Calibration and imaging with ALMA

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ALMA calibration

Atmospheric Phase Correction :

- either by Fast Switching
- or by Water Vapor Radiometry at 183 GHz
- or (in some cases) by Self-Calibration
- or a combination

Accurate Pointing Calibration :

- Re-pointing every 30 minutes
- Goal 0.6″ i.e. beamwidth/30 at 350 GHz...
- Compare to 2″, i.e. beamwidth/10 at 230 GHz for PdBI

Focus :

- High sensitivity allow frequent re-focus

ALMA calibration

Accurate Amplitude Calibration :

- Excellent site
- High surface accuracy antennas
- High pointing accuracy
- High sensitivity
- Goal 1–2 % at millimeter wavelengths, 3–5 % at sub-mm

Bandpass Calibration :

- No common noise source (100 % correlated signal) because the samplers are in the antennas
- Not as easy than at PdBI
- May be really difficult at sub-mm wavelengths
- We are working on it...

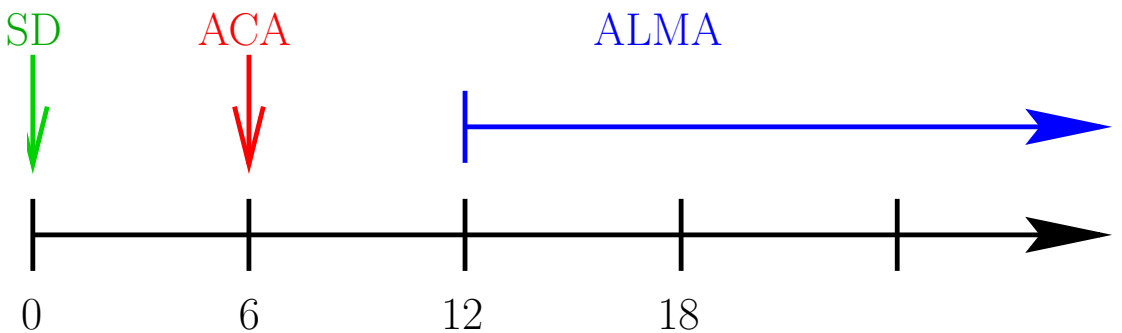
Imaging: what's new with ALMA

Number of baselines :

- 64 antennas $\longrightarrow$ 2016 instantaneous baselines

A complete imaging instrument :

- ALMA = 64 12–m antennas
- 4 antennas equipped for single-dish observations $\longrightarrow$ zero spacing
- ACA = 12 7–m antennas (?) $\longrightarrow$ short spacings



