Netherlands Institute for Radio Astronomy

Cold gas and the disruptive effect of a young jet

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What is the occurrence of HI absorption and HI outflows: building up the statistics

Two papers published
Gereb, Morganti, Oosterloo 2014
Gereb, Maccagni, RM et al. 2015

also talk of Filippo Maccagni

Large survey of radio galaxies extended and compact

Large shallow HI survey (WSRT)
➔ **almost 200 objects observed so far**

Targets: radio sources from FIRST
> 50mJy identified with SDSS z<0.2
(radio power 10^{23} - 10^{26} W/Hz)

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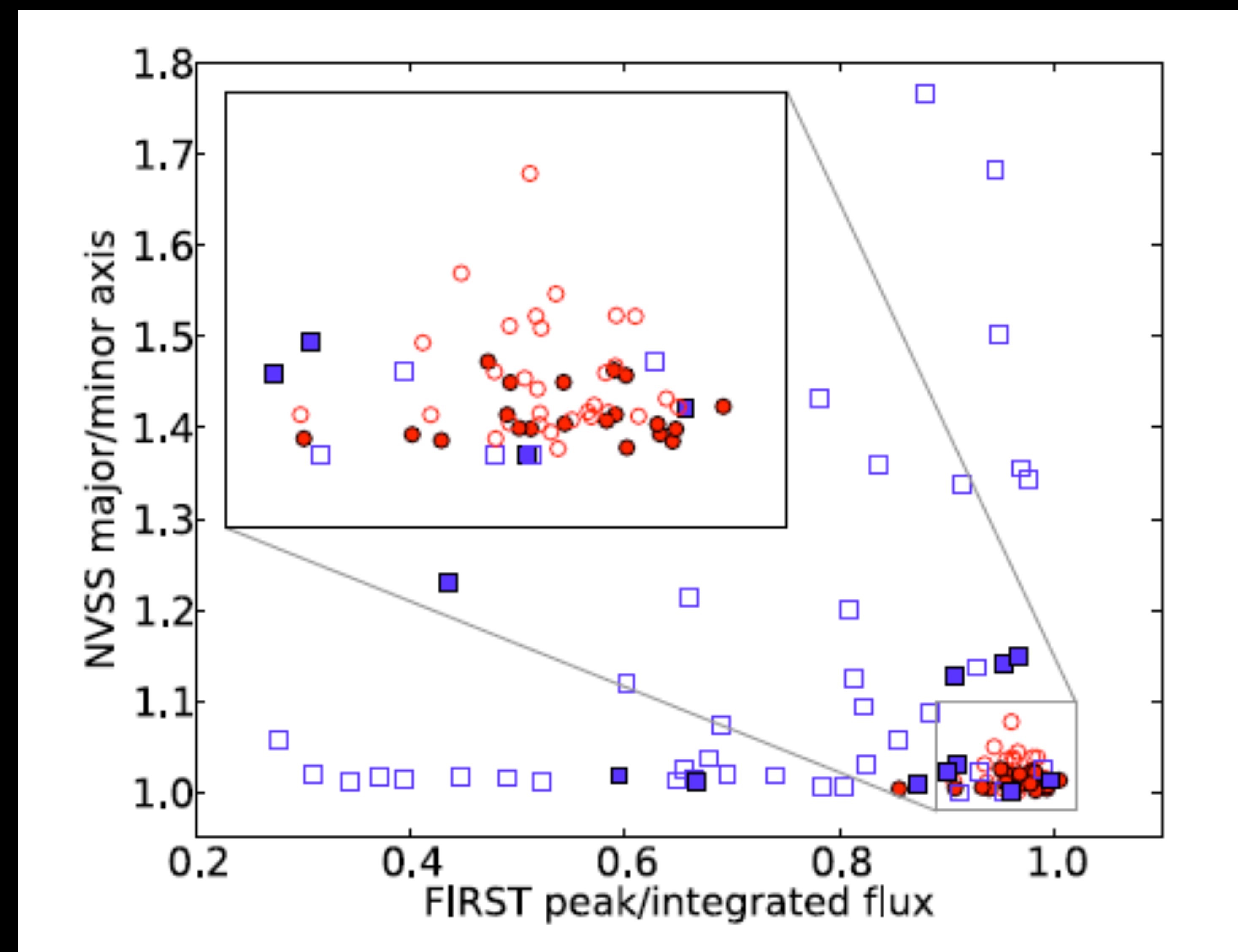
Procedure as much as possible automatic!!

For the first time:

- automatic characterisation of the shapes/asymmetry of the profiles and kinematical properties => *busy function (Westmeier et al.)*
- stacking HI absorption
- in progress: automatic identification of absorption => *software from James Allison*

Automatic selection extended/compact



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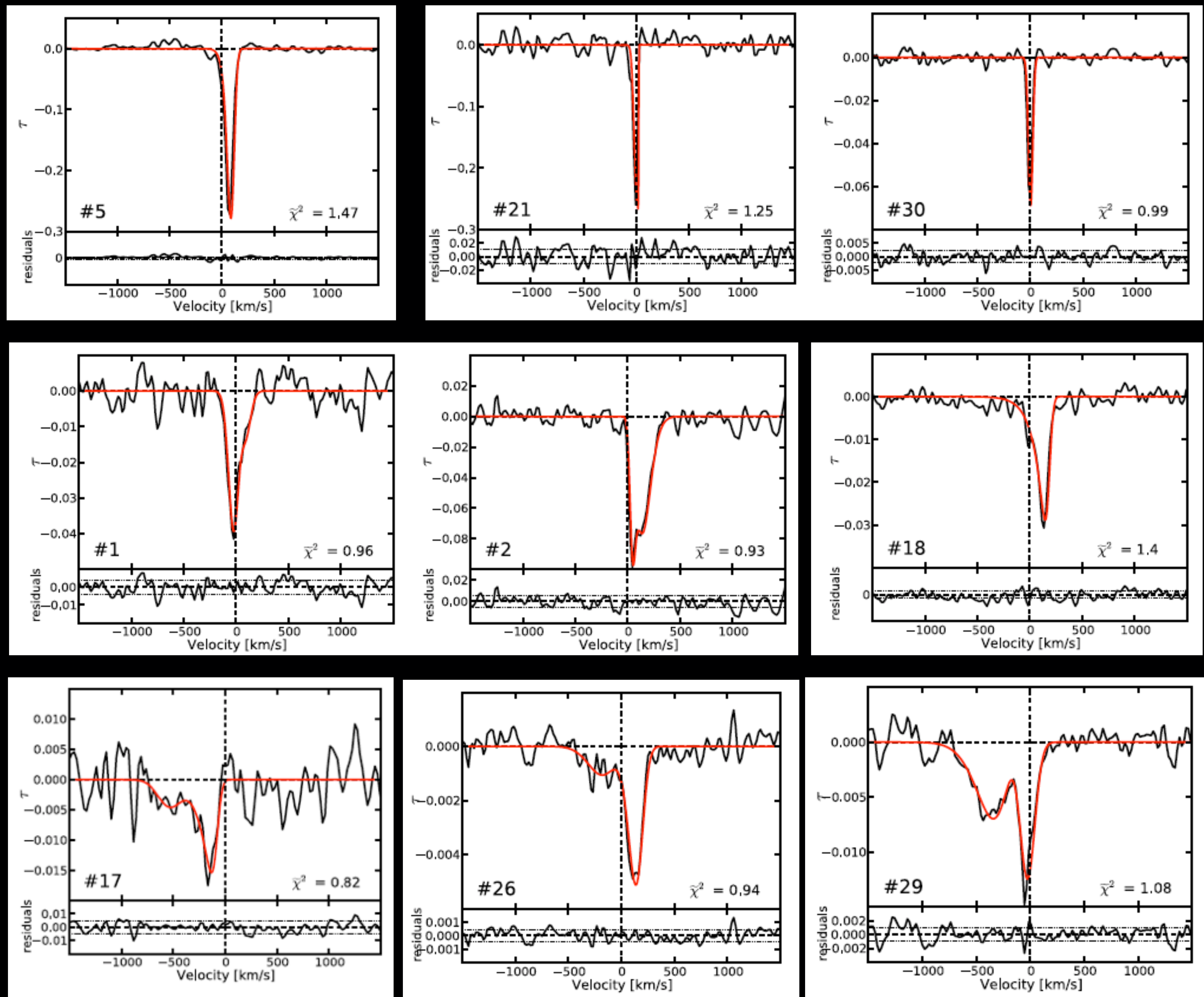
Large survey of radio galaxies extended and compact

...some representative cases!

FWHM < 100 km/s

100 < FWHM < 200 km/s

FWHM > 200 km/s



Gereb, Maccagni, RM et al. 2015

Large shallow HI survey (WSRT)
➔ **almost 200 objects observed so far**

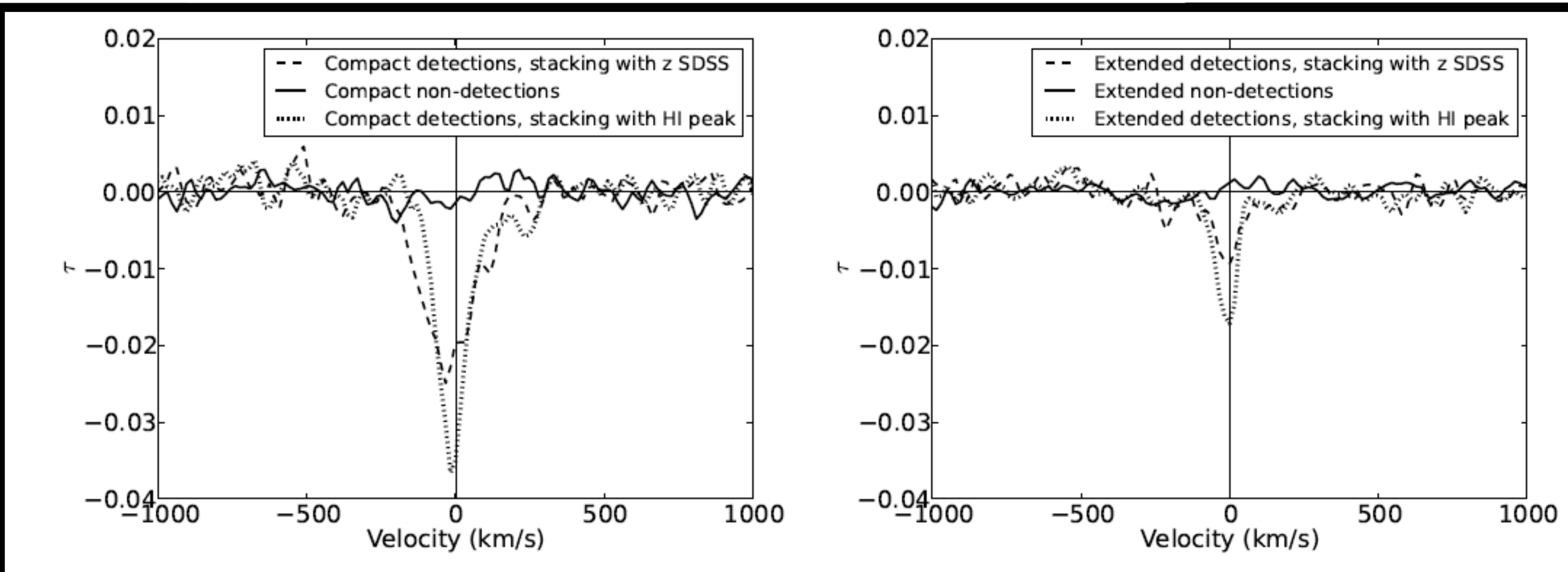
Targets: radio sources from FIRST > 50mJy identified with SDSS z<0.2 *(radio power 10^{23} - 10^{26} W/Hz)*

