Galaxy Clusters selected via the SZ Effect in the SPT-3G Survey

Lindsey Bleem
Argonne National Laboratory/KICP
June 24, 2025


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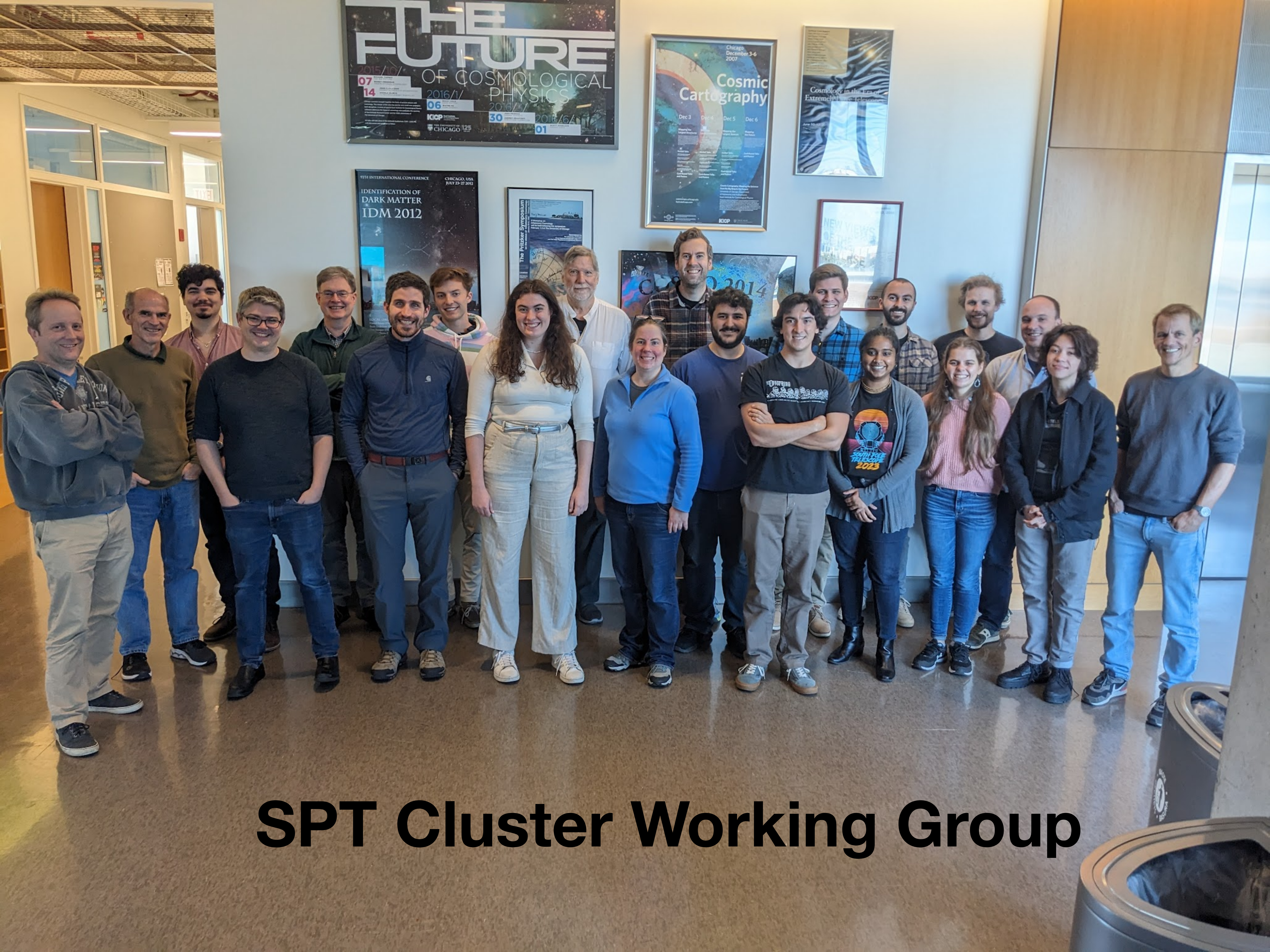
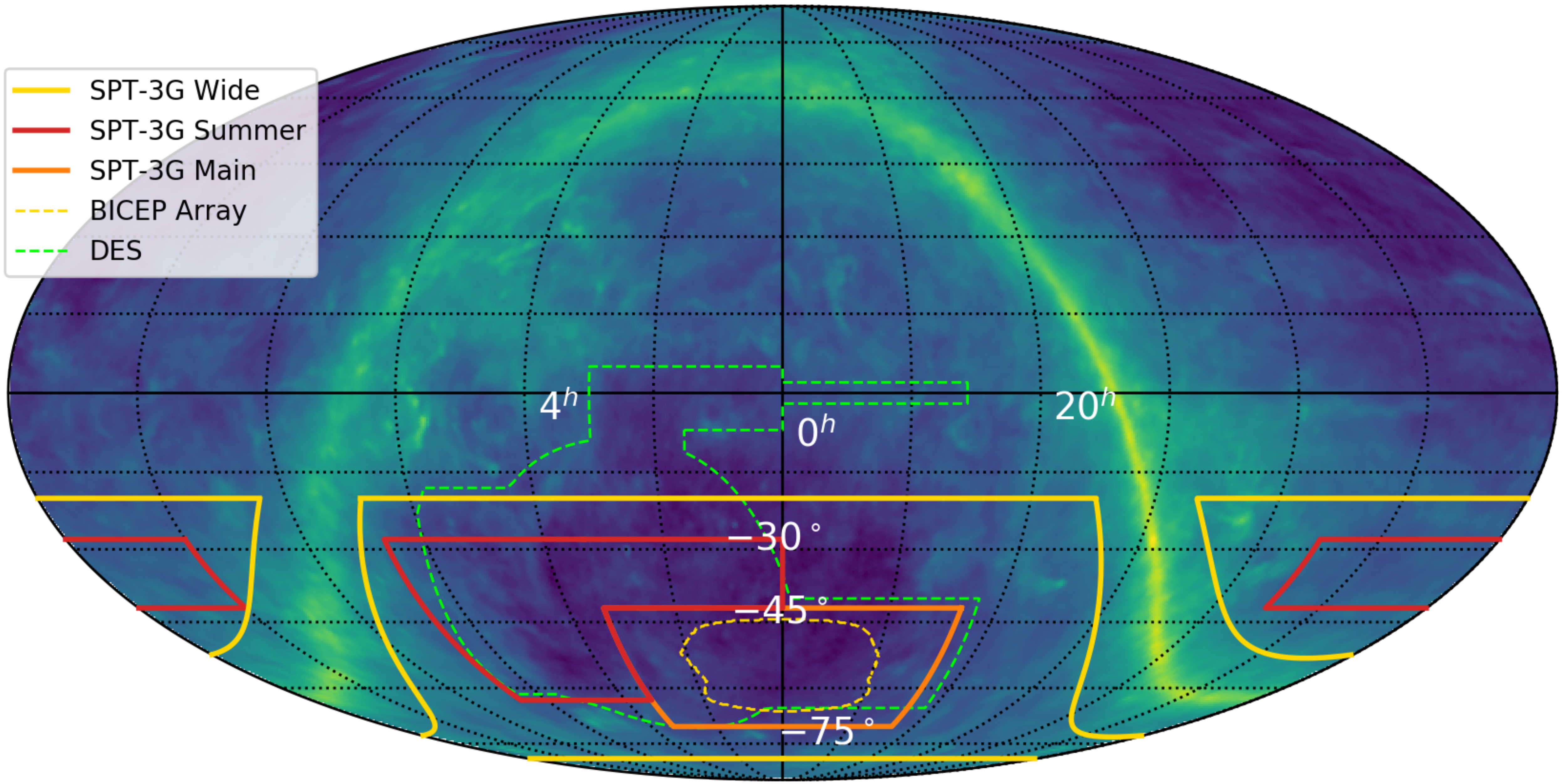


SPT Cluster Working Group


THE FUTURE OF COSMOLOGICAL PHYSICS
Cosmic Cartography
Chicago December 3-6 2007
IDENTIFICATION OF DARK MATTER
IDM 2012
The Pritzker Symposium
S. Bocquet, G. Campitiello^, A. Hryciuk*, F. Kéruzoré^,
M. Gladders, A. Kisare*, M. Klein^, K. Kornoelje*, E.
Marsten*, T. Stark, J. Sobrin^, R. Walker*
^ postdoc, * student

The 10,000 sq-degree SPT-3G Survey(s)



Survey	Area [deg^2]	Years observed	Noise level (T) [μK-arcmin]			
			95 GHz	150 GHz	220 GHz	Coadded
SPT-3G Main	1500	2019-2023, 2025-2026+	<2.5	<2.1	<7.6	<1.6
SPT-3G Summer	2600	2019-2023	8.5	9.0	31	6.1
SPT-3G Wide	6000	2024	14	12	42	8.8

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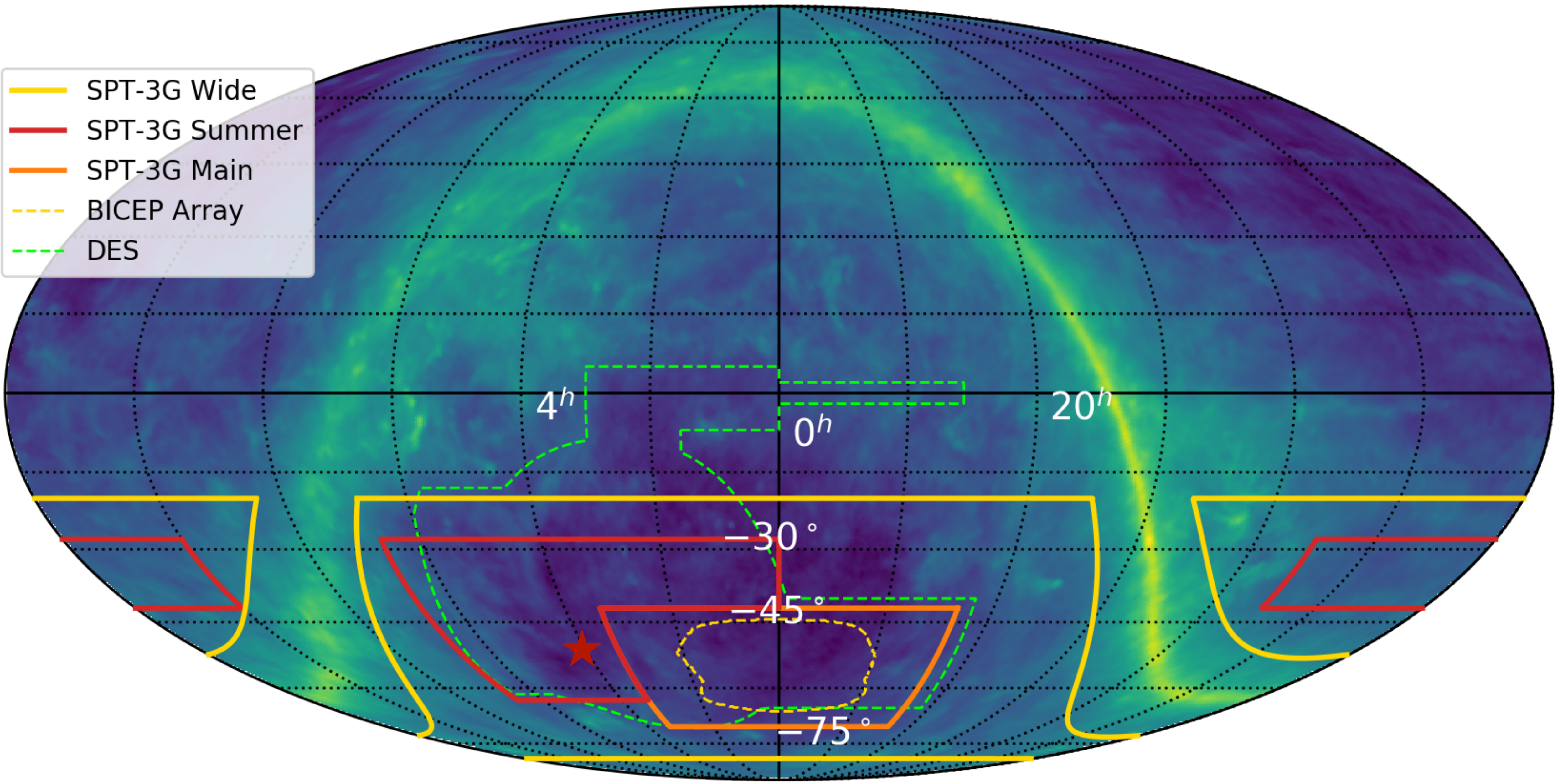

