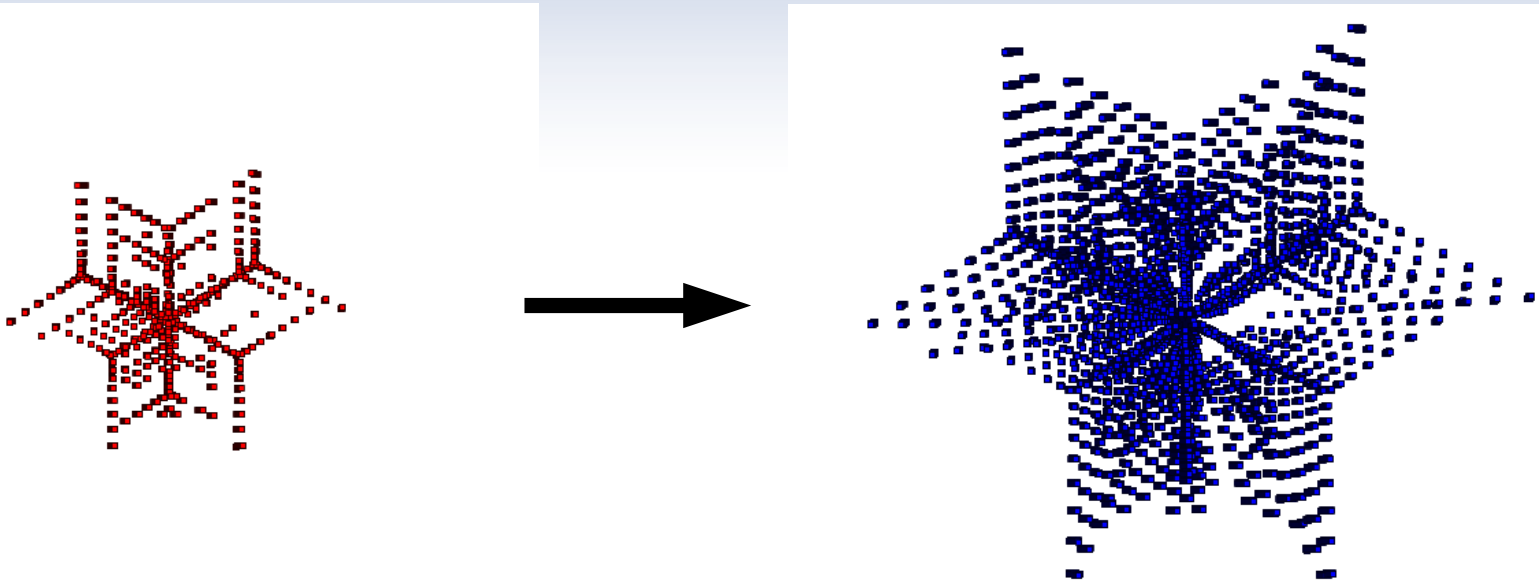
A new approach to multi-frequency synthesis with diffuse and extented sources



Henrik Junklewitz, Mike Bell and Torsten Enßlin

Mainz, Juli 10, 2012,
Annual Meeting DFG Research Unit

Max-Planck-Institut für Astrophysik

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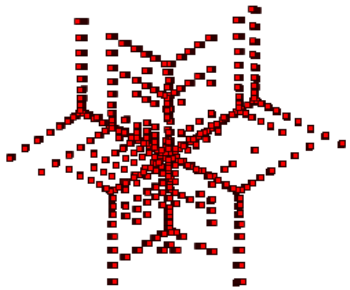

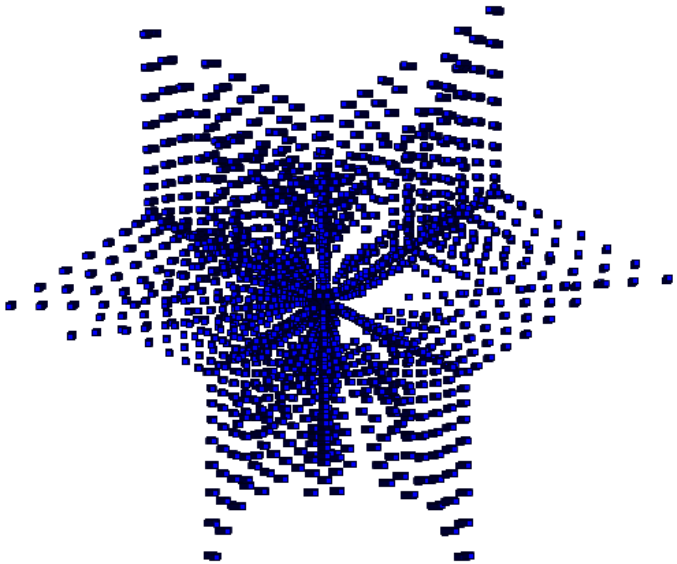

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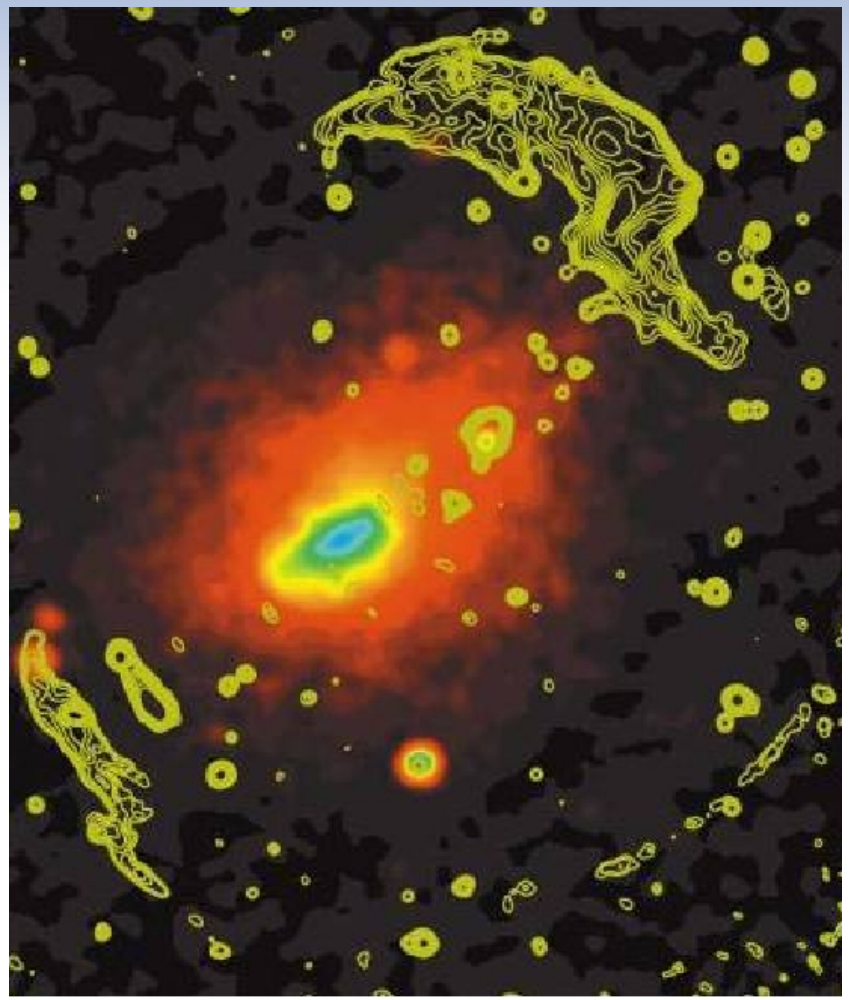
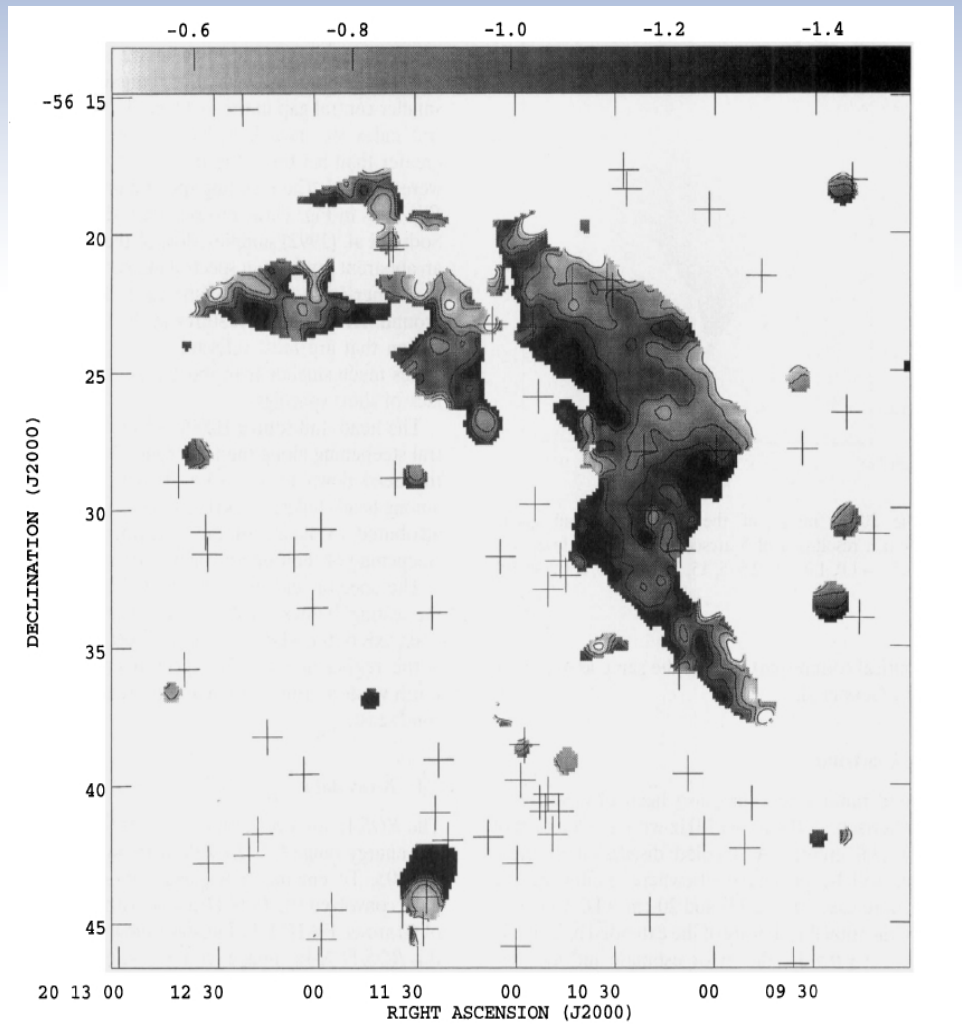


Abell 3667: 20 cm + Rosat X-Ray



Röttgering et al., 1997

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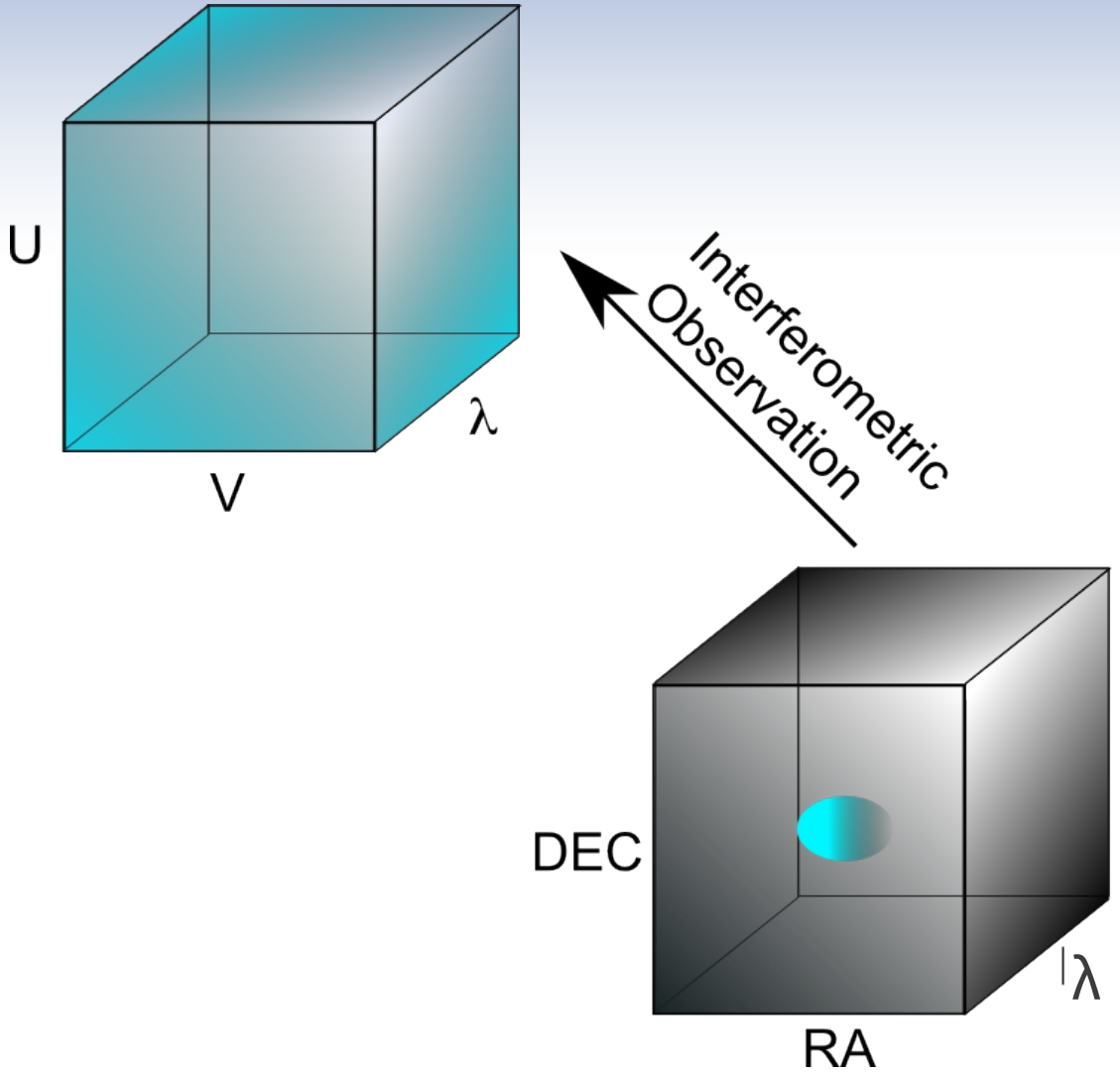

