H I in radio galaxies

Bjorn Emonts (ATNF – CSIRO)

Raffaella Morganti (ASTRON), Christian Struve (Kapt. Inst./ASTRON)

Clive Tadhunter (Univ. Sheffield); Tom Oosterloo (ASTRON), Jacqueline v. Gorkom (Columbia Univ.), Joanna Holt (Leiden obs.), Gustaaf v. Moorsel (NRAO), Thijs vd Hulst (Kapteyn Inst.),


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Radio Galaxies

- Generally hosted by *early type* galaxies
- Many powerful radio galaxies show optical tails, shells, dust-lanes, etc. (e.g. Smith & Heckman 1989, Heckman et al. 1986) or young stellar populations (e.g. Tadhunter et al. 2005, Holt et al. 2007)

*Mergers / interactions as trigger for AGN activity (?)*
Radio Galaxies

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*Mergers / interactions as trigger for AGN activity (?)*

**H I observations** (optical imaging + stellar population analysis)

Look for *long-lived* signs of mergers/interactions in complete samples of nearby radio galaxies:

*Type of merger and timescales involved*
Two complete samples of nearby radio galaxies

HI emission & absorption against radio continuum

1. B2 sample
(low power compact + FR-I)

- 23 sources -- WSRT & VLA-C
- Flux limited (>0.2Jy) B2-catalog
- $v < 12,000$ km/s ($z < 0.04$)
- non-cluster

z-limitations -- only moderately powerful compact and FR-I sources ($22.0 < \log P_{1.4\text{GHz}} < 24.8$ W/Hz); NO powerful FR-II sources (found at higher-z)

2. FR-II sample

- 8 sources -- VLA-D, WSRT & ATCA
- Morphology selected
- 3CRR (Laing et al. ’83) & PKS catalog
- $v < 18,000$ km/s ($z < 0.06$)
- excl. RA 1-4h (scheduling constraints)

$log P_{1.4\text{GHz}} > 25$ W/Hz -- Not as powerful as high-z FR-II sources; only ones observable in HI emission with current-day telescopes

Our project
Powerful radio galaxies

NGC 612
the nearest powerful (FR-II) radio galaxy; $z = 0.030$

S0 with YSP across disc

Powerful radio galaxies

NGC 612
the nearest powerful (FR-II) radio galaxy; $z = 0.030$

1. $M_{\text{HI}} = 1.8 \times 10^9 M_\odot$
2. $M_{\text{HI}} = 8.9 \times 10^9 M_\odot$
3. $M_{\text{HI}} = 2.9 \times 10^8 M_\odot$

Powerful radio galaxies

3C 382
(z = 0.058)

Radio: 6h VLA-C + 3h VLA-D
Optical: 60 min. MDM 2.5m

--- Radio continuum
--- HI emission (6 x 10^9 M_{Sun})
--- HI absorption
Powerful radio galaxies

3C 192
(z = 0.060)

12h VLA (C+D)
1h MDM 2.4m
Powerful radio galaxies

3C 305
(z = 0.041)

Morganti et al. 2005

Massive H I outflow

600 km/s

1h MDM 2.4m
4h VLA (D)

6 x 10^8 M_{Sun}
Small sample of powerful radio galaxies (FR-II)

Large-scale H I in FR-II: 5 out of 7

High-excitation AGN
(two non-detections giant double RG with low-excitation AGN; DA 240 & 4C73.08)

FR-II radio galaxies far away
H I emission-line observations difficult with current instruments!!
Low-power radio galaxies (B2 sample)

Giant H I discs/rings (25%)

Low-power radio galaxies

Giant H I discs/rings (25%)

Low-power radio galaxies

All compact radio sources!

Low-power radio galaxies

B2 0722+30: classical radio source in disc galaxy

Emonts et al. in press. (astro-ph/0904-3381)
Low-power radio galaxies

Extended FR-I radio sources: Devoid of large-scale H I emission

(upper limits $\sim 10^8 M_{\text{sun}}$)

Complete B2 sample of low-power RG

Low-power radio galaxies

To first order similar to samples of radio quiet early-type galaxies

Radio AGN at some point during life of every early-type galaxy?

Morganti et al. 2009, AN, 330, 233
Extended FR-I radio sources: Devoid of large-scale $HI$ emission
(upper limits ~ $10^8 M_{\odot}$)

Comparison low/high-power radio galaxies

Low-power RG (compact + FR-I)
- ■ = FR-II emission
- □ = FR-II absorption
Fundamental differences in H I (?)

- Powerful FR-II:  - Large fraction extended H I
  - Bridges/tails/discs
  - Possibly gas-rich galaxy mergers/collisions

- Low power FR-II:  - Generally devoid of large-scale H I ($>10^8 \text{ M}_{\text{sun}}$)
  - Small fraction (14-21%) H I absorption
  - Not likely associated with gas-rich mergers

- Compact sources:  - Significant fraction (~50%) large and massive, regular rotating H I discs/rings
  - Despite similar H I, optical hosts differ
  - Formation history not always clear, but *old!*

*Emonts et al. in prep.*
Fundamental differences in H I (?)