First surprise:

30% detection rate

Broad variety of shapes and widths
(up to FW20 ~ 820 km/s)

For the first time stacking of HI absorption

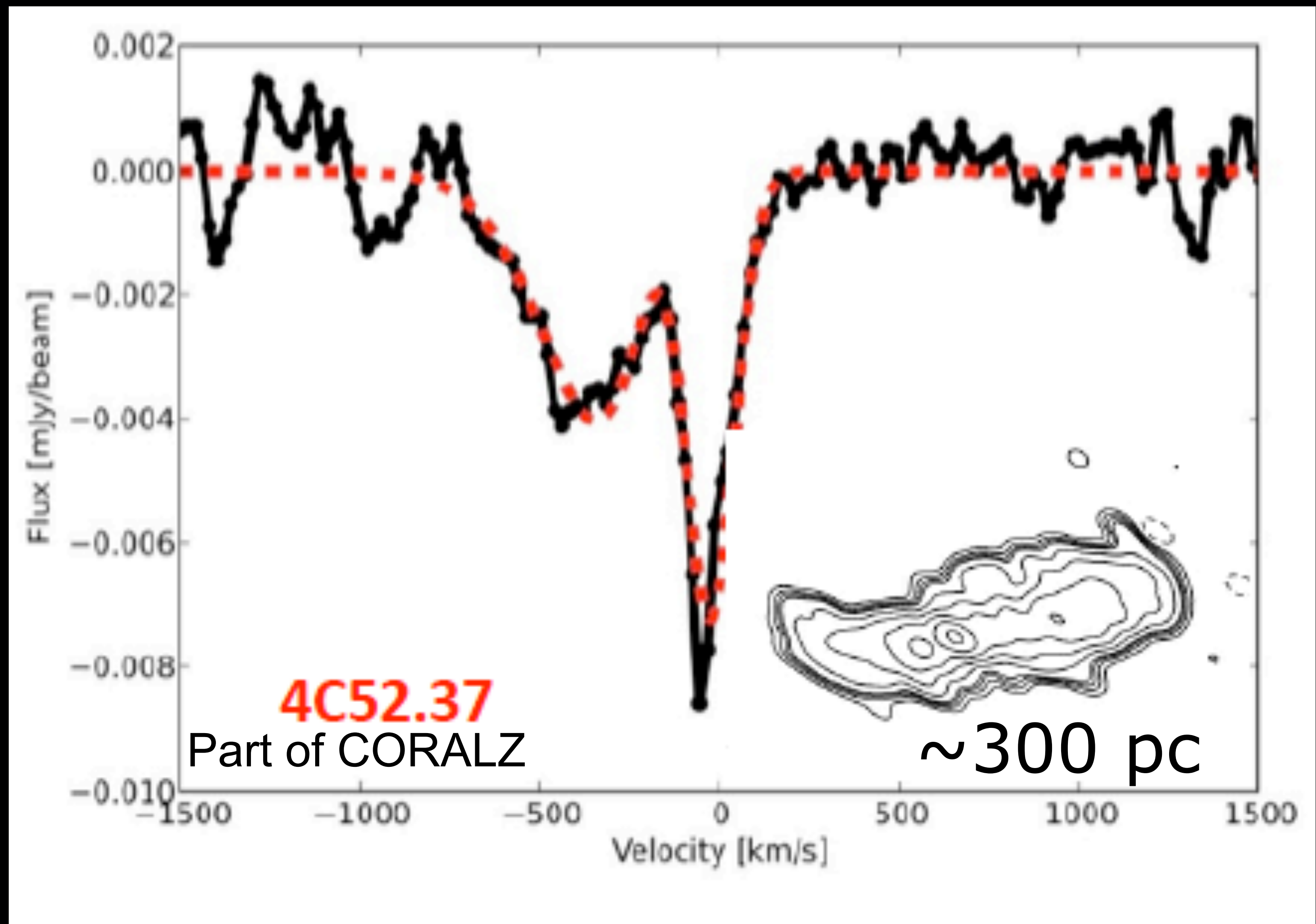


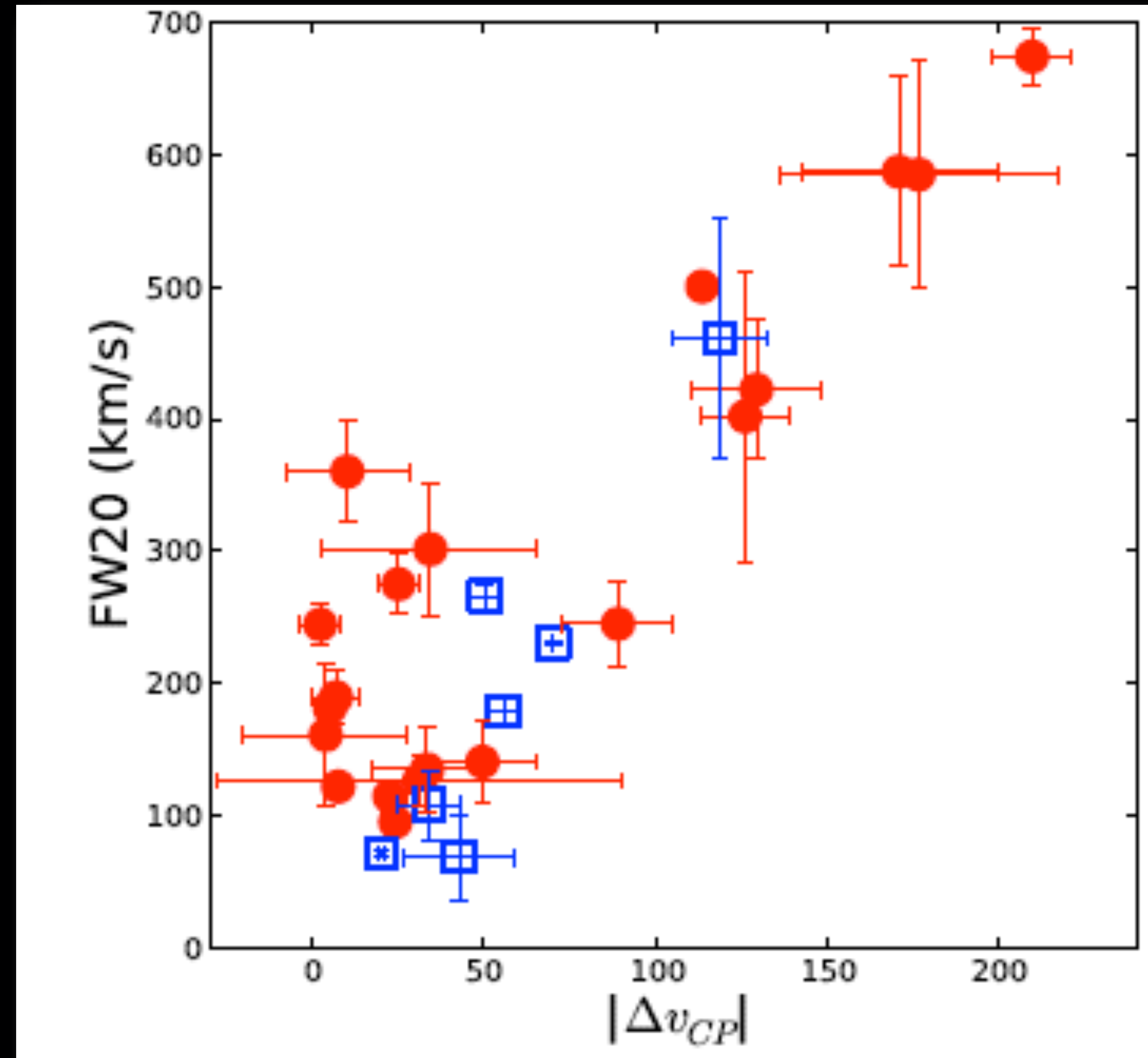
Gereb, Morganti, Oosterloo A&A 2014

Second surprise:

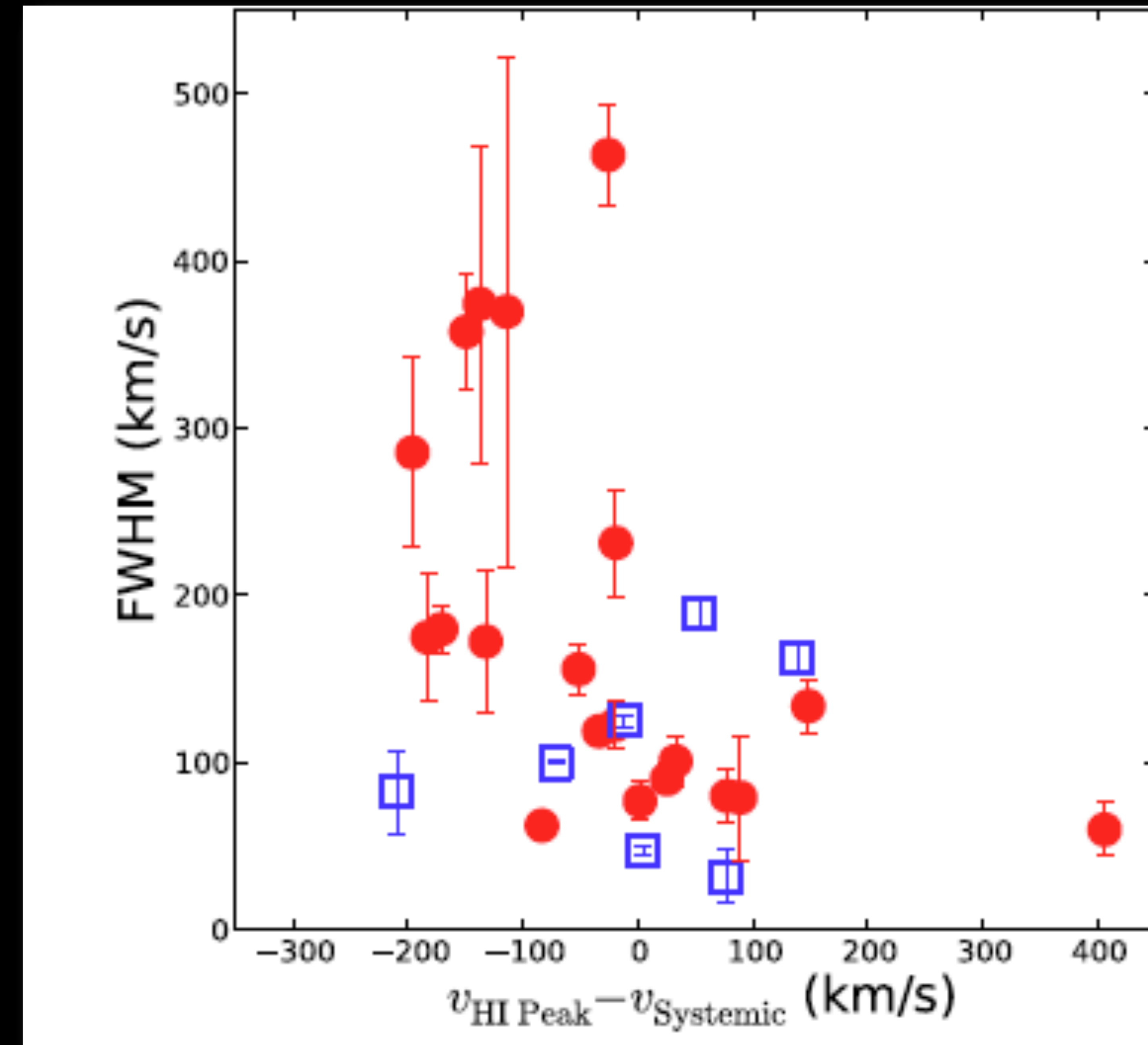
- Difference in the HI properties of young/compact and extended ➔ compact: higher optical depth, column density and FWHM
- Intriguing dichotomy ➔ HI upper limit for undetected ***even after stacking...in both groups***
- Due to orientation effects?

