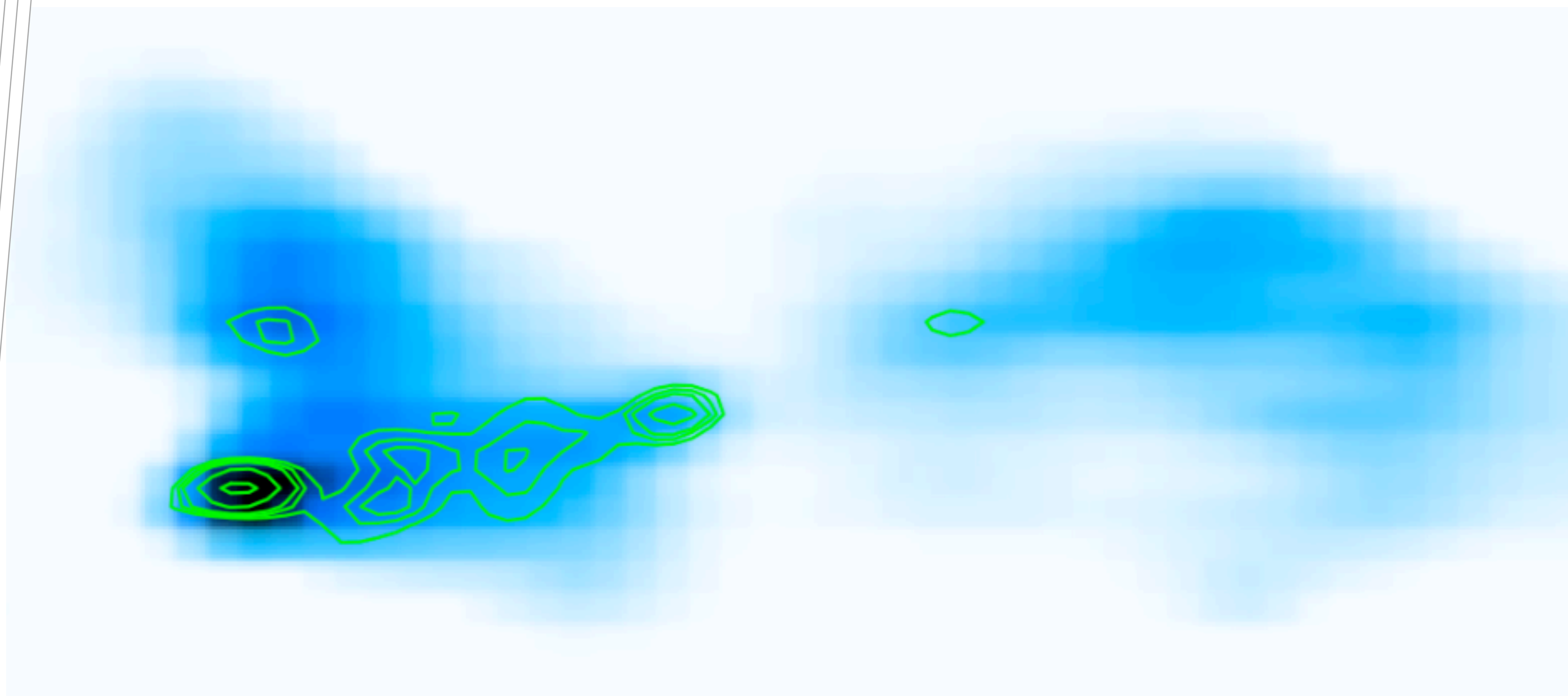


H I in radio galaxies

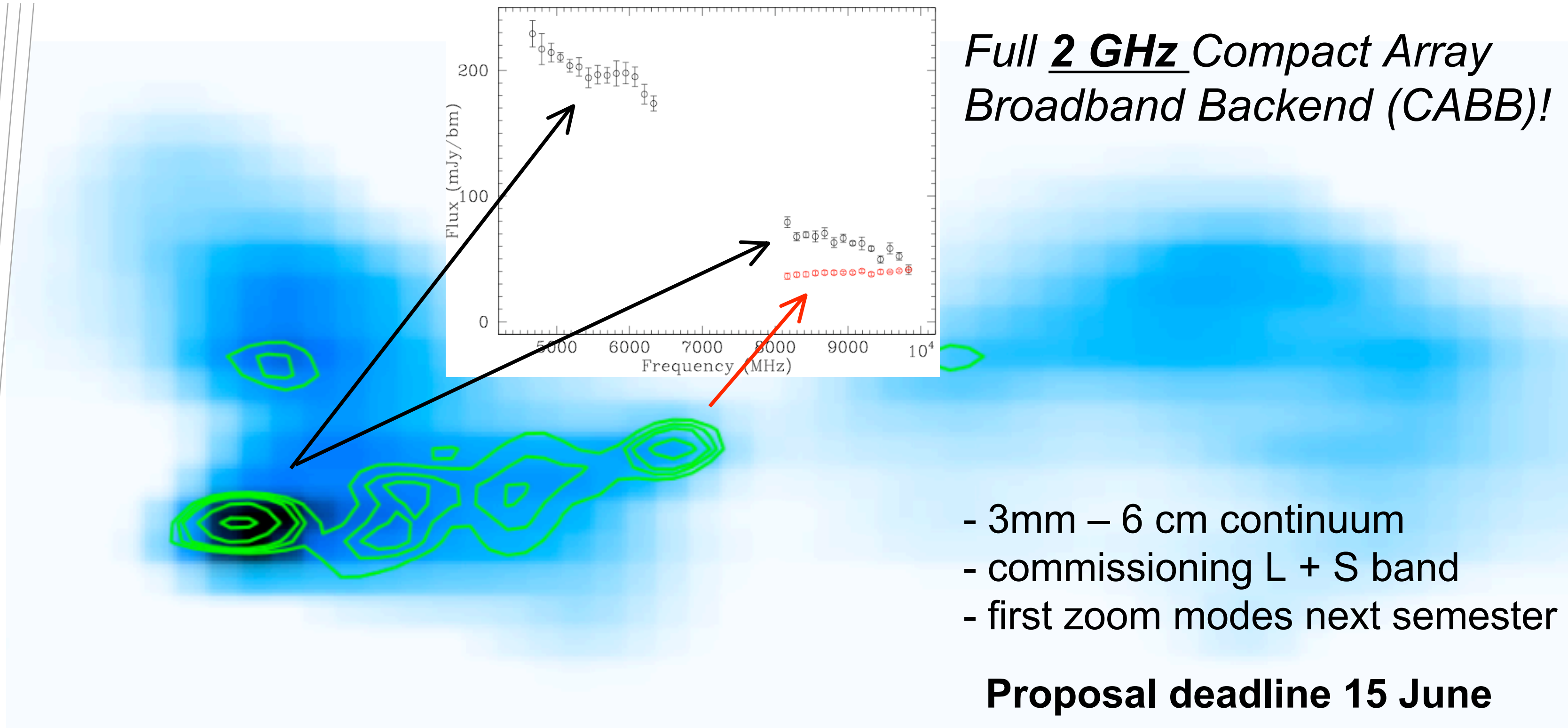
Bjorn Emonts (ATNF – CSIRO)

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.),*

CSIRO

www.csiro.au



*Full **2 GHz** Compact Array Broadband Backend (CABB)!*

- 3mm – 6 cm continuum
- commissioning L + S band
- first zoom modes next semester

Proposal deadline 15 June

www.csiro.au

H I in radio galaxies

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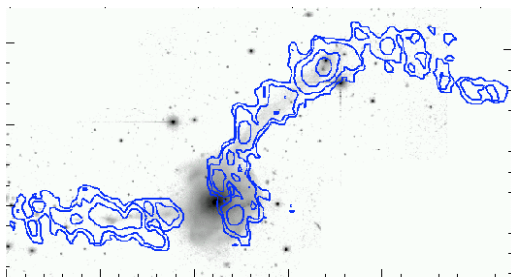
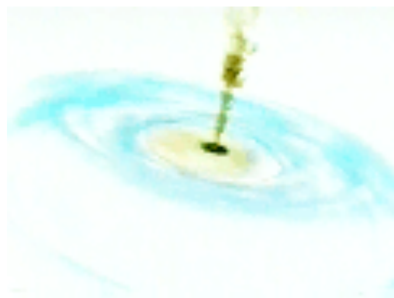
Radio Galaxies

- 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 (?)



? →



CSIRO

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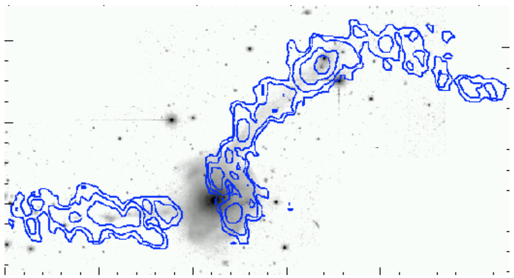
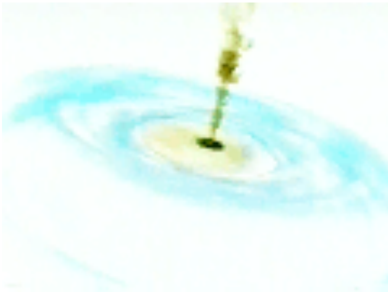




H I observations (optical imaging + stellar population analysis)

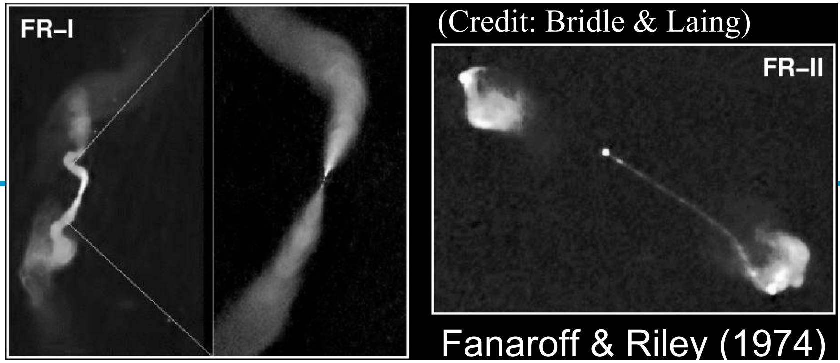
Look for *long-lived* signs of mergers/interactions in complete samples of nearby radio galaxies:

Type of merger and *timescales* involved

Our project

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$P_{1.4Ghz}$< 24.8 W/Hz); NO powerful FR-II sources (found at higher-z)

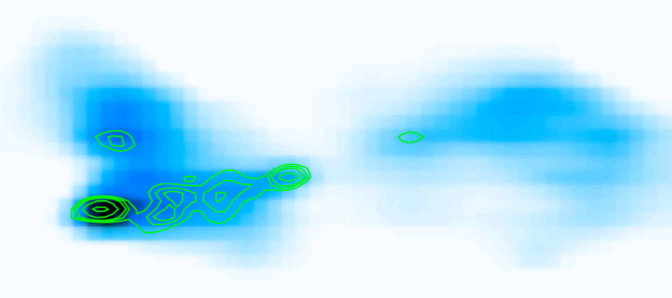
2. FR-II sample

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

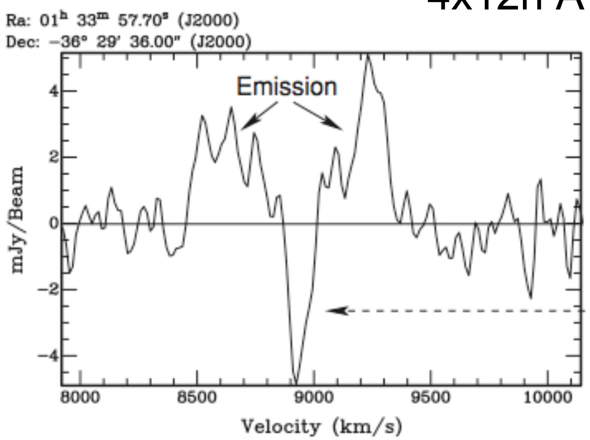
Powerful radio galaxies

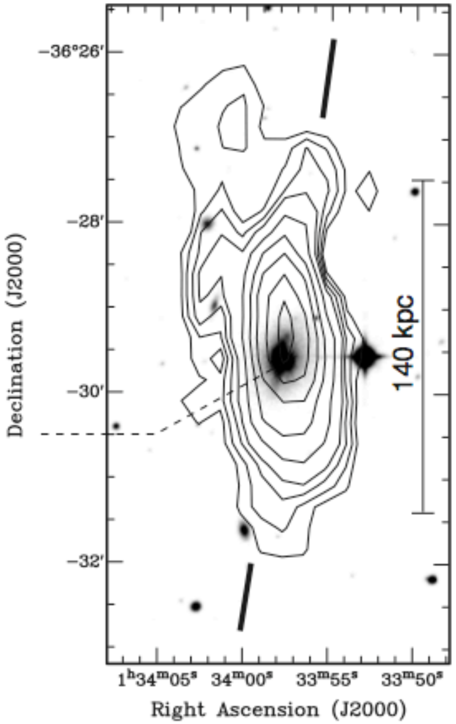


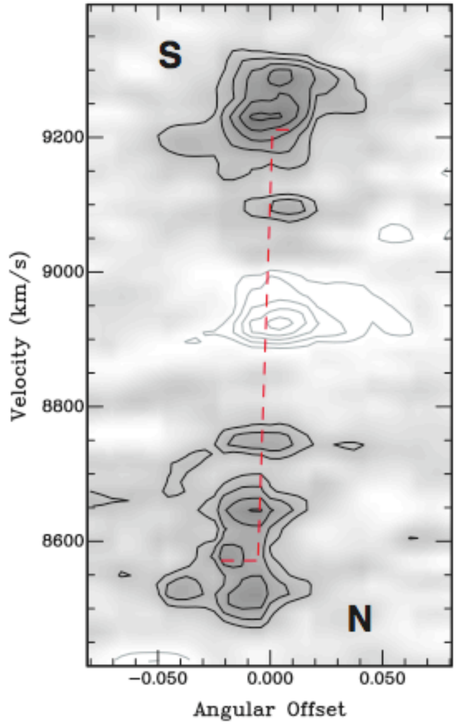
NGC 612

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

4x12h ATCA





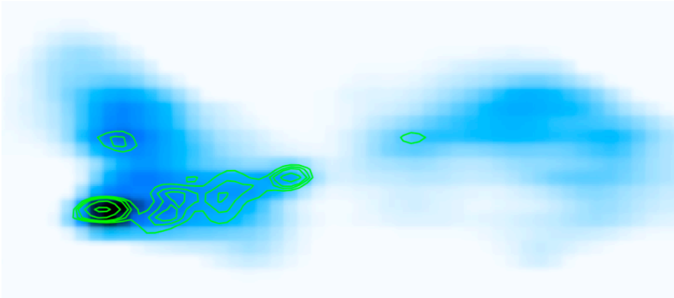


S0 with YSP across disc

(Holt et al. 2007, MNRAS, 356, 480)

Emonts et al. 2008, MNRAS, 387, 197

Powerful radio galaxies



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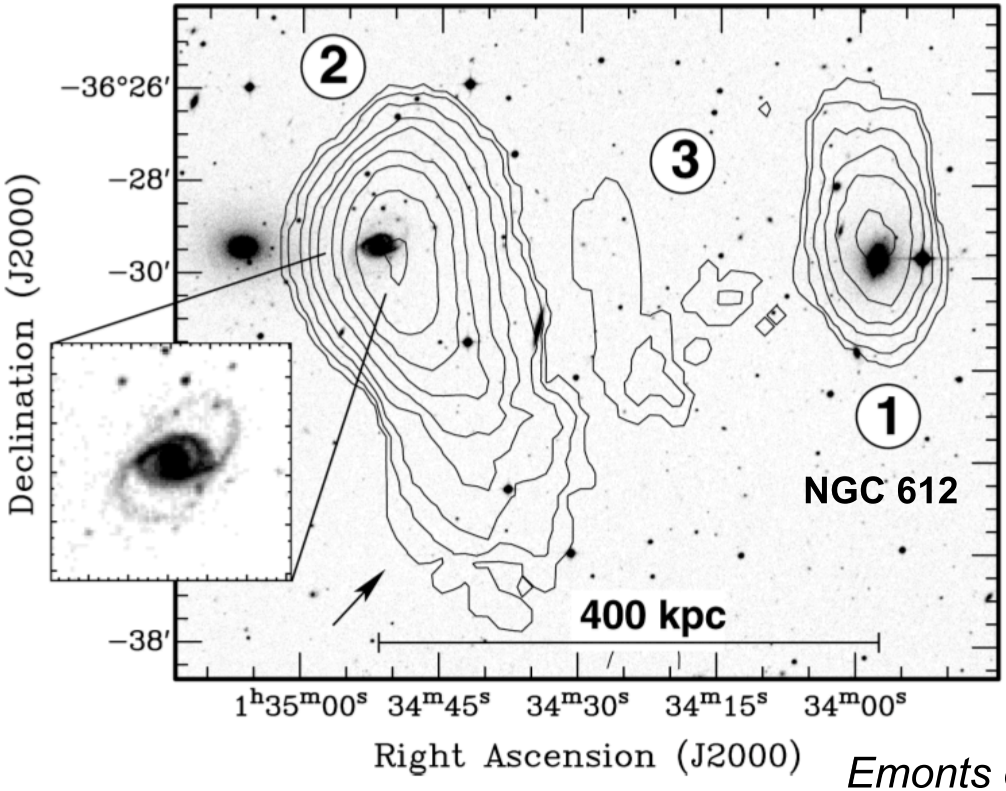


① $M_{\rm HI} = 1.8 \times 10^9 M_\odot$

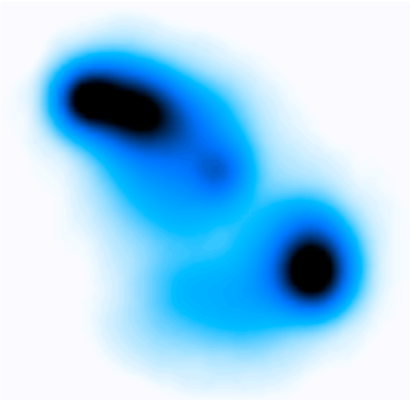
② $M_{\rm HI} = 8.9 \times 10^9 M_\odot$