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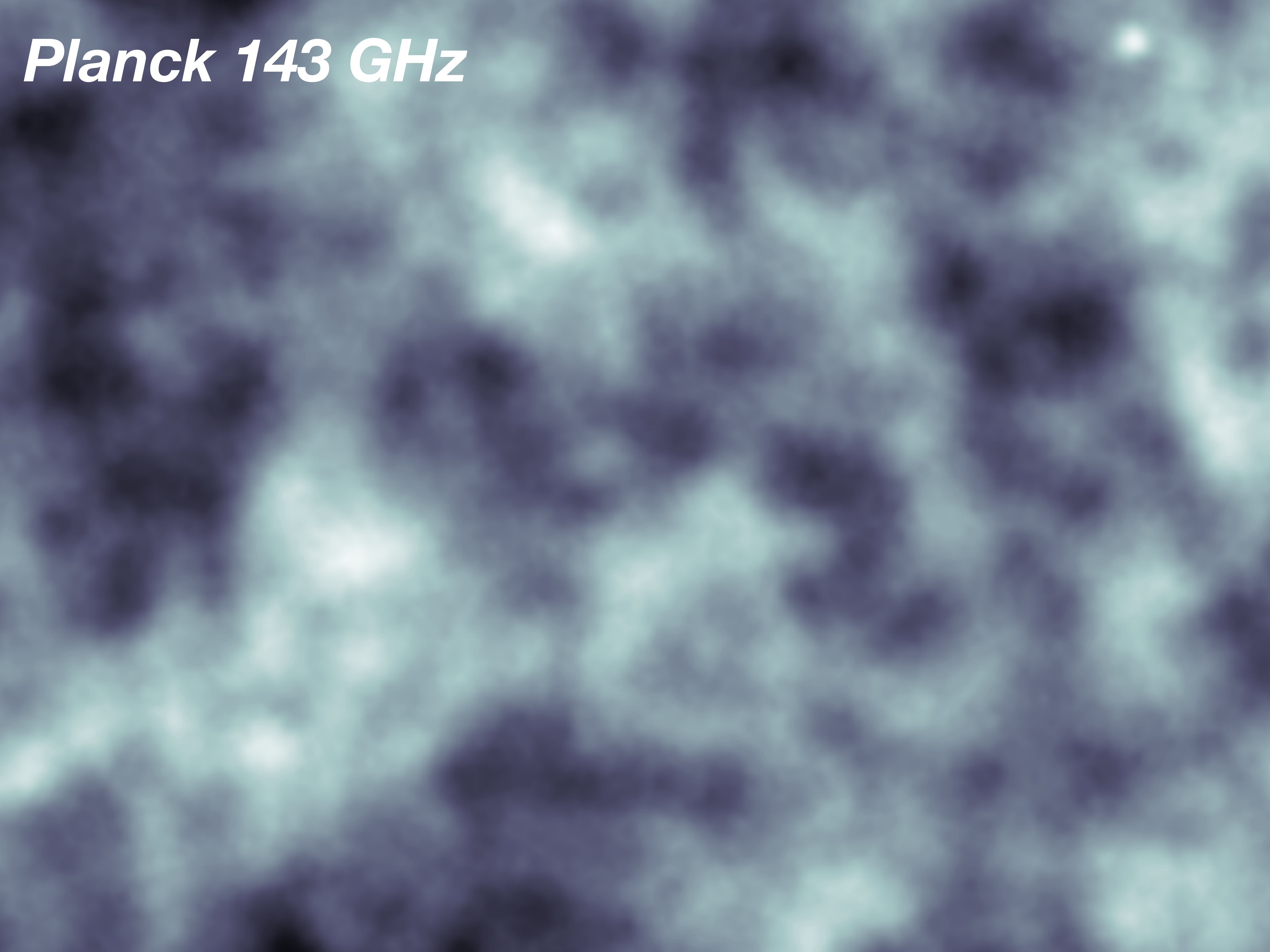
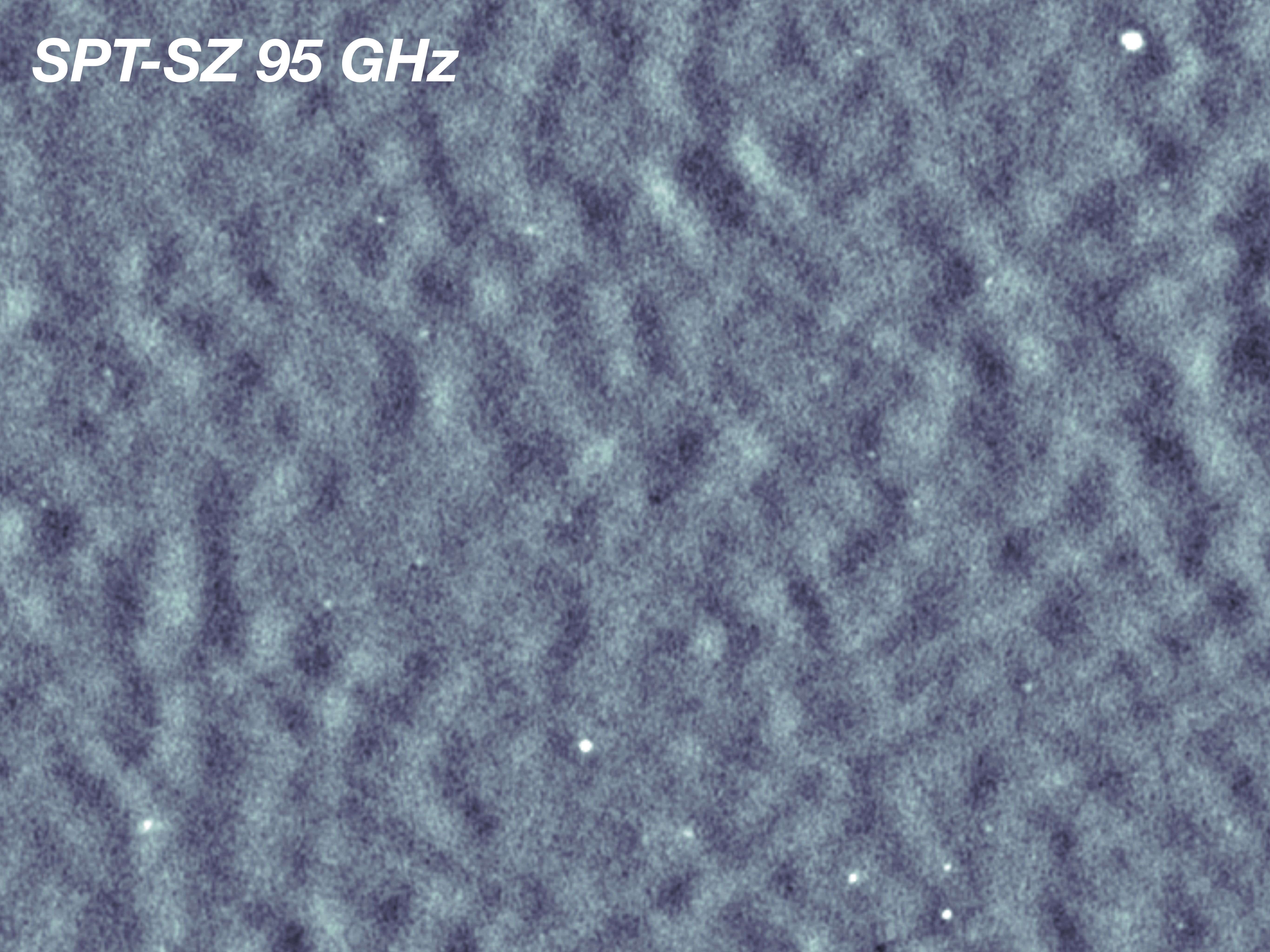
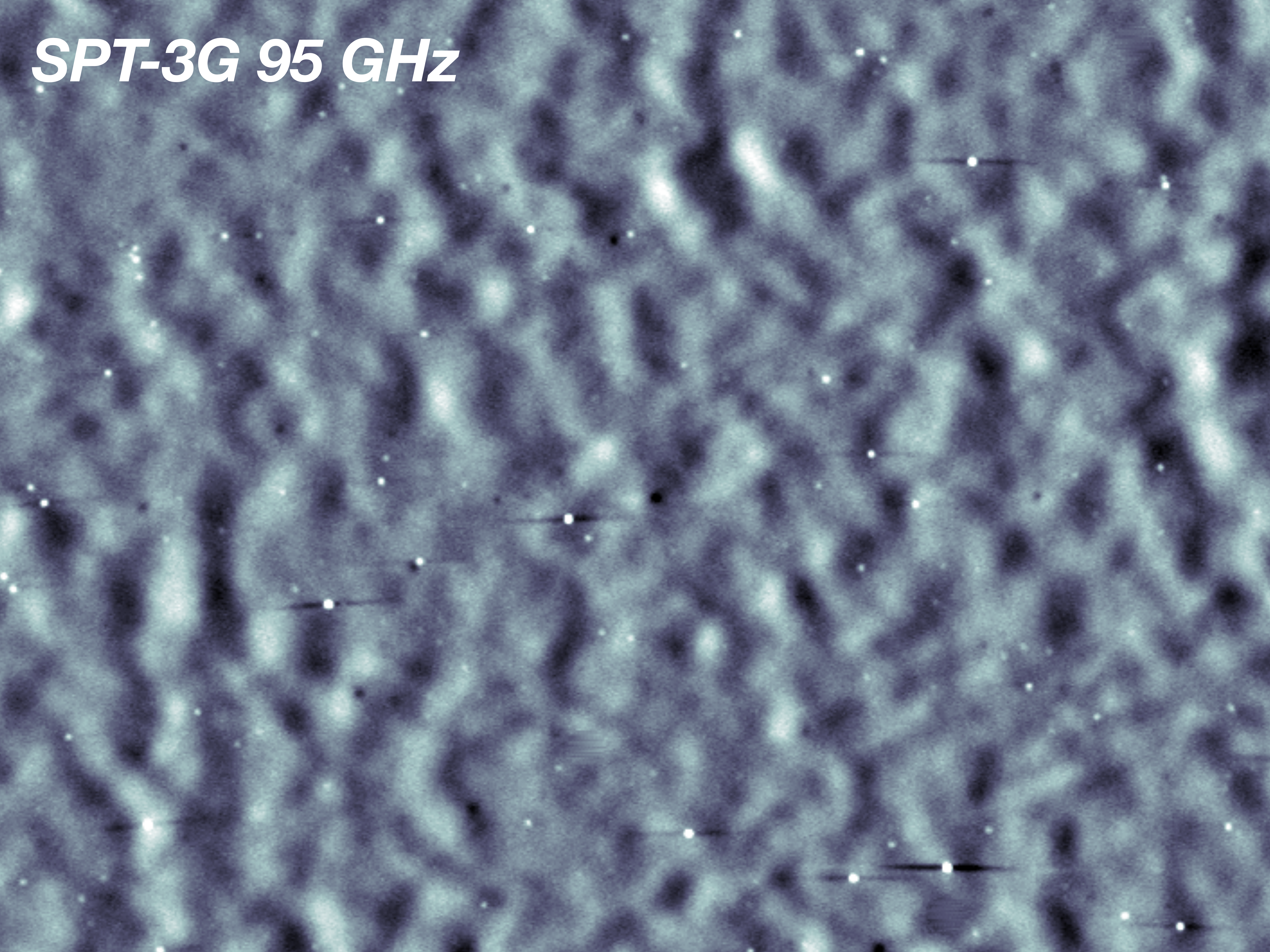
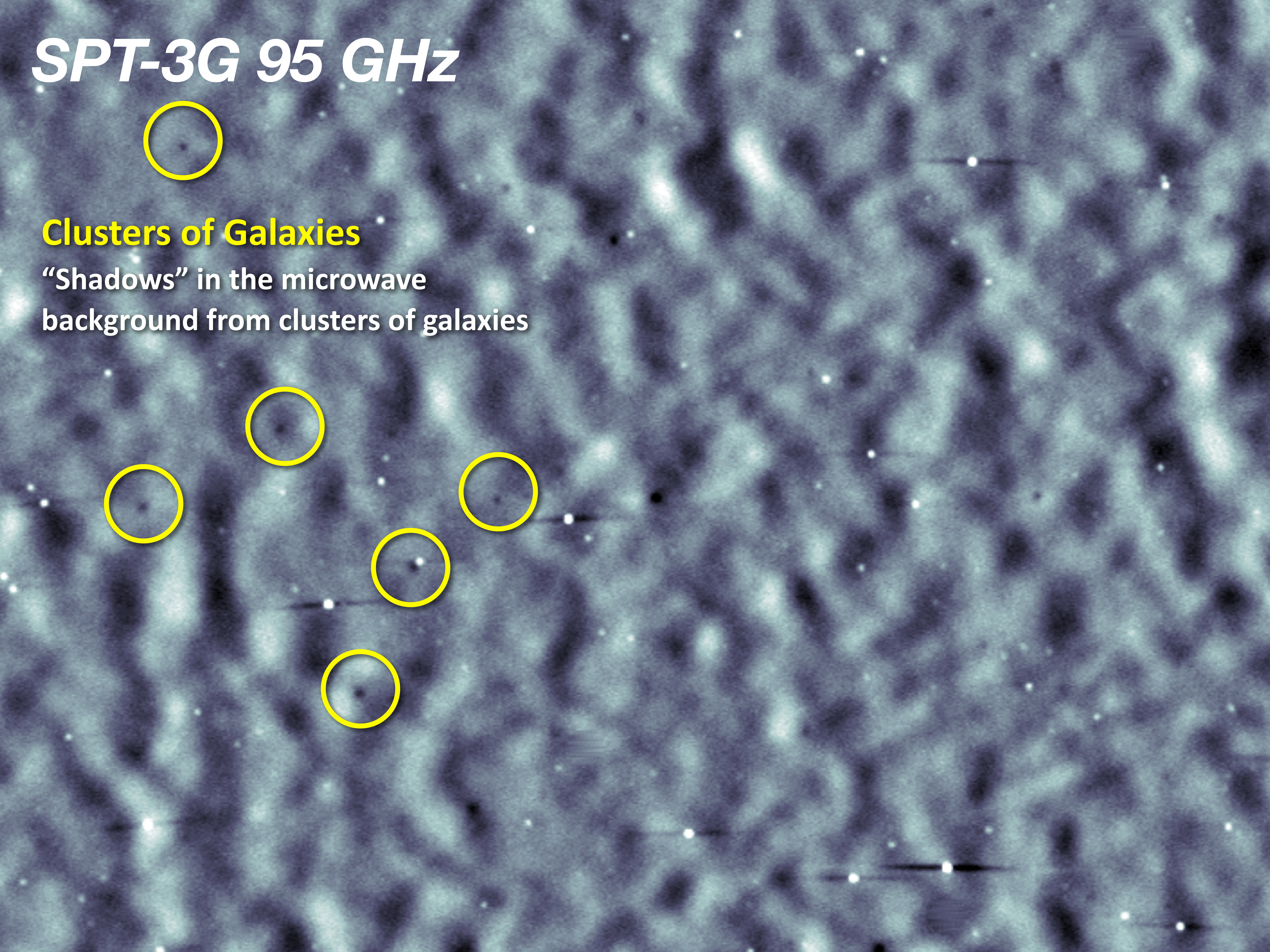
★ Euclid Deep Field South

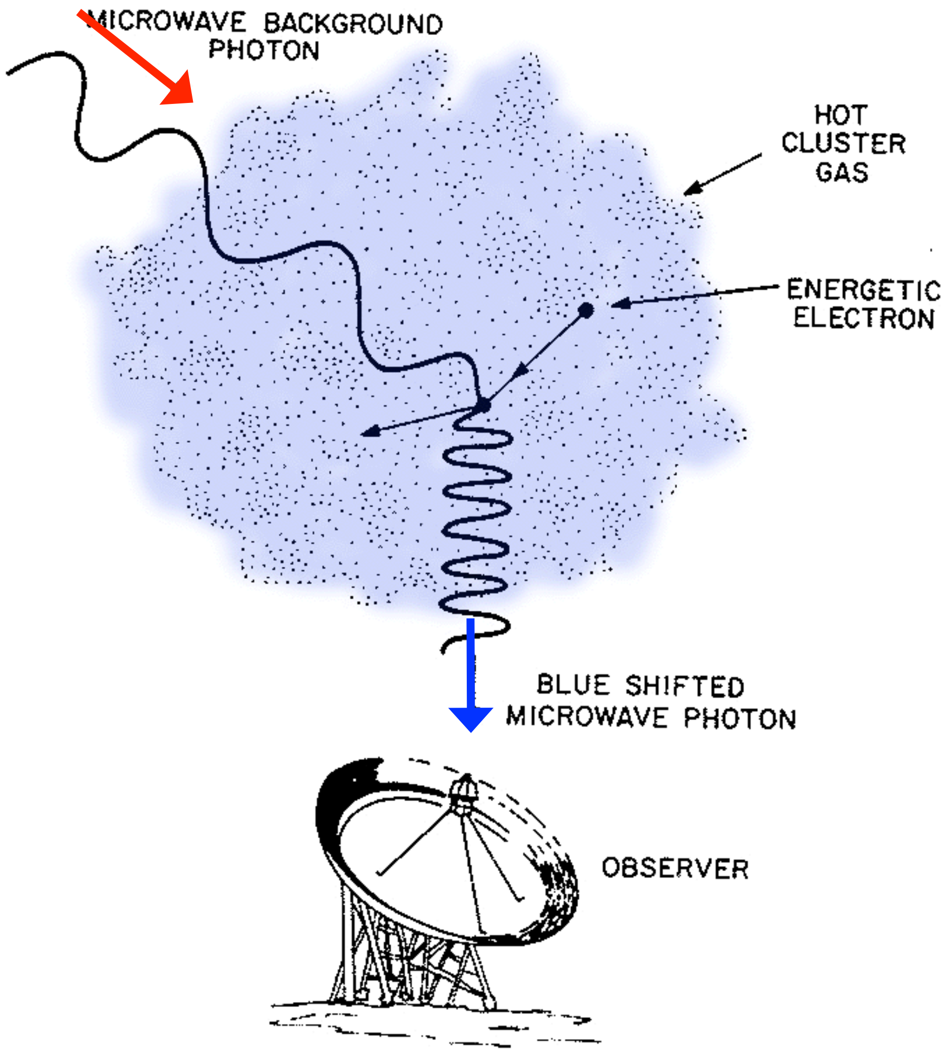

Planck 143 GHz


SPT-SZ 95 GHz

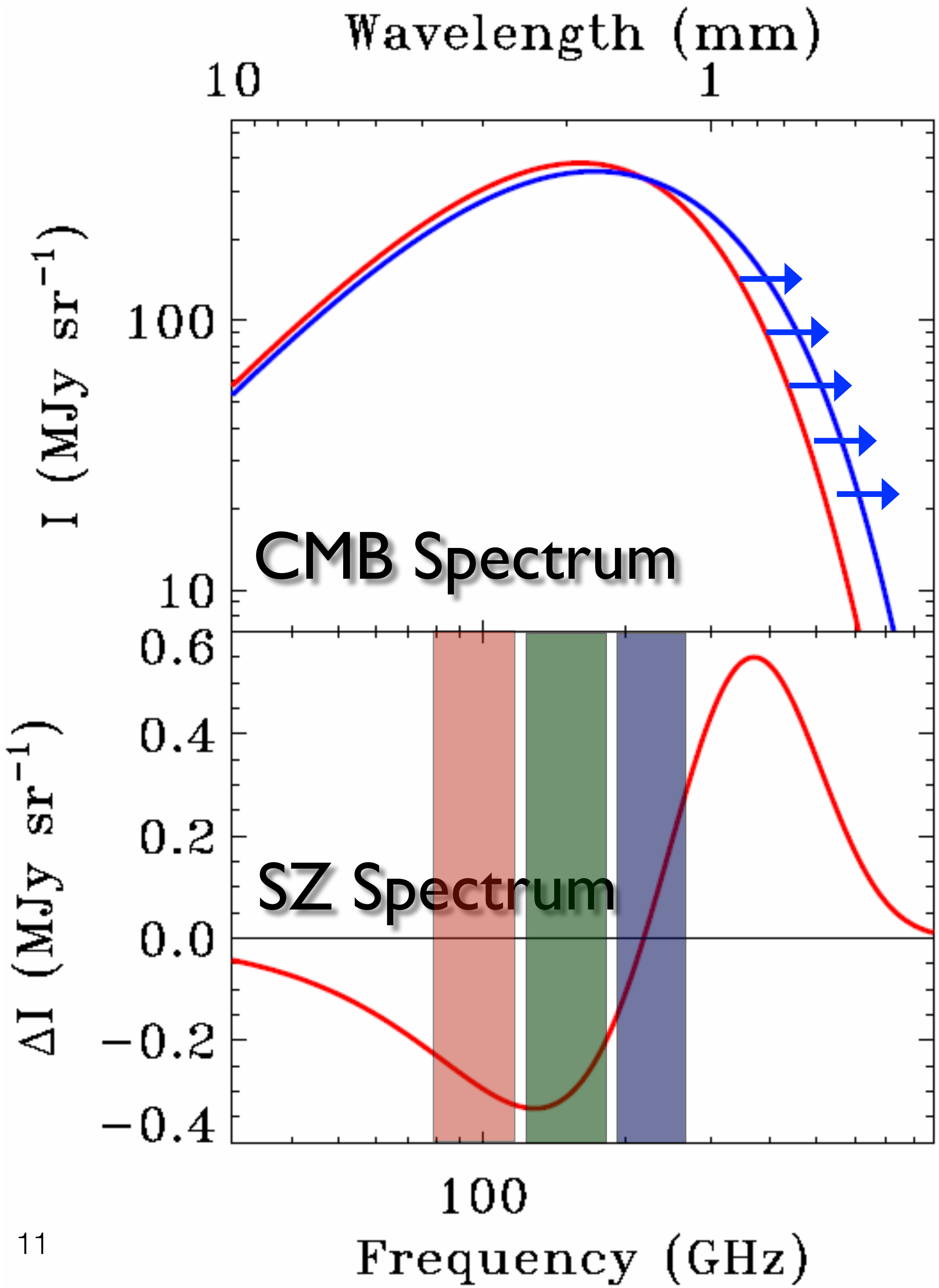

SPT-3G 95 GHz


SPT-3G 95 GHz
Clusters of Galaxies
“Shadows” in the microwave background from clusters of galaxies

The Sunyaev Zel'dovich (SZ) Effect



Adapted from L. Van Speybroeck



Towards a massive cluster, ~1% of CMB photons scatter off of intra-cluster gas

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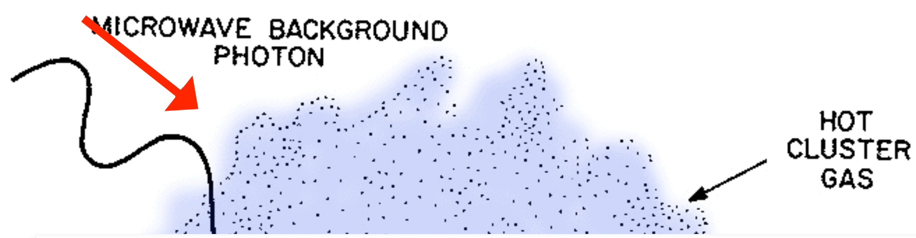

