

# Radio continuum science with the SKA precursors/pathfinders (and the link to LSST)

**Matt Jarvis**

University of Oxford &  
University of the Western Cape

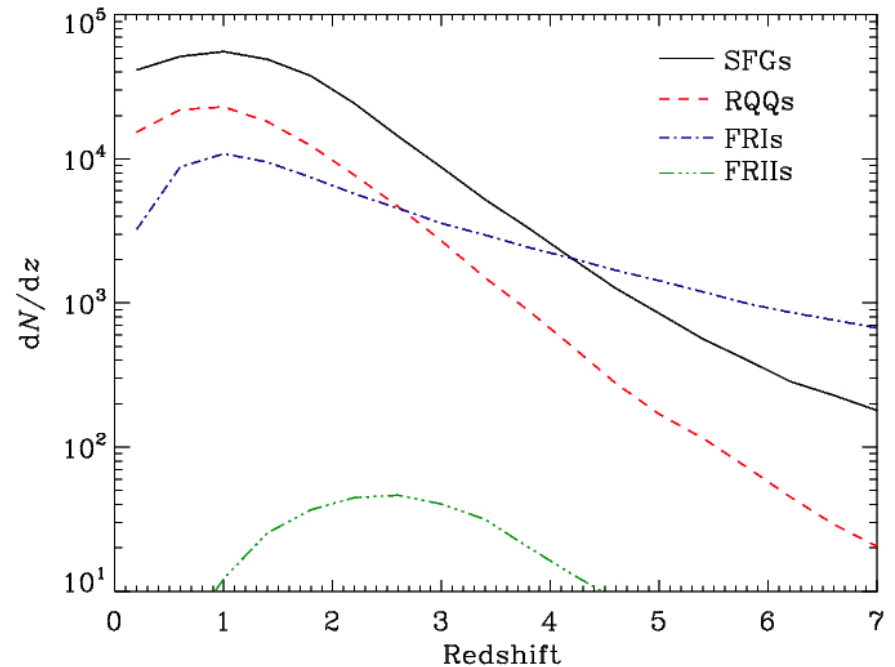
# The SKA Precursor/Pathfinder Telescopes



**LOFAR** - the fastest survey telescope in the world. Multi-tiered survey

**APERTIF + ASKAP** to provide all sky “shallow” surveys

**MeerKAT** will provide very deep observations over  $\sim 30 \text{sq.deg}$  (and probably more)

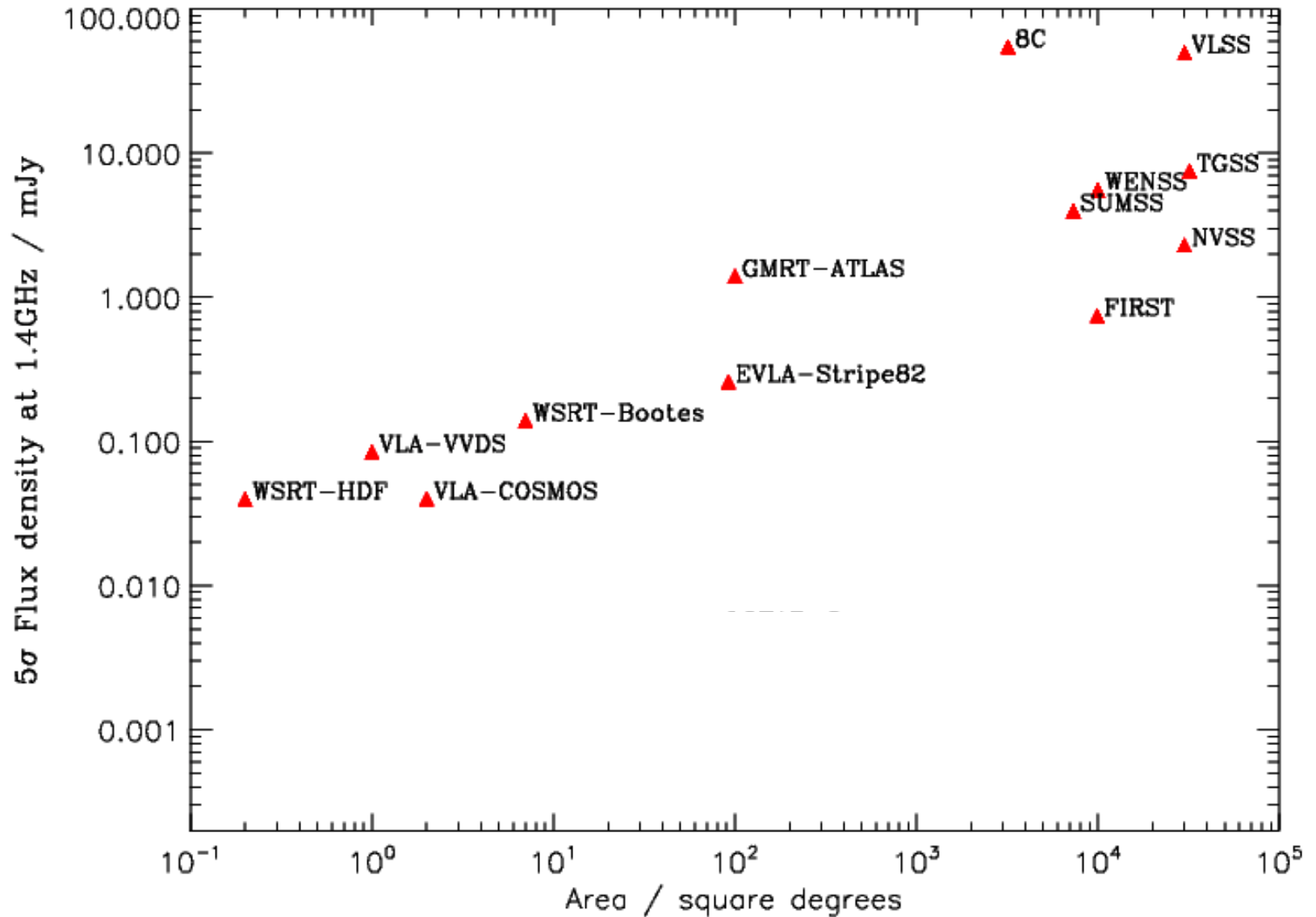


The dominance of star-forming galaxies in the new radio continuum surveys.

