

Restarted Jets: Dynamics, Particle Acceleration and Emission.

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Morganti

Illuminating the Active Universe, Sep 16 2026,
ESO

REVIEW ARTICLE

Active galactic nuclei: what's in a name?

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There is only one animal in the AGN zoo: It is an accreting supermassive black hole.

Restarted Jets

About 10% (1% ?) of AGN are jetted,

A few hundred cases of Restarted Jets have been observed.

Causes of Restart:

- Cooling Flow - Feedback Loop.
- Accretion Disc Instabilities.
- Mergers ...

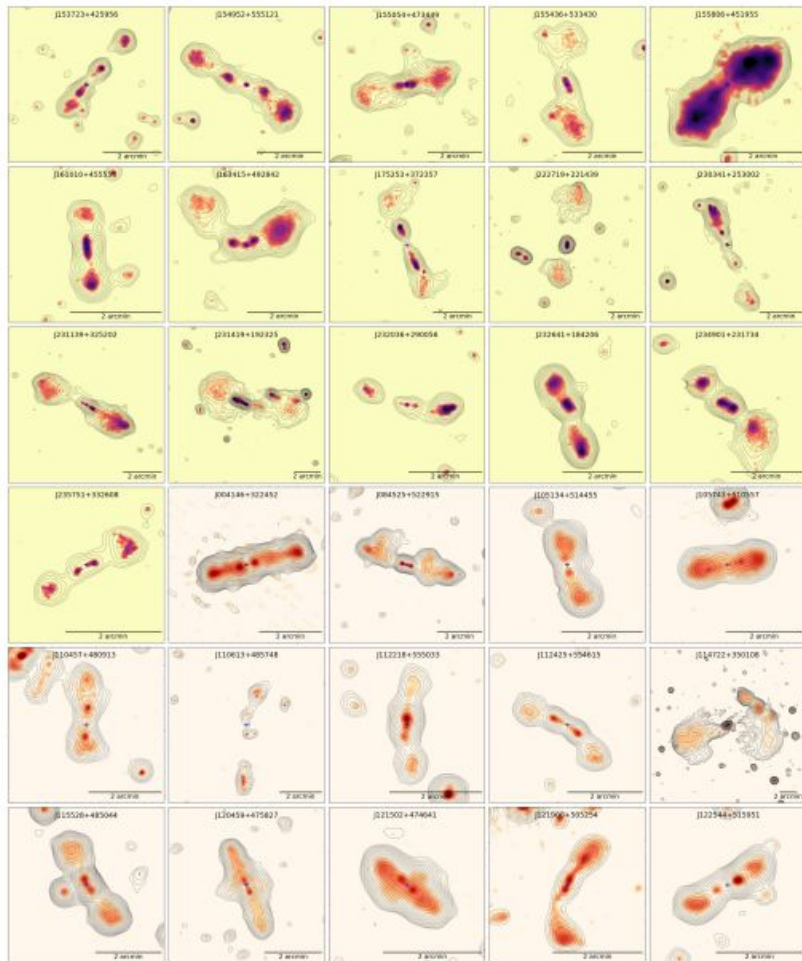


Fig. B.3. Same as Fig. B.1 but for sources 61 to 76 from the upper half of Tab. A.1 and sources 1 to 14 (in different colour scheme) from the lower half of the Tab. A.1 which represent known G-DDRGs in our sample (for more details see Sec. 2).

Science Questions

- Are instabilities efficient at filling the cavity left by the previous episode?
- How do power, magnetic field affect the instabilities?
- What is the source of emission for the new jet: fresh particles or old, re-accelerated particles?
- How the conditions in the old cocoon shape the dynamics of the new jet?

For additional results, please refer to our papers:

Paper 1 : Numerical Simulations of Restarted Jets - I. Dynamics

Ratnaparkhi et. al. 2026

Paper 2 : Numerical Simulations of Restarted Jets II: Particle Acceleration and Emission

Ratnaparkhi et. al. 2026 (to be submitted)

How do we attack the problem?

Fluid simulations with lagrangian particles.

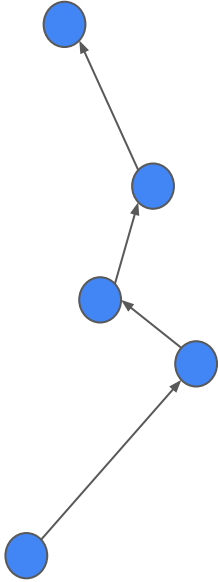
3 Simulations with 2 restarted cases each.

