

Bayesian Radio Interferometric Imaging

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Radio Interferometry

https://de.wikipedia.org/wiki/Very_Large_Array



V_1

V_2

$$V_{i12} = \langle V_1 V_2^* \rangle$$

Radio Interferometry

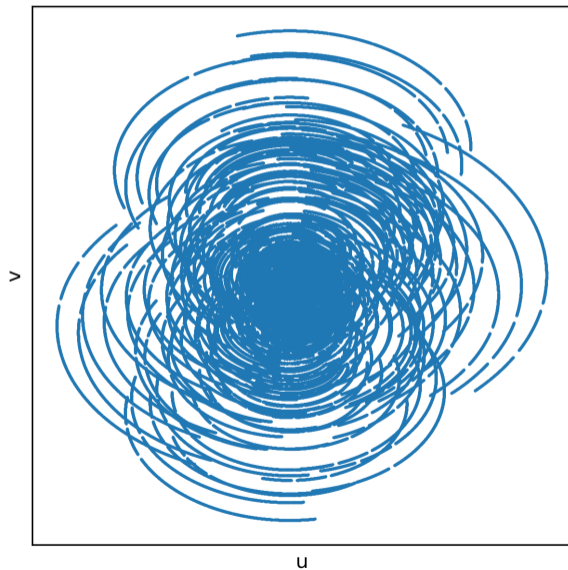


Measurement Equation:

$$vis_{pqt} = \int \frac{dldm}{n(l, m)} G_p(l, m, t) S(l, m) G_q^*(l, m, t) e^{-ik \cdot x} + n$$

- Sky brightness: S
- Antenna gain: G
- Visibilities: vis
- Noise: n

Radio Interferometry



Inverse Problem – Bayes' Theorem

Probabilistic solution: $P(I, G|vis)$

- Likelihood $P(vis|I, G)$: Evaluate measurement equation
- Prior $P(I, G|vis)$: Encode assumptions

Bayes' theorem

$$P(I, G|vis) = \frac{P(vis|I, G)P(I, G)}{P(vis)}$$

Resolve:

- Framework for bayesian imaging and calibration
- Open source: <https://gitlab.mpcdf.mpg.de/ift/resolve>

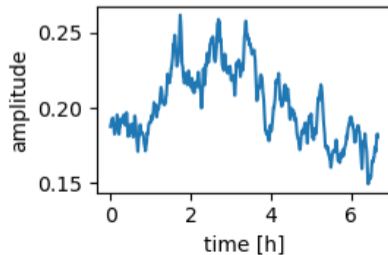
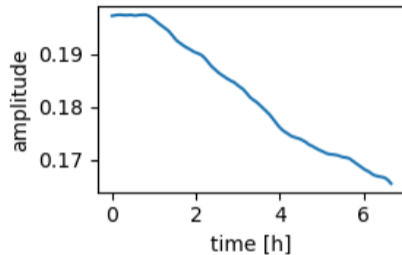
Bayesian Imaging and Calibration

Assumptions:

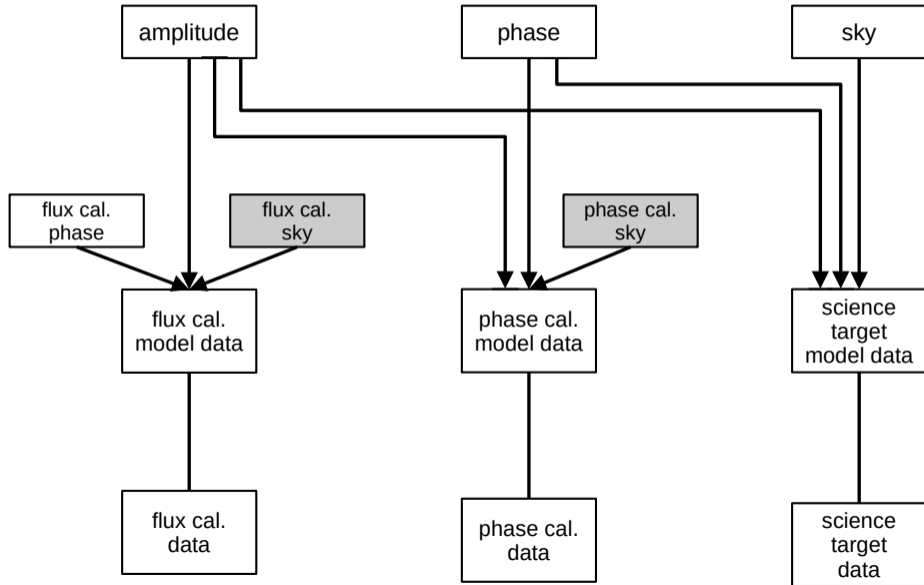
- I , G smooth functions
- Self adaptive degree of smoothness
- Positivity of sky brightness