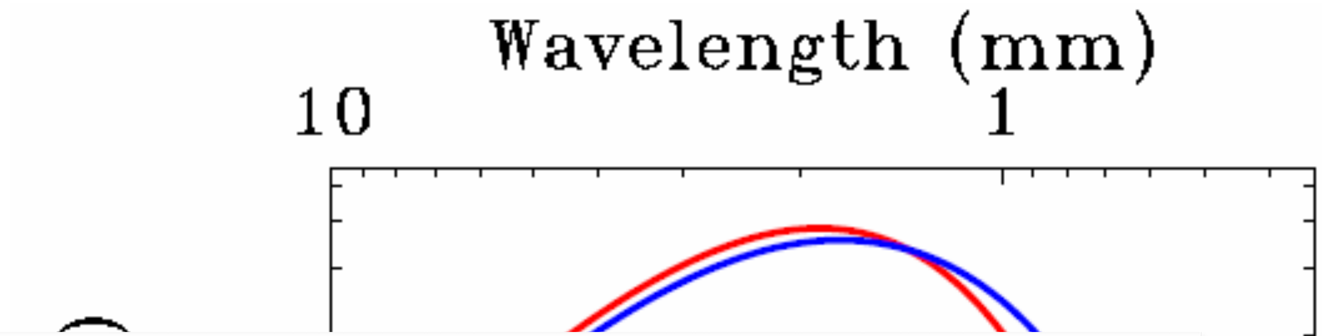

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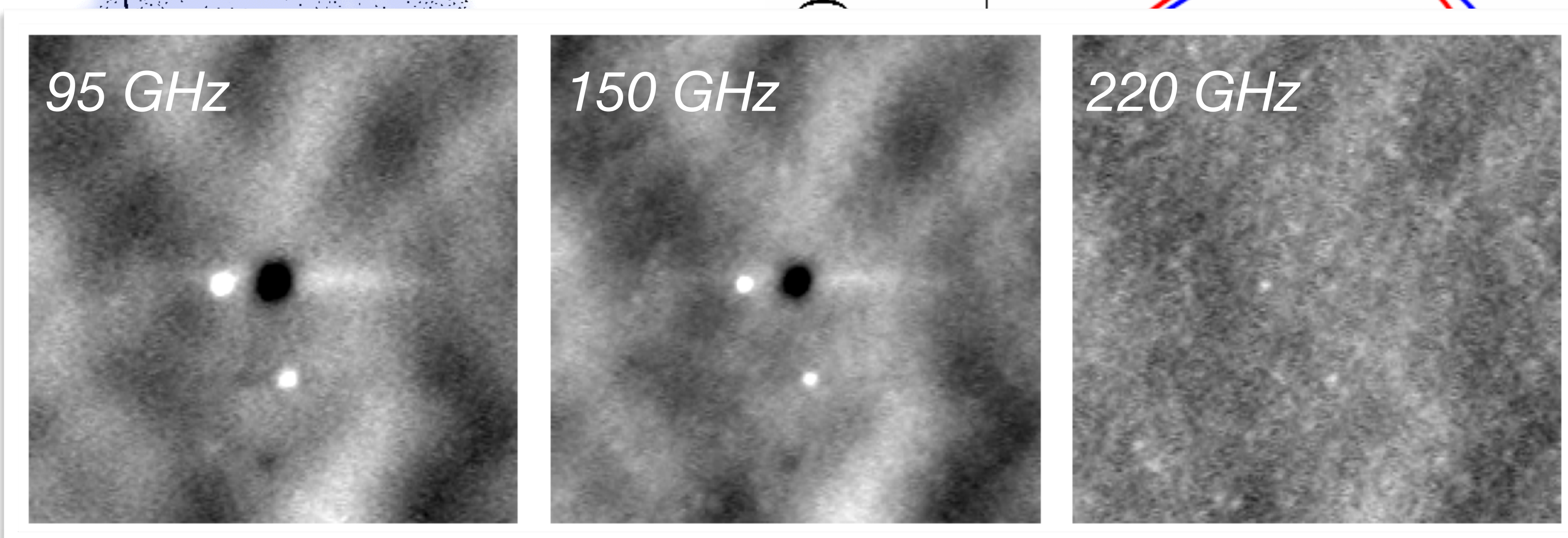
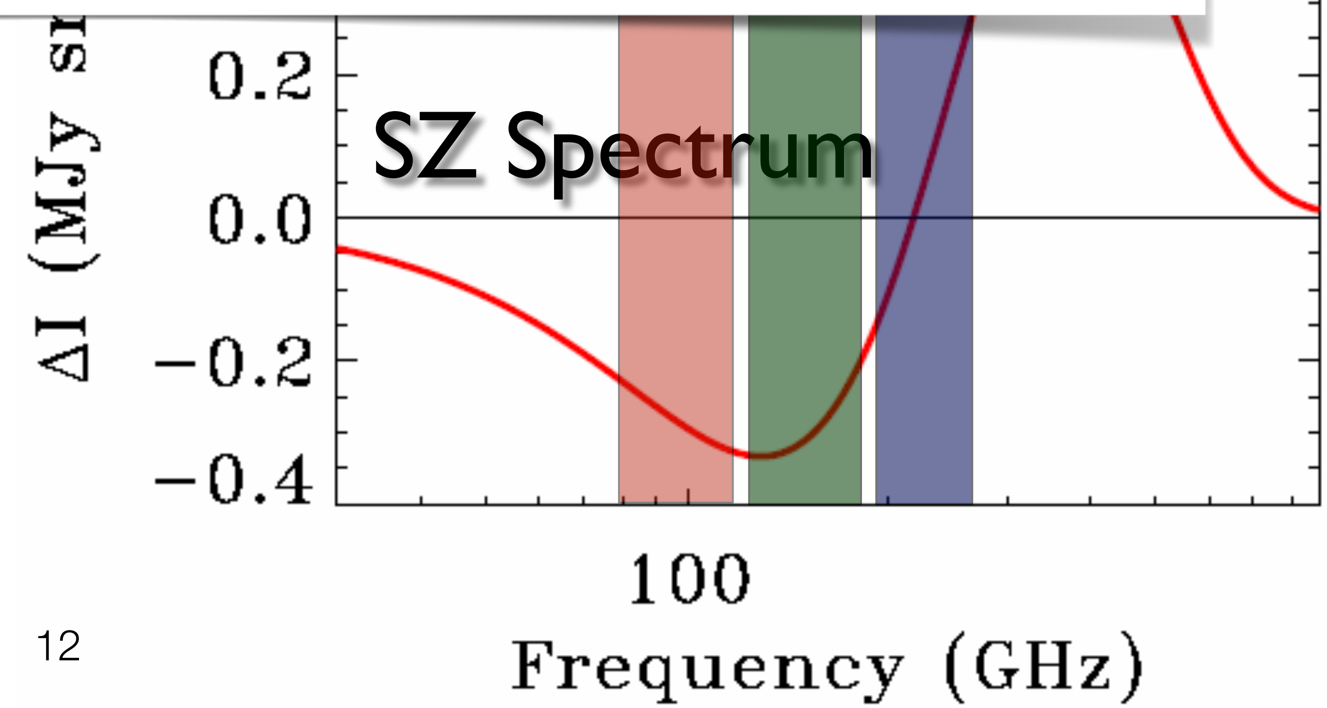
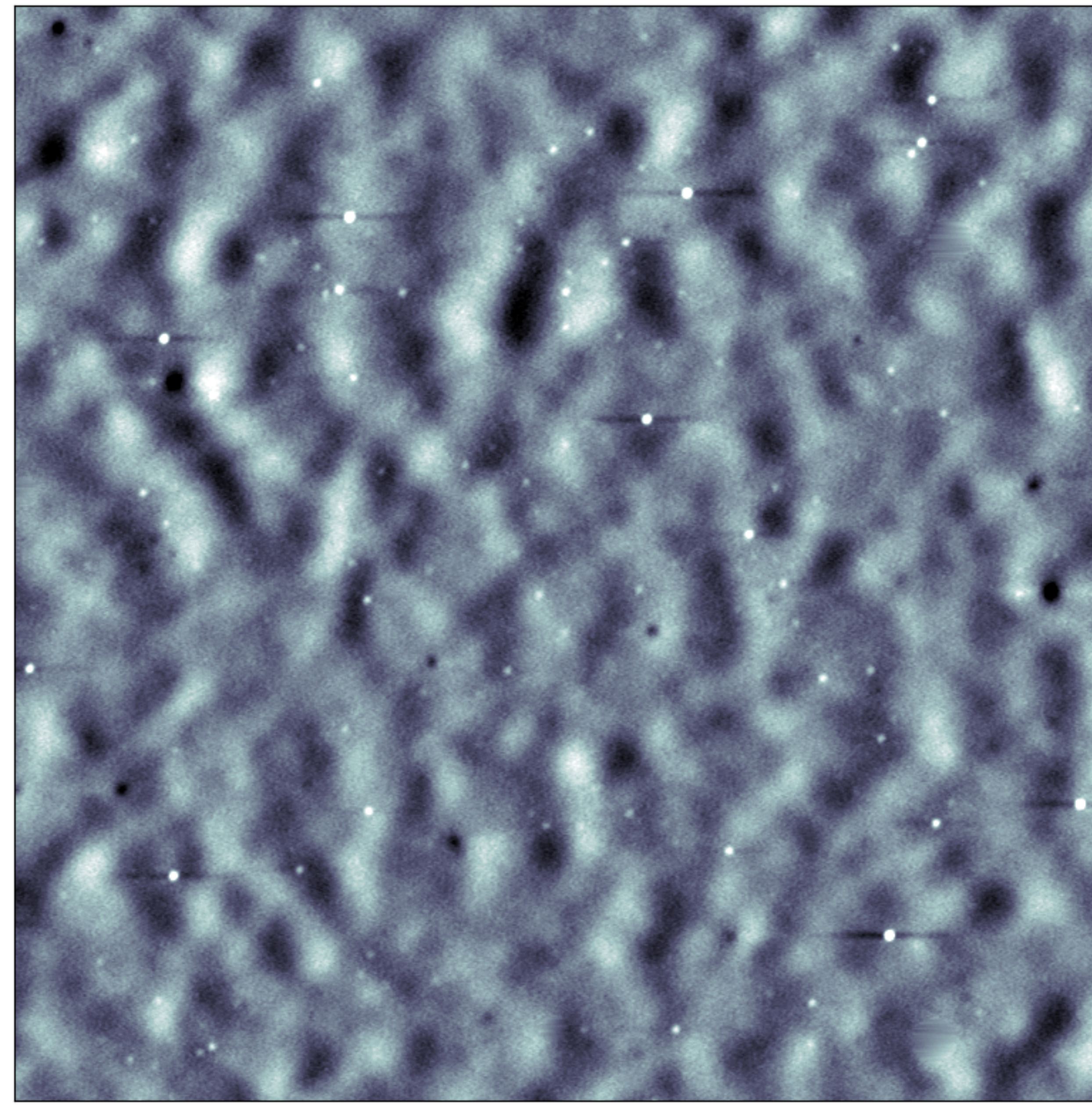




Towards a massive cluster, ~1% of CMB photons scatter off of intra-cluster gas

Finding Clusters in SPT data

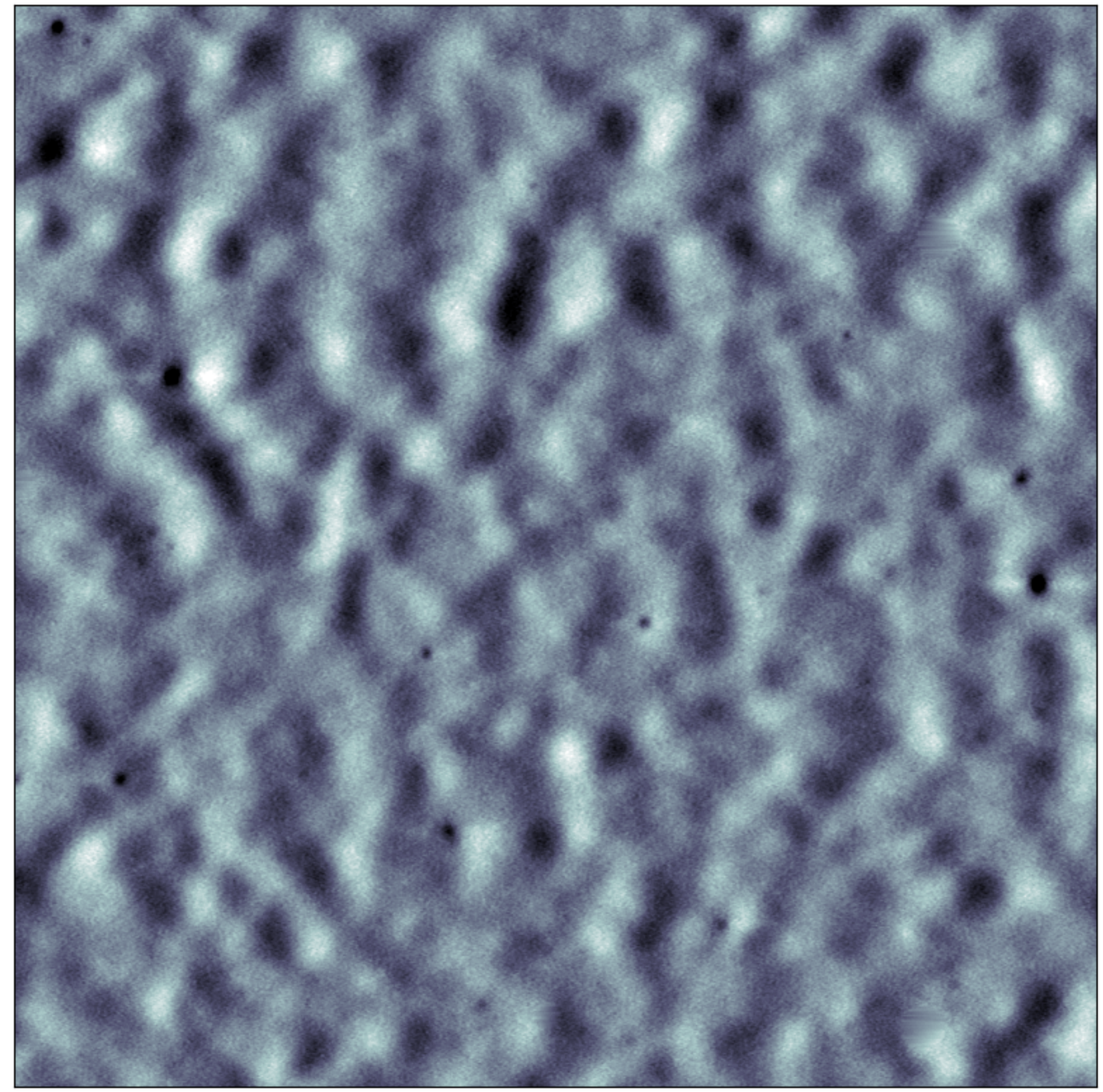
- Remove emissive sources from temperature map to remove negative “wings” caused by time stream filtering of SPT data.



~16 deg^2 of data (1% of Main field data)

Finding Clusters in SPT data

- Remove emissive sources from temperature map to remove negative “wings” caused by time stream filtering of SPT data.
  - Subtract data driven template of all sources detected at S/N>5 at 95 GHz in dedicated source analysis *(see M. Archipley’s talk tomorrow)* from 95, 150, 220 GHz temperature maps.



~16 deg^2 of data (1% of Main field data)

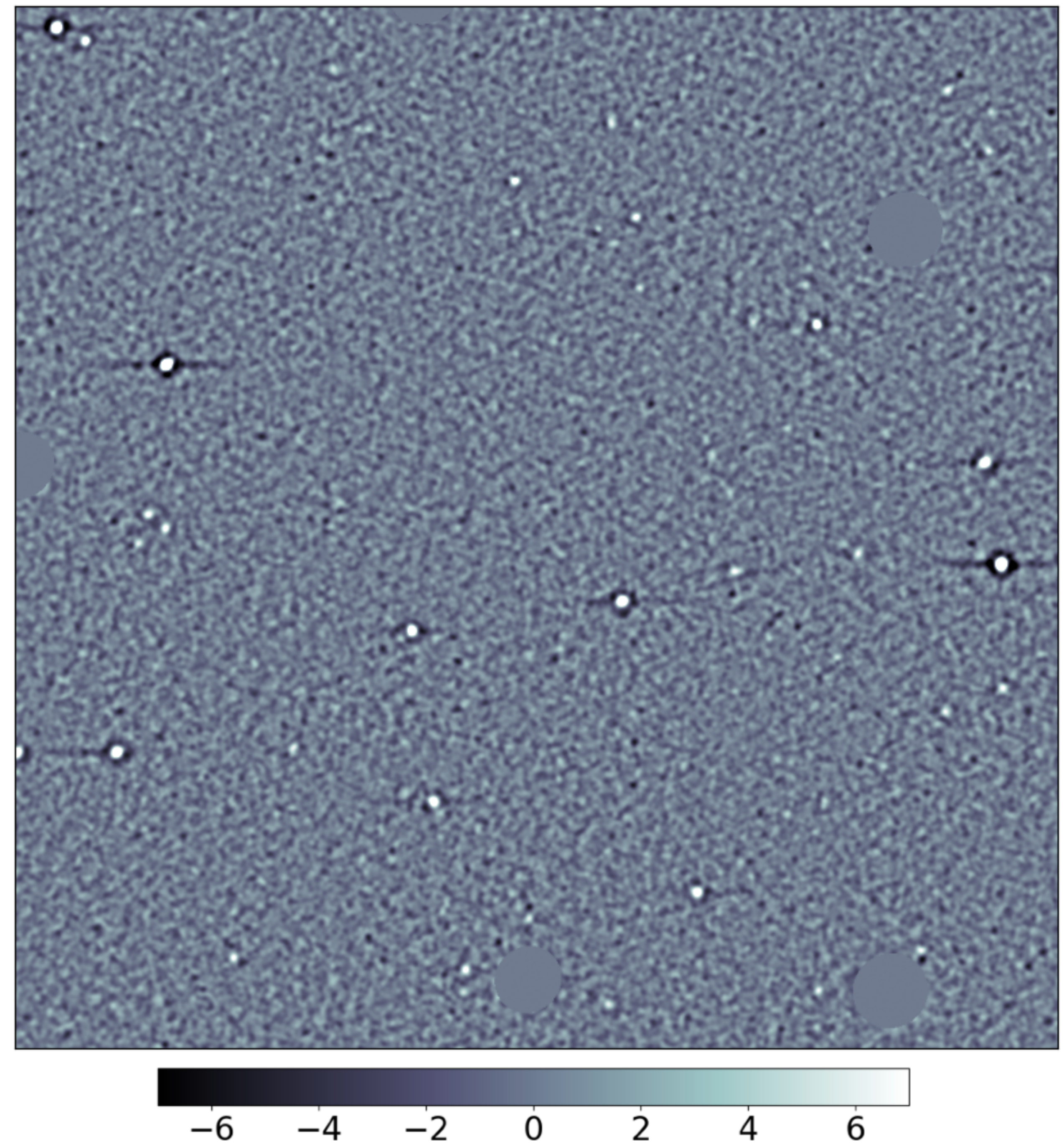
Finding Clusters in SPT data

- Remove emissive sources from temperature map to remove negative “wings” caused by time stream filtering of SPT data.

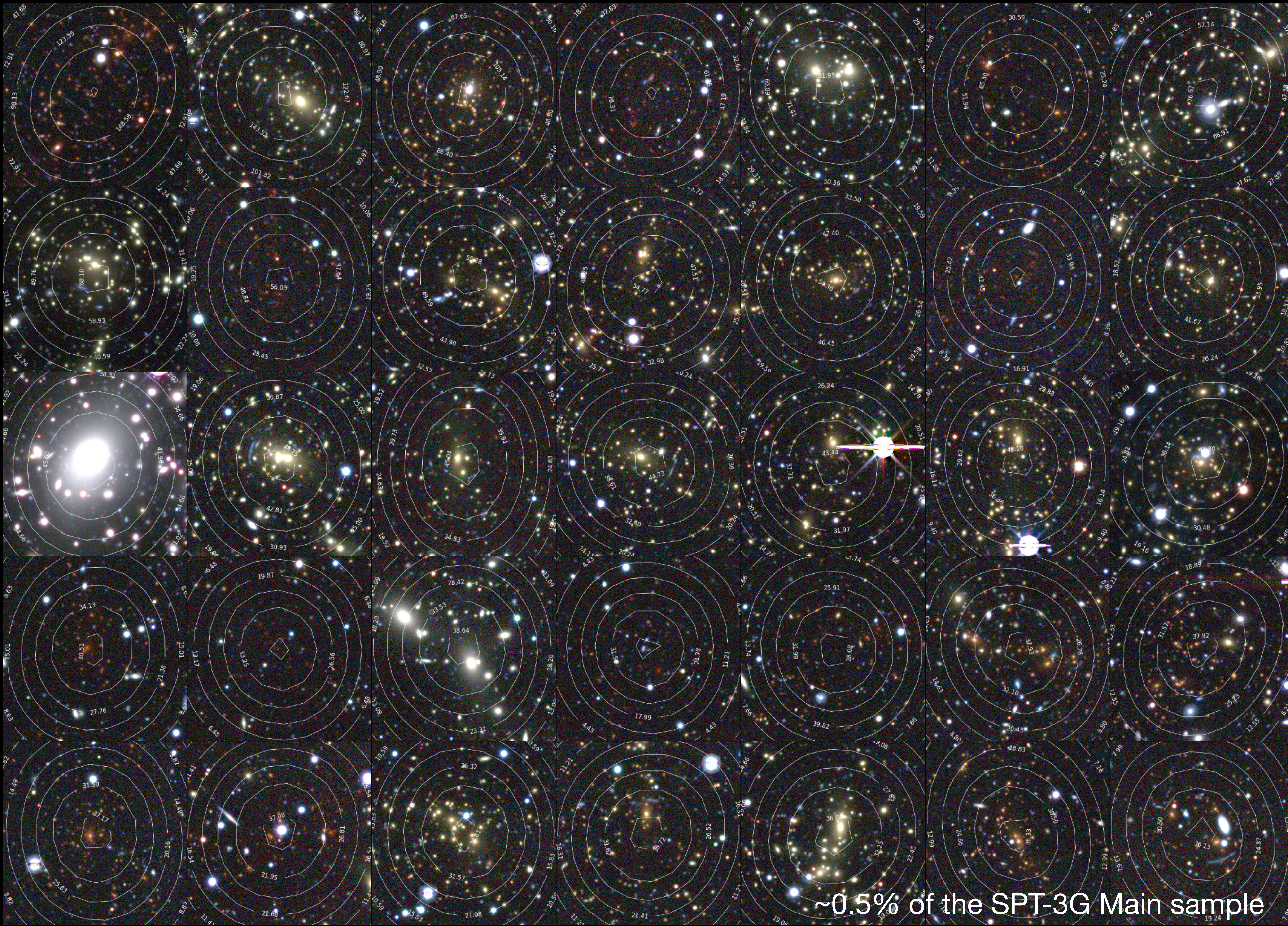
- Use multi-frequency matched filter techniques (e.g., Melin et al. 2006) to produce signal-to-noise maps optimized for cluster detection

