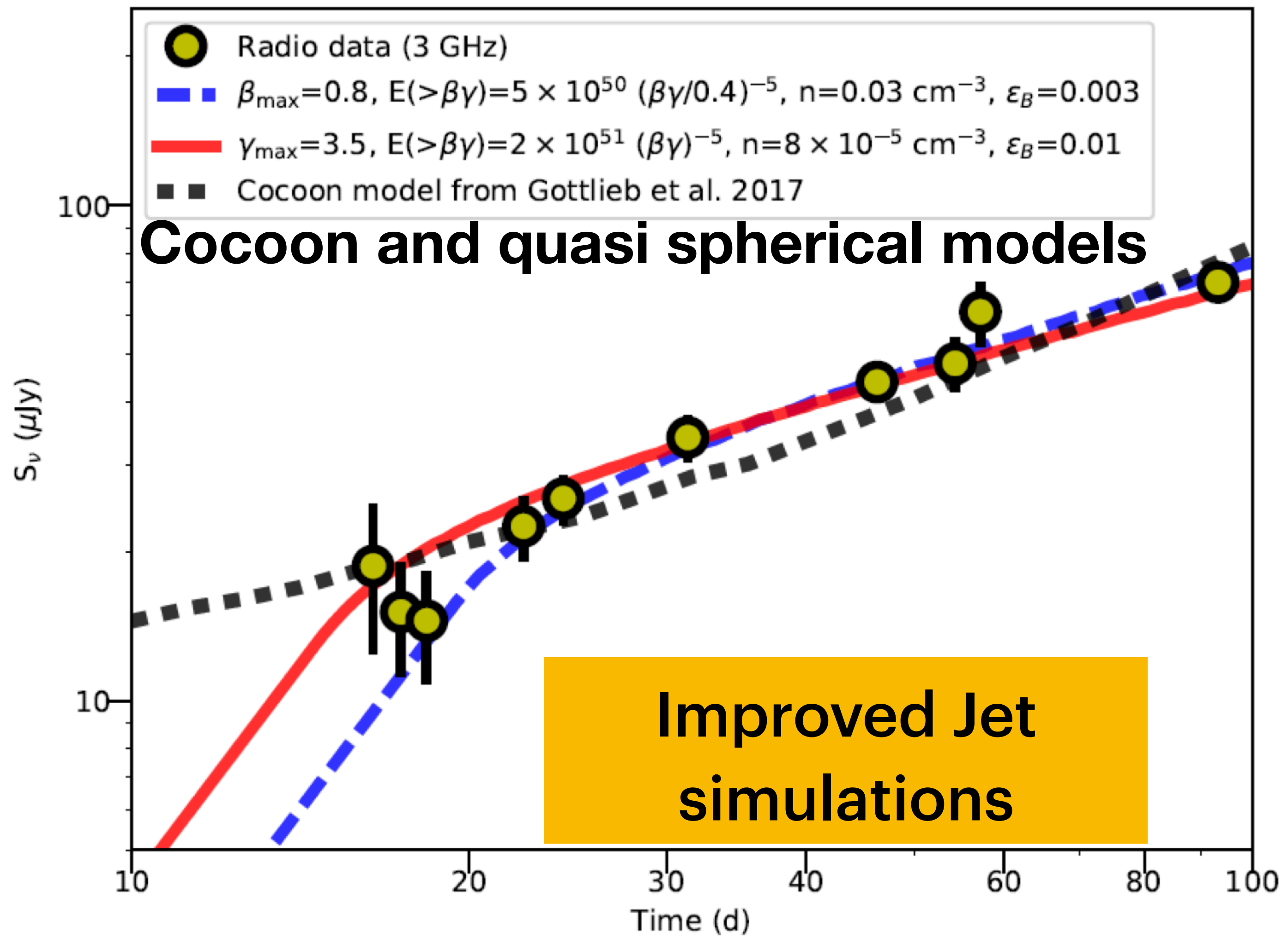


Cartoon of GRB evolution (Stefano Ascenzi)

