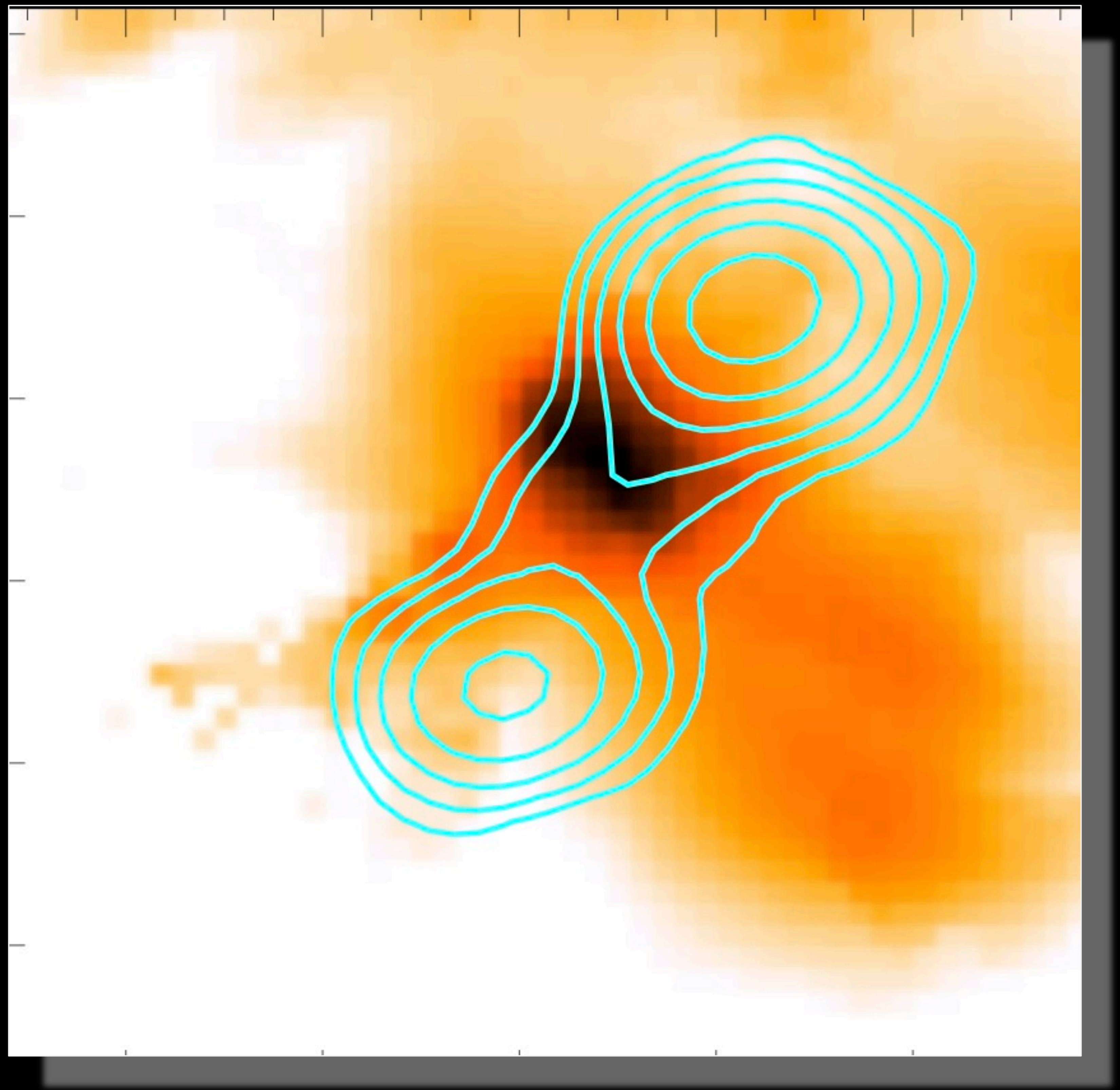
ASTRON
Netherlands Institute for Radio Astronomy

university of groningen / faculty of science and engineering / kapteyn astronomical institute

Taking snapshots of the jet-ISM interplay with ALMA:

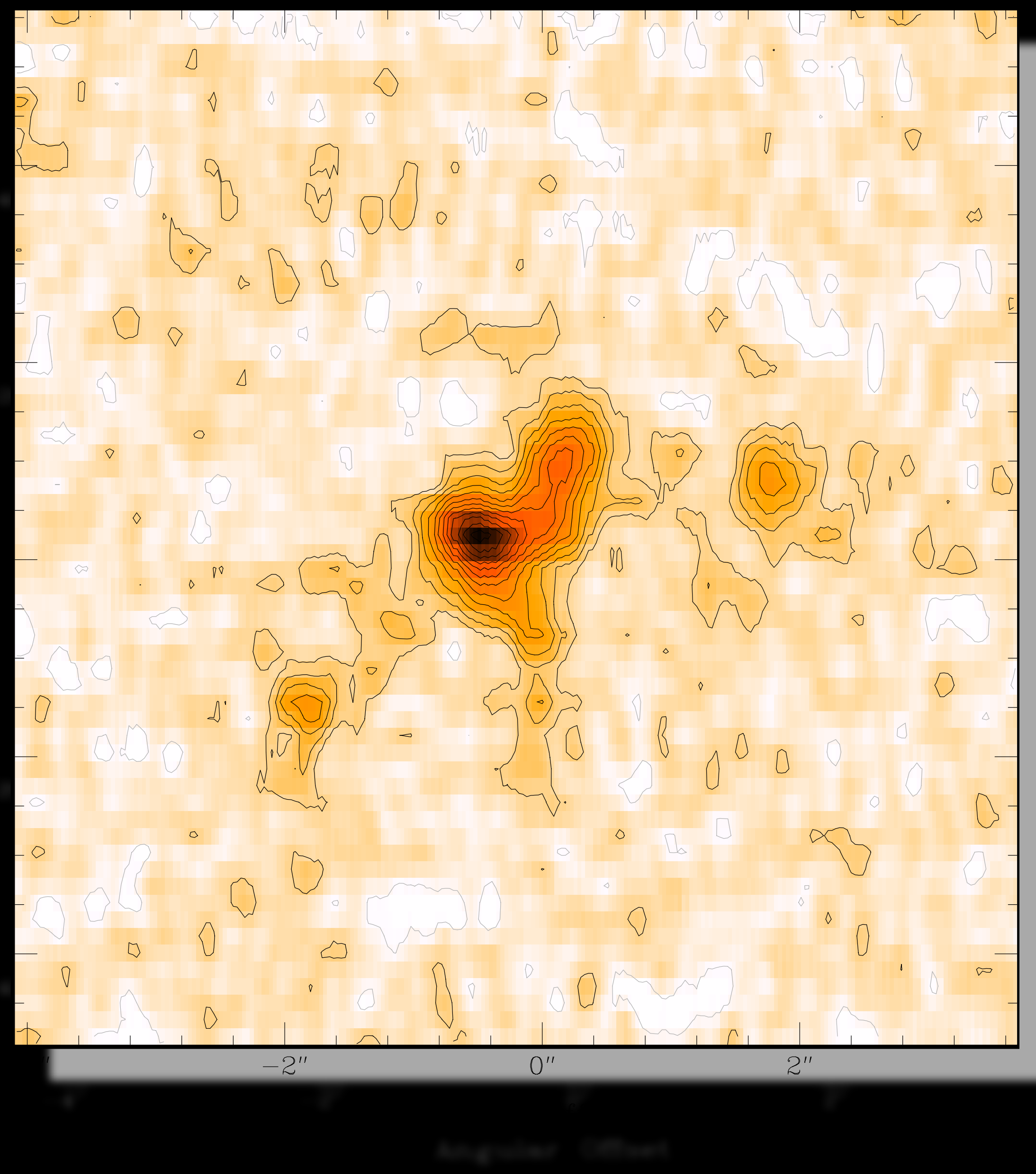
the case of the CSS PKS 0023−26



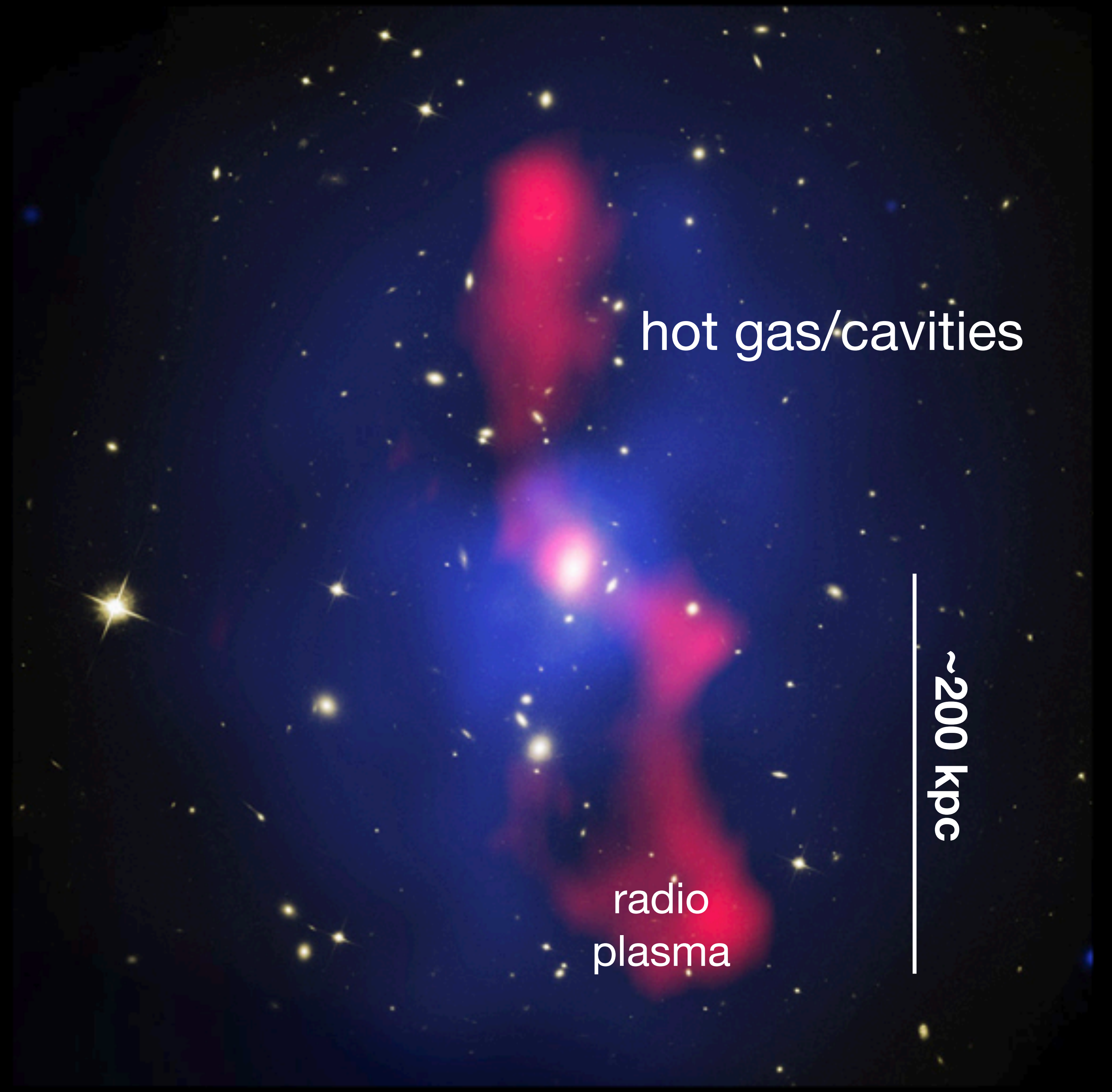
Raffaella Morganti

ASTRON, Kapteyn Institute

Tom Oosterloo, Clive Tadhunter
Suma Murthy and many others....



