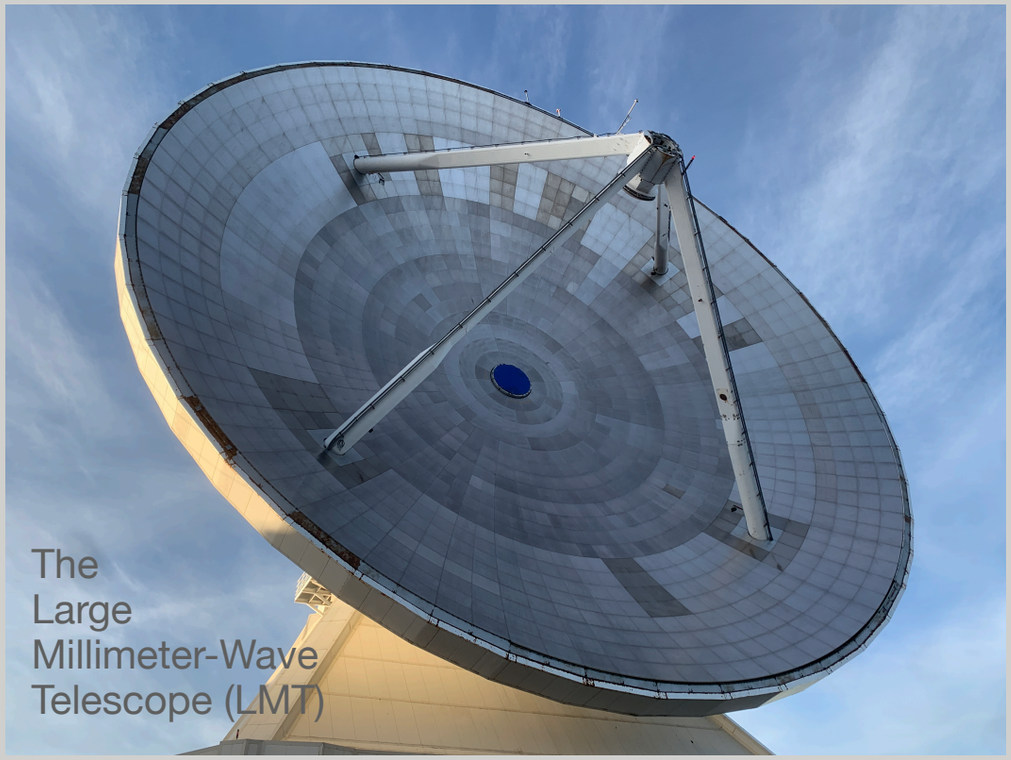
Early High-resolution Millimeter-wave Maps and Instrument Properties of TolTEC

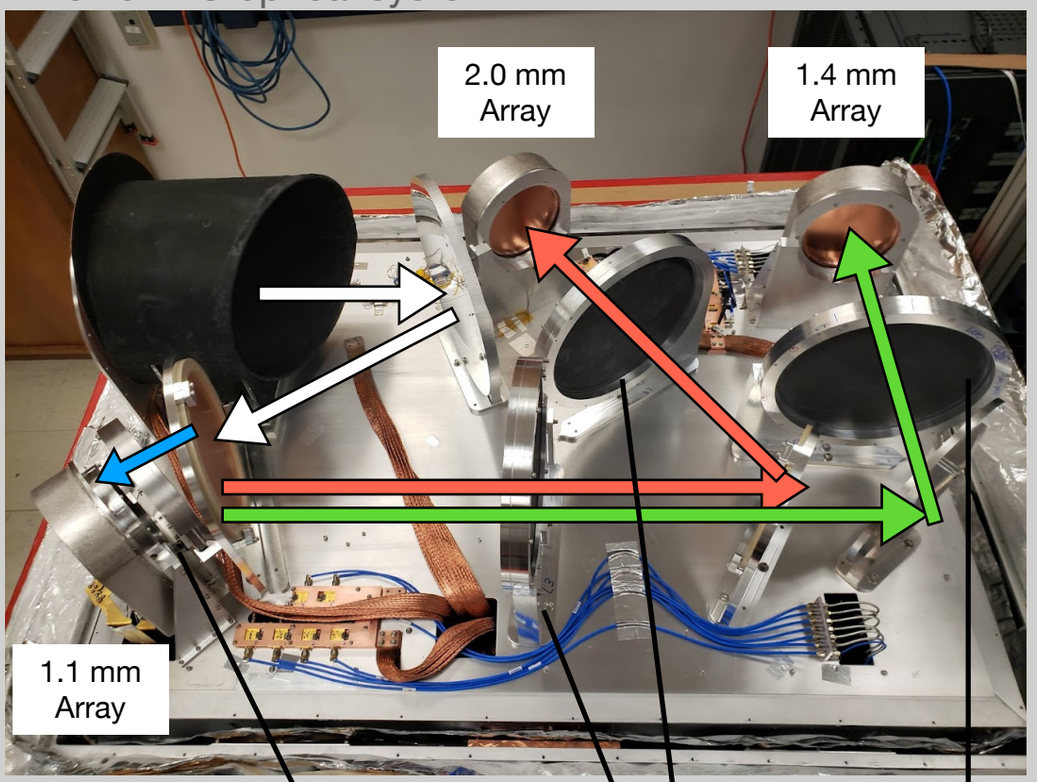
Joseph Golec 6/29/23

The TolTEC Camera



The Large Millimeter-Wave Telescope (LMT)

