Stability of AGN Jets

Serguei Komissarov
University of Leeds

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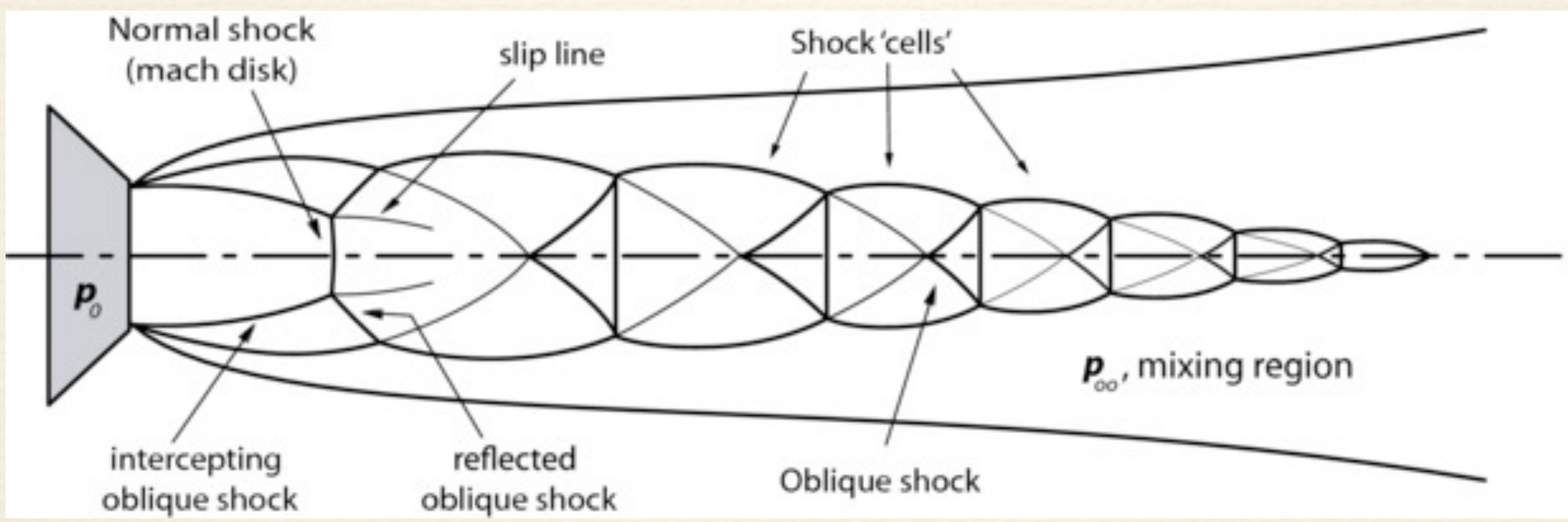
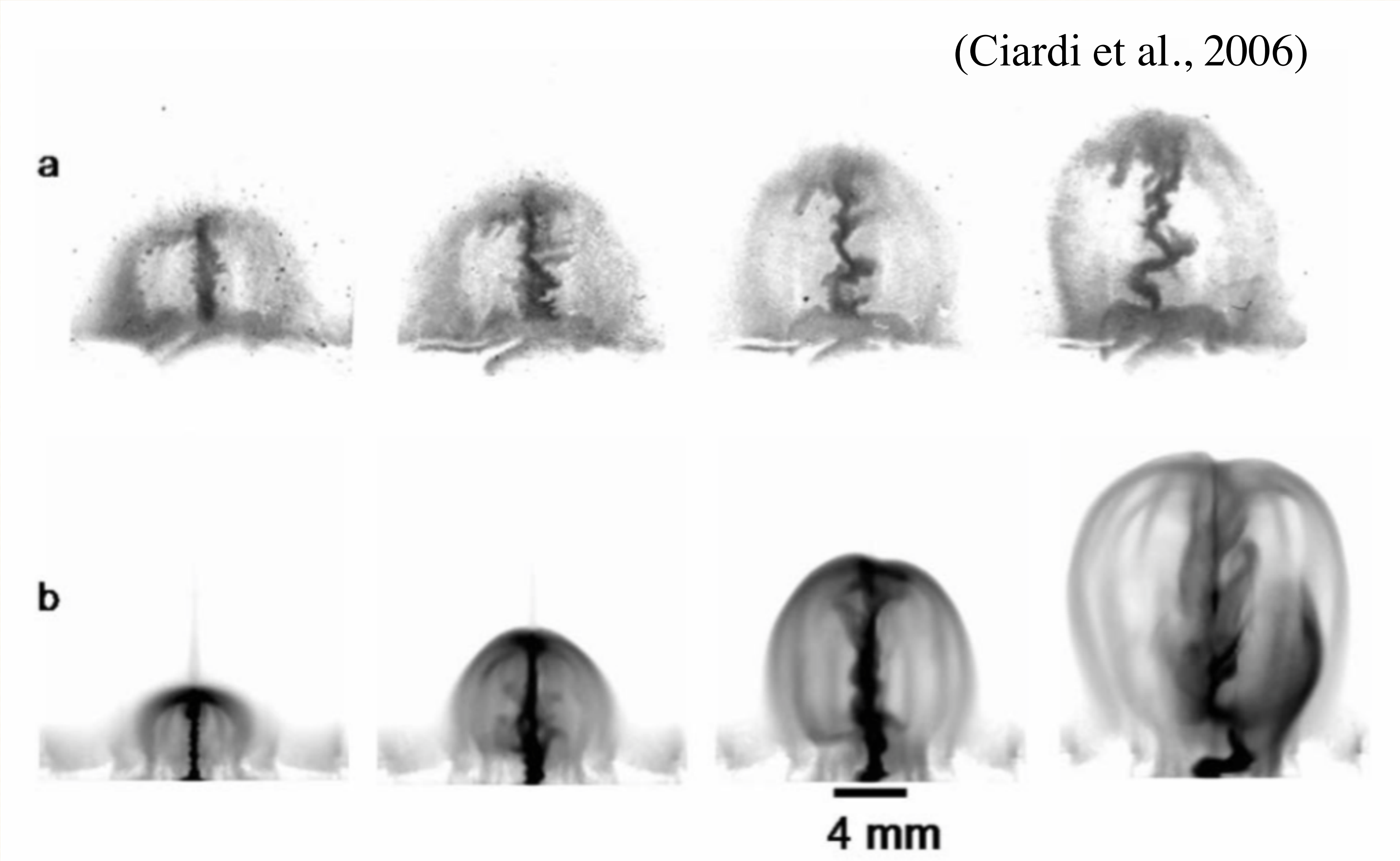
- Fluid/gas/plasma jet made by men do not survive for very long either;
- Human-made fluid/gas/plasma jets do not survive for very long;
- They get destroyed by instabilities.

