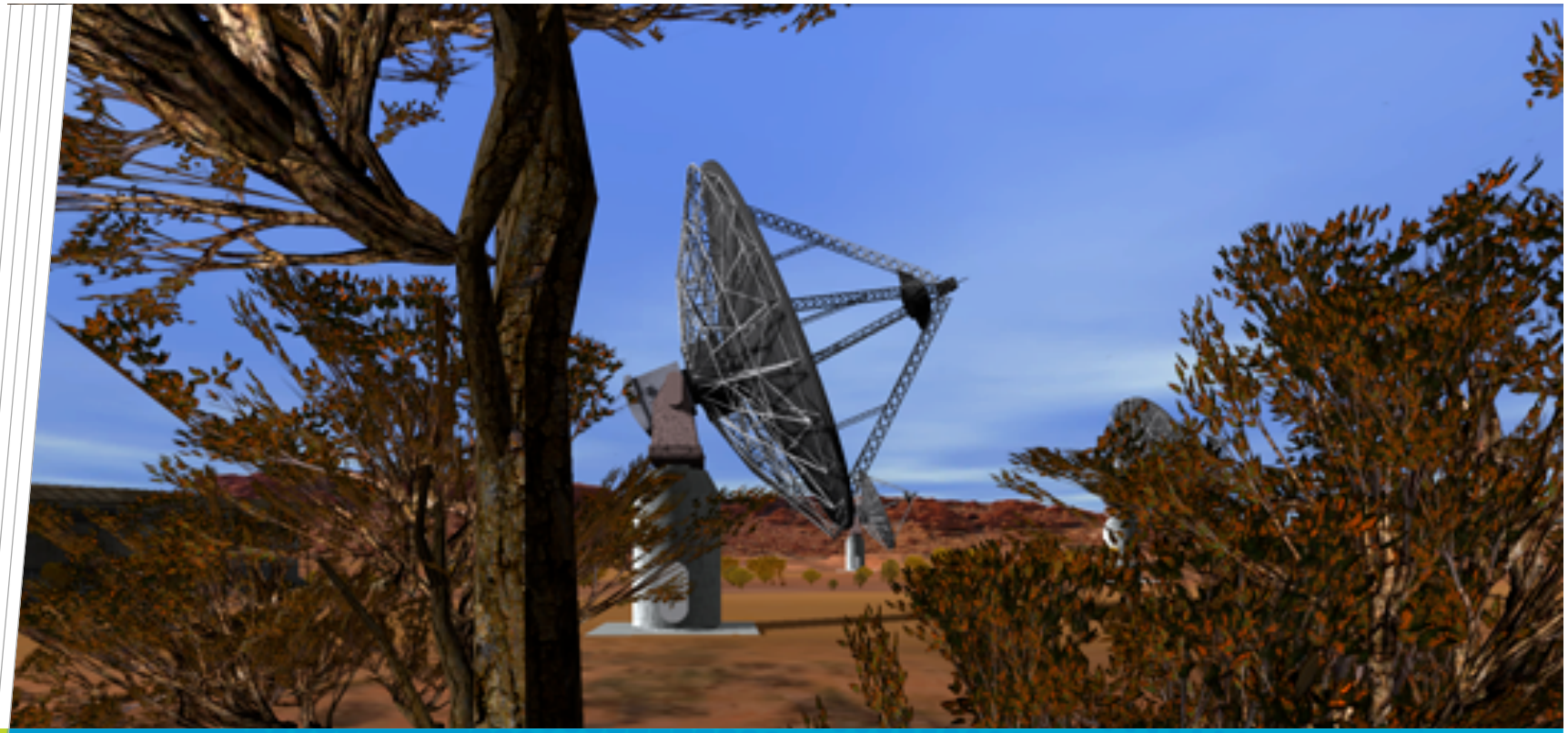

ASKAP-EMU: Overcoming the challenges of wide deep continuum surveys

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CSIRO ATNF
3 June 2009

www.csiro.au

CSIRO

Overview

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

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

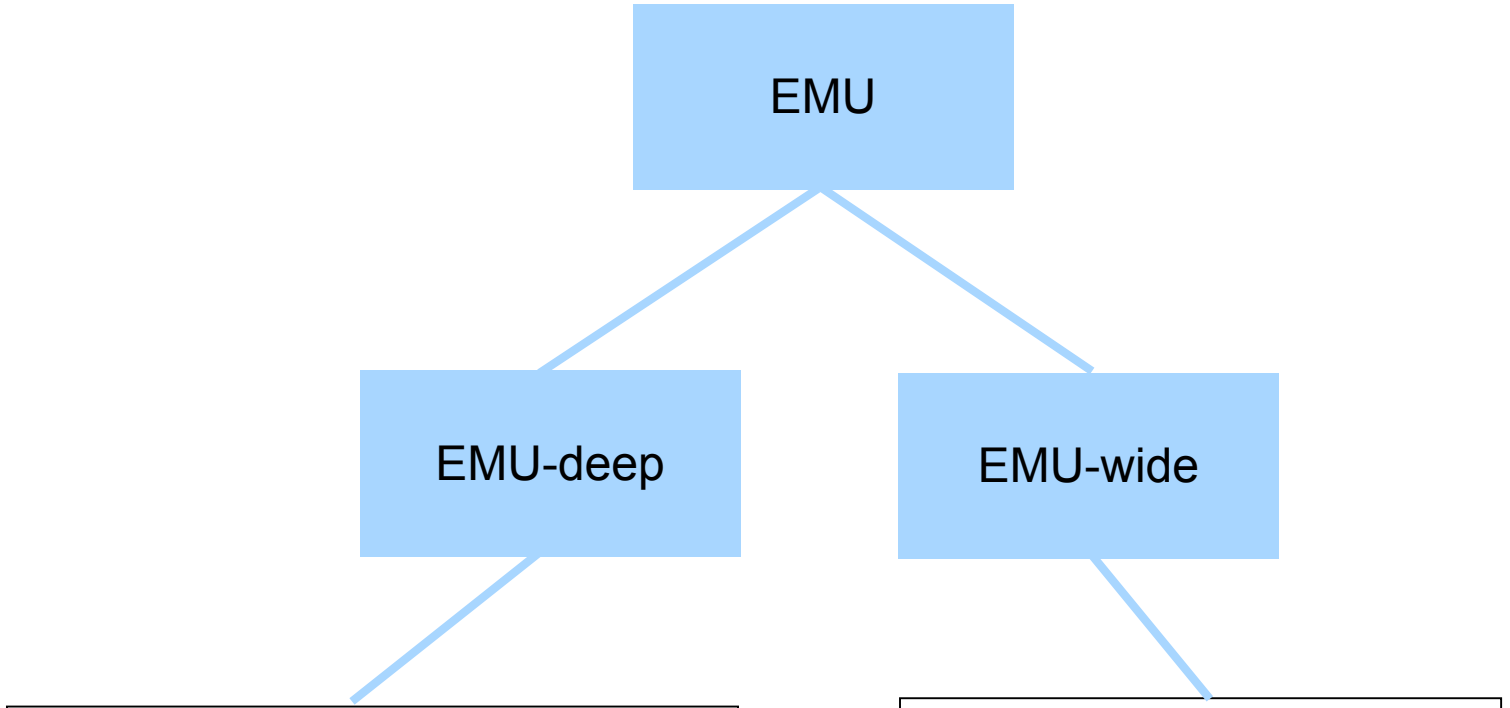
- All data to be processed in pipeline
- Images, catalogues, cross-IDs, to be placed in public domain