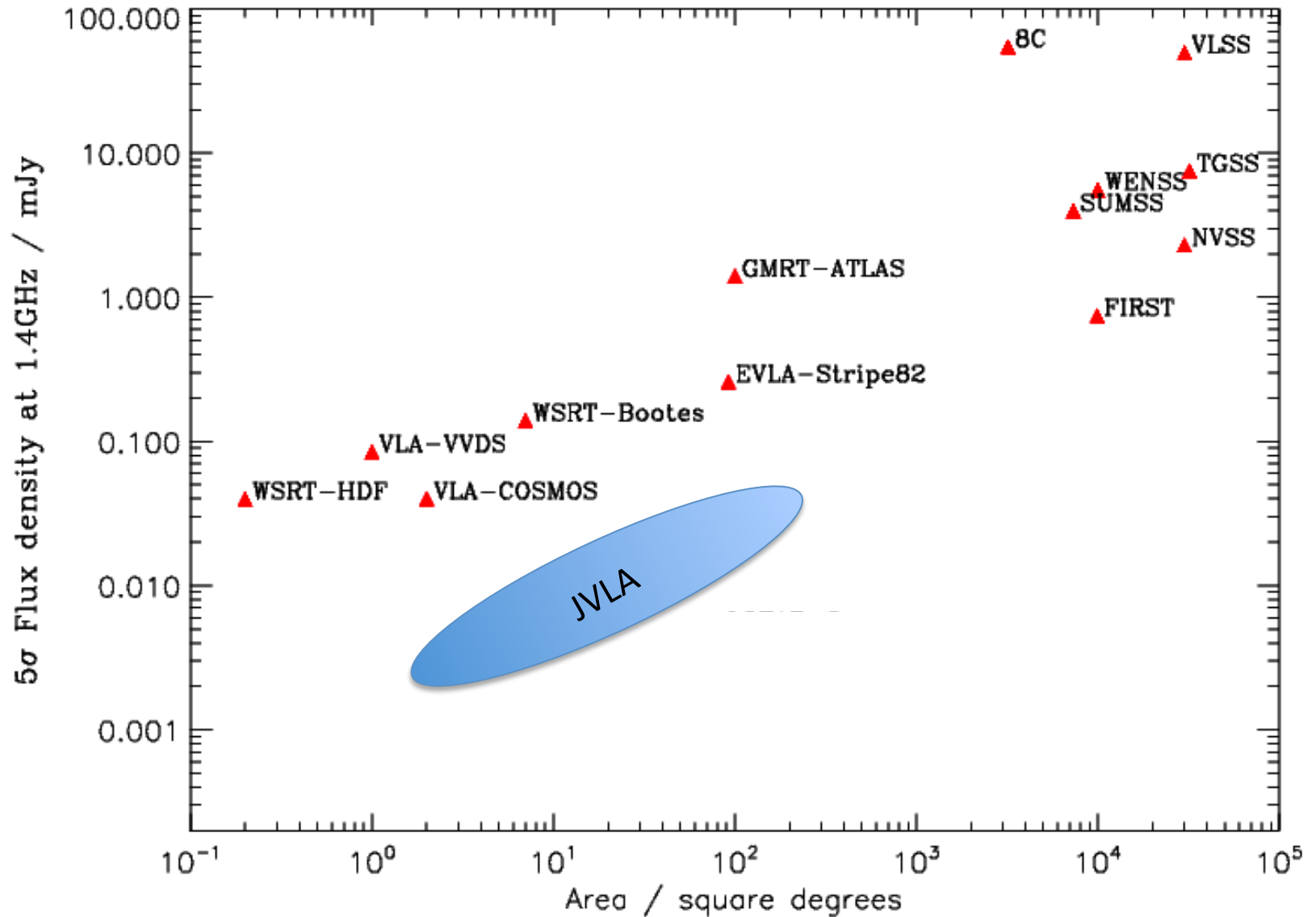
Wilman & MJJ et al. 2010

<http://s-cubed.physics.ox.ac.uk>

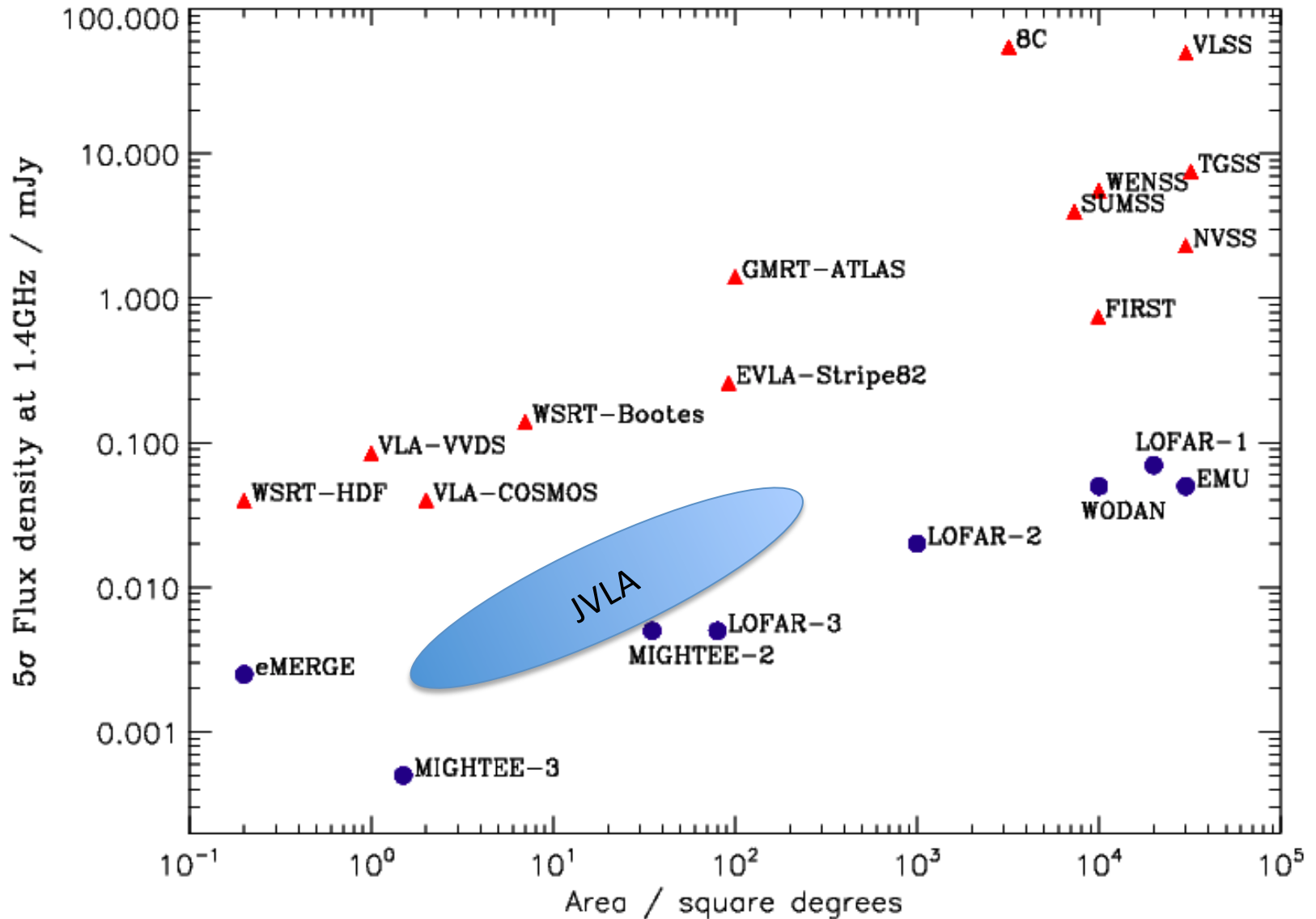
## The new radio continuum surveys



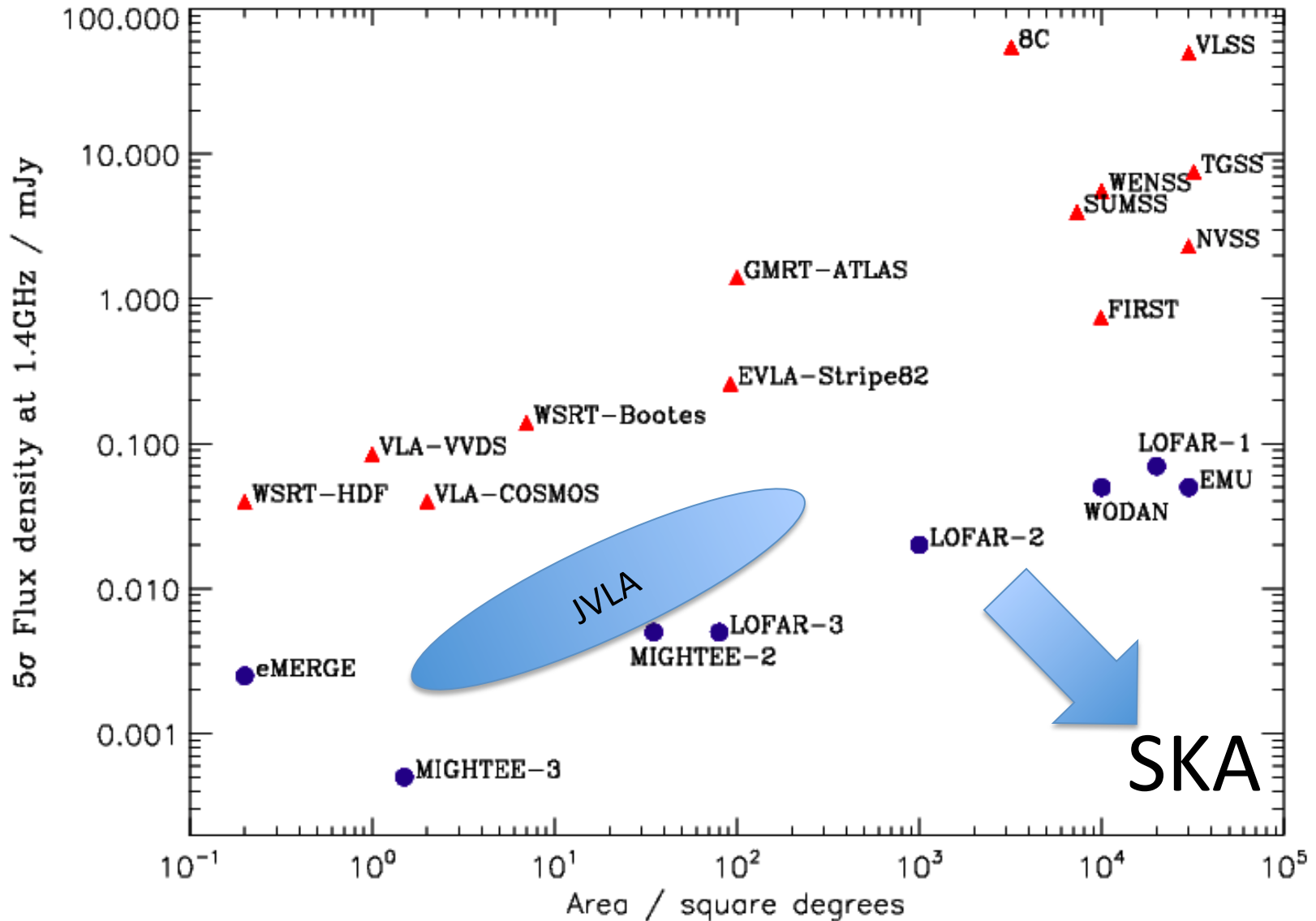
# The new radio continuum surveys



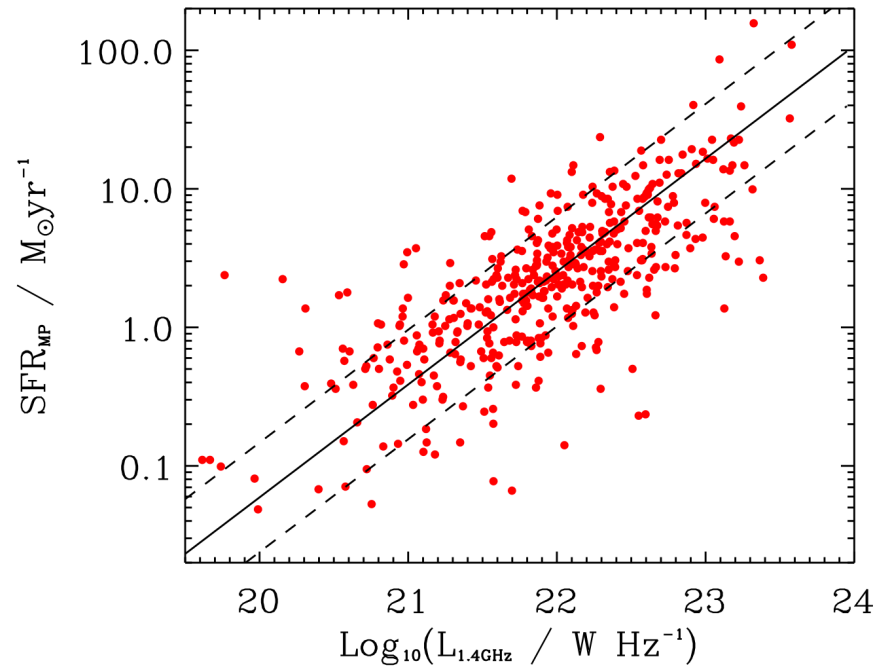
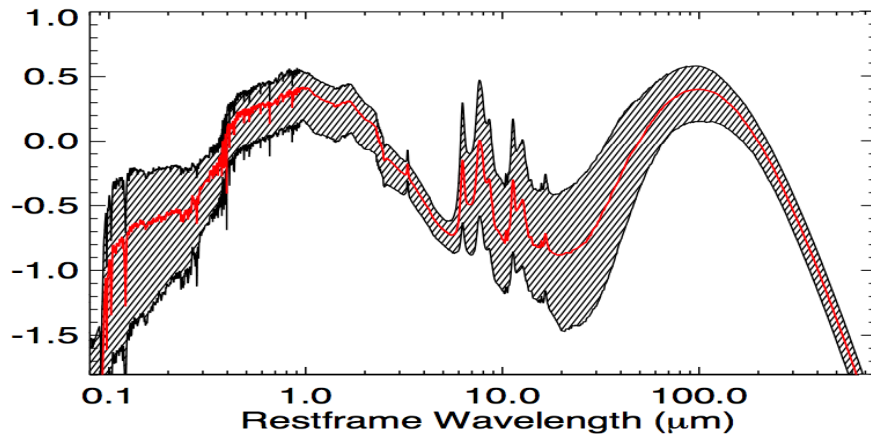
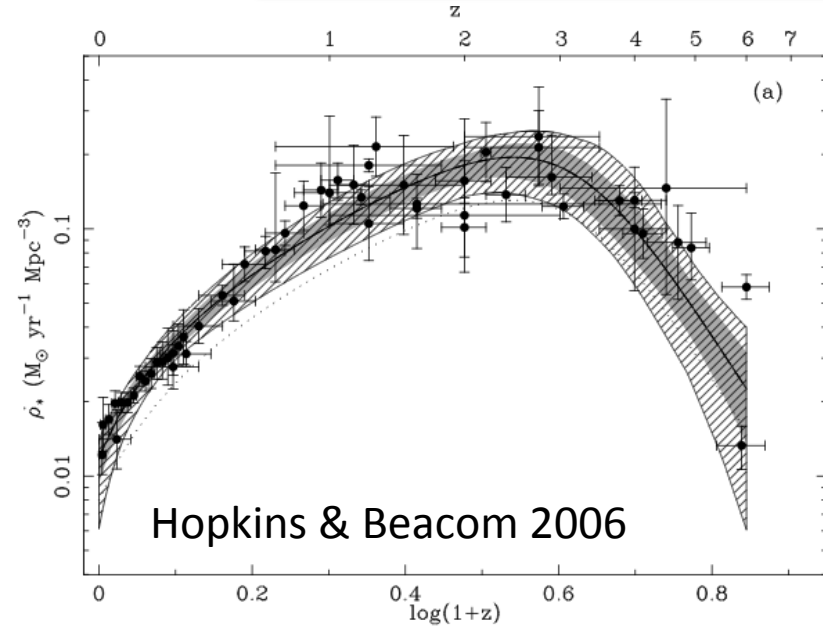
# The new radio continuum surveys



## The new radio continuum surveys

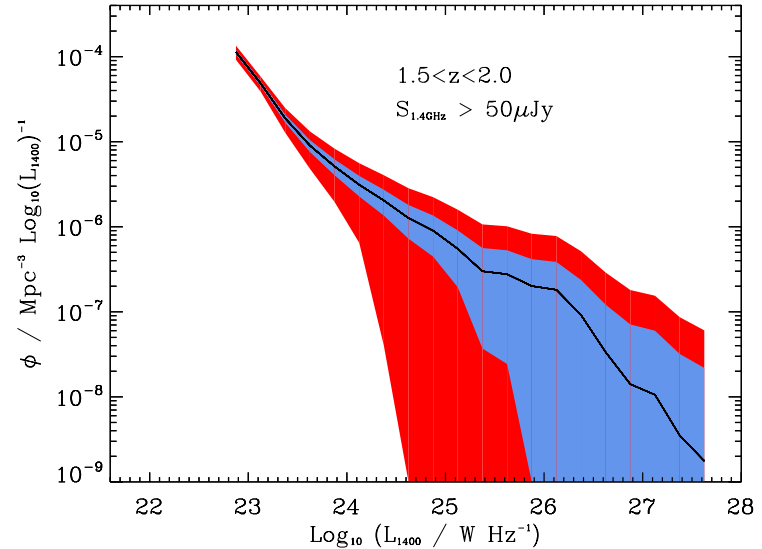
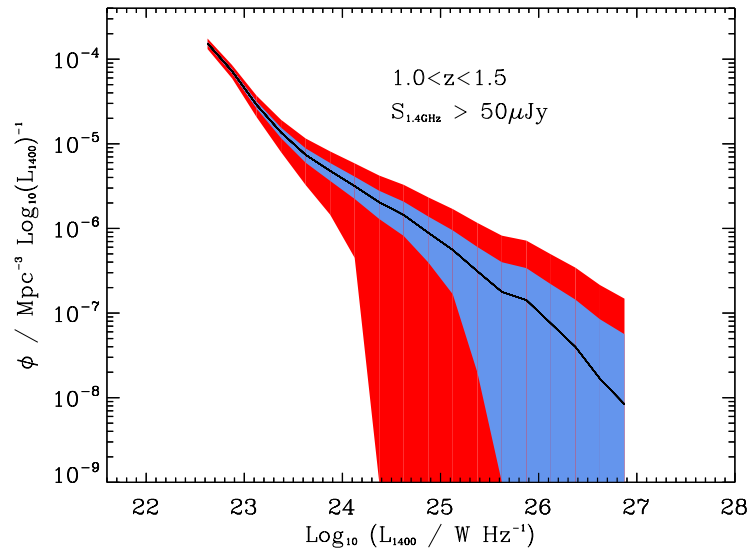


# The new radio continuum surveys & the evolution of activity

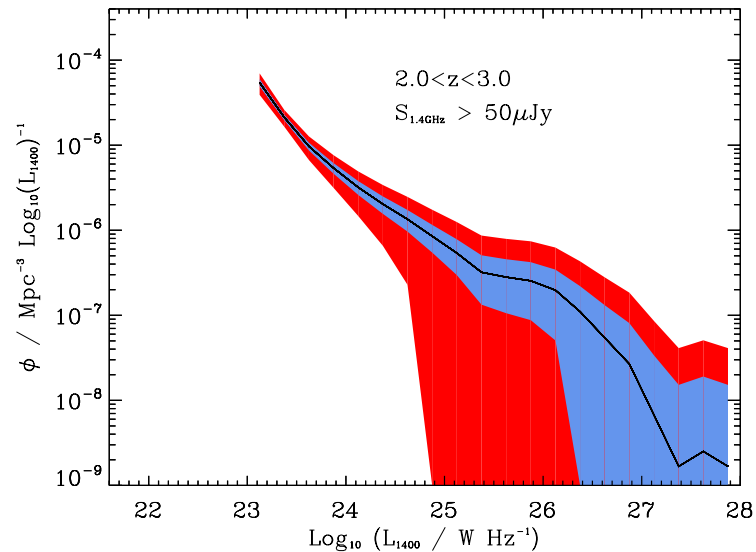


Far-infrared/SFR – radio correlation  
from H-ATLAS (Smith et al. submitted;  
MJJ et al. in prep.)

# The new radio continuum surveys & the evolution of activity

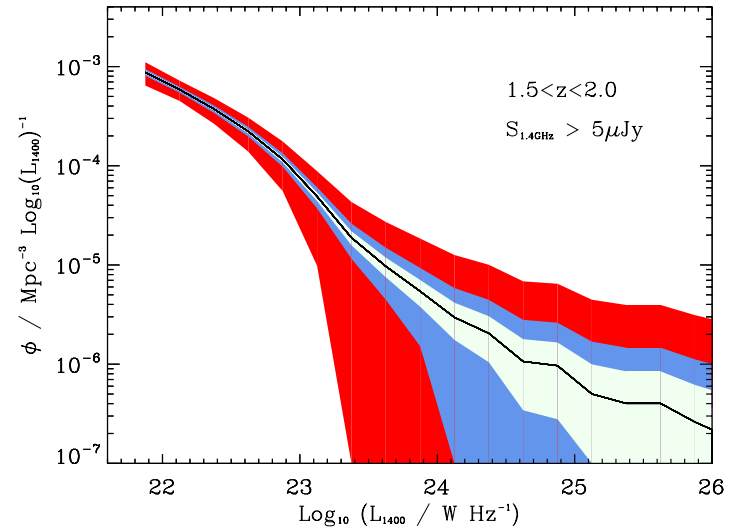
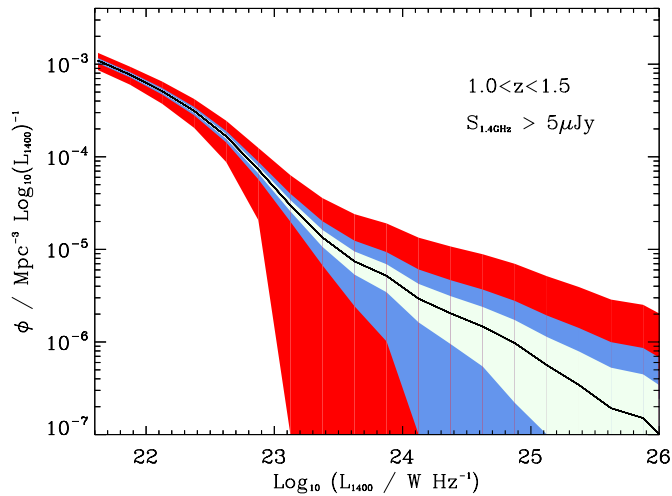


