Spectral evolution of flaring blazars from numerical simulations

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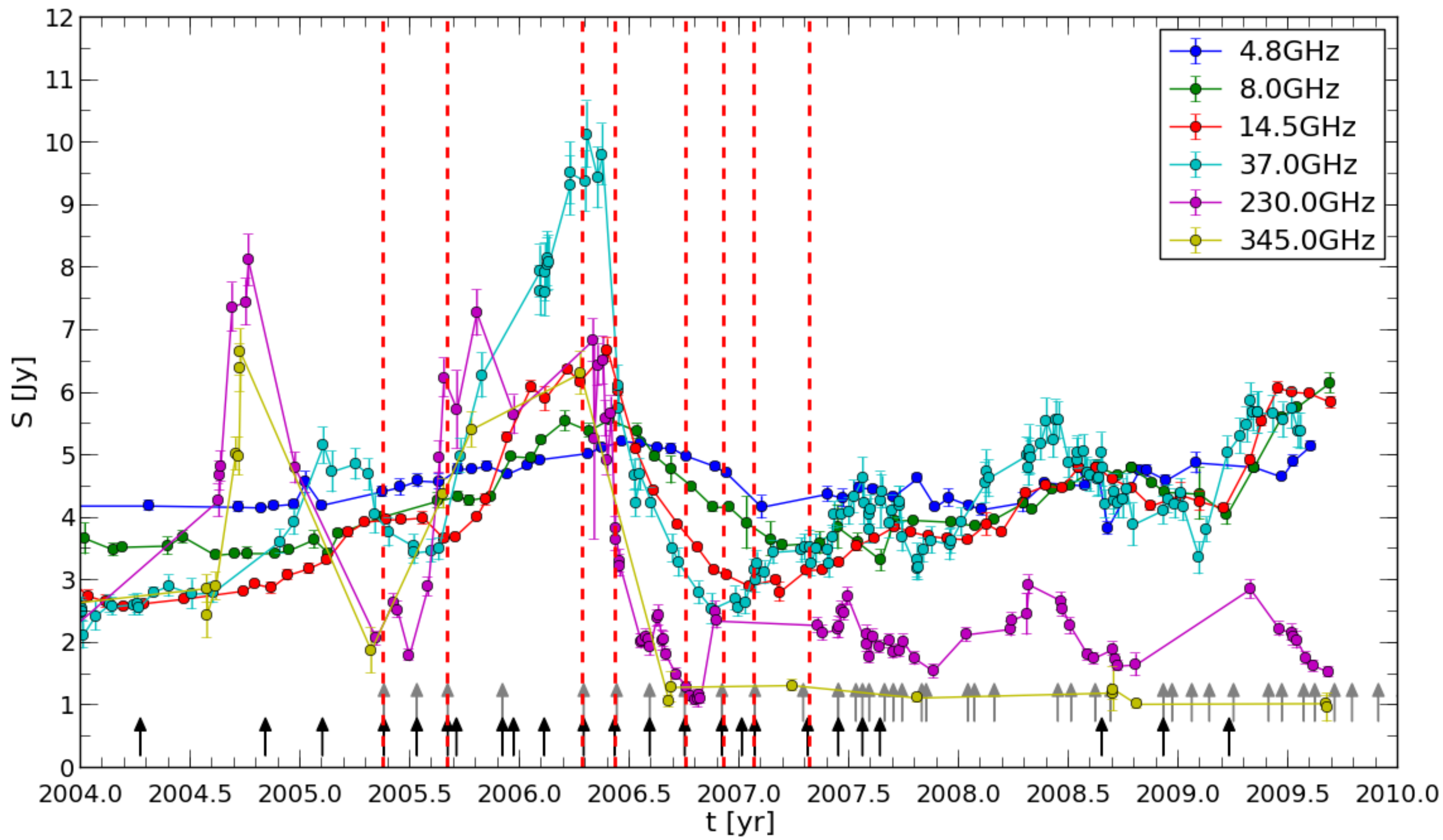
Outline

- Motivation
- Simulation Setup
- Results
- Summary and Outlook

Motivation

2006 radio flare in CTA 102 (z=1.037)

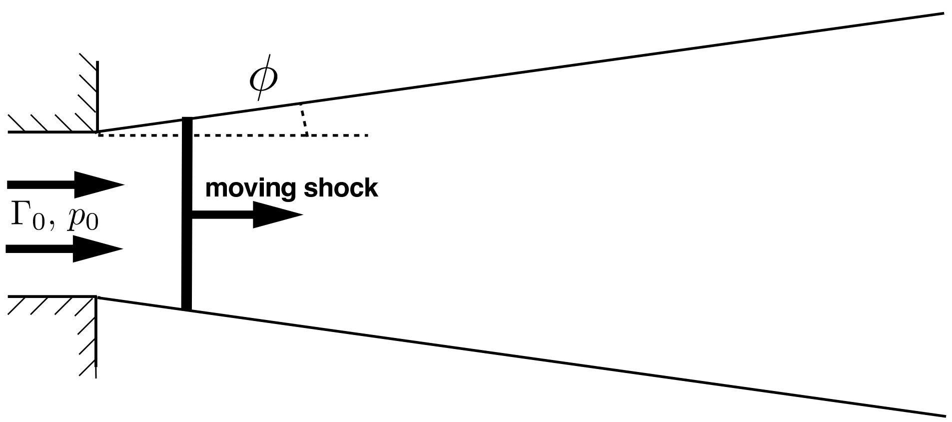


- single dish data 4 GHz -345 GHz (UMRAO, Metsähovi,SMA)
- VLBA observations at 15GHz and 43GHz (MOJAVE & Boston)
- VLBA multi-freq. observations 2GHz -86 GHz

