Recent Advances in Sky/Source Model Construction

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Outline

- Wake you up.
- Talk about the following topics in random order:
  - Image fidelity
  - Dynamic range
  - Source modeling
  - Sky models
  - Deconvolution
- Stop talking.

Motivation: Sky models are essential for self-calibration. Accurate sky models need accurate source models. Cutting down computational cost requires efficient incorporation of sky models to the measurement equation.

Note: Unless otherwise stated, all astronomical images were produced with real LOFAR data

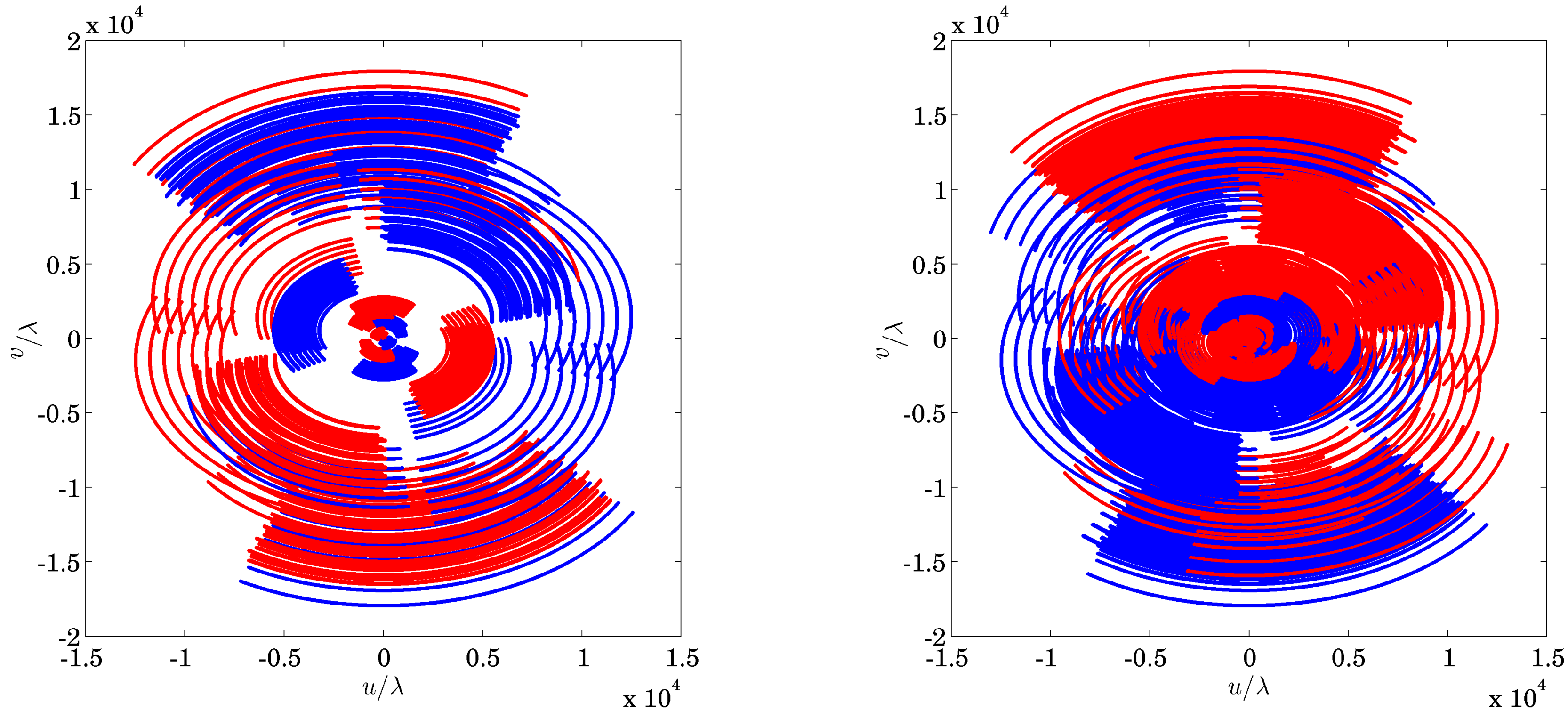
Landau-Pollak Theorem

- Occam's razor: *Entities should not be multiplied unnecessarily*.
- All physical signals are both time and band limited [Slepian, 1976].
- Finite support in image and uv plane due to noise.
- Cramer-Rao Lower Bound on pixelization [Yatawatta, 2010].
- Simplest form [Landau and Pollak, 1962],

$$N_{\text{degrees of freedom}} < A_{\text{image}} \times A_{\text{uv}}$$

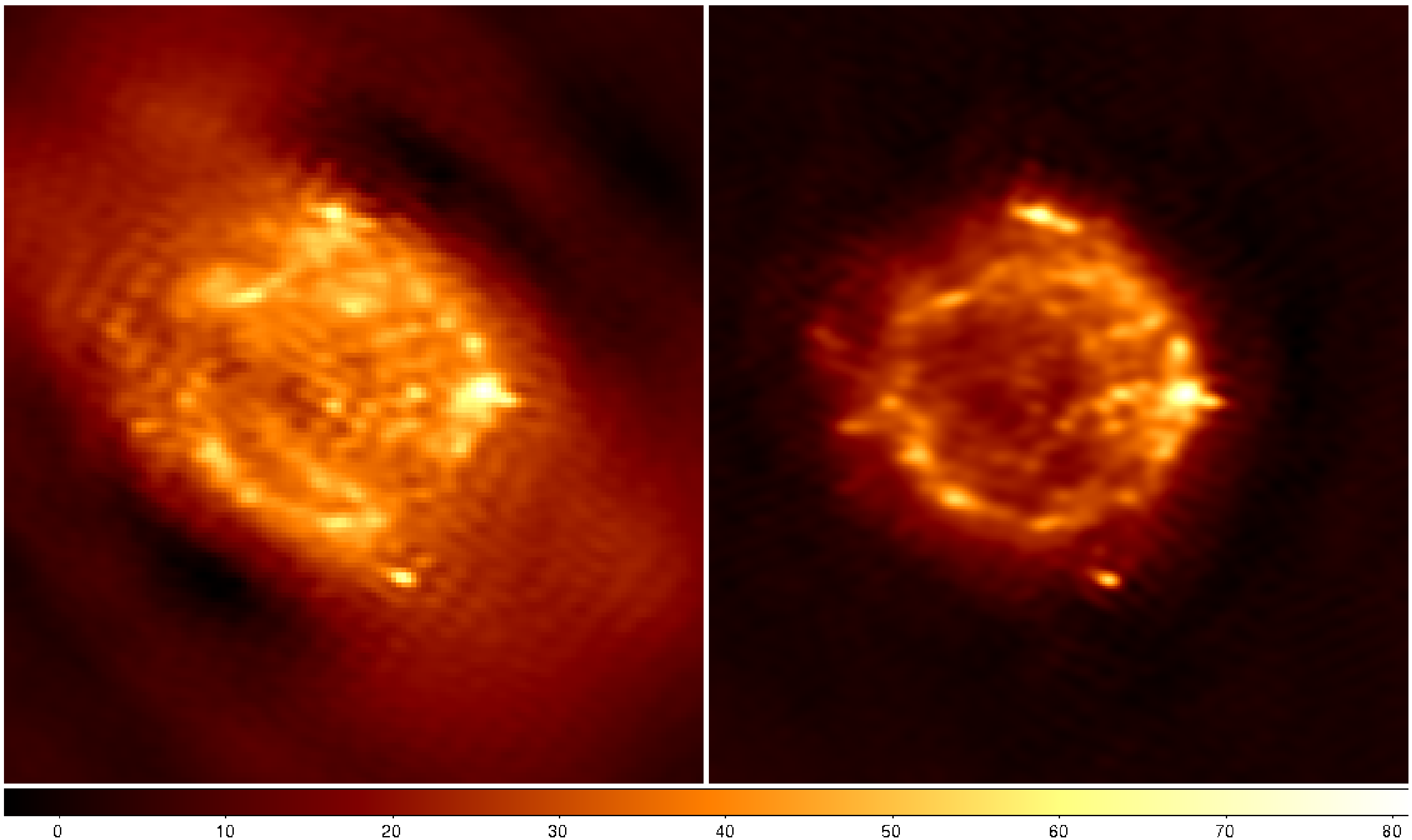
- Also related to Shannon number.

