The high-frequency view of compact radio galaxies

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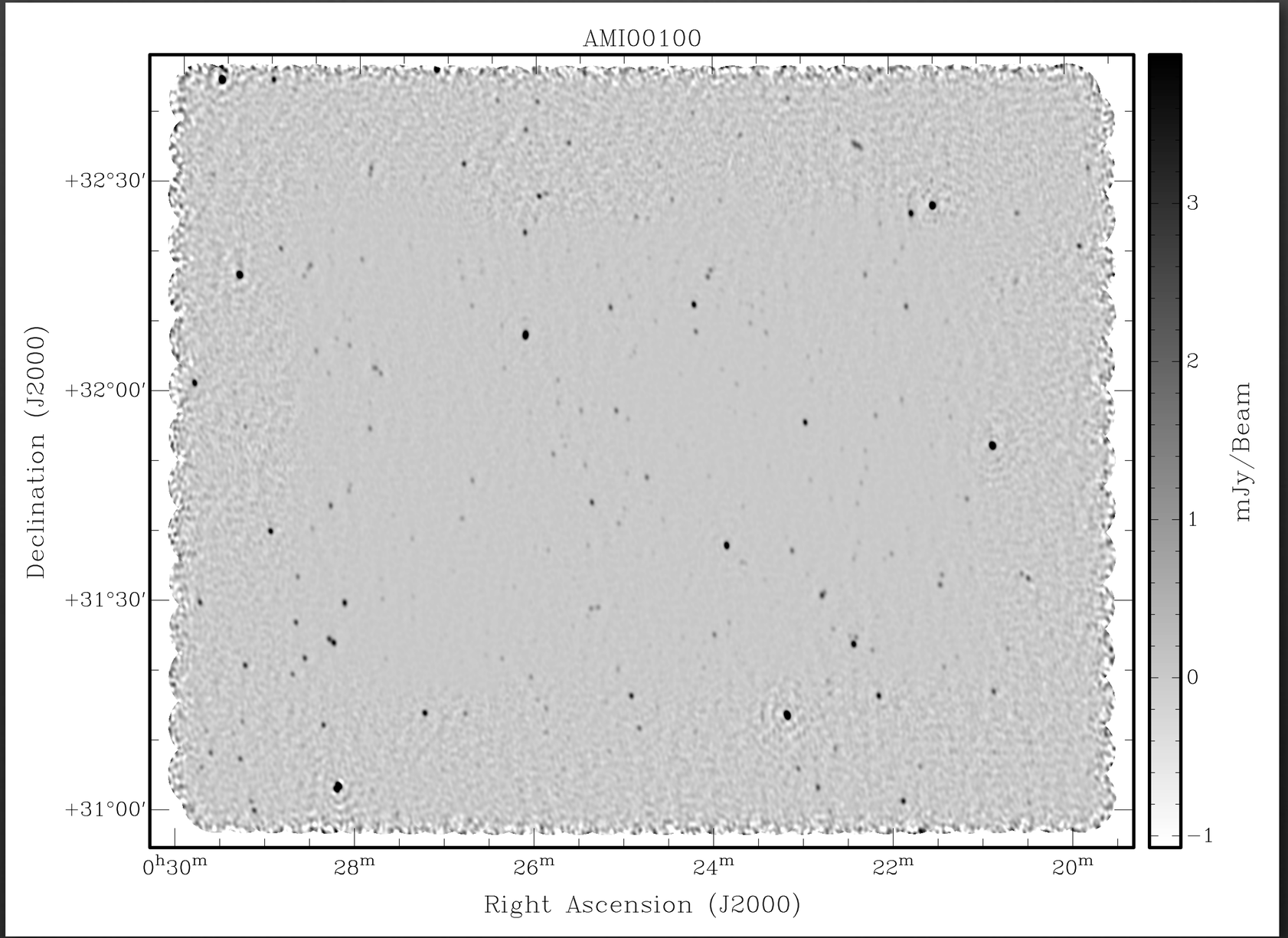
The Tenth Cambridge (10C) Survey

- ★ Observed with Arcminute Microkelvin Imager (AMI) Large Array in Cambridge, UK.
  - ★ Eight 12.8 m dishes
  - ★ Resolution of 30 arcsec
  - ★ 13.2 – 18.9 GHz
- ★ Ten fields observed at 15.7 GHz.
- ★ 27 deg^2 complete to 1 mJy, a further 12 deg^2 complete to 0.5 mJy.
- ★ Extended to 0.1 mJy – see Whittam et al. (2016a).
- ★ Deepest high frequency radio survey to cover a significant area.

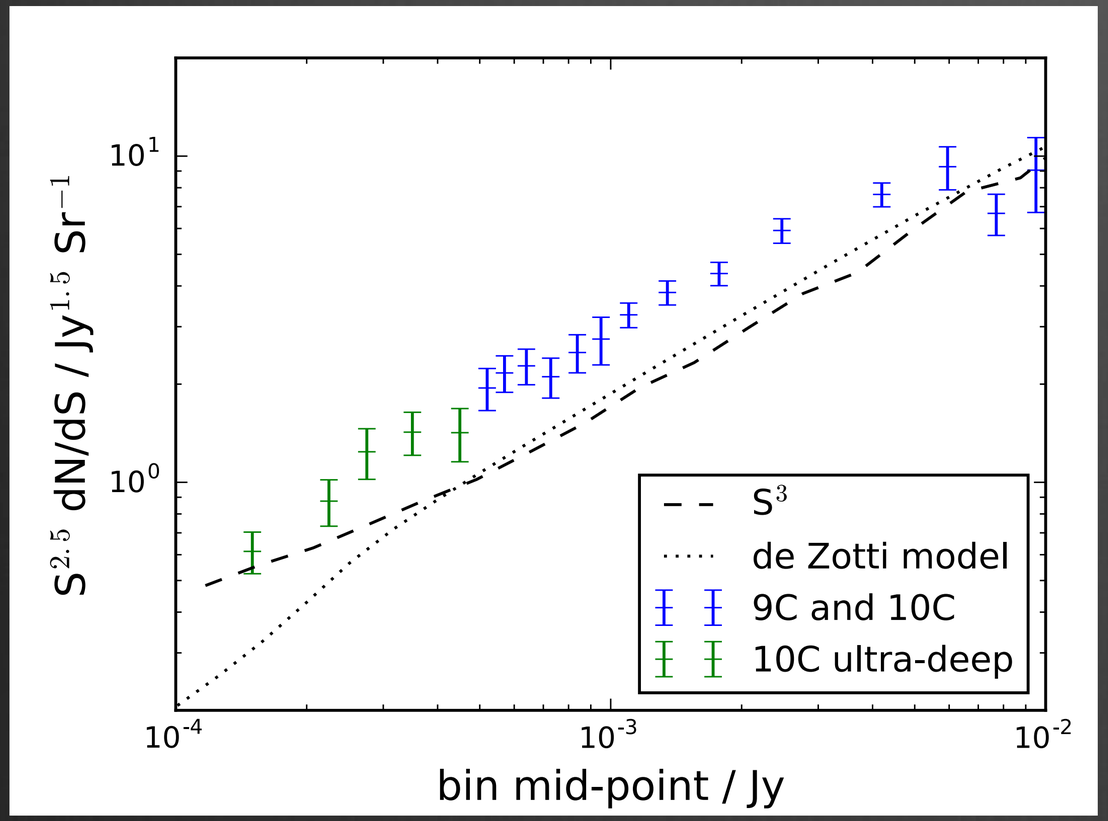
Davies et al. (2011)
Franzen et al. (2011)
Whittam et al. (2016a)