The TolTEC optical system



Metamaterial Anti-Reflection Coatings

Golec et al 2020 for Silicon AR coatings
Golec et al 2022 for Alumina AR coatings

TolTEC is a new large format polarization sensitive camera on the 50m LMT with high resolution and high sensitivity in three bands

- Deployed: 2022
- Commissioning including early science: December 2022 - (resuming) late 2023
- Routine Observations to start in 2024

	2.0 mm	1.4 mm	1.1 mm
Angular Resolution (arcsec)	11	7	5
Detector Count	1172	2532	4012

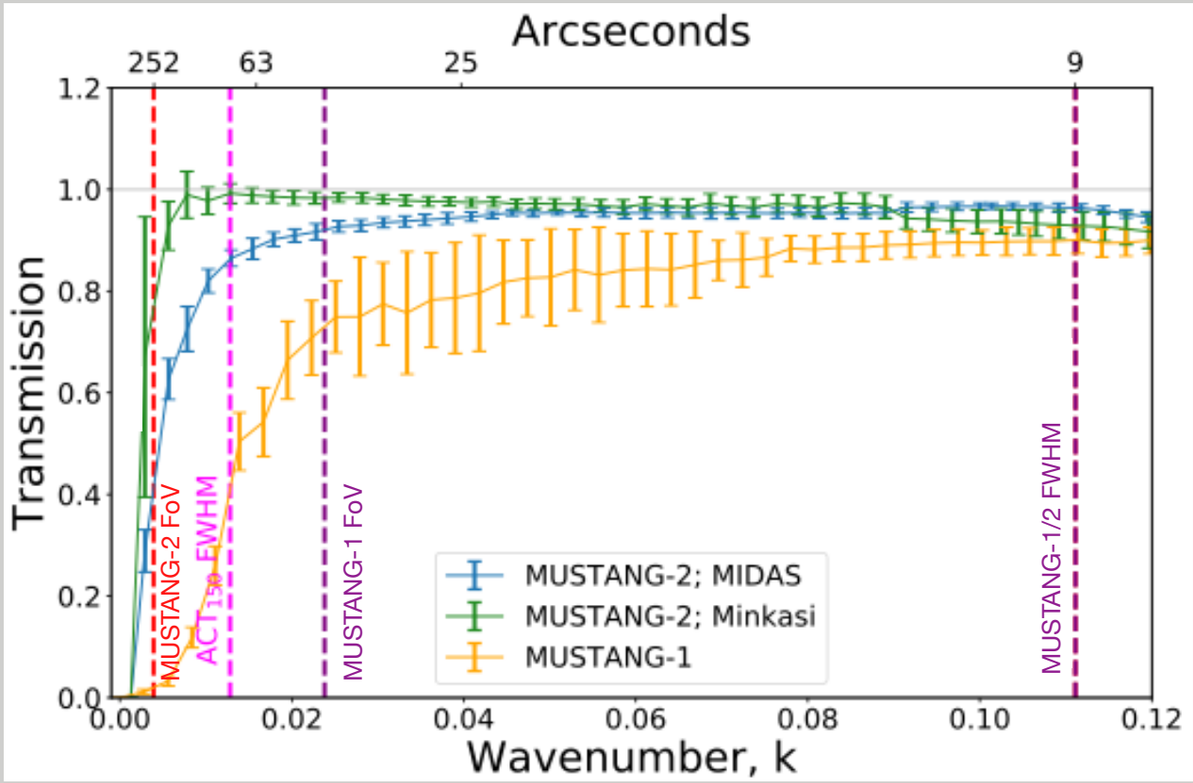
Mapmaking Methods

- Maximum likelihood mapmakers give an *unbiased* map that reduces signal loss at large scales and produces an map that better represents the true signals on the sky.

- The TolTEC pipeline (Citlali) uses two different mapmakers

  - A “filter and bin” naive mapmaker

  - Minkasi[1], a maximum likelihood mapmaker developed for MUSTANG-2 (see papers like Romero 2019, Dicker 2020, and Orlowski-Scherer 2022 for demonstrations of Minkasi)



Example of a transfer function comparison between a “filter and bin” mapmaker, MIDAS, and Minkasi. Adapted from Romero et al. 2019

Maximum Likelihood Mapmaking Basics:

Timestream Vector $\longrightarrow d = Pm + n$

Telescope Pointing Matrix; Sky Map; Noise

Maximum Likelihood Solution

$$\hat{m} = \underbrace{\left(P^T N^{-1} P\right)^{-1}} P^T N^{-1} d$$

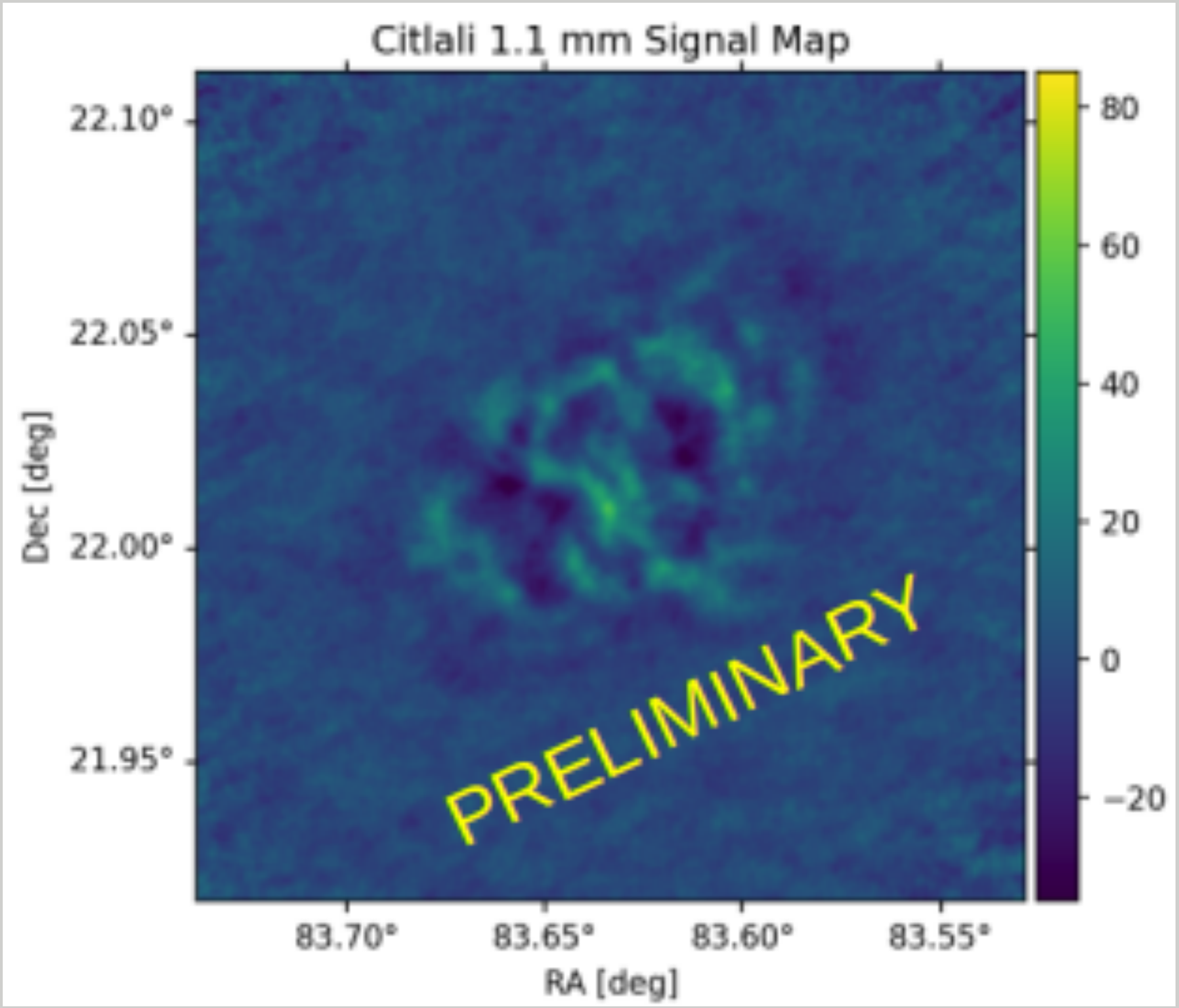
This is impractical to invert

Solve Linear Equation Instead:

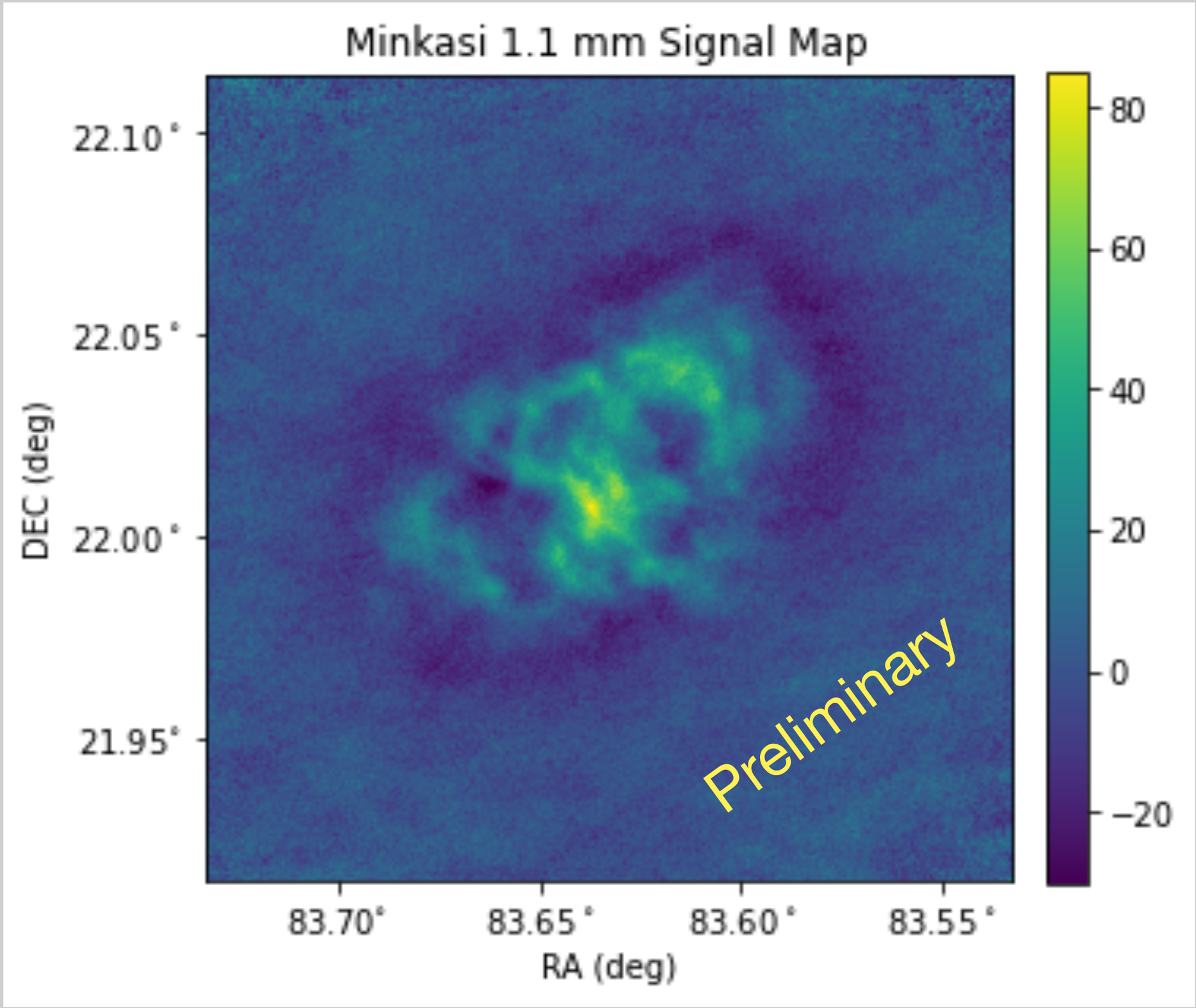
$$A\hat{m} = b \quad \text{where} \quad A = P^T N^{-1} P, \quad b = P^T N^{-1} d$$