Example: CasA



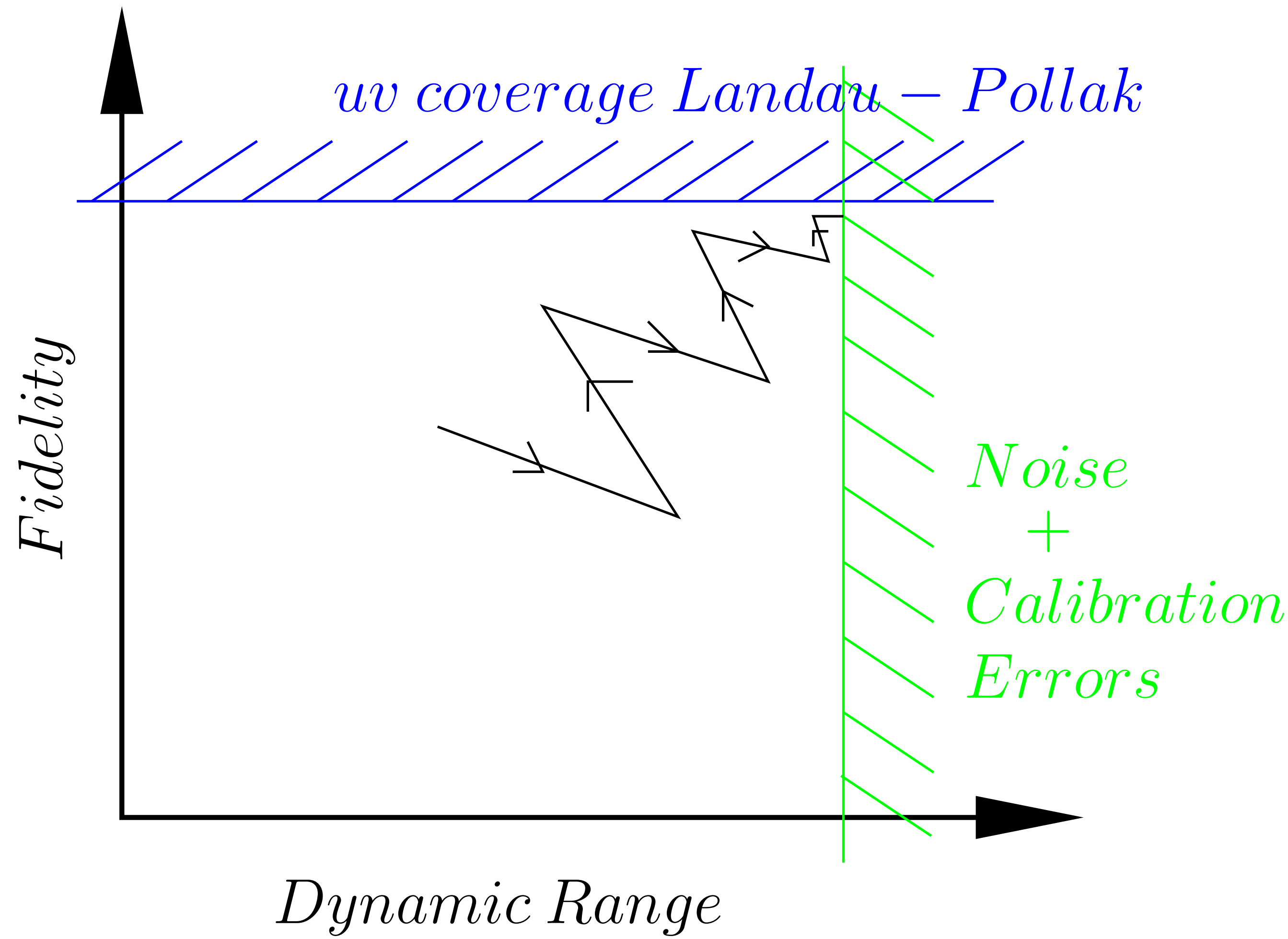
uv coverage for two different observations of CasA

