Simulations of Imaging Extended Sources with The GMRT and uGMRT

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Motivation

- Extended sources – diffuse or/and discrete matter in the Universe
  – Linear size (L) extends to $\sim$ Mpc scale
- Imaging of Mpc size extended sources (e.g. radio halos) through GMRT and its upgrade
- Radio halos: redshift, $z \sim 0.01$ to 1.0
- $\mathrm{L} = 1\mathrm{Mpc} \rightarrow$ angular size (θ) $\sim 79'$ to $2'$ for $z = 0.01$ to 1.0
- Such large angular size are challenging targets for imaging with interferometer
- Limitations: - Largest θ sampling (shortest baseline)
  - differentiation of discrete from diffuse emissions (longest baseline)
- Understanding the limitations in imaging of such large angular size extended sources through GMRT and uGMRT

OVERVIEW

Make model image

↓

Simulate corresponding GMRT visibility

↓

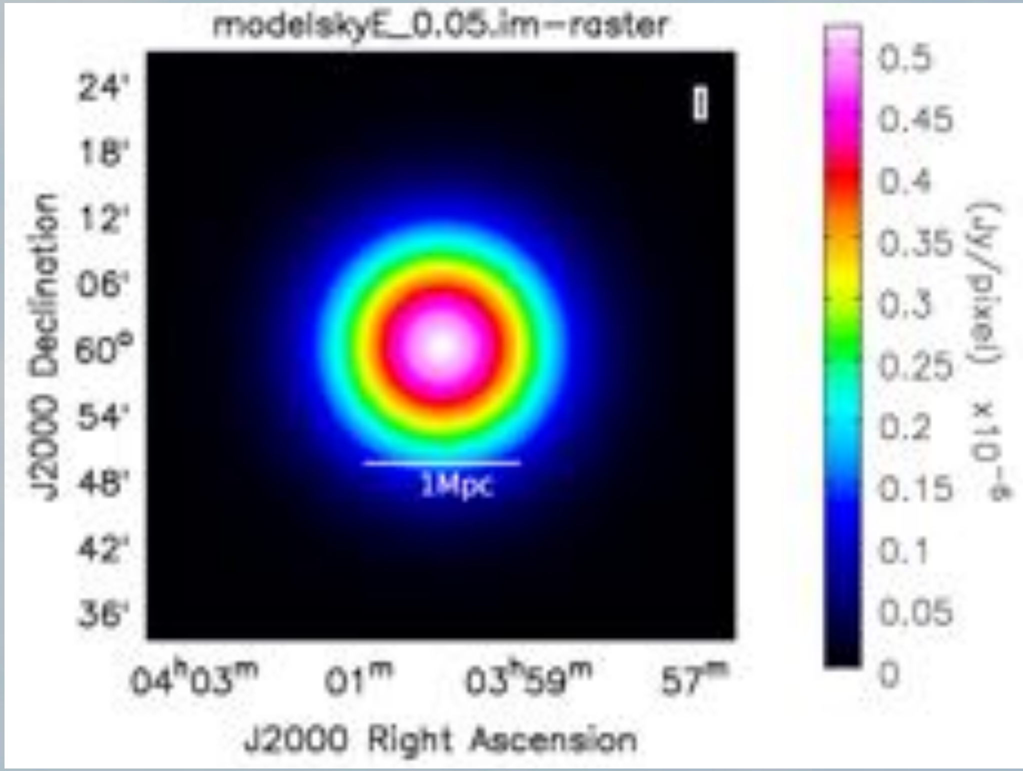
Image it using CASA task *CLEAN*

↓

Compare the *CLEAN*ed image with model

Making model image

- Used CASA Toolkit (image analysis & component list tools)
- Shape: 2D Gaussian;   Ra, Dec : 4hr, 60°
- Linear size, $L = 1$ Mpc (FWHM)
- $z = [0.05 - 1.0],\ \theta \sim [17' - 2'],\ \nu = 610MHz$
- Flux density (S) = 0.6 Jy at z = 0.05 (A2163 radio halo)
- S at higher z was scaled according to distance



Simulating visibility & Imaging

- Image analysis & simulation tools
- Antenna Configuration: GMRT
- Noise free
- Bandwidth: 1 MHz (1chan), $\nu_c = 610\ MHz$

  33 MHz (33 chans), $\nu_c = 316\ MHz$

  100 MHz (100 chans), $\nu_c = 350\ MHz$

  200 MHz (200 chans) , $\nu_c = 400\ MHz$

- CLEAN task in CASA for imaging
- MS-MFS cleaning

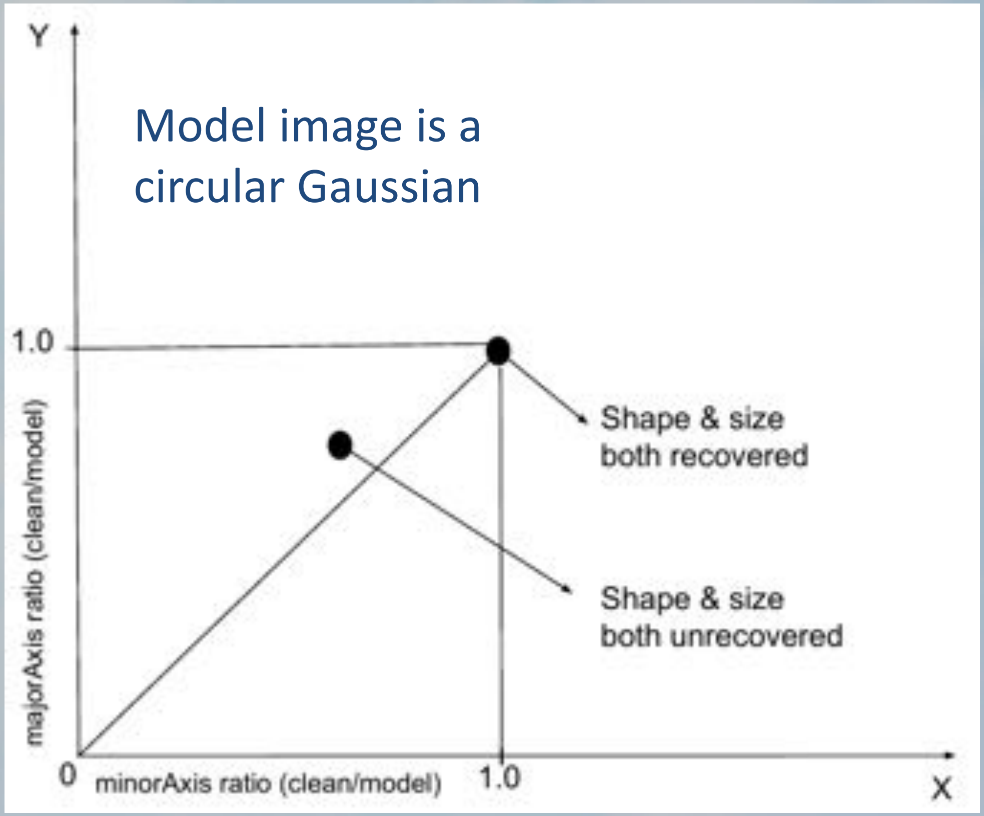
Comparison: Model vs CLEANed

- Flux density (S) recovery

$$\% \, S \text{ recovery} = \frac{S_{CLEANed}}{S_{Model}} \times 100$$

- Morphology recovery

  - Gaussian fit was done for comparison



Cases studied

- Recovery as function of:

angular size (or redshift)

Source flux density (S)

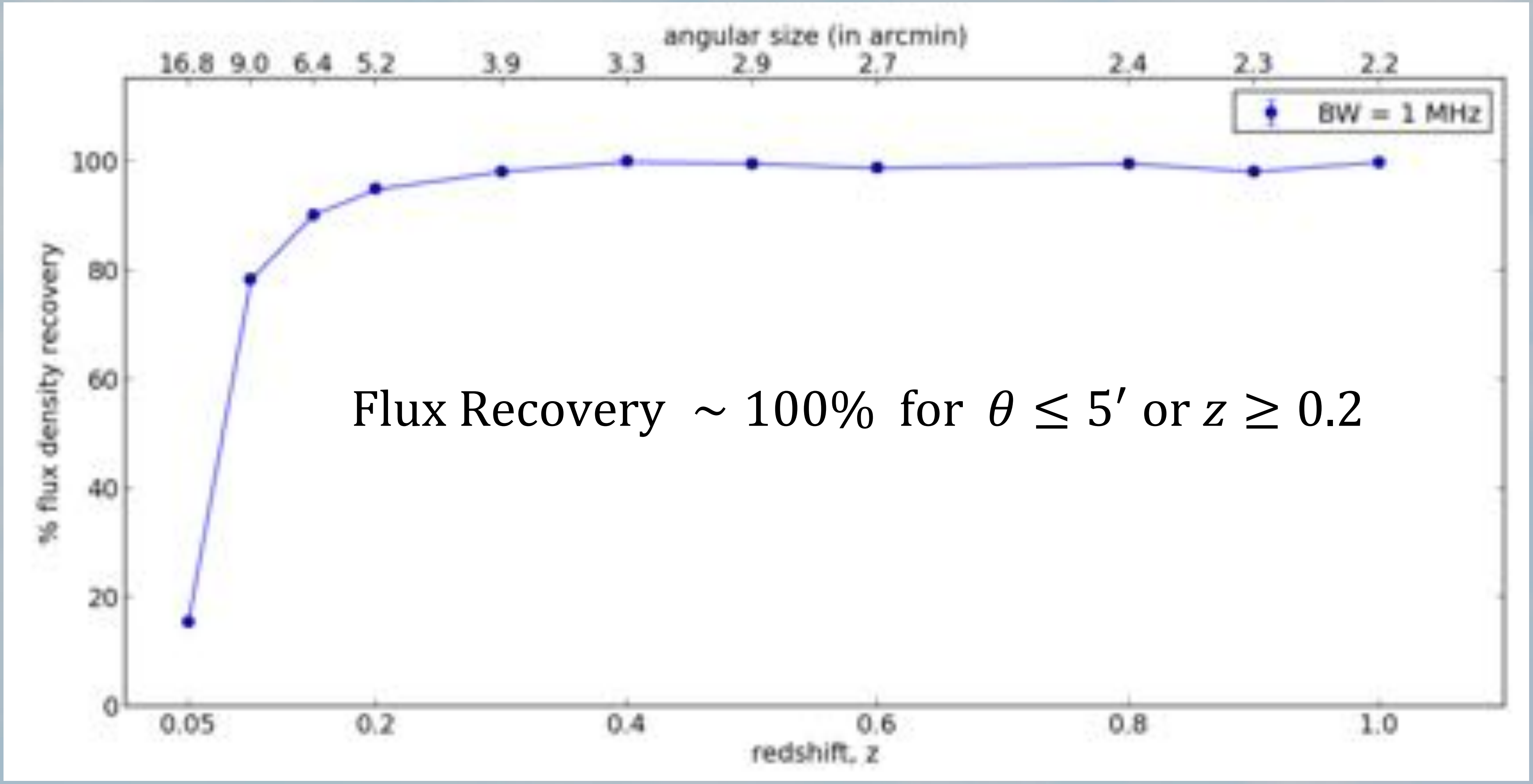
Declination (Dec)

Observing duration (T_{obs})

Bandwidth (BW)

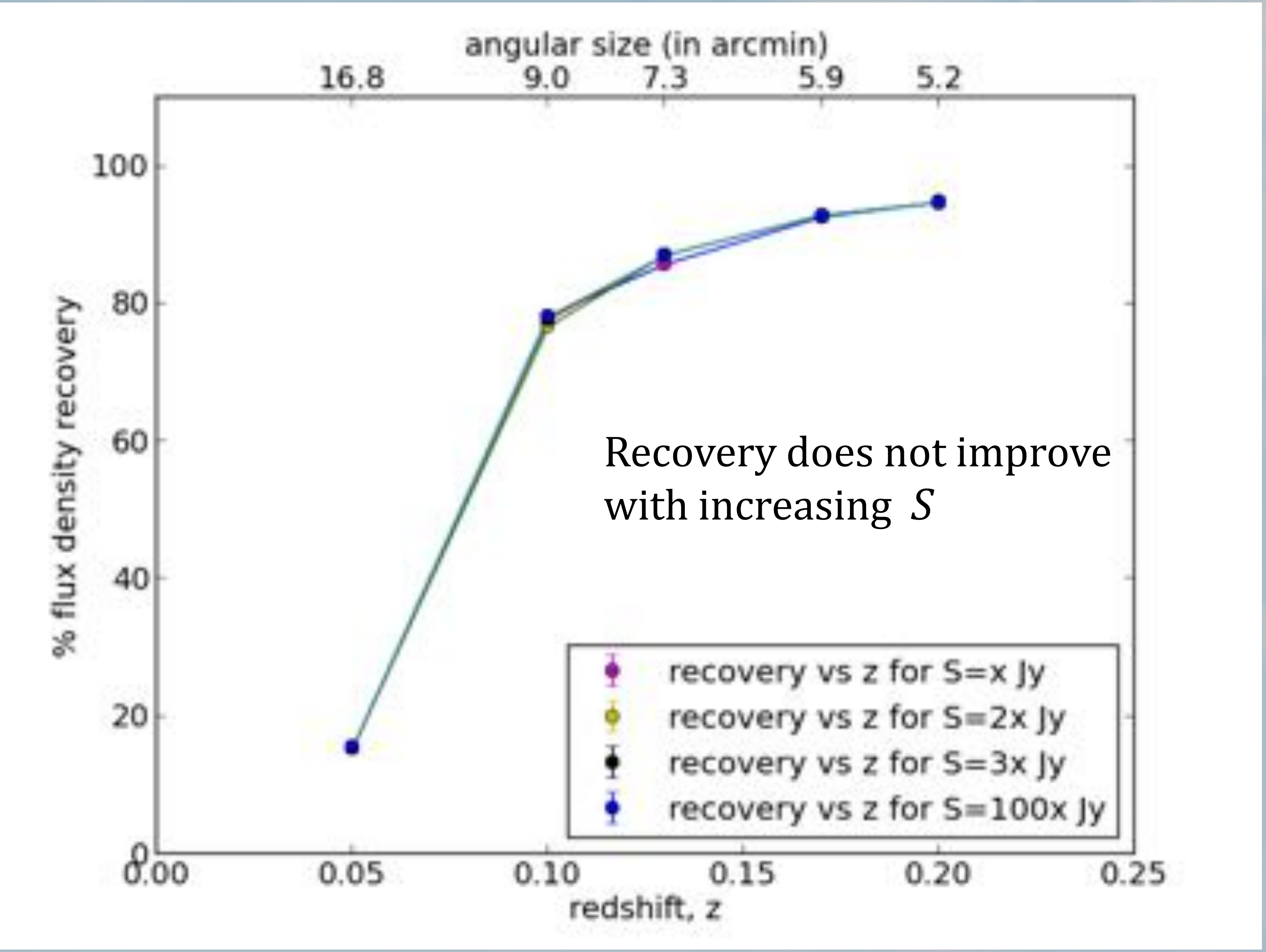
Angular size, θ (or z)

