Netherlands Institute for Radio Astronomy

HI absorption to trace AGN feedback

Raffaella Morganti

ASTRON (NL) and Kapteyn Institute (Groningen)

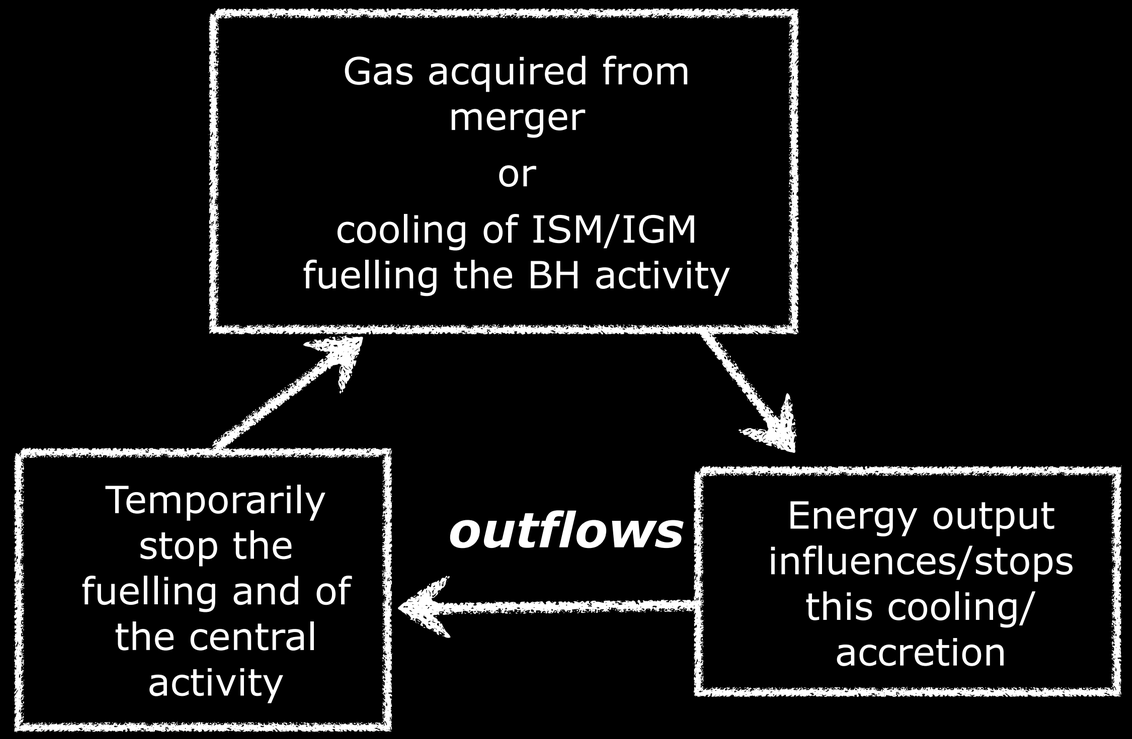
with the help of: T. Oosterloo, C. Tadhunter, K. Gereb , F. Maccagni, Z. Paragi, J. Fogacy, E. Mahony et al.

Photo: Laurens

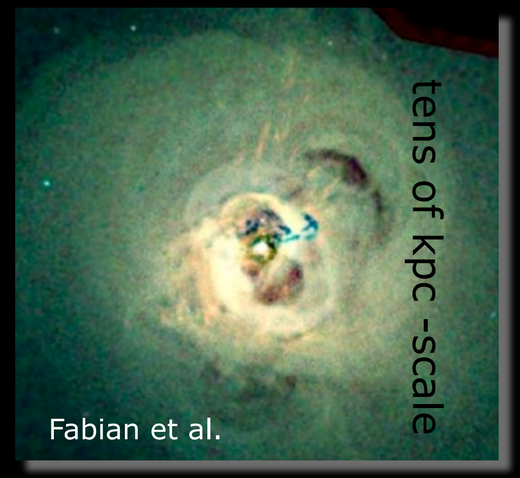
ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)

Why outflows

- Using associated HI absorption to trace **fast & massive AGN-driven outflows**
- Establish characteristics and relevance of such outflows in the nearby Universe.
- Important for constraining theoretical models of galaxy formation/evolution
- Impact likely even more relevant at higher redshift: tasks for future surveys.



Wagner & Bicknell 2011



Why outflows in HI (and cold gas in general)

Presence of outflows in a variety of AGN recognised since long time: mainly by tracing ionised gas

↓

Surprising findings: most of the mass in AGN-driven outflows associated to **cold gas (HI and molecular)**

Not expected/puzzling result ➜ focus of many ongoing projects ➜ need to quantify the characteristics, occurrence & origin of outflows of cold gas

What we have learned so far on HI outflows

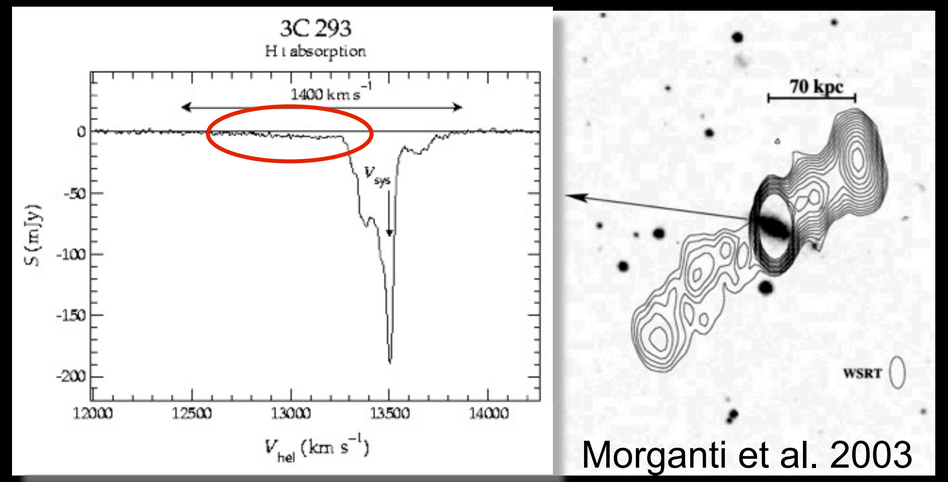
from a restricted (and biased?) number of objects

↓

promising learning ground for future large surveys

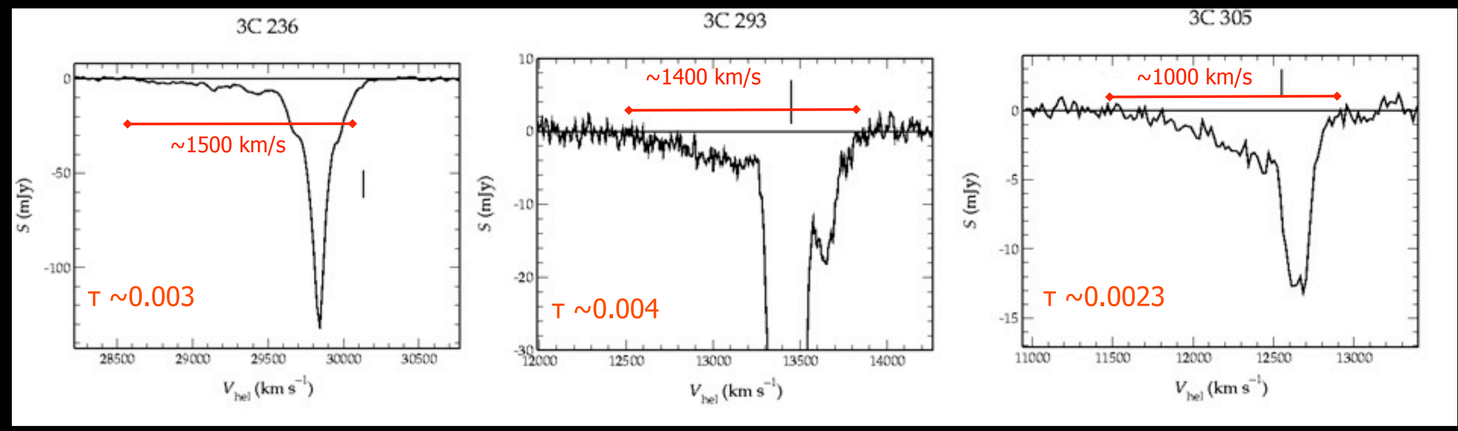
How do we find HI outflows

- Outflows identified by **broad, shallow and blueshifted** HI absorption wings
- Low optical depth τ~0.1 - 0.5%; column densities of a few x 10^{21} cm^{-2} (for a T_{spin}=1000 K)
- **velocities** from many hundreds km/s to >1000 km/s