Example

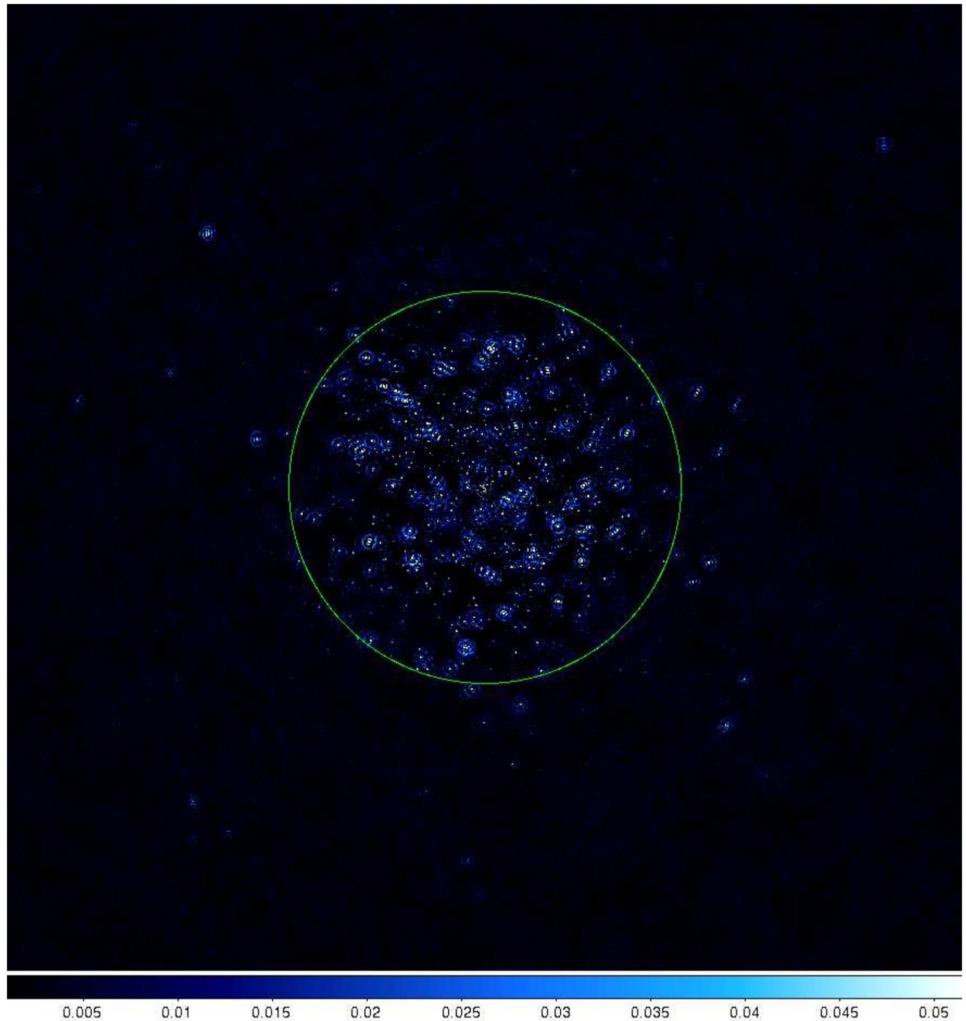


CasA 115-170 MHz [Brentjens, Yatawatta, in prep.]

Fidelity-Dynamic Range Tradeoff

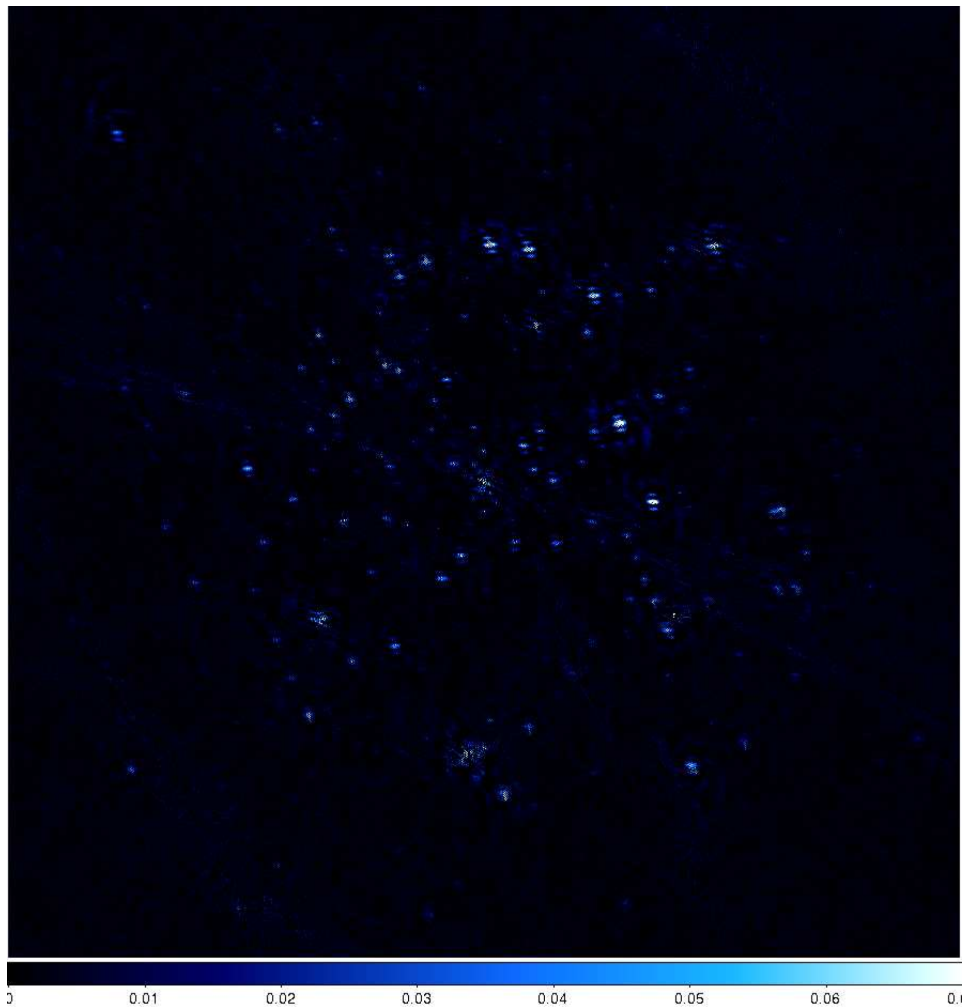


3C61.1



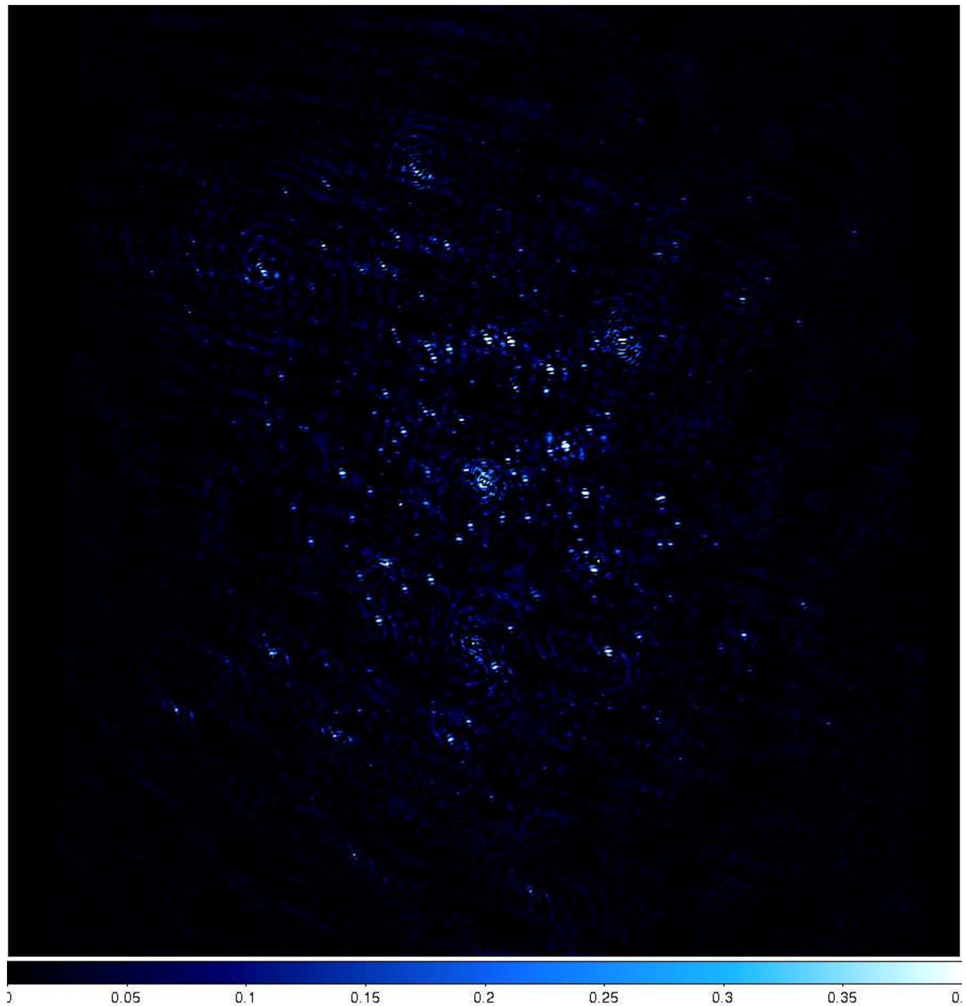
Resolution 45 arcsec, 150 MHz, ○: diameter 9 deg

