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# ASKAP-EMU: Overcoming the challenges of wide deep continuum surveys

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# Overview

- Introduction to EMU
- Science goals
- Emu-wide
- Imaging constraints of wide deep continuum surveys
- Breaking the confusion barrier: Emu-deep

ASKAP

EMU

Evolutionary Map of the Universe

# EMU: Evolutionary Map of the Universe

- Deep radio image of 75% of the sky
- Driven by primary science goal:  
How did galaxies form and evolve?
- EMU team: ~90 members from 9 countries
- Split into ~15 working groups
  - Science areas
  - Technical issues
- Cross-linkages with other major multiwavelength surveys
  
- Project Leader: Ray Norris
- Project Scientist: Andrew Hopkins
  
- All data to be processed in pipeline
- Images, catalogues, cross-IDs, to be placed in public domain

## Radio

- [LOFAR](#)
- [NVSS](#)
- [SUMSS](#)
- [MWA](#)
- [ATLAS](#)
- [South Pole Telescope](#)
- [GMRT-Herschel-ATLAS](#)

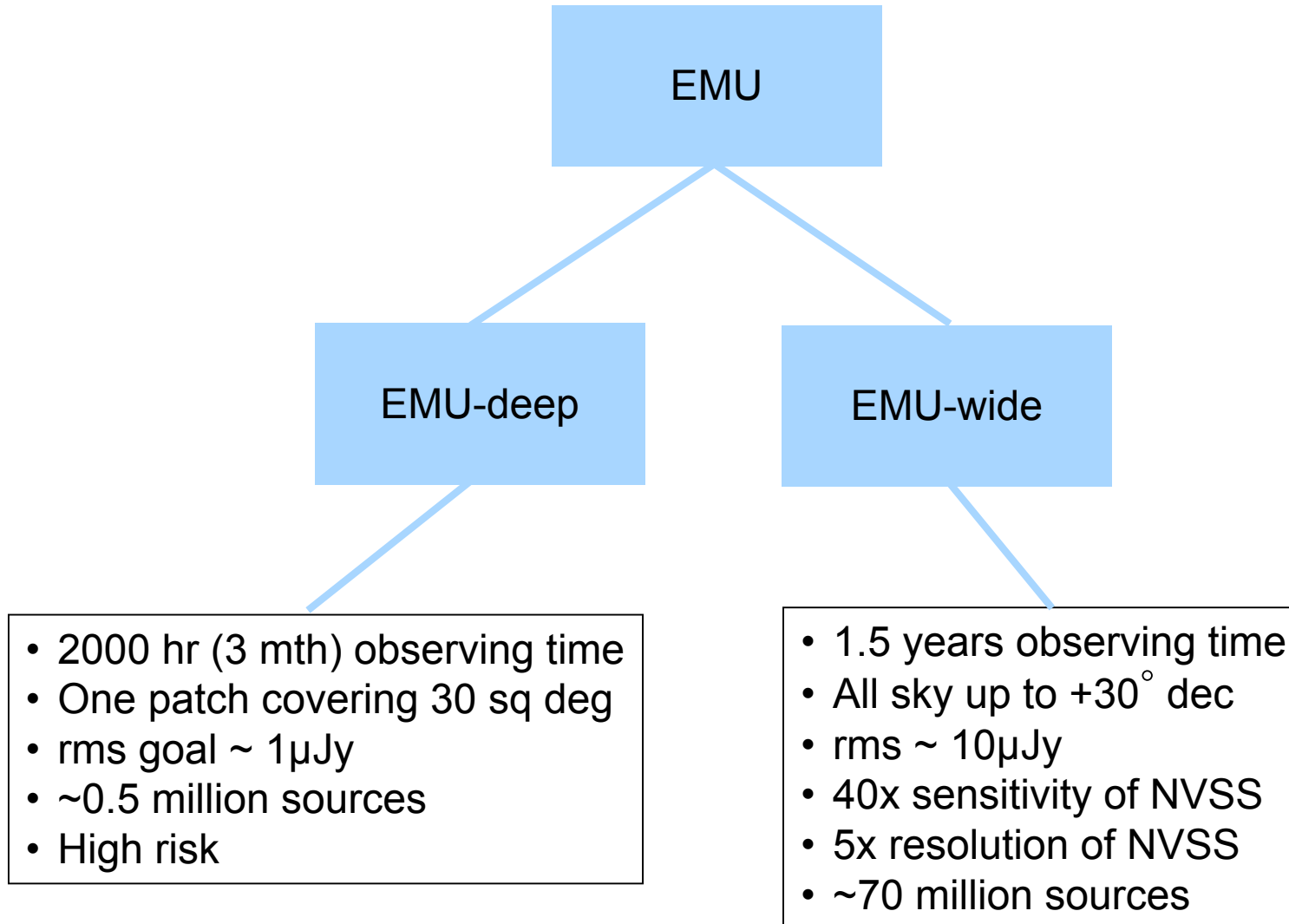
## Optical/IR

- [SDSS](#)
- [LSST](#)
- [Pan-STARRS](#)
- [2MASS](#)
- [HLA](#)
- [VISTA/VIKING/VHS/VIDEO](#)
- [GAMA](#)
- [VST/KIDS](#)
- [UKIDSS](#)
- [Herschel ATLAS/HerMES](#)
- [WISE](#)

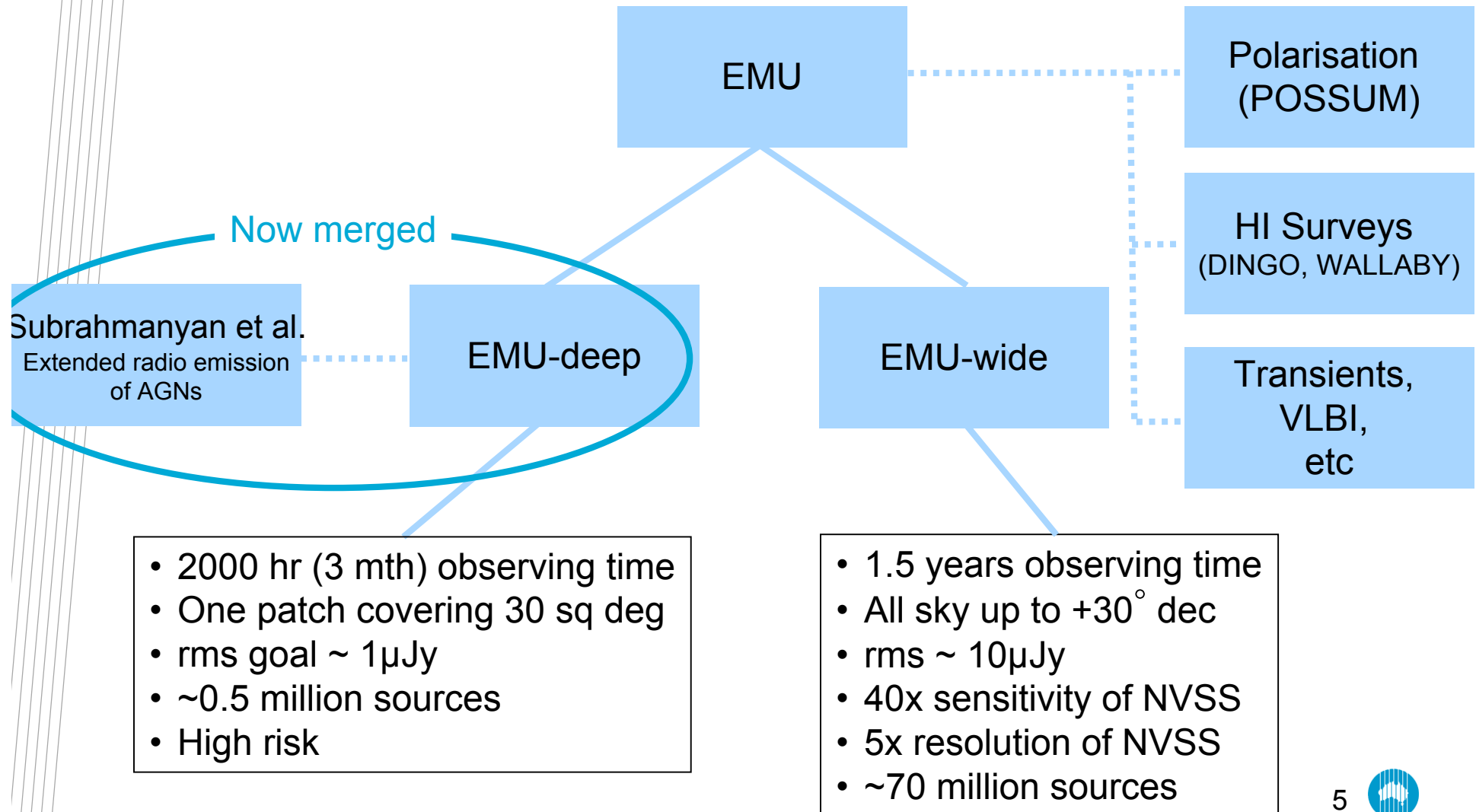
## X-Ray

- [eROSITA](#)
- [IXO](#)

