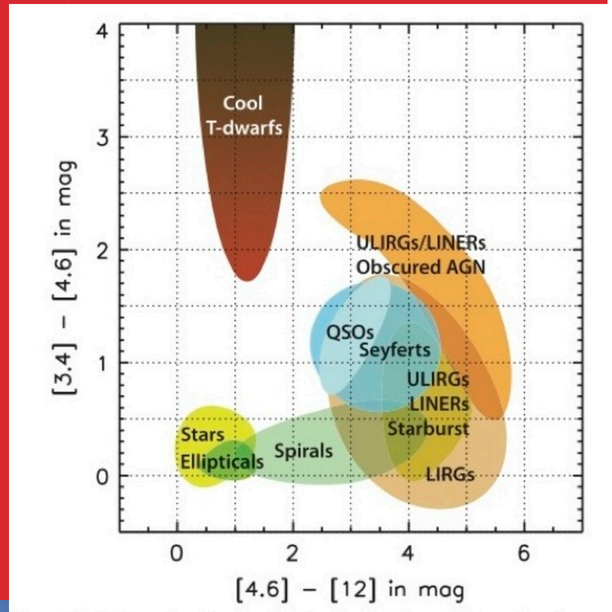
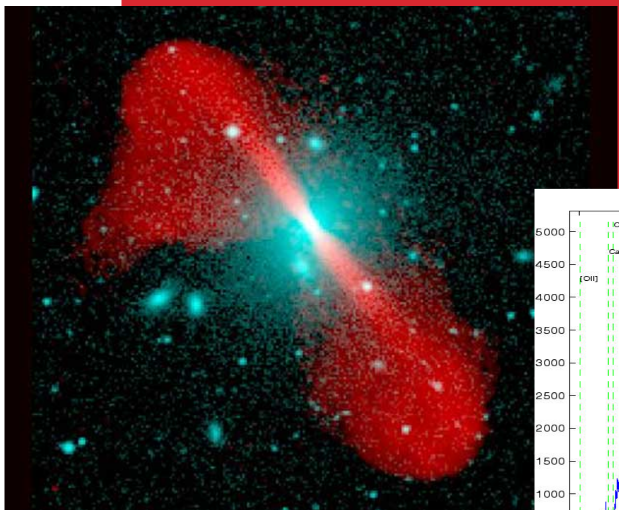
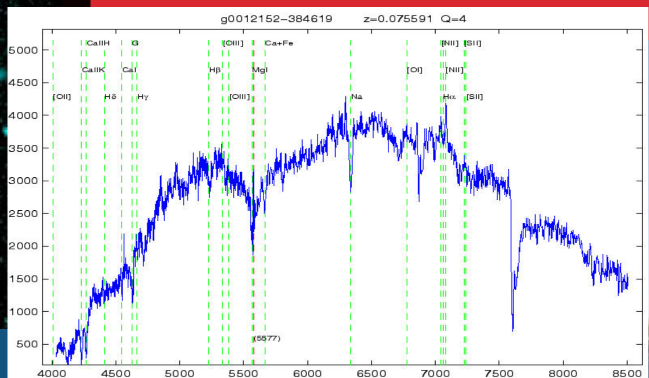
Radio-source populations in the local universe – what's next?

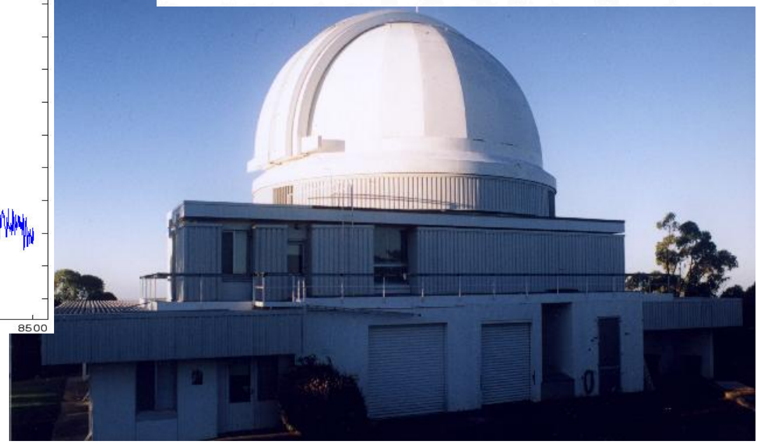
Elaine M. Sadler

School of Physics,
University of Sydney









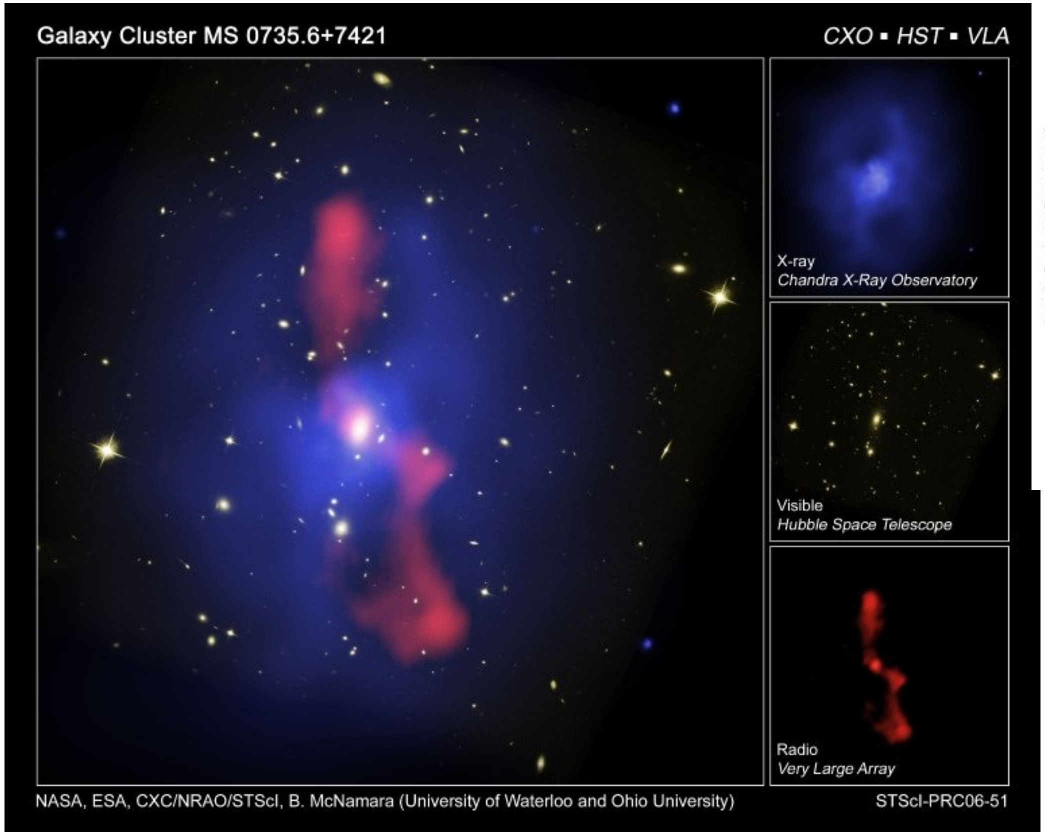
THE UNIVERSITY OF
SYDNEY

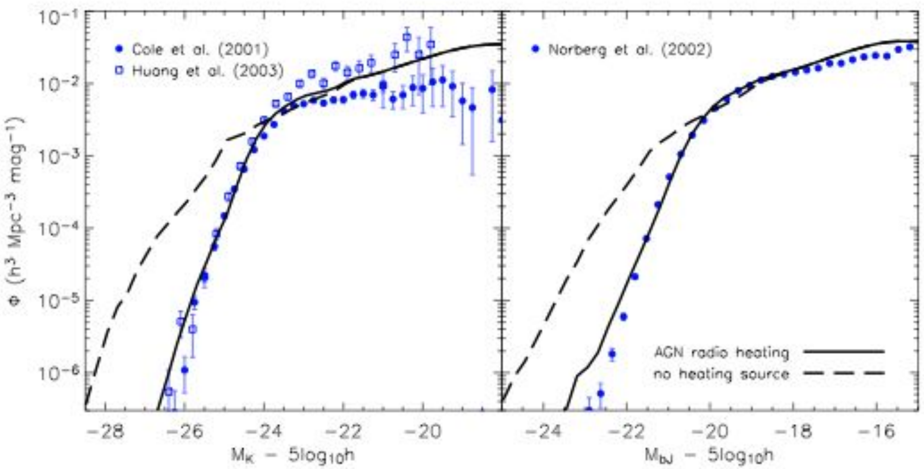
THE UNIVERSITY OF SYDNEY

Main points

- Local ($z < 0.2$) radio-source populations are an essential benchmark for understanding the distant universe
- Current continuum surveys are largely monochromatic, but it's helpful to have data at more than one radio frequency
- We can learn a lot from existing all-sky surveys (6dFGS, NVSS, etc.) - and there's still plenty to do!
- WISE is a fantastic resource (thanks, Tom!)
- Key science areas where Taipan/ASKAP can advance our understanding: <u>environment, gas fuelling, AGN duty cycles and feedback processes</u> *(HI data are vital!)*

Radio jets and galaxy evolution



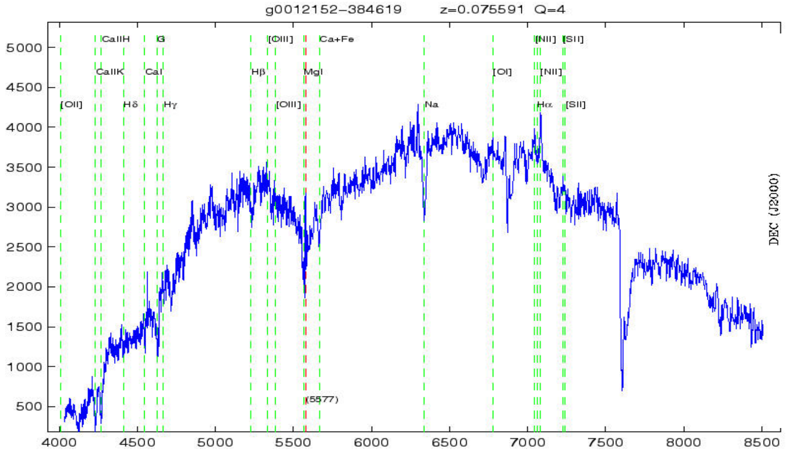


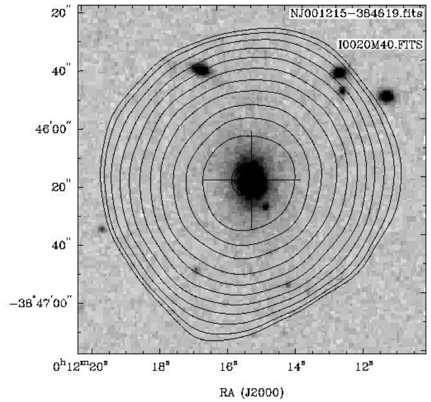
(Croton et al. 2006: **'Radio-mode feedback'**)

