Bluebild: A Next-Generation Radio Interferometric Imager

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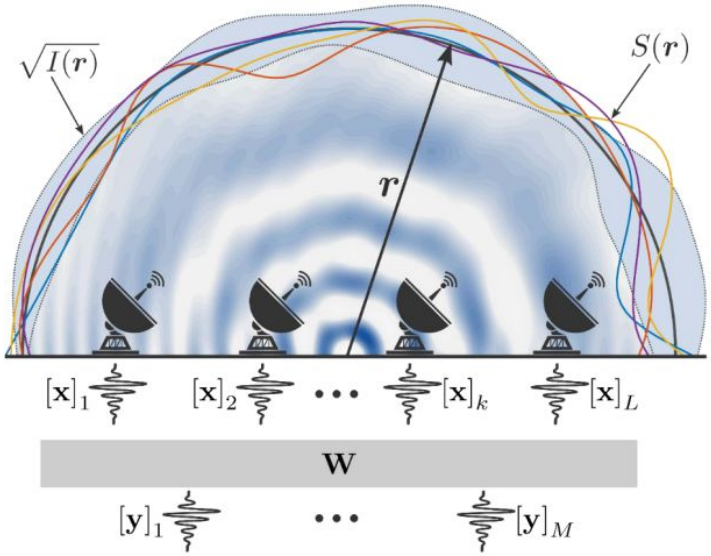
SKACH Spring Meeting 1/6/2023

Radio Interferometric Imaging Process



$$y = B^*S \xrightarrow{\text{Correlator}} y_i y_j = Y$$

Best reconstructed source emissions

$$\boxed{\hat{I} = \tilde{D}Y = \tilde{B}E[y_i y_j *]\tilde{B}^*}$$

Find a least squares fit for the sky image.

CLEAN[1] family of algorithms

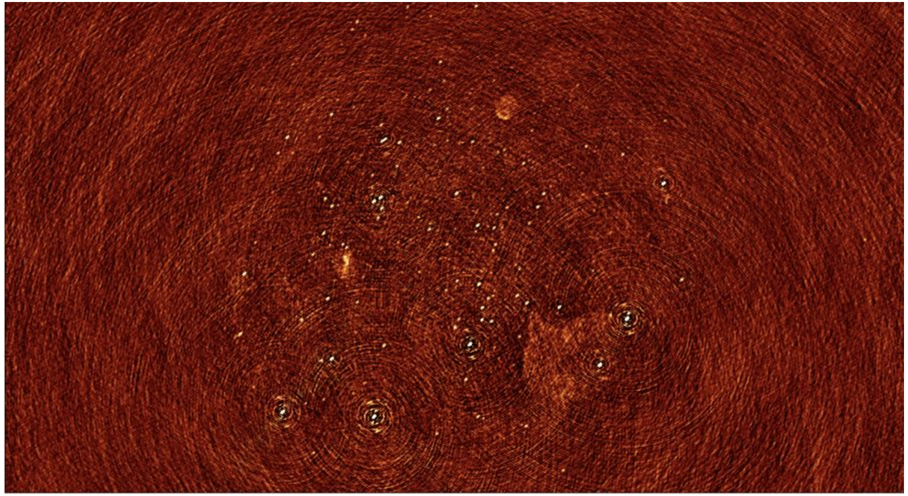
$$\boxed{\tilde{D} = (D\Sigma D^*)^{-1} D\Sigma}$$

