SKA1 and HI

SKA1 and HI

	WSRT	EVLA	SKA1 Mid	SKA1 Survey
FoV ($z = 0$)	0.25	0.25	0.6	18
FoV ($z = 0.5$)	–	–	1.4	18
FoV ($z = 1$)	–	–	2.4	61
SEFD ($0 < z < 0.5$)	22.3	10.4	1.7	7.1
rel. EVLA	0.5	1	6	1.5
SEFD ($0.5 < z < 1$)	–	–	2.8	7.1
SEFD ($1 < z < 3$)	–	–	2.8	12
SSpeed ($0 < z < 0.5$) (10^6)	0.0038	0.018-0.04	1.8-4.0	2.8
SSpeed ($0.5 < z < 1$) (10^6)	–	–	2.4-4.3	2.8
SSpeed ($1 < z < 3$) (10^6)	–	–	4.3-9.9	3.4
Resolution (H I emission)	15	6	*4-2.5*	*8-5*
Resolution (H I absorption)	<11	<1	*<0.4*	*<0.8*

This looks great!!!
- 100x the survey speed of the EVLA
- a telescope 6x more sensitive (36x faster) than the EVLA
- better sensitivity (and less RFI) down to low frequencies (high z)

Is this really true????

Key HI Science

- **HI and galaxy evolution**

  Resolved studies of HI emission in and around galaxies out to z ~ 1, i.e. from Now to ~8 Gyr ago. Current work is out to z=0.2. Pathfinders will cover this redshift range, but will not resolve galaxies.
  Unresolved statistical studies (emission & absorption) beyond 8 Gyr

  Will provide, for large part of the life span of the Universe, information about the cold-gas in galaxies and their environment for multi-wavelength, multi-archive studies of galaxies evolution.

- Star formation declined factor 10 over this period

  WHY???

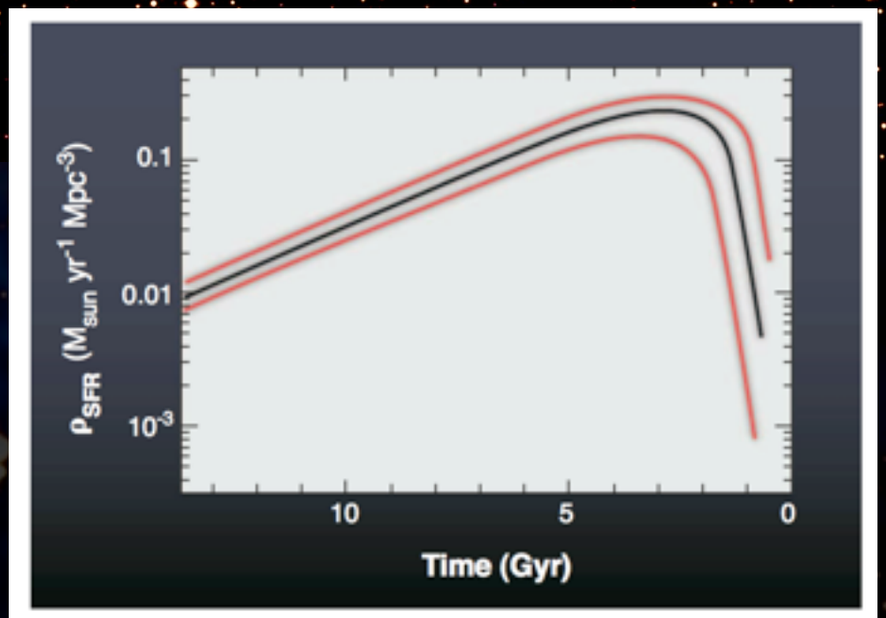


Fig. 2. A simple representation of our current knowledge of the rise and fall of globally averaged star-formation activity over the 13.7 billion years of cosmic history.