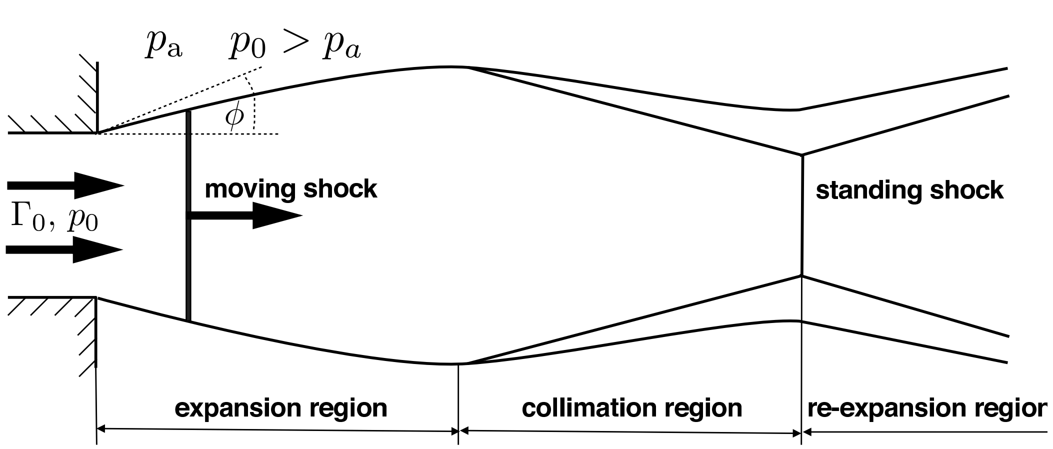
Ref: Fromm et al. 2011,2013a,2013b,2015

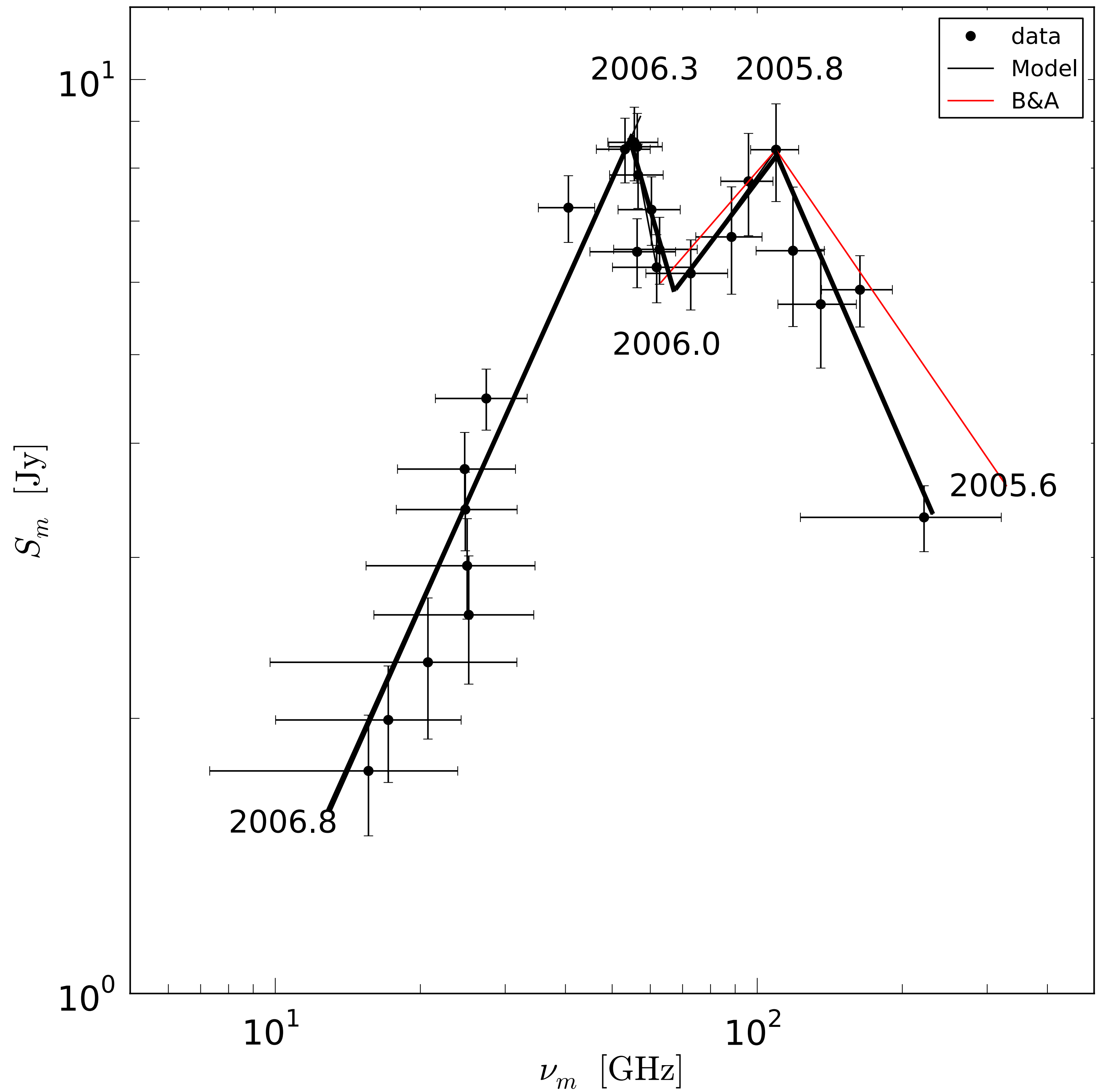
Light curve analysis

conical jet



over-pressured jet

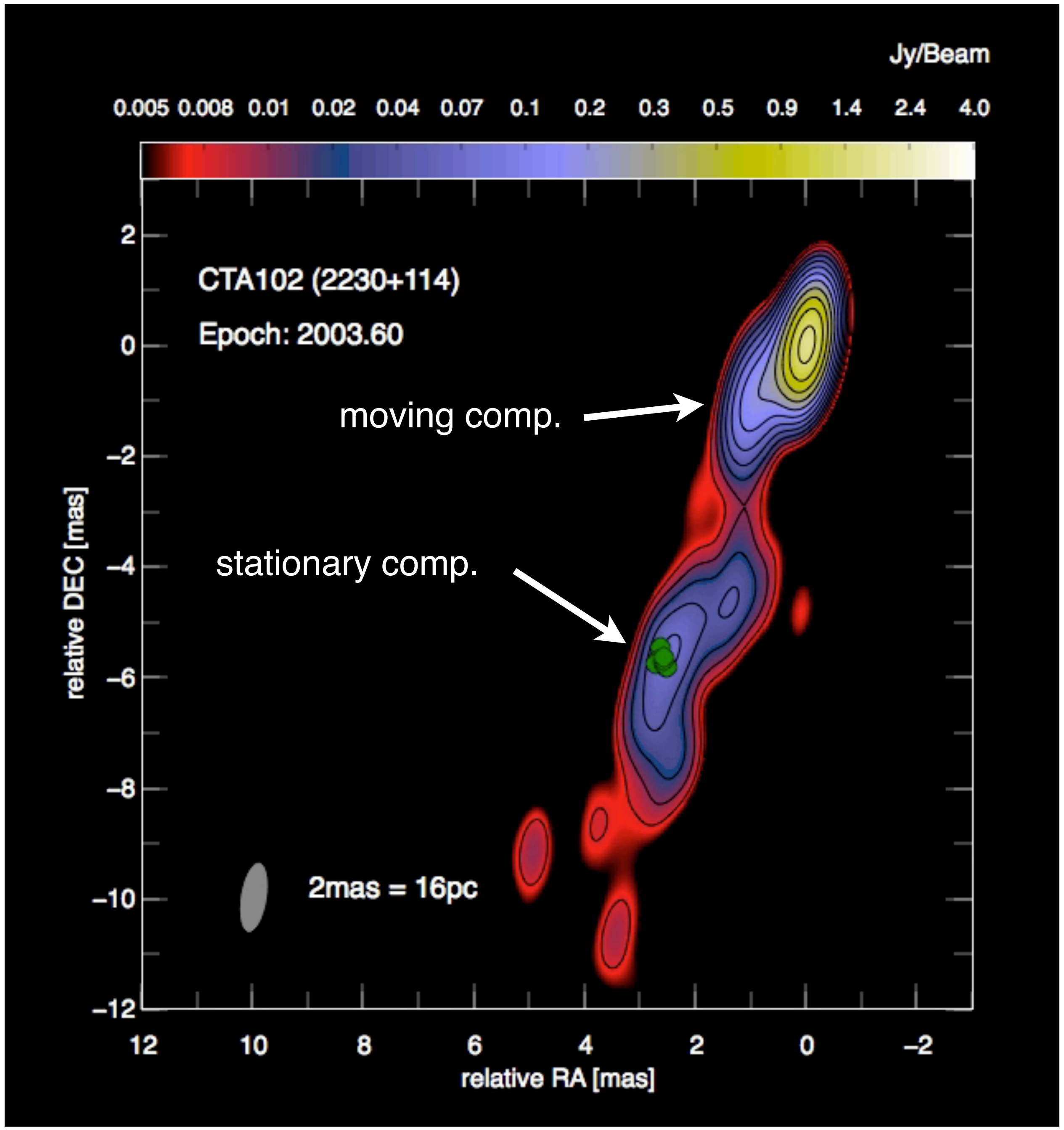




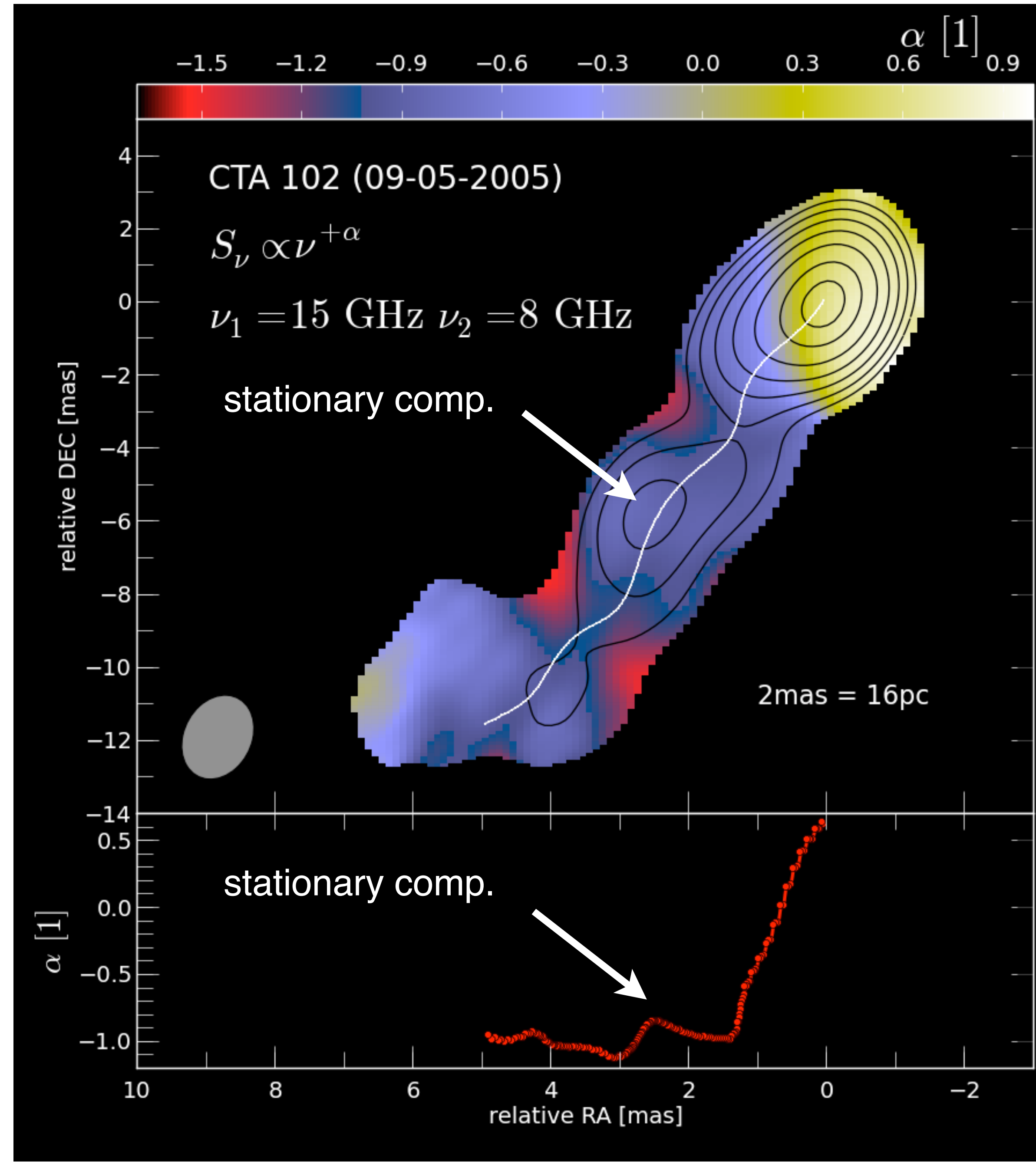
Ref: Marscher & Gear (1985), Fromm et al. (2011)

VLBI observations of CTA102

15GHz Monitoring
(macro-physics)



Multi-frequency
(micro-physics)



Ref: Lister et al. 2009, Fromm et al. 2013a, 2013b

Results of the observations

several stationary features —>recollimation shocks
first at 18pc (43GHz,86GHz)

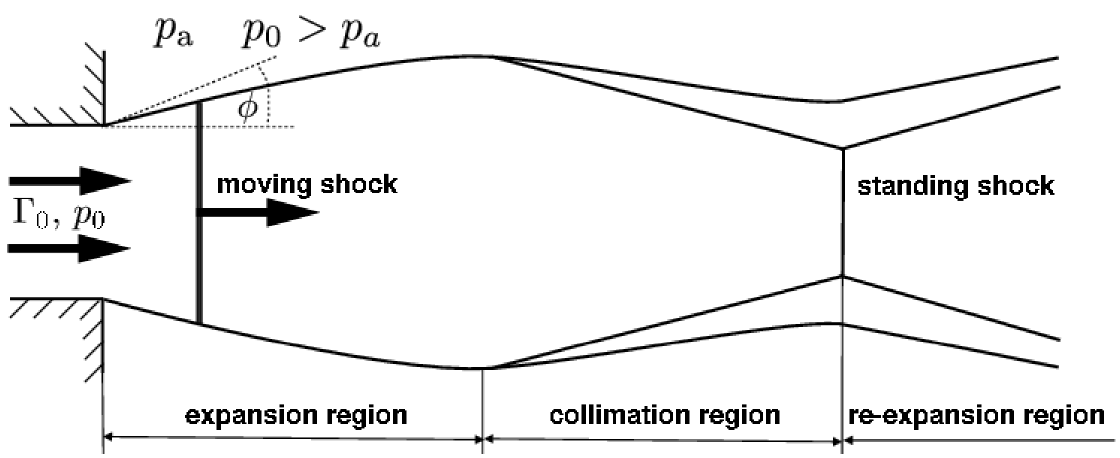
interactions between travelling and recollimation shock interactions

