

Updates from the MeerKAT Large Area Synoptic Survey (MeerKLASS)

Piyanat (Boom) Kittiwisit
On behalf of the MeerKLASS Collaboration

University of the Western Cape & South African Radio
Astronomy Observatory, Cape Town, South Africa



UNIVERSITY of the
WESTERN CAPE



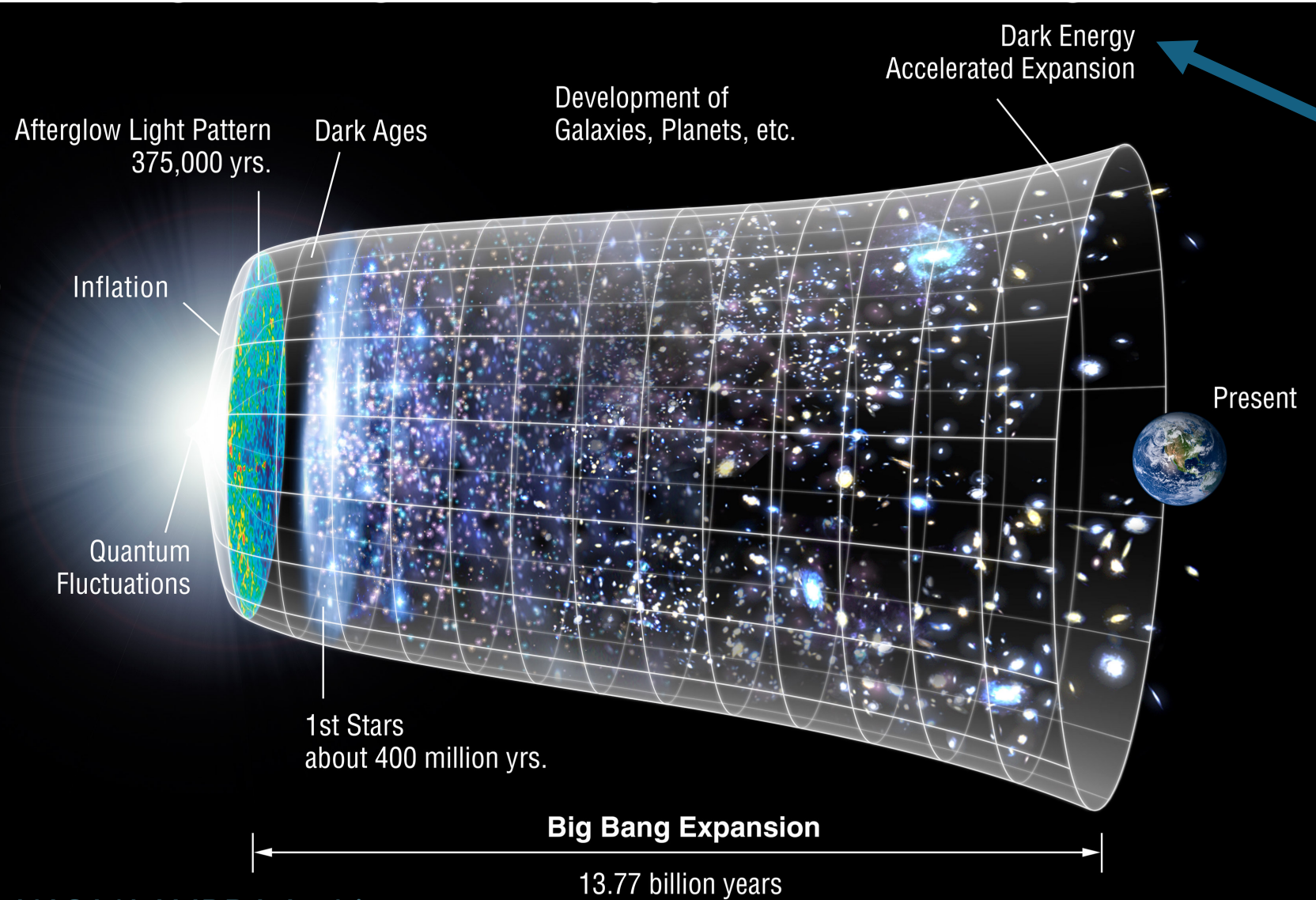
Centre for Radio Cosmology

Cosmology in the Alps 2026



SARAO
South African Radio
Astronomy Observatory

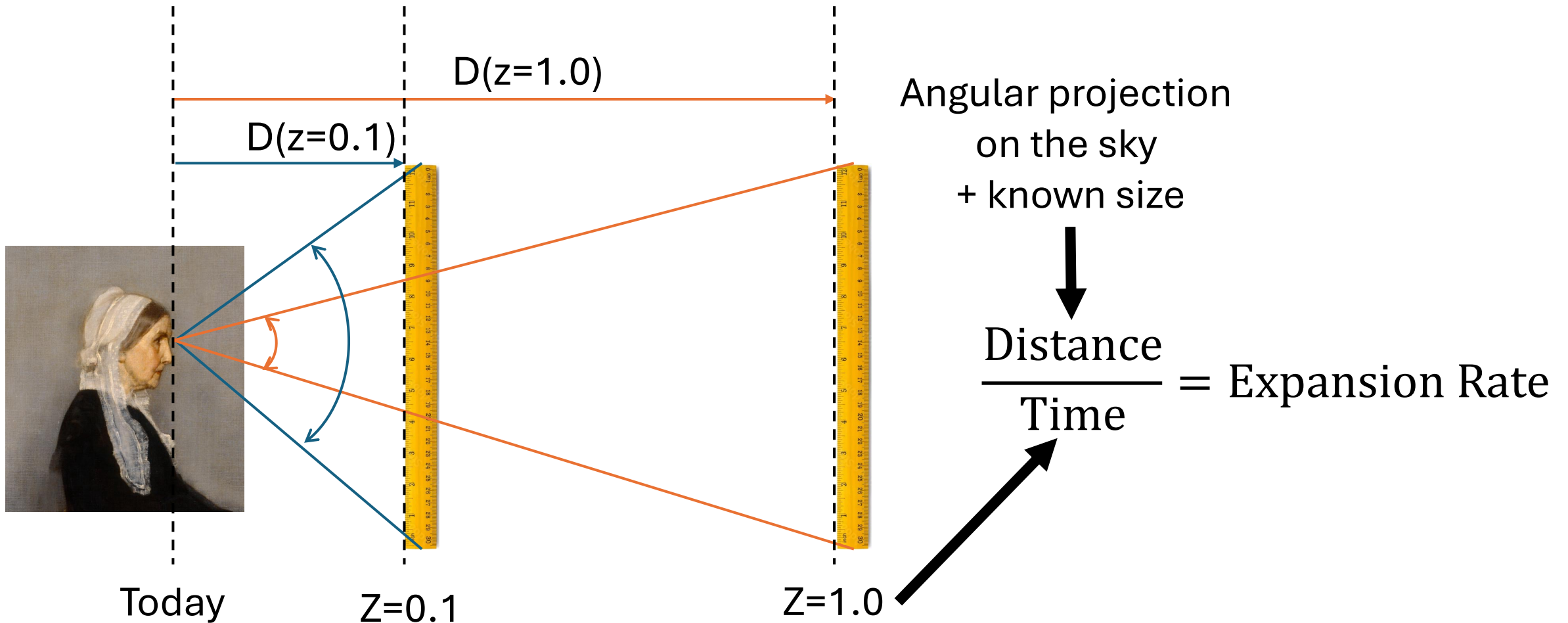
The Expansion History of the Universe



What is dark energy?

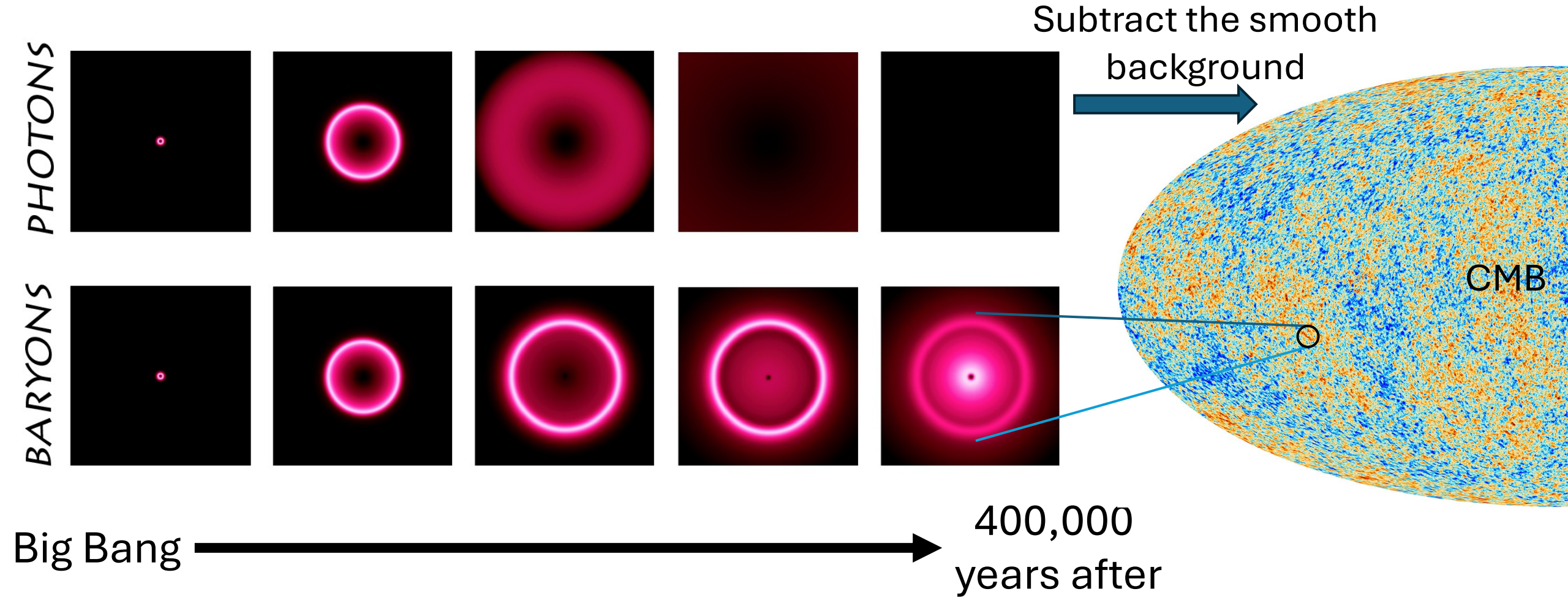
Measure the
expansion rate

Measure the expansion rate with a standard ruler

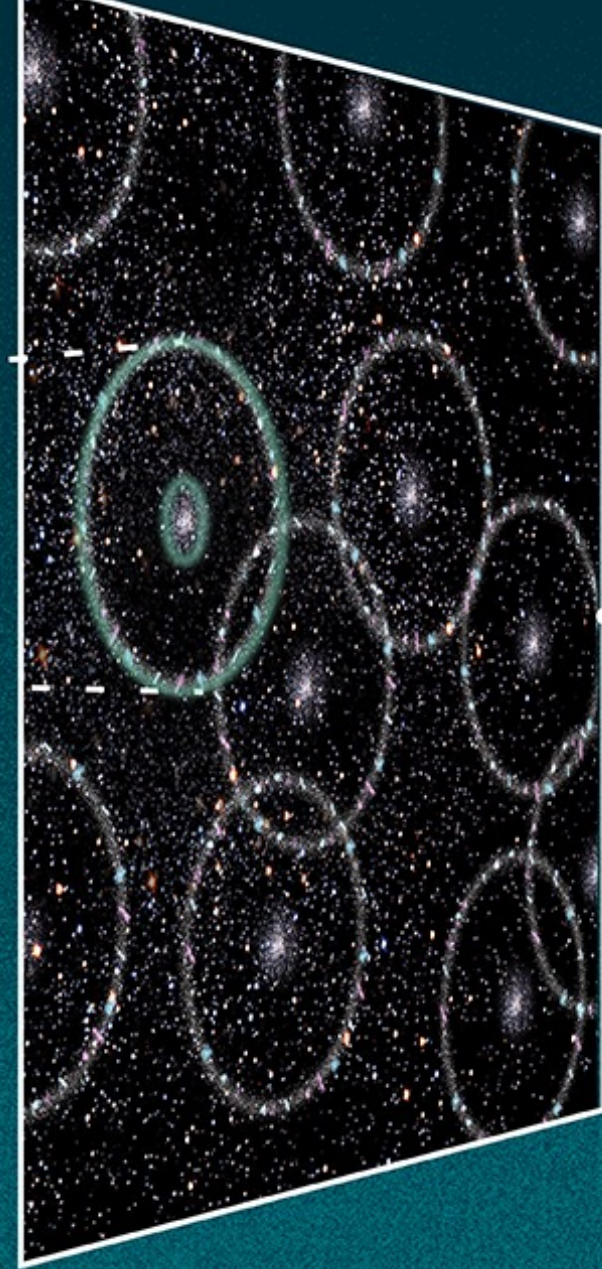
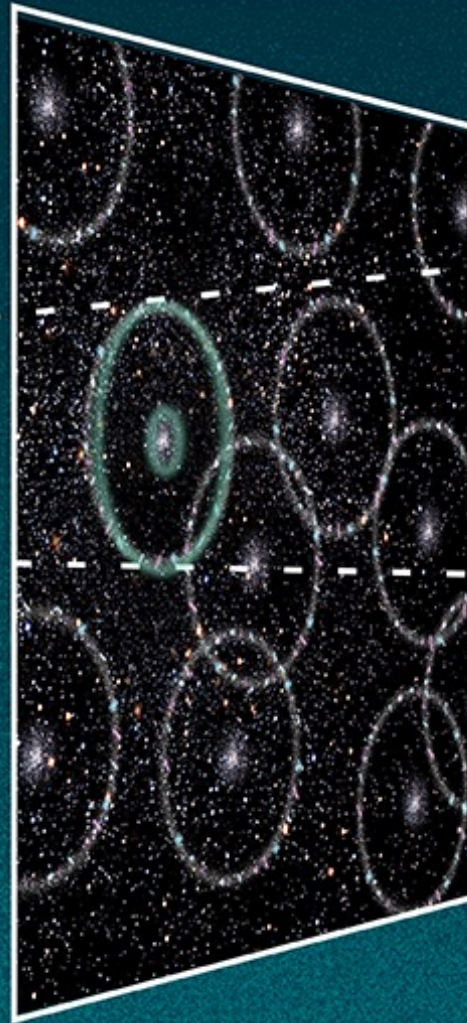
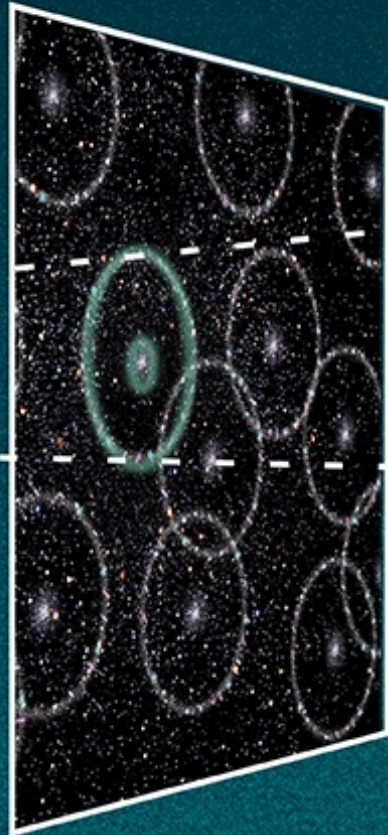
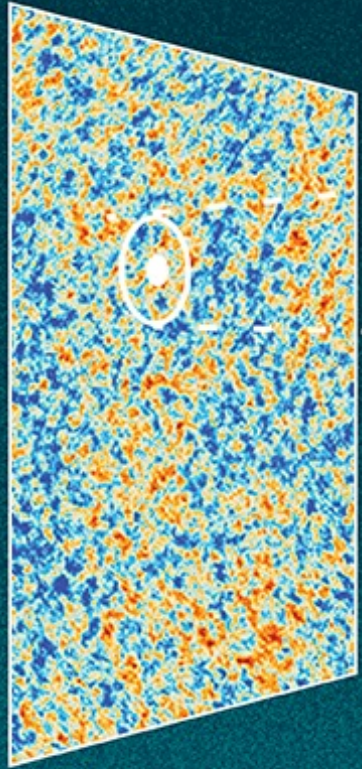


Is there a standard ruler that we can use?

Baryon Acoustic Oscillation (BAO)



