# Radio galaxies: Actors in Cosmological Evolution


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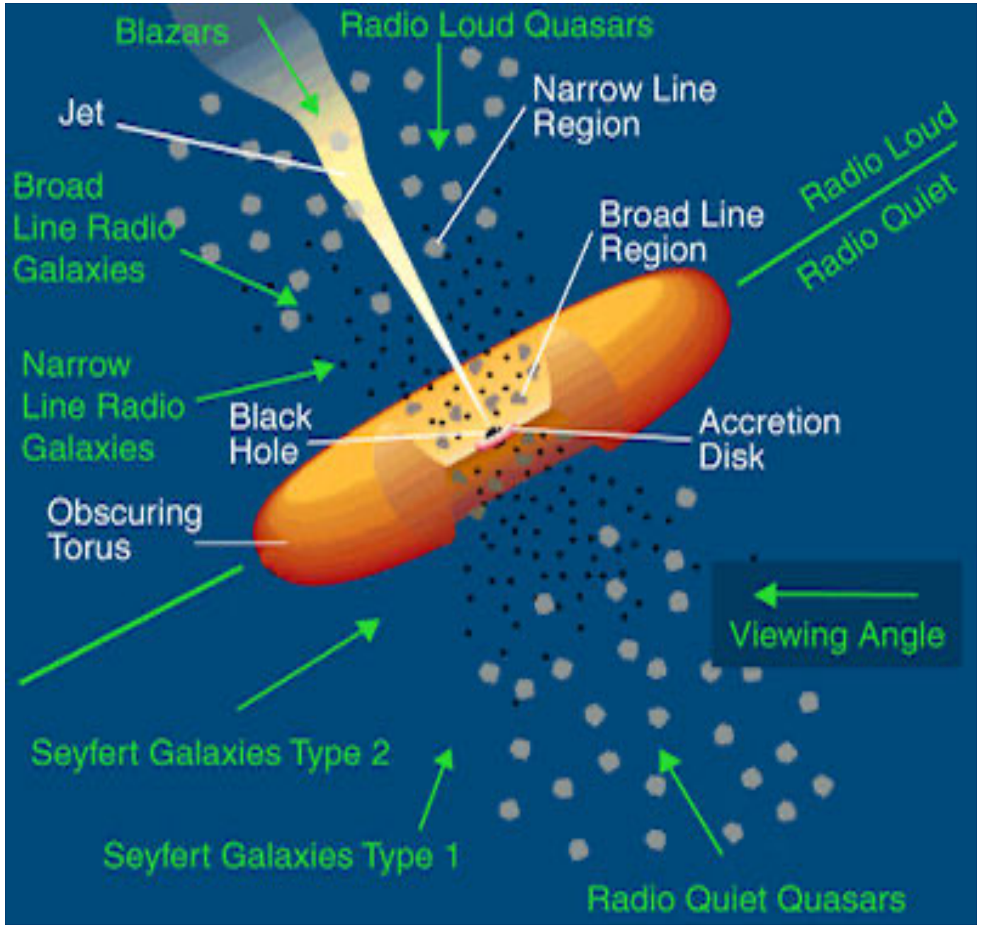
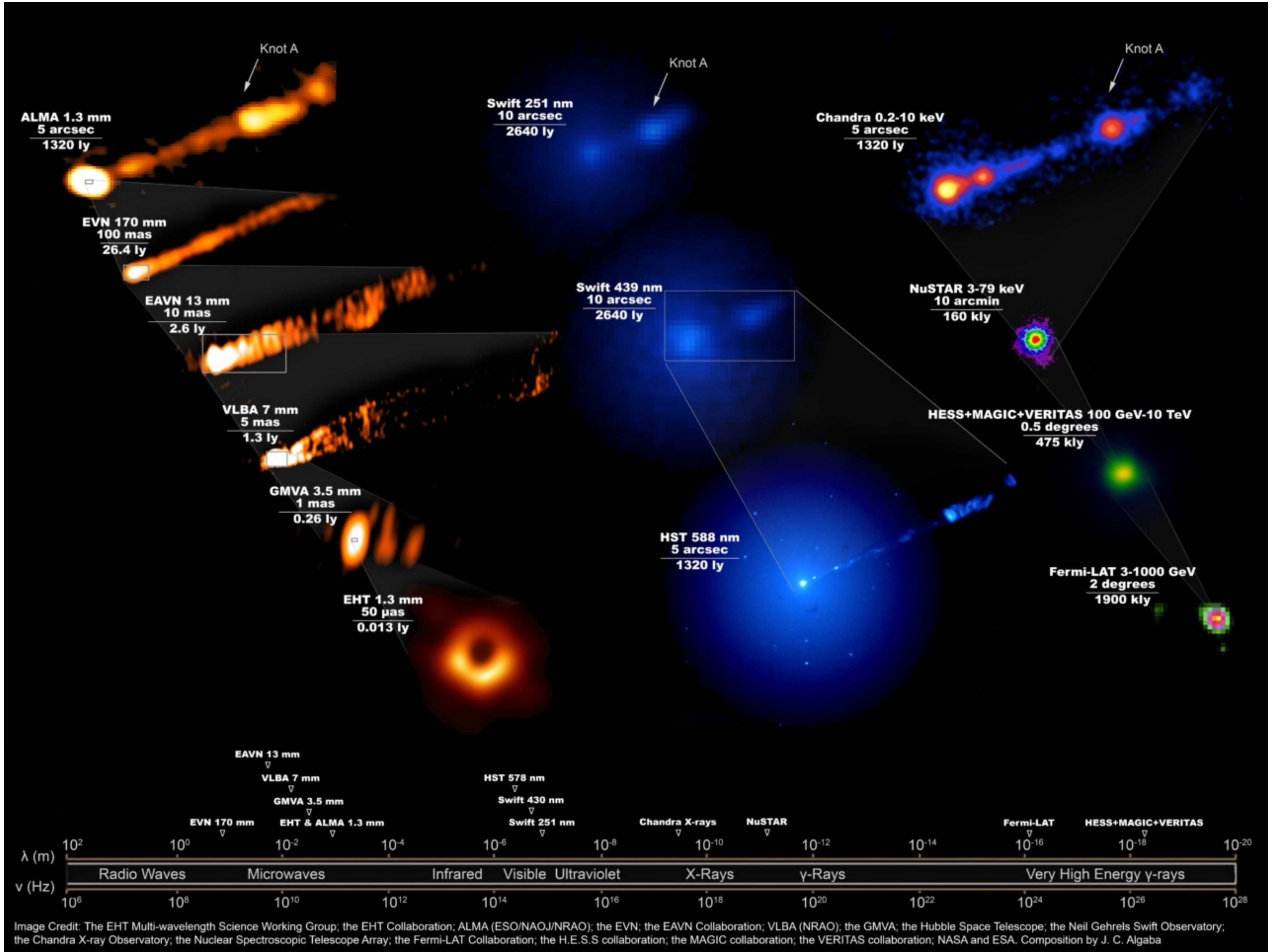
# Active Galaxies