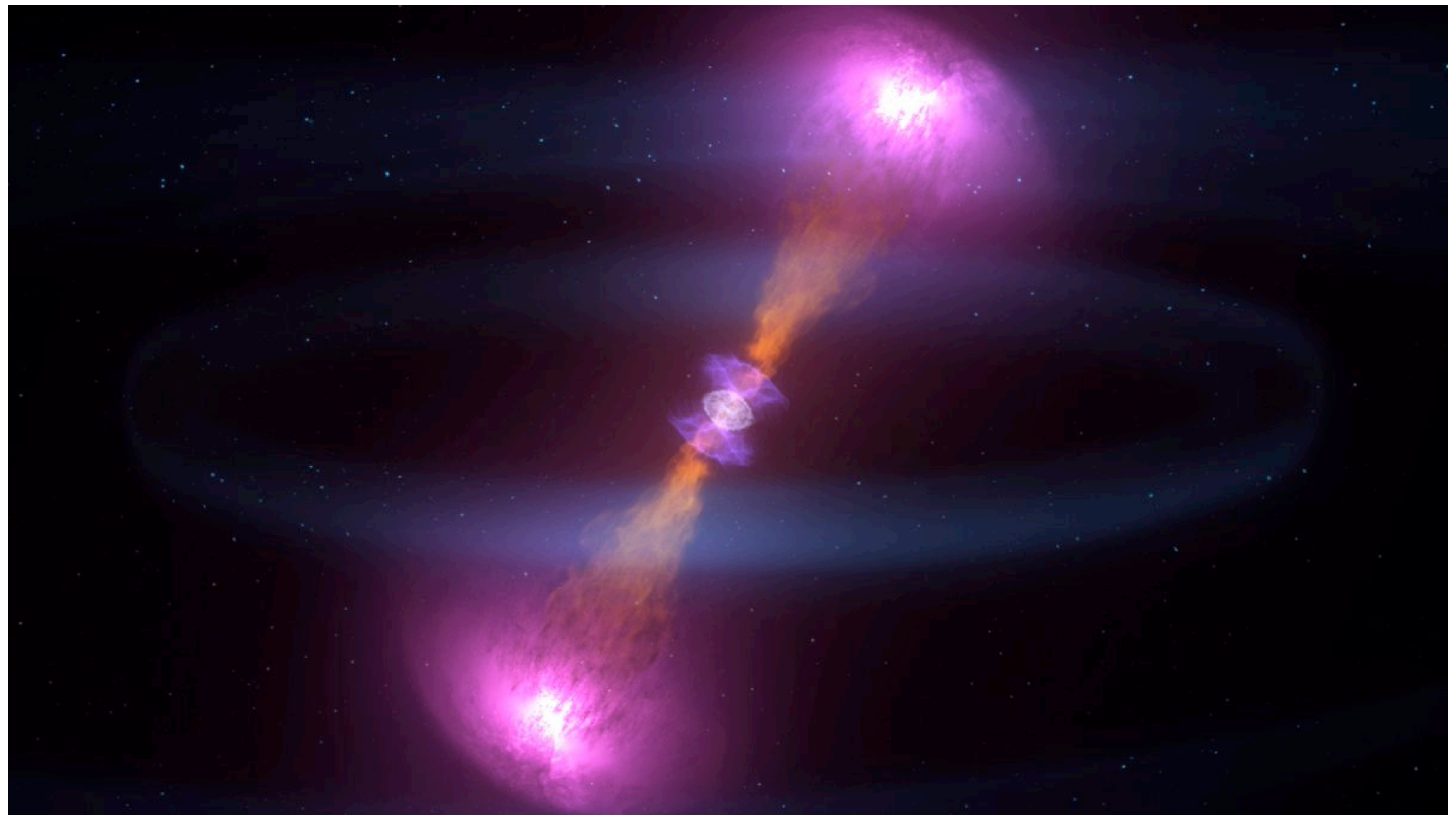
Lessons from GRB170817A

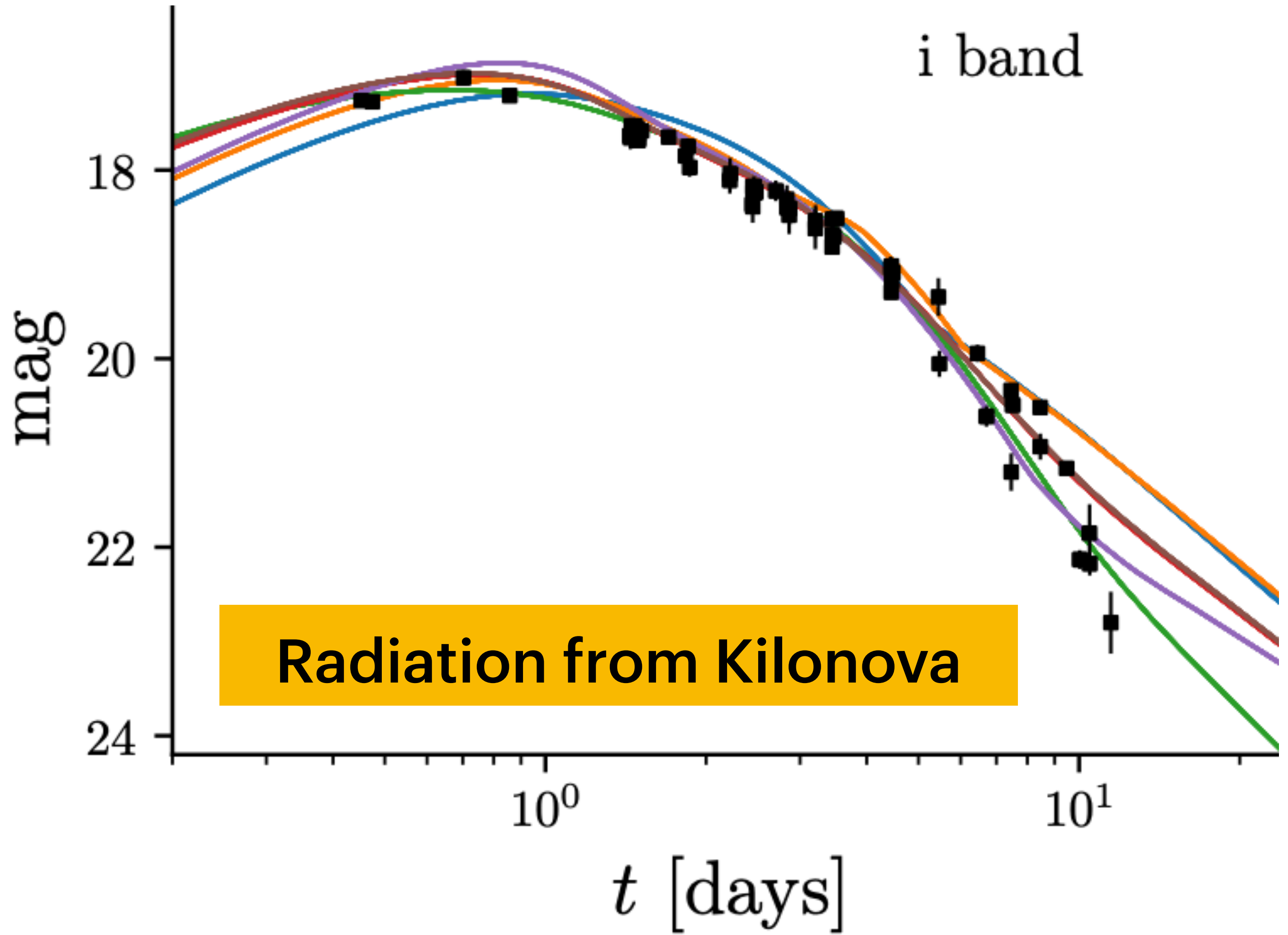






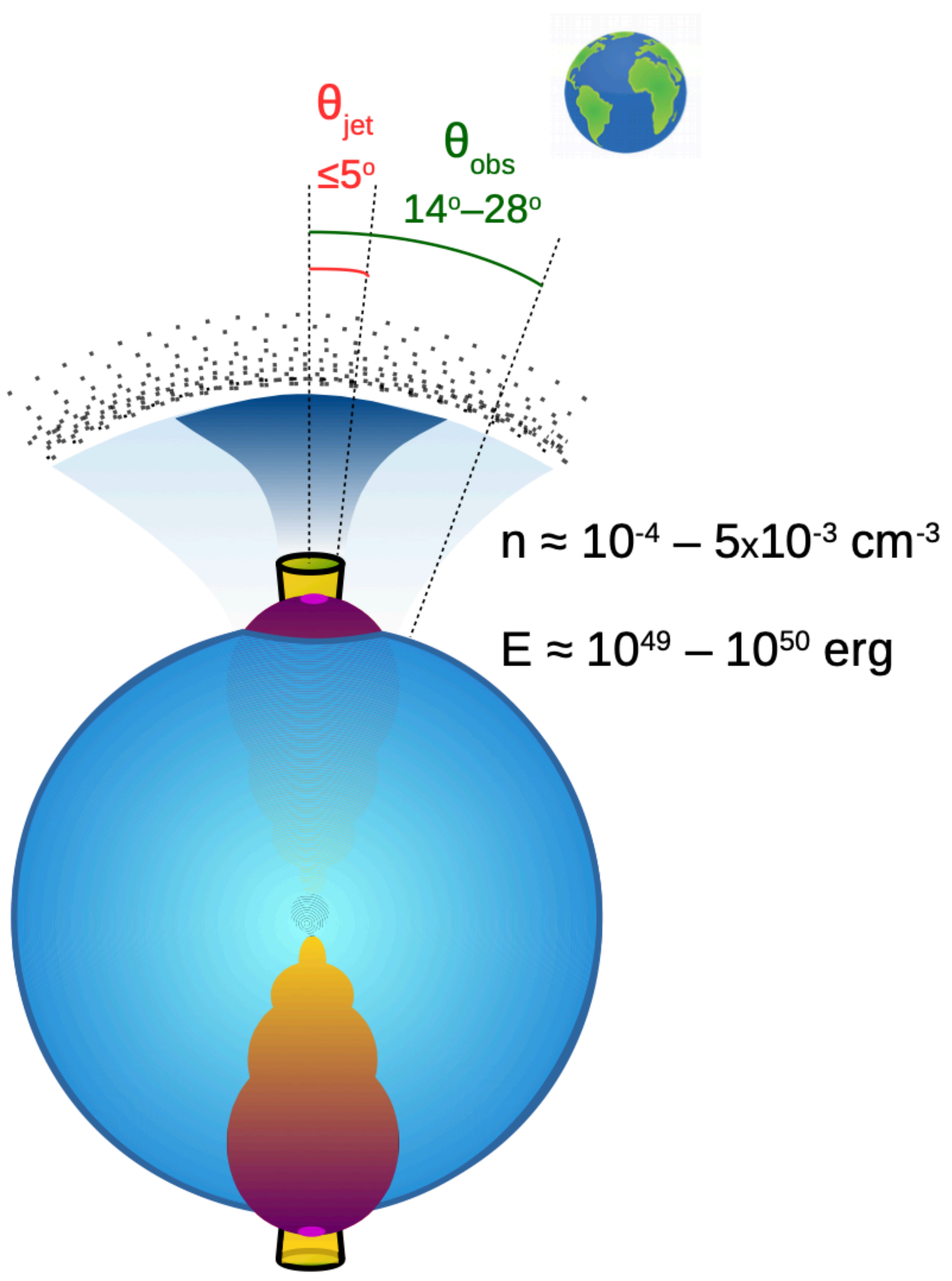
Mooley et al. 2018



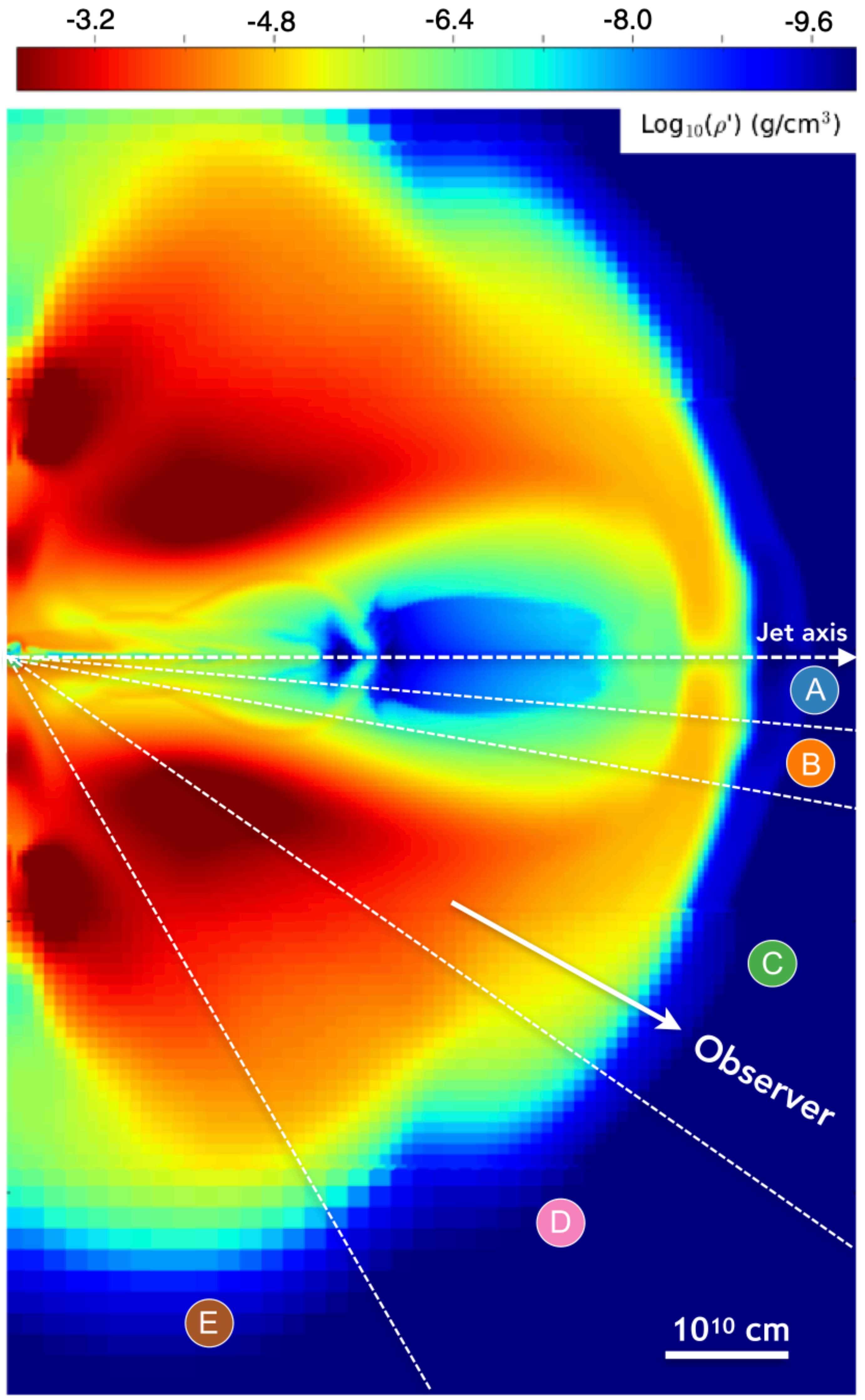


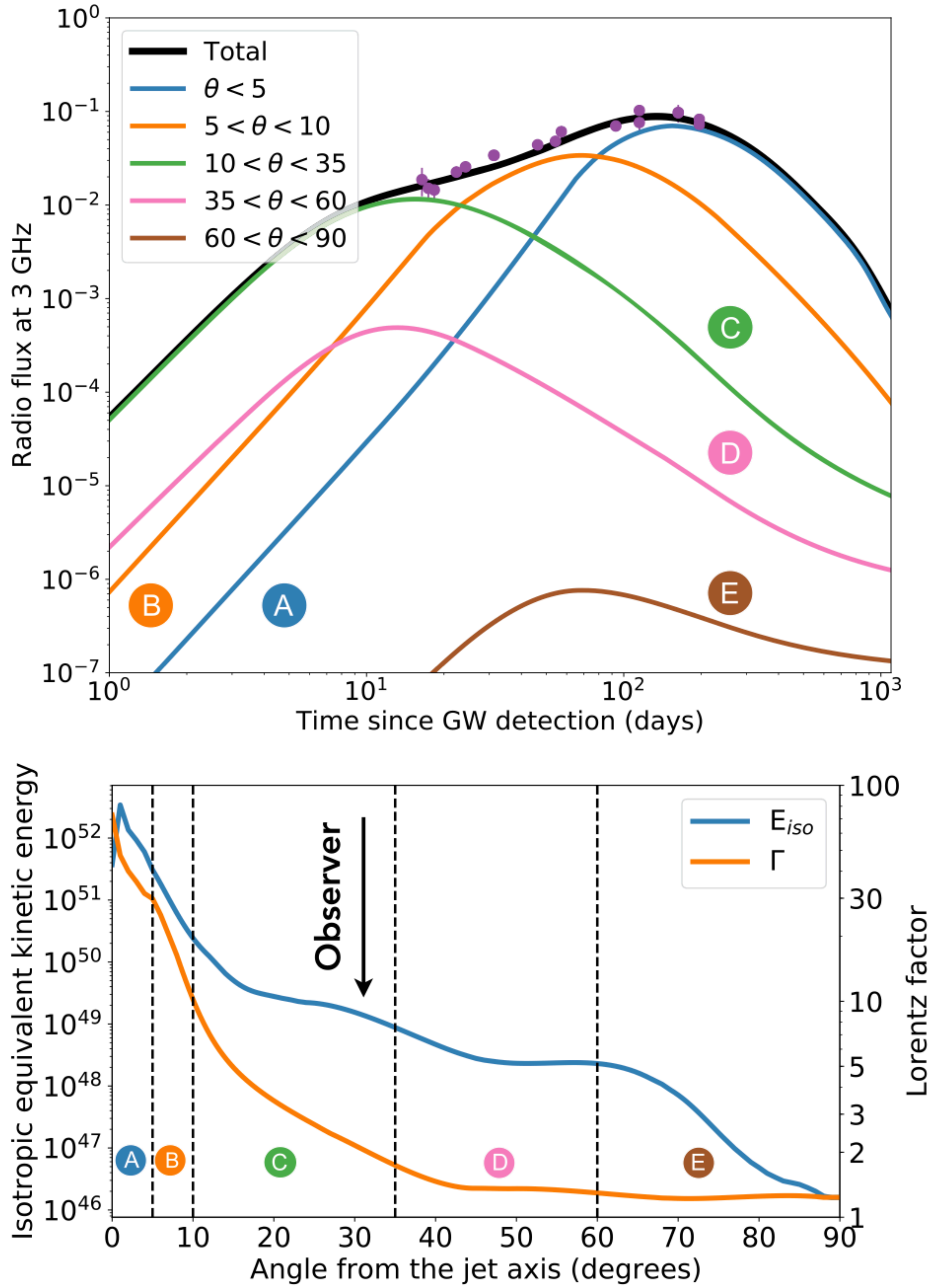
Breschi et al. 2021

GRB170817A: off-axis and structure



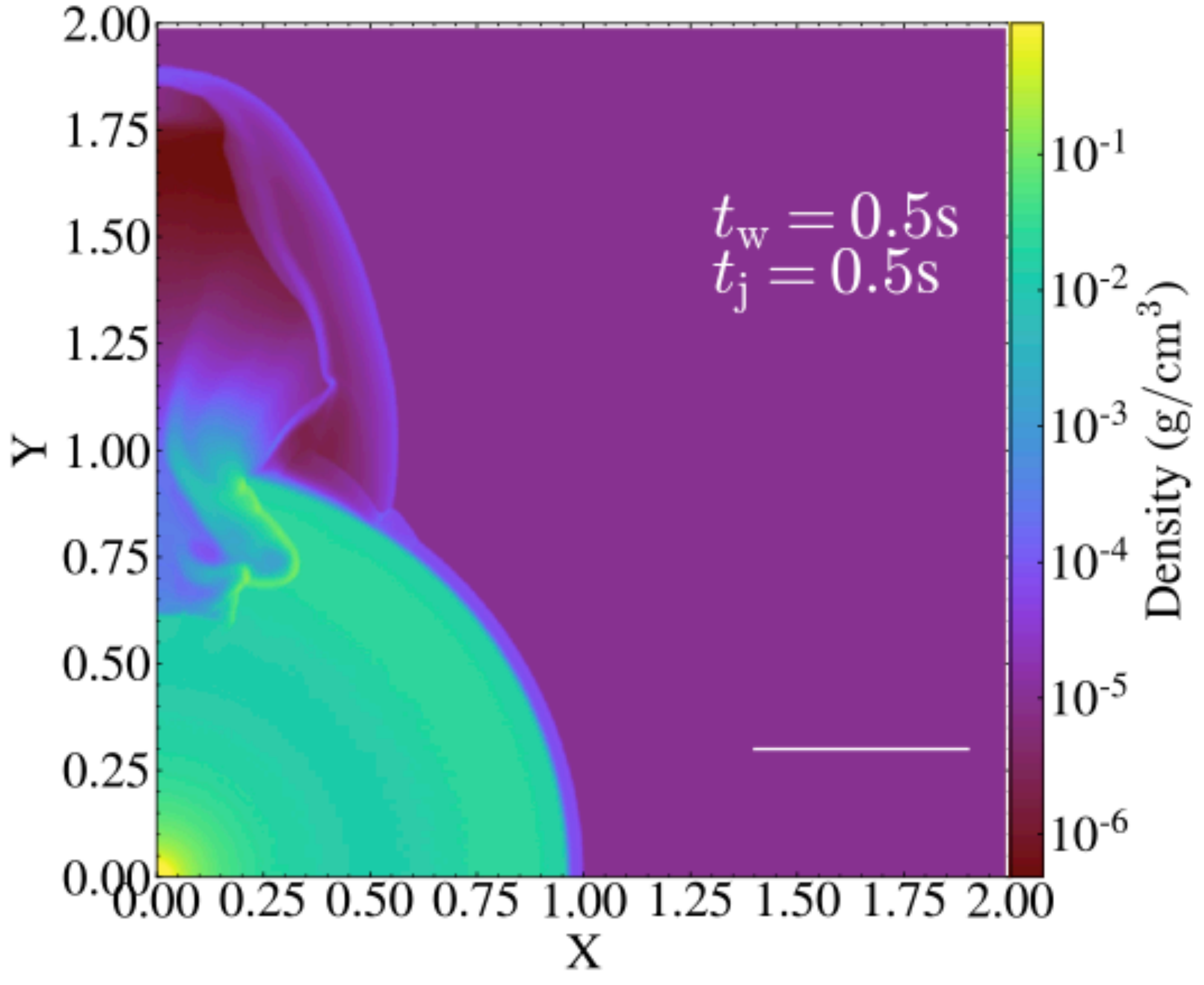
Mooley et al. 2018

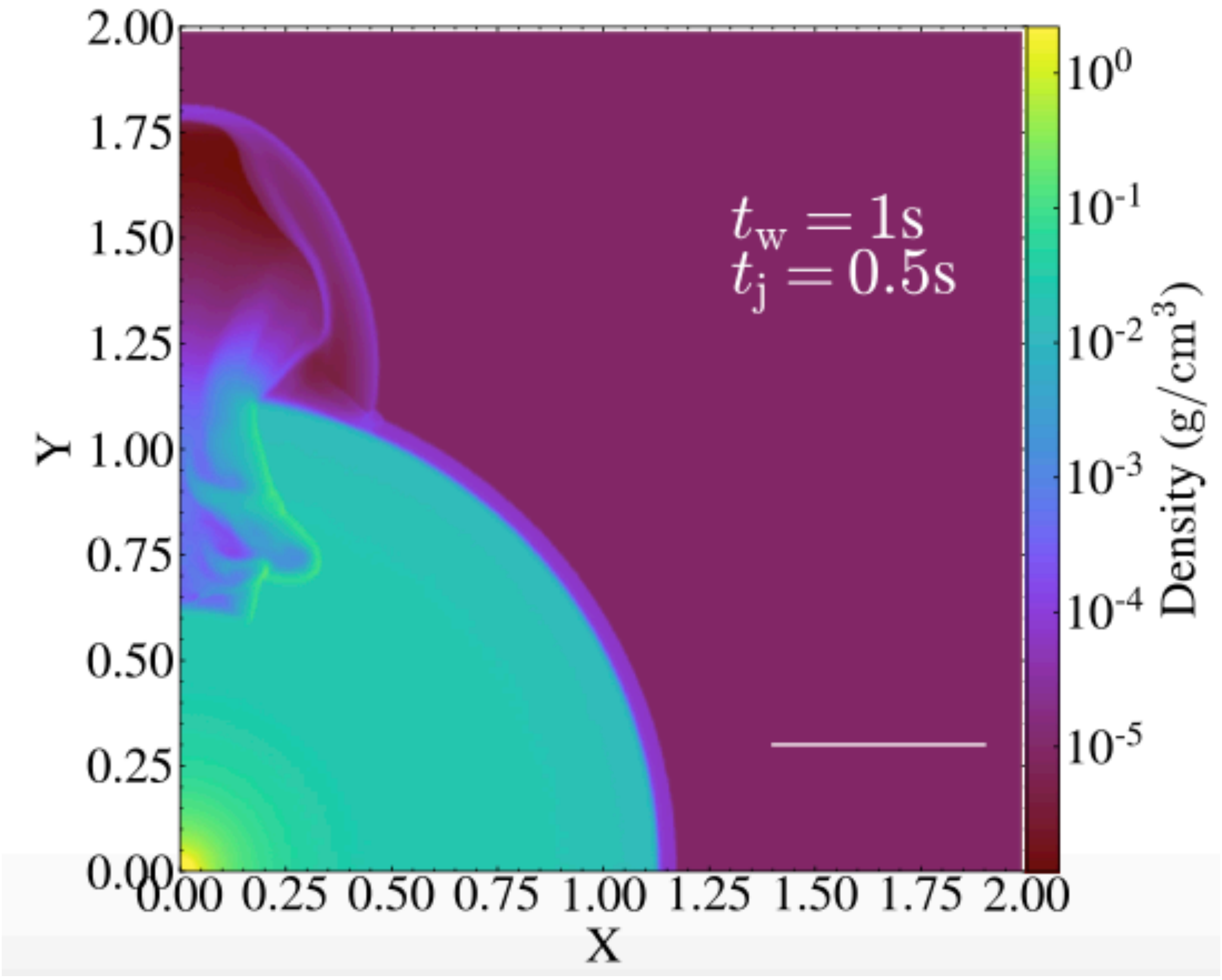




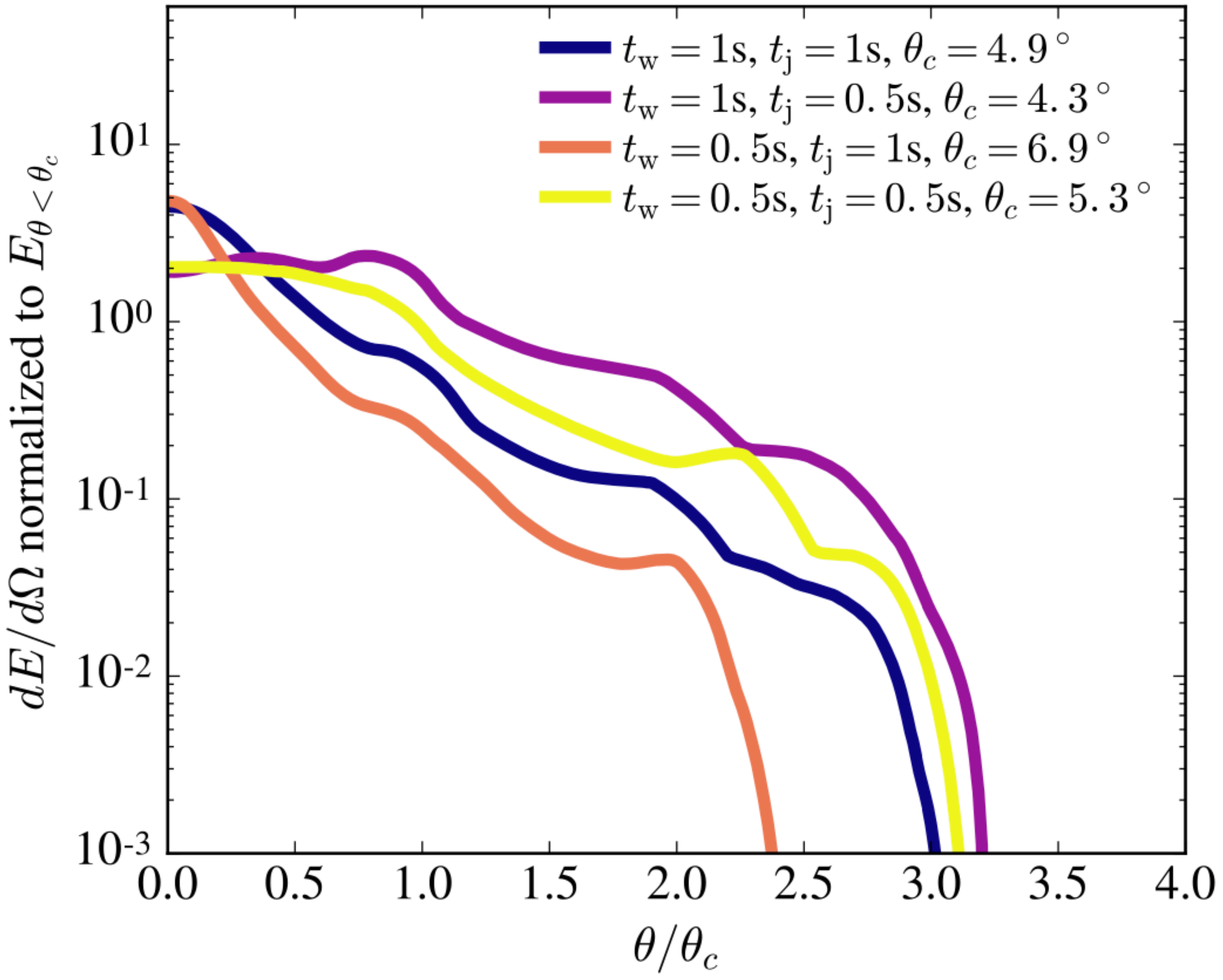
Lazzati et al 2018

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



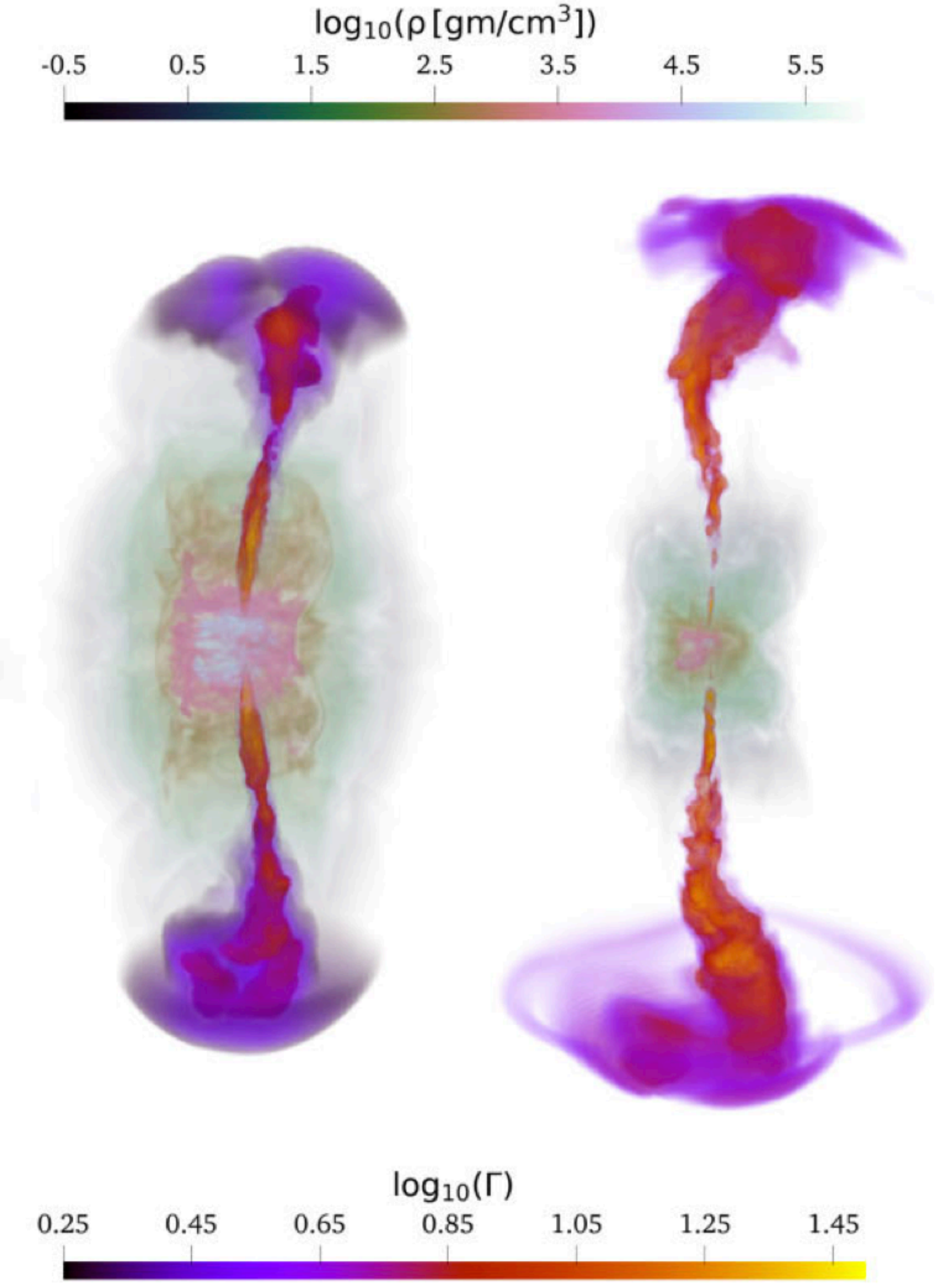


Energy distribution (jet structure)

