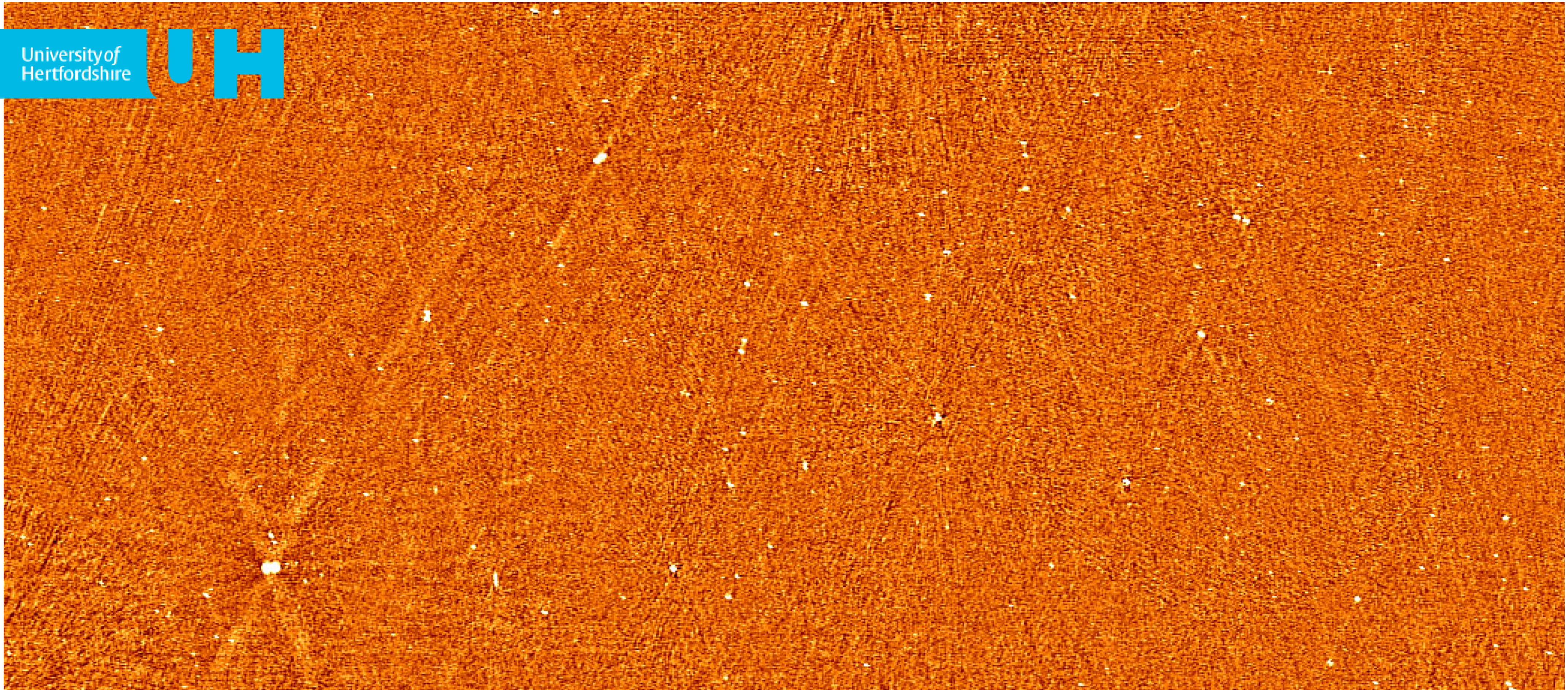

MOS: A critical tool for current & future radio surveys

Daniel J.B. Smith, University of Hertfordshire, UK

www.herts.ac.uk/~dsmith/

MOS: A critical tool for current & future radio surveys
Outline

- Why study radio sources?
- What can MOS spectroscopy do for radio surveys?
- Future synergies between SKA pathfinders/precursors & MOS spectrographs
  - i.e. “what can radio surveys do for MOS spectroscopy?”
- A brief look further ahead

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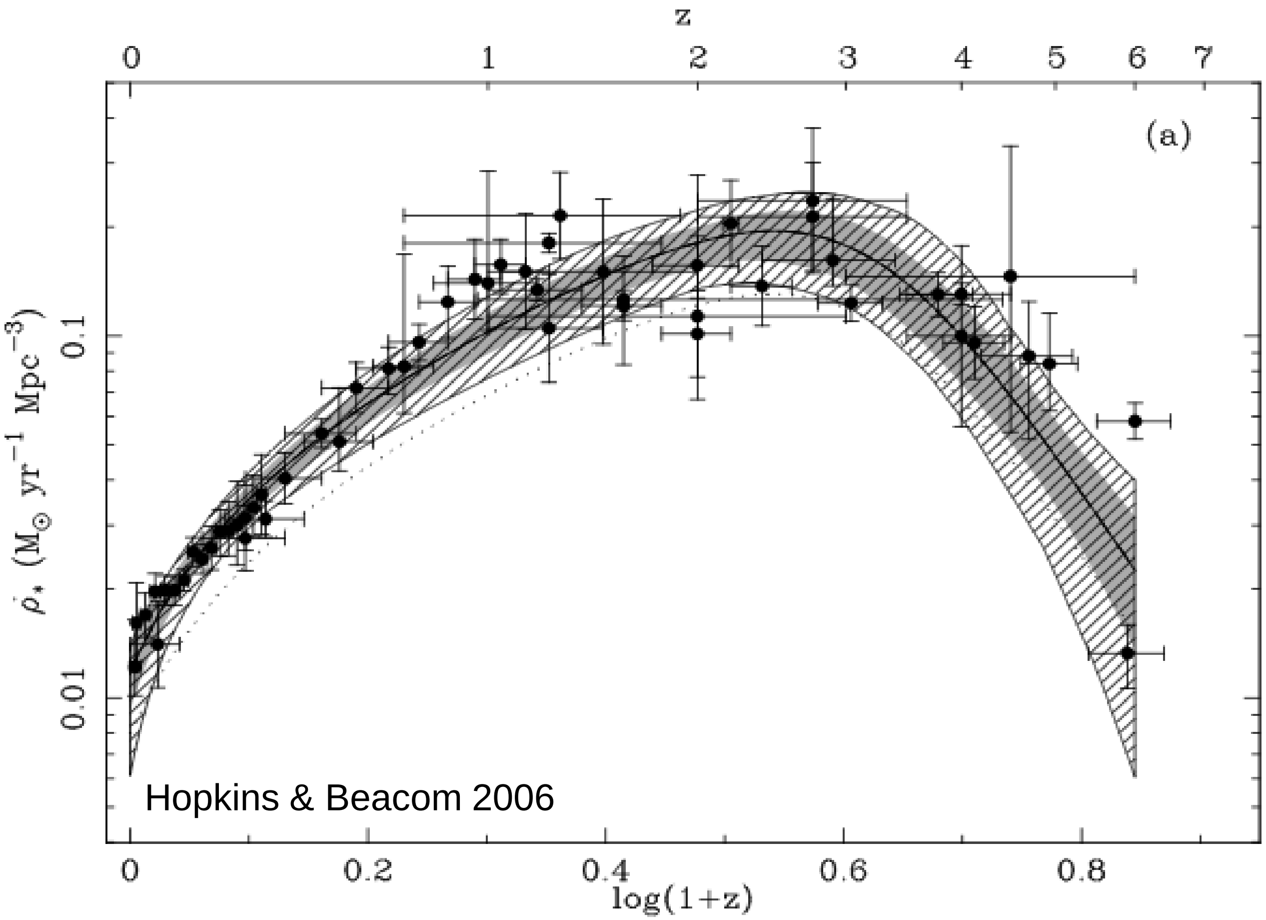
Context:

Evolution of the star formation rate density; one of the “3 little pigs”



Star formation rate indicators:

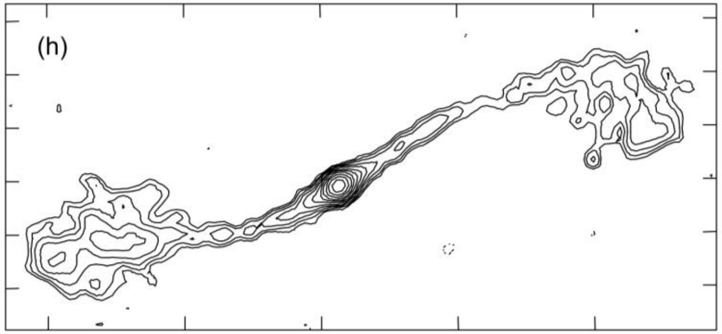
UV/Optical – dust extinction

Far-IR – no obscuration, but poor resolution means confusion

Radio – unaffected by dust, high-resolution

*AGN contamination in all to a lesser/greater extent

Why radio sources are interesting
Radio surveys are changing



At bright flux densities, radio sources are dominated by AGN

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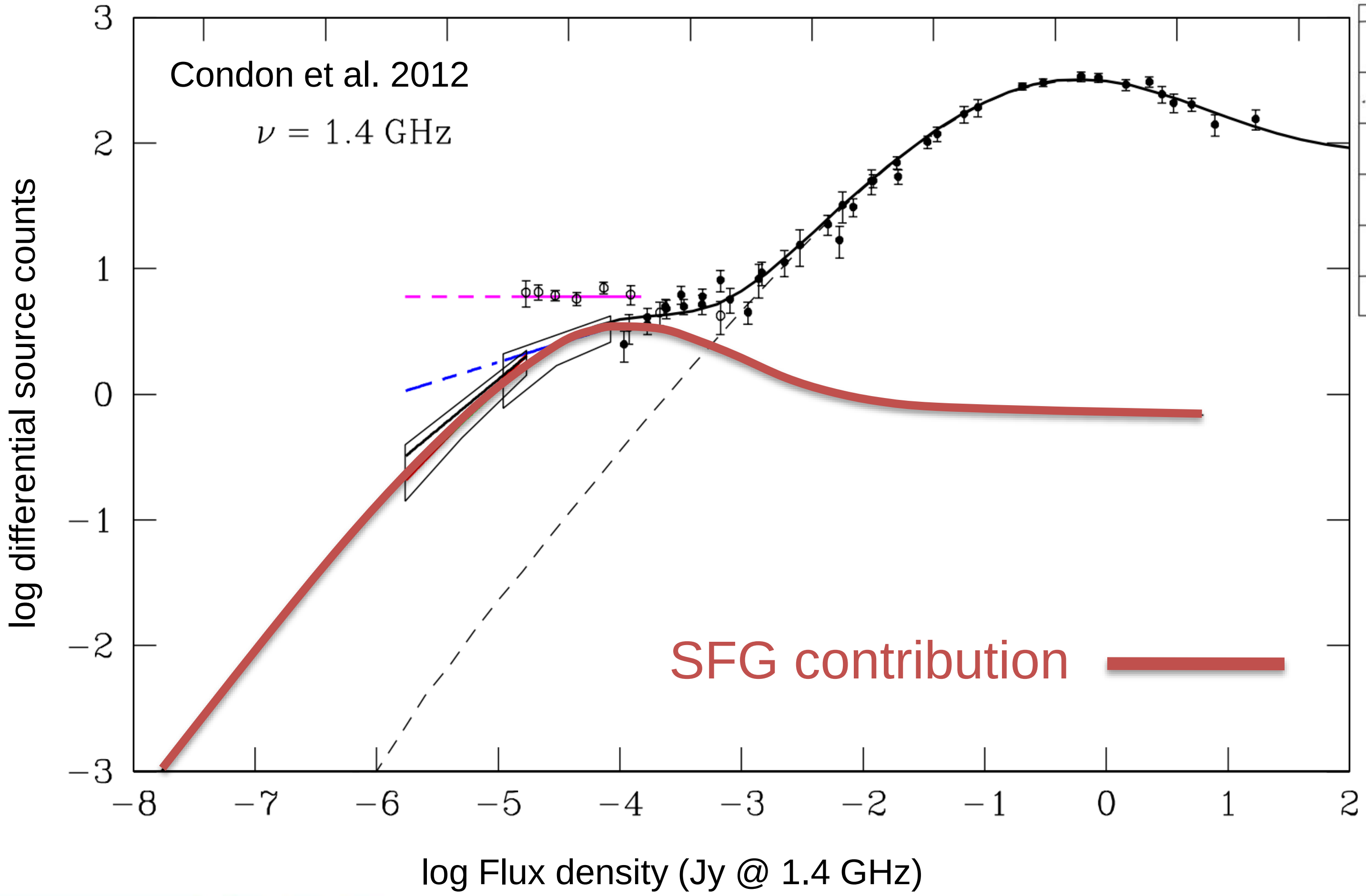
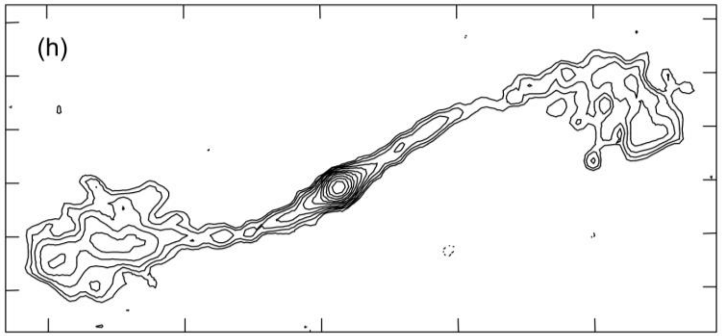
Context:
SFG contribution to the source counts





At bright flux densities, radio sources are dominated by AGN

However, as you move to progressively fainter flux densities, an increasing fraction of sources are normal star-forming galaxies and radio-quiet AGN