Study of the single profiles: confirming and expand results stacking





Asymmetry of the profile:
offset between centroid and peak



● *compact/young*
□ *extended*

For compact/young sources:

- broad profiles (FWHM > 300 km/s) are most asymmetric
- among broadest ➔ more blueshifted than redshifted

Young (or restarted) radio sources have more gas and more unsettled ➔ jets interacting clearing their way

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

Occurrence of HI outflows

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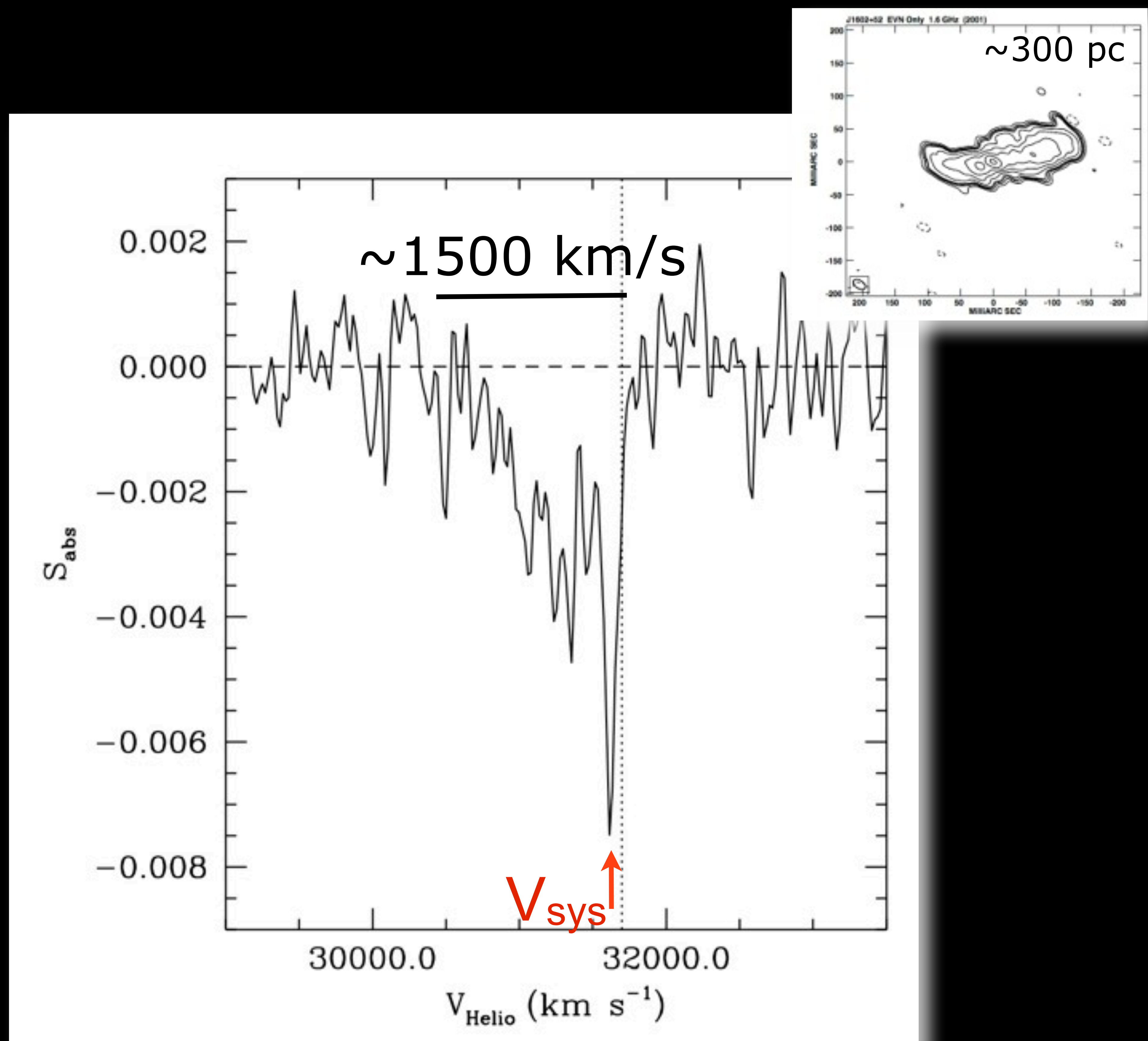
- New cases of HI outflows → ***all in young (or restarted) radio sources ...***
- Preliminary results: ~15% of HI detections show outflows ➡ ~5% of all the radio sources of the sample



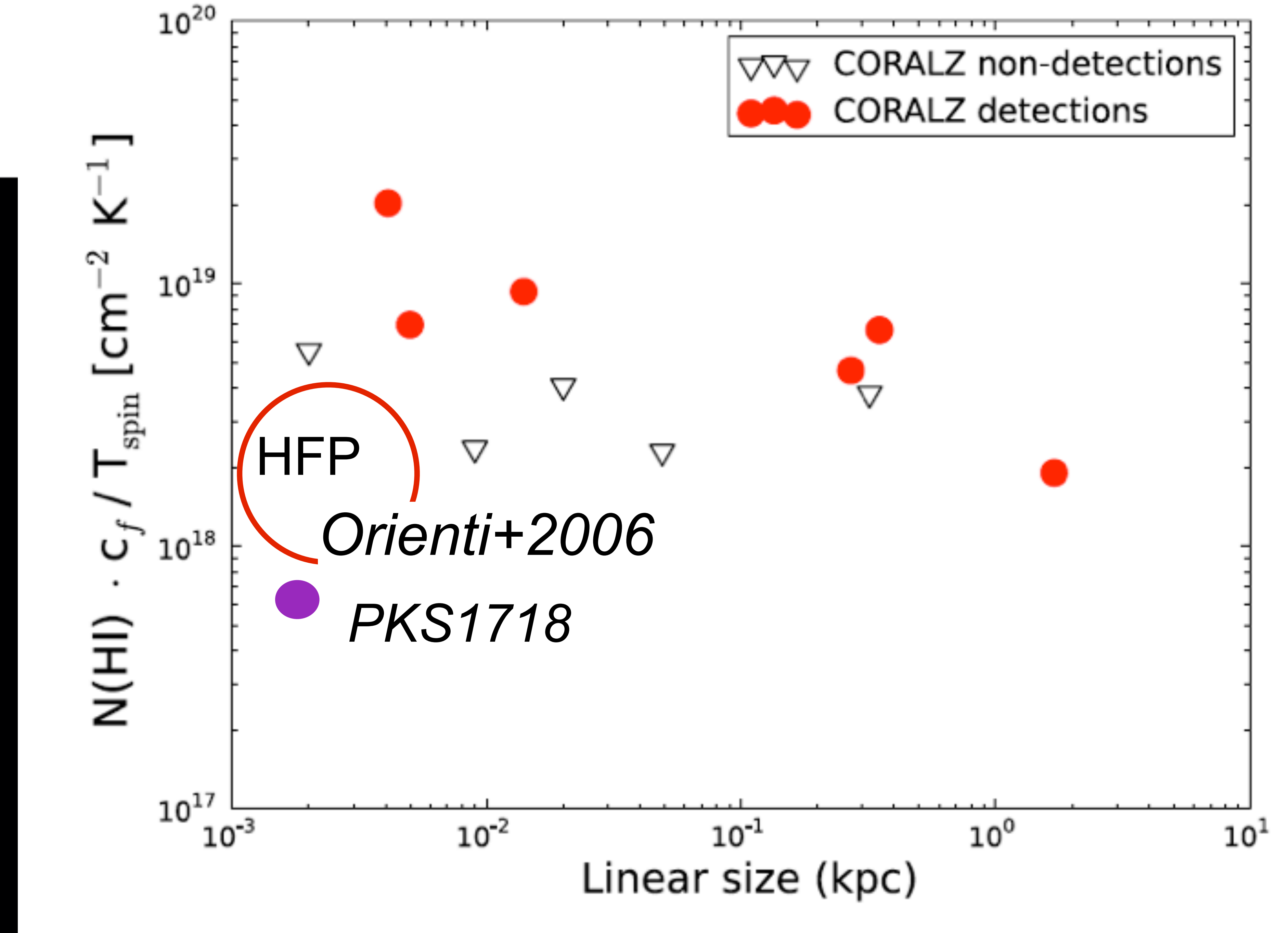
→ if a phase of outflow appears in every object, then it *should last not more than a few x Myr*

→ time-scale *comparable to depletion time* found e.g. in molecular gas

Summary of this first part

Young radio sources are richer in cold gas compared to evolved one (not new but larger/unbiased sample used).
More complex and disturbed kinematic of the gas

Surprising dichotomy ➔ group undetected even after stacking



Gereb, Maccagni, RM et al. 2015

- Effect of orientation and circumnuclear disks?
- Thin circumnuclear disk if also a group of CSS/GPS is non detected with stacking?
- ....*but trend column density vs linear size not confirmed => maybe we need to stack more objects...*
- CSS/GPS tracing the part of the disk with higher velocity dispersion (plus unsettled gas)?