The Tenth Cambridge (10C) Survey - 15.7 GHz



Davies et al. (2011)
Franzen et al. (2011)
Whittam et al. (2016a)

10C source counts



Whittam et al. (2016a)

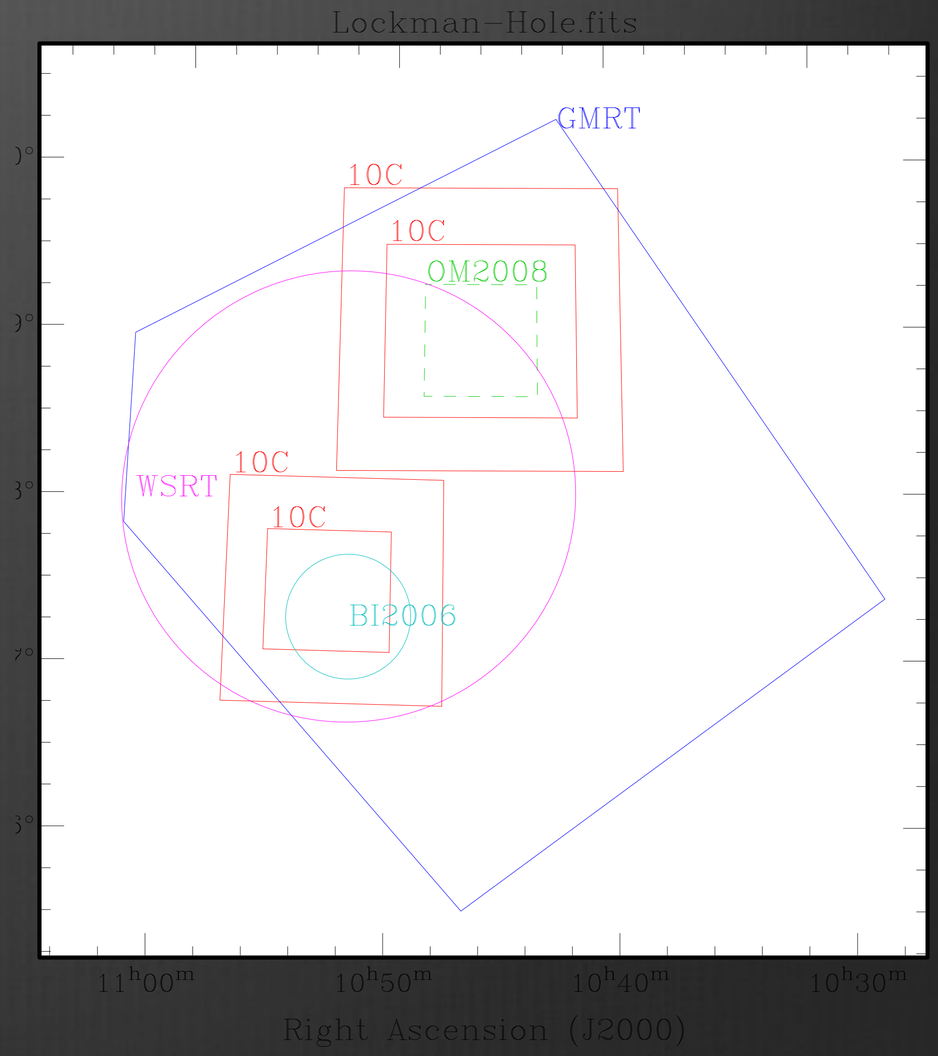
★ Models under-predict the number of sources by a factor of 2 below 10 mJy.

10C Lockman Hole sample

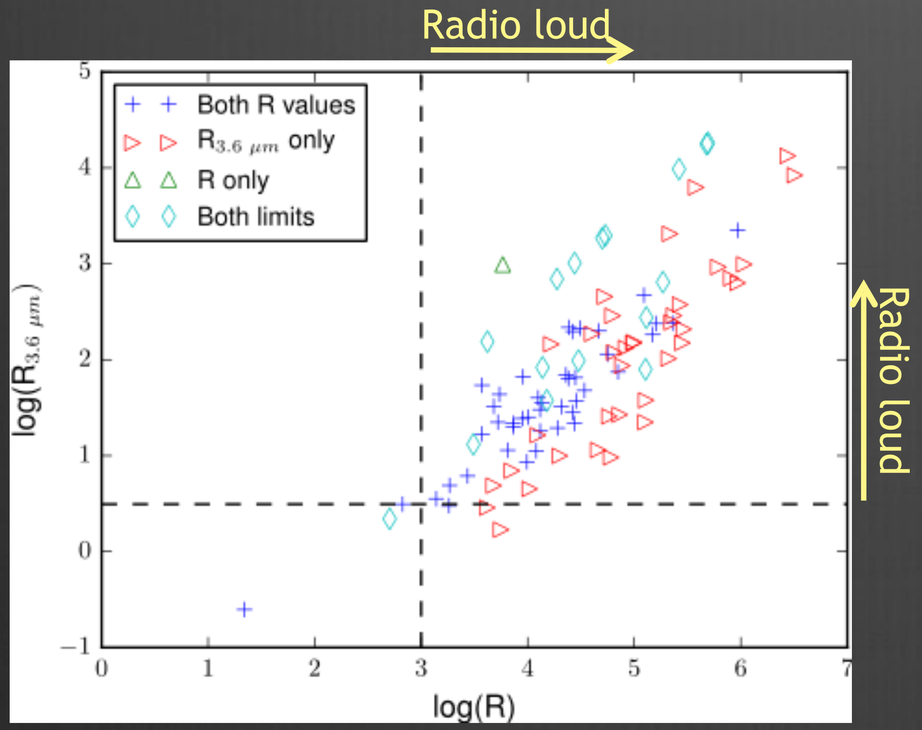
★ Complete sample of 96 sources selected at 15.7 GHz.

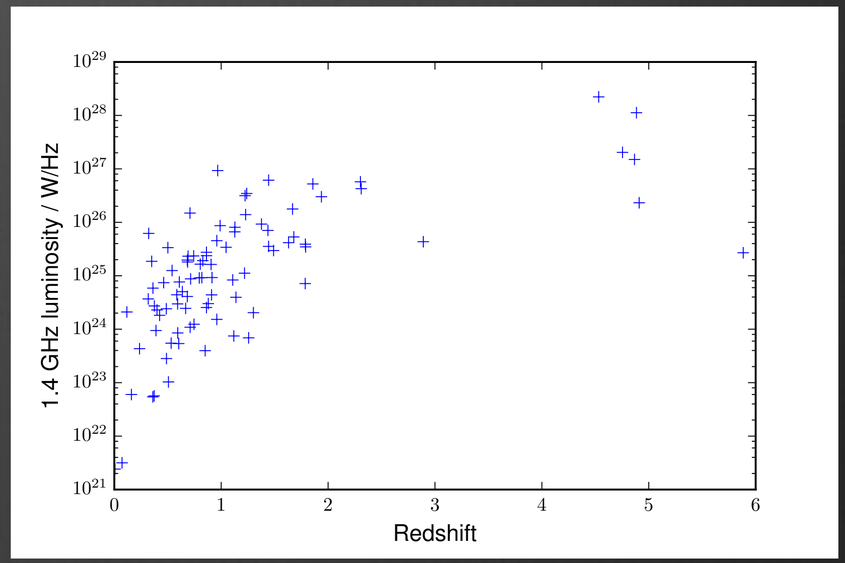
★ 80/96 have multi-wavelength counterpart.