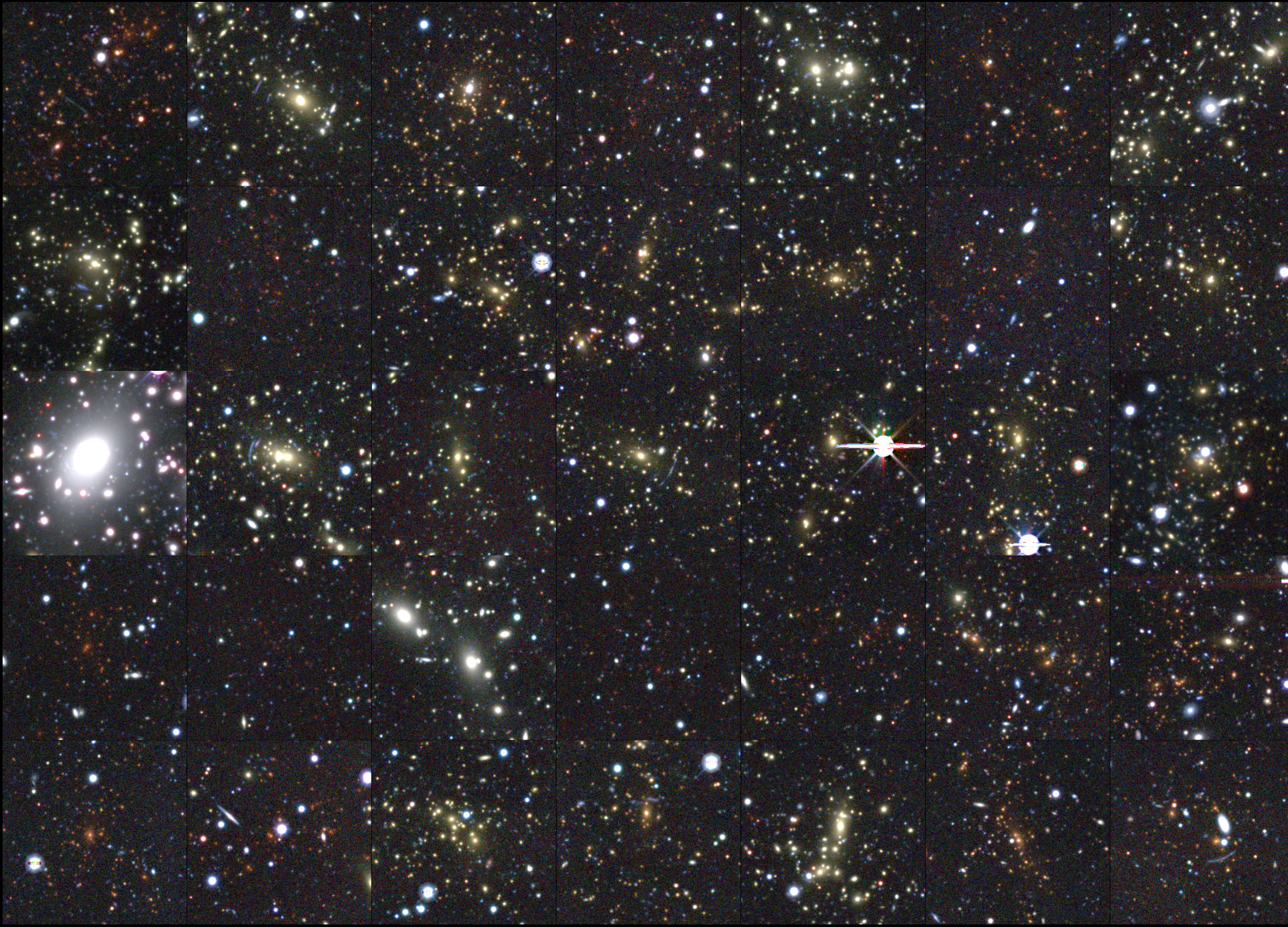
  - Noise is composed of instrumental + residual atmospheric noise as well as “astrophysical noise” from primary CMB (*Planck* 20) and tSZ, kSZ, CIB (Reichardt+21)

  - Apply 16 spatial filters of projected spherical β profiles with θ_{core} 1/8’ to 6’ in scale.



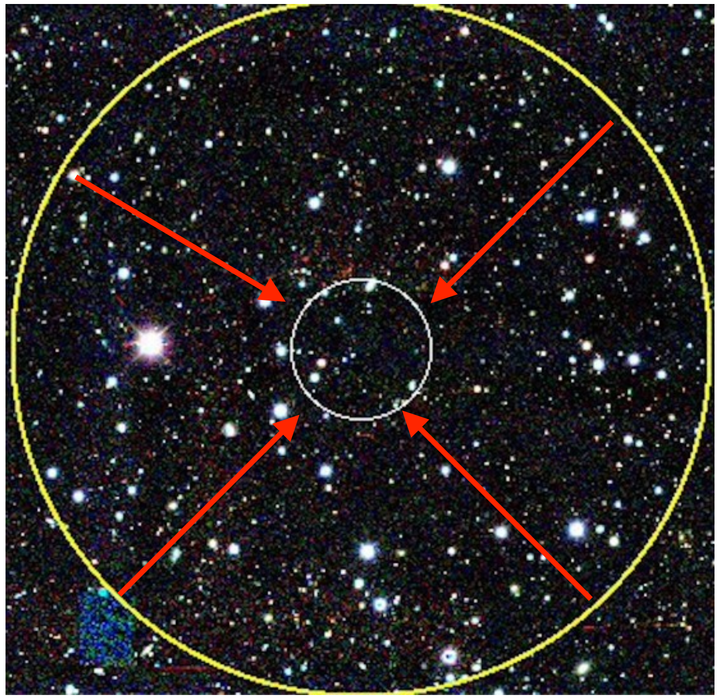
Signal-to-noise map, 0.25’ filter

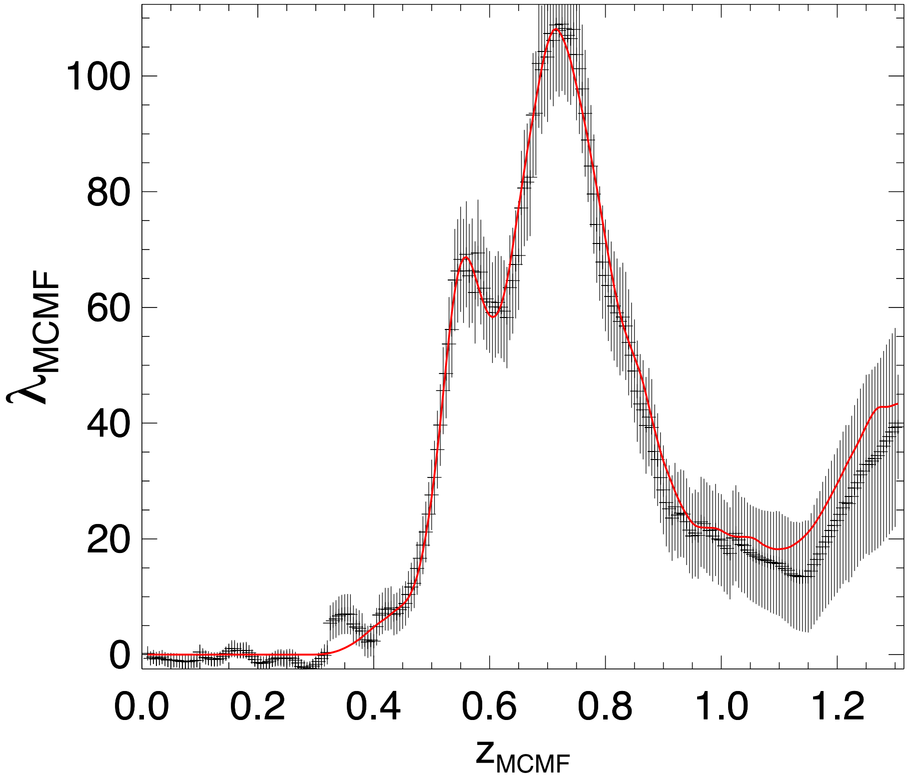

~0.5% of the SPT-3G Main sample

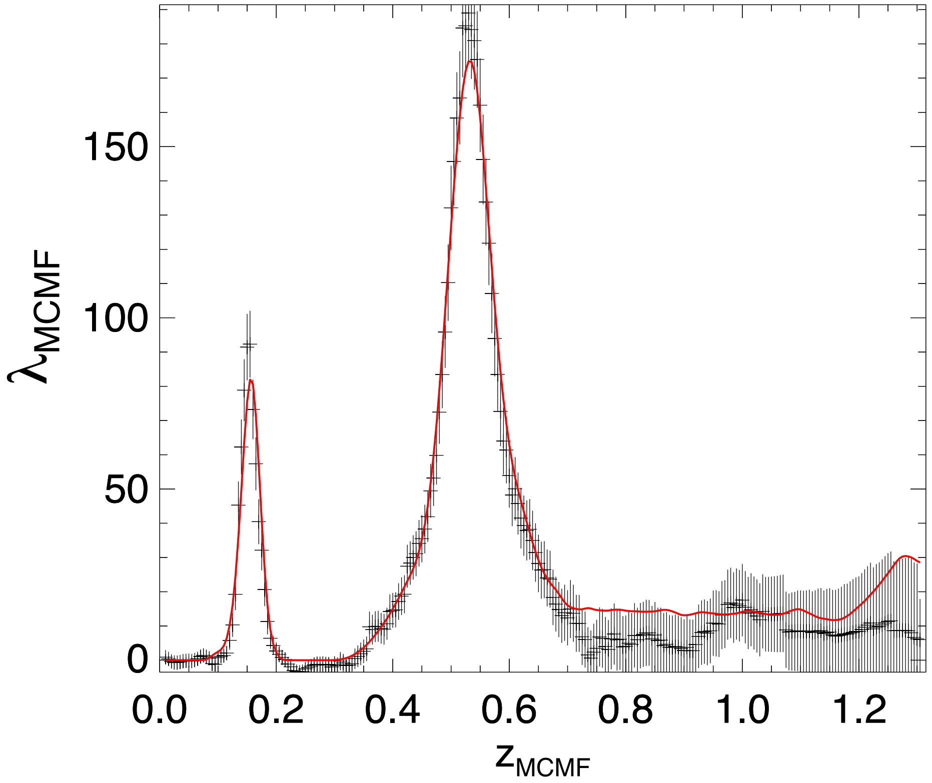


Multi-Component Matched Filter (MCMF) cluster confirmation tool (Klein+18,19, 24)

- uses **red-sequence** to obtain richness & redshift with DES/DECALS *griz* & WISE W1, W2 data
- use ICM based information (flux, ξ) to obtain estimate of r_{500} given redshift
- scans through redshift and calculates richness within apertures of r_{500} around ICM based position
- peak identified and fit by calibrated peak profiles to get redshifts & richness of potential counter parts

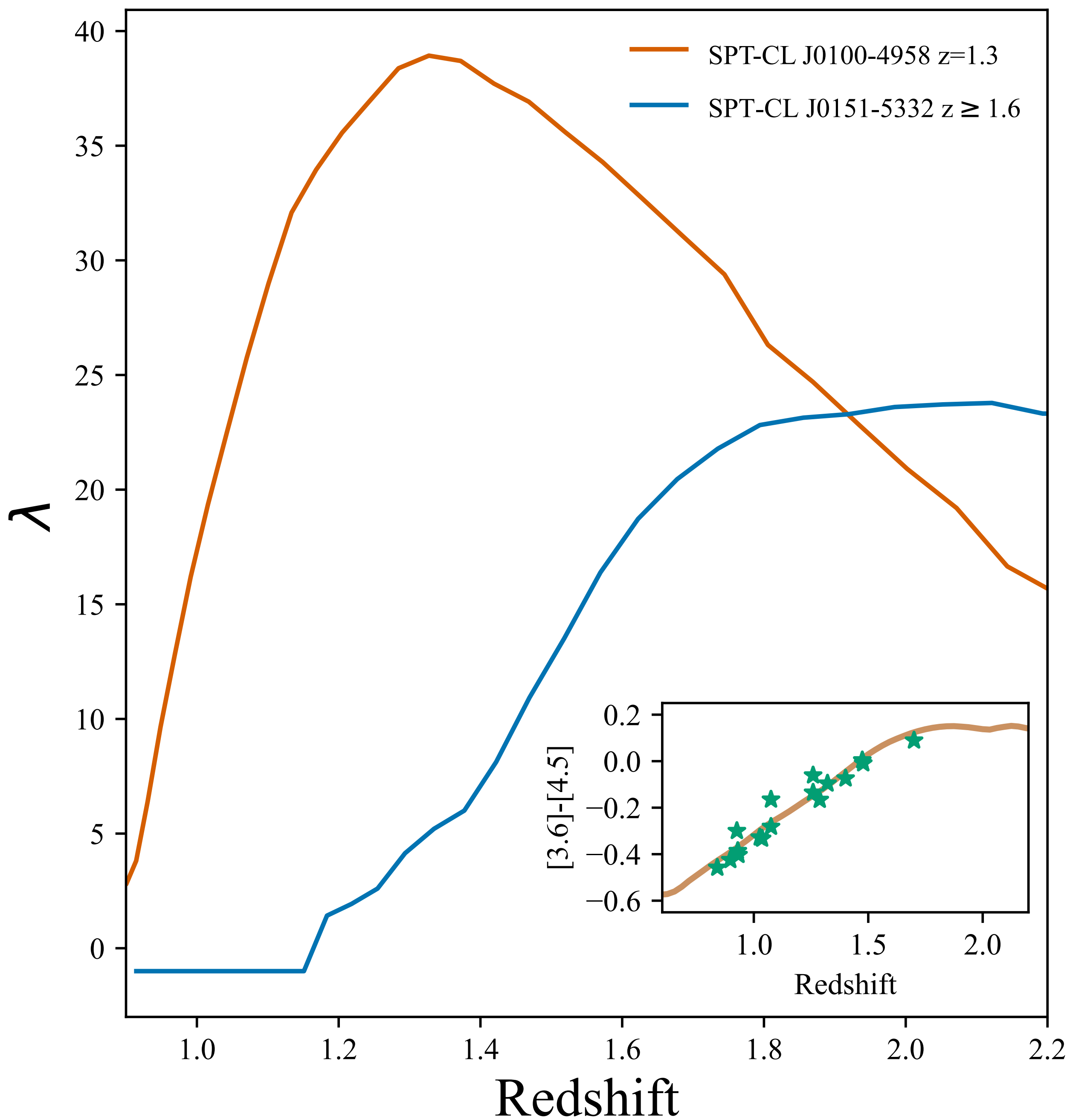


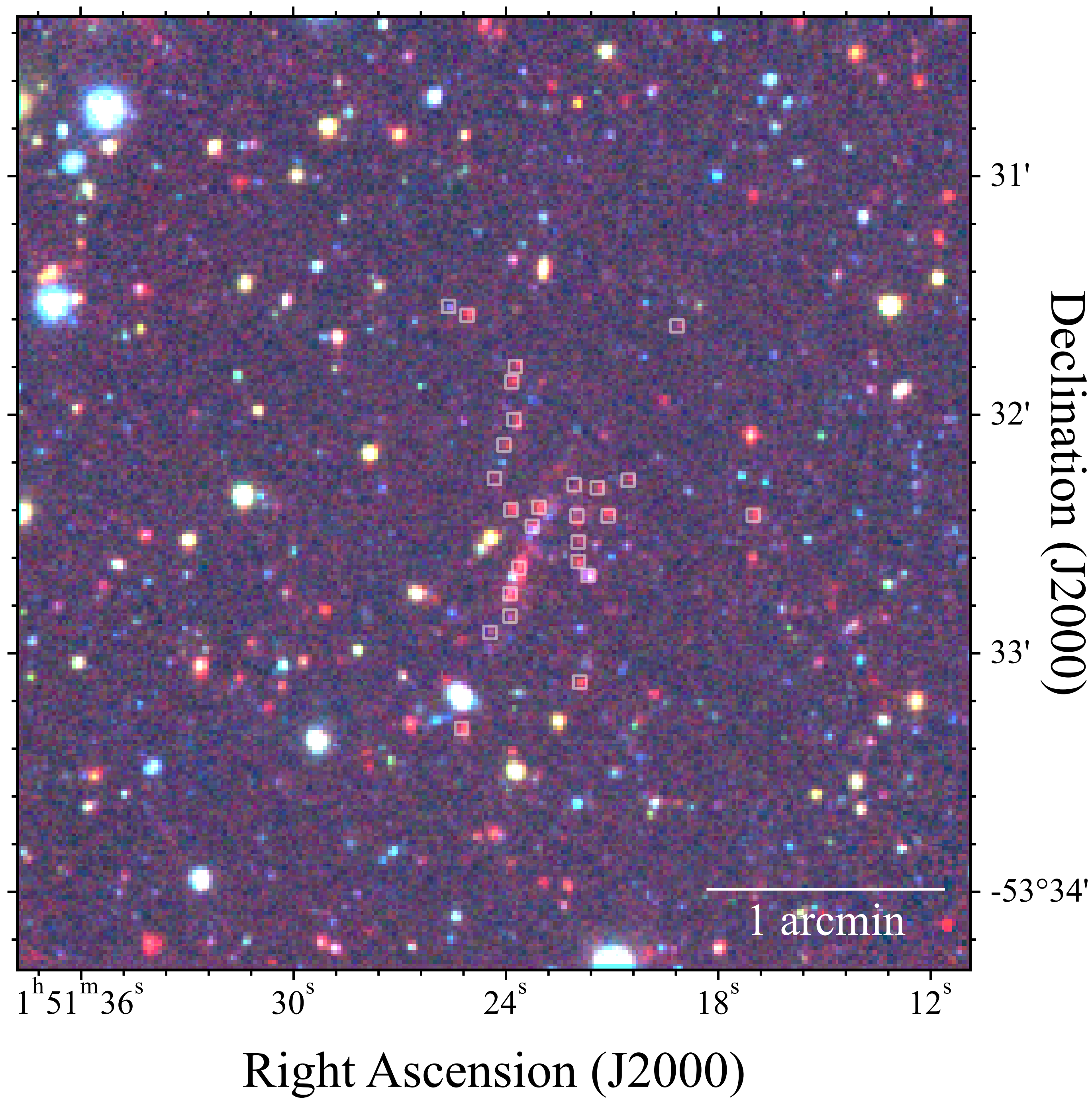




See talk later this afternoon!

