Bayesian Radio Interferometric Imaging

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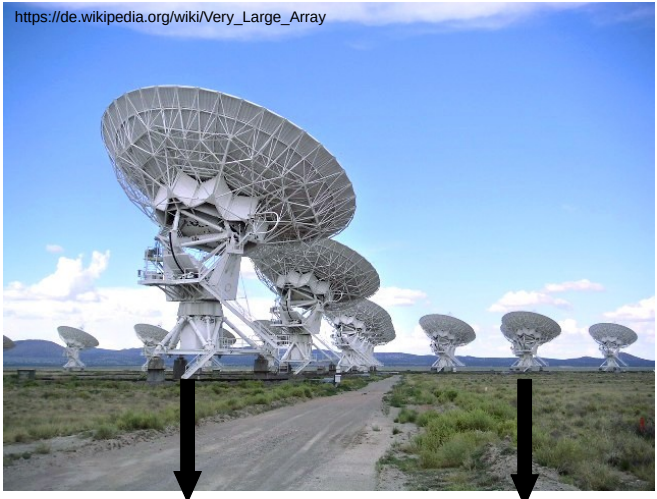
Radio Interferometry



$$Vis_{12} = \langle v_1 v_2^* \rangle$$

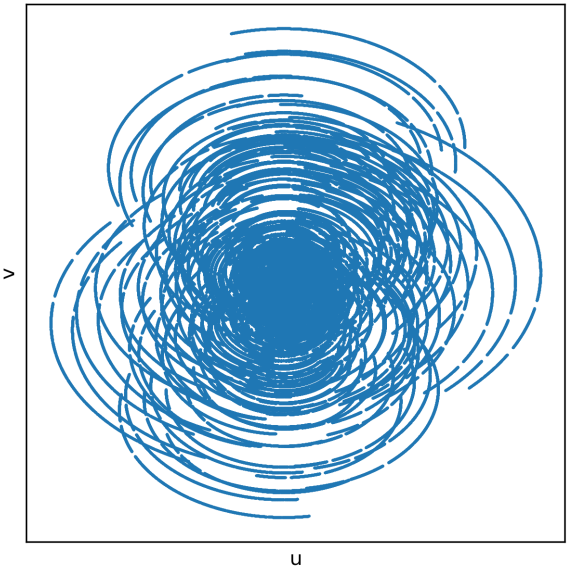
Radio Interferometry

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`

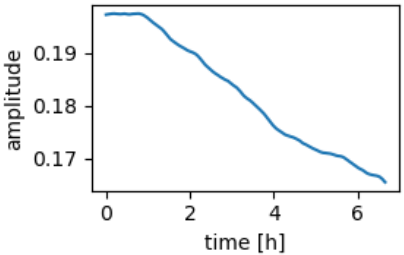
Bayesian Imaging and Calibration

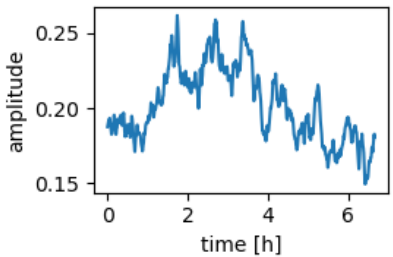
Assumptions:

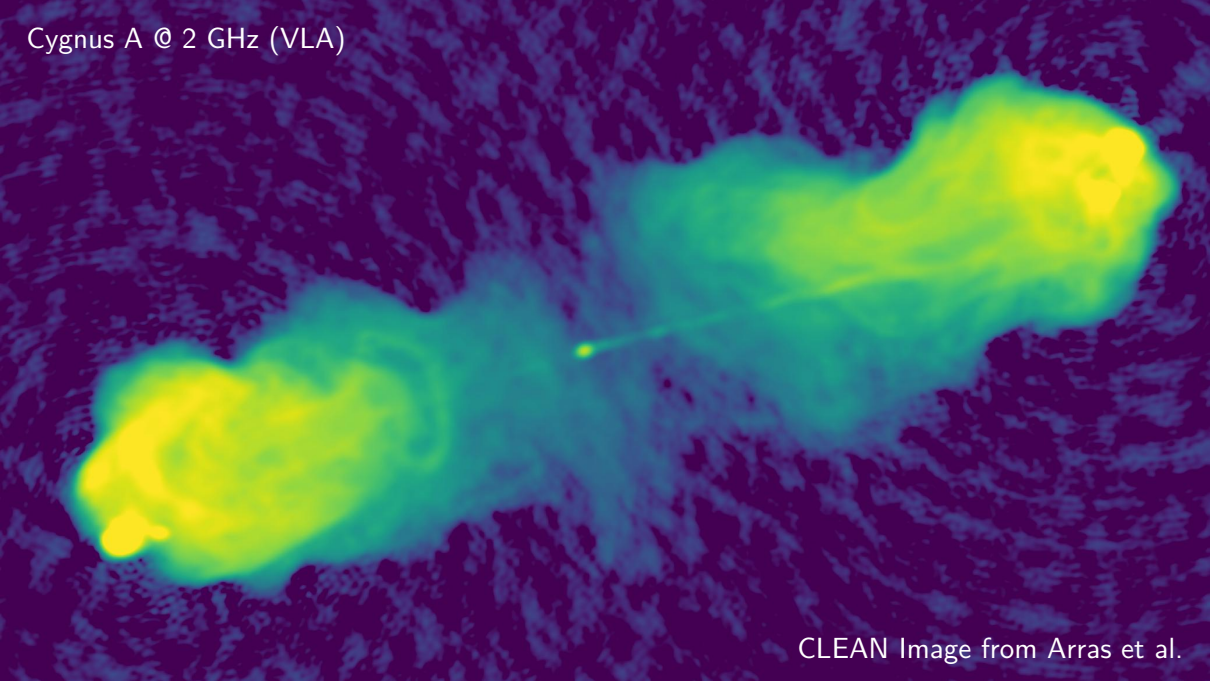
- I, G smooth functions
- Self adaptive degree of smoothness
- Positivity of sky brightness

