

We like the Moon!



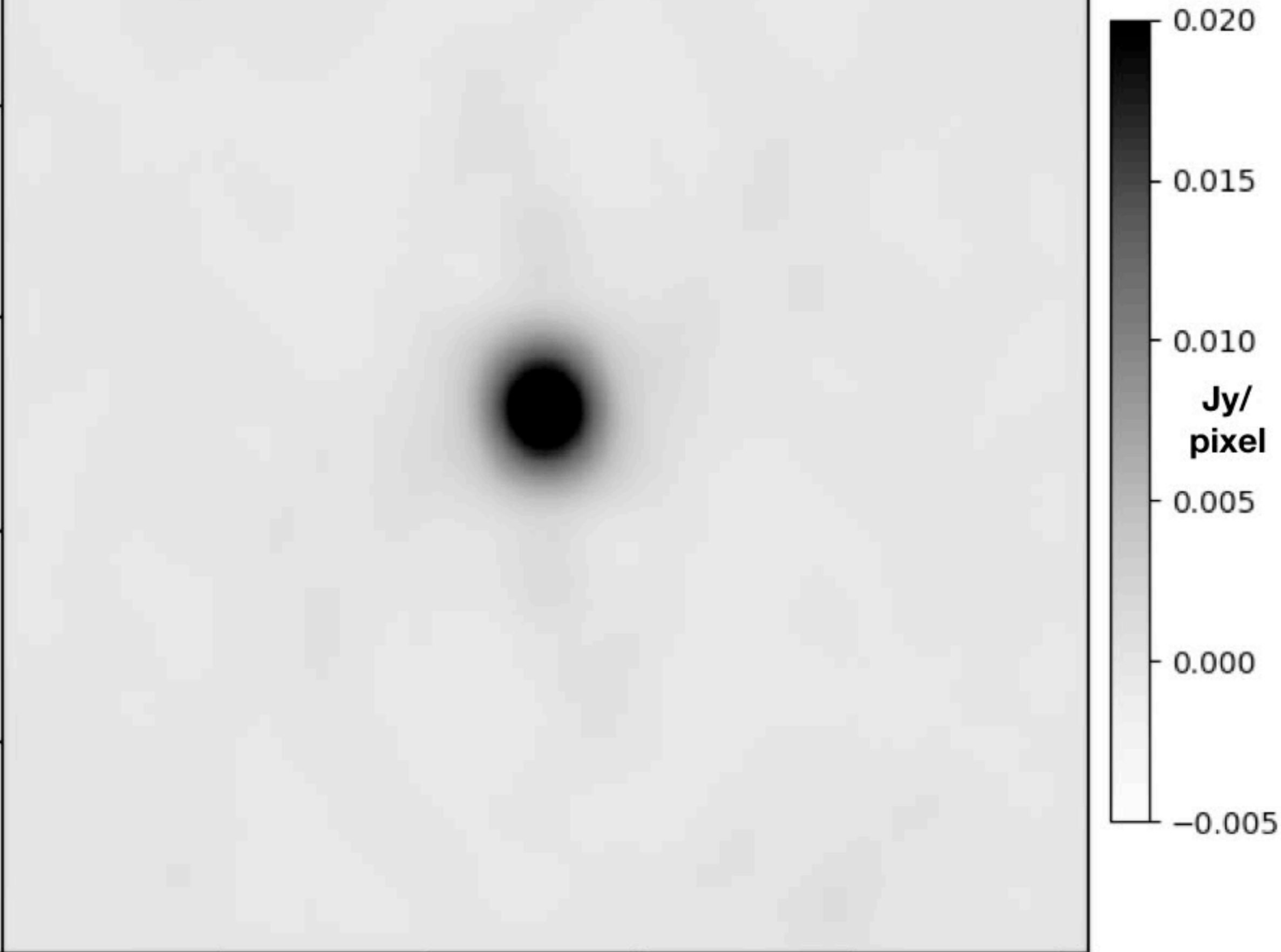
Ben McKinley



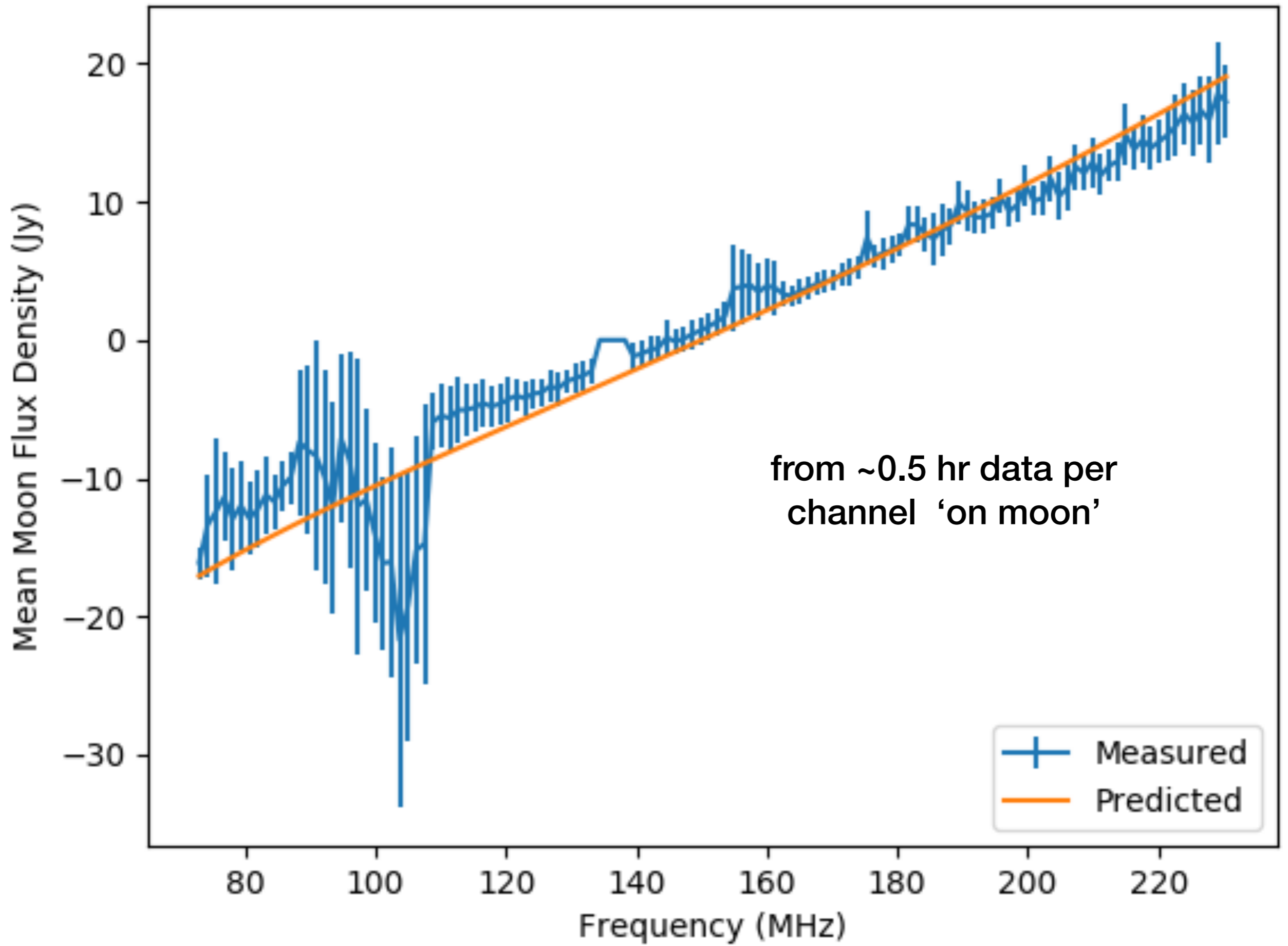
Curtin University



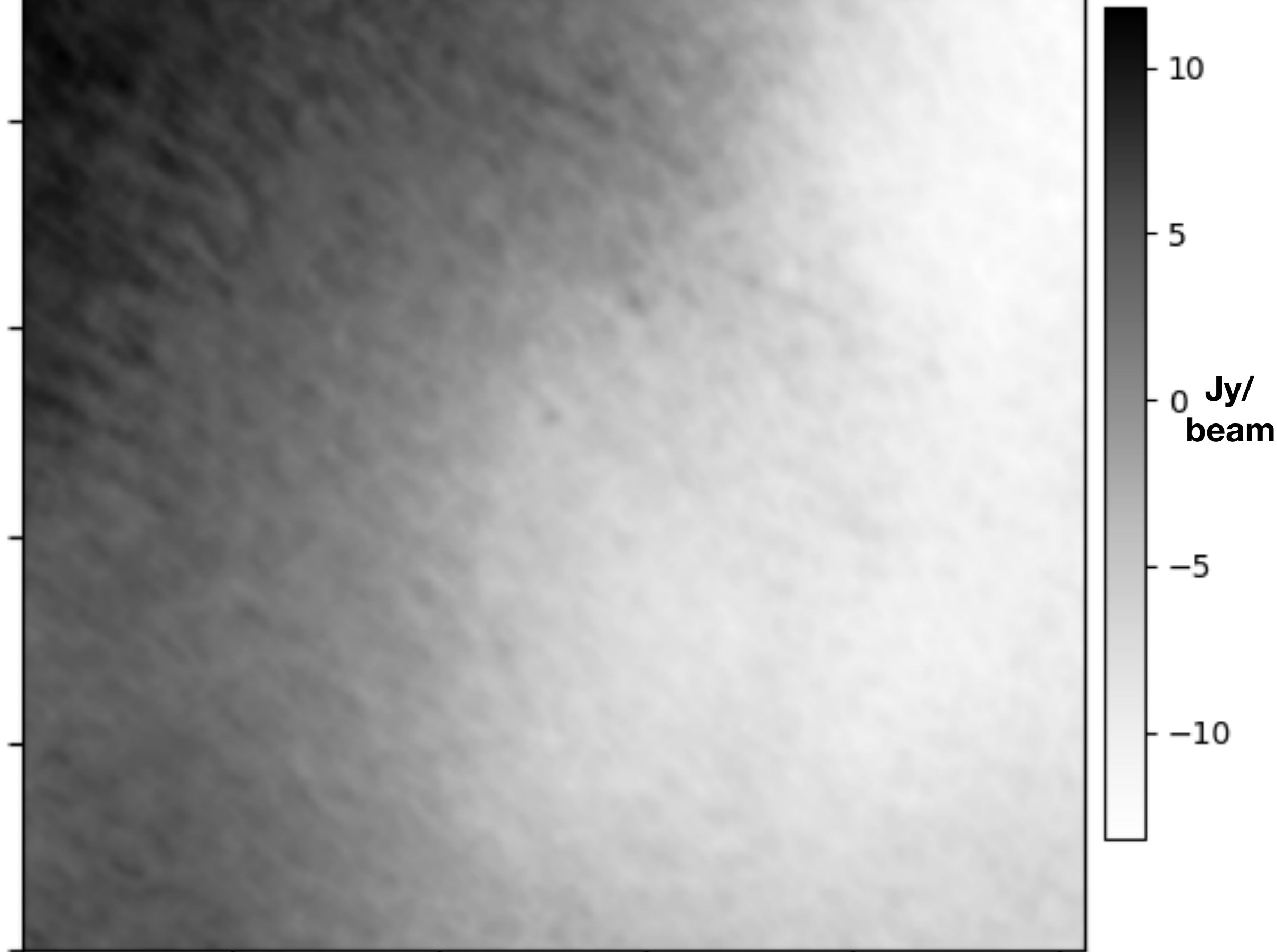
Moon at 232 MHz



Moon Flux Density vs Frequency for MWA



On-Moon 87 MHz



Off-Moon 87 MHz



10

5

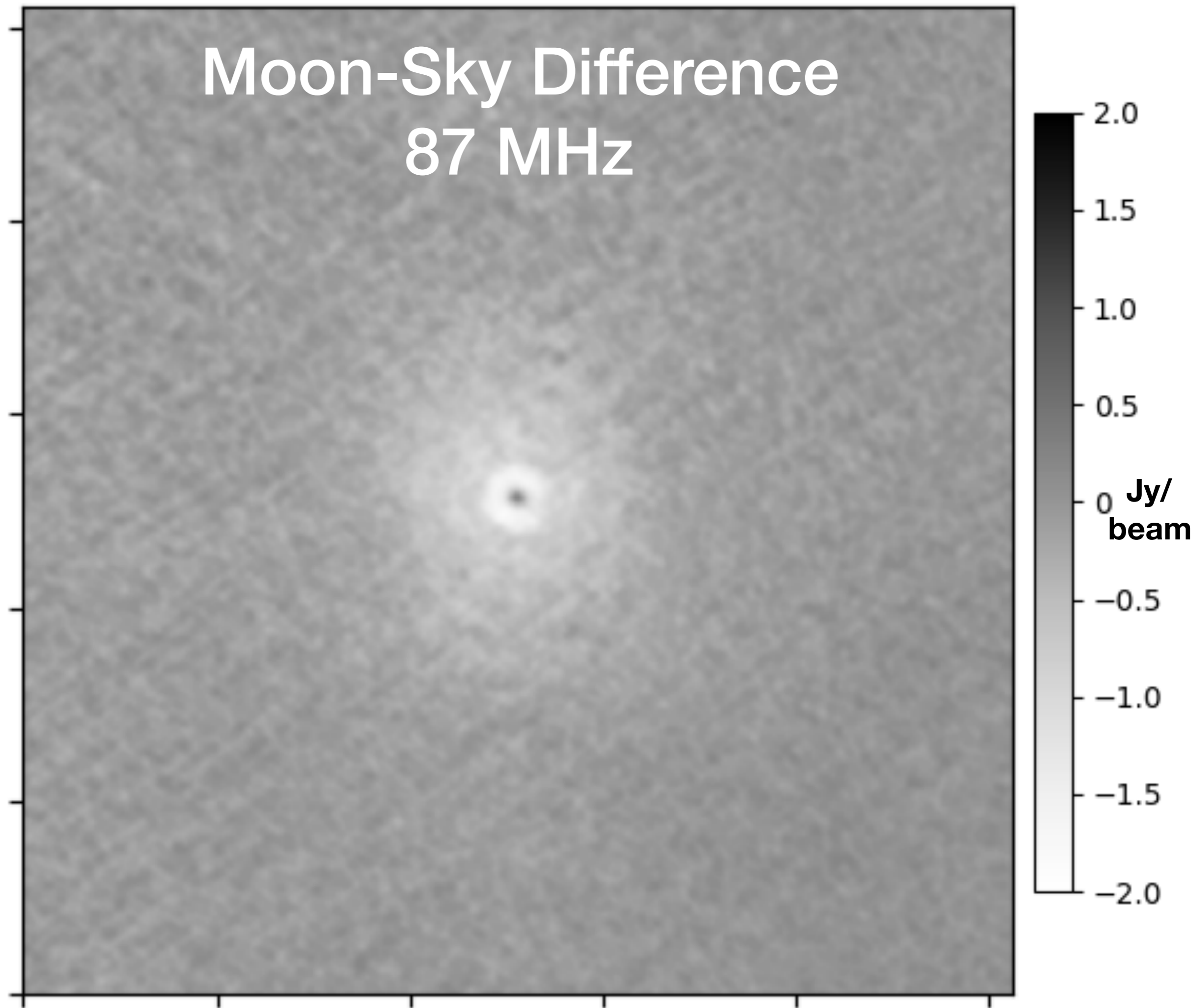
0

-5