Two stage calibration:

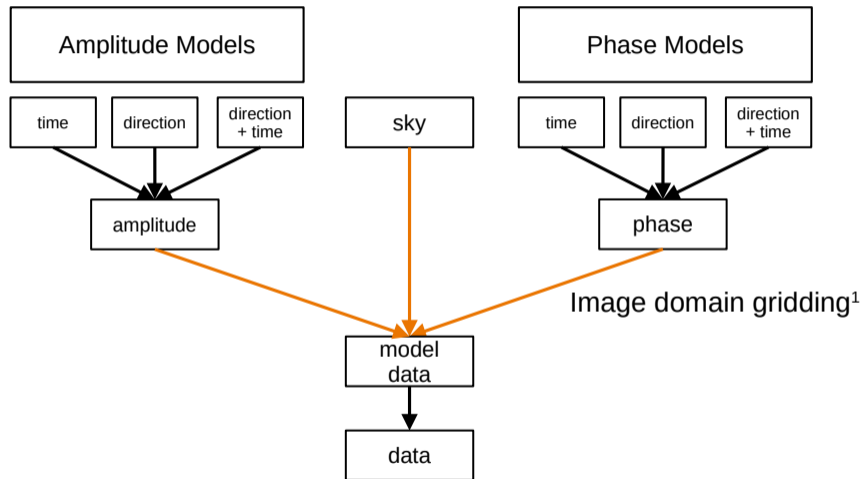
1. Direction independent calibration
2. Include direction dependents



Direction Independent Calibration and Imaging Forward Model



Direction Dependent Calibration and Imaging Forward Model



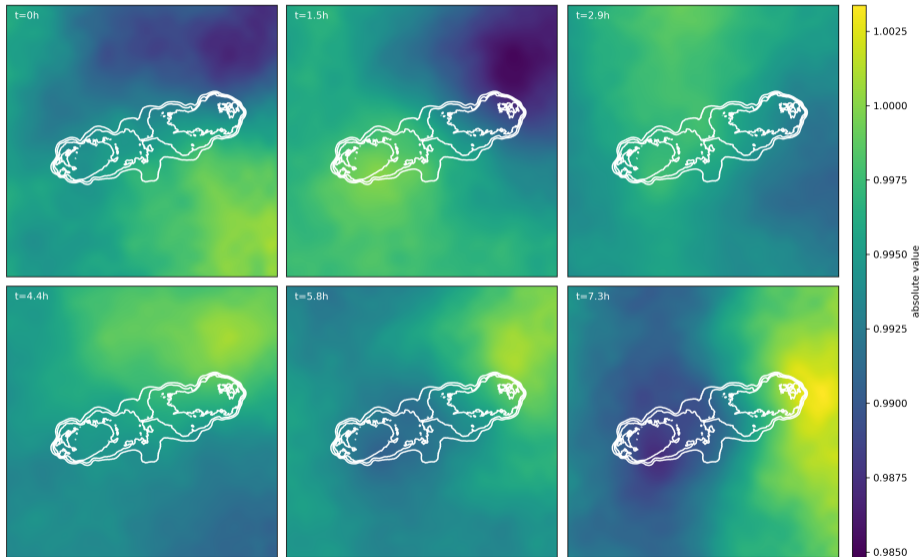
¹Sebastiaan van der Tol, Bram Veenboer, and André R. Offringa. "Image Domain Gridding: a fast method for convolutional resampling of visibilities". In: *A&A* 616, A27 (Aug. 2018), A27.

