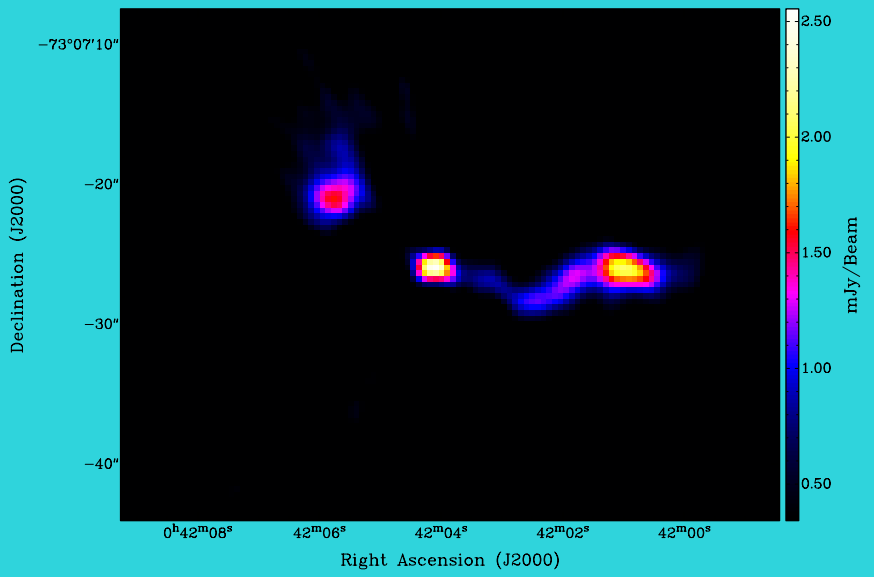


Constraining the Evolutionary Path of the Youngest Radio Galaxies Using Radio Morphology (i.e. jets!)

Jordan Collier | UWS & CASS Student

26th September 2013 | Galaxy Zoo Conference

CSIRO ASTRONOMY & SPACE SCIENCE
www.csiro.au

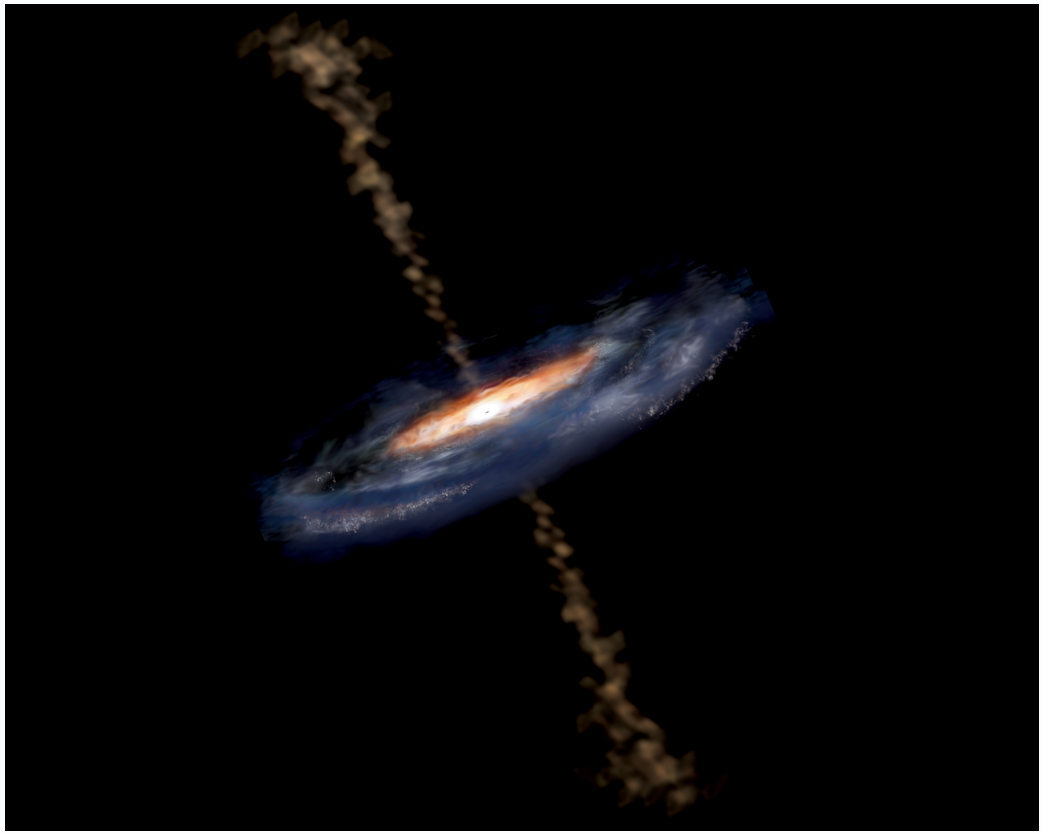
K Chow, R Norris, M Filipović, N Tothill, S Shabala, M Huynh, J Banfield, A Hopkins, E Crawford, G Wong

University of Western Sydney

CSIRO

Outline

- Introduction
  - AGN
  - GPS/CSS sources
  - Project Context
- Data
  - ATLAS
  - SMC
  - ATCA
  - LBA
- Future Work
- Conclusion



AGN

- Active Galactic Nuclei (AGN)
  - Bright & active regions in core of galaxy
  - Powered by SMBHs of ~10^9 $M_\odot$
  - **Radio Galaxies (RGs)** show jets streaming out of AGN
- Problems in AGN studies:
  - Traditional models don't predict SMBHs appear until a few Gyr after big bang (Richstone+ 1998; Volonteri+ 2003)
  - Some observed at 0.5 – 1 Gyr (e.g. Mortlock+ 2011: QSO at z = 7.085)
  - Relationship between AGN & normal galaxies not understood
  - Don't yet understand evolution of young RGs

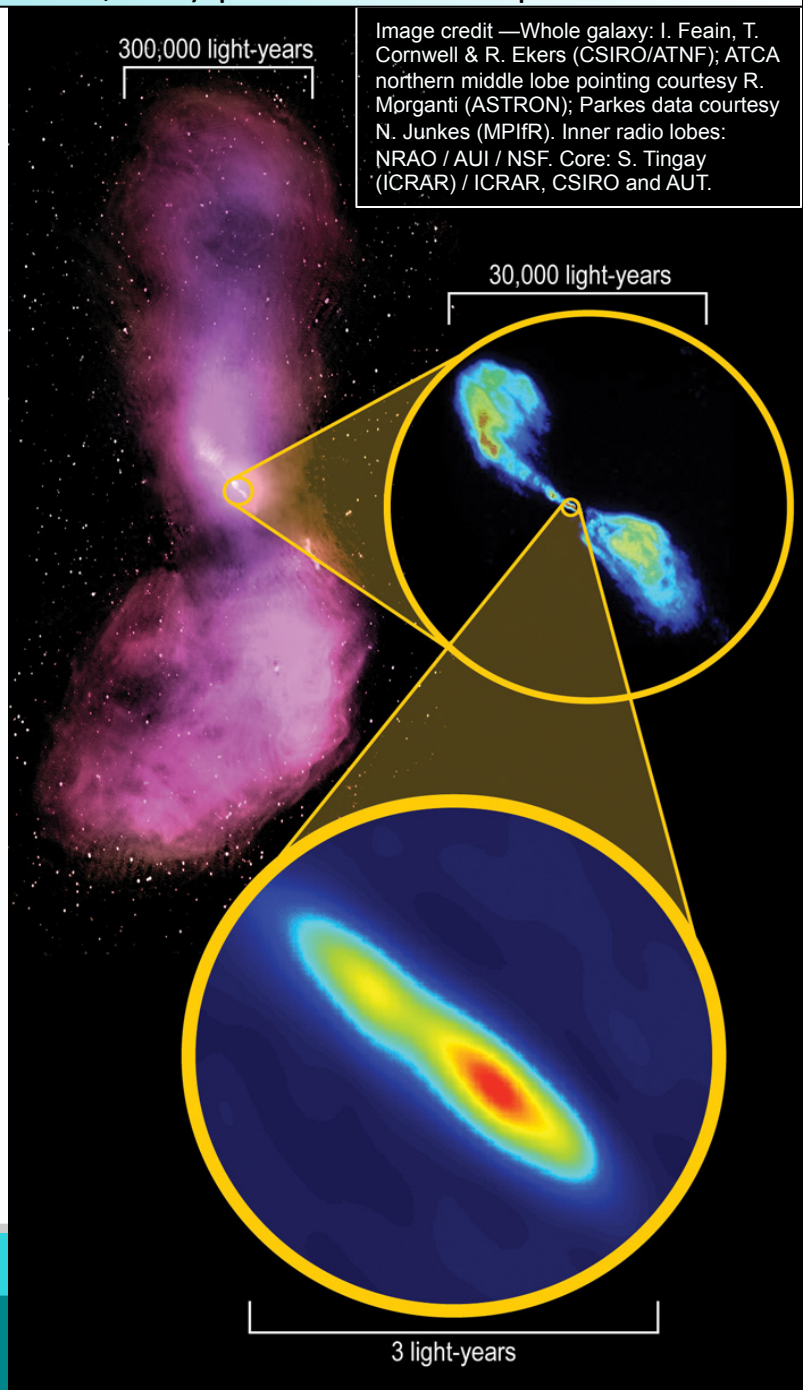
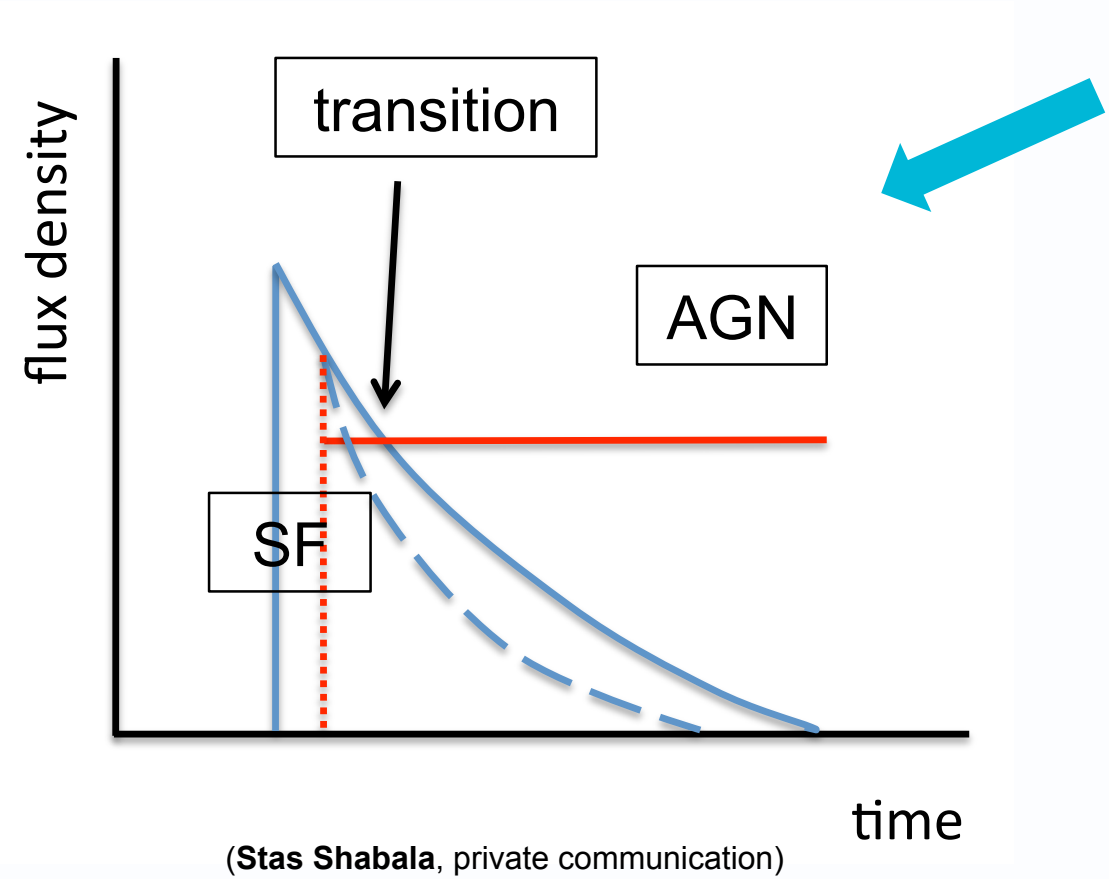


