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Combining Australia and Cambridge surveys to investigate the high-radio-frequency source population

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Outline

- Introduction
- 10C survey
  - Source counts
  - Matching with 1.4-GHz surveys
- Spectral-index properties over range of flux densities covered by AT20G, 9C and 10C surveys
- AT20G-deep pilot survey
  - Data analysis
  - First results
- Conclusions and future work

Background

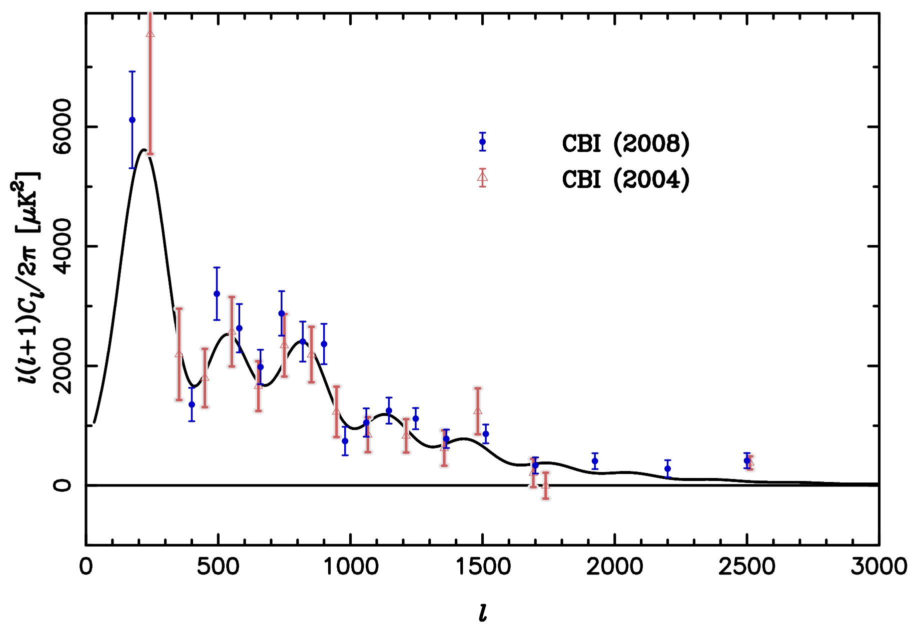
- High-radio-frequency ($\gtrsim$ 10 GHz) sky relatively unexplored
- WMAP survey (Gold et al. 2011) at 23-94 GHz
  - Whole sky complete to ~ 2 Jy
- AT20G survey (Ricci et al. 2004; Sadler et al. 2006; Massardi et al. 2008, 2010; Murphy et al. 2010) carried out using ATCA at 20 GHz
  - Whole southern sky complete to ~ 100 mJy
- 9C survey (Waldram et al. 2003, 2010) carried out using the Ryle Telescope (RT) at 15.2 GHz
  - 520 deg^2 complete to 25 mJy
  - 115 deg^2 complete to 10 mJy
  - 29 deg^2 complete to 5.5 mJy
- 10C survey (Franzen et al. and Davies et al. 2011) carried out using the Arcminute Microkelvin Imager (AMI) Large Array (LA) at 15.7 GHz
  - 27 deg^2 complete to 1 mJy
  - 12 deg^2 complete to 0.5 mJy

Background

- High-frequency radio surveys are highly time consuming
  - Interferometer primary beam area: $\propto \nu^{-2}$
  - Typical synchrotron spectra of radio sources: $S \propto \nu^{-0.7}$
  - Hence survey time scales as $\nu^{3.4}$
- Play a vital role in characterizing and removing astrophysical foregrounds for CMB experiments
- Provide unbiased view of rare, interesting, classes of sources with flat spectra up to high frequencies - blazars, GPS sources

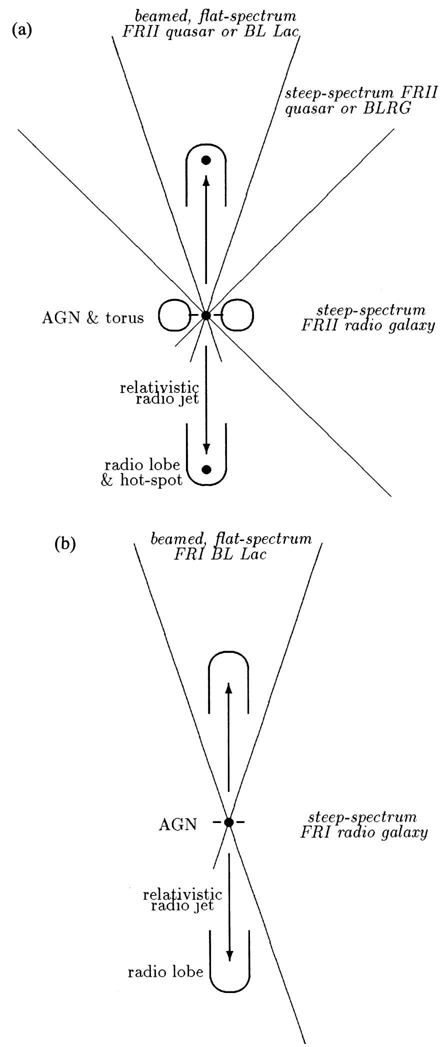
CBI excess

- Using the Cosmic Background Imager at 31 GHz, Sievers et al. (2009) measured a significant excess of power over intrinsic CMB anisotropy at angular multipoles ≳ 2000
- Still not clear whether or not this excess of power is due to incorrect subtraction of extragalactic radio point sources
- 1.4-GHz data were used to characterize the source population at a much higher frequency



Unified scheme for radio-loud AGN

- Based on 2 parent populations: high radio-power FRII galaxies and moderate radio-power FRI galaxies
- Both populations exhibit anisotropic radiation arising from superluminal motion of the radio jets
- In addition, obscuration by a dusty torus contributes to the orientation-dependent appearance of FRIIs
- FRII radio galaxies are the parents of all radio quasars (and some BL Lac-type objects)
- FRI radio galaxies are the parents of BL Lac-type objects