Red = 12 sq.deg  
Blue = 35sq.deg  
Black=30,000 sq.deg

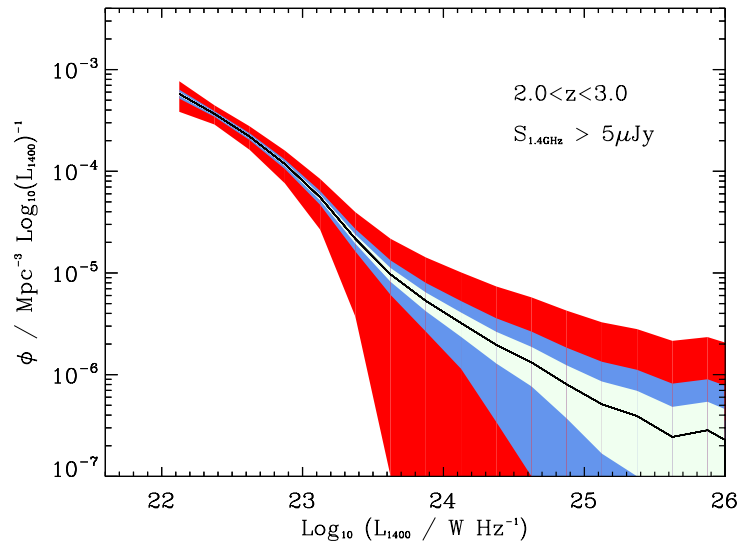




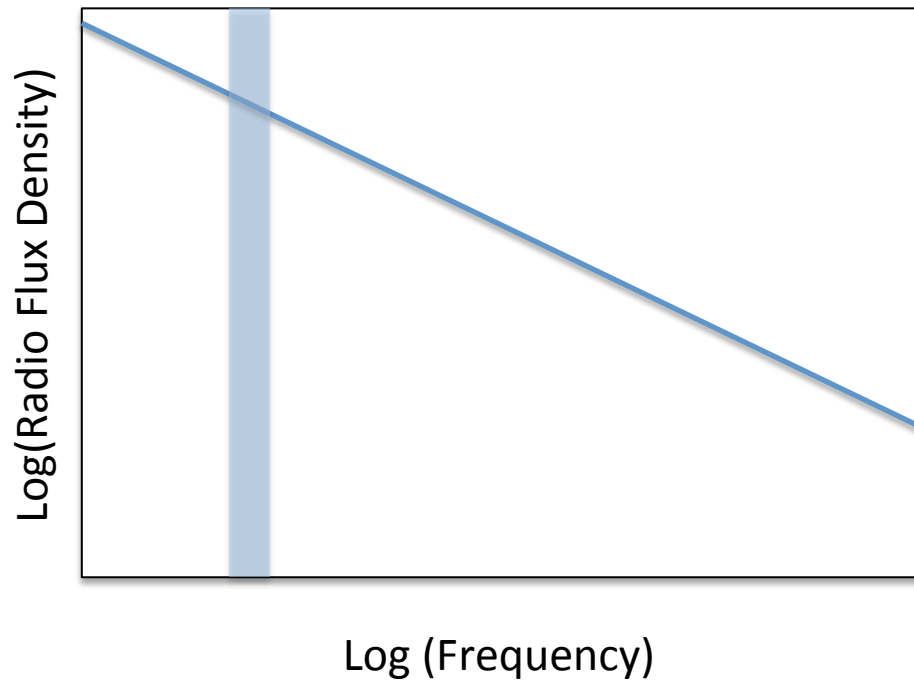
# The new radio continuum surveys & the evolution of activity



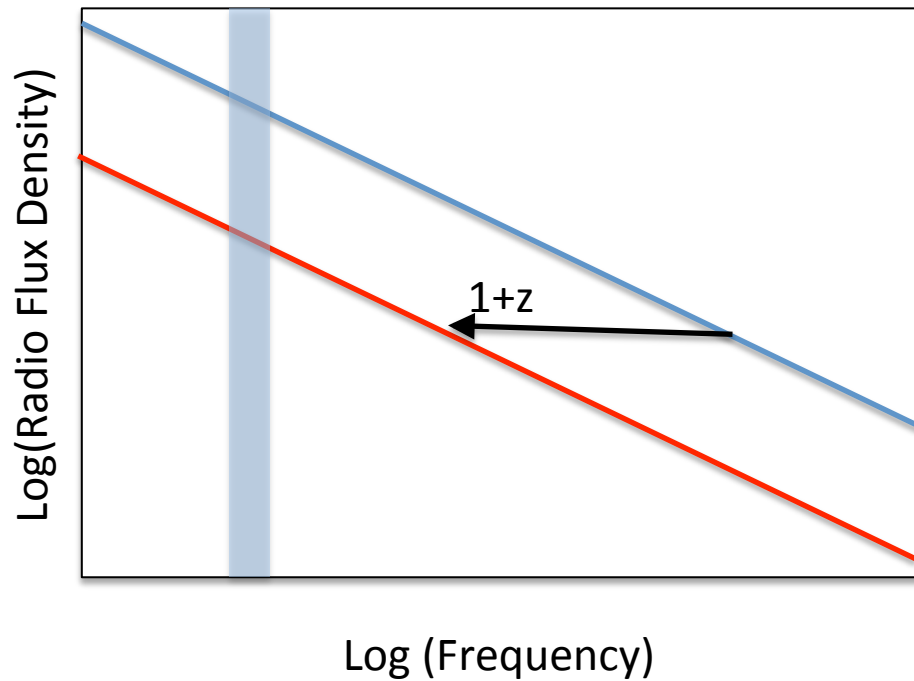
Red = 1 sq.deg  
Blue = 5sq.deg  
Cream=12sq.deg



# The new radio continuum surveys & the evolution of activity

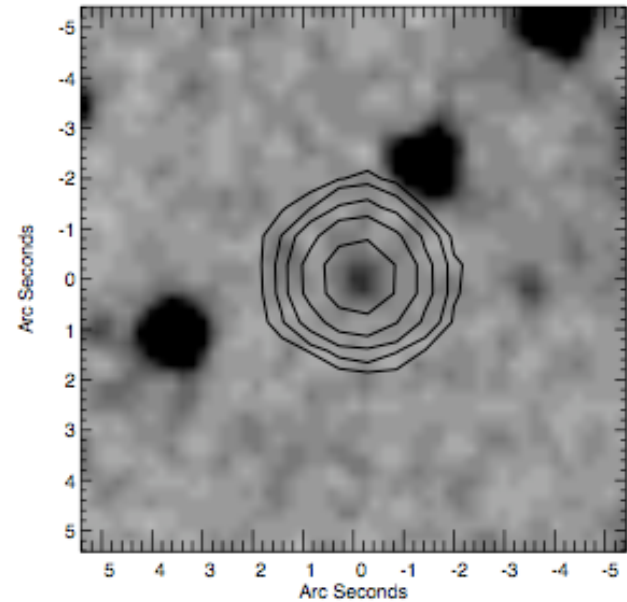
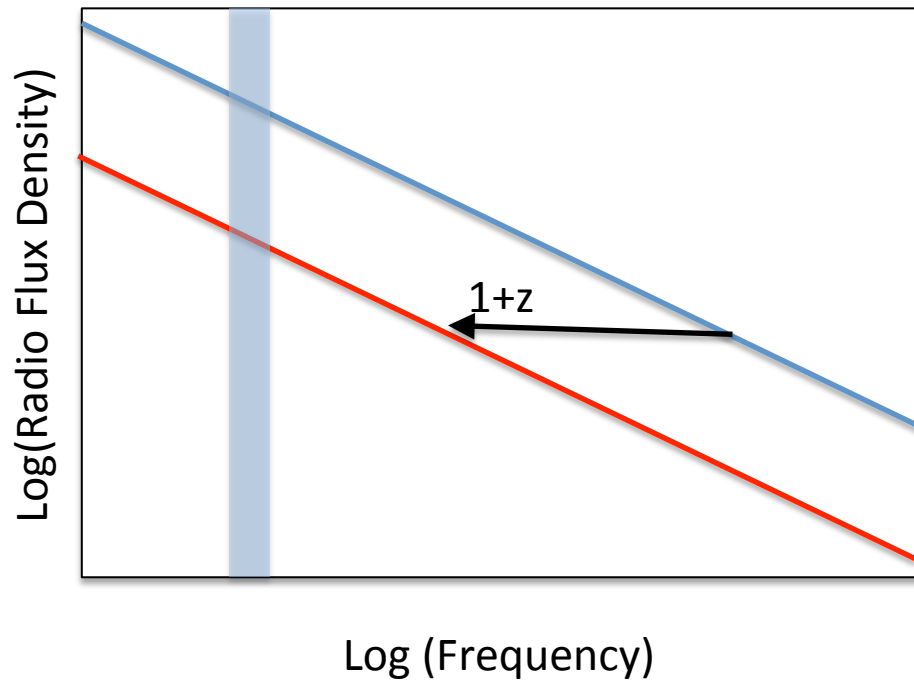


# The new radio continuum surveys & the evolution of activity



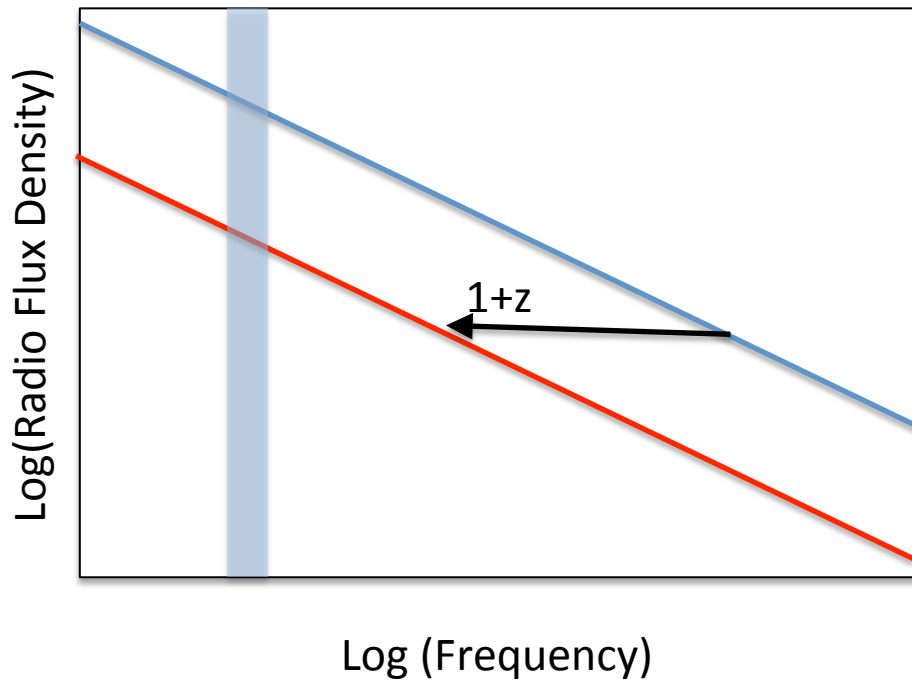
No redshift information!

# The new radio continuum surveys & the evolution of activity

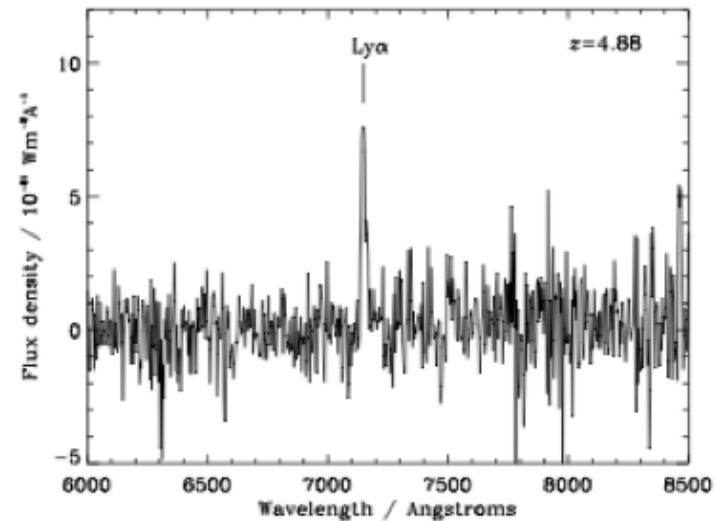
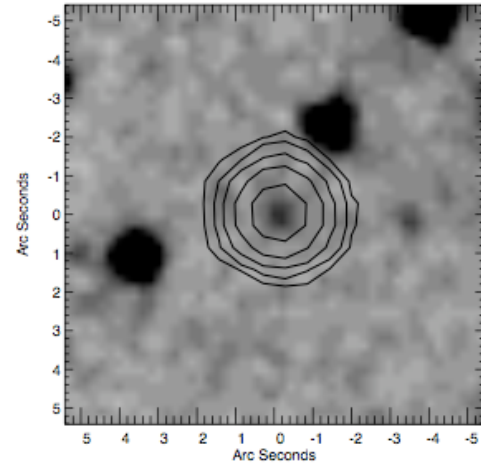


No redshift information!

# The new radio continuum surveys & the evolution of activity



No redshift information!