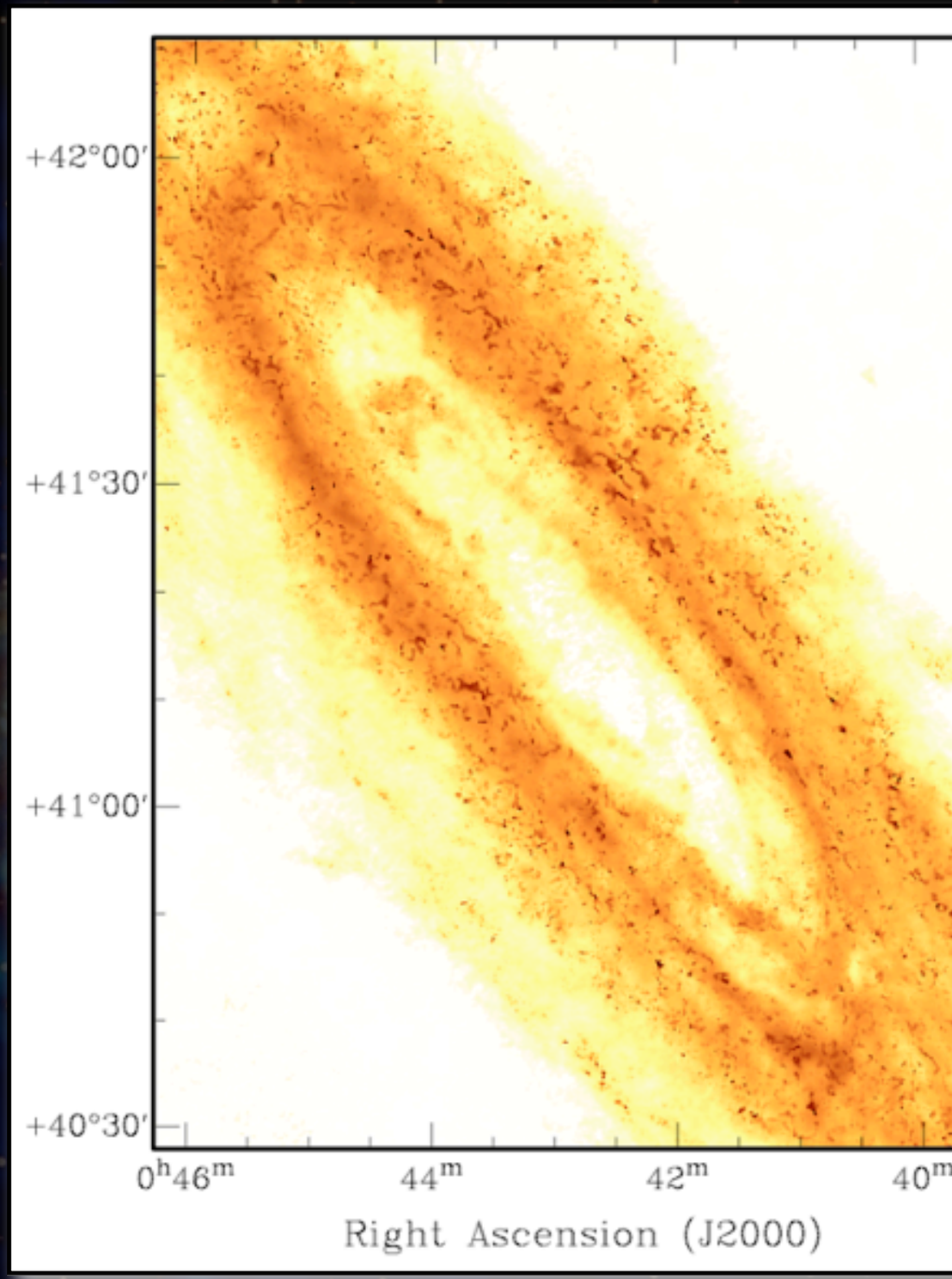
Key HI science

- **ISM in nearby galaxies**

  at high-spatial resolution (< 500 pc) to study the physics of the ISM and star formation below scales where statistical relations (KS-law) break down and simulations cannot (yet) go.

