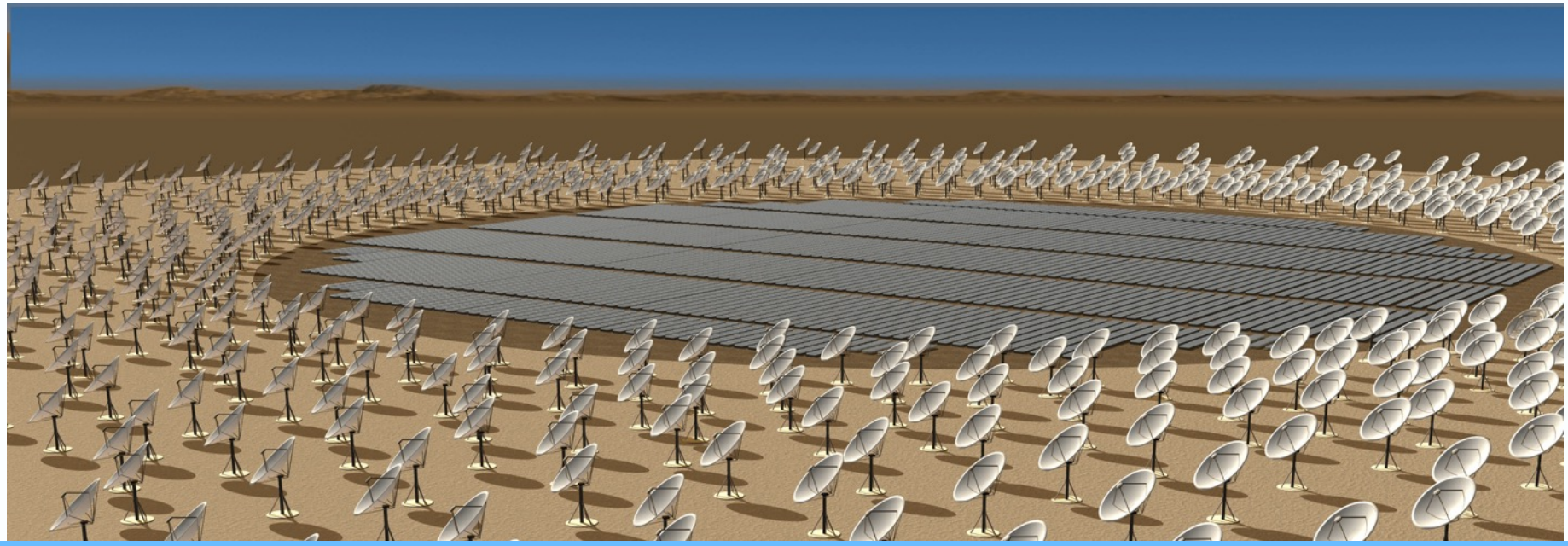
Evolutionary Map of the Universe: complementarity to eROSITA

WESTERN SYDNEY UNIVERSITY

Ray Norris, Western Sydney University &
CSIRO Astronomy & Space Science,

CSIRO

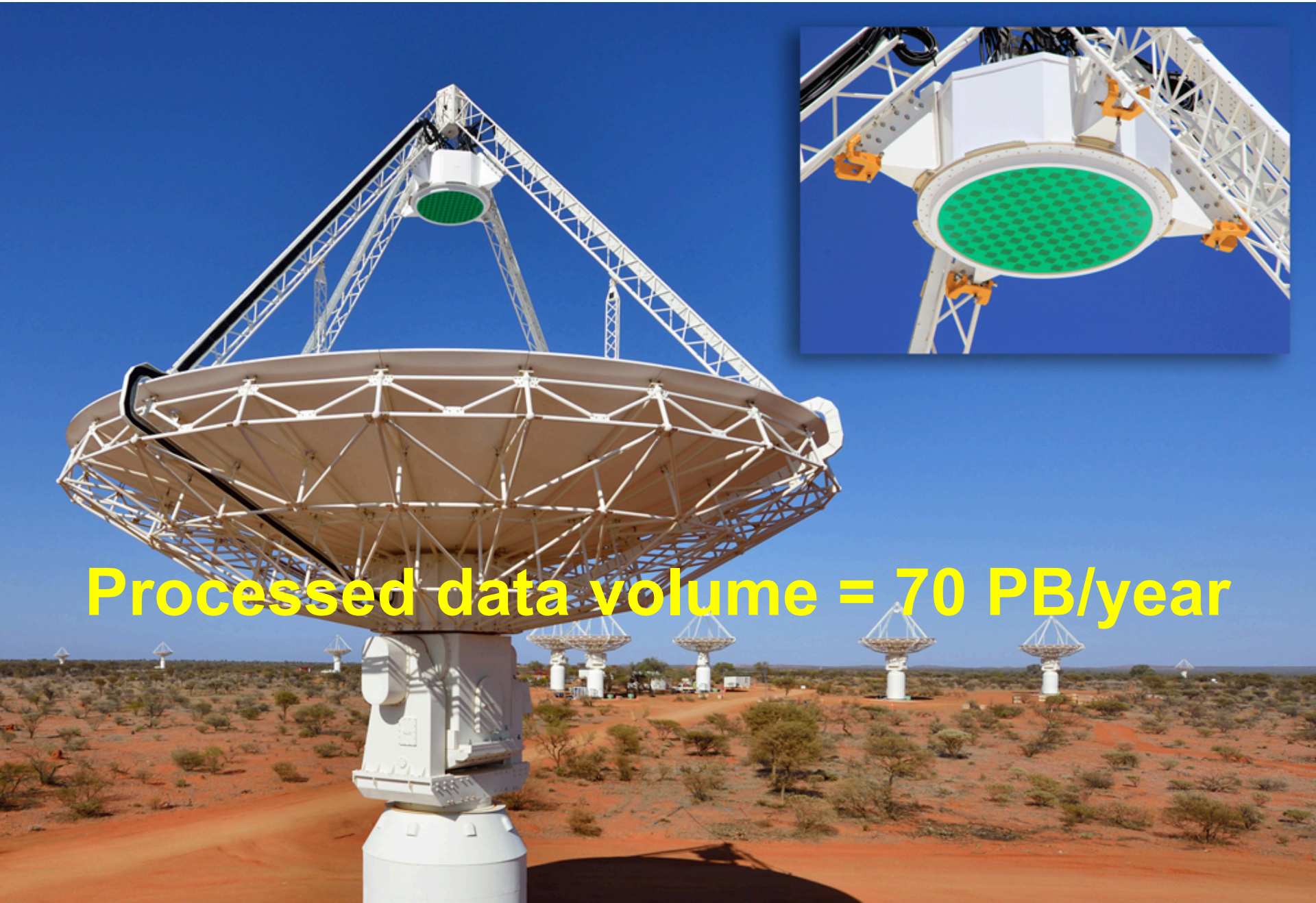
Square Kilometre Array (SKA)



- A $2 billion project, to be funded by the global community
- To be built both in Australia and South Africa
- About 100 times more sensitive than any existing radio-telescope
- Will be able to answer fundamental questions about the Universe
- SKA Phase 1 construction starts ~2020?, completion ~2025?
- SKA Phase 2 some years after that?
- Both Australia and South Africa currently completing “Pathfinder” telescopes