Image credit —Whole galaxy: I. Feain, T. Cornwell & R. Ekers (CSIRO/ATNF); ATCA northern middle lobe pointing courtesy R. Morganti (ASTRON); Parkes data courtesy N. Junkes (MPIfR). Inner radio lobes: NRAO / AUI / NSF. Core: S. Tingay (ICRAR) / ICRAR, CSIRO and AUT.

AGN – Evolution of RGs

- Radio luminosity tracks → AGN age

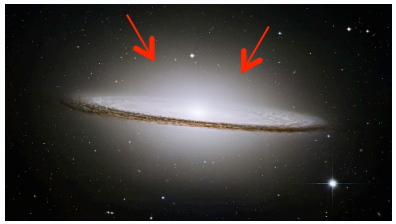


(**Stas Shabala**, private communication)

Merger scenario ("Cold mode")

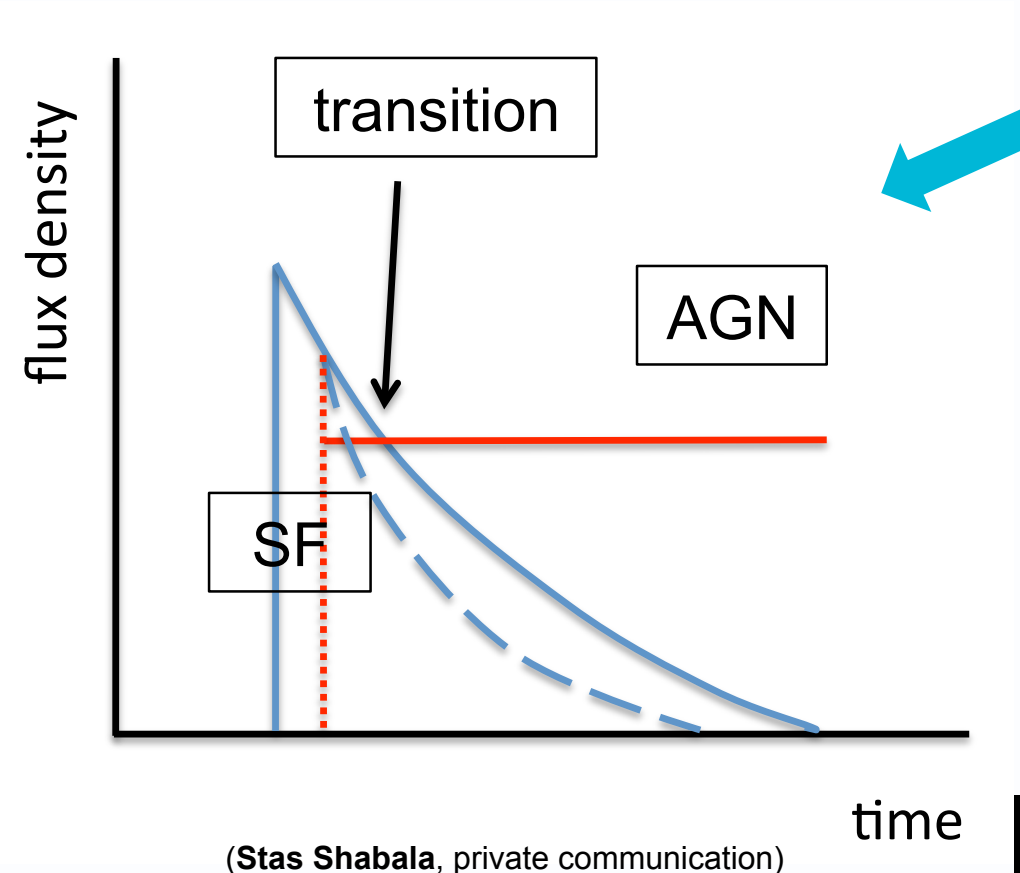
OR

In-falling of hot halo gas ("Hot mode")?



AGN – Evolution of RGs

- Radio luminosity tracks → AGN age



(**Stas Shabala**, private communication)

Merger scenario ("Cold mode")

