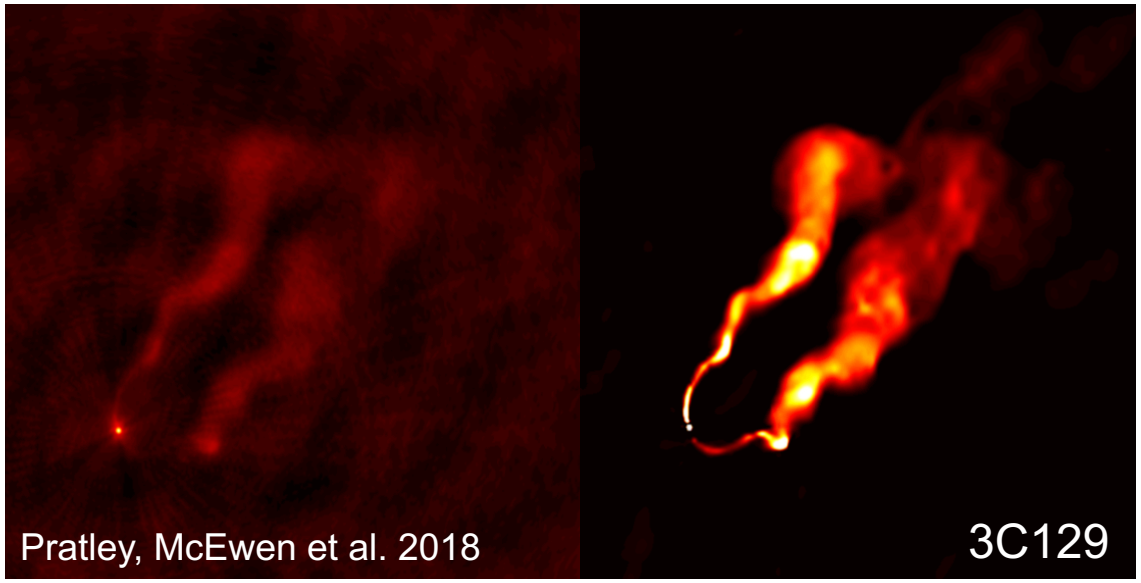
Sparse image reconstruction of radio interferometric observations using PURIFY



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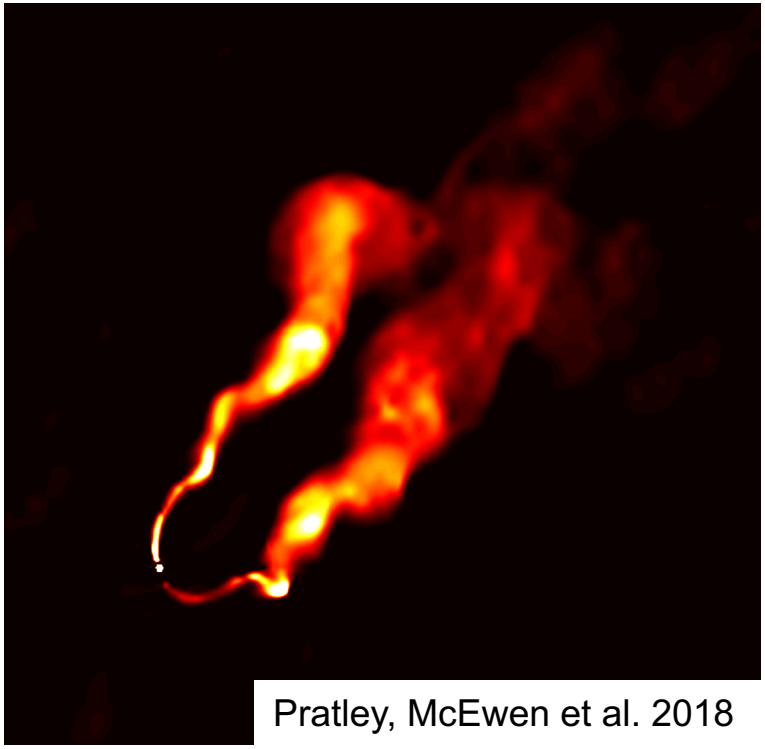
Rafael E. Carrillo, Alexandru Onose, Yves Wiaux (HWU)

