How accurately do our imaging algorithms reconstruct intensities and spectral indices of weak sources ?

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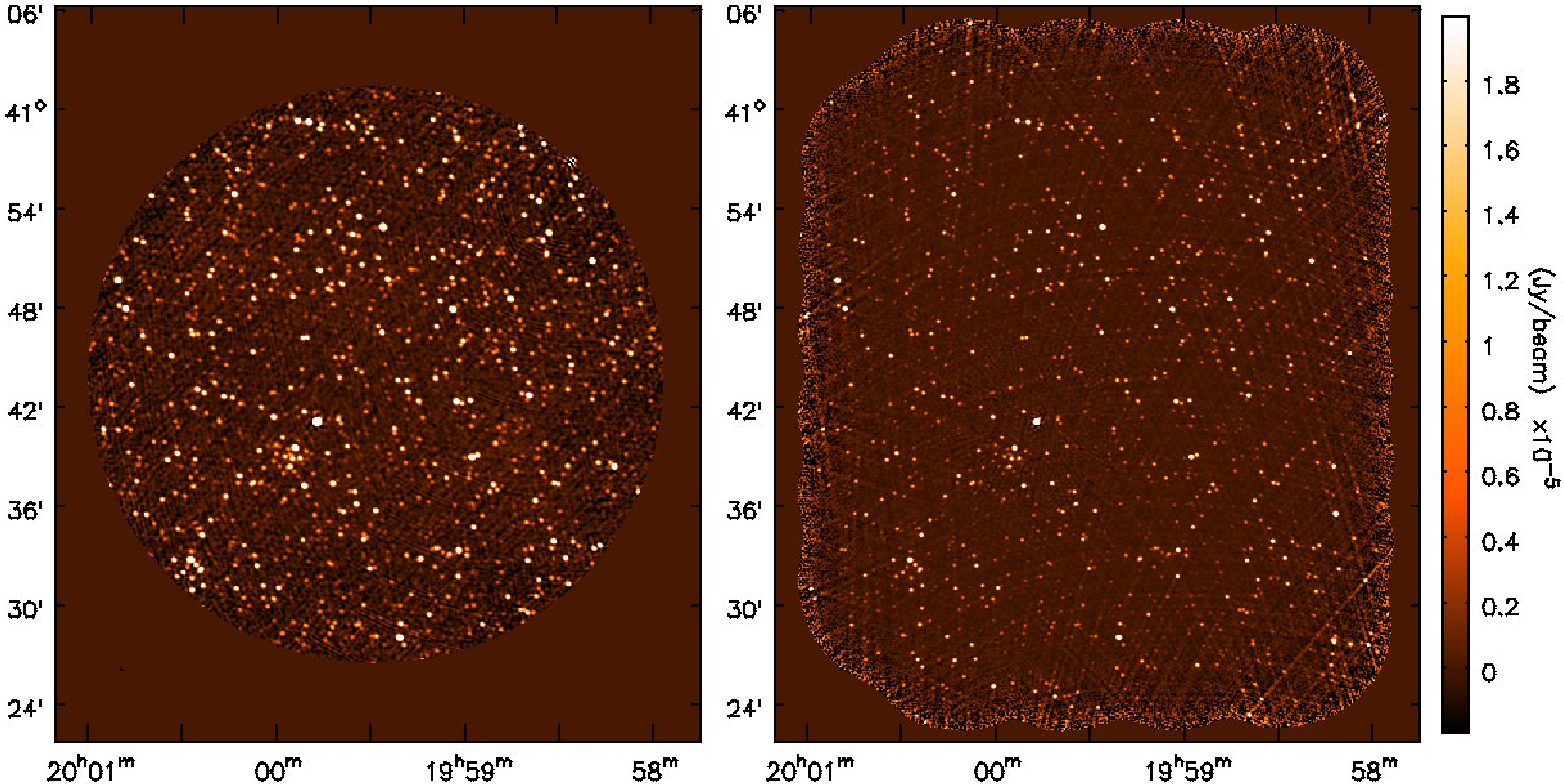
8th SKA Calibration and Imaging Workshop, Kiama, NSW, Australia (6 March 2014)



VLA Wide-band wide-field simulations : (LEFT) L-Band, C-config, 1-pointing , (RIGHT) C-band, D-config, 46 pointings

Simulation Parameters : One Pointing, L-Band (1-2 GHz), C-config

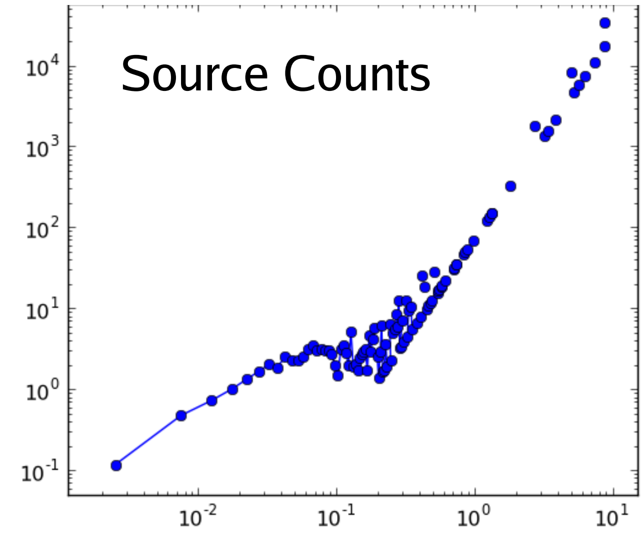
Sky : ~8000 point sources within one deg^2 (SCube)
Sources at pixel centers (+ compared with not)

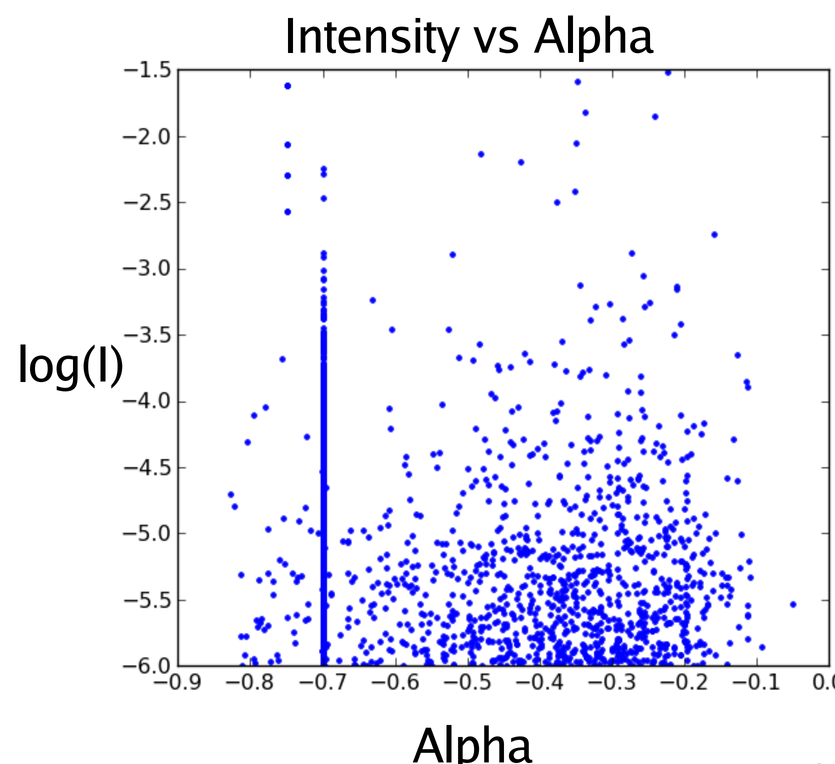
Intensity : between 1 micro Jy and 7 mJy.
(+ one 100 mJy source for HDR test)

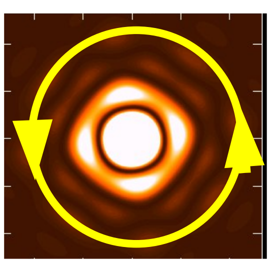
Spectral indices : between 0.0 and -0.8.

Observation : 16 channels/spws across 1-2 GHz
One snapshot every 20 minutes, for 4 hrs
(compare with one snapshot
every 2 minutes, for 4 hrs)

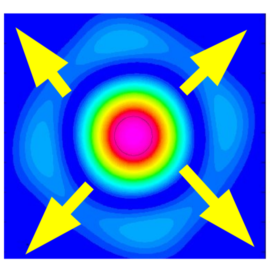
Data Prediction : Visibilities were calculated using the Wideband A-Projection de-gridder. No noise.



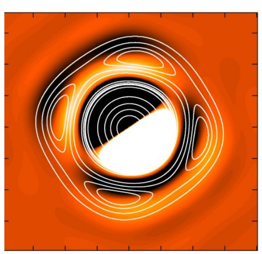



PB (time)

+


PB (freq)

+


PB (pol)

Imaging Options : Wideband MFS [yes/no], A-Projection [yes/no]

MT-MFS (nterms>1)

Multi-term MFS (wideband) Imaging

+

Absorb PB spectrum into sky model

+

Post-deconvolution Wideband PBcor for intensity and alpha

Rau & Cornwell, 2011, Sault &Wieringa 1994

MT-MFS + WB-A-Projection

Multi-term MFS with wideband A-Projection to remove PB spectrum during gridding

+

Minor cycle sees only sky spectrum

+

Post-deconvolution PBcor of intensity only.

