# Numerical study of dynamics and emission from a TDE-powered jet

**Petar Mimica**
Departamento de Astronomia y Astrofísica, Universidad de Valencia

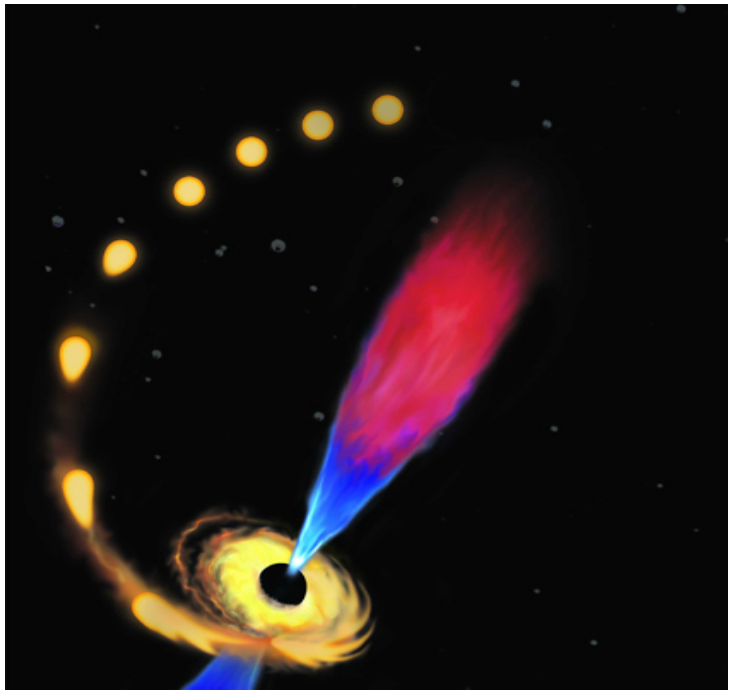
**Brian Metzger, Dimitrios Giannios**
Department of Astrophysical Sciences, Peyton Hall, Princeton

**Miguel Angel Aloy**
Departmento de Astronomia y Astrofísica, Universidad de Valencia

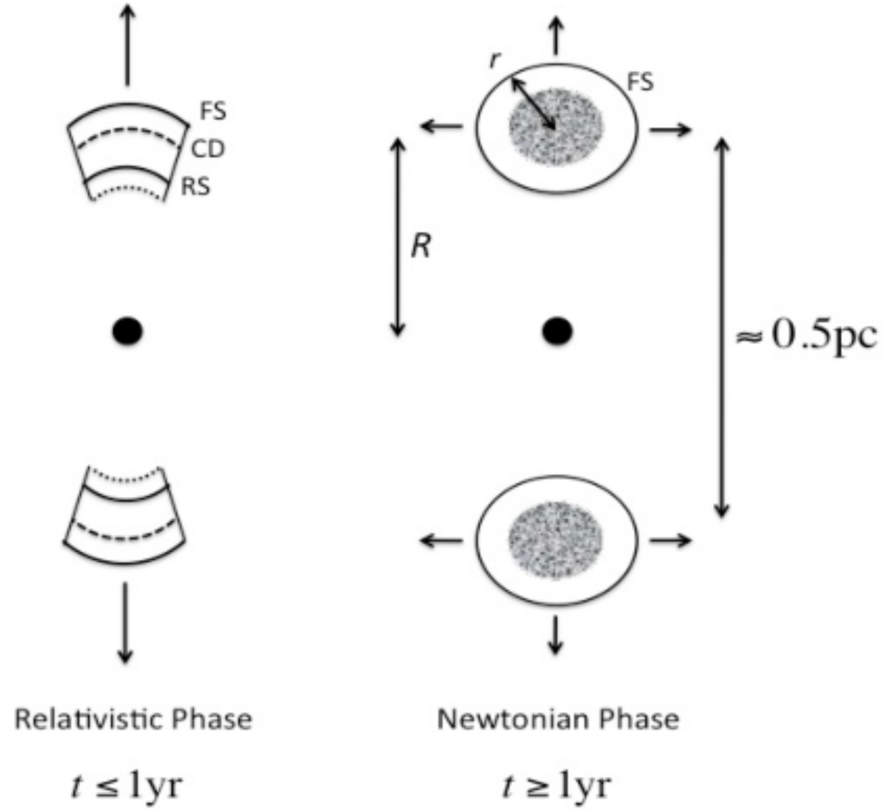
# Outline

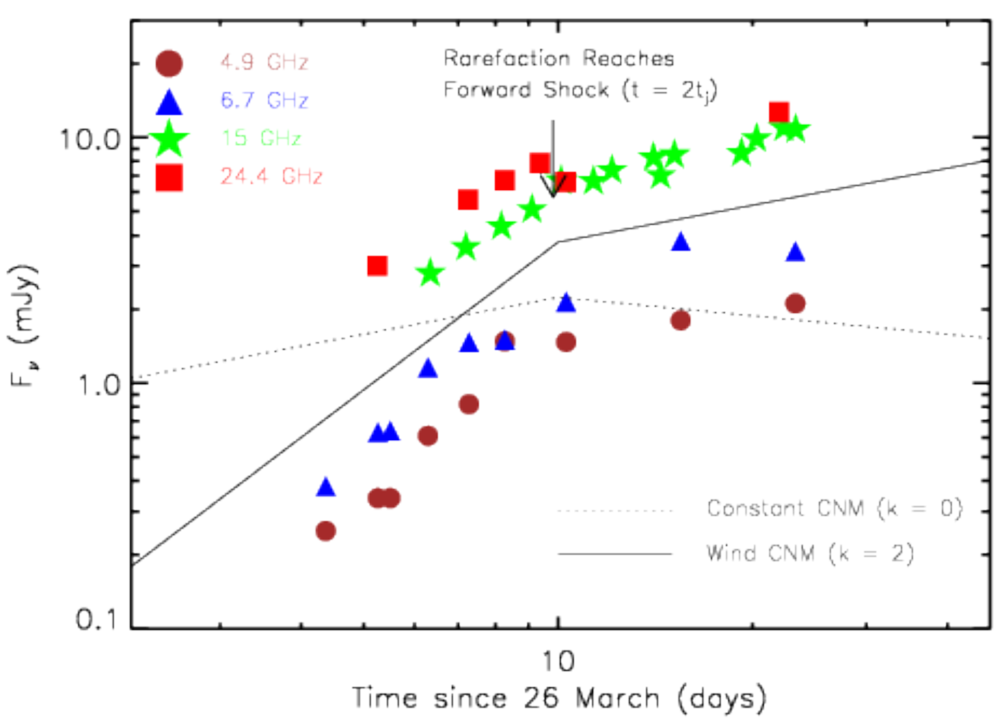
1. Introduction and motivation: why 2D jet models?
2. 1D versus 2D simulations: dynamics
3. Preliminary off-axis results
4. Summary

# Jets powered by tidal disruptions



- complete tidal disruption of a Sun-like star may produce a powerful relativistic jet
- jet interacts with the CNM, decelerates and produces a radio transient