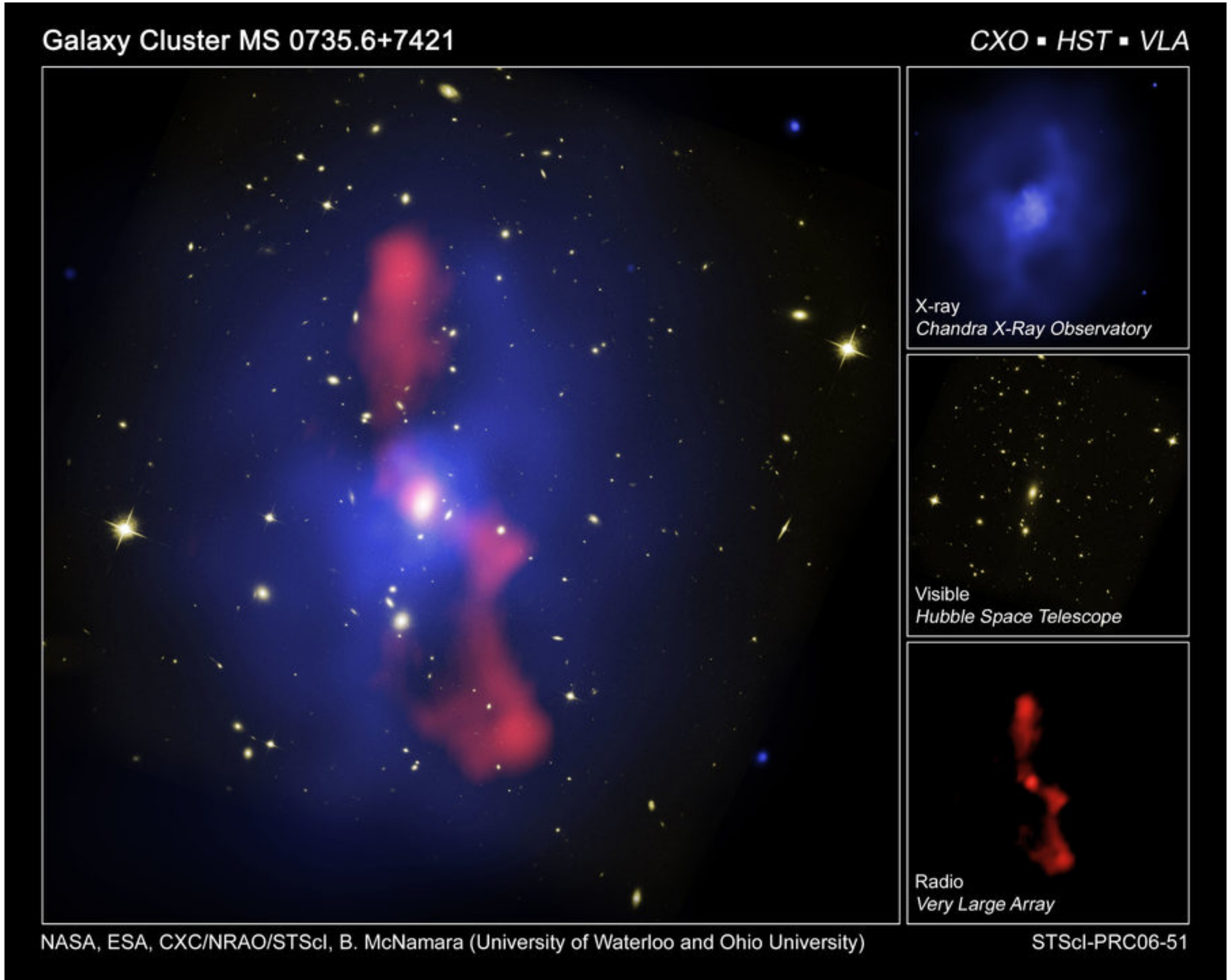

- Around 10% of the galaxies are active: host of an Active Galactic Nucleus (AGN).
- AGN formed by an accreting super massive black hole ($10^{10}\ M_{\odot}$).
- Accretion is the most efficient process we know (7% of rest mass energy in Schwarzschild BH and 40% in Kerr BH).