Next step:
Expand statistics and stacking with data from new surveys (Apertif, ASKAP....)
VLBI follow up
Modelling of the circumnuclear disks and comparison with HI profiles

Detailed kinematics of the molecular gas from ALMA

Morganti et al. 2015 A&A (astro-ph/1505.07190)

Our target: IC5063

radio-loud Seyfert (similar to NGC1068) but relatively low radio power 3×10^{23} W/Hz @ 1.4GHz

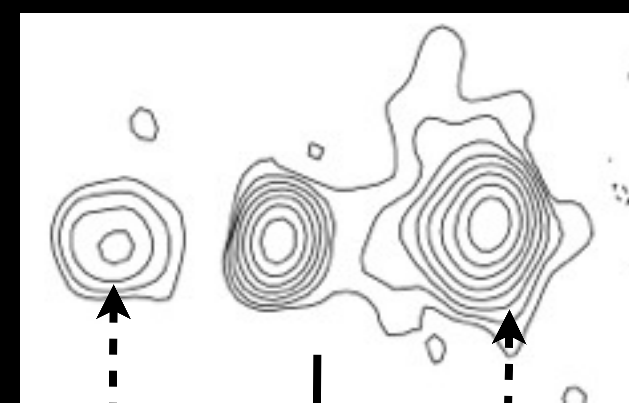
Known multi-phase gas outflow (HI, ionized gas and warm molecular
Tadhunter, Morganti et al. 2014 Nature

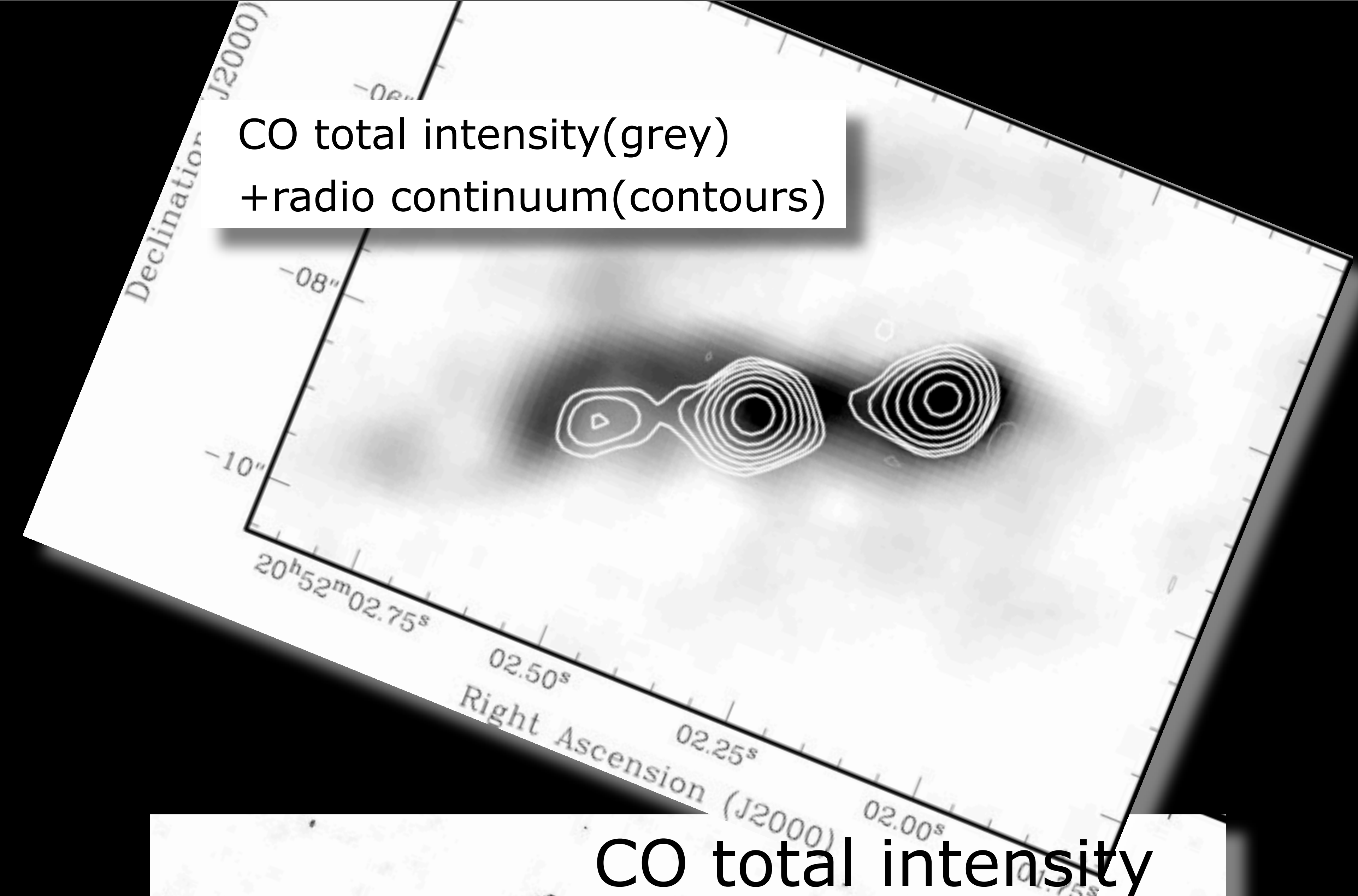

ALMA CO(2-1)
Cycle 1 - 31 antennas
0.6 arcsec resolution
Morganti et al. 2015
~ 1 kpc
CO total intensity
noise 0.3 mJy/b/ch   and 30 microJy continuum

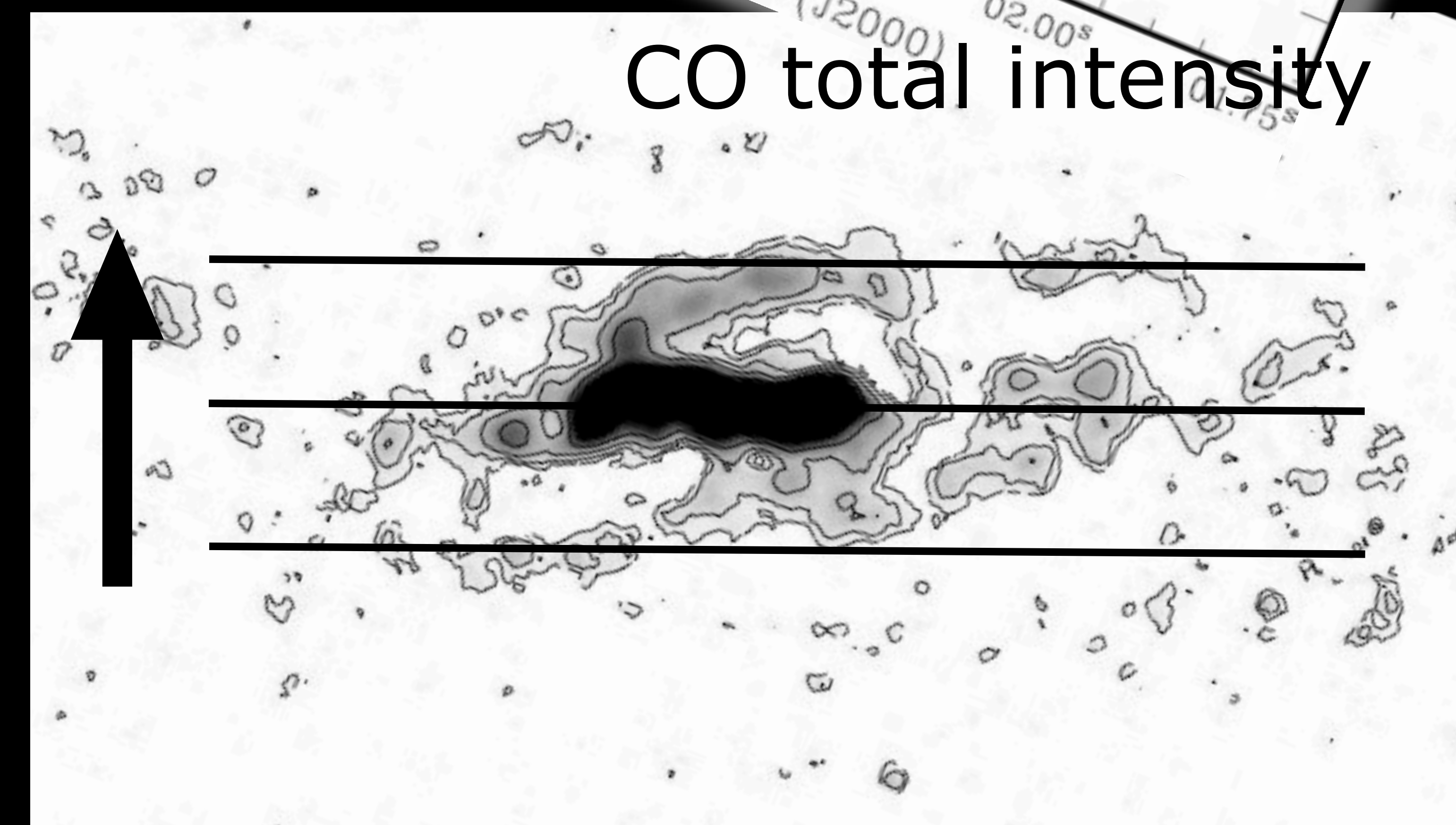

ALMA CO(2-1)
Cycle 1 - 31 antennas
0.6 arcsec resolution
Morganti et al. 2015
CO wrapping around the continuum
Bright region close to the location
of the W hot-spot
~ 1 kpc
CO total intensity
noise 0.3 mJy/b/ch and 30 microJy continuum
CO total intensity+continuum (230GHz)

ALMA CO(2-1) - 0.6 arcsec resolution

illustrating the full complexity of the kinematics of the molecular gas





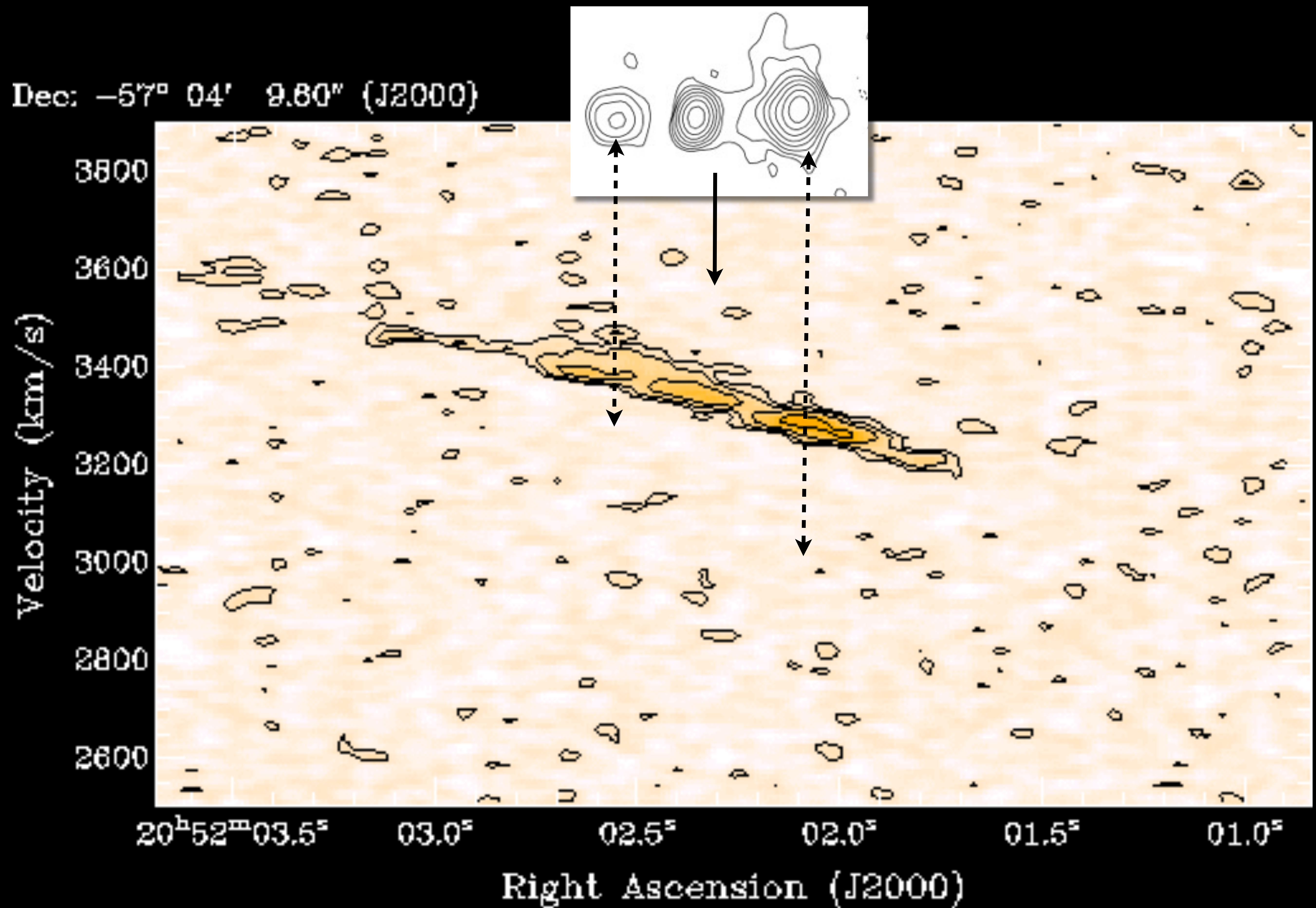


radio source rotated in EW direction to more easily slice along major axis.

