

# A VLBI view of AGN-driven HI outflows



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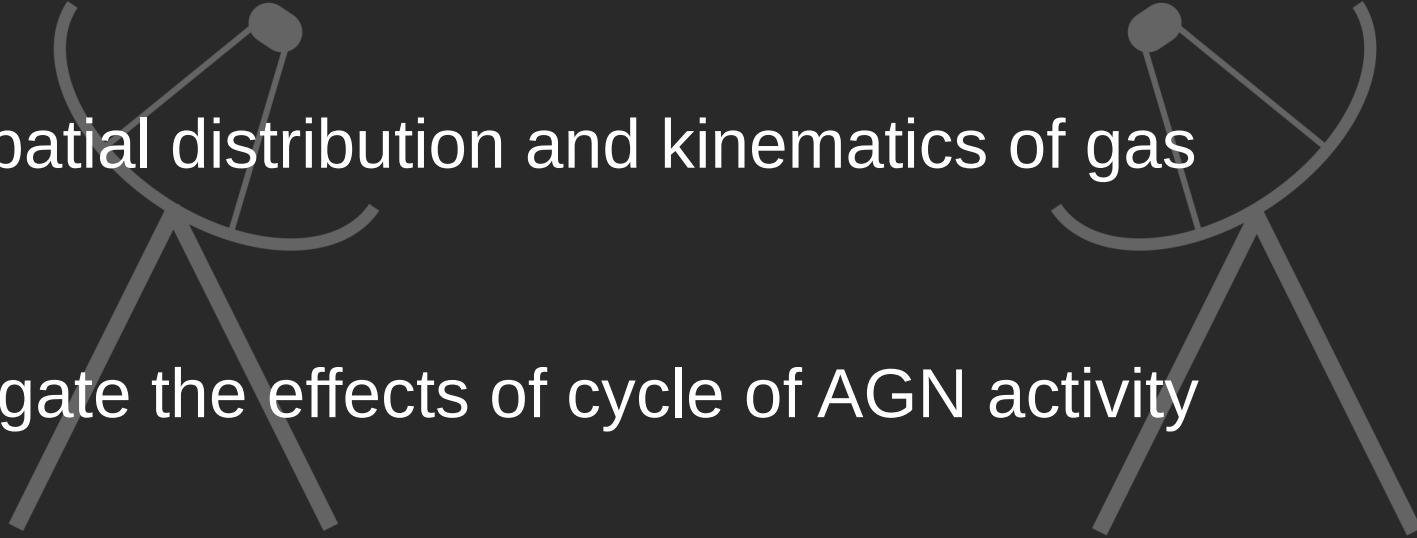


# Why HI VLBI?

Trace interplay between AGN and cold ISM gas

Map spatial distribution and kinematics of gas

Investigate the effects of cycle of AGN activity

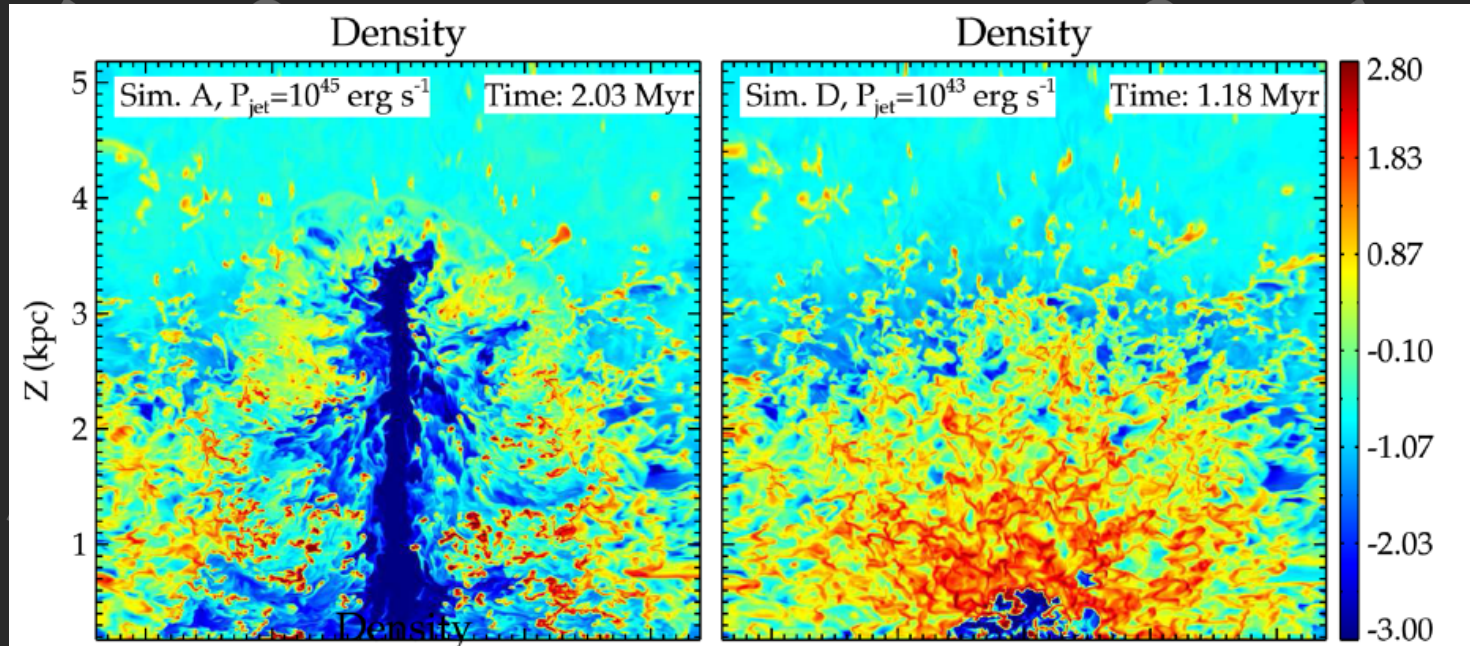


# Why HI VLBI?

High-res numerical simulations are becoming available

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

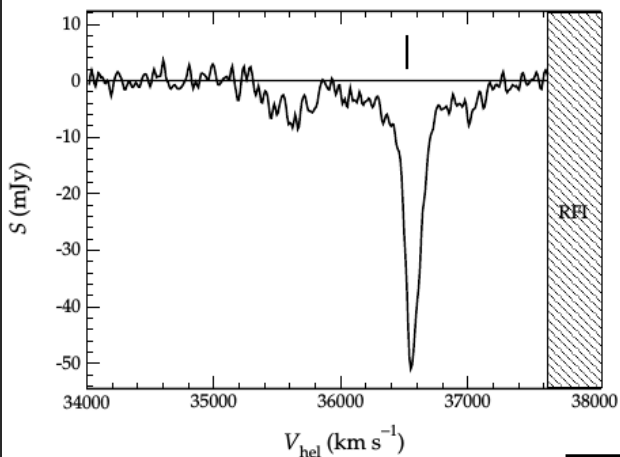
Jet coupling with ISM dominated by clumpiness and jet power