  Approach optical resolution.

  The synergy with ALMA for this kind of work is very exciting



HI in M31 with 100 pc resoution (WSRT) Braun 2013

Other Key HI Science

- HI absorption studies to study the role of AGN feedback in galaxy evolution over large redshift ranges.

- HI studies of the Galaxy and of the Magellanic Coulds down to sub-pc scales

- Low-resolution (~1 arcmin) observations of low-column density HI around nearby galaxies to study the gaseous interface (cold accretion) between galaxies and the IGM. Search for the smallest galaxies.

  SKA1-Mid offers the first possibility to probe the column densities of the IGM.

- Baryonic-acoustic oscillations through Intensity Mapping up to high redshift

Array configuration

HI work is (mostly) column density (i.e. surface brightness) limited
Typical column densities are the same in every galaxy

Better sensitivity can mean detection of fainter emission
but can also mean doing kinematics at higher spectral & spatial resolution.

Key question for HI: what is the sensitivity at what resolution?
Can we really use the high sensitivity at the right resolution or is it only modestly better than, e.g. the EVLA

Current practical limit on resolution for HI at typical column densities is EVLA B-array:
5-6 arcsec (1.4 GHz).

Simple column density sensitivity argument:
If we want to optimally use the sensitivity then, scaling by sensitivity implies SKA1 should have best sensitivity at ~3” (Mid) and ~5” (Survey) at 1.4 GHz

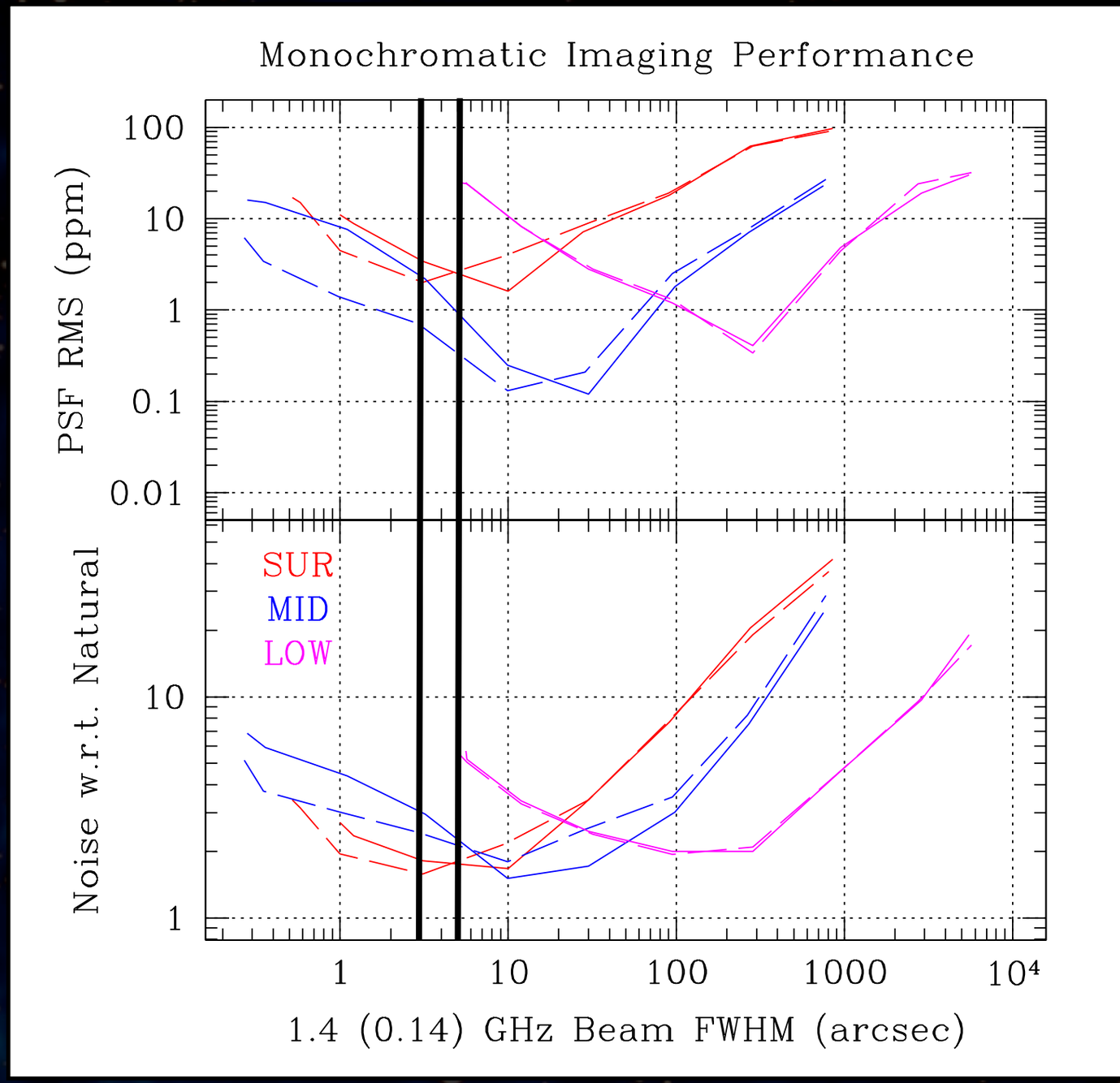
(beam size goes as (1+z))