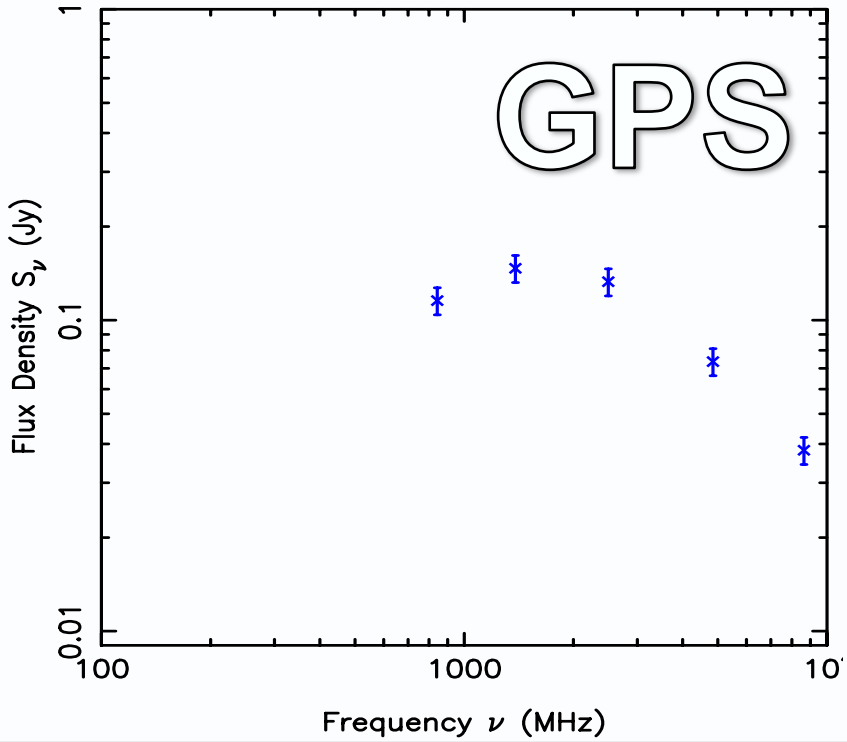
OR

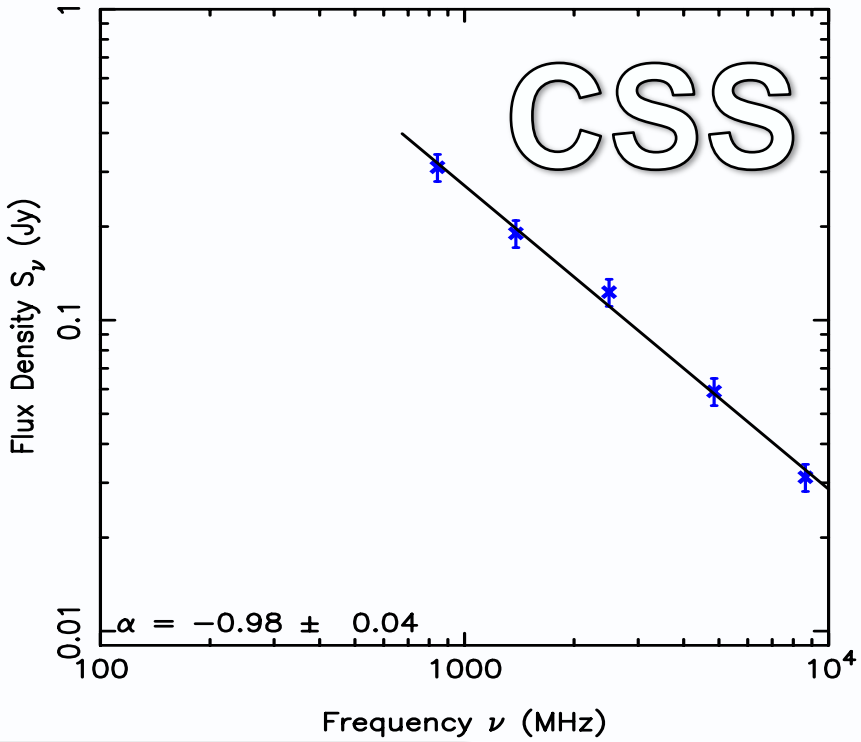
In-falling of hot halo gas ("Hot mode")?

From Galaxy Zoo blog!

GPS/CSS sources – the youngest AGN?

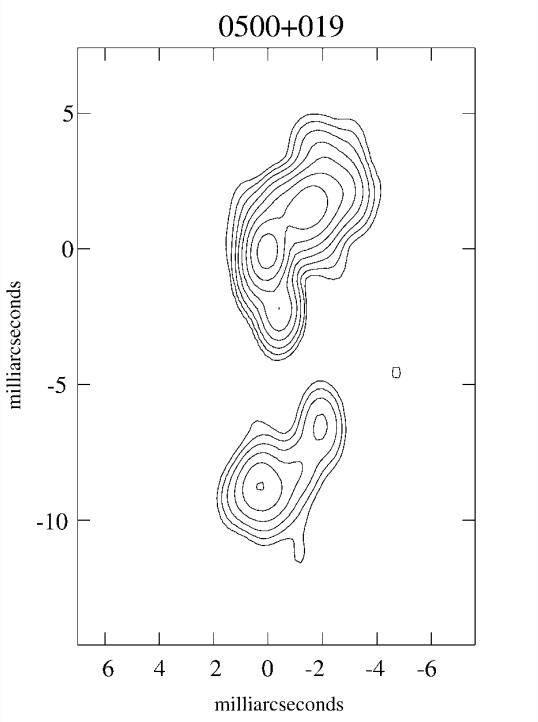
- Gigahertz Peaked Spectrum (GPS) & Compact Steep Spectrum (CSS) sources believed to be youngest RGs

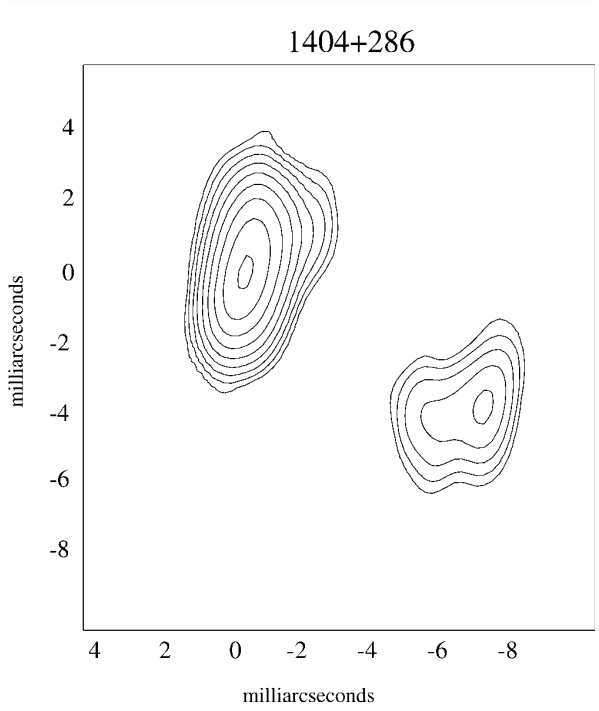


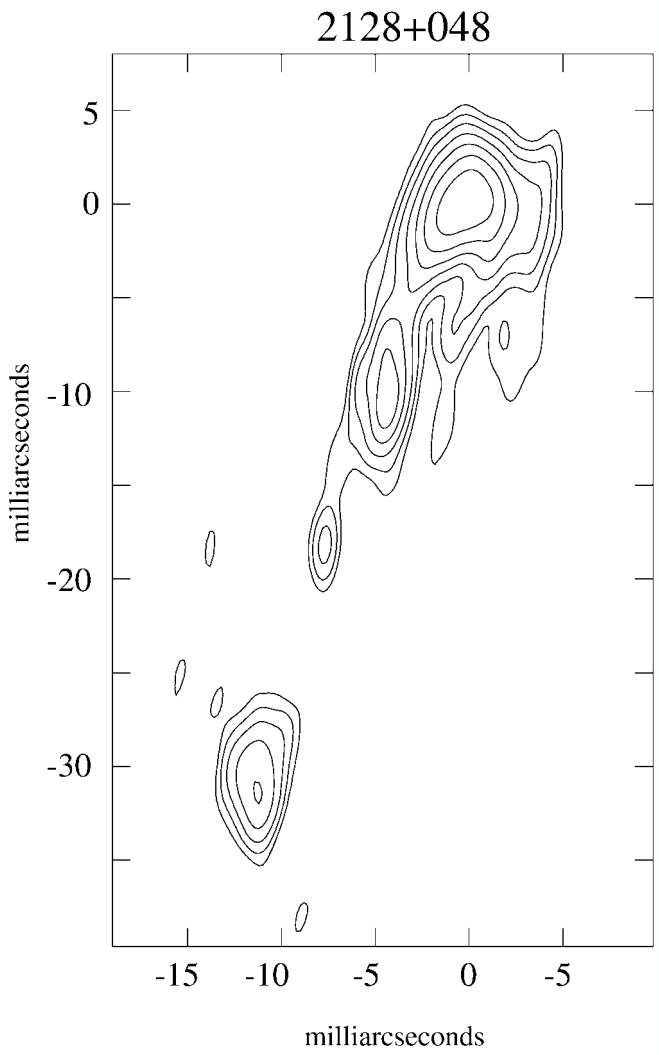


GPS/CSS sources – the youngest AGN?

- Have very small radio jets
  - Usually observed with
    Very Long Baseline Interferometry (VLBI)