position-velocity plot at the along the radio axis

ALMA CO(2-1) - 0.6 arcsec resolution

illustrating the full complexity of the kinematics of the molecular gas



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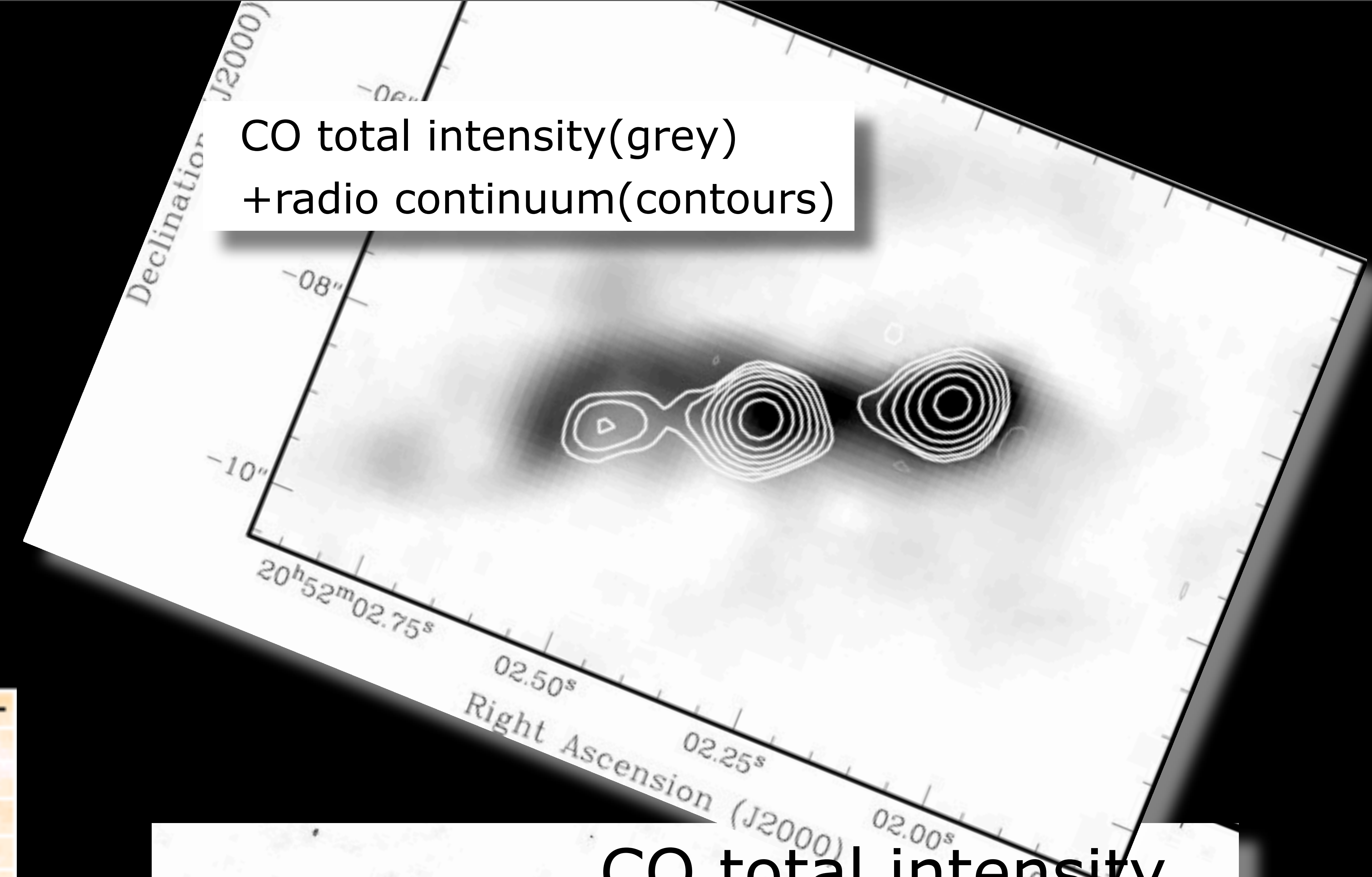

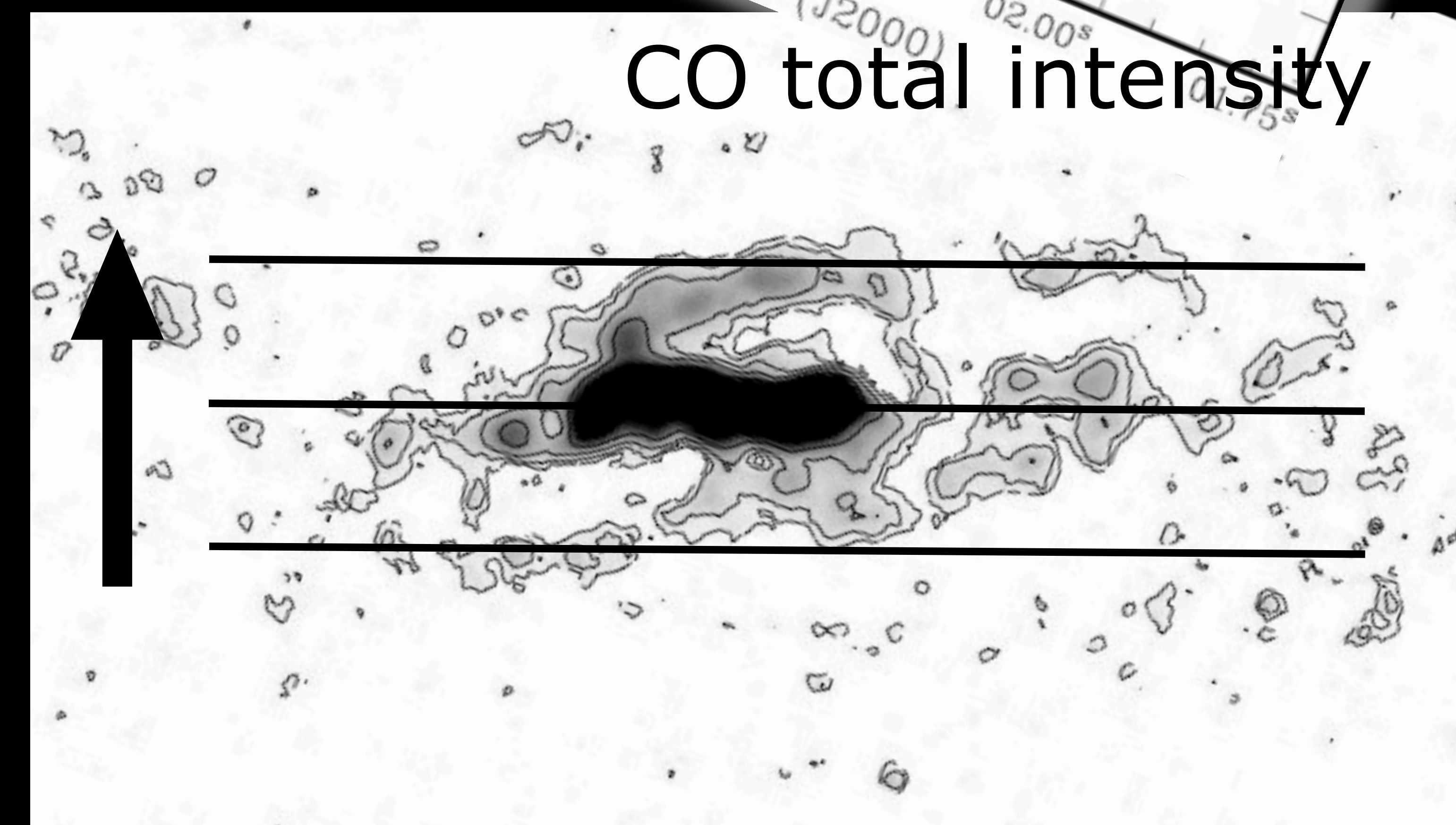

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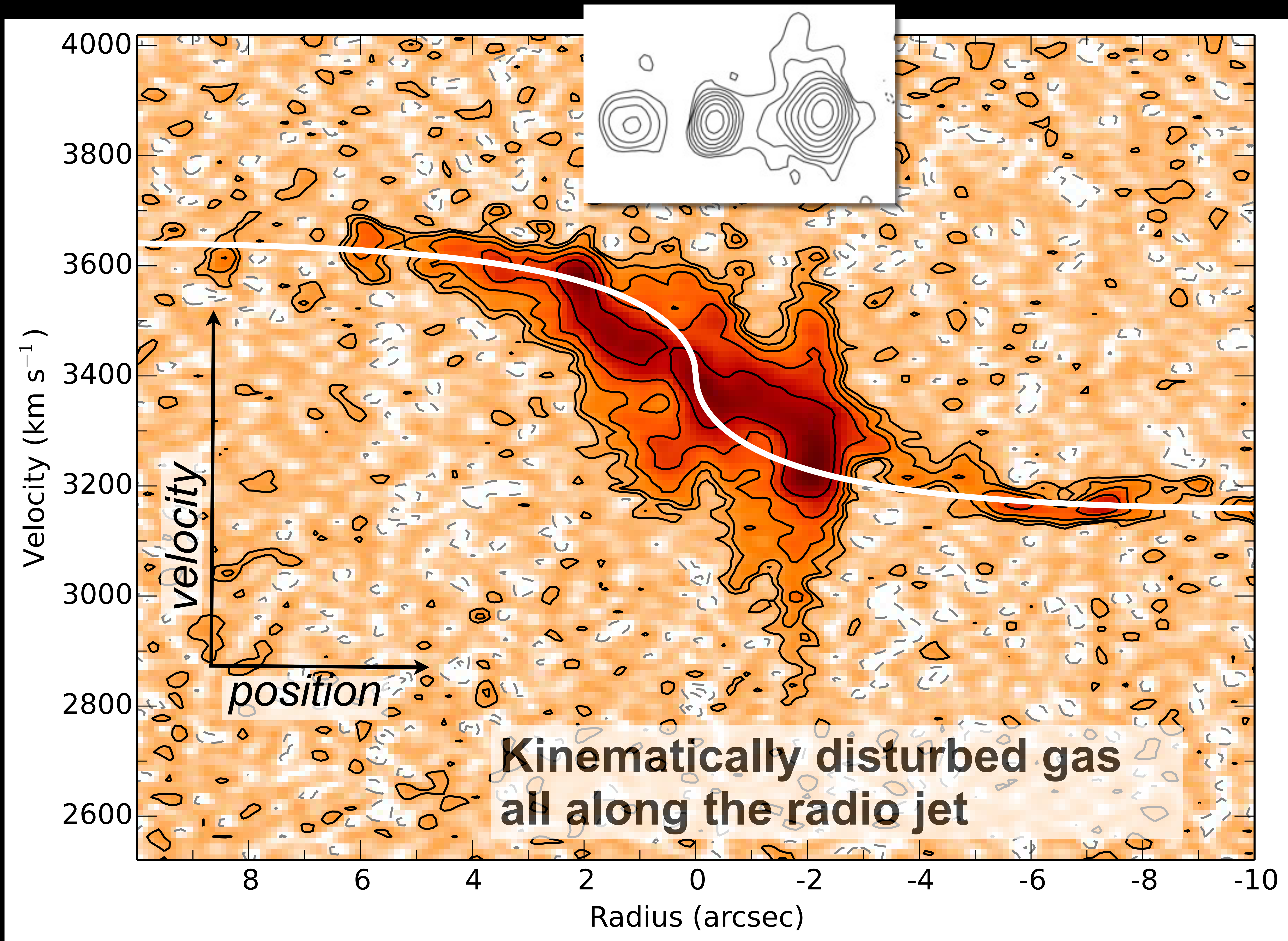

rotation curve from photometry overplotted

Features of the cold, molecular gas:

- disturbed kinematics all along the jet
- redshifted and blueshifted (~150 km/s)
- higher velocities (>500 km/s) at the location of W hotspot
- bright inner region
- large regular disk

mass of the molecular outflow ~ 2 - 5 x10^7 M_{sun}
(for α_{CO}=0.34 - 0.8) ➔ much higher than the warm H_2

Morganti et al. 2015

A possible scenario

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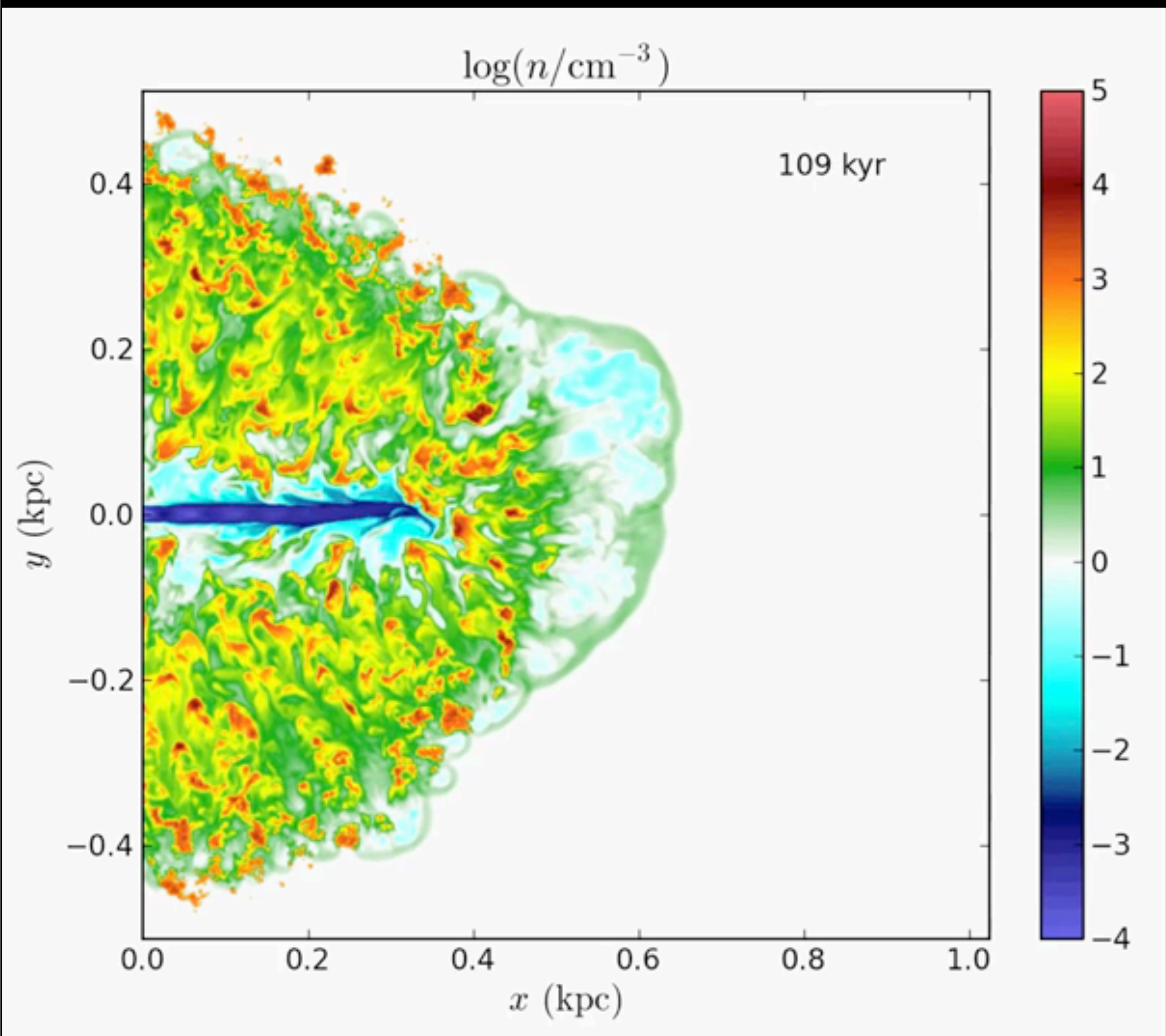
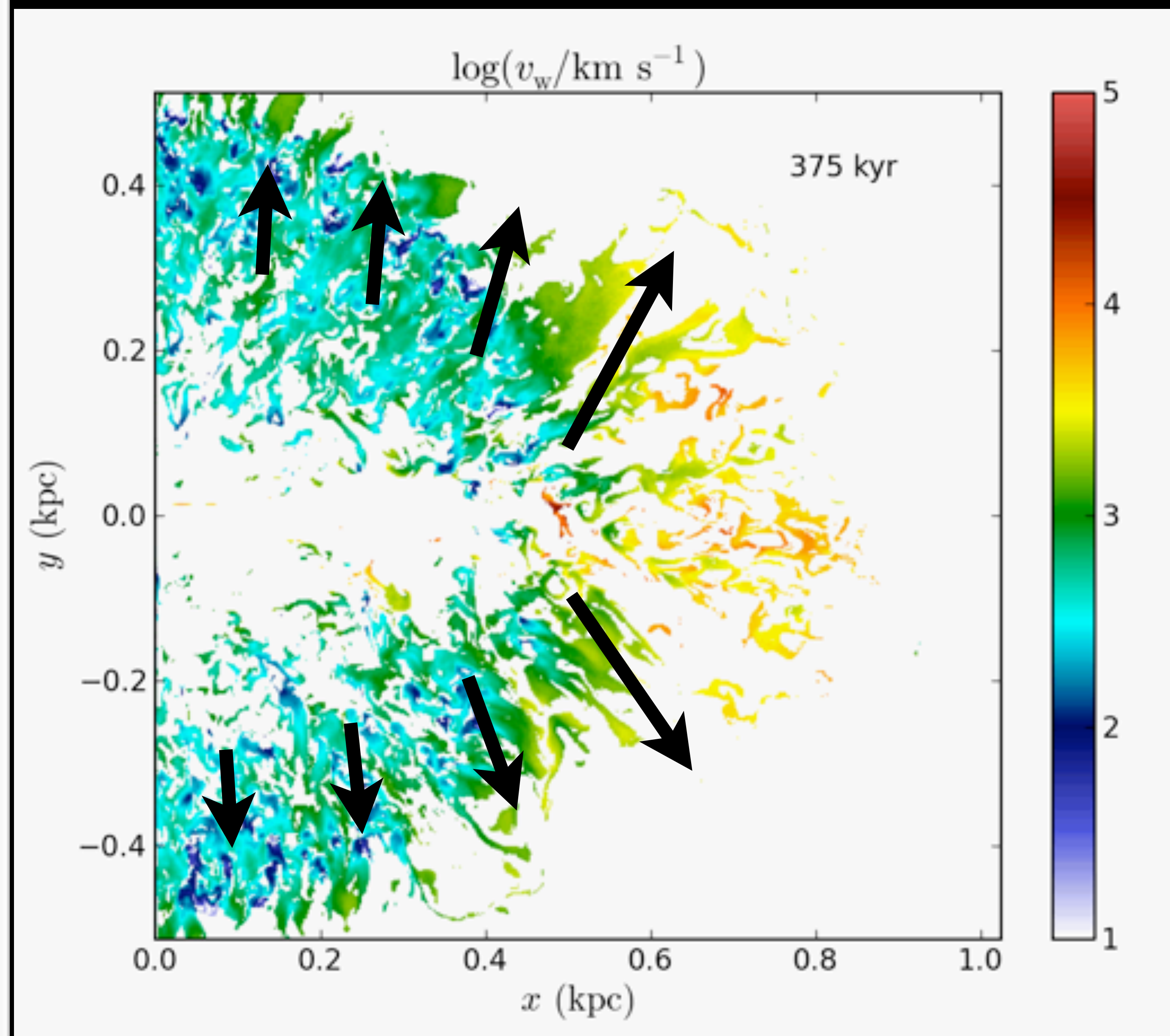
Jet expanding in a clumpy medium ➔ lateral expansion of the gas pushed by the jet's cocoon

stronger, direct interaction at the location of the W lobe



log n (cm^{-3})



log v_{cloud} (km/s)

Numerical simulation of a newly created radio jet

Wagner & Bicknell 2011

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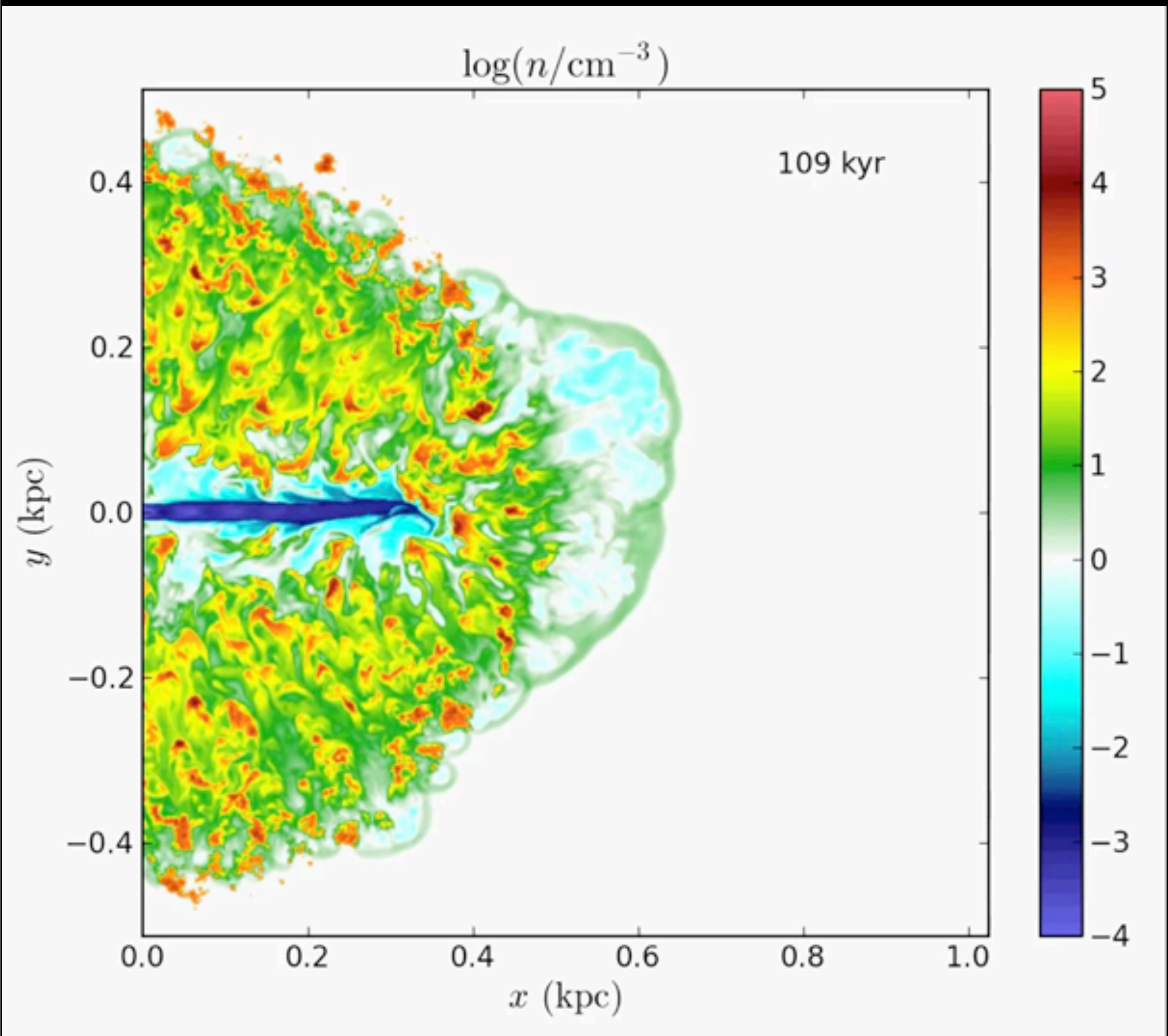