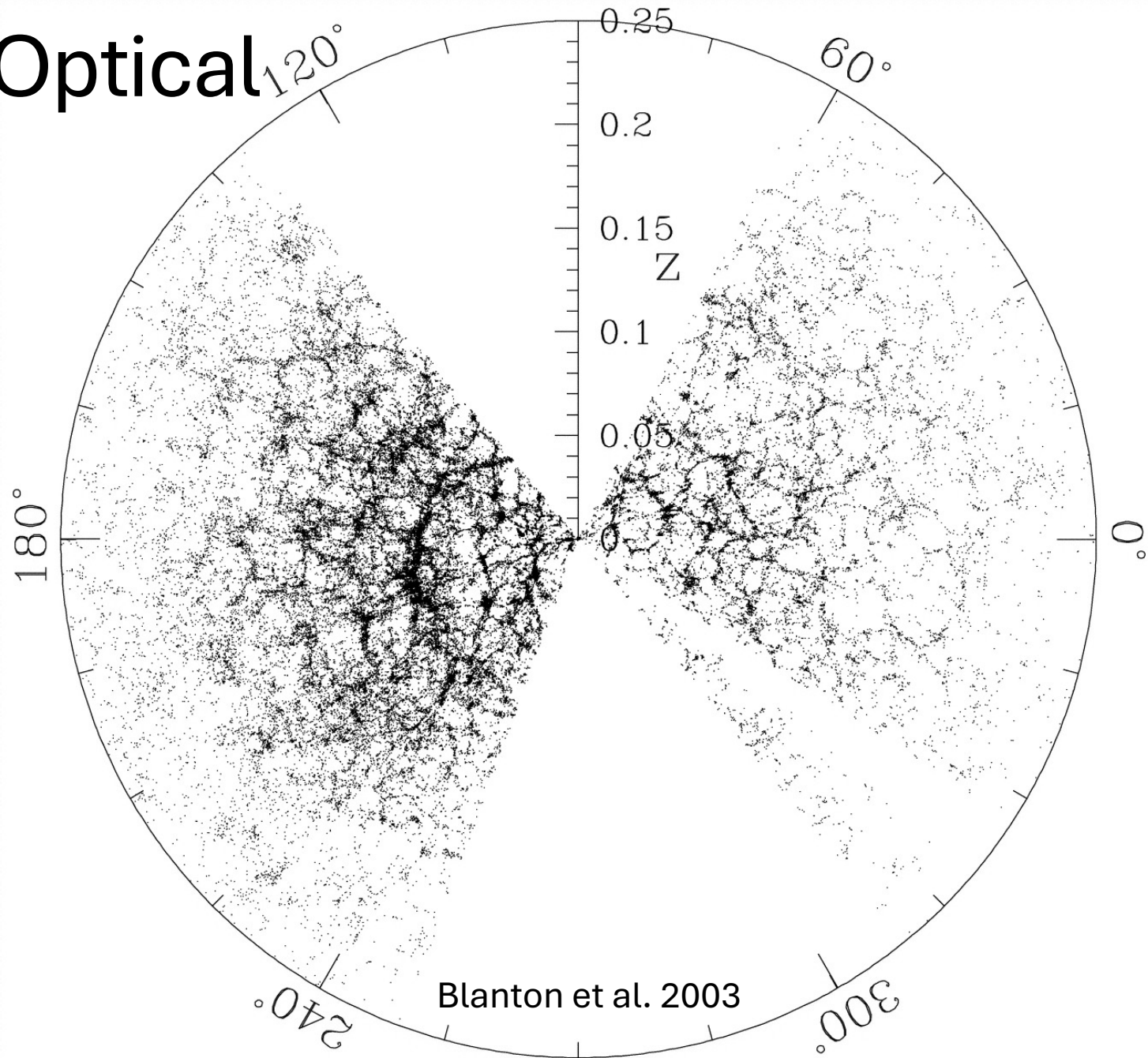
BAO is a standard ruler



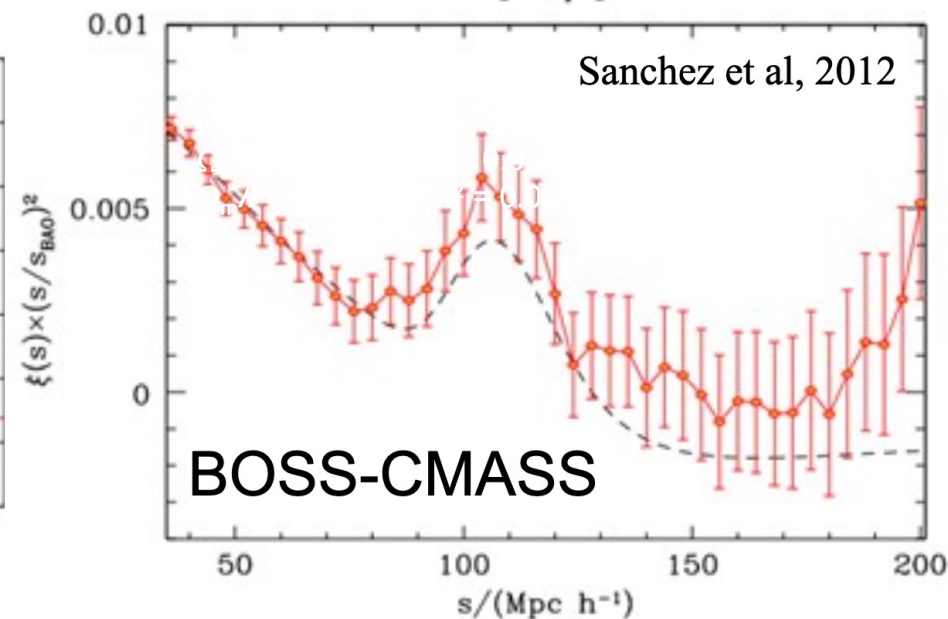
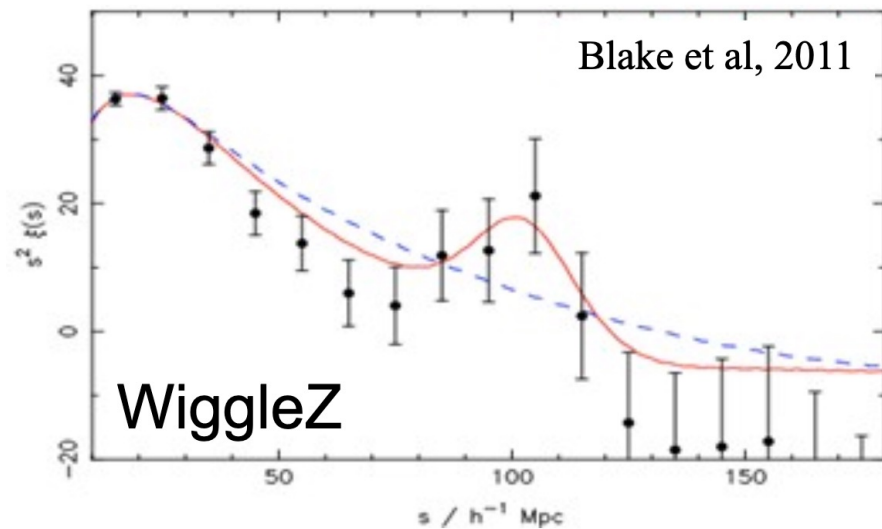
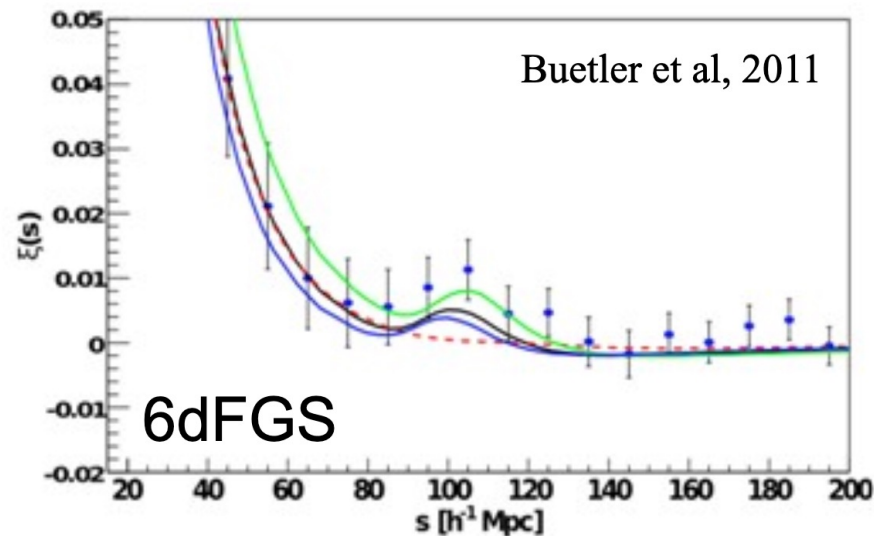
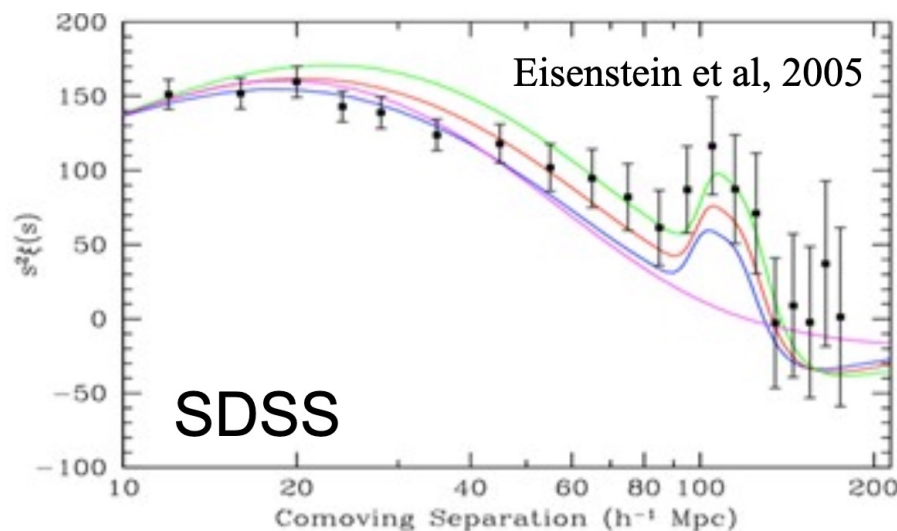
The BAO scale is imprinted in the large scale structure (LSS) of the universe as it expands

Probing BAO scale in Optical

- Get accurate redshifts of a lot of galaxies and make a map of them
- First observed by the SDSS
- Compute the 2-pt correlation function or power spectrum (its Fourier inverse) to measure the BAO scale

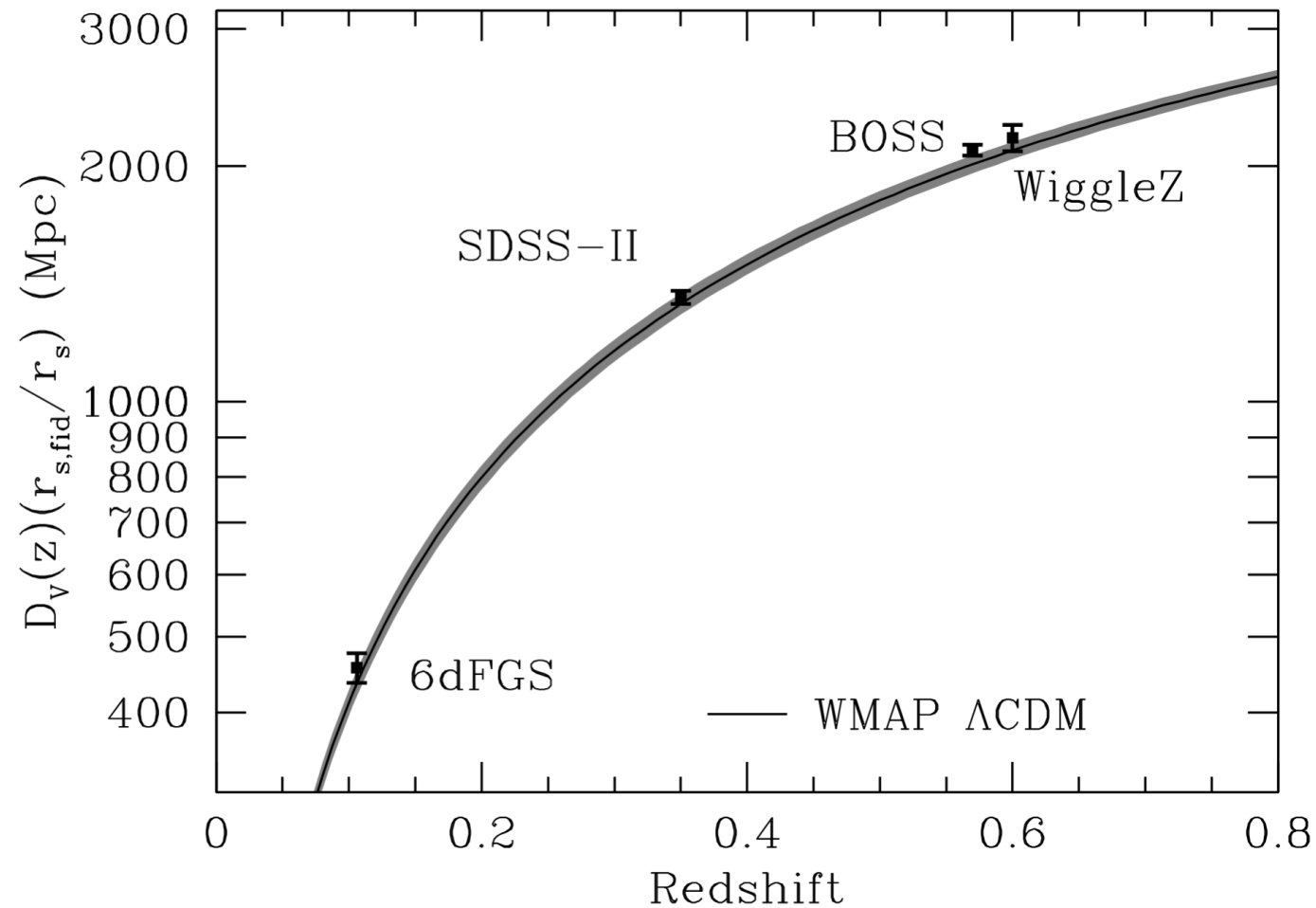


The BAO scale (~ 100 Mpc) is indicated by the bump in 2-point correlation function (or power spectrum)



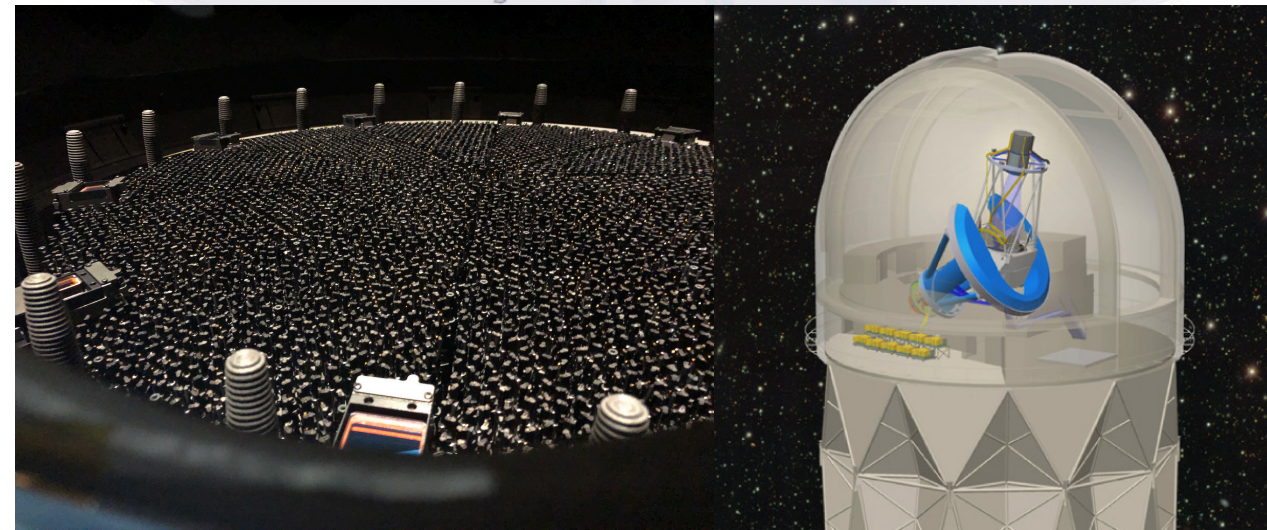
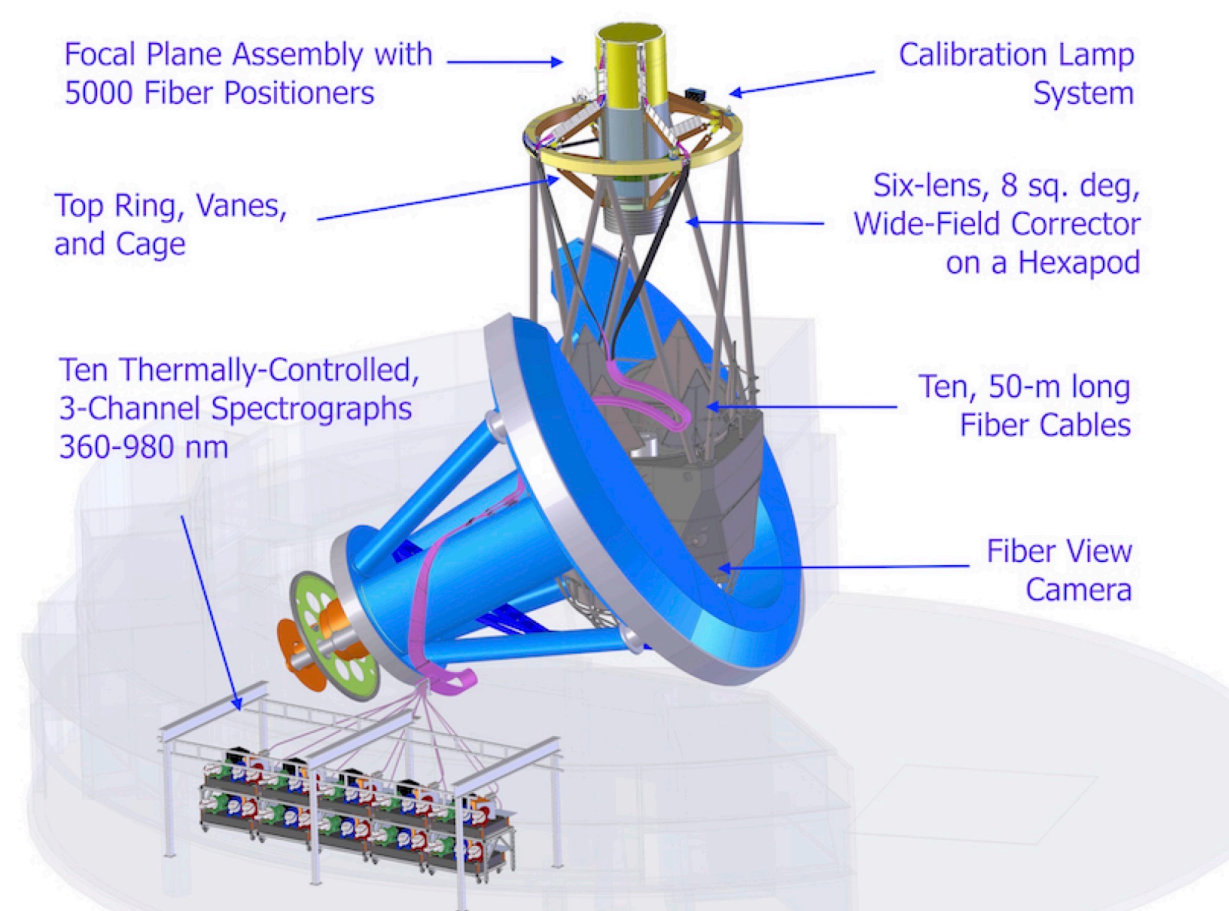
Measure the BAO scale as a function of redshift to trace the expansion rate of the universe

The Universe expands but the standard rule stays fixed



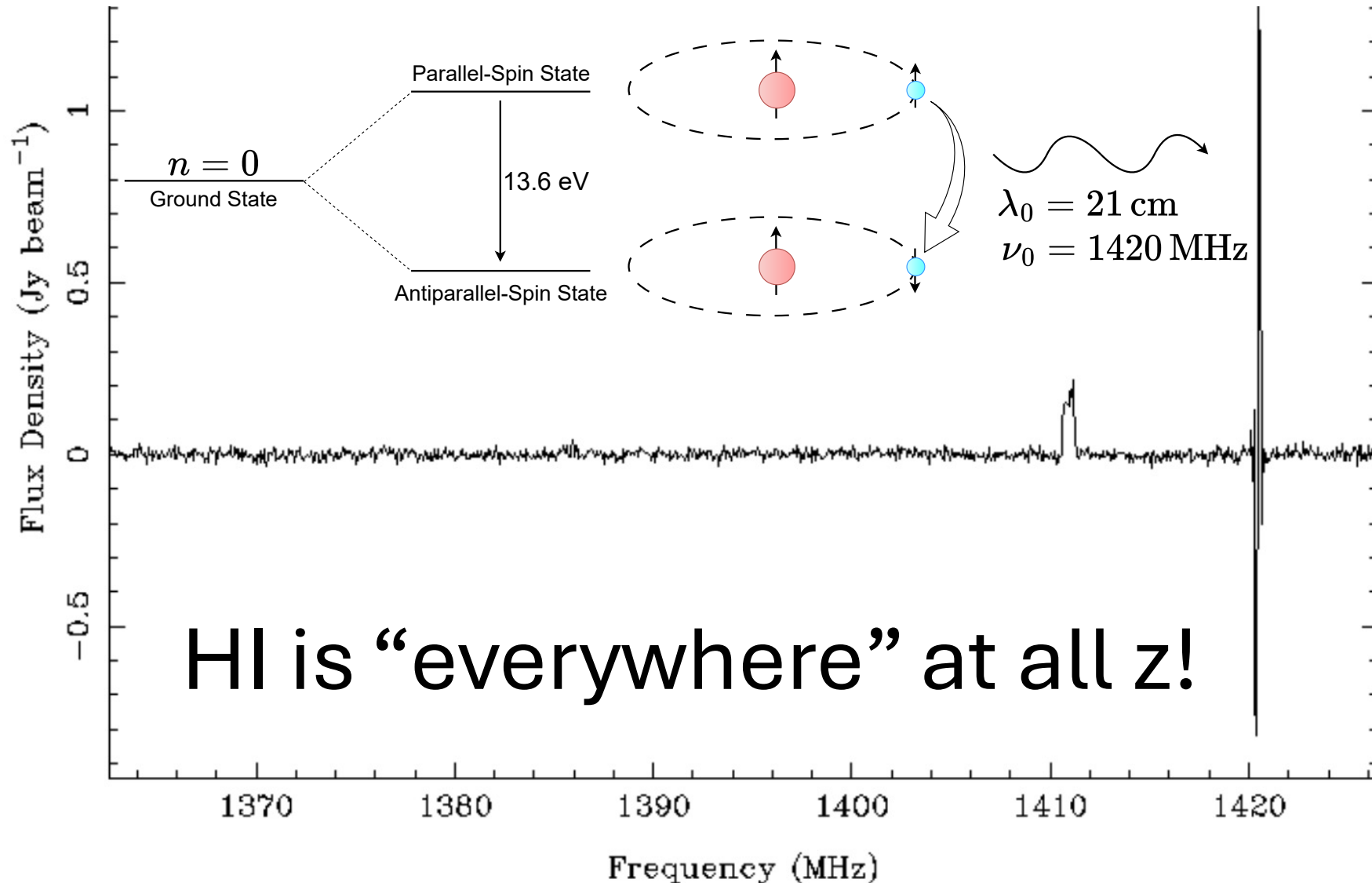
So this works but ...

- Need accurate redshifts
- Thus, need spectroscopic instrument
- Expensive!
 - DESI (Dark Energy Spectroscopic Instrument), the current state-of-the-art dark energy survey instrument cost \$75 million to build + \$11 million operating cost per year
- Hard to do at $z > 1$ as there are less bright galaxies

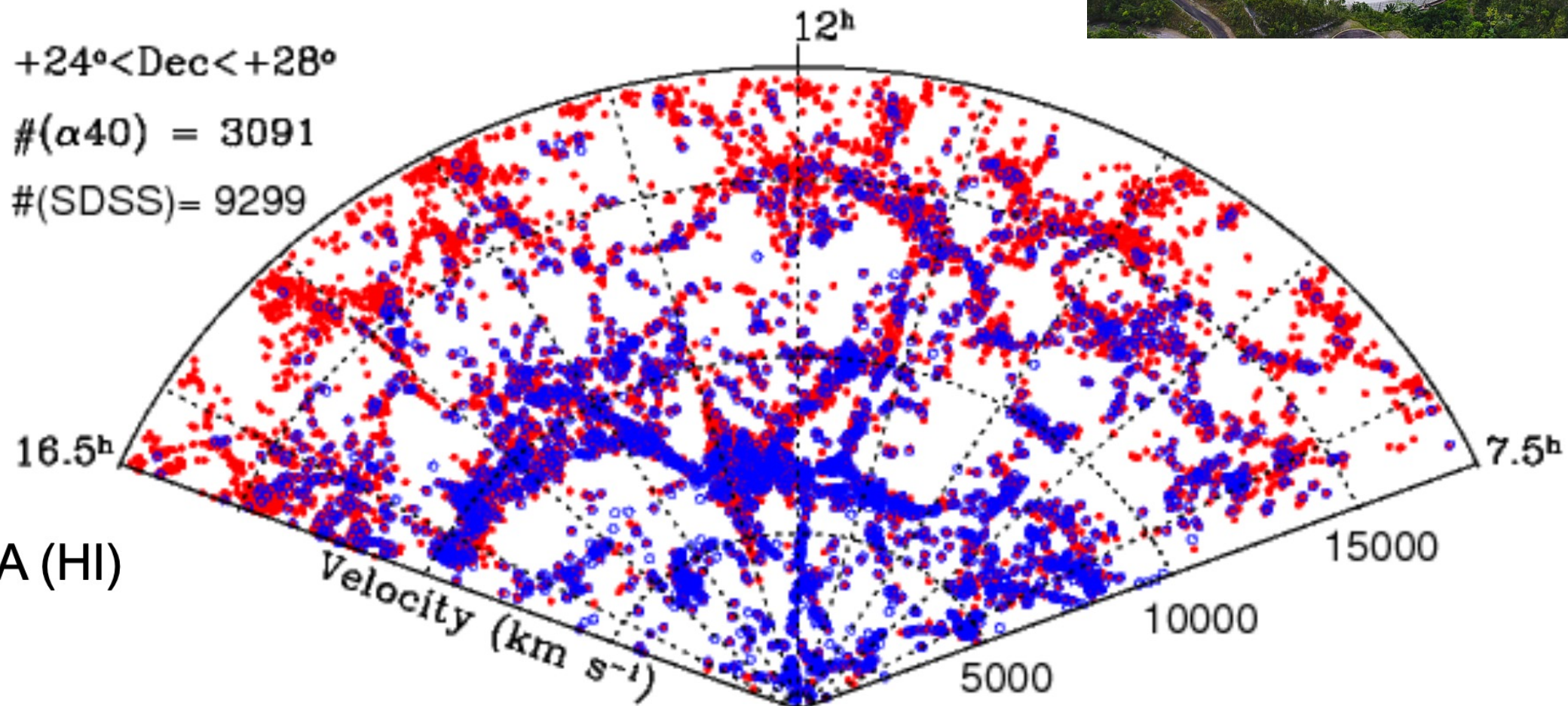


21 cm Emission Line from Neutral Hydrogen Atom (HI)

