Tracing gas accretion and removal with HI (absorption) in radio AGN

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Why associated HI absorption

- Sensitive to HI column density ~few x10^{19} cm^{-2} (T_{spin}=100 K)

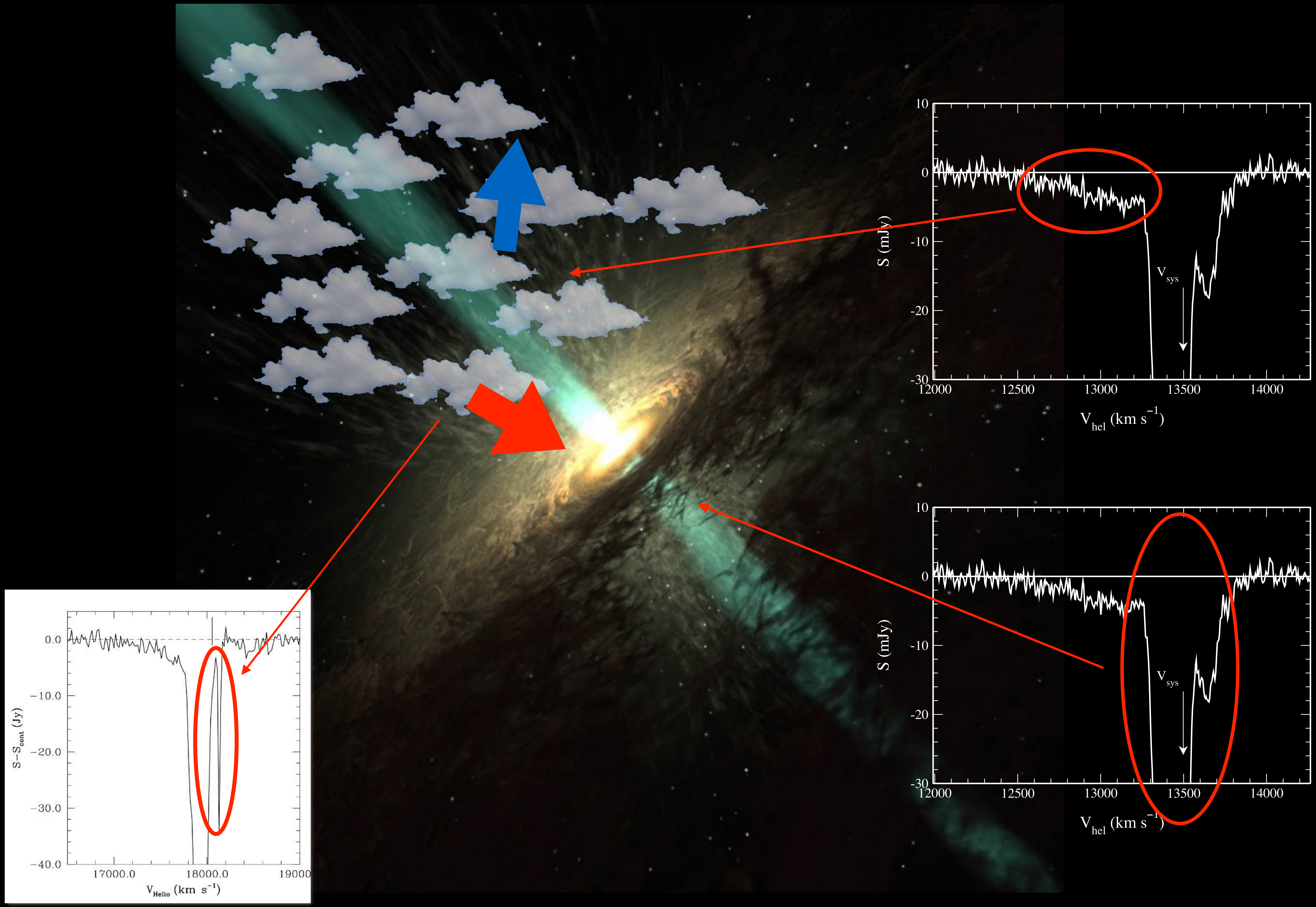
  ➜ against radio continuum typically stronger than 50 mJy
- Possible to detect HI at high spatial resolution down to pc scales
- Possible to detect HI at high redshift

⬇

Ideal for the study of gas in AGN

Main goals from HI associated: trace the presence of gas to high redshift, study kinematically disturbed gas tracing feeding/feedback

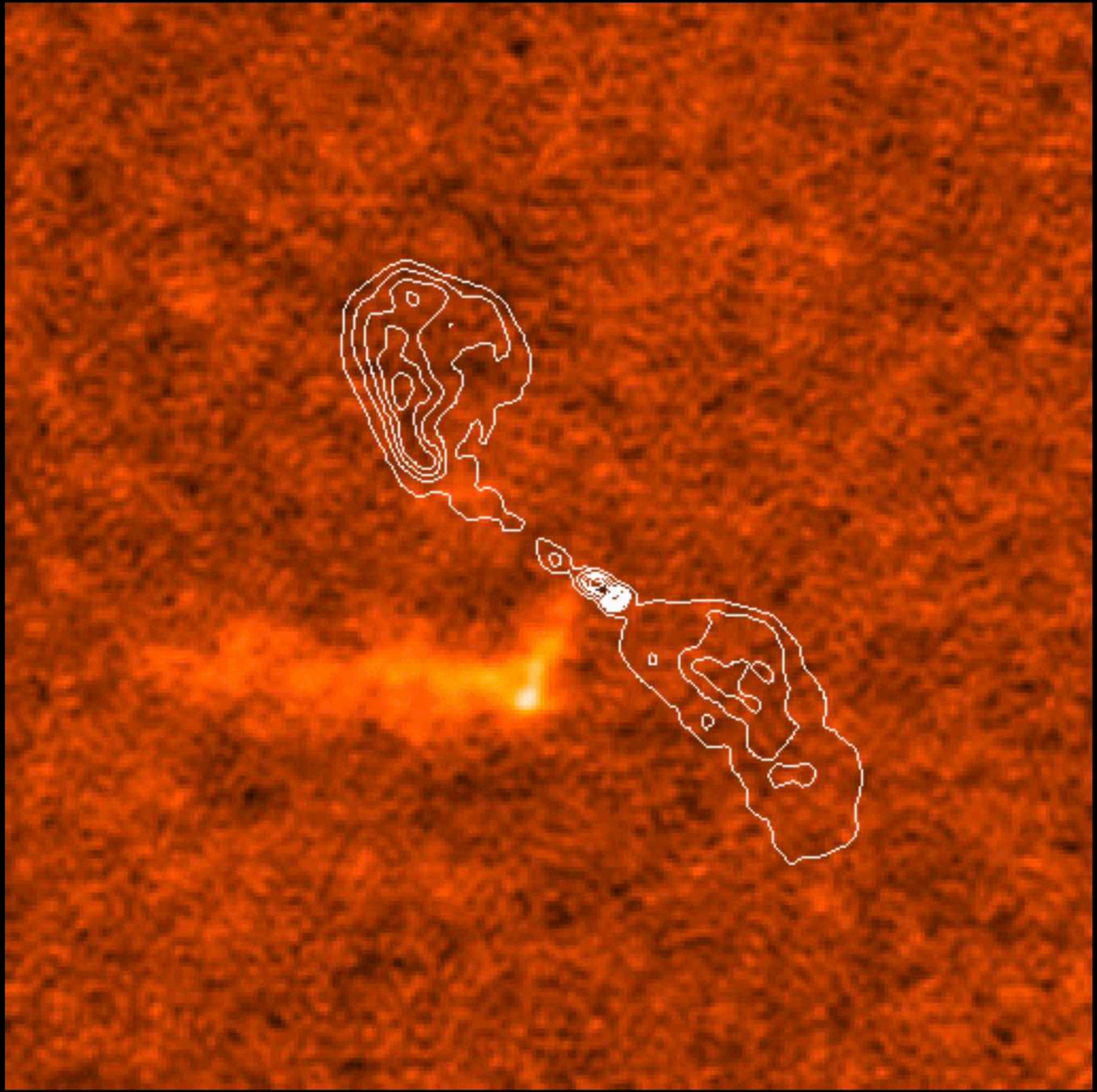
Large potential in the upcoming “blind” surveys



Morganti & Oosterloo A&A Rew 2018

HI absorption to tell us about presence of HI

The case of Centaurus A



Struve et al. 2010

ATCA observations (Struve et al. 2010)

Peak continuum 4.41 Jy - optical depth HI absorption τ=0.8!

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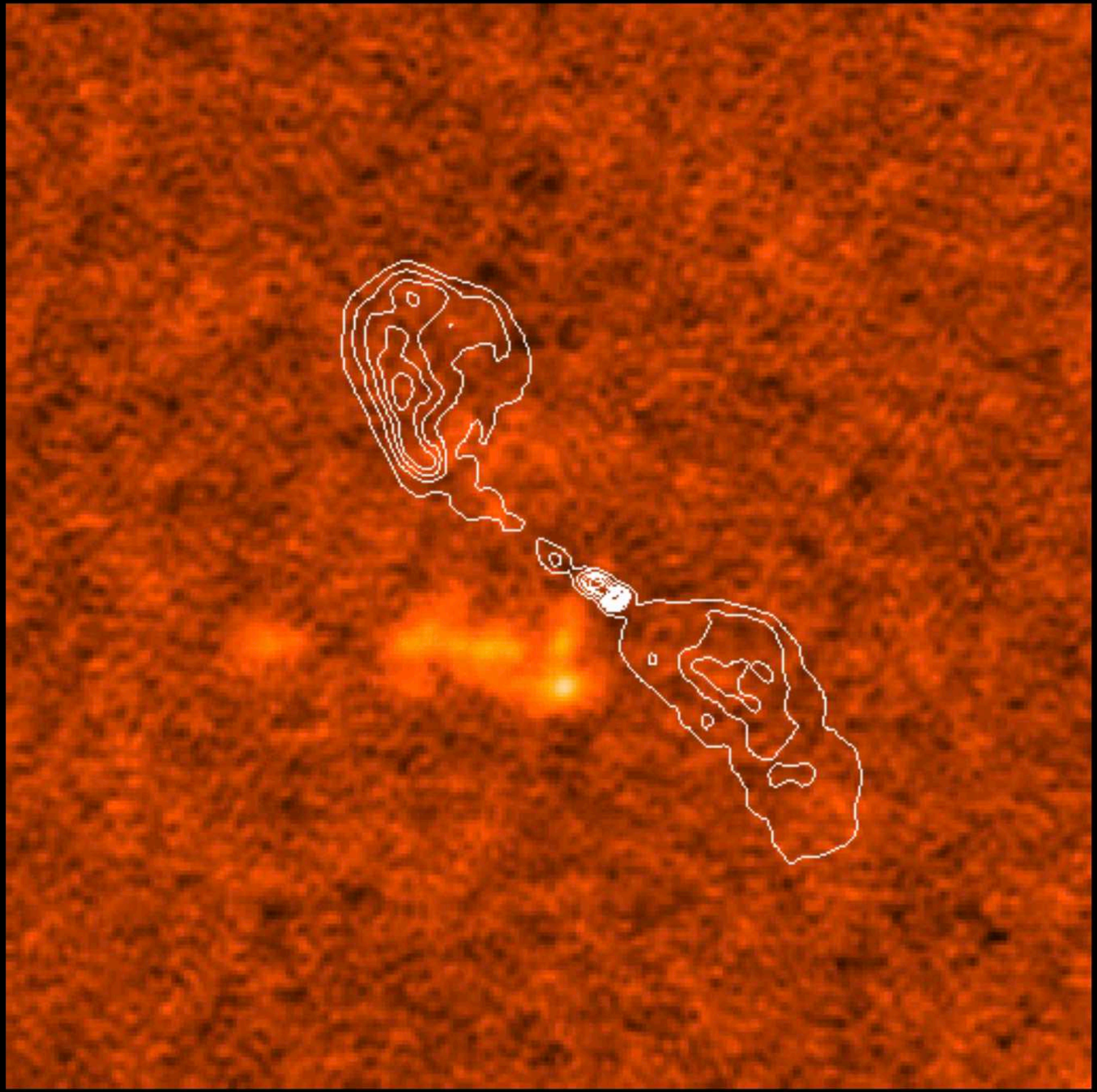

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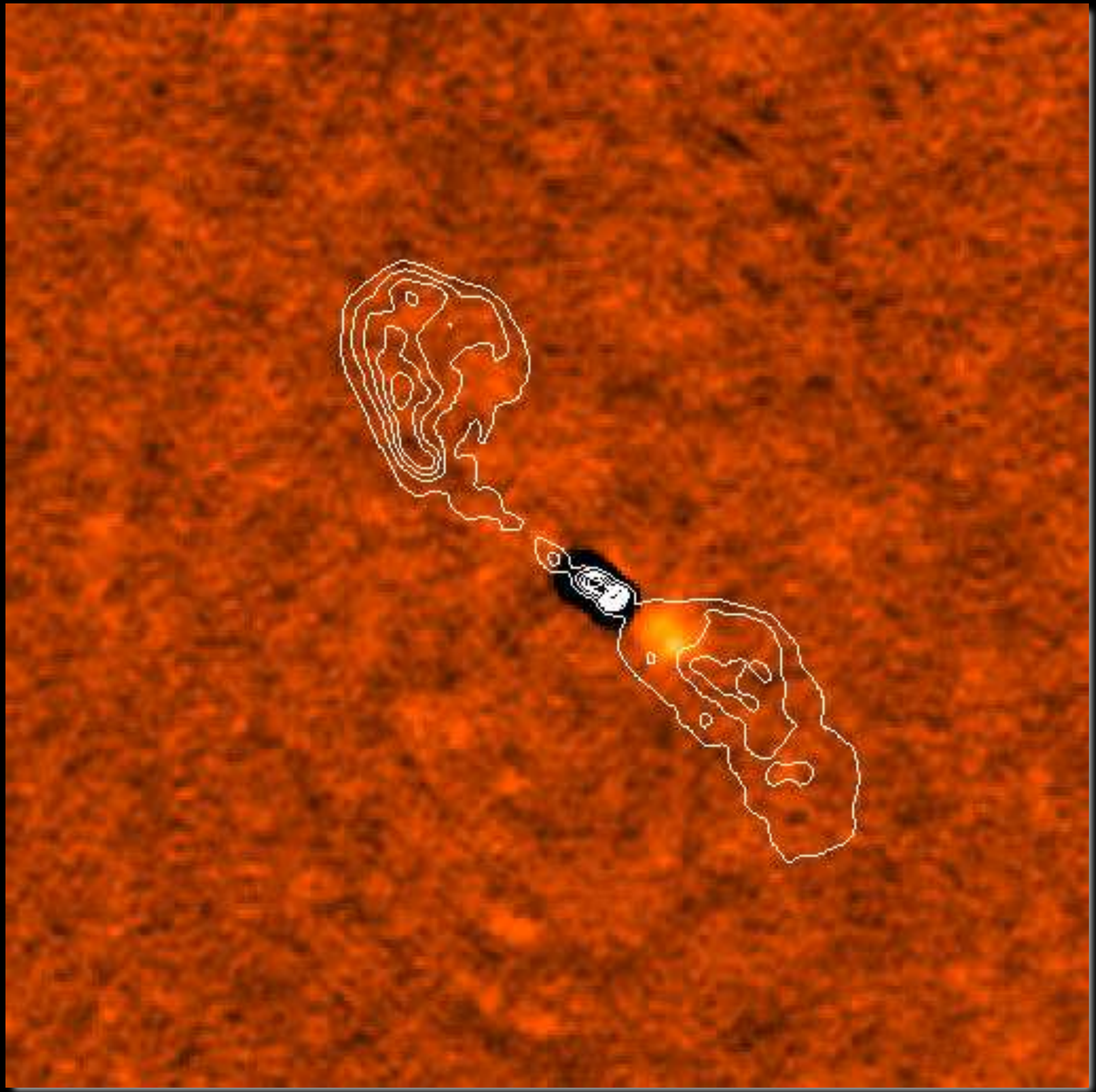

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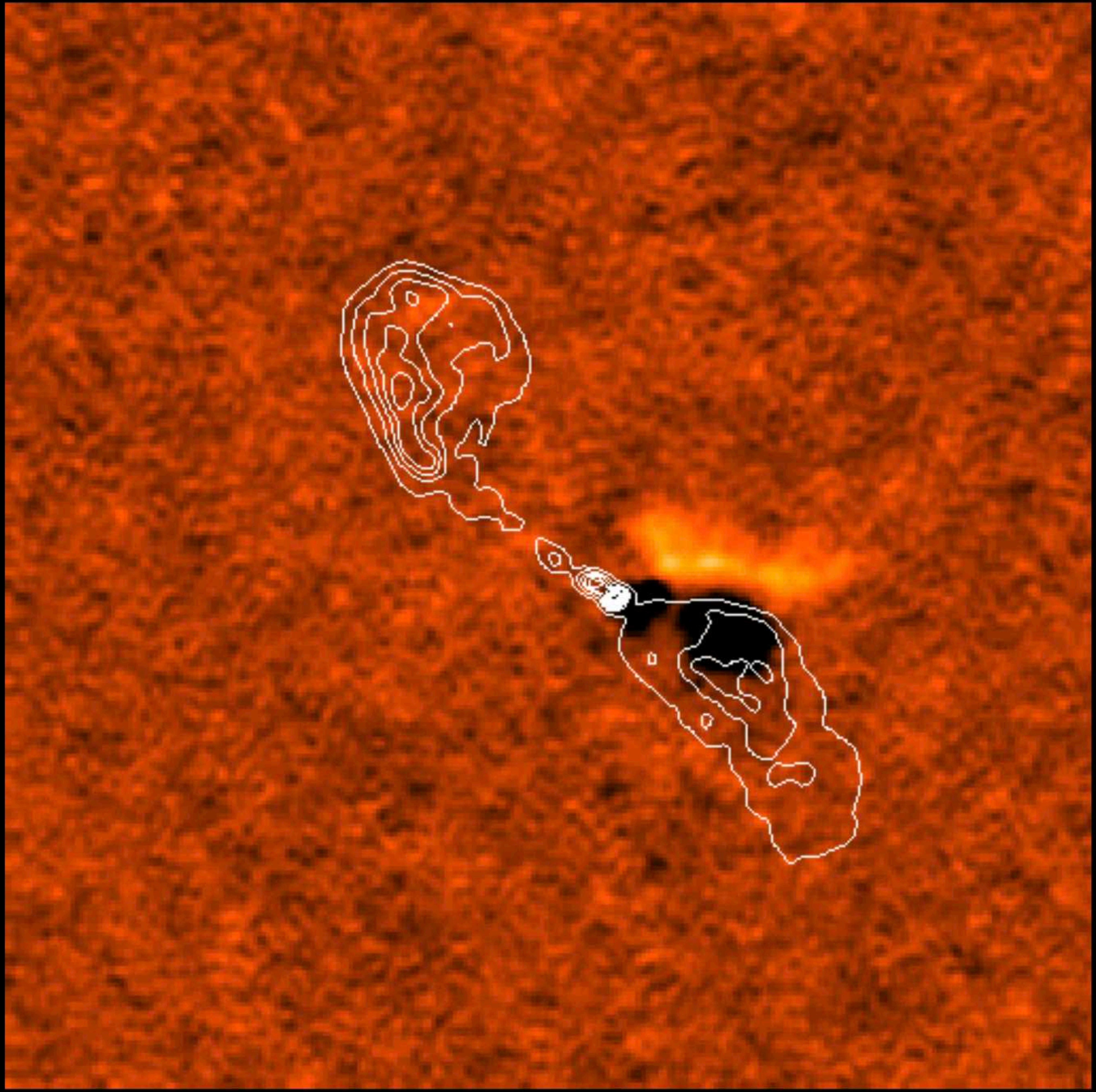

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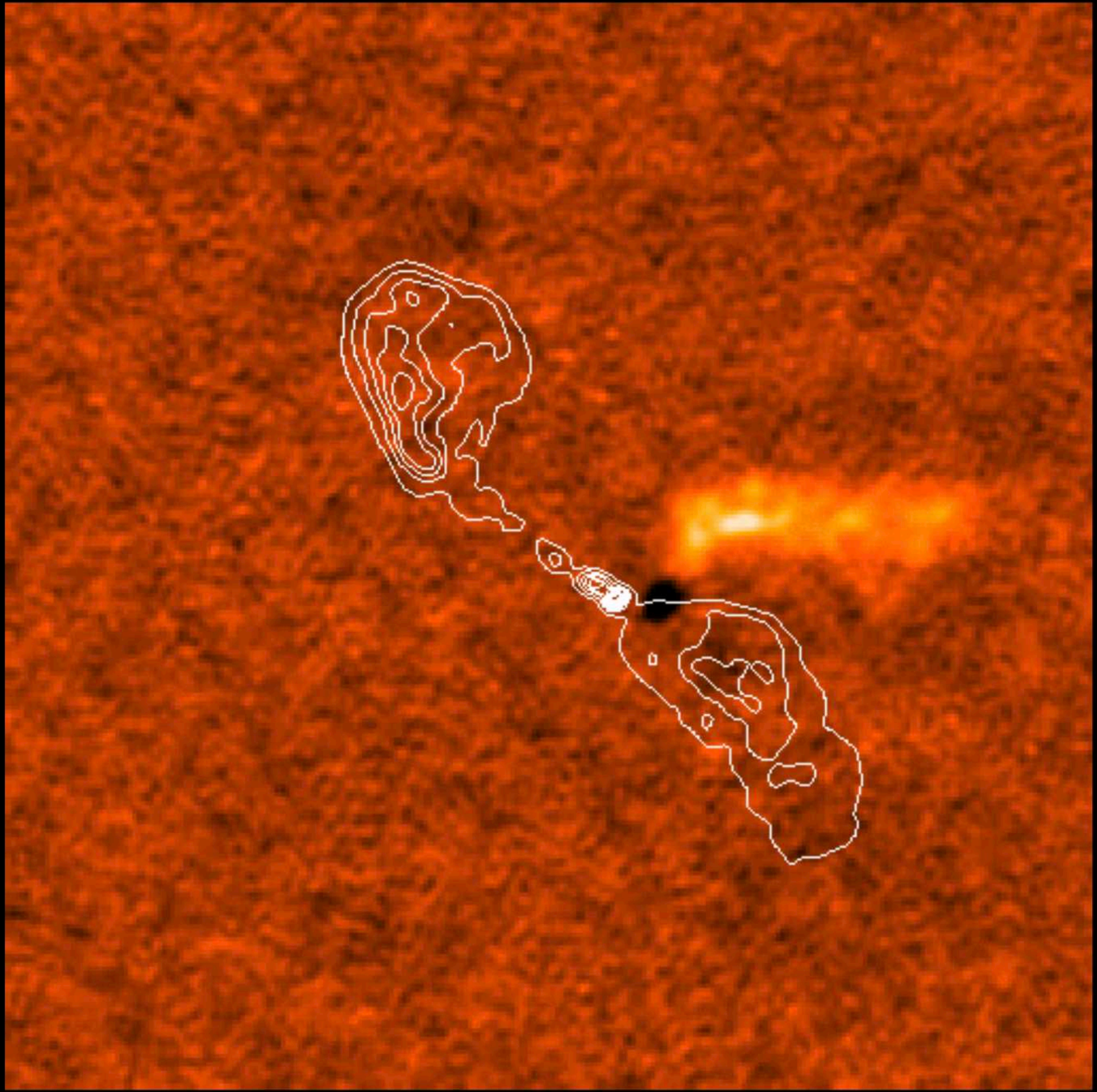

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Peak continuum 4.41 Jy - optical depth HI absorption $\tau=0.8$!

The last WSRT survey was an HI absorption survey!

A pilot sample to get a statistical view…

A shallow pilot survey with the WSRT

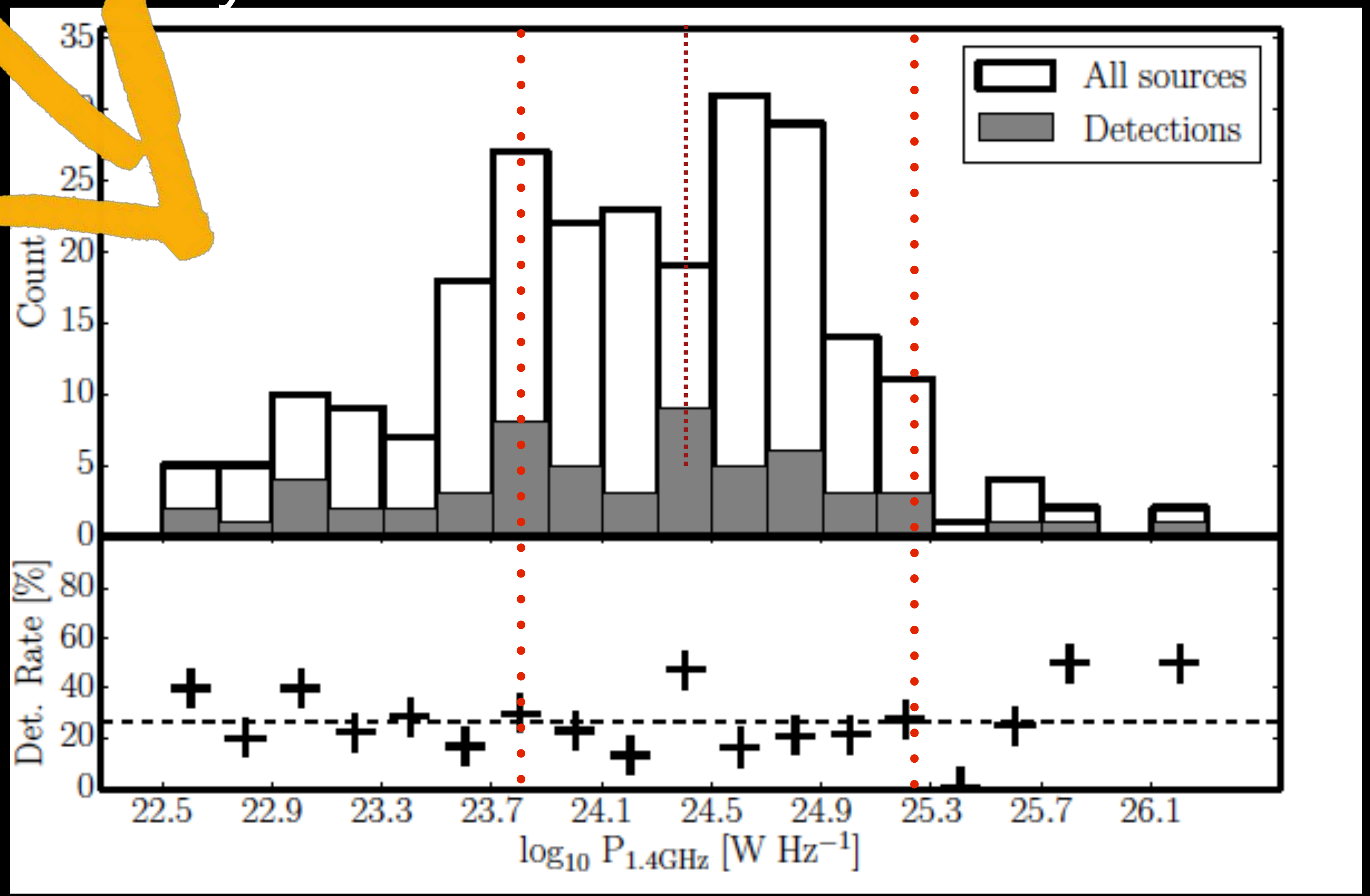
Gereb et al. 2014,2015, Maccagni et al. 2017

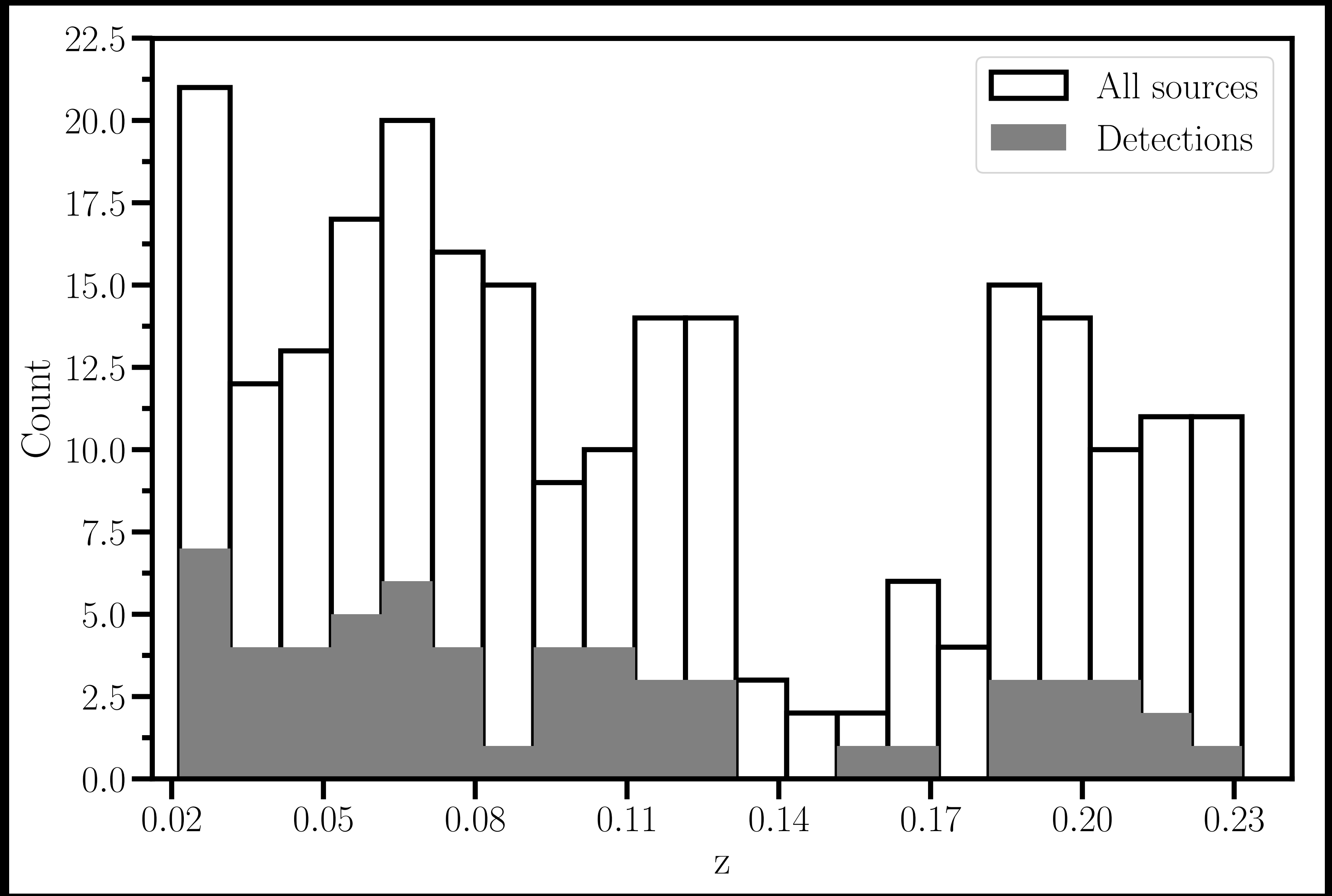
HI traced in absorption: a first uniform (but shallow) census
➜ 248 sources observed with the WSRT

Radio sources from crosscorrelation FIRST and SDSS $S_{1.4GHz}$ > 30mJy identified with z<0.26