$$Y = \mathbf{E}[B^* S (B^* S)^*] = B^* \mathbf{E}[S S^*] B = D^* I$$

Generalized Least-Squares Solution

$$\hat{I} = \tilde{D} Y = (D\Sigma D^*)^{-1} D\Sigma Y$$

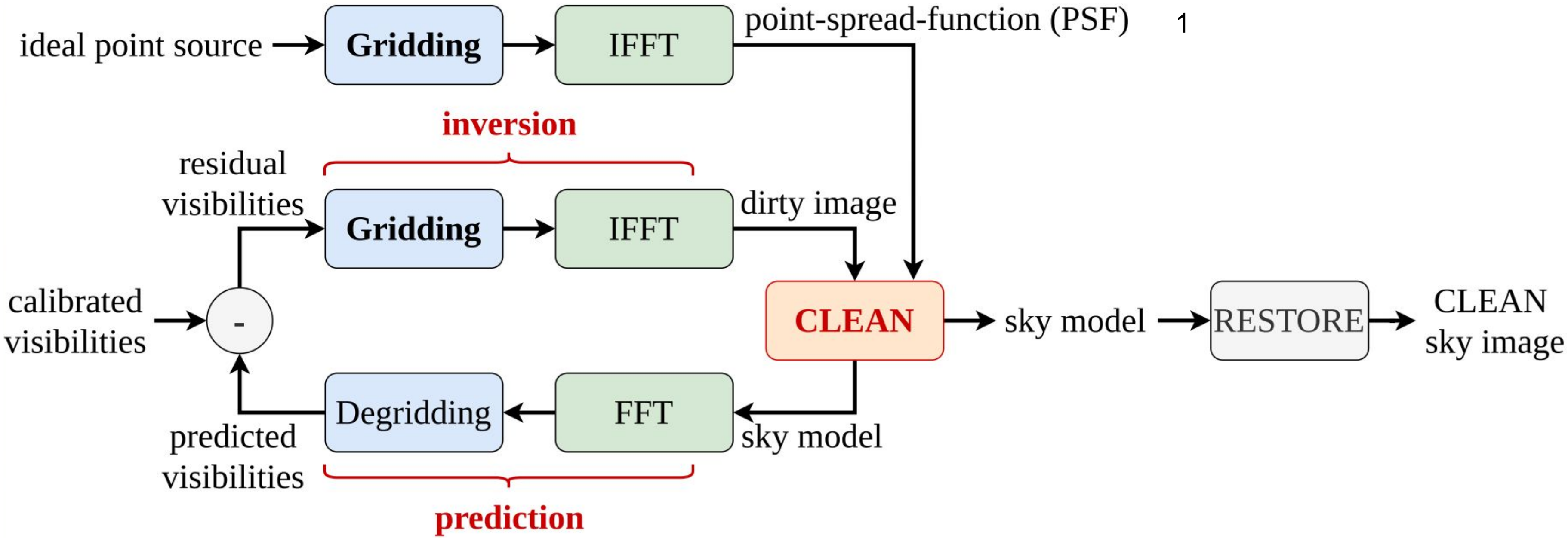
$$\hat{I} = \underset{x}{argmin} ||\Sigma^{-1/2}(\hat{Y} - Y)||$$


[2]

[1] [Högbom 1974]

[2] [LOFAR School 2016, Offringa]

CLEAN family of algorithms



[1]

[1]: [Corda 2022]

Bluebild Algorithm[1]

$$\hat{I}(r) = \tilde{B}\mathbf{E}[yy^*]\tilde{B}^* = BG_B^{-1}\mathbf{E}[yy^*]G_B^{-1}B^*$$

$$\hat{I}(r) = \sum_m \lambda_m |\epsilon_m(r)|^2$$

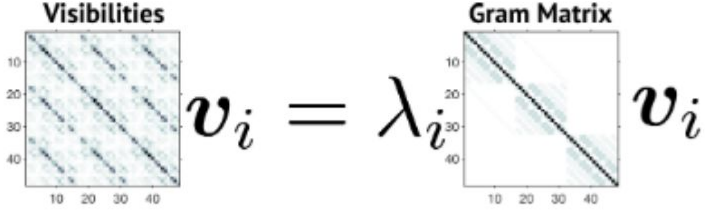
$$\epsilon_m = Bv_m \qquad \hat{I}(r)Bv_m = \lambda_m Bv_m$$

$$\mathbf{E}[yy^*]v_m = \lambda_m G_B v_m$$

1:[Simeoni, Hurley and Kashani, 2023]