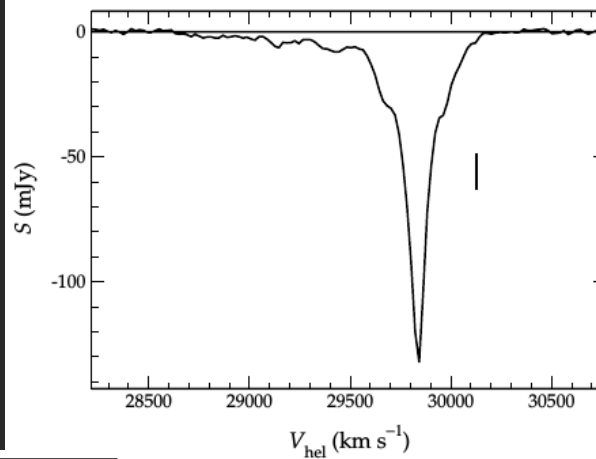
# The sample

All sources are low-excitation radio galaxies (LERGs)

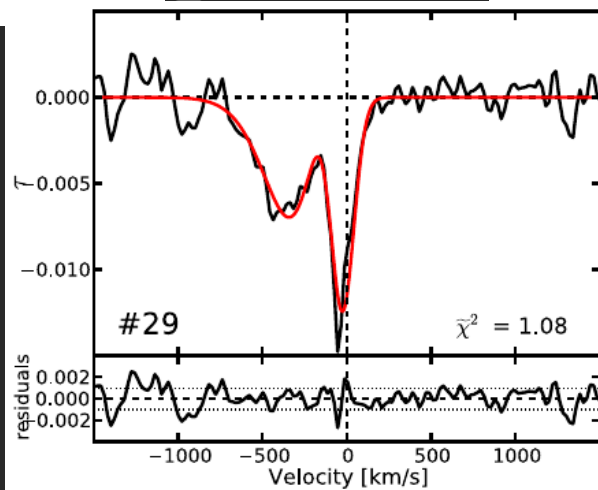
4C 12.50



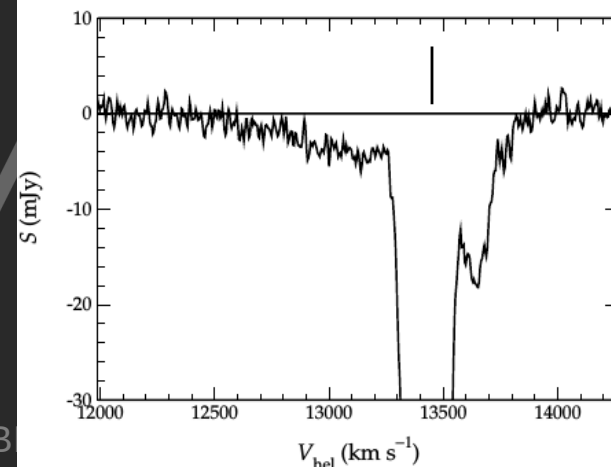
3C 236



4C 52.37



3C 293



Morganti et al. 2005  
Gereb et al. 2015  
2018-08-31

A VLBA



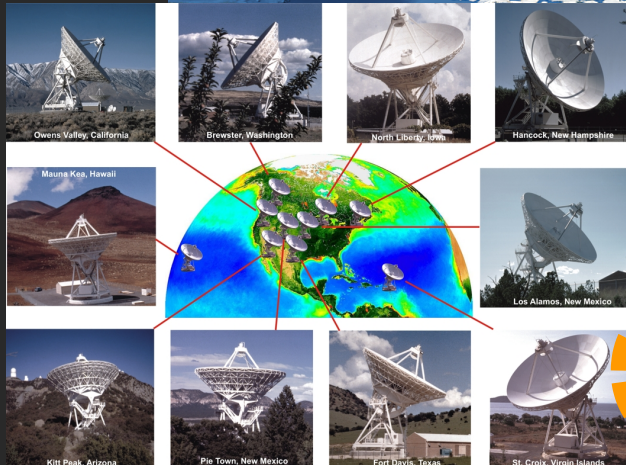
# Global VLBI HI Observation



JIVE  
Joint Institute for VLBI  
ERIC



VLBA



Credit: NRAO



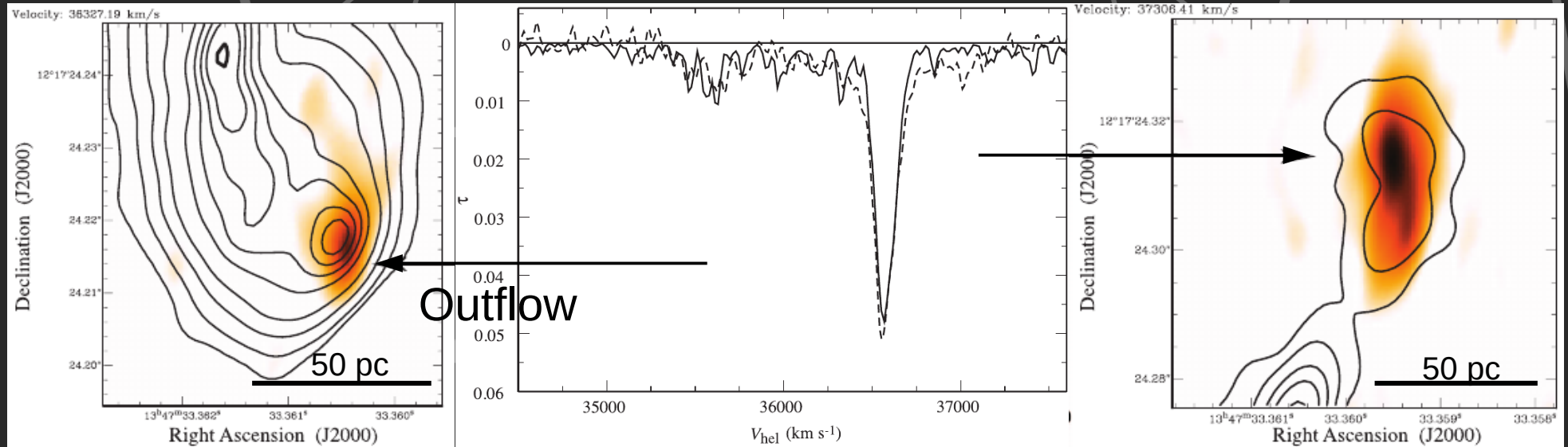
Combined observations by EVN + VLBA + Arecibo