Flux recovery, $1MHz$, $\nu = 610MHz$, T_{obs} = 2hrs from transit



Source strength (S)

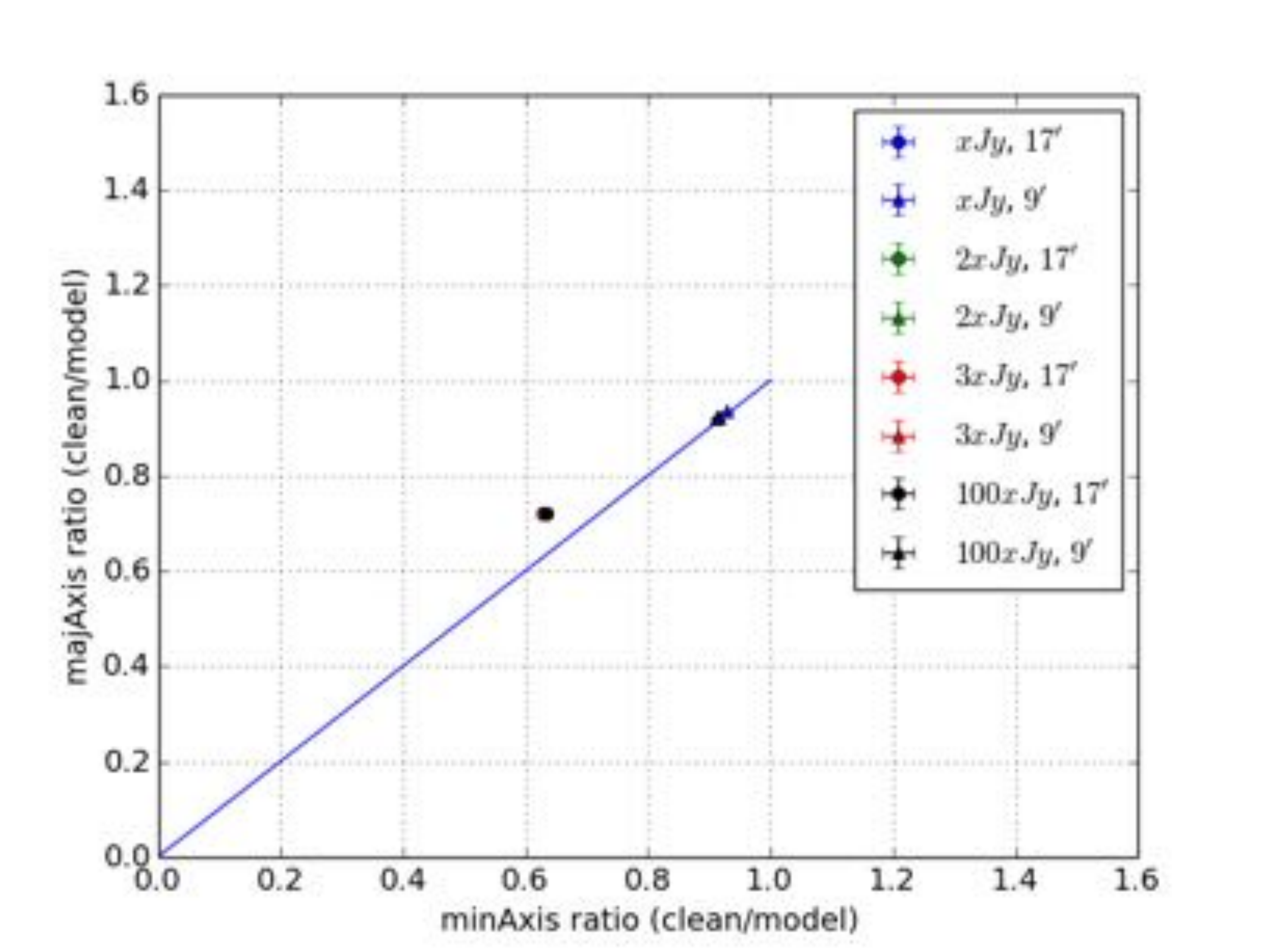
Flux recovery, $1MHz,\ \nu = 610MHz, T_{obs} =$ 2hrs from transit



Recovery does not improve with increasing S

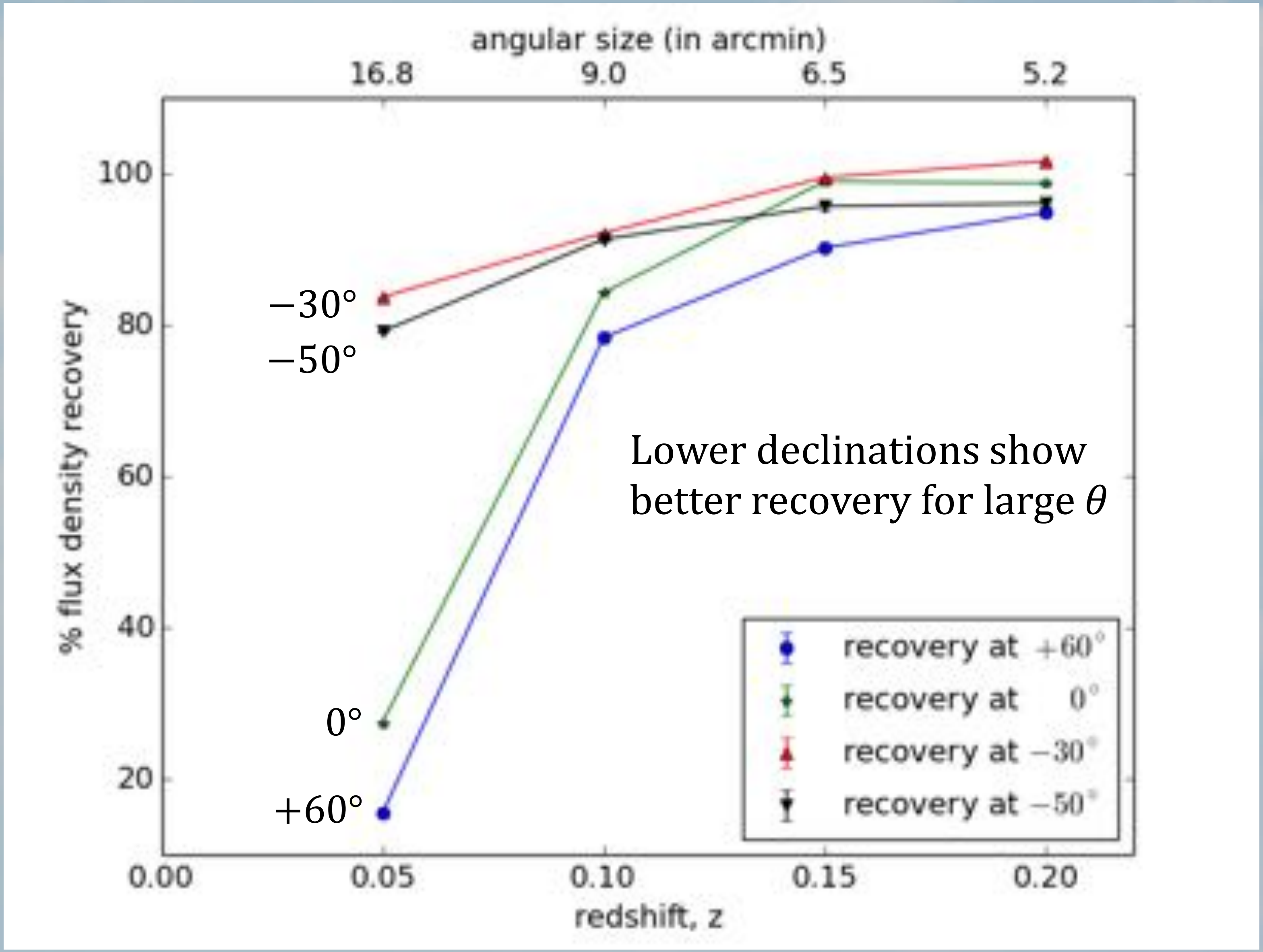
Source strength (S)