Bluebild Algorithm

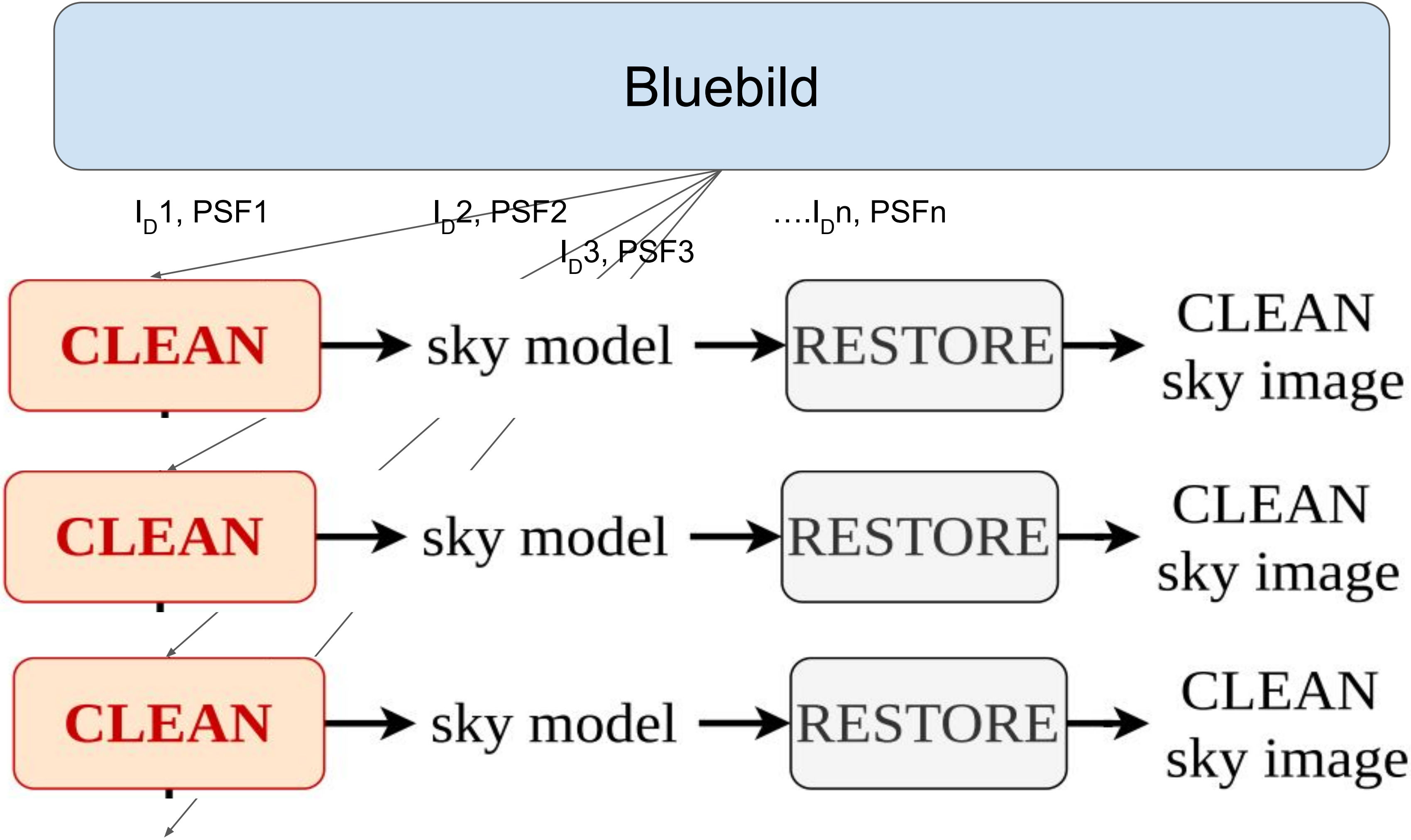
- Flexible continuous spherical imager for interferometric applications
- Solves for I(r) in $\int_{\mathbb{S}^{\neq}} I(r)e^{-j<r,p_i-p_j>}dr = V_{ij}$ by framing a generalised eigenvalue problem and decomposing visibilities into different eigenfunctions, via fPCA $\Longrightarrow$ $\mathbf{E}[yy^*]v = \lambda G_B v$
- Eigenfunctions give eigenimages - independent and sorted by energy. Can be truncated (automatic denoising) or filtered.
- Low computational complexity and affinity for parallel execution



Normalised Eigenfunctions

$$\epsilon_m = \frac{Bv_m}{||Bv_m||} = \frac{Bv_m}{\sqrt{v_m^H G_B v_m}}$$

$$\hat{I}(r) = \sum_m \lambda_m |\epsilon_m(r)|^2 = \sum \lambda_m \frac{|Bv_m|^2}{v_m^H G_B v_m}$$