Morganti et al. 2003

Improvements in technical capabilities of radio telescopes essential for the discovery



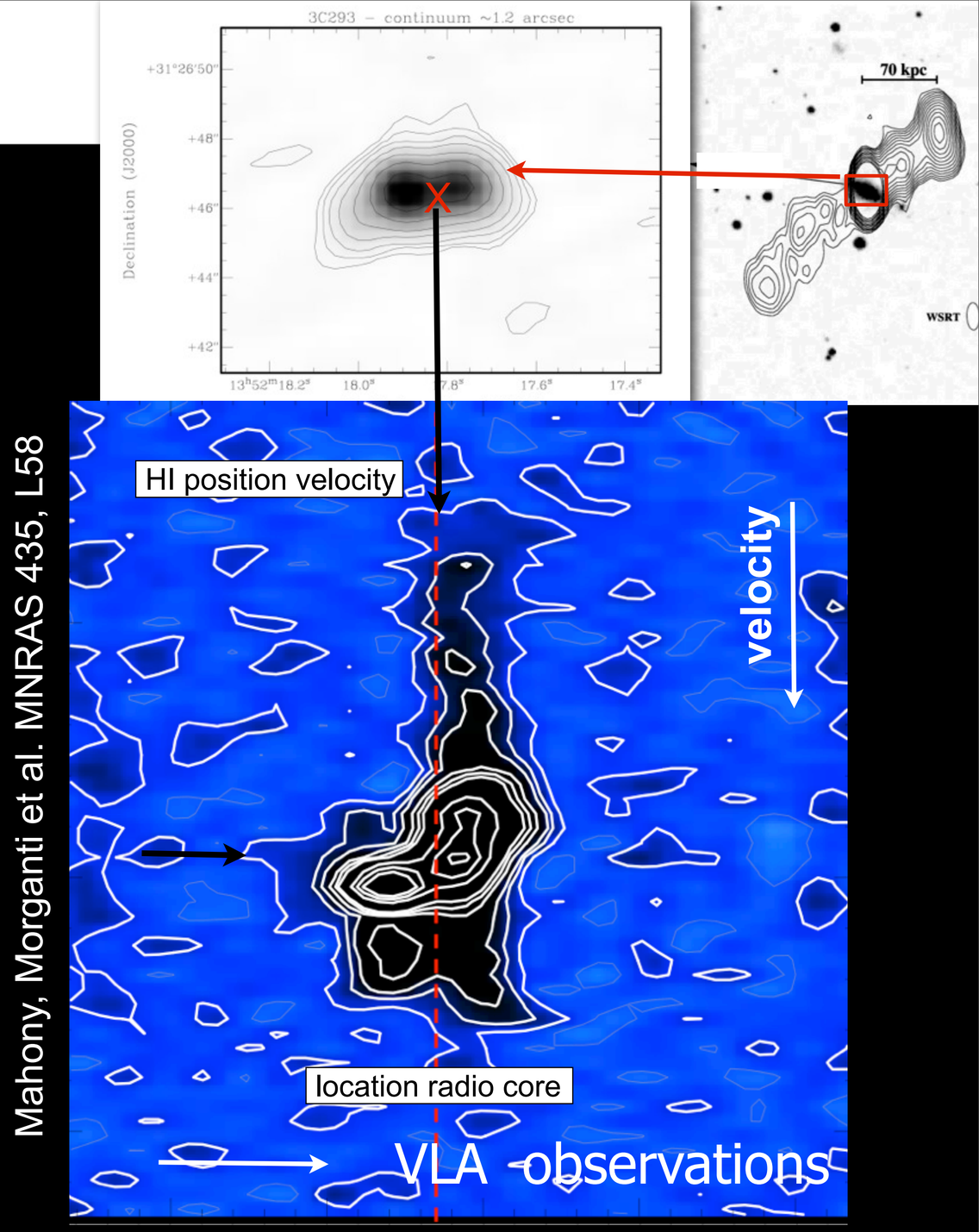
Morganti et al. 2003, 2005, 2010

Where do we find HI outflows

A broad range of objects show HI outflow

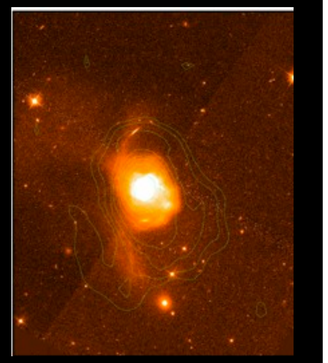
- Powerful radio galaxies, e.g. 3C293
- Easier to be detected because of outflow components have low optical depth

but also.....

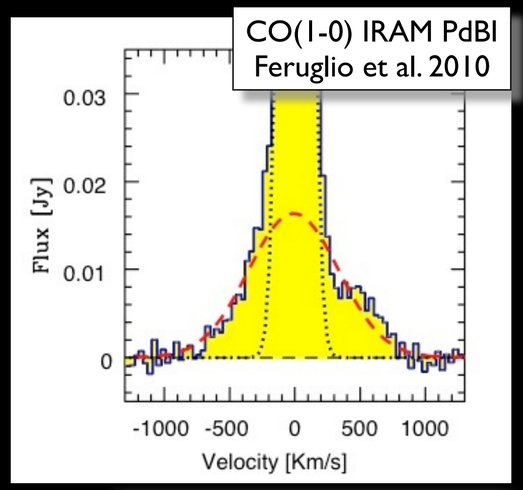


Where do we find HI outflows

From ULIRG.....



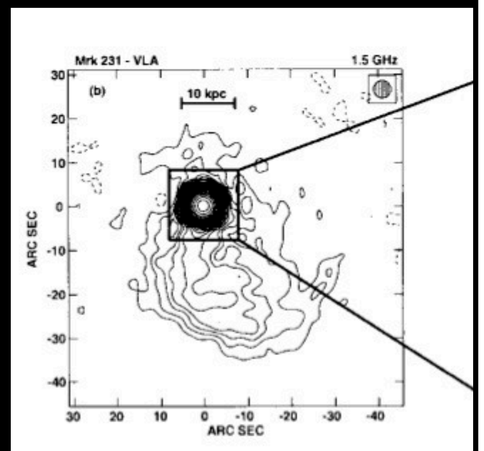
Mrk 231

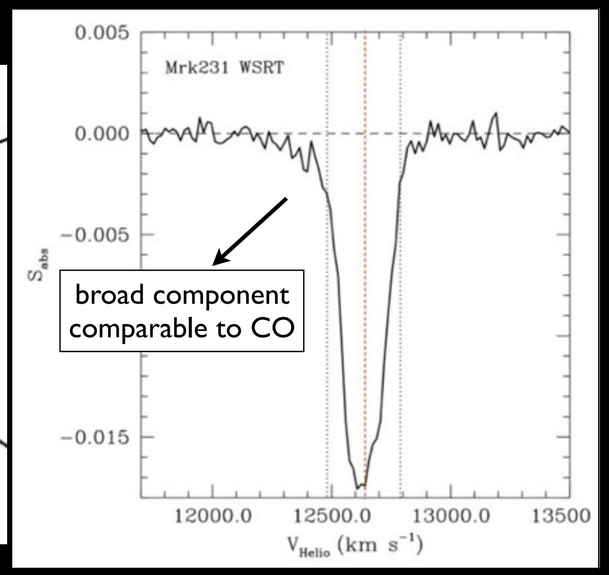


CO detection PdBI

Large mass outflow rate from CO (Feruglio et al. 2010)