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Optical imaging/spectroscopy (Heckman et al. 1986, Baum et al. 1992):

Cooling flows/ accretion IGM vs. Gas-rich
gas-rich galaxy mergers

$FR-I$ vs. $FR-II$
Fundamental differences in H I (?)

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  - Large fraction extended H I
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Optical imaging/spectroscopy (Heckman et al. 1986, Baum et al. 1992)

X-ray (optical) studies (Allen et al. 2006; Hardcastle et al. 2008; Baldi & Capetti 2008):

Low excitation (FR-I, some FR-II)  vs.  High excitation (most FR-II)

Accretion  

HOT CIRCUM-GALACTIC GAS  vs.  COLD GAS FROM MAJOR MERGER
Fundamental differences in H I (?)

- Powerful FR-II: Large fraction extended H I
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- Compact sources: Significant fraction (~50%) large and massive, regular rotating H I discs/rings
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First direct study of the large-scale cold gas
Difference in AGN fuelling?

Need larger, sensitive samples

Optical imaging/spectroscopy (Heckman et al. 1986, Baum et al. 1992)

X-ray (optical) studies (Allen et al. 2006; Hardcastle et al. 2008; Baldi & Capetti 2008):

**FR-I (low excitation AGN)** vs. **FR-II (high excitation AGN)**

ACCRETION
HOT CIRCUM-
GALACTIC GAS

COLD GAS FROM
MAJOR MERGER
Future surveys

Current limitations:
• Relatively small samples
• High percentage non-detections (low-power)
• Lacking comparable good sensitivity among samples
  (FR-II, FR-I and radio-quiet early-type comparison sample)

Next generation surveys:
• Complete statistical samples with comparable sensitivity
  (target hundreds of RG to look for $M_{HI} > 10^8 \, M_{sun}$ with ASKAP)
• Large % non-detection is no problem (problematic for targeted studies)
• Comparison sample radio-quiet early-type galaxies for free
• Synergies continuum & $H\ I$ and emission & absorption surveys

(Possible) limitations:
• Need good spectral dynamic range (few 100-1000)
  (computational limitations?)
• Powerful RG still far away targeted observations (EVLA)?
3C 390.3
(z = 0.056)

Powerful radio galaxies
Optical imaging/spectroscopy (Heckman et al. 1986, Baum et al. 1992):

**Cooling flows/accretion IGM**  
*FR-I*  

**Gas-rich galaxy mergers**  
*FR-II*  

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**Low excitation RG**  
- Weak emission lines  
- Inefficient, quasy-spherical Bondi accretion  
- Old systems  

**High excitation RG**  
- Strong emission lines  
- Classic accretion disc  
- Young stellar component  

**X-ray (optical) studies** (Allen et al. 2006; Hardcastle et al. 2008; Baldi & Capetti 2008):
### AGN triggering

**Optical imaging/spectroscopy** (Heckman et al. 1986, Baum et al. 1992):

- Cooling flows/accretion IGM vs. Gas-rich galaxy mergers

  - *FR-I*
  - *FR-II*

  - Low excitation AGN vs. High excitation AGN

**X-ray (optical) studies** (Allen et al. 2006; Hardcastle et al. 2008; Baldi & Capetti 2008):

- Accretion of hot circum-galactic gas
- Cold gas from major merger
AGN triggering

**Optical imaging/spectroscopy** (Heckman et al. 1986, Baum et al. 1992):

Cooling flows/accretion IGM vs. **Gas-rich galaxy mergers**

**Large-scale HI: direct way to investigate this!**

Important for galaxy evolution. Also at high-z, where radio sources trace galaxies that are often too faint to be studied at other wavelengths.

Current HI results: in agreement with results from optical/X-ray

*But, better statistics needed!*

**Large samples with uniform sensitivity needed**

**ACCRETION OF HOT CIRCUM-GALACTIC GAS**

**COLD GAS FROM MAJOR MERGER**

**X-ray (optical) studies** (Allen et al. 2006; Hardcastle et al. 2008; Baldi & Capetti 2008):
Compact Array Broadband Backend (2 GHz)
(Warwick Wilson & all of ATNF)

NGC 612
The nearest powerful (FR-II) radio galaxy

Full 2 GHz CABB working!
- 3mm – 6 cm continuum
- commissioning L + S band
- first zoom modes next semester

Proposal deadline 15 June
All sky surveys

• Statistical samples
doesn’t matter if we get 90% non-detections

Free comparison samples of radio-quiet early-type galaxies at same sensitivity

Interesting synergies:
HI emission surveys
HI absorption surveys
radio continuum surveys

Possible limitations:

Sensitivity not significantly better than current studies…
Need sufficient spectral dynamic range (computational limitations)
Division/Unit Name
Presenter’s name
Presenter’s title
Phone: XX XXXX XXXX
Email: name.name@csiro.au
Web: www.csiro.au/group

Division/Unit Name
Presenter’s name
Presenter’s title
Phone: XX XXXX XXXX
Email: name.name@csiro.au
Web: www.csiro.au/group

Contact Us
Phone: 1300 363 400 or +61 3 9545 2176
Email: enquiries@csiro.au  Web: www.csiro.au