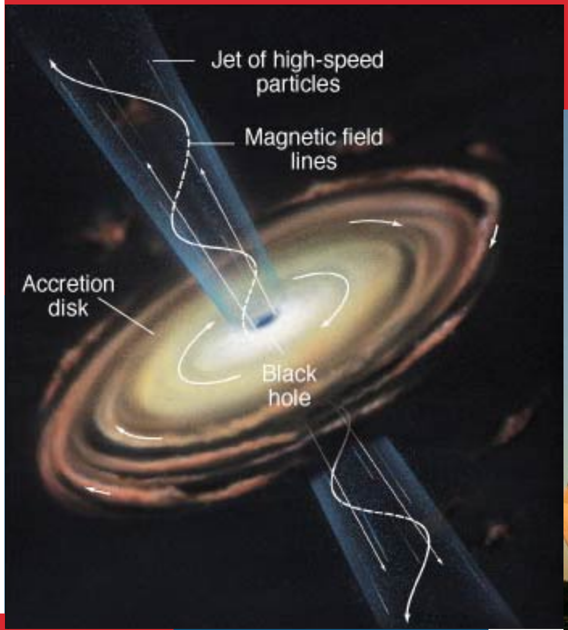
Observational constraints from large-area radio surveys

Elaine M. Sadler

*School of Physics,
University of Sydney*



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Two main topics:

Surveys addressing two main science topics:

1) How does the neutral hydrogen content of galaxies change from z~1 to z=0?

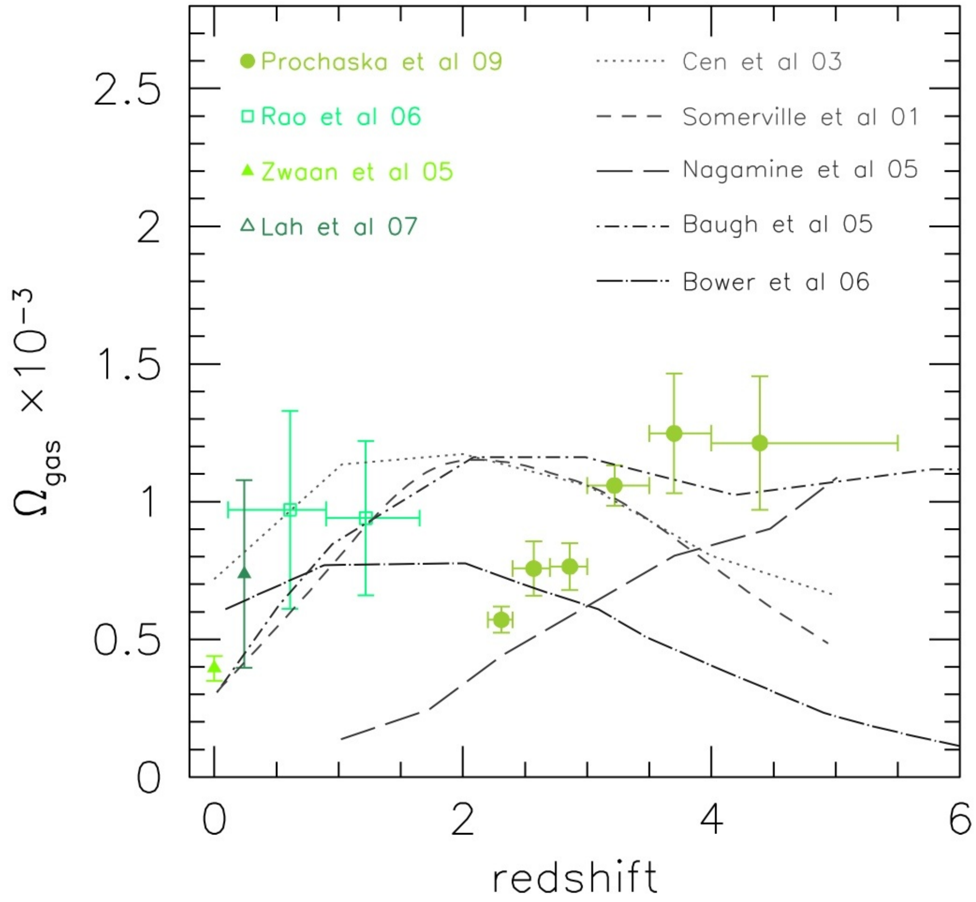
21cm spectral line

2) The role of black holes in the evolution of massive galaxies (AGN feedback)

Radio continuum

Radio data are *essential* to make progress in these areas - they provide information we can't get any other way.

Cosmic HI mass density

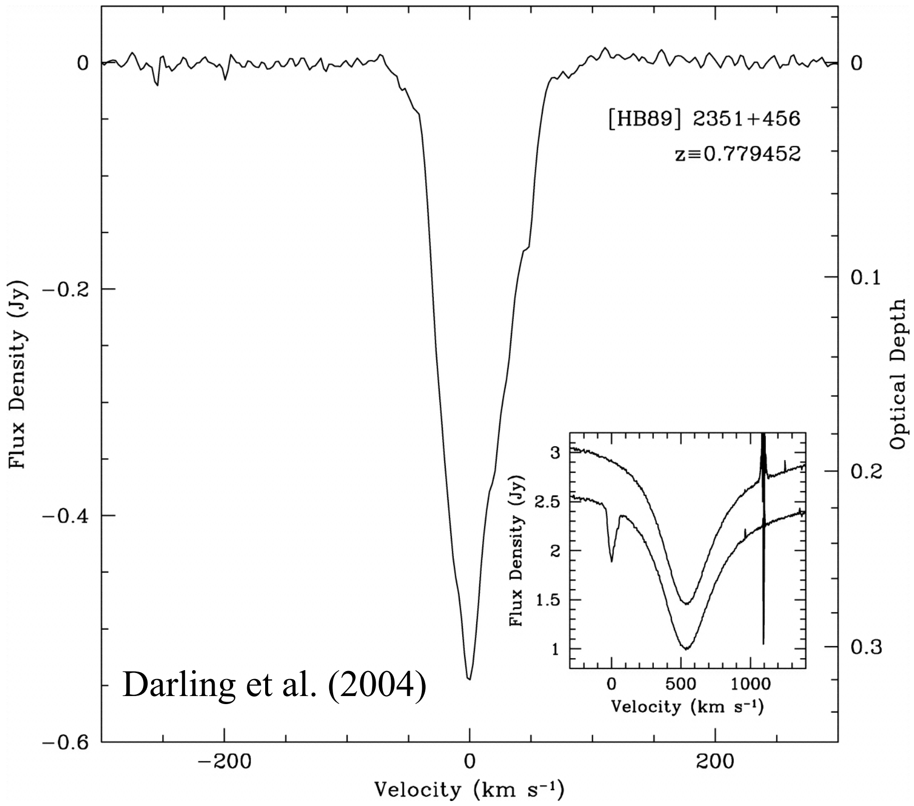


Neutral hydrogen is a *missing link* in current models of galaxy evolution

- Currently know almost nothing about the HI content of galaxies at 0.2<z<2.
- A wide range of models and simulations exist, none of which fit all the data.

Need better data!!

Radio: Intervening HI absorption lines



Unlike optical, no redshift limit for detecting radio 21cm absorption lines.

But do need many targets, wide bandwidth

Radio 21cm measurements are particularly sensitive to cold HI (T_S < 200K)

$\tau \propto N_{HI}/T_s.\Delta V$

for observed optical depth τ

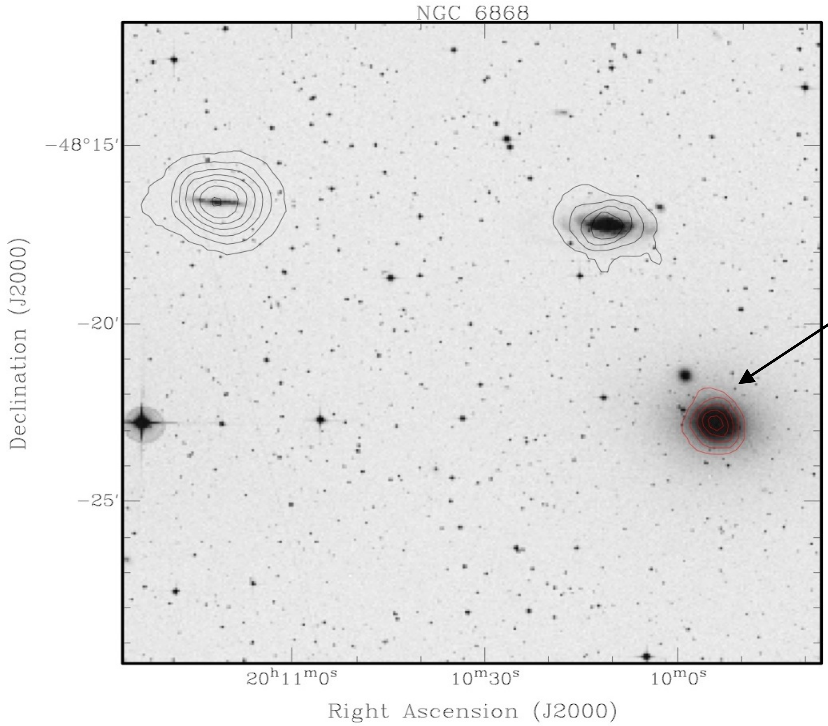
Probability of intercepting a DLA system ($N_{HI} > 2 \times 10^{20}$ cm^{-2}) on a random line of sight?