HI outflow (less massive ~10 M_{sun}/yr)

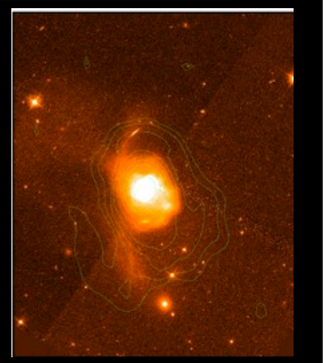




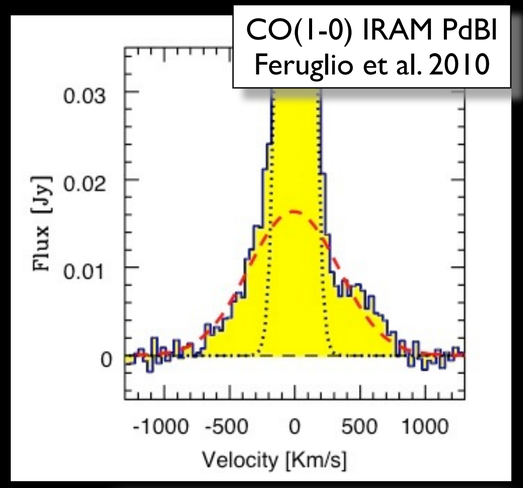
Morganti et al. in prep

Where do we find HI outflows

From ULIRG.....

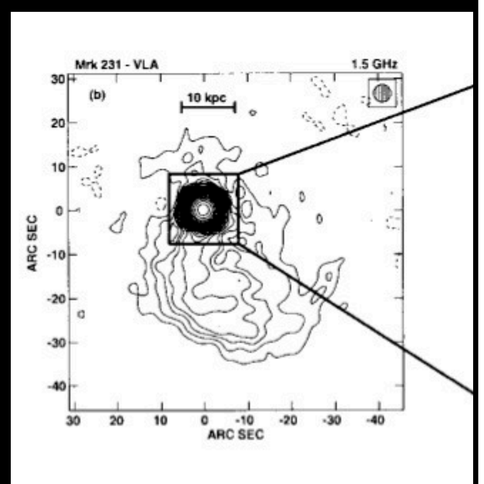


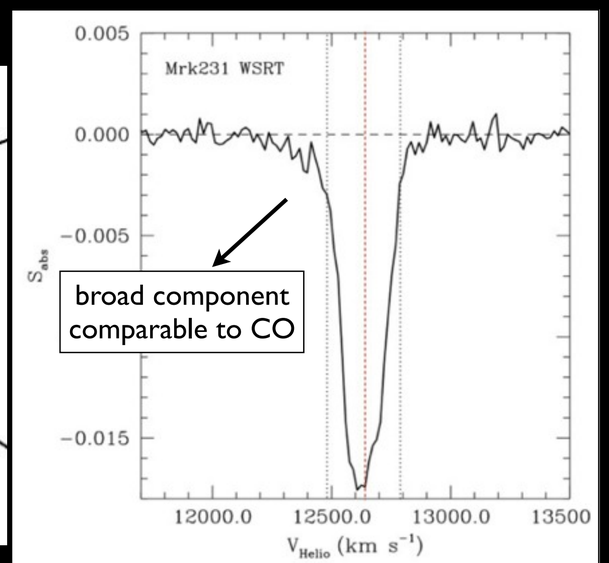
Mrk 231



CO detection PdBI

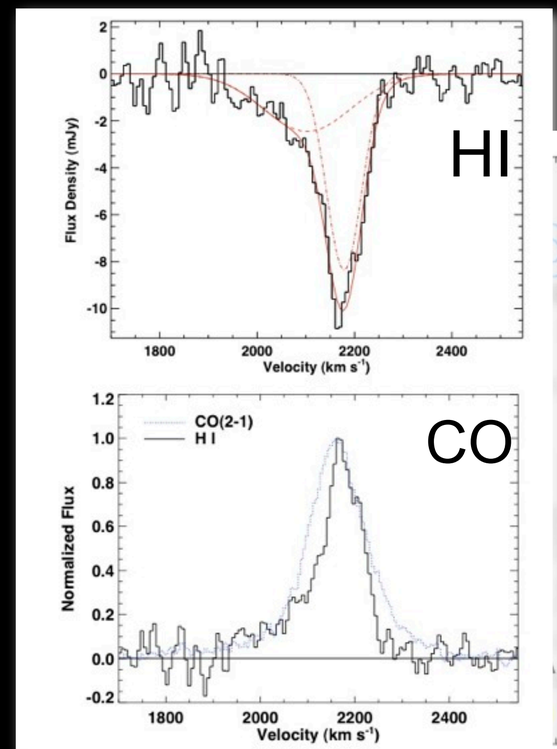
Large mass outflow rate from CO (Feruglio et al. 2010)
HI outflow (less massive ~10 M_{sun}/yr)

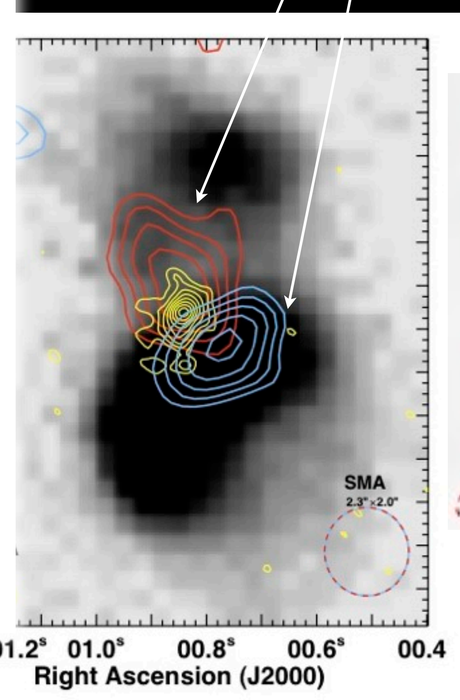


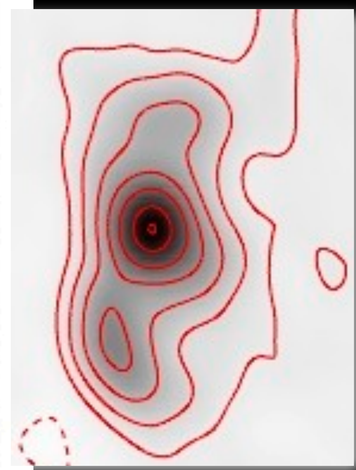


Morganti et al. in prep

...to "normal" galaxies

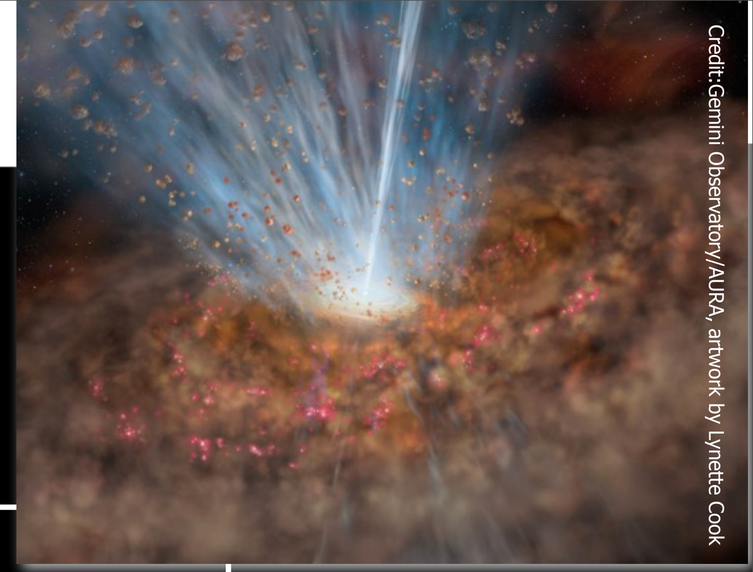






CO mass outflow rate ~13 M_{sun}/yr
Alatalo et al. 2011, Nyland et al. 2014

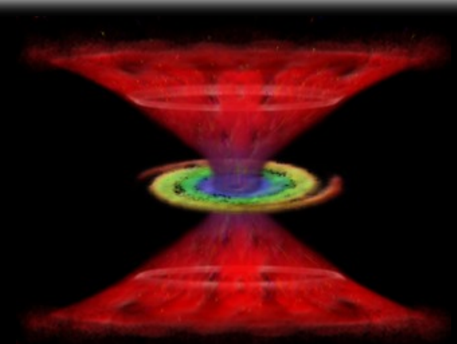
What drives the HI outflows



Outflows can originate in different ways

Nuclear winds, radiative feedback and mechanical feedback

- **Radiation pressure** can launch (wide) winds from the accretion disk
- Cold clumps of gas could be **entrained** and carried with the flow
- **Coupling** of AGN radiation to the dust in the wind



