Deep Imaging Using Sagecal Calibration

Sarod Yatawatta

ASTRON

The Netherlands

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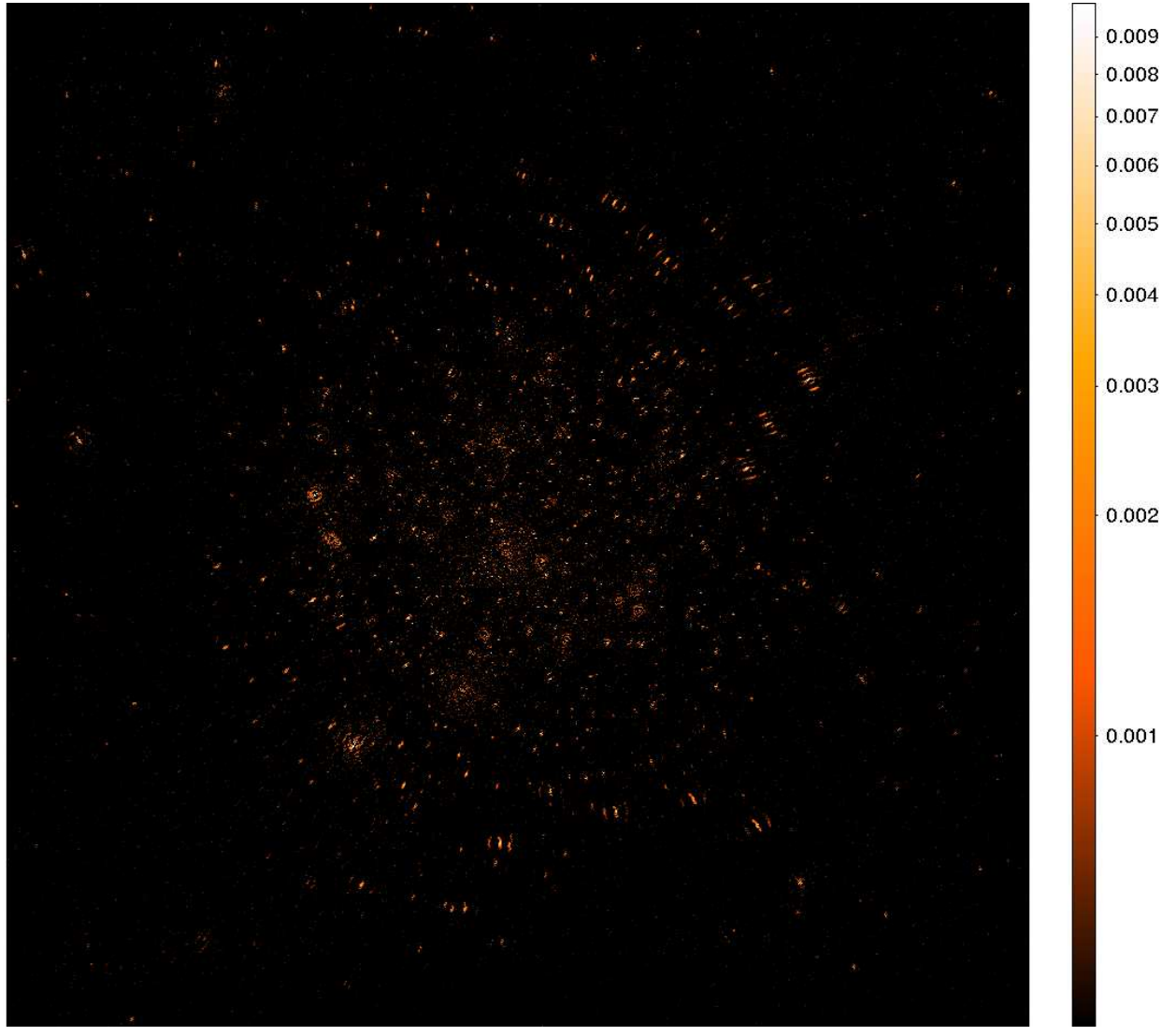
Sagecal

- Theory: [Yatawatta et al., 2009] and [Kazemi et al., 2011].
- The fastest multisource calibration program ($20\times$ to $100\times$ faster than meqtrees or BBS). Linear complexity with no. of directions.
- Very modest memory usage: (1 million data points, 60 000 parameters, < 6 GB RAM).
- Highly parallelized and vectorized. Uses GPU acceleration when available.
- Pure C code with only standard libraries used. Not linked against casacore etc.
- Data I/O done using binary files. Easy conversion to binary format using pyrap.
- Supports all source models: points, Gaussians, disks, rings, (widefield) shapelets (and even prolate spheroidal wave functions in the future).
- Core based on two optimization algorithms: LM [Lourakis] and L-BFGS [Yatawatta].