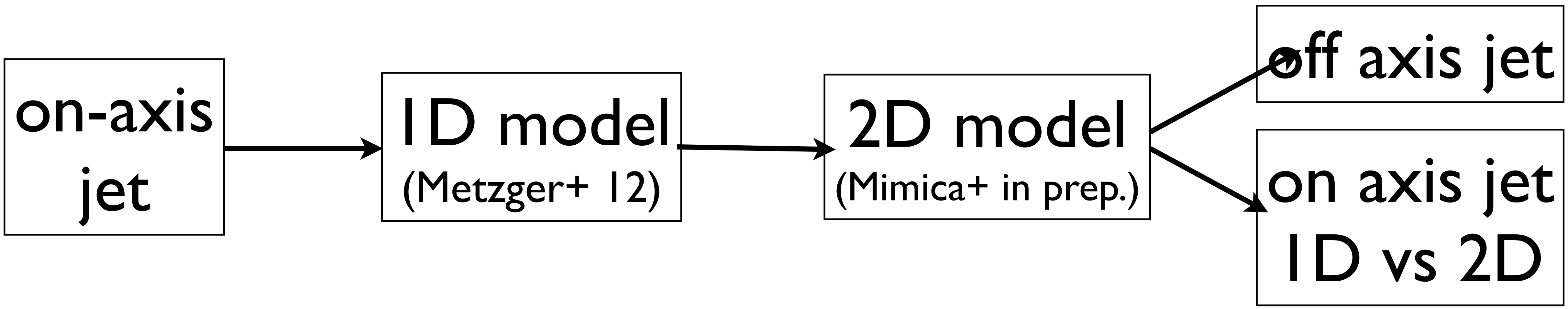



Giannios & Metzger 11; Metzger+ 12

# 2D study

1. 2D effects may become important early in the evolution
2. We can study arbitrary observing angle
3. We can make prediction about jet detection/non-detection (power, CNM properties, timescales, frequencies)



# RHD simulations of TDE jets

## Physical model

$$L_j(t) = L_{j,0}\left(\max\left[1, \left(\frac{t}{t_{j,0}}\right)\right]\right)^{-5/3}$$

$$L_{j,0} = 5 \times 10^{47}\ \mathrm{erg\ s^{-1}}$$

$$t_{j,0} = 5 \times 10^{5}\ \mathrm{s}$$

$$\Gamma_{j,0} = 10 \qquad \theta_{j,0} = 0.1\ \mathrm{rad}$$

$$\Theta_0 := \frac{P_0}{\rho_0 c^2} = 10^{-2}$$

$$\mathrm{TM\ EOS}: h(\Theta) = \frac{5}{2}\Theta + \sqrt{\frac{9}{4}\Theta^2 + 1}$$

(Mignone+ 05, de Berredo-Peixoto+ 05)

$$R_{j,0} = 5 \times 10^{16}\ \mathrm{cm}$$

$$n_{\mathrm{ext}}(R) = 3.33 \times 10^{2}\ \mathrm{cm^{-3}}\left(\frac{R}{R_{j,0}}\right)^{-1}$$

$$T_{\max} \approx 3\ \mathrm{years}$$

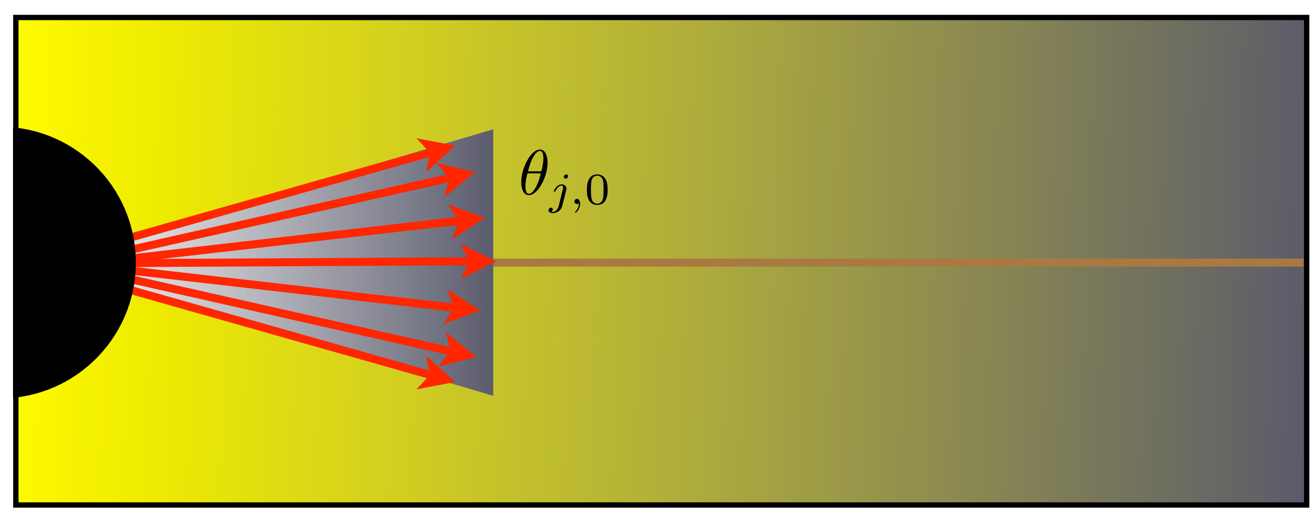
Mimica, Giannios, Metzger & Aloy, in prep.

## Technical details

$$\Delta r_{\mathrm{1D}} = 10^{13}\ \mathrm{cm}$$

$$\Delta r_{\mathrm{2D}} = 10^{14}\ \mathrm{cm} \qquad \Delta\theta_{\mathrm{2D}} = 10^{-3}\pi\ \mathrm{rad}$$

- *MRGENESIS* code (Mimica+ 07, 09), equidistant grid, 2D resolution 25200 x 500
- 12.6 million numerical cells (jet resolved using 32 zones in azimuthal direction)
- 3300 snapshots stored (approx. every 0.4 days of lab frame time): for radiative transfer calculations




(de Colle+ 12 perform similar simulations)