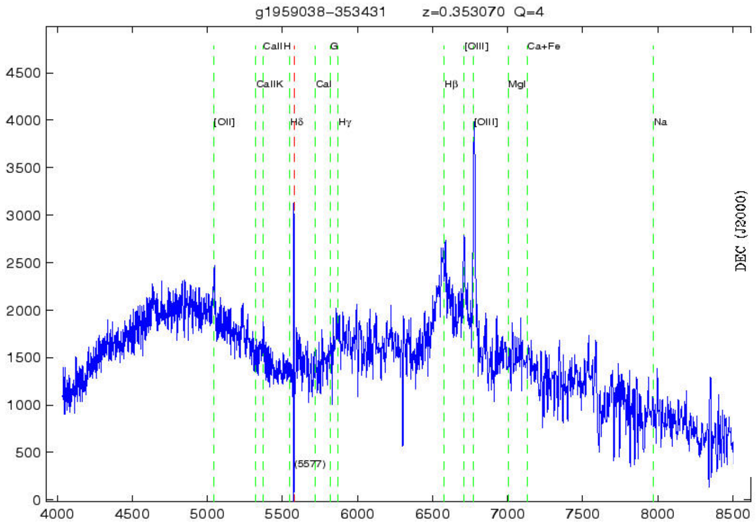
Kinetic energy of a radio jet is typically **100-1000 times higher** than the observed total radio luminosity, i.e. up to 10^{45} erg/s (Bicknell 1995, Birzan et al. 2004, Best et al. 2006).

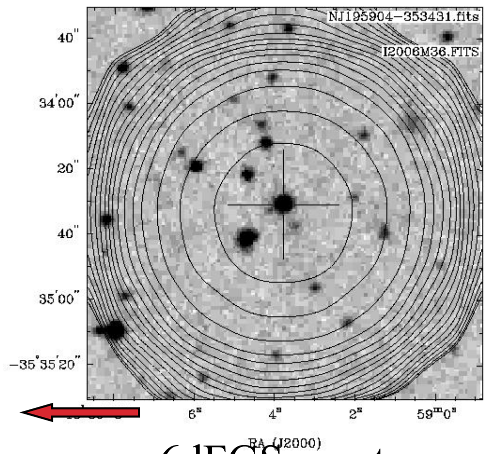
Radio jets provide a way to link large-scale (kpc) and small-scale (sub-pc) physical processes in massive galaxies and suppress late-time star formation in massive galaxies. <u>Local universe is the best place to study these processes.</u>

6dFGS radio sources







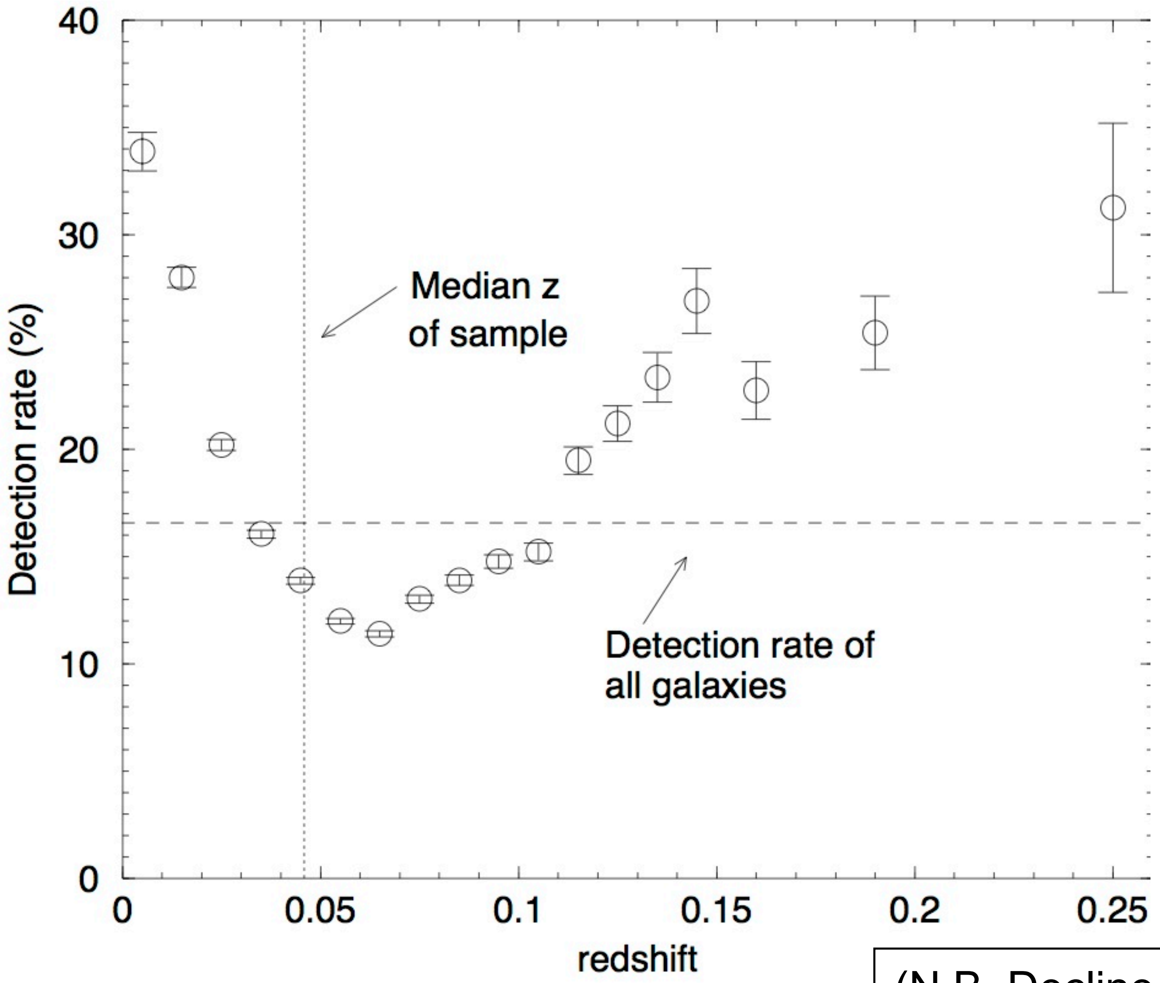


6dFGS spectra

6dFGS provides spectra of 10,000+ nearby radio AGN and starburst galaxies.

Definitive local benchmark for studying the evolution of radio-source populations

Radio detection rate of 6dFGS galaxies (1.4 GHz)



(Mauch & Sadler 2007)

Overall NVSS radio detection rate of 6dFGS galaxies (K < 12.75 mag) at 1.4 GHz is relatively *high* (typically ~17%)

Would expect an even higher detection rate for nearby galaxies in the ASKAP continuum surveys.

(N.B. Decline at low-z end is set by radio flux limit, rise at high end by optical mag limit)