Band	Survey/ telescope	Reference	Wavelength
Mid-infrared	SWIRE	Lonsdale et al. (2003)	3.6, 4.5, 5.8, 8.0 μm
Mid-infrared	SERVS	Mauduit et al. (2012)	3.6, 4.5 μm
Near-infrared	UKIDSS	Lawrence et al. (2007)	J, K
Optical	INT and KPNO	González-Solares et al. (2011)	g, r, i, z
X-ray	Chandra	Wilkes et al. (2009)	0.1 – 10 KeV
X-ray	XMM-Newton	Brunner et al. (2008)	0.5 – 10 KeV



Properties of 10C sources





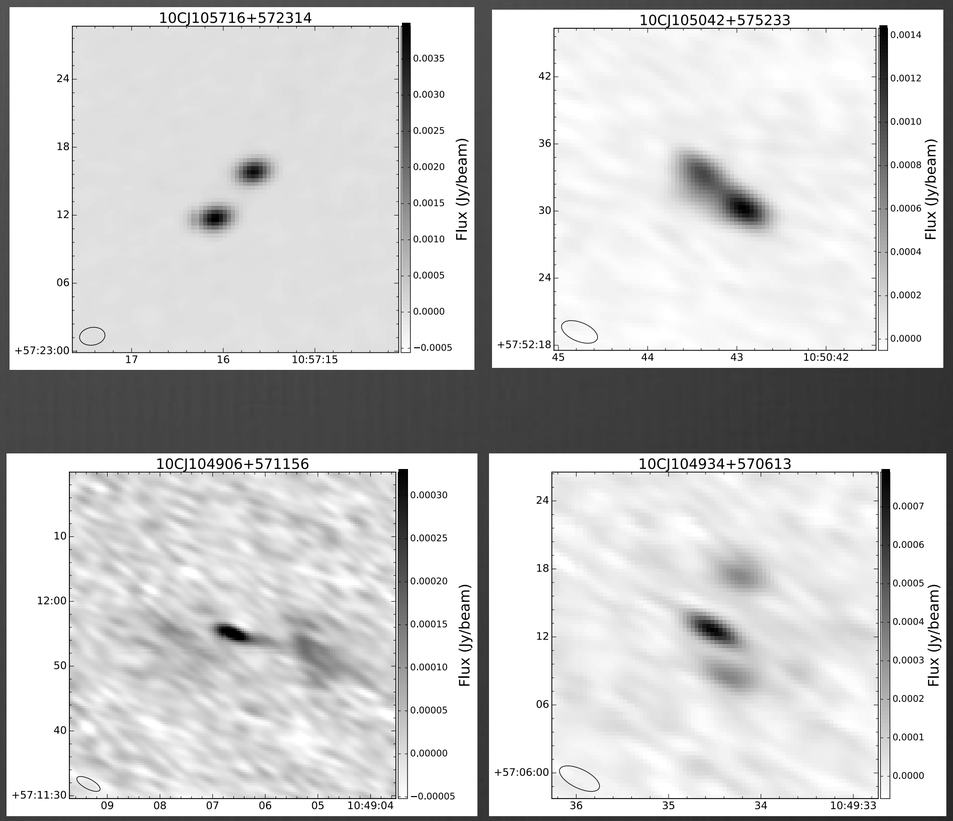
Median z ~ 1

★ (almost) all radio galaxies

Whittam et al. (2015)

Follow-up VLA observations

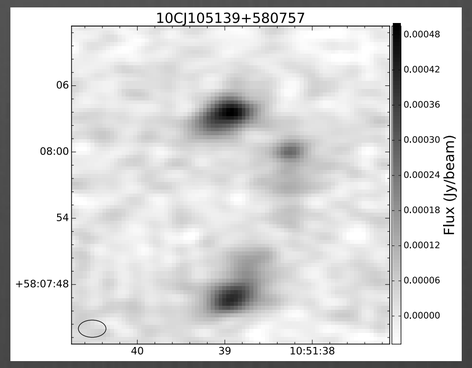
- ★ Snapshot observations of 96 sources.
- ★ C configuration
- ★ Ku band (15 GHz).
- ★ Resolution ~2 arcsec
- ★ rms ~25 uJy/beam.

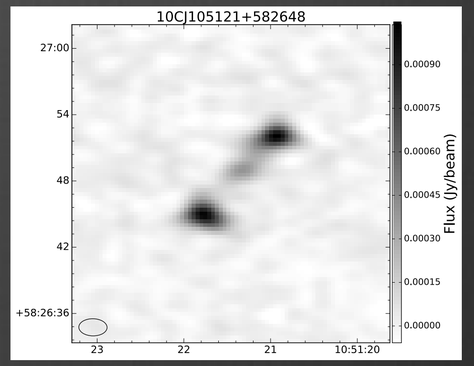


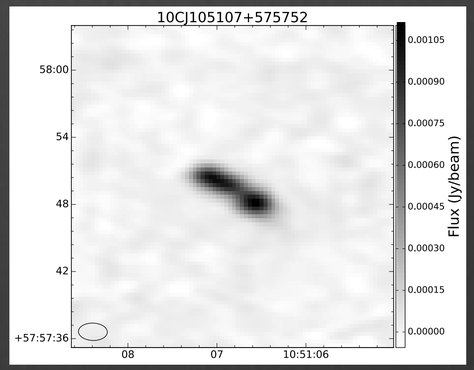
Whittam et al. (2020)

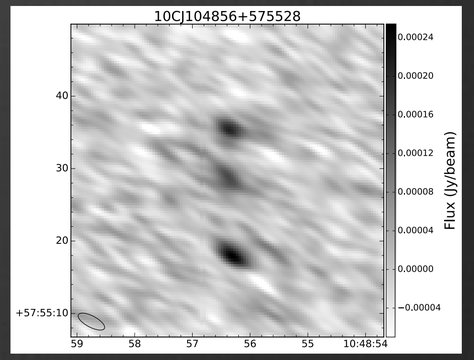
Radio morphology

- ★ 73 out of 95 sources are unresolved.
- ★ 6 of these unresolved sources have extended emission at lower frequencies.
- ★ 10C survey is dominated by compact radio galaxies (67/95).