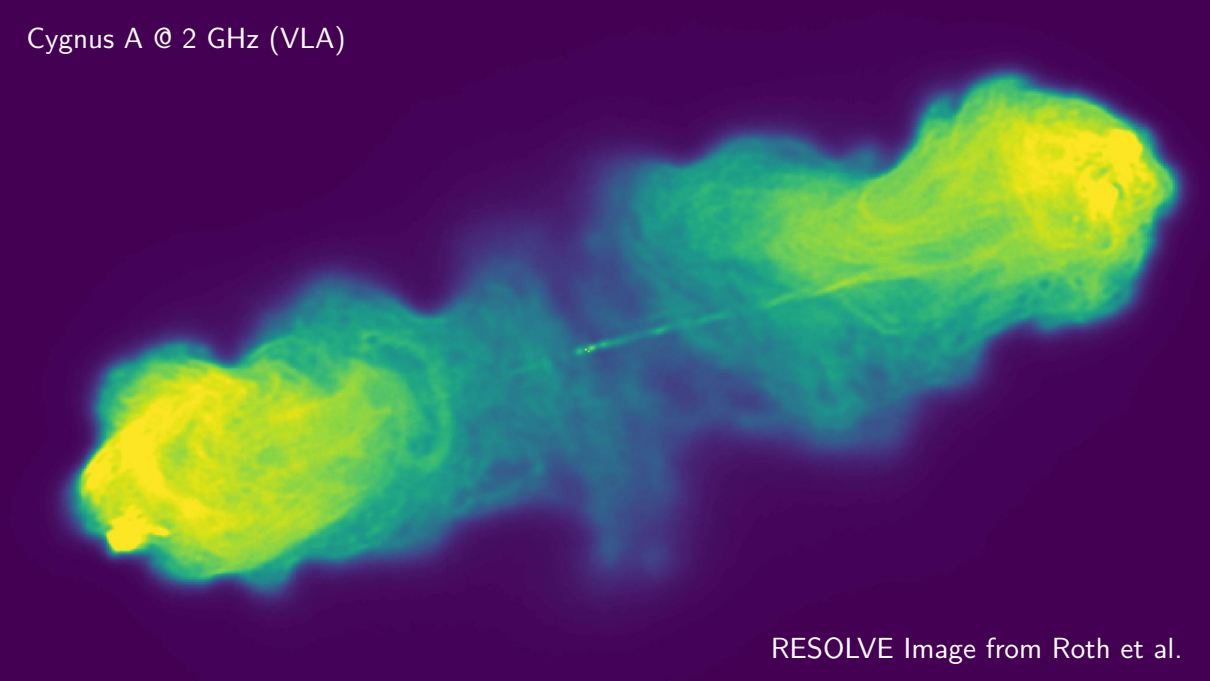
Two stage calibration:

1. Direction independent calibration
2. Include direction dependents

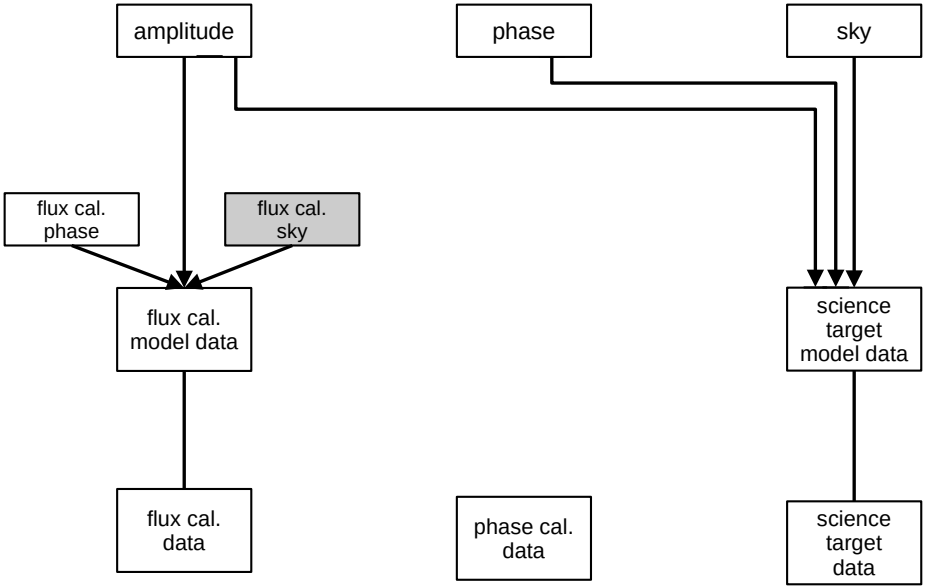




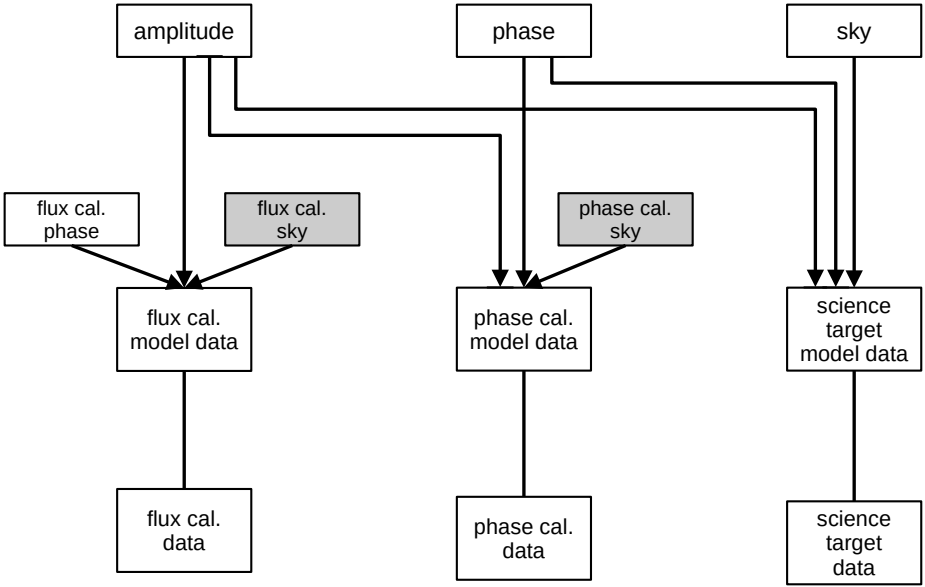

Cygnus A @ 2 GHz (VLA)
CLEAN Image from Arras et al.


Cygnus A @ 2 GHz (VLA)
RESOLVE Image from Roth et al.

