# How do tidal disruption events shine in optical and radio?

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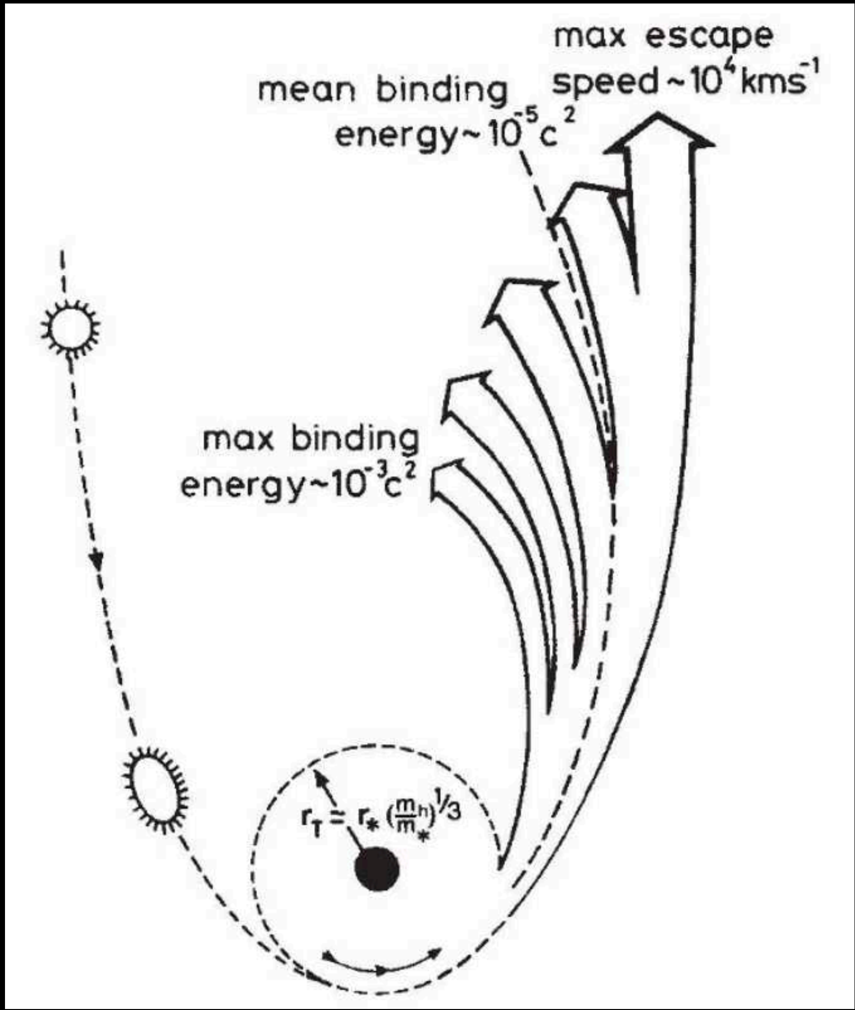
6 Jun 2025 @ 2nd Phantom European workshop

# What is tidal disruption events?

[Rees 1988]

## A free way to murder stars

- Stars approach supermassive black holes
- Tidal force/ diverging geodesics
- Tidal radius $r_t$
- Disrupted into a stream
- Fallback to form accretion disk and launch outflows



# Observations

## Yes but no

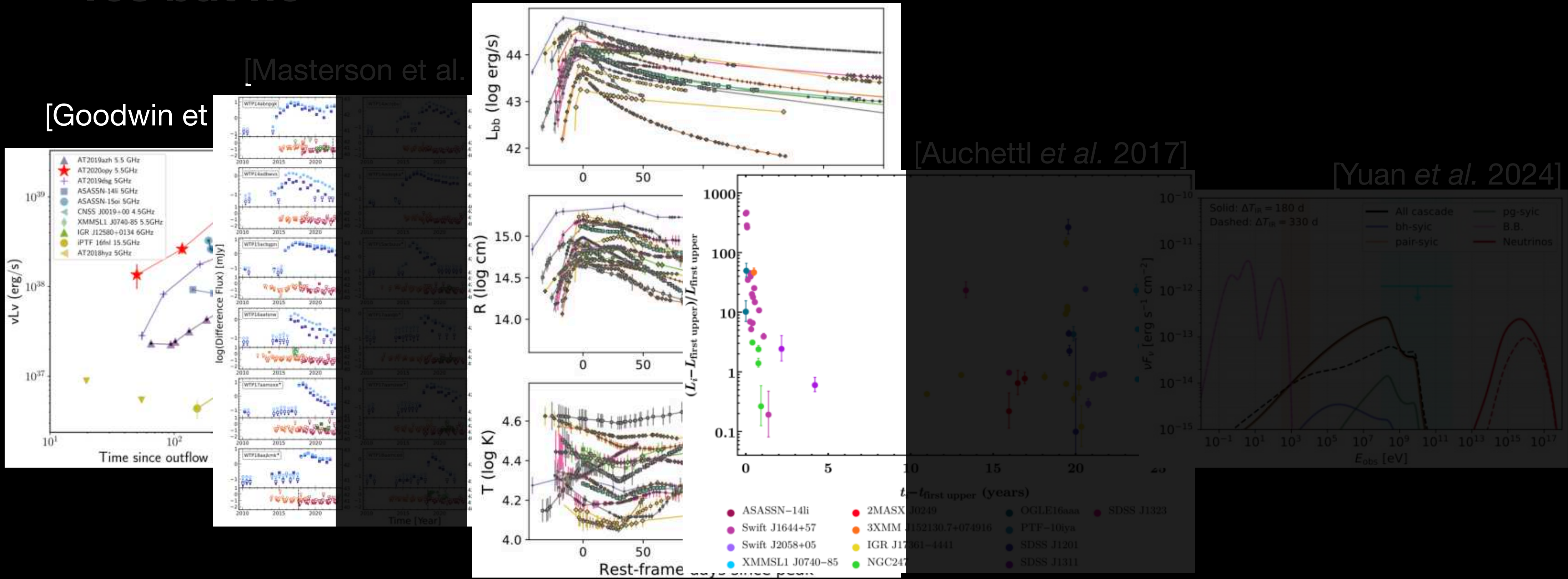
[van Velzen *et al.* 2021]

[Masterson et al.

[Goodwin et

[Auchettl *et al.* 2017]

[Yuan *et al.* 2024]




Radio IR Optical X-ray $\gamma$-ray? PeV neutrinos

# Solutions…Really?

- Tidal compression / nozzle shock [Ryu *et al.* 2023]
- Self-collision [Lu & Bonnerot 2020]
- Reprocessing layer [Loeb & Ulmer 1997] / [Metzgar & Stone 2016]
- Cooling envelope [Metzgar 2022] / [Sarin & Metzgar 2024]
- Stream-disk interaction [Steinberg 2024]

# Hydrodynamics simulations
## Tidal disruption events

- Phantom - General relativistic smoothed particle hydordynamics
- MESA real $1M_\odot$ solar star
- $10^6 M_\odot$ SMBH
- Eccentric $e = 0.95$, deep encounter $\beta = r_t / r_p = 5$ orbit

[Hu *et al.* 2024]