Radio
- LOFAR
- NVSS
- SUMSS
- MWA
- ATLAS
- South Pole Telescope
- GMRT-Herschel-ATLAS

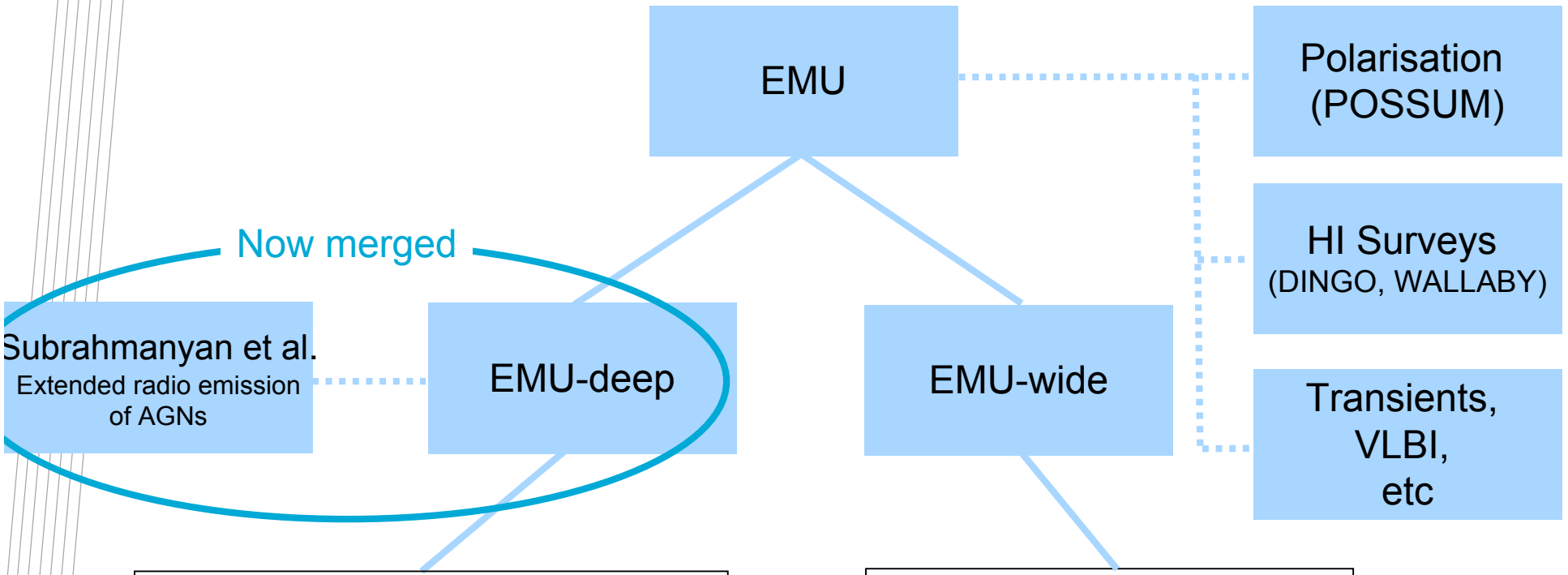
Optical/IR
- SDSS
- LSST
- Pan-STARRS
- 2MASS
- HLA
- VISTA/VIKING/VHS/VIDEO
- GAMA
- VST/KIDS
- UKIDSS
- Herschel ATLAS/HerMES
- WISE

X-Ray
- eROSITA
- IXO

Introduction to EMU



Commensal with other ASKAP surveys



- 2000 hr (3 mth) observing time
- One patch covering 30 sq deg
- rms goal ~ 1μJy
- ~0.5 million sources
- High risk

- 1.5 years observing time
- All sky up to +30° dec
- rms ~ 10μJy
- 40x sensitivity of NVSS
- 5x resolution of NVSS
- ~70 million sources