# Radio galaxies (Jets)



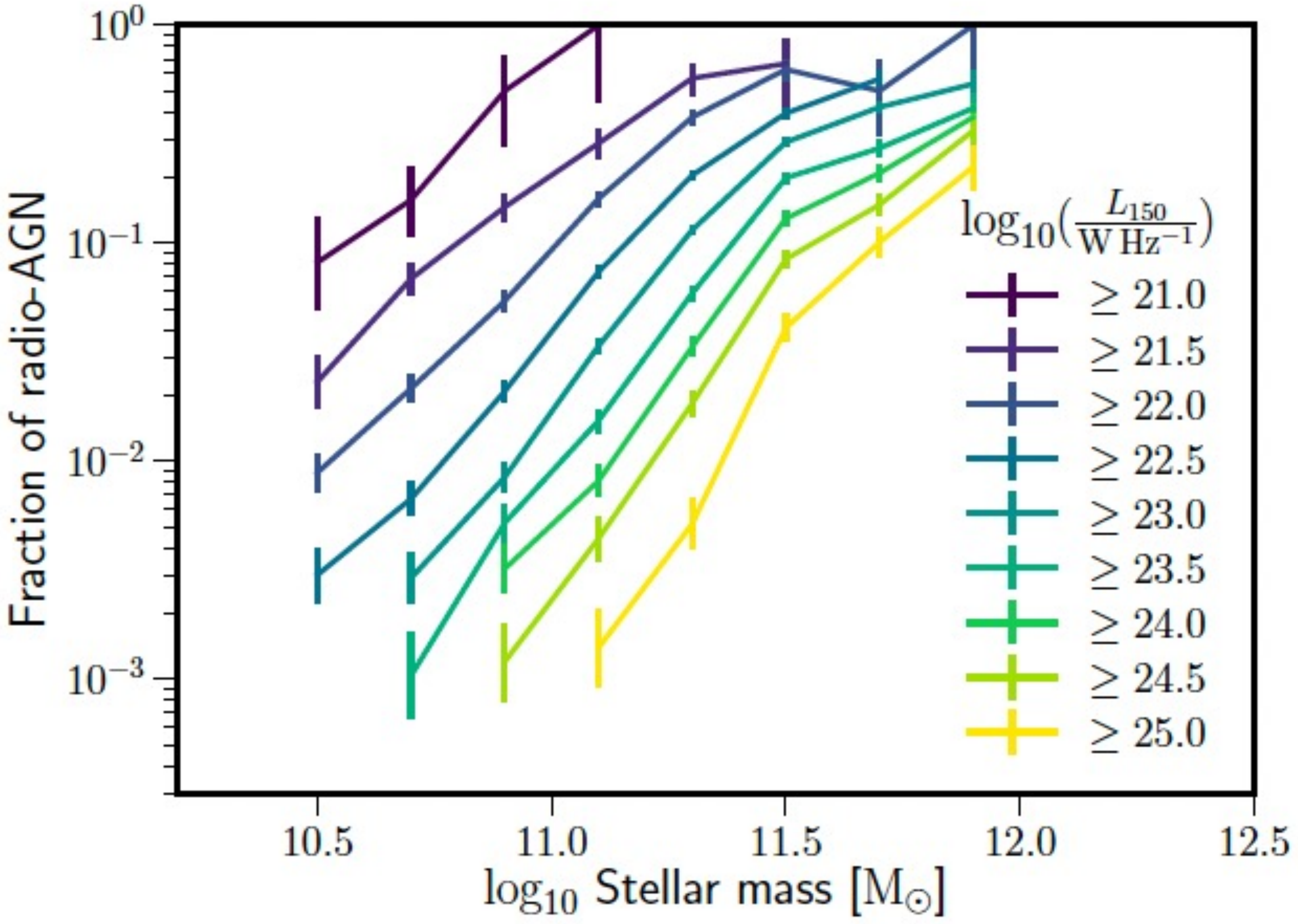

- The spinning of the BH twists the magnetic field, favouring the launching of material in two opposite directions: Jets (Blandford & Znajek 1977)
- Active galaxies with jets emit synchrotron radiation from radio to X-rays.
- Also in X and gamma rays by Inverse Compton
- Jets can reach relativistic velocities. Evidences: One sided (Doppler boosting); Superluminal motion in blazars.

# Feedback of the jets




- The jet affects the galaxy evolution, heating it
- The gas emits in X-rays, and it should cool and fall onto the galaxies, but it does not happen.
- Mechanisms invoked to stop the cooling flows: radiative heating and jet-shocks.
- Evidence that X-ray cavities coincide with radio-lobes (e.g., McNamara et al. 2005, Fabian et al. 2006, Nulsen et al. 2005, Fabian 2012).

# How many active galaxies have jet?




Sabater et al. 2019

- The fraction of radio-AGN grows with sensitivity of the observing arrays: More radio AGN than previously expected
- Massive active galaxies are all radio-AGN
- Observations suggest that most of the active galaxies have jets

# Cosmological relevance

- Evidences that galactic activity plays an important role on the evolution of galaxies along the history of the universe (D. Sijacki et. al., 2015)
- Cosmological simulations need to introduce an injection of energy in the galaxies (galactic activity) to recover observed galaxy distributions.
- The evolution of galactic activity and its populations with redshift would be a fundamental ingredient for cosmological simulations.

# Motivation to our model

- Our aim: a model to generate populations of active (radio) galaxies (Montecarlo simulations) at different redshifts, to predict the density of active galaxies at each epoch of the universe

- Observations at low redshift are complete, we can use them to check the model.

- At high redshift we can only see the most luminous, but most recent and future observatories (James Webb, LOFAR, SKA) are reaching there: The model could make predictions!

- Simulations take too much time to generate so many galaxies: Simplified

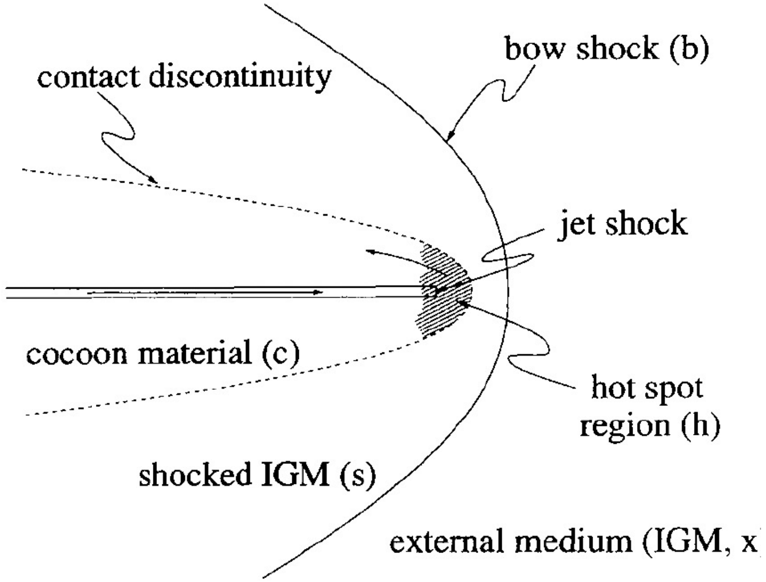
# Our Model

- Model of evolution of jets

- Previous models: Kaiser, Denet-Thorpe & Alexander (1997); Perucho & Martí (2007); Hardcastle (2018)...