③ $M_{\rm HI} = 2.9 \times 10^8 M_\odot$

Emonts et al. 2008, MNRAS, 387, 197

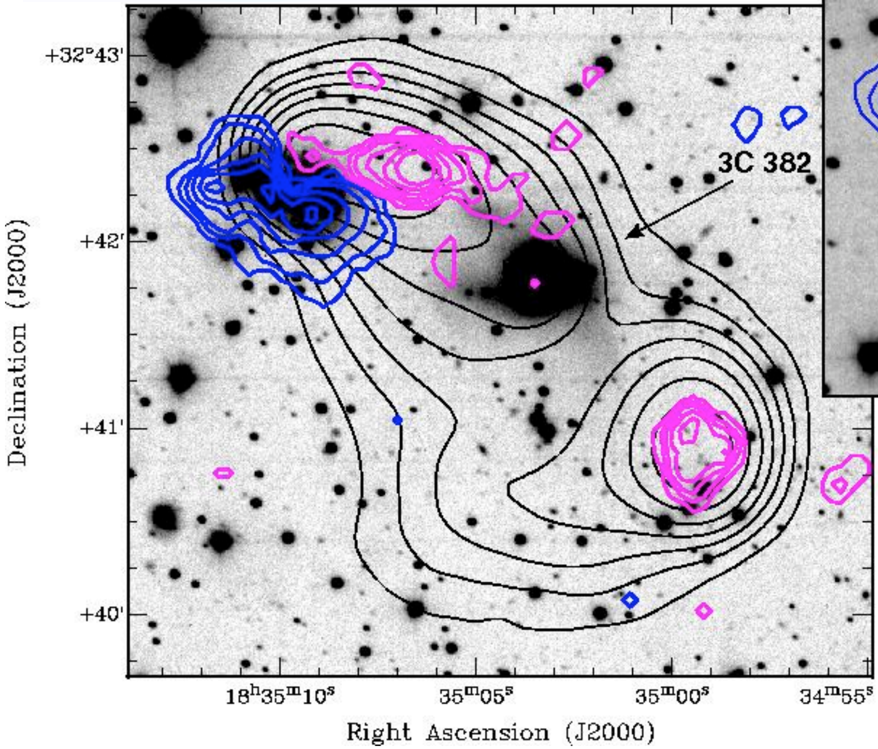
CSIRO

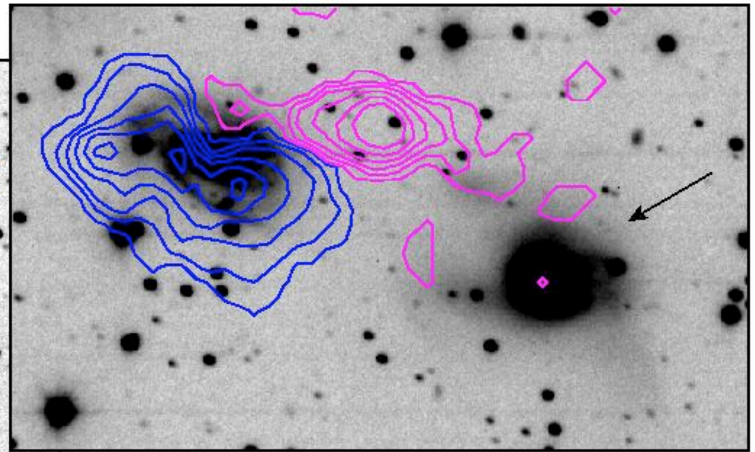
Powerful radio galaxies



3C 382

(z = 0.058)





Radio: 6h VLA–C + 3h VLA–D

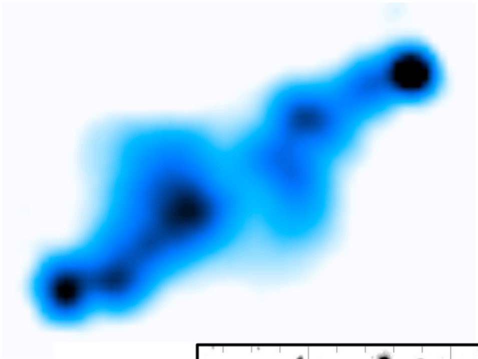
Optical: 60 min. MDM 2.5m

Radio continuum

HI emission **(6×10^9 M_{sun})**

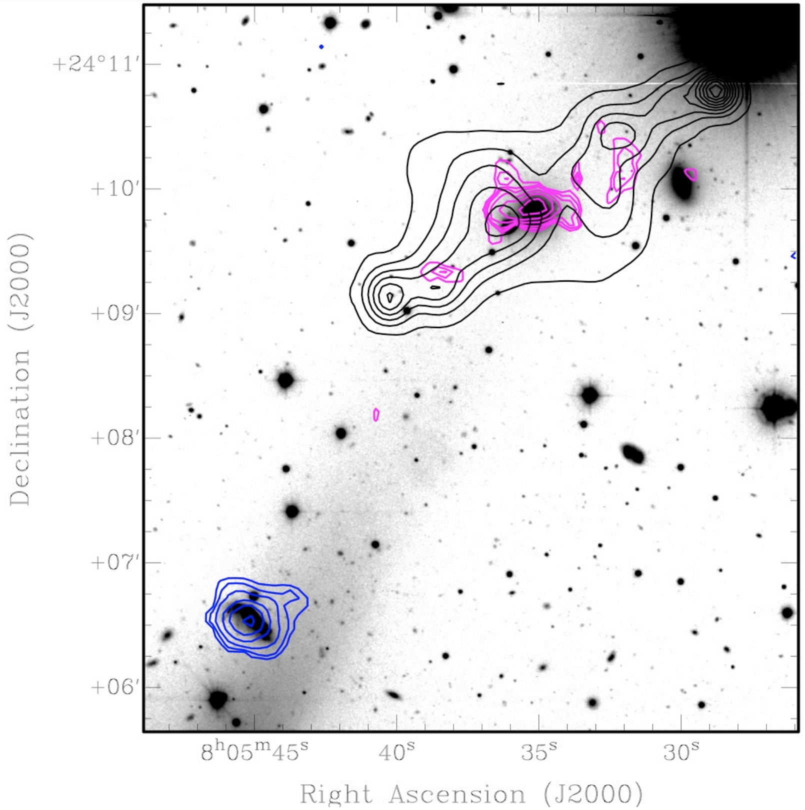
HI absorption

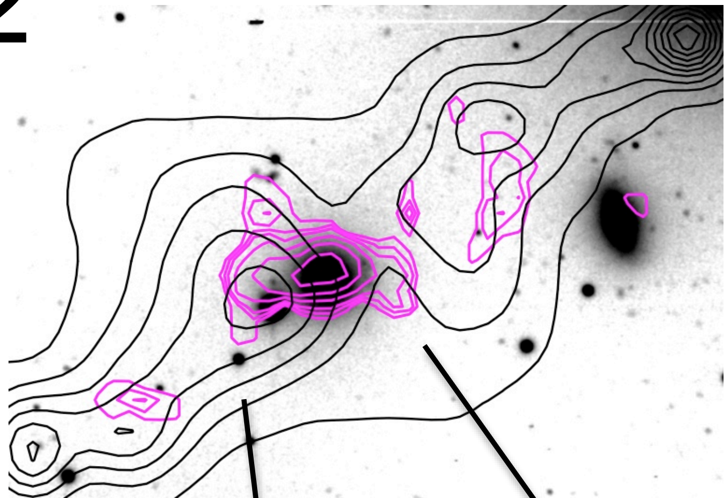
Powerful radio galaxies

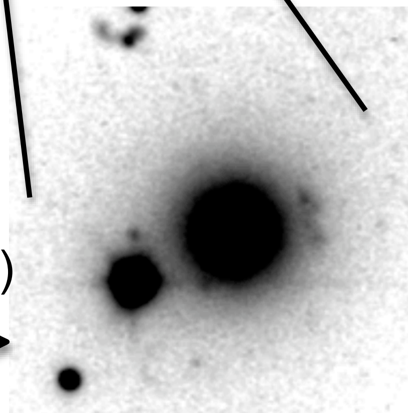


3C 192

(z = 0.060)



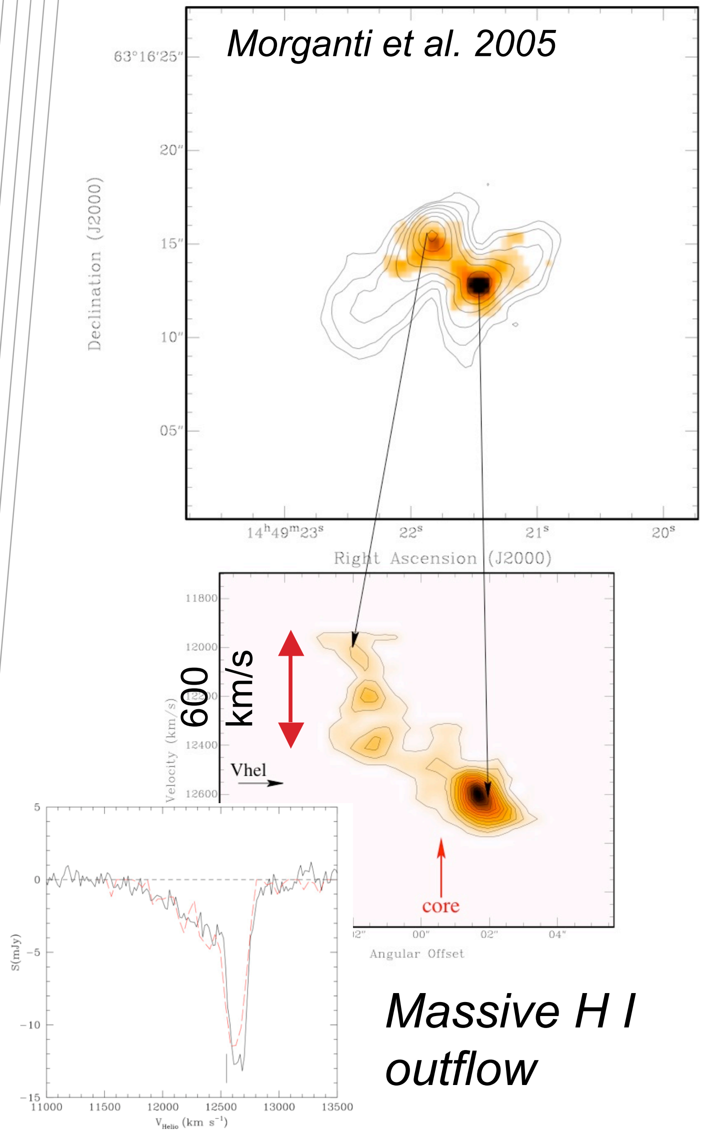




12h VLA (C+D)