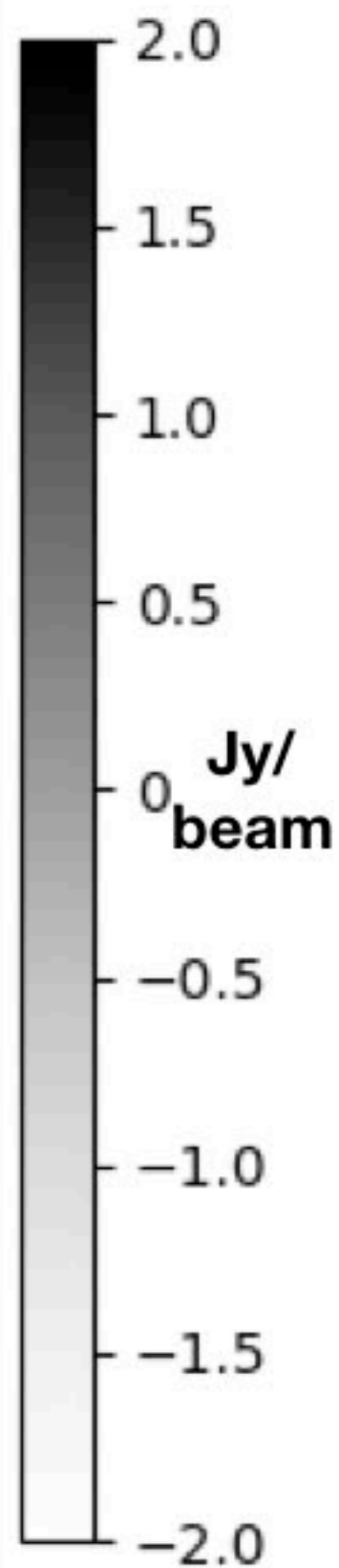
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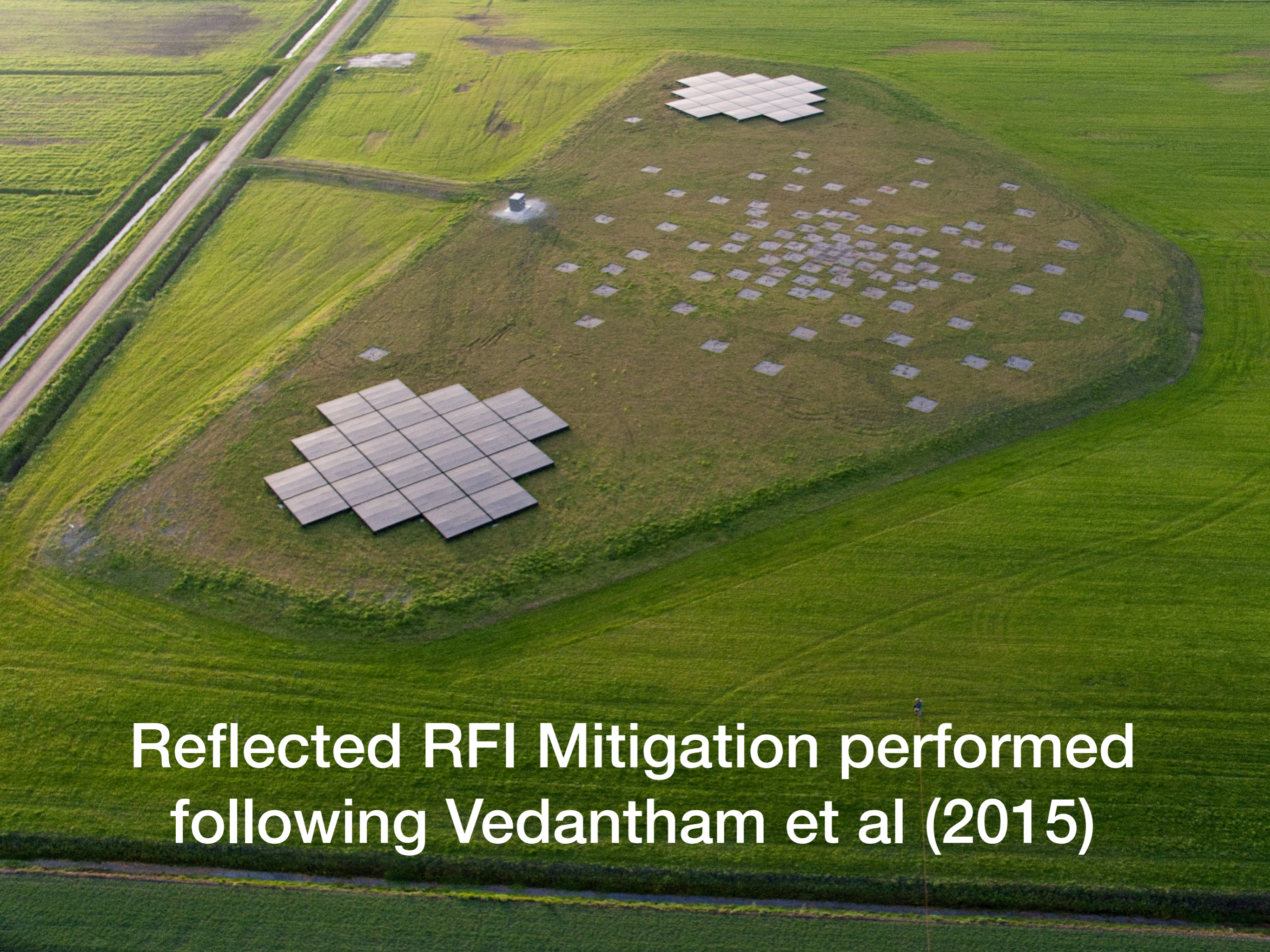
**Jy/
beam**

Moon-Sky Difference 87 MHz



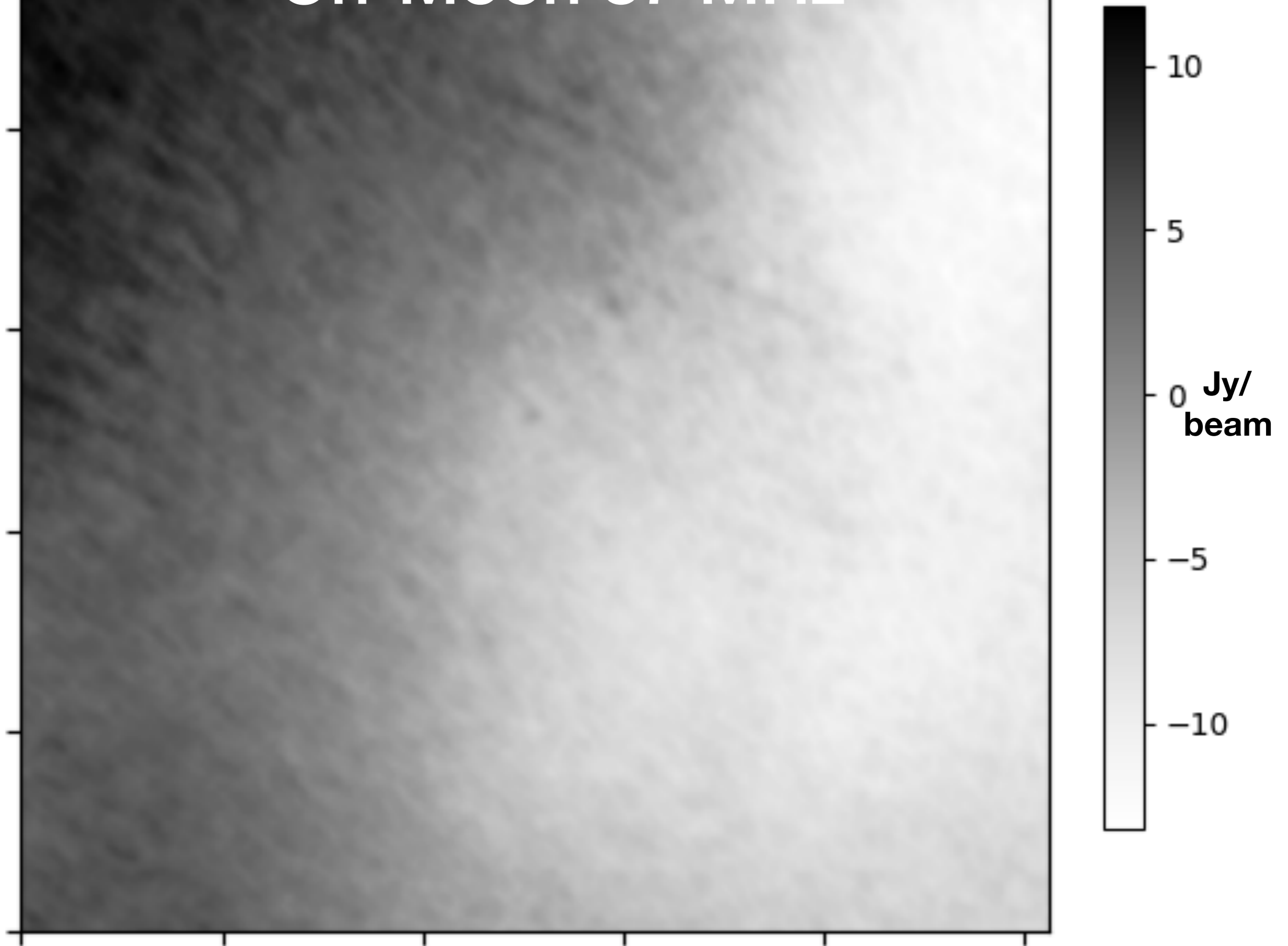
Moon-Sky Difference at 232 MHz



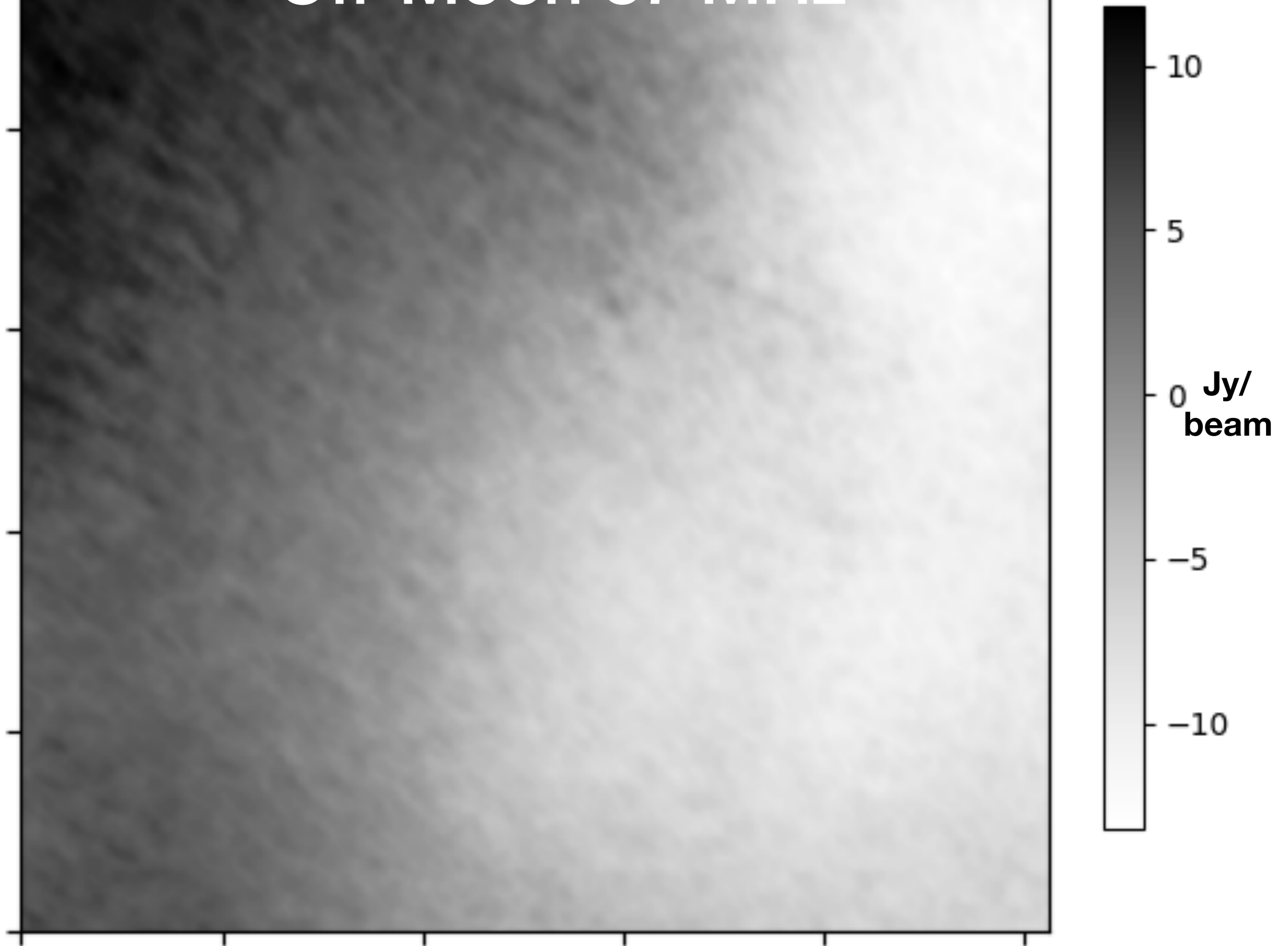


Reflected RFI Mitigation performed following Vedantham et al (2015)