FRII

FRI

Jackson and Wall 1999

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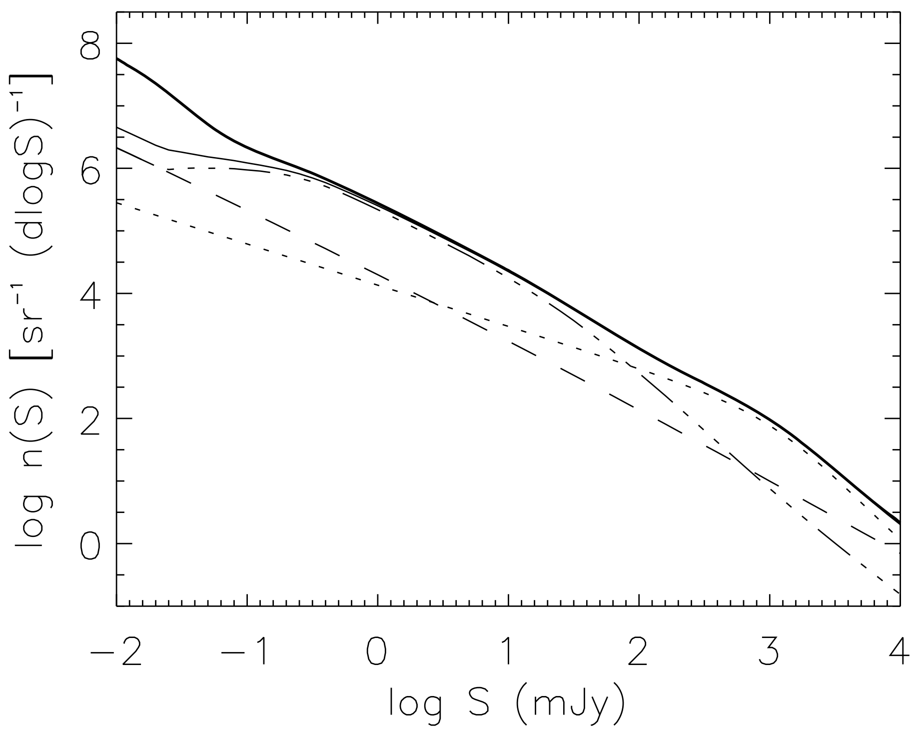
Differential counts at 20 GHz predicted by De Zotti et al. (2005) for classical radio sources



Dotted line: flat-spectrum radio quasars (beamed FRIIs)

Dashed line: flat-spectrum BL Lacs (beamed FRIs)

Triple dot-dashed line: steep-spectrum radio galaxies (unbeamed FRIs and FRIIs)

Thin solid line: sum of contributions from 3 pop.

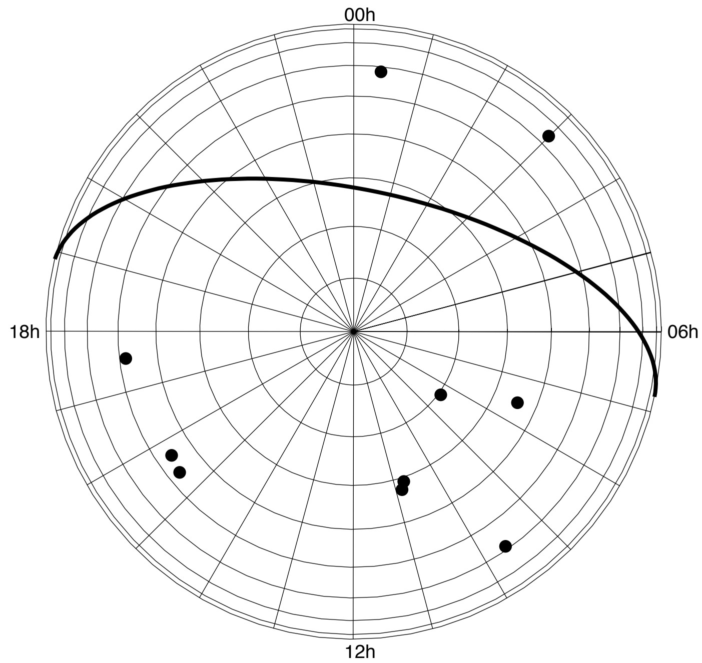
Thick solid line: overall total counts

The AMI LA near Cambridge

- Improved flux sensitivity of the LA, compared with the RT, used to explore the 15-GHz band sky to sub-mJy levels, as part of the 10C survey
- 16 GHz with 4.3-GHz bandwidth
- Resolution ~ 30 arcsec
- Sensitivity ~ 3 mJy in 1 s

10C survey - Matthew Davies, Thomas Franzen, Elizabeth Waldram & AMI Consortium. Astrophysics Group, Cavendish Lab.

- Designed to complement other AMI science programmes, which require knowledge of contaminating radio sources
- Complete to 1 mJy over an area of 27.5 deg^2 and to 0.5 mJy over an area of 12.0 deg^2
- 10 fields distributed more or less uniformly in HA
- 1897 sources detected above 5σ.