Sky Model

- Input to sagecal is a sky model.
- Given an image, use Duchamp [Whiting] to create a mask.
- Buildsky [Yatawatta] creates the best sky model, with the best number of components, and their spectral indices.
- Can filter out false detections due to PSF sidelobes.
- Also does clustering [Kazemi et al., 2011] of sources for directional calibration.
- Also parallelized, but could (and will) be made faster.
- Sagecal will subtract the given sky model (with solved gains) from the data. Also saves solutions.
- Restore [Yatawatta] will restore the sky model back to the residual image (optionally with correction applied).

NCP Field



13 $\times$ 13 Image, 240 subbands, Peak 5 Jy, Noise 0.2 mJy

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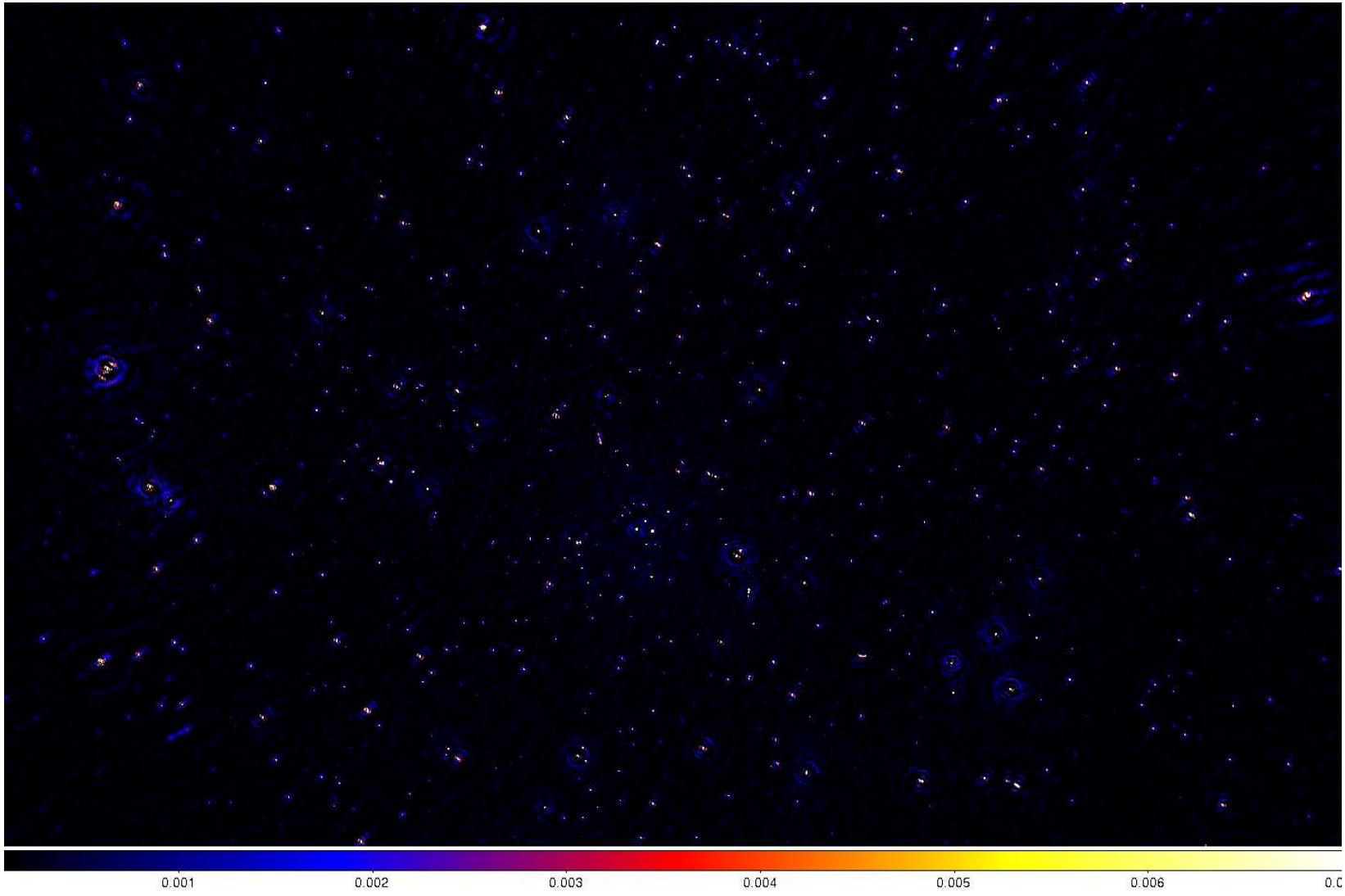
NCP Field