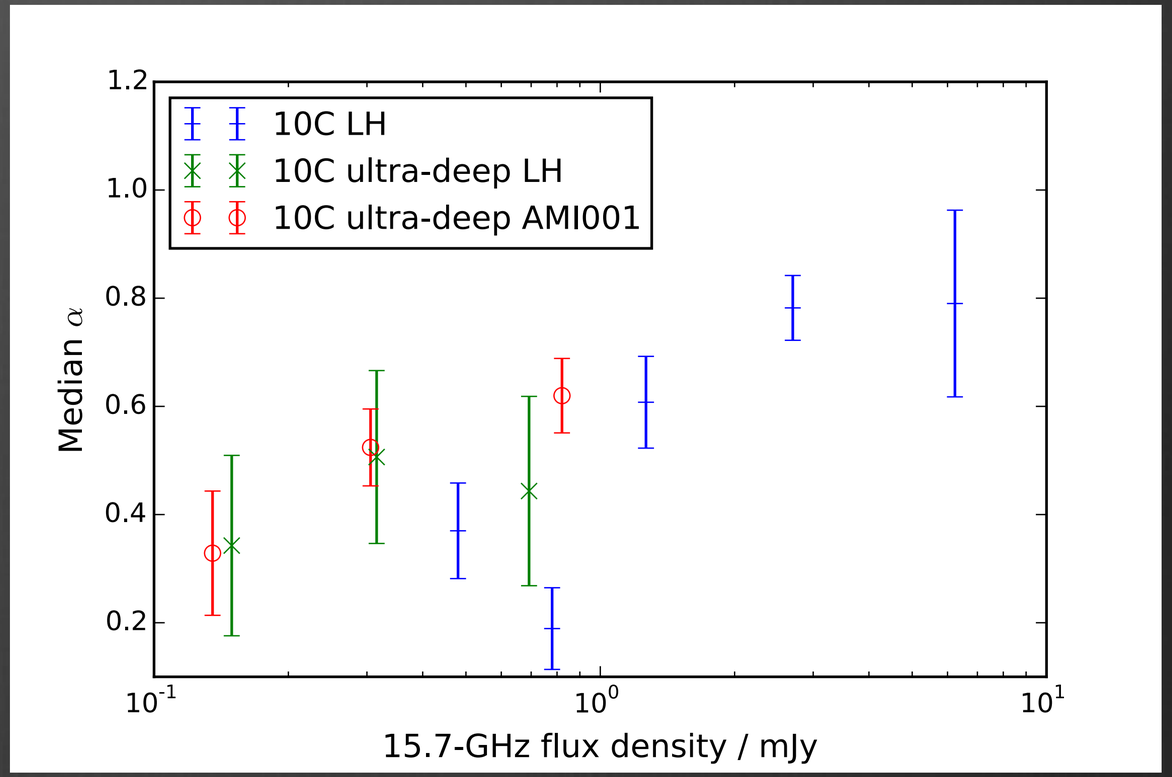


Whittam et al. (2020)

Radio spectral indices

★ Flatter than expected below ~1 mJy.

$$S \propto \nu^{-\alpha}$$



Whittam et al. (2017a)

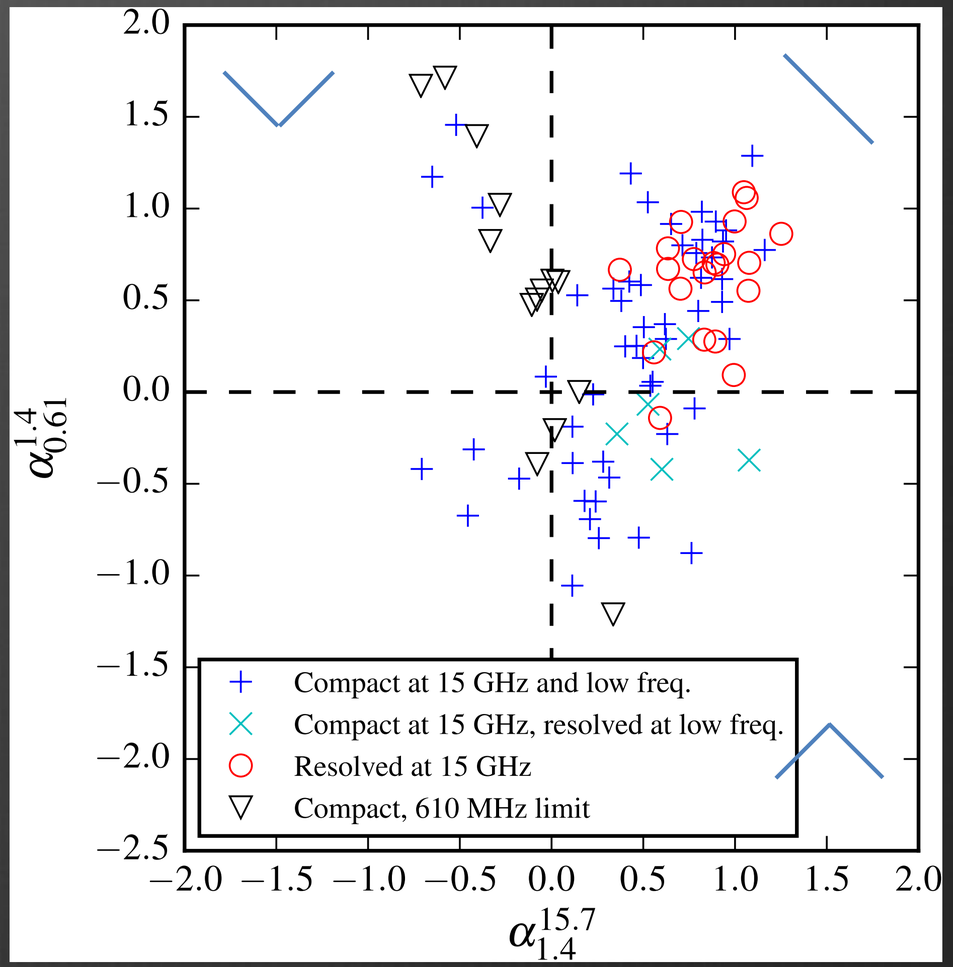
Radio spectral shape

$S \propto \nu^{-\alpha}$

★Compact 10C sources are composite population.

★13 are candidate GPS or CSS sources.

★Similar results found by Salder et al. (2014) using AT20G-6dFGS at low z.



Whittam et al. (2020)

HERGs and LERGs

★ 28 sources have optical spectra - classify using these.

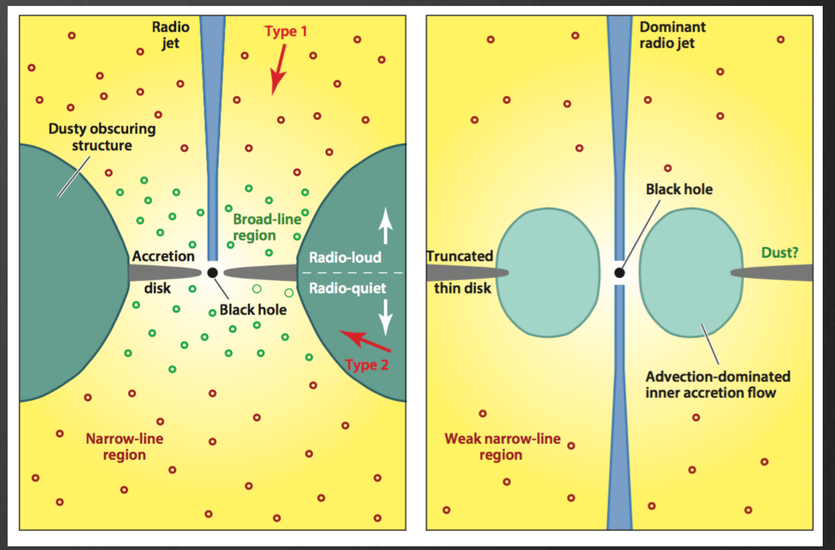
★ For the remaining sources, three methods used:

1) Optical compactness
2) X-ray data
3) Mid-IR colour-colour diagram (Lacy et al. 2004)