Current major 20cm surveys

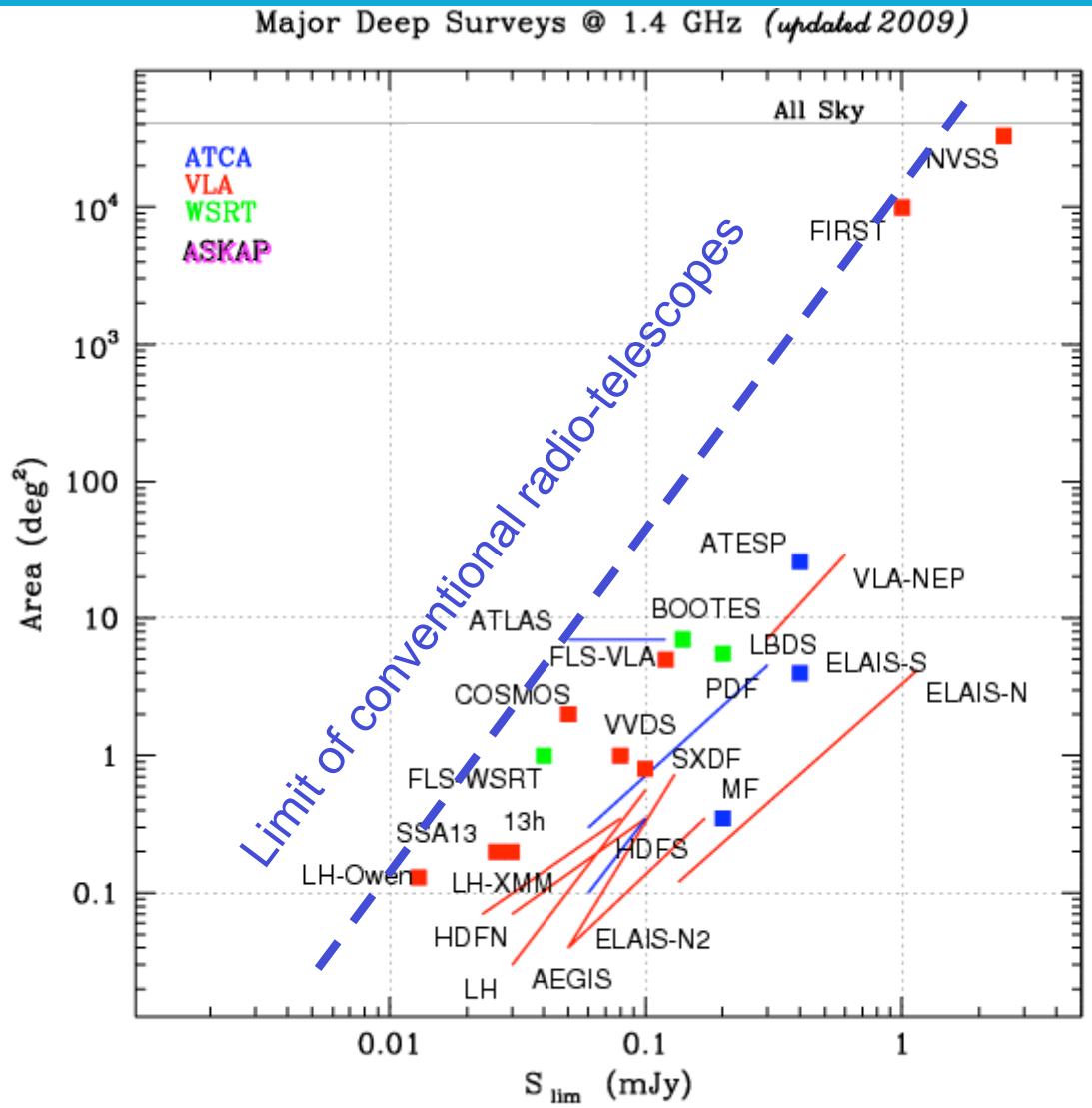


Diagram courtesy of Isabella Prandoni

Current major 20cm surveys

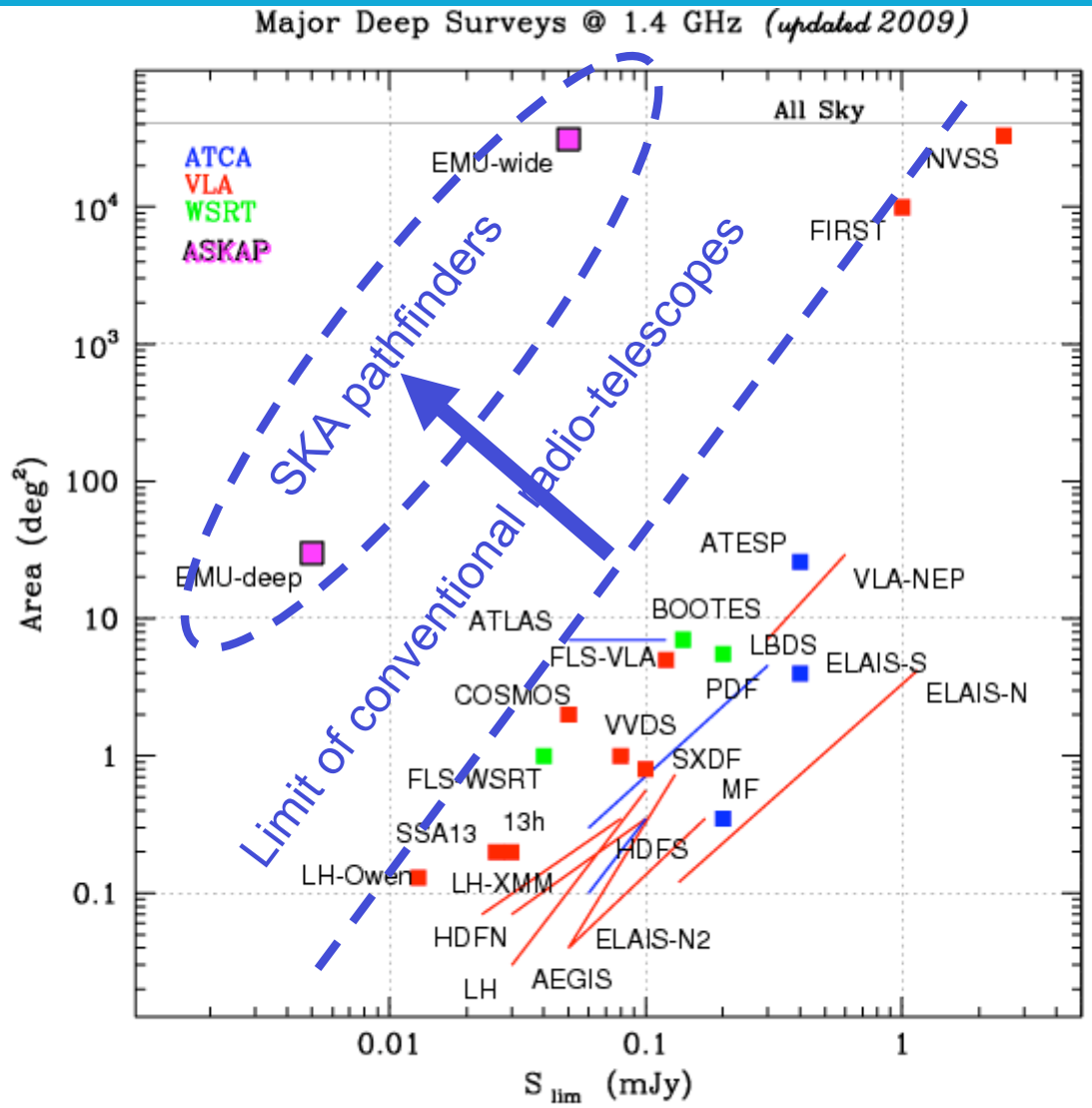


Diagram courtesy of Isabella Prandoni

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.

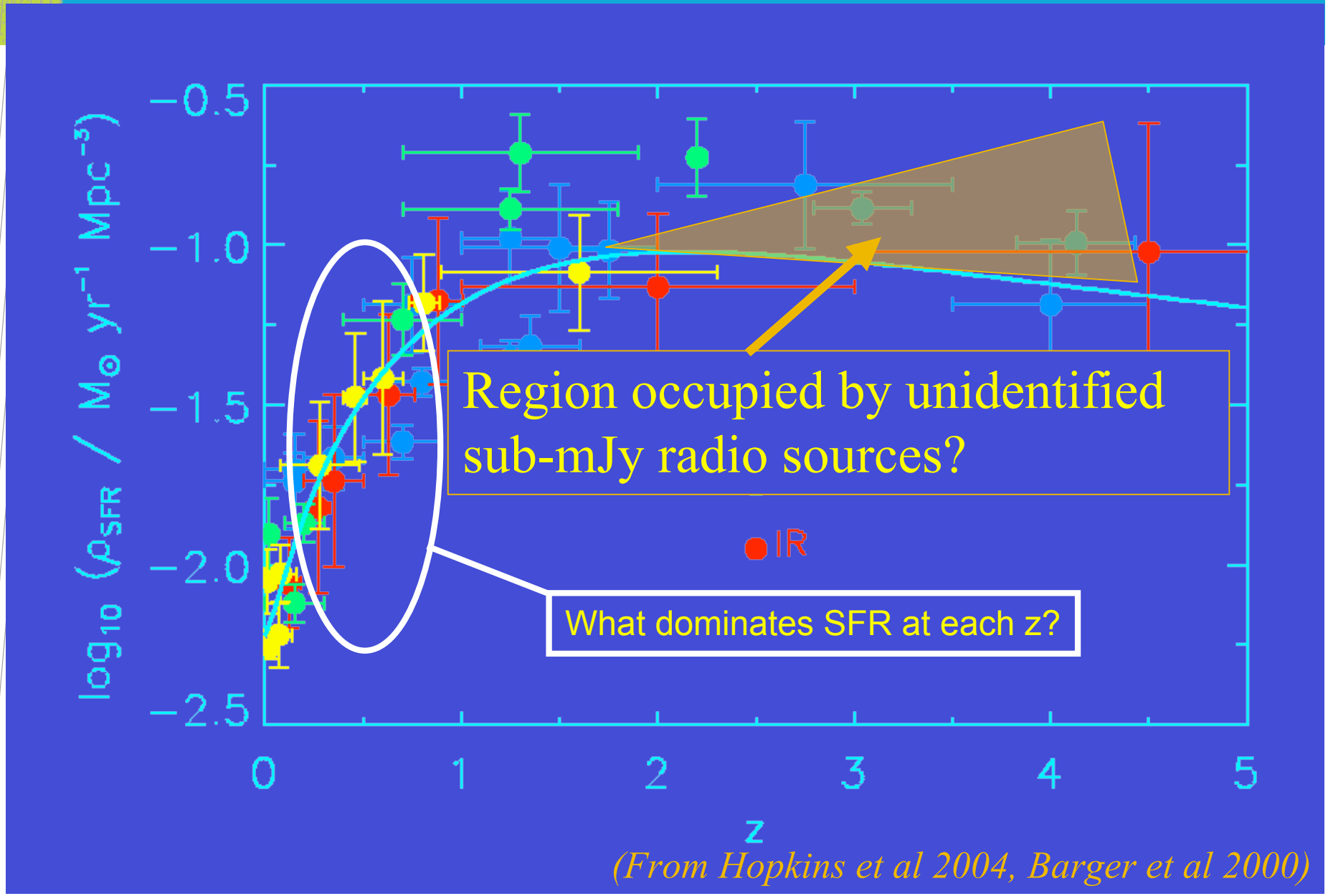
2. To trace the evolution of massive black holes throughout the history of the Universe, and understand their relationship to star-formation.

