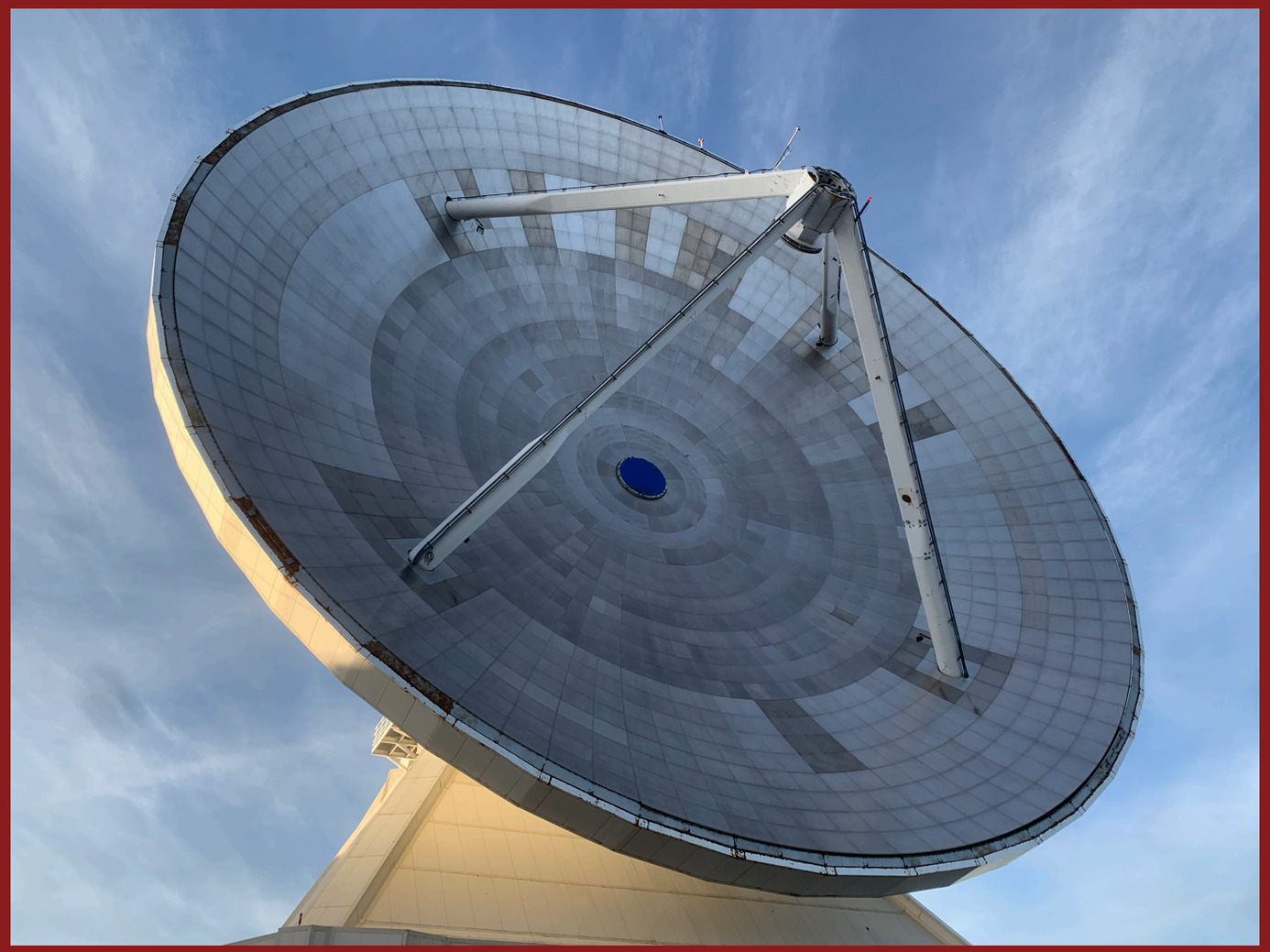
An Update on the Commissioning of the TolTEC Camera



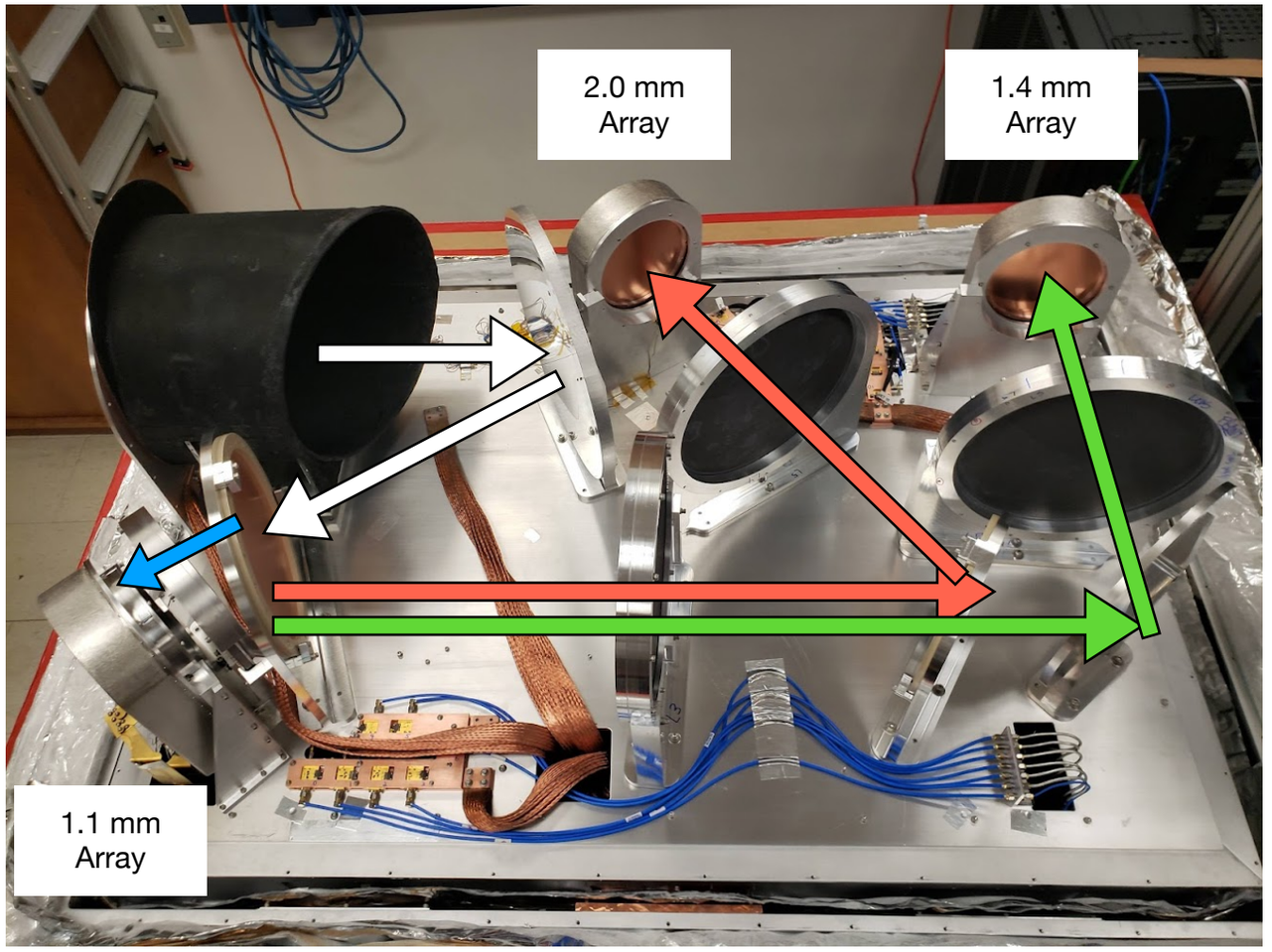
The Large Millimeter Telescope (LMT)