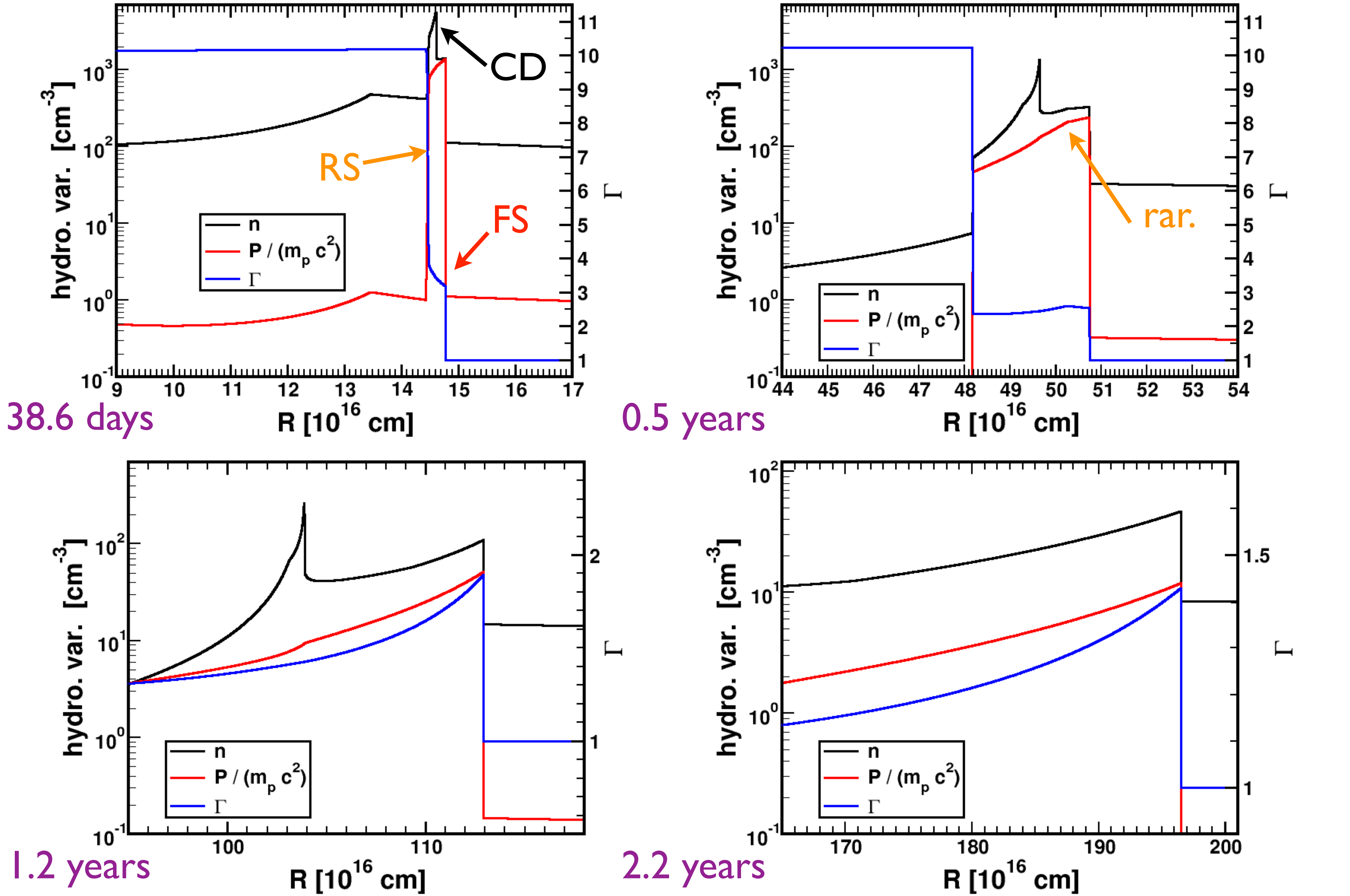
# RHD + emission

- codes: *MRGENESIS* (Mimica+ 07, 09) for RHD + *SPEV* (Mimica+ 09, Tabik+ 11, 12) for the electron evolution and emission calculation
- observed radiation: synchrotron emission from shock accelerated electrons at FS and RS
- power-law distribution $N(\gamma) = N(\gamma_{\rm min})\,(\gamma/\gamma_{\rm min})^{-p}$
- lower and upper cutoffs:

$$\gamma_{\rm min} = \frac{3P_{\rm sh}}{\rho_{\rm sh}c^2}\frac{m_p}{m_e}\frac{p-2}{p-1}\epsilon_e \qquad \gamma_{\rm max} = \left(\frac{3m_e^2c^4}{4\pi e^3 B'}\right)^{1/2}$$

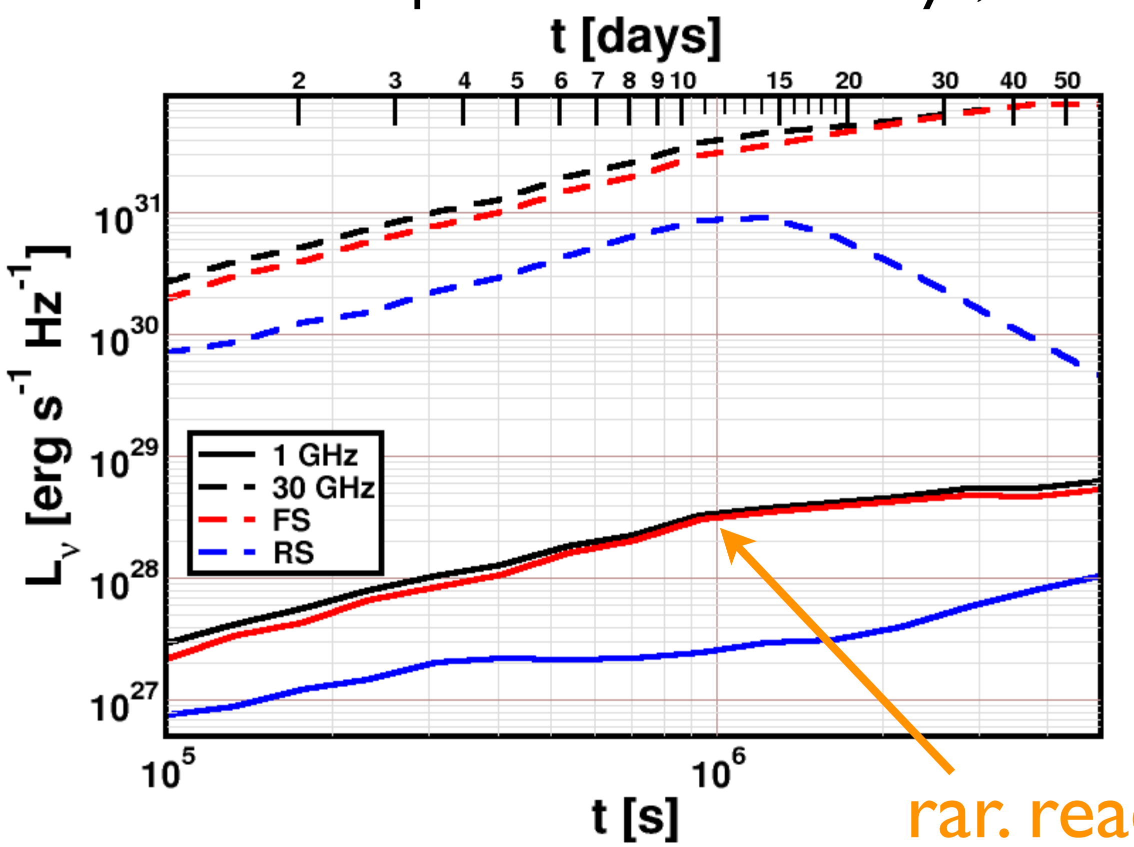
- magnetic field: $B' = \sqrt{8\pi\varepsilon_{\rm th}\epsilon_B}$
- particle distribution evolution (synchrotron + adiabatic losses/gains)
- fast calculation: optically thin medium - emissivity volume integral
- detailed calculation: radiative transfer (SSA)