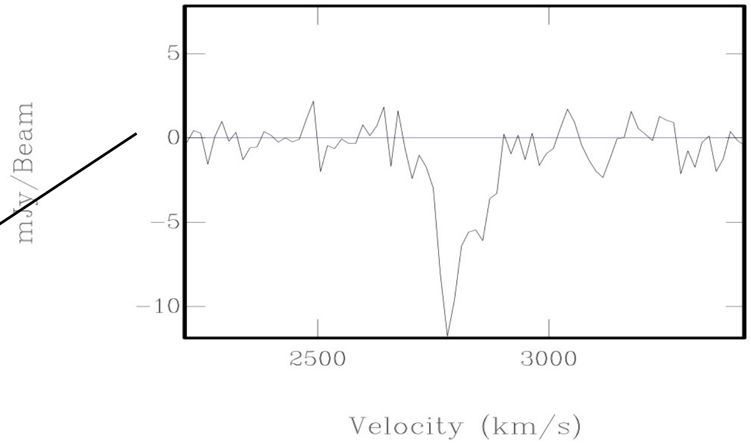
$dN/dZ=0.055\ (1+z)^{1.11}$

(Storrie-Lombardi & Wolfe 2000)

i.e. ~6% for z=0.7, 300 MHz band

Associated HI absorption lines





Nearby galaxy NGC 6868, continuum flux density ~120 mJy at 1.4 GHz.

ATCA: Oosterloo et al., targeted, z = 0.01

Radio HI absorption surveys are unaffected by dust, and particularly sensitive to cold HI (T < 200K)

FLASH (First Large Absorption Survey in HI)

ASKAP-FLASH

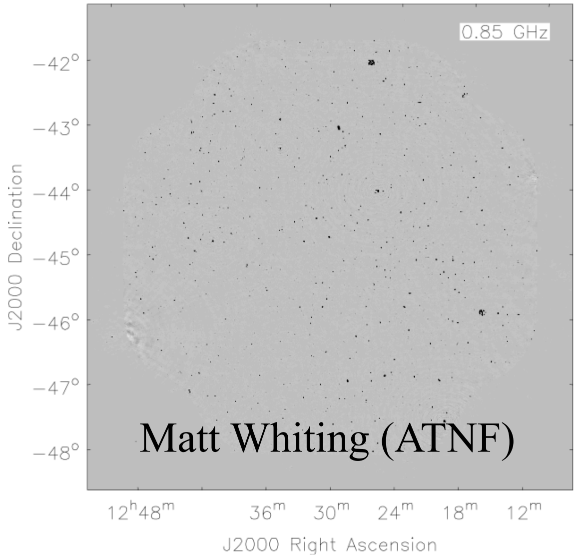
http://www.physics.usyd.edu.au/sifa/FLASH

- HI absorption-line survey at 0.5 < z < 1.0 with ASKAP
- FLASH will cover whole southern sky (dec < +10 deg), 2 hr integration per field, 700-1000 MHz
- Probe ~150,000 sightlines to background radio sources, expect to detect ~ 450 intervening absorption-line systems

Result: an *HI-selected galaxy sample* at z > 0.5

Technique	Redshift	Measures	Notes
HI emission-line surveys	z < 0.4	Individual galaxies	Detection rate **drops** with redshift
HI absorption-line survey	0 < z < 1.0	Individual galaxies/clouds	Detection rate **independent** of redshift
Stacking	0 < z < 1.0	'Average' HI properties	Detection rate depends on redshift **and** the amount and quality of optical redshift data

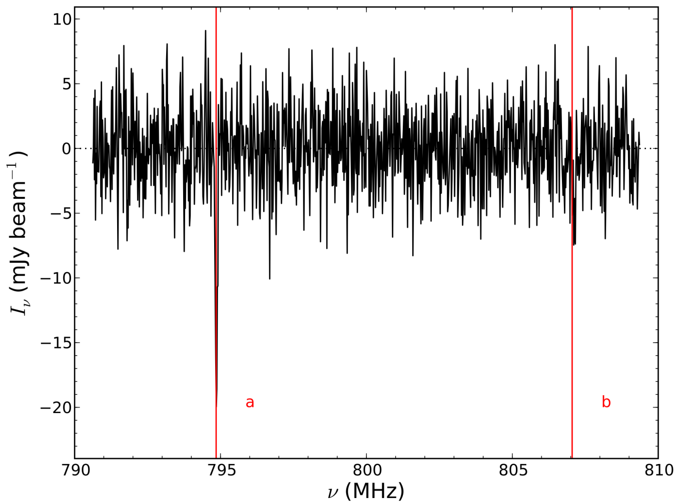
Data simulations



Made by ASKAP computing team, mainly to test line-finding algorithms.
435 continuum sources with a total sample of 600 absorption components "painted on"

Absorption component parameters:
- z = 0.76 – 0.792
- Peak optical depth = 0.01 – 0.30
- Velocity width = 5 – 80 km/s

- Simulate 2hr integration of 30deg^2 field
- 18MHz bandwidth, with 1024 channels
- Sources brighter than 10mJy at 800MHz

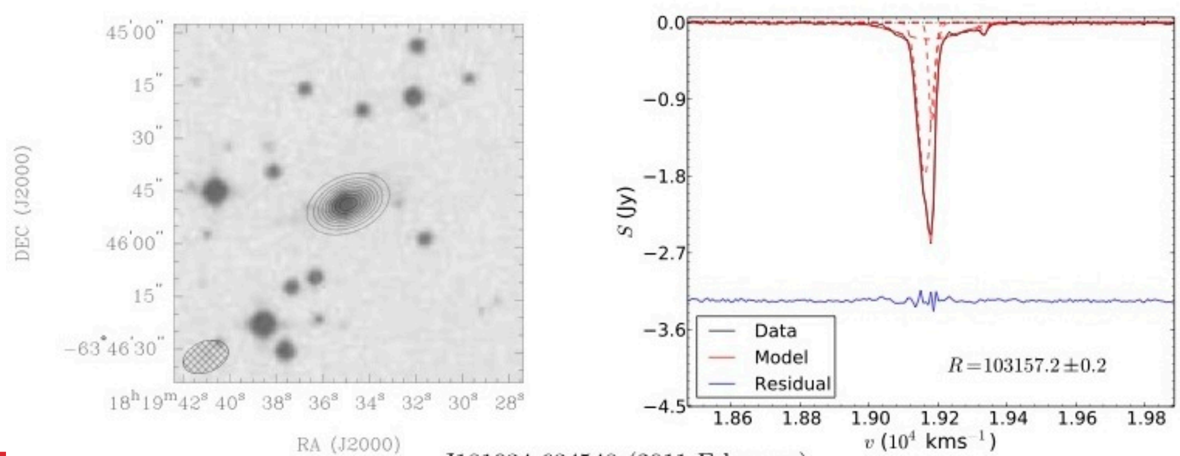


Now published: Allison et al. 2012

Science simulations

1. Semi-analytic models – model galaxy distributions in large cosmic volumes corresponding to ASKAP survey sizes. Observational constraints on the population of HI-rich galaxies out to z ~1. Include jet-driven gas outflows in massive galaxies?

2. Hydrodynamic models – simulate (e.g.) the distribution of HI column density and optical depth expected in a representative subsample of the FLASH volume.



J181934-634548 (2011 February)

(Morganti et al. 2011; Allison et al. 2012)

Hydrodynamical simulations

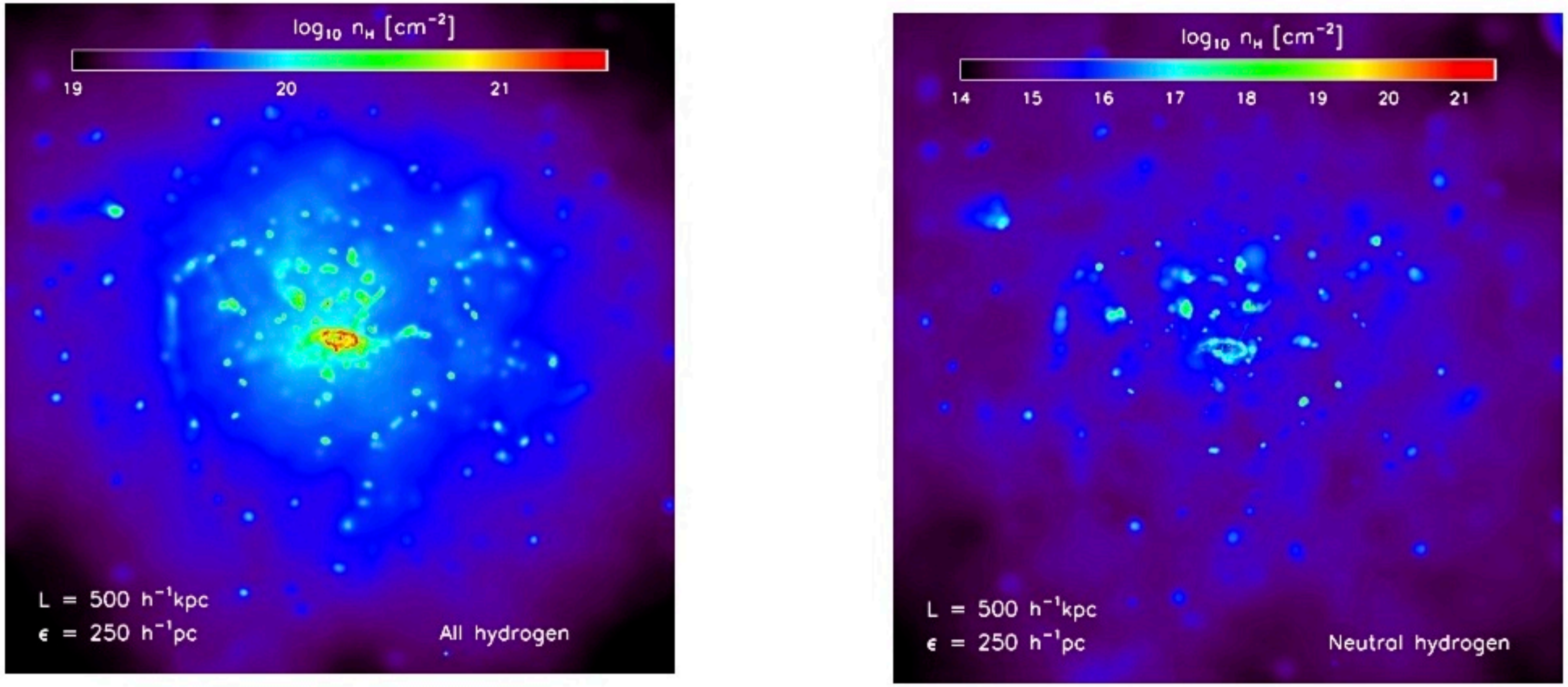


Figure 1: Surface density maps of hydrogen (neutral and ionised; left) and HI (right) around a Milky Way-mass galaxy identified in the GIMIC (Crain et al. 2009) cosmological hydrodynamic simulations, and resimulated from 'zoomed' initial conditions in order to achieve mass a factor of 64 increase in mass resolution. The neutral atomic component was calculated using the TRAPHIC (Pawlik & Schaye 2008) radiation transfer code.