Joseph Golec 6/25/25

The TolTEC Camera

TolTEC in the LMT Receiver Cabin

The TolTEC optical system



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

- Deployed: 2022
- Commissioning: December 2022 - today

	2.0 mm	1.4 mm	1.1 mm
Angular Resolution (arcsec)	10	6	5
Detector Count	1172	2532	4012

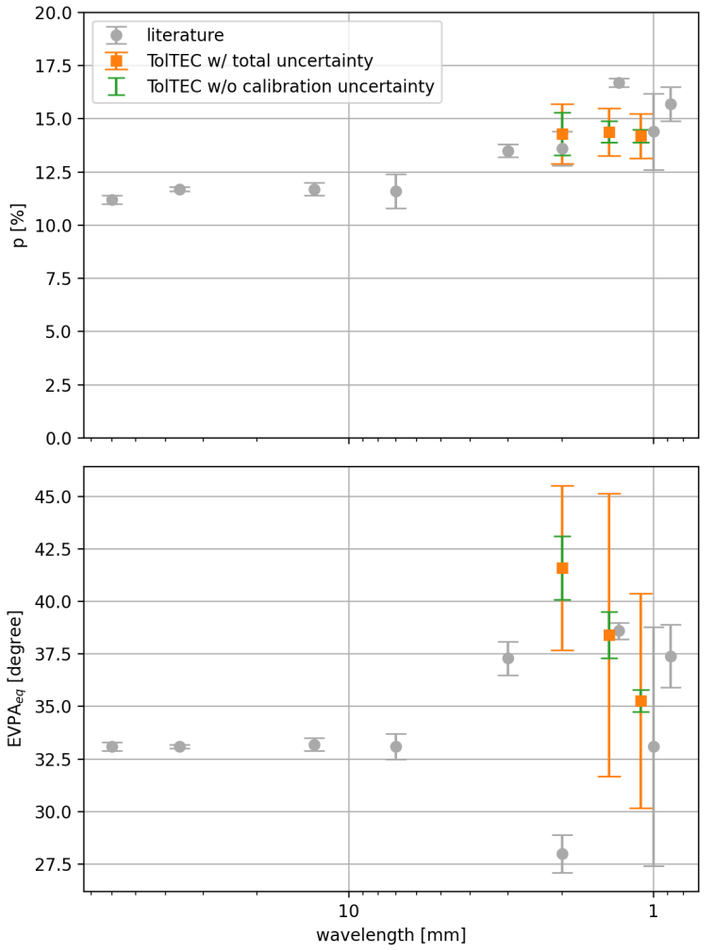
Progress Since 2023

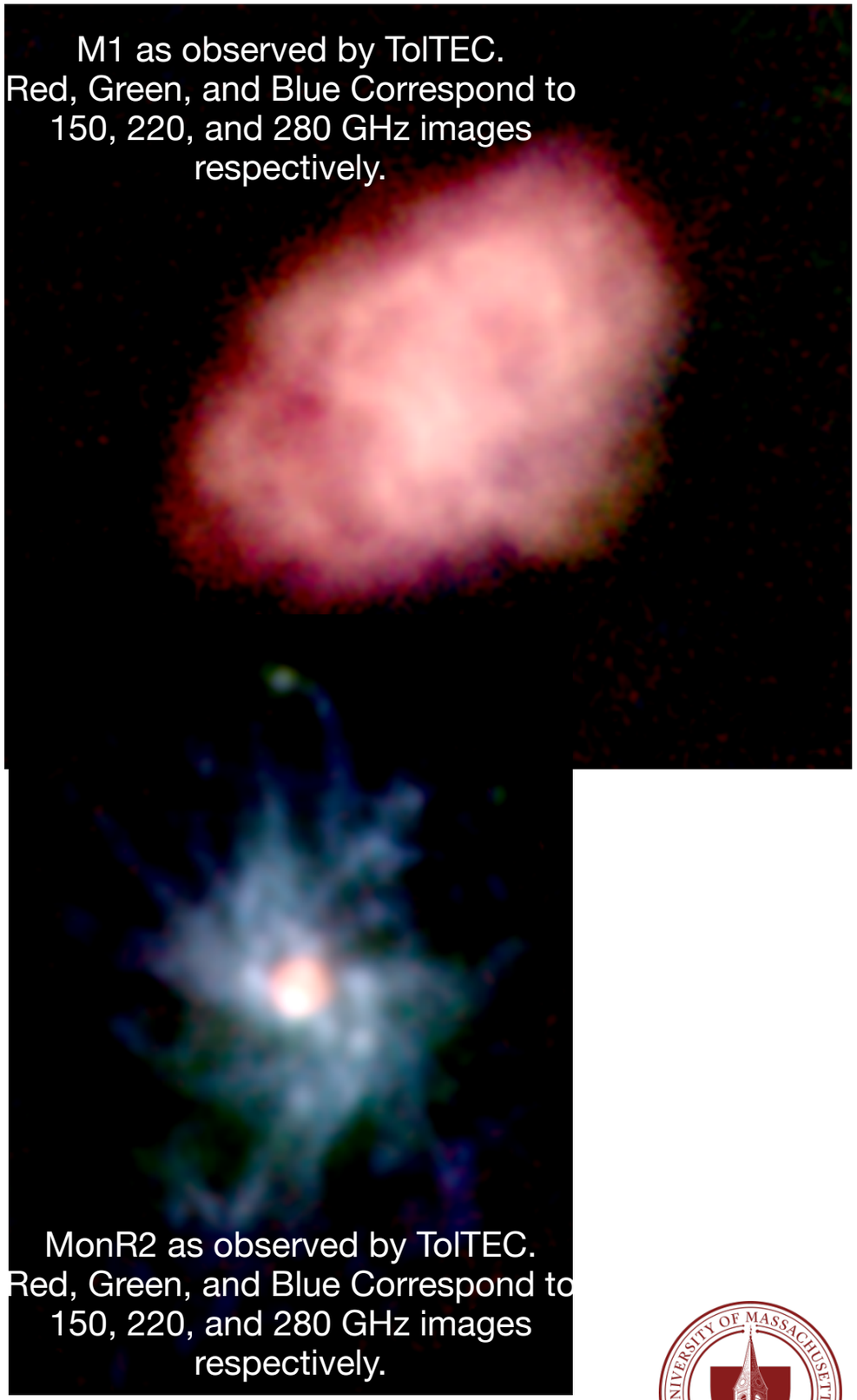
- We released the early commissioning data from 2022 observations in Fall 2024
- Commissioning partly resumed in 2024
- In 2025:
  - We spent **42 nights** observing with most of that time being dedicated to engineering work