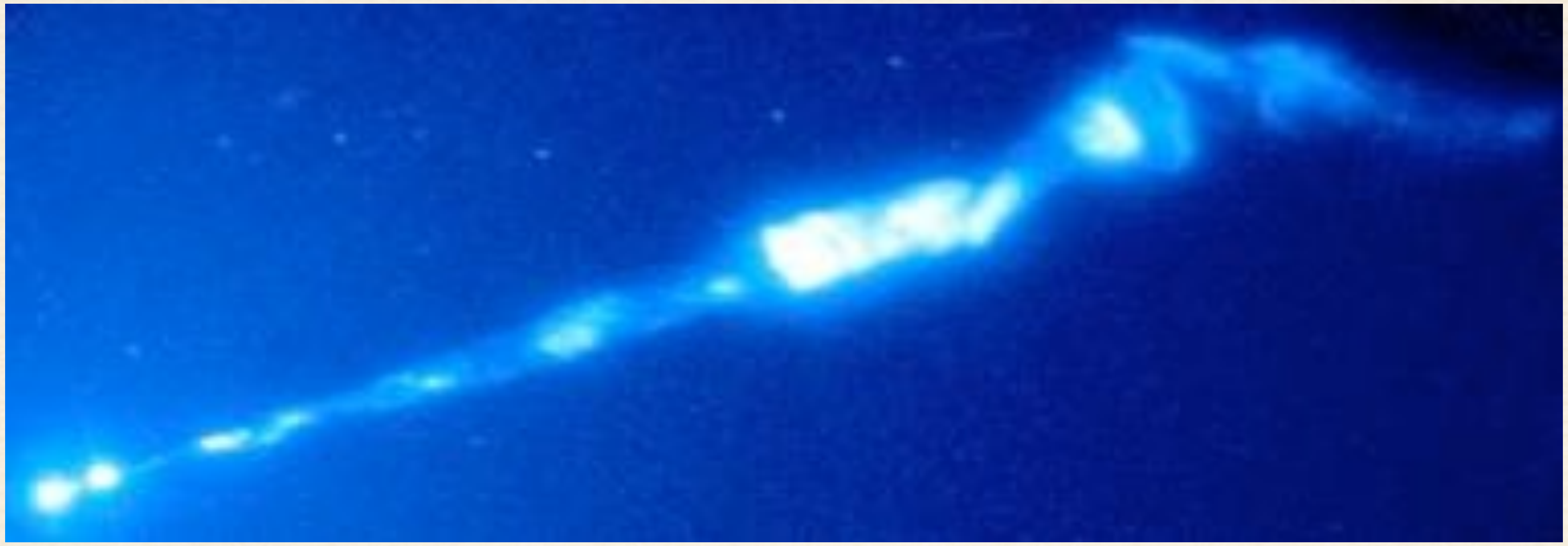


A supersonic gas jet is destroyed by the Kelvin-Helmholtz instability

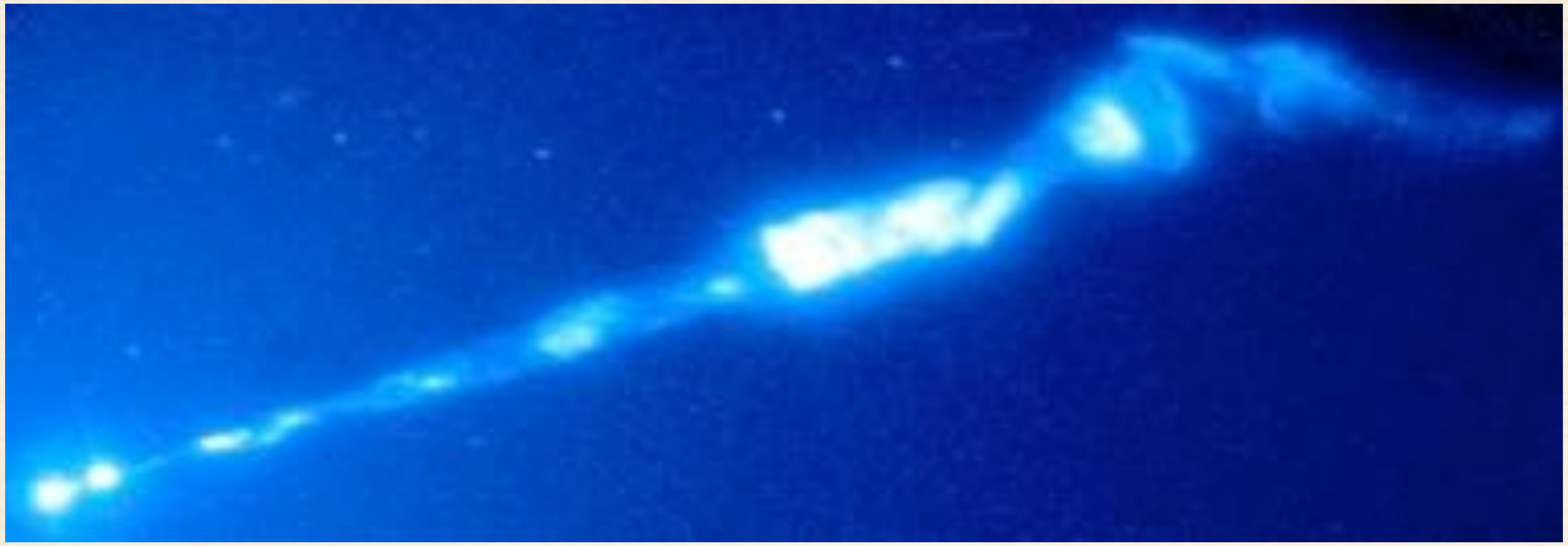


A magnetized plasma jet is destroyed by Current-Driven Instabilities

Lab jets propagate for only up to tens of nozzle radii before they get destroyed instabilities



AGN jets propagate for millions of “nozzle” radii and more !!!



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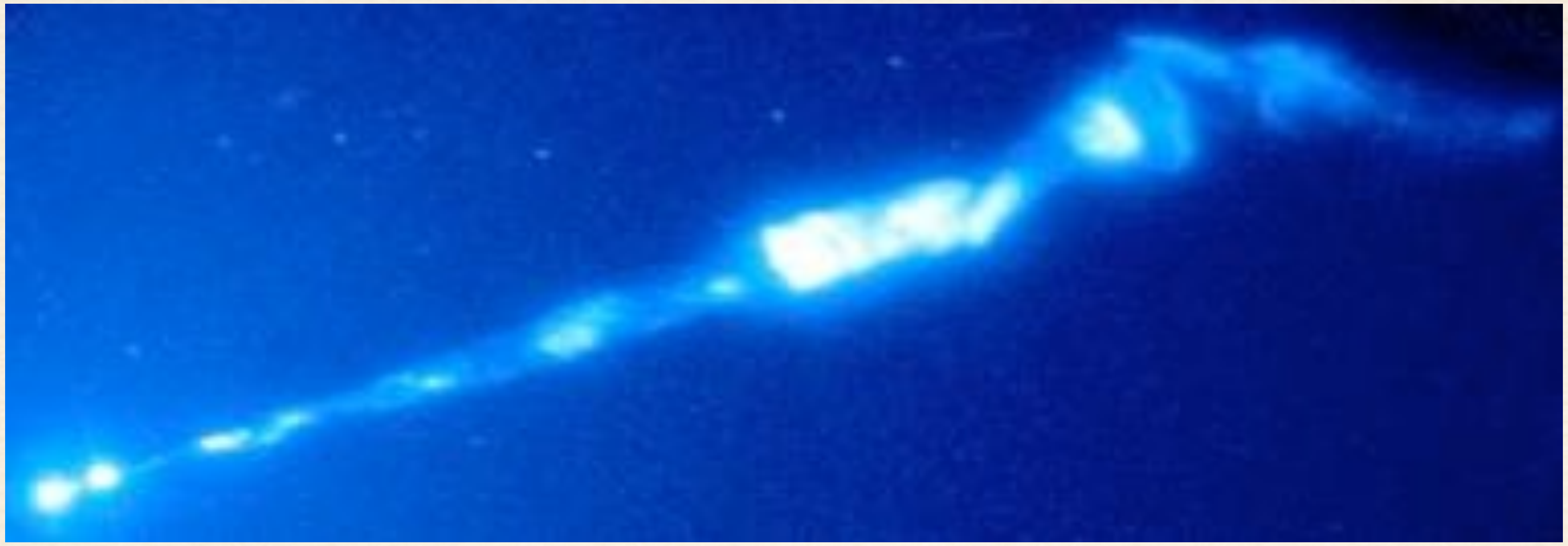
Exotic physics of black hole jets?