Coordination, correlation and support provided by JIVE

# 4C 12.50

VLBI and WSRT spectrum match

Compact clouds (<50pc) with average densities 150 - 300 cm<sup>-3</sup>

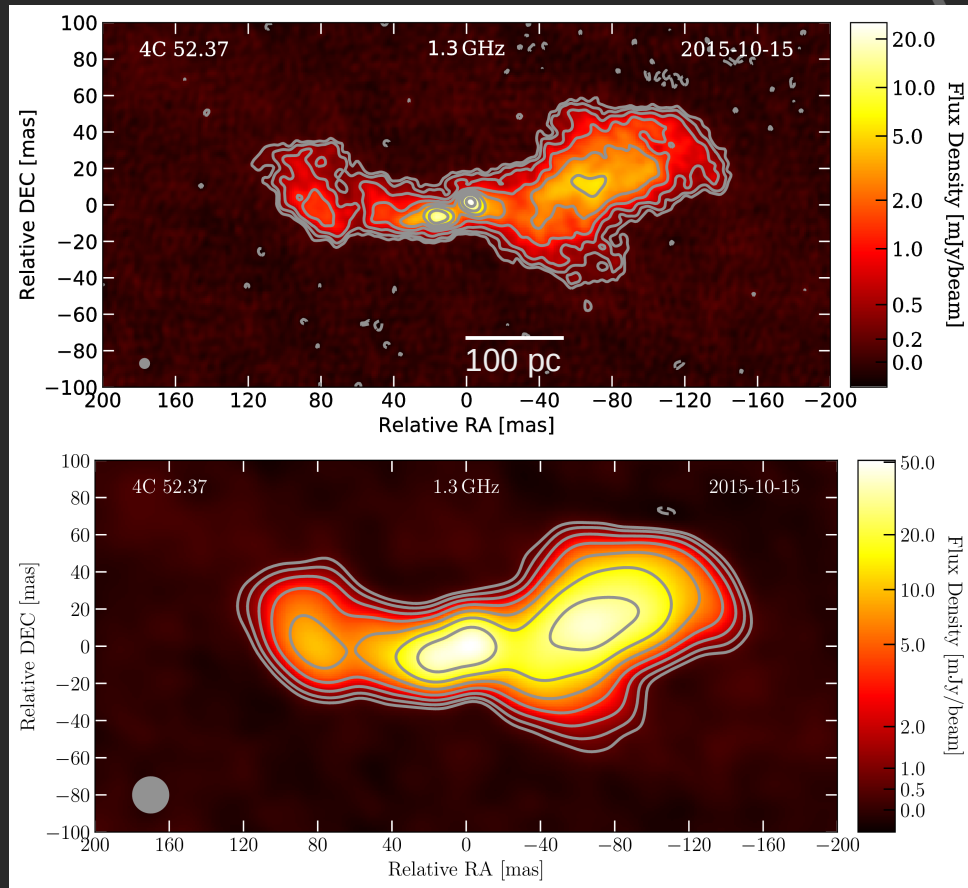
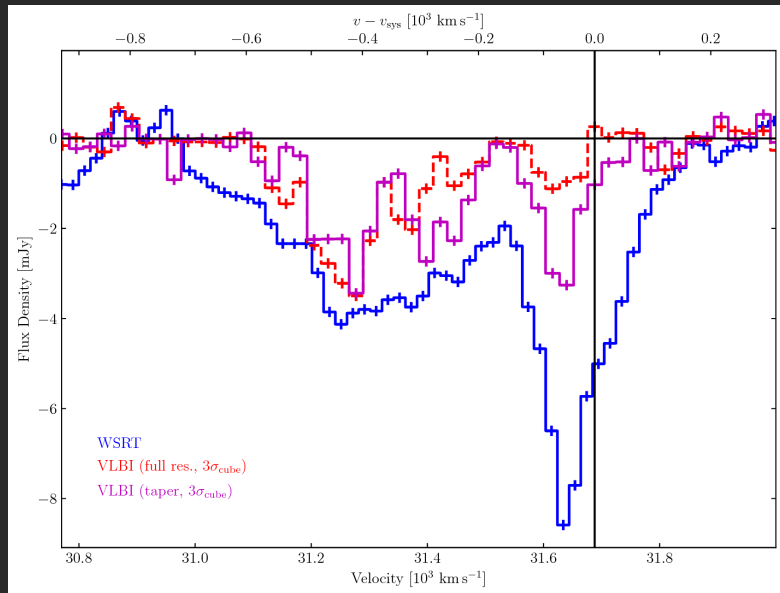


Morganti et al. 2013  
2018-08-31

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# 4C 52.37

VLBI recovers most of the outflow (at multiple resolutions)

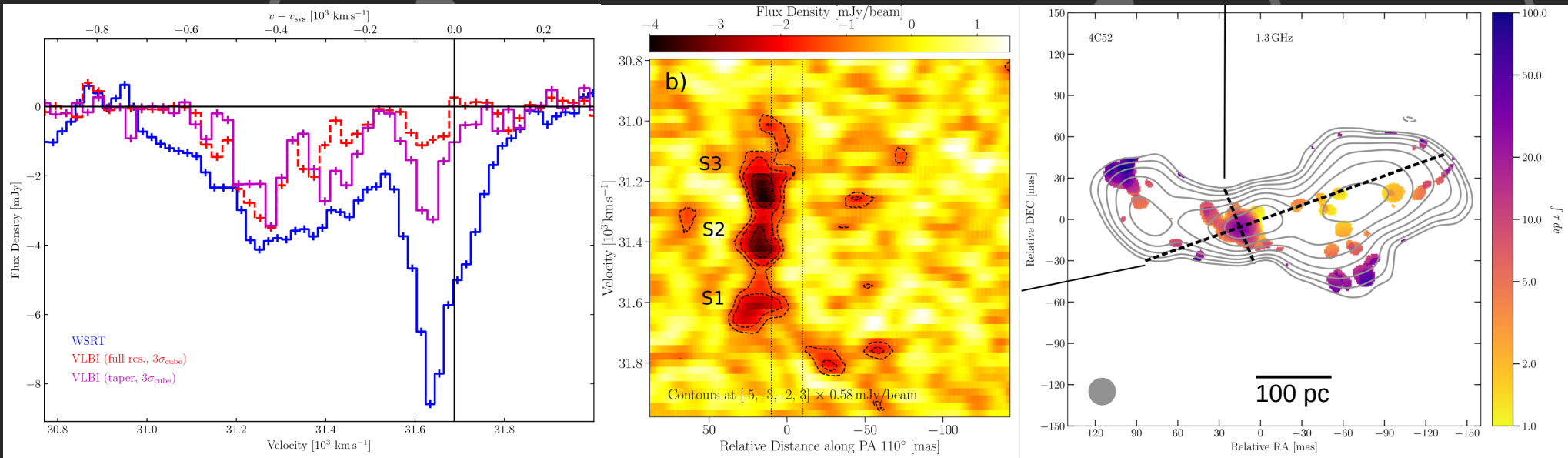




# 4C 52.37

VLBI recovers most of the outflow (at multiple resolutions)

