The complex nuclear regions of young radio galaxies

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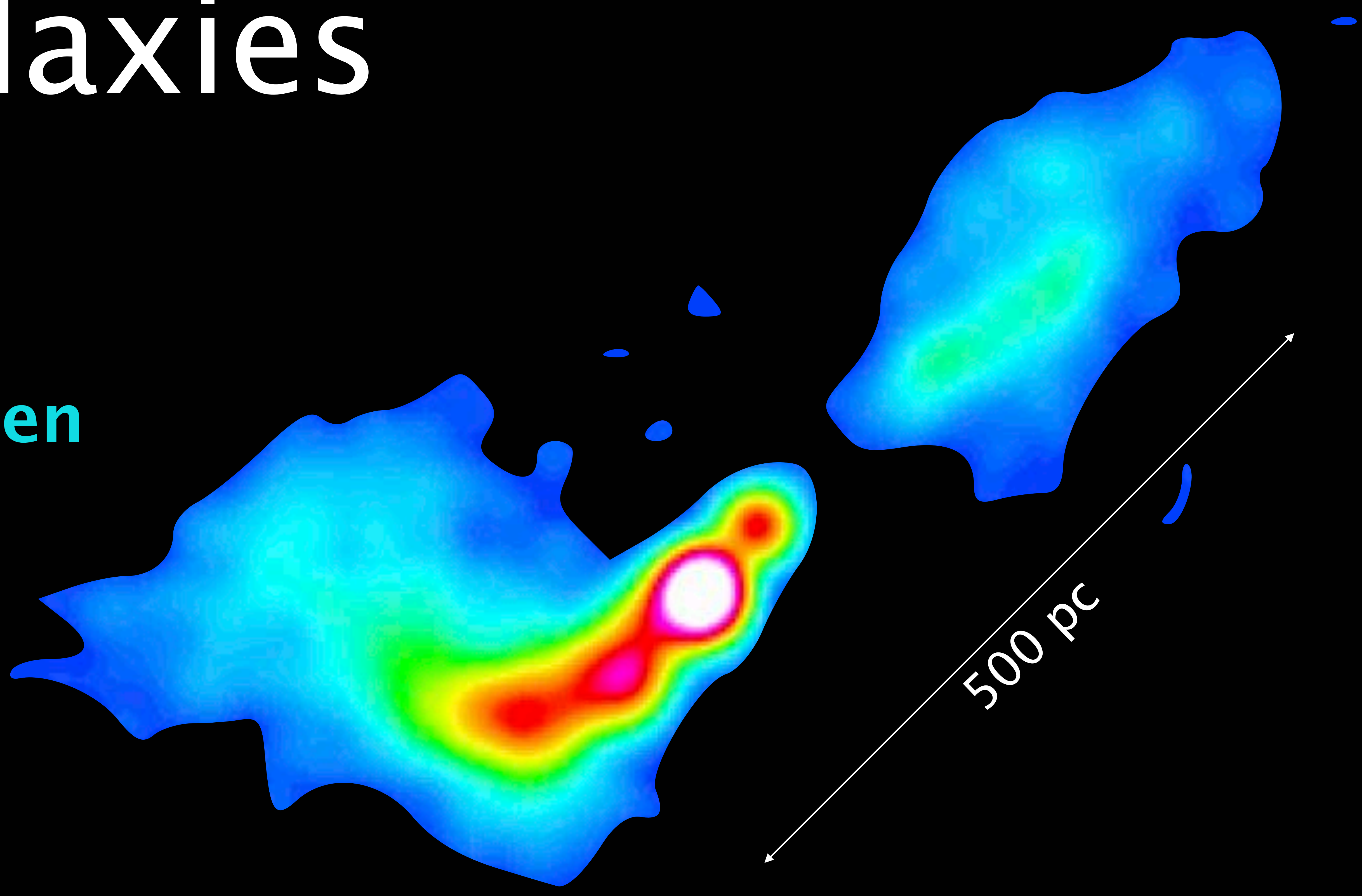
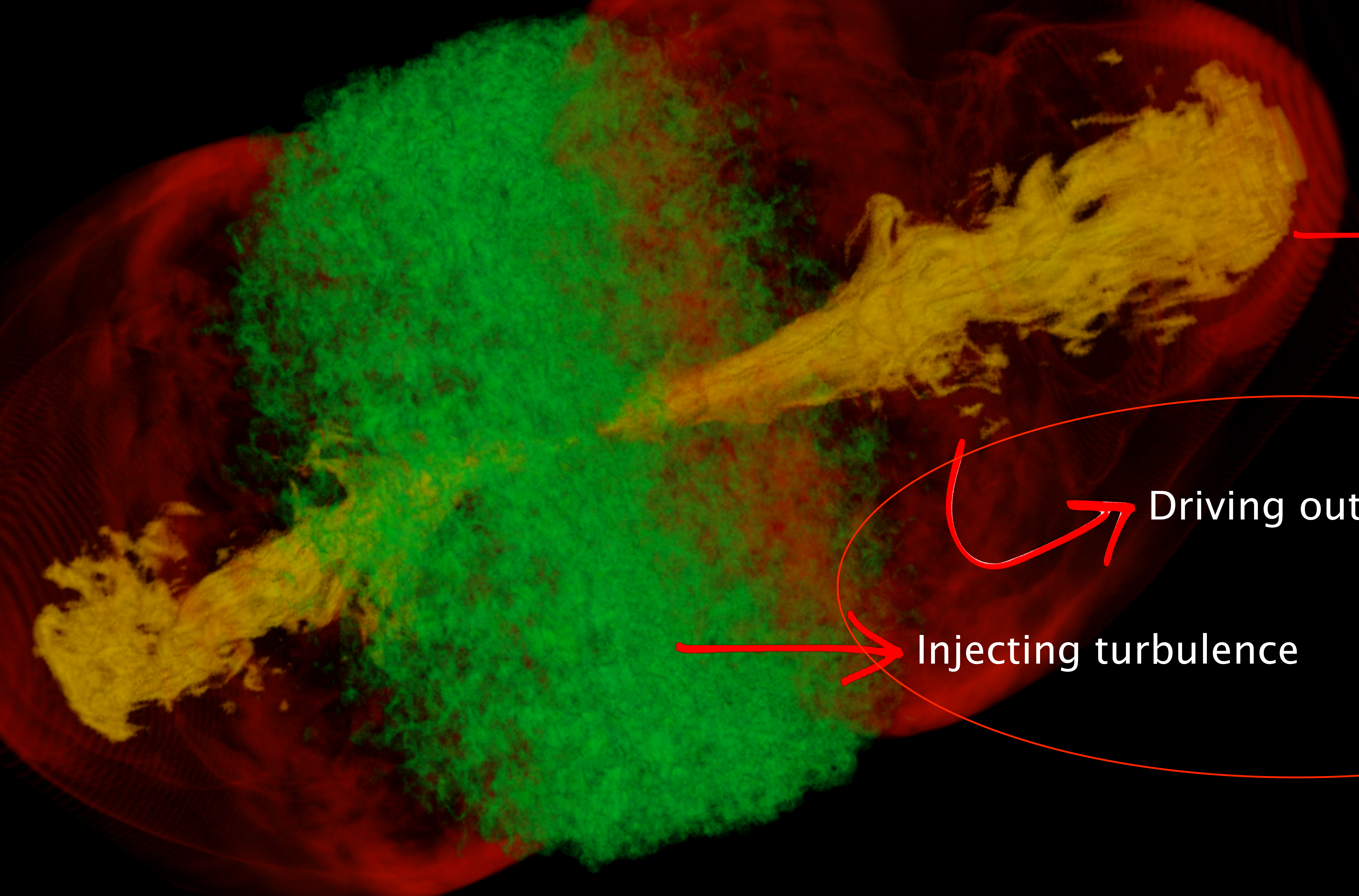


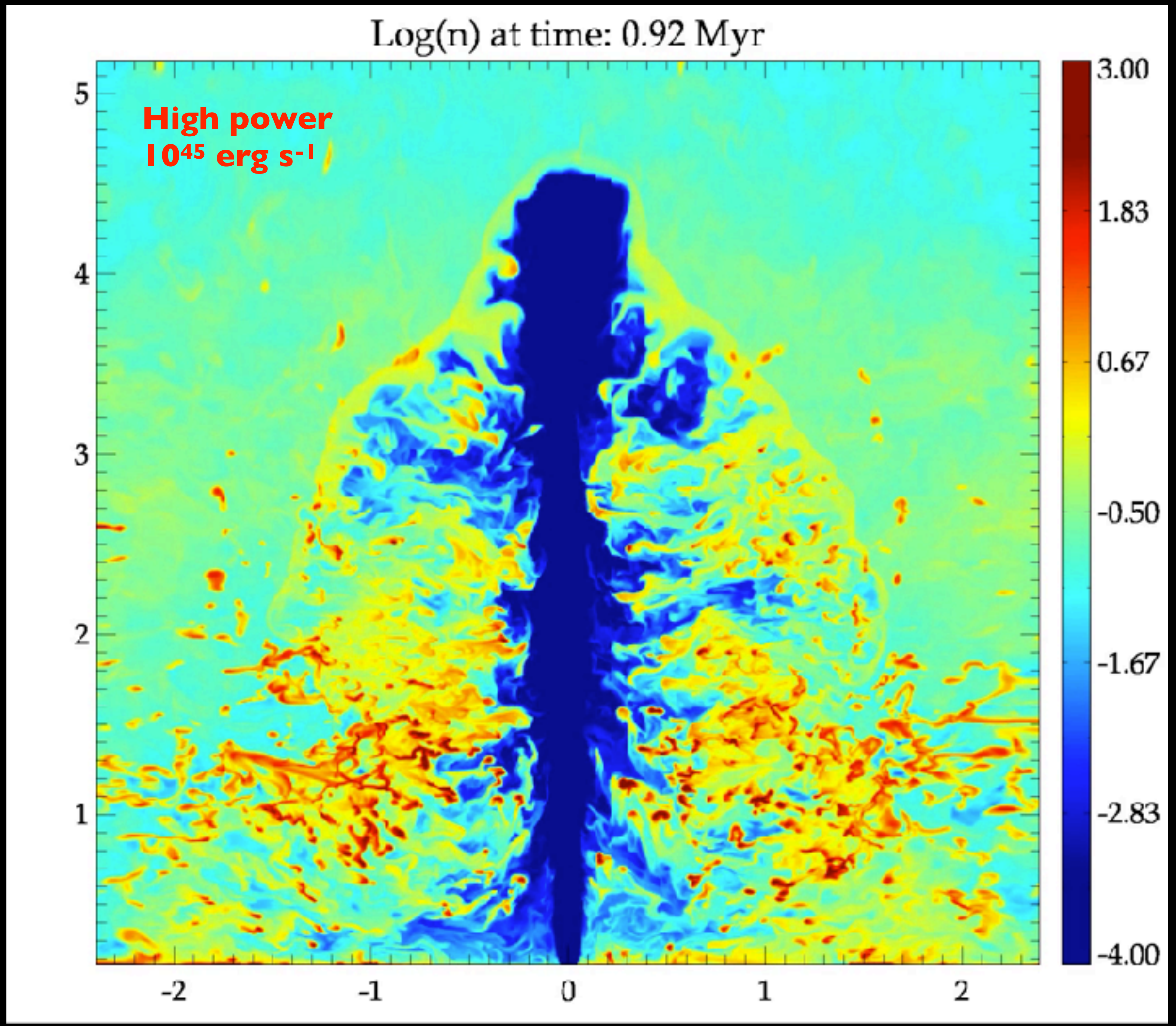
Role of radio jets for feedback



Interplay between radio jets and their "nuclear" surroundings

from Wagner & Bicknell 2011, 2012; Mukherjee, Bicknell et al. 2016, 2017, 2018
But similar results also from Cielo et al. 2018

- Jets couple strongly with host's **clumpy ISM**: whatever the initial narrowness of the jet, the flow is broadened by the interaction with the first cloud (Wagner et al. 2012).
- Effect particularly prominent in the **first phase of evolution**
- **Low power jets are important!** Couple more with the ISM, will induce more turbulence and they are more numerous!



clumpy medium (spherical distribution), high jet power

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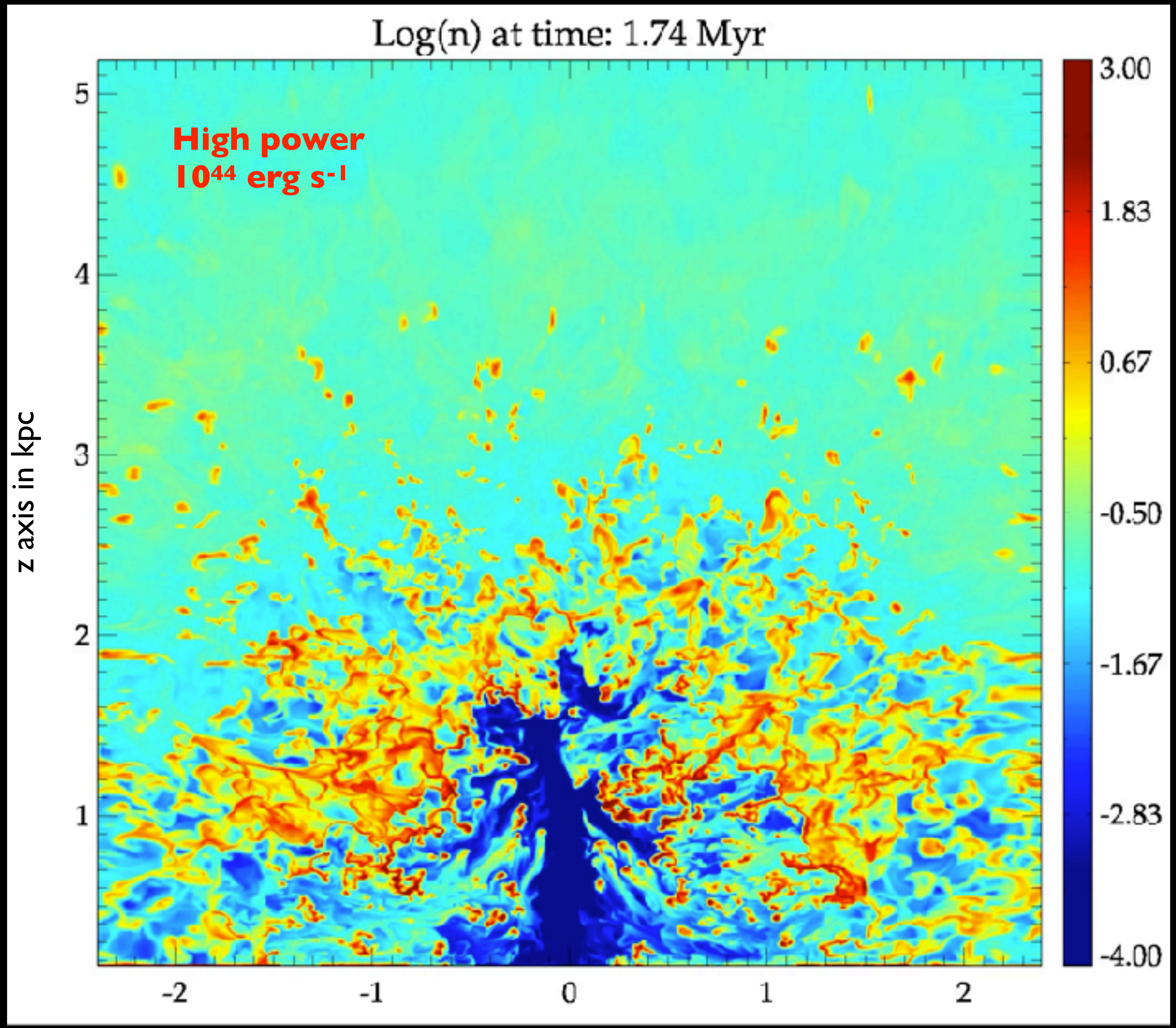
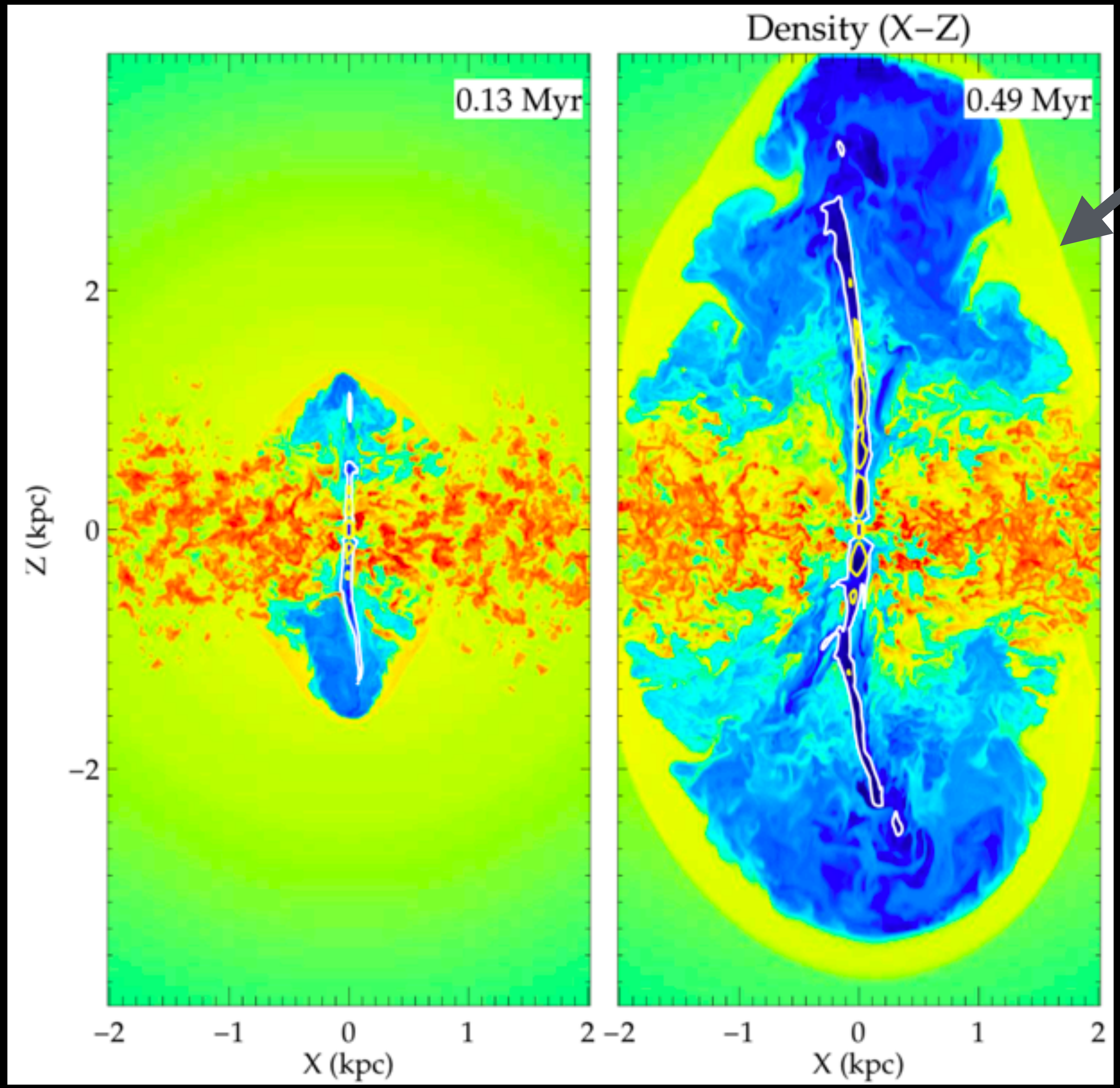
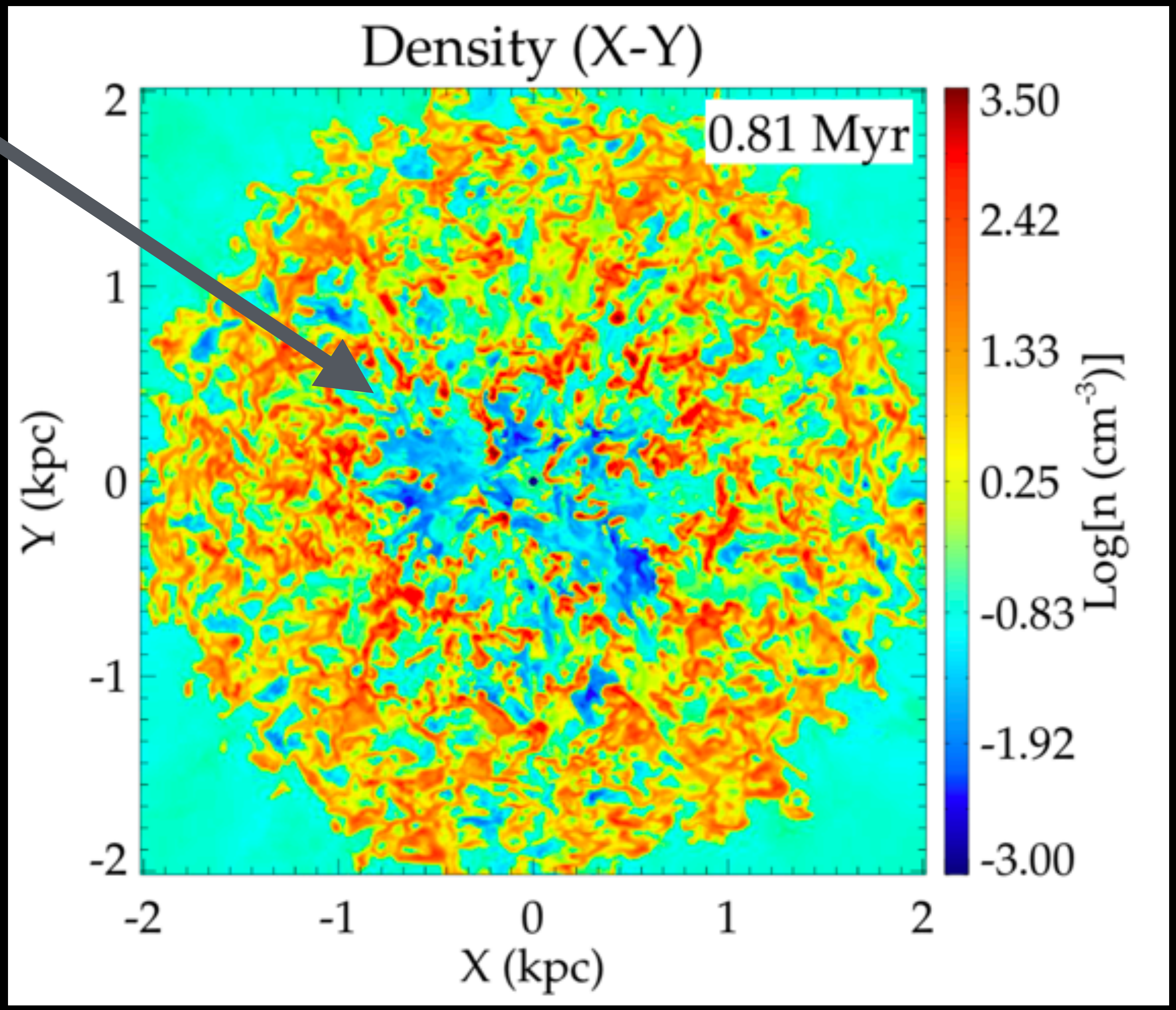