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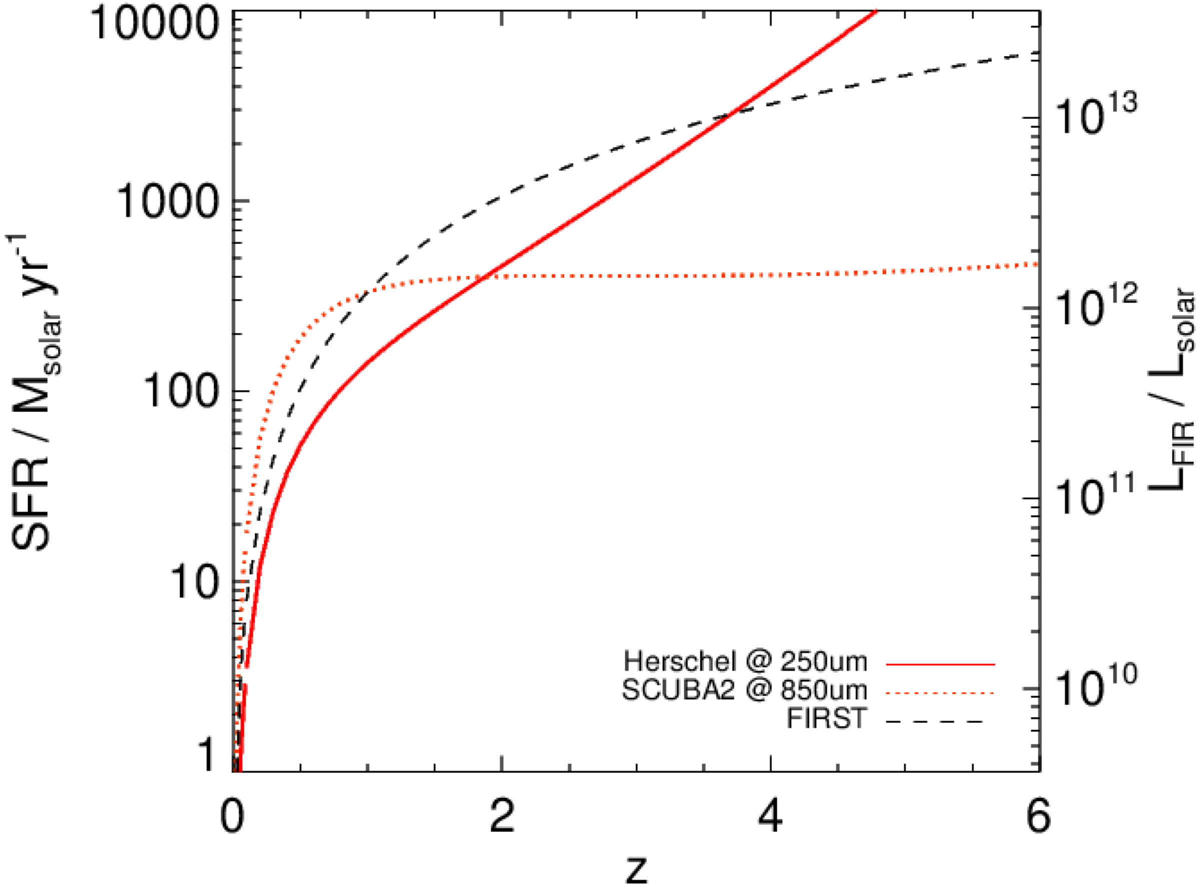
SFR Sensitivity

Radio Continuum vs far-IR observatories as a star formation rate indicator



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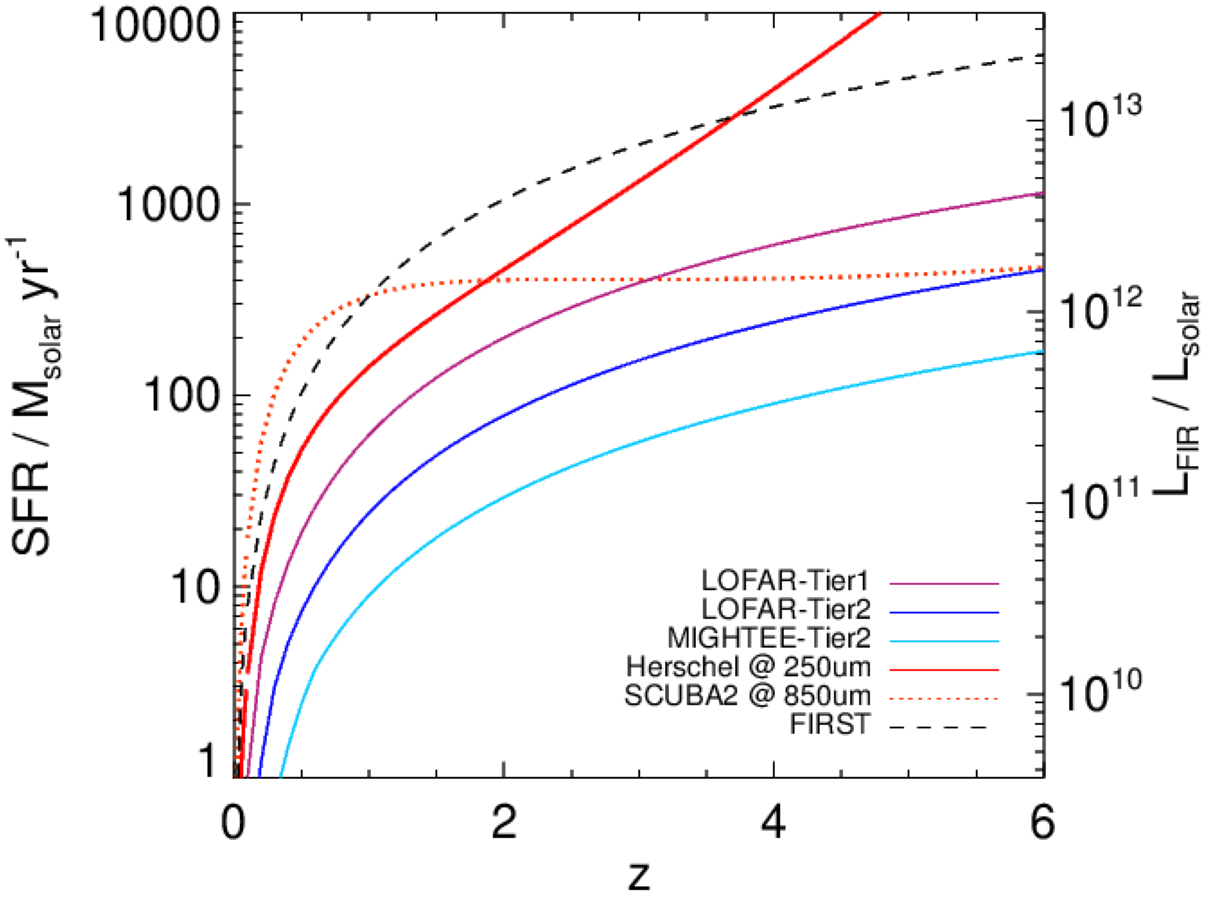
SFR Sensitivity

SKA pathfinders & precursors are about to blow far-IR out of the water



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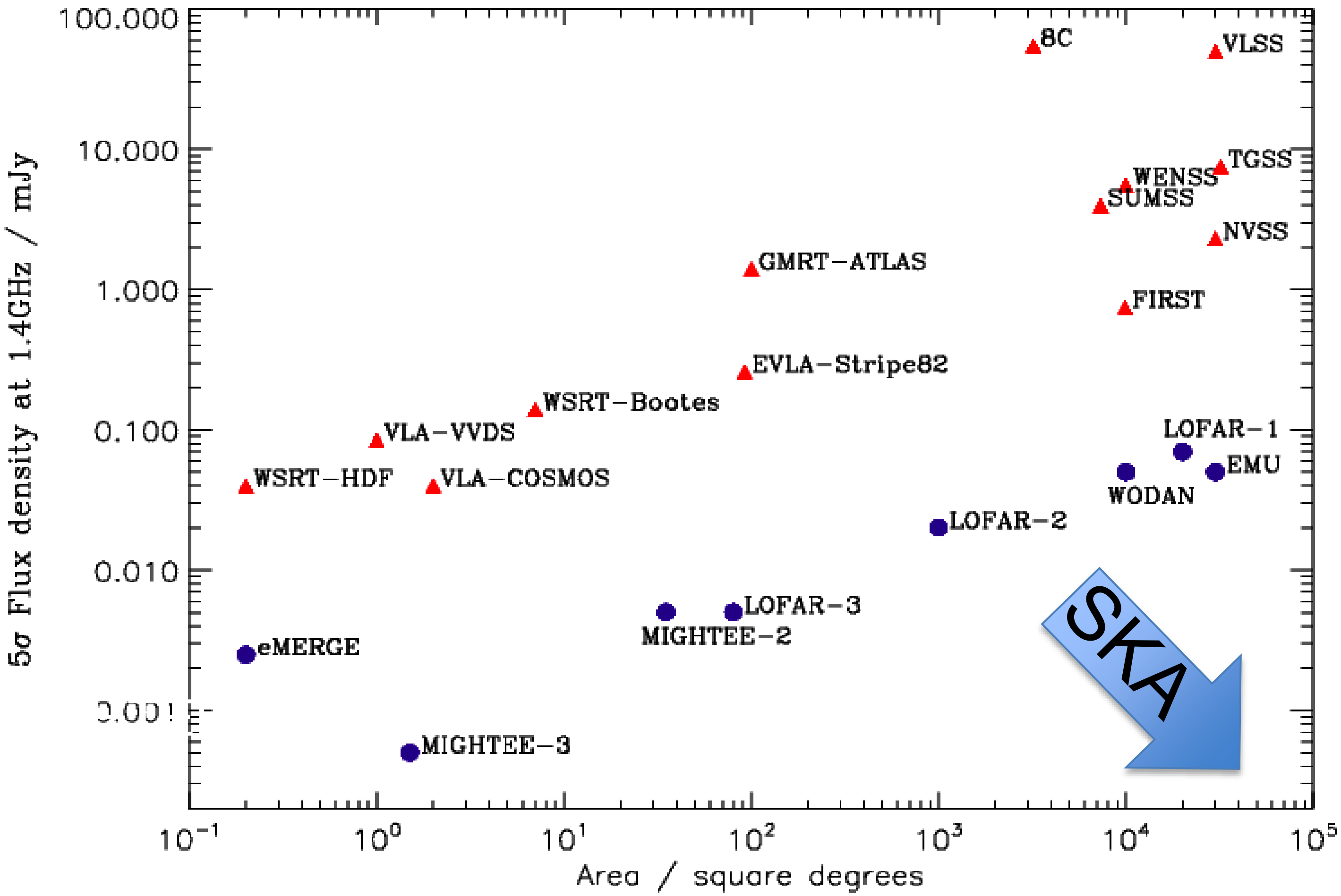
The new radio continuum surveys
LOFAR surveys