# Hydrodynamics simulations

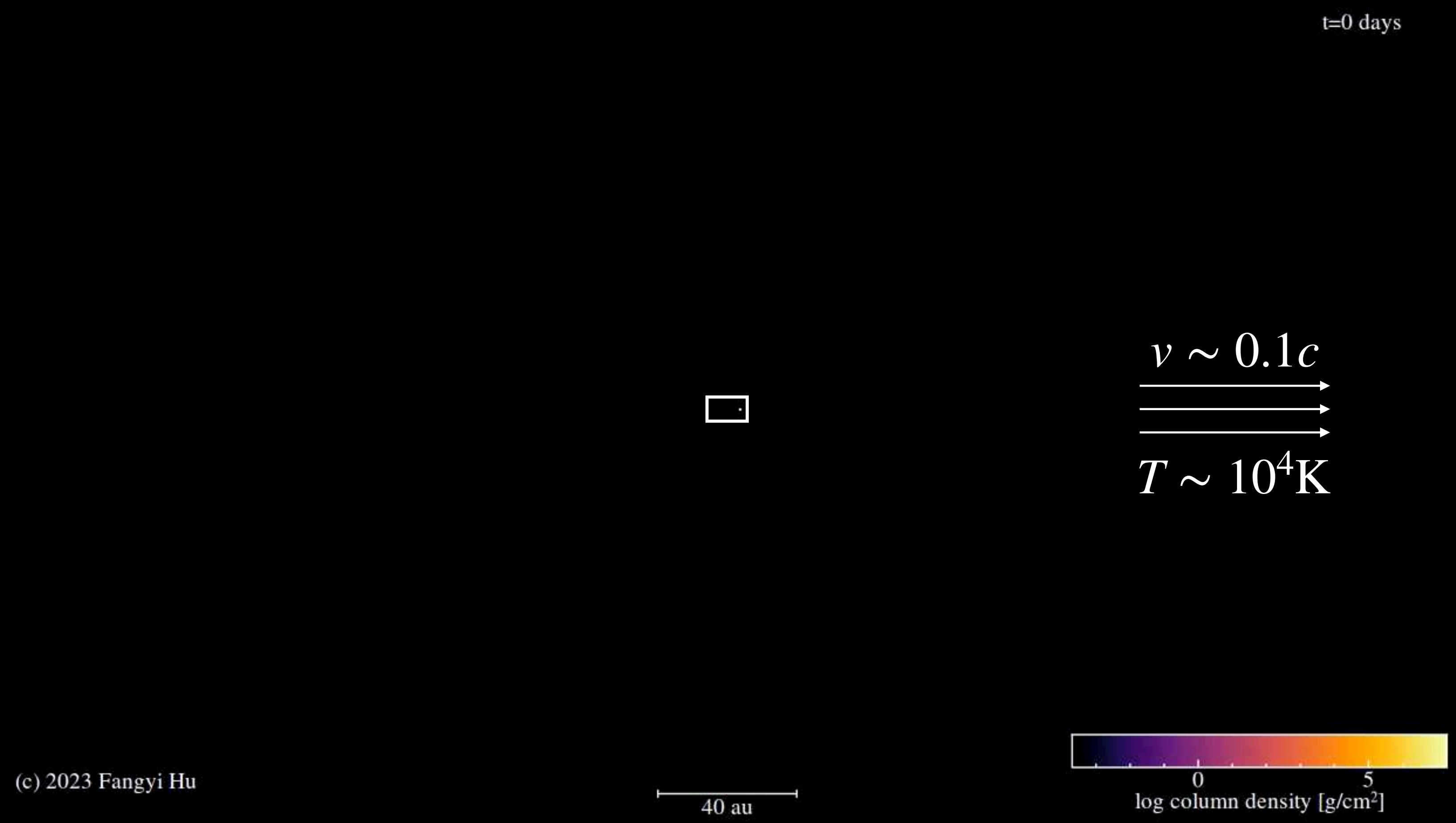
## Tidal




[Hu et al. 2024]

# Hydrodynamics simulations

## Tidal



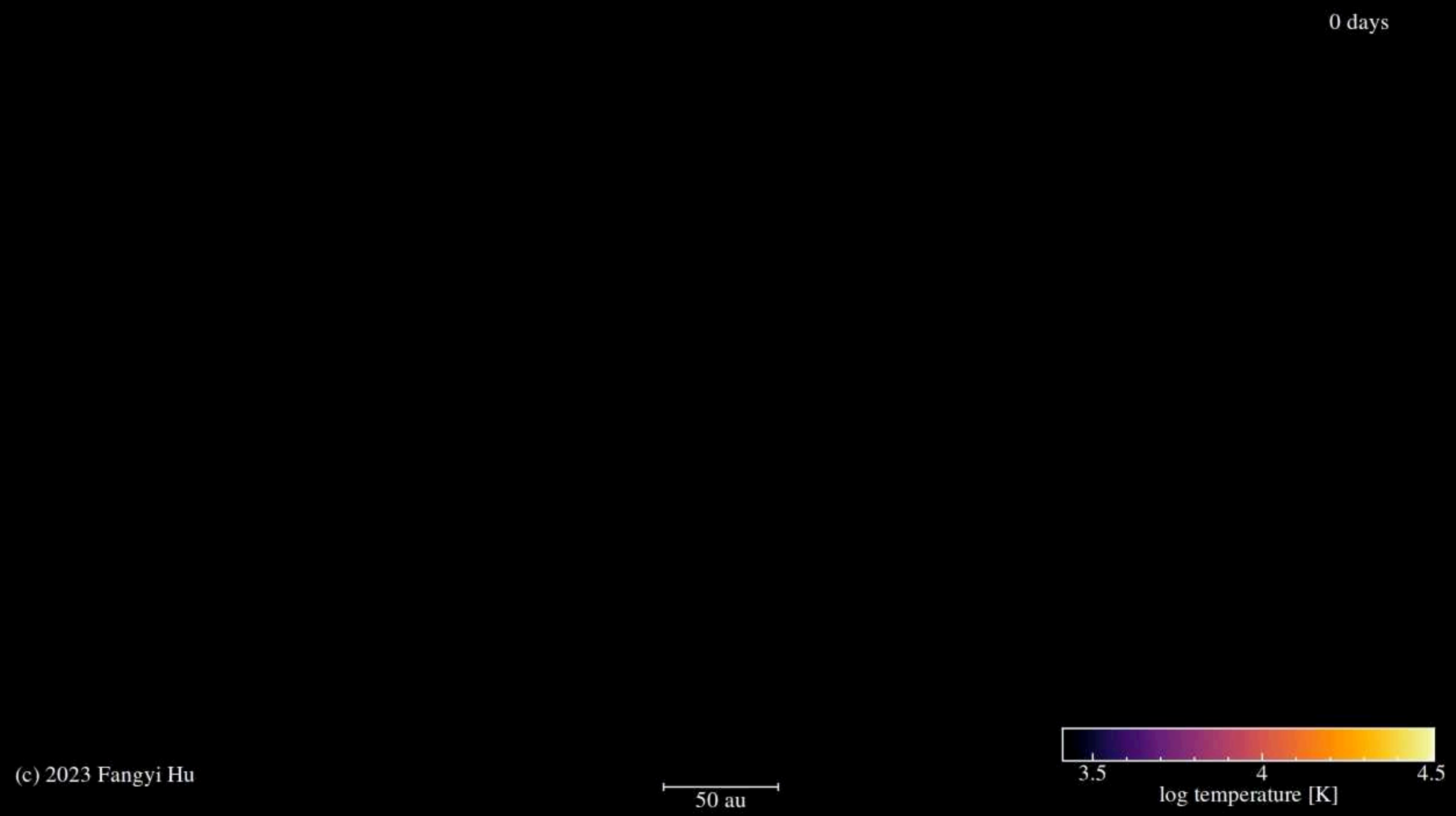

$v \sim 0.1c$

$T \sim 10^4\mathrm{K}$

[Hu *et al.* 2024]

# Hydrodynamics simulations

## Tidal

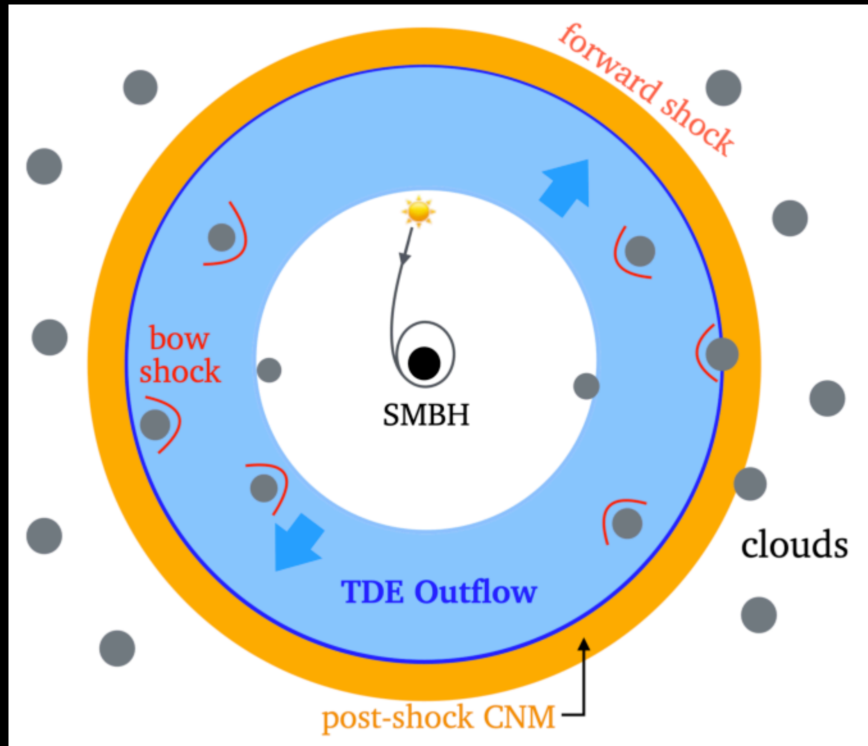



[Hu *et al.* 2024]