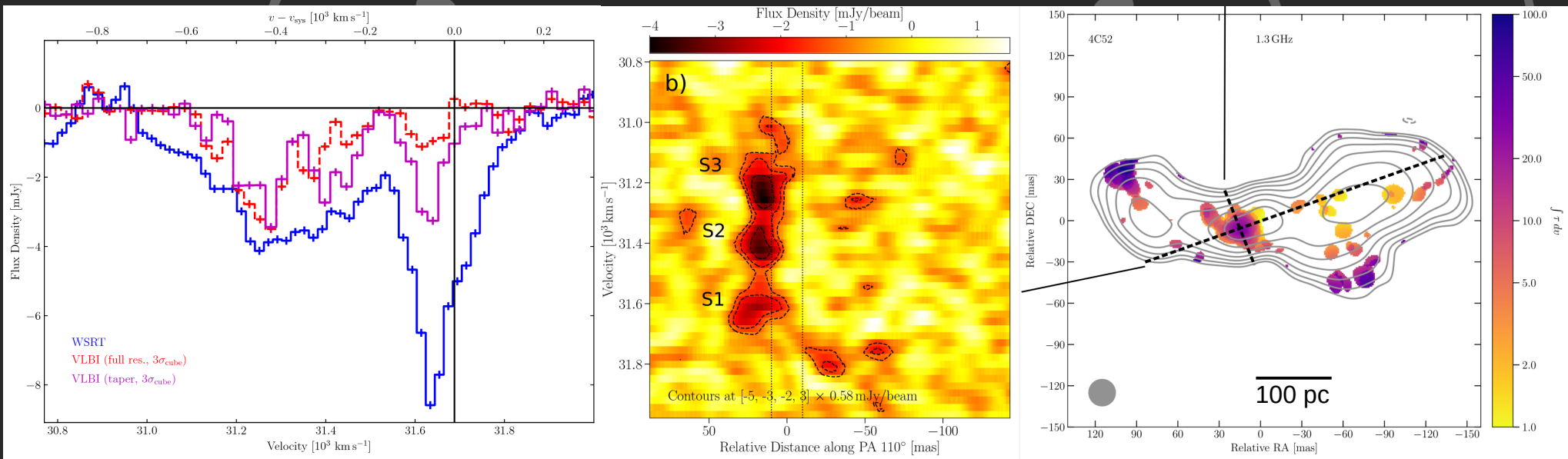
Compact (<40pc) clouds with  $N_{\text{HI}} \sim 2 \times 10^{19} \text{ cm}^{-2} \text{ K}^{-1}$



# 4C 52.37

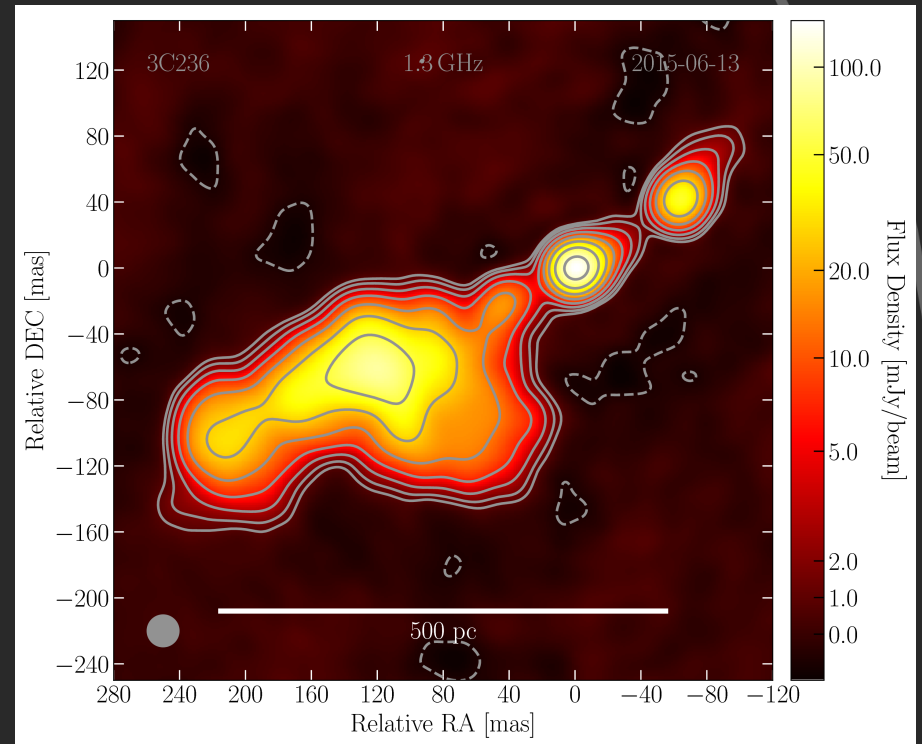
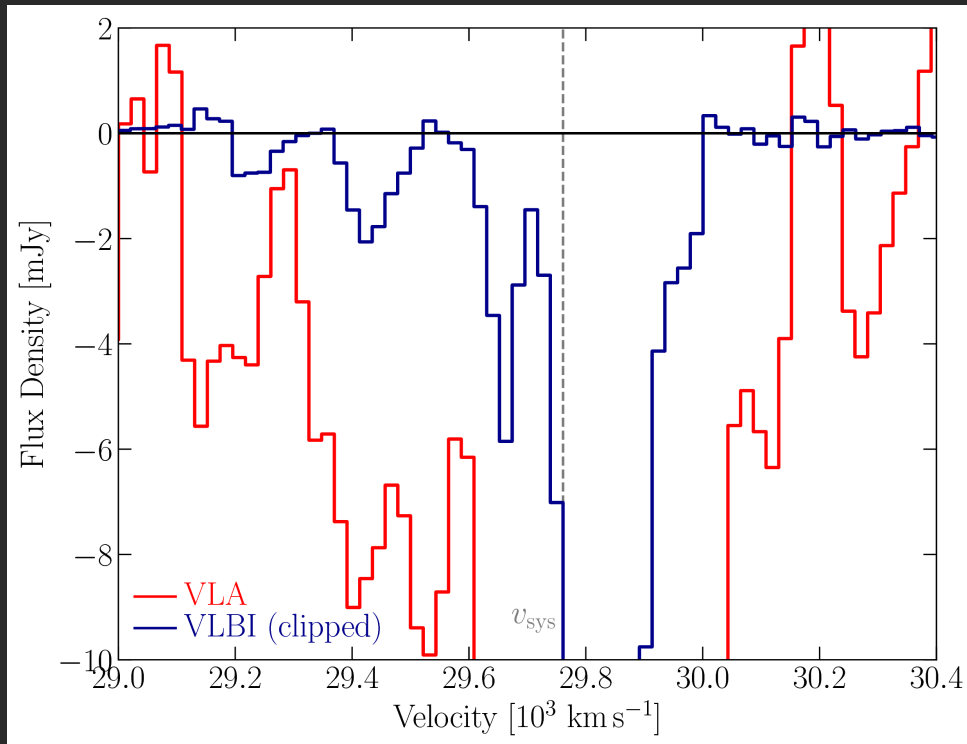
Structure of systemic HI is unclear

