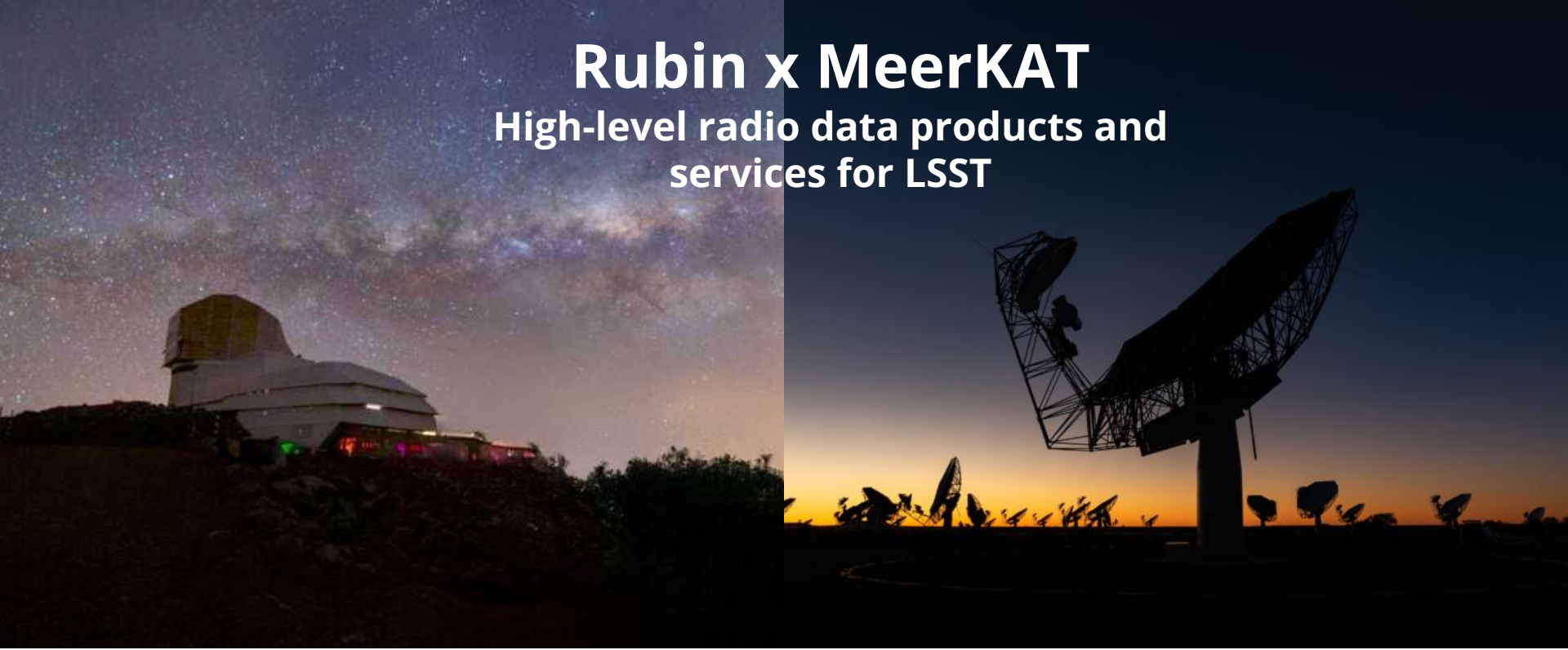


Rubin x MeerKAT

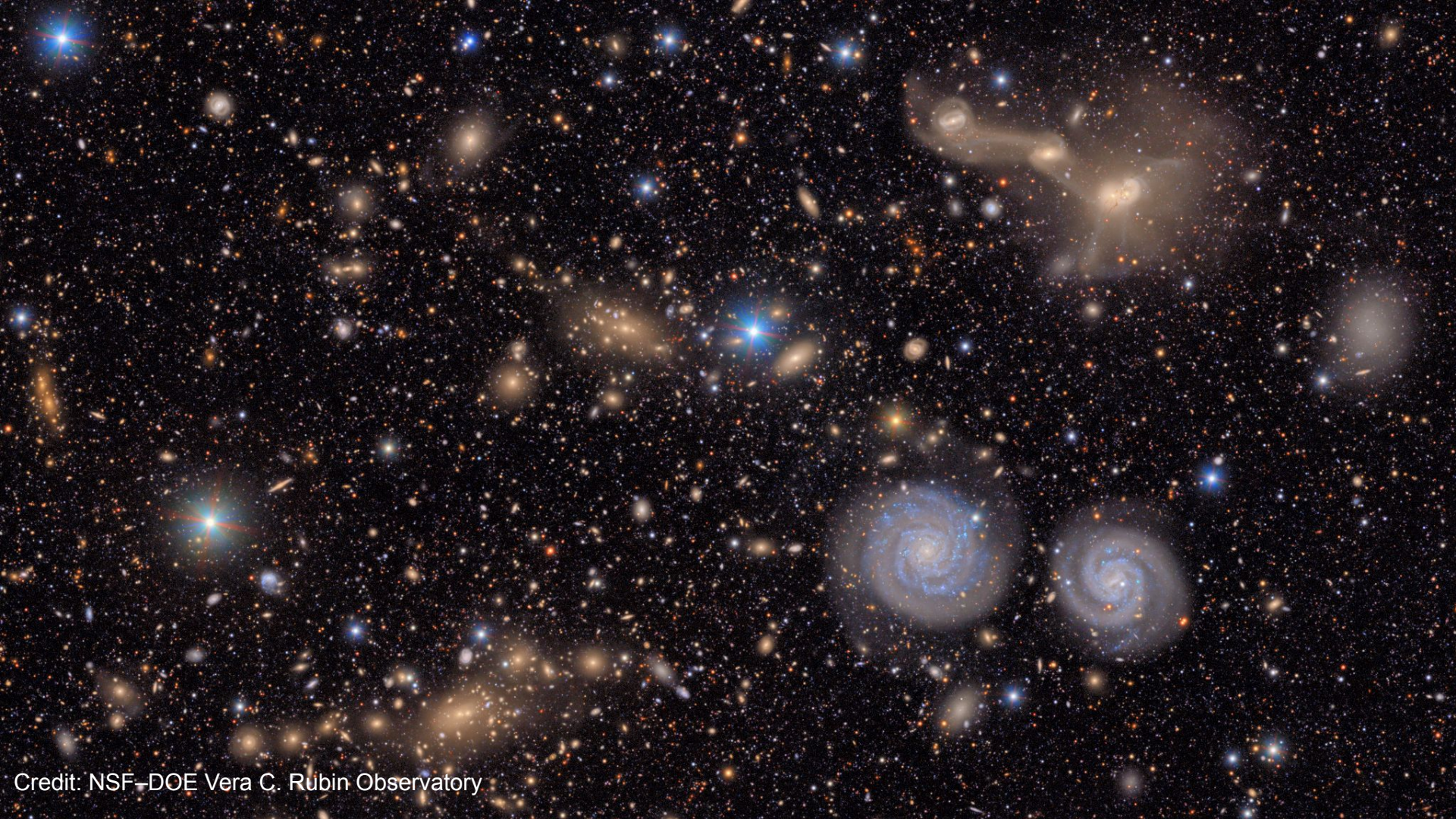
High-level radio data products and services for LSST

