Performance of the SKA1 system baseline design

Attila Popping

International Centre for Radio Astronomy Research

Curtin University

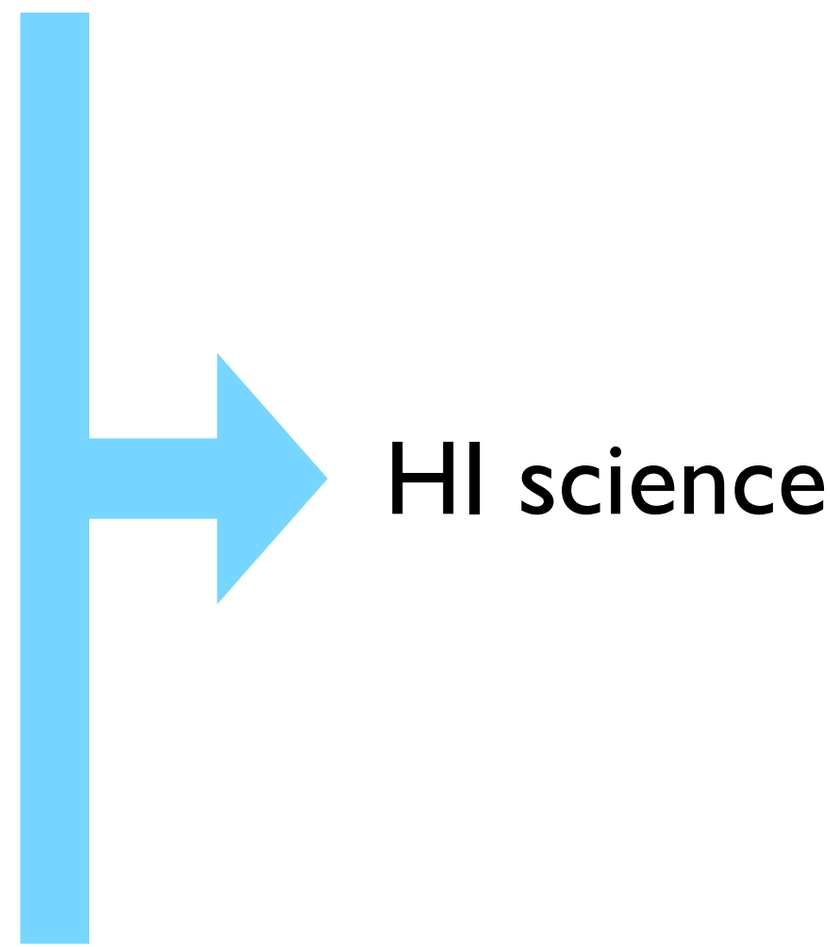
The University of Western Australia
Achieving International Excellence

Phase I SKA

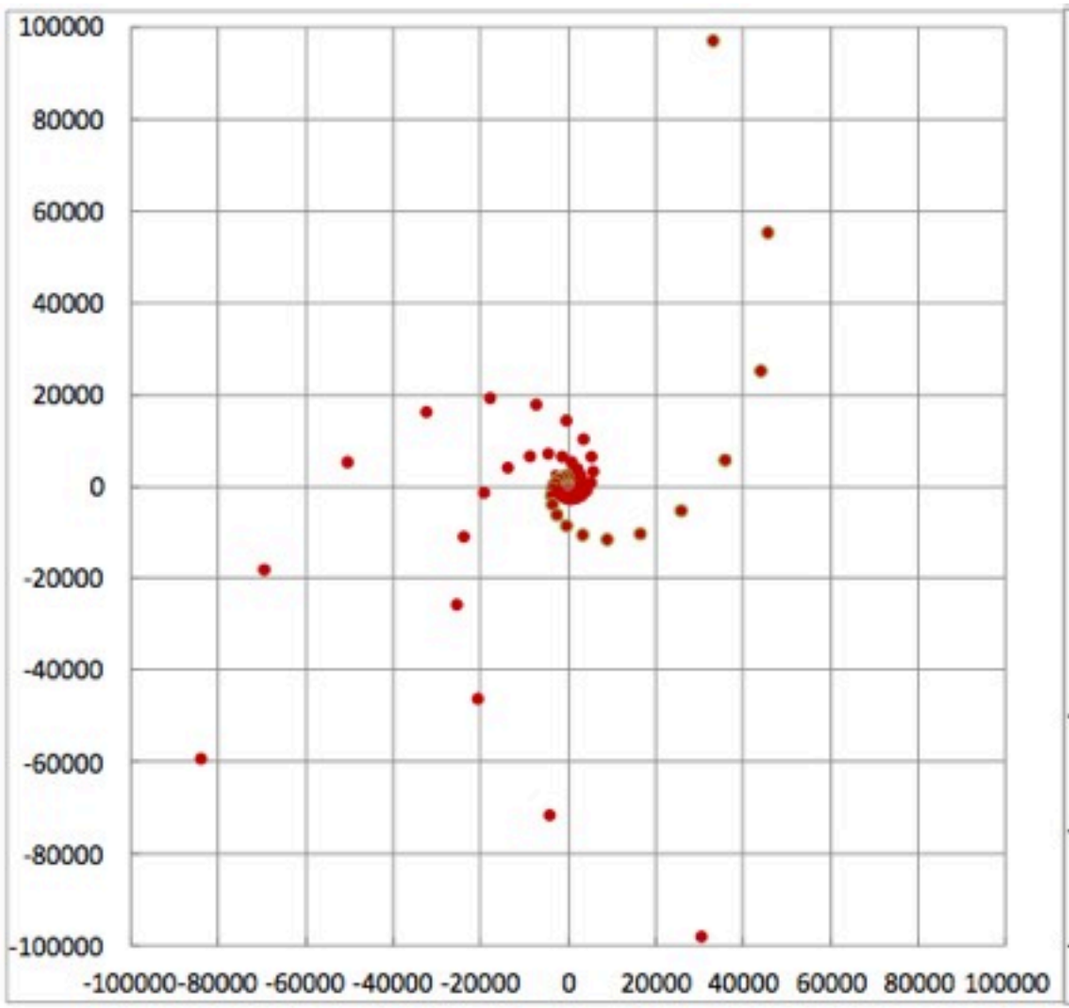
- SKA1-low
  - ~50-350 MHz
  - highly redshifted HI
- SKA1-mid (single pixel)
  - 64 MeerKAT dishes + 190 SKA1 dishes
  - ~350-3050 MHz
- SKA1-survey (PAF)
  - 36 ASKAP dishes + 60 SKA1 dishes
  - ~650-1670 MHz

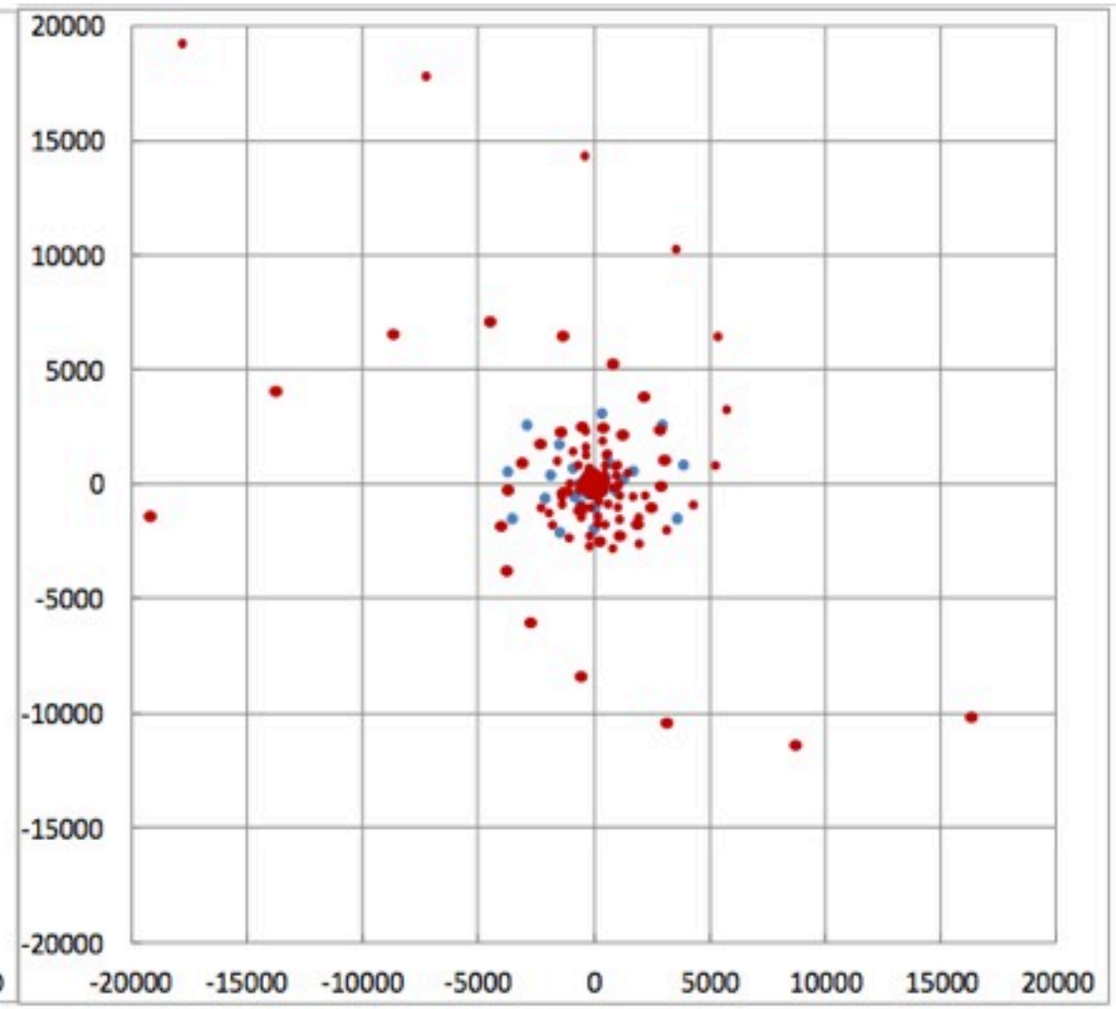
Phase I SKA

- SKA1-low
  - ~50-350 MHz
  - highly redshifted HI
- SKA1-mid (single pixel)
  - 64 MeerKAT dishes + 190 SKA1 dishes
  - ~350-3050 MHz
- SKA1-survey (PAF)
  - 36 ASKAP dishes + 60 SKA1 dishes
  - ~650-1670 MHz

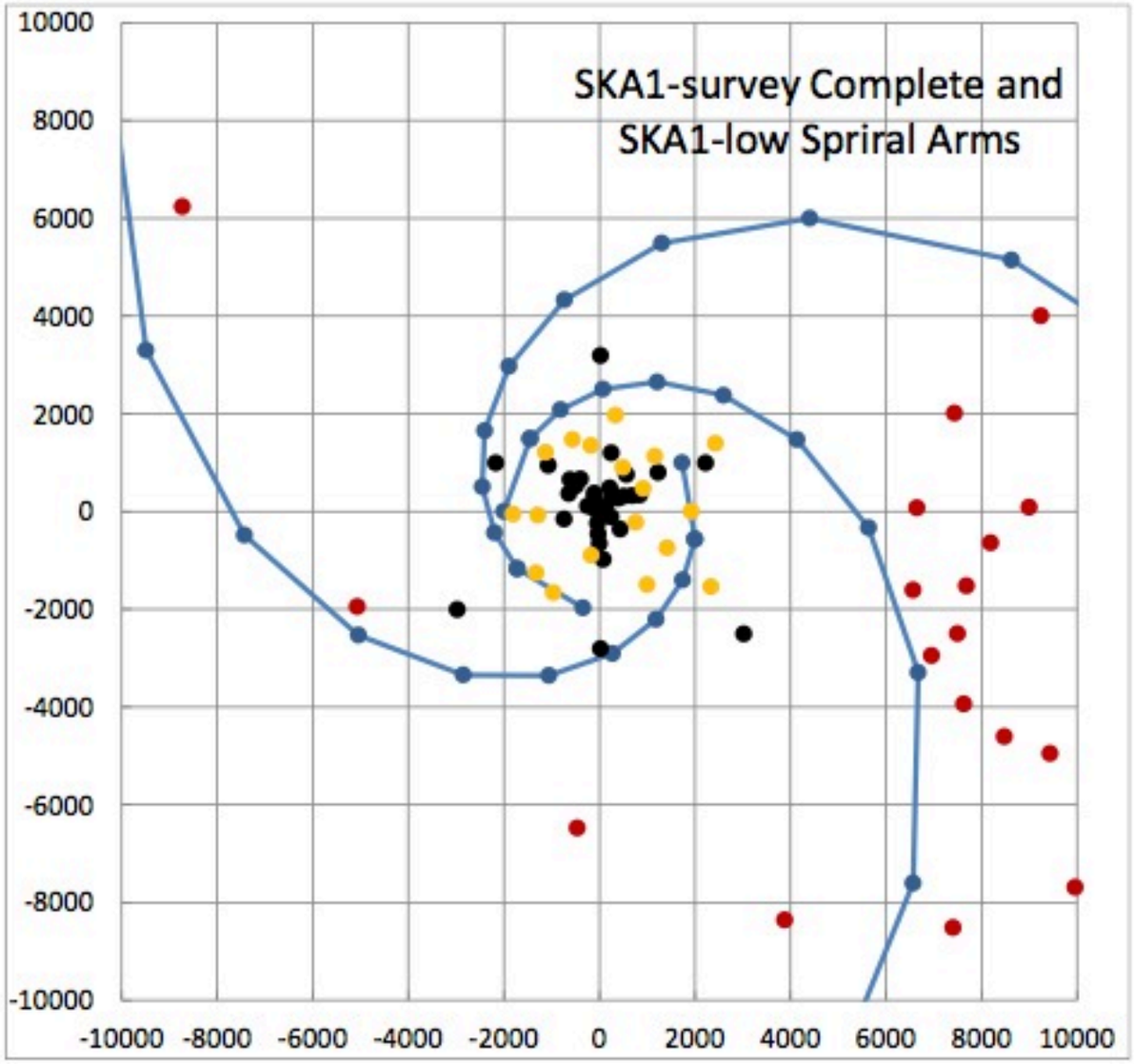


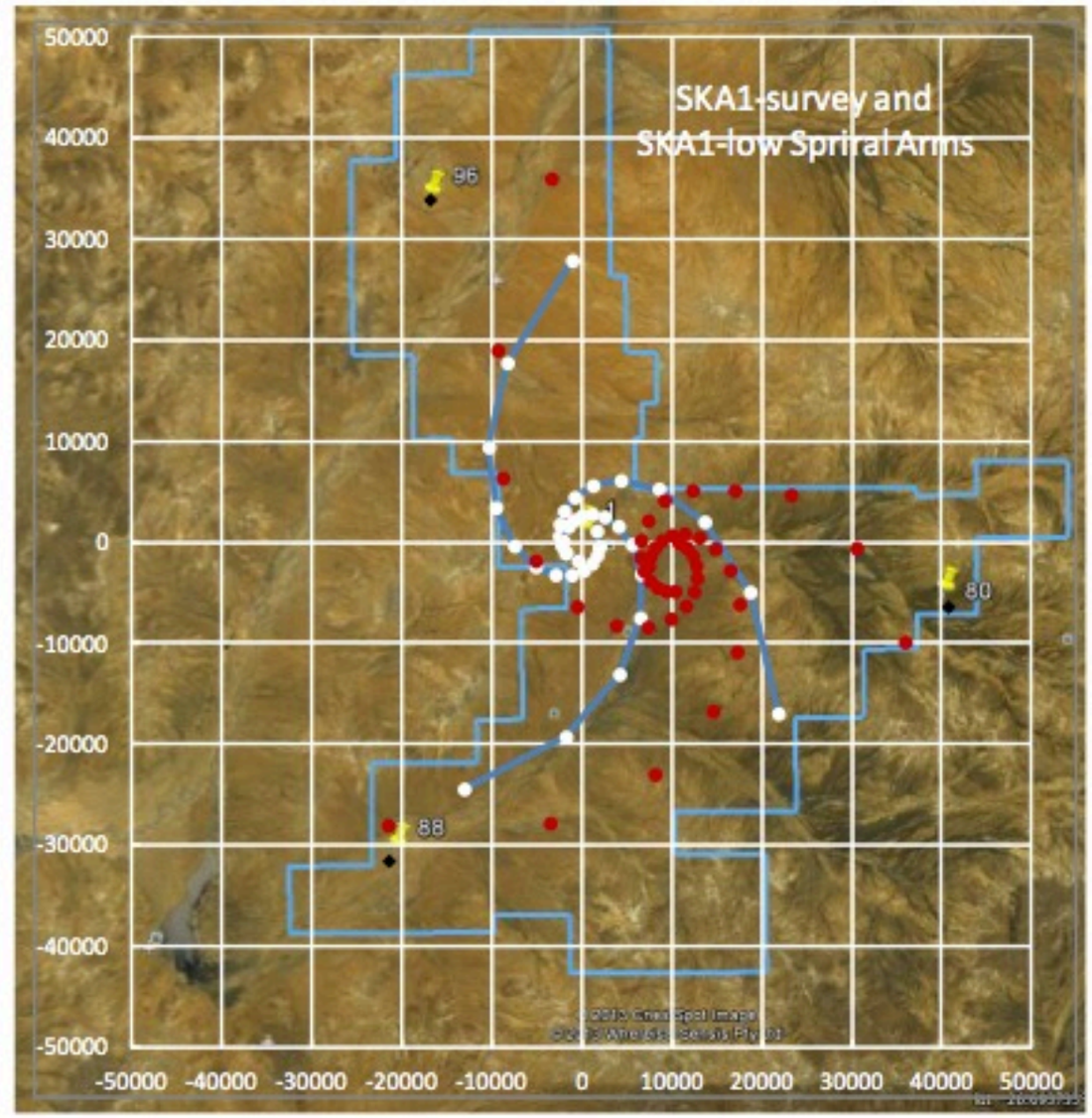
SKA1-mid


100000
80000
60000
40000
20000
0
-20000
-40000
-60000
-80000
-100000
-100000 -80000 -60000 -40000 -20000 0 20000 40000 60000 80000 100000


20000
15000
10000
5000
0
-5000
-10000
-15000
-20000
-20000 -15000 -10000 -5000 0 5000 10000 15000 20000

SKA1-survey


SKA1-survey Complete and
SKA1-low Spriral Arms
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
-10000
-10000 -8000 -6000 -4000 -2000 0 2000 4000 6000 8000 10000


SKA1-survey and
SKA1-low Spriral Arms
50000
40000
30000
20000
10000
0
-10000
-20000
-30000
-40000
-50000
-50000 -40000 -30000 -20000 -10000 0 10000 20000 30000 40000 50000
96
80
88

Simulations

The performance of the SKA is tested and compared with other telescopes using simulated models

Telescopes:
VLA, ASKAP, MeerKAT, SKA1-survey, SKA1-mid

Declinations:
0, -30, -60 degrees

Weighting:
Uniform -> Natural (robust -2,-1,0,1,2)

Hour angle range:
snapshot, 12 hour synthesis

Frequency:
1 GHz, 50 khz bandwidth

Simulations

Telescope parameters are extracted from SKA1 baseline design document.