	Magnetisation	Power (erg / s)
Sim A	0.1	10^{45}
Sim B	0.05	10^{45}
Sim C	0.05	10^{44}

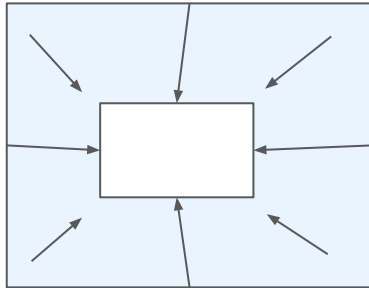
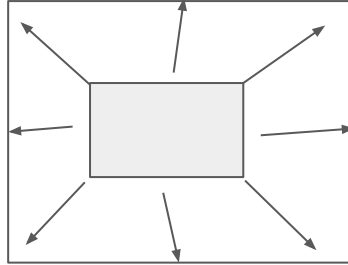
Vastly different scales for particle acceleration and fluid simulations.
How to bridge the gap?

Lagrangian Particles

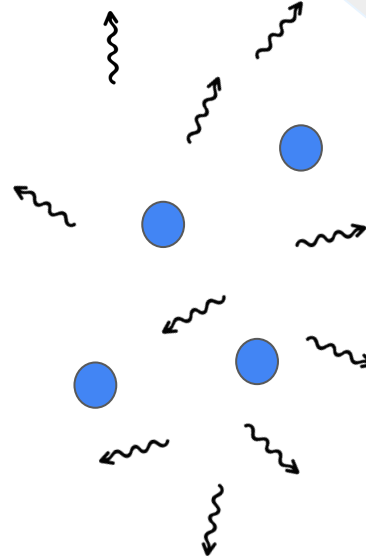
Advection



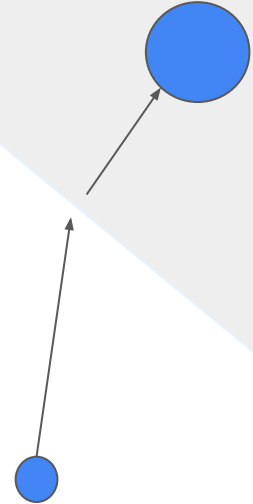
Adiabatic cooling/
heating



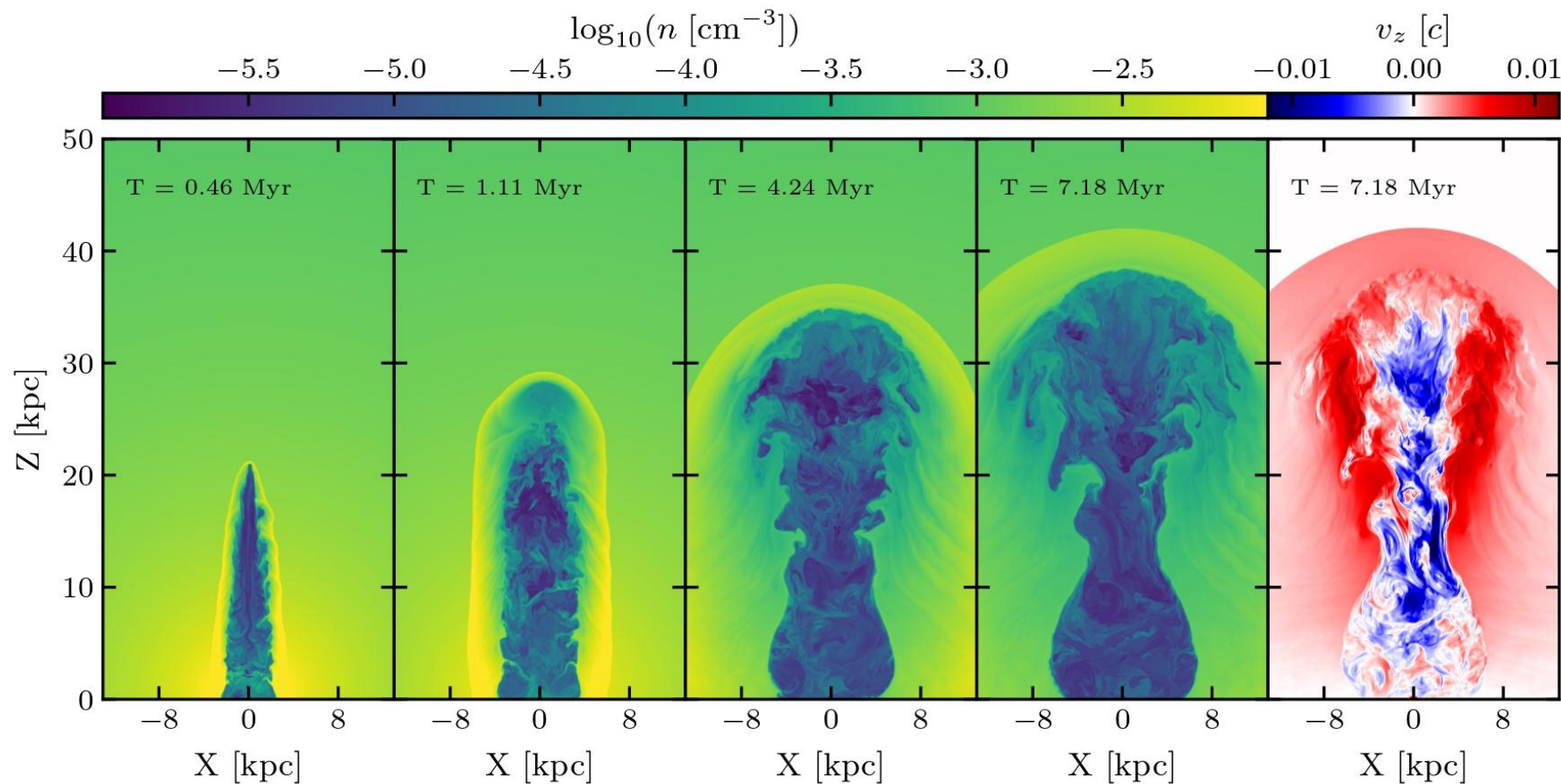
Synchrotron and IC
CMB cooling



Shock
Acceleration

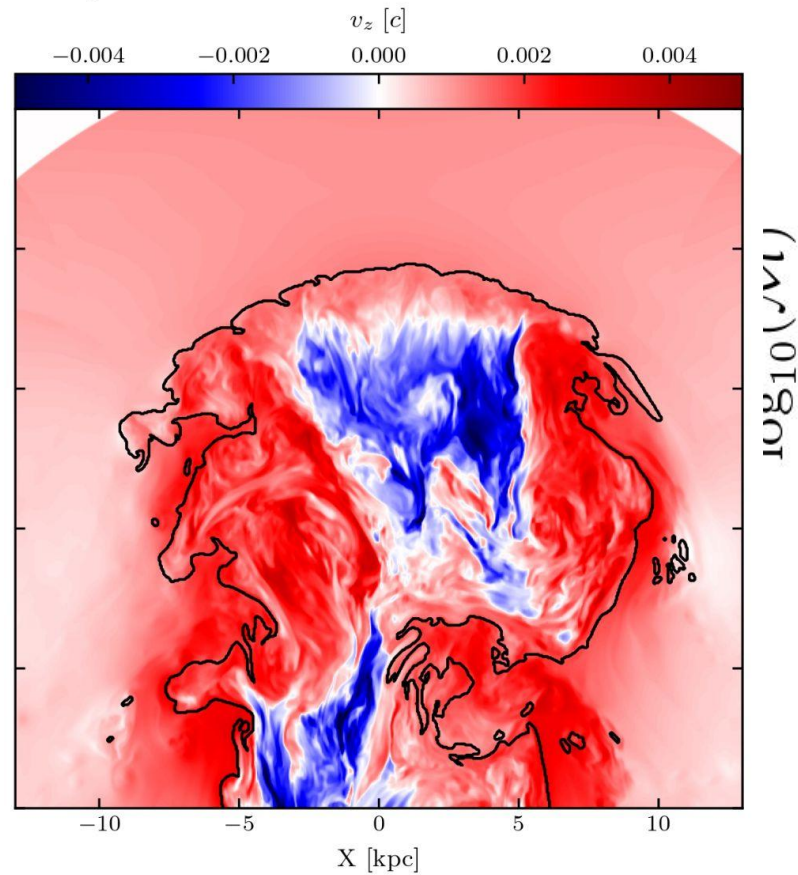
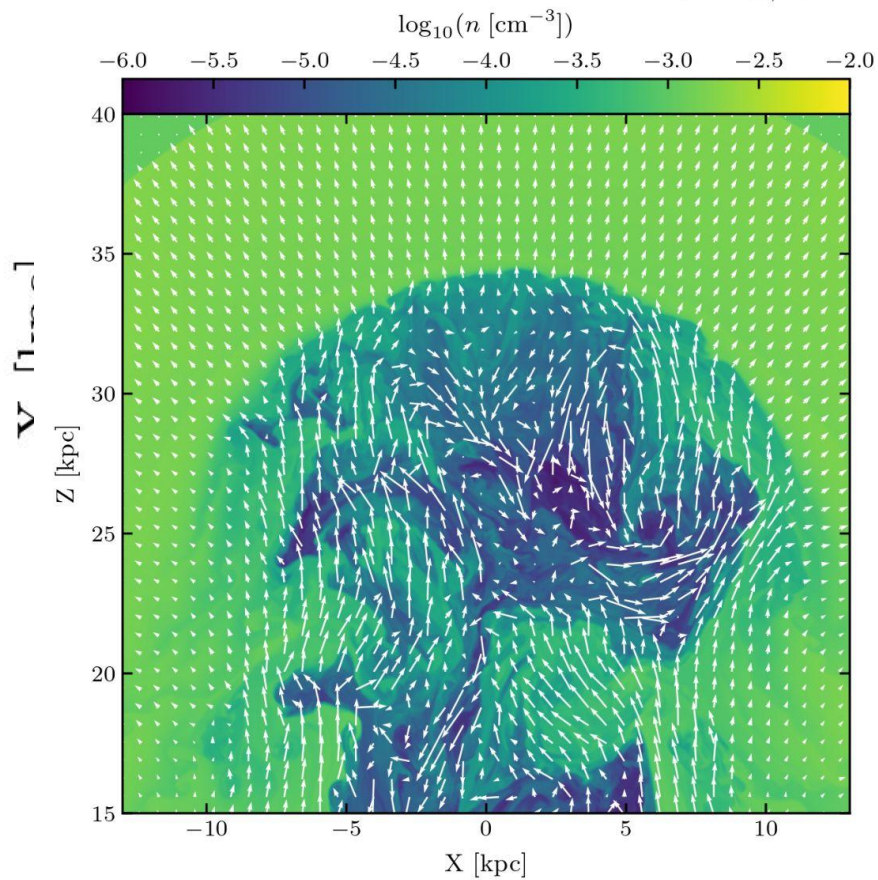


