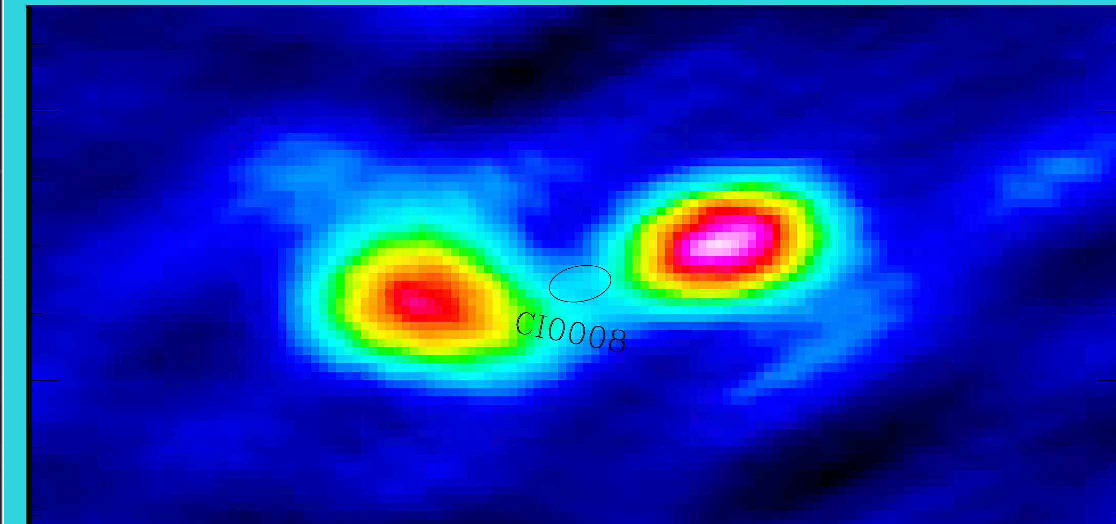

A progress report:
The Evolutionary Sequence of Young Radio Galaxies

Jordan Collier | UWS & CASS Student

27th May 2015 | 5th workshop on CSS & GPS radio sources | Rimini, Italy

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K Chow, R Norris, M Filipović, **J Callingham**, N Tothill, S Shabala, M Huynh, J Banfield, E Crawford, G Wong

Context – AGN evolution

- AGN evolution
  - Relationship between AGN & normal galaxies not understood
  - Don't yet understand evolution of young radio galaxies
- Some questions to address:
  - When do AGN first appear? What evolutionary path do they follow?
  - Does AGN evolution occur in a short burst or gradually within first few Gyr?
  - What are the properties of AGN & host throughout their evolution?
  - Are GPS/CSS sources the youngest radio galaxies?
- To pinpoint when AGN becomes active, and the timescales over which they evolve, we observe GPS/CSS sources

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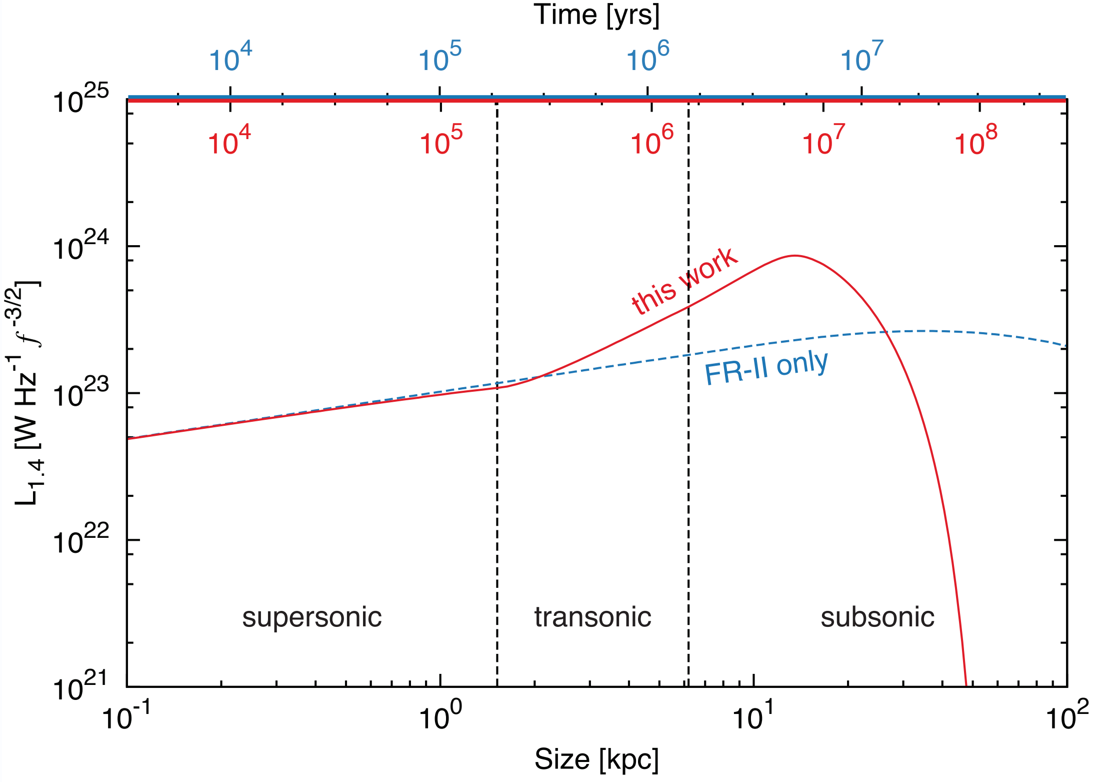
GPS/CSS sources – the youngest AGN?

- Jets grow with age
  - GPS → CSS → Large RGs
- Typical sizes:
  - GPS: < 1 kpc
  - CSS: 1 – 10s kpc
- **Jet size excellent tool for dating RGs**

$10^{11} M_\odot$ AGN w/ jet power $Q_{tot} = 10^{35.5}$ W



Ross Turner et al. (2015)

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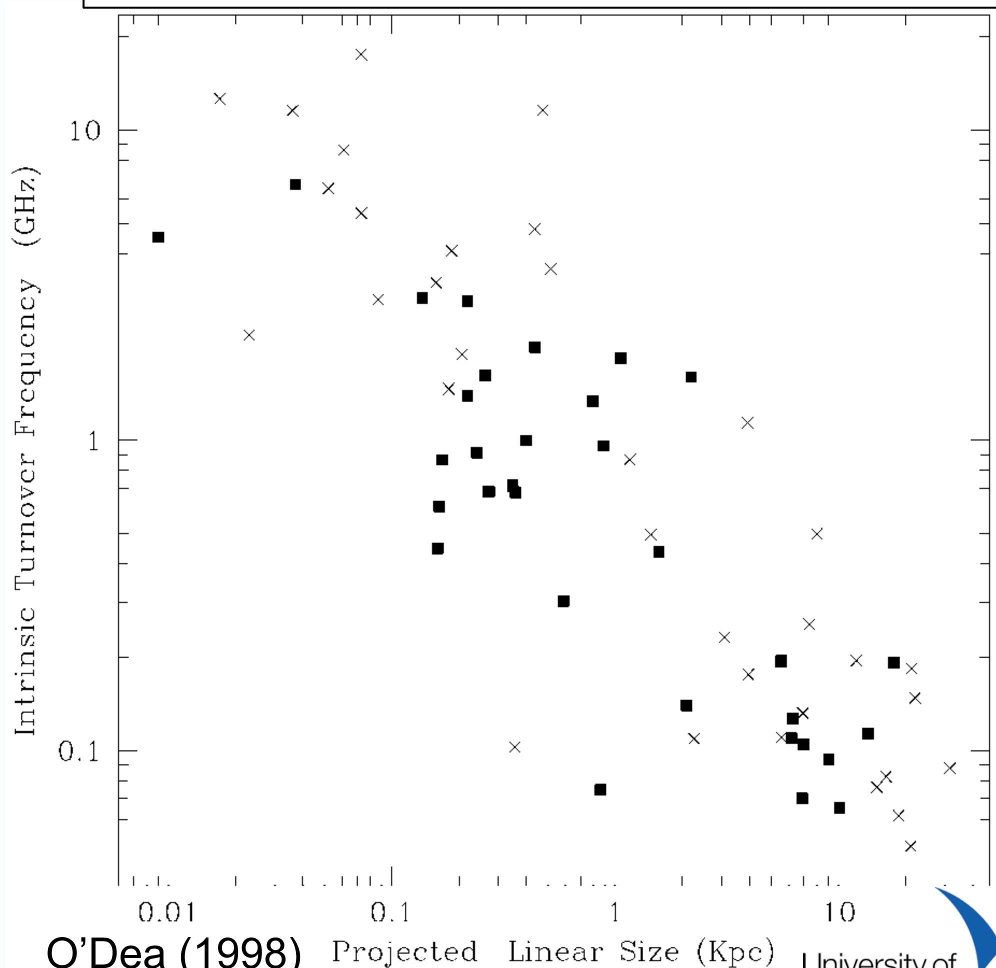
GPS/CSS sources – the youngest AGN?