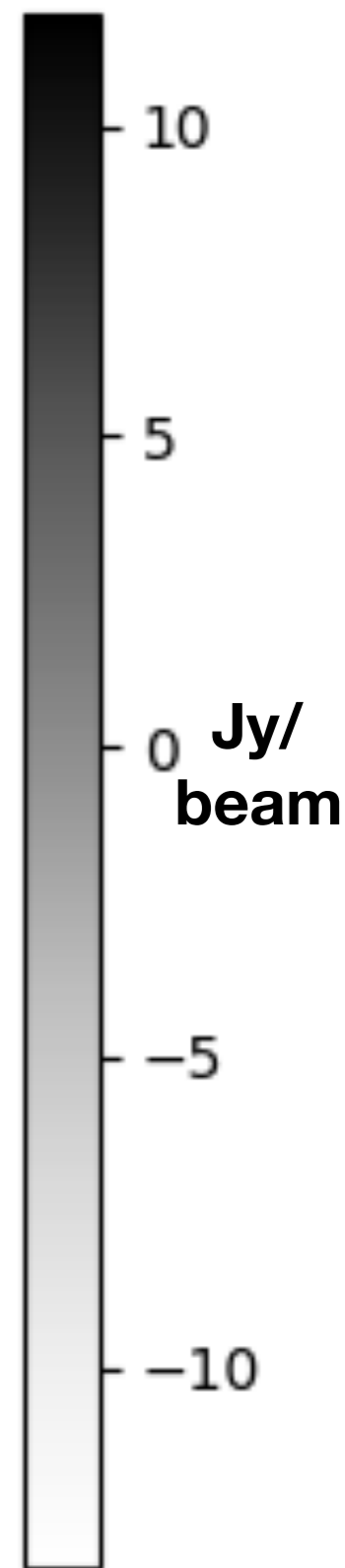
On-Moon 87 MHz



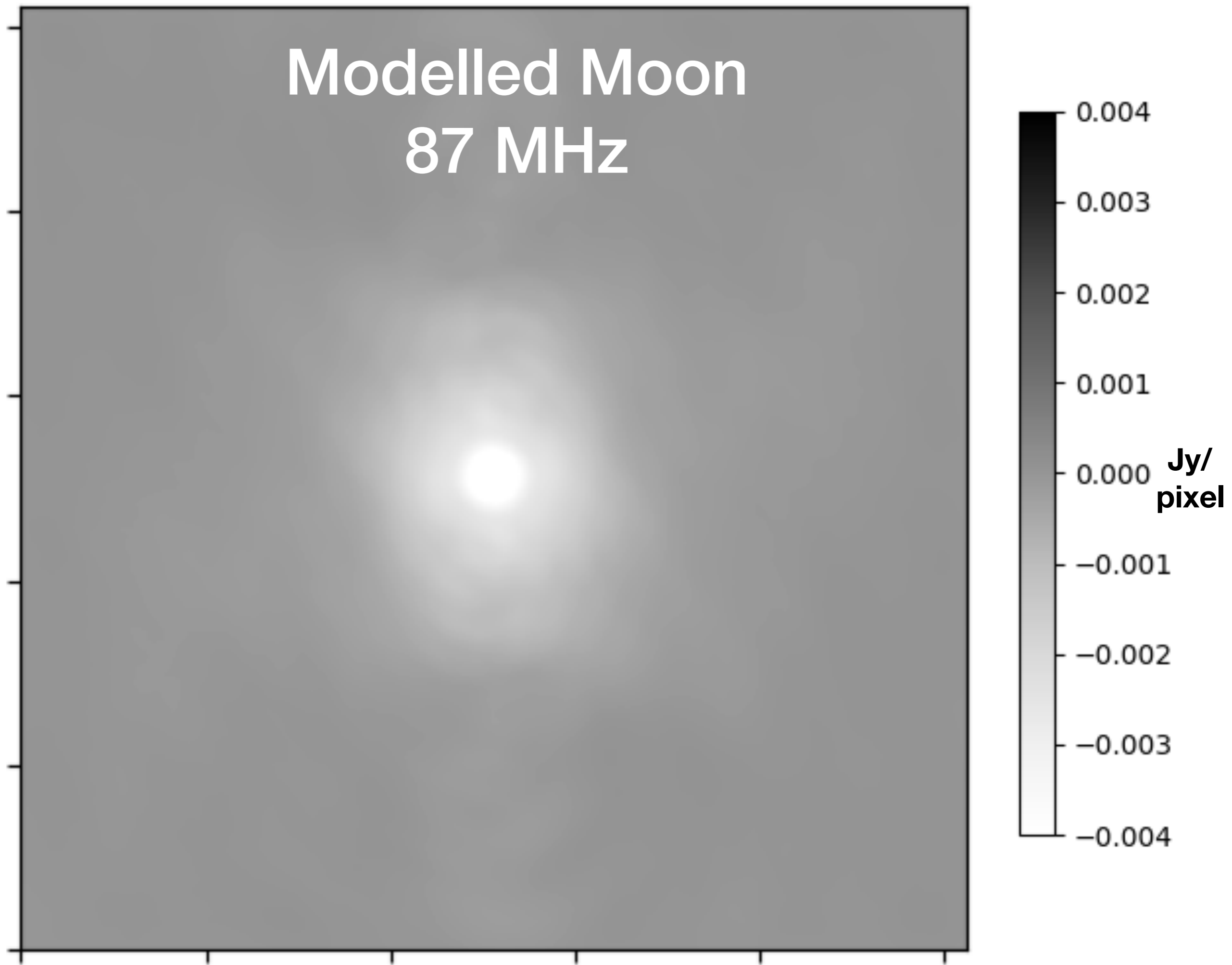
Off-Moon 87 MHz



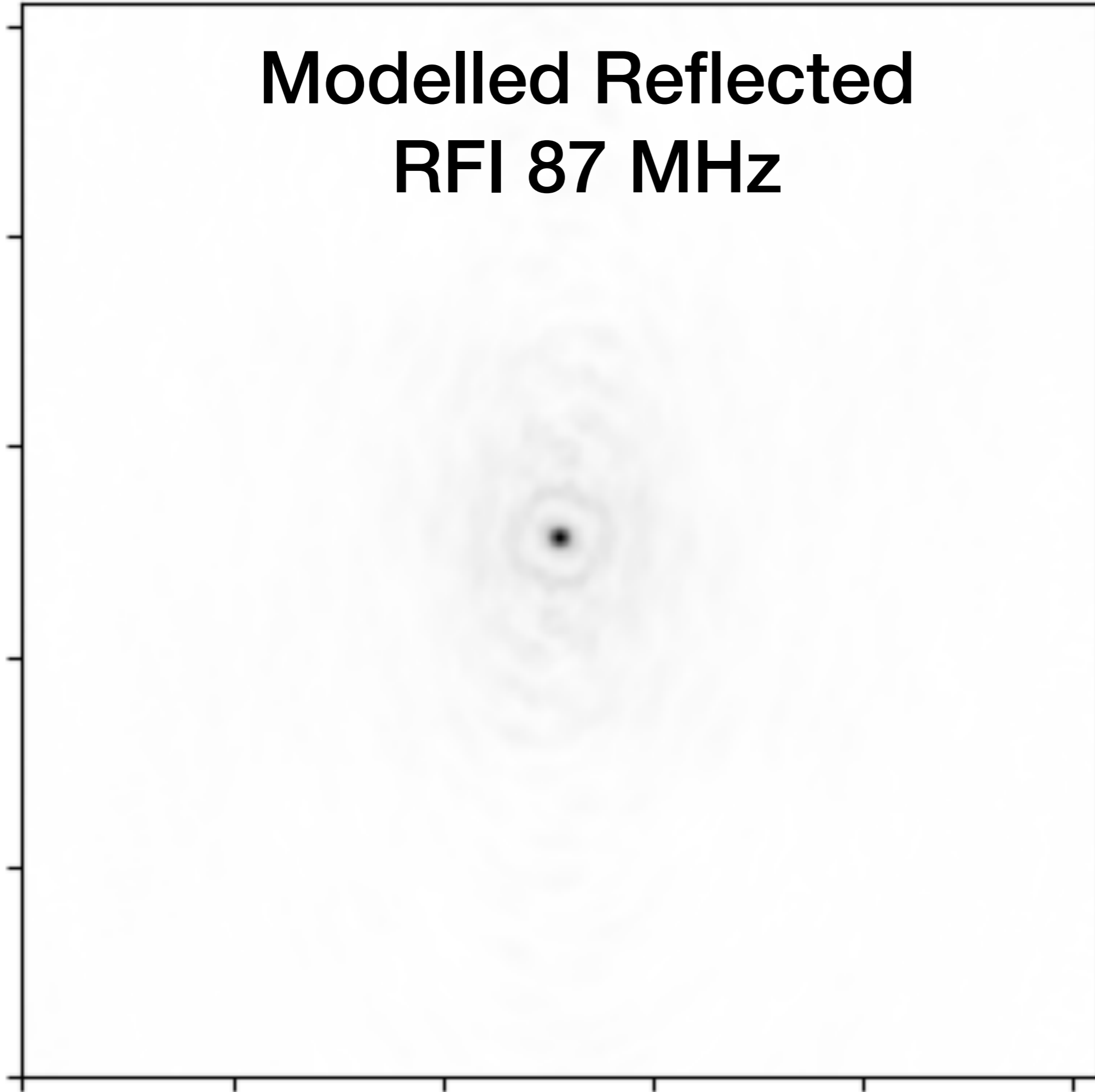
Moon-Sky Difference 87 MHz



Modelled Moon 87 MHz



Modelled Reflected RFI 87 MHz



0.005

0.004

0.003

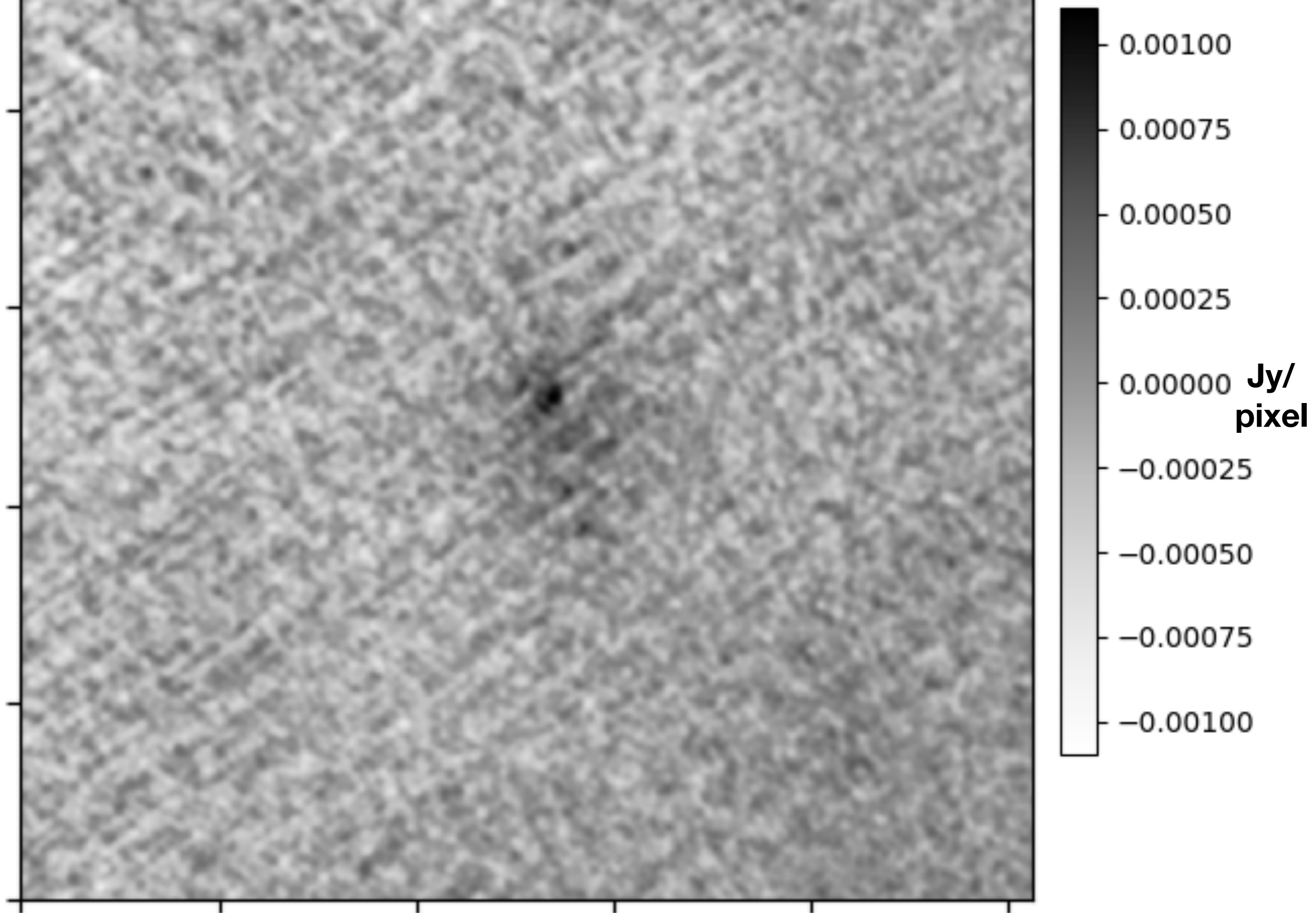
**Jy/
pixel**

0.002

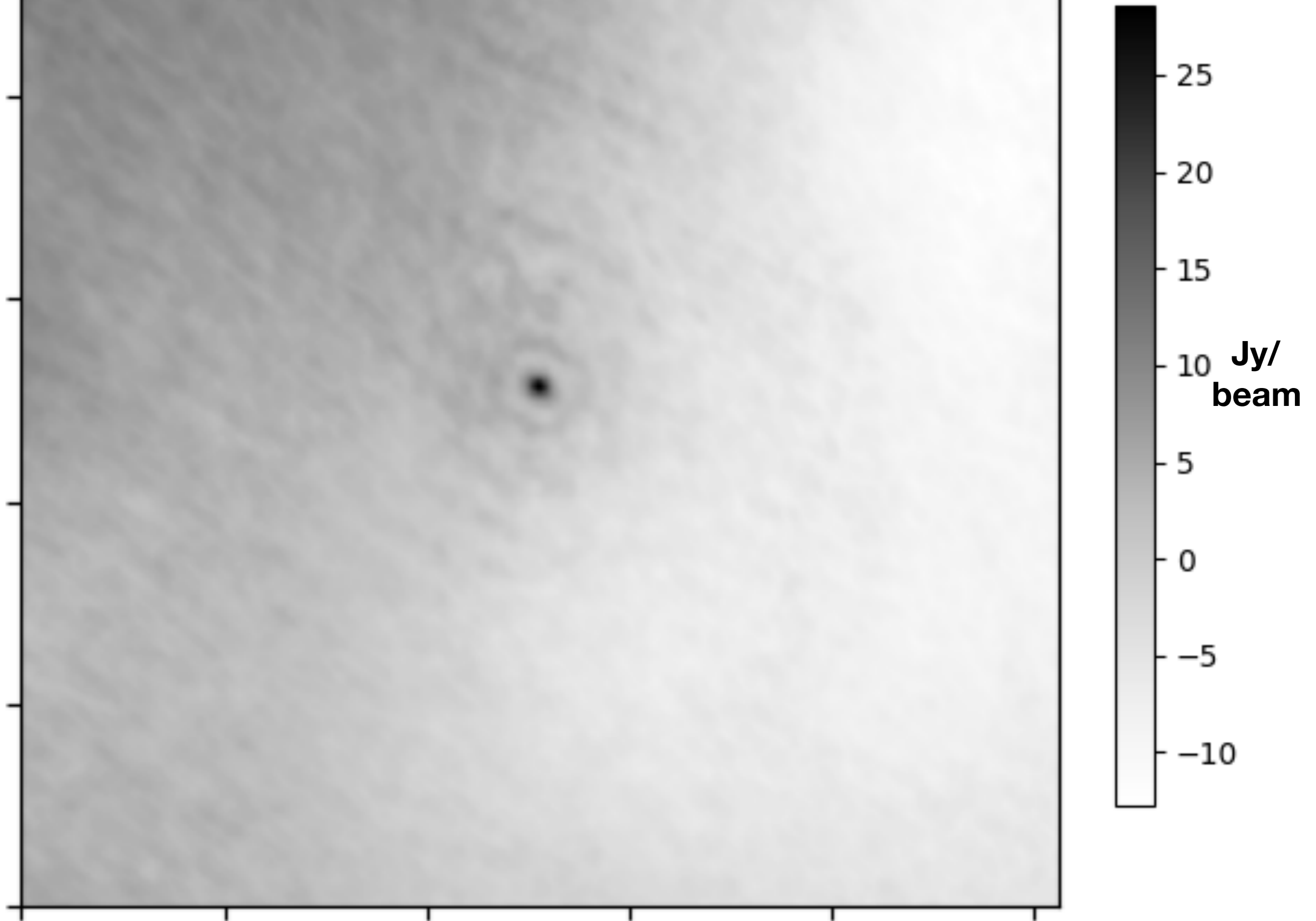
0.001

0.000

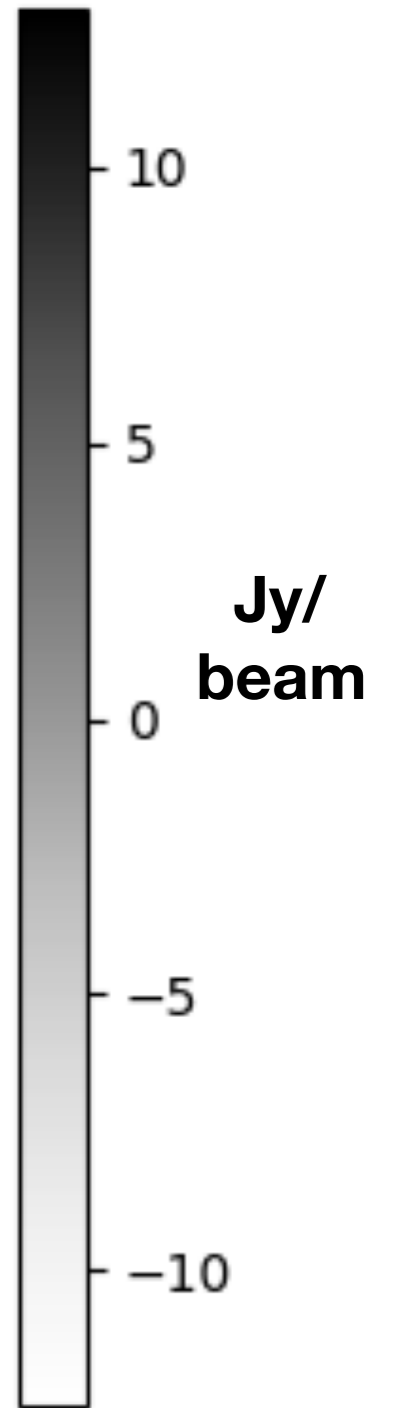
Residual 87 MHz



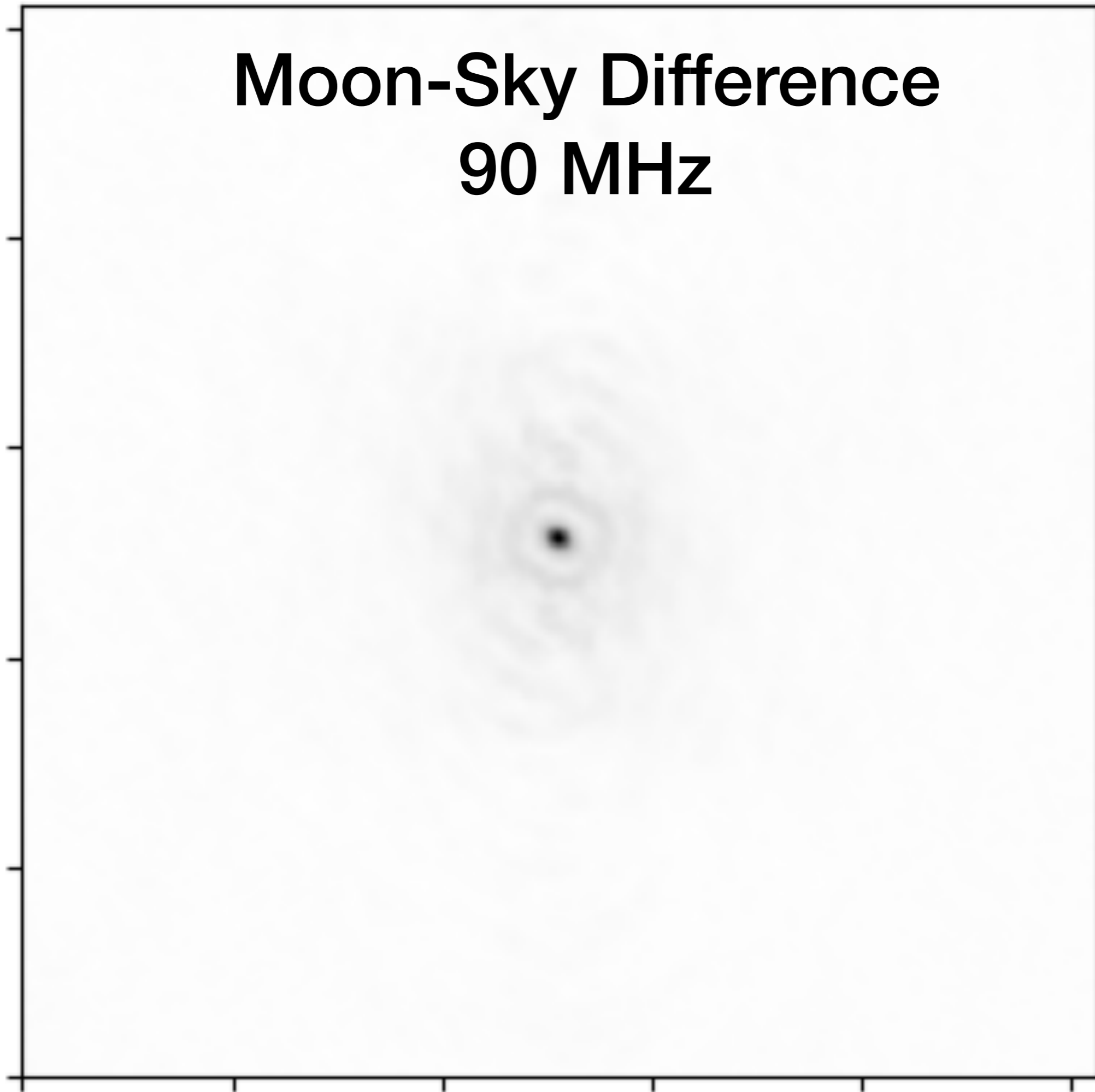
On-Moon 90 MHz