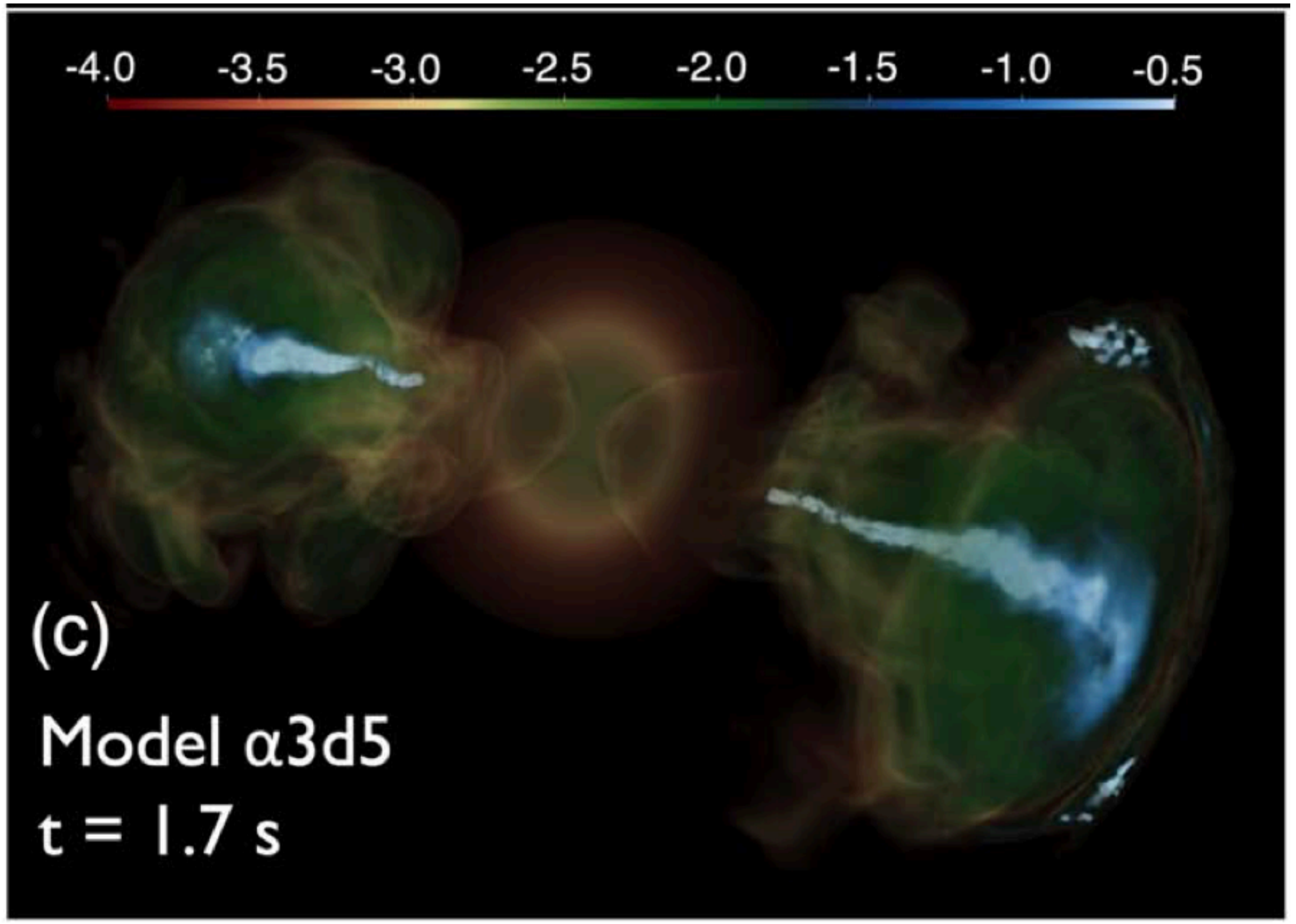


Murguia-Berthier et al., 2021

Looking for self-consistency at intermediate scales



Pavan et al. 2023



Gottlieb et al 2022

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

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

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 $10^8\,\mathrm{cm} < \mathrm{r} < 10^{11}\,\mathrm{cm}$

Special Relativistic HD simulation

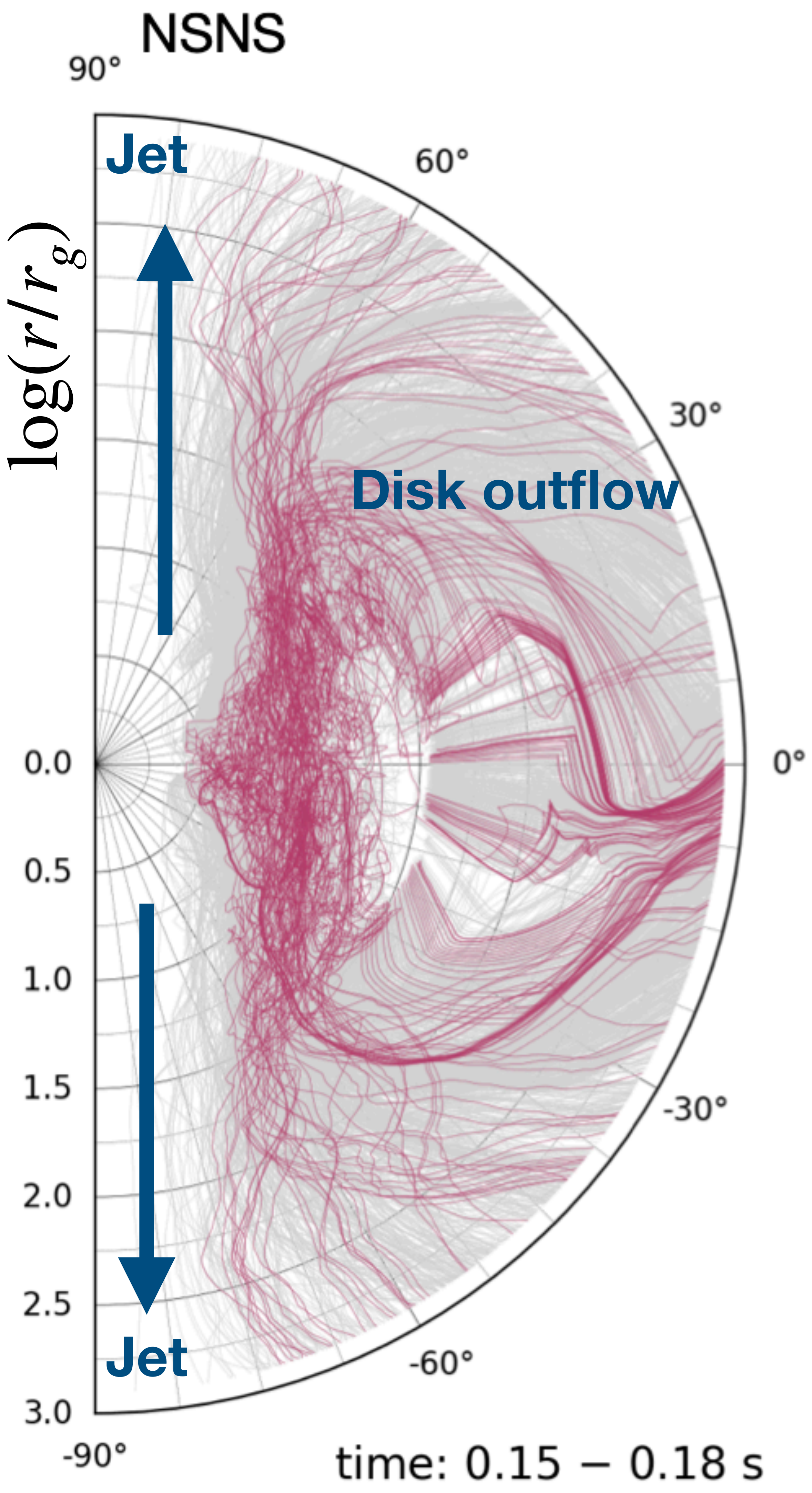
$$(\rho u_\mu)_{;\nu} = 0$$

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

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

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

Outflow characteristics



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

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

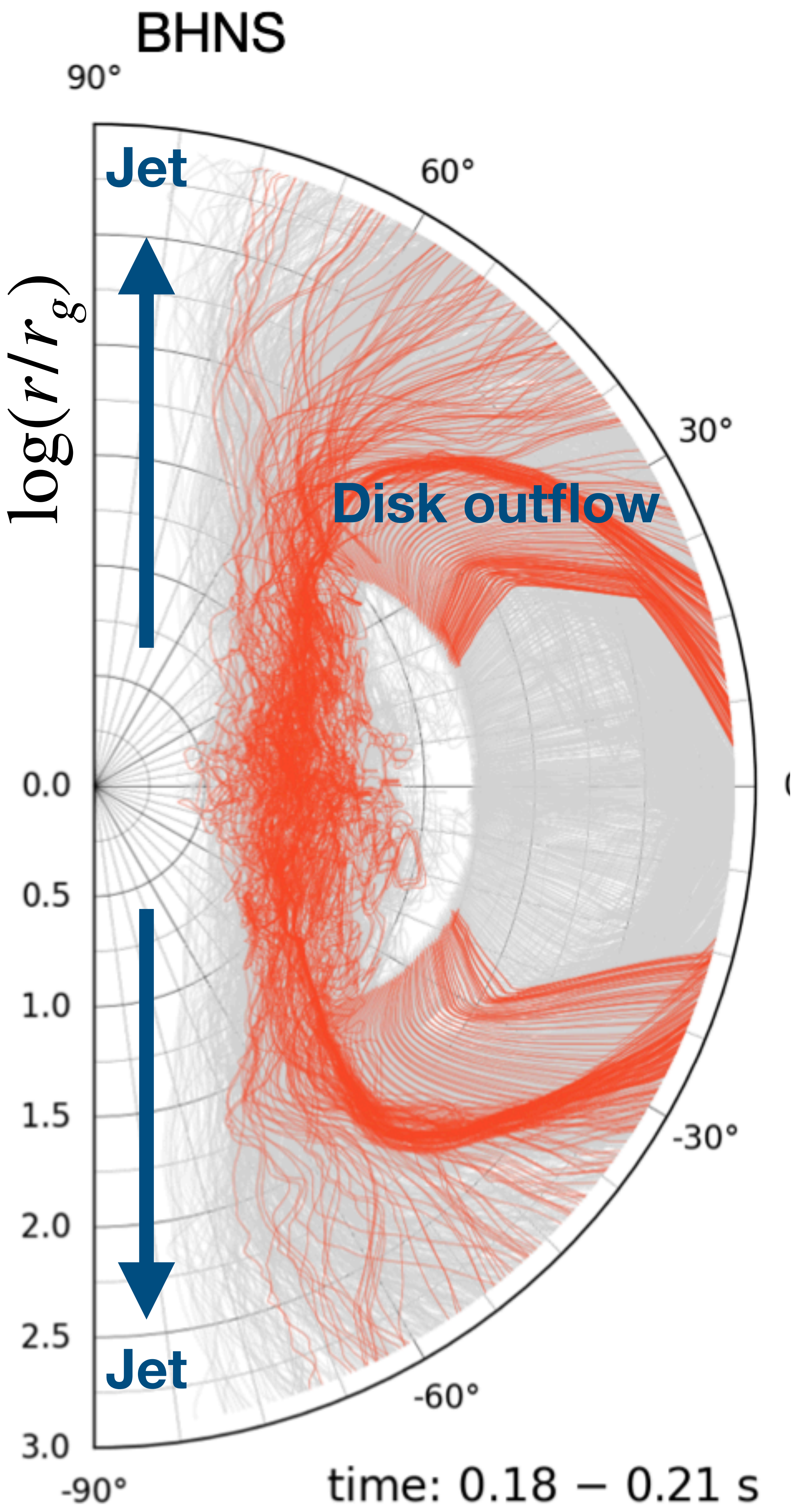
$\dot{M}_{\rm out} = 3.27 \times 10^{-2}\, M_\odot\ {\rm s}^{-1}$