Very narrow radio spectral line \rightarrow precise redshift information

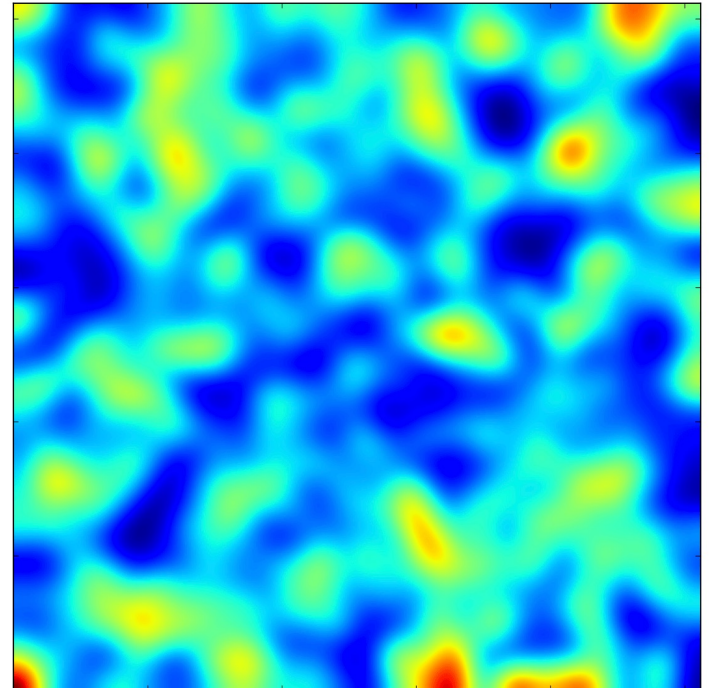
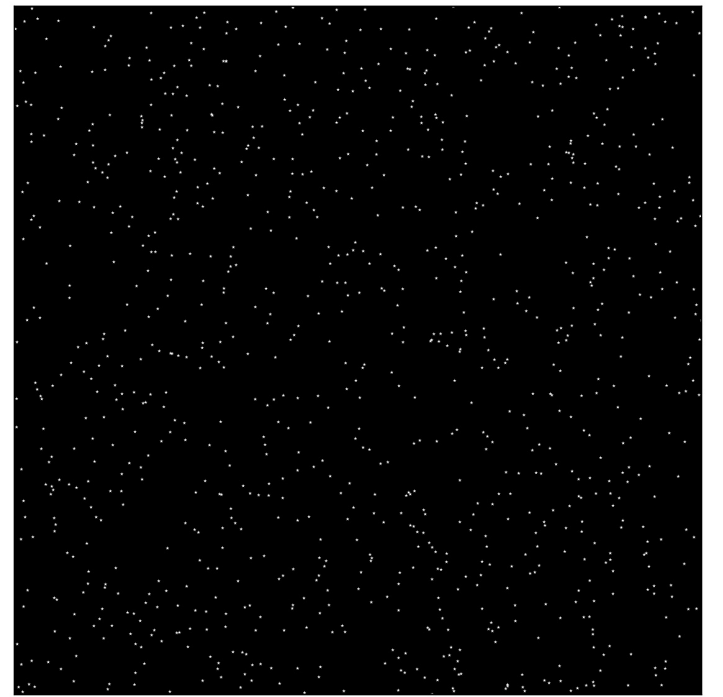


HI and galaxies trace the same galaxy structure at low z



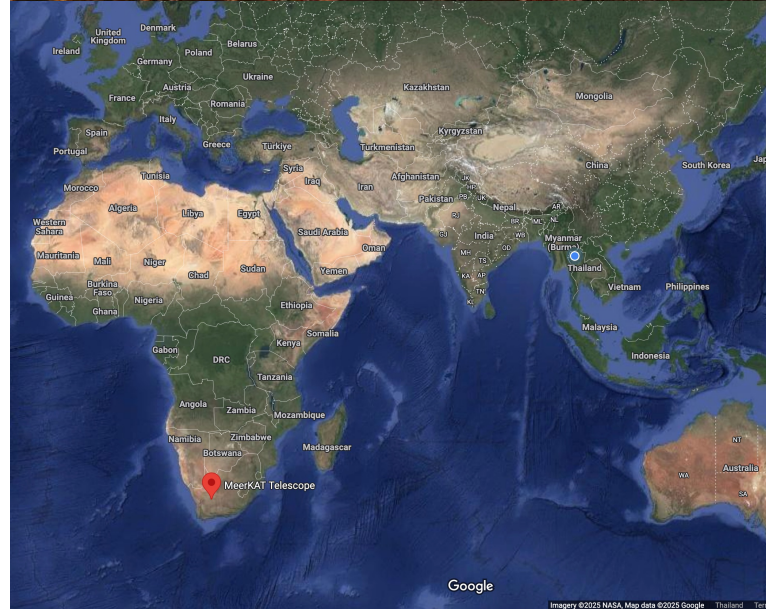
21 cm Intensity Mapping

- Map the redshifted 21 cm emission at large angular scale to trace the LSS without resolving individual galaxies
- Very narrow line width \rightarrow Precise redshift
- Observable between ~ 30 -1420 MHz \rightarrow large range of redshifts
- Modern radio telescope \rightarrow Wide field of view and wide frequency bandwidth \rightarrow LSS can be mapped cheaply and fast!



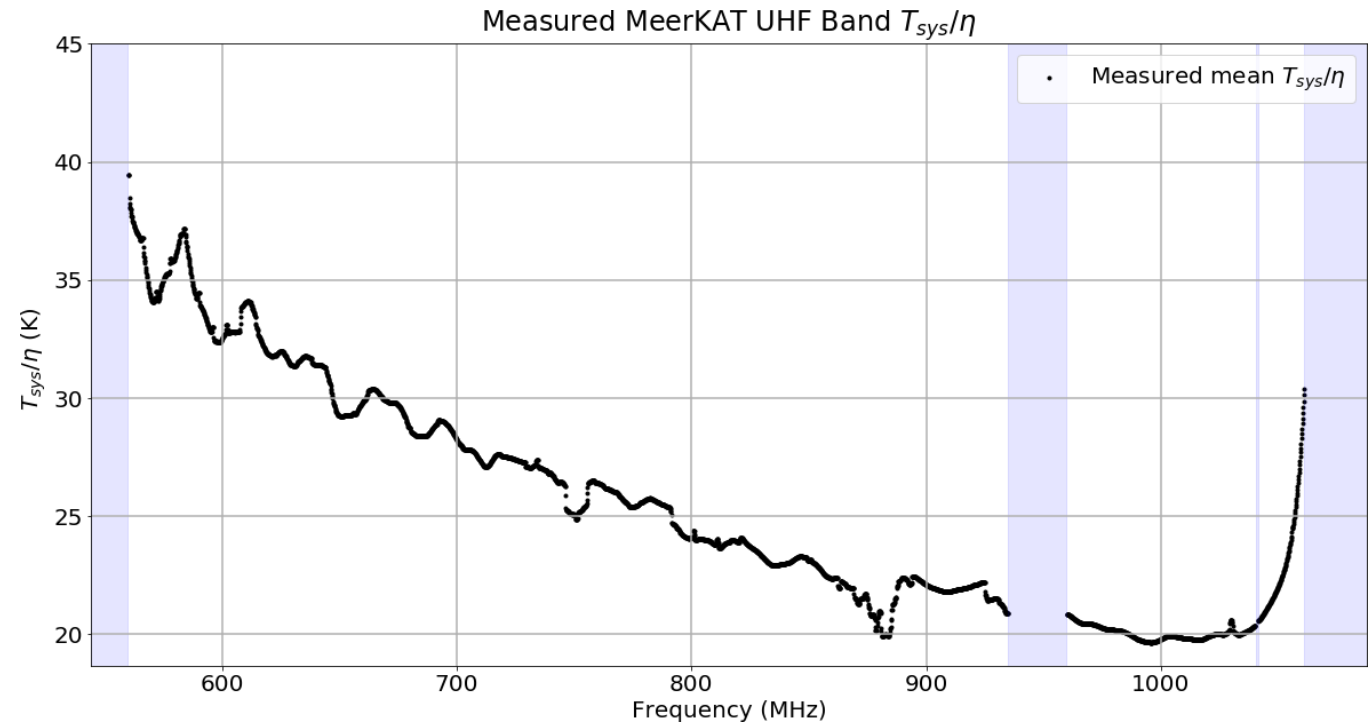
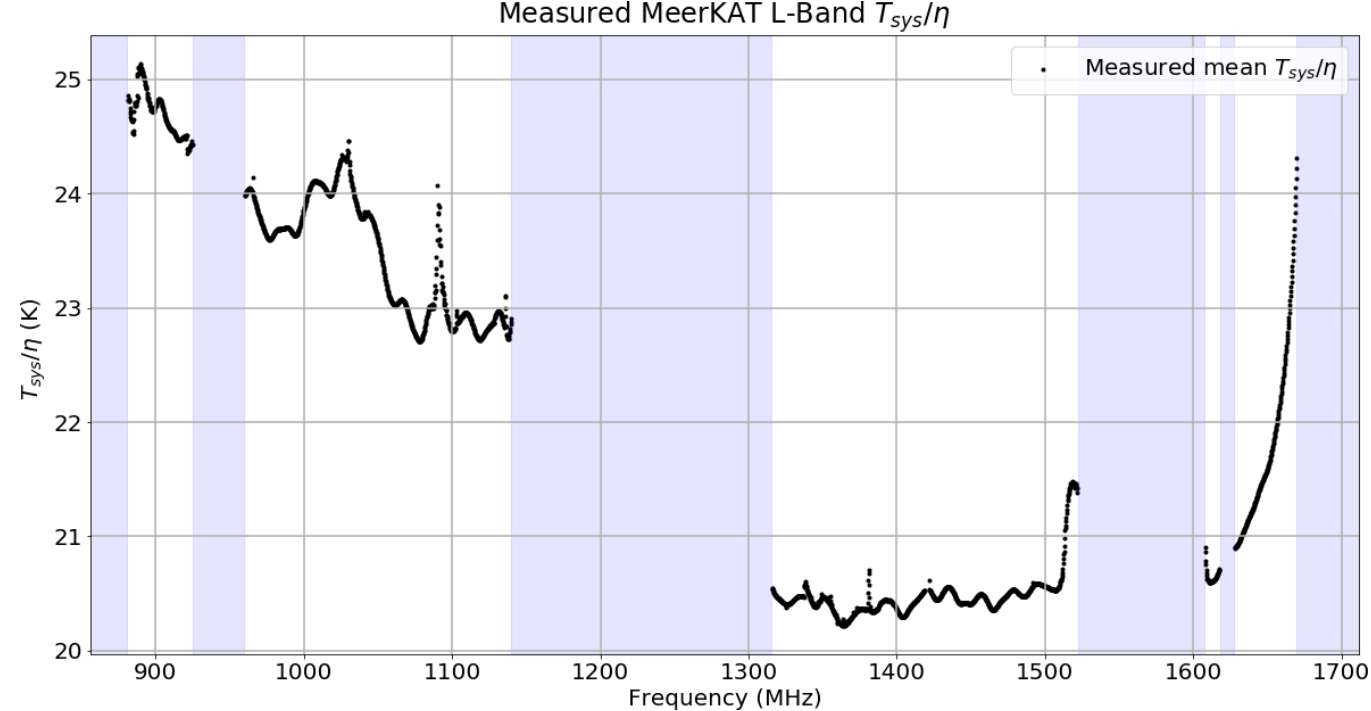
MeerKAT

- Radio interferometer with 64 13.5m offset-Gregorian reflector antennas
- Located in the South African Karoo desert
- Will form part of SKA-mid (133 antennas) from 2030+



MeerKAT

- Radio interferometer with 64 13.5m offset-Gregorian reflector antennas
- Located in the South African Karoo desert
- Will form part of SKA-mid (133 antennas) from 2030+
- UHF, L and S bands (550-3500 MHz)
- **Most sensitive telescope in the world in its frequency range**



MeerKAT KLASS

MeerKAT Large Area Synoptic Survey

<http://arxiv.org/abs/1709.06099>

A “single-dish” 21 cm intensity mapping survey

+

On-The-Fly (OTF) continuum imaging

<https://meerklass.org/>

MeerKLASS Collaboration

- PI Mario Santos, Deputy PI Laura Wolz
- Steering Team: Jingying Wang, Joe Mohr, Keith Grainge, Marta Spinelli, Stefano Camera
- Currently we have ~40 Full Members and ~40 Project Collaborators
- Members are based globally, incl. UK, SA, CH, IT, FR, SP, GER
- Major hubs at University of Western Cape and University of Manchester



MeerKLASS Collaboration – Working Group Leads

- Power Spectrum



Steve Cunnington
(Portsmouth)



Zhaoting Chen
(Edinburgh)

- Calibration



Wenkai Hu
(NAOC)



Karin Fernandez
(UWC)

- Forecast and Inference



Jose Louis Bernal
(CSIC)

- Foreground



Isabella Carucci
(INAF & IFPU, Trieste)



Isabella Carucci
(INAF & INFN, Milan)

- Observation Planning



Piyanat Boom Kittiwisit
(UWC & SARA0)

- On-the-fly Imaging



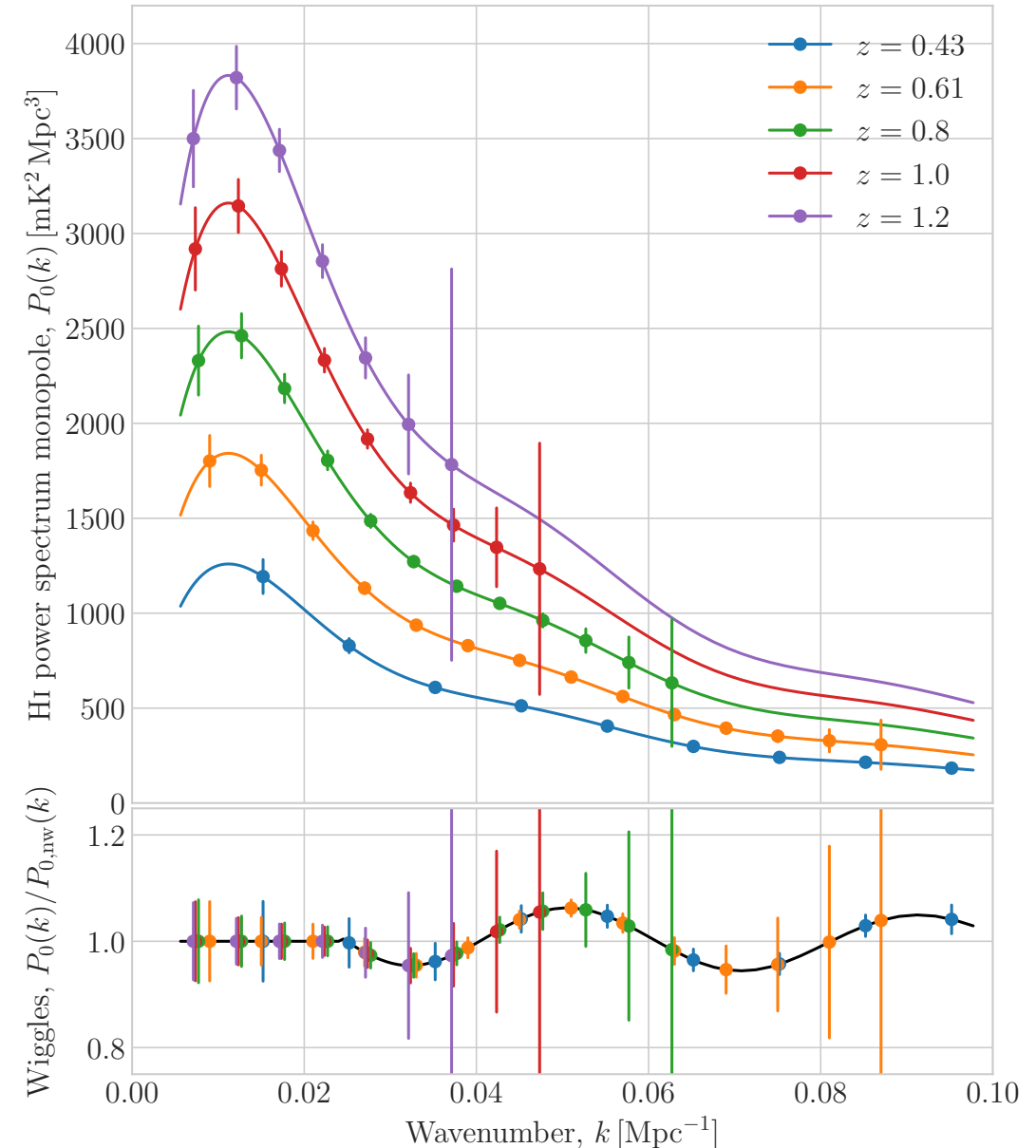
Sourabh Paul
(Manchester)



Suman Chatterjee
(UWC)

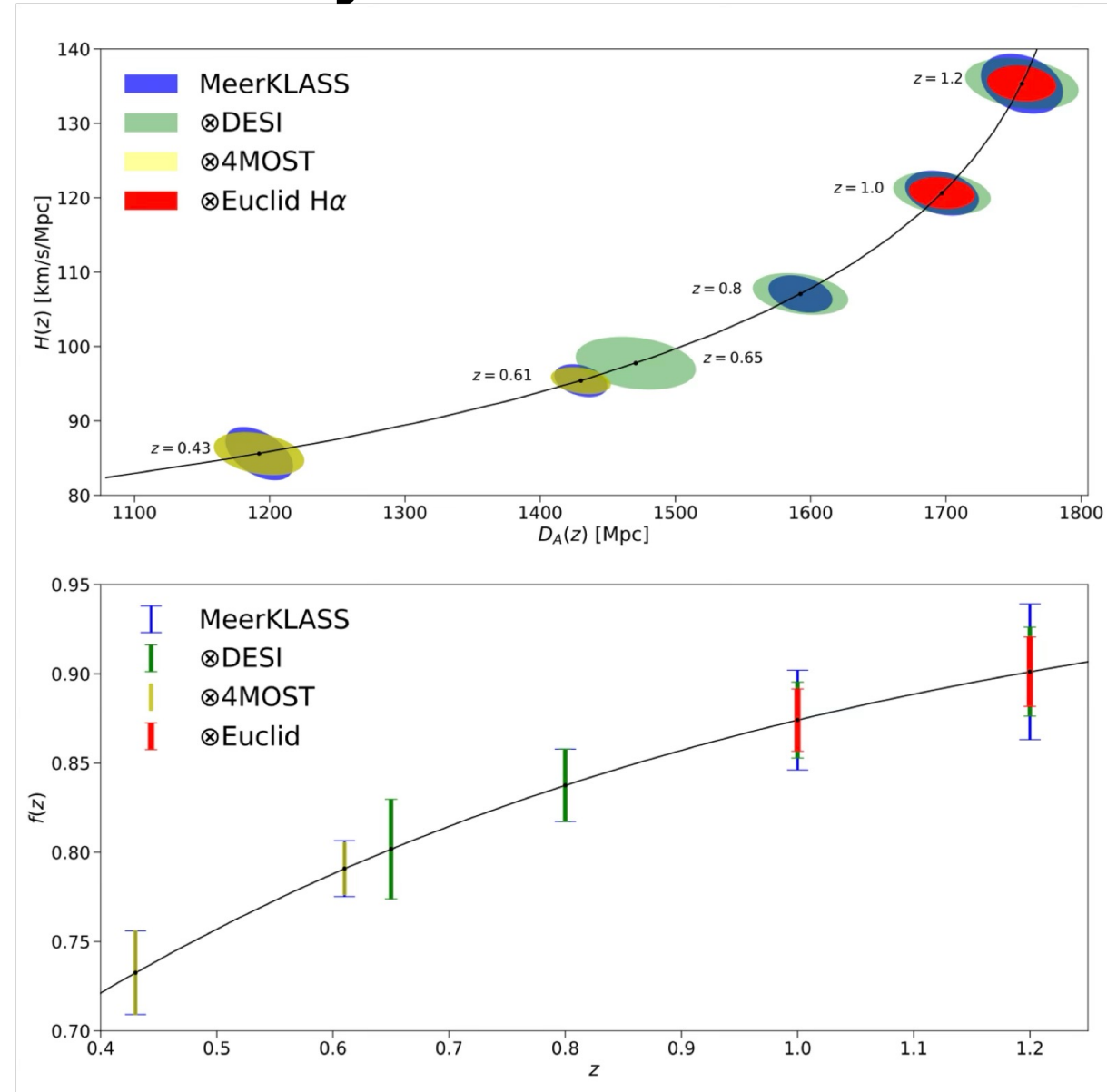
MeerKLASS – Single Dish IM Survey

- Aim: **Cosmology on large scales**
→ BAO measurement → test Dark Energy models
- Observations in L-Band and UHF-Band equivalent to $0 < z < 1.5$