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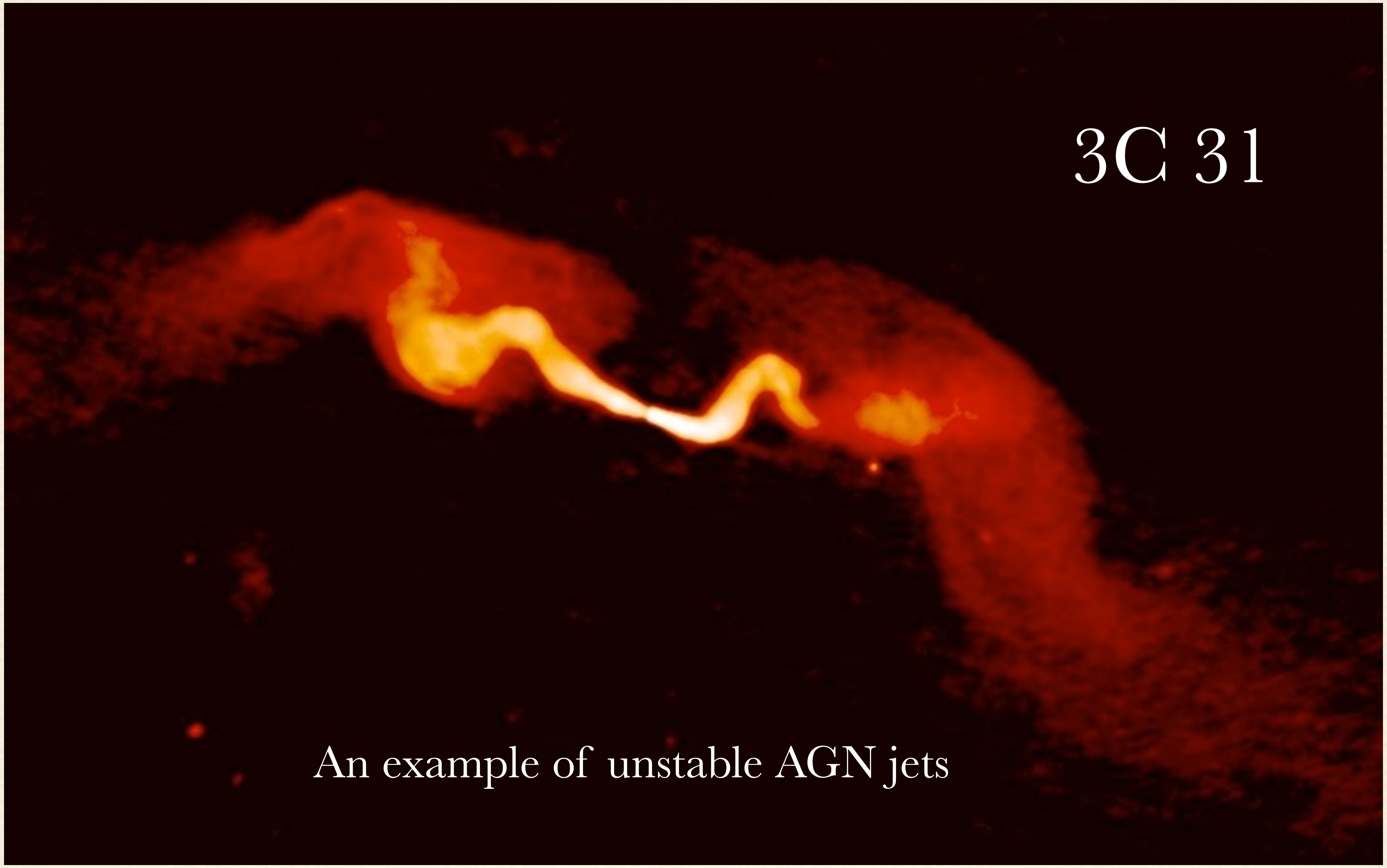
Exotic physics of black hole jets?

• Numerous studies of magnetized and unmagnetized relativistic jets show that they are still subject to instabilities.
• Non-relativistic stellar jets as impressive as AGN jets.
• Some AGN jets show clear sings of instabilities on kpc scales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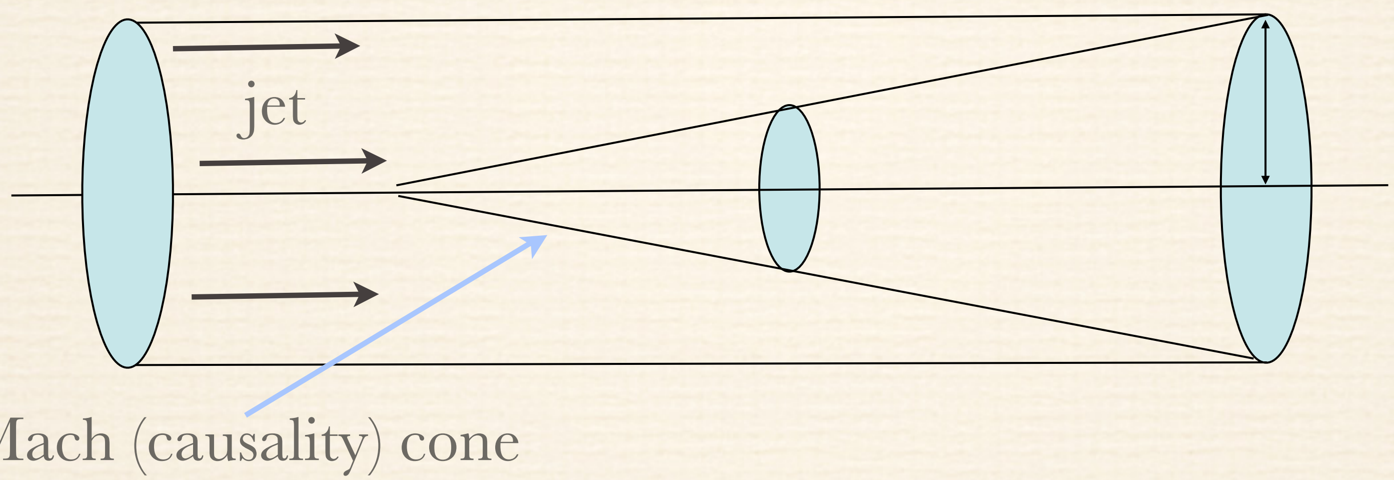
An example of unstable AGN jets

2. Causality and Stability

Only global instabilities can threaten jet survival.
For those to develop, jets must be causally connected.



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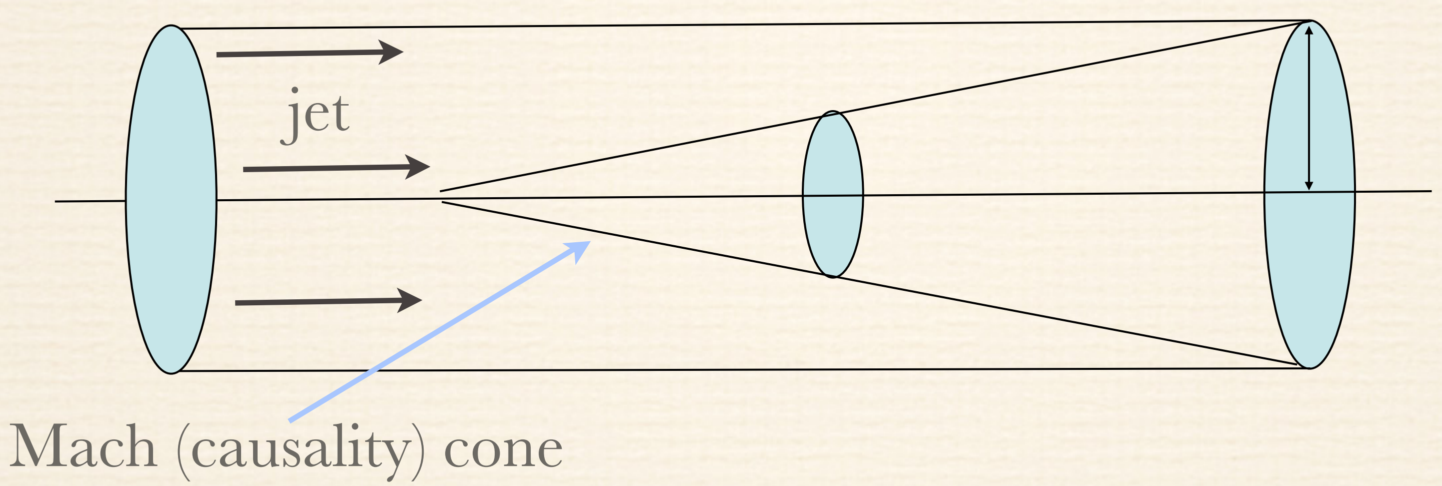

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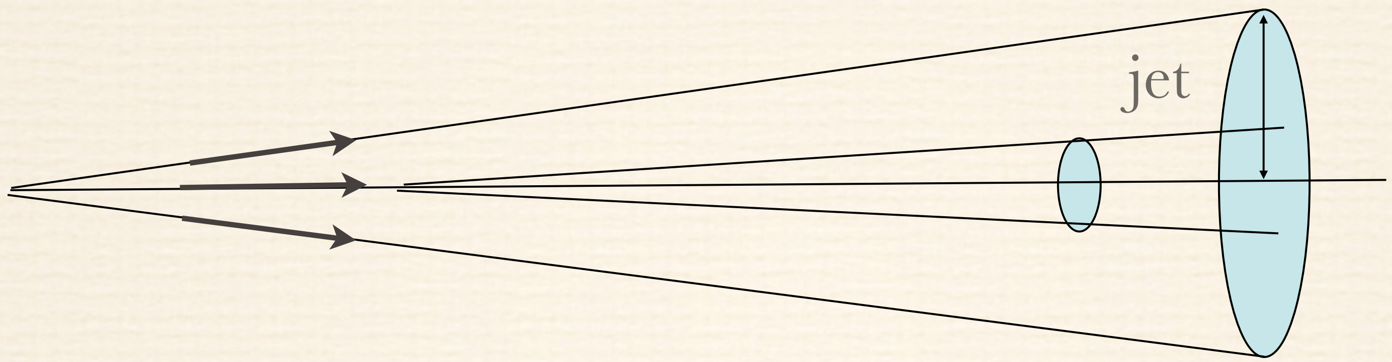
Astrophysical jets are not cylindrical. They expand a lot!