Off-Moon 90 MHz



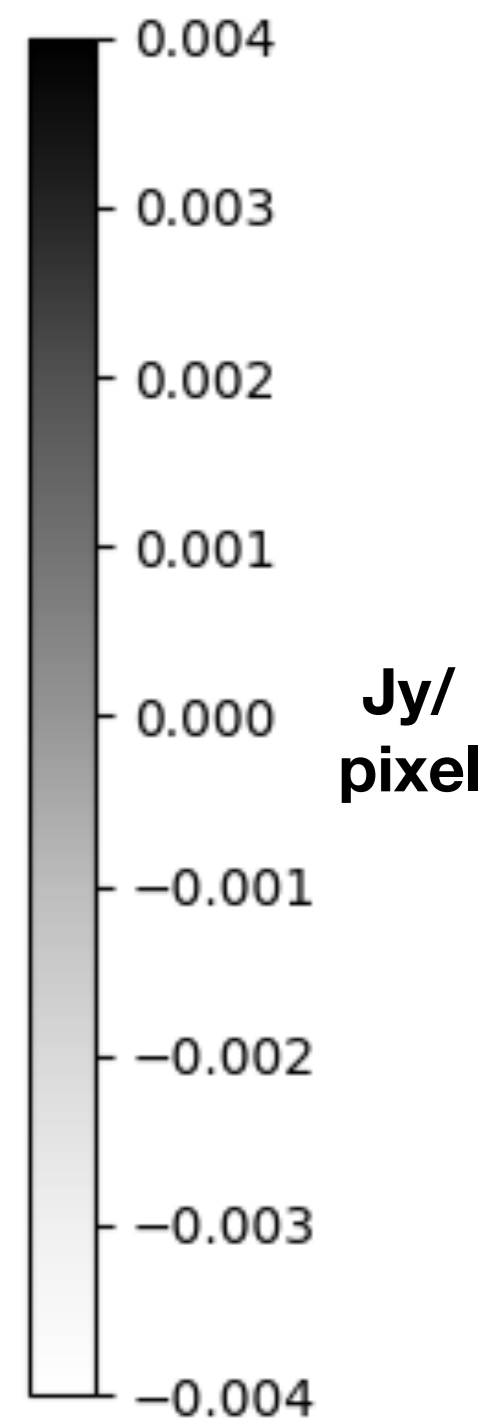
Moon-Sky Difference 90 MHz



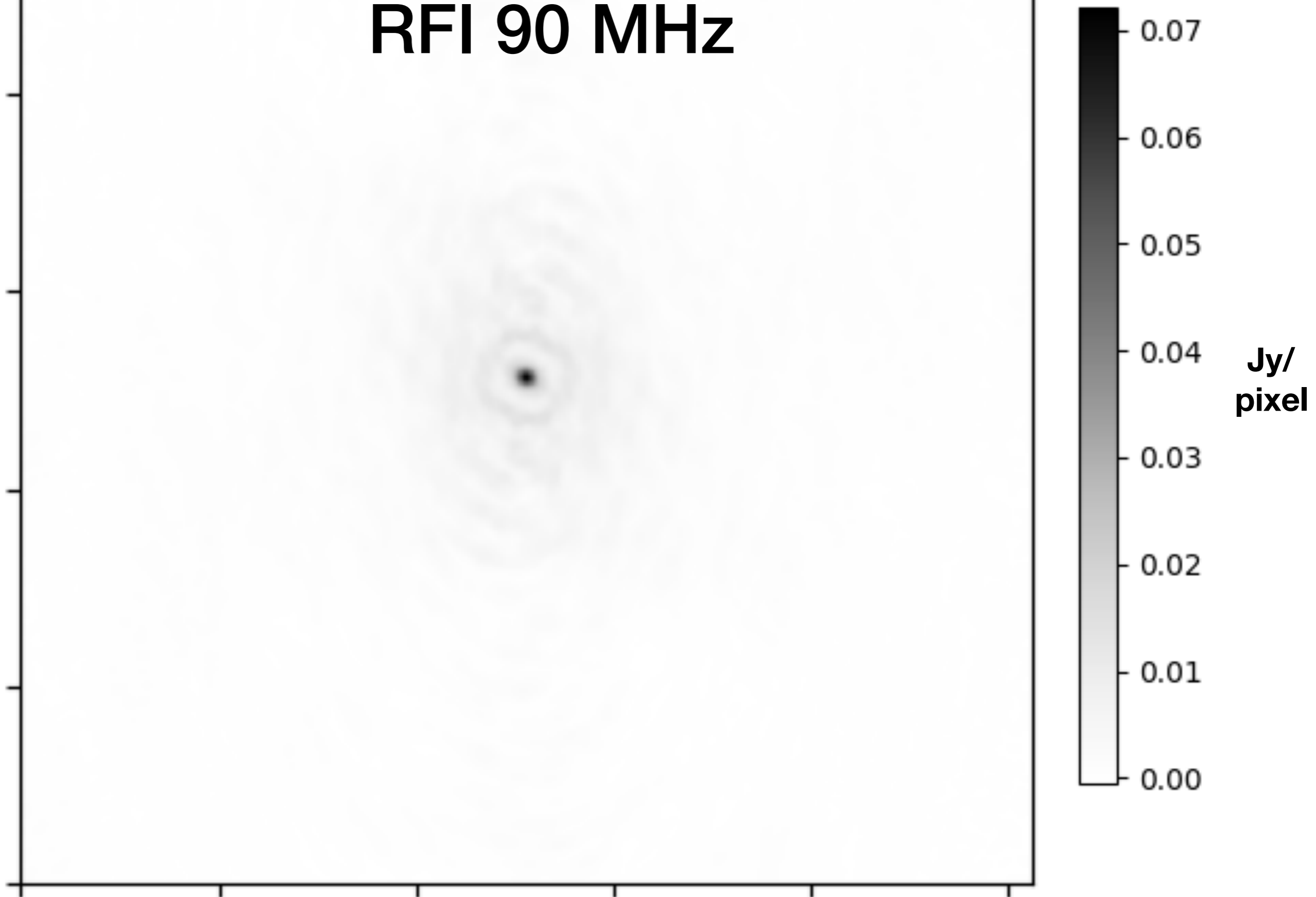
30
25
20
15
10
5
0

**Jy/
beam**

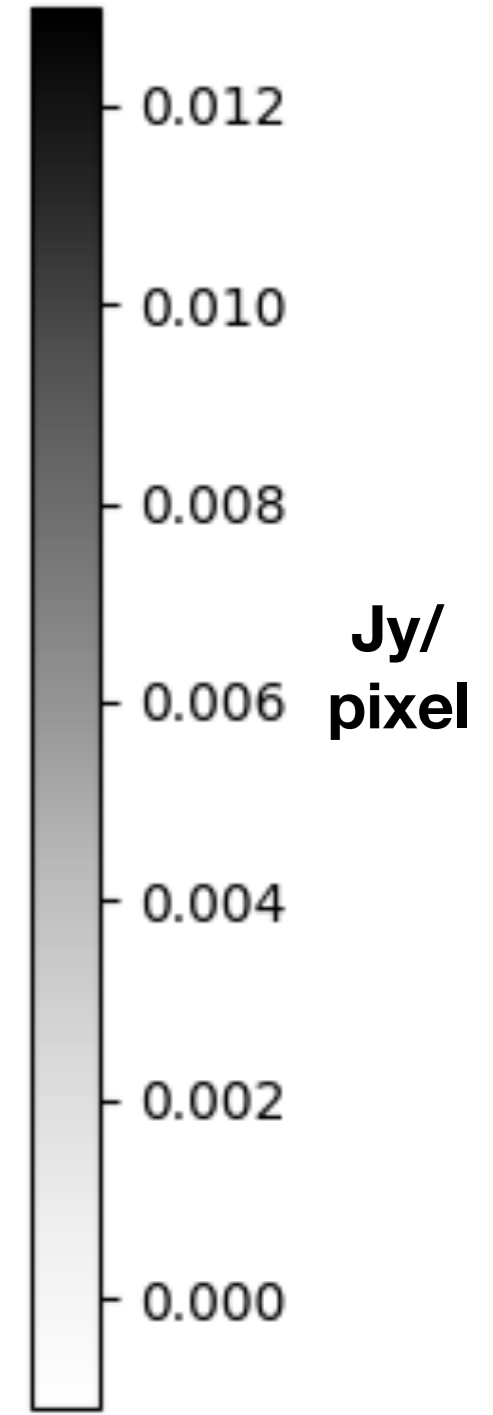
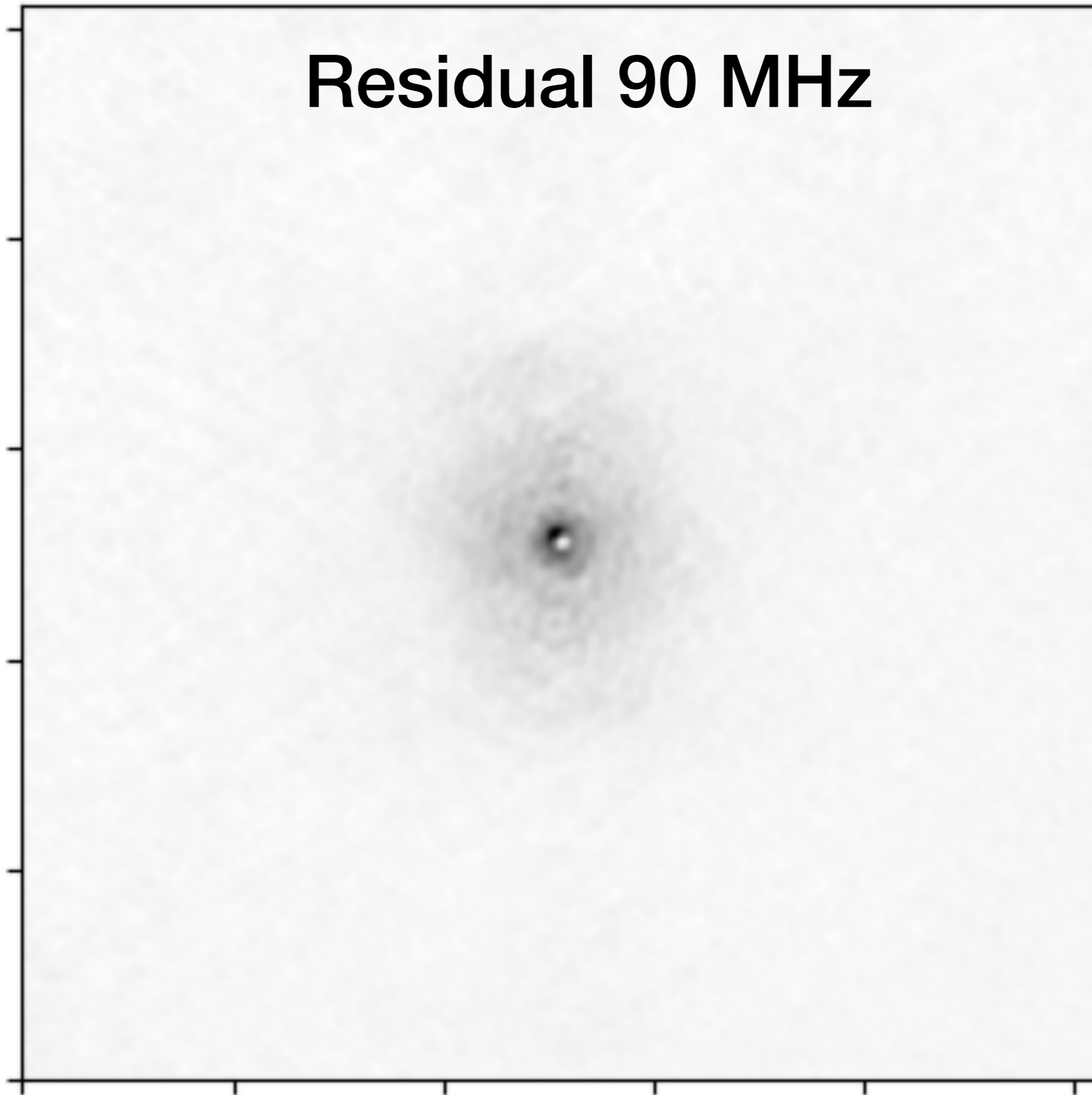
Modelled Moon 90 MHz



Modelled Reflected RFI 90 MHz



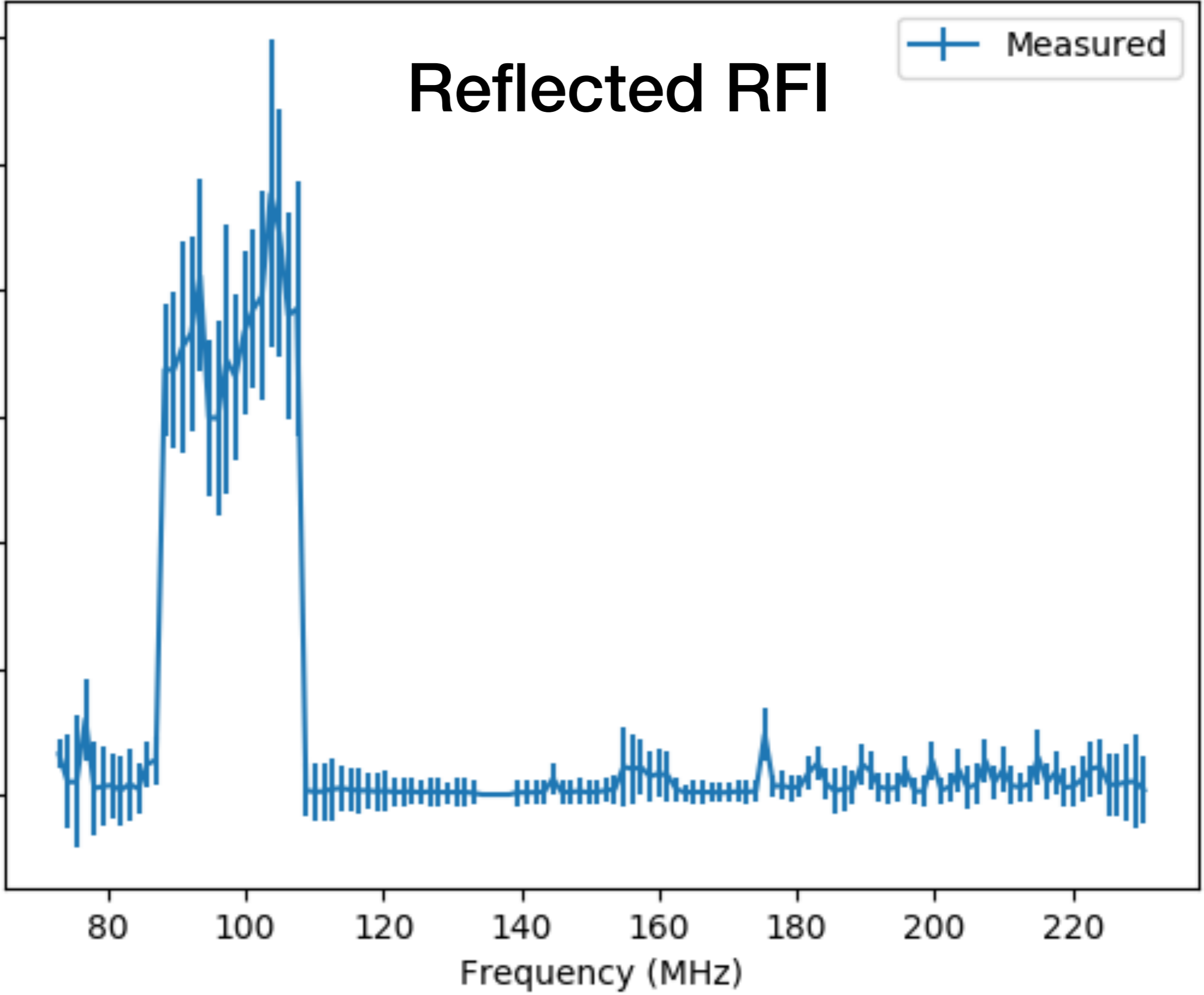
Residual 90 MHz



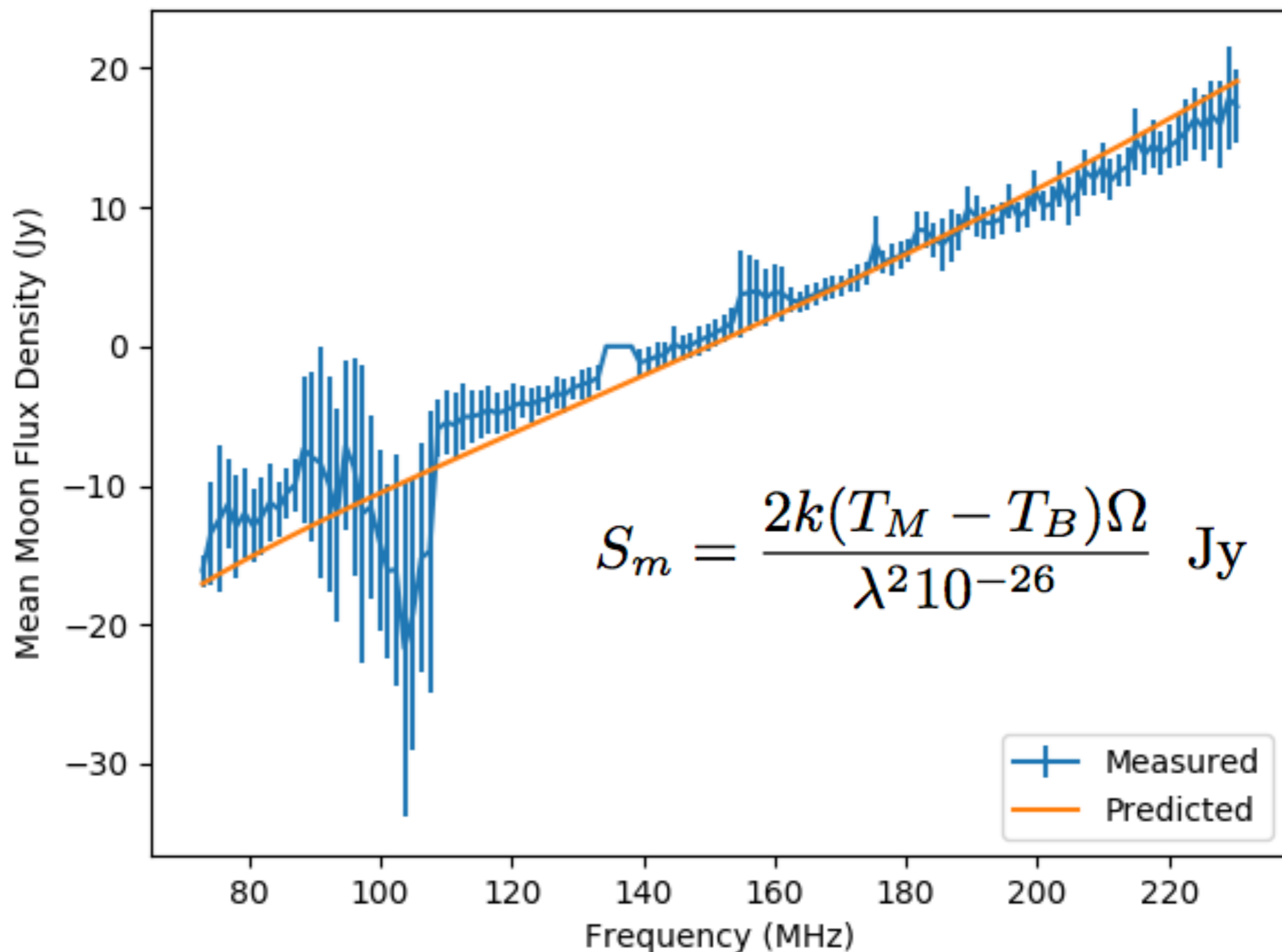
Reflected RFI

Measured

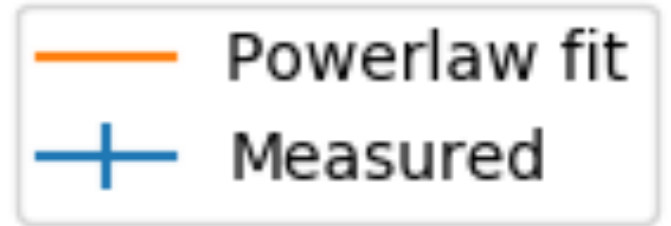
Mean Reflected RFI Flux Density (Jy)