Outline

- PURIFY: Real Data
- Error Maps and Hypothesis Tests
- Online Imaging
- All Sky Imaging

PURIFY: State-of-the-art Imager

- Next-generation imager (beyond CLEAN)
- Statistical-Foundations (critical for science)
- State-of-the-art algorithms (fast, distributed, multi-threading)
- Naturally built for polarization (Pratley & Johnston-Hollitt, 2016)



Pratley, McEwen et al. 2018

PURIFY/SOPT

- PURIFY can be found at http://basp-group.github.io/purify

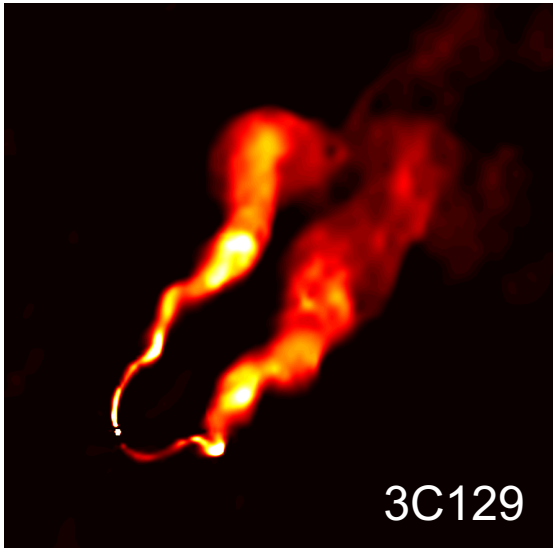
- Developed with UCL research computing

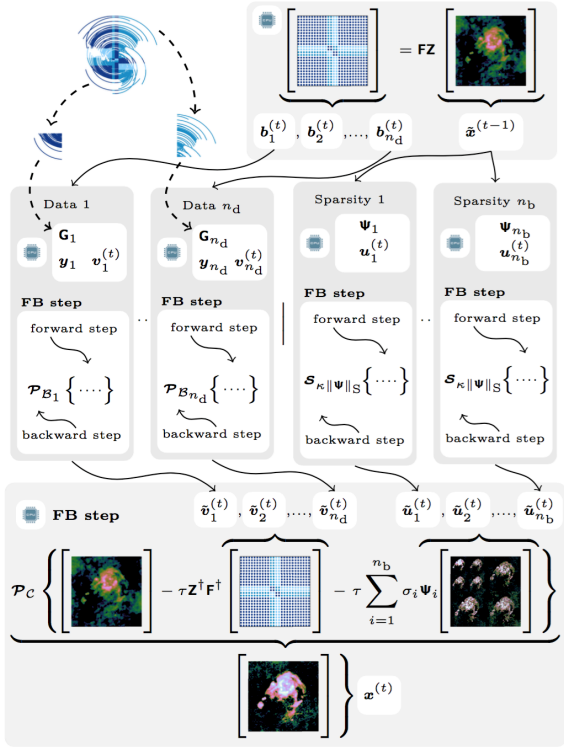
- It uses sparse optimisation solvers from SOPT http://basp-group.github.io/sopt (developed with PURIFY)