Bluebild

I_D1, PSF1

I_D2, PSF2

I_D3, PSF3

....I_Dn, PSFn

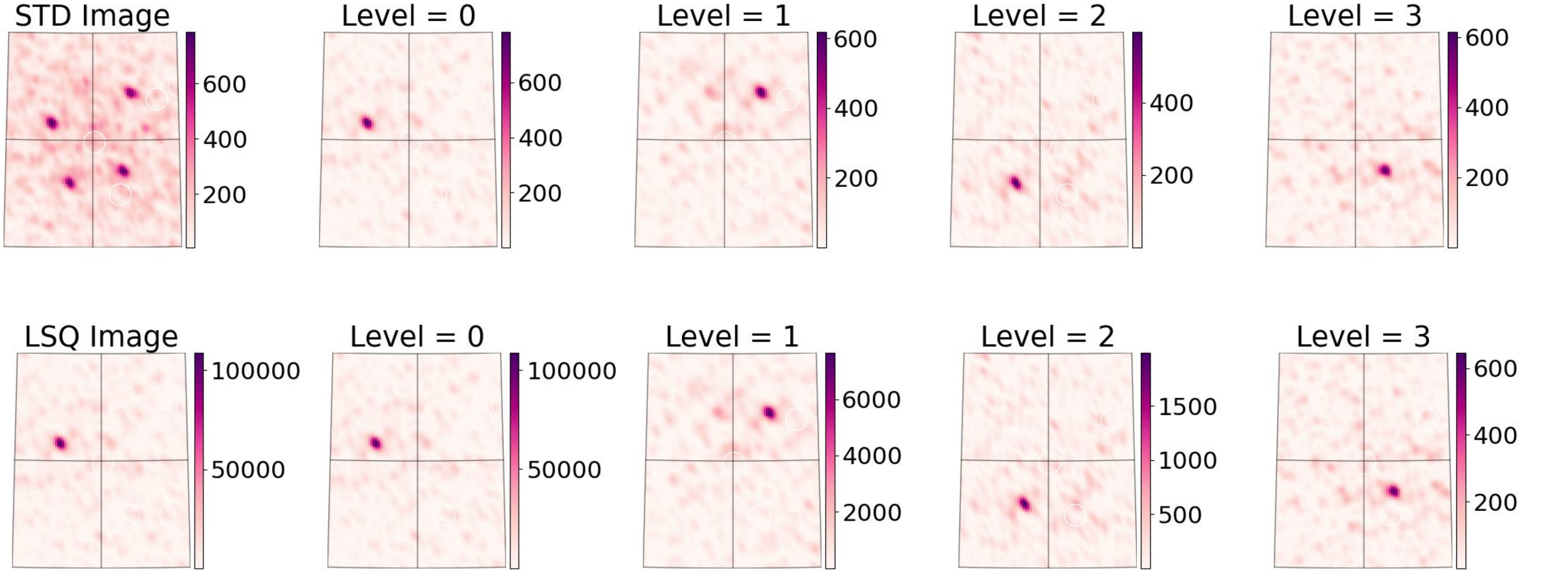
CLEAN → sky model → RESTORE → CLEAN sky image

CLEAN → sky model → RESTORE → CLEAN sky image

CLEAN → sky model → RESTORE → CLEAN sky image

Bluebild Example

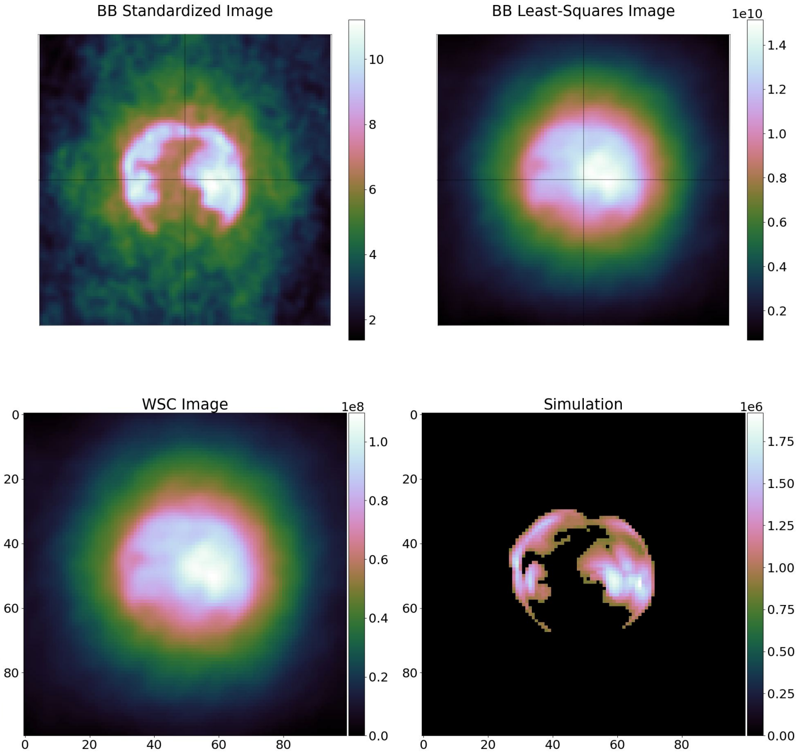
$$\hat{I}_{std} = \sum_m |\epsilon_m|^2$$