66 Detections
27 % detection rate

range radio-quiet Seyferts *range FRI* *range FRII*



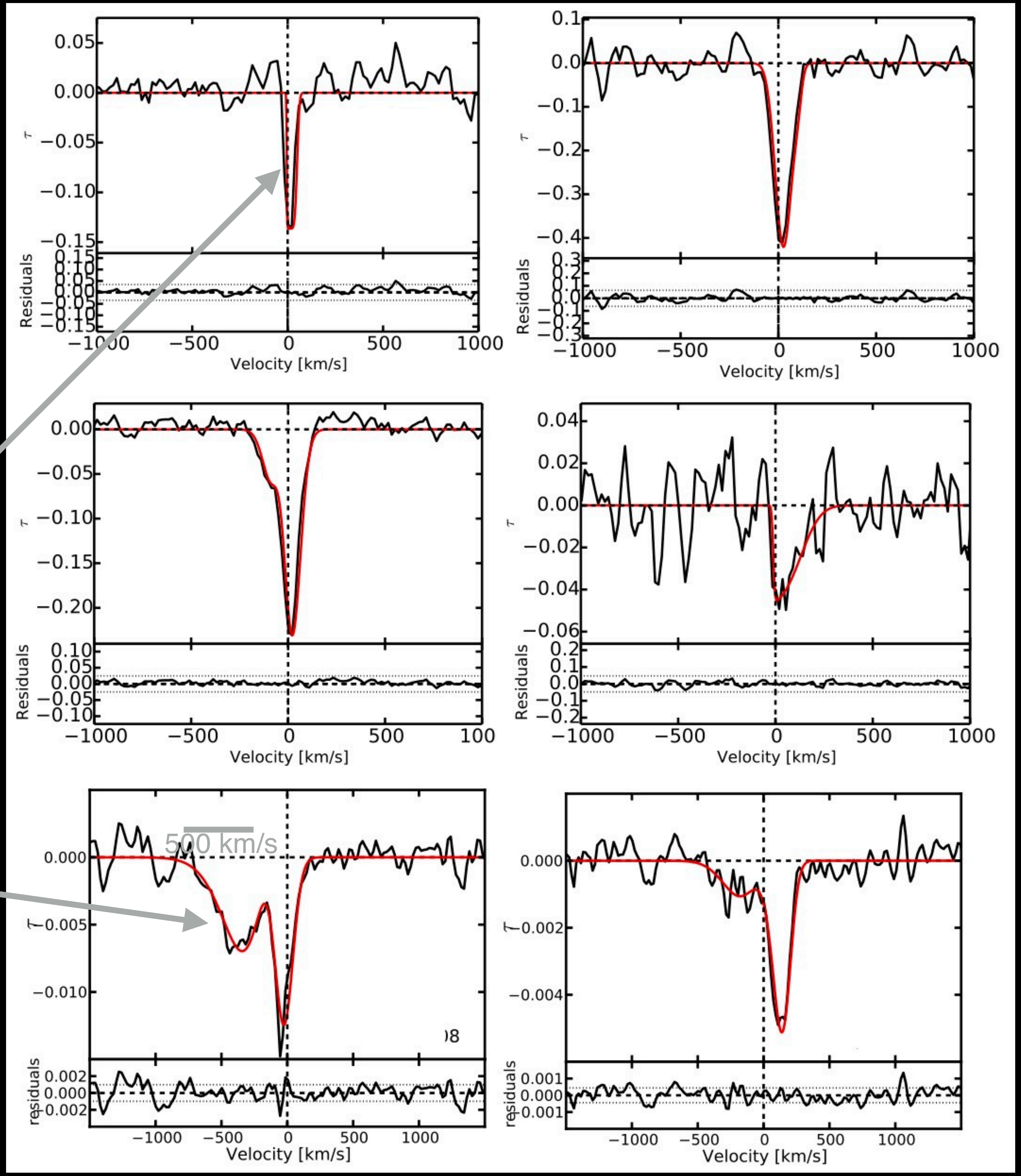


Variety of HI profiles

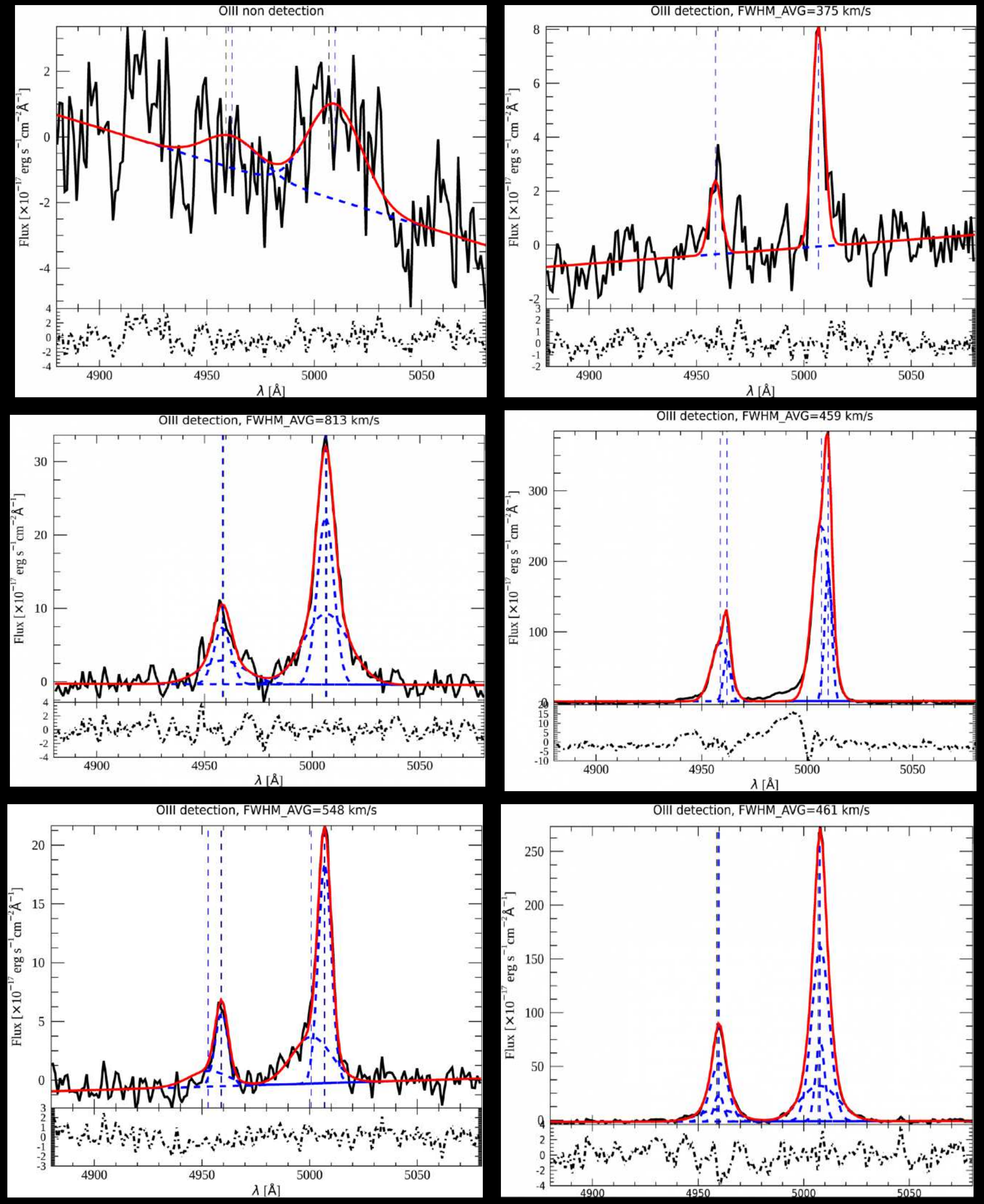
Examples of HI profiles

Narrow absorption:
likely due to regular disks

Broad absorption:
always blueshifted, likely due to outflows



[OIII] lines from SDSS spectra
(Santoro et al. in prep)

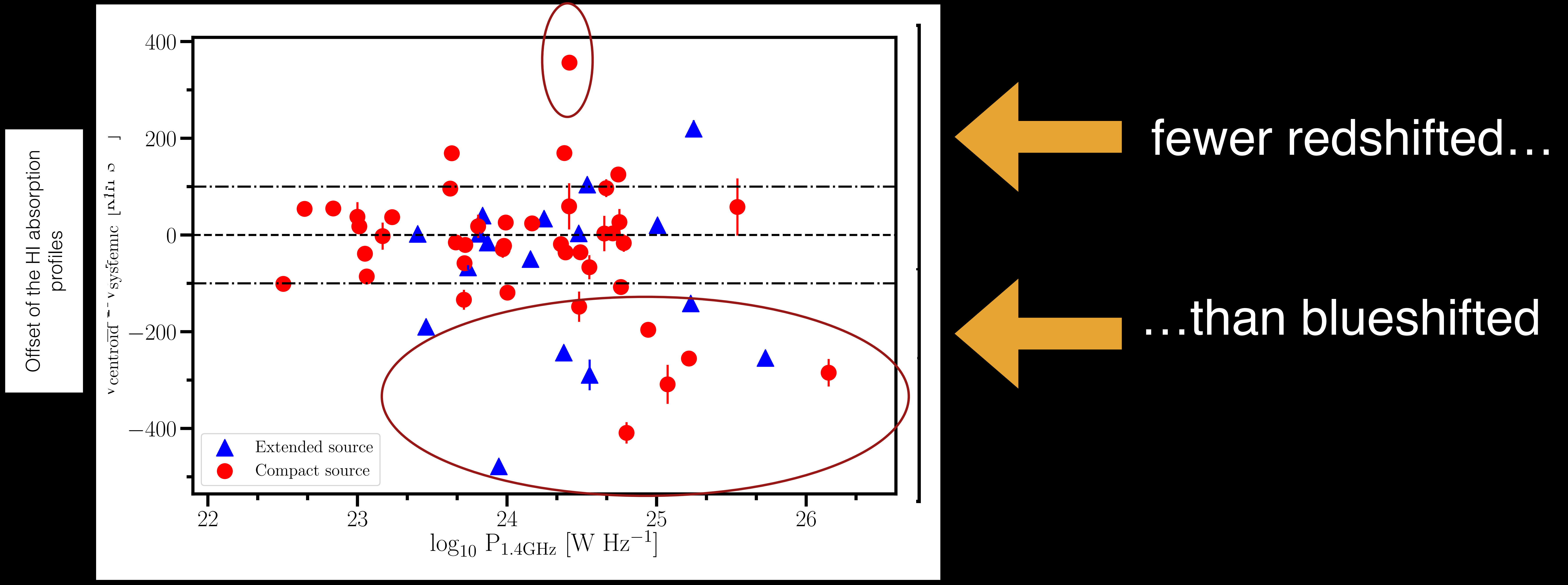


Variety of HI profiles

(Gereb et al. 2014,2015; Maccagni et al. 2017)

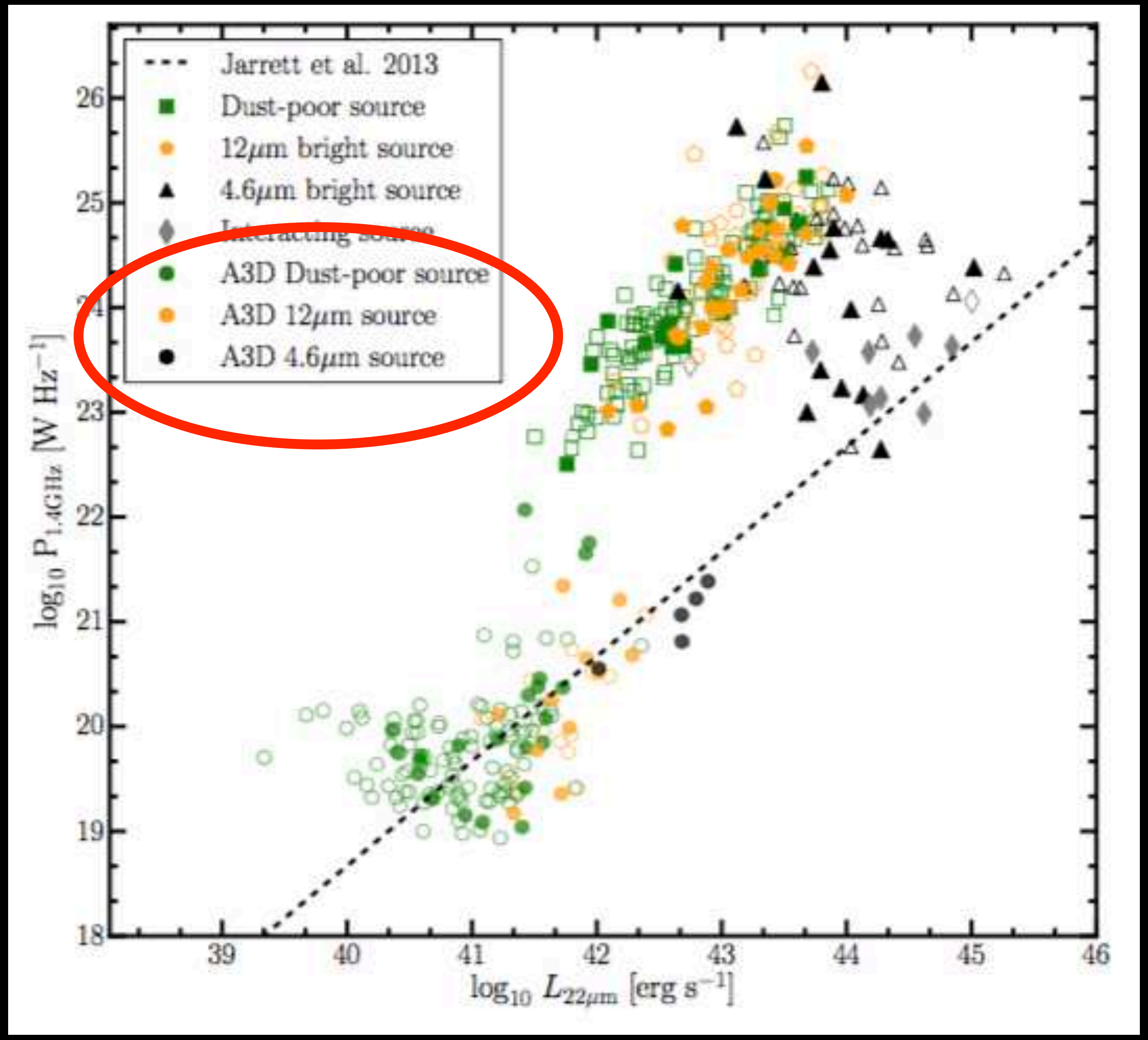
➔ the distribution and kinematics of the absorbing HI gas appear to depend on radio power, the properties of the radio continuum emission, and the dust content/farIR of the sources.

Powerful radio sources
(or strongly interacting systems)
have very broad HI absorption profiles
Dust-poor have narrow HI profiles



Amplitude larger for HI outflows than for infall

Putting this into perspective…



HI detections (filled symbols)

HI non-detections (empty symbols)

Radio galaxies ➜ early type galaxies (and mergers)

Comparison to the ATLAS3D sample ➜ detection HI absorption in ATLAS3D ~20% (for lower radio power <$10^{22.5}$ W/Hz)

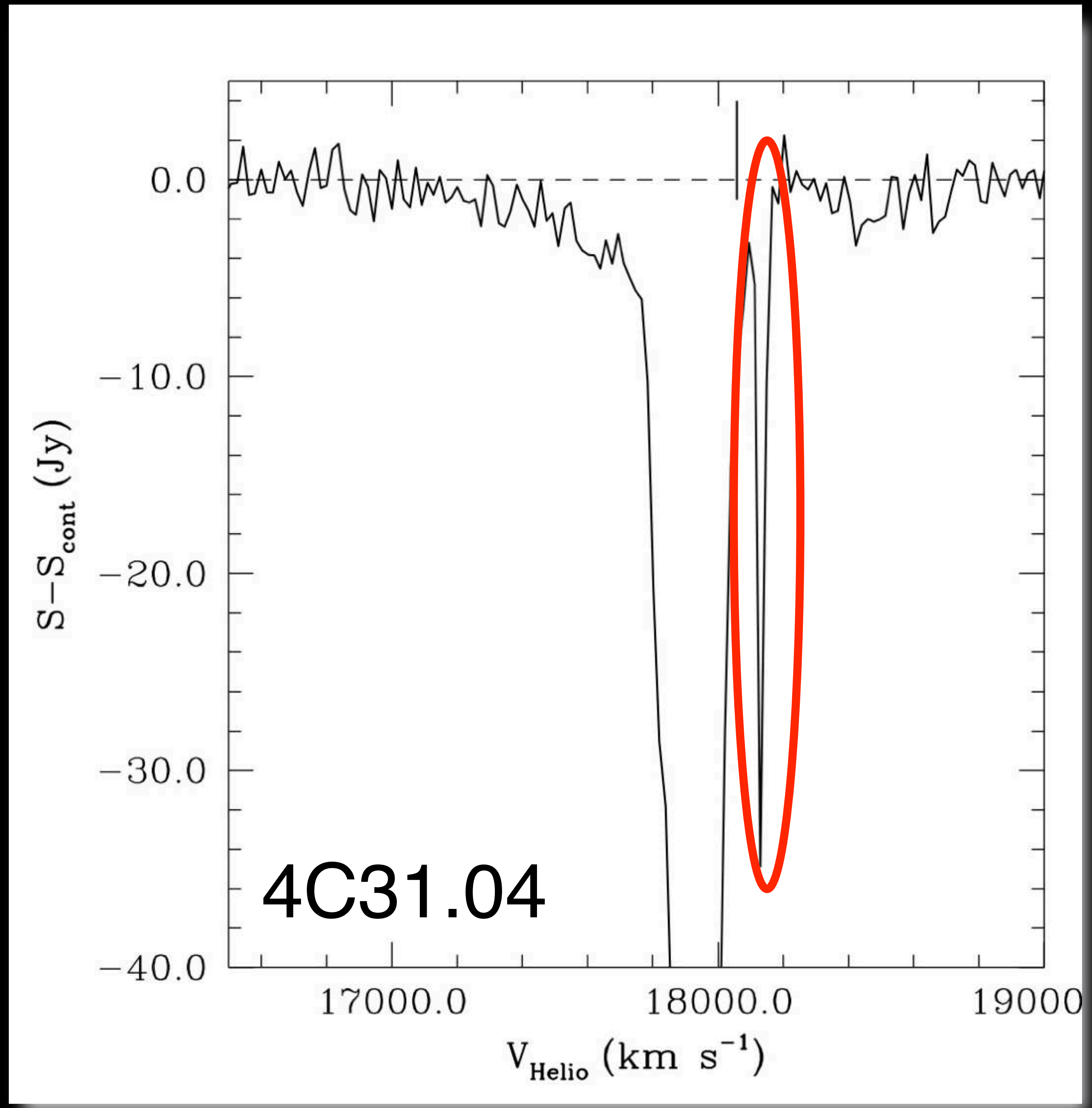
all narrow HI absorption profiles (<100 km/s)

Not the most exciting results of ATLAS3D, but suggests that to first order HI absorption could be used to trace presence of gas in the host galaxy: can we use it for at high redshift?

HI for the feeding of the AGN

How to identify infalling HI gas?

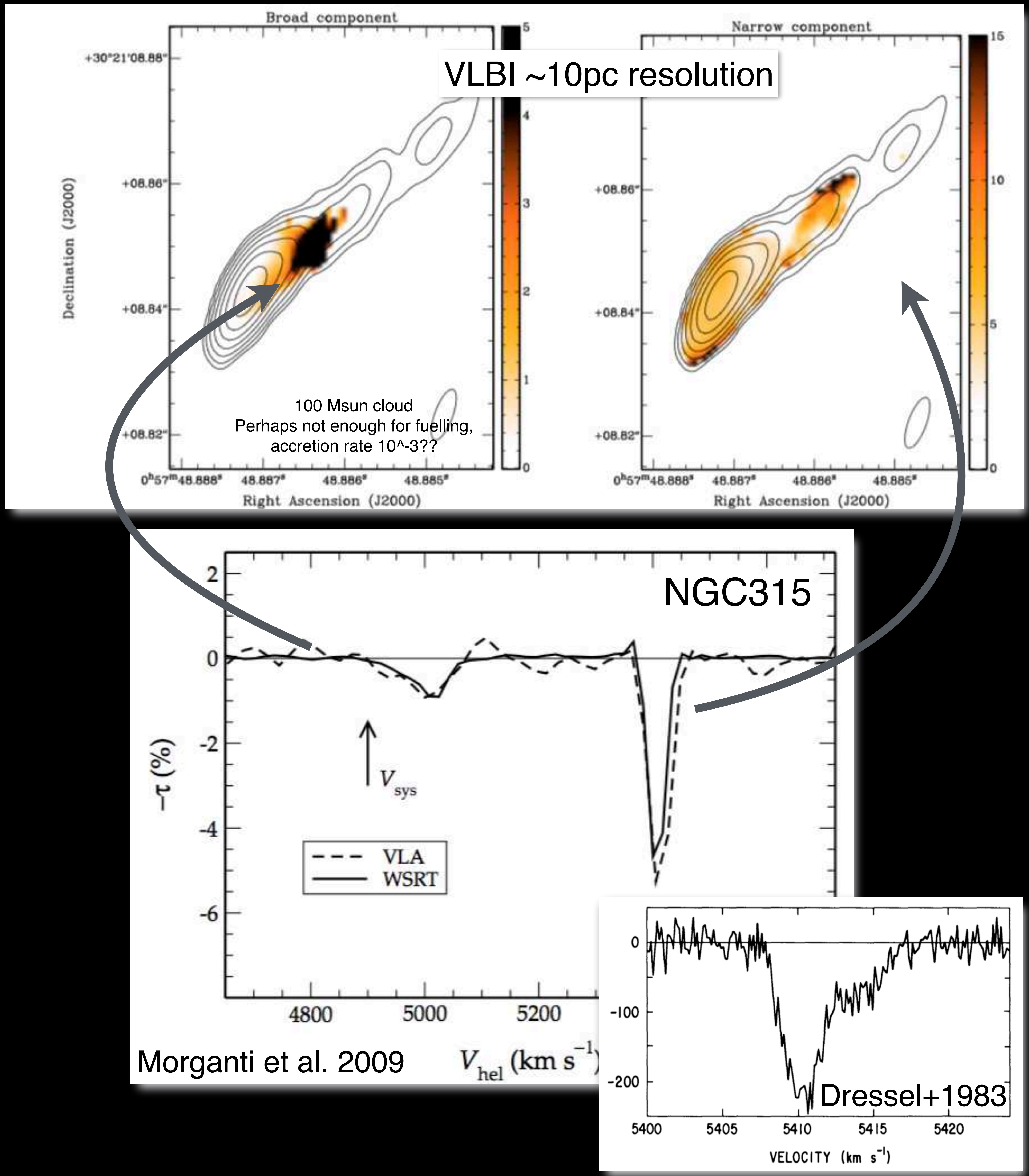
Difficult to disentangle from regularly rotating gas



From VLBI (Struve & Conway 2012)

Most of the narrow absorption component is detected against the northwestern lobe, but absorption at the same velocity is also observed against the southeastern lobe structure.

Gas likely >100 pc from nucleus



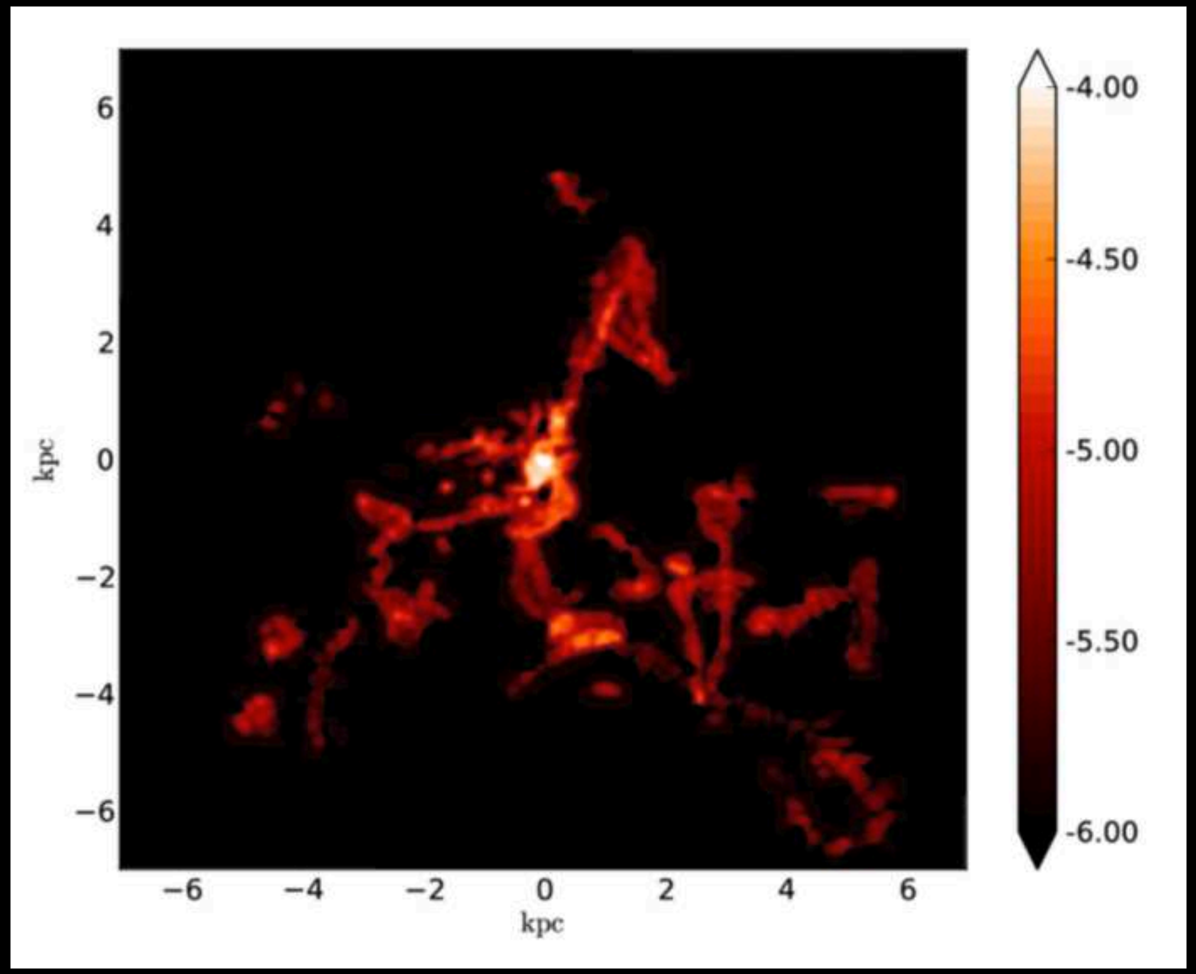
Synergy with molecular gas

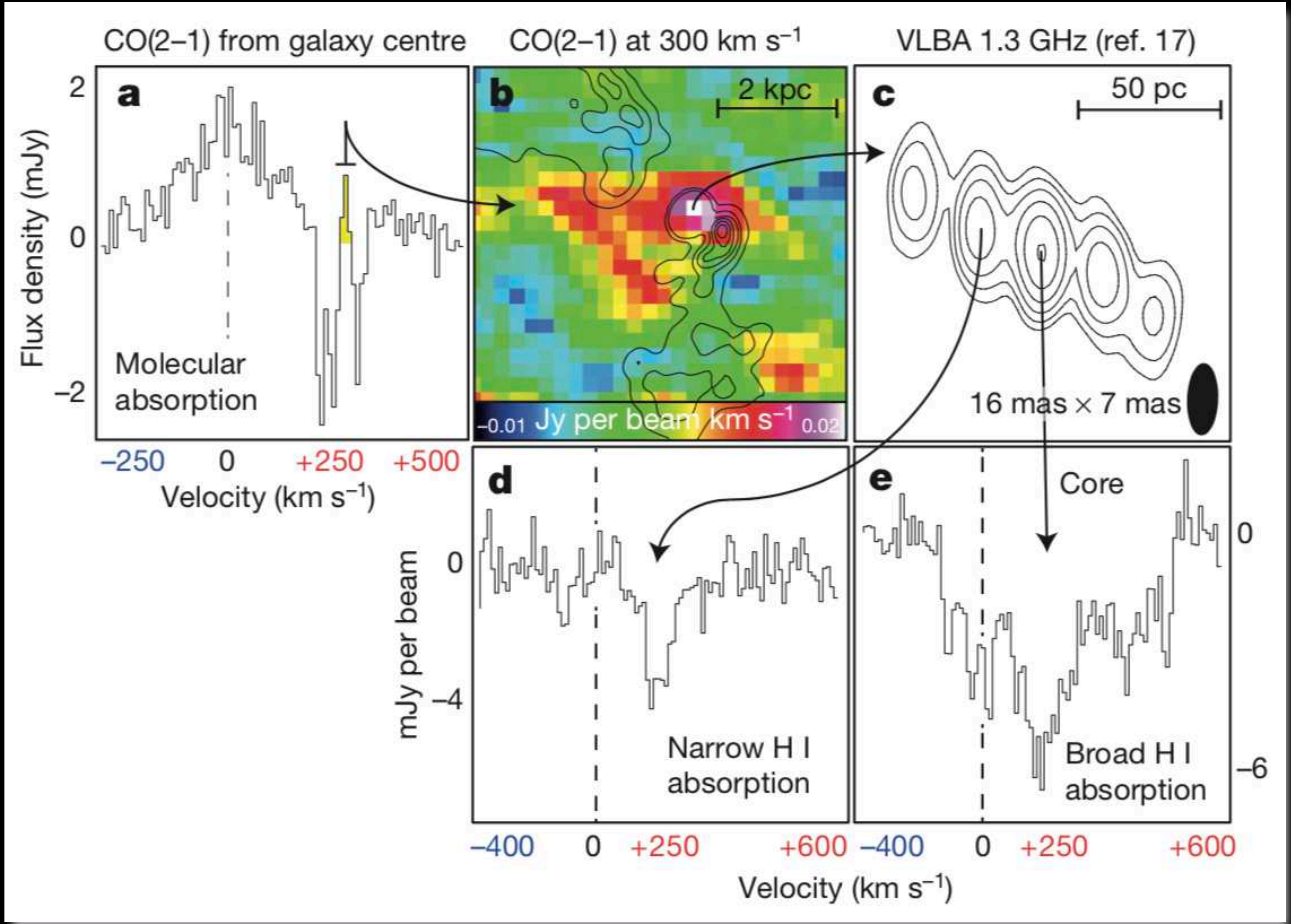
ALMA data (Tremblay et al. Nature 2016) and VLBI HI absorption (O'Dea et al.)

Mass of the clouds of molecular gas 10^5–10^6 $M_\odot$

Enough mass accretion rate to fuel the AGN.