Bhatnagar, Rau, Golap, 2013

Cube

Per channel Hogbom/Clark/CS Clean

+

Per channel post-deconvolution Pbcor

+

Smooth to lowest resolution

+

Fit spectrum per pixel, Collapse channels

Hogbom 1974, Clark 1980, Schwab & Cotton 1983, Schwarz, 1978

Cube + A-Projection

Same as Cube,

- with narrow-band A-Projection per channel

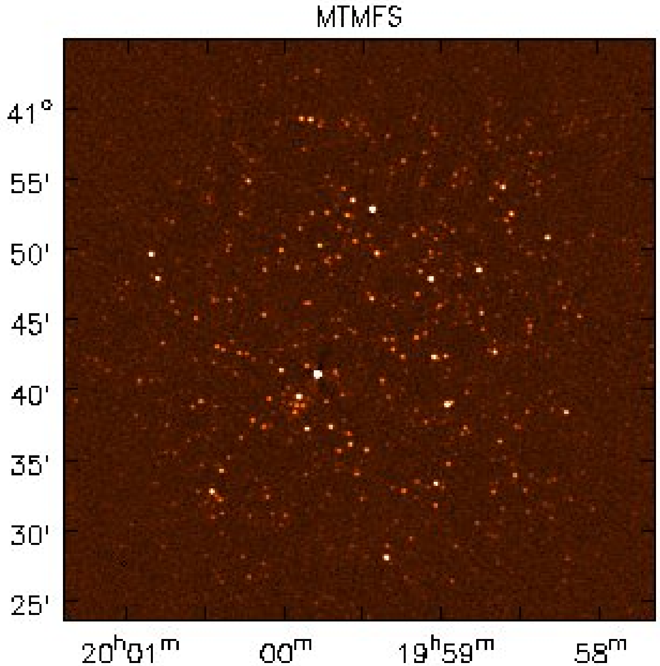
(A-Projection : Construct gridding convolution operators from antenna aperture illumination models. Removes beam squint and accounts for aperture rotation)