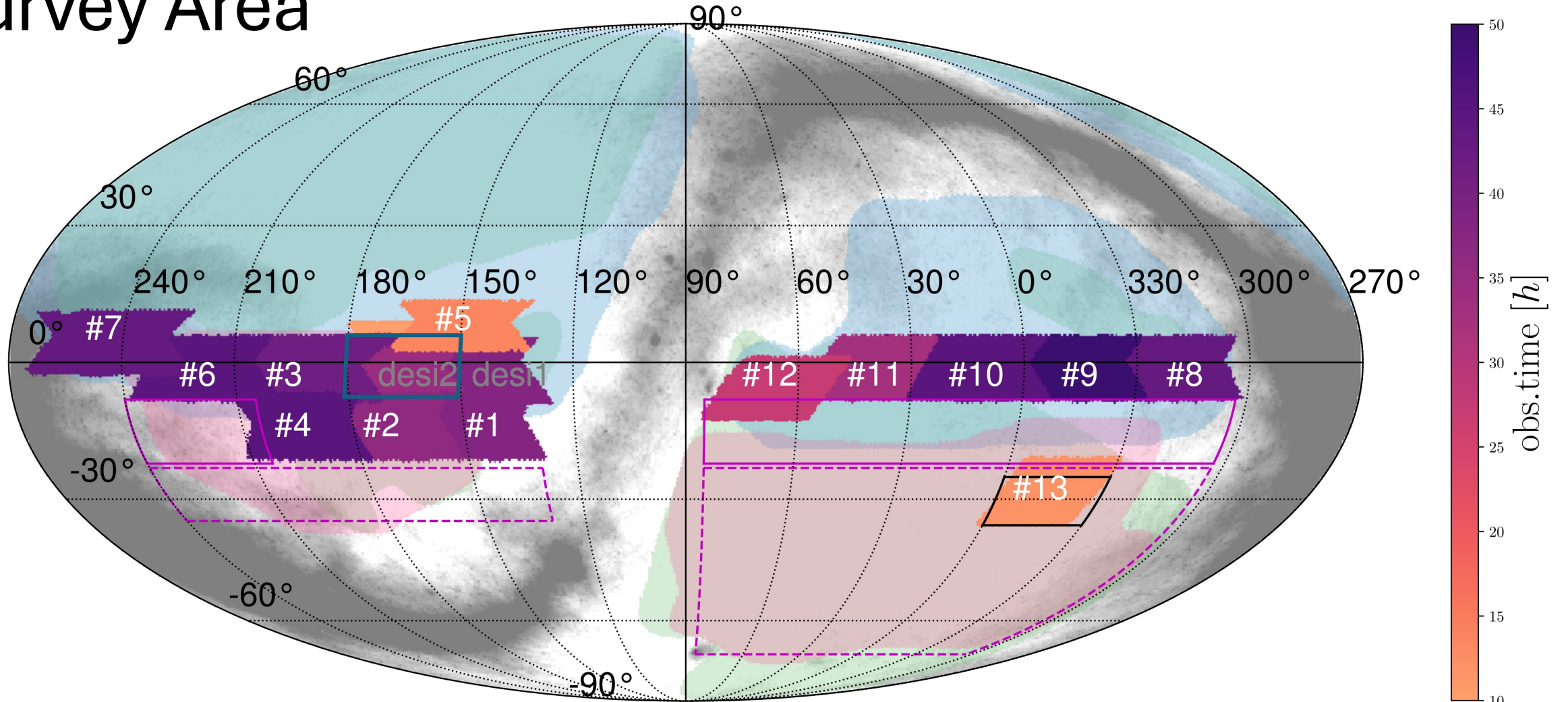






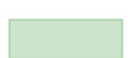
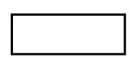

MeerKLASS – Single Dish IM Survey

- Aim: **Cosmology on large scales**
→ BAO measurement → test Dark Energy models
- Observations in L-Band and UHF-Band equivalent to $0 < z < 1.5$
- Focus on sky patches with multi-wavelength data for cross-correlation and joint parameter constraints (DESI, DES, 4MOST, etc)



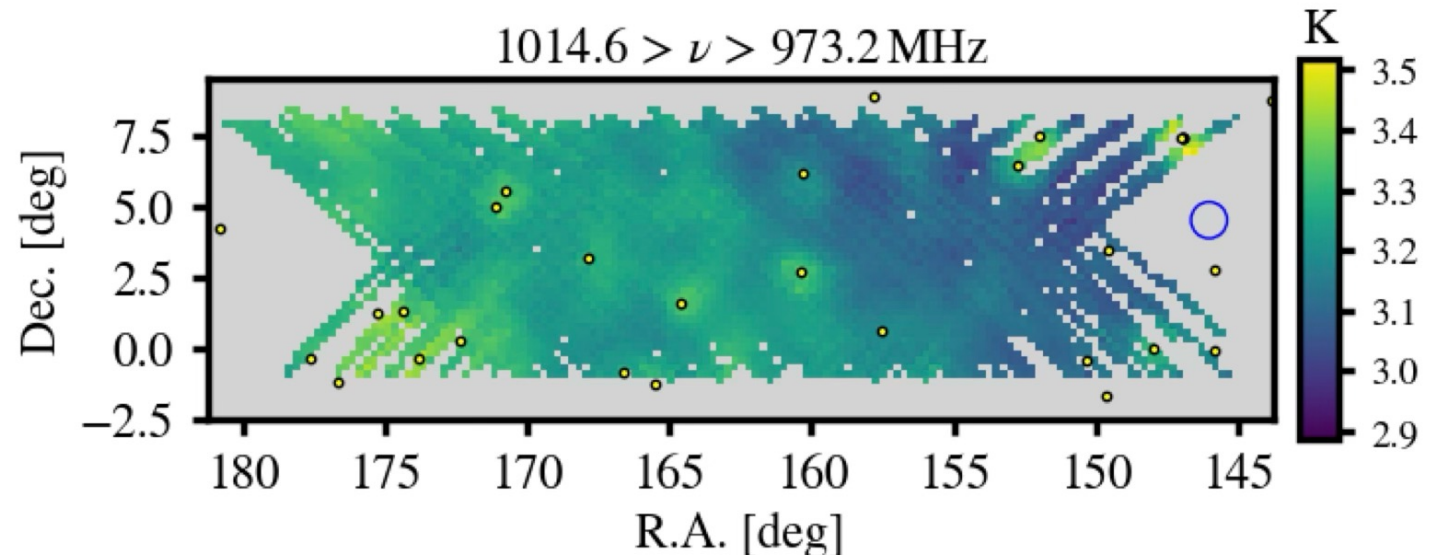
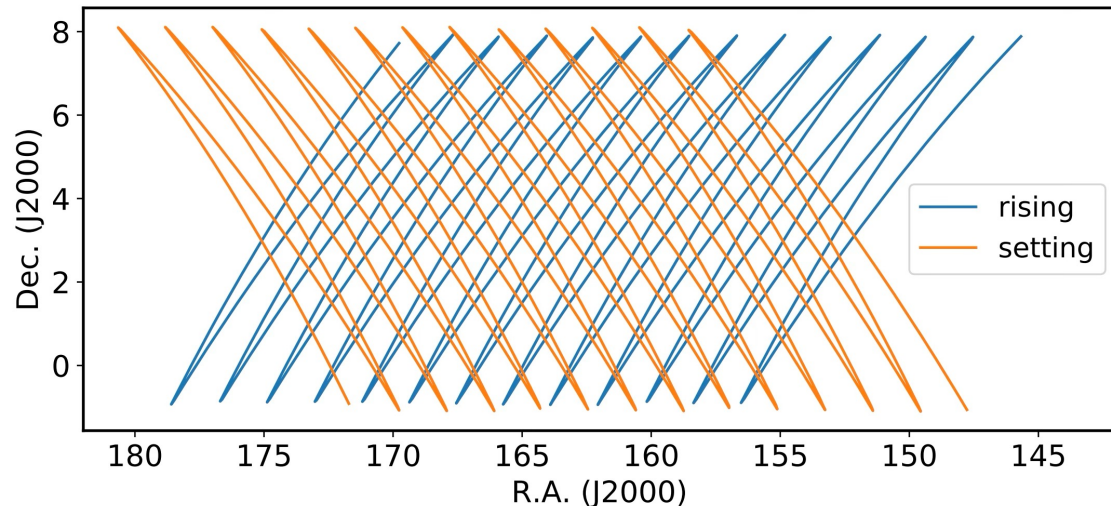
Survey Area



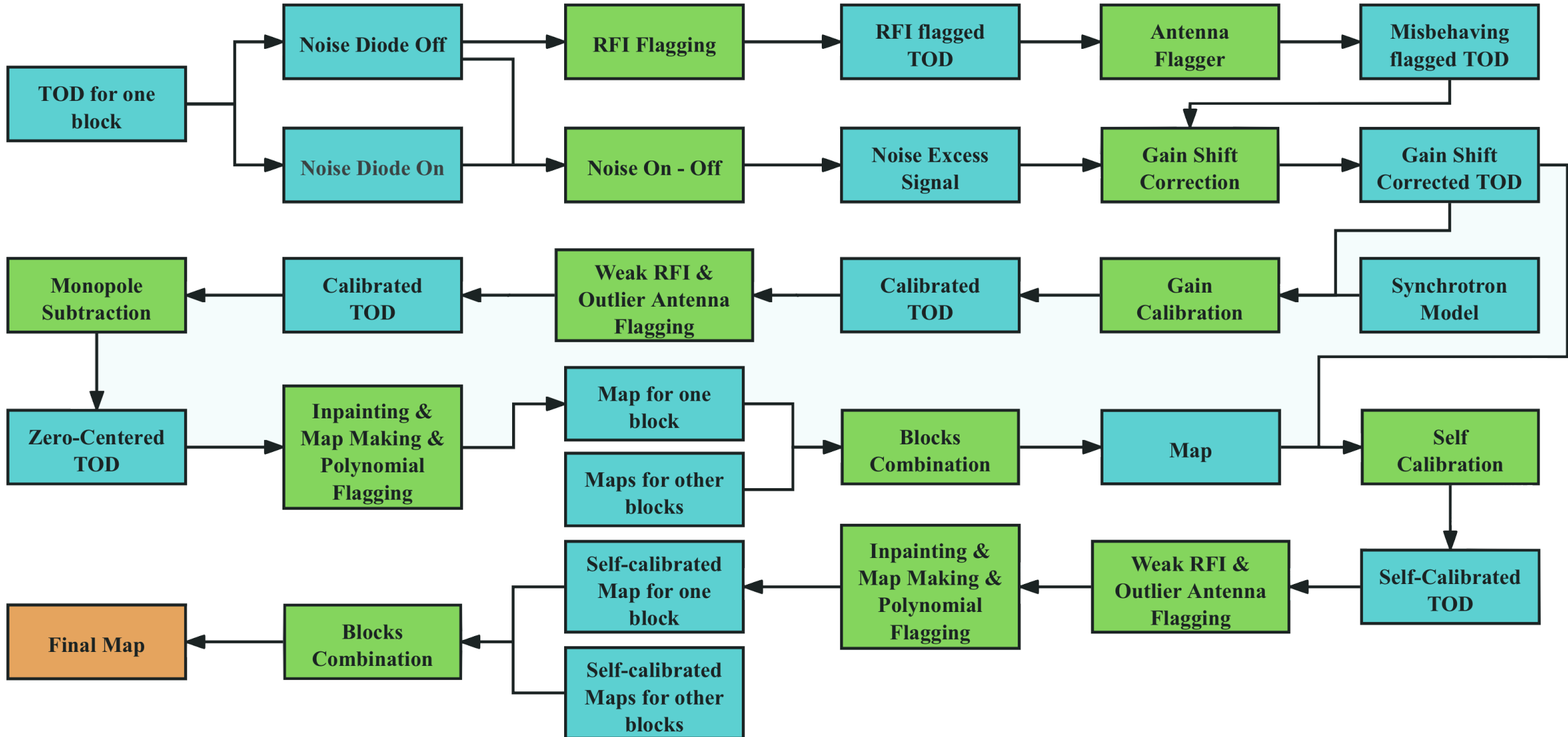
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|---|---|--|--|
|  DESI |  4MOST |  L-band 2019 |  UHF 2026 (This Year) |
|  Euclid | |  L-band 2021 |  Future |

Survey Strategy

- Use MeerKAT in “single dish” mode one antenna = one single-dish telescope
- Azimuth scans at constant elevation on $\approx 200\text{-}300 \text{ deg}^2$ patches
- Multiple scans per patch, each 1.5-2 hours, ≈ 40 hours per patch
- Rising and setting scans create raster of patch
- 5-pointing (star shape) on-off tracking of single dish calibrators
- Standard bandpass and polarization calibrators for OTF