At high-redshifts we leverage the 1.6 μm stellar bump feature



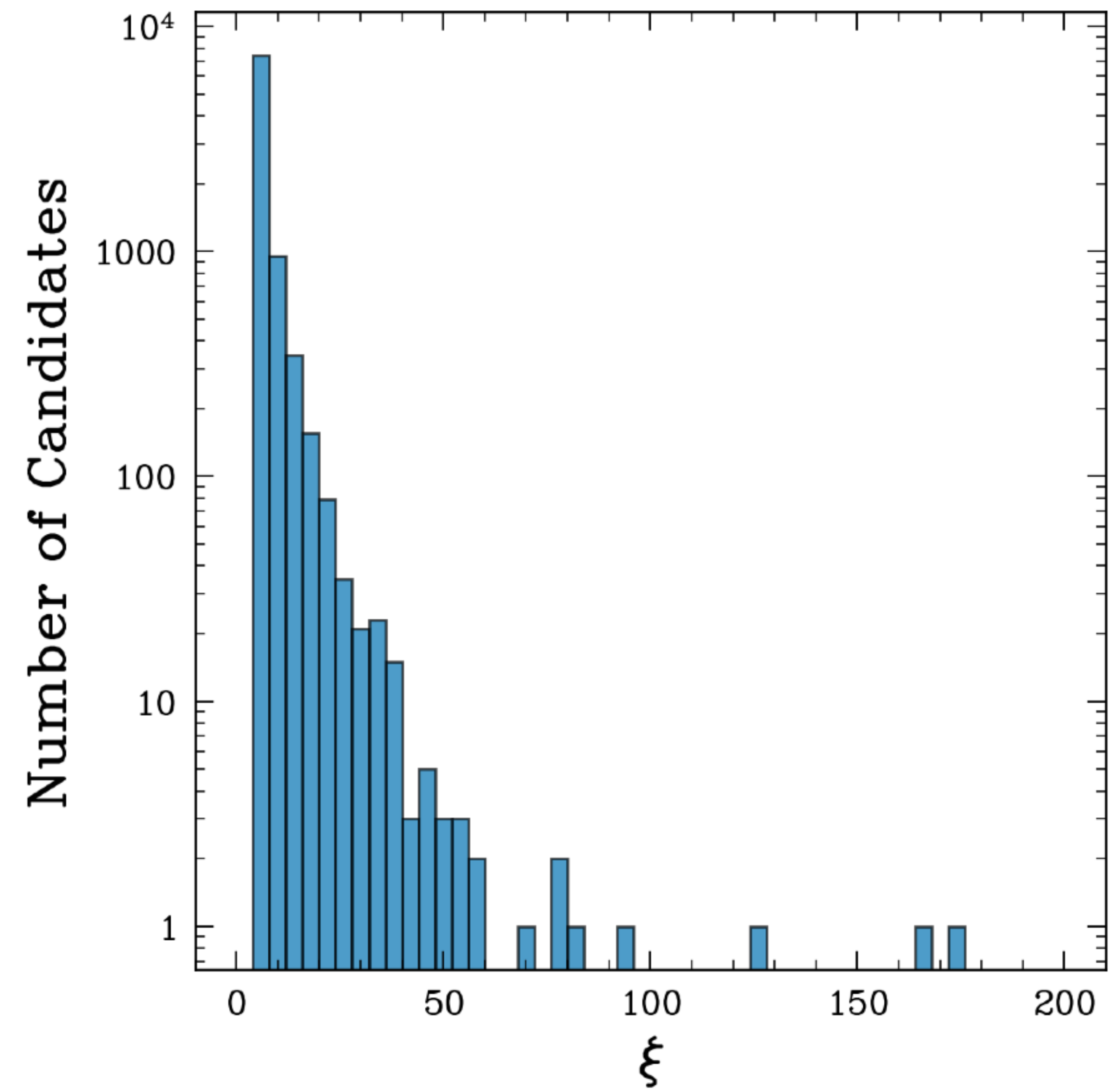


Bleem, Klein et al
SPTpol & DES Collaborations
OJA 7, 3 (2024)

Preliminary Results - Main Field

- Catalog drawn from 1605 deg^2 of data at noise levels of 3.2, 2.6, 9 μK-arcmin at 95, 150, 220 GHz

- 9097 candidates at detection significance $\xi > 4$ (>88% purity), 4568 at $\xi > 5$ (>99% purity)



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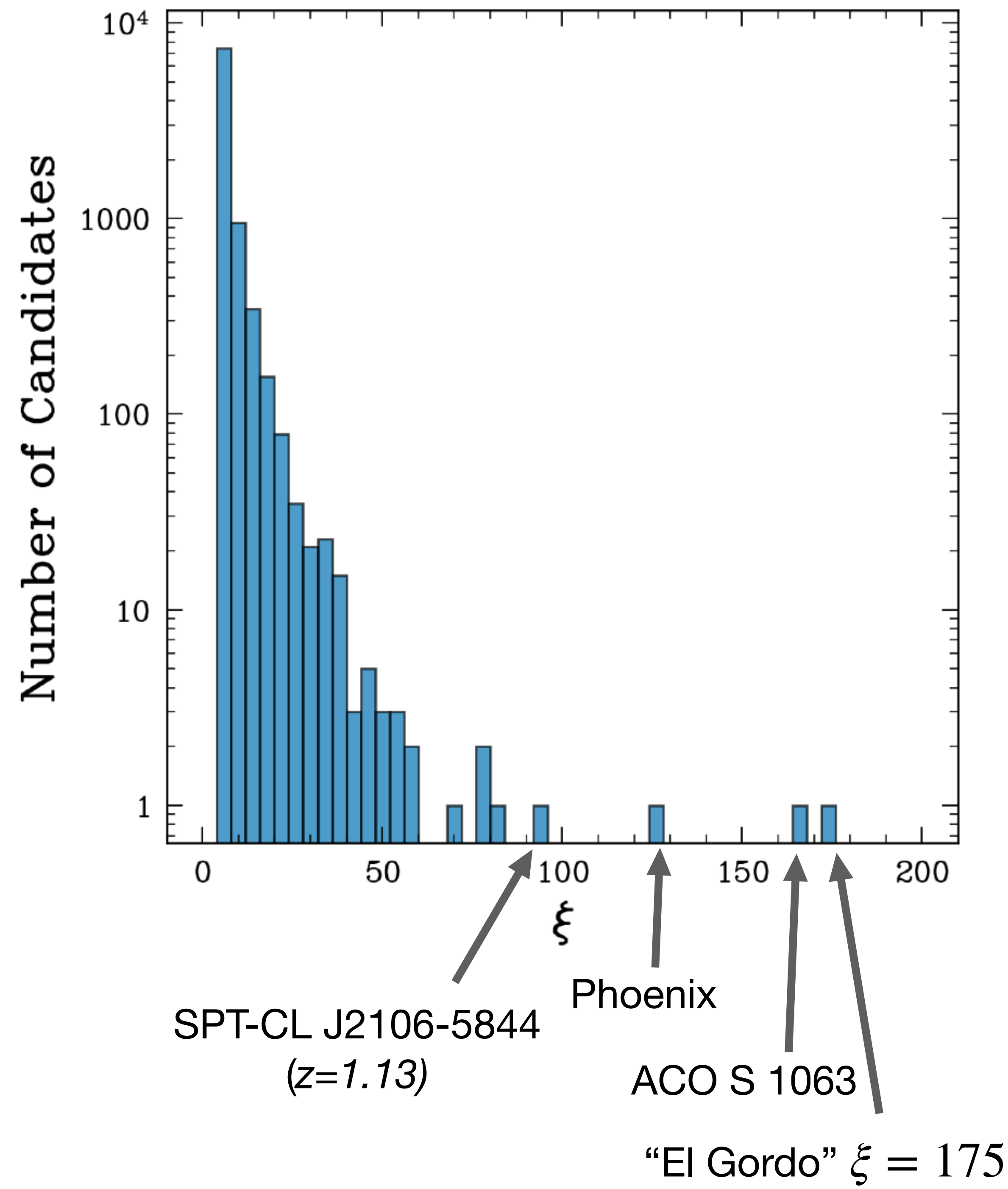

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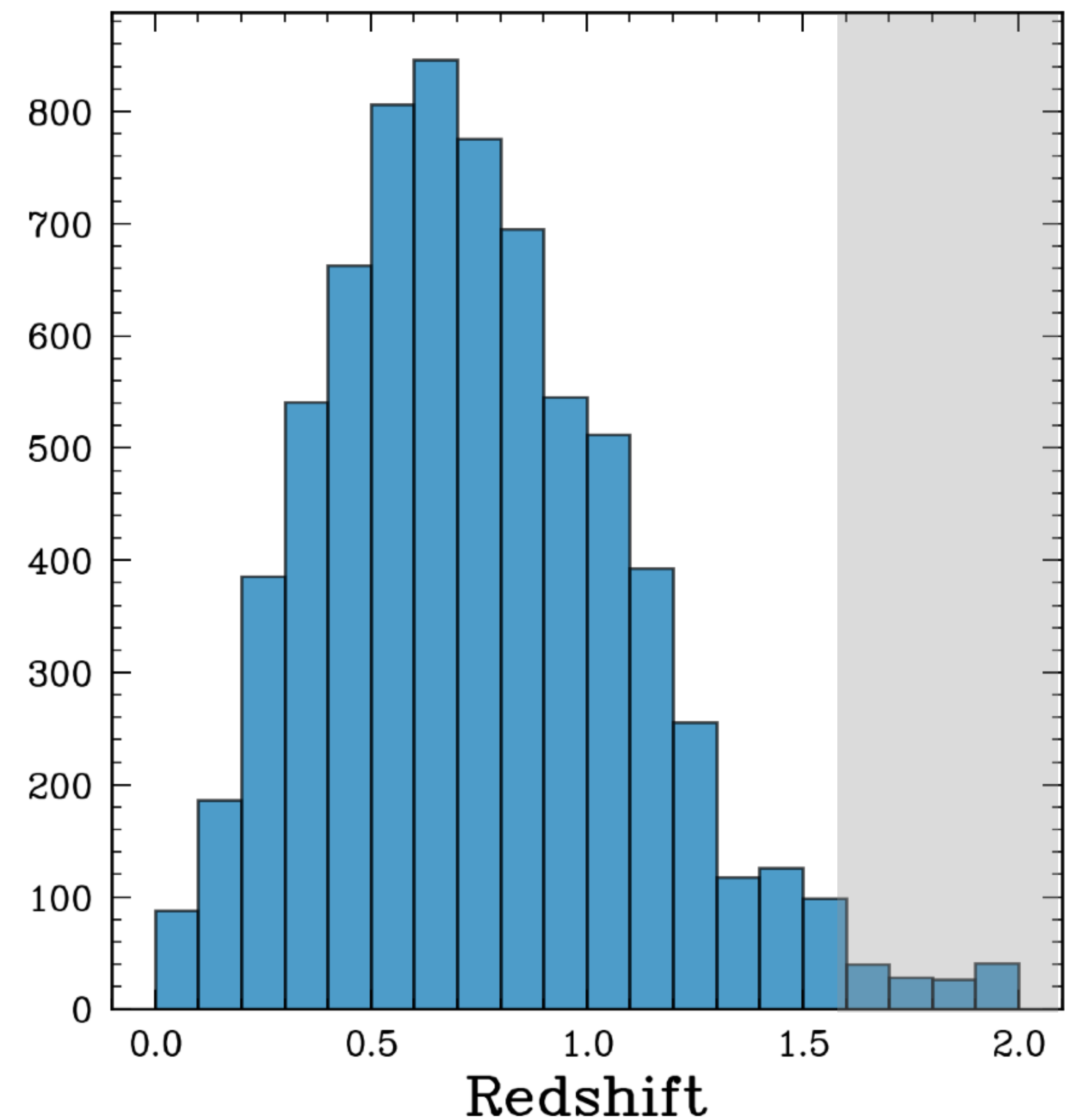
- 7172 candidates (and counting) confirmed at optical contamination statistic f_{cont} < 0.2

$$f_{\mathrm{cont}}(\lambda_i, z_i) = \frac{\int_{\lambda_i}^{\infty} f_{\mathrm{rand}}(\lambda, z_i) d\lambda}{\int_{\lambda_i}^{\infty} f_{\mathrm{obs}}(\lambda, z_i) d\lambda} < 0.2$$

- Median redshift z_{med} = 0.71
  - 1636 clusters at *z>1 (23%)*
  - 231 at *z*> 1.5 (3%)
  - 337 candidates at $\xi > 5$, 126 at $\xi > 6$ remain unconfirmed by this statistic



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- Median redshift $z_{med} = 0.71$
    - 1636 clusters at $z>1$ (+74 $\xi > 5$ & $f_{cont} < 0.3$)
    - 231 at $z > 1.5$ (+25 $\xi > 5$ & $f_{cont} < 0.3$)
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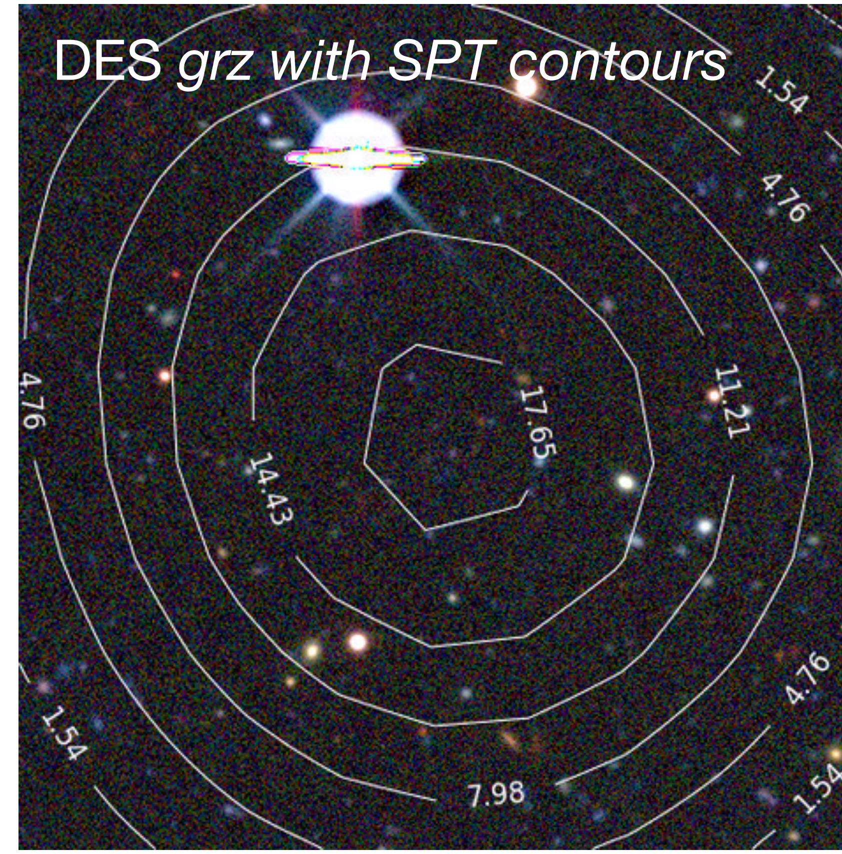

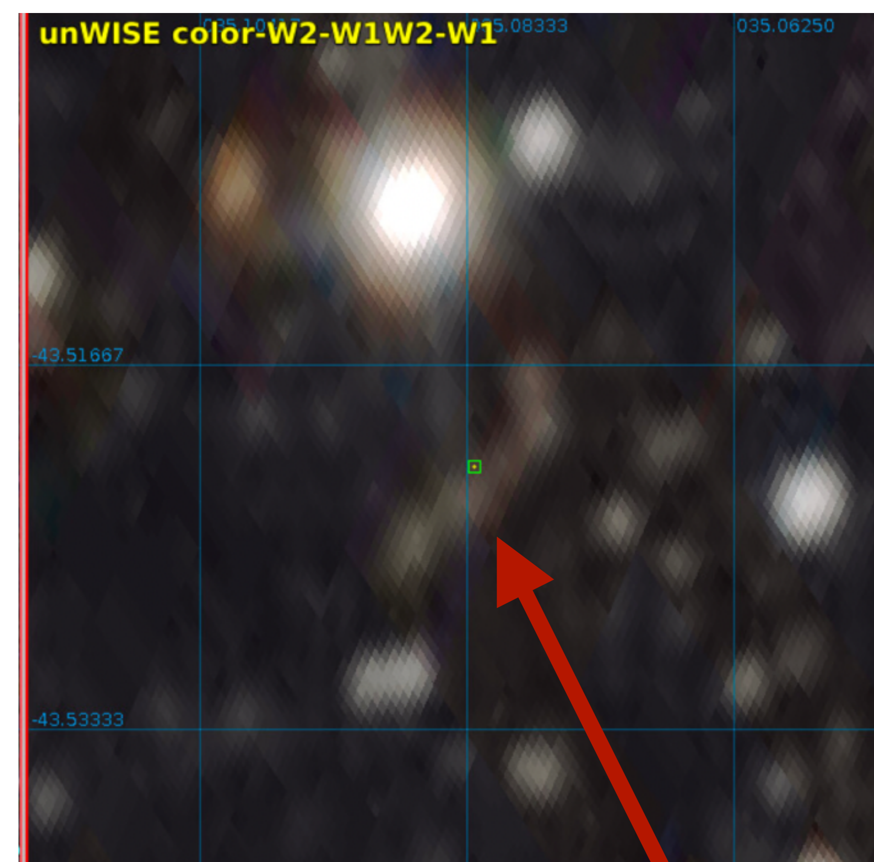

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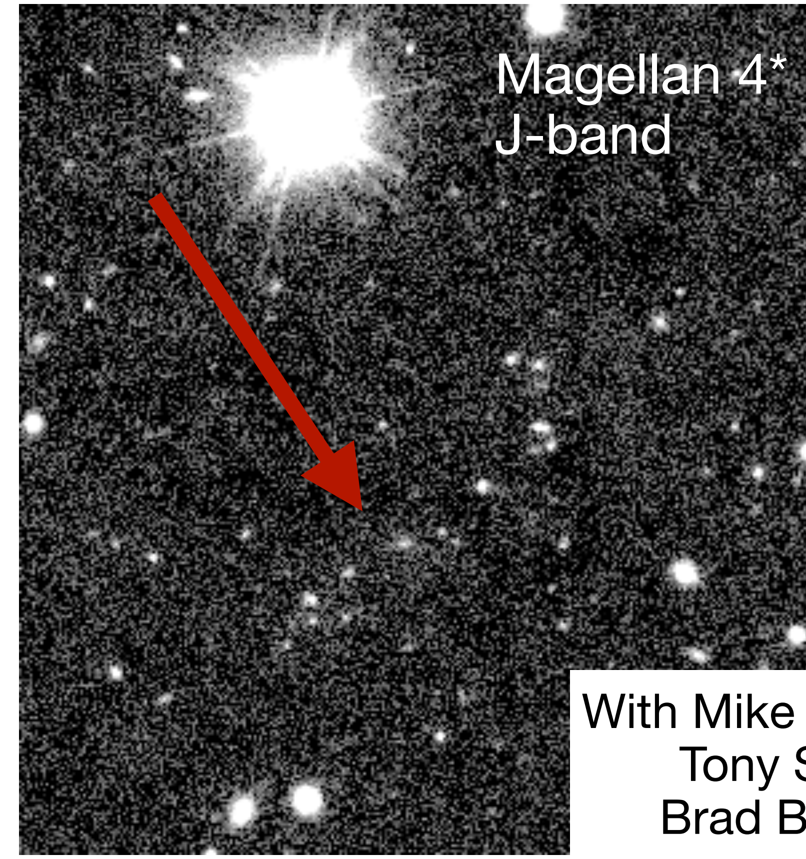