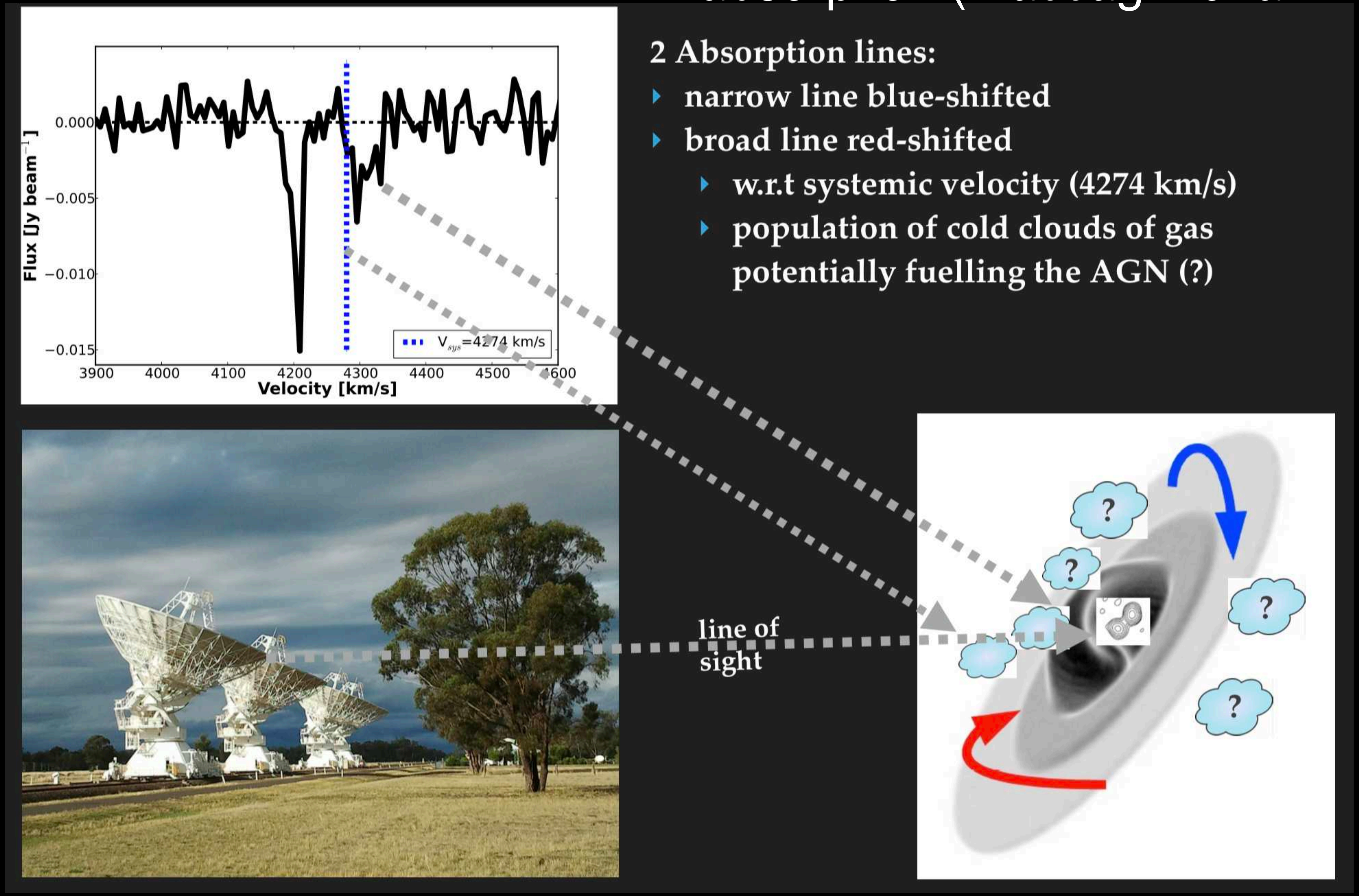
Chaotic cold accretion possible mechanism to fuel the AGN (Gaspari et al. 2017)



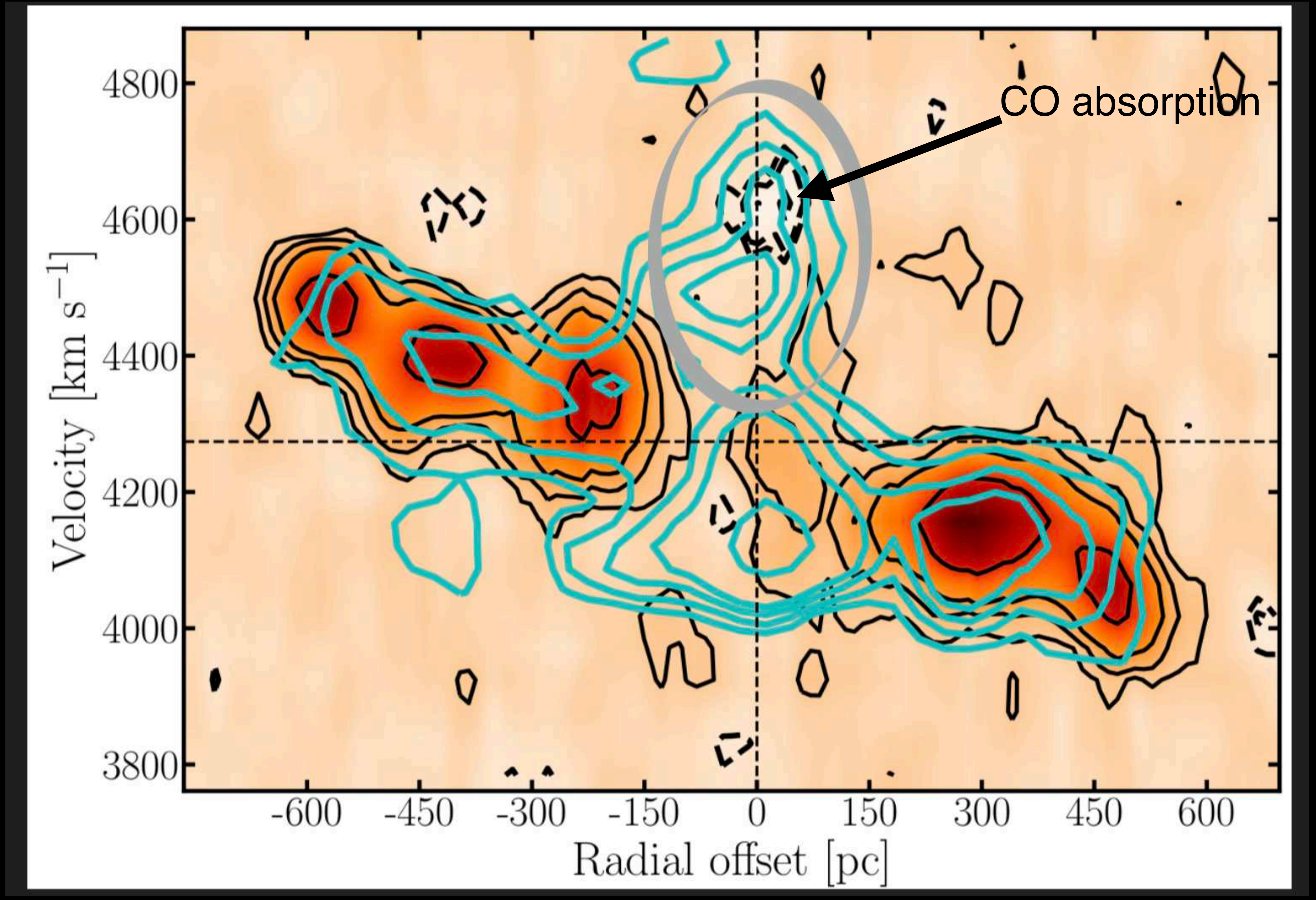


Synergy with molecular gas

HI absorption (Maccagni et al. 2014)



Sinfoni (H2), ALMA CO(2-1)
Maccagni et al. 2017



Mass of the clouds of molecular gas 3 × 10^2 M⊙ – 5 × 10^5 M⊙

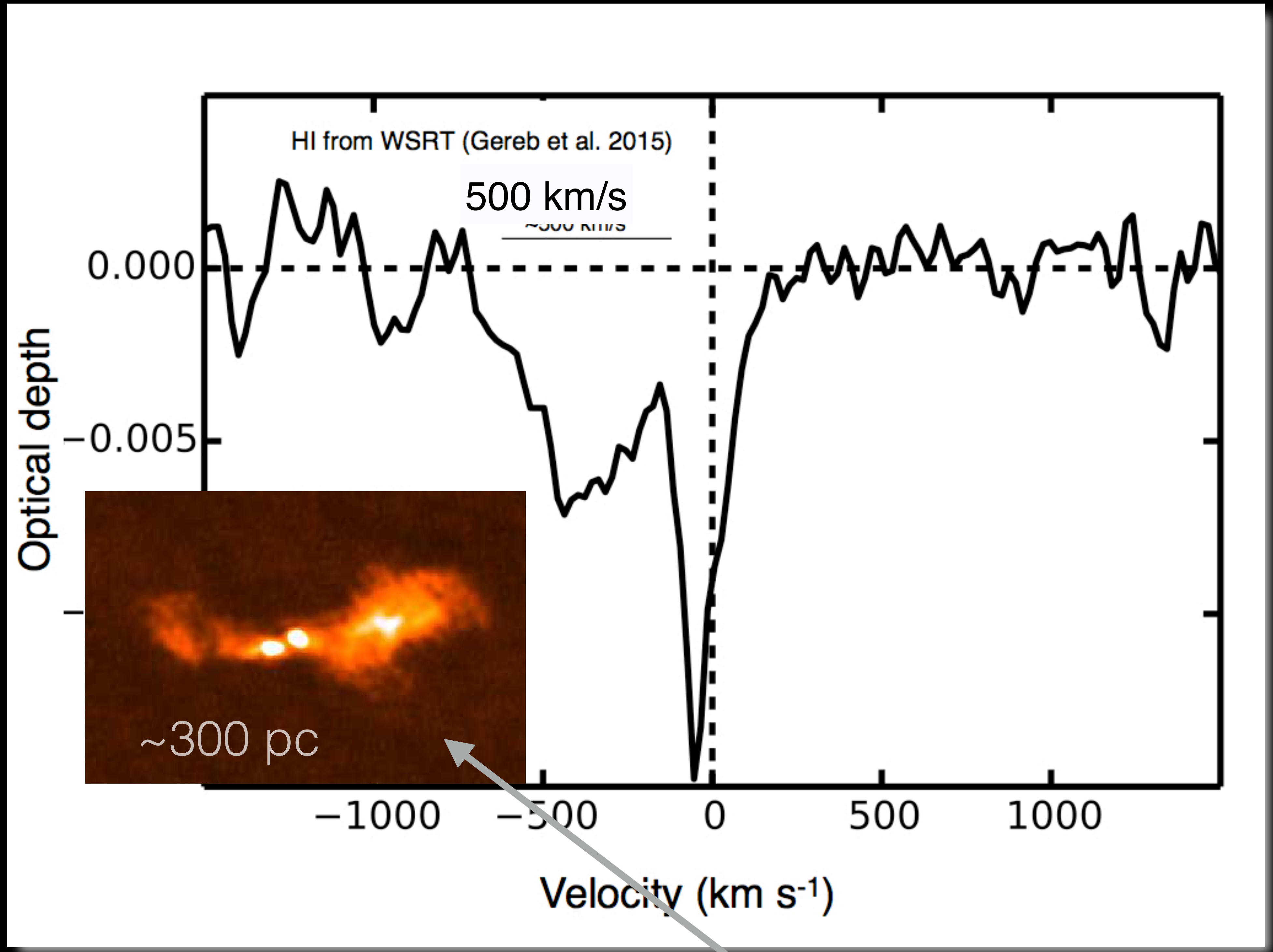
Enough mass accretion rate to fuel the AGN (but very uncertain)

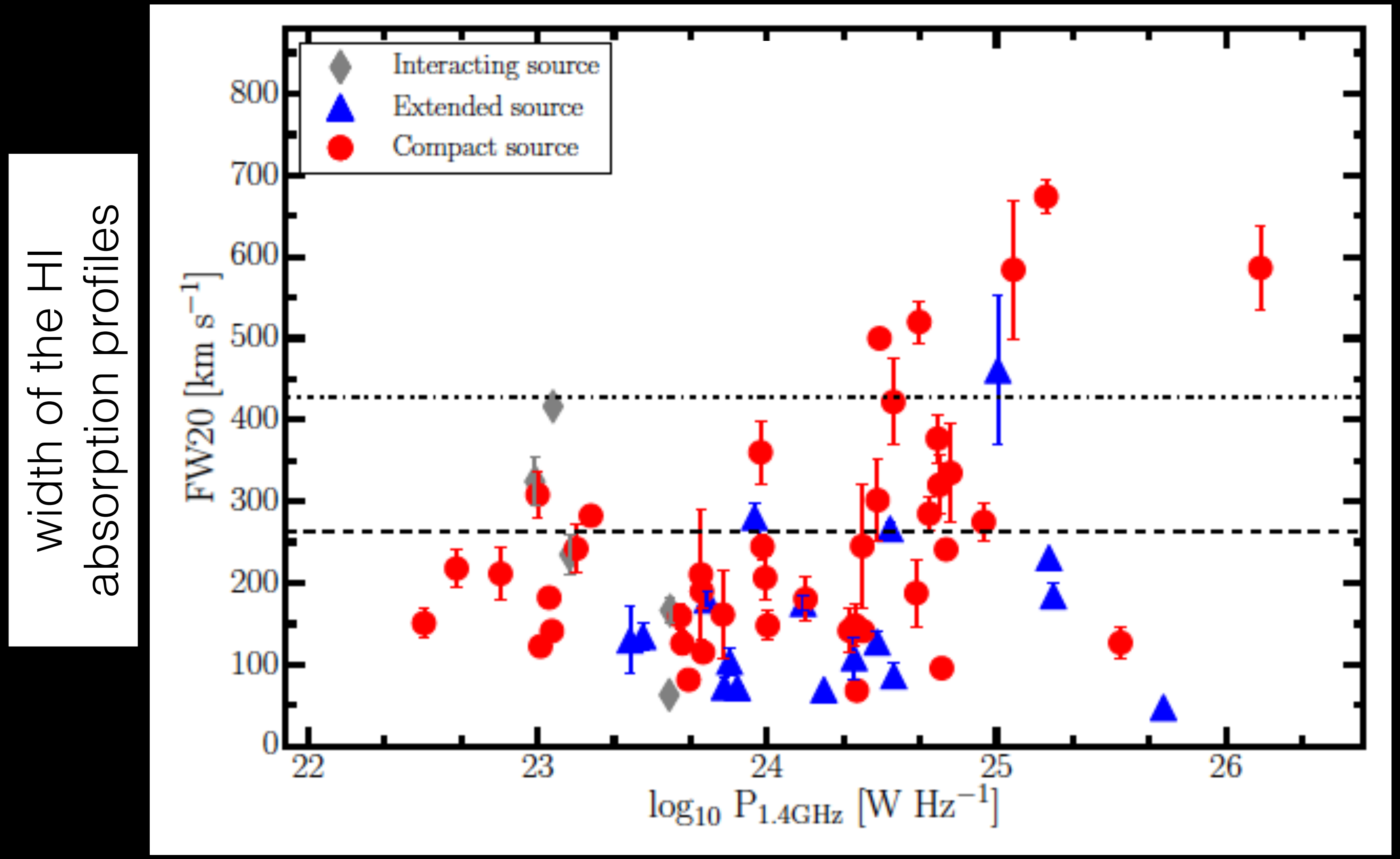
Also here chaotic cold accretion is a possible mechanism to fuel the AGN

Outflowing HI and relevance for feedback

Occurrence of HI outflows

Gereb et al. 2015, Maccagni et al. 2017





at least 5% of the all sources (15% of HI detections) show HI outflow (500-1000 km/s)

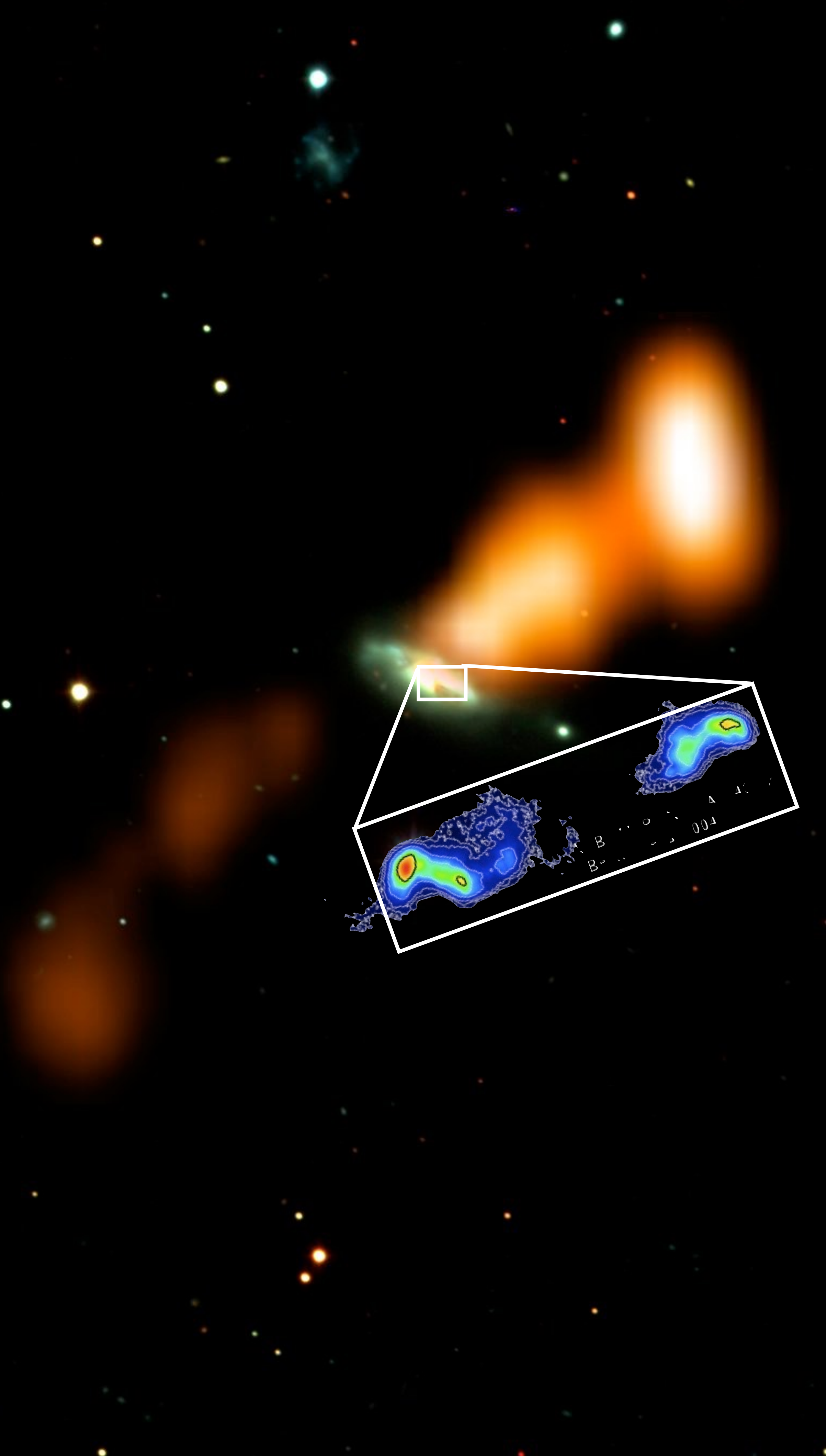
higher detection rate for young (and restarted) radio galaxies and trend with radio power

(consistent with results from the ionised gas, e.g. Holt et al. 2008)

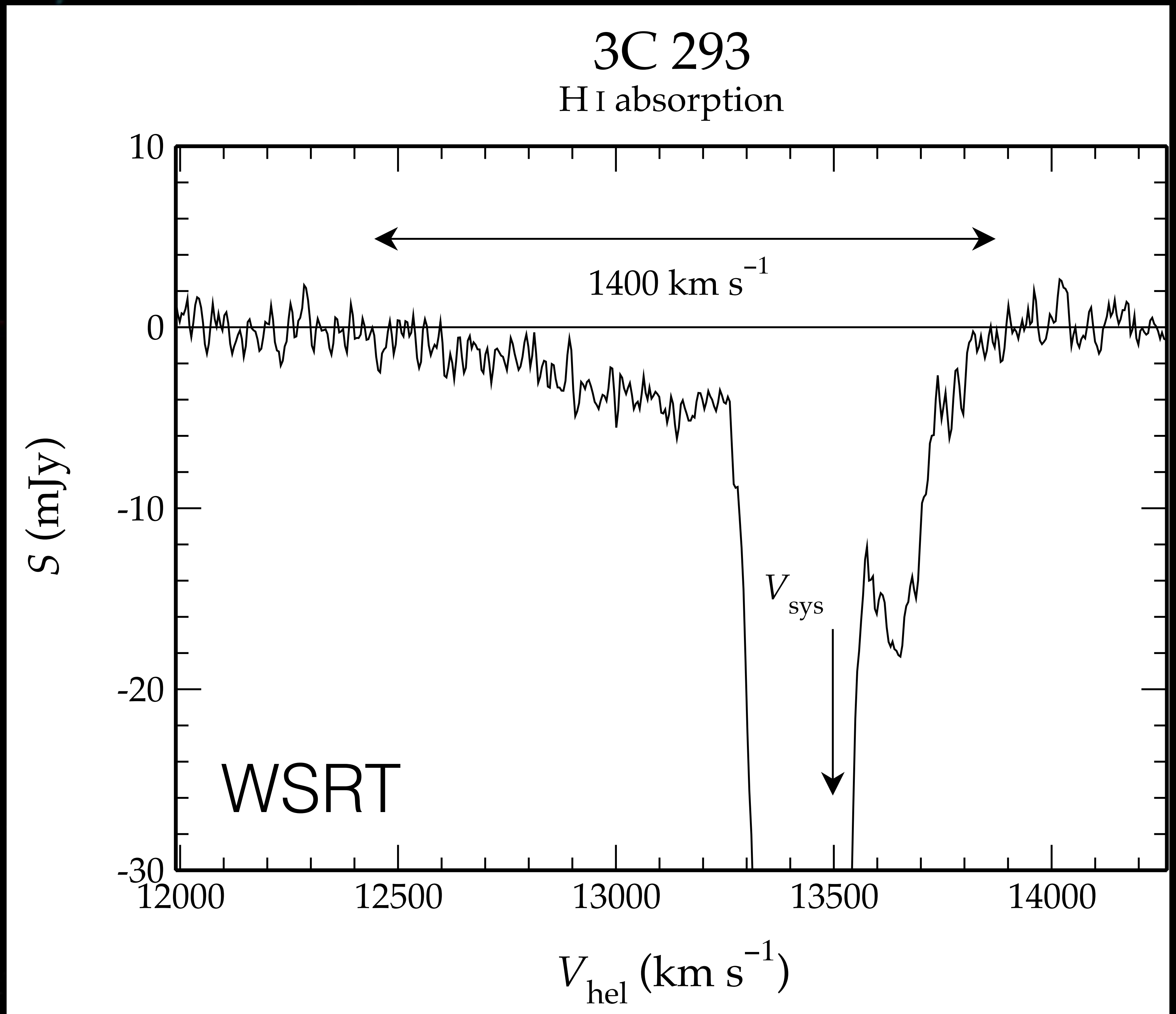
Small sub-kpc size and steep, peaked spectrum

Suggest a role for the radio jet
Efficient cooling of the gas after being shocked

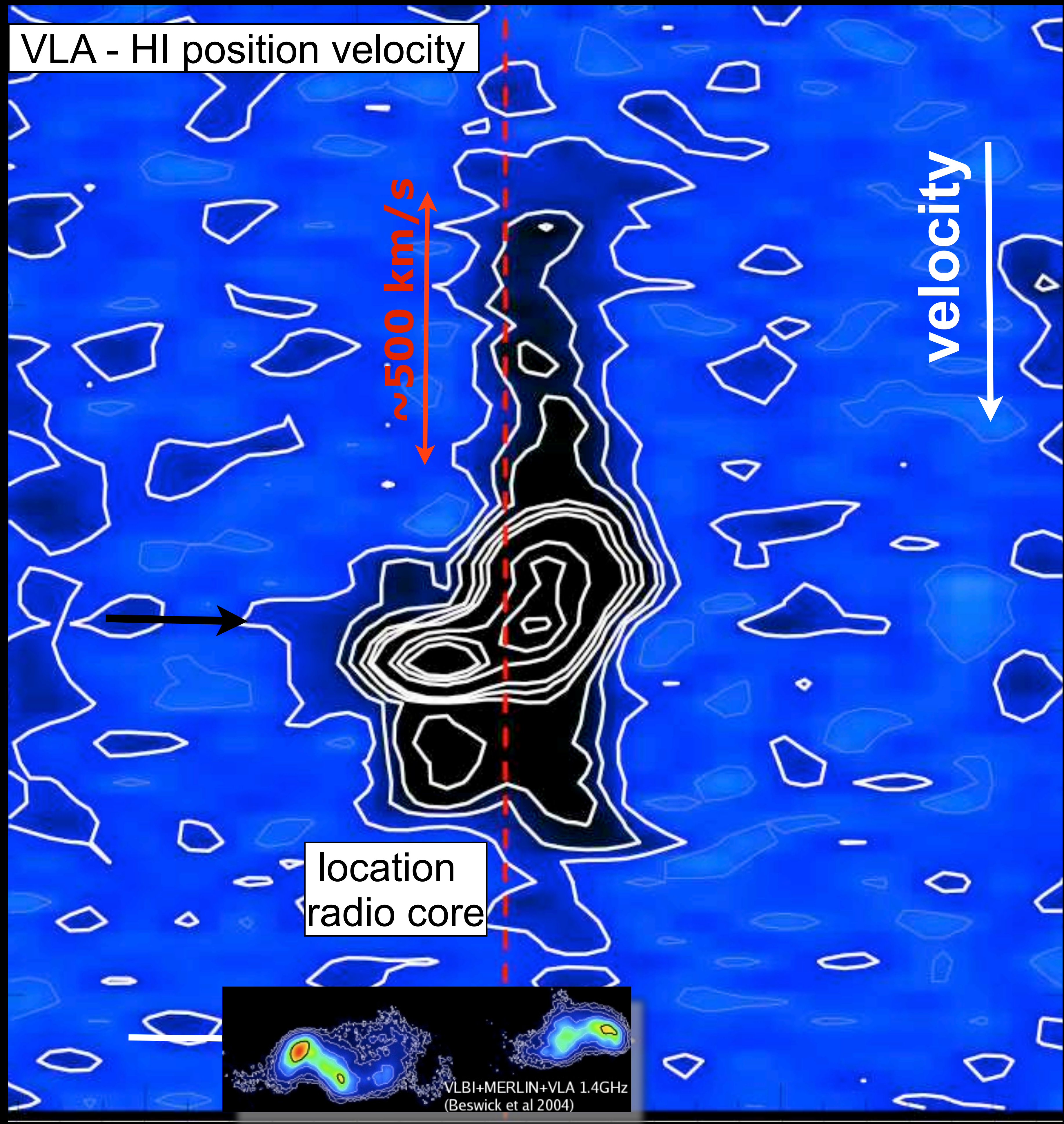
Spatially resolving the HI outflow: the case of 3C293



Morganti, Oosterloo, Emonts, van der Hulst et al. 2003



Mahony et al. MNRAS 435, L58



HI mass in the outflows from a few x10^6 to 10^7 $M_\odot$; **mass outflow rates** up to 20-50 $M_\odot$/yr

For HI outflows $\dot{E}_{kin}/L_{edd}$ ~10^{-4} (few x 10^{-3} bolometric luminosity)

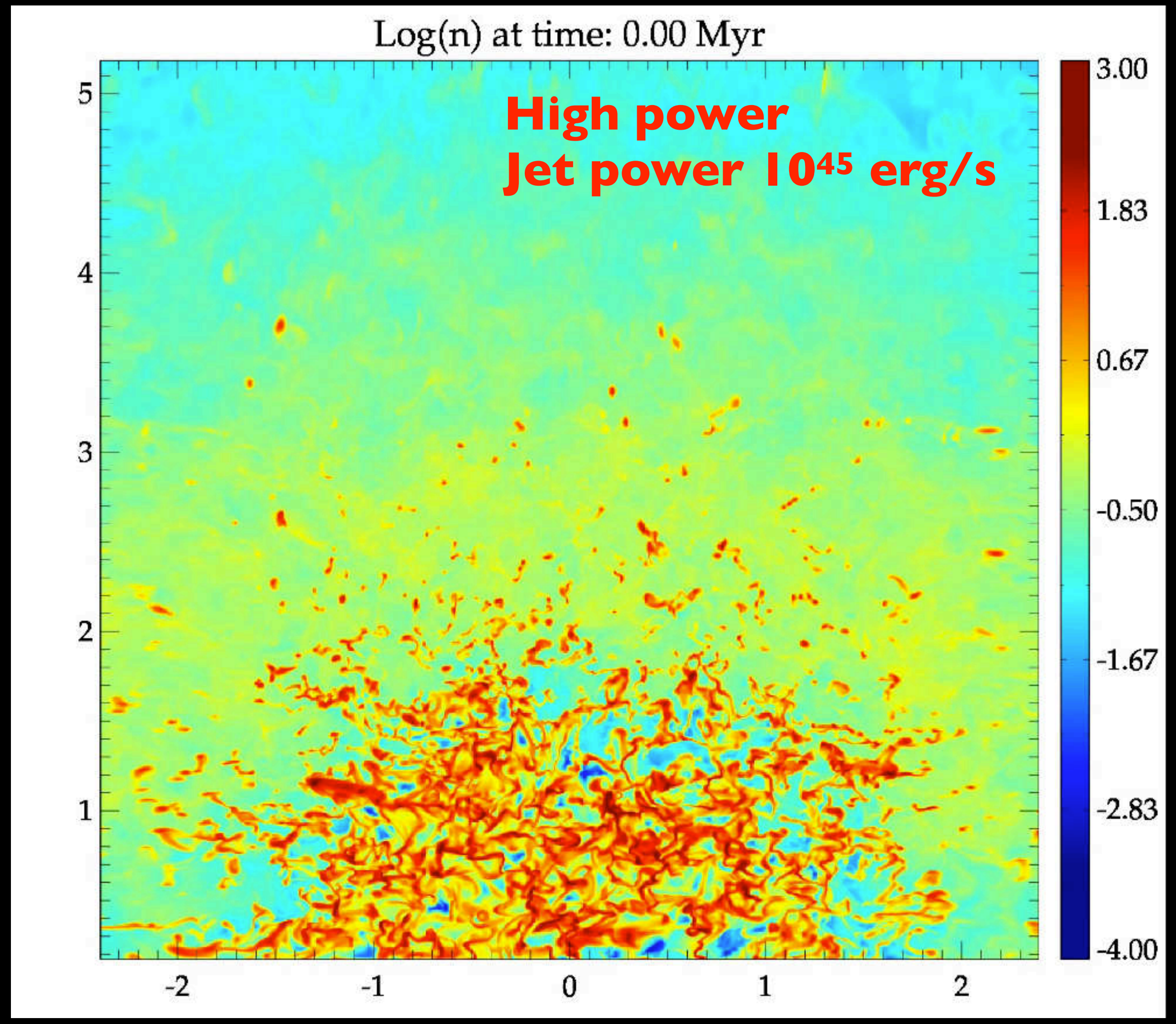
Can the jet drive the outflows?

from Wagner & Bicknell 2011, 2012, Mukherjee, Bicknell et al. 2016, 2017, 2018

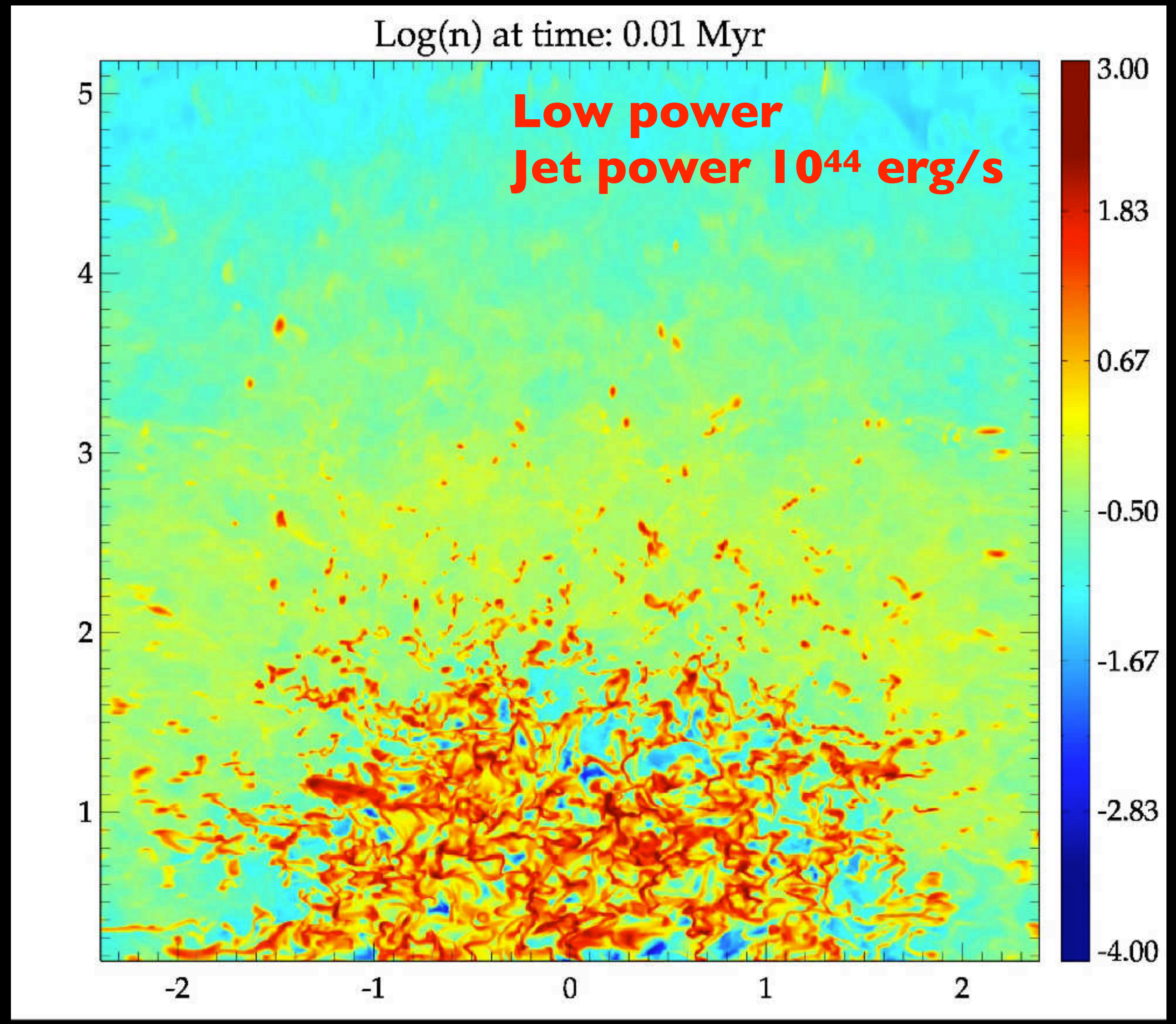
Numerical simulations of a newly created radio jet

- 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).
- A newly created jet (or restarted) jet has the largest impact
- Effect depends on **jet power: low power jets are important!** Couple more with the ISM, will induce more turbulence and they are more numerous!