LOFAR Tier 1: "Large Area"
Whole northern sky, 10x as deep as FIRST; similar to ASKAP-EMU in the South

LOFAR Tier 2: "Deep"
~500 deg^2, 10 M_{solar}/yr @ z=1

LOFAR Tier 3: "Ultra Deep"
100 deg^2, deeper than deepest existing data
ULIRGs at z=8!

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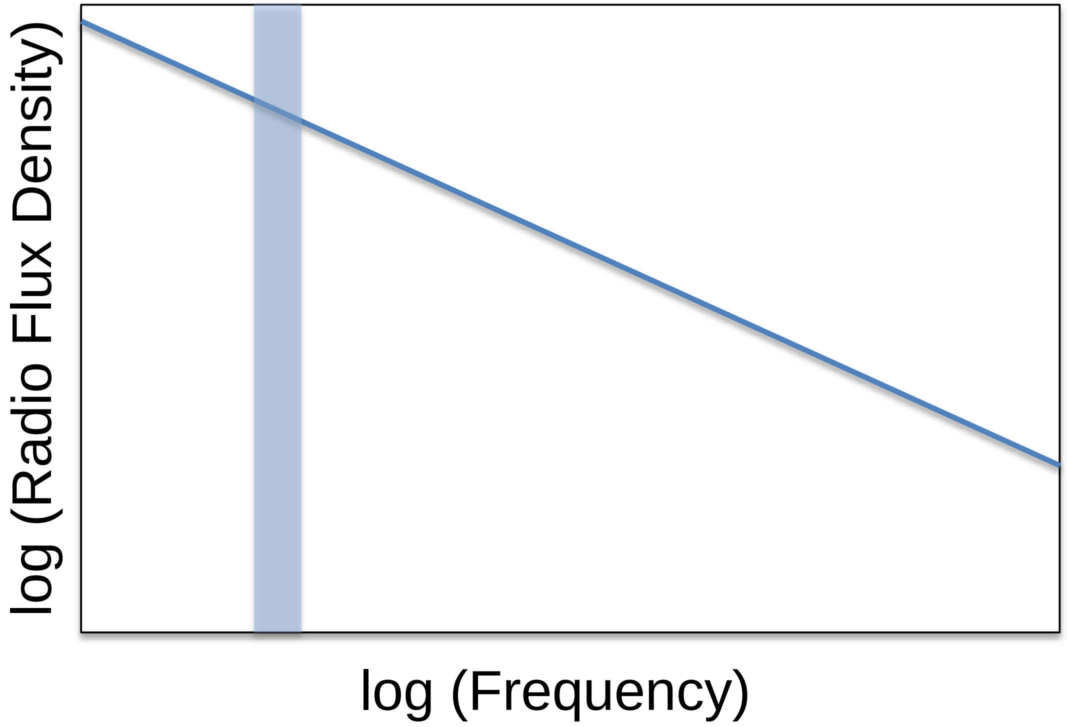
“There’s nothing as useless as a radio source”
Jim Condon, 2013



Radio source spectra are well-described by power laws:

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

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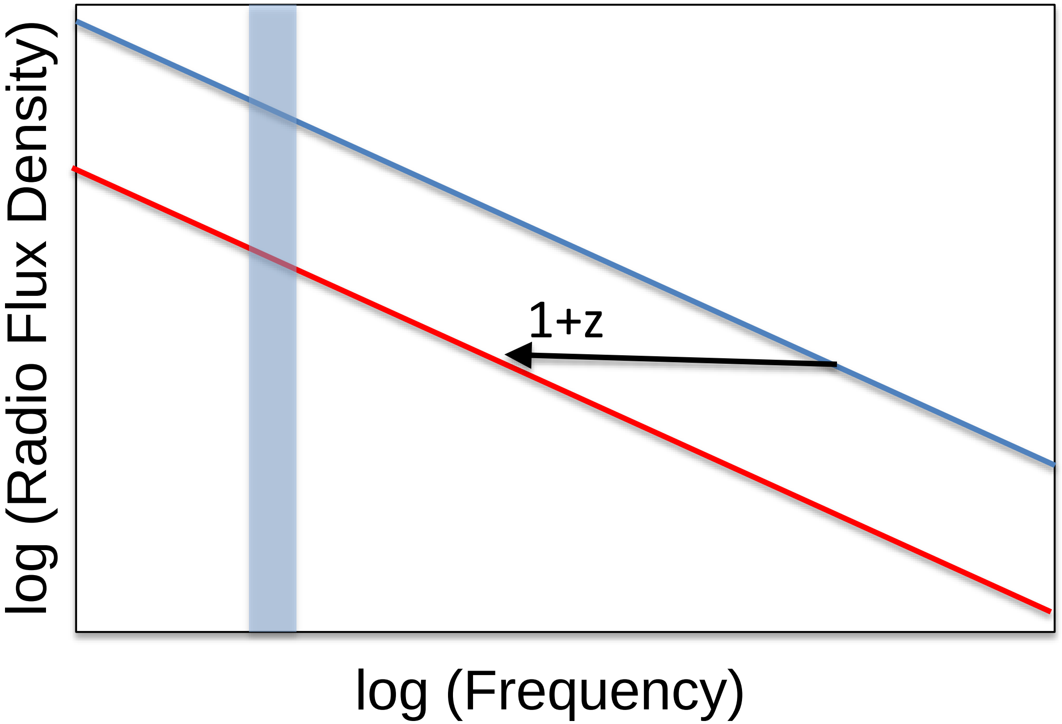

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No redshift information!