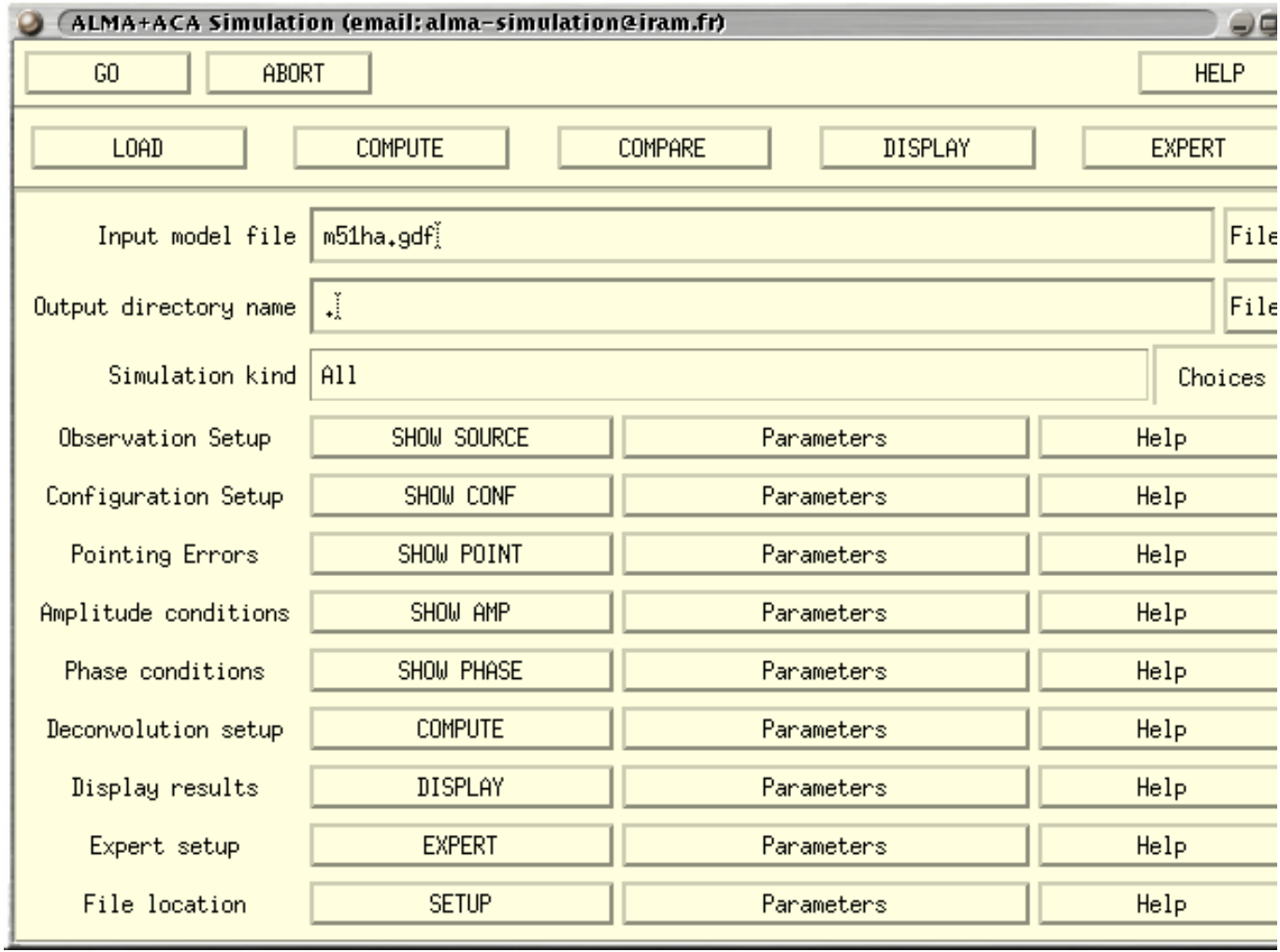
ALMA/ACA simulations

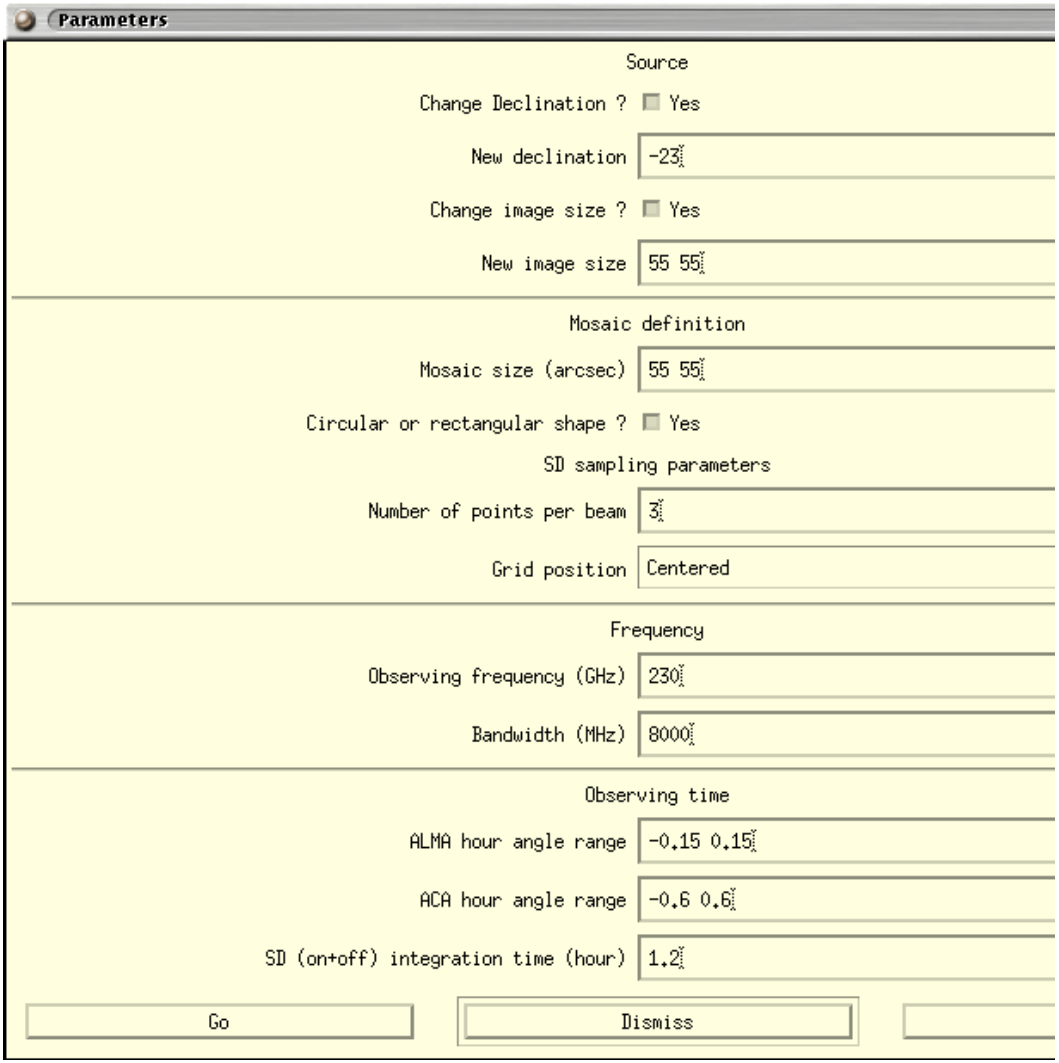
The simulator :

- ALMA/ACA/SD imaging calibrator
- Implemented in (and distributed with) GILDAS

Inputs :

- Source model
- Source size $\longrightarrow$ number and location of mosaic fields automatically found
- Hour angle range to be observed
- Array configurations (incl. the real ones!)
- Observing frequencies


ALMA+ACA Simulation (email: alma-simulation@iram.fr)
GO
ABORT
HELP
LOAD
COMPUTE
COMPARE
DISPLAY
EXPERT
Input model file
m51ha.gdf
File
Output directory name
.
File
Simulation kind
All
Choices
Observation Setup
SHOW SOURCE
Parameters
Help
Configuration Setup
SHOW CONF
Parameters
Help
Pointing Errors
SHOW POINT
Parameters
Help
Amplitude conditions
SHOW AMP
Parameters
Help
Phase conditions
SHOW PHASE
Parameters
Help
Deconvolution setup
COMPUTE
Parameters
Help
Display results
DISPLAY
Parameters
Help
Expert setup
EXPERT
Parameters
Help
File location
SETUP
Parameters
Help


Parameters
Source
Change Declination ? Yes
New declination -23
Change image size ? Yes
New image size 55 55
Mosaic definition
Mosaic size (arcsec) 55 55
Circular or rectangular shape ? Yes
SD sampling parameters
Number of points per beam 3
Grid position Centered
Frequency
Observing frequency (GHz) 230
Bandwidth (MHz) 8000
Observing time
ALMA hour angle range -0.15 0.15
ACA hour angle range -0.6 0.6
SD (on+off) integration time (hour) 1.2
Go
Dismiss

ALMA/ACA simulations

Visibility simulation :

- Pointing errors
  - Thermal
  - Wind
  - Both
- Errors on amplitude calibration
- Atmospheric phase noise (phase screen)
- Several calibration schemes
- Pointing errors associated to dynamic (anomalous) refraction

ALMA/ACA simulations

Deconvolution :

- Mosaic deconvolution as standard method (CLEAN)
- Joint (ALMA–ACA–SD) deconvolution
- Hybridization in the *uv* plane

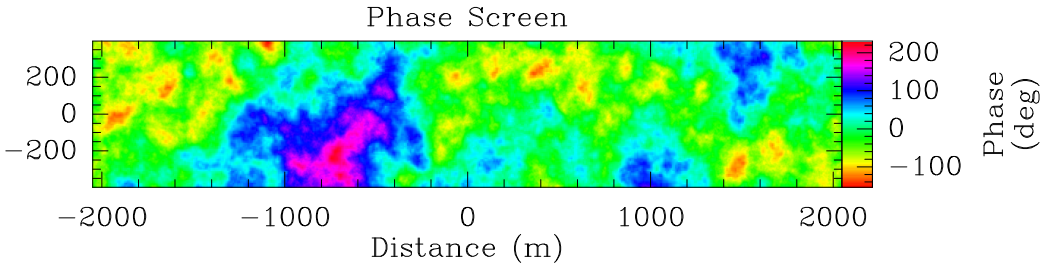
Results analysis :