# 1D evolution

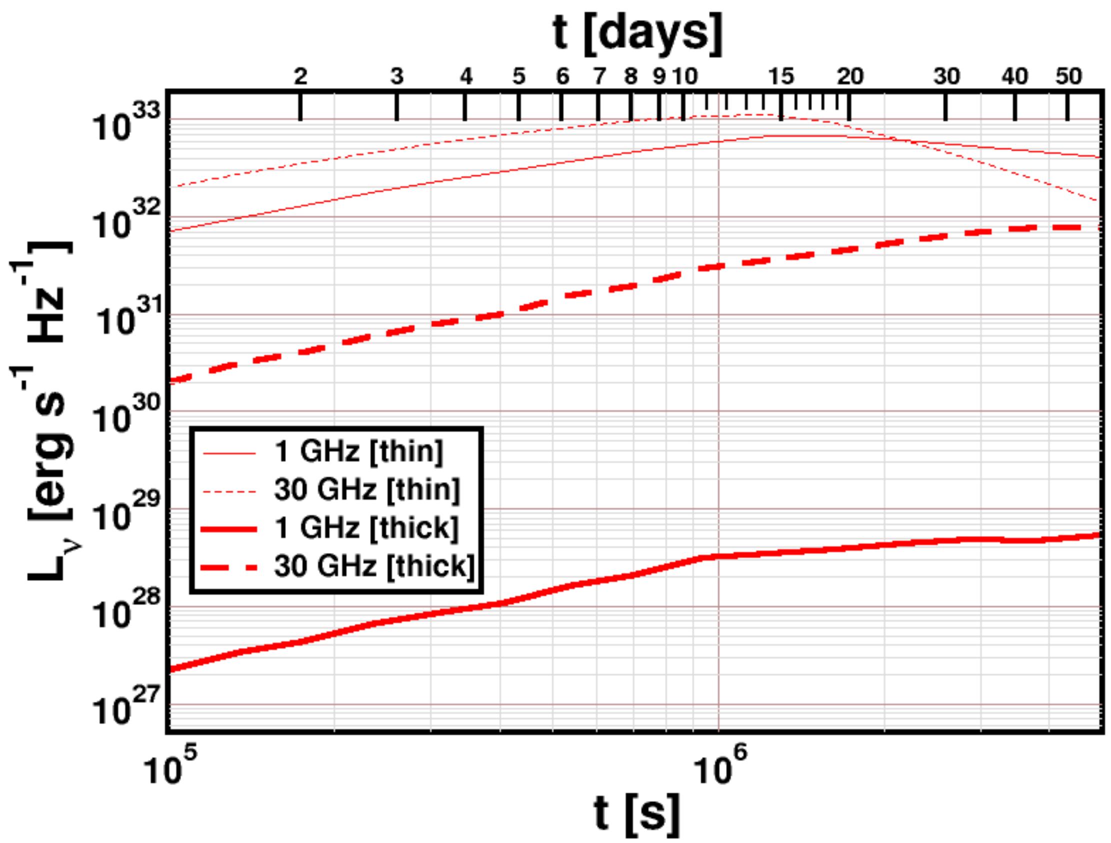


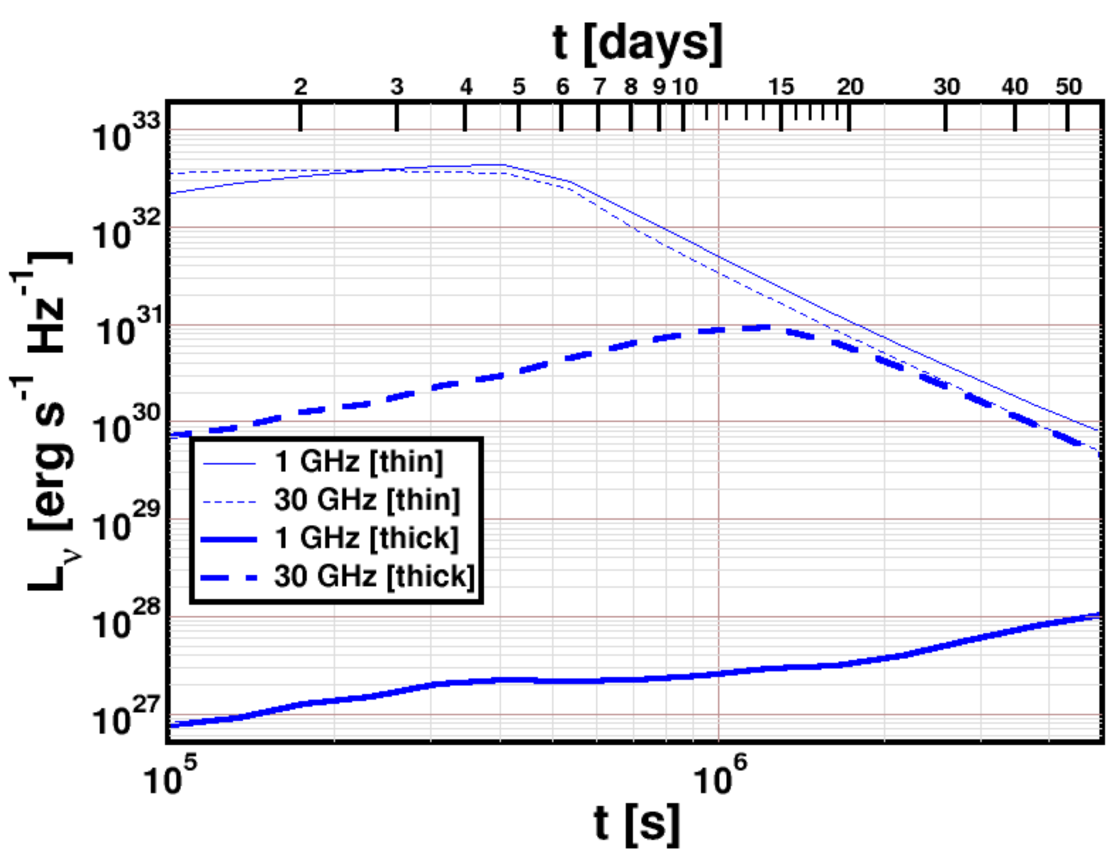
# Radio light curves

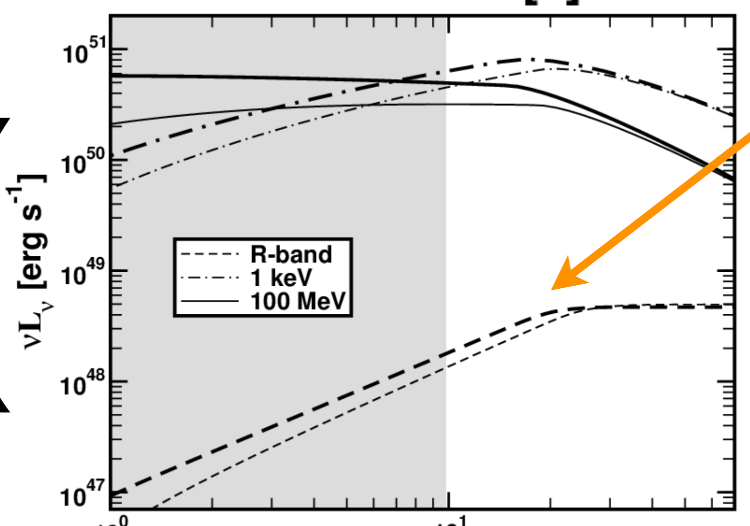
- procedure analogous to the afterglow light curve calculations in Mimica, Giannios & Aloy (2010)
- 1GHz synchrotron self-absorbed
- 30GHZ: FS opt. thin after ~60 days, RS after ~ 20d