Causally-disconnected expanding jet



If the Mach cone is narrower than the jet

- the jet cannot move as a whole - no kink, no pinch;
- interface instabilities are confined to the boundary.

In a conical free-expanding adiabatic unmagnetized jet, the Mach angle decreases with distance

$$\Theta_m \propto r^{-(\gamma-1)} .$$

For a jet in pressure balance with surrounding gas with pressure

$$P_{ex} \propto r^{-\kappa}$$

one has

$$\Theta_m/\Theta_j \propto \frac{r^{(2-\kappa)/2}}{\kappa} .$$

2 is the critical value of the external pressure index.

Summary of studies

k<2 jets can remain causally-connected but it takes longer to establish longer for higher k. They can become unstable and get destroyed;

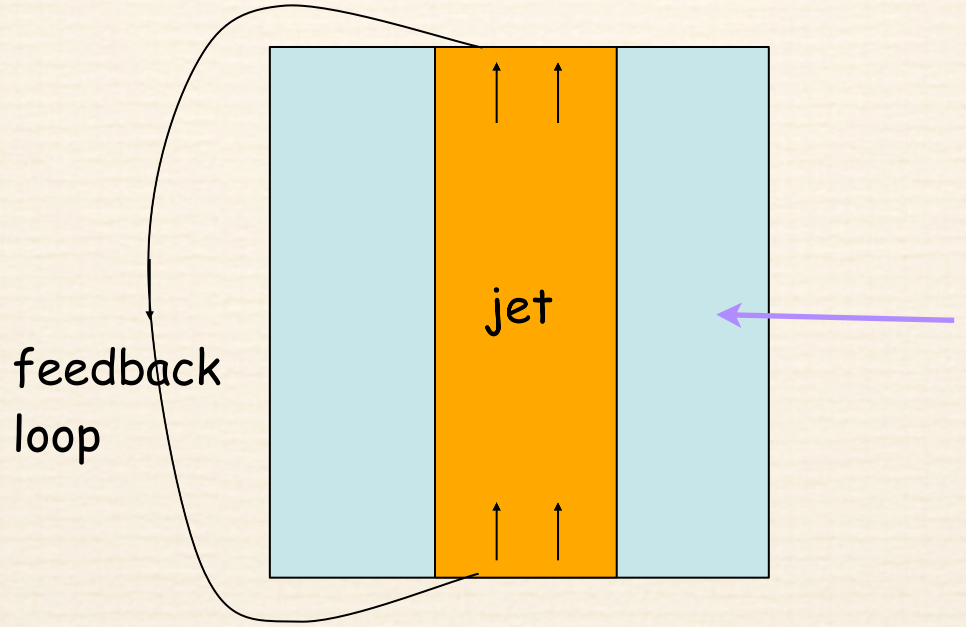
k>2 jets quickly lose connectivity and become free-expanding. Only local instabilities can develop. Such jets live long.

This applies to all types of jets.

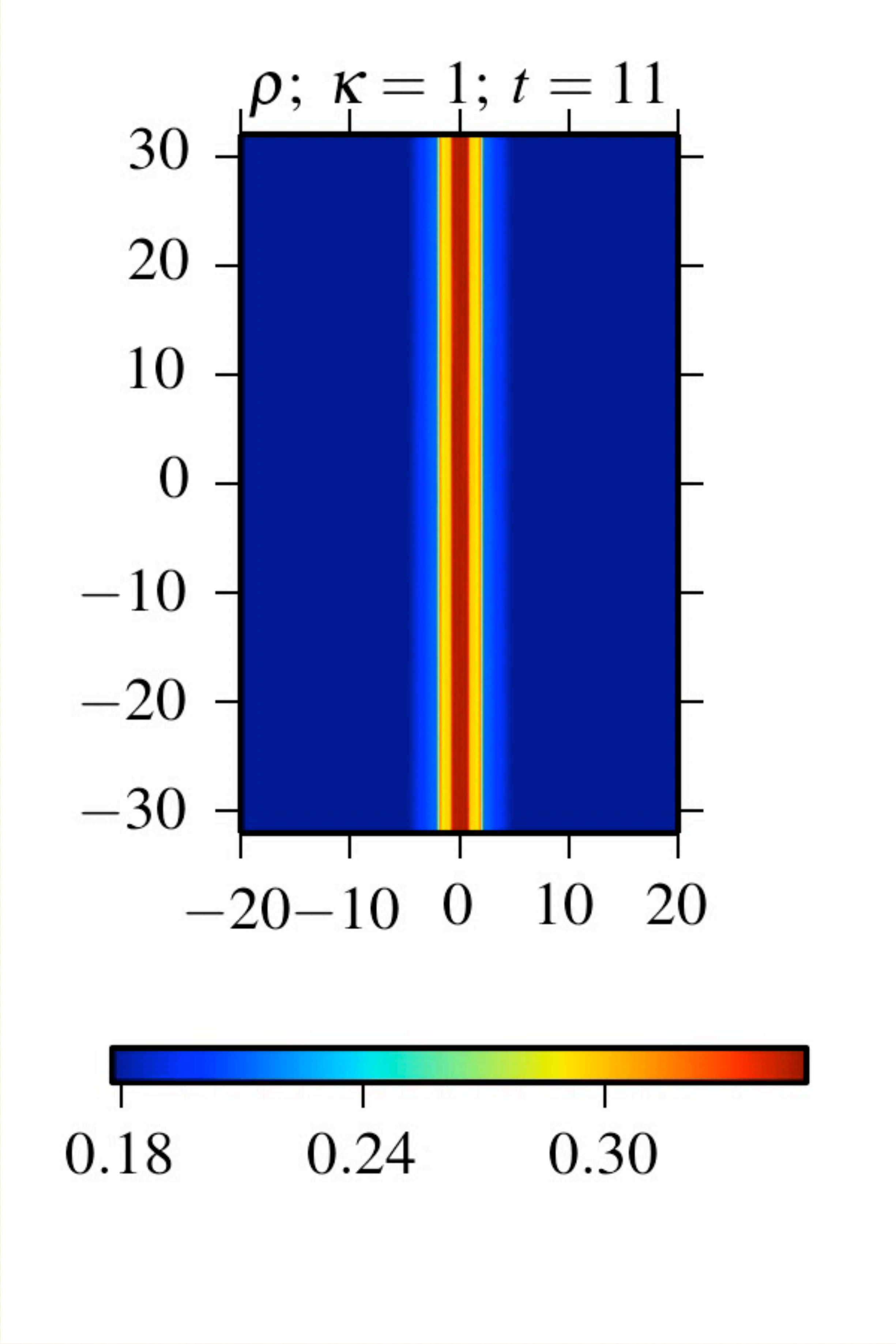
3.Computational experiment.

Porth & Komissarov (2015)

Relativistic magnetized jets;
3D simulations;
Periodic box with forced variation of external pressure;