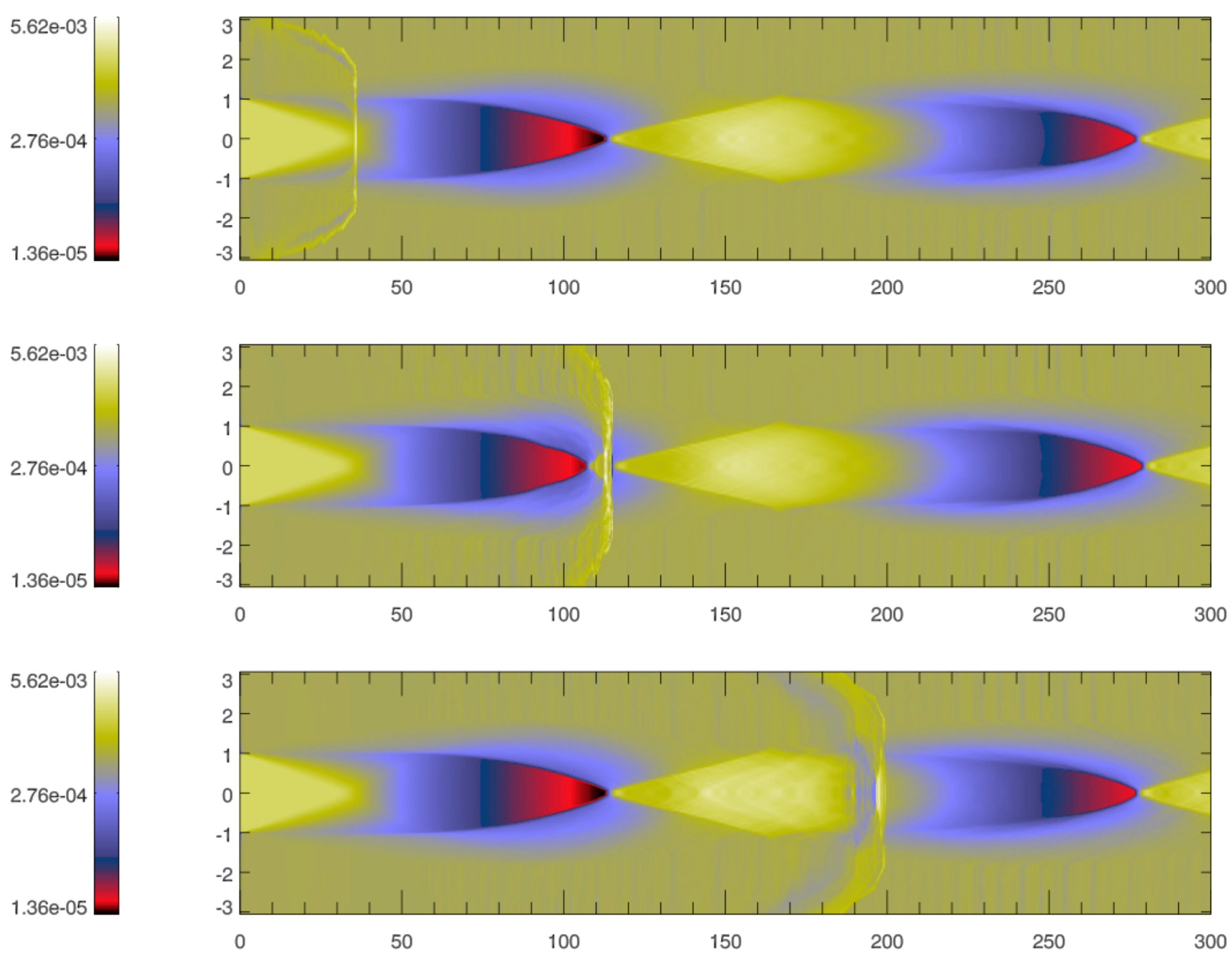
➡ simulations to investigate shock-shock interactions
(focusing on the first recollimation shock)

relativistic hydrodynamics + emission simulations
(Perucho et al. 2010) (Mimica et al. 2009 & Fromm 2013)

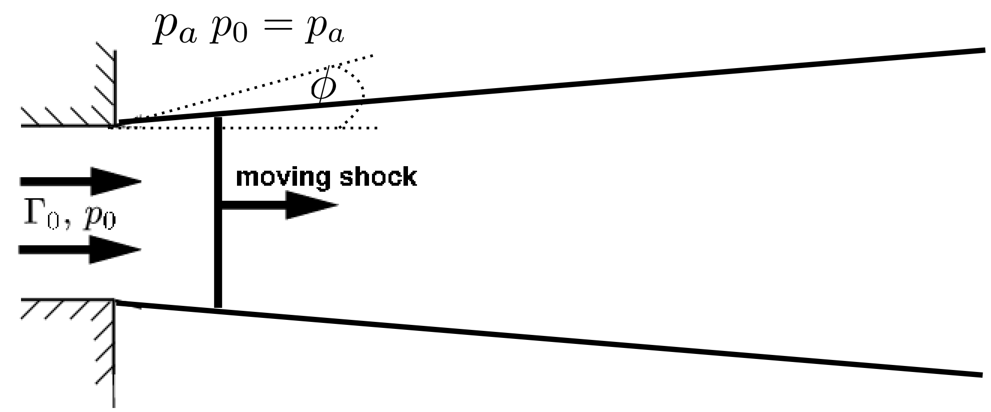
RHD simulations

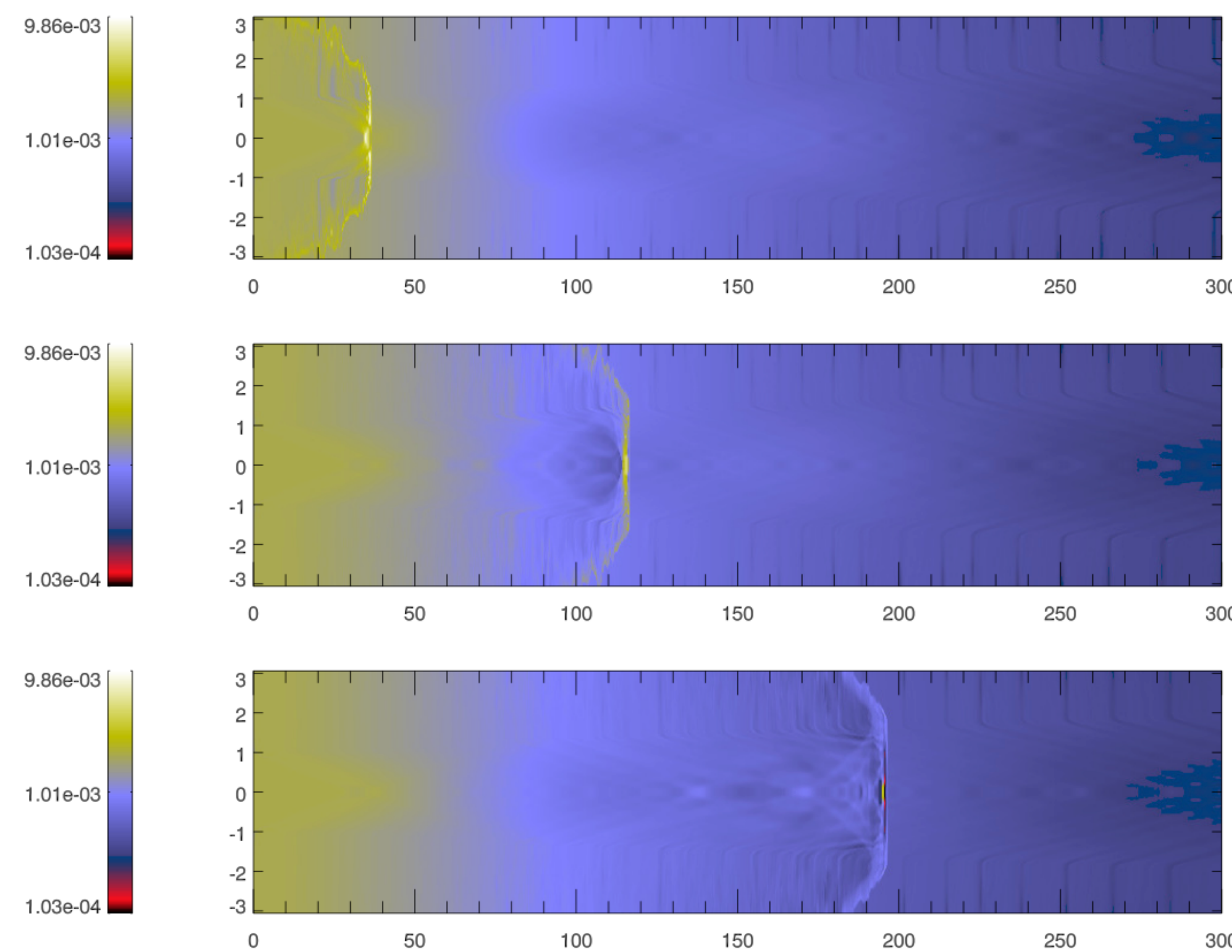
over-pressured jet





pressure matched jet

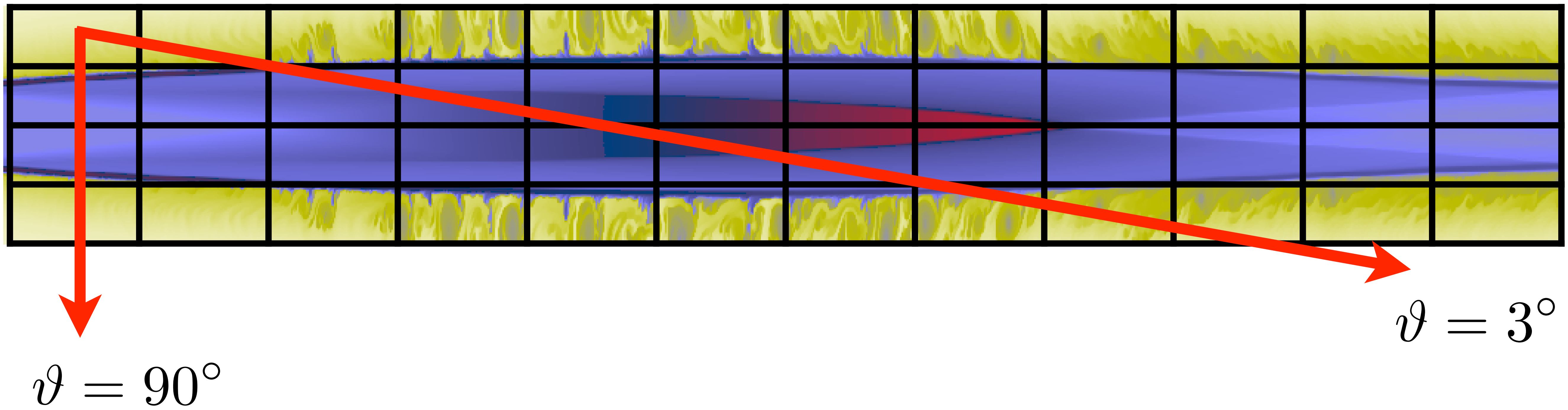




Radiative transfer (ray tracing)