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Matt Hilton & Unnikrishnan Sureshkumar

University of the Witwatersrand, Johannesburg, South Africa

NRF National Research Foundation | SAAO South African Astronomical Observatory


Credit: NSF–DOE Vera C. Rubin Observatory

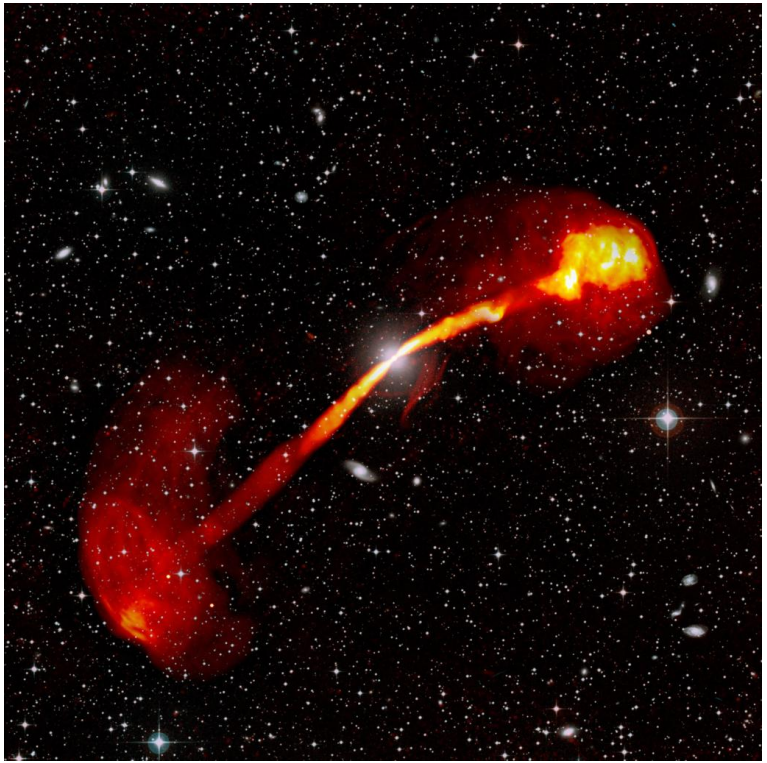
In-kind contribution to Rubin Observatory from South Africa

Project: MeerKAT high-level data products and services for Rubin LSST

PI: **Matt Hilton** (Wits University / University of KwaZulu-Natal)

Science with radio data

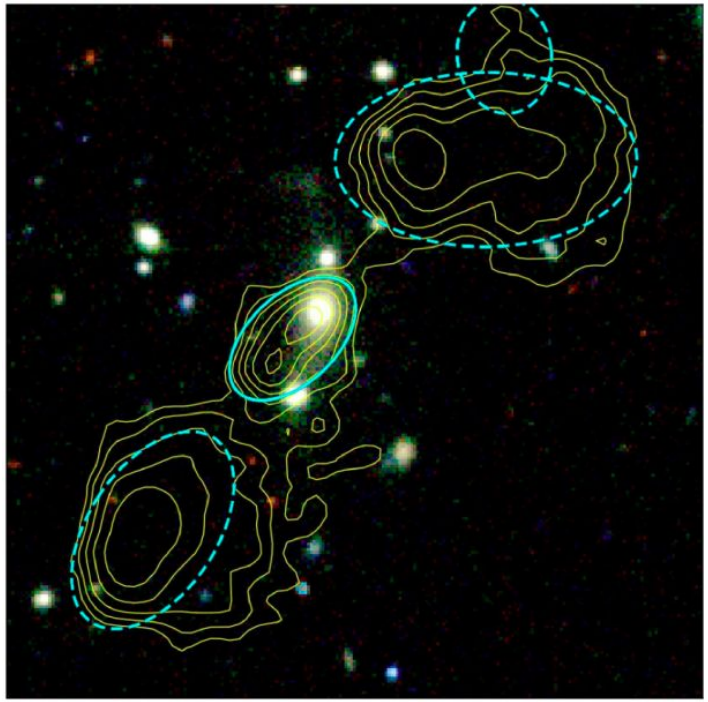
- **AGN activity**: radio galaxies, jets, and lobes
- **Dust-unbiased star formation rates :** synchrotron emission traces recent star formation that is unaffected by dust
- **Neutral hydrogen (21 cm)**:
  - Fuel for star formation (galaxy evolution)
  - Mapping the matter distribution in the large-scale structure (cosmology)
- **Radio halos/relics in clusters**
- **Magnetic field and polarisation**



IC 4296; Condon et al. 2021

Why combine radio and optical data?

- Host galaxy position and morphology
- Redshift information
  - Radio luminosities
  - Star formation rates
  - Radio luminosity functions
  - Environment of radio sources
- Link between AGN activity and host galaxy properties
- Large-scale structure and cosmology
- Transients and variable sources