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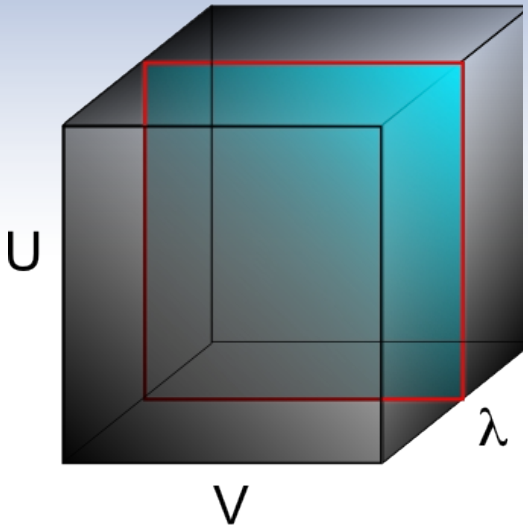

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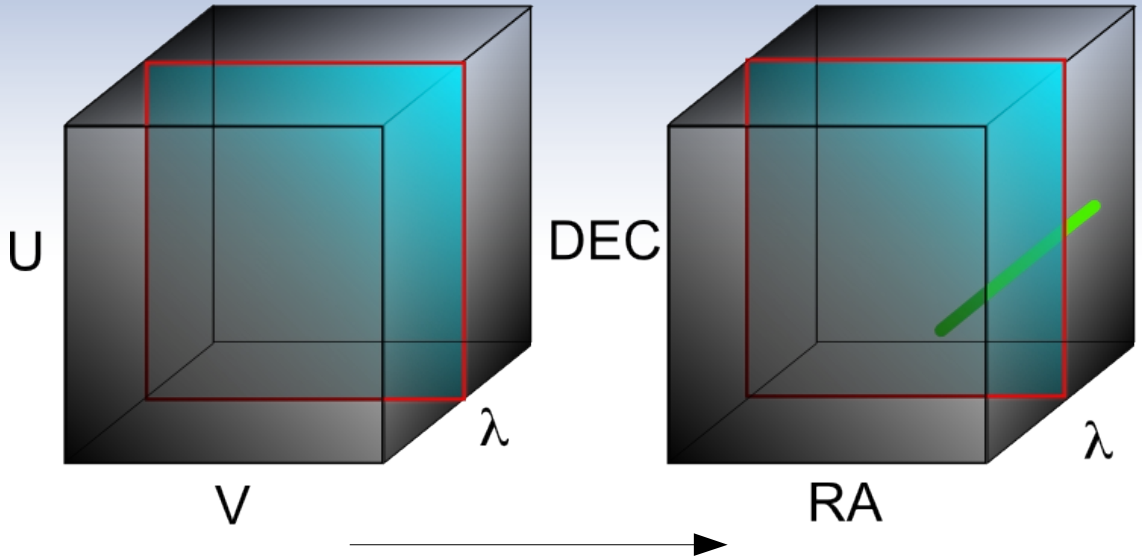

Aperture synthesis and deconvolution at single frequencies

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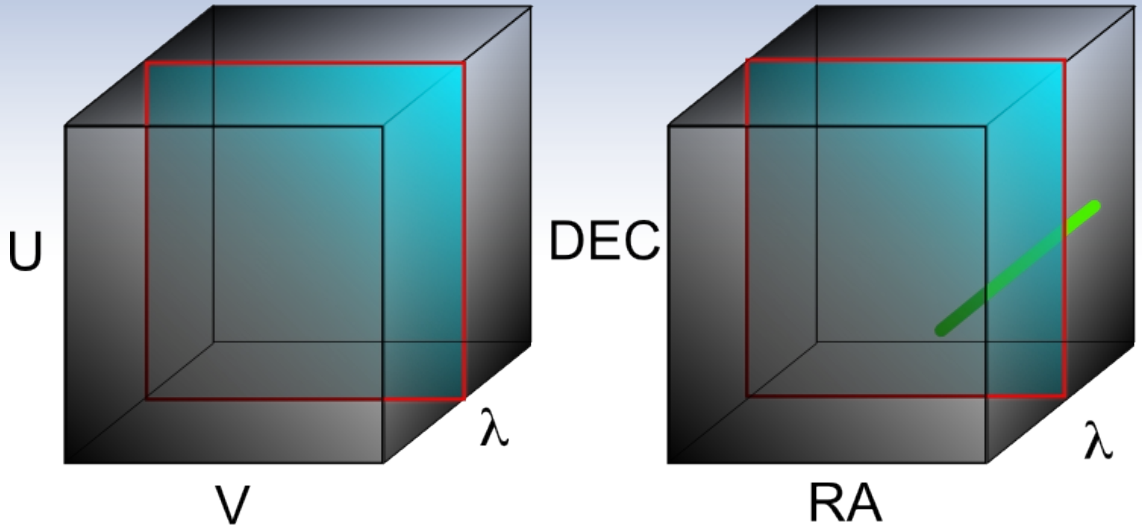
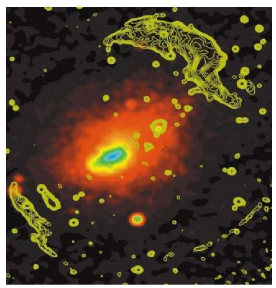
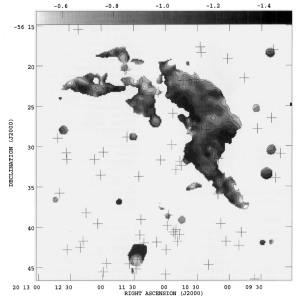


Aperture synthesis and deconvolution at single frequencies

Spectral interpolation method





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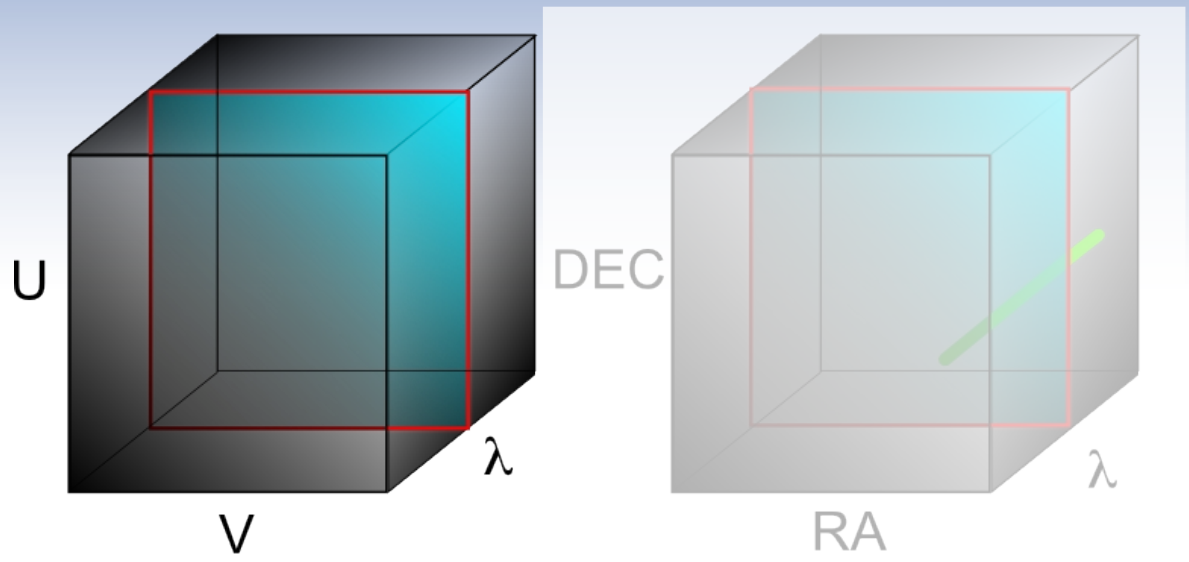

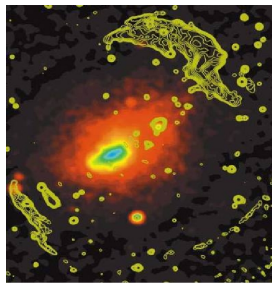

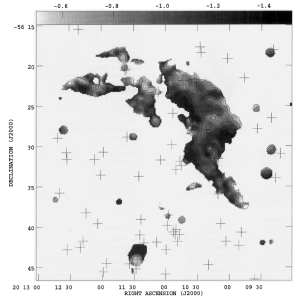

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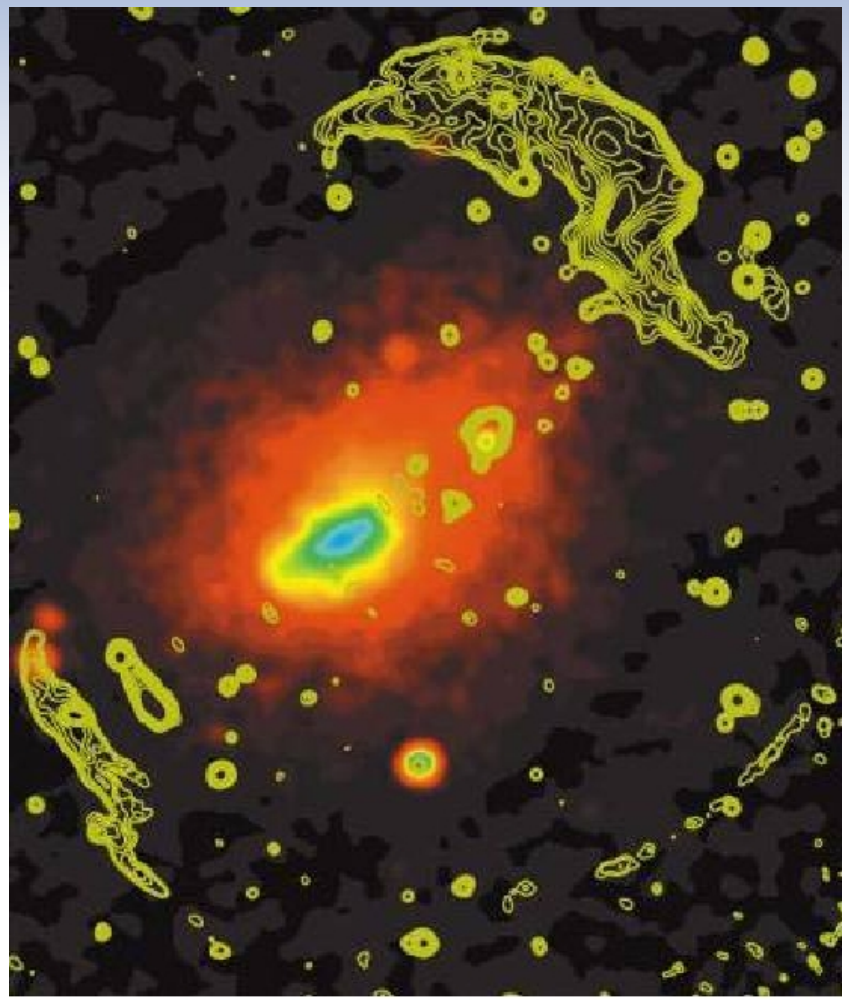