- $\upsilon_m - \ell$ relation
- Studies mostly limited to Jy levels
  - Need depth, many frequencies and high res
- Hancock+ (2010) & Randall+ (2012) are among the faintest samples
  - Only goes down to a few mJy

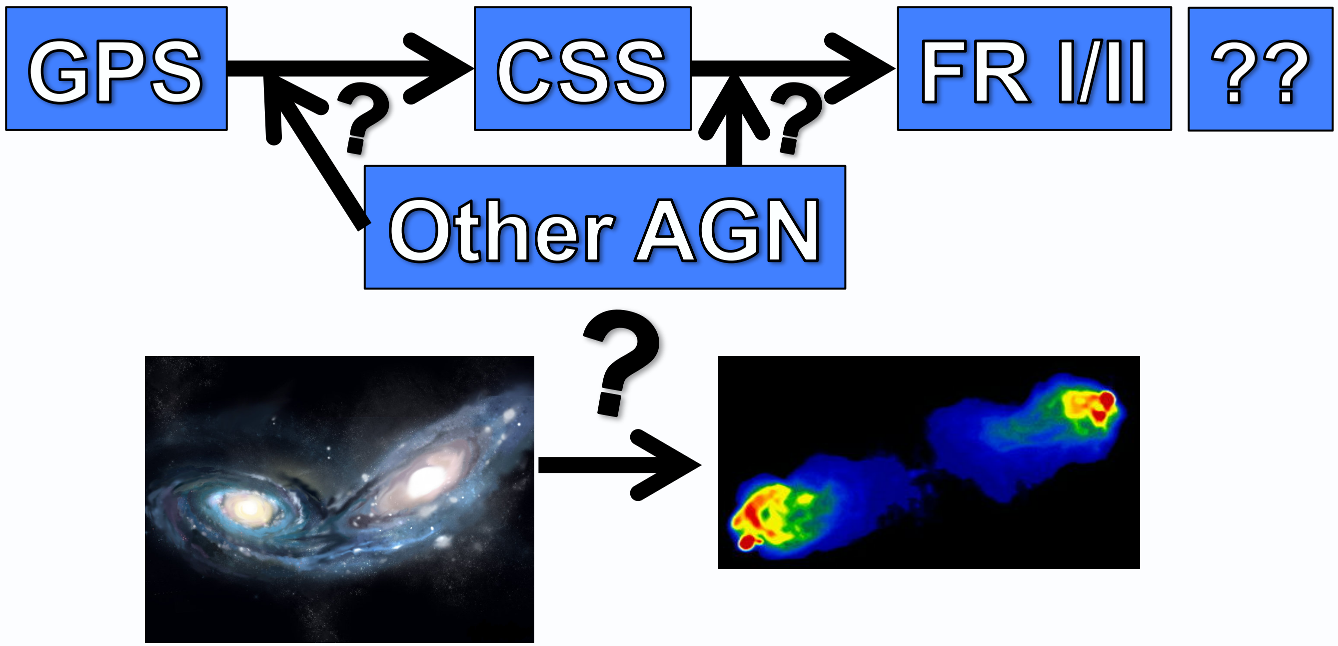
$$\log \upsilon_m = -0.21(\pm 0.05) - 0.65(\pm 0.05) \log \ell$$



O'Dea (1998)

Goal – construct evolutionary sequence

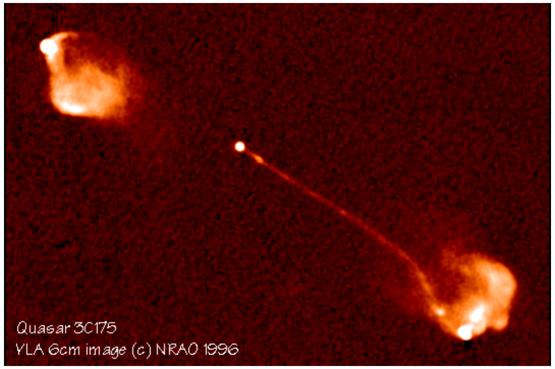
- Aim: To construct an evolutionary sequence for the early stages of AGN, with a particular focus on faint GPS/CSS sources



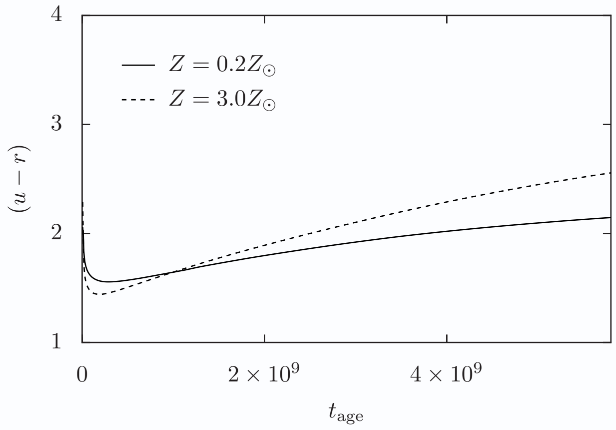
- Place in evolutionary sequence not well understood
- We study very faint RGs from radio – X-rays over a large sample in order to detect meaningful tracers of their age (e.g. **<u>jet sizes</u>**, spectra, colours, etc)

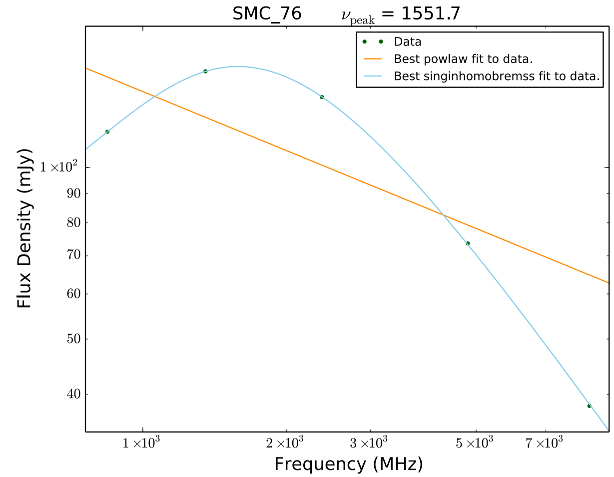
Main age indicators

- **Jet sizes**
- Electron lifetimes / spectral age & index (based on break & turnover frequency)
- Separation of nuclei (binary AGN)?
- Colours & SED of host



Shabala+ (2011)





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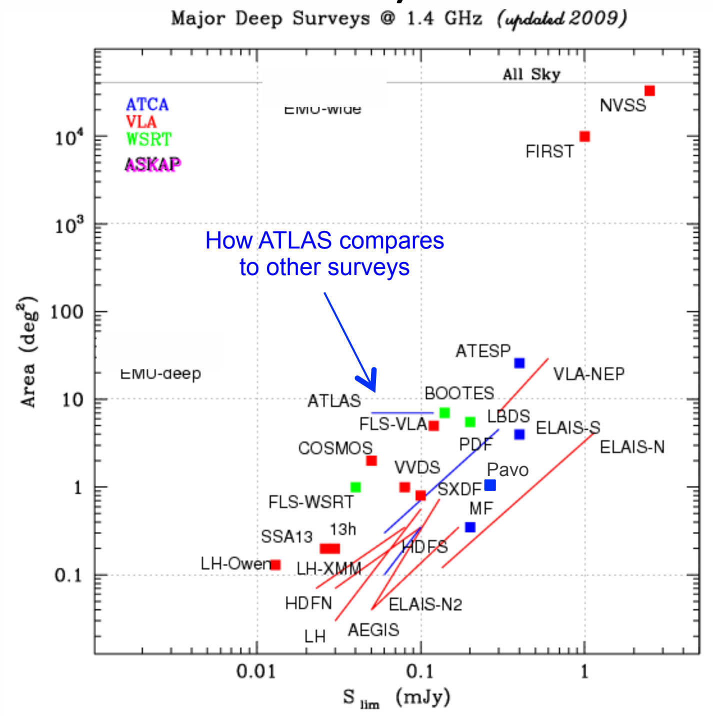
Faint Sample: ATLAS
(The Australia Telescope Large Area Survey)

- Widest deep radio survey (Norris+ 2006; Franzen+ 2015)
  - 7 square degrees of CDFS and ELAIS-S1
  - r.m.s. (σ) of 15 μJy
- Overlaps with deep observations in:
  - X-ray – e.g. Chandra
  - Optical – e.g. AAT spectra (500 redshifts)
  - Infrared – e.g. Spitzer, VISTA, Herschel
- Data Release 3 (DR3; Franzen+ 2015)
  - > 5 000 galaxies (about half AGN)
  - Redshifts for most sources with more coming



- **First time this research will have taken place using such a faint sample of this size – will pave the way for ASKAP science**

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Mid-Strength Sample: SMC (Small Mag Cloud)

- Additional data set of radio-continuum mosaics compiled by merging a number of observations together at λ = 20cm, 13cm, 6cm, 3cm by Wong+ (2011) & Crawford+ (2011)
  - Many background sources (mostly AGN) – 1560 at 20 cm from Wong+ (2011)
  - Great spectral coverage across shorter wavelengths from 3 cm – 36 cm
  - Wider & shallower (0.4 – 0.8 mJy –> complimentary to fainter AGN)
  - Well-studied
    - Surveys from other bands include Spitzer, Chandra, XMM
    - Many spectroscopic redshifts (Kozlowski+ 2011/13) and RMs (Mao+ 2008)

Selection Strategy

Find young AGN from Radio Data

Select subsample of unresolved* AGN with GPS/CSS spectrum

GMRT | MOST | ATCA

Observe at higher resolution (3/6 cm) & repeat process for VLBI

Range of [low to high redshift / small to large linear sizes / bright to faint] young AGN to construct our evolutionary sequence

*some resolved in SMC

Observations

High resolution ATCA (~1 arcsec) obs.
the faintest GPS/CSS sample to date

Now we have significant spectral coverage:

- **ATLAS** – 8-13+ frequencies between 0.150 – 9 GHz (*MWA, GMRT, ASKAP, MOST, ATCA*)
- **SMC** – 5+ frequencies between 0.843 – 9 GHz (*MOST, ATCA*)

- **Sample: 151 GPS/CSS sources (8 with VLBI) from several mas – several 10s arcsec (few 100s pc – several 10s kpc) PLUS handful of larger FR I/II**