# Hydrodynamics simulations

## Outflow interaction with circumnuclear material

[Mou *et al.* 2022]

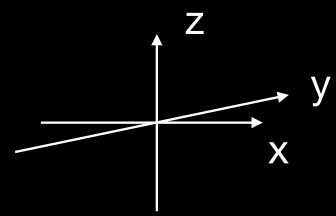


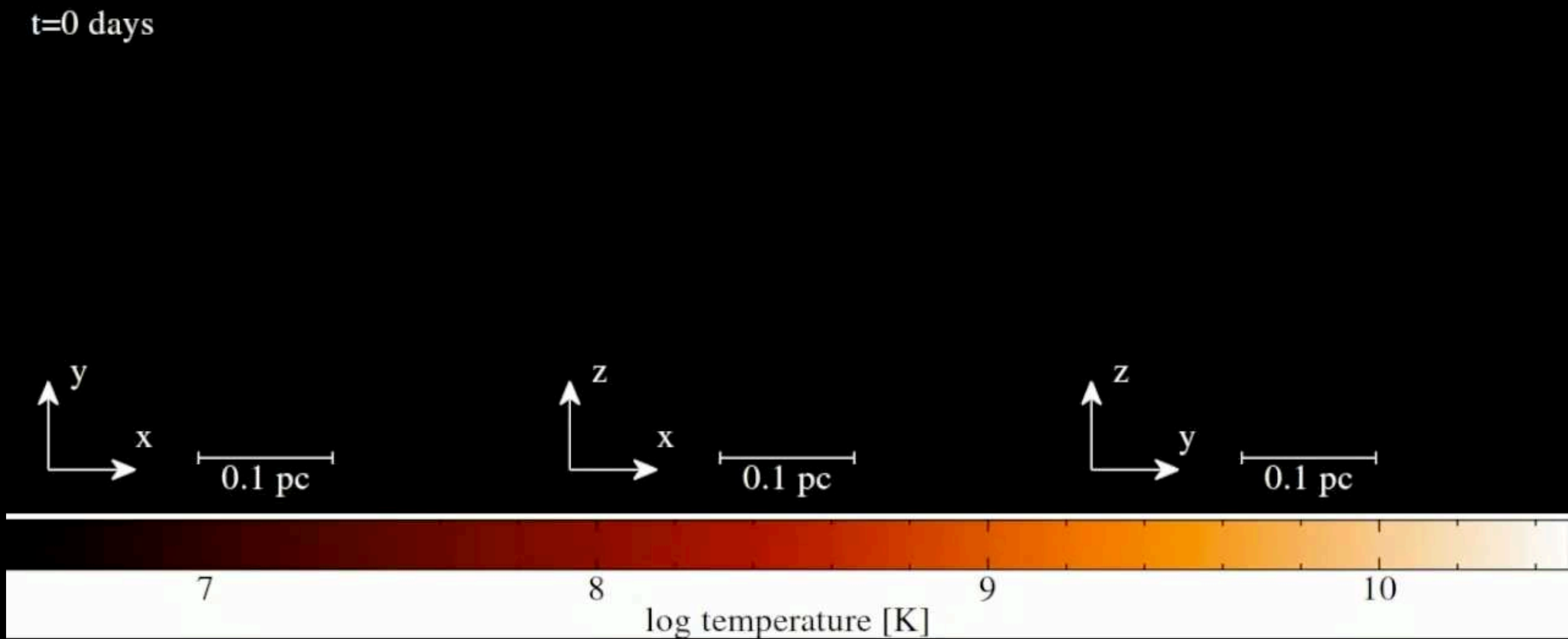

- Shock amplifies magnetic field
- Free electrons form synchrotron/radio radiations
- Spherically symmetric CNM shell
  - Power law density profile $\rho \propto r^{-1.7}$ (Cendes *et al.* 2021)
  - $\rho_0 = 5.03 \times 10^{-17}$ g cm$^{-3}$, $r_0 = 10^{15}$ cm $\approx 66.8$ au
  - Stationary, cold $T = 10$ K

[Hu *et al.* 2025 submitted]

# Hydrodynamics simulations

## Outflow interaction with circumnuclear material

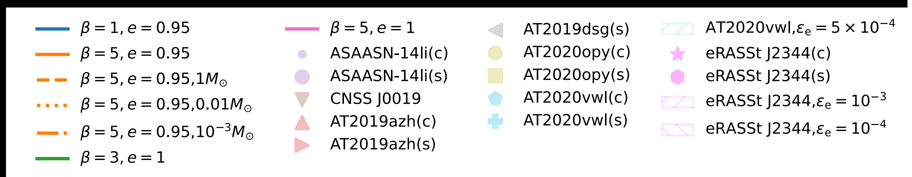


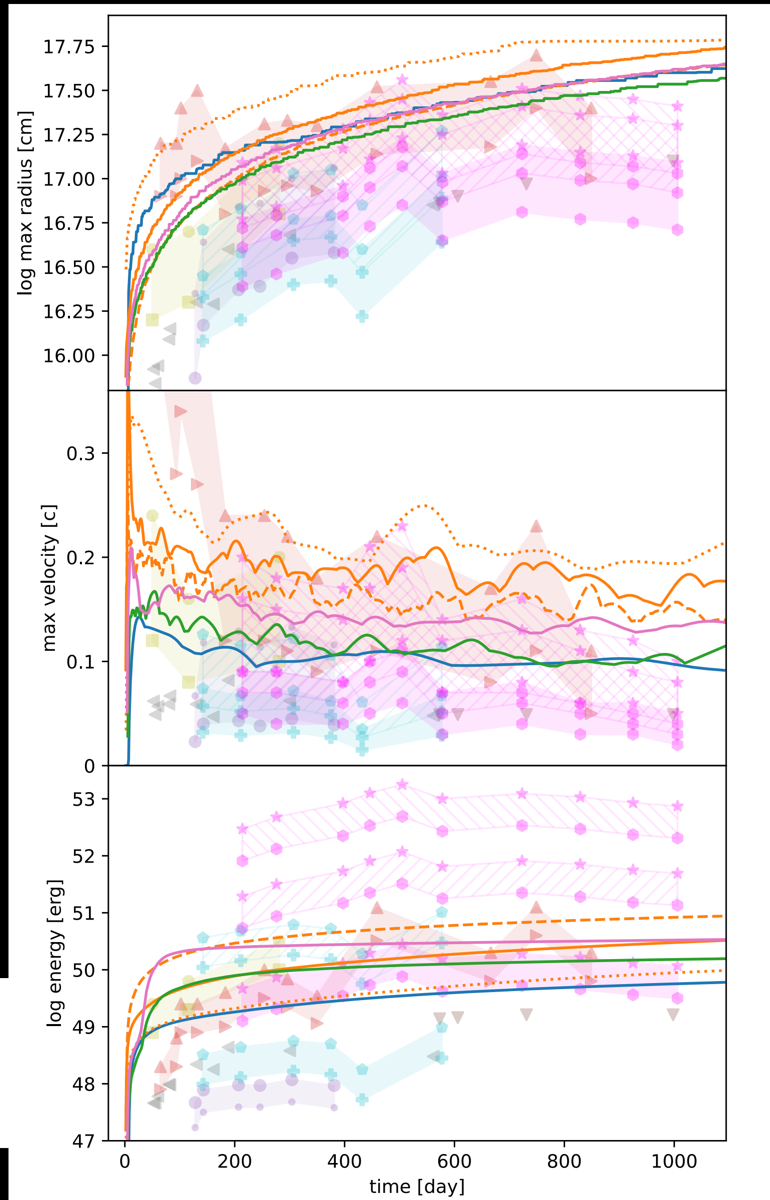




[Hu *et al.* 2025 submitted]