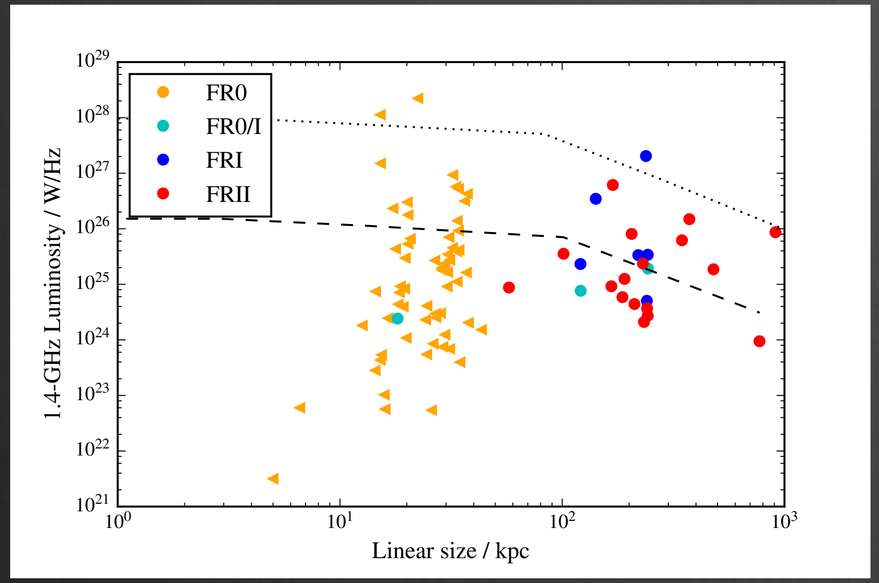
HERGs = 32
LERGs = 43
Not classified = 20

HERG

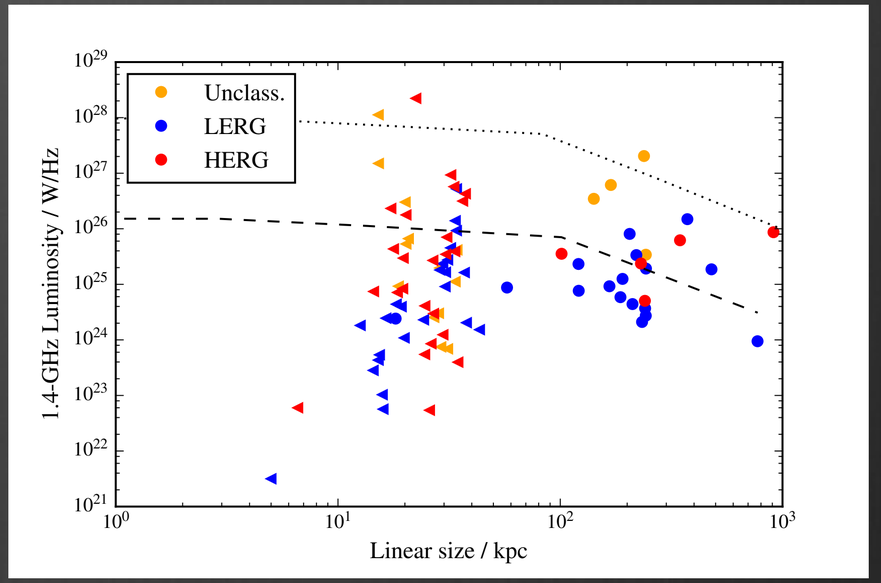
LERG



Heckman & Best (2014)

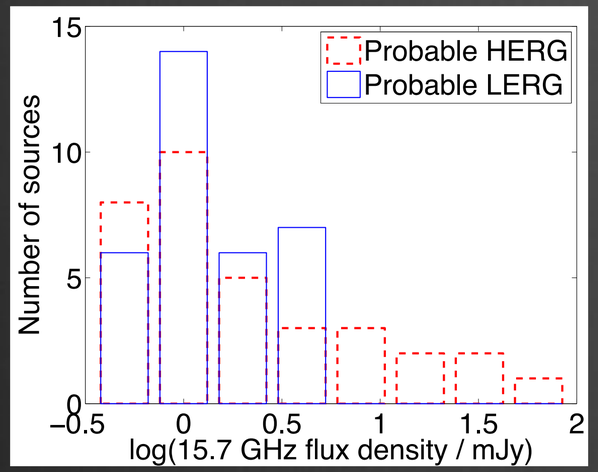


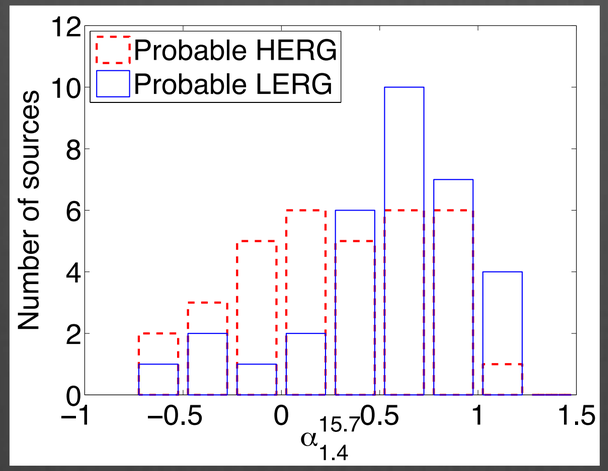
Evolutionary tracks from An and Baan (2012)

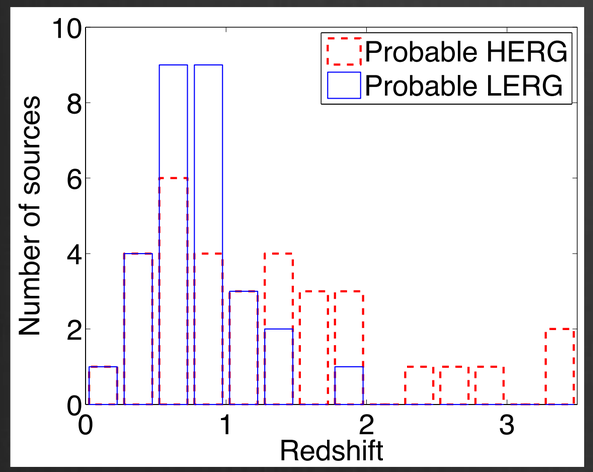


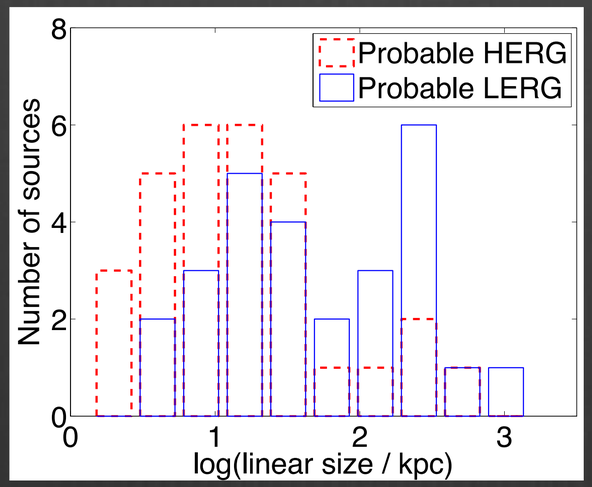
Whittam et al. (2020)

Properties of HERGs and LERGs









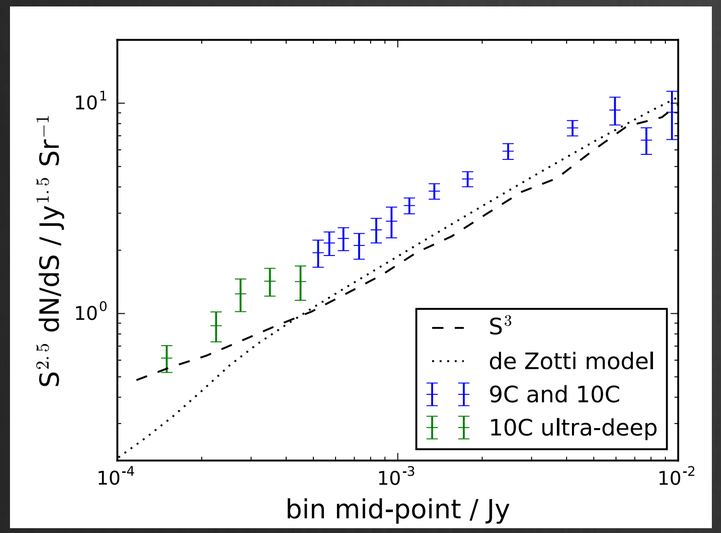
HERGs have higher flux densities, larger redshifts, flatter spectra and smaller linear sizes.
Suggests they are dominated by emission from their cores.