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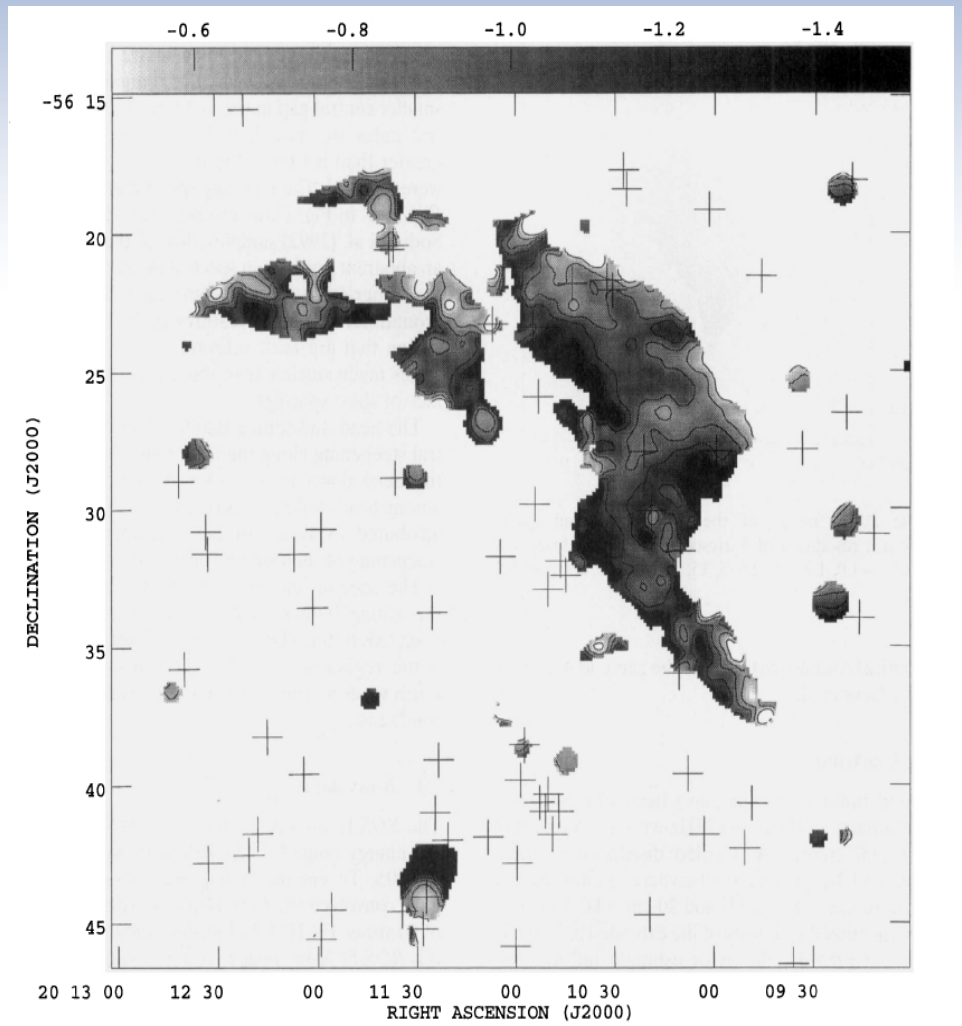

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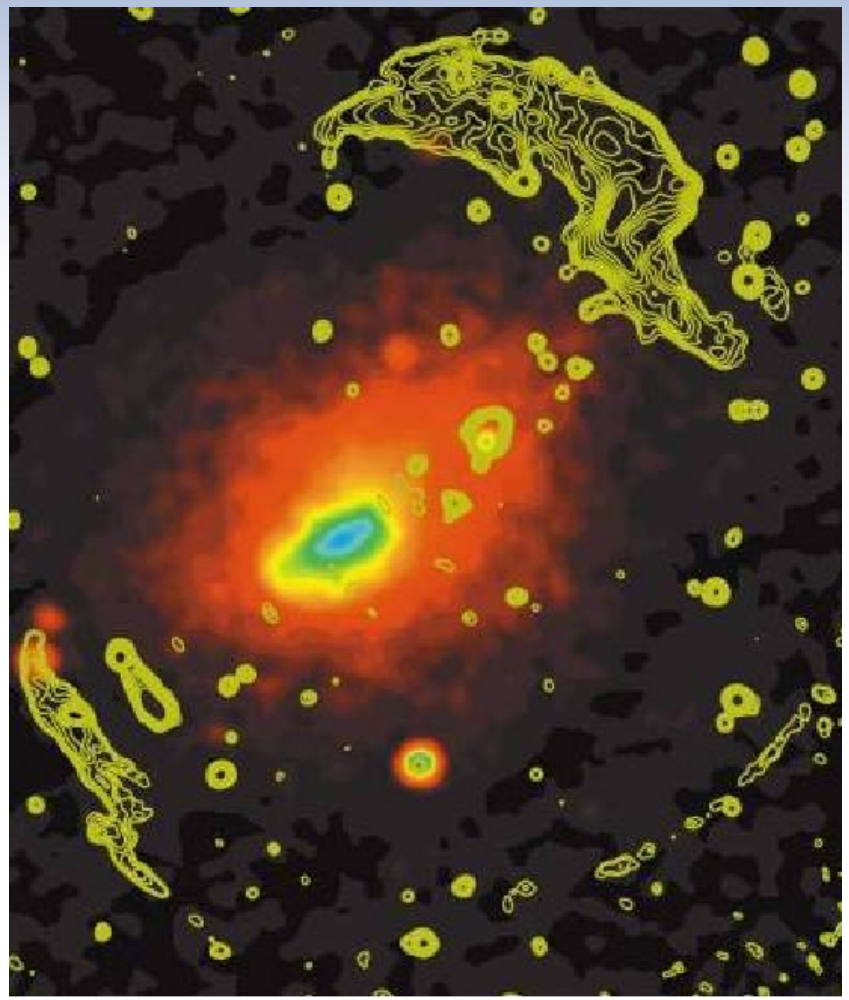

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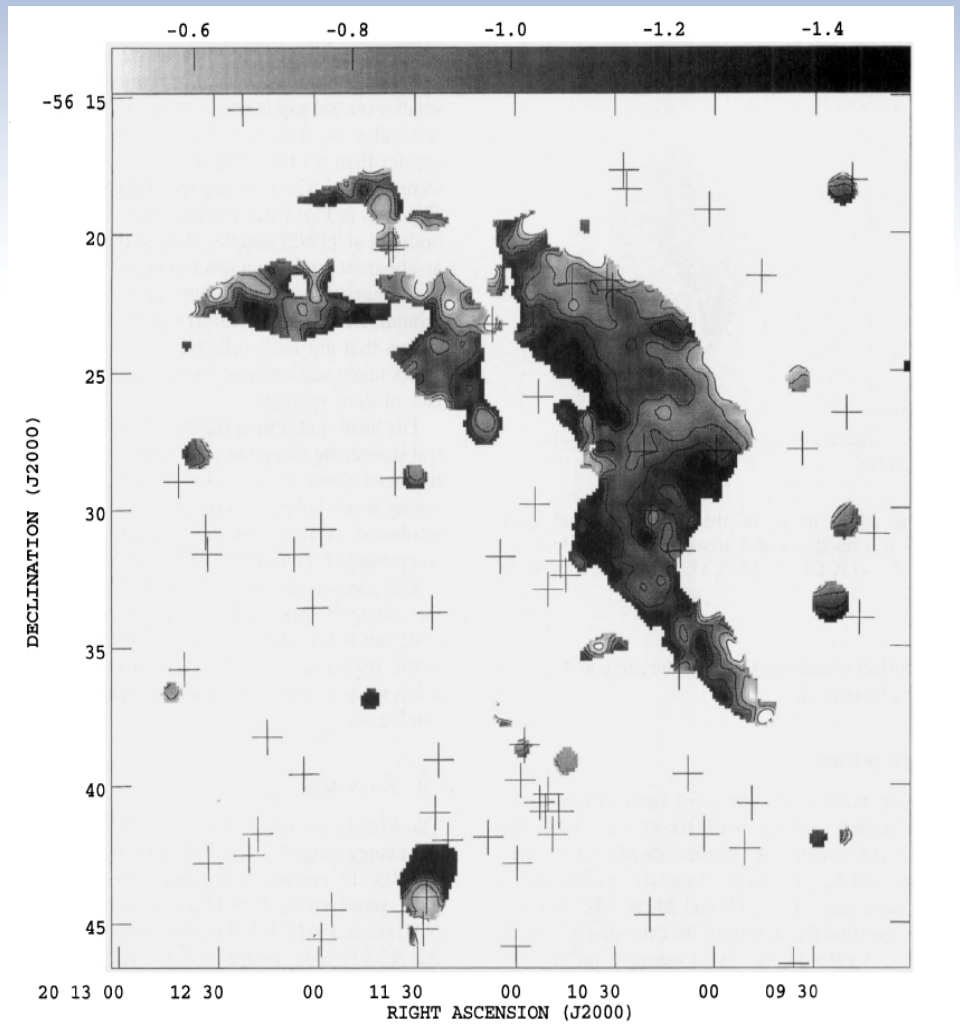

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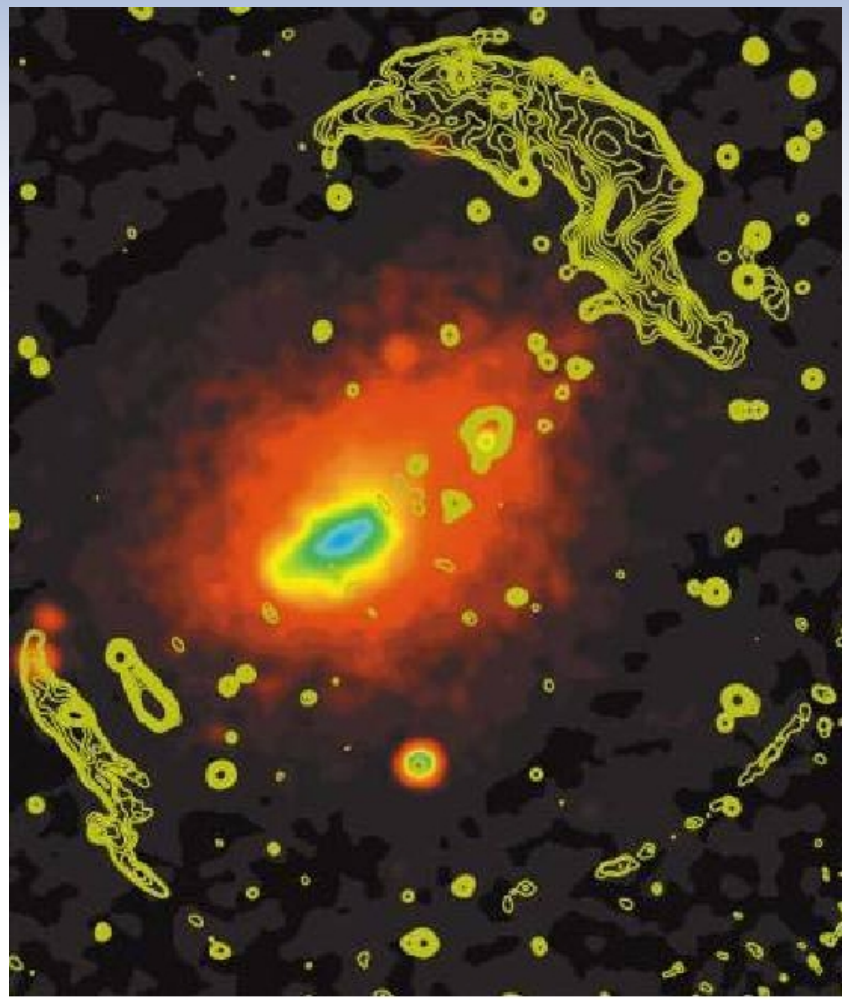

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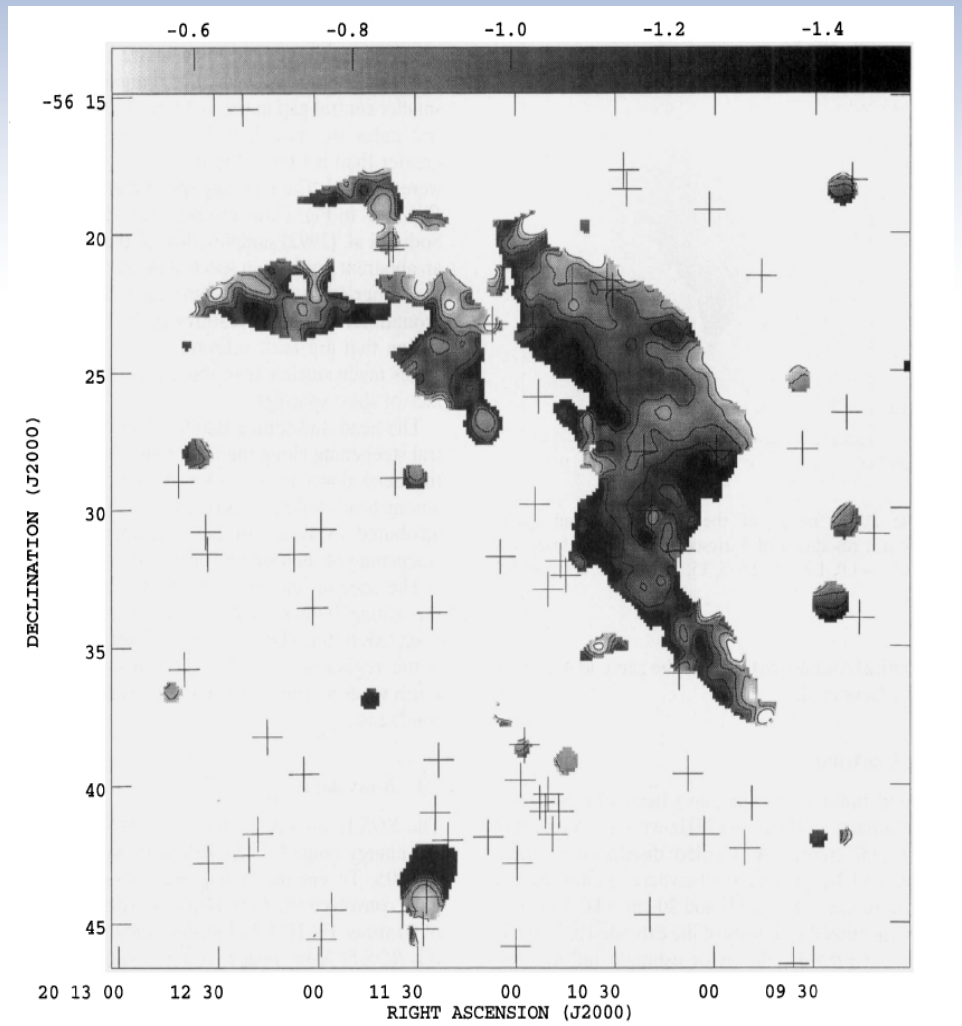

Röttgering et al., 1997

Introduction

Multi-frequency synthesis (MFS):

Technique of using measurements from several frequencies for aperture synthesis imaging.