3C196



Peak 72 Jy, Noise 4 mJy, 150 MHz, Dynamic range $\approx$ 18000

3C196 (First Multibeam)



Multibeam (5 beams), 170 MHz, FOV 14×14 degrees

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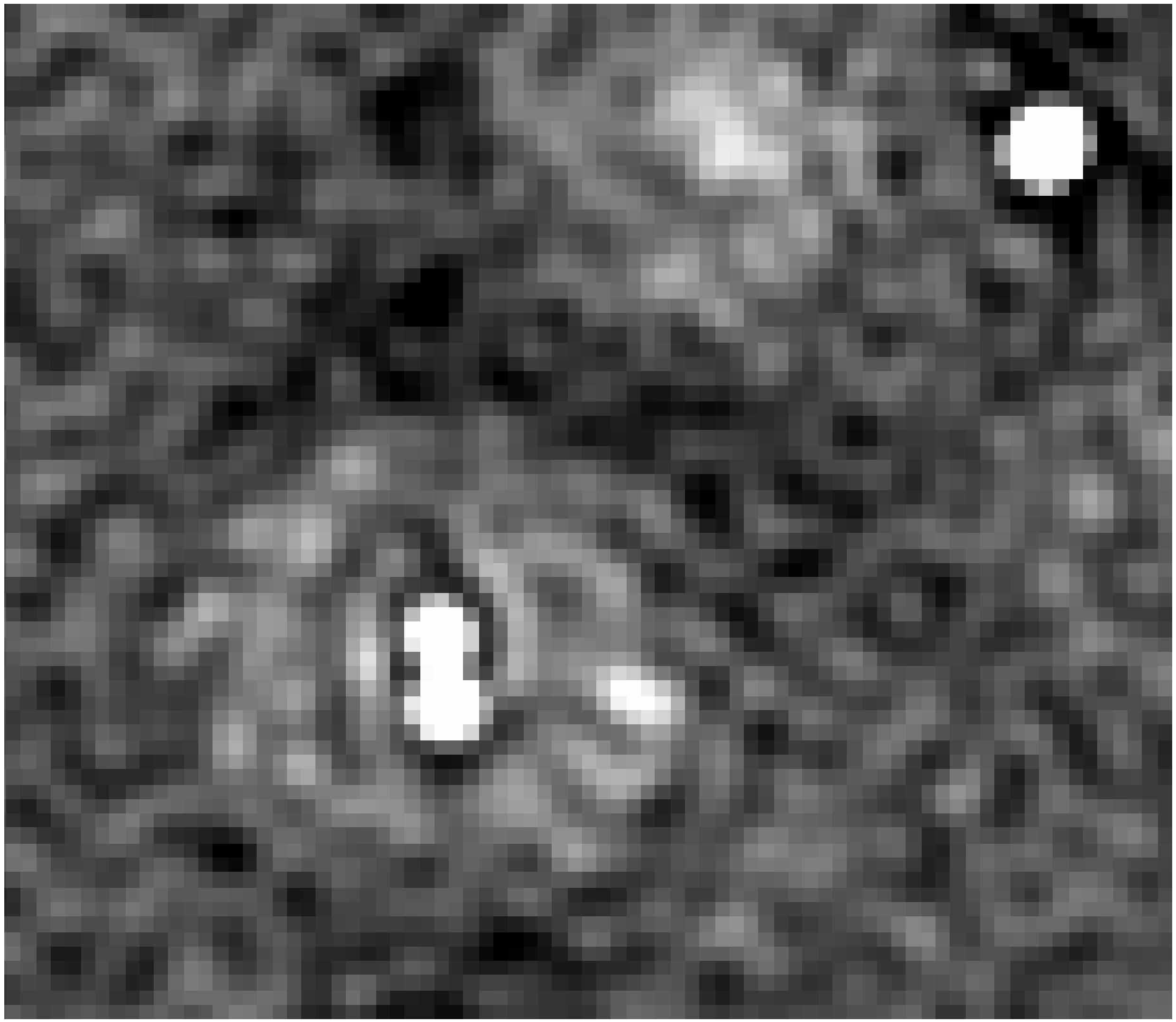
Sky Model Construction