$$P_{ex} \propto t^{-\kappa}$$

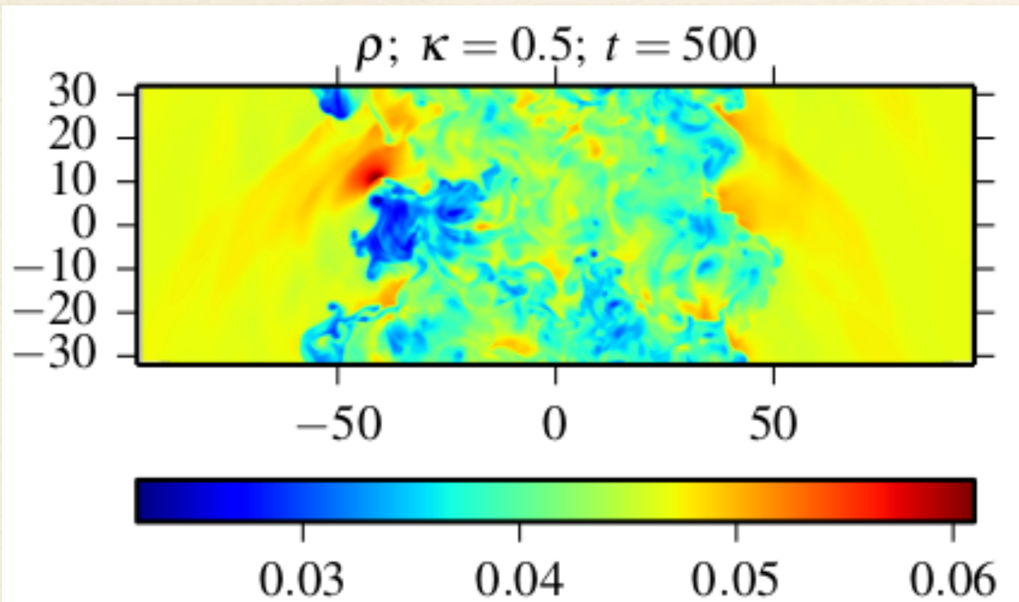


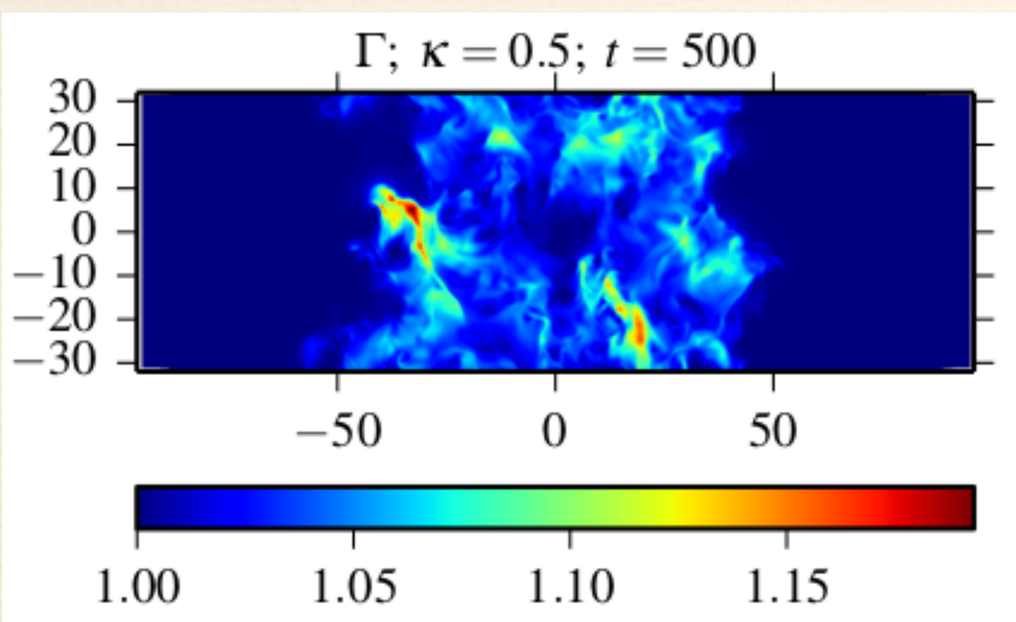
Animation

Watch for

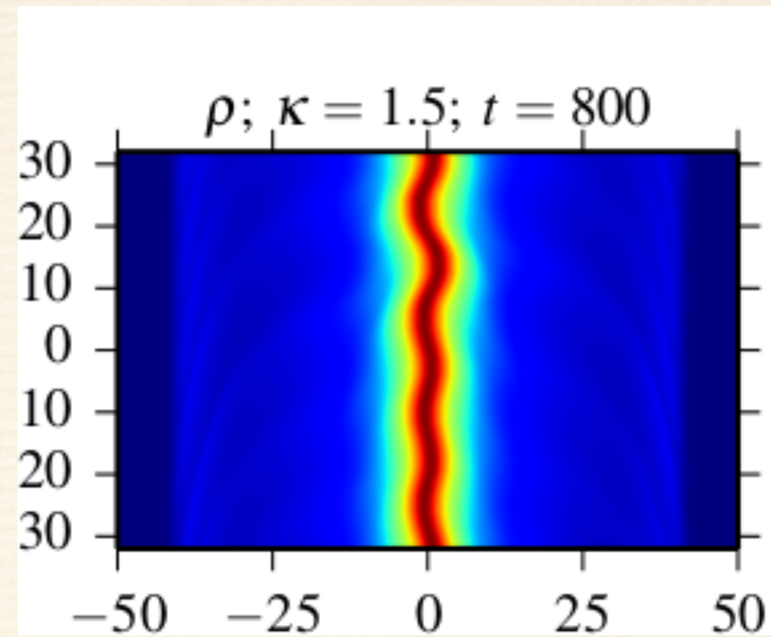
- jet expansion;
- kinks of magnetically confined core.