ASKAP: Australian SKA Pathfinder

Total bandwidth = 2.1THz per antenna



Processed data volume = 70 PB/year

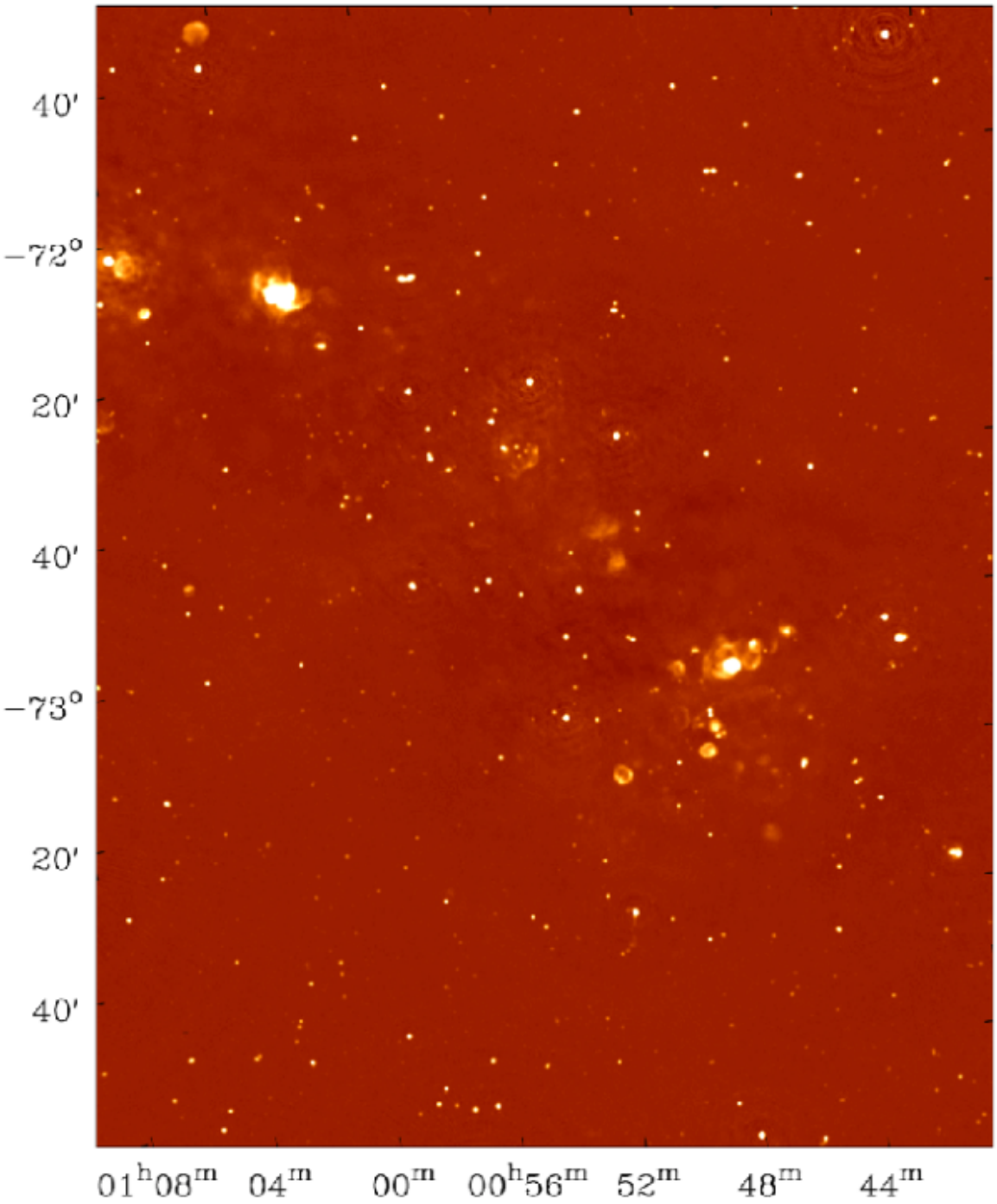
MRO hybrid power station Dec 2017

ASKAP Status in a nutshell

- Phased Array Feeds (PAF) give 30 sq deg FOV and an amazing survey speed
- Fully funded
- All 36 antennas & infrastructure completed
- All 36 PAFS complete and installed
- Currently debugging and commissioning backend and processing pipeline

ASKAP Timeline

2009	Project initiated
2014-2016	BETA operational (6 antennas)
2017-mid 2018	Early Science Phase 1 (12-14 antennas) plus commissioning and debugging
mid-late 2018	Early Science Phase 2 (18 antennas) plus commissioning and debugging
Jan 2019	Commissioning of final survey array 36 antennas, 36 beams, 300 MHz bandwidth
Mid 2019?	Full surveys start (for ~ 5 years)



Obs duration was ~9 hours
Bandwidth 240MHz
Tsys/eff = 75K
Naturally weighted
Expect rms = 32uJy/bm.

Actual 50uJy/bm in the Stokes-V
60uJy/bm in the Stokes-I
Used robustness of -0.5

Image by Wasim Raja

Slide courtesy Dave McConnell

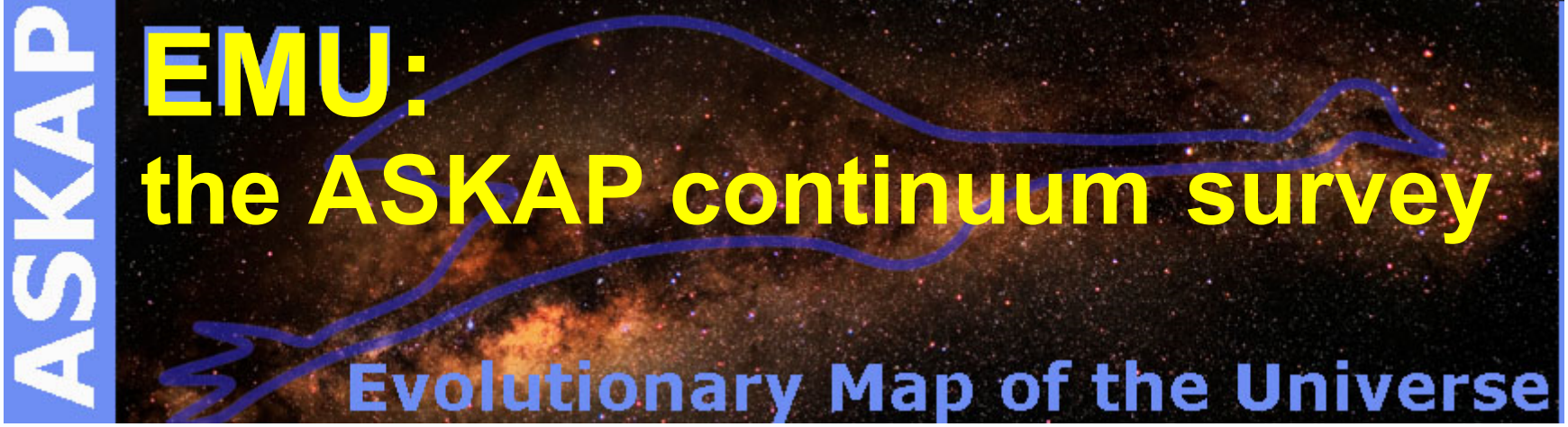
ASKAP Science Surveys

2 science survey projects are highest priority, and primarily drive the ASKAP design

- EMU all-sky continuum (PI Norris)
- WALLABY all-sky HI (PI Koribalski & Staveley-Smith)

8 others supported at a lower priority

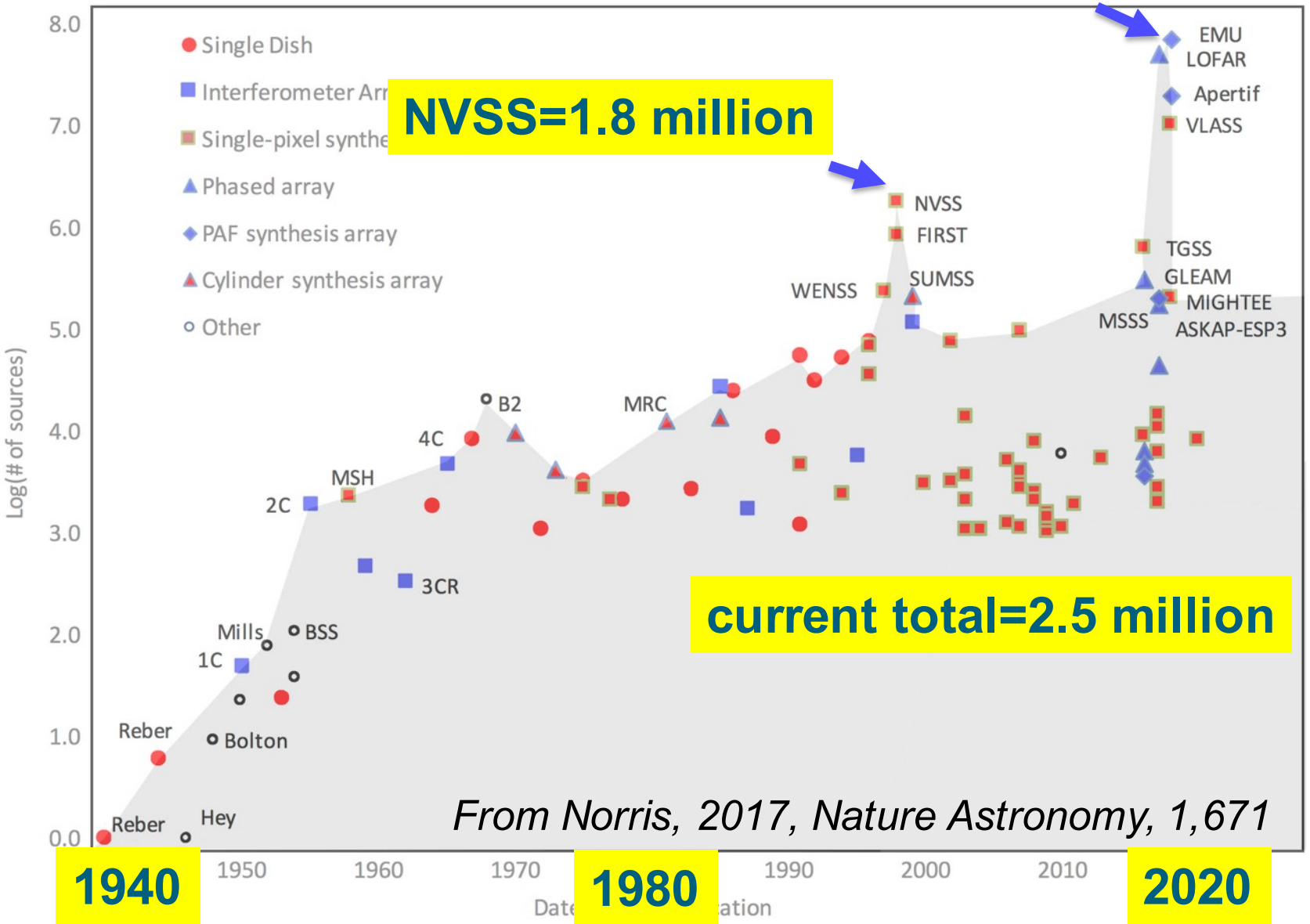
- COAST pulsars etc
- CRAFT fast variability
- DINGO deep HI
- FLASH HI absorption
- GASKAP Galactic
- POSSUM polarisation
- VAST slow variability
- VLBI