- Dinamical part based on Perucho & Martí (2007) and Begelman & Cioffi (1989). Radiative part based on Kaiser, Denet-Thorpe & Alexander (1997)

- Main contributions of our model: Thermal matter (protons), ambient density dependent on redshift




# Our Model

Rankine–Hugoniot conditions for a 1D shock:

$$\rho_1 u_1 = \rho_2 u_2 \equiv m \quad \text{Conservation of mass}$$

$$\rho_1 u_1^2 + p_1 = \rho_2 u_2^2 + p_2 \quad \text{Conservation of momentum}$$

$$h_1 + \frac{1}{2}u_1^2 = h_2 + \frac{1}{2}u_2^2 \quad \text{Conservation of energy}$$

Applied to cocoon and hotspot discontinuities

$$\dot{r}^2 = \frac{1}{2\rho_a}\left[(\Gamma + 1)p_c + (\Gamma - 1)p_a\right]$$

$$\dot{d}^2 = \frac{1}{2\rho_a}\left[(\Gamma + 1)p_h + (\Gamma - 1)p_a\right]$$

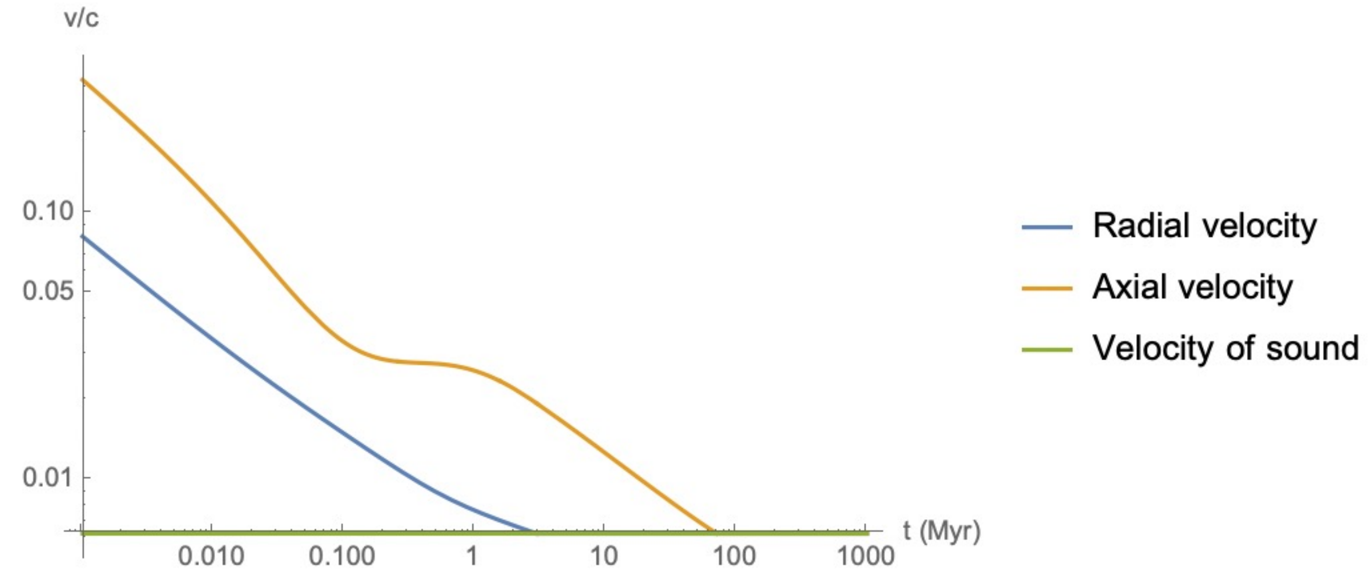
Constrains imposed from simulations:

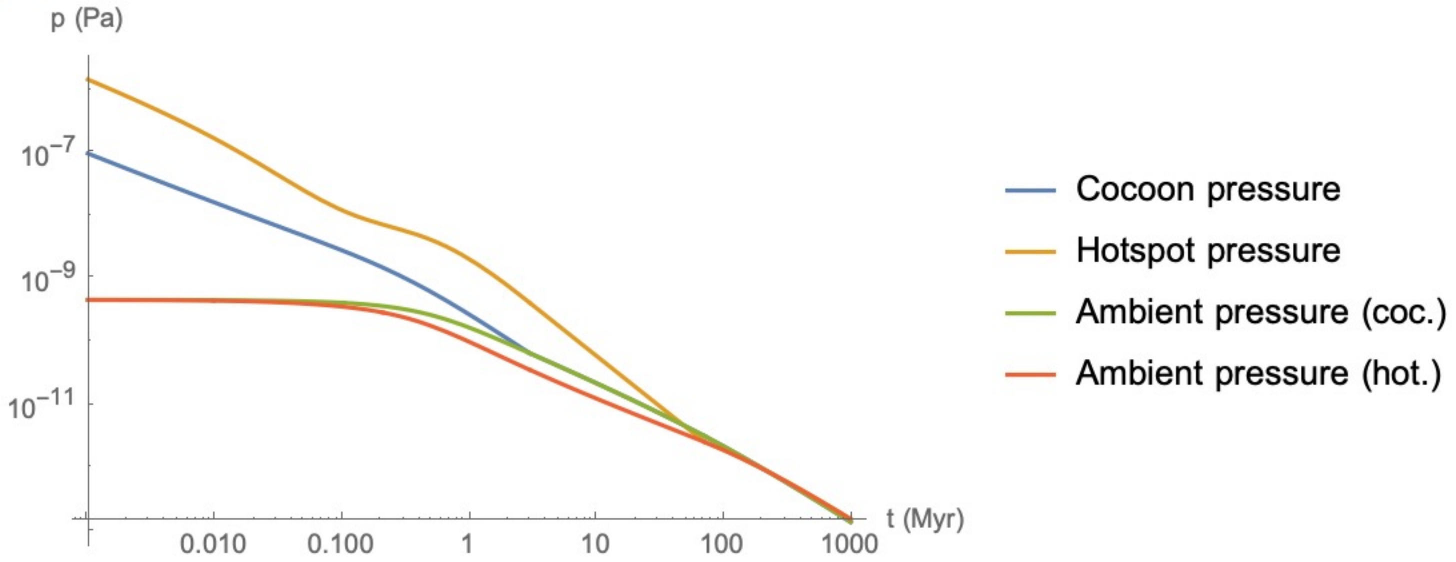
$$p_c V = 0.4 L_0 t$$

$$p_c \sim t^b$$

# Results

Example of evolution of relevant variables that determine the synchrotron radio emission.