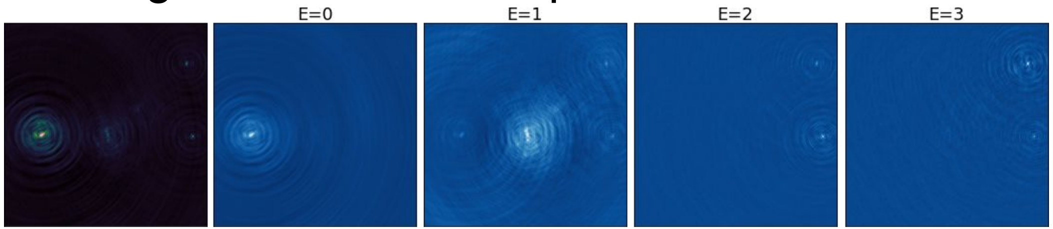


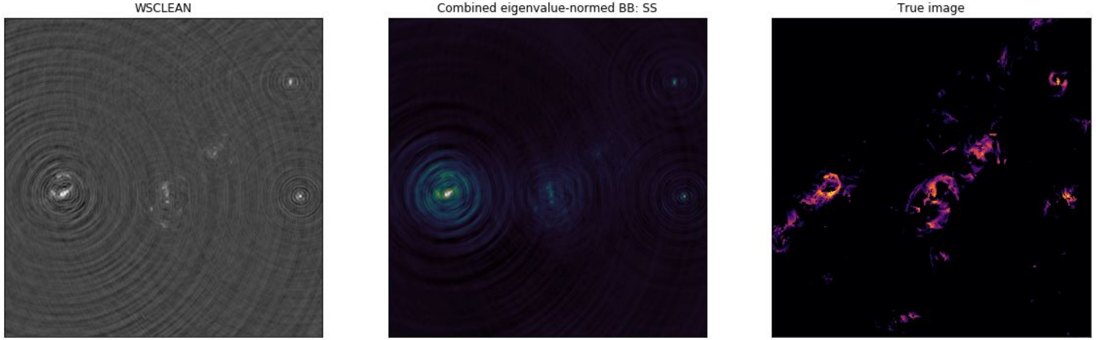
$$\hat{I}_{lsq} = \sum_m \lambda_m |\epsilon_m|^2$$

Some science-use cases:
Plots courtesy Michele Bianco

- Solar limb brightening
- Galaxy cluster emission
- Bright Source PSF separation





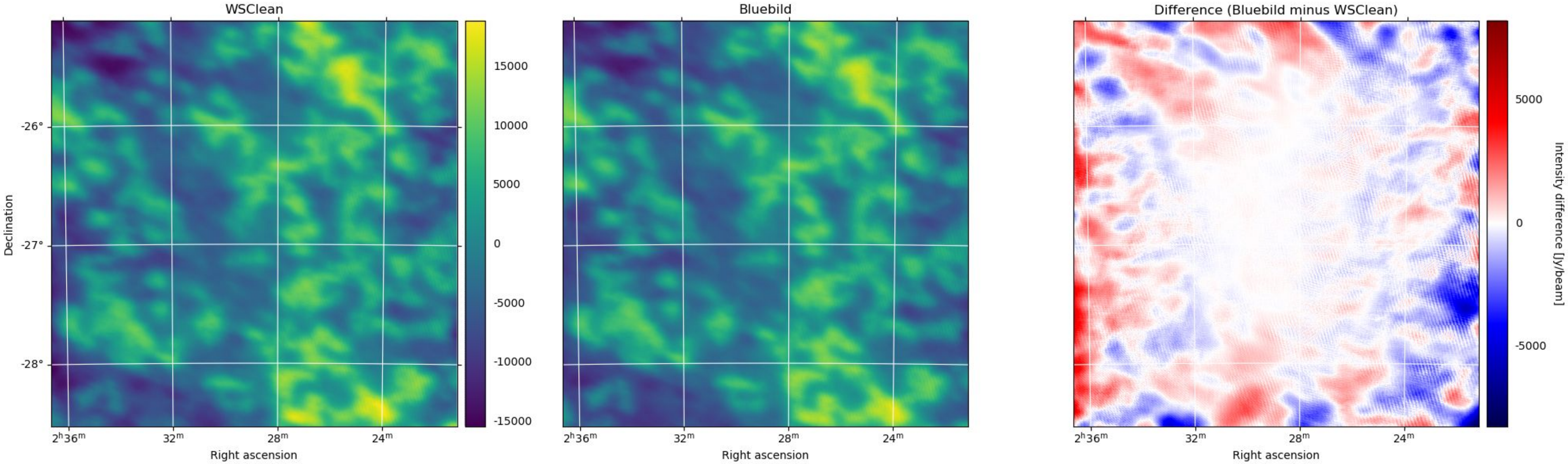


Updates:

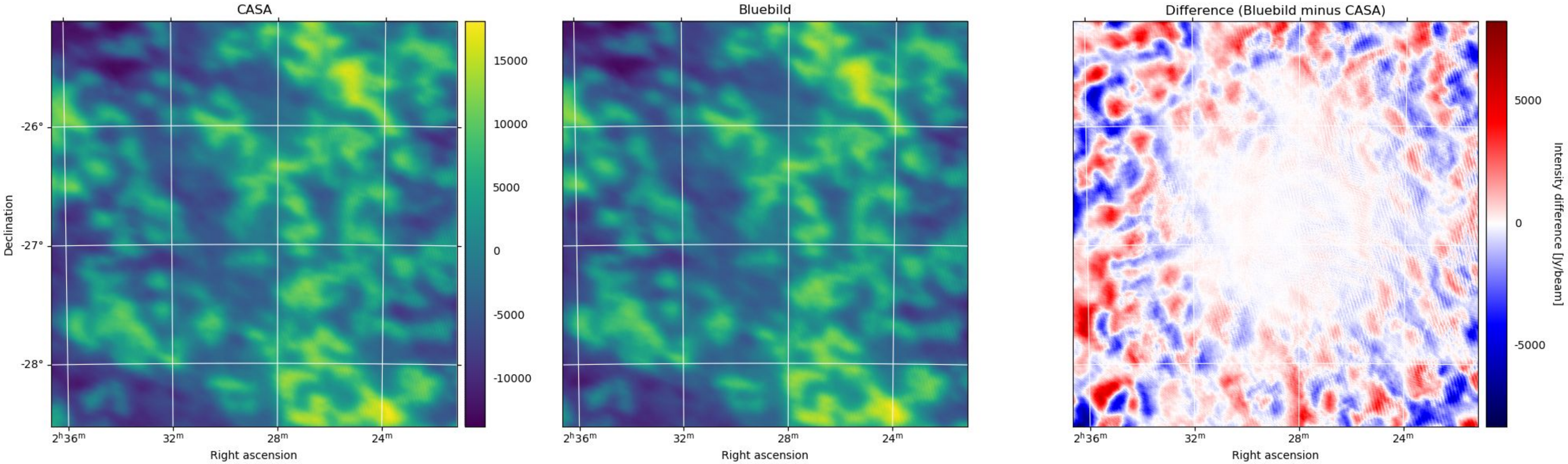
- Normalisation Fix
- BIPP 0.1.0 release + documentation + paper
- Domain partitioning

Normalisation - Plots courtesy of Etienne Orliac

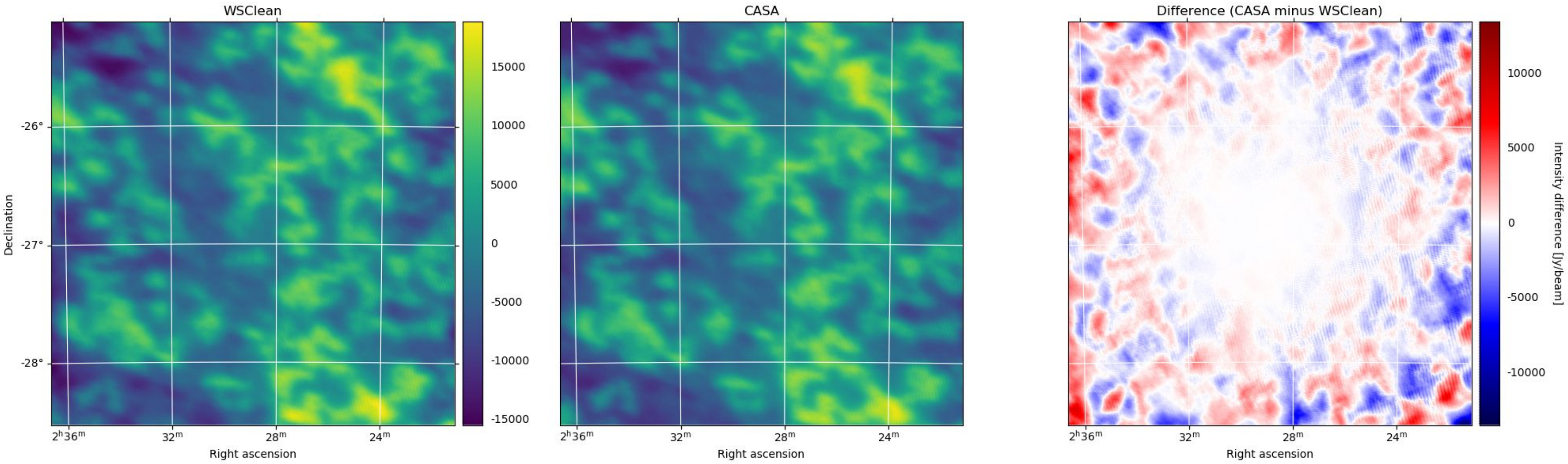
Earlier: Mismatch in flux values when imaged by bluebild v/s WSClean