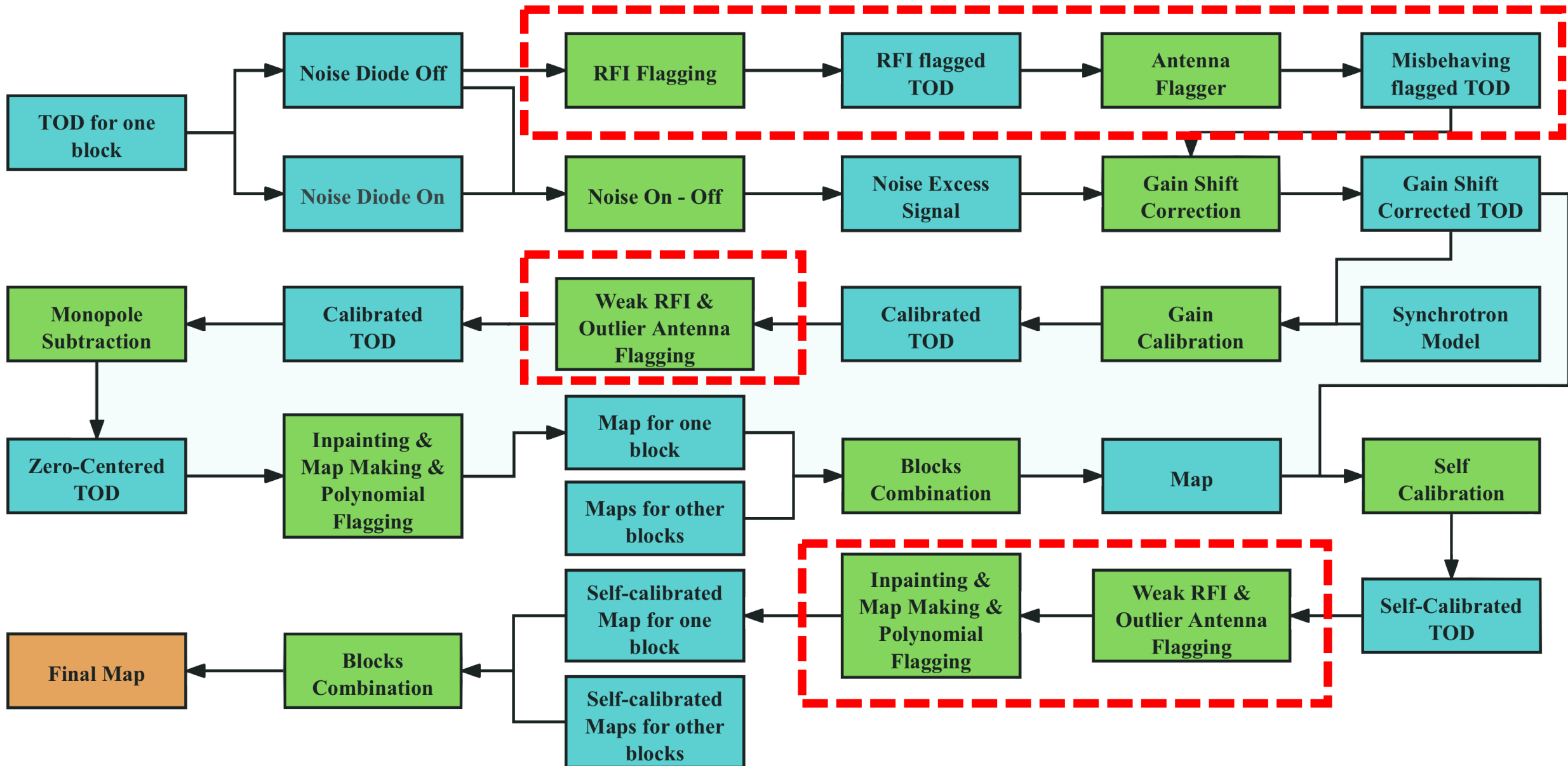


Data Analysis Pipeline



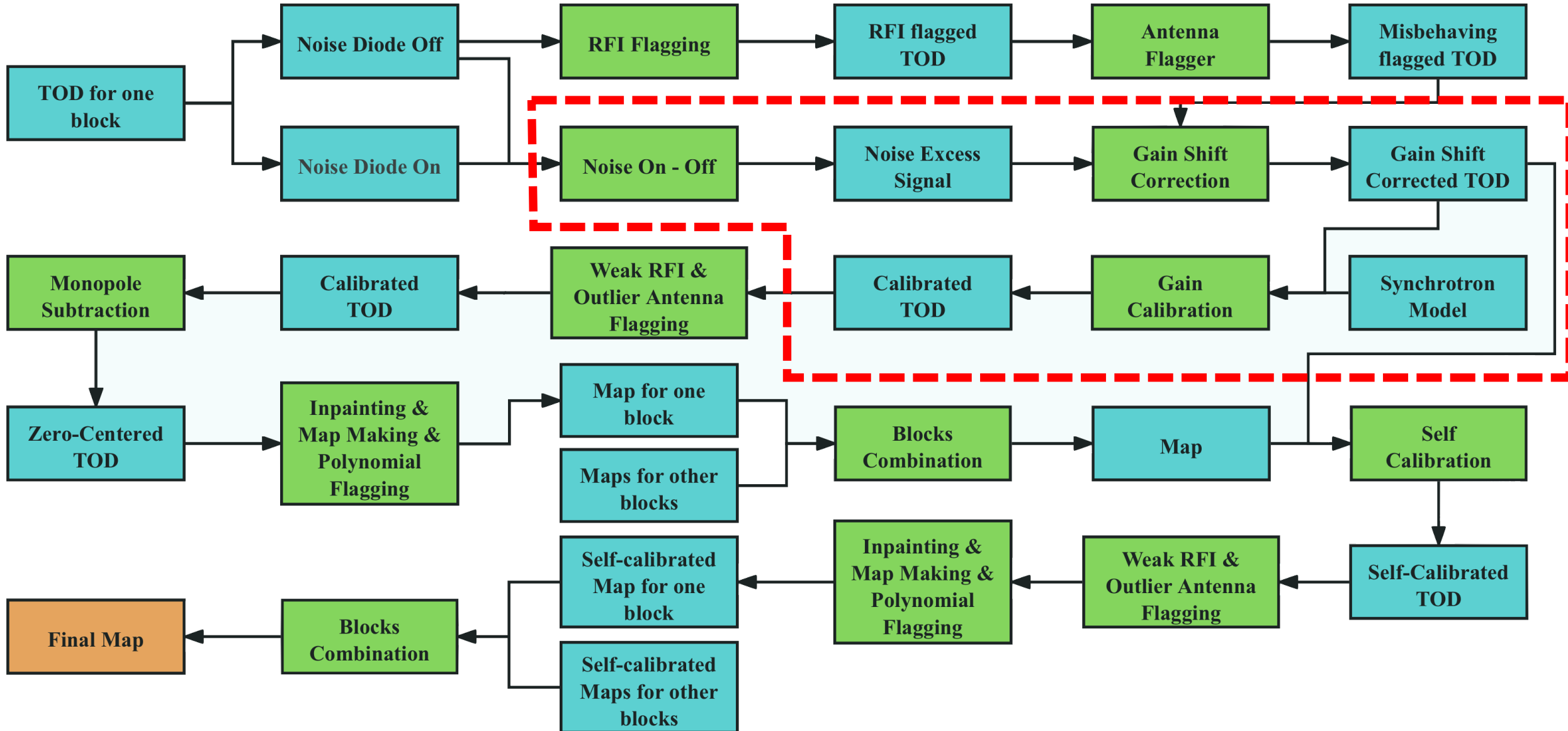
Data Analysis Pipeline

Multiple stages of RFI flagging



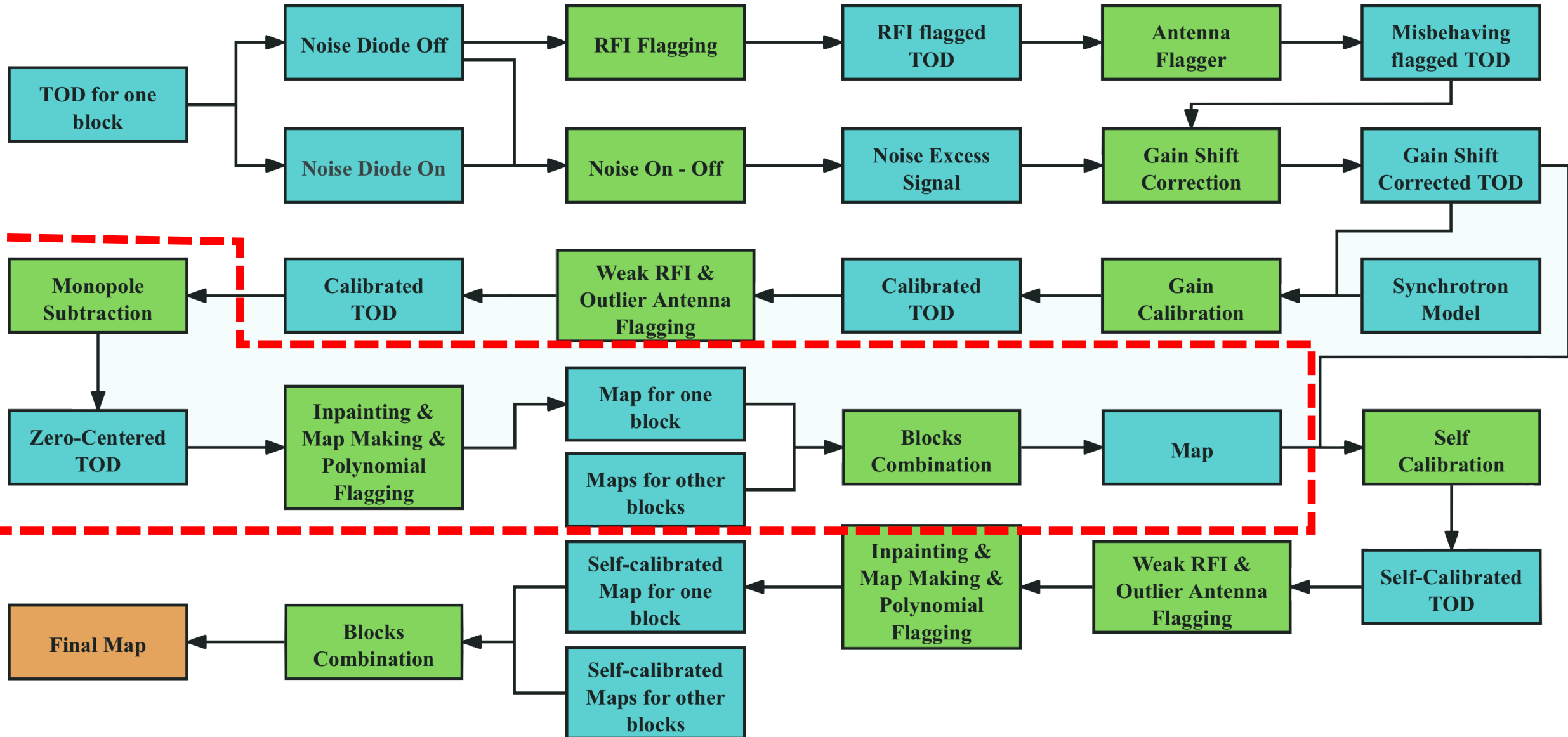
Data Analysis Pipeline

Calibration with noise diodes, synchrotron and point sources



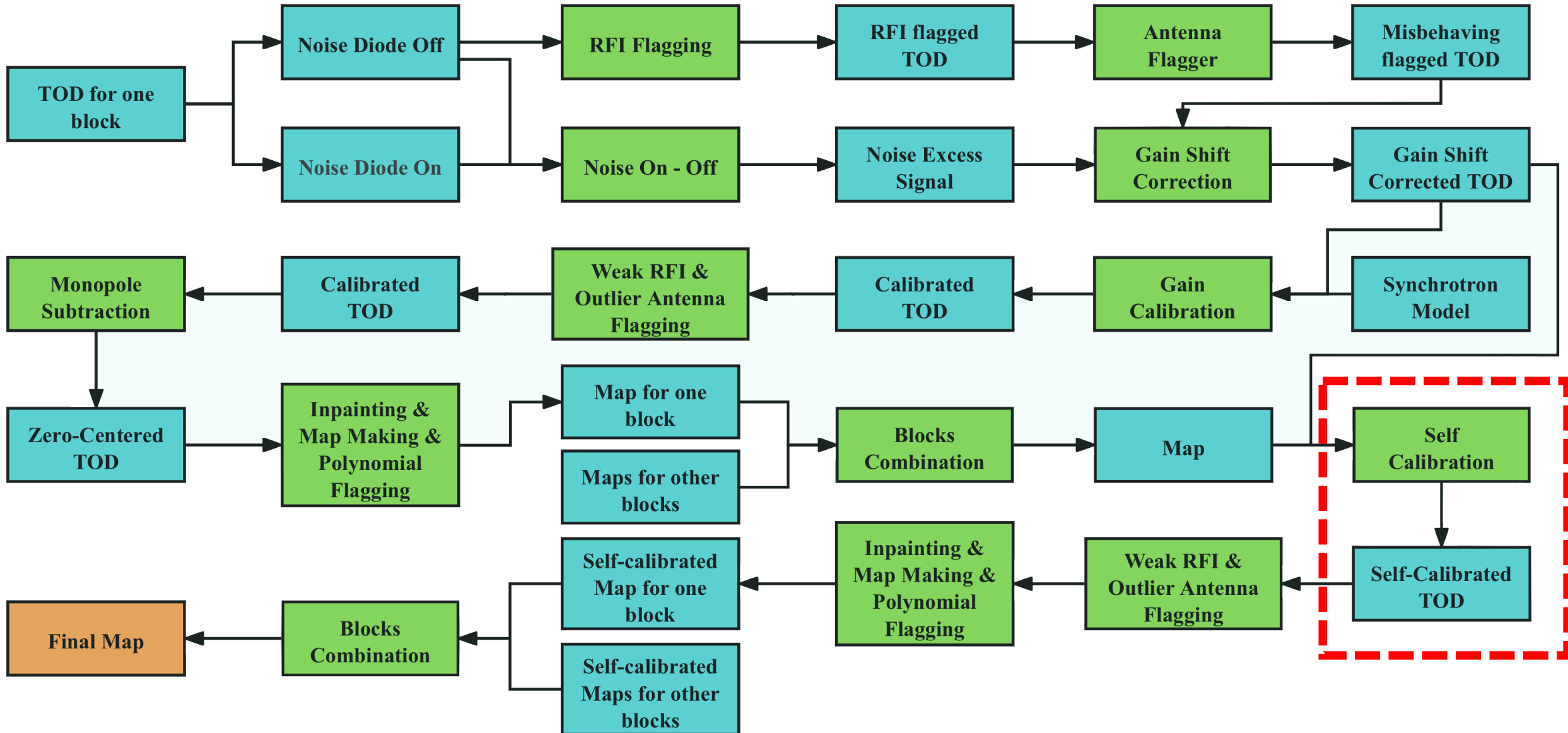
Data Analysis Pipeline

Map making



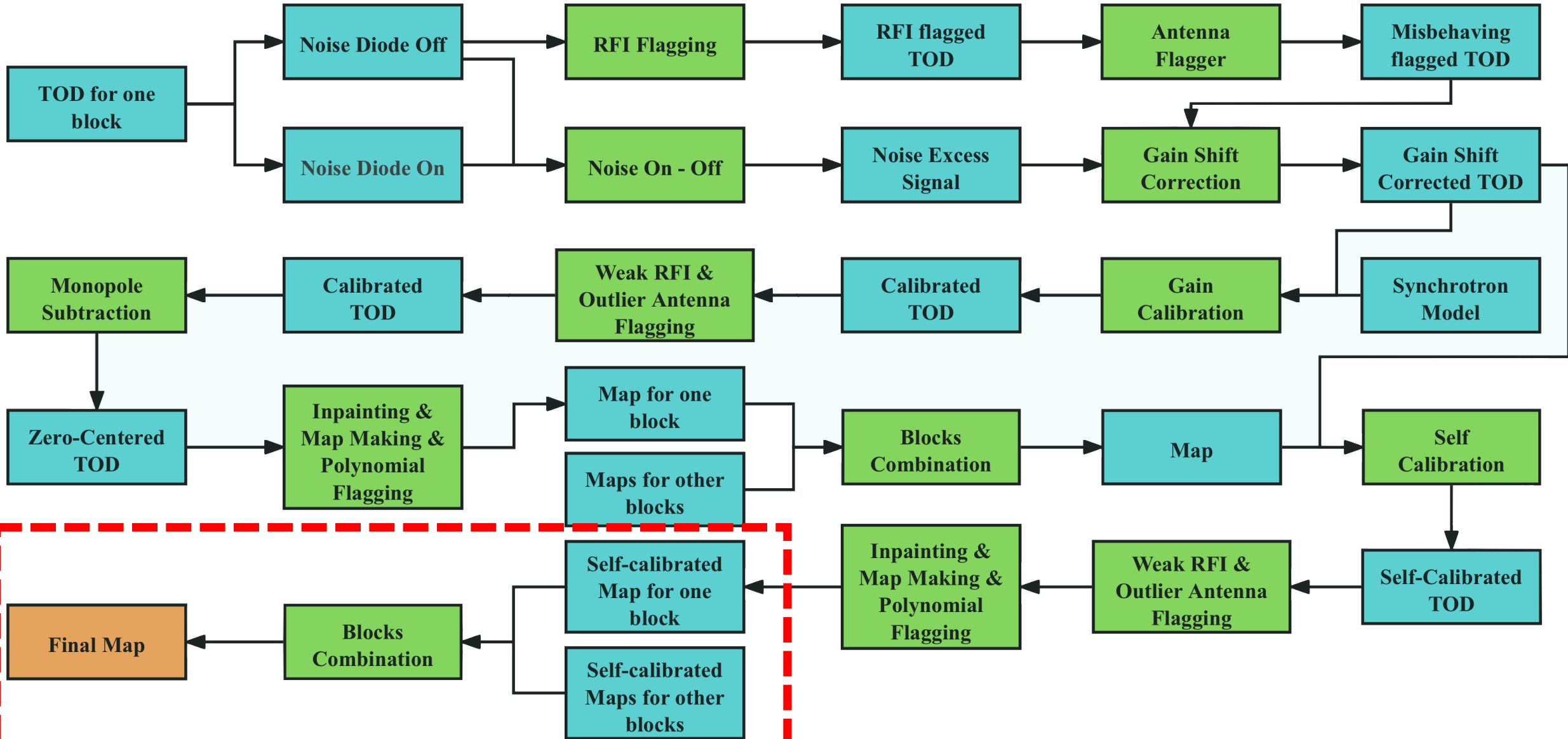
Data Analysis Pipeline

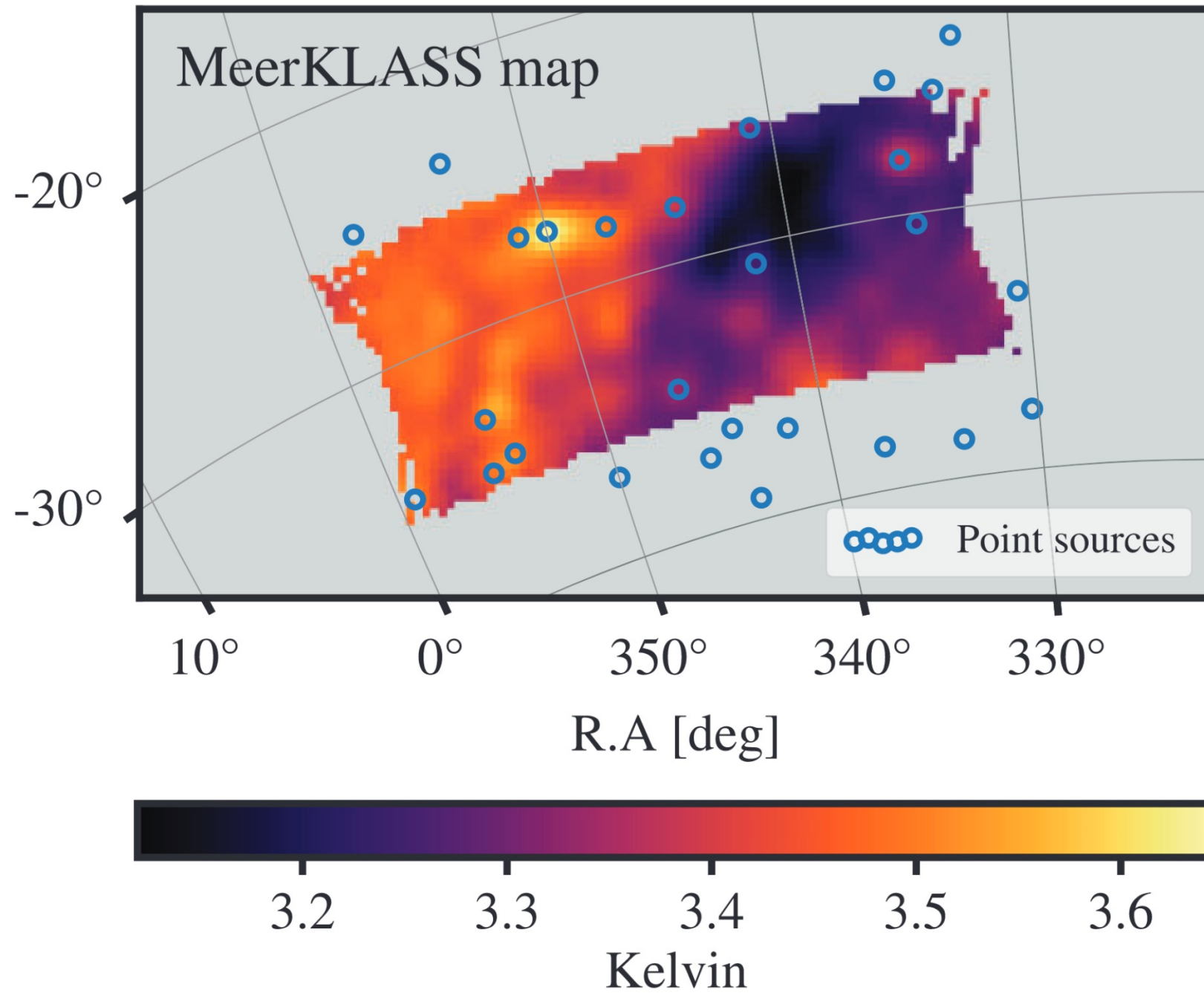
Self-calibration



Data Analysis Pipeline

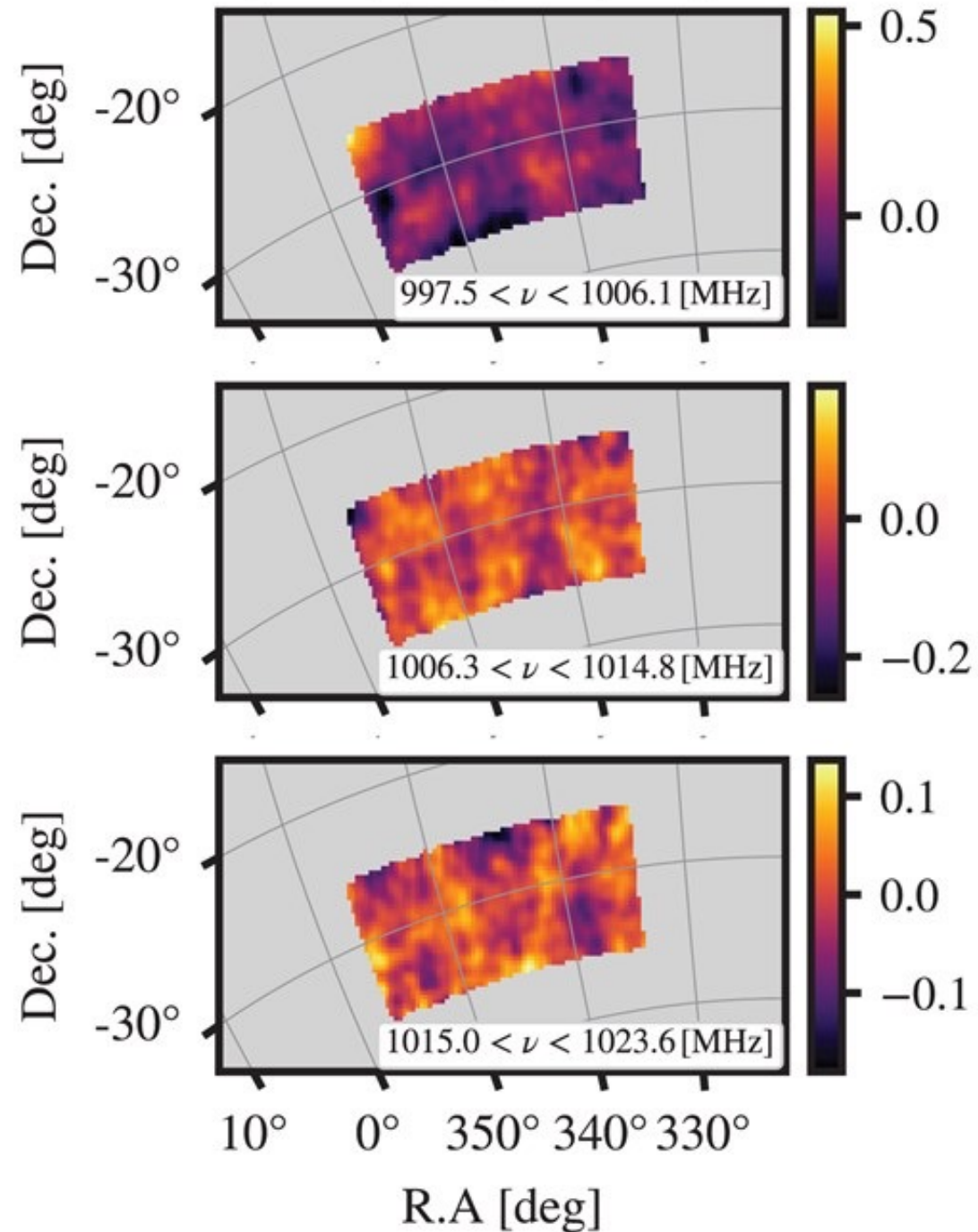
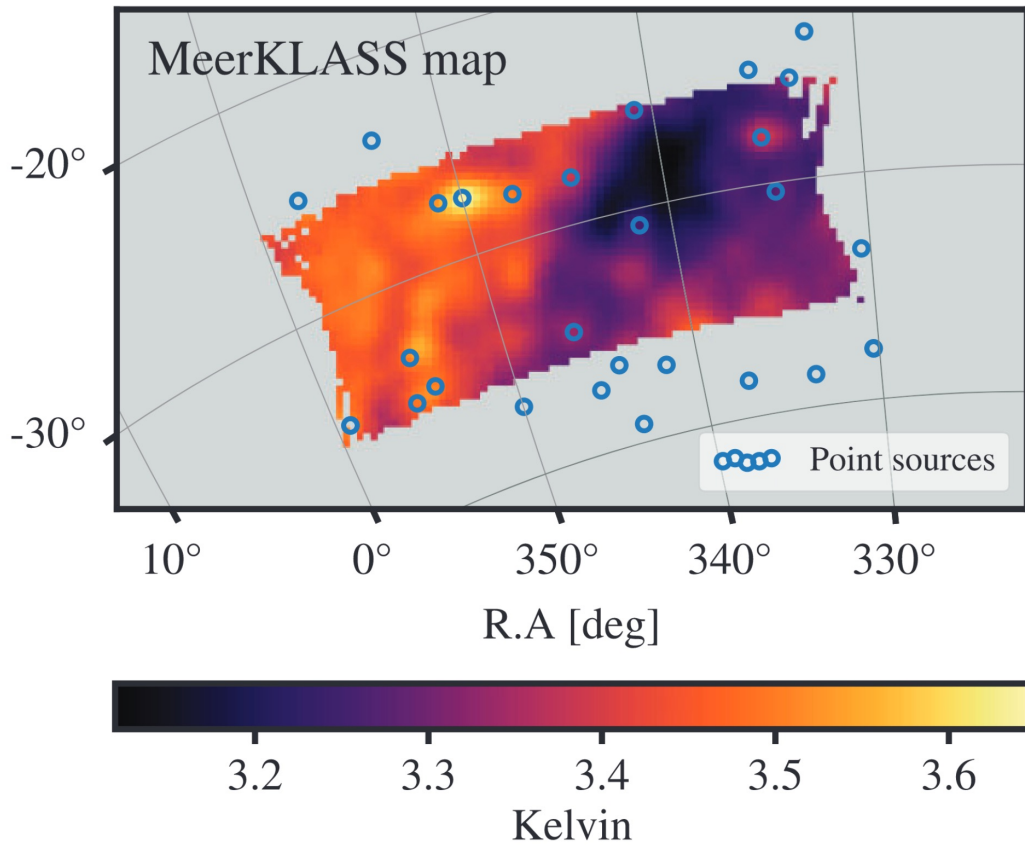
Combined maps from multiple observation blocks





Foreground Cleaning

- Blind and multiscale PCA cleaning (Carucci et al. 2025, Cunnington et al. 2021, Carucci et al. 2020)