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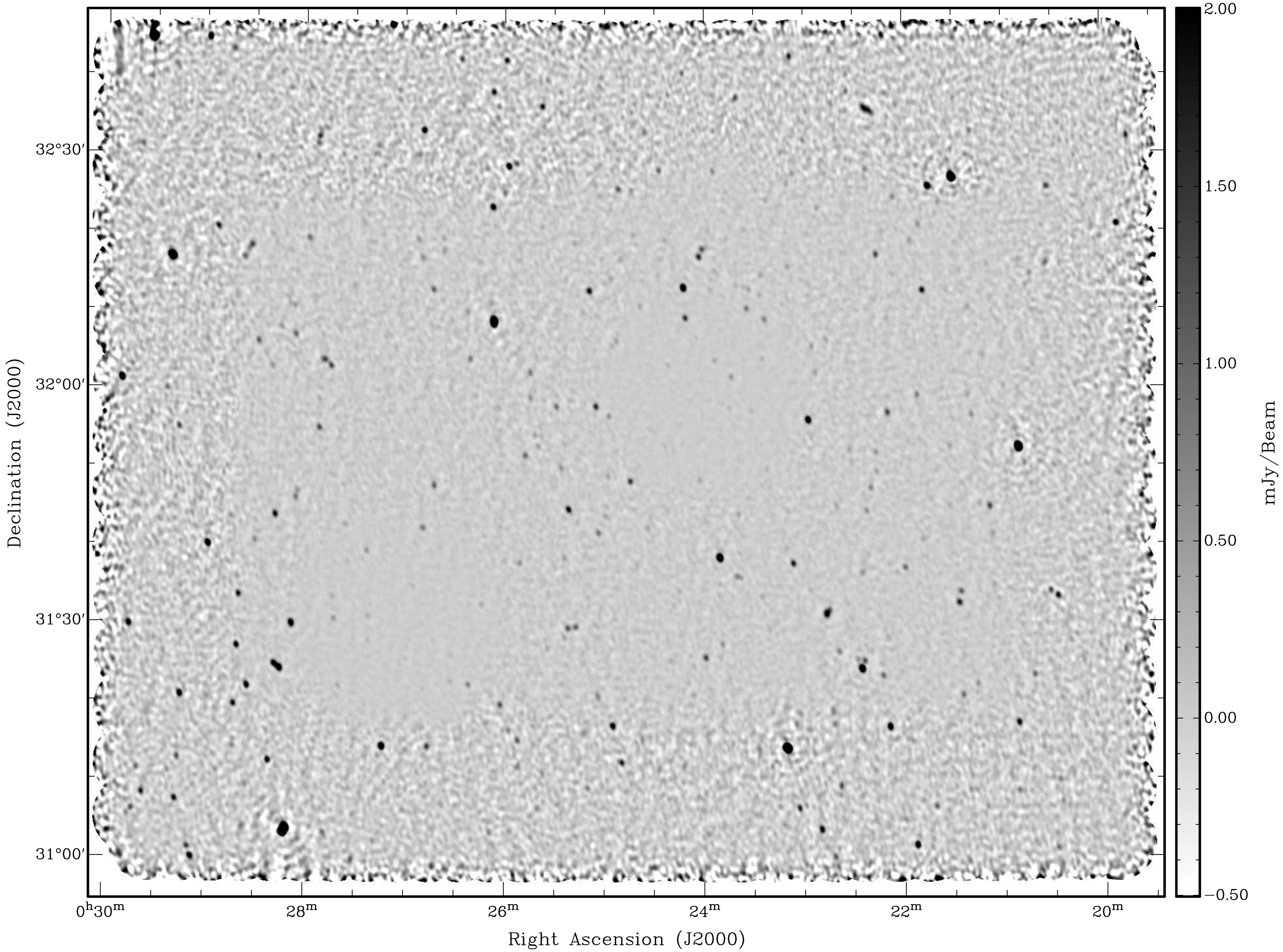
Raster map of one of the survey fields



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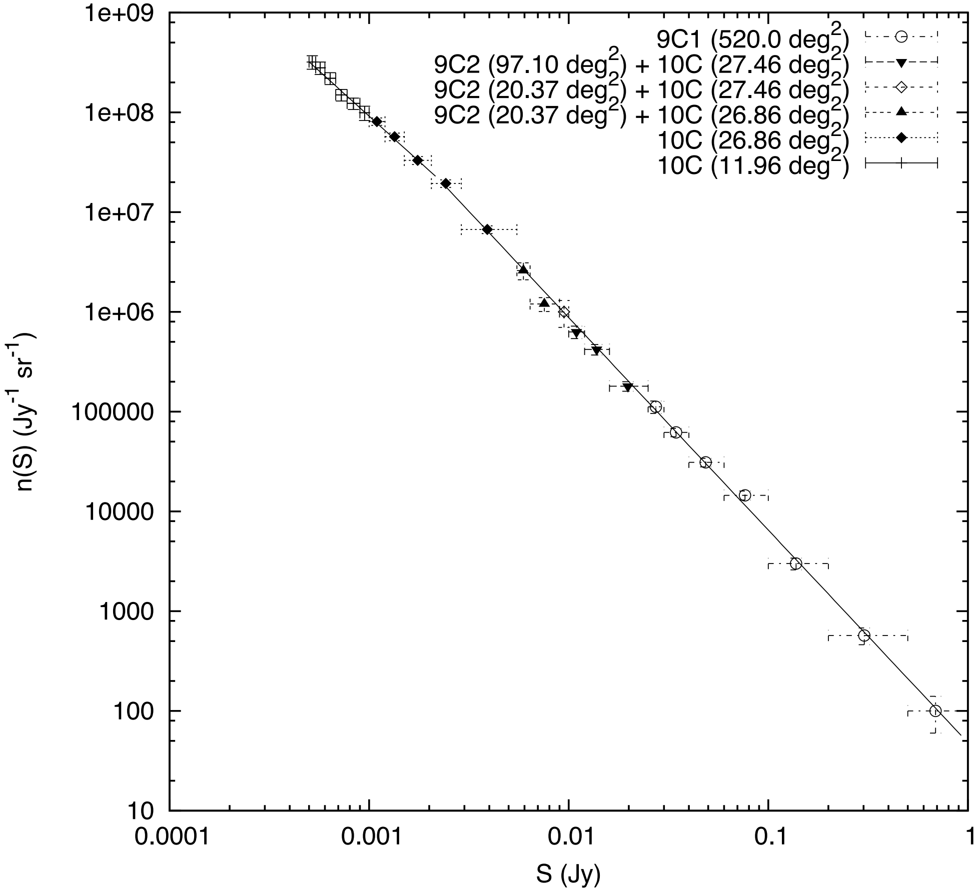
Combined 9C and 10C 15.7-GHz differential source count

- Source count between 0.5 mJy and 1 Jy measured by combining 9C and 10C data
- Differential source count best parameterized using a broken power law



$$n(S) \equiv \frac{dN}{dS} \approx \begin{cases} 48\left(S/Jy\right)^{-2.13} Jy^{-1} sr^{-1} & \text{for } 2.2 \text{ mJy} \le S \le 1 \text{ Jy} \\ 340\left(S/Jy\right)^{-1.81} Jy^{-1} sr^{-1} & \text{for } 0.5 \text{ mJy} \le S \le 2.2 \text{ mJy} \end{cases}$$