Direction Independent Calibration and Imaging Forward Model



Direction Independent Calibration and Imaging Forward Model



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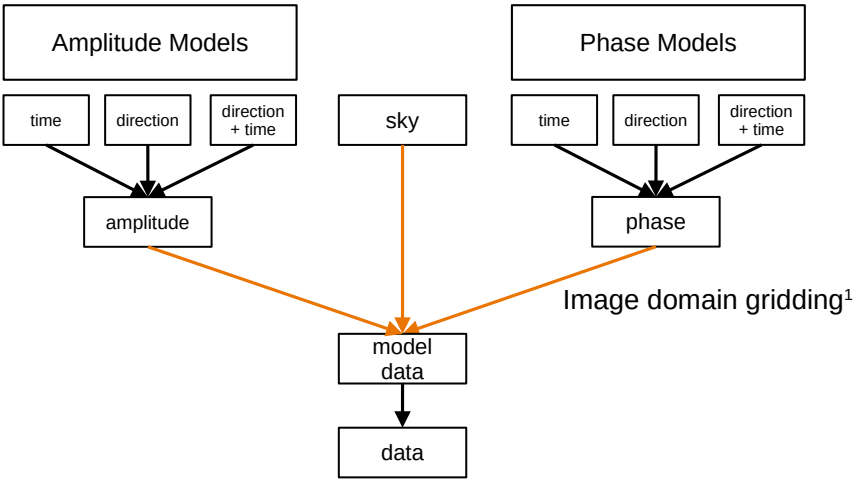


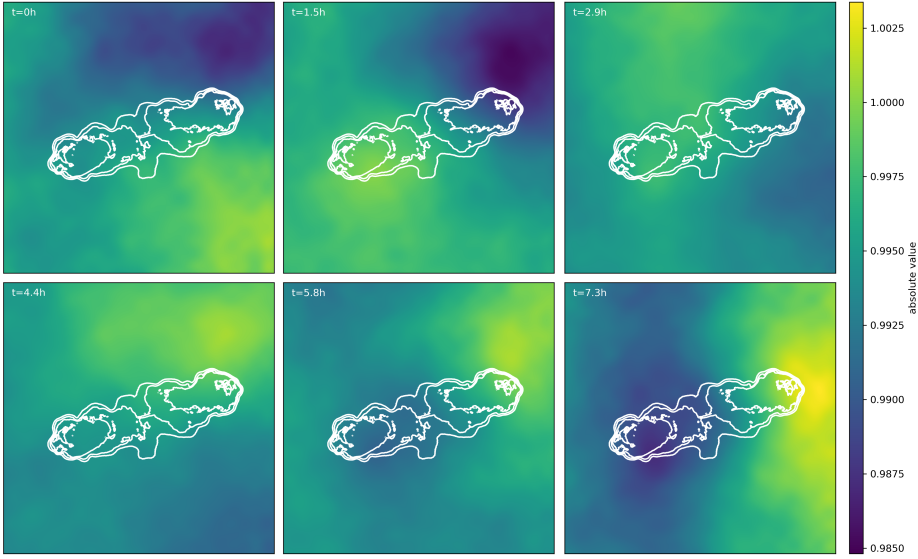
[1] Sebastiaan van der Tol, Bram Veenboer, and André R. Offringa. "Image Domain Gridding: a fast method for convolutional resampling of visibilities". In: *A&A* 616, A27 (Aug. 2018), A27.

Application to VLA Data

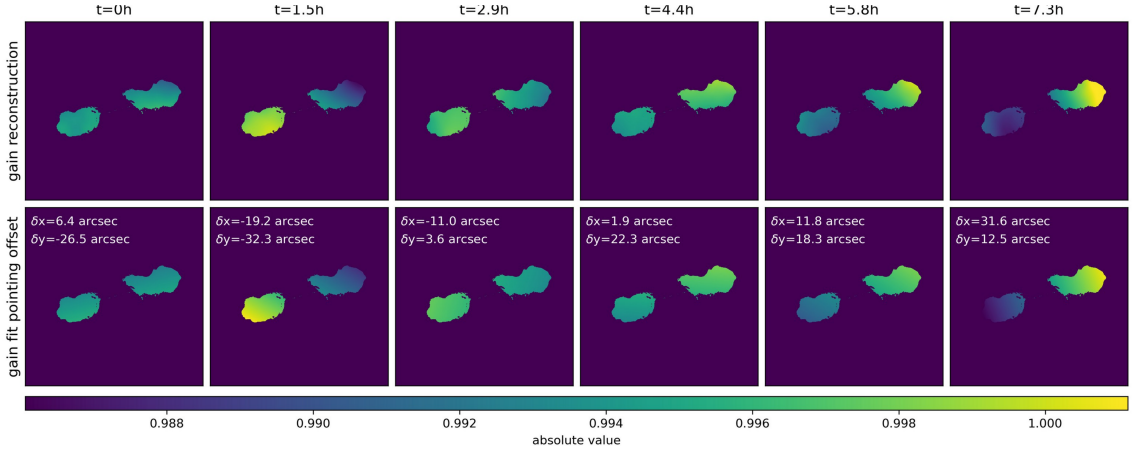
Test data set:

- 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 Erros



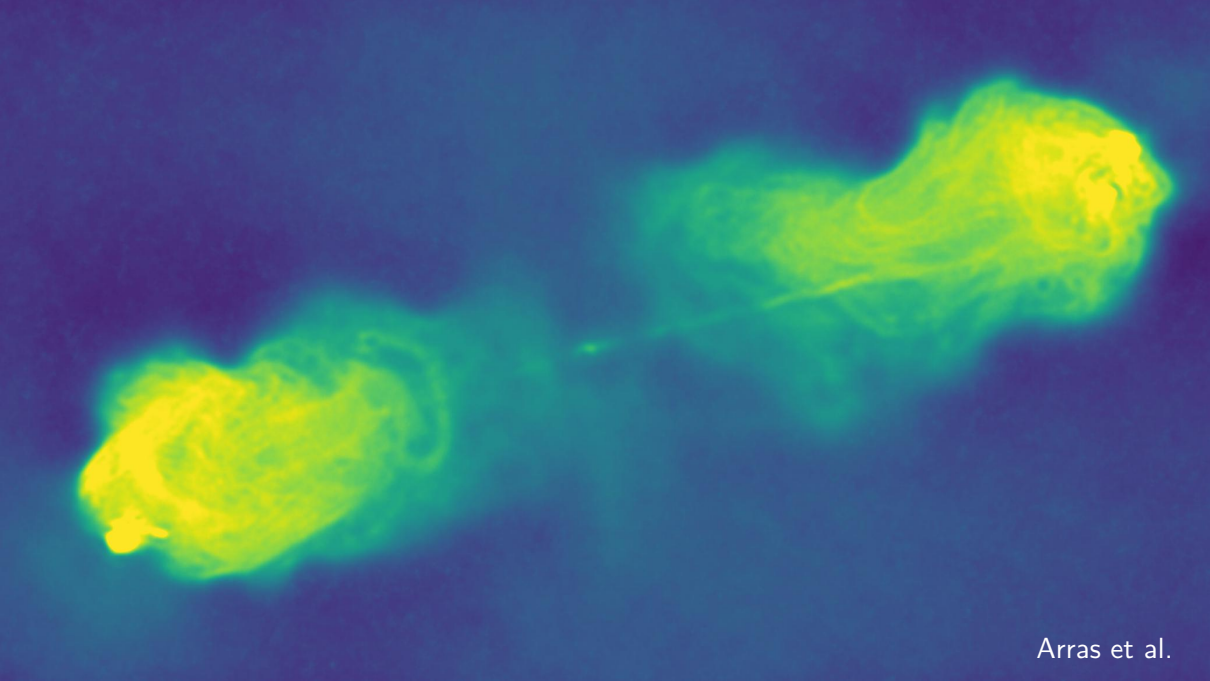
Comparison

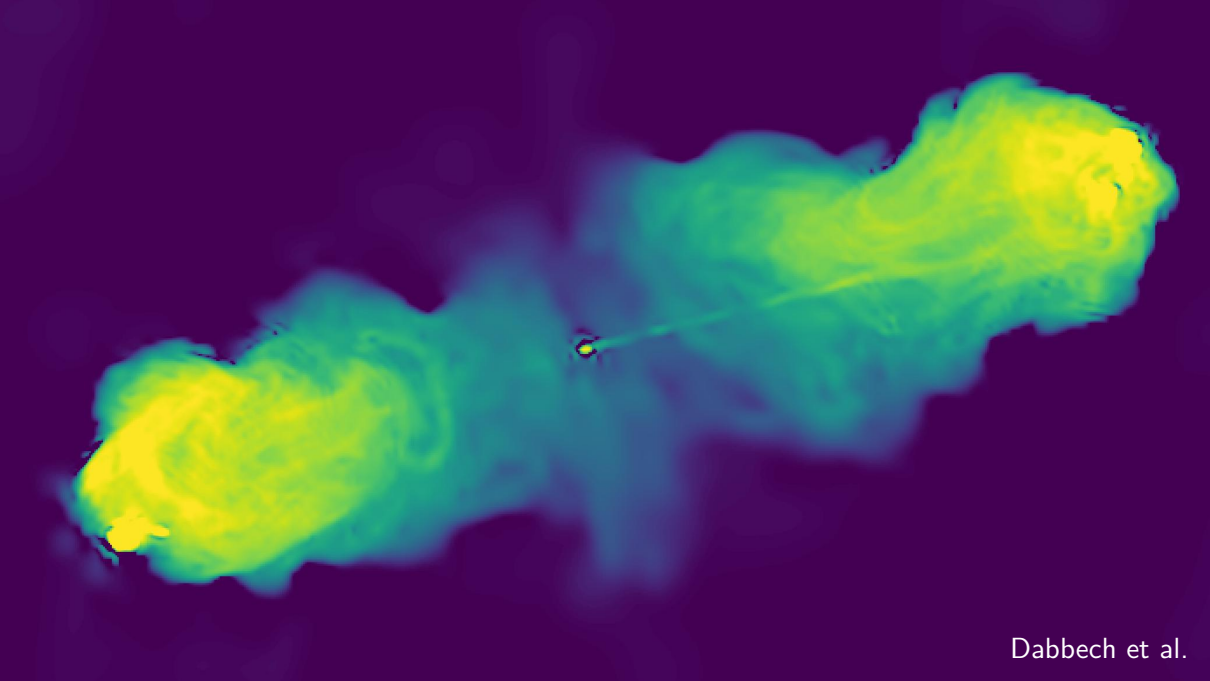
Comparison on VLA 2.05 GHz Data of Cygnus A:

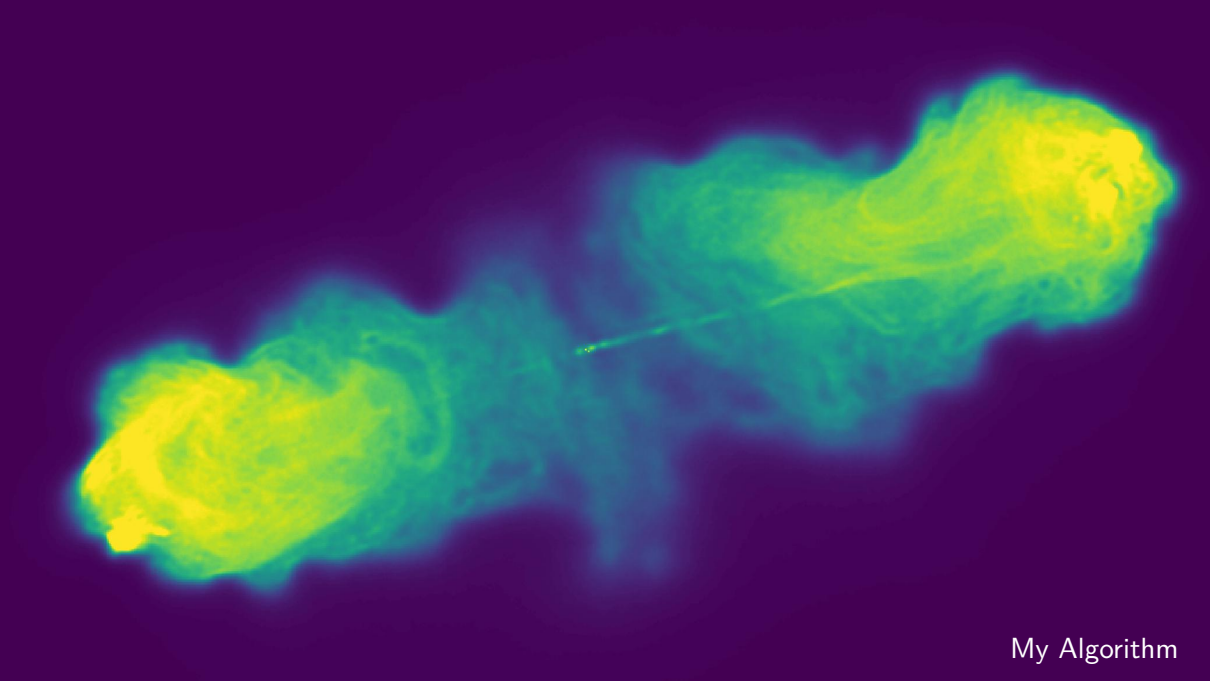
- Arras et al. 2021[2]:
  - Bayesian Imaging with `resolve`
  - Classically calibrated data
- Dabbech et al. 2021[3]:
  - Compressed sensing method
  - Joint calibration and imaging via non-convex optimization
  - Calibration includes direction dependents