Whittam et al. (2016b)

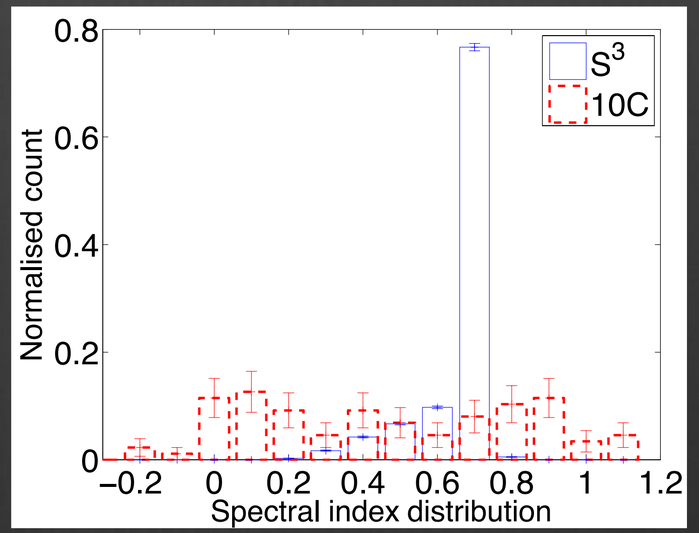
Comparing to models: SKADS Simulated Skies

★ Semi-empirical simulation of the extra-galactic radio sky (Wilman et al. 2008, 2010).

★ Fails to reproduce observed spectral index distribution or source count at 15 GHz.



Whittam et al. (2016a)



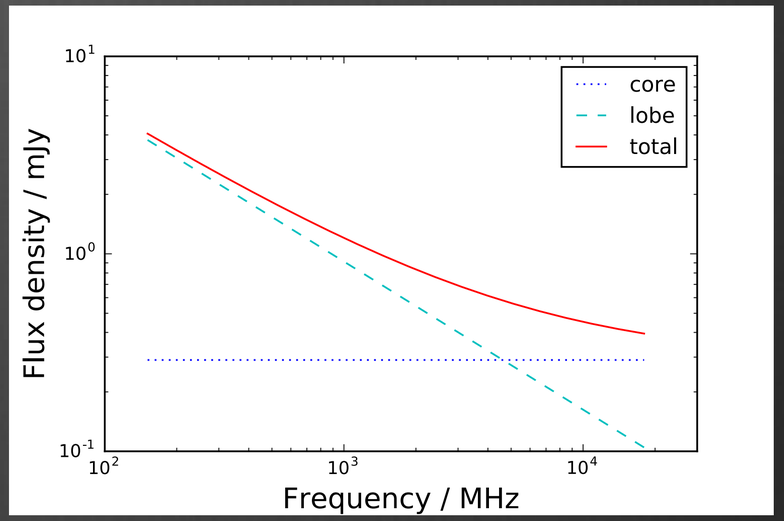
Whittam et al. (2013)

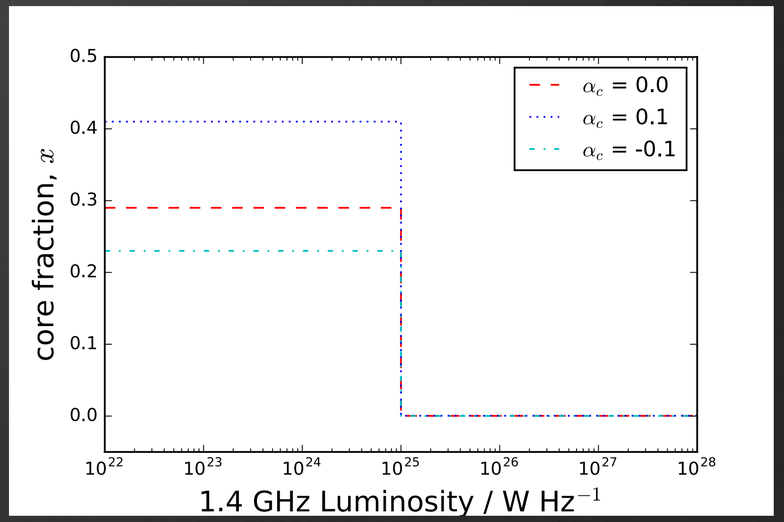
Source type	Percentage
FRI	71
FRII	13
GPS	3
Radio quiet AGN	3
Starburst	4
Quiescent starforming	3

Modifying S^3

- ★ For each FRI sources in simulation, assume fraction *x* of 1.4 GHz flux density is in the core.
- ★ *x* varies with luminosity.
- ★ Assign this fraction a spectral index of 0, give the remaining (extended emission) a spectral index of 0.75.
- ★ Use this to produce a revised 15 GHz flux density of each source.

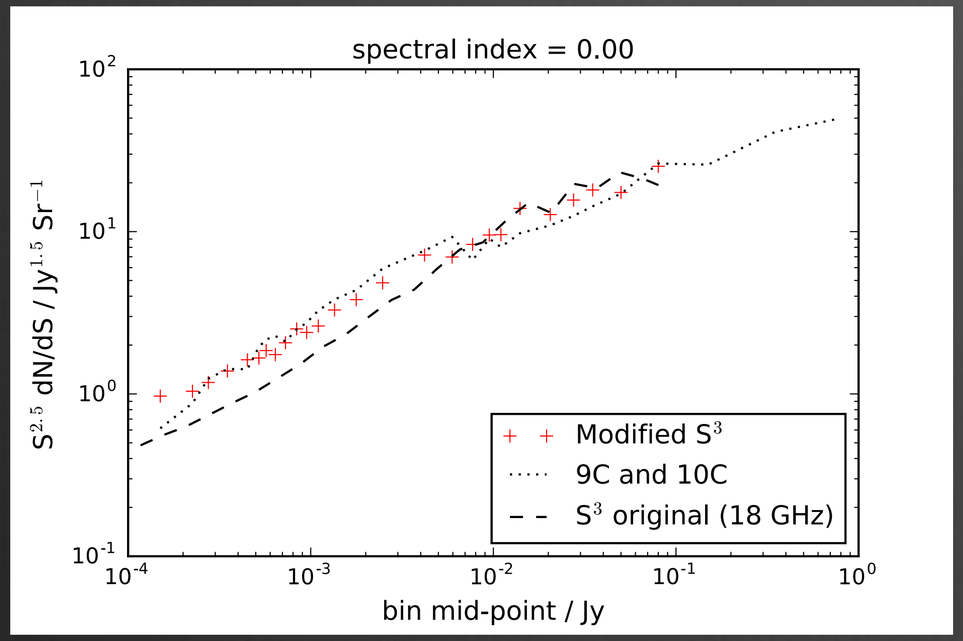
Whittam et al. (2017)