  Change in balance outflows vs turbulence?
- **Fast multiphase outflows** but not always enough to escape.
- Orientation jet expansion wrt gas distribution



clumpy medium (spherical distribution), different jet power



See also talk Suma Murthy

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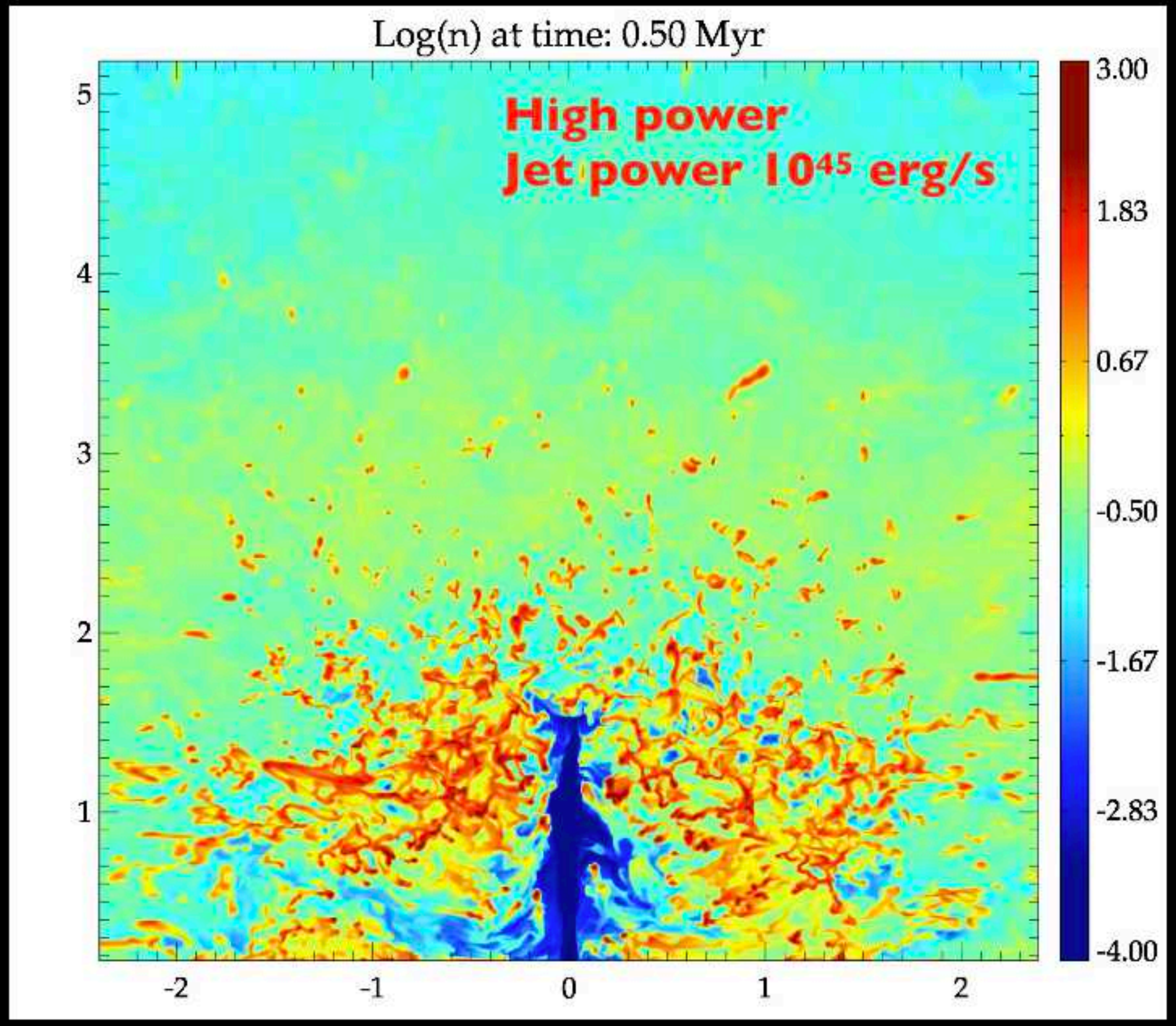

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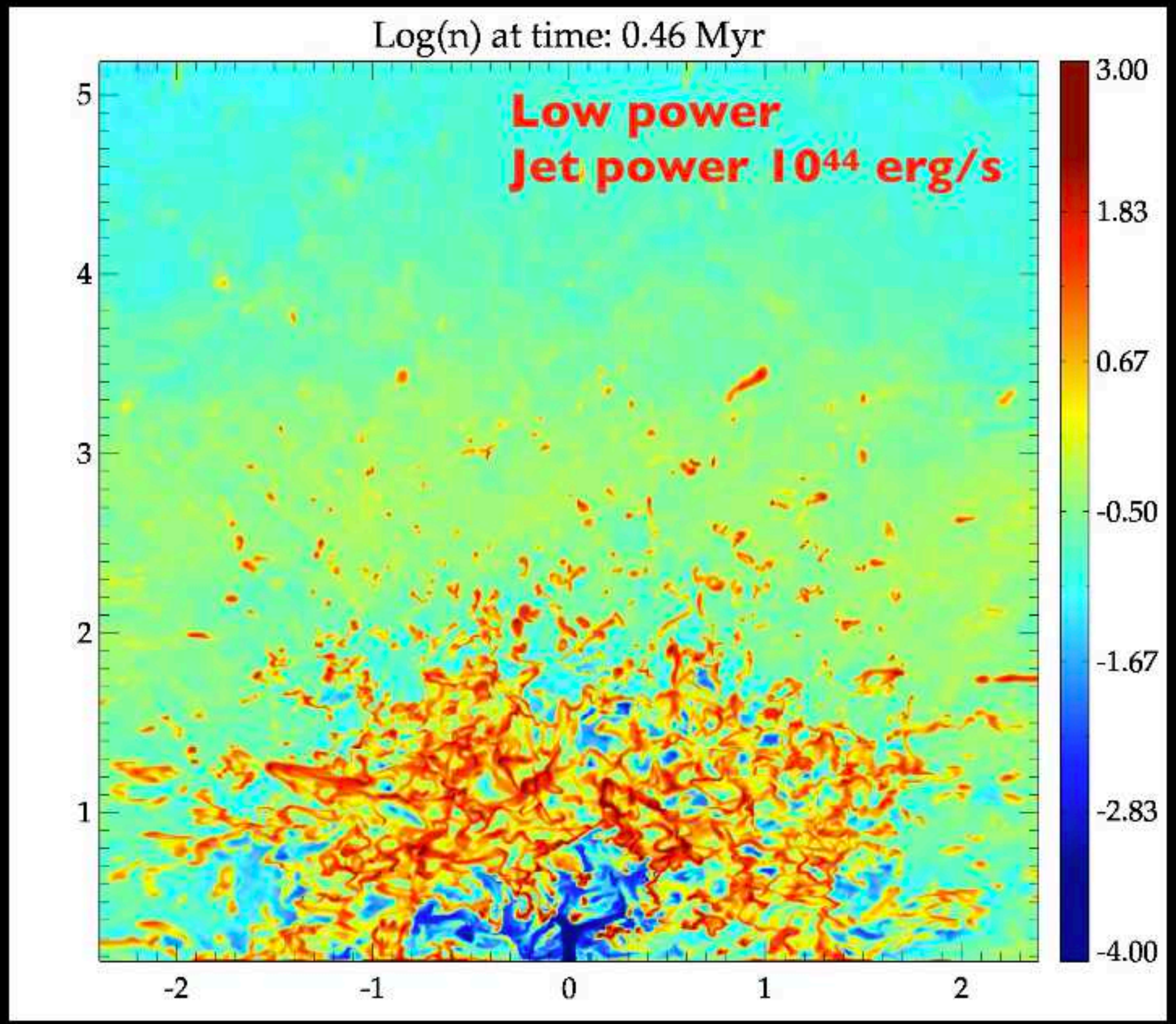

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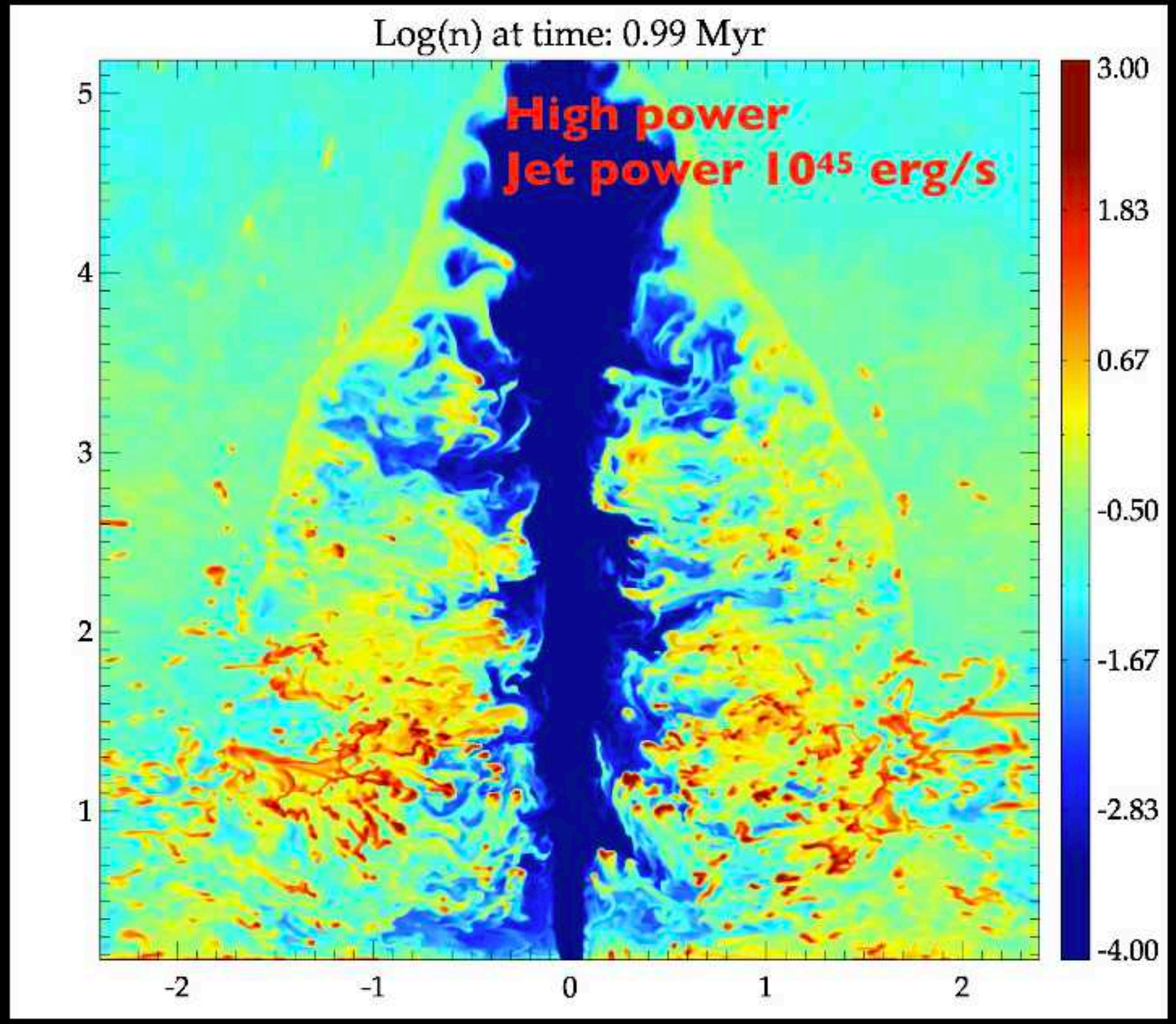

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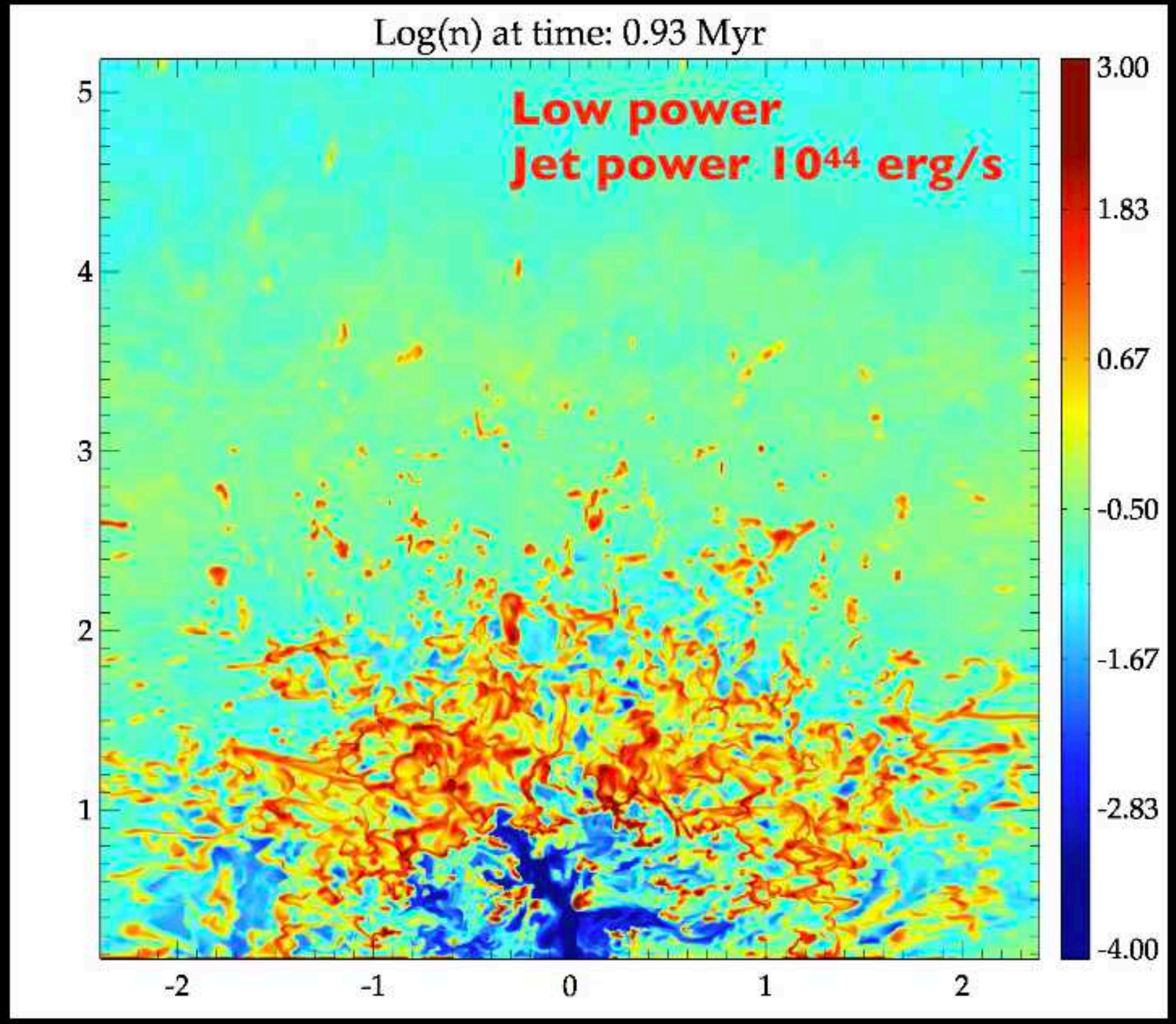

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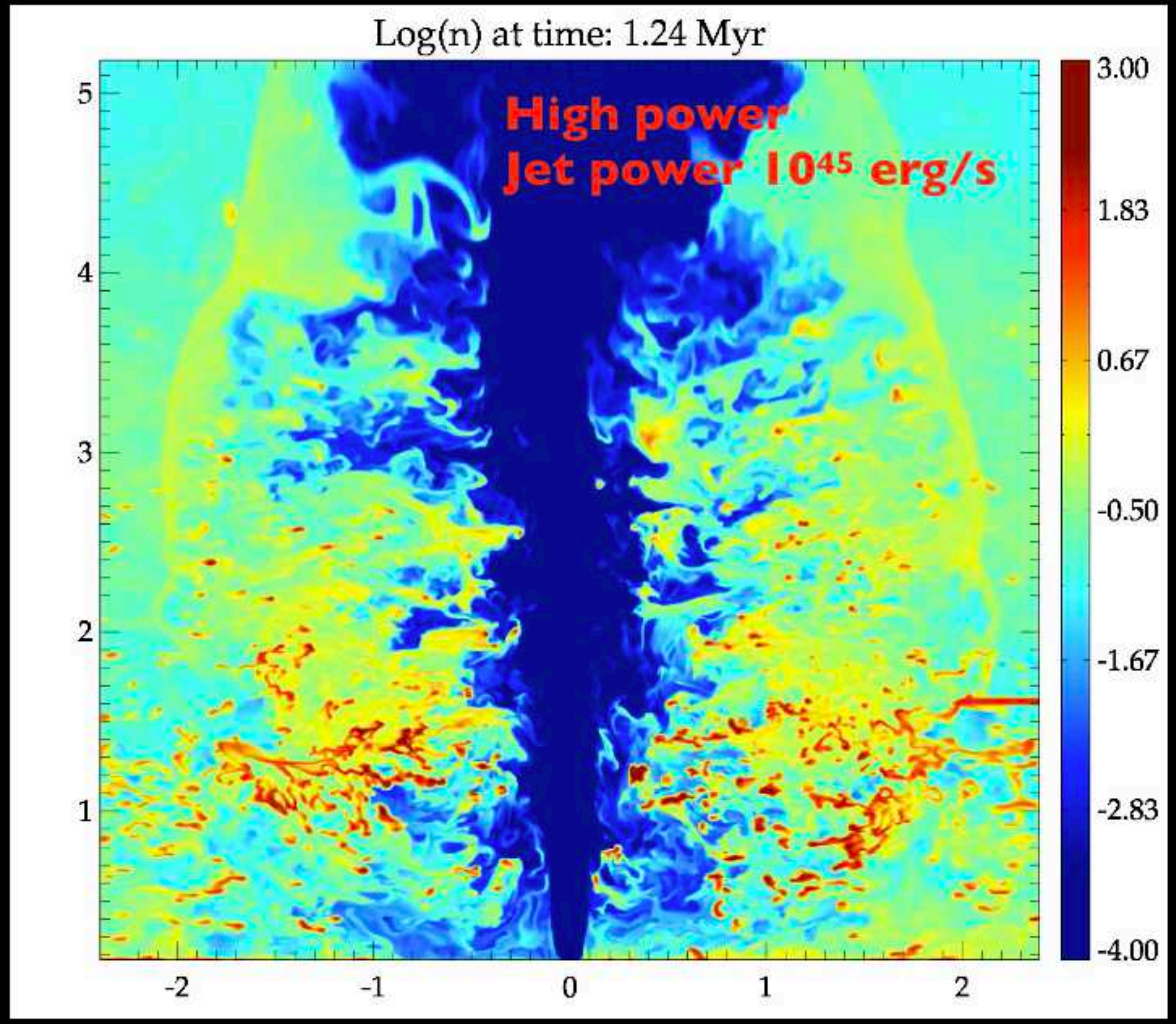

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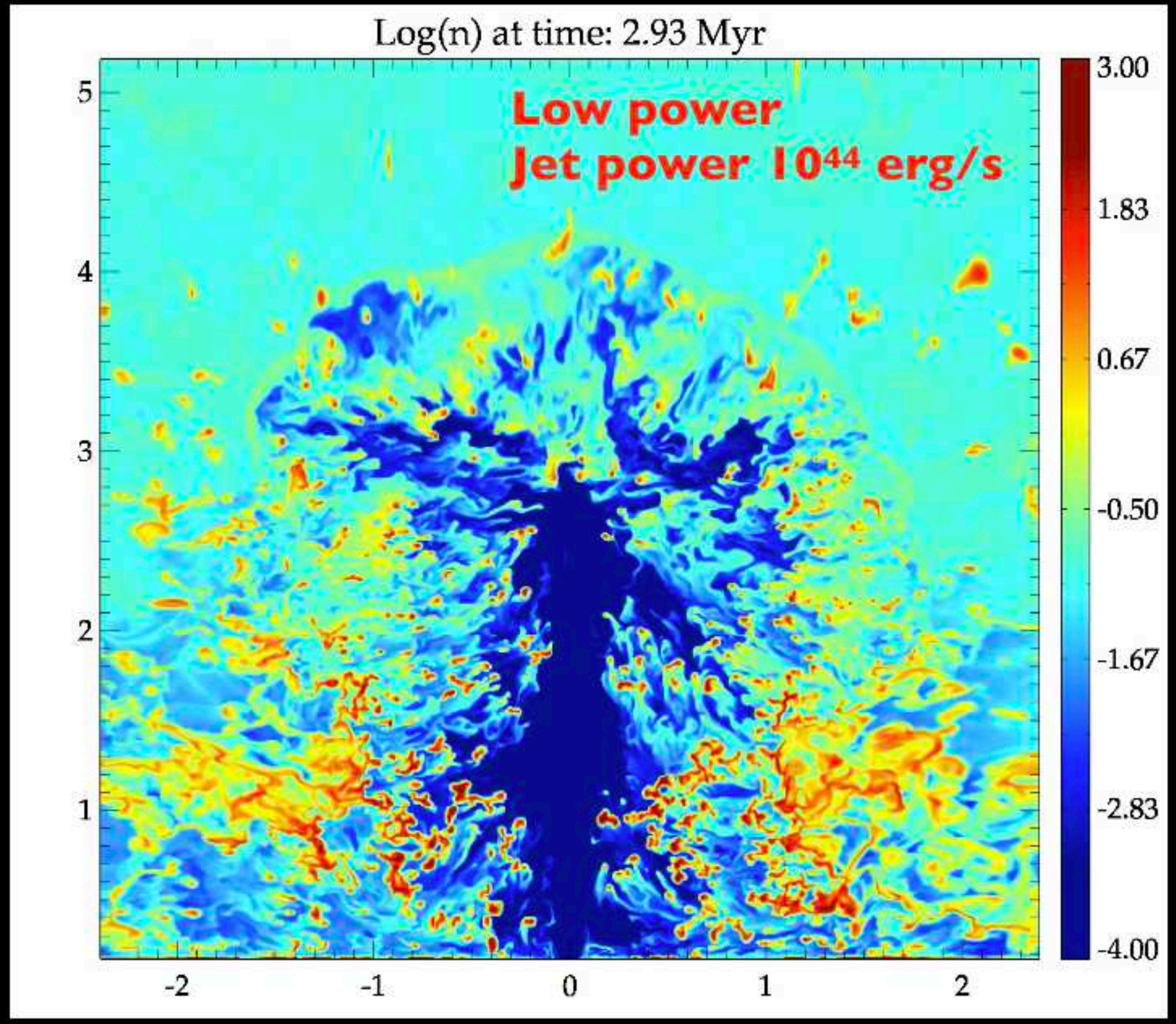

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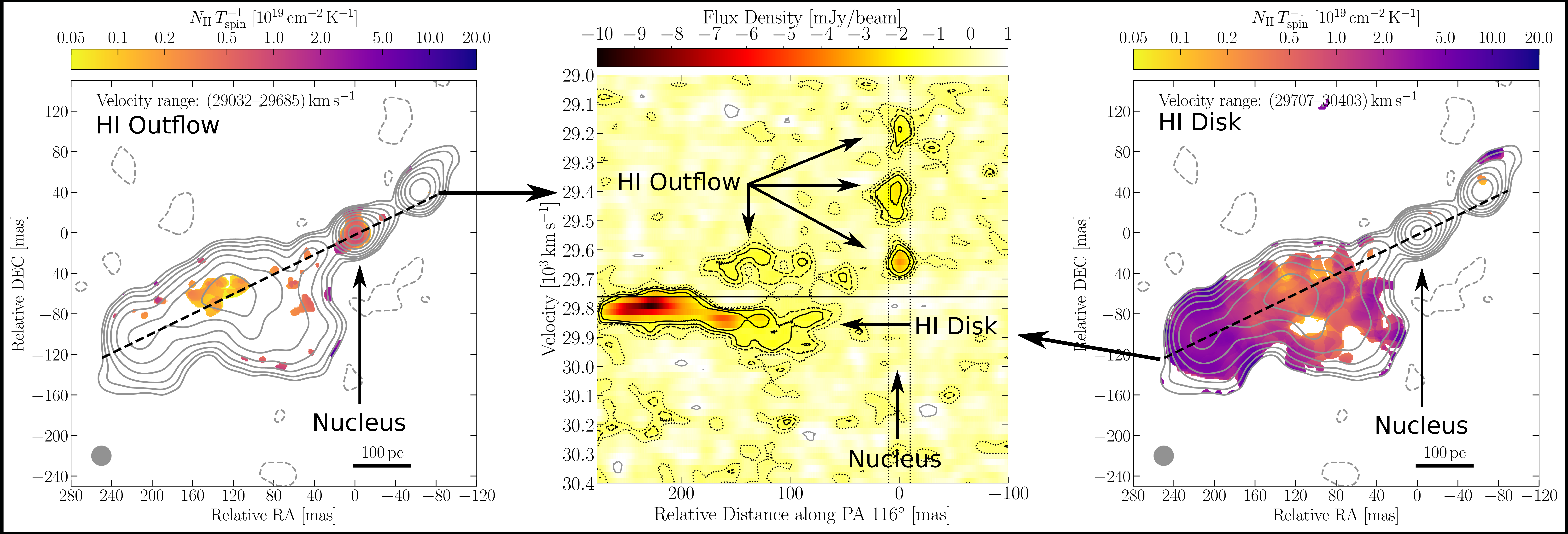
Tracing the clumpy medium at pc resolution

HI VLBI observations (resolution ~10 pc)

HI clouds outflowing at ~ 600 km/s observed already in the inner few x 10 pc from the nucleus (< 40pc).
Average density of the HI clouds n_e ~150-300 cm^{-3} (0.28–1.5 x 10^4 $M_\odot$)



Case of the radio galaxy 3C236

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

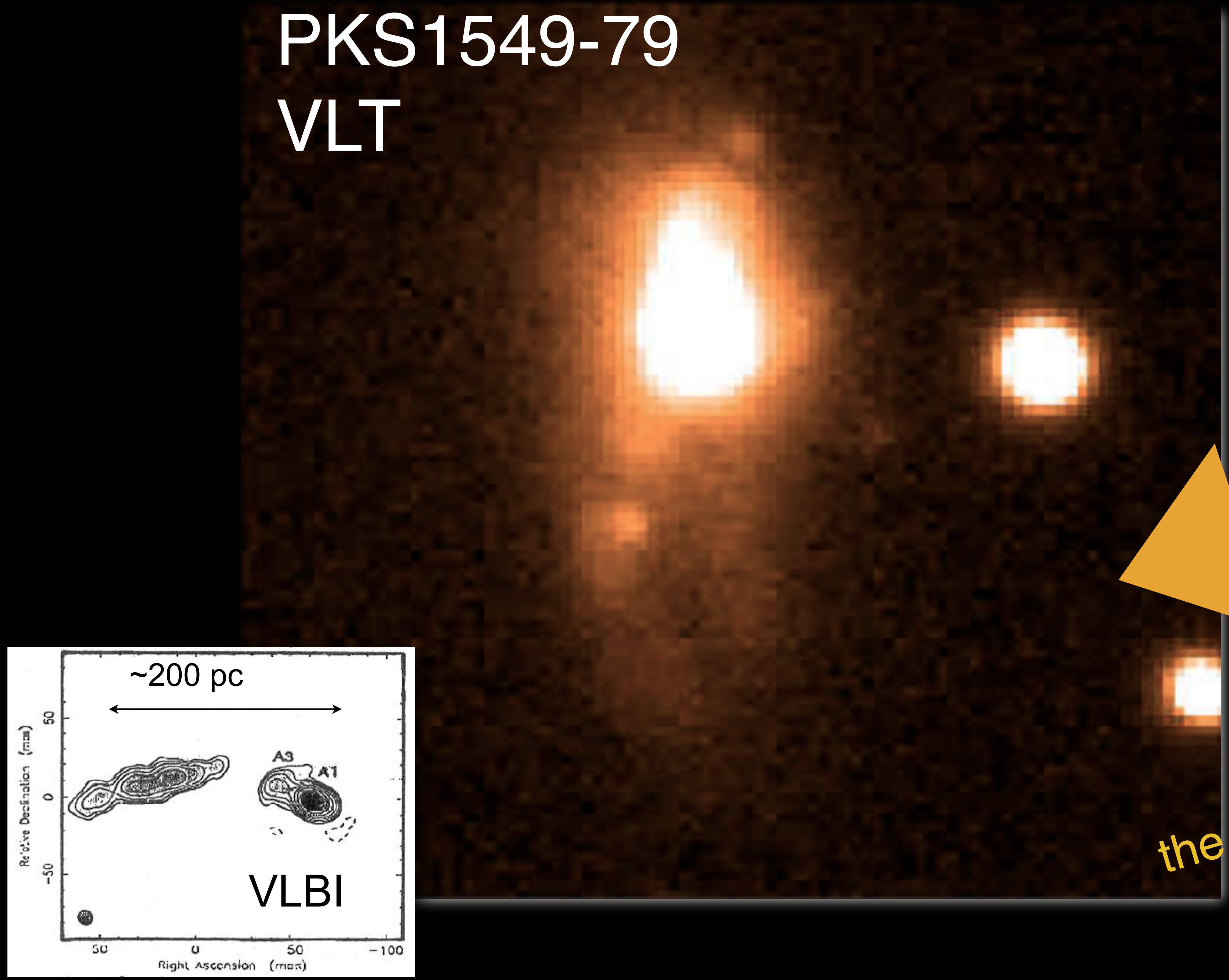
Some (preliminary) results from HI and VLBI