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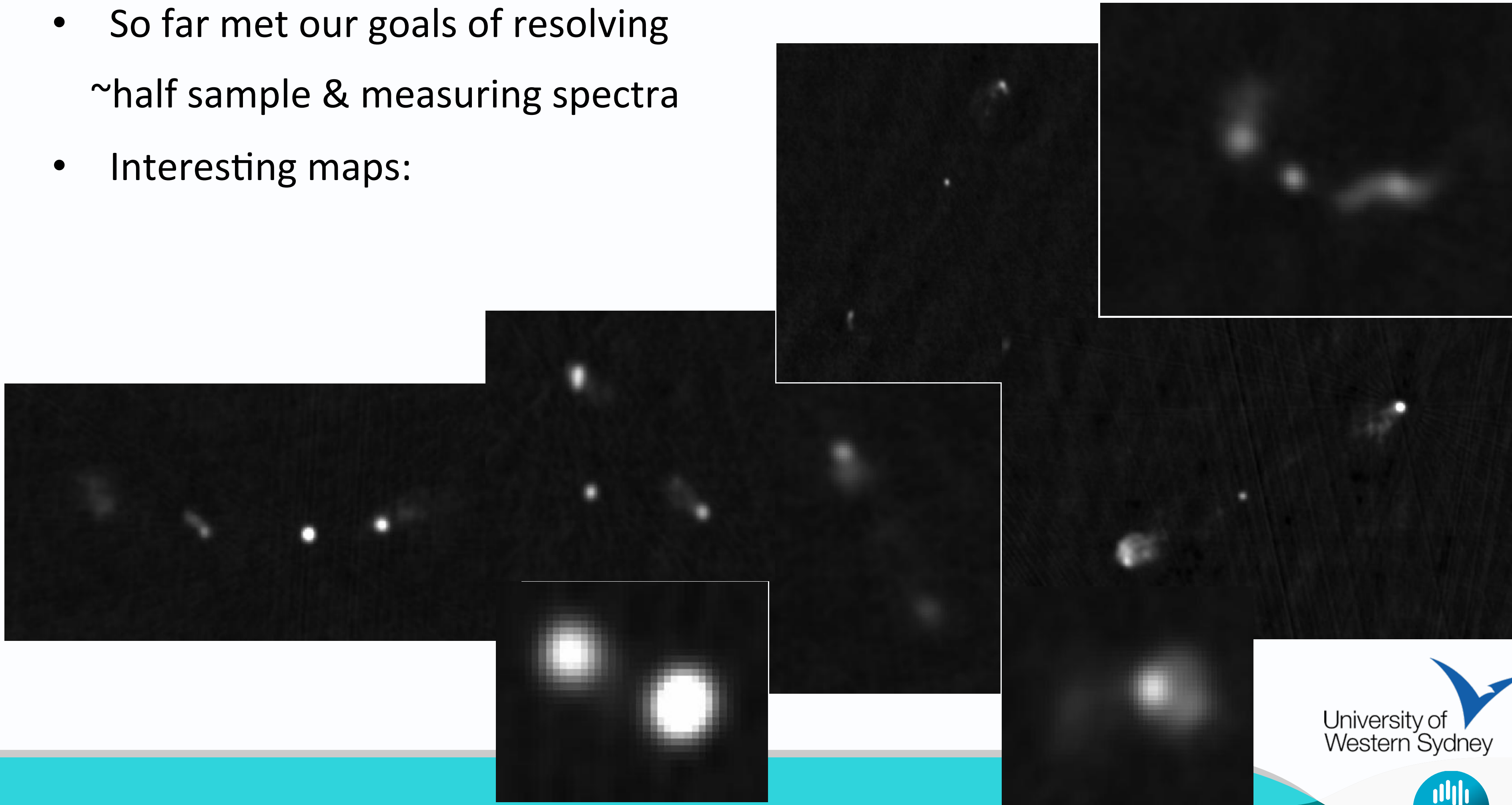
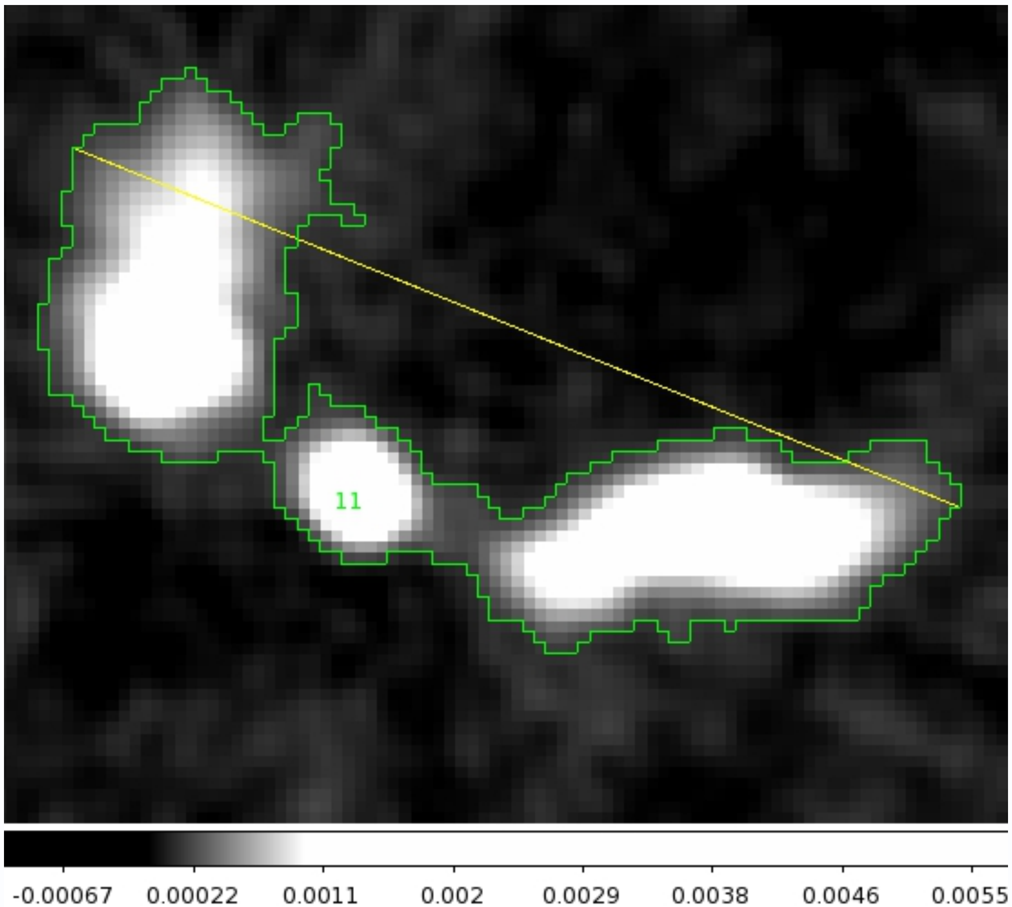
ATCA images of 143 ATLAS / SMC sources

- ELAIS-S1 & CDFS sources "complete" down to ~100 μJy (5σ)
- So far met our goals of resolving ~half sample & measuring spectra
- Interesting maps:



Obtain morphology & linear size – Aegean

- Using --island option in Aegean source finder



	island	components	max_angular_size	area
1	3	1	0.00091	3.003231E-7
2	4	1	0.00211	1.356760E-6
3	5	1	0.00187	1.103059E-6
4	7	1	0.00101	4.109768E-7
5	8	1	0.00156	5.887982E-7
6	9	1	0.00091	2.821879E-7
7	11	7	0.0096	1.734860E-5
8	12	1	0.00197	1.109501E-6
9	13	2	0.00156	8.921999E-7
10	14	1	0.00138	6.691690E-7
11	15	1	0.00147	5.272520E-7
12	17	11	0.00613	1.114713E-5
13	18	1	0.00161	5.479265E-7
14	19	1	0.00116	4.263714E-7
15	20	1	0.00147	1.082028E-6
16	21	1	0.00157	7.427616E-7
17	23	1	0.00154	1.114280E-6
18	24	1	0.00101	3.068133E-7
19	25	1	0.00291	1.335407E-6
20	27	1	0.00141	7.483095E-7

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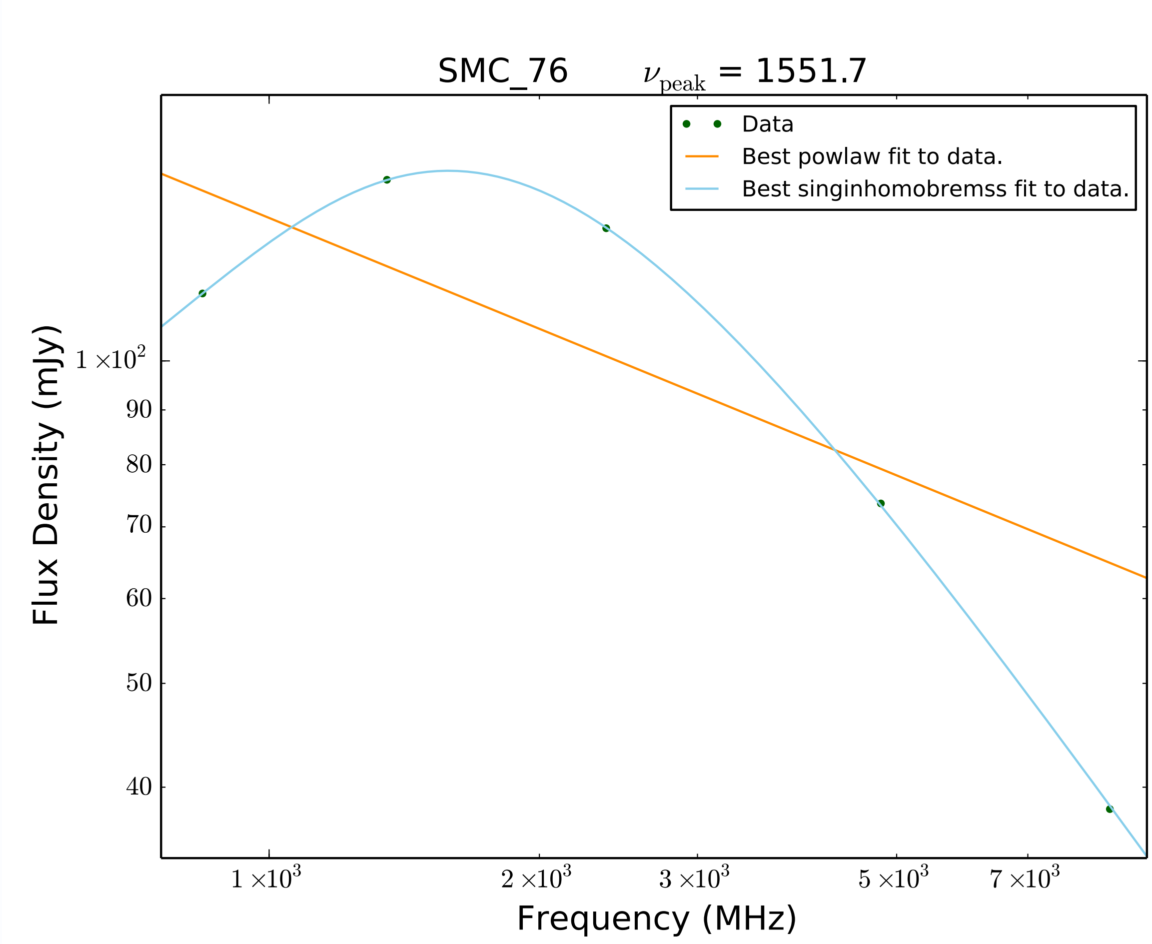
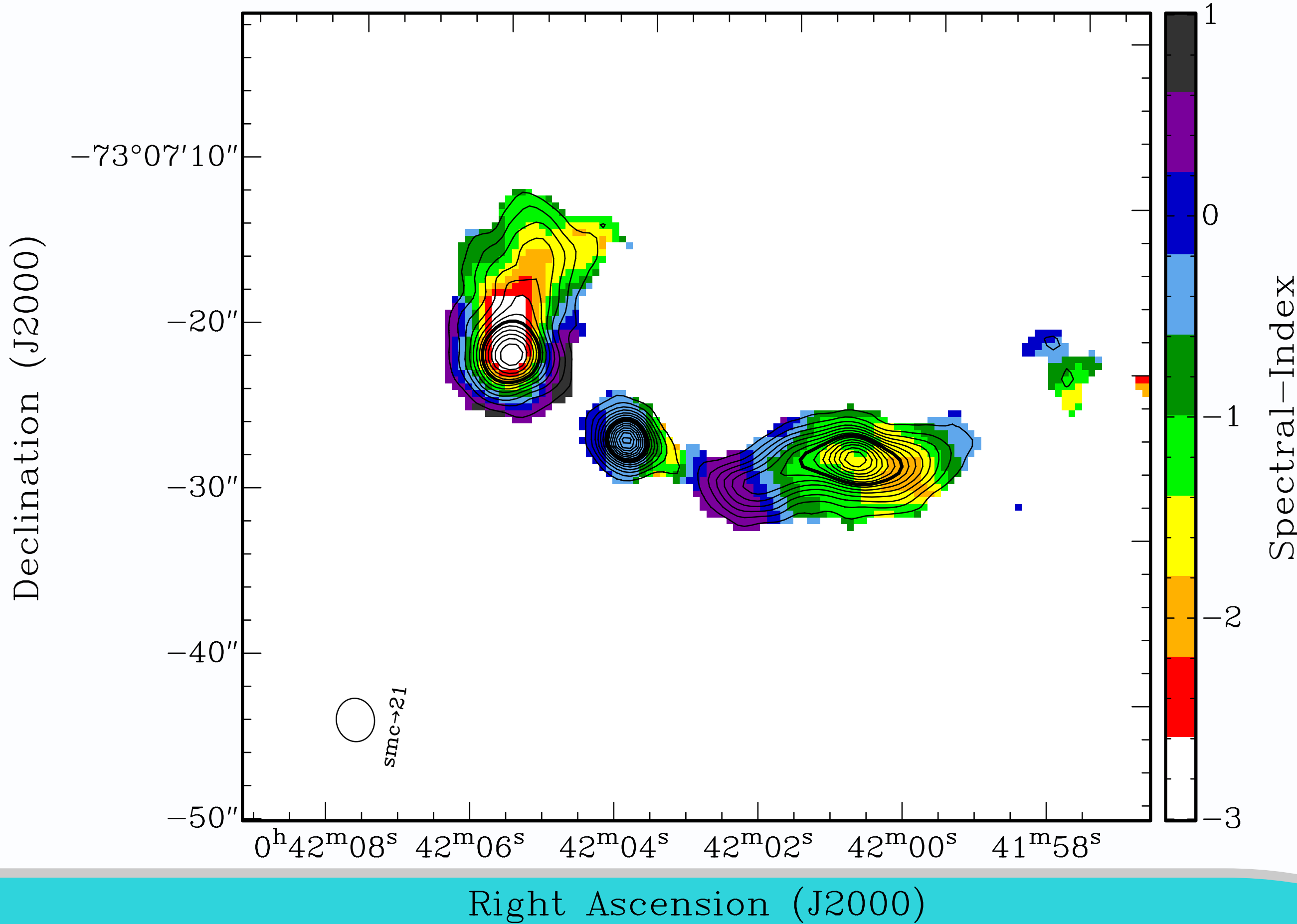
Obtain accurate spectrum – turnover / break