Role of radio jets for feedback

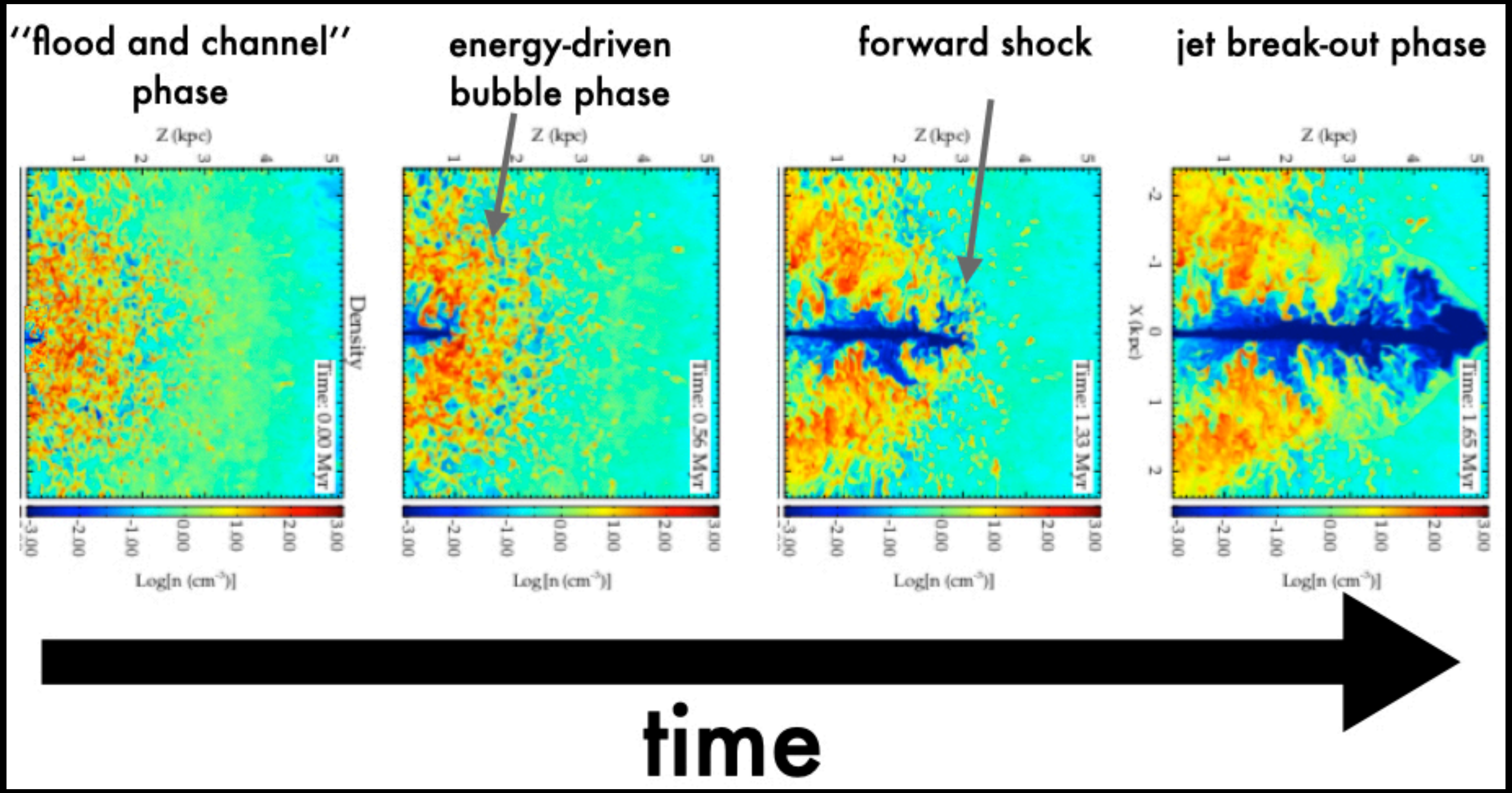


Hundreds of kpc-scales

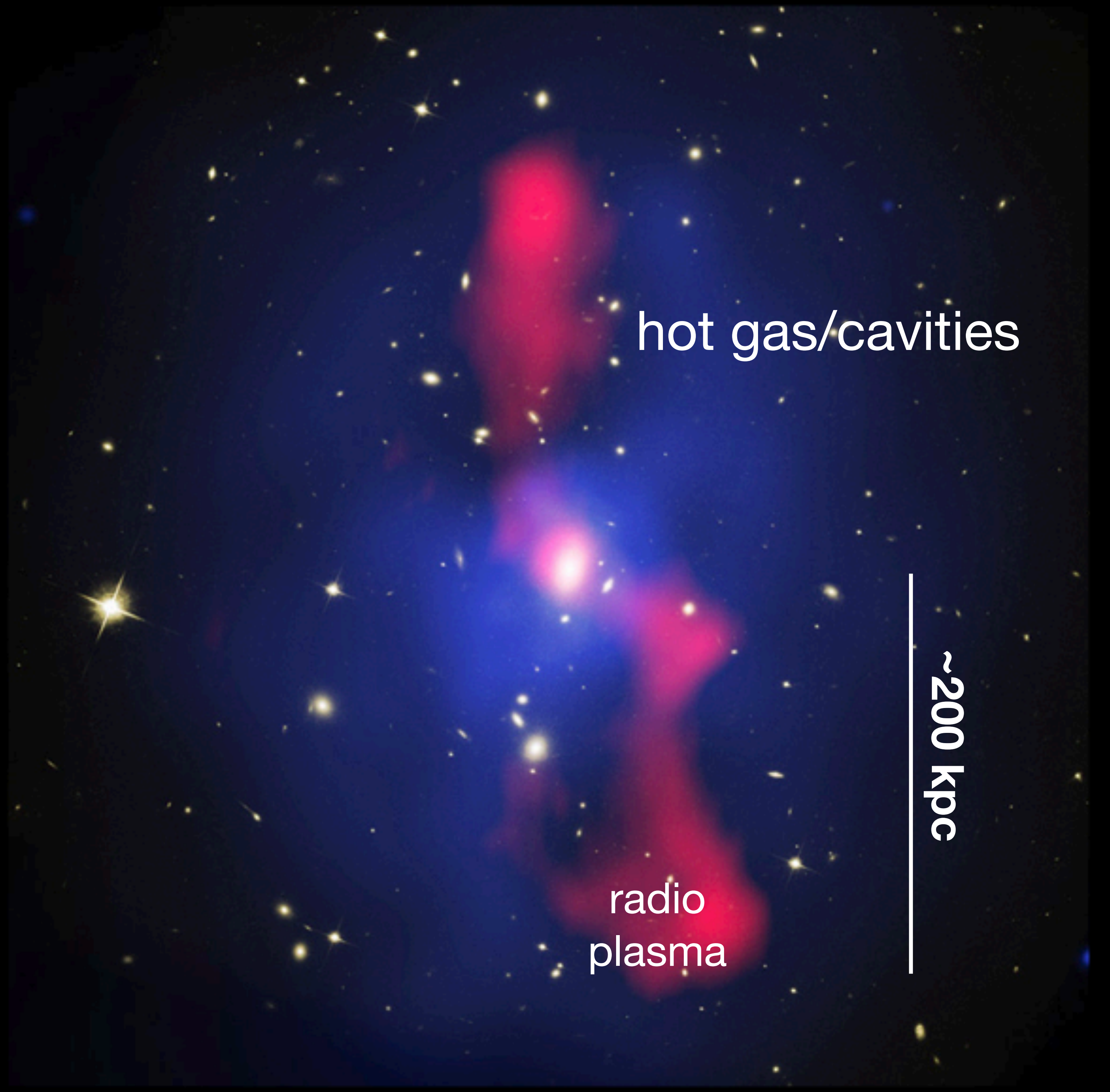
Maintenance mode: prevent cooling of gas: radiative inefficient radio AGN

Role of radio jets for feedback

but the impact of jets starts already in the very inner regions and when the radio source is young!