Morphology recovery, $\theta \sim [17', 9']$



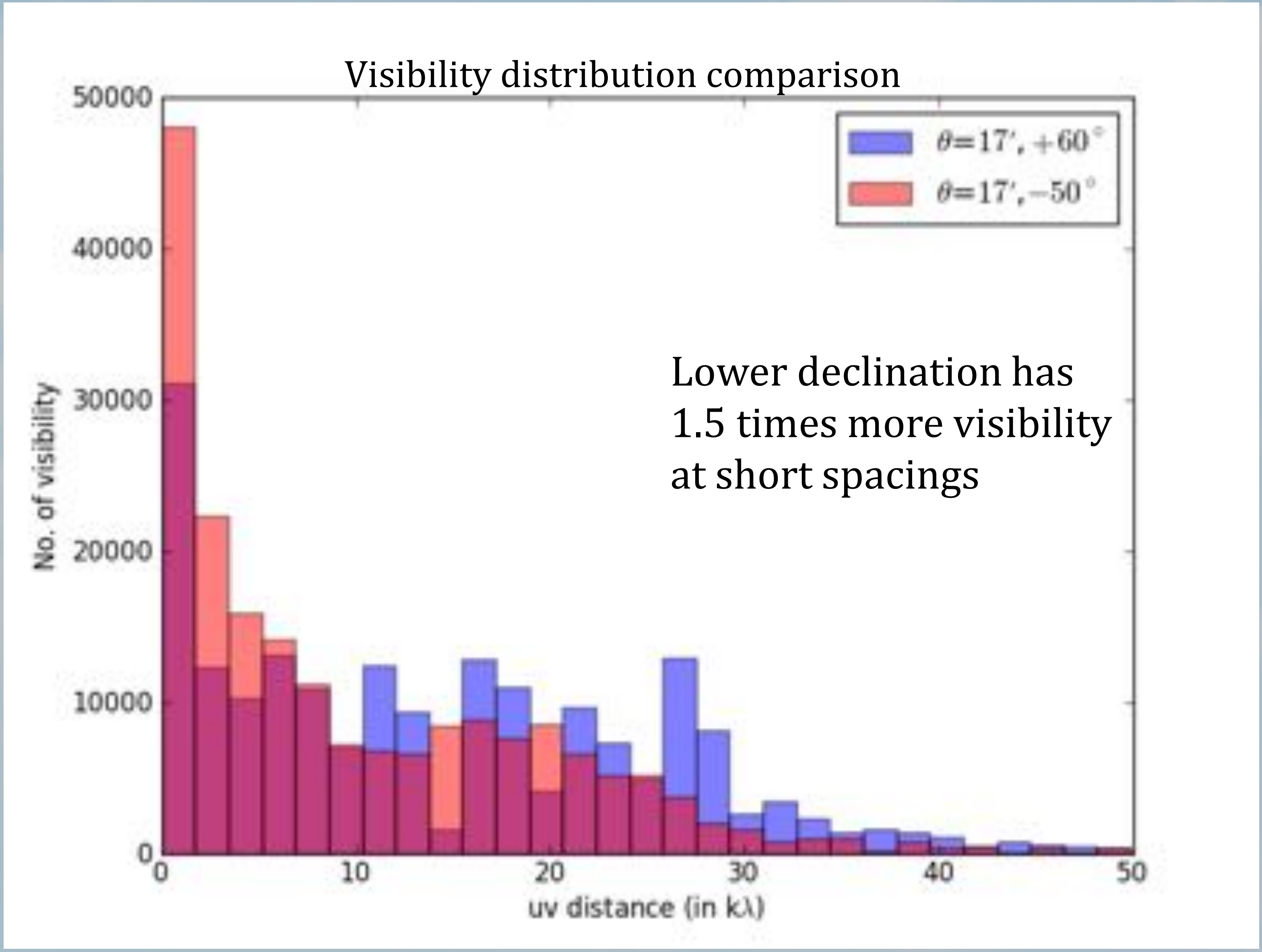
Declination

Flux recovery, $1MHz,\ \nu = 610MHz, T_{obs} =$ 2hrs from transit



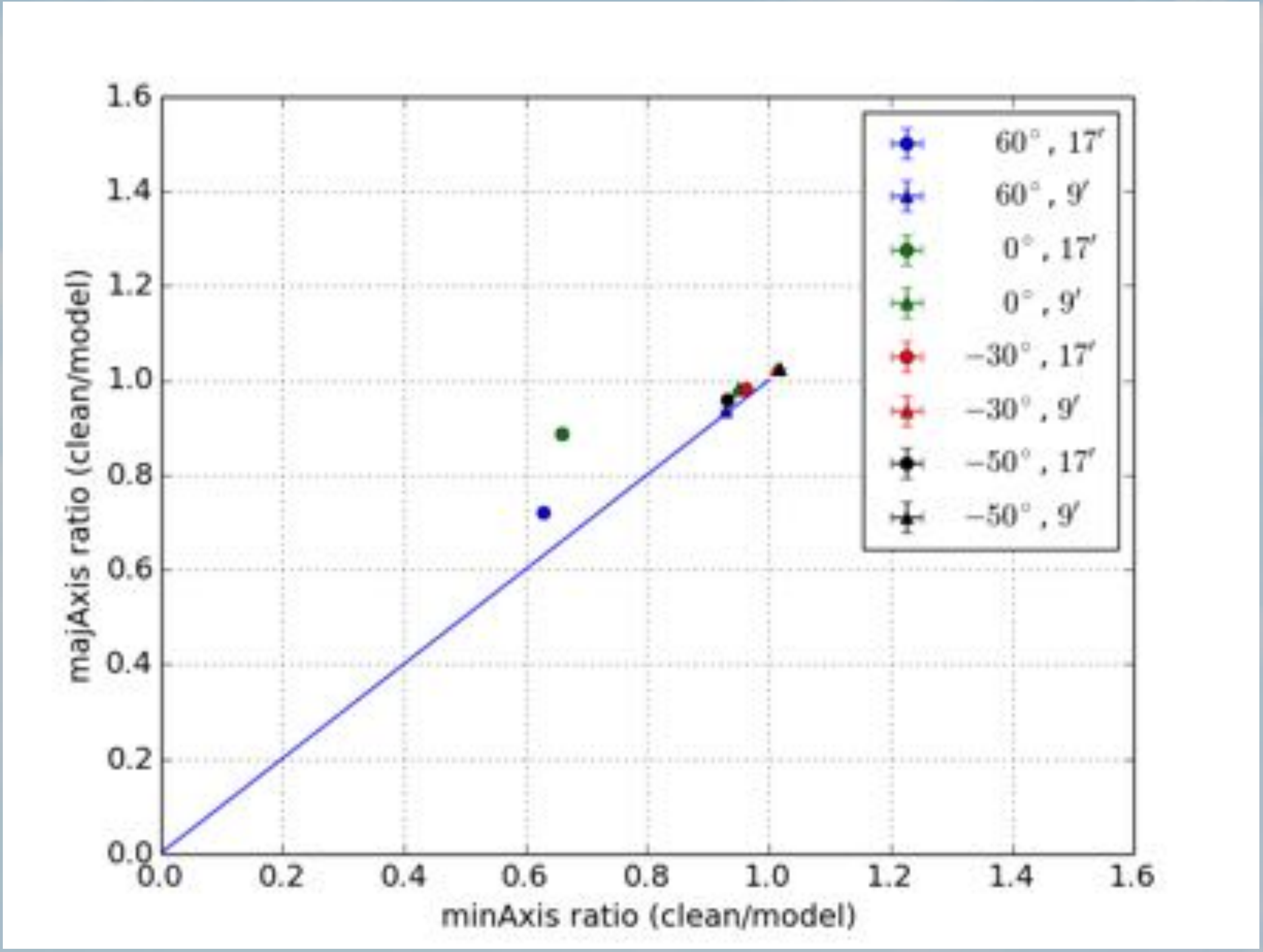
Declination

Visibilities, $1MHz,\ \nu = 610MHz, T_{obs} =$ 2hrs from transit



Declination

Morphology recovery, $\theta \sim [17', 9']$



Observation duration

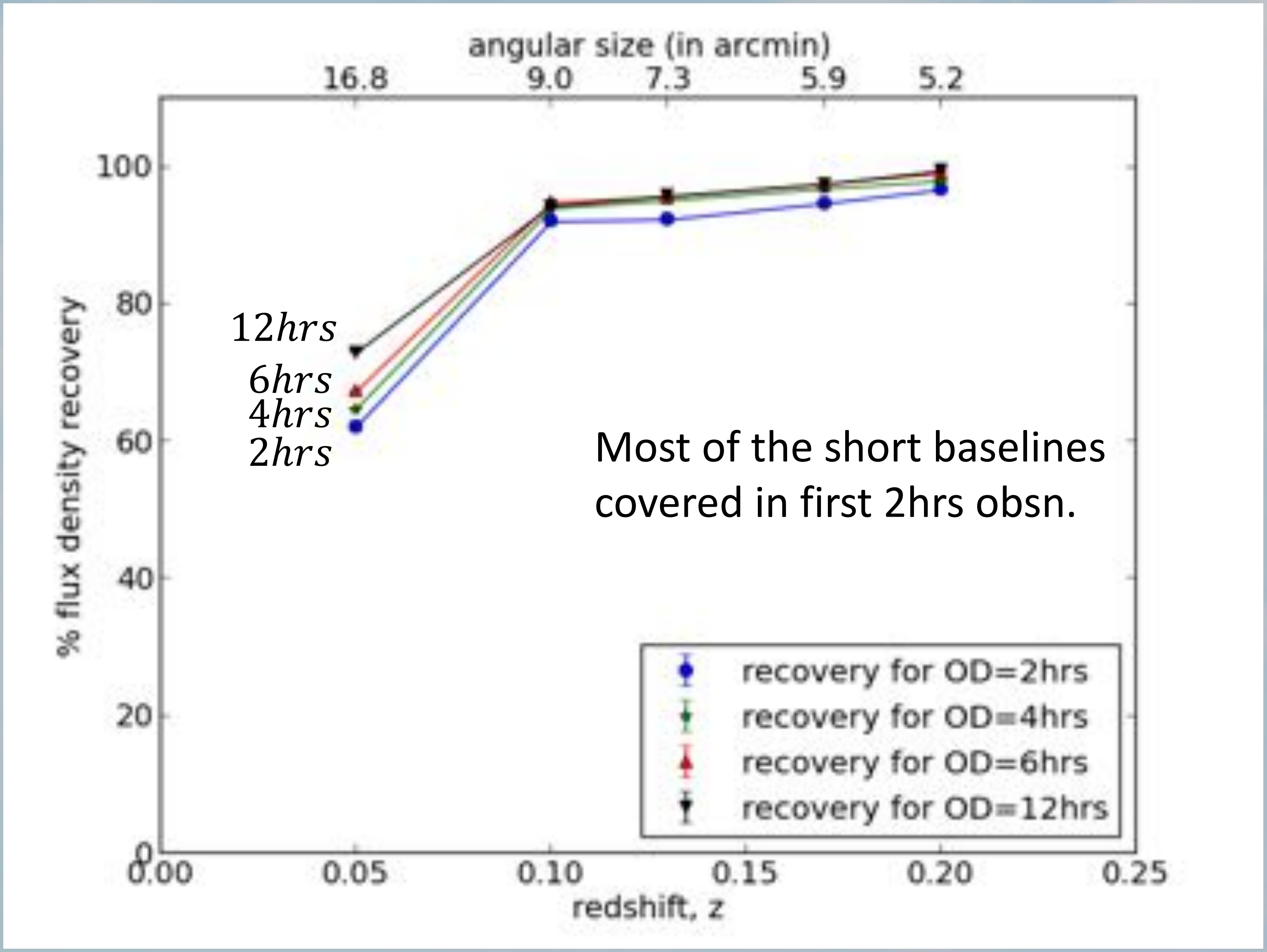
- Source was observed for different durations beginning from the rise time
- Observation was made at 2, 4 , 6 and 12hrs (full synthesis) leading to improved PSF gradually
- $\mathrm{BW} = 1\mathrm{MHz},\ \ \nu_{obs} = 610\mathrm{MHz},\ \mathrm{Dec.} = \ +60°$

▪ 2hrs spread over 12hrs

- 6 scans of 20 minutes each

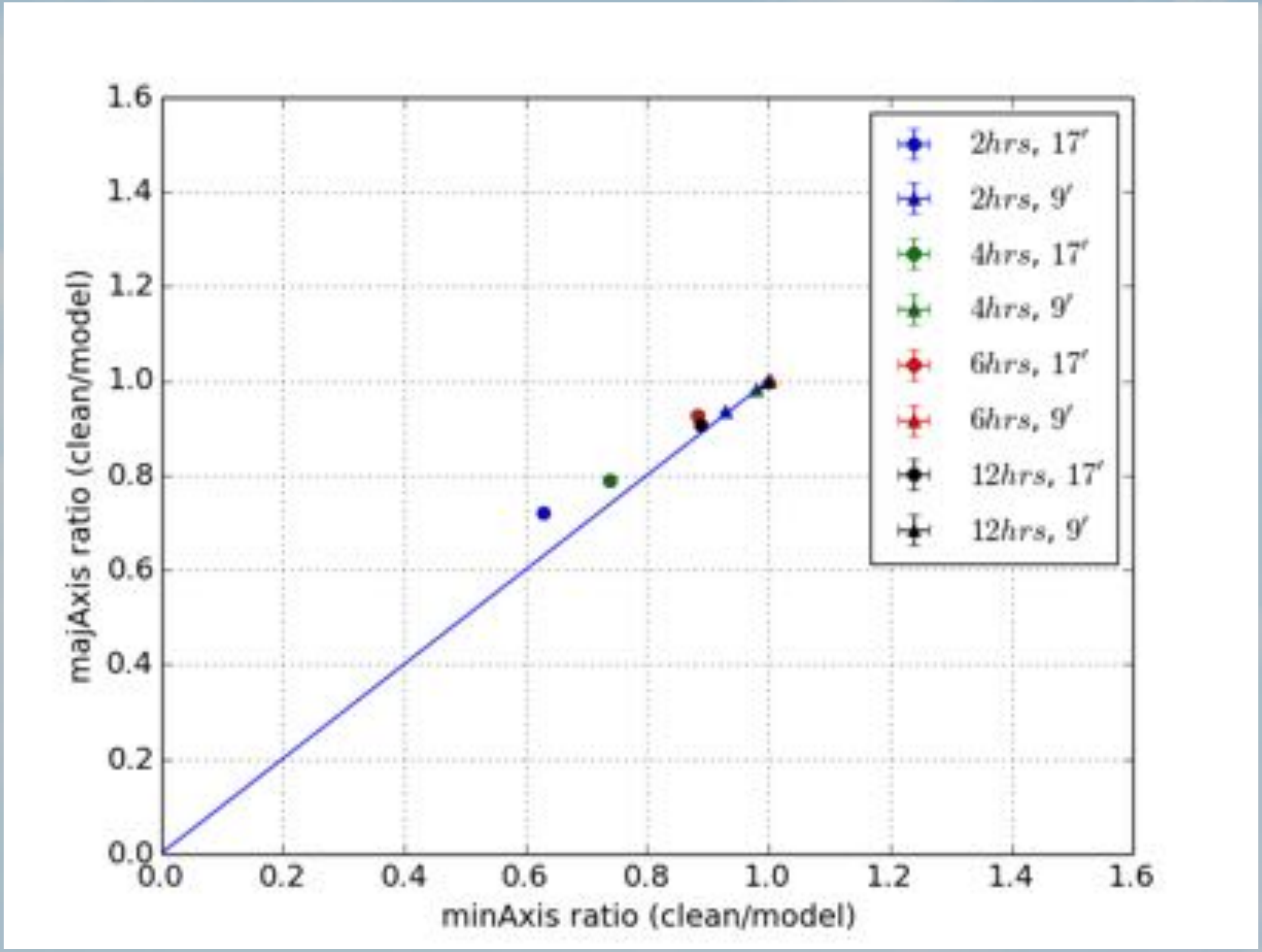
Observation Duration

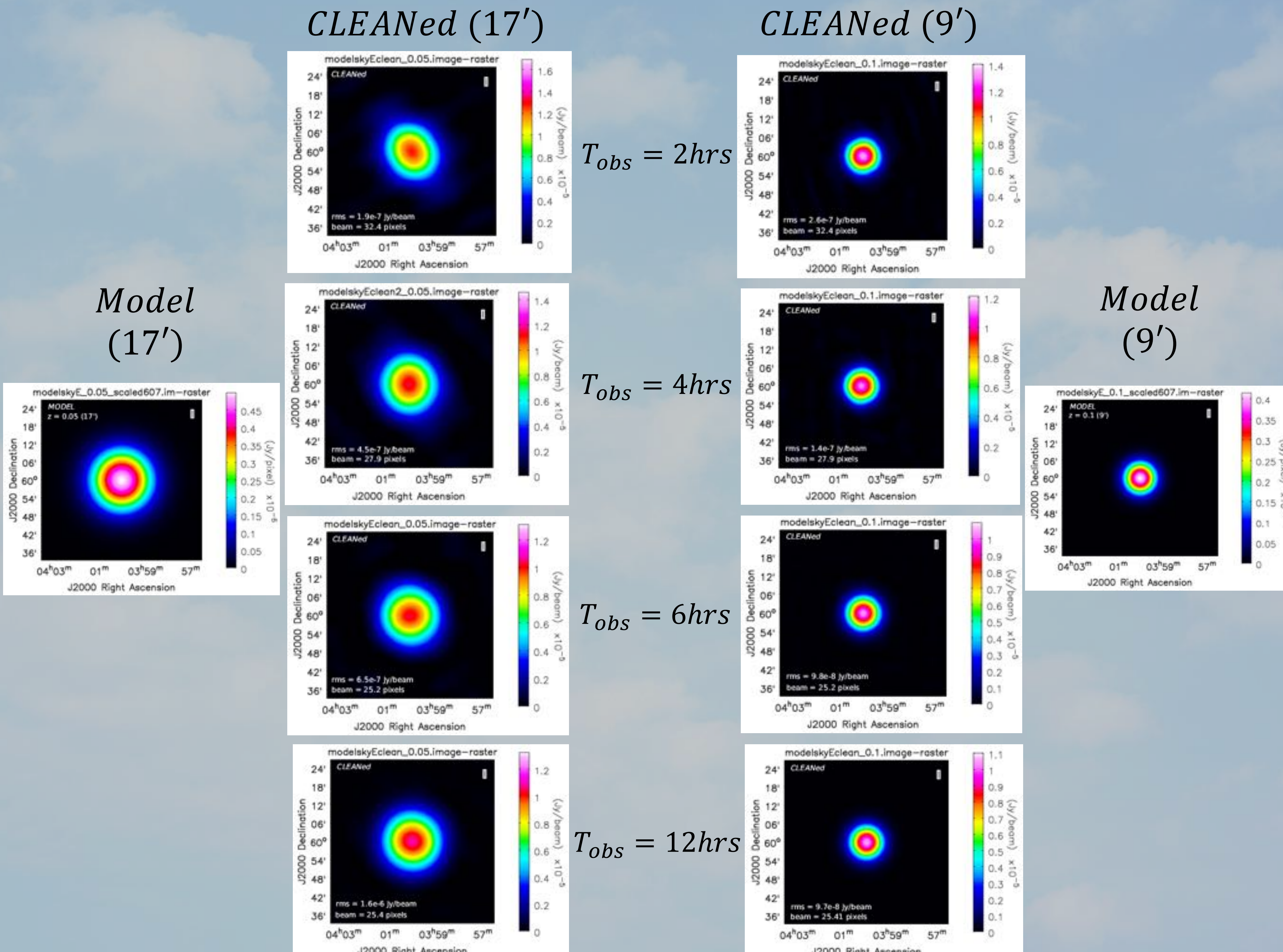
Flux recovery, $1\text{MHz}, \nu = 610\text{MHz}$