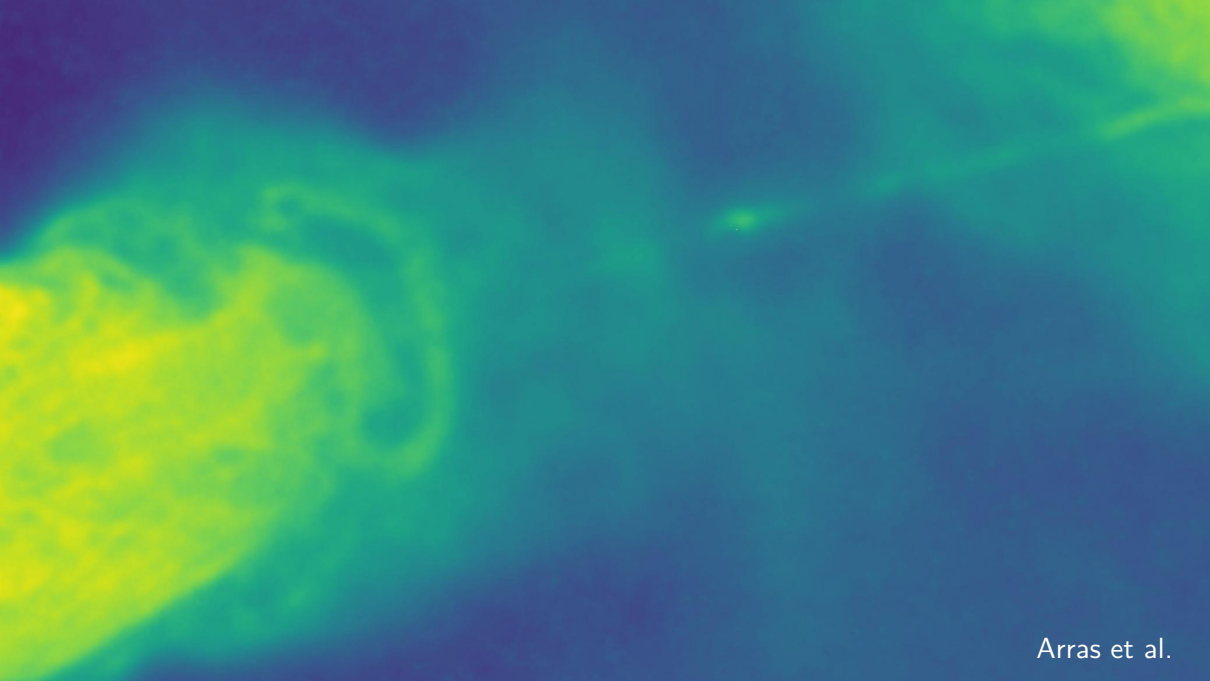
[2] P. Arras et al. "Comparison of classical and Bayesian imaging in radio interferometry. Cygnus A with CLEAN and resolve". In: *A&A* 646, A84 (Feb. 2021), A84.

[3] 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.


Arras et al.


Dabbech et al.