Distributed Algorithms

Observation

Final Image





Compressive Sensing

Convex Optimization

Multi-node distribution

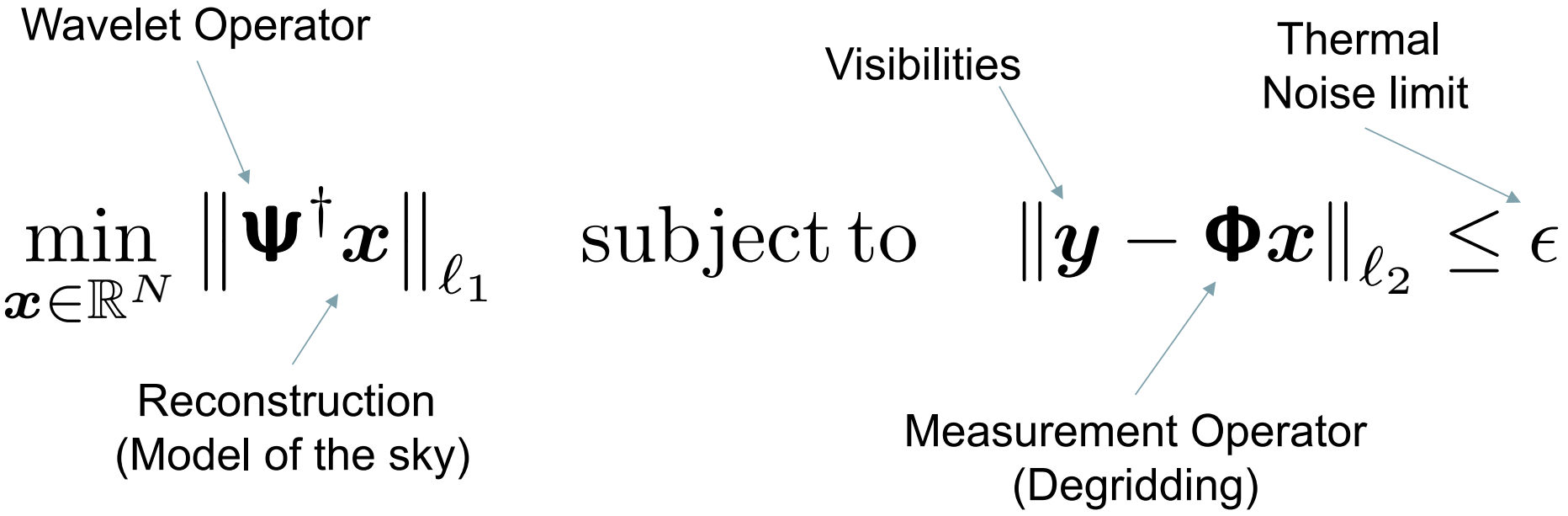
Multi-thread parallelisation

Distributed Algorithms

Onose et al, 2016

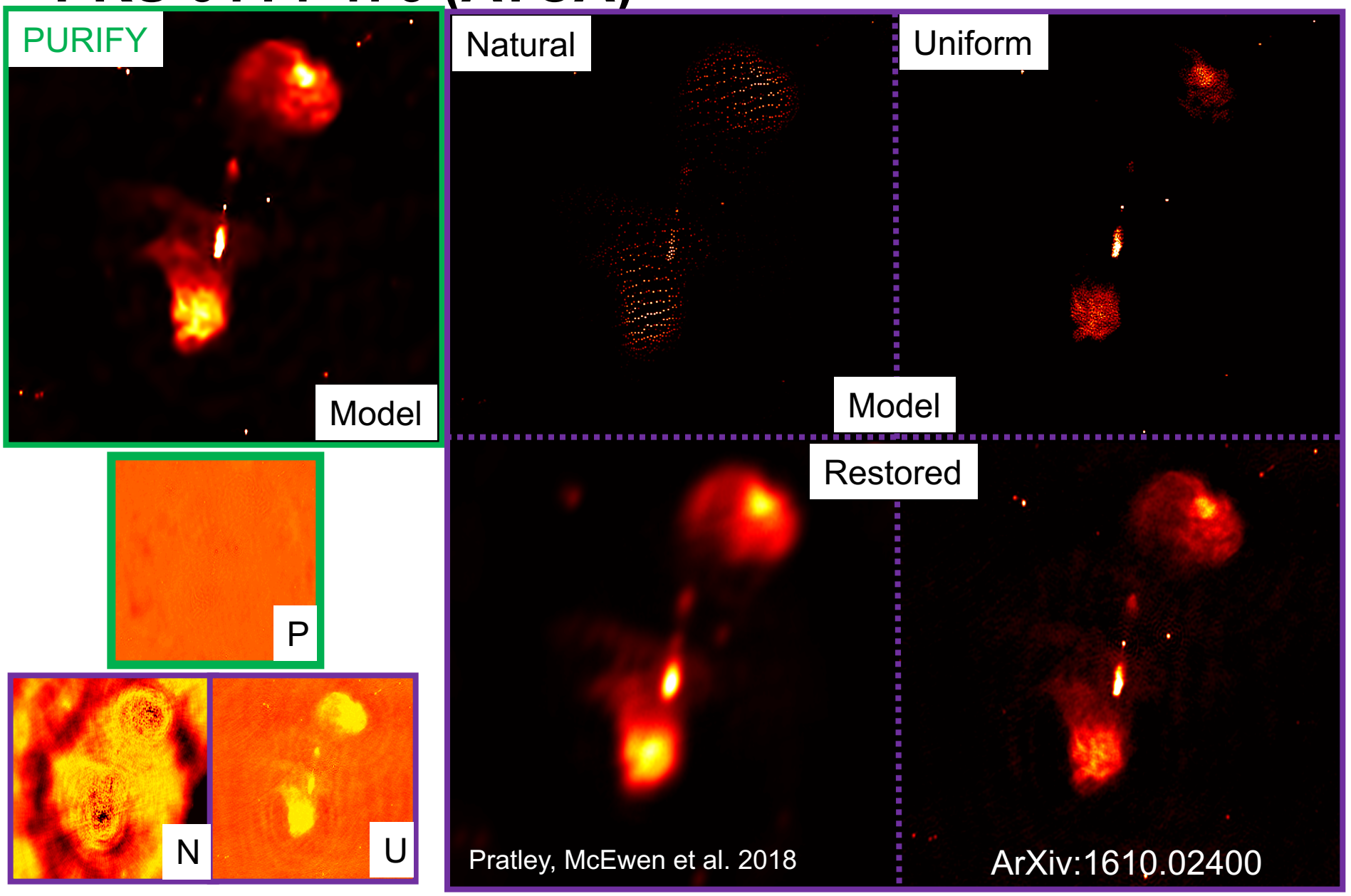
Carrillo, McEwen, Wiaux, 2014

PURIFY: Sparsity

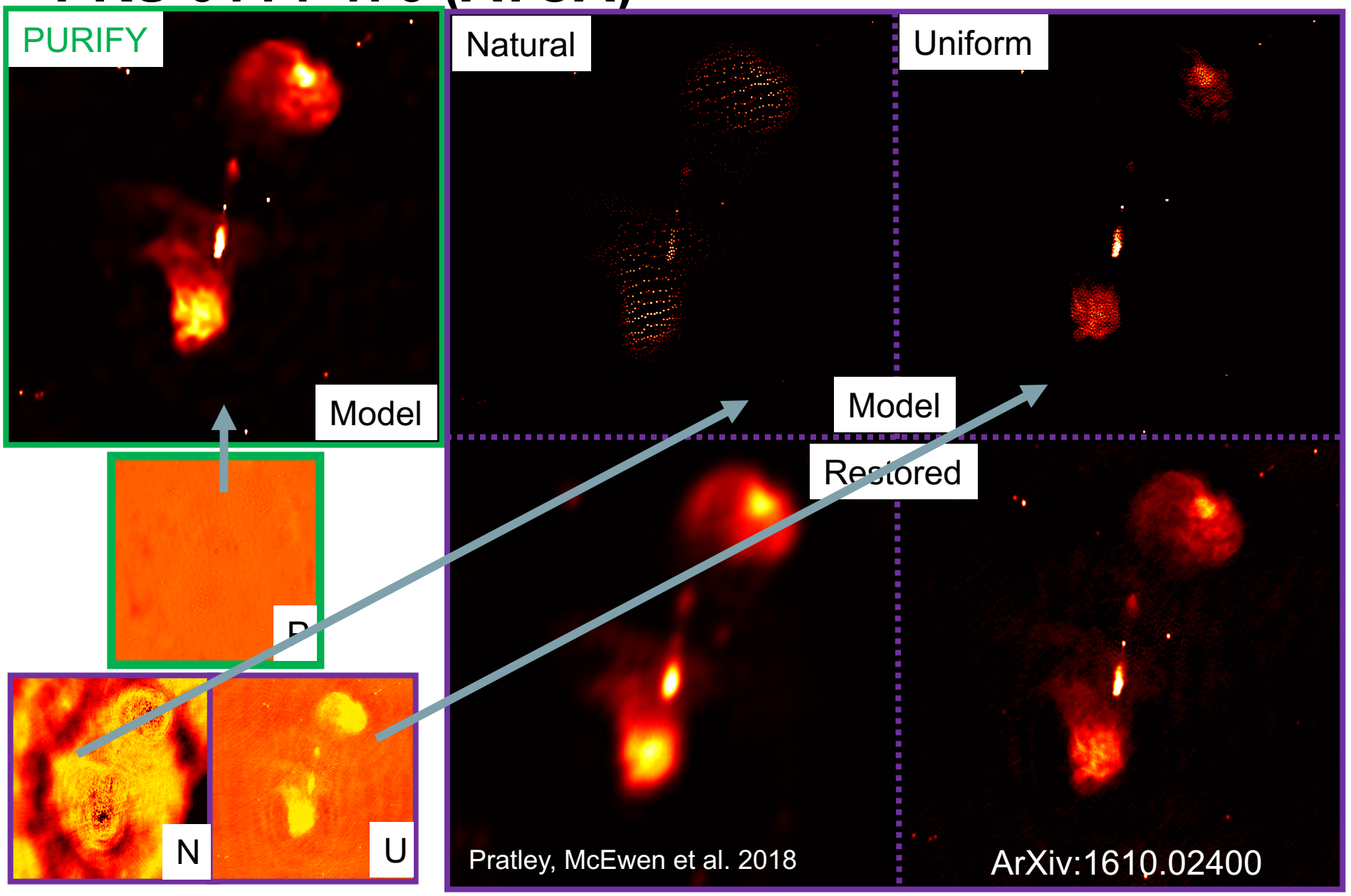


- Model the sky using a minimal (sparse) amount of CLEAN components. (Occam's Razor)
- Uses wavelets for compact/extended structures.
- Works for simulations and real data.