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

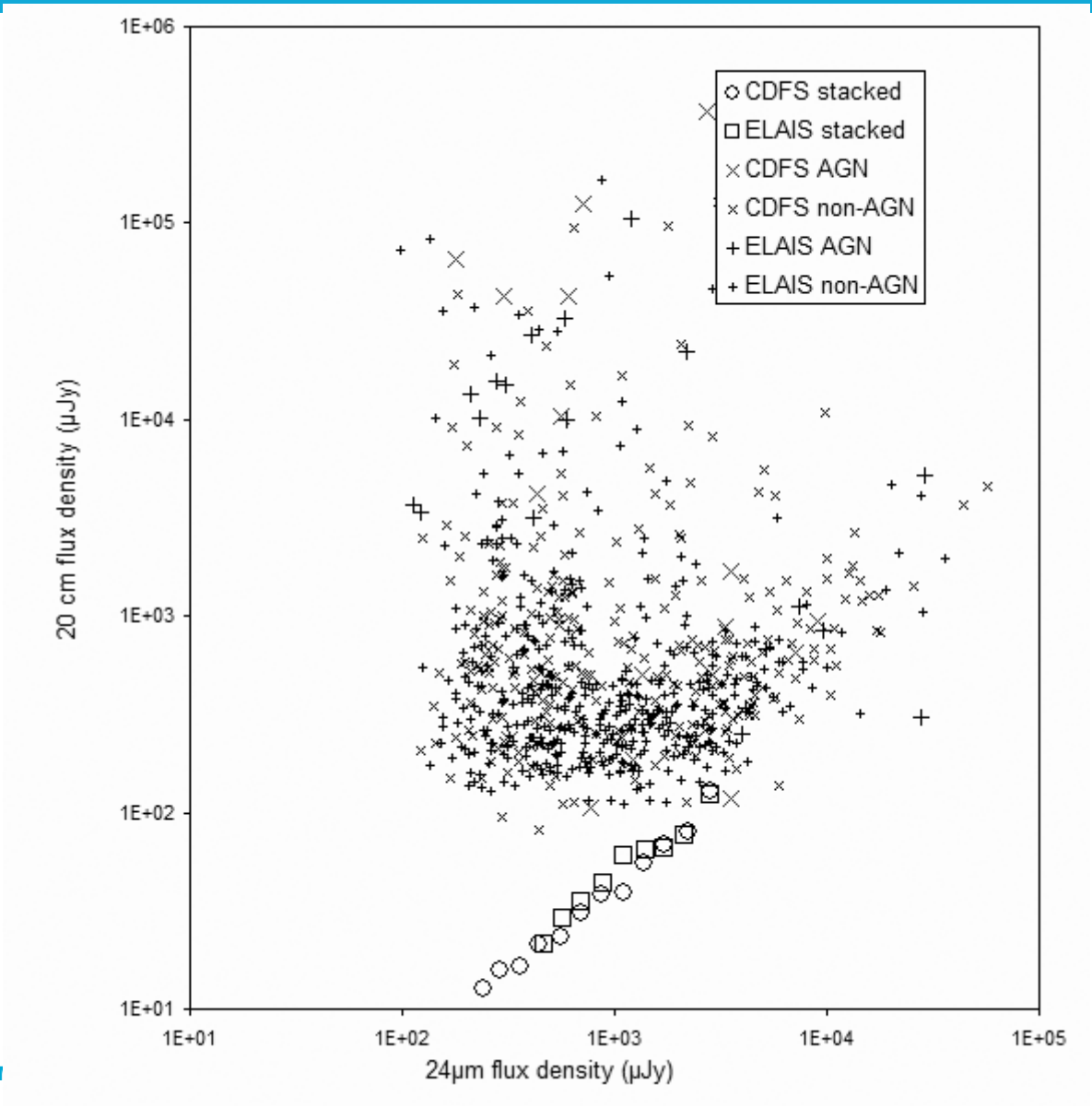
5. **To explore an uncharted region of observational parameter space, almost certainly finding new classes of object.**

How has the global star formation rate evolved with time?



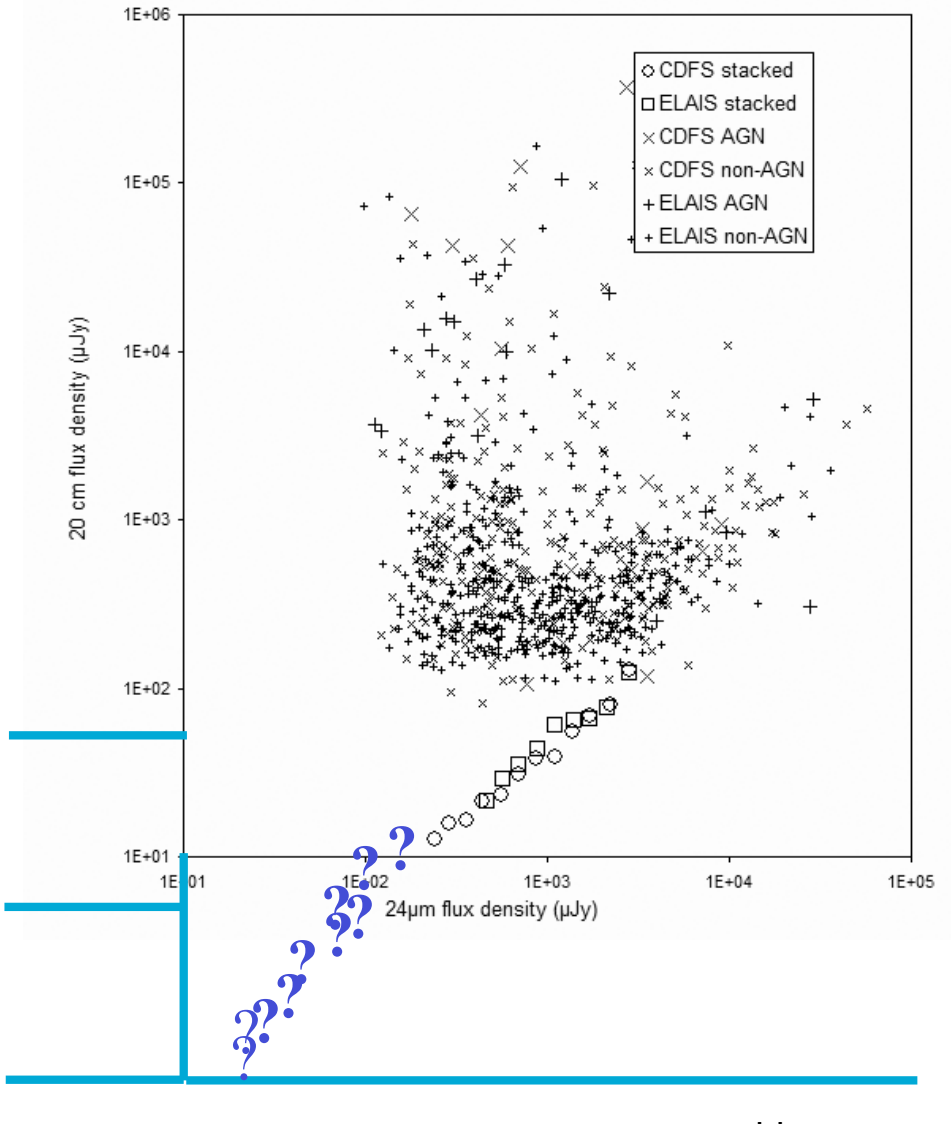
(From Hopkins et al 2004, Barger et al 2000)

What is the origin of the radio-FIR correlation?