With Mike Gladders,
Tony Stark,
Brad Benson

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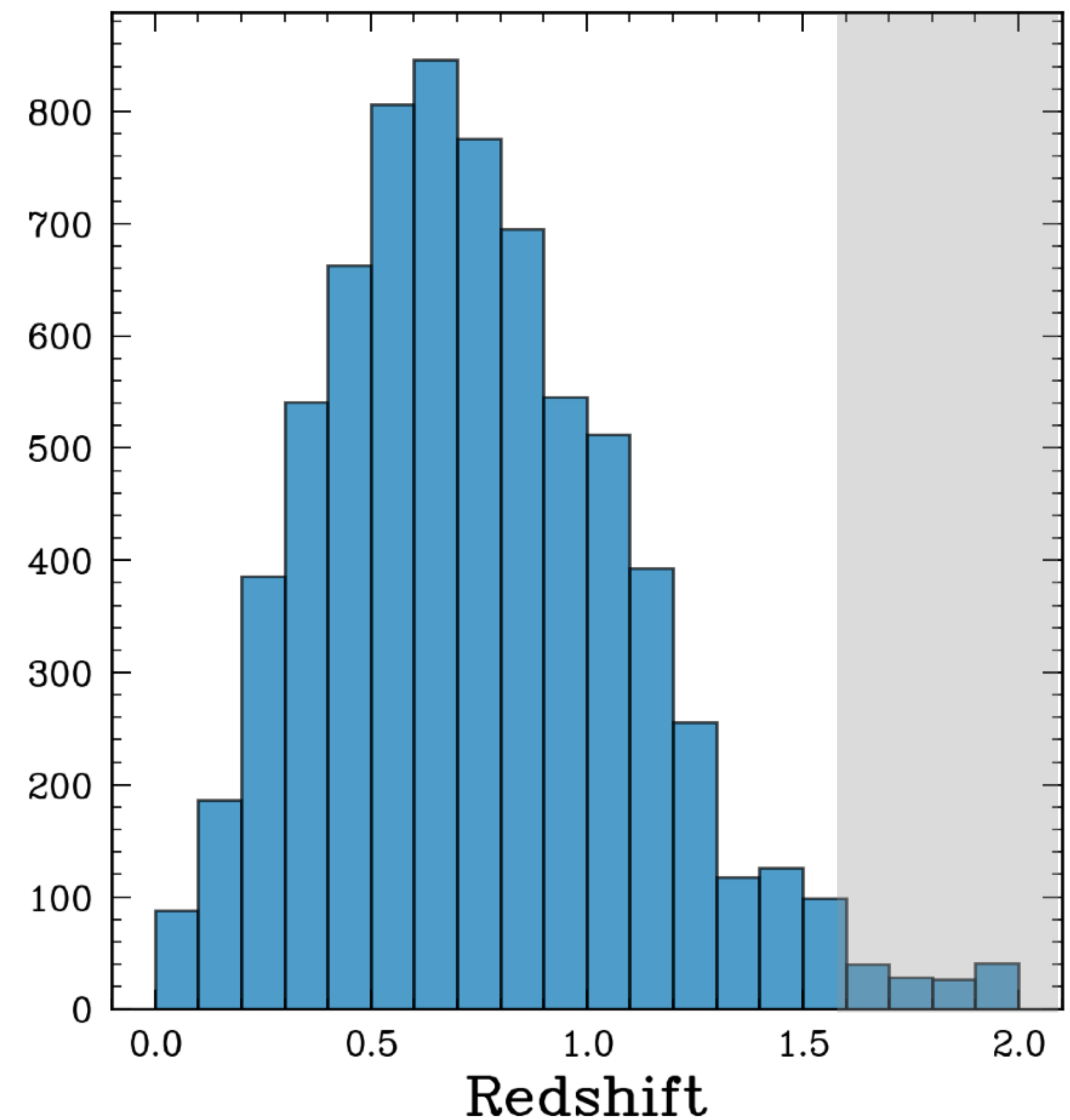
- Masses estimated via scaling relation

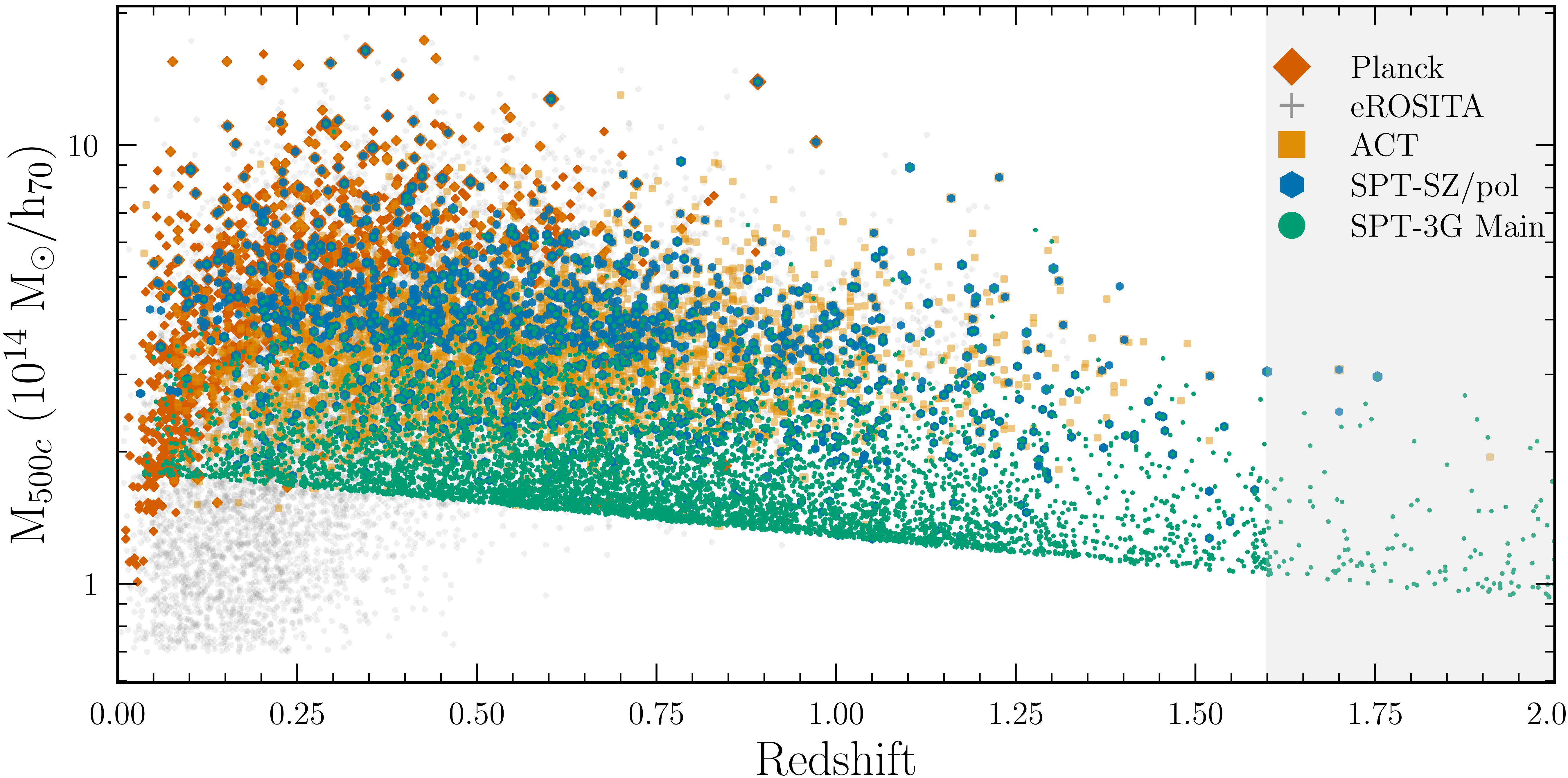
- Catalog properties include position, ξ, θ_{core}, y(0.75') + [redshift, mass, optical richness, and contamination estimation from optical association] for confirmed clusters



$$\langle \ln \zeta \rangle = \ln \left[A_{\mathrm{SZ}} \left(\frac{M_{500c}}{3 \times 10^{14} M_{\odot} h^{-1}} \right)^{B_{\mathrm{SZ}}} \left(\frac{H(z)}{H(0.6)} \right)^{C_{\mathrm{SZ}}} \right]$$

$$P(\xi | \zeta) = \mathcal{N}(\sqrt{\zeta^2 + 3}, 1)$$

SPT-3G Main Field Mass-Redshift Distribution



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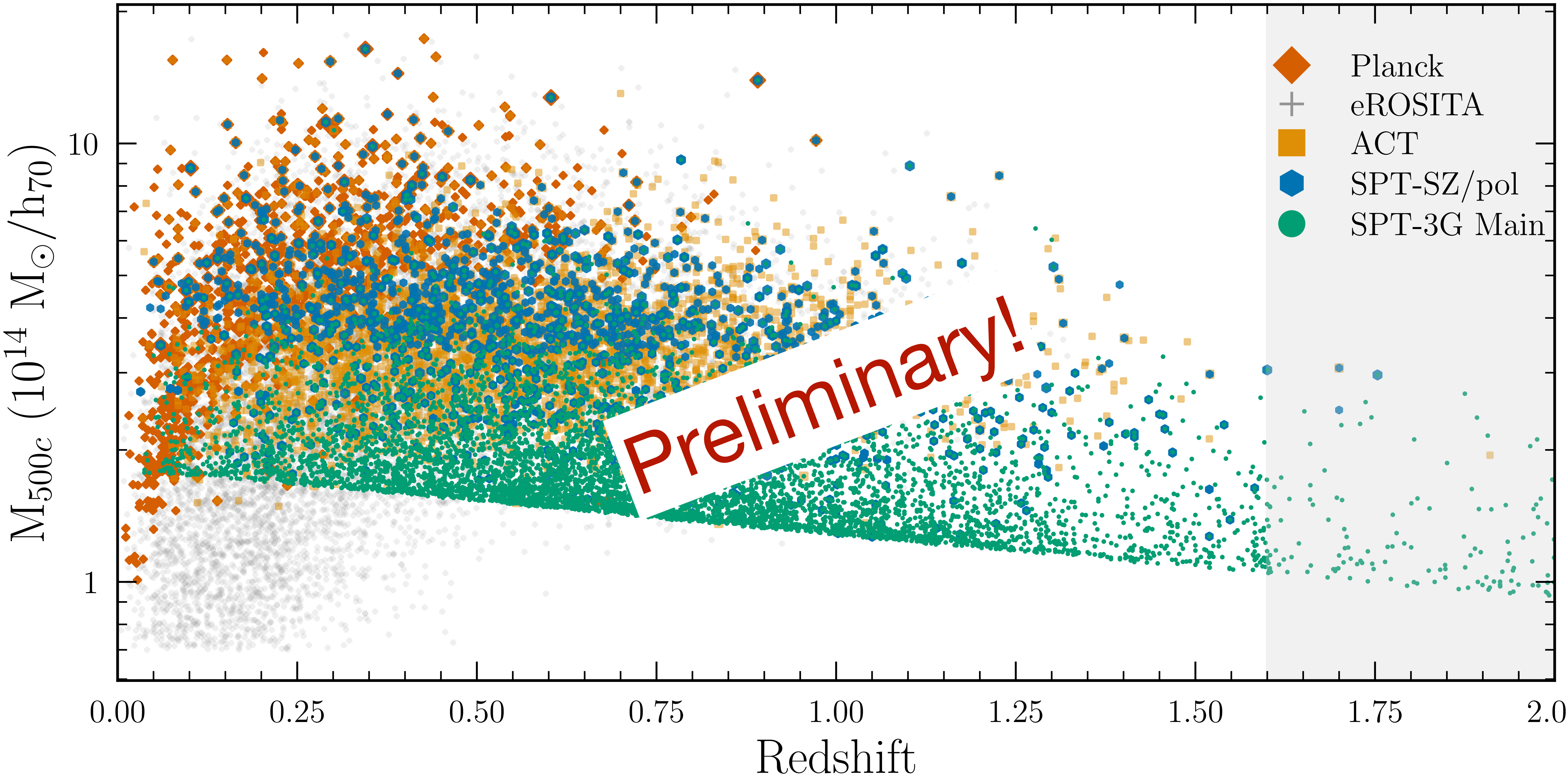
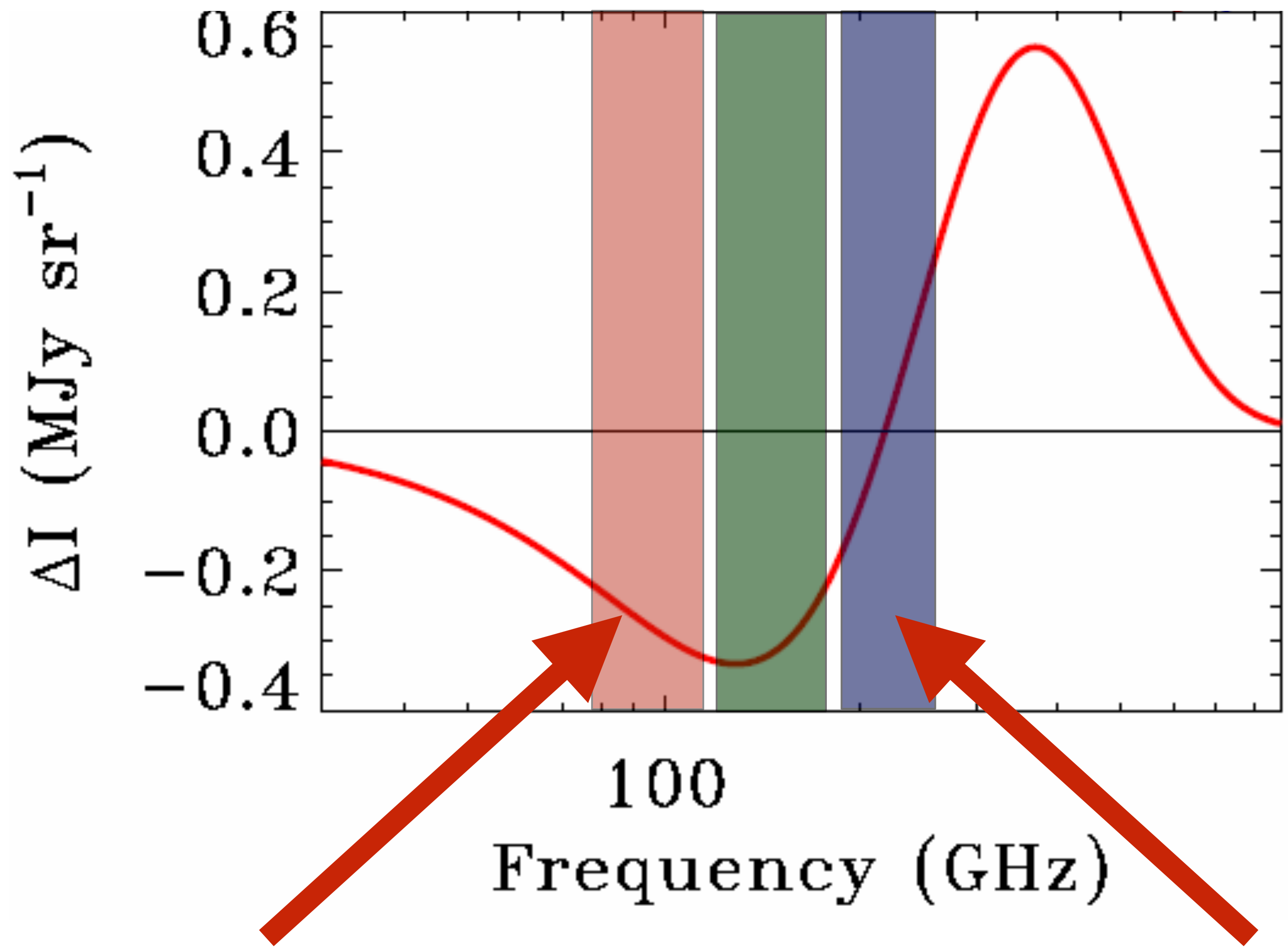
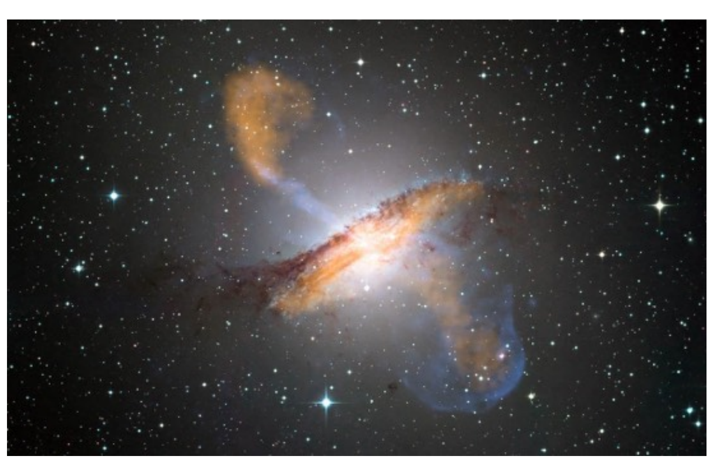
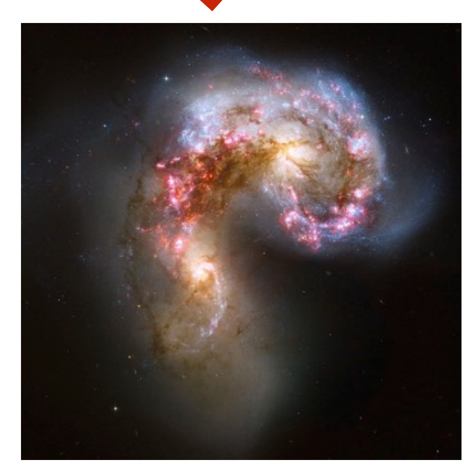


Characterizing SZ Selection*

*** especially at high redshift and low mass**

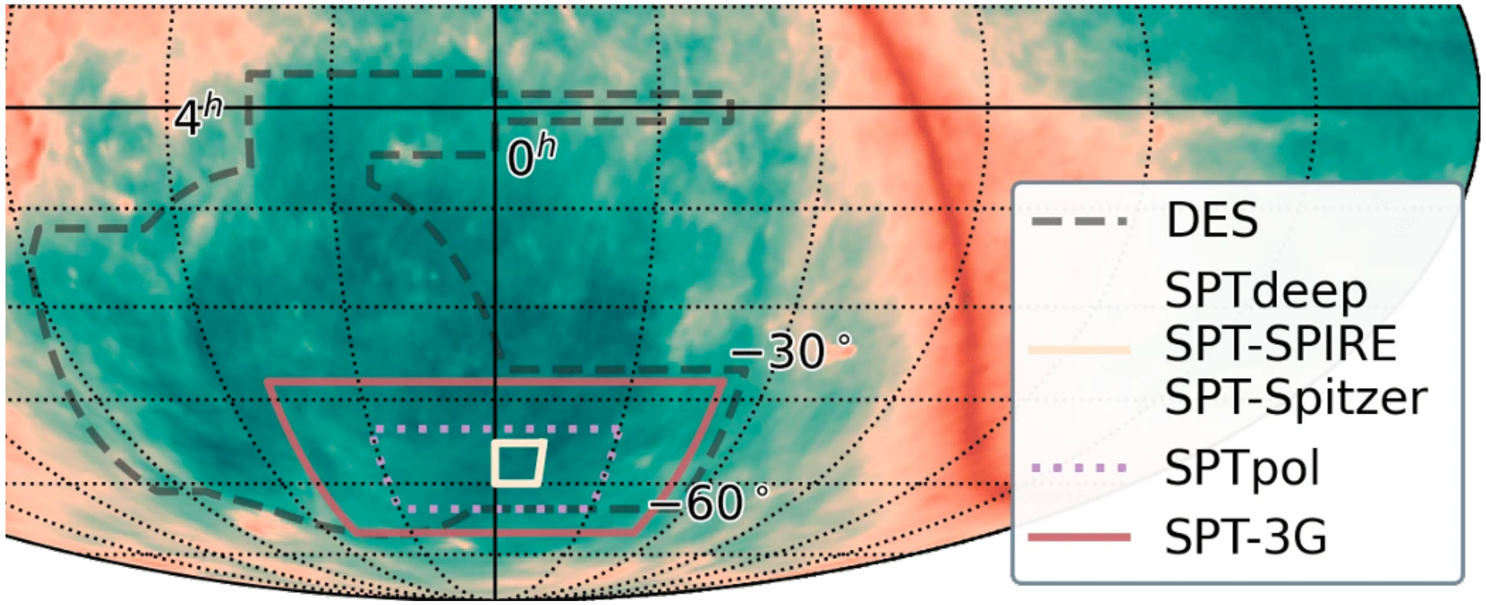






The First SPT-3G Cluster Catalog: 100d Deep Field

- The 100d SPT deep field combines data from 5 years of SPT-3G with the SPTpol 100d+ 500d surveys (10 years of CMB observations in total!)
- 442 clusters detected from $0.12 < z \lesssim 1.8$
- SPT 100d field overlaps with multi-wave surveys:
  - **Herschel** SPIRE (250, 350, 500 um) (Viero et al., 1810.10643)
  - **Spitzer** SSDF (3.6, 4.5 um) (Ashby et al., 1308.0201)
  - **MeerKAT** (PI Vieira)
  - **XMM-XXL** (25 deg^2) (Pierre et al.)
  - Wide field surveys from **DES**, **eROSITA**, and (soon) **Euclid**