Spectroscopic classification

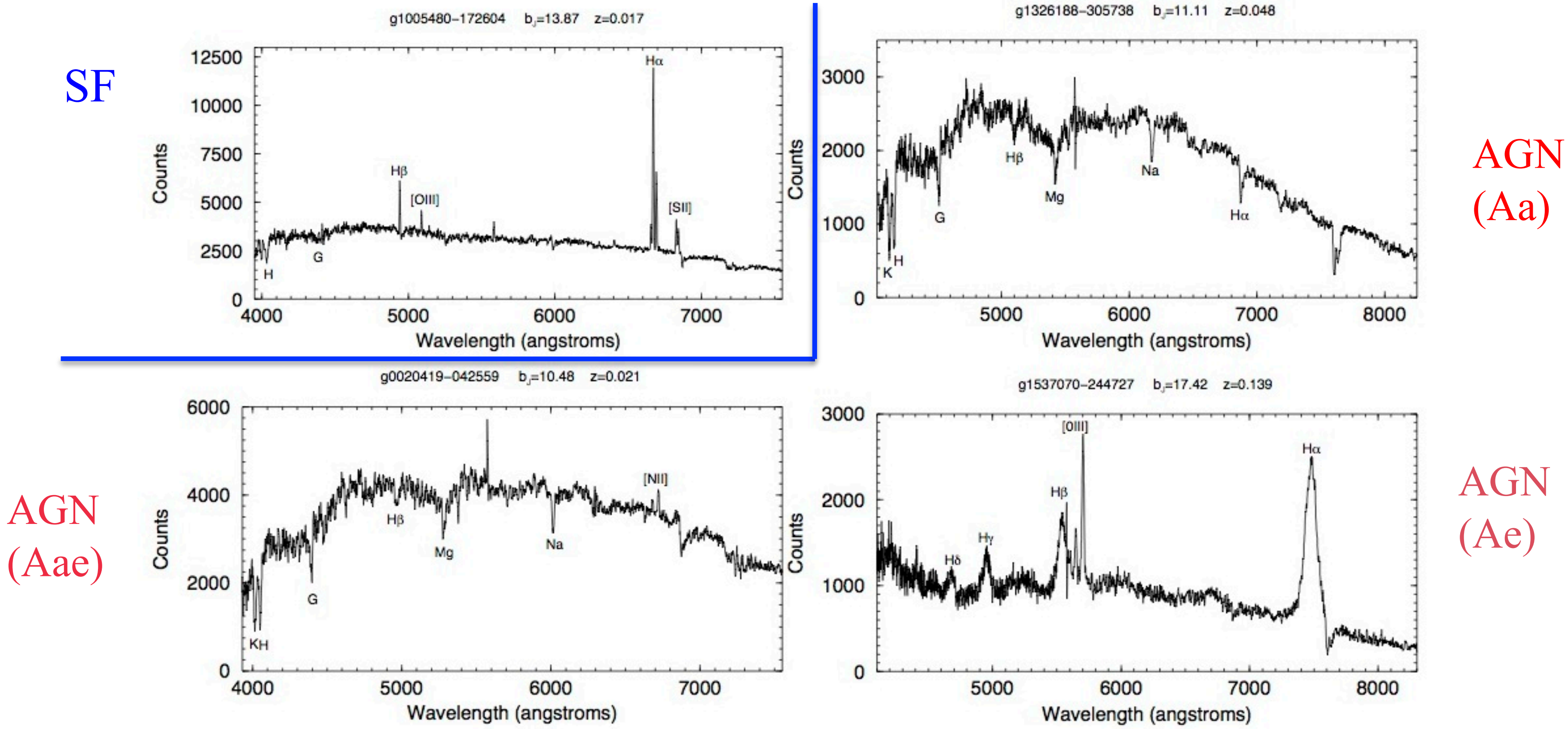
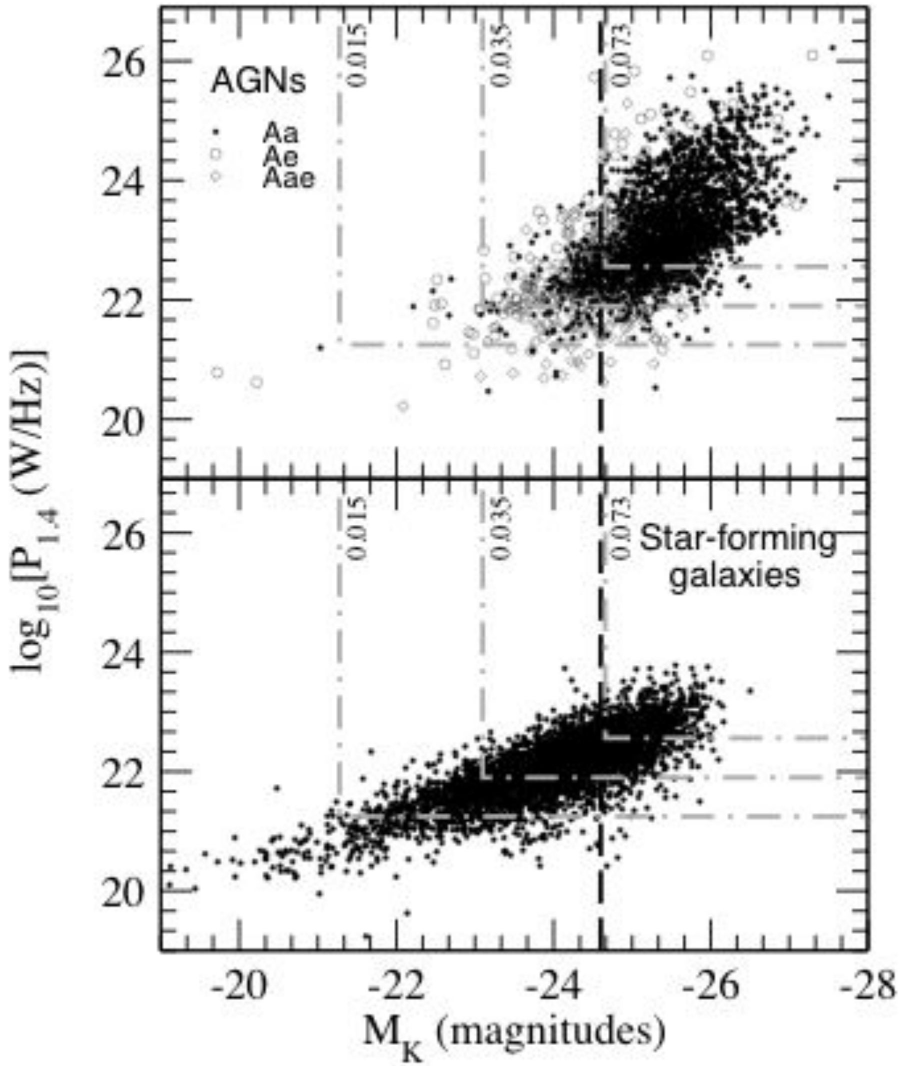


Figure 4. Example 6dFGS spectra of 4 spectral classes. In each spectrum common redshifted absorption/emission lines are labelled at the measured redshift. Top left: An 'SF' galaxy, with characteristic strong and narrow Balmer lines. Top right: An 'Aa' galaxy, containing broad Mg absorption as well as a distinct break close to the H & K lines. Bottom Left: An 'Aae' galaxy. This looks similar to an 'Aa' galaxy but has a weak [NII] line. Bottom right: An 'Ae' galaxy. This has broad Hα emission and strong [OIII] lines.

Important to separate AGN from star-forming galaxies – these are physically distinct radio populations

6dFGS radio-source populations



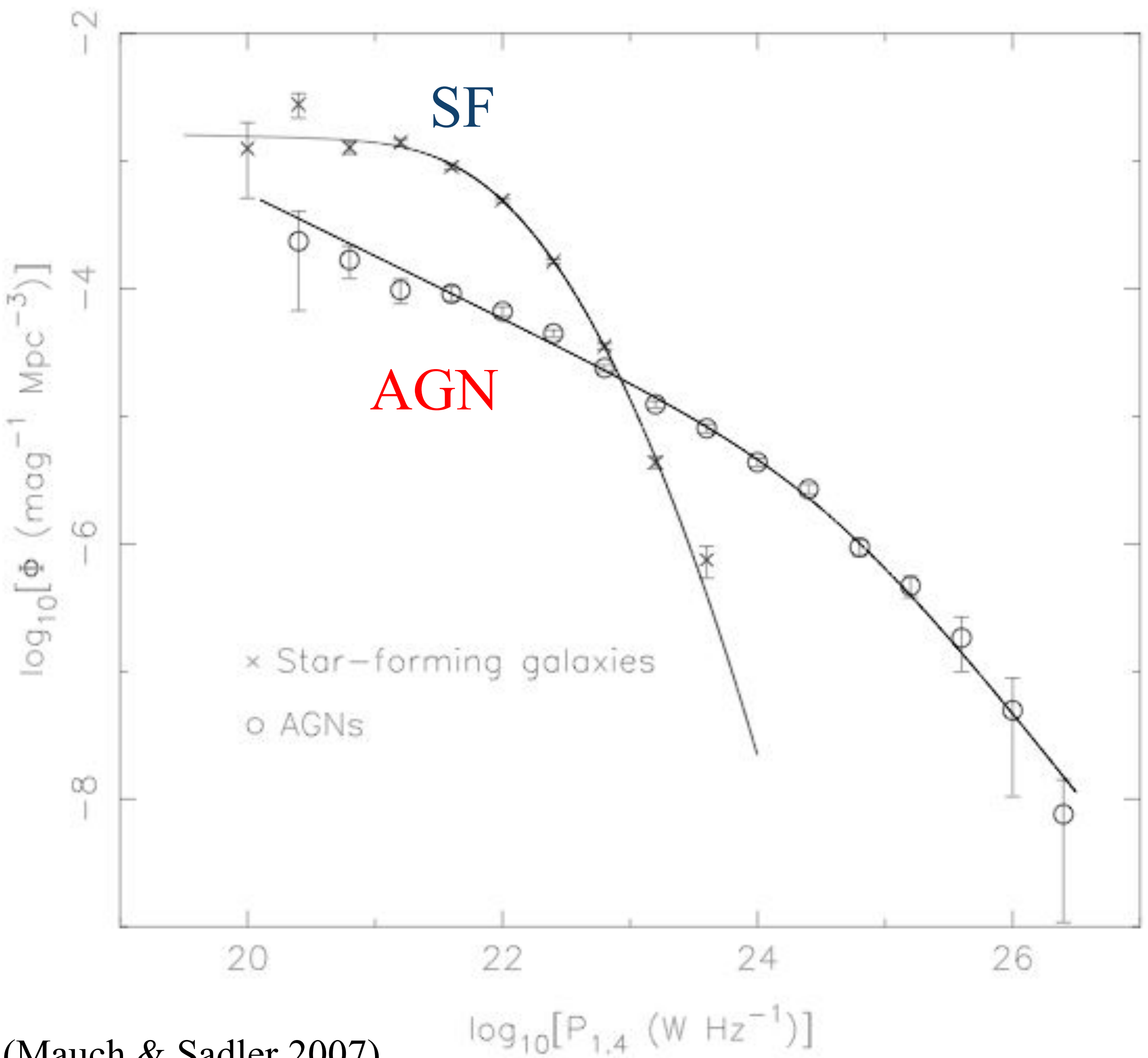
(Mauch & Sadler 2007)

Local radio continuum source populations 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.