Inner region, Noise 0.2 mJy

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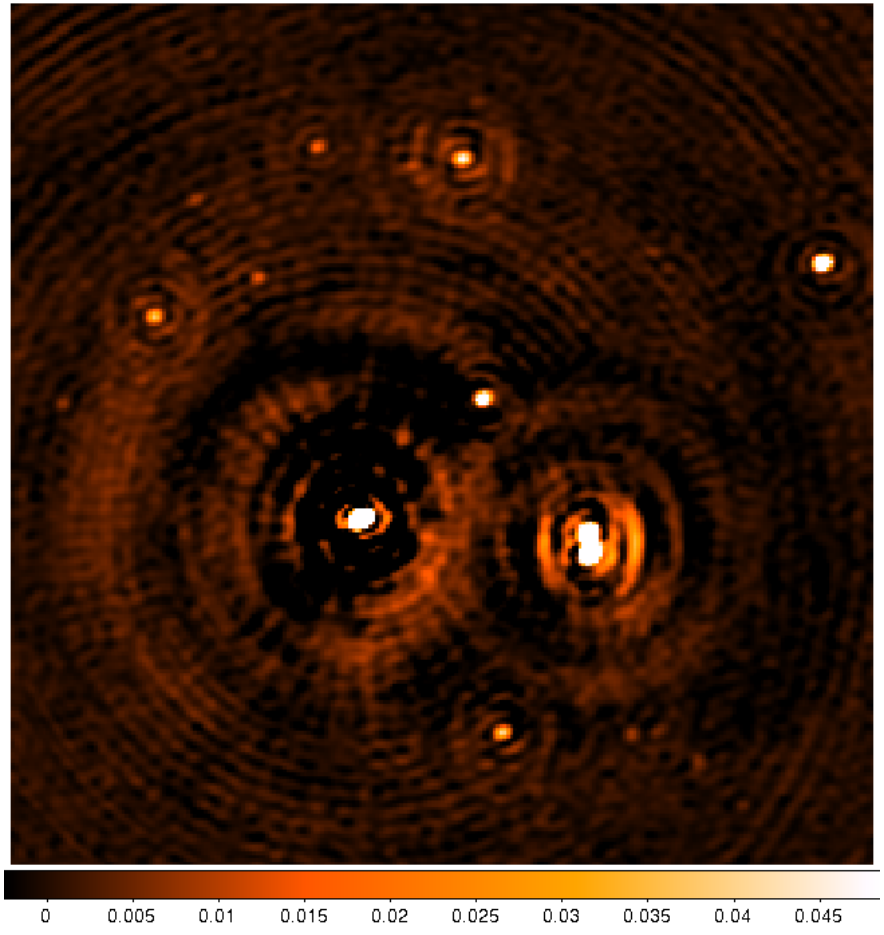
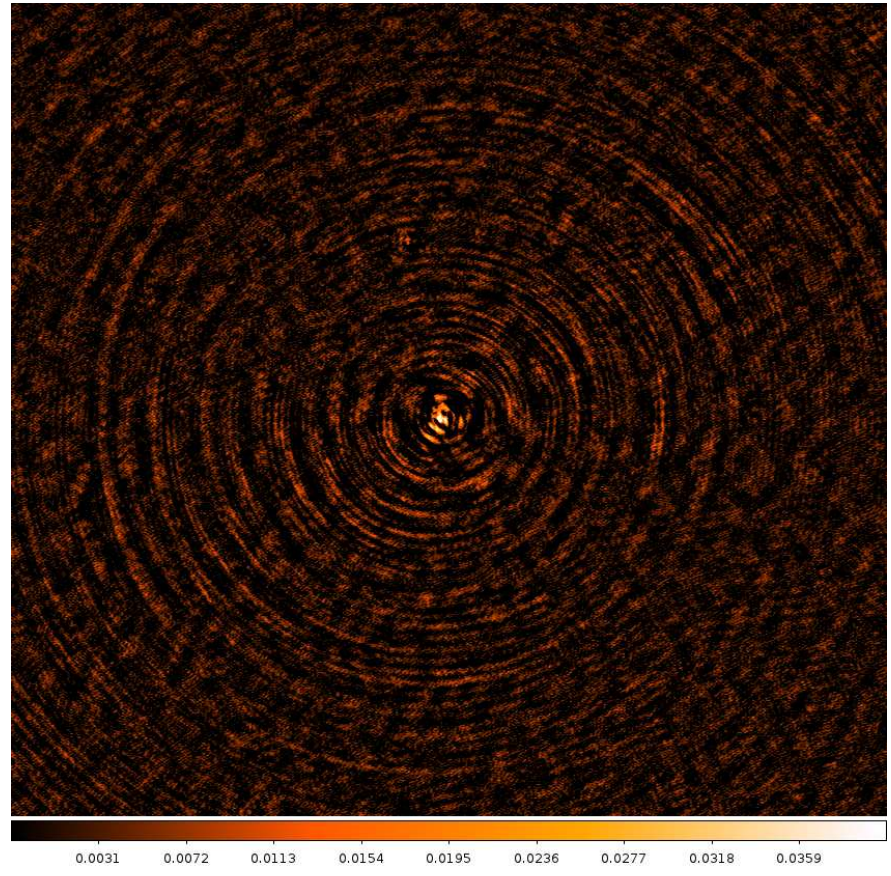
Before Sagecal