- Signs of clumpy medium (on tens of pc scales) in all sources
- Young/smaller sources showing the *most direct sign of interaction*
- Tentative signs of evolution of the outflow: presence of a *diffuse component* - not recovered by the VLBI observations - in larger sources (3C236, 3C293, B2 0258+35)
- HI outflows are also localised in the nuclear region of the AGN (<40 pc) ➜ showing *clumpy structure*

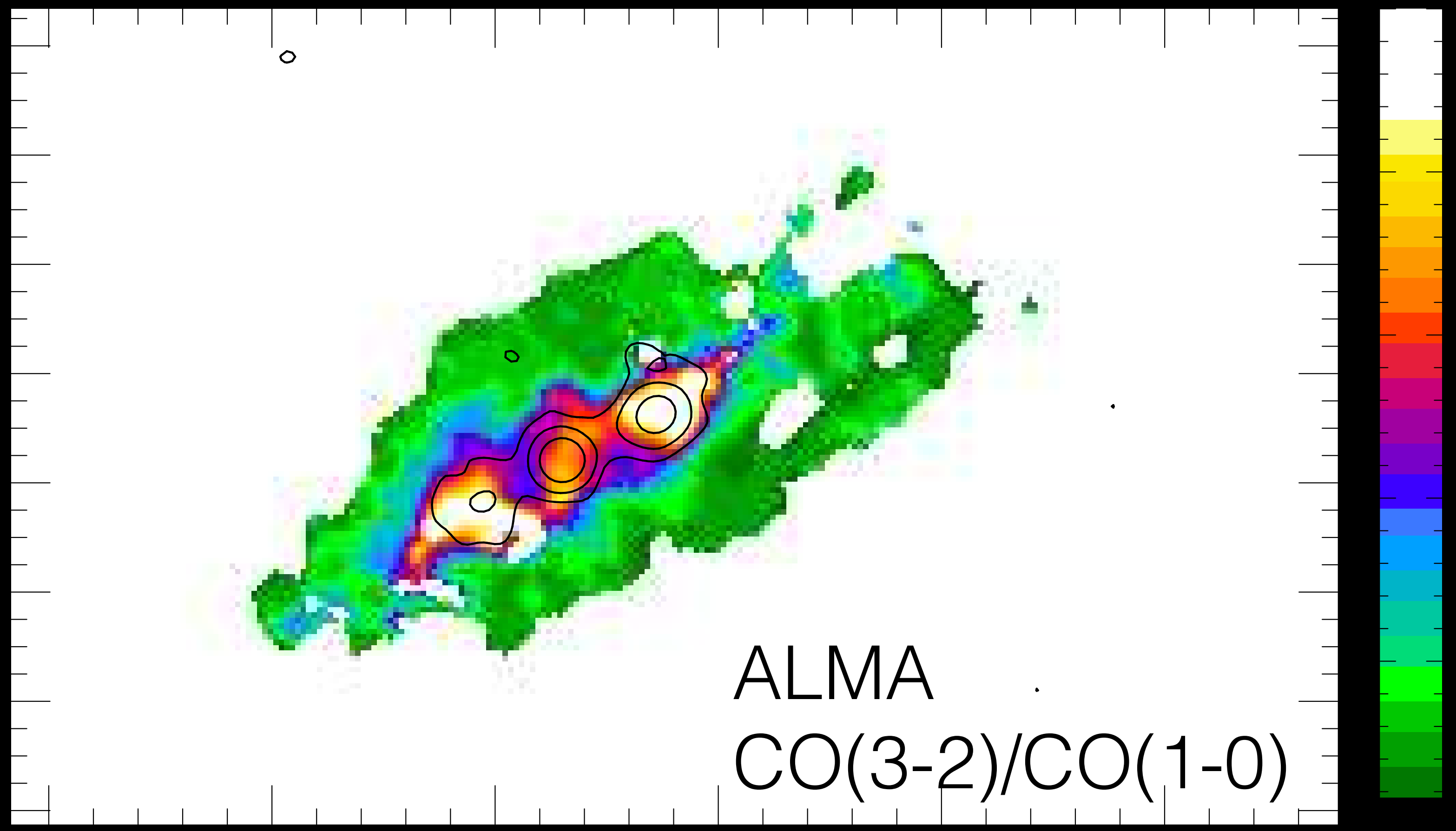
Molecular outflows traced by ALMA

Morganti et al. 2015, Oosterloo et al. 2017

Best case illustrating
the effect of a radio jet



Best case illustrating
the effect of a new-born powerful radio jet

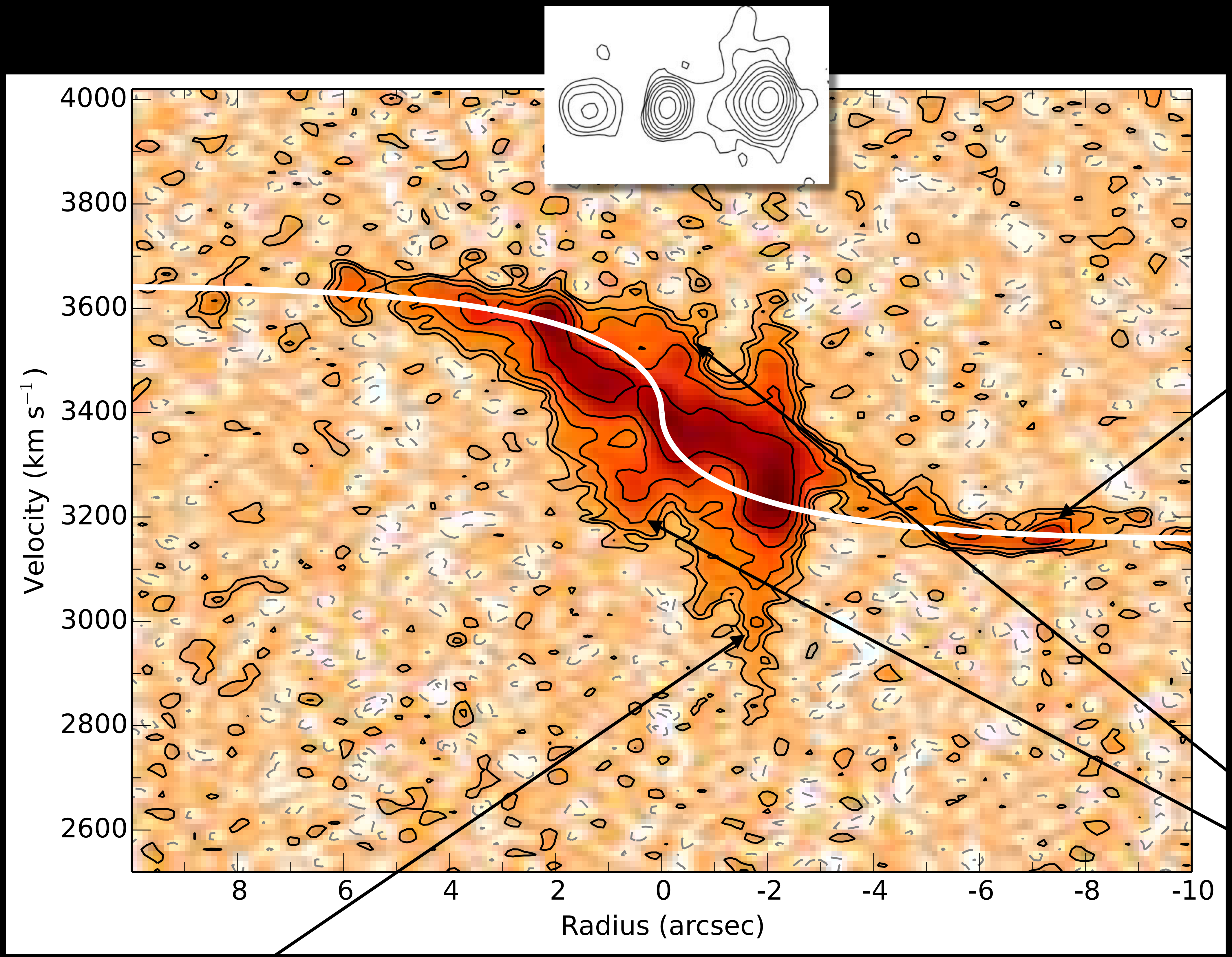


Radio power 10^{26} W/Hz

Radio power 10^{24} W/Hz

Impact of the jet as seen by ALMA

Strong molecular outflow exactly coinciding with the radio jet.
outflow is also lateral and driven by cocoon inflated by jet

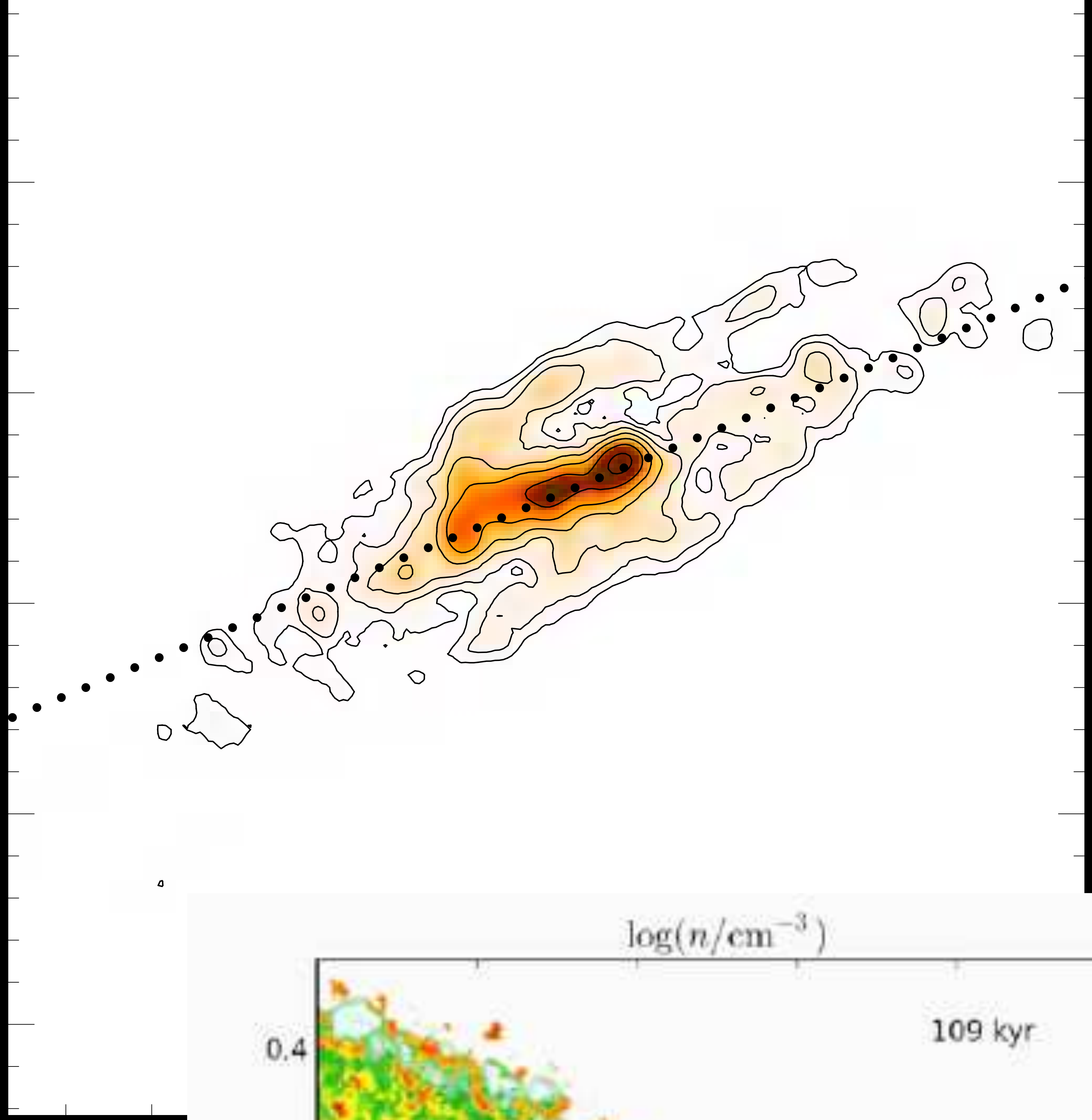


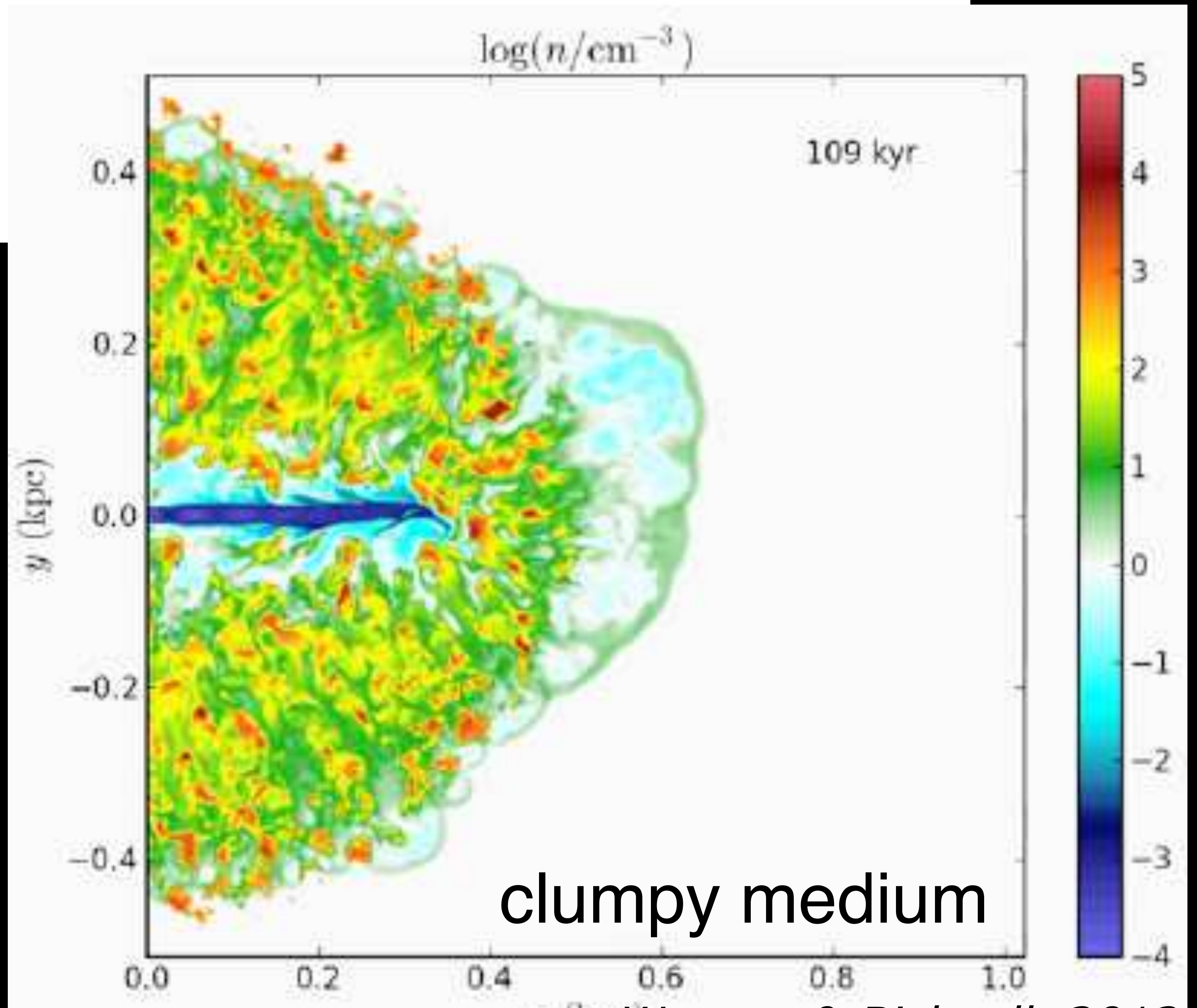
Regular disk

Outflow (cocoon)

pv diagram of CO(2-1)

Extreme outflow
at hot spots





Wagner & Bicknell 2012

Morganti et al. 2015

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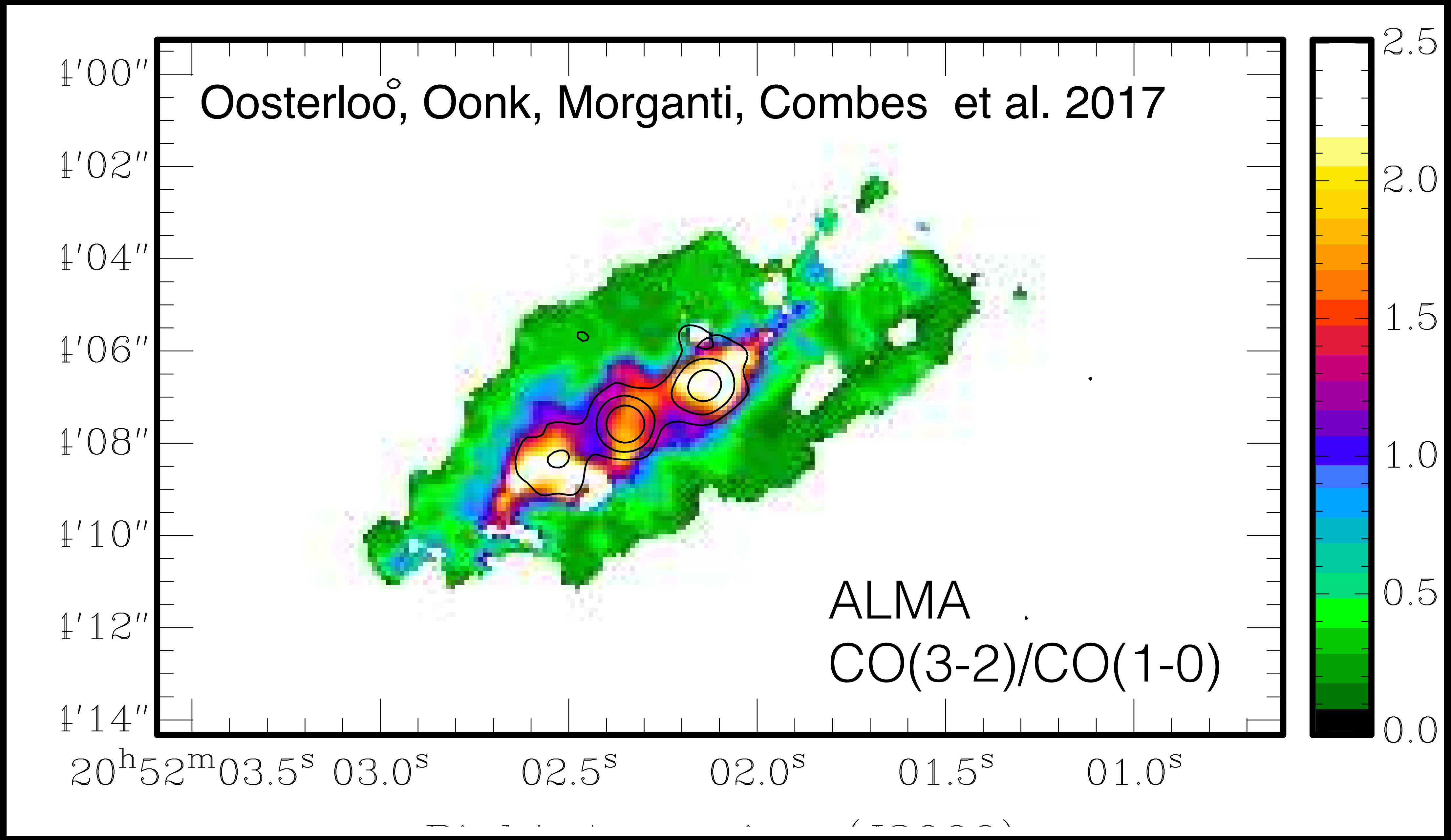


Disturbed kinematics
AND
different conditions of the molecular gas in the jet-affected regions.

Successful modelling as result of the impact of the jet

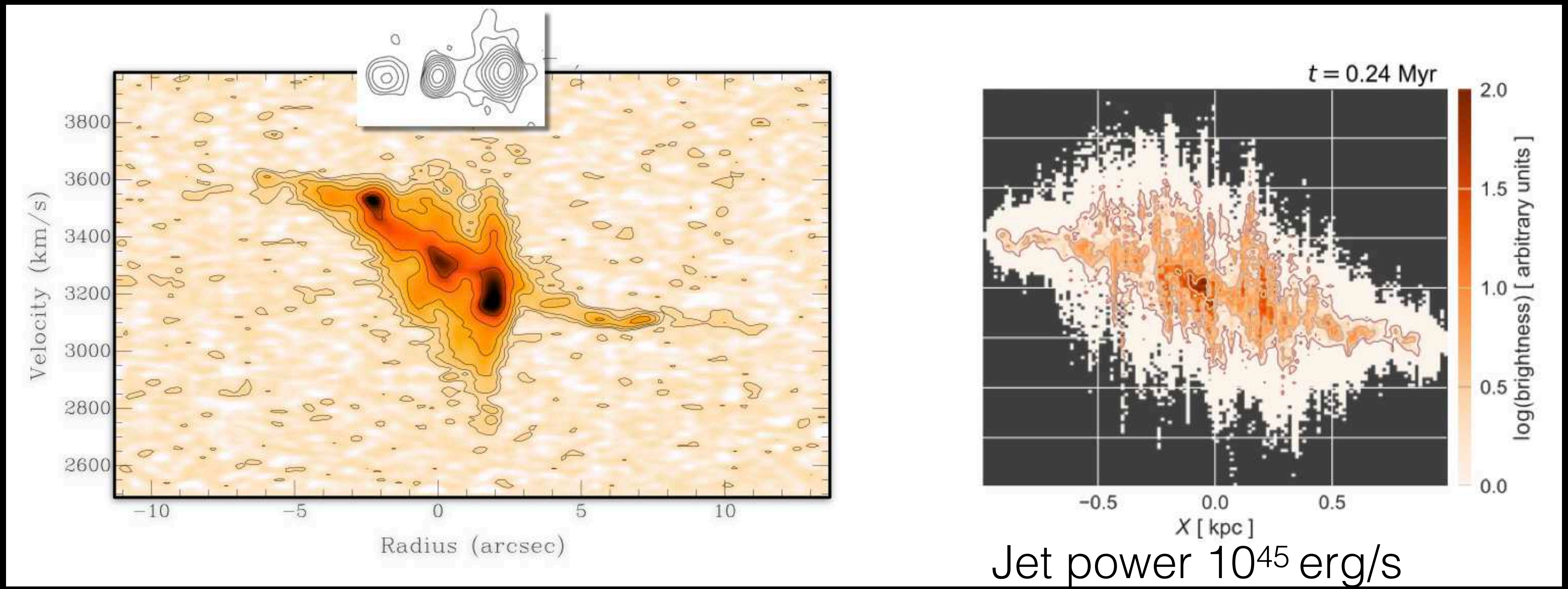
Highest ratios clearly associated with outflow
➔ gas must be optically thin

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)

Mass of outflowing gas few x 10^6 $M_\odot$; ~0.1% of total ISM
Mass outflow rate ~10 $M_\odot$/yr

Significant impact of AGN feedback, but only in inner few kpc
Small fraction of the gas will leave the galaxy, main effect of the outflow: redistribute the gas

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



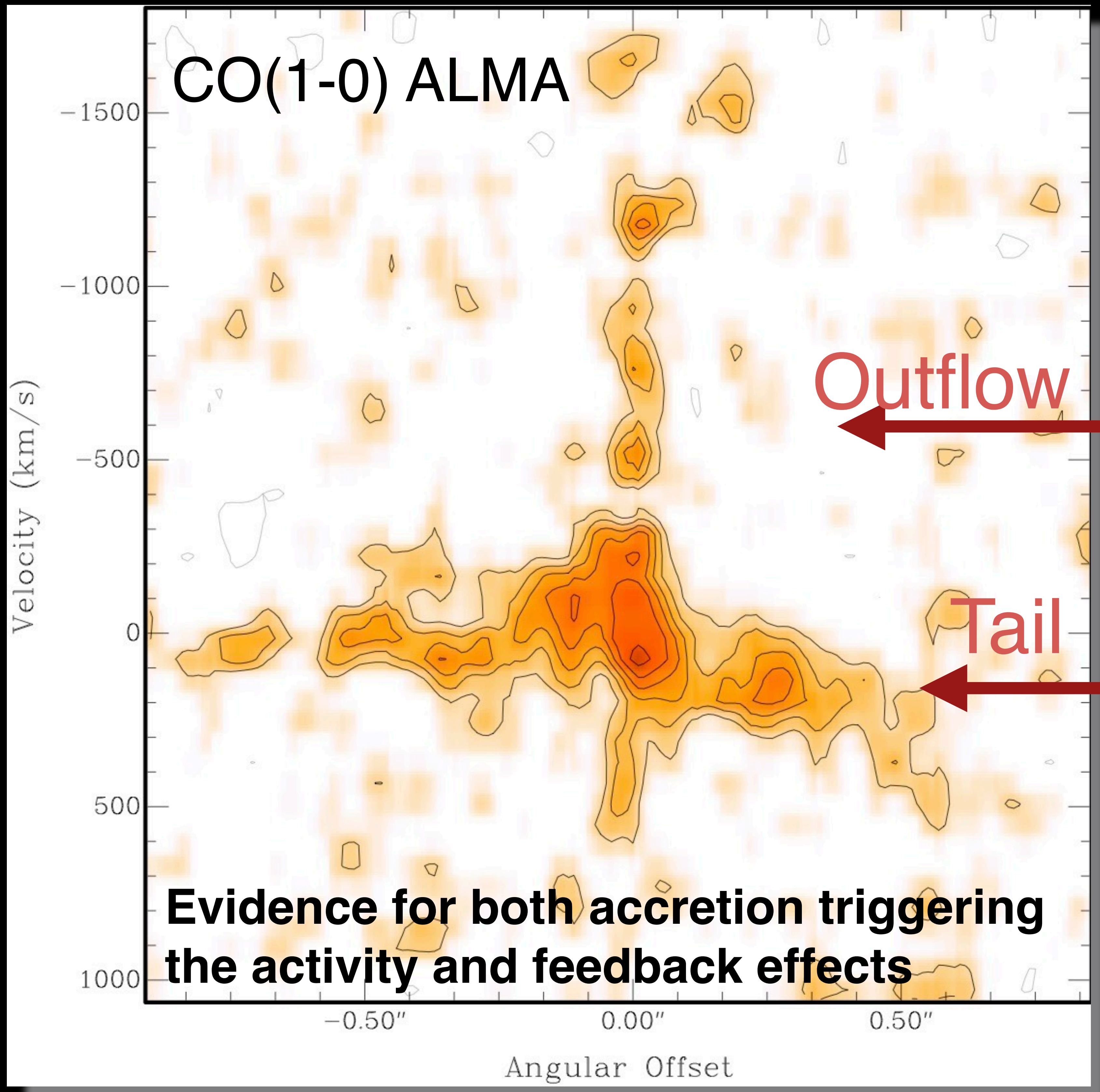
Mukherjee, Wagner, Bicknell, Morganti et al. 2018

PKS 1549-79 quasar in the early stage of evolution

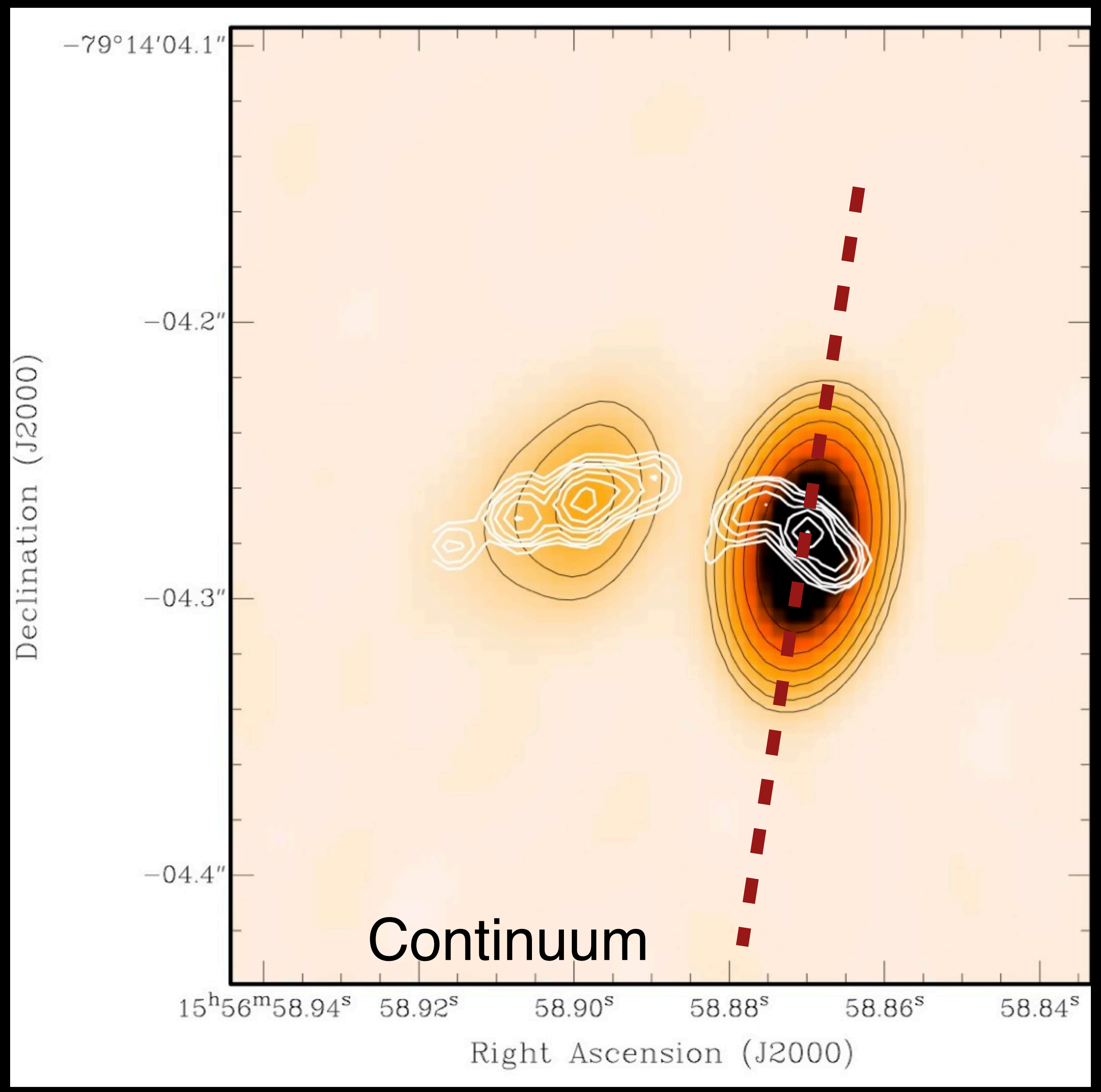
ALMA CO(1-0) detected in emission: large tail AND fast outflow (accretion and feedback)

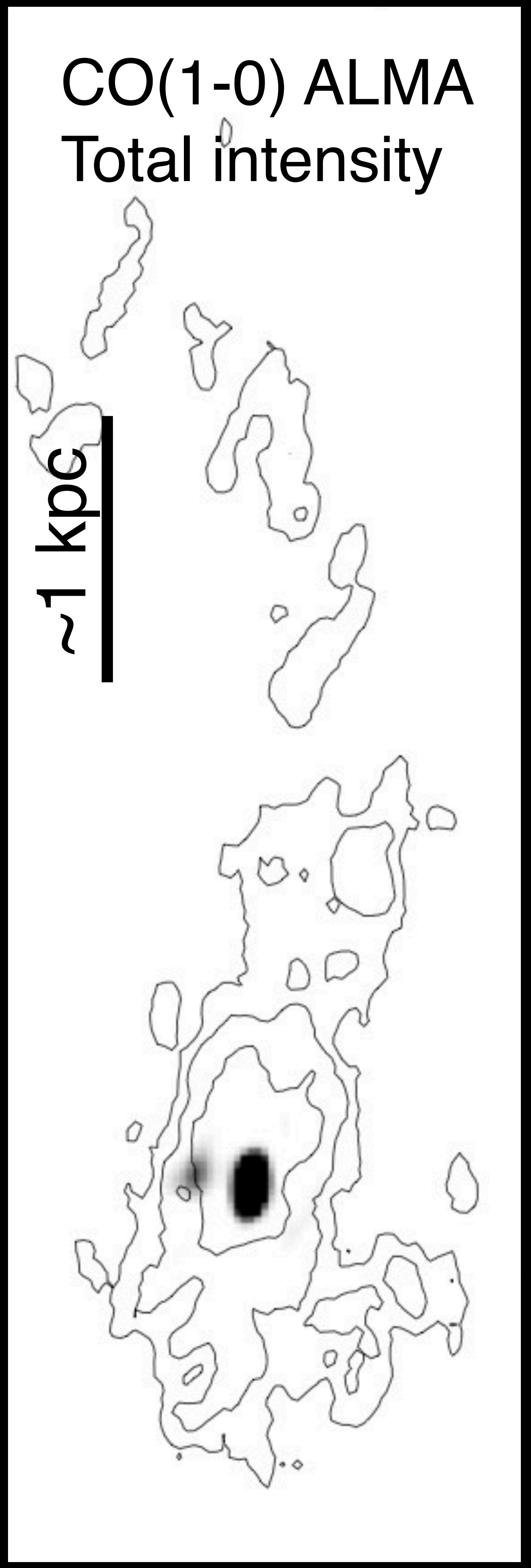
Large molecular outflow already in the central regions (<100 pc) ➜ ~100 $M_\odot$/yr

Much higher than in more evolved radio galaxies: enough to produce the expected feedback effects?