Wind from Accretion Disk around a Black Hole
Illustration: NASA/CXC/M.Weiss)

What drives the HI outflows

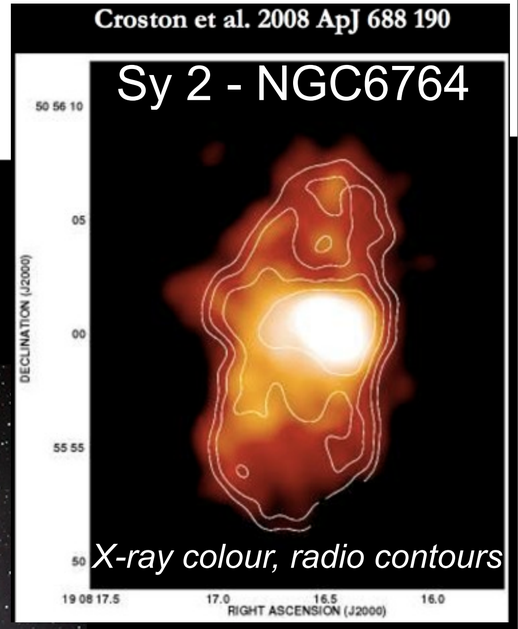
Expanding radio plasma can also provide an efficient mechanism

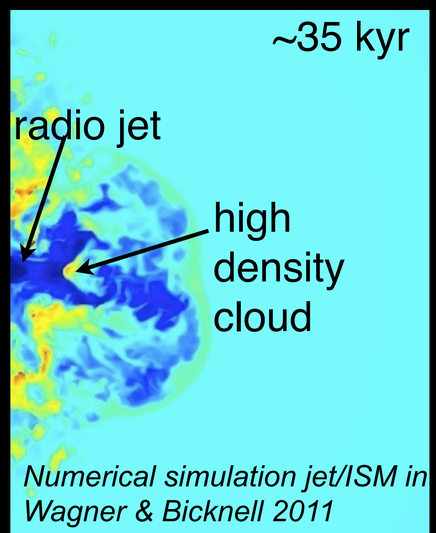
- **Expansion of loosely collimated lobe/bubbles**
  - A variety of cases => including weak radio sources able to produce outflows

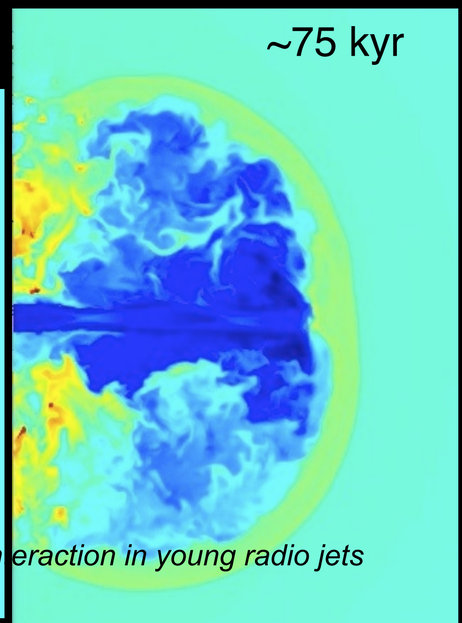
    => NGC1266 *(Alatalo et al. 2011)*, Mrk231 *(Rupke 2010, Morganti et al. 2011, in prep)*, NGC1433 (Combes et al. 2014)

    => showing the **general** relevance of jet/ISM interaction in creating outflows

- **Jets/ISM direct interaction**
  - Possibility of having cold gas - even in the presence of strong interaction/shocks - has been shown for a number of objects.







Numerical simulation jet/ISM interaction in young radio jets
Wagner & Bicknell 2011

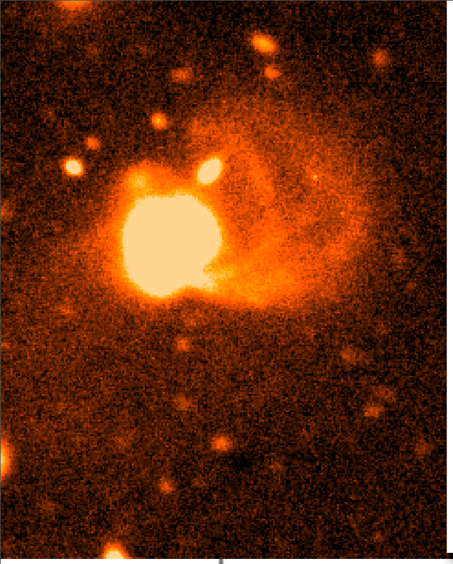
Location and distribution of the outflowing HI

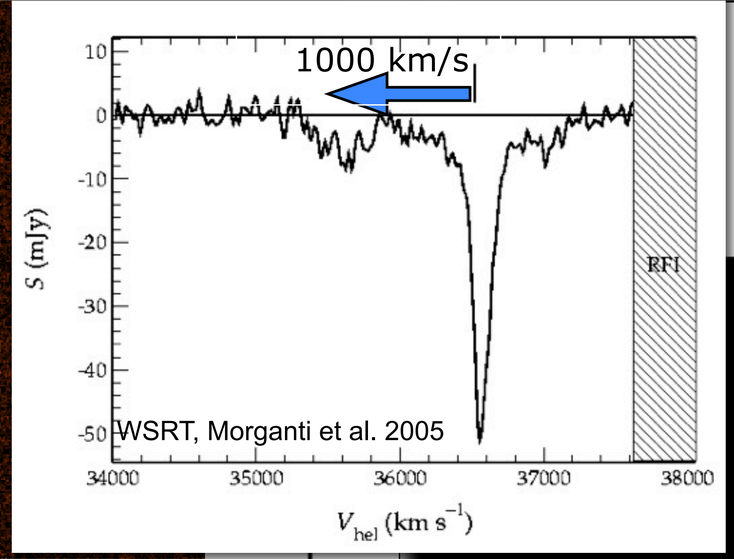
Location and distribution of the gas essential for understanding what is going on ➜ exact location known for an handful of cases