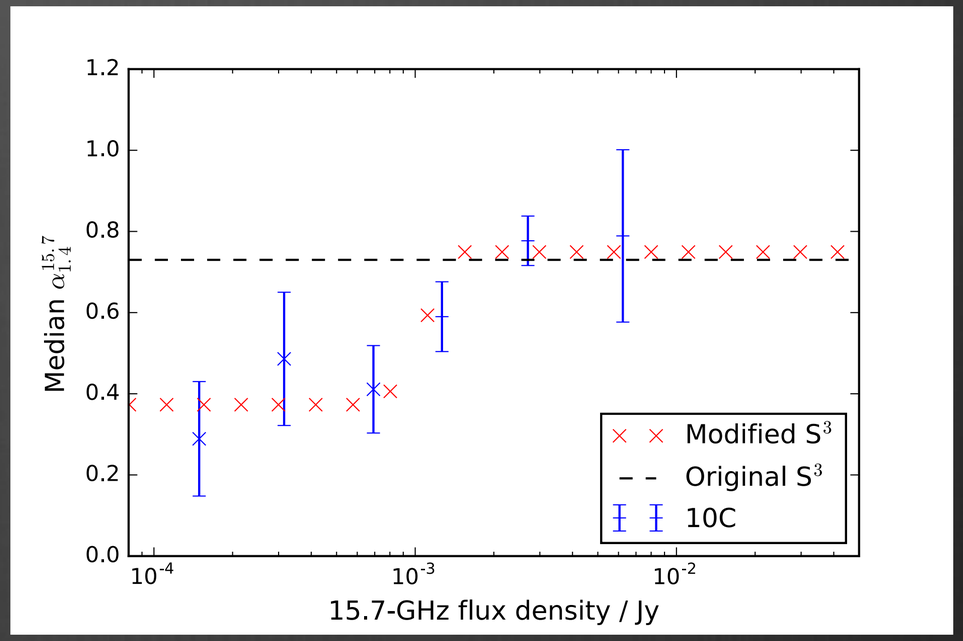


Modified S^3

Source counts



Spectral index

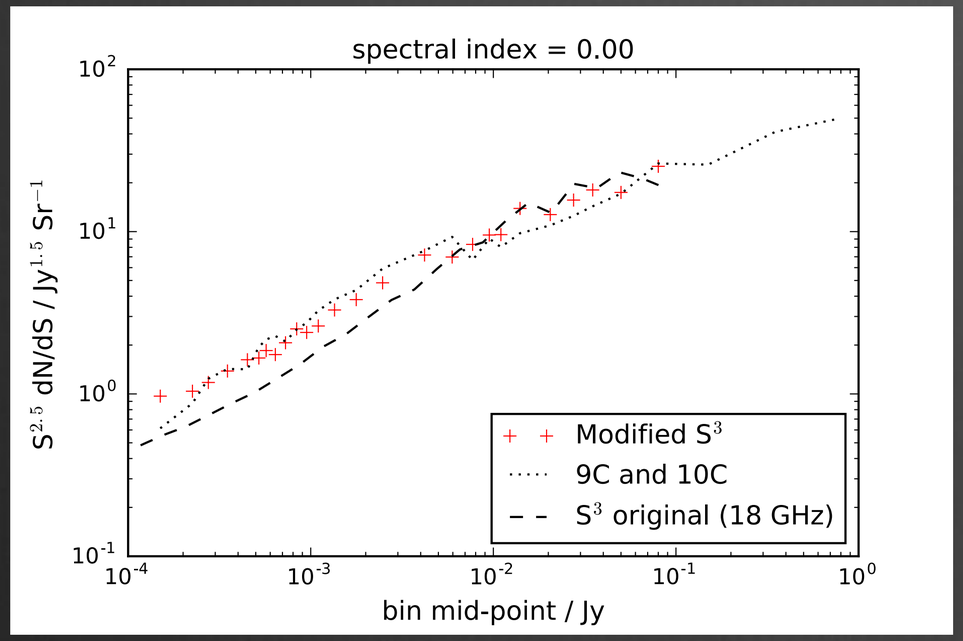


Whittam et al. (2017)

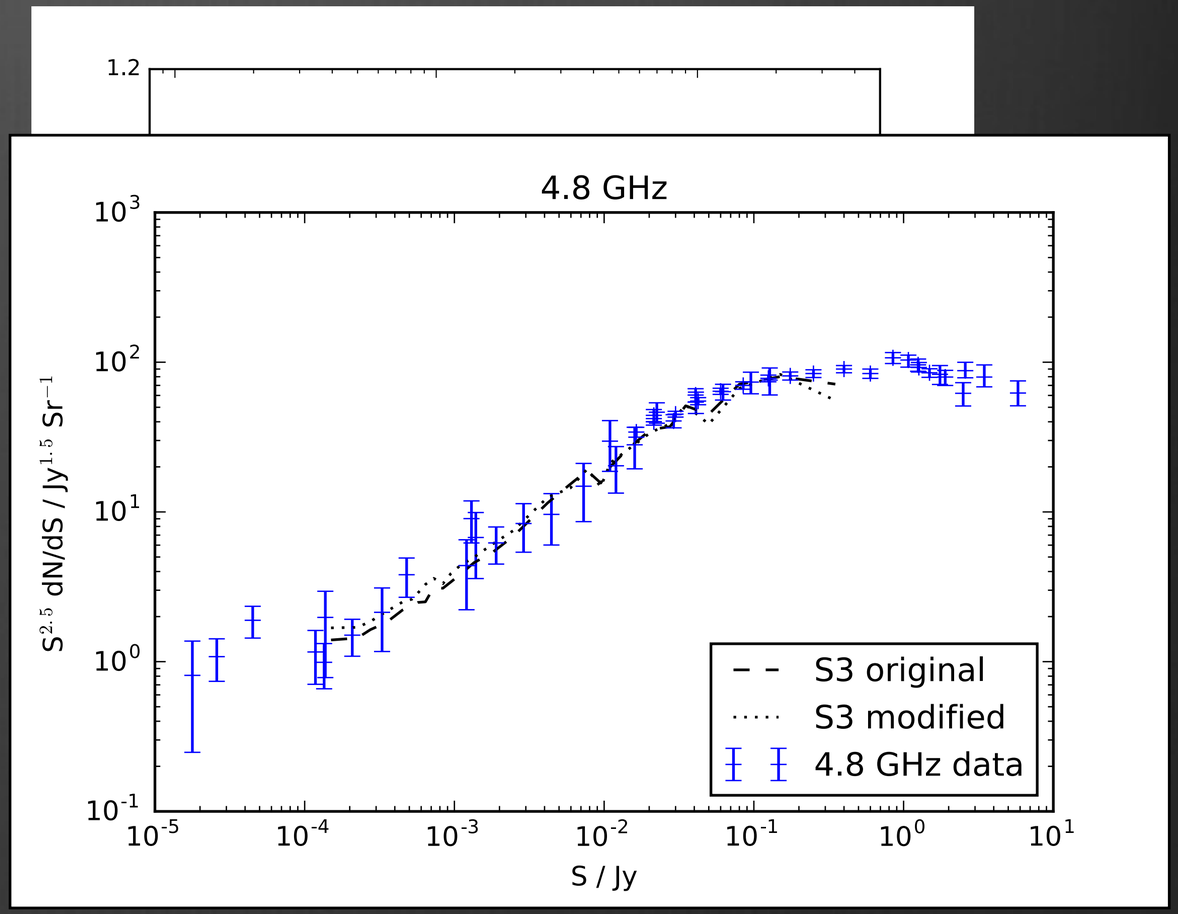
★Much better fit to observations!