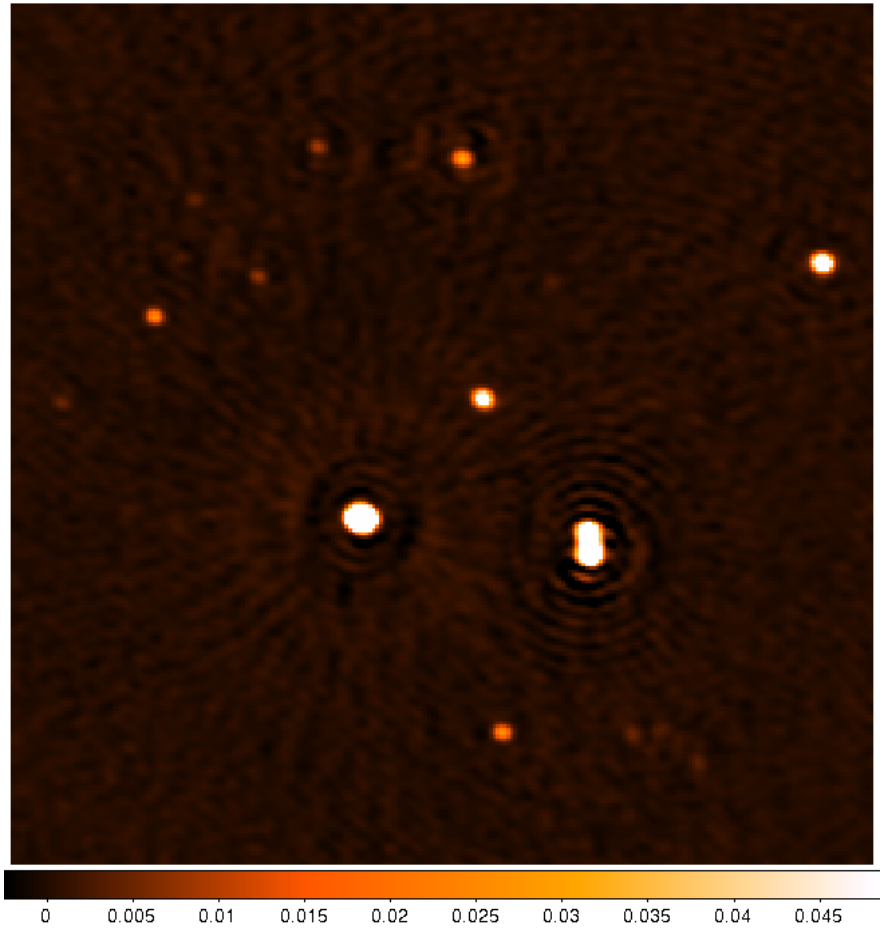


Center

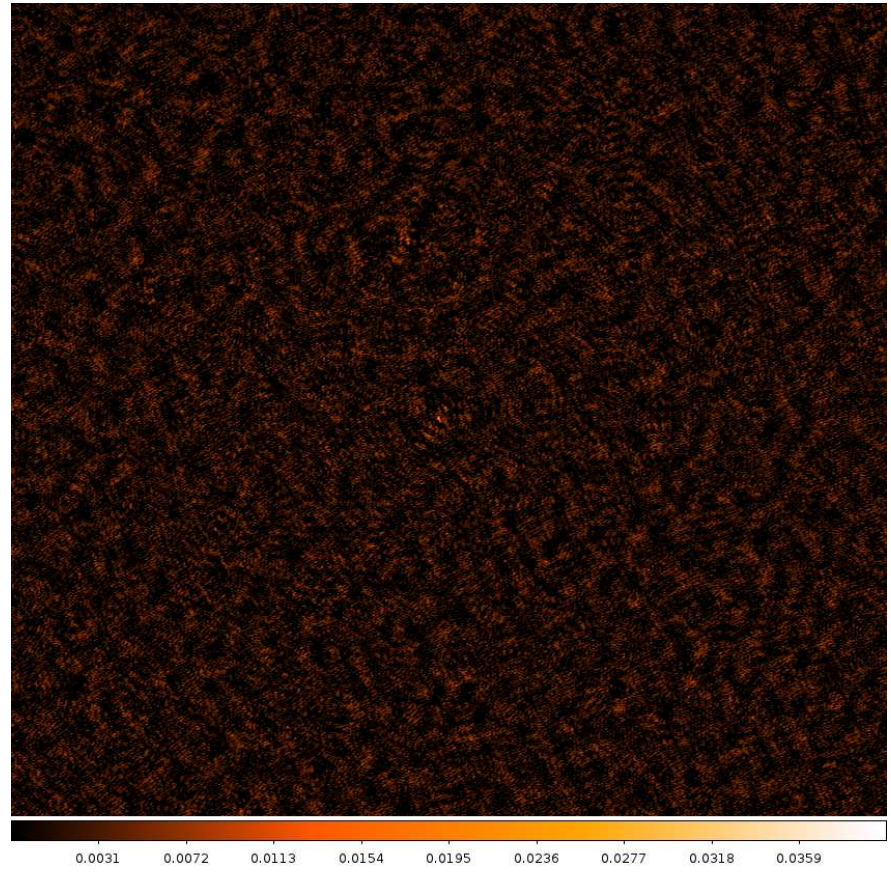