# Introduction to EMU



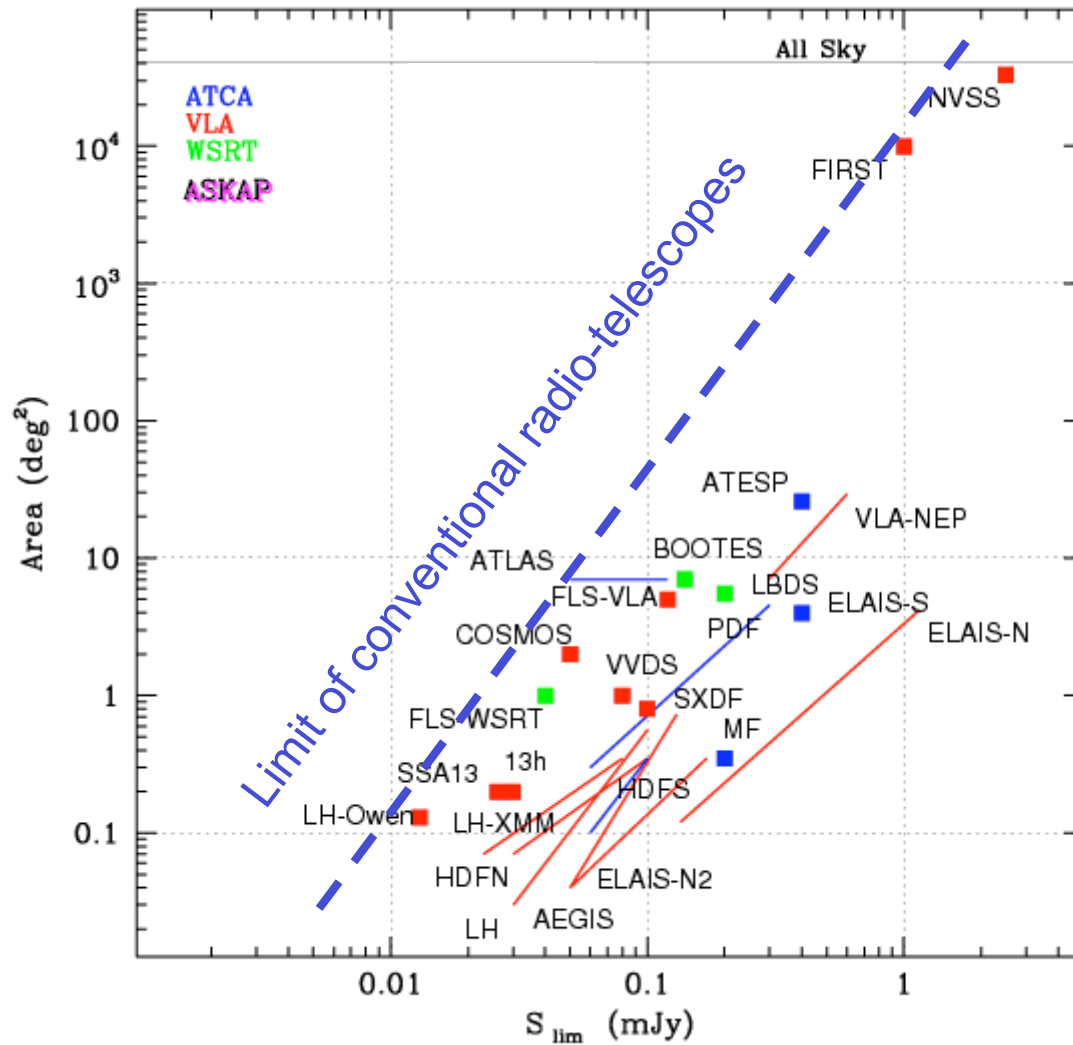
# Commensal with other ASKAP surveys



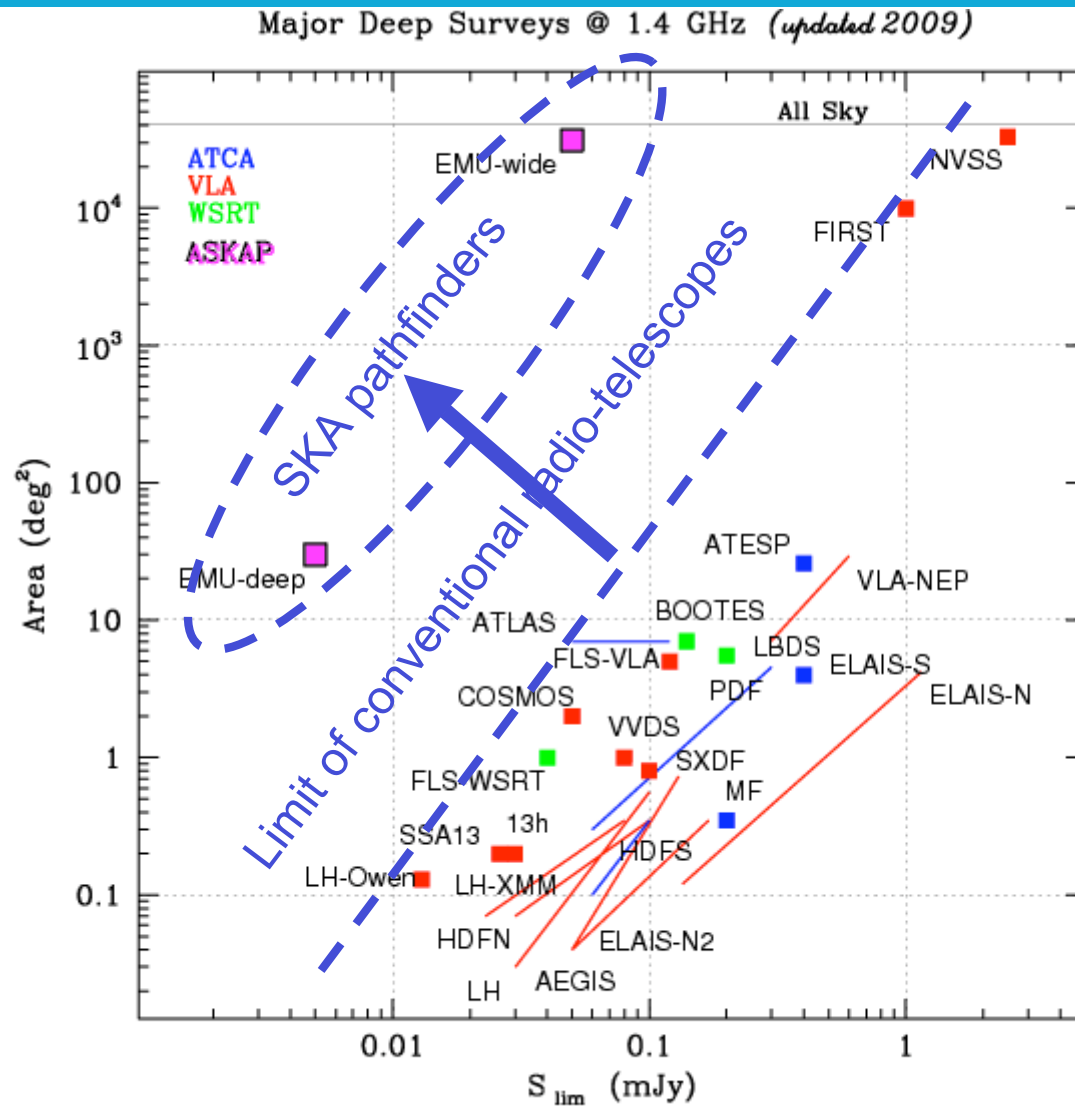


# Current major 20cm surveys

Major Deep Surveys @ 1.4 GHz (updated 2009)