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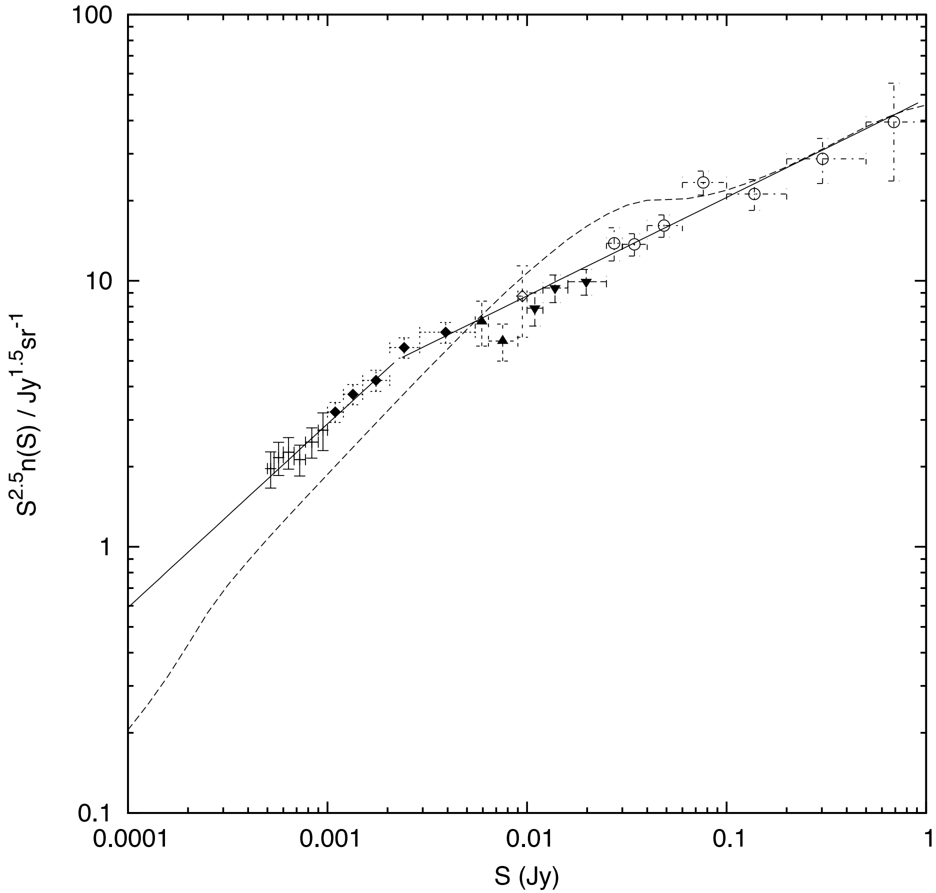
Comparison with the 15-GHz de Zotti model

- Model counts by de Zotti et al. (2005) under-predict total number of sources per unit area, over entire flux-density range, by ≈ 30%
- Deficit is attributable to model underestimating count at lowest flux densities



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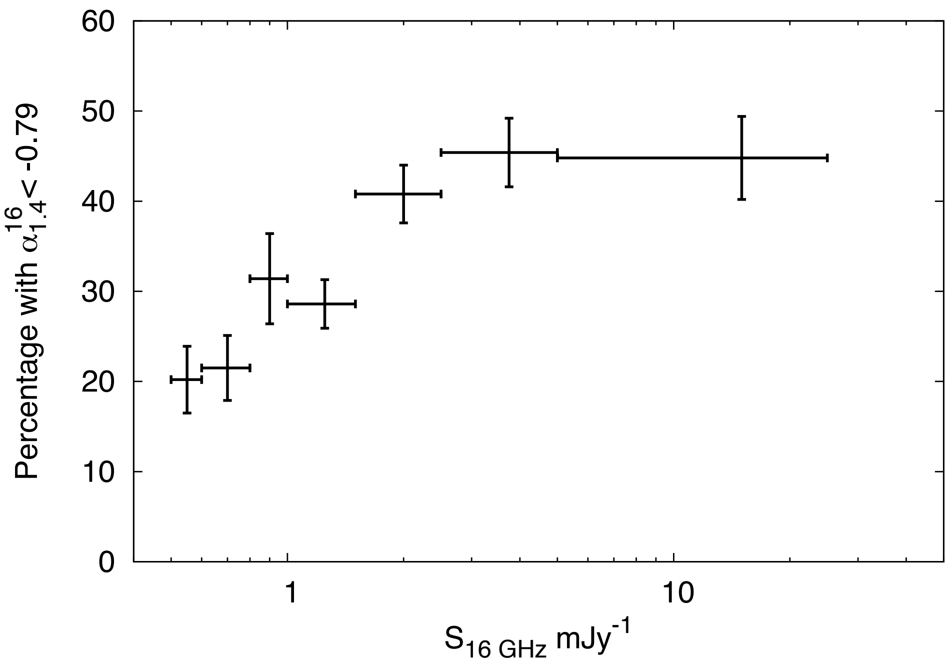
Matching with NVSS catalogue at 1.4 GHz

- Over range of flux densities covered by 10C survey, fraction of steep-spectrum sources decreases with decreasing flux density
- Steep-spectrum source defined as α < -0.79 to overcome problem of missing sources in NVSS at low flux density end



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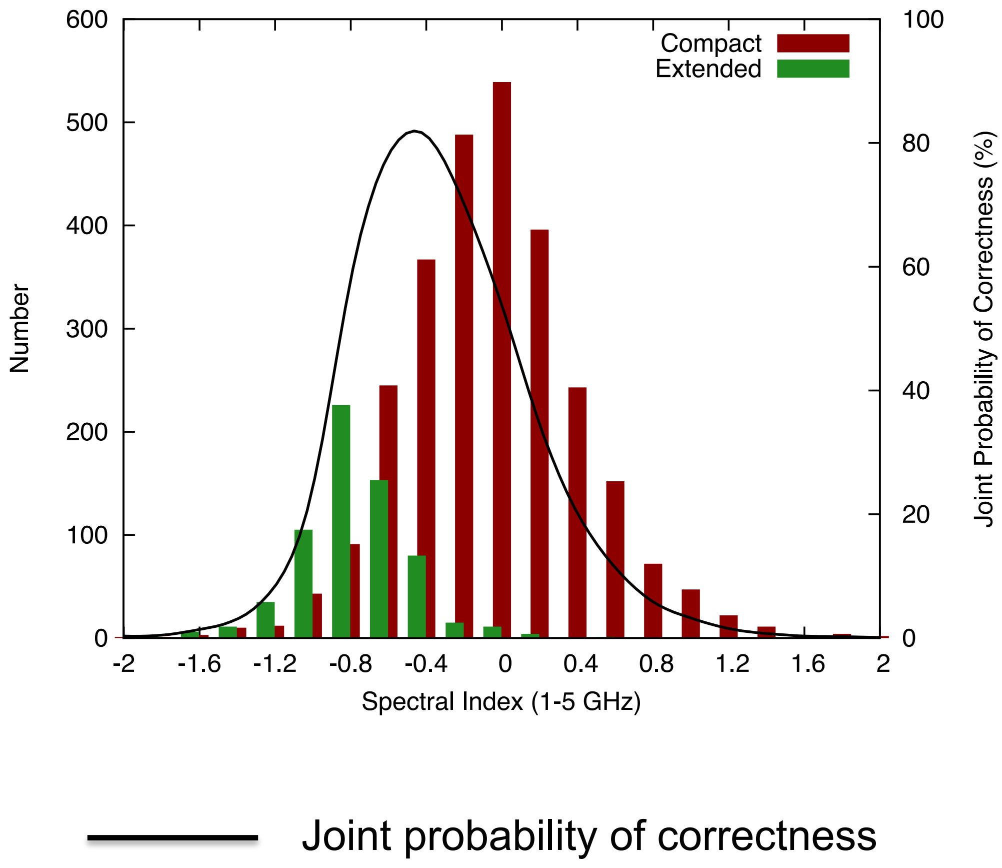
Spectra for compact and extended sources in AT20G survey (Chhetri et al. 2012)