Published IM Cosmological Results

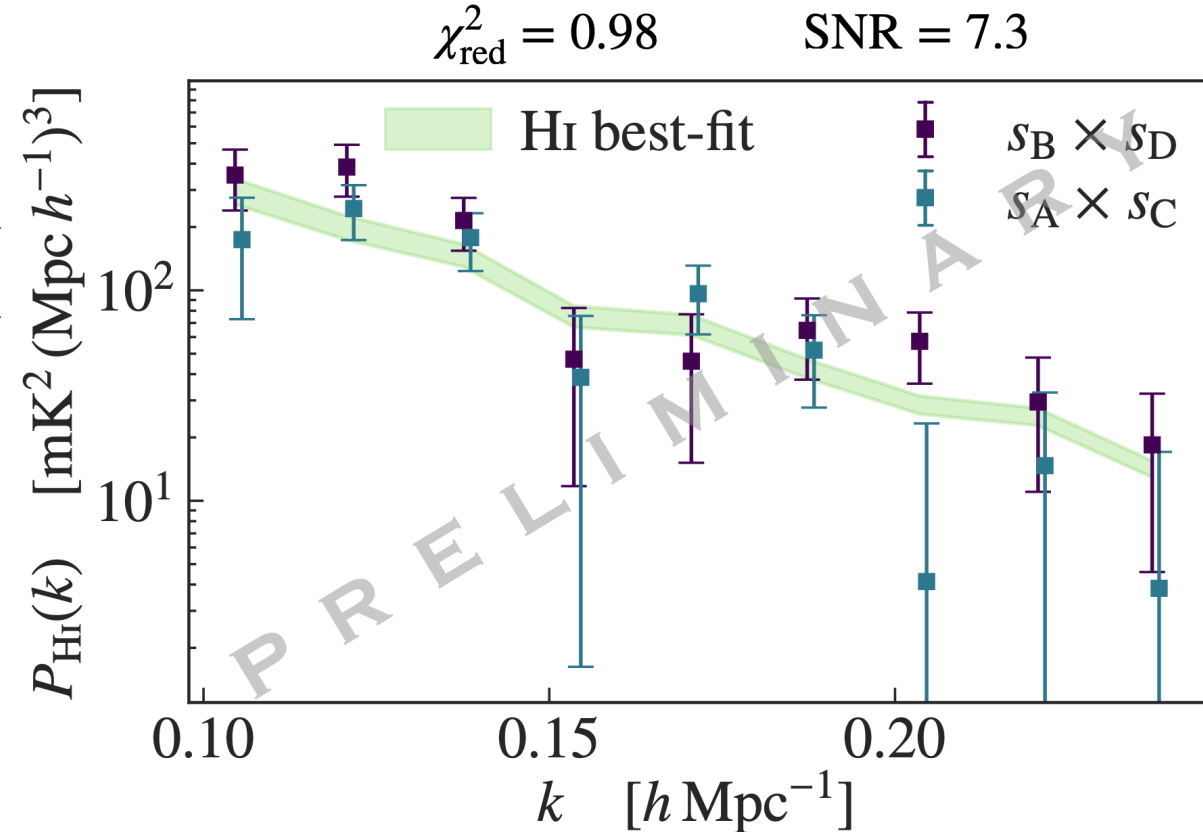
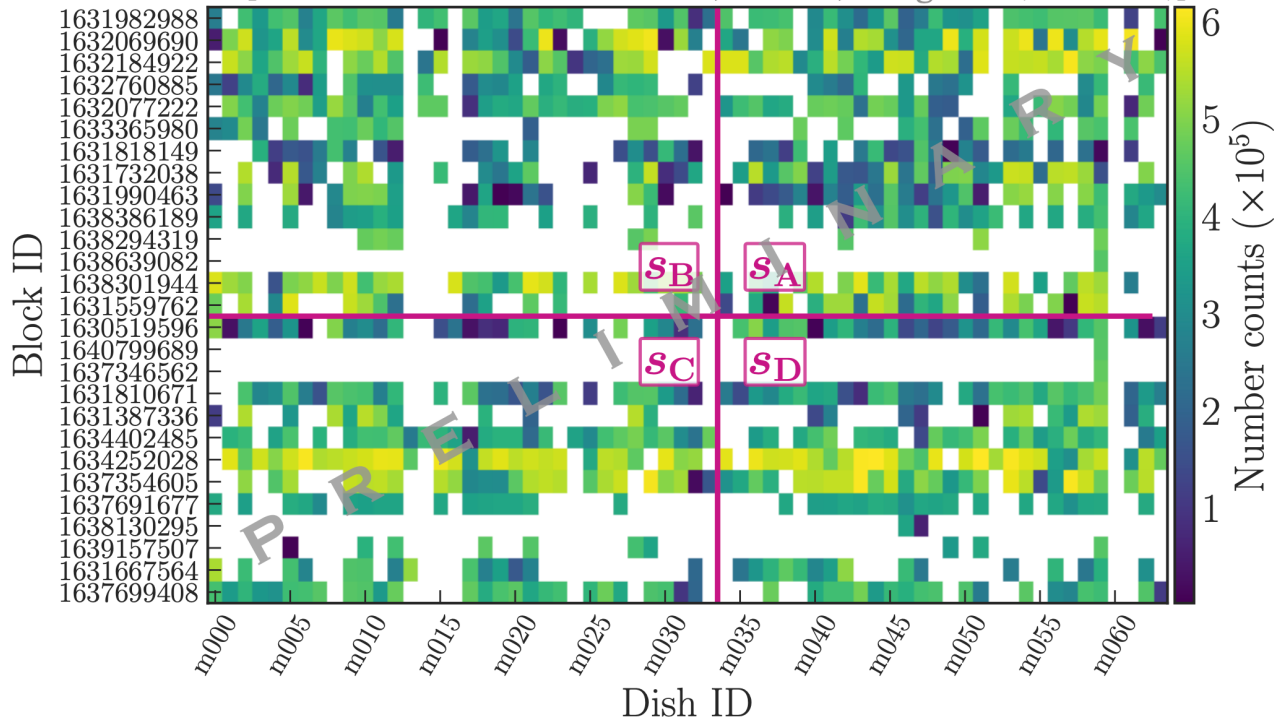
- MeerKLASS Collaboration, in review – L-band 2021 deep-field auto power spectrum detection
- MeerKLASS Collaboration (2025) – L-band 2021 deep-field cross power spectrum and stacking detections with GAMA galaxies
- Cunnington et al. (2023) – Cross power spectrum detection with WiggleZ galaxies
- Supporting papers in our full [ADS Library](#)

L-band Deep-Field Auto PS Detection



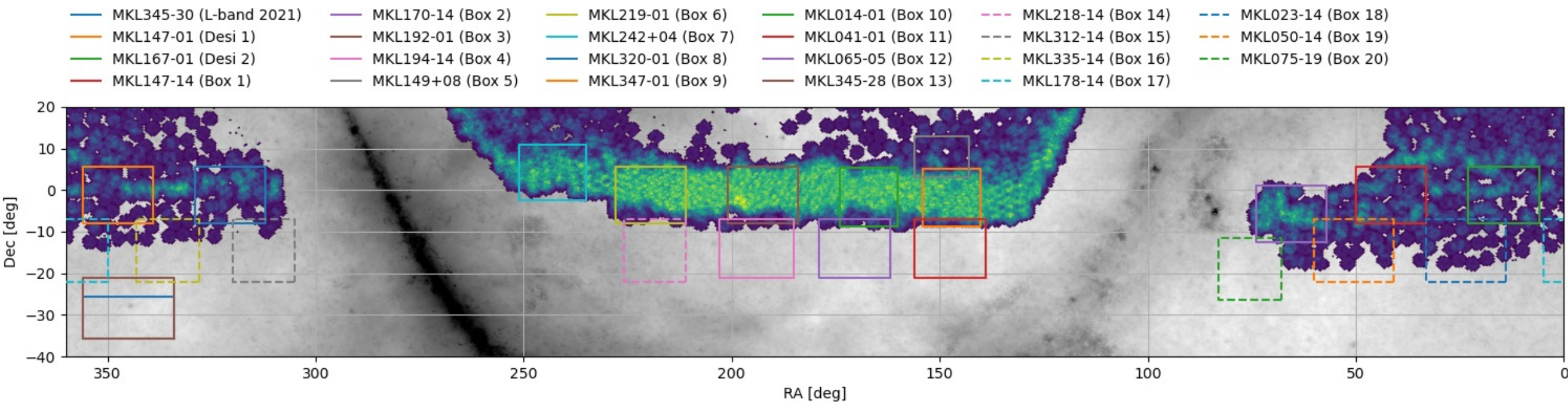
- Paper under review, led by Matilde B. Squarotti, a PhD student at Milan
- Internal correlation between dishes and time blocks for consistency check

[MeerKLASS Collaboration: MBS, Carucci, Wang et al. (submitted)]



2023+ UHF Survey

- Better RFI environment, wider redshift range $0.4 < z < 1.5$
- 2023-2024: 380 hours (Desi 1, Desi 2, Box 1 – 6)
- MeerKAT eXtra Large Project (XLP)
 - 2025: 500 hours Box 7 – 13
 - 2026: 500 hours Box 14 – 20 (tentative)
- Large overlap with DESI surveys (blue—green dots)

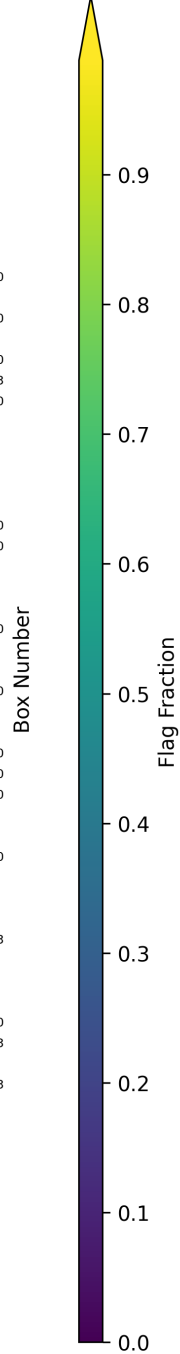
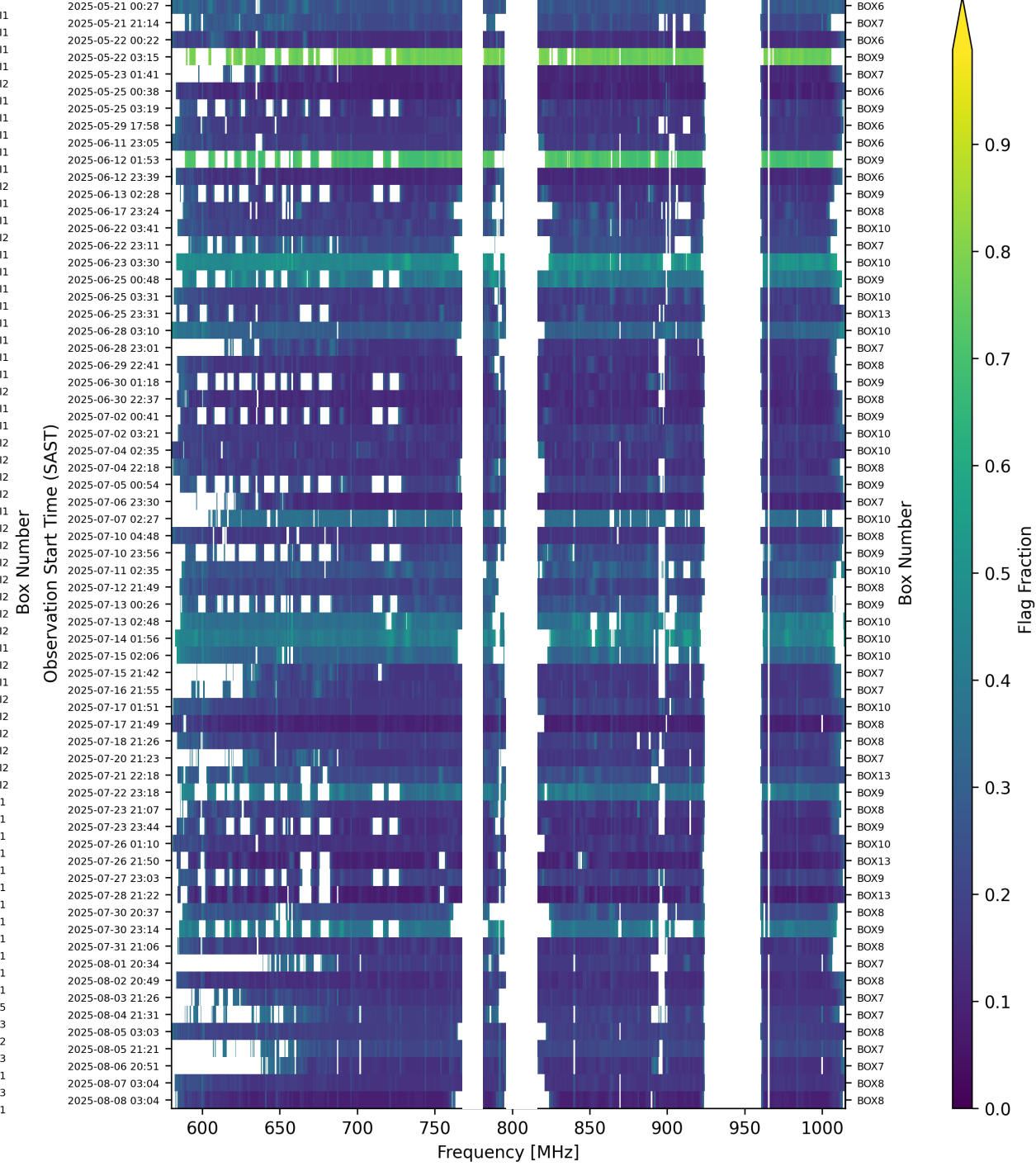
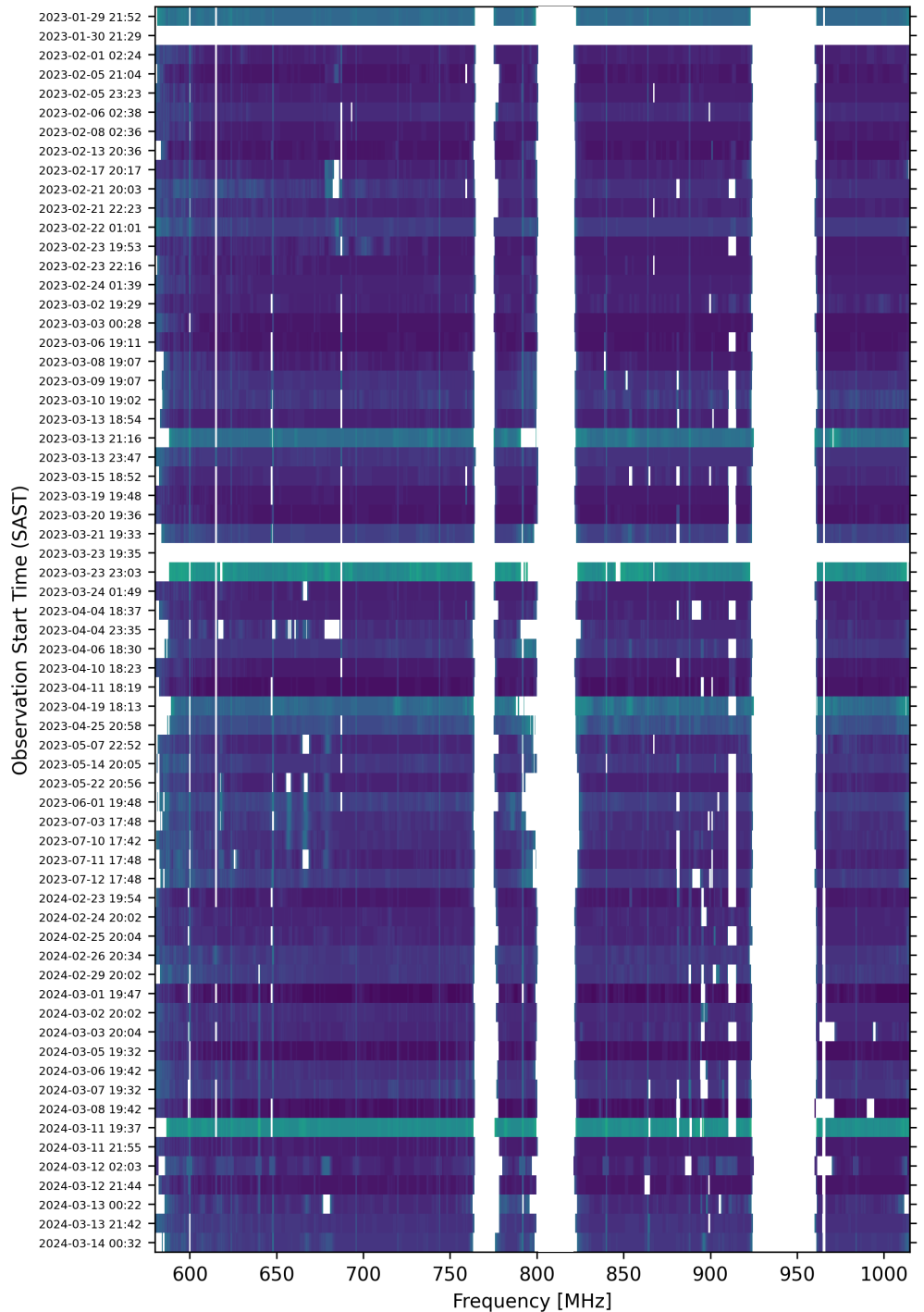


RFI

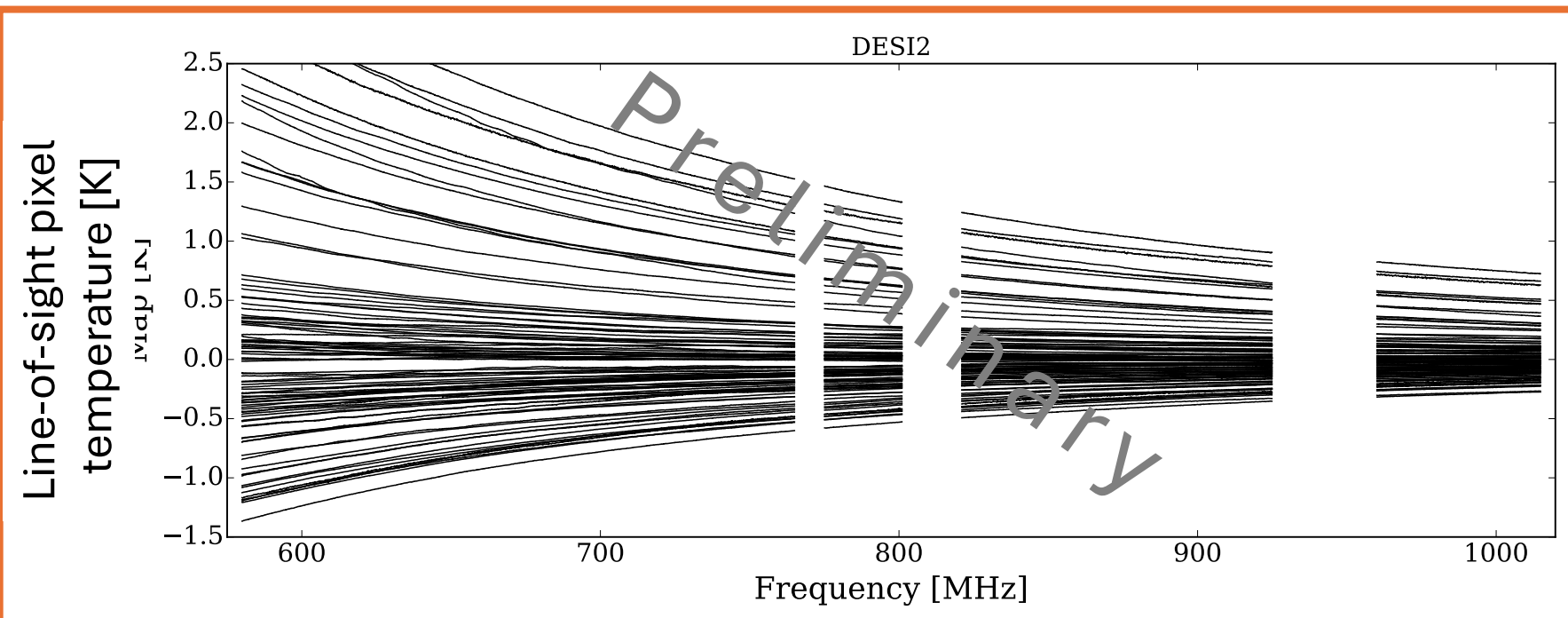
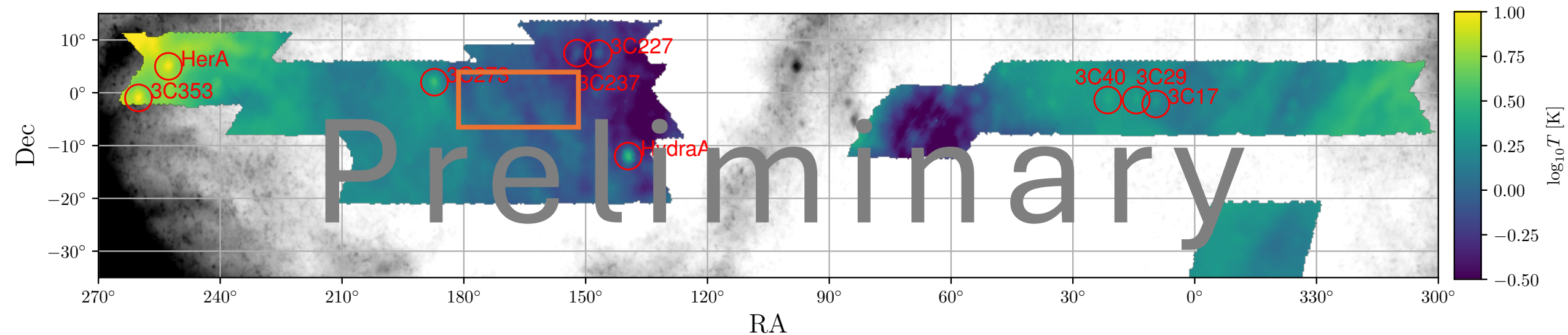
is

an

Issue



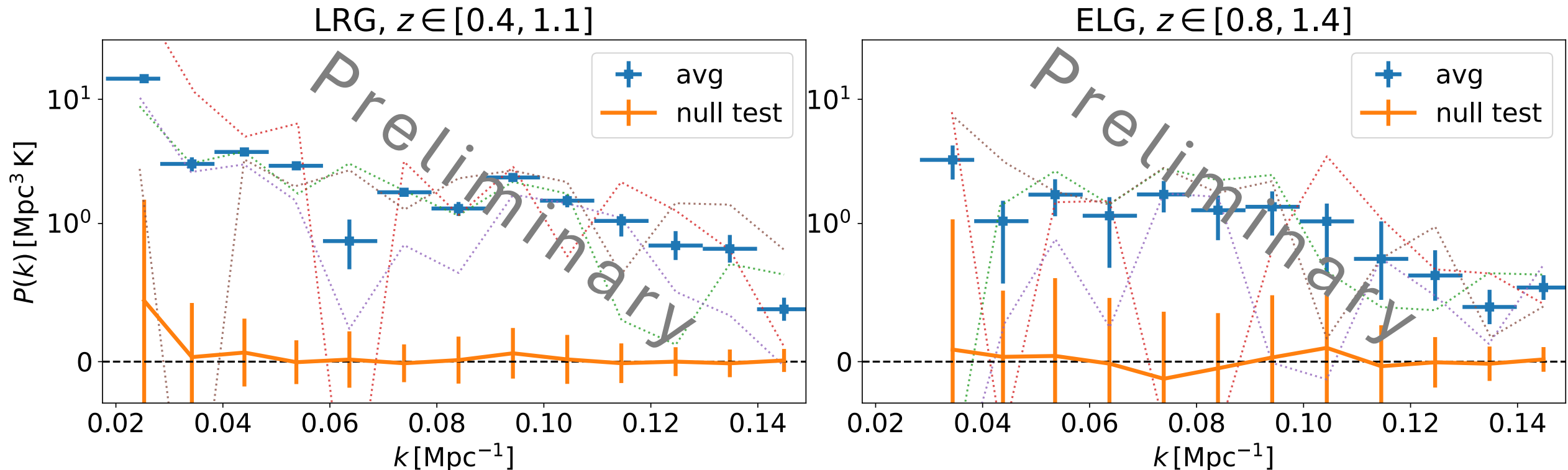
2023+ UHF Survey Preliminary Analysis



- Calibrated maps look okay, dominated by synchrotron

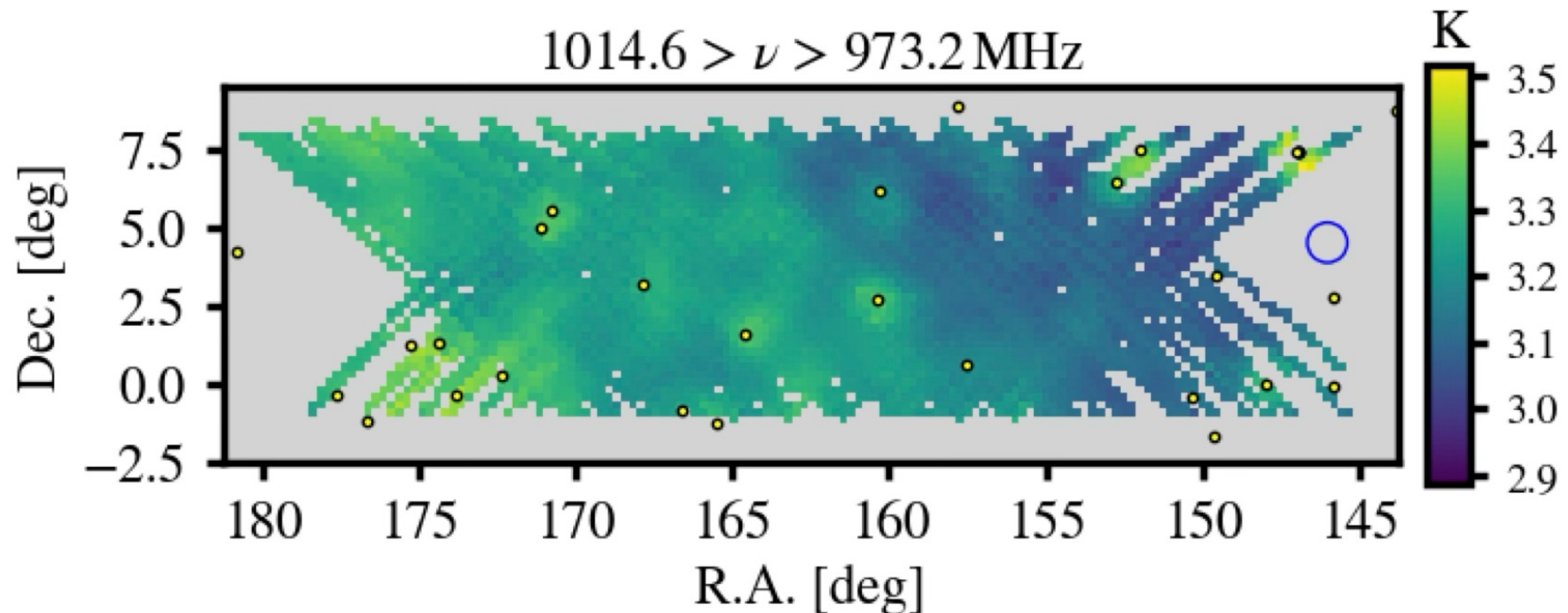
2023+ UHF Survey Preliminary Analysis

- Preliminary cross power spectrum with DESI Luminous Red Galaxies (LRG) at $z \in [0.4, 1.1]$ and Emission Line galaxies (ELG) at $z \in [0.8, 1.4]$ from 4 sky patches
- Null test is consistent with zero