- 71 ATLAS sources & 72 SMC sources – thanks Joe!



Spectral Index maps

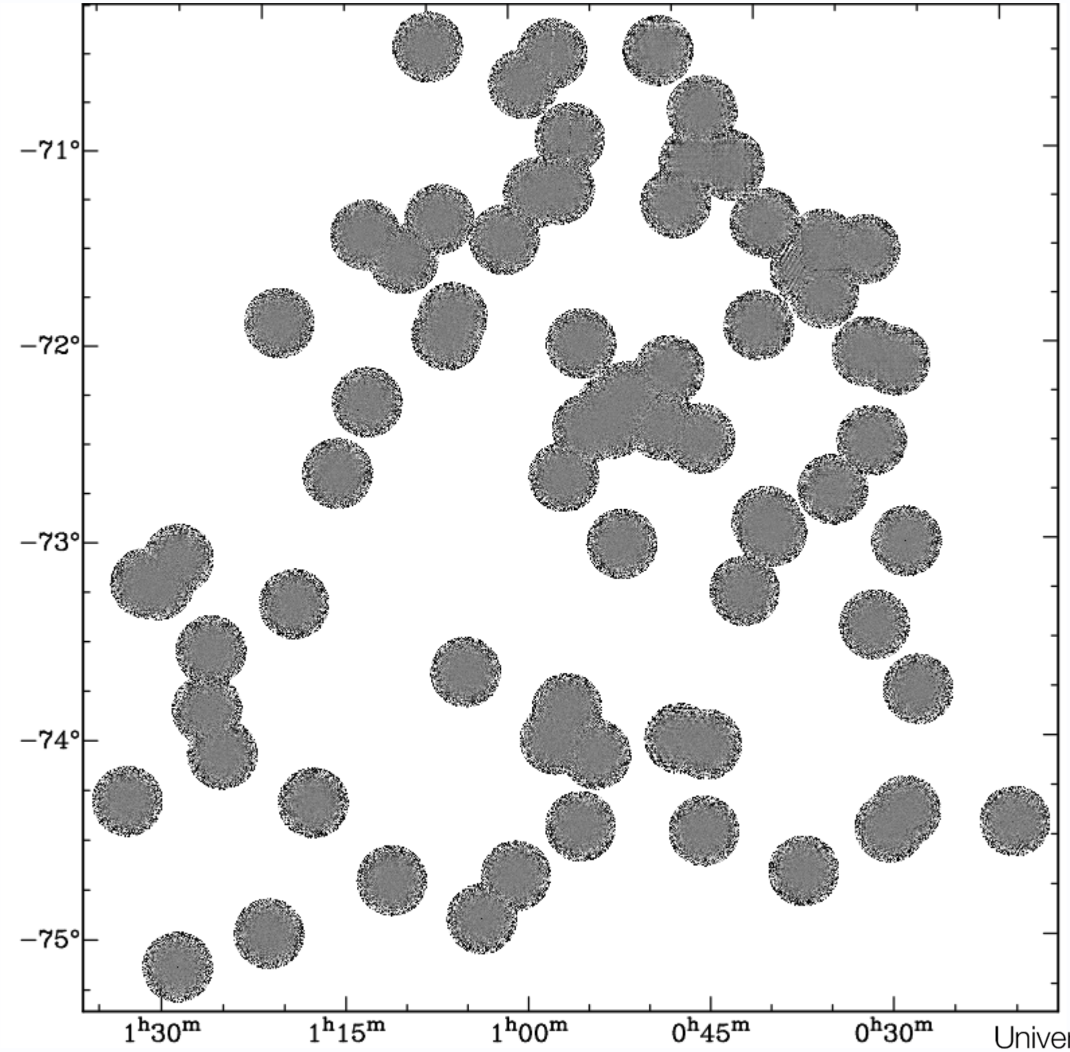
- 71 ATLAS sources & 72 SMC sources
- Spectral index maps (e.g. 5.5 GHz):



SMC mosaic of 72 pointings

Overcoming computational challenges:

~40,000 x 40,000 pixel image!
But mostly empty!



Fraction of GPS sources in SMC

- In the SMC, at mJy levels:

Is fraction of GPS sources the same as in O'Dea (1998)?

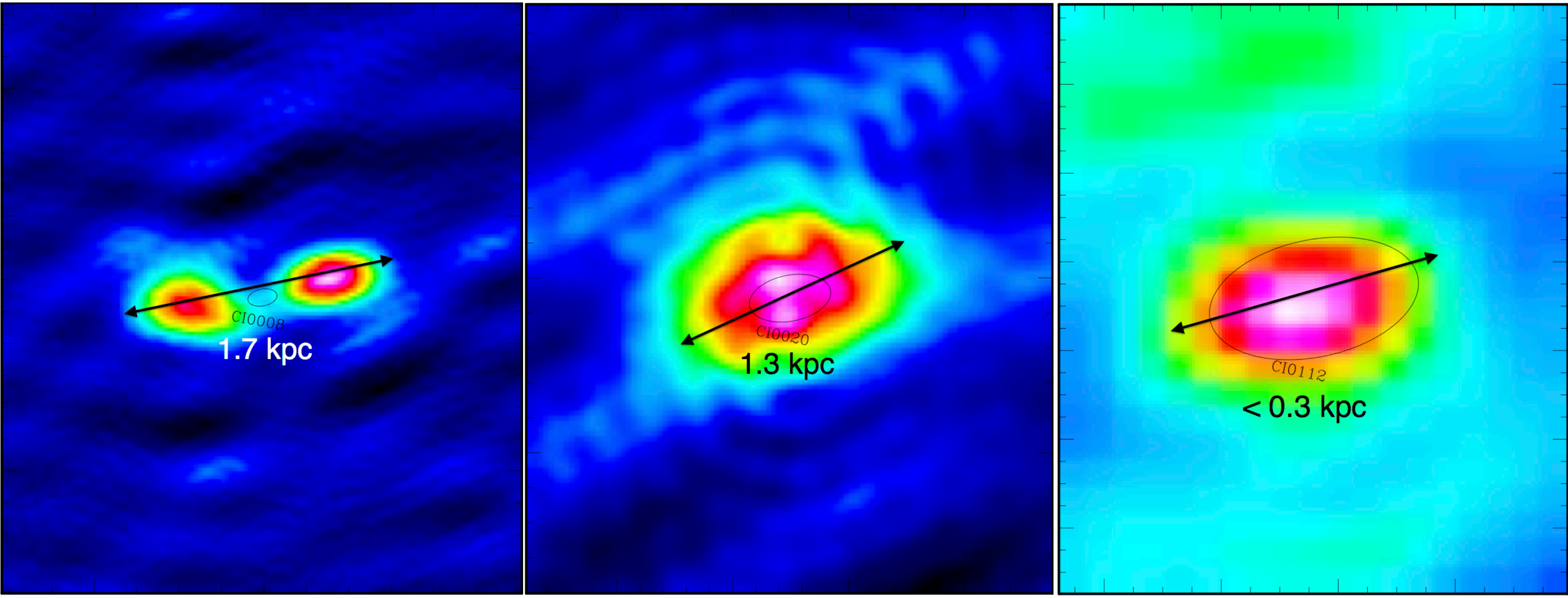
– i.e. ~**10%**

- Classifying spectra is hard, so some only tentative GPS
- Therefore large error on fraction
- Result:

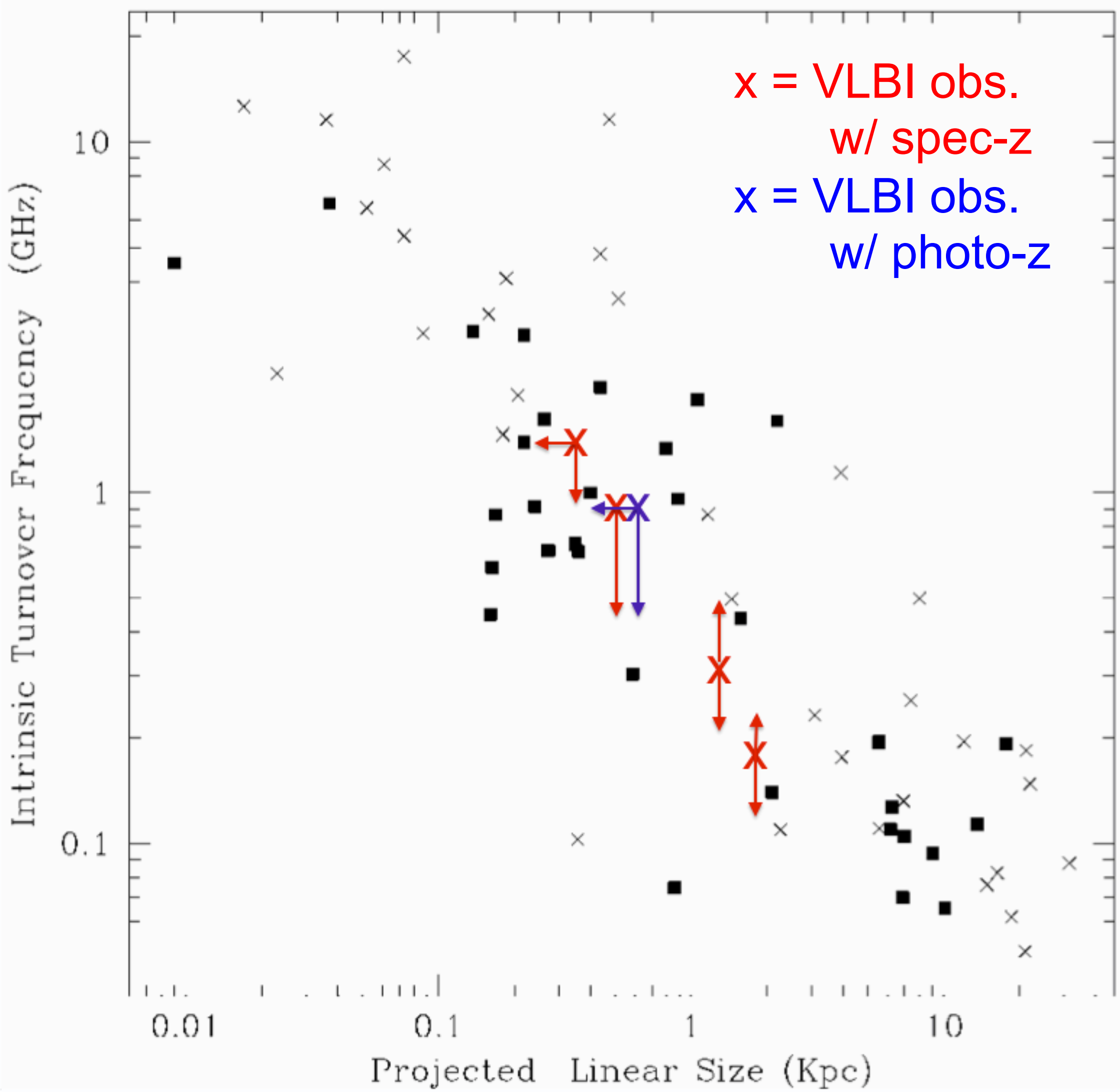
2.5-12.5% of mJy sky behind SMC consists of GPS sources

VLBI images of 8 most compact sources

- 8 of the most compact GPS/CSS sources from 1” 3/6 cm obs
  - 3 are resolved, 2 not detected
  - Ranging from approx. 0.3-2 kpc, $L_{20cm} = 10^{23\text{-}26}$ W/Hz



VLBI obs. – turnover-linear size relation

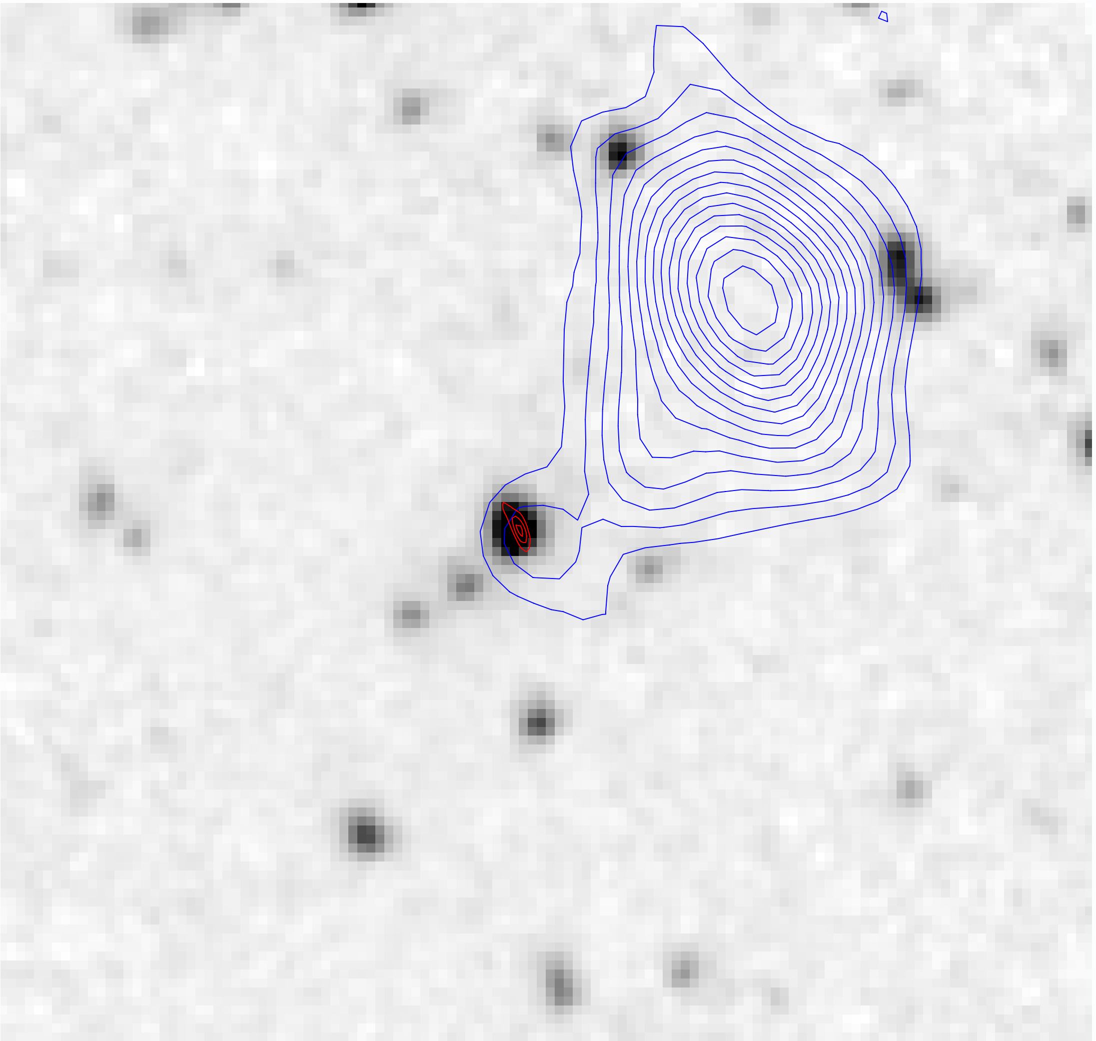


VLBI obs. – what can we do?

- Since we now have range of source sizes, we will be able to confirm or reject the young RG hypothesis using age indicators
- We will be able to separate AGN/SF
- We may catch some RGs being "born"
  - Measure (or place limits on) timescales
- We hope to detect some binary AGN
  - Few known – Only **one** generally accepted radio binary AGN w/ separation < 1 kpc (Rodriguez+ 2006)
  - Test hierarchical merging + gravitational waves

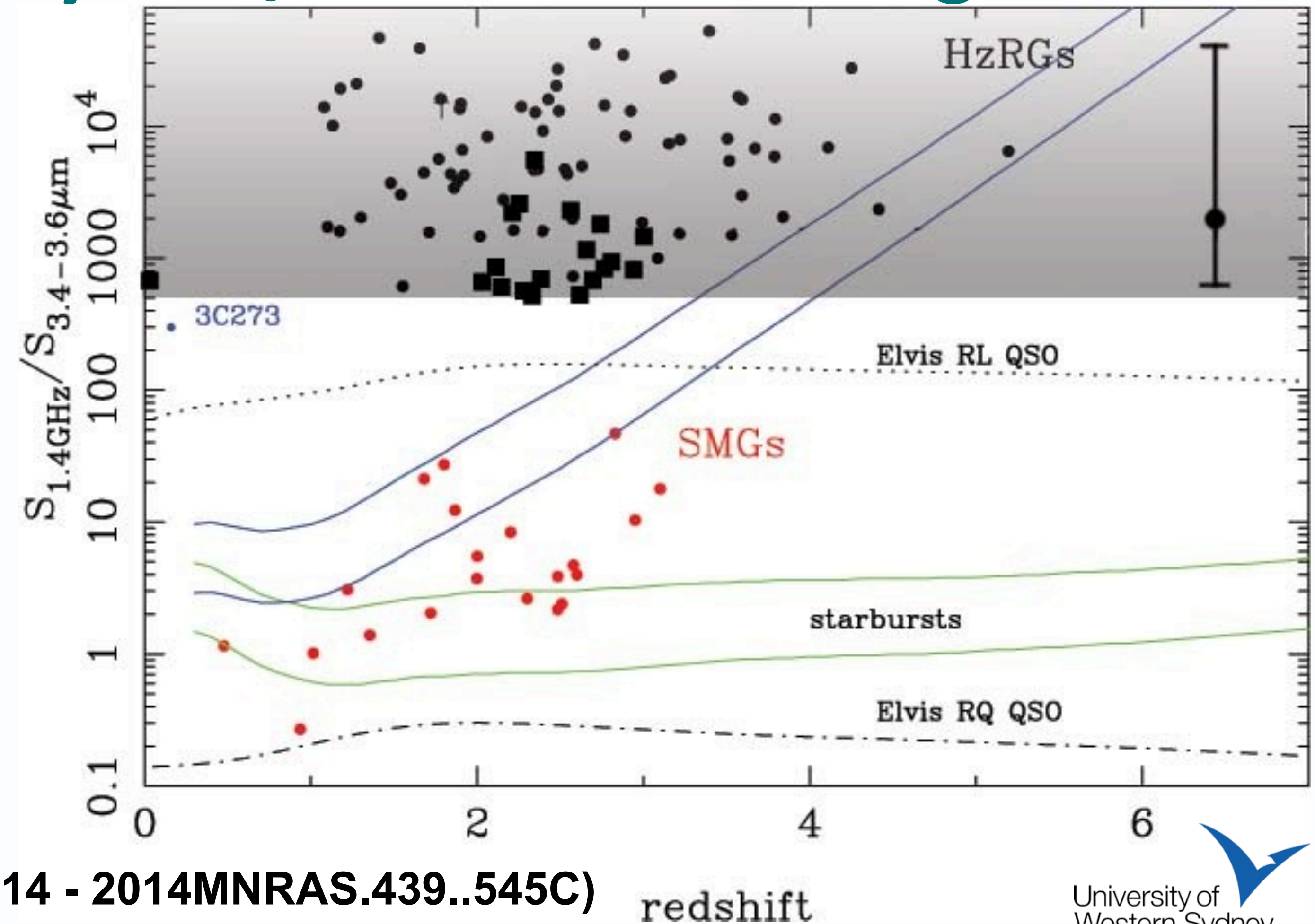
GPS mis-ID in ATLAS – one-sided RG??