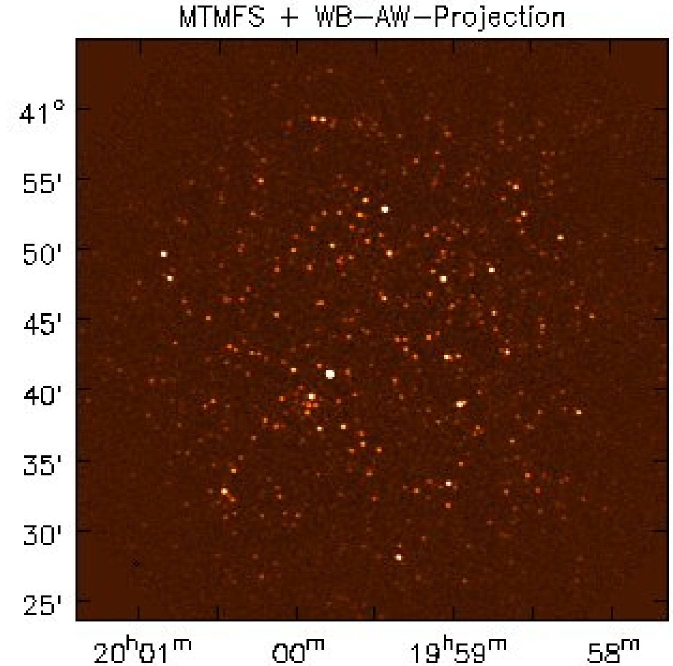
Bhatnagar, Cornwell, Golap, Uson, 2004

Low dynamic range test (< 10^4) – compare four methods

MT-MFS

2 uJy rms





MT-MFS
+
WB-AWP

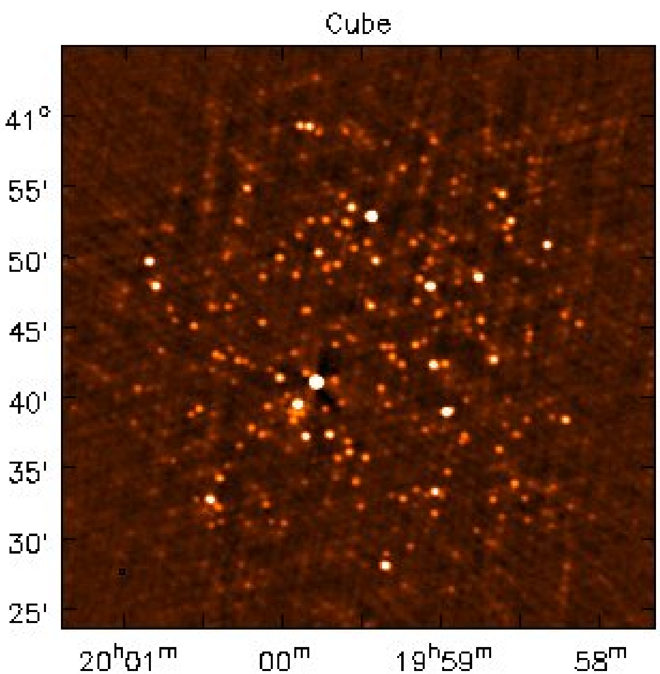
2 uJy rms

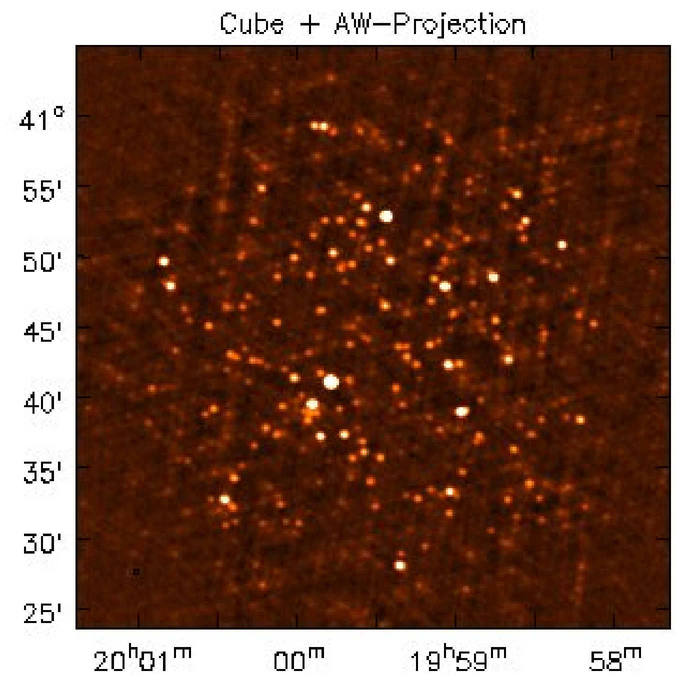
Brightest Source : 7 mJy

Cube

3 uJy rms

peak res : 9 uJy



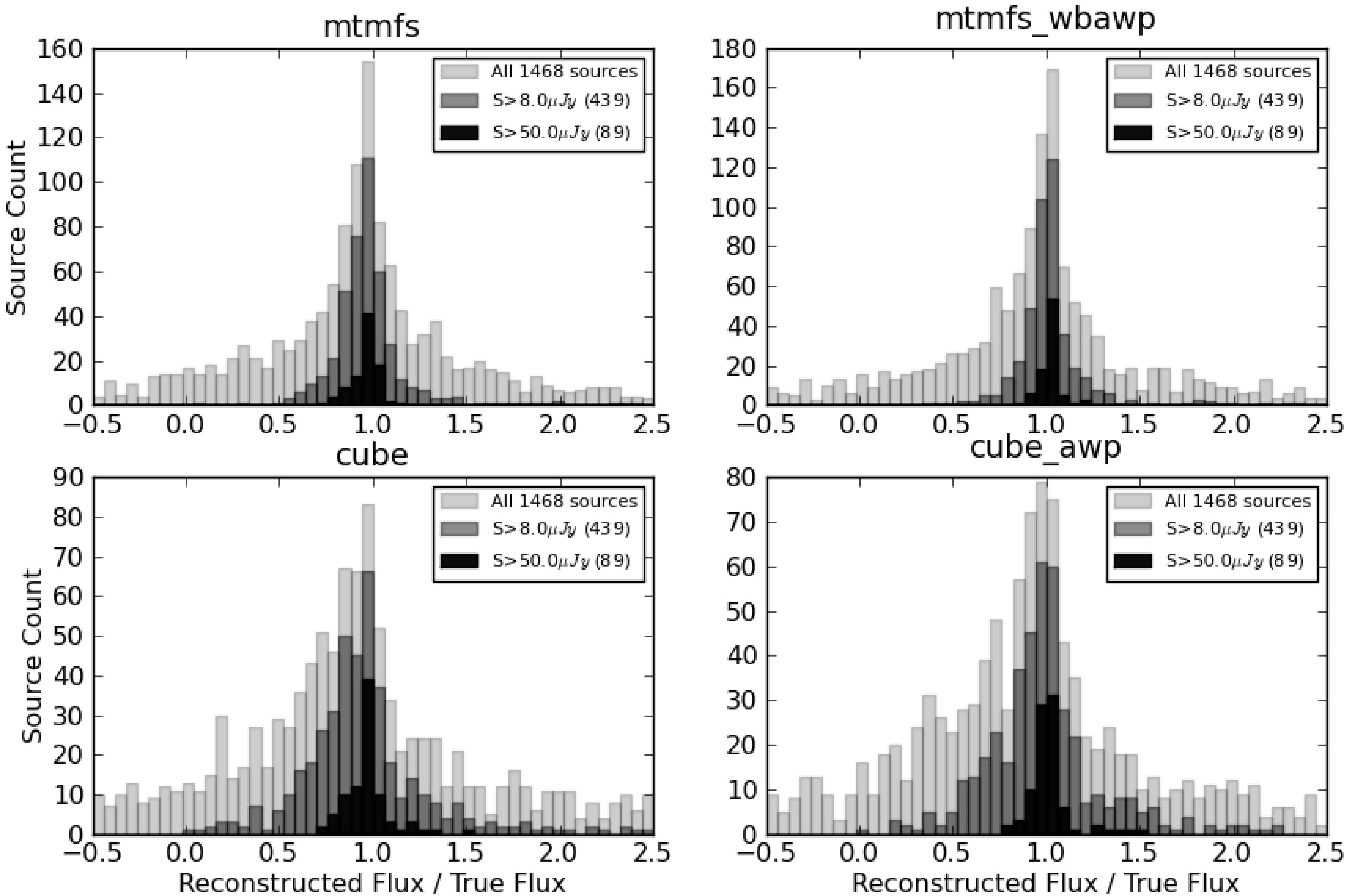


Cube
+
AWP

3 u Jy rms

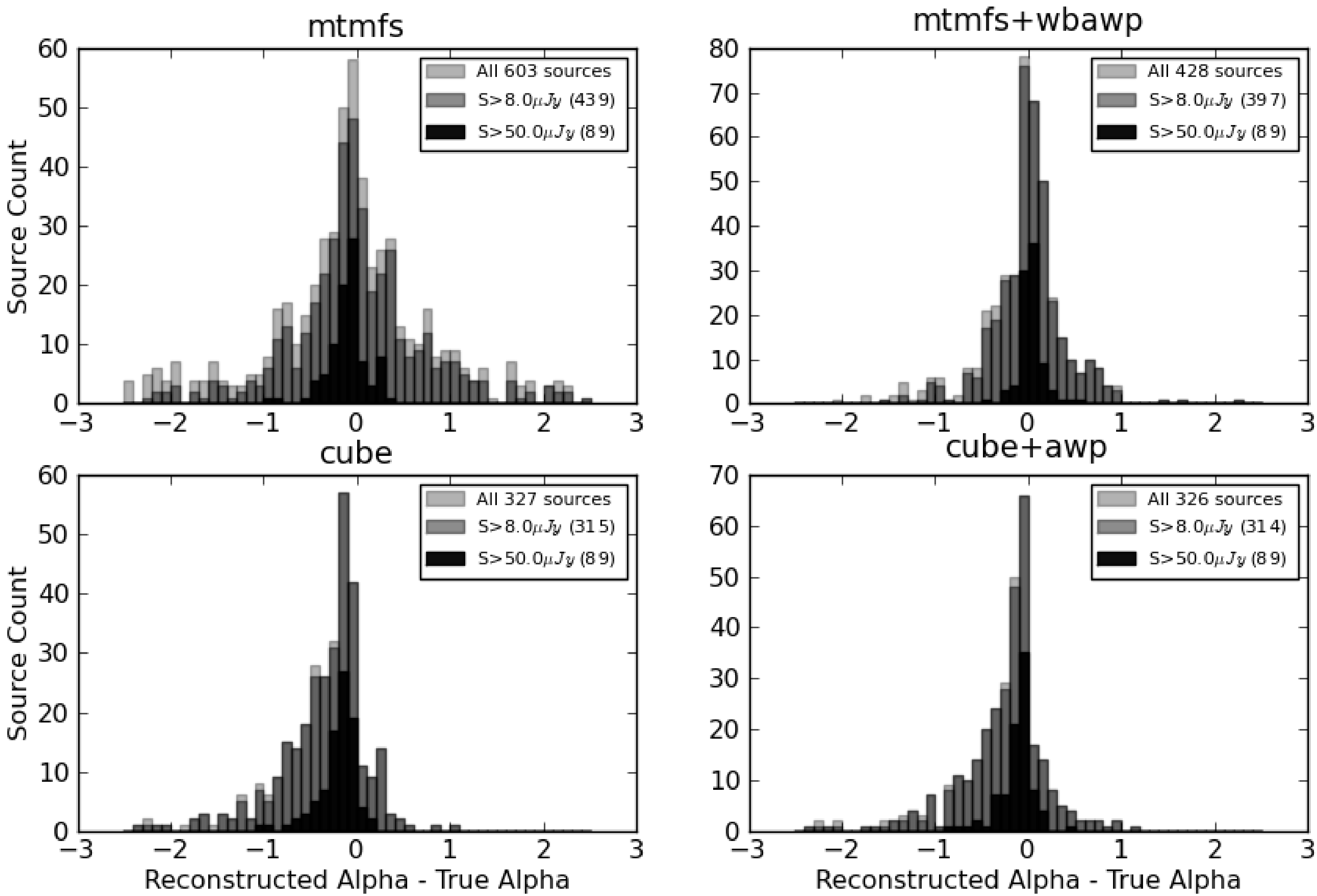
(Reconstructed / True) Intensity for different intensity ranges

Locate sources in true image. Plot all sources >1 micro Jy. (Brighter sources are more accurate)
No source-finding uncertainty. Single spw PSF sidelobe : 0.13 / Wide-band PSF sidelobe : 0.05



(Reconstructed – True) Alpha for different intensity ranges

Spectral index for brighter sources are more accurate. Degrades quickly with lower intensity.
(note different numbers of sources with alpha detections)



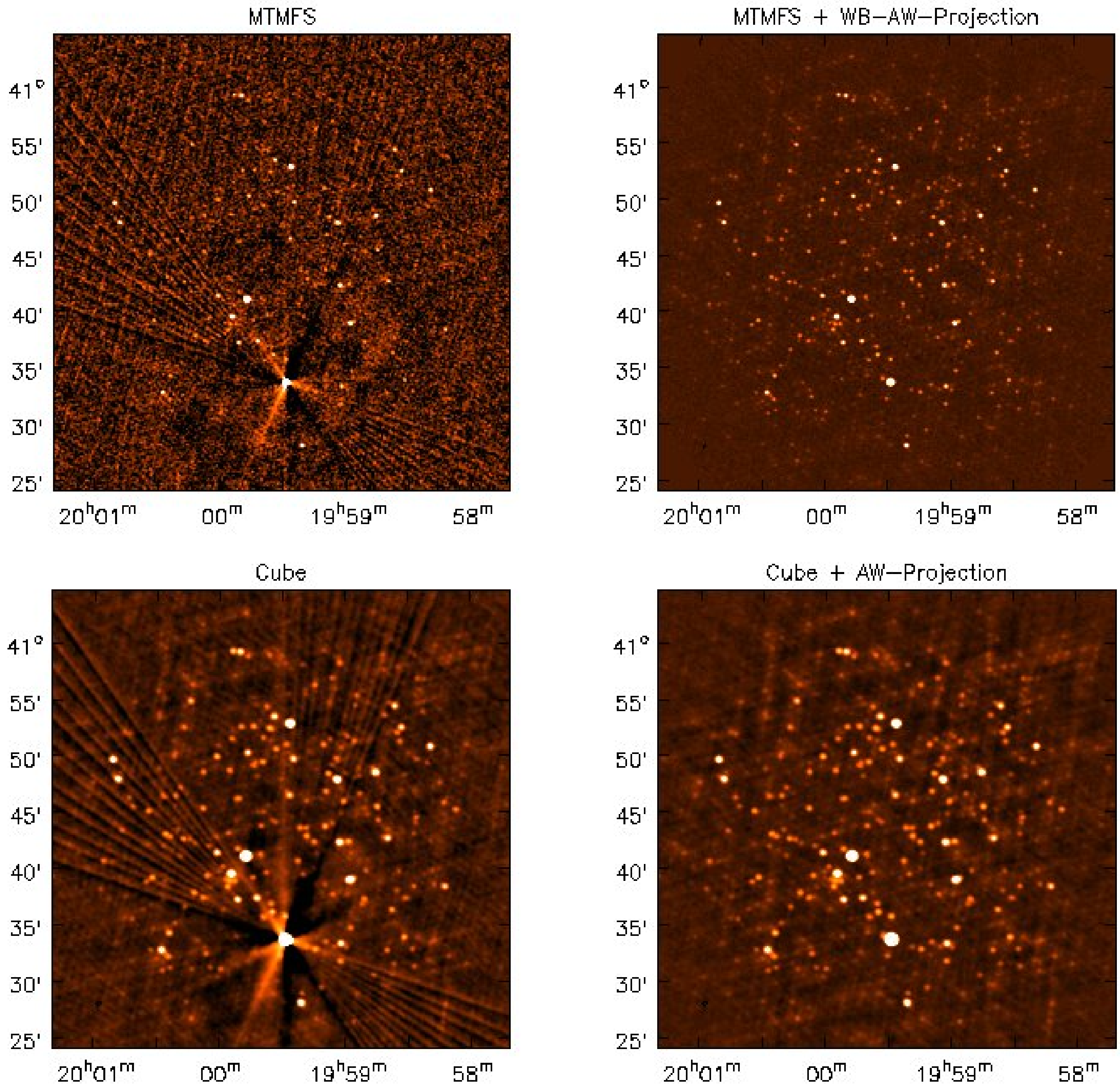
High dynamic range test (>10^4) - compare four methods

MT-MFS

6 uJy rms*

peak res :
15 uJy

Brightest Source : 100 mJy



MT-MFS + WB-AWP

2 uJy rms

Cube

4 uJy rms

peak res :
20 uJy

Cube + AW-Proj

3 uJy rms

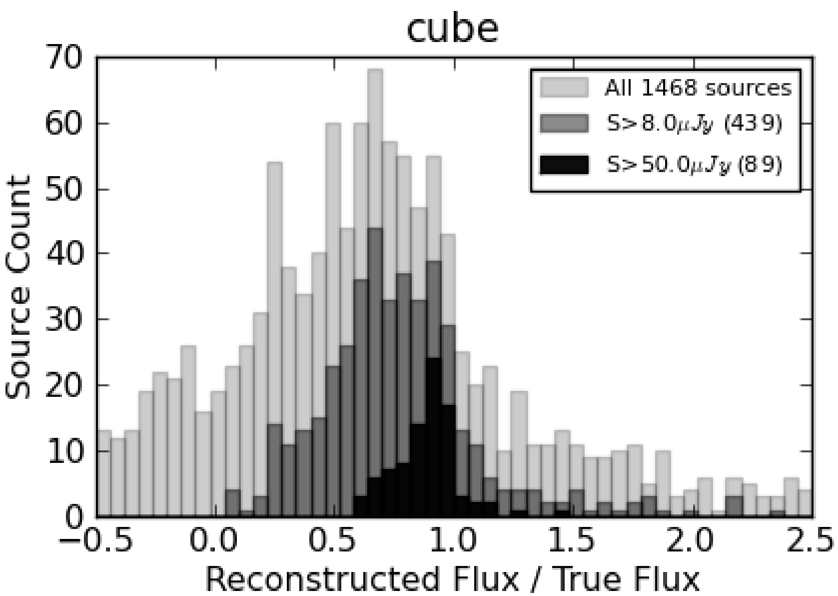
Details : validating simulations and testing algorithm limits