SPT100d Noise Levels

- 90: 3 μK
- 150: 2 μK
- 220: 9 μK

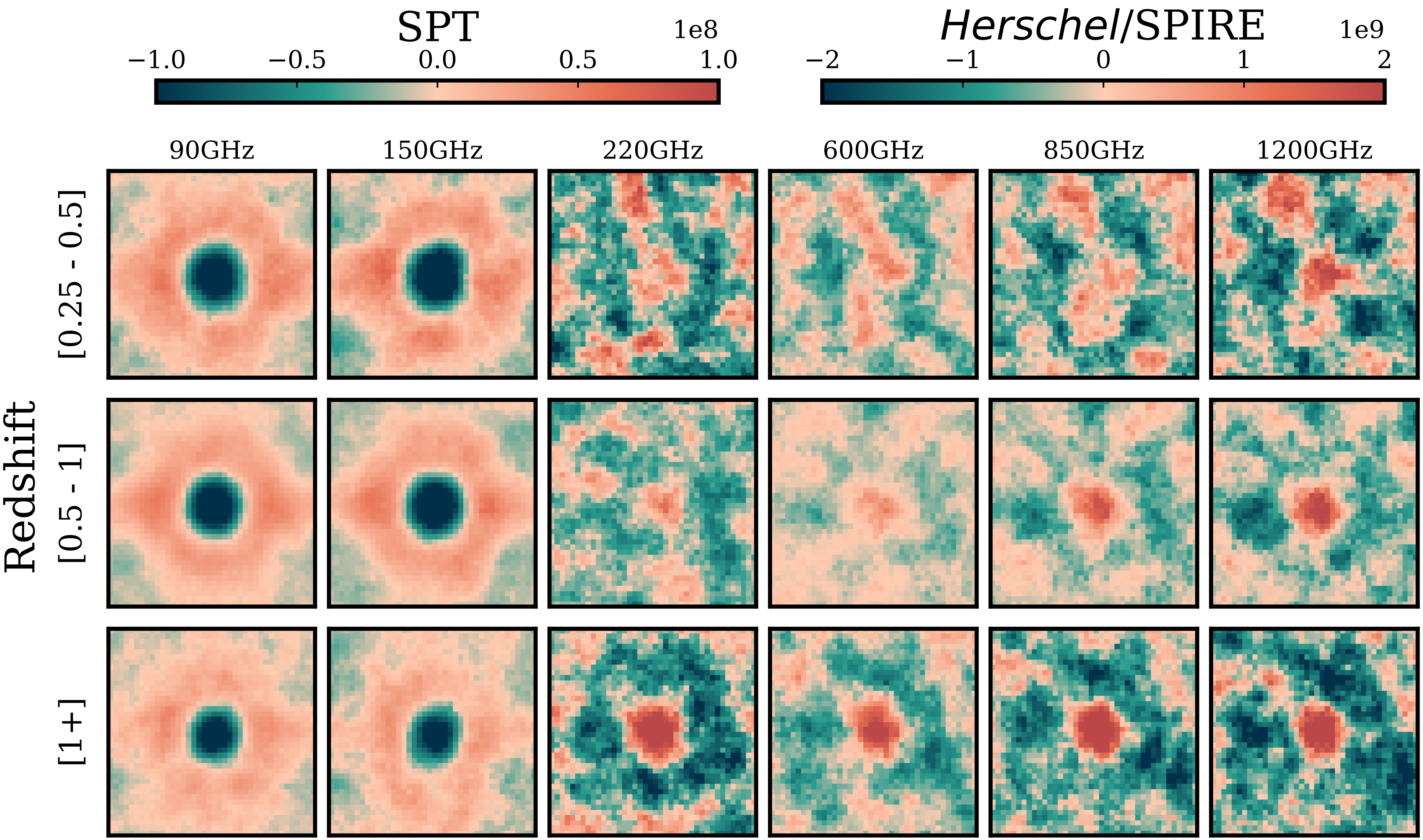
CMB-S4 Wide Noise Levels:

- 93: 1.89 μK
- 145: 2.09 μK
- 225: 6.9 μK

See Kayla's talk this afternoon!

Kornoelje, Bleem, Rykoff et al. (SPT-3G+DES), arXiv:2503.17271

Analysis of Dust Contamination on High-*z* SZ Selection



Kornoelje et al (arXiv:2503.17271)

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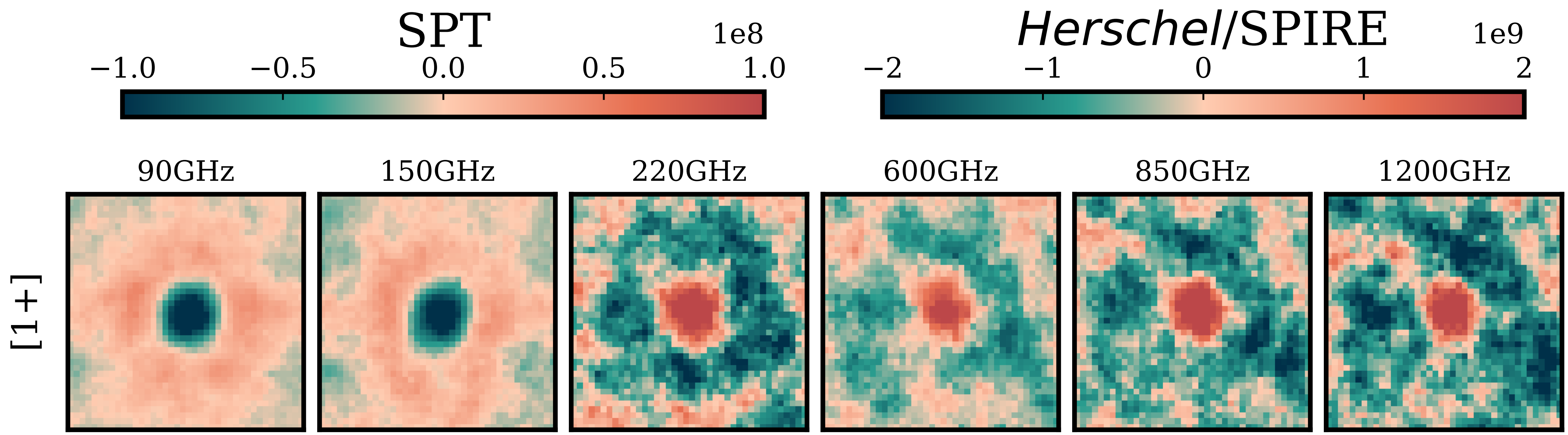
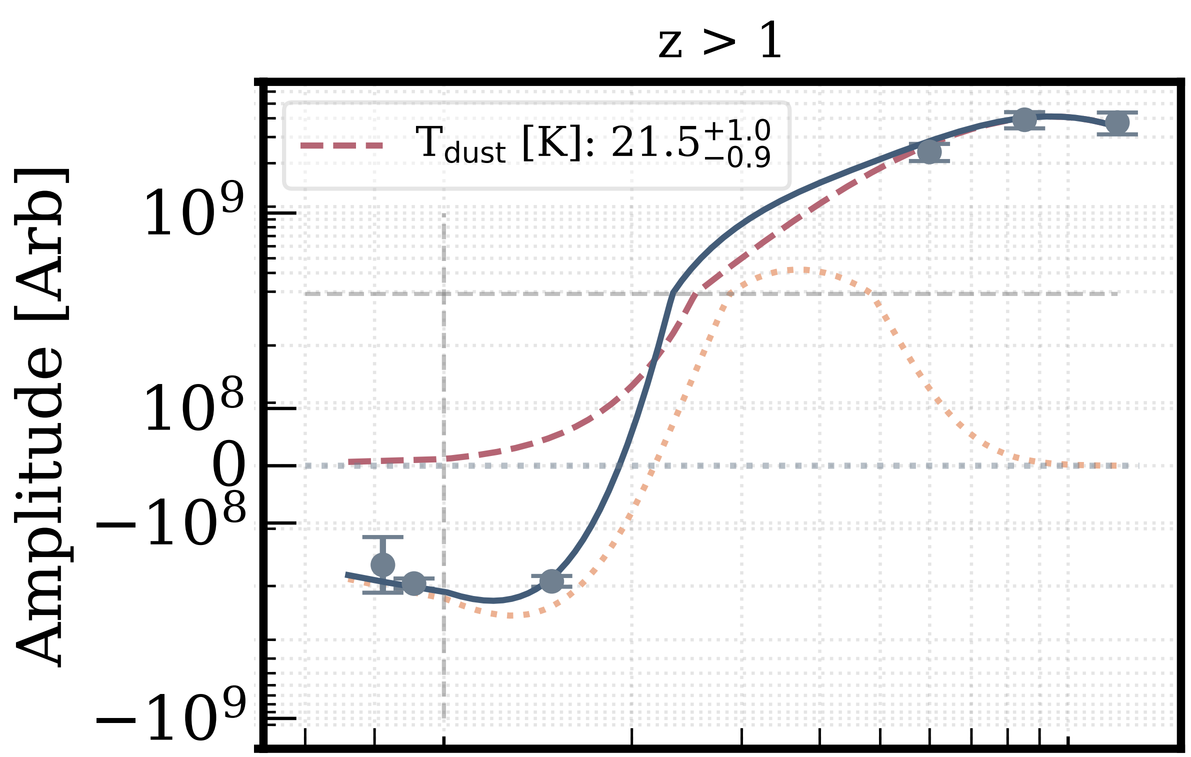
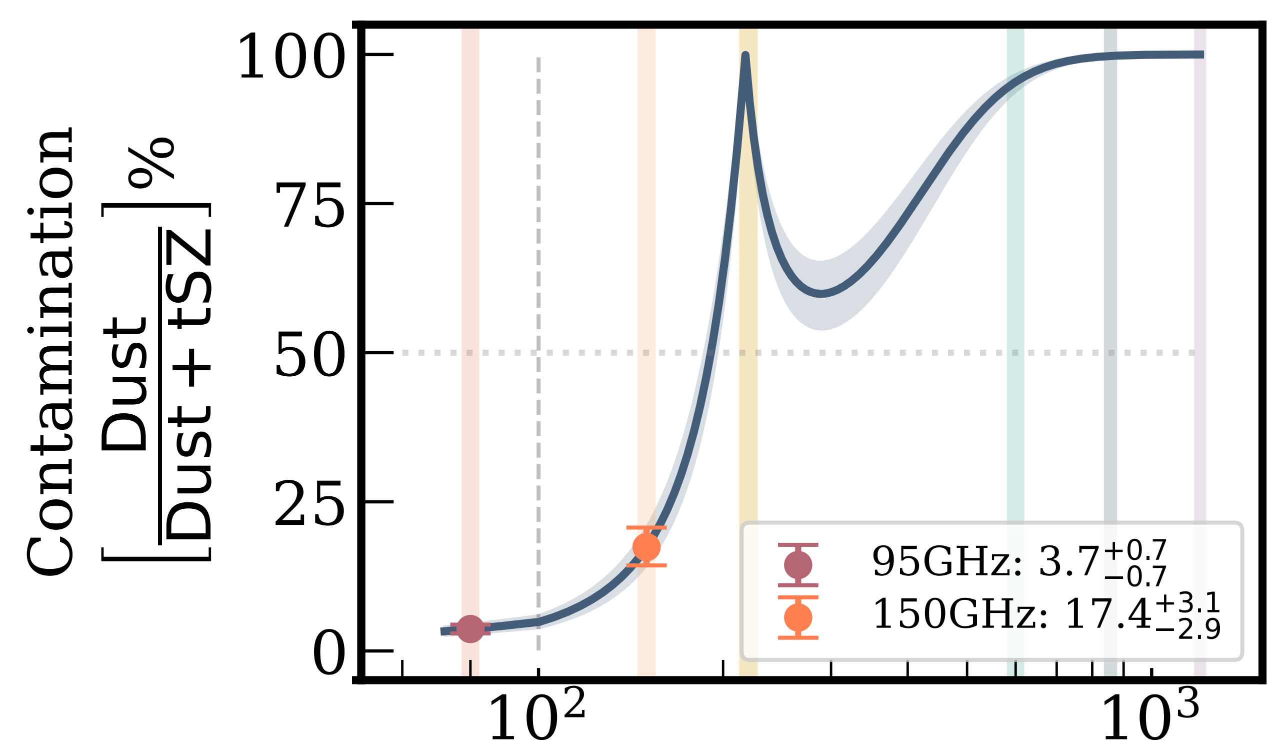


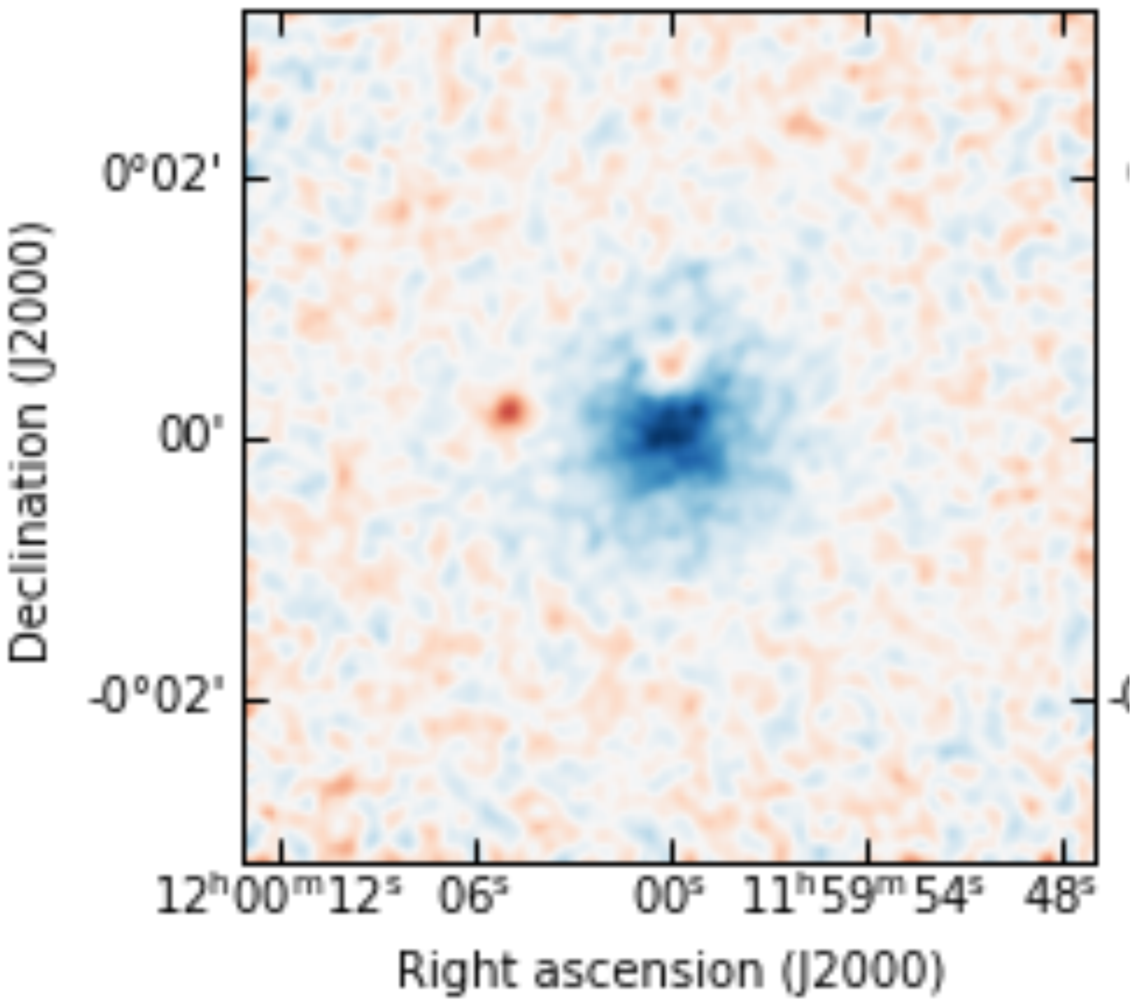




Kornoelje et al (arXiv:2503.17271)

Assessing the contamination from radio galaxies (Work in Progress)

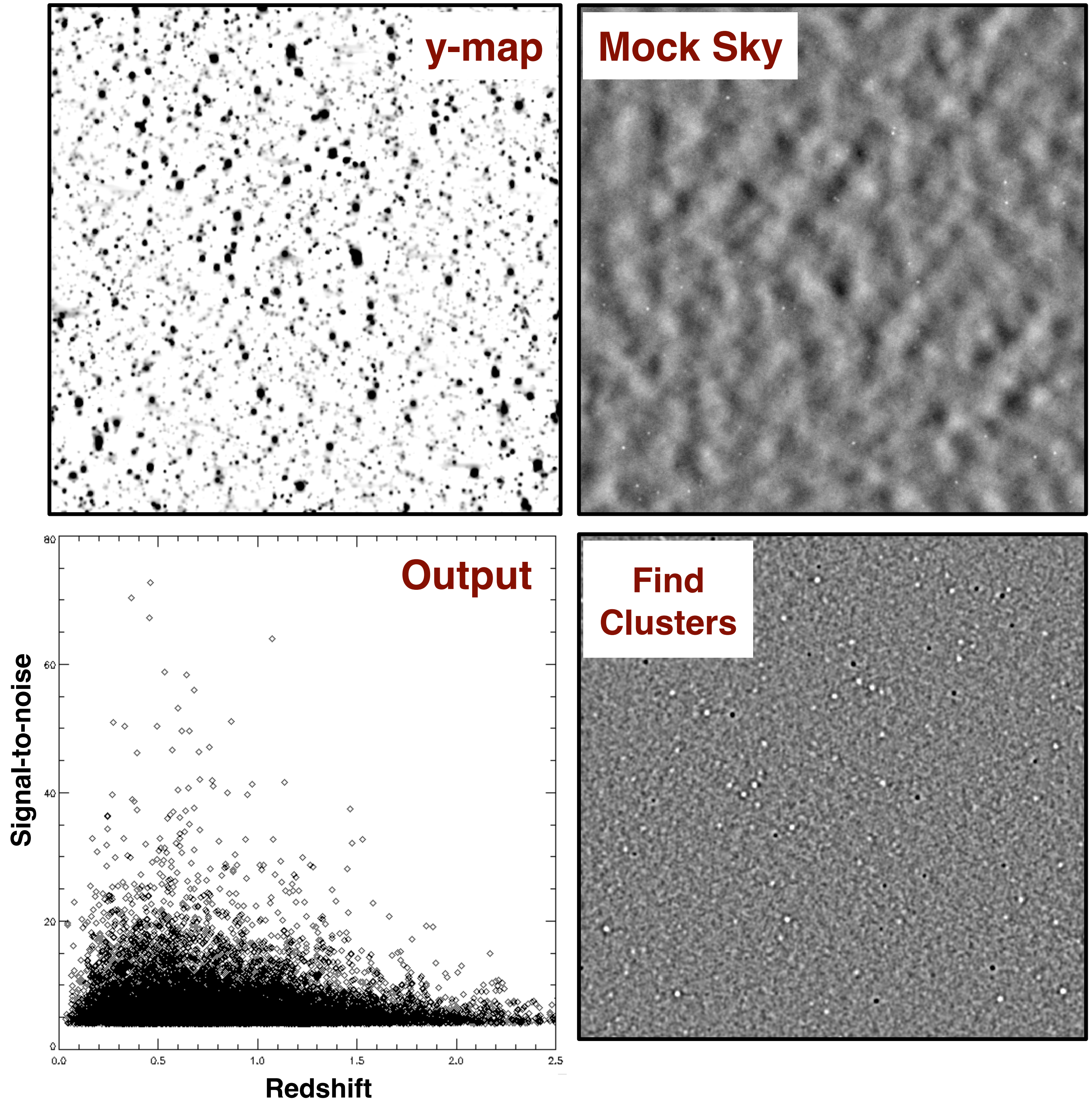
- Using a low-frequency radio source catalog (ASKAP, ~1.4 GHz) to model population level biases in SZ cluster selection from correlated synchrotron emission. Two parallel approaches in progress:
  - Cross-matching with **optical cluster samples**: The ASKAP sources are cross-matched with galaxy clusters identified by Wen & Han (2024). A spectral model is used to extrapolate the 1.4 GHz fluxes to SPT frequencies (90, 150 and 220 GHz). The model is then fit to the observed SPT data to identify and quantify contamination from galaxy clusters.
  - Cross-matching with the **eROSITA** cluster catalog: ASKAP sources resulting from the previous step are cross-matched with clusters detected by eROSITA. For the matched sources, the contamination from cluster emission is estimated using simulations. The point source fluxes are then corrected, and the luminosity function of radio sources in galaxy clusters is derived.