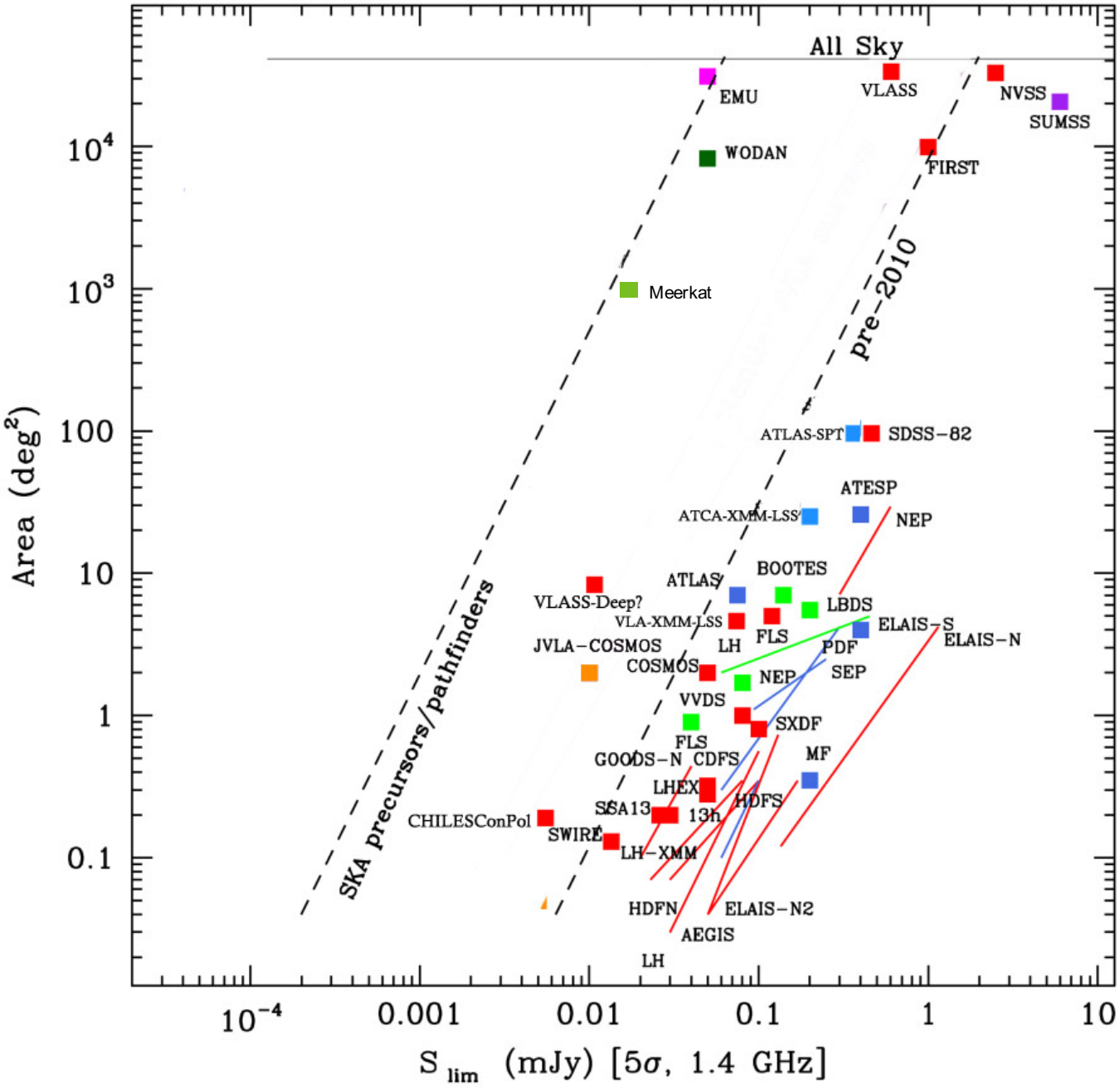
- Deep radio image of 75% of the sky (to declination +30°)
- Frequency range: 1100-1400 MHz
- 40 x deeper than NVSS (the largest existing radio survey)
  - Target is 10 μJy rms across the sky
- 5 x better resolution than NVSS (10 arcsec)
  - Better sensitivity to extended structures than NVSS
- Expect to detect and image ~70 million galaxies at 20cm
  - c.f. 2.5 million detected over the entire history of radio-astronomy so far
- All data to be processed in real-time pipeline
- Images, catalogues, cross-IDs, to be placed in public domain
- The EMU team has over 300 members in 21 countries

Size of radio continuum surveys over time

ASKAP Radio Continuum survey: EMU = 70 million



From Norris, 2017, Nature Astronomy, 1,671



Surveys at other frequencies have been converted to 1.4 GHz equivalent assuming $S \propto \nu^{-0.7}$

- **EMU has the additional challenge of trying to do astrophysics with a sample of 70 million galaxies**

- **With challenges come opportunities!**

- **This leads to a new way of doing astronomy (large-n astronomy)**

Mao et al. 2010MNRAS.406.2578M

How does EMU differ from earlier surveys?

1. Scale – increases the number of known radio sources by a factor of ~30
2. Key science projects as an integral part of the project
3. Uses "Large-n astronomy" techniques
   - Triggered machine learning group – http://mlprojects.pbworks.com
4. Will not be dominated by AGN
   - about half the galaxies will be normal SF galaxies
5. Ambition – includes:
   - Cross-identification with optical/IR/Xray data
   - Ancillary data (redshifts etc)
6. Explicitly includes "discovering the unexpected"

EMU Data Processing Pipeline

68 Tb/s

correlator

730km fibre
24 Gb/s

ASKAPsoft processing pipeline (calibration, imaging, source extraction)

22 TB/day

Level 6 data (public domain)

Validation by EMU team

- Merge multiple observations of one field
- Remove artefacts
- Extract diffuse sources
- Merge components into sources
- Source classification
- Cross-id with multiwavelength
- Assign redshifts

Added value by EMU team

EMUCAT
Level 7 data
(proprietary)

CASDA database (4PB/year)
Access via custom & VO interfaces

EMU Key Science Projects

Key project	Title	Project Leader
KP1.	EMU Value-Added Catalogue	Nick Seymour (
KP2.	Characterising the Radio Sky	Ian Heyw
KP3.	EMU Cosmology	Davi Korea)
KP4.	Cosmic Web	(USA)
KP5.	Clusters of Galaxies	ohnston-Hollitt ralia)
KP6.	cosmic star formation history	ndrew Hopkins (Australia)
KP7.	Evolution of radio-loud AGN	Anna Kapinska (USA)
KP8.	Radio AGN in the EoR	Jose Afonso (Portugal)
KP9.	Radio-quiet AGN	Isabella Prandoni (Italy)
KP10.	Binary super-massiv	Roger Deane (S Africa)
KP11.	Local Universe	Josh Marvil (USA)
KP12.	The Galact	Roland Kothes (Canada)
KP13.	SCO uing the Radio Stars in our Galaxy	Grazia Umana (Italy)
KP14.	ering the Unexpected	Ray Norris (Australia)
KP1	gellanic Clouds	Miroslav Filipovic (Australia)

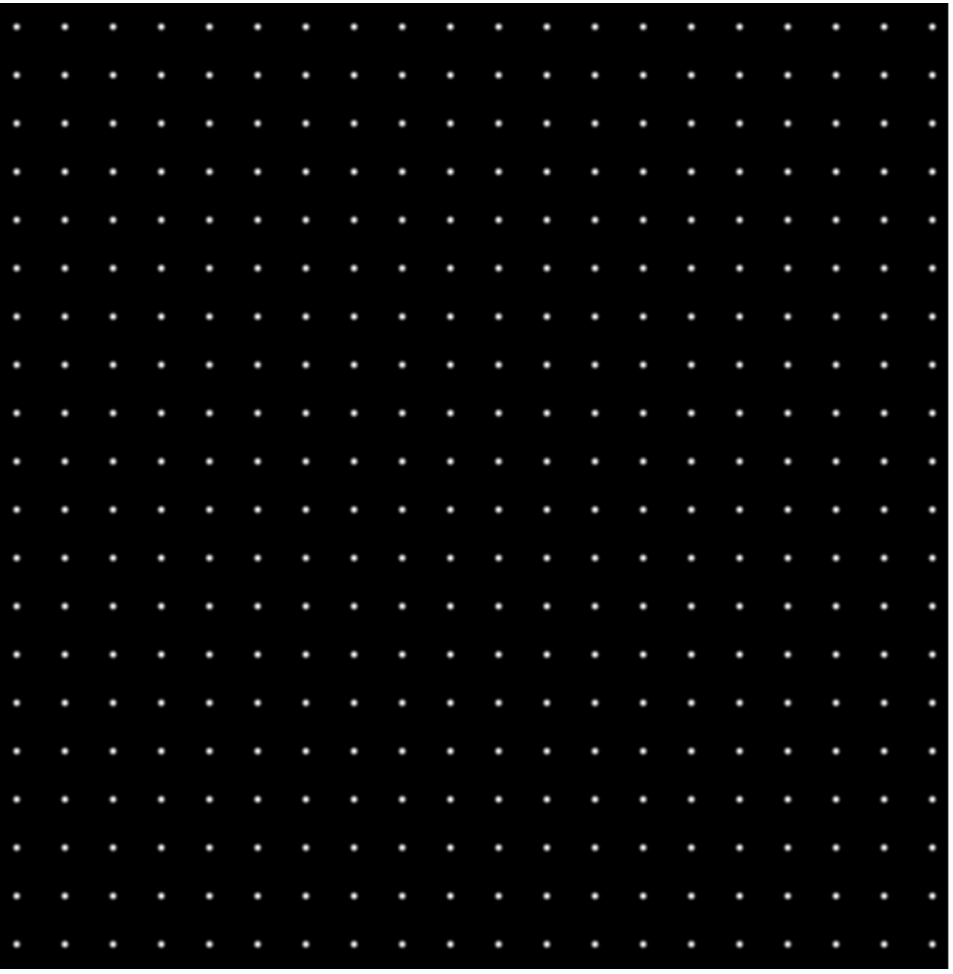
How did galaxies form and evolve?