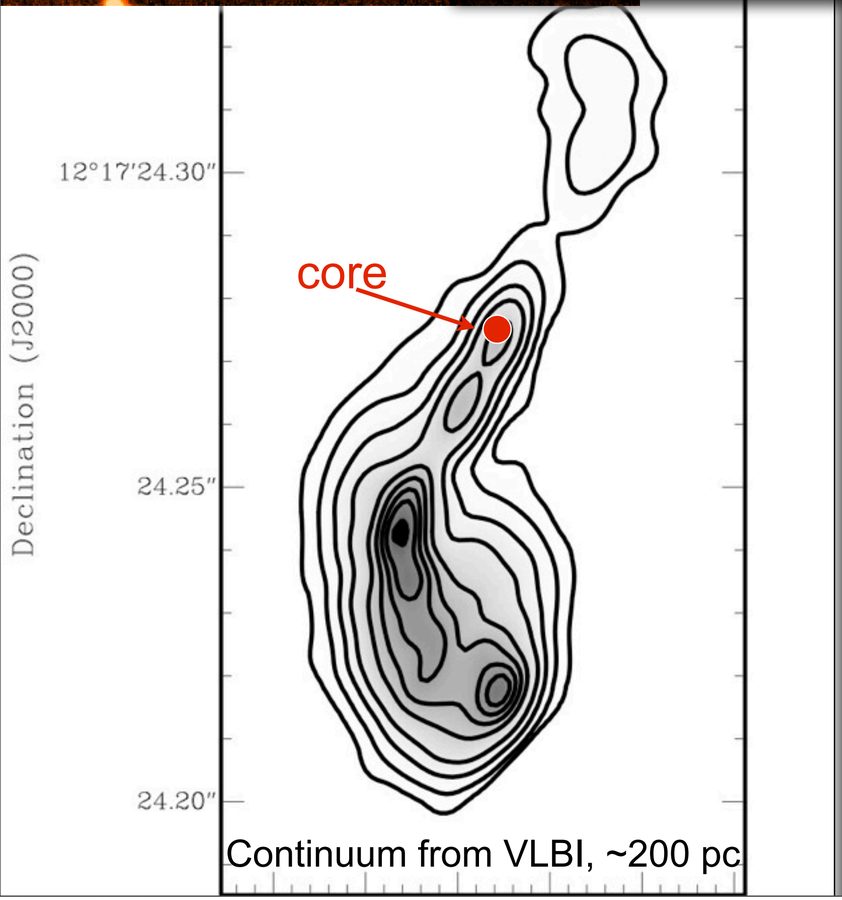
The outflows in radio galaxies are often located *hundred pc to kpc* from the core and coincident with radio features

FarIR bright young radio source: 4C12.50

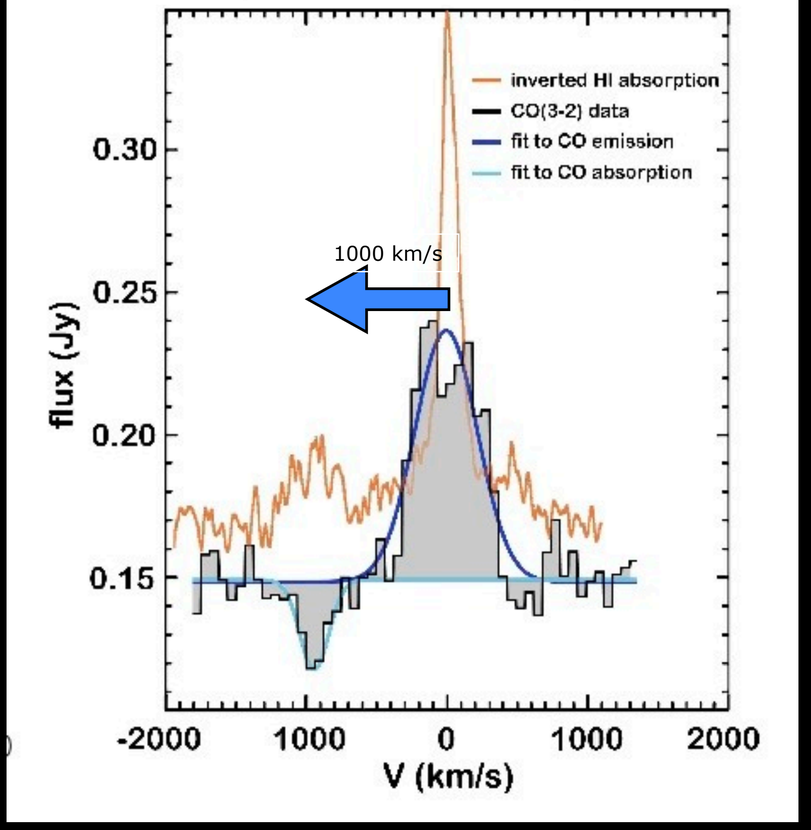
Morganti, Fogasy, Paragi et al. 2013, Science 341, 1082