include micro-physics: absorption, emission, losses and delays

using 3D ray-tracing technique and large frequency range

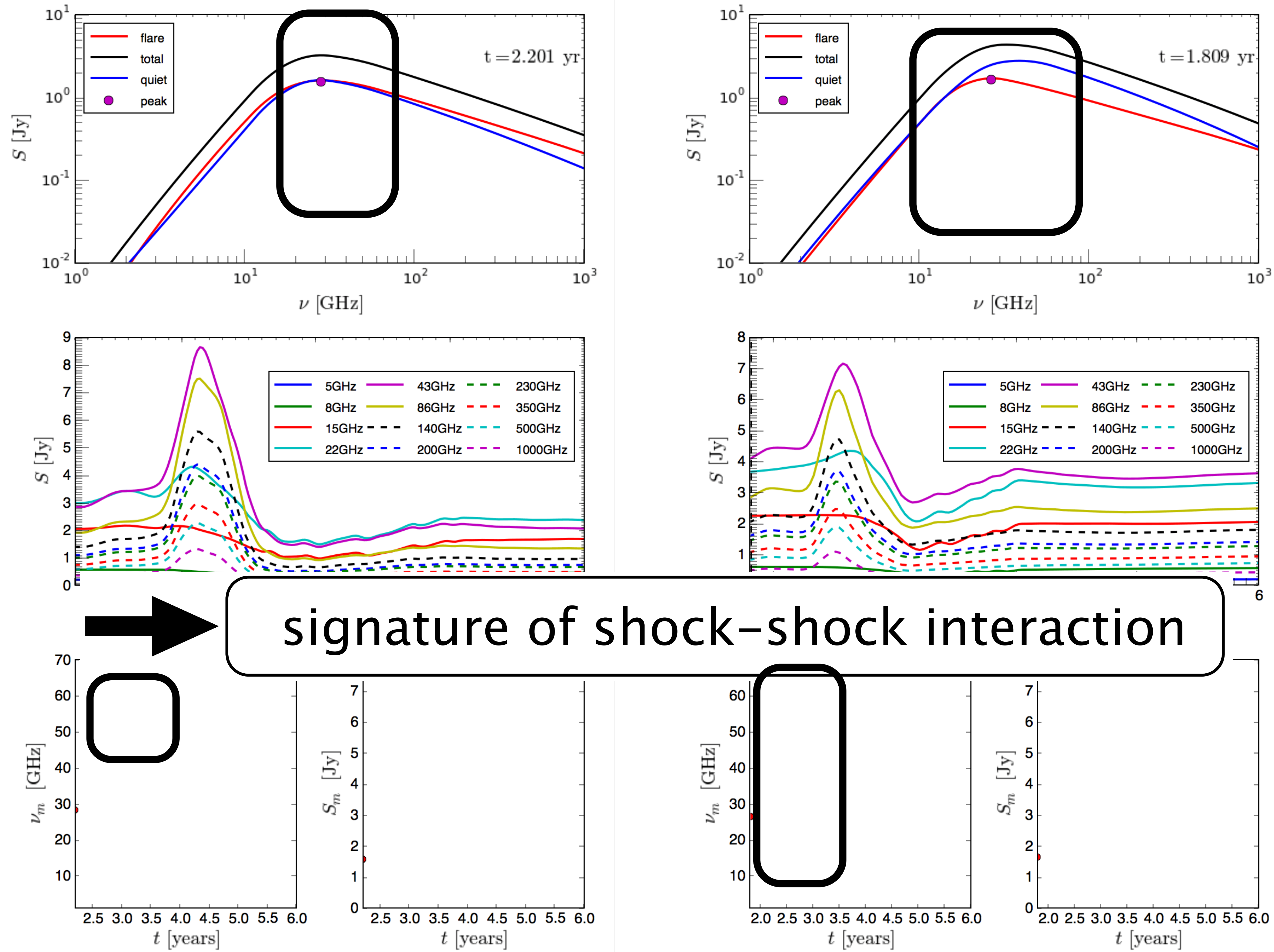


ρ_a	R_j	ϑ	s	ϵ_B	ϵ_e	ζ_e	z
$1.67 \times 10^{-21}\mathrm{g/cm^3}$	$3.08 \times 10^{17}\mathrm{cm}$	3°	2.3	0.1	0.5	1.0	1.0