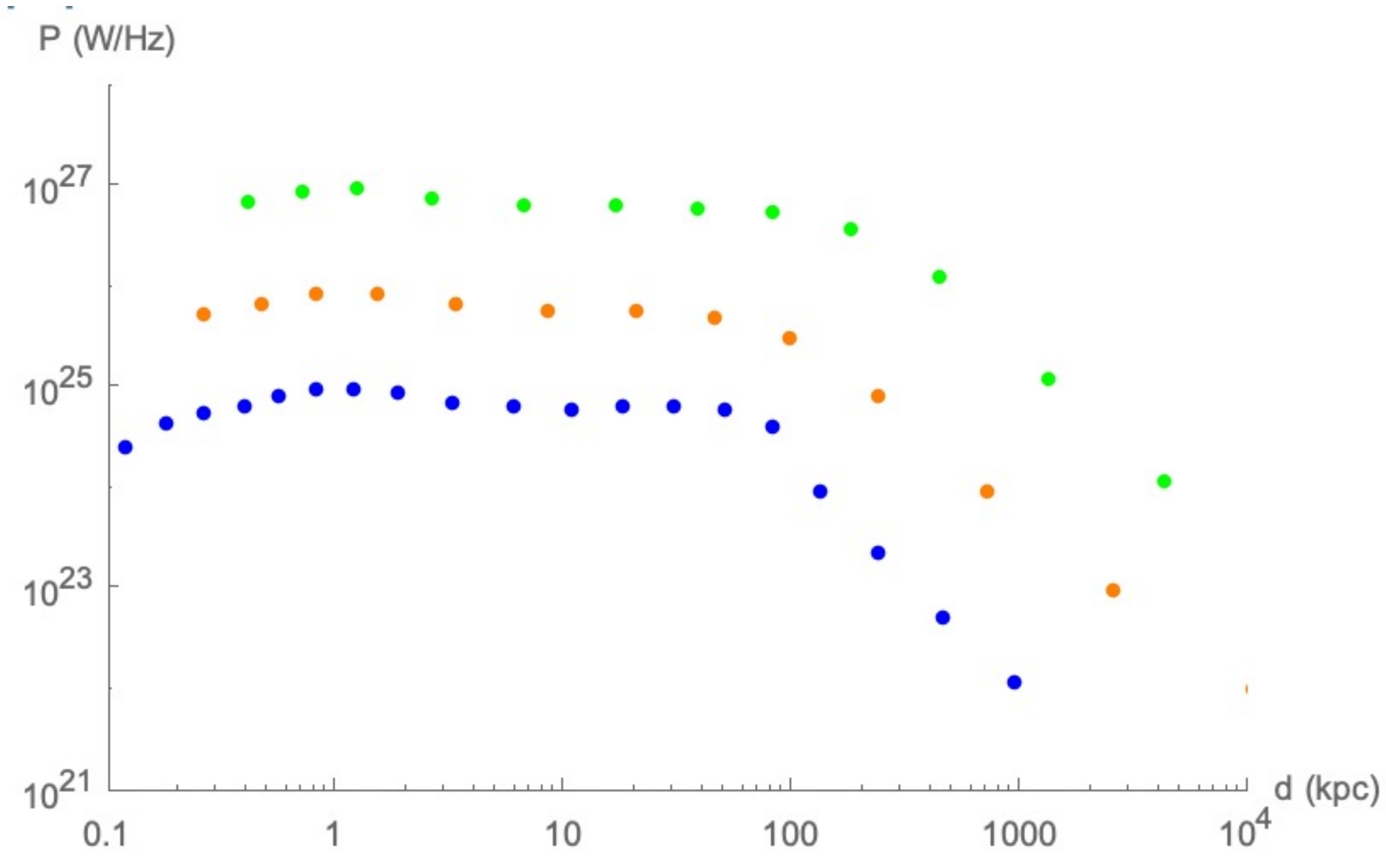


# Results

Synchrotron luminosity from an emiting volume V

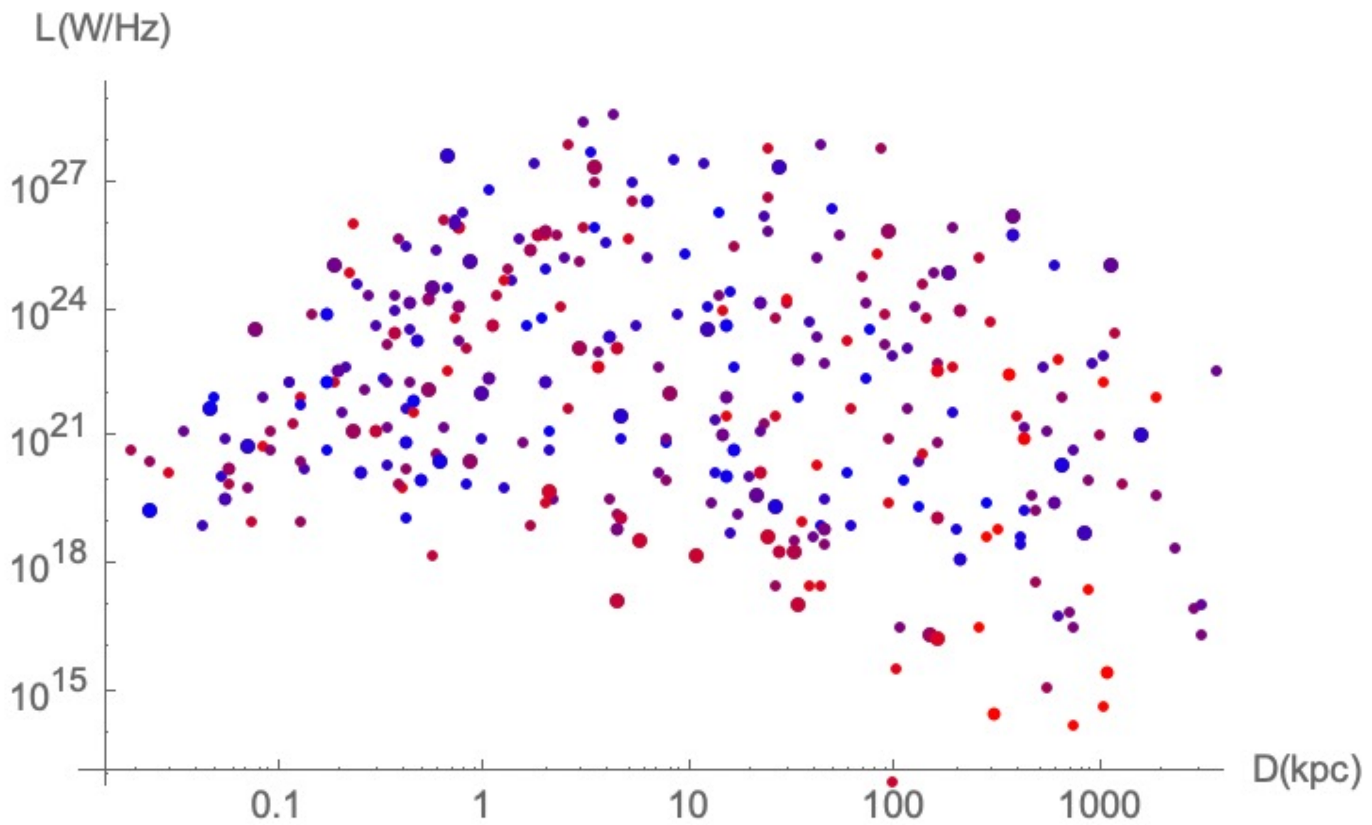
$$P_\nu = \frac{1}{6\pi}\sigma_T c u_B \frac{\gamma^3}{\nu} n(\gamma) V.$$



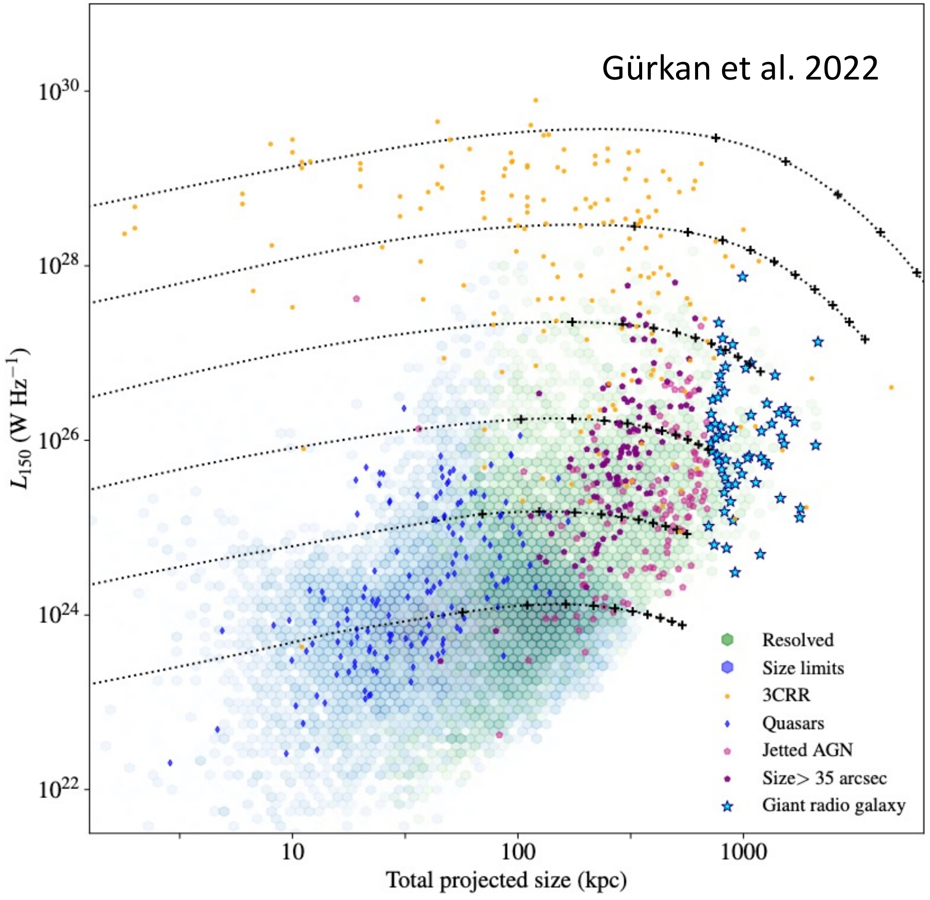

Power of the jet: 10^39 W (green), 10^38 W (orange), 10^37 W (blue)

# Monte Carlo simulation

Our model:




Obsevations:



# Conclusions

- Activity of galaxies plays a fundamental role in the evolution of galaxies.