  - However we spent some secondary time on science targets
- We have improved our instrument performance since the 2022 commissioning run

Data Products We Have Released

- So far we have released 3 science verified datasets
  - M1 total intensity
  - MonR2 total intensity
  - 3C286 total intensity and polarization

Polarization properties of 3C286 measured by TolTEC

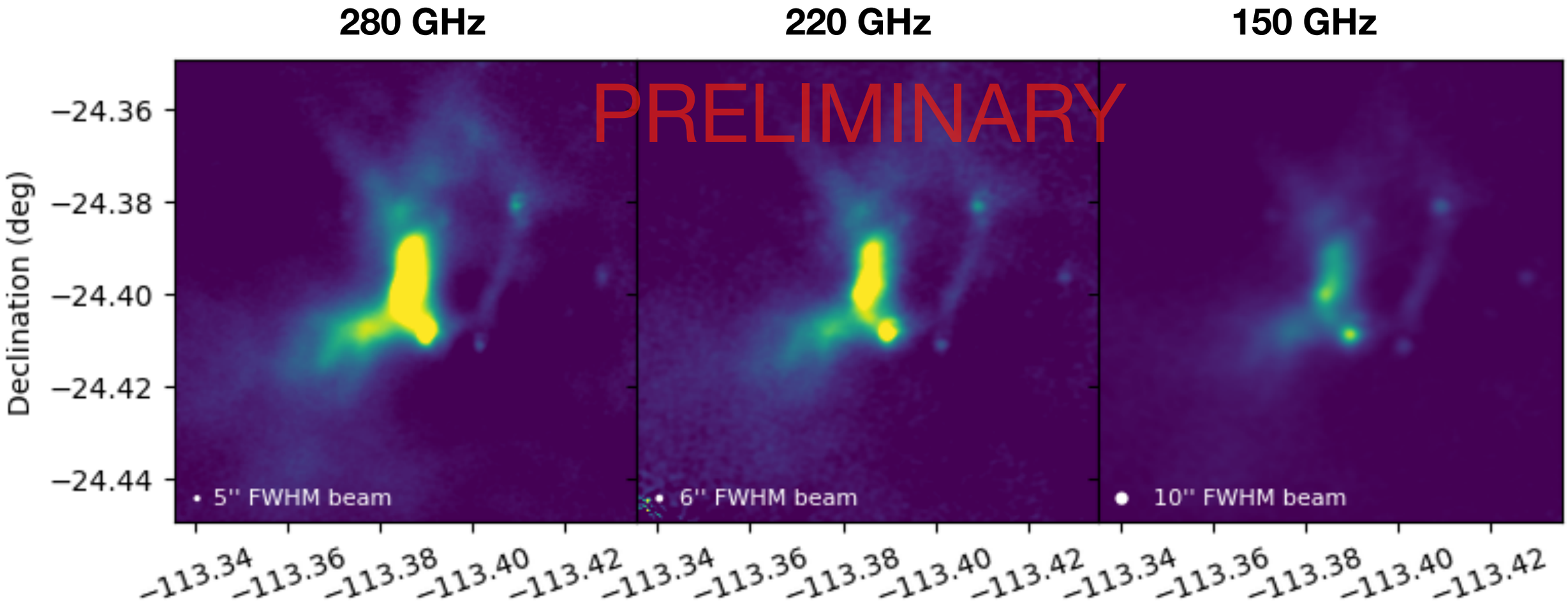




The Following Images Are PRELIMINARY

They are still in the process of being verified by the commissioning working groups and may still be subject to changes such as overall calibration