→ synchrotron spectrum (1–1000GHz) at each pixel

Ref: Mimica et al. 2009, Fromm et al. 2013, 2016

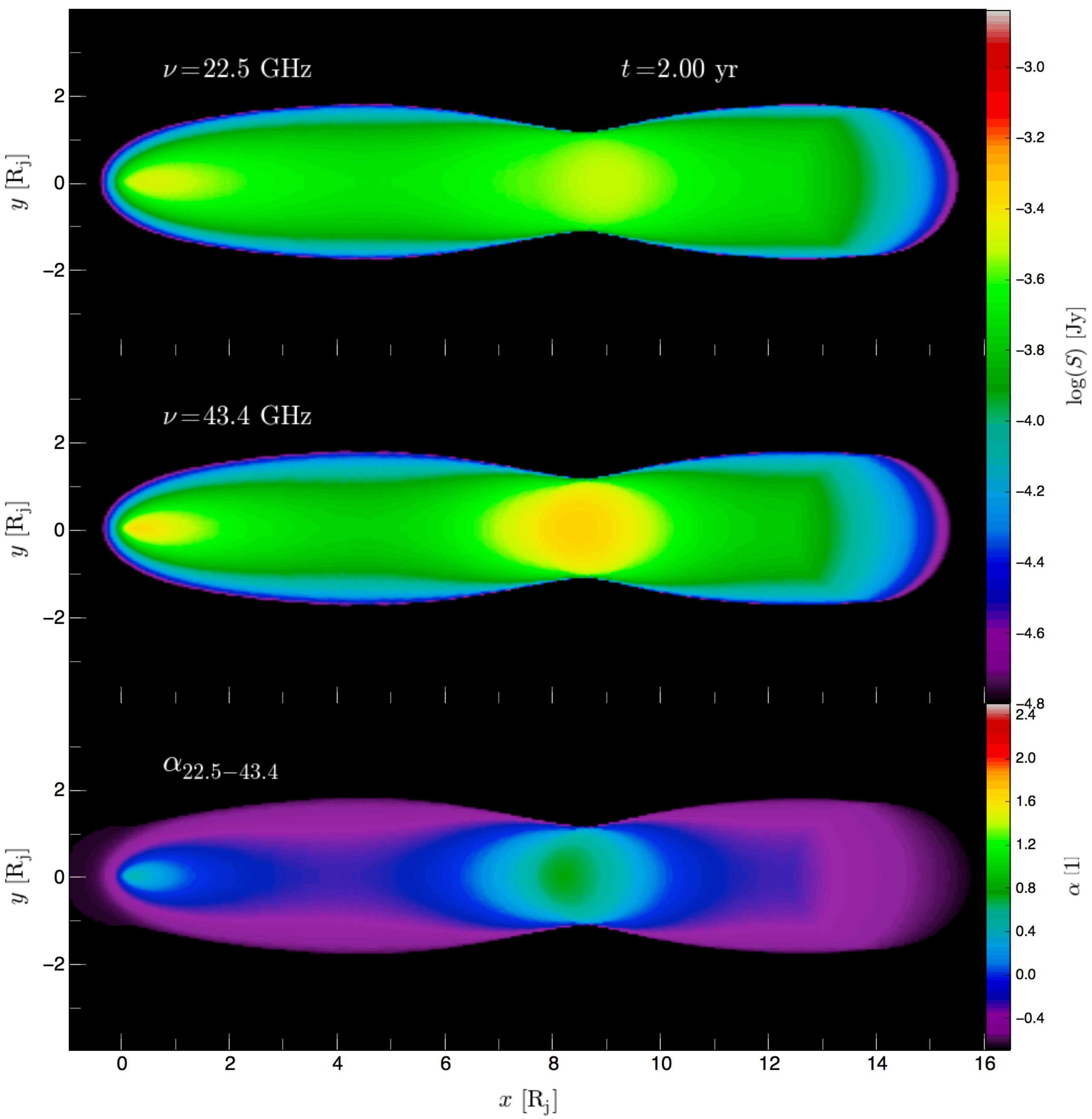
Single dish light curves



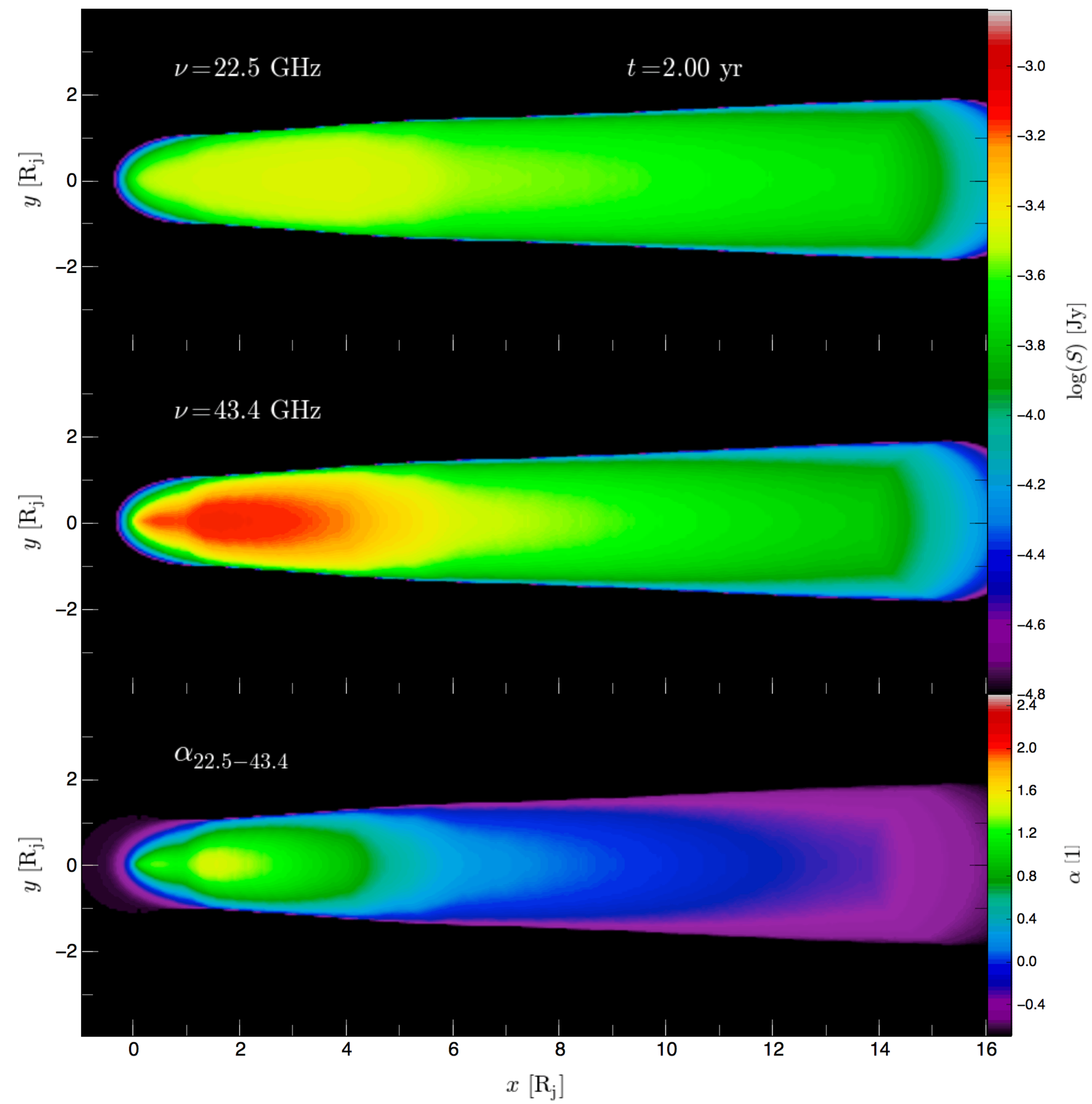
signature of shock-shock interaction

Radio maps

over-pressured jet



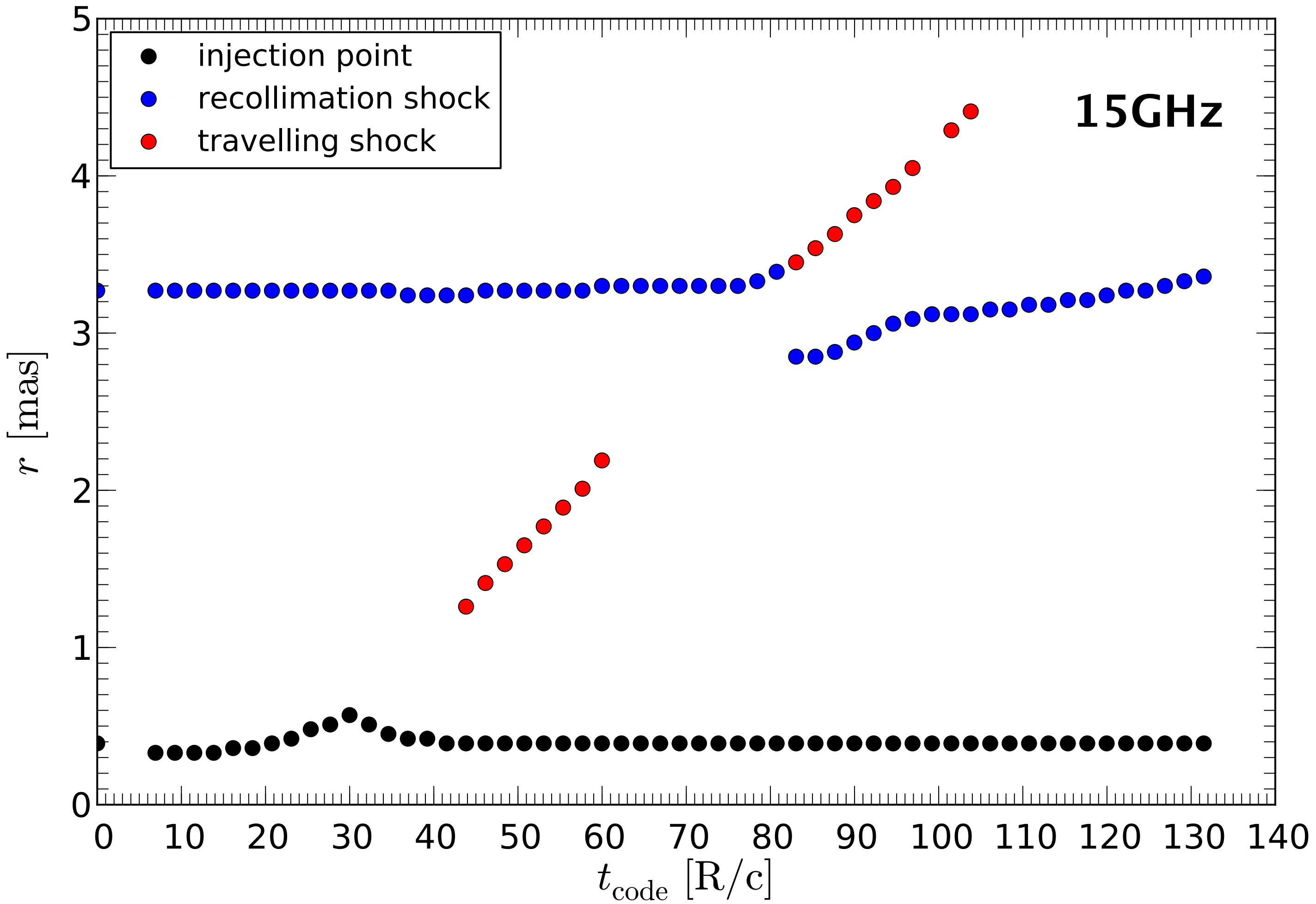
pressure matched jet



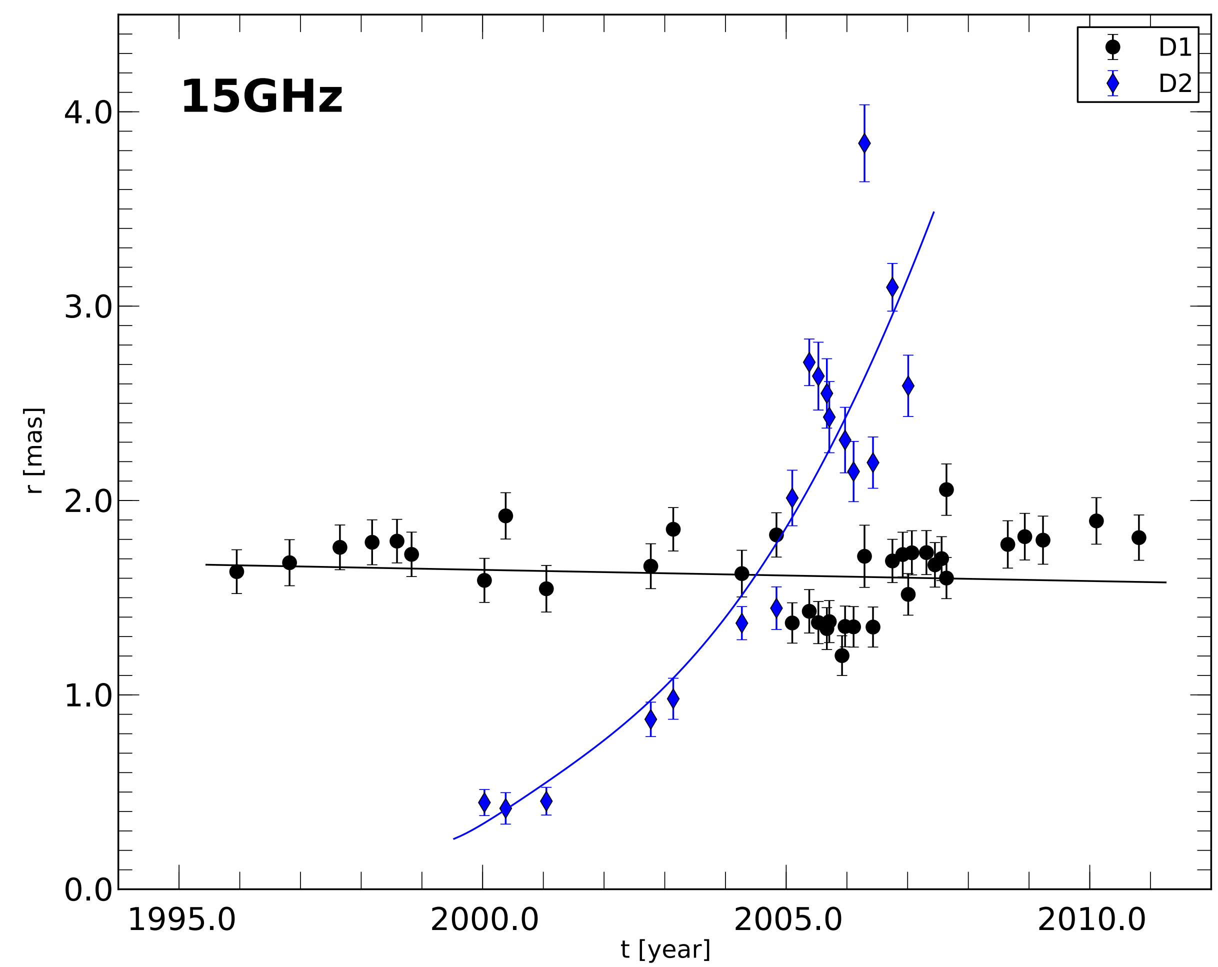
Ref: Fromm et al. 2016

Shock-Shock interaction (re-scaled)

eRHD simulations



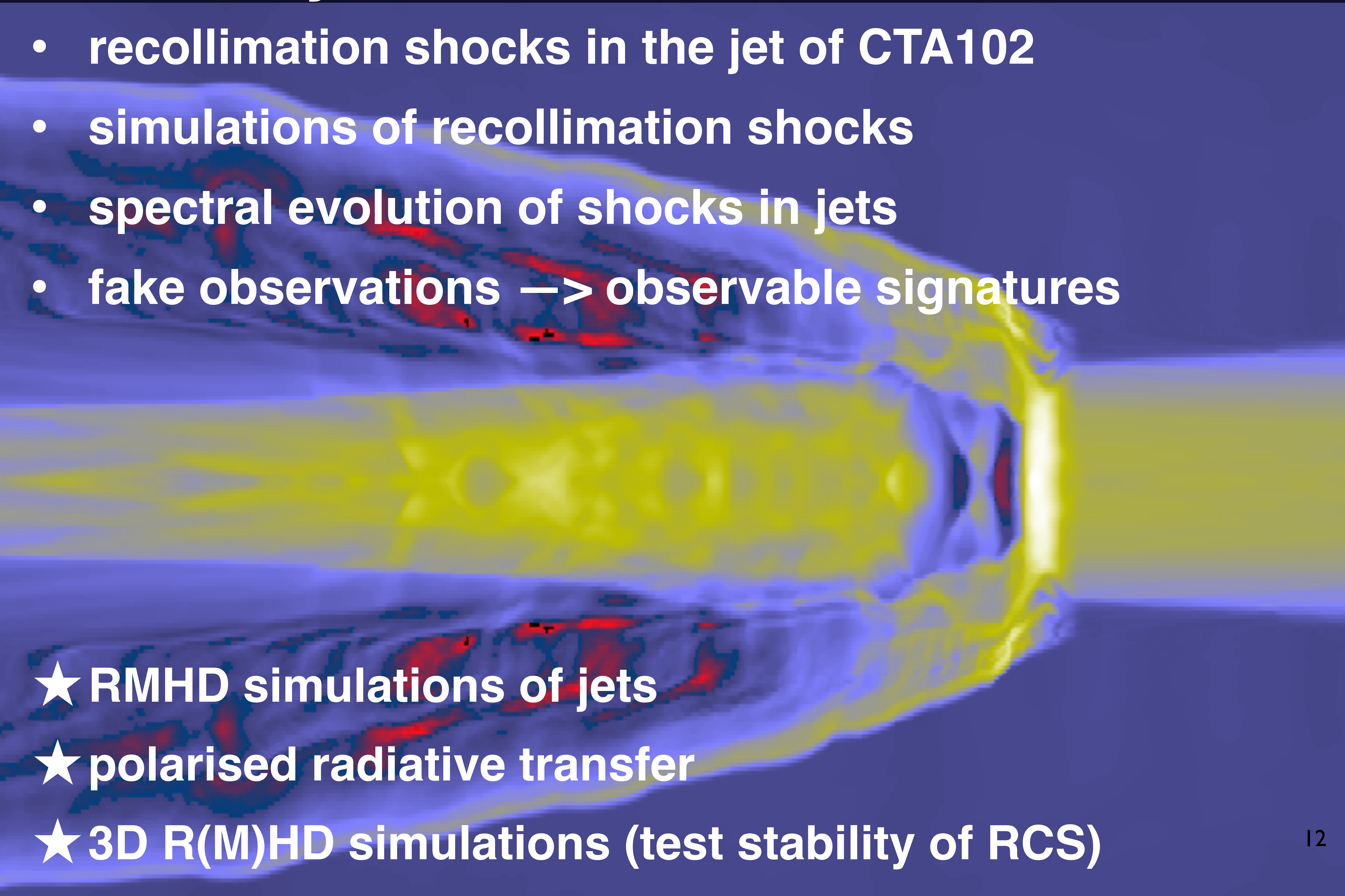
CTA102@15GHz



signature of shock-shock interaction

Ref: Fromm in prep.