Jet power comparable to NGC1068! → low jet power, clumpy medium (spherical distribution)

Cocoon of shocked gas…





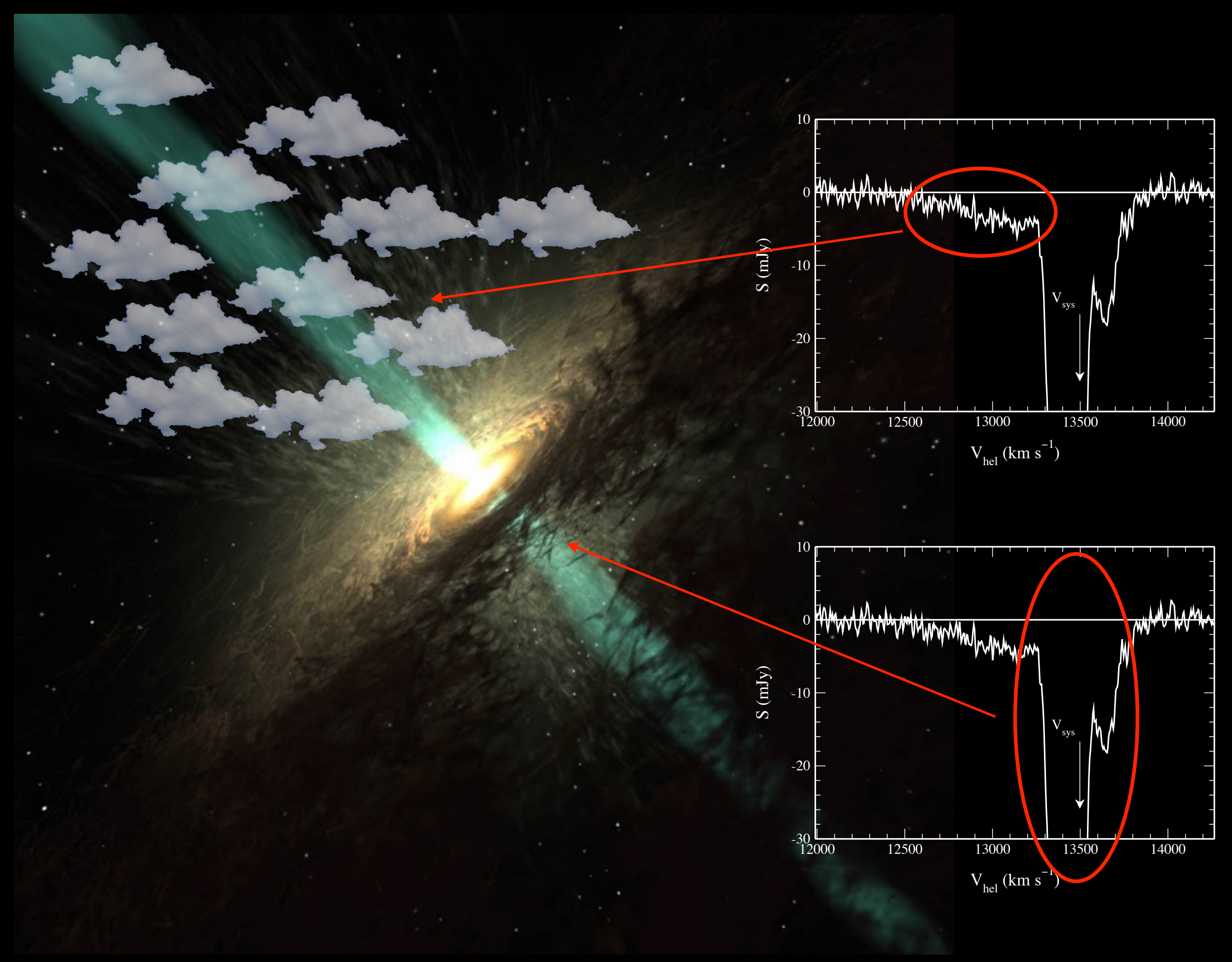
Mukherjee et al. 2018

- Do we actually see these signs of interaction from newly born radio jets?
- Do we see the clumpy medium that should enhance the impact of the jet?
- How do the jet affect the circumnuclear regions?

This talk

- **Jet-driven HI outflows in young radio galaxies using VLBI:** do we have the conditions for the jet to have an impact?