Location of VLBI core is unknown => EVN follow-up under way



# 3C 236

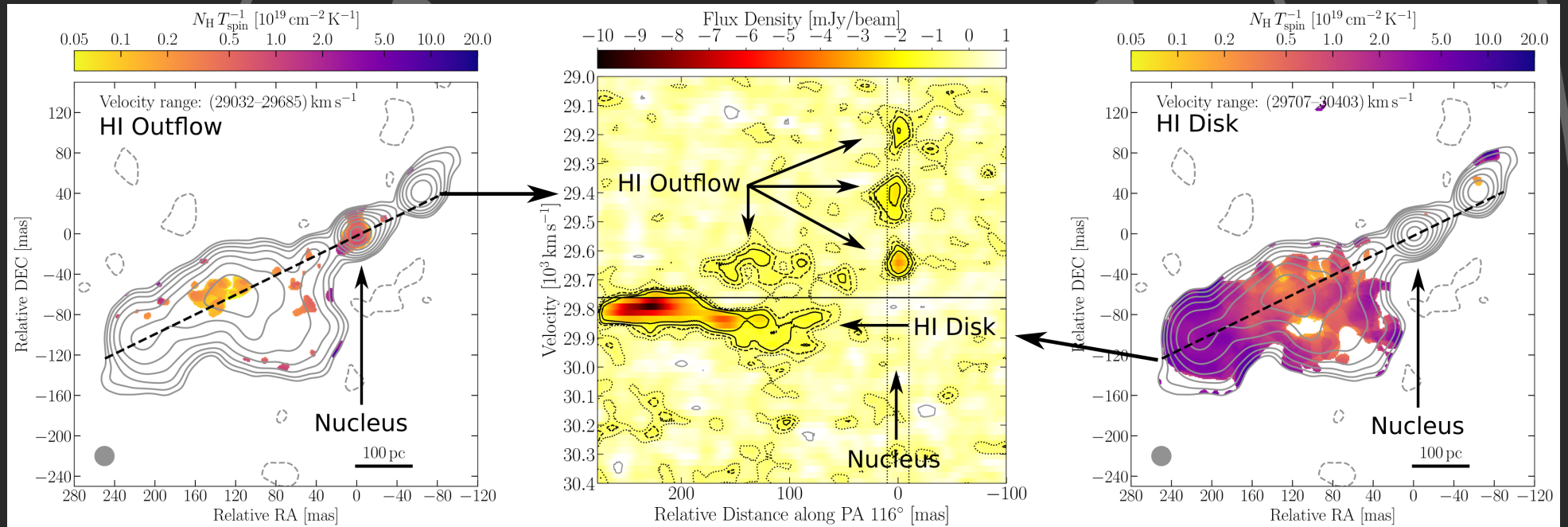
## VLBI recovers fraction of HI absorption



# 3C 236

Clouds with  $0.28\text{-}1.5 \times 10^4 M_{\text{Sun}}$  towards nucleus ( $<40\text{pc}$ )

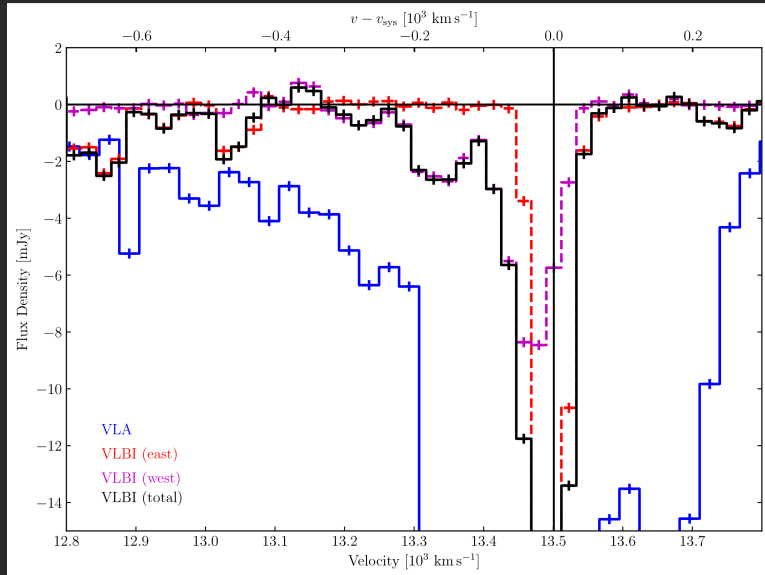
Indications for outflow also towards radio lobe