Kaur and Bari, 2022

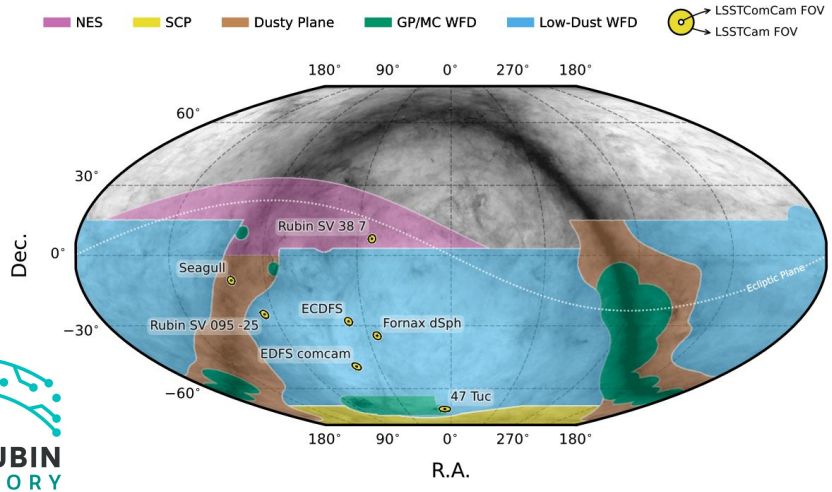
MeerKAT Telescope

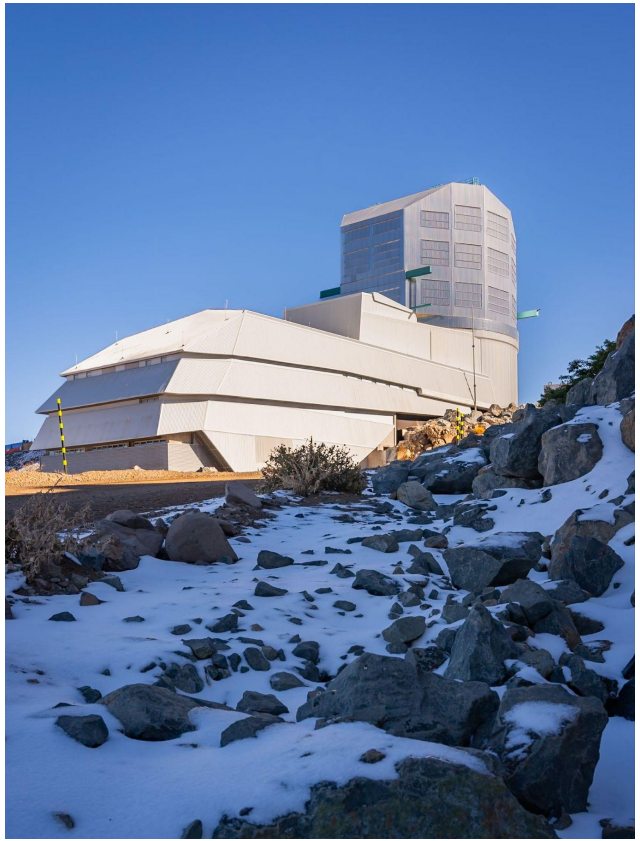
Source: NordNordWestderivative work by HtonI

- Precursor to the Square Kilometre Array (SKA) Mid
- Karoo Desert in South Africa
- 64 x 13.5 m dishes
- Three frequency bands:
  - 580 - 1015 MHz (UHF-band)
  - 900 - 1670 MHz (L-band)
  - 1750 - 3500 MHz (S-band)
- Maximum baseline: ~8 km ⇒ 6" resolution at 1.3 GHz

Rubin Observatory Legacy Survey of Space and Time

- Cerro Pachón in Chile
- Ten years of operation using the 8.4 m Simonyi Survey Telescope
- Southern sky - overlapping with MeerKAT
- Field of view: 3.5 deg (9.6 deg^2)
- Sky coverage ~ 18, 000 deg^2
- Resolution: 3.2 Gpixels - 0.2 arcsec/pixel





Credit:RubinObs/NOIRLab/SLAC/NSF/DOE/AURA/A. Pizarro D.

The `Berk` package

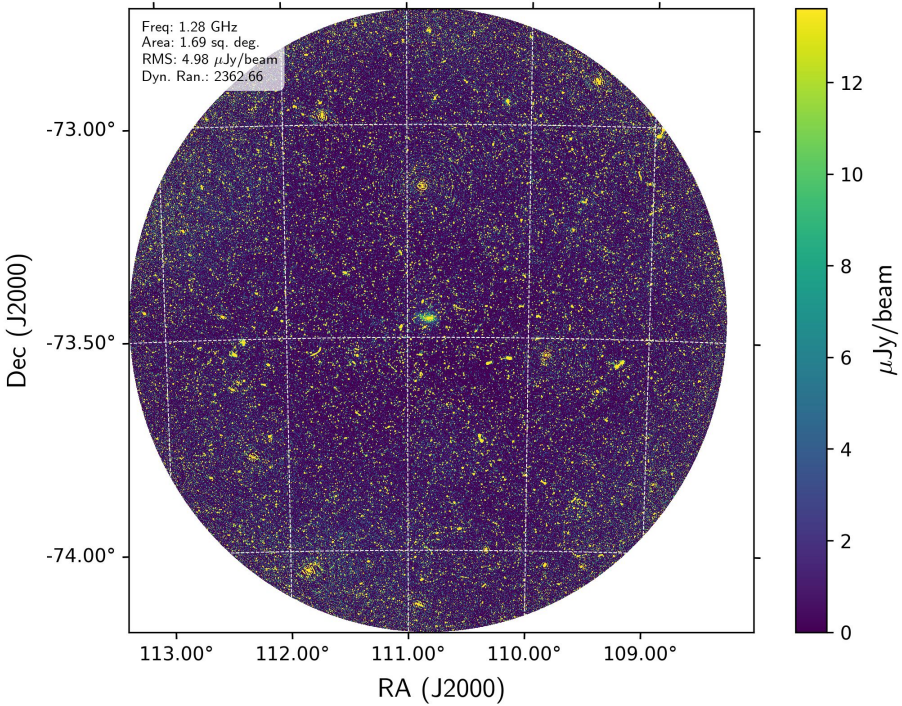
- A package for producing and managing MeerKAT continuum survey data
- MeerKAT data processing:
  - MeerKAT data gets public typically after 12 months
  - Retrieval from SARAO public archive
  - Pipeline based mostly on **`oxkat`** (Credits: Ian Heywood; https://github.com/IanHeywood/oxkat)
  - Softwares used: **`CASA, CubiCal, DDFacet, killMS, tricolour, wsclean`**
  - Produce continuum images
  - Extract sources using PyBDSF.
- Association with optical data:
  - Cross matching methods
  - Currently cross-matching with DECaLS DR10.
- Currently designed to work at the CHPC (SA)