# Radio synchrotron shocks
## Properties

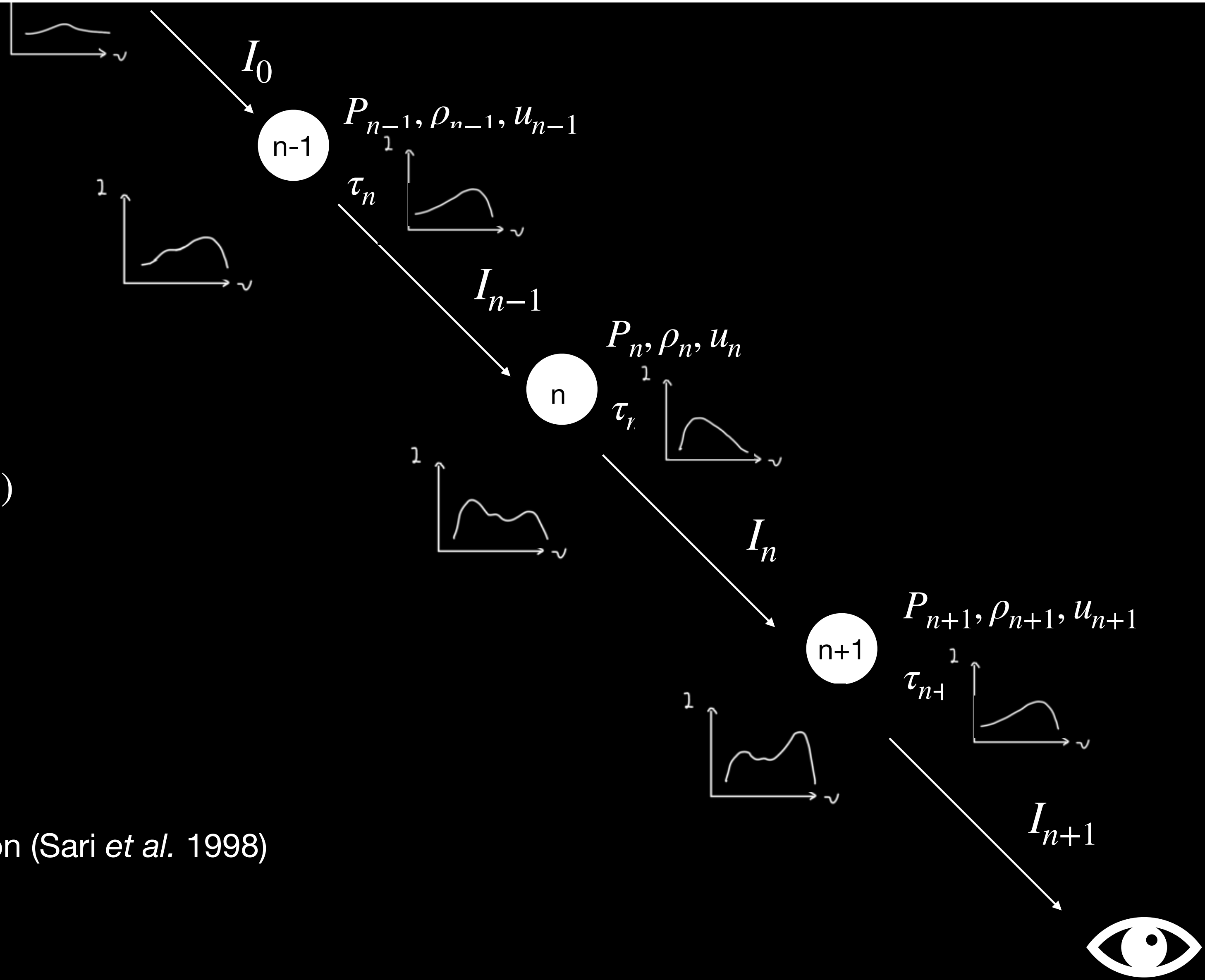
- Radius, velocity ≈ obs
- Energy range ≪ obs
- Low CNM density → large initial rad, vel



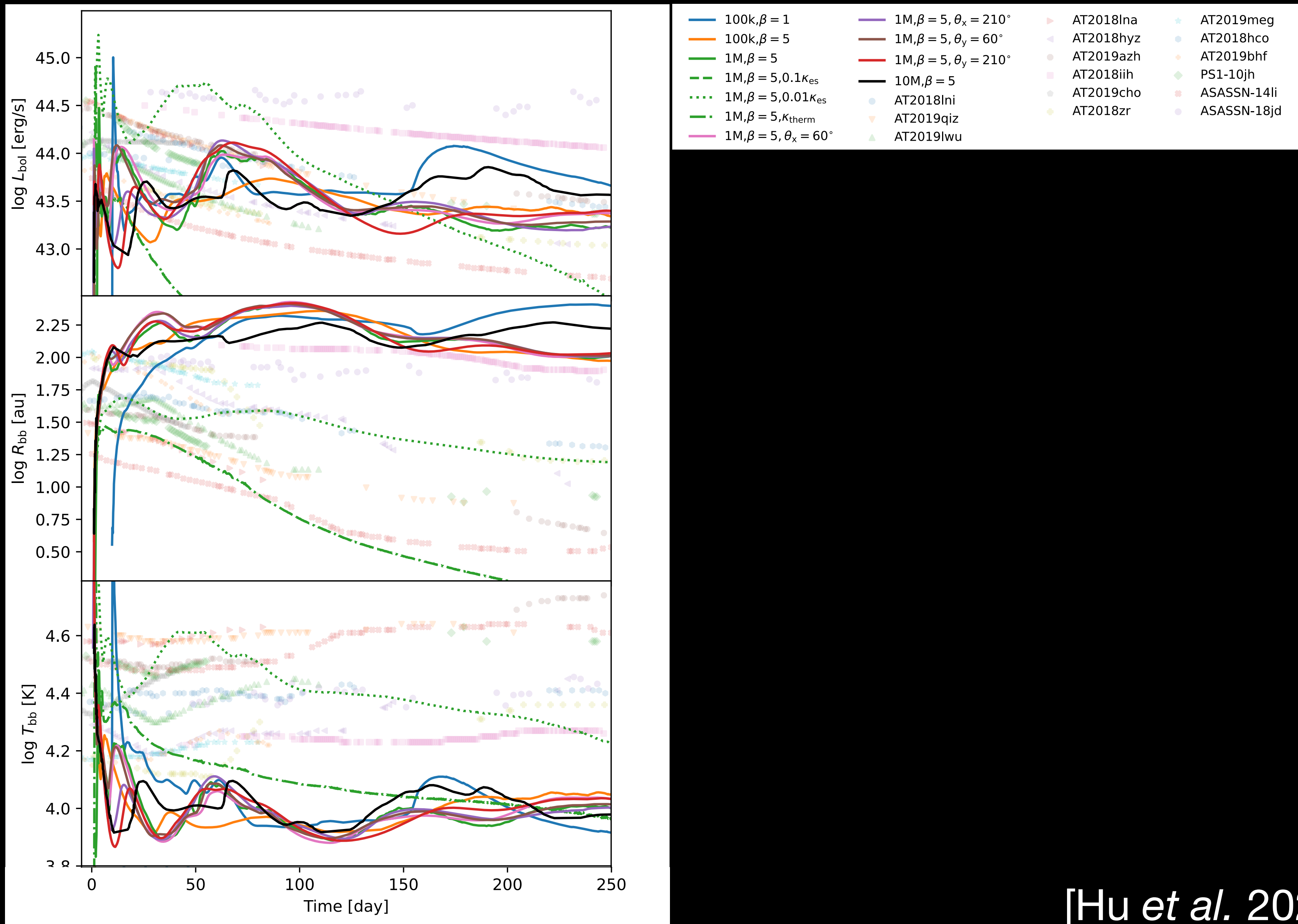



# Ray tracing

- Post-processing
- Radiative transfer equation
  - $I_{n+1} = I_n e^{-\tau_n} + S_n(1 - e^{-\tau_n})$
- Optical
  - $S_\nu$ - blackbody
  - $\tau$ - electrion scattering
- Radio
  - $S_\nu$ - slow cooling synchrotron (Sari *et al.* 1998)
  - $\tau_\nu$ - self-absorption