Performance of SKA1

- SKA1-Mid:
  optimum at 10”
  at higher resolution lose sensitivity
  due to weighting

- SKA1-Survey:
  less sensitive but higher resolution

- Ugly beams at high resolution



Braun

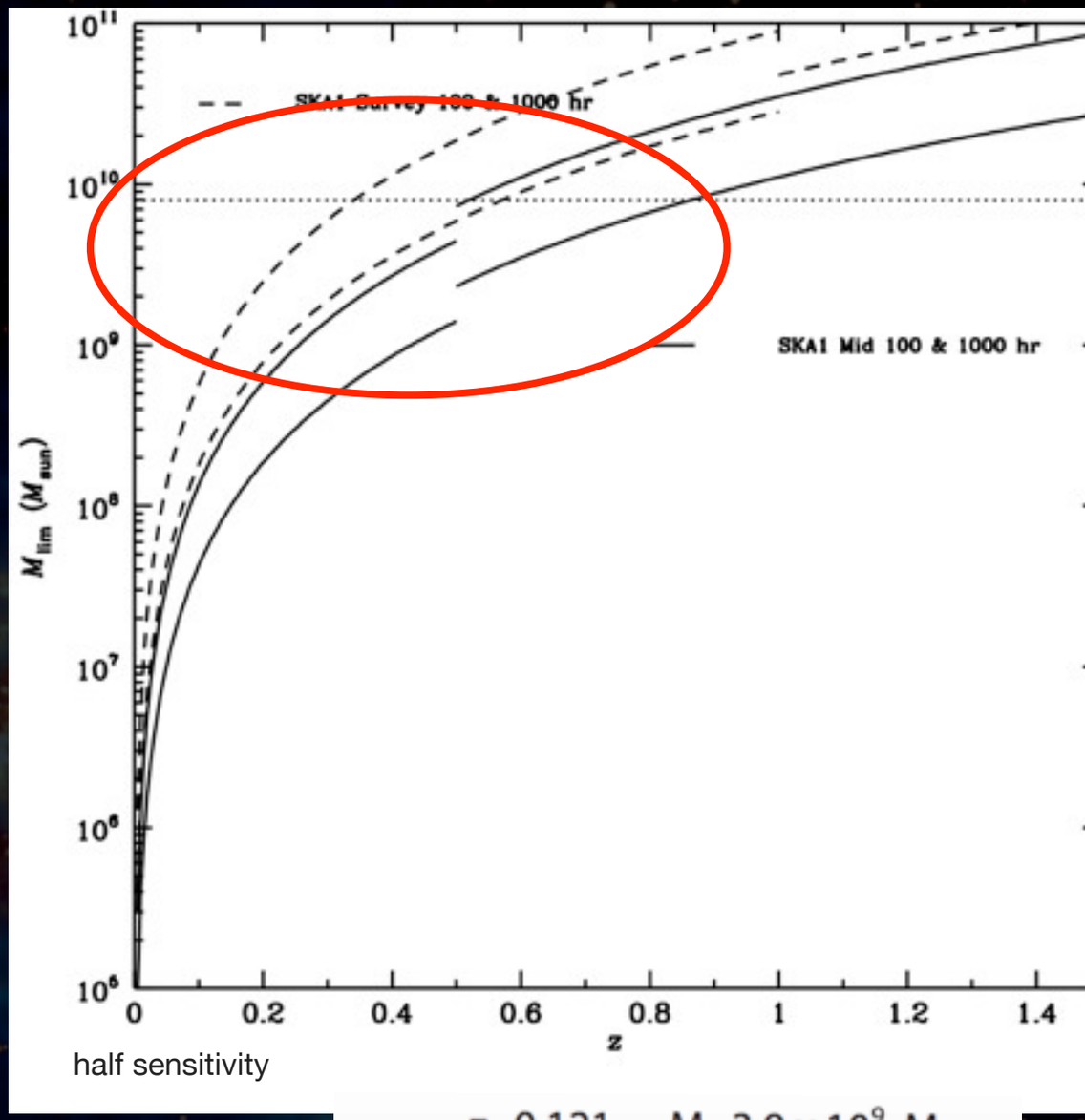
What do we need for Galaxy evolution