Dynamical Stages

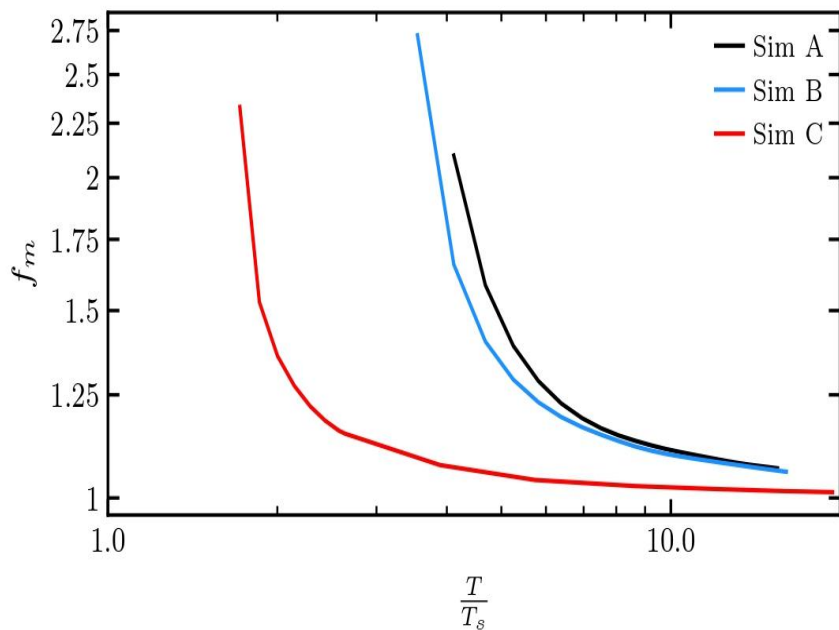


The Role of Instabilities

Sim C, $T = 19.57$ Myr



Role of Magnetic Field



$$\tau = \sqrt{\frac{\rho_1 \rho_2 (\mathbf{k} \cdot \mathbf{v}_1 - \mathbf{k} \cdot \mathbf{v}_2)^2}{(\rho_1 + \rho_2)^2} - \frac{(\mathbf{k} \cdot \mathbf{B}_1)^2 + (\mathbf{k} \cdot \mathbf{B}_2)^2}{4\pi(\rho_1 + \rho_2)}}$$