The `Berk` package

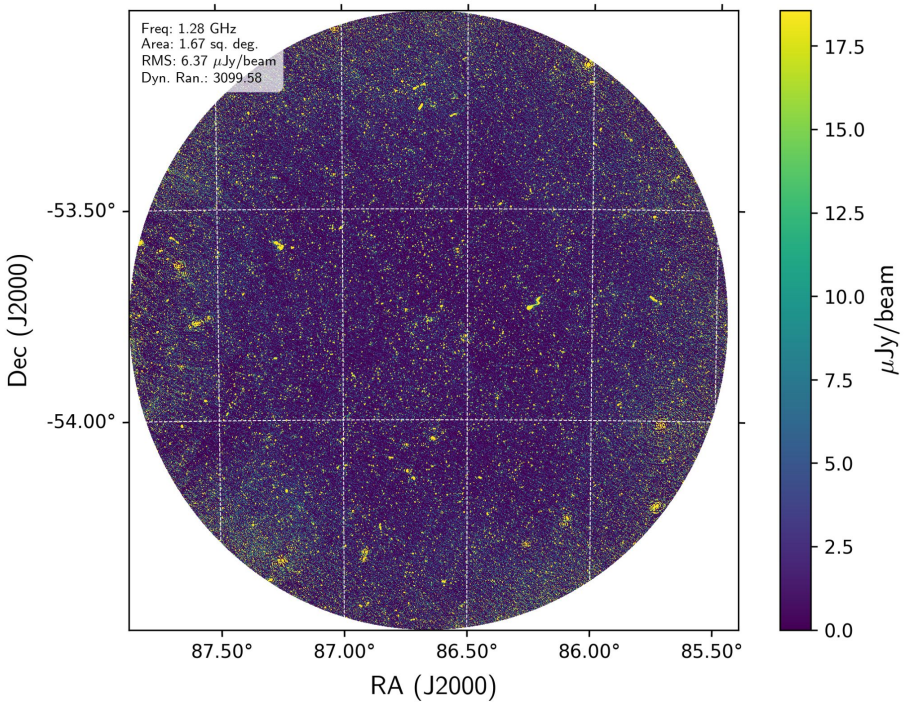
- **`fetch`** - uses **katdal** to download the full MS from the SARAO archive
- **`setup`** - prepares the data for processing
- **`process1`** - Averages down the MS to 1024 channels and performs first-generation calibration (1GC)
- **`process2`** - Flagging and second-generation calibration (2GC): direction-independent self-calibration.
- **`analyze`** - Runs **PyBDSF** to extract sources
- **`xmatch`** - applies likelihood-ratio cross-matching with optical catalogues - currently designed for DECaLS DR10.

Examples of MeerKAT continuum images

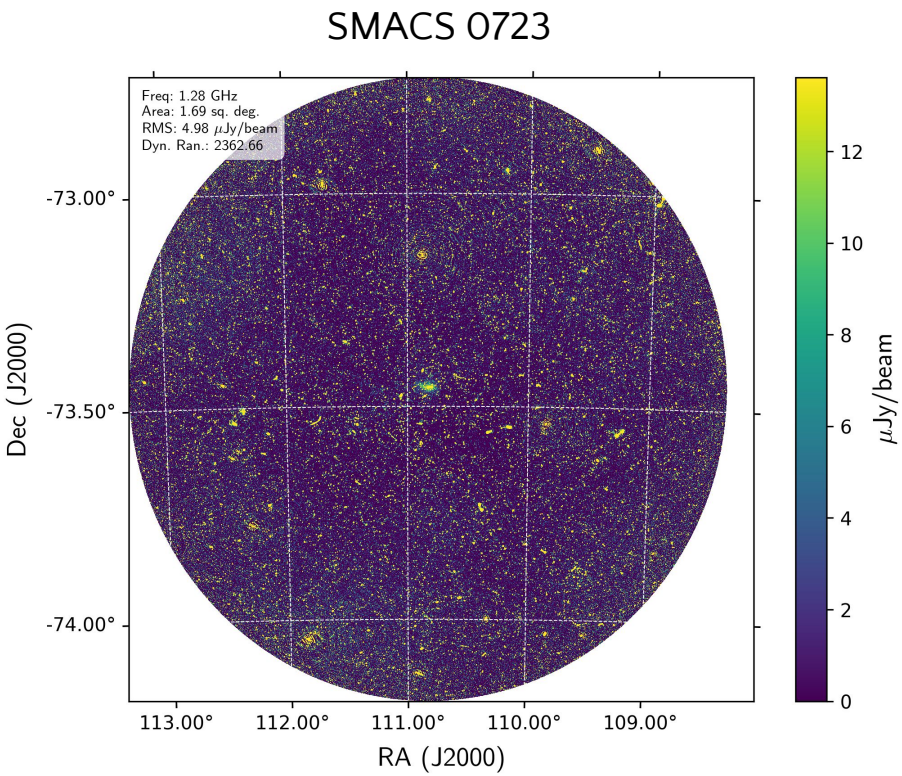
SMACS 0723

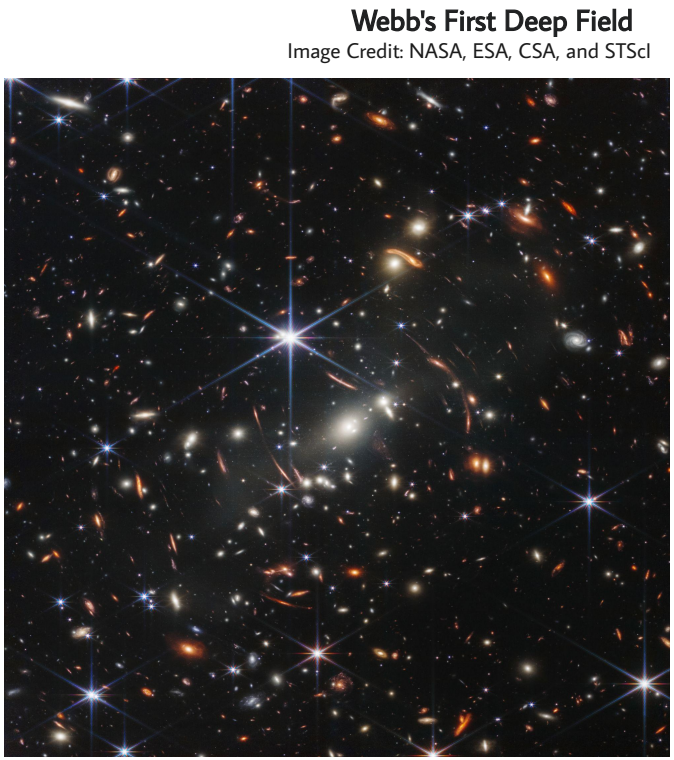


J0546.6-5345



Examples of MeerKAT continuum images



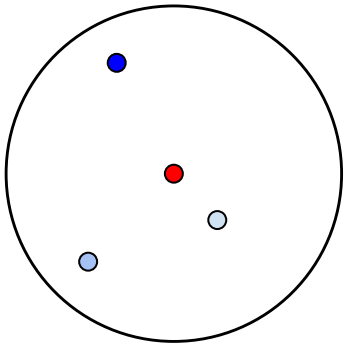


Cross-matching using Likelihood ratio method

For a given radio-optical pair, the likelihood ratio is the ratio of probability that the optical source is the true counterpart, to the probability that it is a random association.