Oosterloo, Morganti et al. in prep





In agreement with simulations: a more powerful source has a faster/more massive outflow

➜ Now we need proper statistics!!! ongoing!

Expansion to the high-z

Expansion to the high-z

In progress but more difficult…

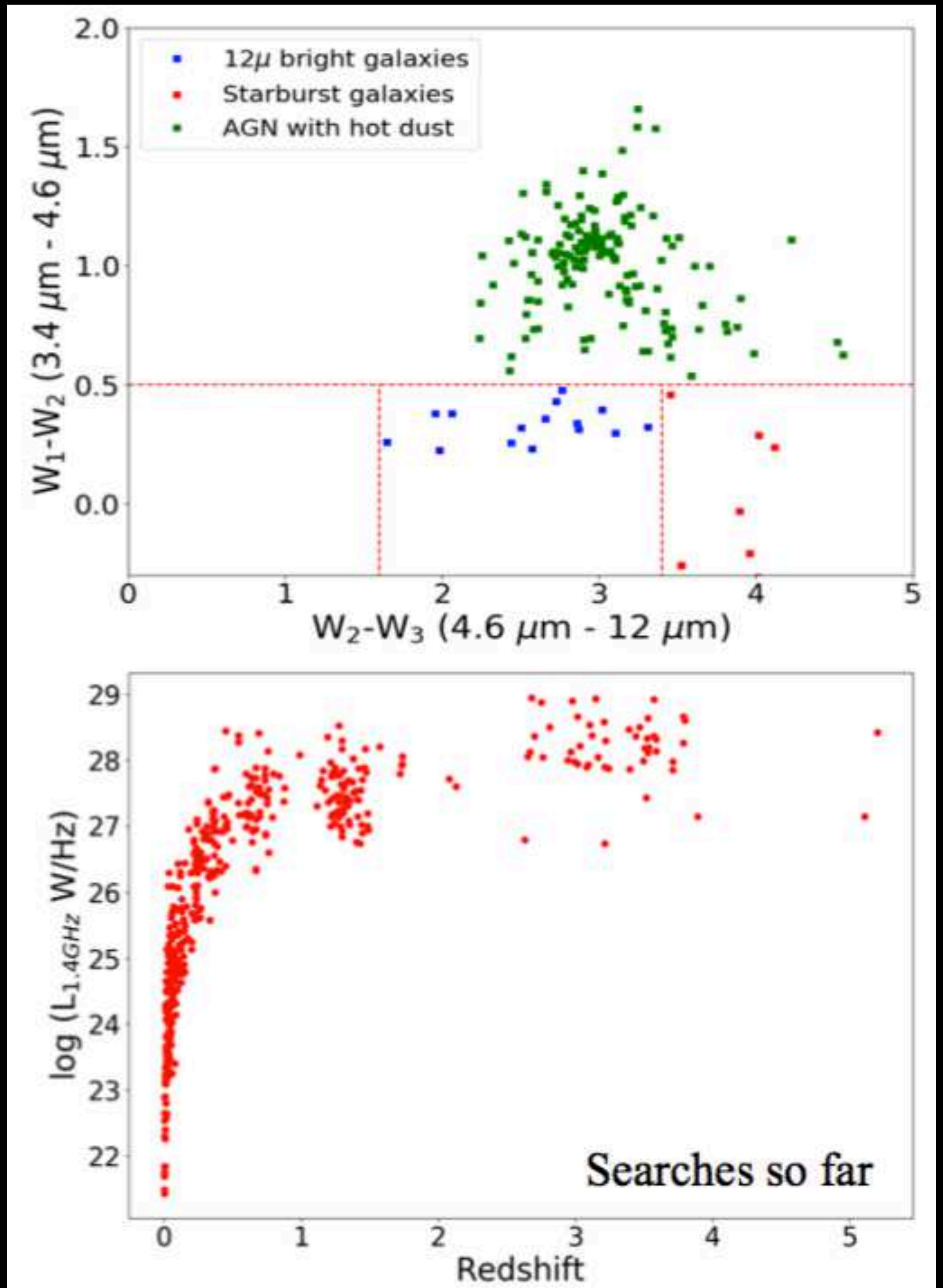
What do we know about HI absorption at high redshift:
only a limited number of detections so far
(from uniform sample i.e. flat spectrum quasars, CSS/GPS…
see e.g. Aditya & Kanekar, Curran et al.)

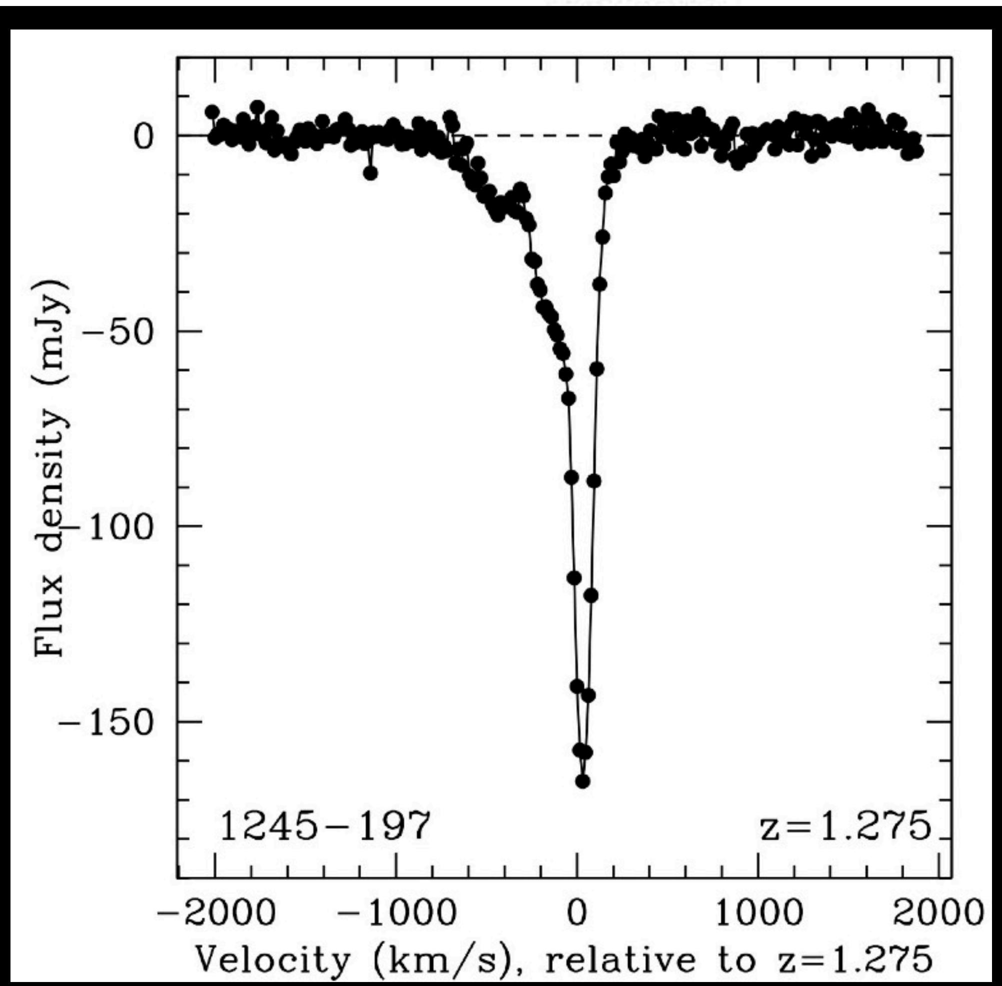
➜ low detection rate so far (5%)

Possible reasons but clearly a key point to explore:

– Redshift evolution of cold gas?
– High AGN Luminosity (UV and 1.4 GHz)?

And interesting objects among the detections ⟶





Aditya et al. 2018

Exploiting the uGMRT

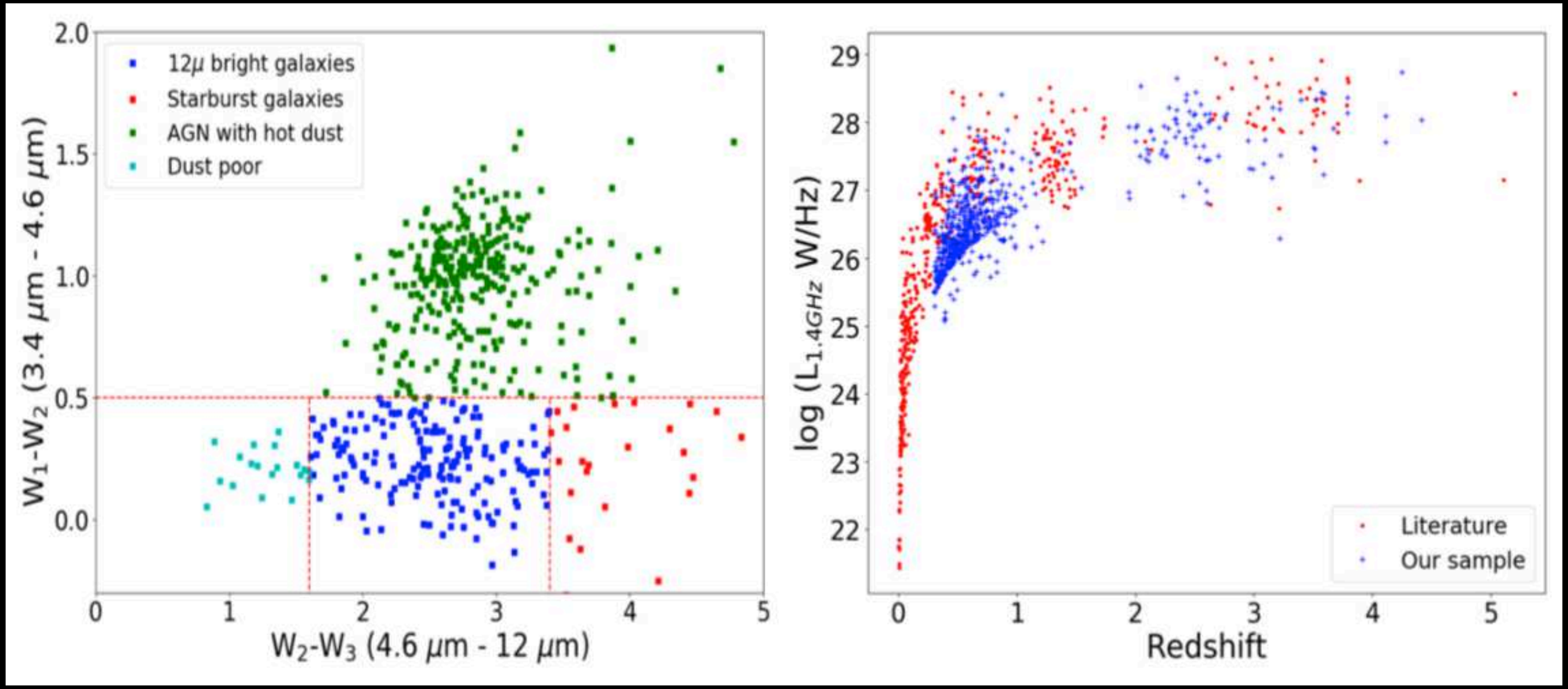
Murthy et al. in progress

Search similar to what done with the WSRT

$0.3 < z < 4.5$; 1.4 GHz flux density > 70 mJy: 500 targets.

SDSS, WiggleZ, VIPERS with FIRST & de Breuck et al. 2006.
(Alam et al. 2015, Parkinson et al. 2012, Guzzo et al. 2014)

300 extended radio sources. Classification based on Gereb et al. 2015.



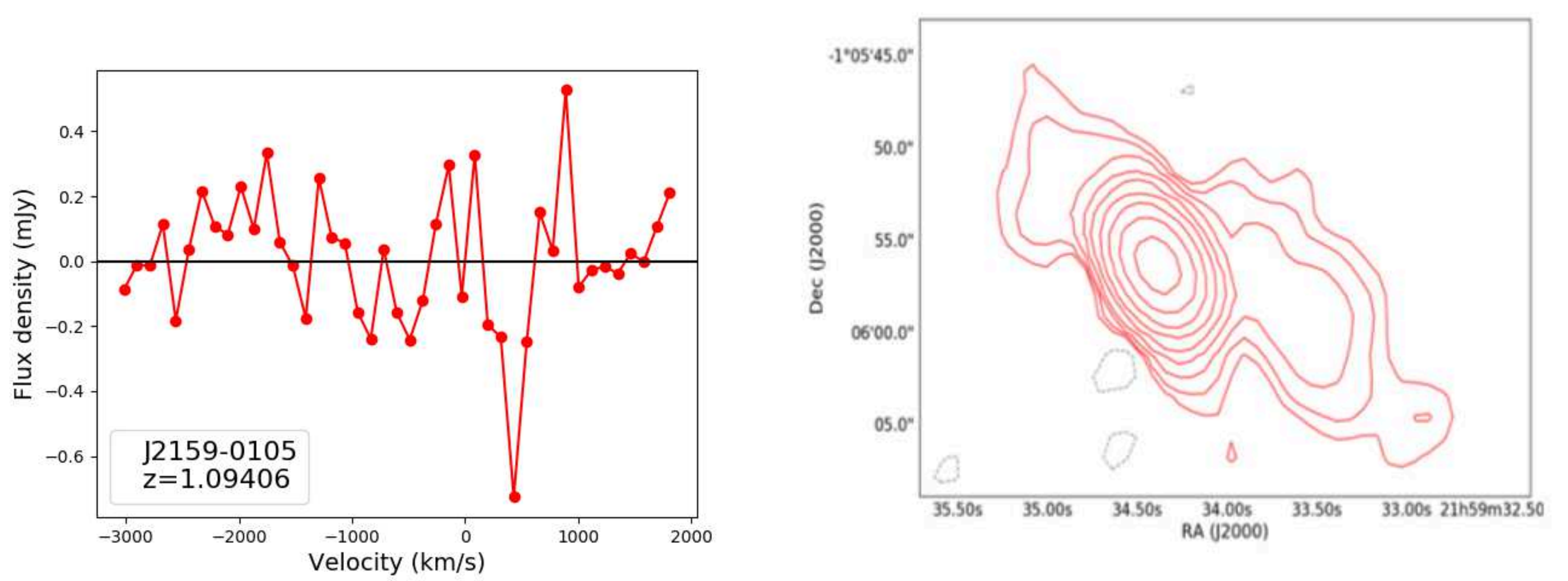
Preliminary results…

Five tentative detections of associated HI absorption
If confirmed, number of detections at z > 2 doubled!

Overall detection rate ~9% at z > 1

1.4 GHz luminosity: $10^{26.5}$ - $10^{28.5}$ W Hz^{-1}.

UV luminosity: Well below the cut-off limit (10^{23} W Hz^{-1}, e.g. Curran et al. 2008)

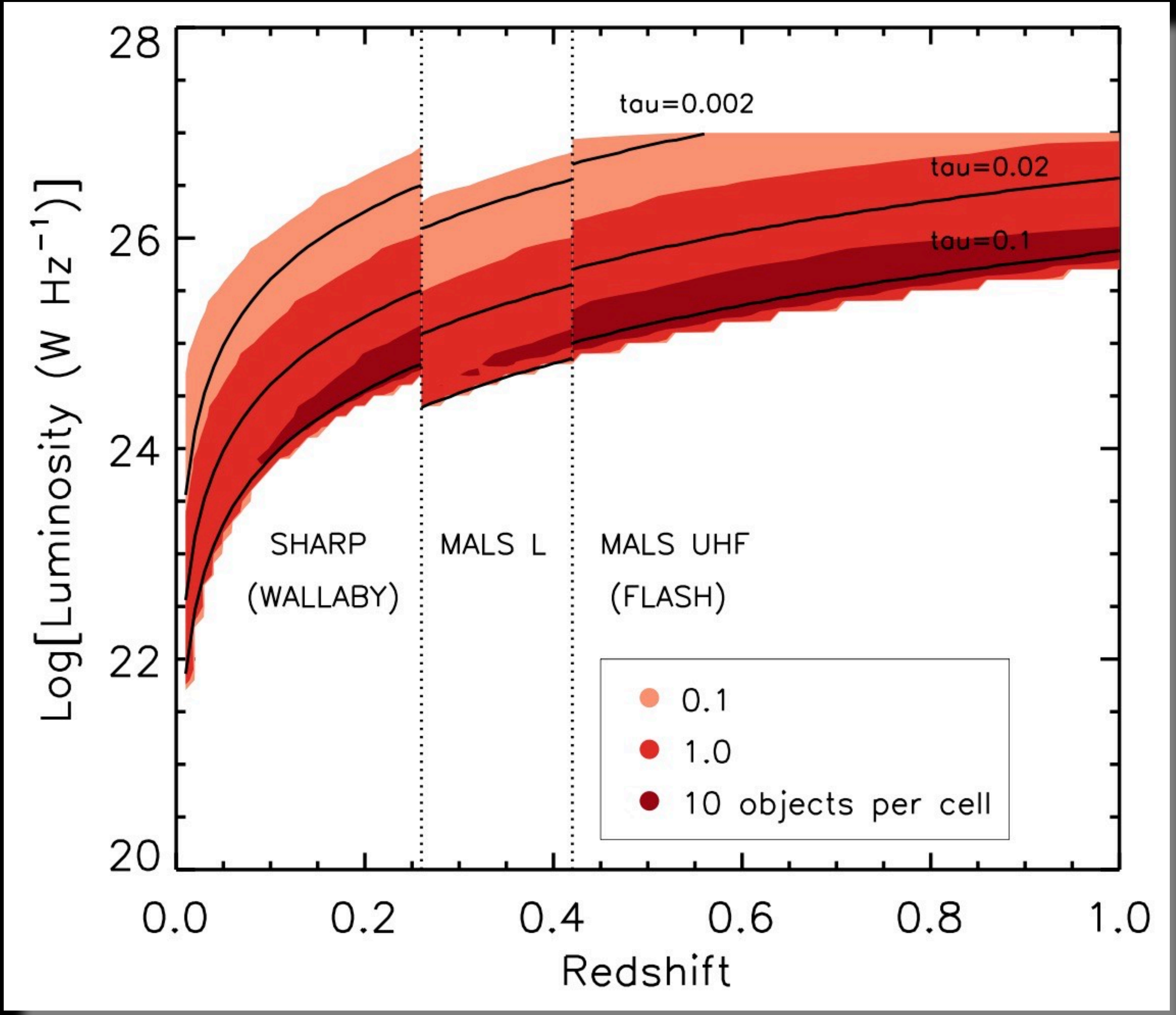


Low surface brightness extended emission (~330 kpc): restarted activity?

Peak tau 0.6%
Column density 2.5 x10^{20} /cm^2 for T_{spin}=100K

Murthy et al. in progress

The future



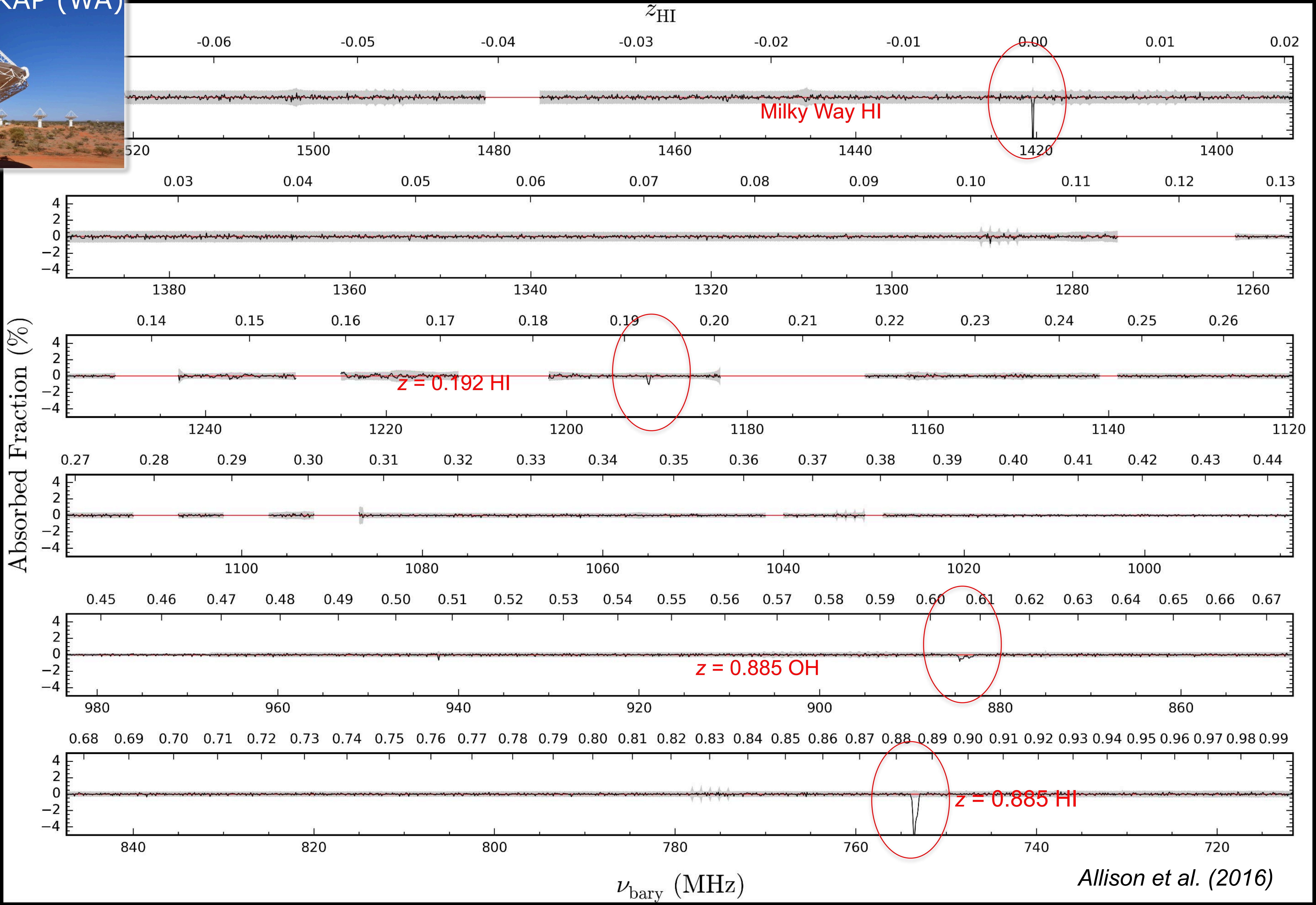
N. Maddox, see Maccagni et al. 2017

ASKAP: The First Large Absorption Survey in HI
FLASH (PI: E. Sadler)

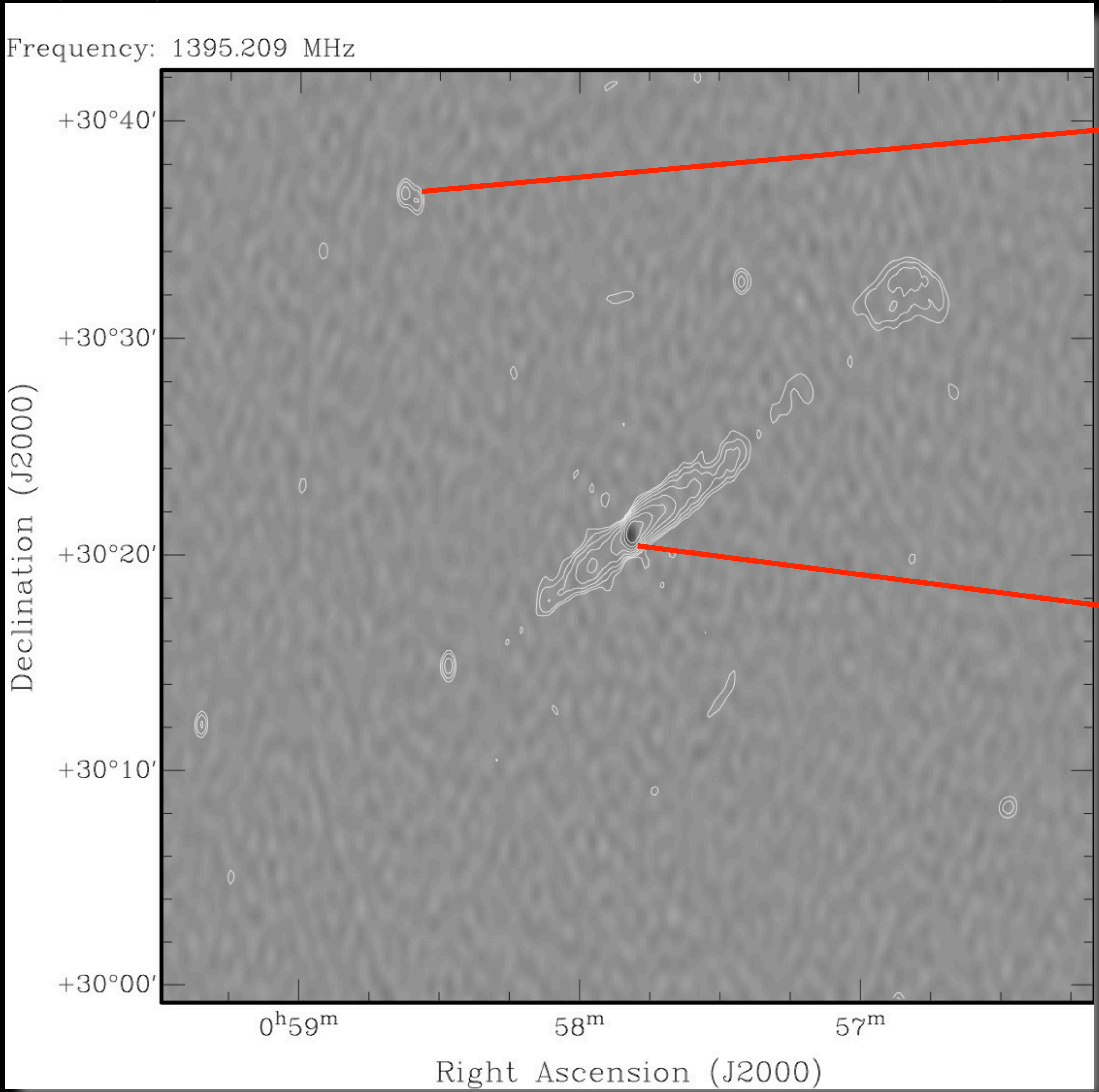
Search for HI absorption with APERTIF
SHARP (PI: R. Morganti)

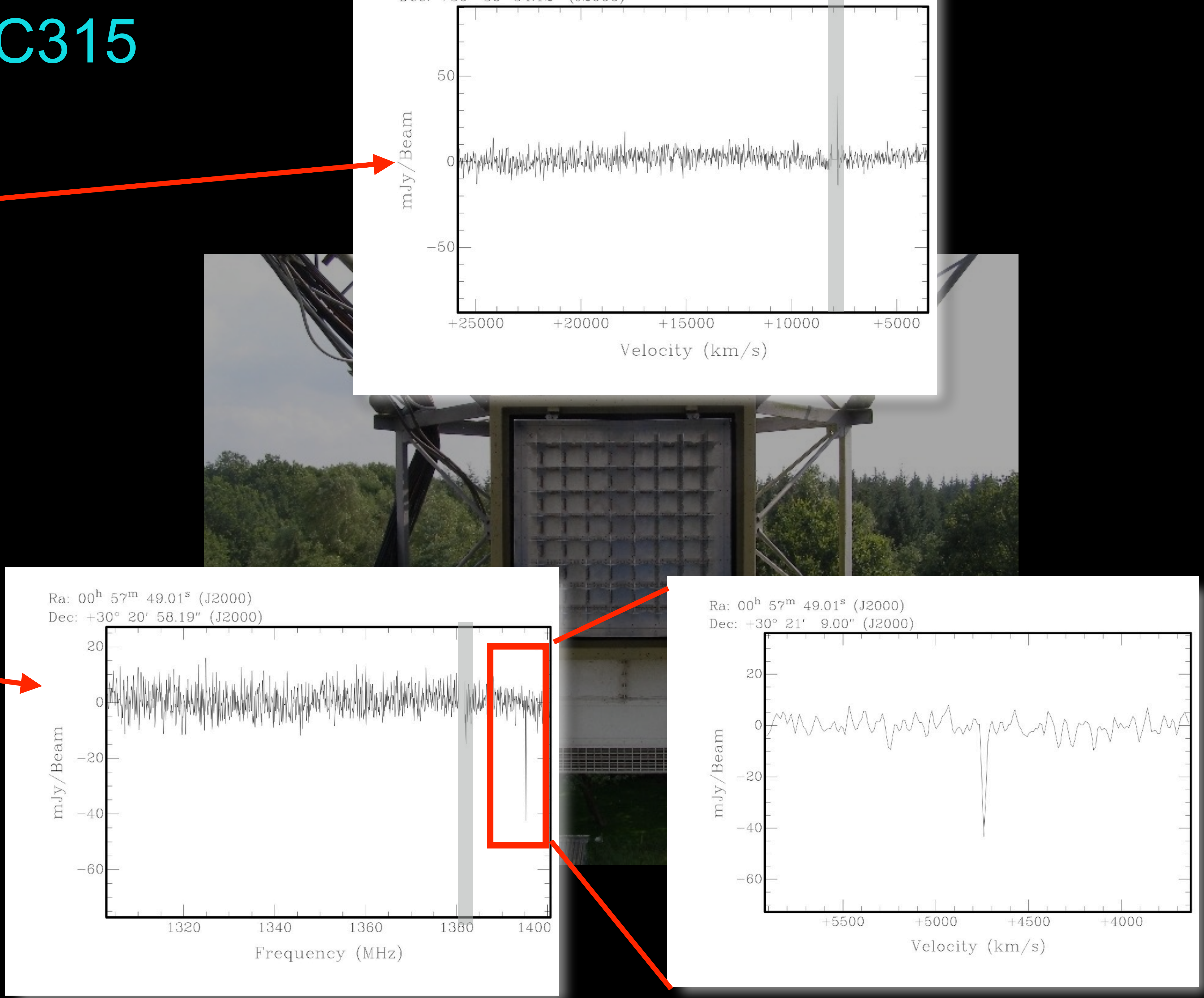
The MeerKAT Absorption Line Survey
MALS (PI: N. Gupta)