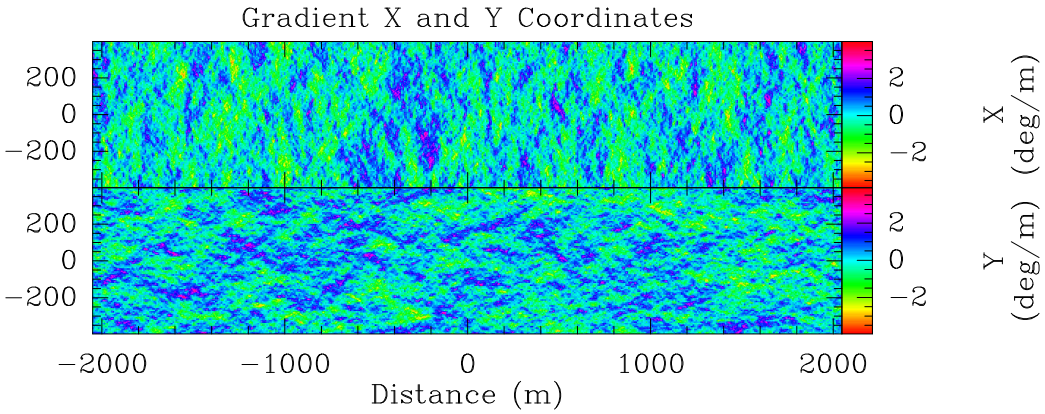
- Comparison with input model in the image plane
- Comparison with input model in the *uv* plane
- Fidelity estimators

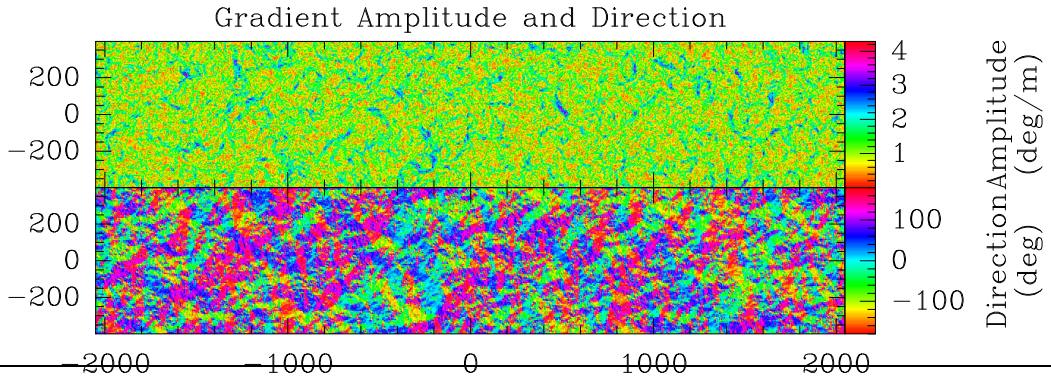
Atmospheric phase model

Model :

- 2-D screen generated in the Fourier plane (statistical properties correct)
- Elevation dependence as $\sqrt{\text{Air} - \text{mass}}$


Phase Screen
200
0
−200
−2000
−1000
0
1000
2000
Distance (m)
200
100
0
−100
Phase
(deg)


Gradient X and Y Coordinates
200
0
−200
200
0
−200
−2000
−1000
0
1000
2000
Distance (m)
2
0
−2
2
0
−2
X
(deg/m)
Y
(deg/m)


Gradient Amplitude and Direction
200
0
−200
200
0
−200
−2000
−1000
0
1000
2000
Distance (m)
4
3
2
1
100
0
−100
Direction
(deg)
Amplitude
(deg/m)

Atmospheric phase model

Model :

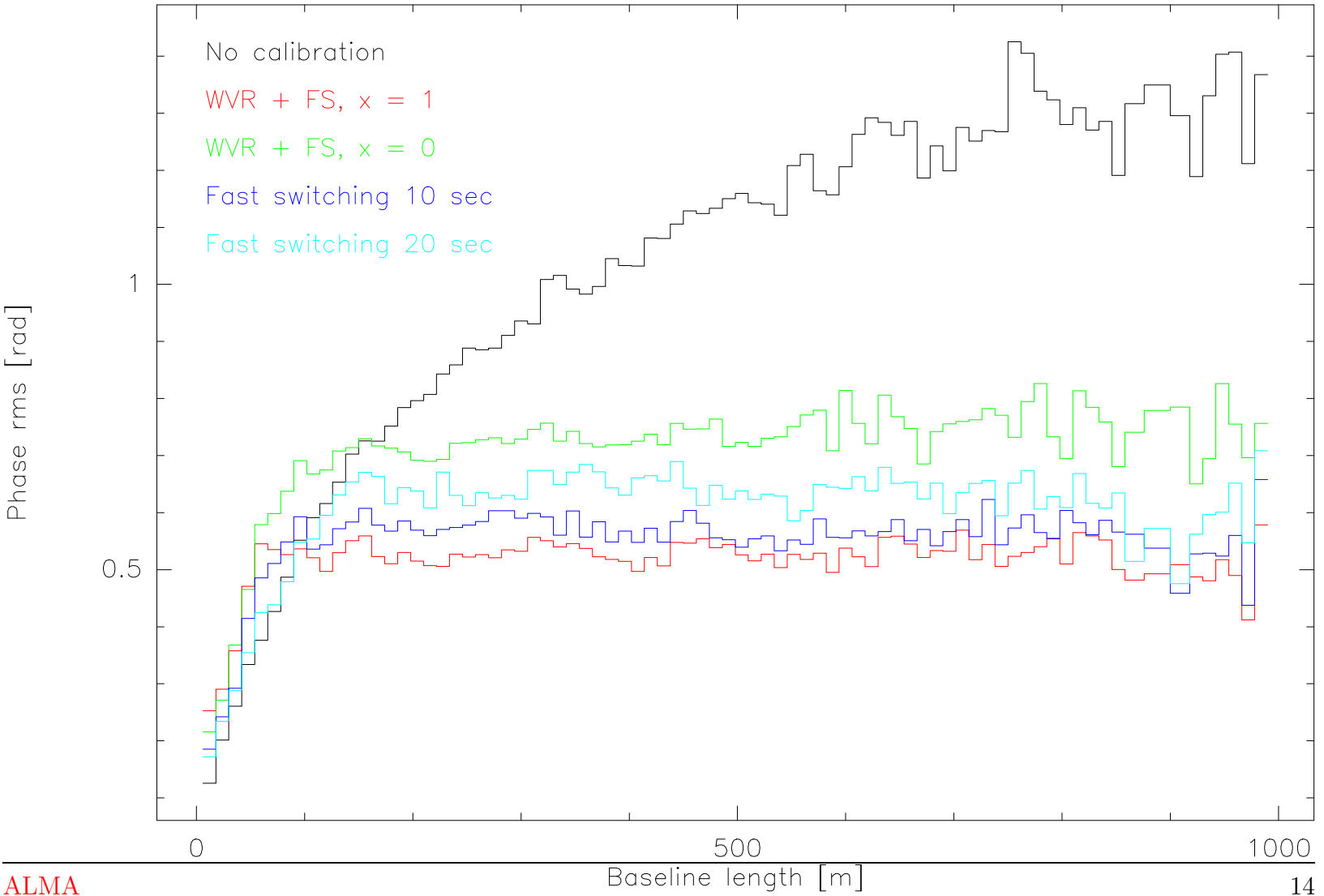
- 2-D screen generated in the Fourier plane (statistical properties correct)
- Elevation dependence as $\sqrt{\text{Air} - \text{mass}}$