# 3C 293

## VLBI HI detection limited

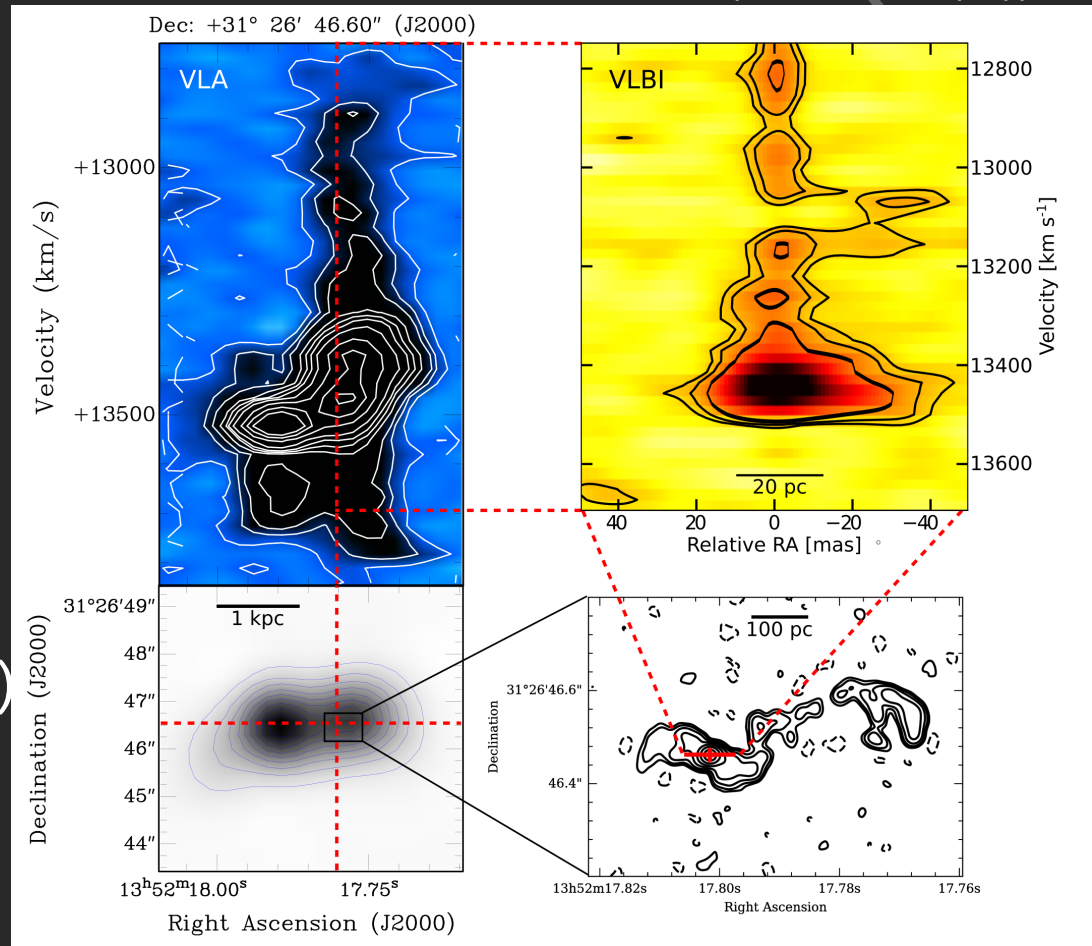


HI clouds towards VLBI core ( $<50 \text{ pc}$ )

From VLA: outflow extends  $\sim 0.5 \text{ kpc}$

VLA (Mahony et al. 2013)

VLBI (Schulz et al. in prep)



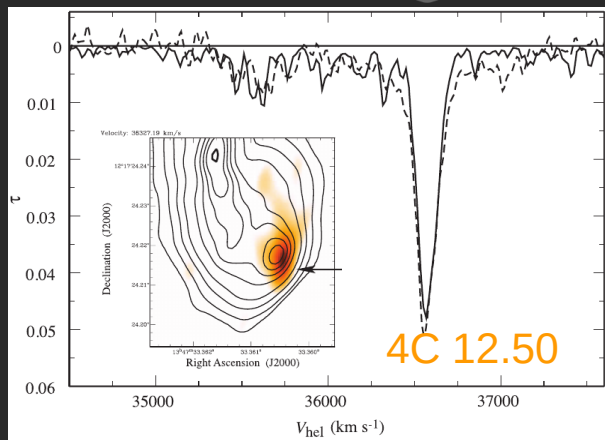
# Tracing AGN Evolution?

Smaller / Younger?  
Stronger interaction?



Larger / Older?

# Tracing AGN Evolution?

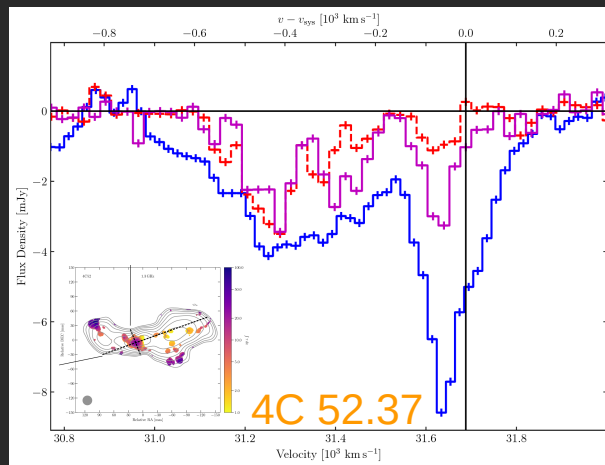
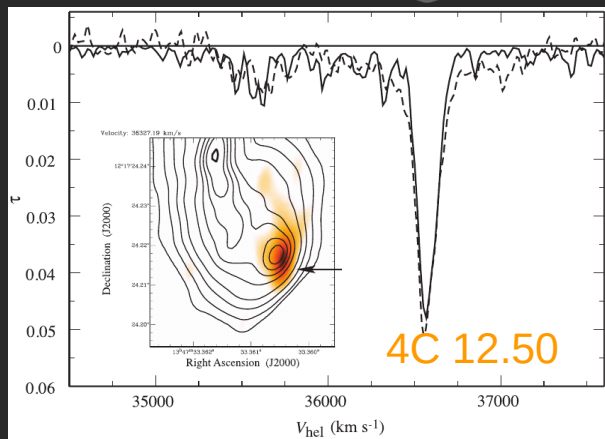


Smaller / Younger?  
Stronger interaction?

Larger / Older?