Distribution of the positional offset between the radio source and candidate counterpart

expected magnitude distribution of true counterparts

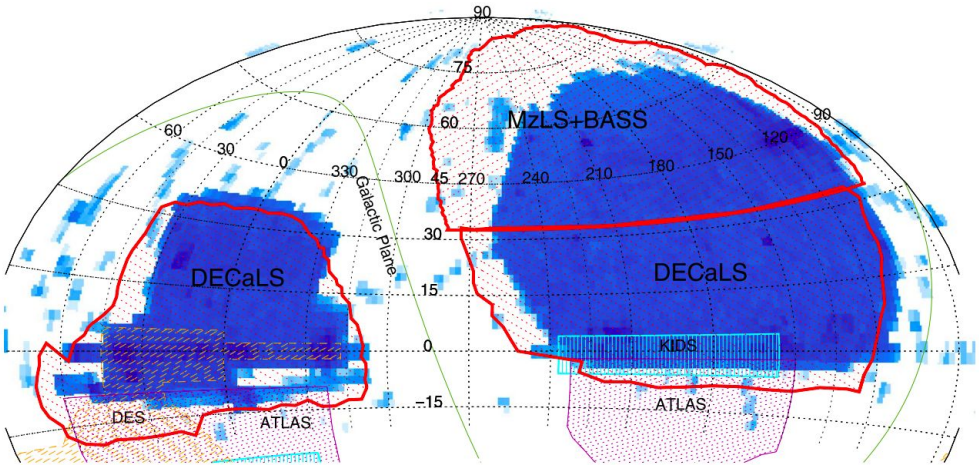


$$LR = \frac{f(r)\, q(m)}{n(m)}$$

surface density of all objects in the field as a function of magnitude *m*

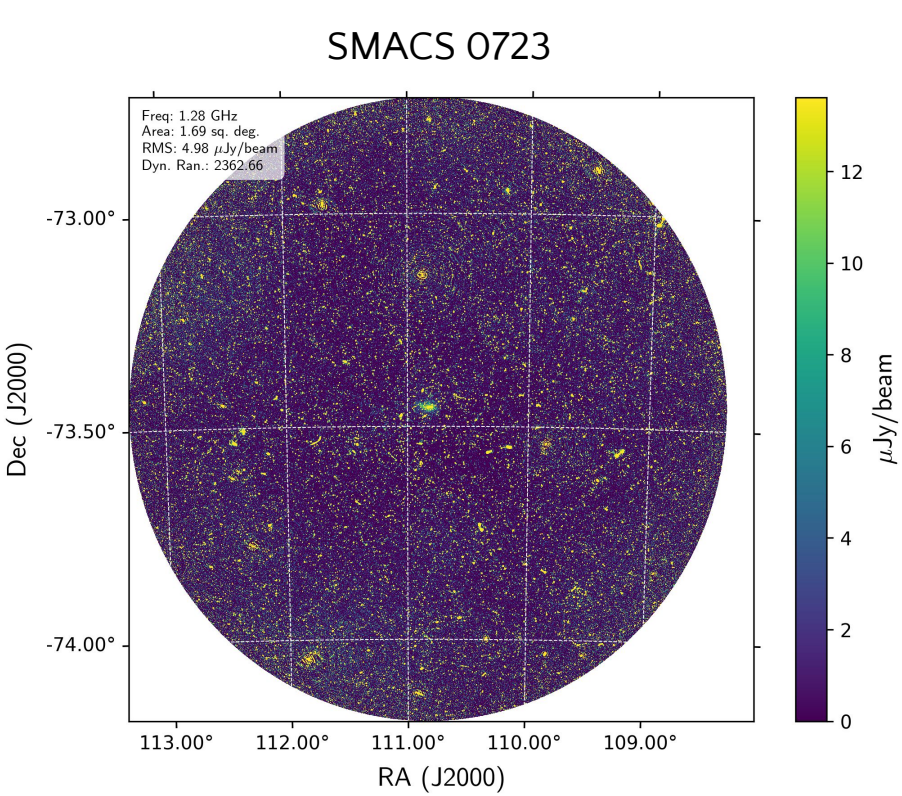
Optical cross-matching with DECaLS

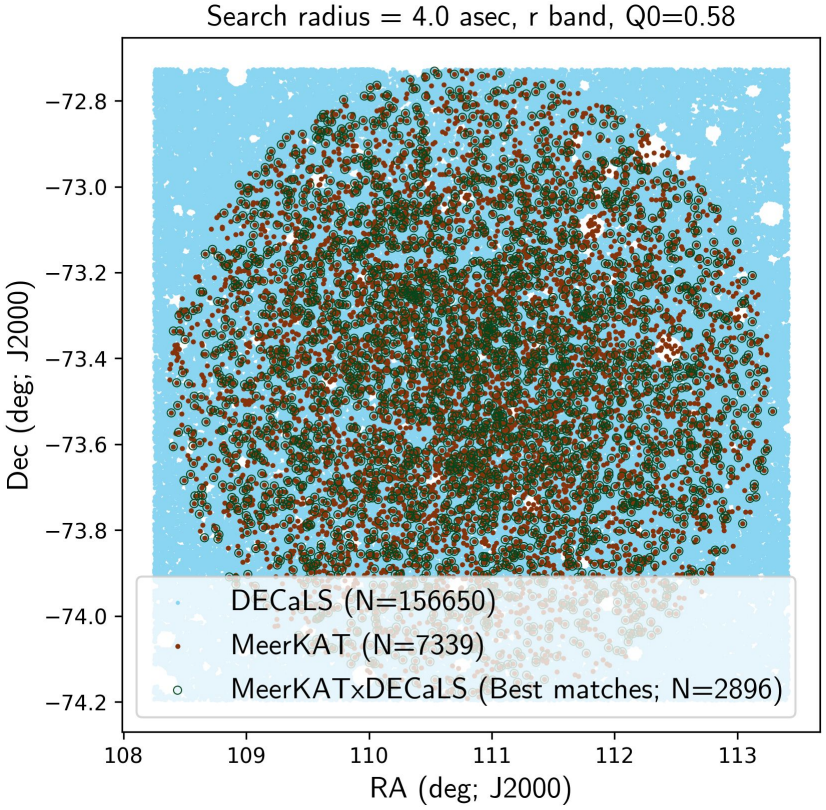
- Survey using the Dark Energy Camera (DECam) on the 4-m Blanco Telescope at Cerro Tololo Inter-American Observatory (CTIO) in Chile.
- Part of the DESI Legacy Imaging Surveys.
- Covers over 9000 sq. deg. of the southern sky.
- Available bands in **DECaLS DR10**: *g, r, i, z, W1, W2*



