Towards More Accurate and Efficient Beamformed Radio Interferometry Imaging

MASTER THESIS

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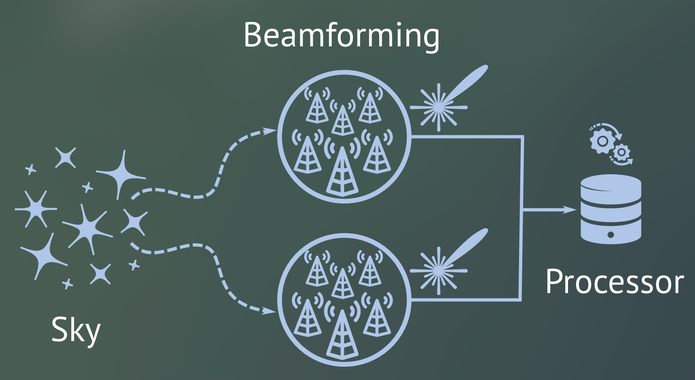
Introduction

Modern radio interferometers combine many small antennas together in a **phased array.** The data generated by such instruments is enormous. For the SKA, it is estimated at 157 Tb/s.

157 Tb/s
or enough to fill up
350,000 DVDs/s

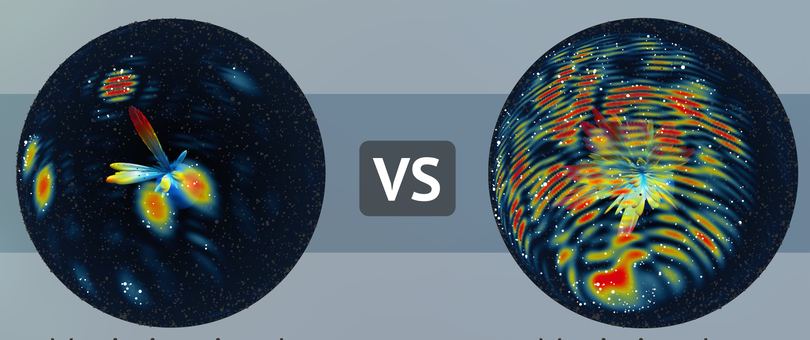
Hierarchical Designs

To reduce the amount of data sent to the central processor, antennas are grouped in **stations** and the data is **beamformed** (i.e. compressed) at the station level.



Generalized Beamforming

Beamforming can be leveraged to maximize the information content withinthe data. The beamforming strategy is not **flexible** enough in the current imaging pipeline.



Maximize signal power

Maximize sky coverage

Modelling Assumptions

1. Sources lie on a sphere

2. Signals are parallel

3. Signals are narrow band

4. Signals are independent

CURRENT IMAGING PIPELINE

No Beamforming

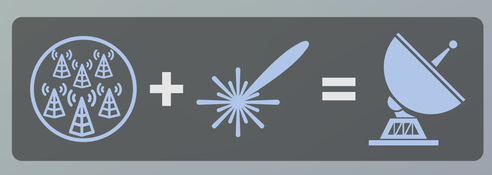
Signals from each antenna are correlated. For small field of views, we have

$$V_{i,k} \simeq \iint I(l,m) e^{-j2\pi(u_{i,k}l + v_{i,k}m)} dl dm.$$

The correlations can be seen as samples of the sky Fourier transform. Sampled frequencies depend on the telescope layout.

With Beamforming

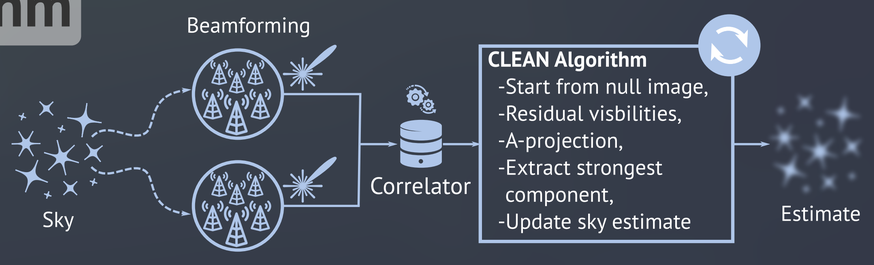
Beamformed data is seen as coming from virtual antennas with different **beamshapes**.