	VLA	ASKAP	MeerKAT	SKA1-survey	SKA1-mid
Aeff/Tsys	265	65	321	391	1630
Receptor Size	25	12	13.5	15	15
Tsys	25	50	20	30	30
efficiency	0.5	0.8	0.7	0.7	0.78

- Visibility and image data is generated.
- In the imaging step a cutoff has been applied to use uv-points within a length $q=(u^2+v^2)^{1/2}$.
- Telescope performance is compared for baselines of over 100 km
- Typically q values align with baselines of VLA in A,B,C,D config.

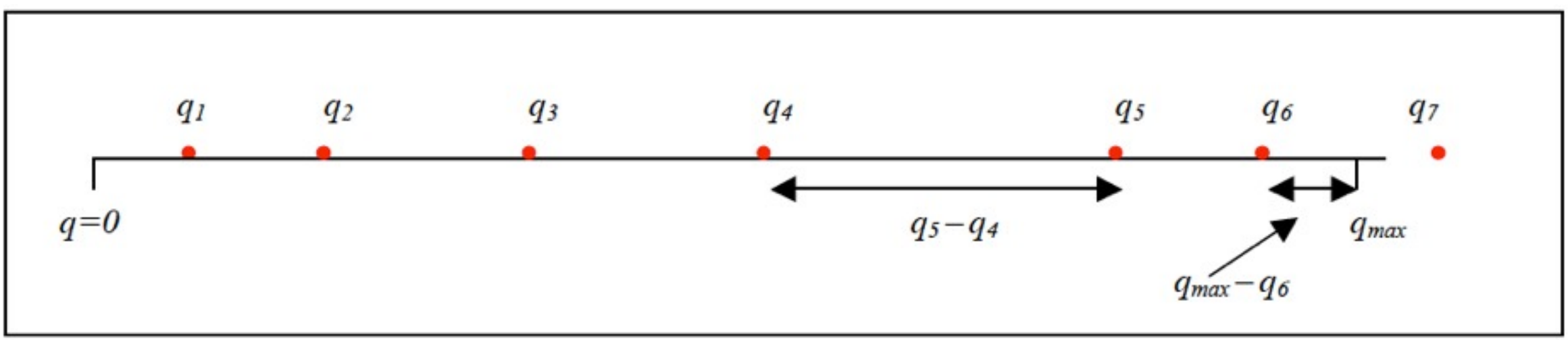
Performance parameters

1. RMS: 1 sigma noise value in image maps (2048^2 pixels)
2. Beam size: the size of the synthesized beam, *FWHM* b_{maj} & b_{min}
3. HI column density: the 1 sigma brightness sensitivity
4. Survey Speed: FoV / rms^2
5. PSFRMS: The standard deviation of the occupancy of uv-points in uv-cells

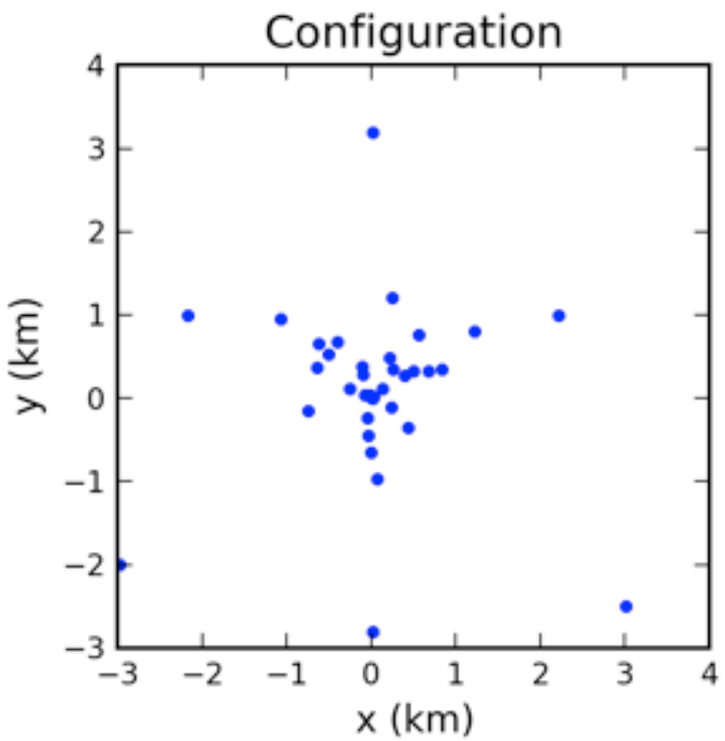
$$PSFRMS = \sqrt{\Sigma_{i,j} n_{ij}^2} / N_{uv}$$

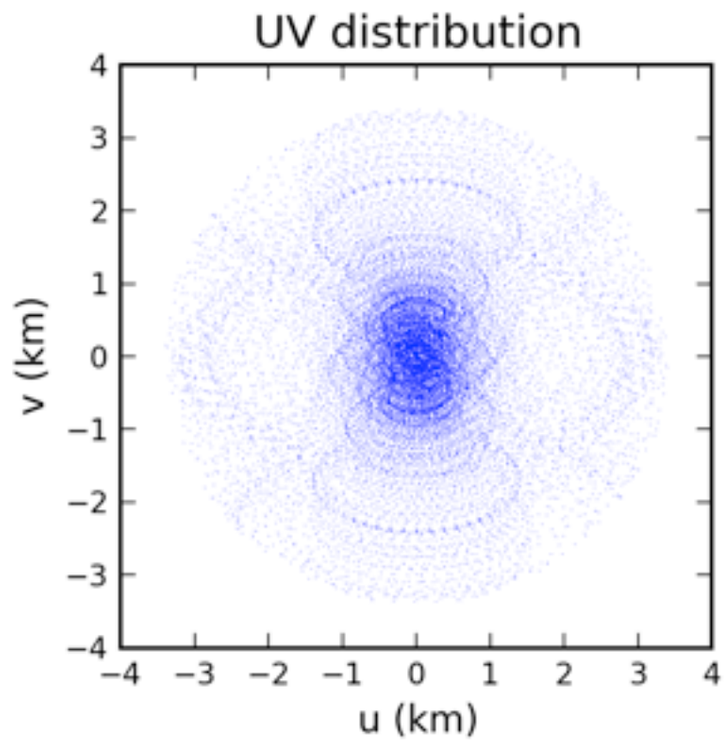
6. UVGAP: fraction between the gap between two baselines and the baseline length

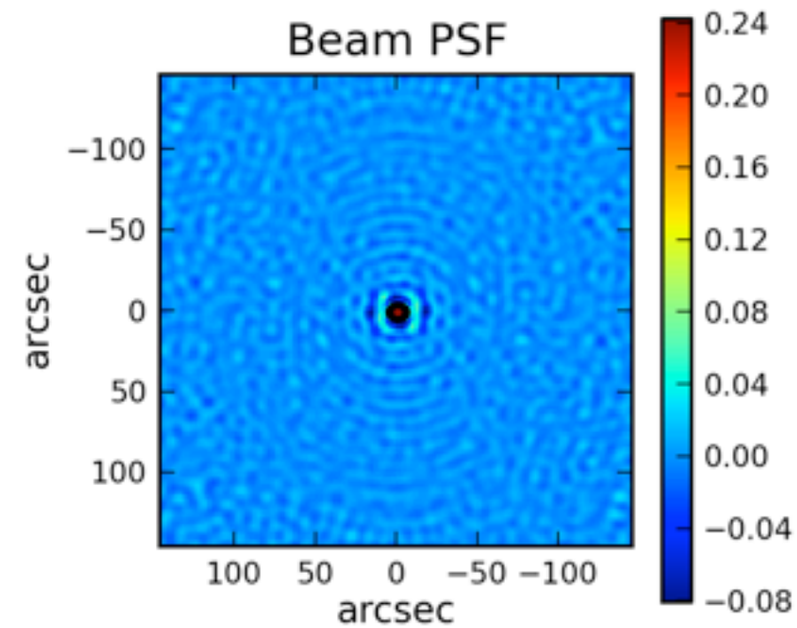
$$uvgap = \frac{1}{q_{max}} \sum_{k=1}^{n} \partial q_k \times (q_k - q_{k-1}), \text{ with } q_0 = 0 \text{ and } q_n = q_{max}$$

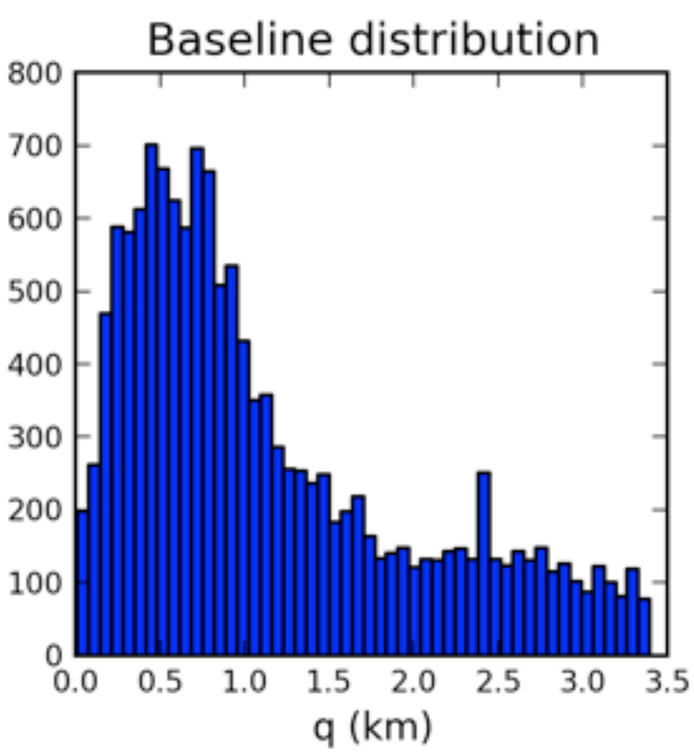


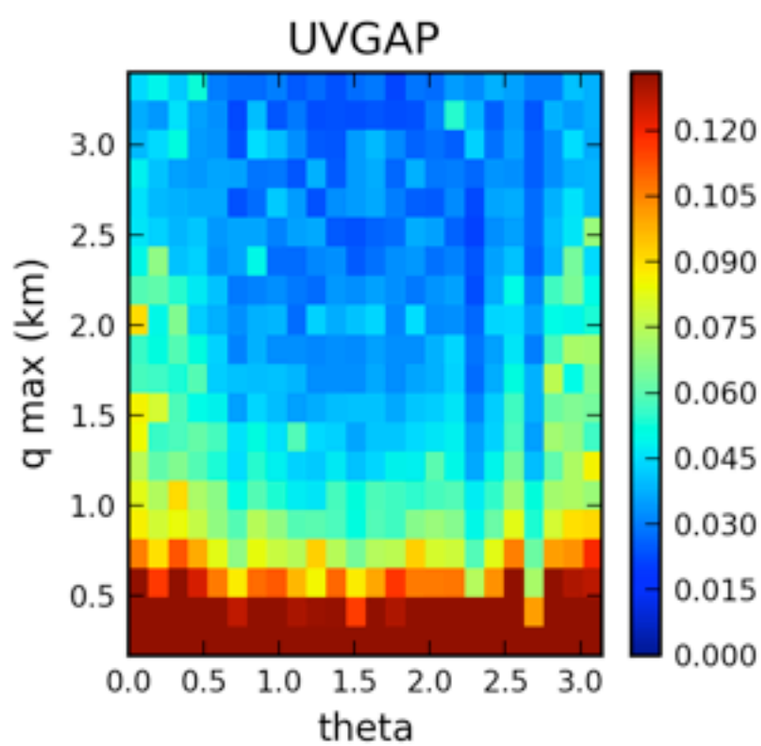
Output









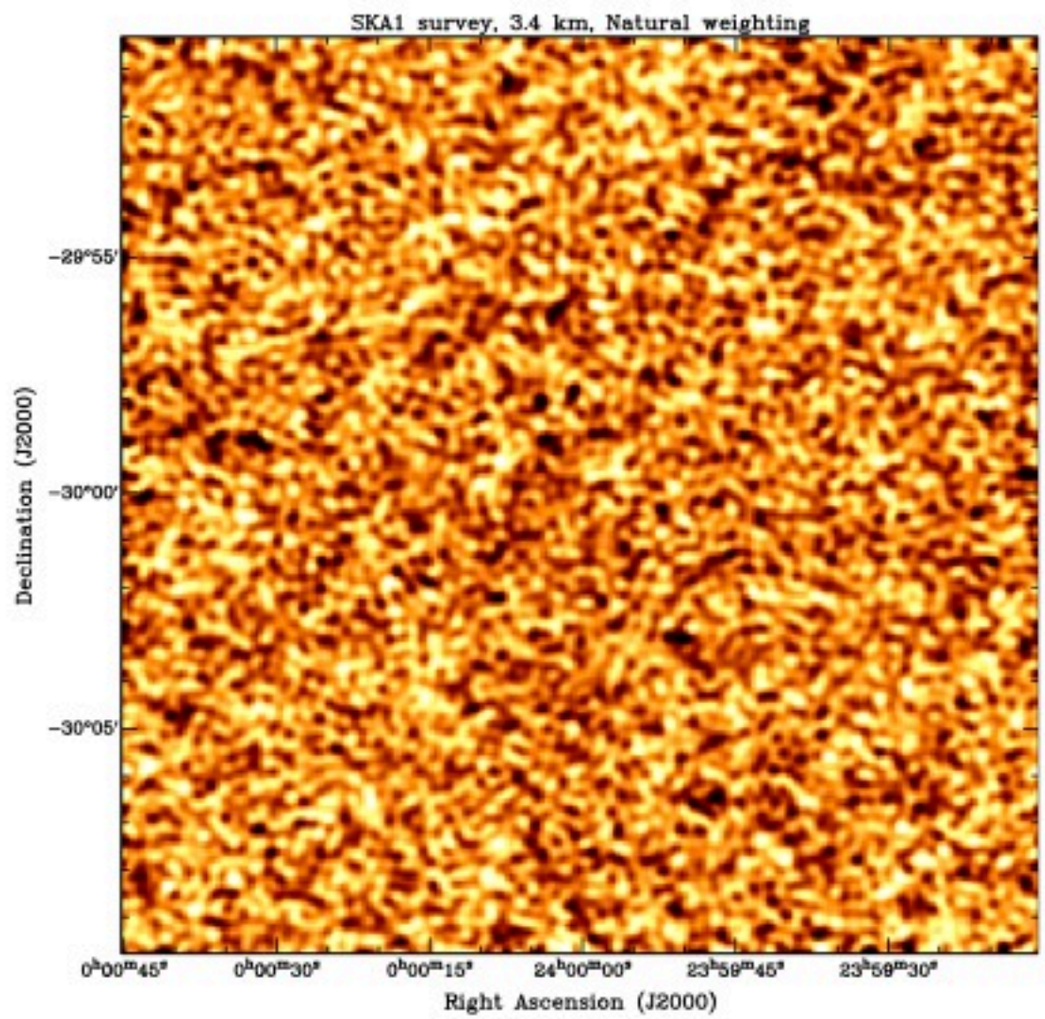


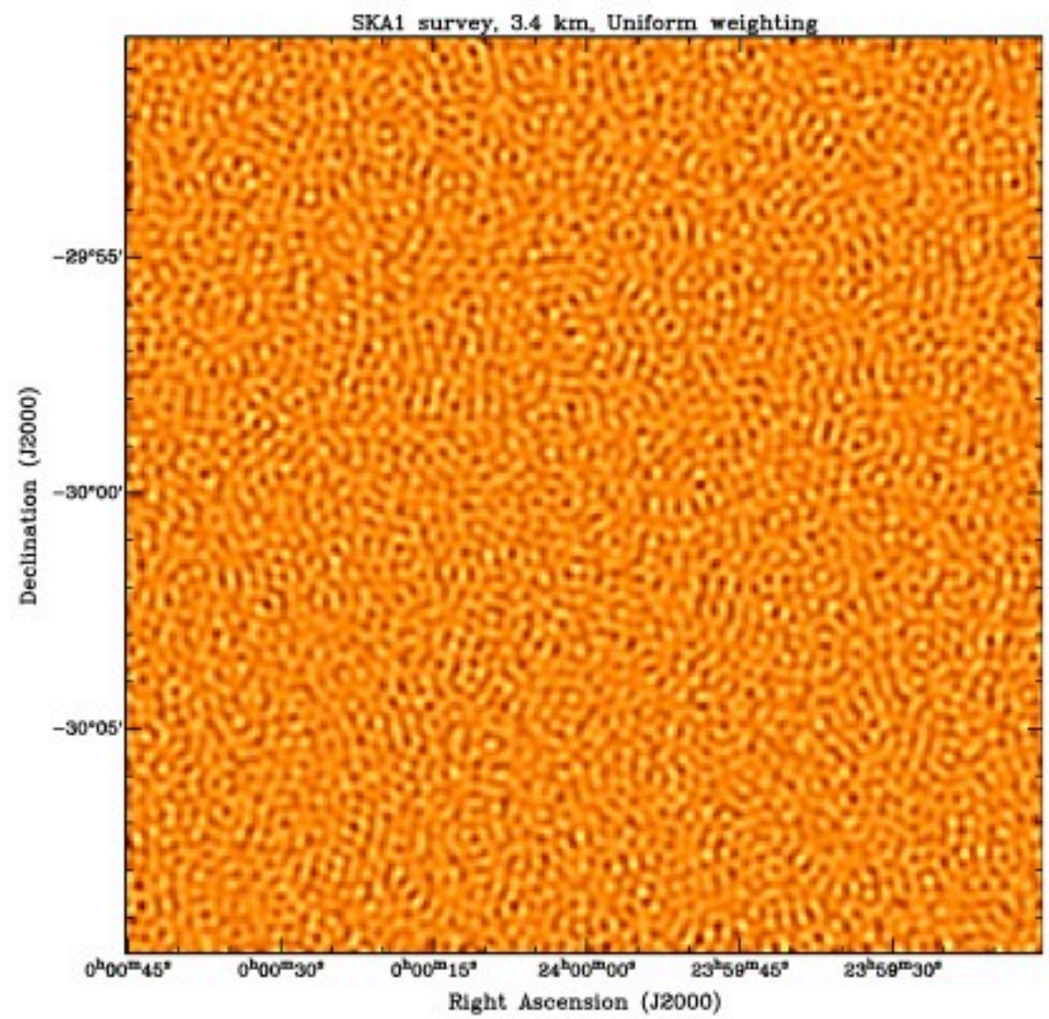
askap

Declination: -30
Frequency: 1000.0
Bandwidth: 0.05
HA min: -6
HA max: 6
Robust: -1
UVrange: 3400