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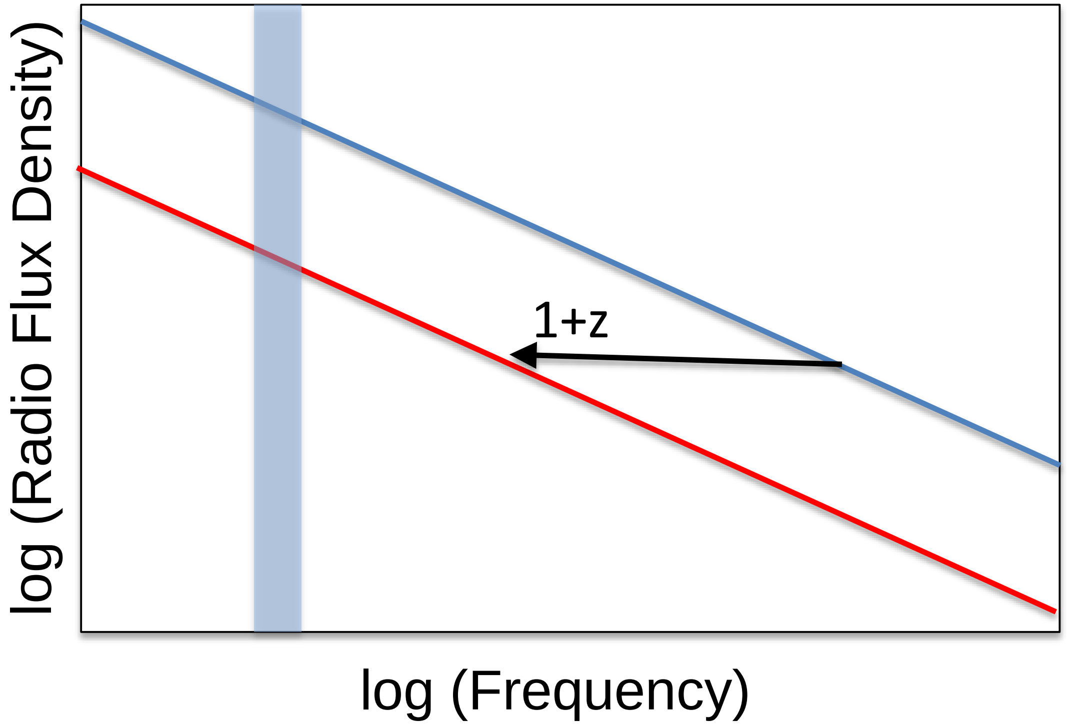

Radio source spectra are well-described by power laws:

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

No redshift information!

“Gone are the days of single facility surveys”
Simon Driver, yesterday

Getting the redshift information that we need
Can we use photometric redshifts?

- Faint radio sources are among the most difficult sources to estimate photometric redshifts for, due to:
  - The presence of radio-quiet AGN
  - The presence of high-EW emission lines
- You can't believe photometric redshifts for individual objects, especially those which are dusty (i.e. star forming) or low-mass (i.e. star forming)
- This is especially true for radio surveys, which select galaxies based on their SF (c.f. emission line surveys vs e.g. K-band samples)
- The fact that they have bright emission lines makes them ideal for spectroscopy as you don't have to detect the continuum to get precise and reliable redshifts; spectroscopy is very efficient

What can you do with MOS spectroscopy of radio sources?
Lots – there's [not much?] as informative as radio sources with redshifts!

- Precisely trace the assembly history of galaxies as a function of mass, environmental density and galaxy type
- Probe the relationship between accretion and star-formation over cosmic history, with large samples of radio quiet AGN & SFGs
- Discriminate between efficient (cold a.k.a. QSO-mode/high-excitation) and inefficient (hot or radio mode, low-excitation) radio galaxies
- Find the rarest sources (e.g. radio sources in the Epoch of Re-ionization)
- Stack large numbers of spectra to study average properties of very faint galaxies (i.e. individual sources only have emission lines detected; stack to get the continuum)
- Learn to derive good photometric redshifts, including separating the AGN from the SFGs
- Measure galaxy velocity dispersions and metallicities, virial black hole masses in AGNs
- Find galaxy clusters and study Cosmology […]

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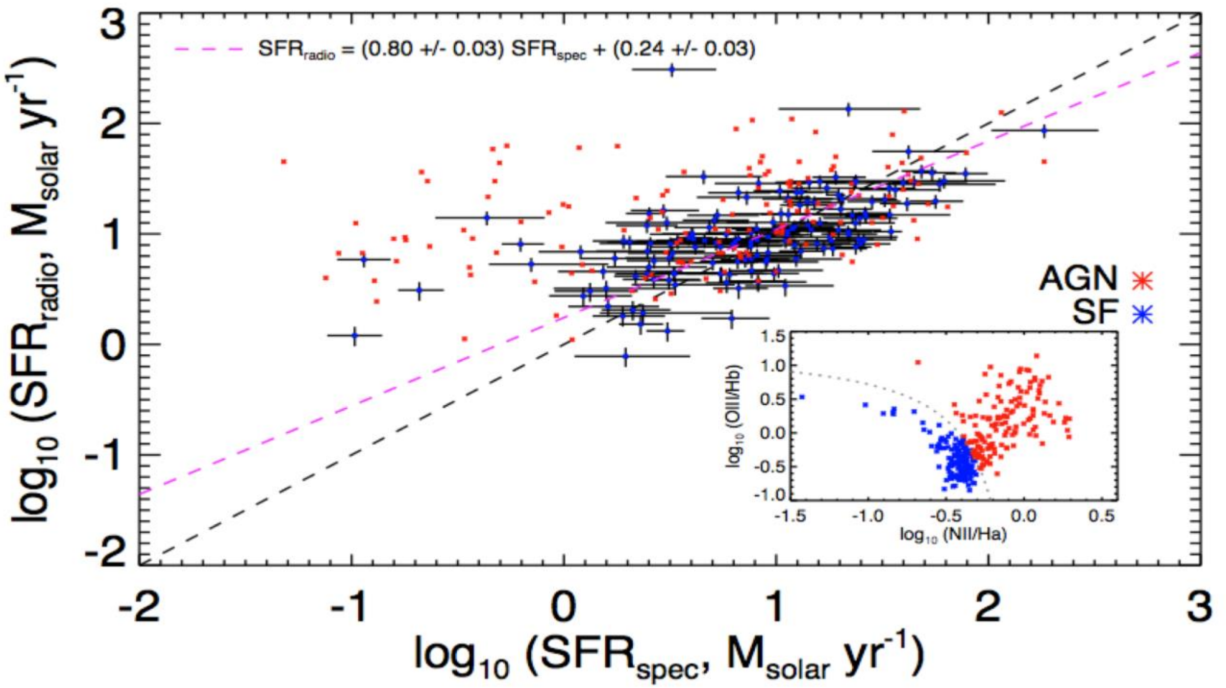
What can you do with MOS spectroscopy of radio sources?

Can we rely on spectroscopic star formation rate indicators?



Even where we have enough spectroscopic information to estimate SFRs (e.g. left) the trend is non-linear.

OII is fine for getting redshifts, but do we believe the SFRs?

[Why] are we still relying on "indicators"?

What can we do using all of these data?
Need to learn to use radio data in SED fitting

- Radio data are calibrated as an SFR indicator by assuming a correlation with the far-infrared (the “FIRC”)
- Recent work (Smith et al. 2014) suggests that the FIRC varies…. This could be a big problem!
- Conspiracies between disparate phenomena necessary to explain constant FIRC (e.g. Lacki+ 2010a,b):
  - Dust cooling timescale
  - Synchrotron loss timescale
  - Cosmic ray escape fraction
- LOFAR data a critical FIRC test (Gurkan et al. in prep)

Critical to treat radio continuum information in conjunction with the spectroscopic and photometric data.

If we can handle them, using radio continuum data as part of the SED fitting arsenal will be the best way to estimate SFRs over the whole sky at all redshifts!