Example with two sources

Model construction

Given: set of image pixels z_i with fluxes and positions

$$z_i = \sum_{j=1}^{K} s_j(\boldsymbol{\theta}_j) + n_i$$

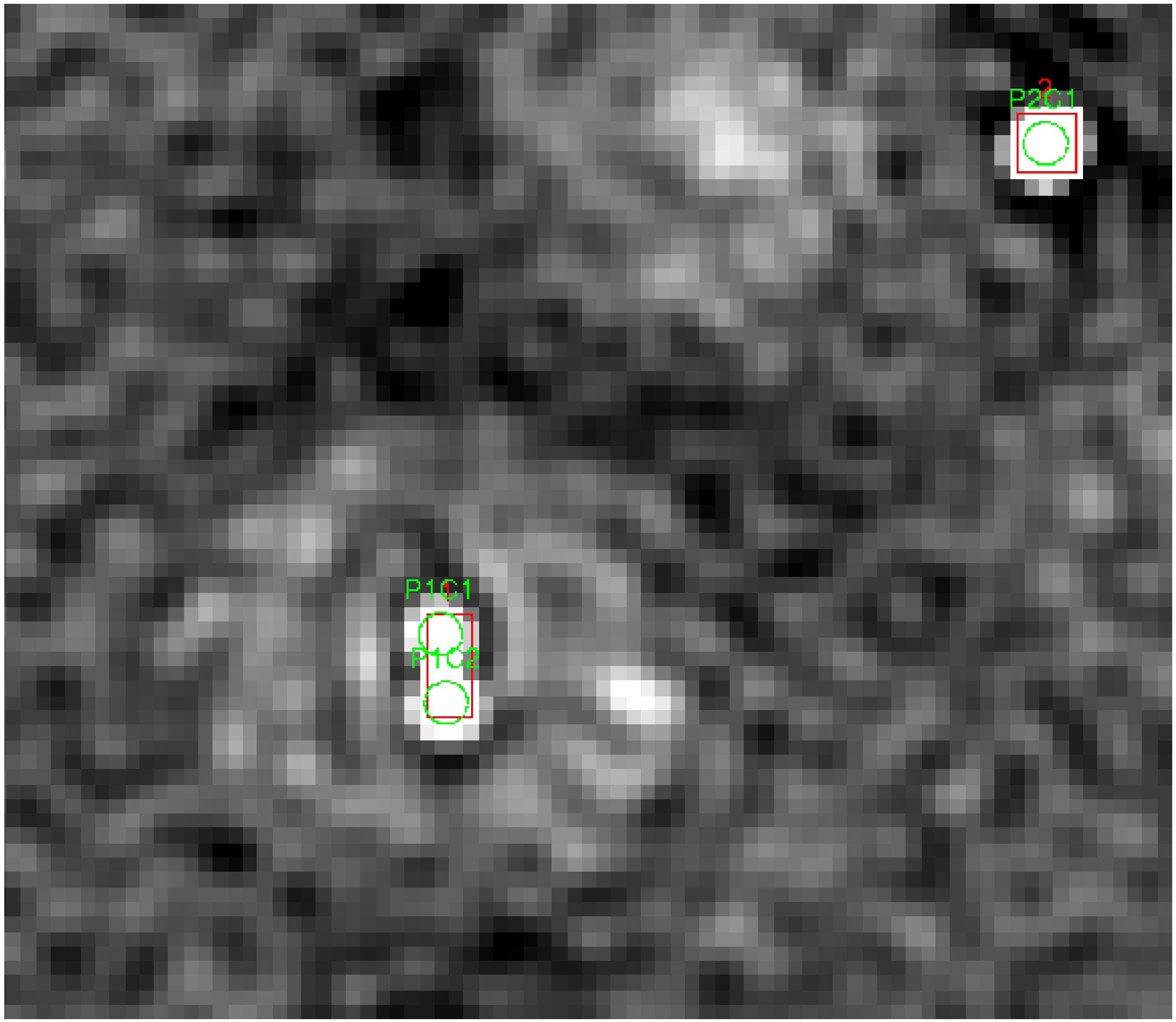
Find $\boldsymbol{\theta}_j$ to minimize

$$\sum_i ||z_i - \sum_{j=1}^{K} s_j(\boldsymbol{\theta}_j)||^2$$

Use Expectation Maximization (EM) [Feder and Weinstein, 1988] to solve this. (Sanaz Kazemi will talk more about EM tomorrow).

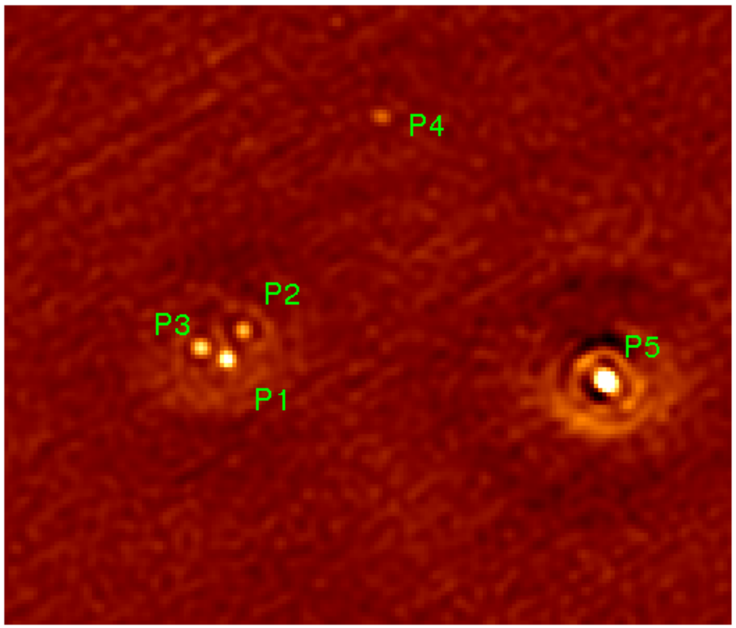
Use Akaike's information [Akaike, 1973] to find the right K.