Boyle et al 2007
Norris et al 2007

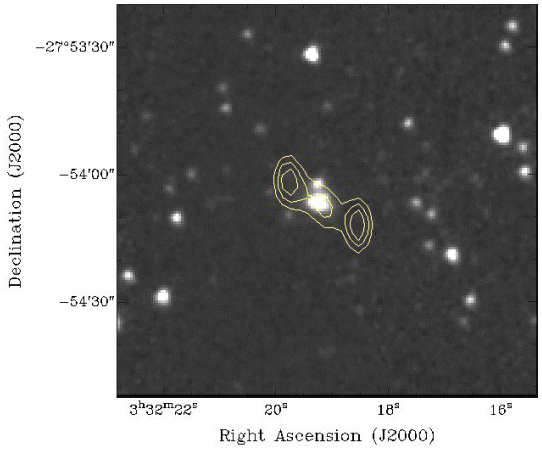
What is the origin of the radio-FIR correlation?

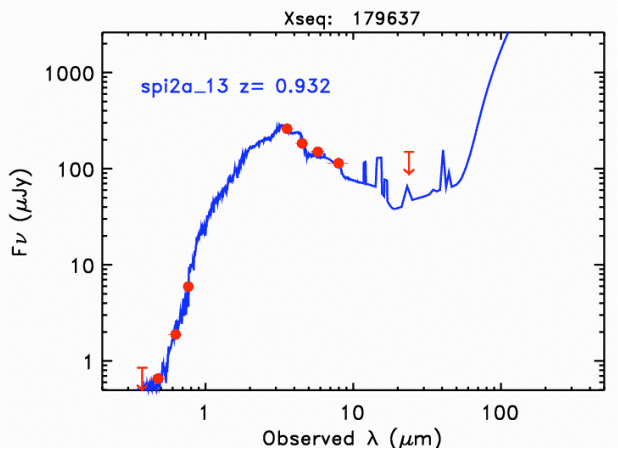


To trace the evolution of massive black holes, and understand their relationship to star-formation.

- 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.



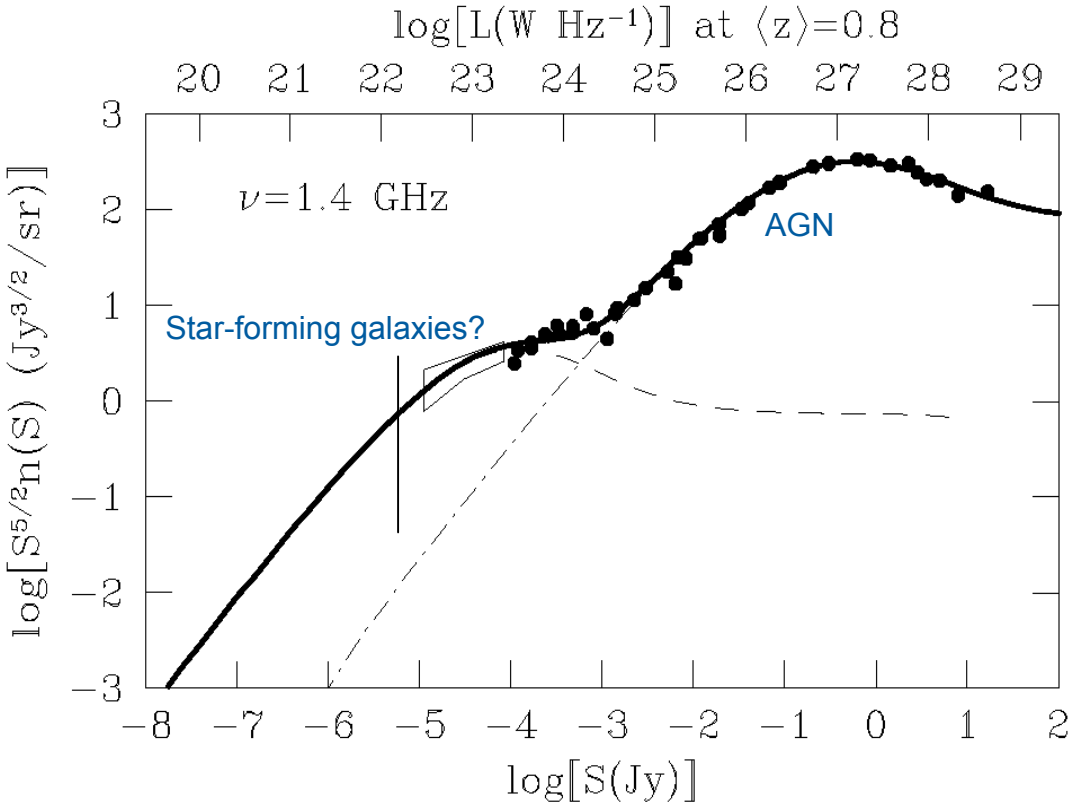


PRONGS=
Powerful
Radio-loud
Objects
Nested in
Galaxies with
Star-formation

- 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.

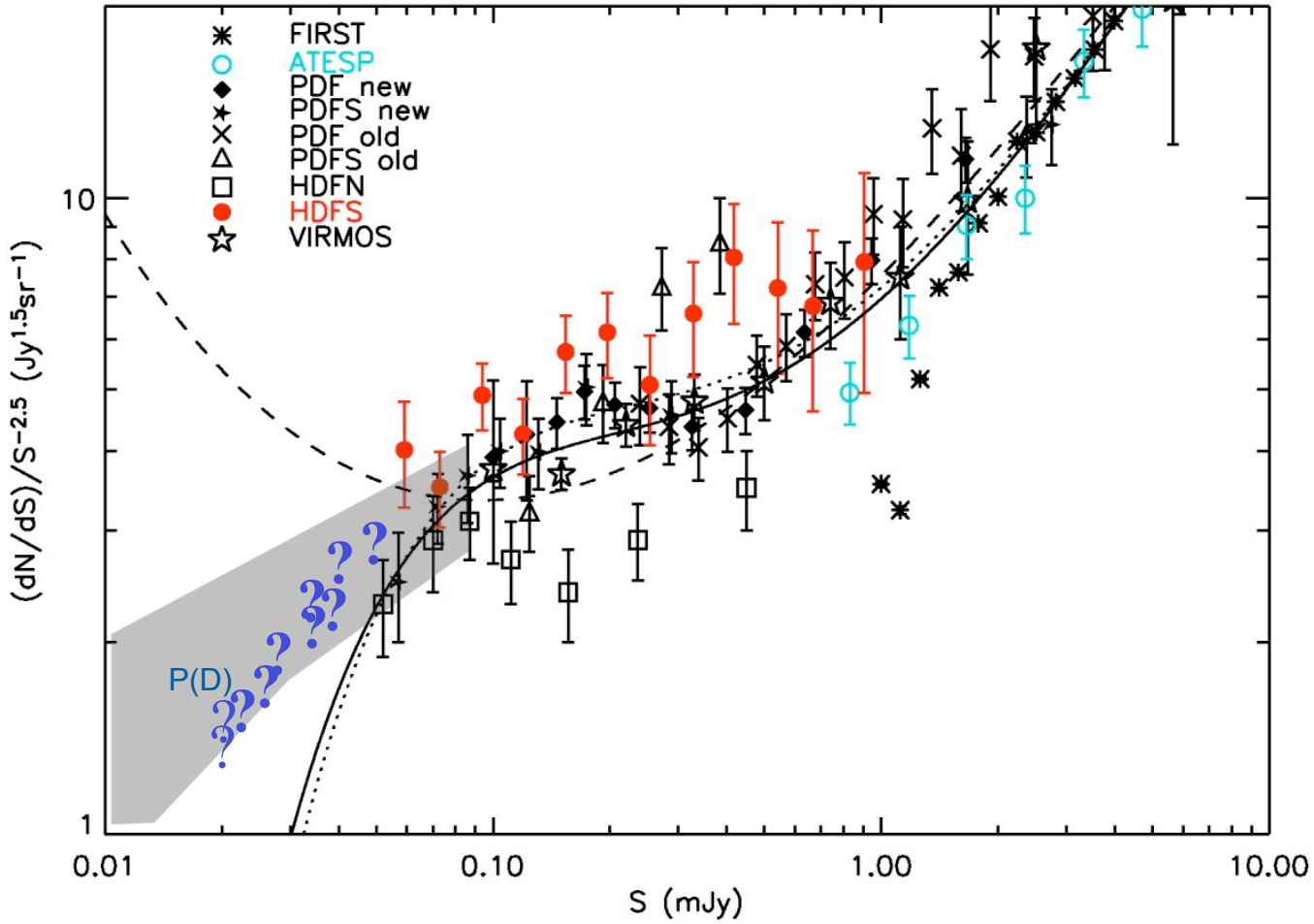
What is the evolutionary relationship between starbursts and AGN?