rar. reaches FS

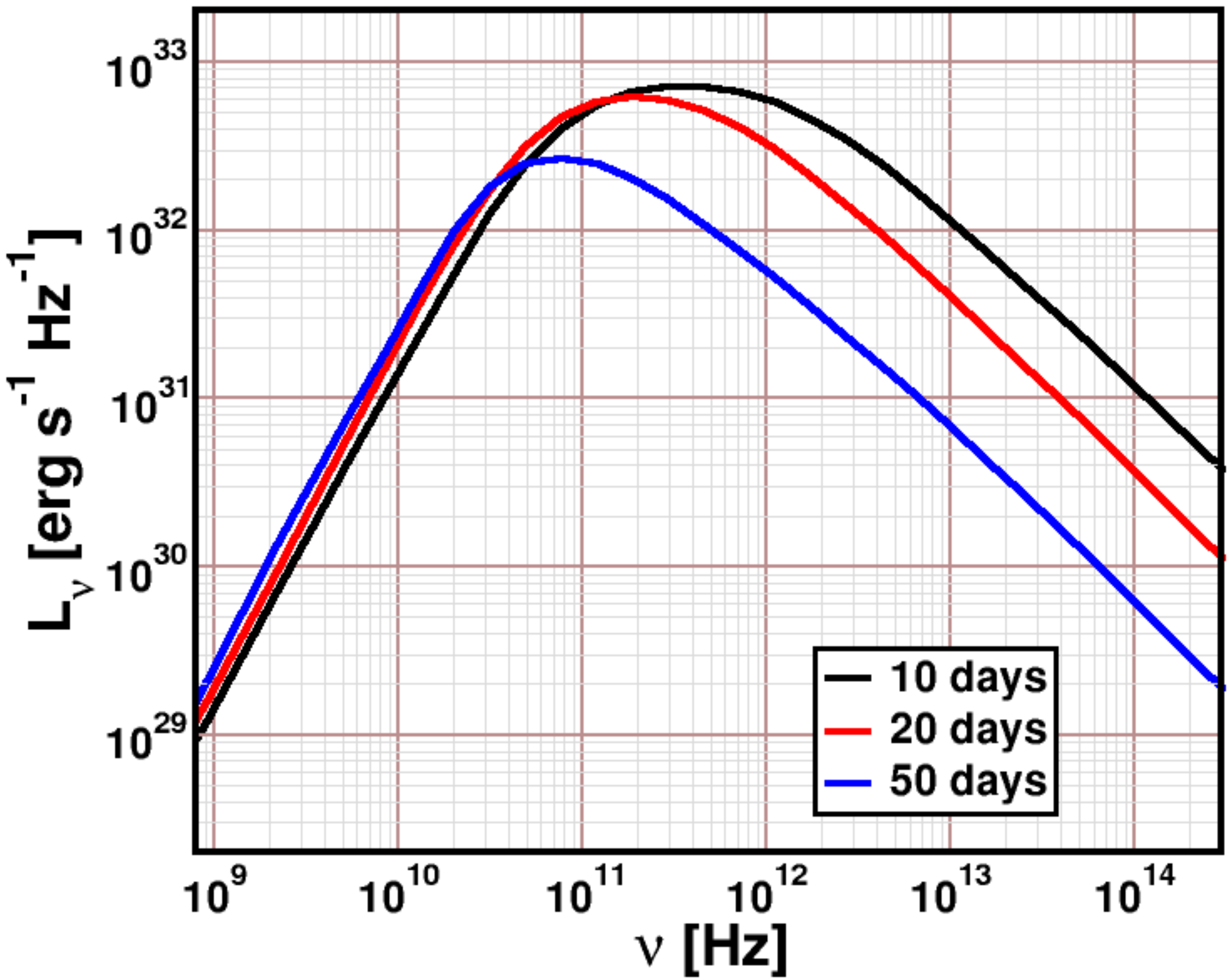


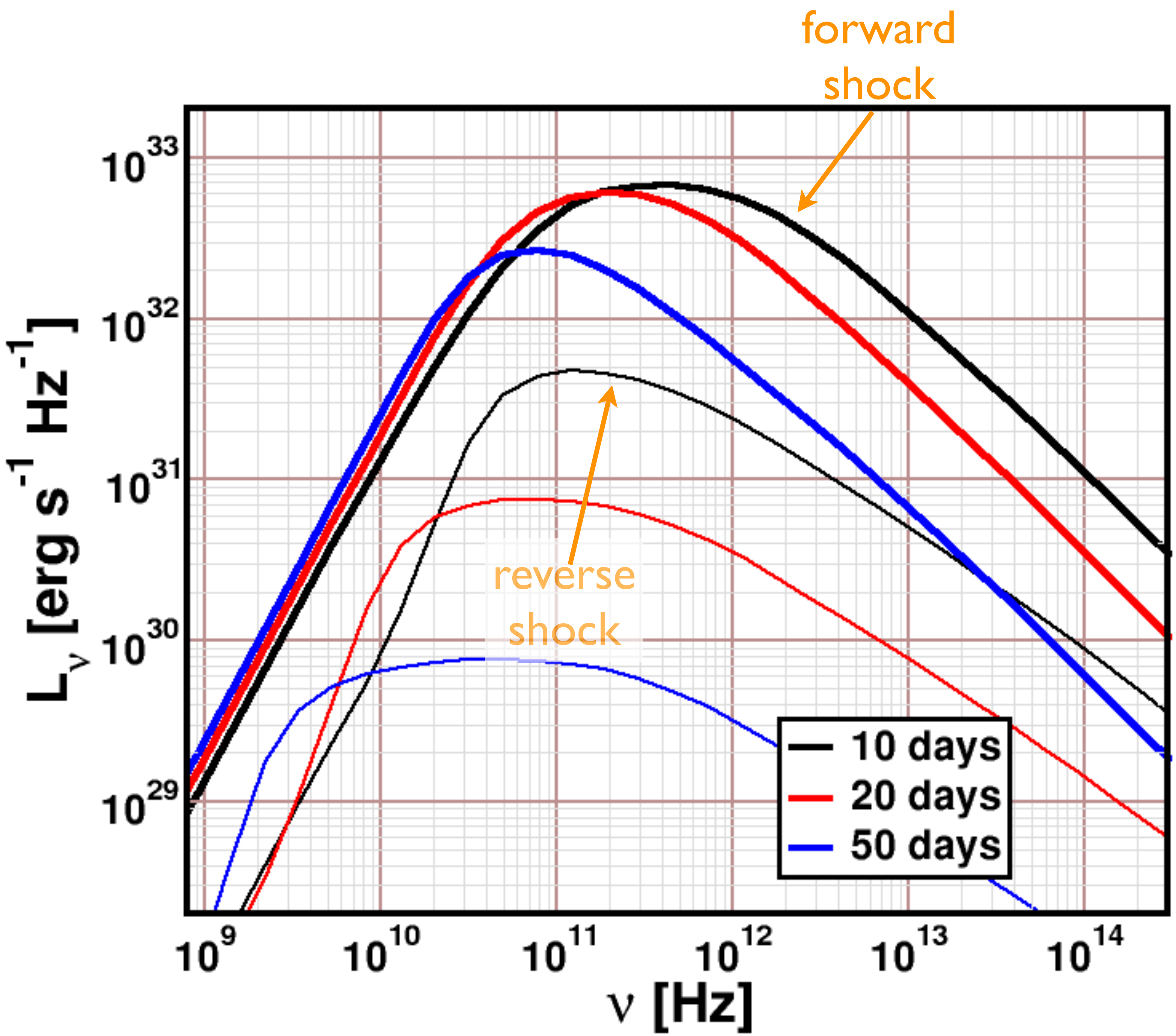



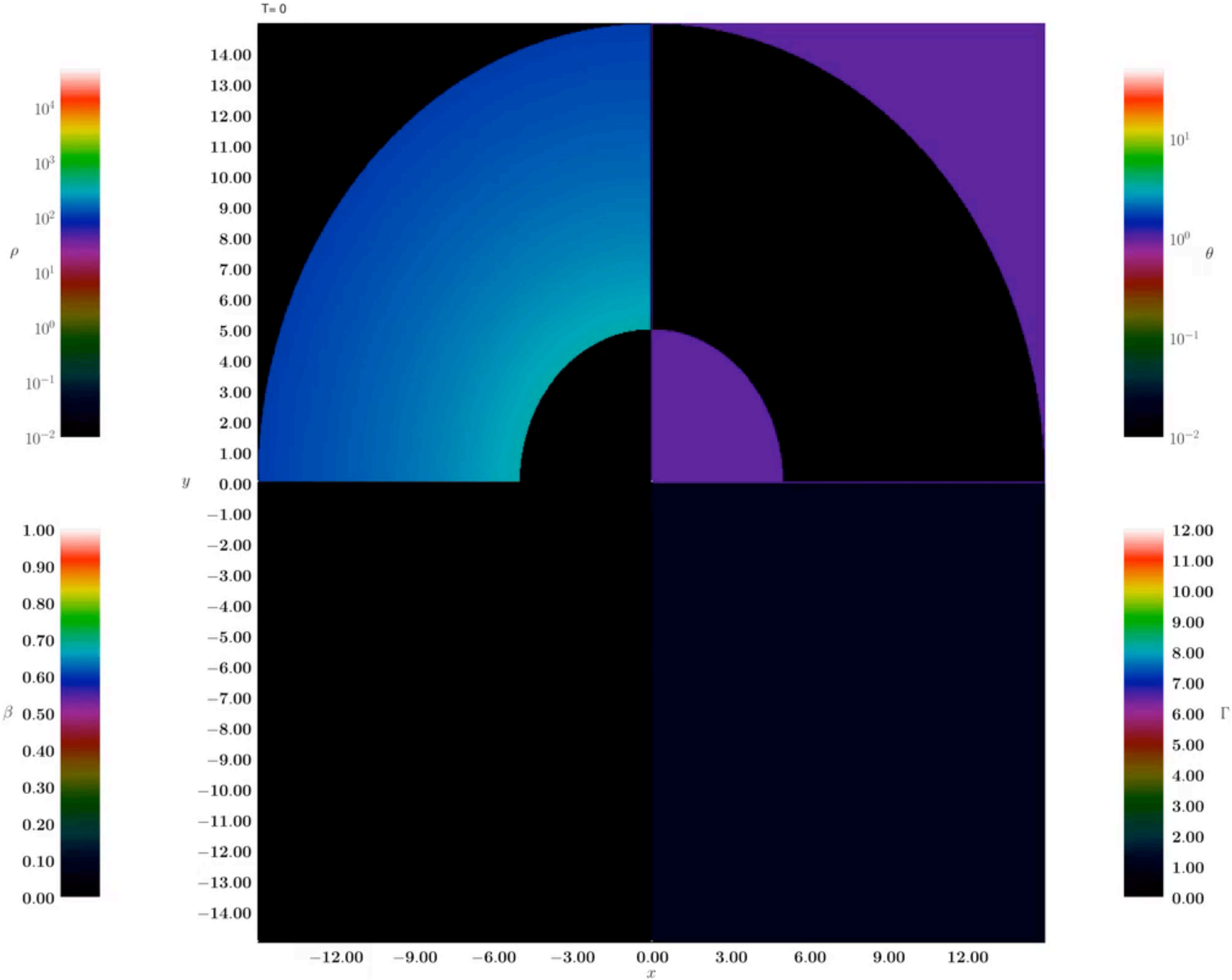

Mimica+ 10

# Instantaneous spectra



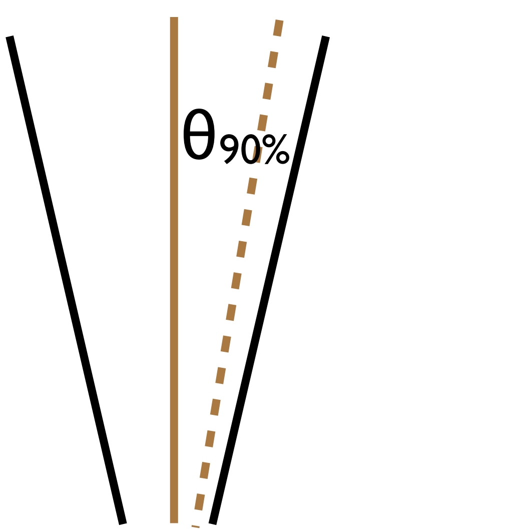
# Instantaneous spectra

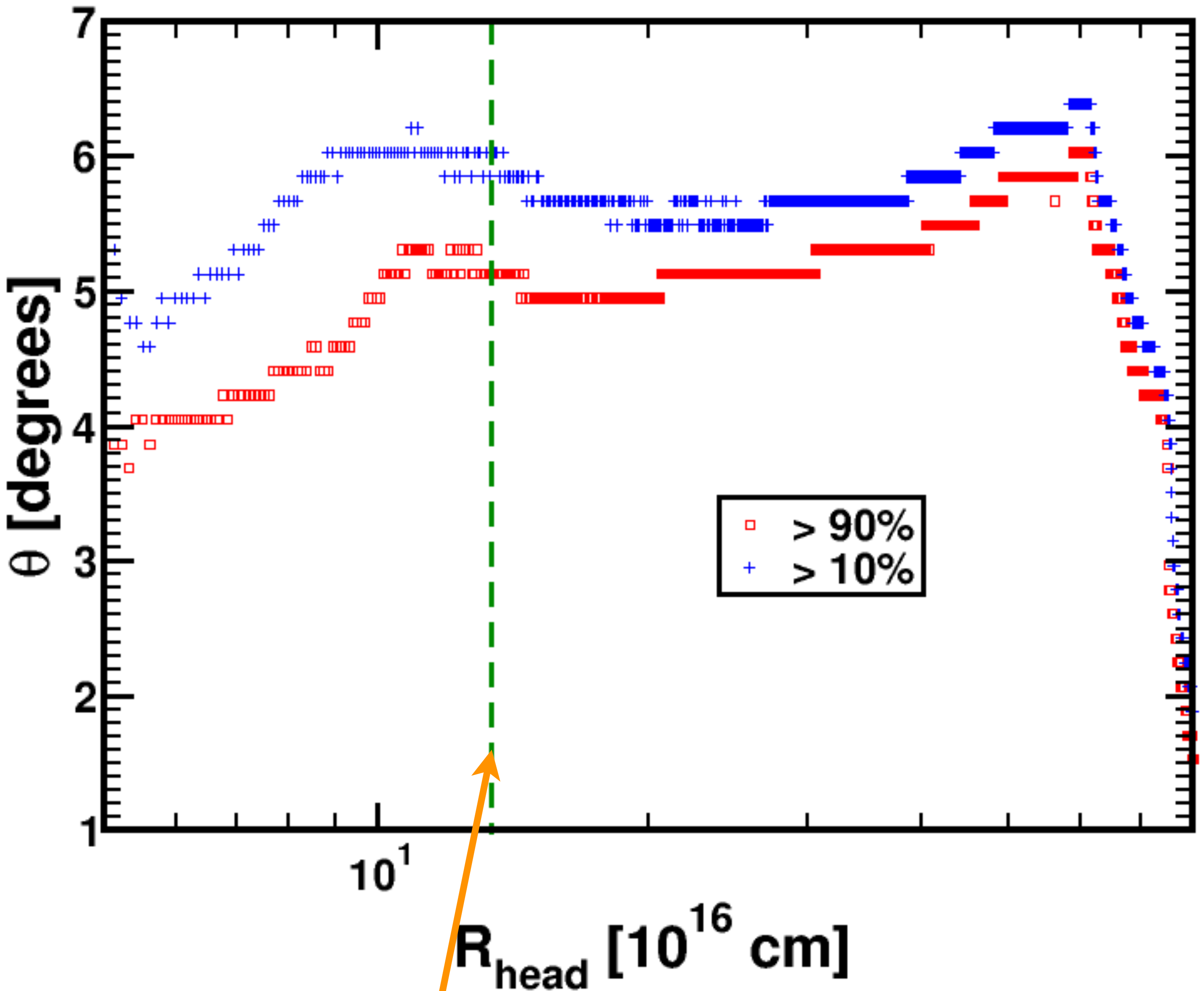



T= 0
$\rho$
$10^{4}$
$10^{3}$
$10^{2}$
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$\theta$
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$\beta$
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
$\Gamma$
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
$y$
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
−1.00
−2.00
−3.00
−4.00
−5.00
−6.00
−7.00
−8.00
−9.00
−10.00
−11.00
−12.00
−13.00
−14.00
−12.00
−9.00
−6.00
−3.00
0.00
3.00
6.00
9.00
12.00
$x$