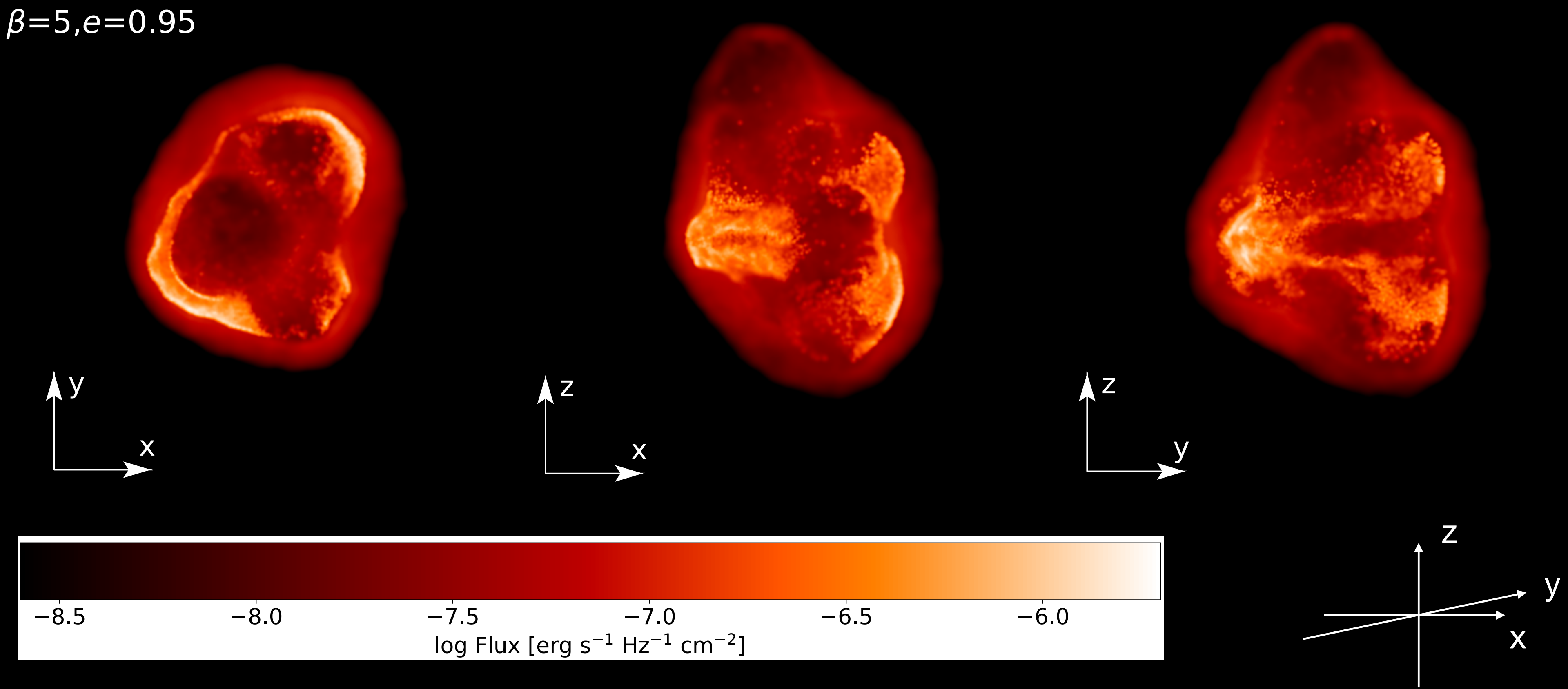
# Optical
## Lightcurve




[Hu *et al.* 2024]

# Radio

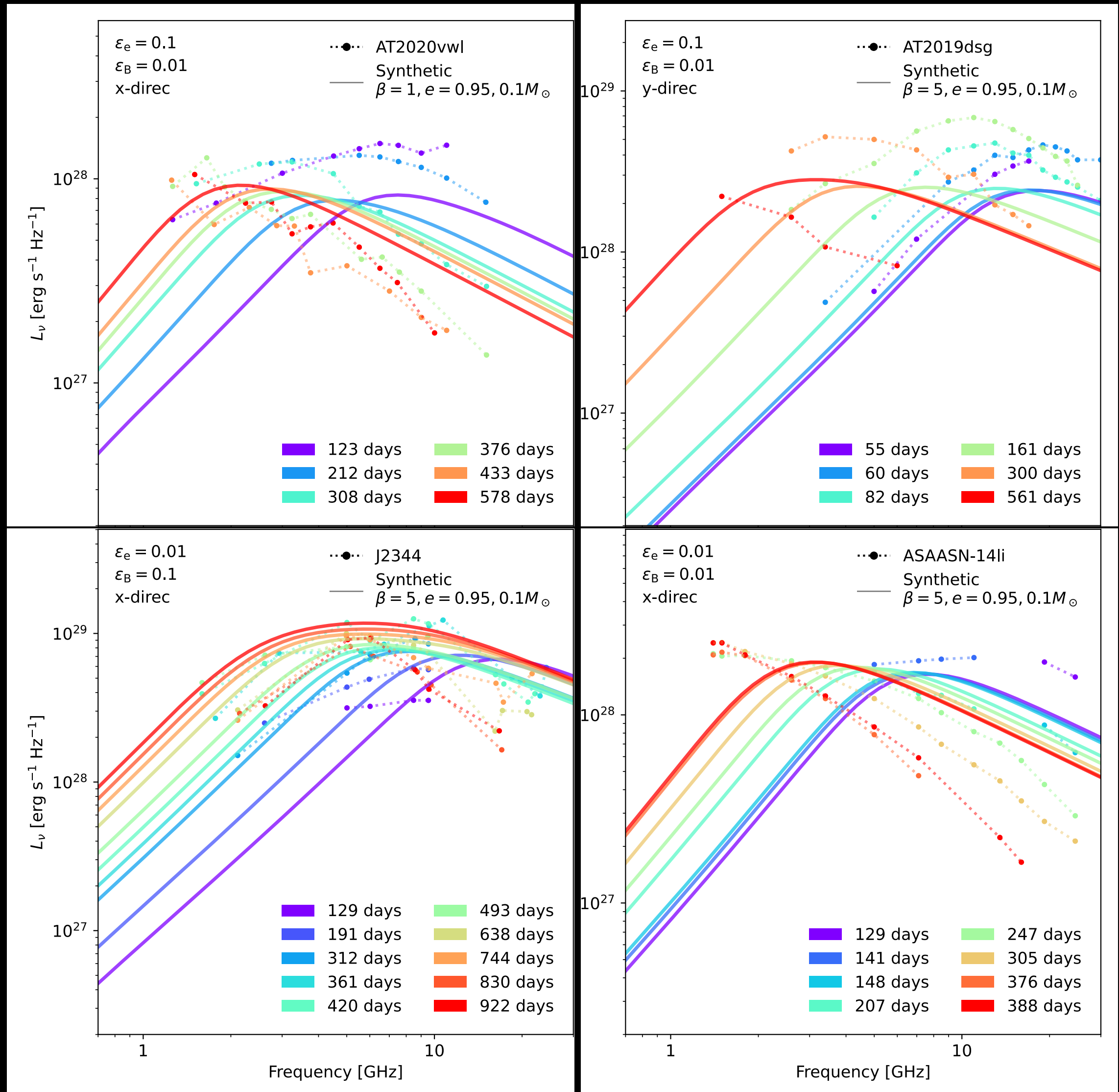
## Images




[Hu *et al.* 2025 submitted]