- It is a fundamental ingredient in cosmological simulations. We need to know how many active galaxies were present in each cosmological epoch.

- Observations indicate that most active galaxies emit in radio, i.e., have jets.

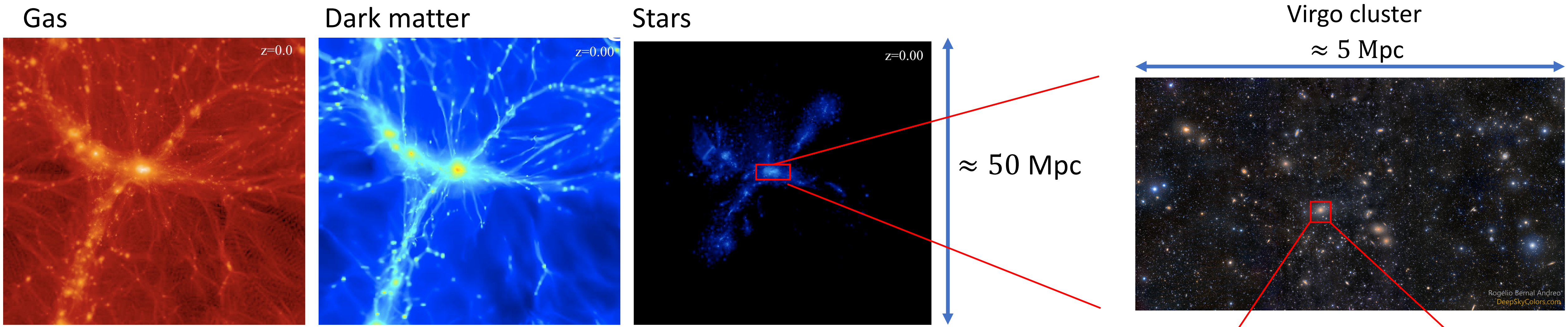
- With our model of evolution of radio galaxies we can perform Montecarlo simulations to compare with observed galaxies.

- Future work:

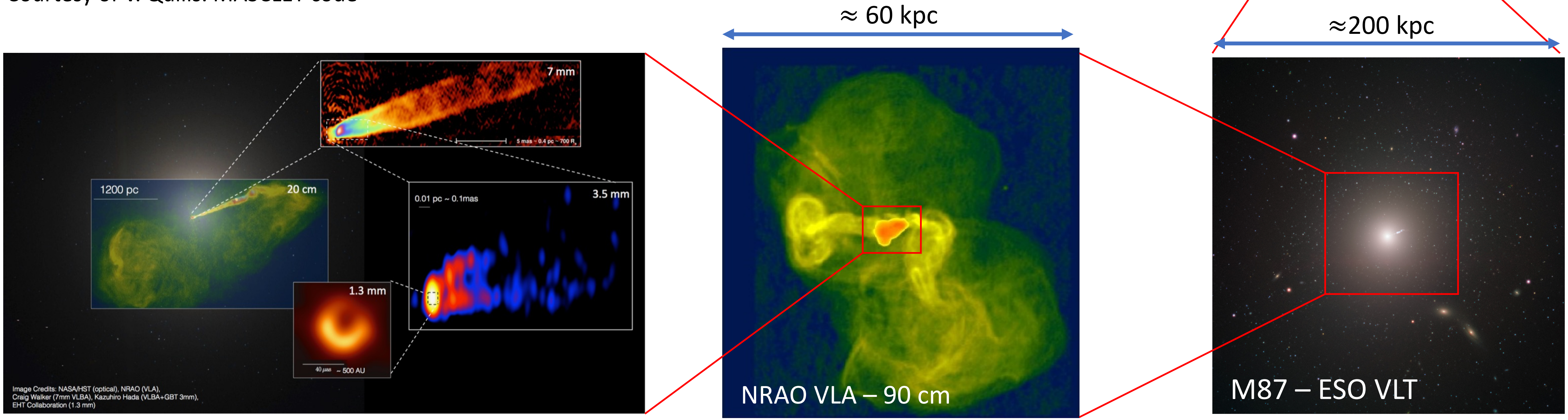
- Check the validity of the model by comparing at low redshift and predict the number of active galaxies at large redshifts.

- Incorporate results in the cosmological simulations in order to improve them.