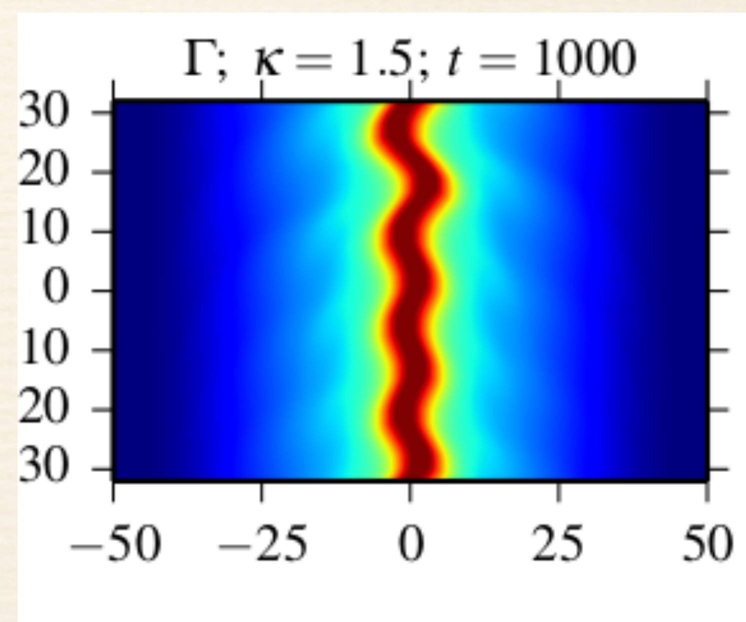
$\kappa = 0.5$



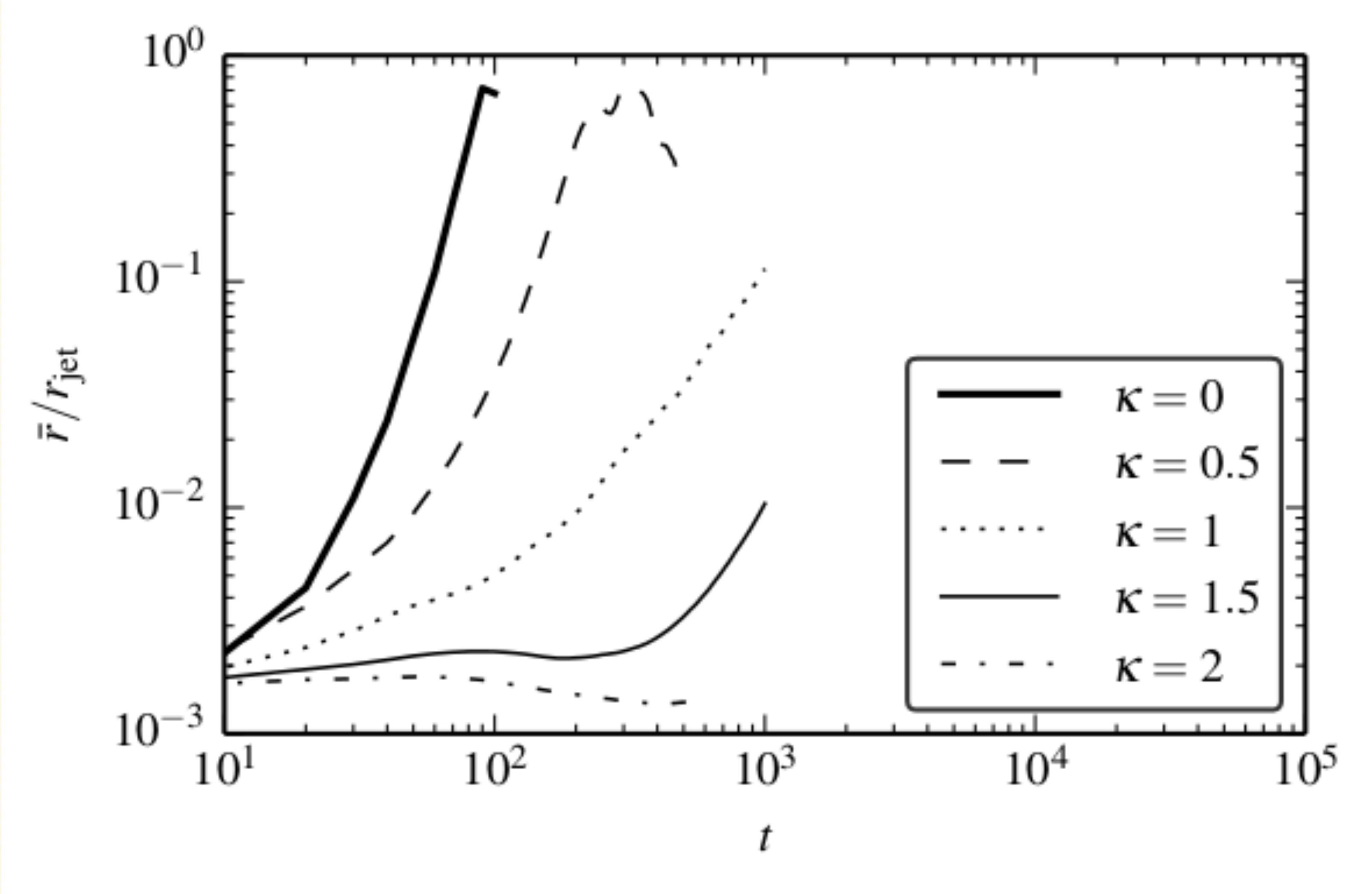


$\kappa = 1.5$





Growth rate of kink mode



No surprises here. The mechanism is simple and robust!

Survival of AGN jets

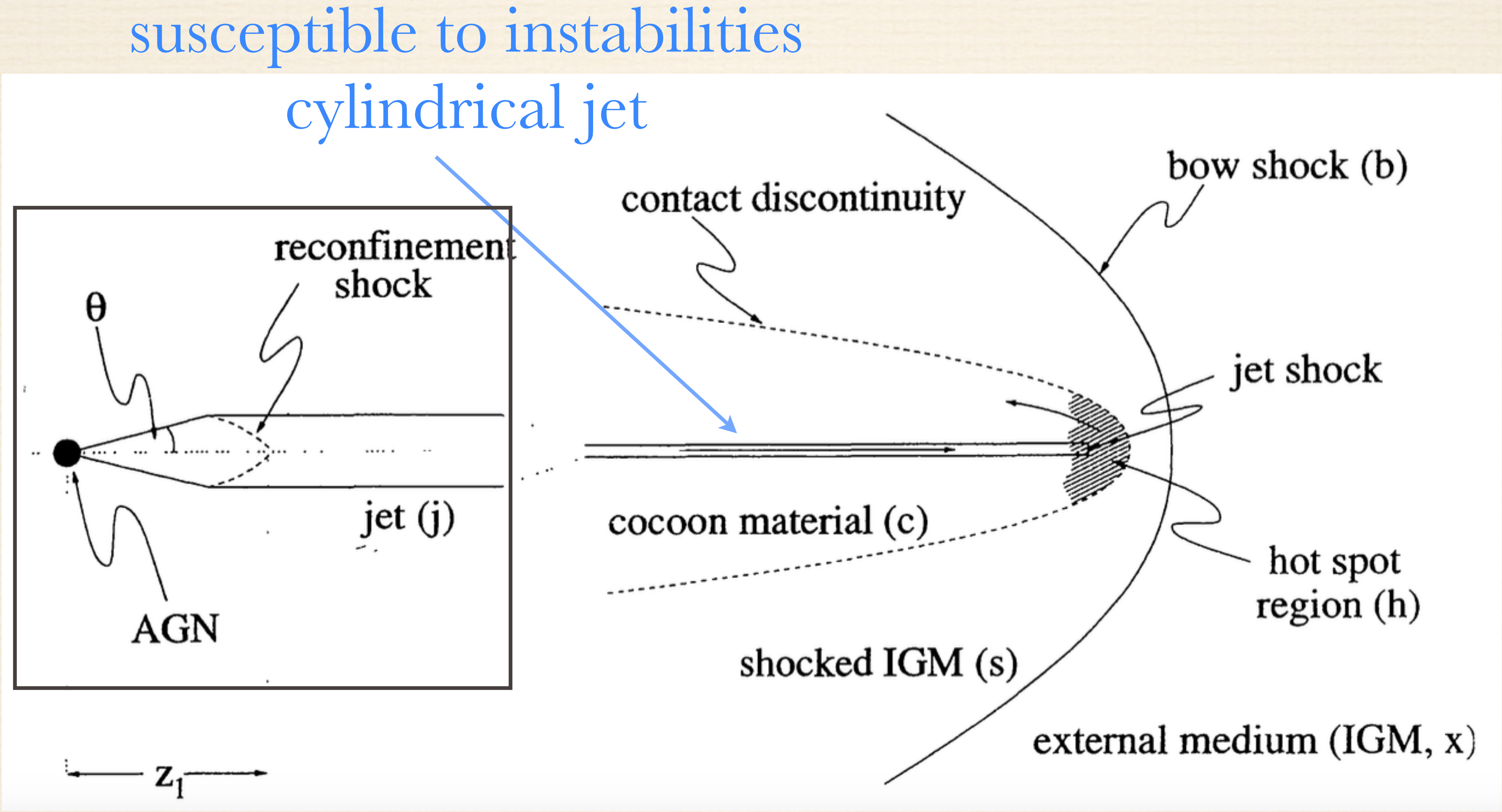
• Rapid drop of external pressure ($k>2$) is expected for AGN jets. Especially in the region dominated by the supermassive BH gravity. There, the jets are mainly free-expanding and stable.

• They can become pressure-confined further out, inside

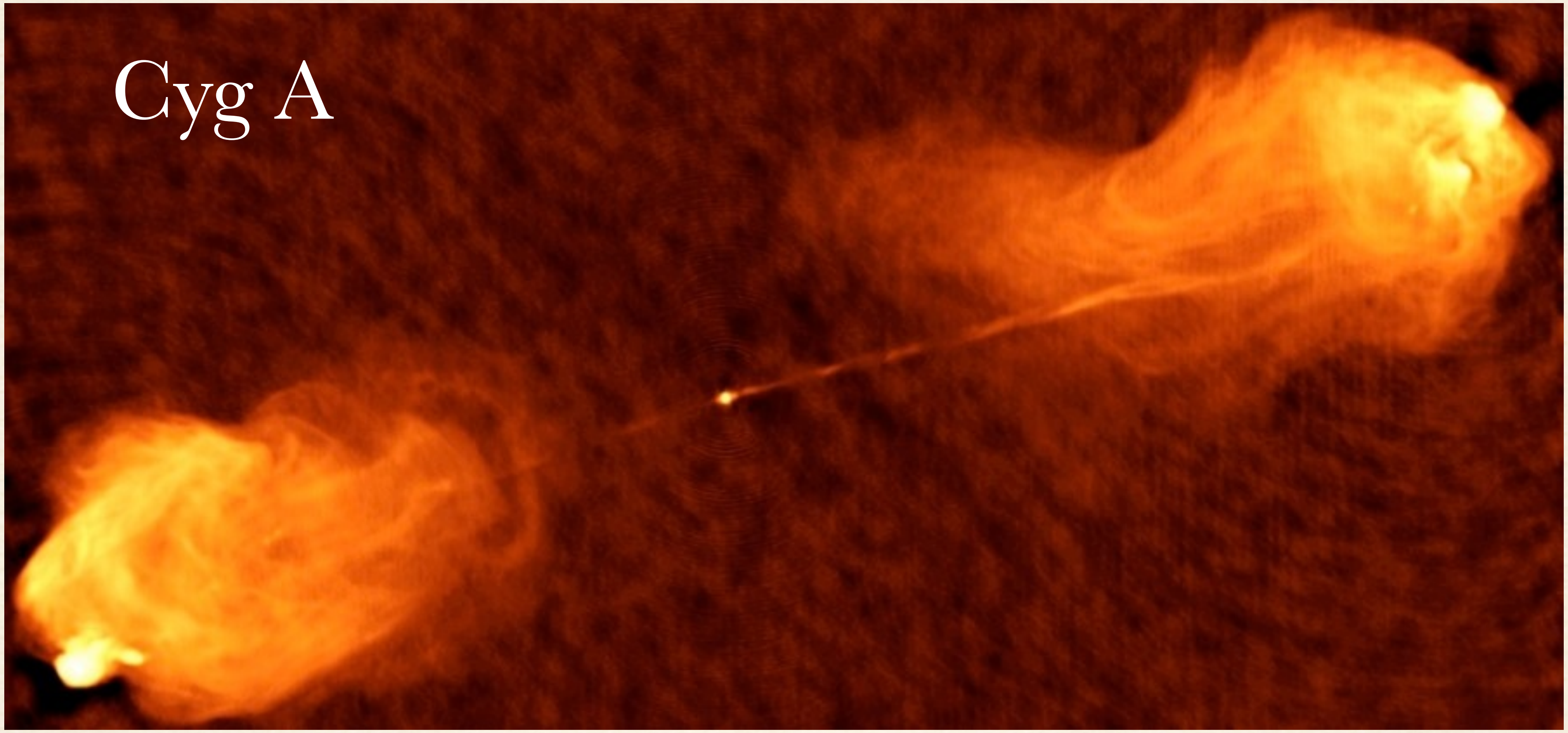
1. their radio lobes (heavy jets imbedded in cocoons);
2. galactic coronas (light naked jets).

and develop global instabilities.