1h MDM 2.4m

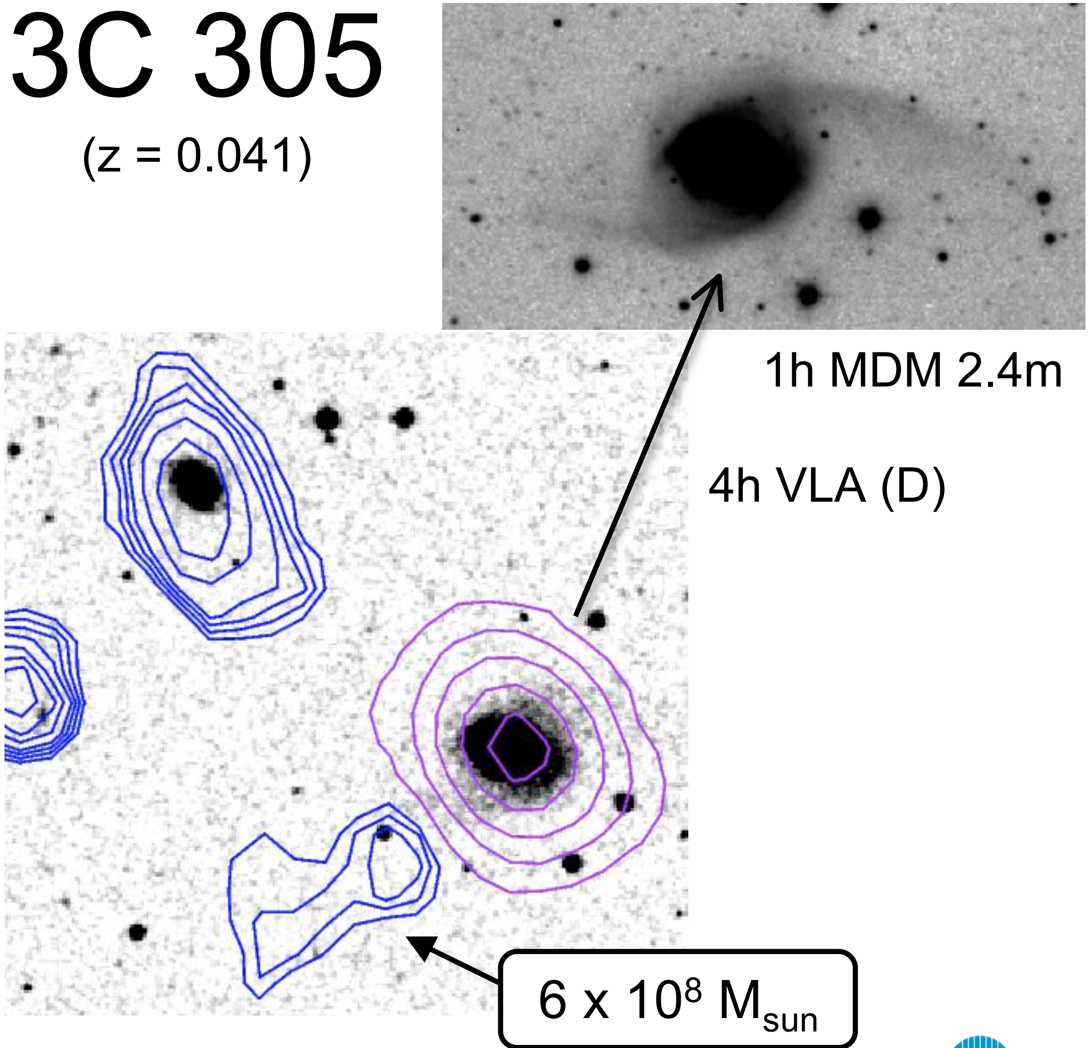
Powerful radio galaxies



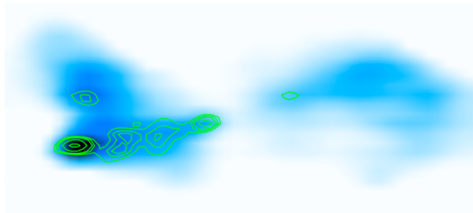
Massive H I outflow

3C 305

(z = 0.041)



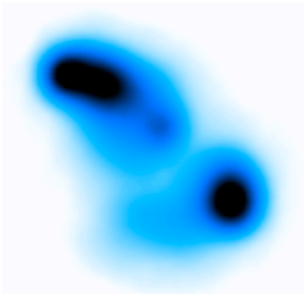
Small sample of powerful radio galaxies (FR-II)



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

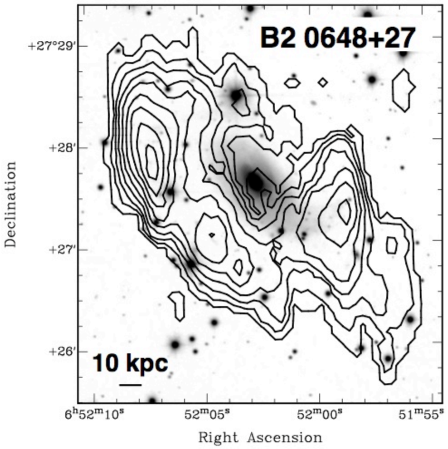
High-excitation AGN

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

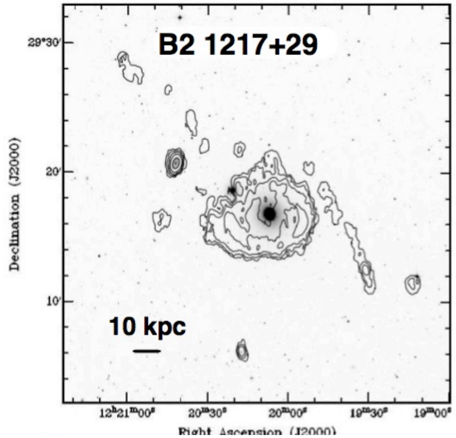


FR-II radio galaxies far away
H I emission-line observations difficult with current instruments!!

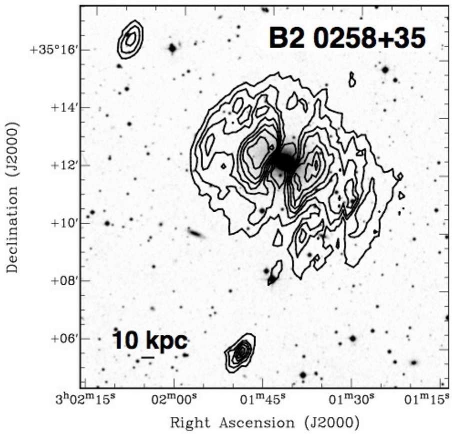
Low-power radio galaxies (B2 sample)



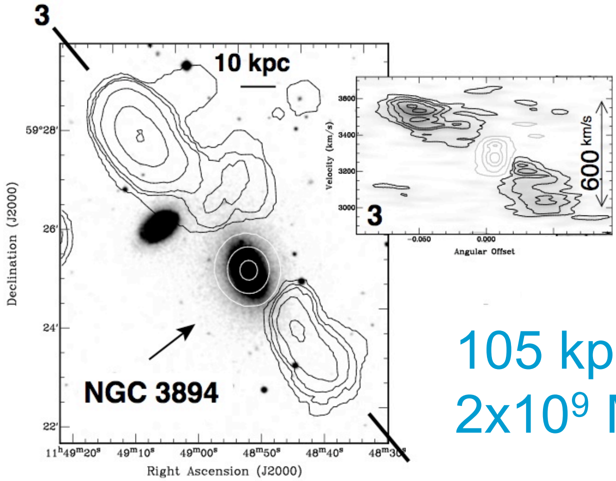
190 kpc
$9 \times 10^9\ M_{sun}$



37 kpc
$7 \times 10^8\ M_{sun}$



160 kpc
$2 \times 10^{10}\ M_{sun}$

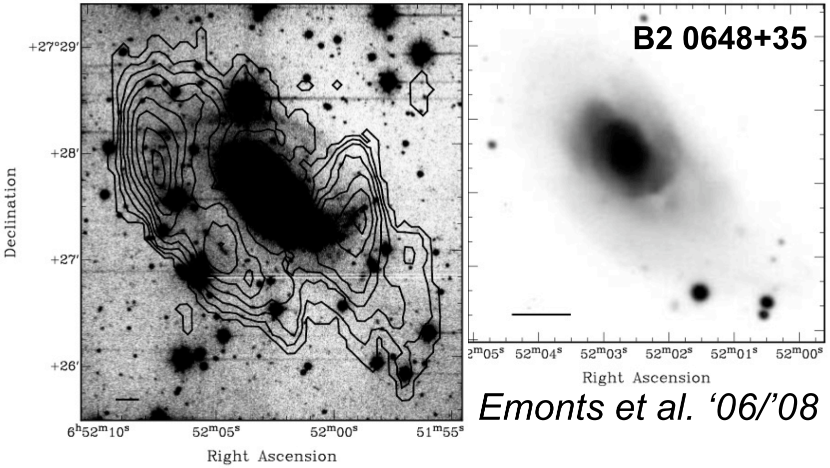


105 kpc
$2 \times 10^9\ M_{sun}$

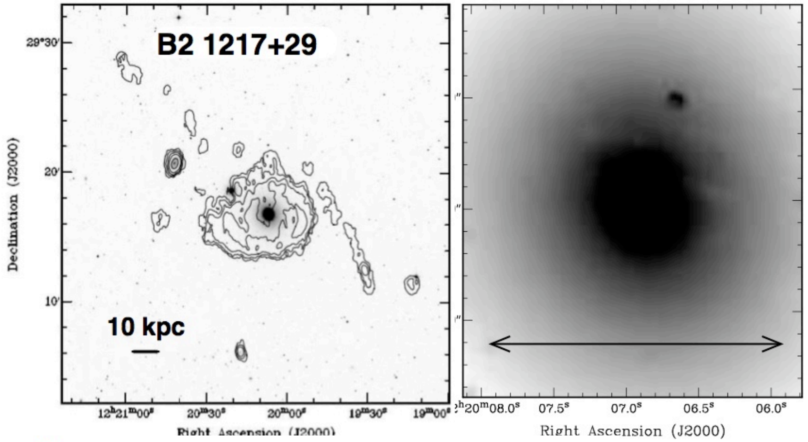
Giant H I discs/rings (25%)

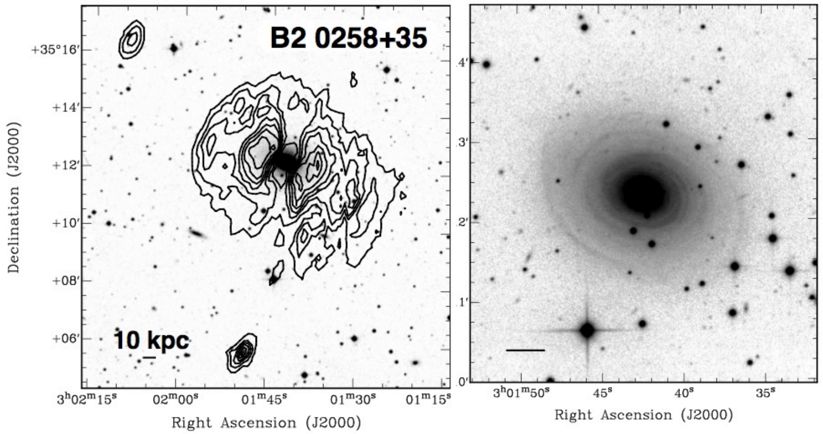
Emonts et al. 2007, A&A, 464, L1
Emonts et al. 2009, in prep.