(images from Rob Crain)

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Interpreting radio continuum data

1. Source Counts

Use radio data alone, no need for optical IDs. Can provide some valuable insights, but detailed interpretation is *highly model-dependent.*

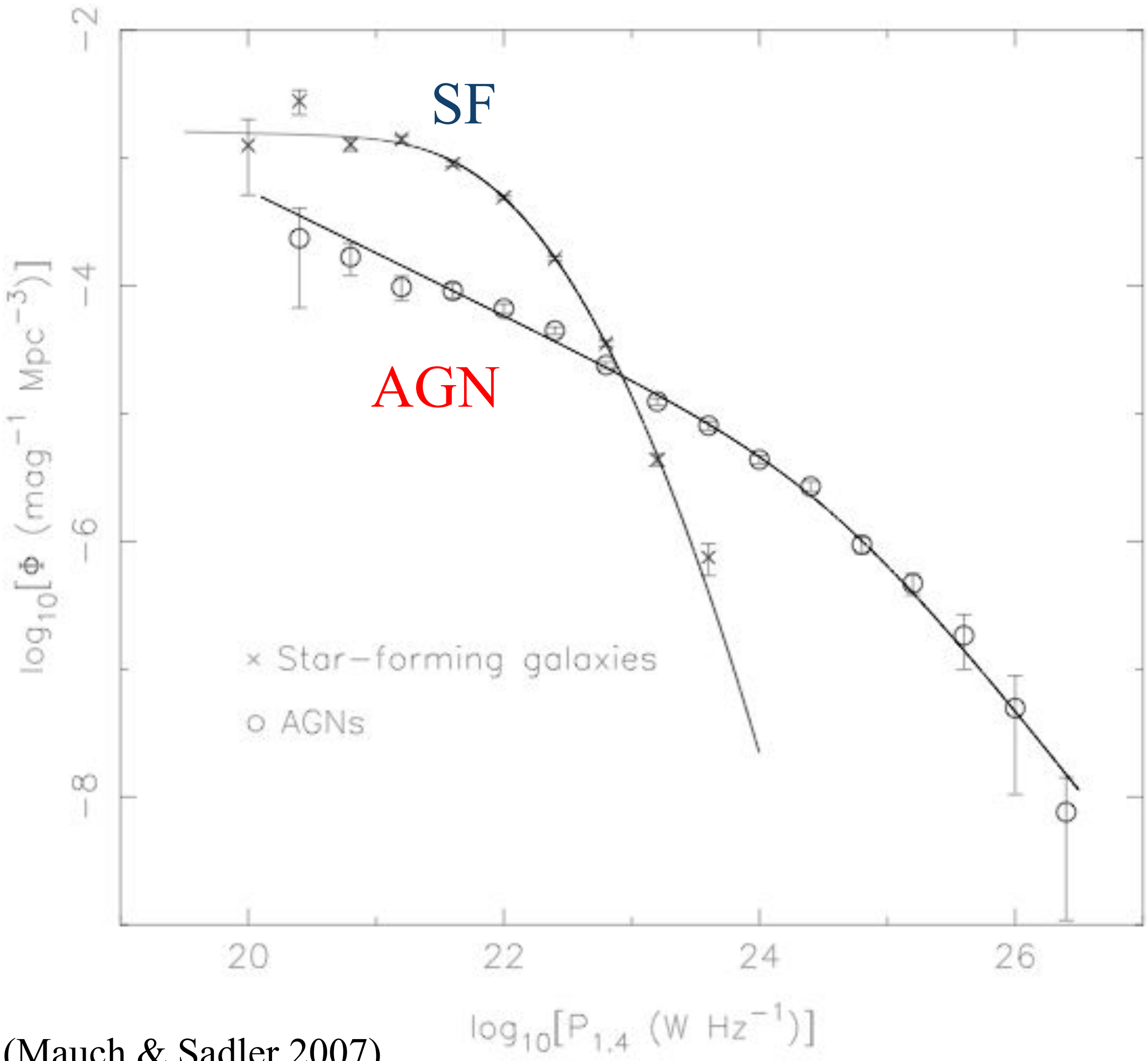
2. 'Classical' source identification ("3CR model")

Attempt to identify and make redshift measurements of all radio sources in a flux-limited sample. Often *expensive in follow-up observing time*, and hard to get 100% completeness.

3. Radio studies of *galaxy populations* * this talk *

Exploit synergies with large optical/IR surveys (e.g. to select samples of galaxies in a fixed redshift range) to address specific scientific questions.

Local radio luminosity function



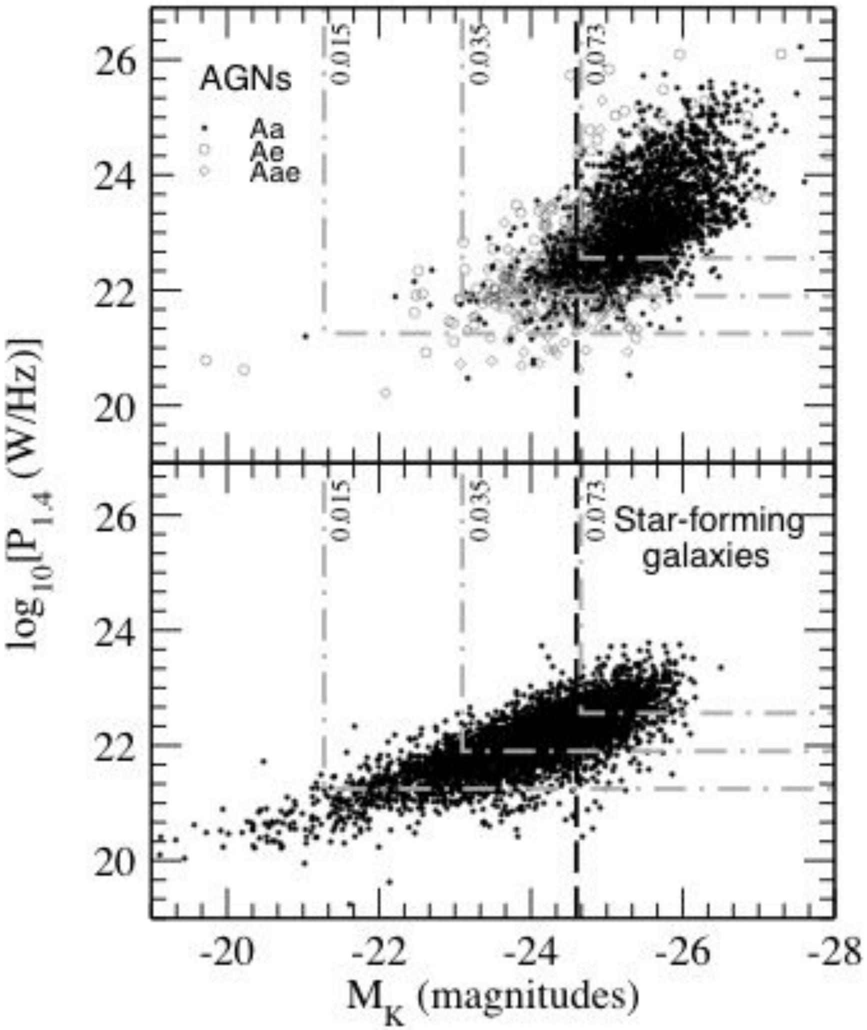
(Mauch & Sadler 2007)

Local (z~0) radio LFs for AGN and star-forming galaxies now accurately measured over six orders of magnitude.

Below about 10^{25} W/Hz, the local radio source population is **always** a mixture of AGN and star-forming galaxies.

[Used two surveys : 6dFGS + NVSS]

Radio-source populations at z~0



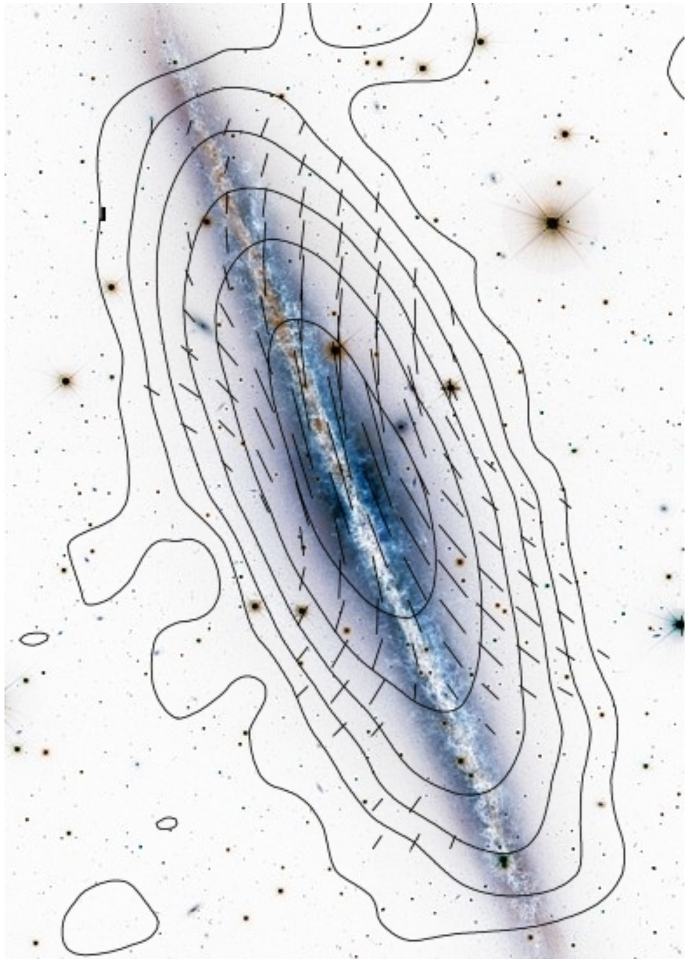
(Mauch & Sadler 2007)

Radio-source populations in the local universe are now well mapped out at frequencies near 1.4 GHz.