- **Accretion and feedback in an obscured young radio quasar using ALMA**



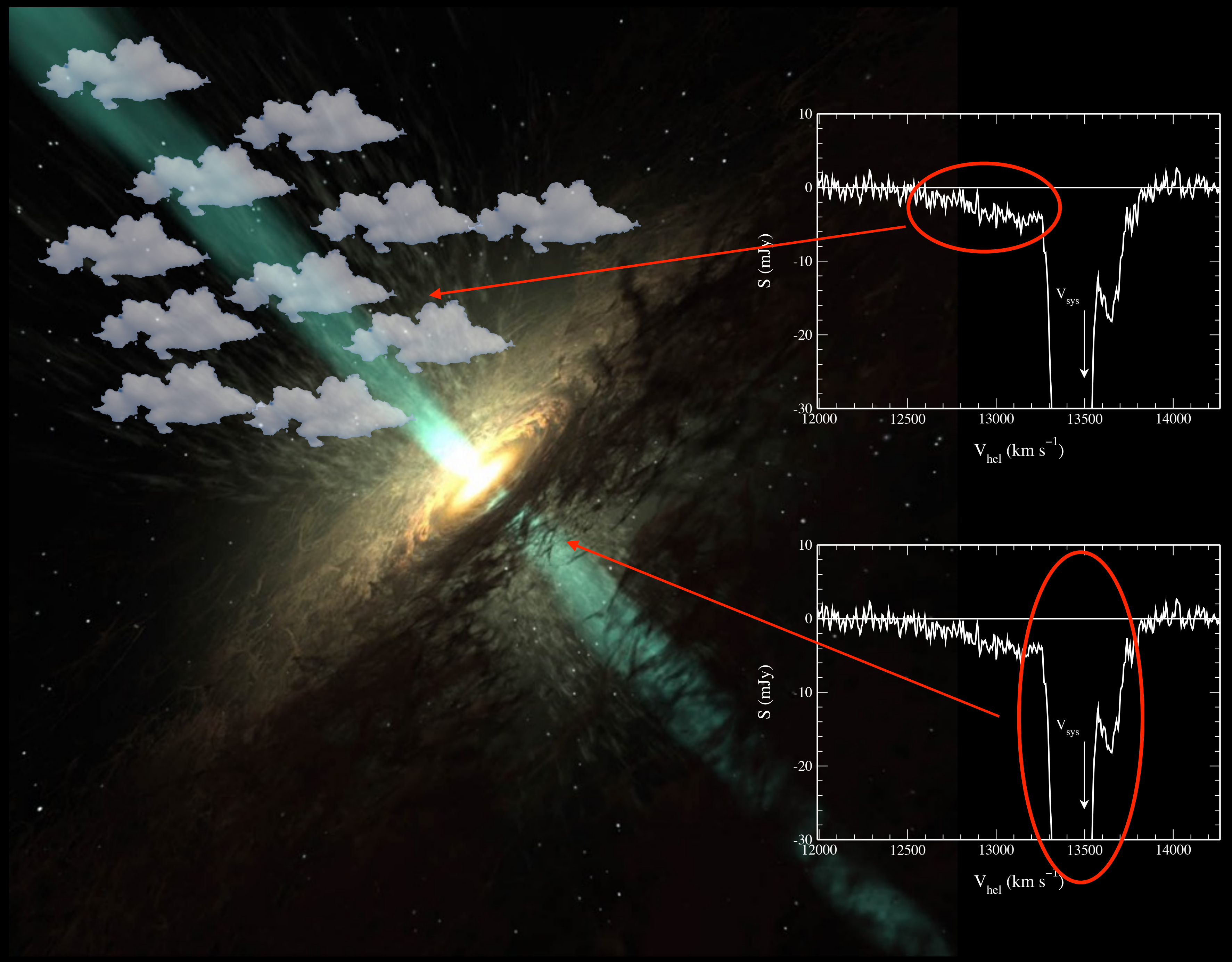
Morganti & Oosterloo A&A Rew 2018

Using cold gas
HI (21 cm) and molecular observed at high spatial resolution

Taking snapshots of the jet-ISM interplay

HI outflows of cold gas in young objects

Morganti & Oosterloo A&A Rew 2018

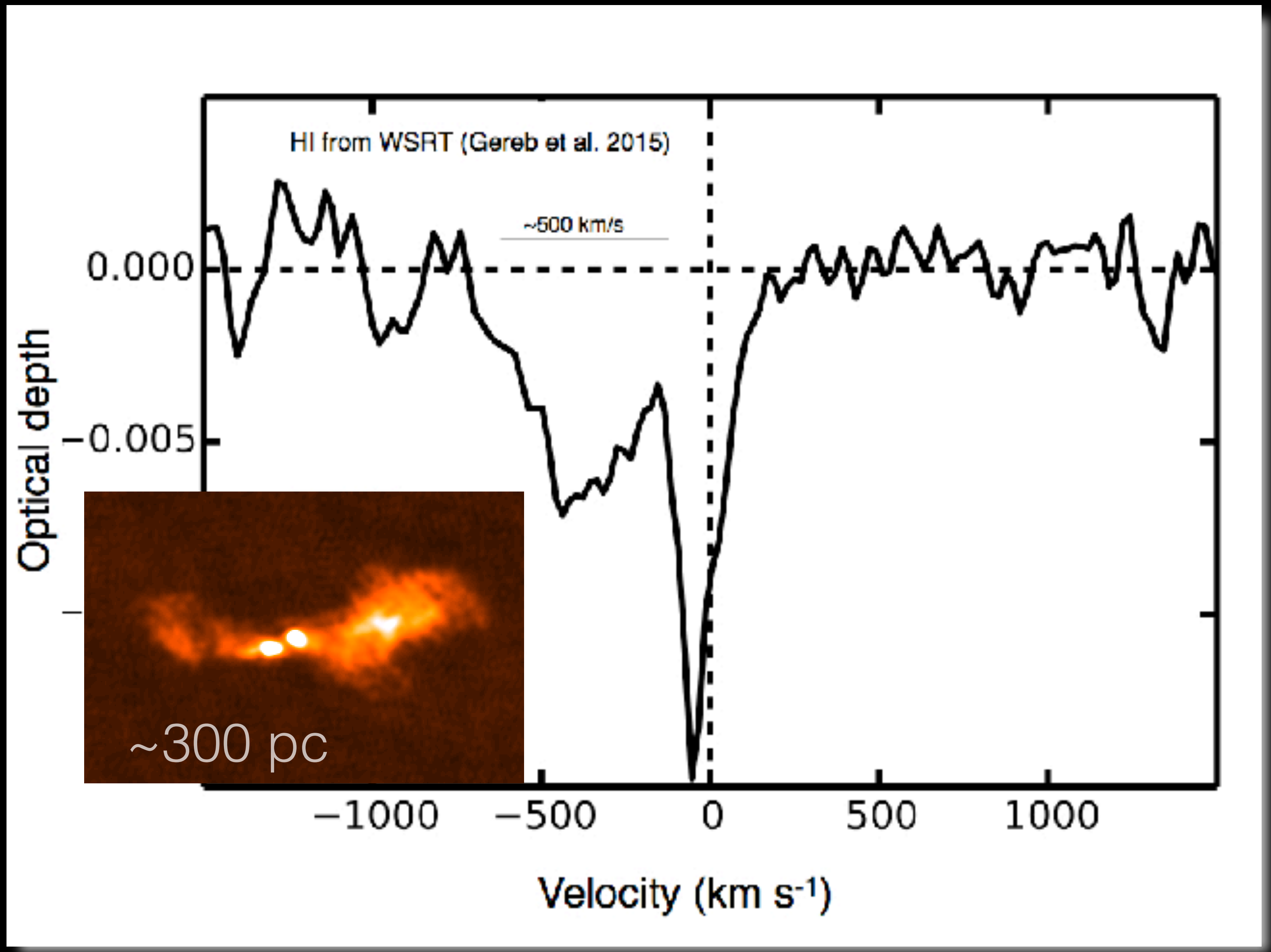


Outflows

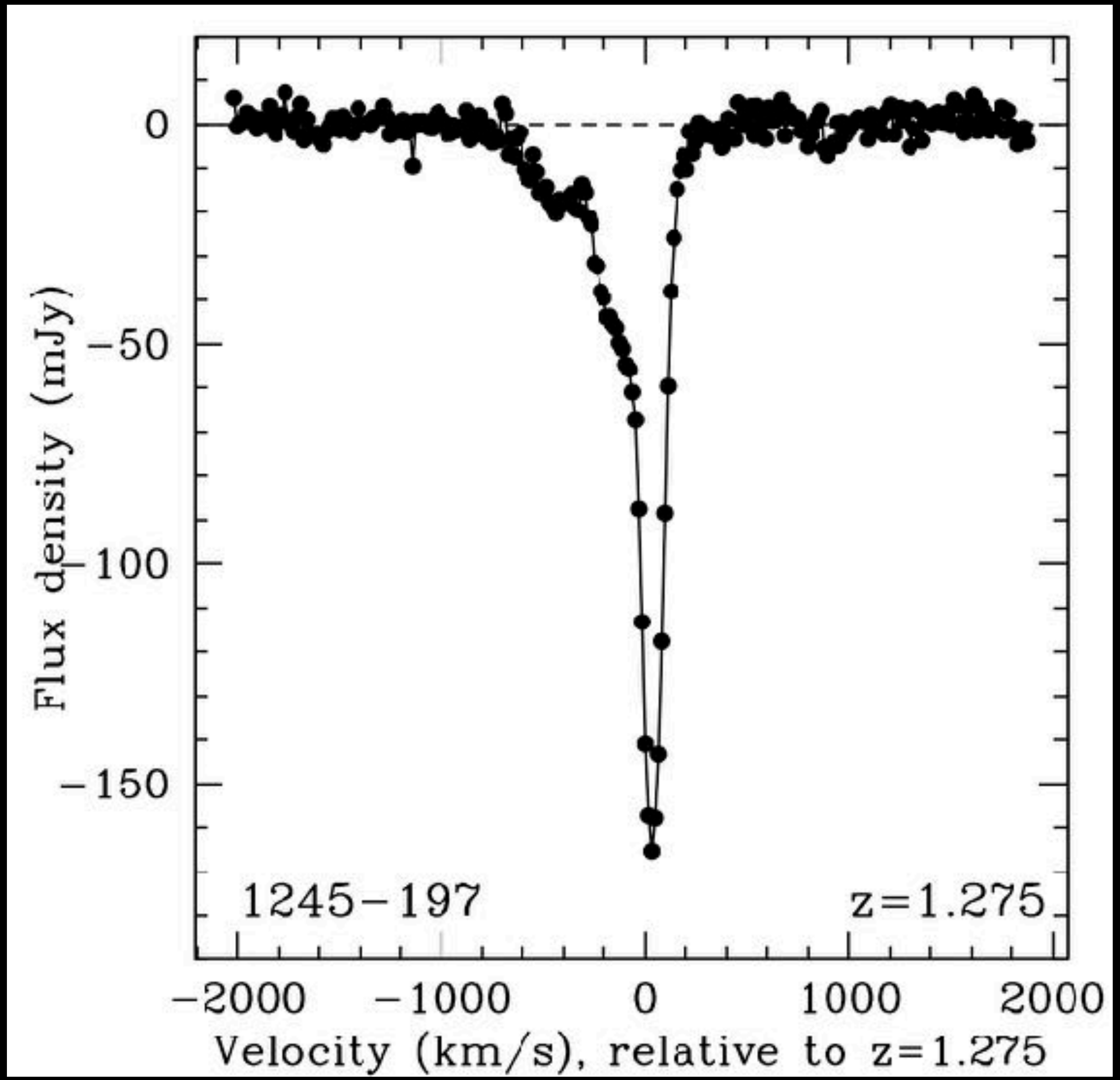
Circumnuclear disks/tori

Advantage of HI: follow up VLBI

Occurence and of the HI absorption outflows…



Gereb et al. 2015, Maccagni et al. 2017

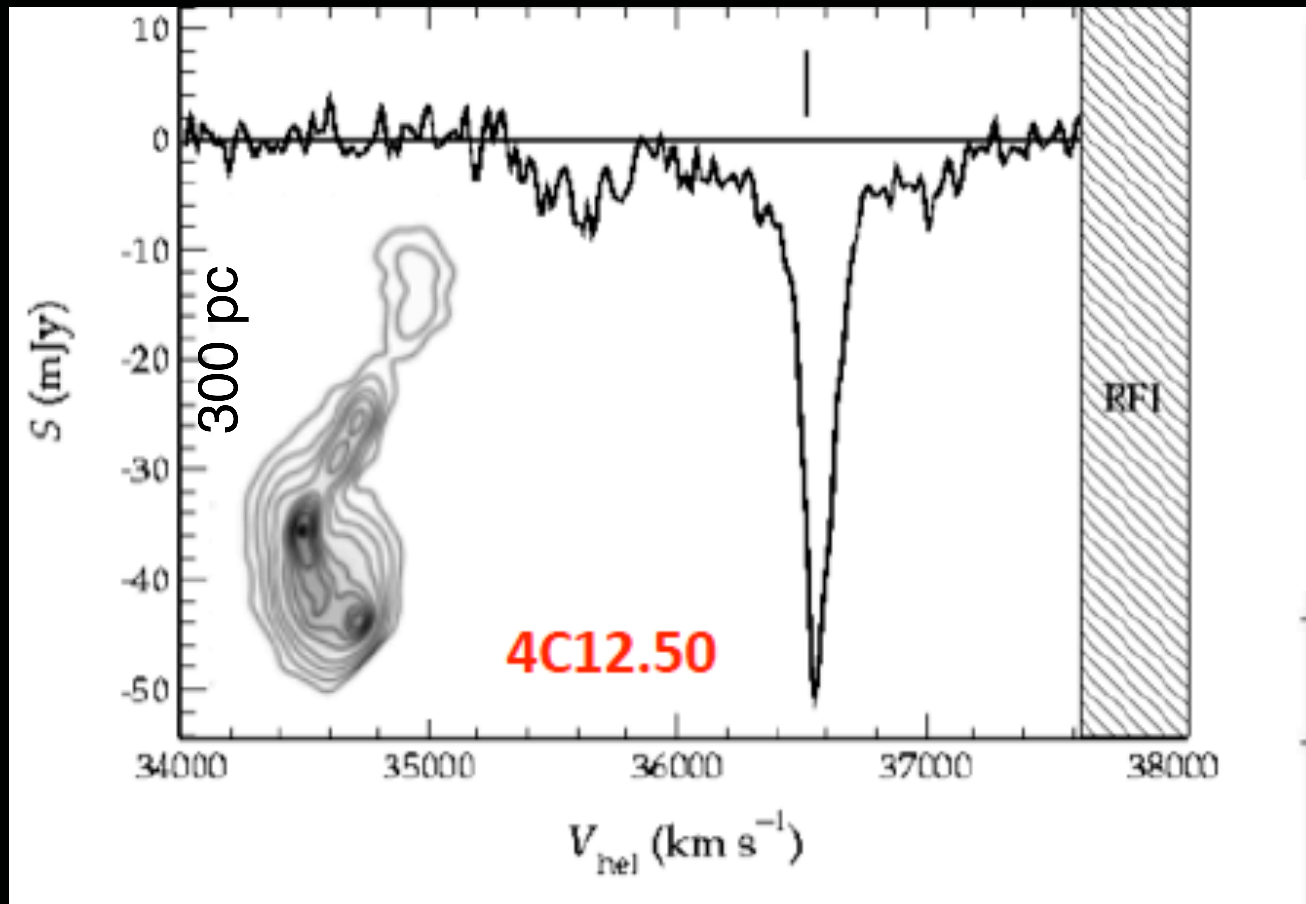


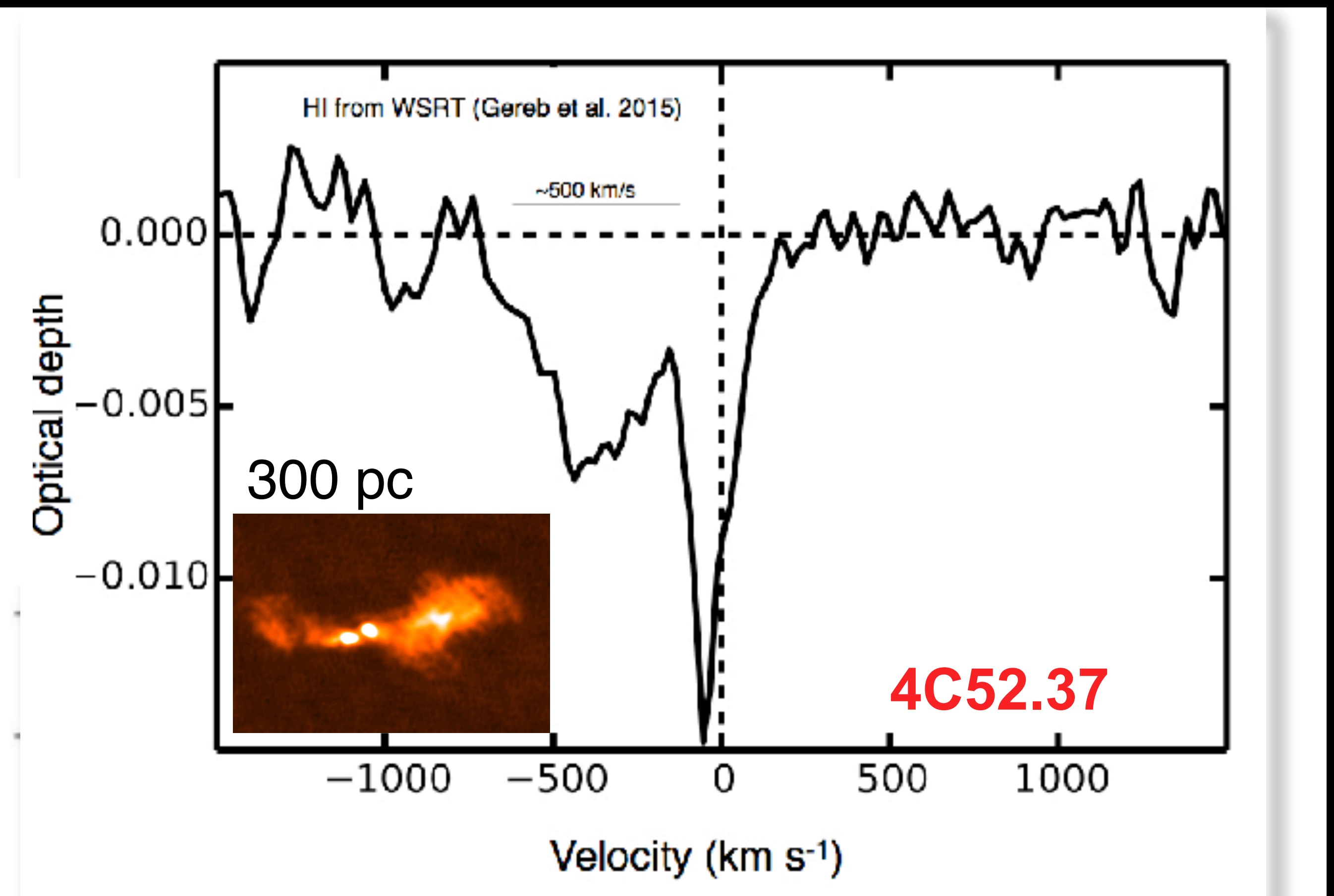
Aditya et al. 2018

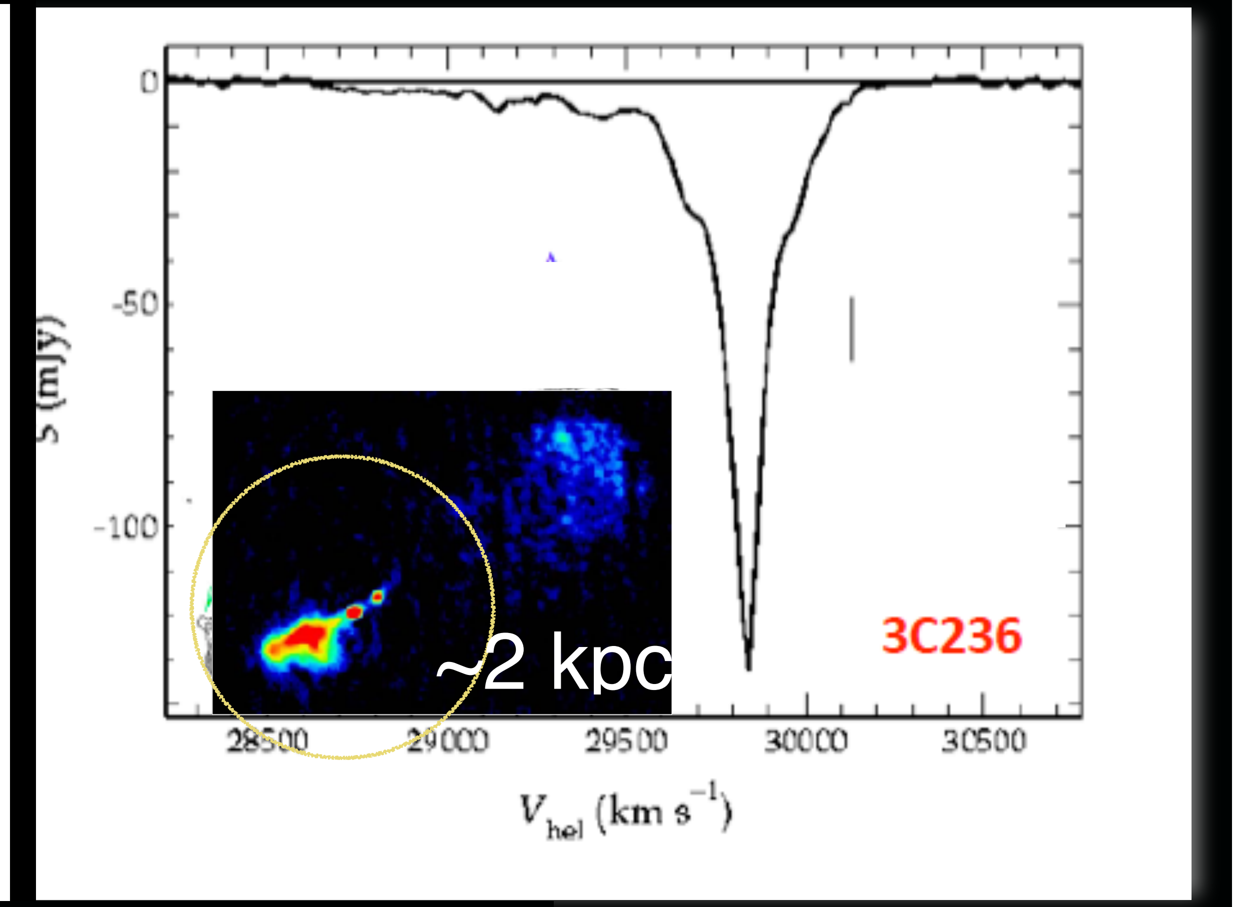
At least 15% of HI detections show HI outflows
Velocities between a few hundred to ~1300 km/s, mass outflow rates a few to 50 $M_\odot$/yr
Mass in the HI outflows from a few x10^6 to 10^7 $M_\odot$
Vast majority found in young (or recently restarted) radio sources (consistent with what found for ionised gas)

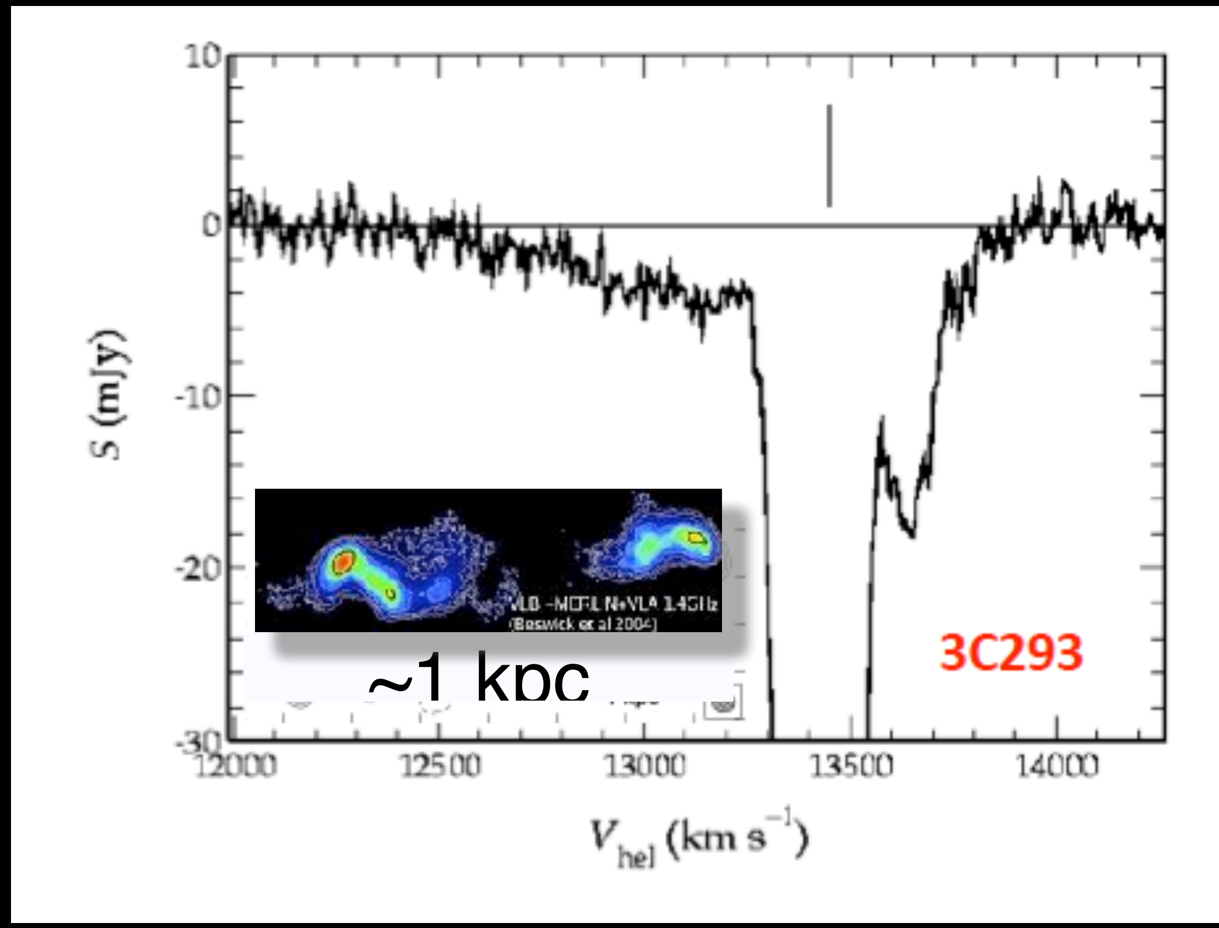
HI outflows traced at high spatial resolution with global VLBI

Cases of jet-driven outflows
(suggested by the location of the outflow and/or low optical luminosity)









Smaller → **Larger**

Younger/Stronger interaction? — Older?