Moon Flux Density vs Frequency for MWA



Inferred average sky temperature

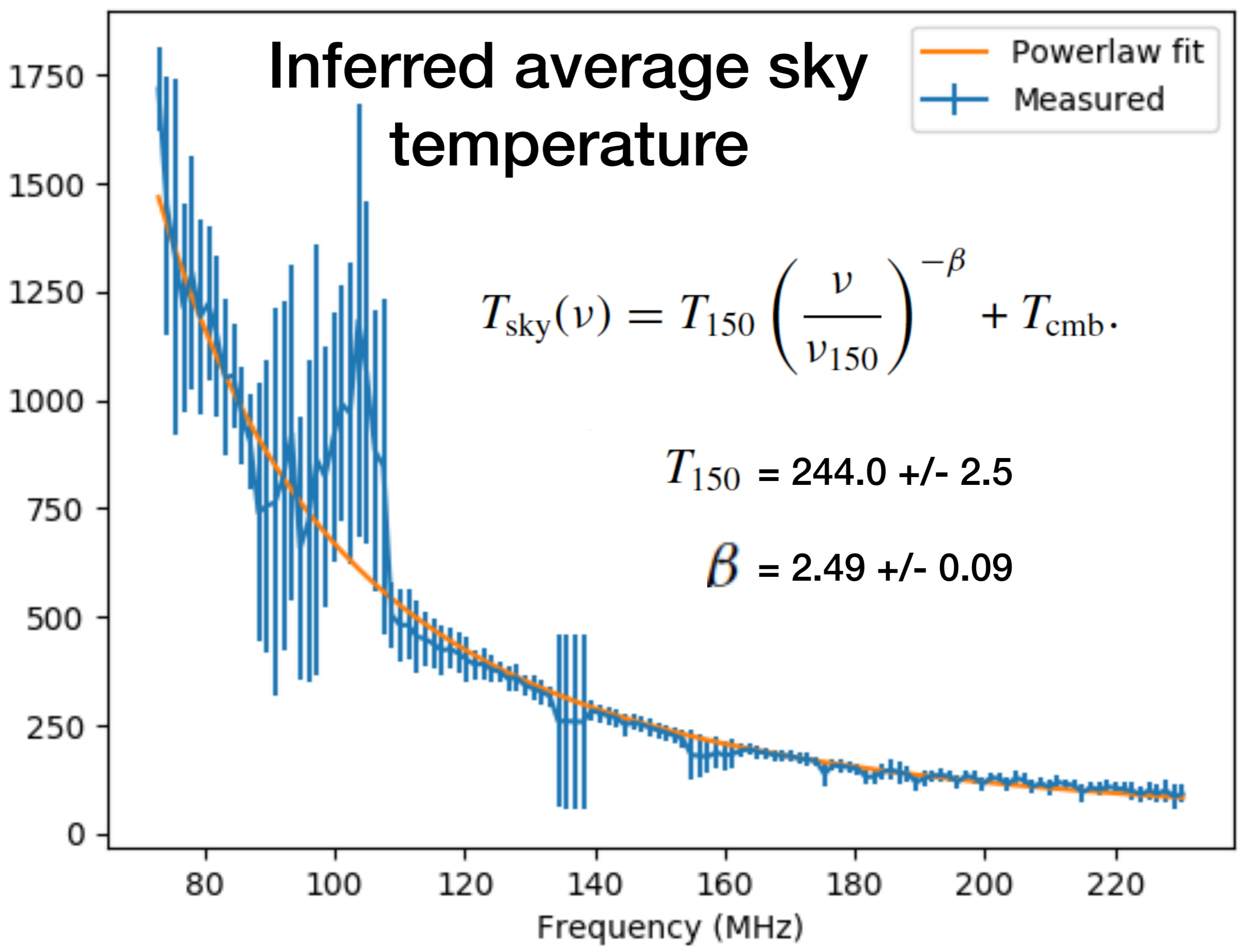


$$T_{\text{sky}}(\nu) = T_{150} \left(\frac{\nu}{\nu_{150}} \right)^{-\beta} + T_{\text{cmb}}$$

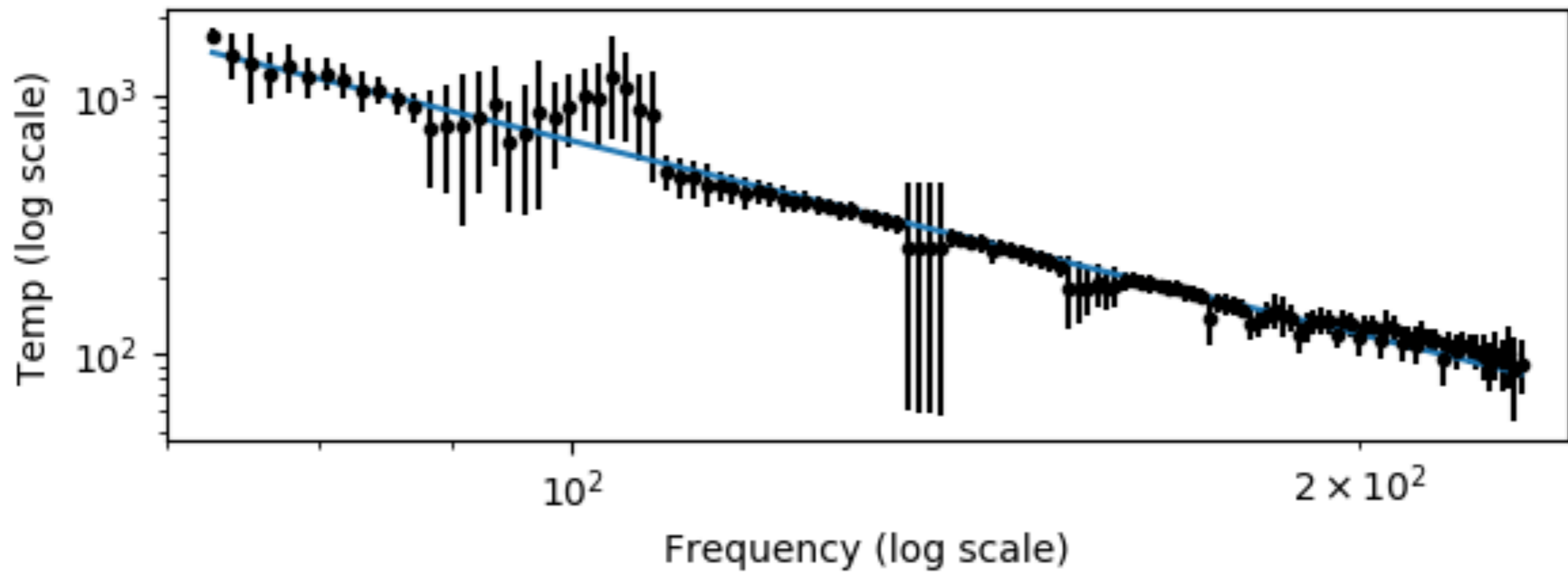
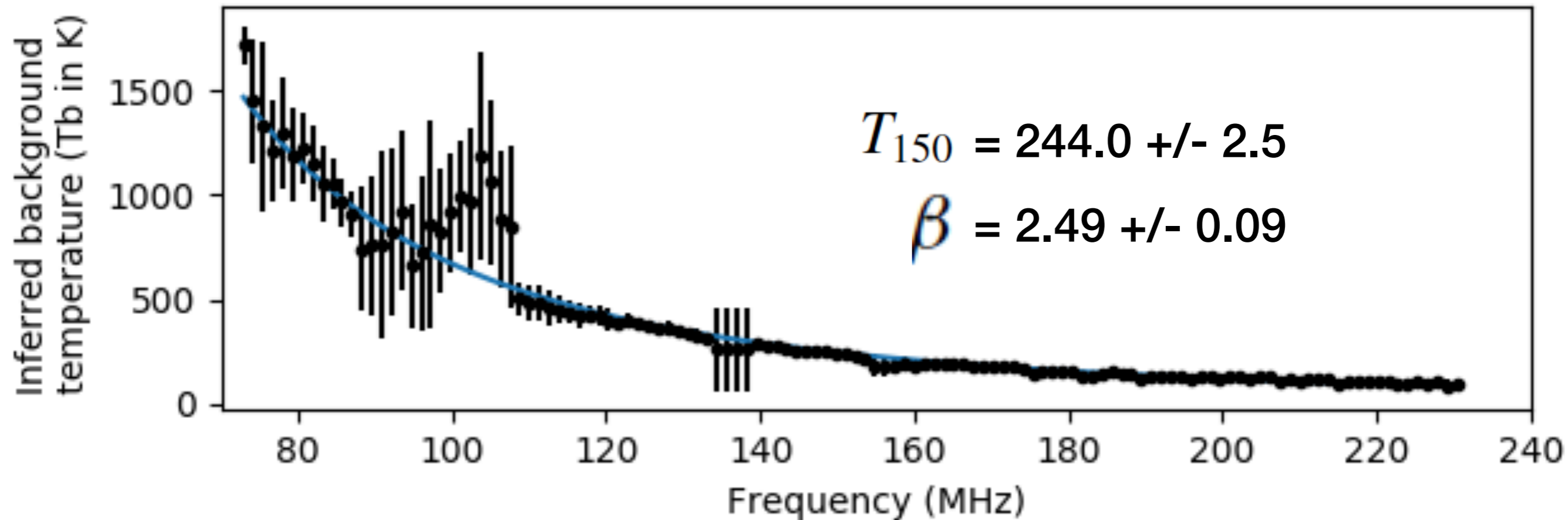
$$T_{150} = 244.0 \pm 2.5$$

$$\beta = 2.49 \pm 0.09$$

Inferred background temperature (Tb in K)



Inferred background temperature vs frequency for MWA

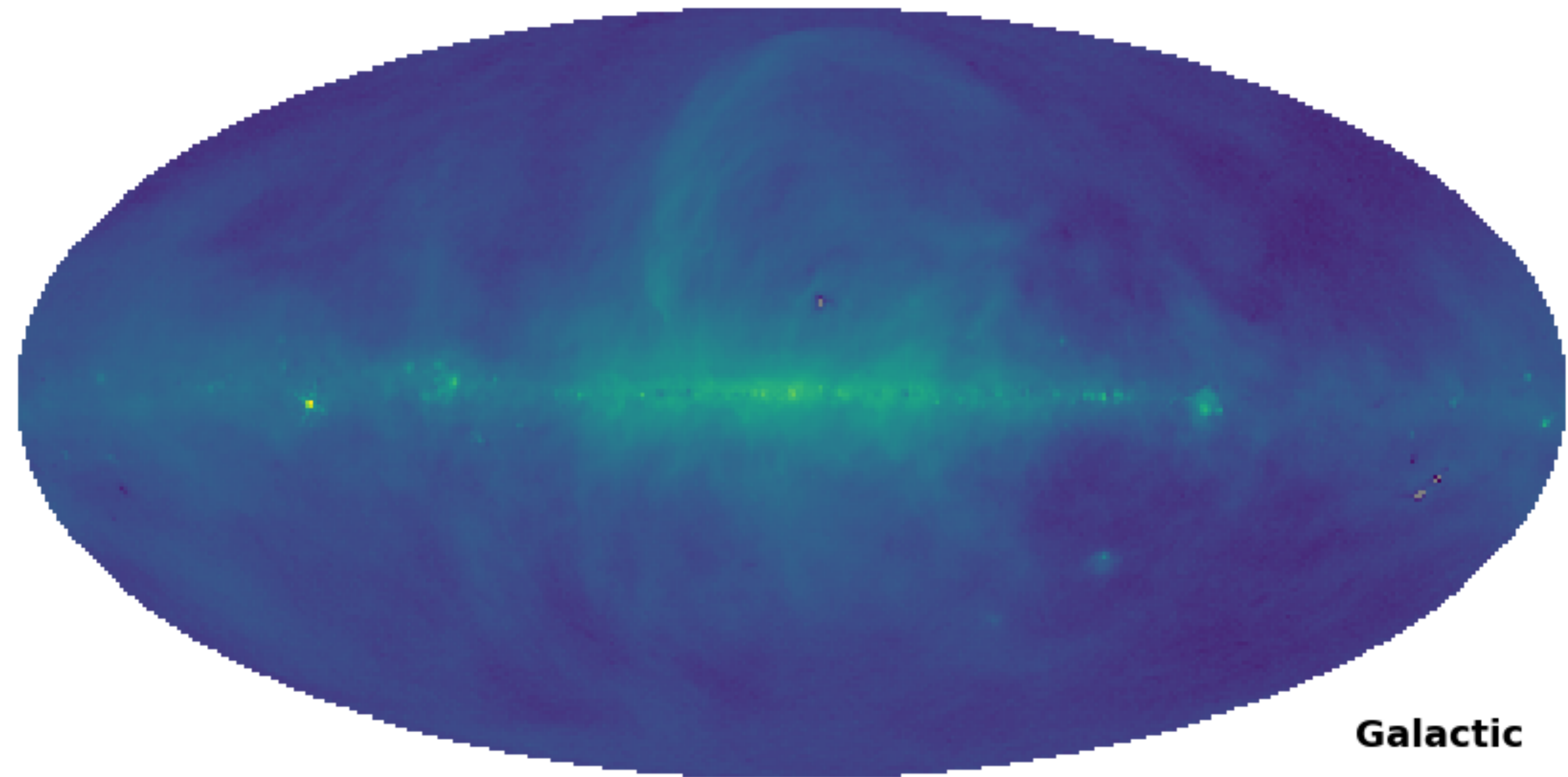


Consistent with Rogers & Bowman (2008)
EDGES: spectral index 2.5 ± 0.1

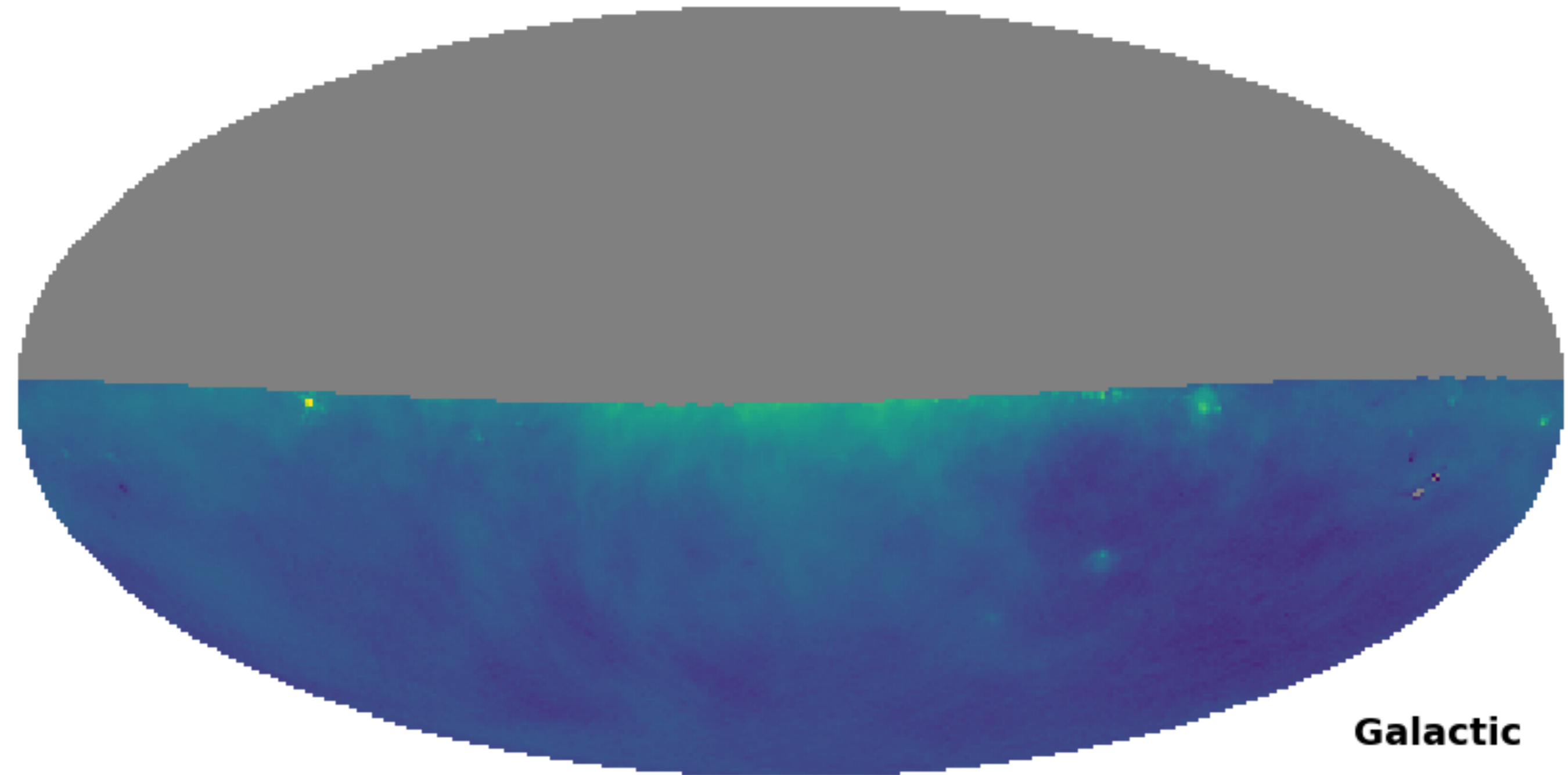


But ours much less 'global'