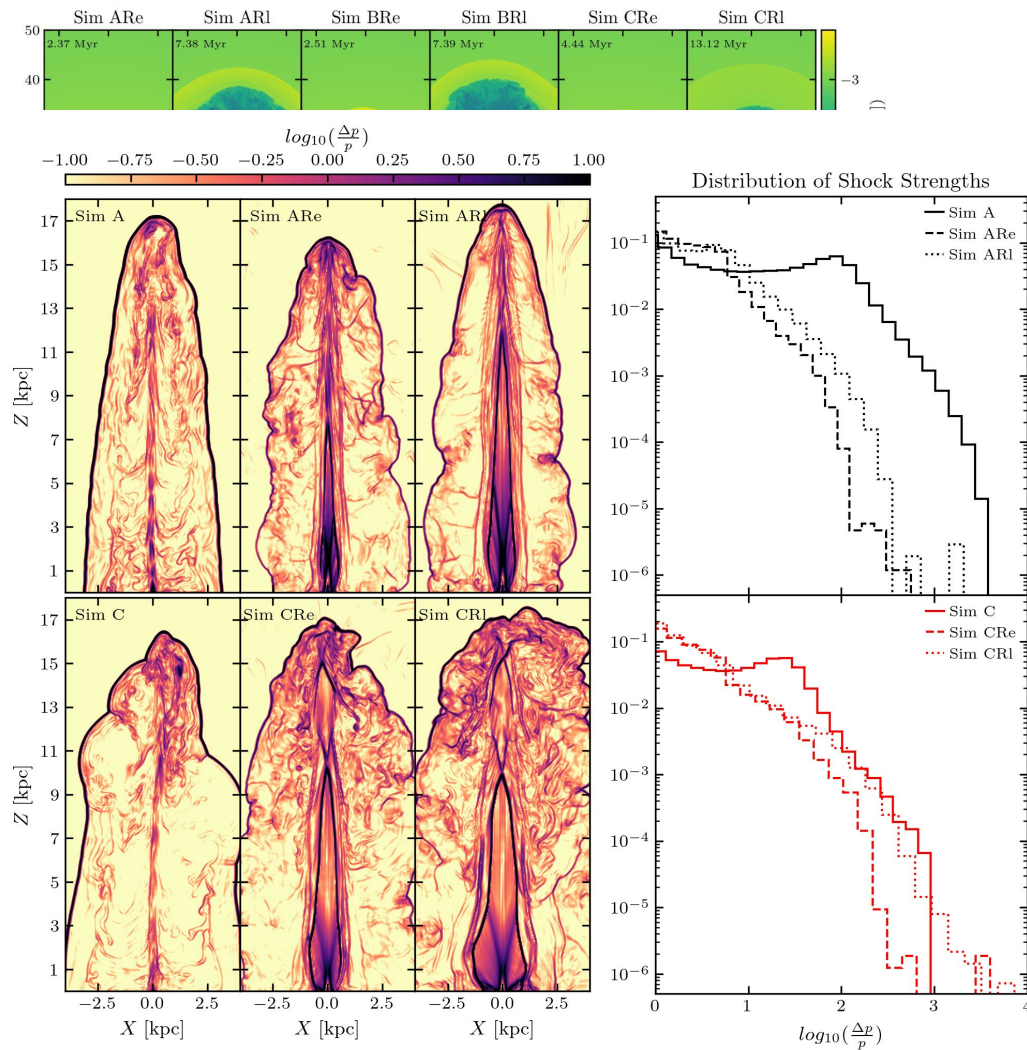
$$t_{\text{KHB}} = \frac{1}{\tau} = \frac{t_{\text{KH}}}{\sqrt{1 - \frac{B_z^2(1+\chi)}{4\pi\rho_1\chi\Delta v^2}}} = f_m \cdot t_{\text{KH}}$$

Instabilities lead to mass entrainment. Sim C > Sim B > Sim A

Dynamics of Restarted jet

When do backflows form?

How bow shock strength depend on restart time?



Particle Acceleration

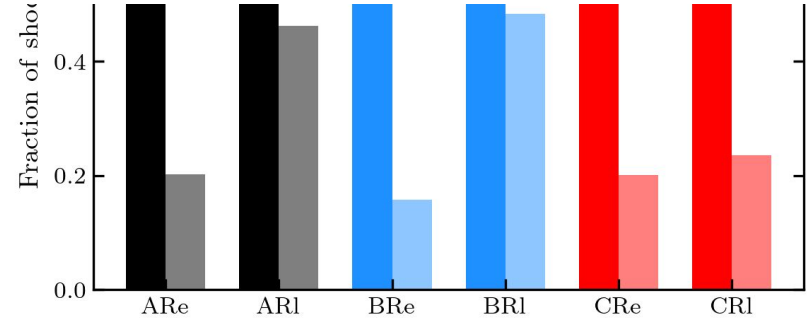
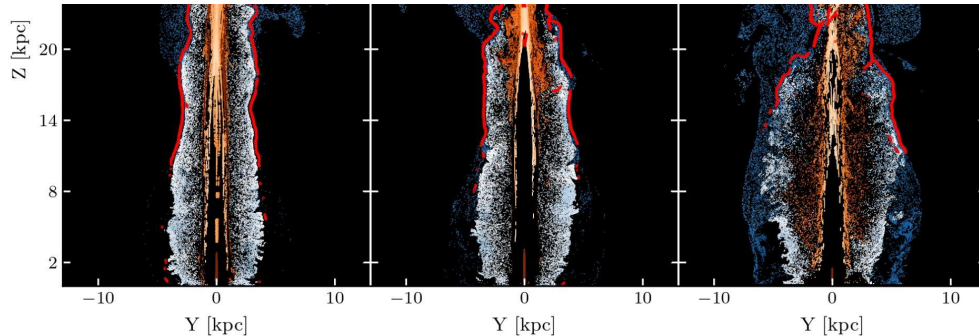
Ratnaparkhi et. al. 2026, b (in prep)

Numerical Simulations of Restarted Jets II: Particle Acceleration and Emission

Prathamesh P. Ratnaparkhi,¹★ Dipanjan Mukherjee,¹ Gianluigi Bodo², Paola Rossi² and others