Far Away

After Sagecal



Center



Far Away

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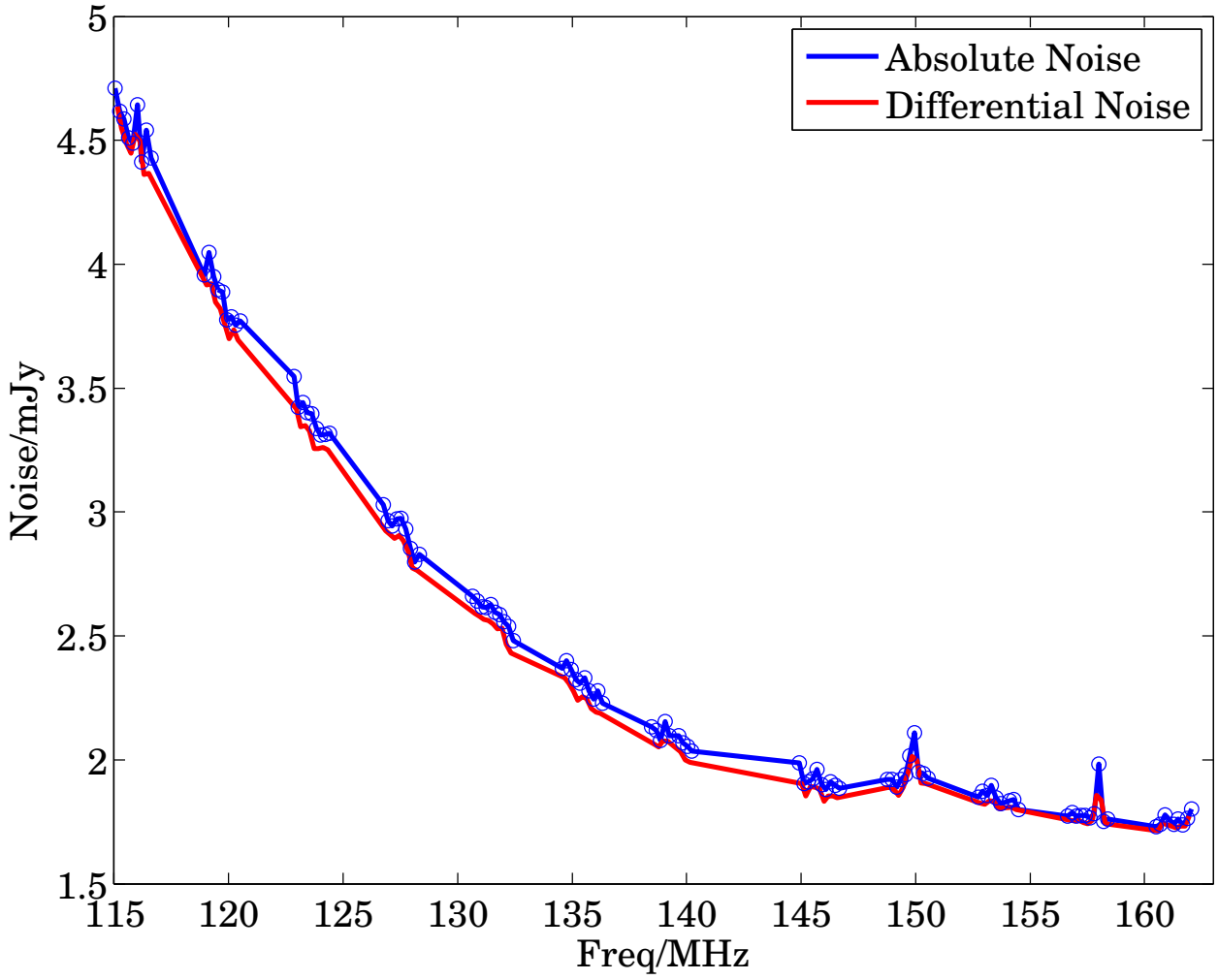
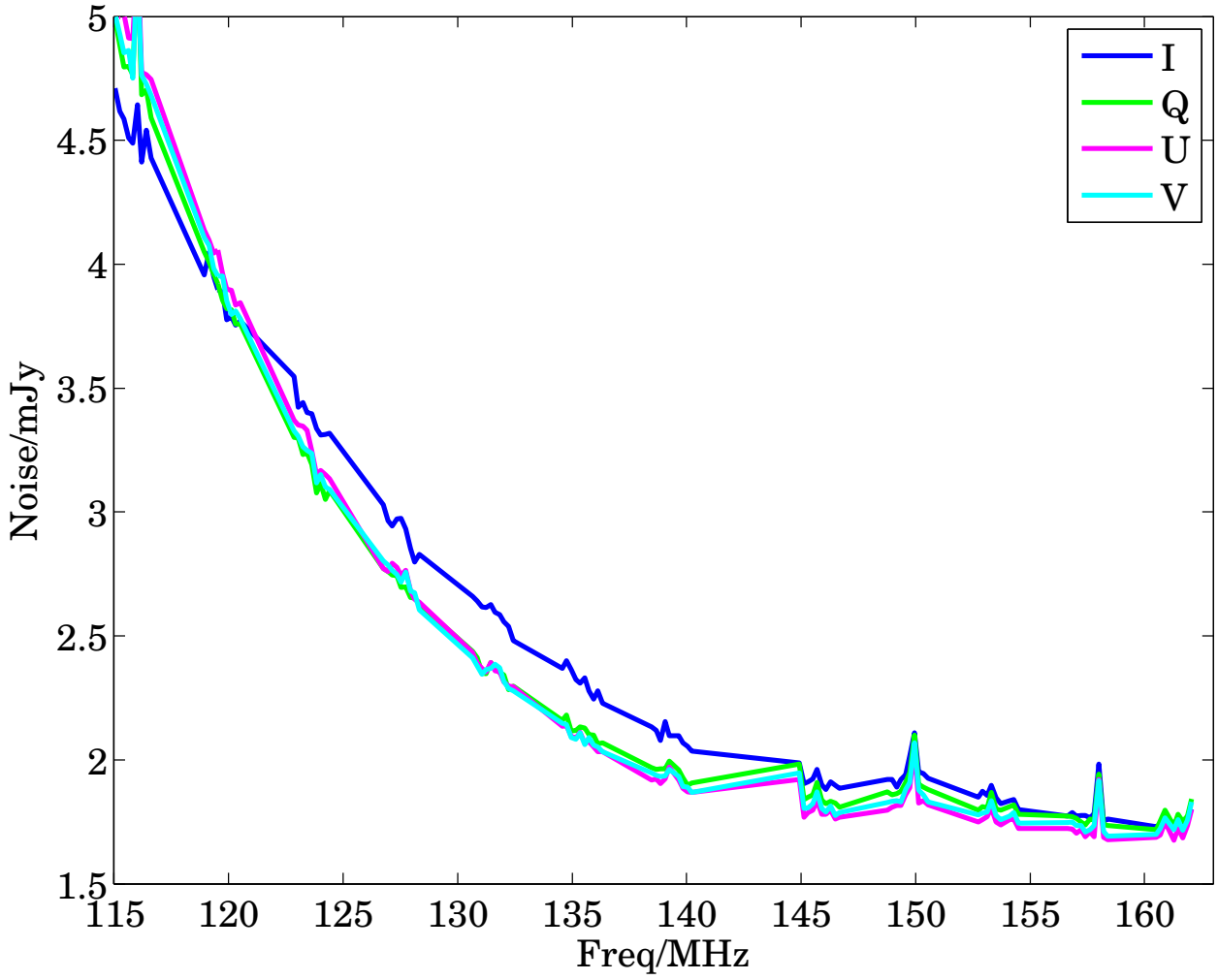
Noise