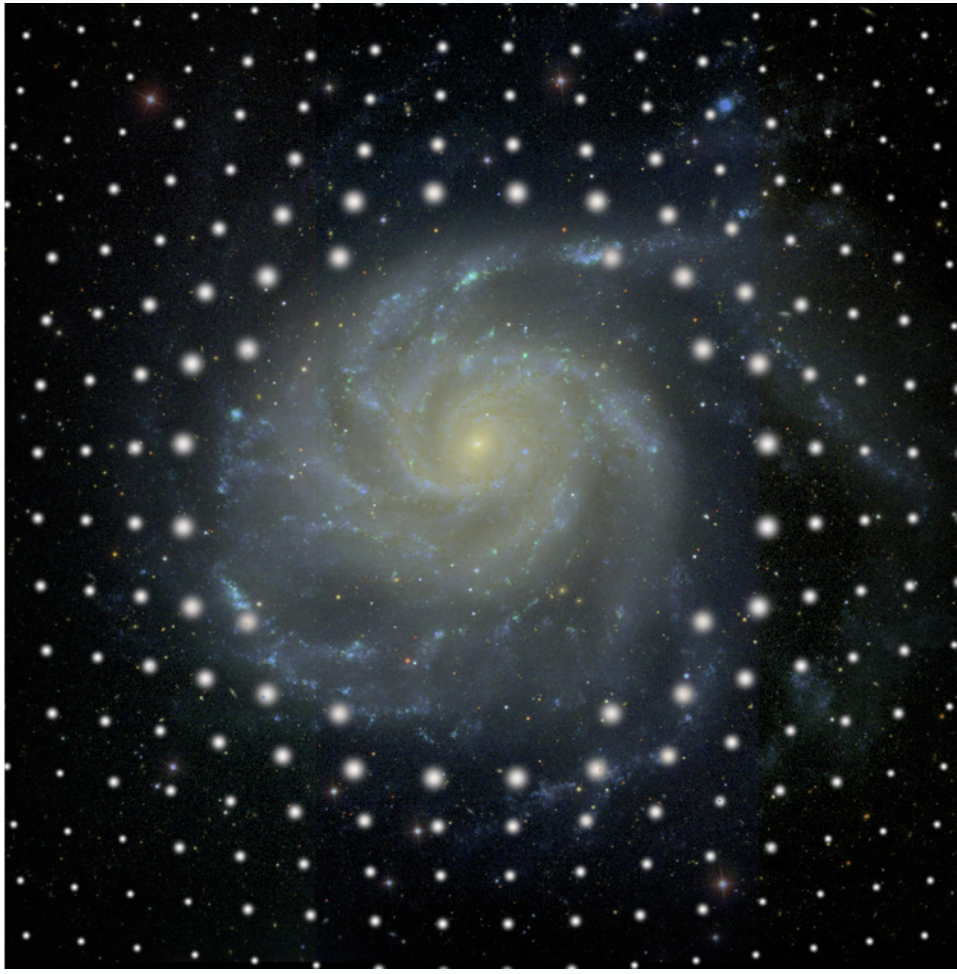
EMU Cosmology KSP

EMU can (in principle) measure four different cosmological observables:

1. **Angular correlation function of EMU galaxies (no z required)**
2. **Cosmic Magnification of high-redshift EMU galaxies by low-redshift optical foreground galaxies**
   - **Cross correlation of EMU and (e.g. Skymapper or TAIPAN) sample**
3. **Cosmic Magnification of CMB by EMU galaxies (no z required)**
   - **Cross-correlation between EMU density and CMB on small scales**
4. **Integrated Sachs-Wolfe effect (no z required)**
   - **Cross-correlation between EMU density and CMB on large scales**