$\Gamma_j = 7.2$

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

$\theta_j = 15^\circ$

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



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

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

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

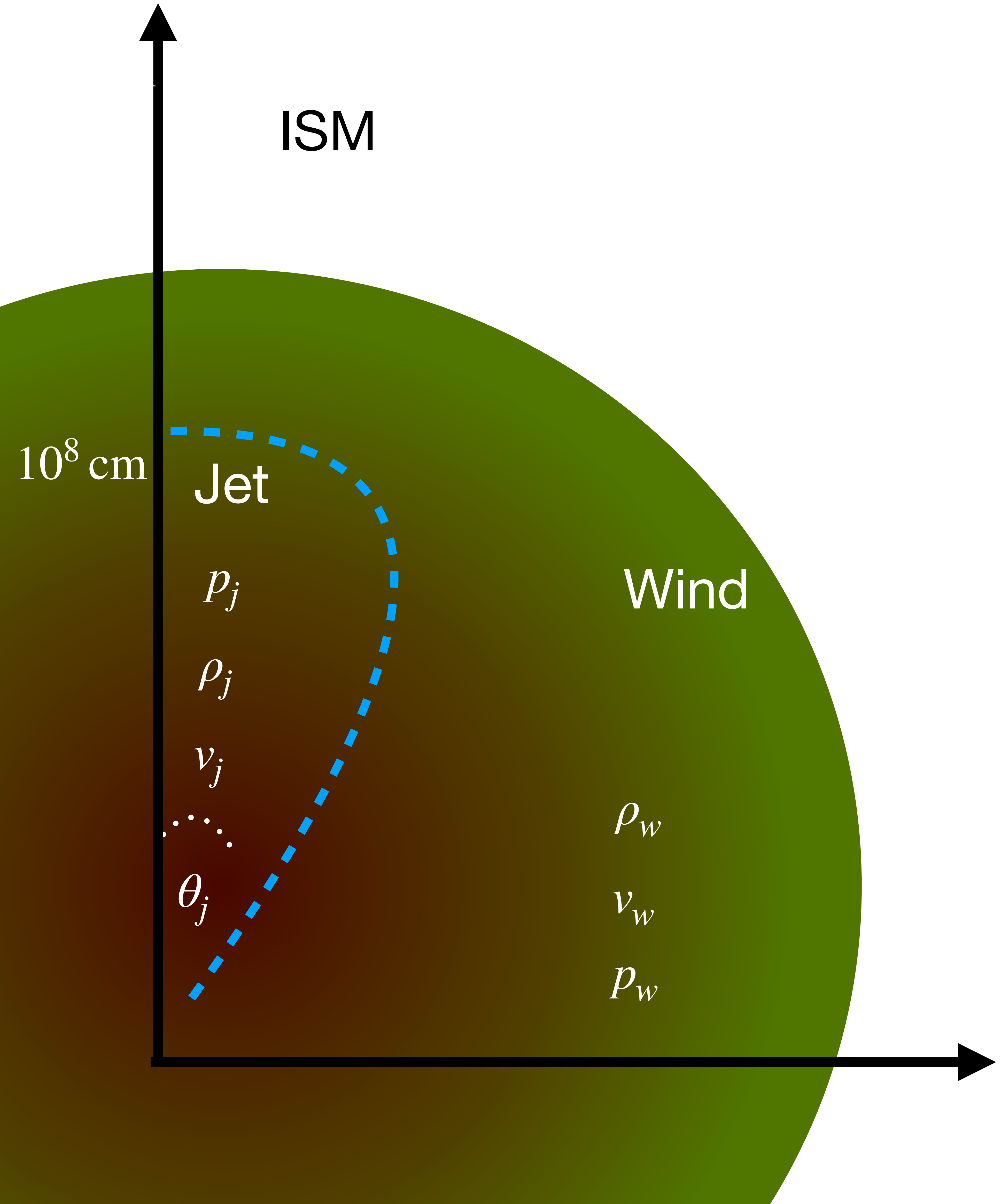
$\Gamma_j = 12$

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

$\theta_j = 15^\circ$

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

Initial conditions



$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F^i}}{\partial x^i} = 0$$

$$\mathbf{U} = \left(D, m_j, \tau\right)$$

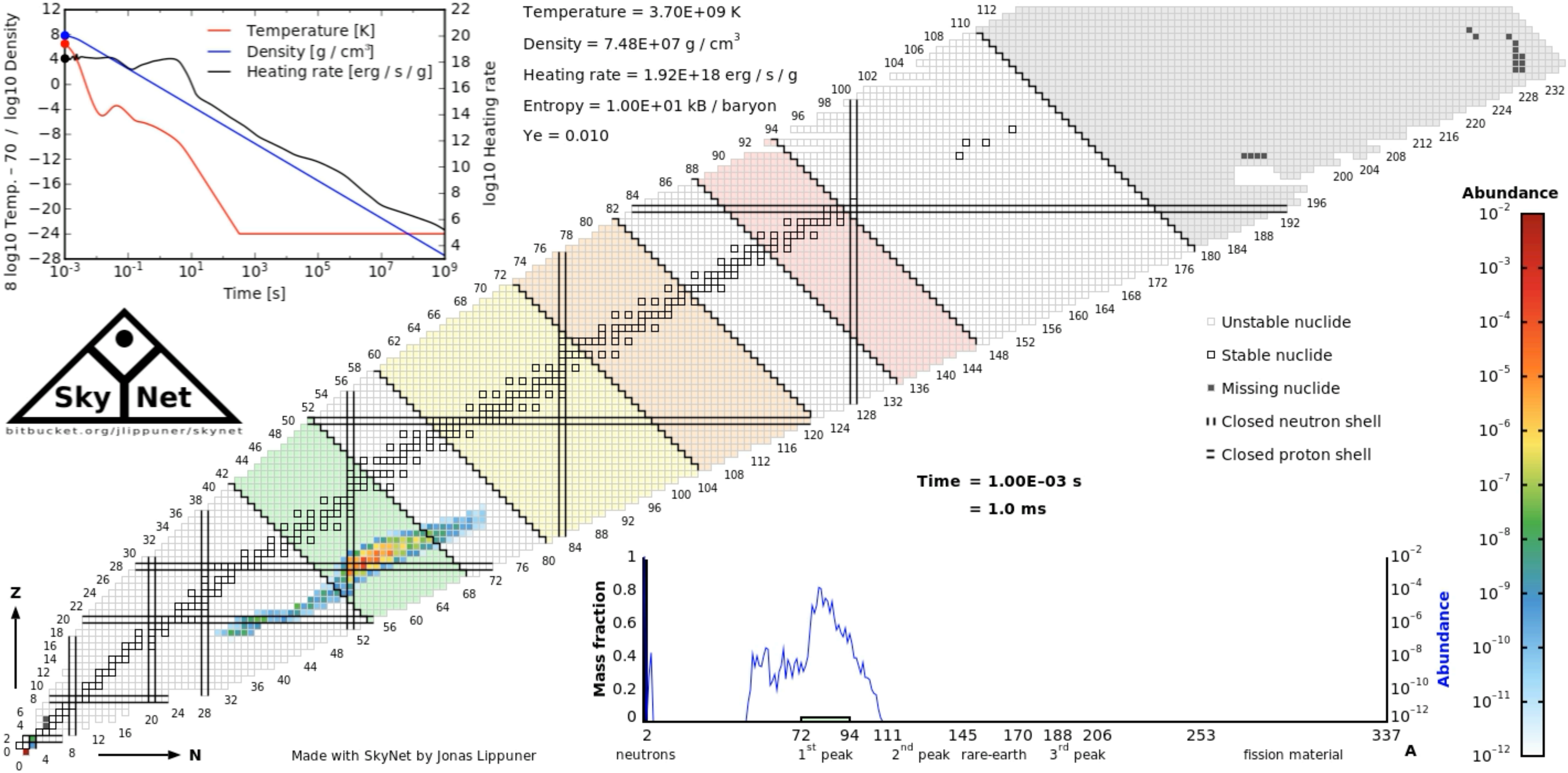
$$\mathbf{F^i} = \left(Dv^i, m_j v^i + p\delta^i_j, \tau v^i + p v^i\right)$$

$$D = \Gamma\rho$$

$$m_j = Dh\Gamma v_j$$

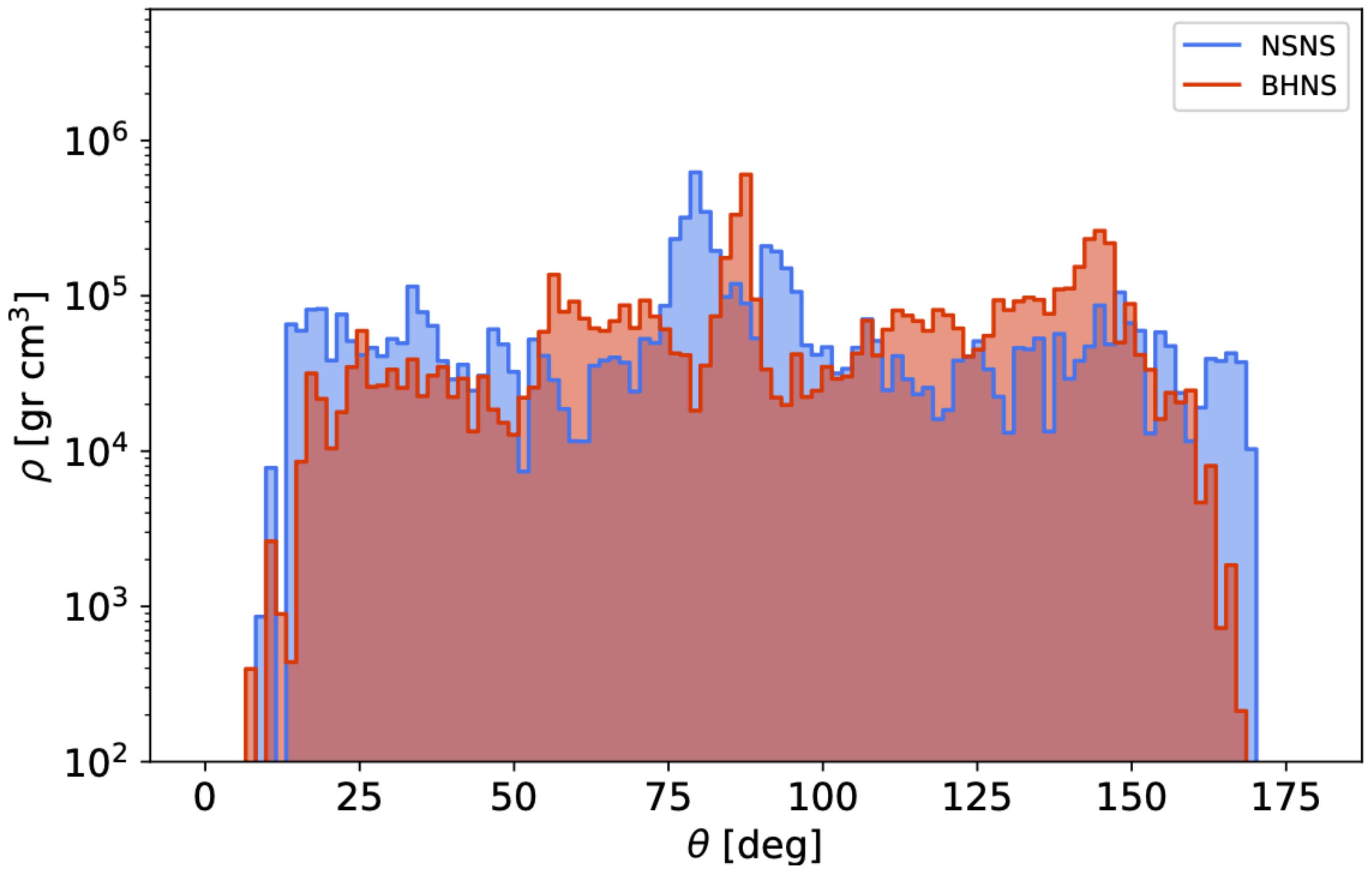
$$\tau = Dh\Gamma c^2 - p - Dc^2$$

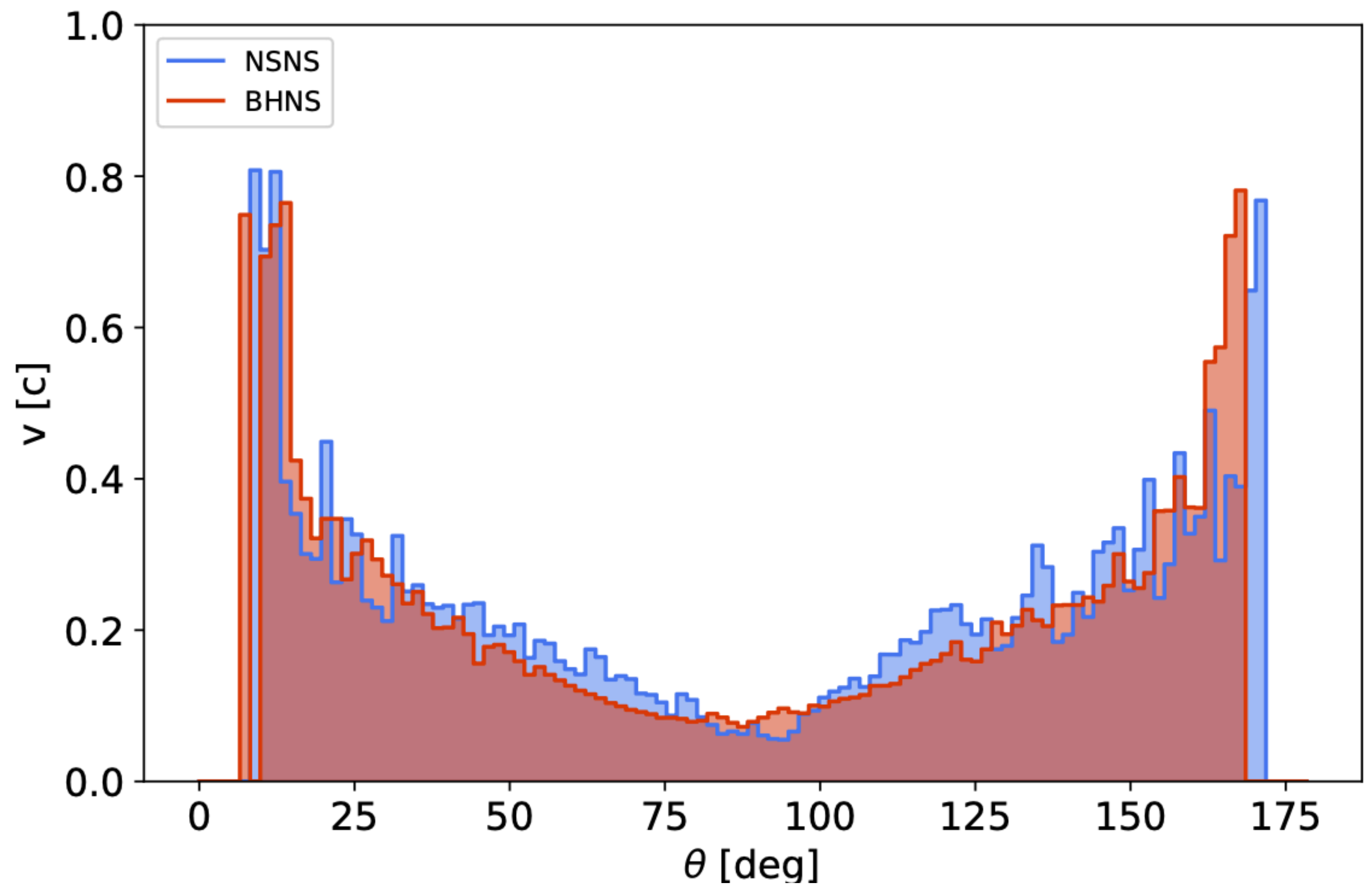
Outflow tracers processed to follow r-process and get the gas pressure

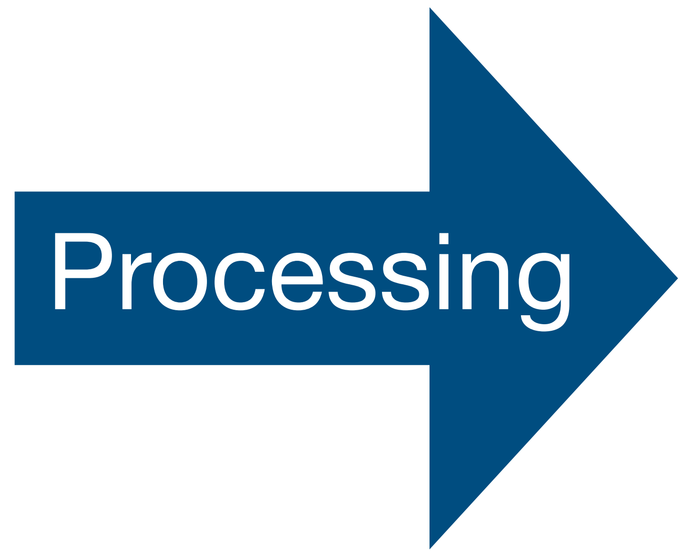


(Lippuner & Roberts 2017)

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



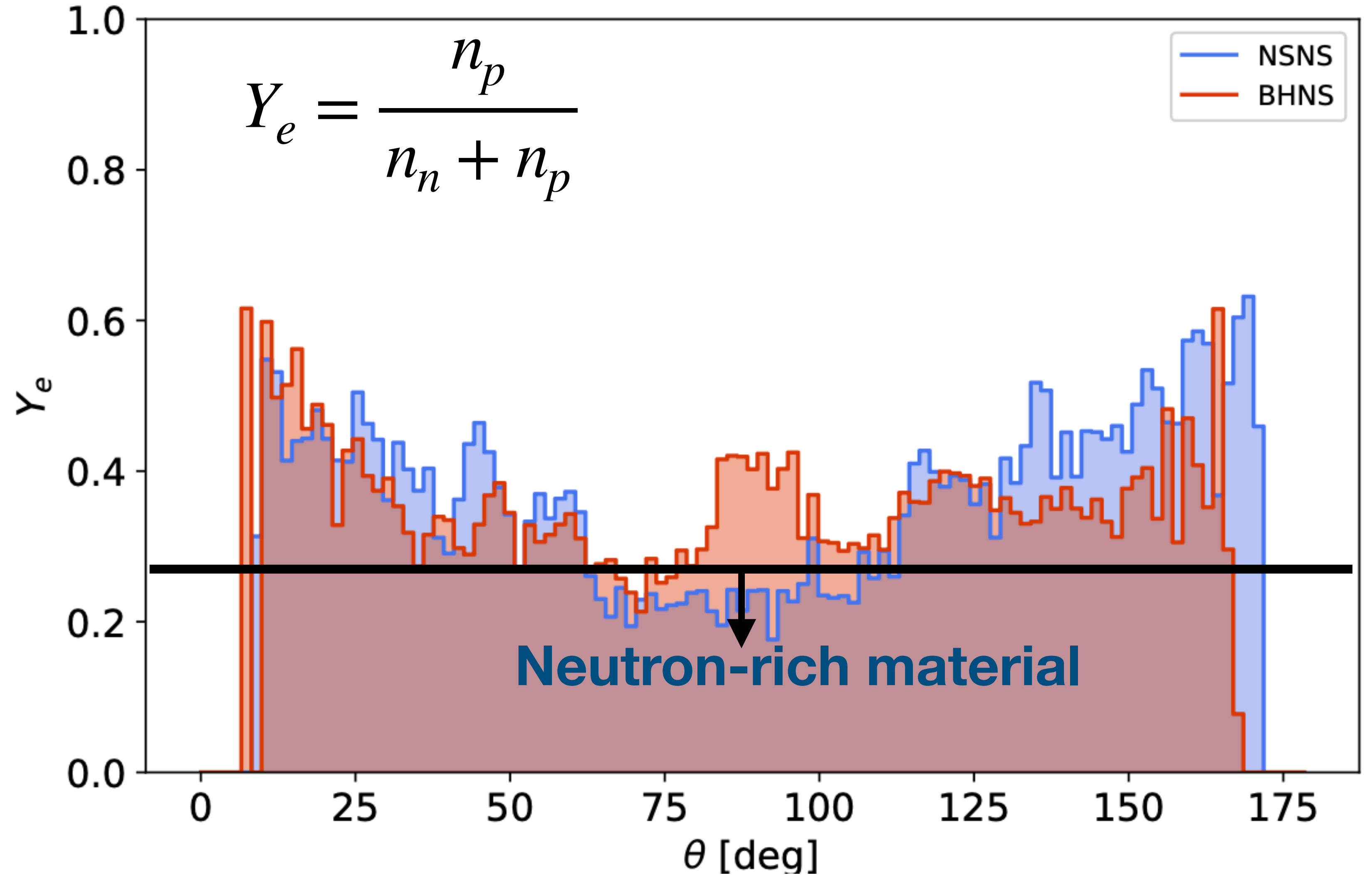


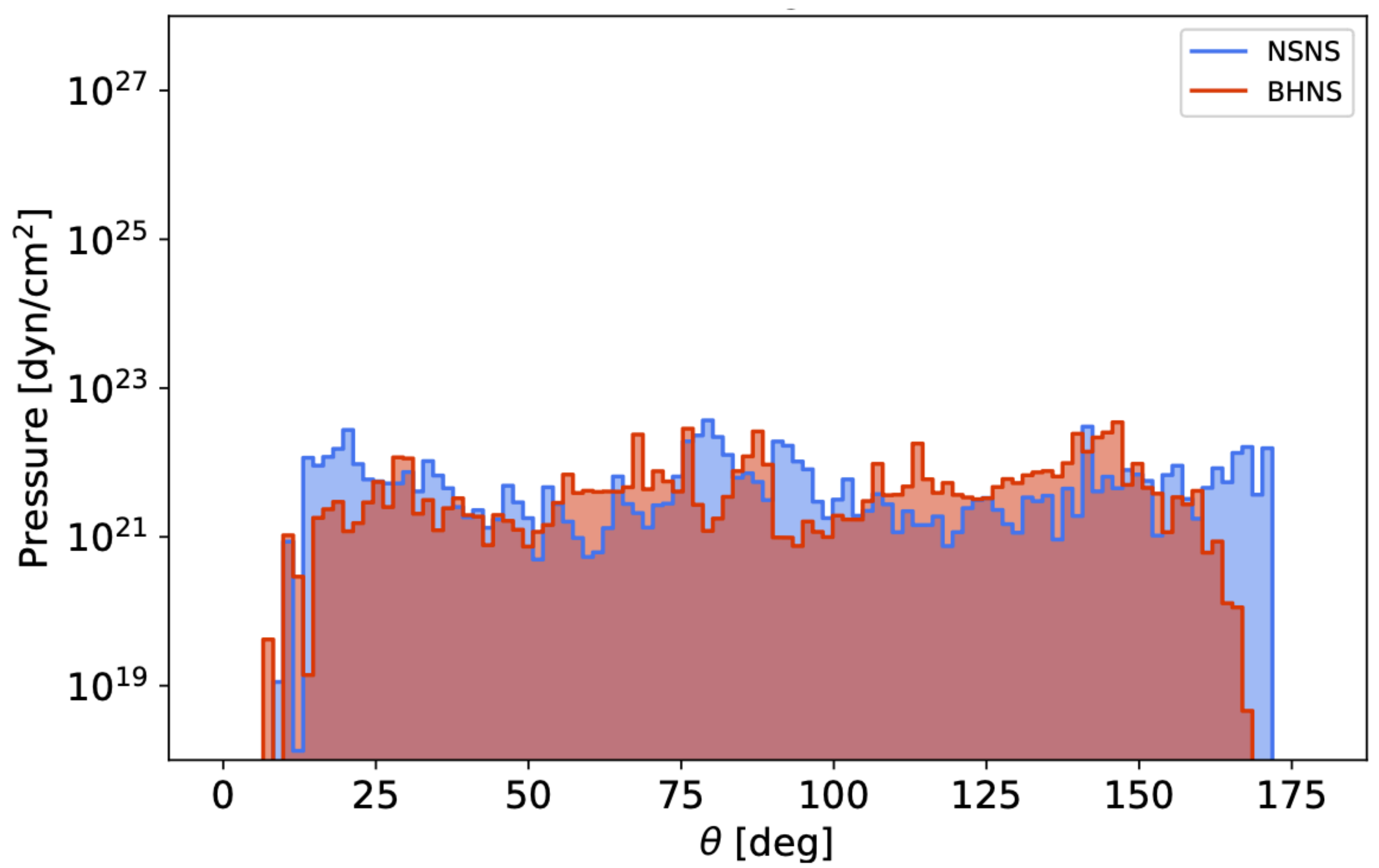


SkyNet nuclear reaction network (Lippuner & Roberts 2017)