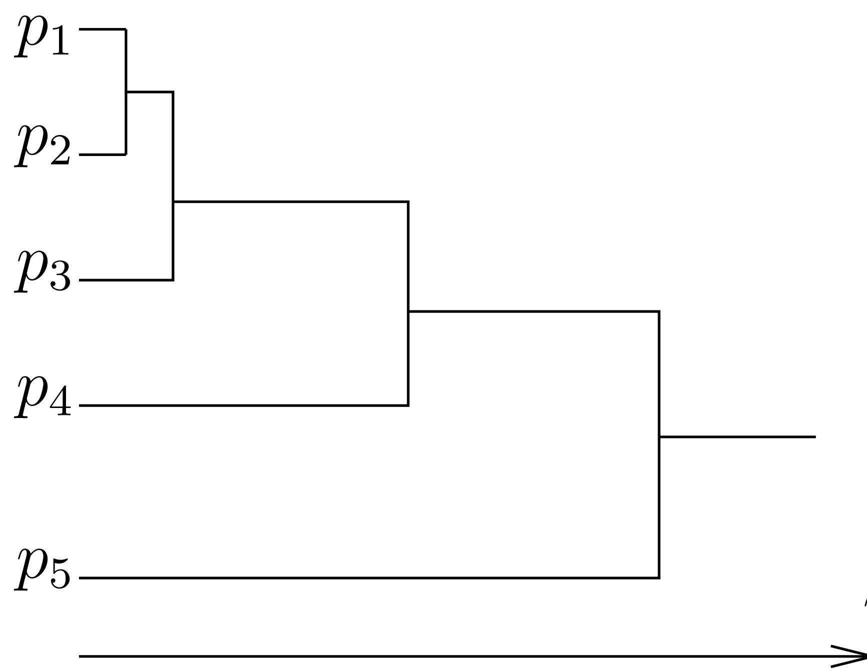
Sky Model



Sky model

Hierarchical Clustering



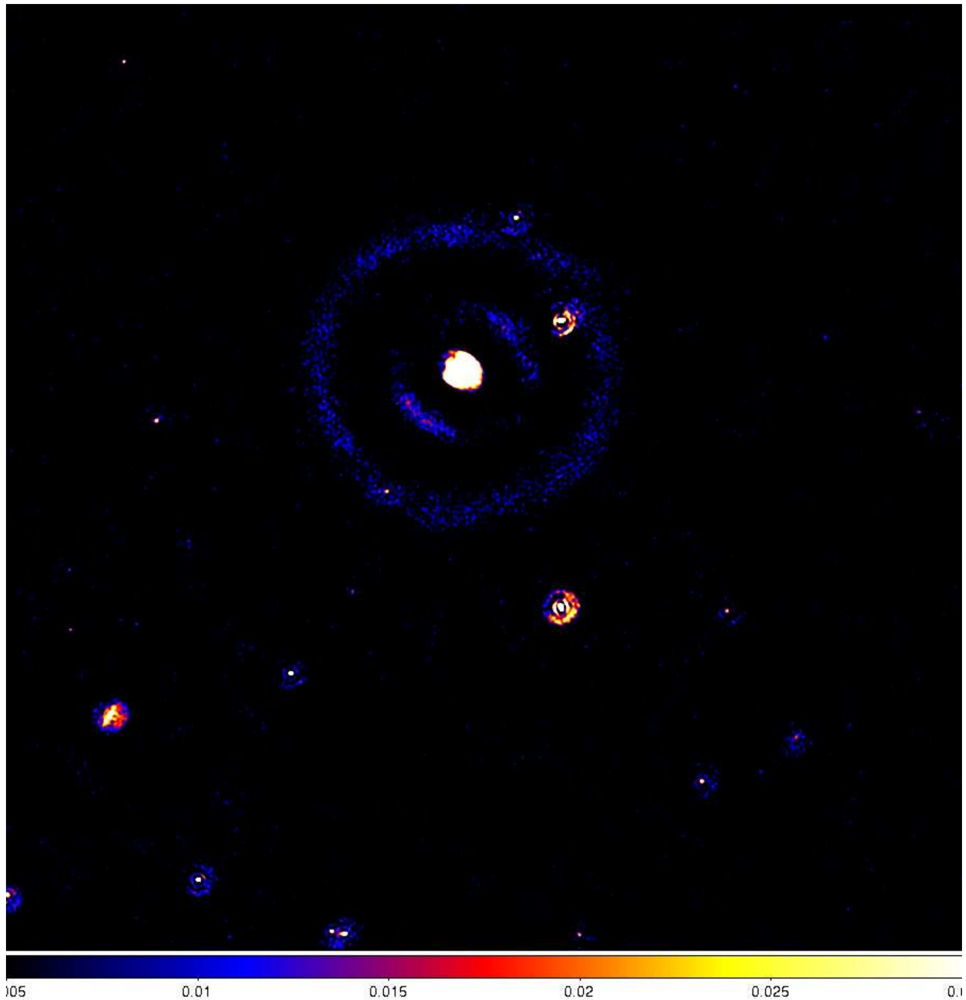


Dendrogram

Cut down the cost of computing direction dependent terms

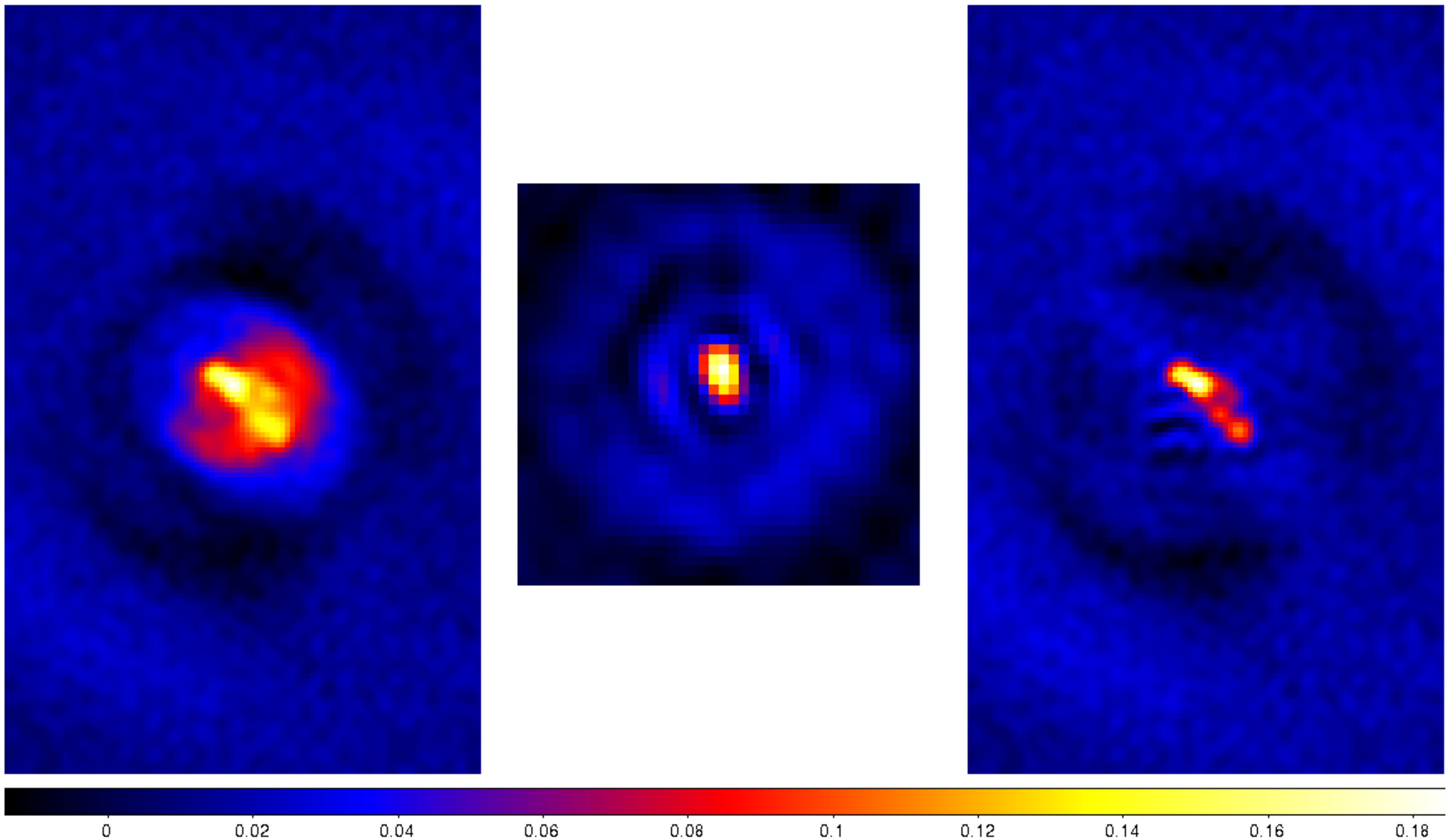
$$\mathbf{V}_{pq} = \sum_i \mathbf{J}_{ip}\mathbf{K}_{ipq}\mathbf{C}_i\mathbf{J}_{iq}^H \Leftrightarrow \sum_i \mathbf{J}_{ip}\Big(\sum_{j\in S_i} \mathbf{K}_{jpq}\mathbf{C}_j\Big)\mathbf{J}_{iq}^H$$