6dFGS radio luminosity functions

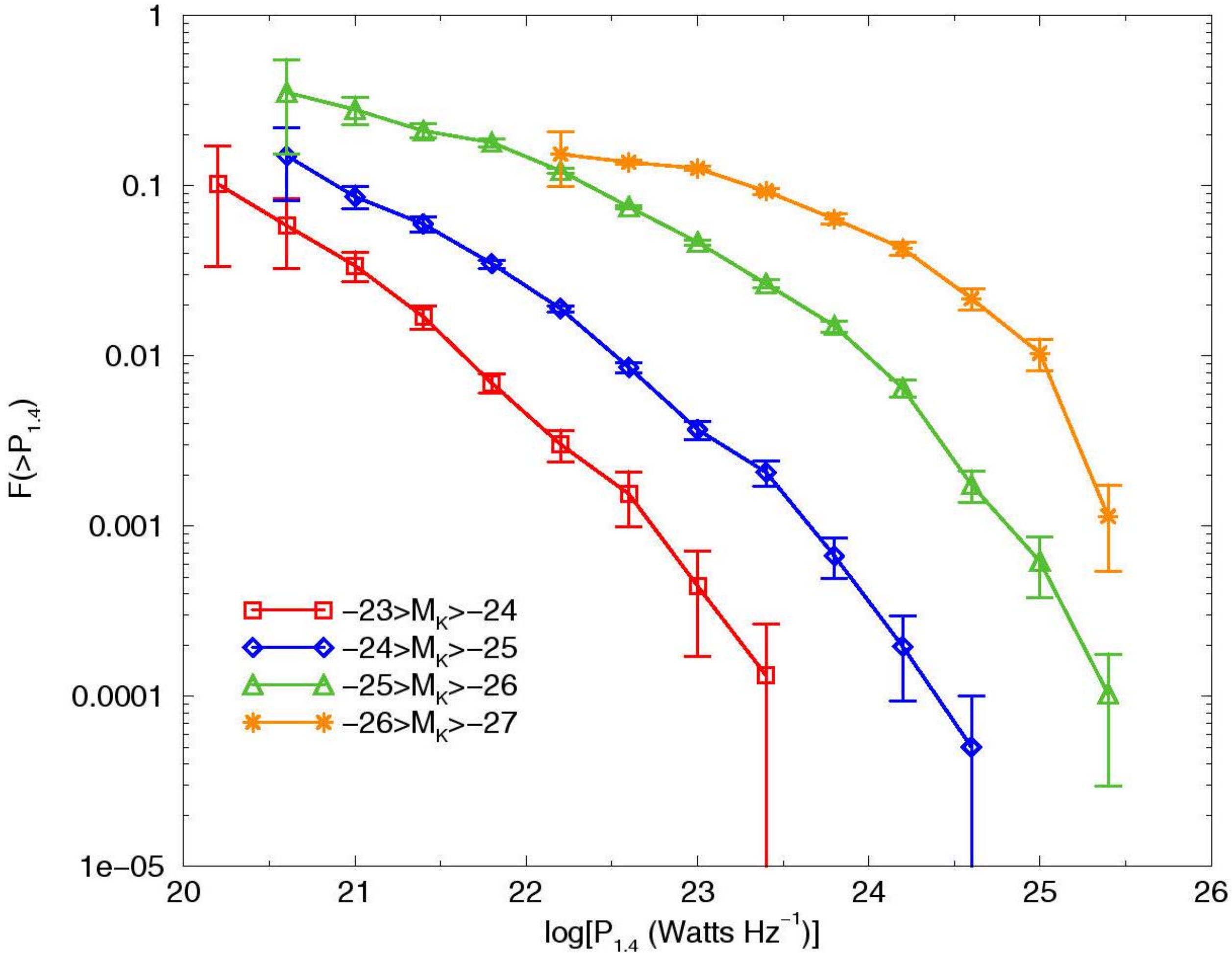


(Mauch & Sadler 2007)

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

6dF sample is large enough to split by galaxy absolute magnitude M_K

Radio LF for AGN, split by galaxy mass

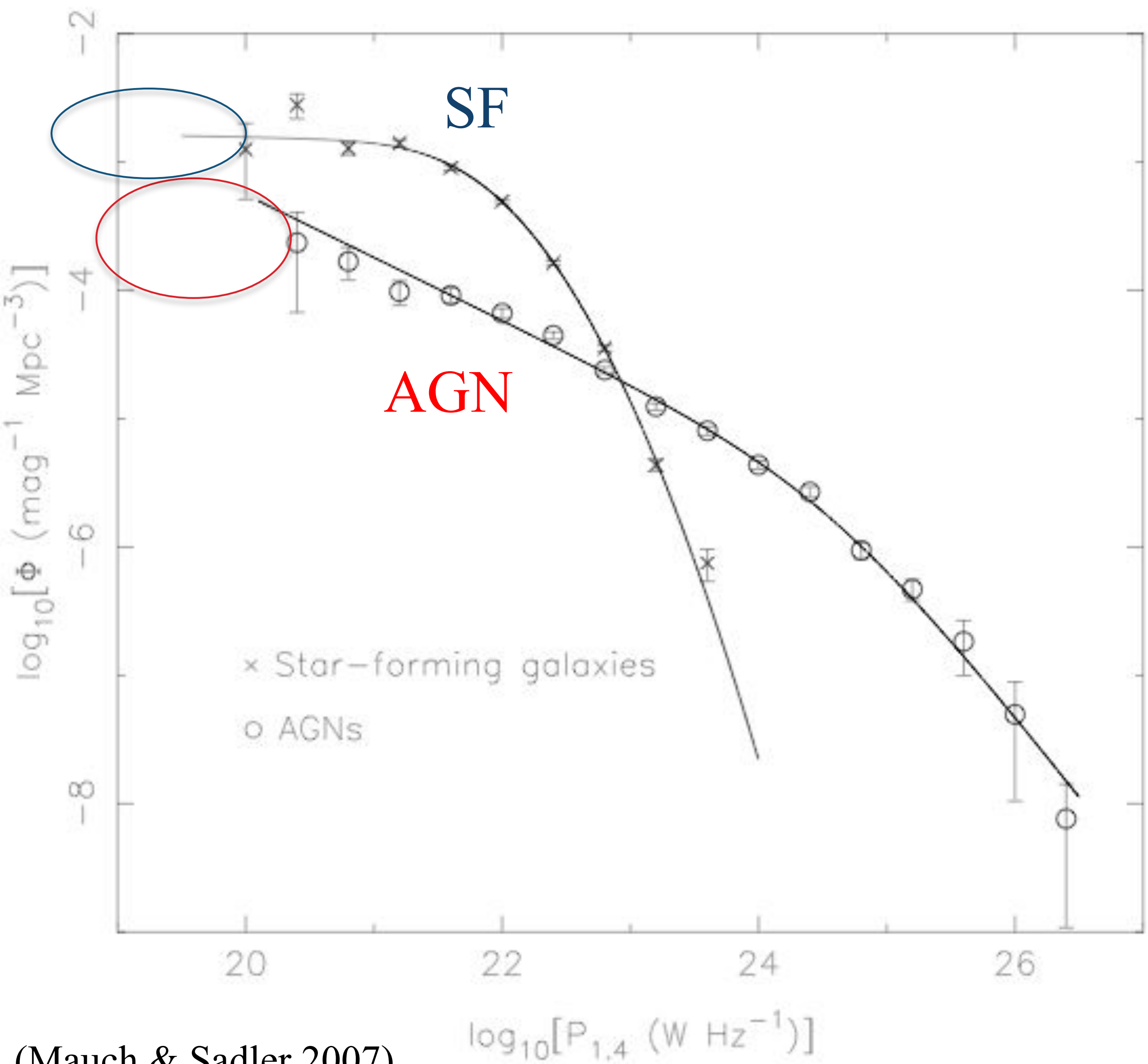


Fraction of galaxies hosting radio-loud AGN increases with galaxy stellar mass (Auriemma et al. 1977, Sadler et al. 1989, Best et al. 2005)

Black-hole duty cycle must be *high* in the most massive local galaxies

(Mauch & Sadler 2007)

6dFGS radio luminosity functions



(Mauch & Sadler 2007)

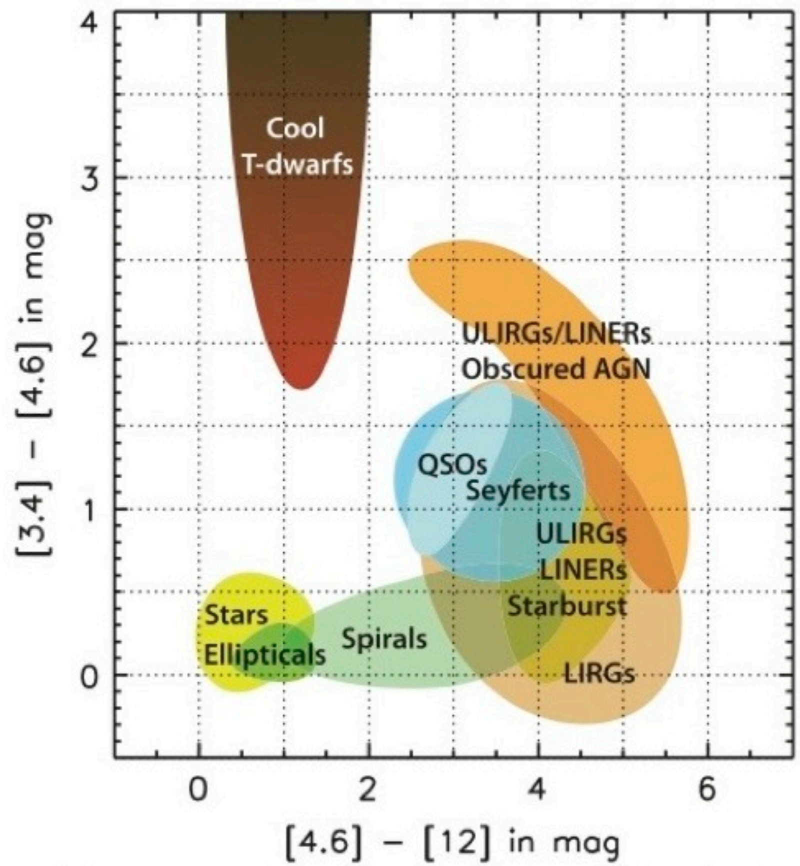
What will EMU (and Taipan) add to this?

- Should reach ~1.6 dex fainter in radio luminosity, better statistics at bright end.