Inversion of Helmholtz equation (Timmes & Arnet 1999)

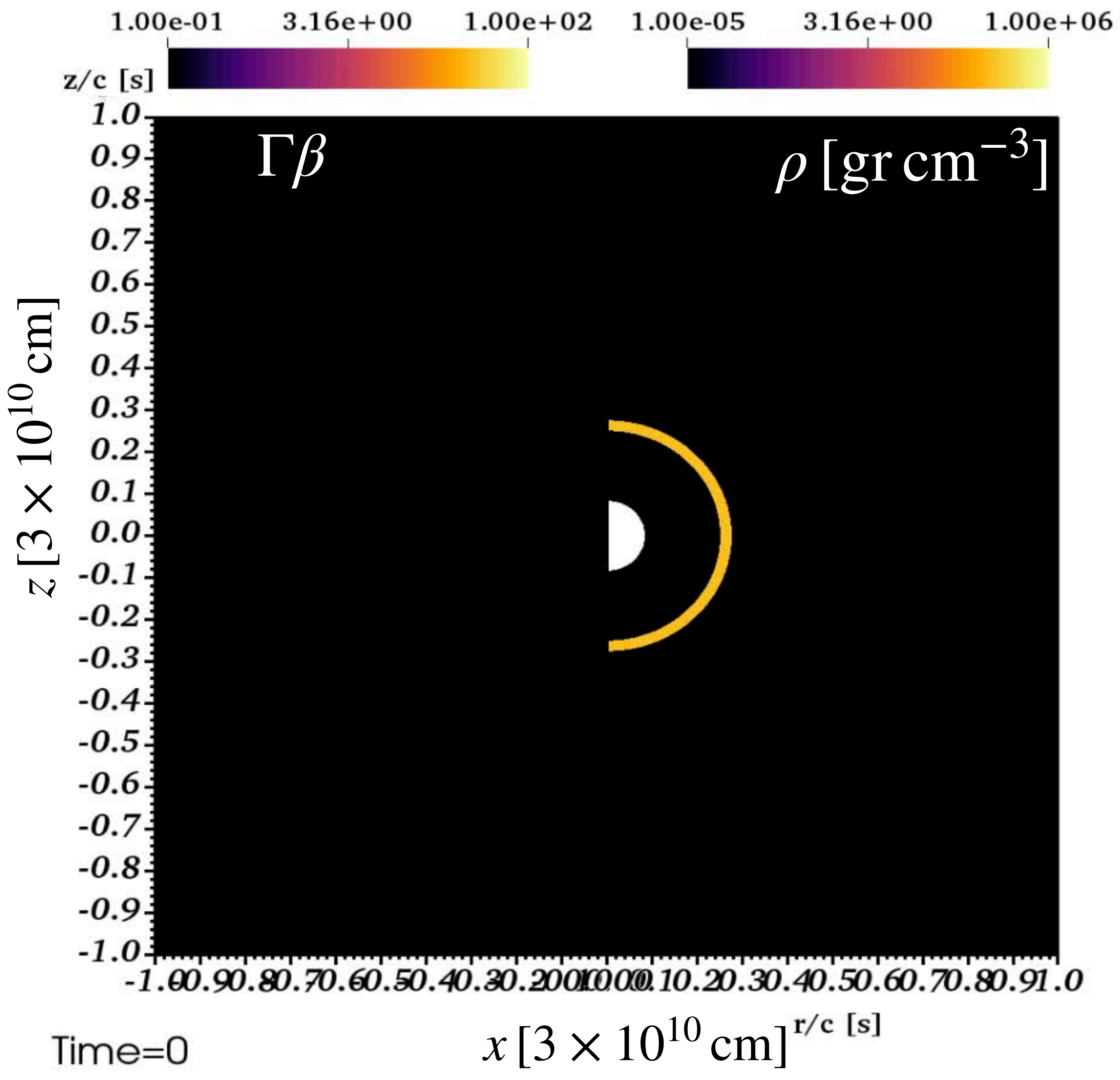
Note: Abundances of these models are discussed in Nouri et al., 2023