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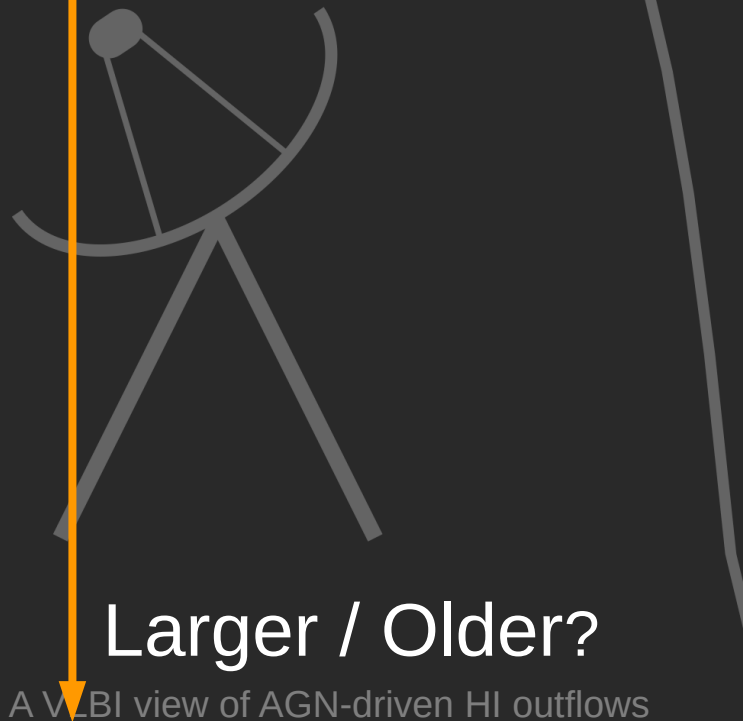
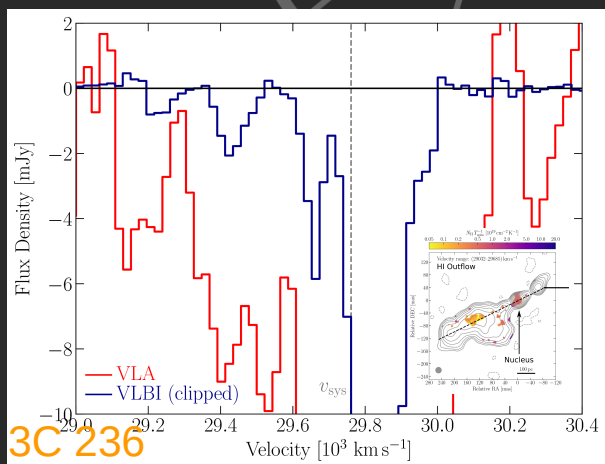
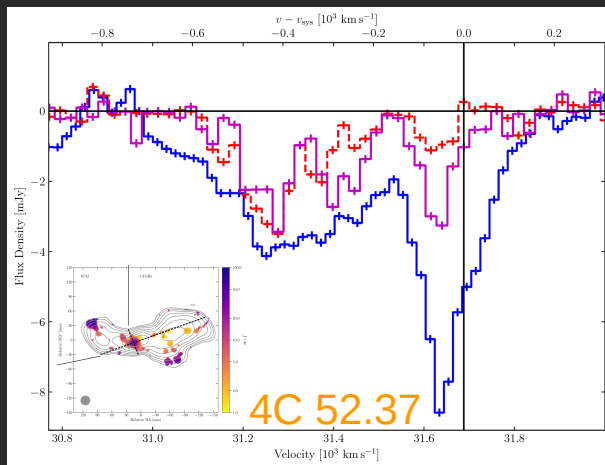
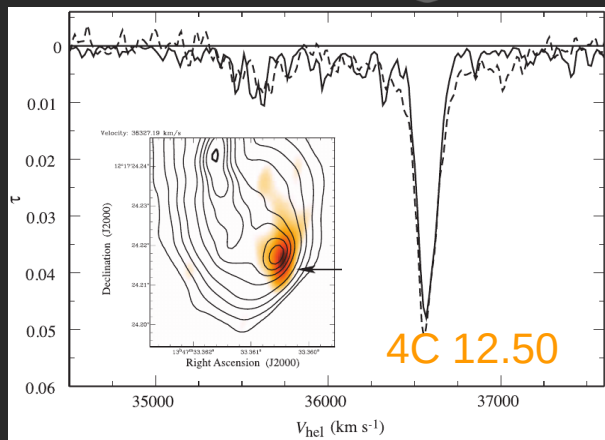


Smaller / Younger?  
Stronger interaction?

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# Tracing AGN Evolution?

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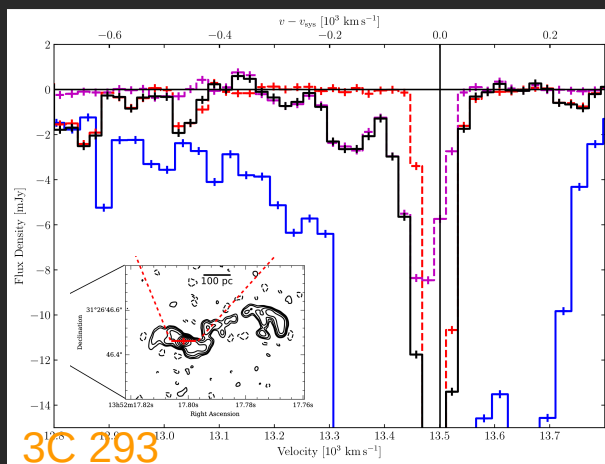
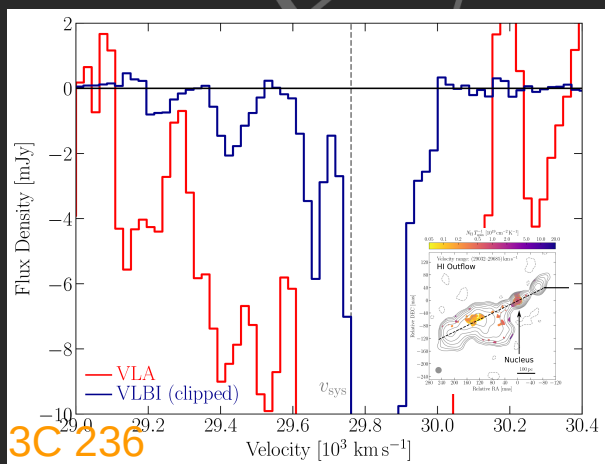
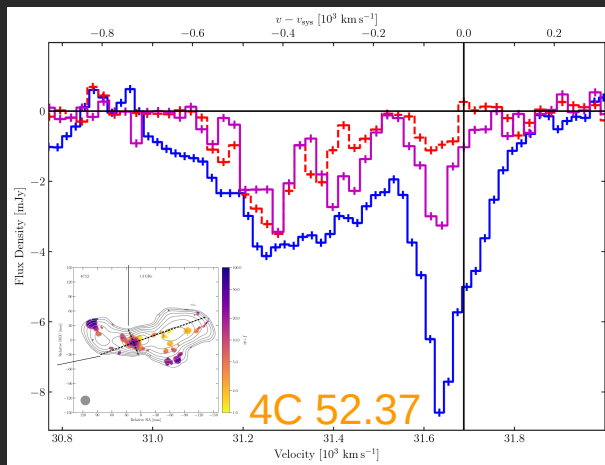
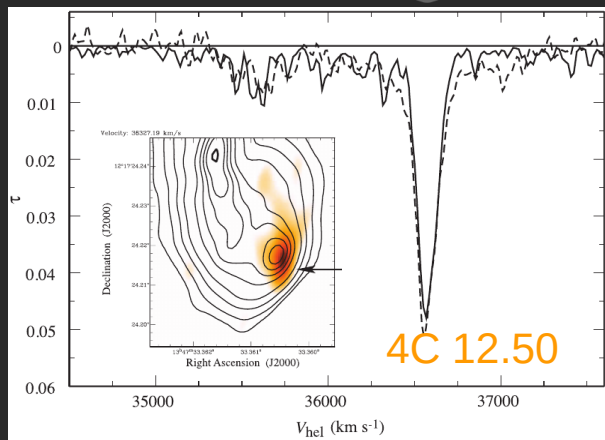


Larger / Older?