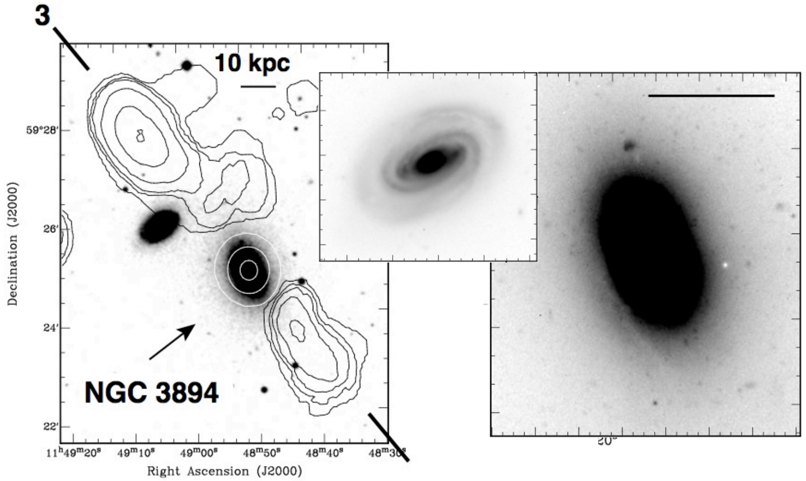
Low-power radio galaxies



Emonts et al. '06/'08







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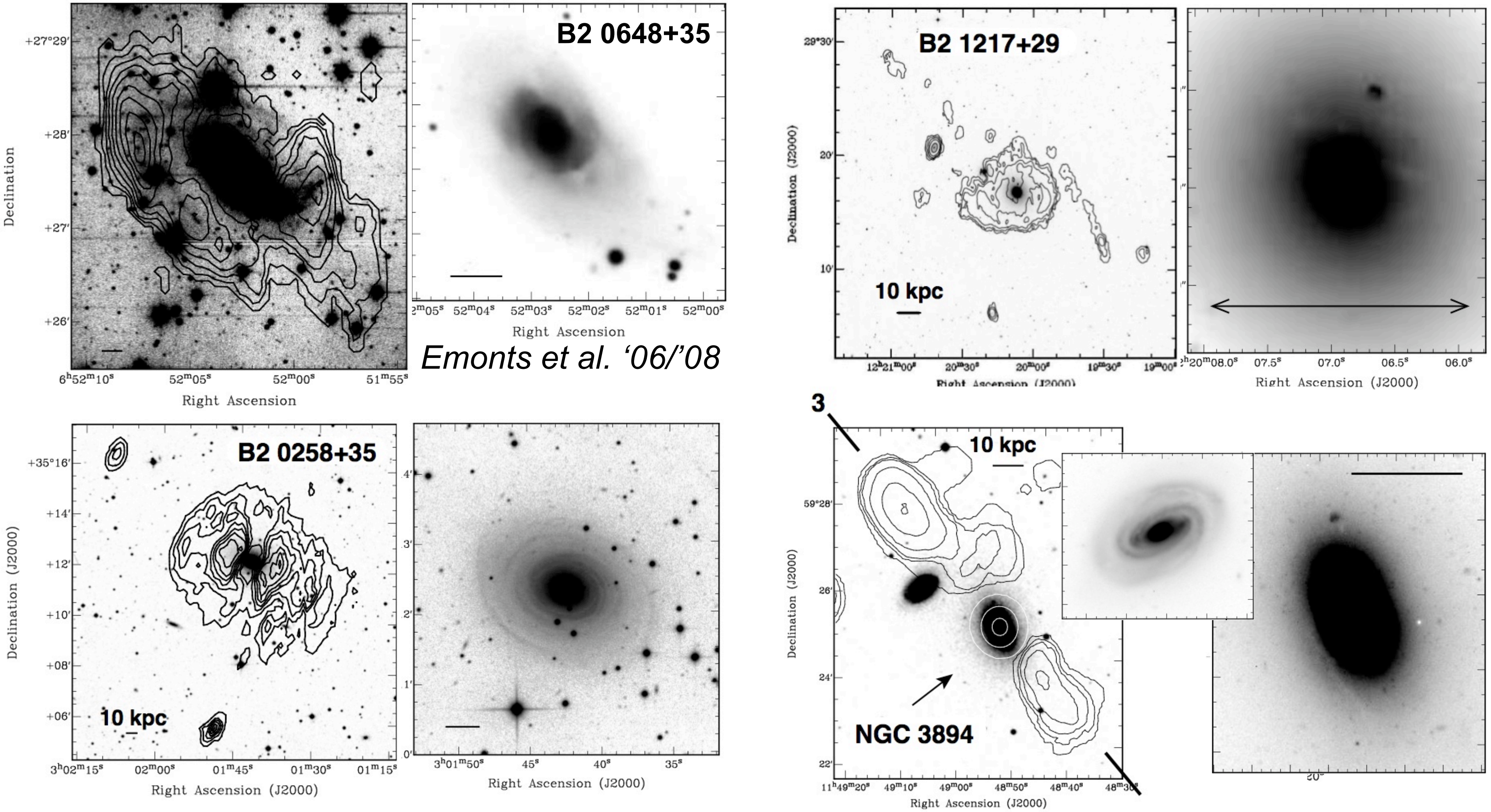
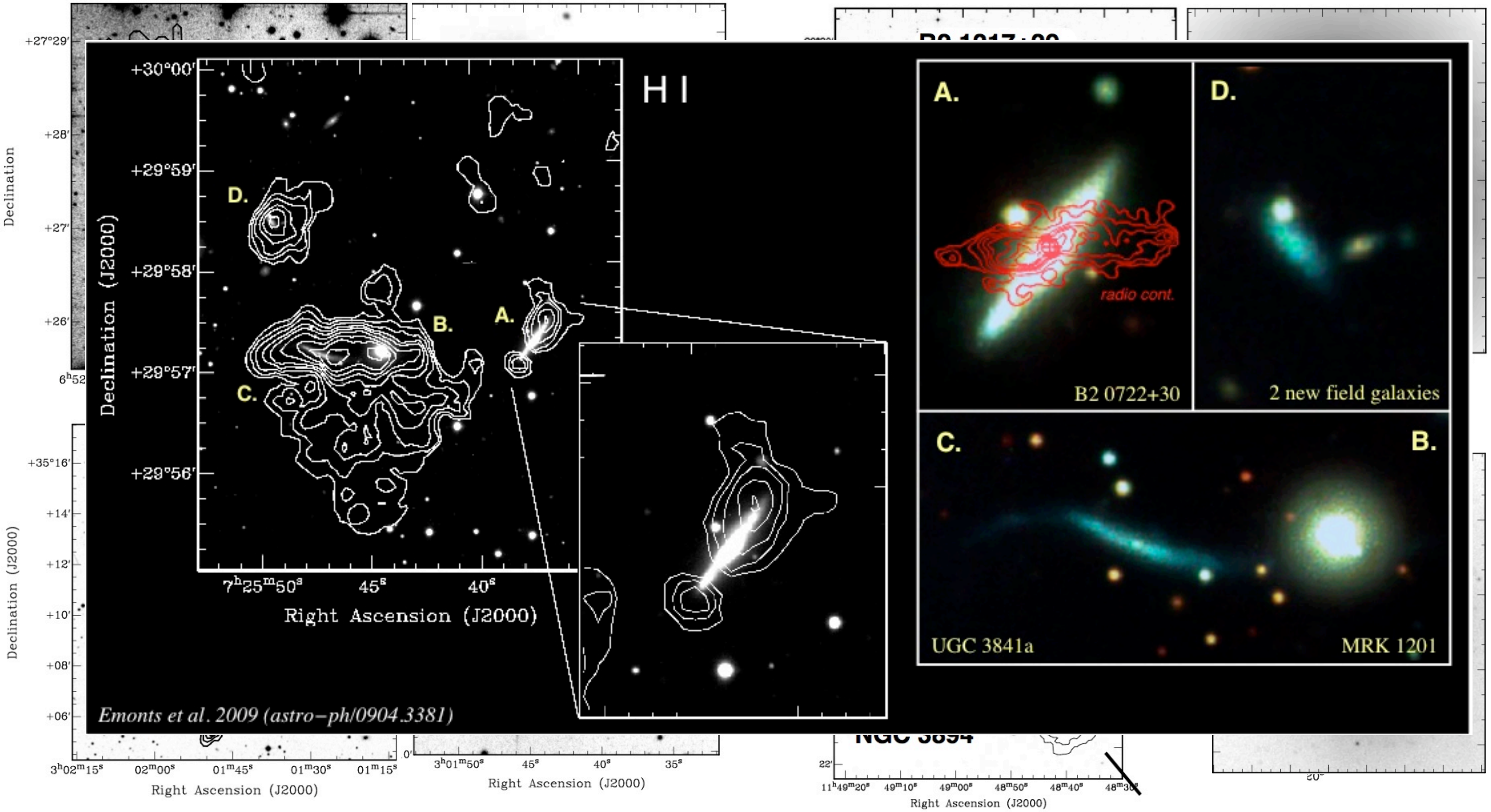


All <u>compact</u> radio sources!