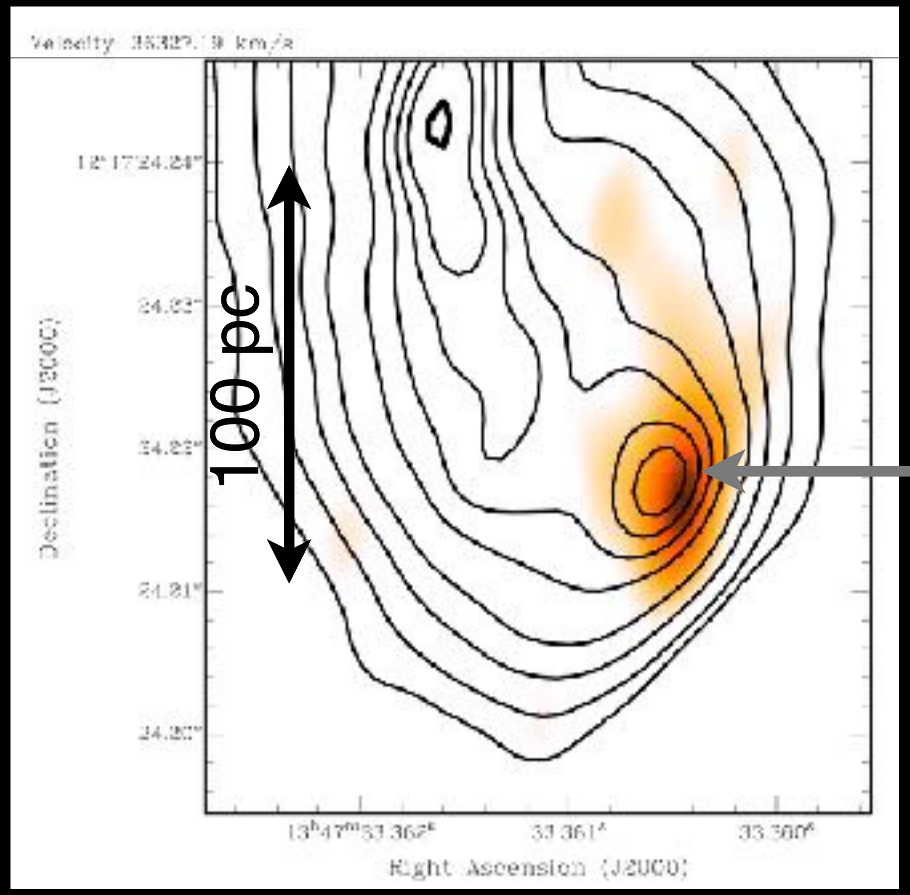
Ages: between **10^3 and 10^4 yrs**

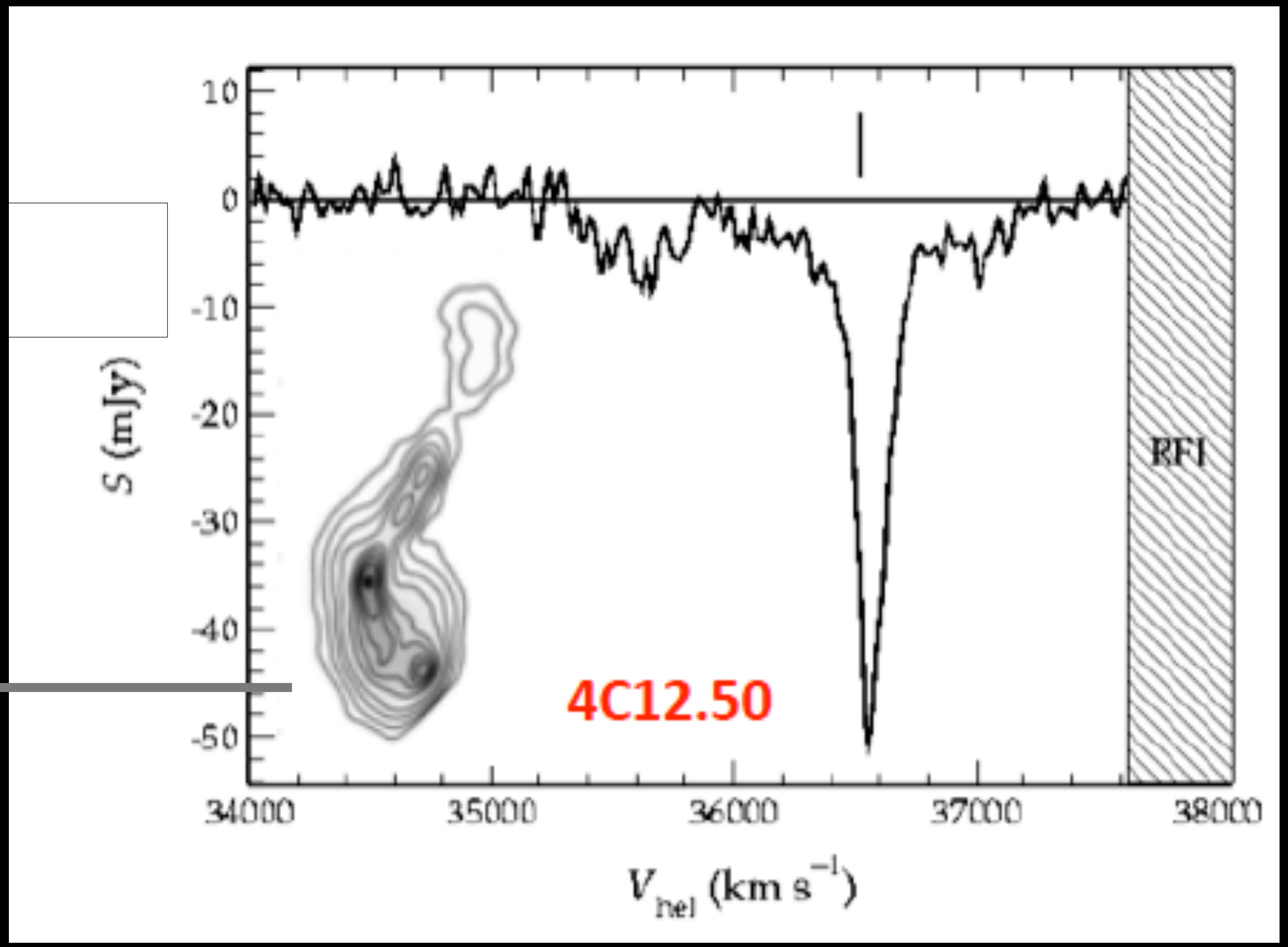
Ages: between **10^5 yr and 10^6 yr**

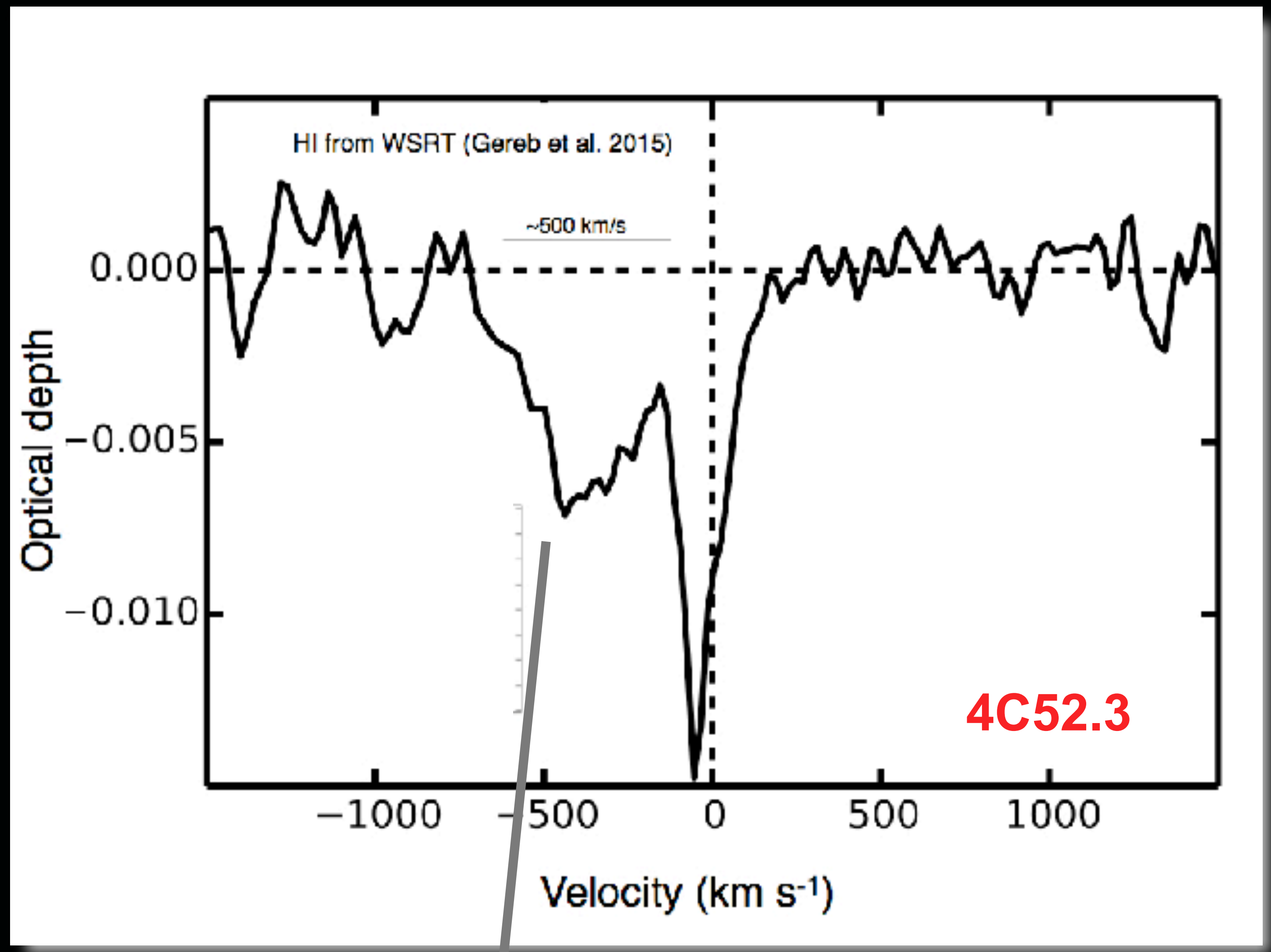
Resolution HI observations ~9 mas ➜ a few tens of pc

Clumpy medium and evolution of the outflows as the source expands?

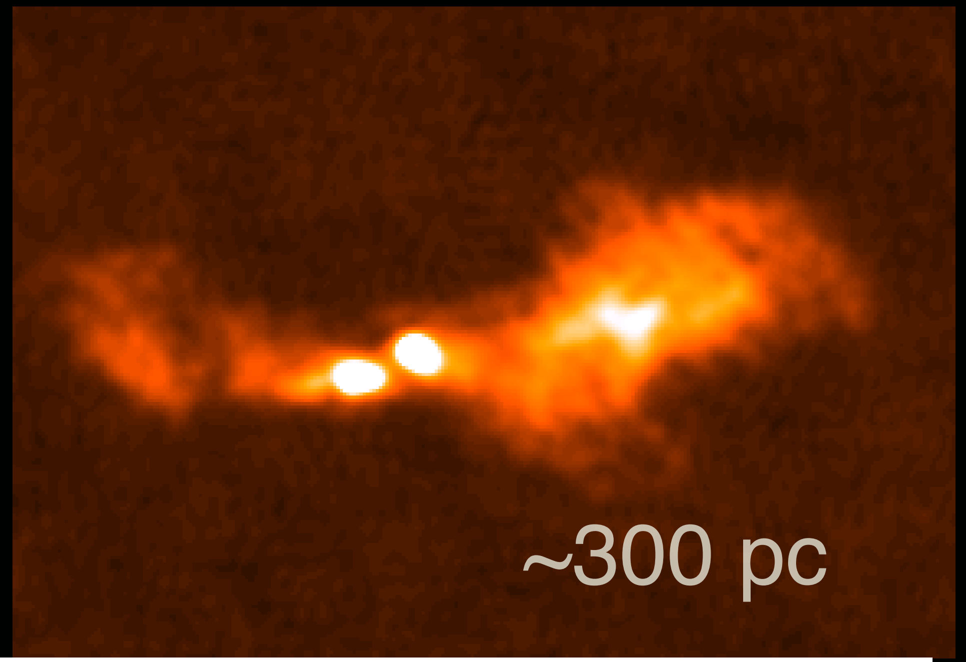
Morganti et al. 2013





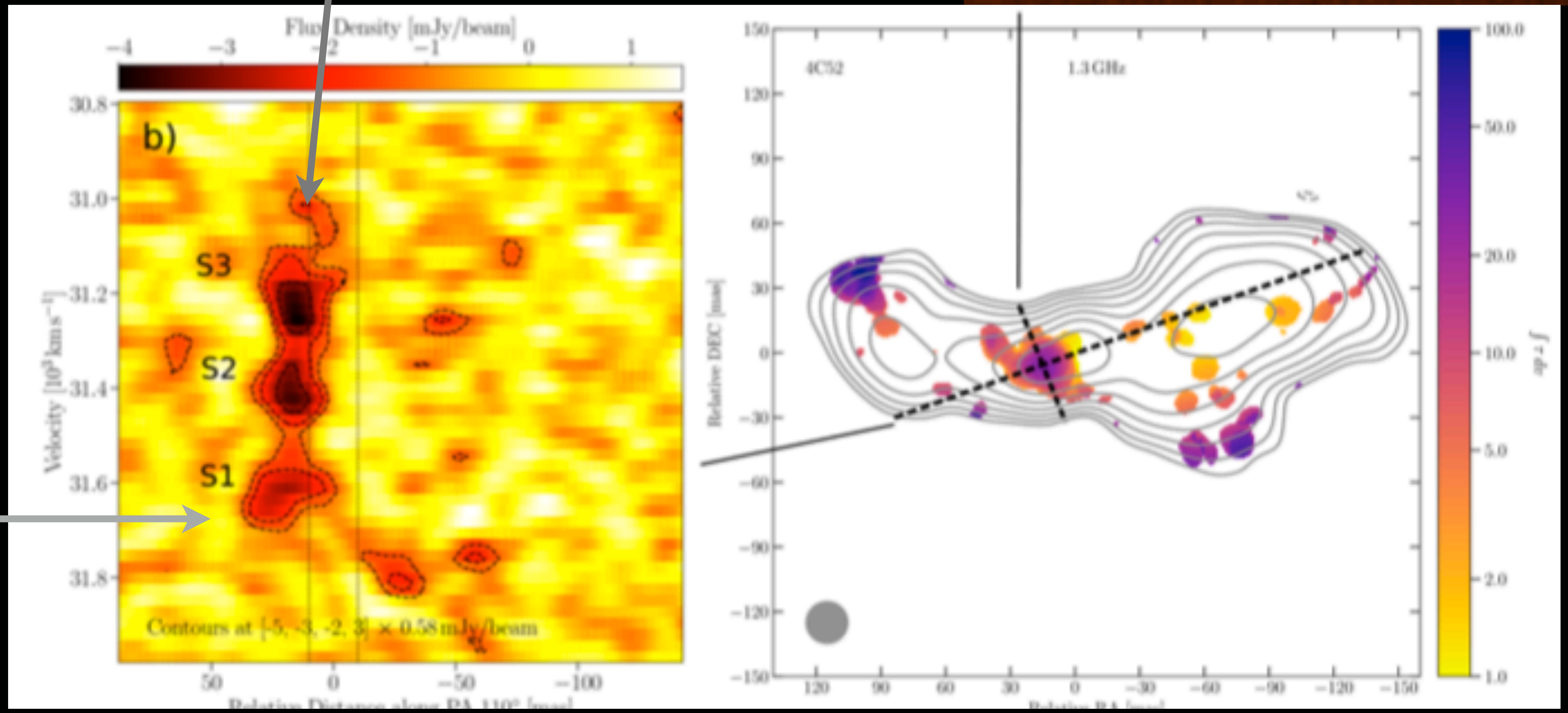


Schulz, RM et al. in prep



600 km/s

Systemic velocity



Clumpy medium

The average densities of the clouds range between 150 cm^{-3} and 300 cm^{-3}

(Morganti et al. 2013)

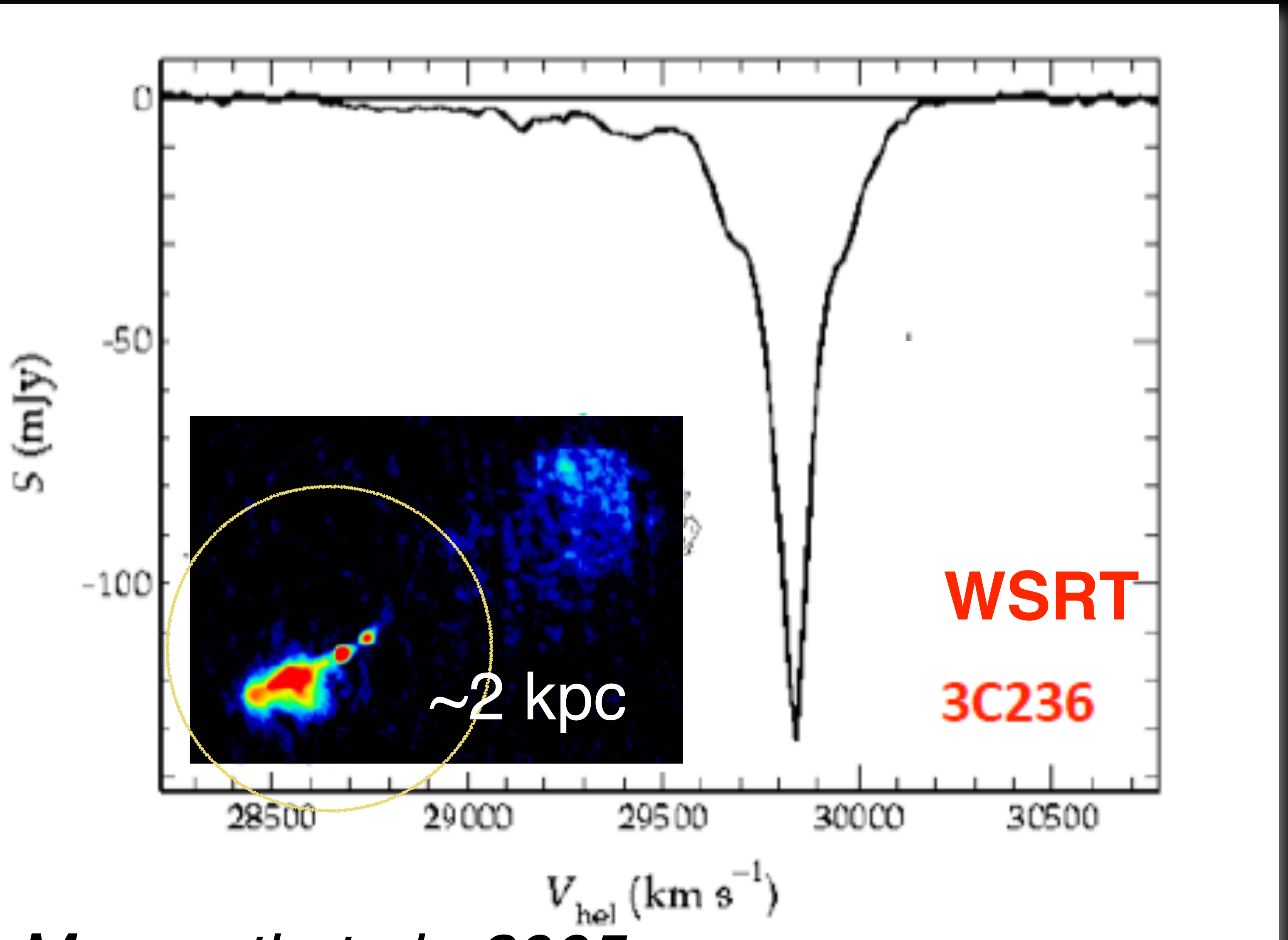
Younger sources:

VLBI recovers all flux of the HI outflows

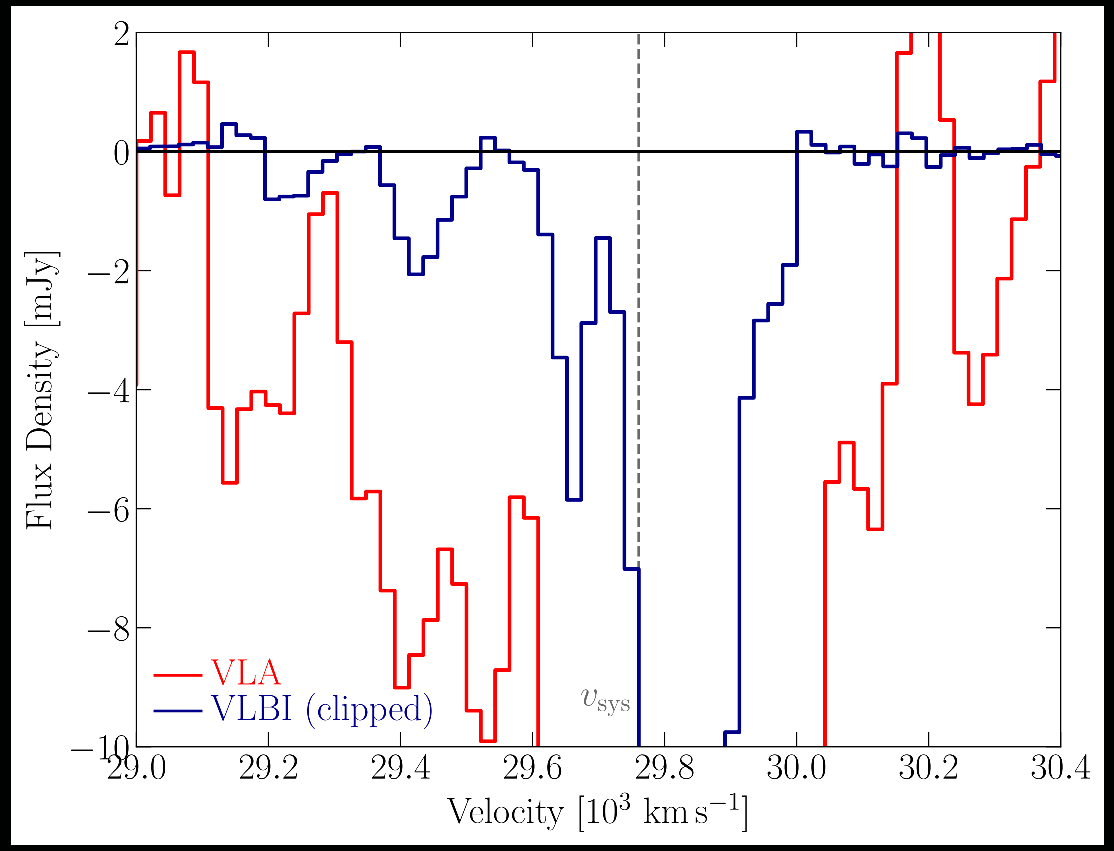
➜ absorption produced by (a few) dominant clouds

Outflowing HI clouds in the inner ≤100pc

Clumpy medium and evolution of the outflows as the source expands?