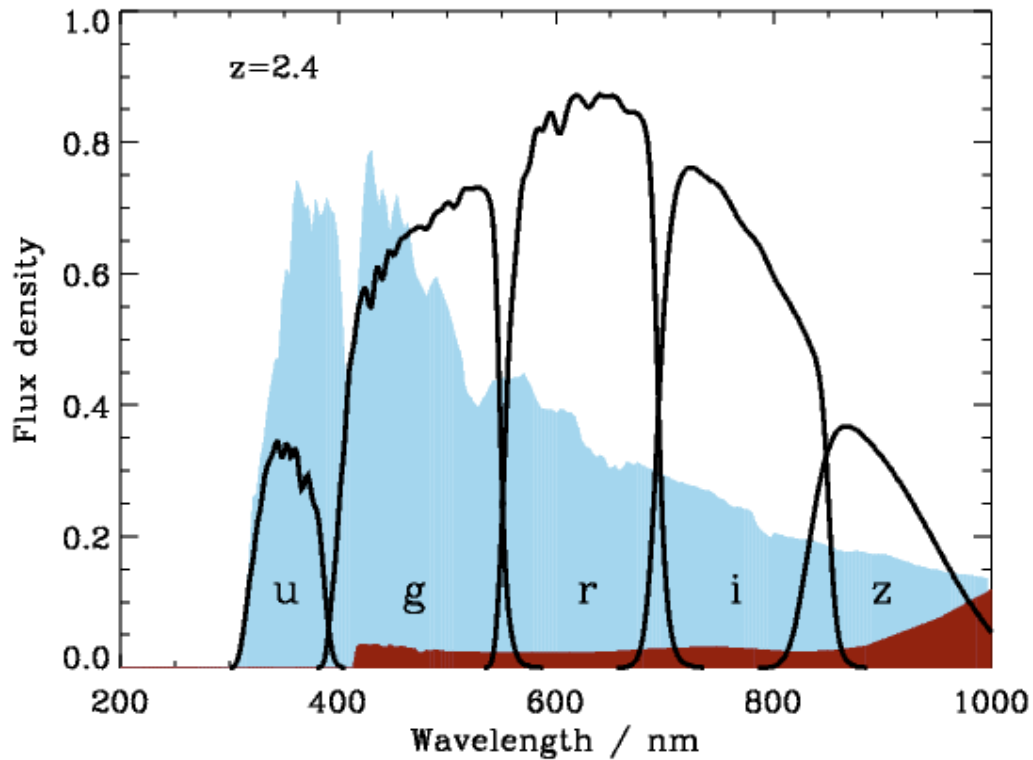


MJJ et al. 2009; Optical spectrum of  $z=4.88$  radio source

## The new radio continuum surveys & the evolution of activity

- So in order to measure the radio luminosity function and thus the evolution of star-formation and AGN activity from radio continuum surveys, we need redshifts from somewhere else
- Deep optical and near-IR imaging is needed to measure photo-zs.
- Role of spectroscopy would be to obtain accurate redshifts and to determine the presence of AGN activity via emission line diagnostics

# The optical view



Different filters sample different galaxy properties at different redshifts

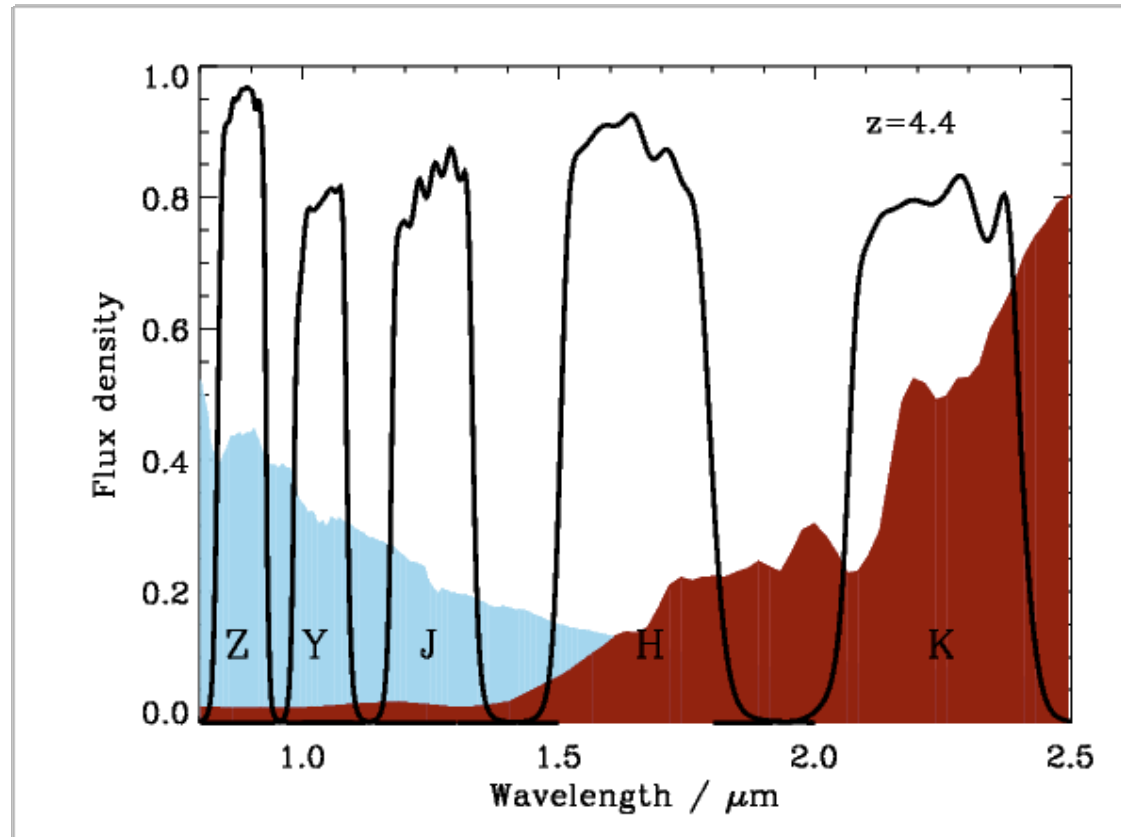
So difficult to get a consistent picture of galaxies over the history of the Universe.

# Moving to the near-IR

We can move to longer wavelengths.

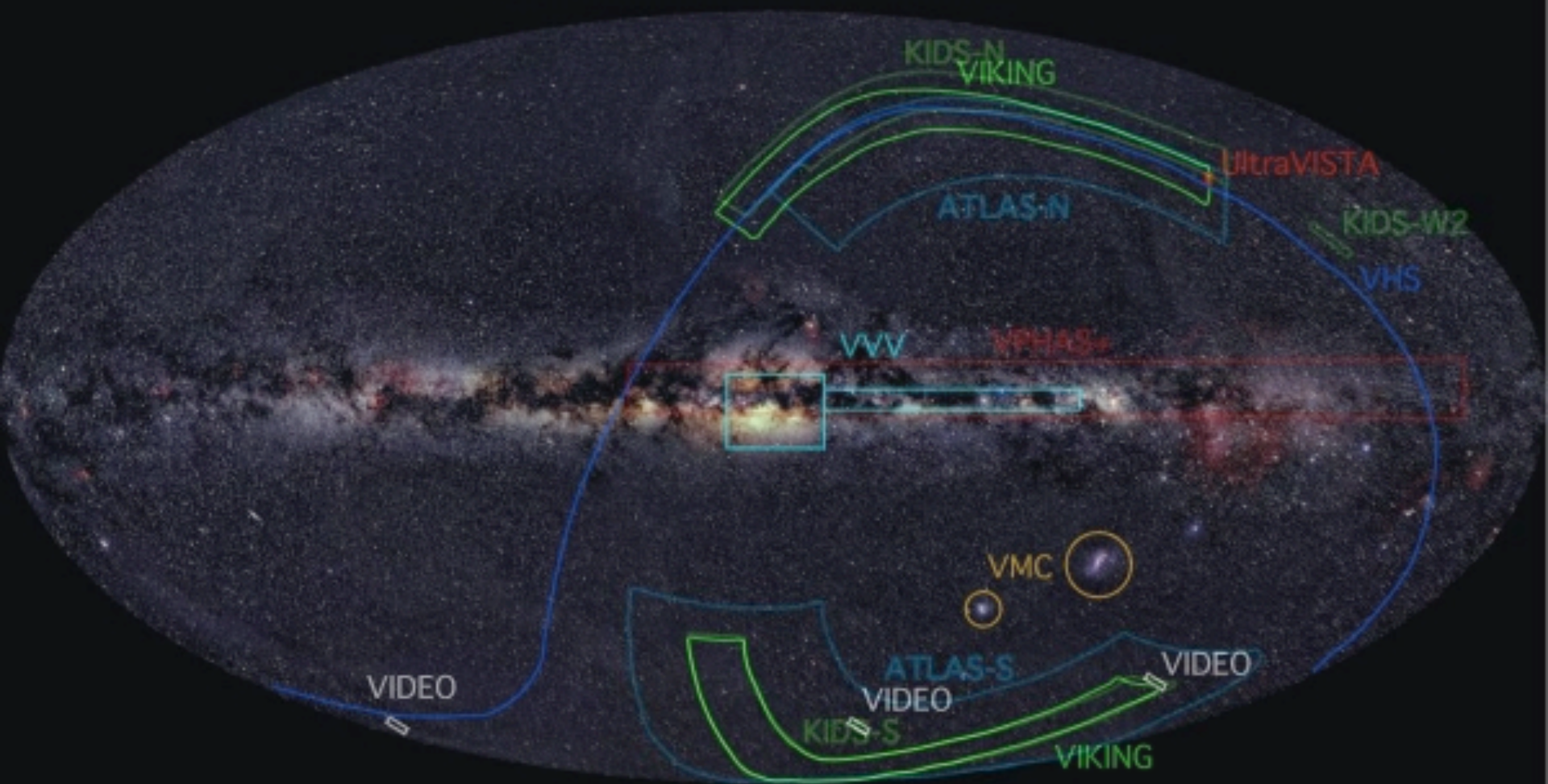
But need different detectors, telescopes and techniques.