Observation Duration

Morphology recovery, $\theta \sim [17', 9']$

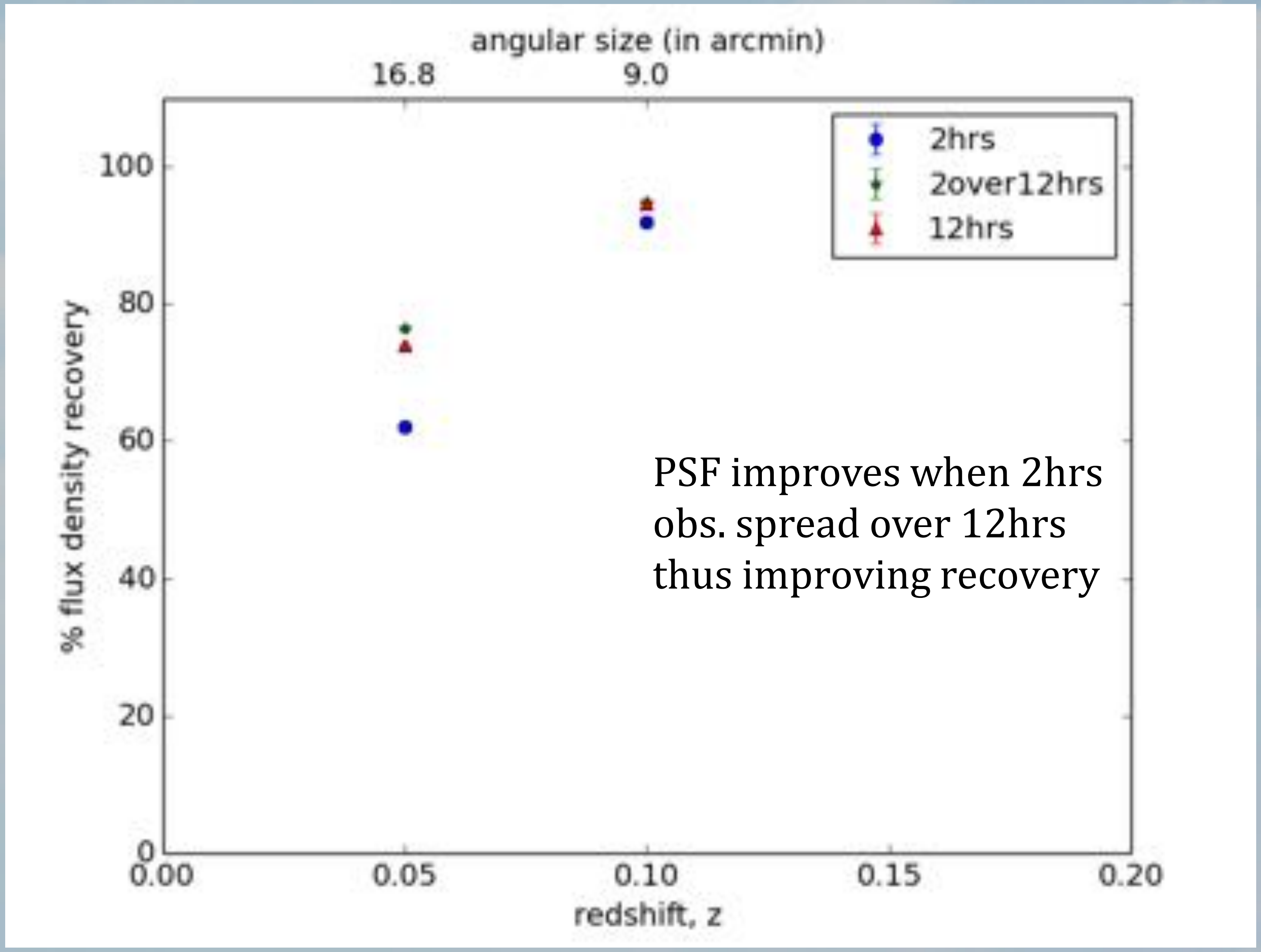




CLEANed (17′)
CLEANed (9′)
Model (17′)
Model (9′)
$T_{obs} = 2hrs$
$T_{obs} = 4hrs$
$T_{obs} = 6hrs$
$T_{obs} = 12hrs$
modelskyEclean_0.05.image-raster
modelskyEclean2_0.05.image-raster
modelskyEclean_0.1.image-raster
modelskyE_0.05_scaled607.im-raster
modelskyE_0.1_scaled607.im-raster
CLEANed
MODEL
z = 0.05 (17')
z = 0.1 (9')
rms = 1.9e-7 Jy/beam
beam = 32.4 pixels
rms = 2.6e-7 Jy/beam
beam = 32.4 pixels
rms = 4.5e-7 Jy/beam
beam = 27.9 pixels
rms = 1.4e-7 Jy/beam
beam = 27.9 pixels
rms = 6.5e-7 Jy/beam
beam = 25.2 pixels
rms = 9.8e-8 Jy/beam
beam = 25.2 pixels
rms = 1.6e-6 Jy/beam
beam = 25.4 pixels
rms = 9.7e-8 Jy/beam
beam = 25.41 pixels
J2000 Declination
J2000 Right Ascension
(Jy/beam) ×10⁻⁵
(Jy/pixel) ×10⁻⁵

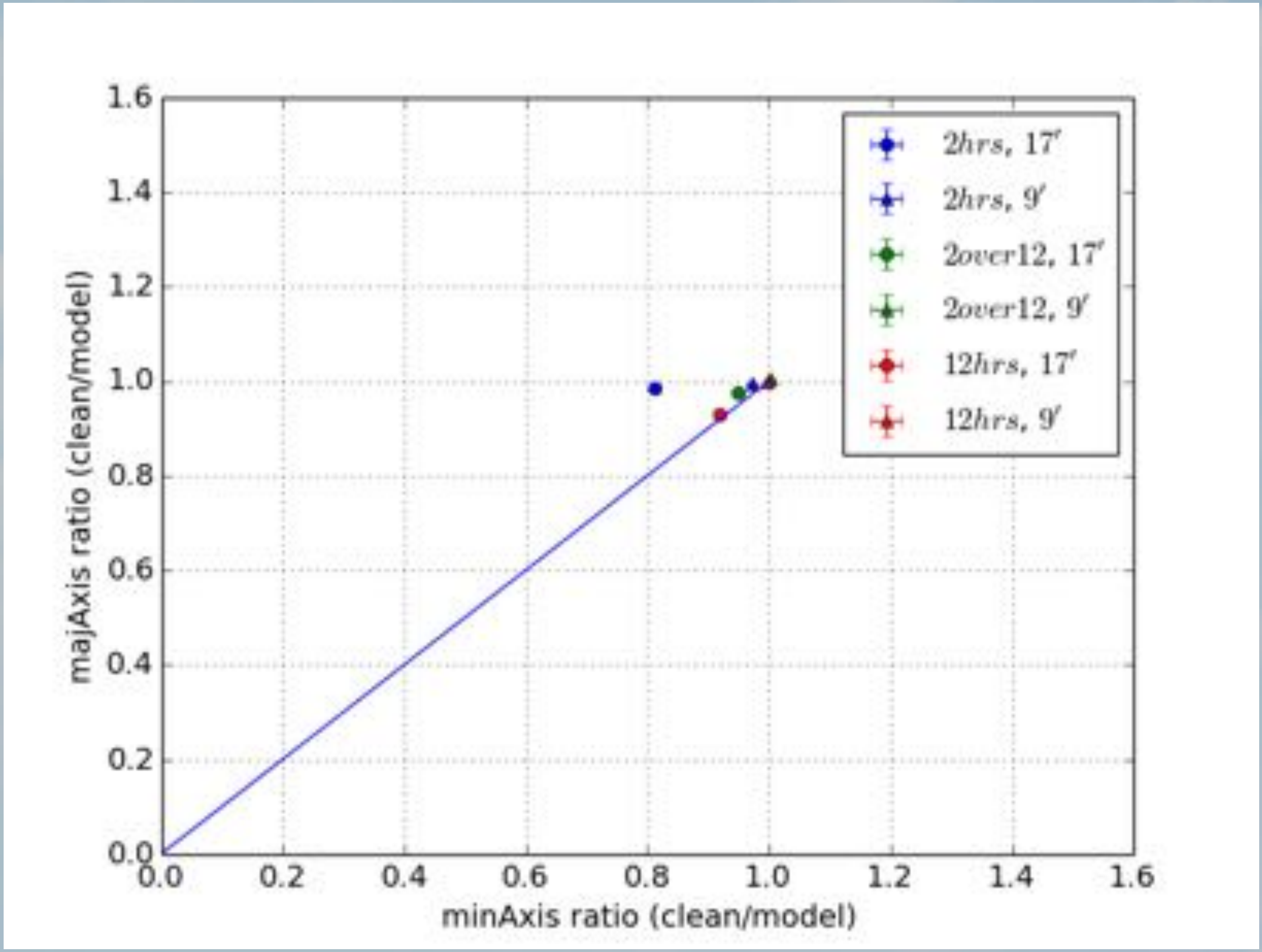
2hrs spread over 12hrs

Flux recovery, $1\text{MHz}, \nu = 610\text{MHz}, \theta \sim [17', 9']$



2hrs spread over 12hrs

Morphology recovery, $\theta = [17', 9']$

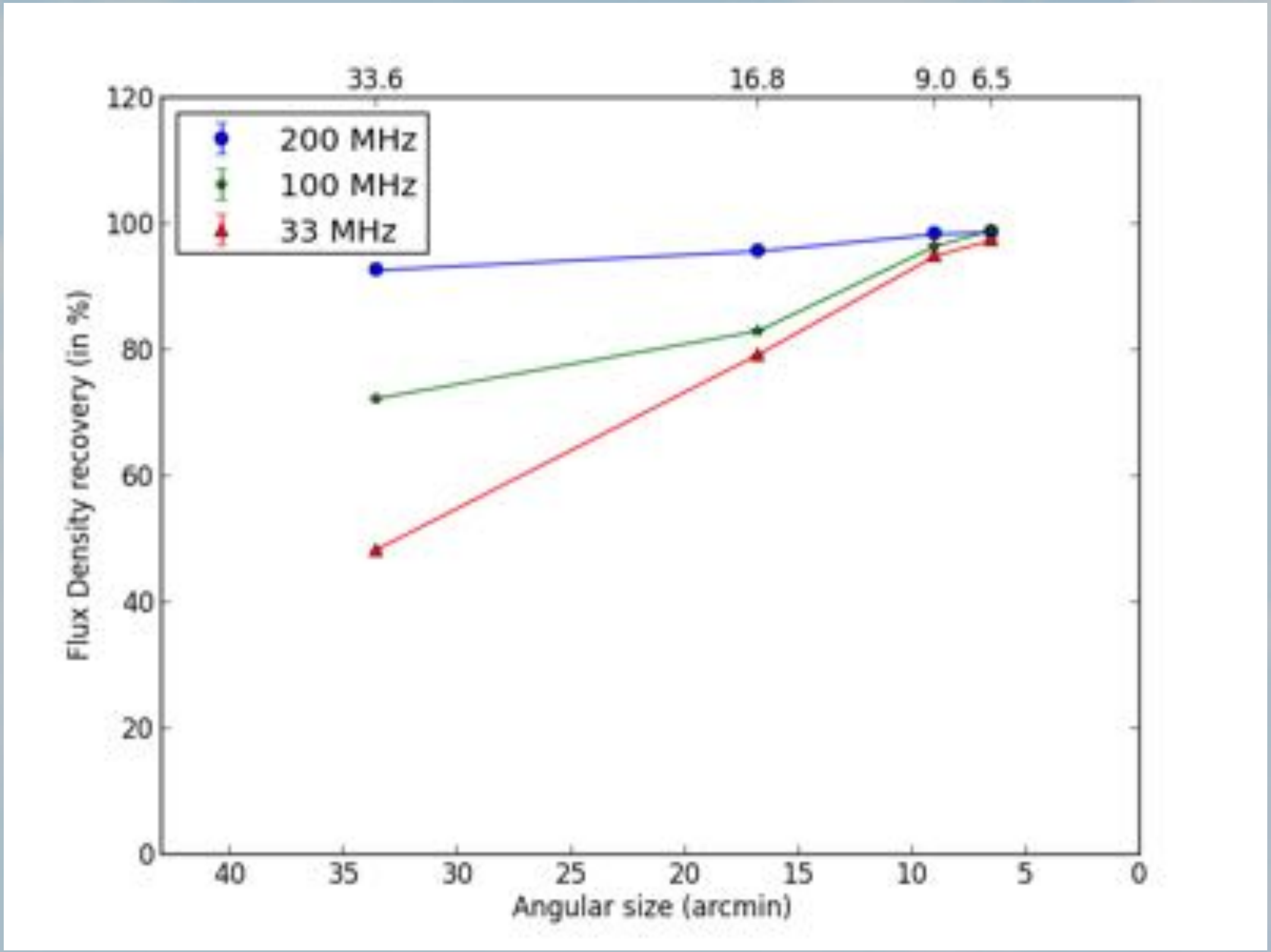


Bandwidth

- Comparison was made in P-band
- Observations simulated:
  - $\text{GMRT: } 33\text{MHz } (300 - 332 \text{ MHz})$
  - $\text{uGMRT: } 100\text{MHz } (300 - 399 \text{ MHz})$
  - $\text{uGMRT: } 200\text{MHz } (300 - 499 \text{ MHz})$
- Largest angular size at $300\text{MHz} = 34'$
- $\text{T}_{\text{obs}} = 2\text{hrs}$ from rise time
- $\text{Dec.} = +60°$

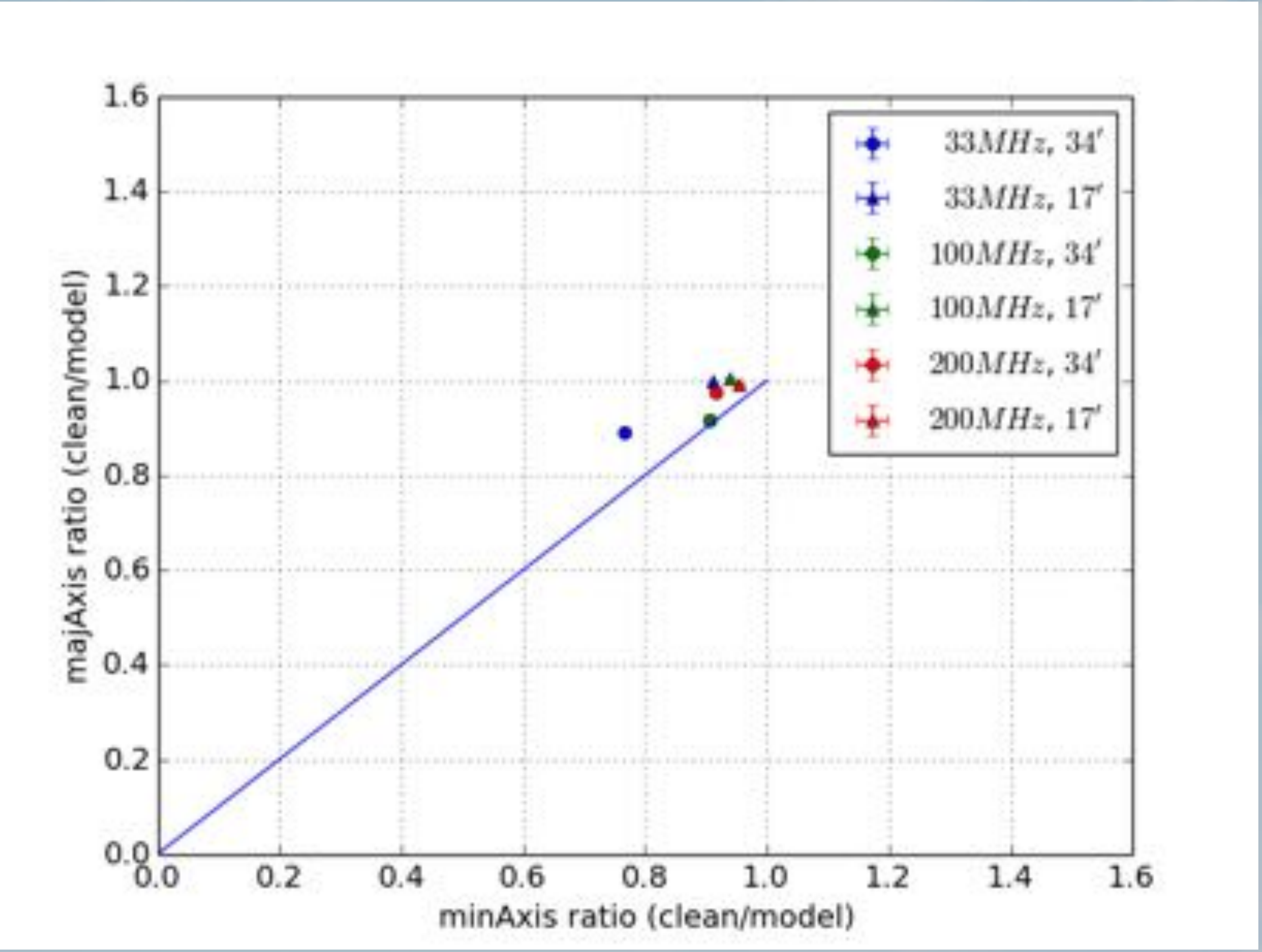
Bandwidth

Flux recovery, $T_{obs} = 2\text{hrs from rise}, +60°$



Bandwidth

Morphology recovery, $\theta \sim [34', 17']$



Summary

- S and morphology recovery ~ 100% for sources at
  $z > 0.2$ or $\theta < 5'$ for $T_{obs} = 2hrs, \nu = 610MHz$
- Recovery is independent of source strength (noise free simulation)
- Lower declination sources shows better recovery at
  $z < 0.2\ or\ \theta > 5'$ ($\nu = 610MHz$)