IM Data Release I

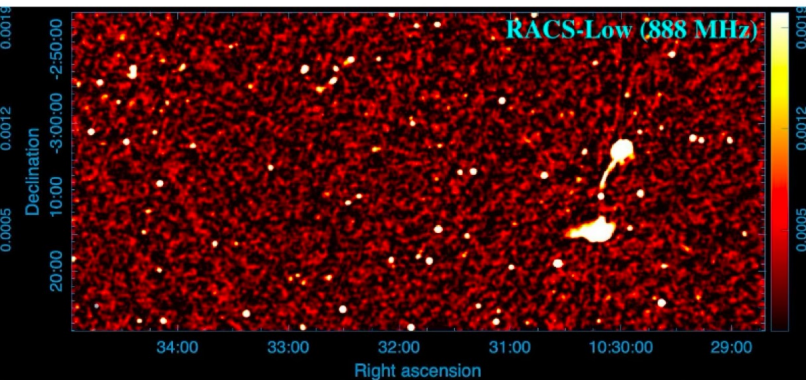
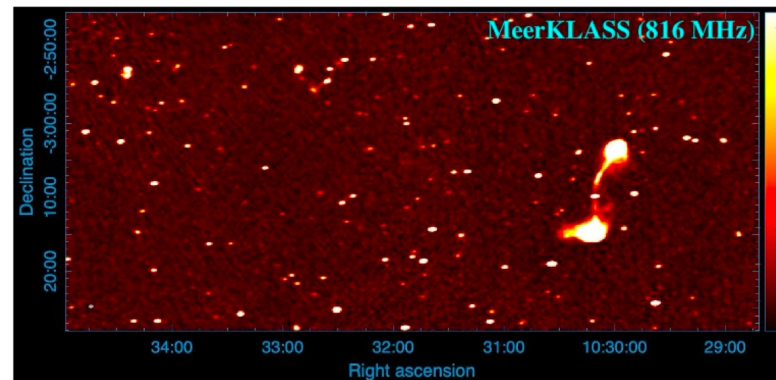
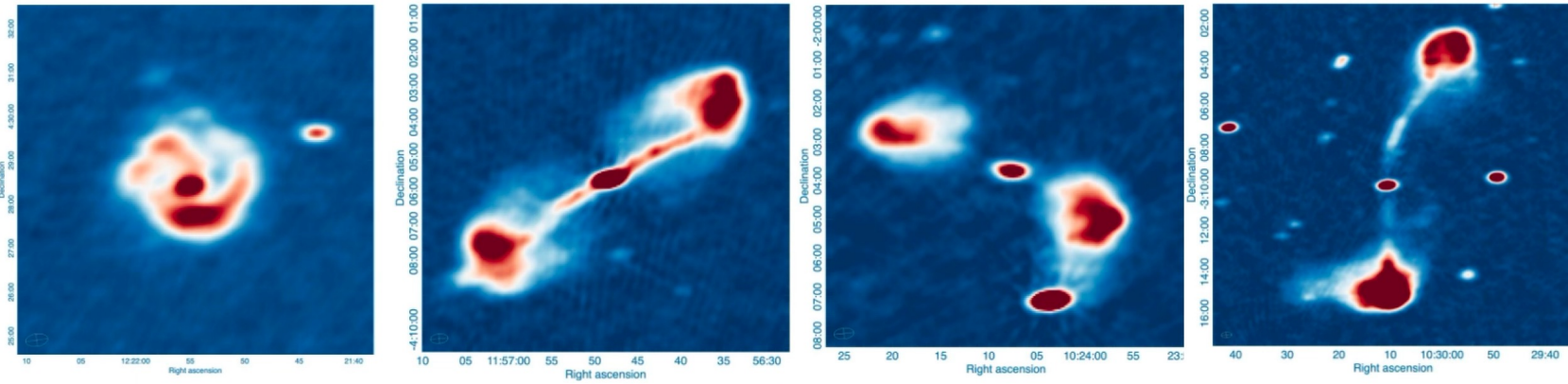
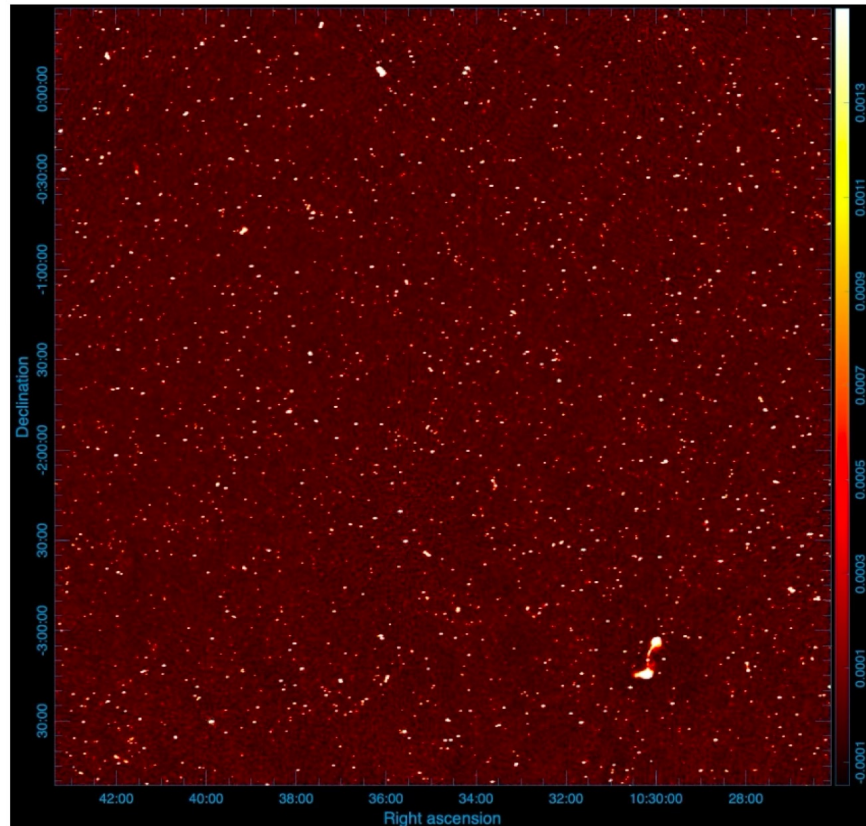
- We are committed to releasing data from our survey in regular intervals starting in December 2025
- We have released the HI intensity cubes after map-making accompanied by a Jupyter notebook with basic data I/O from the 2019 L-band campaign
- <https://meerclass.org/data.html>



On-the-Fly (OTF) Mapping

- Combine interferometric data from the 2s integrations from the scans to form mosaicked continuum images (Chatterjee et al., submitted to MNRAS, arXiv:2512.11978)
- ~ 35 μ Jy rms noise (currently) in Stokes I at angular resolution of $\sim 14'$
- Sciences: galaxy evolution and cosmology, clusters, transients

(images by Sourabh Paul)



OTF Data Release I

- 268 deg² of L-band (856-1712 MHz) and 800 deg² of UHF band (544-1088 MHz) continuum imaging and associated source catalogs.
- <https://meerklass.org/OTFdata.html>
- Mangla et al., “The MeerKLASS L-band On-the-Fly Continuum Survey: Data Release 1”, submitted to MNRAS, arXiv:2512.17685
- Paul et al., “The MeerKLASS UHF On-the-Fly Continuum Survey – Data Release I”, submitted to MNRAS, arXiv:2512.11964

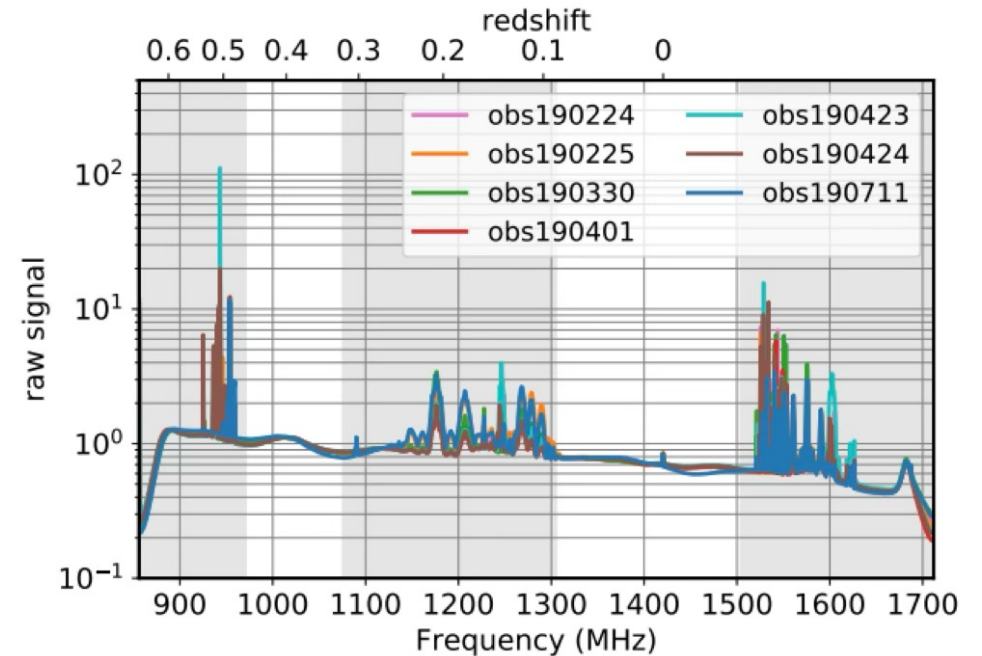
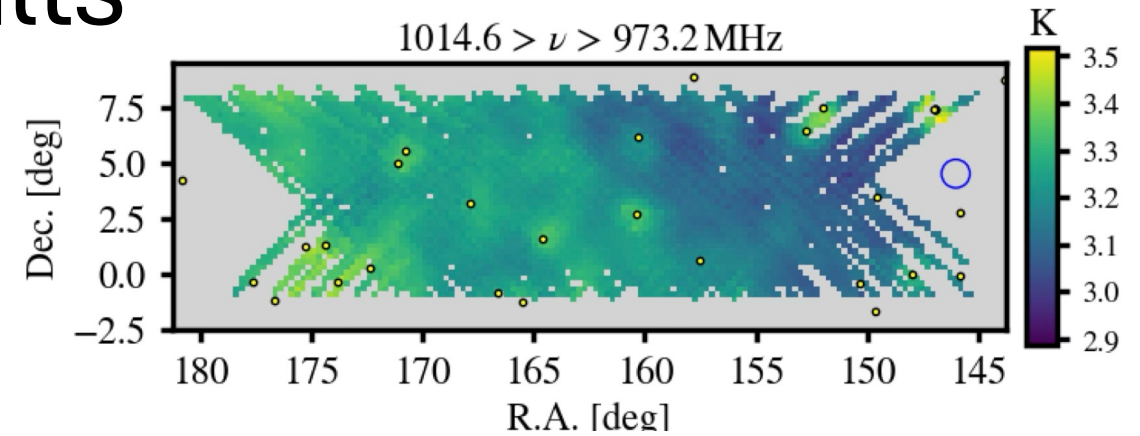
Summary

- HI intensity mapping with MeerKAT (and from 2030s SKAO) in single dish mode will deliver state of the art cosmological constraints: BAO in HI – dark energy, RSDs – modified gravity, primordial non-Gaussianity
- Huge potential in cross-correlating with galaxy surveys!
- We have solid detections of the HI IM power spectrum in “cross” and tentative in “auto”
- We also produce high-angular resolution continuum images with the MeerKAT interferometer data – millions of galaxies/transients!
- Ongoing observations and data processing with UHF data – goal is to observe 2,500 hours over 10,000 deg² (25 μ Jy in continuum)

Back up slides

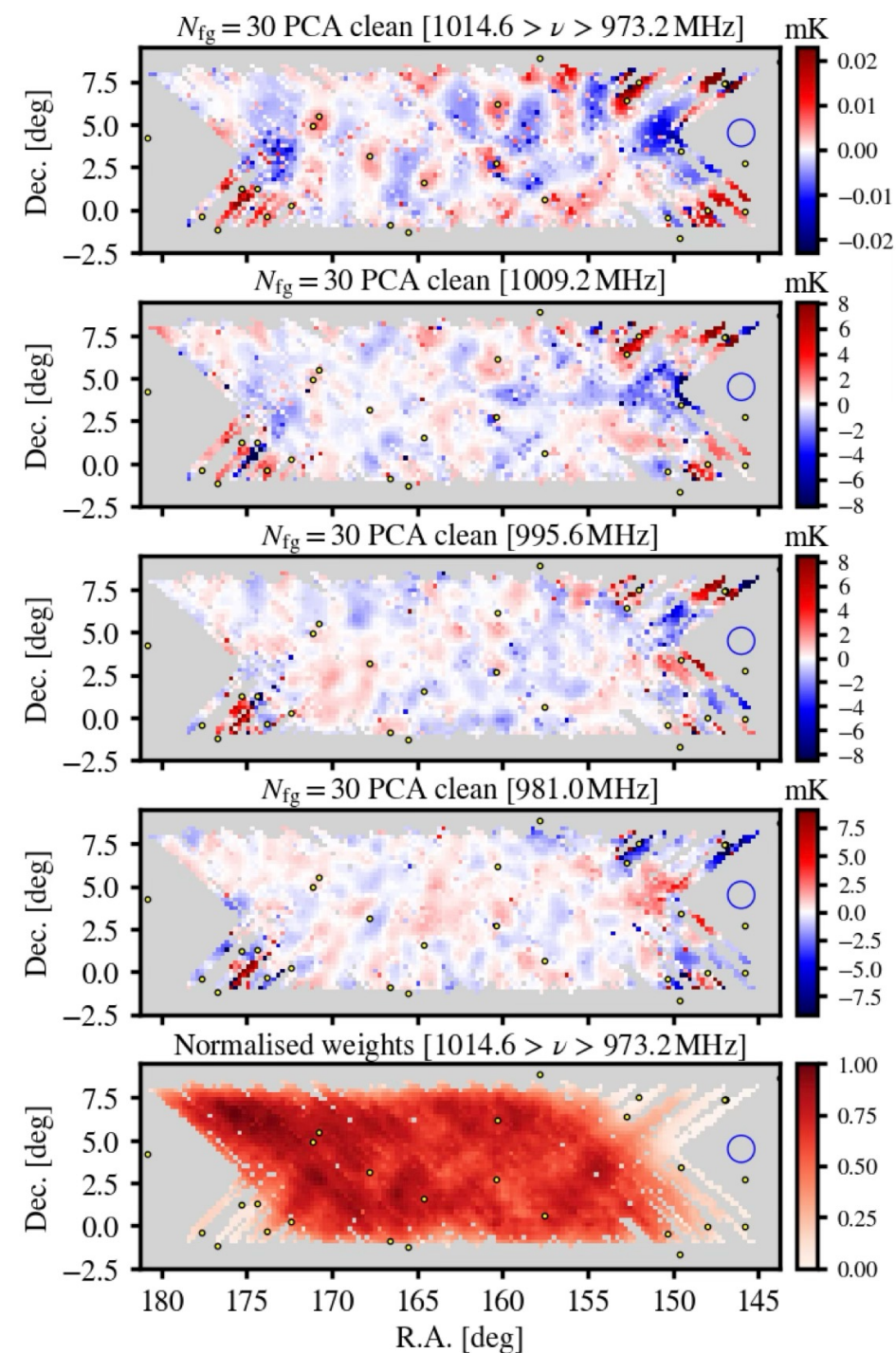
2019 L-Band Survey – Results

- 10.5 hrs data covering 200deg in WiggleZ 11hr field over $0.4 < z < 0.45$
- Calibration following Wang et al 2021



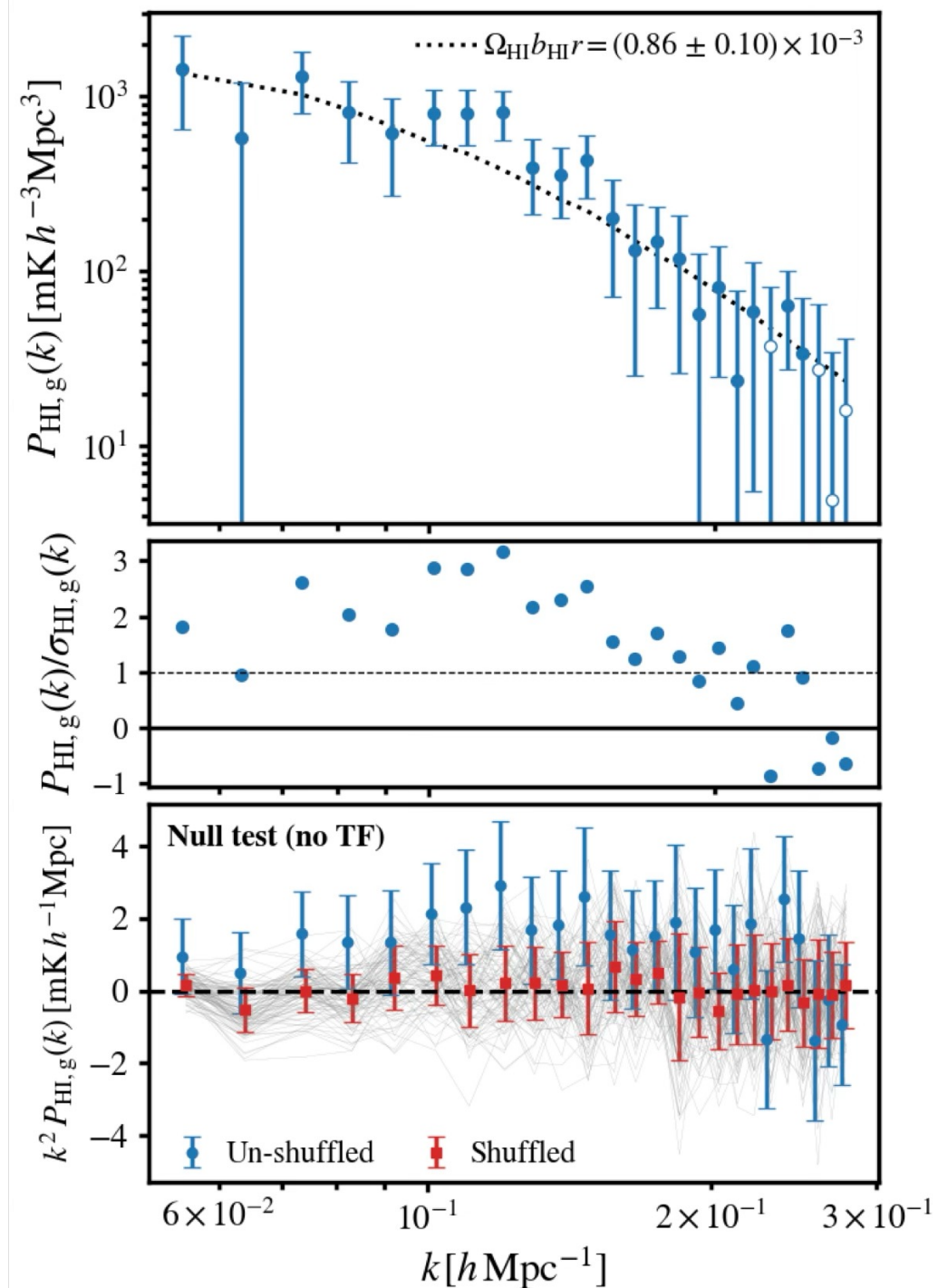
2019 L-Band Survey – Results

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- **Foreground removal with PCA**