Sutherland & Bicknell 2007
Wagner, Bicknell et al. 2011; Mukherjee et al. 2015

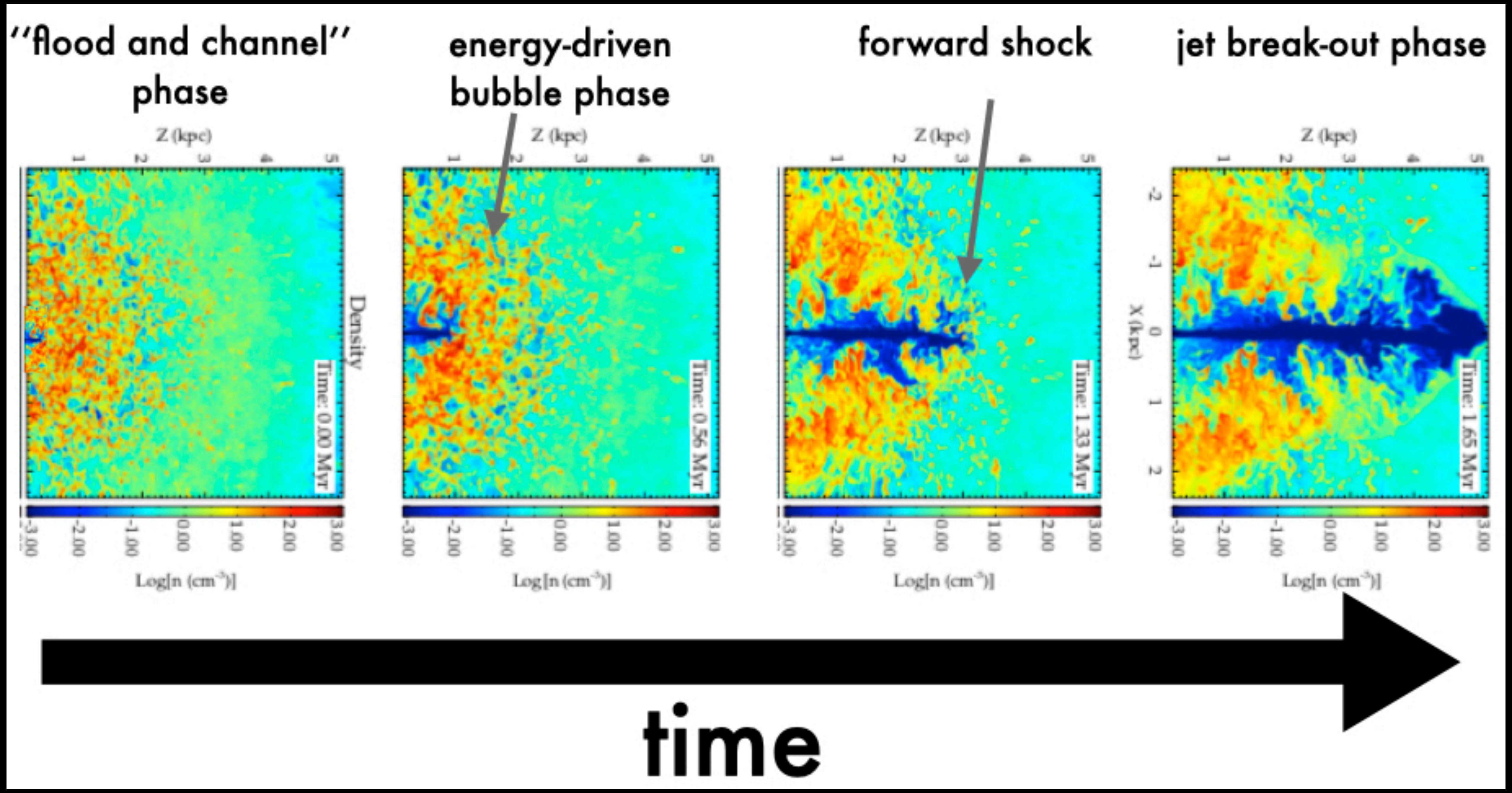


Hundreds of kpc-scales

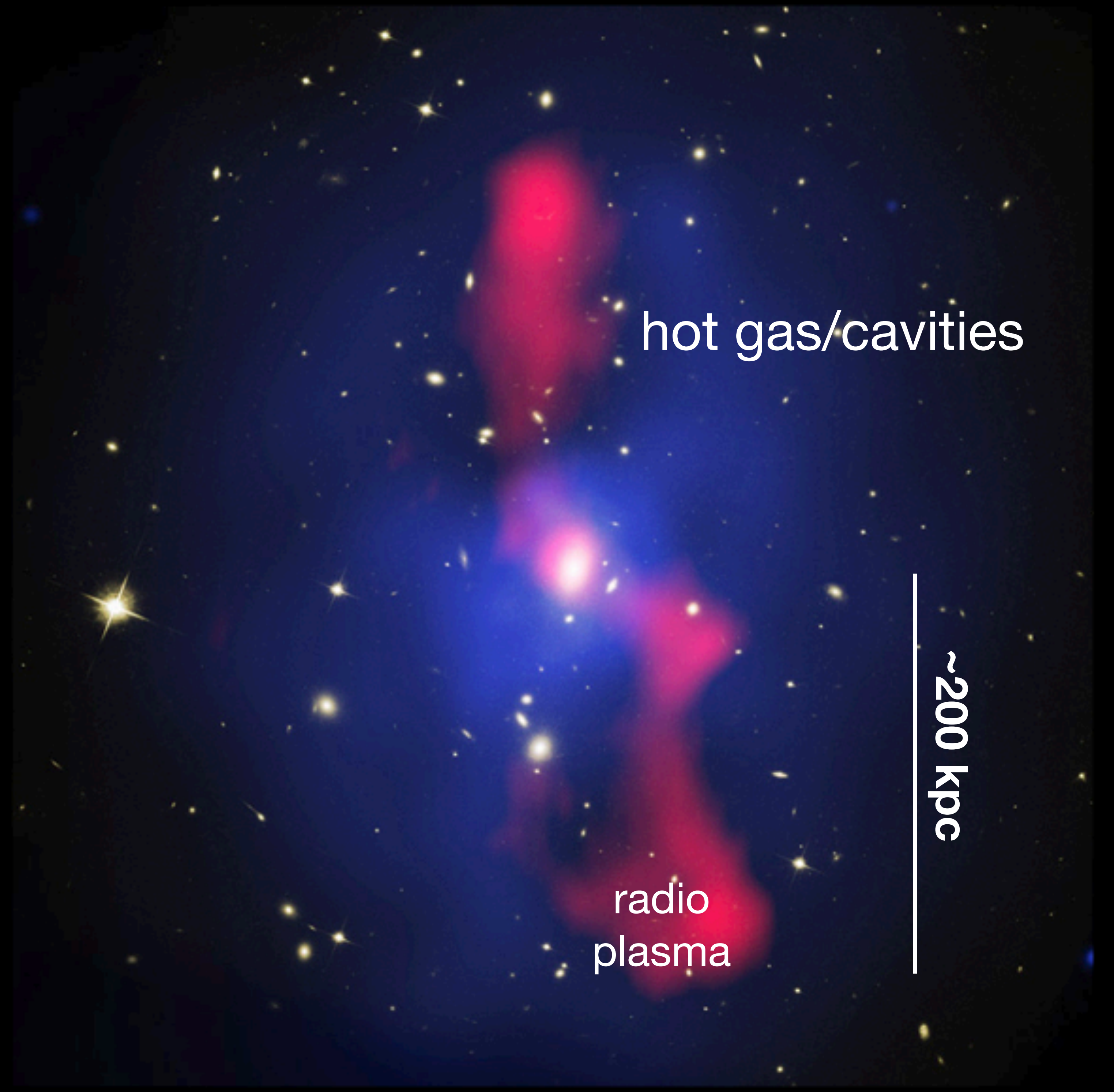
Maintenance mode: prevent cooling of gas: radiative inefficient radio AGN

Role of radio jets for feedback

but the impact of jets starts already in the very inner regions and when the radio source is young!



Sutherland & Bicknell 2007
Wagner, Bicknell et al. 2011; Mukherjee et al. 2015



Hundreds of kpc-scales

Maintenance mode: prevent cooling of gas: radiative inefficient radio AGN

Impact can be traced by gas in different phases, e.g. outflows common in warm ionised gas (especially in CSS/GPS), but the most massive component in cold gas

We use the cold molecular gas as tracer

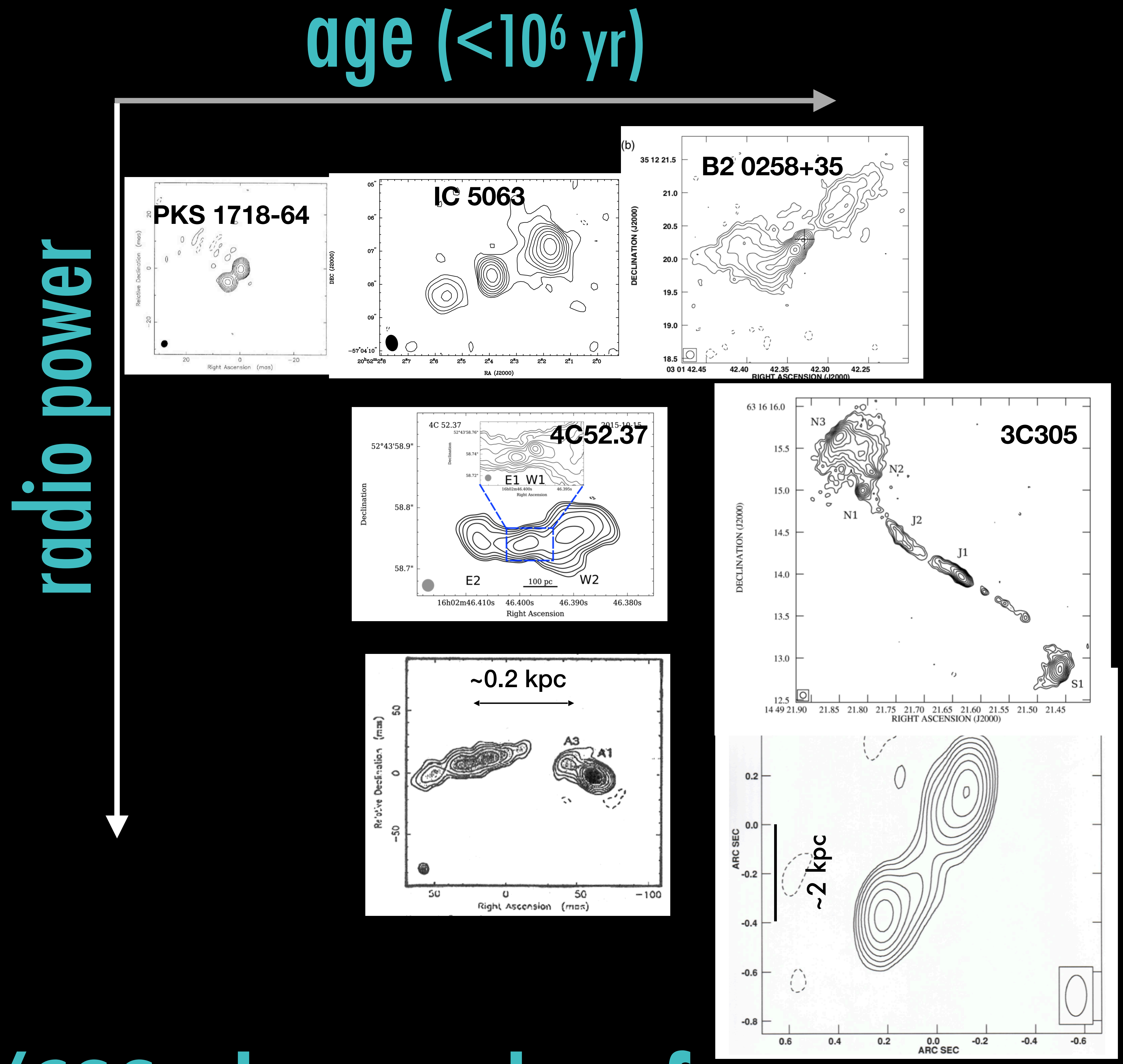
Complex multi-parameter space to explore!

radio power

evolutionary stage/age

multi-phase outflows and location

orientation jet/ISM



our ALMA (and NOEMA) sample of GPS/CSS observed so far

high spatial resolution (~0.2 arcsec) to follow the molecular gas across the radio emission

see also talk by Suma Murthy (Friday's session)

Complex multi-parameter space to explore!

radio power

evolutionary stage/age

multi-phase outflows and location

orientation jet/ISM

our ALMA (and NOEMA) sample of GPS/CSS observed so far

high spatial resolution (~0.2 arcsec) to follow the molecular gas across the radio emission

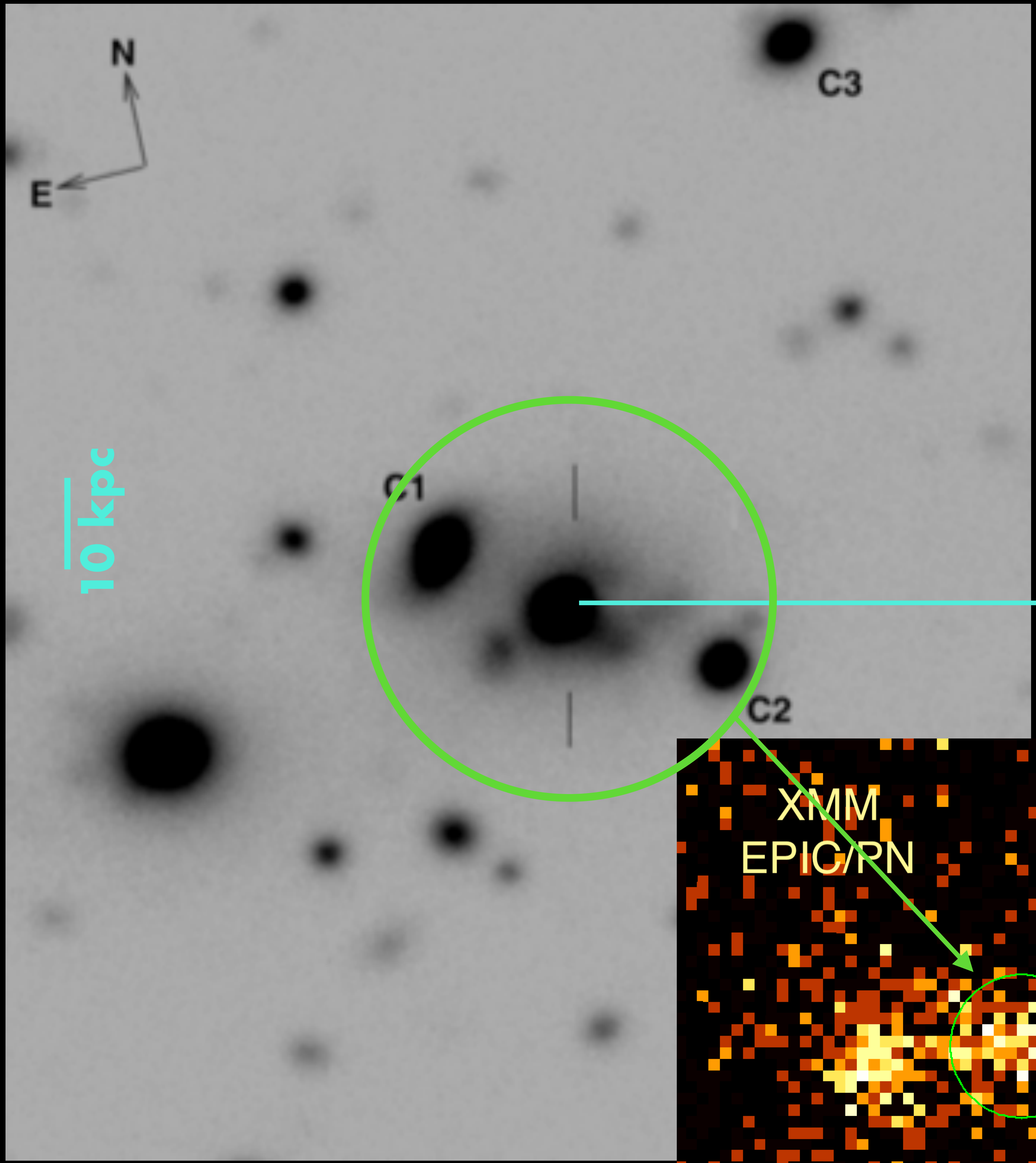
see also talk by Suma Murthy (Friday's session)

PKS 0023-26 a young (CSS) radio galaxy....