Crucial for accurately measuring photometric redshifts at  $z > 1$

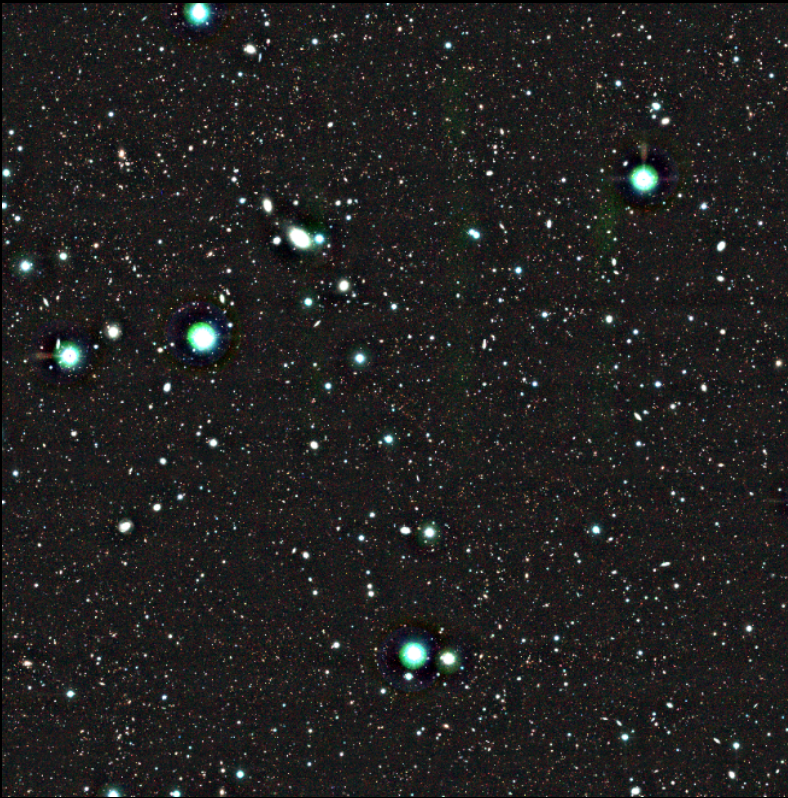




# The new generation of near-infrared surveys with VISTA

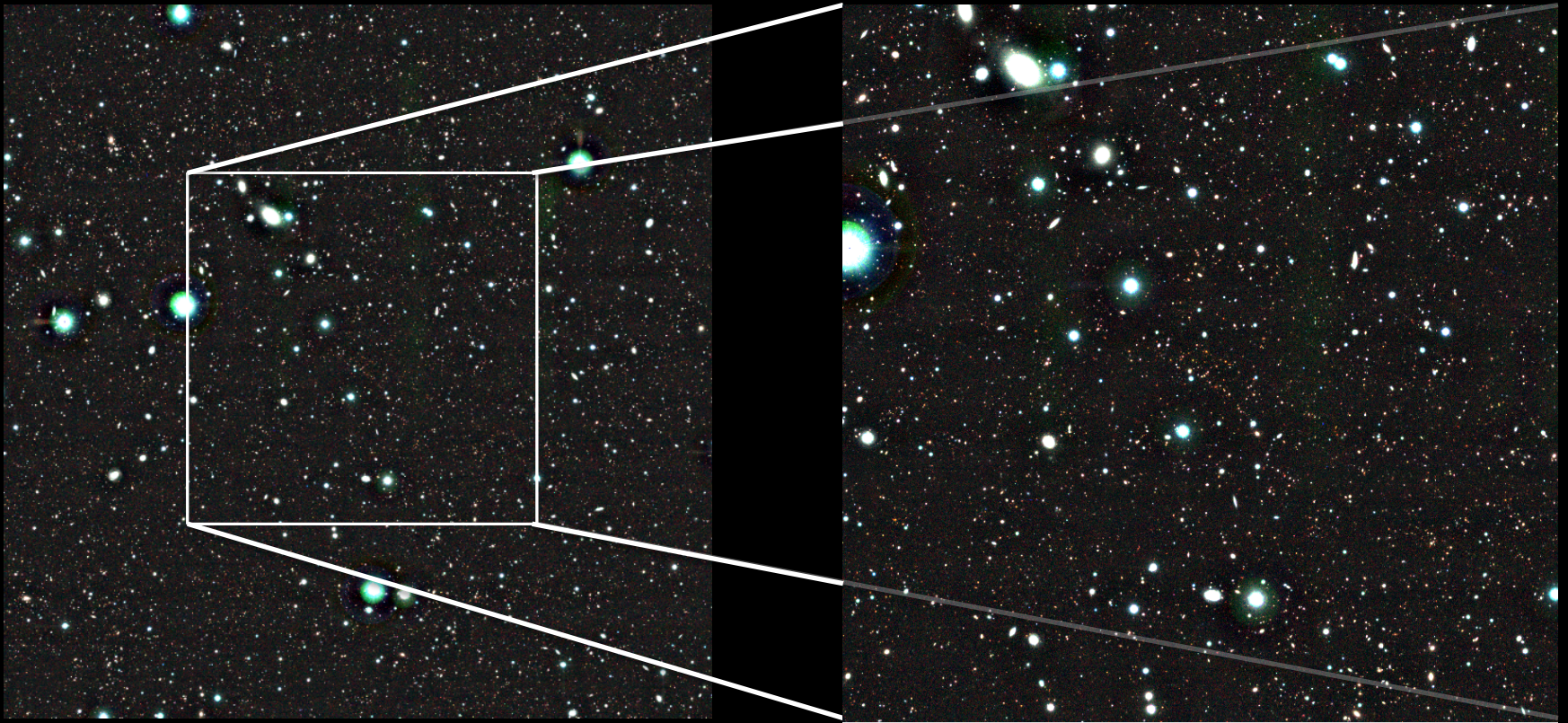


# The VISTA Deep Extragalactic Observations (VIDEO) Survey



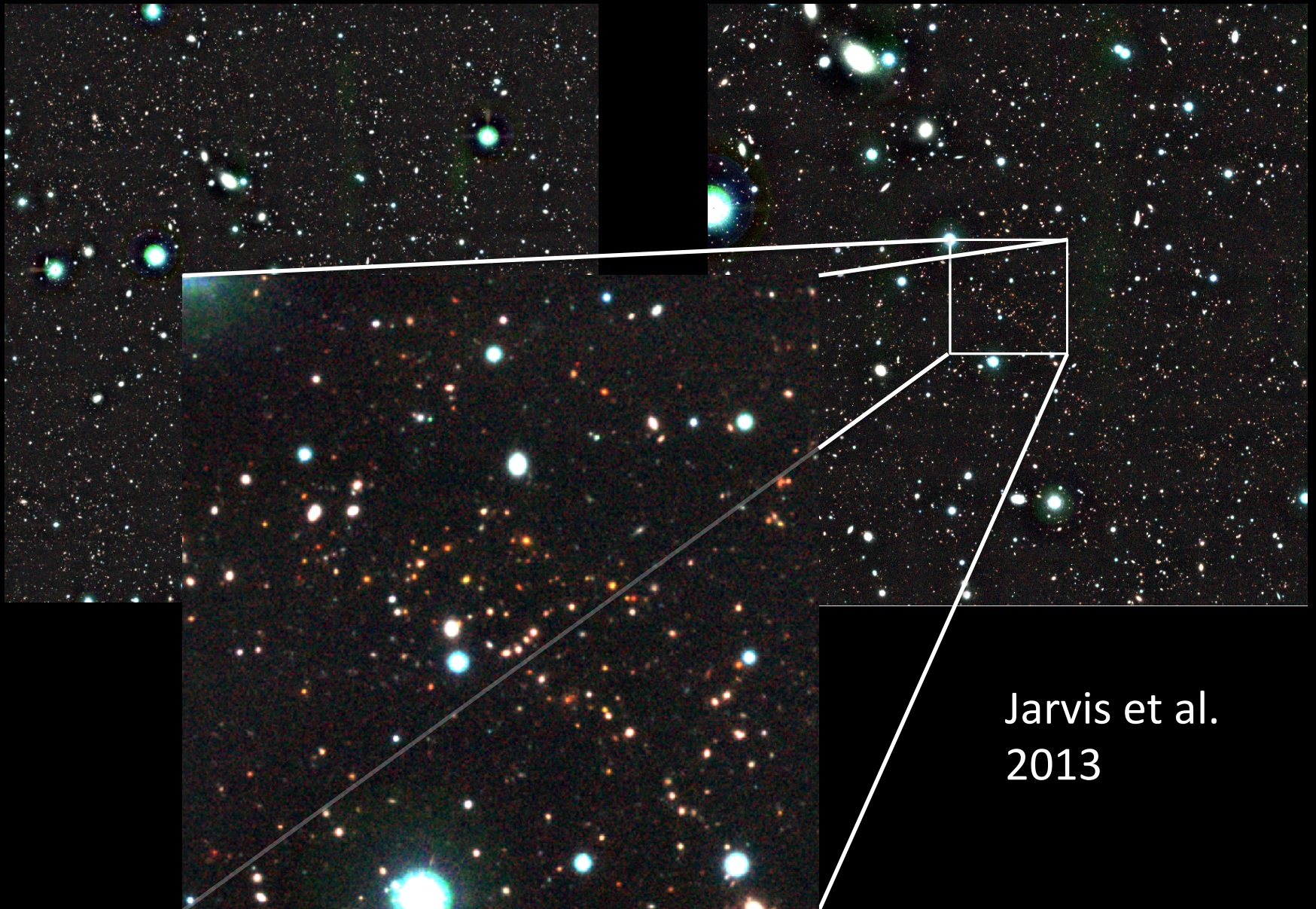
Jarvis et al  
2013

# The VISTA Deep Extragalactic Observations (VIDEO) Survey



Jarvis et al.  
2013

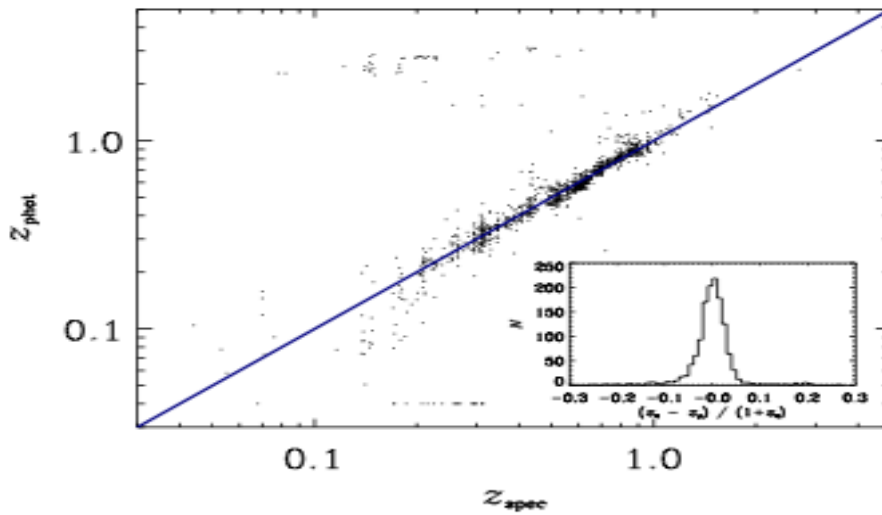
# The VISTA Deep Extragalactic Observations (VIDEO) Survey



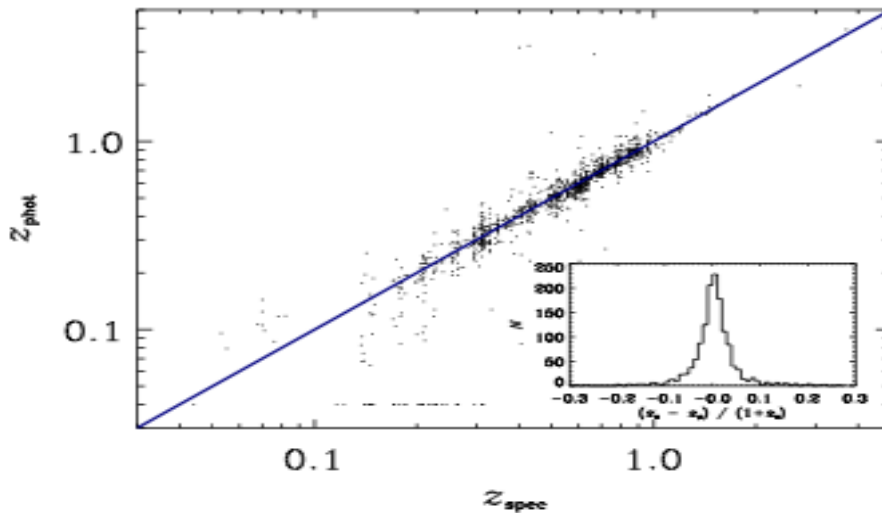
Jarvis et al.  
2013

# The VISTA Deep Extragalactic Observations (VIDEO) Survey

Jarvis et al. 2013



Feeds directly in to photo-z work for *Euclid* (and LSST)



The link between VIDEO+SERVS+DES+HerMES+MeerKAT  
+LSST++

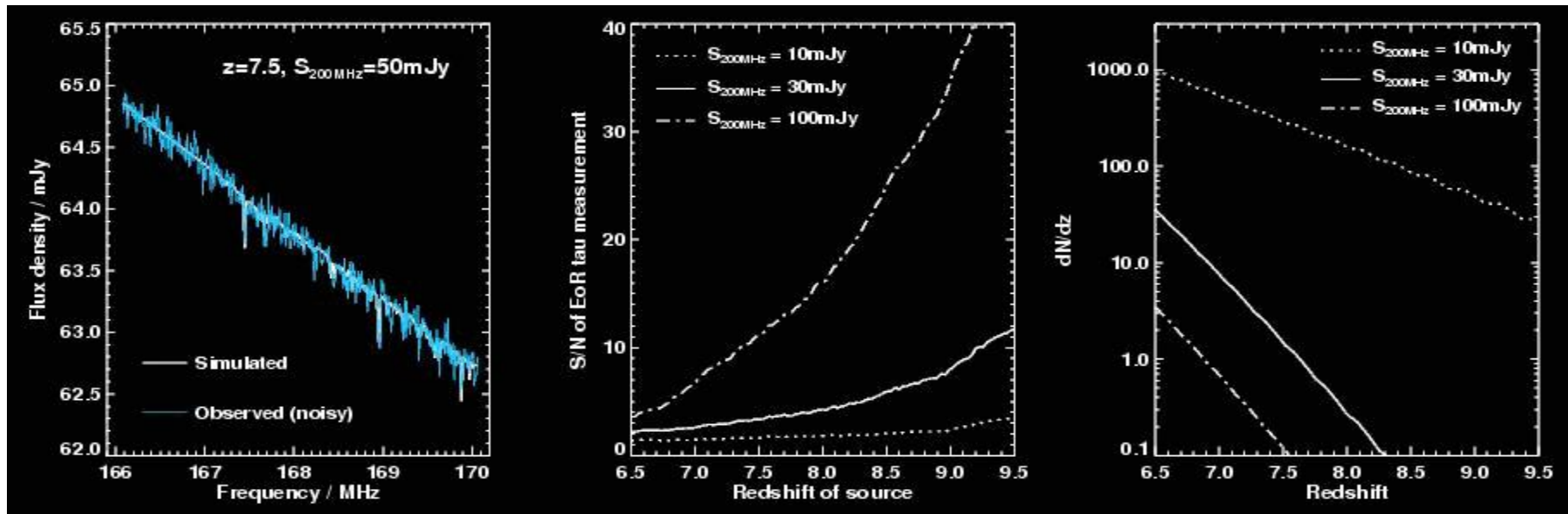
- Spitzer Representative Volume Survey (SERVS) (1400 hours). Provides 3.6 and 4.5um data to similar depth as VIDEO (PI Mark Lacy)
- VIDEO data sharing agreement with the Dark Energy Survey for SNe science. *grizy* photometry to depths of AB~27 (5sigma)
- Covered by VST in optical (Guaranteed Time Consortium) – u-band niche and again SNe science
- Covered by Herschel-HerMES survey (100-500um)
- SCUBA-2 CLS to cover 4.5 sq.deg over the VIDEO-XMM-LSS footprint
- ECDFS field is also the LADUMA field (Deep HI survey with MeerKAT)
- All fields covered by MeerKAT's MIGHTEE Survey (co-PI Jarvis)

# The new radio continuum surveys & the evolution of activity

- So in order to measure the radio luminosity function and thus the evolution of star-formation and AGN activity from radio continuum surveys, we need redshifts from somewhere else
- Deep optical and near-IR imaging is needed to measure photo-zs.
- Role of spectroscopy would be to obtain accurate redshifts and to determine the presence of AGN activity via emission line diagnostics (e.g. large scale MOS and HETDEX)
- Really the realm of deeper narrower surveys. Need  $\sim 20\text{-}40\text{sq.deg}$  to fully sample radio populations and overcome sample variance – LSST Deep Drilling fields
- Current limitation is radio data
- But SKA and the precursors also allow **wide-area AND deep data**, what can we use this for?

# In to the Epoch of Reionization? – see Minh's talk

- Using powerful radio sources within the EoR, the properties of the EoR can be studied in absorption, via the 21 cm forest.
- High flux limit (5mJy @1.4GHz), gives  $\sim 24$  sources per sq.deg.
- Obtain spectra for all of these and expect 1  $z > 6$  powerful radio source per  $\sim 1000$ sq.deg for EoR absorption

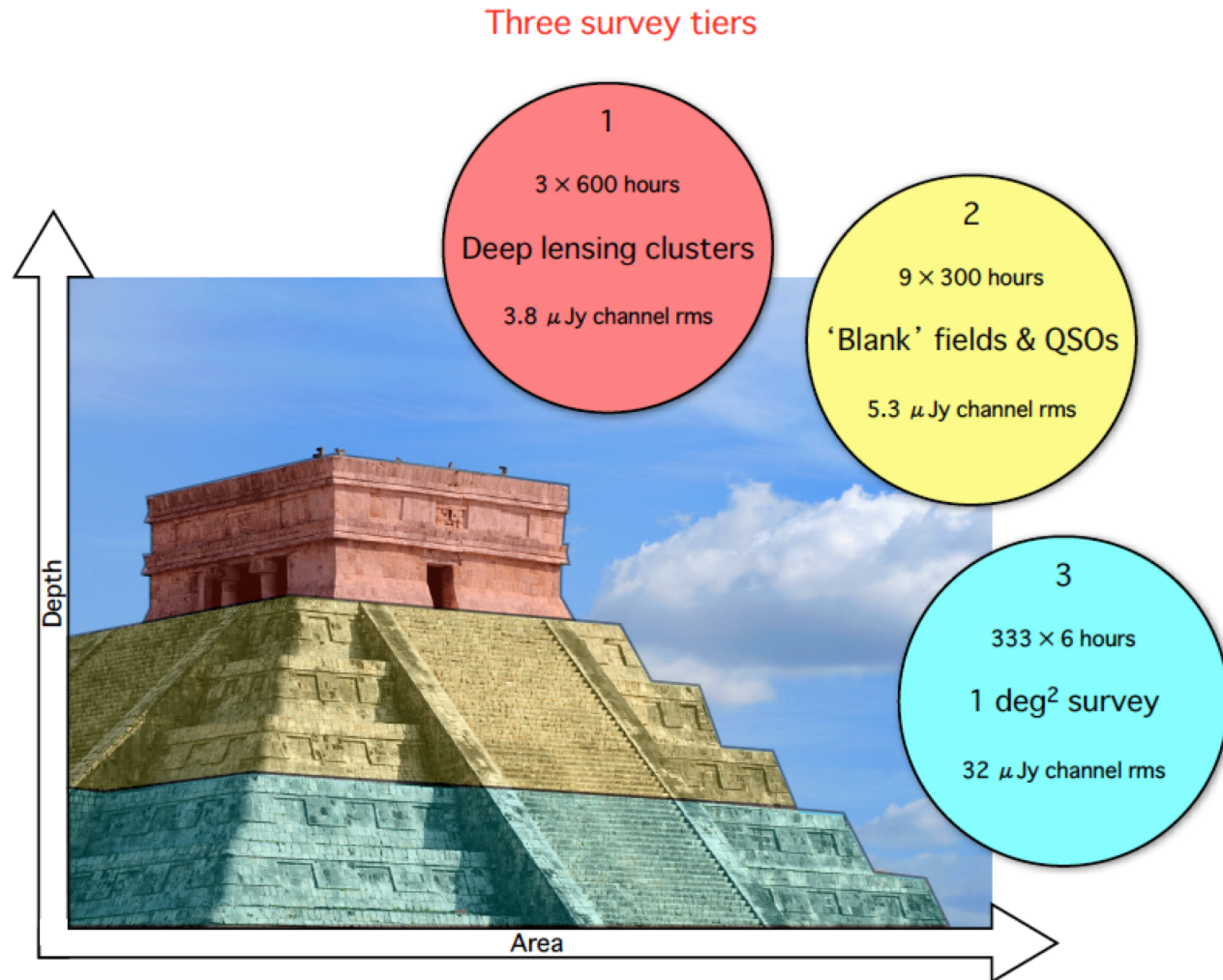




# Epoch of Reionization with MESMER

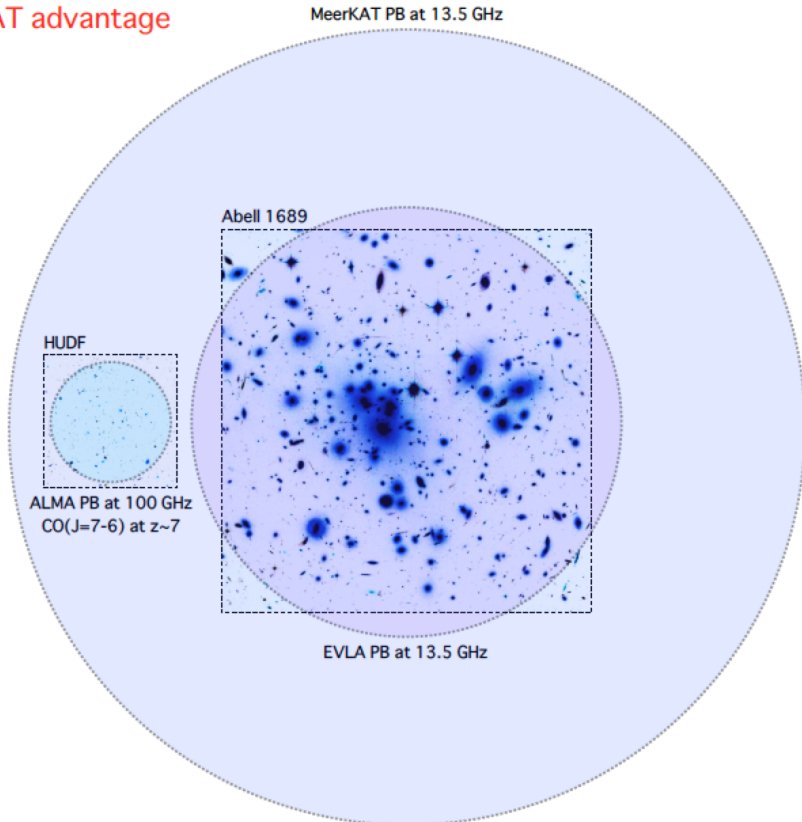
The **MeerKAT Search for Molecules in the Epoch of Reionization**