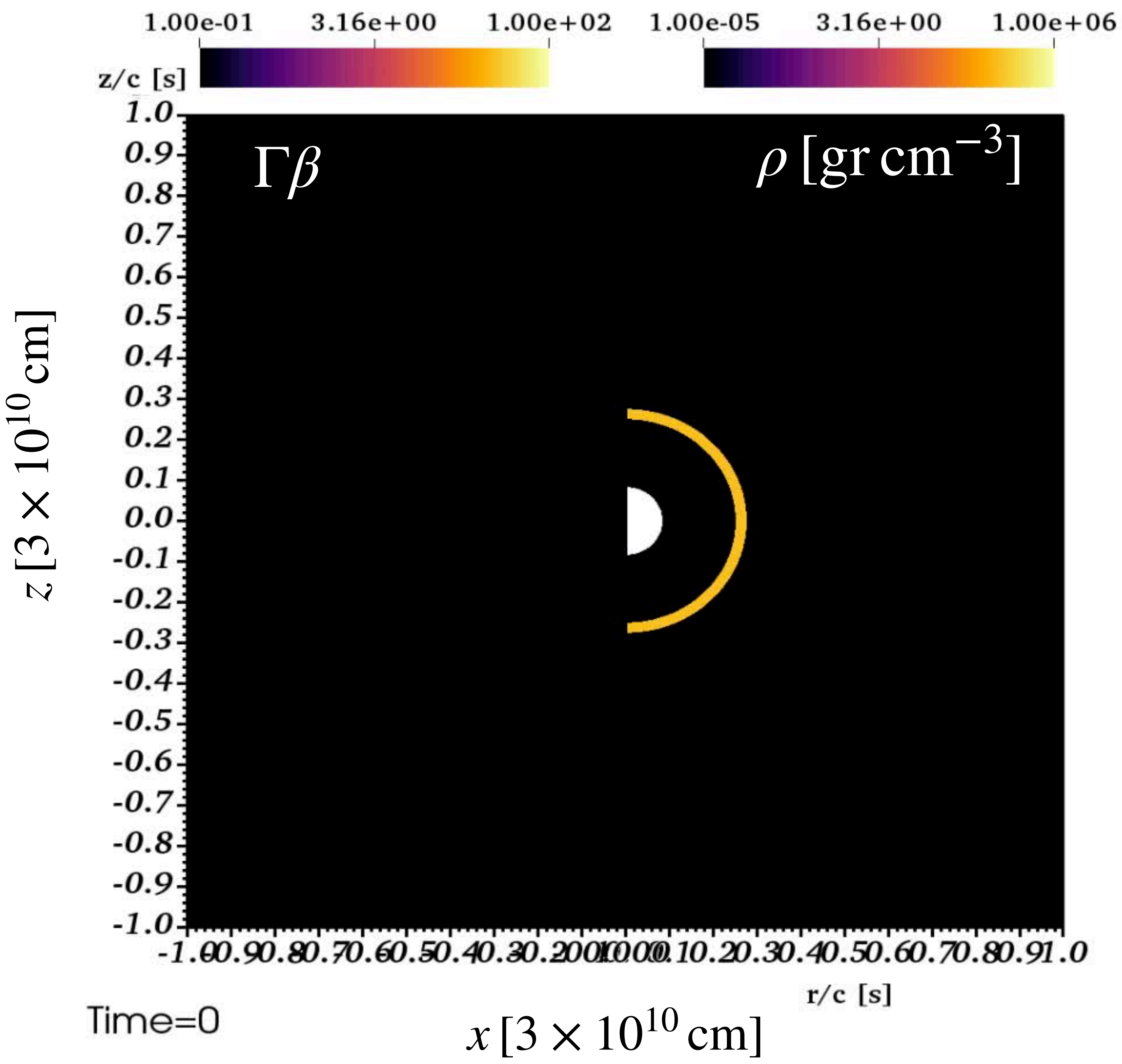


Results of jet interaction

Jet from NSNS merger

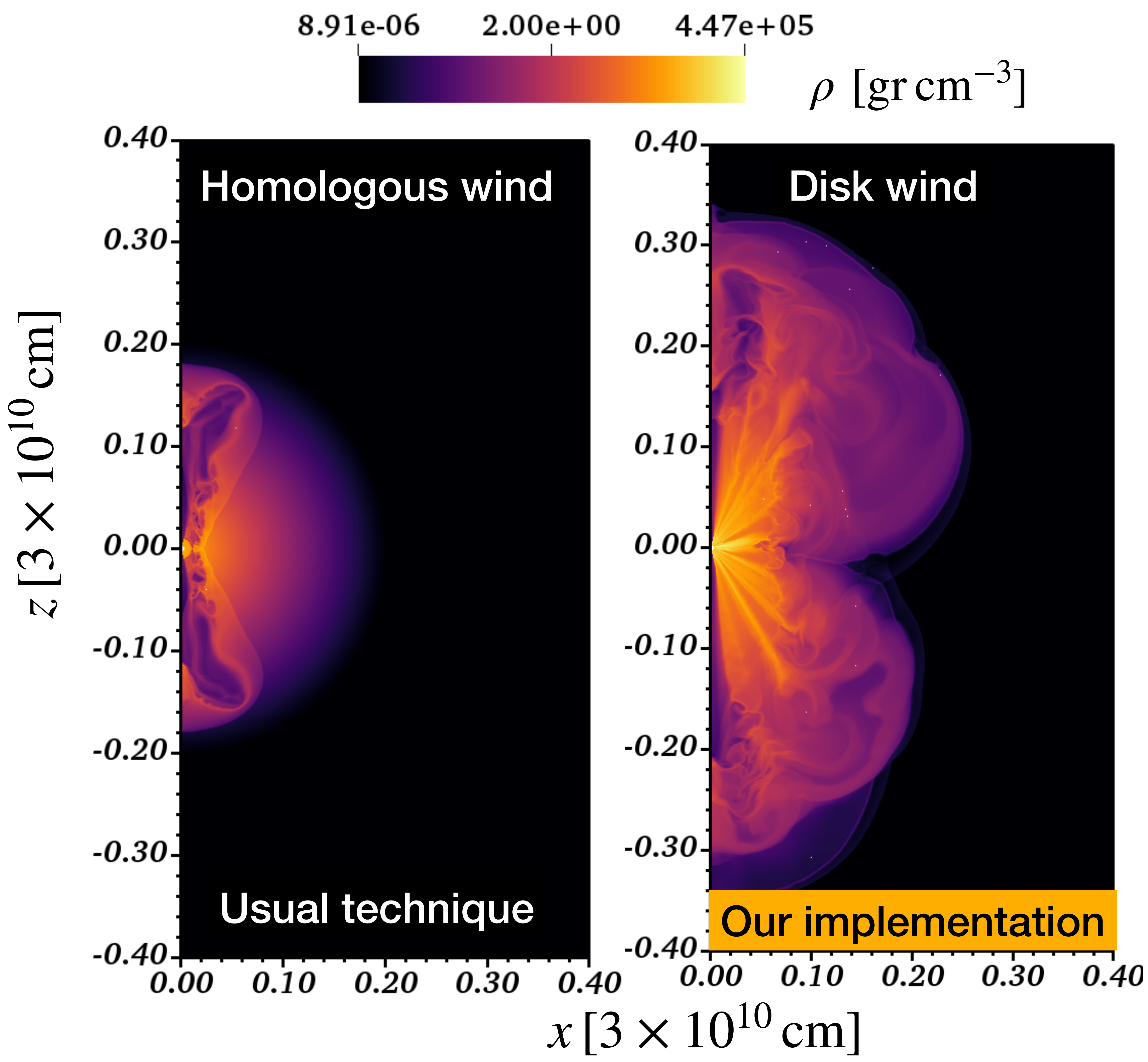


Jet from BHNS merger

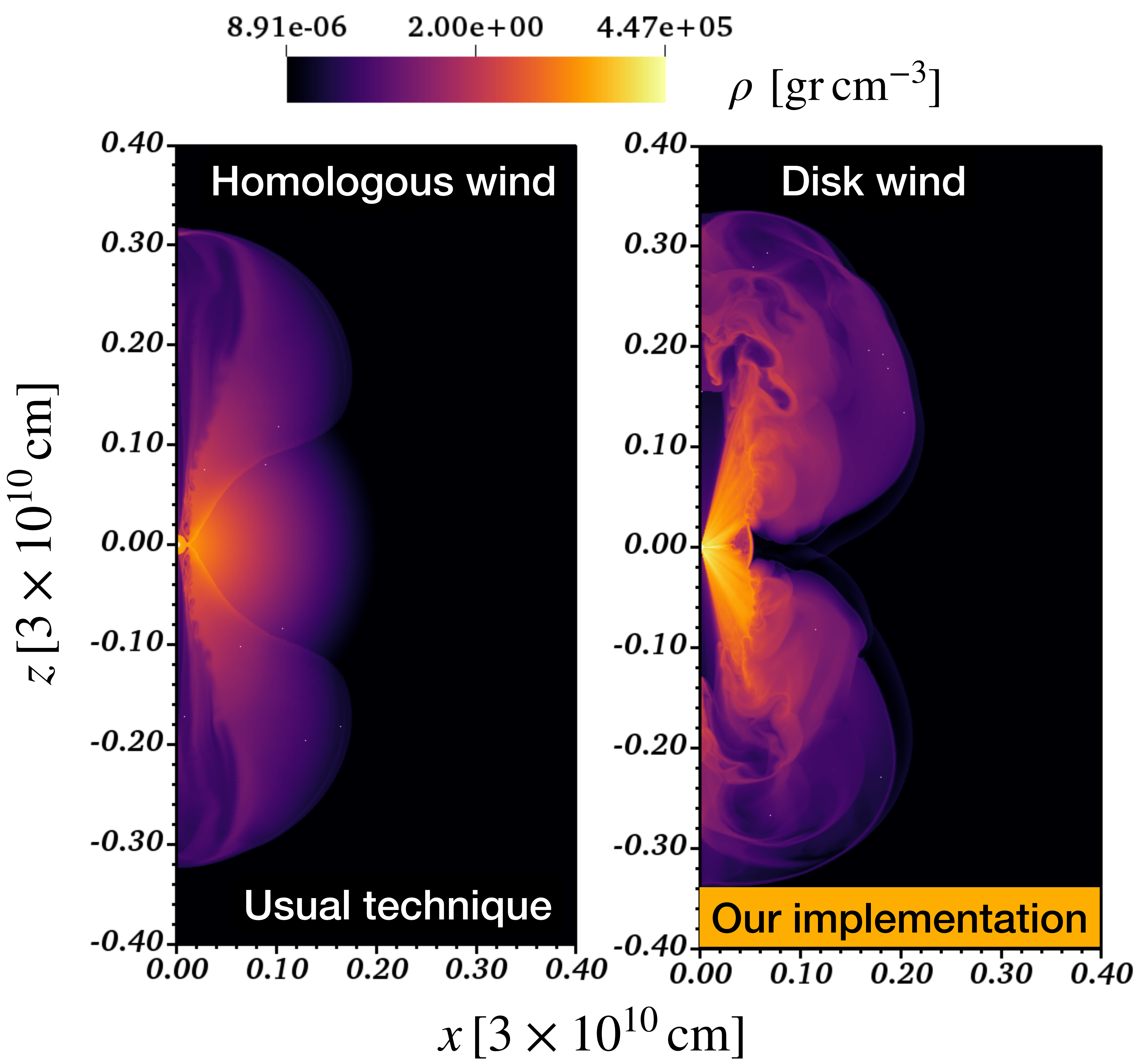


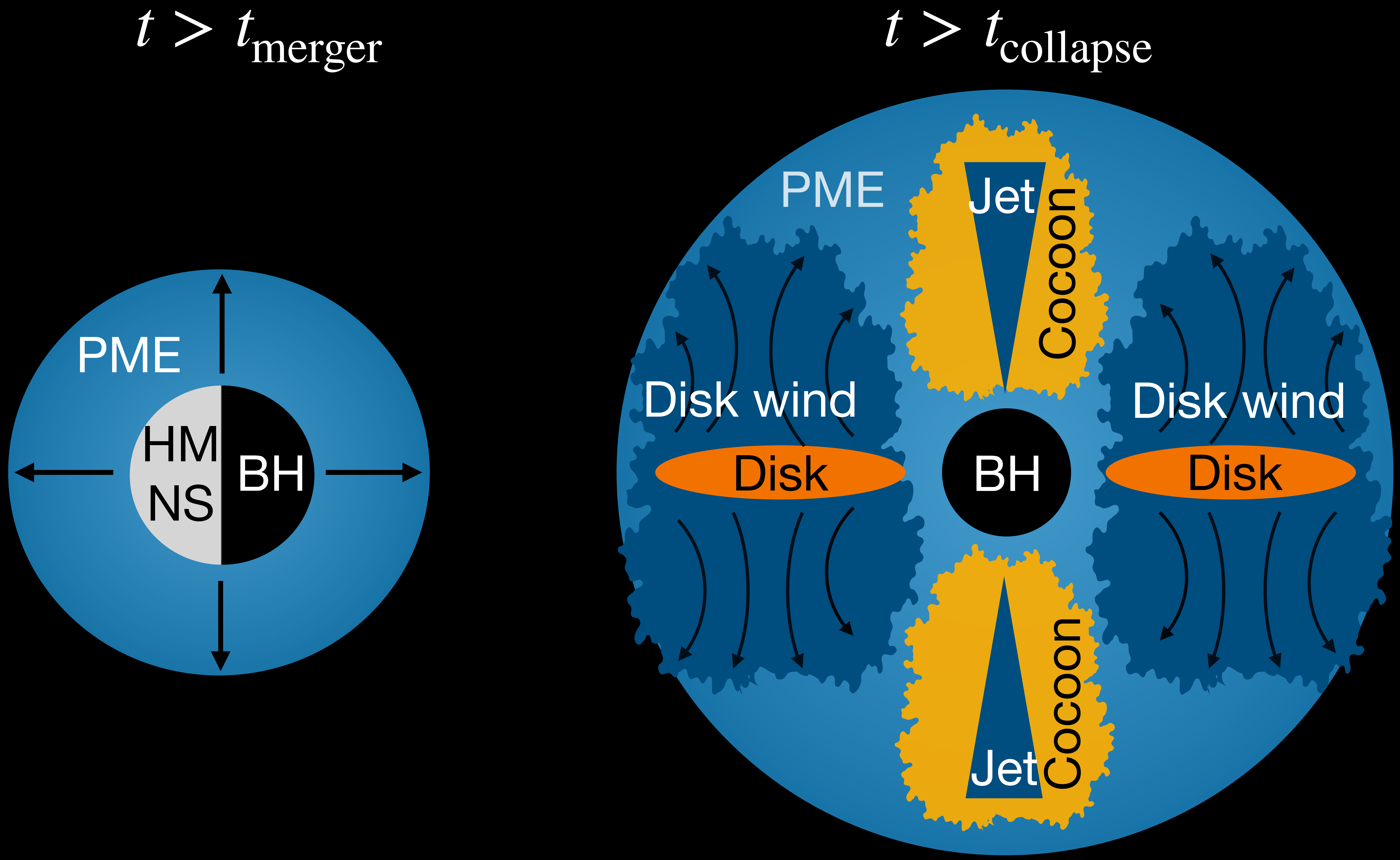
Results of jet interaction

Jet from NSNS merger

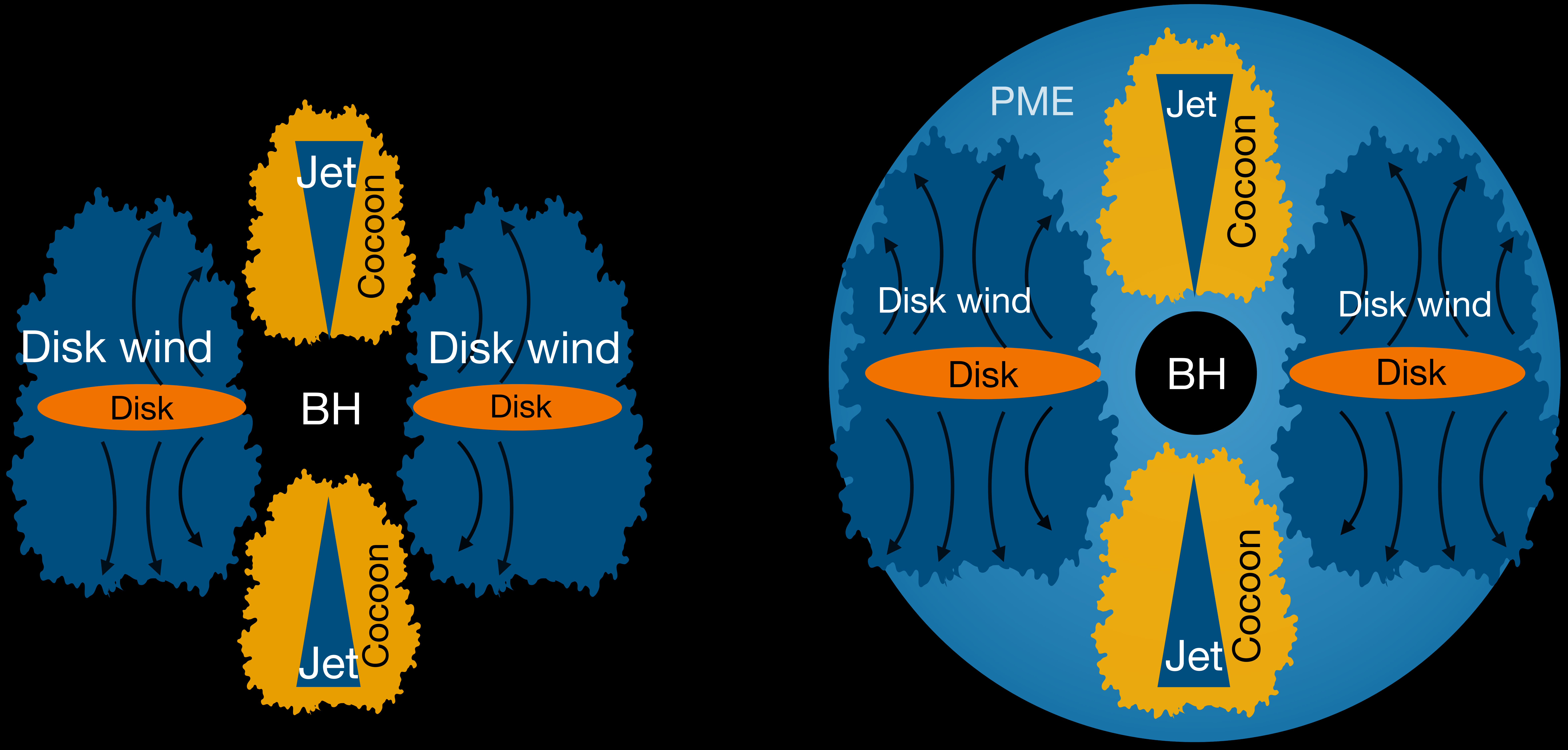


Jet from BHNS merger

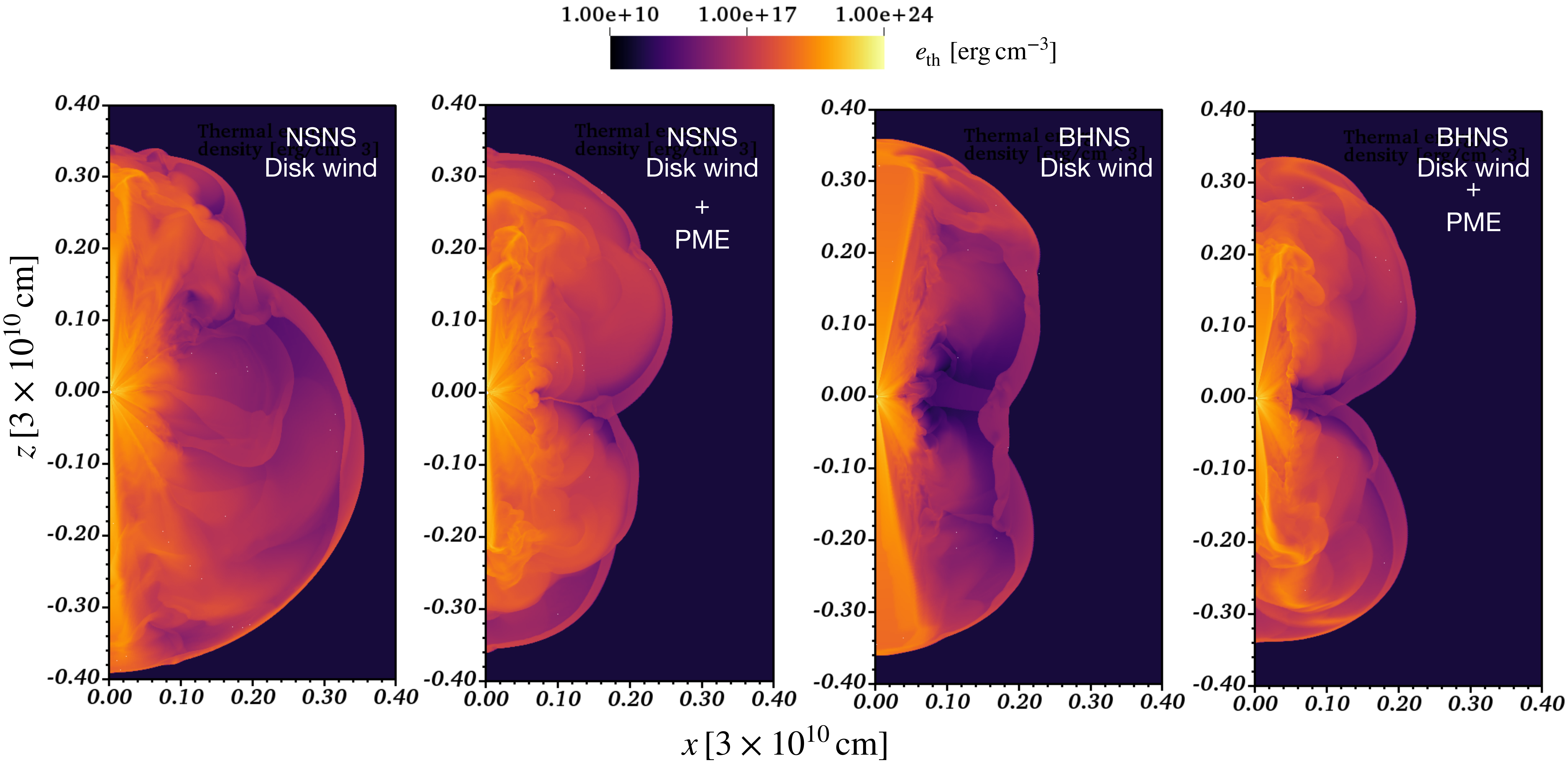



t > t_merger
PME
HMNS
BH
t > t_collapse
PME
Jet
Cocoon
Disk wind
Disk
BH
Disk wind
Disk
Cocoon
Jet