[1] https://github.com/sievers/minkasi

The Crab Nebula - Filter and Bin

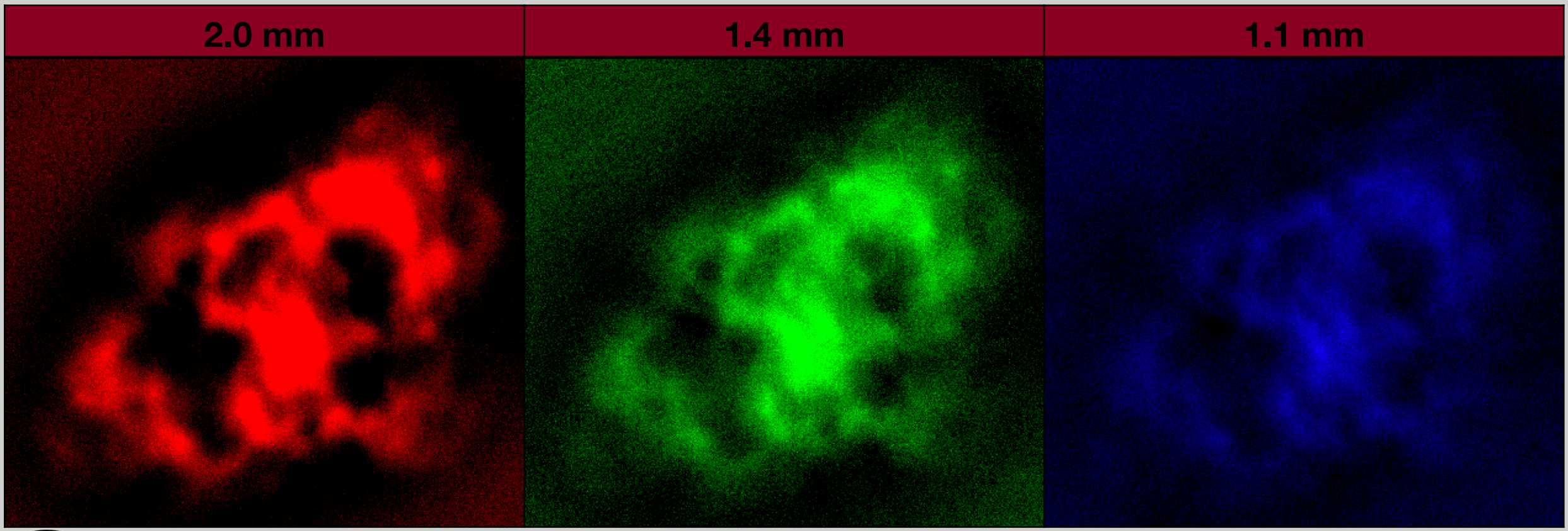


The Crab Nebula - Minkasi



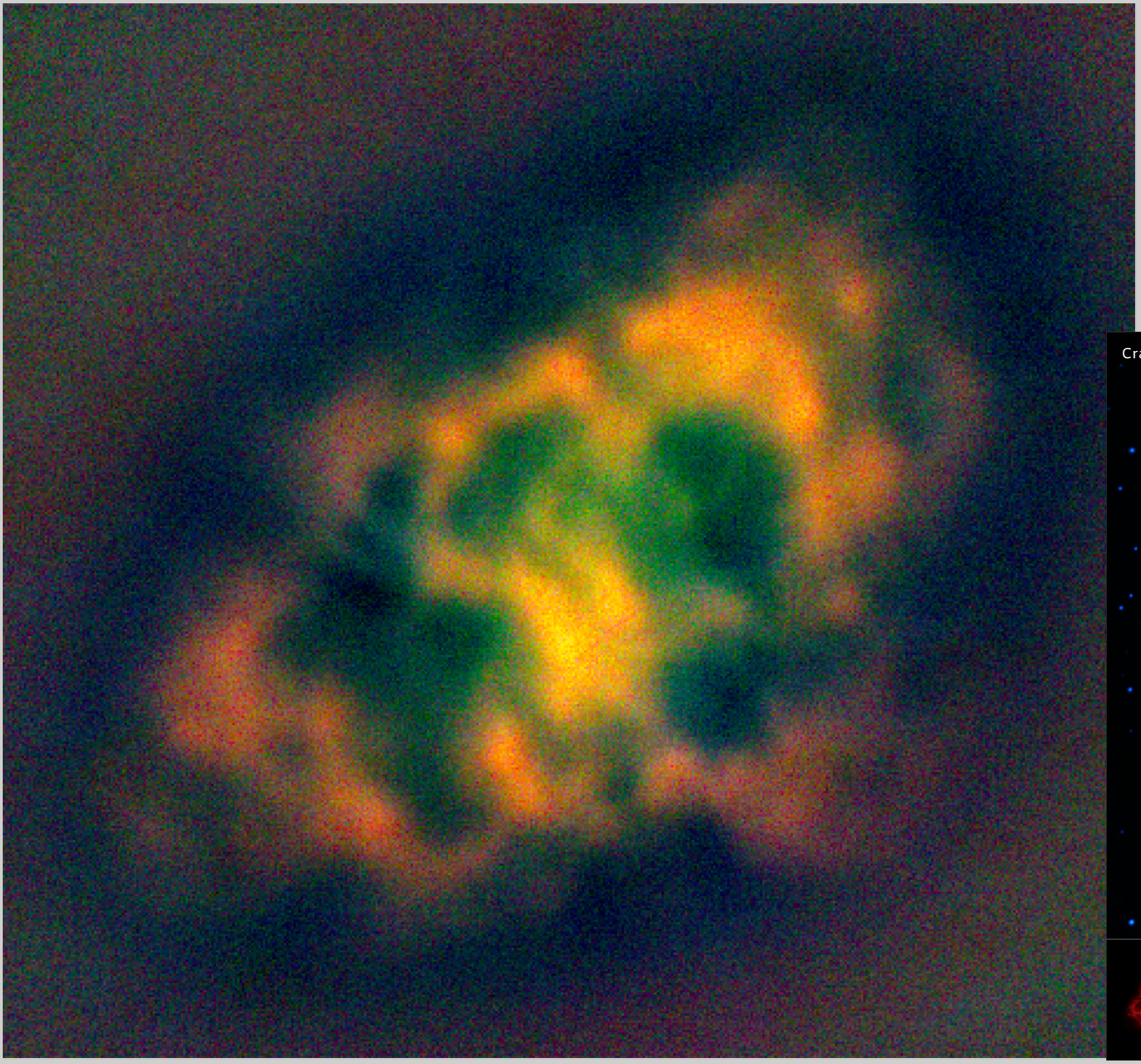
The Crab Nebula in Three Colors

- TolTEC observed the Crab Nebula for a total of **22 minutes** in December of 2022 as part of commissioning observations
- Six 10’ x 12’ raster scans
- Decreasing intensity with frequency is indicative of synchrotron emission



* All Three Share The Same Color Scale

The Crab Nebula



- Morphologically our image agrees with images at other wavelengths
- Great proof of the TolTEC instrument and mapmaking pipeline