A VLB I view of AGN-driven HI outflows

# Tracing AGN Evolution?

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Stronger interaction?



# Summary

Clumpy medium observed in all sources

HI on small scales towards nuclear region ( $< 40\text{pc}$ )

Tentative signs of evolution

Young/smaller sources show stronger signs of interaction

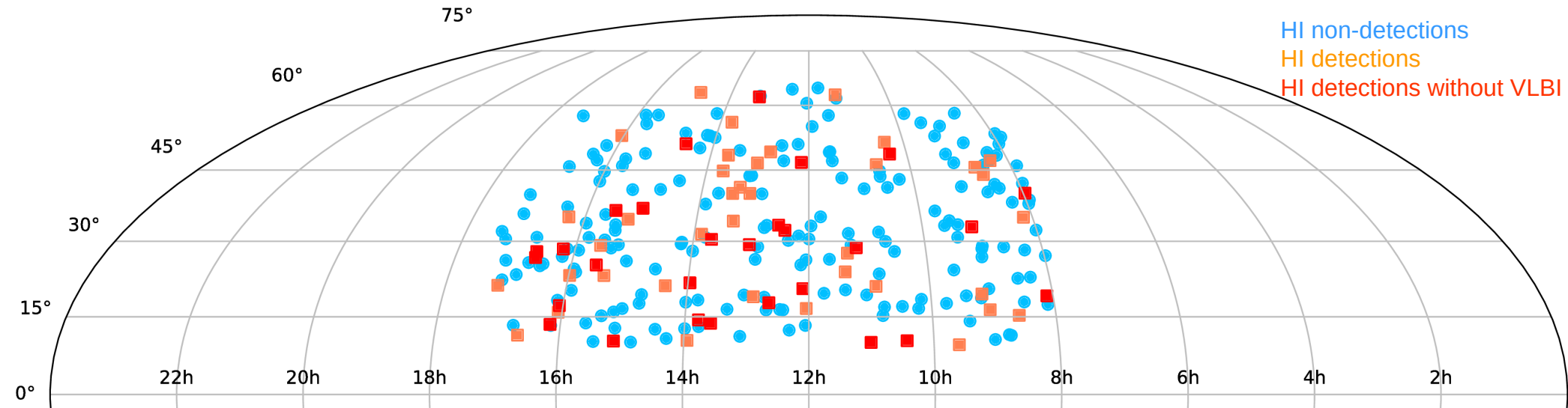


# Outlook

HI Sample from Maccagni et al. 2017

45 out of 66 sources with  $z < 0.11$

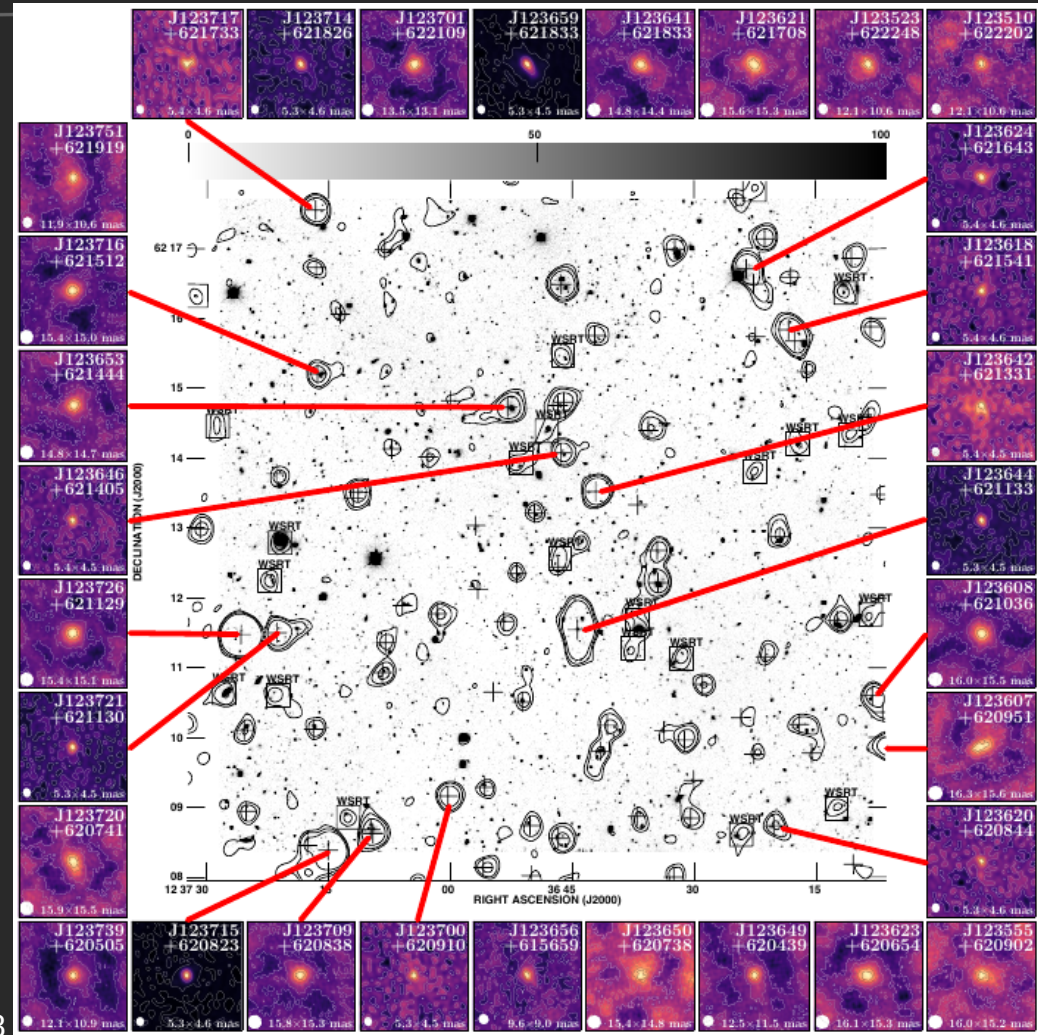
28 without VLBI information => EVN observations underway



# VLBI follow-up

Short term: Improvements  
Use wide field of view  
and e-MERLIN integration  
(in the North)

Long term: Major limits  
1) Redshift ( $< 0.12$ )  
2) Number of stations





# Towards the SKA era



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