# Current major 20cm surveys

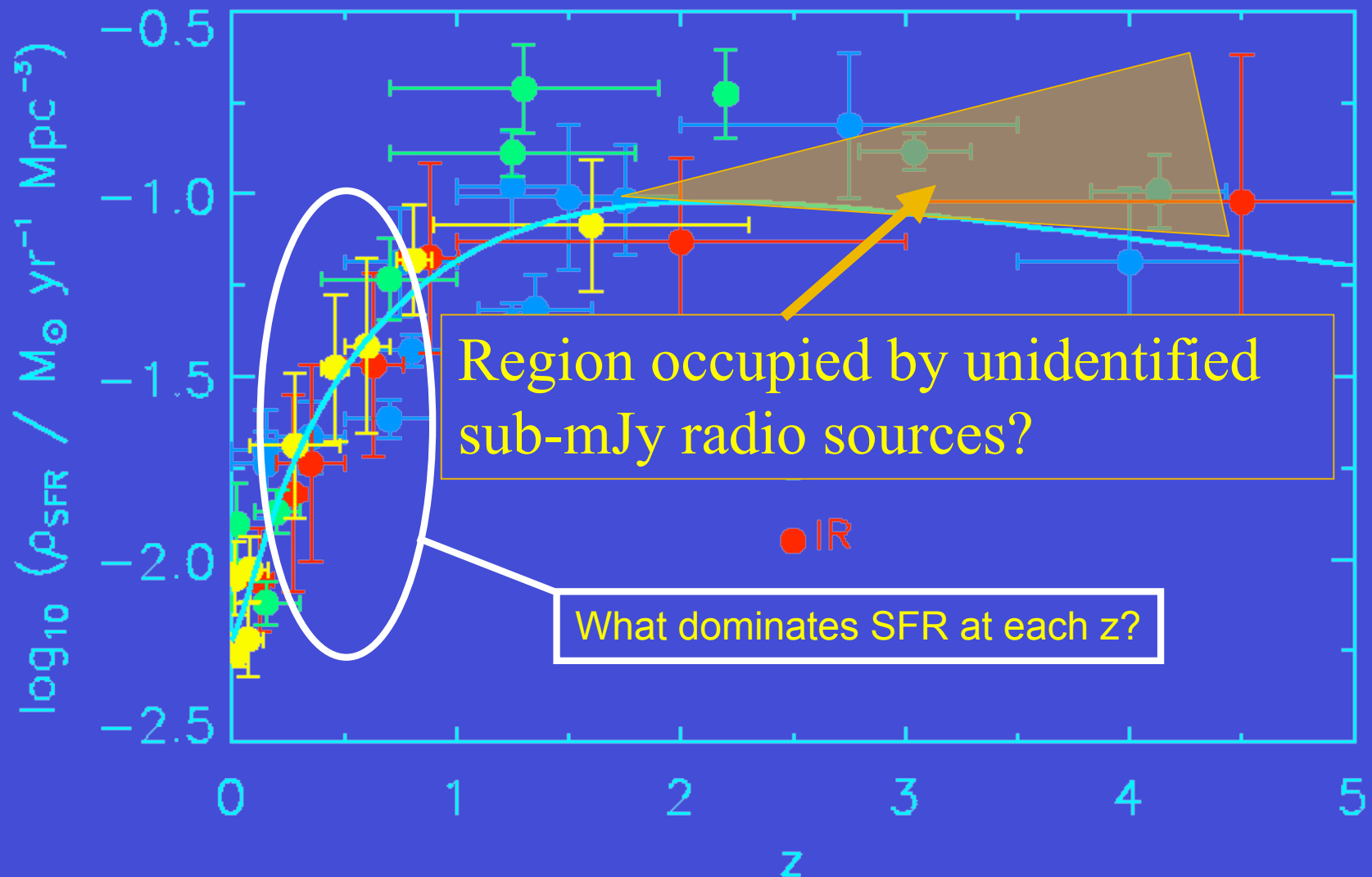


# Key science goals

1. To trace the evolution of star-forming galaxies from  $z=2$  (EMU-wide) or  $z=5$  (EMU-deep) to the present day, using a wavelength unbiased by dust or molecular emission.
2. To trace the evolution of massive black holes throughout the history of the Universe, and understand their relationship to star-formation.
3. To use the distribution of radio sources to explore the large-scale structure and cosmological parameters of the Universe.
4. To create the most sensitive wide-field atlas of Galactic continuum emission yet made, addressing areas such as star formation, supernovae, and Galactic structure
5. **To explore an uncharted region of observational parameter space, almost certainly finding new classes of object.**

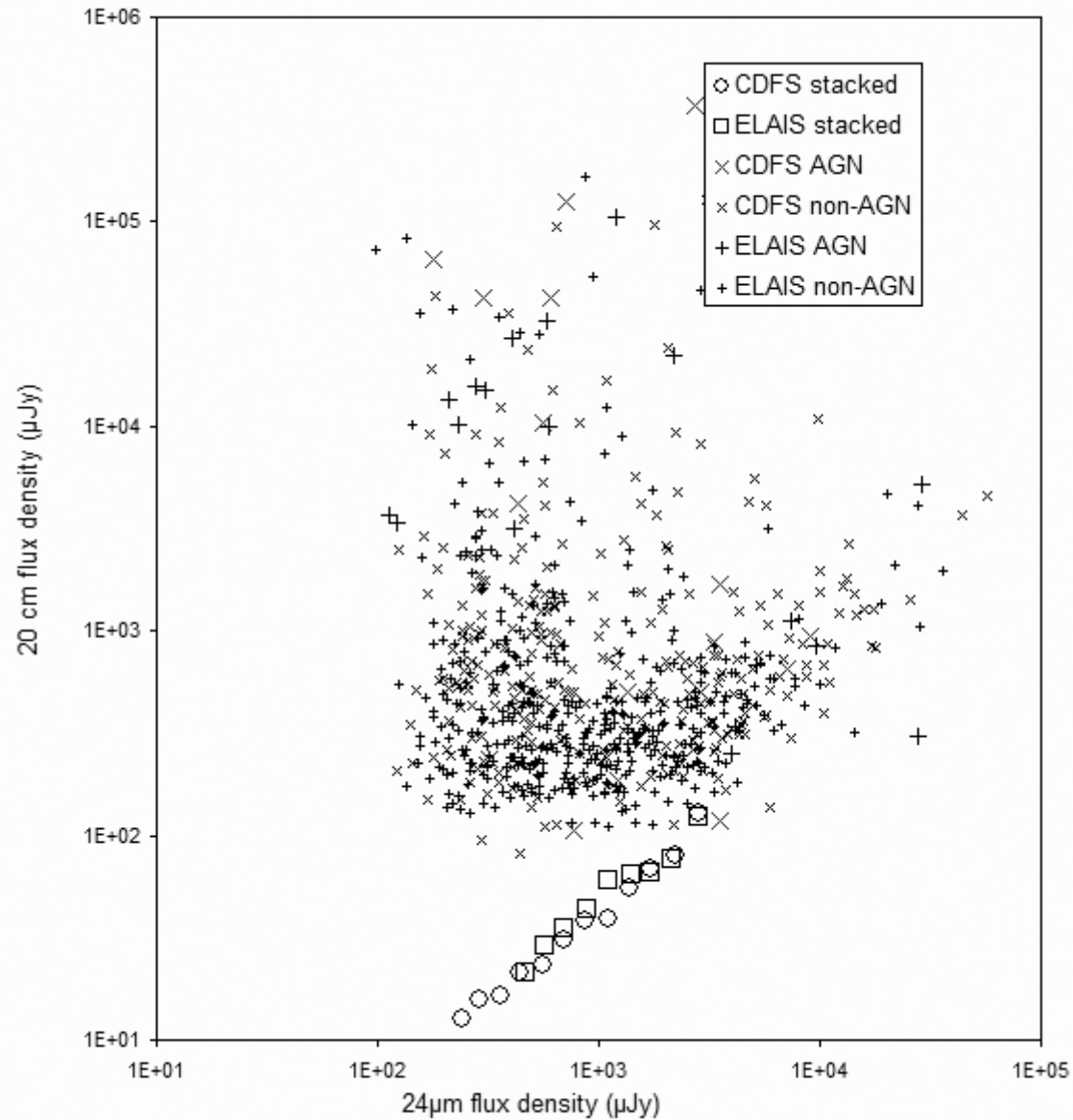


# How has the global star formation rate evolved with time?



(From Hopkins et al 2004, Barger et al 2000)