Deconvolution



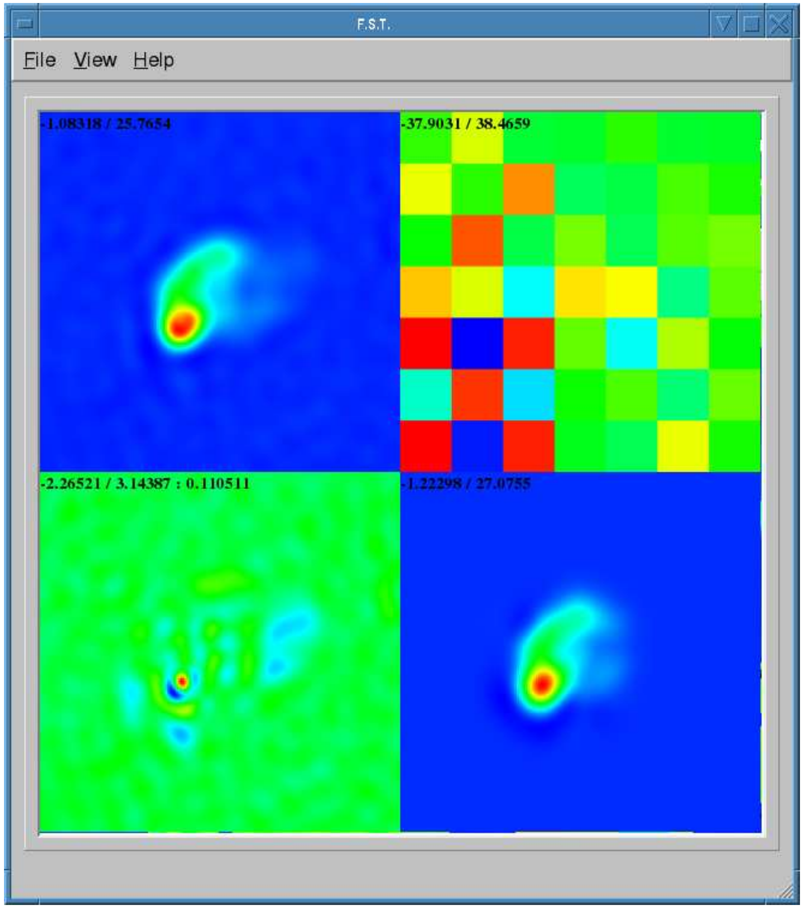
Cup-saucer PSF

Deconvolution

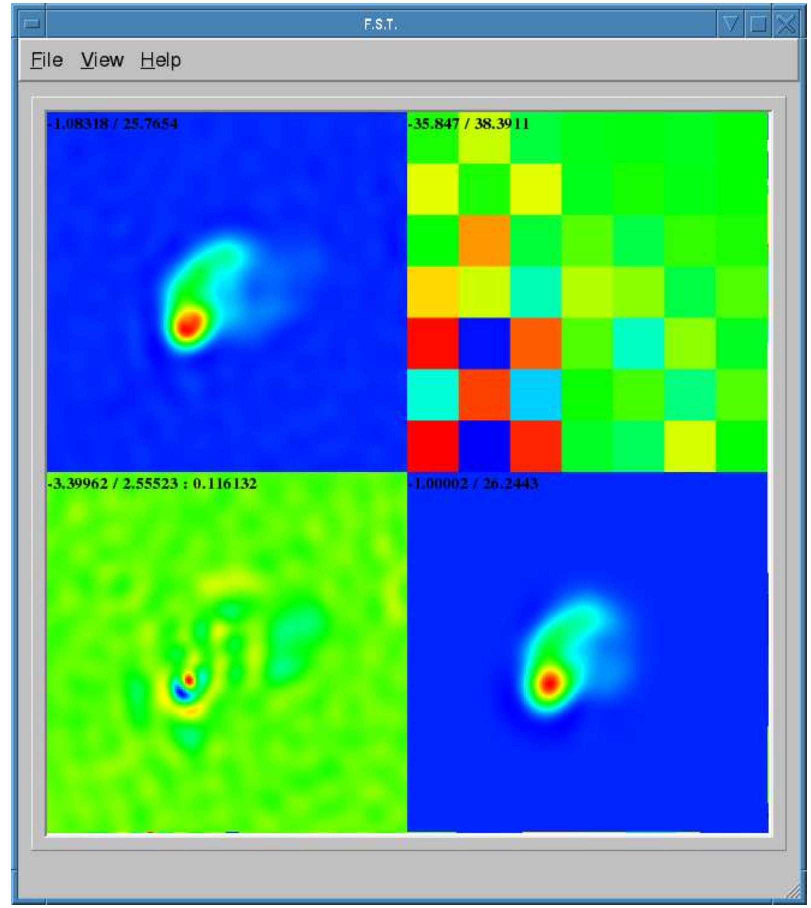


Original (left), PSF (middle), Deconvolved (right)

L1 Regularization



$\min ||Ax - b||_2^2$



$\min ||Ax - b||_2^2 + \lambda ||x||_1$

[Kim et al., 2007] Truncated Newton Interior Point Method

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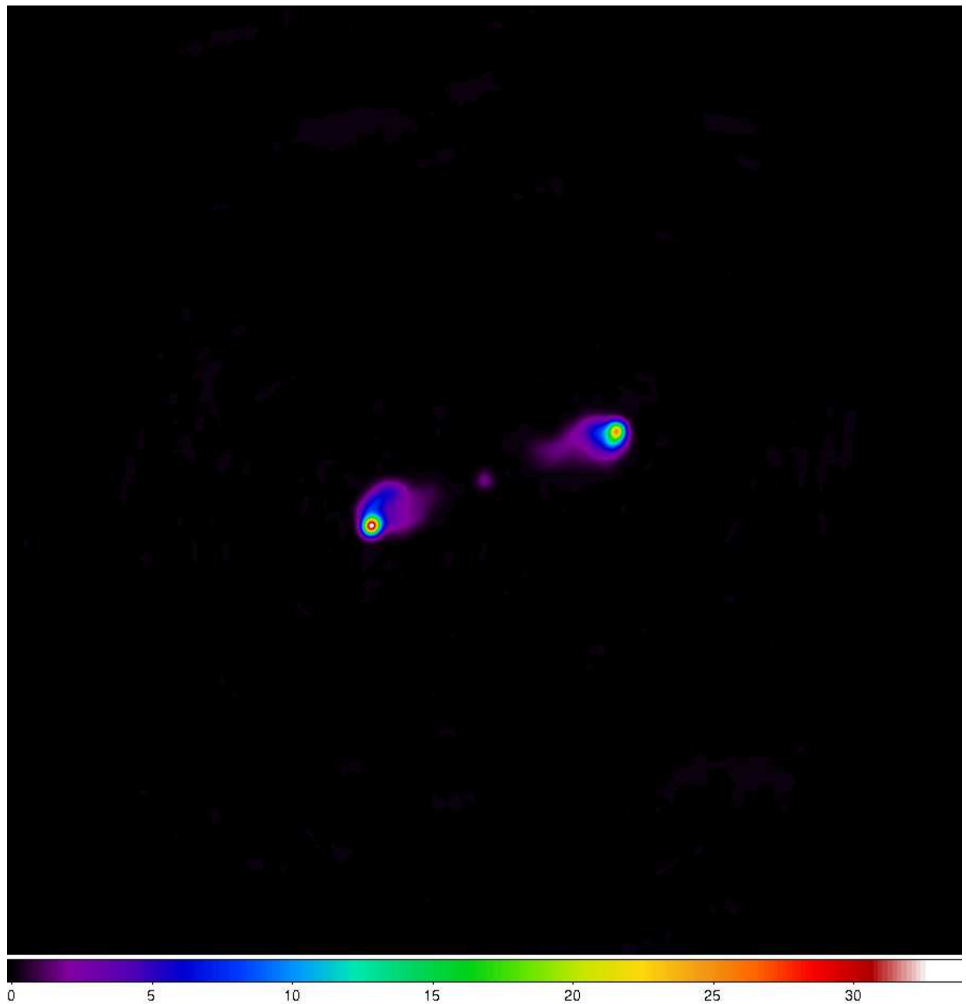
EVLA Cygnus A