  - more short projected baselines
- Recovery increases with observing duration

  - 2hrs over 12hrs ≡ 12hrs observation
- uGMRT shows better recovery than GMRT

  - S recovery from uGMRT improves by factor of 2 for the source with θ corresponding to shortest baseline
- Implication to survey strategies

Future work

- Adding noise in the simulated observation

  - Studying the cases in presence of noise

- Studying the cases with model sky as a real source

  - Abell 2163 1.4 GHz VLA image

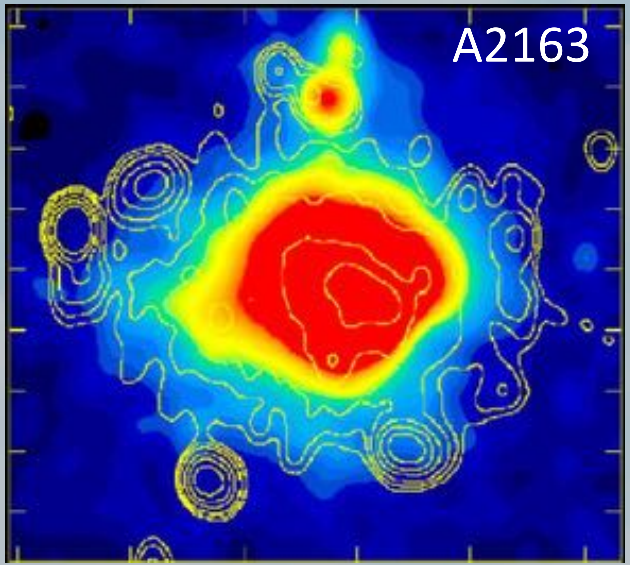
- Imaging the real uGMRT data

  - Comparing real and simulated observation

THANK YOU

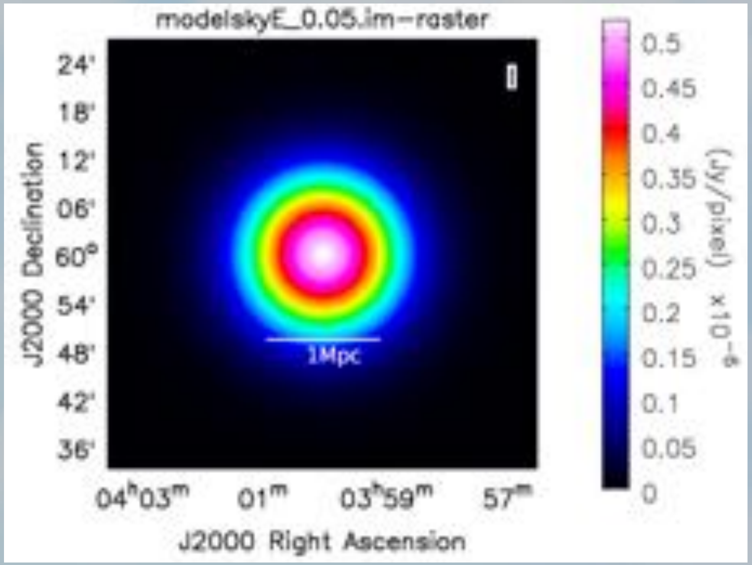
Supplementary slides

Flux density (S) of the model source



$$S \propto \nu^{\alpha}$$

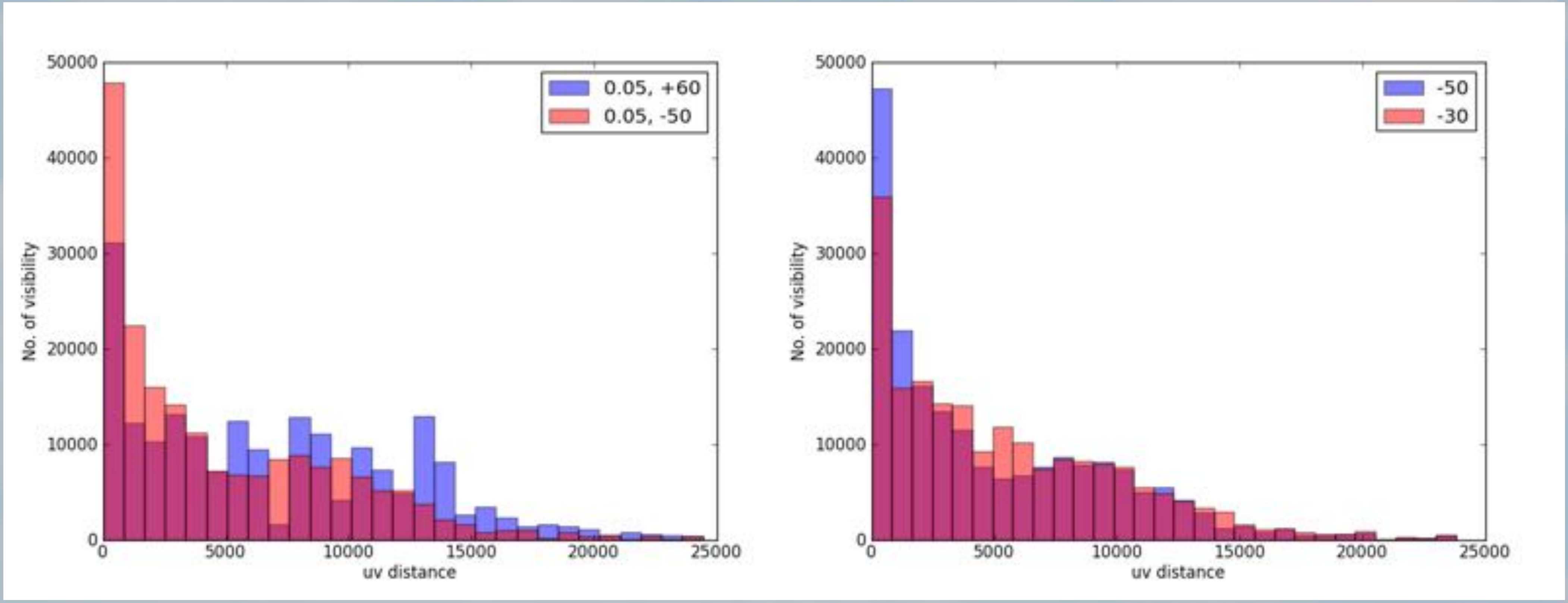
$$\frac{S_{model}}{S_{A2163}} = \left(\frac{\nu_{model}}{\nu_{A2163}}\right)^{\alpha}$$



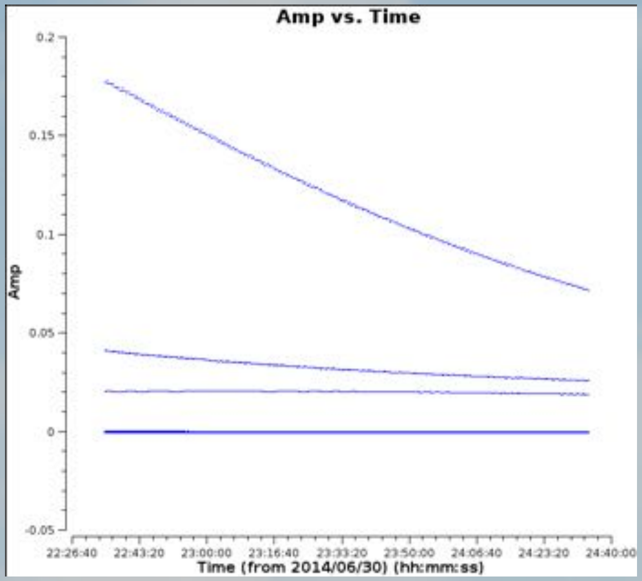
$S_{A2163} = 0.155\,Jy$
$\nu = 1.4\,GHz$
$\alpha = -1.6$
(Feretti et al. 2001)

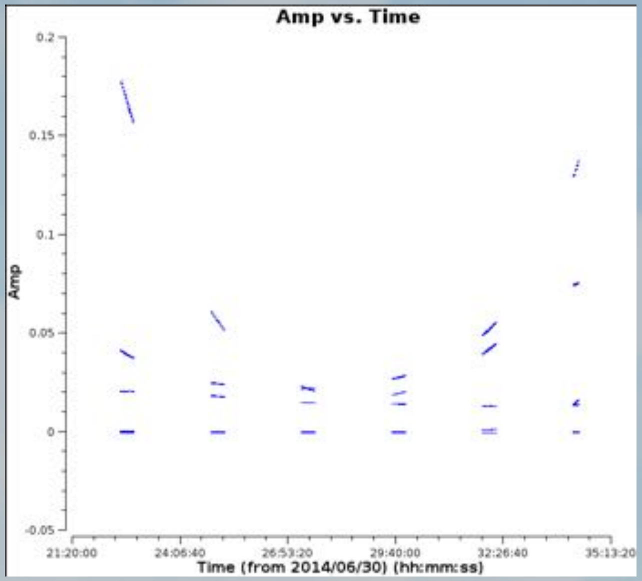
$S_{model} \sim 0.6\,Jy$
$\nu = 610\,MHz$
$z = 0.05$