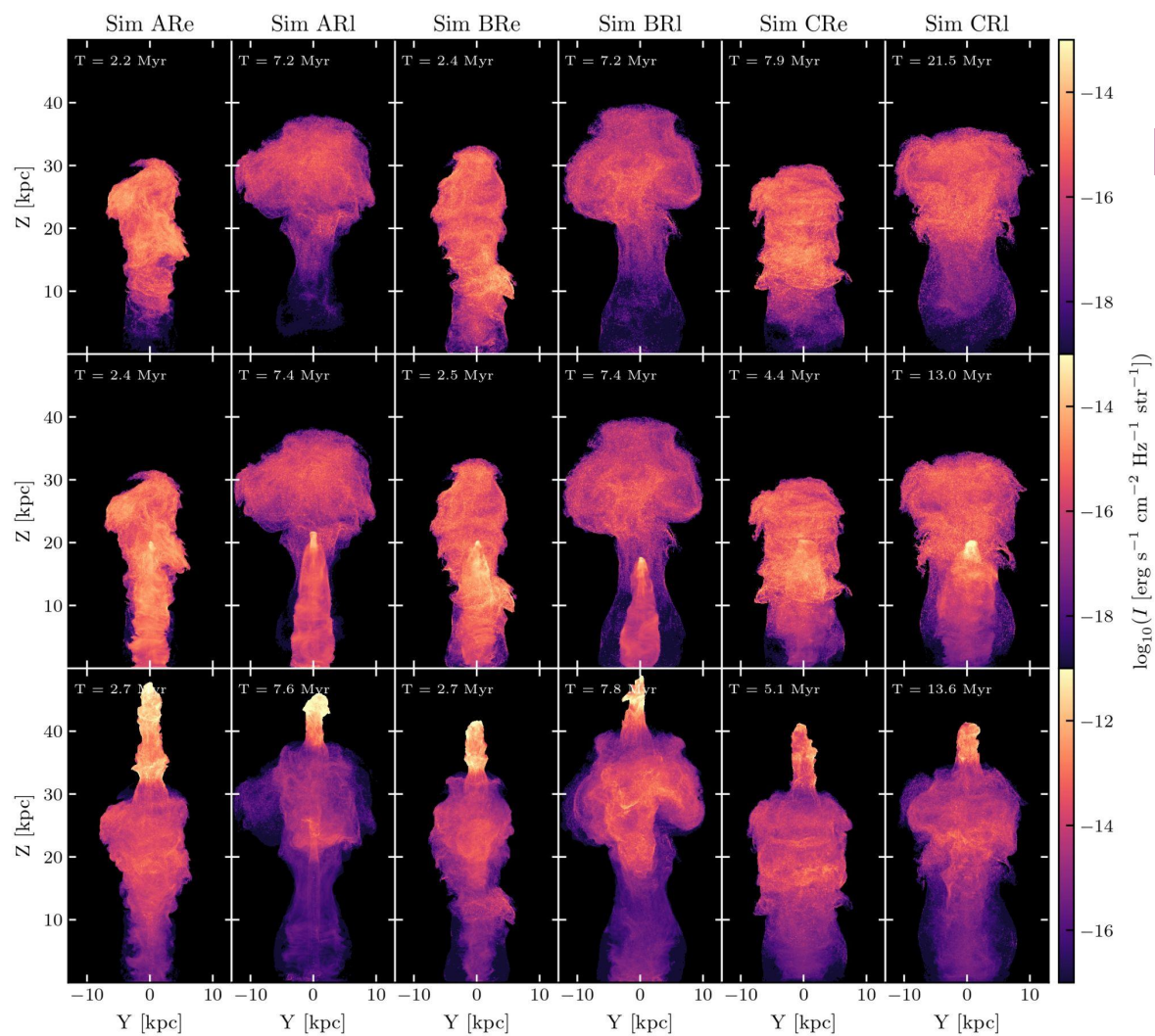
¹Inter-University Centre for Astronomy and Astrophysics, Pune-411007, India

²INAF, Osservatorio Astrofisico di Torino, Strada Osservatorio 20, I-10025 Pino Torinese, Italy