Emonts et al. 2007, A&A, 464, L1
Emonts et al. 2009, in prep.

Low-power radio galaxies

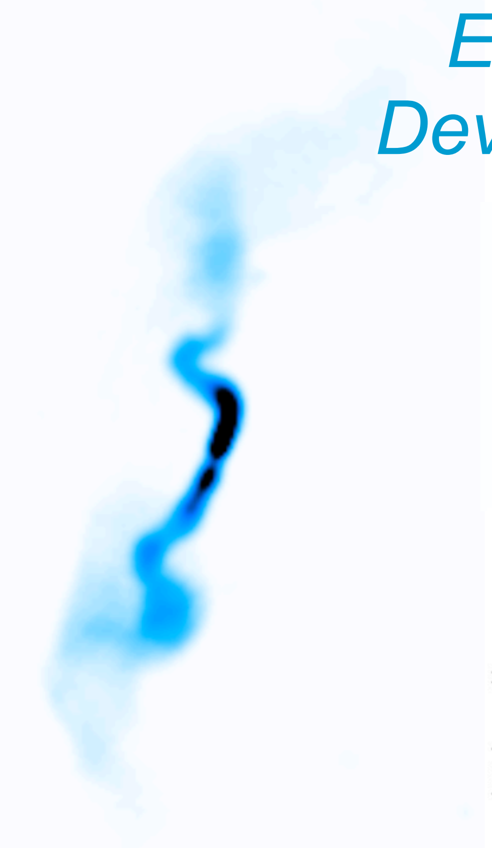


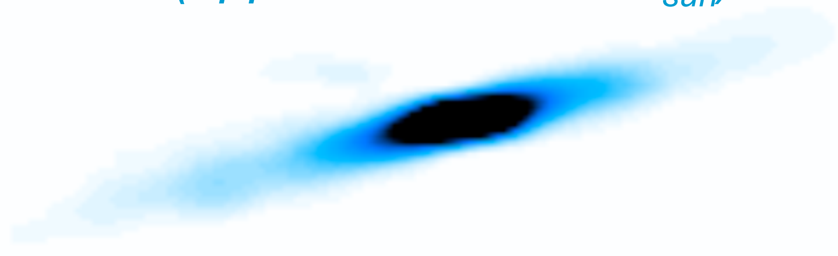
B2 0722+30: classical radio source in disc galaxy

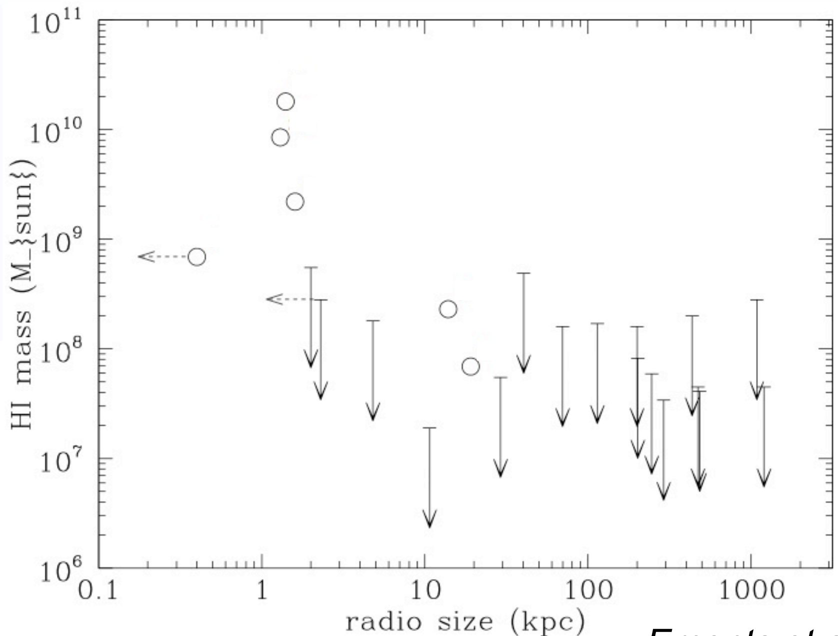
Emonts et al. in press. (astro-ph/0904-3381)

Low-power radio galaxies

Extended FR-I radio sources:
Devoid of large-scale H I emission
(upper limits ~ 10^8 M_{sun})