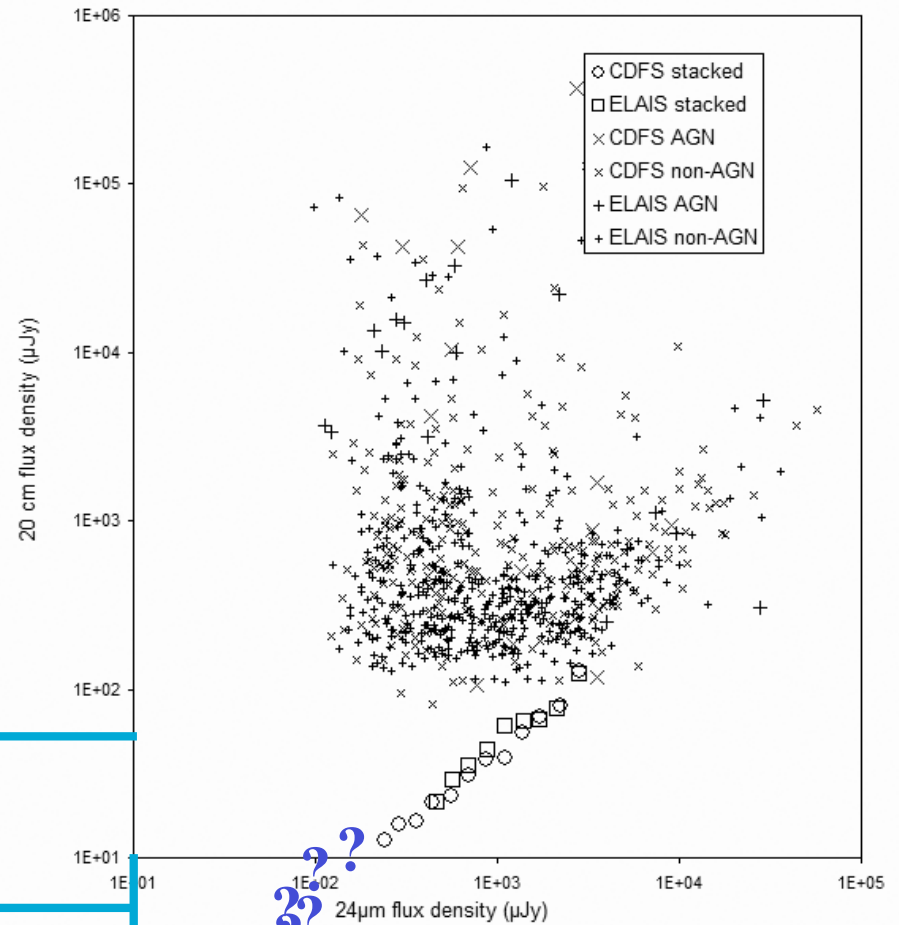
# What is the origin of the radio-FIR correlation?



Boyle et al 2007  
Norris et al 2007

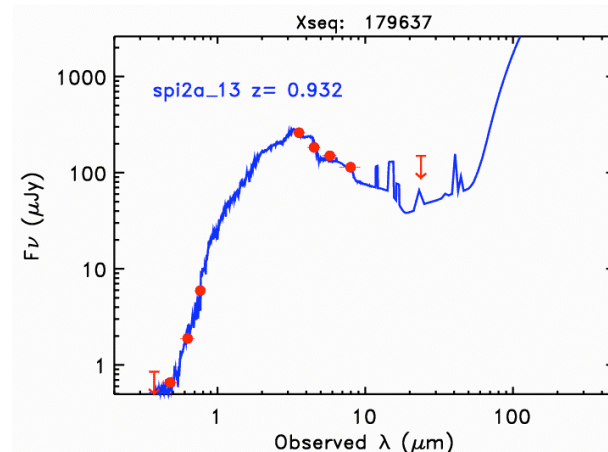
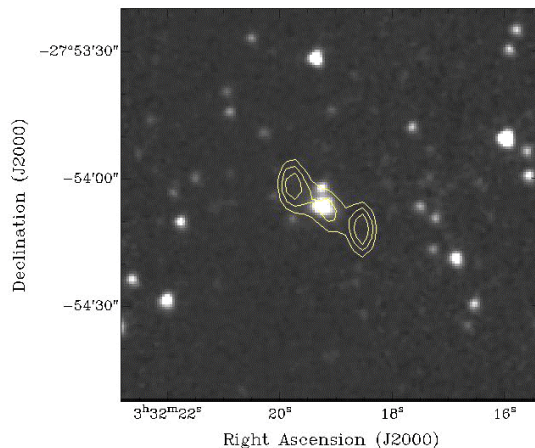
# What is the origin of the radio-FIR correlation?

Herschel +  $\left\{ \begin{array}{l} \text{EMU-wide} \\ \text{EMU-deep} \\ \text{Stacking} \end{array} \right.$



# To trace the evolution of massive black holes, and understand their relationship to star-formation.

- Cosmic AGN accretion rate and cosmic SF rate appear to be linked. Why?
- Feedback mechanism couples AGN to galaxy evolution?
- EMU will provide a deep homogenously selected sample of SF galaxies and AGN over the majority of cosmic history, to test this.

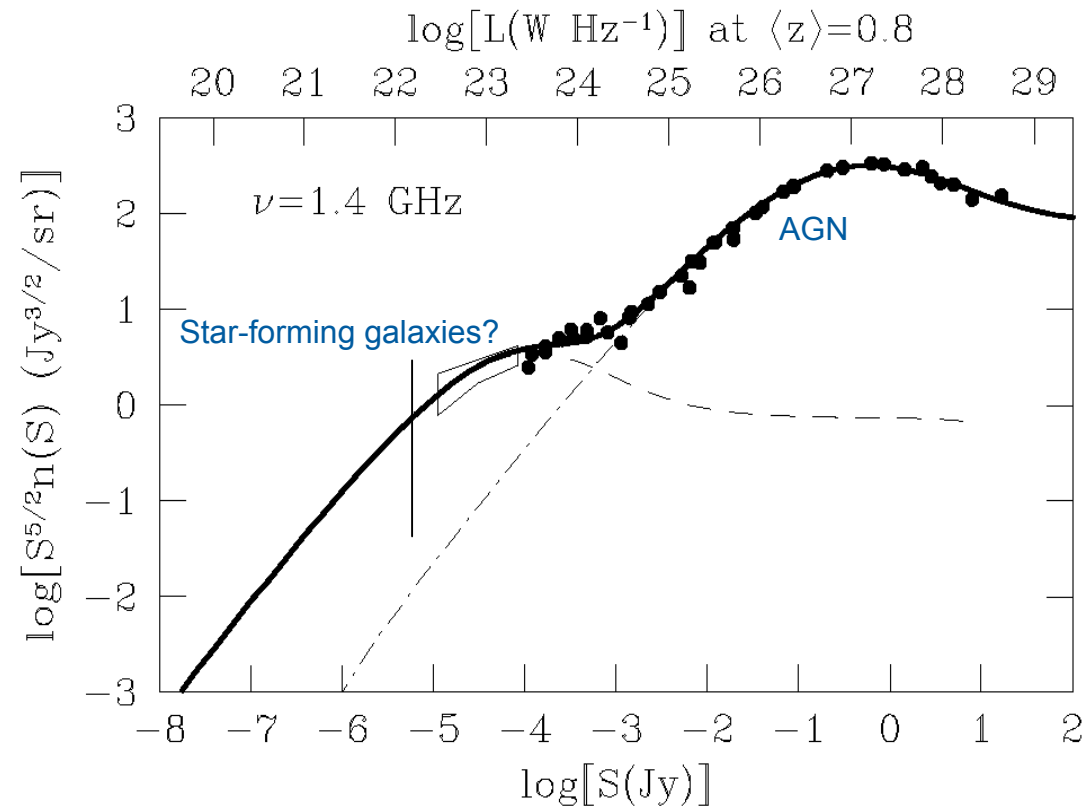


PRONGS=  
Powerful  
Radio-loud  
Objects  
Nested in  
Galaxies with  
Star-formation

- How much early activity is obscured from optical views?
- Can we make an “AGN Madau diagram” tracing the evolution of different types of radio AGN (FRI/FRII/WAT/PRONGS/etc)?
- Can we use this to trace the evolution of MBH with  $z$ ?
- When did the first MBH form?