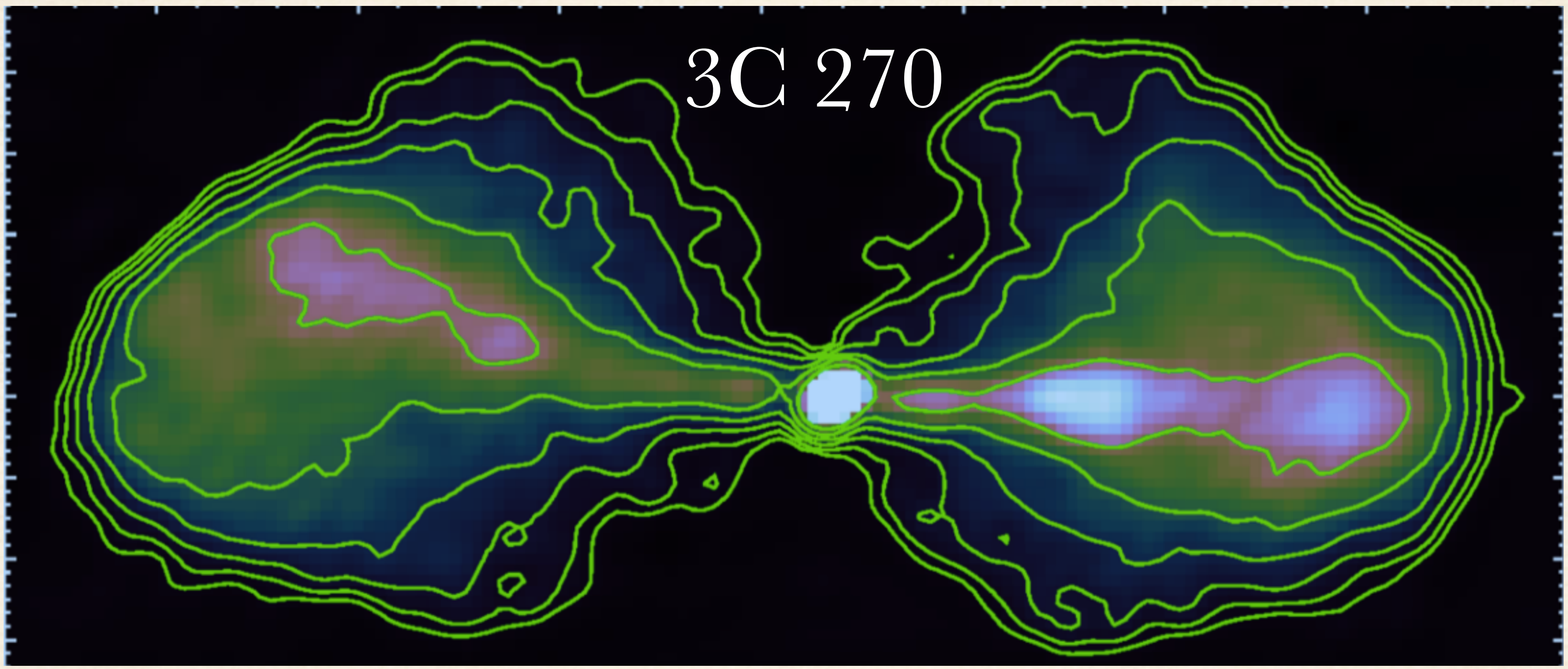
• This transition may explain the Fanaroff-Riley division of extragalactic radio sources into two main classes (e.g. Kaiser & Alexander 1997, Porth & Komissarov 2015, Tchekhovskoy & Broomberg 2016).



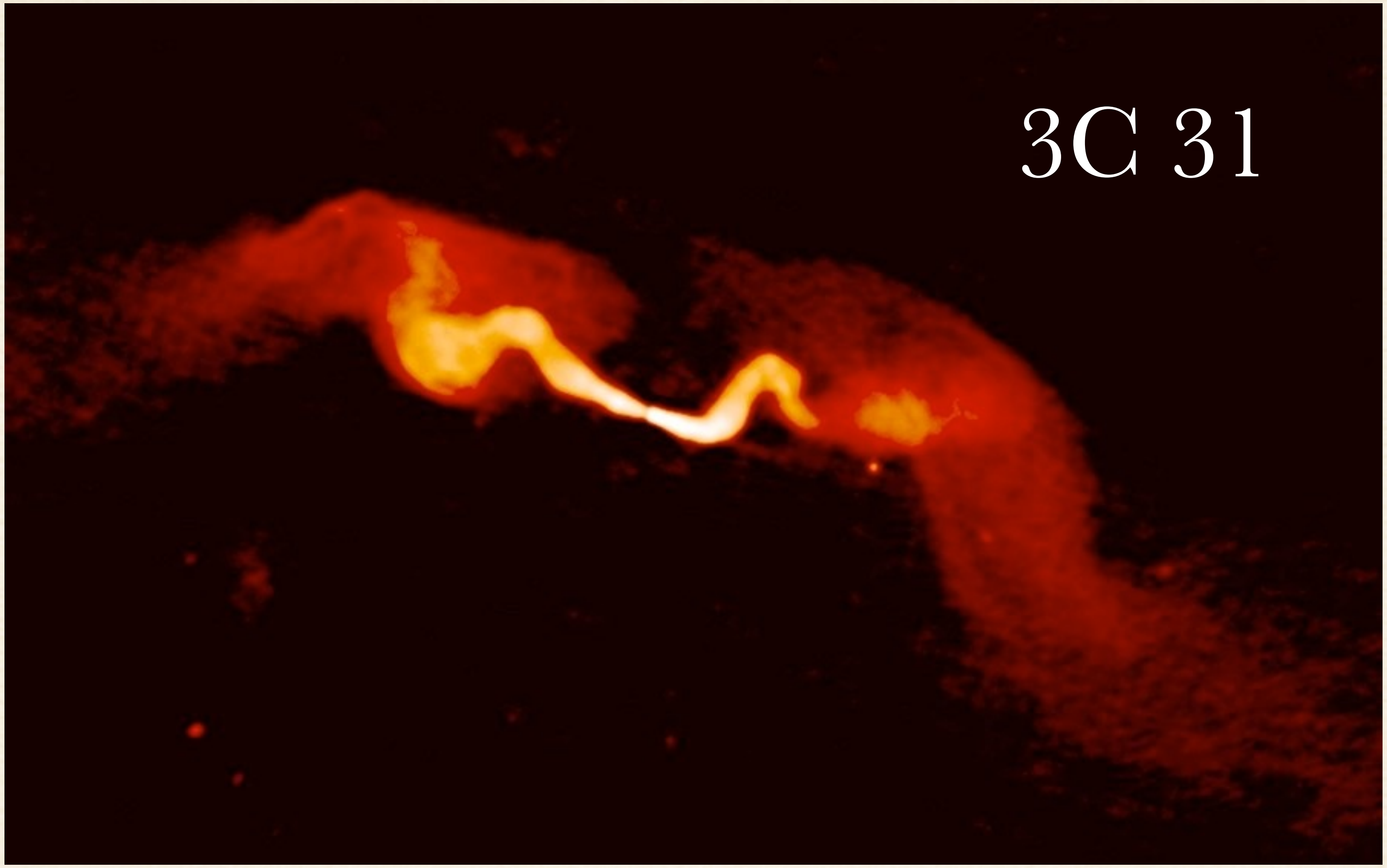
(Falle 1991, Kaiser & Alexander 1997)



A typical FR-II source. Jets get re-confined inside their cocoon and begin to develop instabilities.