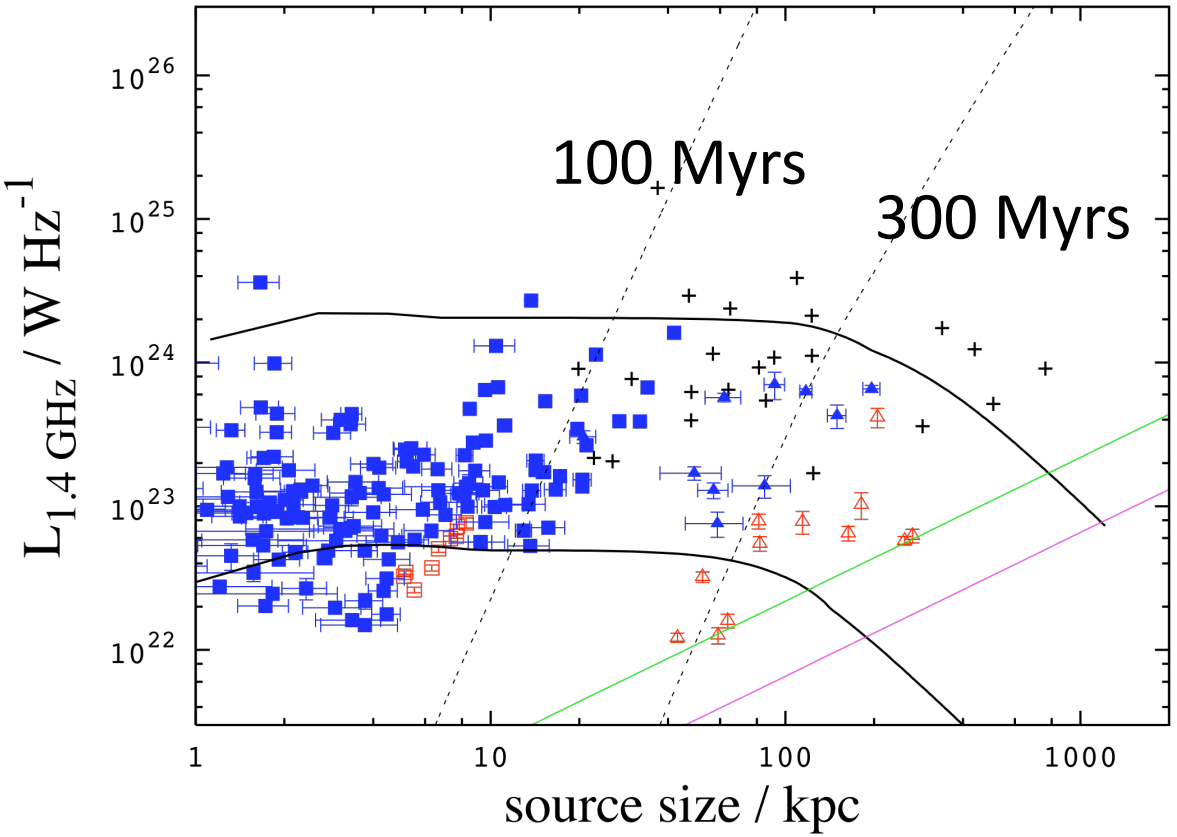


Images: O'Dea (1998)

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

Shabala et al. 2008, MNRAS 388, 625



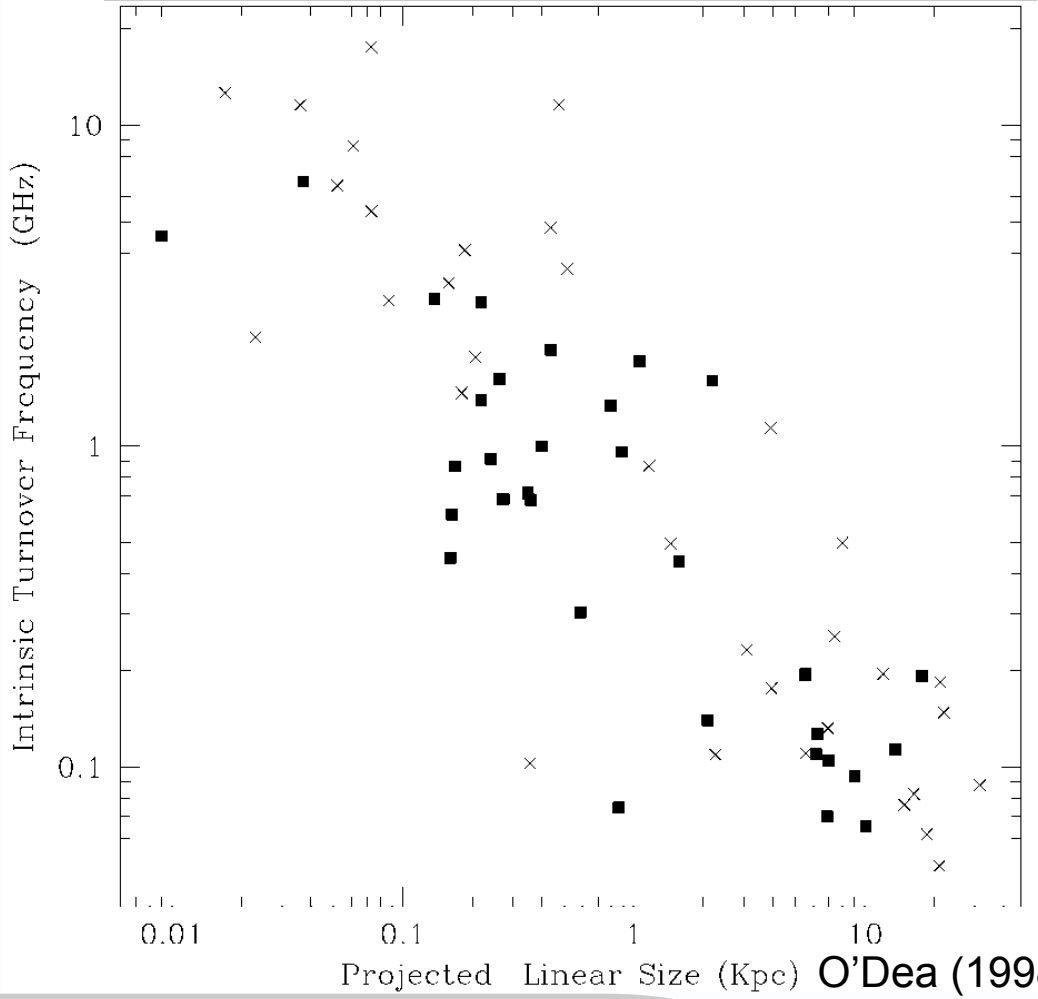
GPS/CSS sources – the youngest AGN?

- $\upsilon_m - \ell$ relation

- $P_{radio} - \ell$ relation?
  - Large luminosities
  - How far down in flux density is this power seen?

- Studies limited to Jy levels
- Randall+ (2012) is faintest sample
  - Goes down to a few mJy

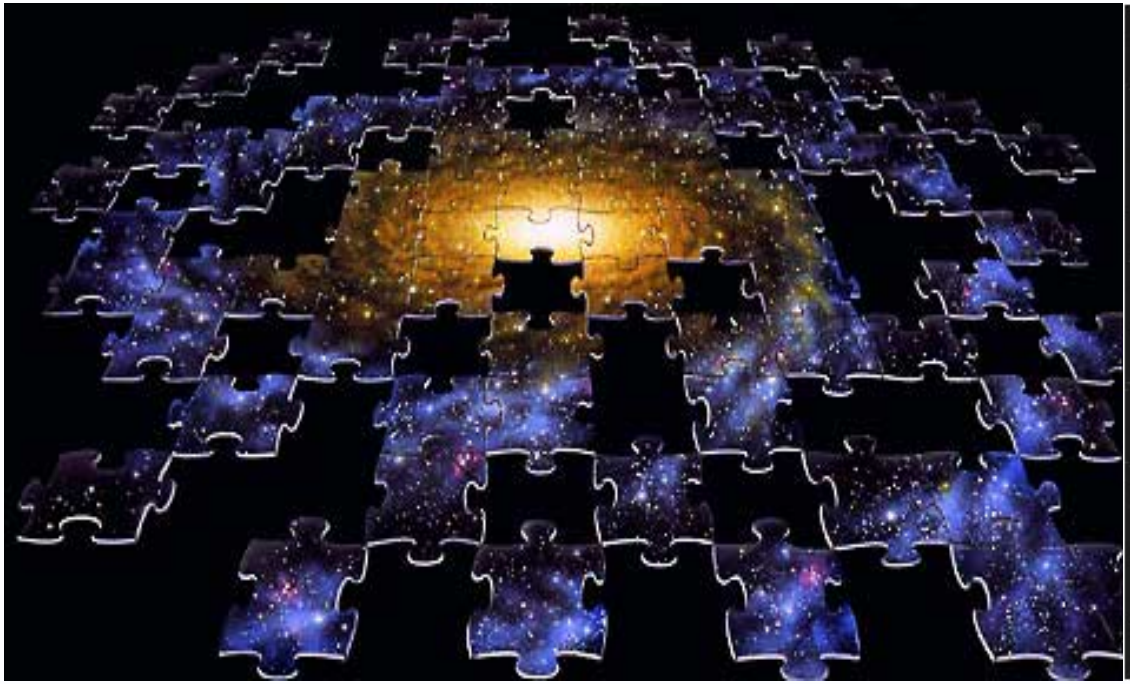
$$\log \upsilon_m = -0.21(\pm 0.05) - 0.65(\pm 0.05) \log \ell$$



O'Dea (1998)

Project Goal

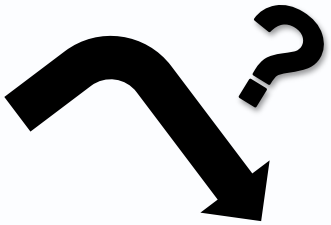
- Aim: To construct an evolutionary sequence for the early stages of AGN, with a particular focus on faint GPS/CSS sources

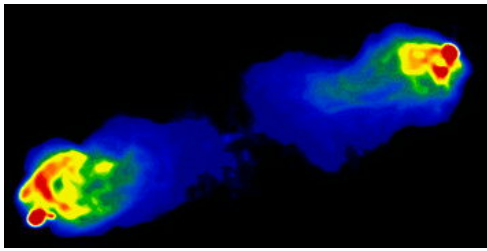


- Never had place in evolutionary sequence confirmed
- We will study very faint RGs from radio – X-rays over a large sample in order to detect meaningful tracers of their age (e.g. **jet sizes**, colours, LFs, etc)