# Radio

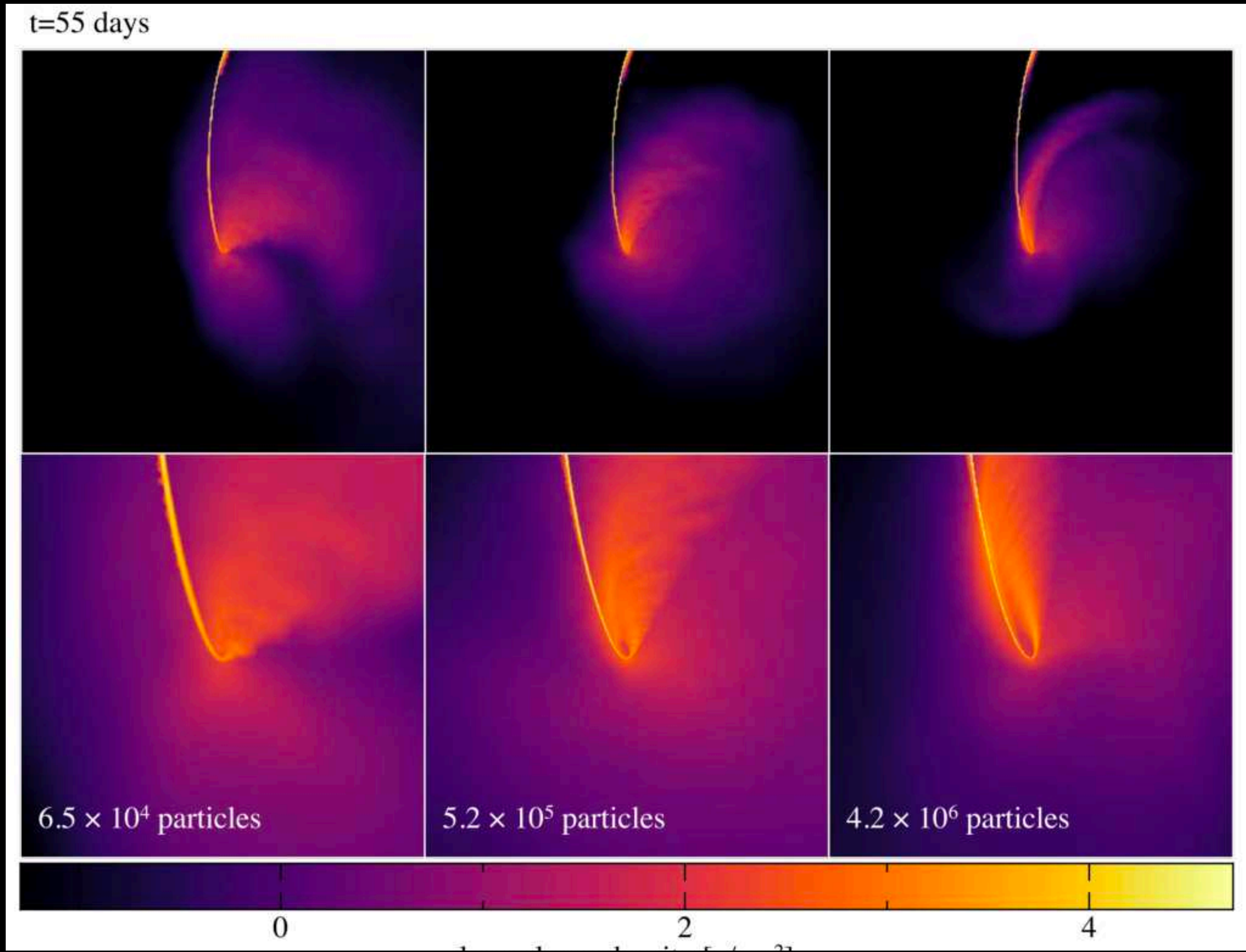
## Spectra




[Hu *et al.* 2025 submitted]

# TDE nozzle shock

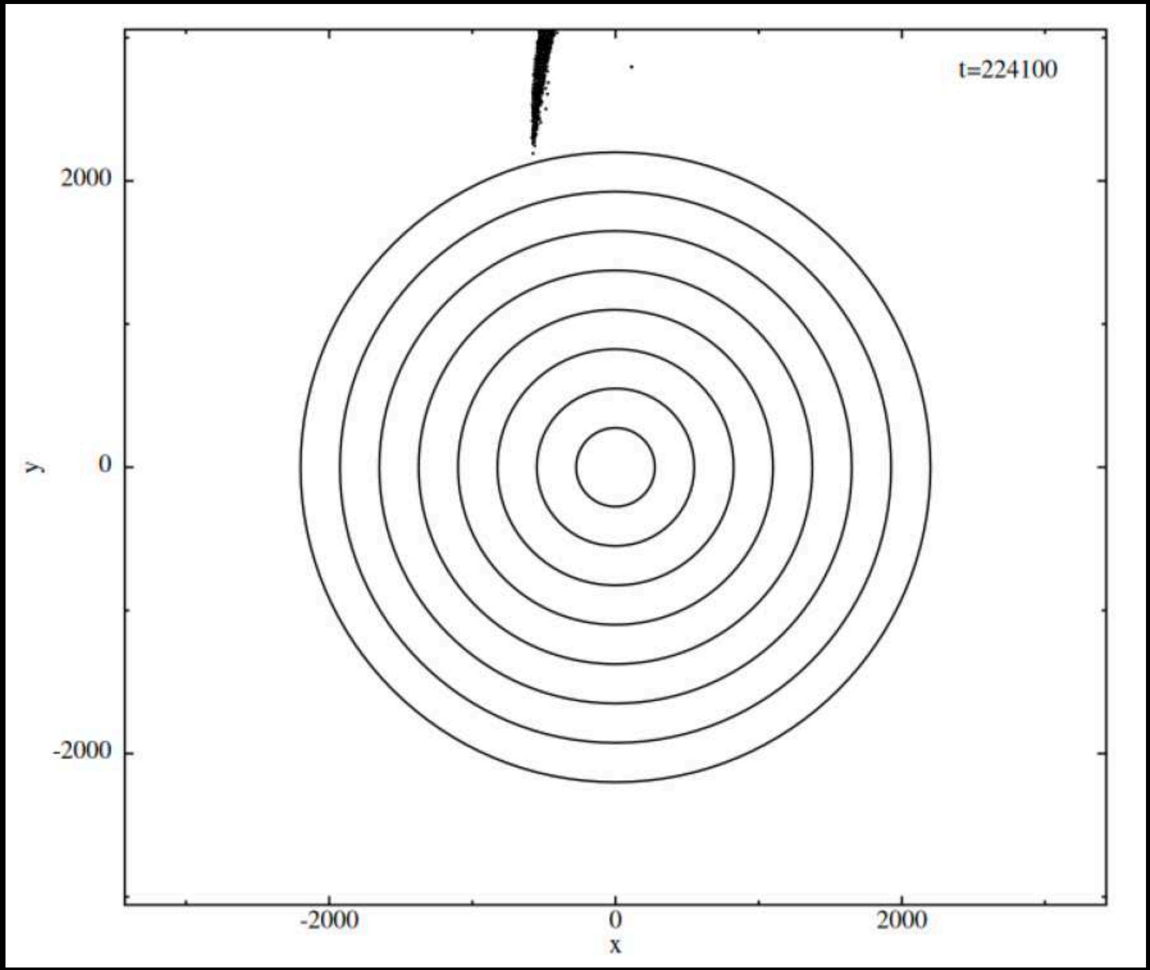
- Nozzle shock at pericenter
- Heat dissipation
- Convergence issue

