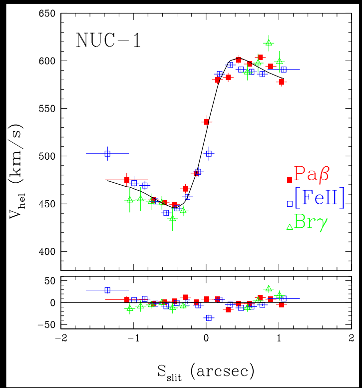
Probing the nature of the ISM in Active Galactic Nuclei through HI

Raffaella Morganti (ASTRON)

Gas: essential tool to explore the nuclear regions of galaxies

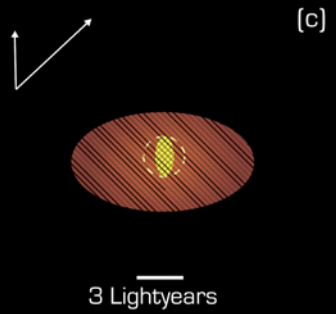


Cen A, VLT
Marconi et al.

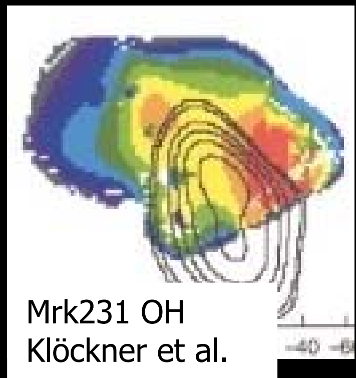
- mass of the Black Hole

- structure of the torus
- circumnuclear disks

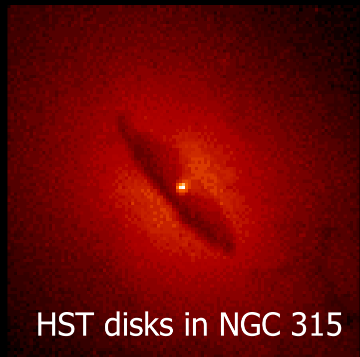
} obscuration
unified schemes



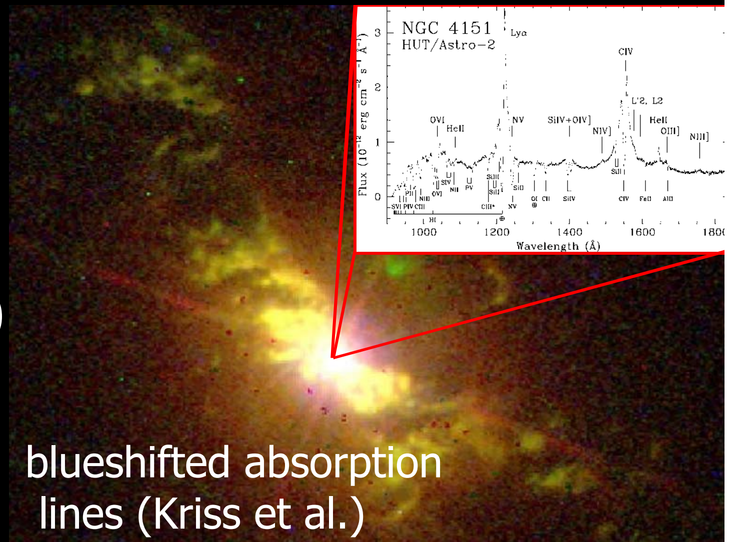
VLTI, Jaffe et al.



Mrk231 OH
Klöckner et al.



HST disks in NGC 315



blueshifted absorption lines (Kriss et al.)

- gas outflows (optical, X-ray, UV)
  feedback
  influence on the ISM

All the phenomena described above
can be observed in the HI: why is this important?

The study of these different phases of the gas is important

- stratification of the different phases of the gas
- to which phenomena are they associated ?
- provide constraints for theoretical models

HI detected in absorption against a strong continuum to study the neutral hydrogen on the sub-arcsec scale around the AGN
(HI in emission cannot be detected – even SKA will not manage at such high resolution)

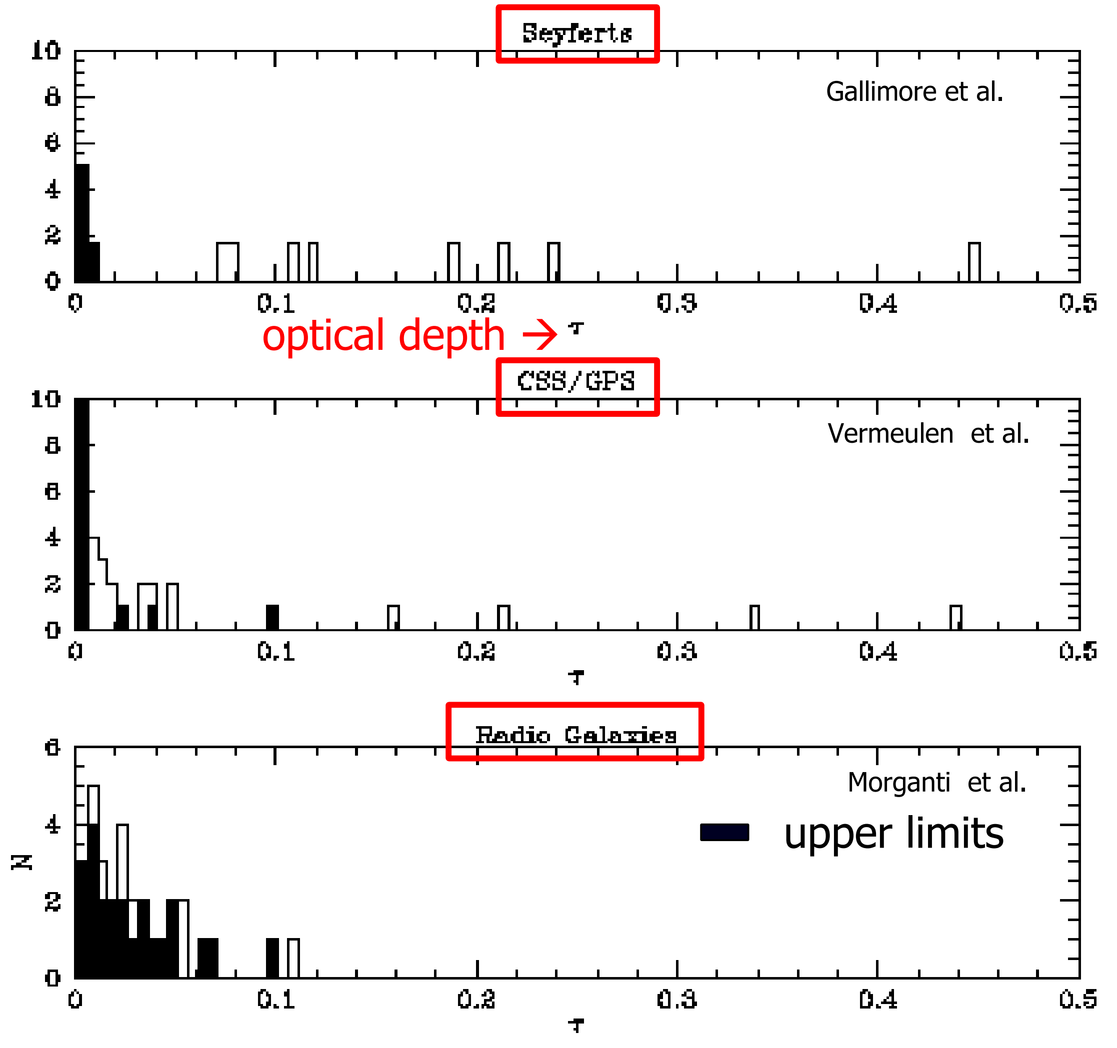
Overview of recent results and some future perspectives

HI absorption detected in various type of radio loud AGN

$S \quad c_f S_c(1 \quad e \quad)$

- Typical optical depth for radio galaxies is $\tau \rightarrow 0.01 - 0.05$
- Objects with $\tau \sim 0.1-0.2$ are detected especially among Seyferts.
- Interesting → some among CSS/GPS radio sources but not among radio galaxies.

rms noise ~0.5 mJy/beam/ch
a 3σ detection of $\tau = 0.02$ can be reached
only for sources >75 mJy:
easy for CSS/GPS; more difficult for the cores
of radio galaxies (bias in the detection rate)



Typical HI column densities detected: 10^{19} - few times 10^{20} cm^{-2}

for T_{spin}=100 K → BUT T_{spin} can be up to few 1000 K

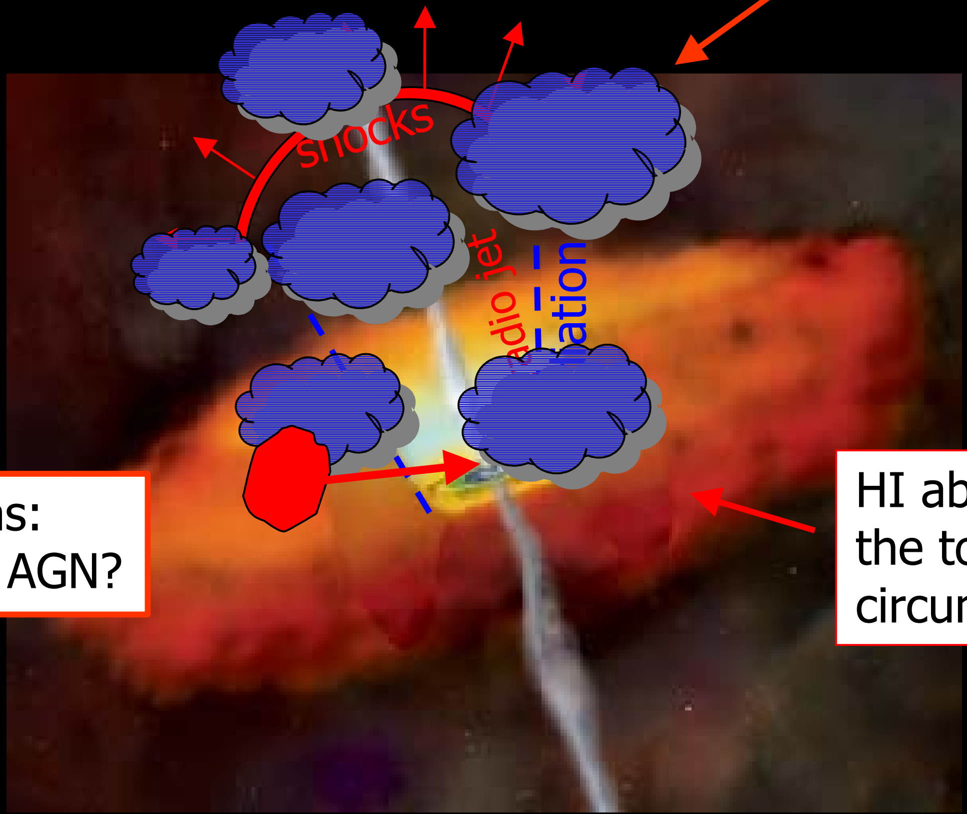
column density for the HI detected in absorption against Lyα → up to 10^{18} cm^{-2}

HI absorption @21cm probes gas with higher column densities

The nuclear regions probed by the HI

extra-gas surrounding the AGN, e.g. left over from the merger that triggered the AGN

Gas outflows



Infalling gas: fueling the AGN?