- 3403 AT20G sources were followed up with ATCA at 5.5, 9 and 20 GHz
- Sources were classified as compact (< 15'') or extended (> 15'') by measuring visibility data on 6-km baselines at 20 GHz
- Very strong correlation of compact and extended sources with flat- and steep-spectrum sources respectively
- Maximum value of joint probability that both flat- and steep-spectrum sources are correctly classified is at $\alpha = -0.46$ and 80% of sources are correctly classified



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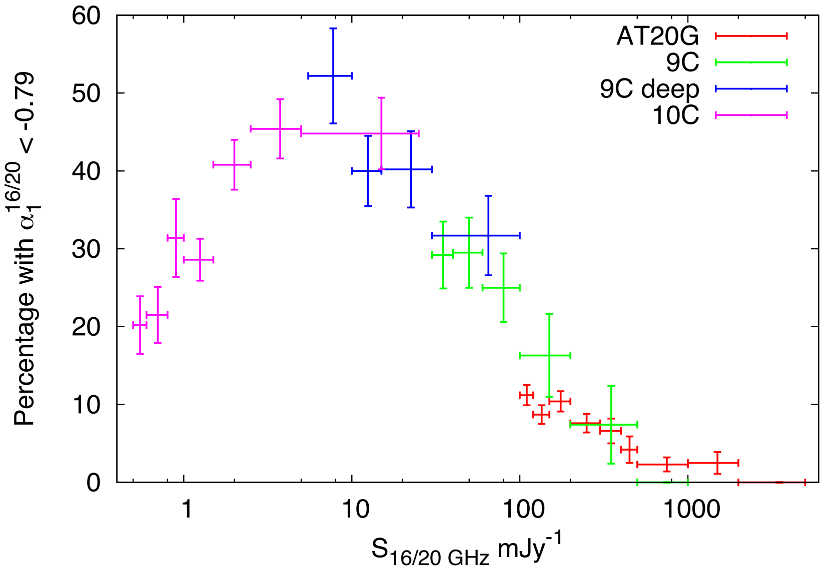
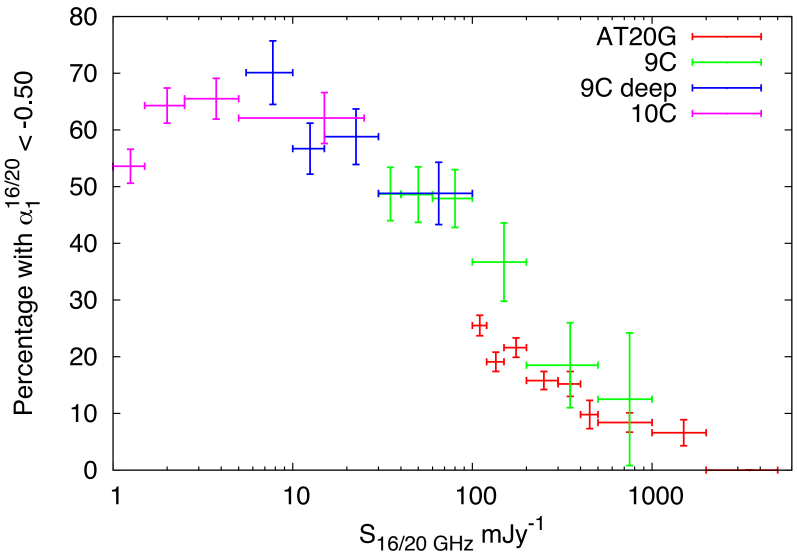
Spectral-index shifts as revealed in data from the AT20G, 9C and 10C surveys





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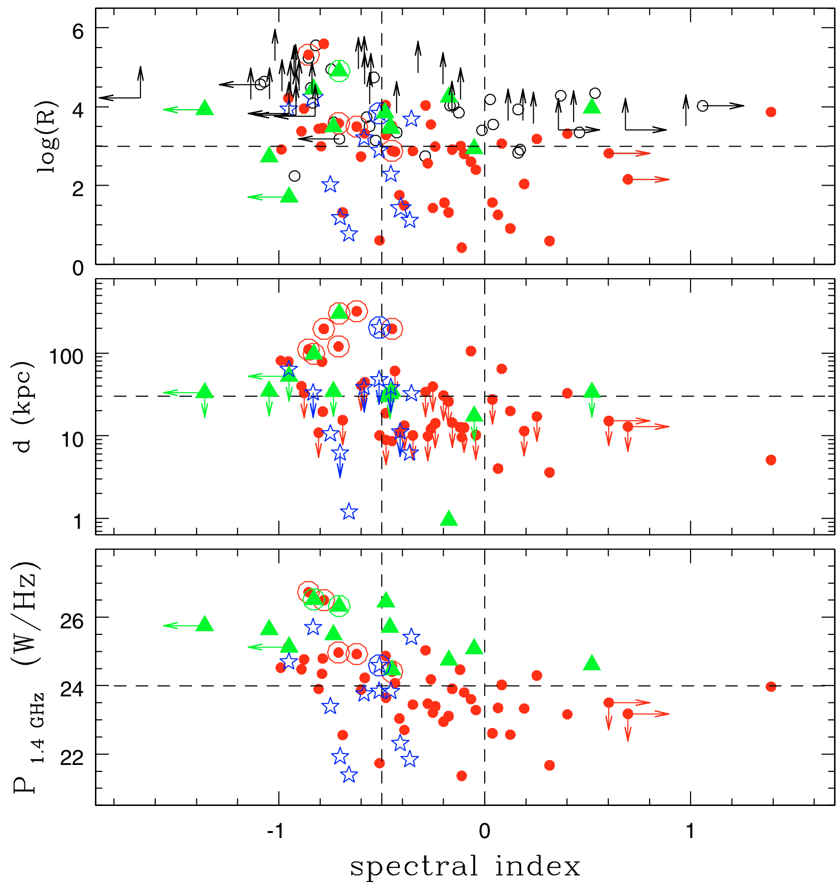
ATESP 5-GHz survey (Prandoni et al. 2006)