Application to VLA Data

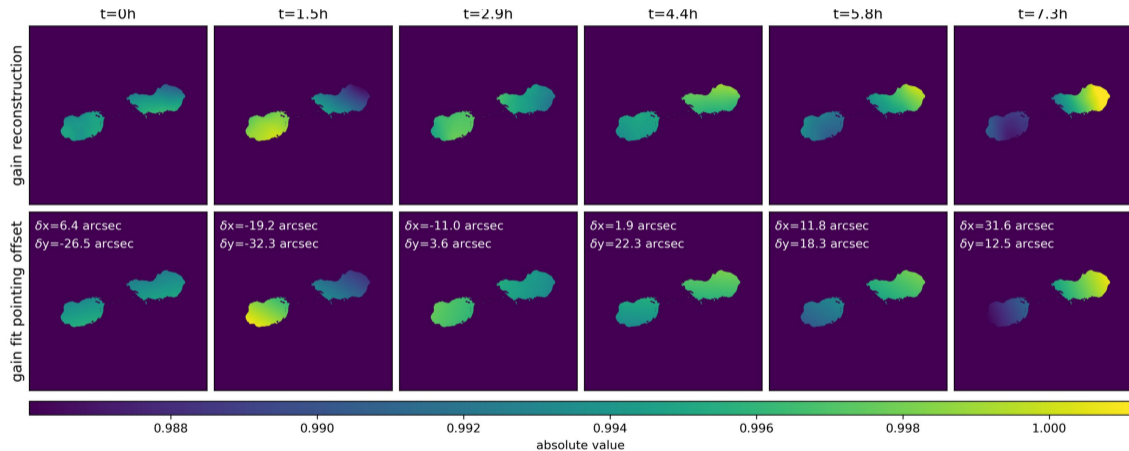
Test data set:

- VLA Data of Cygnus A at 2.05 Ghz
- All 4 VLA configurations
- in total \approx 1 million data points

Direction and Time Dependent Calibration



Direction and Time Dependent Calibration – Pointing Errors



Comparison

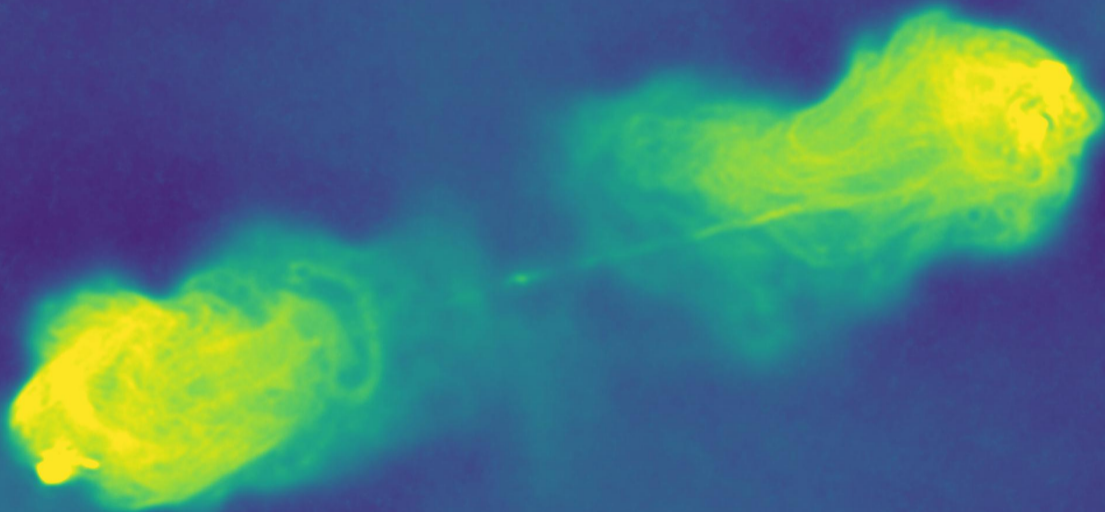
Comparison on VLA 2.05 GHz Data of Cygnus A:

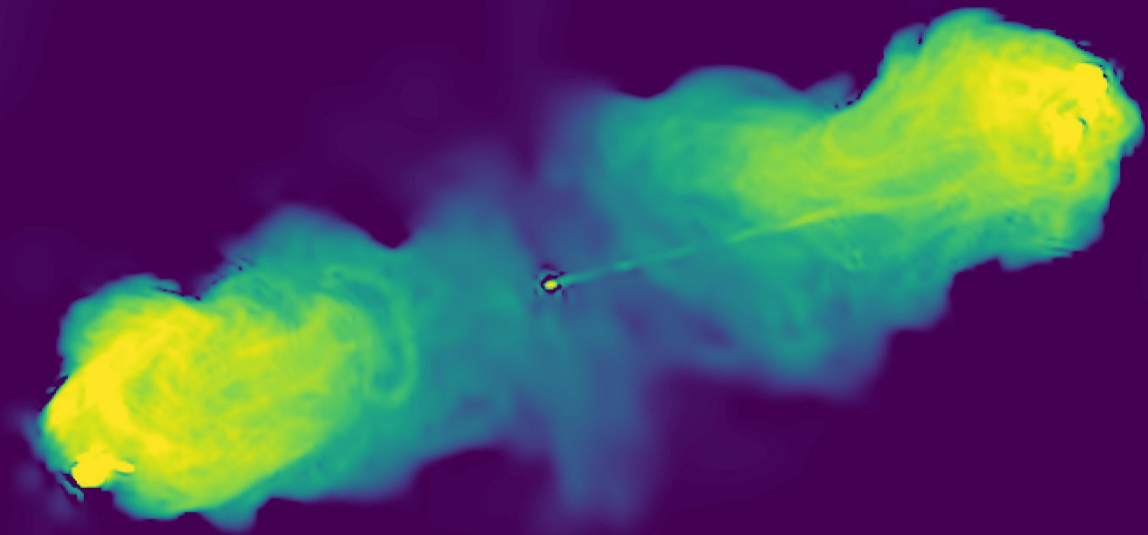
- This method²
- Arras et al. 2021³:
 - Bayesian Imaging with `resolve`
 - Classically calibrated data
- Dabbech et al. 2021⁴:
 - Compressed sensing method
 - Joint calibration and imaging via non-convex optimization
 - Calibration includes direction dependents

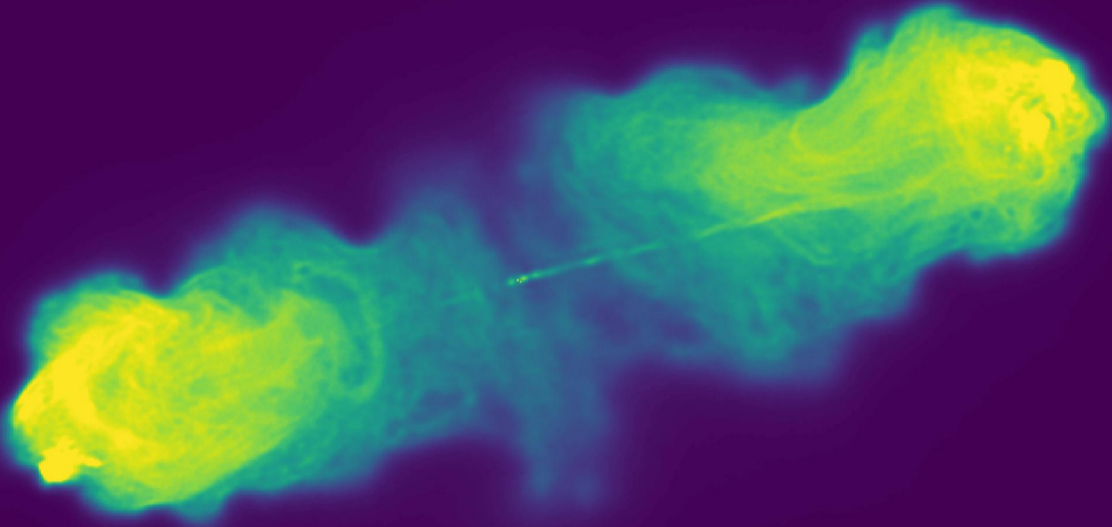
²Jakob Roth et al. “Bayesian radio interferometric imaging with direction-dependent calibration”. In: *A&A* 678, A177 (Oct. 2023), A177. DOI: 10.1051/0004-6361/202346851. arXiv: 2305.05489 [astro-ph.IM].