HI absorption from the torus or from circumnuclear disks

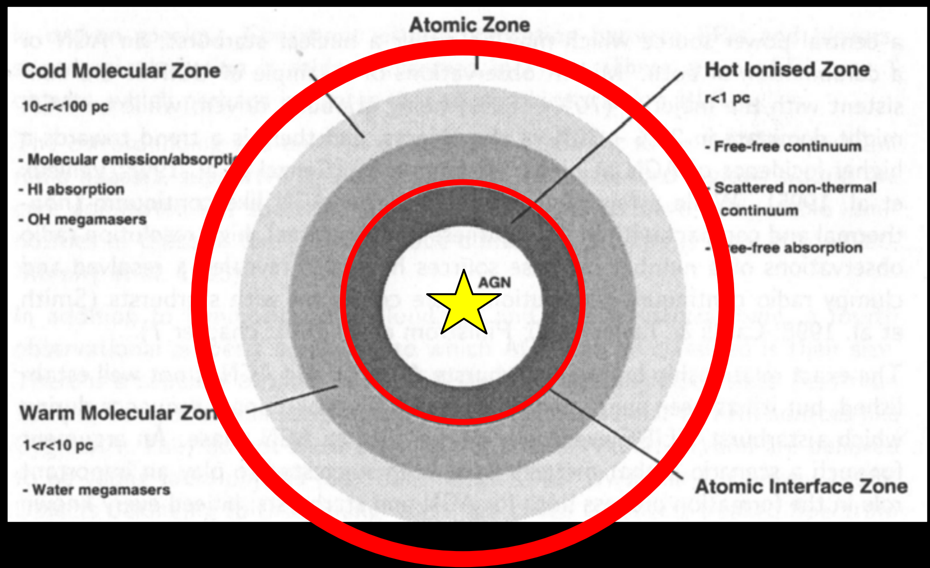
Study of these phenomena using HI in absorption

HI associated with circum-nuclear tori/disks

Stratification of the gas:

because of the strong energetic X-ray source in the centre, the gas is mostly ionized close to the centre

→ increasing fraction of atomic and molecular gas with increasing distance

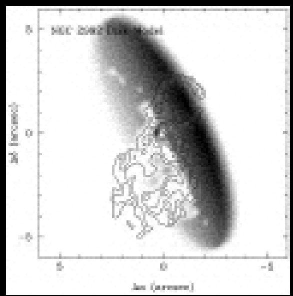


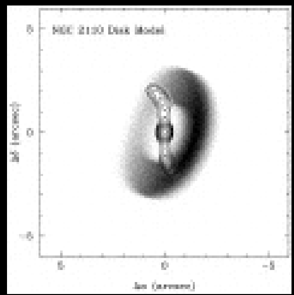
from Pihlström PhD thesis
Maloney et al.

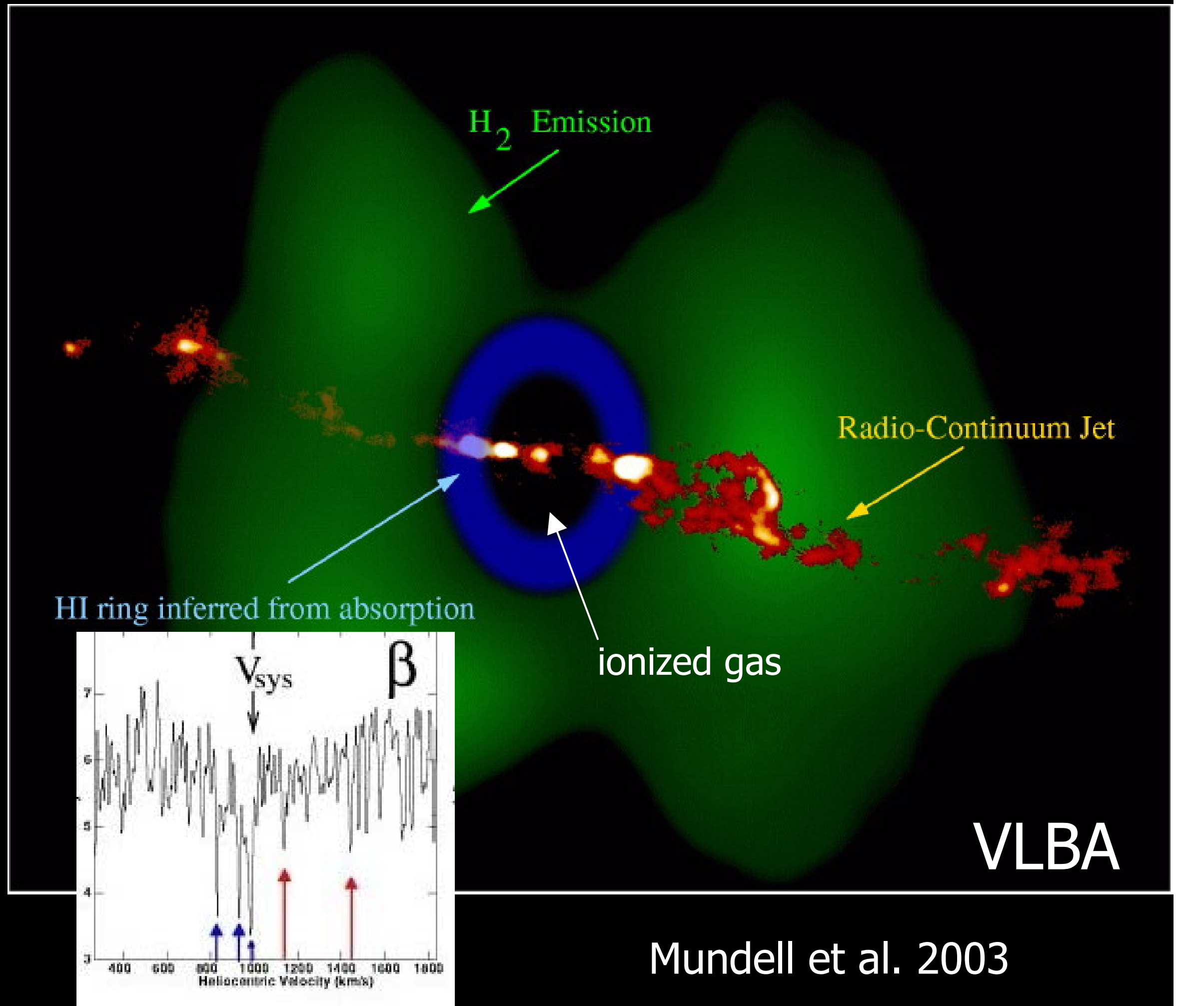
→ not easy to detect the kinematical signature of a rotating torus/disk: limited by underlying continuum

Nuclear tori: NGC 4151

In Seyfert galaxies HI absorption traces (few) 100 pc-scale rotating disks (Gallimore et al.1999)
→ HI suppress in the centre by free-free absorption







Mundell et al. 2003

Exception: NGC 4151
torus 70pc in radius, 50 pc height derived from the location of the HI absorption
(at larger radii, molecular hydrogen)

Circumnuclear tori/disks in radio galaxies

The case of Cygnus A

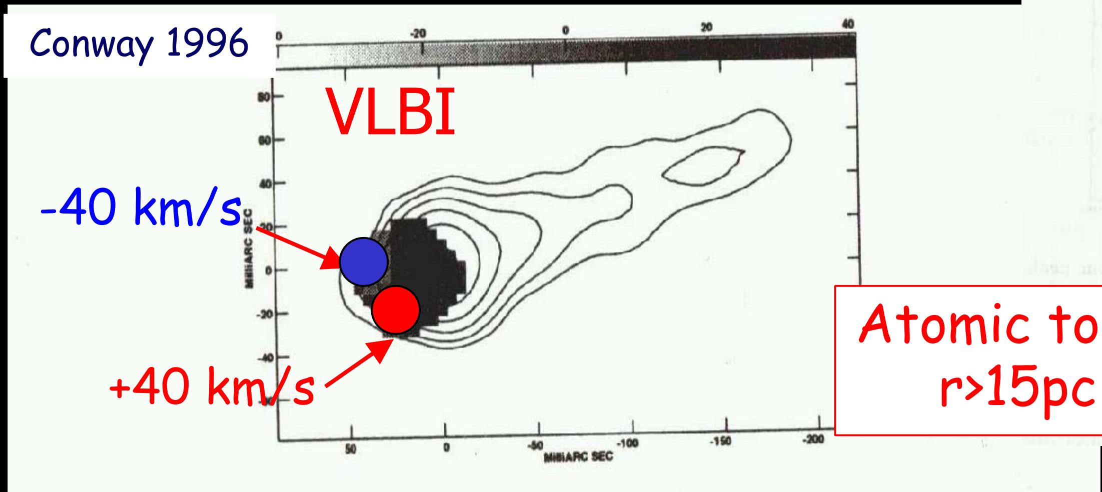
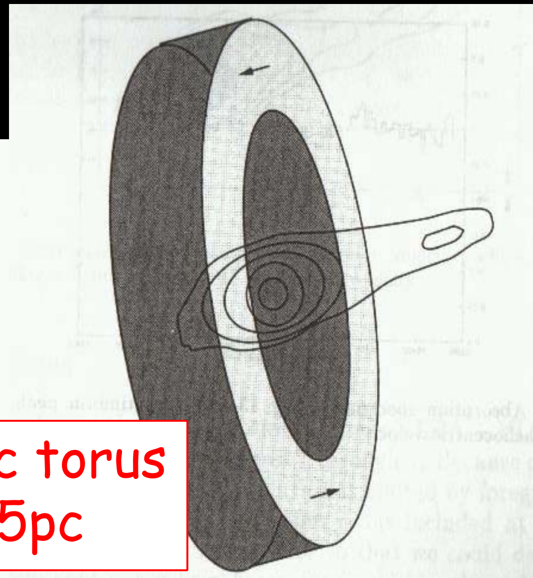
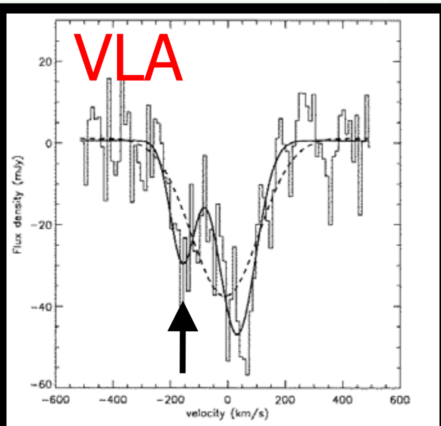


Figure 2. Greyscale shows centroid of absorption velocity, white is −40km/s and black is +40km/s from the mean HI absorption velocity