- Blue = ATLAS DR3
  (10 arcsec @ 1.4 GHz)
- Red = ATCA
  (~1 arcsec @ 9 GHz)
- Background = Spitzer
  (~1.5 arcsec @ 3.6 um)



Infrared-Faint Radio Sources (IFRSs): dominated by GPS/CSS sources at high-z

- ~20% of IFRSs at 2 < z < 3 are GPS/CSS
- >50% at z > 3?



(Collier+2014 - 2014MNRAS.439..545C)

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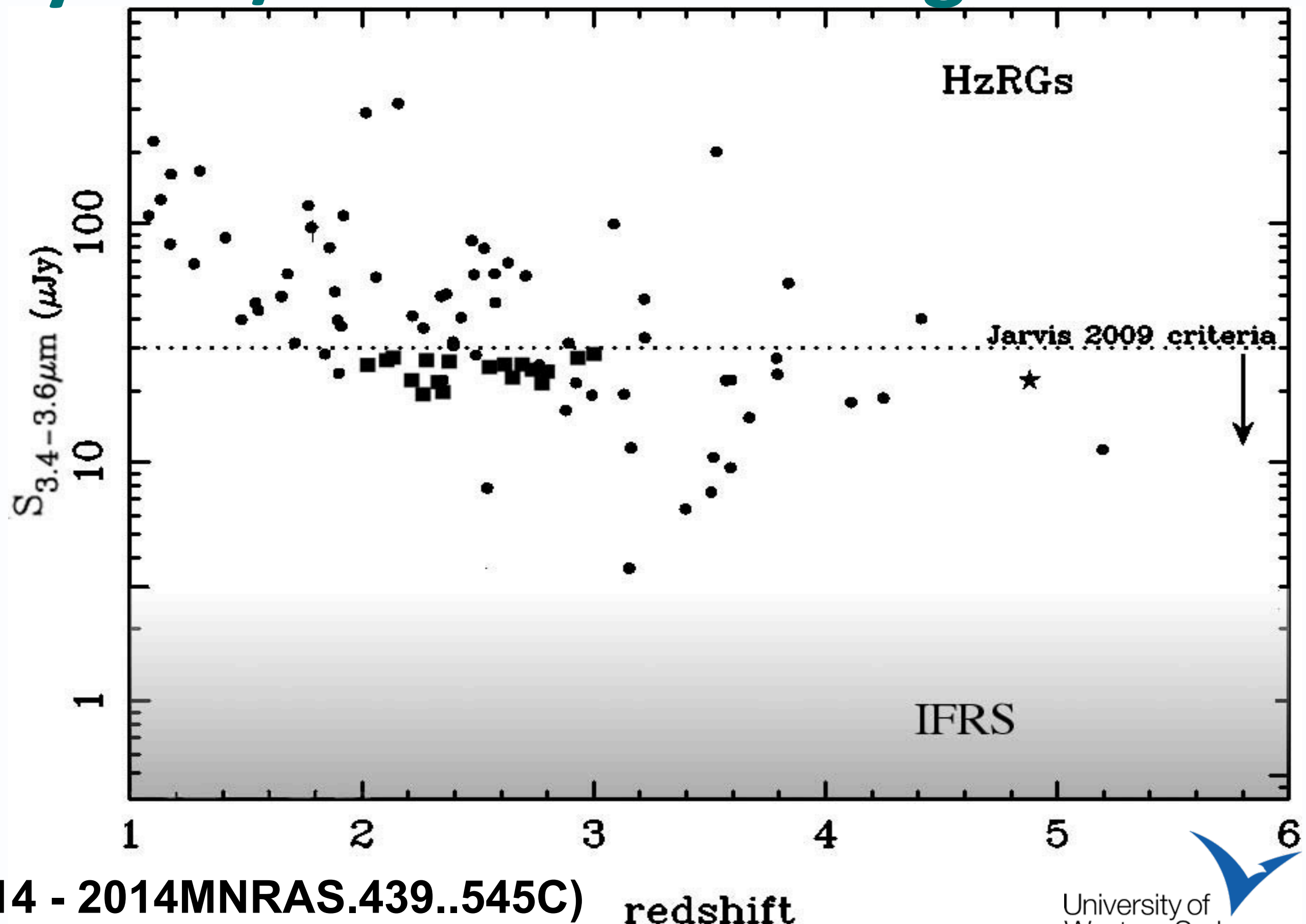
Infrared-Faint Radio Sources (IFRSs): dominated by GPS/CSS sources at high-z

- ~7 IFRSs / deg^2
- Up to ~100 000 IFRSs across sky
  - Only ~200 HzRGs currently known
  - Large number of previously unseen RGs at 2 < z < 5?



(Collier+2014 - 2014MNRAS.439..545C)

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Conclusion

- We have observed the faintest GPS/CSS sample to date
- High-res. obs. have allowed us to resolve jets of many sources
- VLBI obs. have resolved the most compact (young?) sources and follow the $\upsilon_{\mathrm{m}} - \ell$ relation
- mJy sky behind SMC consists of 2.5-12.5% GPS sources
- IFRSs are dominated by GPS/CSS sources at high-z
- Age from jets will be compared to a many other multi-λ age tracers
- We will place GPS/CSS sources into an evolutionary sequence
- We will help confirm / reject the young RG hypothesis
- We will discover the properties of faint GPS/CSS sources

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Control freak moving the telescope:

Thank you

CSIRO / UWS

Jordan Collier

UWS & CASS Student

t +61 414 443 622
e j.collier@uws.edu.au

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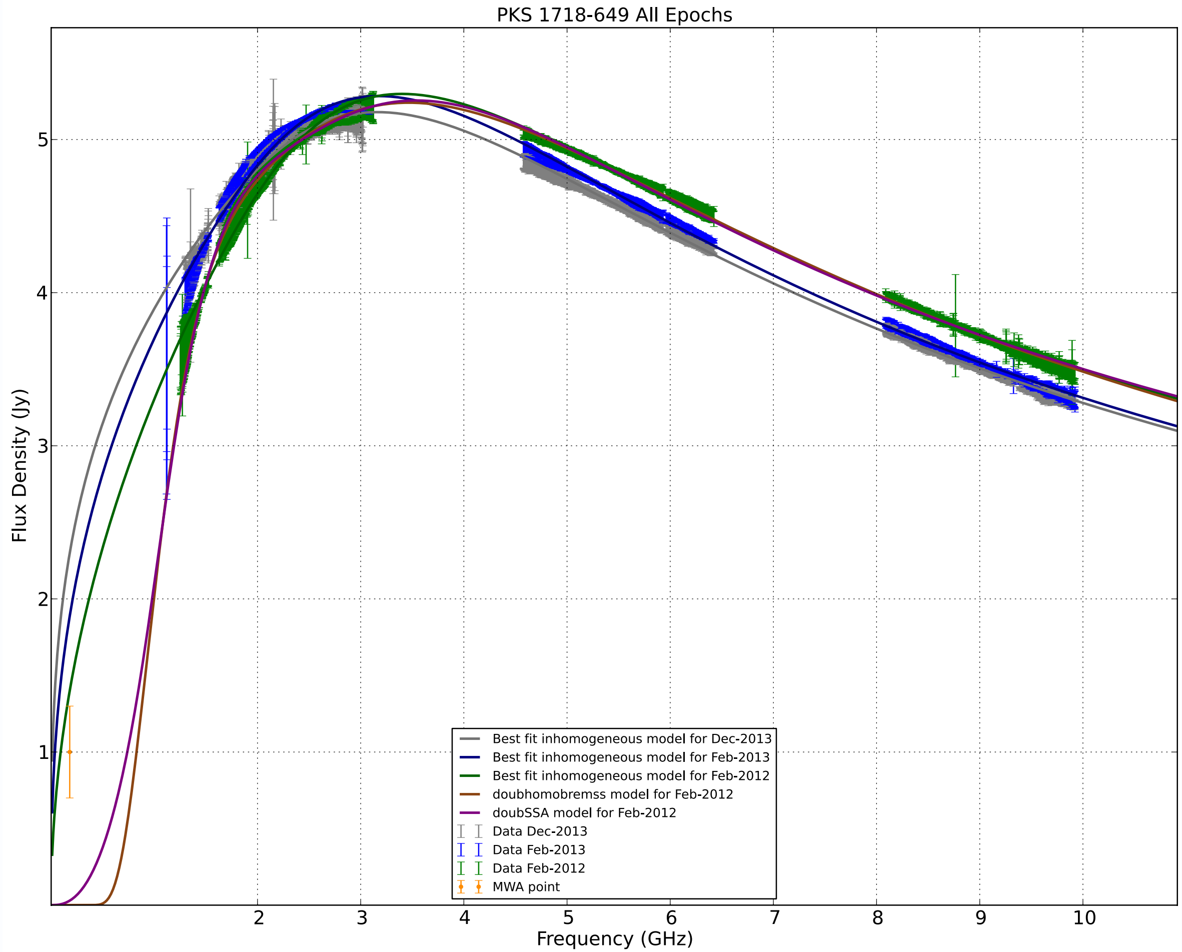
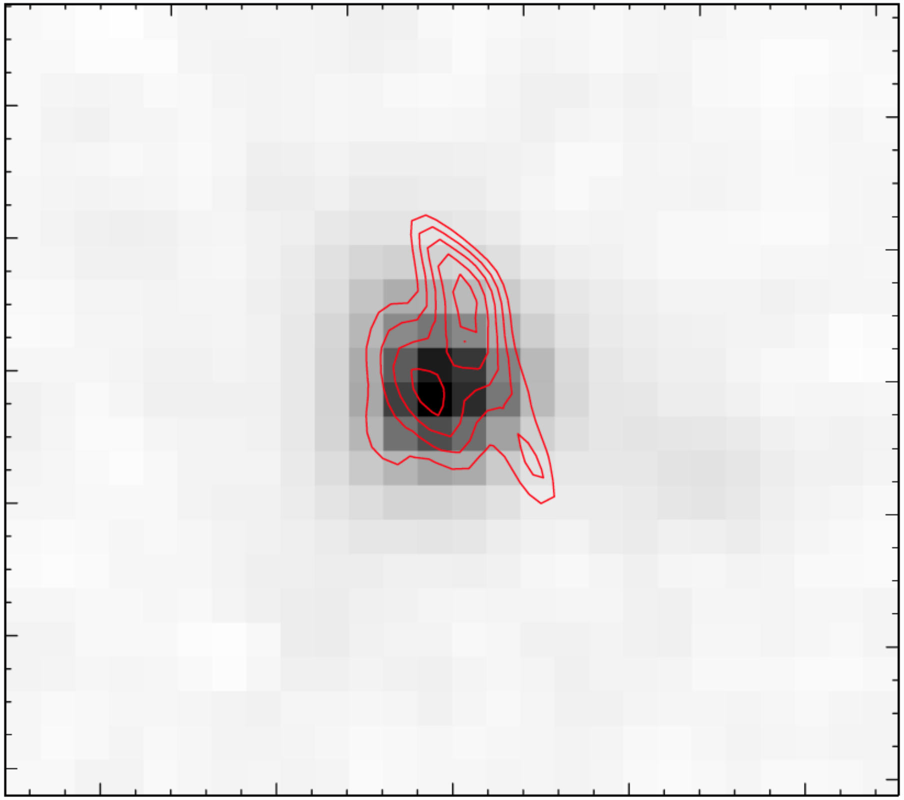
Observations – preliminary radio spectra