Cosmic Magnification

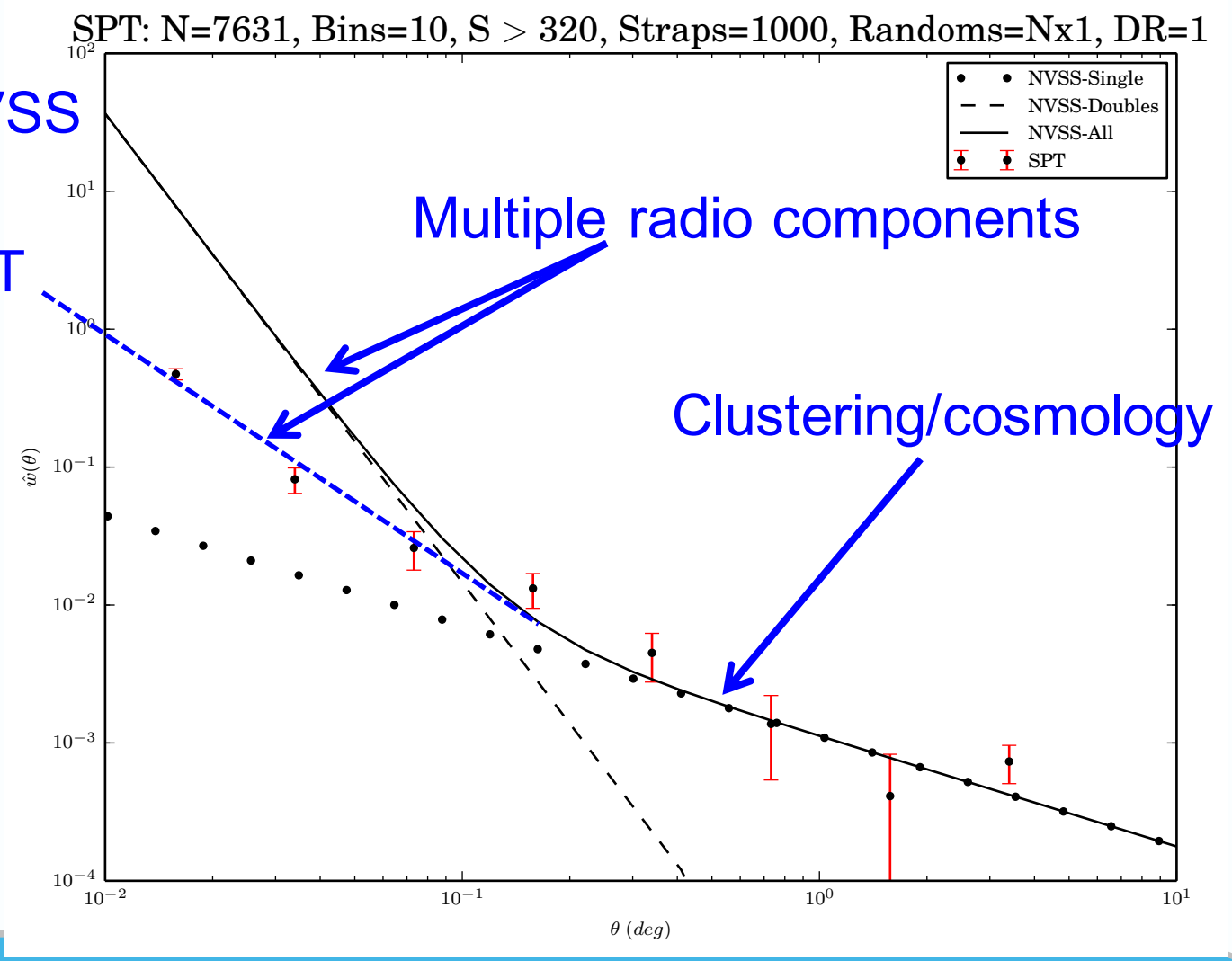


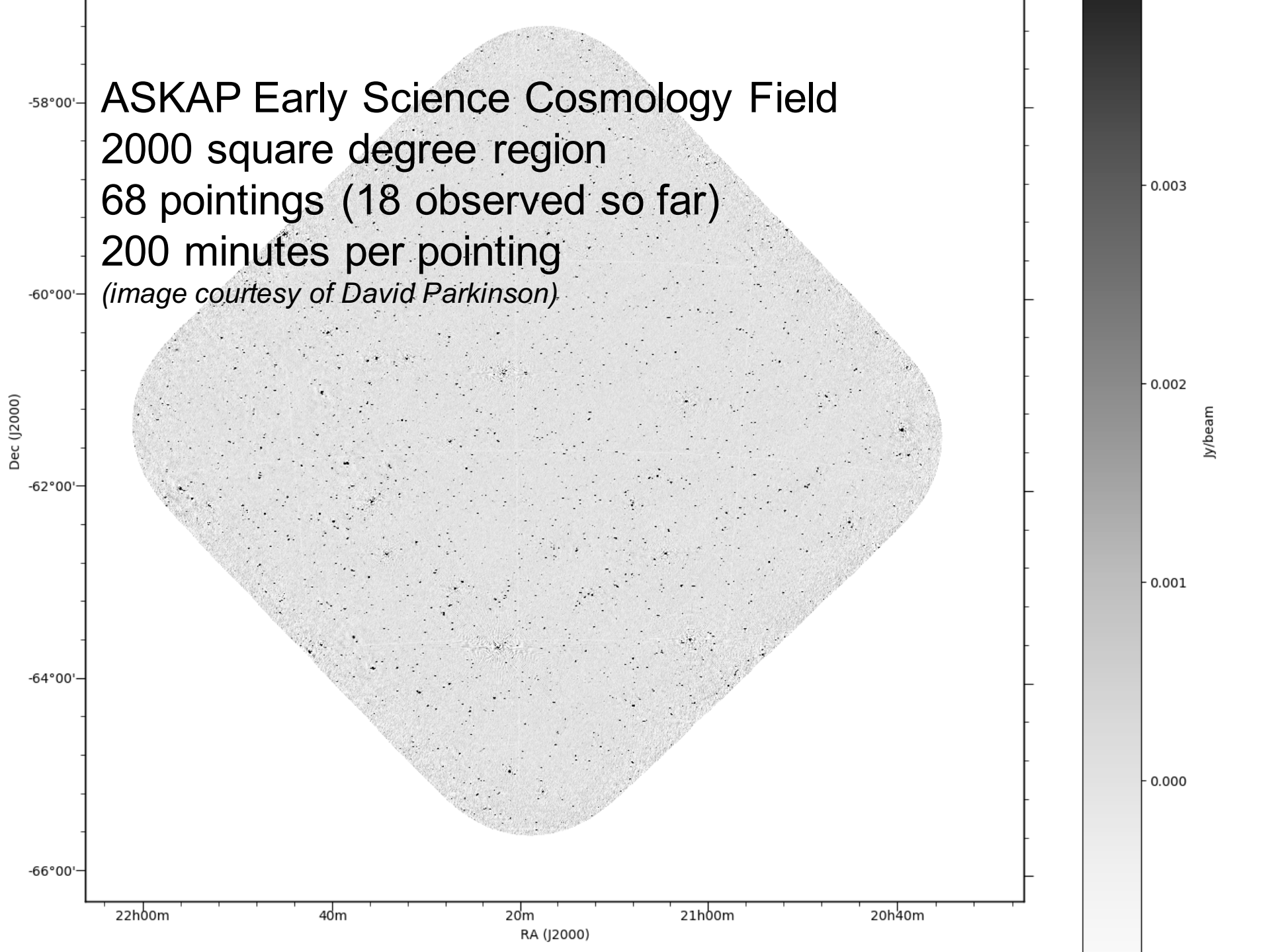


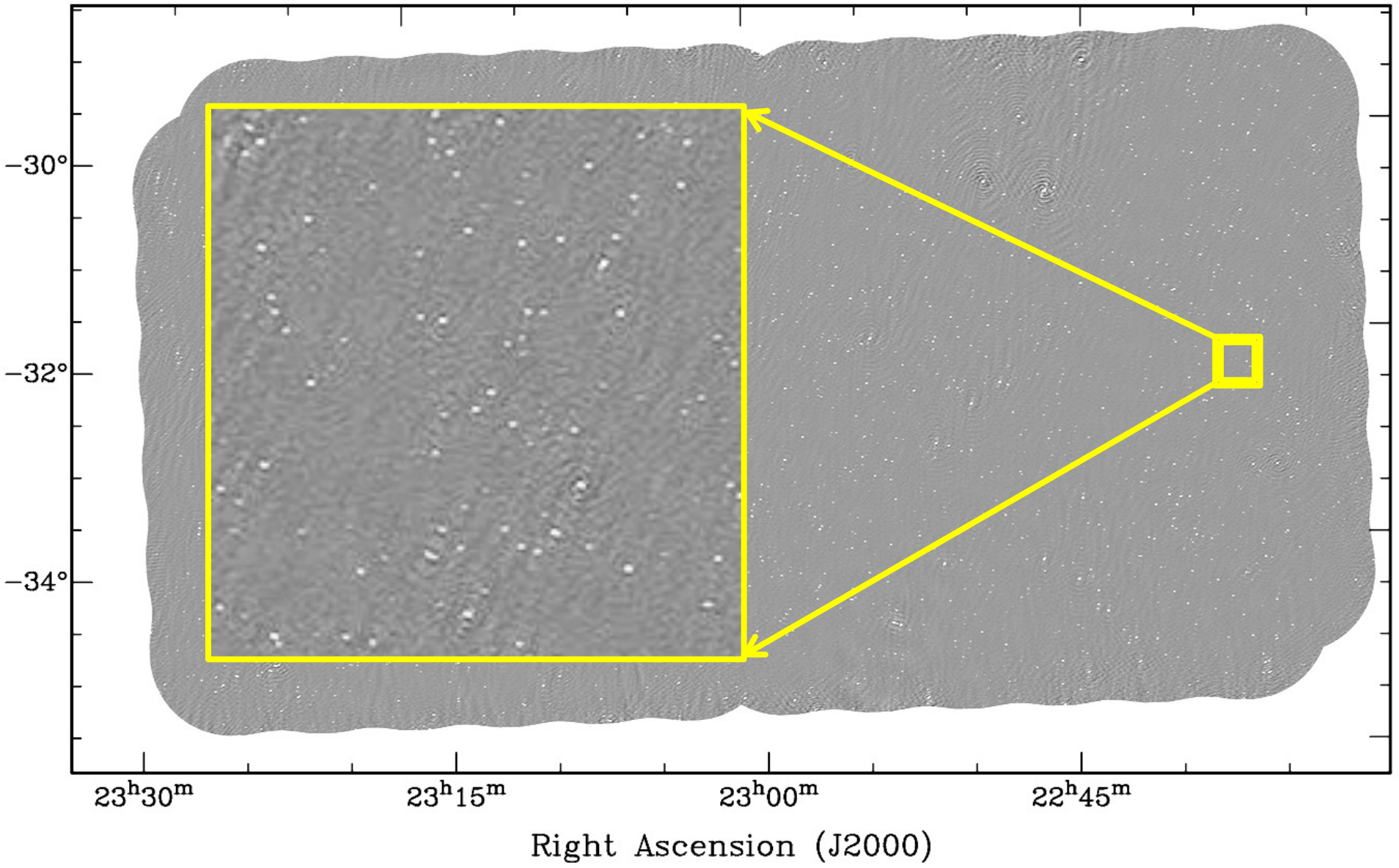
Don't need to know individual z's, just the z-distribution

BUT do need to ensure there is no overlap between samples

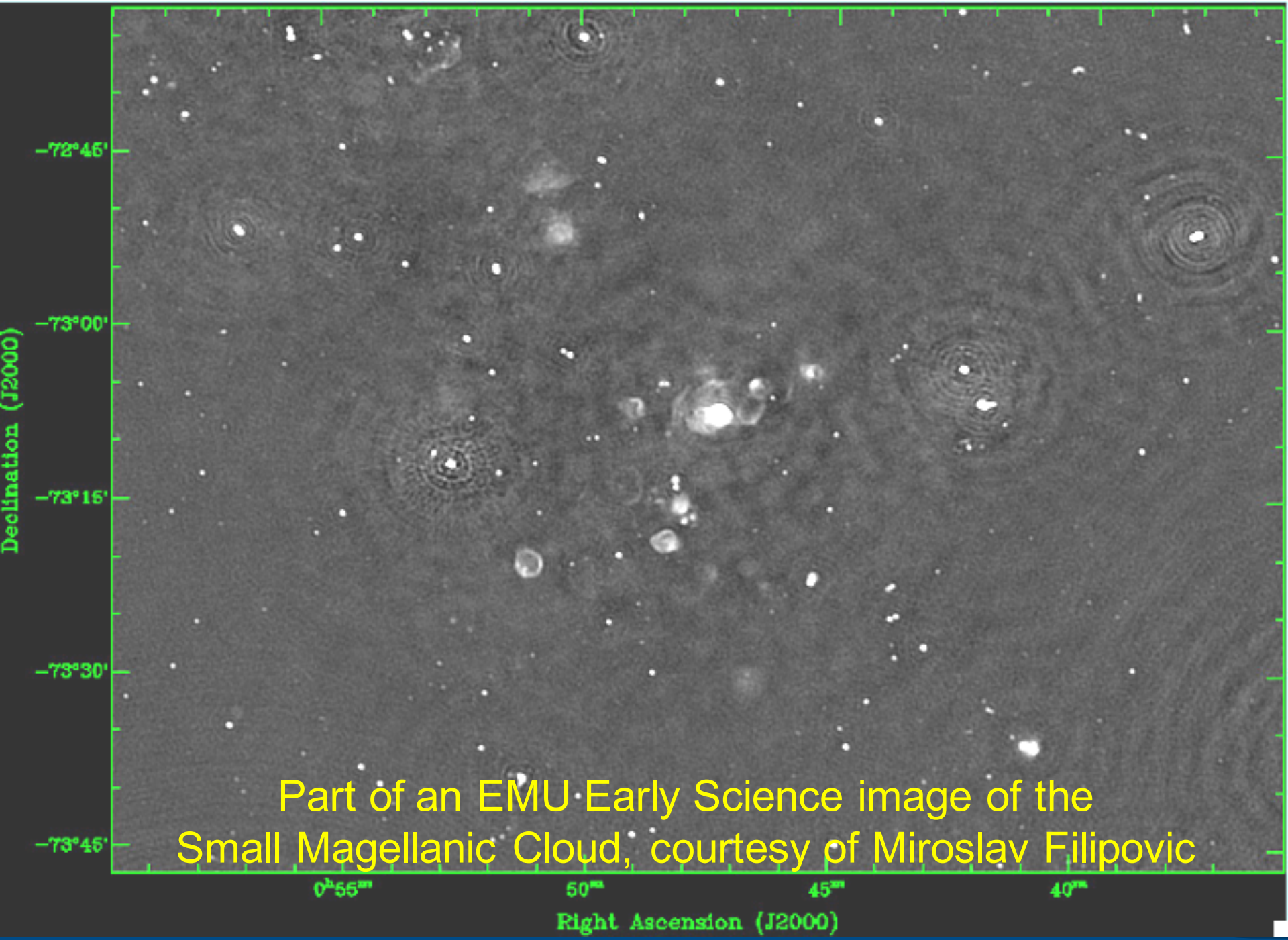
Autocorrelation function on our radio observations of the SPT field, from Glen Rees PhD thesis