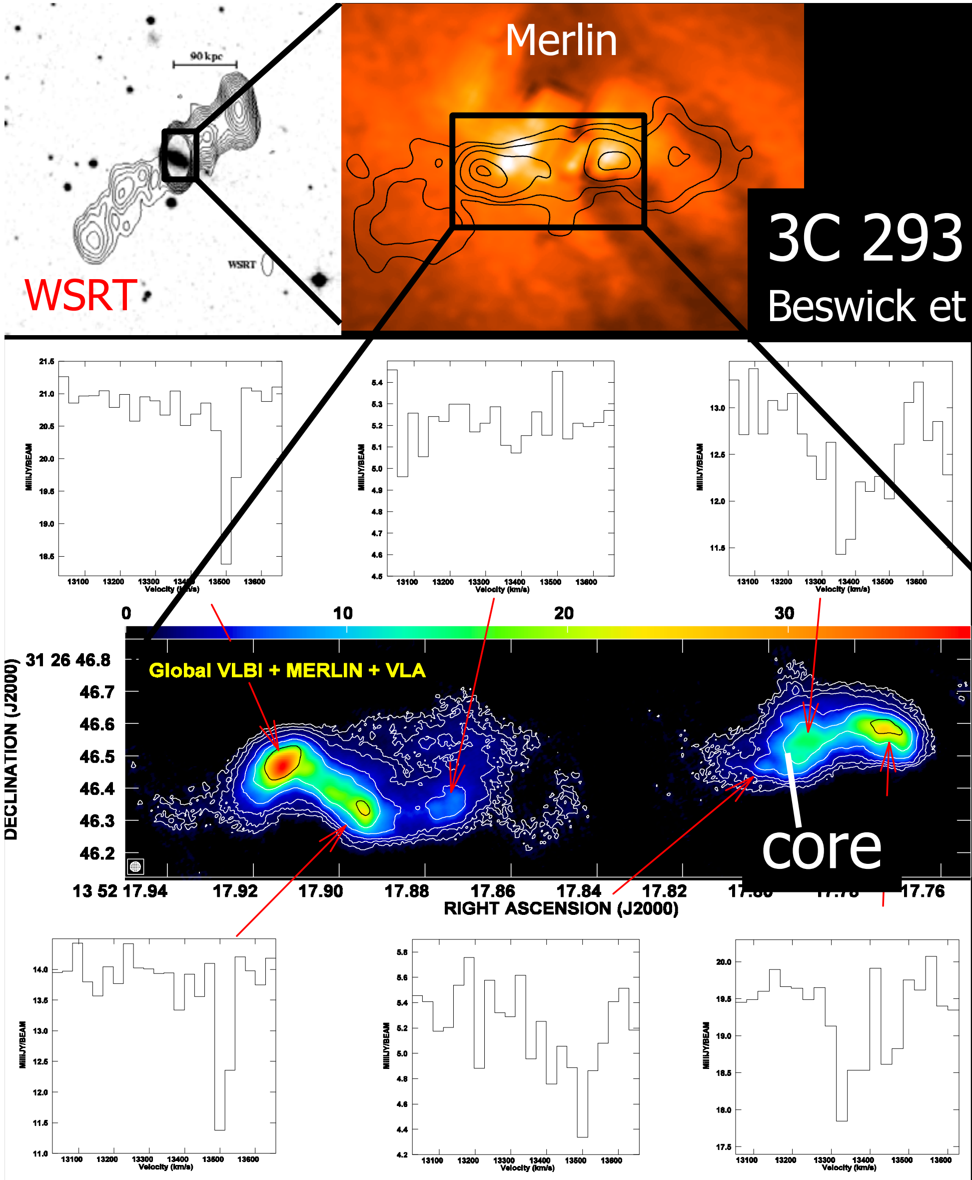




V_{sys}=16774 km/s

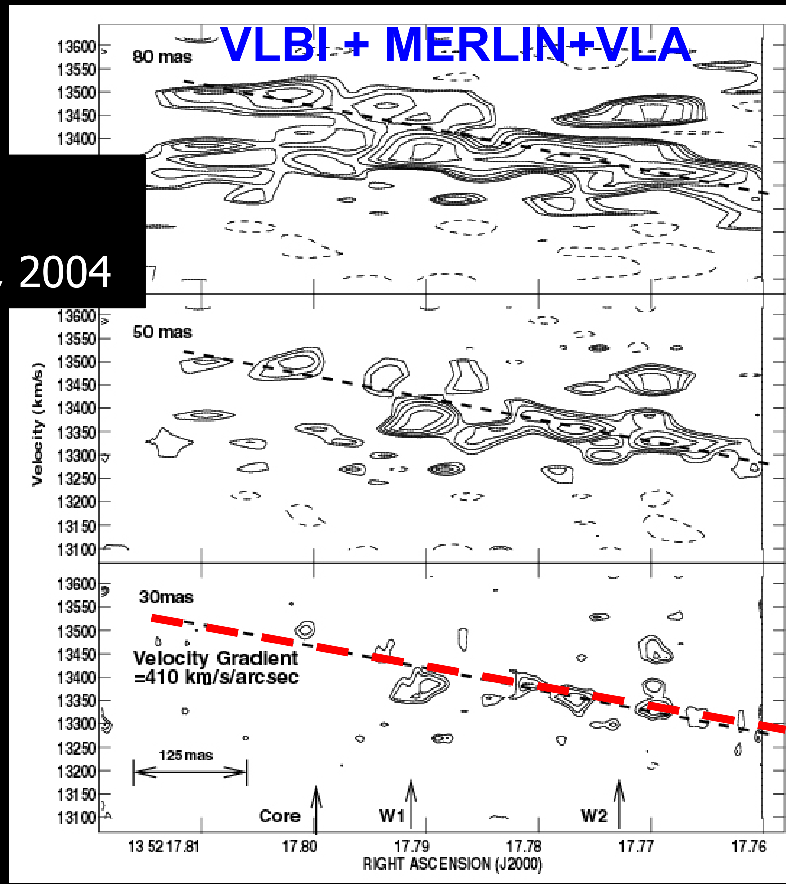
...but the situation is more complicated

Conway & Blanco 1995



3C 293

Beswick et al. 2002, 2004

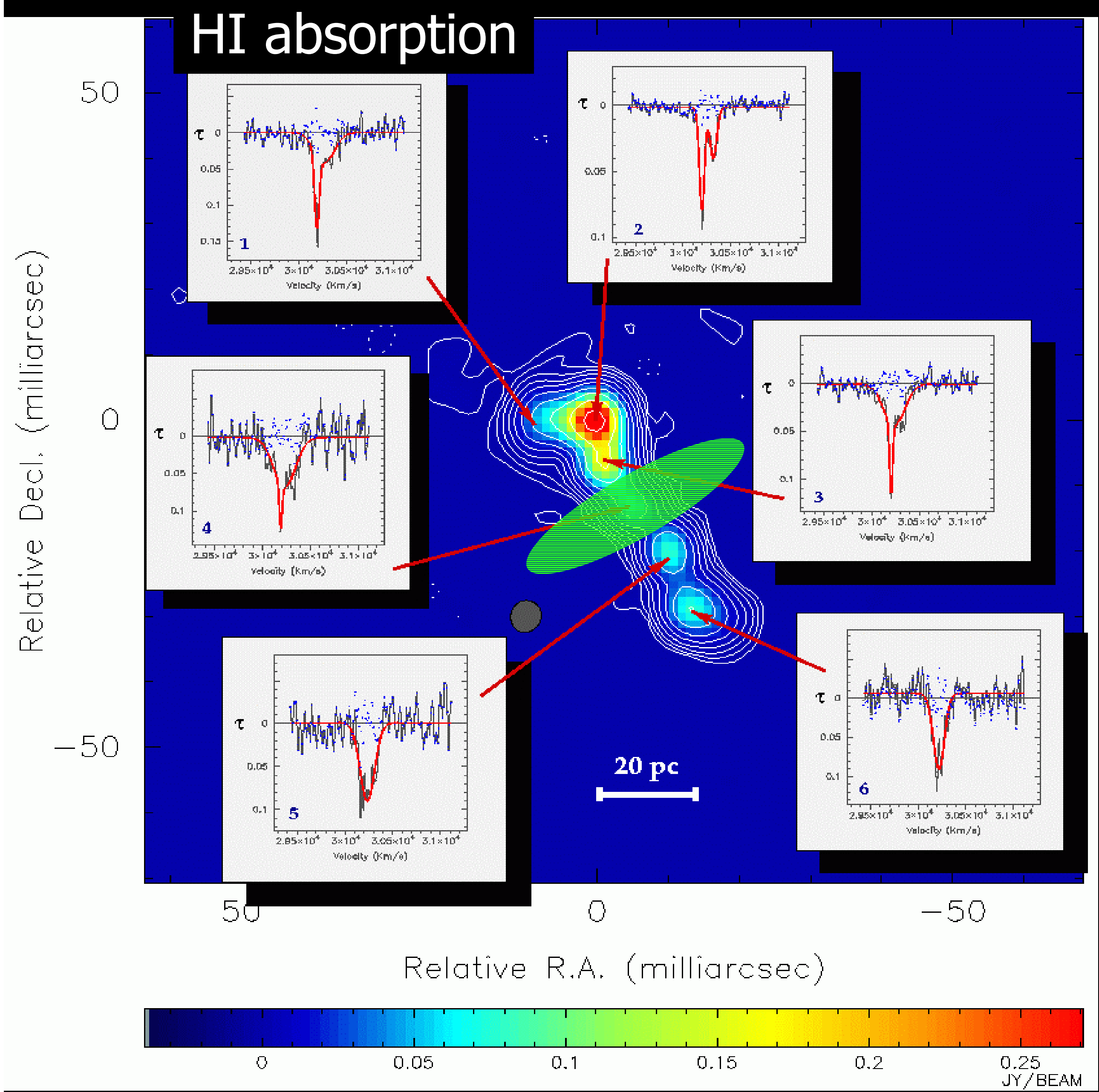


Beswick et al 2004

see also talk by R. Beswick

<u>Two dynamical systems:</u>

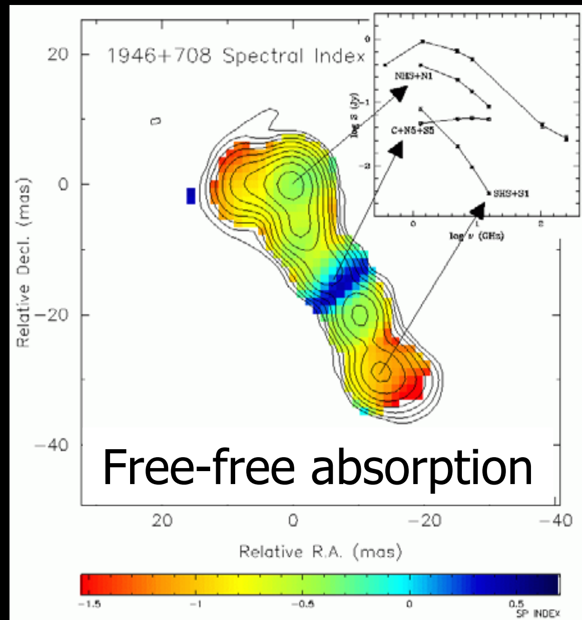
- E side narrow HI absorption, co-spatial with dust-lane and with similar velocity gradient (~50 km/s/acrsec) as the ionized gas
- W side, broader HI absorption detected with higher velocity gradient. Could be a nuclear disk.



Compact Symmetric Object 1946+708

$\tau \sim 0.2$
FWHM = 350 km/s
$N_{HI} = 3 \times 10^{23}\ cm^{-2}$
for $T_{spin} = 8000$ K
$M \sim 10^8\ M_{sun}$

broad line → thick torus
narrower line → gas further out



Global VLBI (Peck & Taylor 2001)

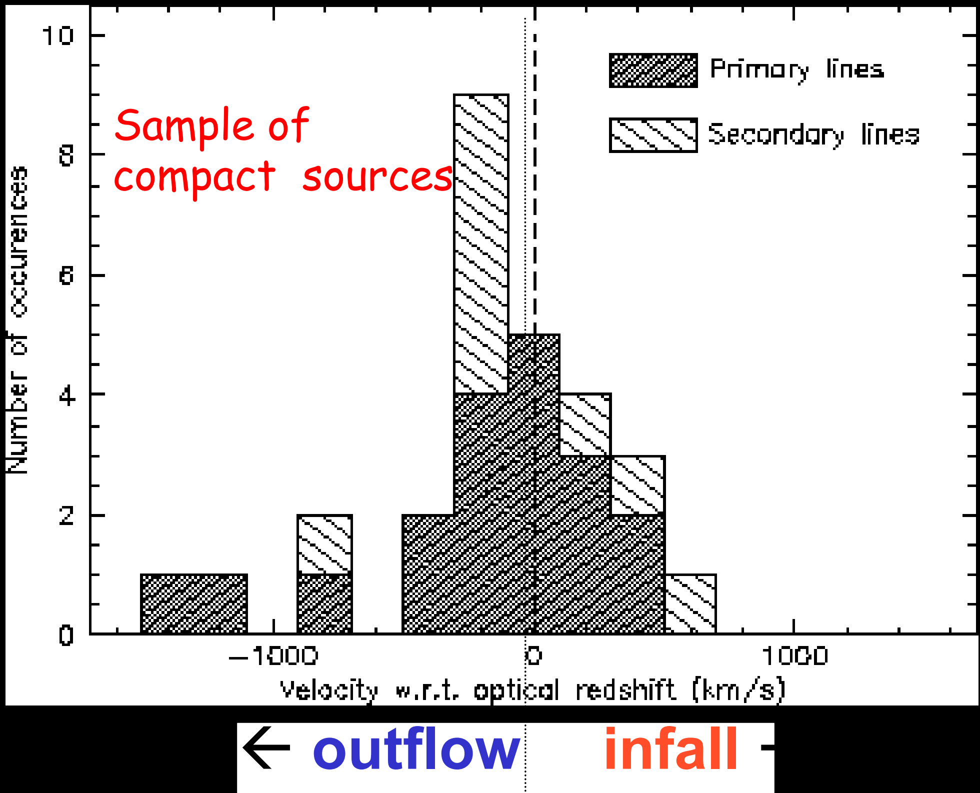
- some of the HI absorption features are associated with circumnuclear tori or disks

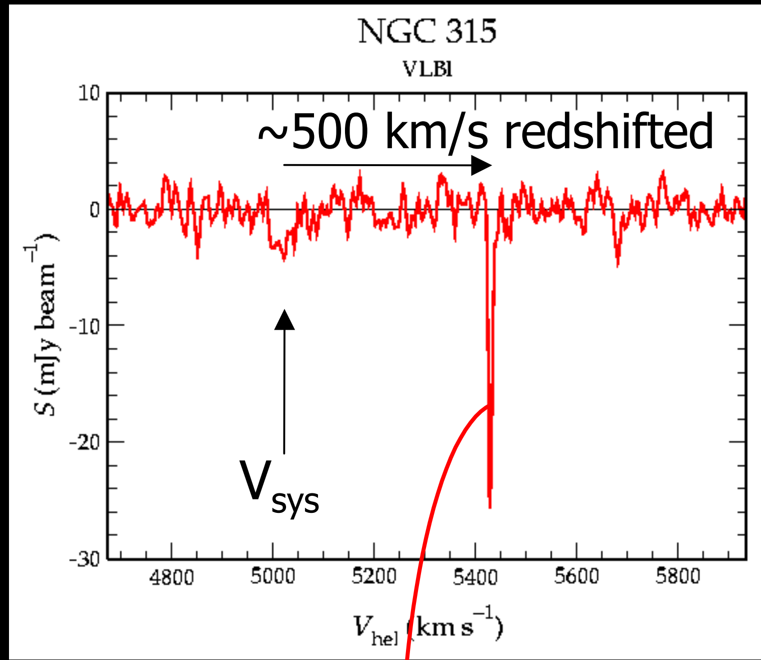
- not always easy to find clear kinematical signatures

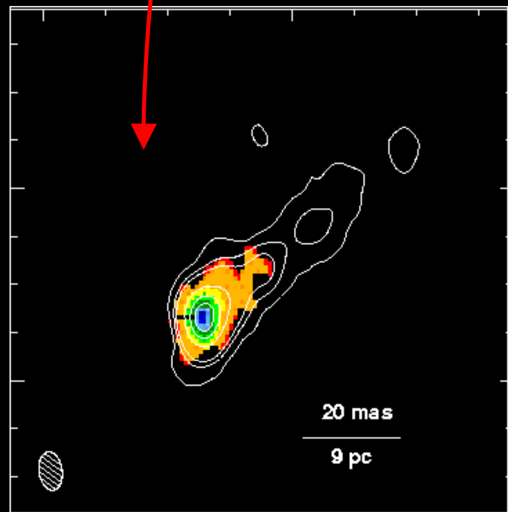
- HI absorption can be due to more than one structure

Infall/outflow of the HI

Infalling gas feeding the AGN?