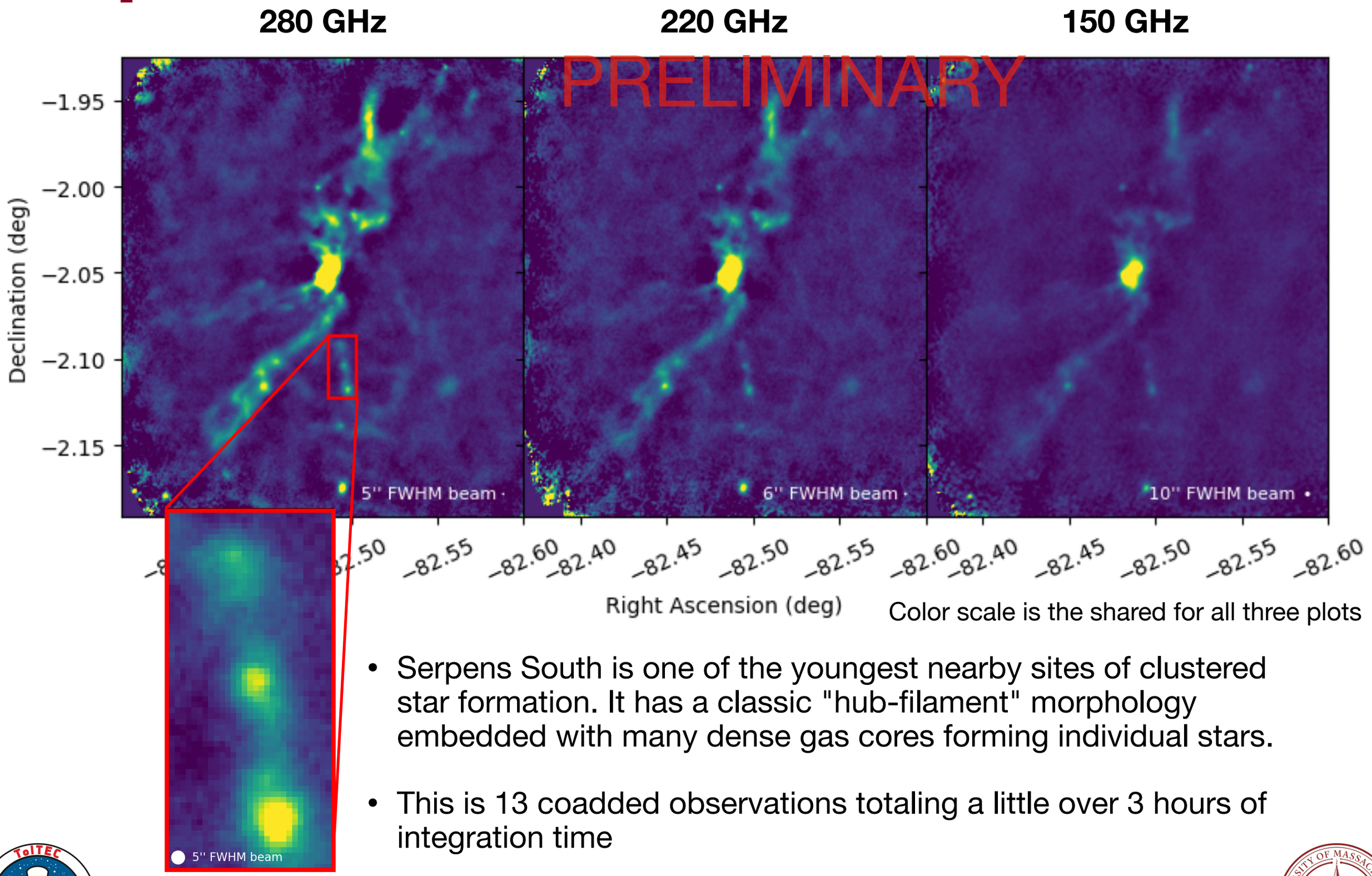
Rho Oph A



Color scale is the shared for all three plots

- Rho Oph A is a single dense gas core of the star-cluster forming L1688 dark cloud located in the Ophiuchus molecular cloud
- This is a coaddition of two maps for a total integration time of 40 minutes
- We also have observations of this with a rotating HWP!

Serpens South



Color scale is the shared for all three plots

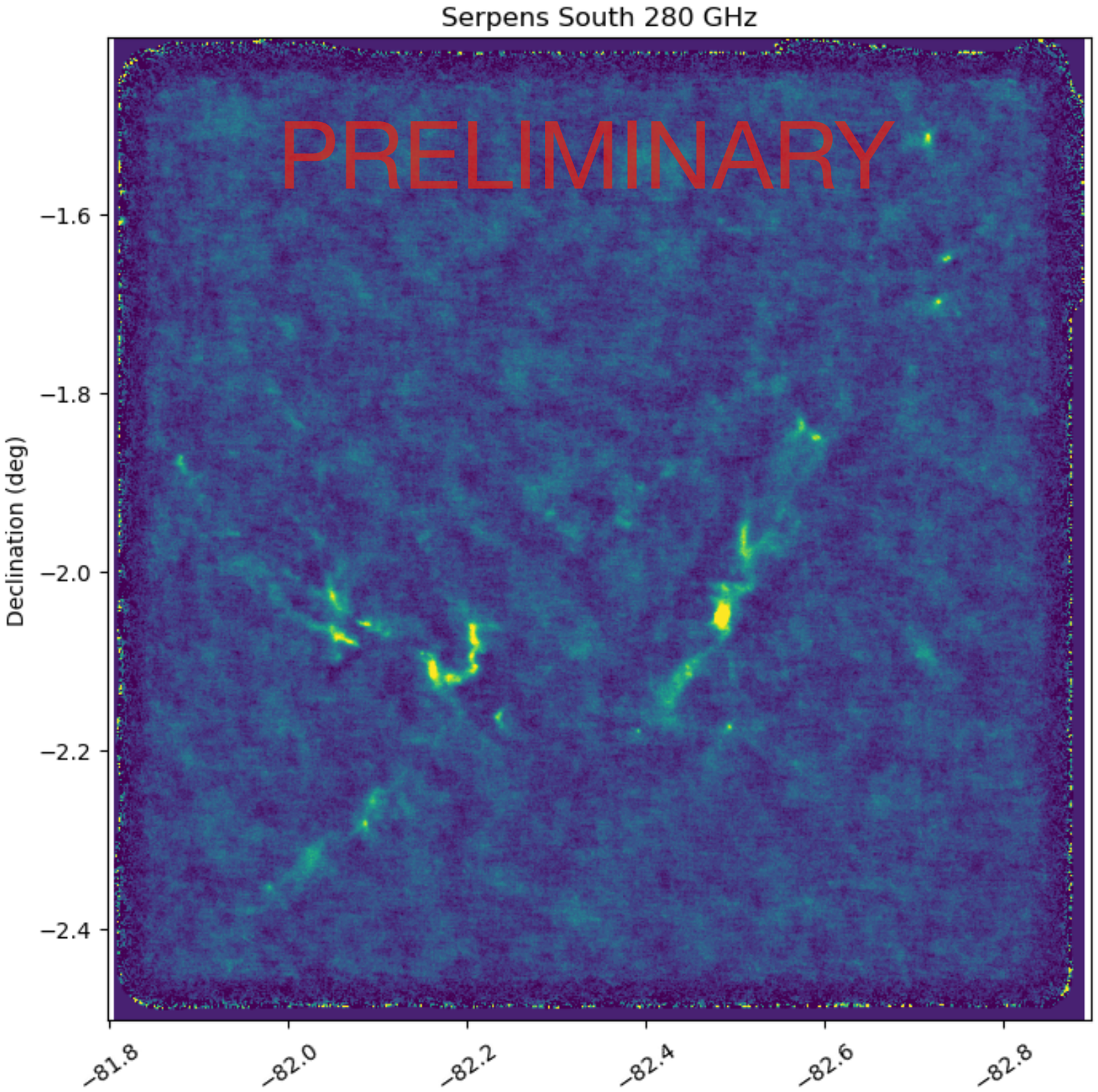
- Serpens South is one of the youngest nearby sites of clustered star formation. It has a classic "hub-filament" morphology embedded with many dense gas cores forming individual stars.
- This is 13 coadded observations totaling a little over 3 hours of integration time