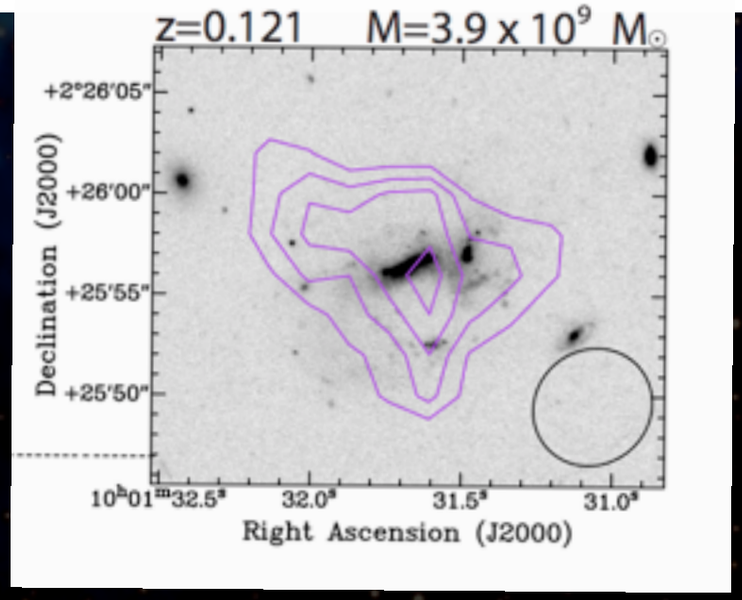
- Current state:
  - WSRT (Verheijen) 1000 hr at z=0.2
  - EVLA (van Gorkom) 1000 hr z < 0.4

- Pathfinders will cover this redshift range
  but will not resolve galaxies
  Need to reach at least $M_\star$ and to resolve galaxies.