NGC 315

redshifted narrow HI absorption:
extended (~9 pc)
→ tidal debris at large distance from the nucleus?

(Peck 1999, Morganti et al. 2002)

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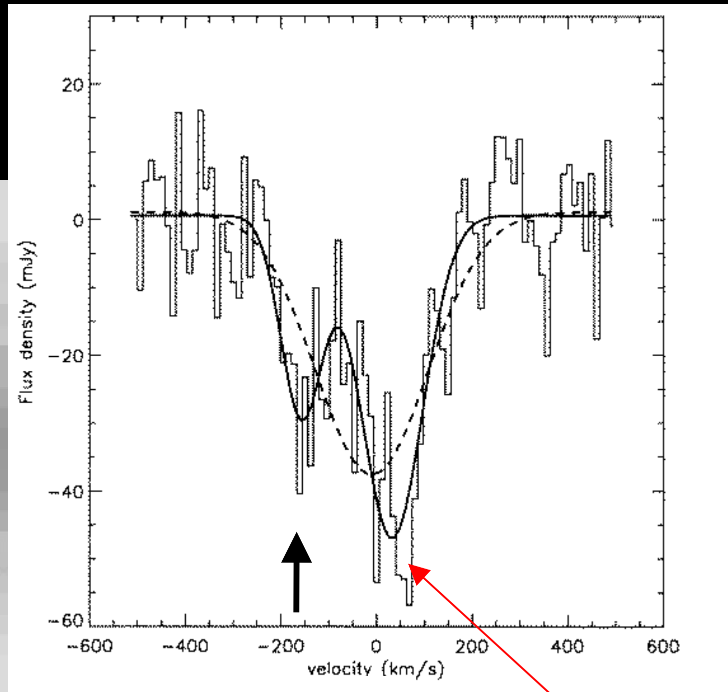
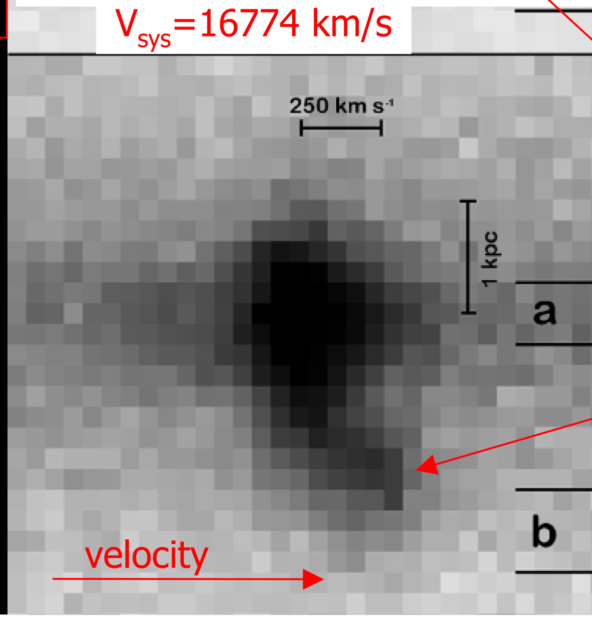
...more on Cygnus A



Conway & Blanco 1995

Systemic velocity
from stellar absorption lines

V_{sys}=16774 km/s

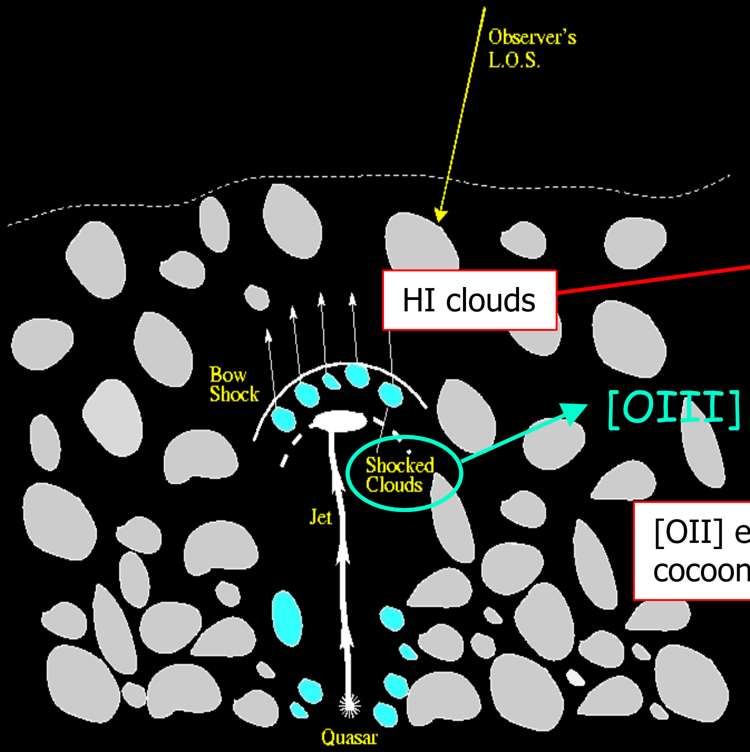


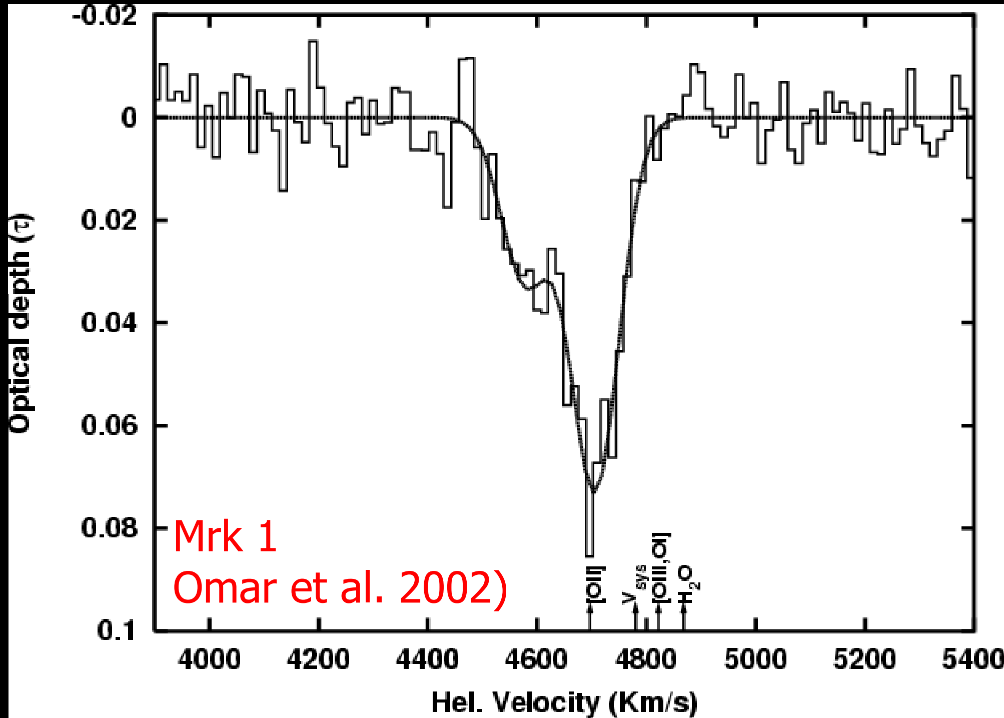
redshifted features
16950 km/s

H_2 spectra
Bellamy et al. 2004
NIRSPEC/Keck

Accurate measure of the systemic velocity is crucial.
Extra complication→ cases where different redshifts are derived from different optical emission lines

Mrk 1 (Omar et al. 2002)
B1221-42 (Johnston et al.)
PKS 1549-79 (Tadhunter et al. 2001)
…





Confirmed by follow up observations of PKS 1549-79 with the LBA

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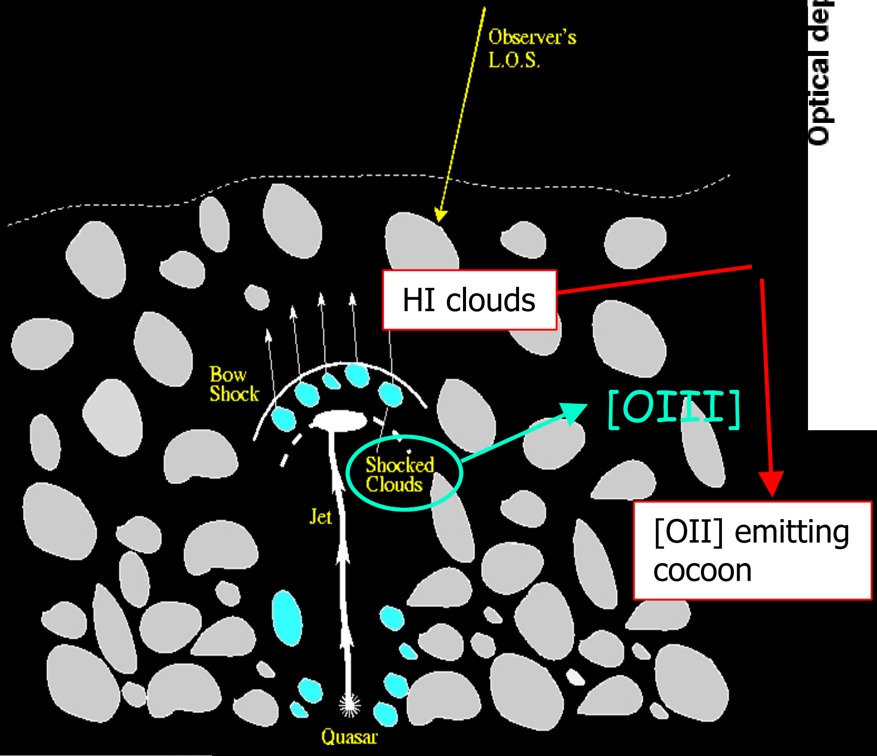