Dey et al. 2019

Optical cross-matching with DECaLS





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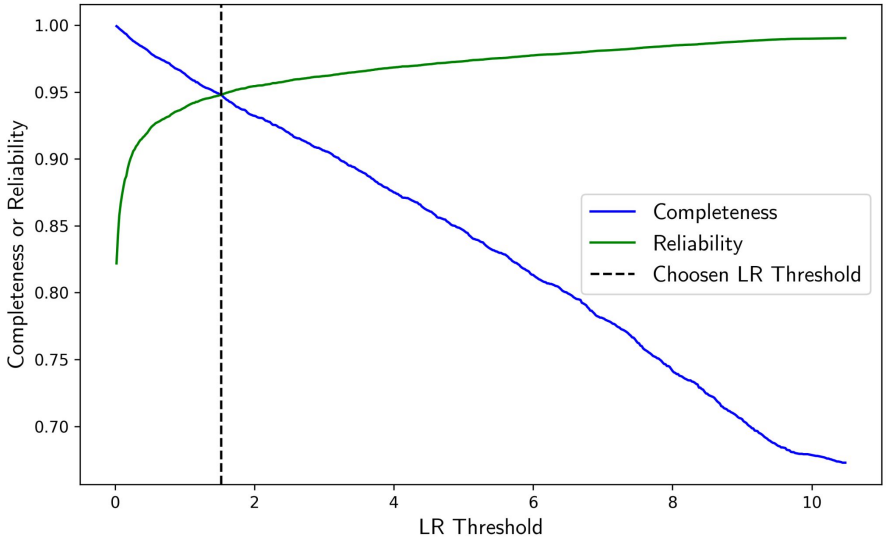
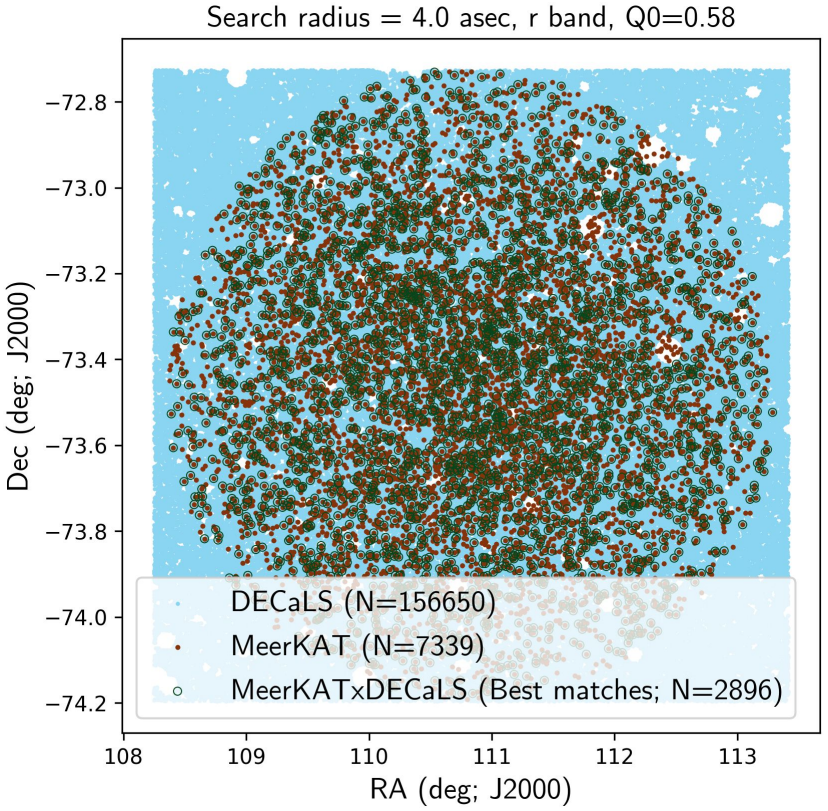
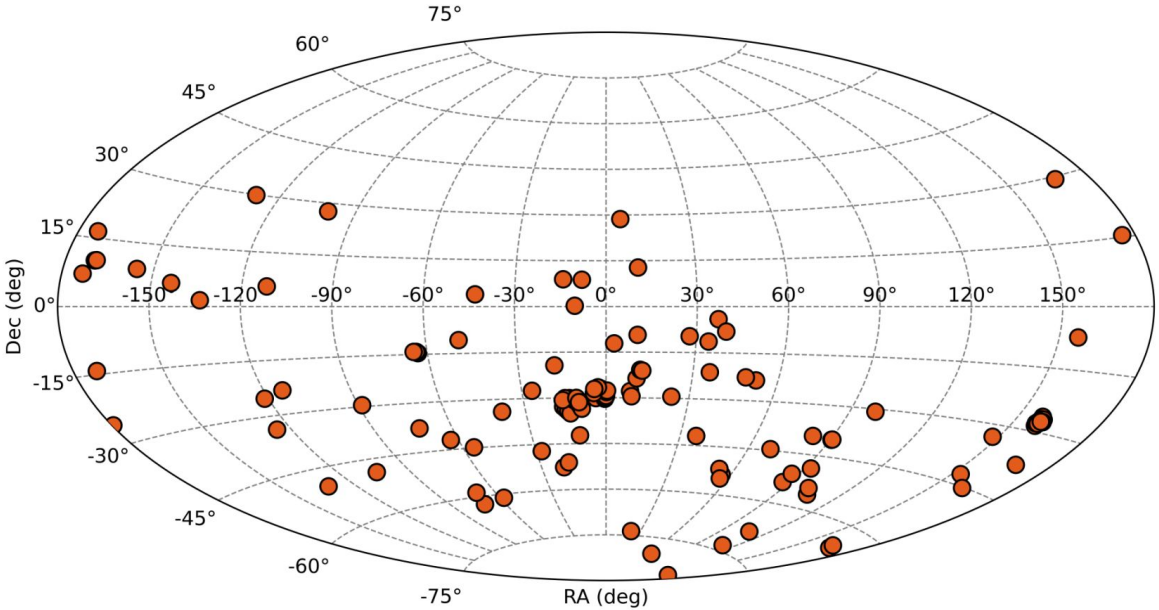