Serpens South and W40 HII Region

- Degree-scale maps are a necessity for two of the TolTEC Legacy Surveys (Clouds to Cores and Ultra-Deep Galaxy Survey)

- This is a 280 GHz coaddition of 6 observations totaling around 1.8 hours

- We continue to commission these large fields with the goal of optimizing scan speed, sampling rate, etc.



Polarization

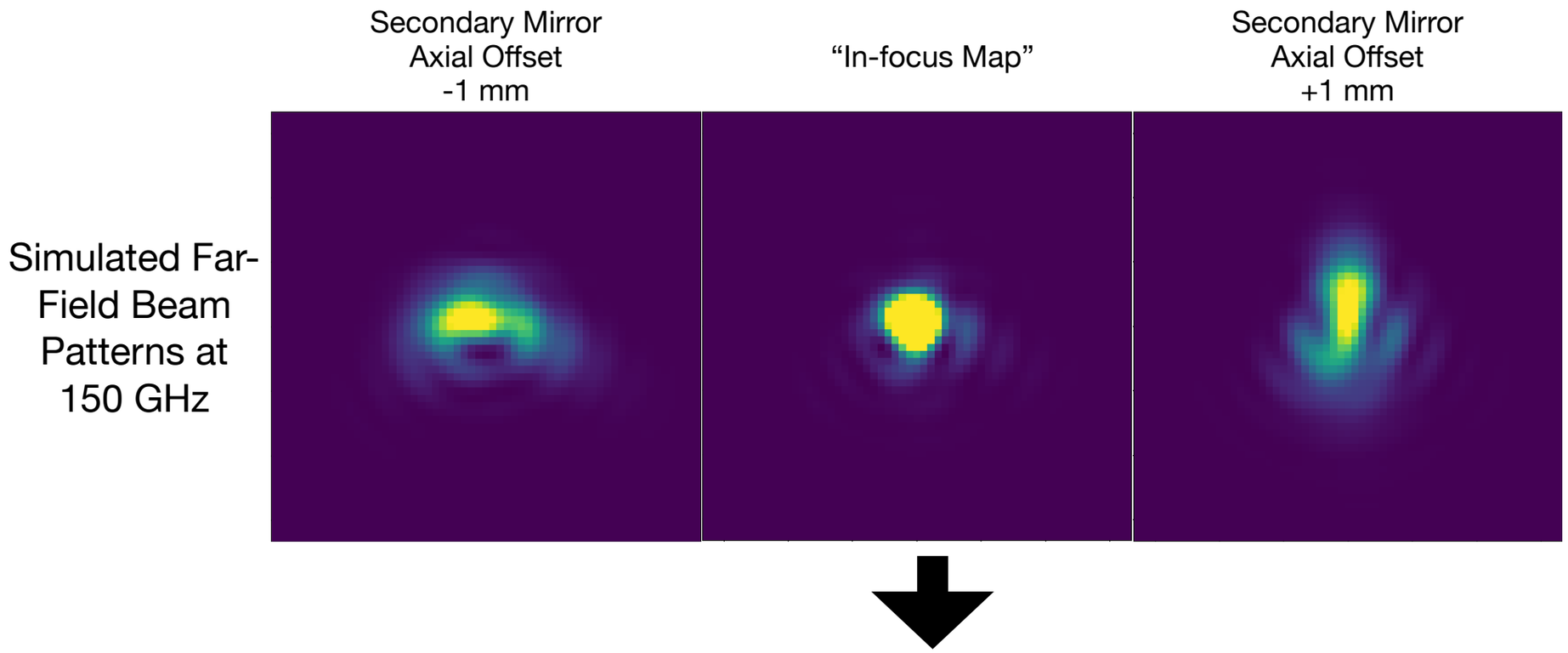
- We have observations of several fields that have interesting science cases related to galactic magnetic fields and polarized dust emission
- Reduction of that data using TolTEC's inherent polarization capabilities (ie orthogonal antennae pairs at 0 and 90, and 45 and 135 degrees) is ongoing
- We have also made several observations of compact and extended sources using a continuously rotating HWP