My Algorithm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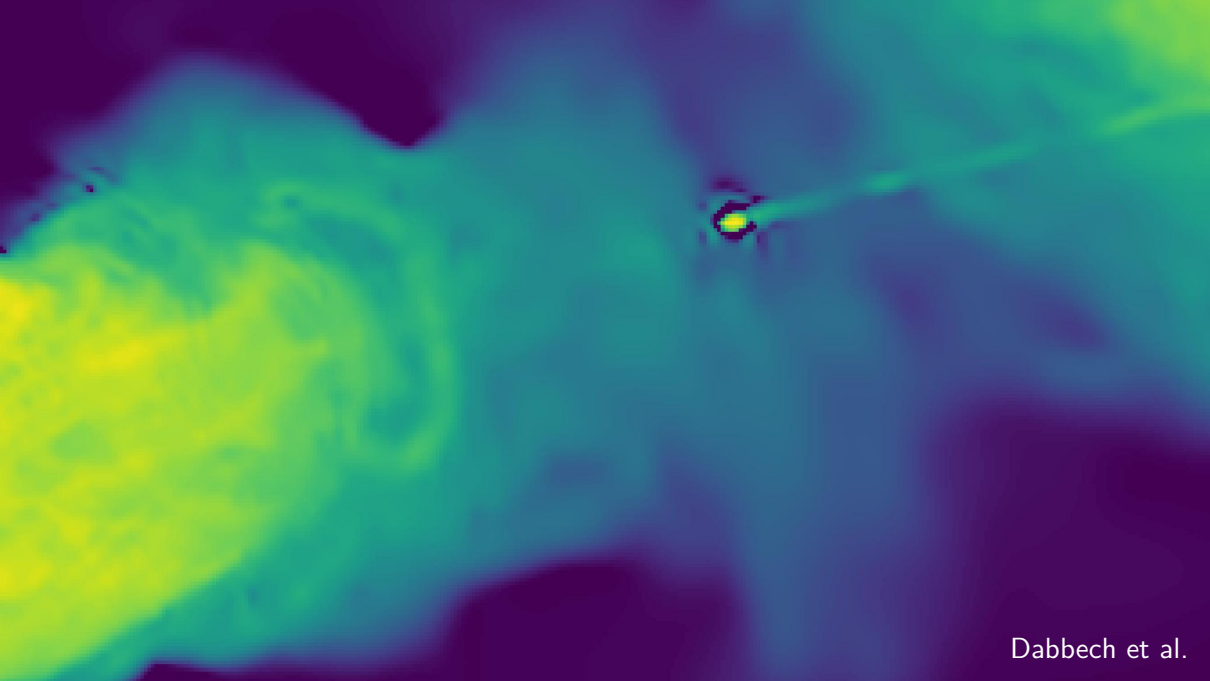
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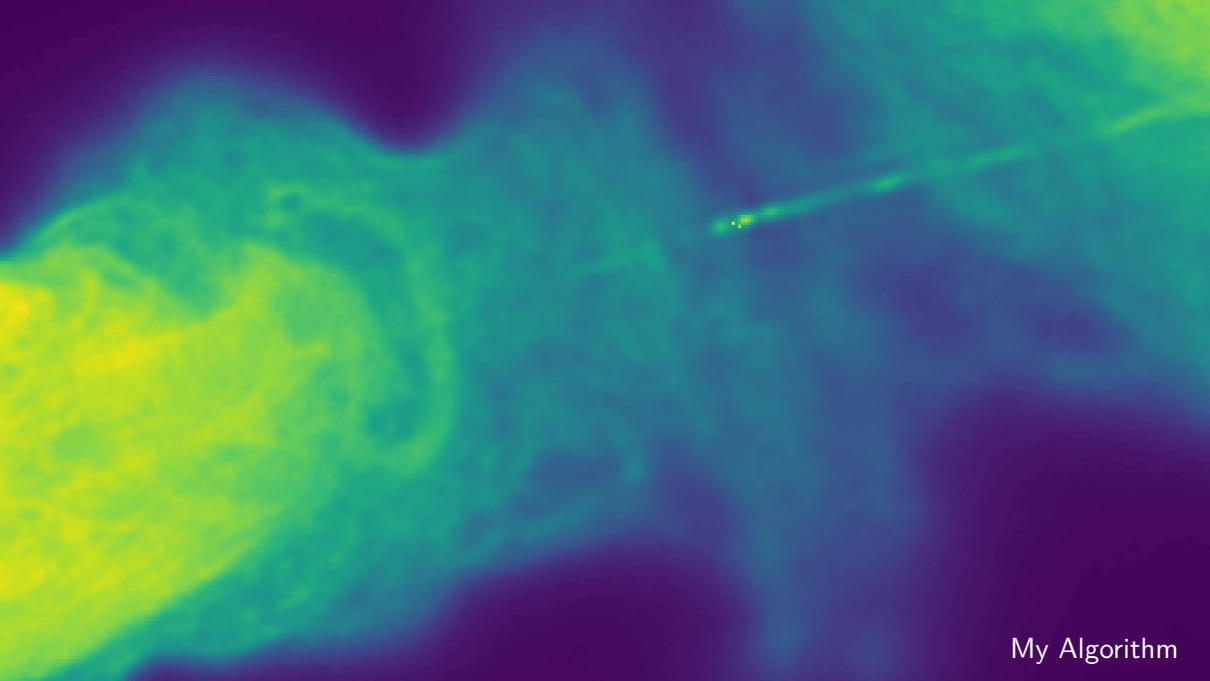
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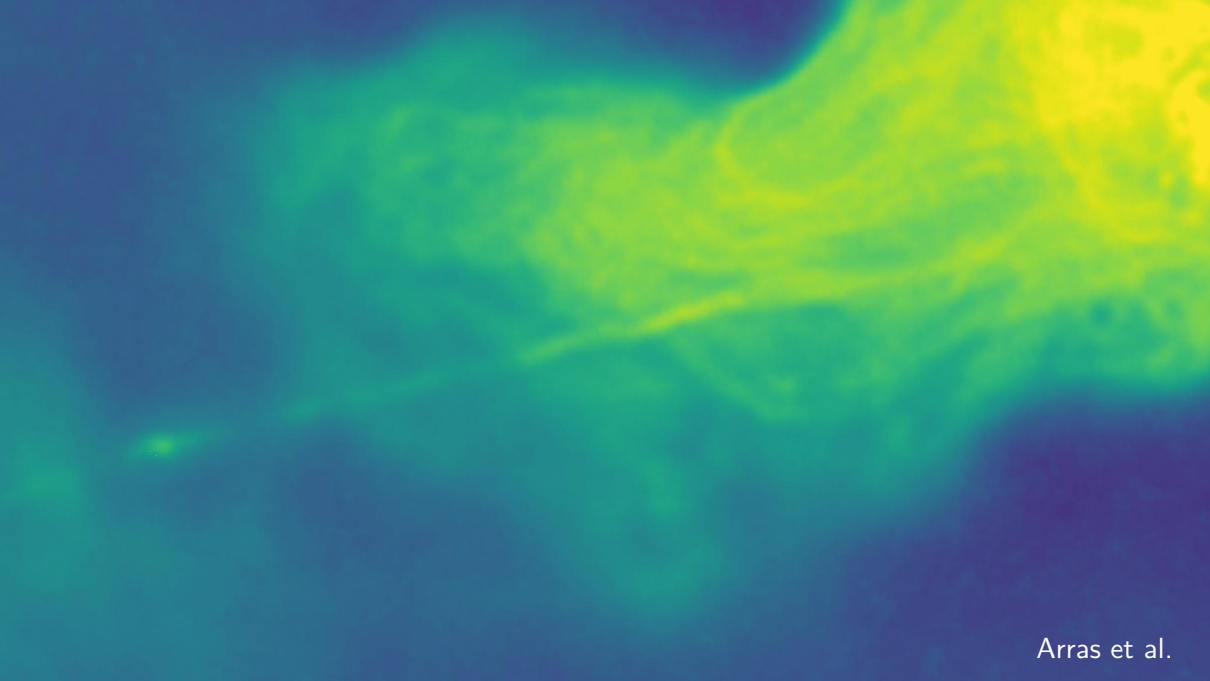