# To trace the evolution of massive black holes, and understand their relationship to star-formation.

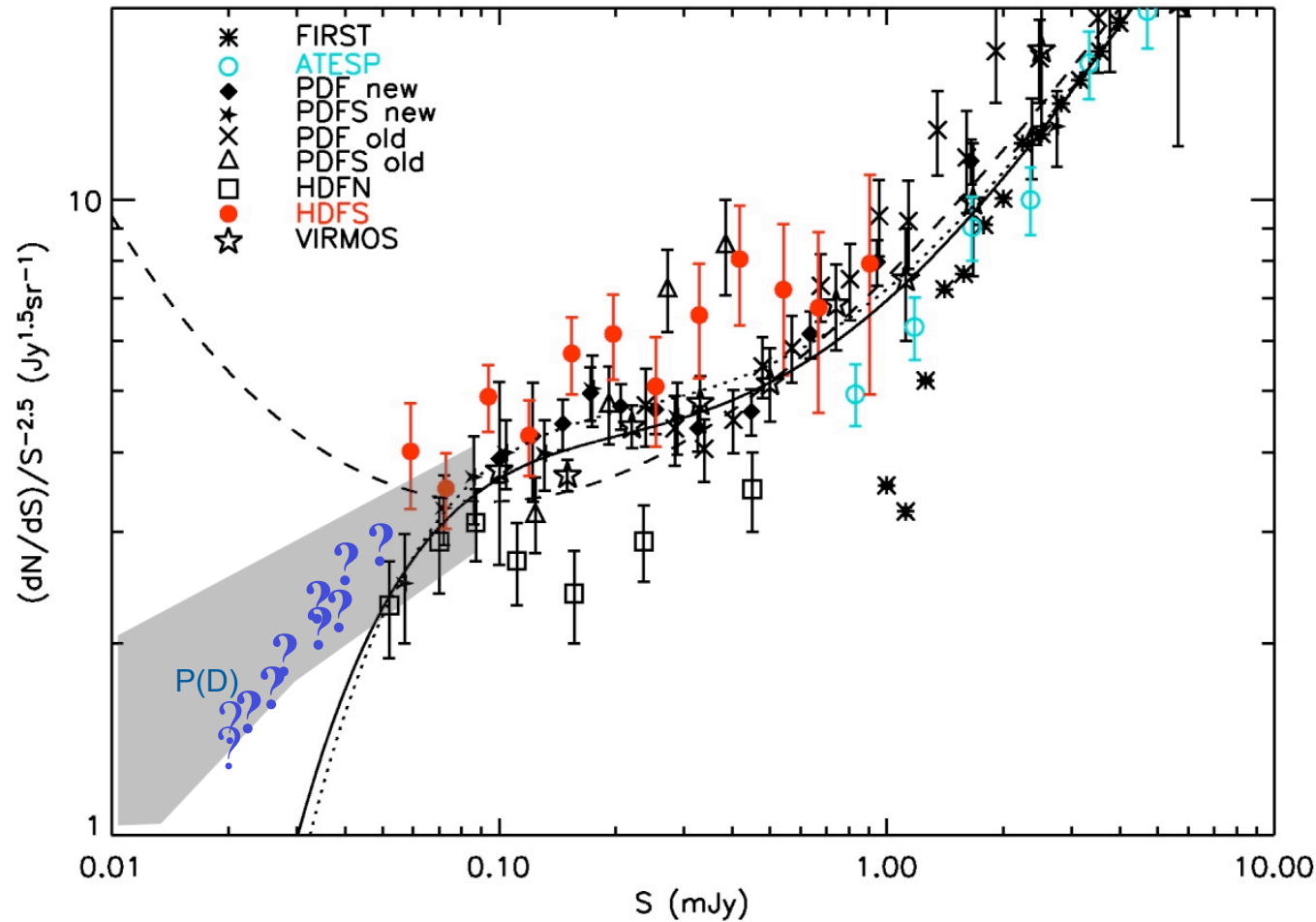
What is the evolutionary relationship between starbursts and AGN?



Condon et al 2006

# To trace the evolution of massive black holes, and understand their relationship to star-formation.

## Faint-source counts (1.4 GHz)



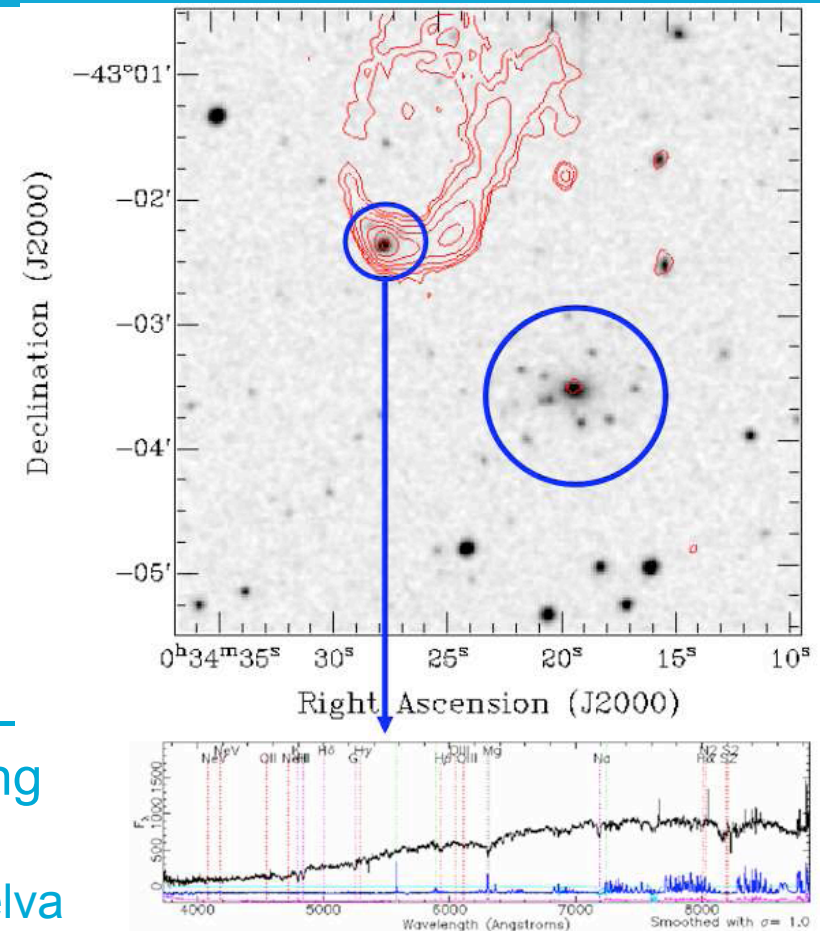
Huynh et al. (2006)



To use the distribution of radio sources to explore the large-scale structure and cosmological parameters of the Universe.