(Conway et al. 1990)

Introduction

Spectral structure of source:

Synchrotron emission

power law spectrum

$$I(l,m,\nu) = I(l,m,\nu_0)\,(\frac{\nu}{\nu_0})^{-\alpha}$$

Introduction

Multi-frequency synthesis

uv - coverage

Improved uv-coverage:

$$u = b/\lambda$$

Introduction

Multi-frequency synthesis

uv - coverage

Improved uv-coverage:

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N antennas

$N(N-1)/2$ datapoints

Introduction

Multi-frequency synthesis

uv - coverage

Improved uv-coverage:

$$u = b/\lambda$$

N antennas

$N(N-1)/2$ datapoints

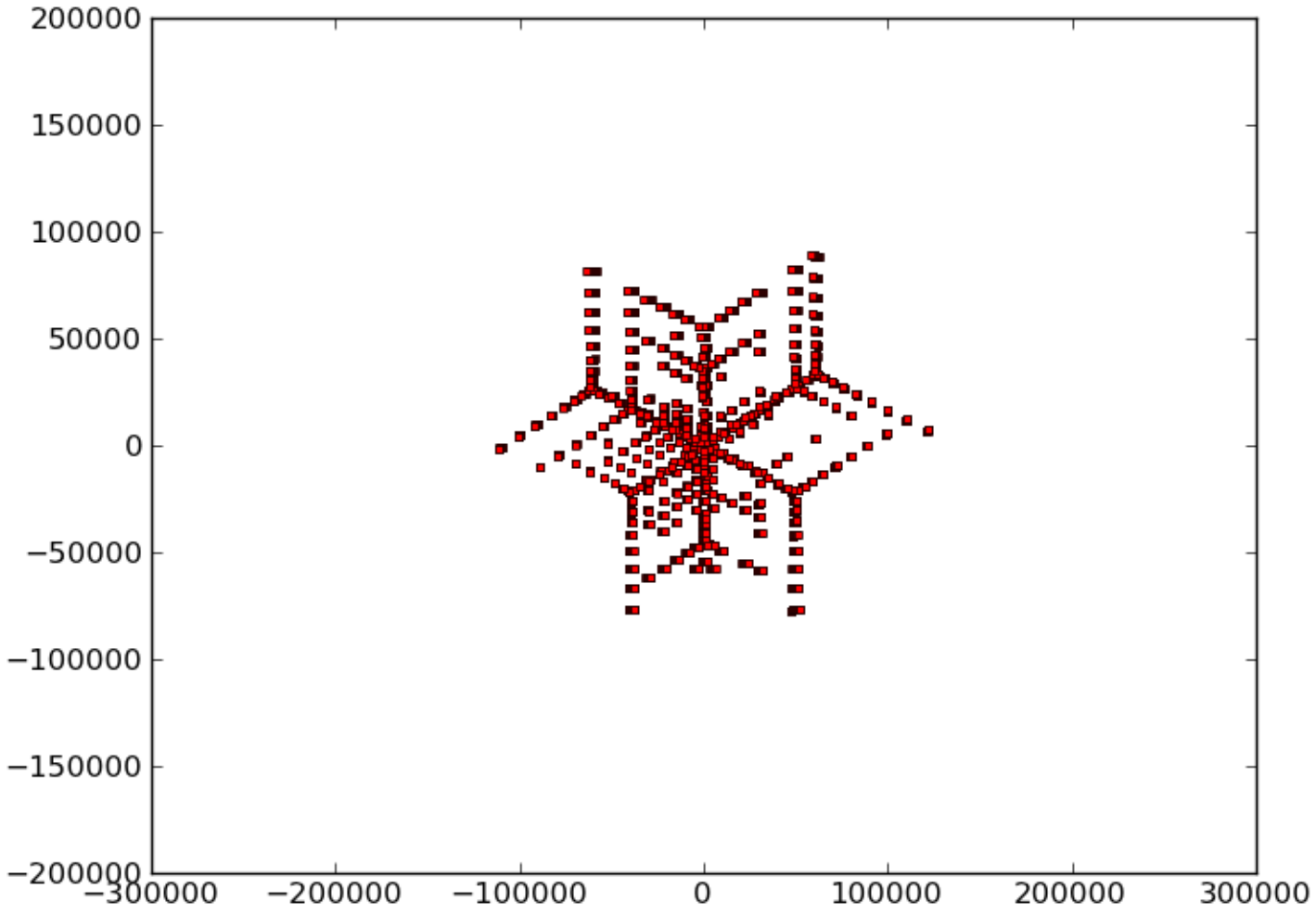
n_f channels → extra data

$\sim \sqrt{n_f}$ „antennas“

Introduction

Multi-frequency synthesis

uv - coverage

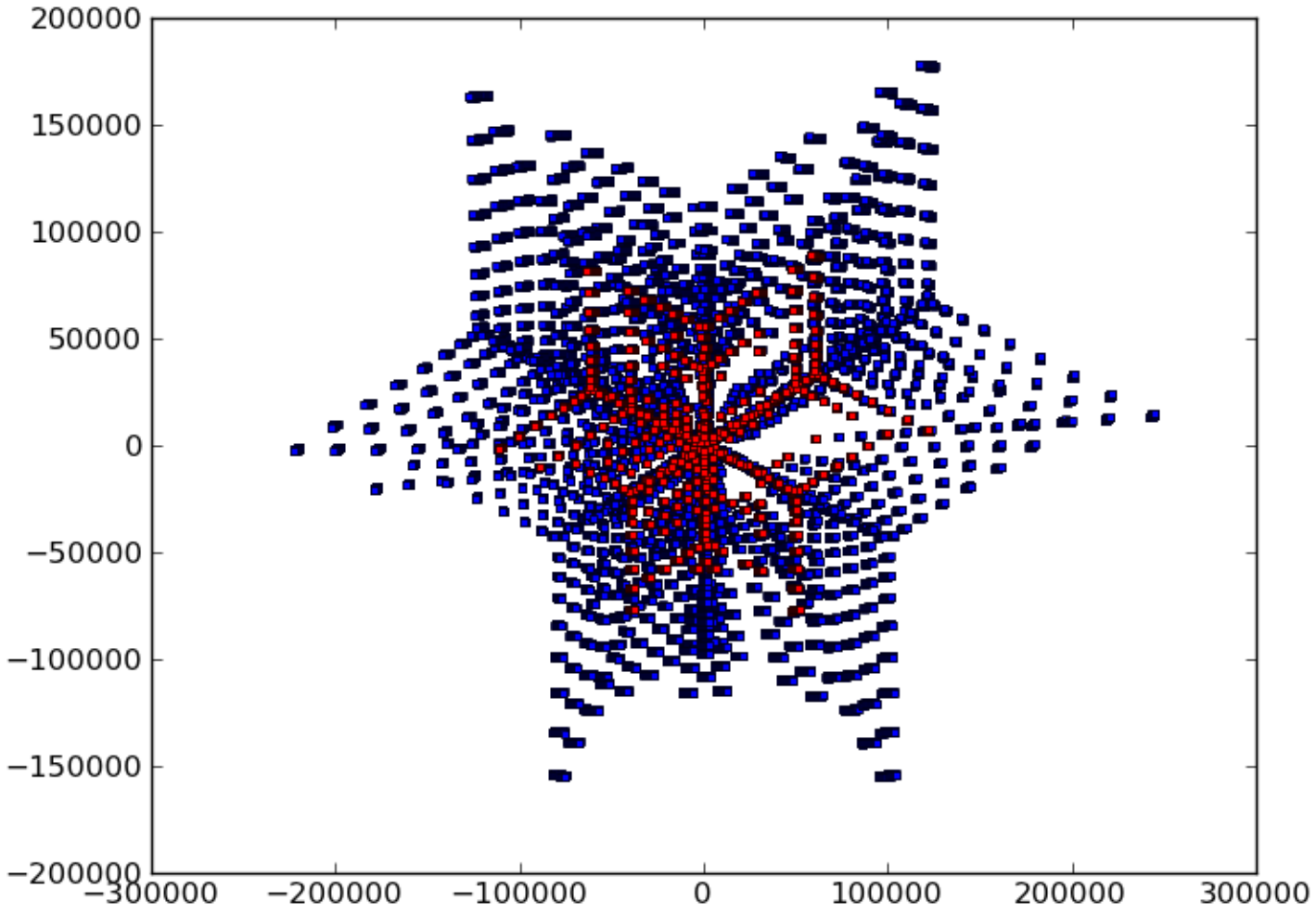


7020 datapoints

Introduction

Multi-frequency synthesis

uv - coverage



7020 *24 = 168480 datapoints

Introduction

Broad-Band interferometers:

new generation of radio interferometers provide tremendously increased bandwidth.

Introduction

New Instruments

Broad-Band interferometers:

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EVLA

up to 8 GHz bandwidth

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32 (48) MHz bandwidth per station beam at very low frequencies

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up to 8 GHz bandwidth

LOFAR

32 (48) MHz bandwidth per station beam at very low frequencies

ASKAP

300 MHz bandwidth

Introduction

Current status:

Introduction

Current status:

- Imaging of diffuse fields: CLEAN

Introduction

Current status:

- Imaging of diffuse fields: CLEAN and MEM

Introduction

Current status:

- Imaging of diffuse fields: CLEAN and MEM and recently MS-CLEAN (Cornwell ,2008)

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- MFS with Double Deconvolution (DD), (Conway et al. 1990)

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- Diffuse imaging and MFS: MF-MS CLEAN (Rau et al. 2011), implemented in CASA

Introduction

Problems?

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Introduction

Problems!

Current status:

- Expansions of $I(l, m, \nu)$ → full bandwidth can't be used.

Introduction

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Solutions

Our proposal:

- Expansions of $I(l, m, \nu)$ → full bandwidth can't be used.
- Full $I(l, m, \nu)$ over all frequencies.
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Bayesian Approach

New Method

Solutions

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Bayesian Approach

Bayes Theorem

$$\mathcal{P}(s|d) = \frac{\mathcal{P}(d|s)\ \mathcal{P}(s)}{\mathcal{P}(d)}$$

Bayesian Approach

Bayes Theorem

Likelihood

Prior

$$\mathcal{P}(s|d) = \frac{\mathcal{P}(d|s)\ \mathcal{P}(s)}{\mathcal{P}(d)}$$

Posterior

Evidence

Bayesian Approach

Data model

$$d = Rs + n$$

Response

$$Rs = S(u,v)\,\mathcal{FT}\left[B(l,m)\;I(l,m,\nu_0)\;\left(\frac{\nu}{\nu_0}\right)^{-\alpha}\right]$$

Bayesian Approach

Data model

$$d = Rs + n$$

Response

$$Rs = S(u,v)\,\mathcal{FT}\left[B(l,m)\,I(l,m,\nu_0)\left(\frac{\nu}{\nu_0}\right)^{-\alpha}\right]$$