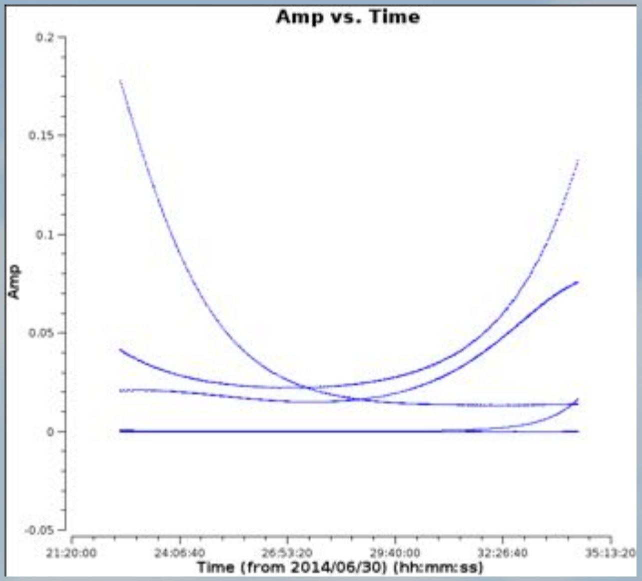
Quantifying UVcoverage



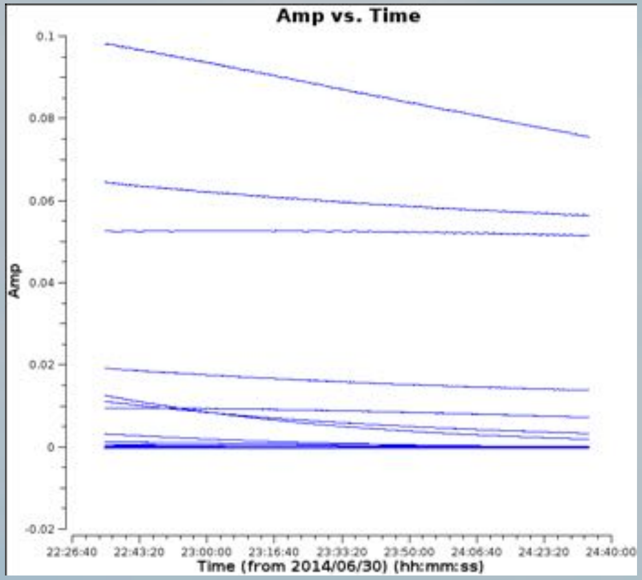
$Z = 0.05,\ \theta \sim 17'$

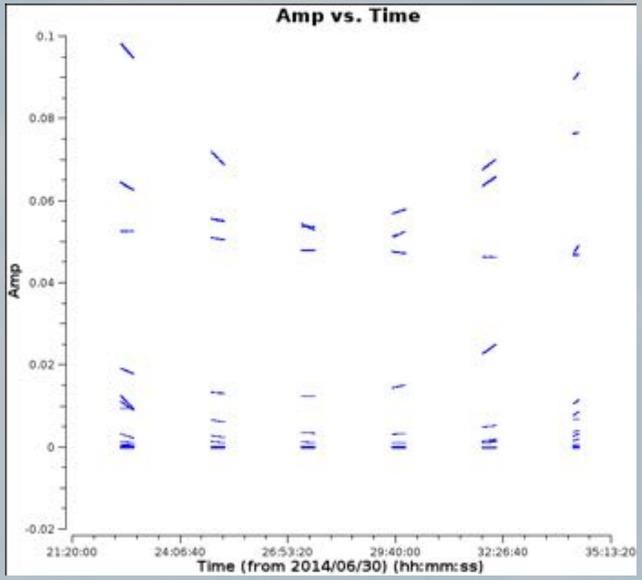


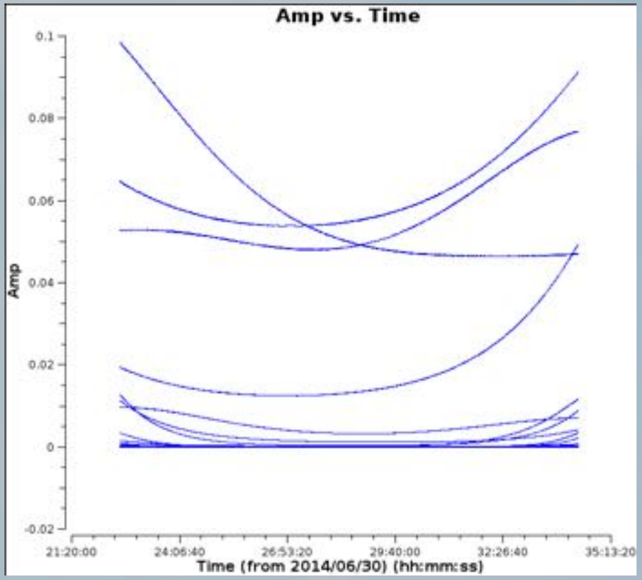




$2hrs$ $\quad$ $2hrs$ over $12hrs$ $\quad$ $12hrs$



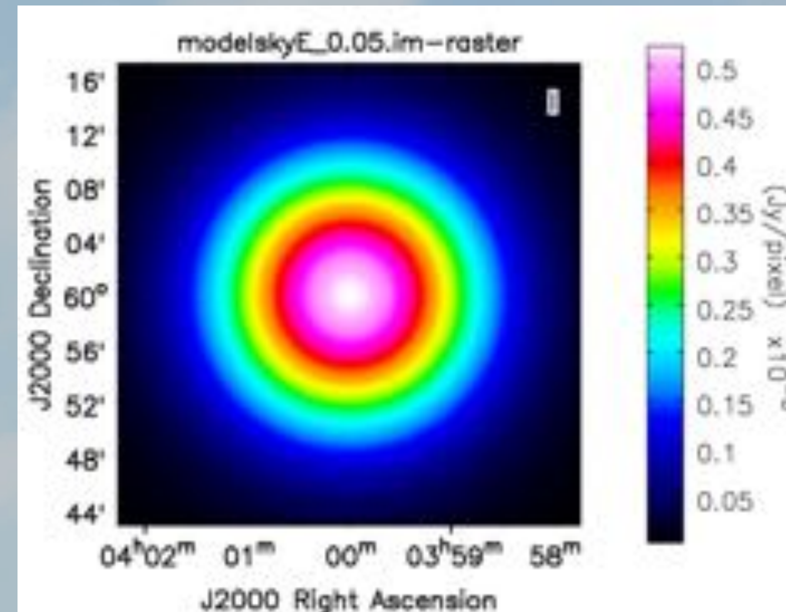




$Z = 0.1,\ \theta \sim 9'$

Simulating model image

- Used Python and CASA Toolkit
- Shape: 2D Gaussian
- Linear size, $L = 1\ Mpc$
- Redshift, $z = [0.05,\ 1.0]$
- Ang. Size, $\theta \sim [17',\ 2']$



$$\theta\ (in\ arcmin) = \frac{L}{D_A(z)} \times 3437.75$$

$Mattig's\ relation$:

$$D_A(z) = \frac{c}{H_o} \frac{2}{\Omega_m^2 (1+z)^2} \left[\Omega_m z + (\Omega_m - 2)(\sqrt{1 + \Omega_m z} - 1) \right]$$

Where $D_A(z) =\ angular\ diameter\ distance,\ H_o = 67.8 \frac{km}{s} / Mpc,\ \Omega_m = 0.3$

Flux density (S) of the source

$$S = \frac{L}{4\pi D_L^2(z)}\,,\quad D_L(z) \; = \; Luminosity\ distance$$

$$D_L(z) = (1+z)^2 D_A(z)$$

$$S\,(z_2) = \; S(z_1) \times \left(\frac{1+z_1}{1+z_2}\right)^4 \times \left(\frac{D_A(z_1)}{D_A(z_2)}\right)^2$$

$$S \;\propto \nu^{\alpha}$$

$$\frac{S_{model}}{S_{Abell2163}} = \left(\frac{610}{1400}\right)^{-1.6}$$

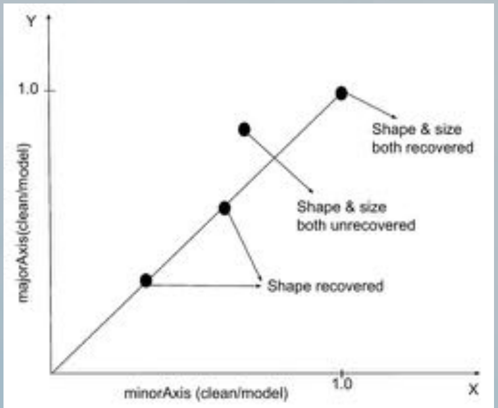
$$S_{Abell2163} = 0.155\,Jy, \qquad S_{model} \sim 0.6\,Jy$$

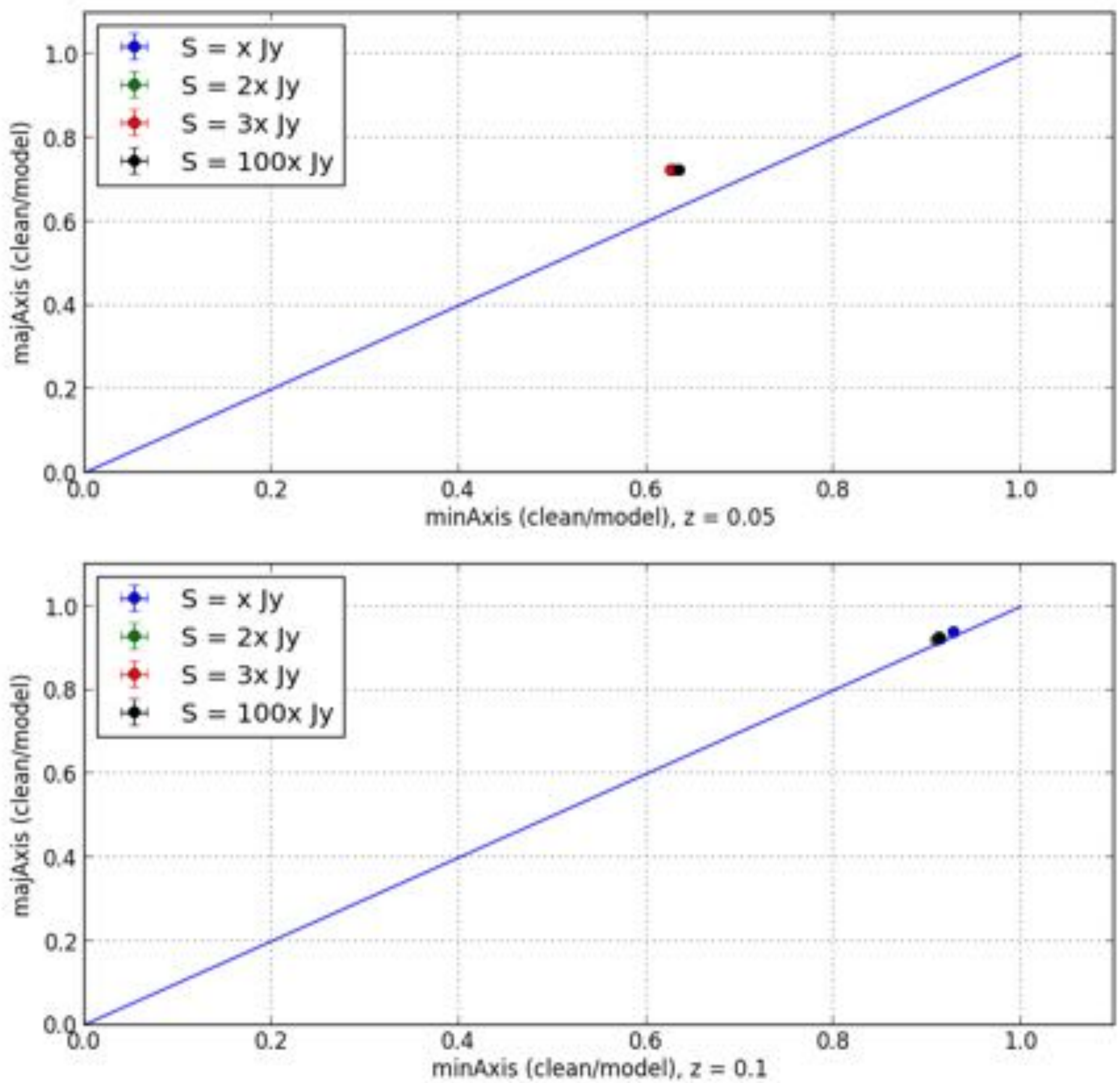
Morphology recovery

$z = [0.05, 0.1]$

$\theta = [17', 9']$

$variable$: S



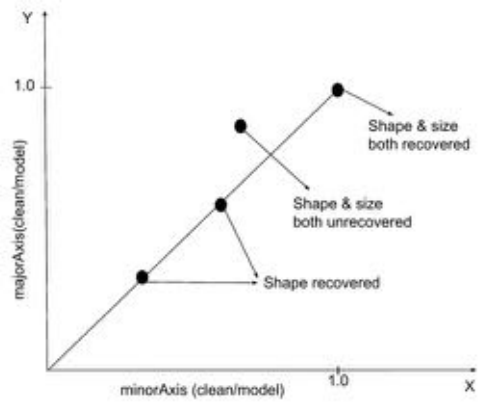


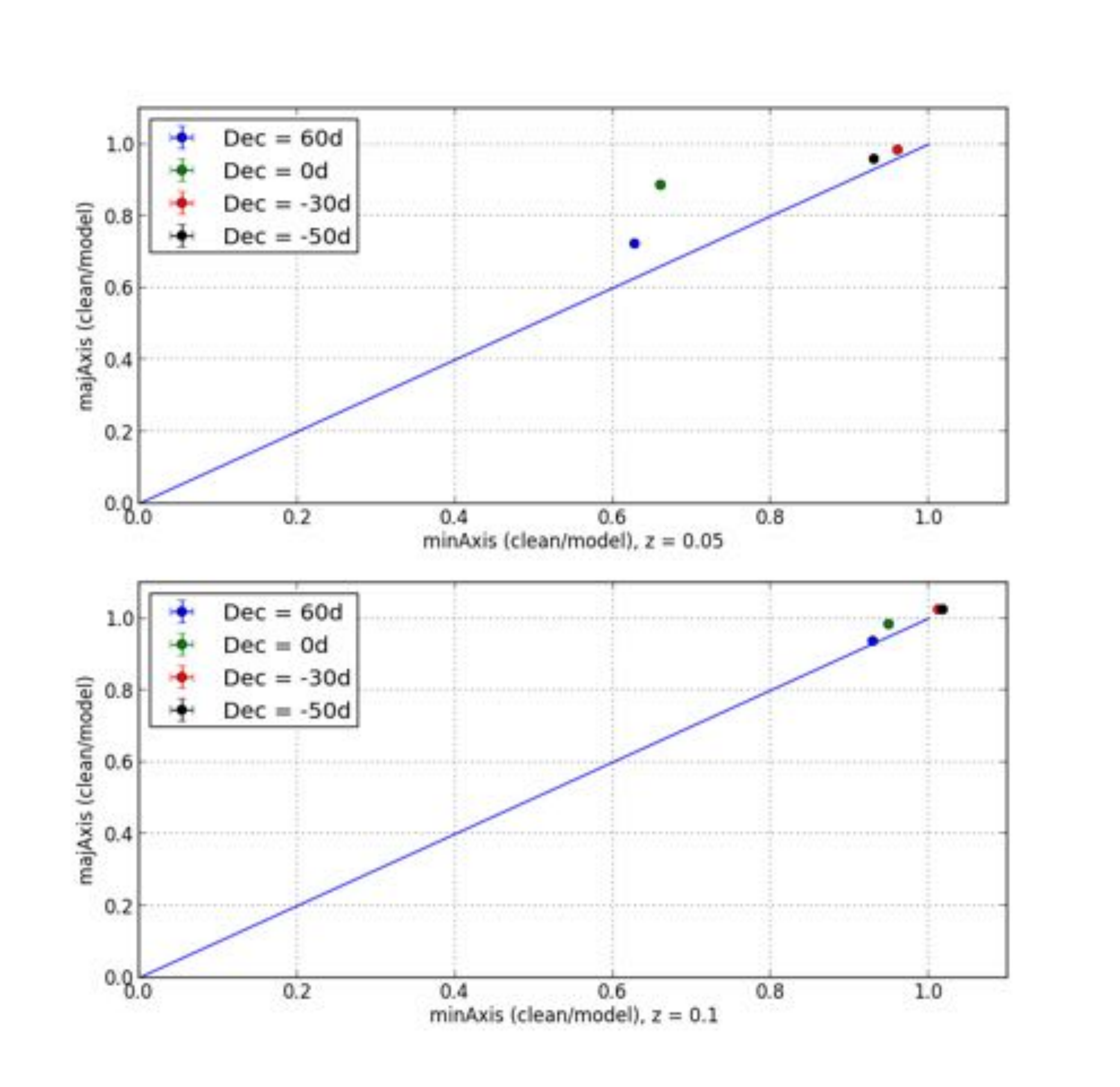
Morphology recovery

$z = [0.05, 0.1]$

$\theta = [17', 9']$

variable: Dec.