Dynamic (anomalous) refraction :

- Anisotropic when the wind direction is constant (observable?)
- But effect negligible compared to direct phase noise effect

Calibration schemes

- Standard calibration: continuum curve fitted through the calibrator data
- Fast switching: linear interpolation of the phase between two consecutive calibrator measurements
- Water Vapor Radiometry: a WVR is used to correct the phase in real time. Still need a subsequent phase calibration.
- WVR + FS: a WVR is used, and the last calibration phase is removed (offset)


No calibration
WVR + FS, x = 1
WVR + FS, x = 0
Fast switching 10 sec
Fast switching 20 sec
Phase rms [rad]
0.5
1
0
500
1000
Baseline length [m]

Joint ALMA+ACA+SD deconvolution

A multi-scale CLEAN approach

(1) Start with two dirty mosaics (ALMA and ACA+SD)

(2) Selection of mosaic with highest SNR

(3) Search for clean components using

- `Clark` algorithm for the ALMA image
- `SDI` algorithm for the ACA+SD image

(4) Remove components from both images

(5) Go to (2)

(6) Convolve CLEAN components with the ALMA clean beam

(7) Add weighted residuals

Hybridization in the uv plane

Combine data in the uv plane

(1) Deconvolution of ALMA+SD

(2) Deconvolution of ACA+SD

(3) FFT of the two clean images

(4) Linear combination:

- ALMA+SD data for $\sqrt{u^2 + v^2} > 15$ m
- ACA+SD data for $\sqrt{u^2 + v^2} < 15$ m

(5) Inverse FFT of resulting data

Fidelities

Fidelity image :

$$\text{fidelity} = \frac{\text{input model}}{\text{difference}}$$

Histogram of cumulated fidelity:

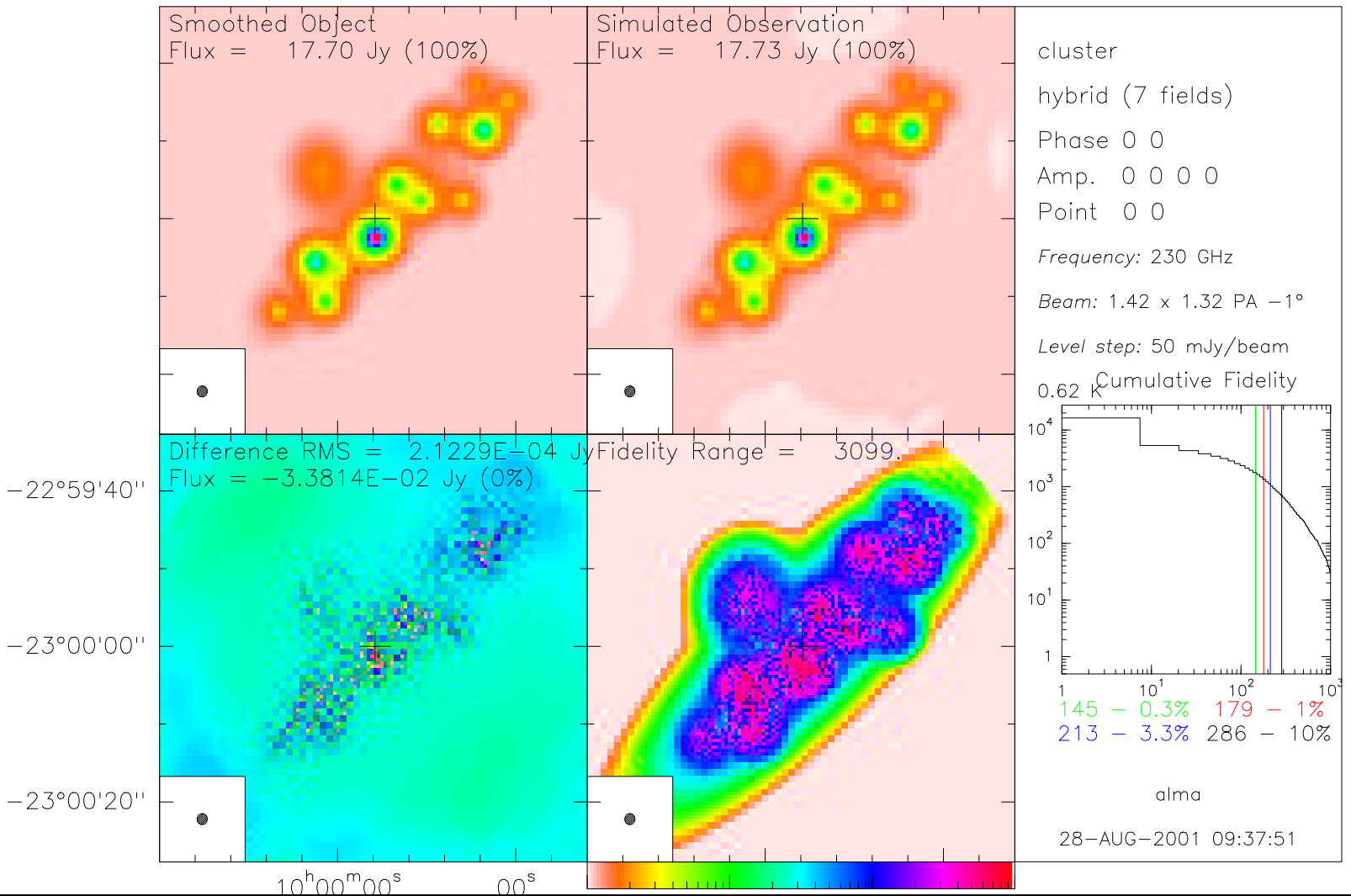
number of pixels whose fidelities are larger than a given value