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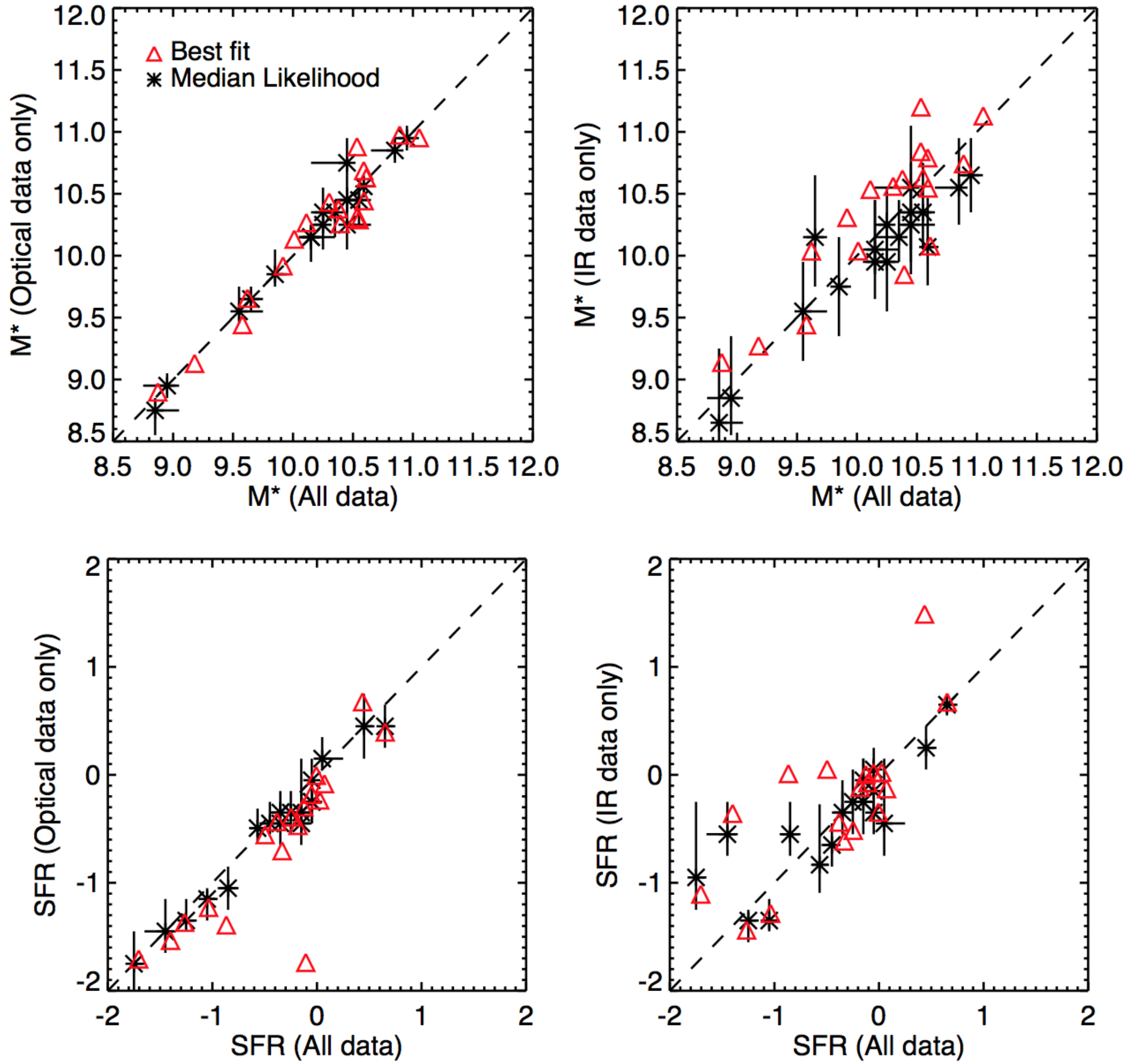
What can we do using all of these data?
On the necessity of obscuration-free SFR sensitivity

- Obscuration-free measurements are critical for estimating SFRs

- Even with exquisite UVOIR data, and state-of-the-art SED fitting, SFRs can be systematically underestimated in absence of obscuration-free SFR sensitivity (Safarzadeh et al in prep)



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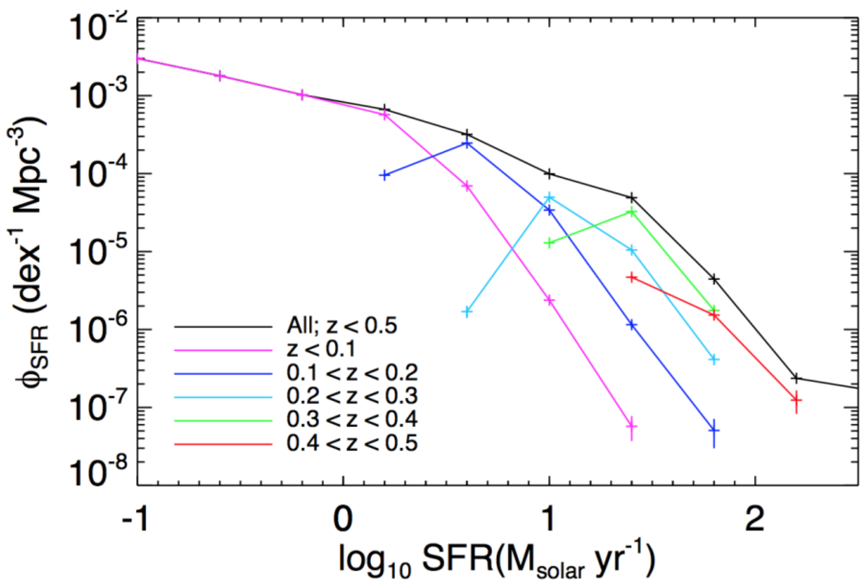
Current Efforts: S4 “The Stripe 82 Radio Source Spectroscopic Survey”
PIs: D. Smith & H. Röttgering

- Uses WYFFOS & AF2 on the WHT
- Blind follow-up of radio sources in SDSS Stripe 82 region:
  - 100 deg^2 of 1.4 GHz radio data from:
    - VLA (Hodge et al. 2011)
    - JVLA (Heywood et al. in prep)
- Aim to get 2k blind spectra of radio sources primarily at $z < 1.5$, $S_{1.4\ GHz} > 200$ uJy (Observed ~400 targets so far)
- Goals include galaxy & AGN co-evolution since z=1.5, FIRC evolution, SFR functions, desire to add RC data into SED fitting



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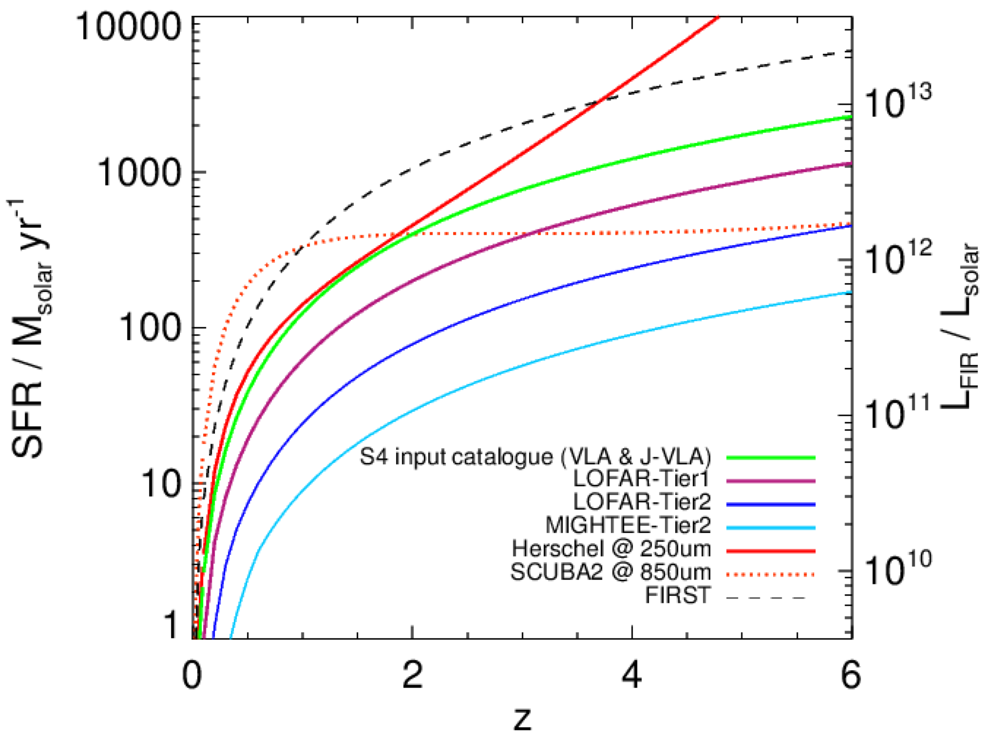