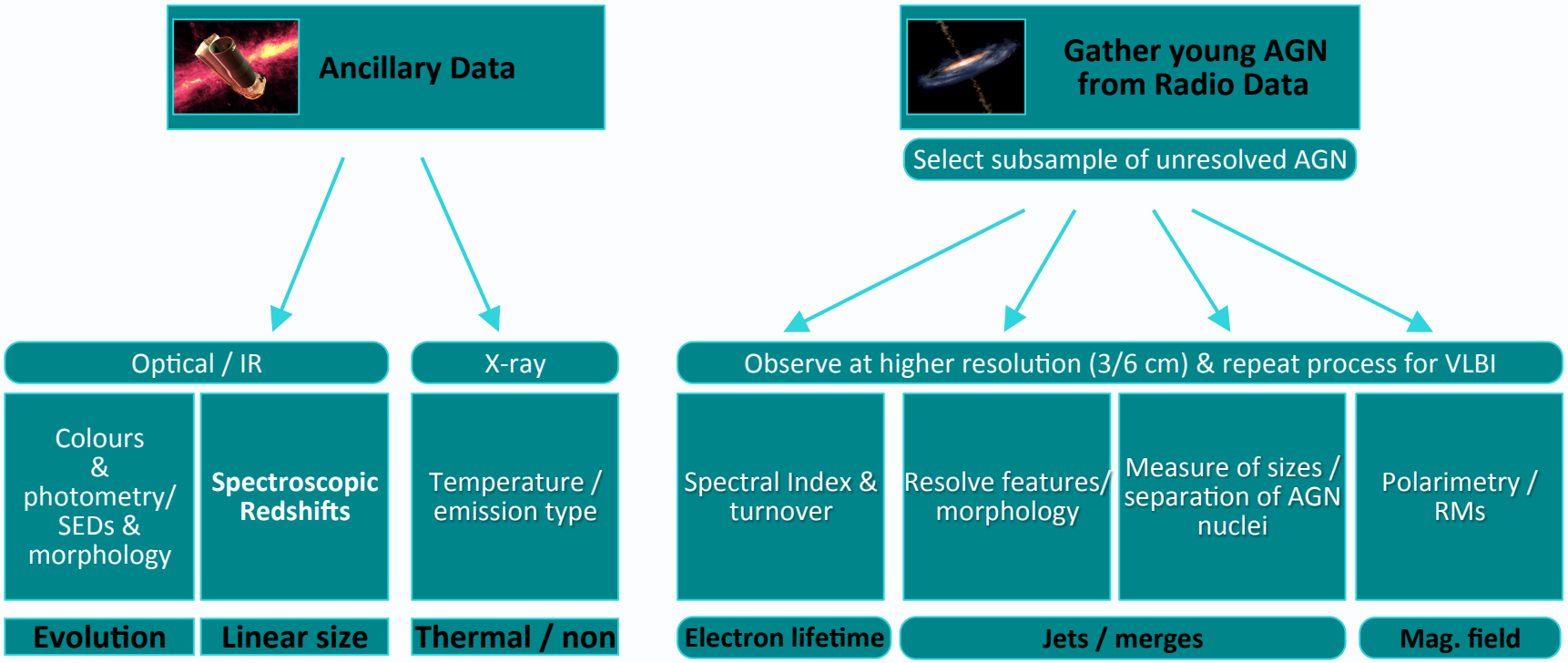
AGN – questions to address

- AGN evolution
  - When do AGN first appear? What evolutionary path do they follow?
  - Does AGN evolution occur in a short burst or gradually over few Gyr?
  - Why are AGN seen so early in the universe?
- Young RGs
  - GPS → CSS → Large-scale RGs (FR I/II)?
  - What are the properties of very faint GPS/CSS sources?
  - Are their large luminosities present at low flux density?
- What we need:
  - Good radio spectral coverage
  - High resolution radio images
  - Deep multi-wavelength data



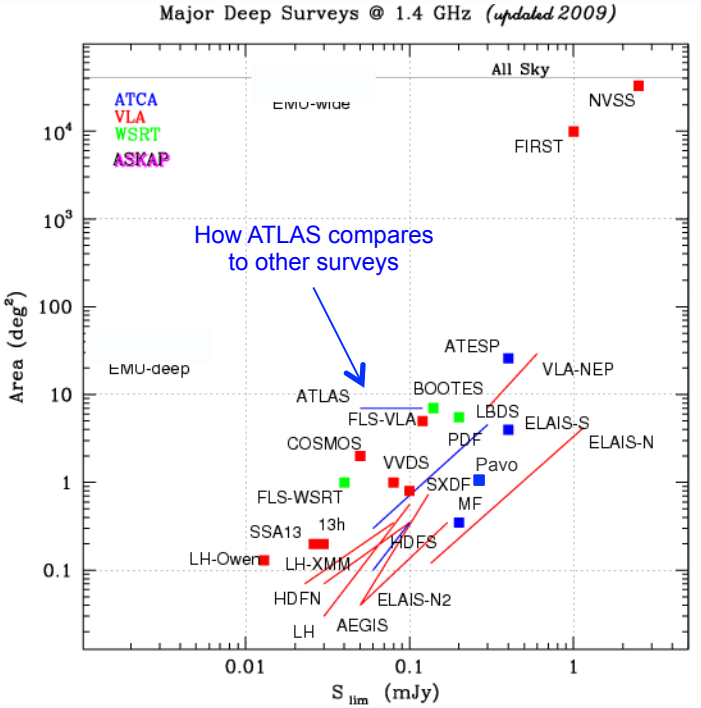


Project Method



The Australia Telescope Large Area Survey (ATLAS)

- Widest deep radio survey (Norris+ 2006; Banfield+ 2013, in prep.)
  - 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; Banfield+ 2013)
  - > 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

Small Magellanic Cloud (SMC)

- 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 (probably AGN) – 1560 at 20 cm from Wong+ (2011)
  - Great spectral coverage across wavelengths from 3 cm – 36 cm
  - Wider & somewhat deep (0.4 – 0.8 mJy –> complimentary to fainter AGN)
  - Well-studied
    - Surveys from other bands include Spitzer, Chandra, XMM
    - Many spectroscopic redshifts (Kozlowski+ 2013) and RMs (Mao+ 2008)

Samples

Ancillary Data

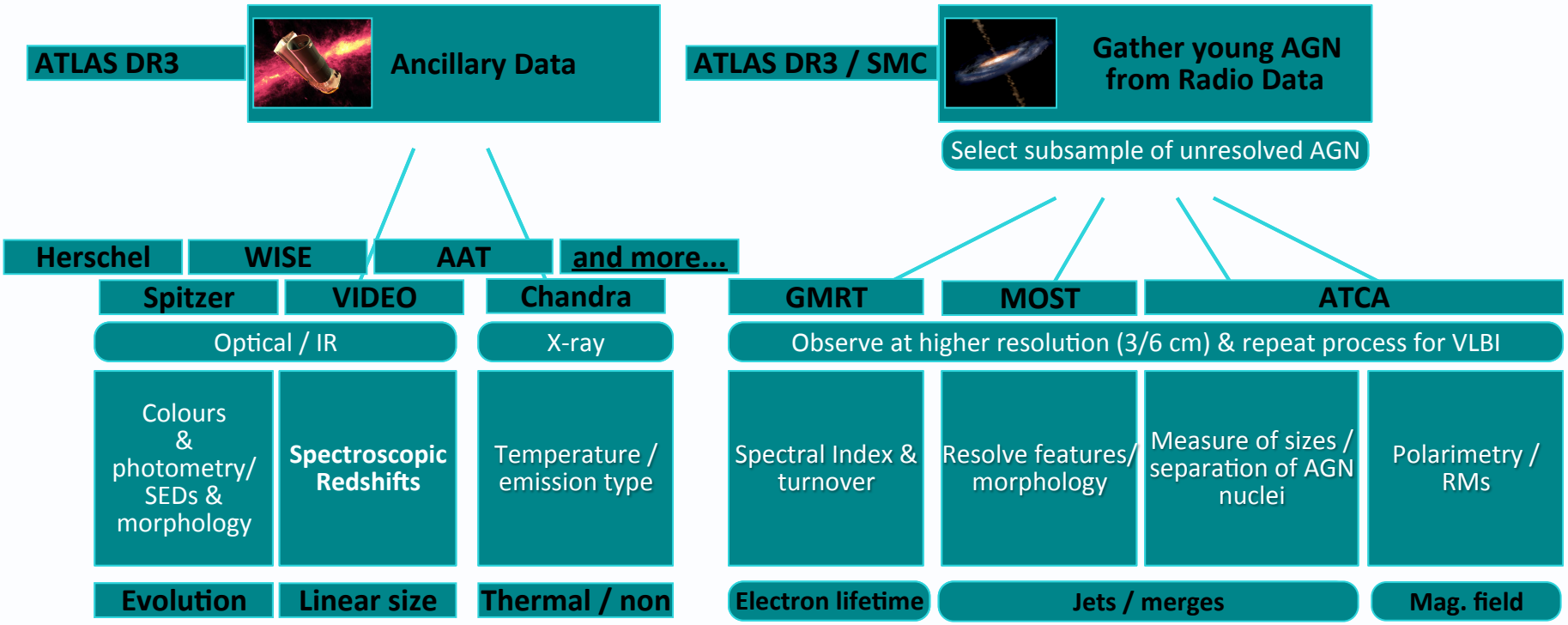
Gather young AGN from Radio Data

Select subsample of unresolved AGN

Optical / IR		X-ray
Colours & photometry/ SEDs & morphology	**Spectroscopic Redshifts**	Temperature / emission type
Evolution	**Linear size**	**Thermal / non**