Bmin: 13.379
Bmaj: 14.865
rms: 0.001051
NHI: 3.56457170279e+20
PSFRMS: 0.00997518388239
UVGAP (med): 0.0331335938253
UVGAP (mean): 0.0305073127439

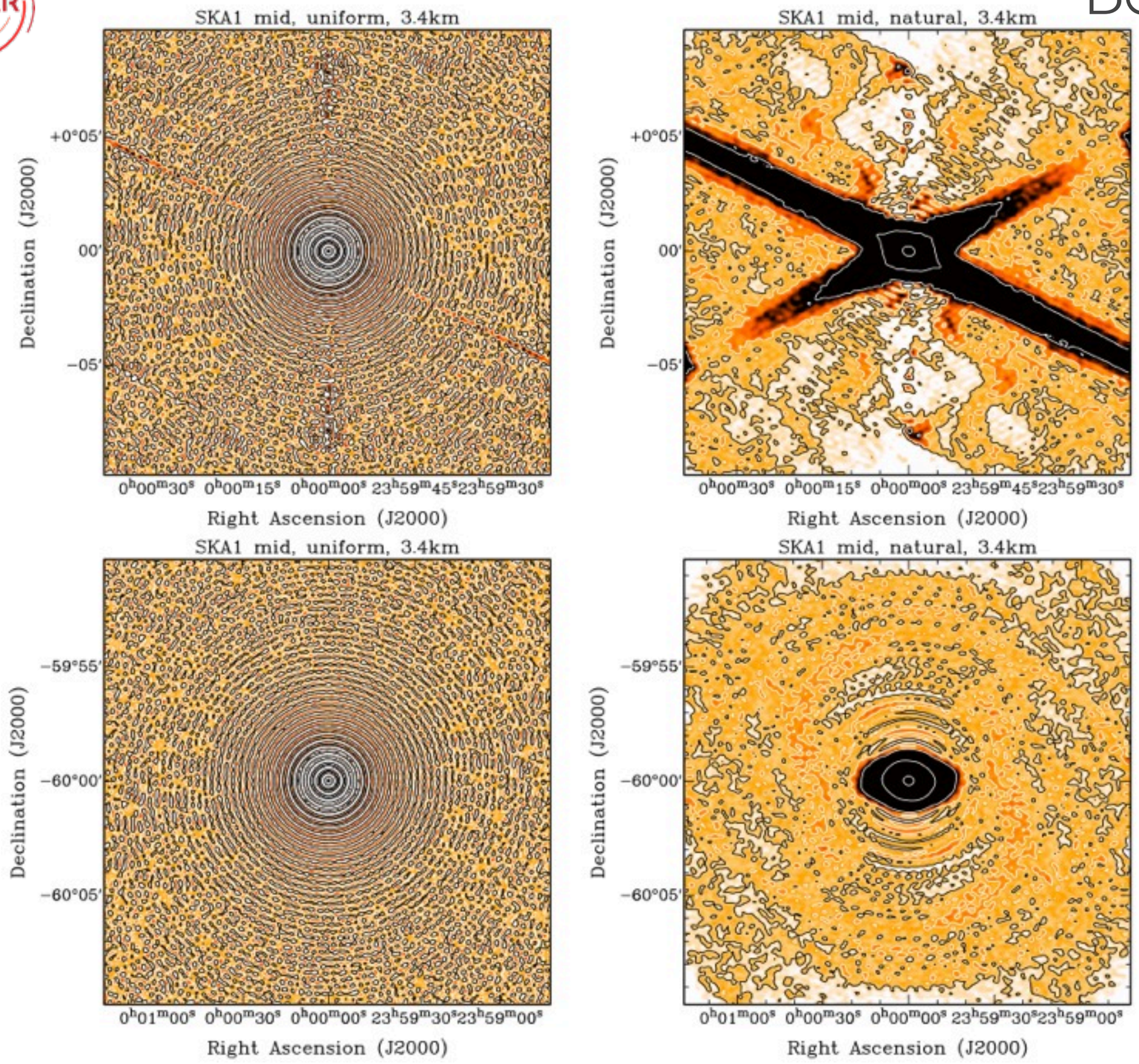
Noise



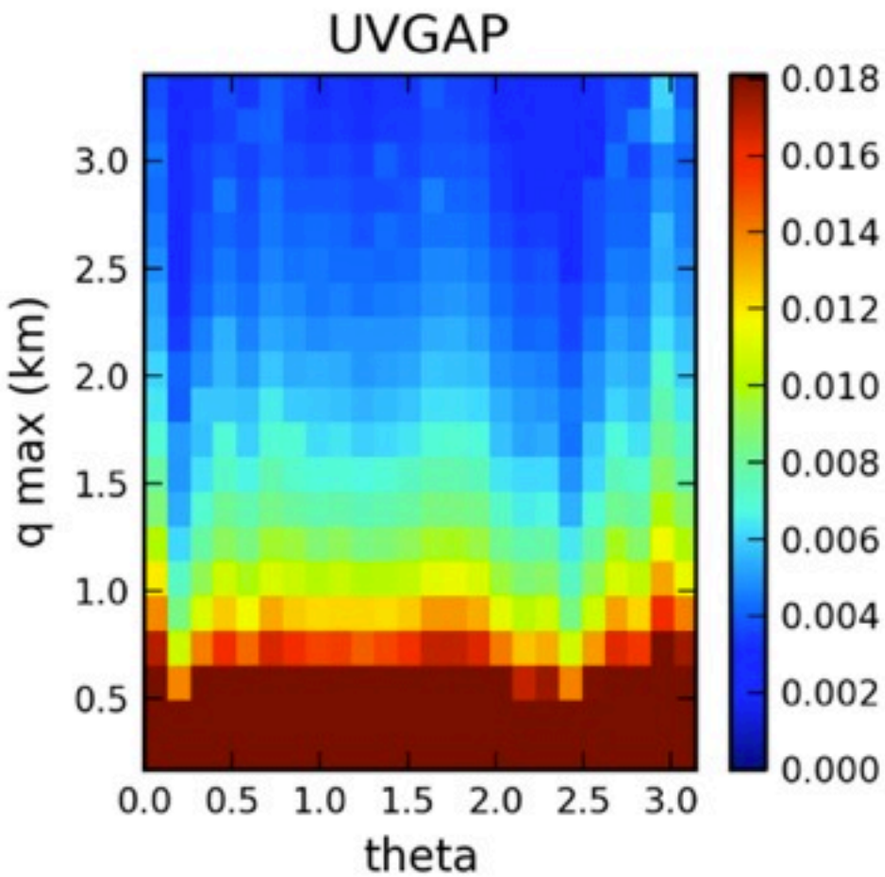


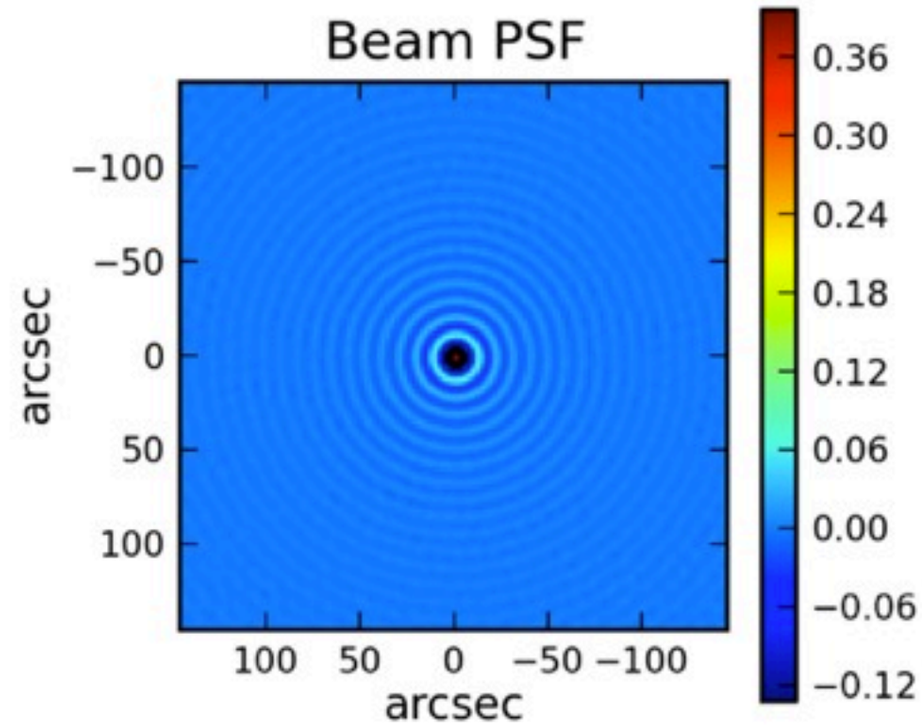
Noise maps for SKA1-survey (q < 3.4 km) natural (left) and uniform (right)

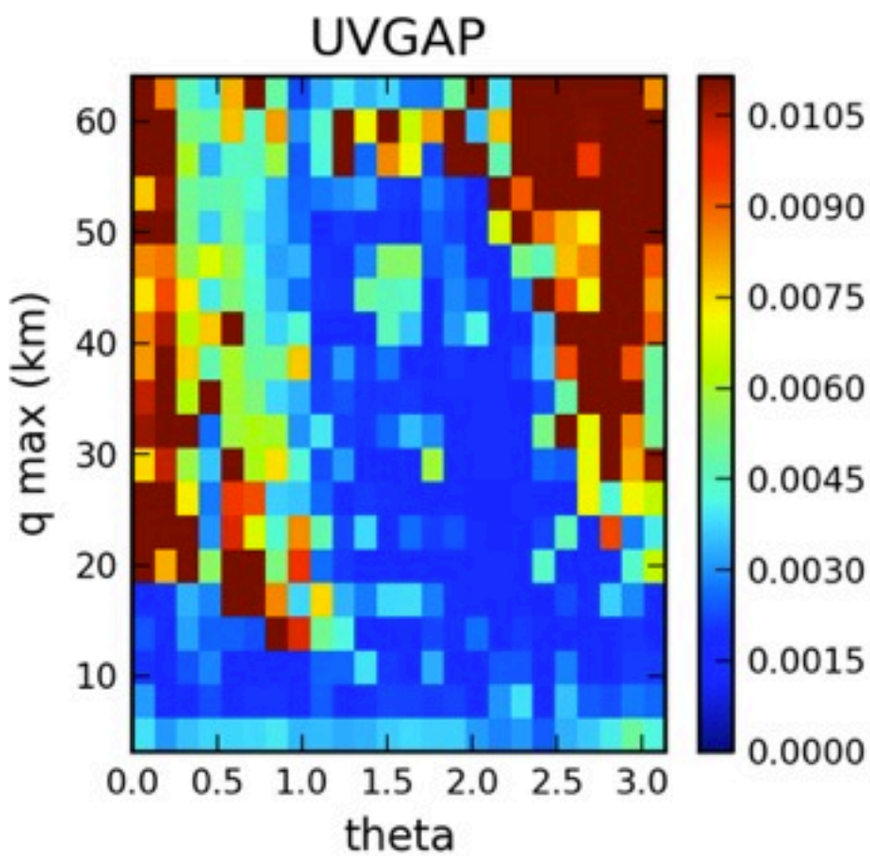
Beam

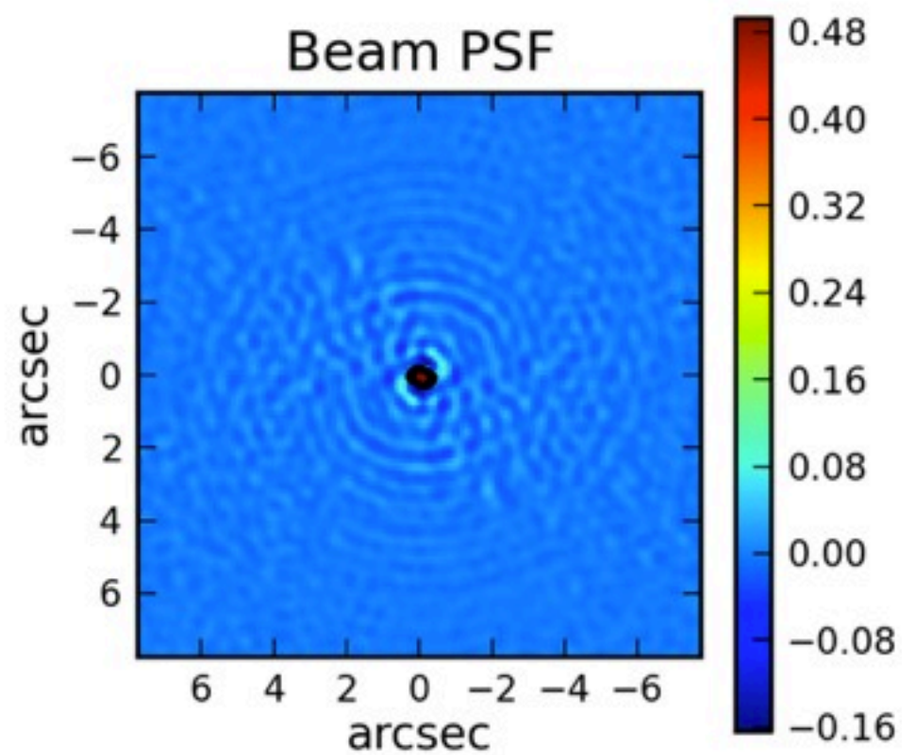

SKA1 mid, uniform, 3.4km
SKA1 mid, natural, 3.4km
SKA1 mid, uniform, 3.4km
SKA1 mid, natural, 3.4km
Declination (J2000)
Right Ascension (J2000)
+0°05'
00'
−05'
−59°55'
−60°00'
−60°05'
0h00m30s 0h00m15s 0h00m00s 23h59m45s 23h59m30s
0h01m00s 0h00m30s 0h00m00s 23h59m30s 23h59m00s

UVGAP

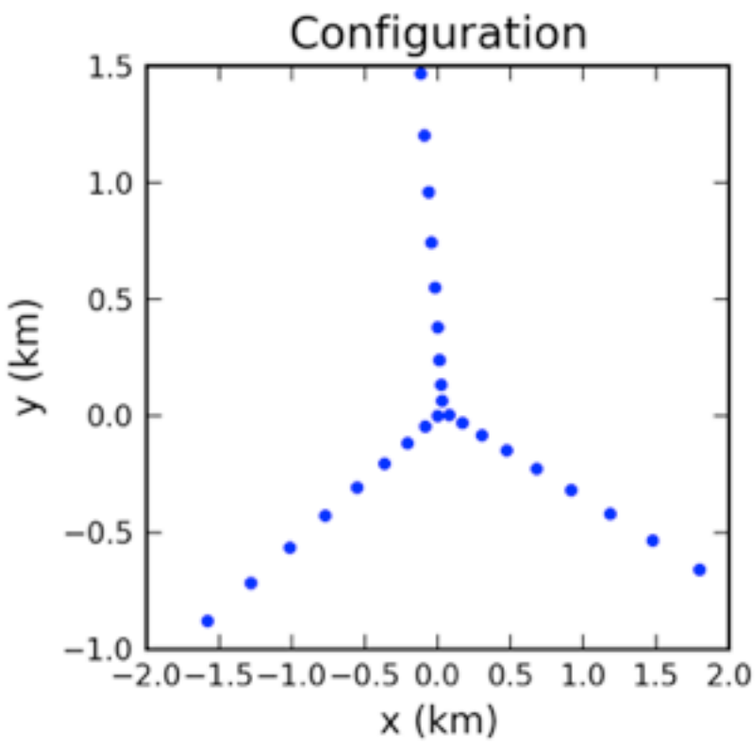

UVGAP
q max (km)
theta
0.0 0.5 1.0 1.5 2.0 2.5 3.0
0.5 1.0 1.5 2.0 2.5 3.0
0.000 0.002 0.004 0.006 0.008 0.010 0.012 0.014 0.016 0.018