- *What redshift success rate should we target/can we expect for WEAVE LOFAR?*

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Future Efforts: WEAVE follow up of LOFAR surveys
Way beyond S4

- WEAVE science driver; combination with LOFAR gives an unique Northern Hemisphere capability

- Will obtain spectra for millions of LOFAR sources
  - Allows sub-division by e.g. mass, environment, type, redshift
  - “Wedding cake” design to sample full parameter space

- Additional benefits of low-frequency radio selection:
  - Low-frequencies less orientation dependent
  - Also less susceptible to spectral ageing

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Future Efforts: WEAVE follow up of LOFAR surveys
Build on S4

- WEAVE science driver; combination with LOFAR gives an unique Northern Hemisphere capability
- Will obtain spectra for millions of LOFAR sources
  - Allows sub-division by e.g. mass, environment, type, redshift
  - “Wedding cake” design to sample full parameter space
- Additional benefits of low-frequency radio selection:
  - Low-frequencies less orientation dependent
  - Also less susceptible to spectral ageing

WEAVE LOFAR spectroscopy is unique & complementary to other MOS surveys:

4MOST on VISTA (Southern)

DESI at Kitt Peak
(focus on BAO/Cosmology)

~2017 Subaru PFS (deg^2 FOV, northern, 2400 fibers, z-desert capability)

~2020 VLT-MOONS (500 arcmin^2 FOV, 1000 fibers, Southern, but can hit the z-desert in the deep equatorial fields)

~2024 MSE (3200 fibers, 1.5 deg^2 FOV; see talk no 2 by Hopkins)

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What can you do with WEAVE MOS spectroscopy of LOFAR sources?
Lots – there's [not much?] as informative as millions of radio sources with redshifts!

- Precisely trace the assembly history of galaxies as a function of mass, environmental density and galaxy type
- Probe the relationship between accretion and star-formation over cosmic history, with large samples of radio quiet AGN & SFGs
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Thanks very much!

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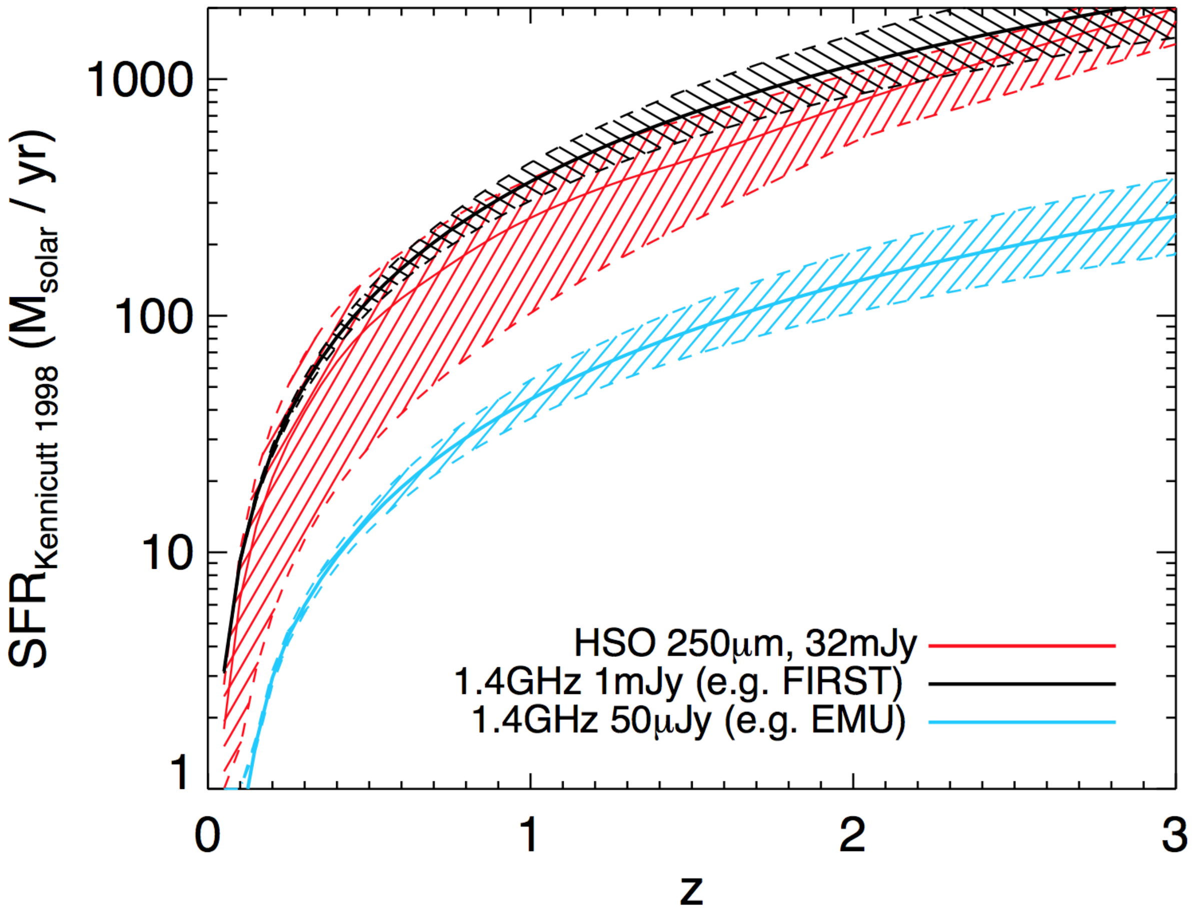
SFR sensitivity
Dependence on FIR SED and spectral index