Observe at higher resolution (3/6 cm) & repeat process for VLBI			
Spectral Index & turnover	Resolve features/ morphology	Measure of sizes / separation of AGN nuclei	Polarimetry / RMs
Electron lifetime	**Jets / merges**		**Mag. field**

Samples



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

Observations

- High resolution (~1 arcsec) obs.

  of **faintest GPS/CSS sample to date**

Telescope	Project number	Date	Array Config.	Frequency / wavelength	Time	Objects
ATCA	C2730	Dec 2012	6B	9 GHz (3/6cm)	39 h	49 faint ELAIS-S1 GPS/CSS
ATCA	C2768	Feb 2013	6A	9 GHz (3/6cm)	12 h	72 mid-strength SMC GPS/CSS

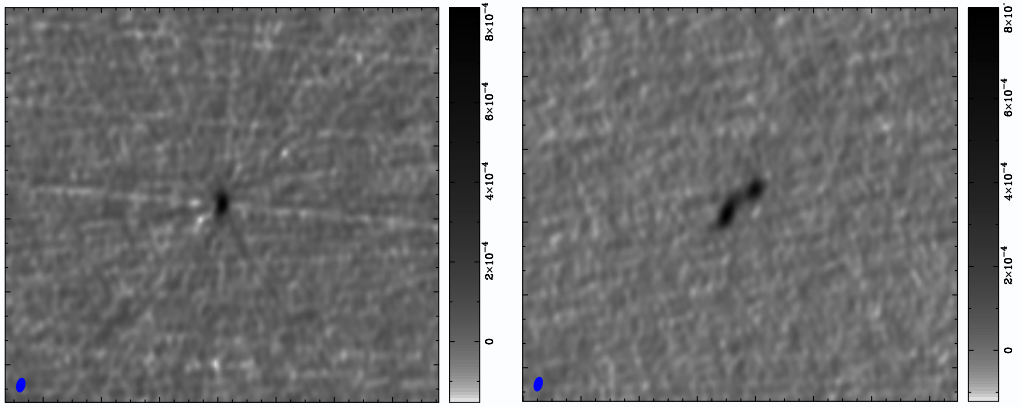
- Sources selected to be unresolved at 10” and have a GPS/CSS spectrum
  - Using Randall+ (2011) for ELAIS-S1 and Wong+ (2011) & Crawford+ (2011) for SMC
- Now we have significant spectral coverage:
  - **ATLAS** – 8+ frequencies between 0.150 – 9 GHz (*GMRT, MOST, ATCA*)
  - **SMC** – 5+ frequencies between 0.843 – 9 GHz (*MOST, ATCA*)

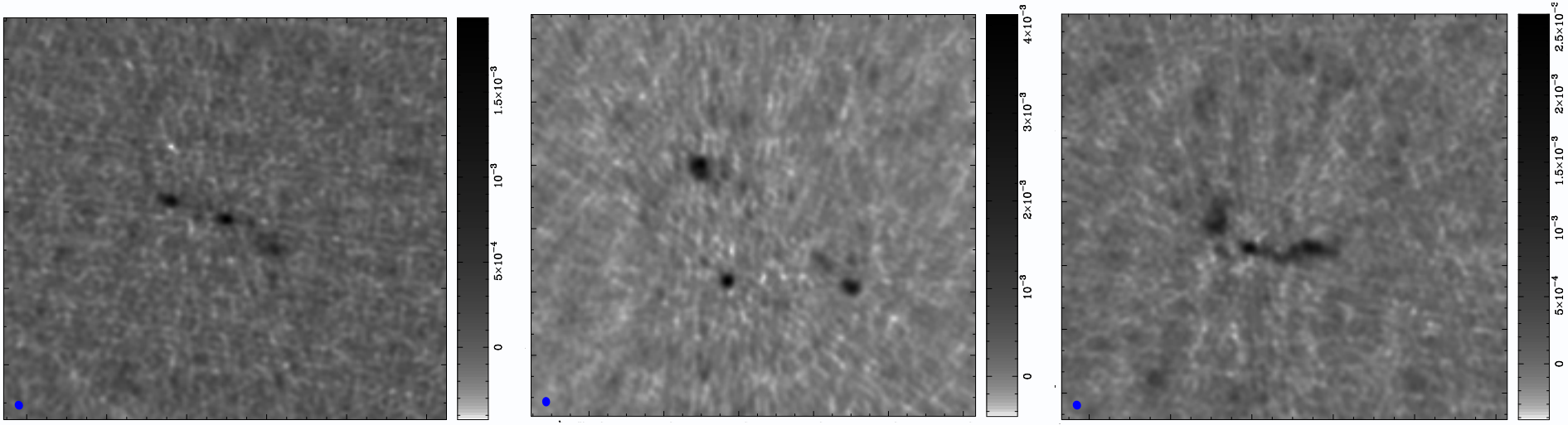
Observations – goals

- 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

Observations – preliminary maps

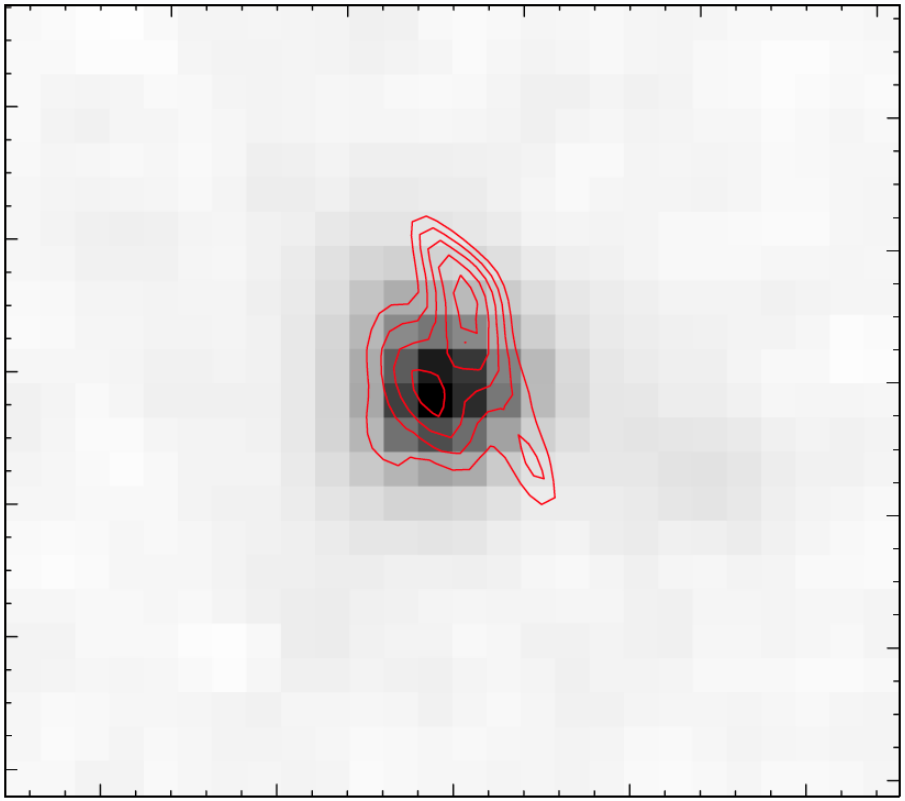
- First pass reduction of 49 ATLAS sources & 72 SMC sources
  - ELAIS-S1 sources "complete" down to ~100 μJy (5σ)
- So far met our goals of resolving ~half sample & measuring spectra
- Interesting maps:



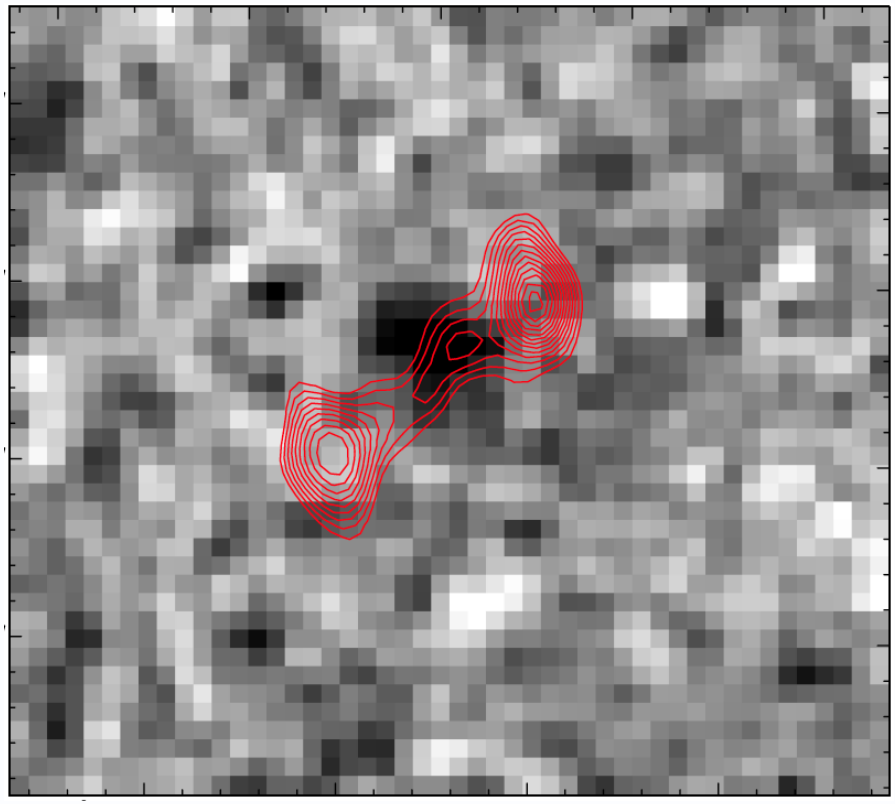


Observations – preliminary maps

- First pass reduction of 49 ATLAS sources & 72 SMC sources
- Interesting maps (radio contours on *Spitzer* 3.6 μm image):