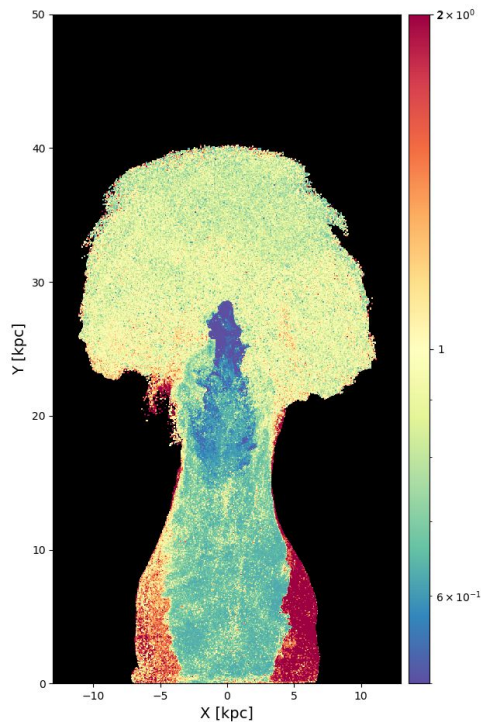


Emission

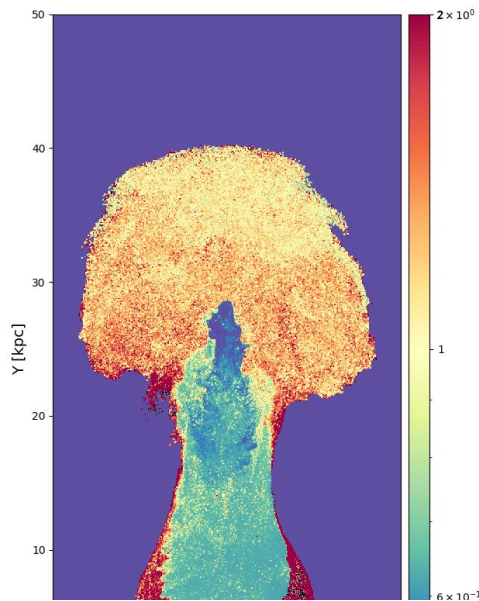
Ratnaparkhi et. al. 2026, b (in prep)



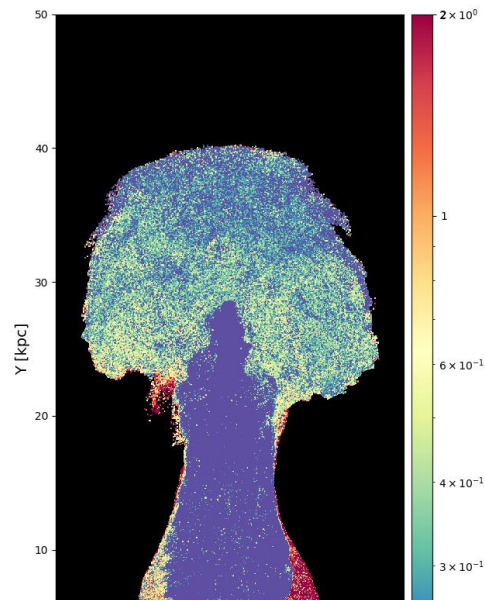
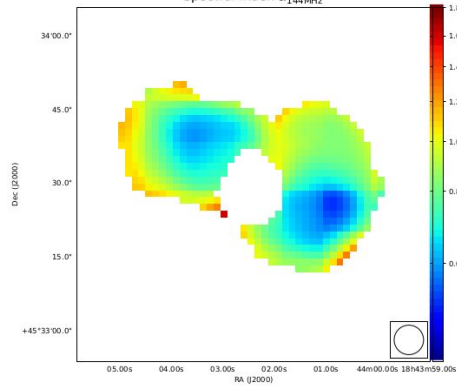
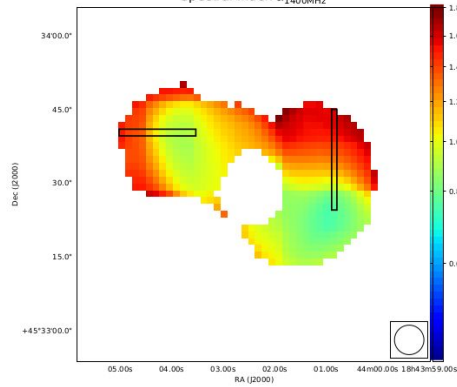
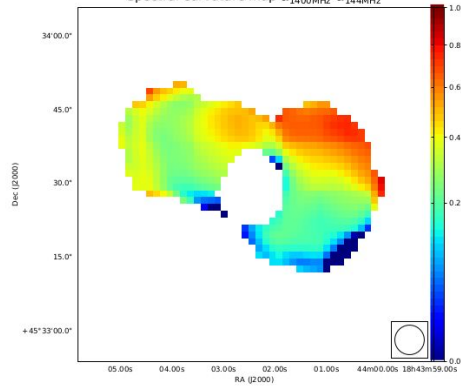
Spectral Index 0.15-0.6 GHz (Time: 7.46 Myr)



Spectral Index 1.4-5 GHz (Time: 7.46 Myr)



Spectral Index Difference (Time: 7.46 Myr)

Spectral index $\alpha_{\frac{614\text{MHz}}{144\text{MHz}}}$ Spectral index $\alpha_{\frac{4850\text{MHz}}{1400\text{MHz}}}$ Spectral curvature map $\alpha_{\frac{4850\text{MHz}}{1400\text{MHz}}} - \alpha_{\frac{614\text{MHz}}{144\text{MHz}}}$ 

3C388

M. Brienza et al, 2020.

Key Takeaways

- Instabilities can cause entrainment of matter.
- Magnetic fields can suppress entrainment.
- Turbulence or Clumpiness in the old cocoon can disrupt the bow shock.