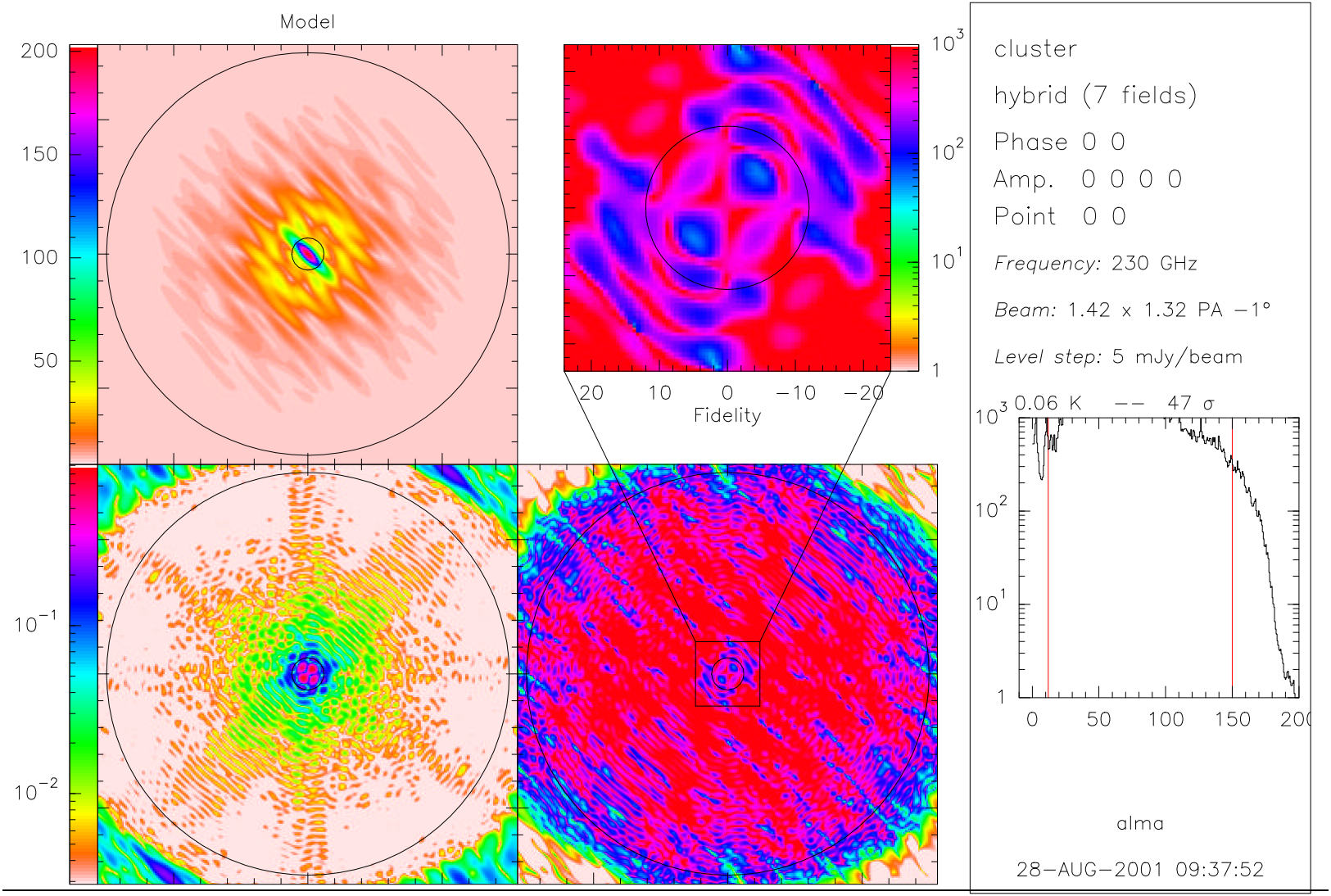
Fidelity range :

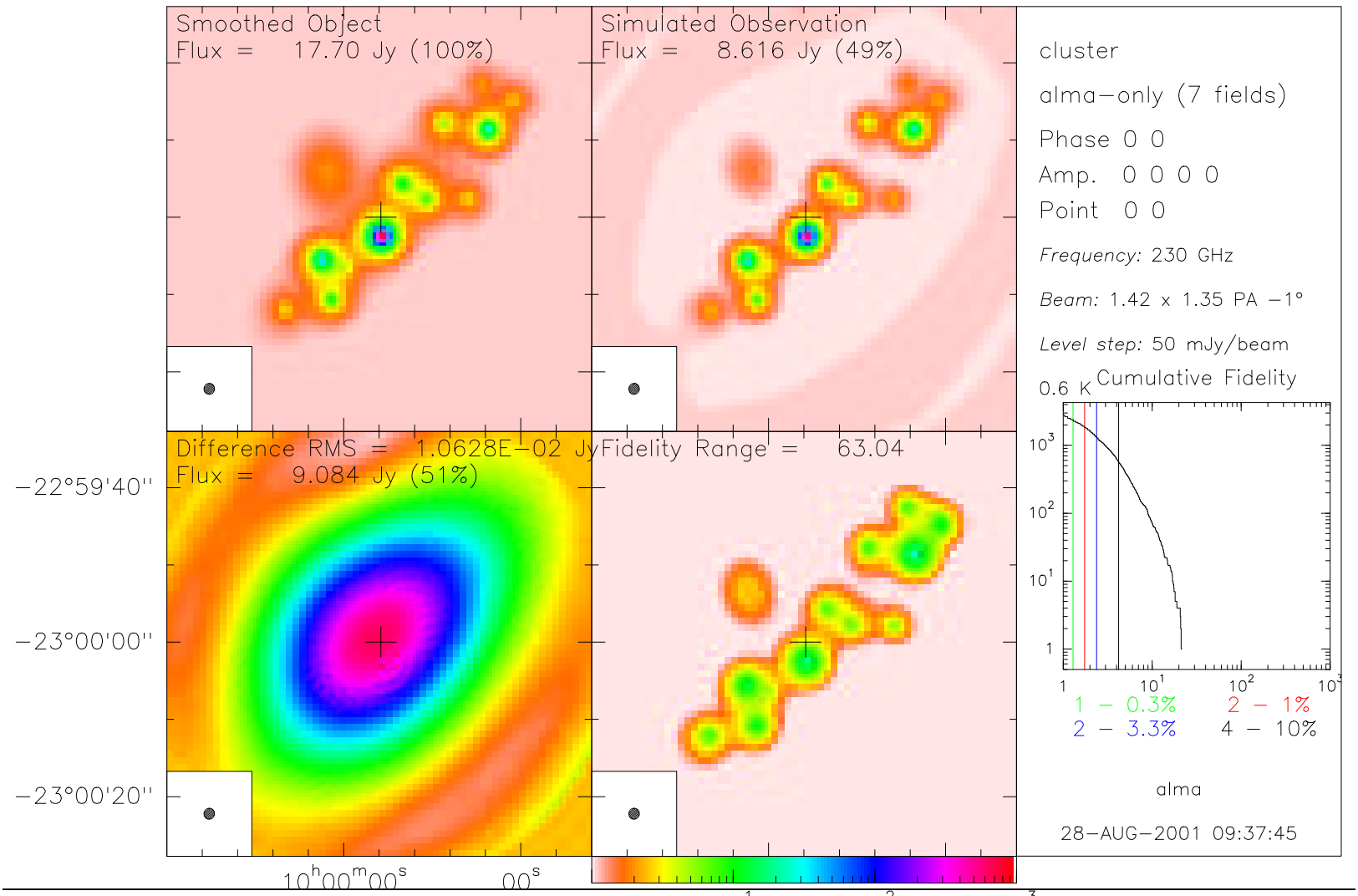
$$\text{fidelity range} = \frac{\max(\text{abs}(\text{model}))}{\text{rms}(\text{difference})}$$