PI Ian Heywood (Ox)



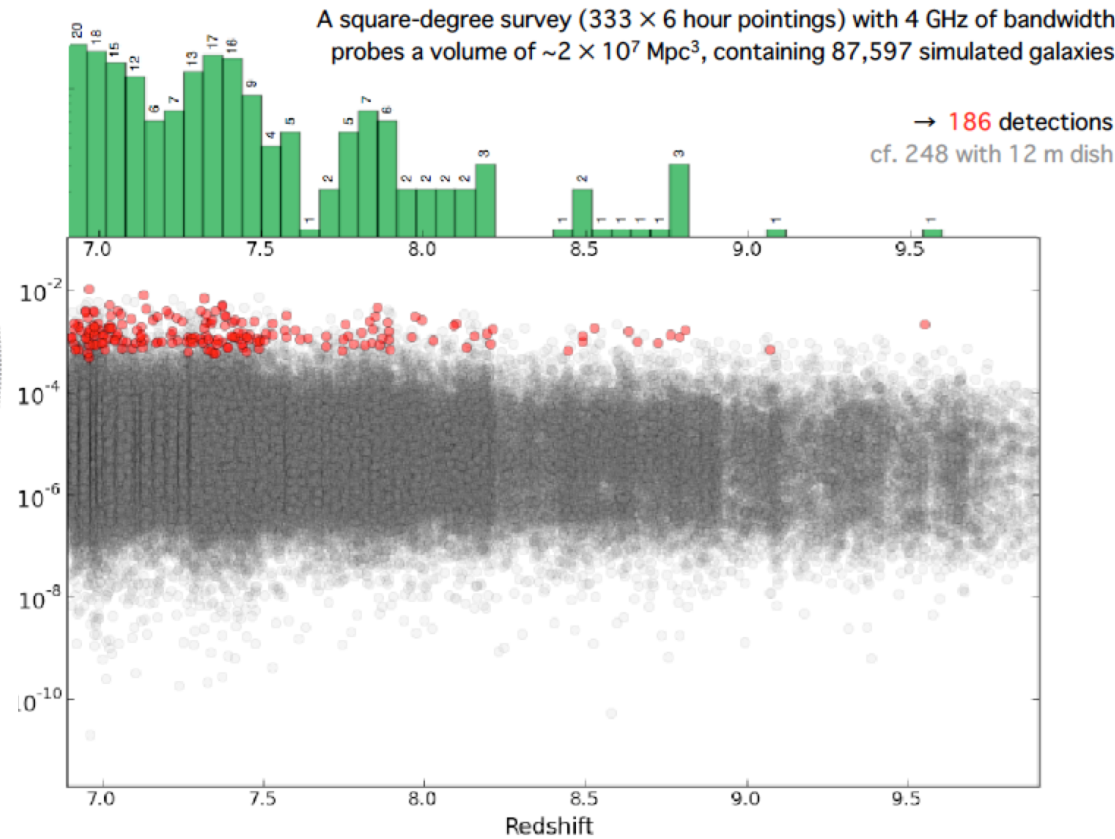
# Epoch of Reionization with MESMER

AT advantage



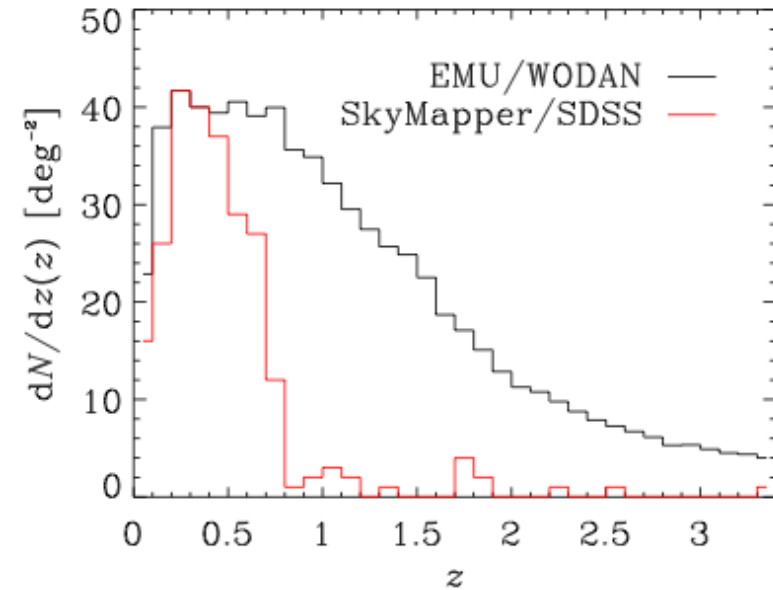
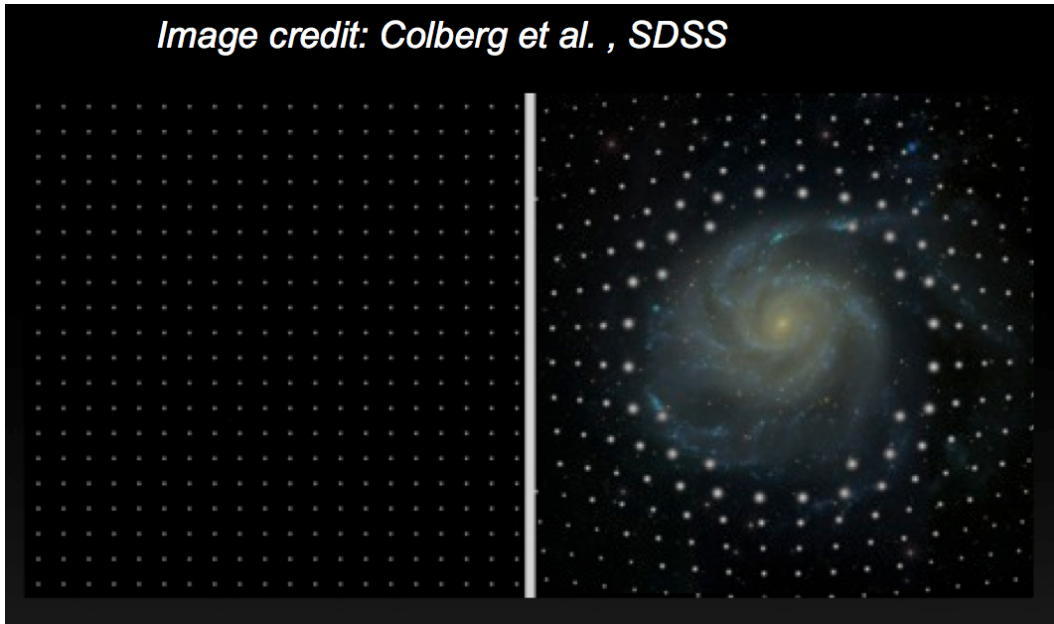
The resolution of an 8 km baseline is about 1.2 pixels on this slide

Analytic simulations for Tier-3 (likely to be E-CDFS)