PKS 0114-476 (ATCA)



PKS 0114-476 (ATCA)



Uncertainties: MAP Estimation

- Most likely model given data

$$p(\boldsymbol{x}|\boldsymbol{y}) = \frac{p(\boldsymbol{y}|\boldsymbol{x})p(\boldsymbol{x})}{\int_{\mathbb{R}^N} p(\boldsymbol{y}|\boldsymbol{s})p(\boldsymbol{s})\mathrm{d}\boldsymbol{s}}$$

$$\boldsymbol{x}_{\mathrm{MAP}} = \underset{\boldsymbol{x}}{\operatorname{argmin}} \left[-\log p(\boldsymbol{x}|\boldsymbol{y}) \right]$$

- Gaussian error on visibilities, sparsity on model

$$\boldsymbol{x}_{\mathrm{MAP}} = \underset{\boldsymbol{x}}{\operatorname{argmin}} \left[\mu \|\boldsymbol{\Psi}^\dagger \boldsymbol{x}\|_1^2 + \|\boldsymbol{y} - \boldsymbol{\Phi} x\|_2^2 / 2\sigma^2 \right]$$

(Analysis)

- Forward Backward Algorithm

$$\boldsymbol{a}^{(i+1)} = \mathrm{soft}_{\lambda^{(i)}\mu} \left(\boldsymbol{a}^{(i)} - \lambda^{(i)} \boldsymbol{\Psi}^\dagger \boldsymbol{\Phi}^\dagger (\boldsymbol{\Phi}\boldsymbol{\Psi}\boldsymbol{a}^{(i)} - \boldsymbol{y})/\sigma^2 \right)$$

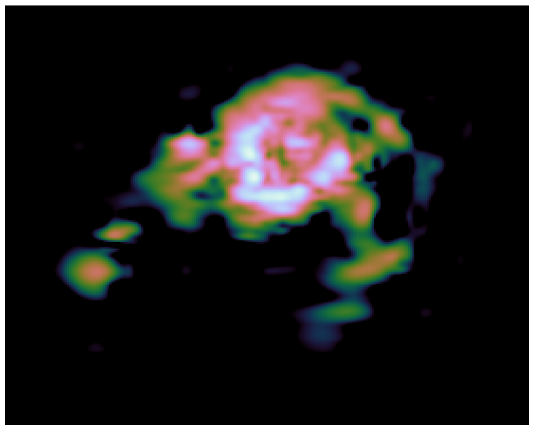
$$\boldsymbol{x}^{(i+1)} = \boldsymbol{\Psi}\boldsymbol{a}^{(i+1)}$$