PKS 0023-26 (z = 0.321): young but evolved powerful jet (~ 4 kpc)
Also powerful optical AGN

FarIR bright and young stellar population → SFR~24 $M_\odot$/yr

Redshift z=0.32188



Optical, Ramos Almeida et al. 2013

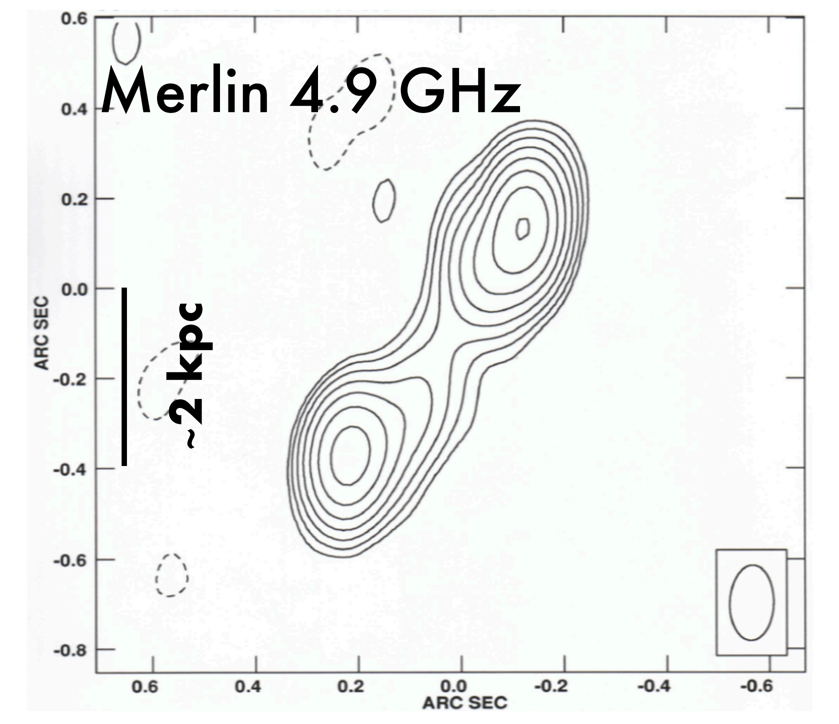
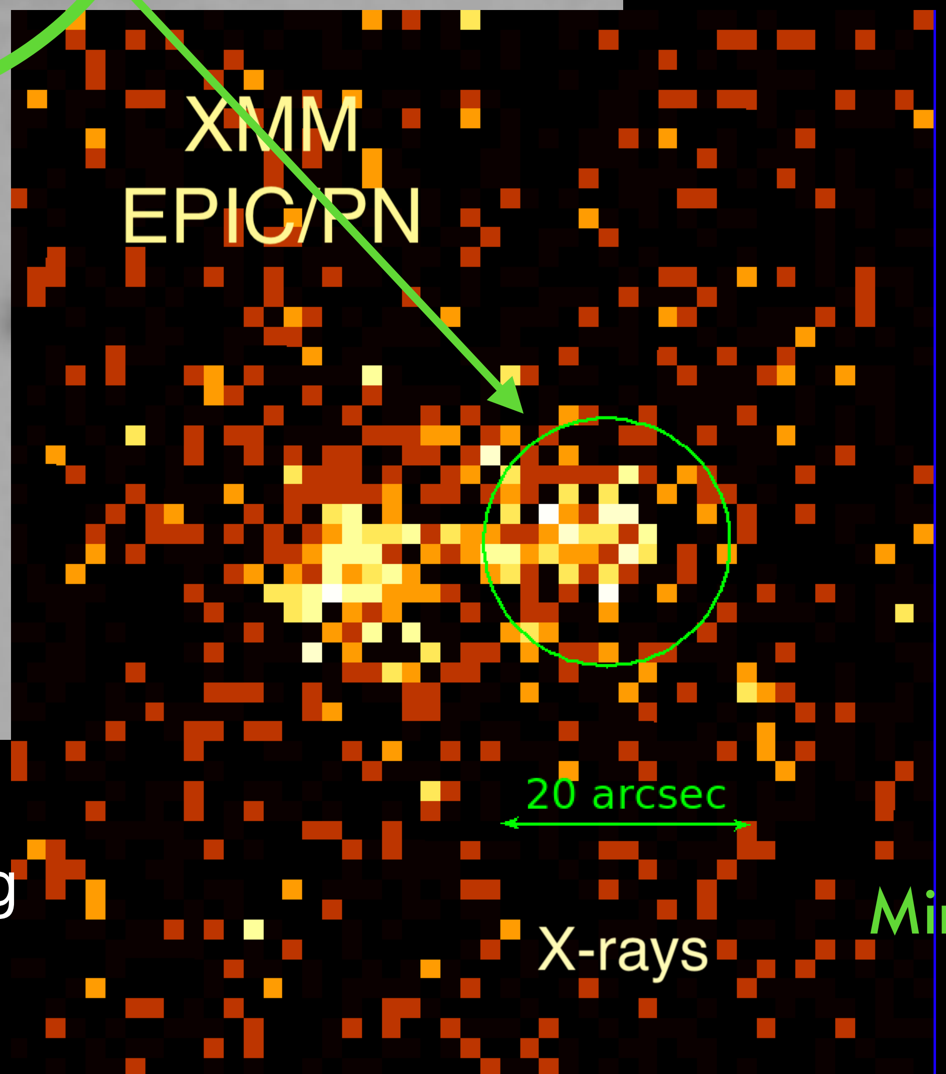


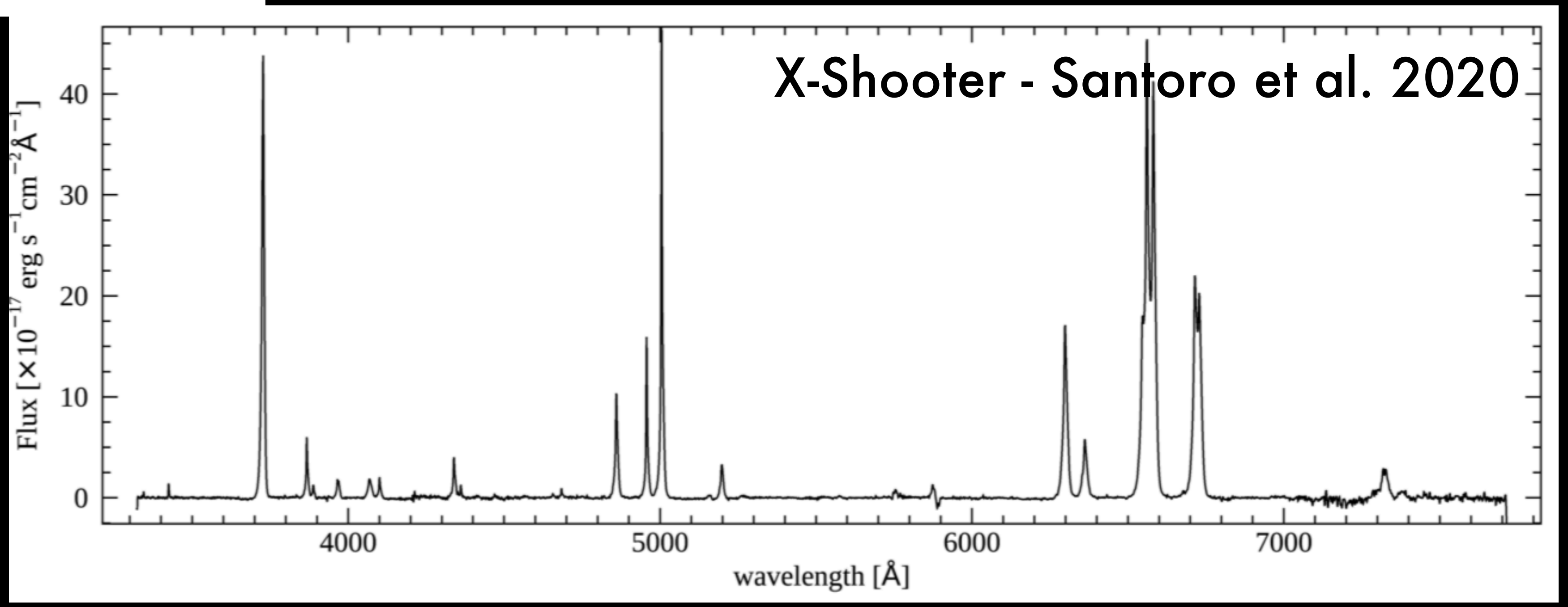
Fig. 4. PKS 0023-263 at 4996 MHz from the MERLIN array. The peak level is 1.41 Jy/beam and contours are shown at −6, −3, −1.5, −0.75, 0.75, 1.5, 3, 6, 12, 24, 48, 96% of the peak.

Tzioumis et al. 2002

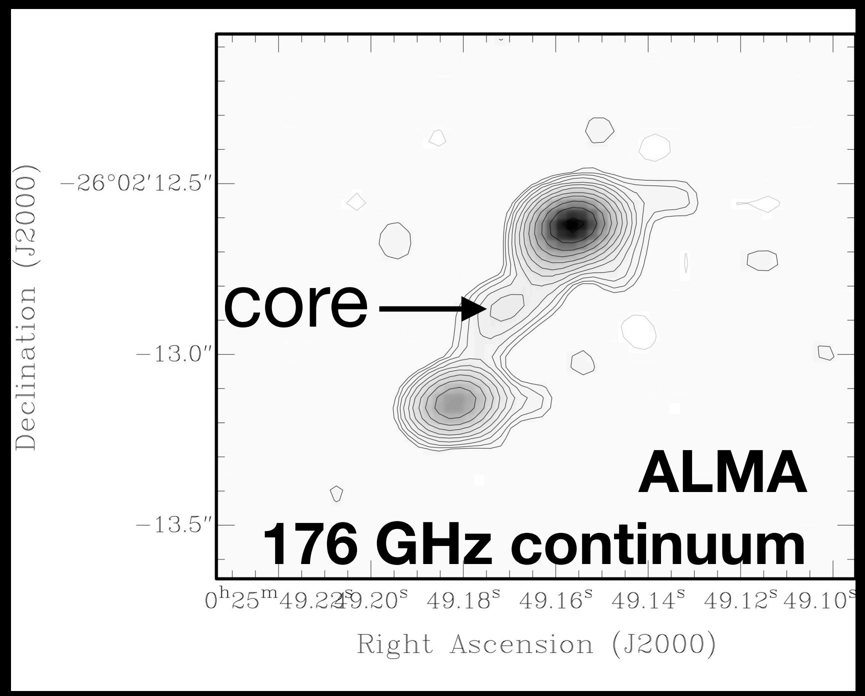


Chandra observations on-going
(PI Siemiginowska)