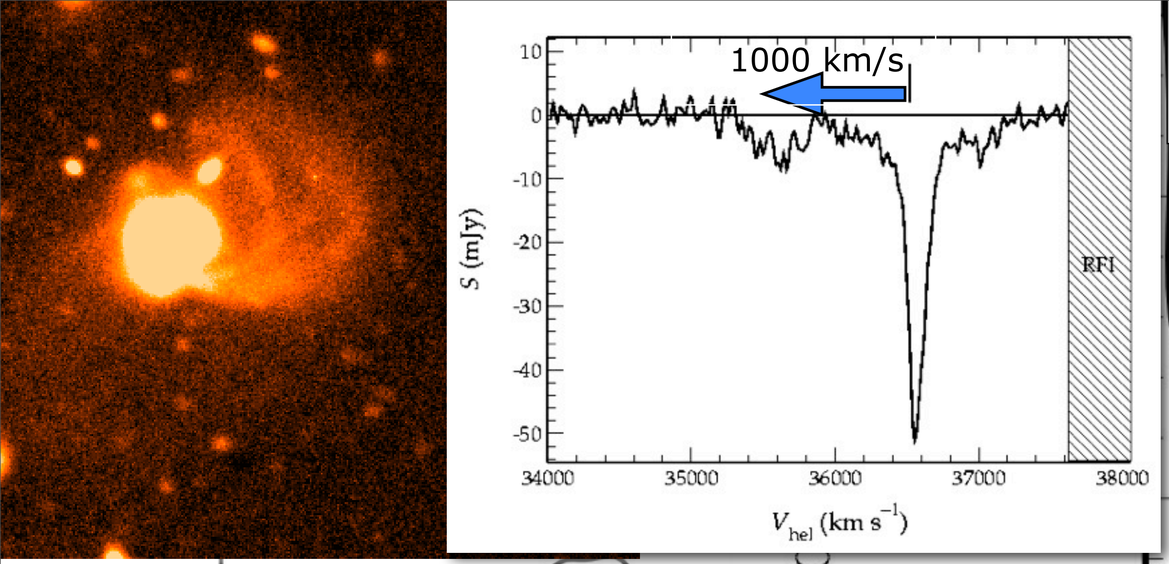


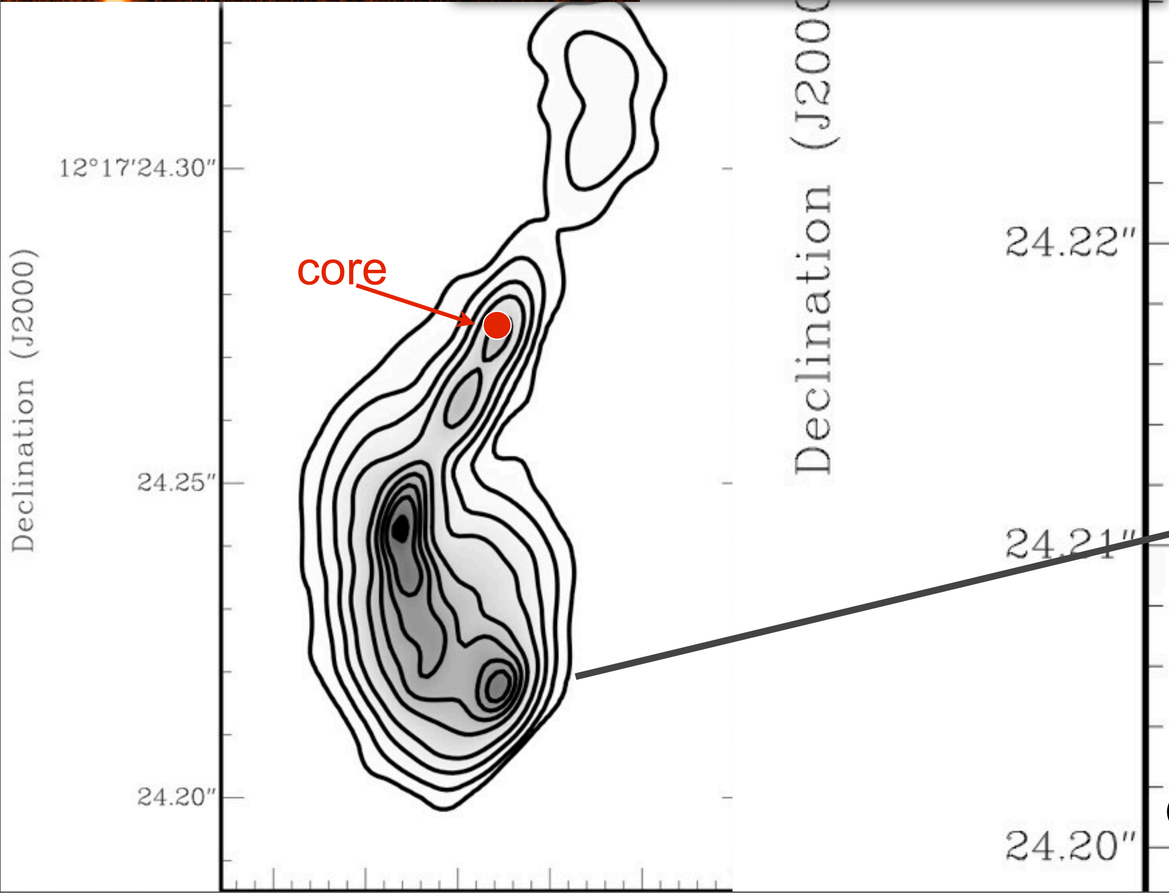
PdB+WSRT, Dasyra & Combes 2012, Morganti et al. 2005