(Synthesis)

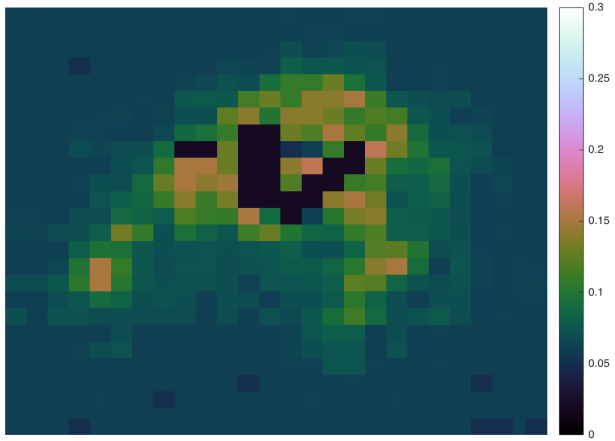
Credible Interval: Error Bars

- Want uncertainty on region in image
- Use MCMC? Very slow!
  (Cai, McEwen, Peryra 2017a, arXiv:1711.04818)
- Alternative: Find the Credible Interval (50,000x faster!)

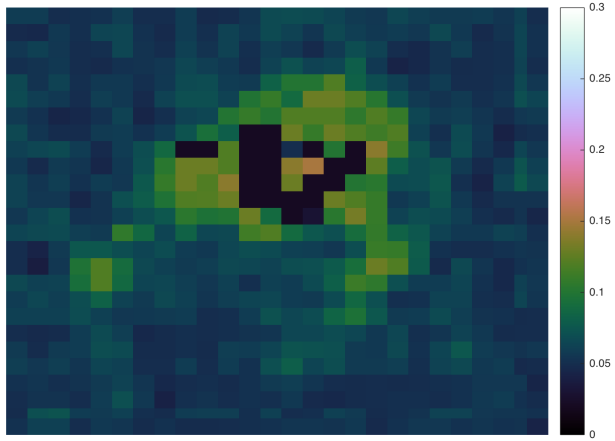
MAP Estimation



Credible Region

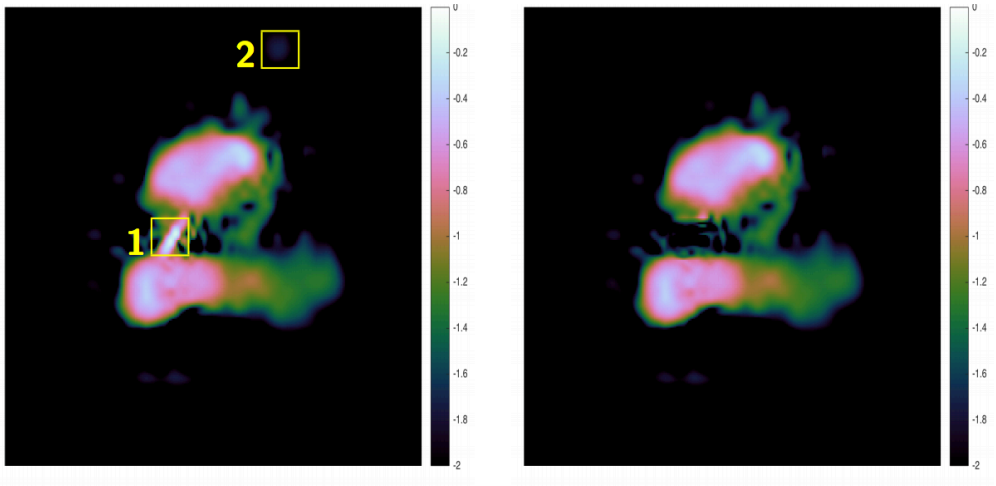


Proximal MCMC



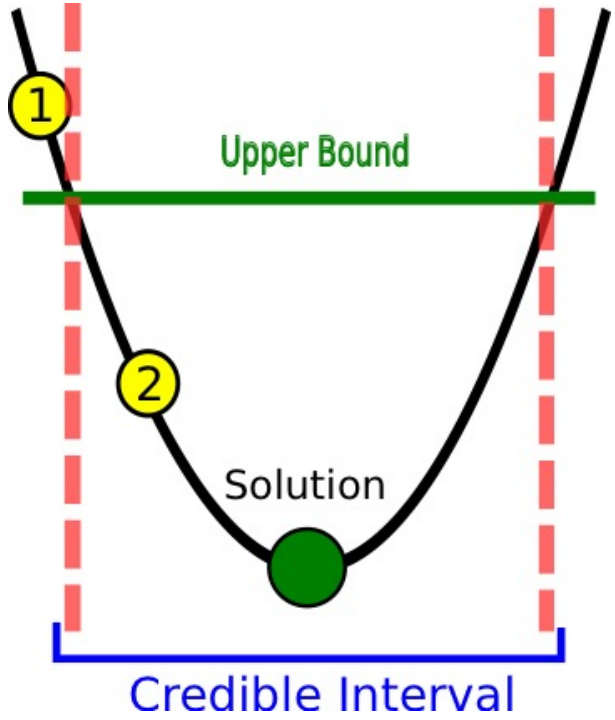
Cai, McEwen, Peryra 2017b arXiv:1711.04819