- 111 radio sources, complete to ~ 0.4 mJy; find flattening of 1.4-5 GHz spectral index with decreasing flux
- Sources studied by Mignano et al. (2008) in the optical
- Sources responsible for flattening thought to be FRIs with core-dominated radio emission



Red: early type spectra; Blue: late type spectra; Green: AGNs

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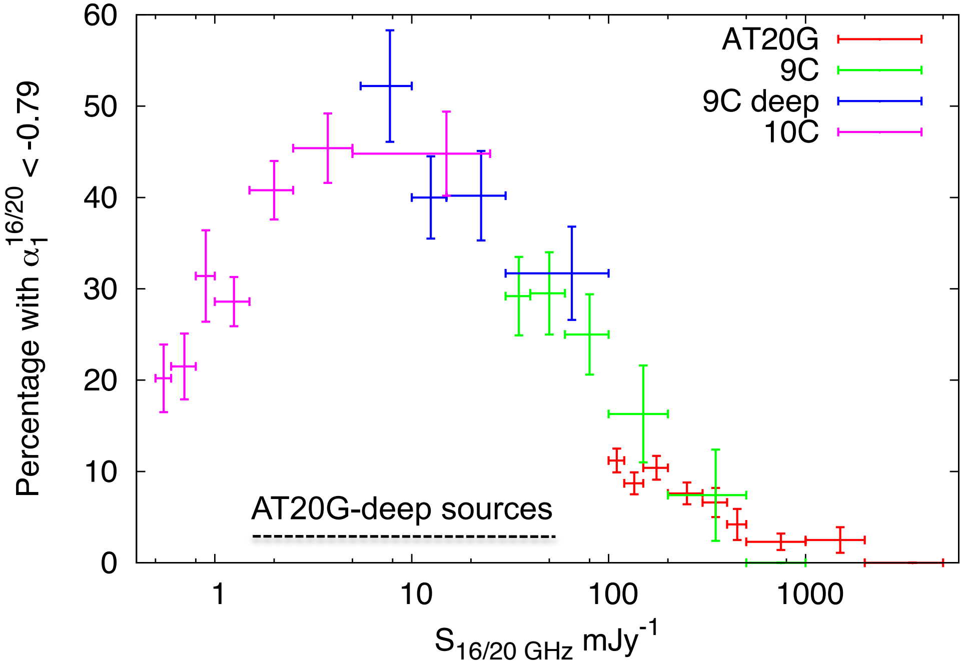
AT20G-deep pilot survey (Elaine Sadler PI)

- Surveyed 2 fields with ATCA at 18-22 GHz in July 2009: CDFS field and SDSS Stripe 82 region.
- Complete to ≈ 2.5 mJy over 5 deg^2
- Data now fully analyzed. 85 sources detected > 5σ
- Have good multi-wavelength and spectroscopic data
  - ATLAS, NVSS, FIRST, SWIRE, SDSS, AAOmega
- Plan a larger proposal for full AT20G-deep survey (at least 500 deg^2 down to 5σ detection limit of 1 mJy)

AT20G-deep pilot survey

- Shift in spectral-index properties most rapid in flux density range 1-40 mJy
- New 20-GHz sources detected in AT20G-deep pilot survey fit into exactly this range, and so can help us understand what is driving this rapid change in source population



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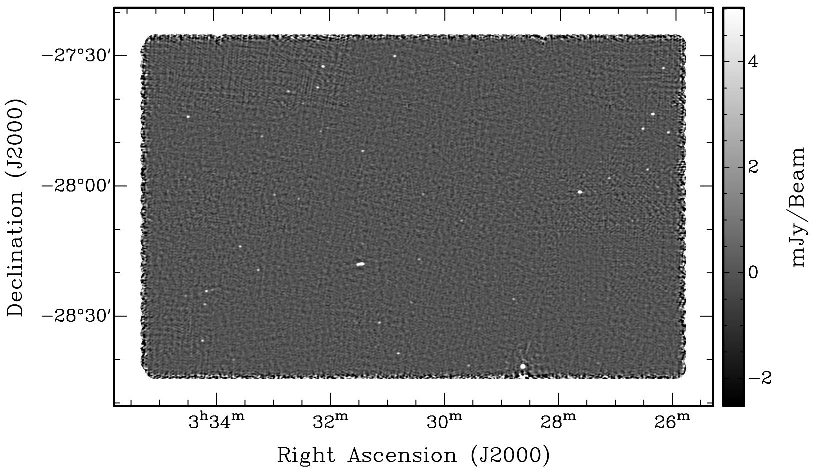
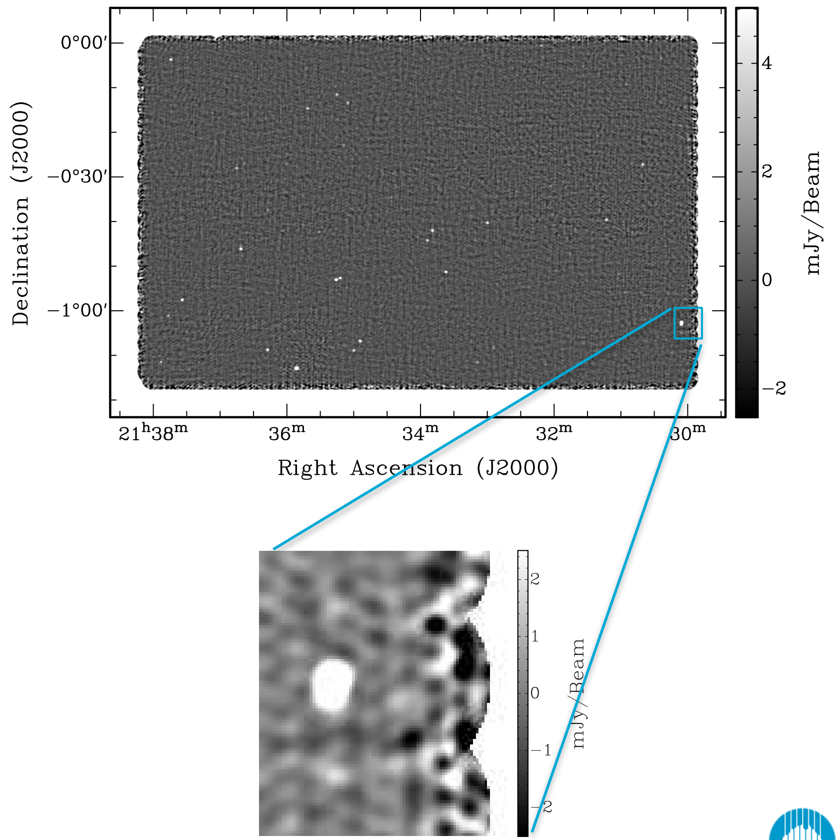
Survey strategy

