

Gas in the Life Cycle of Radio Sources

Raffaella Morganti

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

Thursday, 19 April 2012

Netherlands Institute for Radio Astronomy

ASTRON (NL) and Kapteyn Institute (Groningen)

Resolving The Sky - Radio Interferometry: Past, Present and Future Manchester, Aprile 2012



A complex interplay and the role of AGN

of a galaxy and its surrounding IGM.

Interplay (or feedback) incorporated in galaxy formation models, e.g., to reduce the number of massive galaxies forming and to explain the tight correlation between the mass of the stellar spheroid and that of the central black hole





Thursday, 19 April 2012



Galaxy formation by coalescence of smaller objects and by the accretion of gas directly from its environment => complication: tight interplay between star formation/AGN activity and ISM





Gas outflows: the cold component of gas may be the dominant one!

- outflow of cold gas found in HI and molecular gas
- mass outflow rates comparable with starburst winds
- the mechanism => location of the outflow coincident with bright radio features

-100

Started with the HI.....

Broad (~1000 km/s) blueshifted HI absorption => signature of outflow

...now found also in molecular gas

Thursday, 19 April 2012



- Gas outflows: common in AGN
- originally found in UV/X-ray gas => but limited to pc scale

More promising: cold gas and effect of the radio plasma





An important role for the radio plasma: the small scale

- phases ISM and effective on large scales.
- Cocoons around the jet (shocked/disturbed gas over a large region)
- Focus on the effects of the first phase (or restarted phase) of the radio source





Radio jet can provide a mechanism for producing fast gaseous outflows: coupling with all



~100 kyr

An important role for the radio plasma: the small scale

- Radio jet can provide a mechanism for prod phases ISM and effective on large scales.
- Cocoons around the jet (shocked/disturbed gas over a large region)
- Focus on the effects of the first phase (or restarted phase) of the radio source



2D and 3D simulations: jets interacting with inhomogeneous medium, (Sutherlands & Bicknell et al. 2007; A.Wagner & Bicknell 2011)

Radio jet can provide a mechanism for producing fast gaseous outflows: coupling with all

The radio sources that Richard used to like so much!





~100 kyr

This talk: brief overview of some recent results to quantify the importance of cold gas

Main messages:

- outflows as complex and multiphase structures
- **location** better known in some cases
- the cold gas appears to be the dominant component in jet-induced outflows despite the high energies dumped in the ISM by radio jets
- the estimated mass outflow rates may not be large enough for what needed in cosmological simulations: what is wrong?



• outflow of atomic and molecular gas found in a growing number of radio sources:



Outflows of HI & molecular gas: we keep on finding more



Thursday, 19 April 2012

Outflows of HI & molecular gas: we keep on finding more



Thursday, 19 April 2012





bright radio lobe





First case of fast outflow (700 km/s) of neutral hydrogen (Morganti et al. 1998, Oosterloo et al. 2000) One of the clearer examples of jet/cloud interaction: outflow at the location of the

First case of fast outflow (700 km/s) of neutral hydrogen (Morganti et al. 1998, Oosterloo et al. 2000) One of the clearer examples of jet/cloud interaction: outflow at the location of the bright radio lobe





Galaxy rotation (HI emission)

bright radio lobe





First case of fast outflow (700 km/s) of neutral hydrogen (Morganti et al. 1998, Oosterloo et al. 2000) One of the clearer examples of jet/cloud interaction: outflow at the location of the

bright radio lobe





First case of fast outflow (700 km/s) of neutral hydrogen (Morganti et al. 1998, Oosterloo et al. 2000) One of the clearer examples of jet/cloud interaction: outflow at the location of the

Outflowing gas (HI absorption)

IC5063: HI and CO outflows



Thursday, 19 April 2012



HI absorption

Outflow of molecular gas in addition to the HI

Mass outflow rate: HI gas ~ M_{dot} = 12 M_{\odot}/yr

molecular gas ~ M_{dot} = 7 M_o/y

ionised gas ~ M_{dot} = 0.08 M_{\odot}/yr

- (kinetic) Energy flux ~10⁴² erg s⁻¹
- Eddington luminosity E_{dot}/L_{edd} ~10⁻³ (few x 10⁻² fraction of bolometric luminosity)