Summary & Outlook



- recollimation shocks in the jet of CTA102
- simulations of recollimation shocks
- spectral evolution of shocks in jets
- fake observations —> observable signatures

★ RMHD simulations of jets

★ polarised radiative transfer

★ 3D R(M)HD simulations (test stability of RCS)

Emission Simulation

$$n(\gamma) = n(\gamma_{\min}) \left(\frac{\gamma}{\gamma_{\min}}\right)^{-p} \qquad \gamma_{\min} < \gamma < \gamma_{\max}$$

e- distribution

$$B = \left(\boxed{\epsilon_b} \frac{8\pi p_{th}}{\widehat{\gamma} - 1}\right)^{1/2}$$

magnetic field [G]

$$\boxed{\begin{array}{c} 0 < \epsilon_e < 1 \\ 0 < \epsilon_b < 1 \\ 1e3 < \epsilon_a < 1e6 \end{array}}$$

$$\gamma_{\max} = \left(\frac{9 m_e^2 c^4}{8\pi e^3 \boxed{\epsilon_a} B}\right)^{1/2}$$

max e- Lorentz factor

$$\gamma_{\min} = \frac{\boxed{\epsilon_e} p_{th} m_p (p-2)}{\rho_{th} (\widehat{y} - 1) m_e c^2 (p-1)}$$

min e- Lorentz factor

$$n(\gamma_{\min}) = \frac{\boxed{\epsilon_e} p_{th} (p-2)}{(\widehat{\gamma} - 1)\gamma_{\min}^2 m_e c^2} \left[1 - \left(\frac{\gamma_{\max}}{\gamma_{\min}}\right)^{2-p}\right]^{-1}$$

coeff. e- distribution

Ref: Mimica et al. (2009, 2010), Dermer & Boettcher (2010)

Emission Simulation

evolution of e- Lorentz factor (see Mimica et al. 2009)

$$\frac{d\gamma}{d\sigma} = k_a\gamma - k_s\gamma^2$$

adiabatic losses radiative losses

$$k_a = \frac{1}{3}\frac{dln\rho_j}{d\sigma} \qquad k_s = \frac{2}{3}\frac{e^4}{8\pi m_e^3 c^5}B^2$$

e-Lorentz factor:

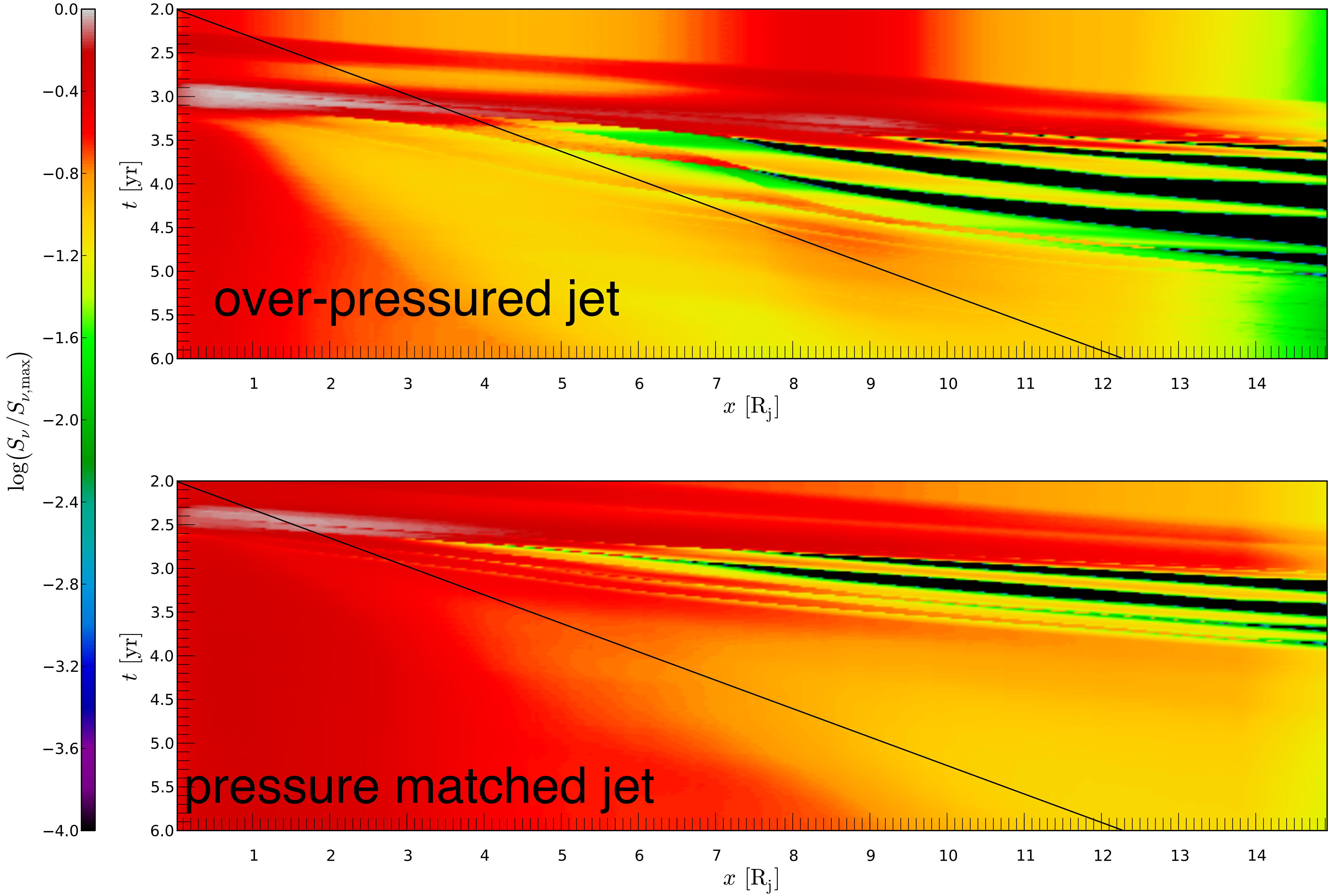
$$\gamma(\sigma) = \gamma_0 \frac{k_a e^{k_a\Delta\sigma}}{k_a + \gamma_0 k_s \left(e^{k_a\Delta\sigma} - 1\right)}$$

coeff. e- distr.

$$n_0(\gamma(\sigma)) = n_0\left(\gamma_0\right)\left[e^{k_a\Delta\sigma}\left(1 + \gamma_0\frac{k_s}{k_a}\left(e^{k_a\Delta\sigma} - 1\right)\right)\right]^2$$

Ref: Mimica et al. (2009, 2010)