Other projects

Synchrotron Self Compton

Particle acceleration (hadronic)

Thank You!

Post hoc vs Post-Doc

The Post hoc Fallacy

To incorrectly assume "A" is the cause of "B" just because "A" preceded "B".

e.g. "All Professors have Ph.D.'s, therefore getting a Ph.D. means you'll get a Professor job (right?)"



The Post-Doc Fallacy

To incorrectly assume you'll have a job just because you have a Ph.D.

*e.g.
"Now what??"*

Extra Slides

RMHD equations

$$\frac{\partial}{\partial t} \begin{pmatrix} D \\ \mathbf{m} \\ E_t \\ \mathbf{B} \end{pmatrix} + \nabla \cdot \begin{pmatrix} D\mathbf{v} \\ w_t \gamma^2 \mathbf{v}\mathbf{v} - \mathbf{b}\mathbf{b} + I p_t \\ \mathbf{m} \\ \mathbf{v}\mathbf{B} - \mathbf{B}\mathbf{v} \end{pmatrix} = \begin{pmatrix} 0 \\ \mathbf{f}_g \\ \mathbf{v} \cdot \mathbf{f}_g \\ 0 \end{pmatrix}$$

$$\gamma = \frac{1}{\sqrt{1 - \mathbf{v}^2/c^2}} \quad (\text{A2})$$

is the bulk Lorentz factor. The thermal pressure is denoted by p , and $\mathbf{B}$ is the magnetic field in the SGF. We define

$$b^0 = \gamma \mathbf{v} \cdot \mathbf{B}, \quad \mathbf{b} = \frac{\mathbf{B}}{\gamma} + \gamma(\mathbf{v} \cdot \mathbf{B})\mathbf{v}, \quad (\text{A3})$$

$$w_t = \rho h + \frac{\mathbf{B}^2}{\gamma^2} + (\mathbf{v} \cdot \mathbf{B})^2, \quad (\text{A4})$$

and the total pressure

$$p_t = p + \frac{1}{2} \left(\frac{\mathbf{B}^2}{\gamma^2} + (\mathbf{v} \cdot \mathbf{B})^2 \right). \quad (\text{A5})$$

The conserved variables are

$$(\text{A8}) \quad D = \gamma\rho, \quad \mathbf{m} = w_t \gamma^2 \mathbf{v} - b^0 \mathbf{b}, \quad \text{and} \quad E_t = w_t \gamma^2 - (b^0)^2 - p_t, \quad (\text{A6})$$

corresponding to the relativistic rest-mass density, momentum density, and total energy density, respectively. The magnetic field satisfies the solenoidal constraint

$$(\text{A9}) \quad \nabla \cdot \mathbf{B} = 0, \quad (\text{A7})$$

which is maintained numerically to machine precision.

A2 Equation of state

The above system is closed using the Taub–Mathews equation of state:

$$\left(h - \frac{p}{\rho} \right) \left(h - 4 \frac{p}{\rho} \right) = 1,$$

where relativistic specific enthalpy, h , is given by

$$h = \frac{5p + \sqrt{9p^2 + 4\rho^2 c^4}}{2\rho}.$$

Subgrid Prescription for Particle Acceleration

Particle Data Structure

Position: x, y, z .

Velocity: v_x, v_y, v_z .

Fluid Quantities: Pressure, Density.

Magnetic field: B_x, B_y, B_z .

Particle Spectrum: $E, X(E)$

Advection

$$\frac{d\mathbf{x}_p}{dt} = \mathbf{v}(\mathbf{x}_p)$$

Spectral evolution

$$\frac{d\chi_p}{d\tau} + \frac{\partial}{\partial E} \left[\left(-\frac{E}{3} \nabla_\mu u^\mu + \dot{E}_l \right) \chi_p \right] = 0$$

Synchrotron Emissivity

$$J'_{\text{syn}}(\nu', \hat{\mathbf{n}}'_{\text{los}}, \mathbf{B}') = \frac{\sqrt{3}e^3}{4\pi m_e c^2} |\mathbf{B}' \times \hat{\mathbf{n}}'_{\text{los}}| \int_{E_i}^{E_f} \mathcal{N}'(E') F(x) dE'$$

Shock Acceleration

1. Flag shocked zones based on $\text{Div}(\mathbf{V})$ and pressure criteria.
2. Find the shock normal using co-planarity theorem.
3. Find shock speed using conservation of mass flux.
5. Calculate shock compression ratio.
6. Update the particle spectrum to a new power law based on r , existing energy in nonthermal particles, synchrotron cooling timescales.

Vaidya, B. et al, 2018

Additional Results.

- Compression Wave
- Speed of LJM.
- Evolution of size and shape.
- Role of Buoyancy.

Technical Details.

Resolution

Solver limiter divergence cleaning.

Simulation set-up

Initial and boundary conditions

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