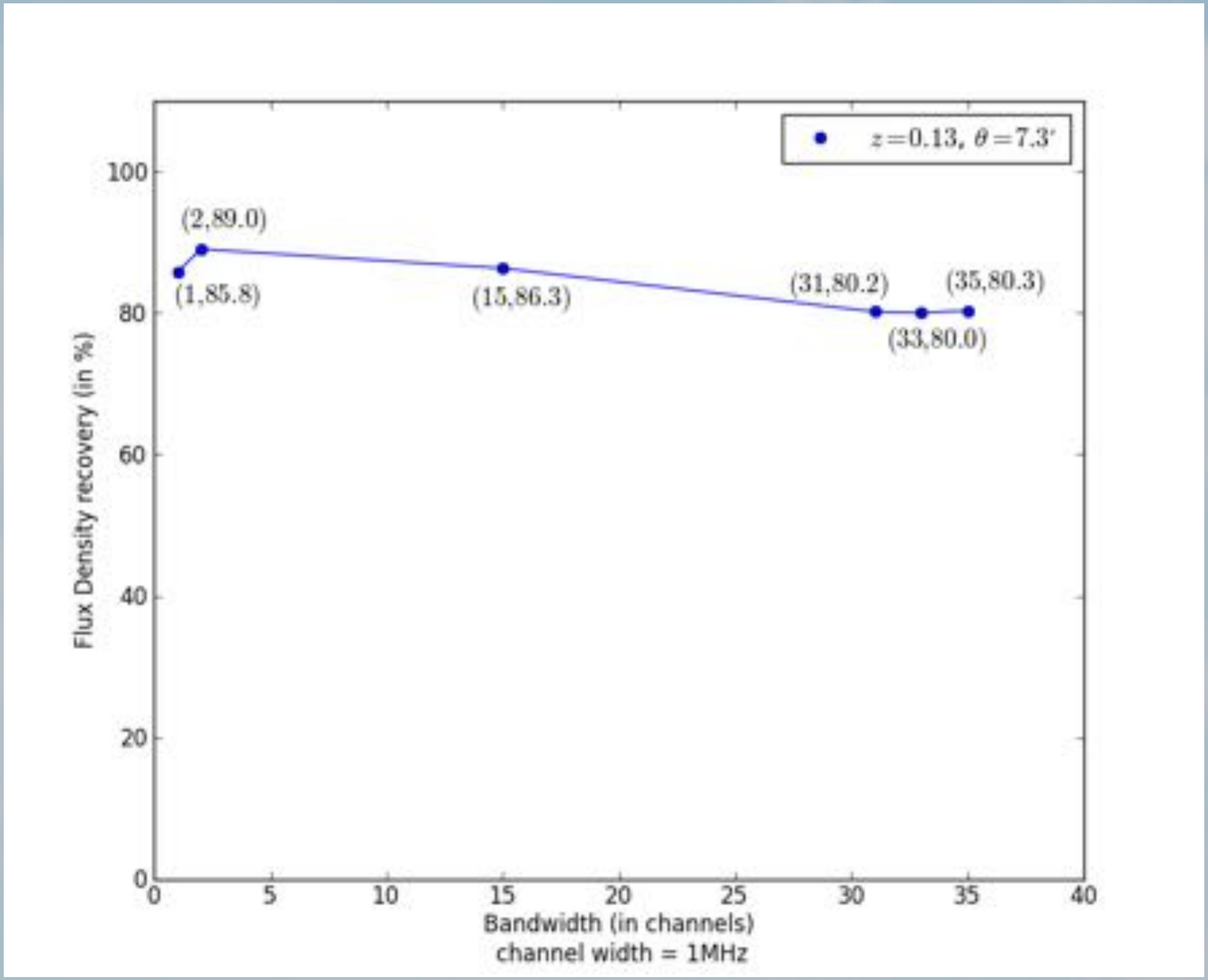




Beam size

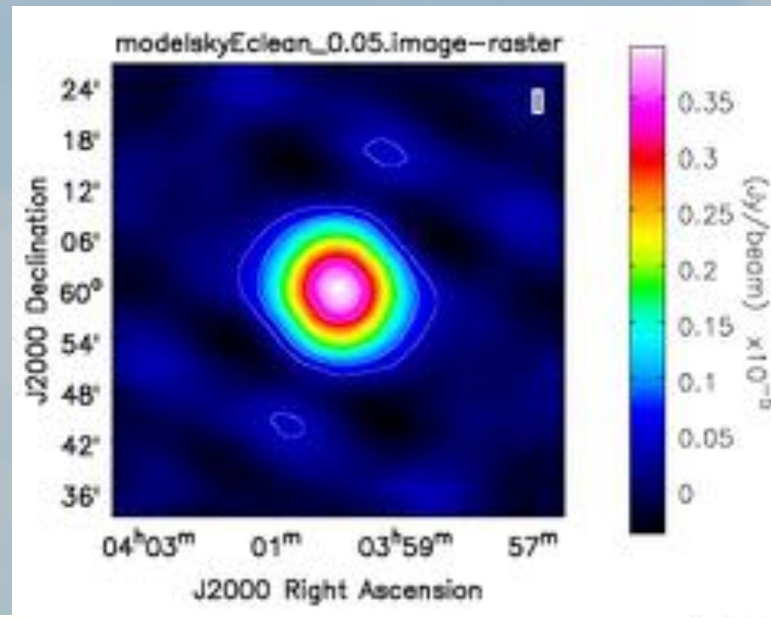
Dec.	1MHz	33MHz	200MHz
+60	4.98"× 4.13"	4.76" × 4.05"	6.84" × 5.99"
0	5.58"× 4.59"	•	•
-30	12.72"× 4.11"	•	•
-50	44.21"× 3.61"	38.80"× 3.34"	•

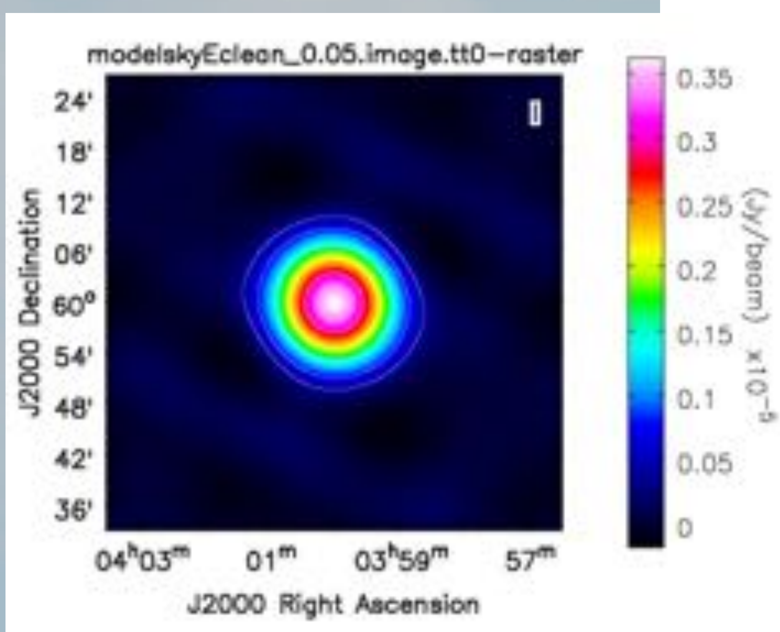
- $1\ MHz, 2hrs, +60°$

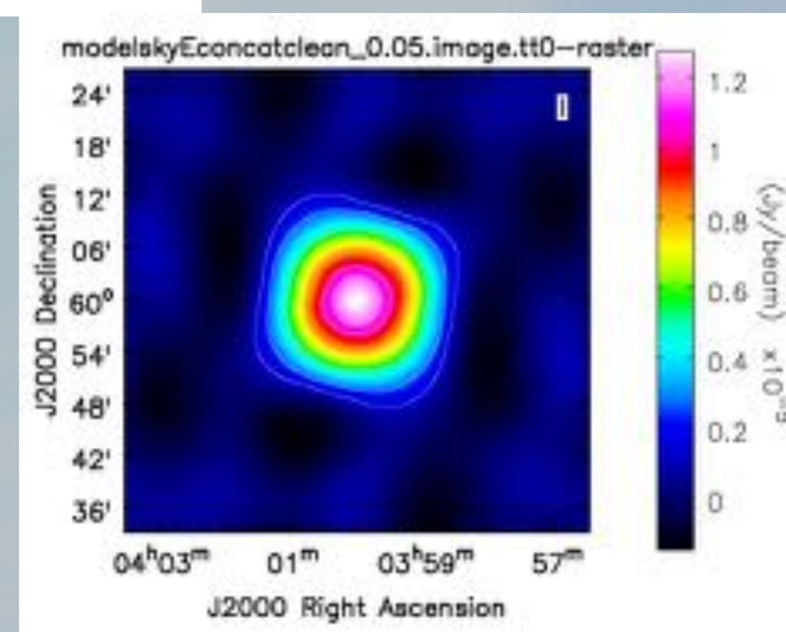


$z=0.13,\ \theta=7.3'$
(2,89.0)
(1,85.8)
(15,86.3)
(31,80.2)
(35,80.3)
(33,80.0)
Flux Density recovery (in %)
0
20
40
60
80
100
0
5
10
15
20
25
30
35
40
Bandwidth (in channels)
channel width = 1MHz