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)

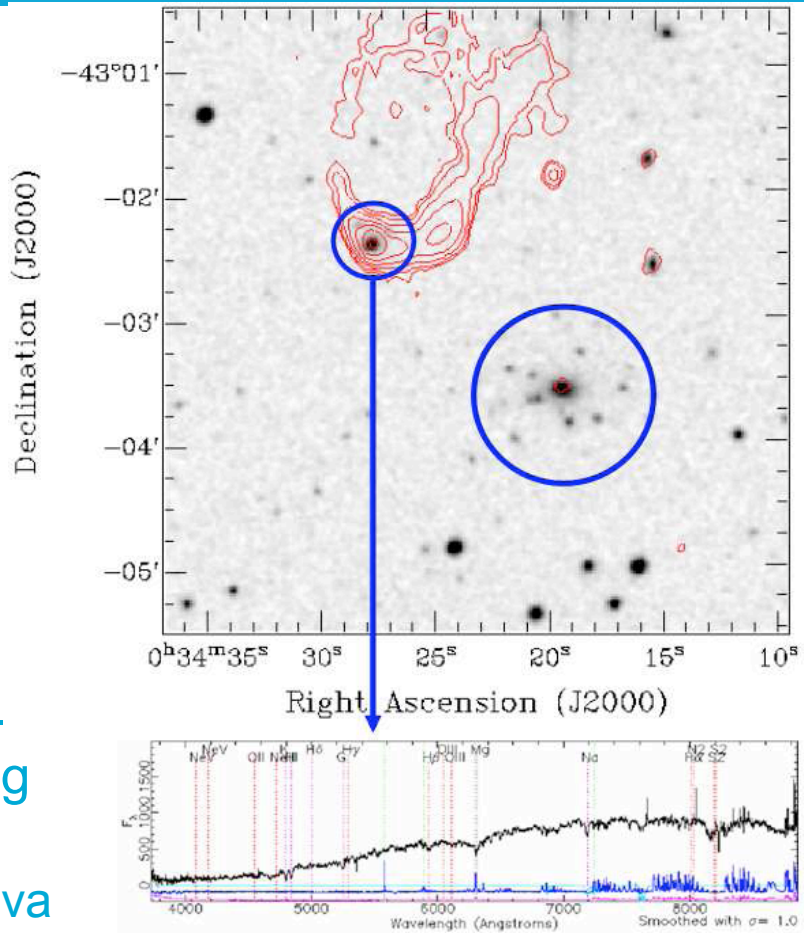


Huynh et al. (2006)

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



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

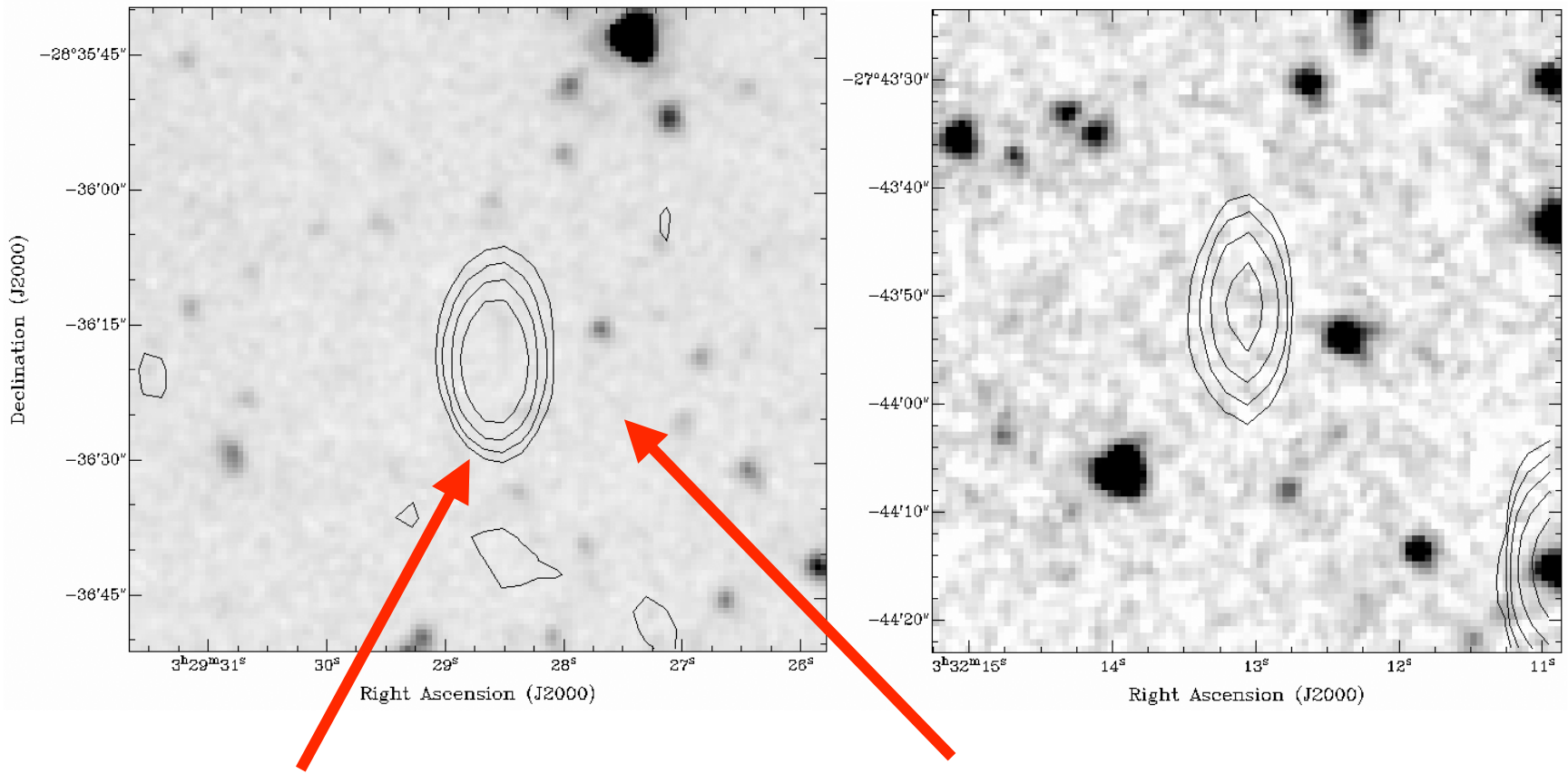
To create the most sensitive wide-field atlas of Galactic continuum emission yet made.