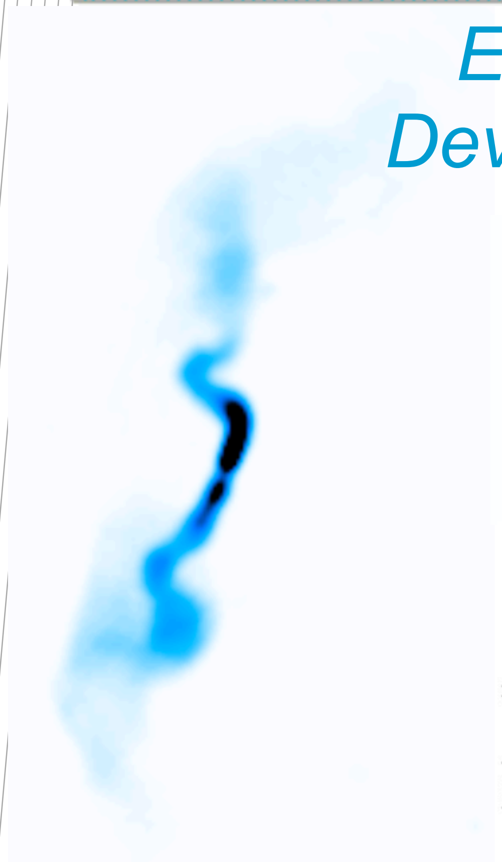


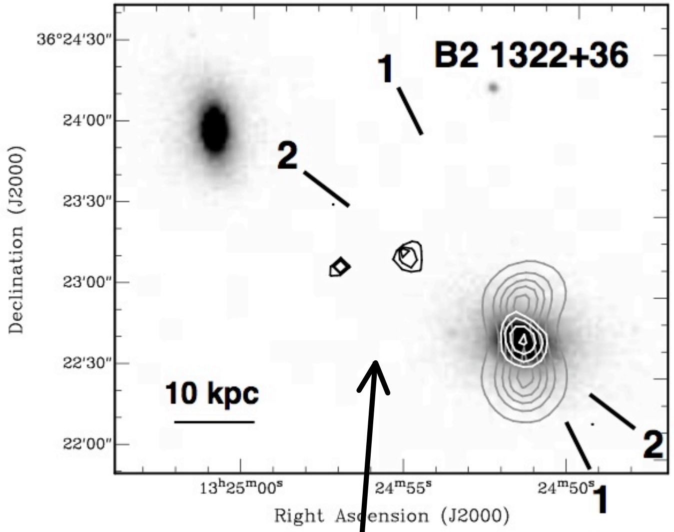
Complete B2 sample of low-power RG

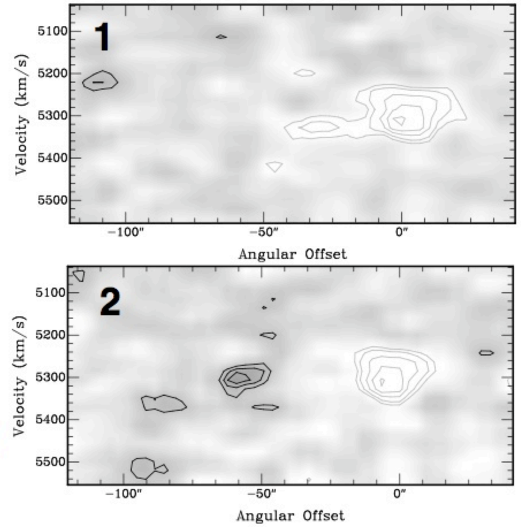
Emonts et al. 2007, A&A, 464, L1

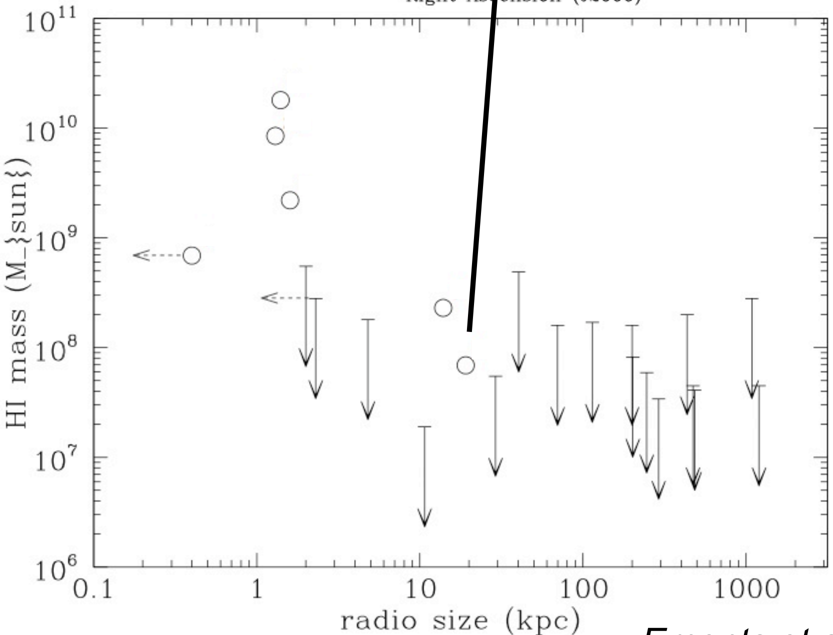
Low-power radio galaxies

Exter
Devoid









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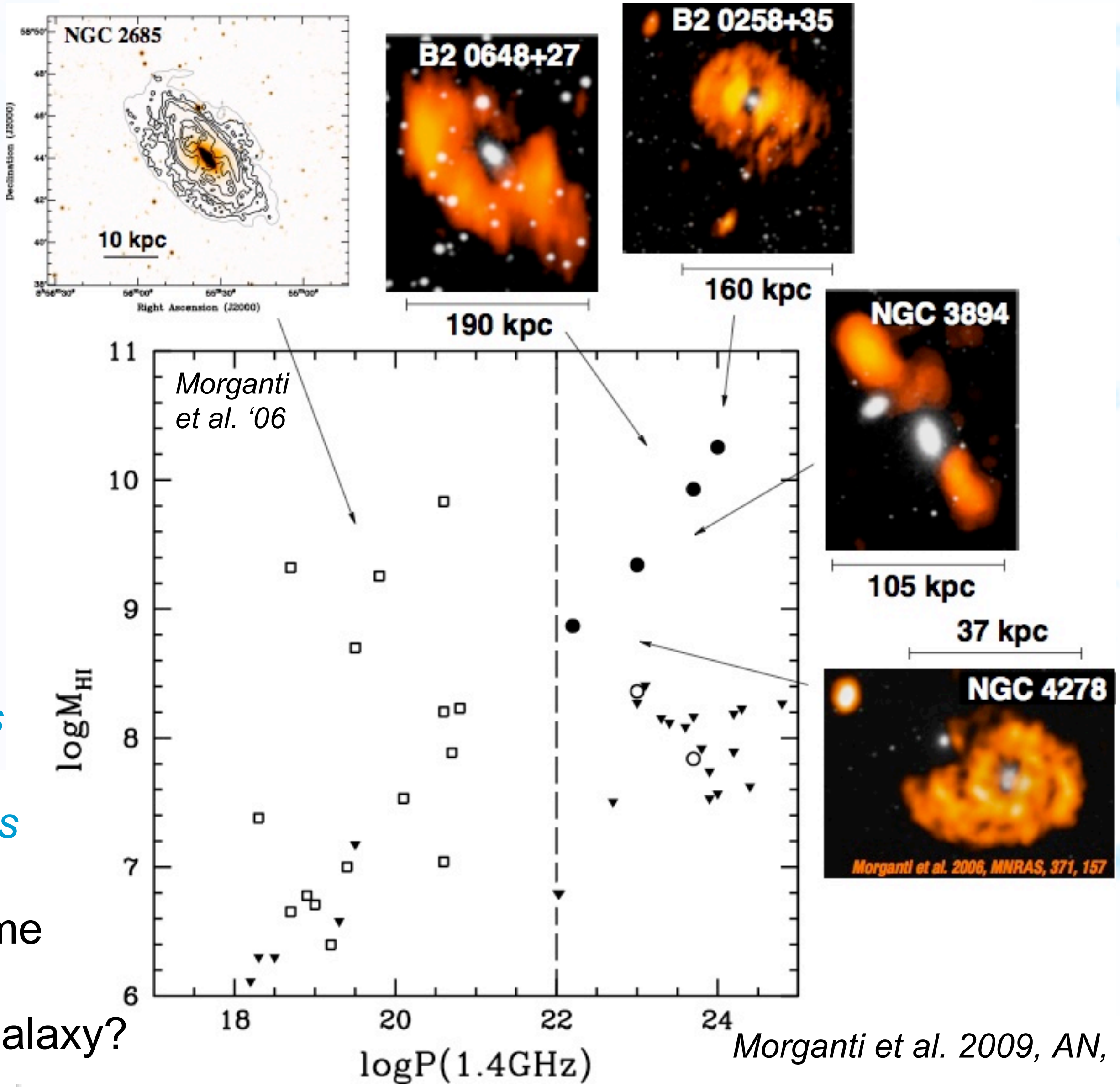
Emonts et al. 2007, A&A, 464, L1

Low-power radio galaxies



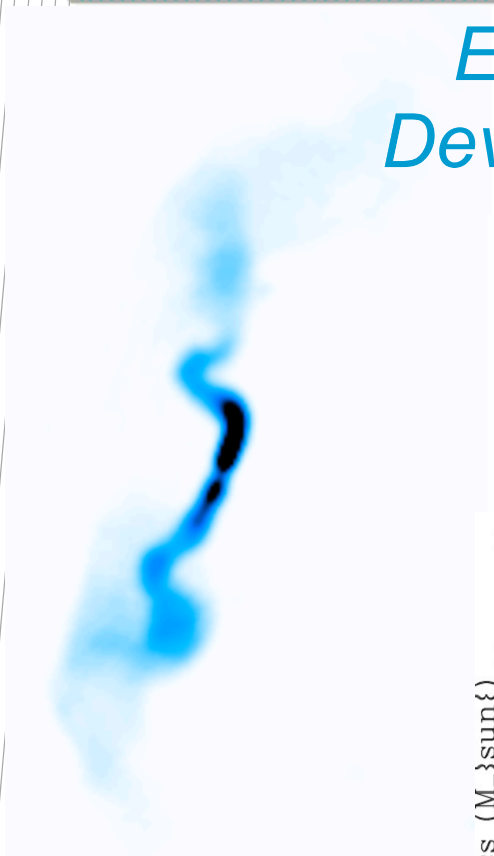
To first order similar to samples of radio quiet early-type galaxies

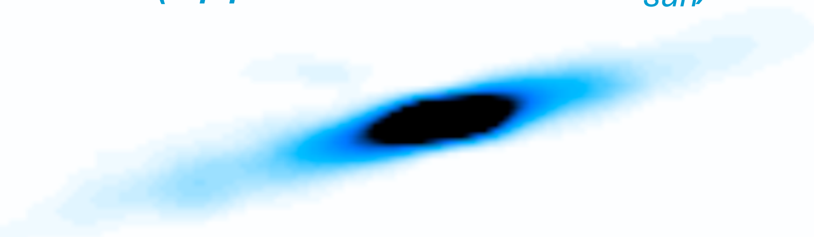
Radio AGN at some point during life of every early-type galaxy?

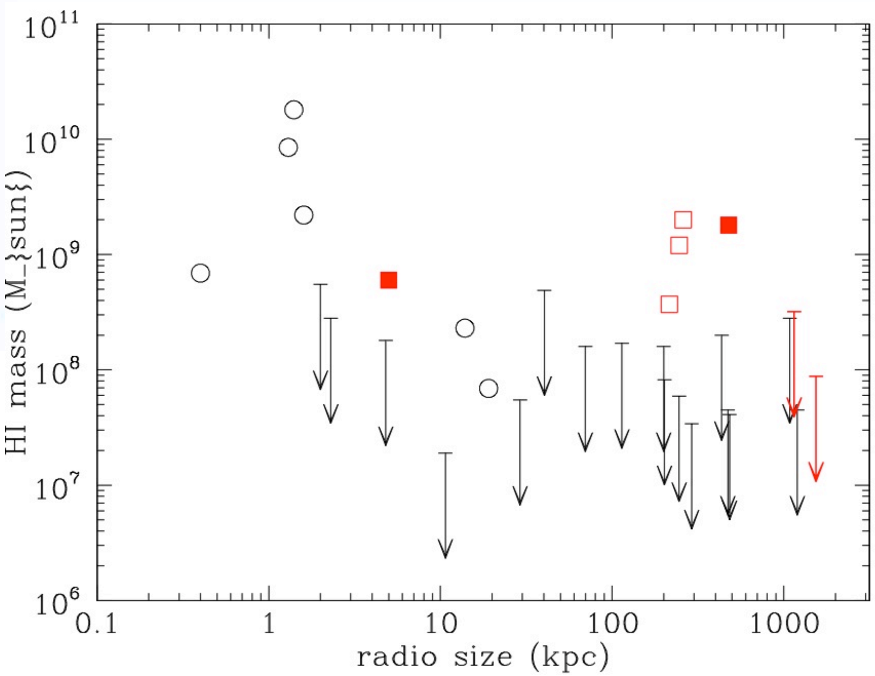
Morganti et al. 2009, AN, 330, 233

Comparison low/high-power radio galaxies

Extended FR-I radio sources:
Devoid of large-scale H I emission
(upper limits ~ 10^8 M_{sun})







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 ($>10^8$ M_{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.

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

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

Fundamental differences in H I (?)

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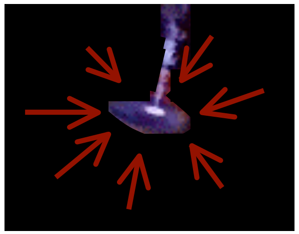
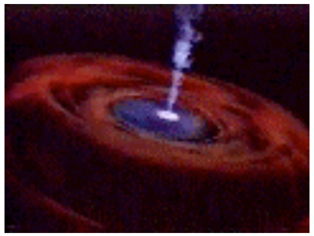
<u>Optical imaging/spectroscopy</u> (Heckman et al. 1986, Baum et al. 1992)

<u>X-ray (optical) studies</u> (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





COLD GAS FROM MAJOR MERGER

Fundamental differences in H I (?)

- Powerful FR-II: - Large fraction extended H I
  - Bridges/tails/discs
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- Low power FR-II: - Generally devoid of large-scale H I
  - 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, *old!*

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

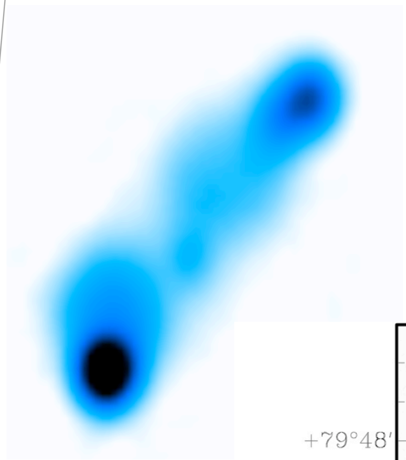
(Possible) limitations:

- Need good spectral dynamic range (few 100-1000)

  (computational limitations?)
- Powerful RG still far away ⟶ targeted observations (EVLA)?