Radio-loud AGN (radio galaxies) have a wide range in radio luminosity, but are only found in the most luminous/ massive optical galaxies.

Star-forming galaxies span a much wider range in stellar mass.

Radio emission from star-forming galaxies



NGC891: M. Krause, MPIfR

Radio continuum emission from spiral galaxies like the Milky Way is dominated by non-thermal *synchrotron radiation* from cosmic-ray electrons accelerated in the supernova remnants of massive stars, plus some thermal *free-free emission* from HII regions.

Here, radio emission arises from processes related to star formation

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Radio-loud AGN in the local universe

Current view: There are two distinct populations of radio-emitting AGN, which may evolve differently with redshift

'High-excitation' radio galaxies (HERGs), also known as cold-mode radio galaxies.

Black hole fuelled by a classical (thin) accretion disk, expected to follow AGN unified schemes

'Low-excitation' radio galaxies (LERGs), also known as hot-mode radio galaxies.

Black hole fuelled in a ***radiatively inefficient*** *way, no classical accretion disk, AGN unification does not apply*

Questions: Can we distinguish these observationally in a reliable and consistent way? What role do these two populations play in AGN feedback/galaxy evolution?

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Spectral classification

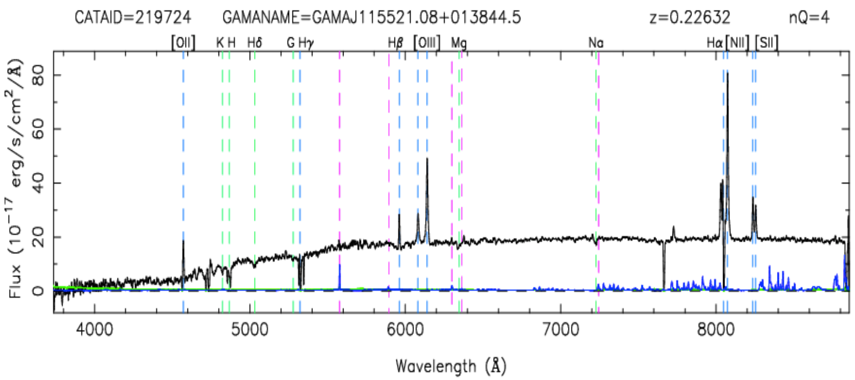
Classification is generally based on optical spectroscopy (large samples)

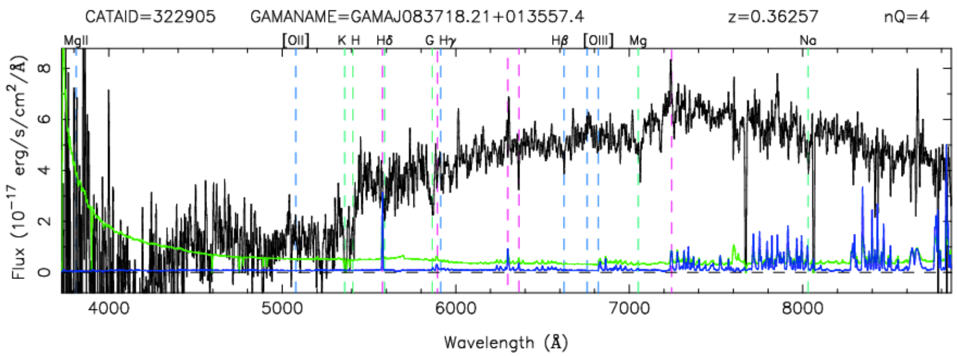
‘High-excitation’ radio galaxies (HERGs):

uv radiation from accretion disk excites strong optical emission lines

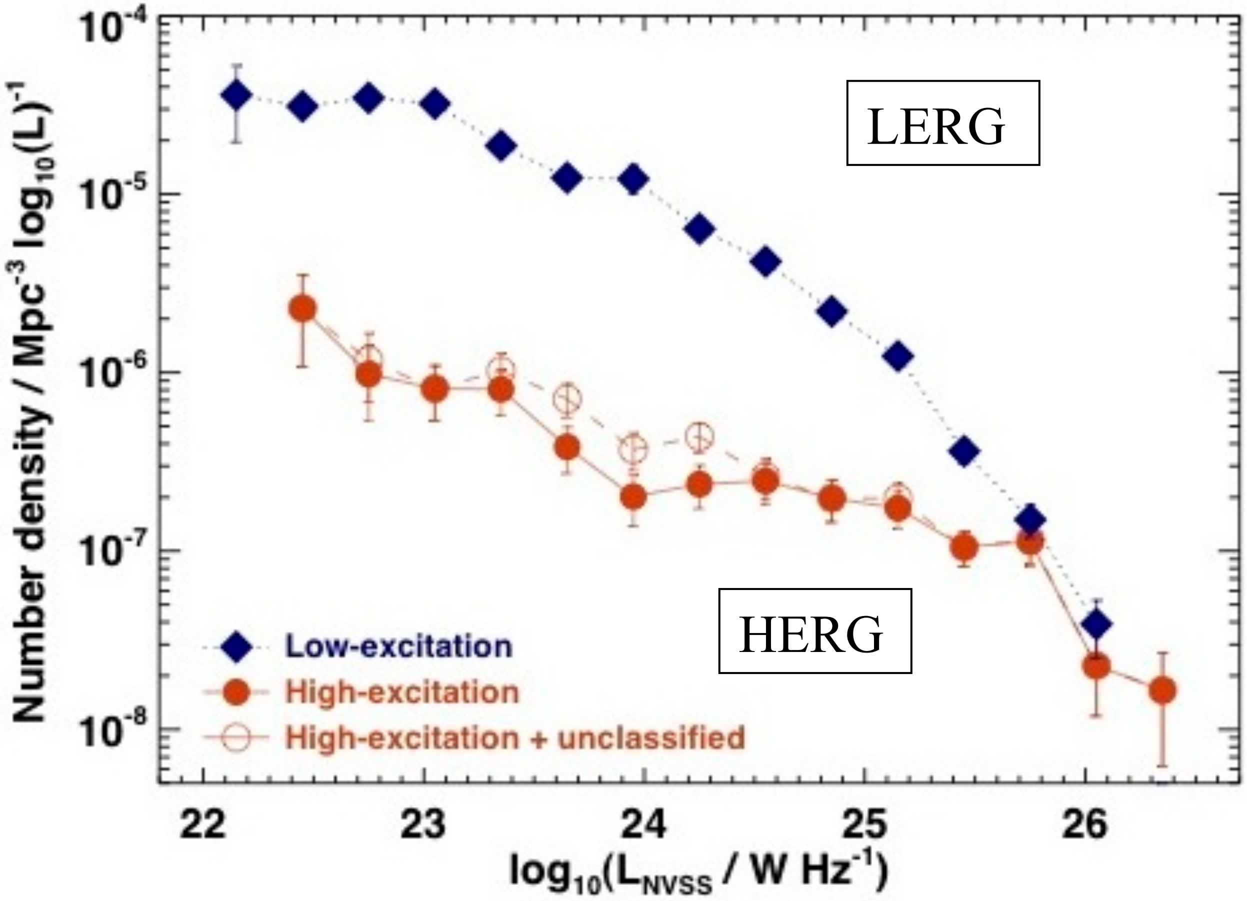
‘Low-excitation’ radio galaxies (LERGs):