# Jet opening angle

- tracers particles track the jet
- jet: X = 1, ext. medium: X = 0
- measure angle at which X drops below 90%, 10%

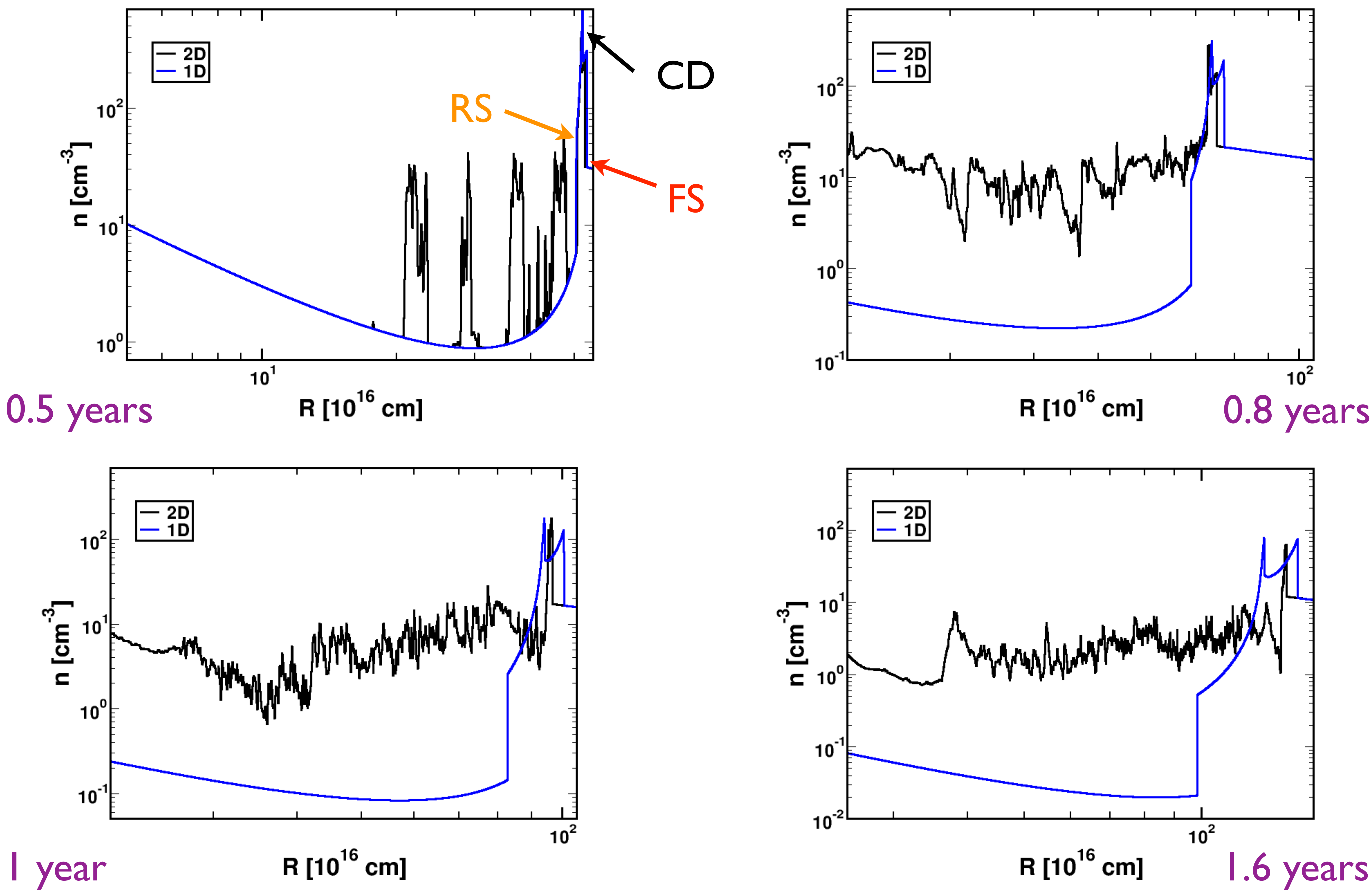


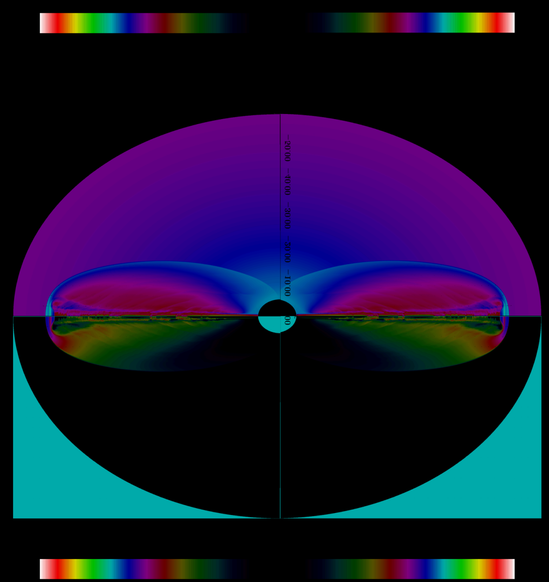




Collimation when $\frac{\rho_j h_j \Gamma_j^2}{\rho_a} \leq \theta_0^{-4/3}$

(Bromberg+ 11)