Mingo et al. 2014



PKS 0023-26 view by ALMA

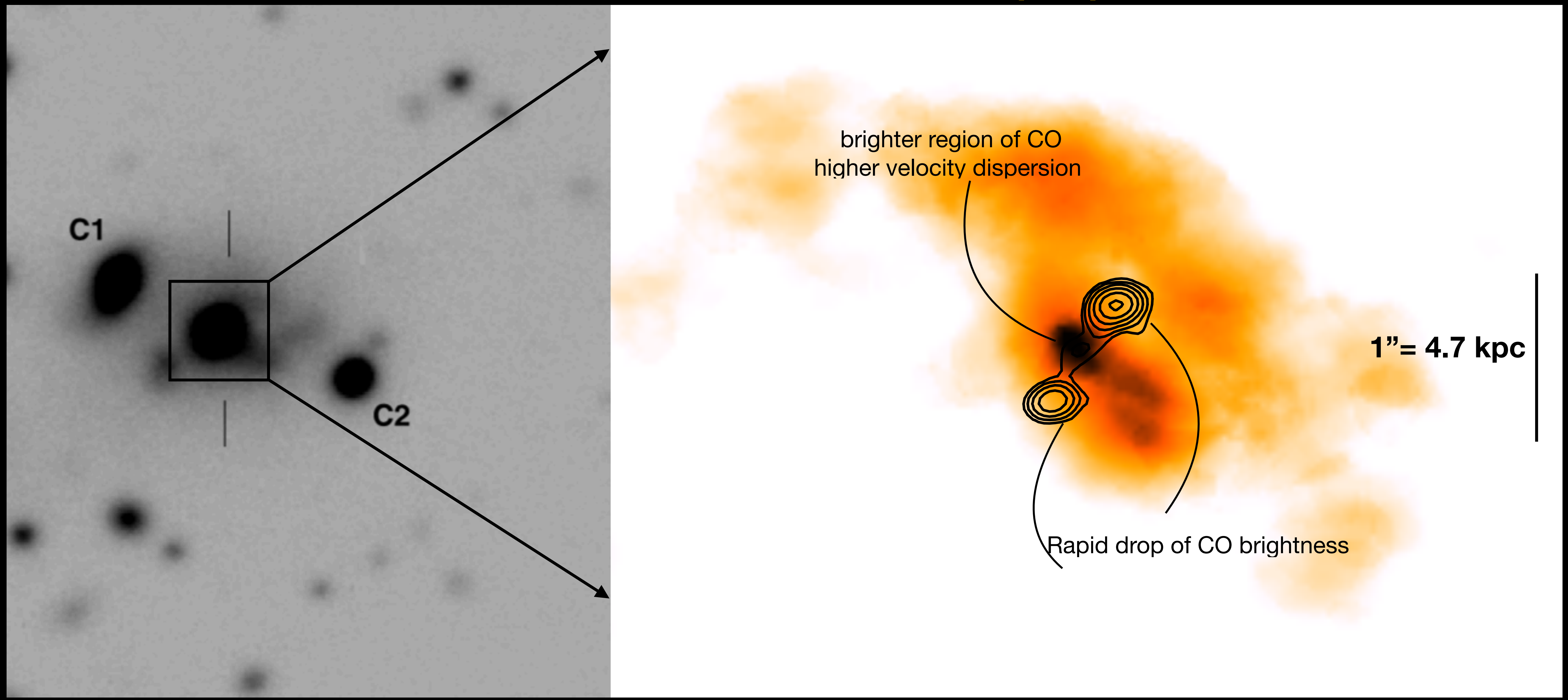


- Mass of molecular gas: about 10^{10} $M_{\odot}$
  ➜ distributed on ~20 kpc, with tidal streams

- Large amount of molecular gas, accretion from companions and cooling of the hot halo: similar to cases found in clusters?

- Bright central region of molecular gas
  ➜ piling up of gas or effect of higher excitation due to AGN (will require more transition to check this)
- Low brightness at the location of the lobes

ALMA view: CO(2-1), 0.2 arcsec resolution

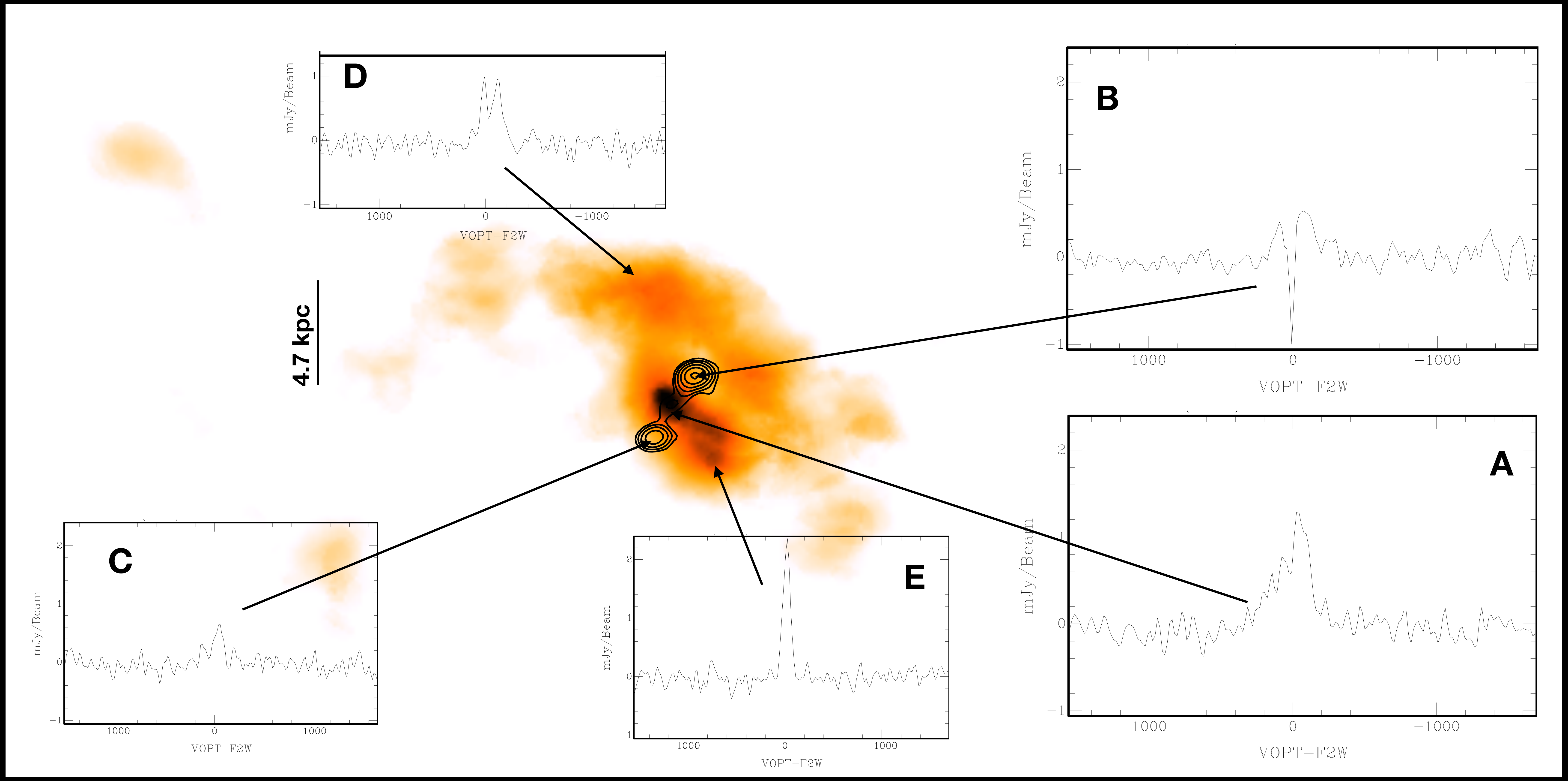


Morganti et al. in prep

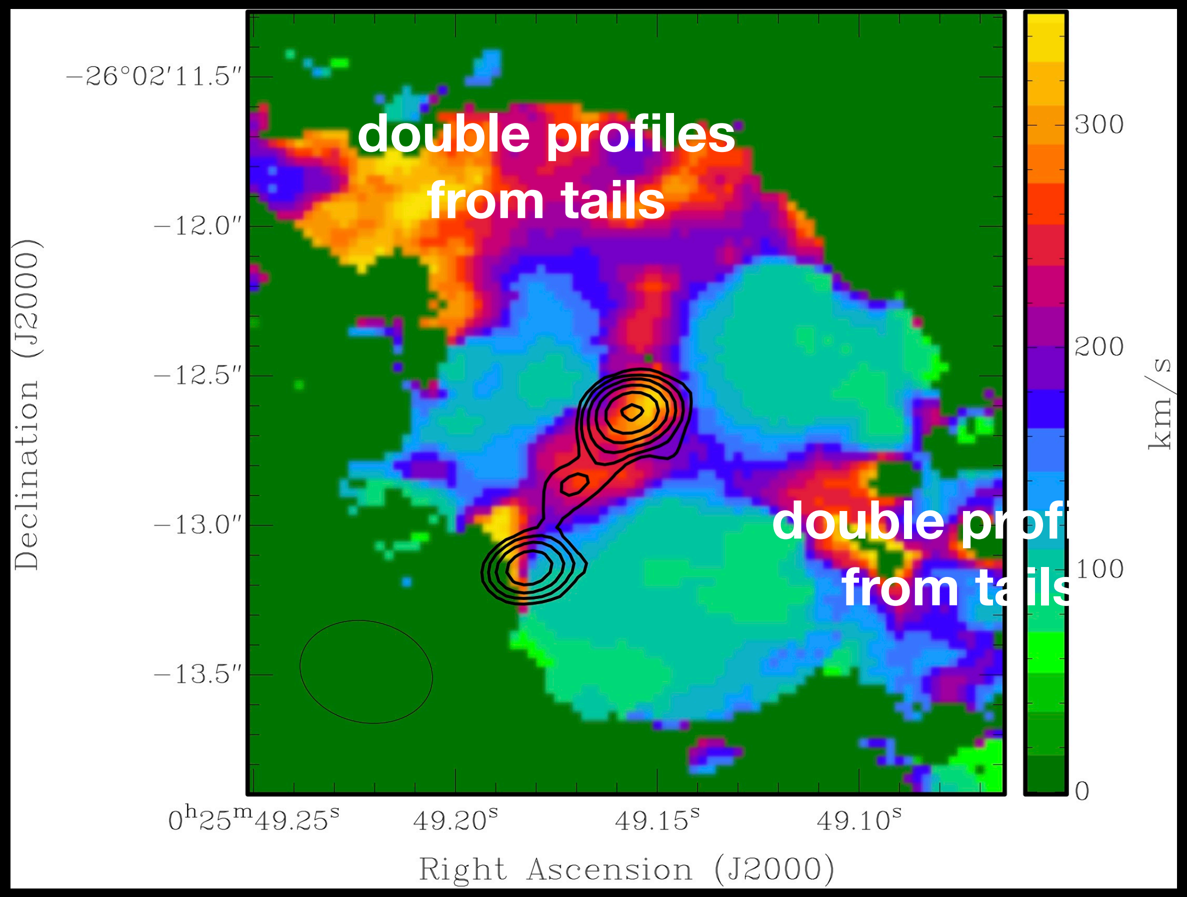
Ideal system for the study of the impact of the (radio) AGN, but the kinematics of the gas had some surprises

From the kinematics of the molecular gas

High velocity dispersion at the location of the radio emission but no fast, massive molecular outflow detected, despite powerful radiative AGN and powerful radio jet