- 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)

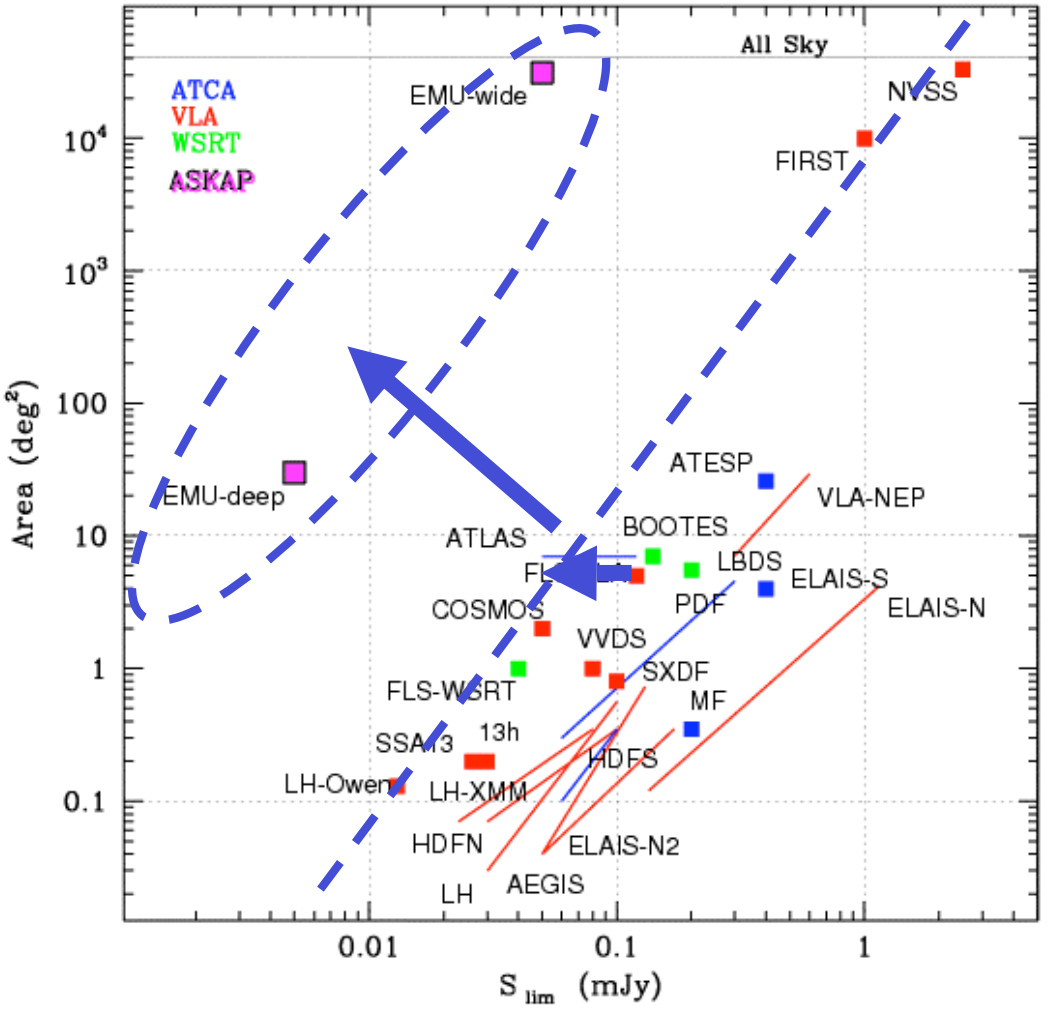


6.1 mJy at 20 cm

<5 μJy at 3.6μm

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° dec
- Want to overlap with northern radio surveys (LOFAR, eVLA, NVSS)
- Want to overlap with major optical surveys (e.g. Sloane, PanStarrs)

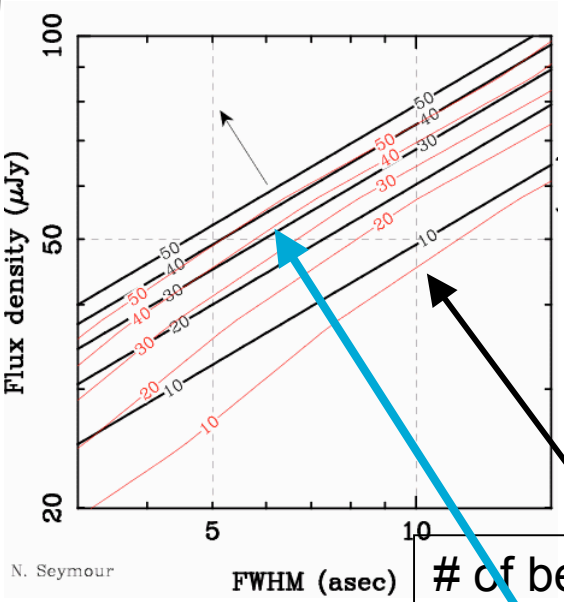
- Mosaicing over many pointings each day
  - smooths out data problems
  - means you have to solve for variability when imaging
  - Means you have to keep, combine, and re-process uv data
  - Better to image each pointing completely in one visit?
- Weighting
  - Natural weighting maximises sensitivity, 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 ~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

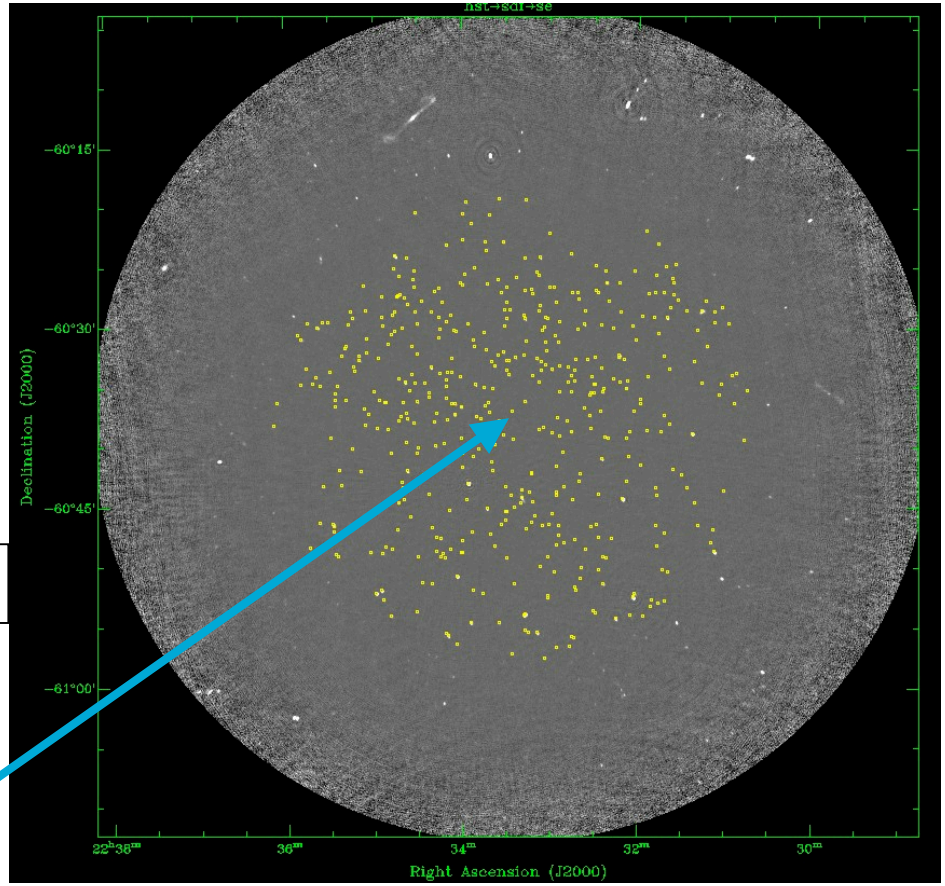
- A commonly adopted rule of thumb is that only 1% of beams should contain a source (i.e. β = beams/source = 100)