(with Tony Willis and Rick Perley) Observation at 8.5 GHz, baselines 34 m to 1 km



8x2 MHz channels, Peak 34 Jy, Noise I 2.5 mJy Q,U 1 mJy, V 2 mJy

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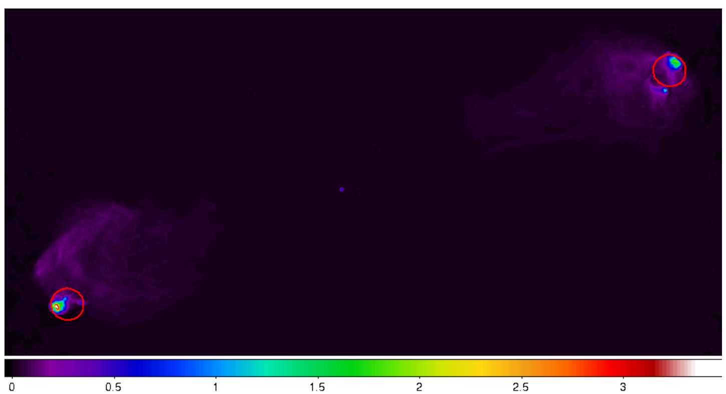
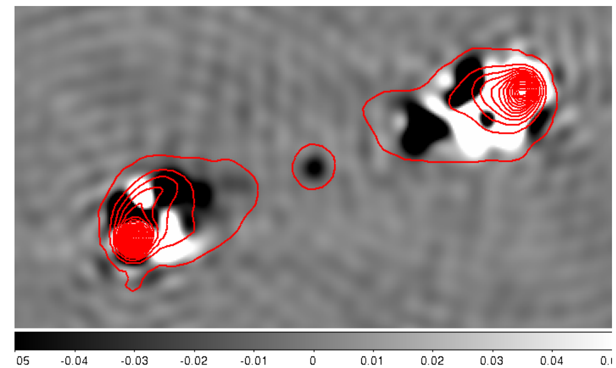
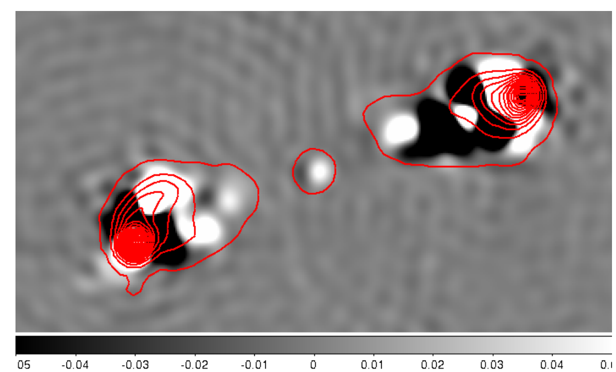
EVLA Cygnus A: Limitations



VLA image, ○: EVLA PSF. Hotspots partially resolved.



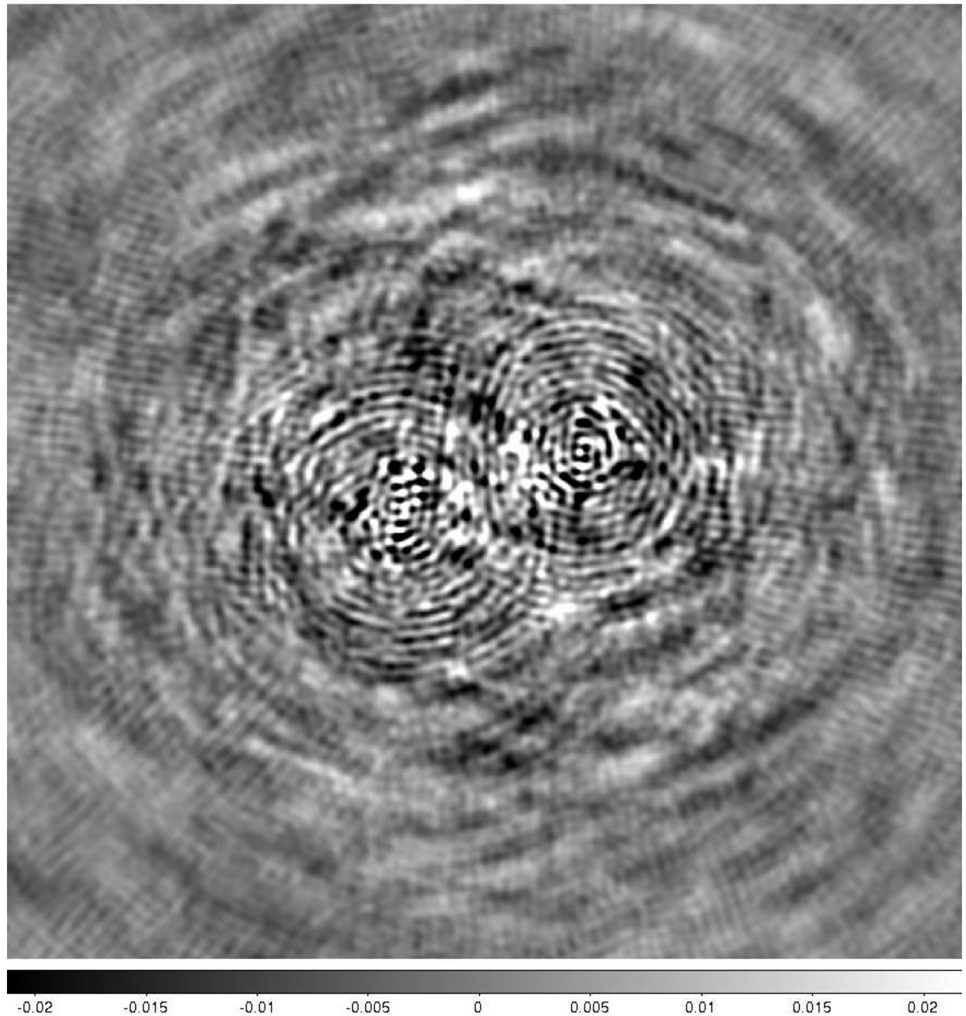
Stokes Q



Stokes U

Peak polarized flux $\approx$ 2 Jy. Need full polarization calibration.

Cygnus A Residual



256x2 MHz channels, residual noise 2.5 mJy