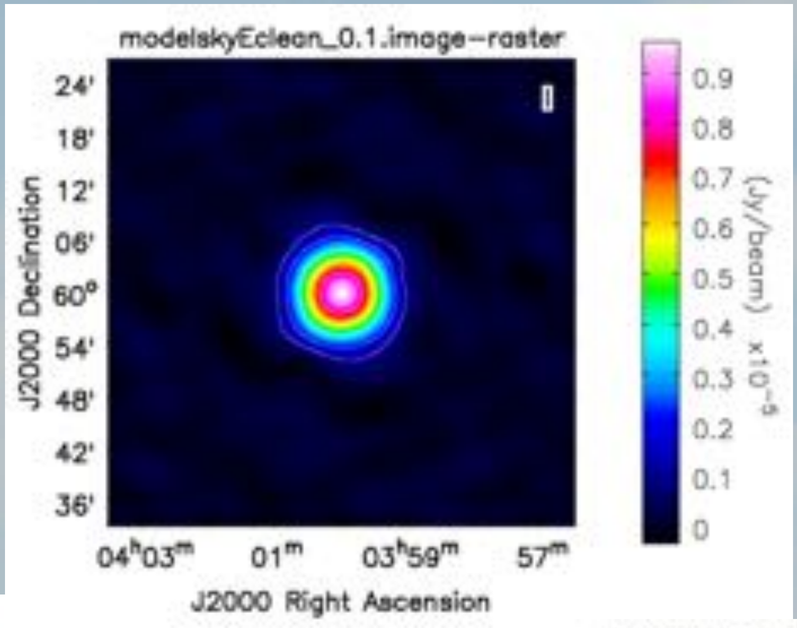
- $2hrs, +60°, z = 0.05\ (16.8')$

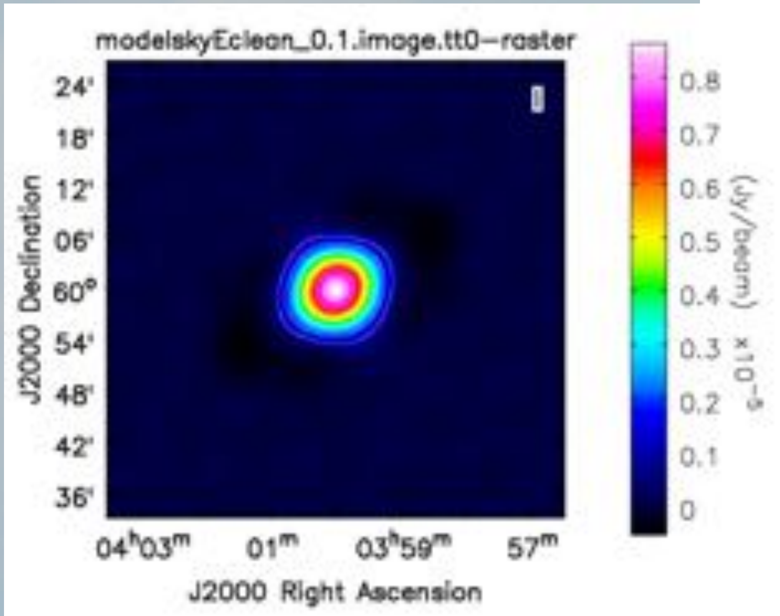


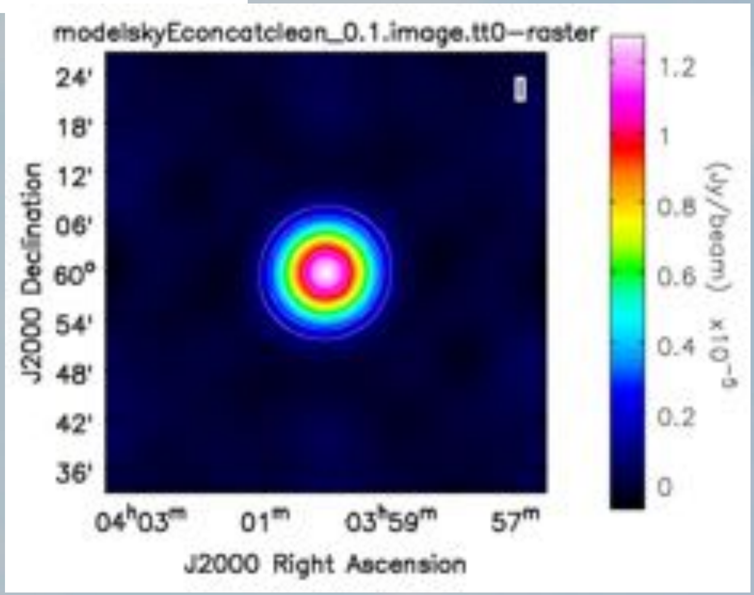




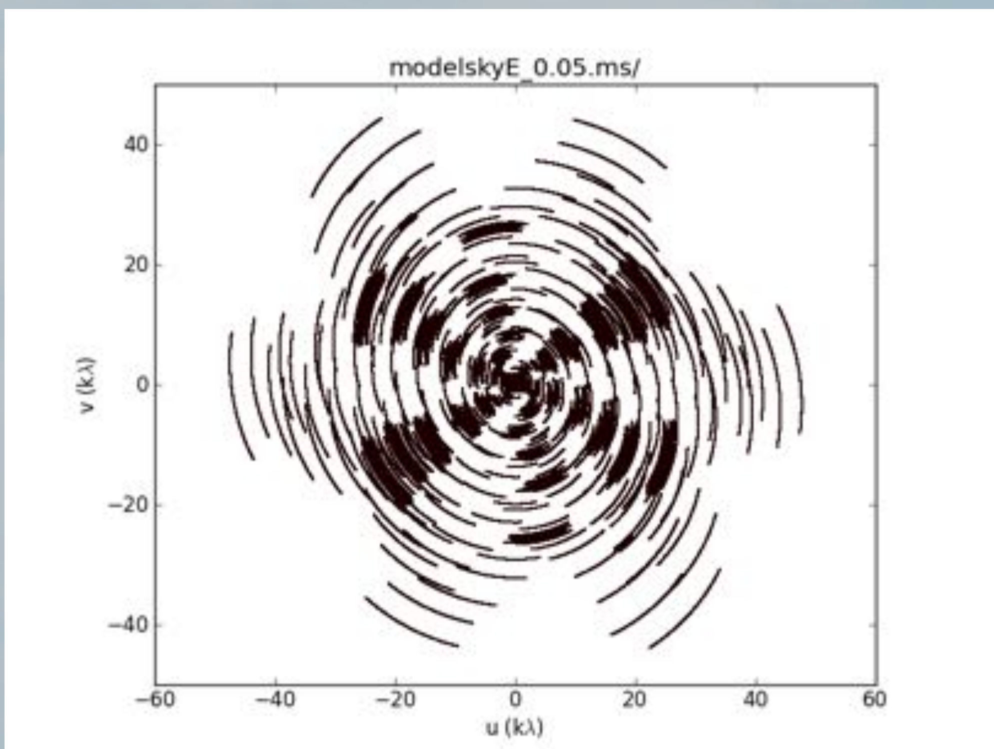
- $2hrs, +60°, z = 0.1\ (9'), BW$

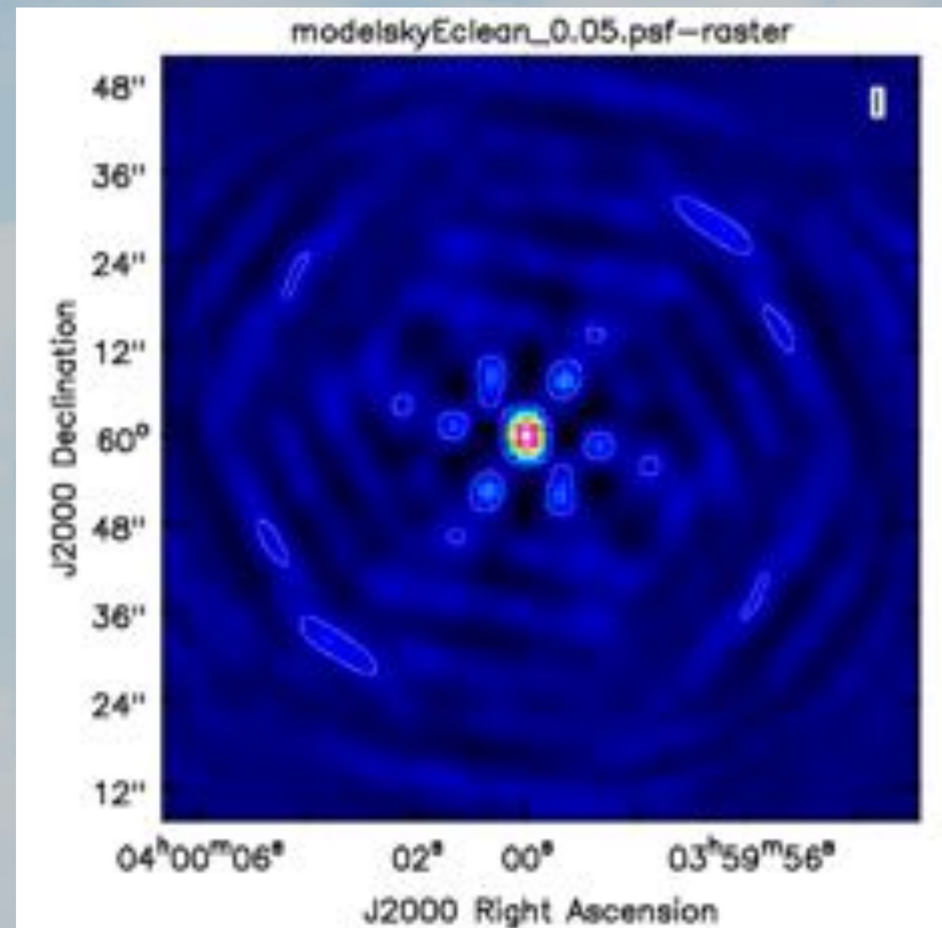




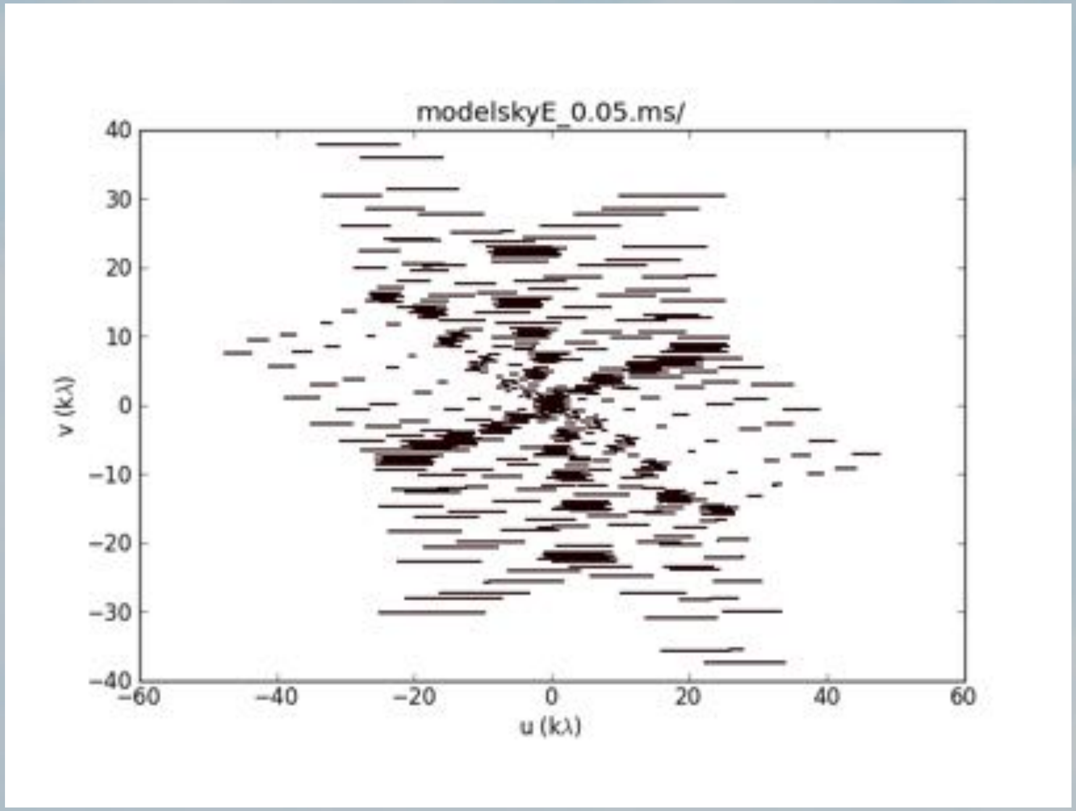


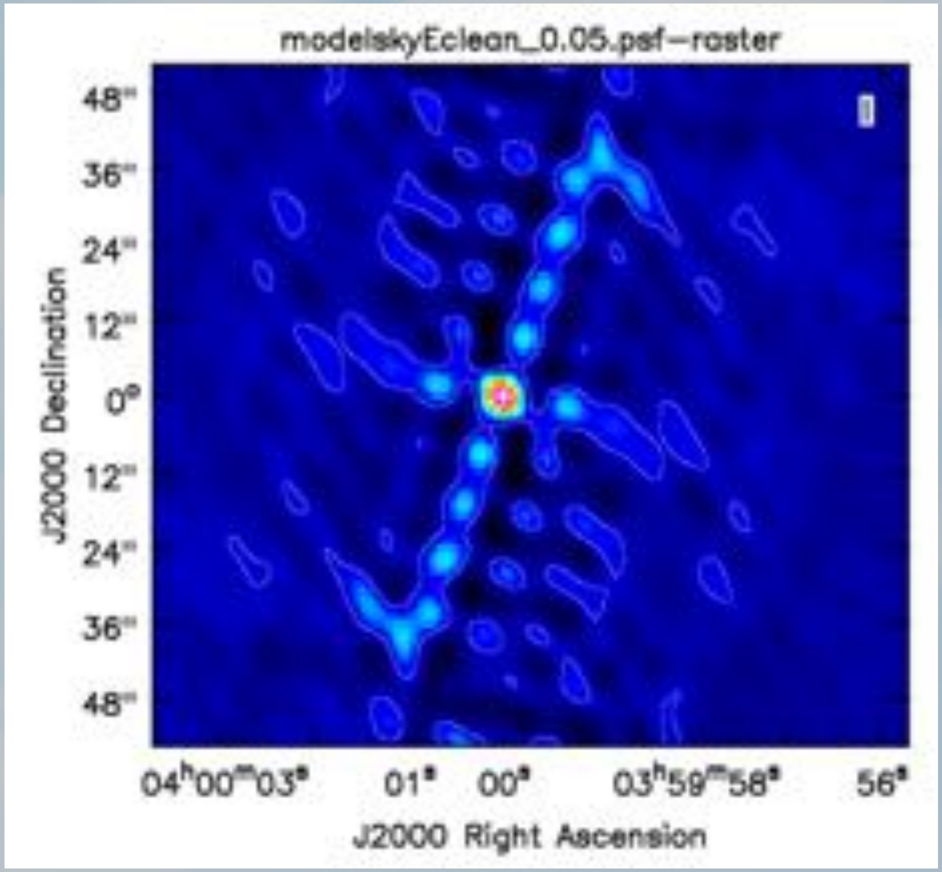
UV coverage and PSf at +60



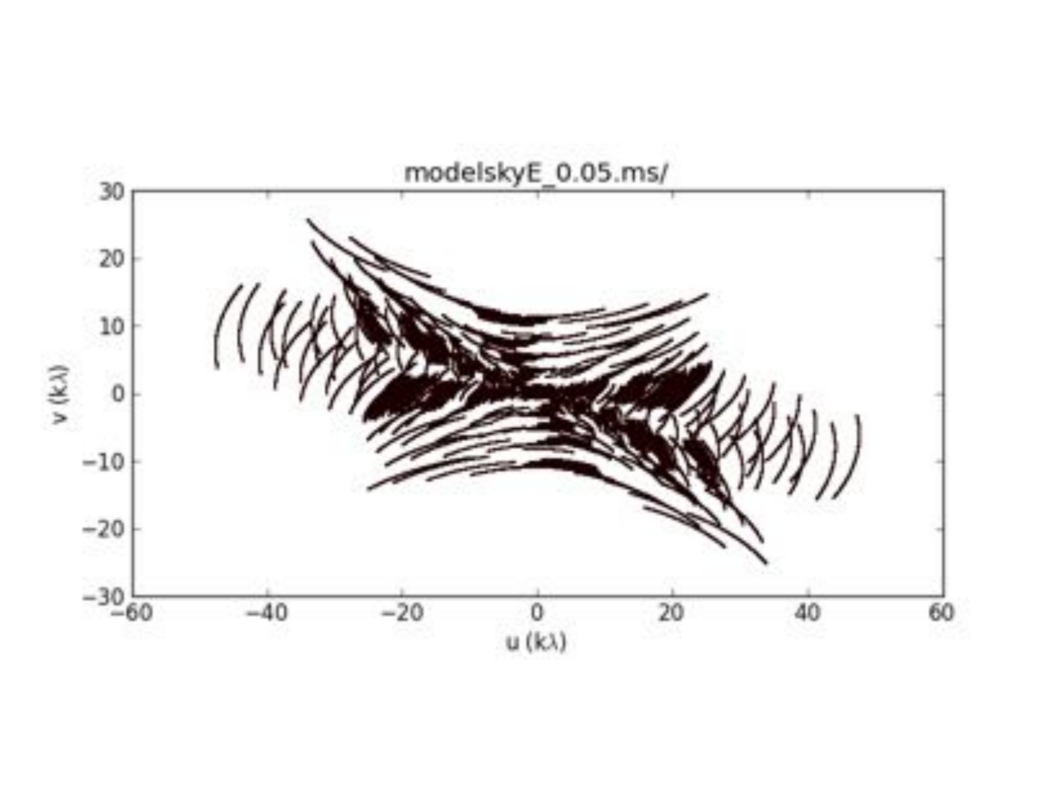


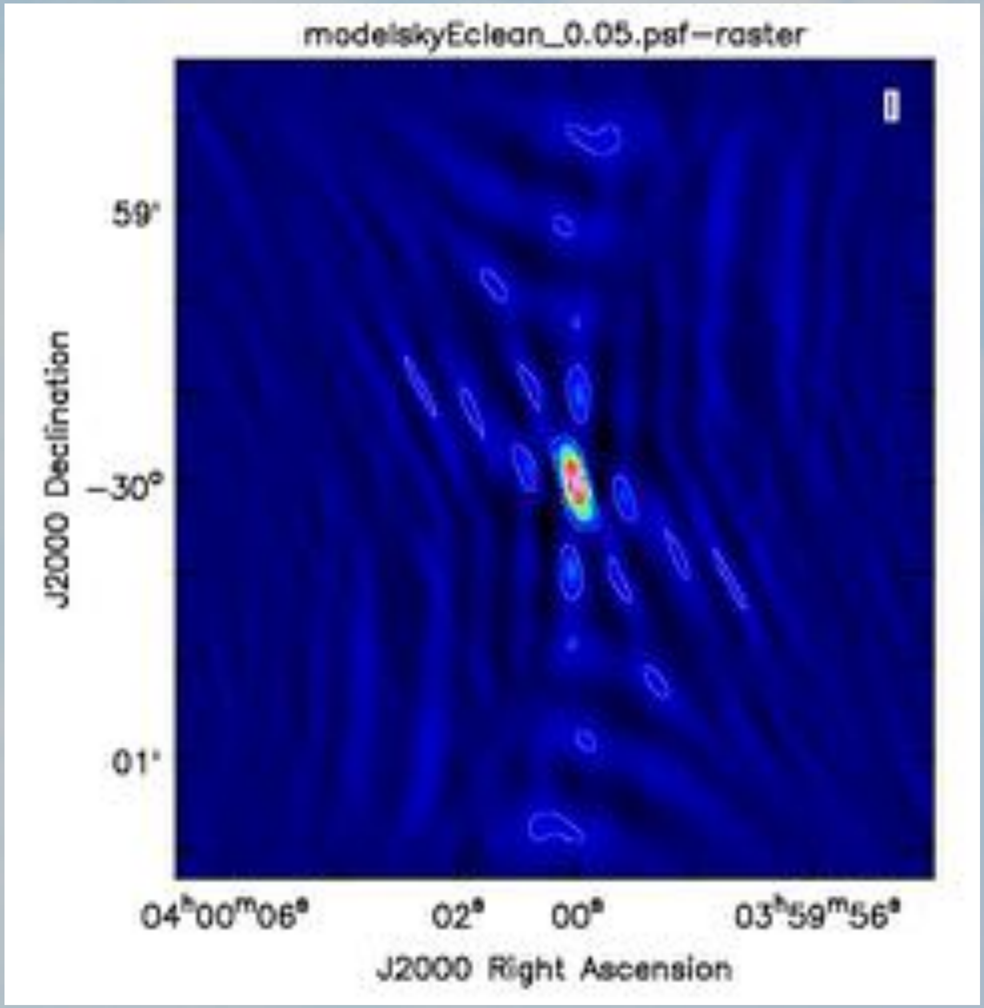
UV coverage and PSF at 0





UV coverage and PSF at -30





UV coverage and PSF at -50