ASKAP - Example of redshift coverage for HI abs



Highlights from Apertif commissioning: NGC315



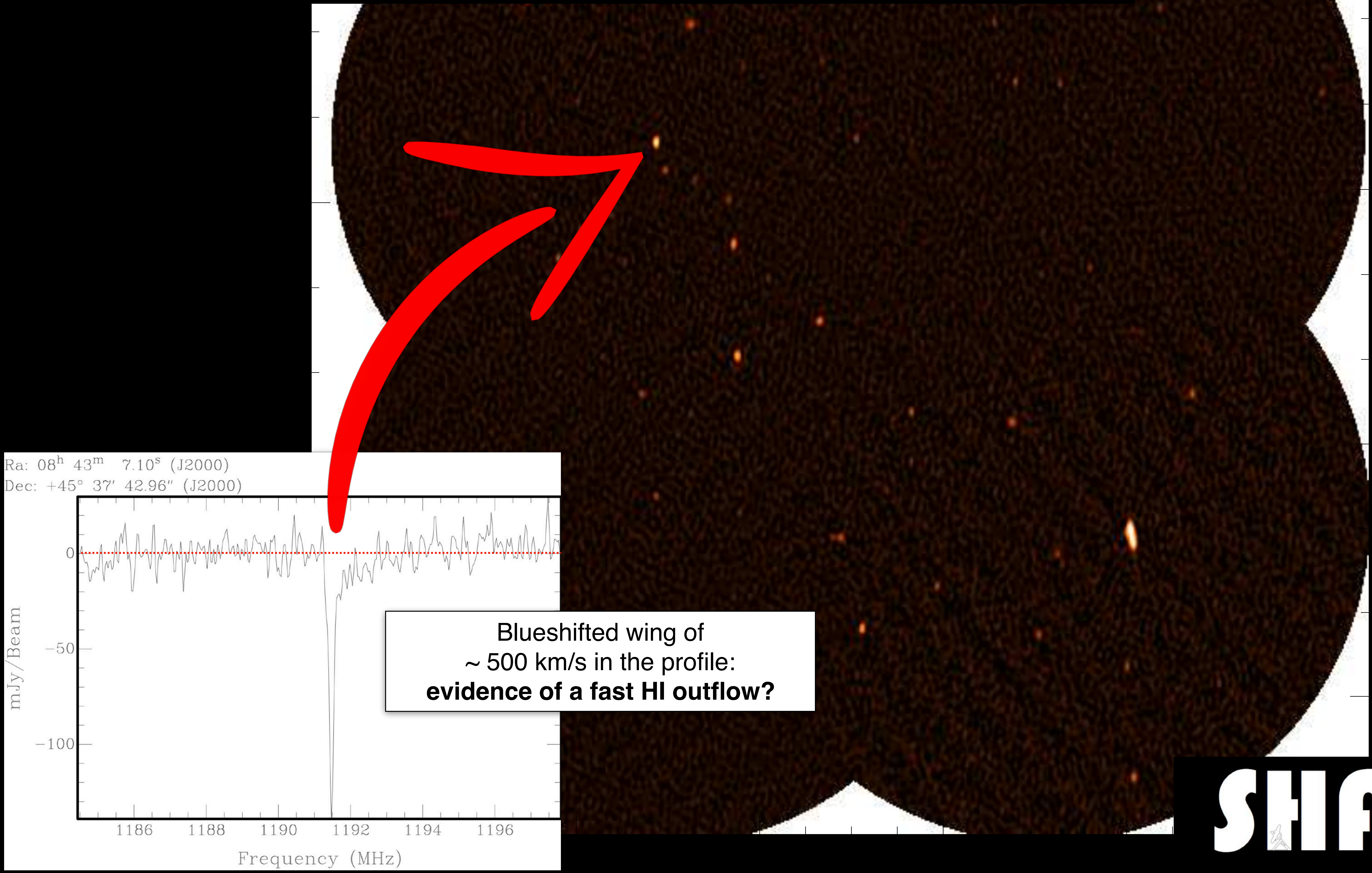


rms noise ~2 mJy/b chan=10km/s+Hanning

Tools to identify location of continuum sources and search for absorption features in the cube

SHARP

Pushing toward the lower frequencies ➜ z=0.19



SHARP

Summary…

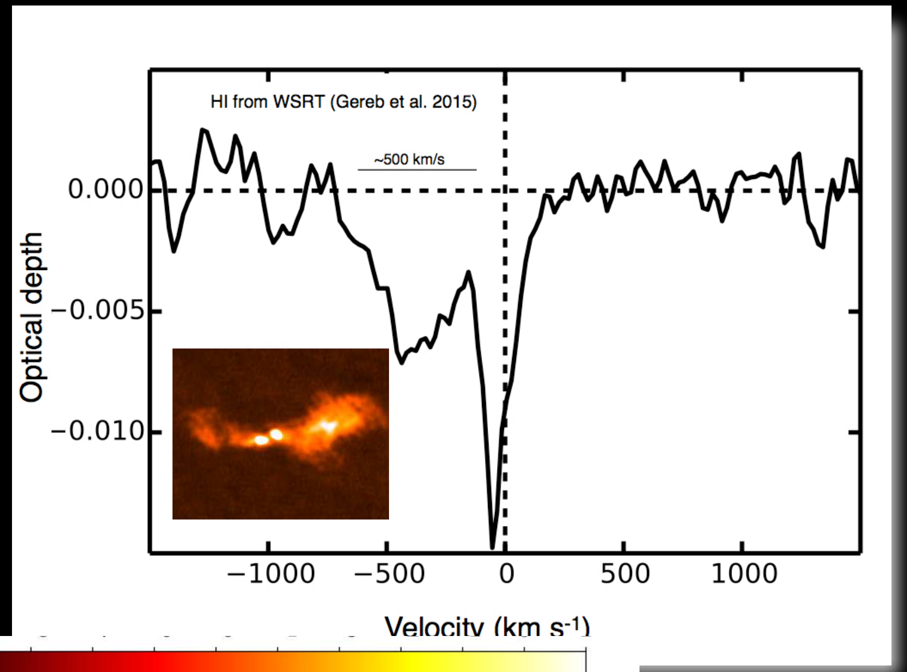
- HI absorption efficient way to learn about gas in radio AGN: occurrence and kinematics

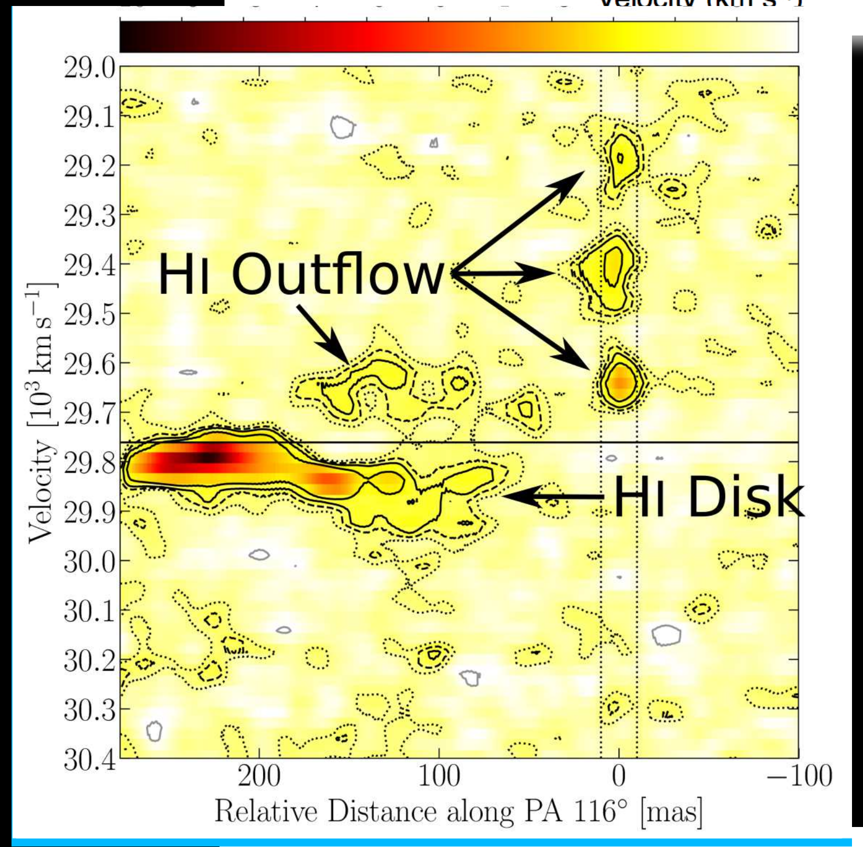
- Upcoming blind surveys are opening up great possibilities and we are finally seeing the first results

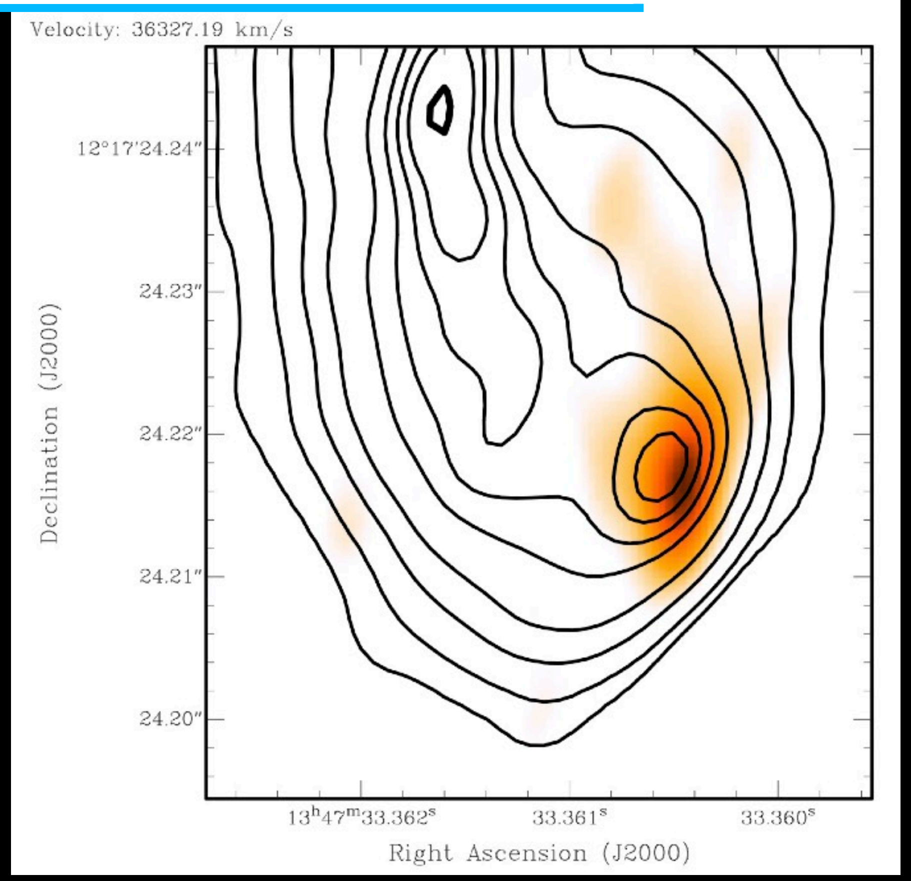
- HI absorption can trace a variety of absorbing structures: regularly rotating, infalling and fast outflowing gas
- Particularly exciting the possibility of tracing infall/outflowing gas
- Fast outflows can be driven also by radio jets ➜ HI outflows traced down to pc scale using VLBI

- Synergy with molecular and ionised gas is needed for fully characterise these phenomena ➜ synergy with surveys like WEAVE very important!

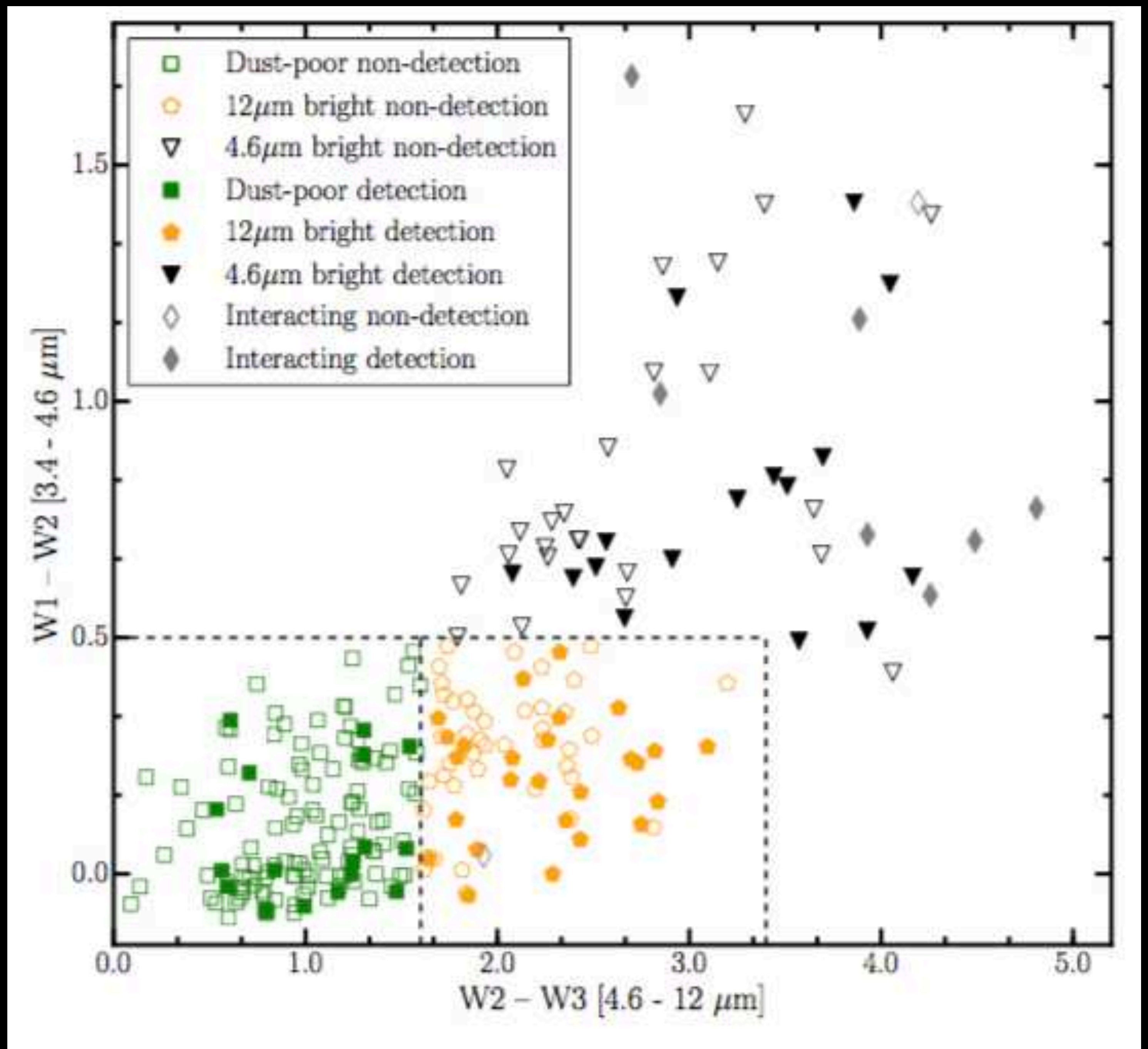
- Expansion at high-z very in progress!

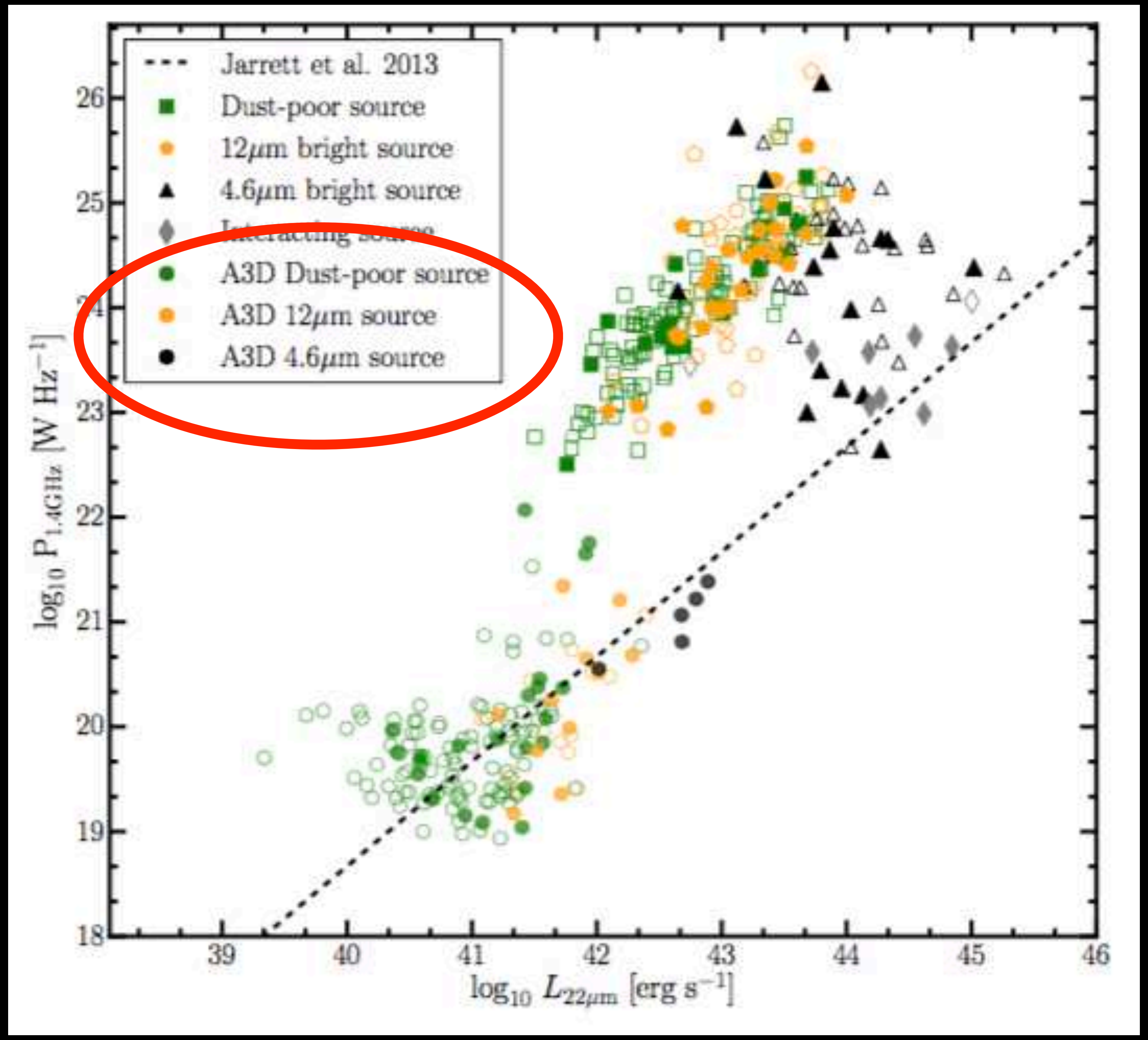






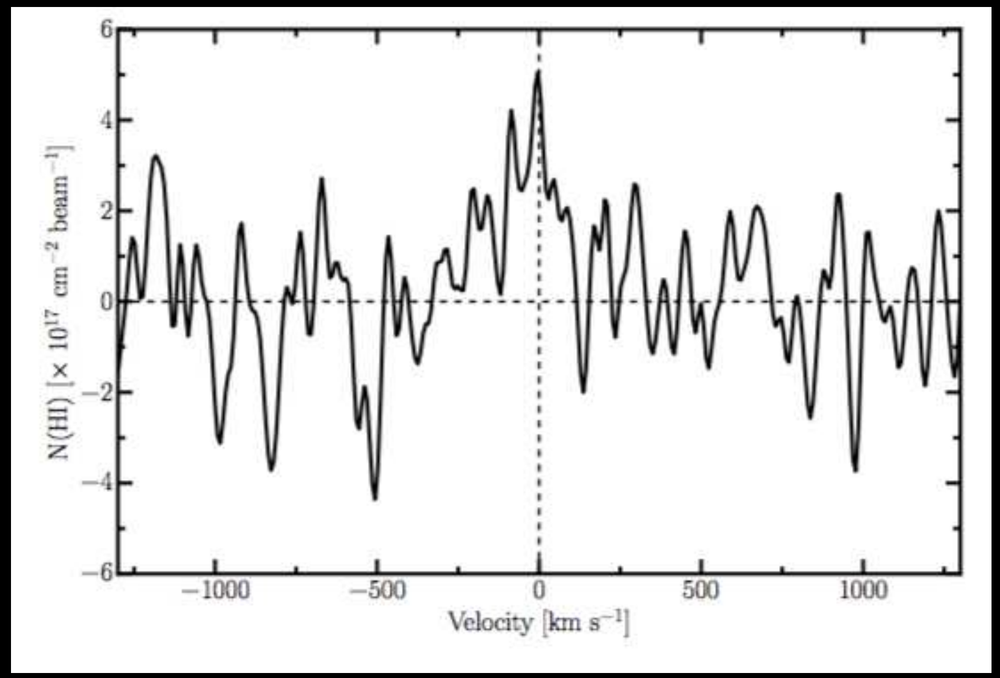
Putting this into perspective…





HI detections (filled symbols)

HI non-detections (empty symbols)



Stacking ATLAS3D HI central undetected column density of the emission line is $N_{HI} \sim 2.1 \times 10^{19}$ cm^{-2}

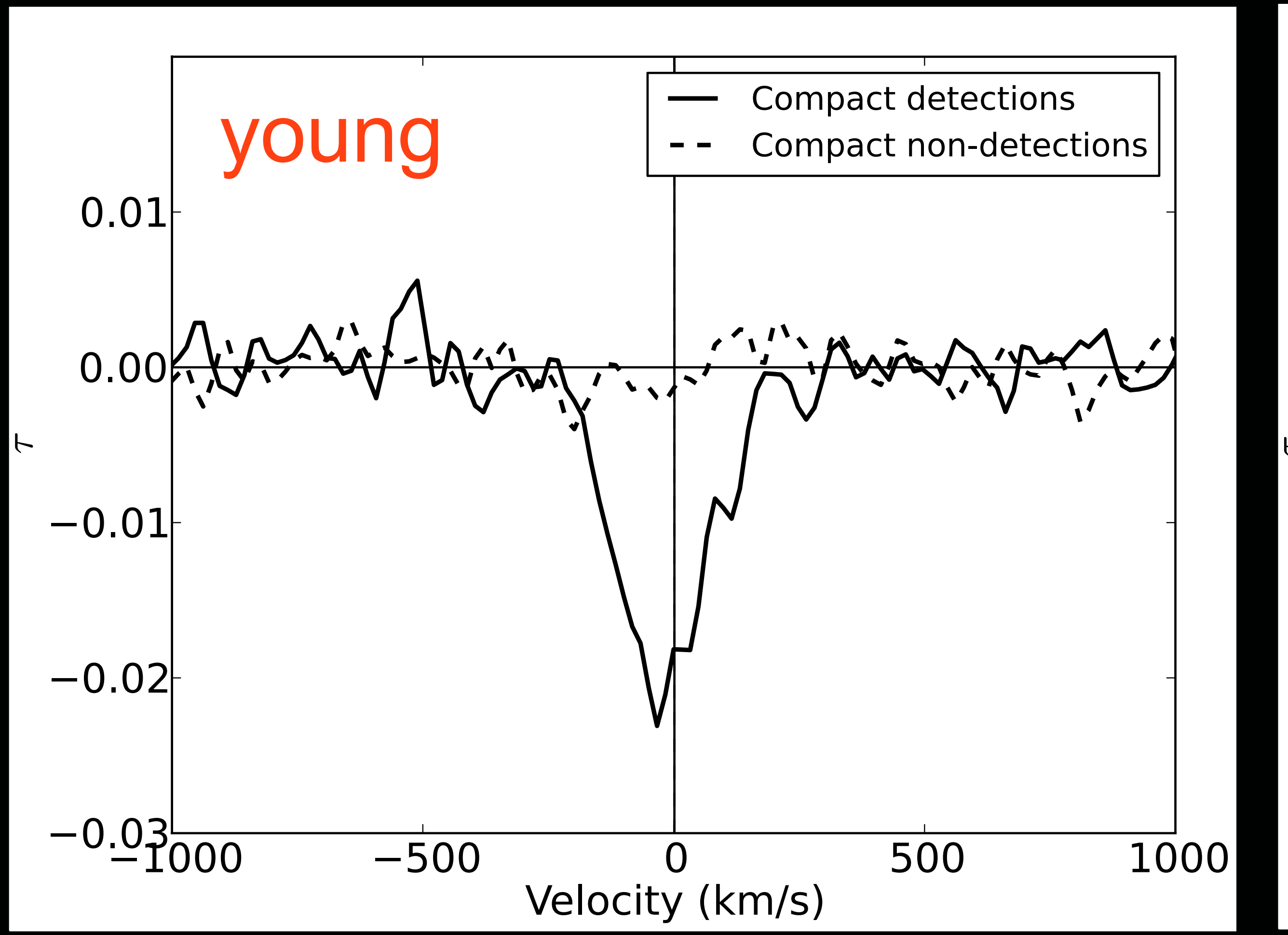
Radio galaxies ➜ early type galaxies (and mergers)

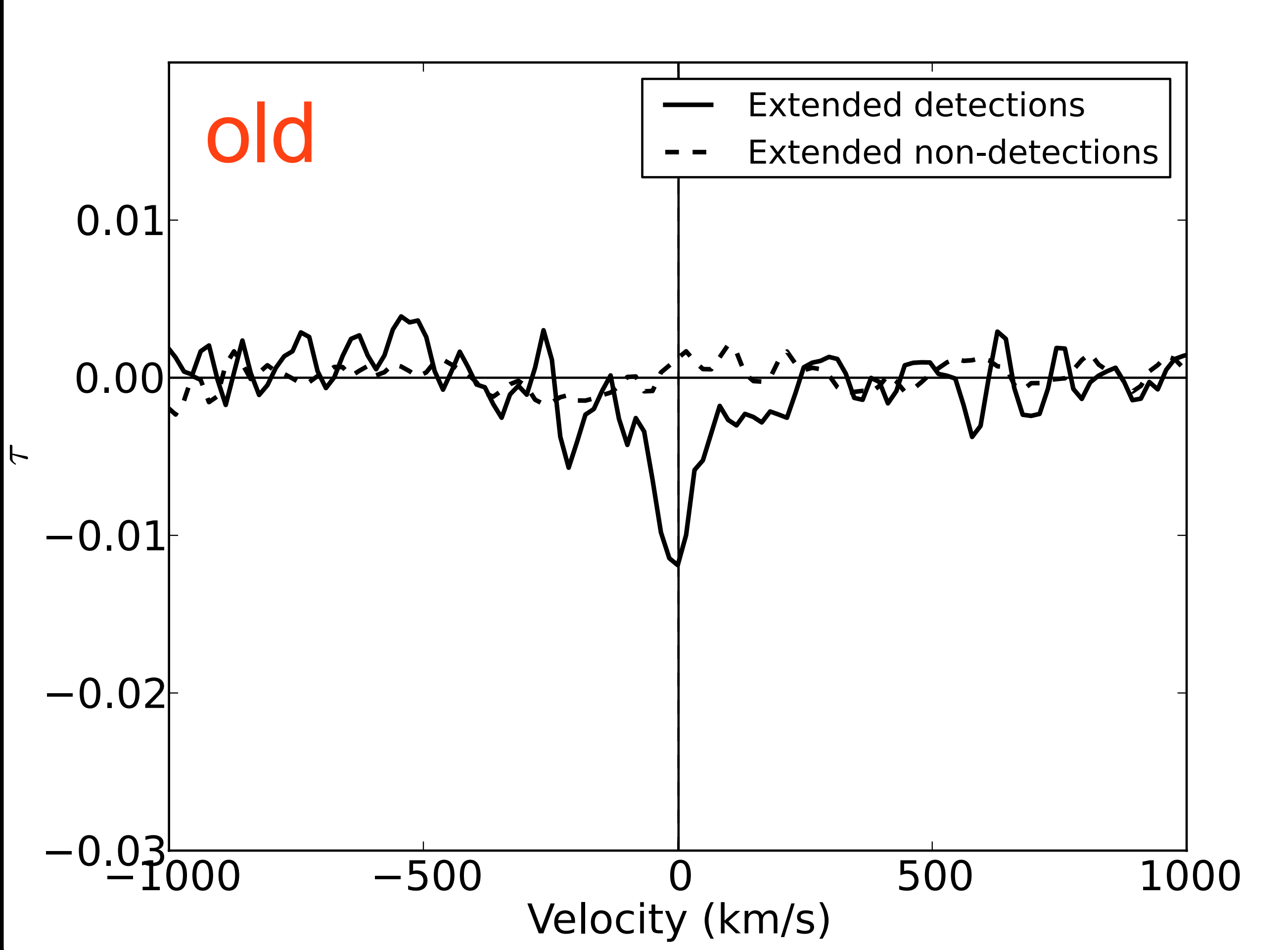
Comparable to ATLAS3D ➜ detection HI absorption in ATLAS3D ~20% (for lower radio power $<10^{22.5}$ W/Hz)
all narrow HI absorption profiles (<100 km/s)

Not the most exciting results of ATLAS3D, but suggests that to first order HI absorption could be used to trace presence of gas in the host galaxy: can we use it for at high redshift?

Stacking HI absorption

Gereb, Maccagni, RM et al. 2015 A&A





Difference between young/compact and extended sources ➜ relation between presence and characteristics of HI and the evolutionary stage of the radio sources

but in both cases group of objects undetected:

Depleted of gas?

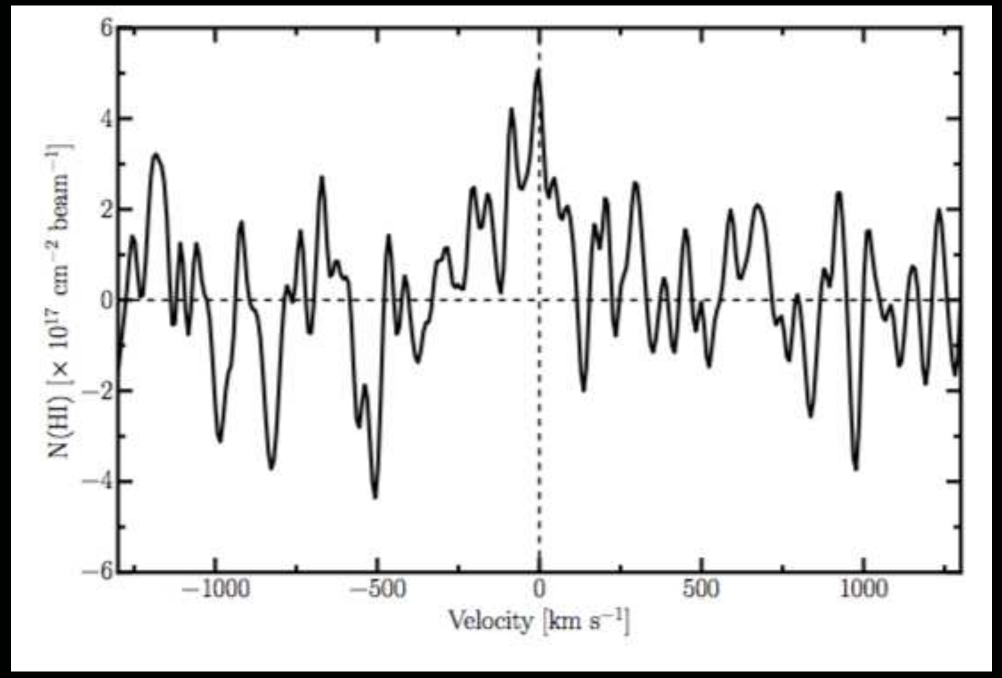
Warm componenet dominating?