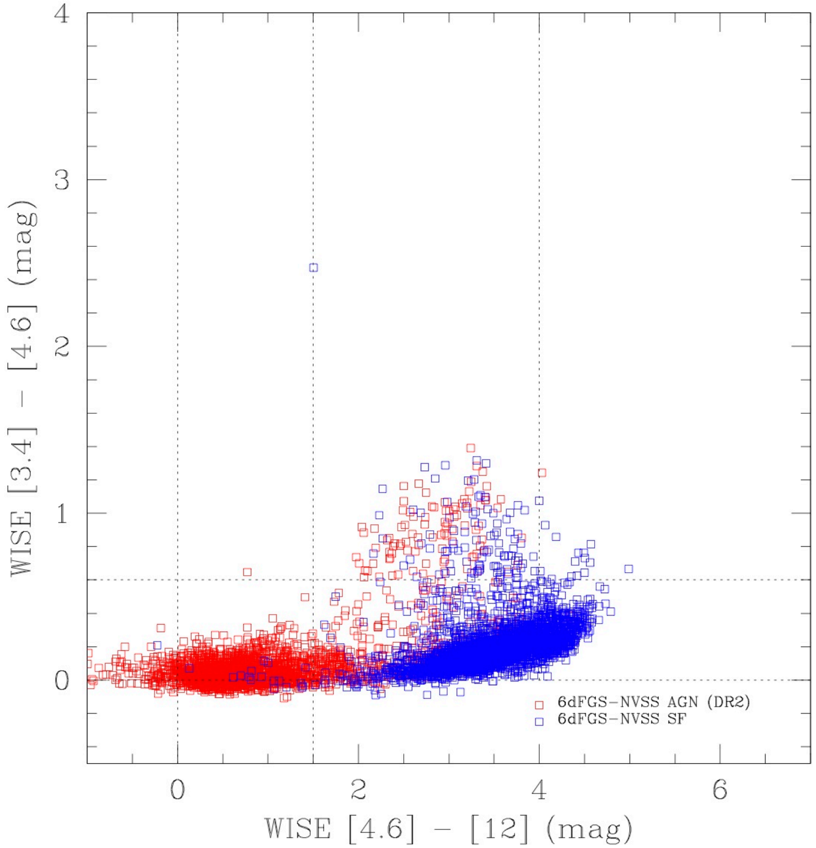
(useful to model this?)

EMU will also have some *surface brightness gains* – i.e. better image quality/resolved structure for sources we already know about (S > 1 mJy)

WISE data for 6dFGS radio sources



Wright et al. (2010): WISE mid-IR colour-colour plot showing location of normal and active galaxy populations



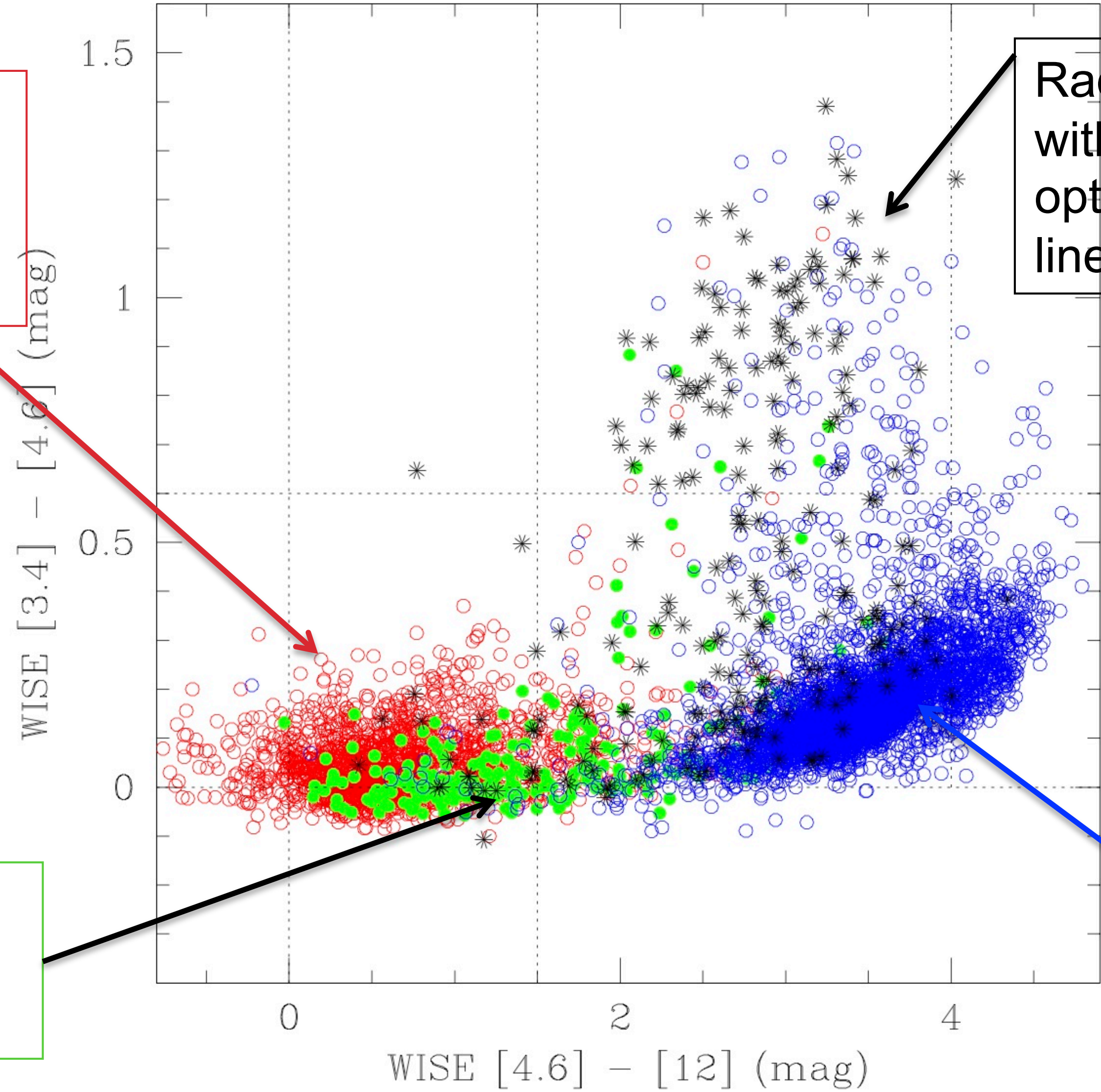
NVSS-6dFGS DR2 radio-detected galaxies from the Mauch & Sadler (2007) sample

WISE-6dFGS-NVSS radio–source populations

Absorption-line AGN (red radio galaxies) **28% of sample**

6433 galaxies in this plot (less than half the final DR3 sample)

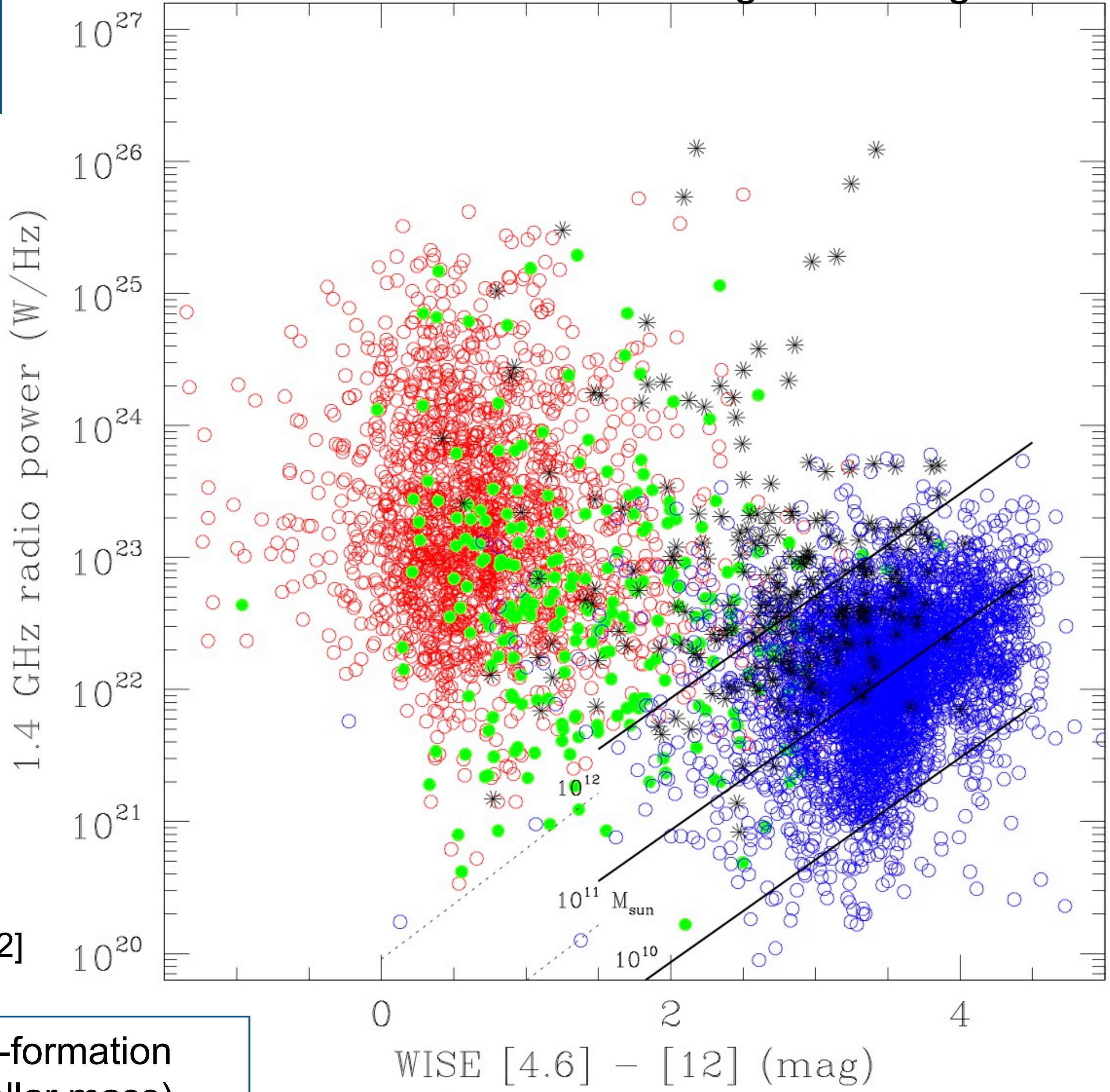
Radio galaxies with weak optical emission lines (4%)



Radio galaxies with strong optical emission lines (5%)

Star-forming normal galaxies **63% of sample**

1.4 GHz/WISE 'colour-magnitude diagram'



Generally good agreement between spectroscopic and WISE-based classifications, emission-line active galaxies bridge the gap between red radio galaxies and blue SF galaxies

[SFR/SSFR relations from Sullivan+2001, Donoso+2012]

Proxy for specific star-formation rate (SSFR = SFR/stellar mass)