Bayesian Approach

Signal reconstruction

$$map = \langle s \rangle_{\mathcal{P}(s|d)}$$

Bayesian Approach

Signal reconstruction

$$map = \langle s \rangle_{\mathcal{P}(s|d)}$$

- Simultaneously for both signals
- Using interative algorithms

Bayesian Approach

Wiener Filter

$$map = \langle s \rangle_{\mathcal{P}(s|d)} = Dj$$

Bayesian Approach

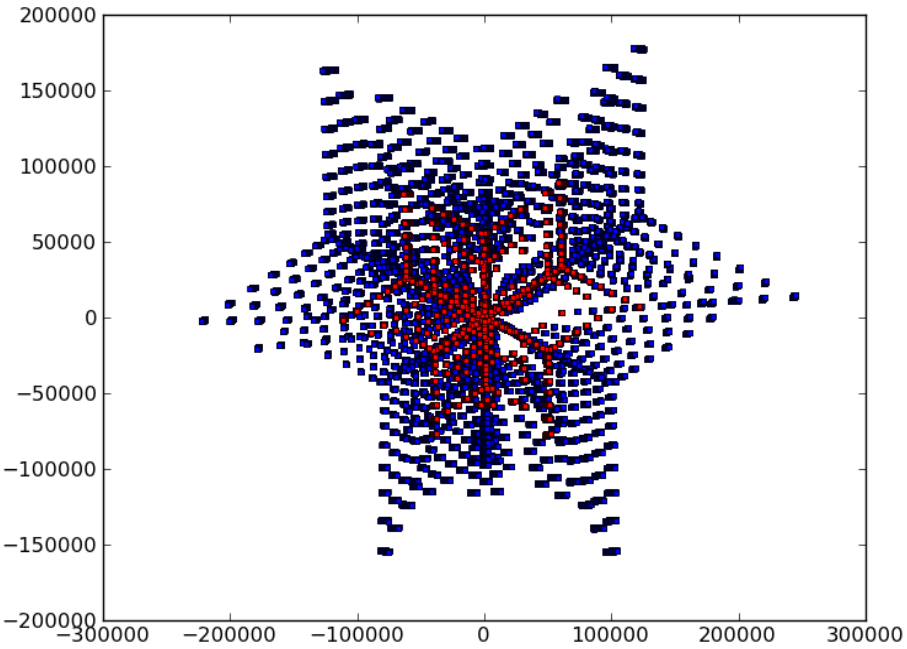
Wiener Filter

$$map = \langle s \rangle_{\mathcal{P}(s|d)} = D\,j$$

- Gaussian signal prior
- Gaussian noise
- Gaussian posterior with covariance D
- j ~ noise weighted data

First Results

Simulated VLA – observation of a Gaussian signal field

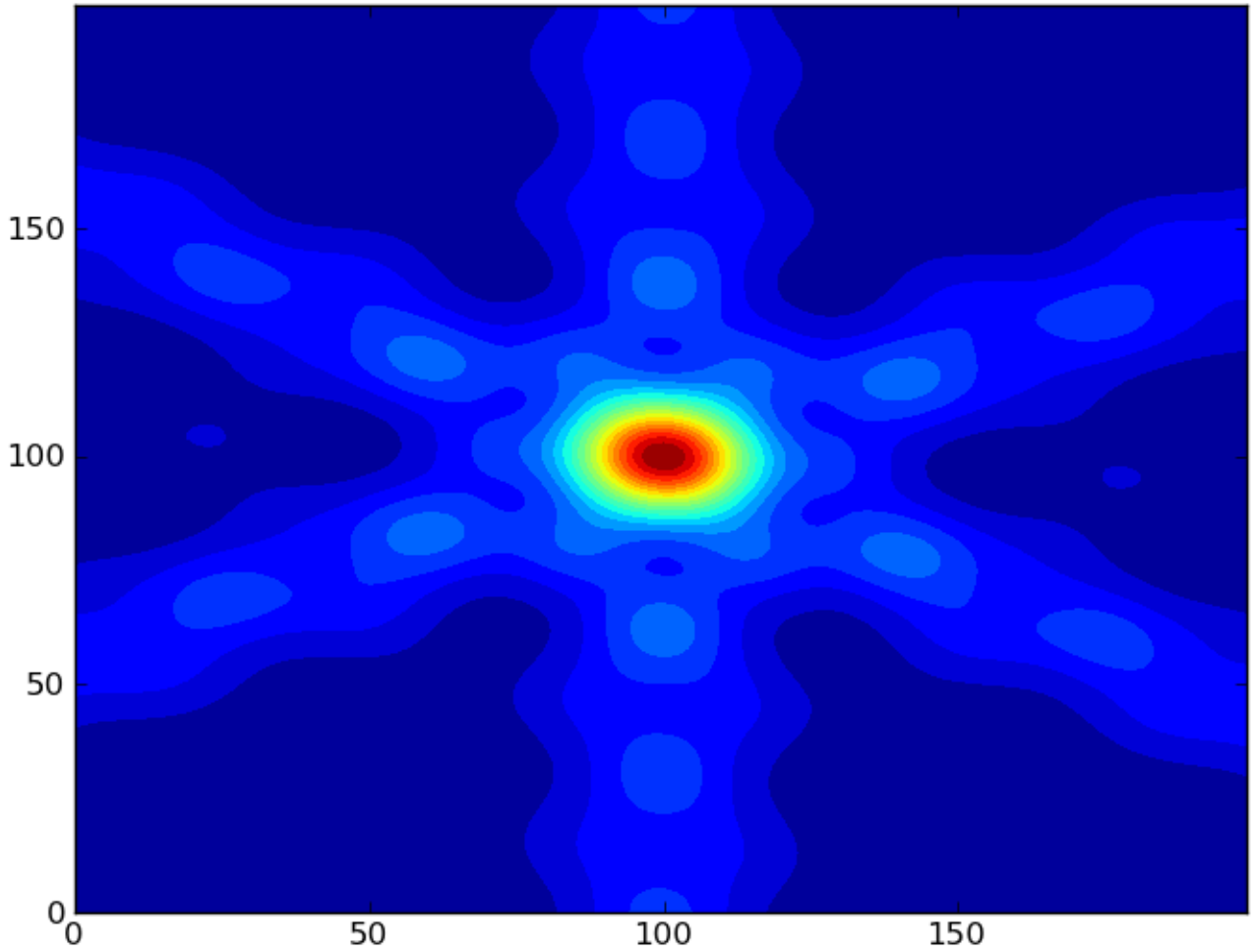


- VLA-A-configuration
- 24 frequencies between 1 – 4 GHz
- 7020 visibilty points per frequency
- Low noise
- No primary beam
- Spectral index assumed to be known
- Spatial correlation structure assumed to be known as well