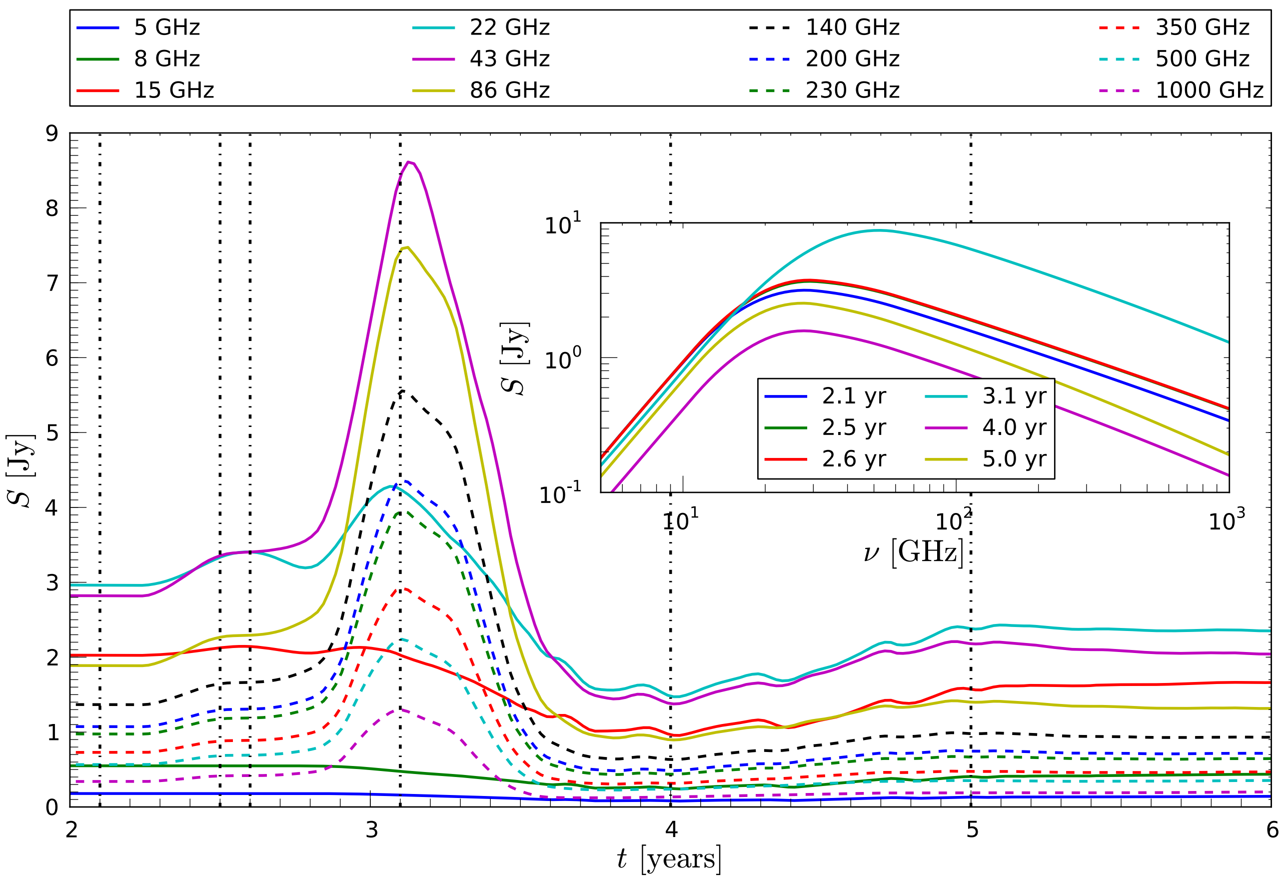
43 GHz evolution



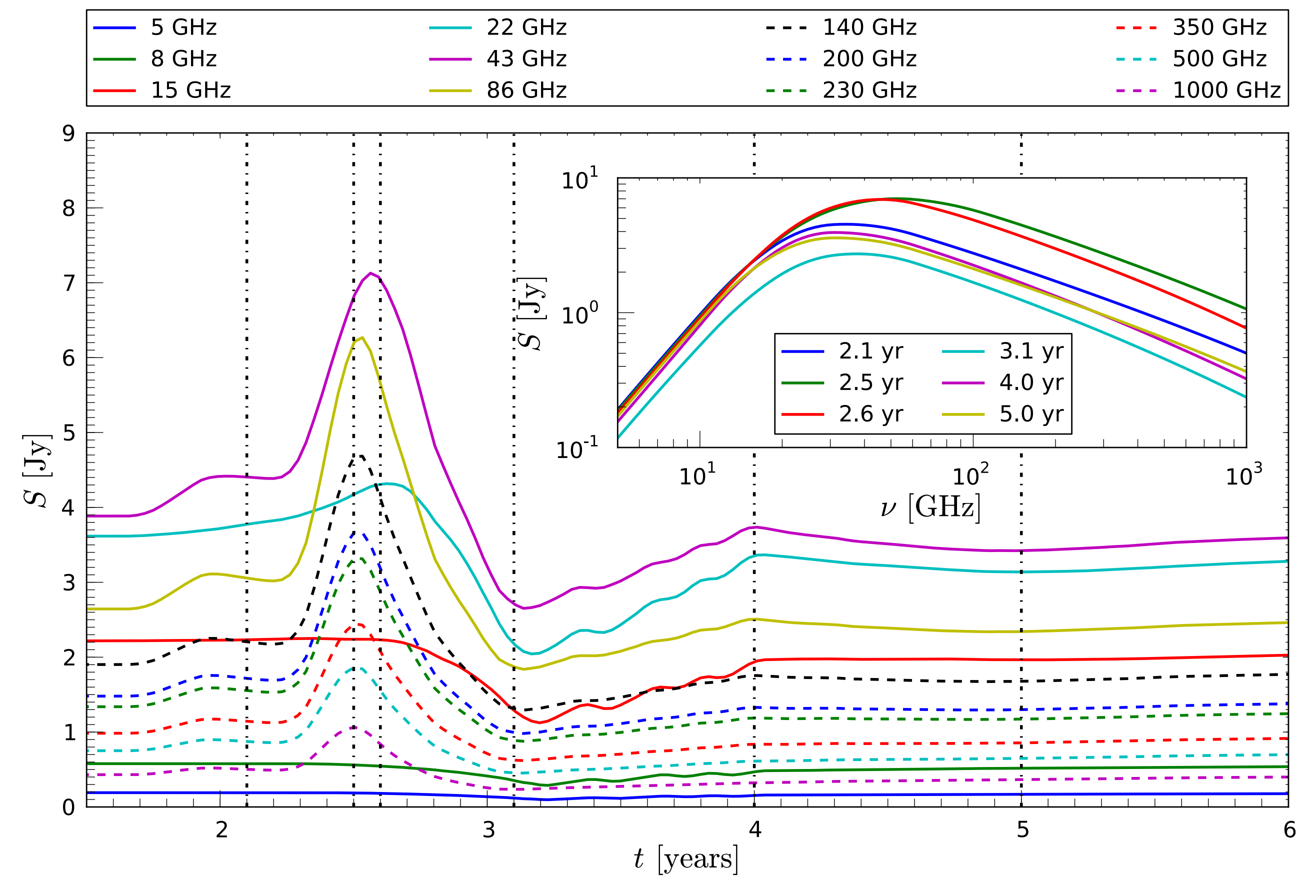
Ref: Fromm et al. 2016

Single dish light curves

over-pressured jet

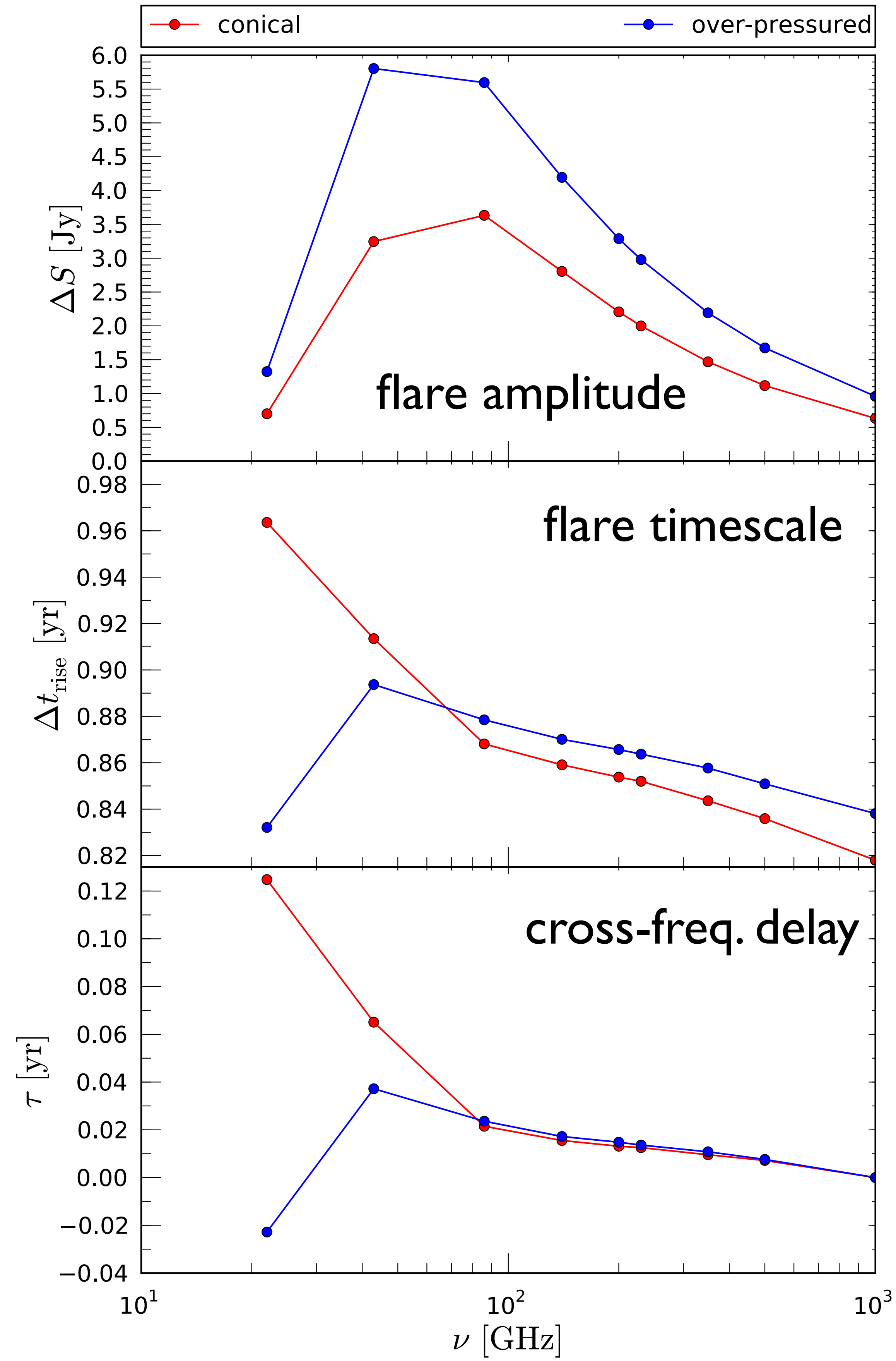


pressure matched jet



Ref: Fromm et al. 2016

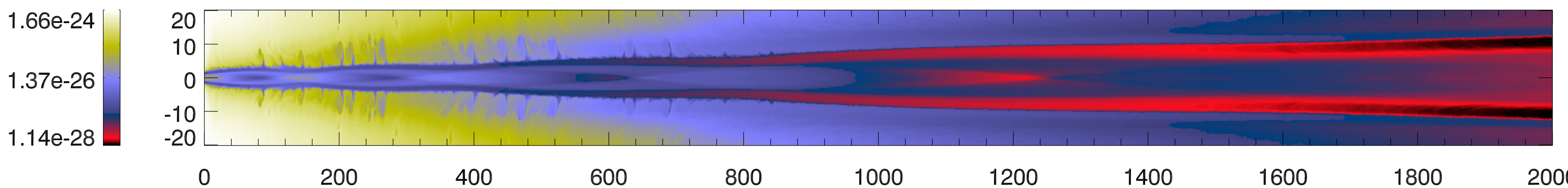
Single dish analysis

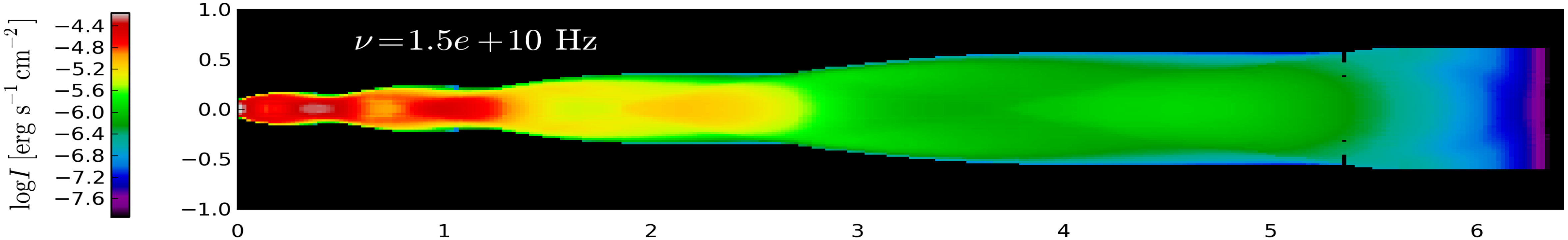