Hypothesis Testing



(a) Recovered image (b) Surrogate with region removed

Figure: 3C288



Remove 1 – outside error – Region 1 unphysical is unlikely

Remove 2 – within error – Region 2 unphysical is possible

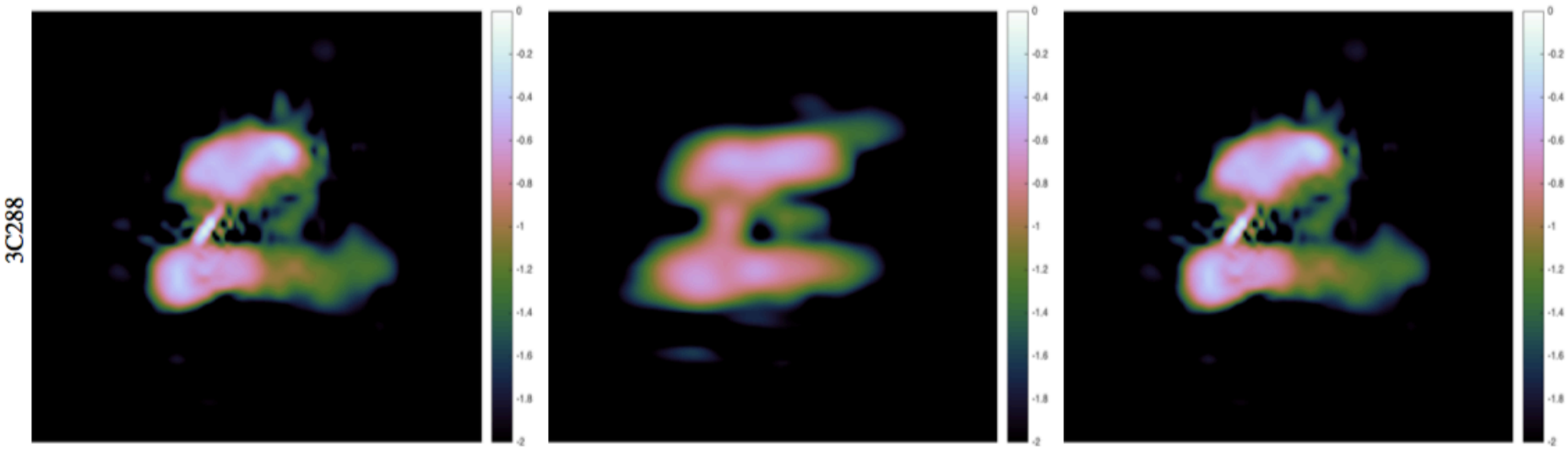
Cai, McEwen, Peryra 2017b arXiv:1711.04819

Online Imaging

Released on ArXiv Today!
ArXiv:1712.04462

- Online Imaging – Reconstruct image while streaming in data.
- Uses less computation and memory than offline method (but same quality!)