Absence *of uv-bright accretion disk means weak or no optical emission lines*





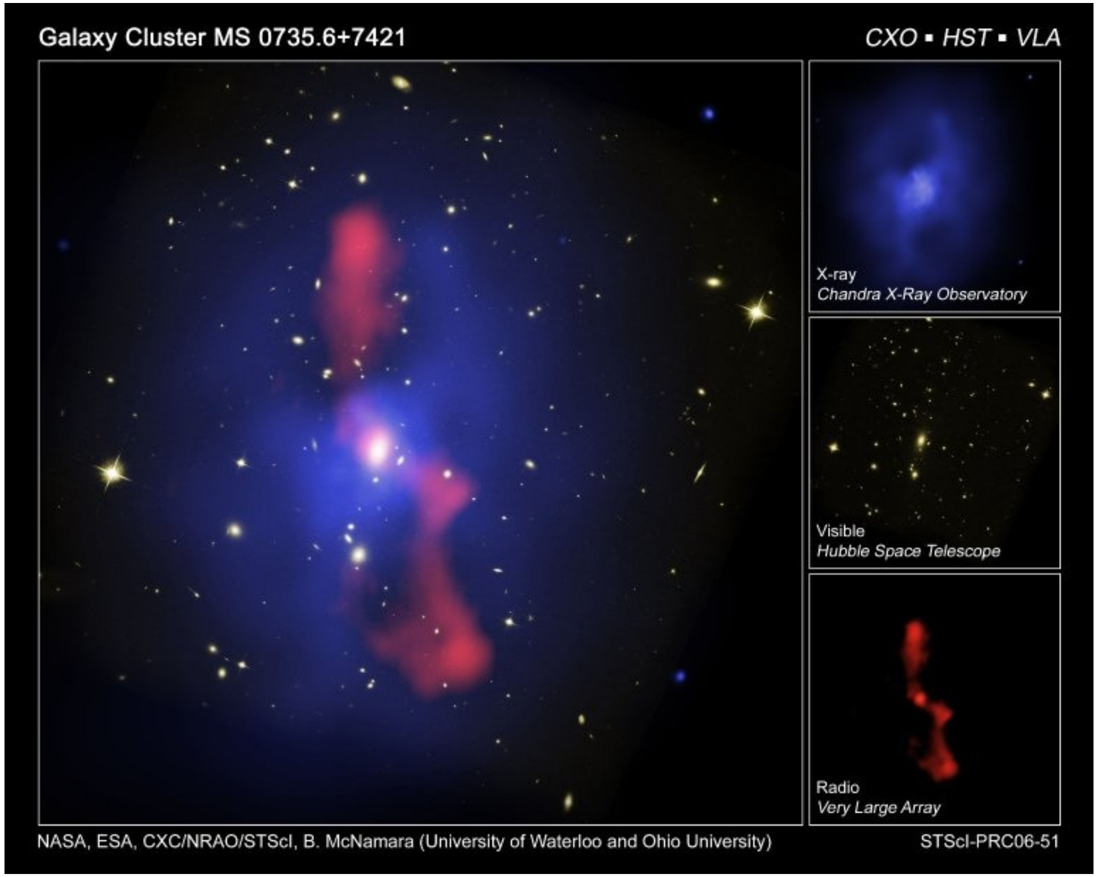
Radio galaxy populations at z~0



Hot-mode (LERG) radio galaxies are the dominant population at z~0, but cold-mode (HERG) radio galaxies are seen across the full range of radio luminosity

(Best & Heckman 2012)

Radio-mode feedback: linking large and small scales



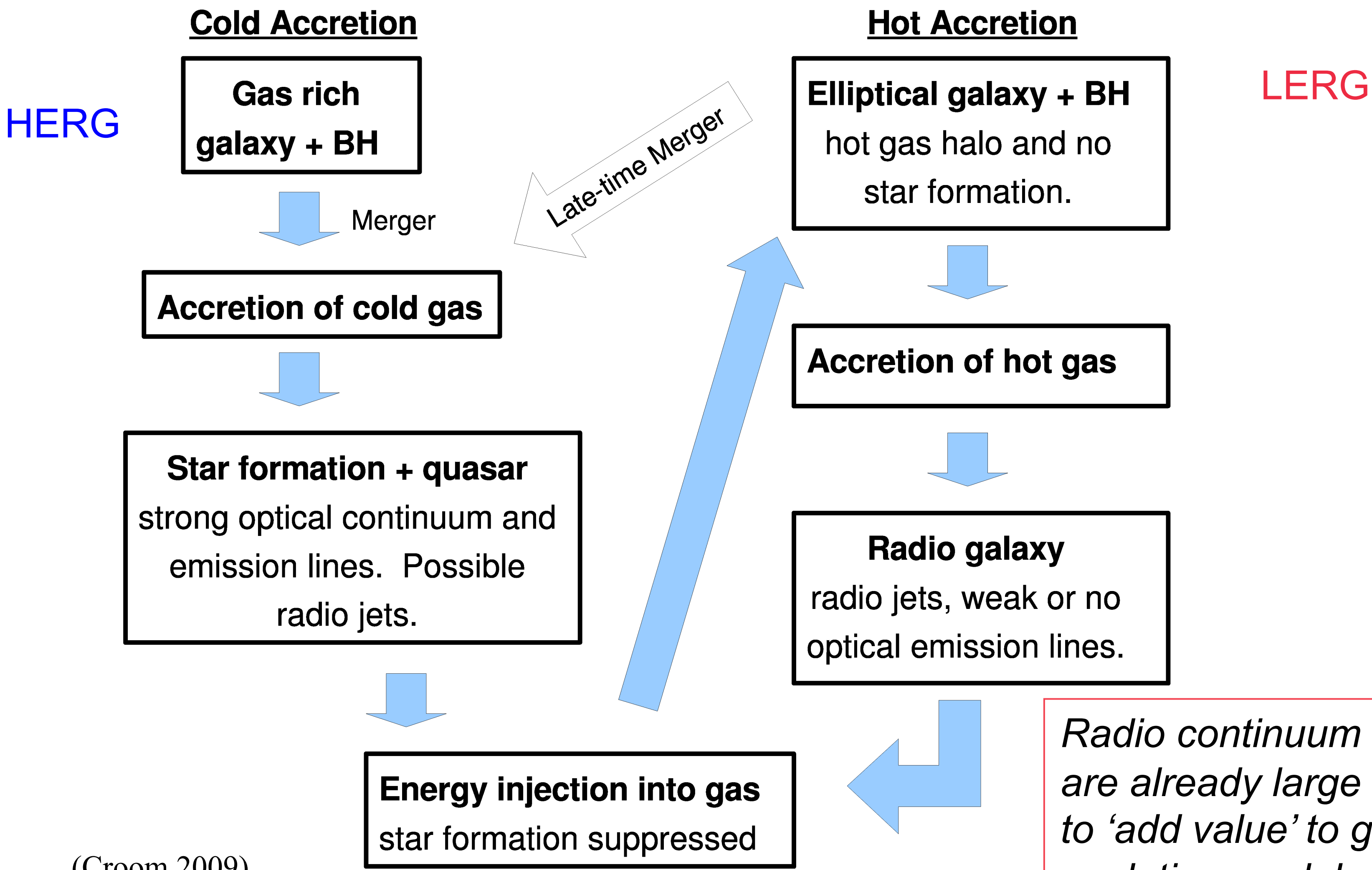
Kinetic energy of a radio jet is typically **100-1000 times higher** than the observed total radio luminosity (Bicknell 1995).

X-ray observations of cavities in the hot gas provide a 'calorimeter' for measuring the energy input by the radio jet into the surrounding galaxy, which is up to 10^{45} erg/s (Birzan et al. 2004, Best et al. 2006)

Mainly LERGs

Radio jets appear to be the key link between large-scale (kpc) and small-scale (sub-pc) physical processes in massive galaxies

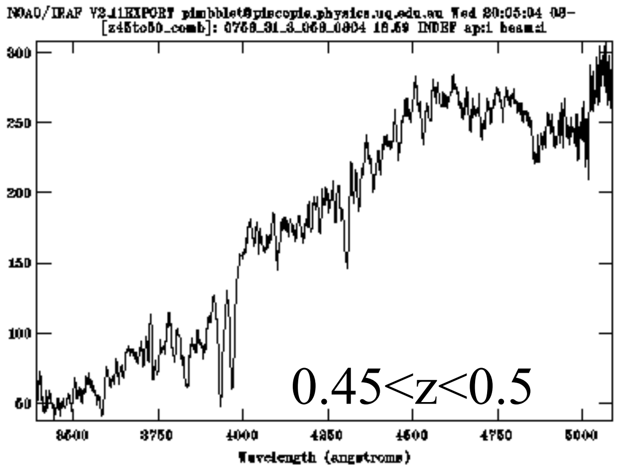
Our current picture…

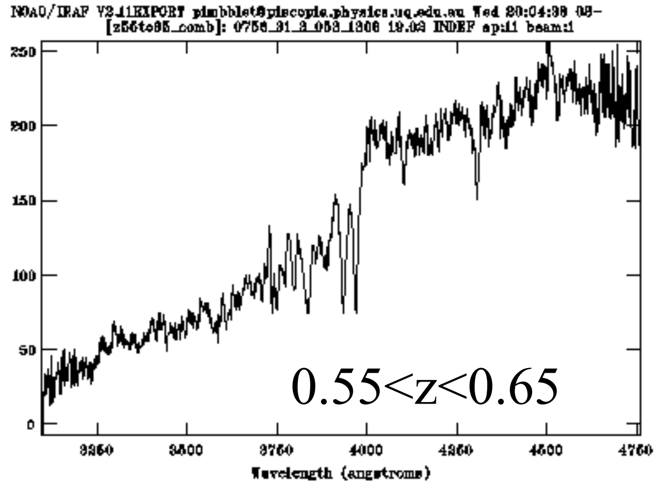


(Croom 2009)

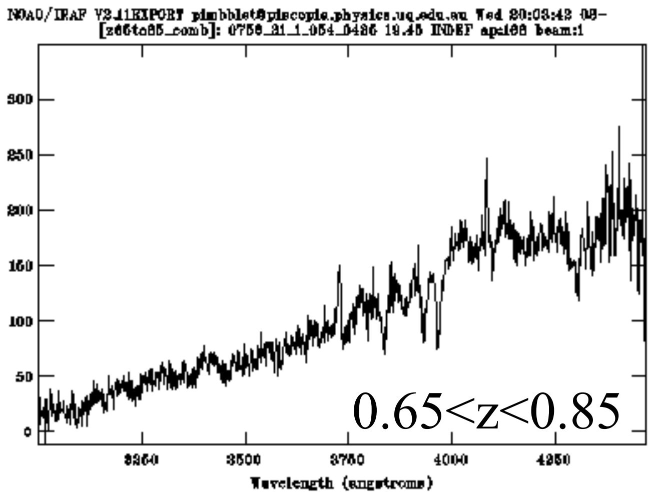
Radio continuum studies are already large enough to 'add value' to galaxy evolution models