This assumption brings beamformed data into the scope of the classical data model.

CLEAN Algorithm

CLEAN is an iterative algorithm that produces sparse sky estimates.



THE NEW IMAGING PIPELINE

Least Squares Imager

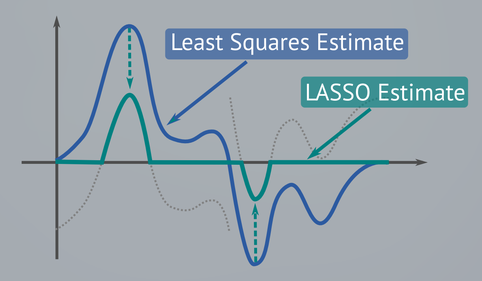
Orthogonalizing the instrument and preconditionning the data permits to compute the least squares estimate directly:

$$\hat{\boldsymbol{I}}_{LS} = \sum_{i,k} V_{i,k}^{\perp} \boldsymbol{\beta}_{i,k}^{\perp}.$$

In practice, for stability and efficiency, we use the **QR-factorization** for the orthogonalization step.

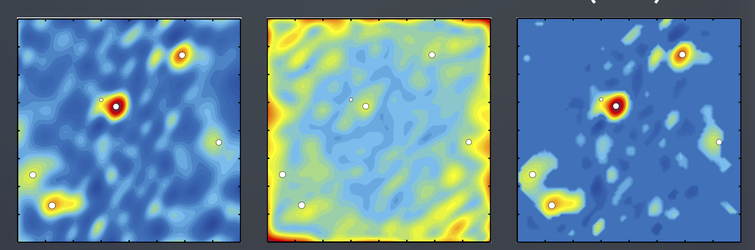
Sparse Recovery

In the orthogonal case, the LASSO estimate can very cheaply be approximated by **thresholding** the least squares estimate.

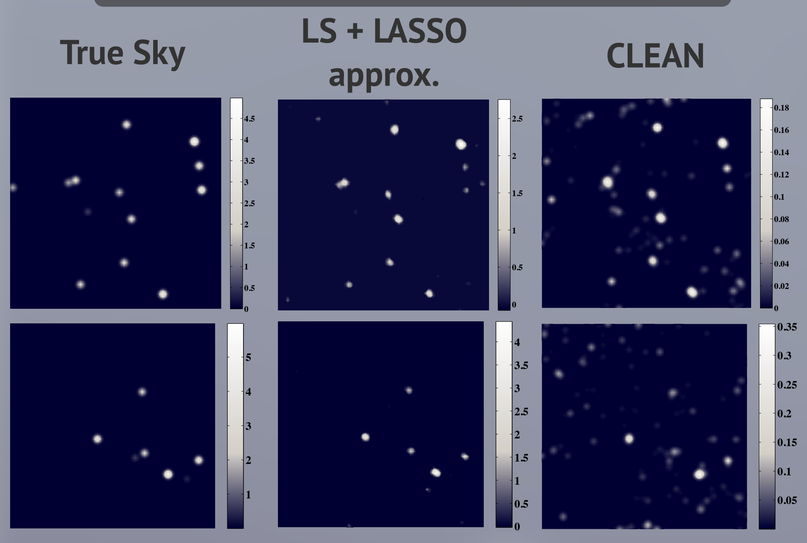


Statistics on Sky

Using asymptotic arguments, we can build confidence intervals on the least squares estimate.



Comparison with CLEAN



Our algorithm is **more accurate** and less subject to false positives.

Complexity Analysis

The analysis of complexity of both imaging pipeline reveals that our imaging pipeline is always faster for LOFAR, and faster in most pratical cases for the SKA. However, our imaging pipeline is still at a very early stage, and can be made even faster.

2 to 34 x faster

Conclusion

Performing a **QR-decomposition** of the system results in a more *intuitive*, *natural* and *flexible* imaging pipeline. Indeed, it permits the use of any beamforming strategy, which is not possible in the classical imaging pipeline. Although at a very early stage, our imaging pipeline is more **accurate** and **faster** than state-of-the-art for LOFAR and many SKA scenarios.

Scan for more on this work