Normalisation



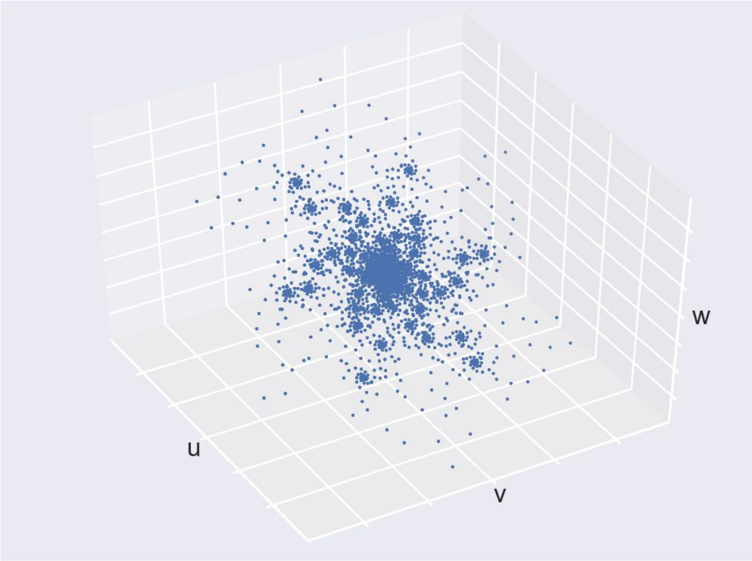
Normalisation

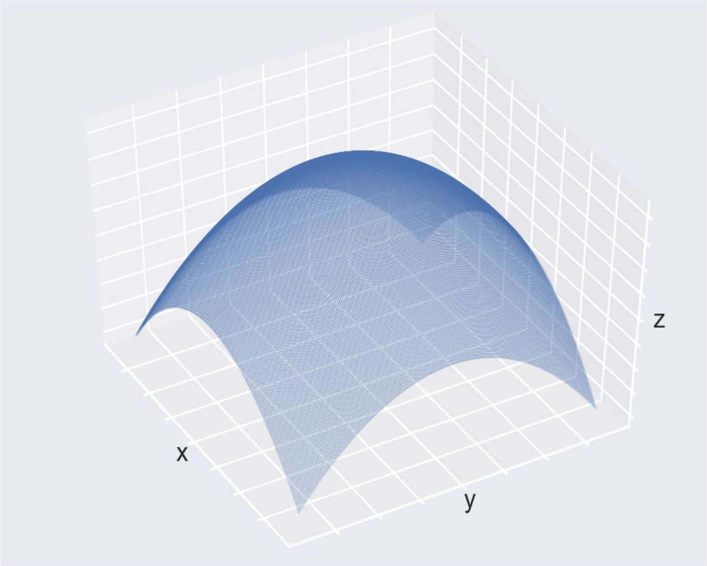


Bluebild Imaging Plus Plus (BIPP)

- C++ ported version with python wrapper for wider community release
- HPC implementation with support for CUDA (NVIDIA) and HIP (AMD)
- Support for LOFAR, MWA, Oskar SKA-Low measurement sets
- Domain partitioning inbuilt
- No deconvolution
- Github: https://github.com/epfl-radio-astro/bipp