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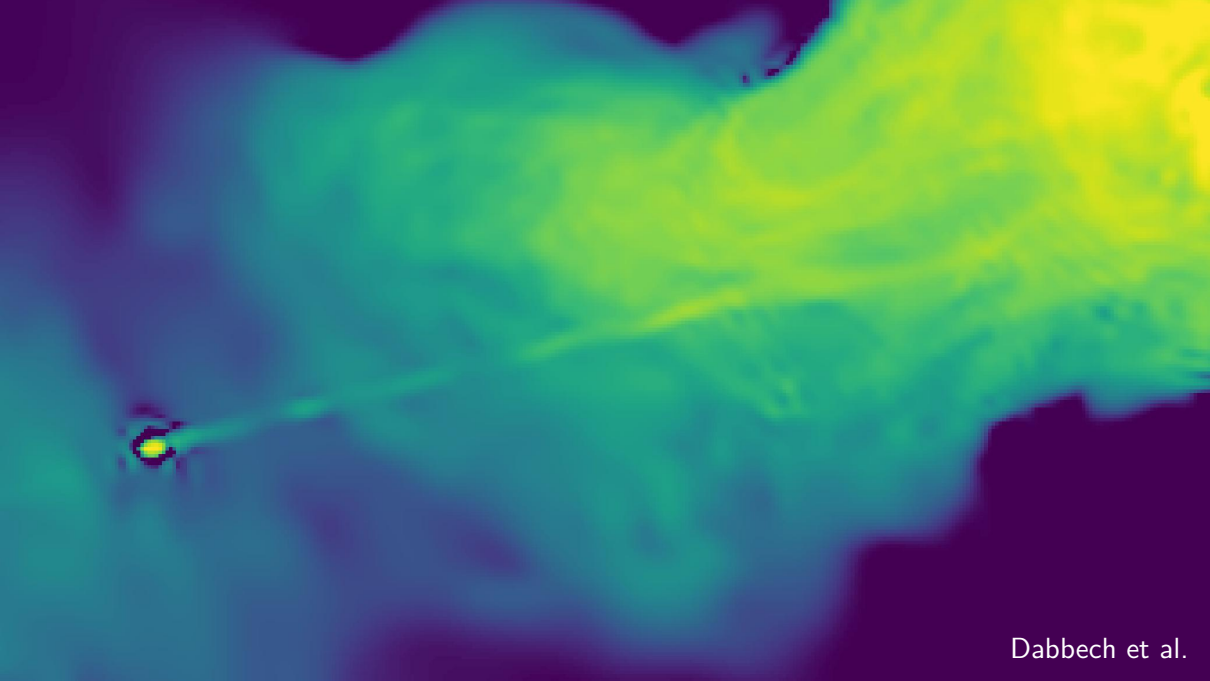
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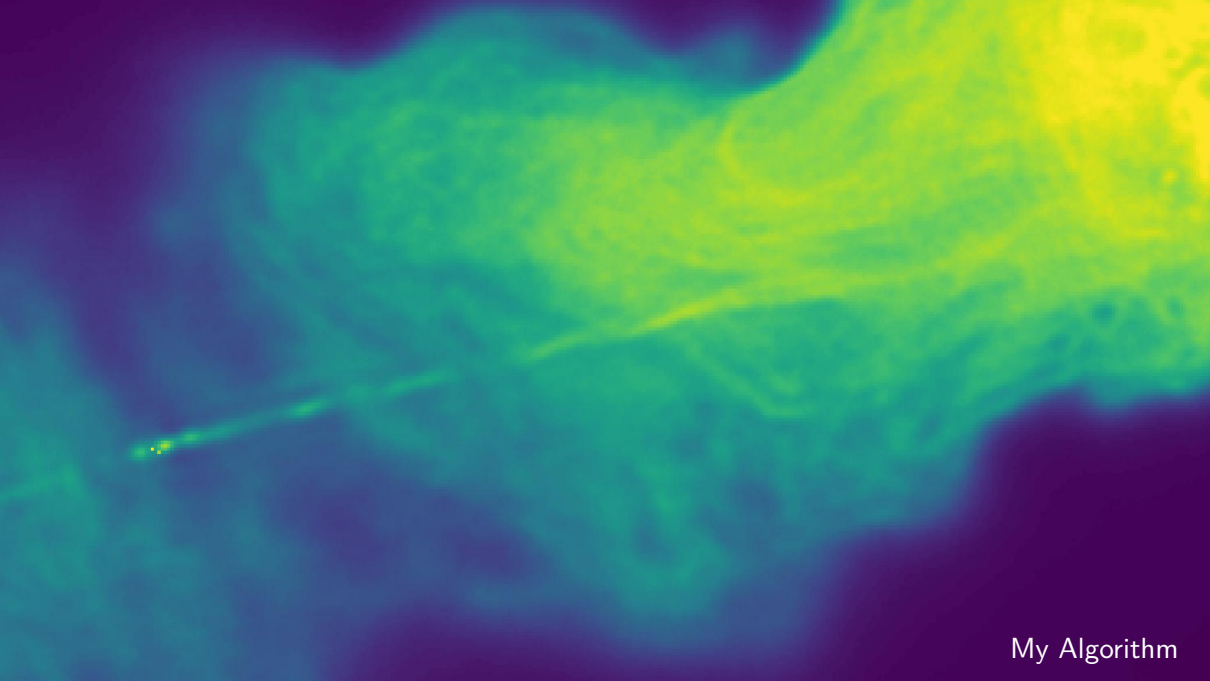
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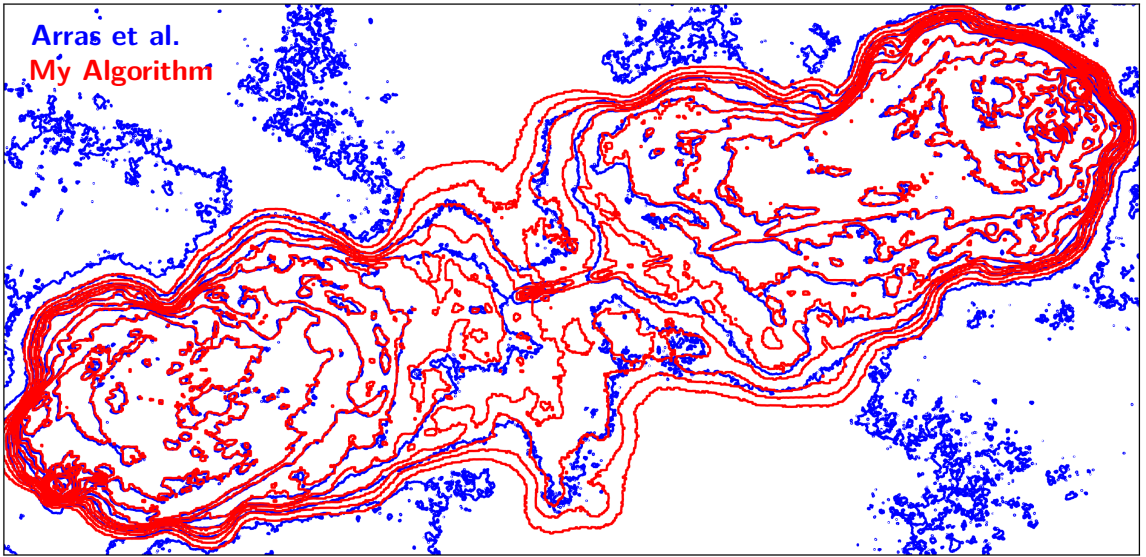
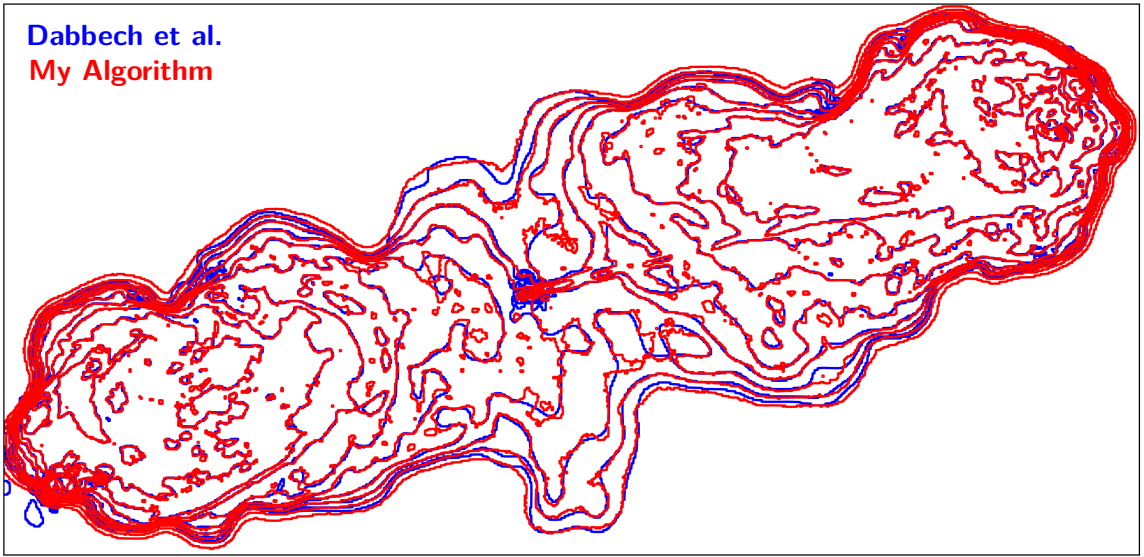
Comparison – Flux Contours