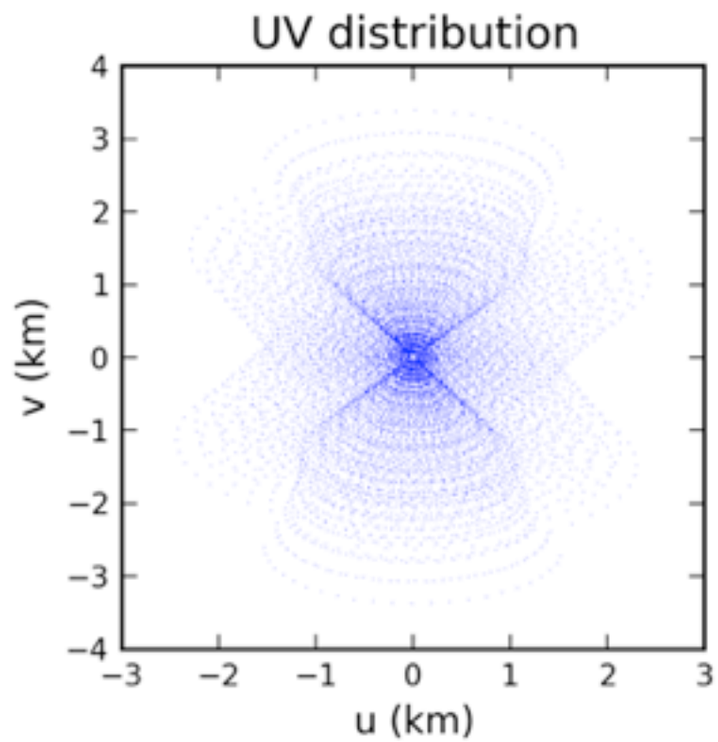

Beam PSF
arcsec
arcsec
−100 −50 0 50 100
100 50 0 −50 −100
0.36 0.30 0.24 0.18 0.12 0.06 0.00 −0.06 −0.12

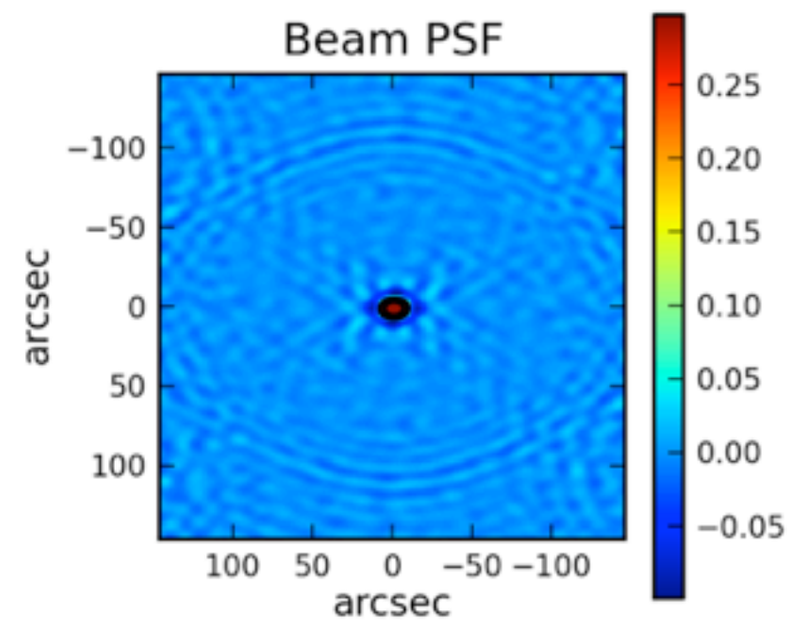

UVGAP
q max (km)
theta
0.0 0.5 1.0 1.5 2.0 2.5 3.0
10 20 30 40 50 60
0.0000 0.0015 0.0030 0.0045 0.0060 0.0075 0.0090 0.0105

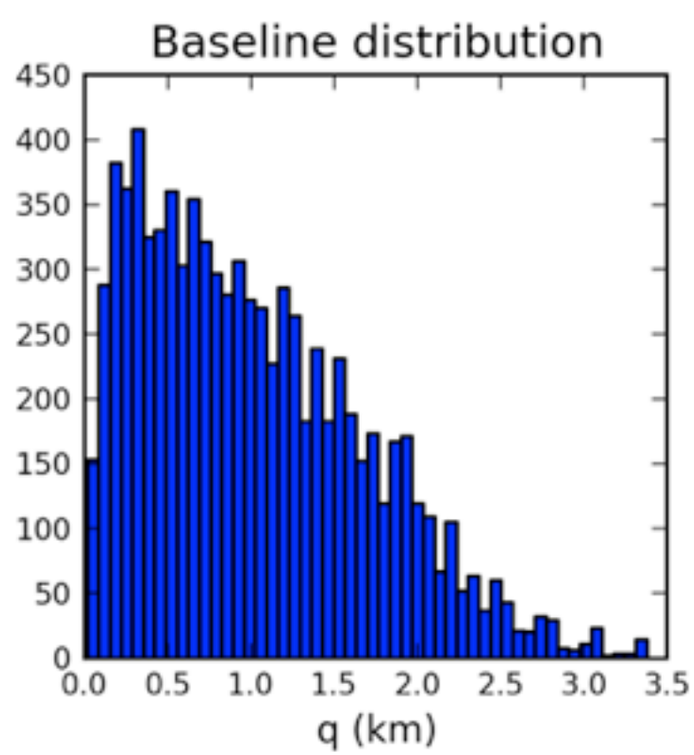

Beam PSF
arcsec
arcsec
−6 −4 −2 0 2 4 6
6 4 2 0 −2 −4 −6
0.48 0.40 0.32 0.24 0.16 0.08 0.00 −0.08 −0.16

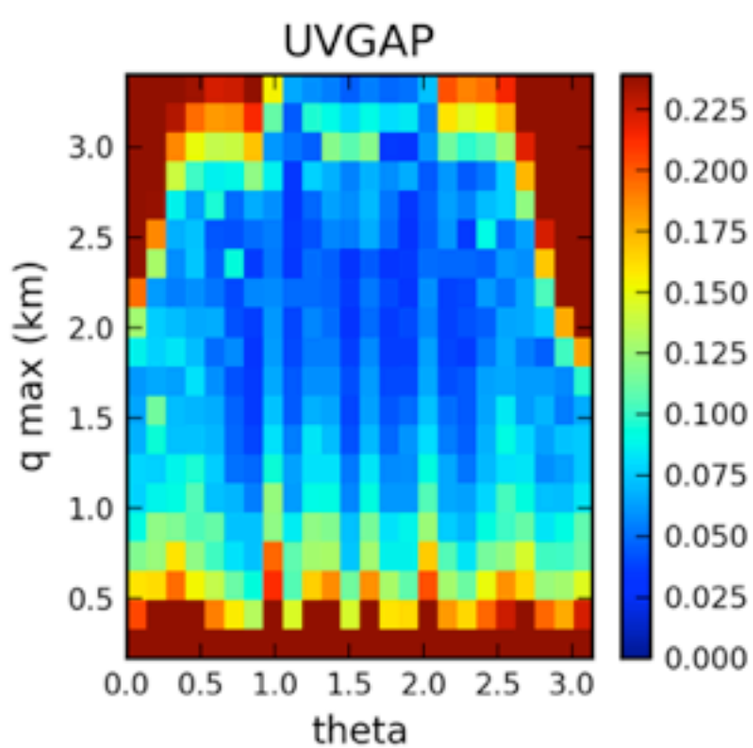
VLA









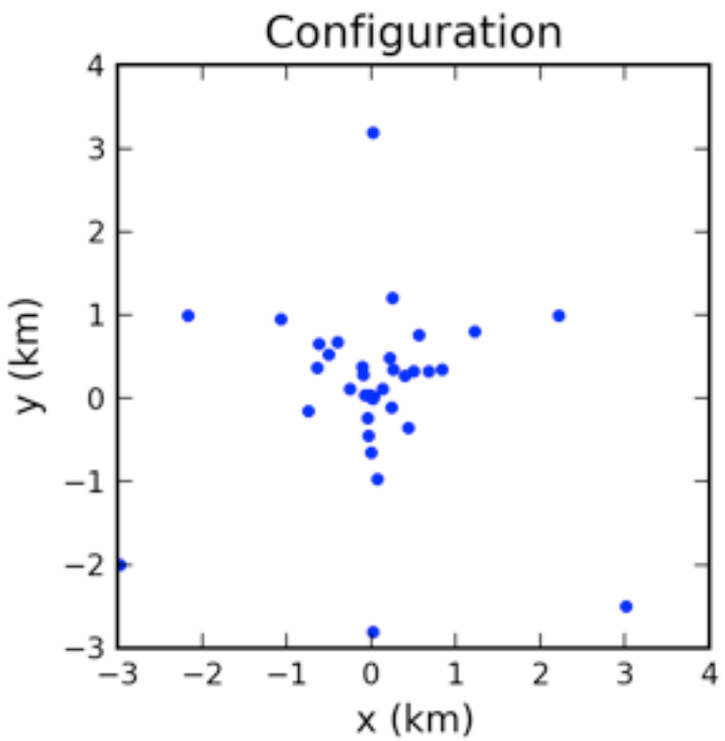


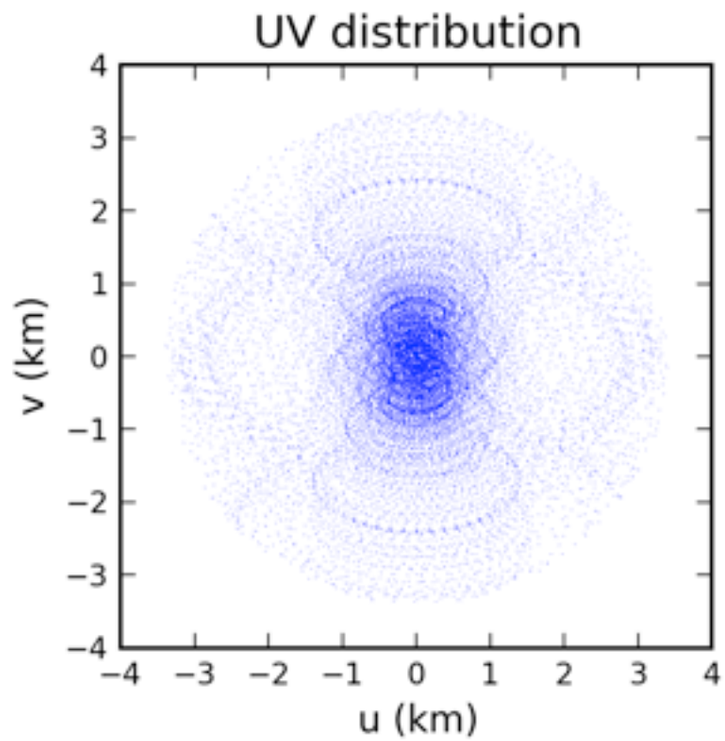
vla_c

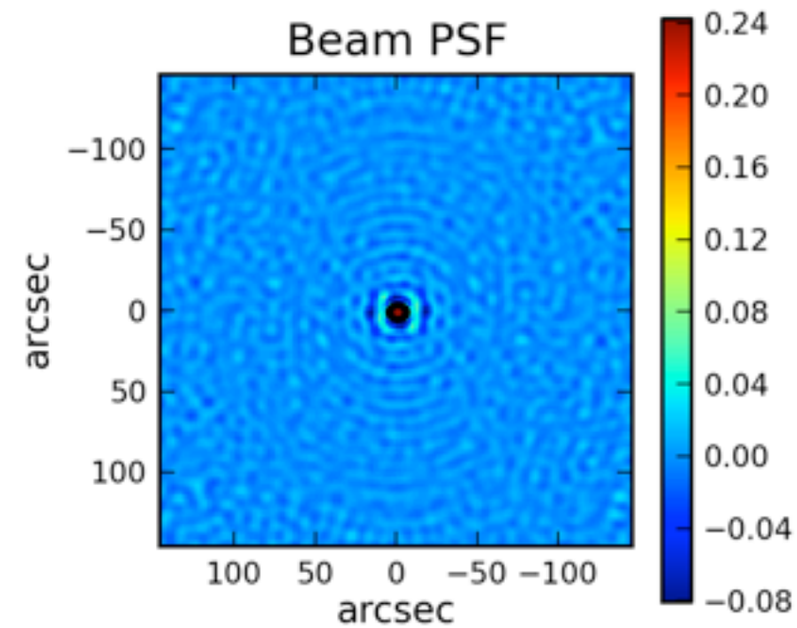
Declination: -30
Frequency: 1000.0
Bandwidth: 0.05
HA min: -6
HA max: 6
Robust: -2
UVrange: 3400

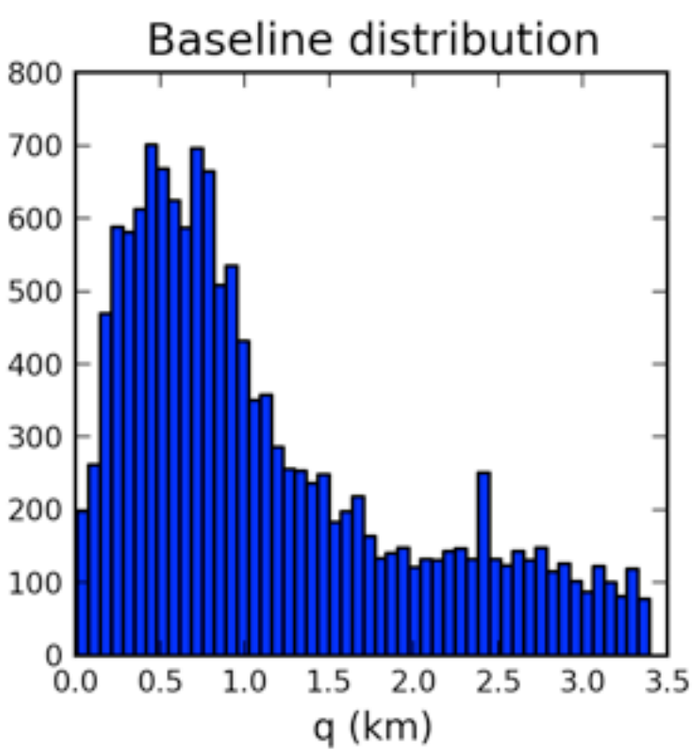
Bmin: 15.066
Bmaj: 22.63
rms: 0.0002283
NHI: 4.51665169425e+19
PSFRMS: 0.016374022696
UVGAP (med): 0.218991836307
UVGAP (mean): 0.208721567307