Commissioning Next Steps

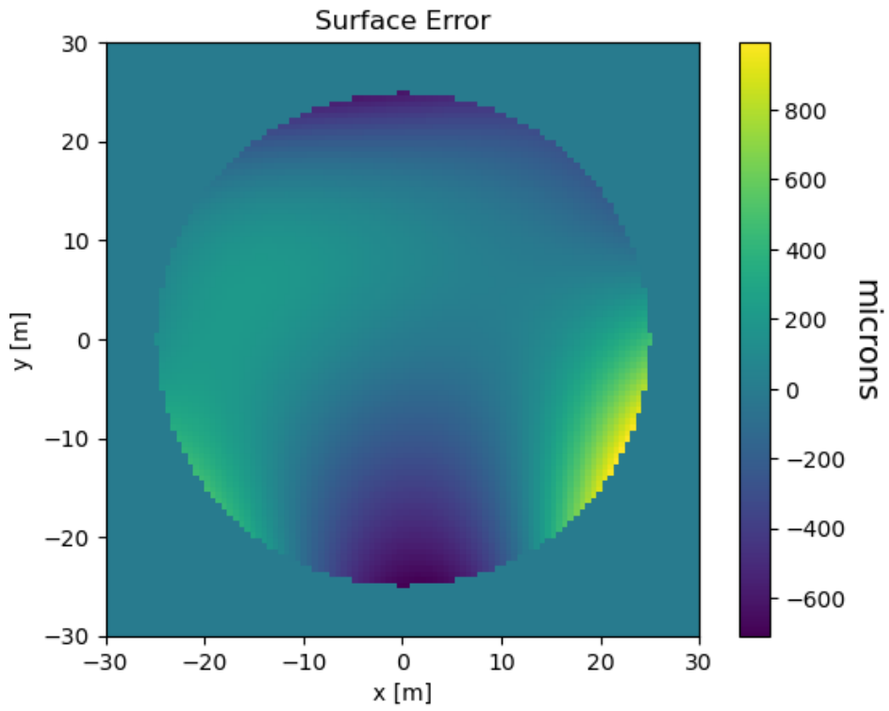
- Need to improve TolTEC's sensitivity
  - Phase errors at the primary surface are dominating our reduced aperture efficiency
  - Our LNA+readout noise is ~5K
  - There is evidence of RFI in our readout chain
- Both of those problems are tractable!
  - We will be addressing the RFI issues in July
  - **Out of Focus Holography (OOF)** work is ongoing to correct the primary surface

Out of Focus Holography

- OOF can reconstruct phase at the aperture by sampling the far field beam at various secondary mirror positions



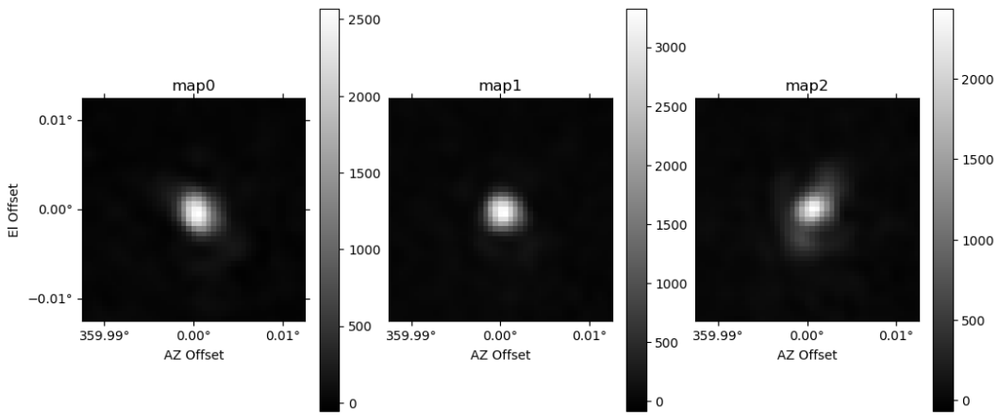
Assume an instrument model



& $\text{Strehl Ratio} = \dfrac{\text{Peak Intensity of Aberrated Beam}}{\text{Peak Intensity of Ideal Beam}}$

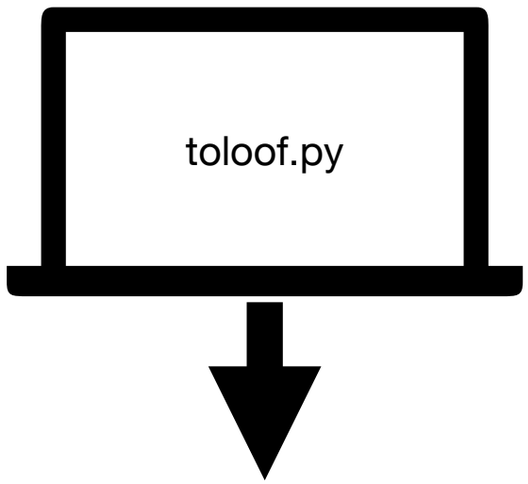
TolTEC OOF Workflow

Make maps of pointing source at
3 secondary mirror positions



Iterate

Feed those maps into the TolTEC
OOF code

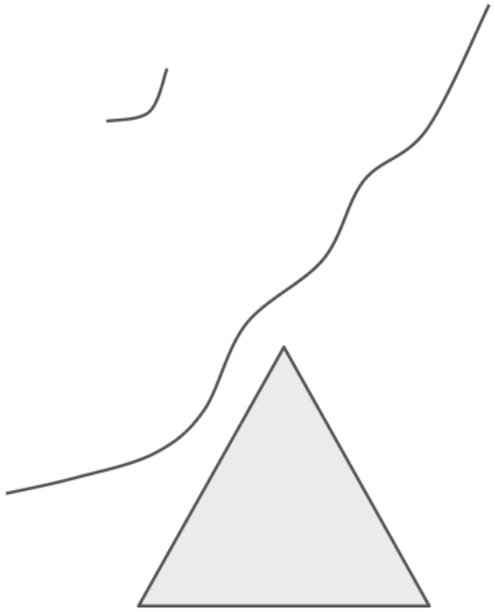


Get Zernike Coefficient Outputs

Label	Value (mm)
AST_V	0.599095
AST_O	−0.361445
COMA_H	−0.226981
COMA_V	0.277195
TRE_O	0.133536
TRE_V	−0.441131
SPH	0.0673498
QUAD_V	−0.346046
QUAD_O	0.101467
AST2_O	0.267089
AST2_V	0.503664