Modelling the radio spectrum of GPS source 1718-649 (Tingay+ 2015):

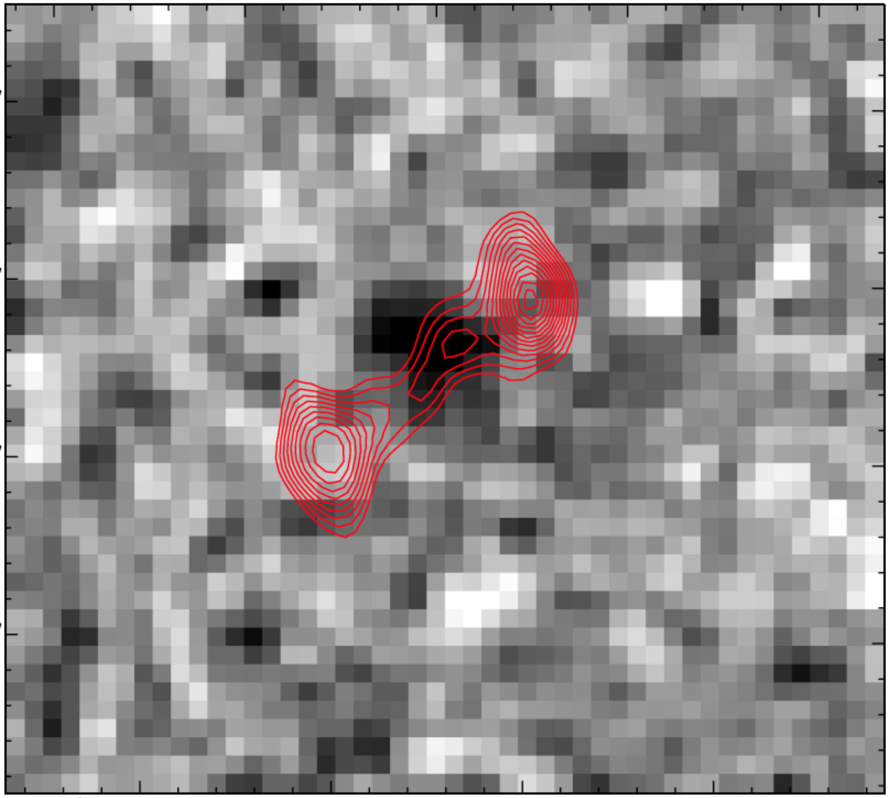


Detecting the hosts of GPS/CSS sources

- 71 ATLAS sources & 72 SMC sources
- Comparing morphologies (radio contours on *Spitzer* 3.6 μm image):