## Radio surveys are unbiased by dust & sky lines

- How similar are the cosmic webs of AGNs and SF galaxies? Did they have a common origin?
- We can use head-tail galaxies as probes of clustering to high  $z$ .
- We should detect Integrated Sachs-Wolfe (ISW) effect directly, so testing the scale of Dark Energy at  $z > 1$ 
  - Marginal detection with NVSS – Vielva et al. [arXiv:astro-ph/0408252v2](https://arxiv.org/abs/astro-ph/0408252v2)



$z=0.22$ . From Mao et al 2009, in preparation

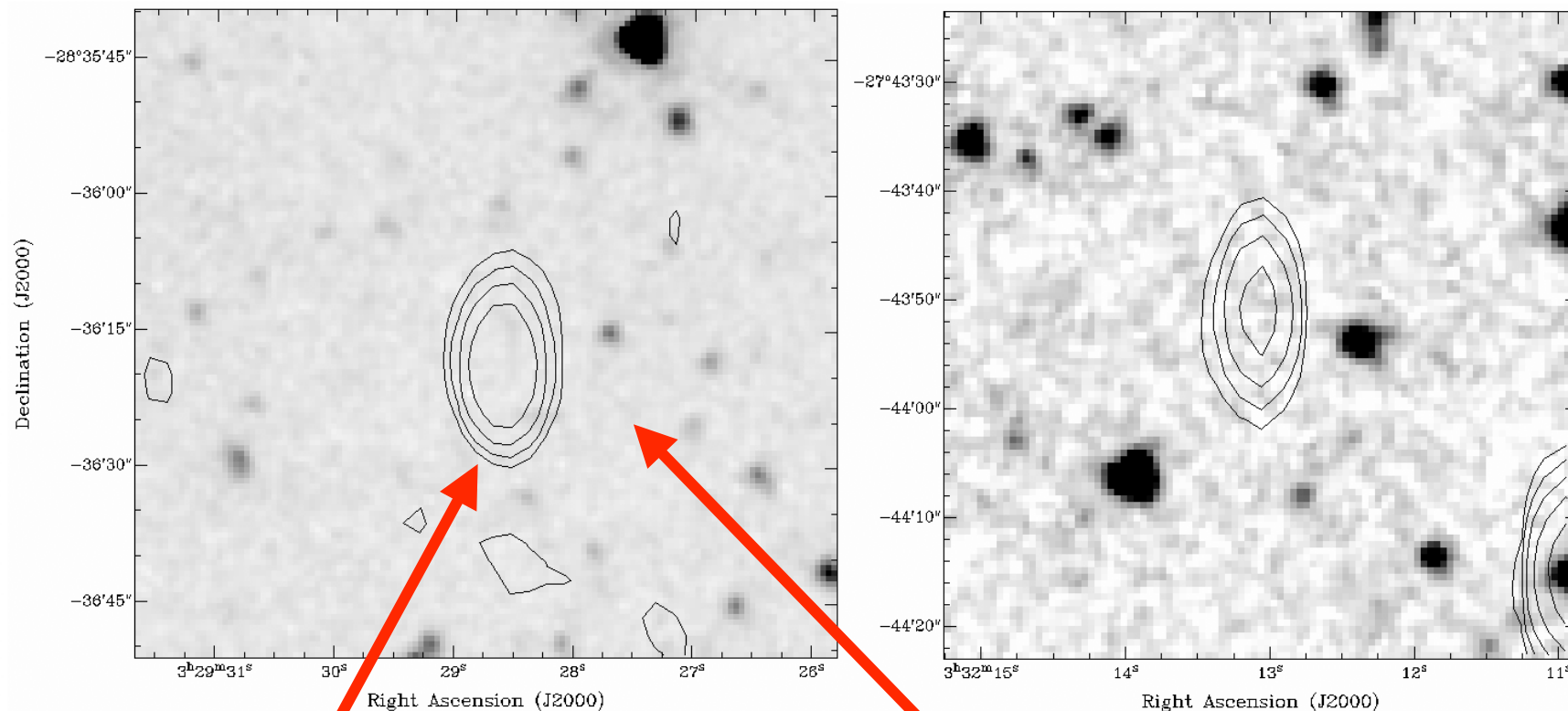
# To create the most sensitive wide-field atlas of Galactic continuum emission yet made.

- addressing areas such as star formation, supernovae, and Galactic structure

To explore an uncharted region of observational parameter space, almost certainly finding new classes of object.

## Example from ATLAS: Infrared-faint radio sources (IFRS)

(Norris et al. 2007, Middelberg et al 2008, Garn et al 2008, Huynh et al. 2009, Emil Lenc poster)



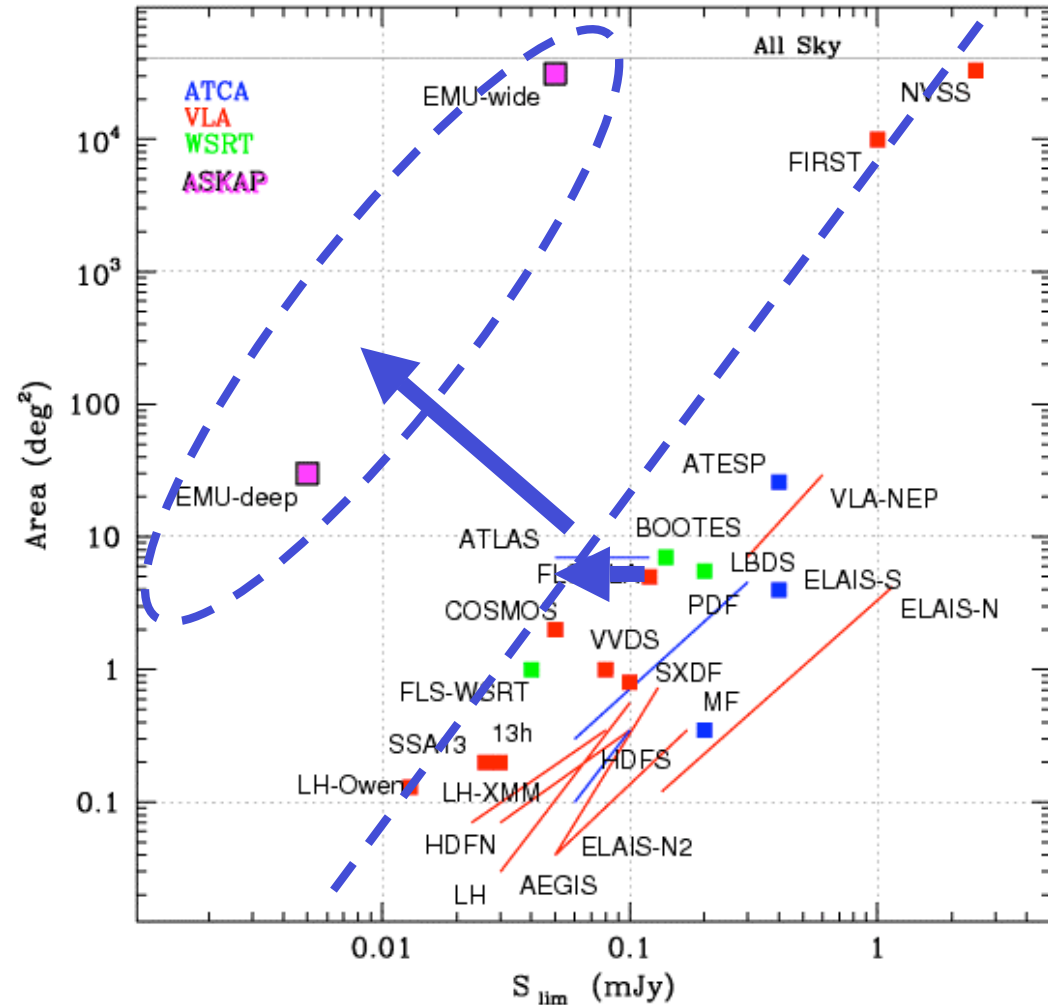
6.1 mJy at 20 cm

CSIRO EMU: Evolutionary Map of the Universe.

$<5 \mu\text{Jy}$  at  $3.6\mu\text{m}$

# To explore an uncharted region of observational parameter space, almost certainly finding new classes of object.

- ATLAS (see Emil Lenc poster) pushed the boundaries by only a factor of a few, yet discovered two new classes of objects (PRONGS, IFRS).
- What happens when we push the boundary by a factor of 40?