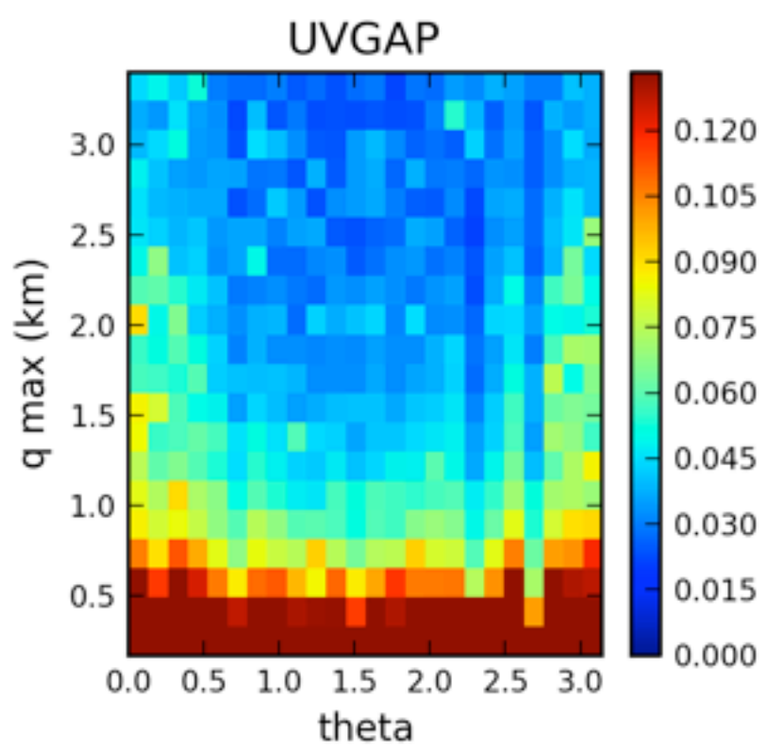
ASKAP









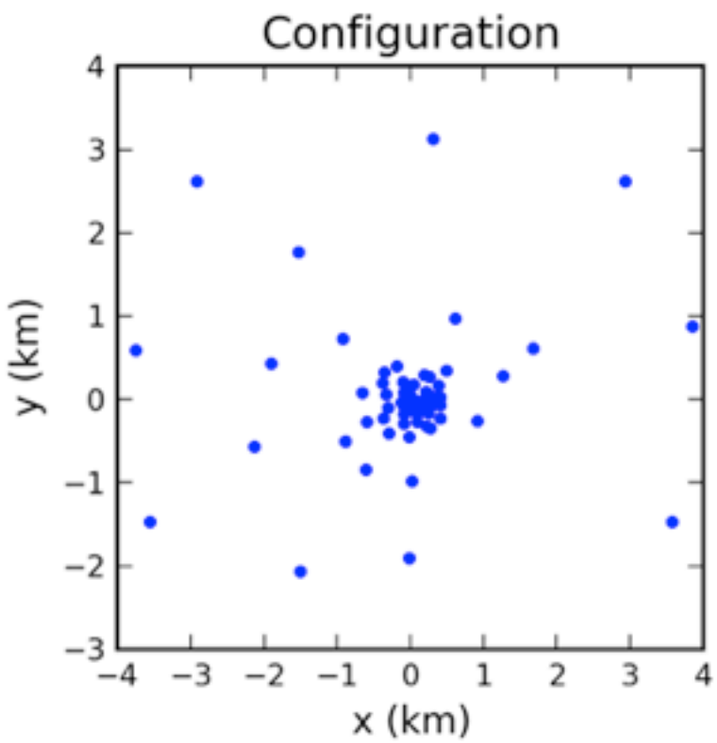


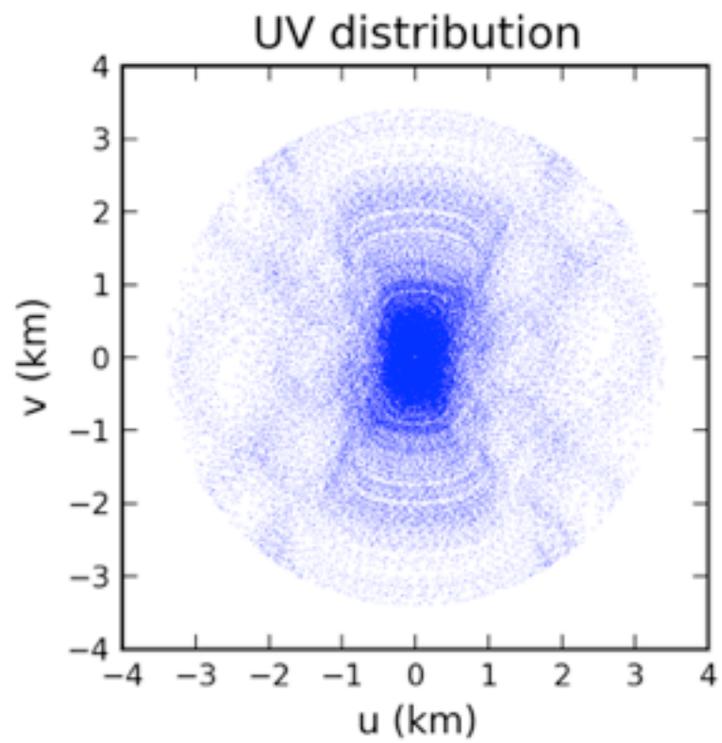
askap

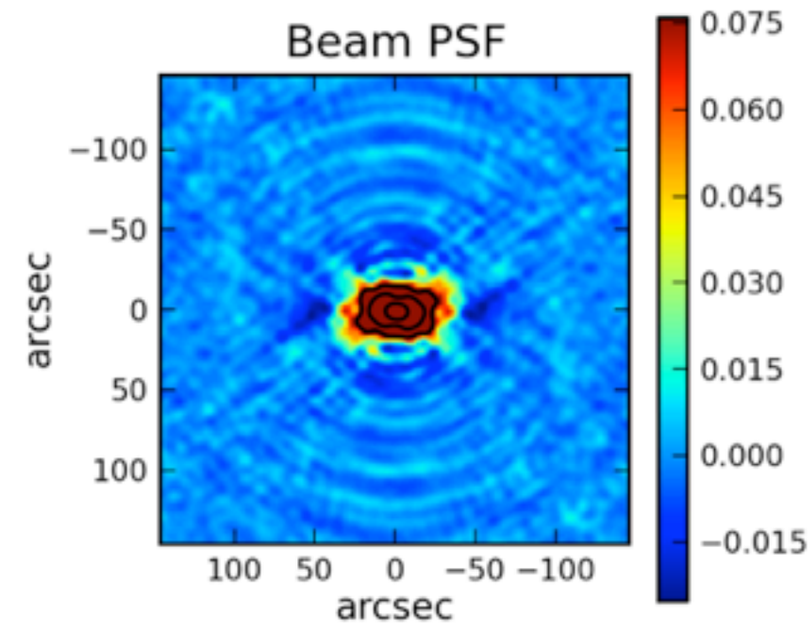
Declination: -30
Frequency: 1000.0
Bandwidth: 0.05
HA min: -6
HA max: 6
Robust: -1
UVrange: 3400

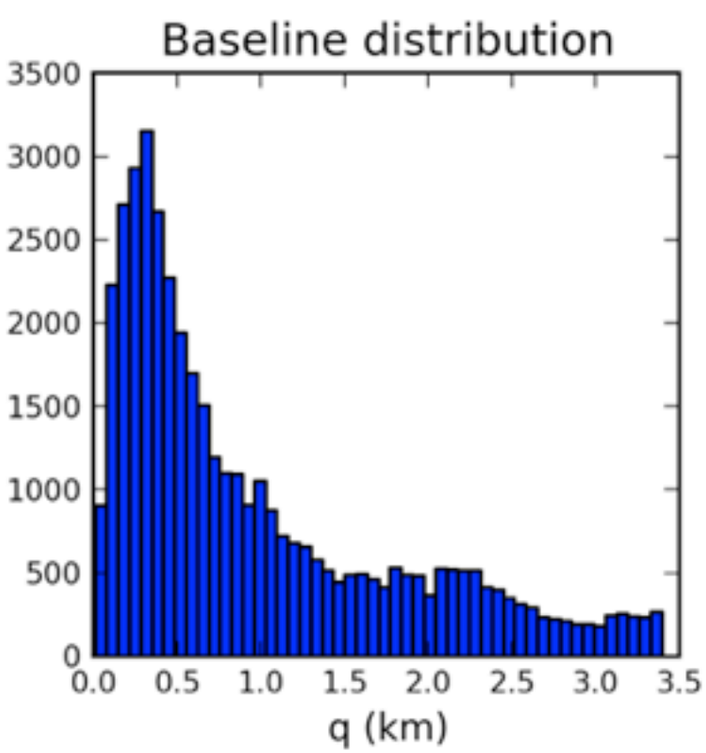
Bmin: 13.379
Bmaj: 14.865
rms: 0.001051
NHI: 3.56457170279e+20
PSFRMS: 0.00997518388239
UVGAP (med): 0.0331335938253
UVGAP (mean): 0.0305073127439

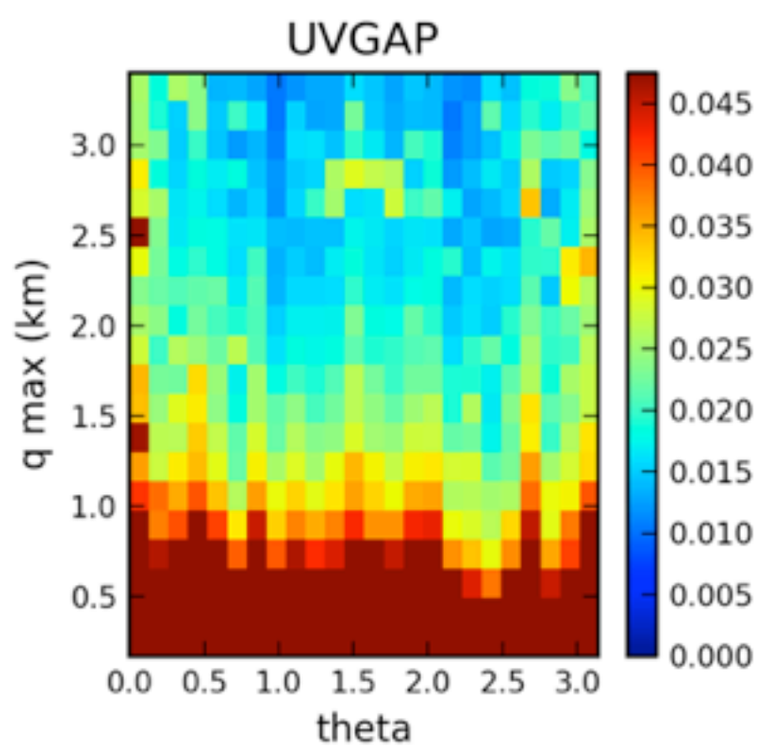
MeerKAT









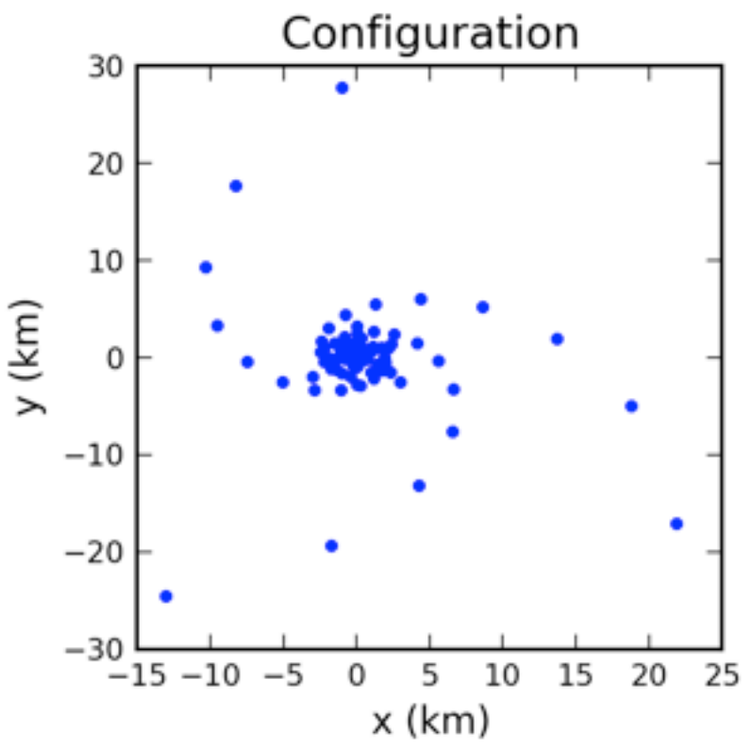


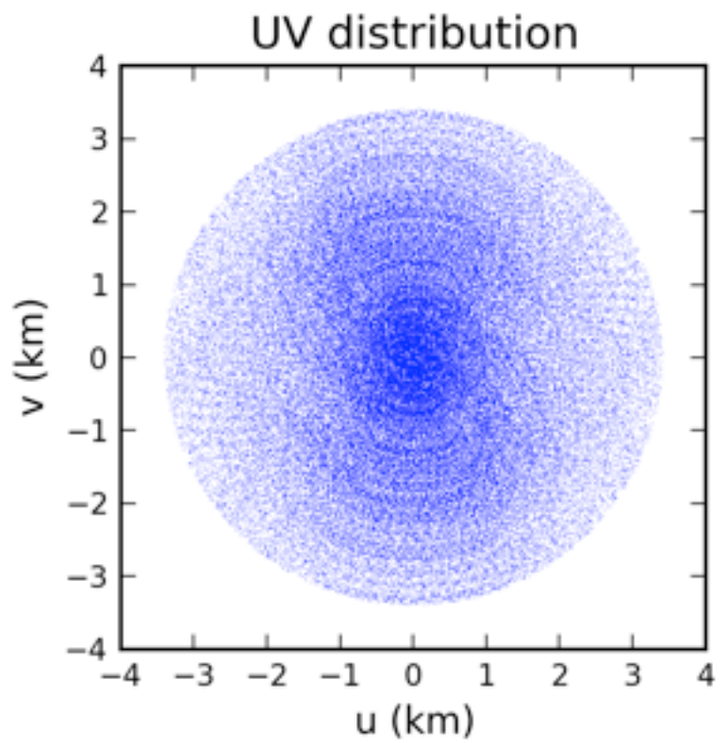
meerkat

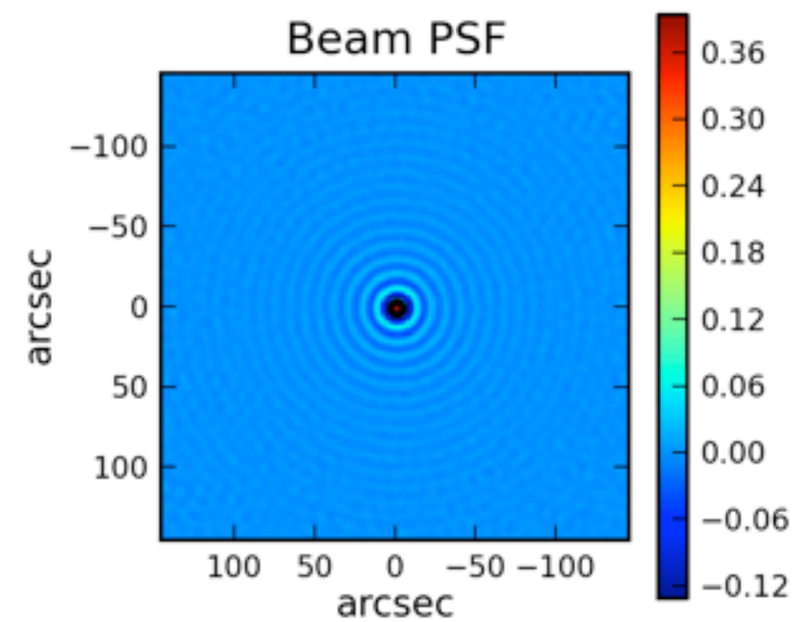
Declination: -30
Frequency: 1000.0
Bandwidth: 0.05
HA min: -6
HA max: 6
Robust: -1
UVrange: 3400

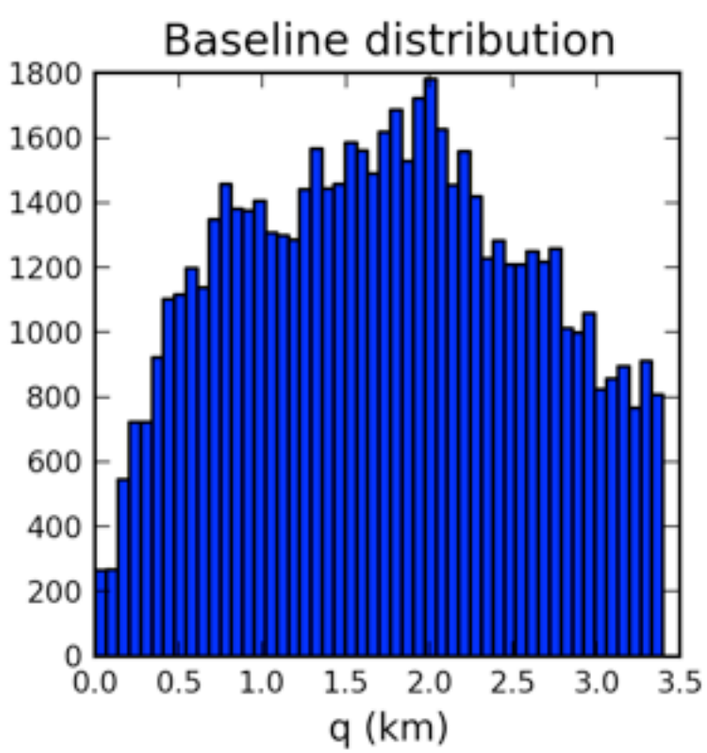
Bmin: 25.467
Bmaj: 41.542
rms: 0.0001583
NHI: 1.00927364226e+19
PSFRMS: 0.00930482585857
UVGAP (med): 0.0162807944101
UVGAP (mean): 0.014532976578