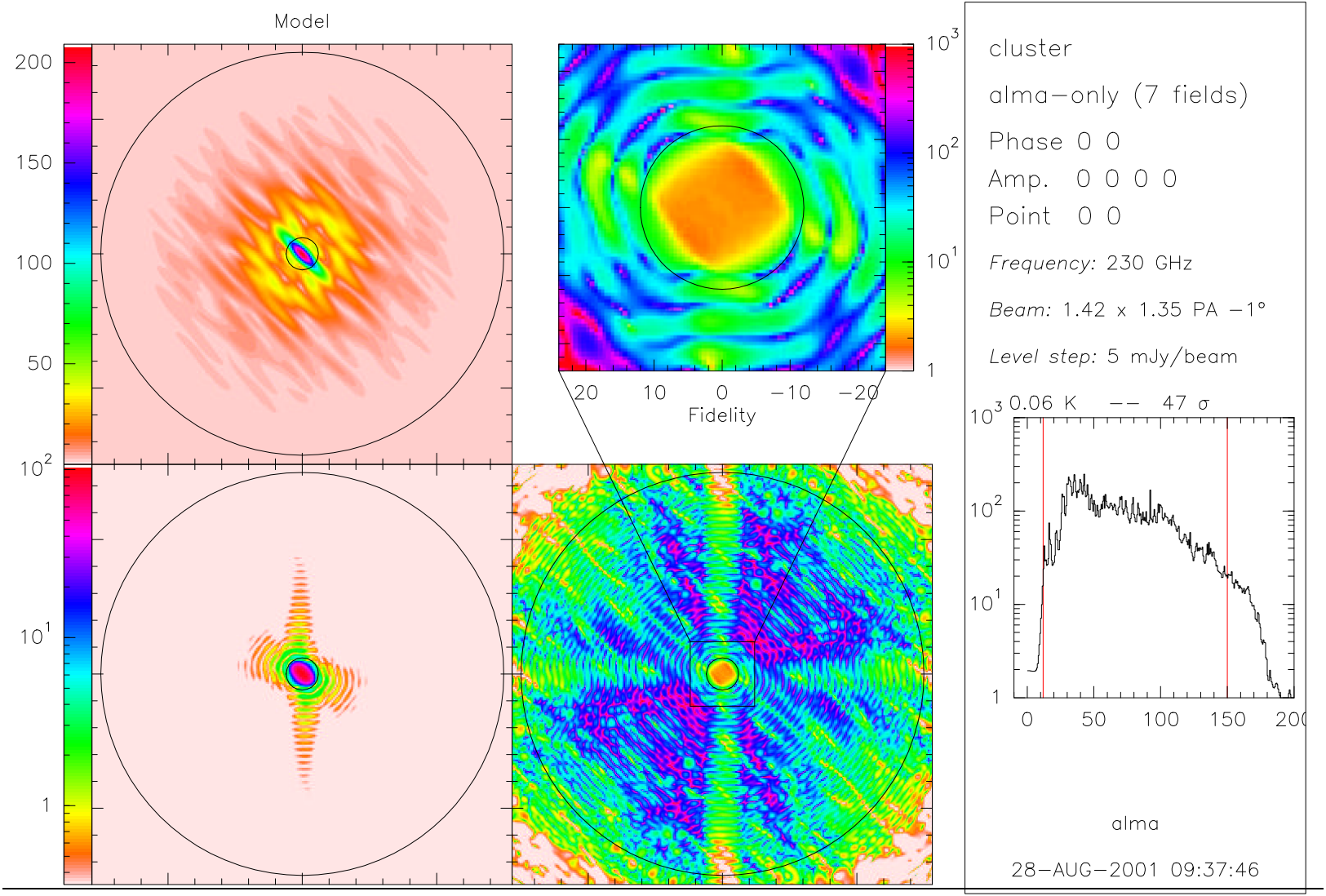
Fourier space estimators :

the fidelity can also be computed in the uv plane


Smoothed Object
Flux = 17.70 Jy (100%)
Simulated Observation
Flux = 17.73 Jy (100%)
Difference RMS = 2.1229E−04 Jy
Flux = −3.3814E−02 Jy (0%)
Fidelity Range = 3099.
cluster
hybrid (7 fields)
Phase 0 0
Amp. 0 0 0 0
Point 0 0
Frequency: 230 GHz
Beam: 1.42 x 1.32 PA −1°
Level step: 50 mJy/beam
0.62 K
Cumulative Fidelity
145 − 0.3% 179 − 1%
213 − 3.3% 286 − 10%
alma
28−AUG−2001 09:37:51
−22°59'40"
−23°00'00"
−23°00'20"
10h00m00s
00s
1
10^1
10^2
10^3


Model
200
150
100
50
10^{-1}
10^{-2}
100
0
−100
Difference
10^3
10^2
10^1
1
20
10
0
−10
−20
Fidelity
100
0
−100
Fidelity
cluster
hybrid (7 fields)
Phase 0 0
Amp. 0 0 0 0
Point 0 0
Frequency: 230 GHz
Beam: 1.42 x 1.32 PA −1°
Level step: 5 mJy/beam
0.06 K −− 47 σ
10^3
10^2
10^1
1
0
50
100
150
200
alma
28−AUG−2001 09:37:52


Smoothed Object
Flux = 17.70 Jy (100%)
Simulated Observation
Flux = 8.616 Jy (49%)
Difference RMS = 1.0628E−02 Jy
Flux = 9.084 Jy (51%)
Fidelity Range = 63.04
cluster
alma−only (7 fields)
Phase 0 0
Amp. 0 0 0 0
Point 0 0
Frequency: 230 GHz
Beam: 1.42 x 1.35 PA −1°
Level step: 50 mJy/beam
0.6 K
Cumulative Fidelity
1 − 0.3%
2 − 1%
2 − 3.3%
4 − 10%
alma
28−AUG−2001 09:37:45
−22°59'40"
−23°00'00"
−23°00'20"
10h00m00s
00s
1
10^1
10^2
10^3


Model
200
150
100
50
10^2
10^1
1
20
10
0
−10
−20
Fidelity
10^3
10^2
10^1
1
100
0
−100
Difference
100
0
−100
Fidelity
cluster
alma−only (7 fields)
Phase 0 0
Amp. 0 0 0 0
Point 0 0
Frequency: 230 GHz
Beam: 1.42 x 1.35 PA −1°
Level step: 5 mJy/beam
10^3 0.06 K −− 47 σ
10^2
10^1
1
0
50
100
150
alma
28−AUG−2001 09:37:46