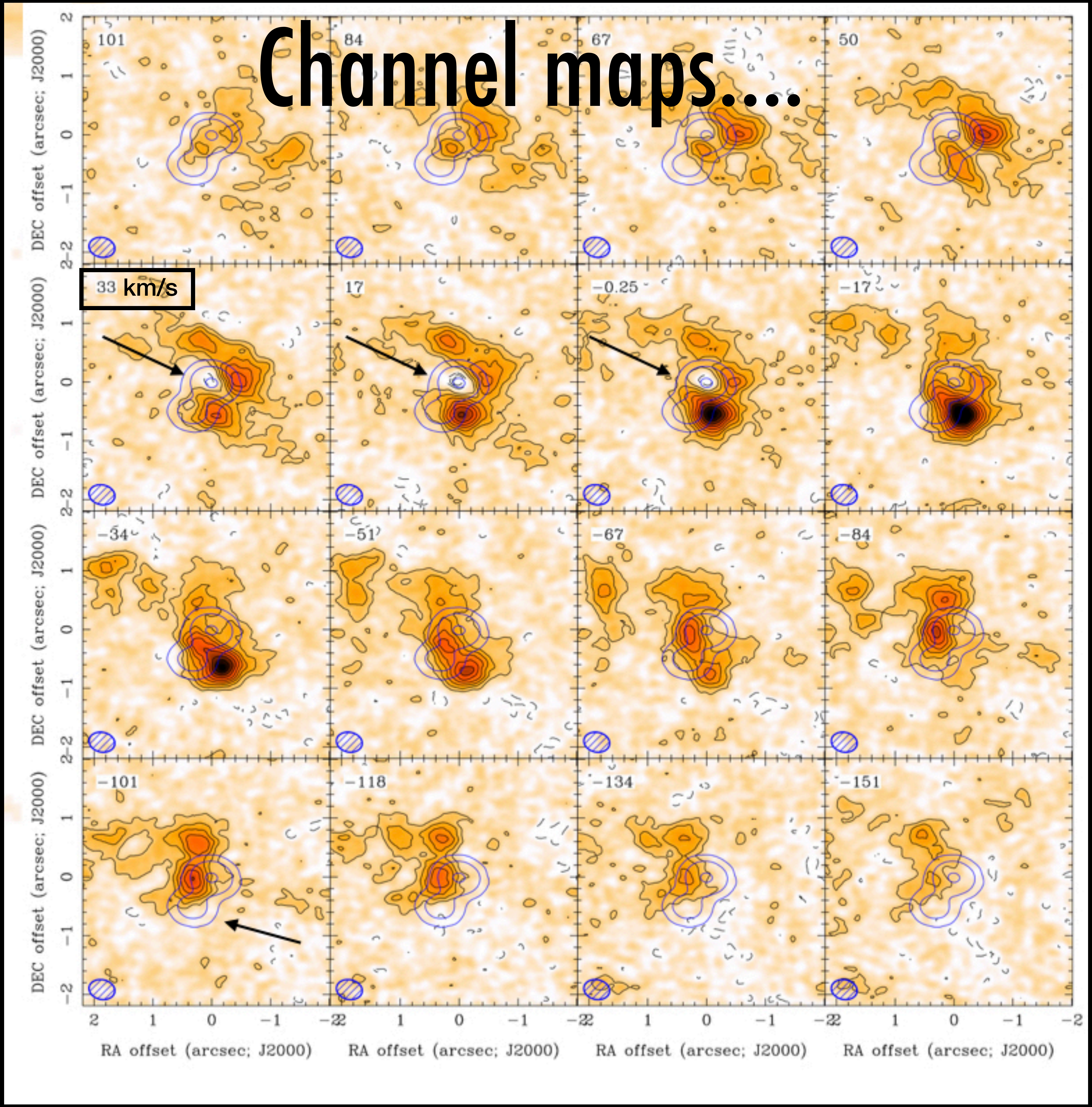
line width (FWHM)



Morganti et al. in prep

- High velocity dispersion at the location of the radio lobes.
- Radio lobes tend to avoid regions rich in molecular gas or they have pushed it aside (seen in intensity and kinematics)

Channel maps....

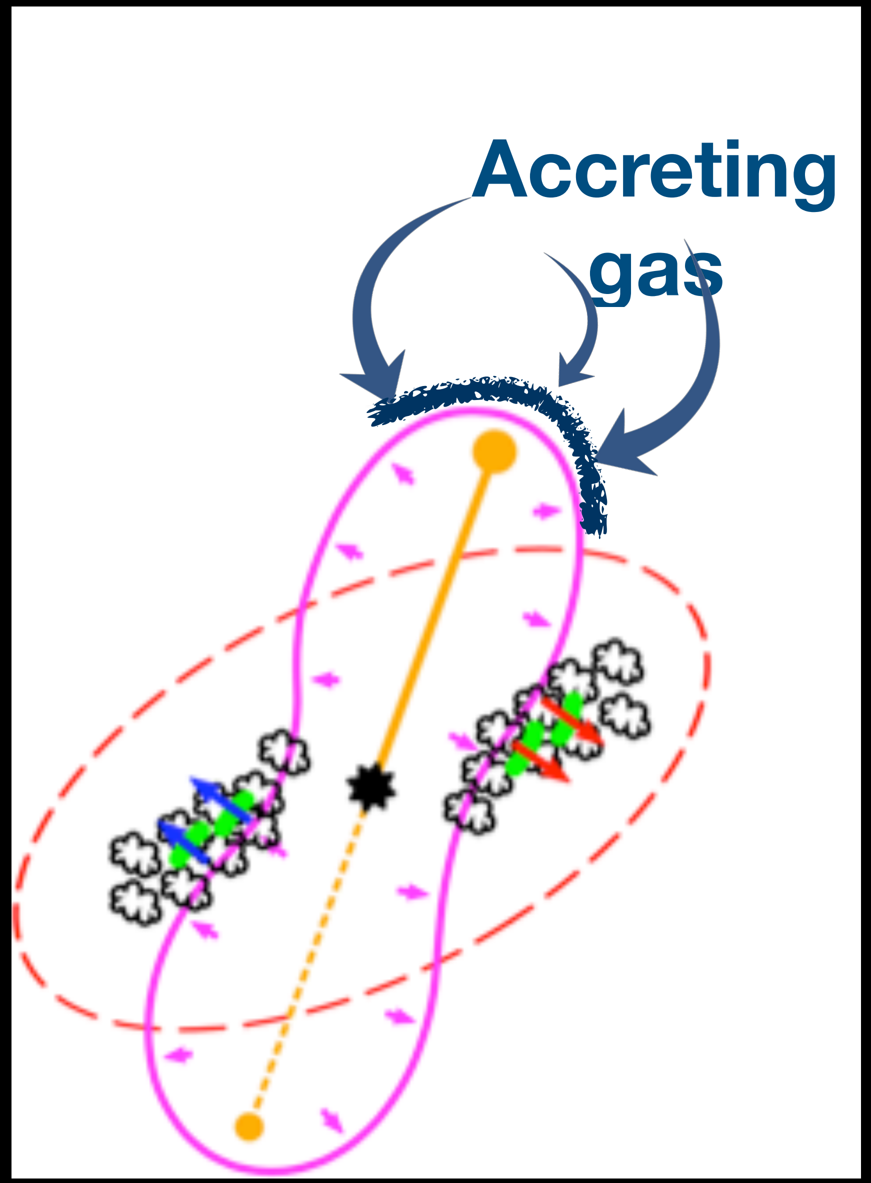


not fast outflows of molecular gas @lobes
→ possible reasons: density of the gas not high enough for a fast cooling + strong interaction from the powerful jet...

BUT

the high velocity dispersion at the location of the radio source suggests the jets/lobes are in the process of **pushing the gas aside**

Jet power (4×10^{46} erg/s) can provides enough energy....

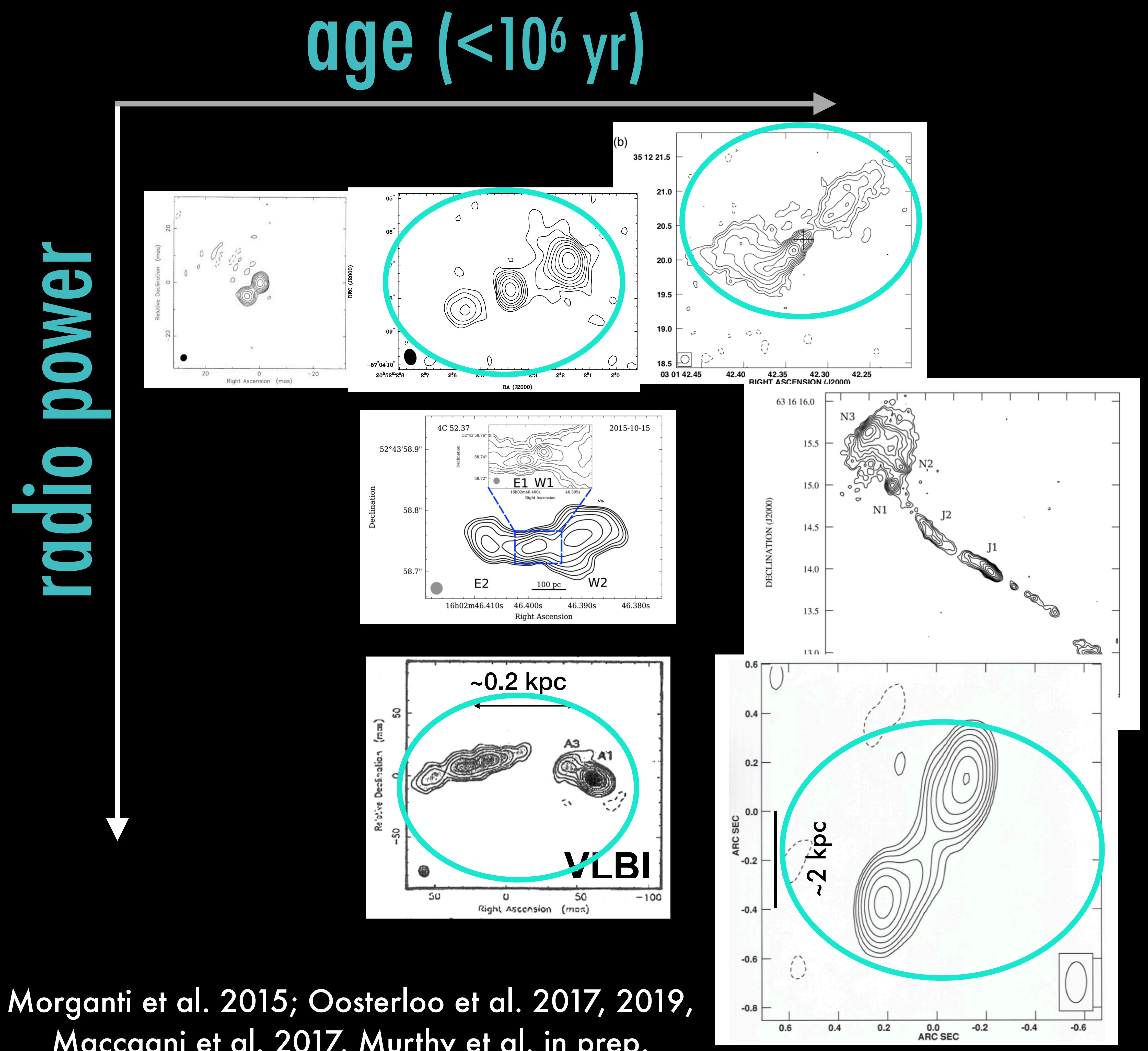


Star formation in the host galaxy not yet strongly affected!

PKS 0023-26 and friends: what have we learned so far...