Early Data Release

- Purpose:
  - initial test release for the Rubin LSST community
  - figure out interfacing with Rubin Science Platform
  - simple science demonstration
- Properties:
  - 141 L-band observations
  - 228 square degrees
  - ~300k radio sources
  - ~93k cross-matched optical sources



Preliminary - Sureshkumar et al. (in prep.)

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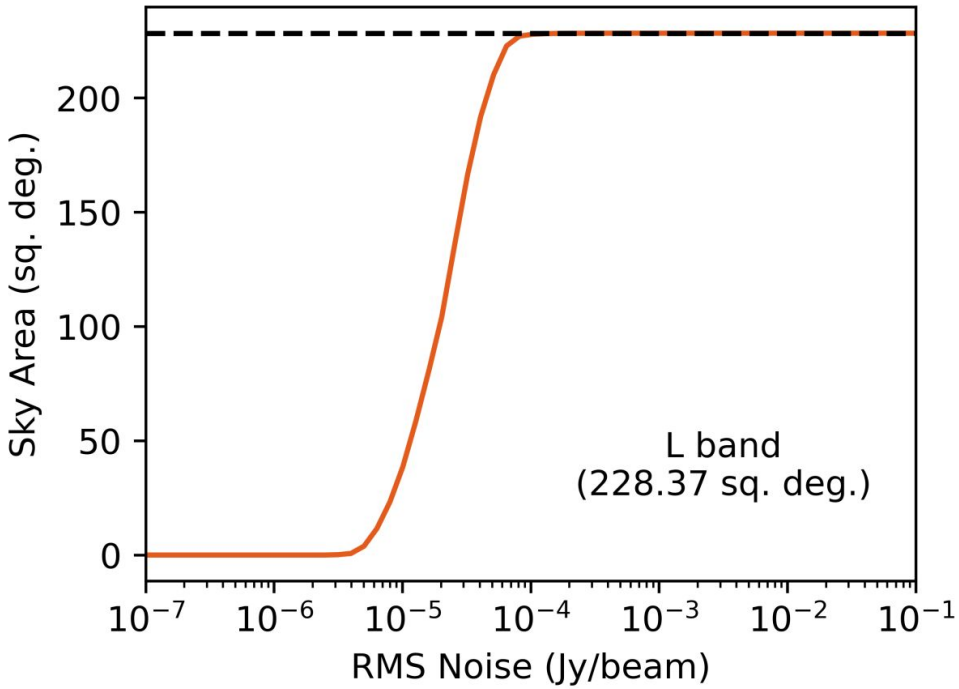

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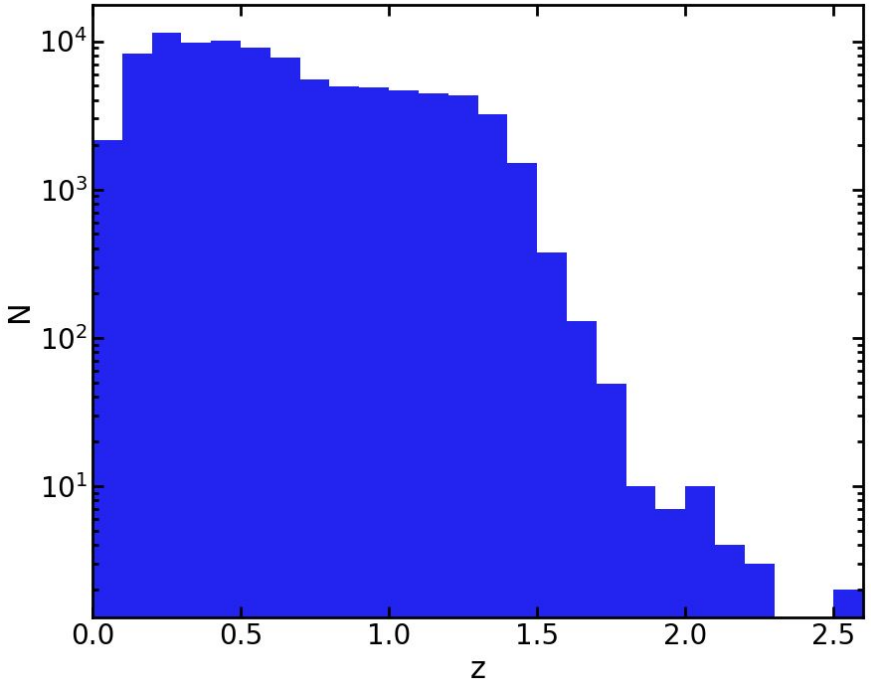
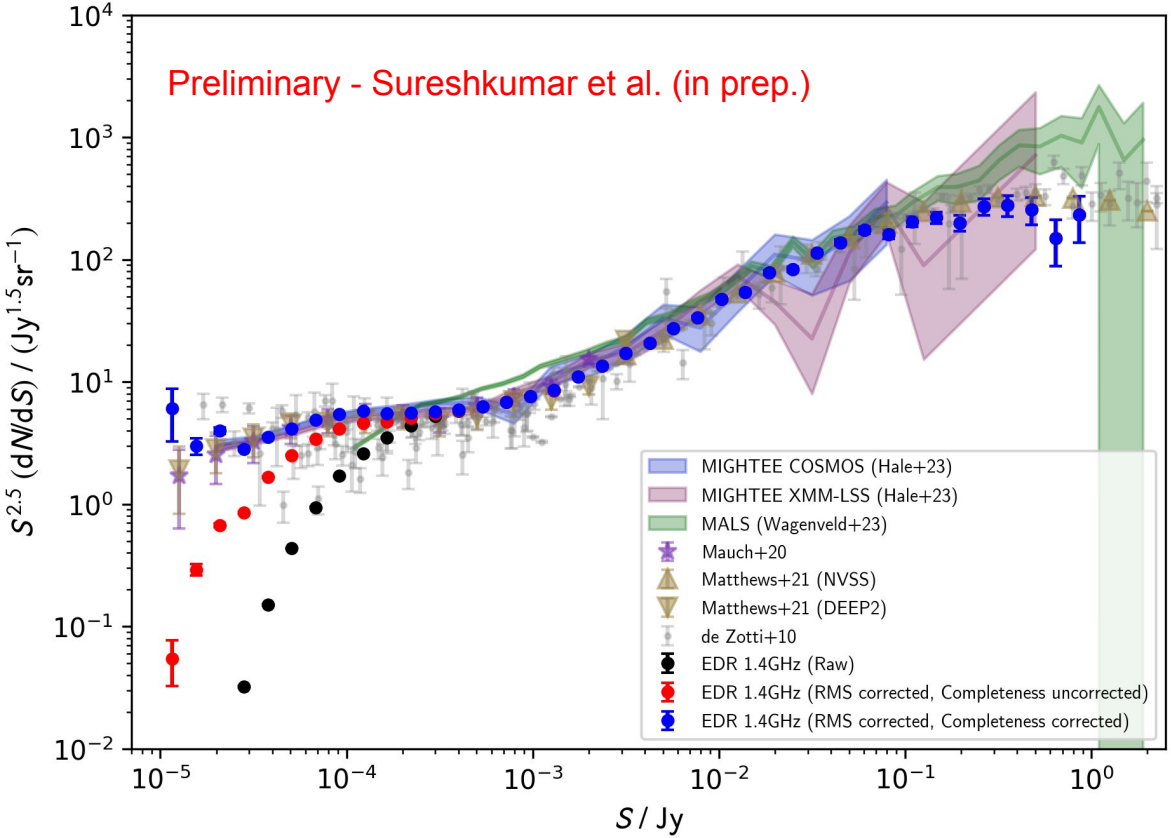