  Galaxies are more than dots in scatter plots

- SKA1-survey: focus on z < 0.6
- SKA1-Mid: focus on z < 0.9
  - break at 950 MHz
  - Deep imaging surveys will have to be done twice





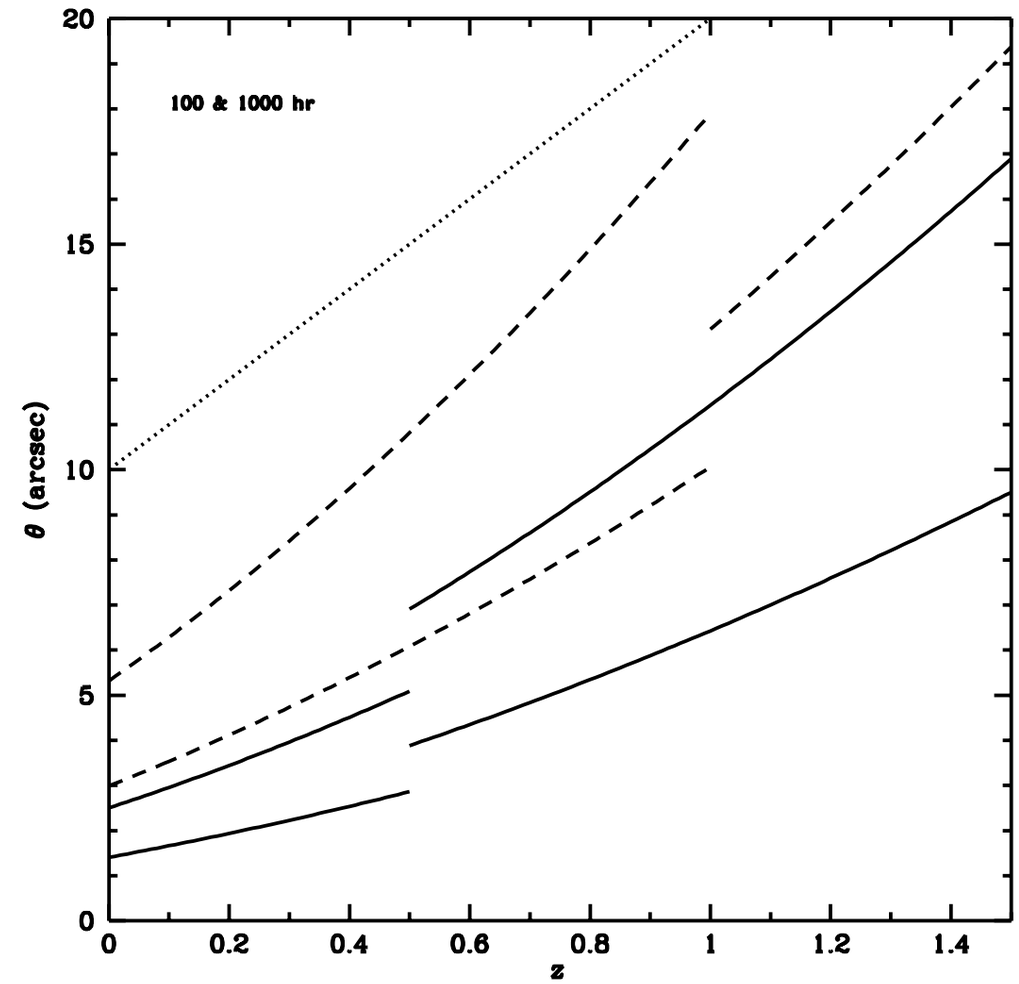
EVLA pilot; Fernandez+ 2013

Beam size

- HI mass strongly correlated with size
- ‘All galaxies have the same average column density’

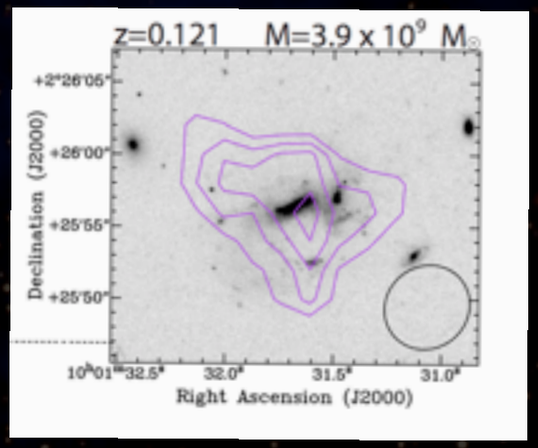
$$M_{\rm HI} = 10^{6.5-6.7}\, D_1^2$$

- Can compute size of detection as function of mass and redshift
- with 10” beam (z=0), only the very most massive galaxies will be resolved,
  Pathfinders will have done this kind of work already.
- 15 arcsec at z = 0.5 means ~90 kpc