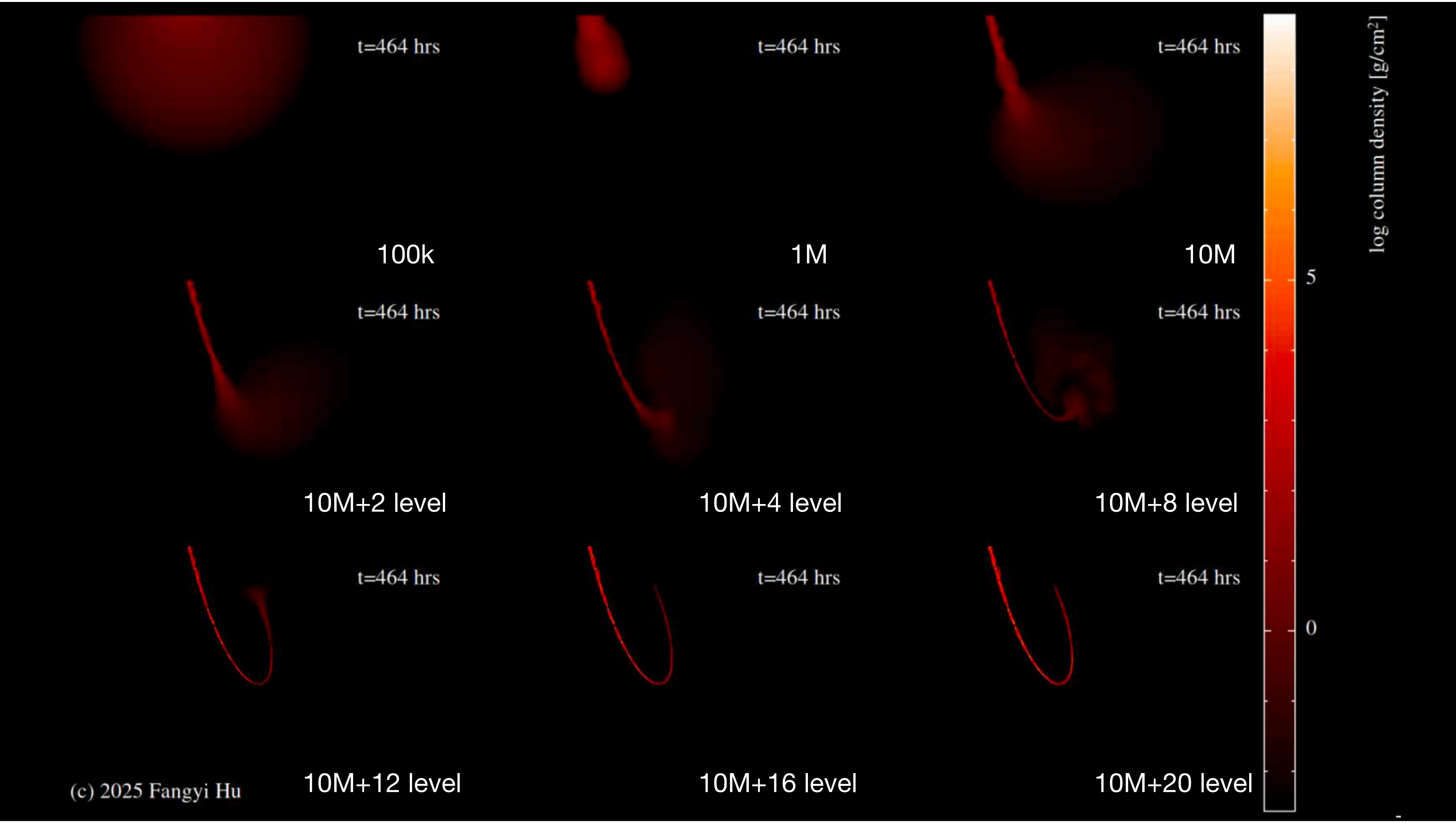



[Price *et al.* 2024]

# TDE nozzle shock

- Adaptive particle refinement [Nealon & Price 2025]
- Split particles before second passage of pericenter
- Increase resolution for a convergent result





t=464 hrs
100k
t=464 hrs
1M
t=464 hrs
10M
t=464 hrs
10M+2 level
t=464 hrs
10M+4 level
t=464 hrs
10M+8 level
t=464 hrs
10M+12 level
t=464 hrs
10M+16 level
t=464 hrs
10M+20 level
log column density [g/cm$^2$]
5
0
(c) 2025 Fangyi Hu

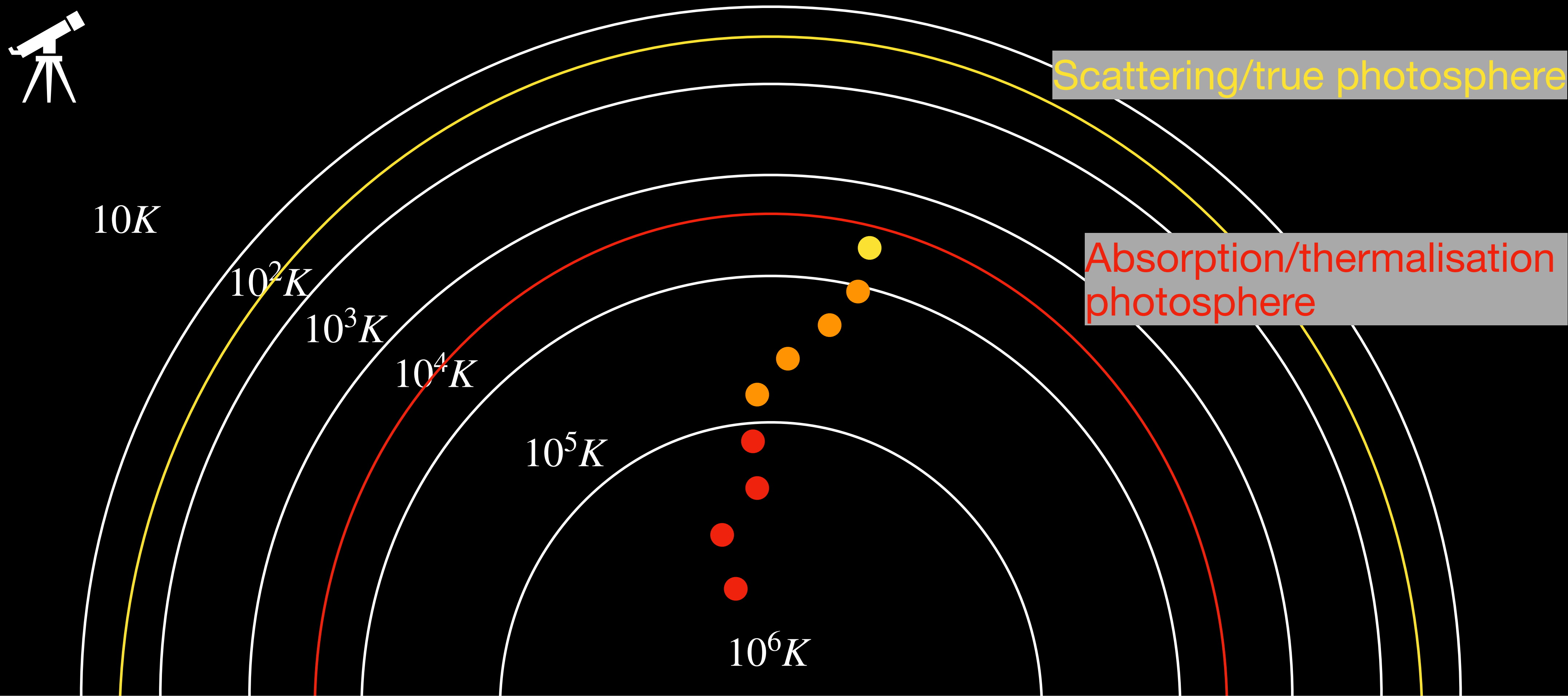
# Conclusions

The models are correct!!

- GR hydro simulations of TDEs and outflow interaction with CNM
- Ray tracing to find spectra/lightcurve
- Results within magnitudes of optical & radio observations despite random parameters/simple setup
- Fangyi (Fitz) Hu, Daniel J. Price, Ilya Mandel, 2024, ApJL, 963, L27