³P. Arras et al. “Comparison of classical and Bayesian imaging in radio interferometry. Cygnus A with CLEAN and resolve”. In: *A&A* 646, A84 (Feb. 2021), A84.

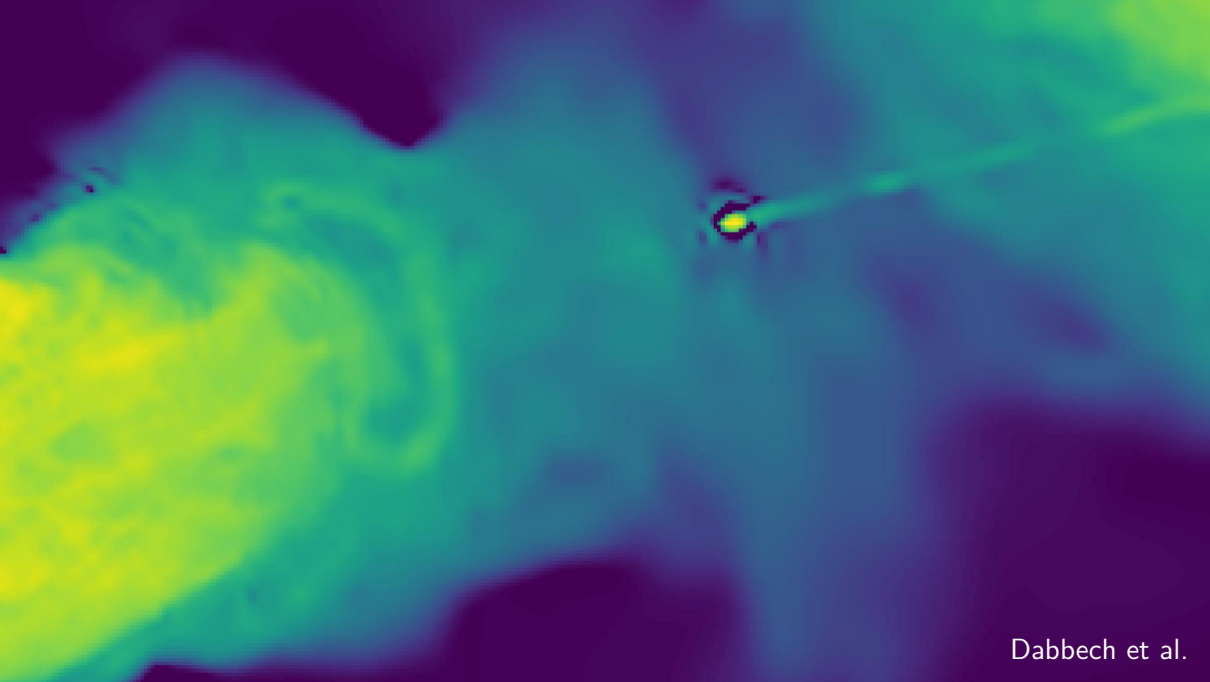
⁴A. Dabbech et al. “Cygnus A jointly calibrated and imaged via non-convex optimization from VLA data”. In: *MNRAS* 506.4 (Oct. 2021), pp. 4855–4876.