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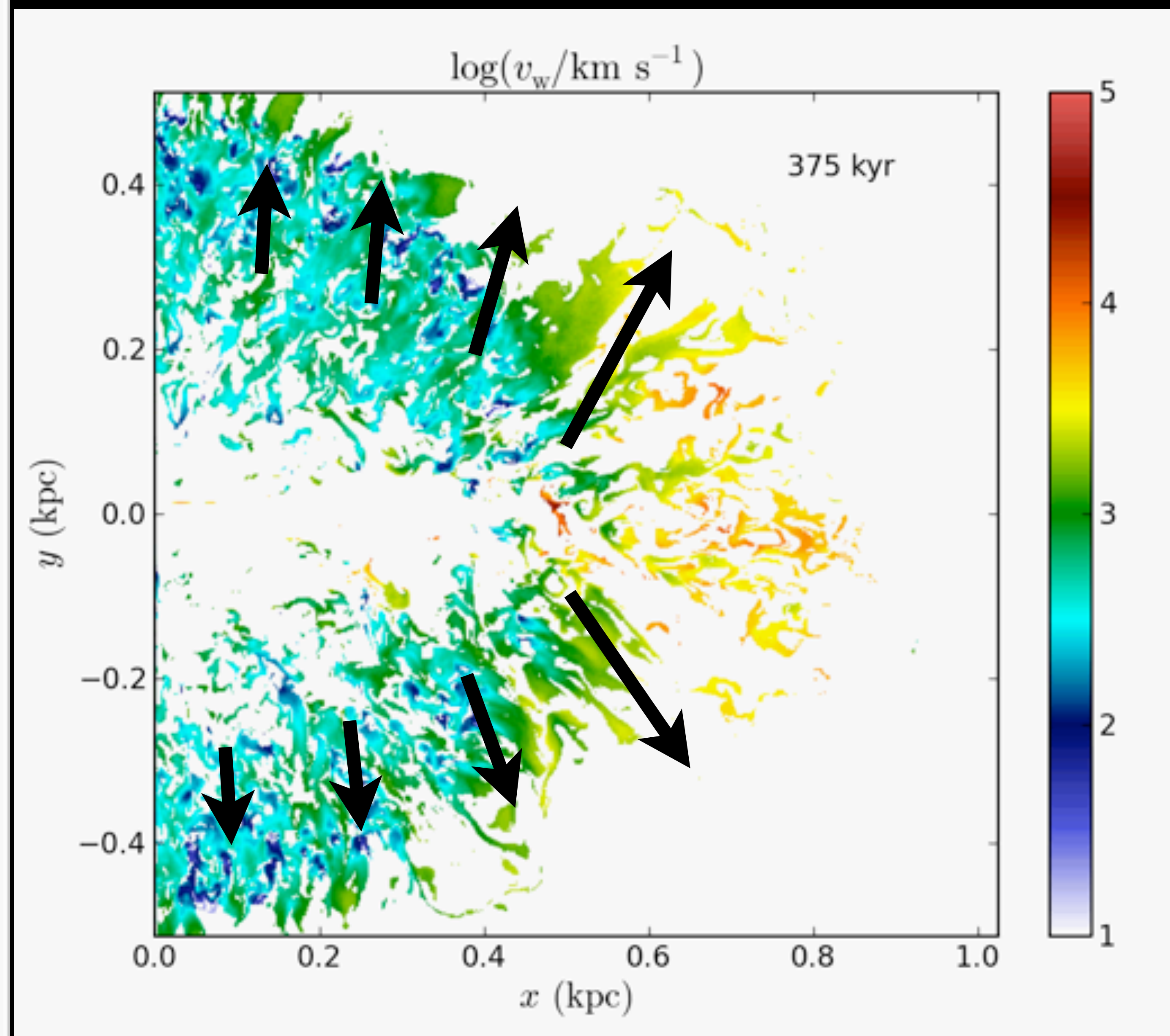

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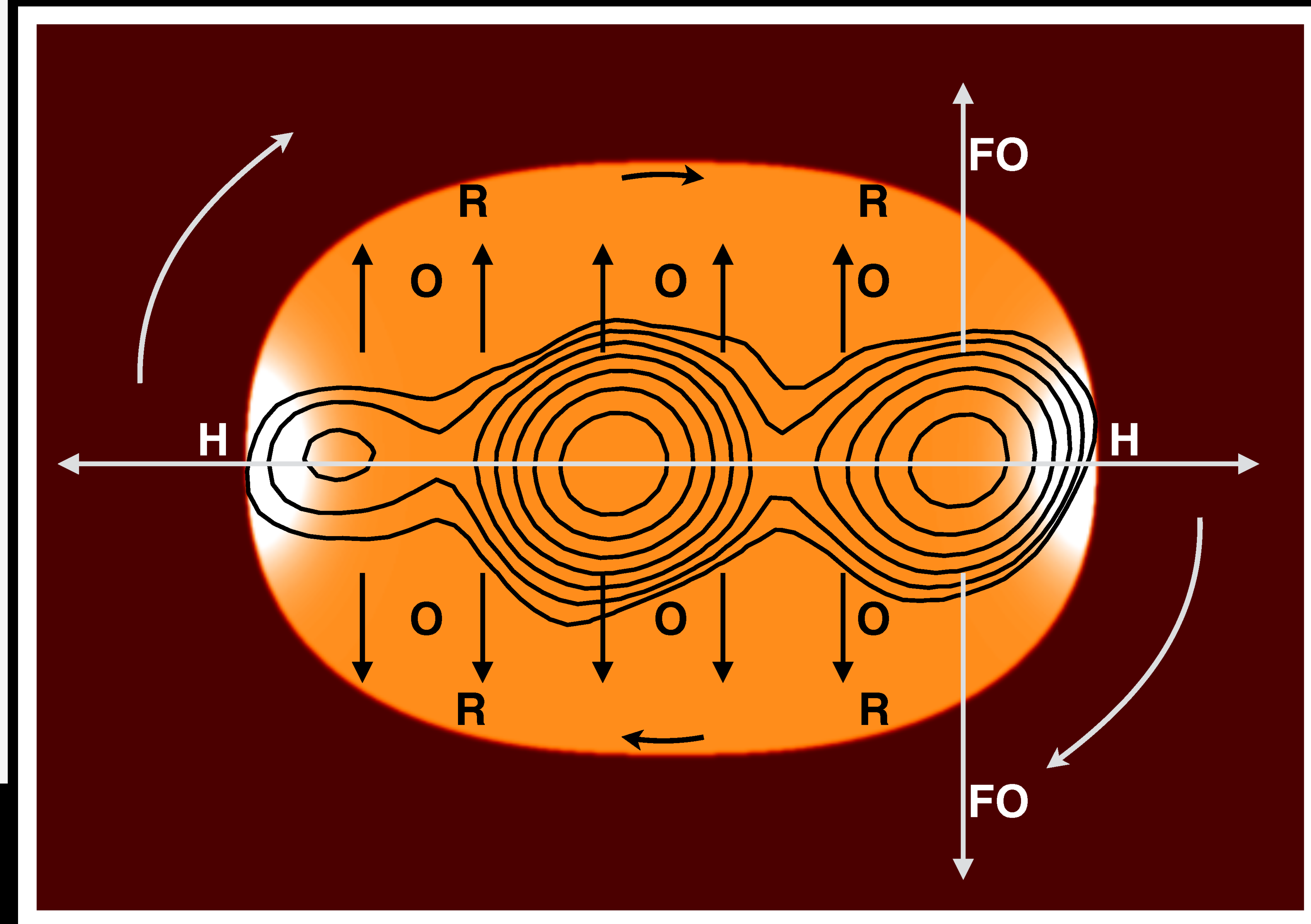
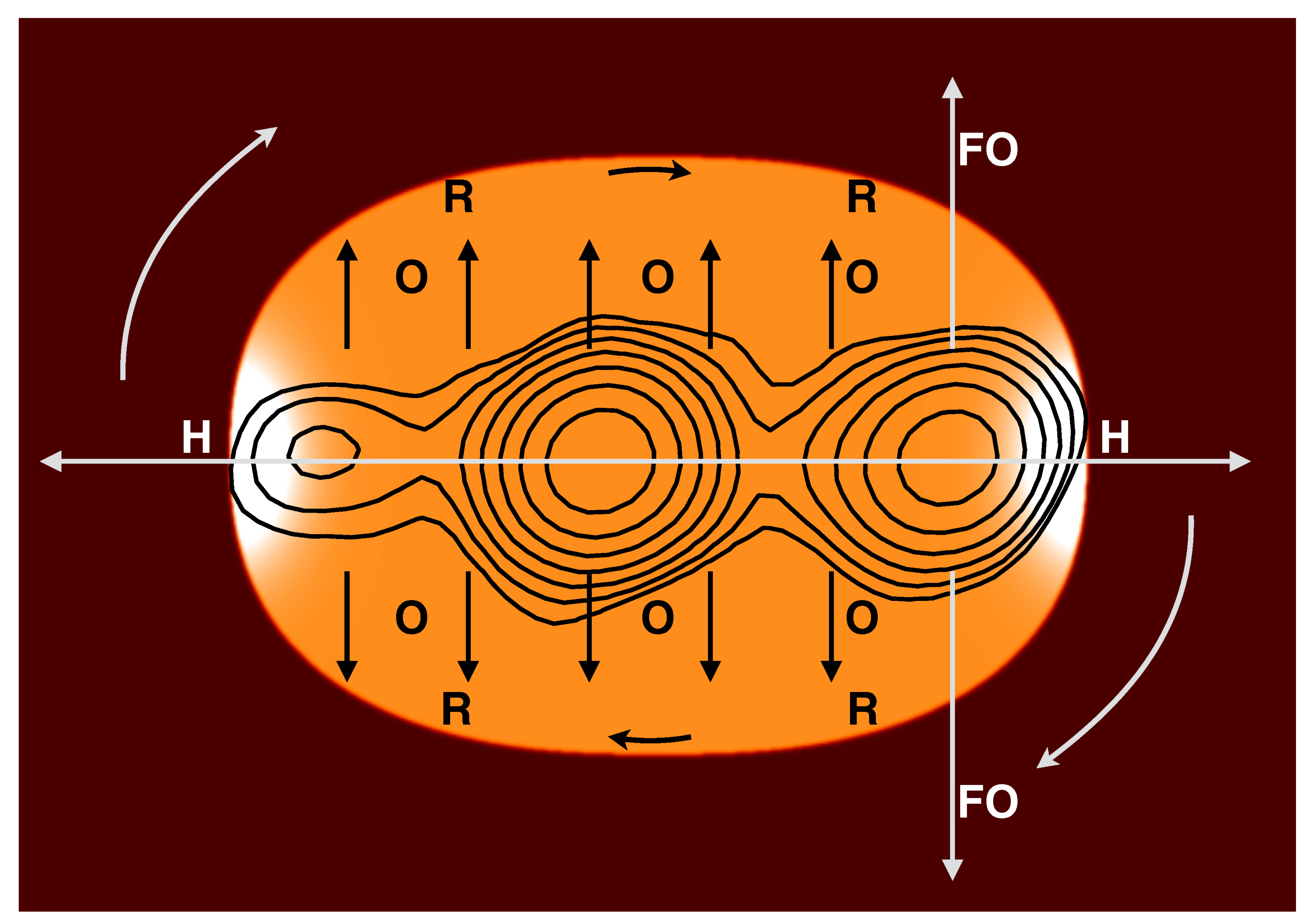