To provide a legacy radio survey rivalling NVSS in scientific impact, to be used by astronomers of all wavelength persuasions

- Scientific impact is (at least) proportional to area covered
- Need to do whole accessible sky, not half of it!
- Complementary to APERTIF
  - (crossover at dec+30°)
- Complementary to MEERKAT
  - (crossover at 10 arcsec)

# Issues for EMU

## How far North to go?

- Observing most efficient South of  $0^\circ$  dec
- Want to overlap with northern radio surveys (LOFAR, eVLA, NVSS)
- Want to overlap with major optical surveys (e.g. Sloane, PanStarrs)
- Mosaicing over many pointings each day
  - smooths out data problems
  - means you have to solve for variability when imaging
  - Means you have to keep, combine, and re-process uv data
  - Better to image each pointing completely in one visit?
- Weighting
  - Natural weighting maximises sensitivity, but gives 18-arcsec beam
  - Tapering gives 10 arcsec beam with 20% loss in sensitivity
  - Uniform weighting gives 7 arcsec beam with 50% loss in sensitivity

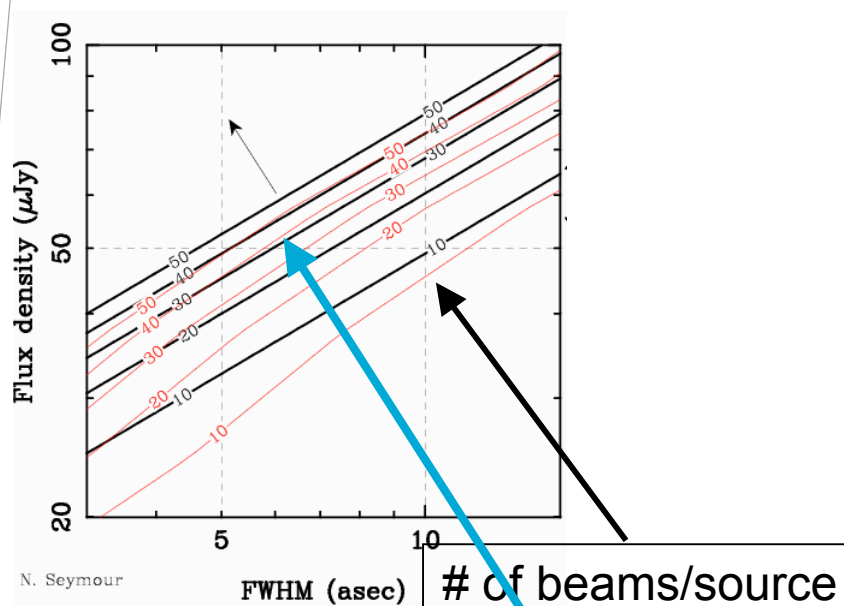


# Issues for EMU

- How much overlap/dither in mosaic?
  - Large overlap -> uniform sensitivity but need multi-day data to process
  - Better to minimise overlap
  - But then need to tile efficiently
- Dynamic Range
  - ATLAS has had problems with strong extended sources which don't clean well (see Emil Lenc poster)
  - EMU will subtract strong sources from uv data in first part of pipeline
  - Can we reach the necessary  $\sim 10^5$  dynamic range?
- Optical / IR / X-ray identifications
  - Need more than a nearest neighbour algorithm
  - 70 million sources -> process must be automated
  - Can we build an identification pipeline?
- Confusion

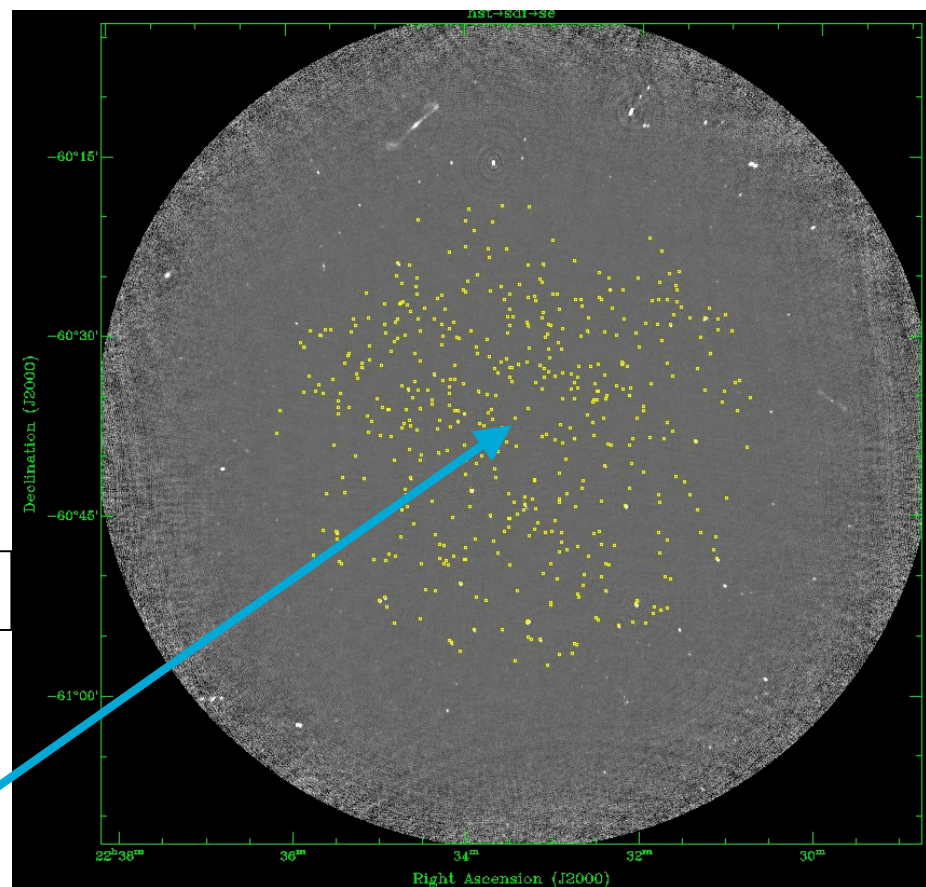
# Confusion in EMU

- A commonly adopted rule of thumb is that only 1% of beams should contain a source (i.e.  $\beta = \text{beams/source} = 100$ )



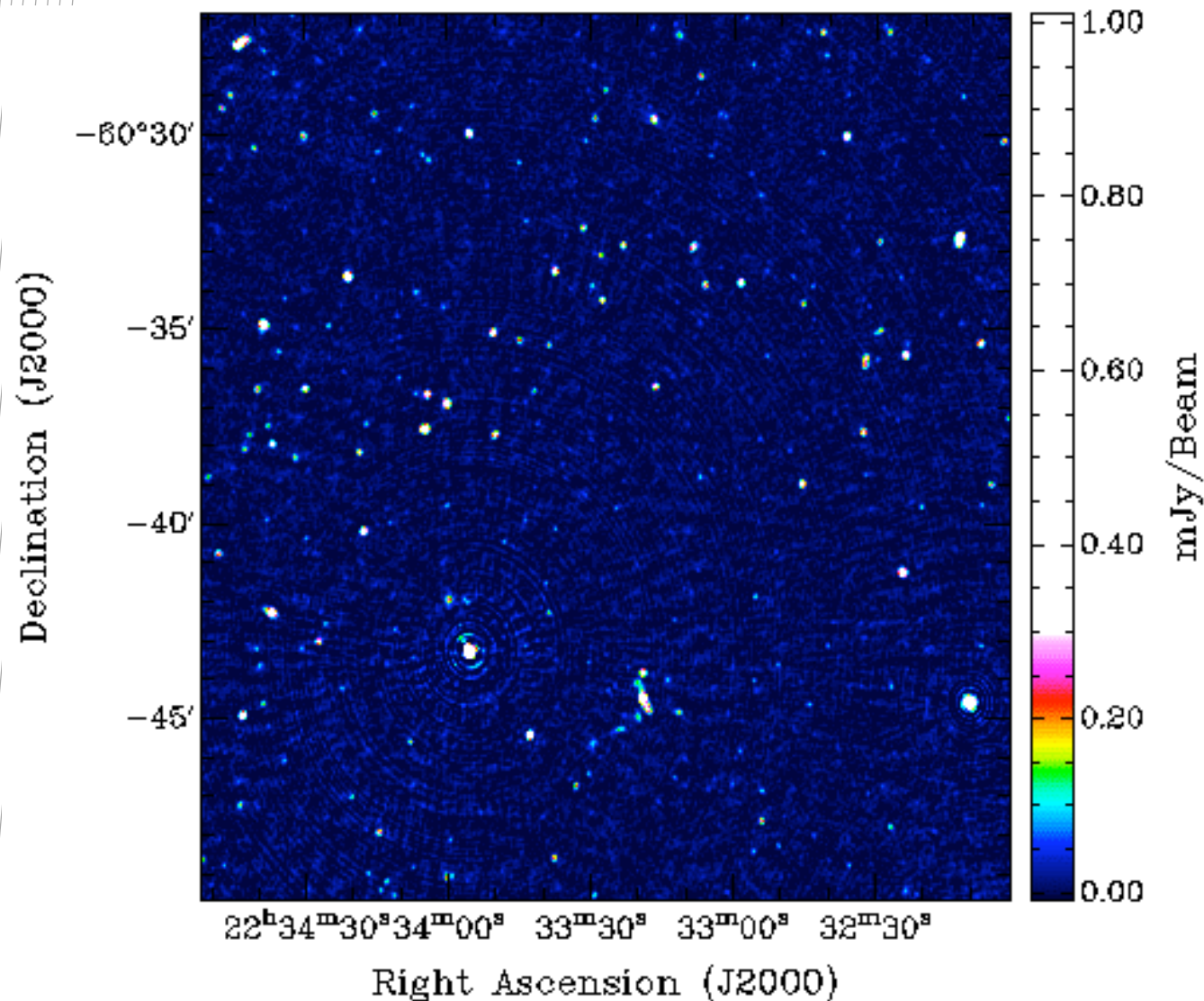
- For the ATCA at 20 cm,  $S_{\text{confusion100}} \sim 80 \mu\text{Jy/beam}$
- We have already passed this point.
- And the sky didn't fall in.