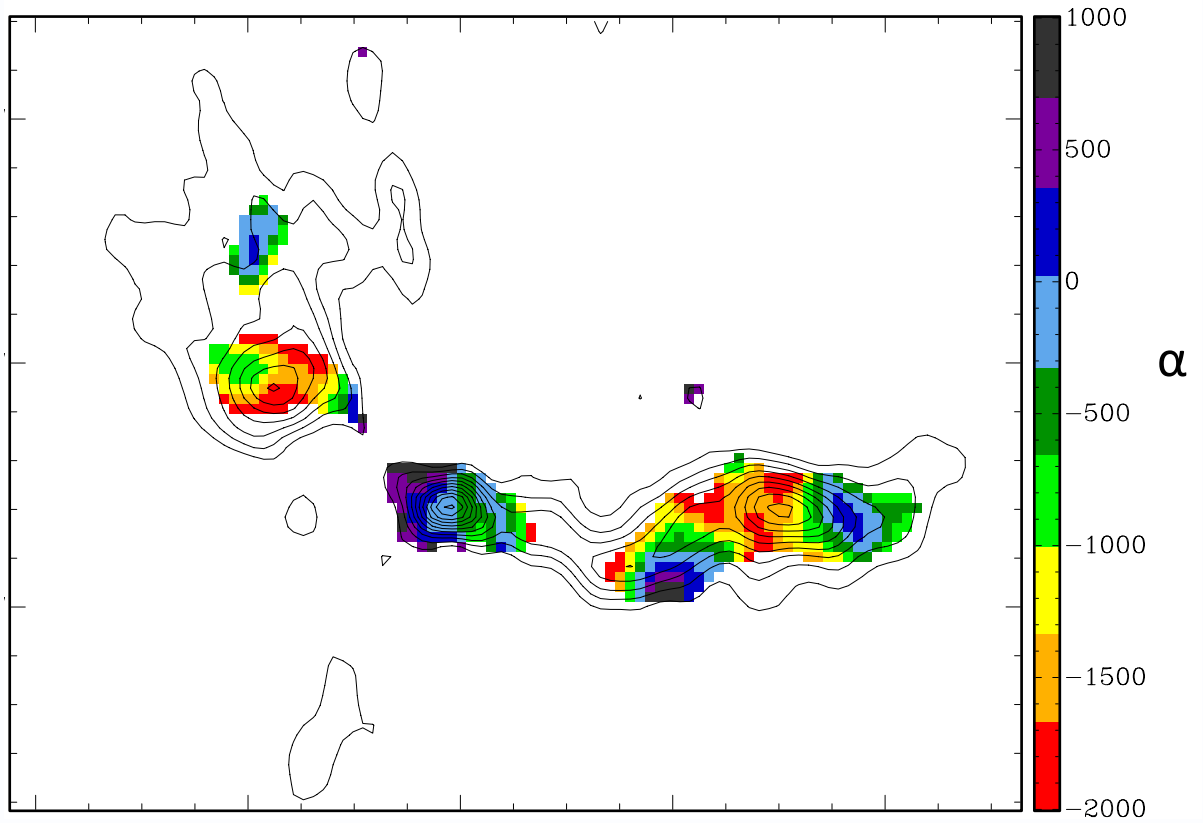
Contour levels: 3,4,5,6,7σ



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

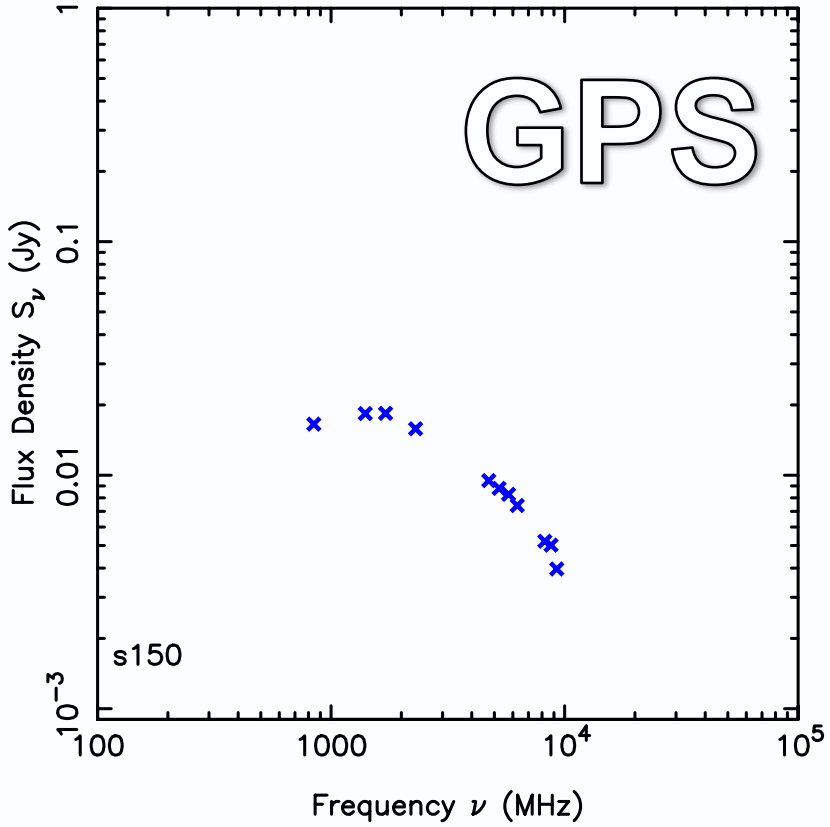
Observations – preliminary maps

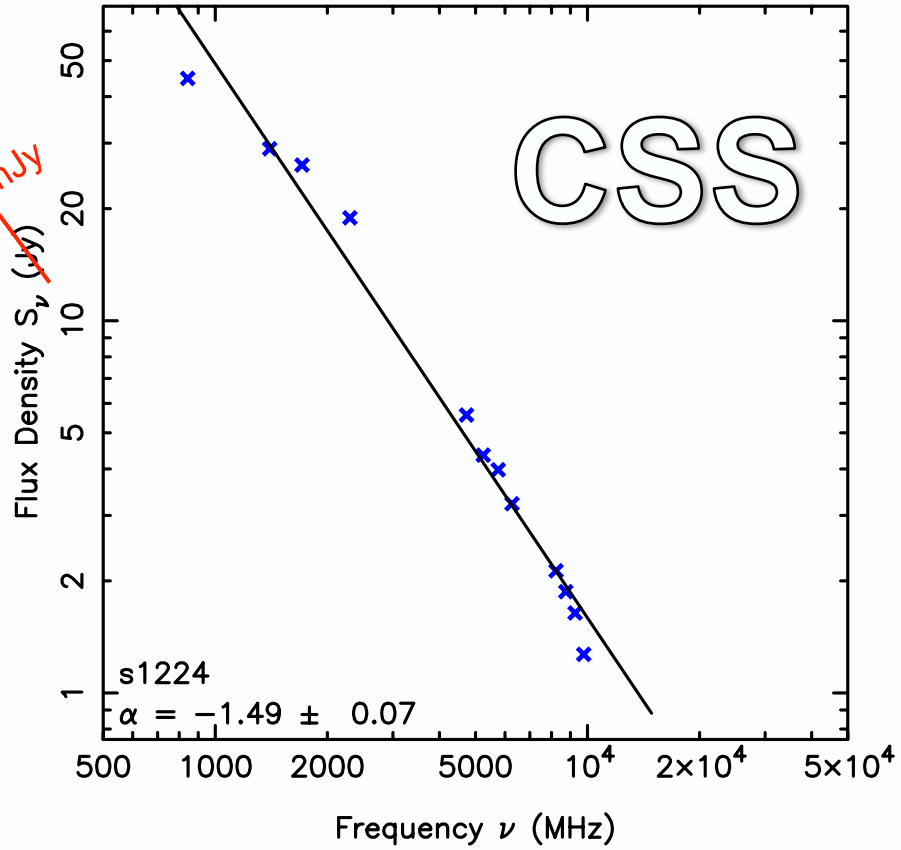
- First pass reduction of 49 ATLAS sources & 72 SMC sources
- Interesting maps (spectral index map between 5.5 & 9.0 GHz):