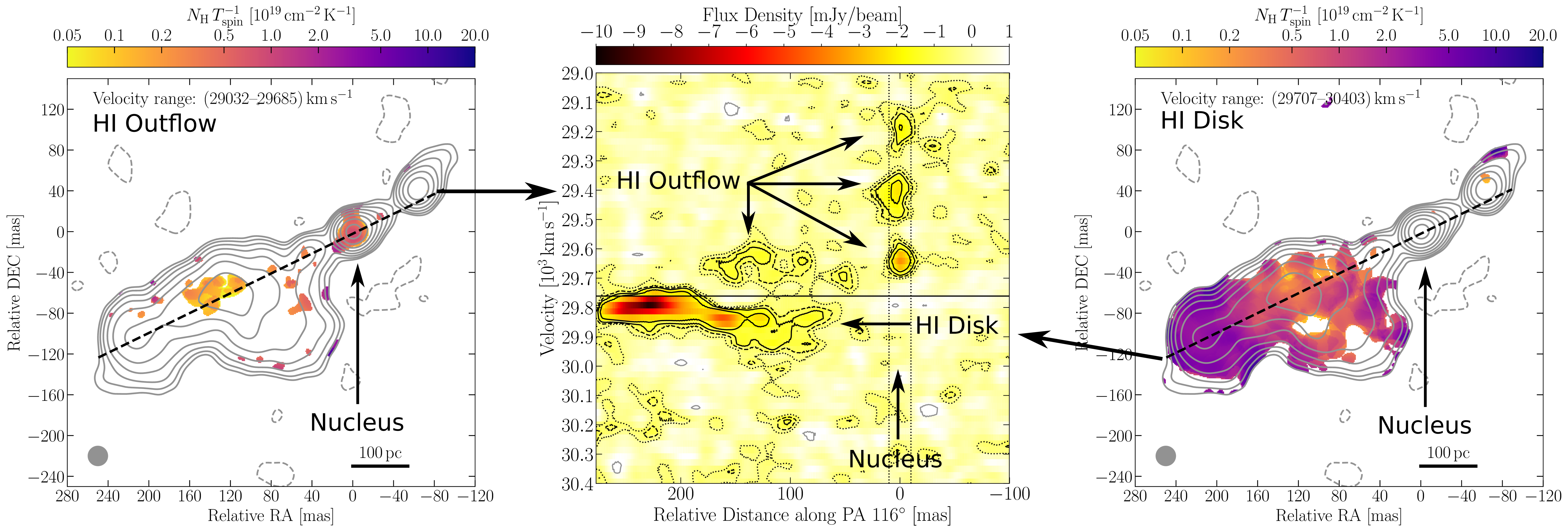
Morganti et al. 2005



More evolved (and restarted) sources

HI outflows only partly recovered by VLBI: likely mix of compact clouds and diffuse gas

HI clouds (0.28–1.5 x 10^4 M$_\odot$) observed in the inner region close to the core (< 40pc)

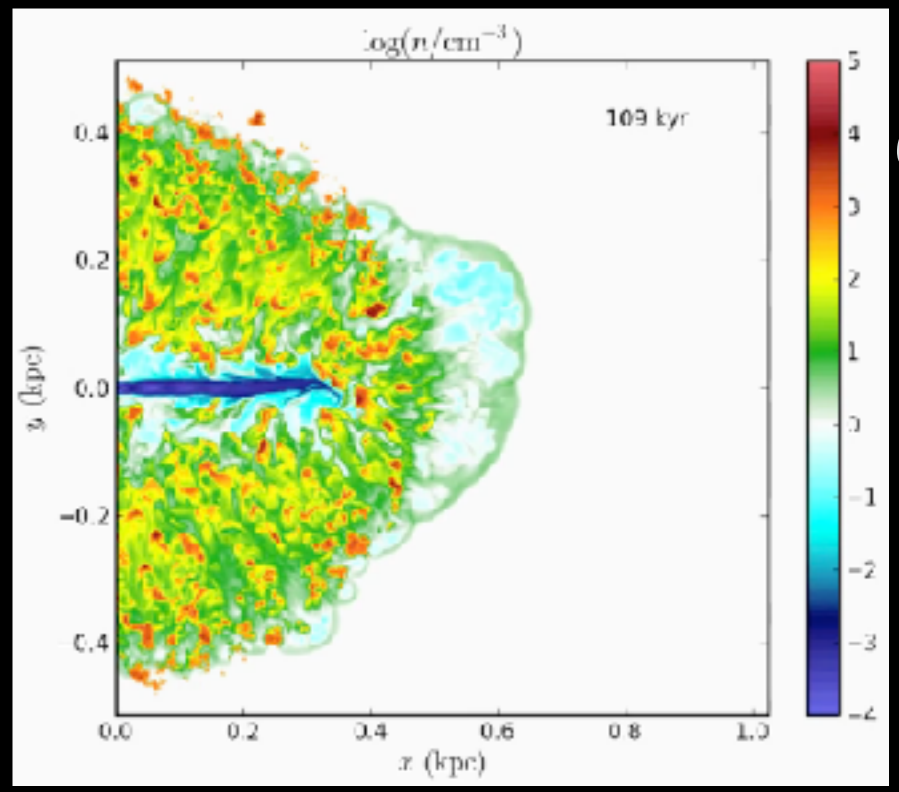


Schulz, RM et al. 2018 (arXiv:1806.06653)

Some results from HI and VLBI

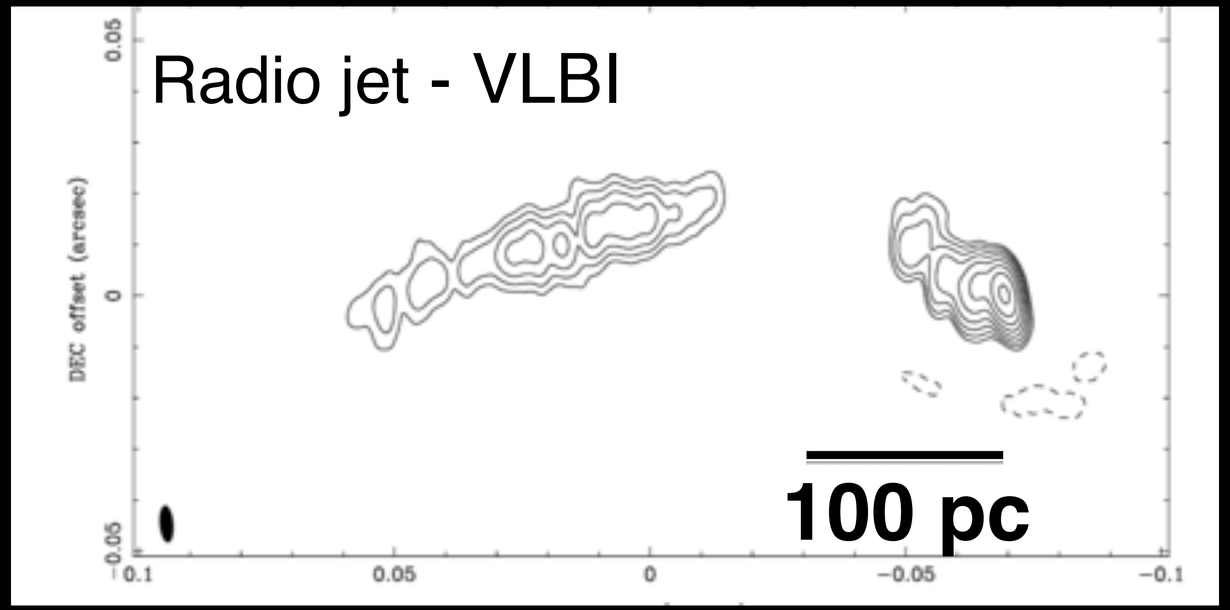
Schulz, RM et al. 2018
Schulz et al. in prep

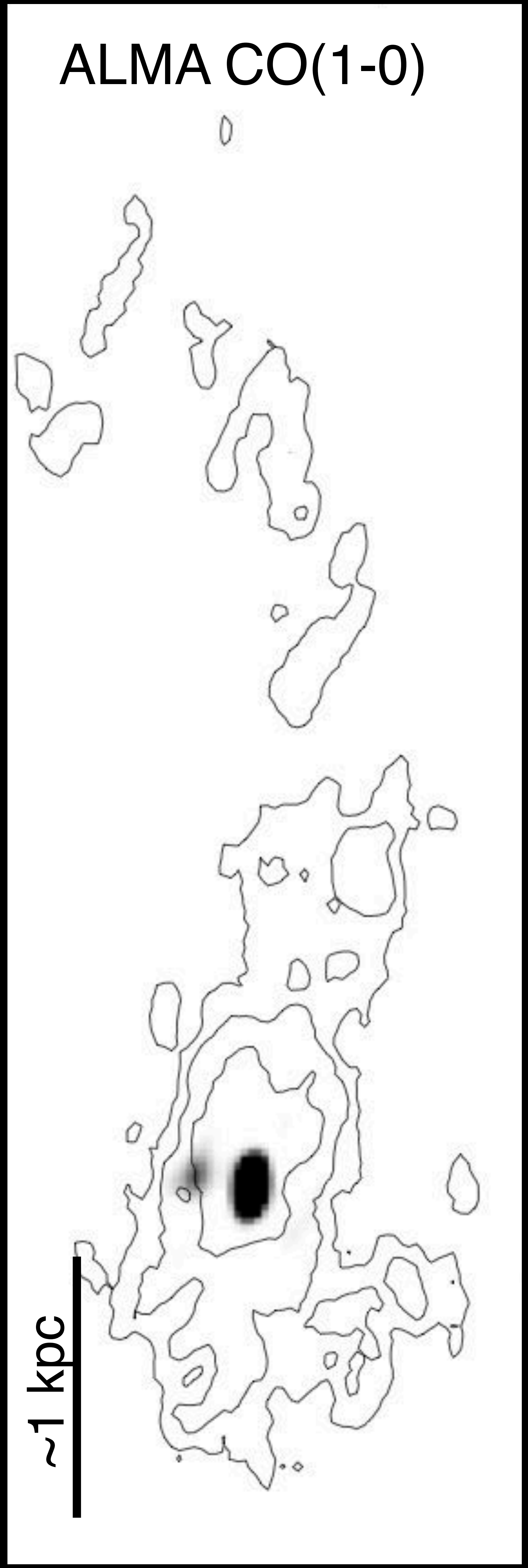
- The radio jets can drive the (HI) outflows
- Young/smaller sources showing the most direct sign of interaction
- Evidence of clumpy medium (on tens of pc scales) in all sources
  ➜ conditions favourable for the jet to have an high impact
- HI outflows observed already in the very centre of the AGN (<40 pc)
- Tentative signs of evolution of the outflow: presence of a diffuse component – not recovered by the VLBI observations – in larger sources



Wagner et al. 2012

Accretion and feedback in an obscured, young radio quasar



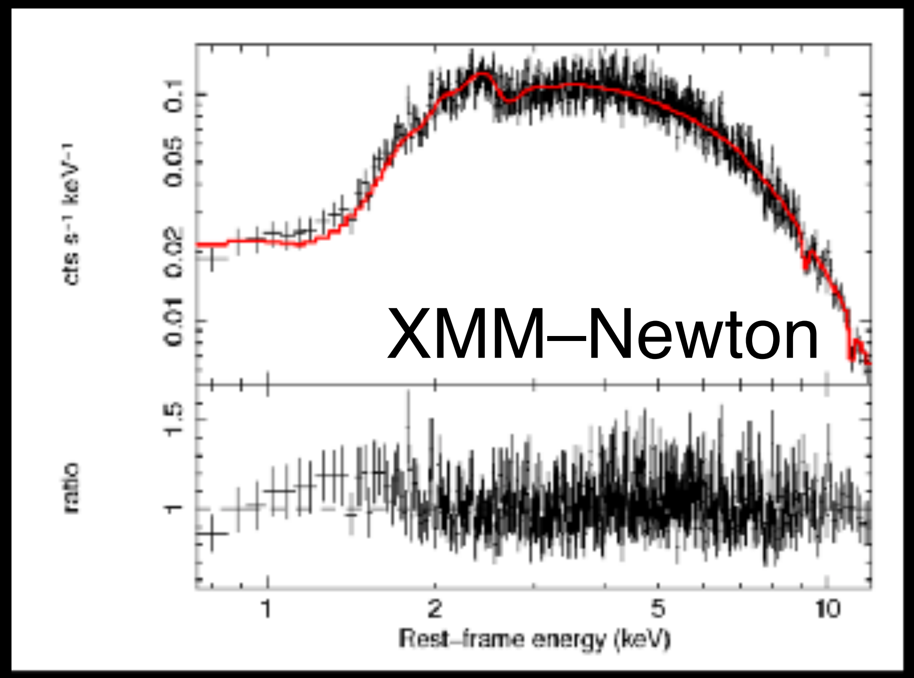


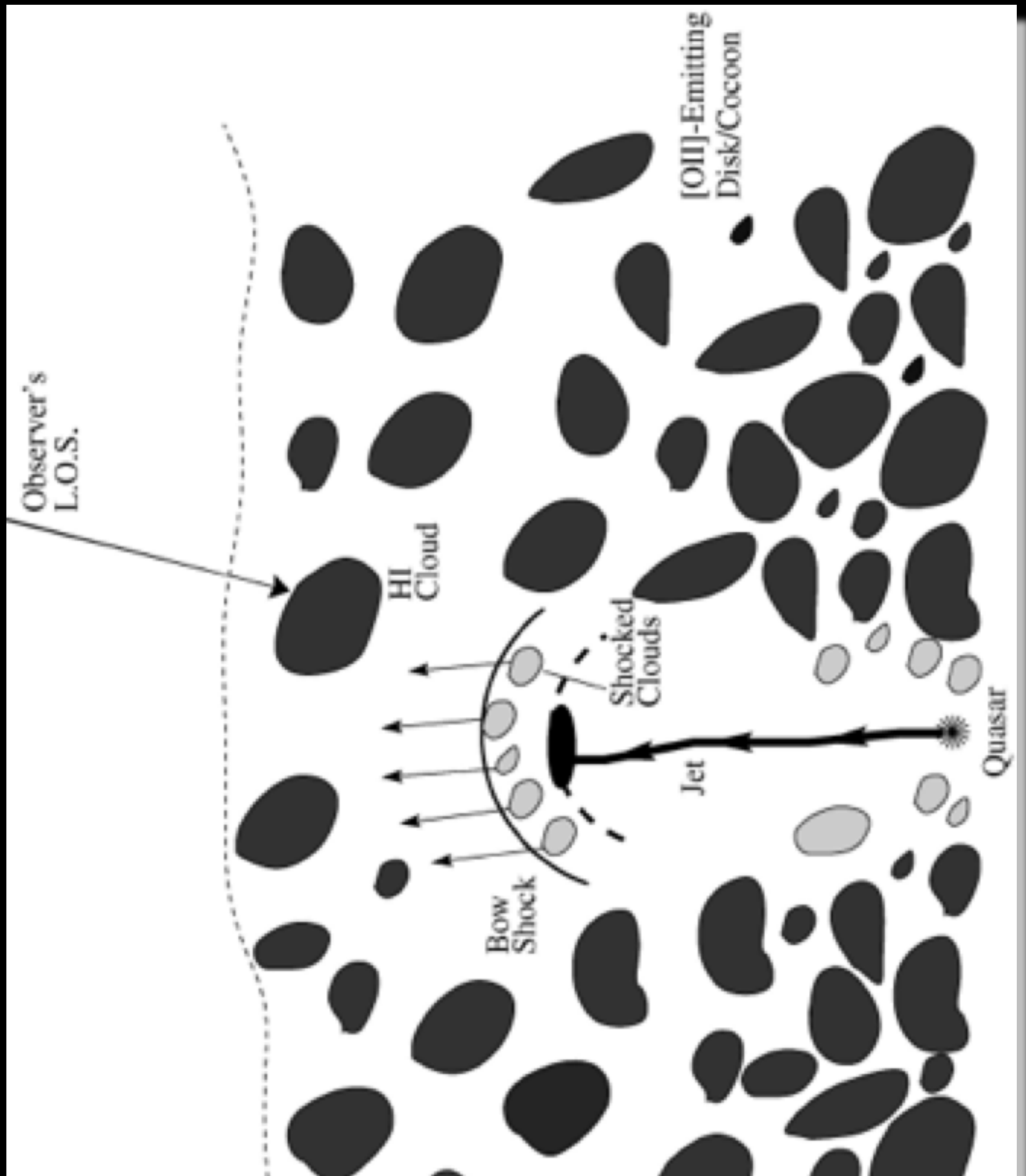
PKS 1549-79 quasar in the early stage of evolution

Newly born AGN in an ongoing merger: large cocoon of material still enshrouding the radio source (highly extinguished $A_V > 4.9$). SMBH accreting at a high Eddington ratio (0.3 < Lbol/Ledd)

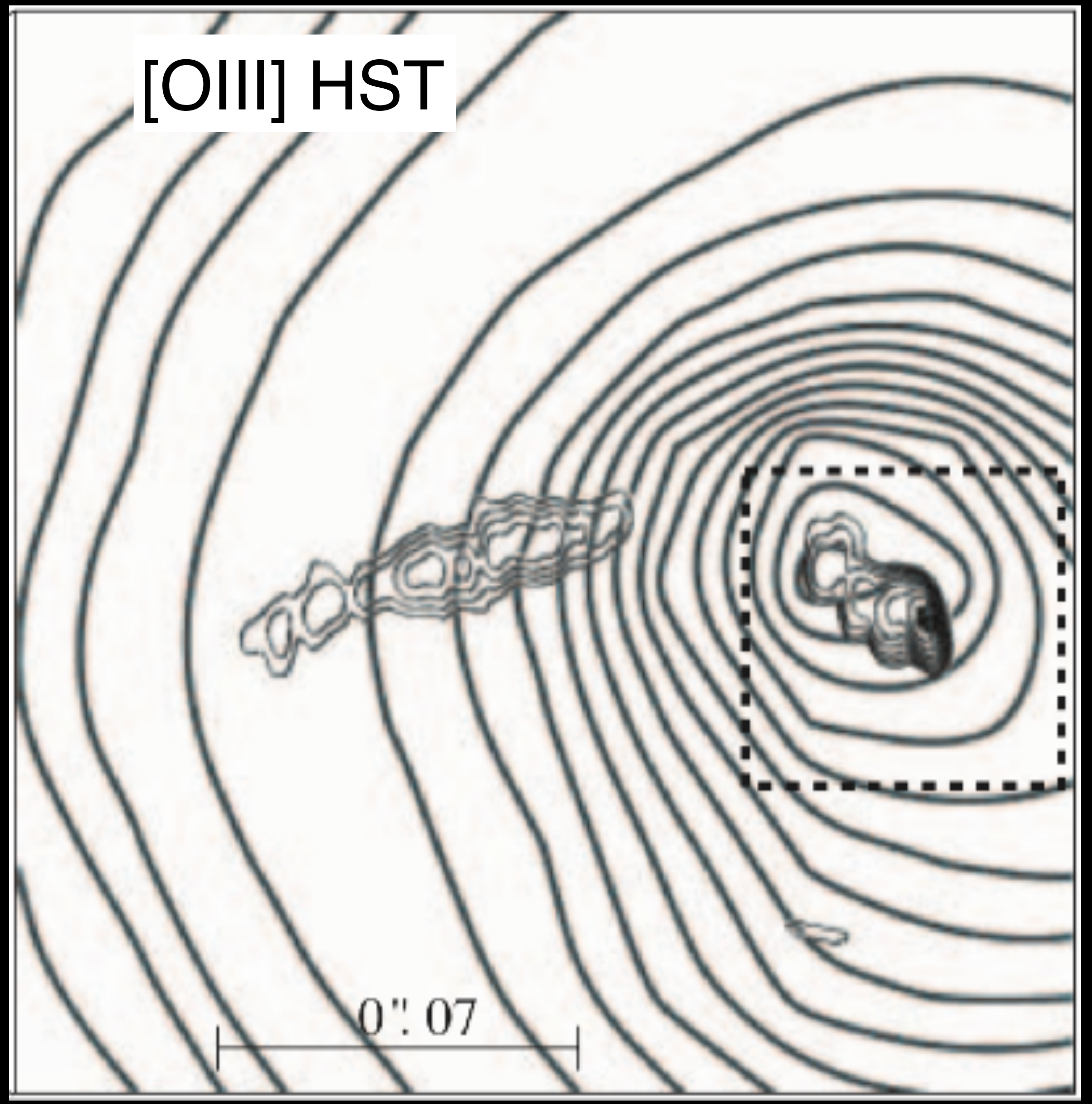
Xray UltraFastOutflow (Tombesi et al. 2013), ~0.2c