Complex multi-parameter space to explore!

radio power
evolutionary stage/age
multi-phase outflows and location
orientation jet/ISM



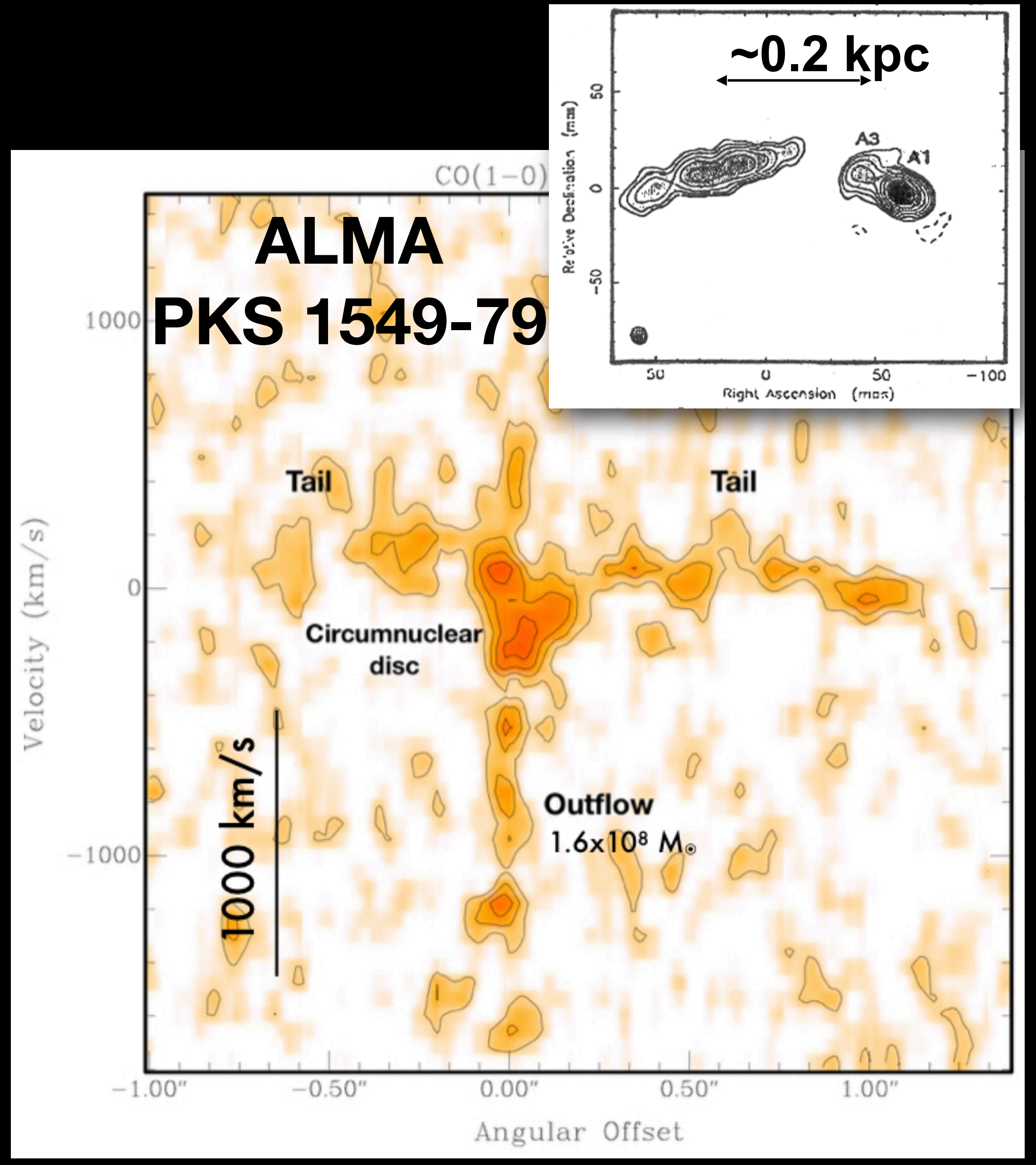
Morganti et al. 2015; Oosterloo et al. 2017, 2019,
Maccagni et al. 2017, Murthy et al. in prep.

Outflows of molecular gas...

- **Outflows** of cold (molecular) gas in the **inner (sub-kpc) region**

origin of molecular outflows: jet interacting with dense clouds followed by **fast cooling**

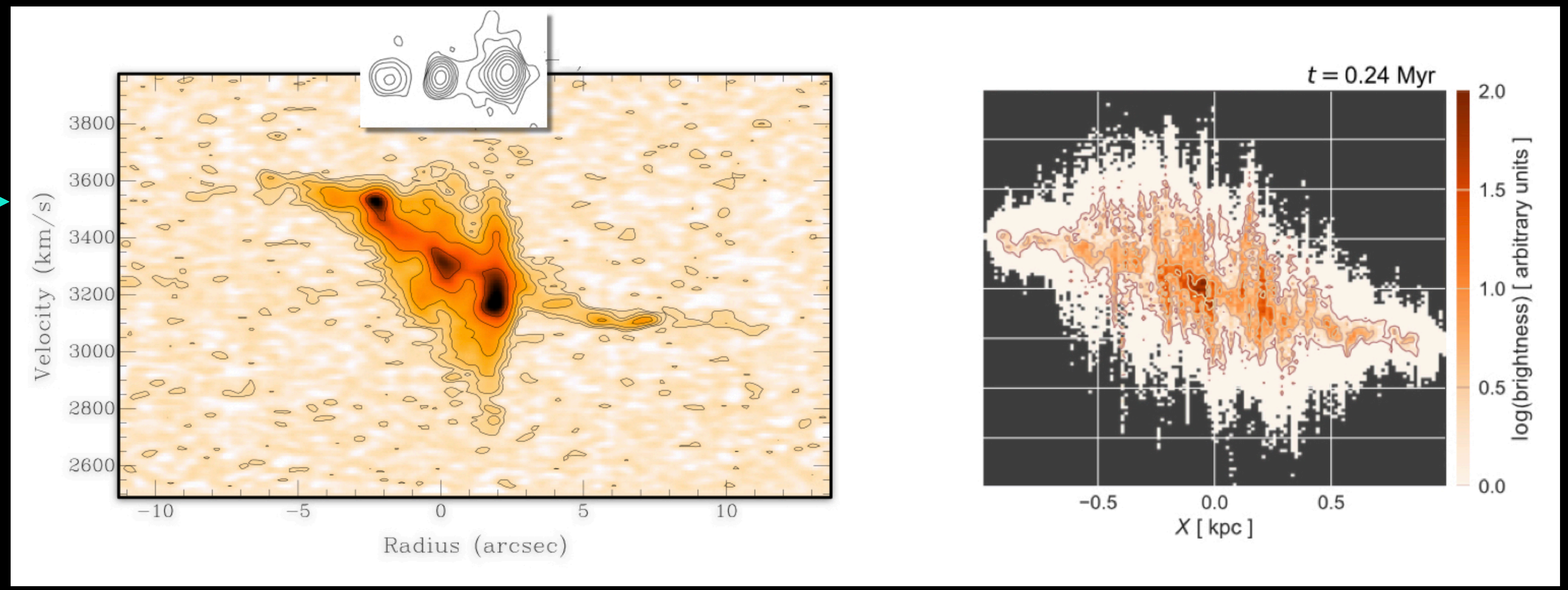
Highest mass outflow rate (>400 M$_\odot$/yr) in the powerful radio source PKS1549-79 but outflows also in low power