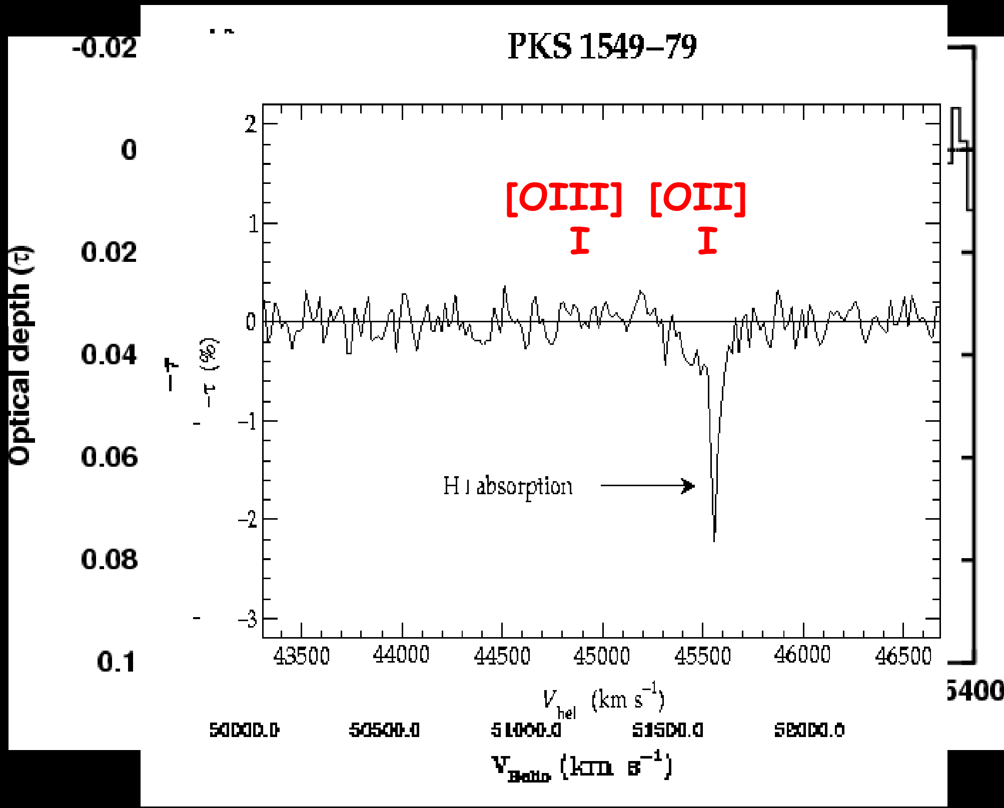

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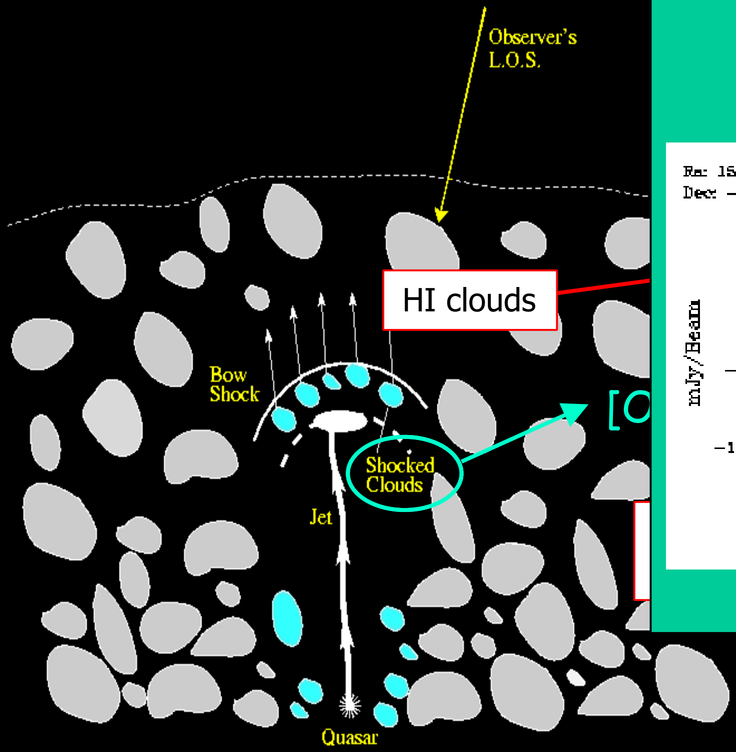

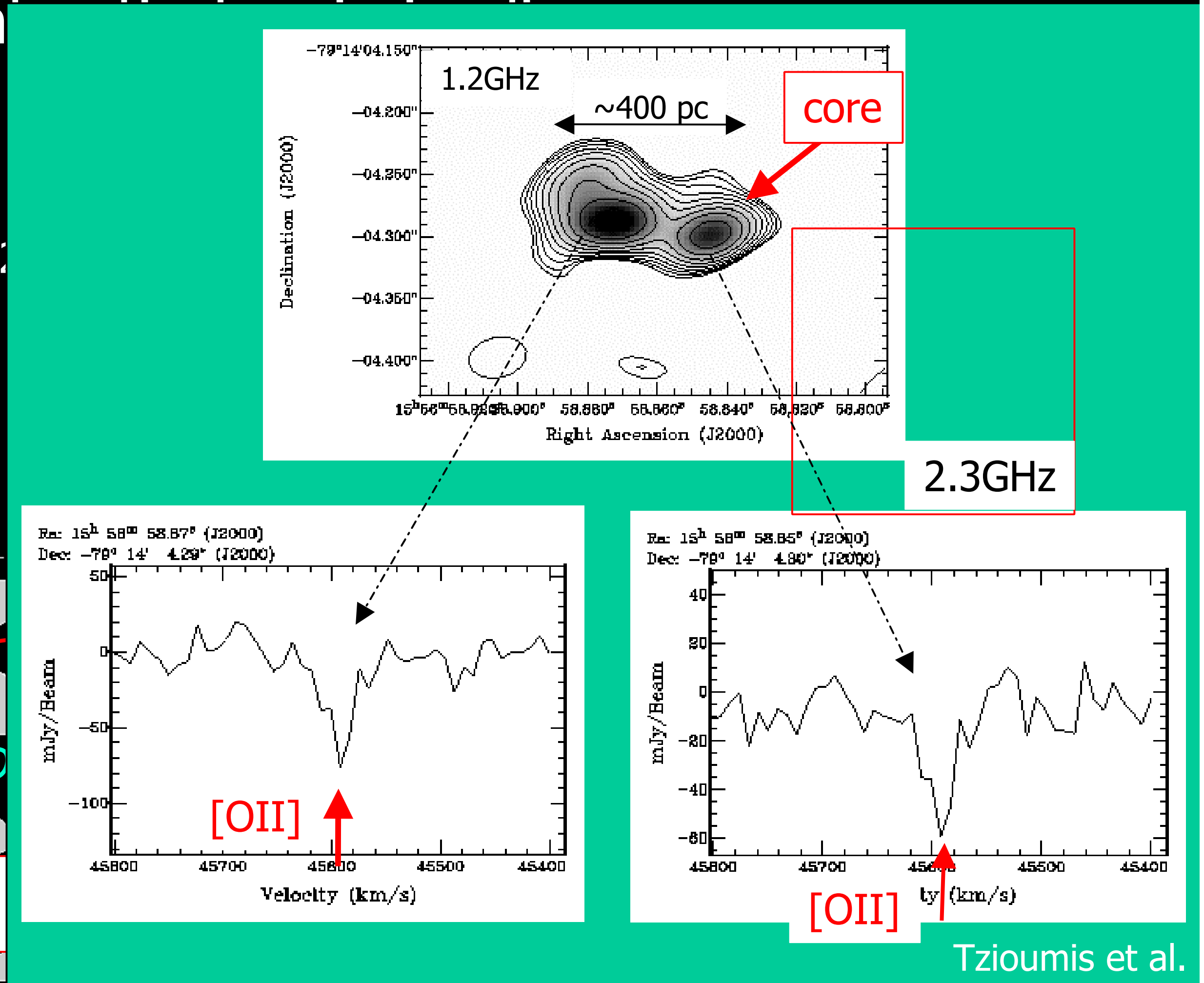

Confirmed by follow up observations of PKS 1549-79 with the LBA

HI outflows

Exploring the low optical depth "territory"

or

what can we see if the source is strong enough!

→ Why not seen before? broad-band available (+ sensitivity)

- So far, 7 cases of broad (up to 2000 km/s) HI absorption found

  (mainly low resolution (arcsec) observations so far)
- Very low optical depth ($\tau \sim 0.001$)→ need very strong radio continuum to be detected (bias!)
- The broad HI is *mostly* blueshifted compared to the systemic velocity→ outflows

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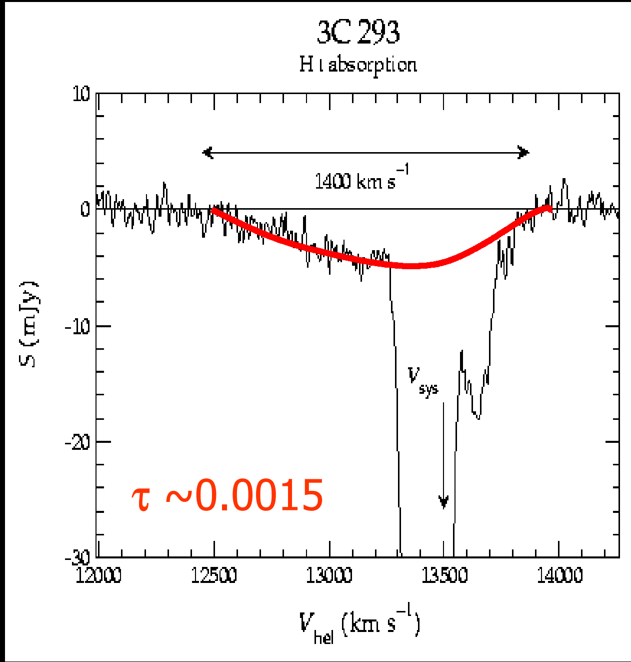
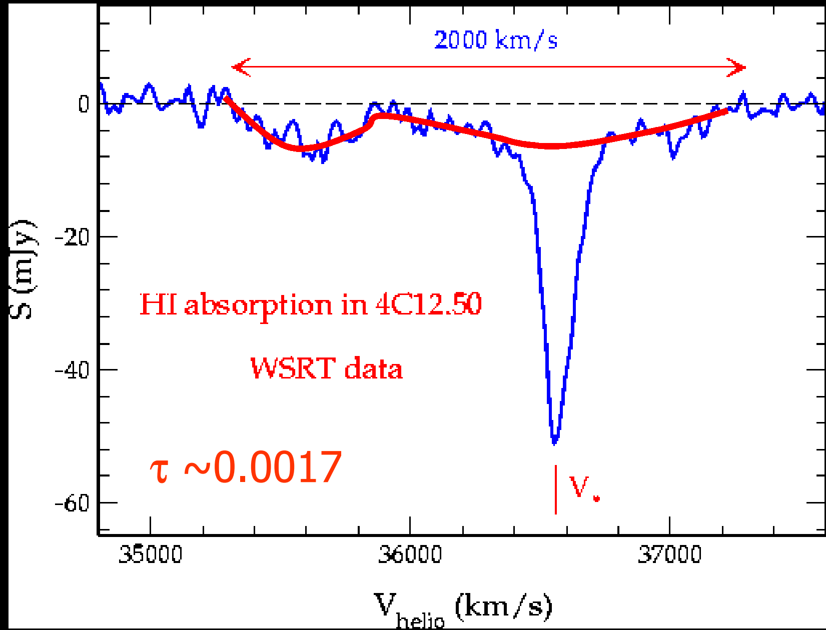
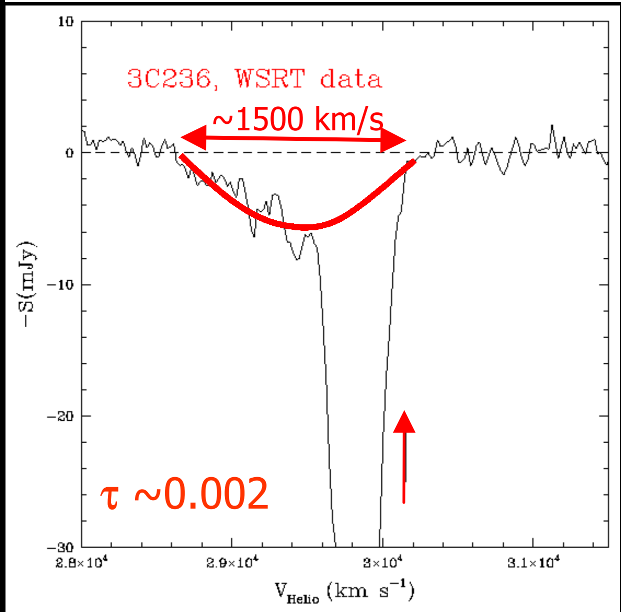
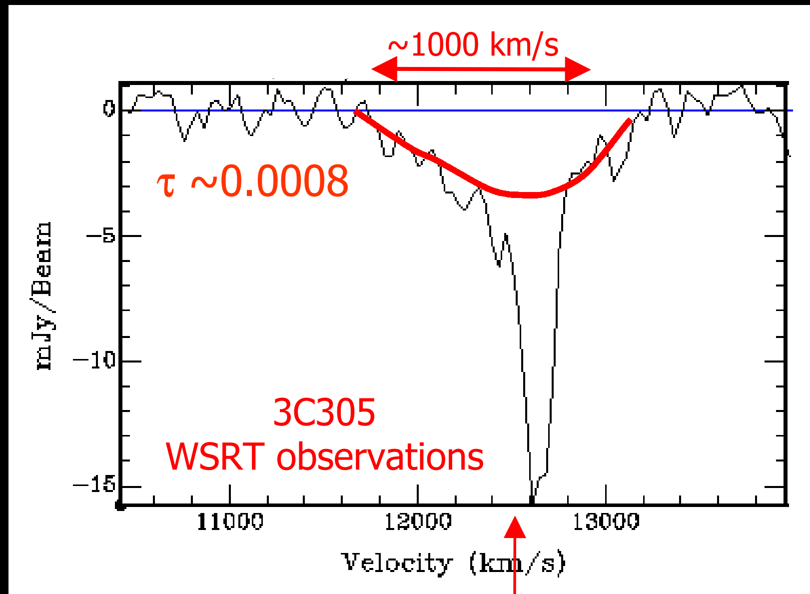
WSRT observations of radio galaxies