Composite optical spectra





2SLAQ LRG survey + VLA FIRST, 0.4<z<0.8



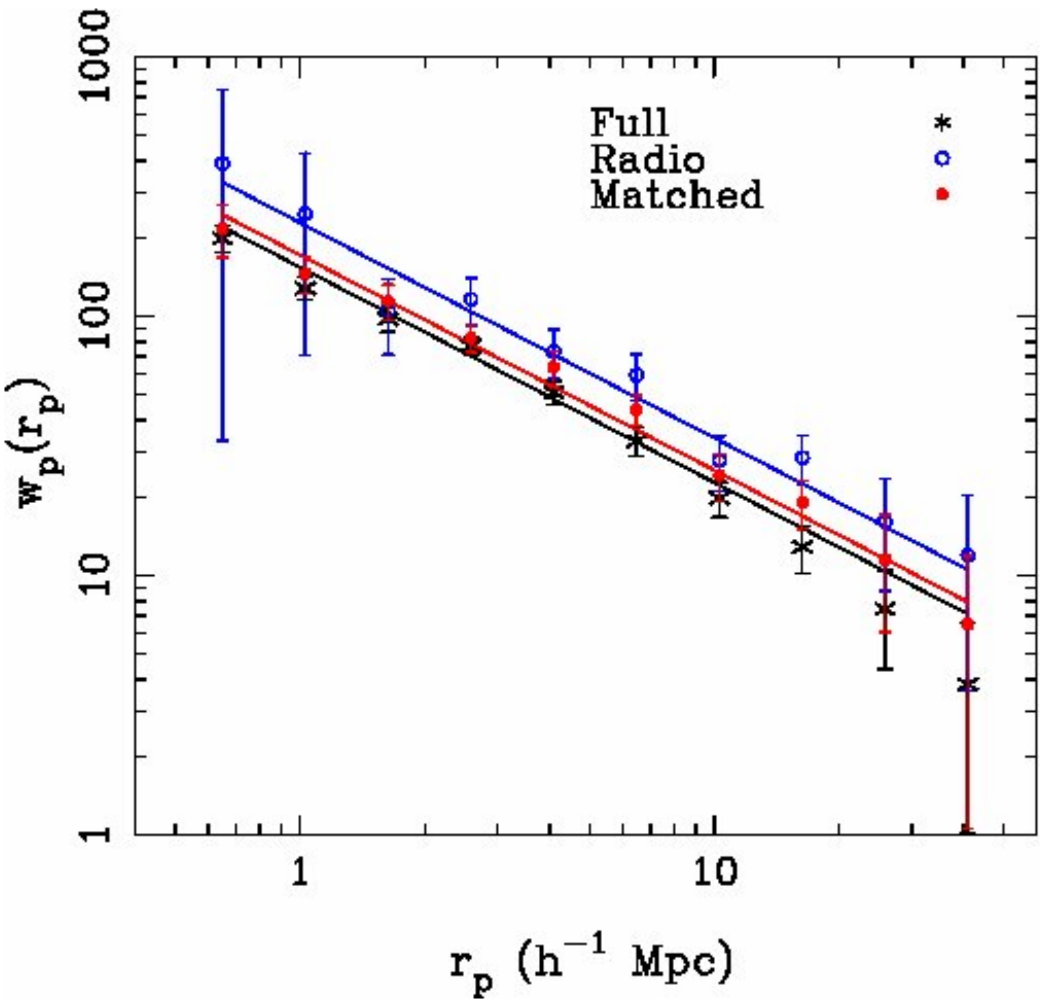
Analysis of matched composite spectra shows *no significant difference* between the stellar populations of radio-loud and radio-quiet LRGs in general (Johnston et al. 2008)

i.e. likely that all massive galaxies go through an intermittent radio galaxy phase

Radio-galaxy clustering at z~0.55

- 10,000 2SLAQ LRGs at z~0.55.
- ~400 "radio-loud" (Sadler et al. 2007)
- Compare to luminosity, colour and redshift matched "radio-quiet" LRGs.

	r_0 (h^{-1} Mpc)
Full	7.7 ± 0.2
Radio	12.3 ± 1.1
Matched	9.0 ± 0.5



Wake et al. (2008) - slide from Scott Croom

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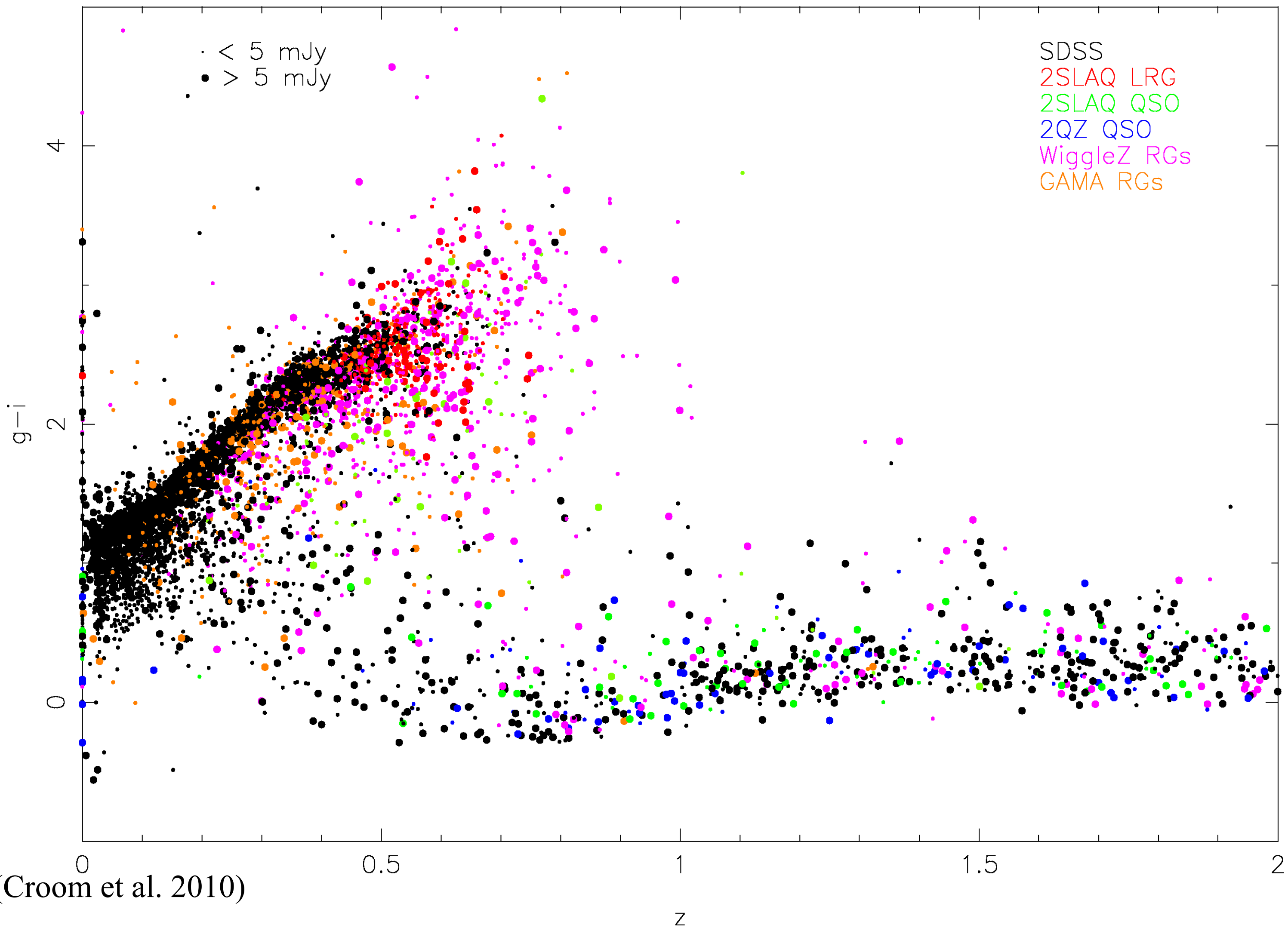
Current work – very large spectrosocopic samples

- What about the effects of colour selection in LRG samples? Are the LRG surveys missing a population of blue/HERG radio galaxies?
- How are radio galaxies and radio-loud QSOs related?

Work in progress: New spectroscopic survey, piggy-backed on AAT large-area WiggleZ and GAMA surveys (LARGESSE survey, John Ching's PhD thesis)