IC5063: HI and CO outflows



Thursday, 19 April 2012



HI absorption

Outflow of molecular gas in addition to the HI

Mass outflow rate: HI gas ~ M_{dot} = 12 M_{\odot}/yr

molecular gas ~ M_{dot} = 7 M_o/y

ionised gas ~ M_{dot} = 0.08 M_{\odot}/yr

- (kinetic) Energy flux ~10⁴² erg s⁻¹
- Eddington luminosity E_{dot}/L_{edd} ~10⁻³ (few x 10⁻² fraction of bolometric luminosity)



HI outflows in radio galaxies: location, location, location!



Thursday, 19 April 2012



HI outflows in radio galaxies: location, location, location!

broad, shallow a

WSRT

Broad absorption $\tau \sim 0.38$ % $N_{\rm H} \sim 6 \ x \ 10^{20} \ {\rm cm^{-2}}$ for T_{SPIN}=100K

(m]y)

S

Broad HI absorption identified with a fast HI outflow

Morganti et al. ApJL (20

Thursday, 19 April 2012















What is the impact on the galaxy?

	warm (ionised)	С
Mass outflows	10 ⁵ Msun	
Mass outflow rate	0.1-10	
Ekin/Ledd	10 ⁻⁵ - 10 ⁻⁶	(

Only small fraction of accretion power Holt et al. 2007, 2011

- \checkmark Significant fraction of the bolometric luminosity (10⁻²) but not of the Eddington luminosity (less than required in cosmological simulations)
- \checkmark In some cases, larger contribution from the molecular gas, but not enough statistics yet
- \checkmark These outflows are nevertheless important for understanding the evolution of the radio jets in particular the first phases of their life







What next?



Quantify the relevance of these outflows for galaxy evolution Explore the apparent connection between phase in the life cycle of radio AGN and presence of gas (and outflows?)



What next?

Explore the apparent connection between phase in

"relics" with e.g. LOFAR

waiting for SKA! => rare objects => large-area search with e.g. Apertif

- molecular gas with e.g. ALMA



- Quantify the relevance of these outflows for galaxy evolution
 - the life cycle of radio AGN and presence of gas (and outflows?)
- Radio jet acting in the first (or in a restarted) phase of activity: how often is this happening? => wide field search at low frequencies to find signatures of
- Deep observations to trace the kinematics of the HI = vsing stacking while



How often a radio source restarts....



... and many more



How often a radio source restarts....



Broad HI absorption identified with a fast HI outflow

 $+36^{\circ}$



ø



LOFAR 60 MHz - 6h 3x3 deg, rms 20-30 mJy/b Shulevski et al.

Using stacking we can reach interesting limits....



Thursday, 19 April 2012



Example: WSRT data Lockman Hole (HI for free from the continuum observations, see poster) + SDSS spectra

Making use of the relatively broad band => covering redshift up to 0.1



Characterising gas in radio sources with stacking



Thursday, 19 April 2012



Using data of a deep field (Lockman Hole) to test characterisation of HI content of sub-mJy radio sources via stacking

HI in emission detected in various groups of radio sources with redshift z<0.1

> The presence of HI absorption has not been yet investigated: those systems will be rarer => larger search area required!



Main results:

- outflows as complex and multiphases structures
- **location** better known in some case
- the high energies dumped in the ISM by radio jets
- the estimated mass outflow rates may not be large enough compared to what needed in cosmological simulations: what is wrong?

For the (near) future:

- wide-field search at low frequencies to find signatures of "relics"
- the presence of outflows)



• outflow of atomic and molecular gas found in a growing number of radio sources:

• the cold gas appears to be the dominant component in jet-induced outflows despite

search for HI absorption and stacking to improve sensitivity (and look for