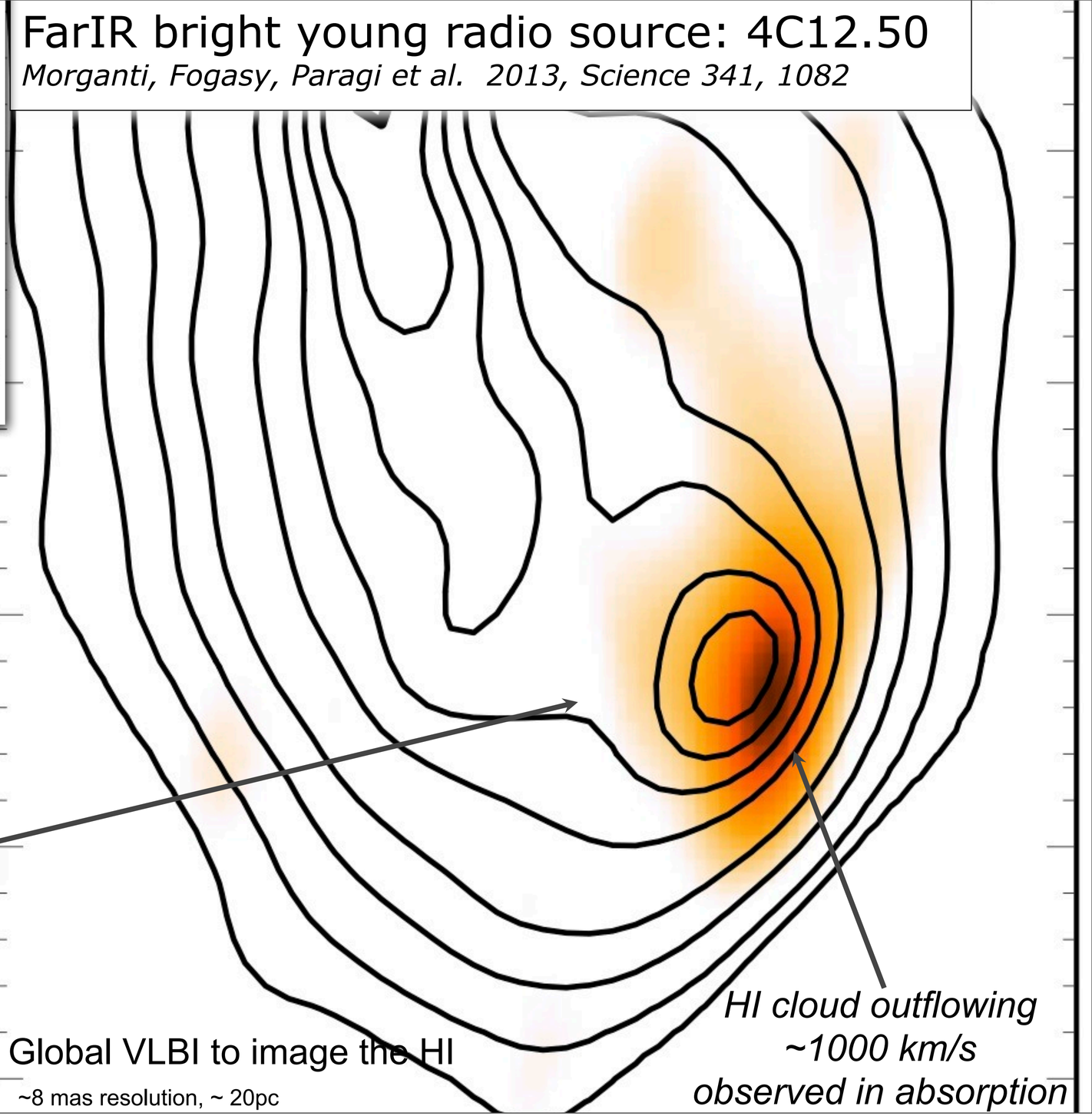


FarIR bright young radio source: 4C12.50

Morganti, Fogasy, Paragi et al. 2013, Science 341, 1082







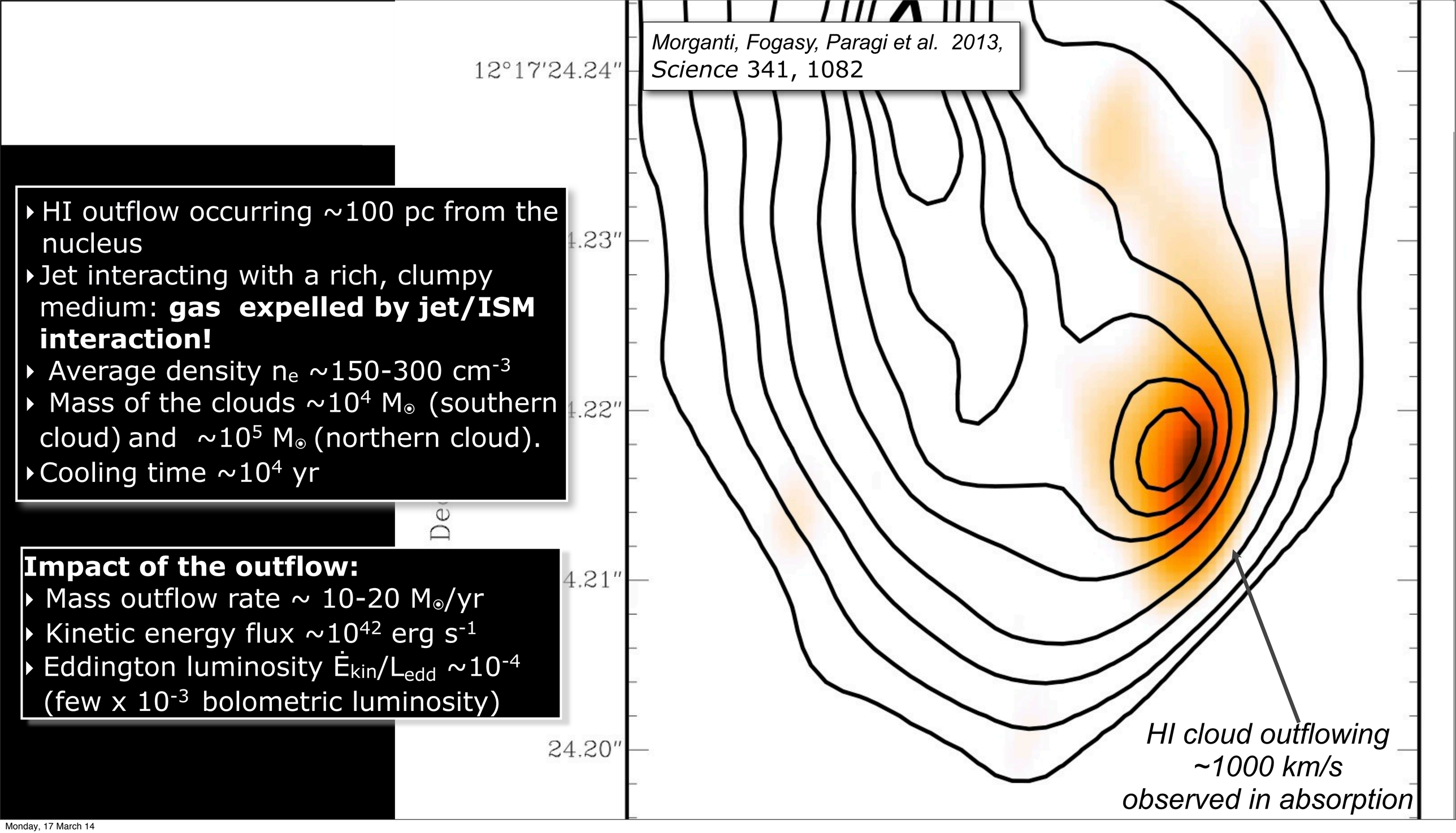
Global VLBI to image the HI

~8 mas resolution, ~ 20pc

HI cloud outflowing ~1000 km/s observed in absorption

- HI outflow occurring ~100 pc from the nucleus
- Jet interacting with a rich, clumpy medium: **gas expelled by jet/ISM interaction!**
- Average density n_e ~150-300 cm^{-3}
- Mass of the clouds ~10^4 $M_\odot$ (southern cloud) and ~10^5 $M_\odot$ (northern cloud).
- Cooling time ~10^4 yr

Impact of the outflow:
- Mass outflow rate ~ 10-20 $M_\odot$/yr
- Kinetic energy flux ~10^{42} erg s^{-1}
- Eddington luminosity $\dot{E}_{kin}/L_{edd}$ ~10^{-4} (few x 10^{-3} bolometric luminosity)



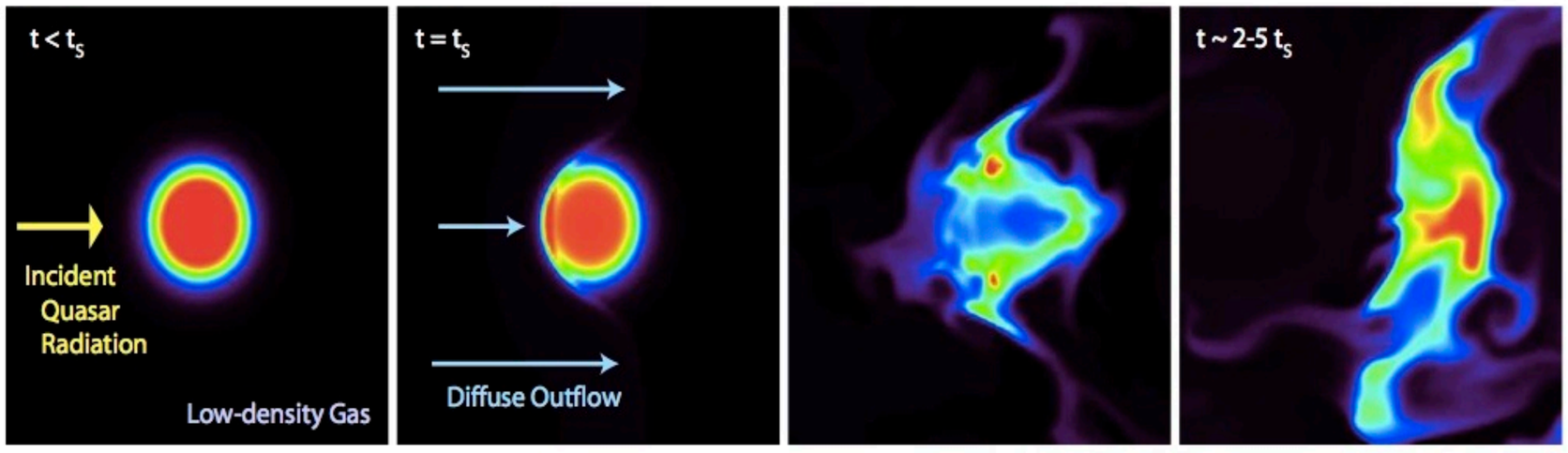
Morganti, Fogasy, Paragi et al. 2013,
Science 341, 1082

12°17′24.24″

24.23″

2000)

Morphological resemblance to the predictions from "two-stage" feedback model



Hopkins & Elvis 2010

Why cold gas after such interaction?

HI clouds outflowing ~1000 km/s observed in absorption

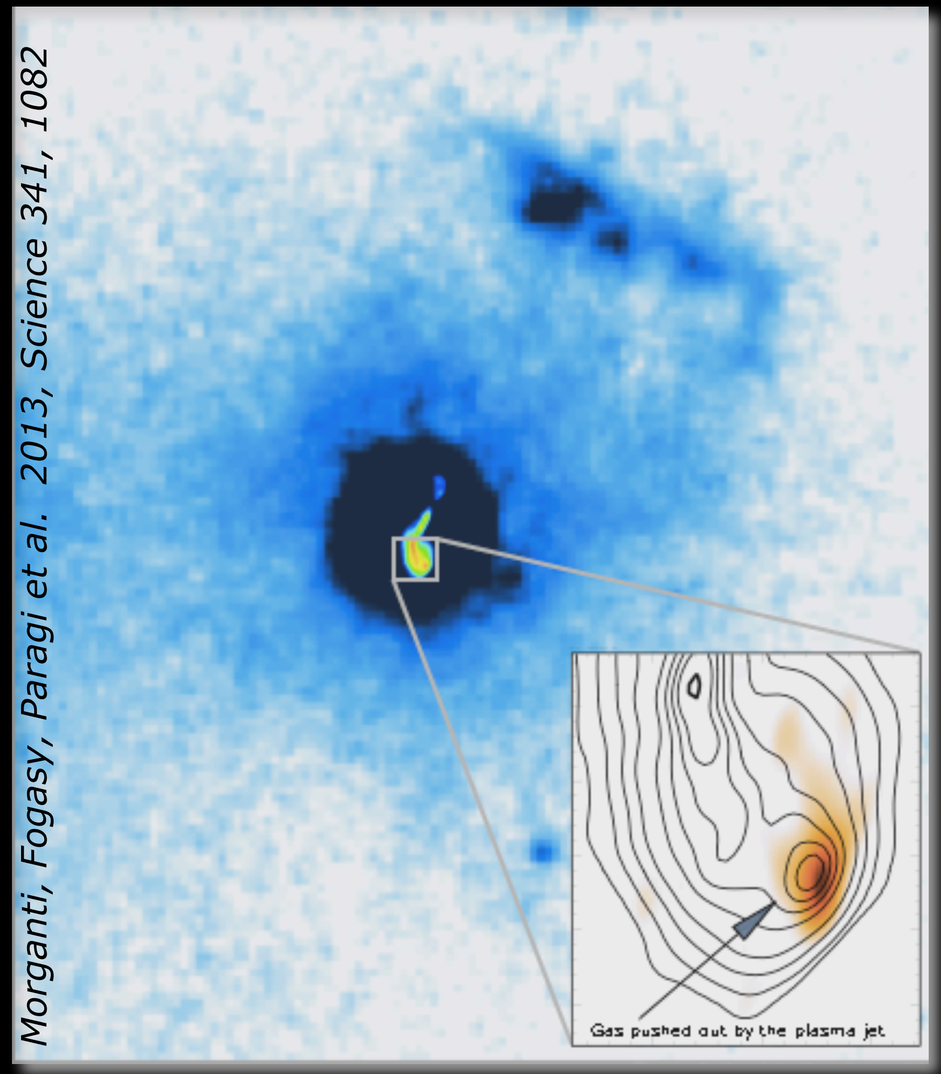
A possible scenario

HI and molecular (and ionised) gas often co-existing
➜ outflows truly multiphase

Gas cooling after a shock ➜ radio through a clumpy medium ➜ shocks accelerate/heat dense molecular clouds and molecules dissociated ➜ post-shock gas cools emitting emission lines (warm ionized gas) ➜ HI ➜ molecular lines

or

pre-existent **cold gas being pushed aside/entrained** (perhaps more likely in low radio power sources) ➜ e.g. case of Cen A?