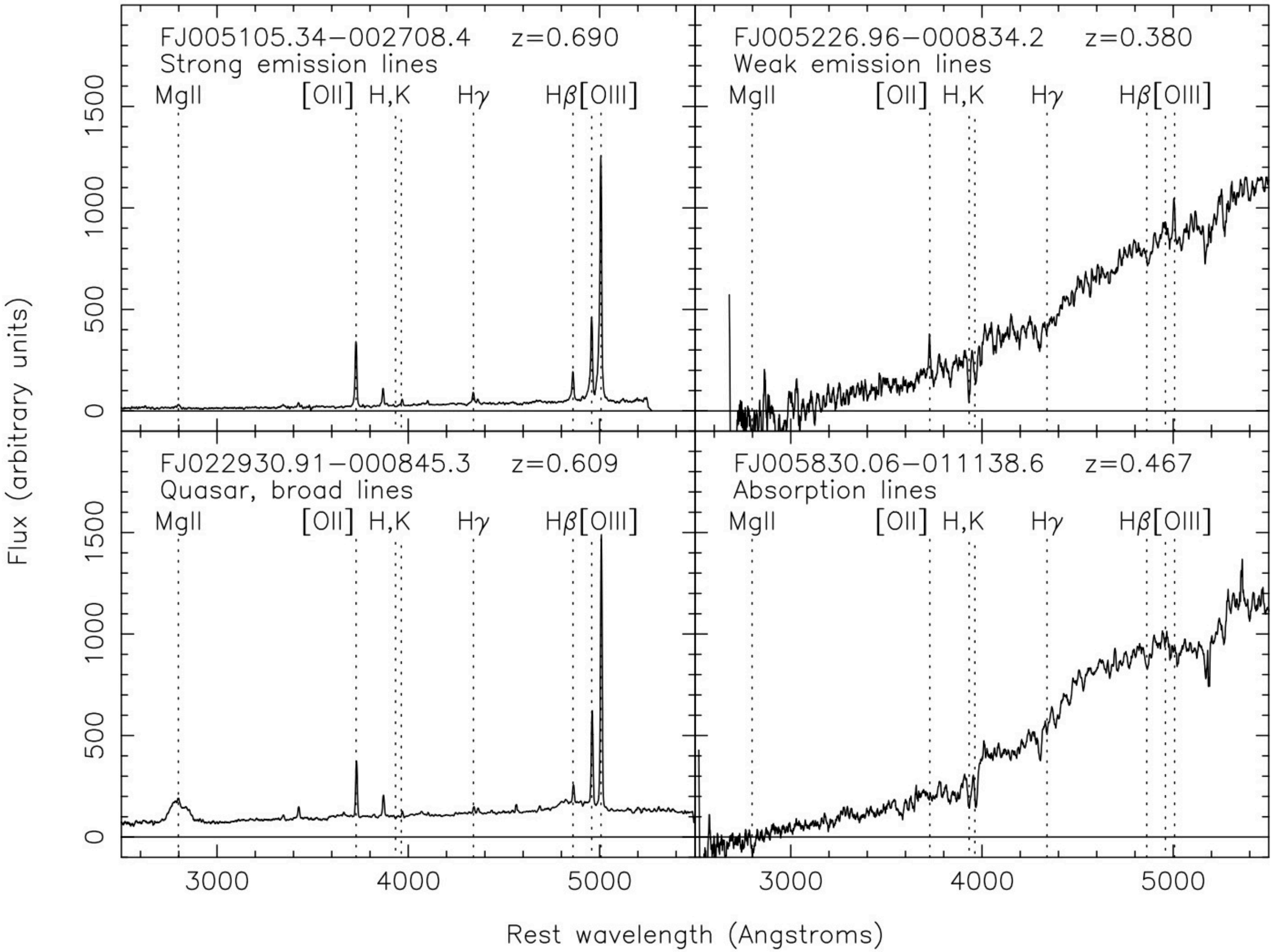
Goal is to measure accurate LFs, investigate LERG duty cycles, map out hot/cold accretion systems vs redshift and clustering environment to z~1.

SDSS colours versus redshift

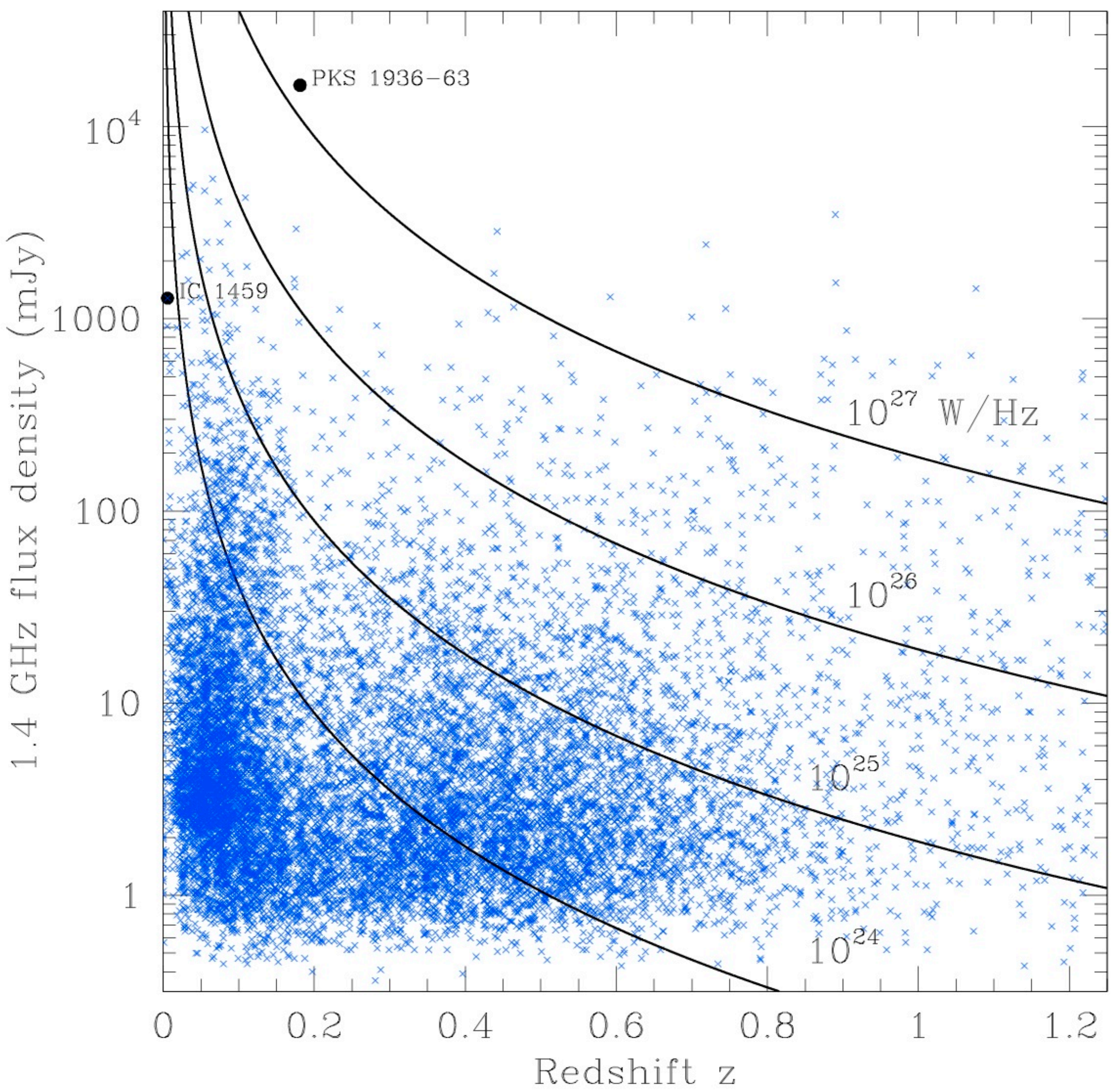


(Croom et al. 2010)

Optical spectra (AAT/AAOmega)

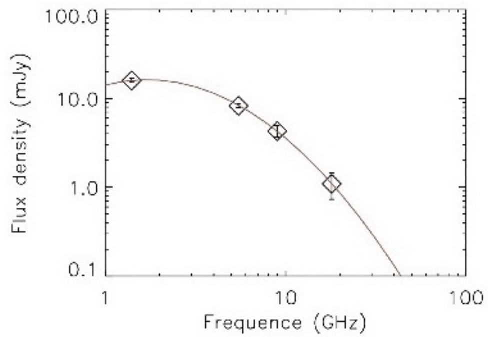


Distribution in radio power and redshift



Selection: FIRST radio sources with i<20.5 mag, *no colour selection.*

Spectroscopy: Piggyback with spare fibres from AAT WiggleZ, GAMA and AUS surveys



Radio-source populations to z~1

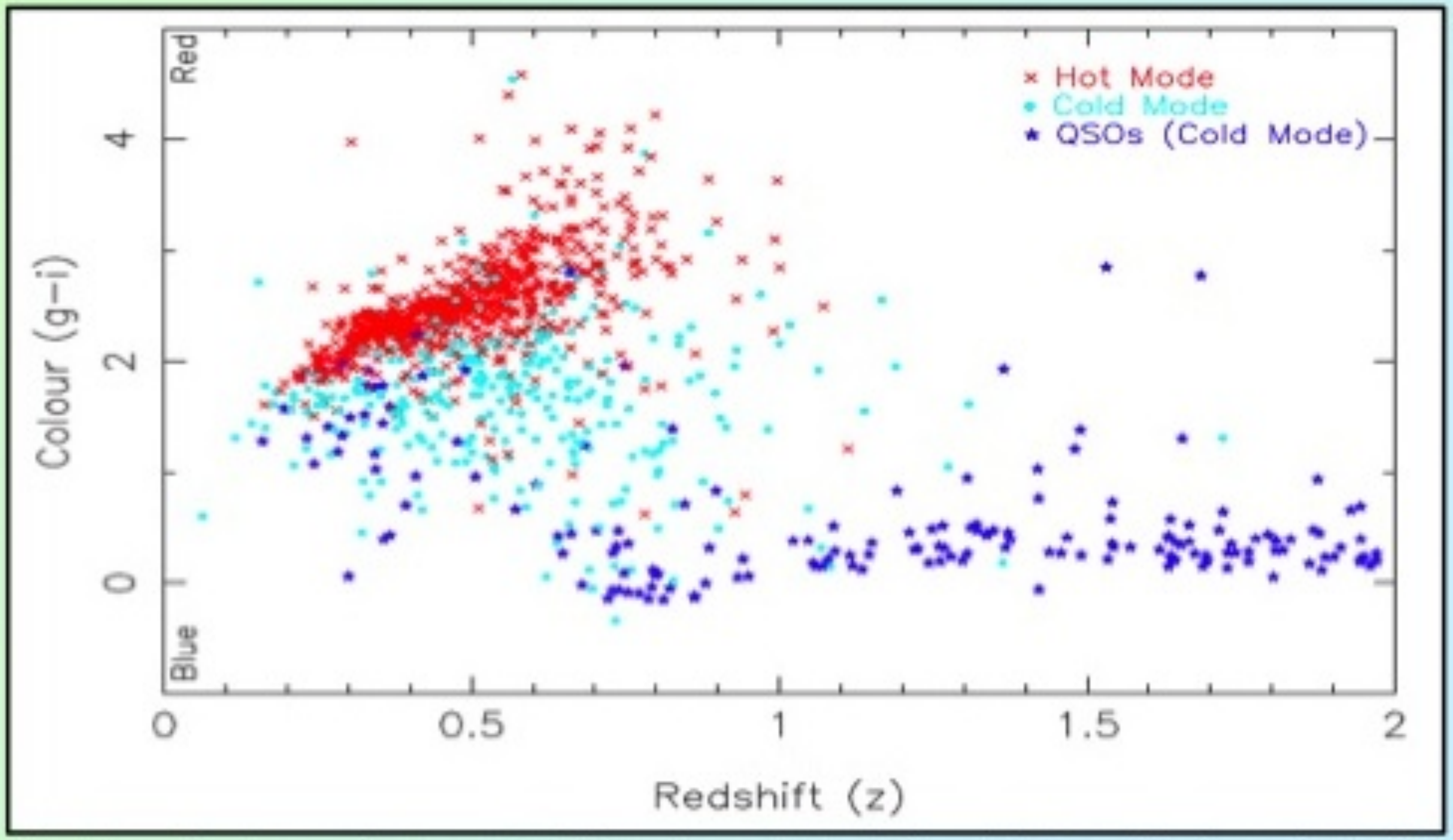


Figure 2 A colour-redshift of our WiggleZ radio-loud AGN sample showing the two different modes.