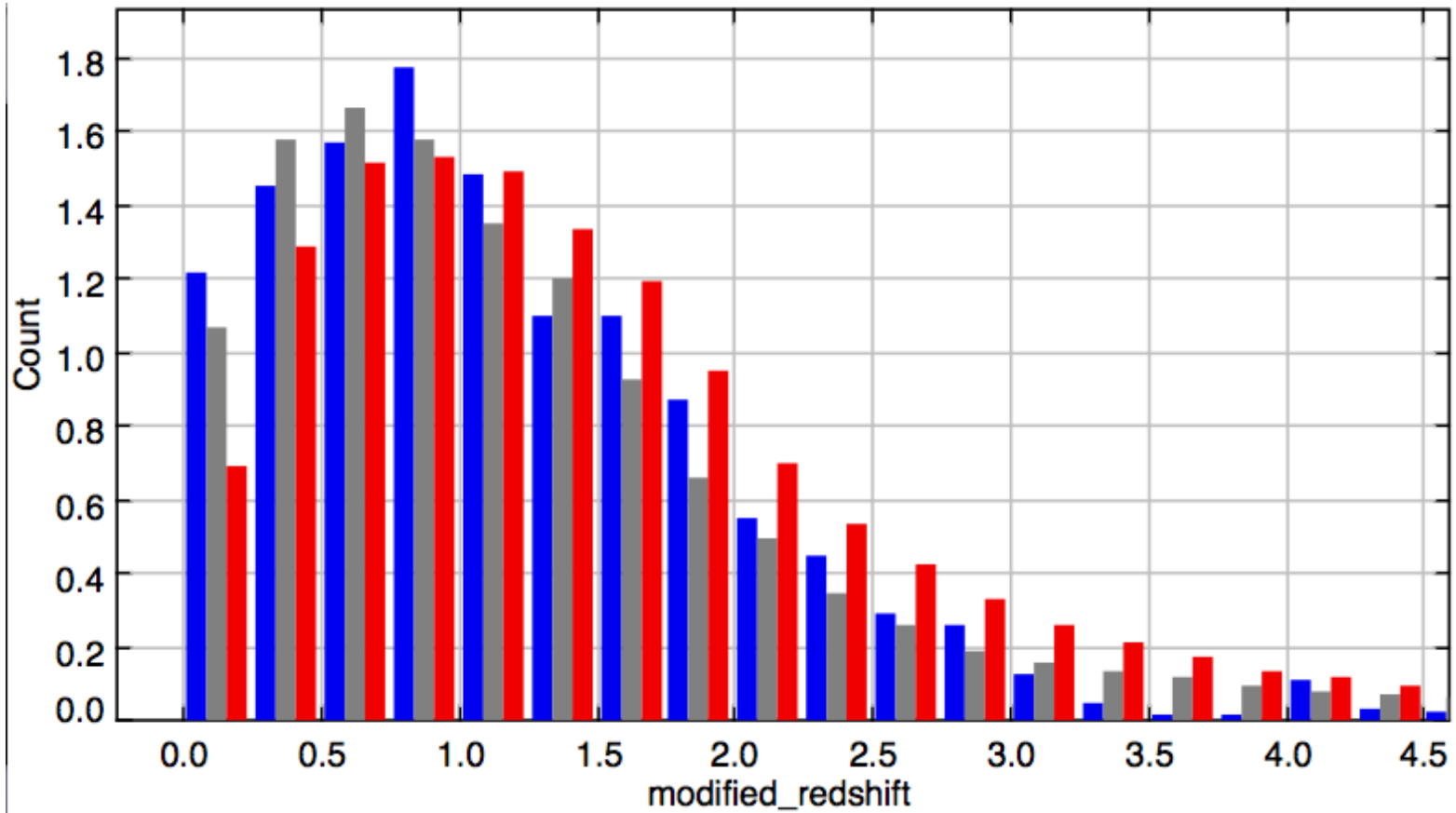


# Multi-wavelength magnification bias

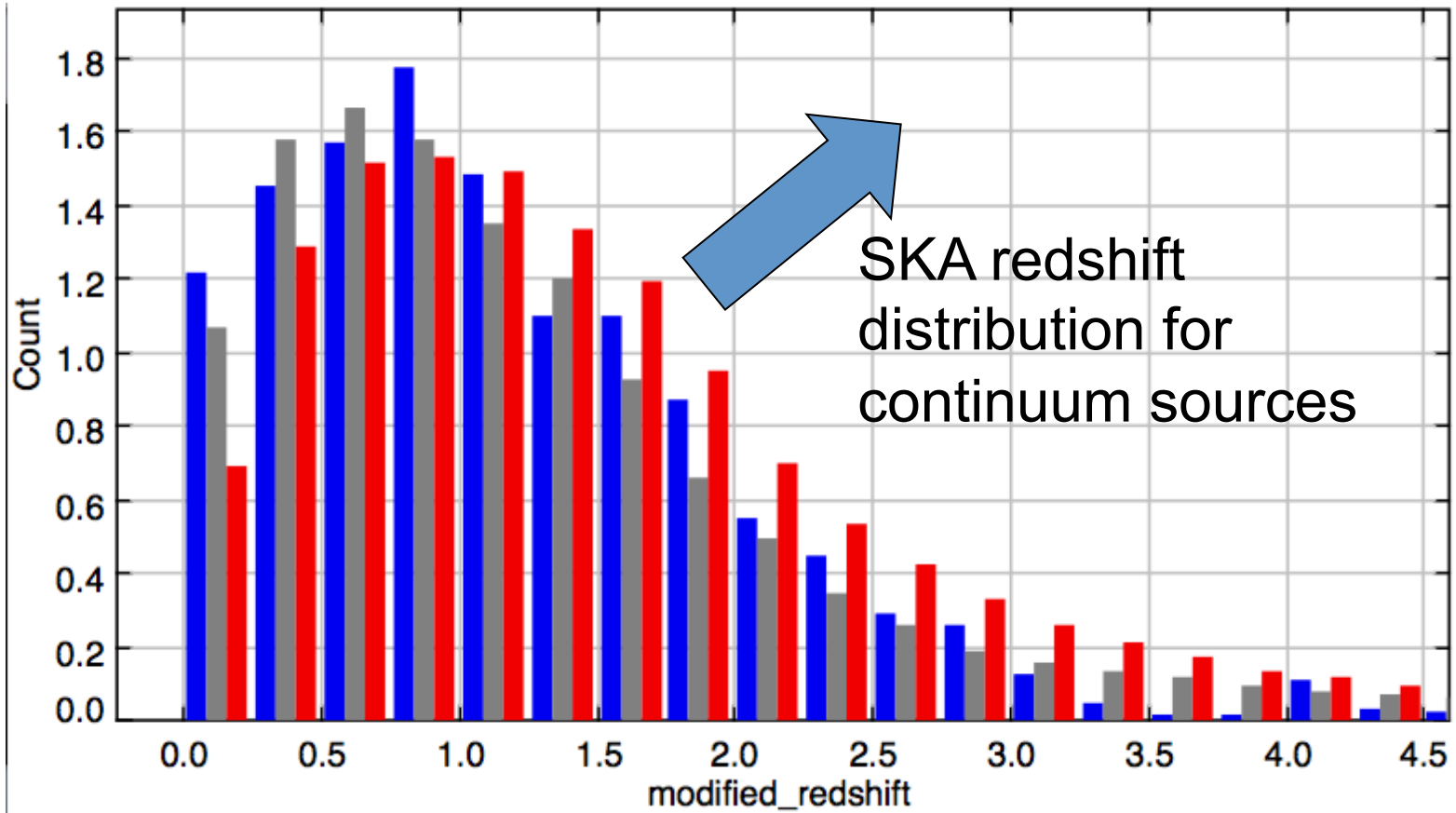
Image credit: Colberg et al. , SDSS



Lensed galaxies give information on the astrophysics in the lensing galaxies

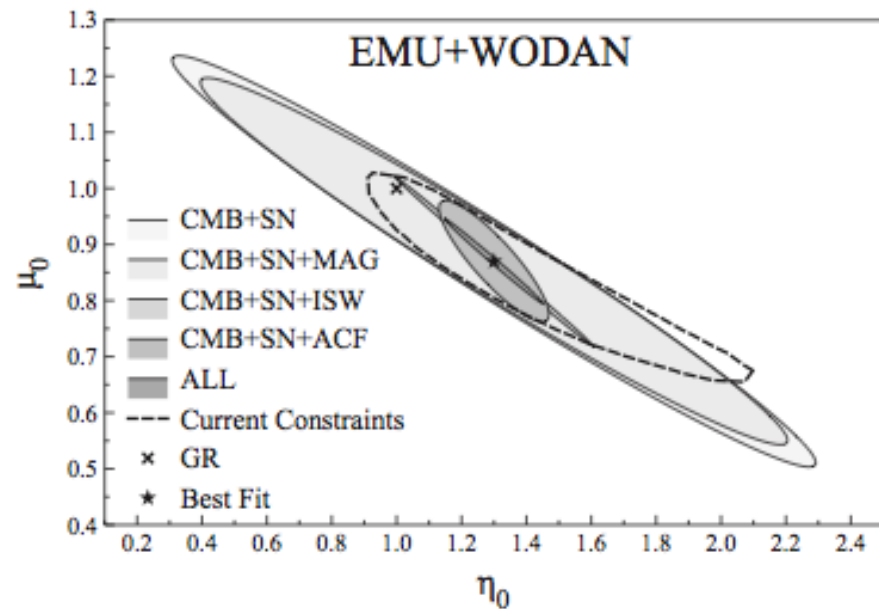
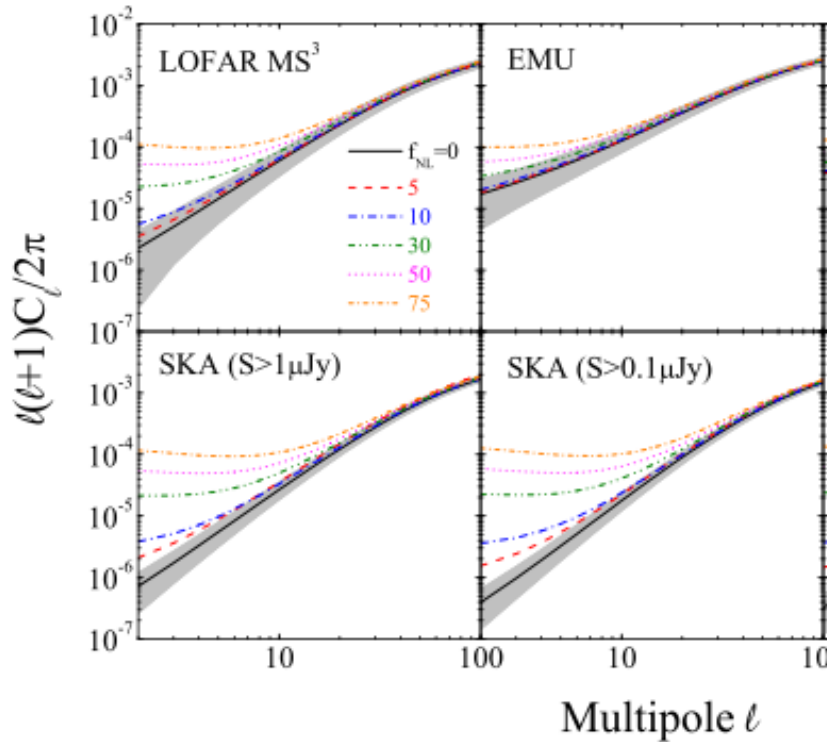


Redshift distributions for Euclid (H=24mag) EMU (10sig)  
MIGHTEE-Tier2 (10sig)



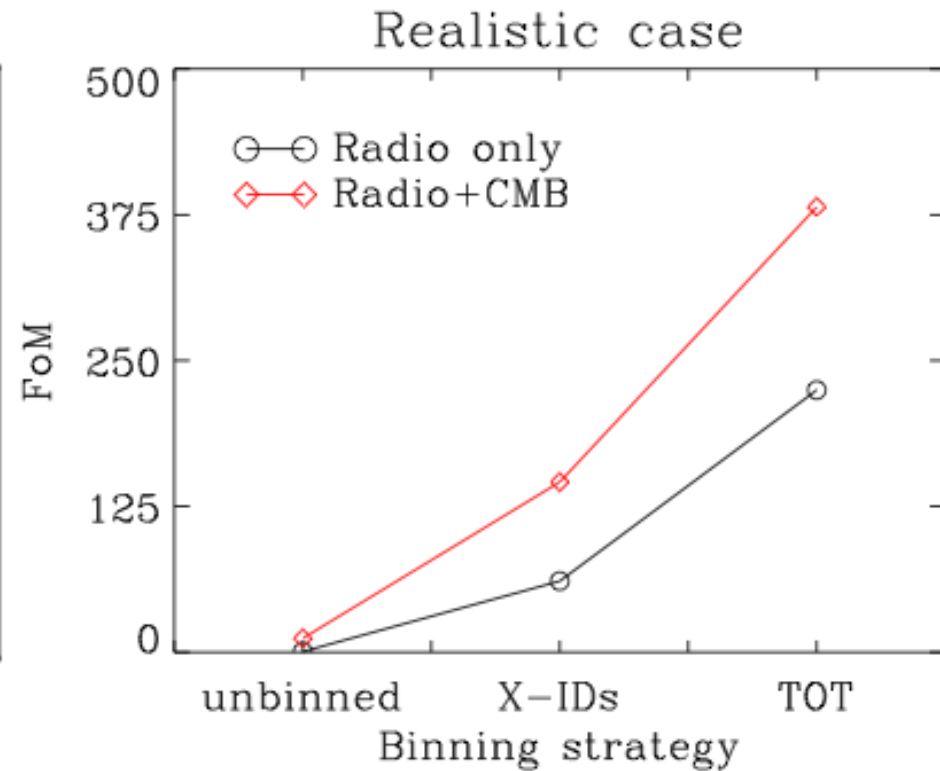
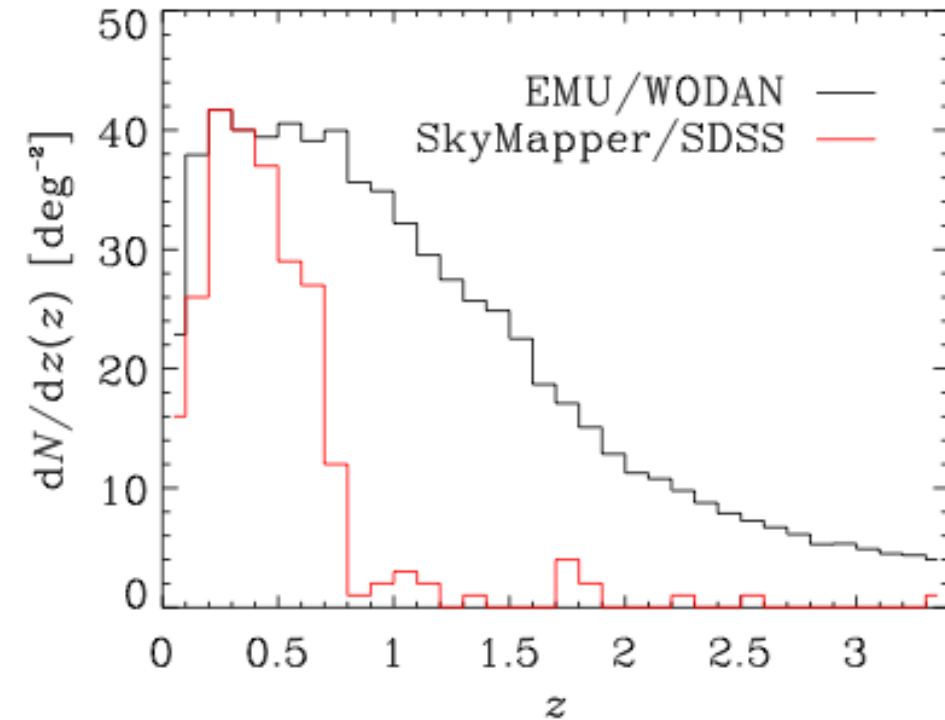
Redshift distributions for Euclid (H=24mag) EMU (10sig)  
MIGHTEE-Tier2 (10sig)

# The link to cosmology



Raccanelli, Zhou, Bacon, MJJ, et al. 20120  
Maartens et al. 2012

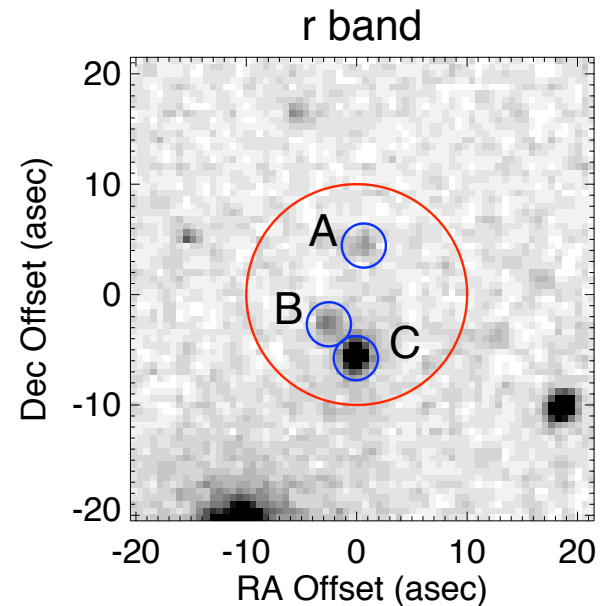
# The link to cosmology



Camera, Santos, Bacon, MJJ, et al. 2012

# Cross-matching: the problem

- 250 $\mu$ m:
  - beam 18.1''
  - positional uncertainty  $\sim 2.4''$
  - minimal z info
  - probes dust properties
- SDSS r band:
  - PSF  $\sim 1-2''$
  - positional uncertainty  $\sim 0.1''$
  - redshift & colour information
  - probes starlight/AGN

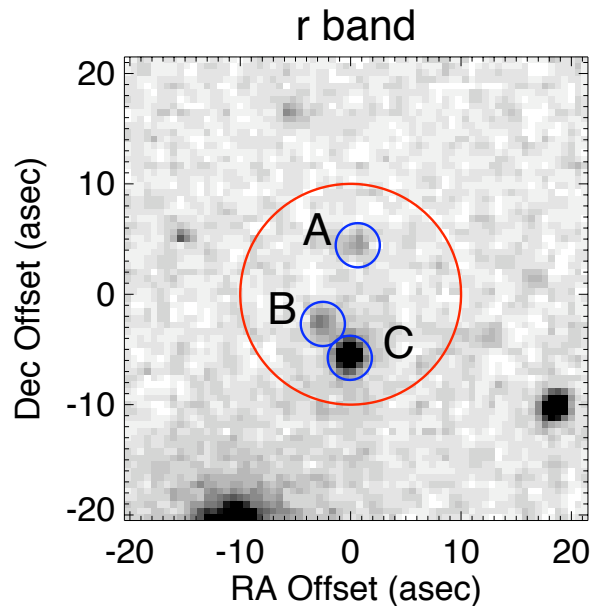


Smith et al. 2011



# Identifying counterparts

- LR method allows for the fact that not all 250um galaxies are detected in Sloan r band:

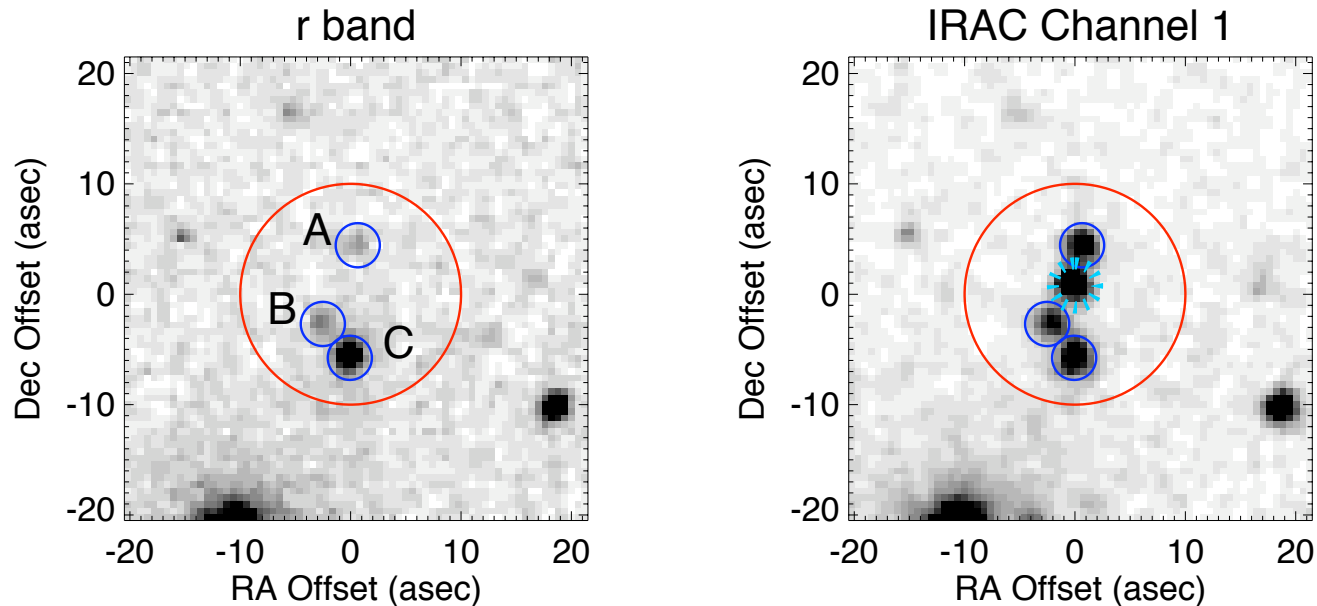


- $Q_0 = \sim 63\%$  of 250um sources have an r band counterpart in SDSS

Smith et al. (2011)