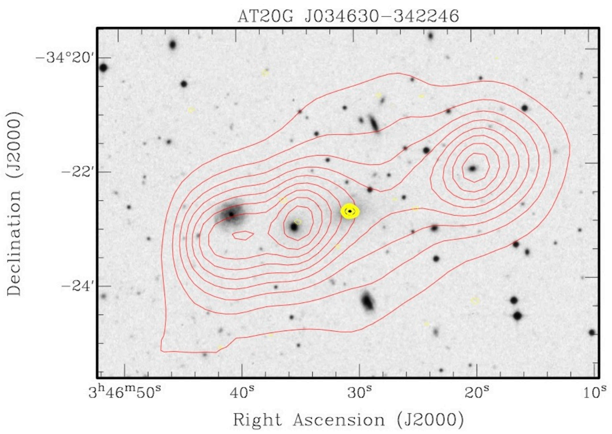
A local radio-galaxy sample selected at 20 GHz

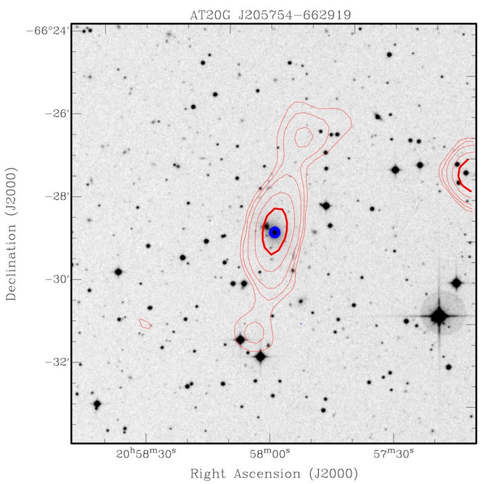
(Work in progress)

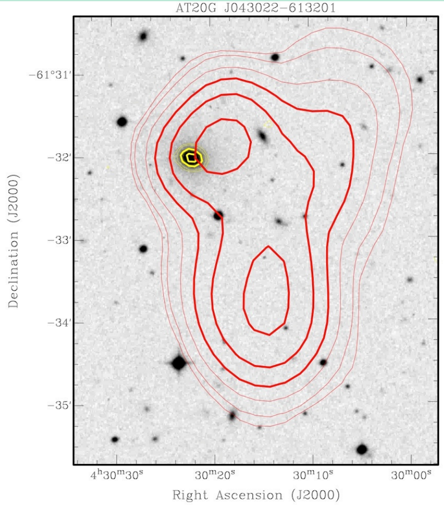
Previous studies were all at frequencies of 1.4 GHz or below – they see a mixture of AGN and star-forming galaxies at low redshift, and detect both core and jet/lobe emission from AGN

By observing a 20 GHz-selected sample:

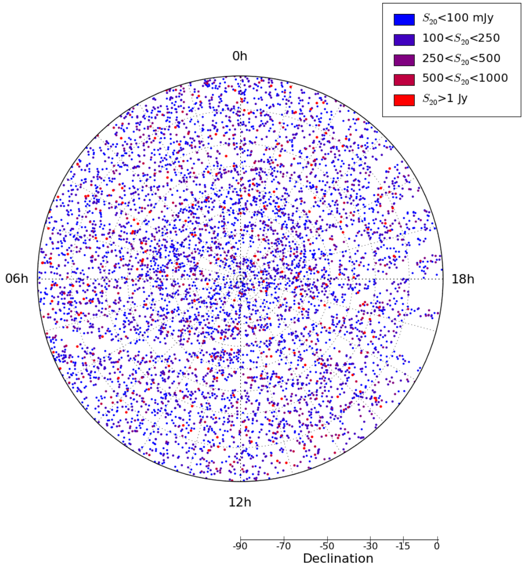
- Work at a frequency where AGN emission dominates
- Preferentially detect the youngest and most powerful local radio galaxies
- Valuable local benchmark for high-redshift radio surveys: e.g. at z ~3, observed frequencies of 1.4 and 5 GHz correspond to rest-frame 6 and 20 GHz





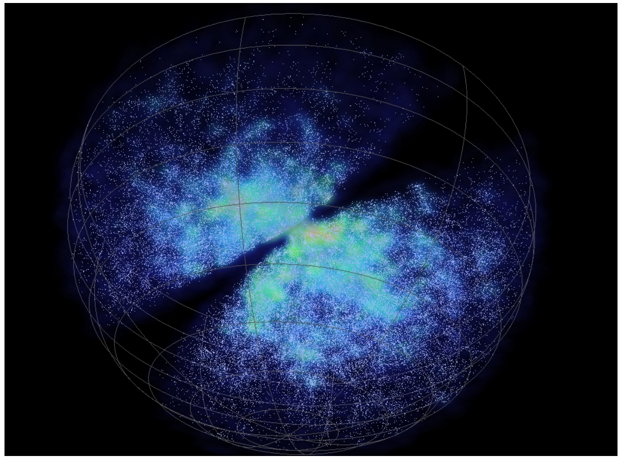


AT20G-6dFGS sample selection



Radio: 20 GHz flux density above 40 mJy from AT20G catalogue (Murphy et al. 2010)

Optical/IR: In 6dFGS main galaxy sample (Jones et al. 2009), K < 12.75 mag.

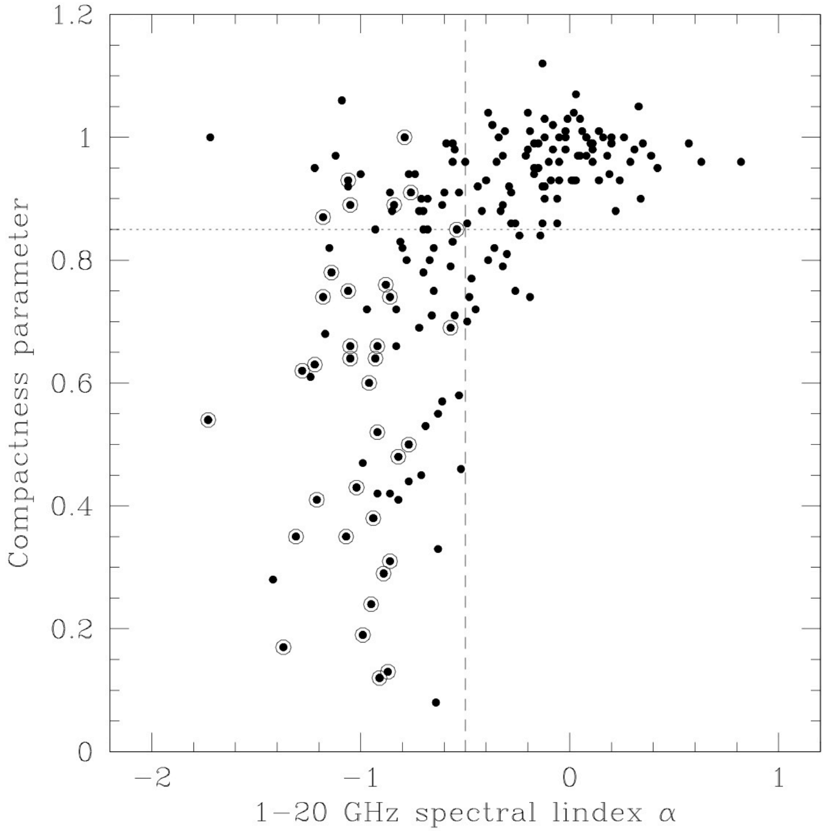


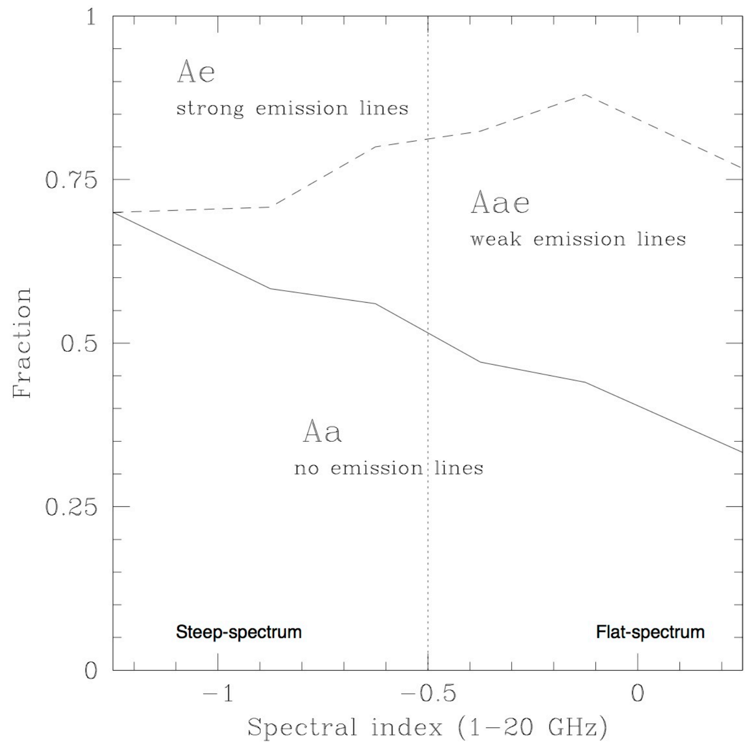
Final 'AT20G_Local' sample:

- 202 galaxies (201 AGN)
- Median redshift z = 0.058
- 50% have 'flat' radio spectra at 1-20 GHz