Modified S^3

Source counts



Spectral index



★Much better fit to observations!

Comparing to models: T-RECS

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The Tiered Radio Extragalactic Continuum Simulation (T-RECS)

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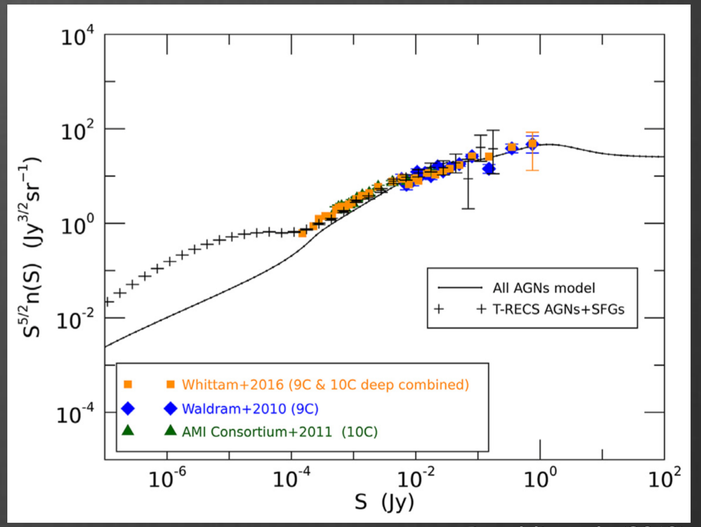
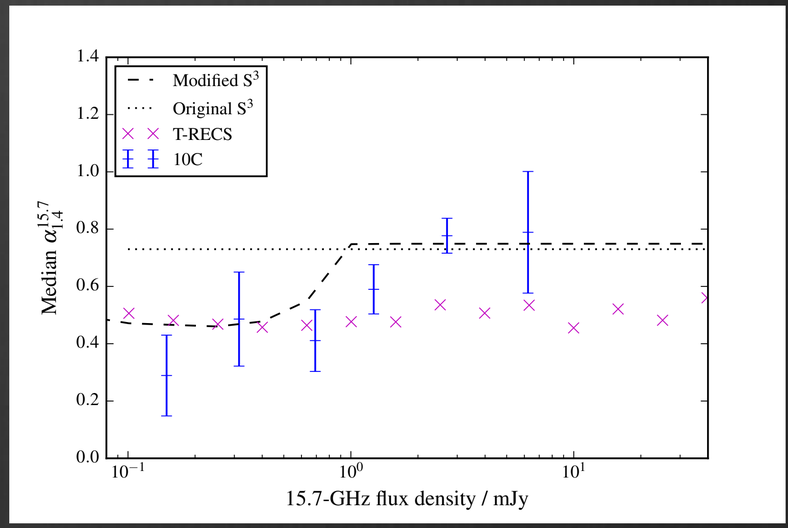


Bonaldi et al. (2019)

★ Successfully reproduces source counts but not spectral index distribution.



Whittam et al. (2020)

Conclusions

- ★ 10C radio survey at 15.7 GHz - deepest high frequency radio survey that covers a significant area.
- ★ 10C sources - majority are compact, core-dominated radio galaxies.
- ★ Compact 10C sources are a composite population - mixture of spectral shapes, HERGs and LERGs.
- ★ May be higher-z (z~1) analogues of FR0 sources found in the local universe (z~0.1) e.g. FR0CAT, Baldi et al.
- ★ Compact HERGs might go on to become FRII sources.

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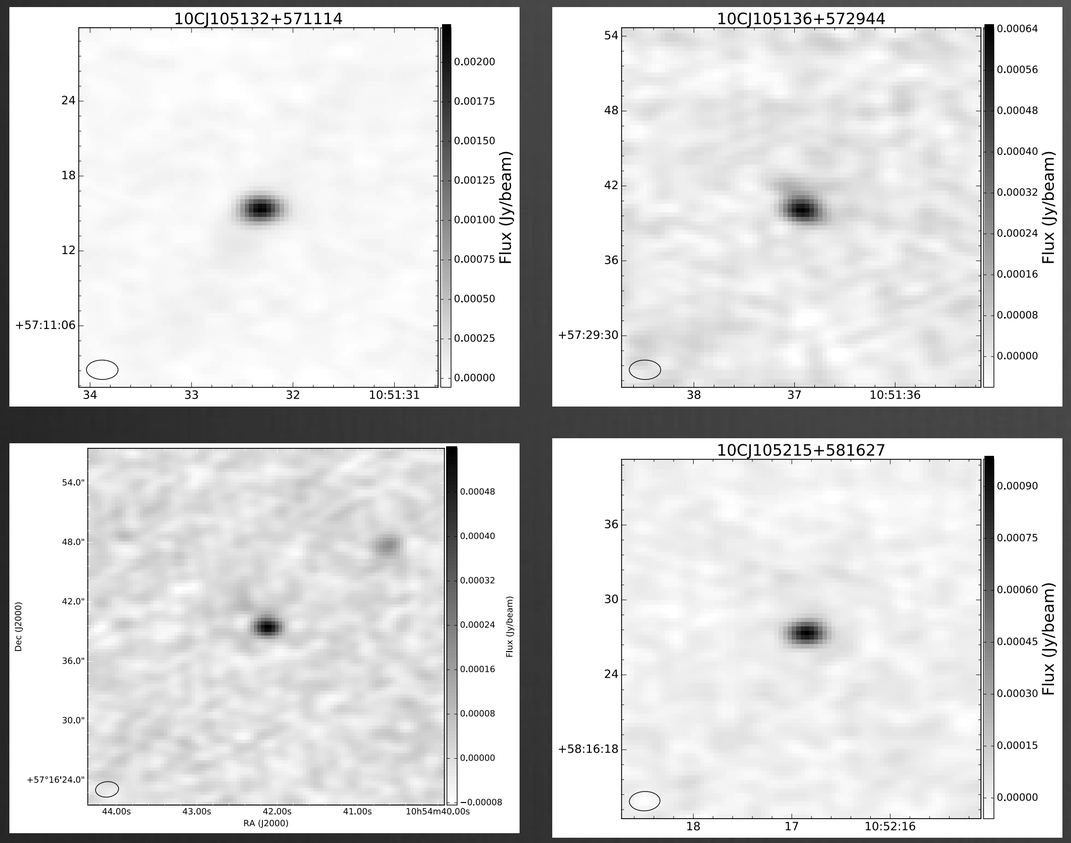
Compact radio galaxies



Whittam et al. (2020)

- ★ Majority of radio galaxies are actually compact.
  (Baldi et al. 2015, Sadler et al. 2014, Whittam et al. 2013).
- ★ We've recently found that faint radio galaxies are more dominated by core emission than previously thought.
  (Whittam et al. 2015, 2017, 2020)
- ★ Mixed population - far too numerous to all be young radio galaxies.