Preliminary - Sureshkumar et al. (in prep.)

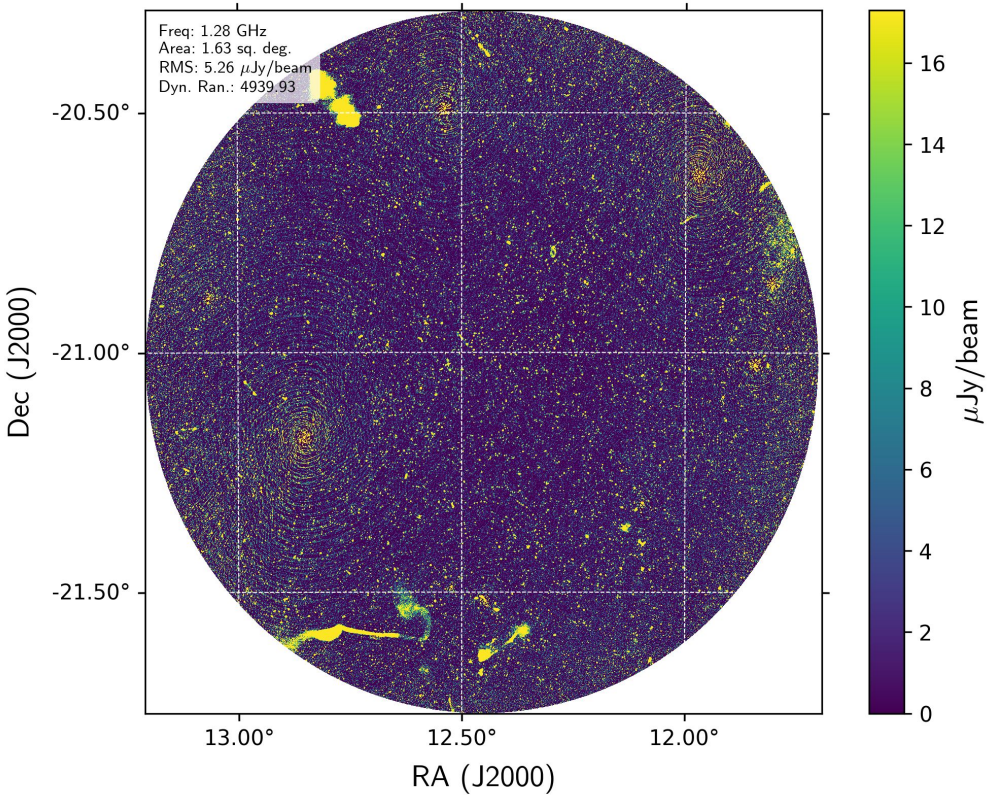
Radio source counts

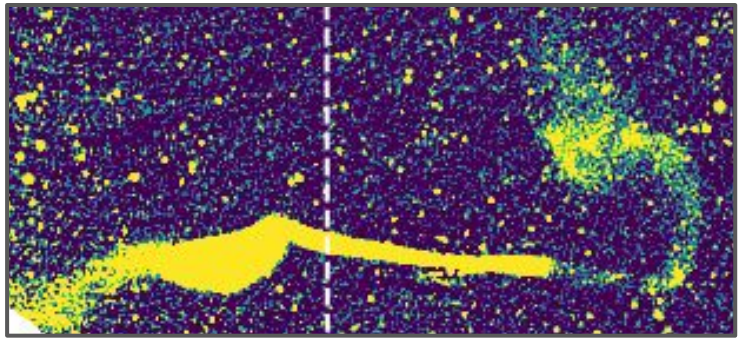
Source counts quantify the number of radio sources per unit flux density and per unit sky area.

We are working on a measurement of the radio luminosity function from the ~93k sources cross-matched with DECaLS DR10



Scope for serendipitous discoveries





Z-shaped source (~1 Mpc size)

Potential to study the environmental effects on such unusually shaped radio sources

Summary

- An in-kind contribution to cross-correlate public MeerKAT data with Rubin Observatory LSST
- MeerKAT continuum images and catalogs, overlays of MeerKAT onto LSST images, cross-matching tools, and associated notebooks will be integrated into the Rubin Science Platform
- Working on an Early Data Release (228 sq. deg) and associated paper describing work to date
- Example science cases with the resulting catalogue include dust-unobscured SFRs, AGN identification, diffuse emission in clusters, radio luminosity function and clustering of radio sources, discovery of unusually shaped sources, etc.
- Please get in touch with us if you are interested!

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ukp1513@gmail.com