$\beta=41$



ATCA image of HDF5  
(Huynh et al 2005, Norris et al 2005)

# HDFS imaged with ATCA at 20cm (B=6km, rms=10 $\mu$ Jy)



Huynh et al 2005  
Norris et al 2005

# Other definitions of confusion

## Beam confusion (few $\mu\text{Jy}$ for 6km baseline)

- At what level does every synthesised beam contain a source?

## Background confusion (few $\mu\text{Jy}$ for 6km baseline)

- At what level does the rms from the sea of background sources equal the  $T_{\text{sys}}$ ?

## Calibration confusion (few $\mu\text{Jy}$ ?)

- At what level do strong sources in the sidelobes limit the dynamic range?

## Natural confusion ( $<1 \mu\text{Jy}$ )

- At what level do sources physically overlap?

# Breaking the confusion barrier: EMU-deep

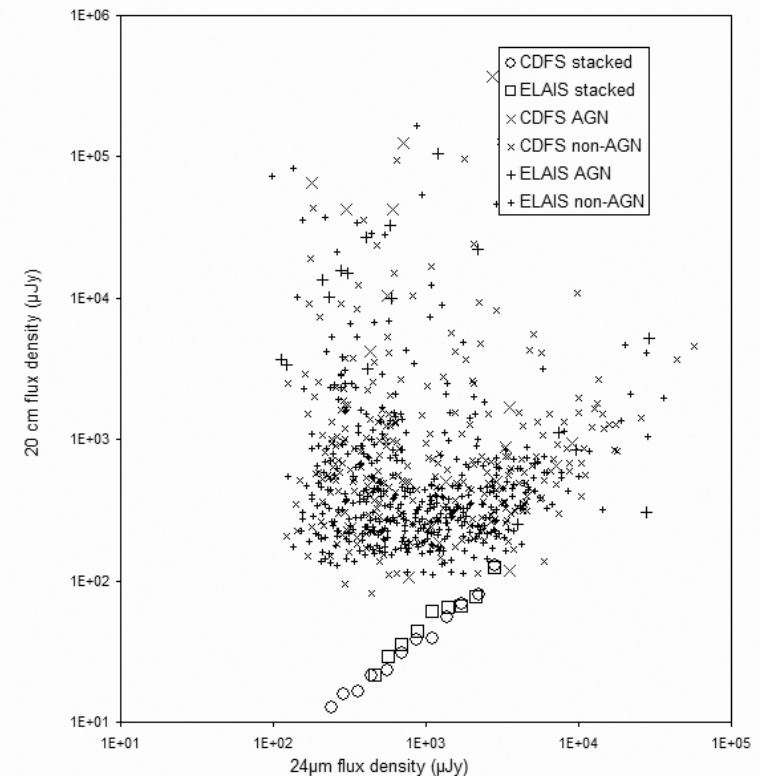
- Can (partially) overcome calibration confusion by choosing a quiet piece of sky (e.g. HDFs) – but only for small areas
- Can overcome beam confusion by removing a significant fraction of sources – but how?

- E.g.1

- Take Herschel FIR image
- Multiply FIR image by the radio/FIR ratio and subtract from radio image
- Will remove > 50% of sources at  $\mu\text{Jy}$  levels

- E.g.2

- Take 1400 MHz and 1000 MHz images
- Multiply 1400 MHz image by the flux ratio corresponding to  $\alpha = -0.7$  and subtract from 1400 MHz image
- Will remove > 50% of sources at  $\mu\text{Jy}$  levels



# Issues for EMU-deep

- Will there be other low-level ASKAP or imaging artefacts?
- How well can we do the subtraction?
  - Use ATLAS data as test-bed
- Can we find a sufficiently quiet piece of sky to overcome calibration confusion?
- Need to find an area which is well surveyed by (e.g.) Herschel

**Won't start EMU-deep until we are confident that we have solved all the issues in EMU-wide**



# Polarisation in EMU: linking to ARMPIT

- EMU explicitly does not include polarisation
  - We consider that to be the domain of ARMPIT
- However, there are strong linkages because:
  - We need to agree on areas of sky (both for Wide and Deep)
  - We need to agree on calibration and imaging strategies
  - Our science goals are strongly linked (as in ATLAS at present)

# Linking EMU to HI surveys

- Can EMU be commensal with HI surveys?
  - Area of sky to be covered (EMU:  $\delta < +30^\circ$ )
  - Time spent per pointing (EMU: 12h/point)
  - Observing frequency (EMU: 1100-1400 MHz)
  - Daytime observing probably OK for EMU
  - EMU will include Galactic Plane
- Should EMU be commensal with HI surveys?
- If HI surveys are to be restricted to night-time observing, it may be better to do EMU in daytime and HI at night

For more info, see: <http://www.atnf.csiro.au/people/rnorris/emu/>  
(or Google on ASKAP EMU)

ASKAP EMU Evolutionary Map of the Universe

**Home** EMU is a proposed radio sky survey project, designed to use the new [ASKAP](#) telescope to make a deep ( $\sim 10\mu\text{Jy}$  rms) radio continuum survey covering the entire Southern Sky (perhaps as far North as  $30^\circ$ ). It can be characterised as a "Southern NVSS", except that it will have about 40 times the sensitivity of the NVSS. As a result, it will be able to probe star forming galaxies up to  $z=1$ , AGNs to the edge of the Universe, and will undoubtedly uncover new classes of object.

**Our Science Goals**

**Current Status** In addition, we are considering proposing a "deep field" covering an area of tens of square degrees in which we use multi-wavelength information to penetrate below the classical confusion limit, reaching a target rms of perhaps  $\sim 1\mu\text{Jy}$  rms

**ASKAP Specifications**

**Project Parameters** The project will be one of several competing to use [ASKAP](#). [Expressions of Interest](#) were solicited in November 2008, with a deadline in December 2008, and full proposals will be solicited in mid-2009. If successful, the EMU Project Team will be invited to play a significant role in ensuring that ASKAP is built and operated to maximise the science return.

**Issues**

**Team Members** Potential participants are invited to join the team, and, if we are successful in the selection process, will then have the opportunity to participate in designing the parameters and processes of the survey, and participate in the commissioning and quality control.

**Wiki Pages (password protected)** All radio data from the survey will be placed in the public domain as soon the data quality has been checked. An integral part of the proposed project will be to perform identifications with other wavelengths, and produce catalogs of these and other "added-value" data products

**ASKAP**

About the banner above: The banner is a representation of the "emu in the sky", which is an important dreaming-spirit of the Aboriginal traditional owners of the land on which ASKAP will be built. For more information on this image, see [http://www.atnf.csiro.au/research/AboriginalAutonomy/Examples\\_emu.htm](http://www.atnf.csiro.au/research/AboriginalAutonomy/Examples_emu.htm)

Done

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