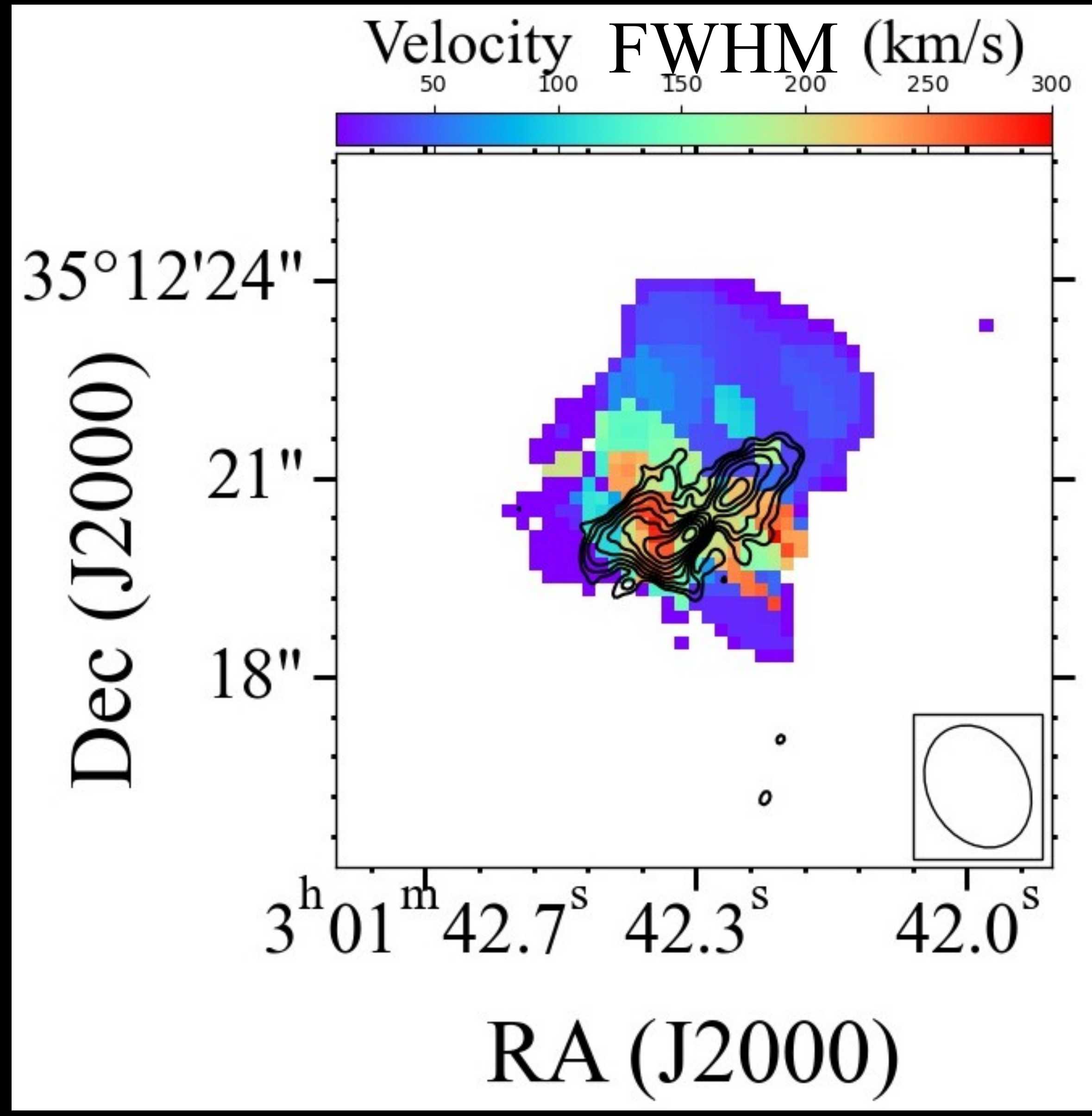
Oosterloo, Morganti et al. 2019

Position-velocity plot of the CO(3-2) ALMA data of IC5063

Data *Modelling*

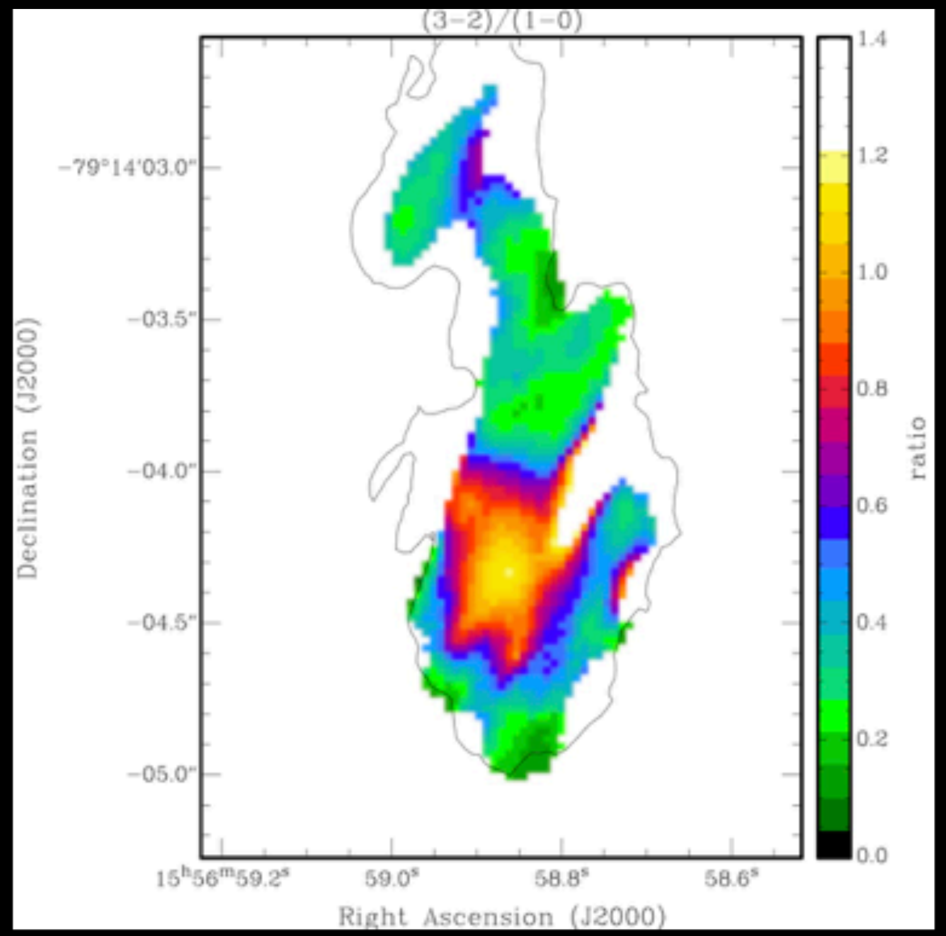


Mukherjee, Wagner, Bicknell, Morganti et al. 2018



B2 0258+35 - NOEMA CO(1-0)
Murthy et al. in prep.
See Murthy's talk tomorrow

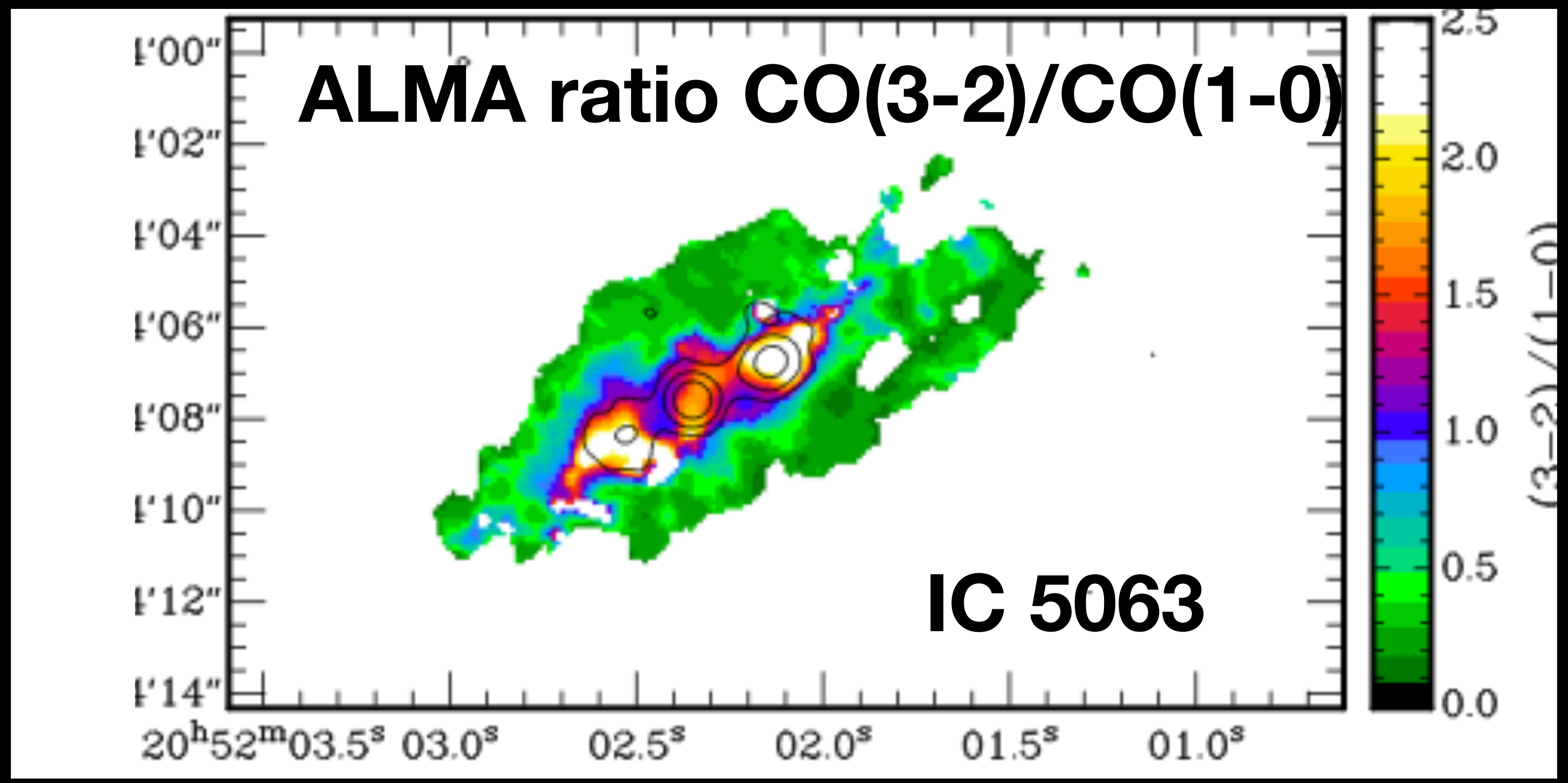
Properties of the outflows of molecular gas...



High CO(3-2)/CO(1-0) ratio in the central region wrt tail: effect of AGN

- **Physical properties** of the molecular gas affected by the interaction: high ratio CO(2-1)/CO(1-0) indicates high excitation and/or optical thin conditions in the region most affected by the jet

Kinetic temperatures in the range 20–100 K and densities between 10^5 and 10^6 cm^{-3}
(best fit of ratio line transitions suggests a clumpy medium)



Morganti et al. 2015,
Dasyra et al. 2016, Oosterloo et al. 2017

Mass outflow rates: tens to a few hundred $M_\odot$/yr

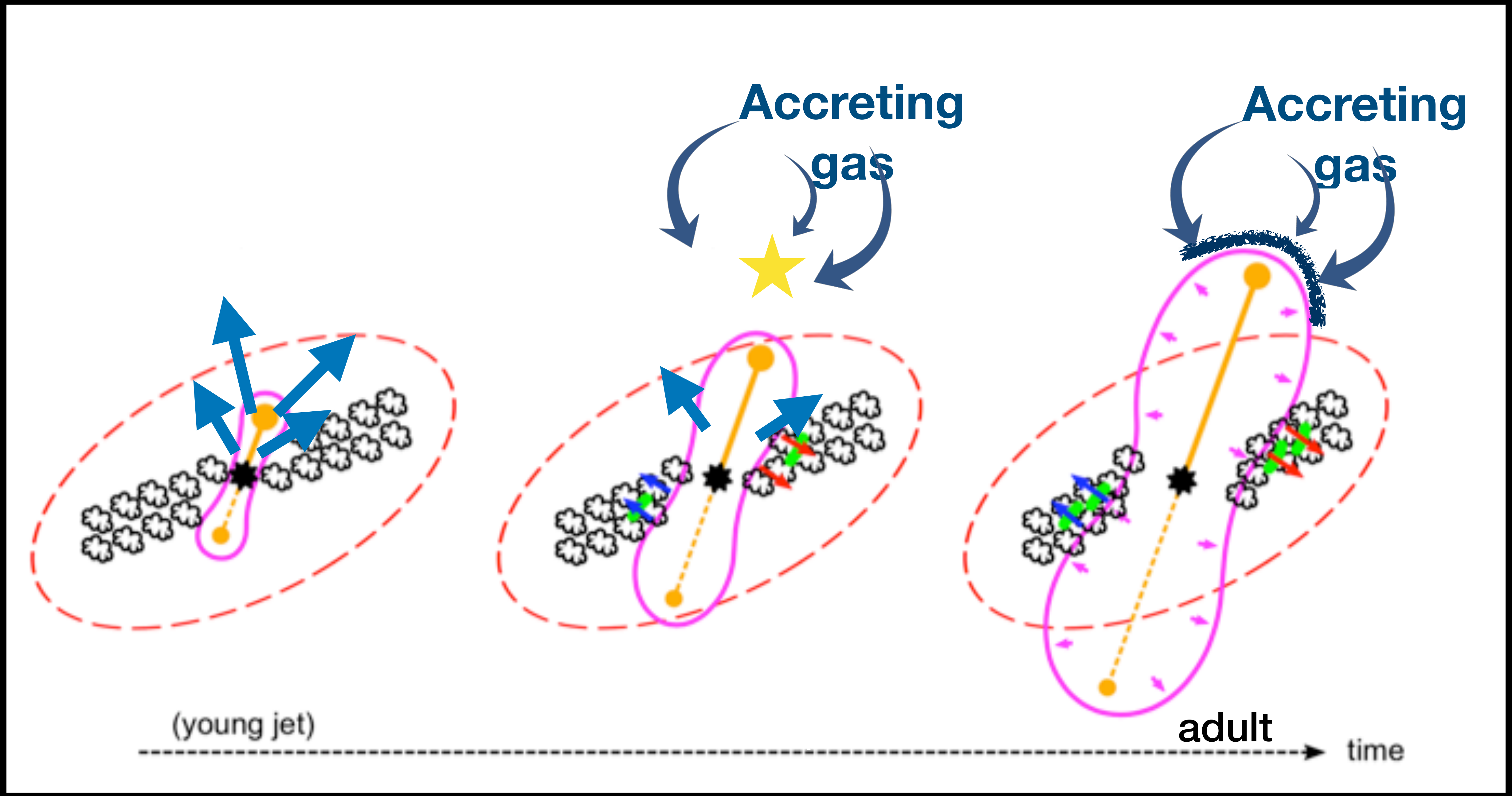
BUT

Small fraction of gas leaves the galaxy: most of the gas raining back, fountain-like effect

Impact of gas outflows limited even in objects with ideal conditions for AGN-driven (jet-driven) feedback: outflows cannot be the entire story!

Not only outflows: changing the impact while evolving...

Jet further expands (PKS 0023-26): lower gas density (longer cooling times) ➜ jet drives mild shocks into the ISM, pushing aside the (molecular) gas, bubble-like structures → this will affect the entire host galaxy when the radio source expands (next few x 10^7 yr)



Adapted from Huseman et al. 2019

transition from *outflows* to *maintenance* mode
→ heating of the ISM

Impact on the e.g. star formation may not be on the same time-scale as the AGN

see also Harrison et al. 2019
Scholtz et al. 2020

Some summary thoughts.....

- Evidence of **impact of jets in young** radio galaxies: observations consistent with predictions from jet simulations
- **Outflows** of cold (molecular) gas in the inner (sub-kpc) regions
- **Small fraction of gas** is leaving the galaxy, the rest "rains" back
  main effect: inject energy, turbulence, redistribute gas
- As the radio lobes **expand in the host galaxy** → mild shocks pushing aside the gas.

- Impact of jets possibly evolving/changing as the jet expands: from driving outflows in the first phase (sub-kpc) to "maintenance" mode (stop gas from cooling) when the jet reaches kpc scales
- This evolution needs to be considered - ideal for linking nuclear region to CGM
- Effect on star formation may be visible only on longer time-scales
- What will the X-ray observations tell us?