ALMA/ACA Imaging study

http://iram.fr/∼alma

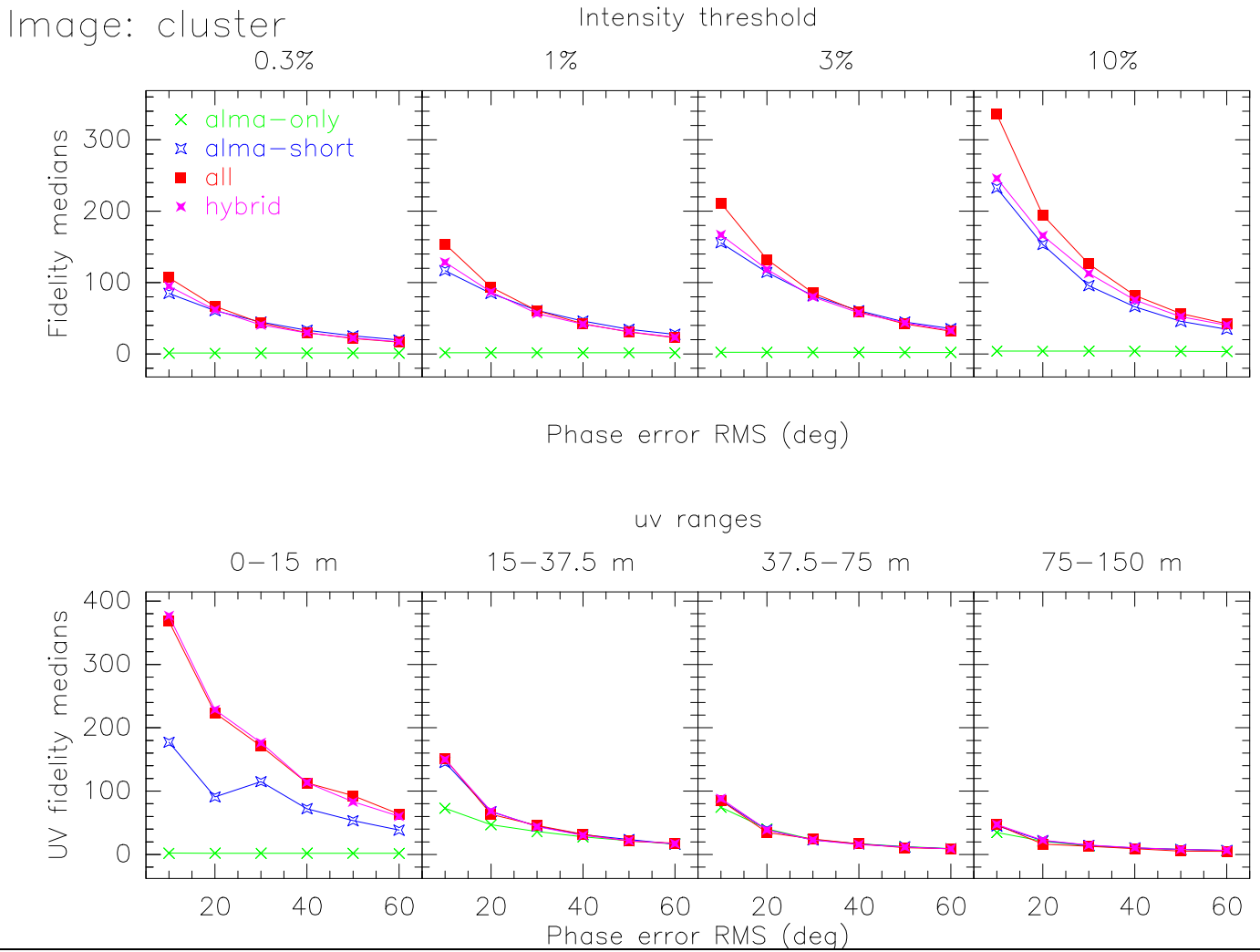


Image: cluster
Intensity threshold
0.3%
1%
3%
10%
alma−only
alma−short
all
hybrid
Fidelity medians
300
200
100
0
Phase error RMS (deg)
uv ranges
0−15 m
15−37.5 m
37.5−75 m
75−150 m
UV fidelity medians
400
300
200
100
0
20
40
60
Phase error RMS (deg)