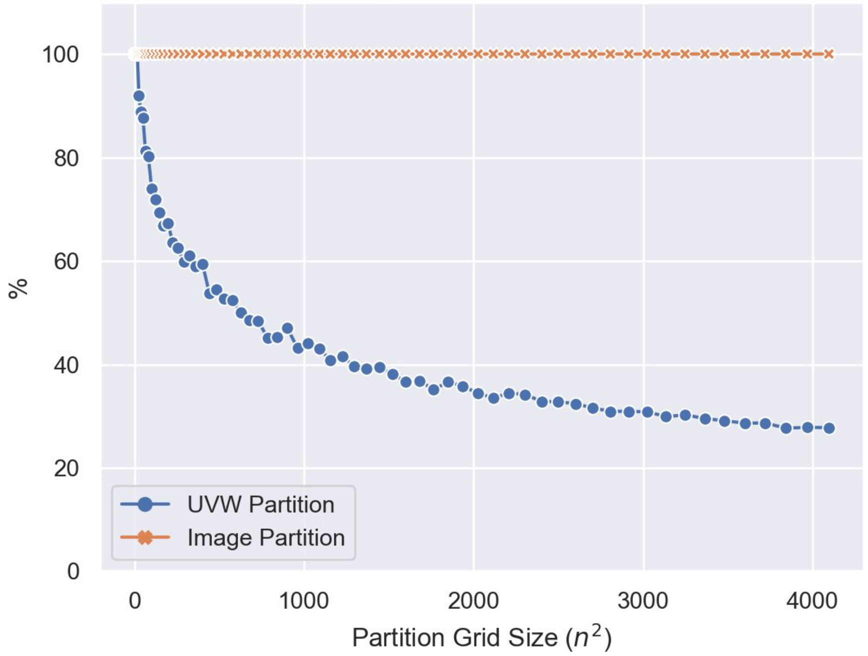
NuFFT Domain Partitioning - Inspired by HVOX[1]
Plots courtesy Simon Frasch

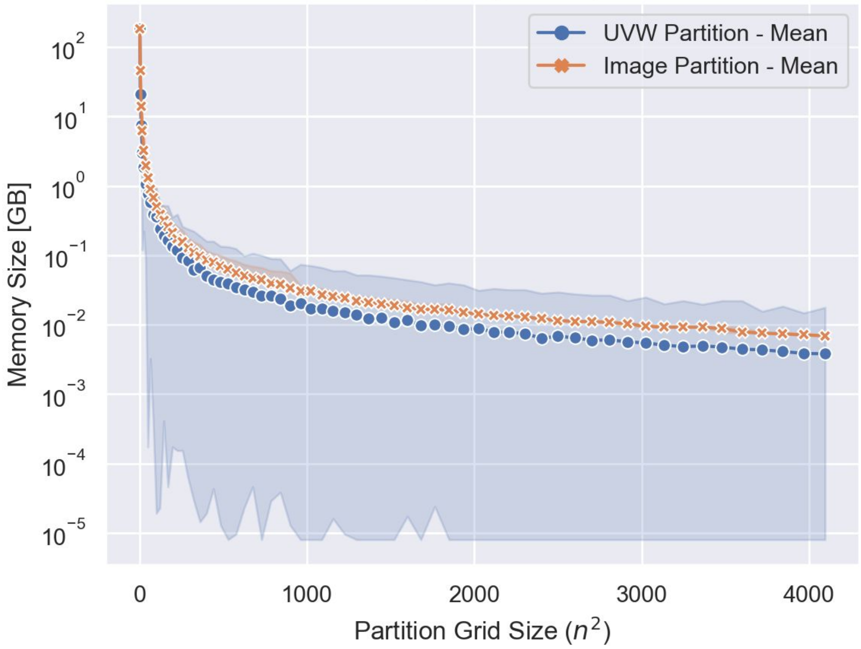




[1] [Kashani, Queralt, Jarret and Simeoni 2023]

$$\tilde{B}_{pix} = \sum_{n=1}^{N_1} V'_n e^{ix'_{pix}\dot{b}'_n} + \ldots + \sum_{n=N_{I-1}+1}^{N_I} V'_n e^{ix'_{pix}\dot{b}'_n}$$


Percentage of Non-Zero Sized FFTs


FFT Grid Memory Usage in Single Precision

Ongoing and Future Work:

- WSClean benchmarking
- LOFAR LoTSS data imaging
- A-Term Correction (Primary Beam) for dish arrays
- Eigen-image recombination
- SDC3A fPCA
- Radler (Radio Astronomical Deconvolution Library) incorportaion