First Results

Simulated observation

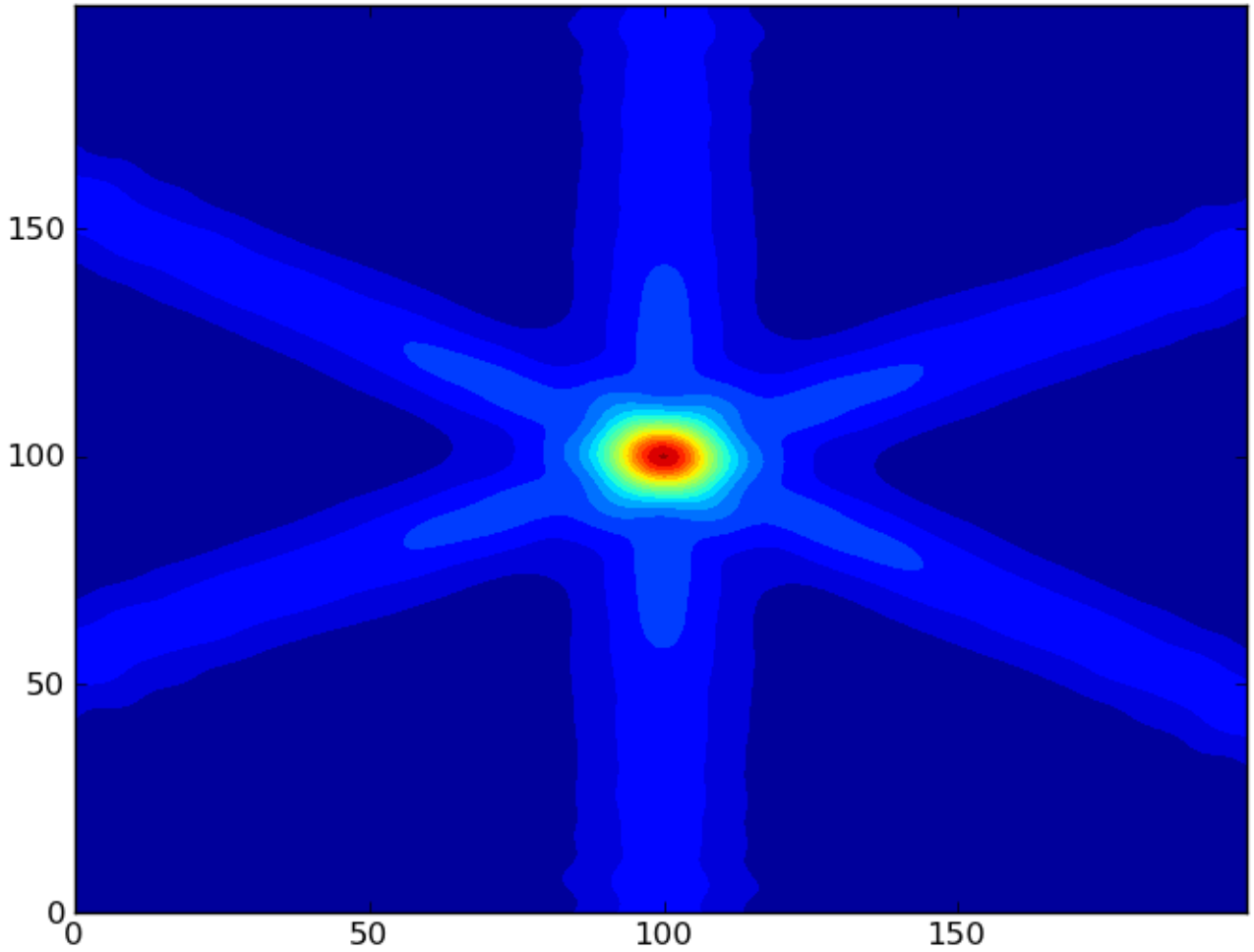
Dirty beam at reference frequency



First Results

Simulated observation

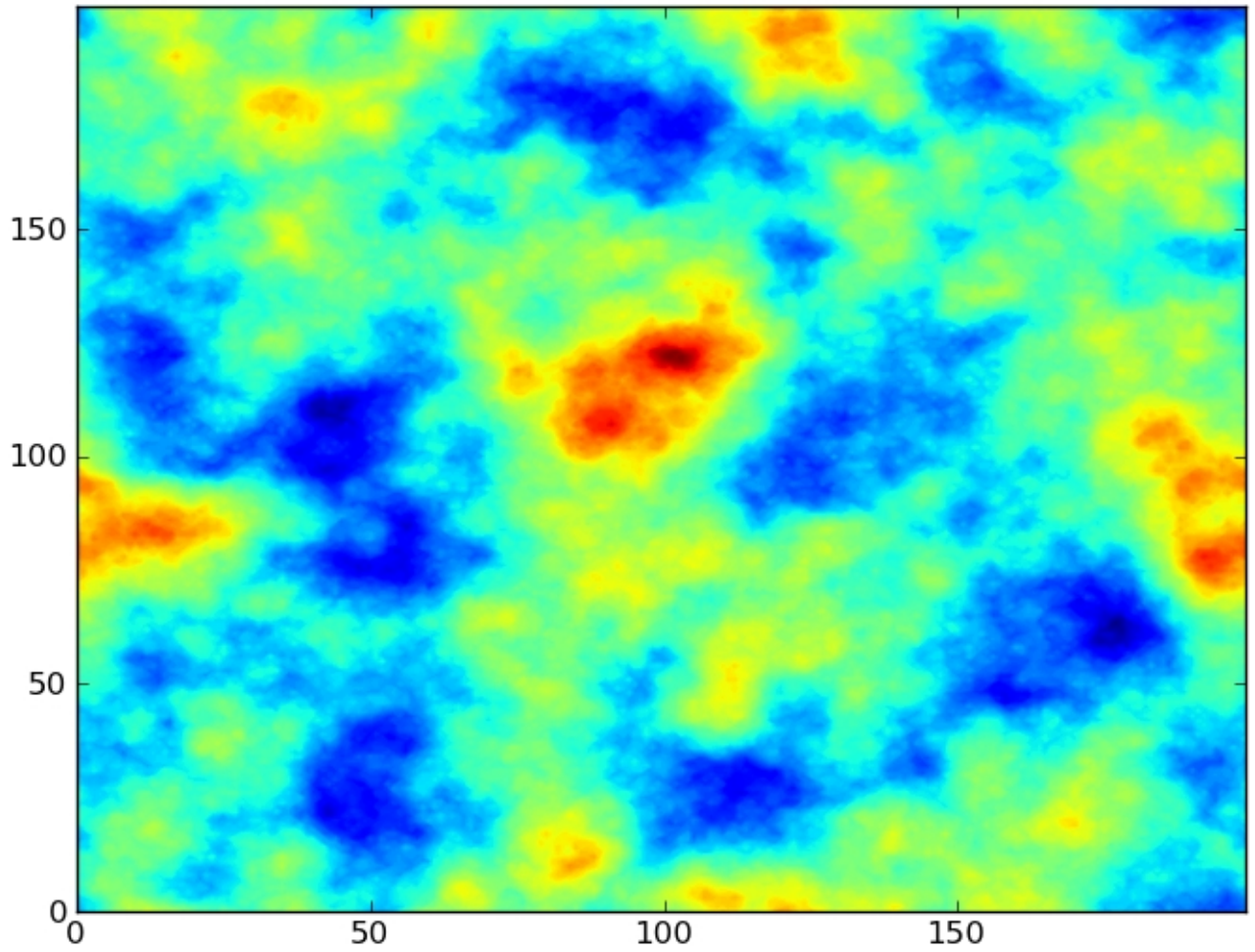
...and using the full mfs-uv coverage



First Results

Simulated observation

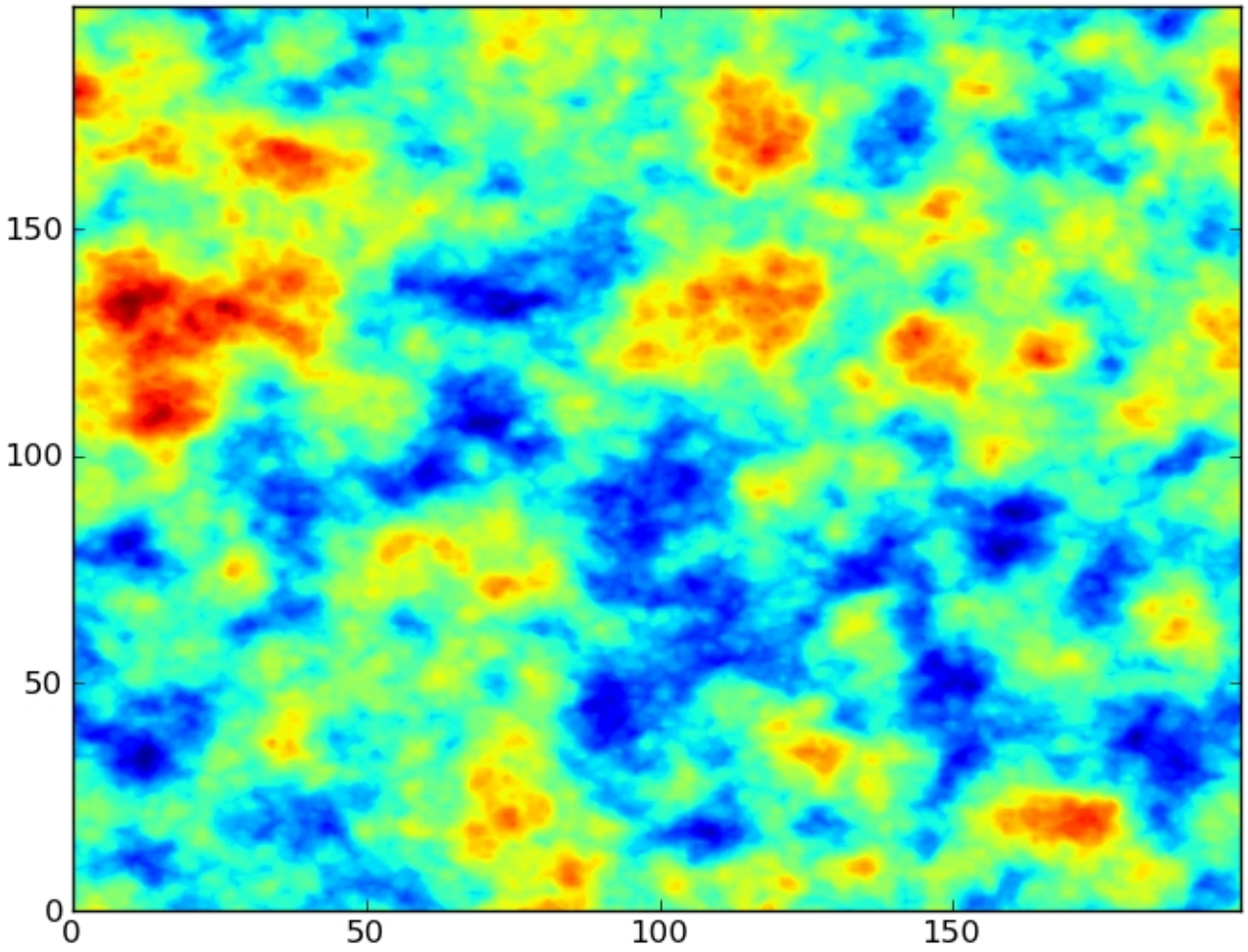
Spectral index signal



First Results

Simulated observation

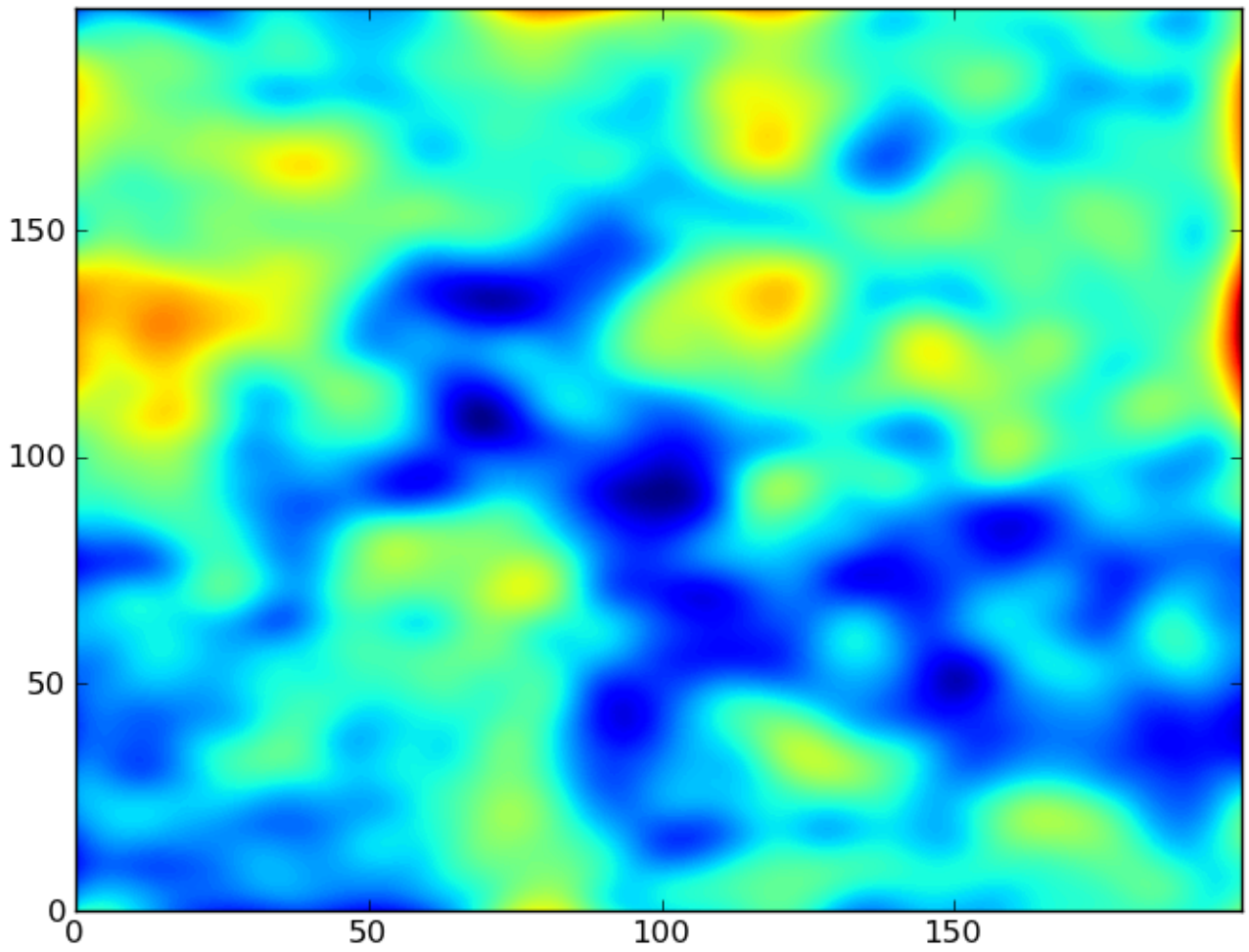
Total intensity signal



First Results

Simulated observation

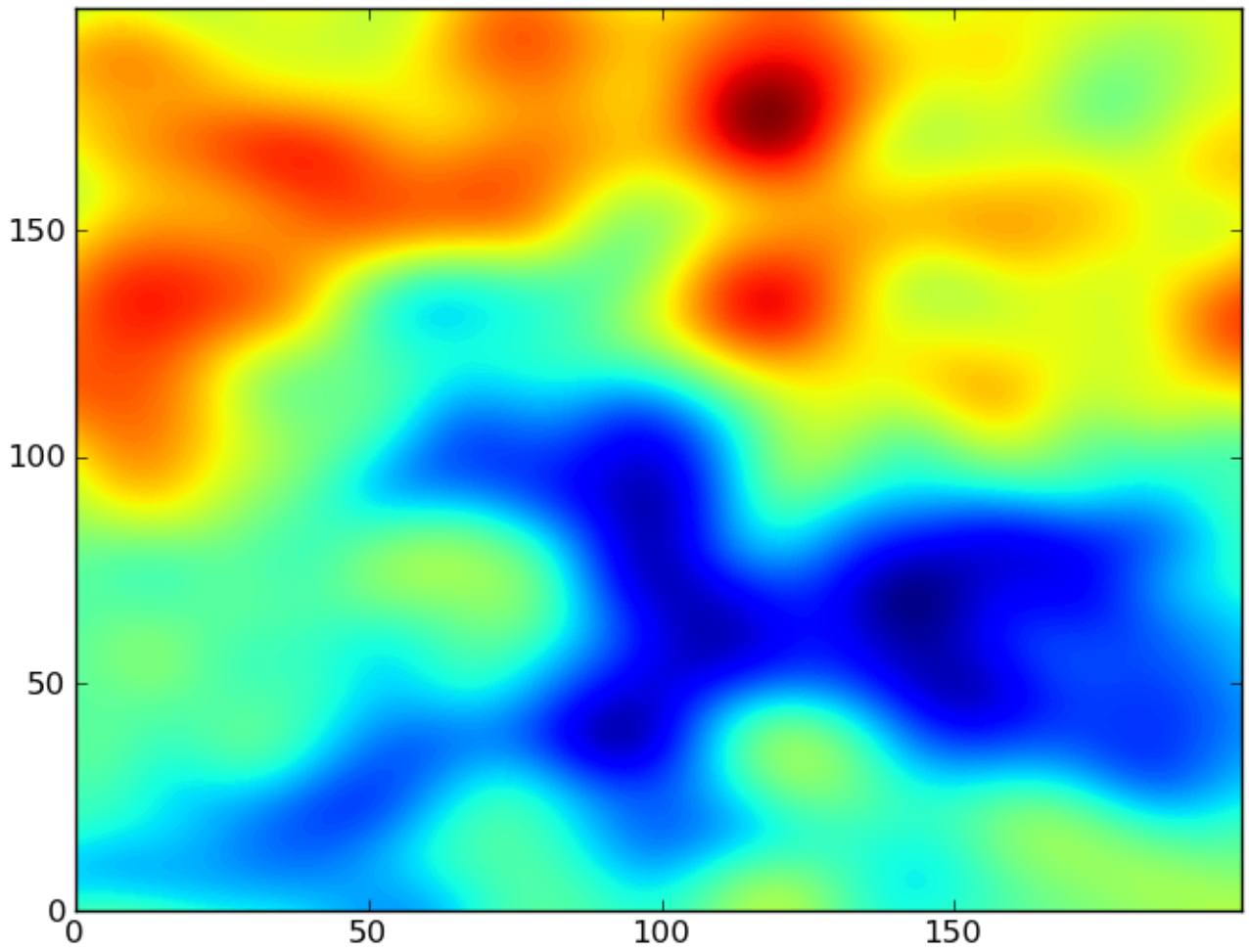
Signal reconstruction using all frequencies