Is the powerful jet (10^{26} W/Hz) clearing the central regions

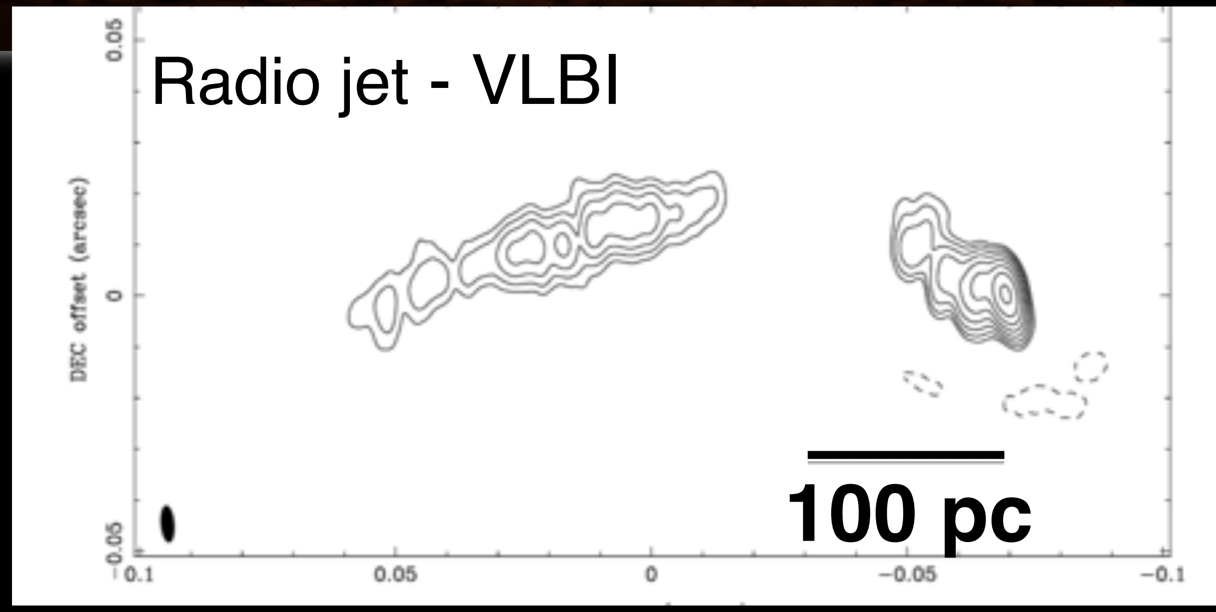




Holt et al. 2006



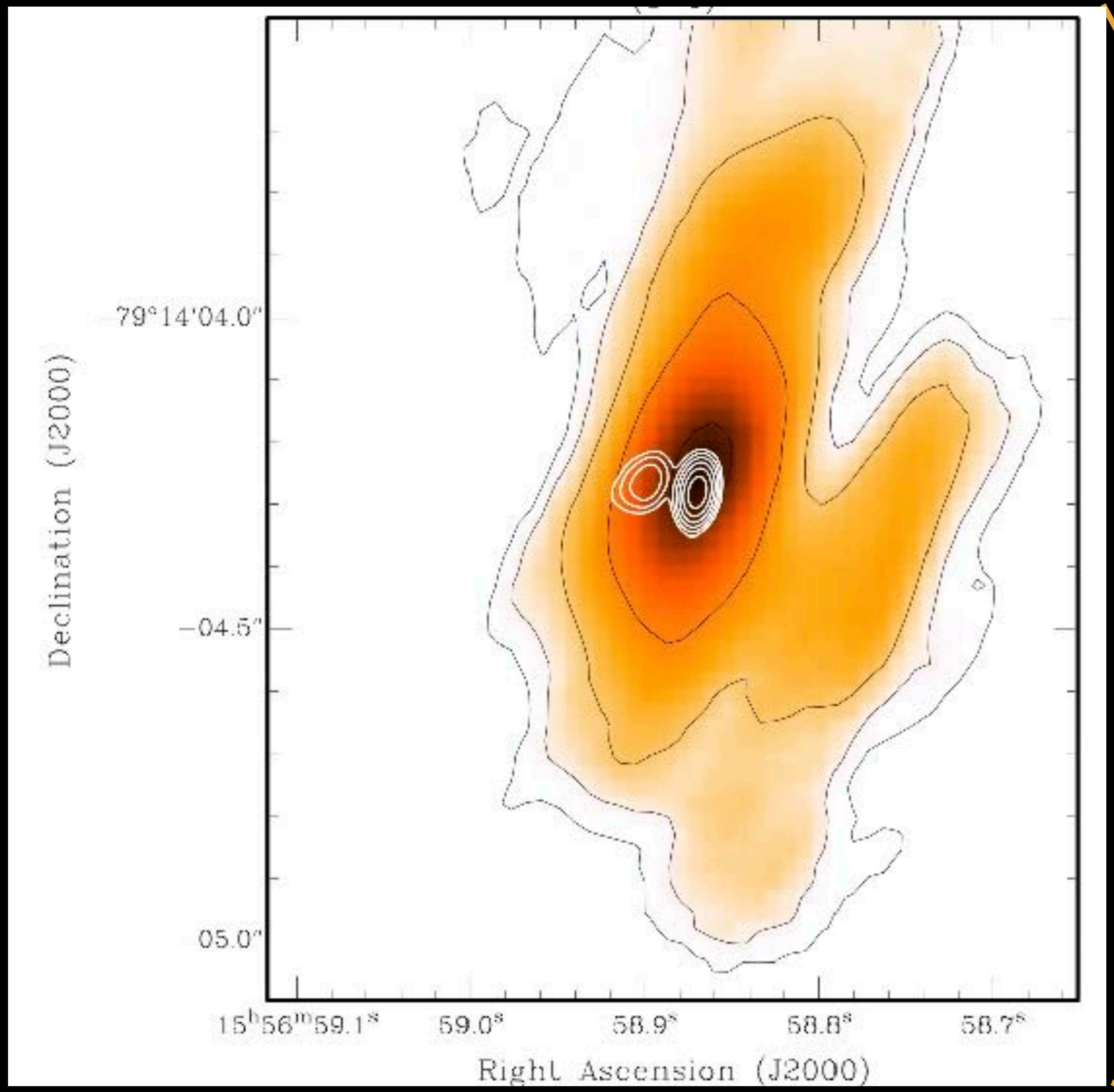
Batcheldorn et al. 2007

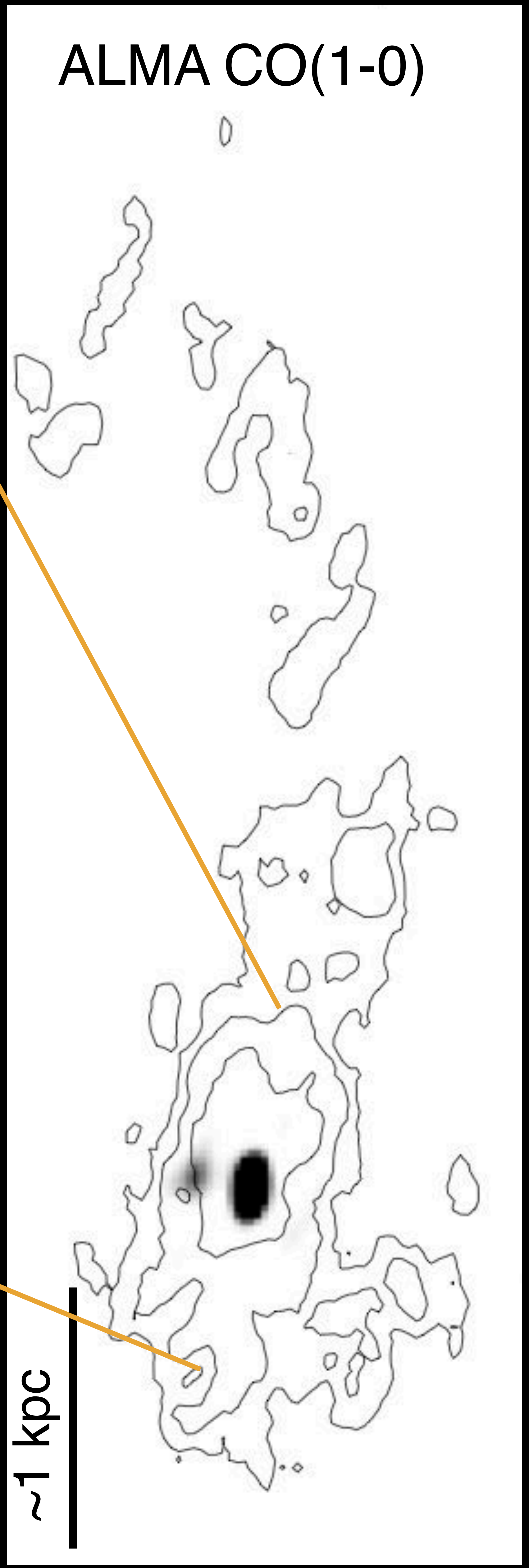


Crucial stage in the evolution
Needs the spatial resolution to trace the gas close to the nucleus => ALMA!

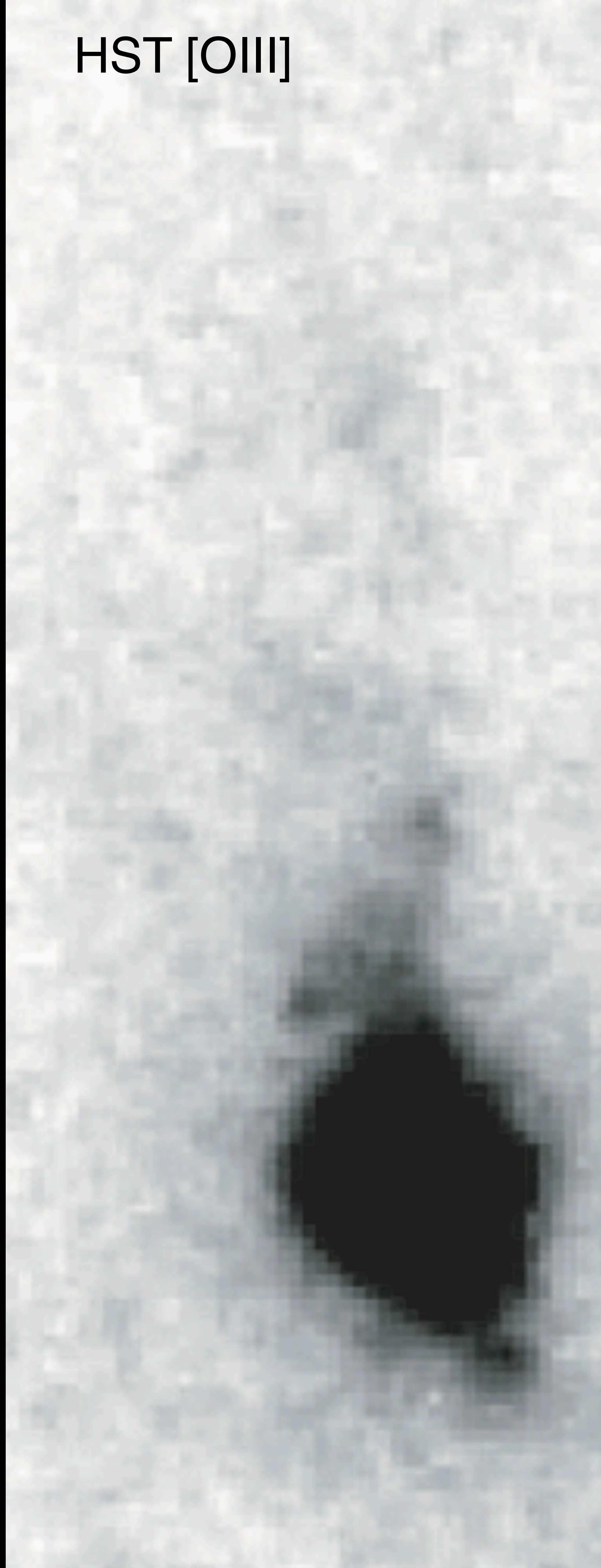
PKS 1549-79 quasar in the early stage of evolution

ALMA CO(1-0) and CO(3-2) detected in emission resolution from 0.05” ~ 100 pc to 0.2” (z=0.150)





Oosterloo, Morganti et al. in prep

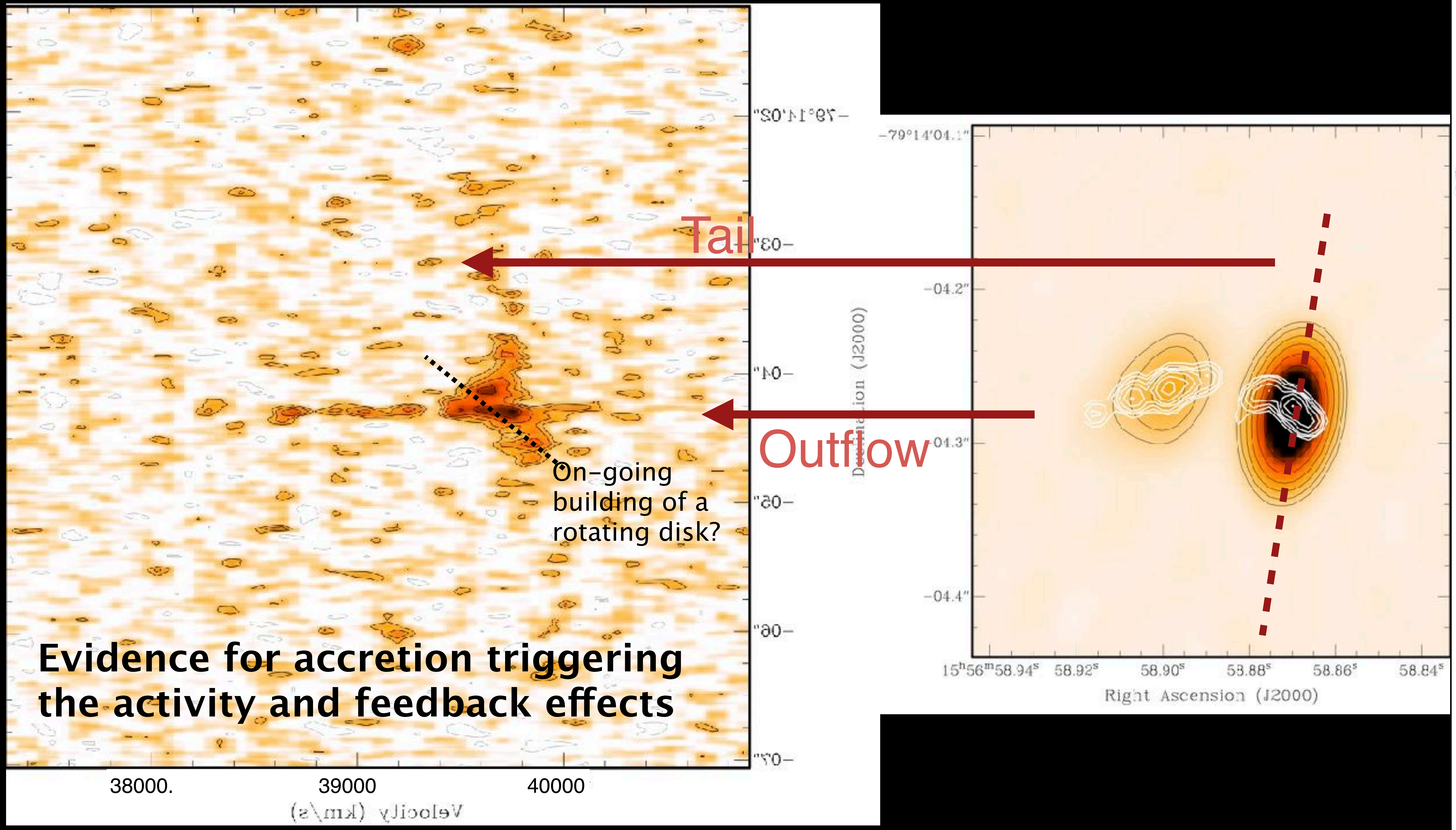


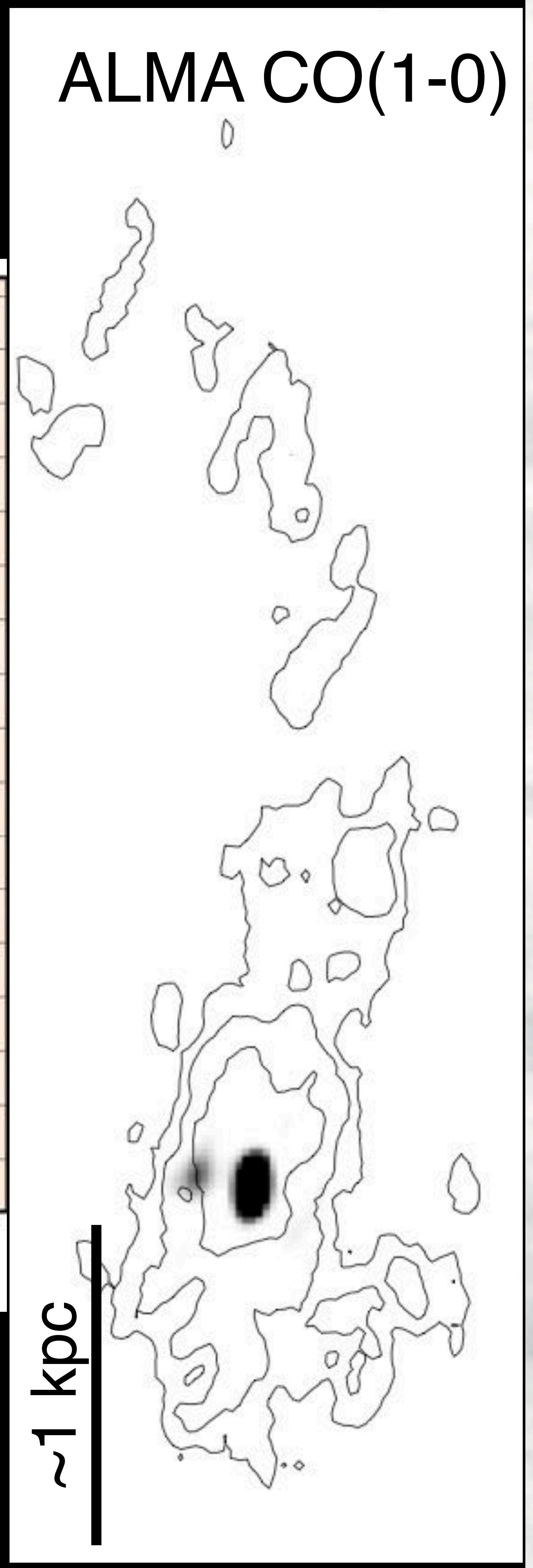
Most of the “action” in the very central region and N-S direction, extended part of the jet has already emerged…