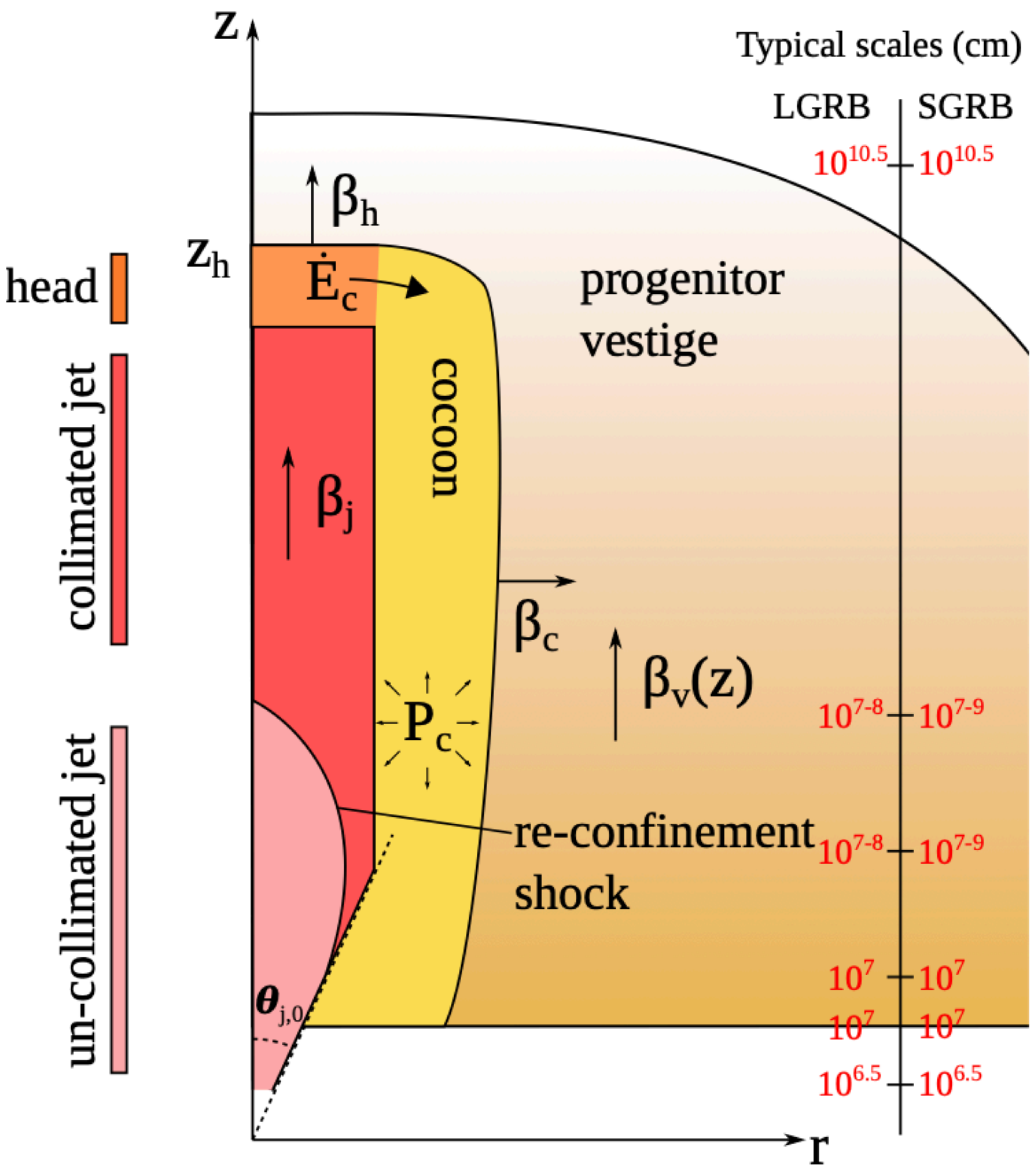
$t > t_{\rm collapse}$



Results of jet interaction

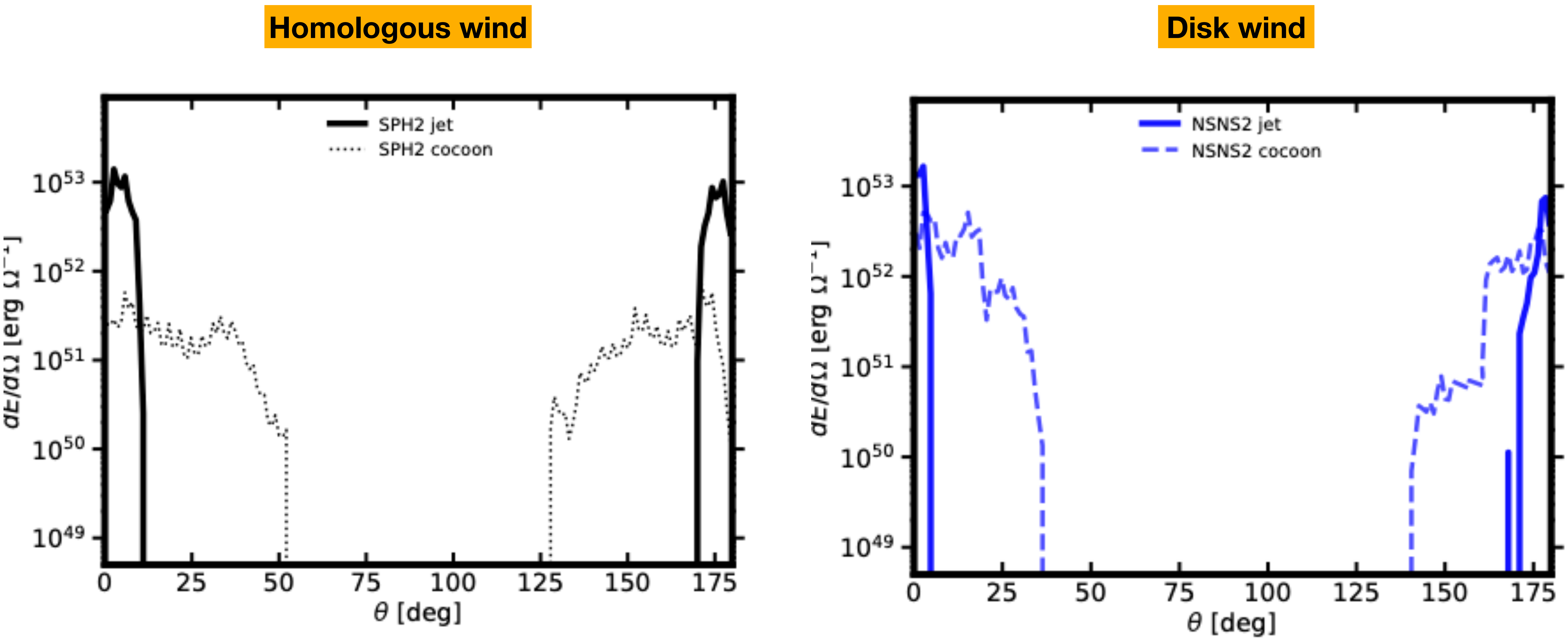


Jet anatomy: each component is distinguished by the velocity



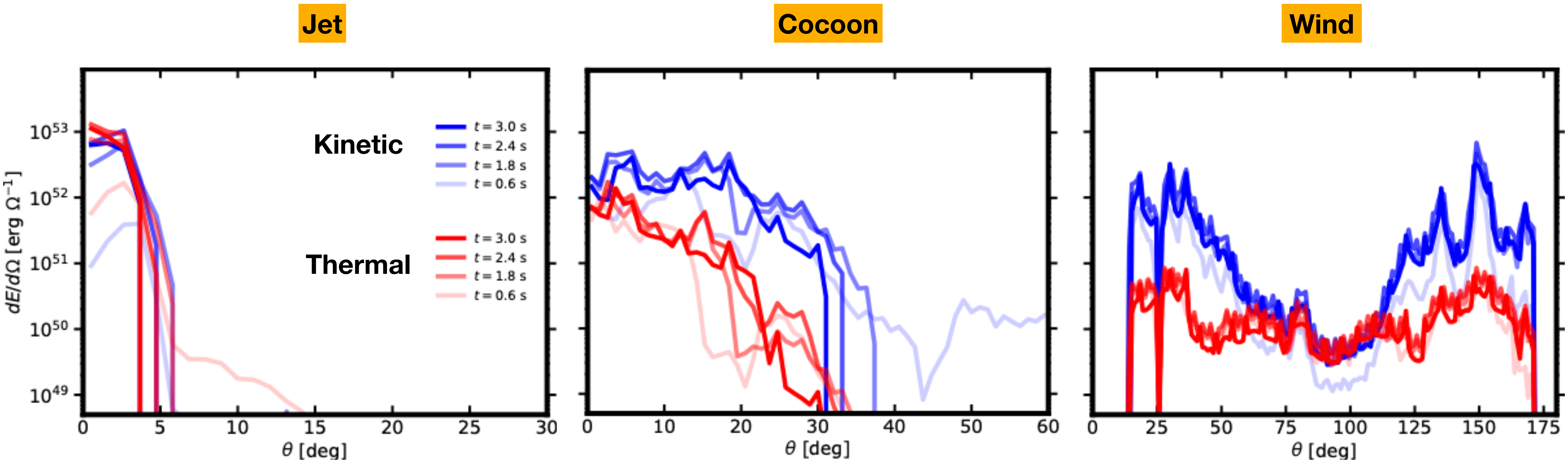
Credits: Salafia & Ghirlanda 2022

Disk wind changes the jet collimation and cocoon lateral expansion

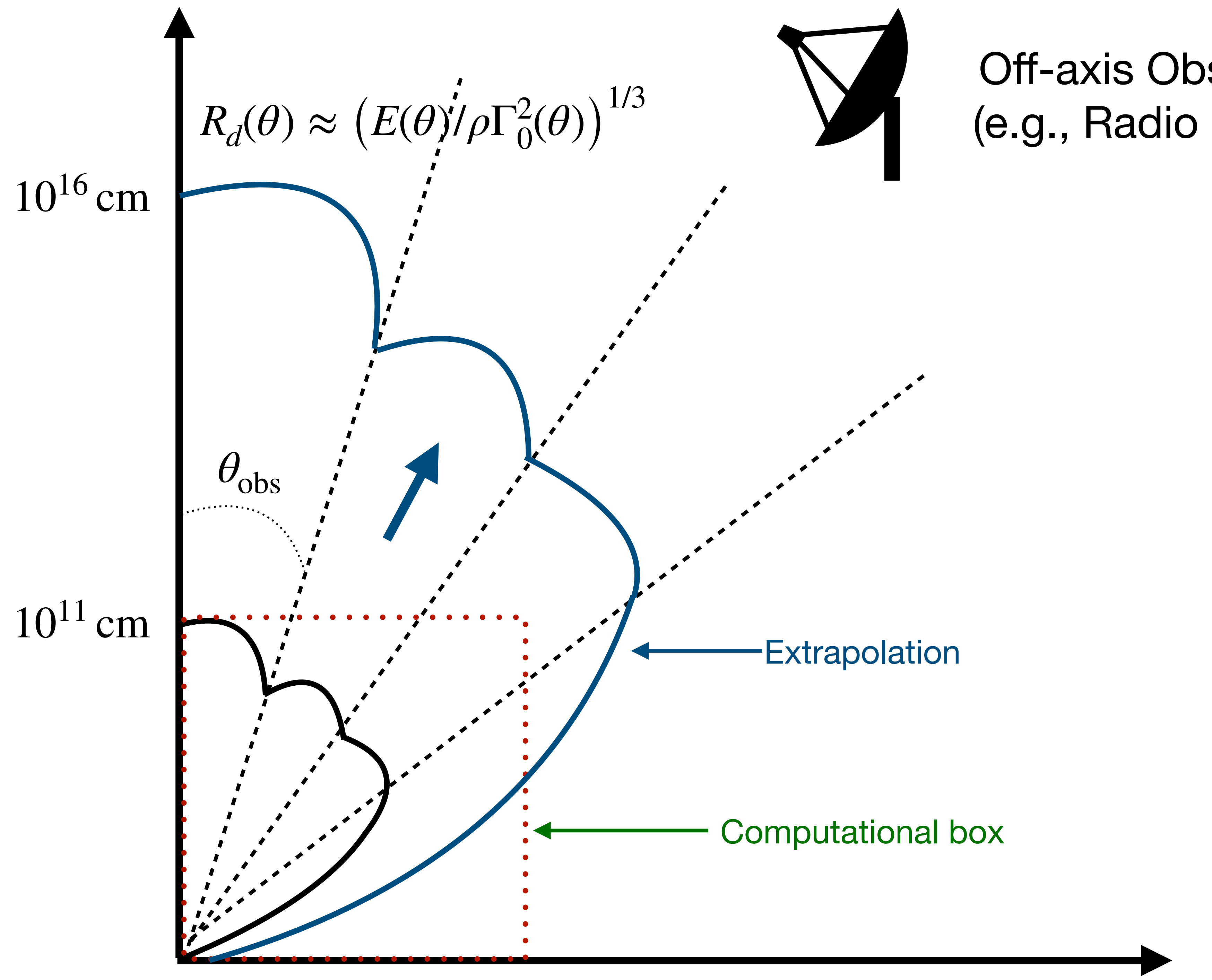


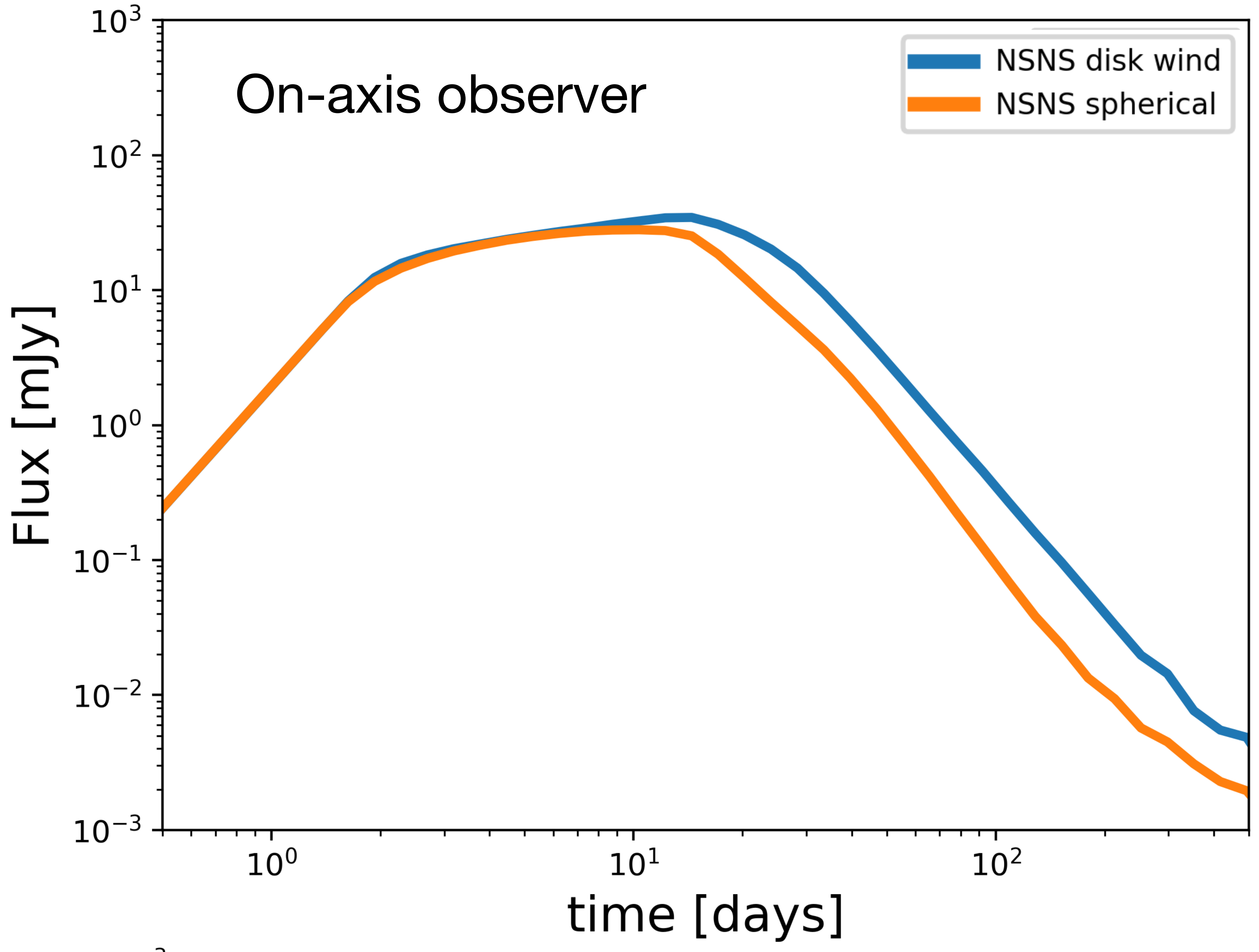
$$E = \int \left(\Gamma(\Gamma - 1)\rho c^2 + p(4\Gamma^2 - 1) \right) dV$$

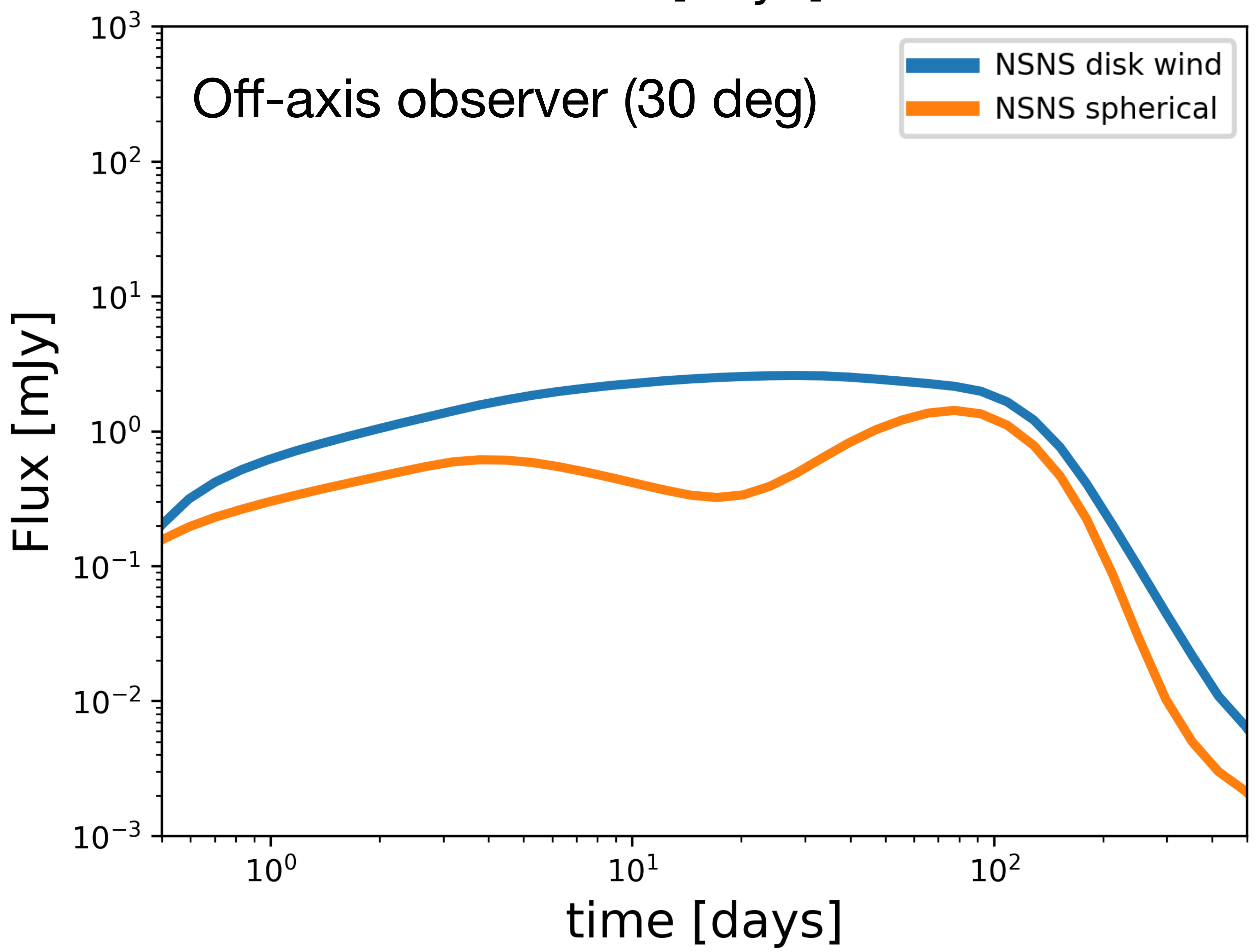
Energy evolution (jet from NSNS)



$$E = \int \left(\Gamma(\Gamma - 1)\rho c^2 + p(4\Gamma^2 - 1) \right) dV$$





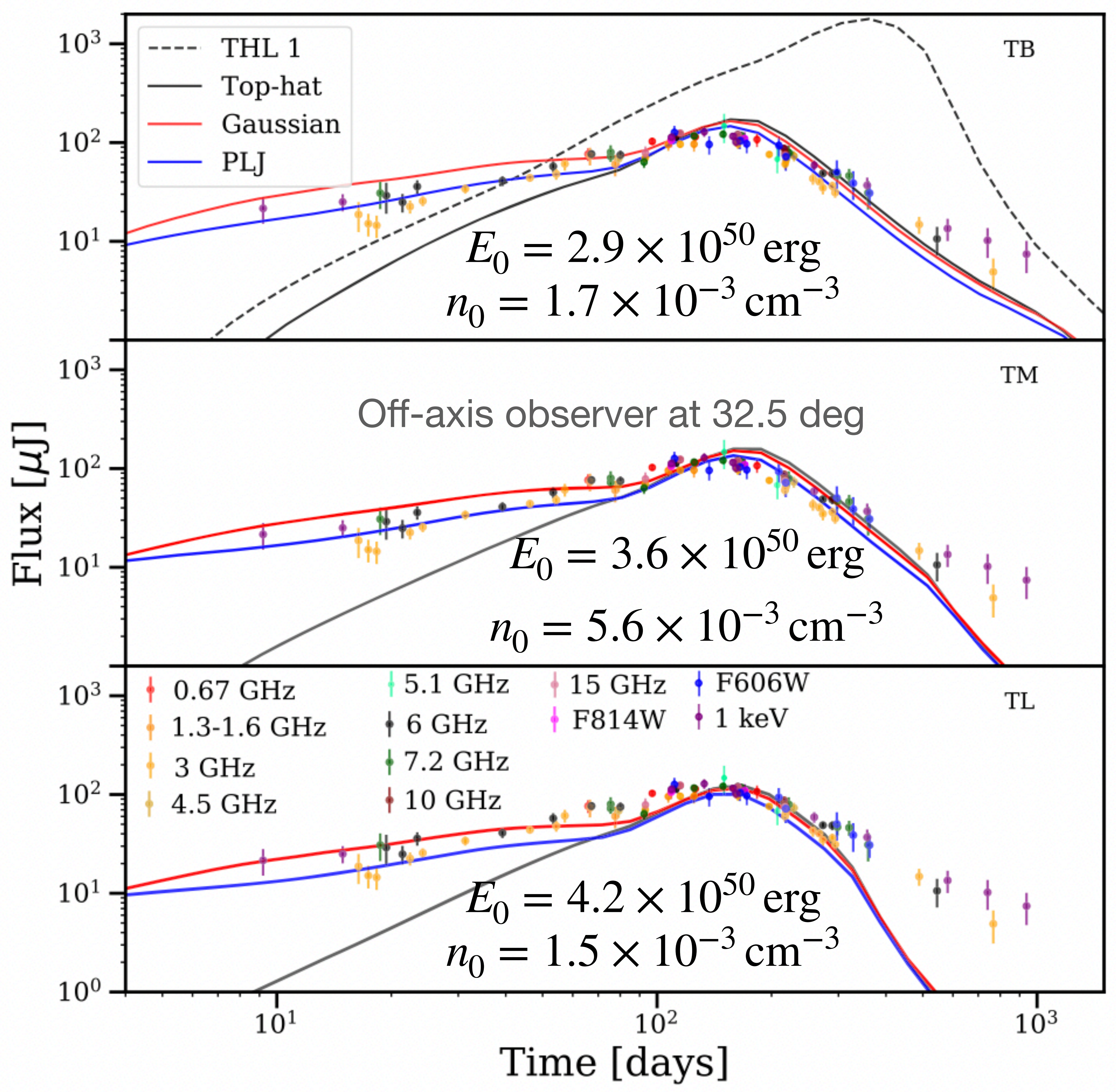


We follow the standard afterglow estimation
(Sari, Piran & Narayan 1990; Granot & Sari 2002)