# Scales



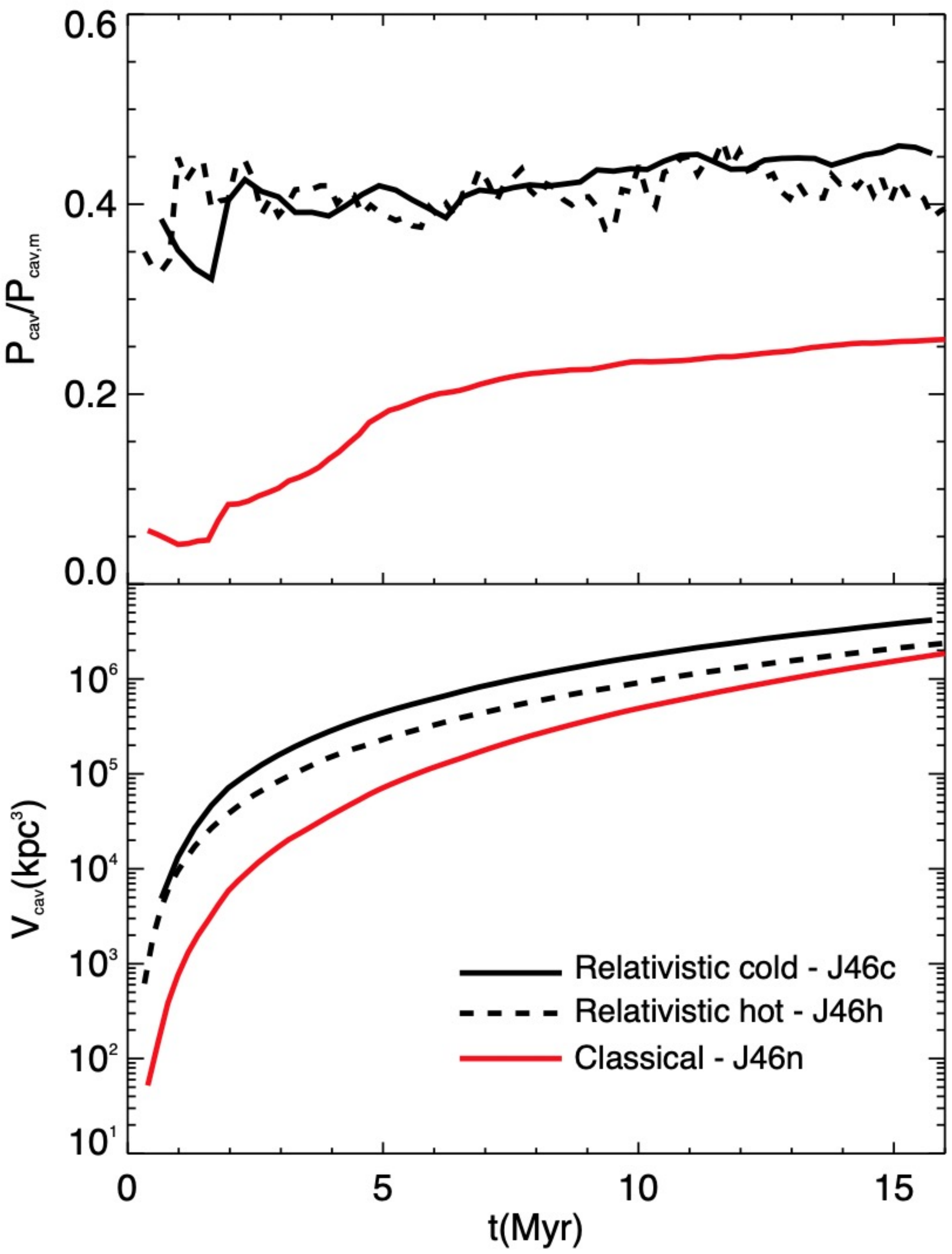

Courtesy of V. Quilis. MASCLET code



# Our Model

Perucho et. al. (2017):

$$p_c V = 0.4 L_0 t$$



# Our Model

Perucho et. al. (2011 and 2014):

$$p_c \sim t^b$$

b takes different values for different periods.

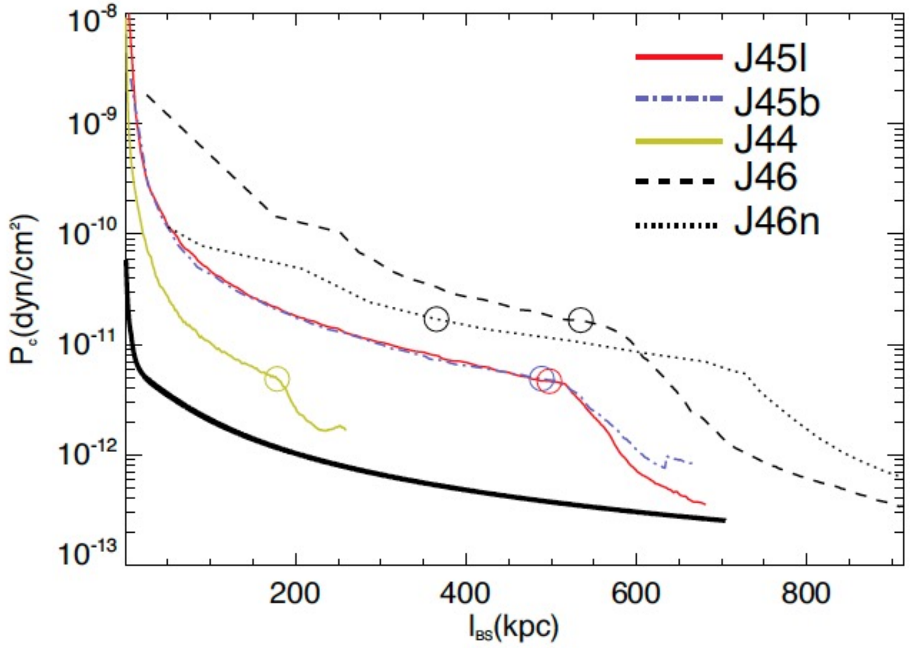



**Table 2**
Parameters for the Three Stages of the Evolution within Each of the Simulations

| Simulation | | 1D Phase | | | | 2D Phase | | | | Sedov Phase | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\alpha$ | $\beta$ | $P_c$ | $R_c$ | $\alpha$ | $\beta$ | $P_c$ | $R_c$ | $\alpha$ | $\beta$ | $P_c$ | $R_c$ |
| J1 | Sim | 0.07 | −1.55 | −1.58 | 0.75 | −0.23 | −0.52 | −1.09 | 0.66 | −0.74 | −1.02 | −1.70 | 0.90 |
| | Model | | | −1.65 | 0.79 | | | −1.05 | 0.64 | | | −1.43 | 0.58 |
| J2 | Sim | 0.27 | −1.55 | −1.67 | 0.67 | −0.57 | −0.52 | −0.95 | 0.81 | −0.83 | −1.02 | −1.67 | 0.72 |
| | Model | | | −1.68 | 0.71 | | | −0.91 | 0.74 | | | −1.40 | 0.61 |
| J3 | Sim | 0.13 | −1.55 | −1.55 | 0.67 | −0.35 | −0.52 | −1.08 | 0.74 | −0.60 | −1.02 | −2.16 | 1.00 |
| | Model | | | −1.66 | 0.76 | | | −1.00 | 0.68 | | | −1.47 | 0.54 |