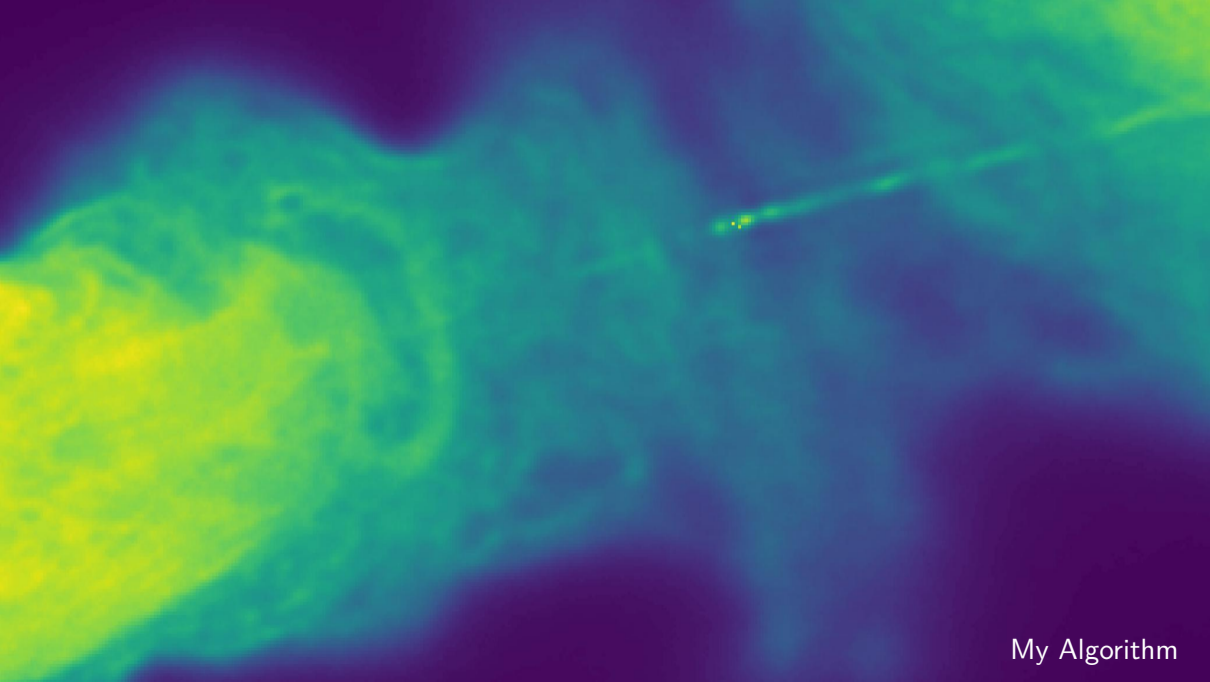




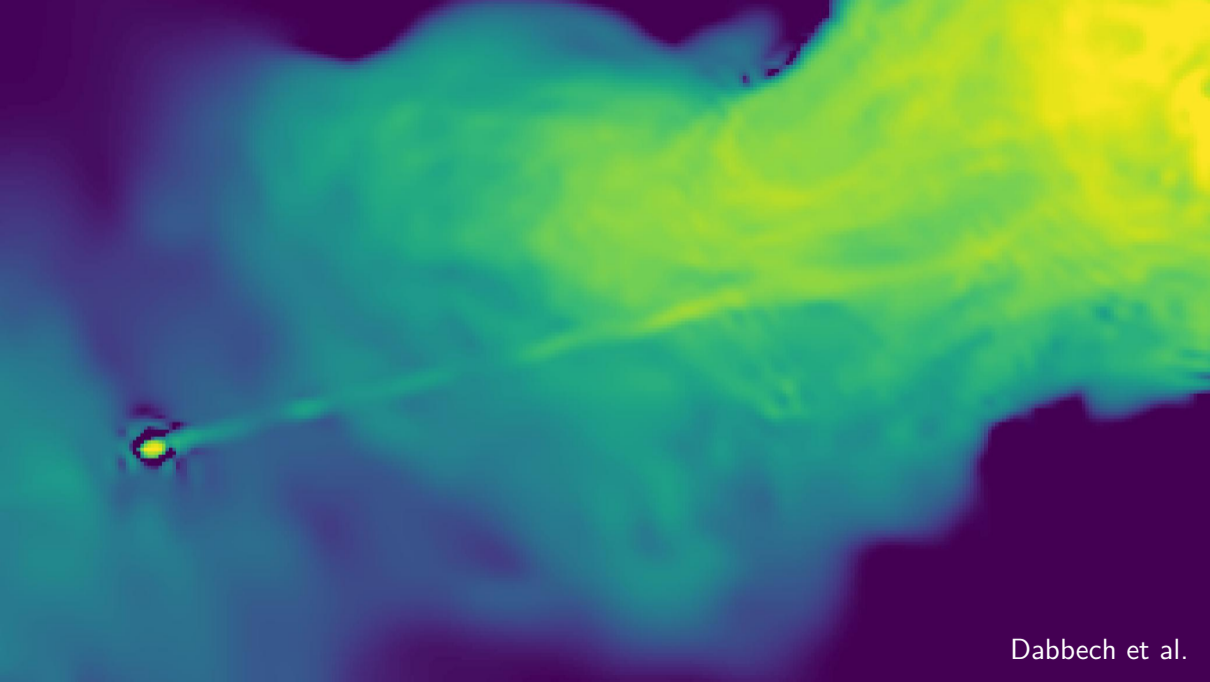


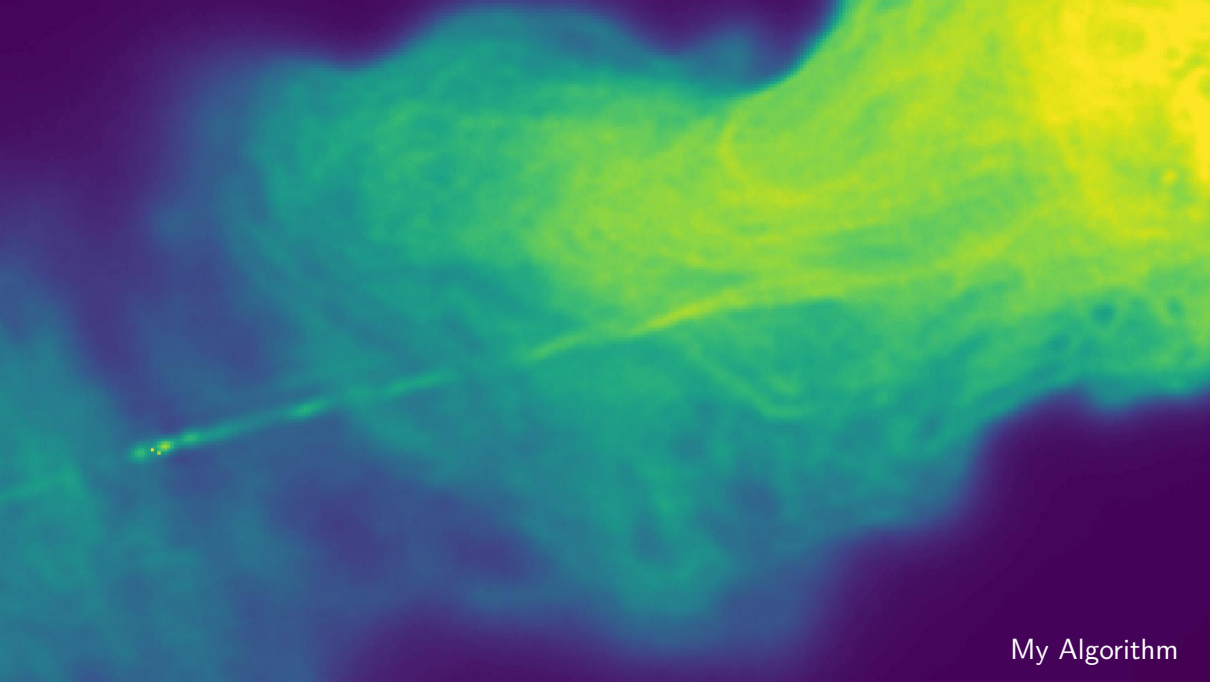
My Algorithm



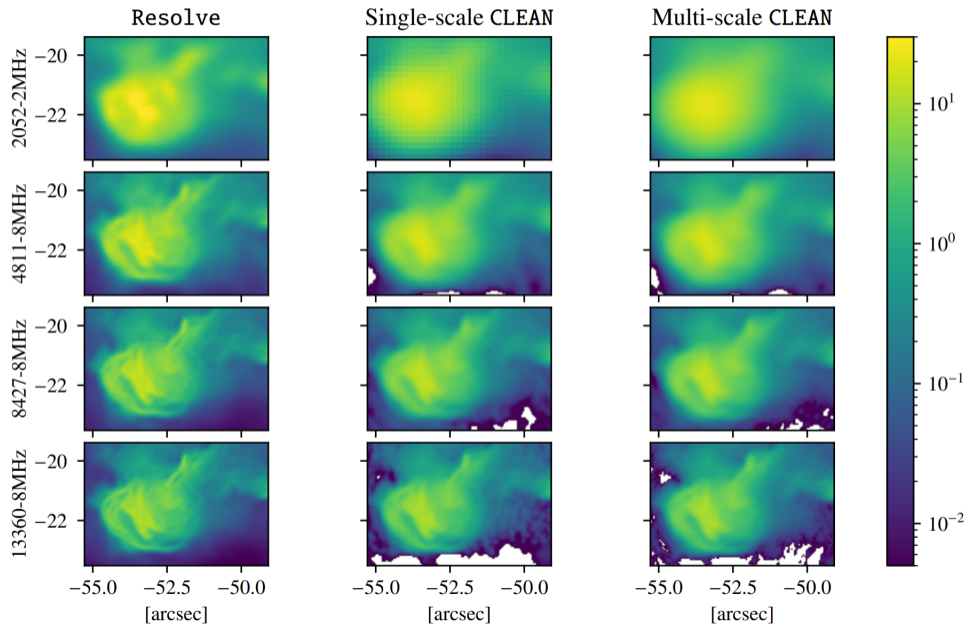


My Algorithm



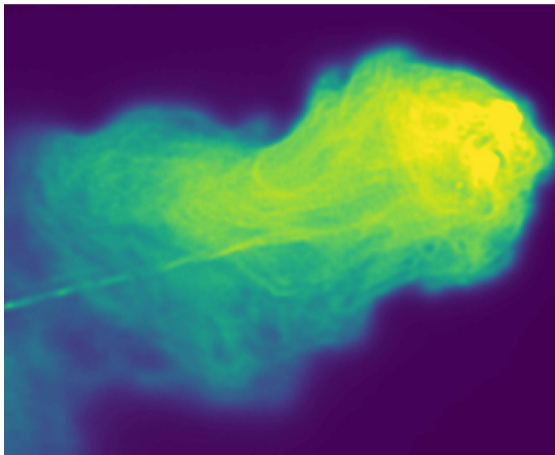


My Algorithm



Summary

- RESOLVE: Radio interferometric imaging with NIFTy
- Joint calibration and imaging
- Direction dependent calibration
- Significant improvement compared to previous work
- Accurate calibration including DDE essential for
 - high resolution
 - high dynamic range
- Currently very high computational costs (compared to CLEAN)



- [1] Sebastiaan van der Tol, Bram Veenboer, and André R. Offringa. “Image Domain Gridding: a fast method for convolutional resampling of visibilities”. In: *A&A* 616, A27 (Aug. 2018), A27.
- [2] Jakob Roth et al. “Bayesian radio interferometric imaging with direction-dependent calibration”. In: *A&A* 678, A177 (Oct. 2023), A177. DOI: [10.1051/0004-6361/202346851](https://doi.org/10.1051/0004-6361/202346851). arXiv: 2305.05489 [astro-ph.IM].
- [3] P. Arras et al. “Comparison of classical and Bayesian imaging in radio interferometry. Cygnus A with CLEAN and resolve”. In: *A&A* 646, A84 (Feb. 2021), A84.
- [4] A. Dabbech et al. “Cygnus A jointly calibrated and imaged via non-convex optimization from VLA data”. In: *MNRAS* 506.4 (Oct. 2021), pp. 4855–4876.