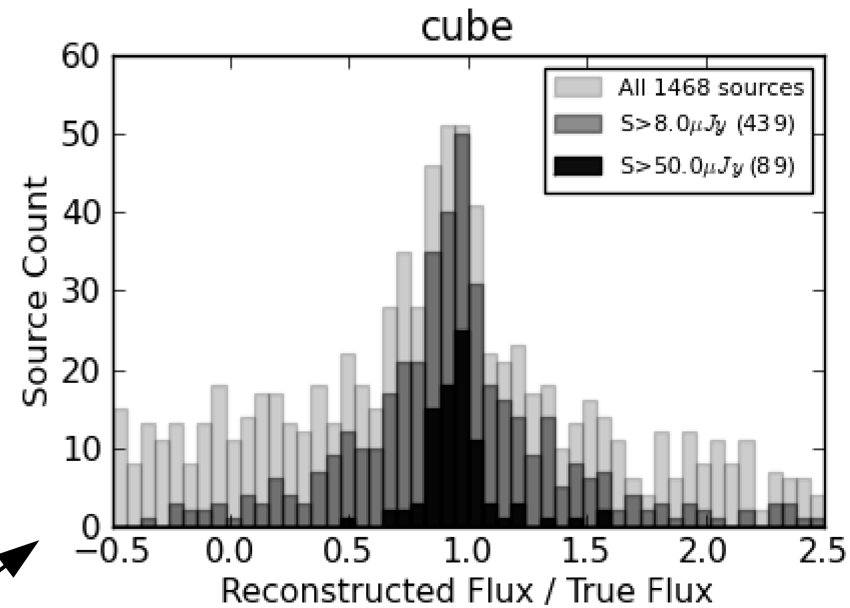
- Clean bias and the role of masks : Need masks with PSFs from sparse coverage
- Effect of PSF quality : Side-lobe confusion and weak source accuracy
- Un-deconvolved weak sources with Cube CLEAN : A hybrid of Cube and MFS on residuals
- Instrumental polarization correction : Stokes V residuals with/without WB-A-Projection
- Effect of sources not at pixel centers : Nothing significant upto dynamic ranges of 10^4
- Effect of baseline based averaging : No noticeable effect with A-Projection (2xPB fov).
- Numerical / implementation details :
  - Differences due to choices of oversampling of gridding convolution functions.
  - Some uv-coverage patterns leave artifacts for multi-term runs beyond 10^5 dynamic range.
  - Different algorithms react differently to bright outlier sources.
  - Different achieved noise levels with MosaicFT / FT / A-Projection for single pointings.
  - Non identical results between different implementations of the same algorithms.
- Other tests : diffuse emission, visibility noise, calibration error, etc...

==> Provide guidelines for astronomers who want automation via advanced algorithms and processing heuristics, plus the ability to analyse their data in ways they are used to.

Details : validating simulations and testing algorithm limits

– Clean bias and the role of masks : Need masks with PSFs from sparse coverage

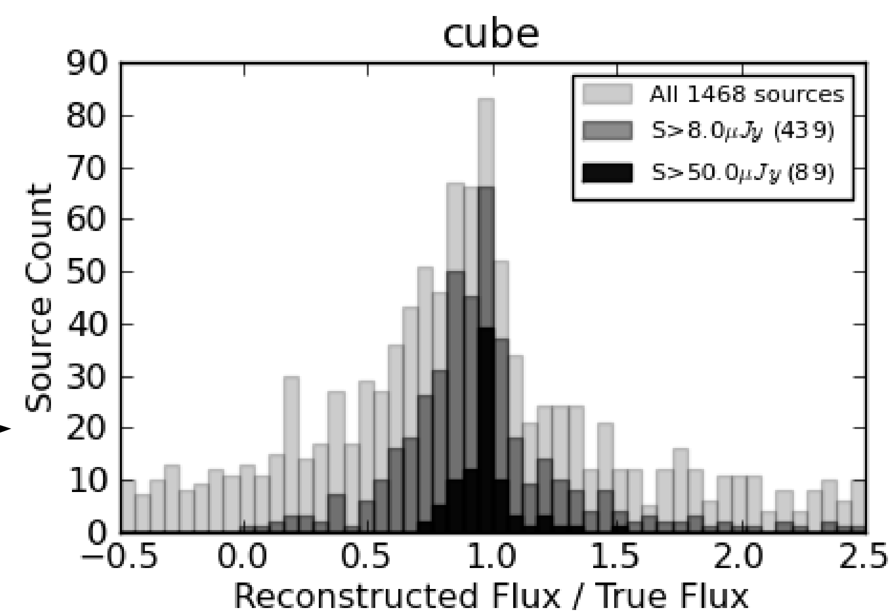




- Un-assisted CLEAN

- CLEAN with boxes around brightest sources (~ 5)

- CLEAN with boxes around many sources (~100s)

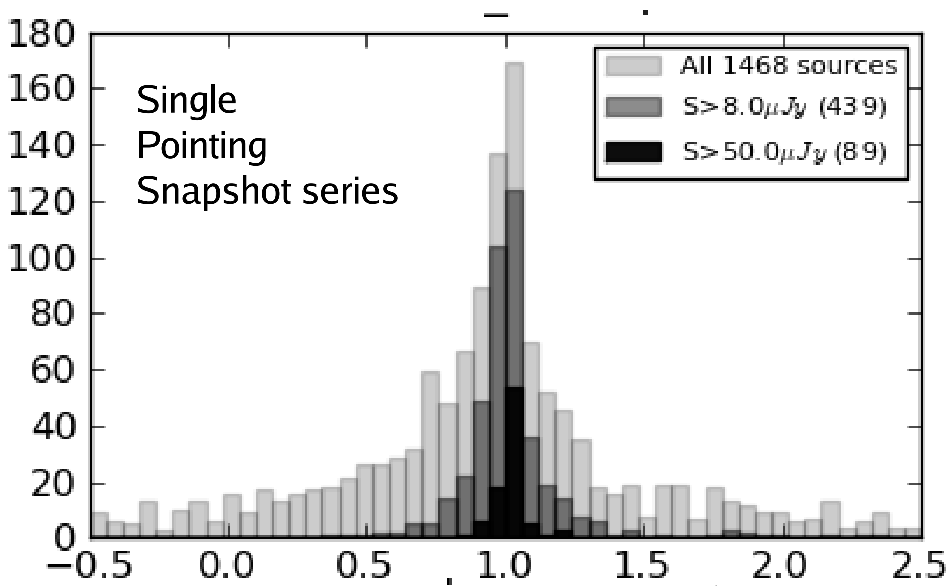


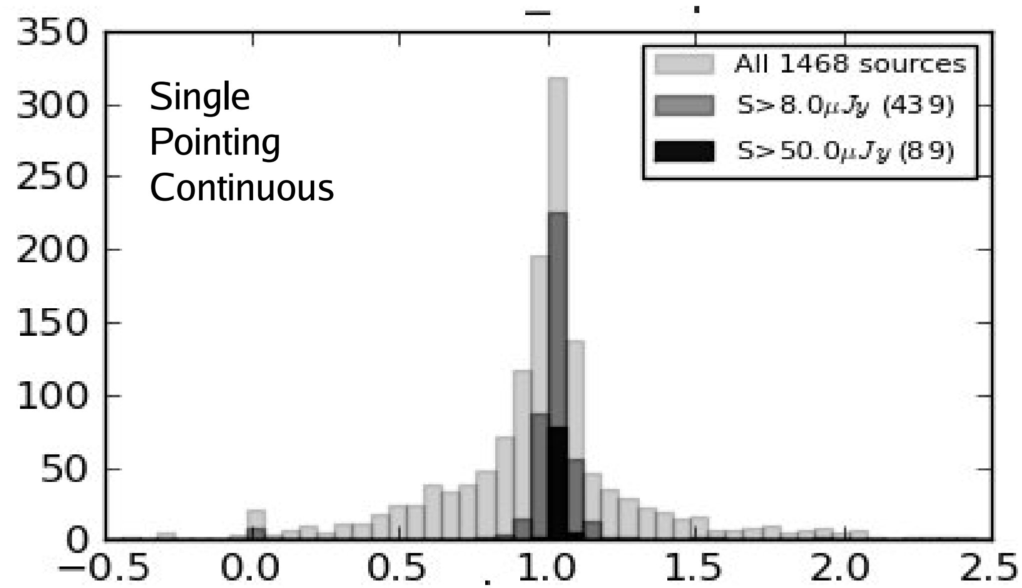
Single spw PSF sidelobe level : 0.13
Wide-band PSF sidelobe level : 0.05

Details : validating simulations and testing algorithm limits

– Clean bias and the role of masks : Need masks with PSFs from sparse coverage

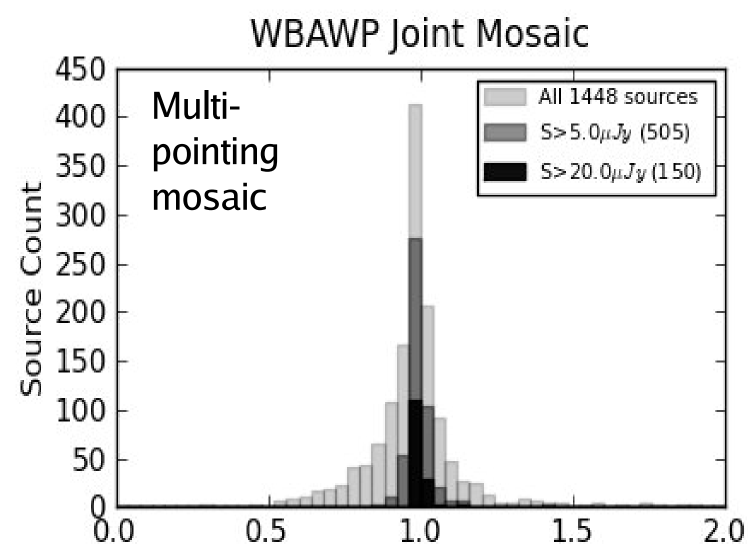
– Effect of PSF quality : Side-lobe confusion and weak source accuracy