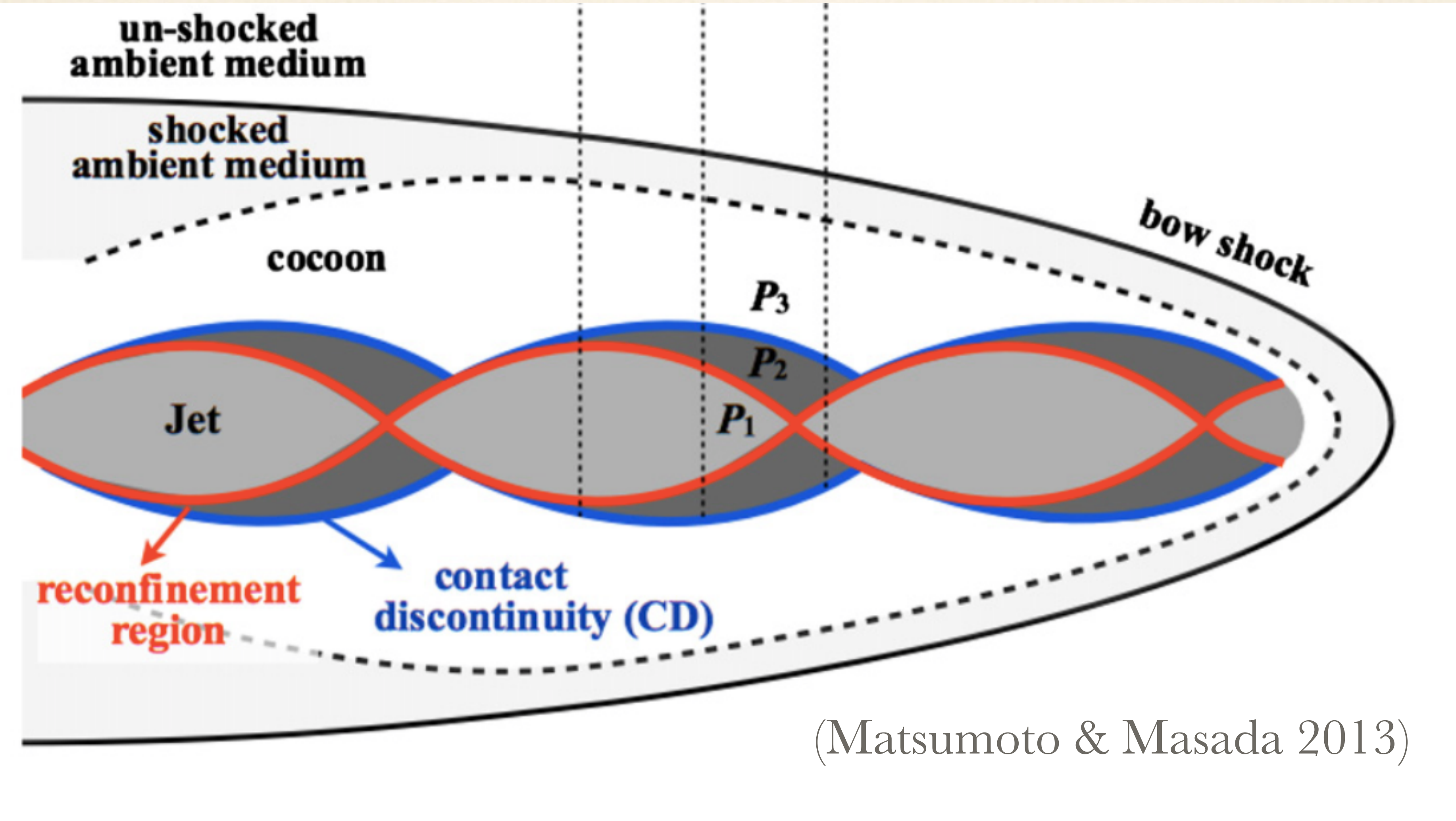


A typical FR-I source. Jets get destroyed by instabilities inside their cocoons.



“Naked-jet” FR-I source. The cocoons turn into plumes. Jets become pressure-confined by the galactic corona and get destroyed by instabilities.

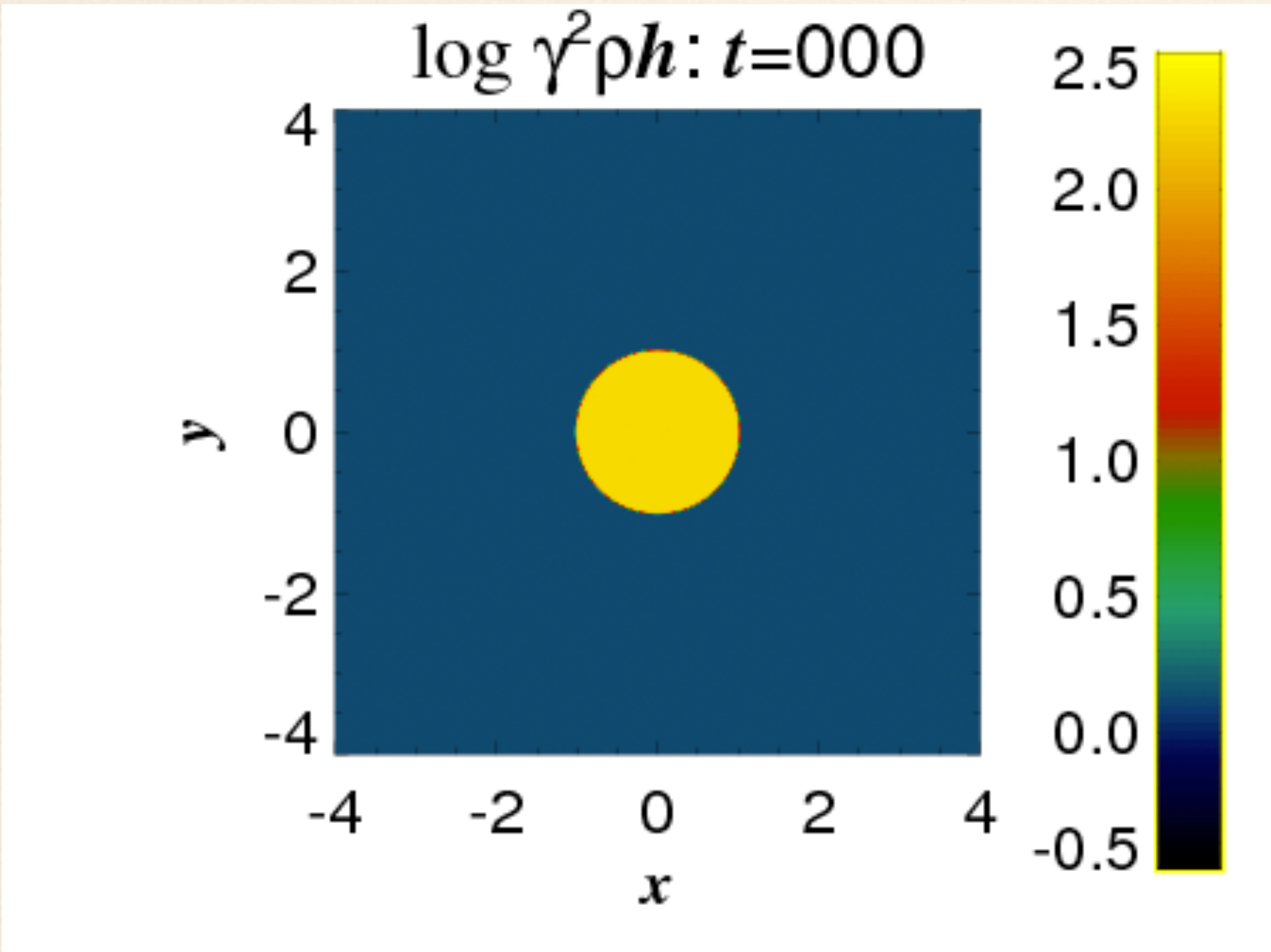
4. A note on RTI in jets



(Matsumoto & Masada 2013)

FR-II jet gets reconfined inside its own cocoon. It is heavy. It bounces. Favorable conditions for Rayleigh-Taylor instability.

Jet RTI in action



(Matsumoto & Masada 2013)

Bouncing, heavy, relativistic unmagnetized jet.

2D simulations, jet cross-section. Over-pressured jet.

RTI, not KHI, may be the dominant instability for FR-II jets.

The End