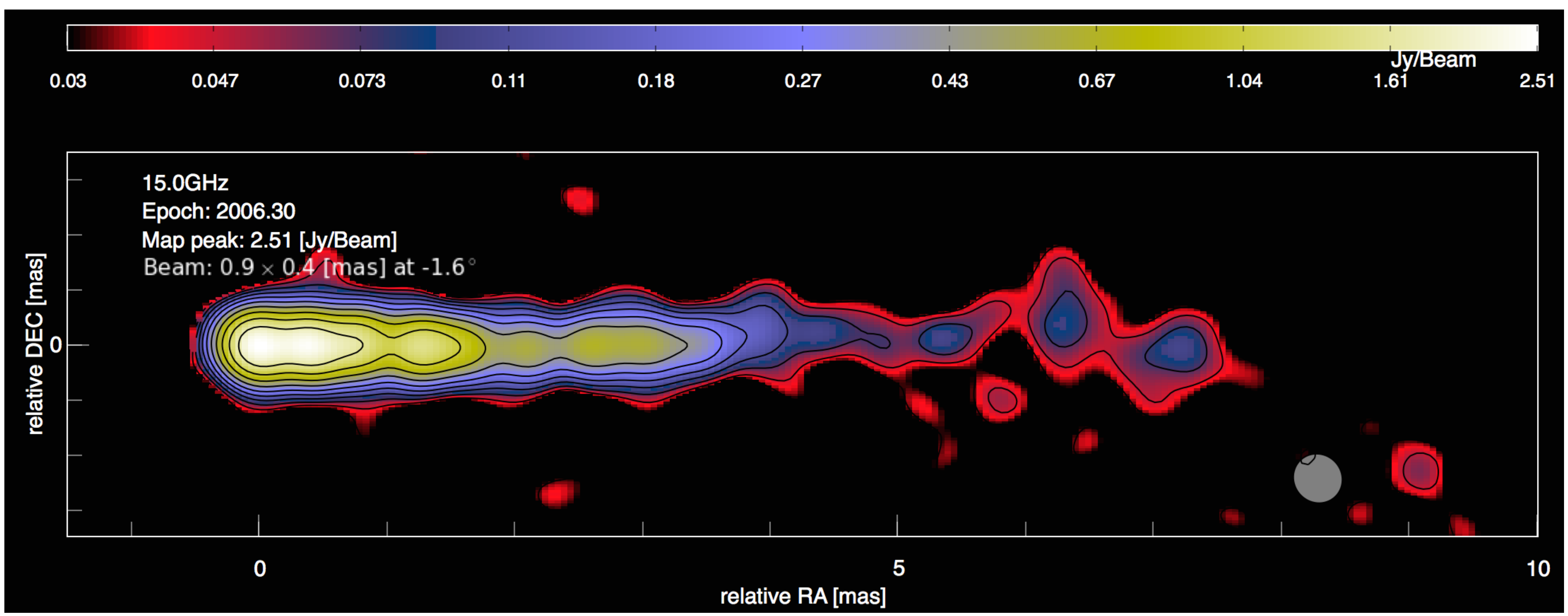
Ref: Fromm et al. 2016

Large scale simulations

Log Rest-mass density





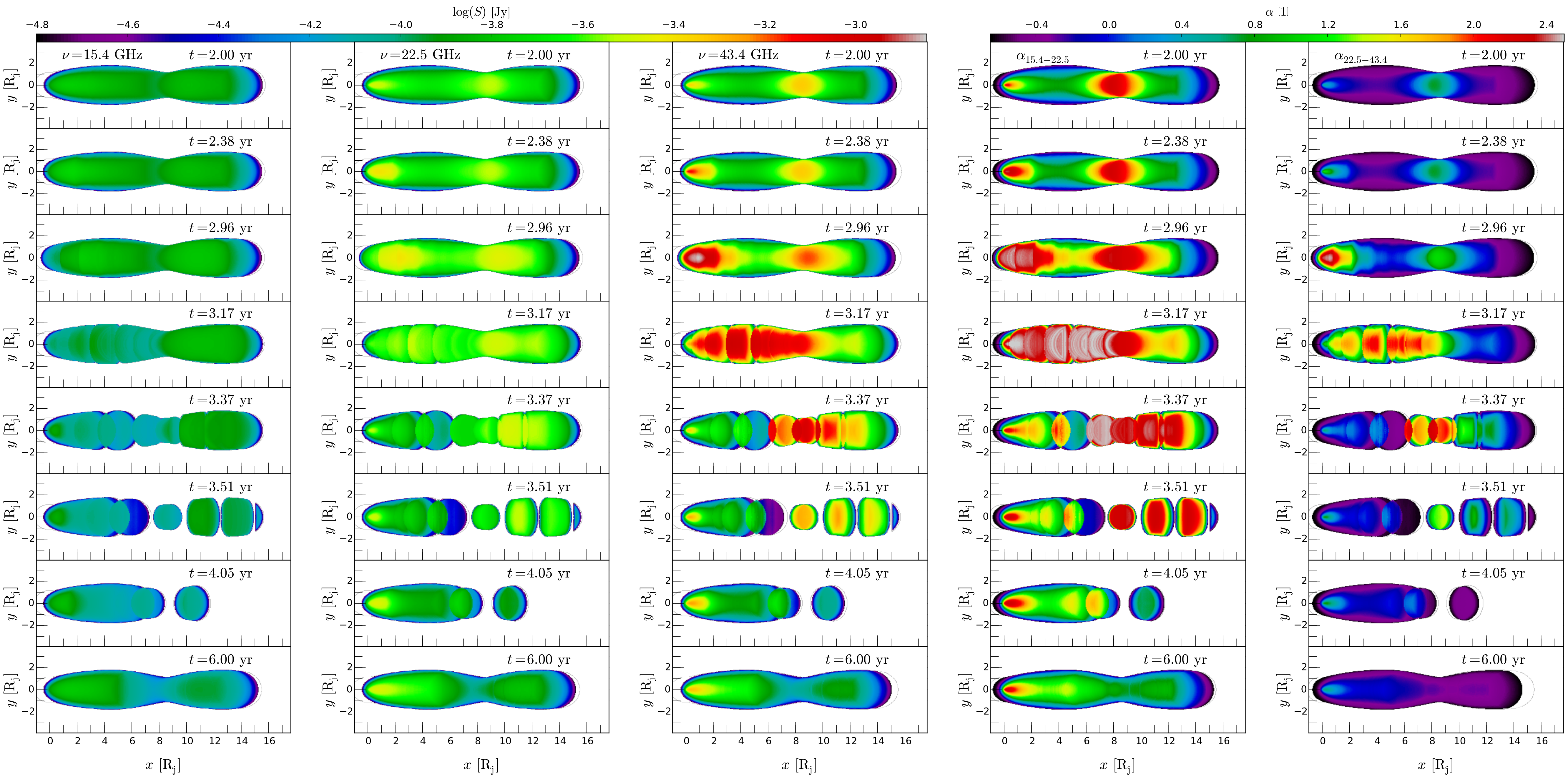


using VLBA properties and observation settings

Ref: Fromm in prep.

Radio maps (back-up)

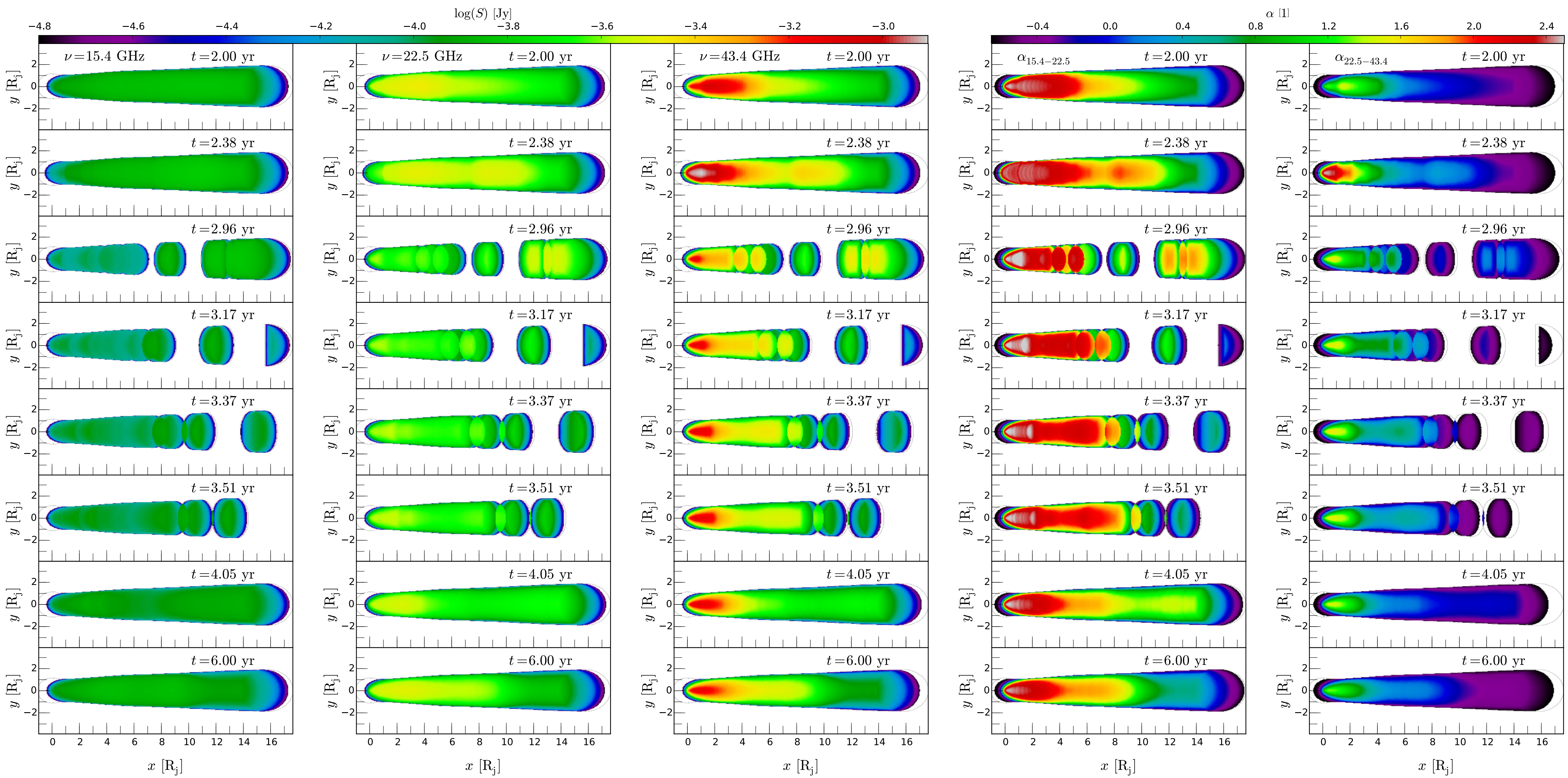
over-pressured jet



Ref: Fromm et al. 2016

Radio maps (back-up)

pressure-matched jet



Ref: Fromm et al. 2016