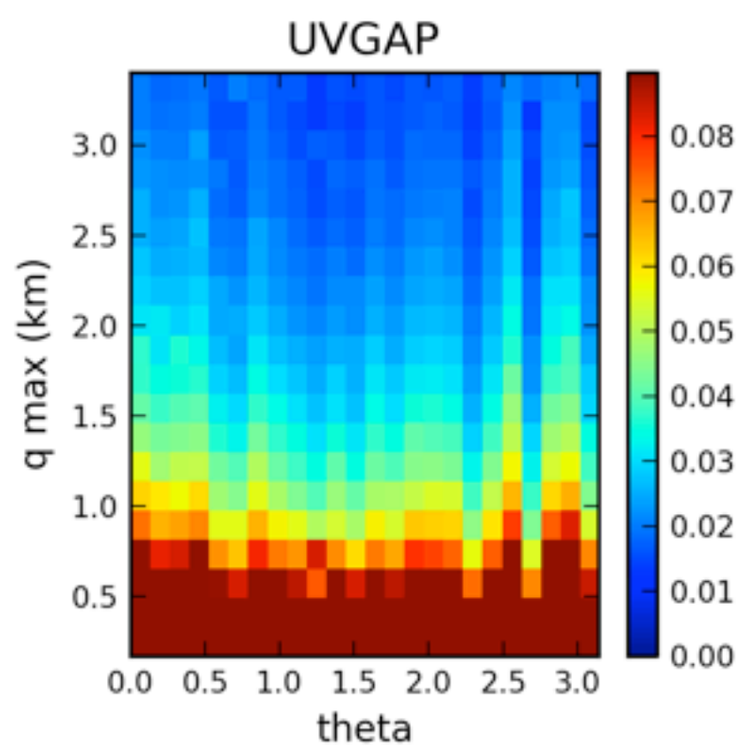
SKA1-survey









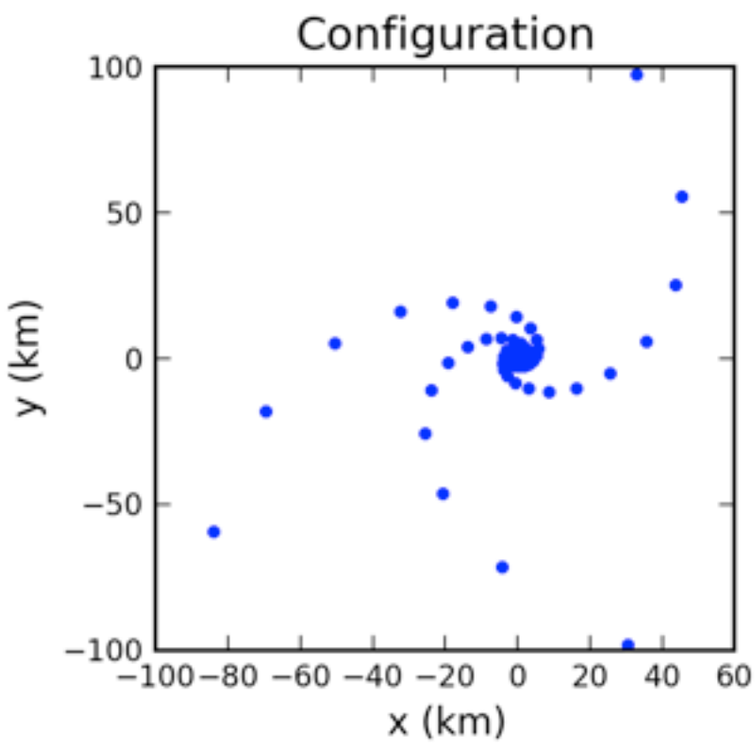


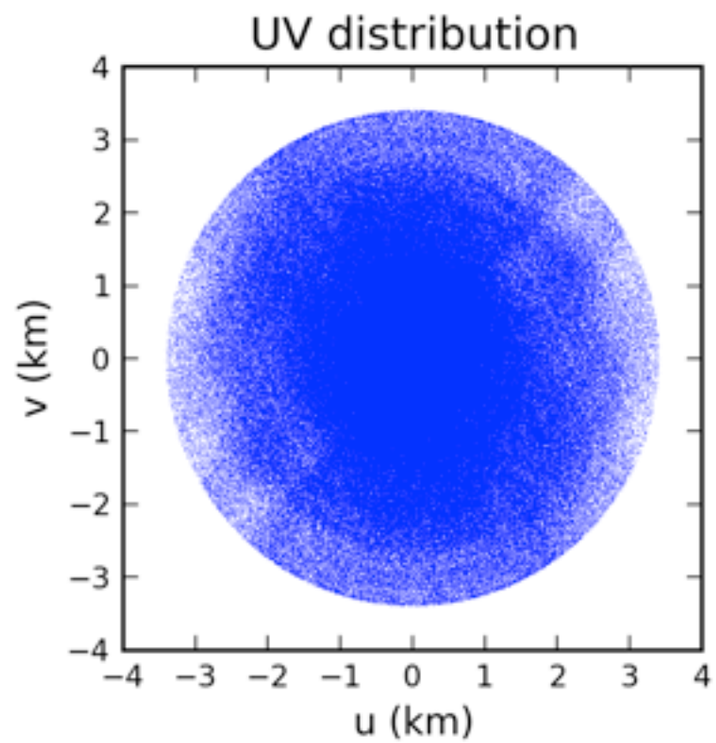
survey

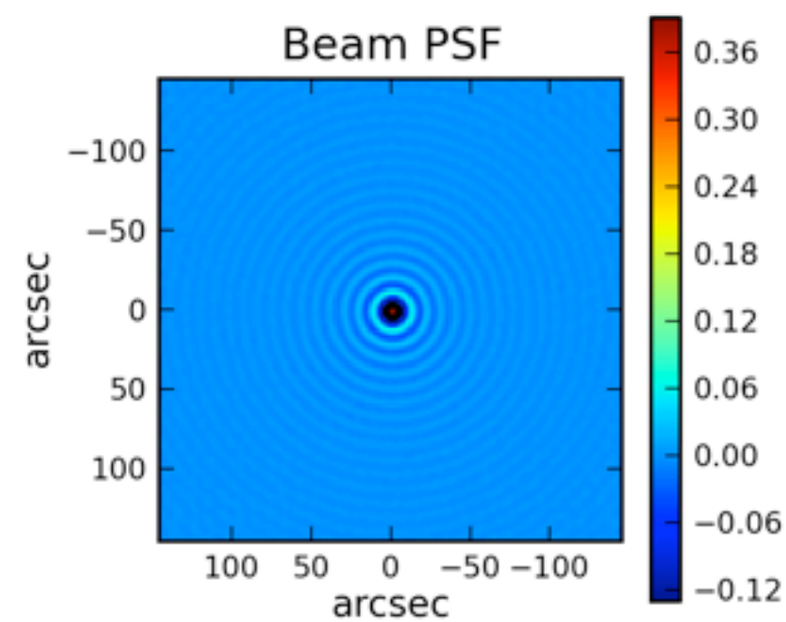
Declination: -30
Frequency: 1000.0
Bandwidth: 0.05
HA min: -6
HA max: 6
Robust: -1
UVrange: 3400

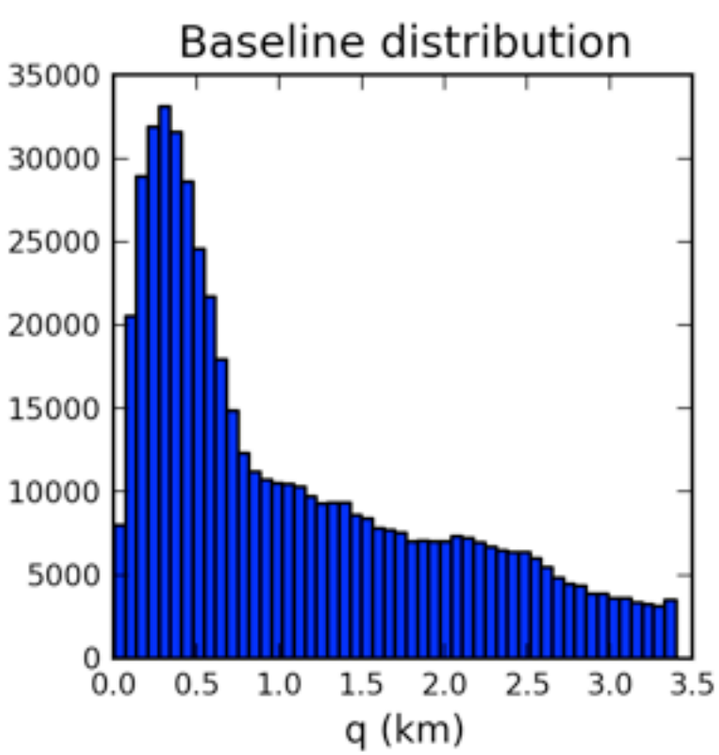
Bmin: 11.829
Bmaj: 12.004
rms: 0.0002018
NHI: 9.58606456461e+19
PSFRMS: 0.00551151411601
UVGAP (med): 0.0176145499757
UVGAP (mean): 0.0175127748556

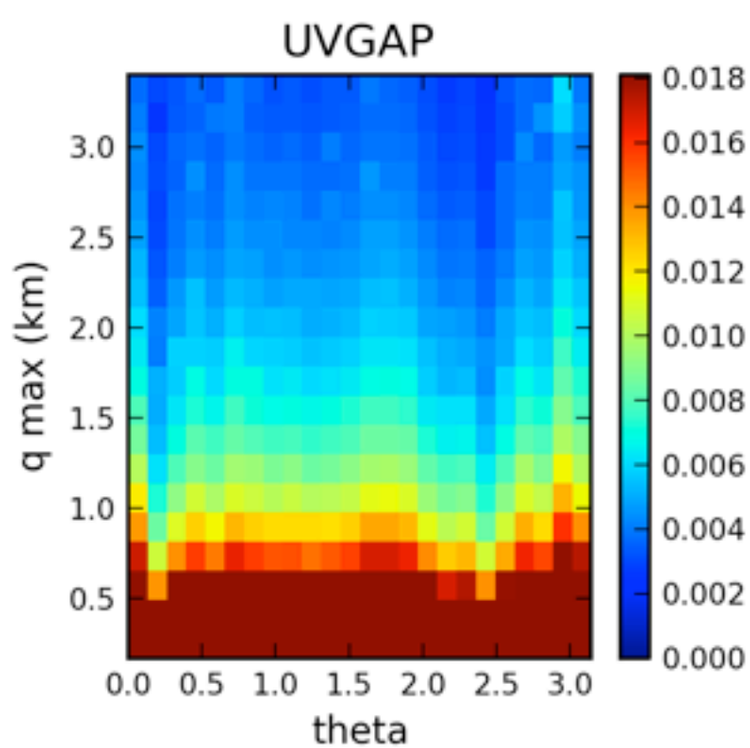
SKA1-mid









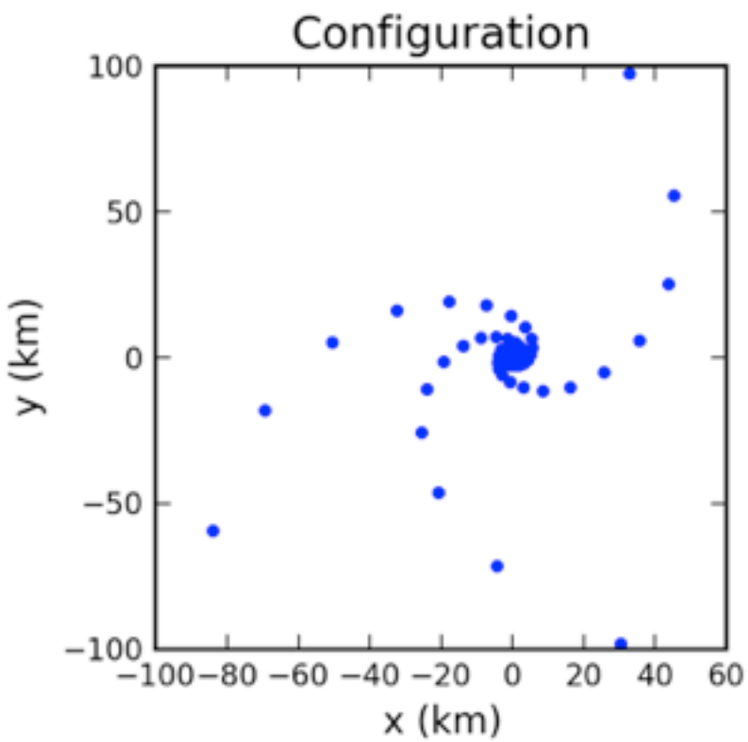


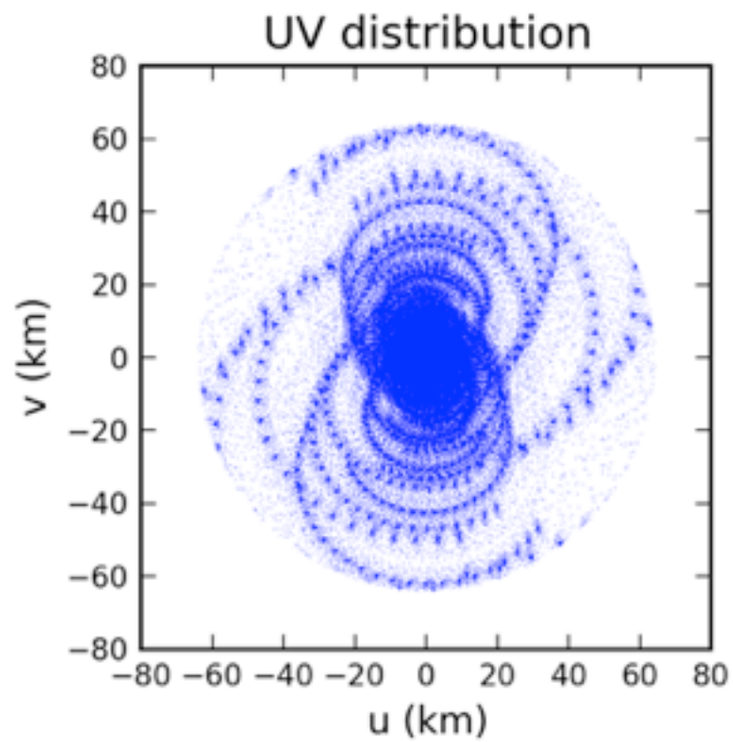
mid

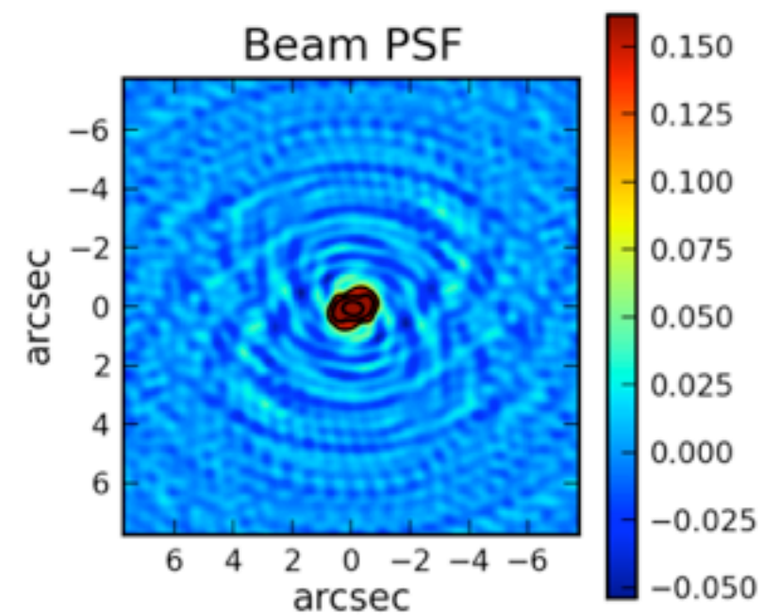
Declination: -30
Frequency: 1000.0
Bandwidth: 0.05
HA min: -6
HA max: 6
Robust: -1
UVrange: 3400

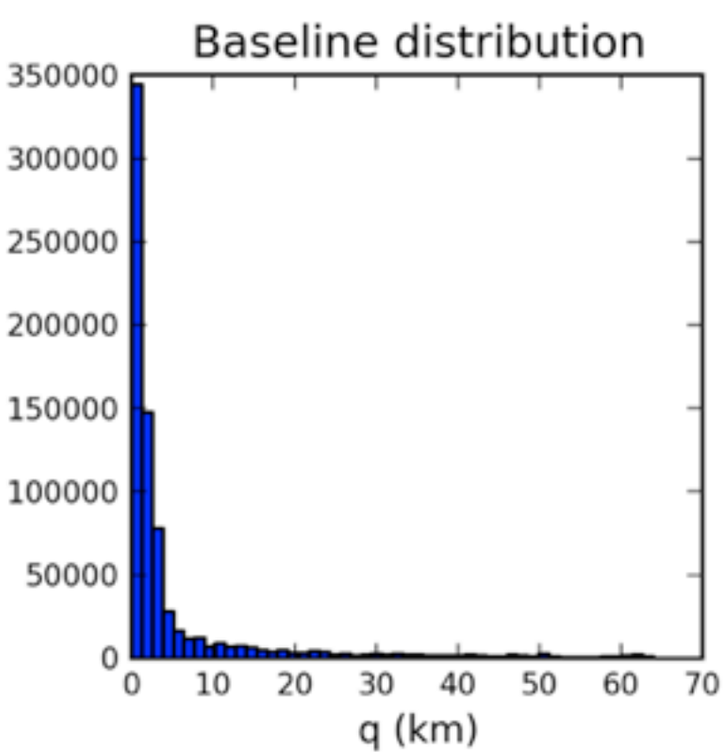
Bmin: 11.78
Bmaj: 12.009
rms: 5.597e-05
NHI: 2.66867924502e+19
PSFRMS: 0.00738119047159
UVGAP (med): 0.00351693820765
UVGAP (mean): 0.00337028089293

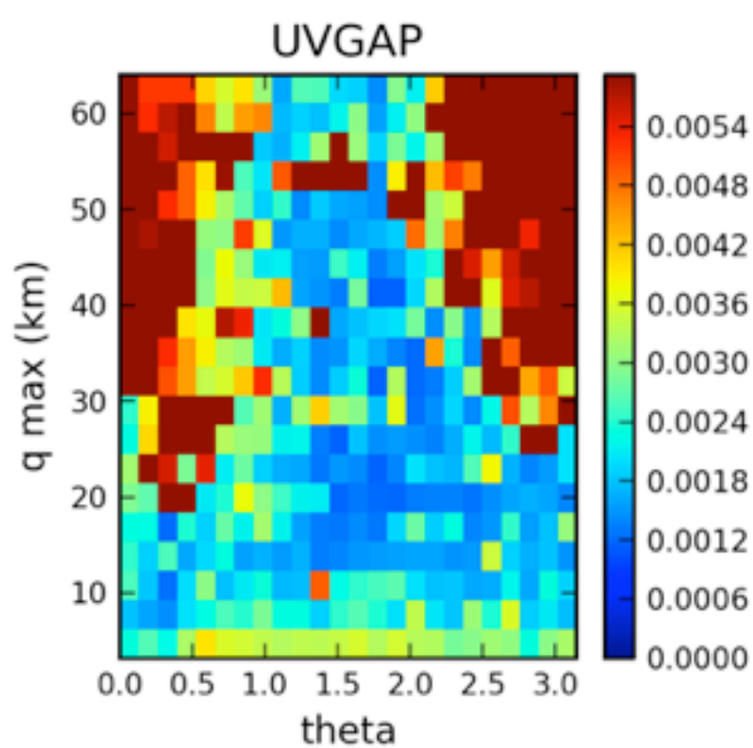
SKA1-mid; Dec = -60









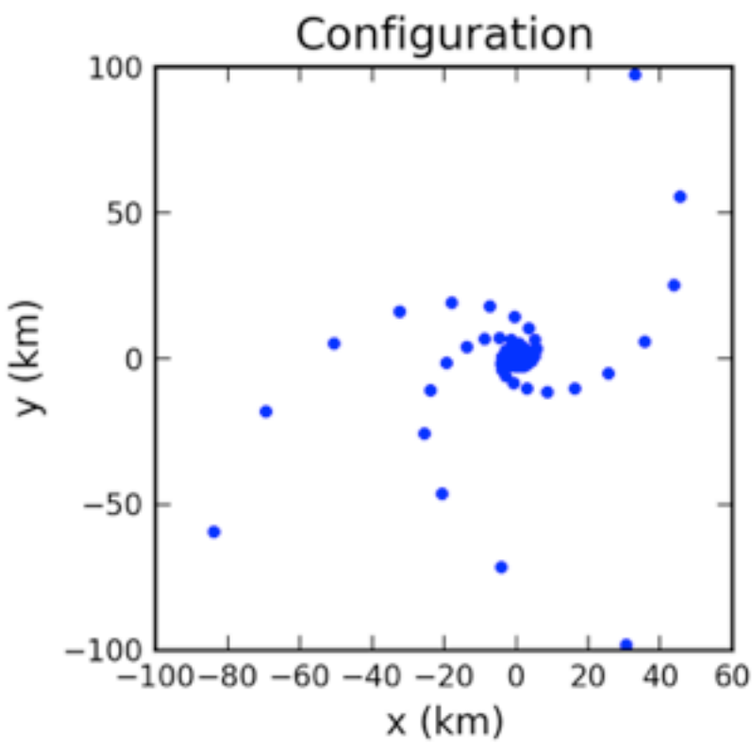


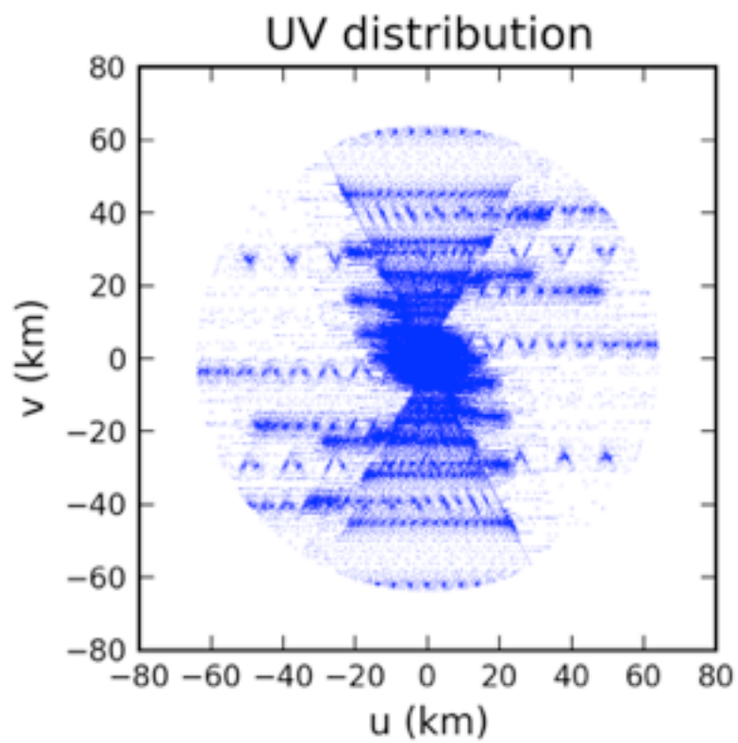
mid

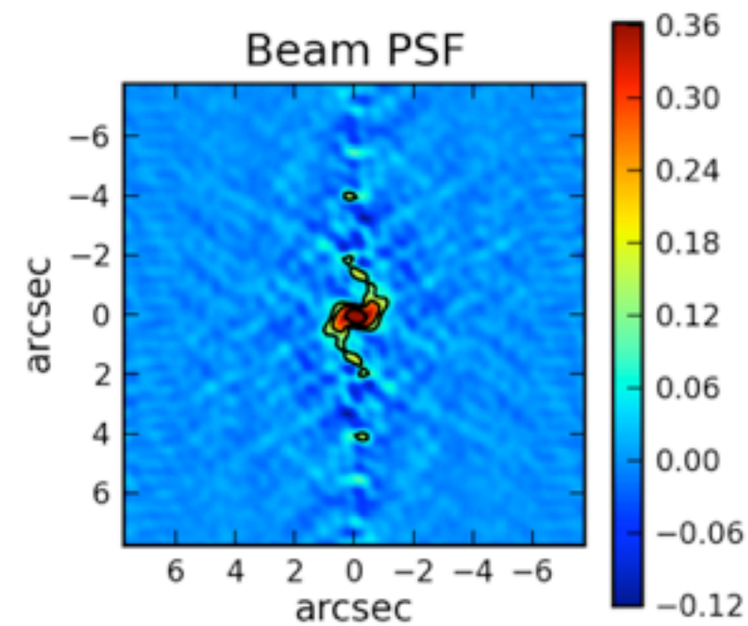
Declination: -60
Frequency: 1000.0
Bandwidth: 0.05
HA min: -6
HA max: 6
Robust: -2
UVrange: 64000