ASKAP Early Science Cosmology Field
2000 square degree region
68 pointings (18 observed so far)
200 minutes per pointing
(image courtesy of David Parkinson)
-58°00'
-60°00'
-62°00'
-64°00'
-66°00'
Dec (J2000)
22h00m
40m
20m
21h00m
20h40m
RA (J2000)
0.003
0.002
0.001
0.000
Jy/beam

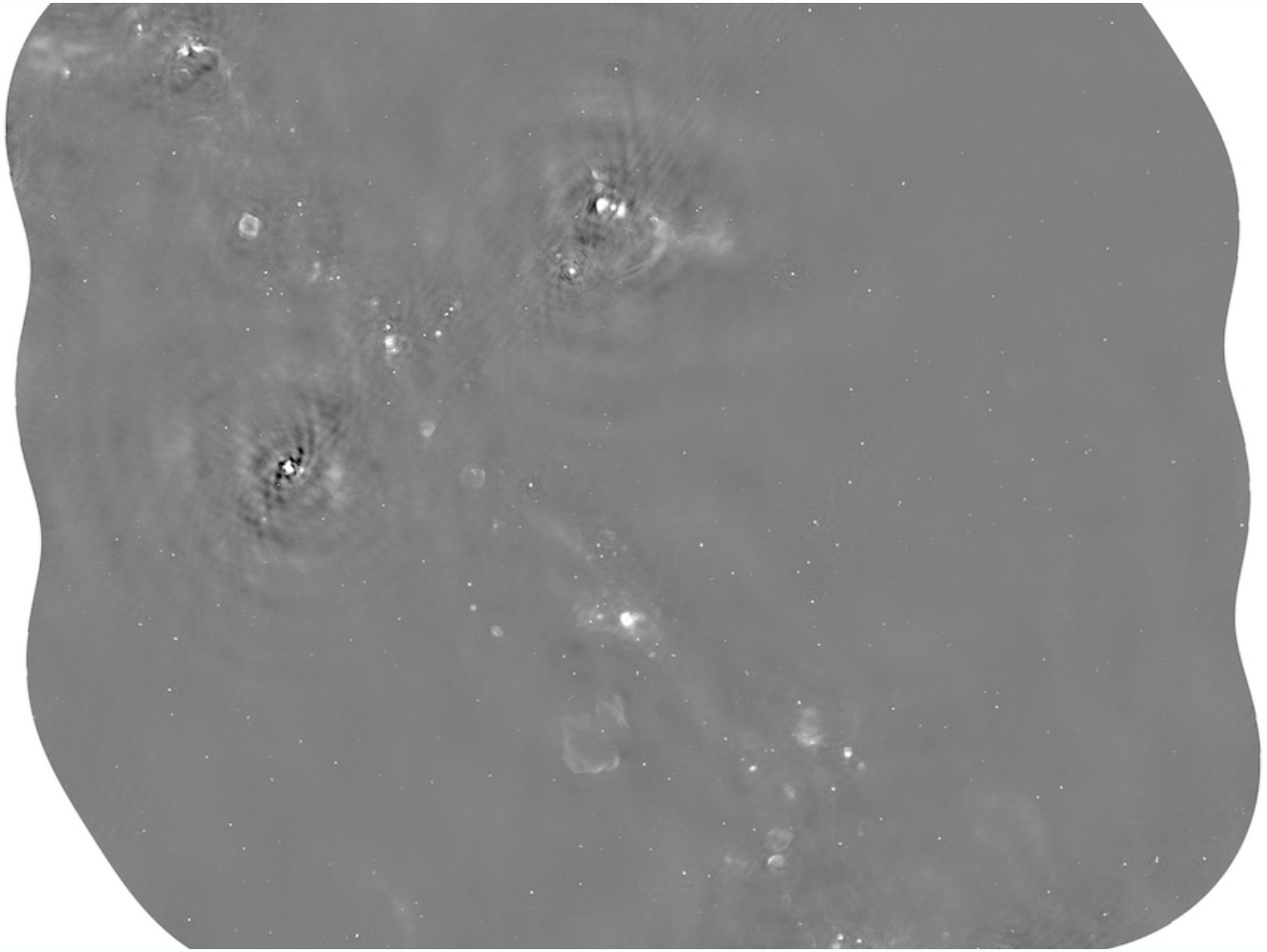


GAMA-23 field from EMU early science,
image courtesy of Isabella Prandoni



Part of an EMU Early Science image of the Small Magellanic Cloud, courtesy of Miroslav Filipovic

EMU will generate the deepest, highest resolution atlas yet of the Galactic Plane. Already we have discovered several new SNR, planetary nebulae, and radio stars

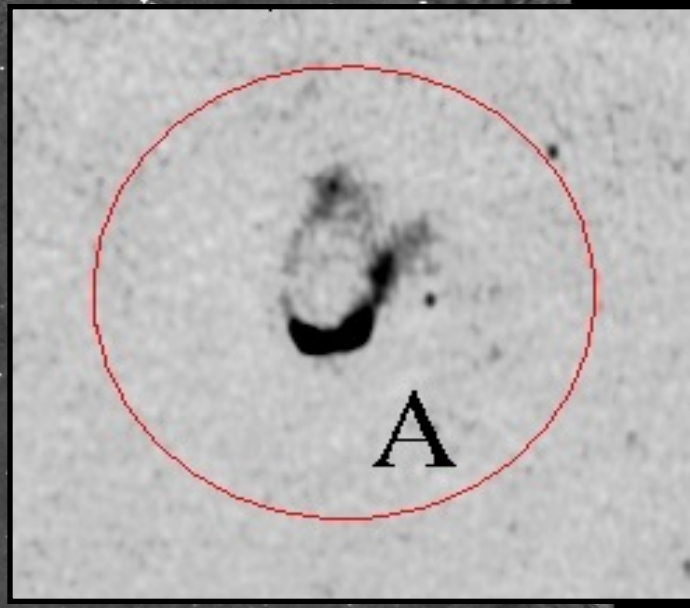


5 deg

EMU Early Science image of the SCORPIO region of the Galactic Plane, courtesy Francesco Cavallero

Currently surveying the South Pole Telescope field in ASKAP early science, to study radio emission from clusters.

Image courtesy Pero Manjolovich



EMU will generate a large catalog of clusters of galaxies:

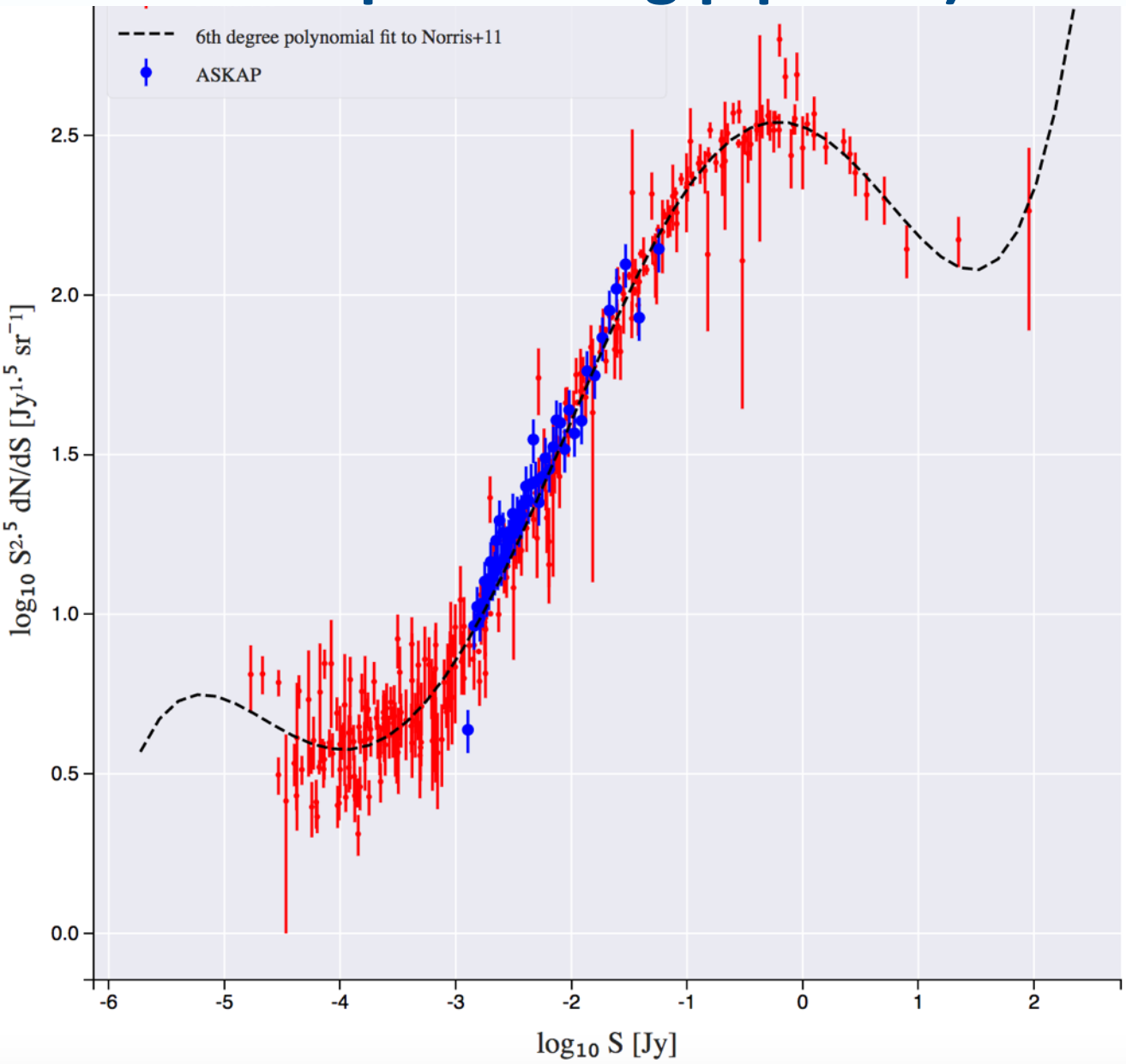
- **~100,000 clusters detected via tailed galaxies**
- **Thousands of radio haloes and relics**

EMU Development Projects

#	Description & link to wiki	Project Leader
DP1.	Ensure the CASDA database satisfies EMU's storage and access needs. This will include checking CASDA specs, and attending CASDA meetings.	
DP2.	Development, set up, and execution of the data quality/validation process	Jordan Collier
DP3.	Ensure ASKAPSOFT imaging satisfies EMU needs	Wasim Raja & Jordan Collier
DP4.	See what special imaging is needed for the Galactic Plane and diffuse sources, including addition of single-dish data, and coping with strong Galactic Plane emission	Simone Riggi & Francesco Cavallaro
DP6.	Development of algorithms for extraction of diffuse emission	
DP7.	Development of the self-ID and cross-ID algorithms	Ray Norris & Nick Seymour
DP10.	Redshifts	Ray Norris
DP11.	Machine Learning (a forum to promote interaction between ML projects and people.)	Ray Norris
DP13	Source classification (primarily AGN)	Larry Rudnick
DP14	Observing Strategy	Josh Marvil

Data Validation script, courtesy Jordan Collier (run at the end of the processing pipeline)

Source counts plots are generated automatically in the validation stage of the pipeline



EMU Development Project 7: Cross-identification and source classification

- Expert Manual Cross-ID: Jesse Swan et al.,
- Likelihood ratio: Stuart Weston et al.
- Citizen Science (Radio Galaxy Zoo): Ivy Wong et al.
- Bayesian: Fan and Budavari
- Several machine learning experiments:
  - Laurence Park,
  - Nathan Kayani,
  - Matthew Alger,
  - Gary Segal,
  - Tim Galvin

  (See Mlprojects.pbworks.com)

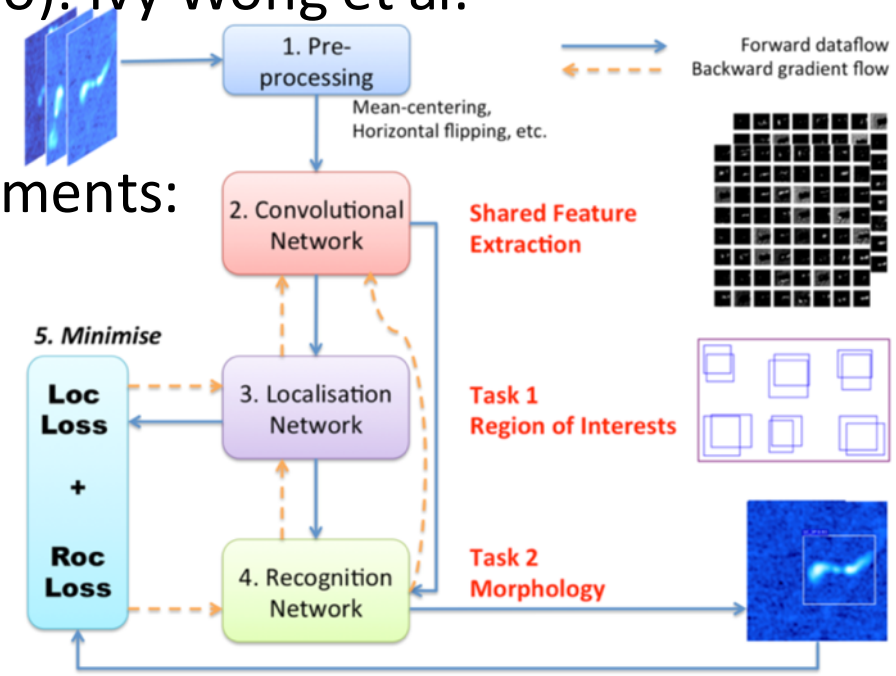
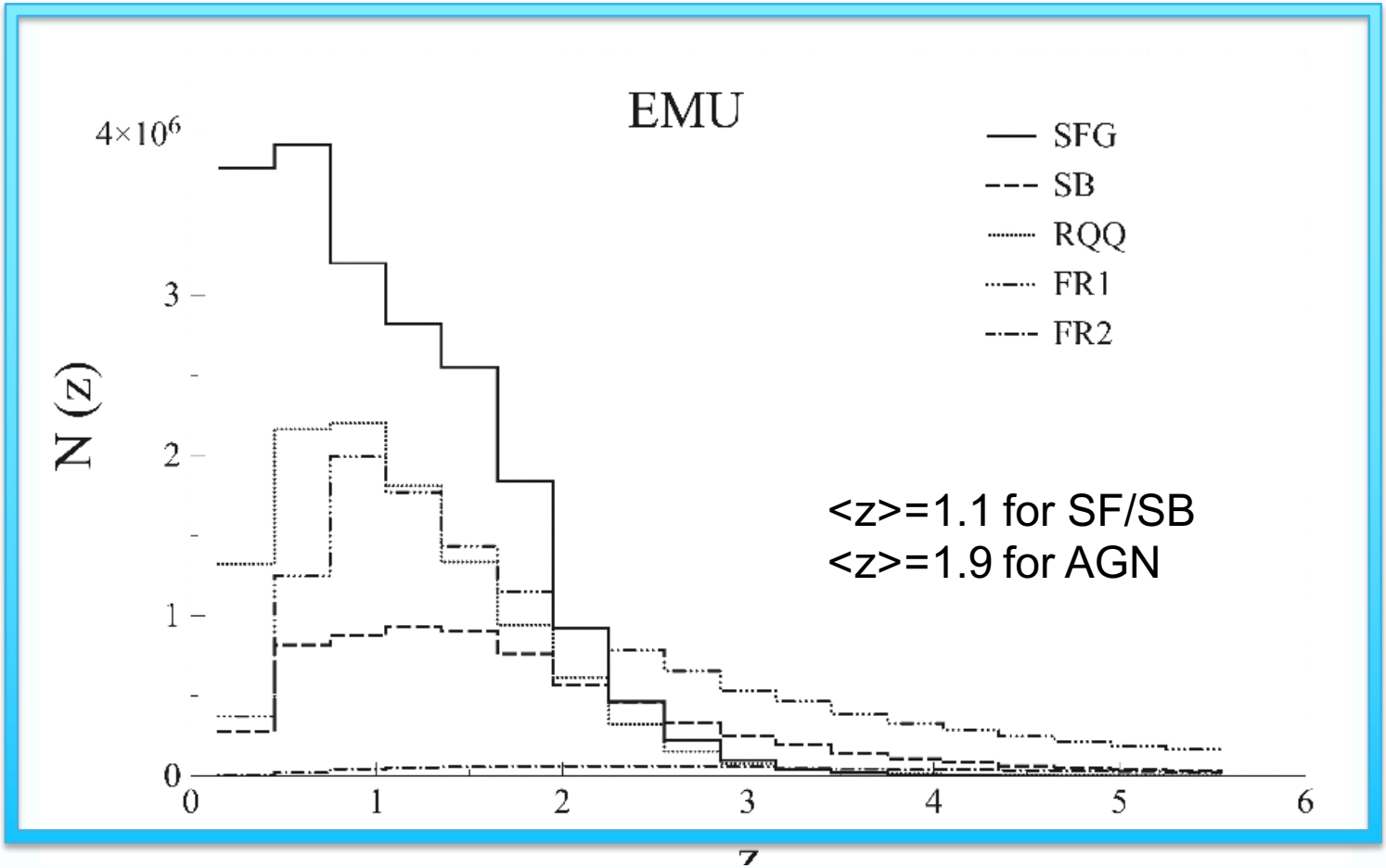