First Results

Simulated observation

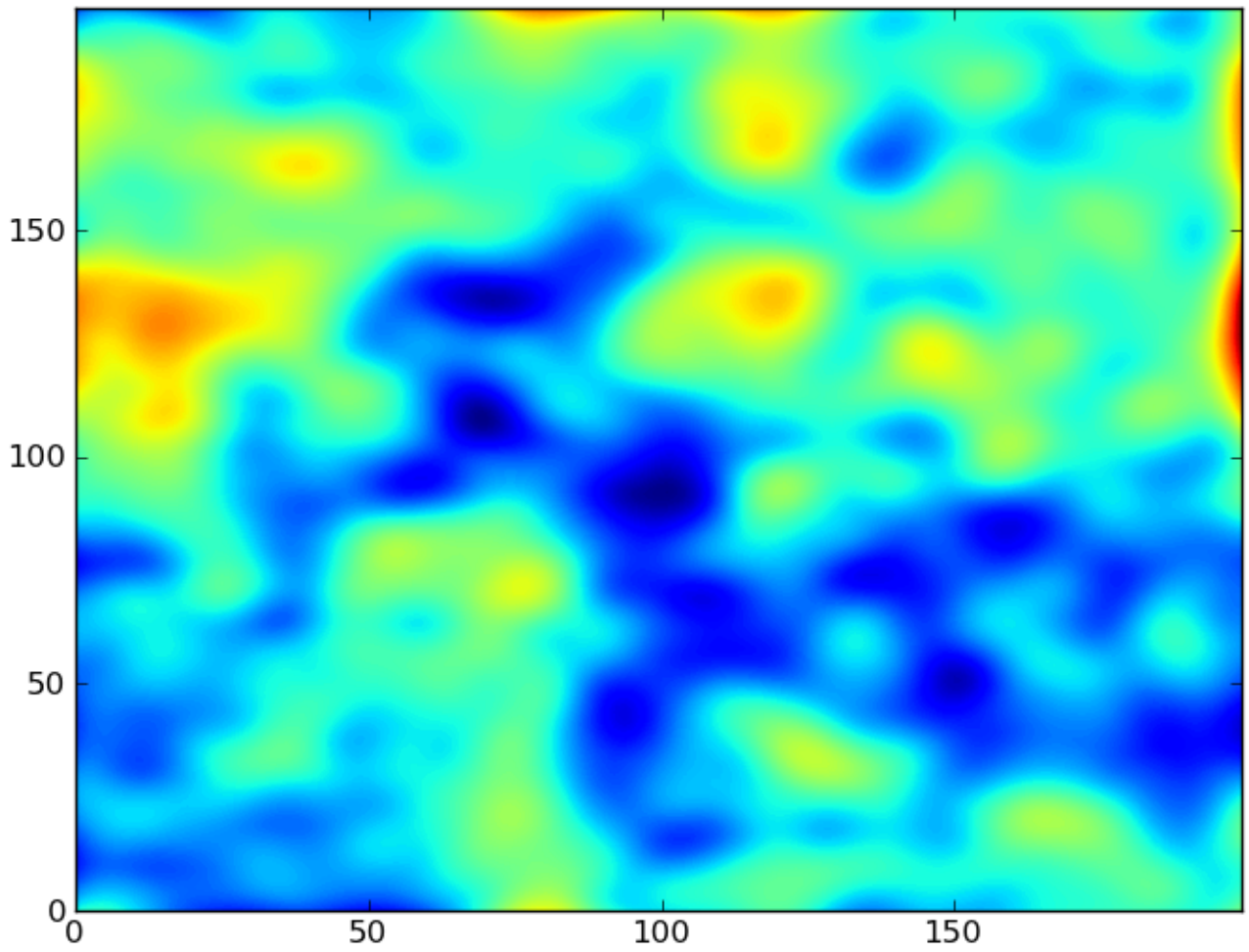
Dirty image at reference frequency



First Results

Simulated observation

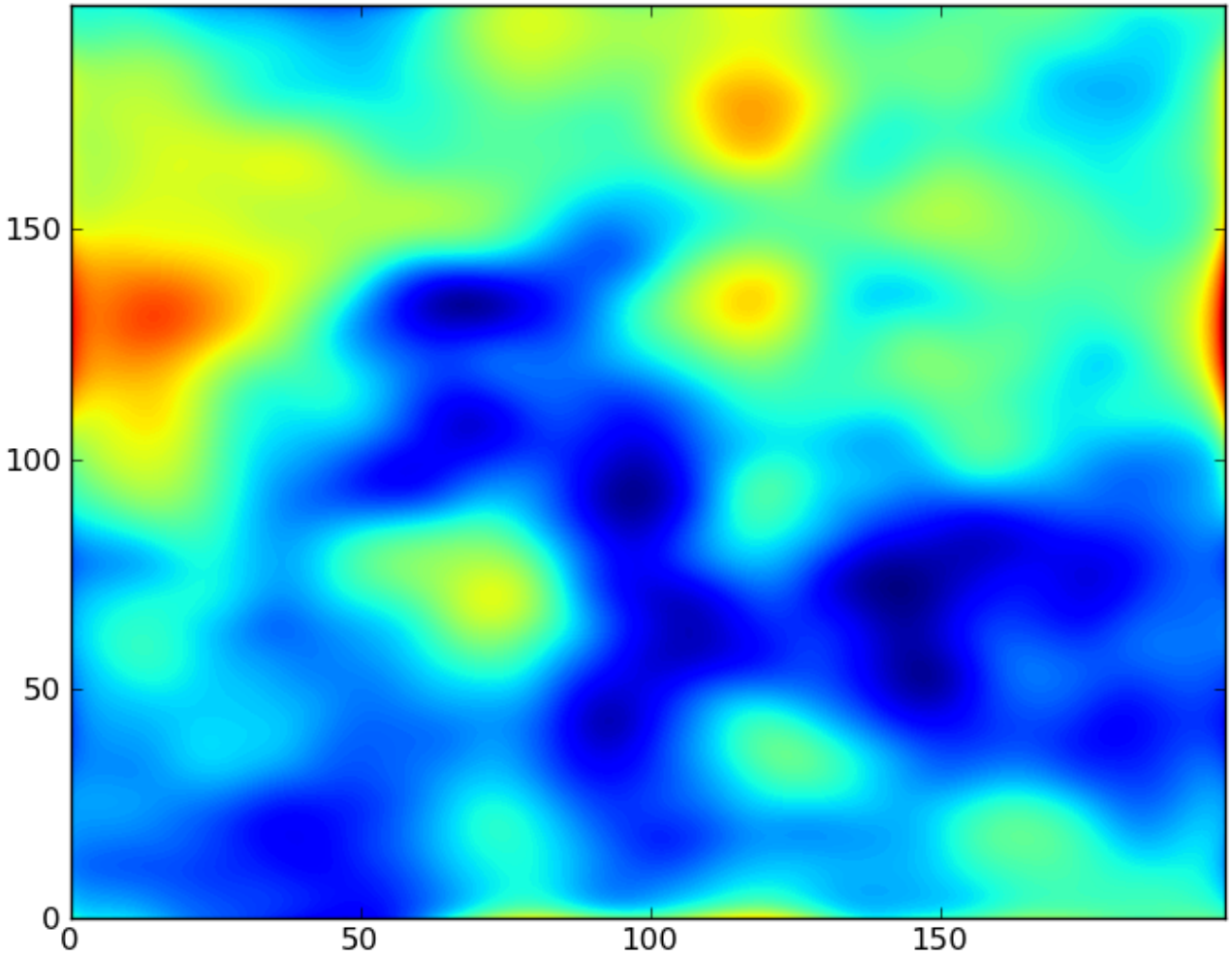
Signal reconstruction using all frequencies