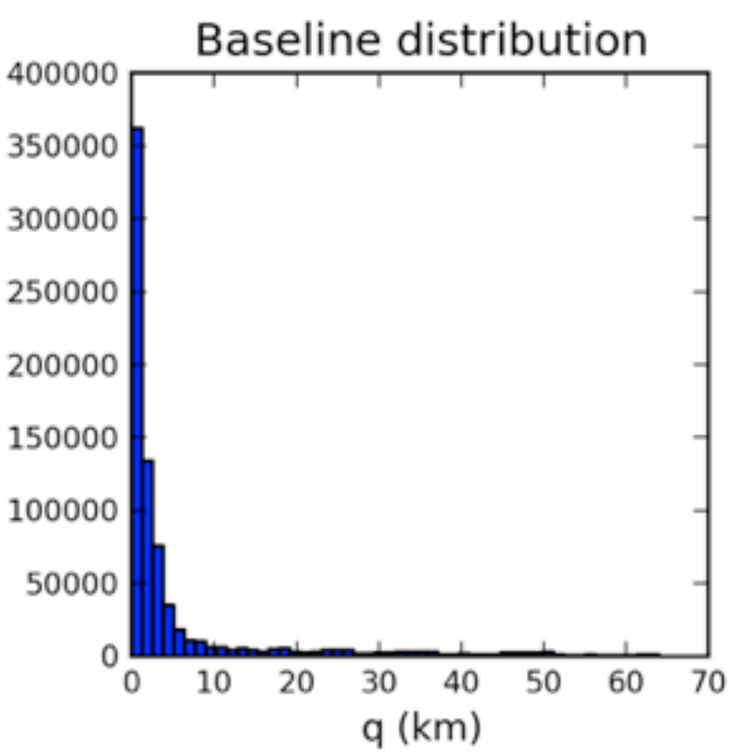
Bmin: 1.091
Bmaj: 1.668
rms: 7.151e-05
NHI: 2.65056944687e+21
PSFRMS: 0.00538194964853
UVGAP (med): 0.00531612124576
UVGAP (mean): 0.00411720641912