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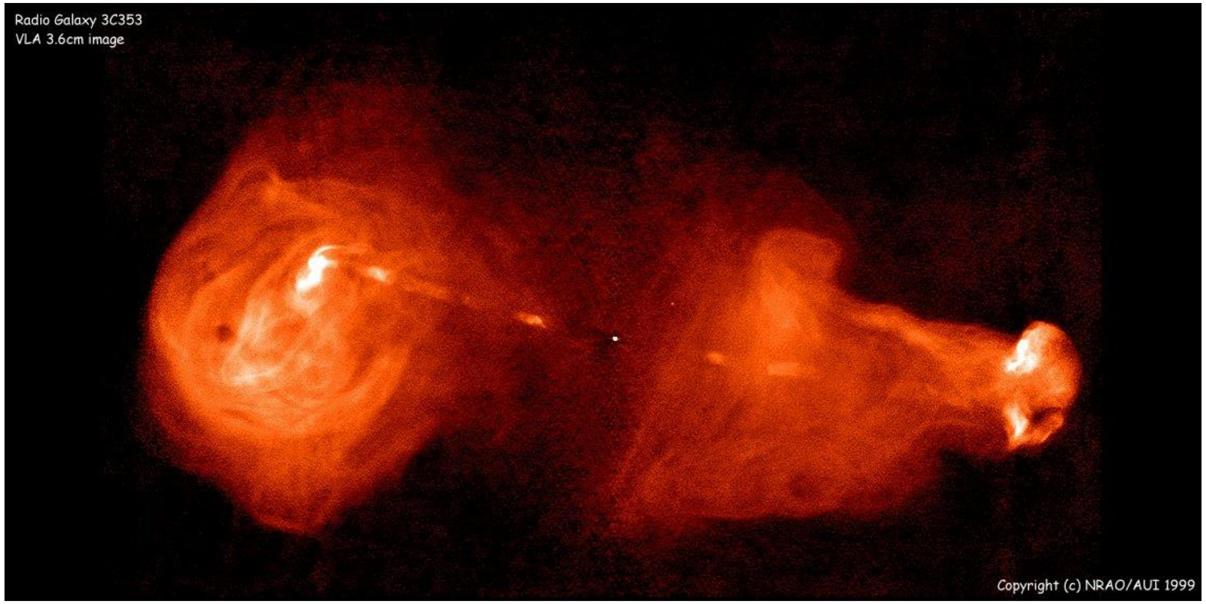
Identifying AGN
What tools are available to do this?

- Spectral index of radio spectra (we will get these “for free” from LOFAR surveys)



- Some morphological information
- Ancillary data critical for this
  - Spectra help enormously
  - Photometry
- (RL?) AGN have a FIRC radio excess
- SEDs = more data; best hope!

The new radio continuum surveys
SKA pathfinders/precursors

Resolution:
NVSS: 45 asec @ 1.4 GHz
FIRST: 5 asec @ 1.4 GHz
EMU: 10 asec @ 1.4 GHz
LOFAR: 15 asec @ 60 MHz, 5 asec @150 MHz
MeerKAT: 6 asec @ 1.4GHz

LOFAR 150 MHz positional uncertainties should be ample for WEAVE follow-up:

$$\sigma_{pos} = \frac{0.6 \times FWHM}{SNR}$$

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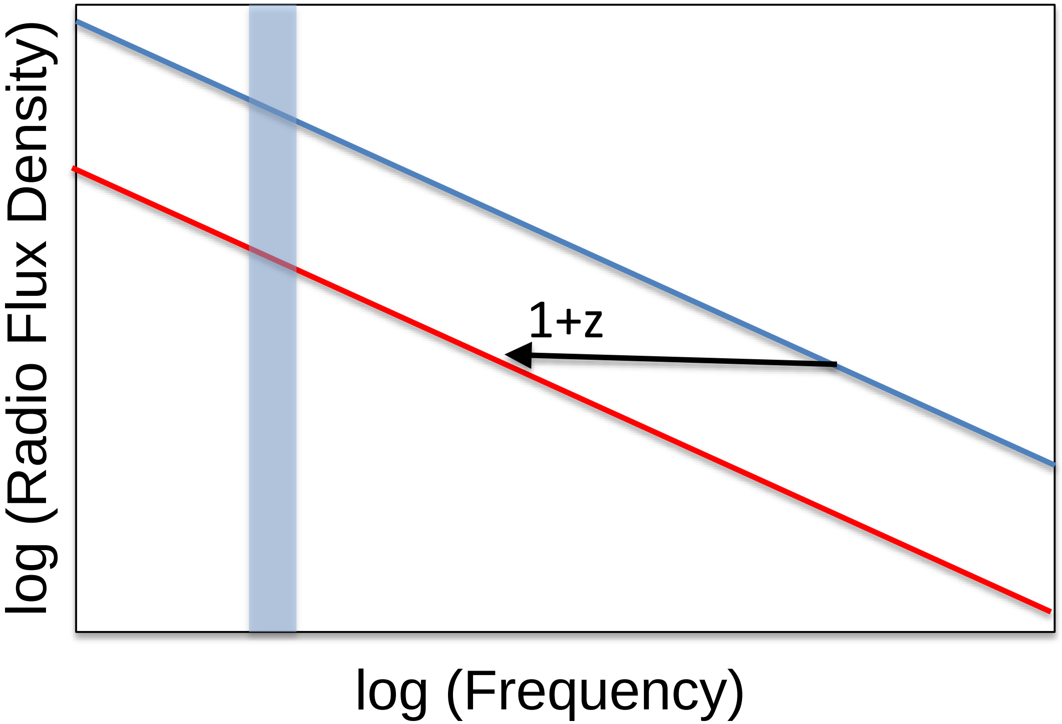
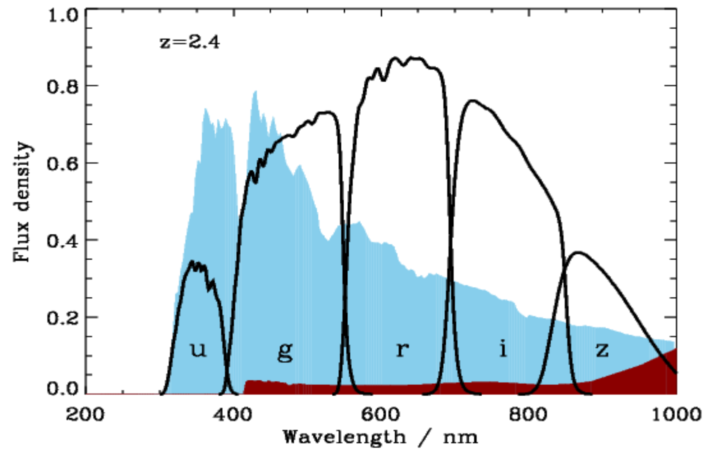
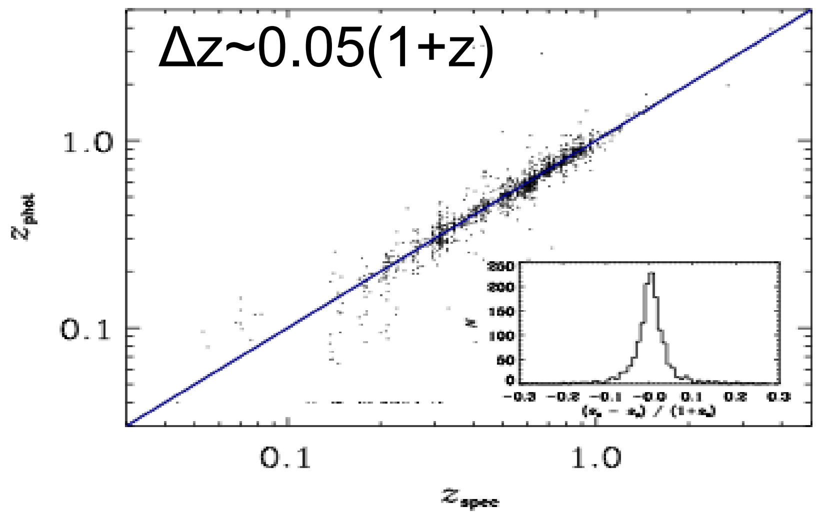
The new radio continuum surveys
SKA pathfinders/precursors timelines

Timelines:
NVSS: Done
FIRST: Done
EMU: Start next year (will take 3 or 4 years)
LOFAR: Observing already underway/done
MeerKAT: Starts next year (similar timeline to EMU)

“There’s nothing as useless as a radio source”
Jim Condon, 2013







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AF2 40x40 arcmin, up to 150 fibers (theoretical, ~100 practical, 50 reality); compare density to WEAVE resolution = 200-4000, wave 3800-9000A

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