Sky at 73 MHz



Sky at above horizon at 73 MHz

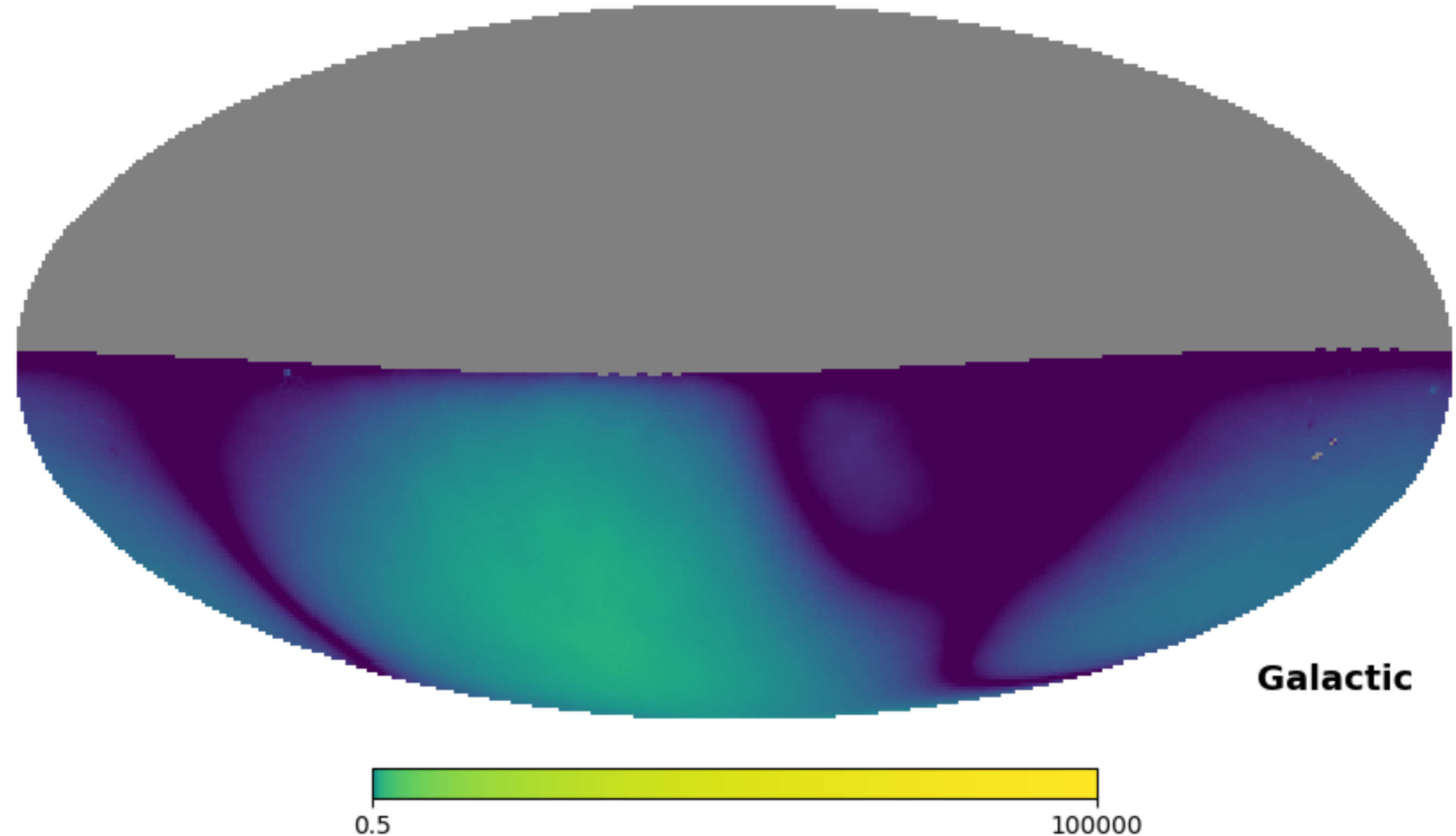


485.909

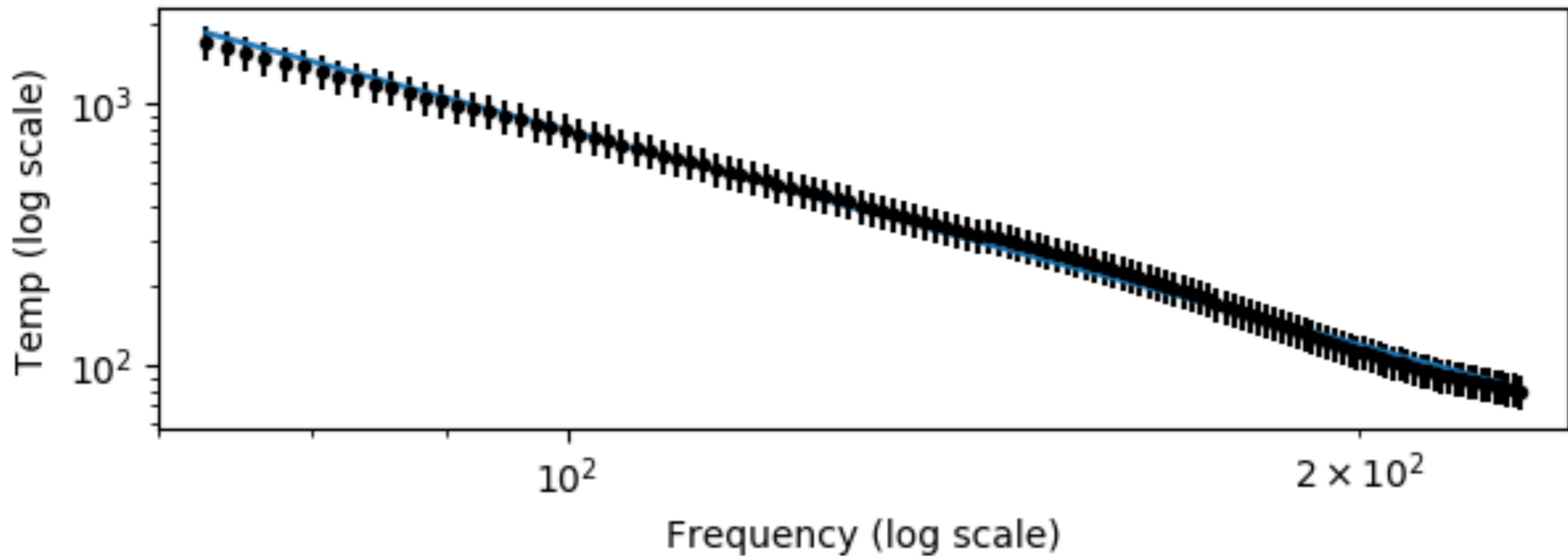
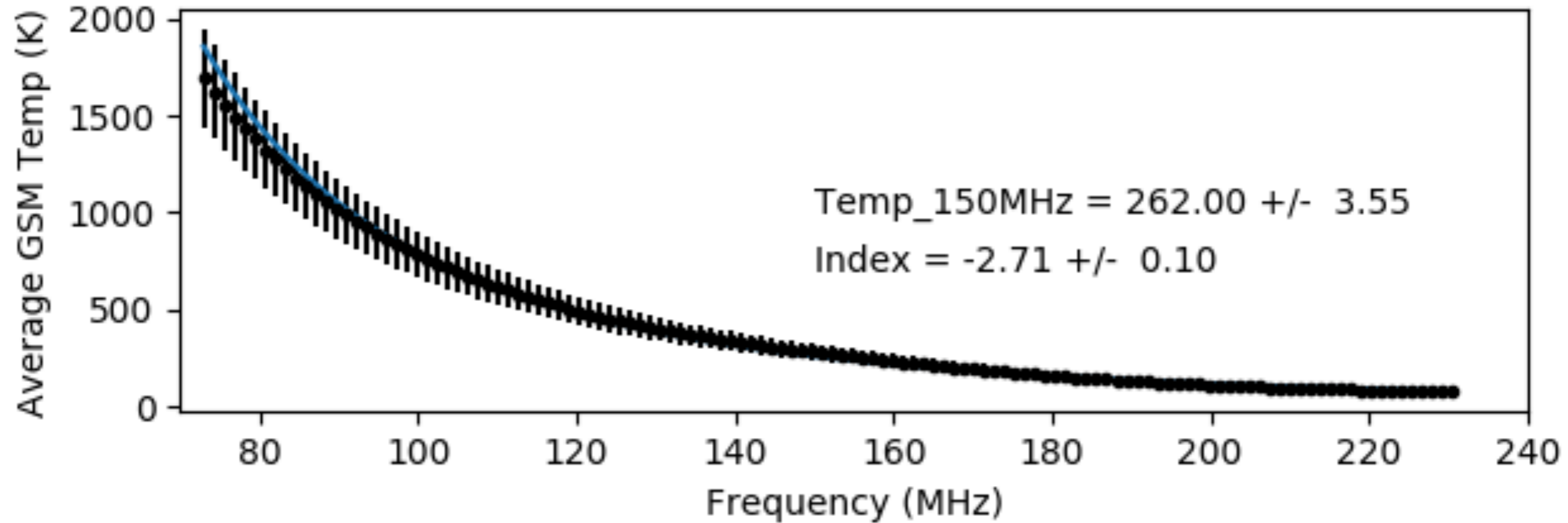
100000

Galactic

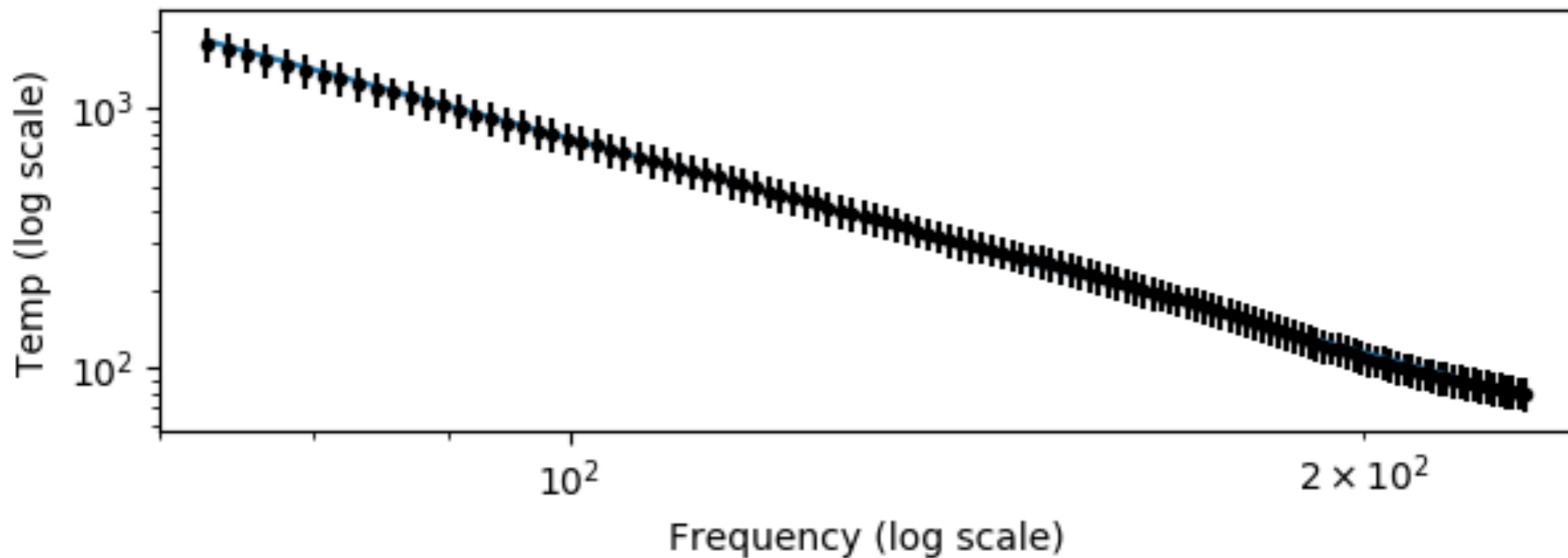
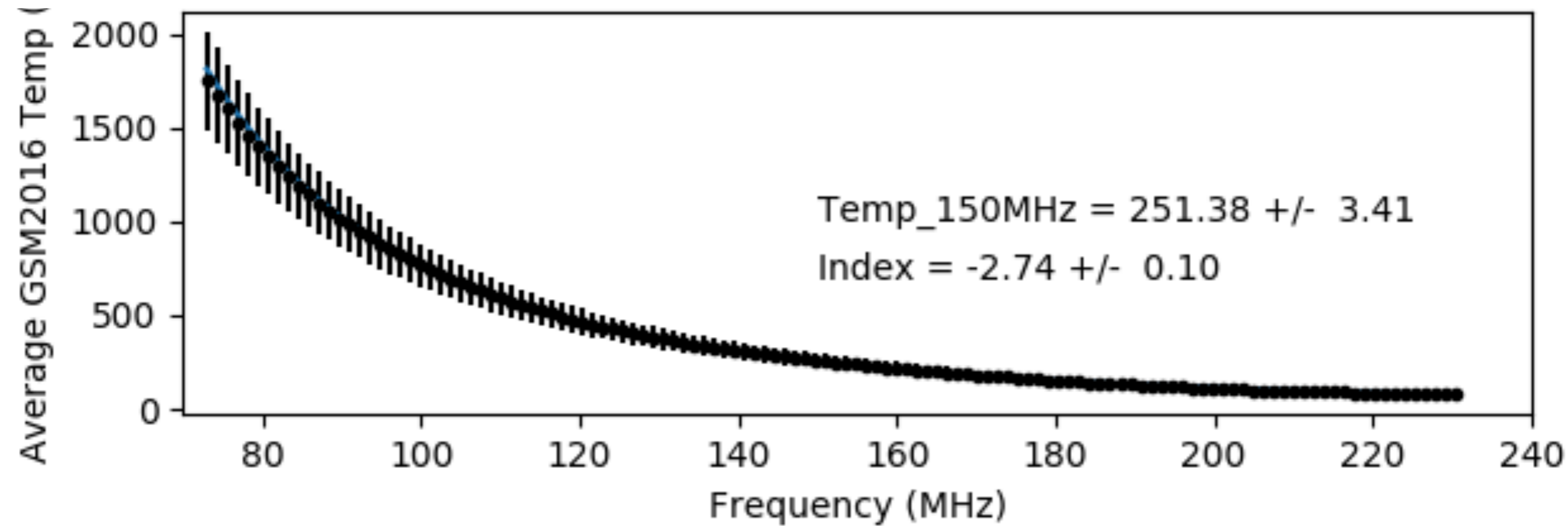
Sky seen by MWA at 73 MHz



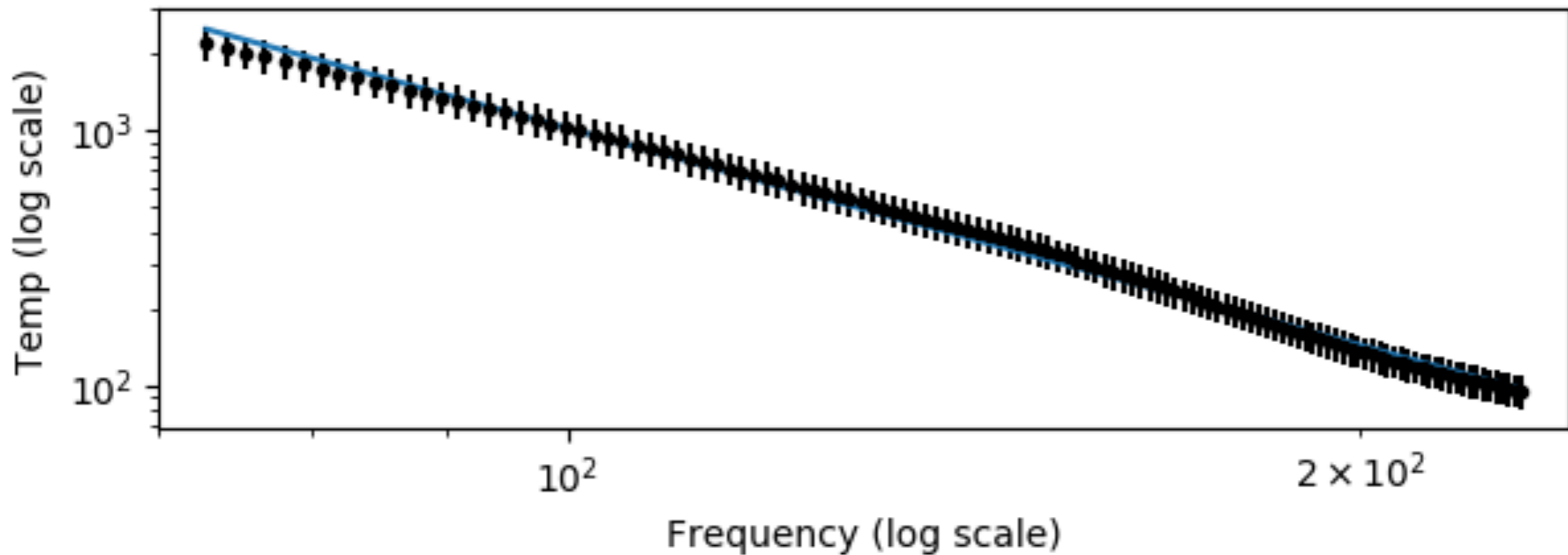
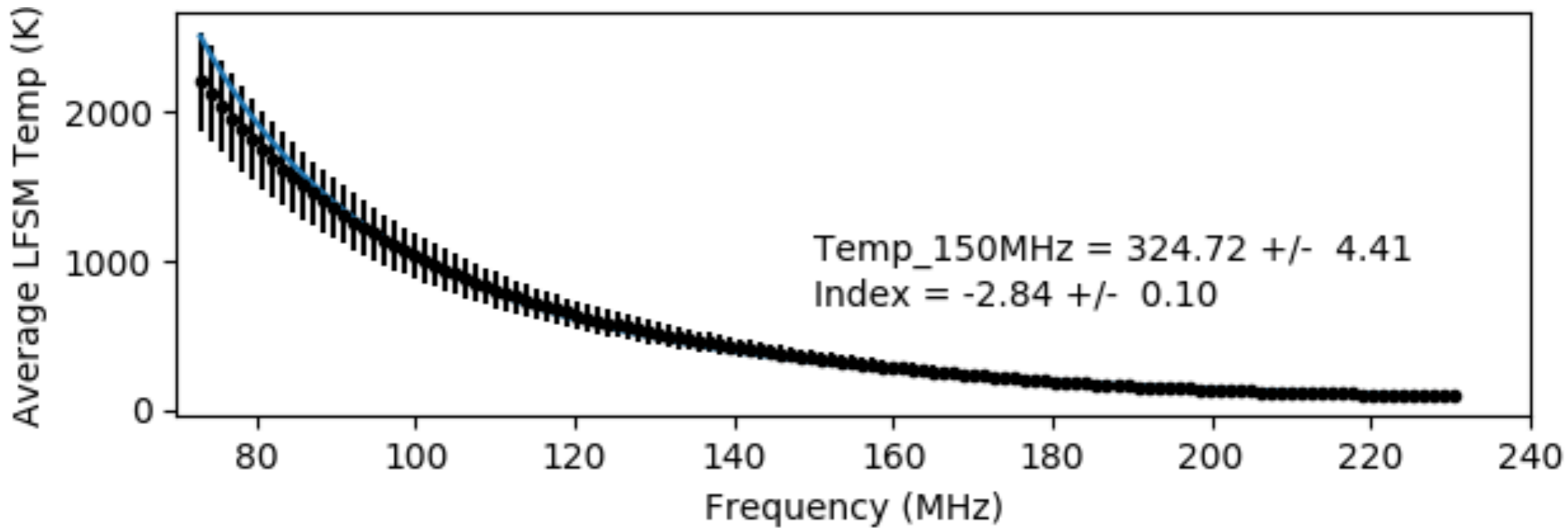
Best Fit Powerlaw GSM (de Oliveira-Costa et al., 2008)