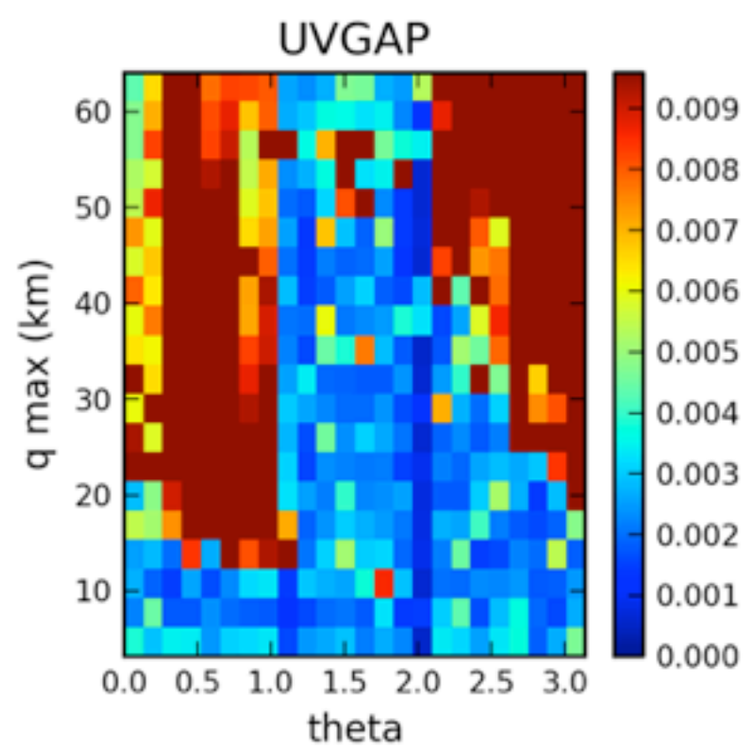
SKA1-mid; Dec = 0







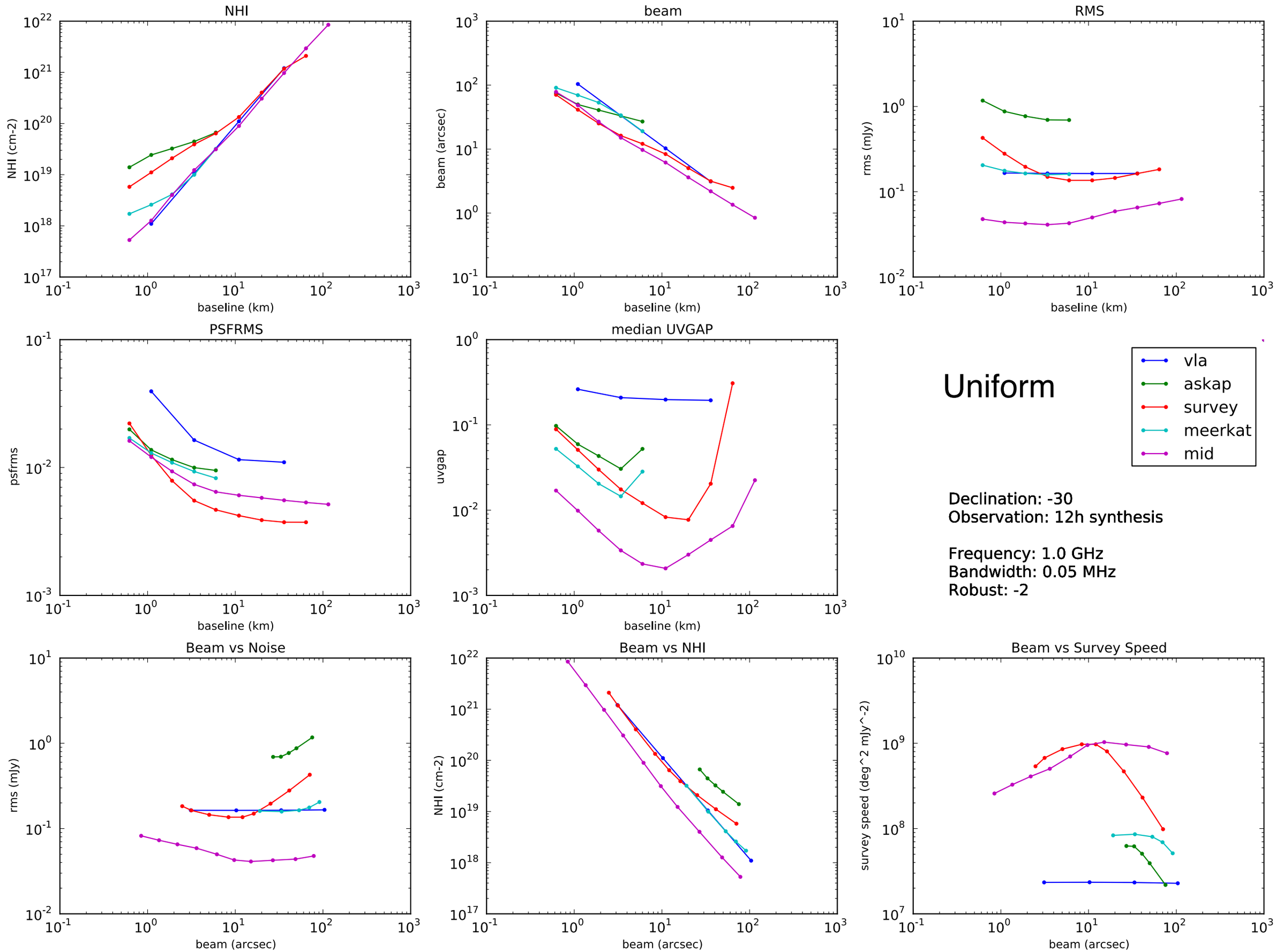


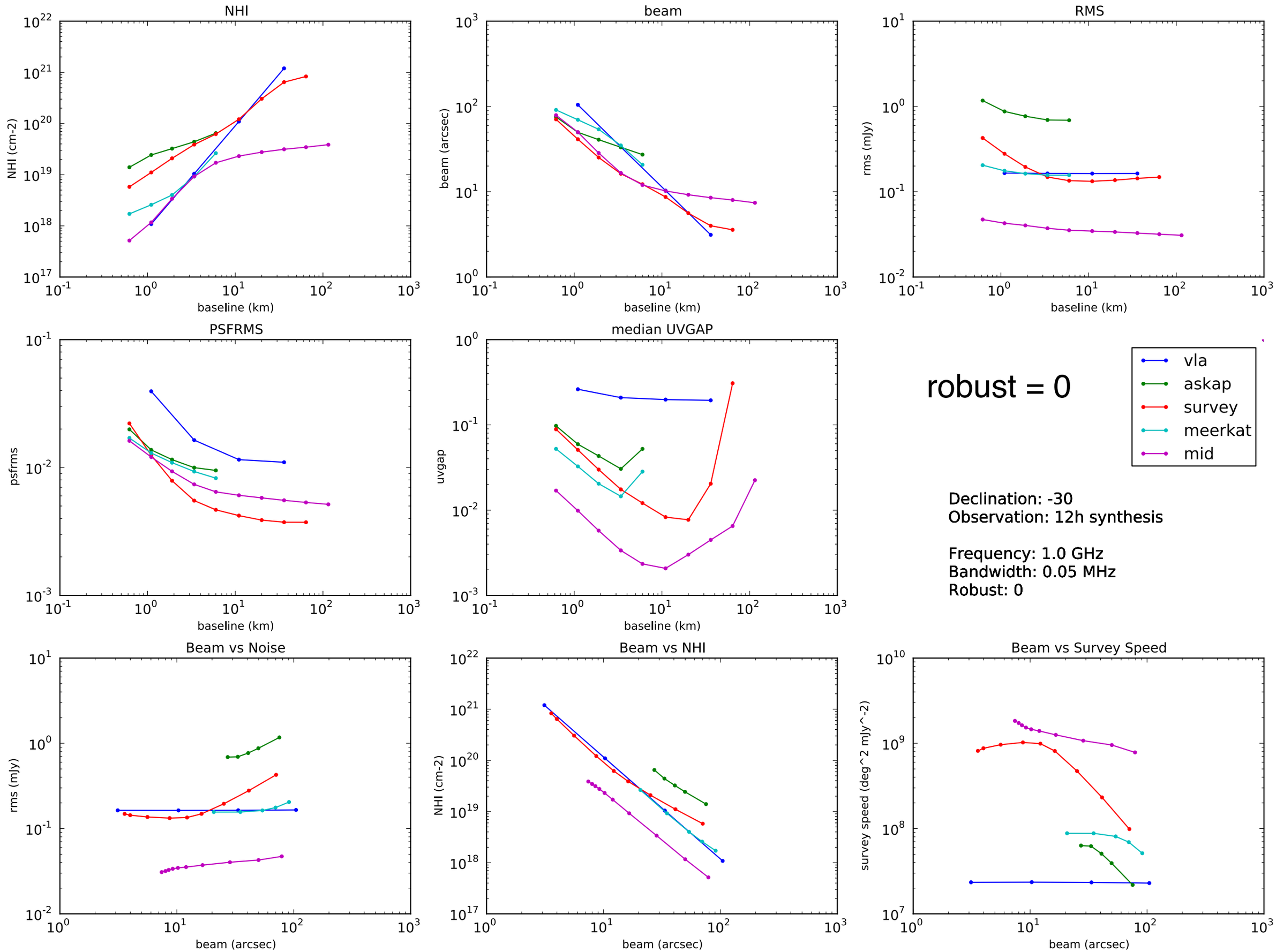


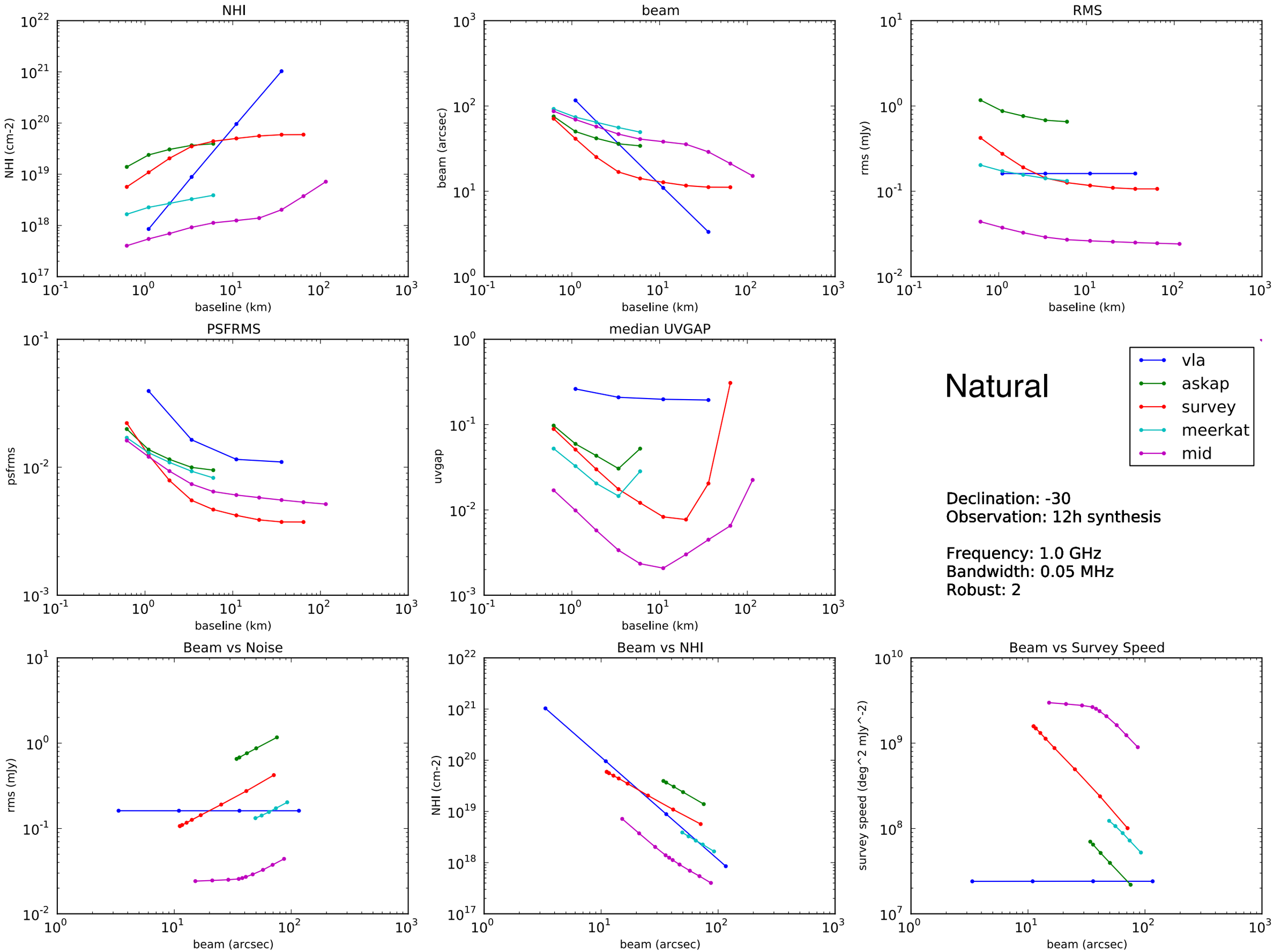
mid

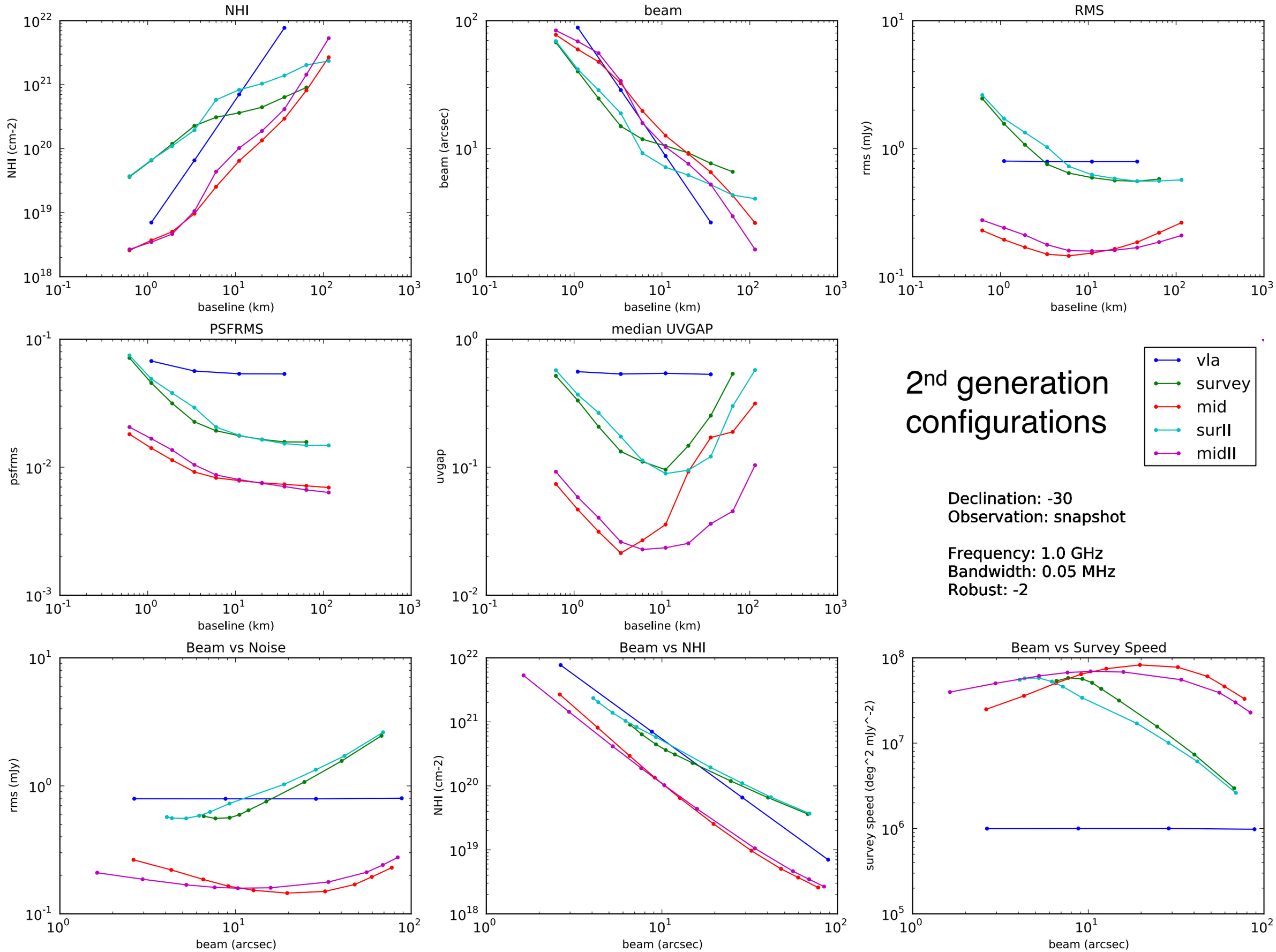
Declination: 0
Frequency: 1000.0
Bandwidth: 0.05
HA min: -6
HA max: 6
Robust: -2
UVrange: 64000

Bmin: 0.954
Bmaj: 1.85
rms: 7.747e-05
NHI: 2.96078355058e+21
PSFRMS: 0.00637070226228
UVGAP (med): 0.0135395161424
UVGAP (mean): 0.00813686091525

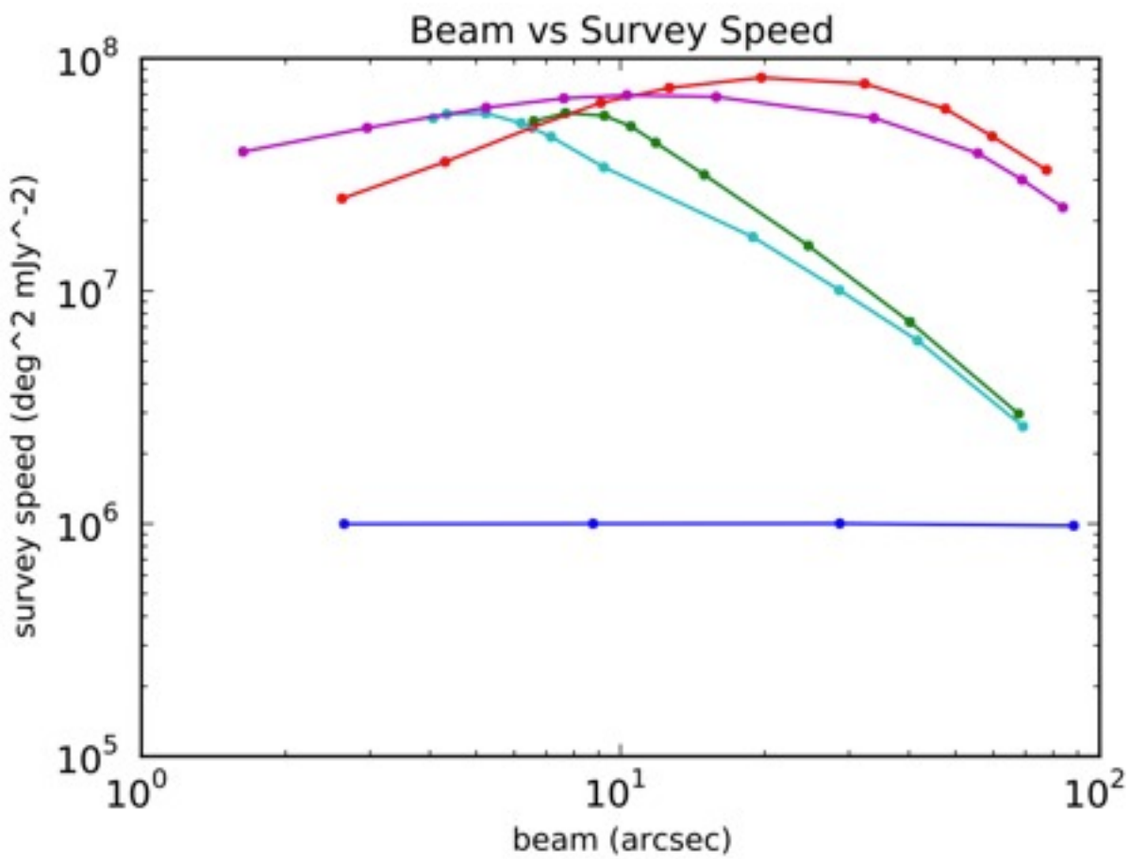

NHI
NHI (cm-2)
baseline (km)
beam
beam (arcsec)
baseline (km)
RMS
rms (mJy)
baseline (km)
PSFRMS
psfrms
baseline (km)
median UVGAP
uvgap
baseline (km)
Uniform
vla
askap
survey
meerkat
mid
Declination: -30
Observation: 12h synthesis
Frequency: 1.0 GHz
Bandwidth: 0.05 MHz
Robust: -2
Beam vs Noise
rms (mJy)
beam (arcsec)
Beam vs NHI
NHI (cm-2)
beam (arcsec)
Beam vs Survey Speed
survey speed (deg^2 mJy^-2)
beam (arcsec)


NHI
NHI (cm-2)
baseline (km)
beam
beam (arcsec)
baseline (km)
RMS
rms (mJy)
baseline (km)
PSFRMS
psfrms
baseline (km)
median UVGAP
uvgap
baseline (km)
robust = 0
vla
askap
survey
meerkat
mid
Declination: -30
Observation: 12h synthesis
Frequency: 1.0 GHz
Bandwidth: 0.05 MHz
Robust: 0
Beam vs Noise
rms (mJy)
beam (arcsec)
Beam vs NHI
NHI (cm-2)
beam (arcsec)
Beam vs Survey Speed
survey speed (deg^2 mJy^-2)
beam (arcsec)

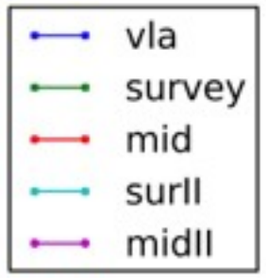

NHI
NHI (cm-2)
baseline (km)
beam
beam (arcsec)
baseline (km)
RMS
rms (mJy)
baseline (km)
PSFRMS
psfrms
baseline (km)
median UVGAP
uvgap
baseline (km)
Natural
vla
askap
survey
meerkat
mid
Declination: -30
Observation: 12h synthesis
Frequency: 1.0 GHz
Bandwidth: 0.05 MHz
Robust: 2
Beam vs Noise
rms (mJy)
beam (arcsec)
Beam vs NHI
NHI (cm-2)
beam (arcsec)
Beam vs Survey Speed
survey speed (deg^2 mJy^-2)
beam (arcsec)


NHI
NHI (cm-2)
baseline (km)
beam
beam (arcsec)
baseline (km)
RMS
rms (mJy)
baseline (km)
PSFRMS
psfrms
baseline (km)
median UVGAP
uvgap
baseline (km)
2nd generation configurations
vla
survey
mid
surII
midII
Declination: -30
Observation: snapshot
Frequency: 1.0 GHz
Bandwidth: 0.05 MHz
Robust: -2
Beam vs Noise
rms (mJy)
beam (arcsec)
Beam vs NHI
NHI (cm-2)
beam (arcsec)
Beam vs Survey Speed
survey speed (deg^2 mJy^-2)
beam (arcsec)

Survey Speed

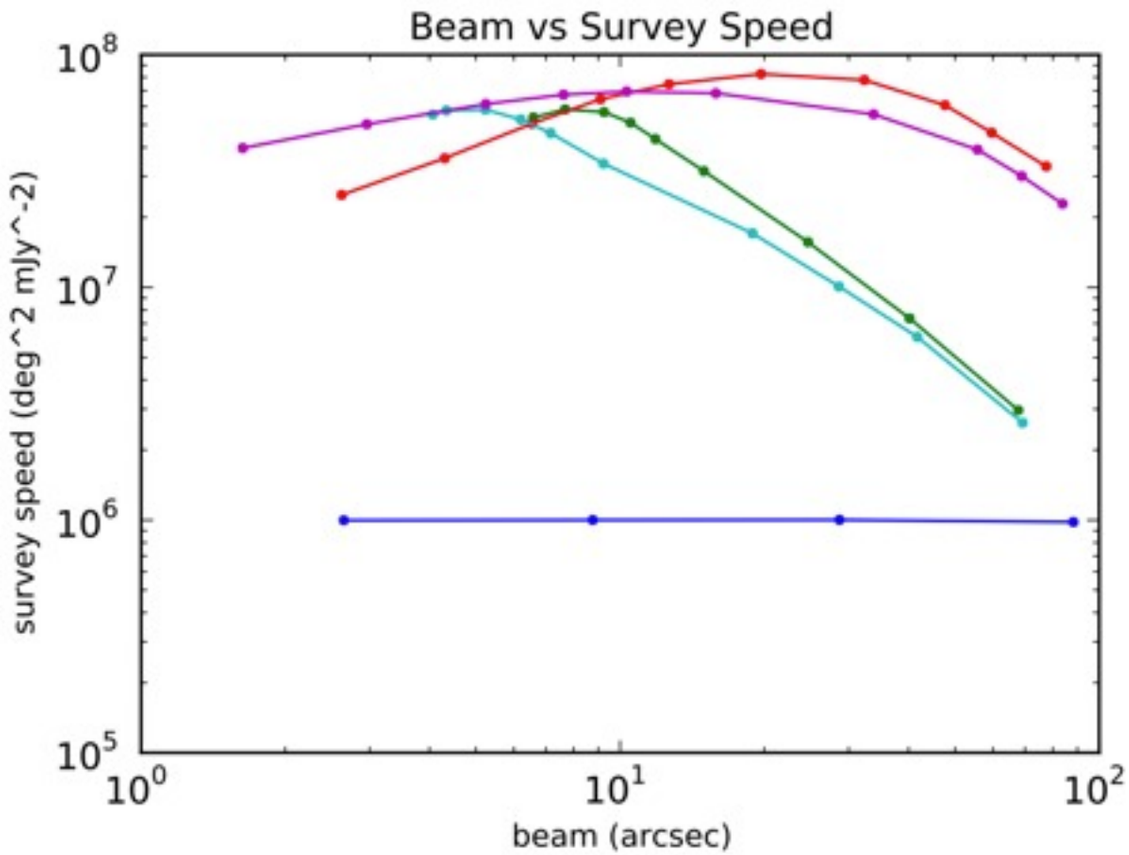


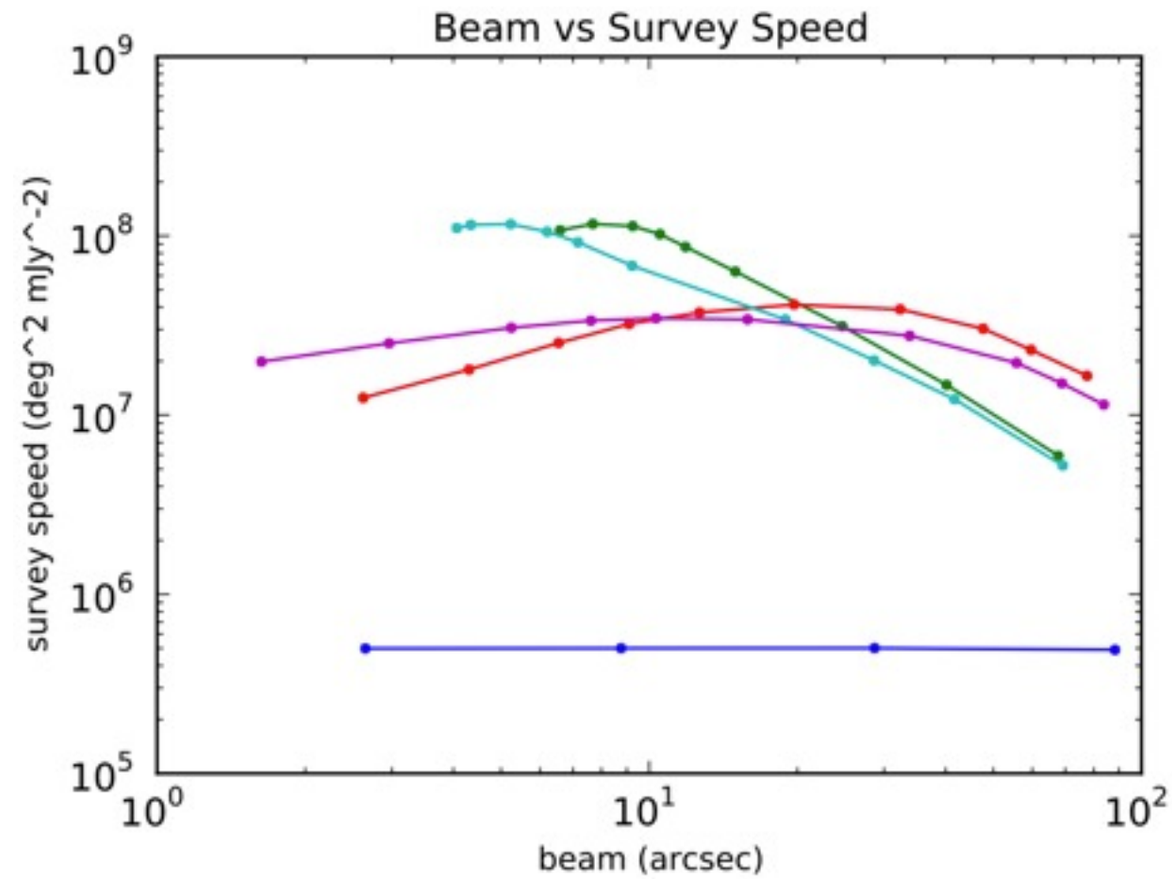
		JVLA	SKA1-survey	SKA-mid
A_{eff}/T_{sys}	m^2/K	265	391	1630
FoV	deg^2	0.25	18	0.49
Receptor Size	m	25	15	15
Fiducial frequency	GHz	1.4	1.67	1.67
Survey Speed FoM	$deg^2\ m^4\ K^{-2}$	1.76×10^4	2.75×10^6	1.30×10^6



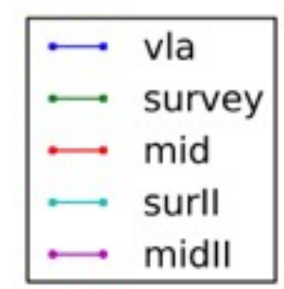
Survey speed of SKA-survey is two times better, however at 1.67 GHz ...
at lower (more interesting) frequencies SKA-mid takes over at ~1.16 GHz

Survey Speed





		JVLA	SKA1-survey	SKA-mid
A_{eff}/T_{sys}	m^2/K	265	391	1630
FoV	deg^2	0.25	36	1.0 / 2
Receptor Size	m	25	15	15
Fiducial frequency	GHz	1.4	1.16	1.16
Survey Speed FoM	$deg^2\ m^4\ K^{-2}$	1.76×10^4	5.5×10^6	1.30×10^6



When changing the Fiducial frequency of the PAFS, the survey speed of SKA-survey improves significantly

Discussion

The problem is complex and there is no single best solution

What is the best performance parameter, are there others ?

1. What is the HI science you are interested in?
2. What are the requirements (redshift, resolution, sensitivity, position etc.)?
3. Is this possible with the SKA?
4. If yes/no would you change the baseline design?
5. Are there aspects in the design that are not so useful?

All performance plots:
https://dl.dropboxusercontent.com/u/108468270/performance_plots.tar

Specific scenarios can be calculated (relatively) quickly