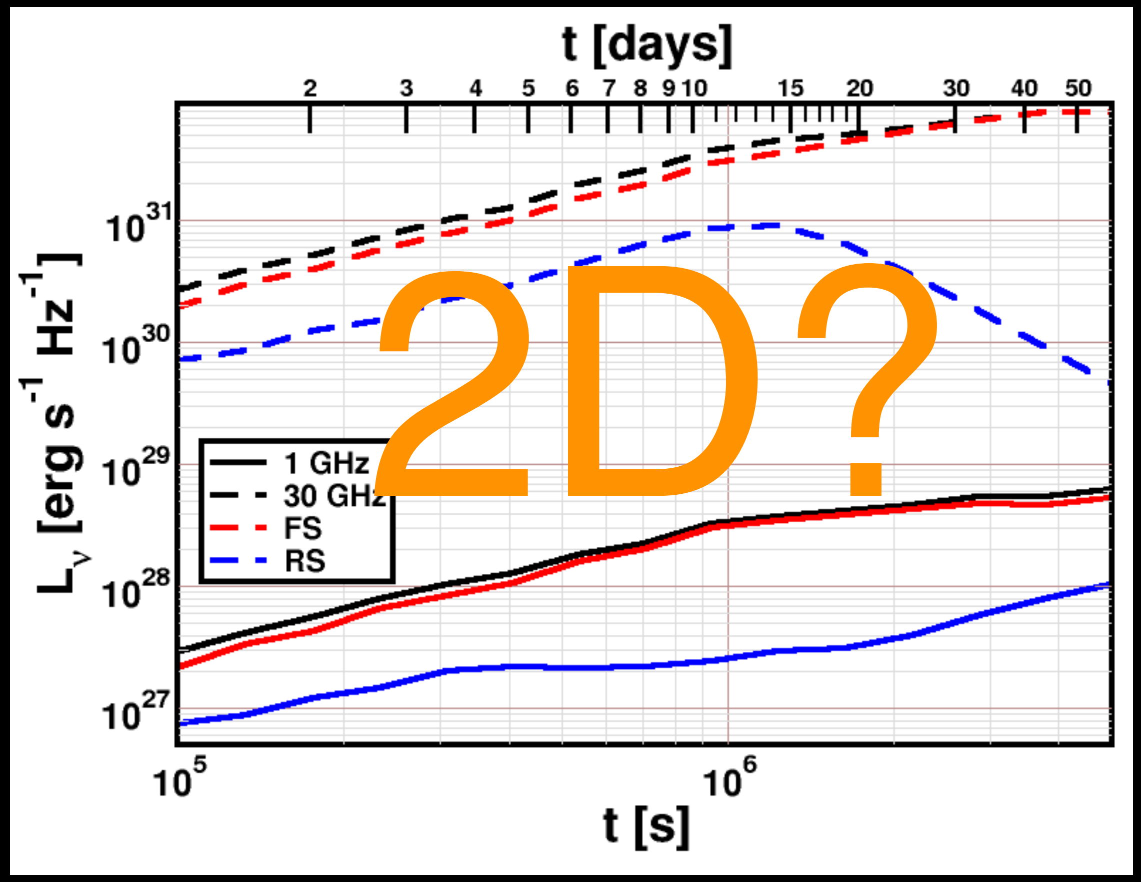
# 1D versus 2D dynamics





on-axis obs.

off-axis obs.




0.1 years

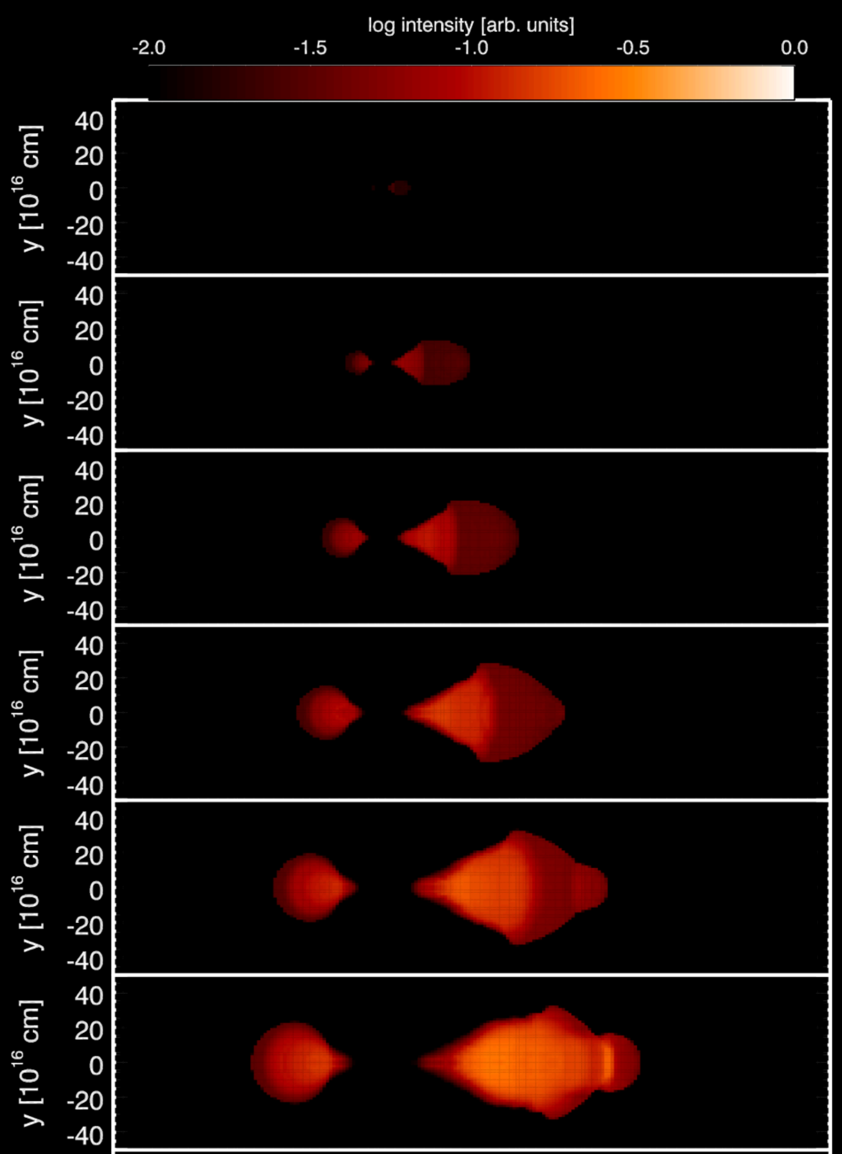
0.2 years

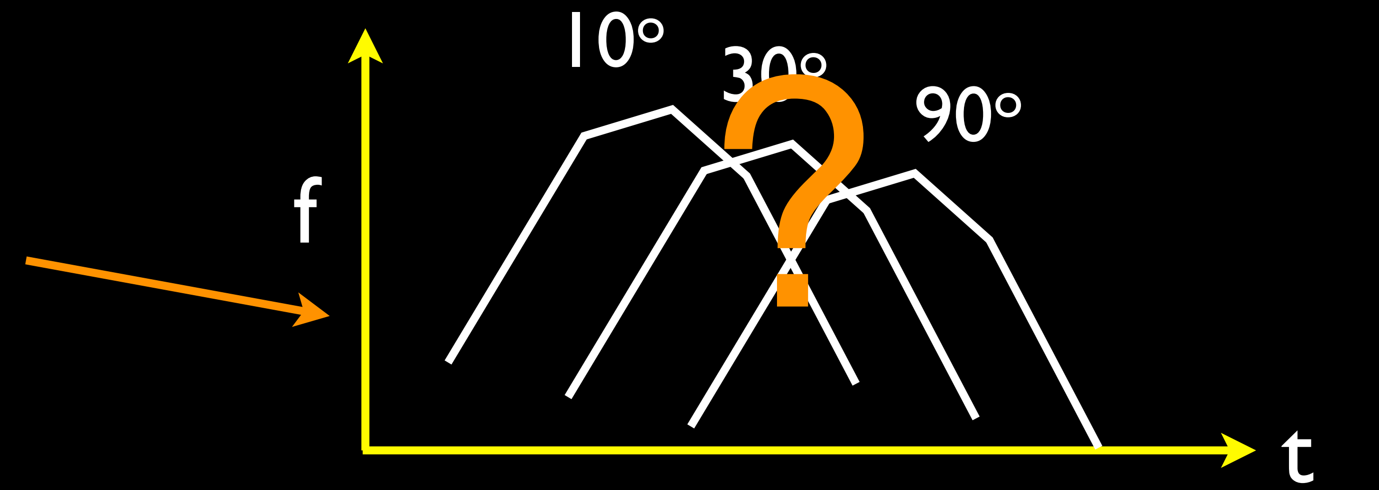
0.3 years

0.4 years

0.5 years

0.6 years



# Summary

- we perform 1D/2D RHD simulations of TDE jets
- 1D dynamics and emission dominated by FS/RS
- 2D dynamics influenced by the cocoon, differs substantially from 1D at later times
- work in progress:
  - light curves for different $\theta_{obs}$ from 0° to 90°
  - jet simulations in different CNM profiles