Contours $5 \cdot 10^7$ - $2 \cdot 10^{12}$ **Jy/sr**

Comparison – Flux Contours



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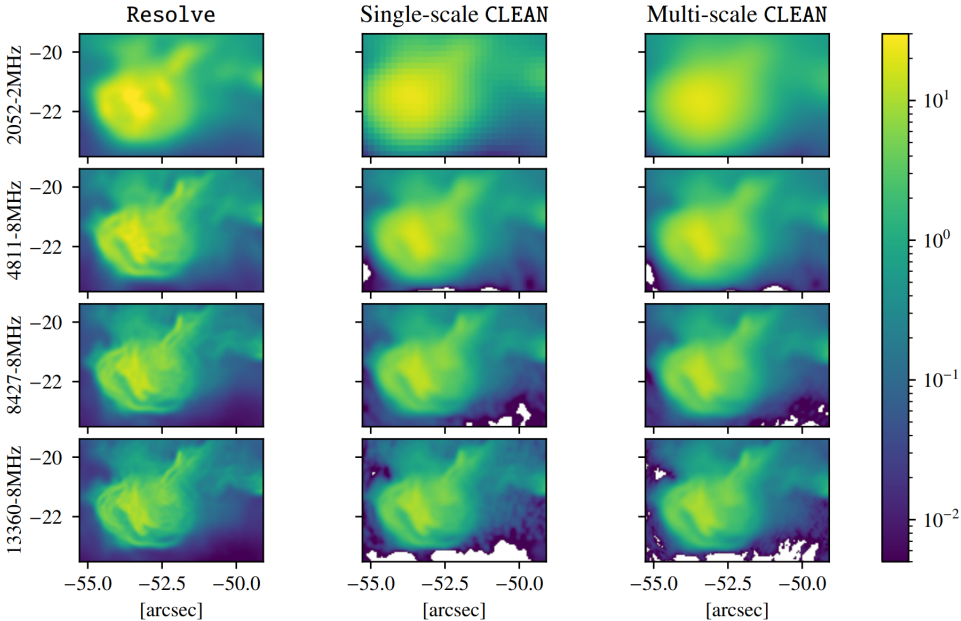
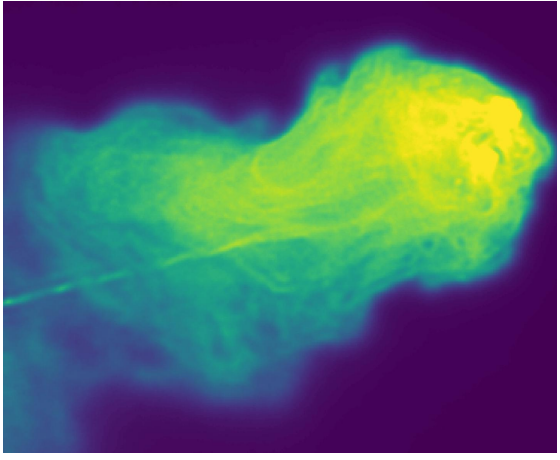

Resolve
Single-scale CLEAN
Multi-scale CLEAN
2052-2MHz
4811-8MHz
8427-8MHz
13360-8MHz
−20
−22
−55.0
−52.5
−50.0
[arcsec]
10^{1}
10^{0}
10^{-1}
10^{-2}

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)



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