- H75 array with 30 arcsec beam at 20 GHz
- Mosaic mode; ≈ 3500 pointings per field; 2 10-s cuts per pointing

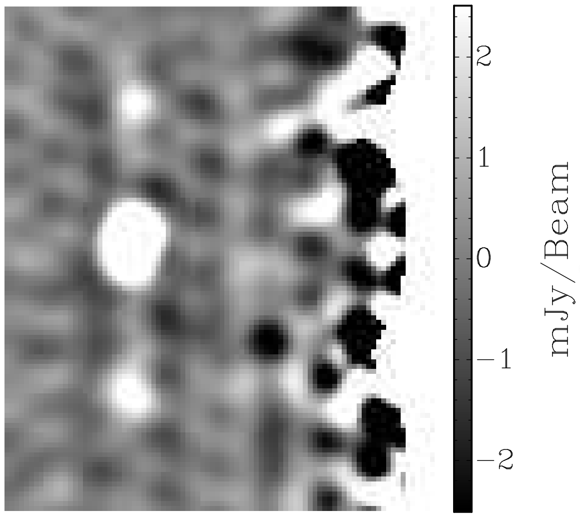




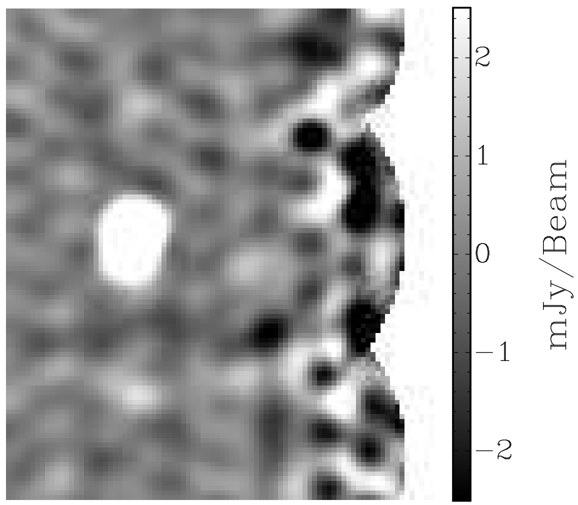
Noise ≈ 0.3-0.4 mJy
87 components > 5σ
2 doubles → 85 sources

Joint versus individual approach when mosaic imaging at 20 GHz

- Individual approach: CLEAN each pointing separately before forming a mosaic
- Joint approach: CLEAN mosaiced image
- Joint approach gives significantly higher dynamic range