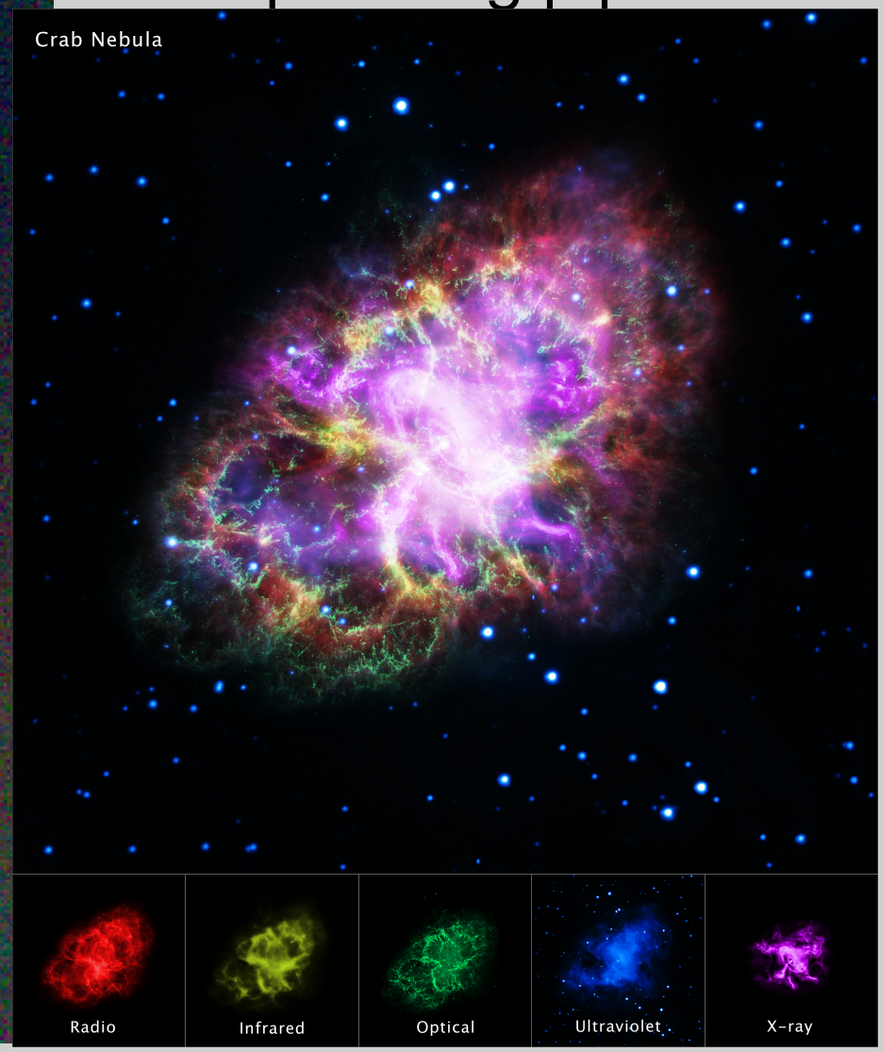
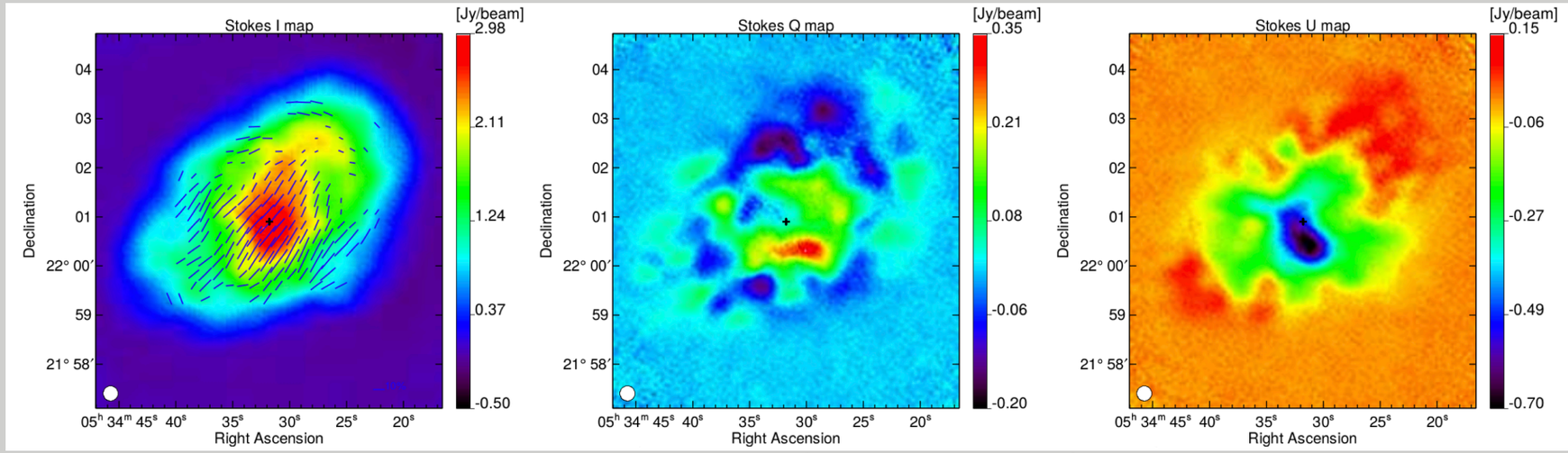