Best Fit Powerlaw GSM2016 (Zheng et. al., 2016)

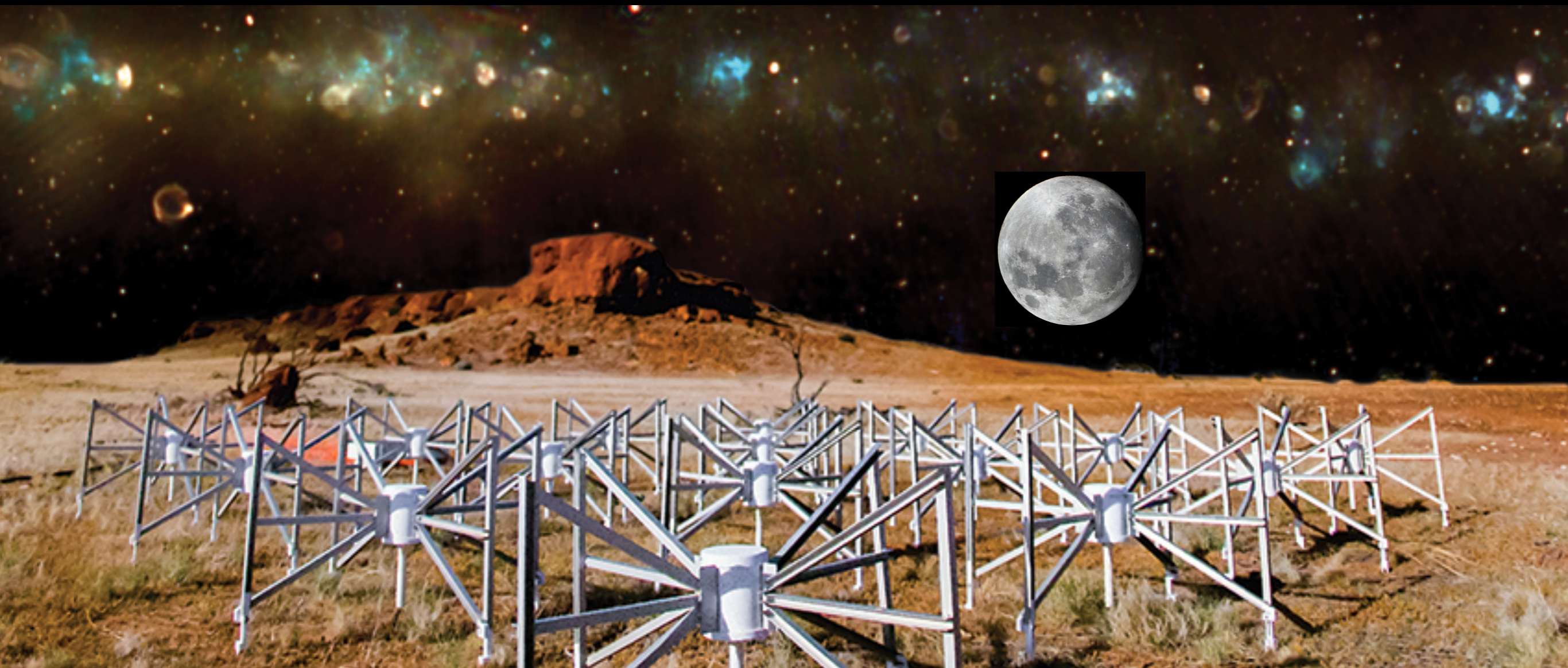


Best Fit Powerlaw LFSM (Dowell et. al., 2017)



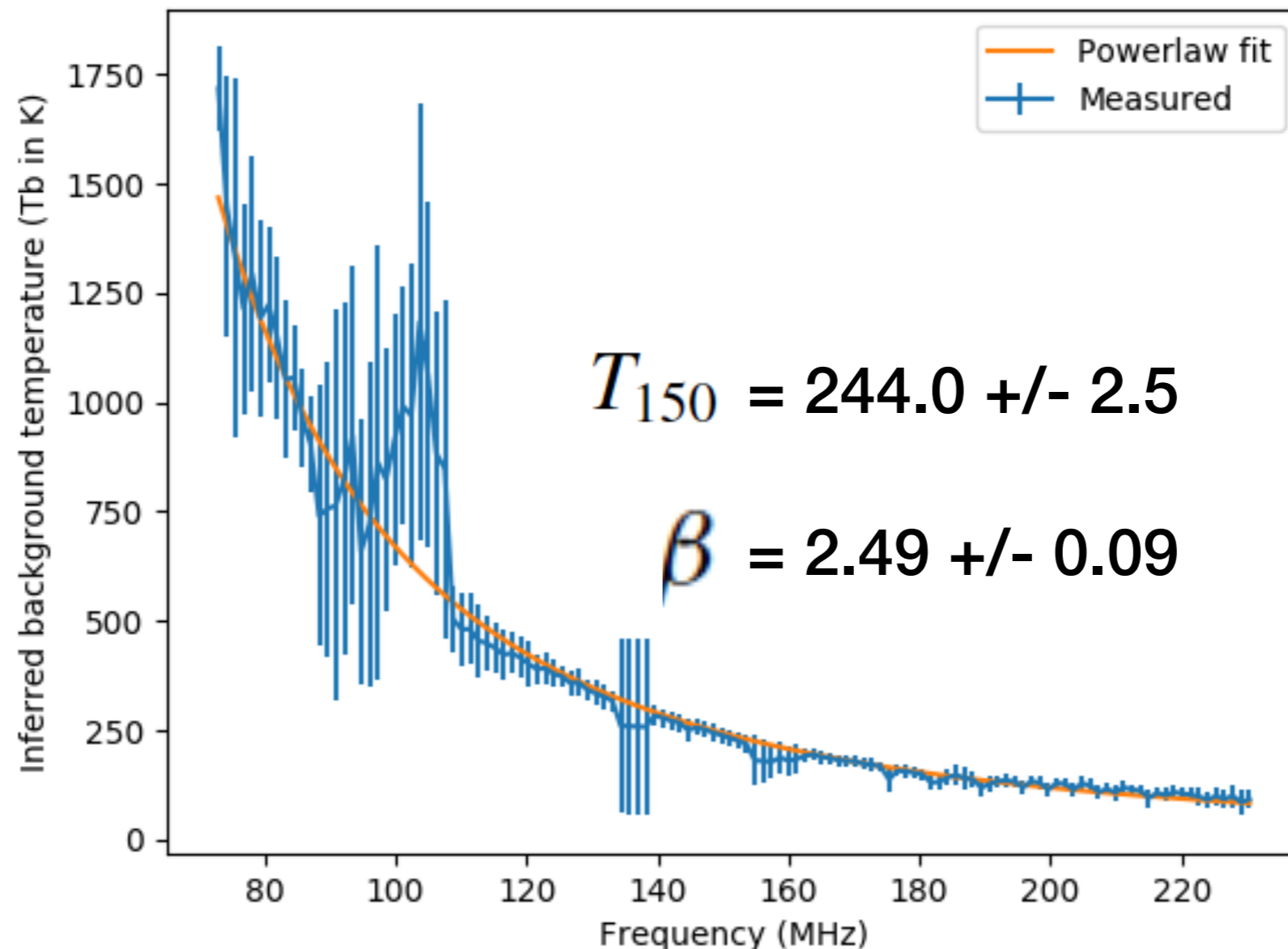
Next steps

- Process the remainder of the 2015 data
- EoR signal extraction/model rejection
- New observations with extended MWA 2017B/2018A



Conclusions

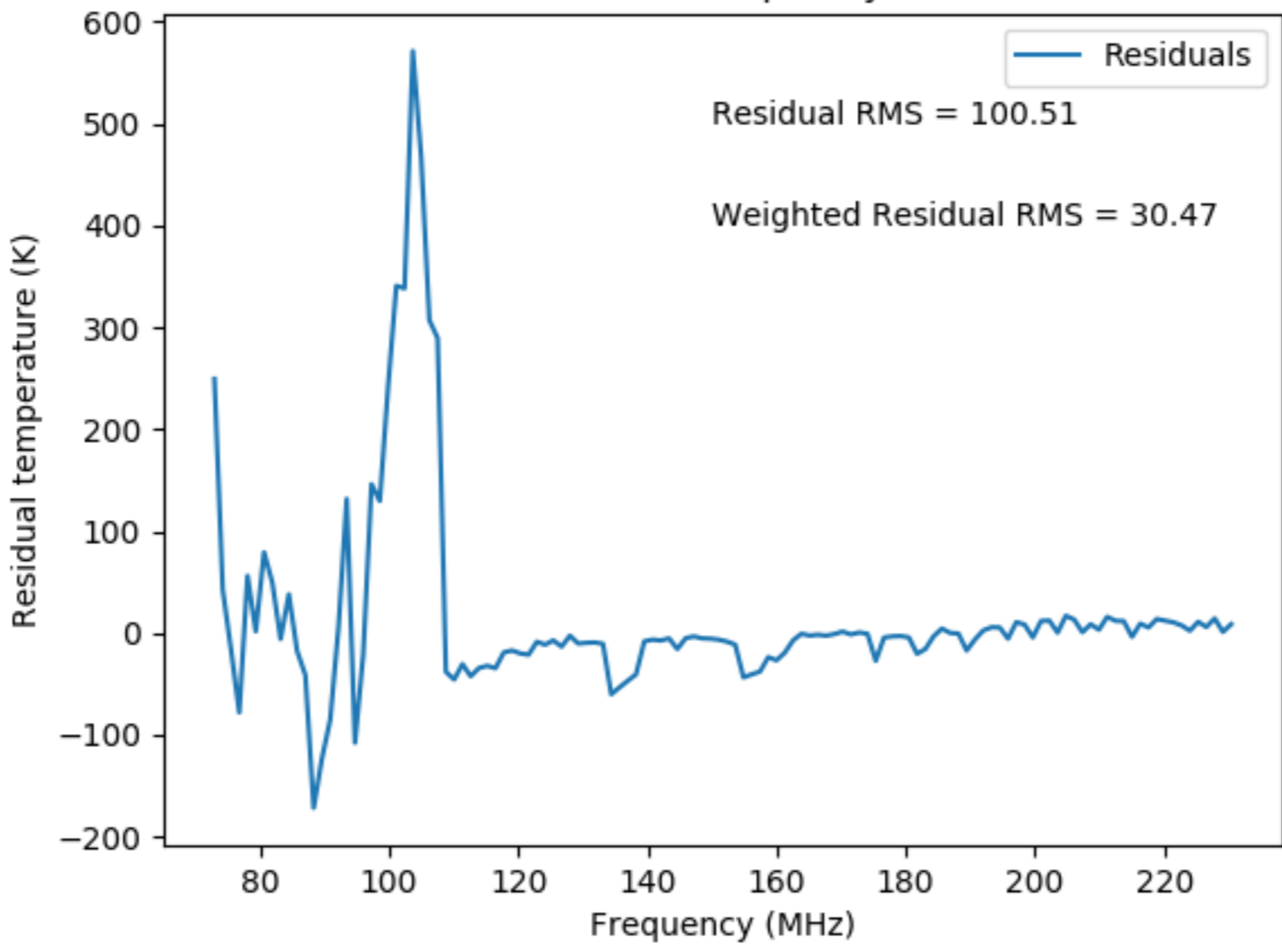
- Can measure the global sky temperature with an interferometer and the Moon
- Current diffuse sky models unreliable between 70-230 MHz
- Need to catch up to EDGES2 and SARAS2 and detect the EoR!