Morganti, Fogasy, Paragi et al. 2013, Science 341, 1082

A possible scenario

HI and molecular (and ionised) gas often co-existing
➜ outflows truly multiphase

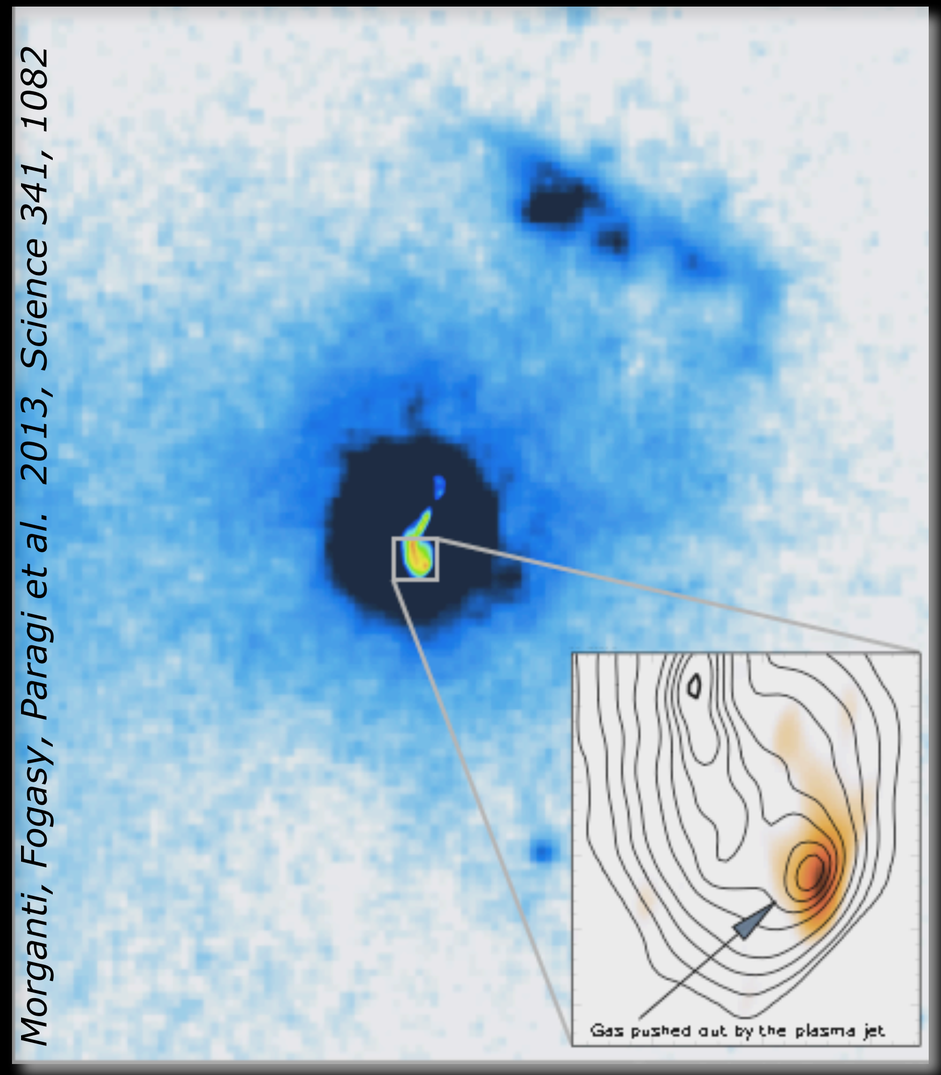
Gas cooling after a shock ➜ radio through a clumpy medium ➜ shocks accelerate/heat dense molecular clouds and molecules dissociated ➜ post-shock gas cools emitting emission lines (warm ionized gas) ➜ HI ➜ molecular lines

or

pre-existent **cold gas being pushed aside/entrained** (perhaps more likely in low radio power sources) ➜ e.g. case of Cen A?

mass outflow rates: 1-80 M_{sun}/yr from HI, >100 from CO for some ULIRG,
energetics: kinetic energy $10^{42\div43}$ erg/s $\dot{E}_{kin}/L_{edd}$= few x $10^{-4\div-3}$

Not consistent with the requirements from models of galaxy formation ➜ need for more realistic models (e.g. two-phase scenario)



Morganti, Fogasy, Paragi et al. 2013, Science 341, 1082

What do we expect from the new radio telescopes

Larger samples

Expand to lower radio fluxes

Make use of stacking

What do we expect from the new radio telescopes

Larger samples

Expand to lower radio fluxes

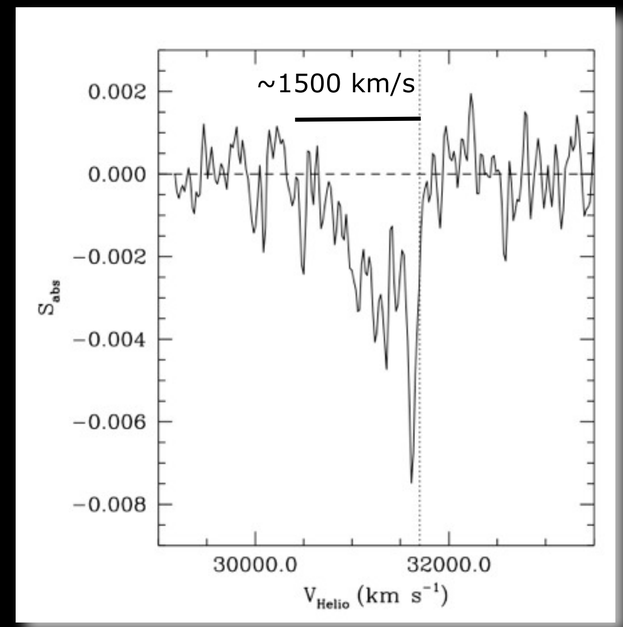
Make use of stacking

Exploratory survey using the WSRT **in preparation of Apertif**;
already with exciting results:

see presentation of K. Gereb

- observed more than 100 objects with SDSS redshifts
- down to 50 mJy *[extension down to 30 mJy in progress (PI F. Maccagni) filling the WSRT schedule (more than 200 sources)!]*
- stacking of absorption profiles

A newly found HI outflow from the WSRT shallow survey (Gereb et al. 2014)



What do we expect from the new radio telescopes

Blind surveys ➜ Apertif, ASKAP

Explore higher redshift ➜ FLASH

Working on how to set up this part

Ready (almost) to **piggyback on any Apertif survey**

Summary

- Exciting results from the study of fast and massive outflows of COLD gas
- Similarities between HI and molecular gas found in many cases: HI intermediate step in the cooling of the outflowing gas? ➜ ALMA will be crucial for this topic
- Possibilities for studies of HI absorption and detection of HI and molecular outflows opened by the new telescopes (both pathfinders/precursors and SKA1) ➜ *down to weak radio sources (good prospect ➜ see Katinka's talk) and with blind surveys*
- Outflows LIKELY even more relevant at higher redshift: important to extend the studies at low frequencies (see e.g. FLASH)
- Location and distribution of the gas important for the interpretation: high spatial resolution needed (and VLBI)