HI absorption to trace AGN feedback

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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.
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 $\tau \approx 0.1 - 0.5\%$; column densities of a few $\times 10^{21} \text{ cm}^{-2}$ (for a $T_{\text{spin}} = 1000 \text{ K}$)
- **Velocities** from many hundreds km/s to $>1000 \text{ km/s}$

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

Mrk 231

CO detection PdBI

Morganti et al. in prep
Where do we find HI outflows

**From ULIRG......**

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From ULIRG to "normal" galaxies

**...to “normal” galaxies**

**CO outflow**

**CO**

**HI**

**NGC1266**

CO mass outflow rate ~13 $M_{\text{sun}}$/yr

Alatalo et al. 2011, Nyland et al. 2014

**broad component comparable to CO**

Monday, 17 March 14
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
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.
Location and distribution of the outflowing HI

Location and distribution of the gas essential for understanding what is going on \( \rightarrow \) 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

Continuum from VLBI, ~200 pc

Continuum from WSRT, Morganti et al. 2005

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Continuum from VLBI, ~200 pc
continuum from Lister et al. 2004

HI cloud outflowing ~1000 km/s

observed in absorption

Global VLBI to image the HI

~8 mas resolution, ~20pc

FarIR bright young radio source: 4C12.50
Morganti, Fogasy, Paragi et al. 2013, Science 341, 1082
HI outflow occurring ~100 pc from the nucleus
Jet interacting with a rich, clumpy medium: **gas expelled by jet/ISM interaction!**
- Average density $n_e \sim 150-300 \text{ cm}^{-3}$
- Mass of the clouds $\sim 10^4 M_\odot$ (southern cloud) and $\sim 10^5 M_\odot$ (northern cloud).
- Cooling time $\sim 10^4 \text{ yr}$

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

Morganti, Fogasy, Paragi et al. 2013, *Science* 341, 1082
Why cold gas after such interaction?

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

Continuum from Lister et al. 2004

HI and continuum

Hopkins & Elvis 2010

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

Why cold gas after such interaction?

INcident Quasar Radiation

Low-density Gas

Diffuse Outflow

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

HI clouds outflowing ~1000 km/s observed in absorption

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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?
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**mass outflow rates**: 1-80 $M_{\odot}$/yr from HI, >100 from CO for
some ULIRG,
**energetics**: kinetic energy $10^{42 \pm 43}$ erg/s $\dot{E}_{\text{kin}}/L_{\text{edd}} = \text{few } x 10^{-4 \pm 3}$

Not consistent with the requirements from models
of galaxy formation → need for more realistic
models (e.g. two-phase scenario)
What do we expect from the new radio telescopes

Larger samples
Expand to lower radio fluxes
Make use of stacking
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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)

\[\text{~1500 km/s}\]
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)