Wide-band PSF sidelobe : 0.05

Wide-band PSF sidelobe : 0.02



Wide-band PSF sidelobe (avg) : 0.008

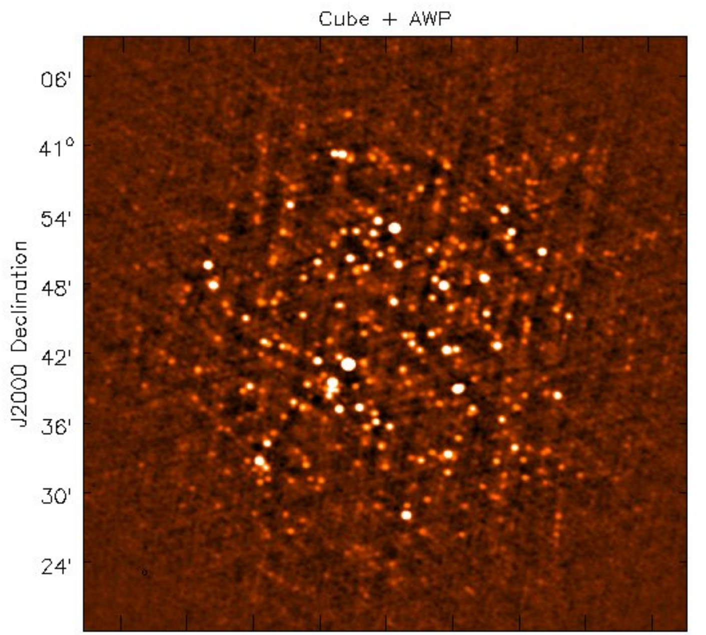
Details : validating simulations and testing algorithm limits

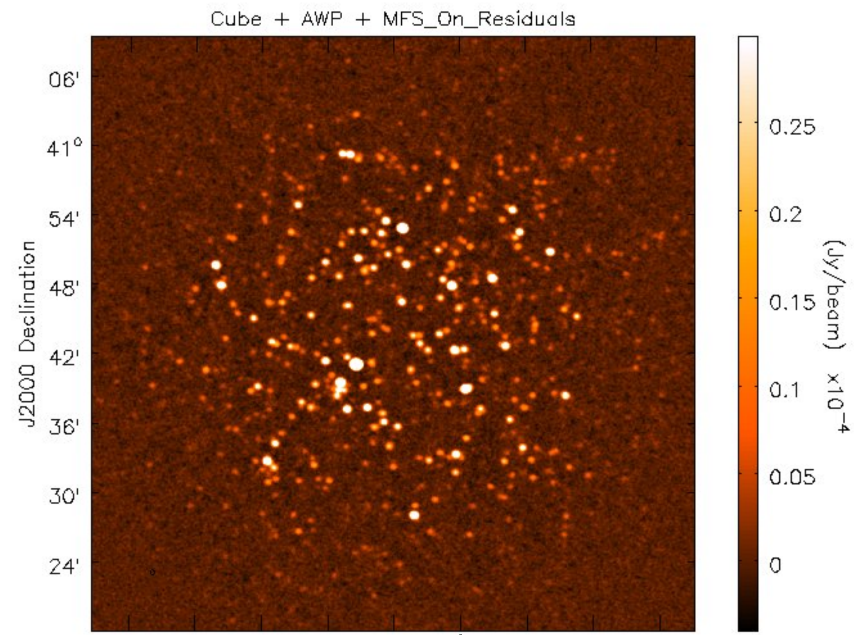
- Clean bias and the role of masks : Need masks with PSFs from sparse coverage
- Effect of PSF quality : Side-lobe confusion and weak source accuracy
- Un-deconvolved weak sources with Cube CLEAN : A hybrid of Cube and MFS on residuals

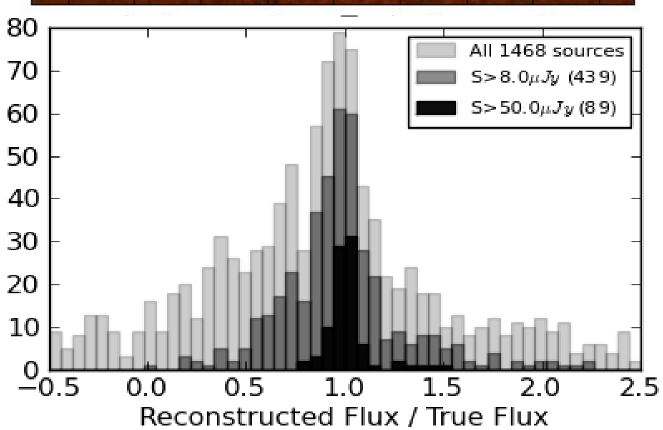
LEFT :
Cube Imaging + Channel collapse

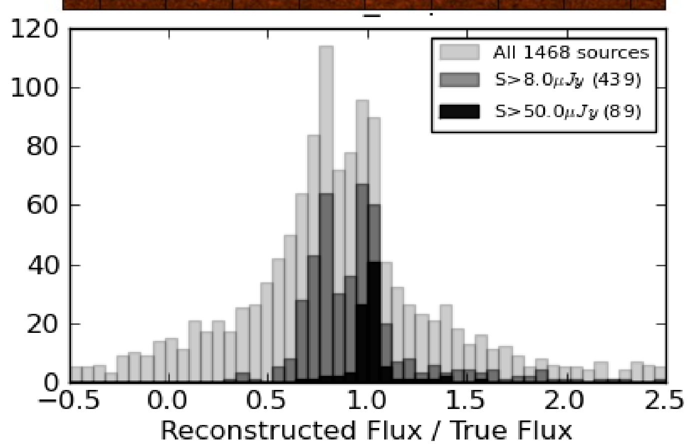
RIGHT :
Cube + MFS on residuals

Image RMS improves, but flux accuracy does not.

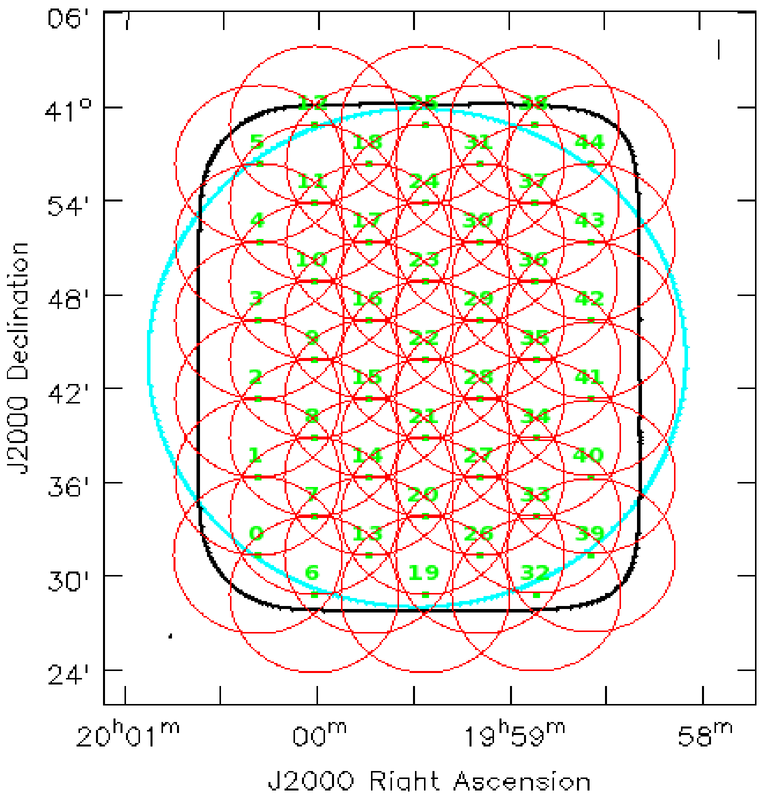








Wideband Mosaics – Simulation and Algorithms



EVLA D-config, C-band (4-8 GHz), 16 spws/chans
[Same field as with C-config L-band single pointing]

– 46 pointings at 5 arcmin spacing, 2 loops
– One snapshot every 6 min => 8.8 hr synthesis

Algorithms :

- Deconvolve Pointings separately or together
- Deconvolve Channels separately or together
- Use A-Projection or not

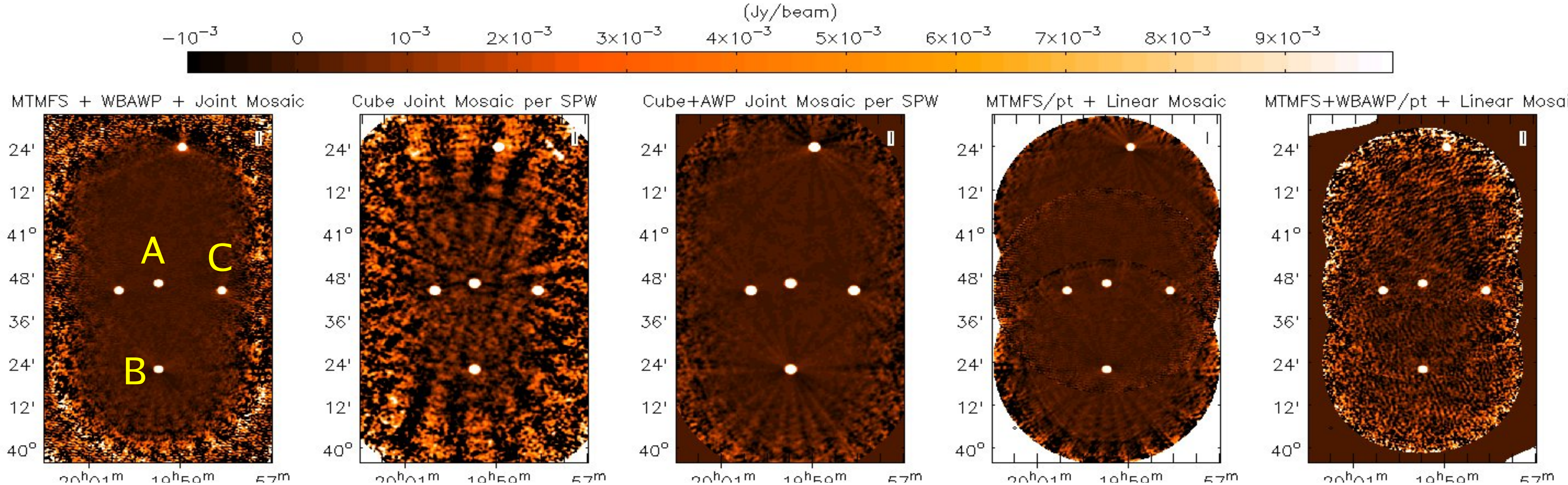
(1) Joint Mosaic with Wideband AW-Projection with MT-MFS (nterms=2)

(2,3) Cube Imaging with Joint Mosaic per SPW –With/Without rotating,squinted PBs

(4,5) MT-MFS per pointing with wideband PBCOR and post-deconvolution linear mosaic.
– With/Without rotating,squinted PBs.