First results for the 6dFGS - 20 GHz radio sample

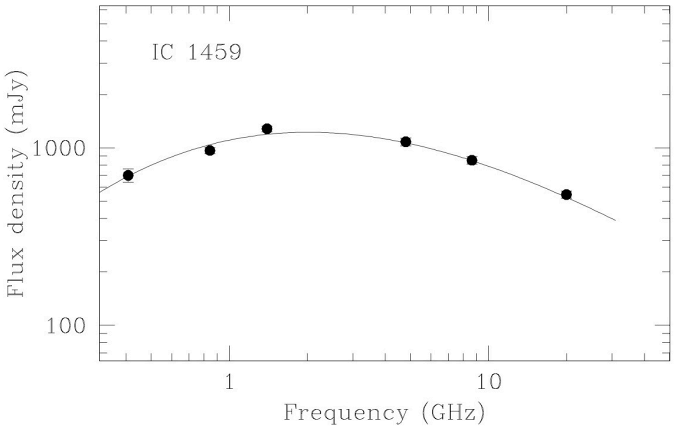
Source size





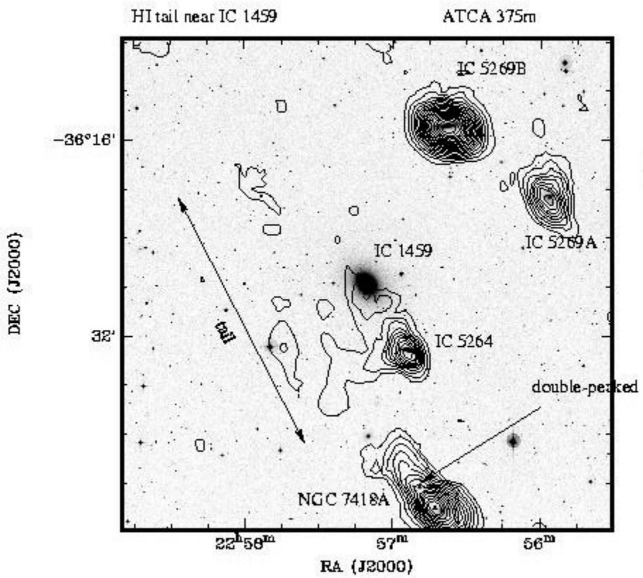
See a high fraction of very compact ('FR-0') sources (mainly with radio size < 1 kpc, 'flat' radio spectra and weak optical emission lines) – they make up ~45% of the local AGN population at 20 GHz. *Are these all 'young' (or recently restarted) radio galaxies?*

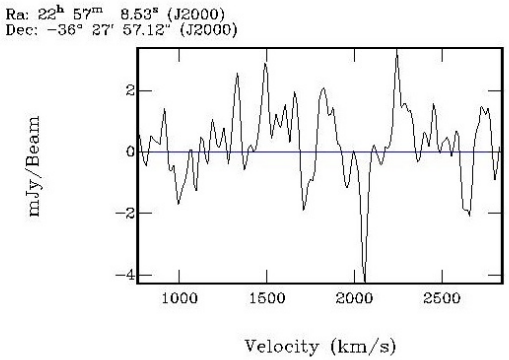
IC1459: a prototype FR-0 radio galaxy?



IC 1459 (IC 5265). This galaxy presents an unresolved nuclear source on top of a diffuse halo at high energies (Fig. 5), in agreement with the classification by Satyapal et al. (2004). It hosts a Super-massive black hole ($2 \times 10^9\ M_\odot$, Cappellari et al. 2002) but with rather moderate nuclear activity. Fabbiano et al. (2003) find that it shows a rather weak ($L(2\text{–}10\ \text{keV}) = 8.0 \times 10^{40}$ erg s^{-1}) unabsorbed nuclear X-ray source with $\Gamma = 1.88$ and a faint FeKα line at 6.4 keV. These characteristics describe a normal AGN radiating at sub-Eddington luminosities, at 3×10^{-7} below the Eddington limit. They suggest that ADAF solutions can explain the X-ray spectrum, but these models failed to explain the high radio power of its compact source (Drinkwater et al. 1997). Our fitting parameters are in a remarkably good agreement with theirs ($\Gamma = 1.89$, $kT = 0.30$ keV and $L(2\text{–}10\ \text{keV}) = 3.6 \times 10^{40}$ erg s^{-1}).

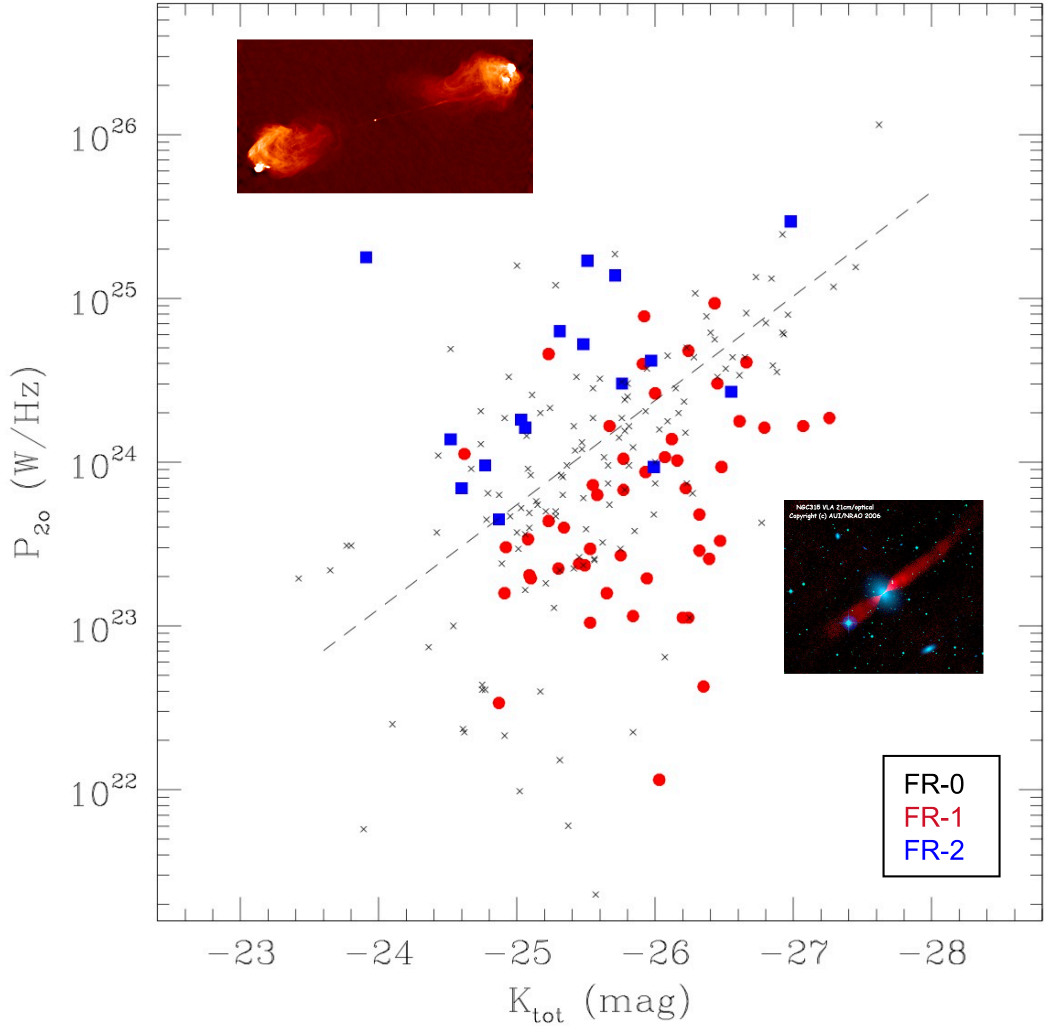
(Gonzalez-Martin et al. 2006)





Compact (GPS) radio galaxy, LINER/LERG spectrum, but in a gas-rich group with evidence for recent HI accretion.
How does this fit into the 'dual population' picture?

Global properties – radio power vs stellar mass



- 20 GHz-detected galaxies classified as FR-0 (compact), FR-1 or FR-2 from literature or NVSS/SUMSS images

- At 20 GHz, FR-1 and FR-2 galaxies are roughly split by the same 'Ledlow-Owen' line seen at 1.4 GHz (Ledlow & Owen 1996)

- Compact (FR-0) sources are seen over the full range of optical and radio luminosity spanned by the FR-1/2 radio galaxies. *So, why no extended emission? Duty cycle is short? Surface brightness below detection limit?*

WISE colour-colour diagram at 20 GHz

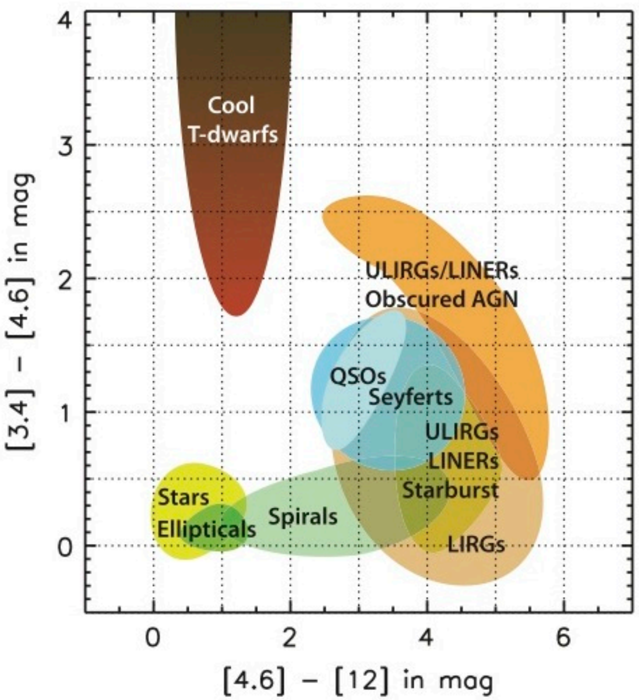
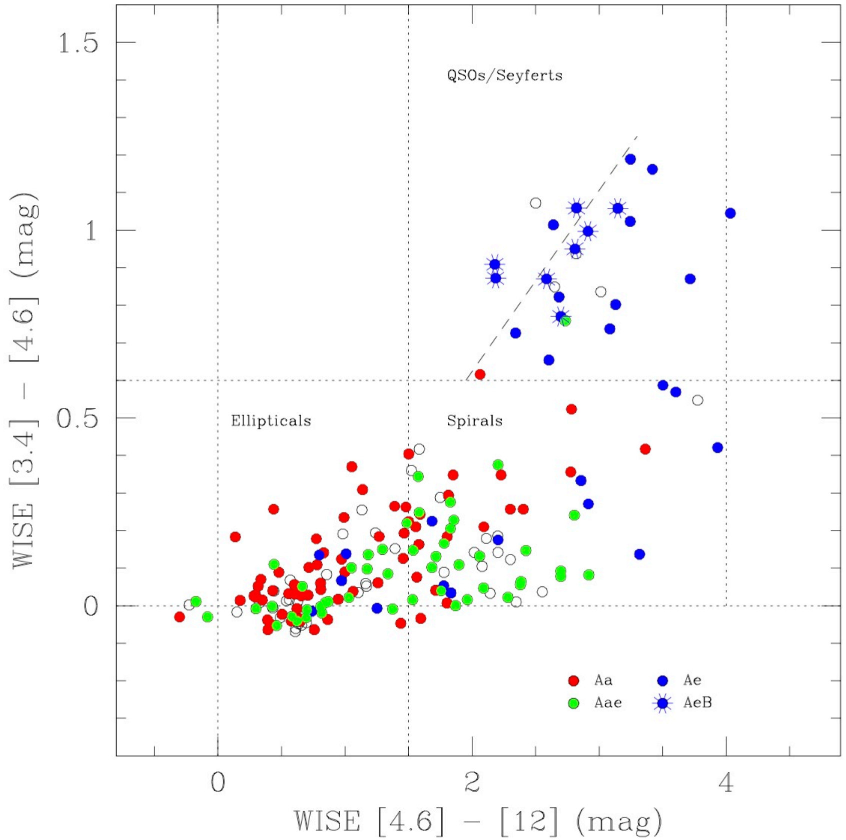