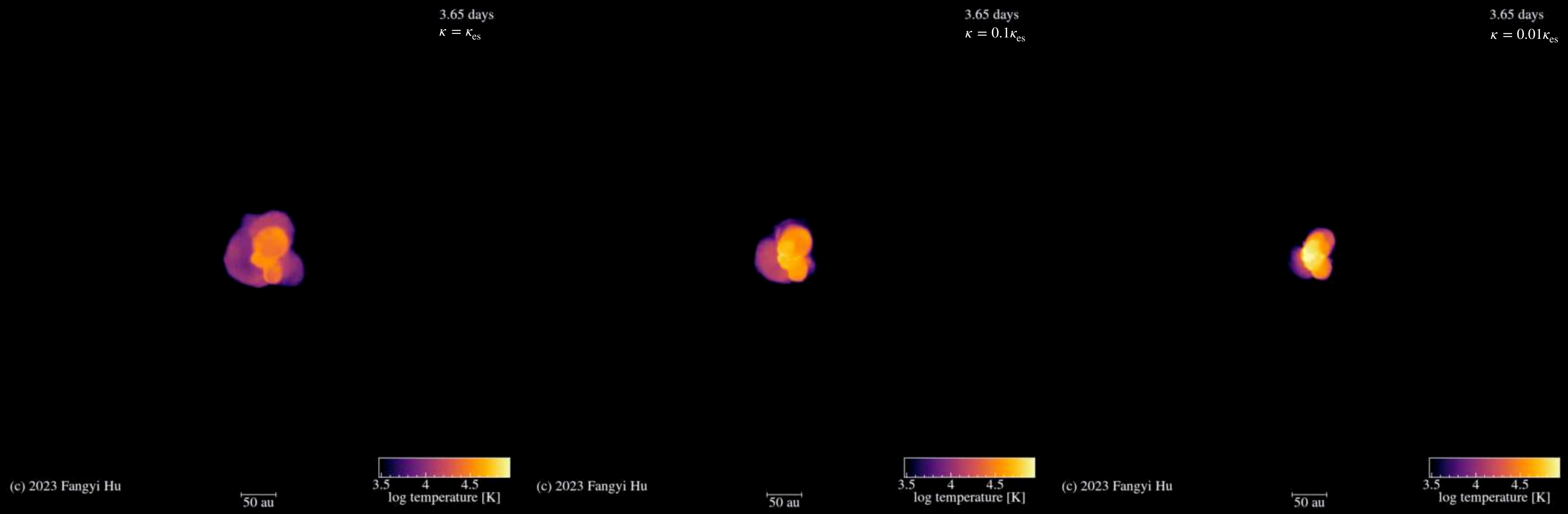
# Too much photosphere!

## Separation between absorption & scattering photosphere



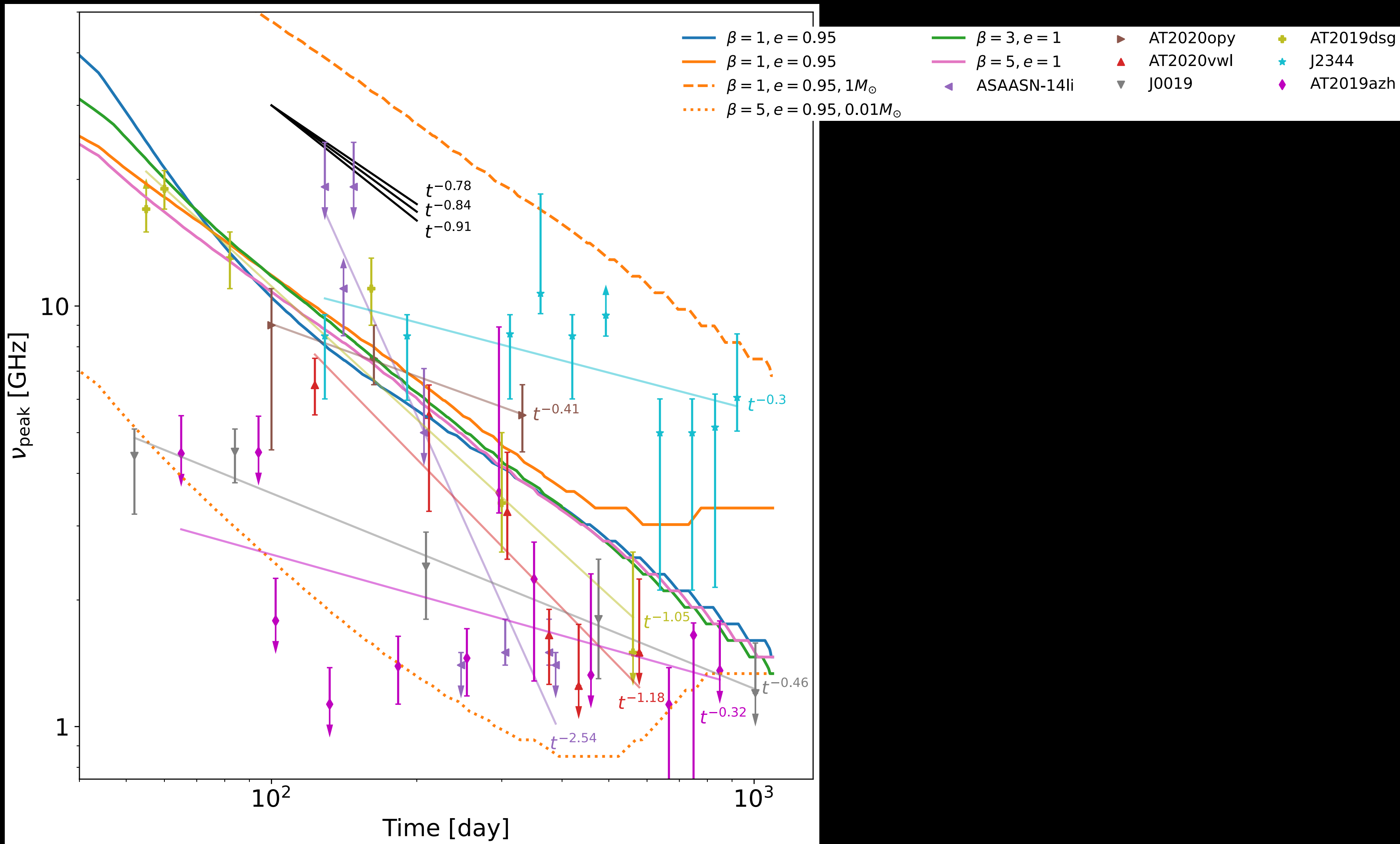
# Optical

## Opacity



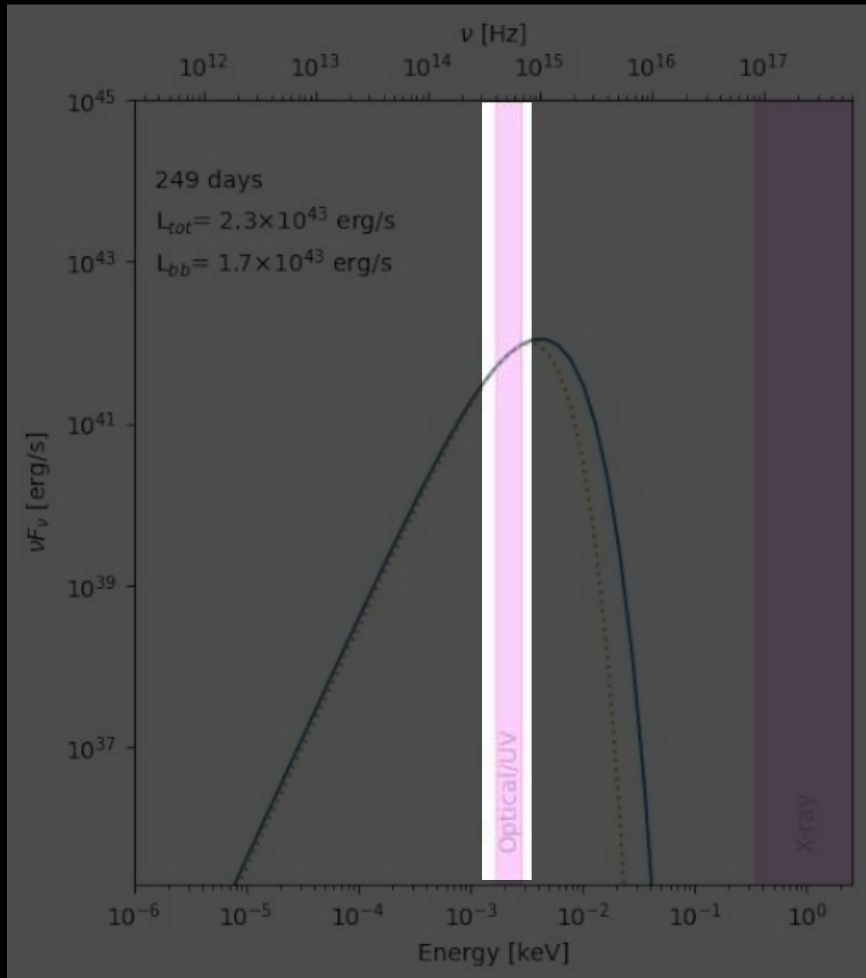
# Radio

## Spectra




[Hu *et al.* 2025 submitted]

# Optical
## Spectra




[Hu *et al.* 2024]