Assimilate and Discard!



a) Standard Algorithm
100% visibilities

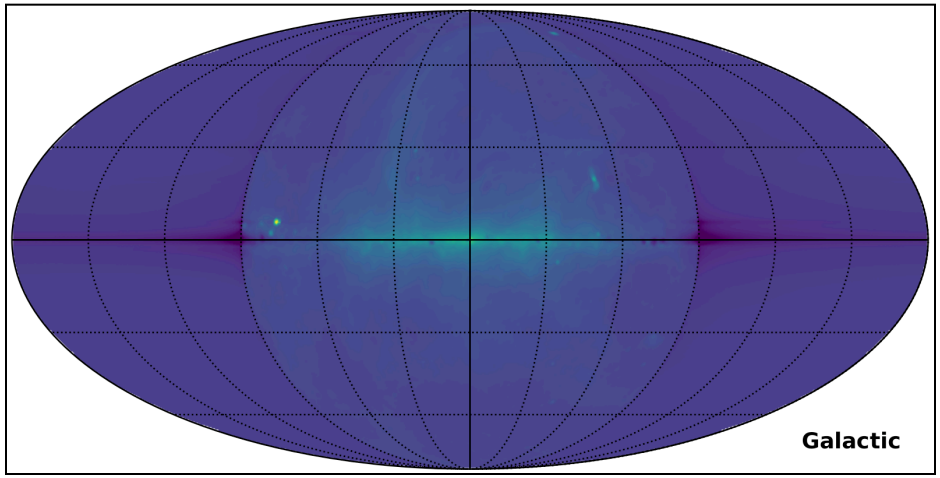
b) Standard Algorithm
2% visibilities

c) Online Algorithm
+ 2% visibilities until 100%

All Sky Imaging/Reconstruction

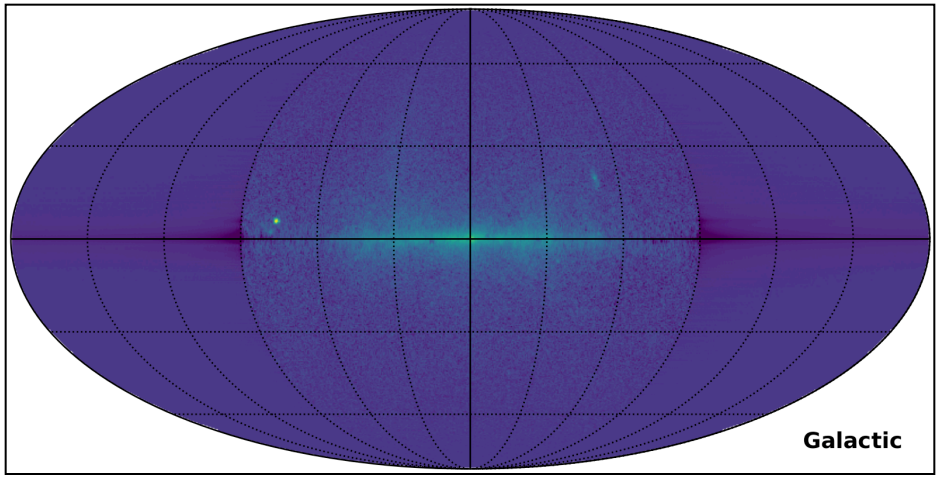
- Image efficiently on the sphere

Ground Truth



Pratley & McEwen (in prep.)
McEwen & Scaife, 2008
Shaw et al. 2014

Simulated Dirty Image



Eastwood et al. 2017
Carozzi 2015

- Perform Sparse reconstruction on the sphere.

See Wallis, Wiaux, McEwen et al. 2017, ArXiv:1608.00553

Summary

- Sparse image reconstruction works on simulations and real data
- Distributed image reconstruction
- Uncertainty Quantification
- Online Imaging (reduce memory and computation)
- All-sky modelling and imaging