Figure 12. Color–color diagram showing the locations of interesting classes of objects. Stars and early-type galaxies have colors near zero, while brown dwarfs are very red in *W*1–*W*2, spiral galaxies are red in *W*2–*W*3, and ULIRGS tend to be red in both colors.



Wright et al. (2010)

WISE plot for the AT20G- 6dFGS radio galaxies – 30% are in the 'spiral' area

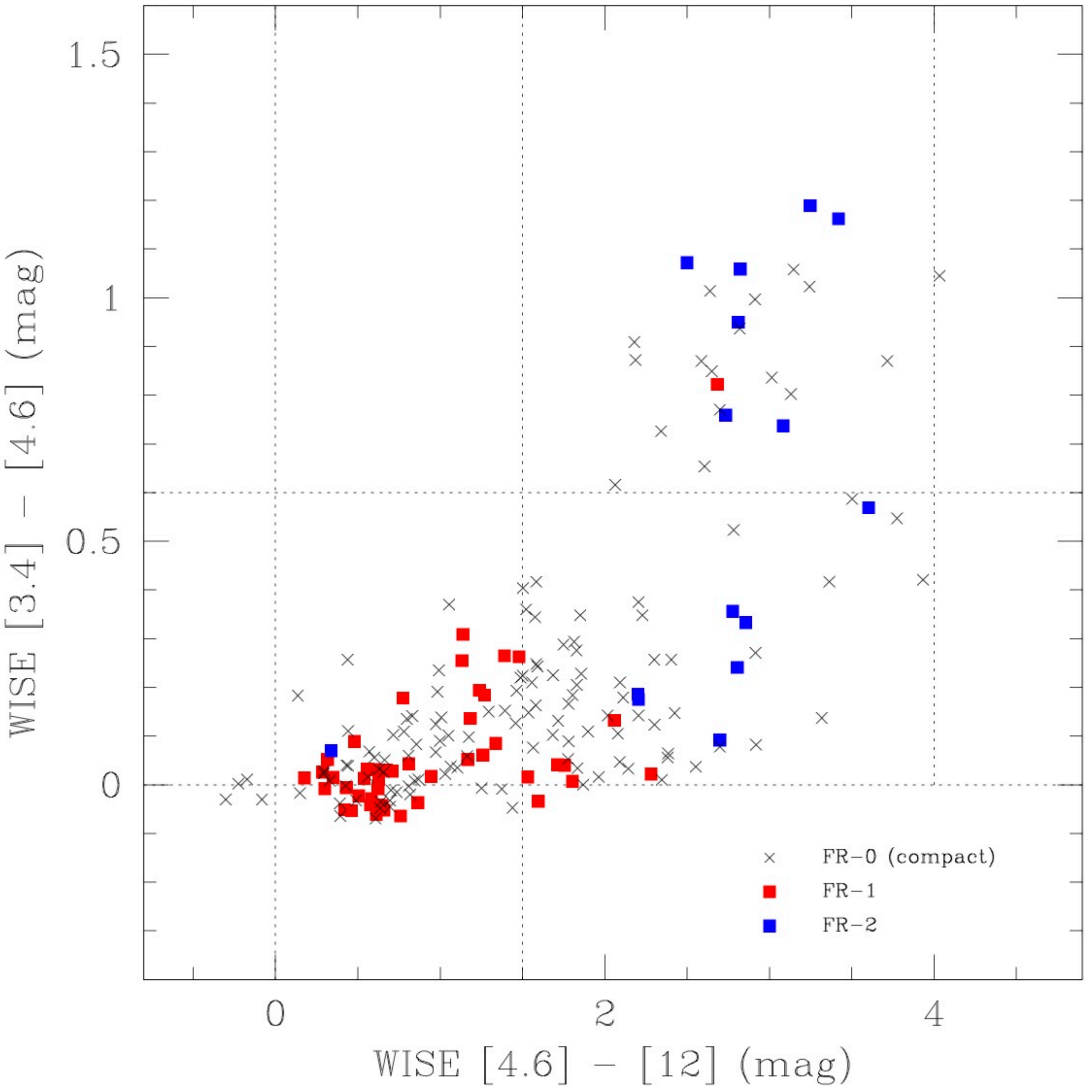
Global properties – radio structure vs WISE colours

Dramatic difference in the WISE [4.6]-[12] colours of FR-1 and FR-2 radio galaxies!

FR-1s almost all in WISE 'elliptical' galaxies, FR-2s in WISE 'spirals'

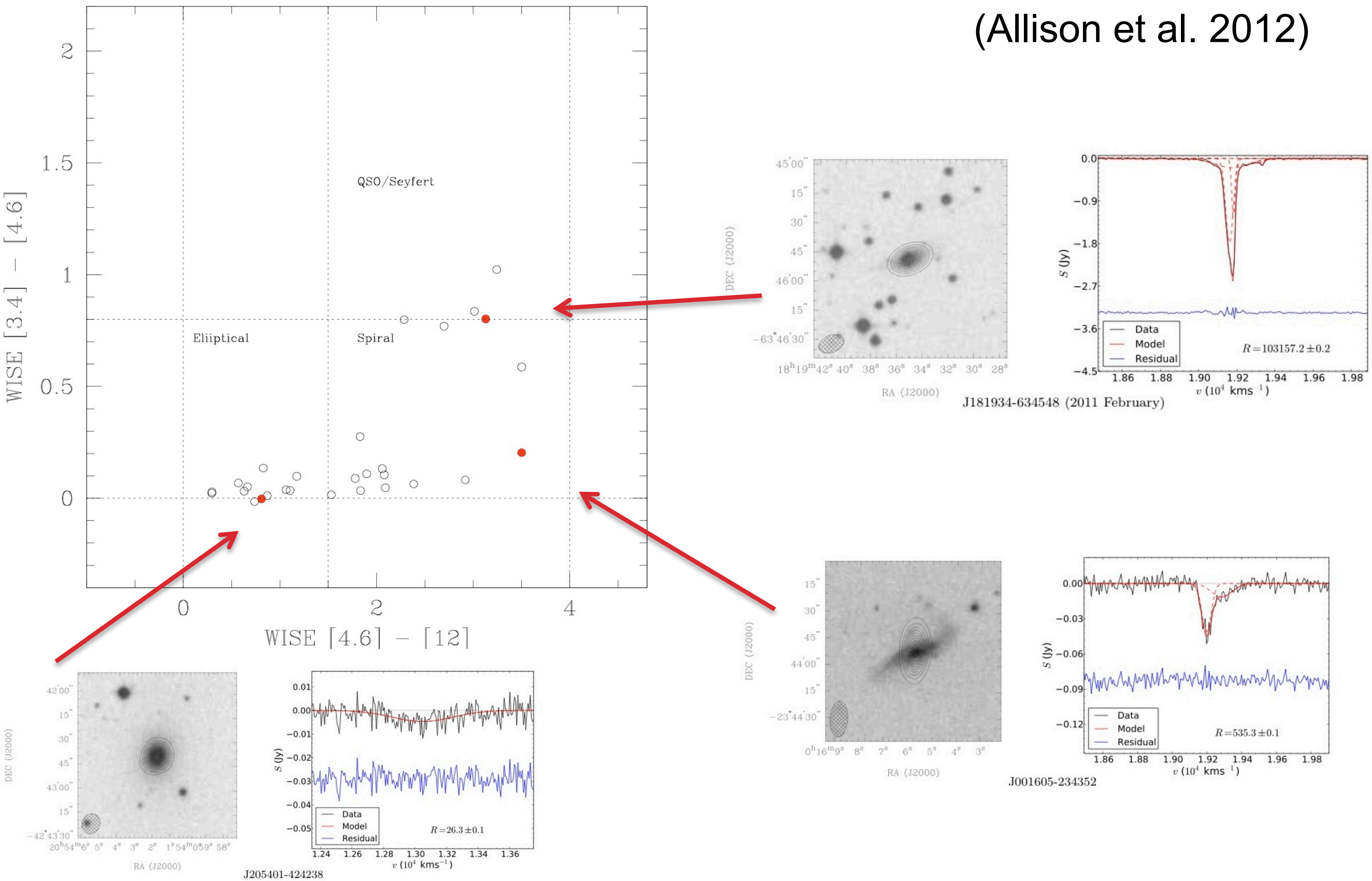
Compact (FR-0) radio galaxies found across the whole colour range.

(Physical) environment/ gas supply is important!



HI absorption-line studies

(Allison et al. 2012)



Some thoughts for Taipan

- 6dFGS target selection process was good – especially the K-band selection and public call for ‘additional target’ proposals

- Excellent science is still coming from 6dFGS data, but the science team was small (too small?) compared to many other surveys – do we have enough people/resources for Taipan science?

JB-H yesterday: “It’s all about the gas supply” – I agree!!
Key Taipan science is HI-related – we can’t understand galaxy evolution without understanding what happens to the neutral gas