Comparison of several wideband mosaic methods

Dataset : L-Band D-config, 3 pointings, 5 sources (intensity = 1 Jy, alpha= -0.5)

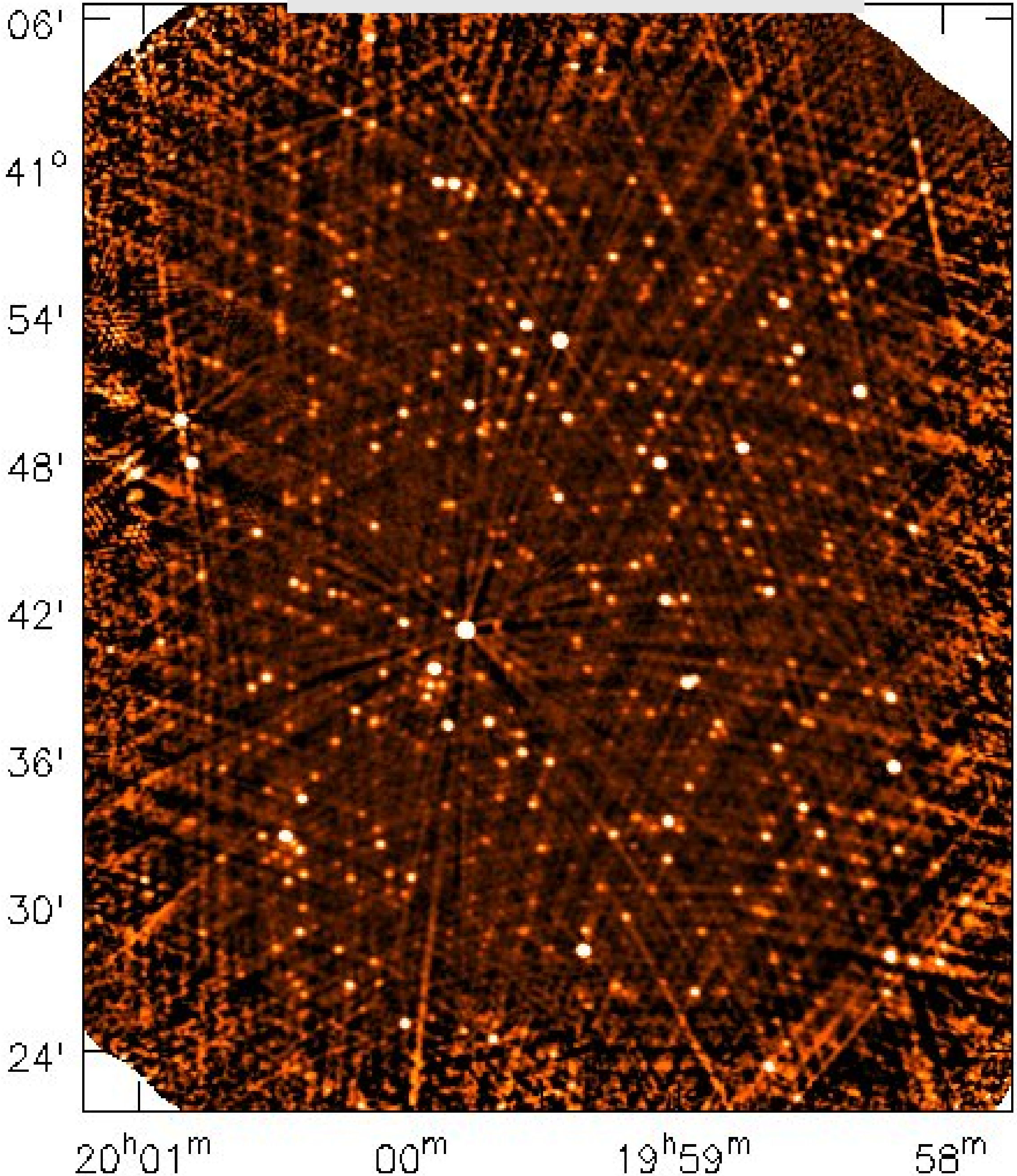


Joint Mosaic Wideband-AP	Joint Mosaic Cube	Joint Mosaic Cube-AP	Linear Mosaic Wideband	Linear Mosaic Wideband-AP

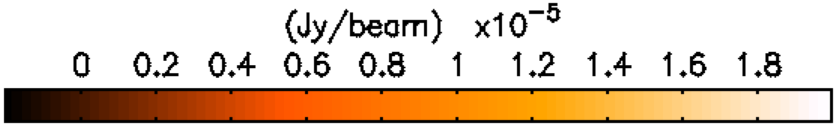
	Joint Mosaic Wideband-AP	Joint Mosaic Cube	Joint Mosaic Cube-AP	Linear Mosaic Wideband	Linear Mosaic Wideband-AP
A	1.0002	0.98	1.011	0.88	1.01
	-0.508	-0.52	-0.51	-0.87	-0.48
B	1.0004	0.99	1.012	0.90	0.99
	-0.502	-0.47	-0.48	-0.80	-0.50
C	1.0005	0.887	1.04	0.73	1.007
	-0.507	-0.62	-0.53	-1.6	-0.7