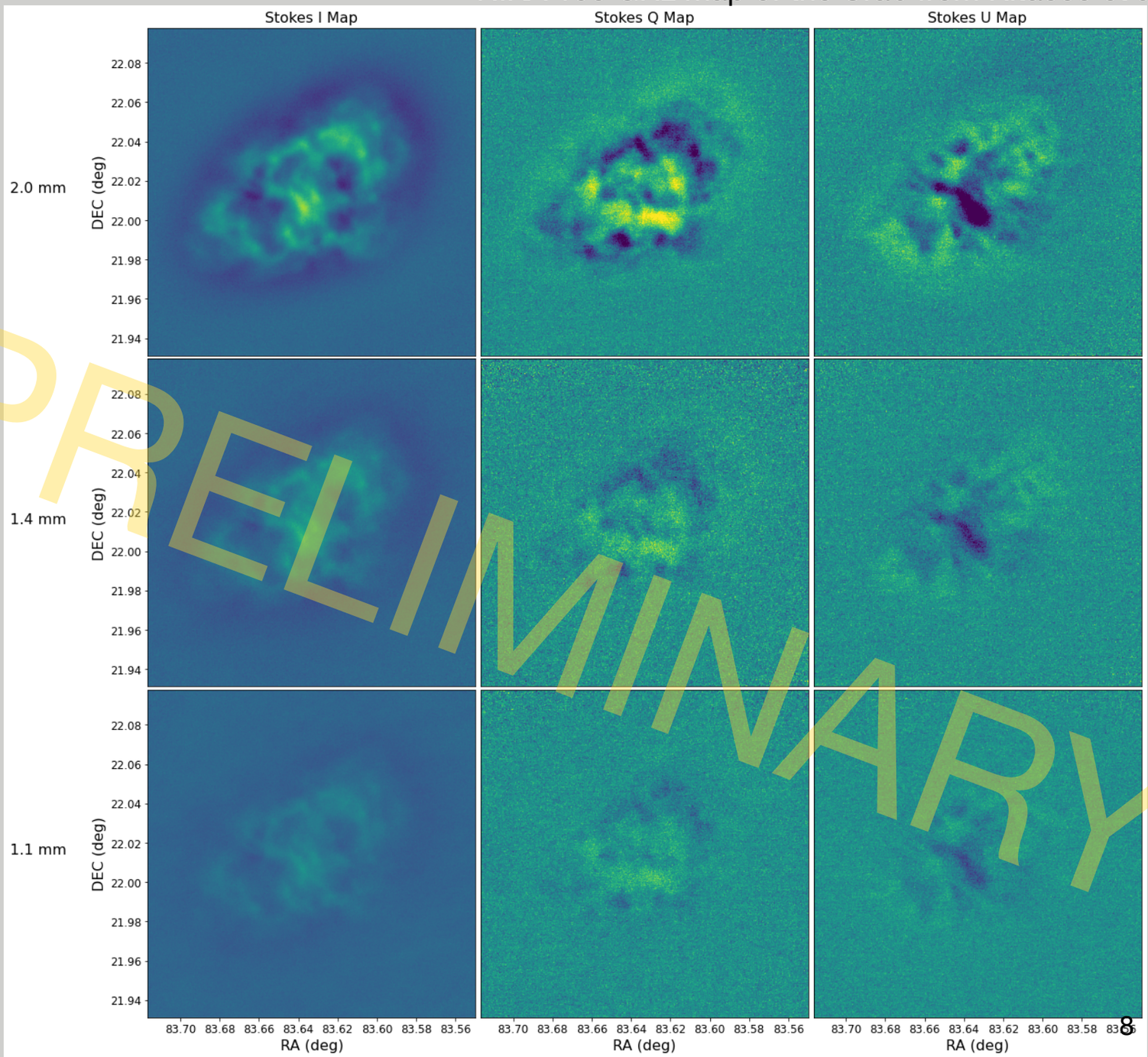
Image Credit: NASA, ESA, G. Dubner (IAFE, CONICET-University of Buenos Aires) et al.; A. Loll et al.; T. Temim et al.; F. Seward et al.; VLA/NRAO/AUI/NSF; Chandra/CXC; Spitzer/JPL-Caltech; XMM-Newton/ESA; and Hubble/STScI

Polarized Emission

- Calibration of the Stokes Q and U fluxes (among other things) still needs to be finalized
- Q and U morphology at 150 GHz roughly agree with comparable observations by experiments like NIKA