[Example of contamination from a point source simulated with the PANCO2 code, Kéruzoré at al. arXiv:2212.01439.]

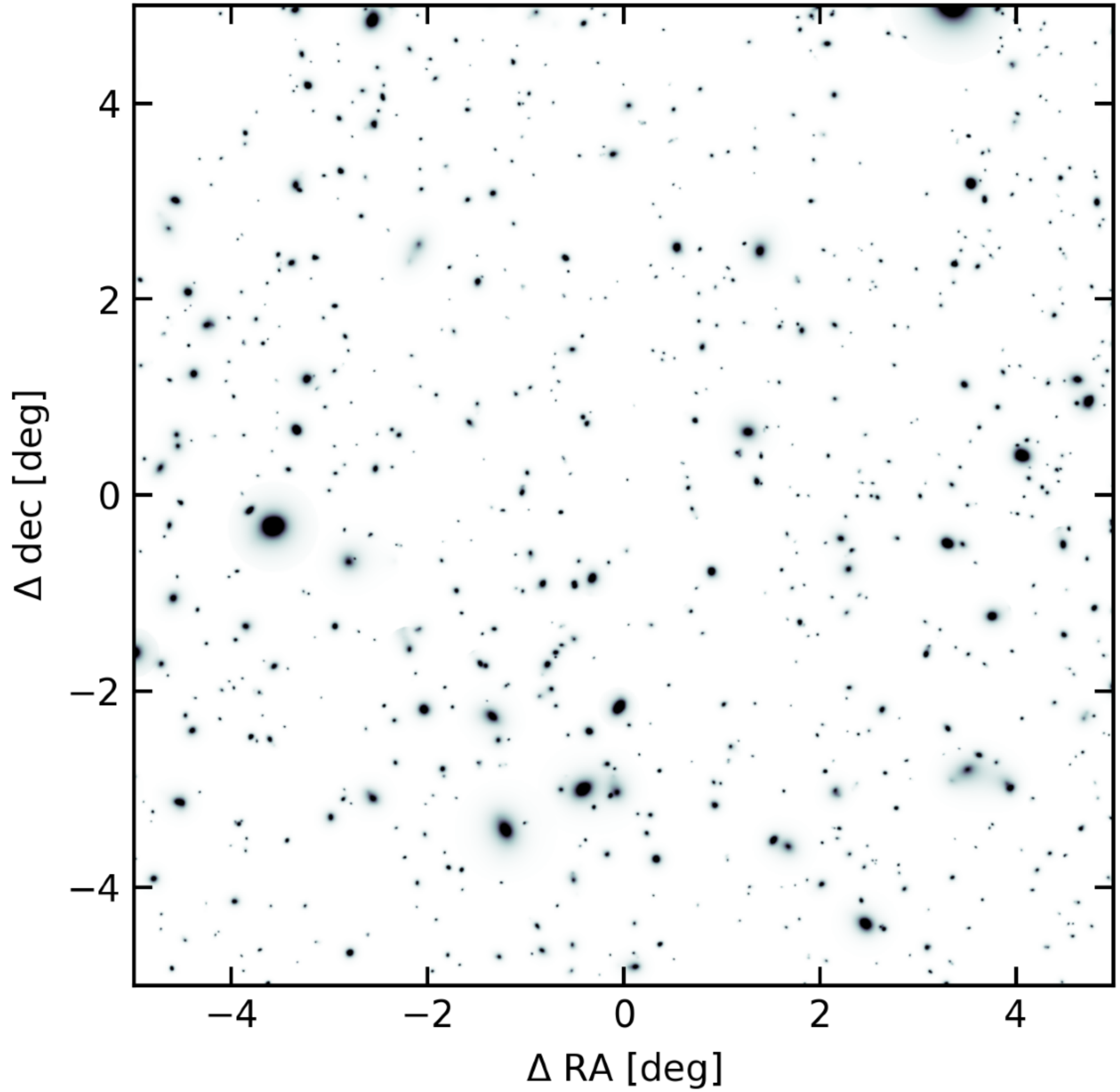
Modeling SZ selection through simulations

- Used for (1) relative calibration of ξ-mass scaling relation for SPT samples from different depth data and (2) to estimate expected numbers of spurious detections.
- SPTpol/first SPT-3G analyses based upon simulated sky maps with:
    - tSZ+kSZ from OuterRim simulation; added in post processing (Flender+16)
    - Instrumental noise from data jackknife noise maps
    - CMB, CIB power added to match observations
    - Poisson distributed radio sources



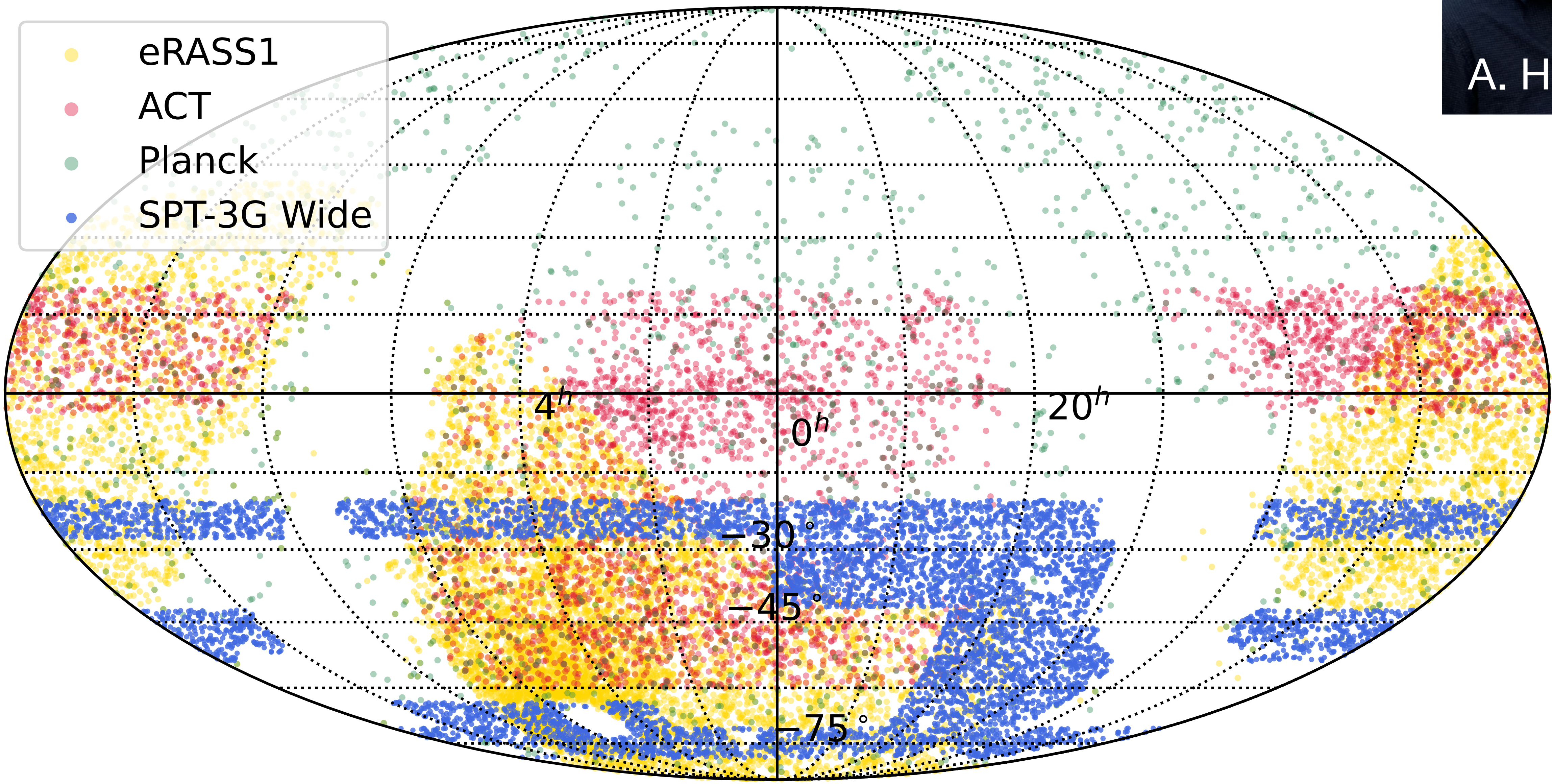
Modeling SZ selection through simulations

- Used for (1) relative calibration of ξ-mass scaling relation for SPT samples from different depth data, (2) to estimate expected numbers of spurious detections and (**3) biases associated with weak lensing calibration/clustering statistics.**
- Significant Improvements using Argonne *Last Journey* simulation include:
    - Improved **picasso** "baryon-painting" model for tSZ
    - Correlated CIB (M. Mallaby-Kay) and Radio Sources (G. Campitiello)
    - Ray traced weak lensing maps for optical and CMB lensing (P. Larsen)



100 sq-degree cutout of **picasso** sky, (see F. Kéruzoré's talk Thursday!)

The SPT-3G Wide Field Survey



- 6,000 sq-degree survey
- >6,800 cluster candidates at $\xi > 4$
- Cluster confirmation from DeCALS and DECADE surveys using targeted redMaPPer (Chun-Hao To)

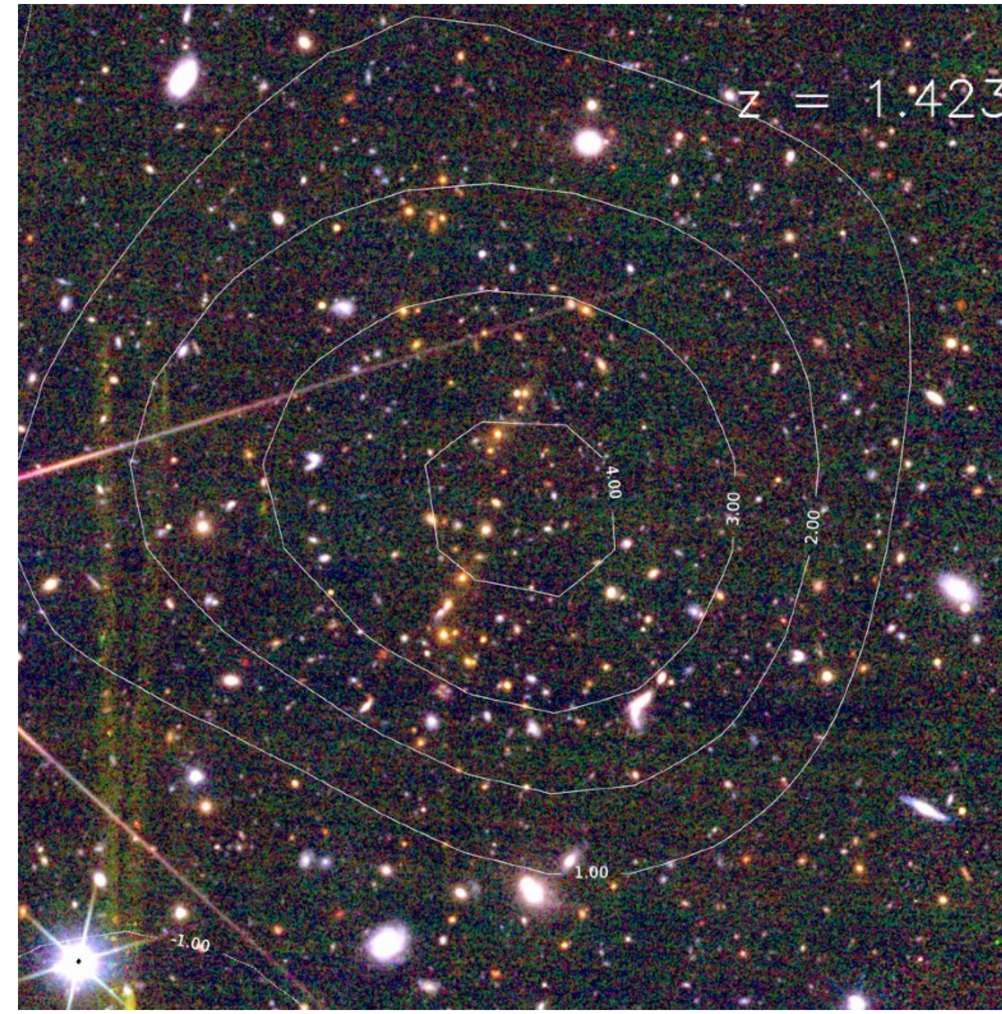
Conclusions

- Using the deepest wide-field high-resolution CMB data-to-date, SPT-3G has produced an SZ cluster catalog with over 7,000 confirmed clusters in its Main survey of 1600 sq-degrees (4.5 clusters/deg^2).

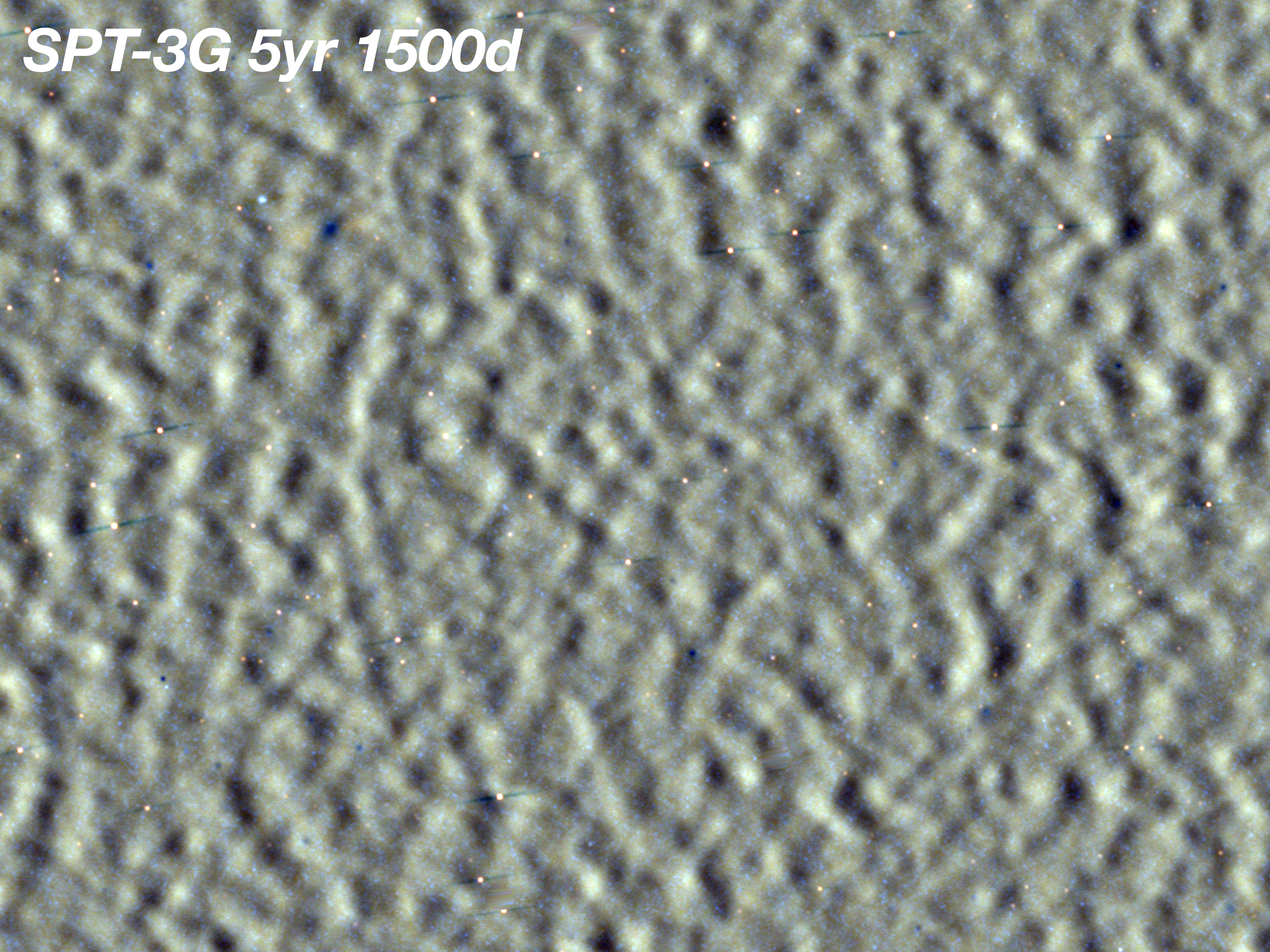
- The sample has a median mass of $1.8 \times 10^{14} M_{\odot}/h_{70}$ and spans $0.037 < z \lesssim 2$ in redshift.

- Using both data-driven and simulation-based approaches, we are working to construct robust models of the SZ selection function at the low-masses and high-redshifts probed by this new sample. *(Very excited to discuss multi-wavelength studies with eROSITA, Euclid, DES+LSST)*

- Expect >15,000 clusters from full SPT-3G 10k surveys. Stay tuned!



SPT-CL J0416-4800 in Euclid Deep Field South (Archipley et al. arXiv: 2506.00298)


SPT-3G 5yr 1500d