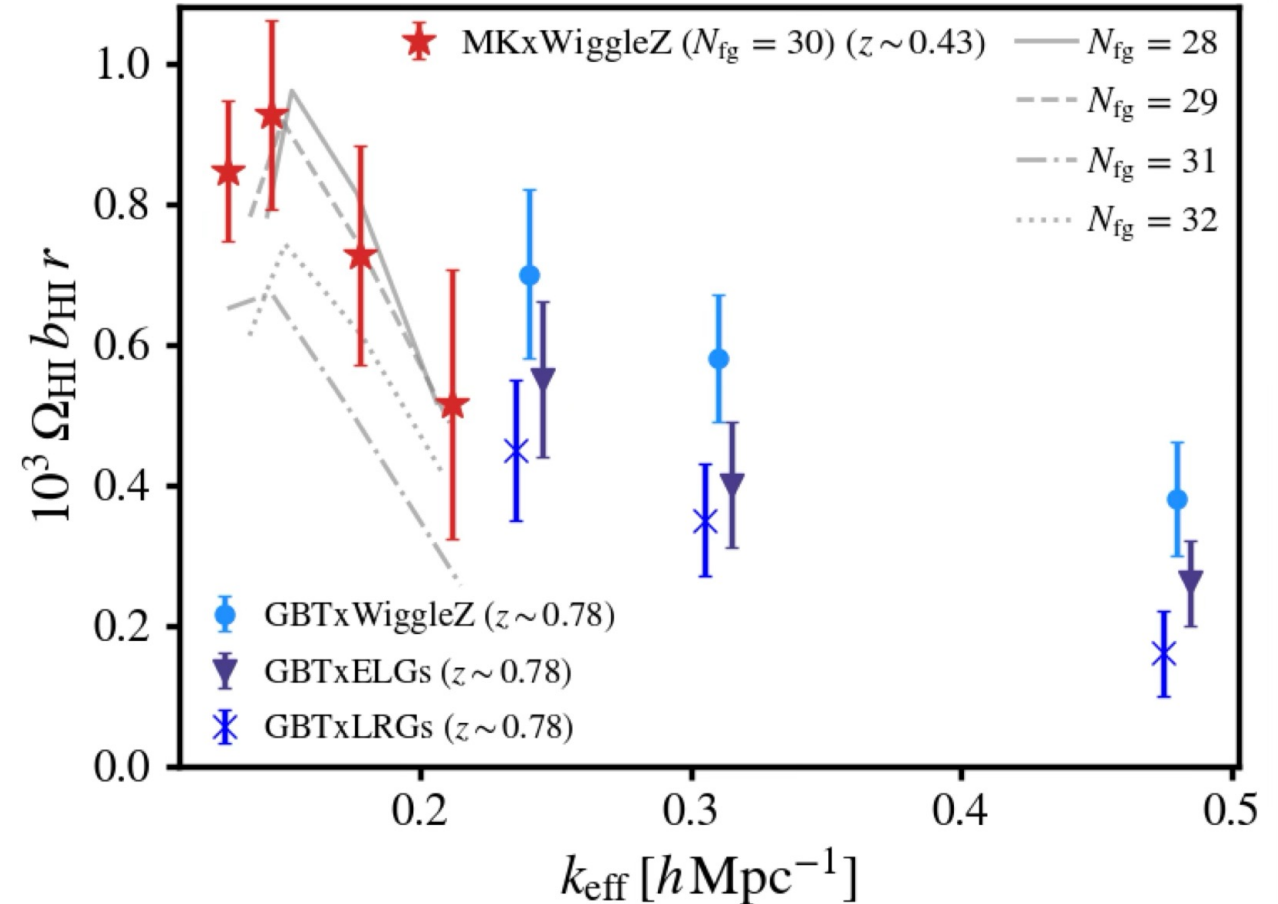
2019 L-Band Survey – Results

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- Foreground removal with PCA
- Signal loss corrected via transfer function
- **Cross-correlation with WiggleZ galaxies**



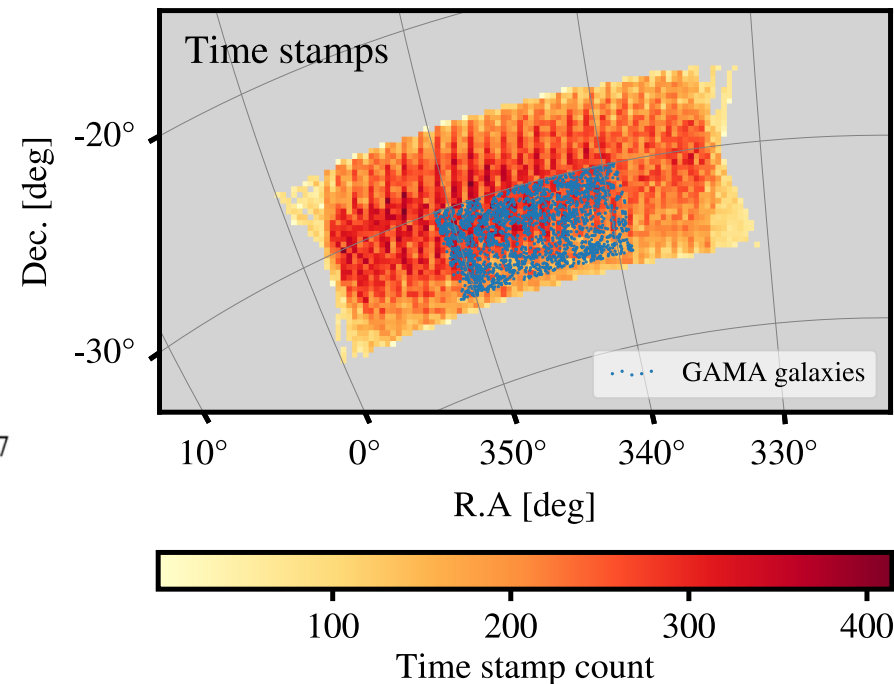
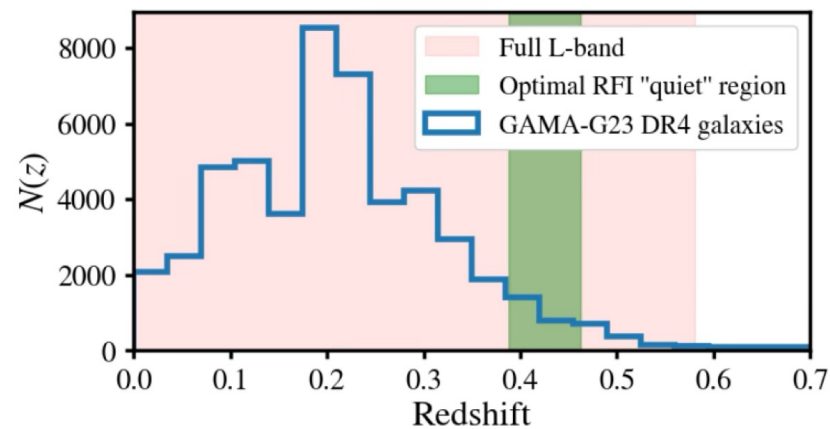
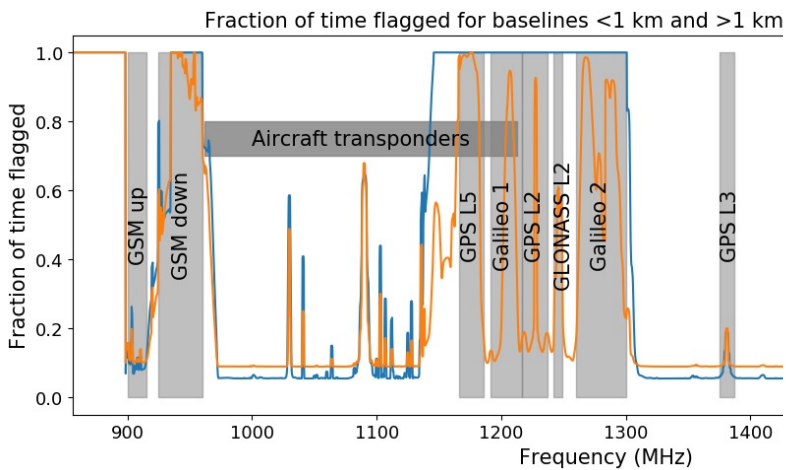
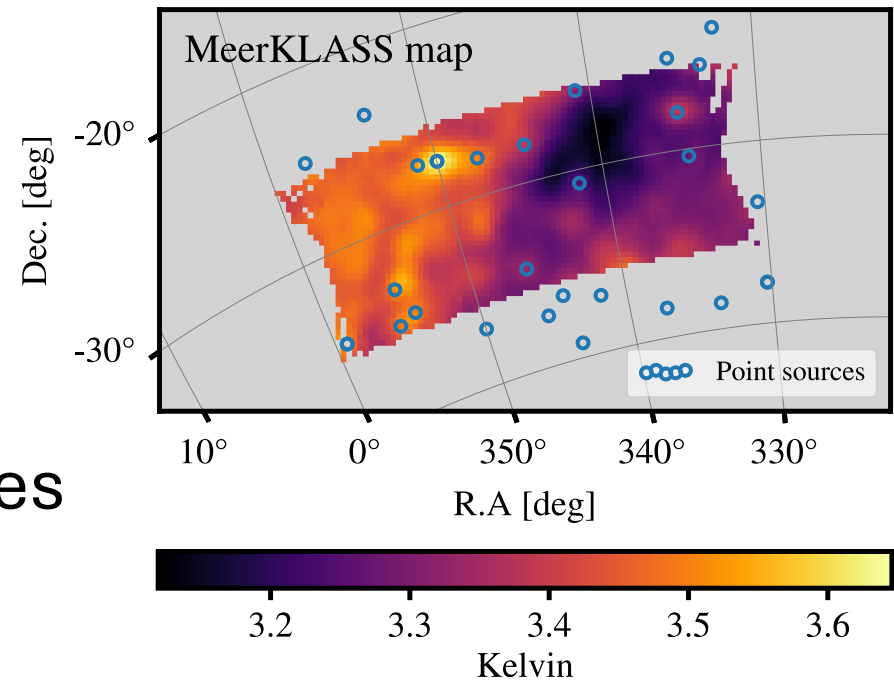
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- Calibration following Wang et al 2021
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- Signal loss corrected via transfer function
- Cross-correlation with WiggleZ galaxies
- **Constraints on HI density**



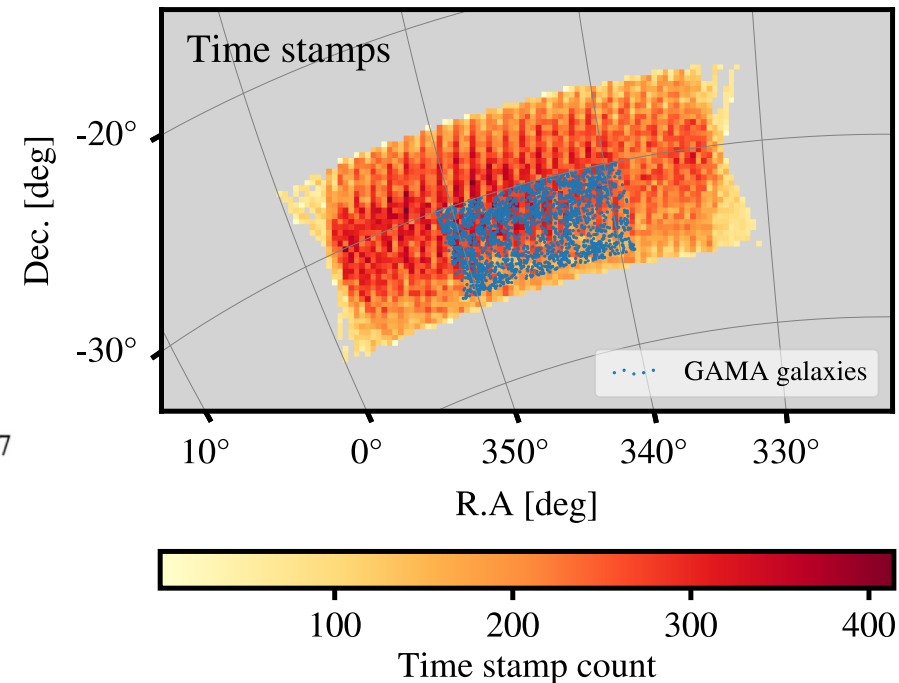
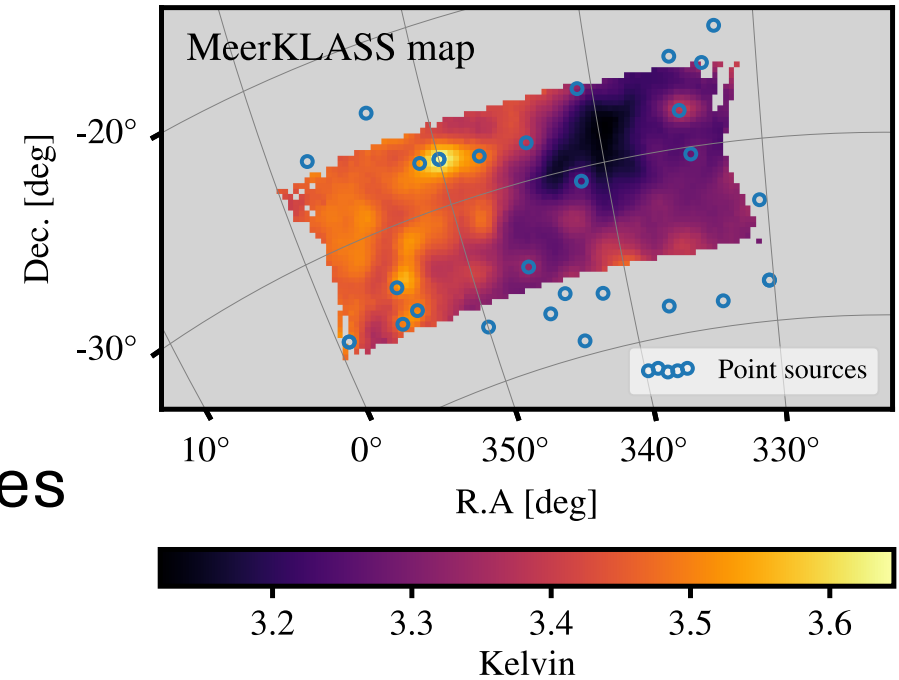
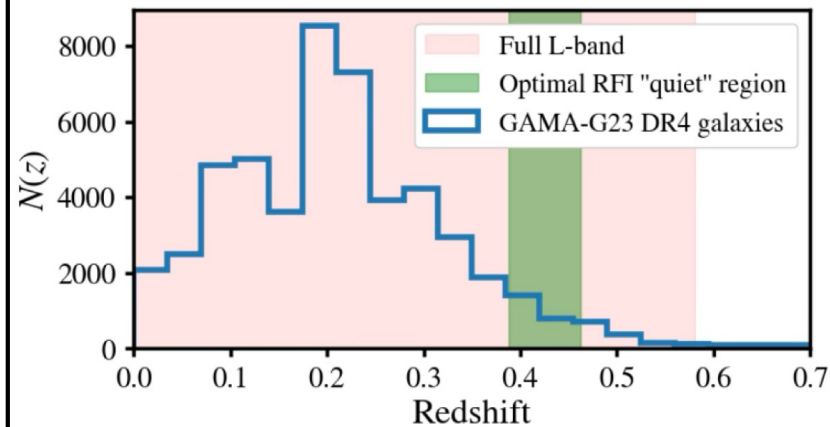
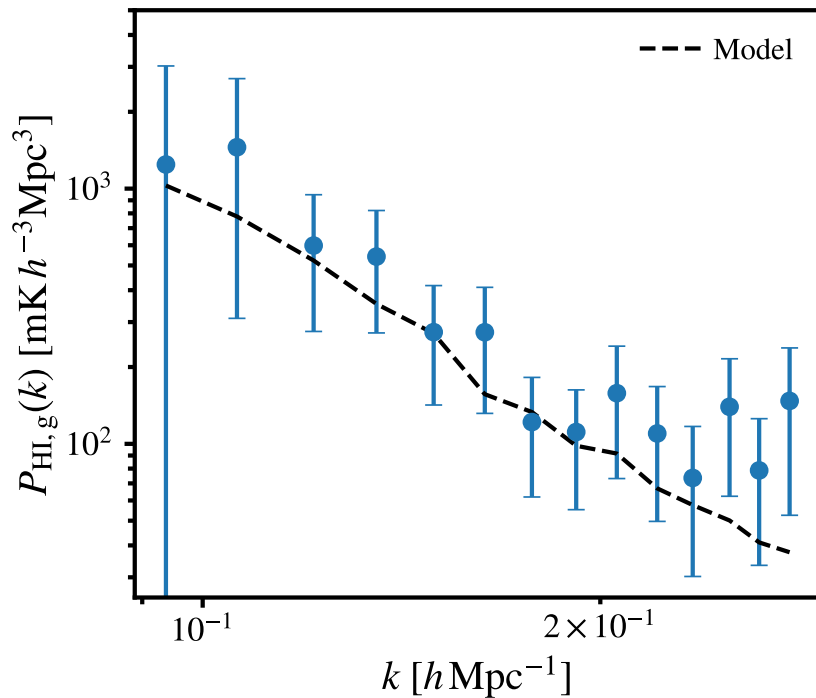
2021 L-Band Survey

- 61.5 hr data covering 300sqdeg deep field at the GAMA G23 galaxy survey field
- Small overlaps due to RFI from telecom satellites

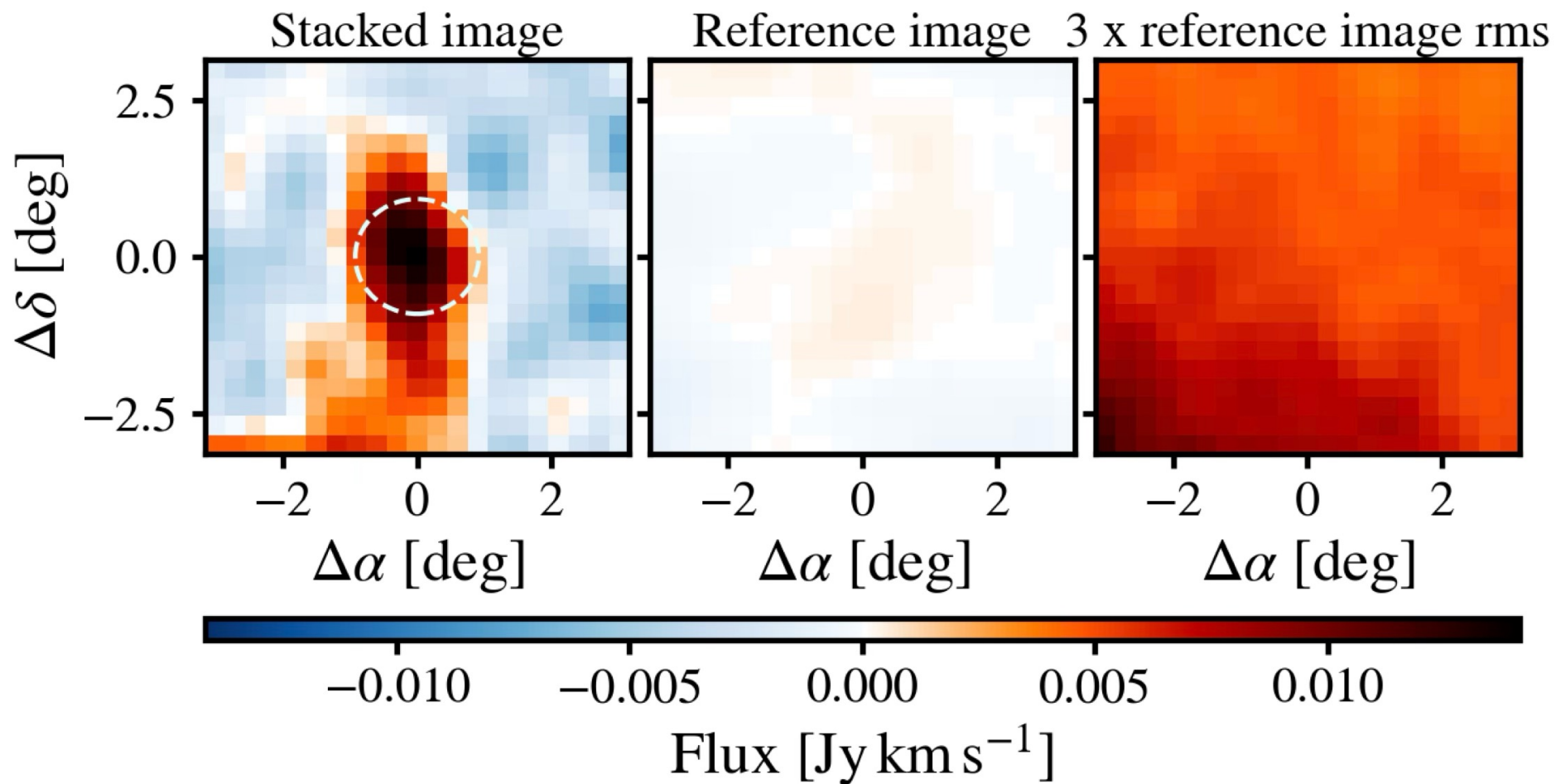


2021 L-Band Survey

- 61.5 hr data covering 300sqdeg deep field at the GAMA G23 galaxy survey field
- Small overlaps due to RFI from telecom satellites
- $>4\sigma$ detection in cross-correlation with GAMA



2021 L-Band Survey – Stacking Analysis



Left panel: The angular stacking of the GAMA galaxies on the HI intensity map. The dashed circle denotes the FWHM of the beam. Central panel: The reference null detection image from 100 realizations of random galaxy positions. Right panel: The standard deviation of the reference image multiplied by 3 to visualize the 99.7 per cent confidence interval.