Morganti et al. ApJL (2003)







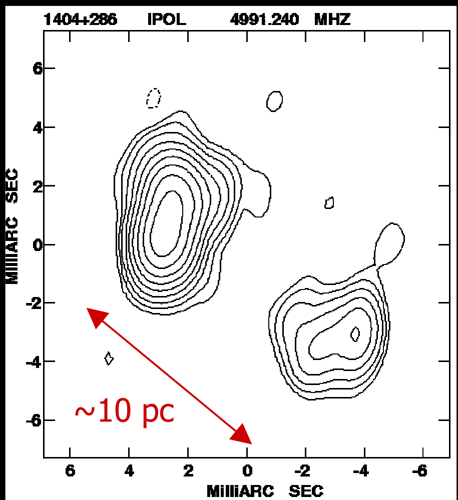


- ➢ Narrow components of the HI absorption were known before

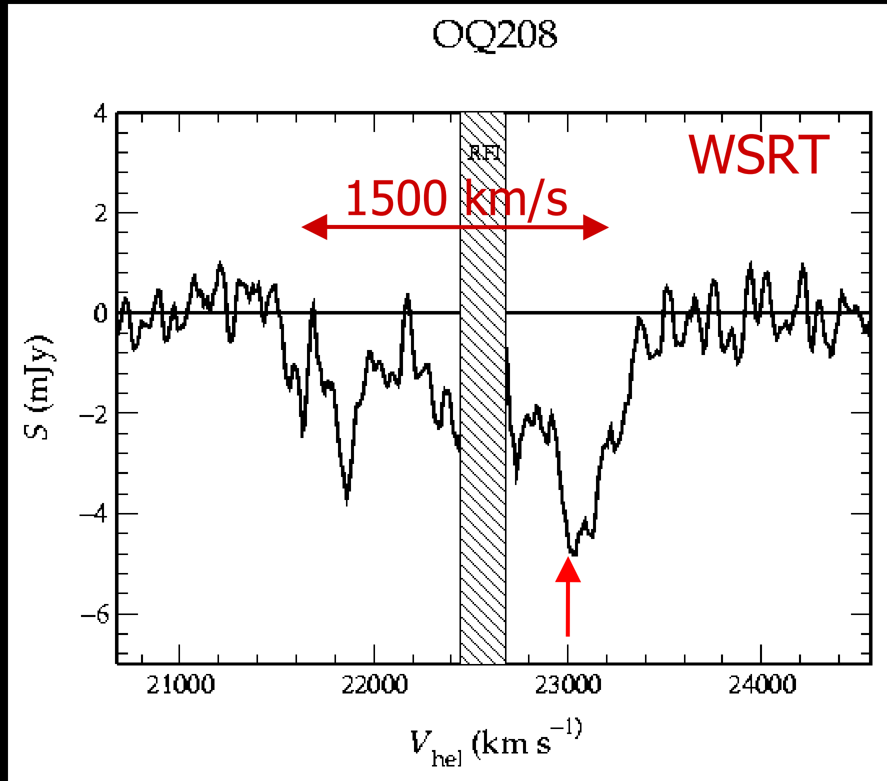
A recent new case: the compact radio source OQ208

- known to have fast outflow in the broad emission lines (Marziani et al.)

- particularly rich medium from X-ray absorption:
radio jets possibly piercing their way through a Compton-thick medium pervading the nuclear environment
(Guainazzi et al. 2004)



Stanghellini et al. 1993



Optical depth of the peak absorption
$\tau \sim 0.005$

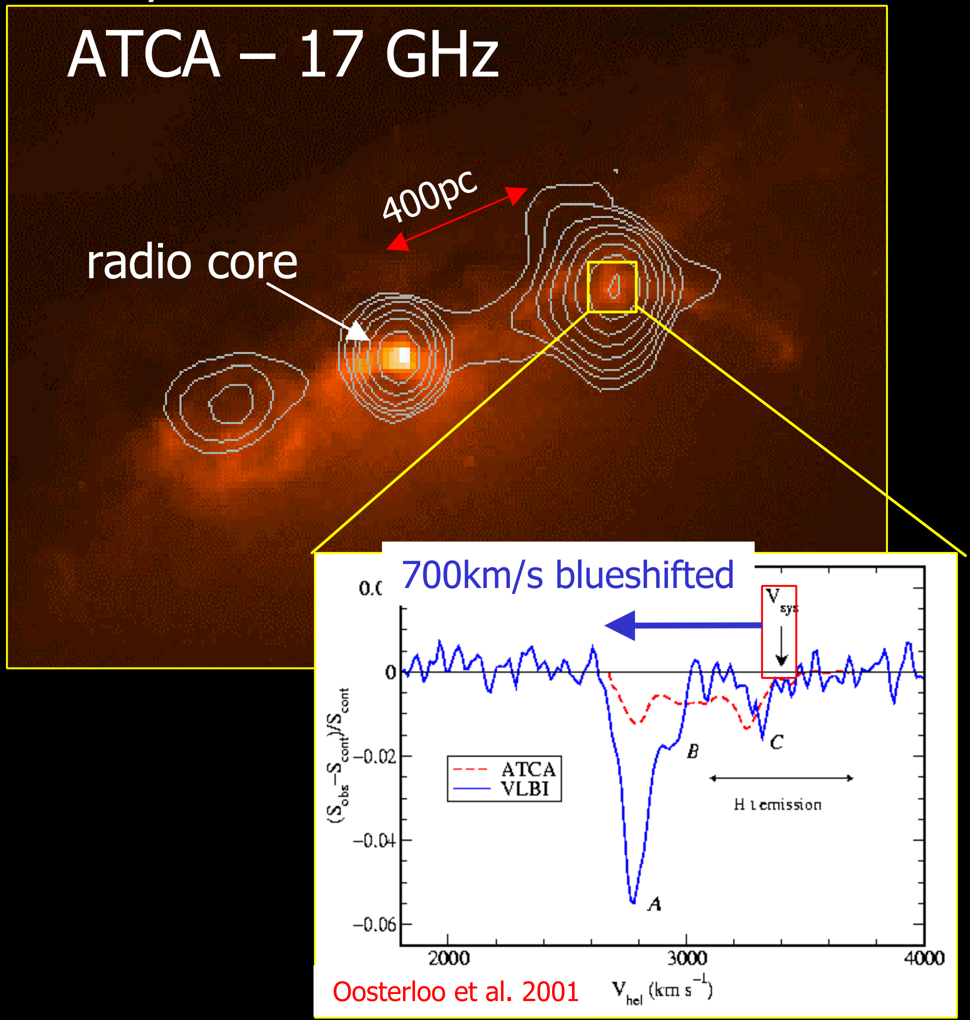
The neutral gas needs to be accelerated to velocities many times its local sound speed: how this is done is not yet clear

Physical parameters of the outflows (under many assumptions!)

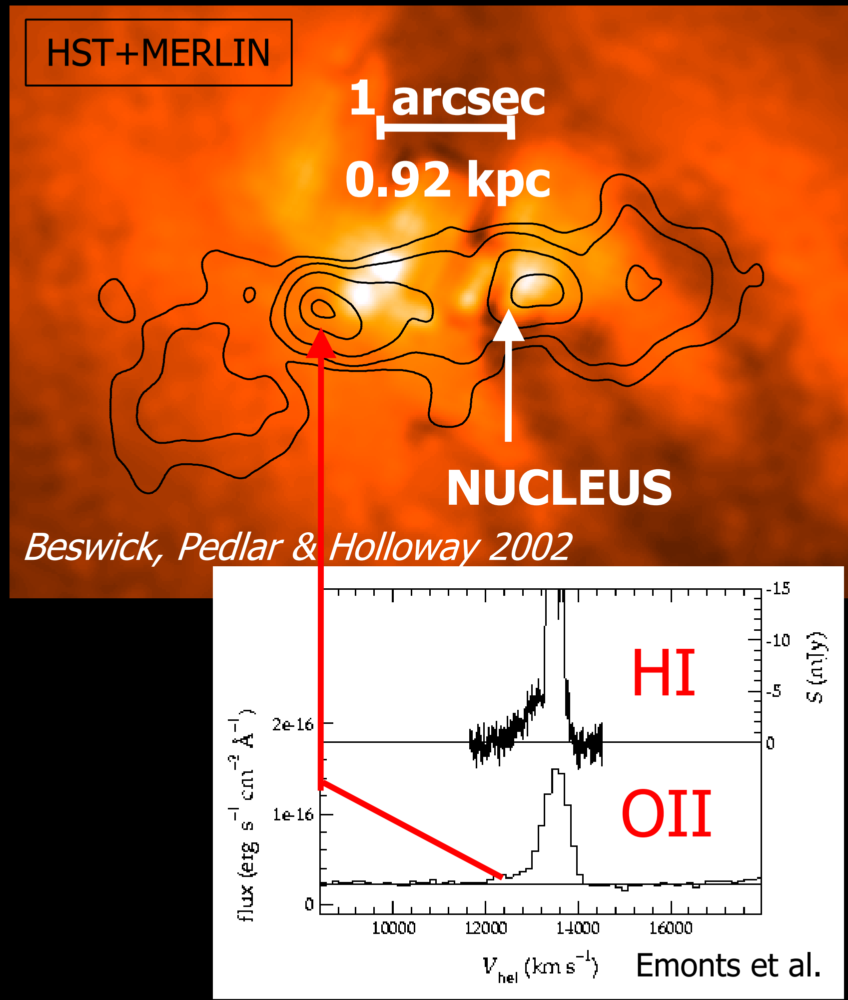
- Column densities: few x 10^{20} cm^{-2} (for T_{spin}=100K)
  assuming the HI uniformly covers the radio source
  but can go up to few x 10^{21} -- 10^{22} cm^{-2}
  if the HI is localized (e.g. 4C12.50?)
- Density of the neutral hydrogen: again very depended of the location/size
  from 0.2 cm^{-3} (3C293) to 30 cm^{-3} (e.g. OQ208).
- HI masses involved: wide range, from ~10^3 M_{sun} up to $2x10^6$ M_{sun}
- log Energy flux ~ 40 – 41.5 erg/s of the HI outflows

**The information on the location of the outflows is crucial but still very poor:
VLBI broad-band data are needed for this.**

The case of the radio-loud Seyfert IC 5063



Indirect evidence for the HI outflow at ~1kpc of the nucleus of 3C293



But there can be cases where the HI outflow is very close to the AGN (OQ208?)

Blueshifted wing of ionized gas at location of lobe: striking similarity with the HI

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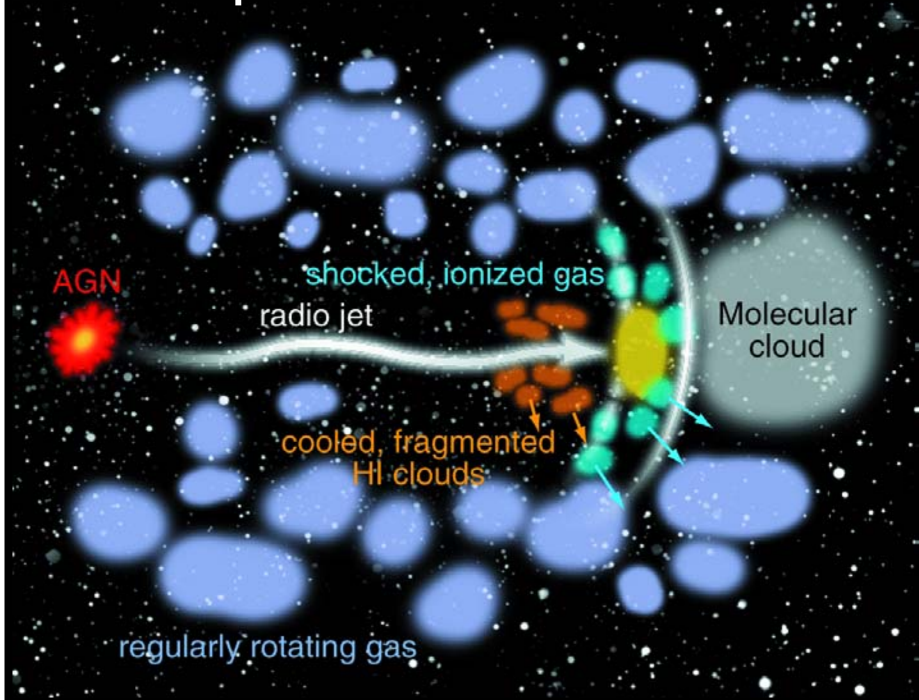
What produces the HI outflows?