Diagram courtesy of Chen Wu

EMU Development Project 10: Redshifts

- About 2 million of our 70 million galaxies will have spectroscopic redshifts
- About 7 million will have good photometry (DES, SDSS, etc) enabling good photometric redshifts
- About 60% will have some photometry, (WISE, Skymapper, VHS)
- Most of our science goals don't need accurate redshifts – just redshift bins
- So we are exploring novel techniques for estimating "statistical redshifts"

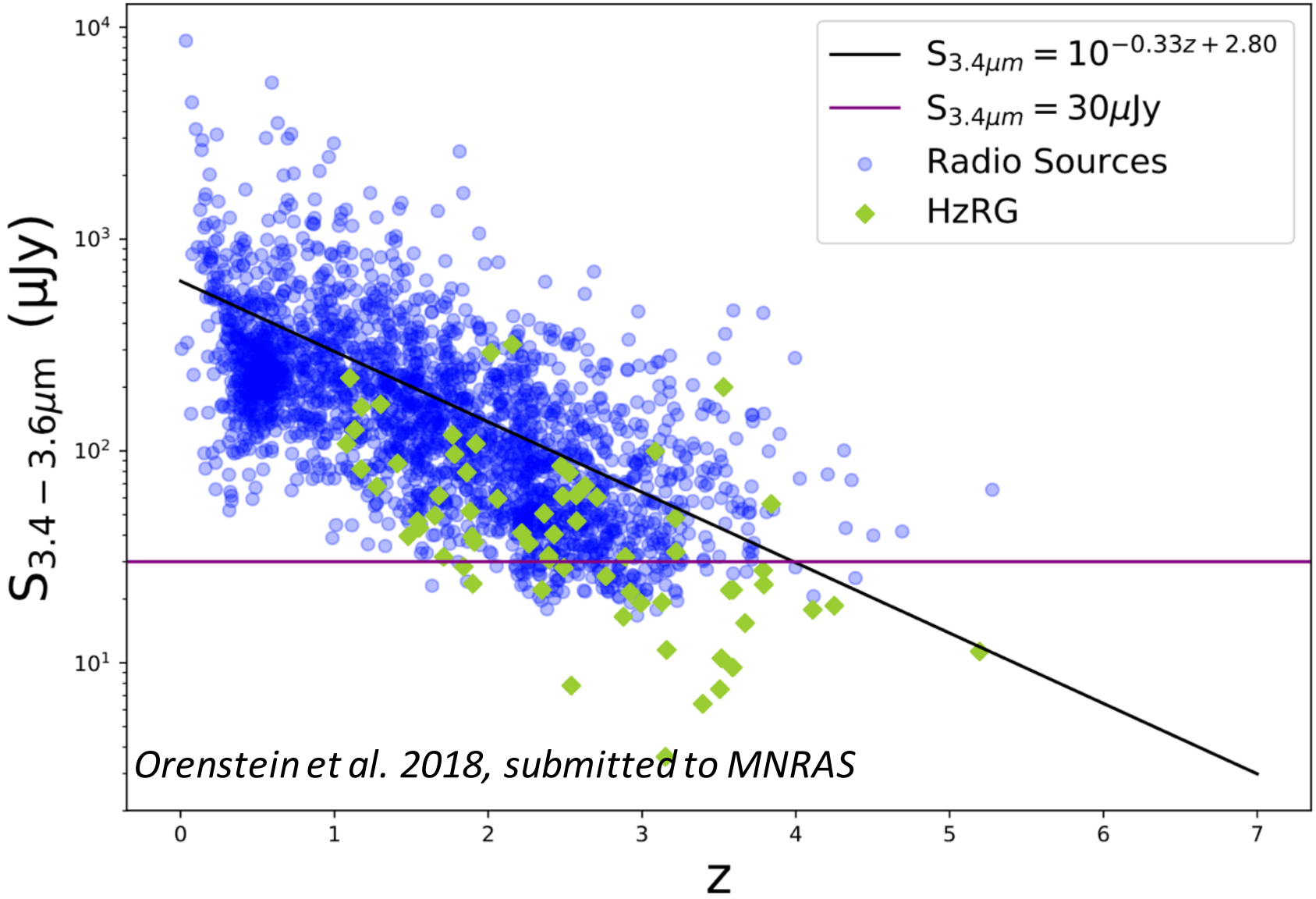
Redshift distribution of EMU sources



- EMU will increase the number of known radio-loud AGN from about 2.5 million to about 35 million
- It will measure the broad-band radio SED, identifying GPS and CSS
- It will cross-identify with IR/optical, producing catalogs of blazars and quasars

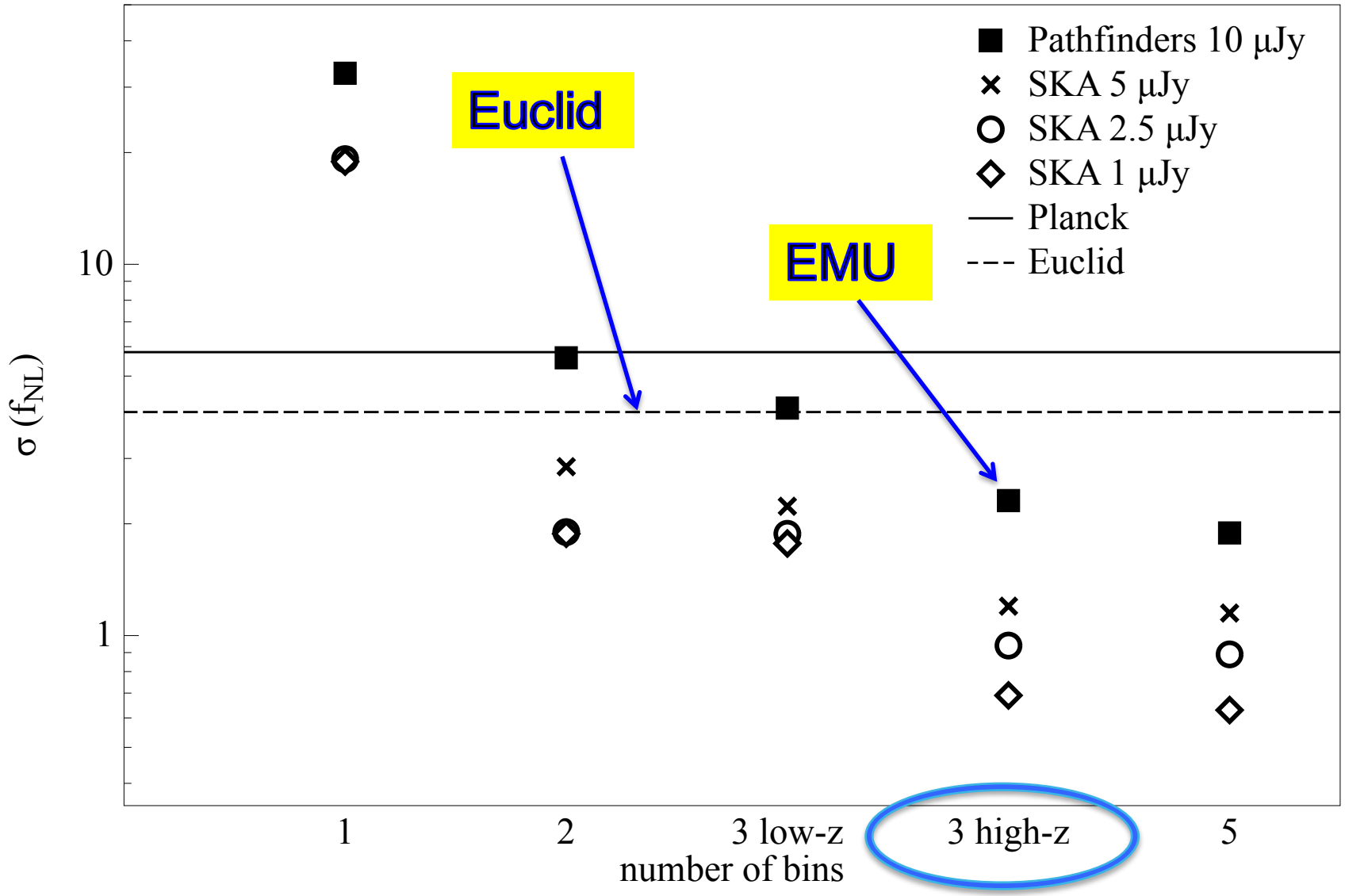
Infrared-faint radio sources

S(20cm) > 1 mJy & S(W1) < 30 uJy => z > 2



Non-gaussianity

Raccanelli et al., 2014, arXiv1406.0010



We acknowledge the Wajarri Yamaji people as the traditional owners of the ASKAP site

EMU is an open collaboration
Please see me if you would like to play a role
(Also mlprojects.pbworks.com discussion group for machine learning in astronomy)