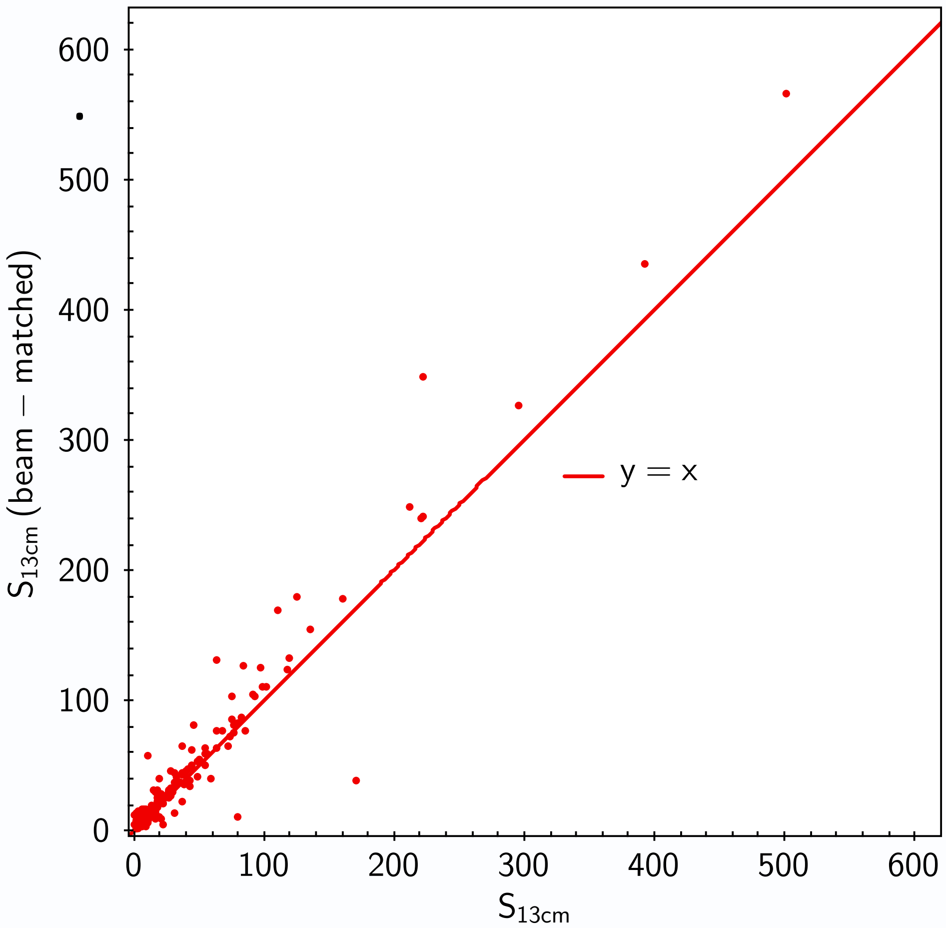


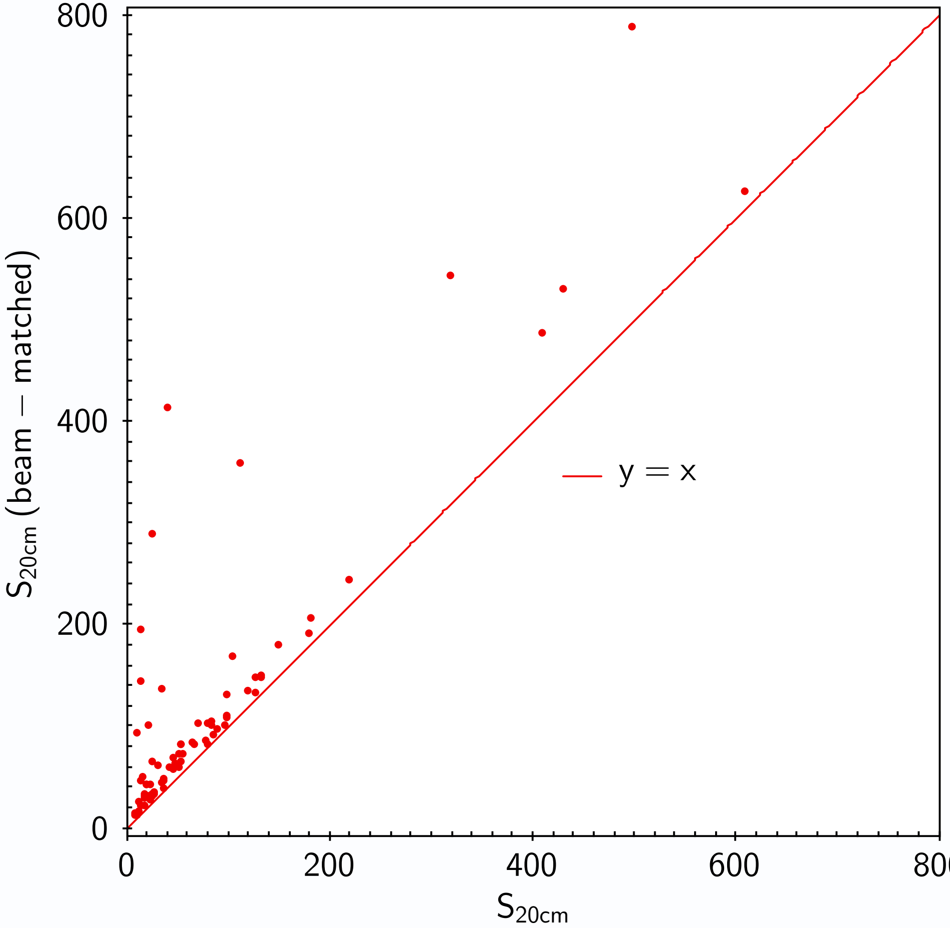
Contour levels: 3,4,5,6,7σ



Contour levels: 5 - 17σ, in 1σ increments

Using accurate fluxes





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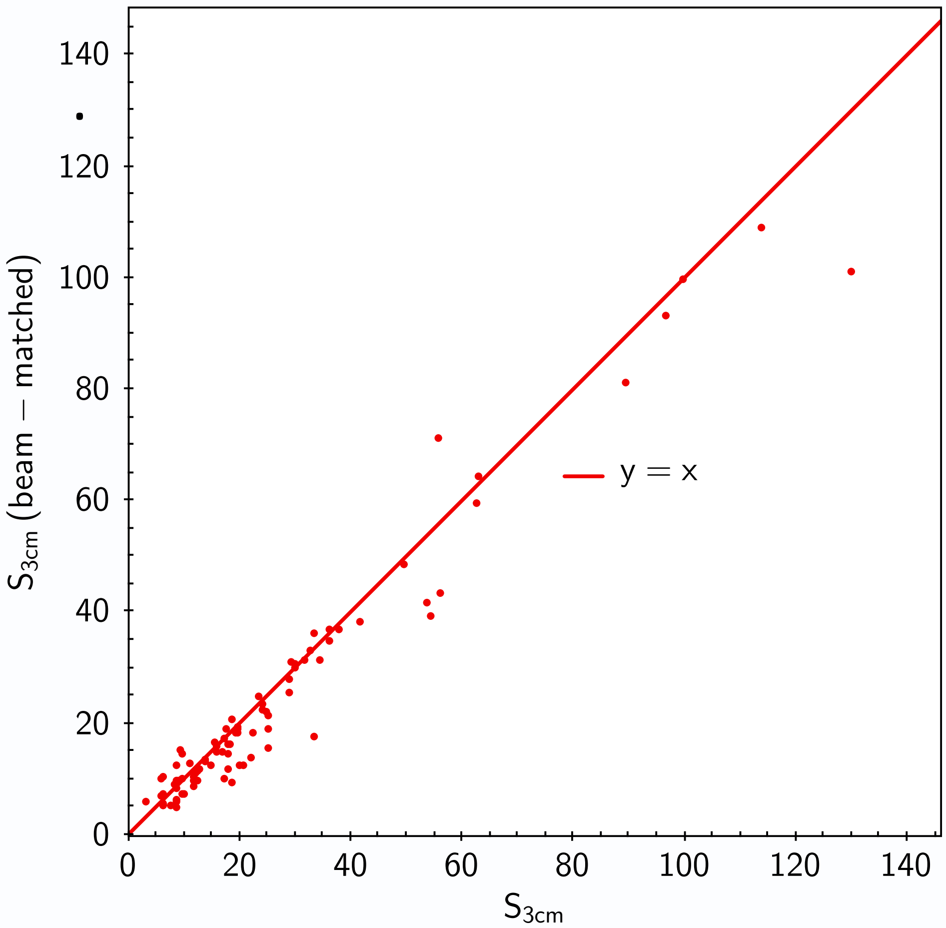

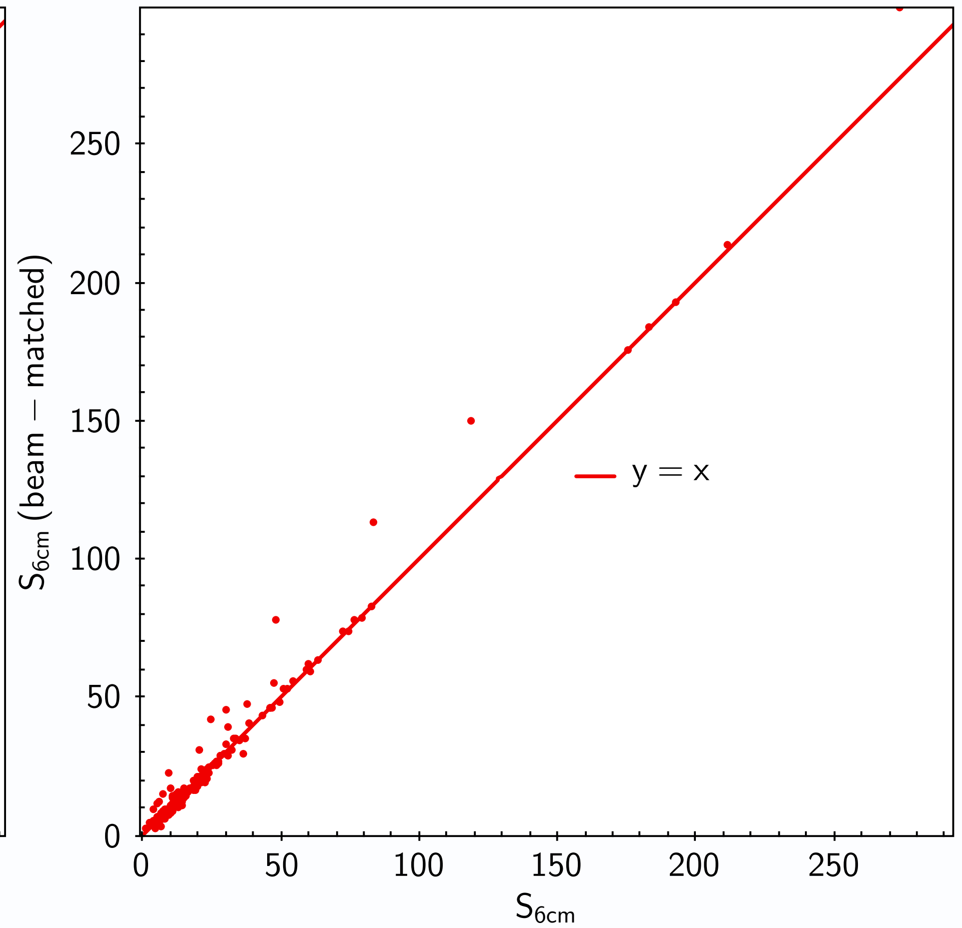

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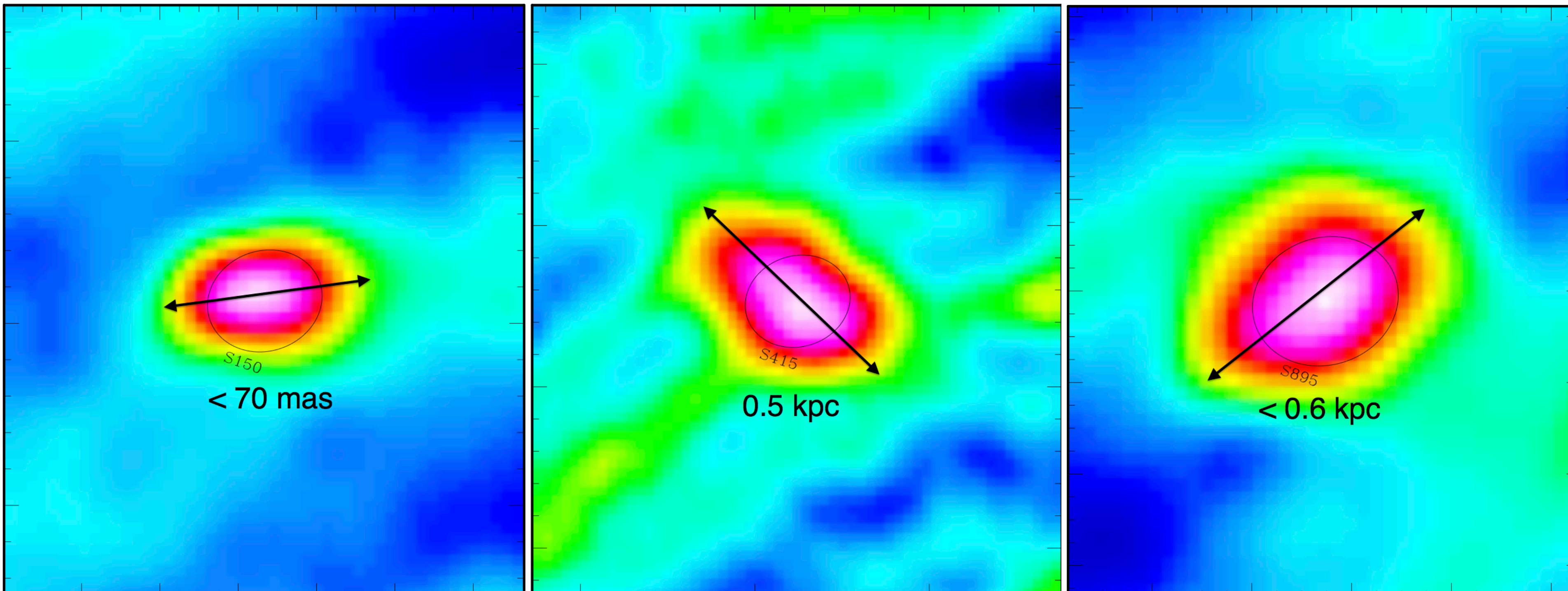

Observations – goals

- Science goals
  1. Test hypothesis that GPS/CSS sources are the youngest radio galaxies
  2. Place GPS/CSS sources into evolutionary sequence with other young AGN
  3. Search for evidence of evolving accretion mode and its relationship to SF
- Observational Goals
  1. Resolve about half sample
     - Measure jet sizes
     - Observe small-scale morphology
     - Construct sub-sample for VLBI follow-up
  2. Measure radio spectra
  3. Select subset of unresolved sources for follow-up with VLBI

Multi-wavelength data

- Data:
  - Radio – MWA, GMRT, ASKAP, MOST, ATCA (150 MHz – 9 GHz)
    - Spectra index, turnover & break frequencies
    - Resolved features / morphologies
    - Measure jet sizes / separation of AGN nuclei
    - Polarimetry / RMs
  - IR / optical – Herschel, WISE, Spitzer, VIDEO, AAT, etc
    - Colours & photometry, SEDs & morphologies, spec-z
  - X-ray – Chandra
    - Temperature / emission type

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