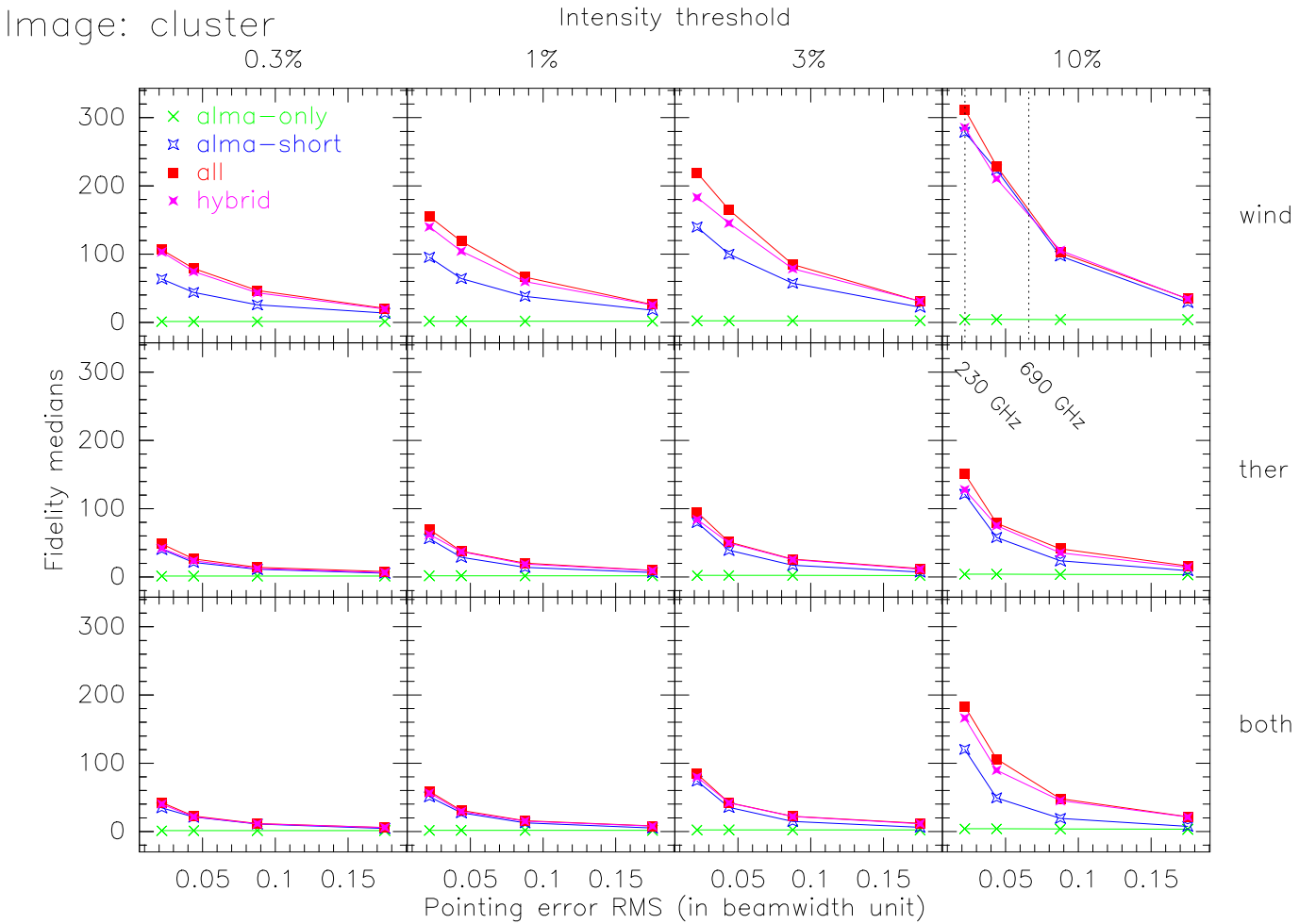
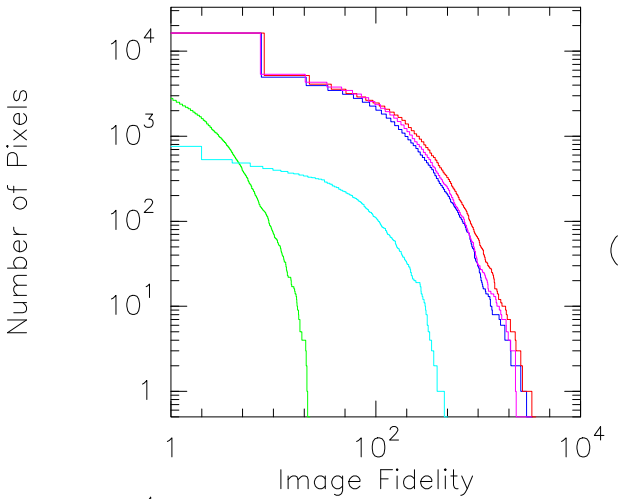
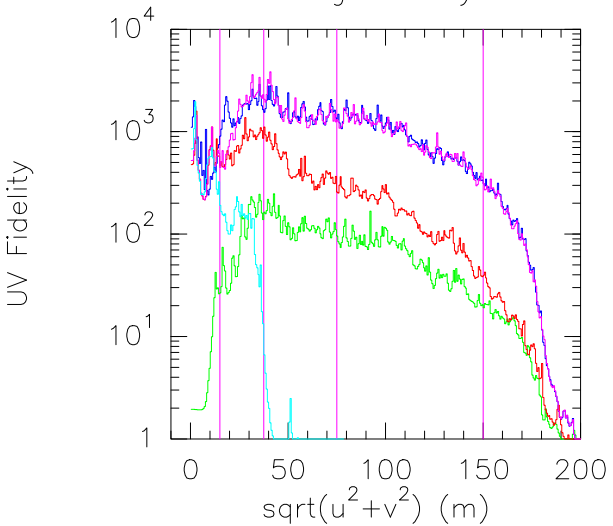


Image: cluster
Intensity threshold
0.3%
1%
3%
10%
alma−only
alma−short
all
hybrid
wind
ther
both
230 GHz
690 GHz
Fidelity medians
300
200
100
0
0.05
0.1
0.15
Pointing error RMS (in beamwidth unit)



Cumulative Histogram (Image plane)



Azimuthal Average (uv plane)

aca−short

alma−only

alma−short

all

hybrid

cluster

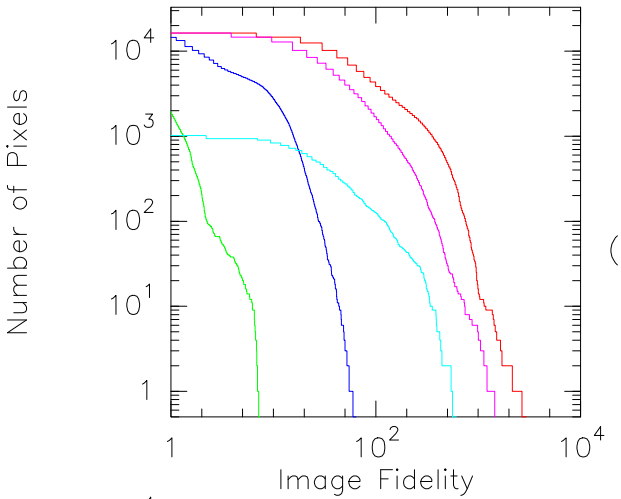
aca−short (7 fields)

Phase 0 0

Amp. 0 0 0 0

Point 0 0

Frequency: 230 GHz



Cumulative Histogram (Image plane)

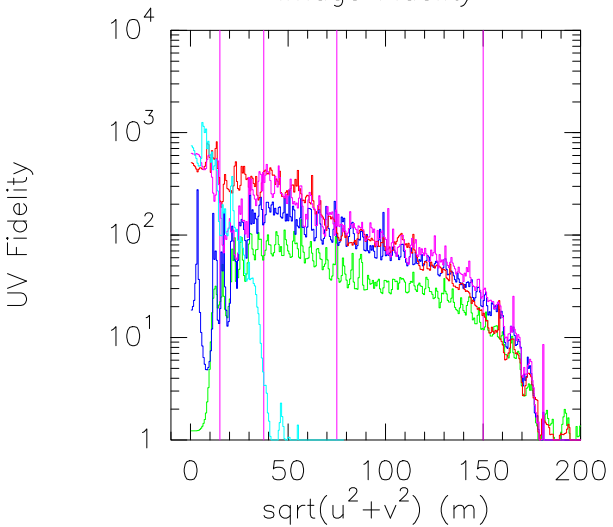
aca−short

alma−only

alma−short

all

hybrid



Azimuthal Average (uv plane)

hco43

aca−short (7 fields)

Phase 0 0

Amp. 0 0 0 0

Point 0 0

Frequency: 230 GHz

Concluding remarks

- ALMA(+ACA) will provide excellent images
- ... but not perfect images
- A proper data analysis will still require to understand the image formation principles and the data procesing techniques
- Simulator available for ALMA prospective studies (example: Wolf & Klahr 2002, ApJL)