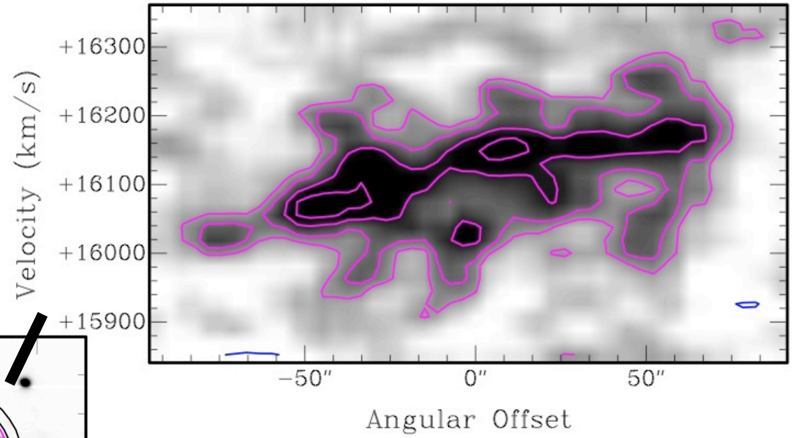
CSIRO

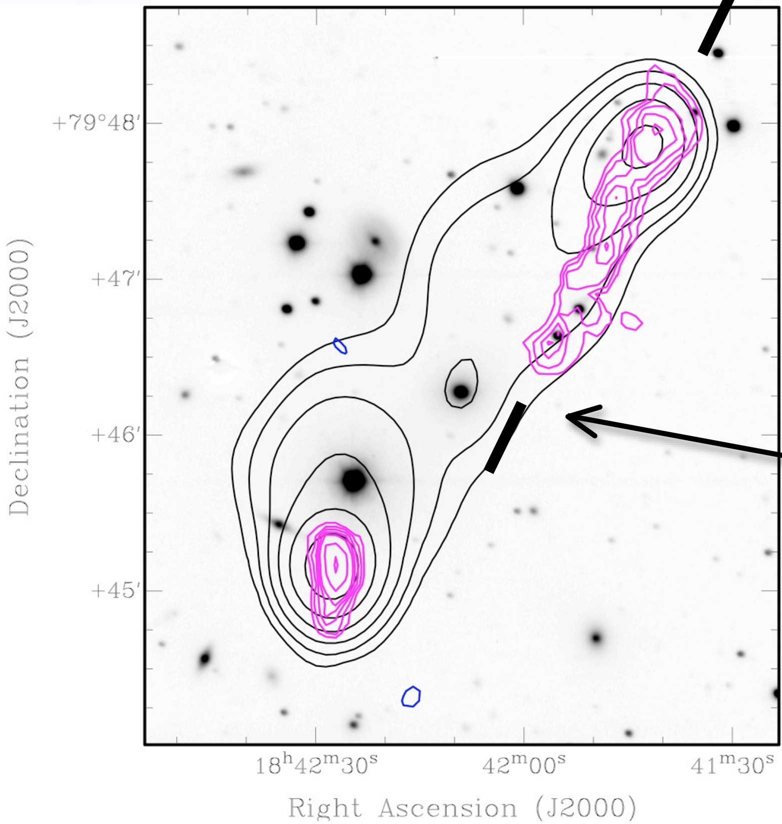
Powerful radio galaxies

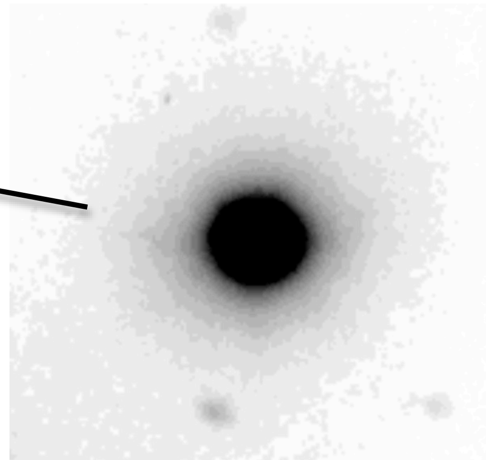


3C 390.3

(z = 0.056)







AGN triggering

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

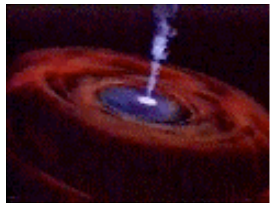
Cooling flows/accretion IGM vs. **Gas-rich galaxy mergers**

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

Low excitation RG vs. *High excitation RG*

- Weak emission lines
- Inefficient, quasy-spherical Bondi accretion
- Old systems

- 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):

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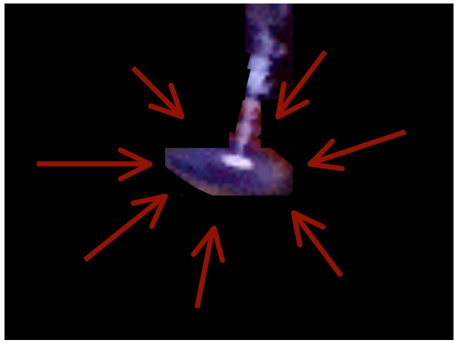
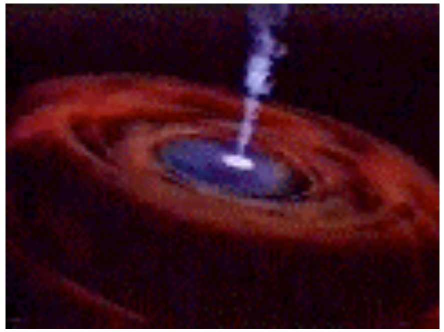
FR-I ***FR-II***

Low excitation AGN ***vs.*** ***High excitation AGN***



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):

AGN triggering

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

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

Large-scale H I: 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 H I 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

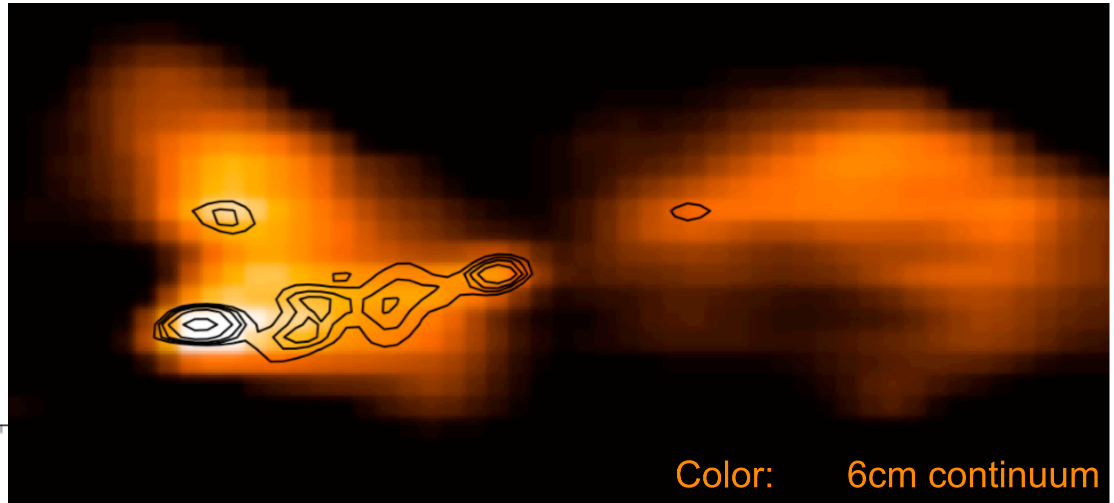
<u>X-ray (optical) studies</u> (Allen et al. 2006; Hardcastle et al. 2008; Baldi & Capetti 2008):

Compact Array Broadband Backend (2 GHz)

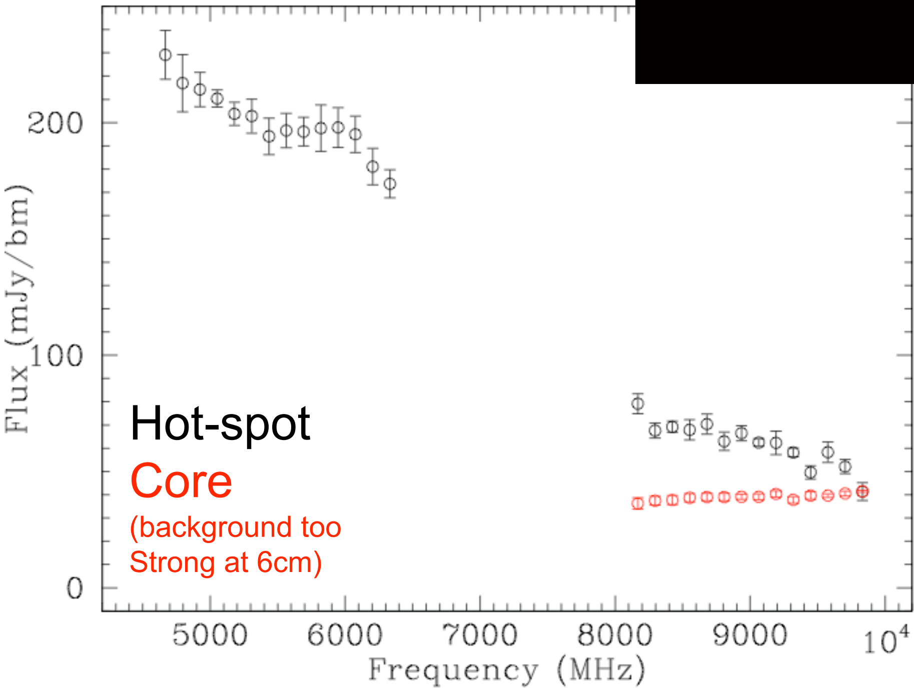
(Warwick Wilson & all of ATNF)

NGC 612

The nearest powerful (FR-II) radio galaxy



Contours: 3cm continuum



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)

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