Orientation?

…

Young (or restarted) radio sources have:

- ➔ higher detection rate of HI
- ➔ higher optical depth/column density, FWHM
- ➔ gas more unsettled ➔ signature of the effect of radio jets



Stacking ATLAS3D HI central undetected column density of the emission line is $N_{HI} \sim 2.1 \times 10^{19}$ cm^{-2}

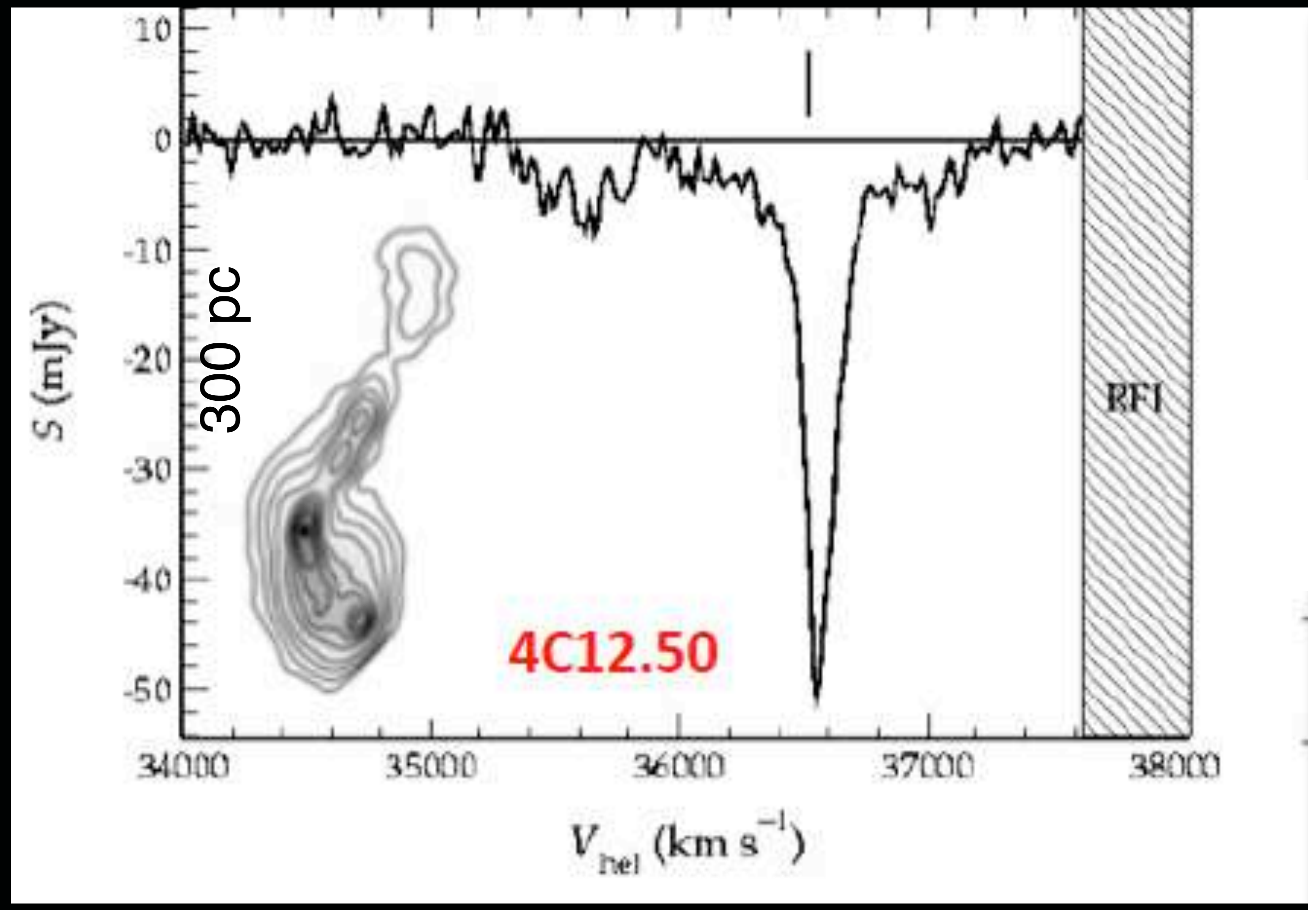
HI absorption stacking doesn't reach yet the sensitivity of deep emission stacking for nearby galaxies (HI absorption limit $N_{HI} \sim 4 \times 10^{19}$ cm^{-2} for Ts=100 K)

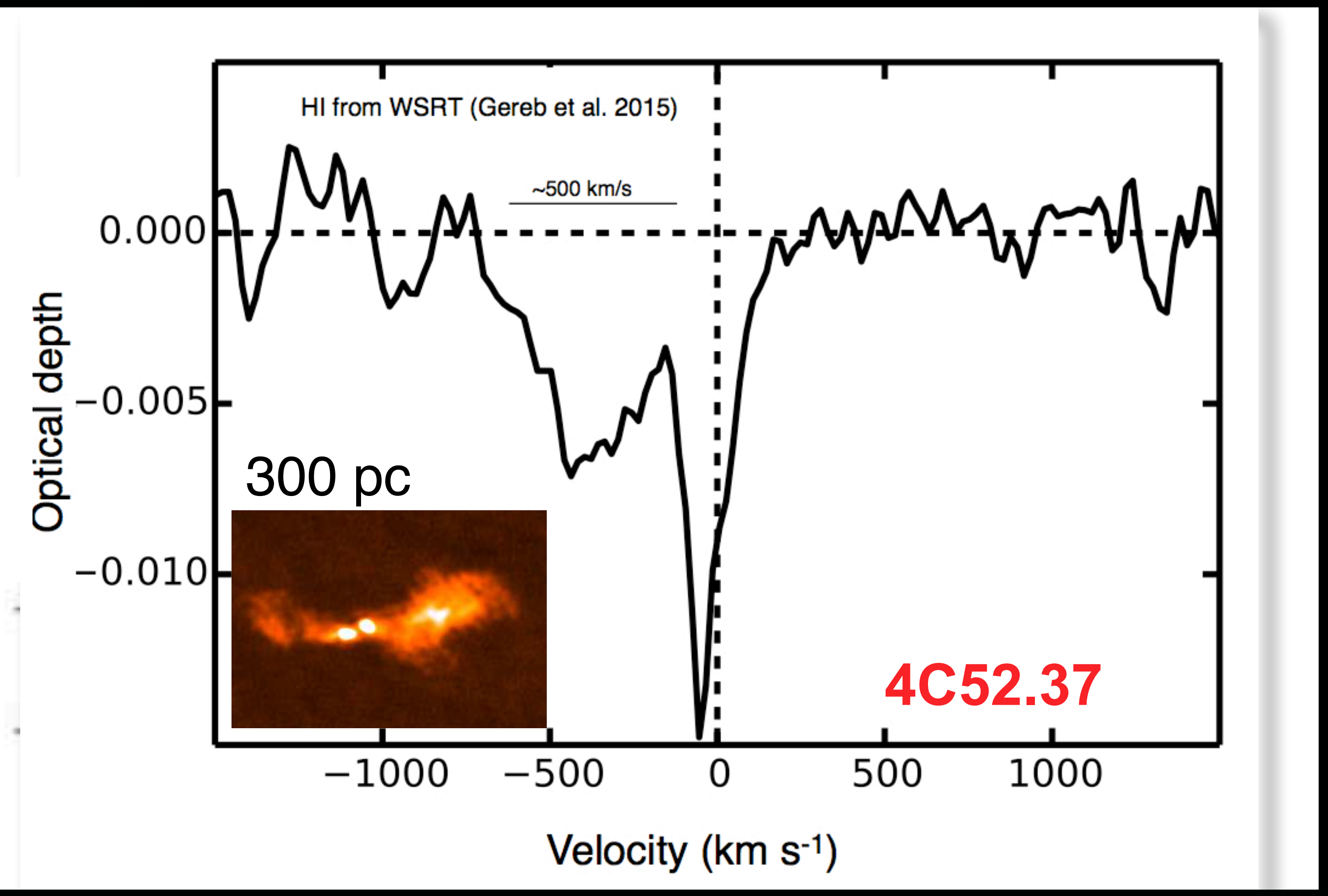
A task for the upcoming surveys!

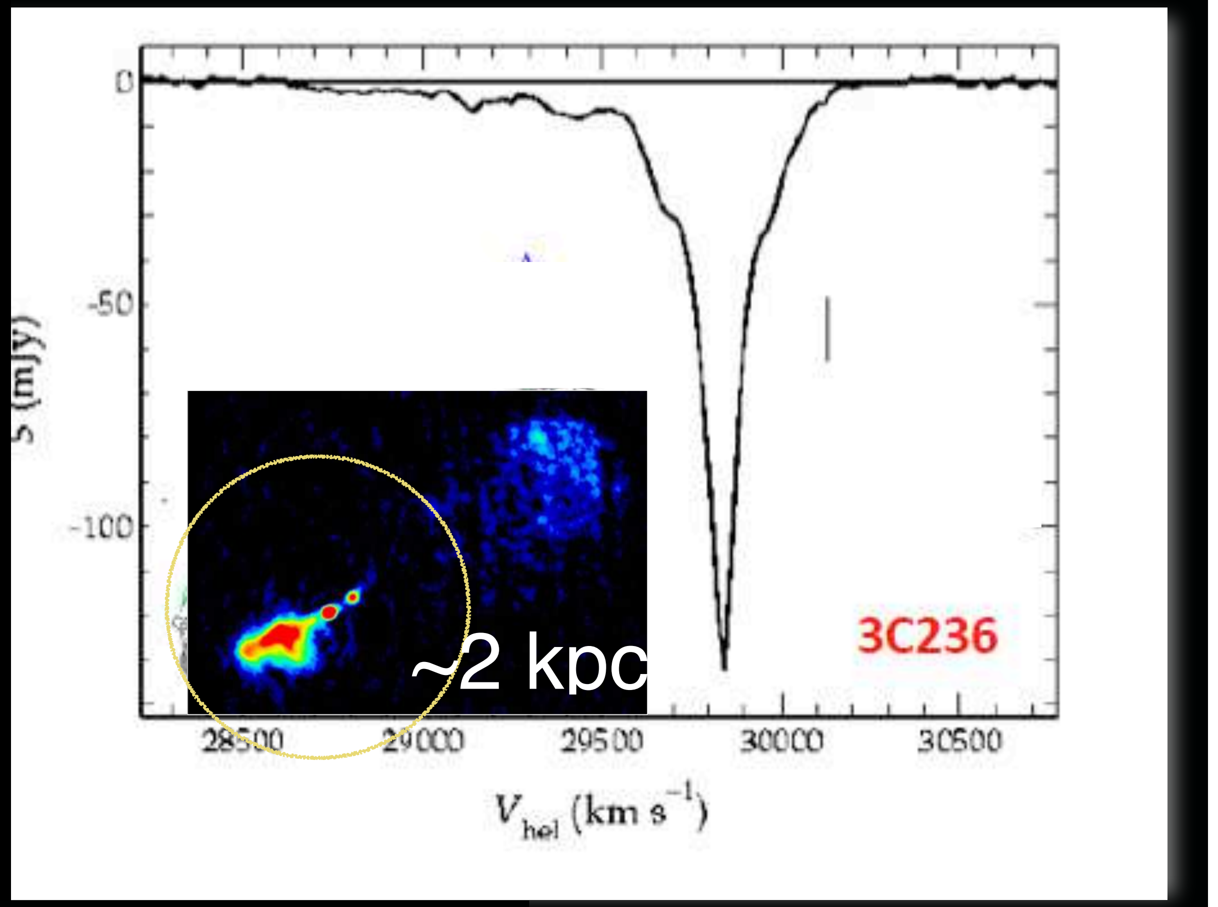
HI outflows traced at high spatial resolution with global VLBI

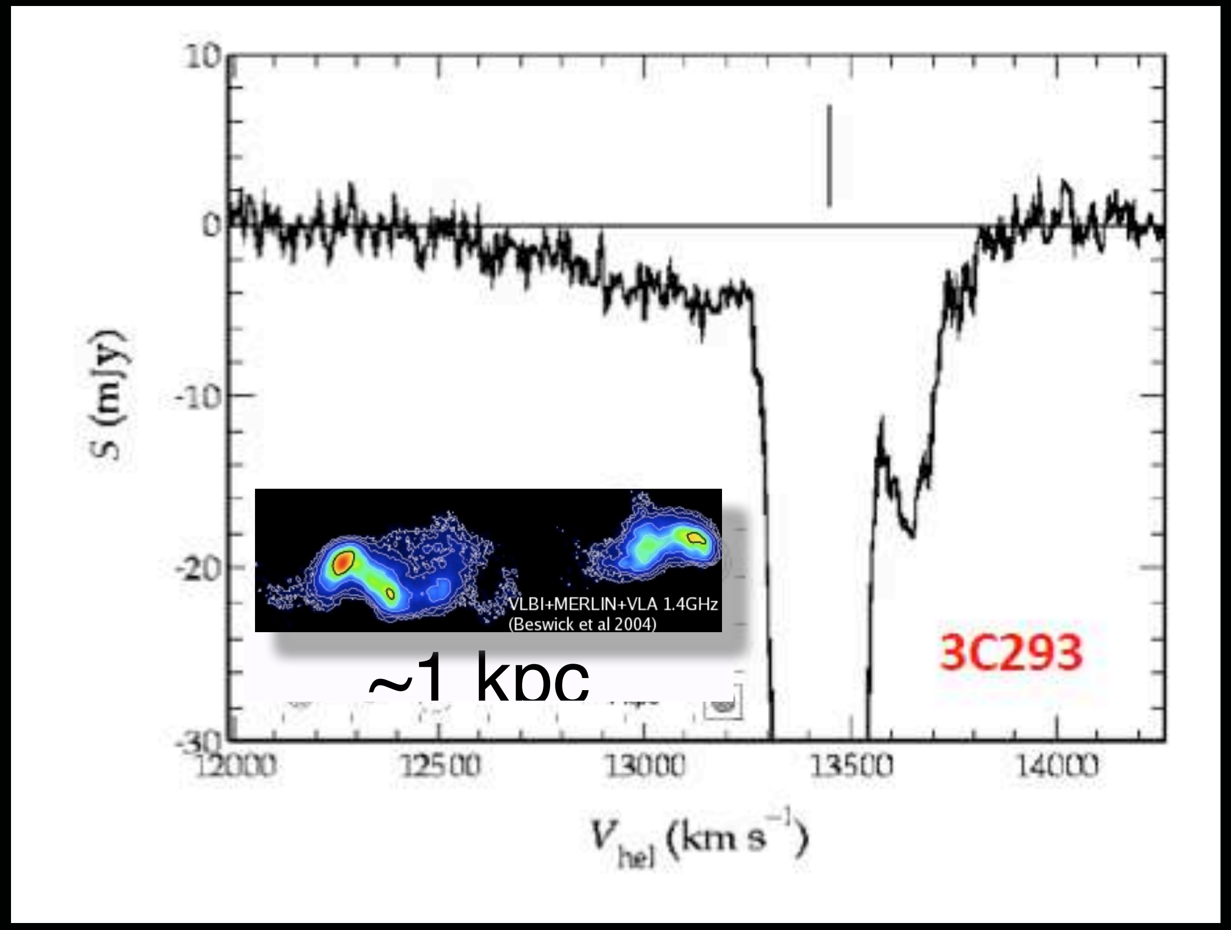
Cases of jet-driven outflows

(suggested by the location of the outflow and/or low optical luminosity)









Smaller → **Larger**

Younger/Stronger interaction? Older?

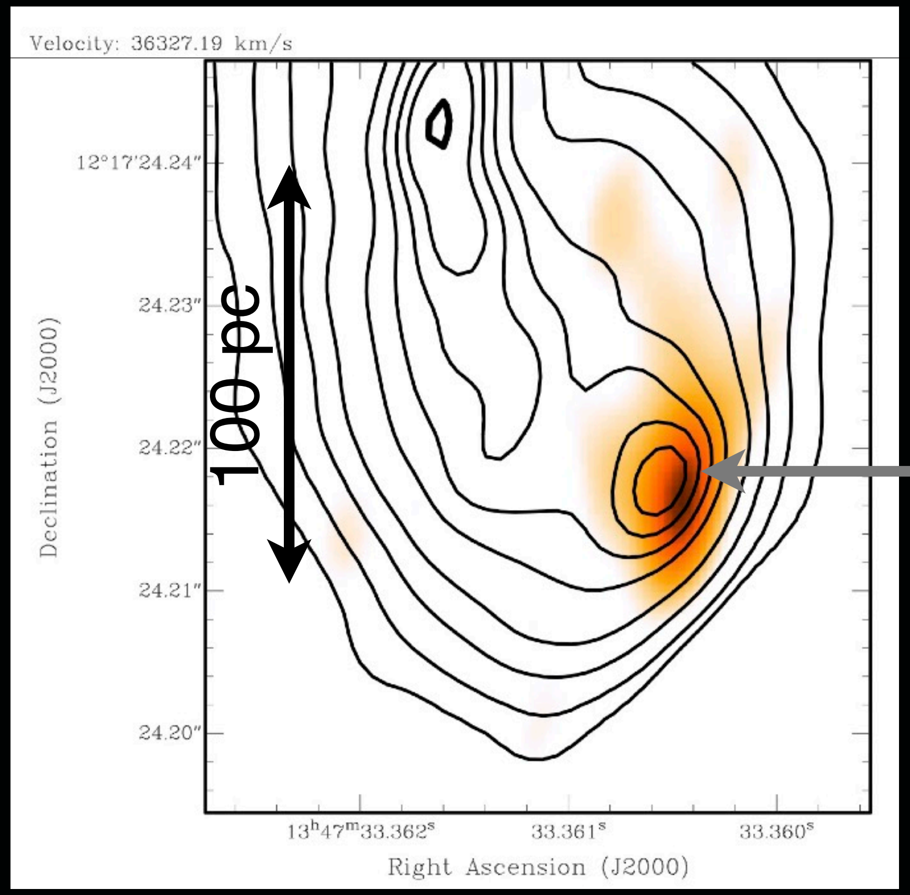
Ages: between **10^3 and 10^4 yrs**

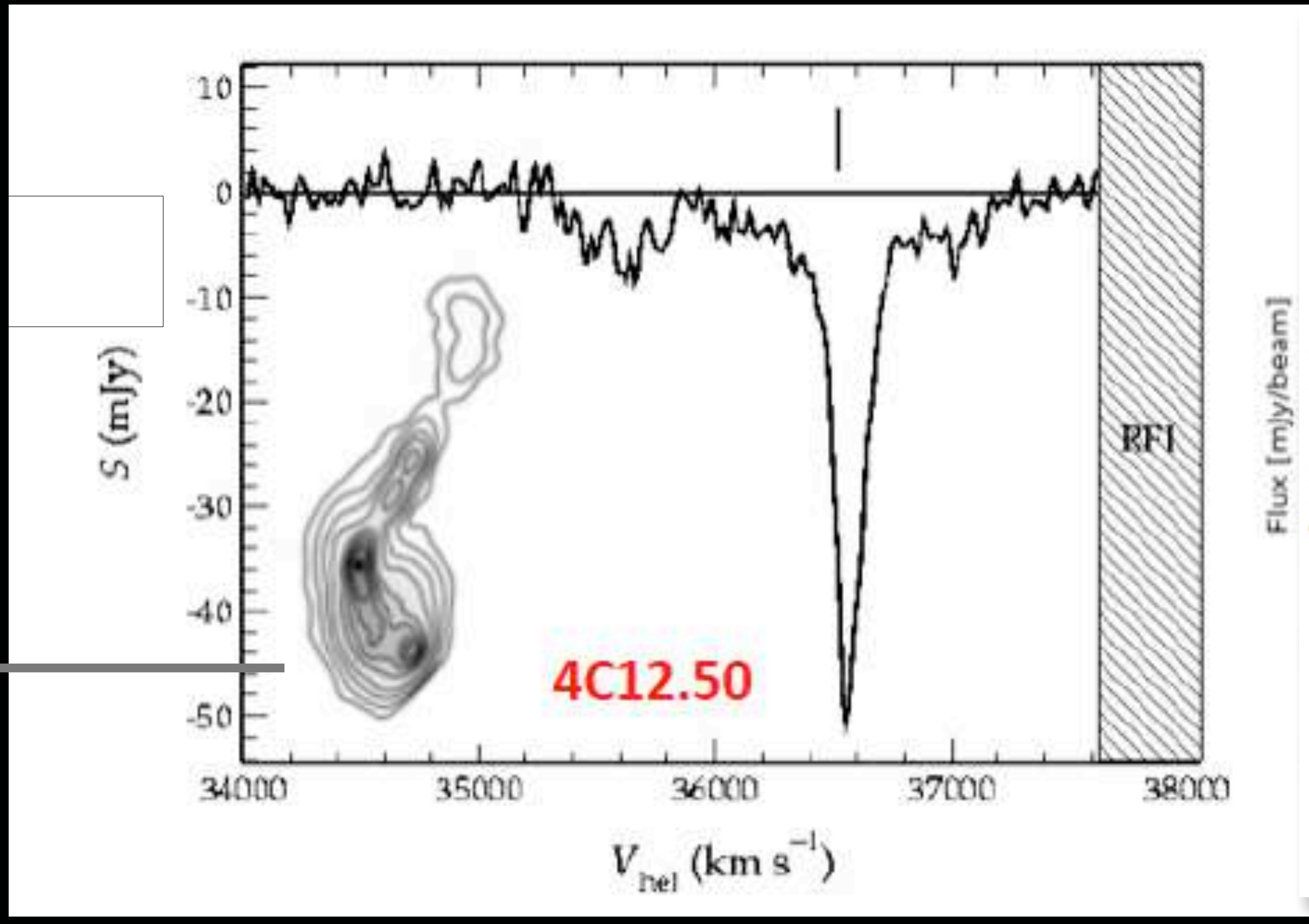
Ages: between **10^5 yr and 10^6 yr**

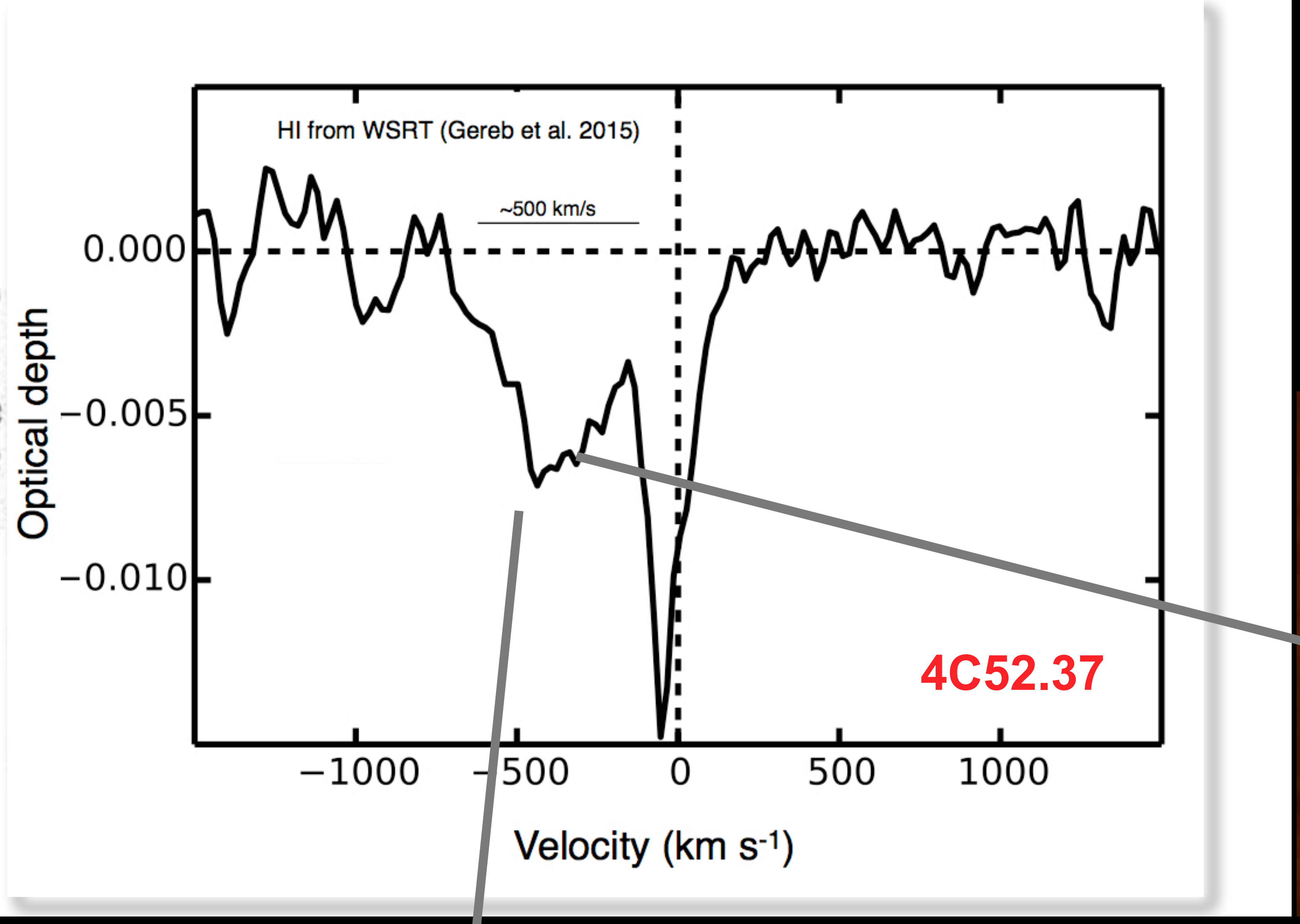
Resolution HI observations ~9 mas ➜ a few tens of pc

Evolution of the outflows as the source expands?

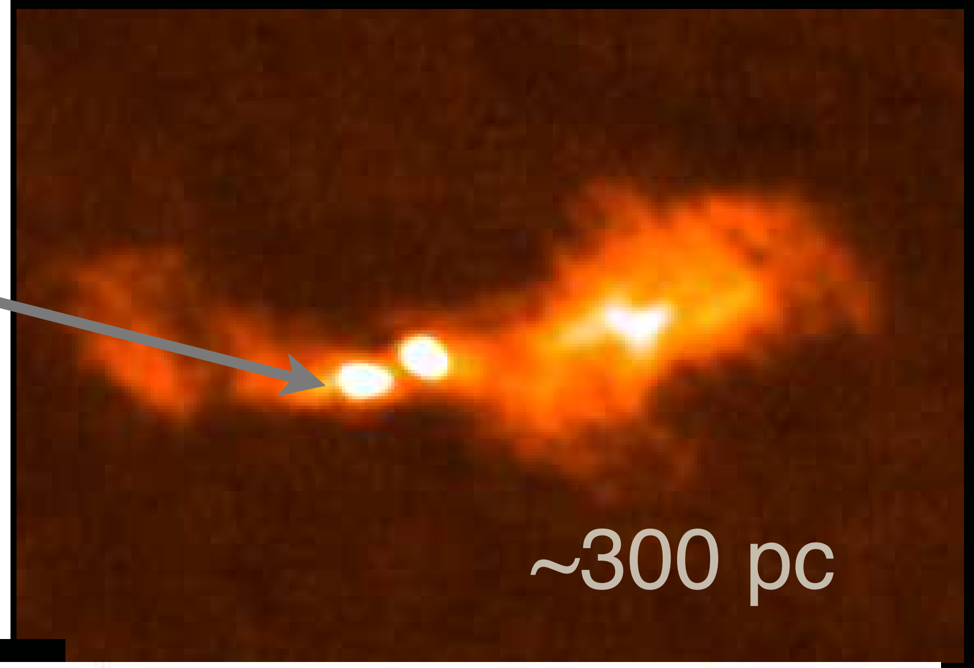
Morganti et al. 2013,







Schulz, RM et al. in prep

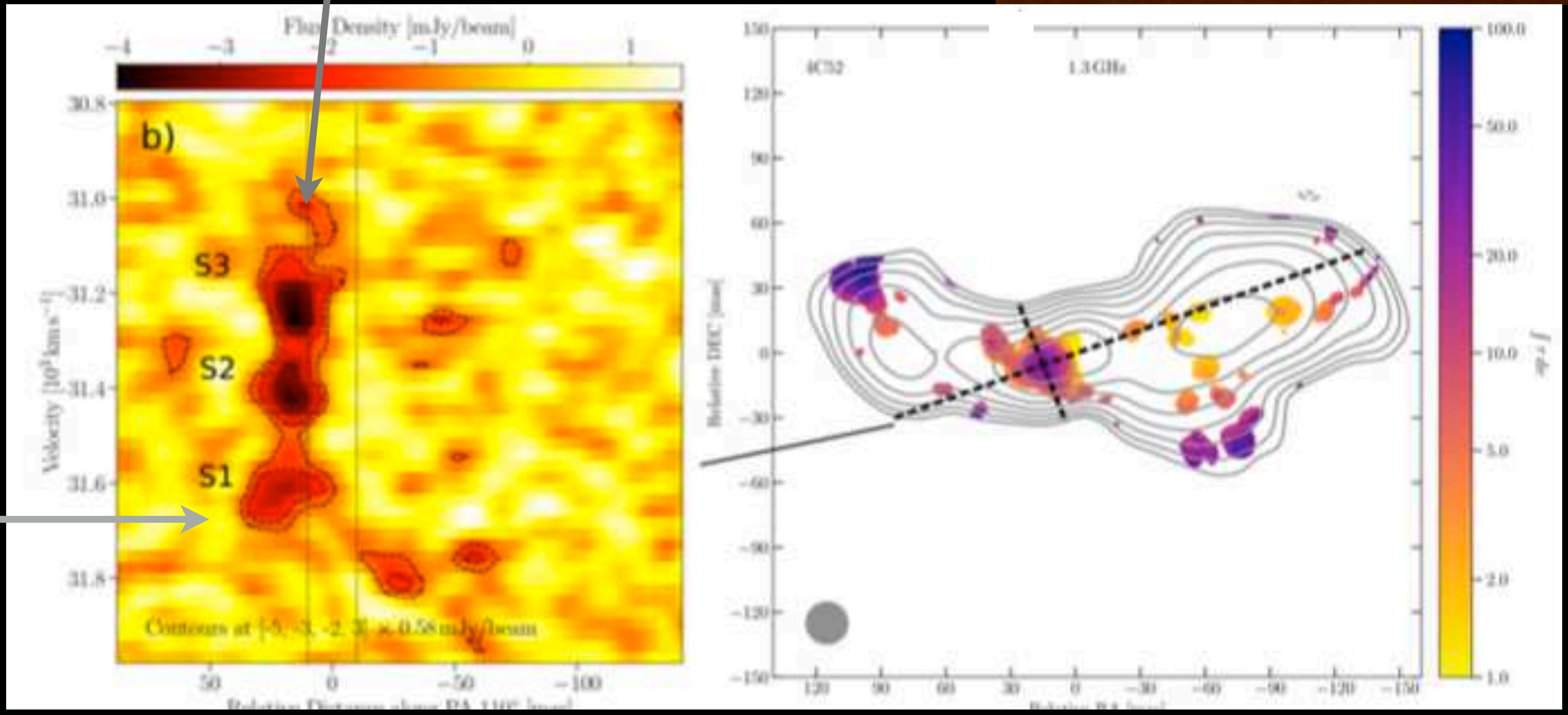


Clumpy medium

The average densities derived for the compact clouds we observed range between 150 cm^{-3} and 300 cm^{-3}

(Morganti et al. 2013)

600 km/s



Systemic velocity

Younger: VLBI recovers all flux of the HI outflows, ➜ absorption produced by (a few) dominant clouds

Outflowing HI clouds in the inner ≤100pc