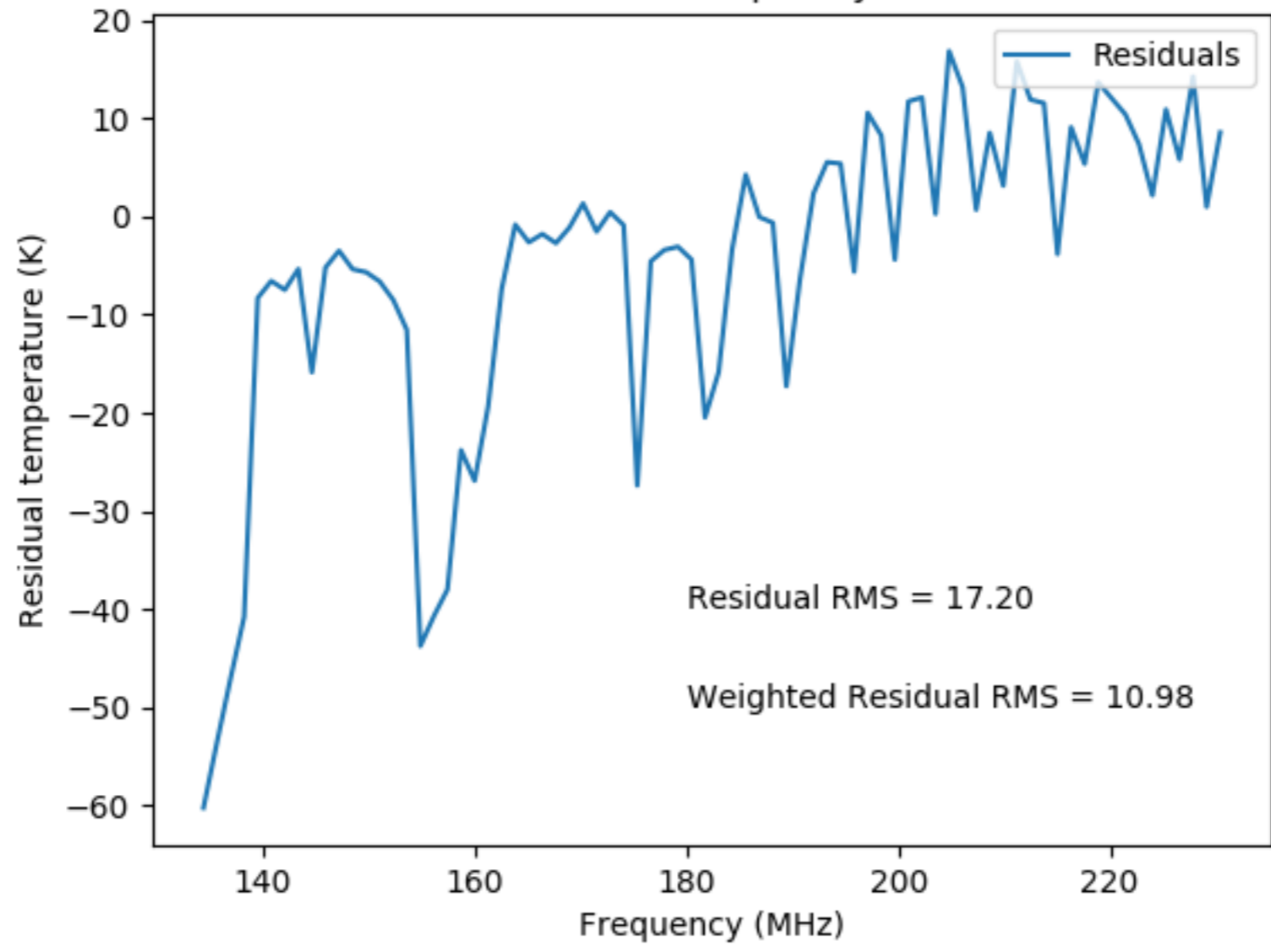
Spare

Comparison to Sky Models - only using lower frequencies

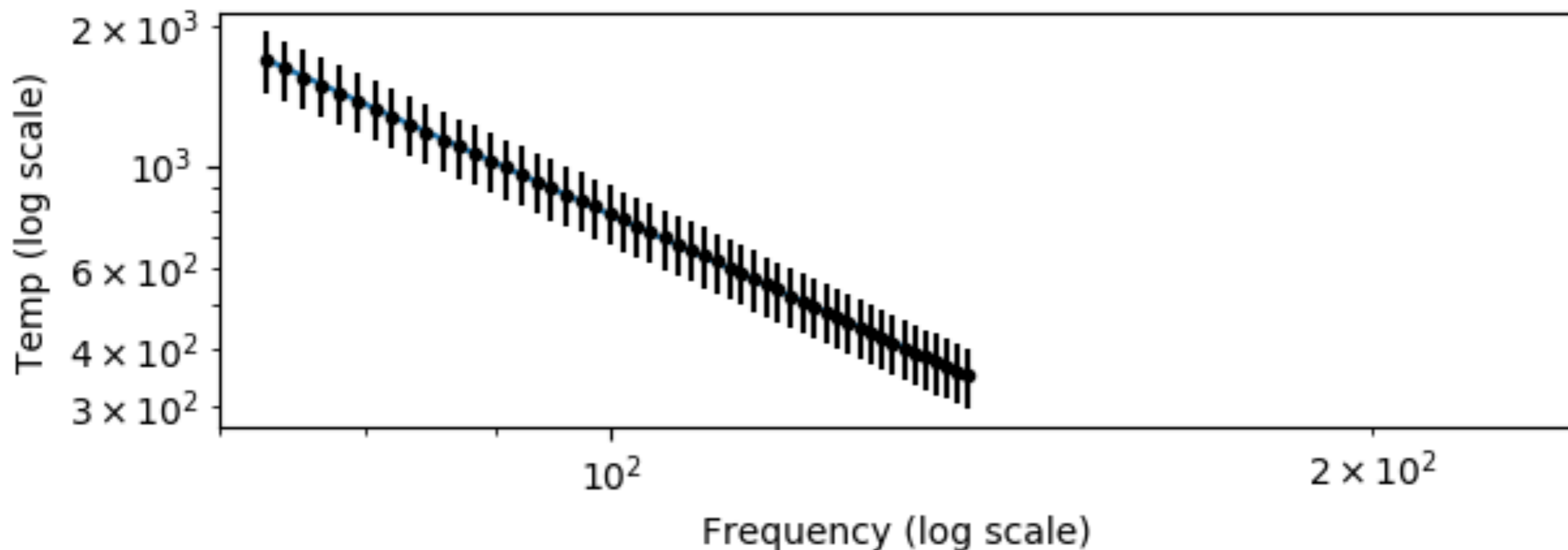
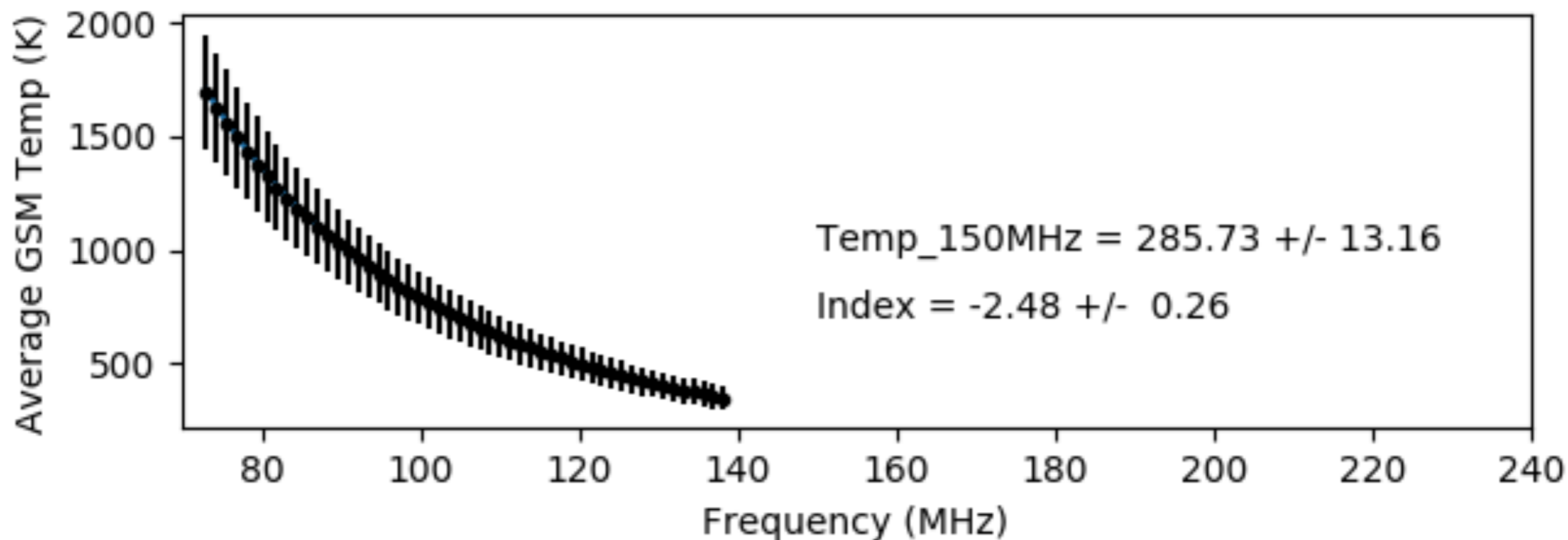
Fit residuals vs frequency for MWA



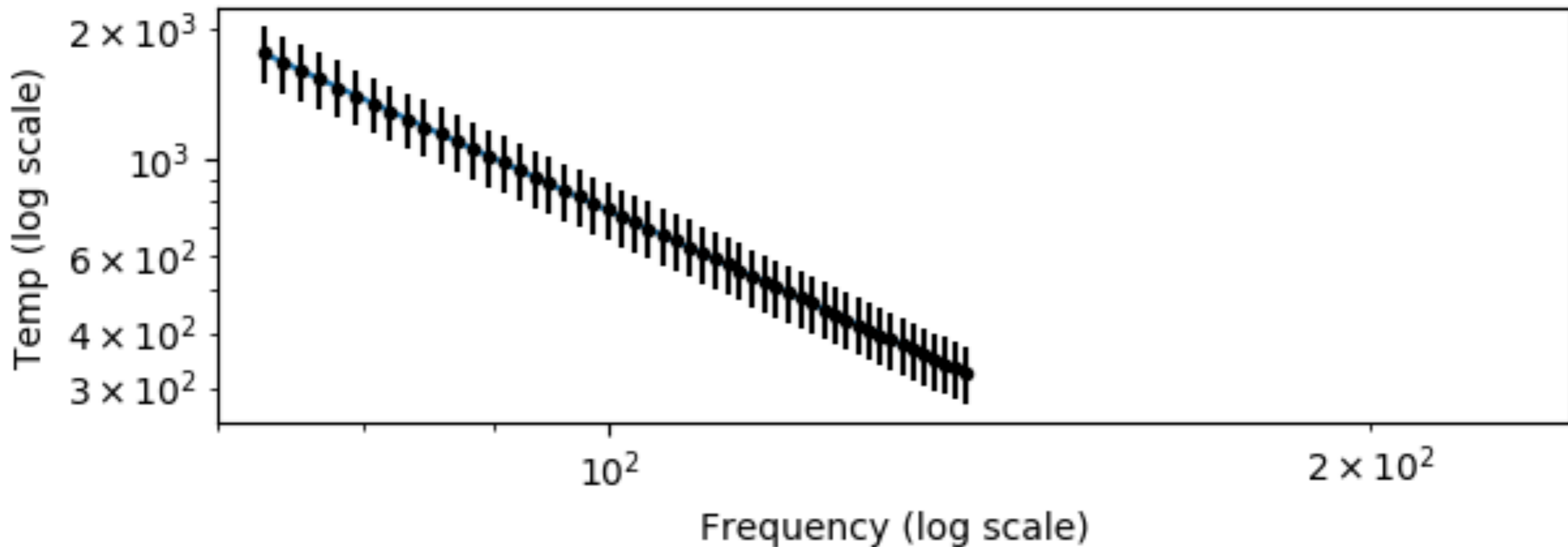
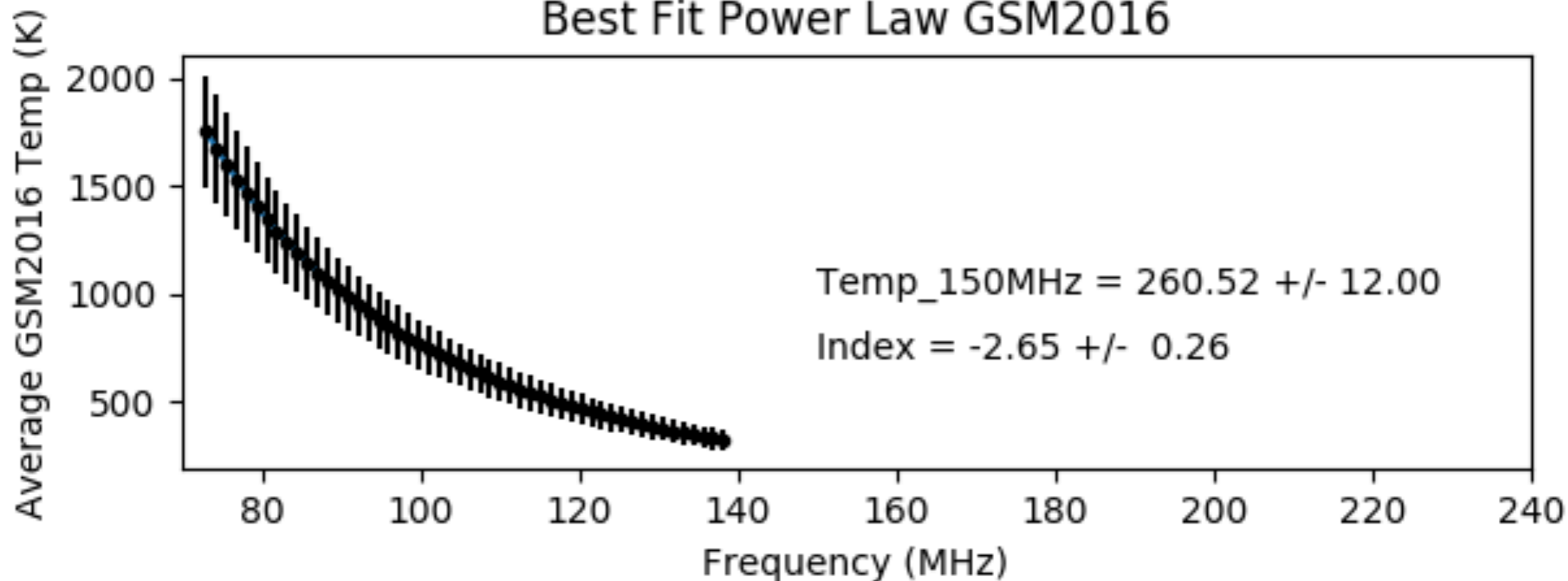
Fit residuals vs frequency for MWA



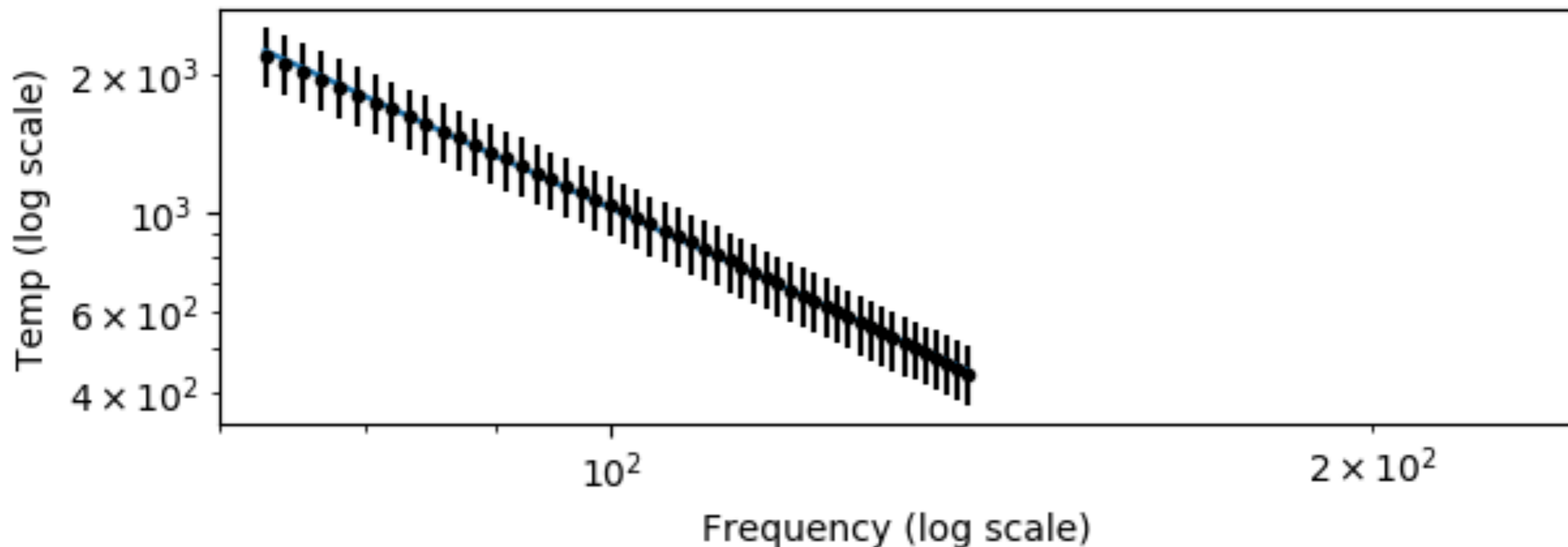
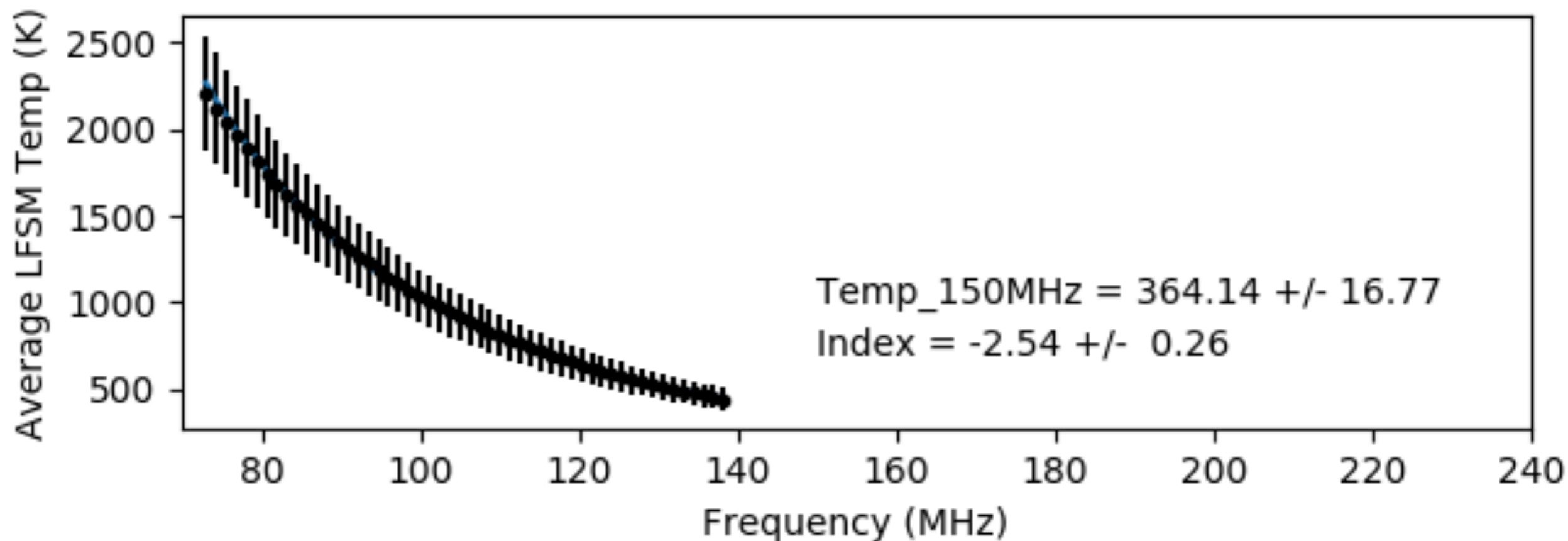
Best Fit Power Law GSM



Best Fit Power Law GSM2016



Best Fit Power Law LFSM



Maximum likelihood estimation Vedantham et al (2015)

$$\mathbf{D} = (S_m \mathbf{M} + S_{es}) * \mathbf{P} + \mathbf{N}, \quad (13)$$

or equivalently,

$$\mathbf{D} = S_m \mathbf{G} + S_{es} \mathbf{P} + \mathbf{N} \quad (14)$$

where $\mathbf{G} = \mathbf{M} * \mathbf{P}$ is the dirty image of the unit disc given the telescope PSF, and $*$ denotes 2-D convolution. The above equation may be vectorized and cast as a linear model with S_m and S_{es} are parameters:

$$\text{vec}(\mathbf{D}) = \mathbf{H}\boldsymbol{\theta} + \text{vec}(\mathbf{N}) \quad (15)$$

where

$$\begin{aligned} \mathbf{H} &= [\text{vec}(\mathbf{G}) \quad \text{vec}(\mathbf{P})] \\ \boldsymbol{\theta} &= [S_m \quad S_{es}]^T \end{aligned} \quad (16)$$

The Maximum Likelihood Estimate of the parameters is then

$$\hat{\boldsymbol{\theta}} = [\hat{S}_m \quad \hat{S}_{es}]^T = (\mathbf{H}^T \mathbf{H})^{-1} \mathbf{H}^T \text{vec}(\mathbf{D}), \quad (17)$$

and the residuals of fitting are given by

$$\text{vec}(\mathbf{R}) = \text{vec}(\mathbf{D}) - \mathbf{H}\hat{\boldsymbol{\theta}} \quad (18)$$

In practice, we solve Equation 17 with a positivity constraint on \hat{S}_{es} , and a negativity constraint on \hat{S}_m . Finally, if σ_N^2 is the noise variance, the parameter covariance matrix is given by

$$\text{cov}(\boldsymbol{\theta}) = \sigma_N^2 (\mathbf{H}^T \mathbf{H})^{-1} \quad (19)$$

Estimation of Tb (Vedantham et al 2015)

$$T_M = T_{black} + T_{refl} = 230 + 160 \left(\frac{\nu \text{ MHz}}{60} \right)^{-2.24} K$$

Moon albedo of 7% (Evans 1969).

$$S_m = \frac{2k(T_M - T_B)\Omega}{\lambda^2 10^{-26}} \text{ Jy}$$

$$\widehat{T}_B(\nu) = 230 + 160 \left(\frac{\nu \text{ MHz}}{60} \right)^{-2.24} - \frac{10^{-26} c^2 \widehat{S}_m}{2k\Omega\nu^2}.$$

Consistent with Monsalve et al (2017)
EDGES as well (ask Judd)