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

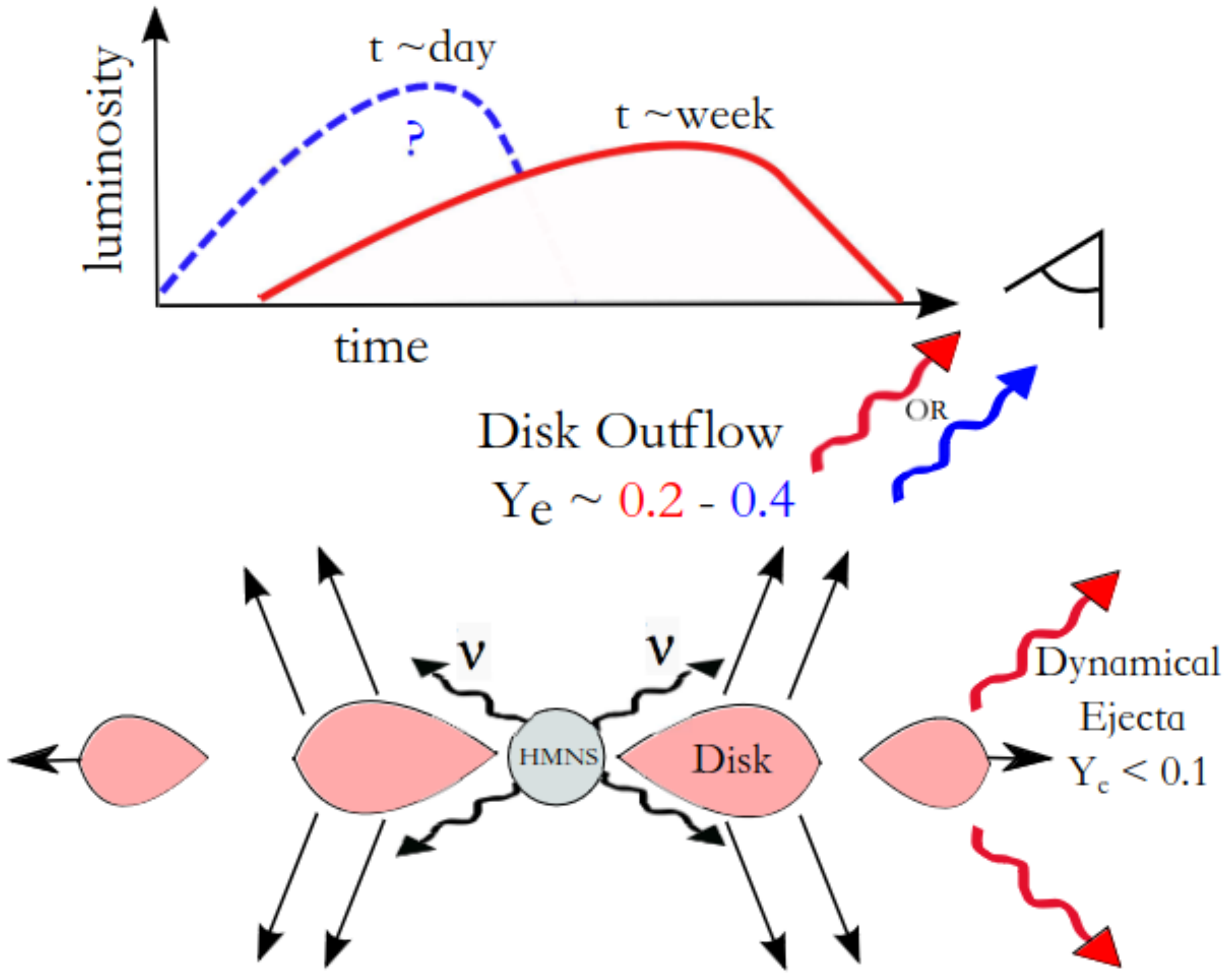
Example

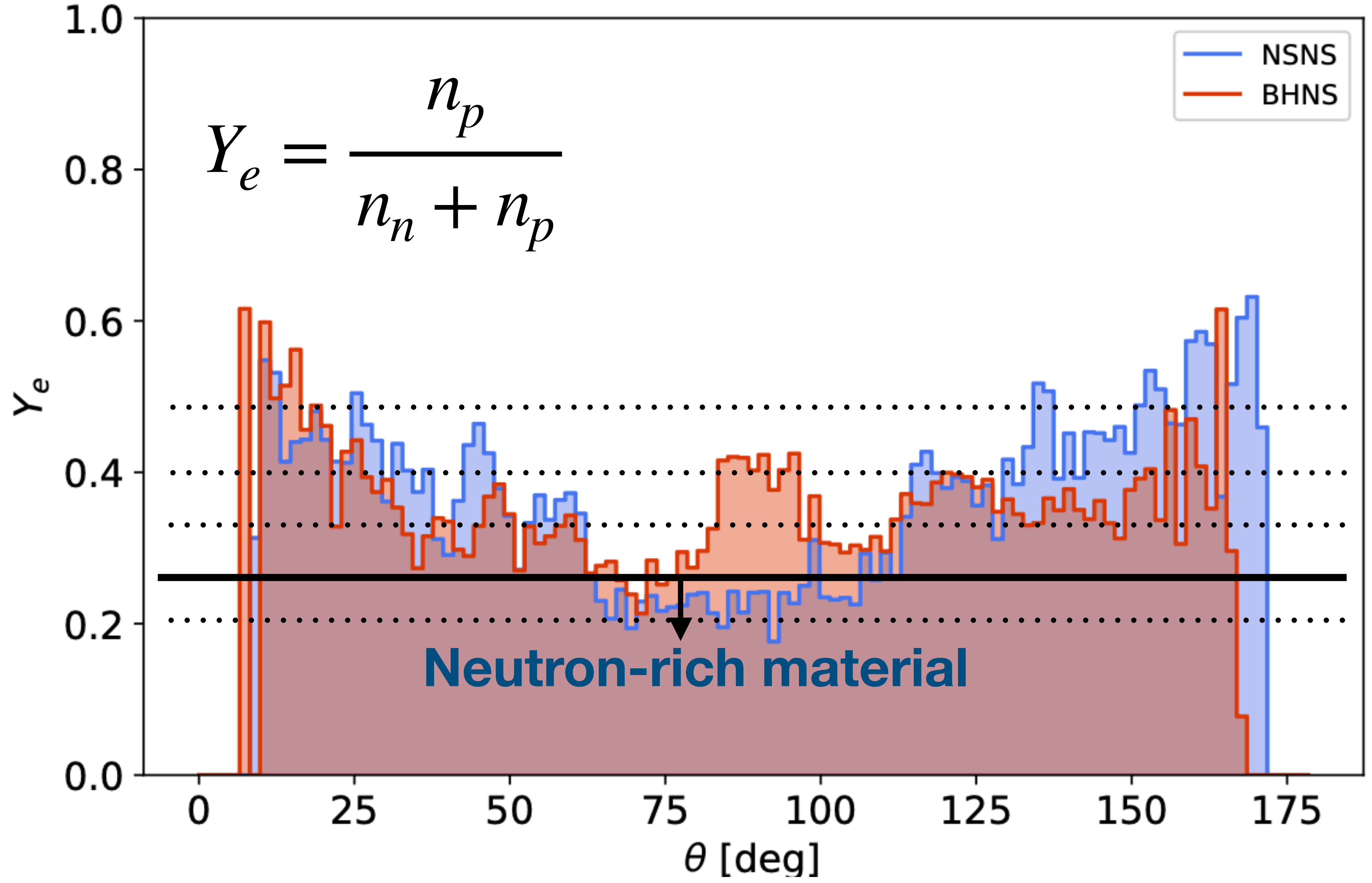
GRB 170817 A



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

Future distribution of the kilonova

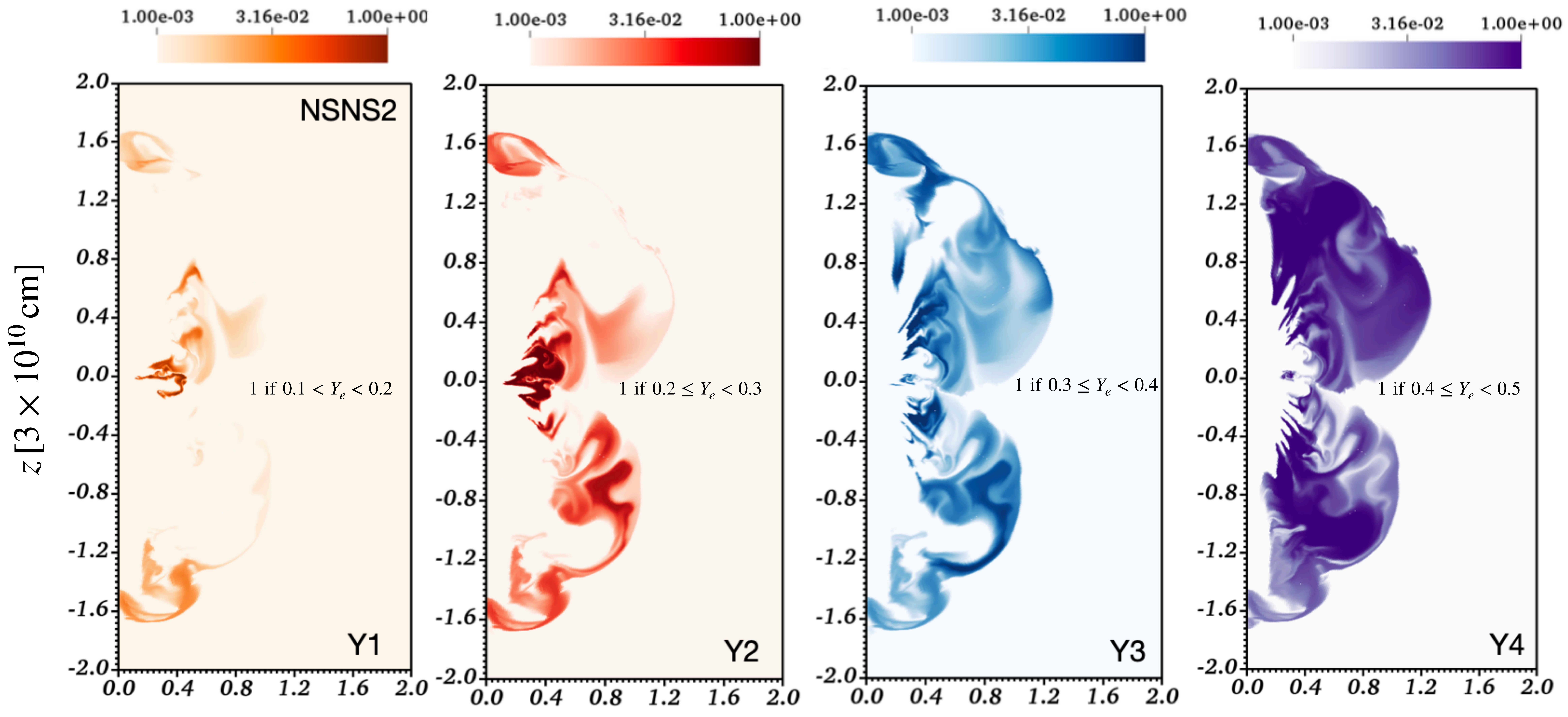




$$Y_e = \frac{n_p}{n_n + n_p}$$

$$(Y1,Y2,Y3,Y4) = \begin{cases} (1,0,0,0) & \text{if} \quad 0.1 < Y_e \leq 0.2, \\ (0,1,0,0) & \text{if} \quad 0.2 < Y_e \leq 0.3, \\ (0,0,1,0) & \text{if} \quad 0.3 < Y_e \leq 0.4, \\ (0,0,0,1) & \text{if} \quad 0.4 < Y_e \leq 0.5. \end{cases}$$

Future distribution of the kilonova

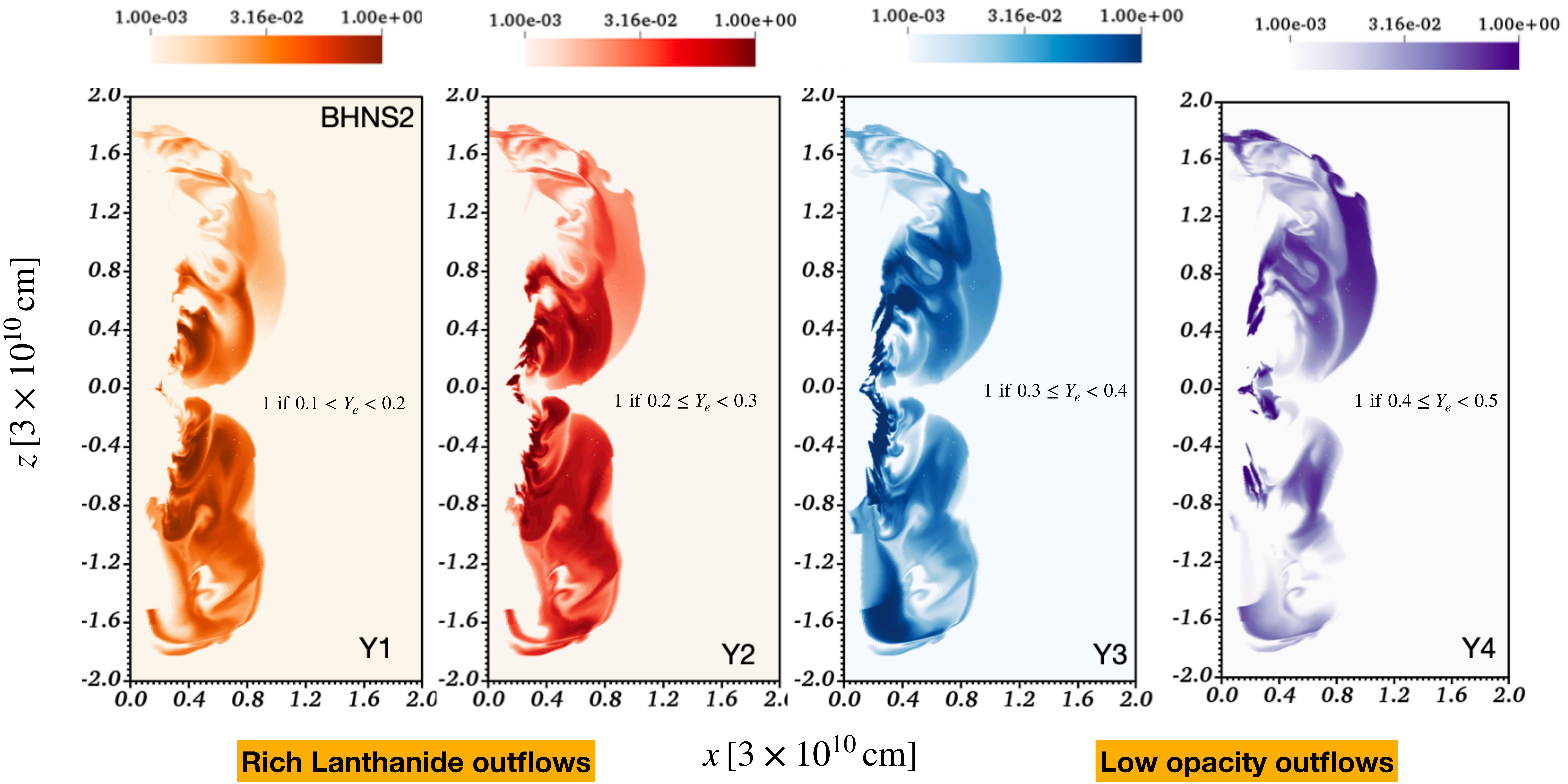


Rich Lanthanide outflows

$x\,[3\times10^{10}\,\mathrm{cm}]$

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 homologous wind 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.

Image credits: chandra.harvard.edu

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)

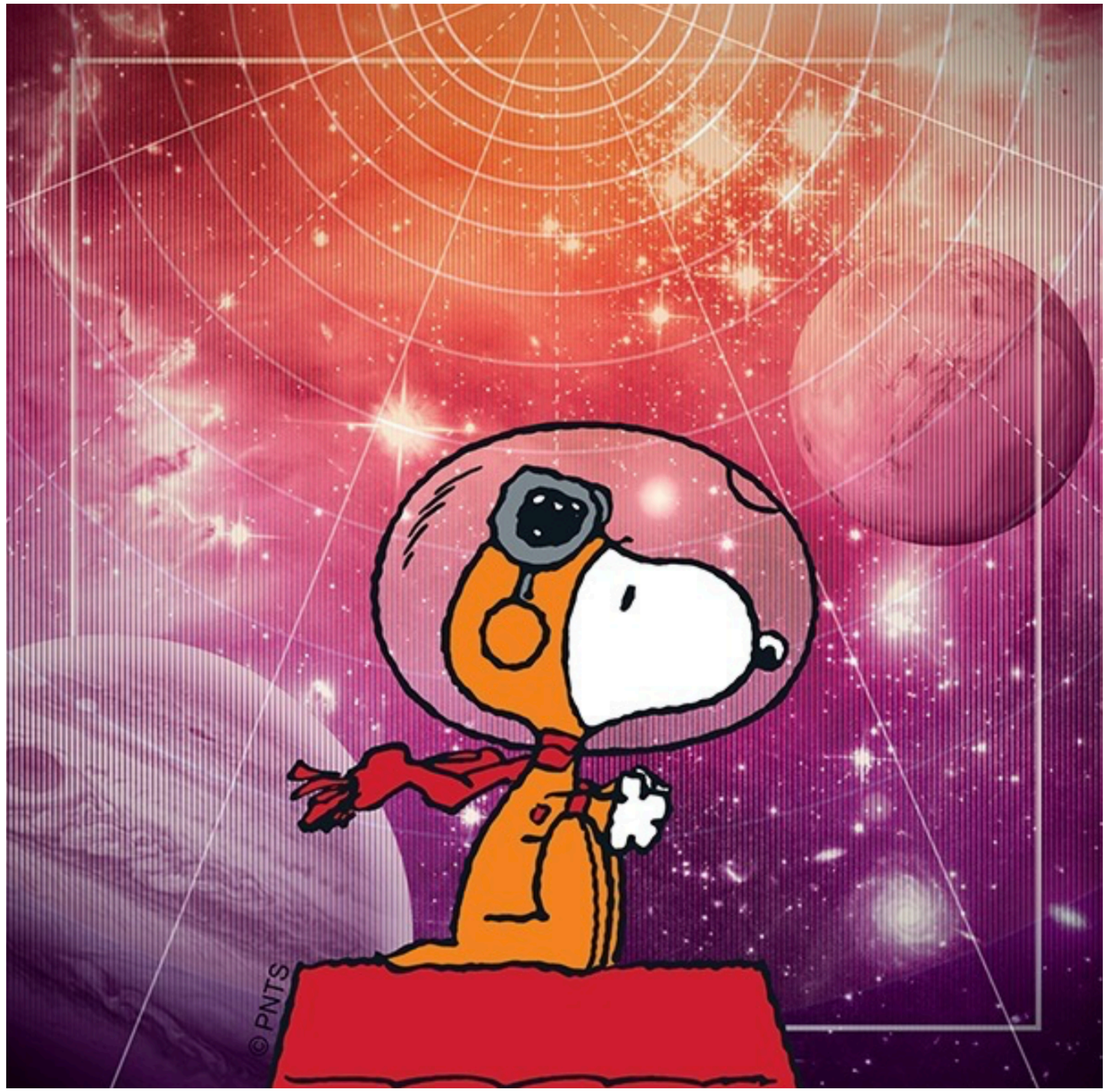
LOC

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

Děkuji - Dziękuję - Thank you! - ¡Gracias!



Gerardo Urrutia
gurrutia@cft.edu.pl

cft

PL GRID

NATIONAL SCIENCE CENTRE
POLAND