# of beams/source

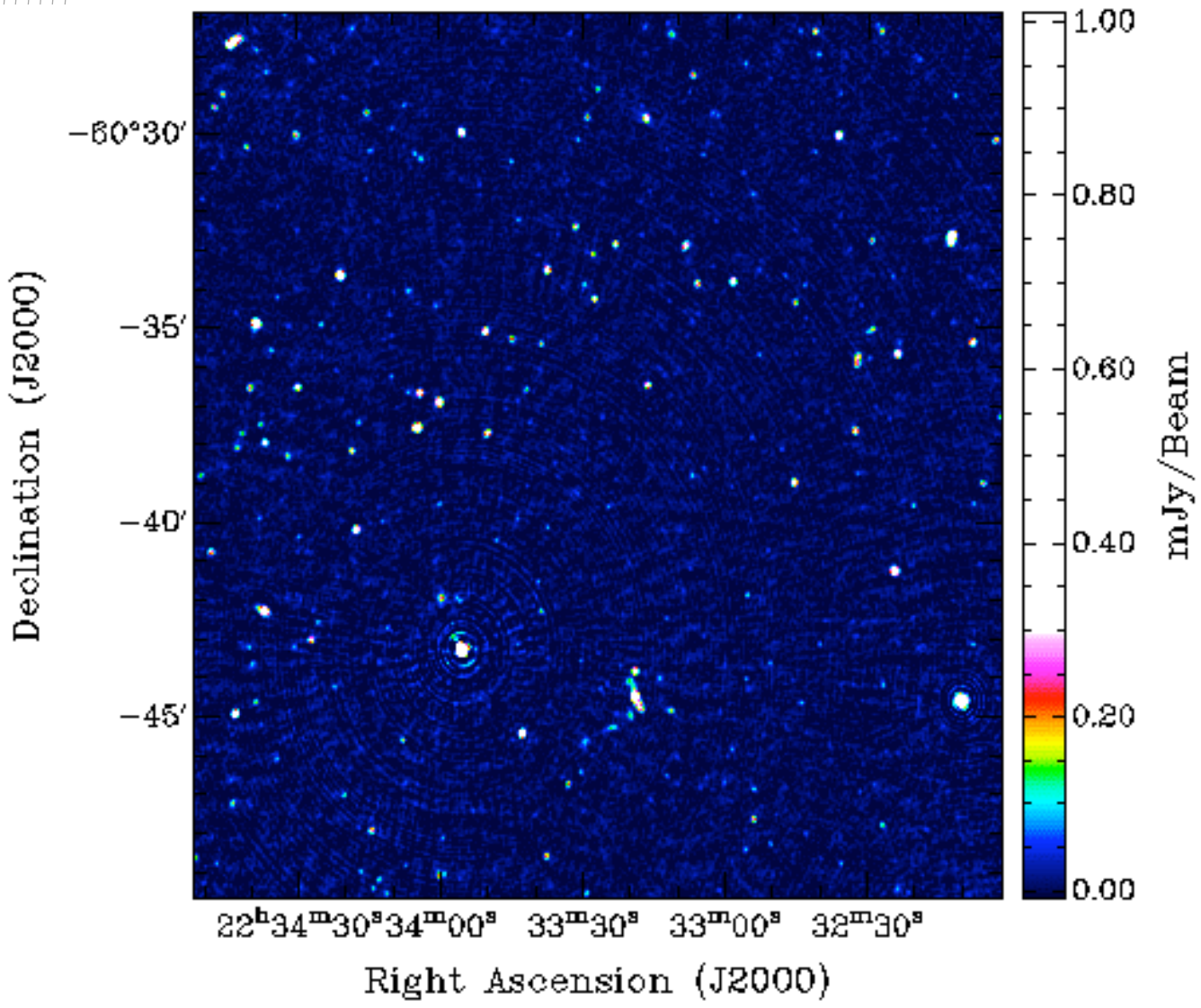
- For the ATCA at 20 cm, $S_{confusion100}$ ~ 80 μJy/beam
- We have already passed this point.
- And the sky didn't fall in.

β=41



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

HDFS imaged with ATCA at 20cm (B=6km, rms=10μJy)



Huynh et al 2005
Norris et al 2005

Other definitions of confusion

Beam confusion (few μJy for 6km baseline)

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

Background confusion (few μJy for 6km baseline)

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

Calibration confusion (few μJy?)

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

Natural confusion (<1 μJy)

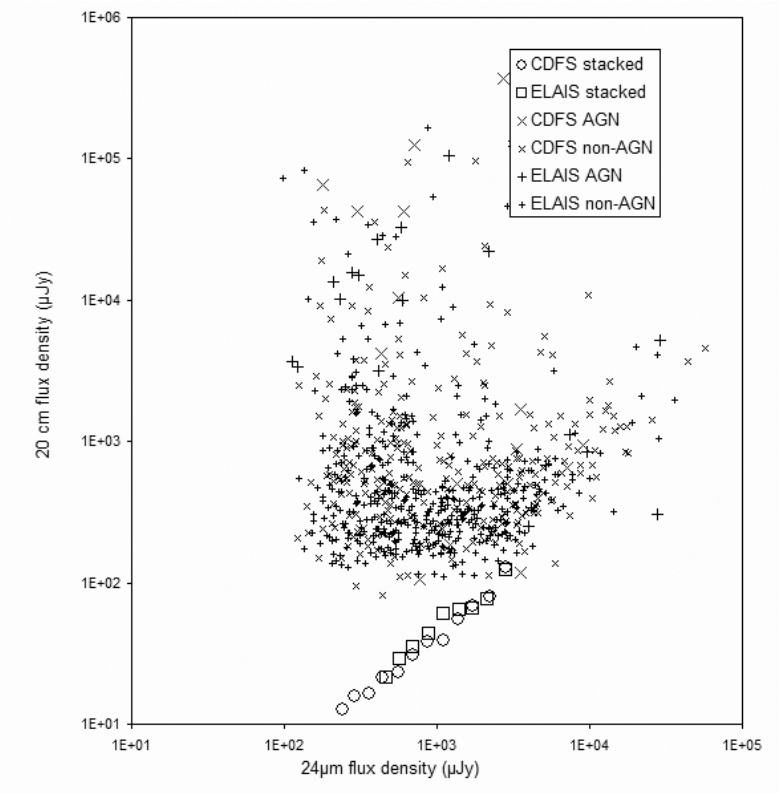
- At what level do sources physically overlap?

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 μJy levels

- E.g.2
  - Take 1400 MHz and 1000 MHz images
  - Multiply 1400 MHz image by the flux ratio corresponding to α =-0.7 and subtract from 1400 MHz image
  - Will remove > 50% of sources at μJy 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: $\delta < +30°$
  - 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)