Observations – preliminary radio spectra

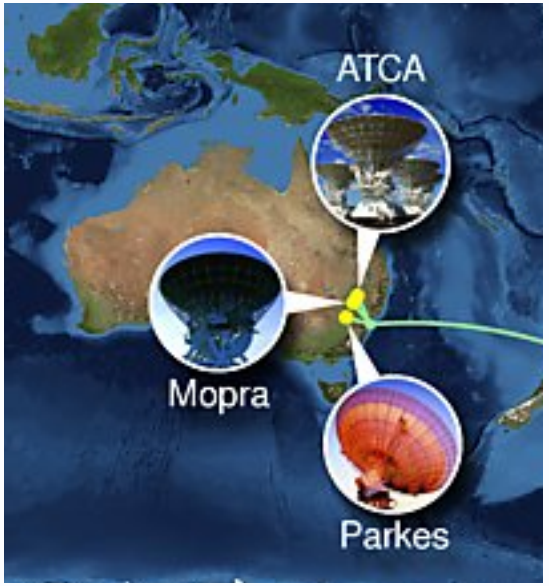
- First pass reduction of 49 ATLAS sources & 72 SMC sources
- Interesting spectra:





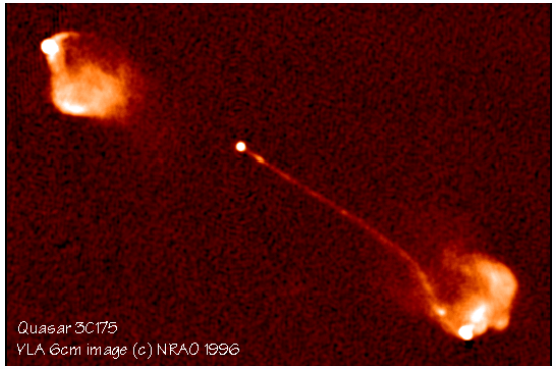
Observations – LBA proposal

- LBA proposal submitted
- Selected unresolved sources with redshifts
  - From ELAIS-S1 & CDFS
- Since we'll have a range of source sizes, we will be able to confirm or reject the young RG hypothesis
- 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** known radio binary AGN with separation < 1 kpc (Rodriguez+ 2006)
  - Test hierarchical merging + gravitational waves

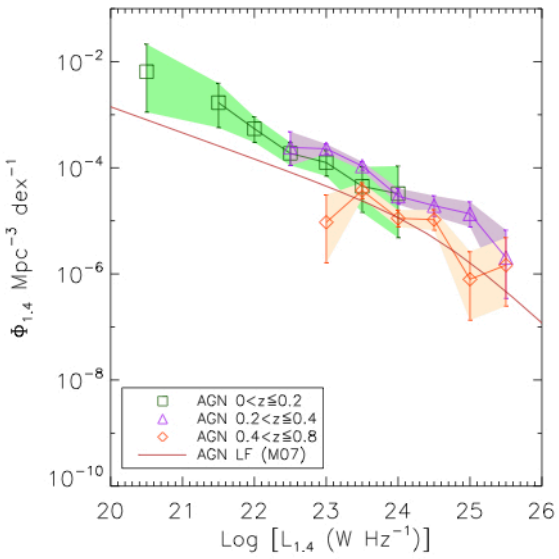


Multi-wavelength Comparison

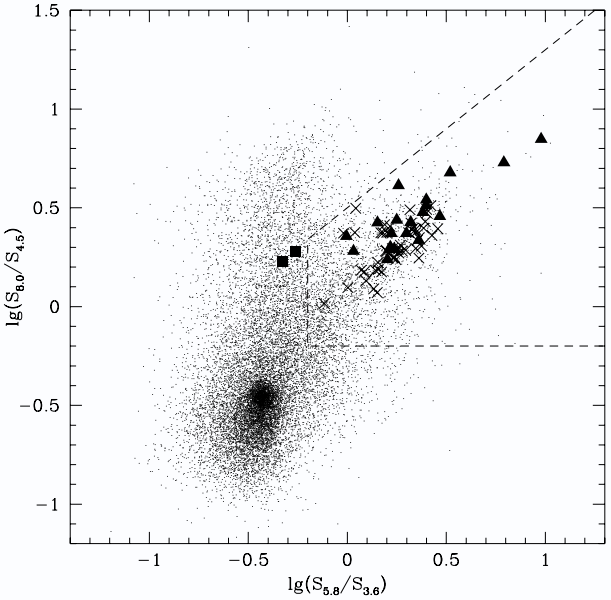
- Main age indicators:
  - Angular size & redshift → linear size & luminosity tracks
    - Herschel SFR against jet age - can we see the quenching in action?
  - Electron lifetimes / spectral age & index (based on break / turnover frequency & polarisation)
  - Separation of nuclei (binary AGN)?
  - Luminosity functions
  - Colours & SED of host



(Mao+ 2012)



(Lacy+ 2004)



Conclusion

- We have observed the faintest GPS/CSS sample to date
- High-res. obs. have allowed us to resolve jets of many sources
- Future VLBI obs. will resolve the most compact (young) sources
- 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 confirm / reject the young RG hypothesis
- We will watch the radio jets quenching the SF (or not!)
- We will discover the properties of very faint GPS/CSS sources

Control freak moving the telescope:

Thank you

CSIRO / UWS

Jordan Collier

UWS & CASS Student

t +61 414 443 622

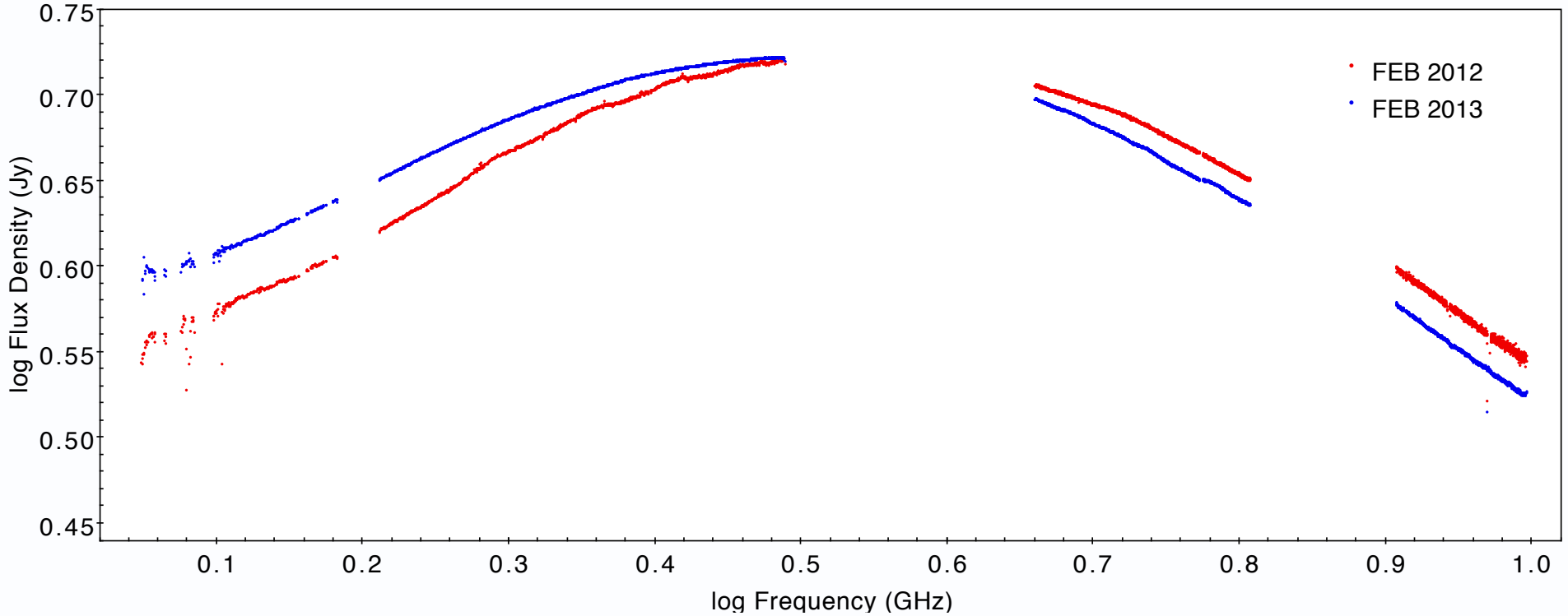
e j.collier@uws.edu.au

University of Western Sydney

CSIRO

Observations – preliminary radio spectra

Modelling the radio spectrum of GPS source 1718-649 (Tingay+ in prep.):



Further Future Plans

Immediate:

- Reduce all ATCA data
  - 8 x 512 MHz maps, 2 x 2 GHz maps (Stokes I, Q, U)
  - Spectral index maps
- Publish SMC catalogue
  - Source counts, morphology, jet sizes, polarisation & RMs, spectral indices, turnovers, compactness, SEDs, multi-wavelength properties, etc

Later:

- LBA obs. and reduction
- Observe CDFS with ATCA at 3/6 cm (next proposal round)?
- Publish ATLAS GPS/CSS sources (ELAIS-S1 + CDFS?)
- Publish LBA obs. & construct evolutionary sequence