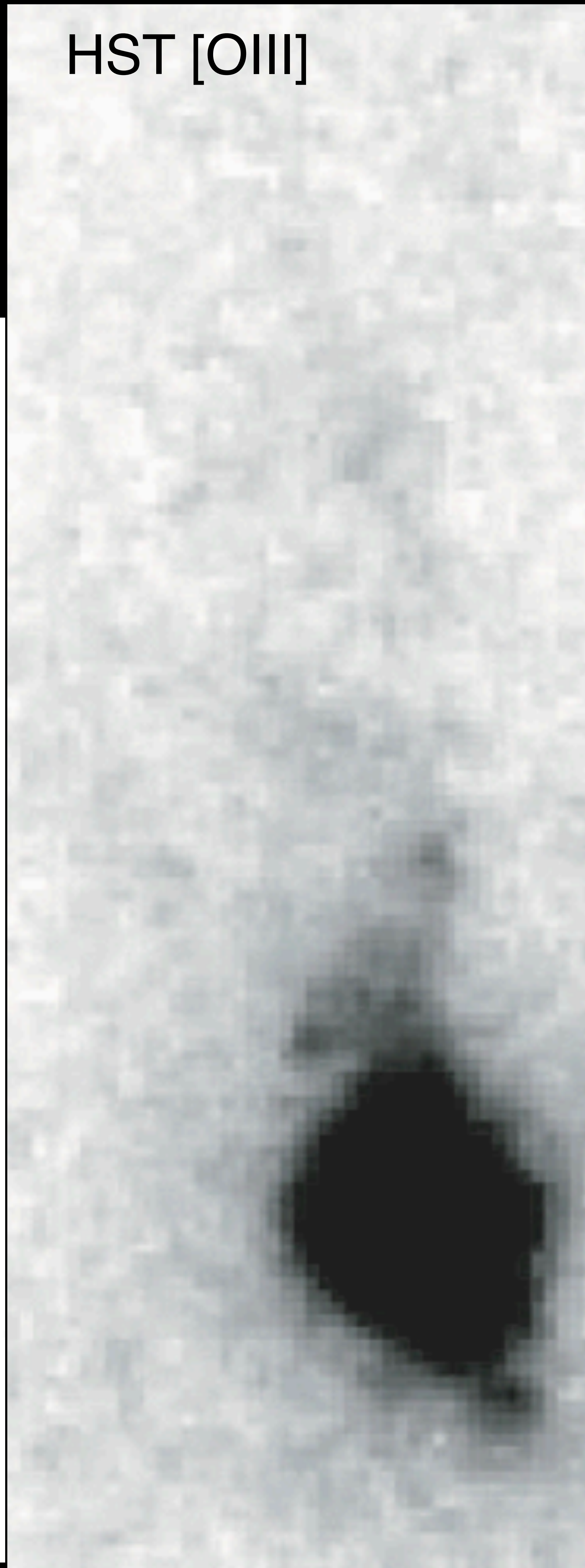
PKS 1549-79 quasar in the early stage of evolution

ALMA CO(1-0) detected in emission
Highest resolution 0.05” ~ 100 pc (z=0.150)
Large molecular outflow in the central regions (<100 pc) ➜ ~100 $M_\odot$/yr

In agreement with simulations: a powerful source (like PKS1549-79) has a faster/more massive outflow

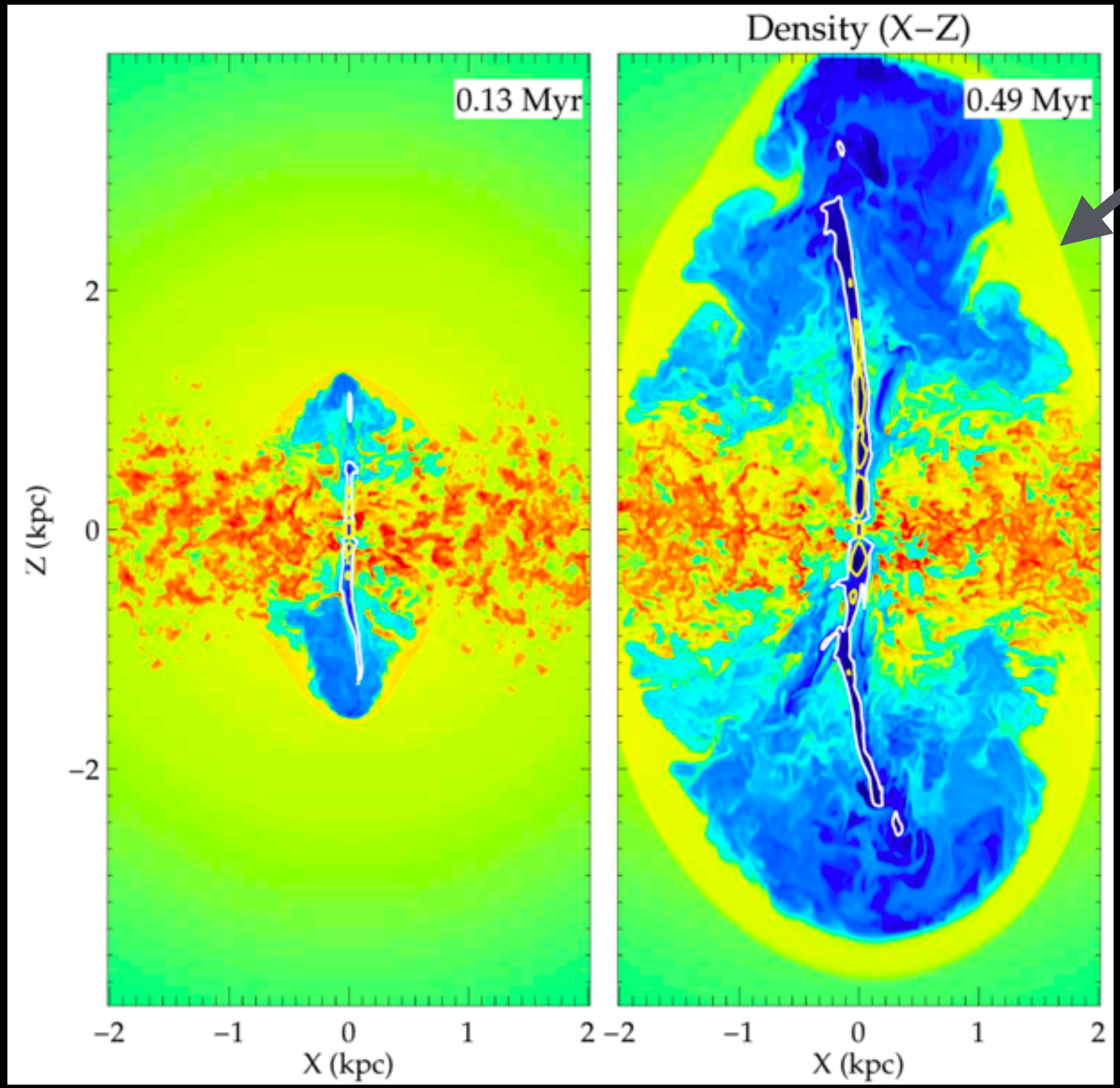


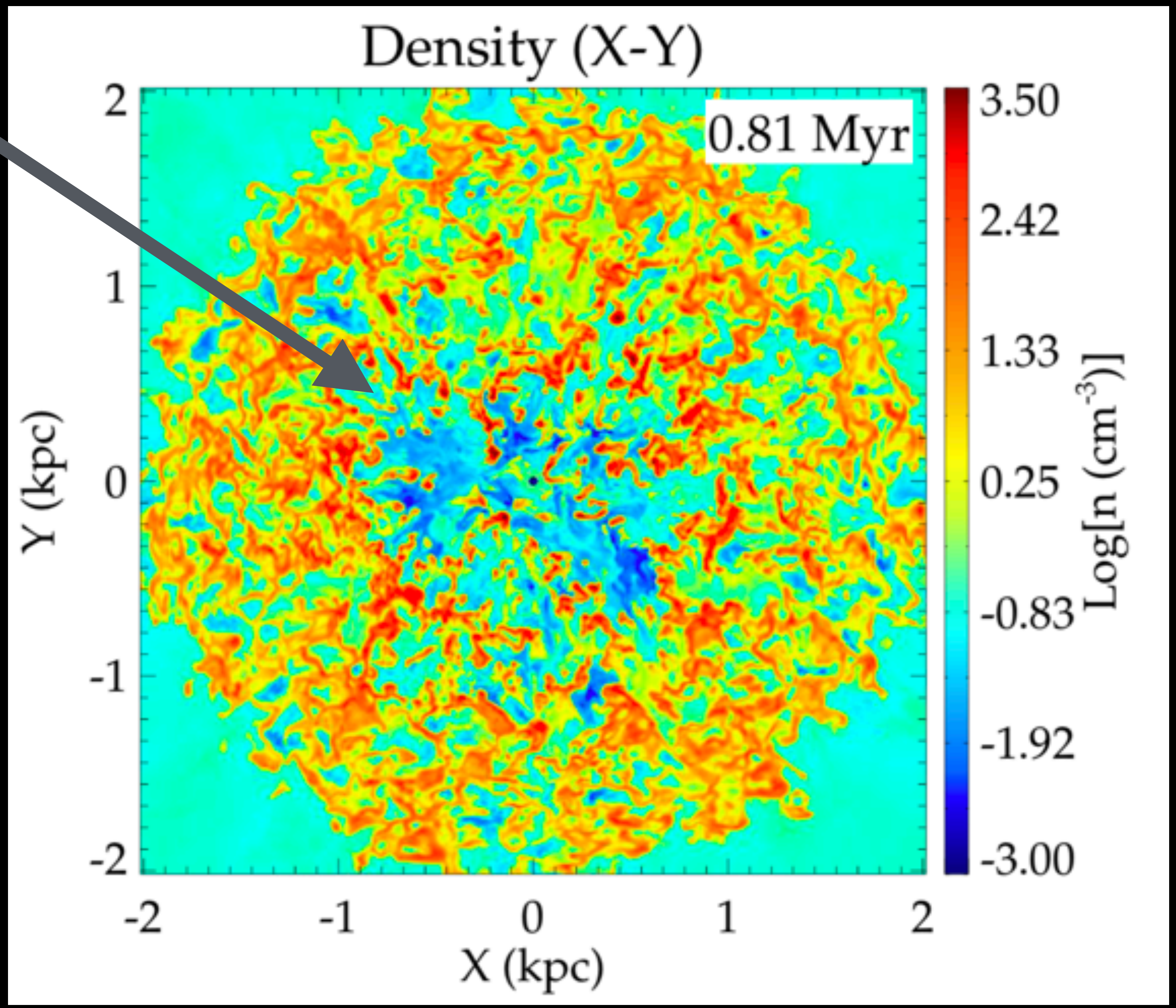




Oosterloo, Morganti et al. in prep

Cocoon of shocked gas…





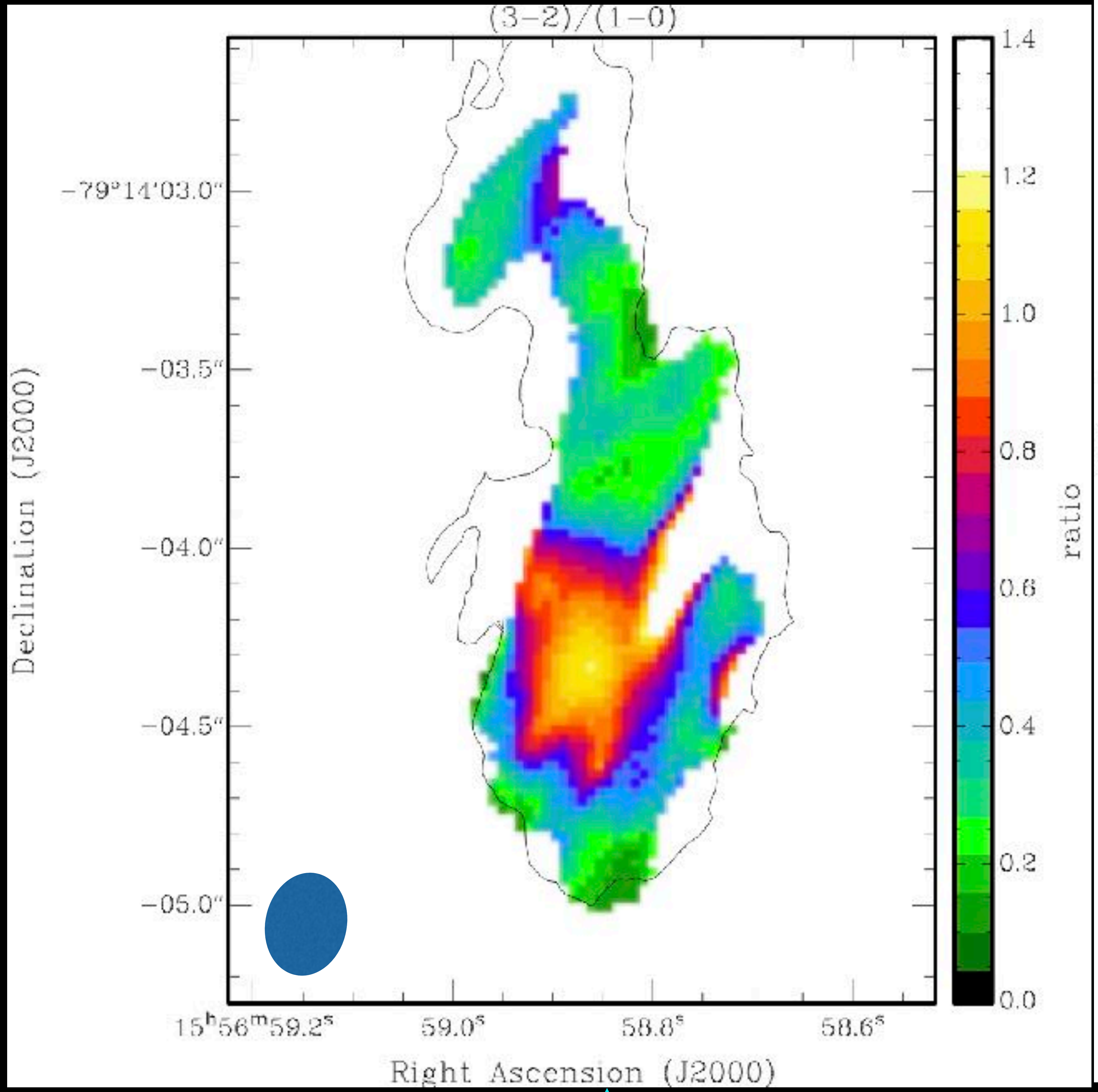
Mukherjee et al. 2018

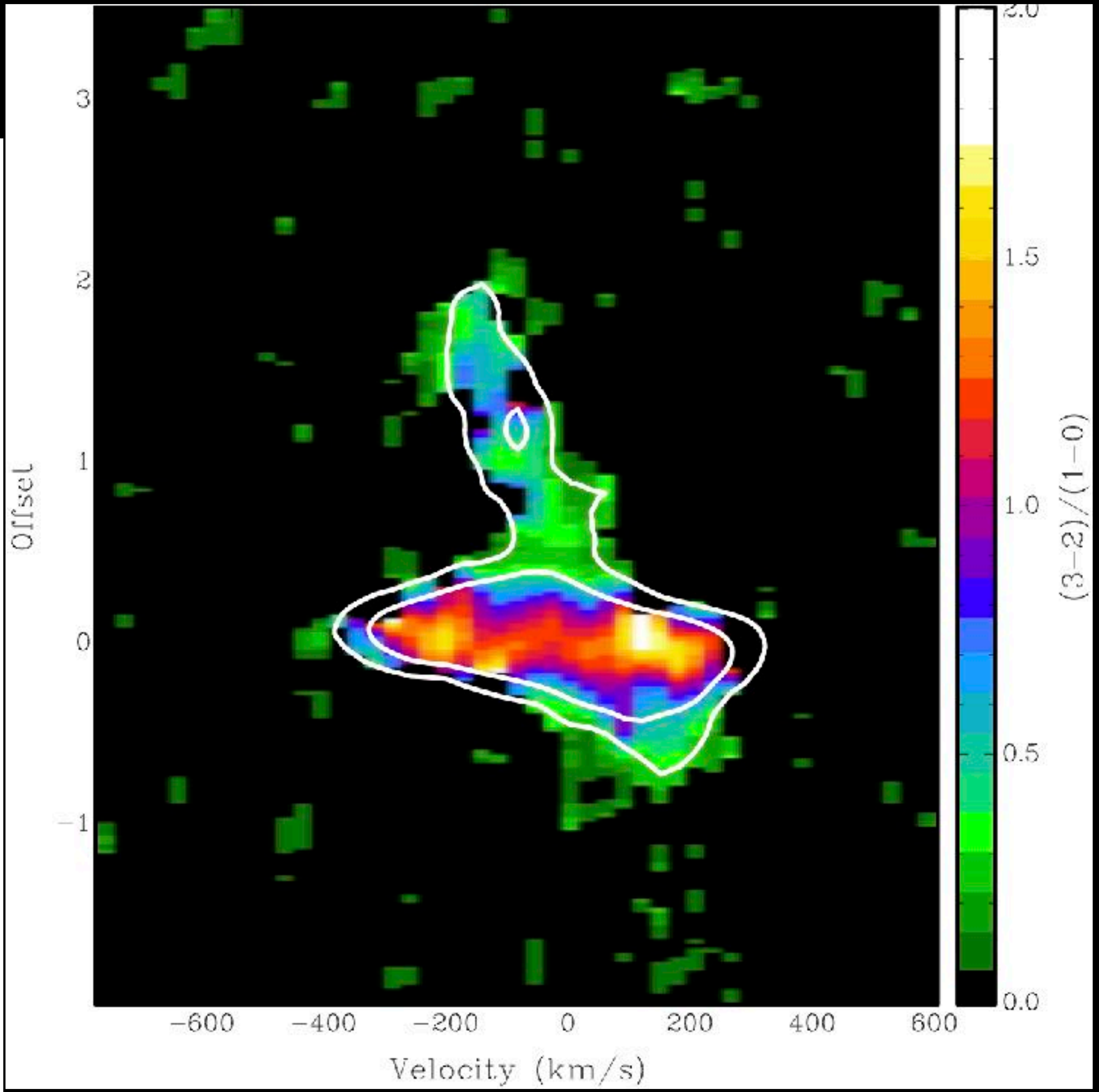
The ALMA observations of PKS1549 show that even if the **jet emerges orthogonal** from a (proto) disk, it can create a cocoon of shocked and kinematically disturbed gas expanding through the disk (as suggested by simulations)