(Ching 2010)

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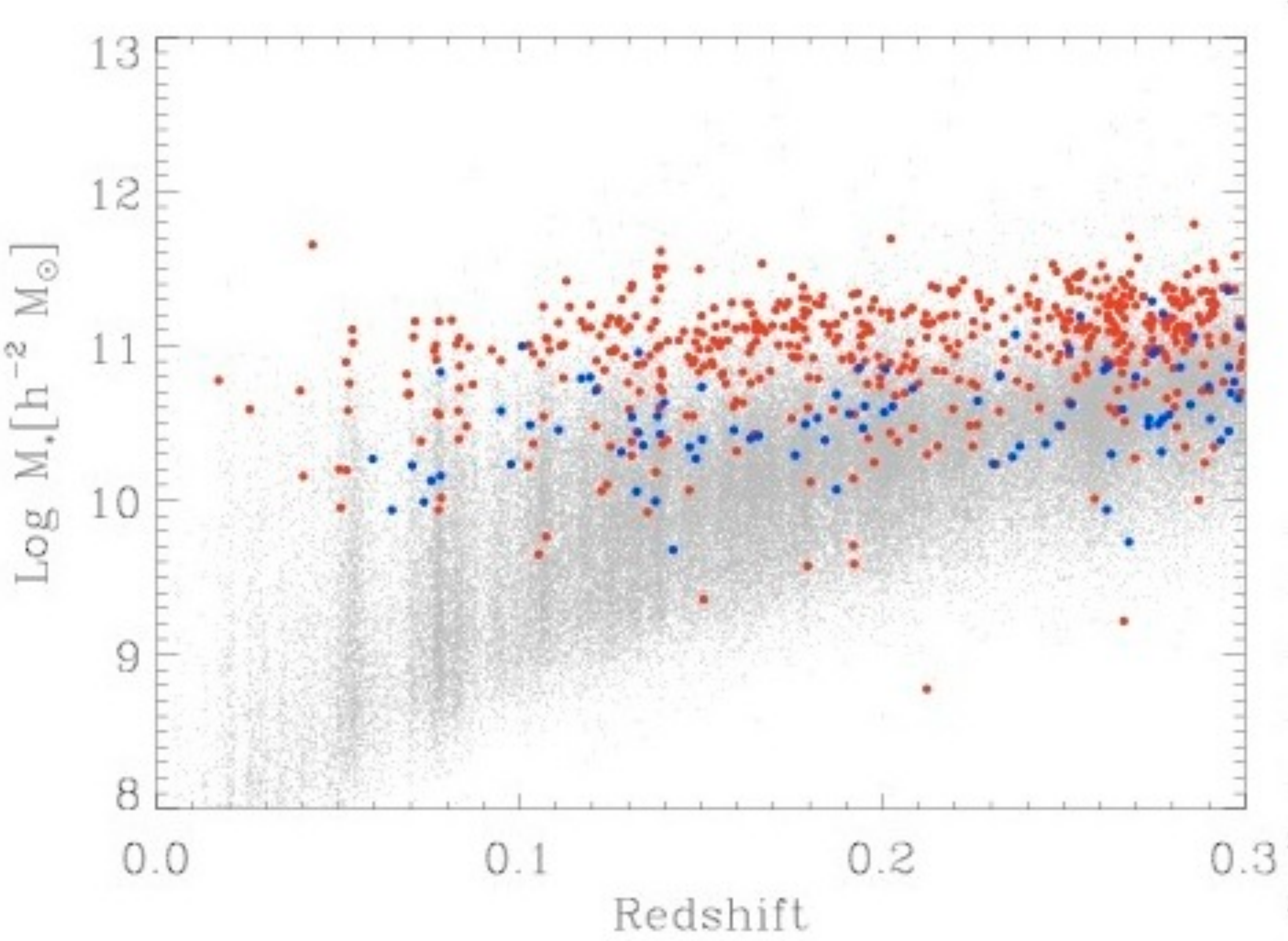
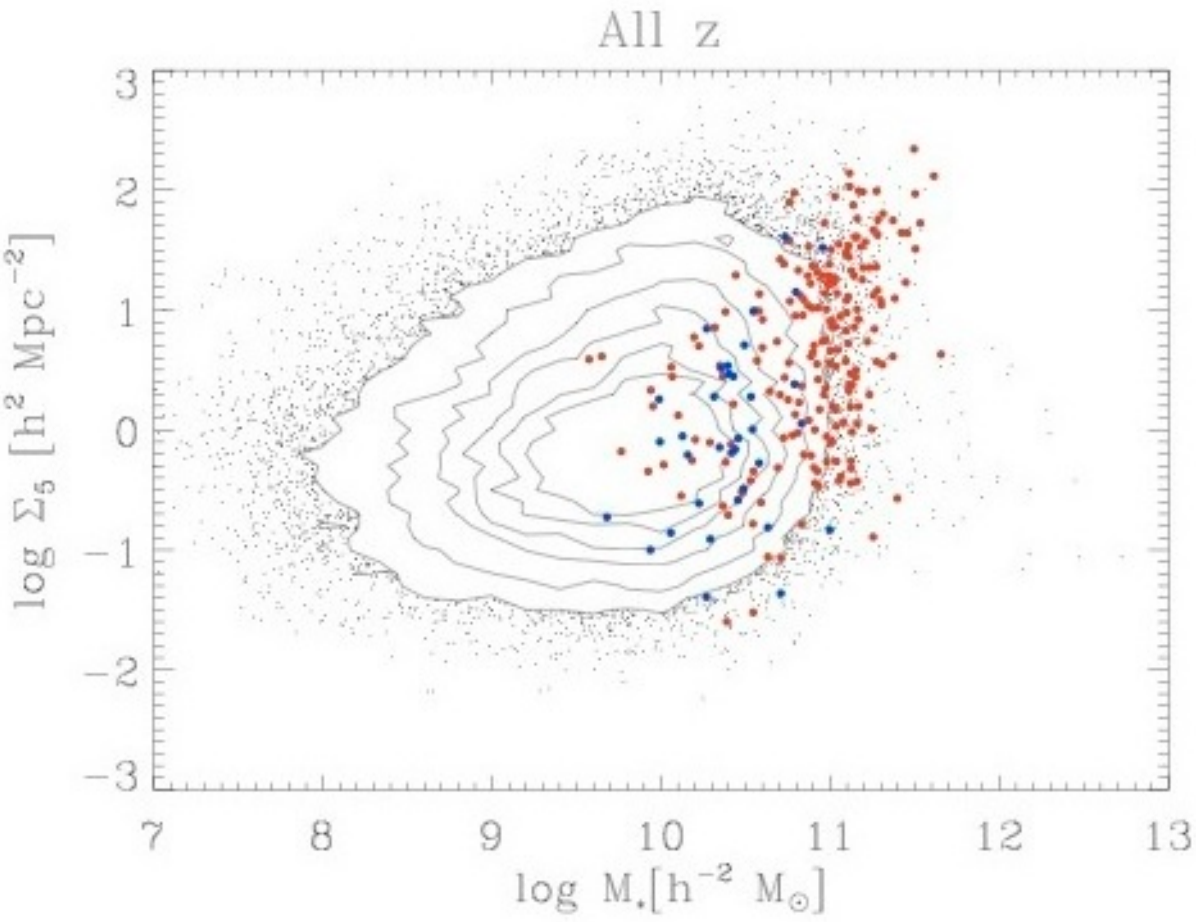
Radio galaxies in the GAMA survey



(GAMA sample, Ching et al. 2012)

Influence of local galaxy density



(Ching et al. 2012)

Stellar mass is the dominant parameter, but environment also plays a significant role in determining ‘radio loudness’ for hot-mode systems

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Future work

- Luminosity functions and evolution of the hot- and cold-mode populations, comparison with models

- New multi-frequency radio measurements: radio-galaxy triggering and duty cycles

- Studies of gas (distribution and kinematics) in distant galaxies and radio galaxies via HI absorption and CO emission

Collaborators in the work presented here include:

James Allison, Russell Cannon, John Ching, Scott Croom, Stephen Curran, Ron Ekers, Paul Hancock, Carole Jackson, Helen Johnston, Tom Mauch, Raffaella Morganti, Tara Murphy, Vince McIntyre, Michael Pracy, Sarah Reeves, David Wake, Martin Zwaan

and members of the 6dFGS, 2dFGRS, 2SLAQ LRG, WiggleZ, GAMA and ASKAP-FLASH survey teams