Interaction between the radio jet and ISM

- Energy flux from the radio jets
  log $F_E \sim 42 - 42.4$ erg/s
  → efficiency between 0.01 and 0.1

From numerical simulations: cool gas can be produced in jet/cloud interaction (Mellema et al., Fragile et al.)

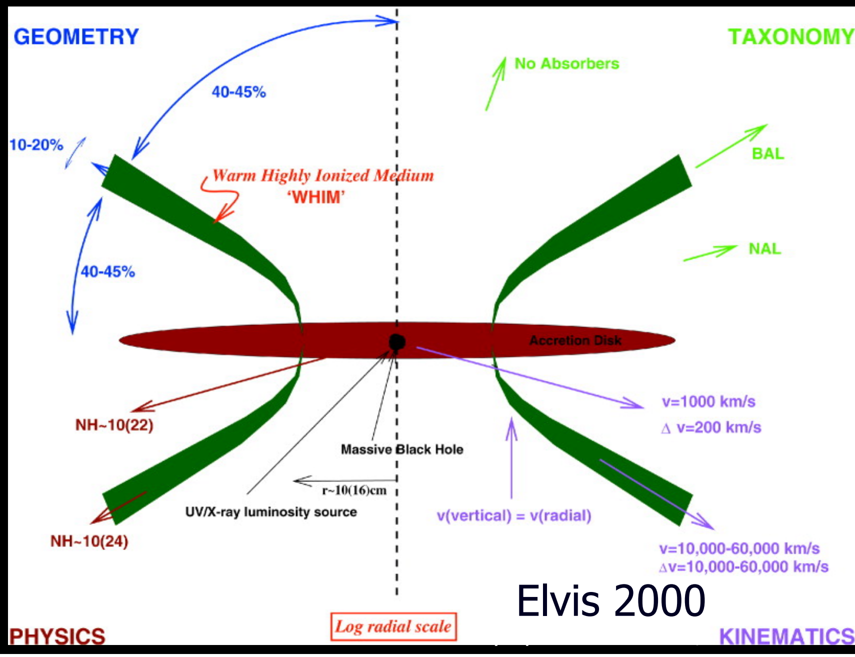
Outflowing Broad Emission Line Clouds (BELC)

- they will expand and cool adiabatically

- they will reach 1000K at ~3pc where they can form dust

- as they cool even further, HI will also form

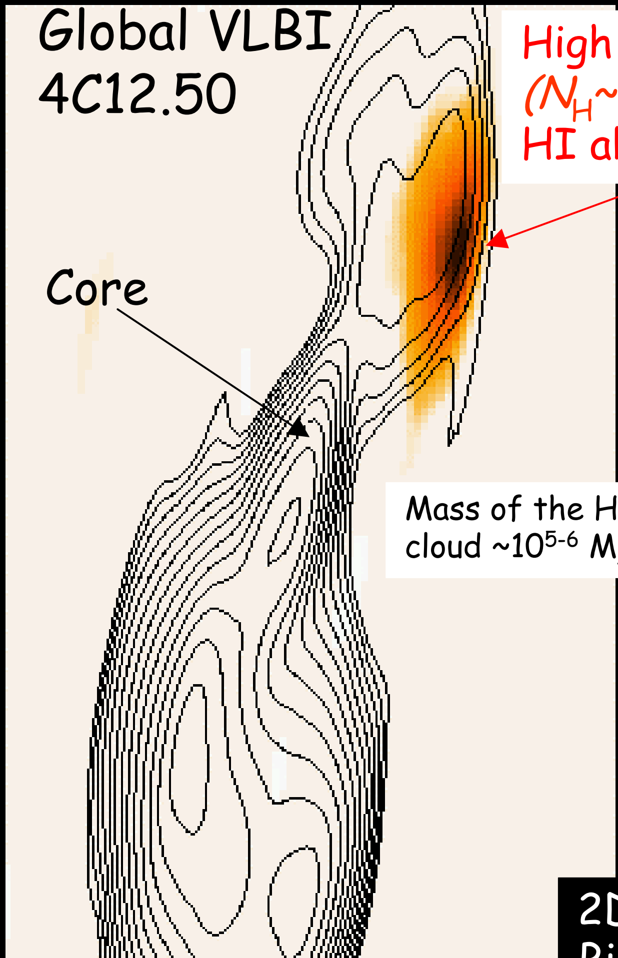
Elvis, Marengo & Karovska 2002



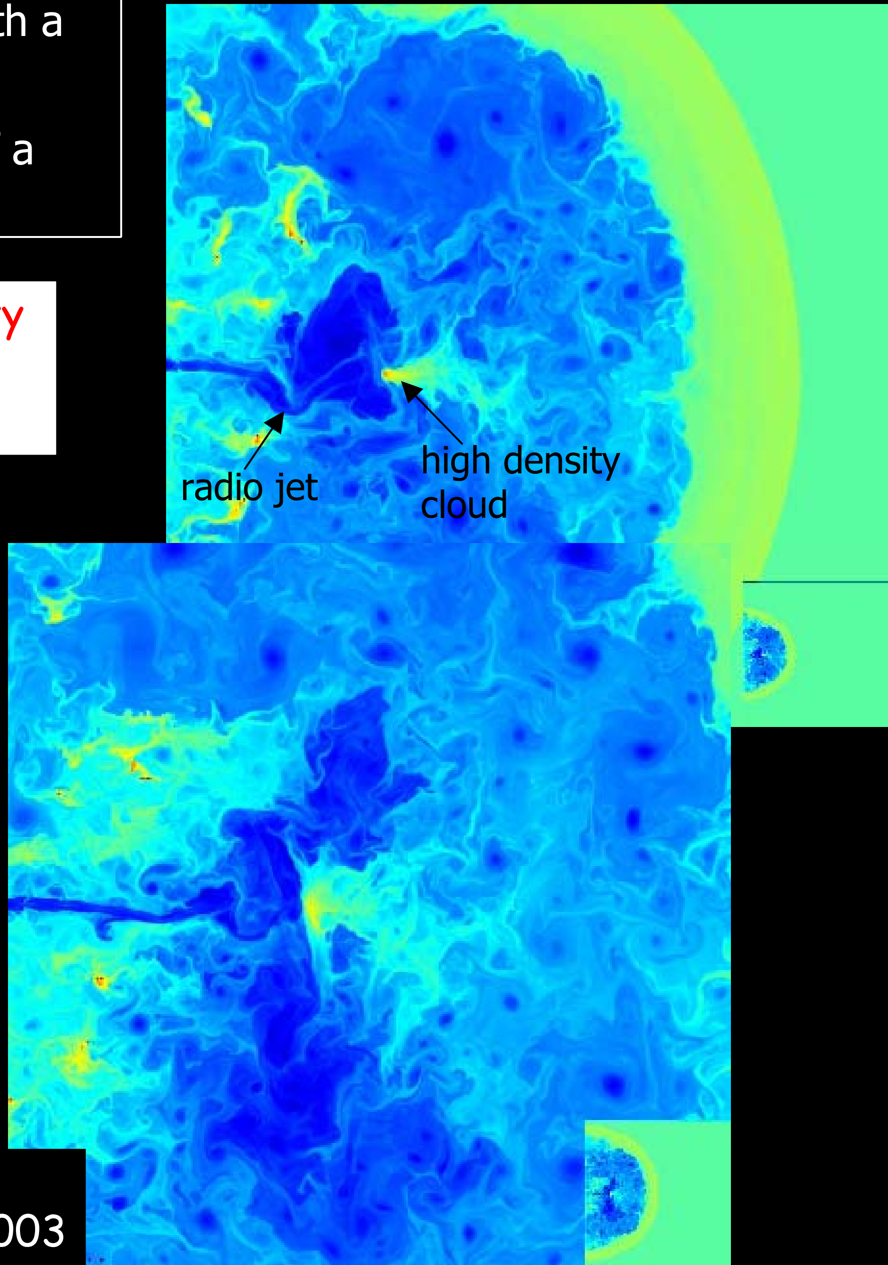
Elvis 2000

Even HI at the systemic can have nothing to do with a torus/disk

Case of 4C12.50: the jet is “fighting” its way out of a rich medium?



Morganti, Oosterloo, Vermeulen et al. 2004



2D simulations Bicknell et al. 2003

Other examples: OQ 208, 3C236?

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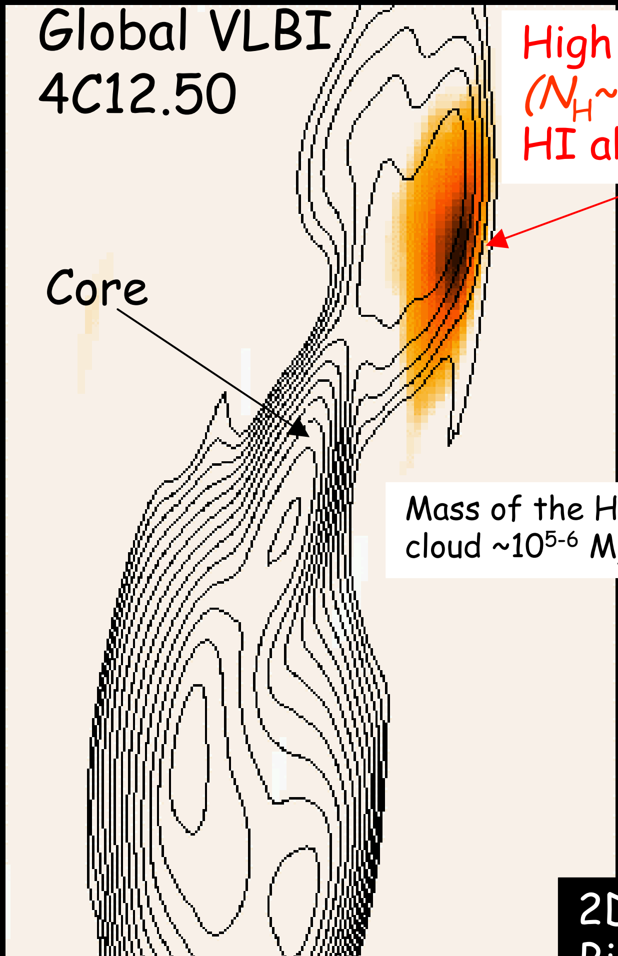
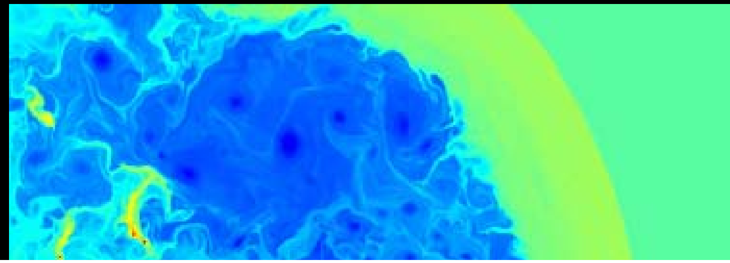
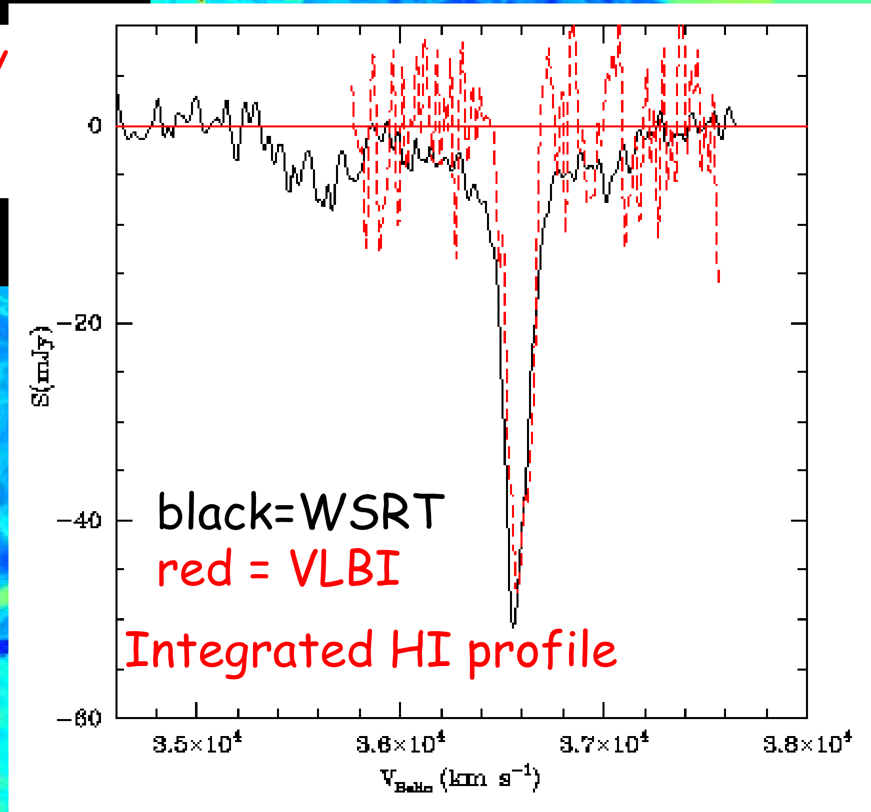


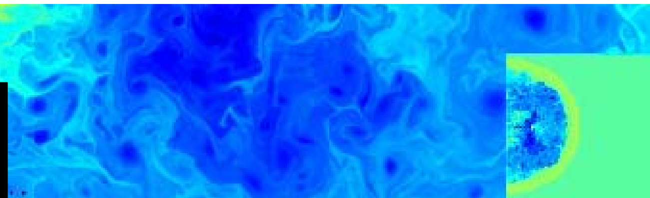
High column density (N_H~10^{22} cm^{-2}) HI absorption

Mass of the HI cloud ~10^{5-6} M_{sun}

Morganti, Oosterloo, Vermeulen et al. 2004







2D simulations
Bicknell et al. 2003

Other examples: OQ 208, 3C236?