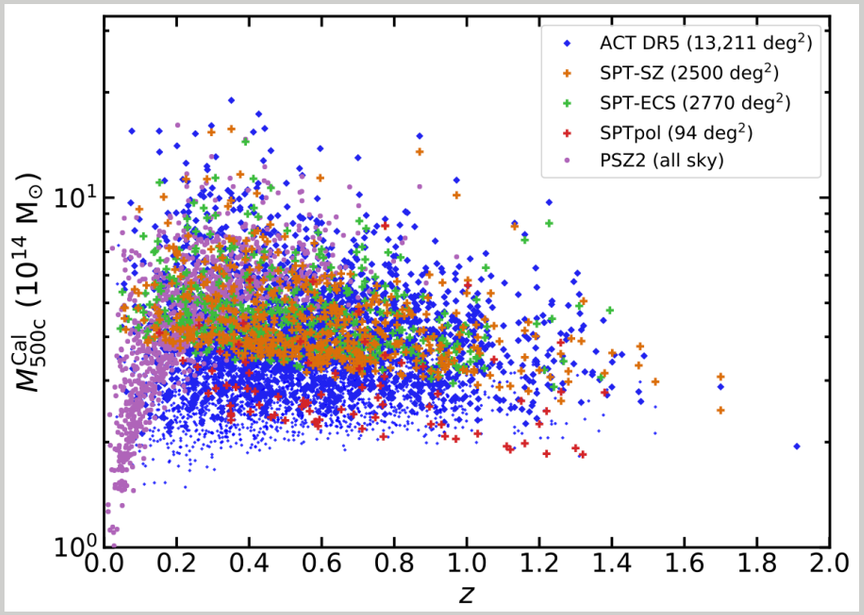


NIKA 150 GHz map of the Crab from Ritacco et al 2018

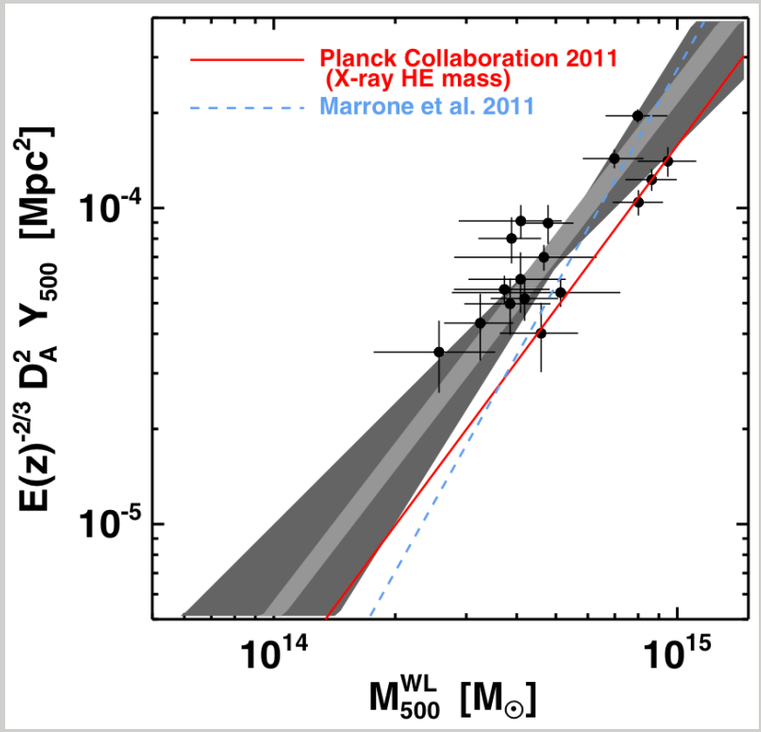


Galaxy Clusters

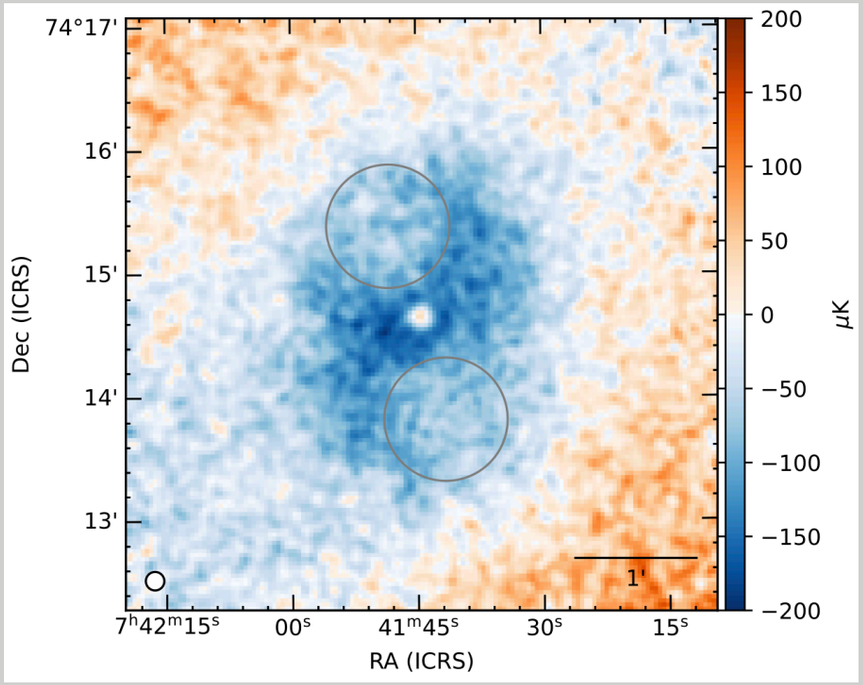
- Galaxy clusters are the most massive gravitationally bound objects in the universe
- CMB surveys catalog thousands (soon to be tens of thousands) of clusters
- Following up these clusters with high-angular resolution mm-wave measurements can lead to
    - Better understanding in the scatter in the Y_{SZ} - M relation of clusters
    - Better understanding of the astrophysical processes (AGN feedback, Shocks, Cluster Mergers,…)



From ACT DR5 Cluster Catalog (Hilton et al 2020)



Y_{SZ} - Weak Lensing Mass relation (Planck 2013)



From Orlowski-Scherer et al 2022

Next Steps to Commission TolTEC

- The cryostat is now warm and a summer trip is planned to make some planned repairs and upgrades
- The LMT is back on sky roughly at the end of August (barring complications)
- The commissioning targets for the fall include galaxies, clusters, and extragalactic fields
- Hope to complete commissioning by the end of the winter so that legacy surveys can begin as soon as possible

The TolTEC Team

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