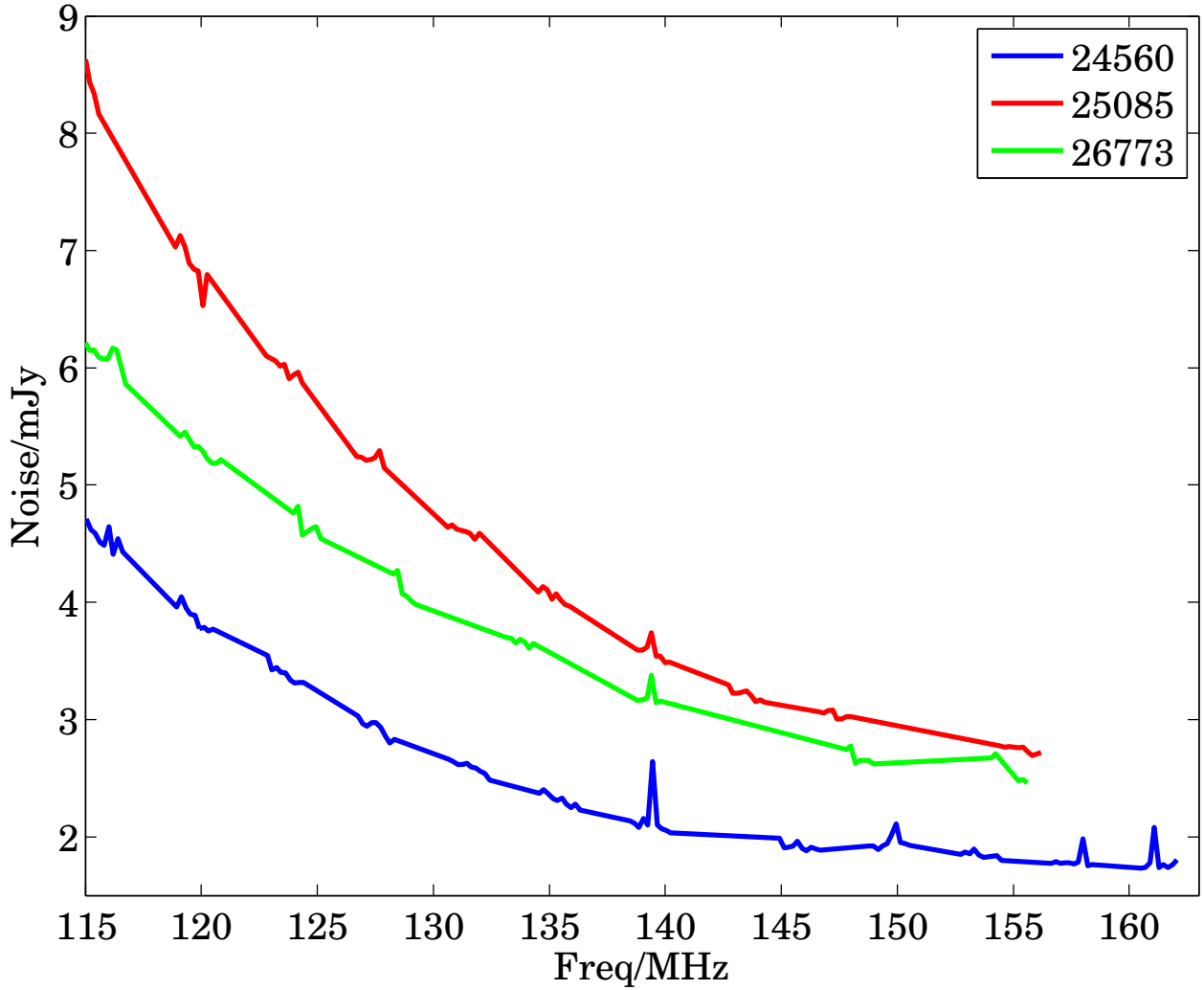
Differential and absolute noise

Noise



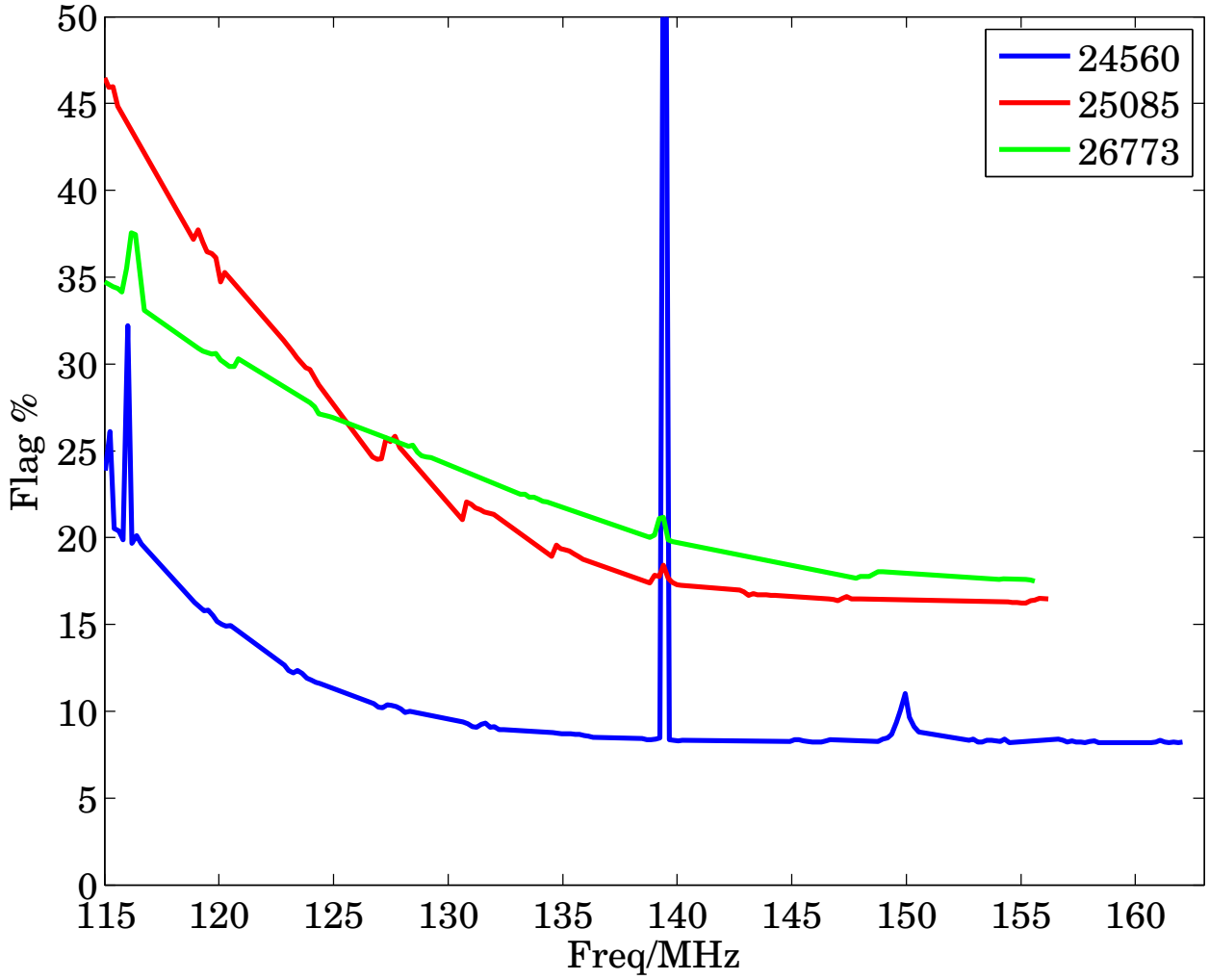
Full polarization

Noise



Three nights data

Flagged Data



Flags in I

Station Beam Model

$$\mathbf{M} = \underset{\mathbf{M},\ \mathbf{M}^T\mathbf{M}=\mathbf{I}}{\arg\min} \sum_{p,q,m} ||\mathbf{e}_p^T \mathbf{M} \mathbf{b}_{pm} \mathbf{b}_{qm}^T \mathbf{M}^T \mathbf{e}_q \widetilde{\mathbf{C}}_{pqm} - \mathbf{J}_{pm} \mathbf{C}_{pqm} \mathbf{J}_{qm}^H||^2$$

- Solutions of sagecal: $\mathbf{J}_{pm}$, $\mathbf{J}_{qm}$.
- Basis functions $\mathbf{b}_{pm}$, $\mathbf{b}_{qm}$.
- Rows of $\mathbf{M}$ give model parameters for each station.
- Orthogonal columns for regularization.
- More detail [Yatawatta et al., in prep.]

Conclusions

- Sagecal and assorted tools provide the fastest way of dealing with directional effects, without losing accuracy.
- LOFAR HBA NCP observations reach the theoretical noise limit. Only known limitations exist.