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- Neutral hydrogen around AGN is telling us about a variety of phenomena!
- They can co-exist
- Because of this the interpretation can be complicated

Many open questions that can be answered only with sensitive, broad-band & high resolution VLBI observations:

- the occurrence of HI in tori *vs* larger scale circumnuclear disks: how many cases like Cygnus A?

  relation with studies of the free-free absorption: insight on the structure of the tori
- differences between different radio morphologies (e.g. FRI *vs* FRII)
- information on the (dense) medium: e.g. relation with polarization studies?
- how common are broad and low optical-depth absorption features

  → they trace different phenomena than usually expected to have HI associated with: constraints for the theoretical models
- some phenomena (e.g. outflows) can only be studied at such high resolution in radio
- ....

What can we do more with present-day radio telescopes

- More objects where HI is imaged on the VLBI scale (combined with information in other wavebands!)

- Relation with studies of free-free and polarization
- Importance of sensitive and broad band observations

→ so far underestimated the importance of broad-band observations

need bandpass stability →10^{-4}

What we cannot do

→

Demography of the HI absorption without bias!

The role of SKA will be crucial

Optical depth $\tau \sim 0.01$ will be detected for sources as weak as few mJy
(like searching for HI absorption every source in the NVSS catalogue!)
→ explore the uncharted region of low luminosity AGN and weak cores

"Blind" search:
- interesting (& successful) for HI emission in nearby galaxies
- so far no detection of HI in absorption:
  deep fields selected to have only weak sources

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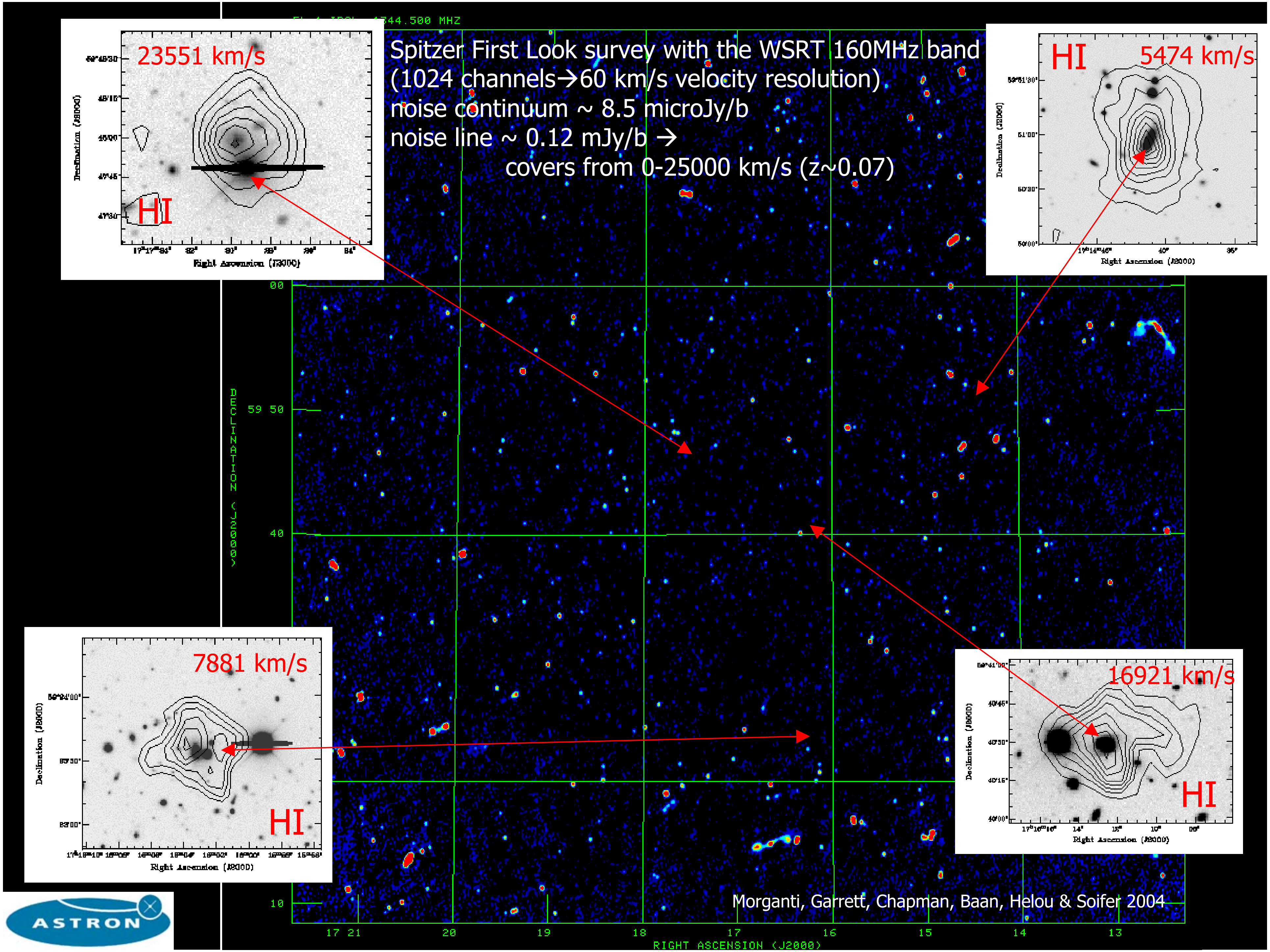
Spitzer First Look survey with the WSRT 160MHz band
(1024 channels→60 km/s velocity resolution)
noise continuum ~ 8.5 microJy/b
noise line ~ 0.12 mJy/b →
covers from 0-25000 km/s (z~0.07)
23551 km/s
HI
5474 km/s
HI
7881 km/s
HI
16921 km/s
HI
DECLINATION (J2000)
RIGHT ASCENSION (J2000)
Morganti, Garrett, Chapman, Baan, Helou & Soifer 2004
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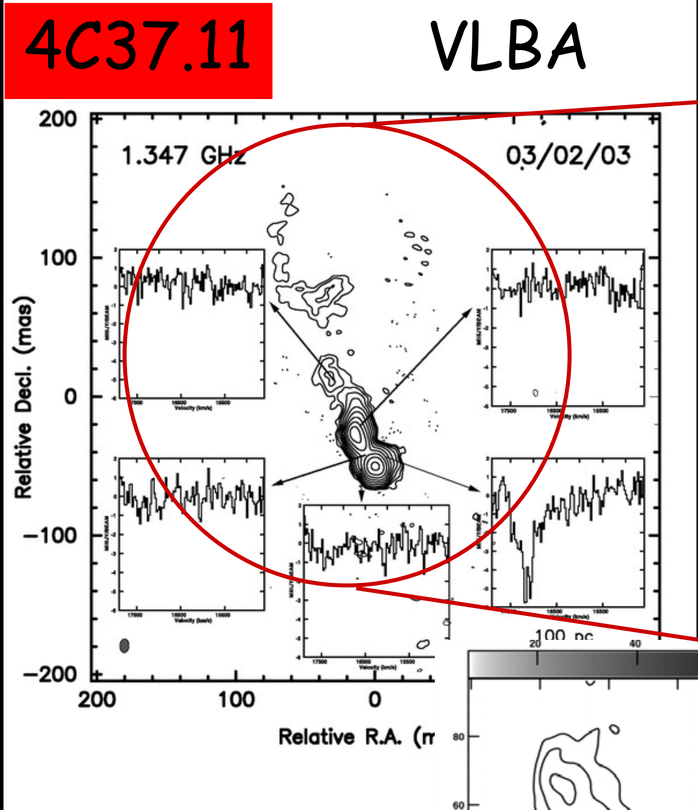
- differences between different radio morphologies (e.g. FRI *vs* FRII)
- information on the (dense) medium: e.g. relation with polarization studies?
- how common are broad and low optical-depth absorption features

  → they trace different phenomena than usually expected to have HI associated with:

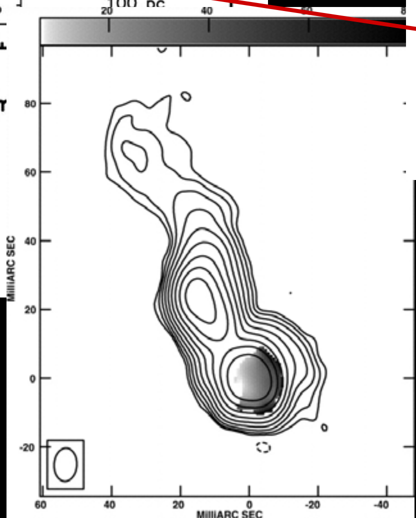
  constraints for the theoretical models
- some phenomena (e.g. outflows) can only be studied at such high resolution in radio
- ....

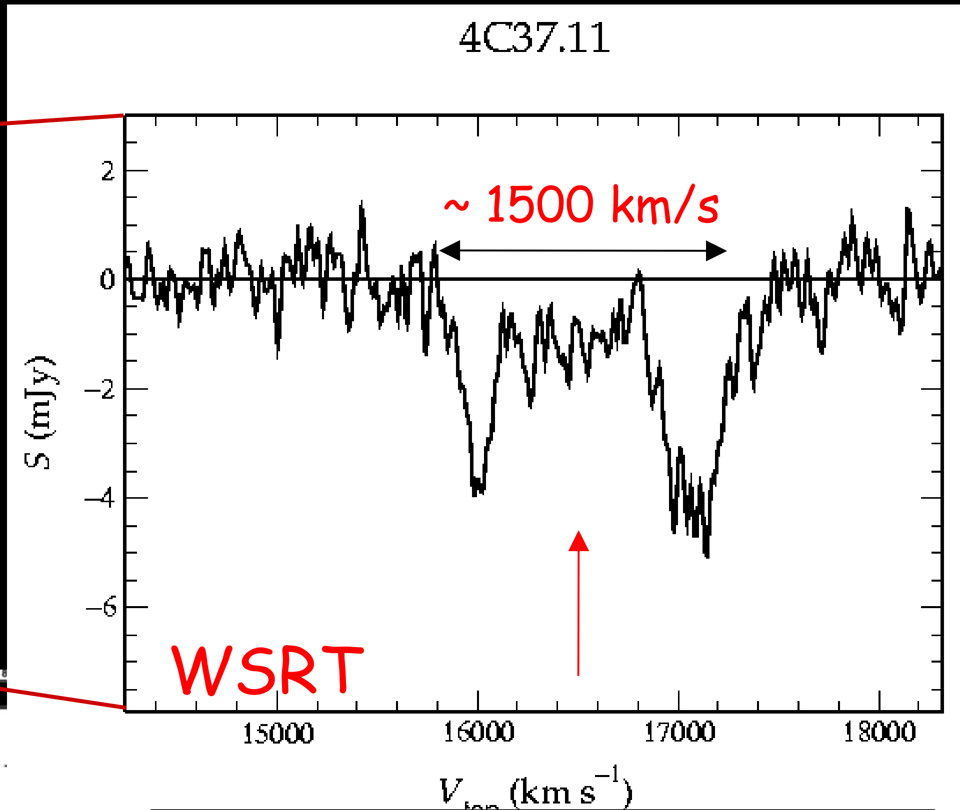
ASTRON

Not all the broad absorption features are outflows?



Taylor et al. (2004)





Optical depth of the peak absorption
τ ~0.3%

PKS 1549-79 with LBA