*Not necessarily typical values

& Strehl Ratio



Apply Zernike Coefficient Outputs
to Primary Mirror with Opposite
Sign

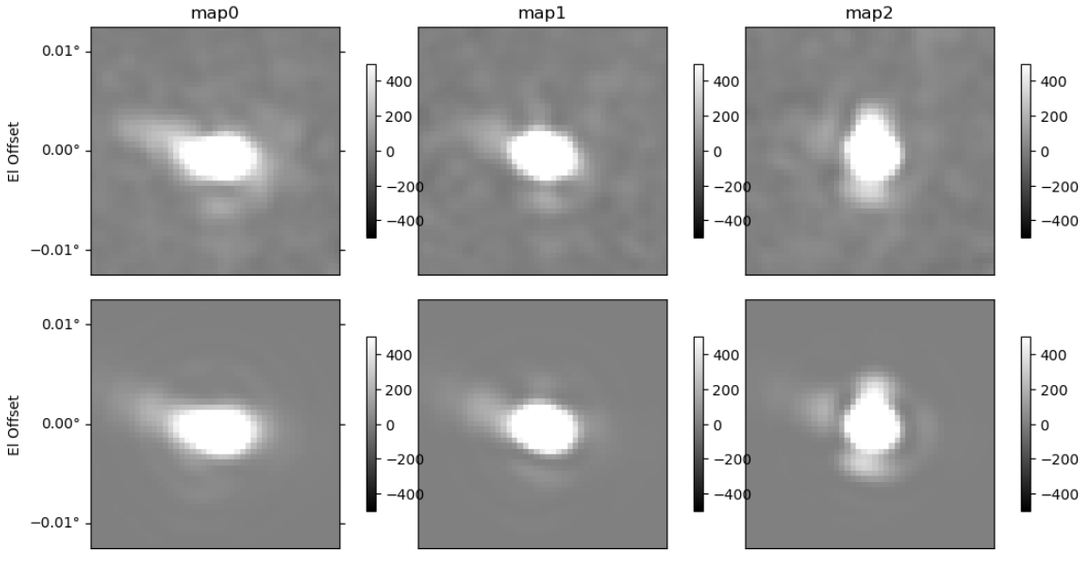
Preliminary OOF results

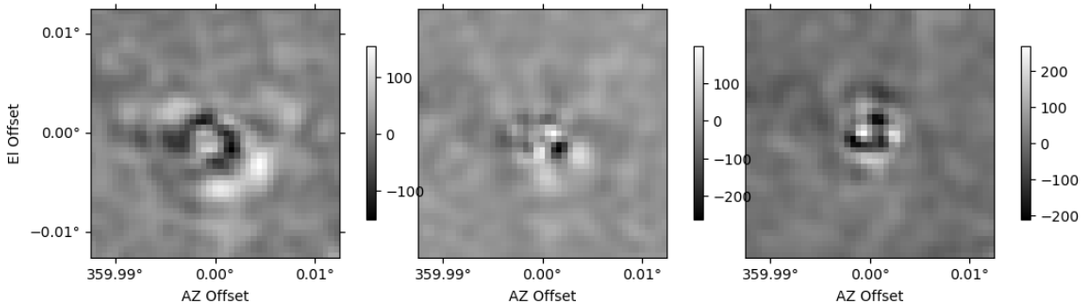
Example of 150 GHz OOF Measurement

Data

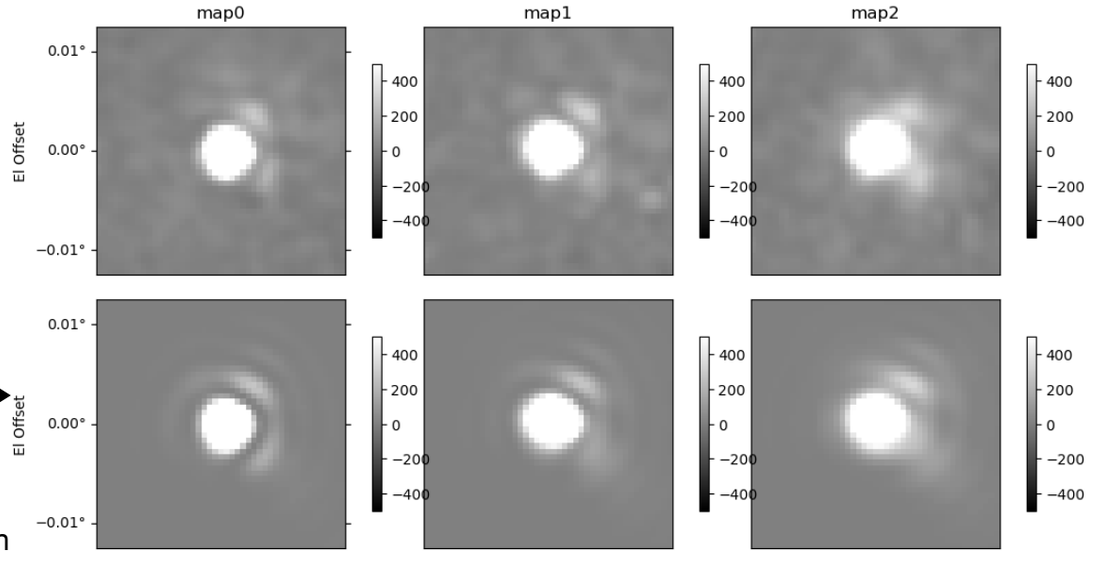
Model

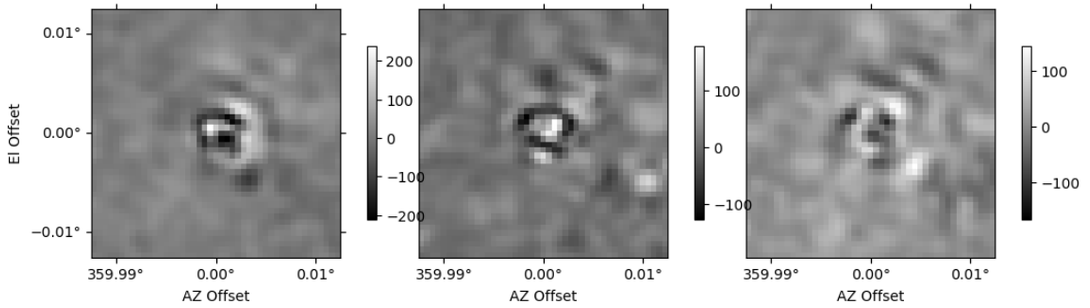
Residual





One OOF Iterration



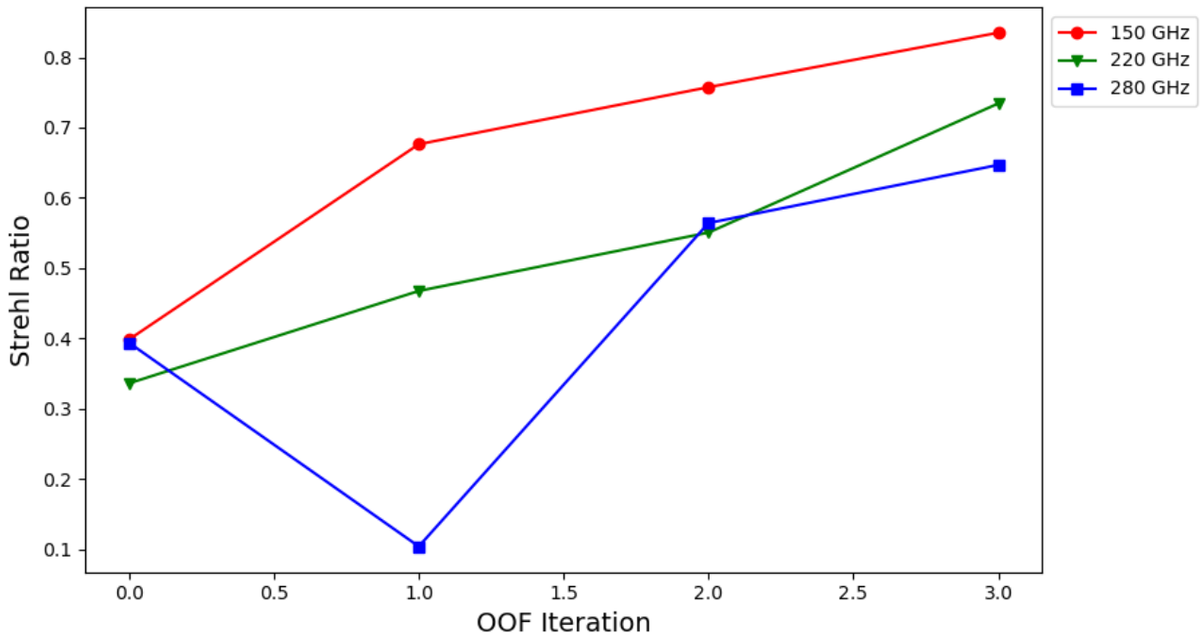


- Strehl ratio ~ 0.4
- Large Vertical Astigmatism
- Applied Corrections addressing Astigmatisms, vertical coma, and spherical aberration

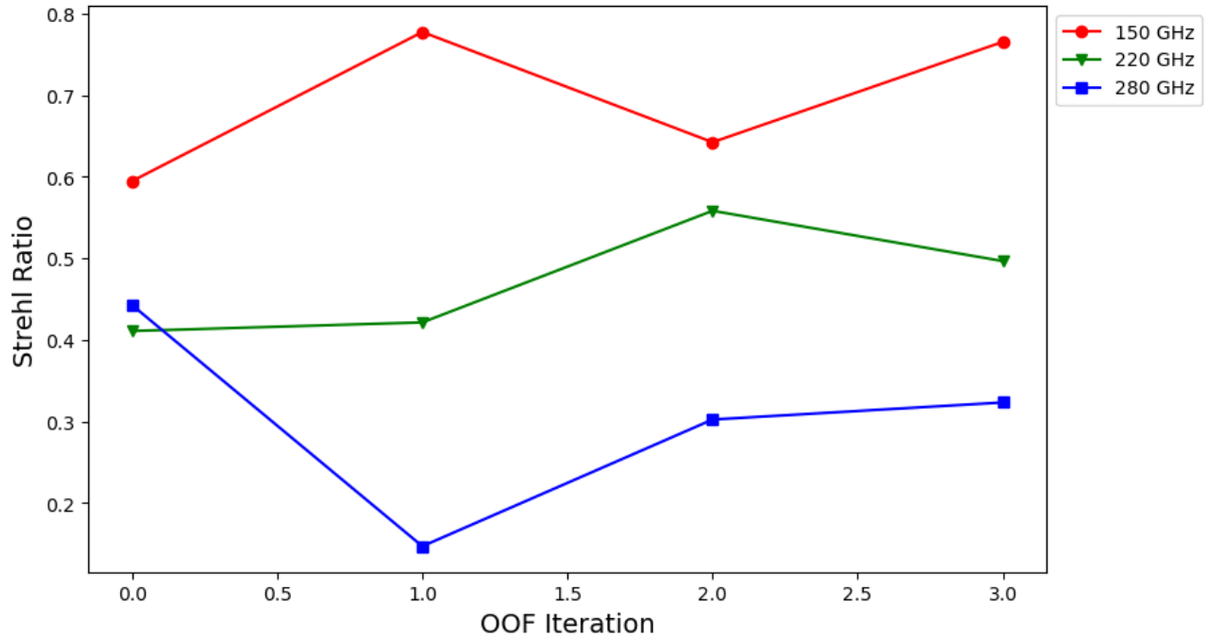
- Strehl ratio ~ 0.7
- Vertical and Oblique Astigmatisms Removed
- Other aberrations remain…

Preliminary OOF results

Sometimes it works well…



Sometimes it doesn't…



- The OOF results are mixed but encouraging!
- Best results have been in the 150 GHz band with sometime inconsistent results in the other two bands
- There still remains work to be done on our procedure
- If you use OOF on your telescope please come talk to me I'd love to pick your brain!

Conclusions

- TolTEC observations this year have been primarily focused on improving the instruments sensitivity with a small secondary focus on science observations

- There are several science targets that have deep data with noise levels below 1 mJy/beam
  - This data is currently being verified and will be released as soon as it is deemed of science quality

- There are continued efforts to improve the sensitivity of TolTEC mainly related to improving the primary mirror surface through OOF

The TolTEC Team

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