➜ effect on the kinematics and physical conditions of the circumnuclear disk

clear effect of the AGN (jet?) on the gas: both kinematics and excitation

ALMA CO(3-2) resolution ~0.2 arcsec





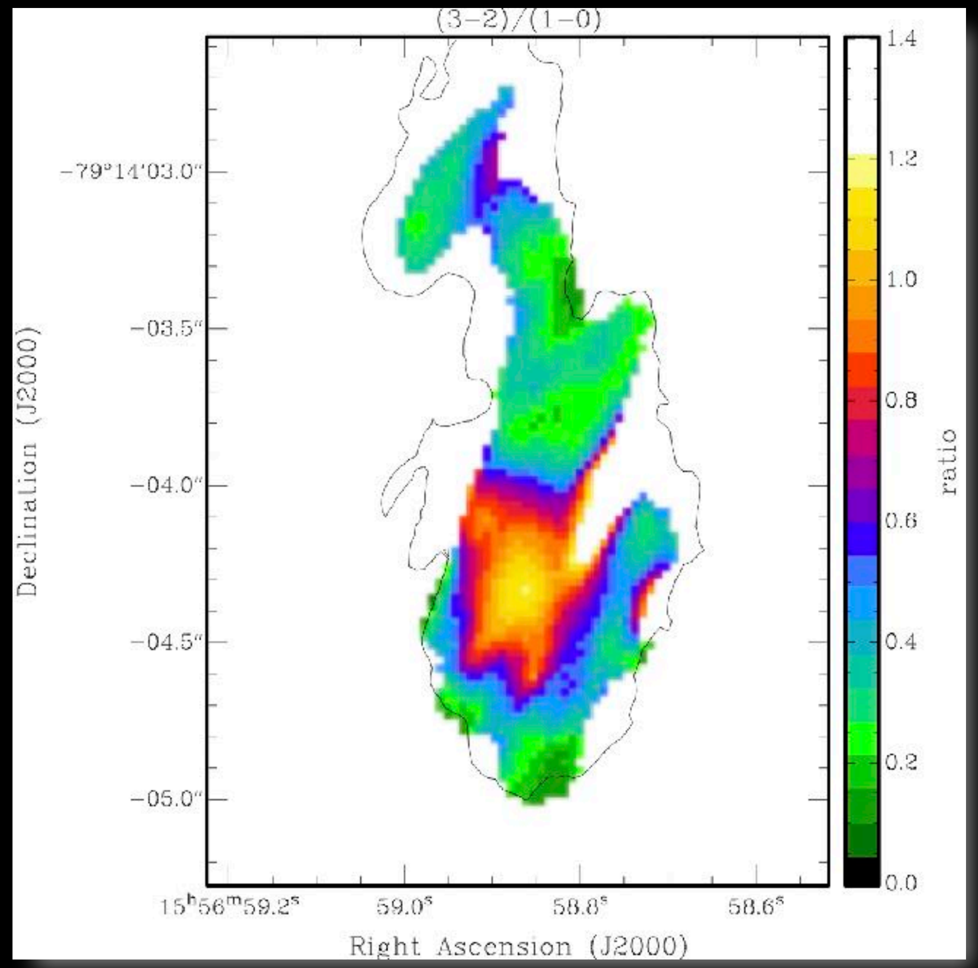
High CO(3-2)/CO(1-0) ratio in the central region wrt tail: effect of AGN

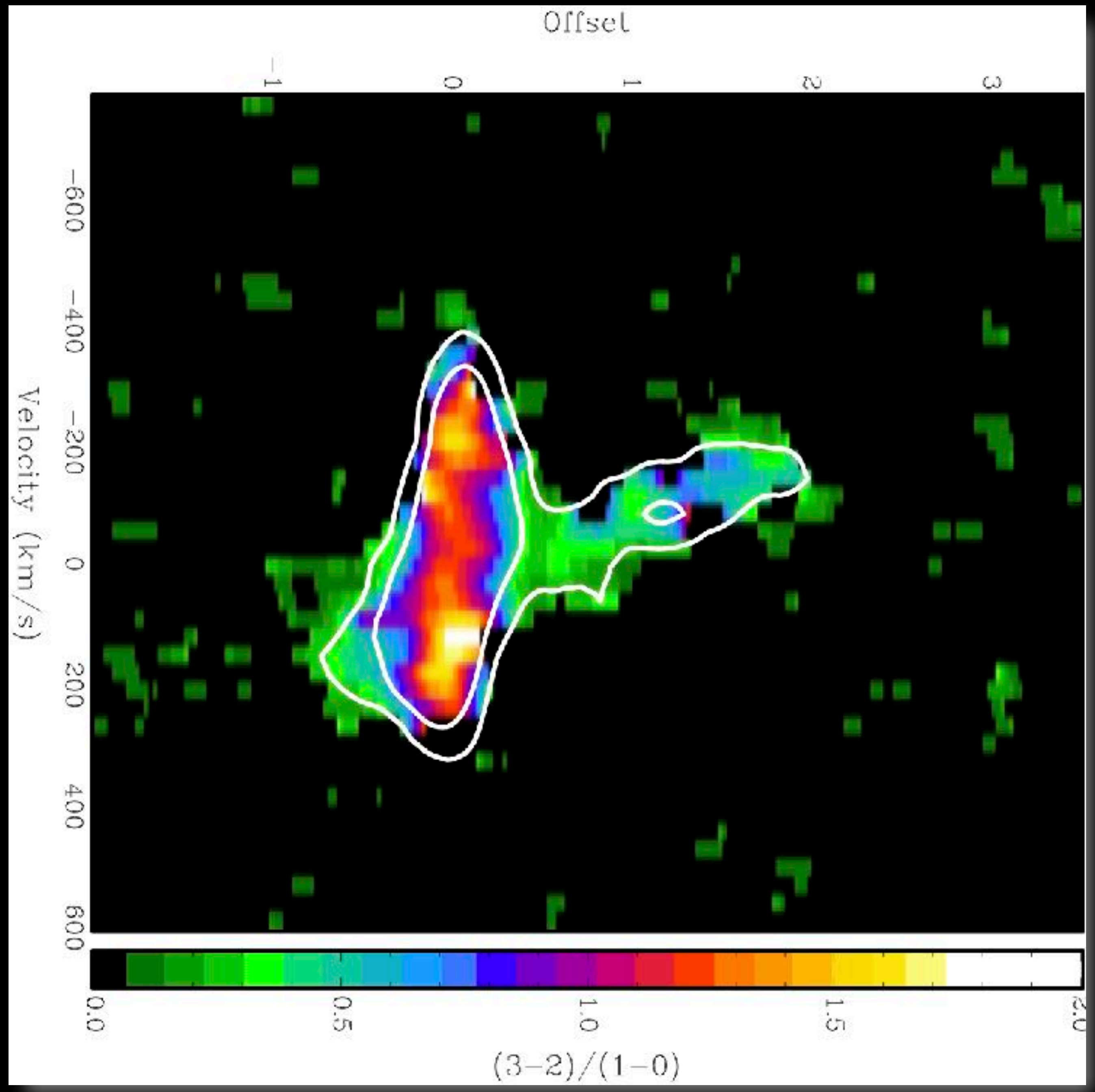
Confirmed by the kinematics

Oosterloo, Morganti et al. in prep.

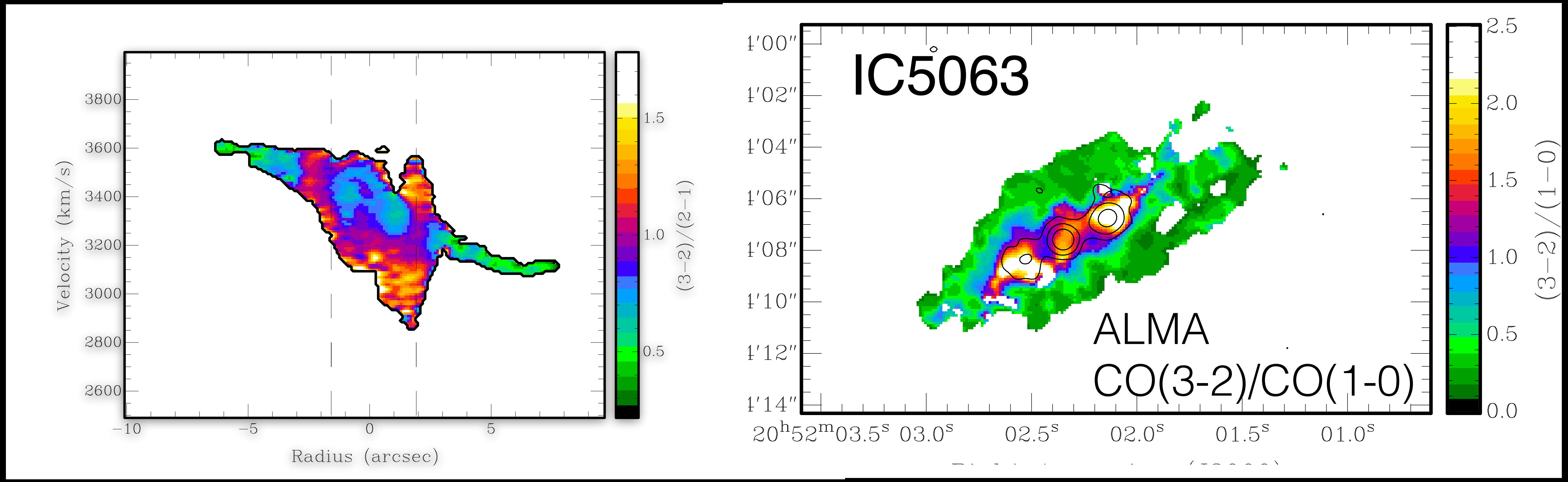
PKS1549-79 is not the only case …

PKS1549-79





Radio power of IC5063 similar to NGC1068!



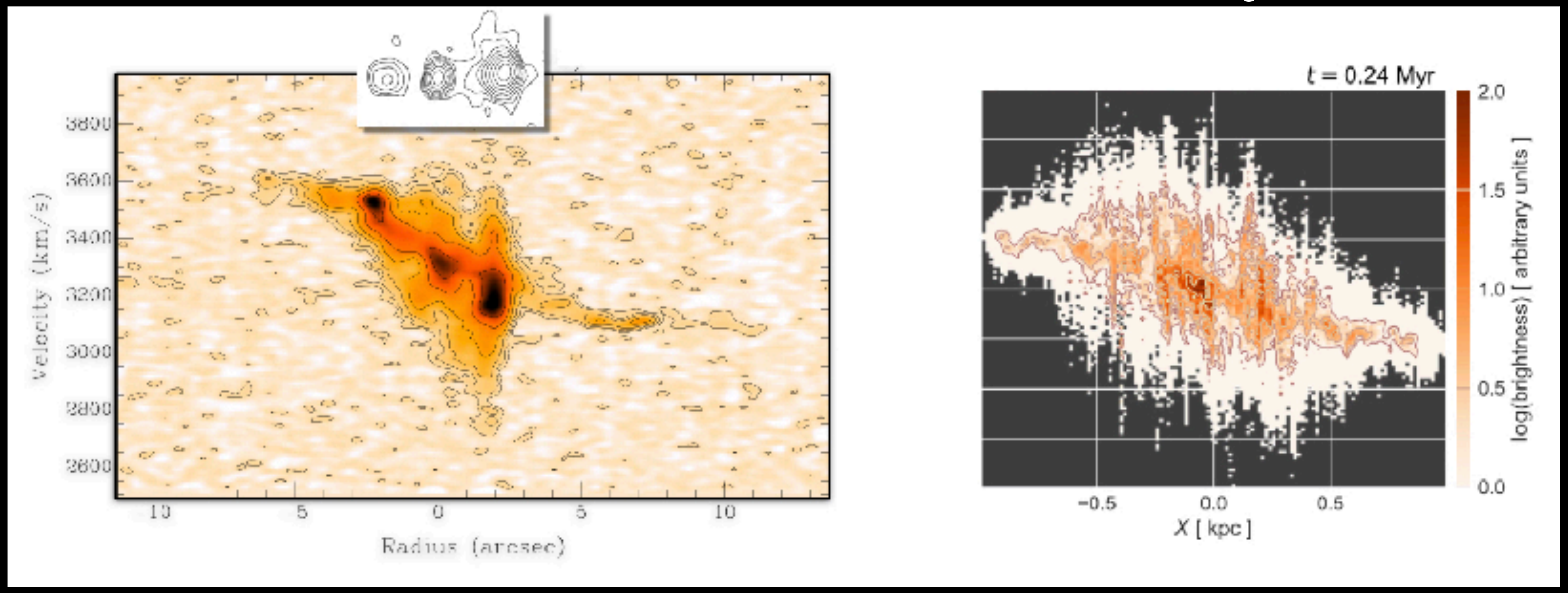
Morganti et al. 2015, Oosterloo, Oonk, Morganti, Combes et al. 2017

Disturbed kinematics AND
different conditions of the molecular gas in the jet-affected regions.
Successful modelling as result of the impact of the jet

The impact of the jet can be seen in both the kinematics and the excitation of the molecular gas

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

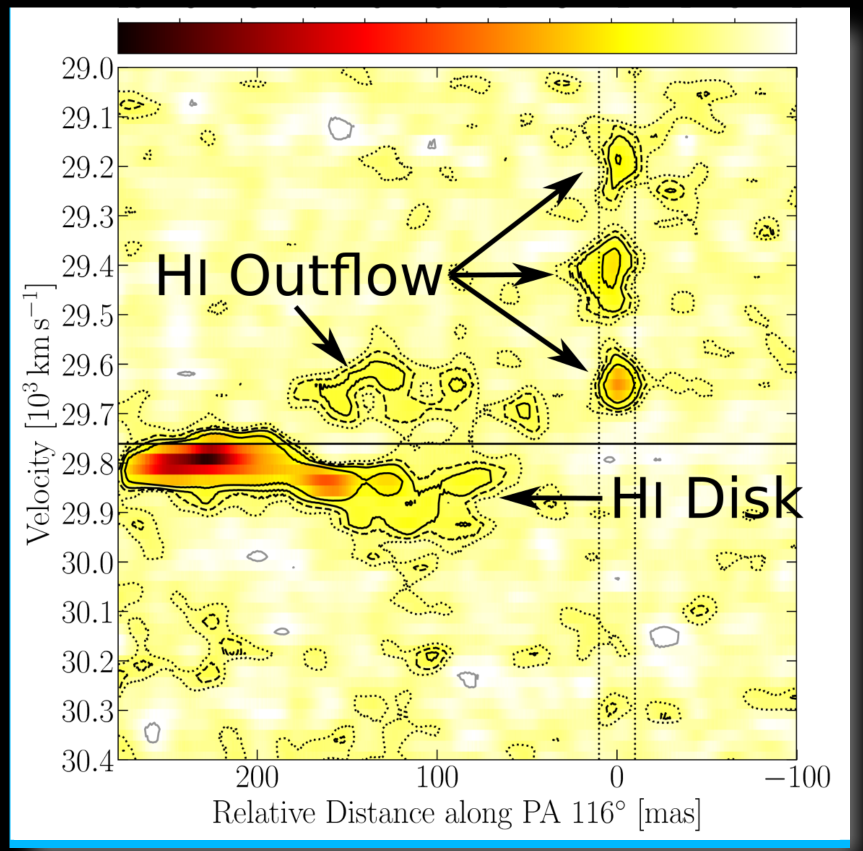
Data *Modelling*

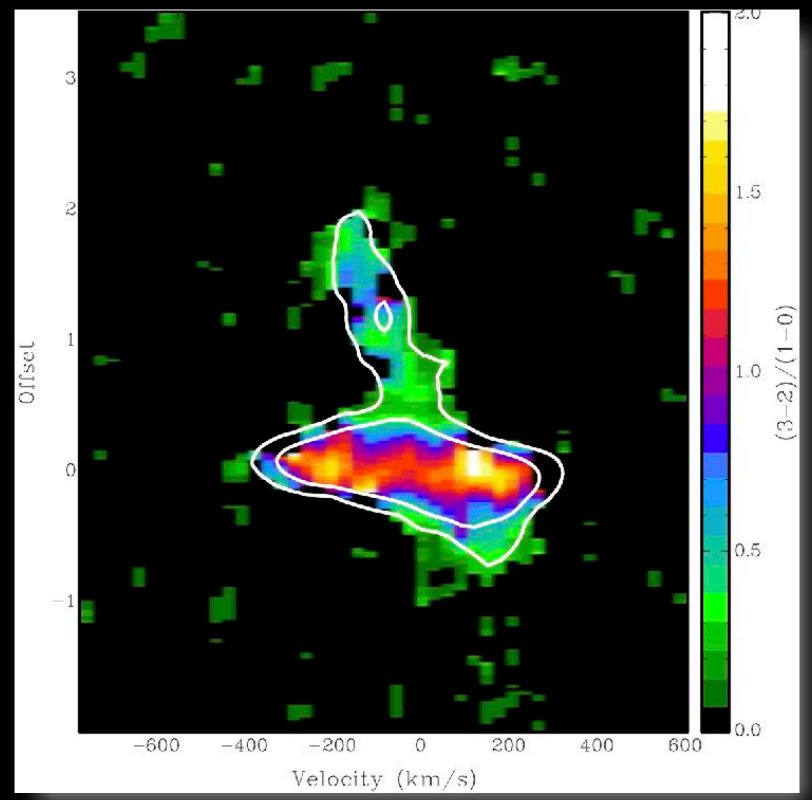


Mukherjee, Wagner, Bicknell, Morganti et al. 2018

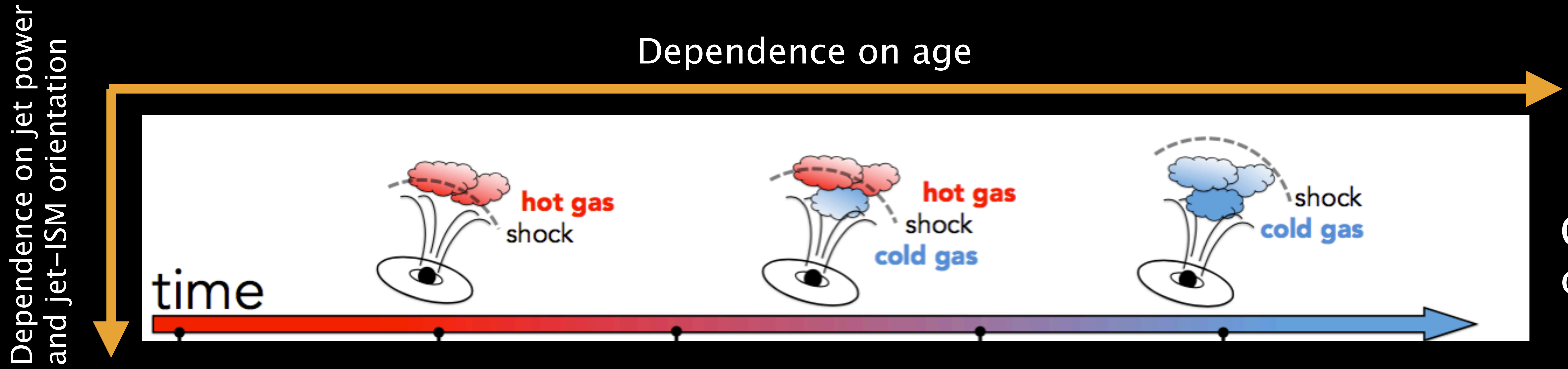
Conclusions

- Young radio jet couple strongly with ISM: also for low power jets!
- Evidence of clumpy medium (on tens of pc scales) in all sources ➜ conditions favourable for the jet to have an high impact
- Conditions of the outflows changing as radio source evolves
- Jets can produce cocoon expanding across the disk, shocking and kinematically disturbing the gas ➜ relevant for the very inner circumnuclear regions/torus?
- Impact of the jet can be seen in both the kinematics and the excitation of the molecular gas





For the future: a large parameter space needs to be explored …



Change in the conditions of the gas outflows

From Santoro et al. 2018