Cube Imaging with a Joint Mosaic (Ap=F) and PBCOR per SPW

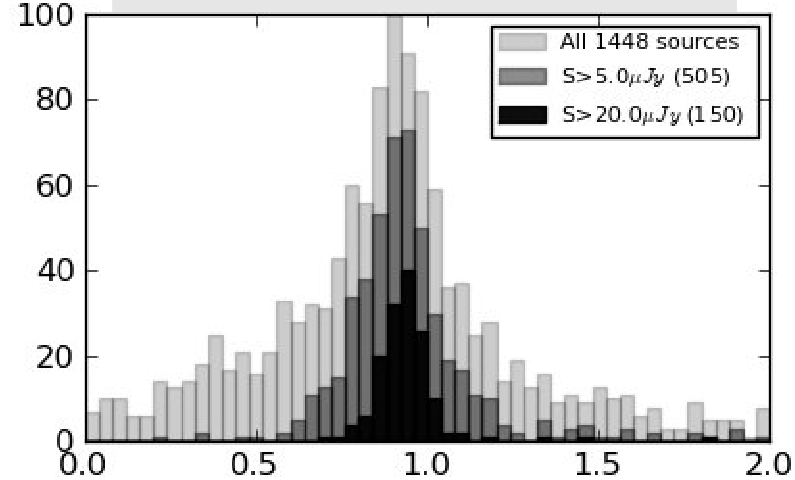
RMS : 1.1 microJy



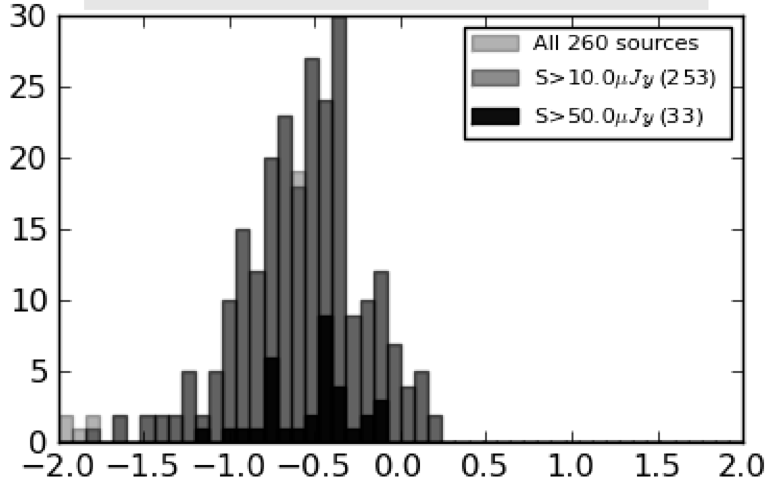
PSF sidelobe level : 0.07



Intensity : Reconstructed / True



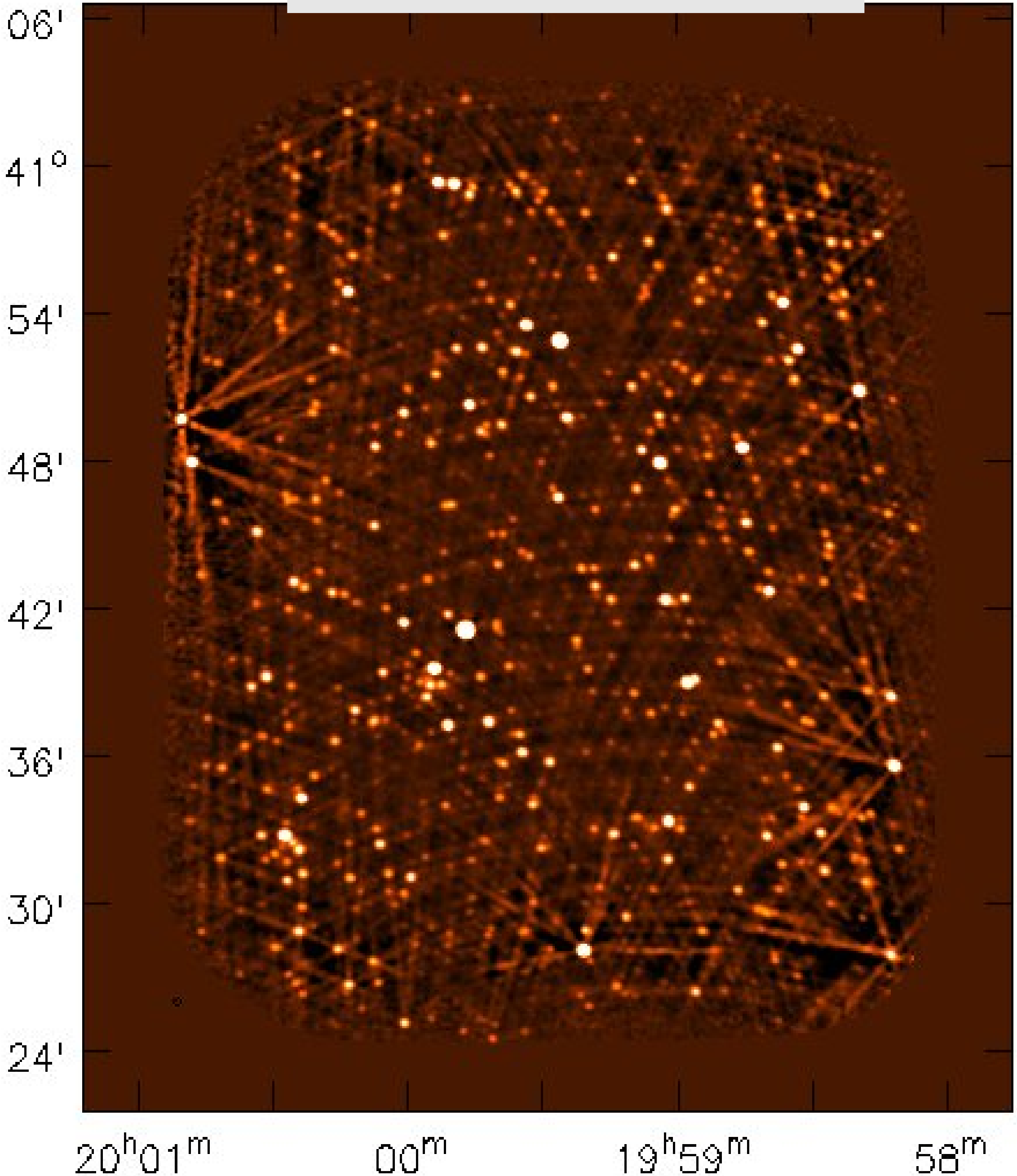
Alpha : Reconstructed - True



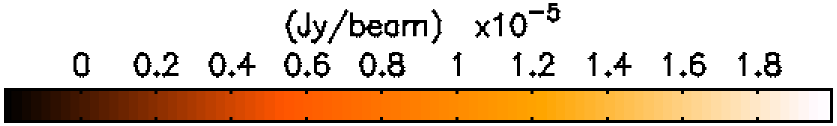
Spectra are too steep => WB PBcor error

Cube Imaging with a Joint Mosaic (Ap=T) and PBCOR per SPW

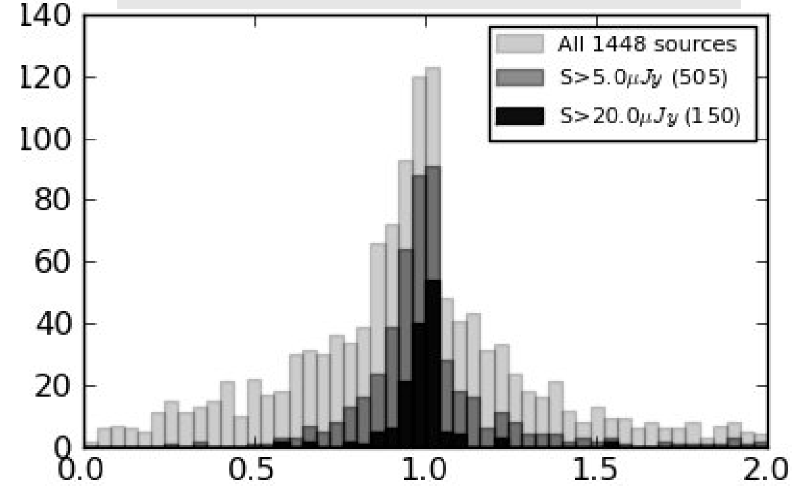
RMS : 0.7 microJy



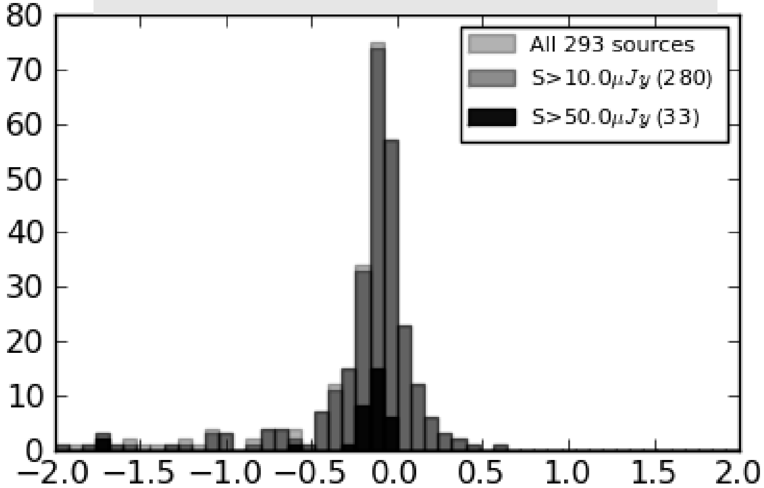
PSF sidelobe level : 0.07



Intensity : Reconstructed / True



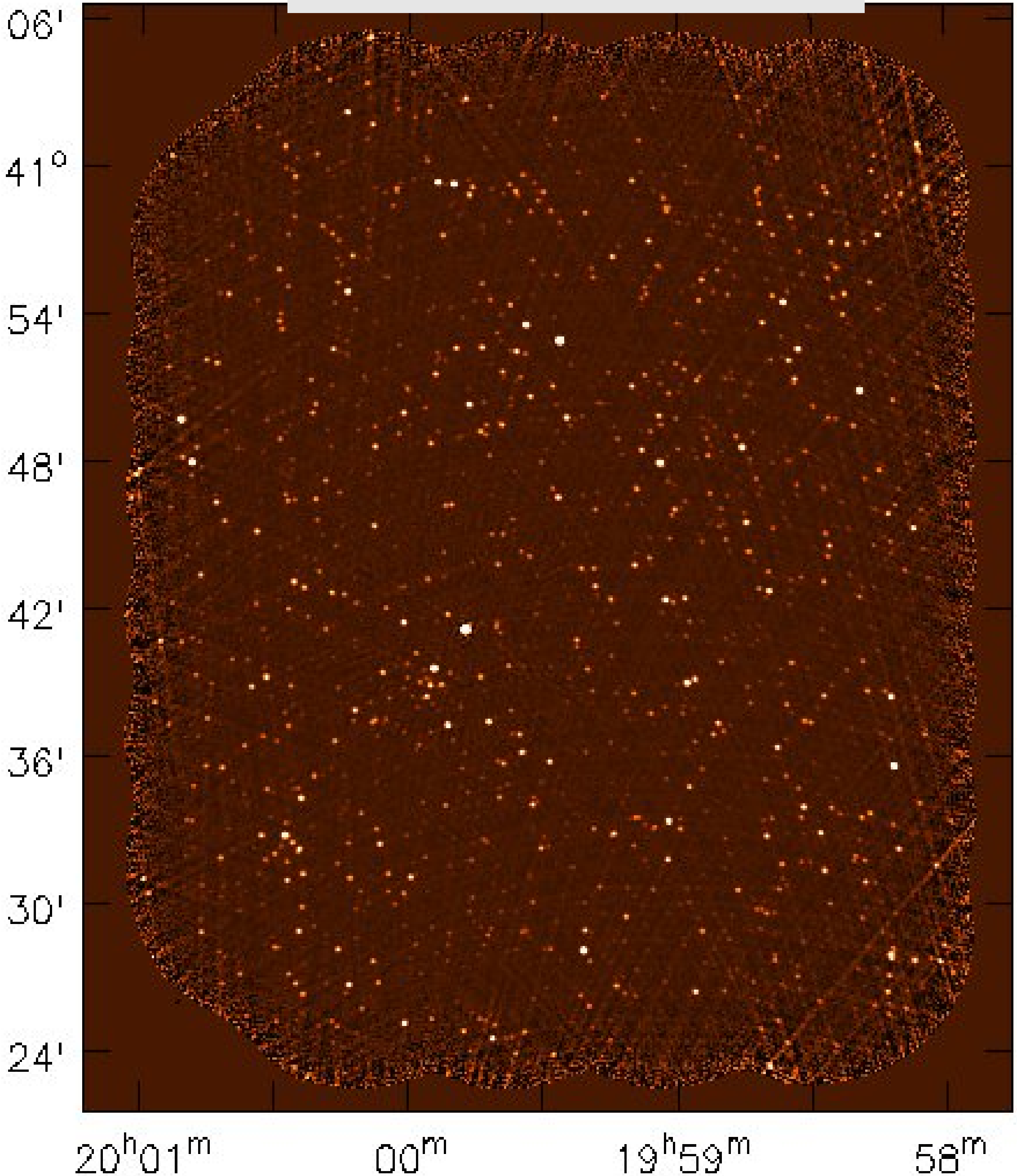
Alpha : Reconstructed - True



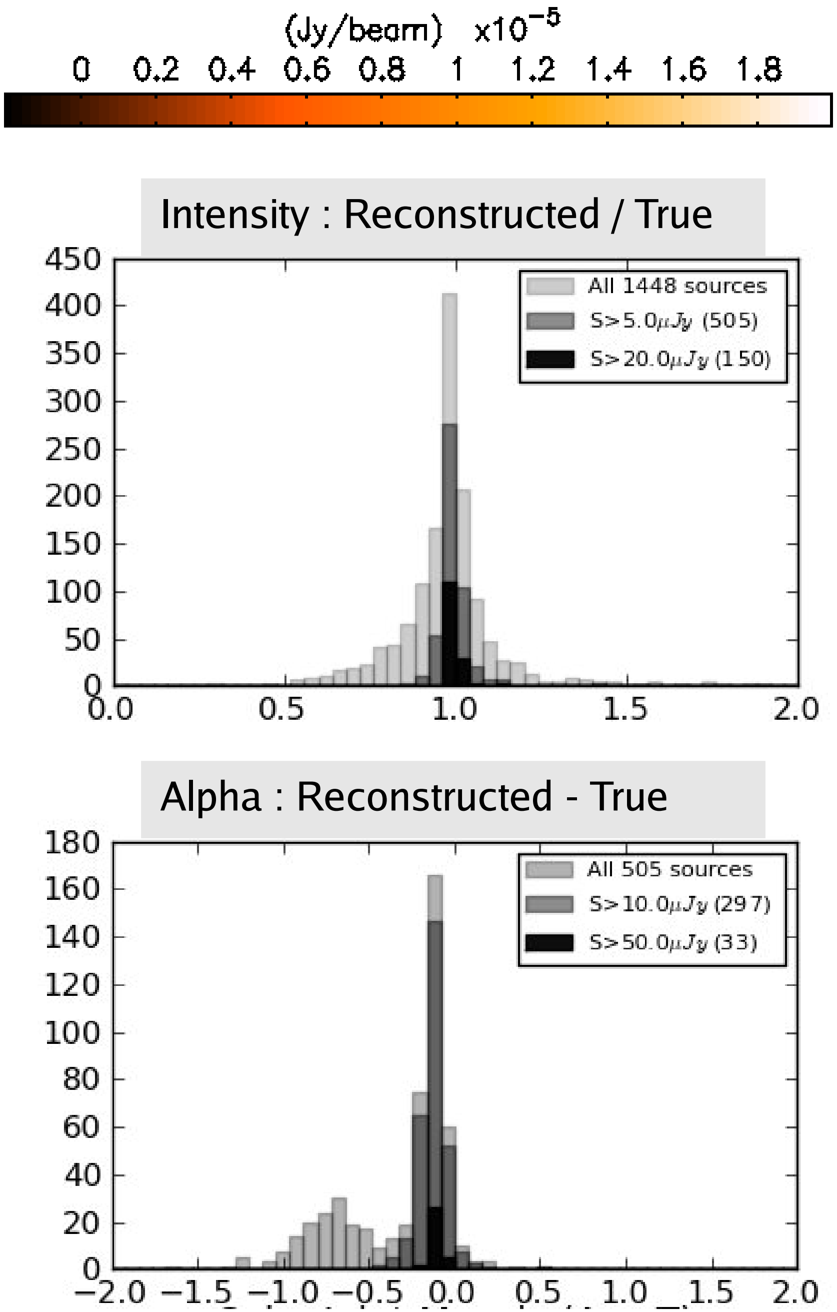
=> Better PB-correction

Joint Mosaic with Wideband AW-Projection and MT-MFS (nt=2)

RMS : 0.2 microJy



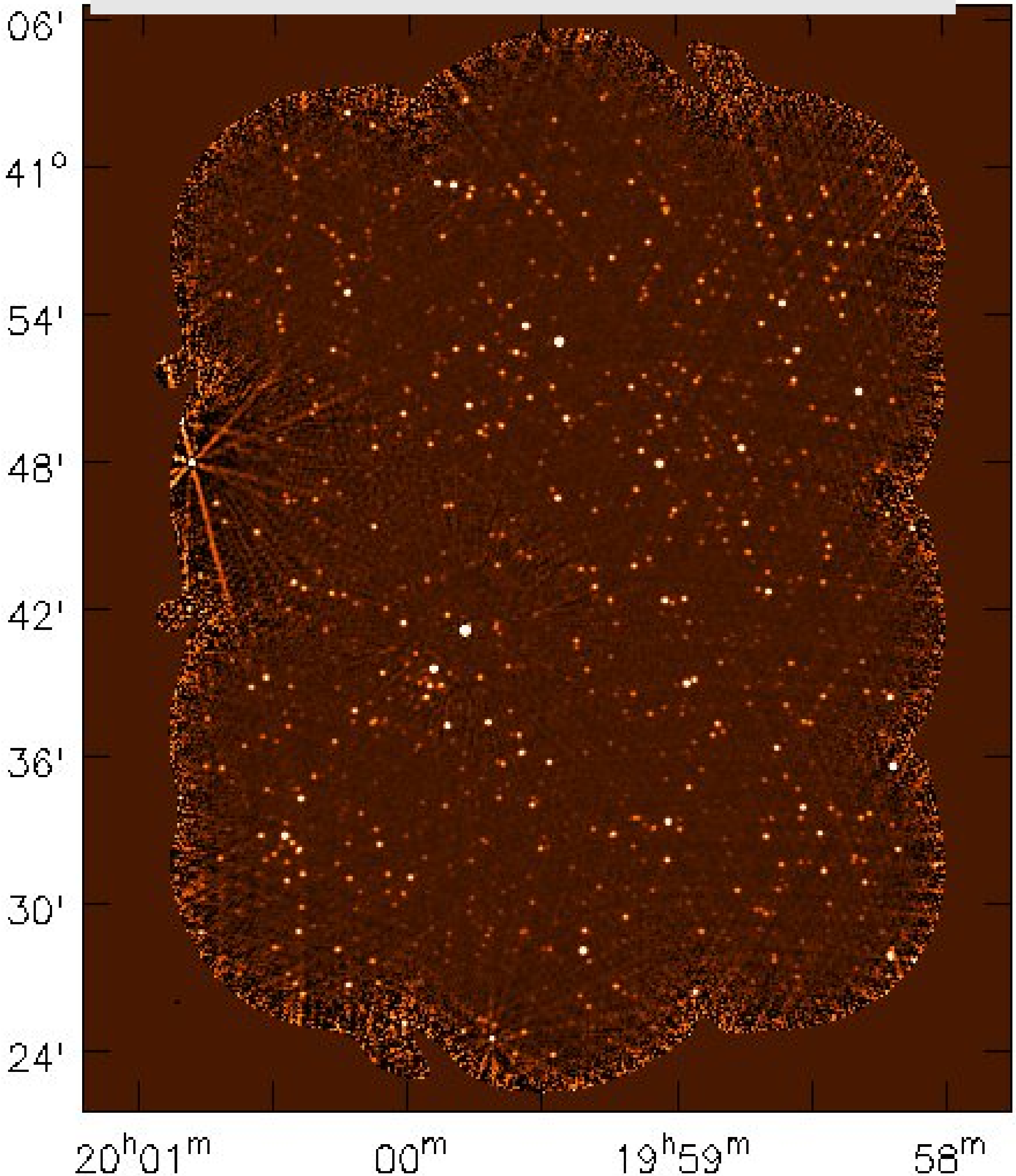
PSF sidelobe level : 0.01



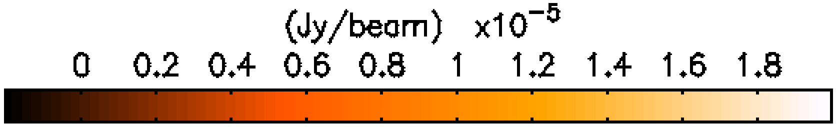
=> Fake steep-spectrum population !

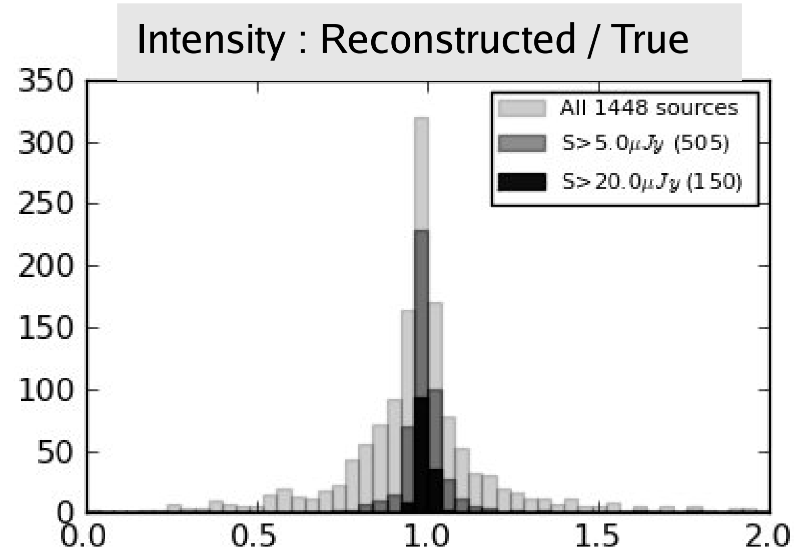
Joint Mosaic with Wideband AW-Projection and MT-MFS (nt=2)

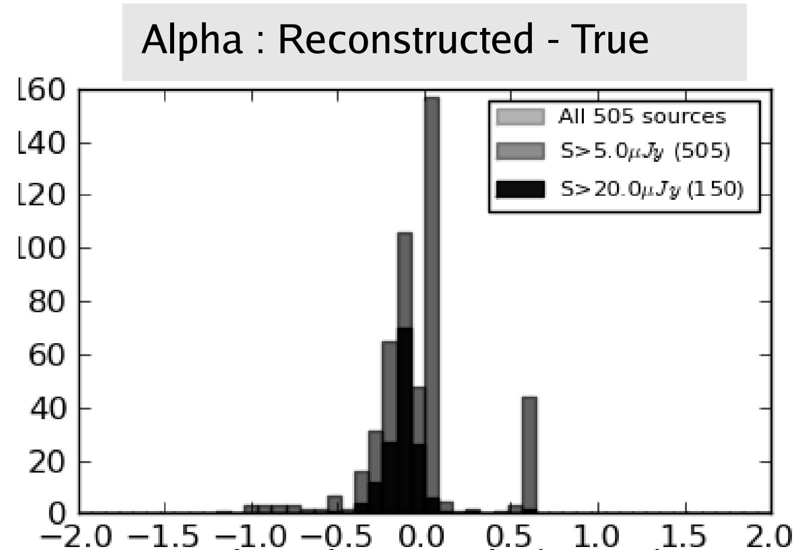
RMS : 0.3 microJy (Alternate Pointings)



PSF sidelobe level : 0.01







=> Still far from perfect....

Summary

- Commissioning wideband mosaic algorithms and understanding analysis strategy

  - Even in perfectly controlled conditions, a number of numerical effects can affect the astrophysical interpretation –need to be aware of and avoid them (Rau et al (in prep))

- Demonstrations on wideband VLA data

  - Single pointings : A225,3C465 at L-Band, IC10 at C-Band, G55 at L-Band, M87 at L-Band, Plaeides at C-Band, SWIRE deep field, ELIAS N1, Cosmos (Chiles)
  - Mosaics : CTB80 field at L-Band, Centaurus-A at C-band, M31 at C-band, ELIAS N1 (GMRT,VLA)

- More simulations

  - Add calibration errors and antenna-dependent PB perturbations
    (Kara Kundert / undergrad intern from U.Michigan : ALMA single pointing, narrow-band)

  - Add source polarization and test wideband IQUV and rotation-measure recovery
    (Preshanth Jagannathan / U.Calgary : part of PhD thesis project + RSRO project (R.Taylor et.al.))

- Image the same wideband mosaic dataset with other algorithms and implementations
  (CS-deconvolution, Peeling, DD-cal, new Imager software, ...)

Anyone interested in participating ?