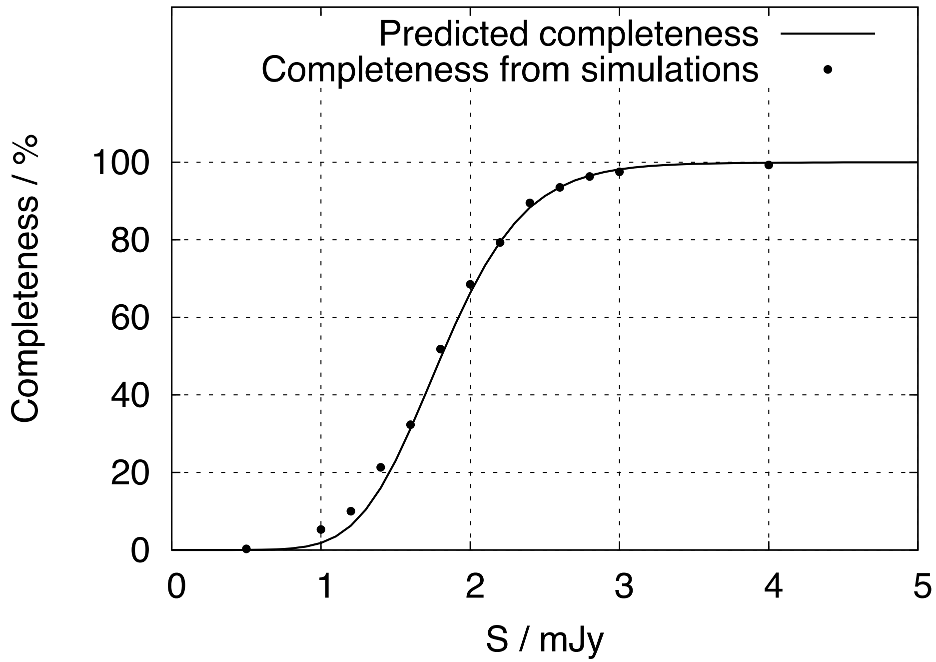
Individual approach



Joint approach

Completeness

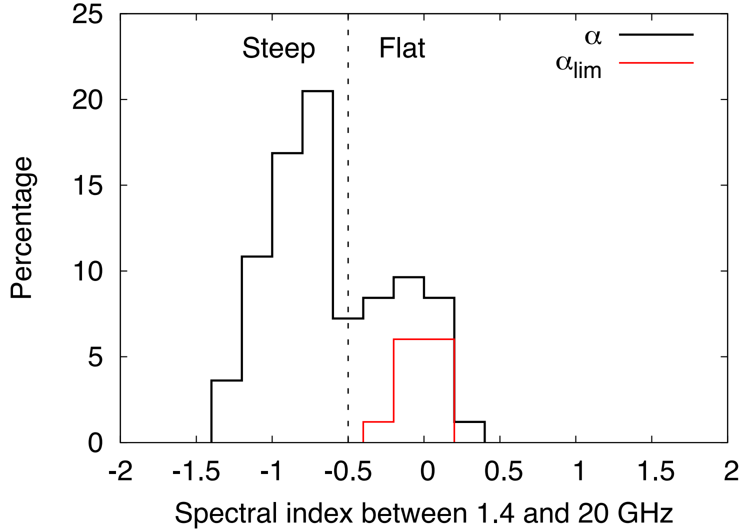
- Monte Carlo simulations show that the survey completeness can be accurately quantified by use of the noise map and simple Gaussian statistics



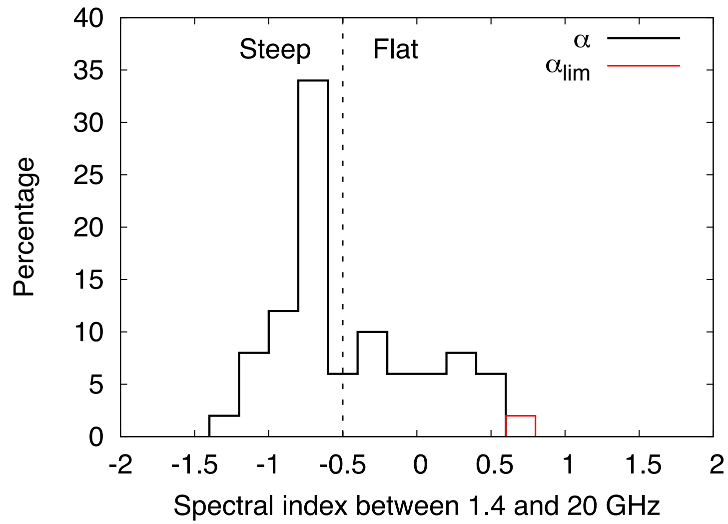
Reach 50% completeness at 1.8 mJy
Reach 95% completeness at 2.7 mJy

Matching with catalogues at 1.4 GHz

NVSS/AT20G-deep
Both fields
11 sources missing in NVSS

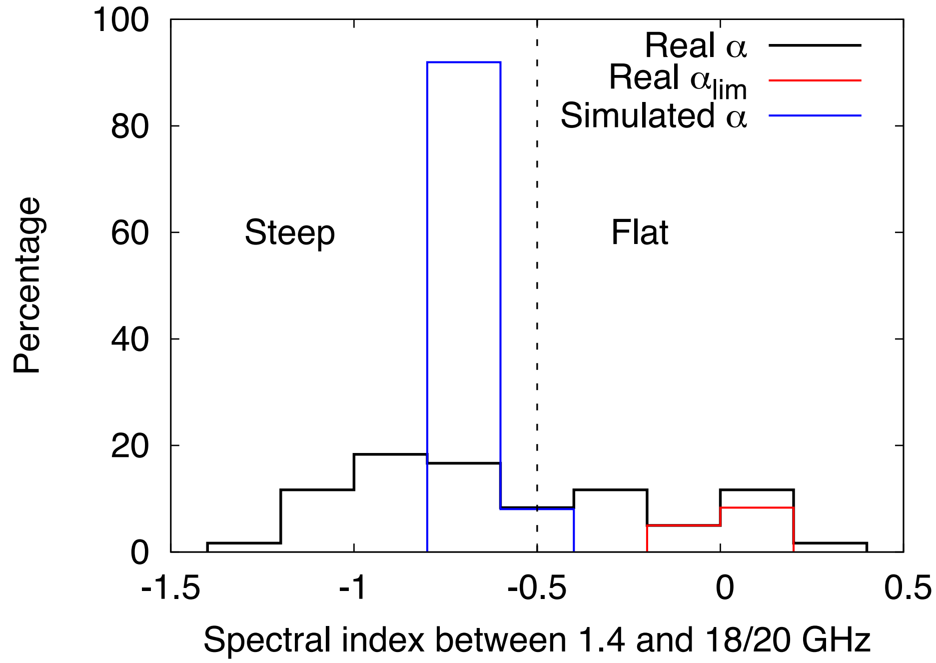


ATLAS/AT20G-deep
CDFS field
1 source missing in ATLAS



Comparison with S-cubed semi-empirical simulations (Wilman et al. 2008)

- Get all galaxies with $S_{18\ GHz}$ > 2.5 mJy in central 5-deg^2 of simulation; find a total of 62 galaxies
- In comparison, 60 sources > 2.5 mJy are detected in AT20G-deep pilot survey over same area of sky
- However, spectral index distributions are remarkably different, implying that the models need refining
- This comparison highlights the need for large samples of high-frequency radio sources



Conclusions

- Find a rapid and puzzling shift in the 15/20-GHz source population over the flux density range 1-40 mJy
- The typical spectral index becomes steeper for sources with decreasing flux densities above ~ 5-10 mJy; at fainter flux densities, this trend is reversed, with a move back toward a flatter spectrum population
- Pilot observations for AT20G-deep survey successful; 85 sources detected > 5σ, 45% of which have flat or rising spectra.
- Compared AT20G-deep pilot survey with S-cubed semi-empirical simulations; spectral index distributions found to be remarkably different

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Future work

- Before starting to plan a larger proposal for the full AT20G-deep survey, need to understand more about the source population seen in the pilot survey
- Will follow up sources with ATCA at 5.5, 9 and 20 GHz
  - Measure variability in flux density over 3-year timescale
  - Obtain angular size information from 6-km visibility data
  - Investigate spectral curvature between 1.4 and 20 GHz
  - Verify reliability of AT20G-deep catalogue
- Will combine the new radio data with optical imaging and spectroscopic data where available, with the aim of identifying the source population responsible for the rapid spectral-index shifts seen between 1 and 40 mJy

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Thank you

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Flat- and steep-spectrum source counts