First Results

Simulated observation

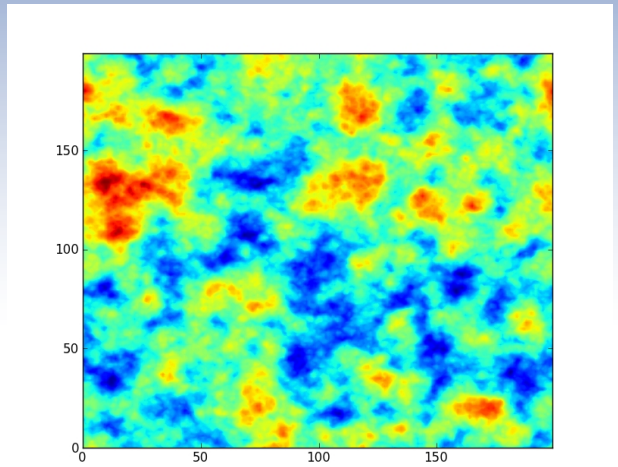
MS-MF-CLEAN image with CASA



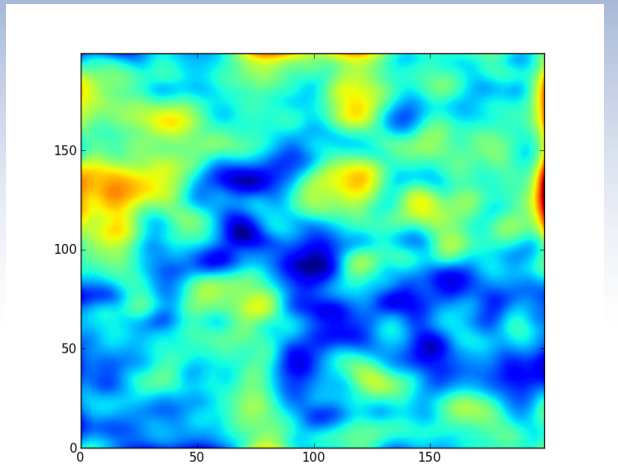
First Results

Simulated observation with low noise and no pimary beam

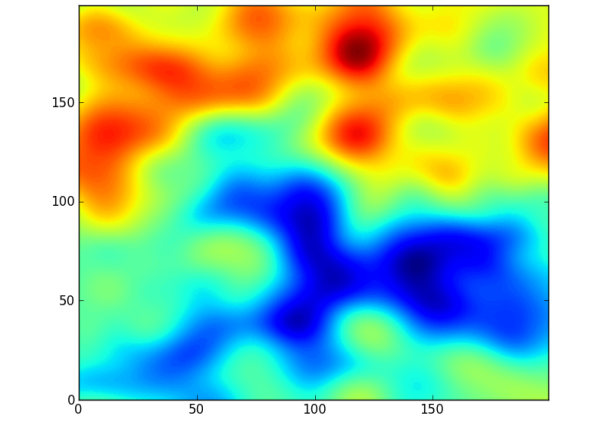
Signal



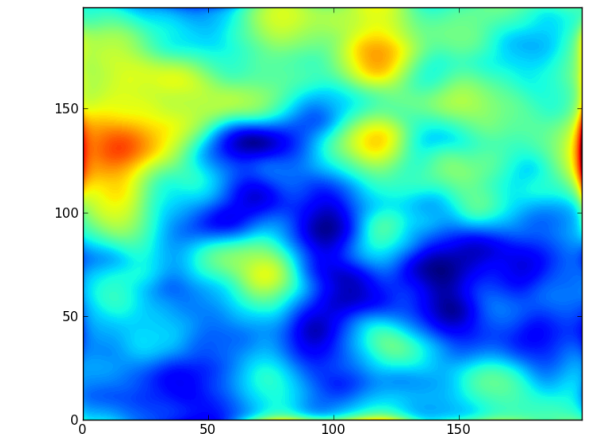
Signal reconstruction



Dirty image



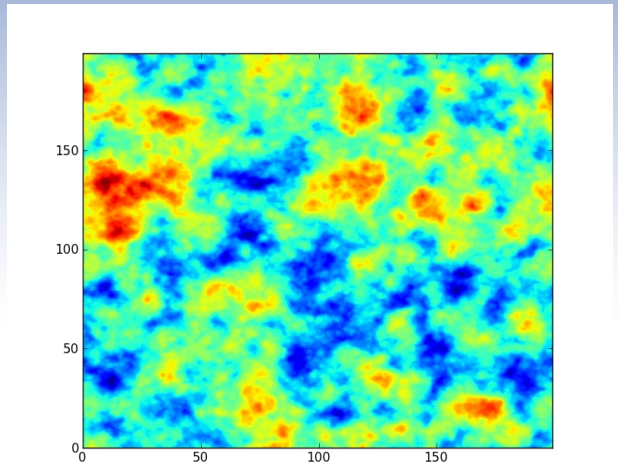
MF-MS-CLEAN



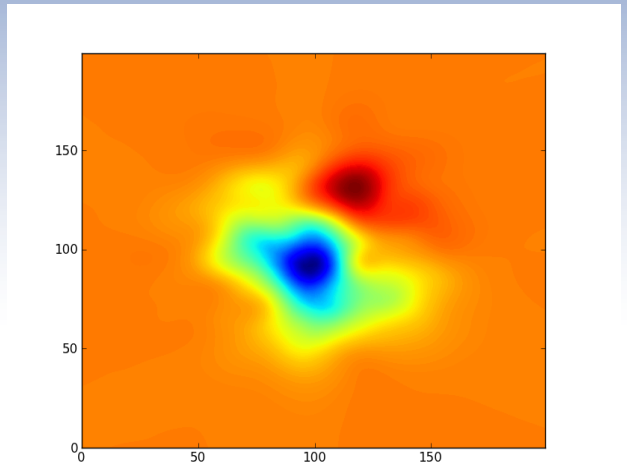
First Results

Simulated observation with high noise and pimary beam

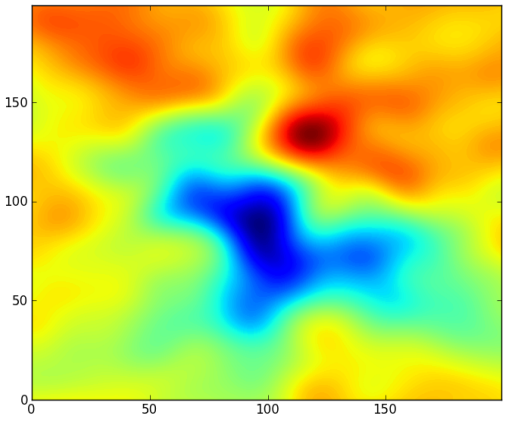
Signal



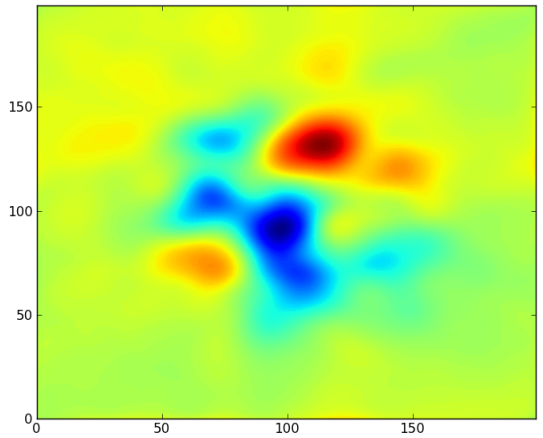
Signal reconstruction



Dirty image

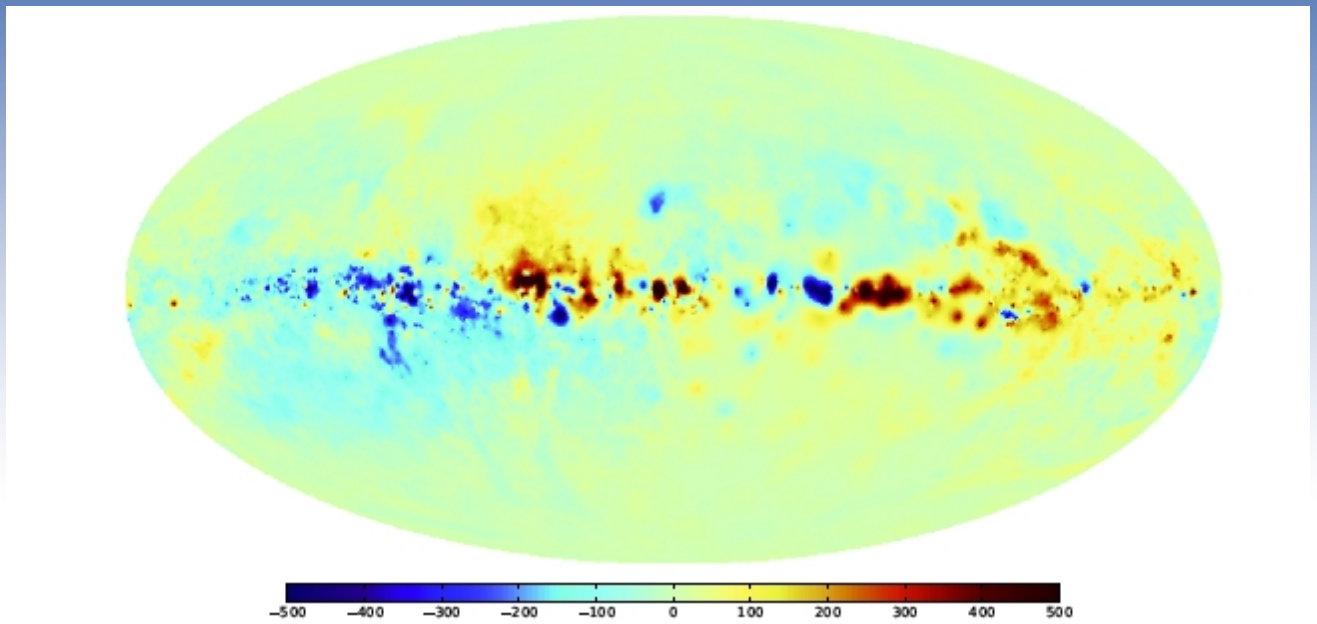


MF-MS-CLEAN



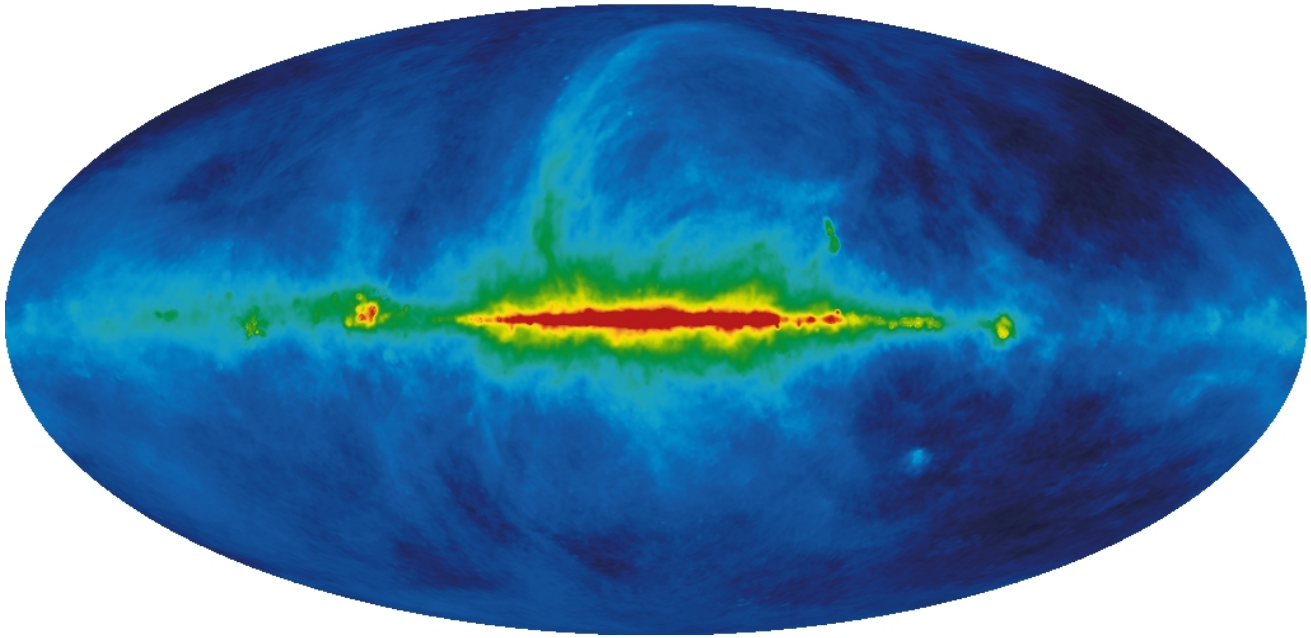
Outlook

Gaussian signal fields?



(Oppermann et al. 2012)

Faraday all sky map

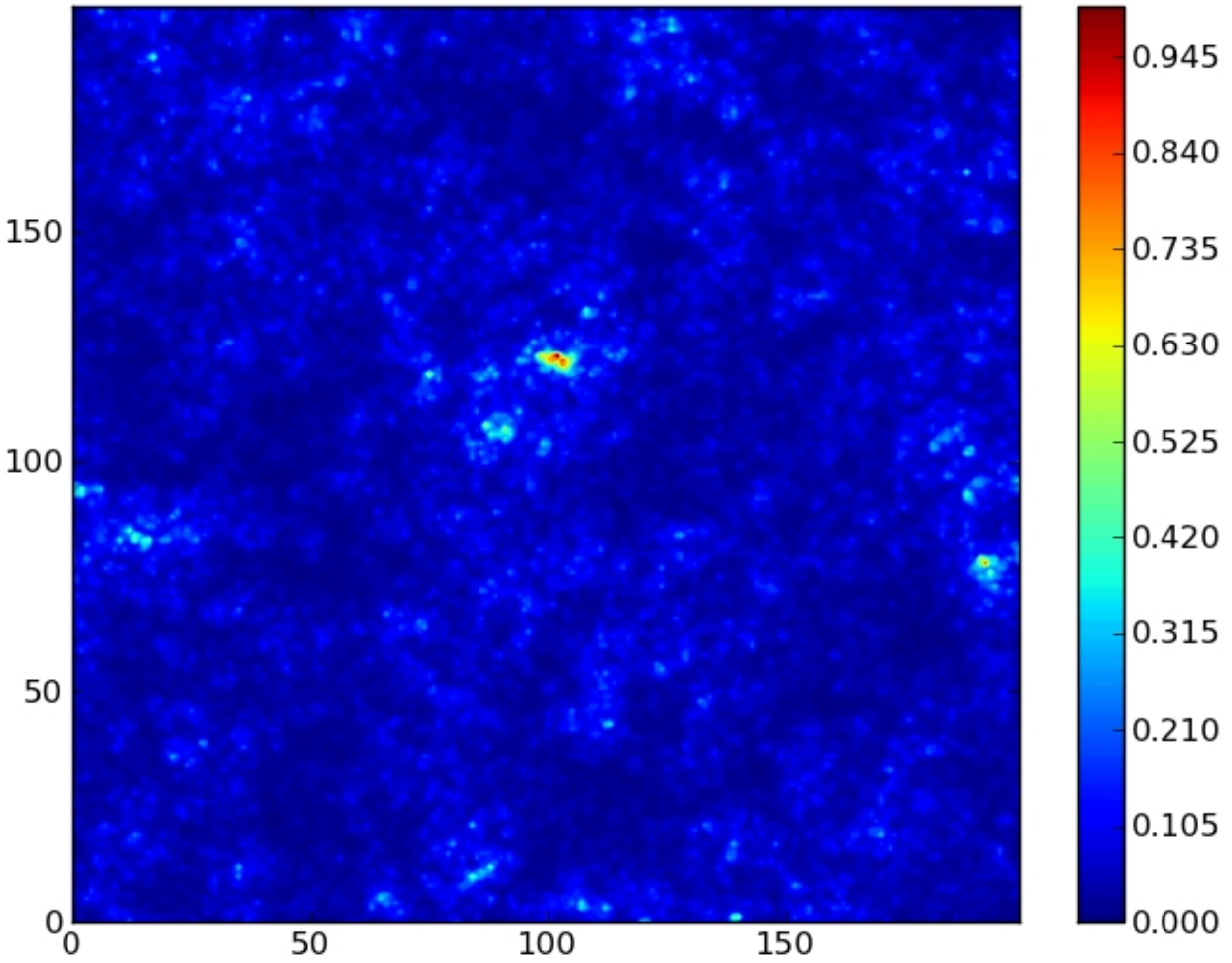


(Haslam et al. 1982)

408 MHz

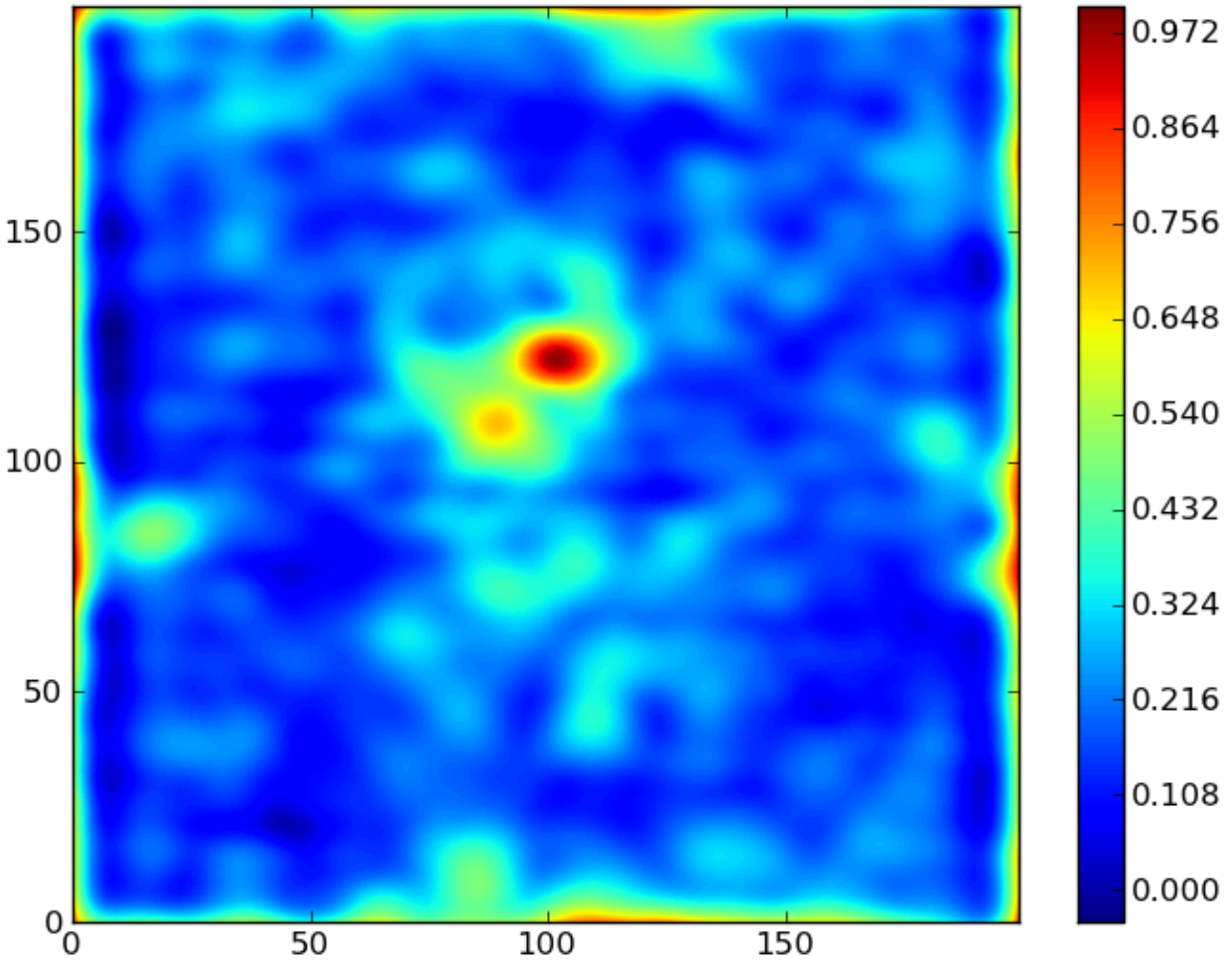
Outlook

More realistic signal priors



Outlook

More realistic signal priors



Conclusions

- New, fully Bayesian approach to MFS and imaging of diffuse fields
- Allows to make full use of modern broadband data
- First Results on mock data : WF
- Next step: reconstruction of total intensity and spectral structure simultaneously