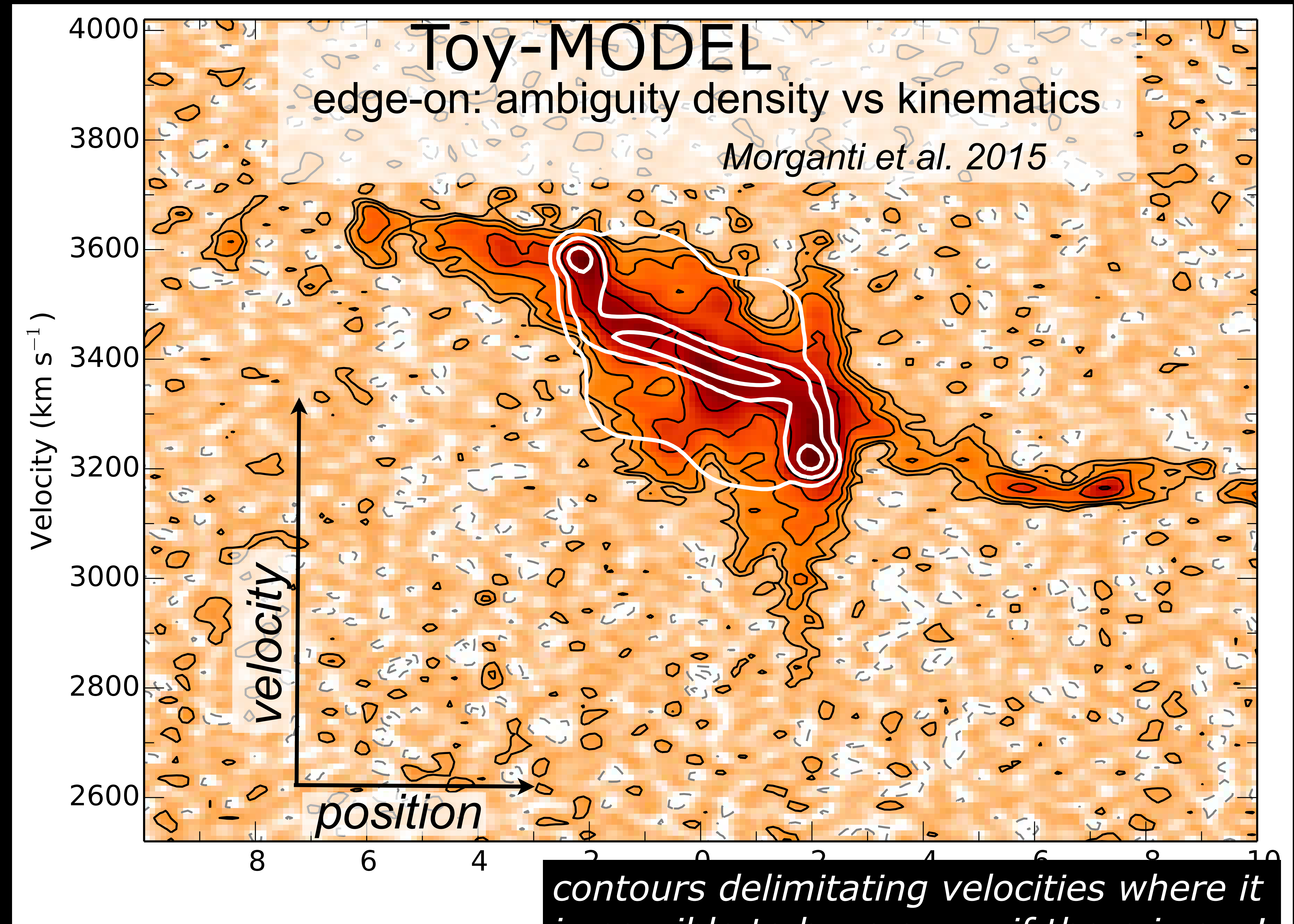
Numerical simulation of a newly created radio jet

Wagner & Bicknell 2011

Extra component compared to the simulations: rotation of the gas disk

Morganti et al. submitted





- Mass outflow rate: molecular gas ~ 12 - 30 M⊙/yr ➔ **most of the gas is not leaving but "relocated"**
- Outflow kinetic power (HI + CO) ~ 8 x 10^{42} erg s^{-1}
- AGN bolometric luminosity L_{bol} ~ 2 - 7.6 x10^{44} erg/s
- Jet power Q_{jet} ~ 5 - 9 x10^{43} erg/s

Both mechanisms can drive the outflow, but effect of radio jet favourite

Summary of the second part

Molecular gas important for tracing AGN-driven outflows
Fast outflows of molecular gas can be driven by relativistic jets

In IC5063 the molecular gas traces the radio plasma jet expanding into a clumpy medium, interacting directly with the clouds and inflating a cocoon that drives a lateral outflow into the interstellar medium

➔ consistent with results obtained by recent simulations such as those of Wagner et al. 2012 => **is this a common phenomenon in CSS/GPS?**

➔ fast cooling of the gas after being shocked

Next step:
Deep observations to detect **and trace** the molecular gas:
but even with ALMA this can be done only for the nearest objects!
=> proposal for PKS1718-63 submitted

Points to take home....

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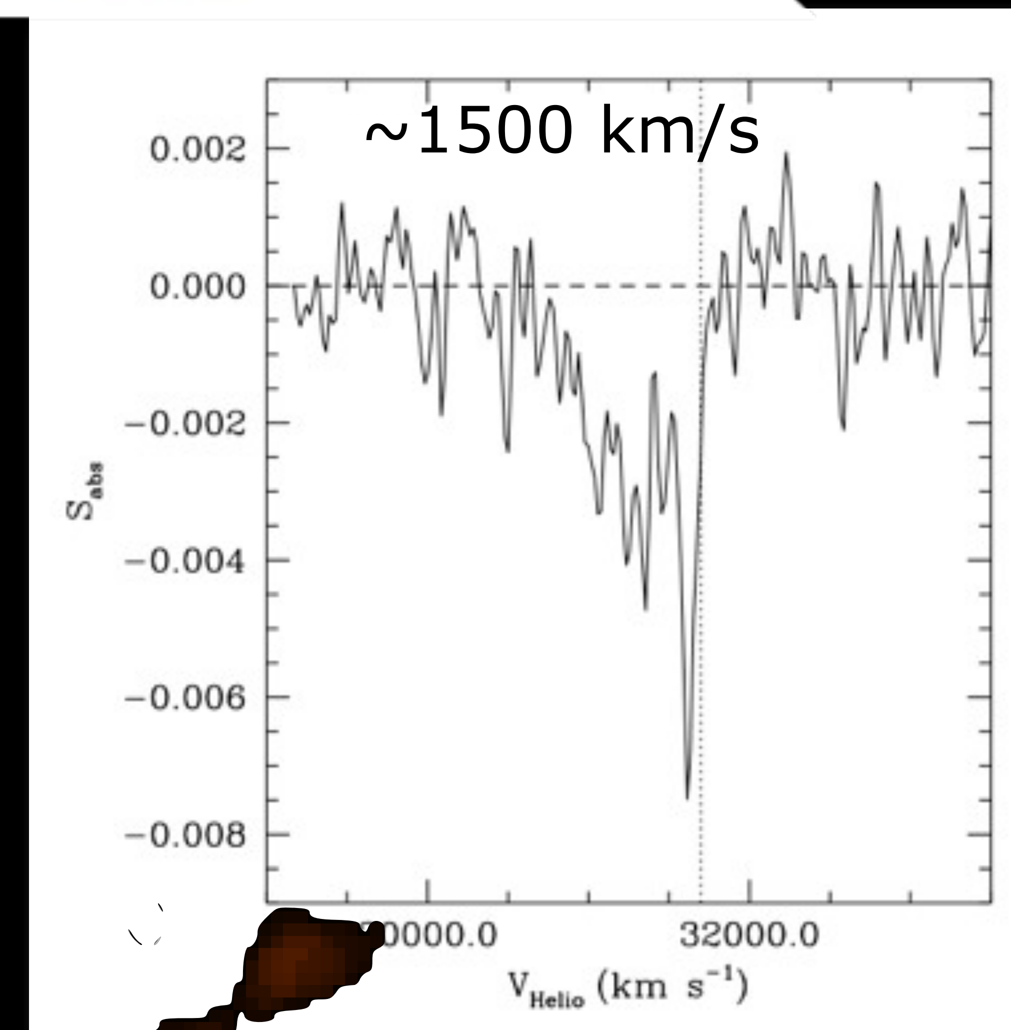
ASTRON

- High detection rate of HI (in absorption): promising for the upcoming surveys
- CSS/GPS, young radio galaxies ➔ higher detection rate, higher column density, wider HI profiles, more asymmetric
- Presence of outflows connected to the early (or restarted) phase in the life of a radiosource

    ➔ *young radio sources: more (disturbed) gas and more outflows!*

- Stacking HI absorption ➔ dichotomy: result from orientation effects (disk?)

    ➔ need larger sample to detect low column density HI



- We have ***located and imaged some of the outflows***: gas not only at the location of the hot-spot but along the radio jet/lobes ➔ ***confirmed the role of jets***
- Jet expanding in a clumpy medium ➔ lateral expansion of the gas pushed by the jet's cocoon confirmed by a first order model
- Gas efficiently cooling after the shock: cold molecular final product, warm molecular and HI intermediate (and less massive) phases

    ➔ expected to be a common phenomena in CSS/GPS: need for ALMA observations