# Identifying counterparts

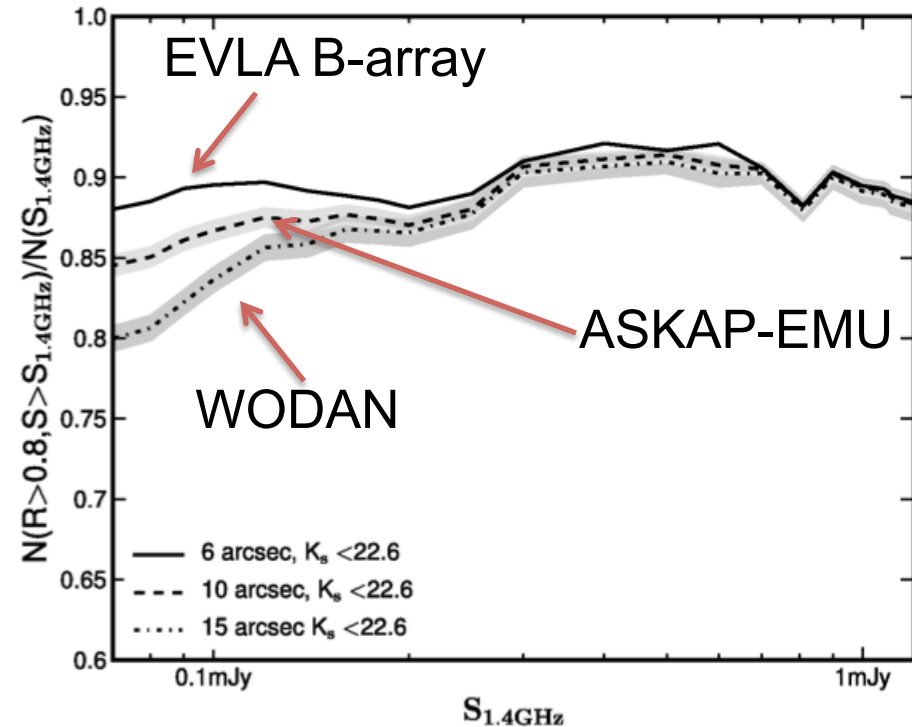
- LR method allows for the fact that not all 250um galaxies are detected in Sloan r band:



- $Q_0 = \sim 63\%$  of 250um sources have an r band counterpart in SDSS

Smith et al. (2011)

# The likelihood ratio on the new radio surveys

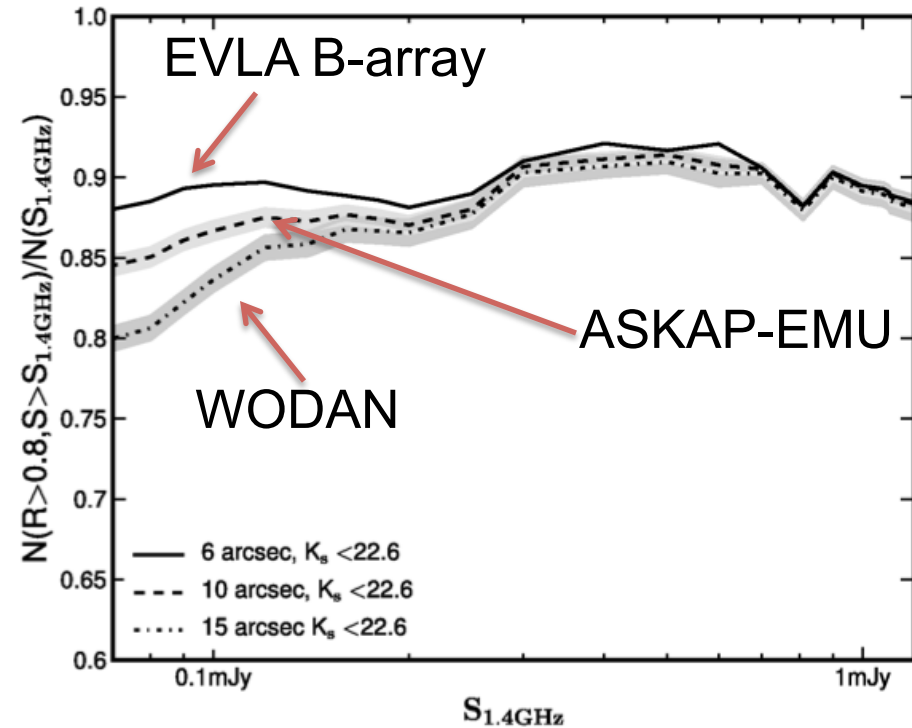


Resolution does matter in radio continuum surveys for X-matching.

Key to almost all science!

MeerKAT will excel at this compared to ASKAP and APERTIF!

# The likelihood ratio on the new radio surveys



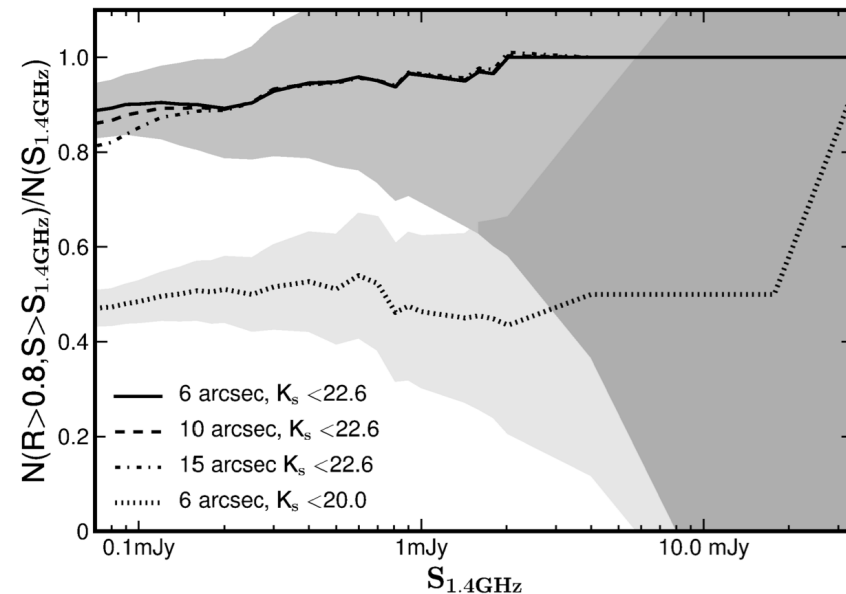
McAlpine, Smith, MJJ, Bonfield, Fleuren 2012

However, real key is deep optical/nearIR data

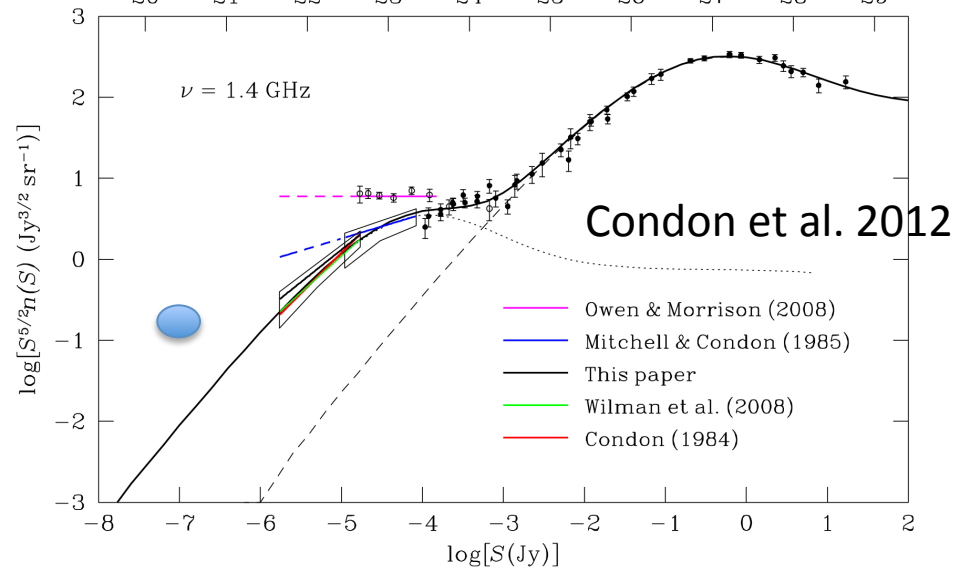
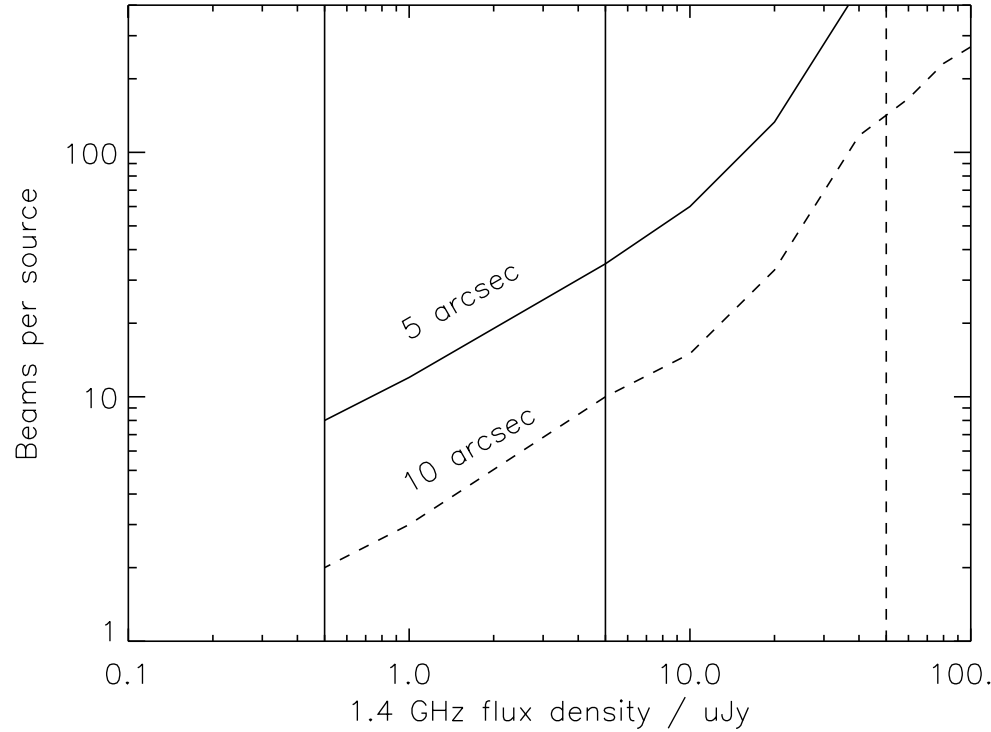
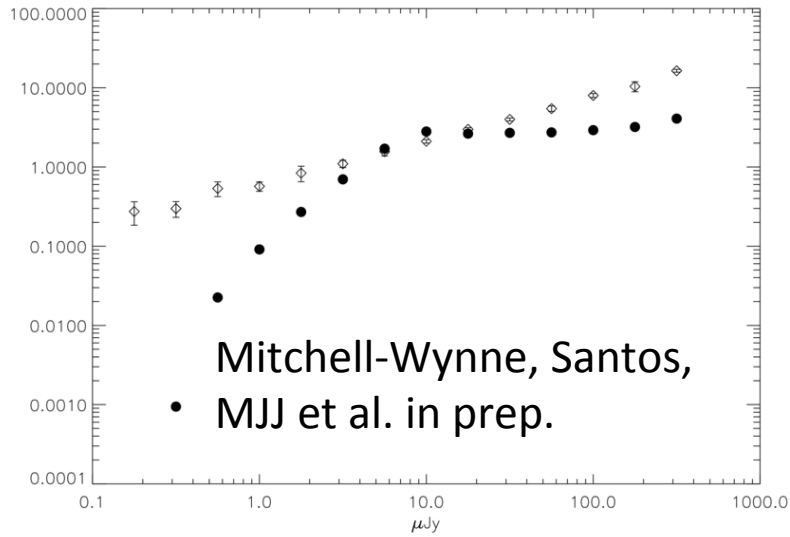
Resolution does matter in radio continuum surveys for X-matching.

Key to almost all science!

MeerKAT will excel at this compared to ASKAP and APERTIF!



# Source counts & confusion



# Something to bear in mind...

- ASKAP – 10 $\mu$ Jy 30,000 sq.deg 13,000hours
- MeerKAT - 1 $\mu$ Jy 30 sq.deg 1,700hours
- MeerKAT – 10 $\mu$ Jy 30sq.deg 17hours
- MeerKAT - 10 $\mu$ Jy 30,000 sq.deg 17,000hours
  
- ASKAP only has 1.3x survey speed of MeerKAT
  
- SKA1-mid and SKA1-survey have similar survey speed too

# Summary

- Key science in radio continuum surveys is dependent on optical/nearIR imaging. **Vast majority of galaxy evolution science will be done in deep fields** (~50 sq.deg)
- Still true in the age of SKA2! Although not as critical if Aperture Arrays work to spec - This is what gives the billion galaxy redshift survey
- Can do cosmology with radio and without optical/nearIR data, but can do more with it – need large areas
- Radio may give the cleanest indication of SFR and/or AGN activity in galaxies - but better with multi-wavelength data. **No dust obscuration**
- MeerKAT and ASKAP will start well before LSST, the data will be waiting for LSST.
- SKA1 and LSST could be observing at the same time, SKA2 and LSST certainly will be
- **Don't forget Euclid** – JH nearIR data to  $H \sim 24$  over 15000 sq.deg, and  $\sim 40$ sq.deg to  $H \sim 26$

...and you can probably do something with polarisation but I haven't thought very much about it