Angular size of the faintest detection, half sensitivity

- SKA1-Survey: θ ~ 5 arcsec at z = 0
- SKA1-Mid: θ ~ 3 arcsec at z = 0



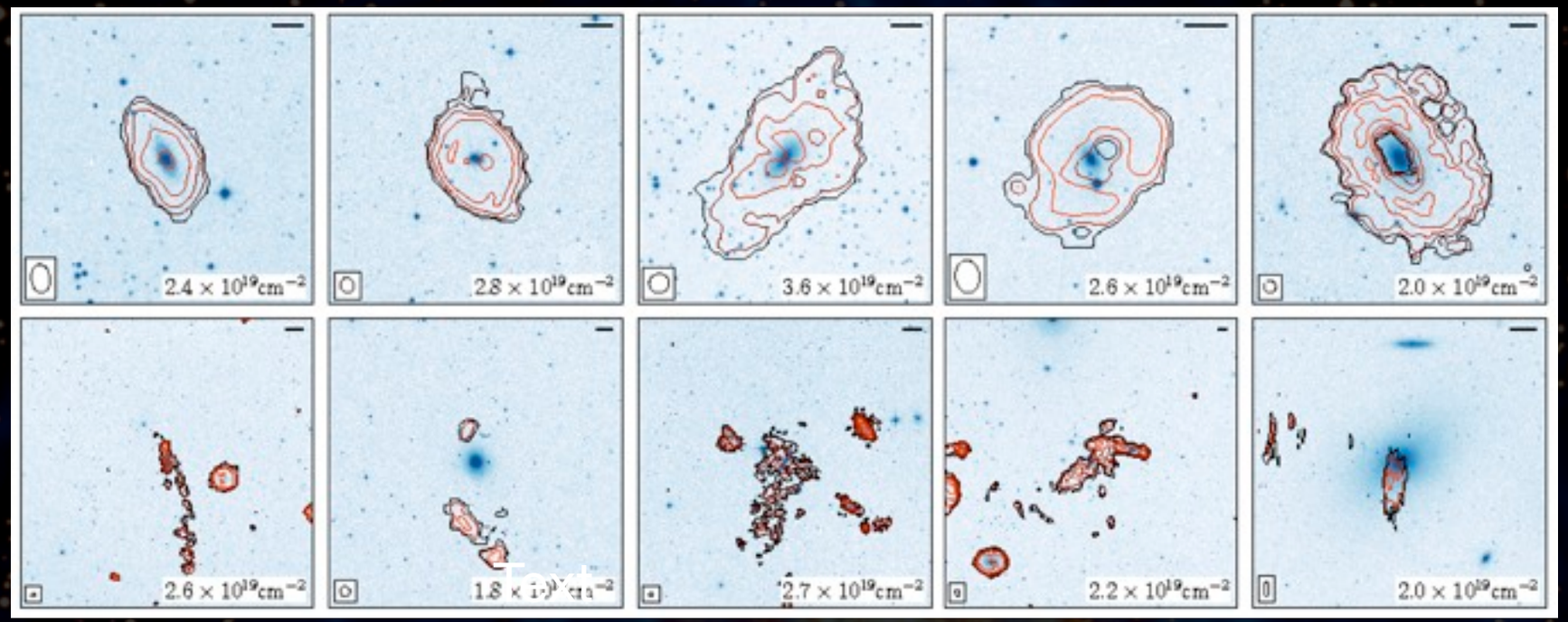
at z=1 galaxies are ~4x smaller

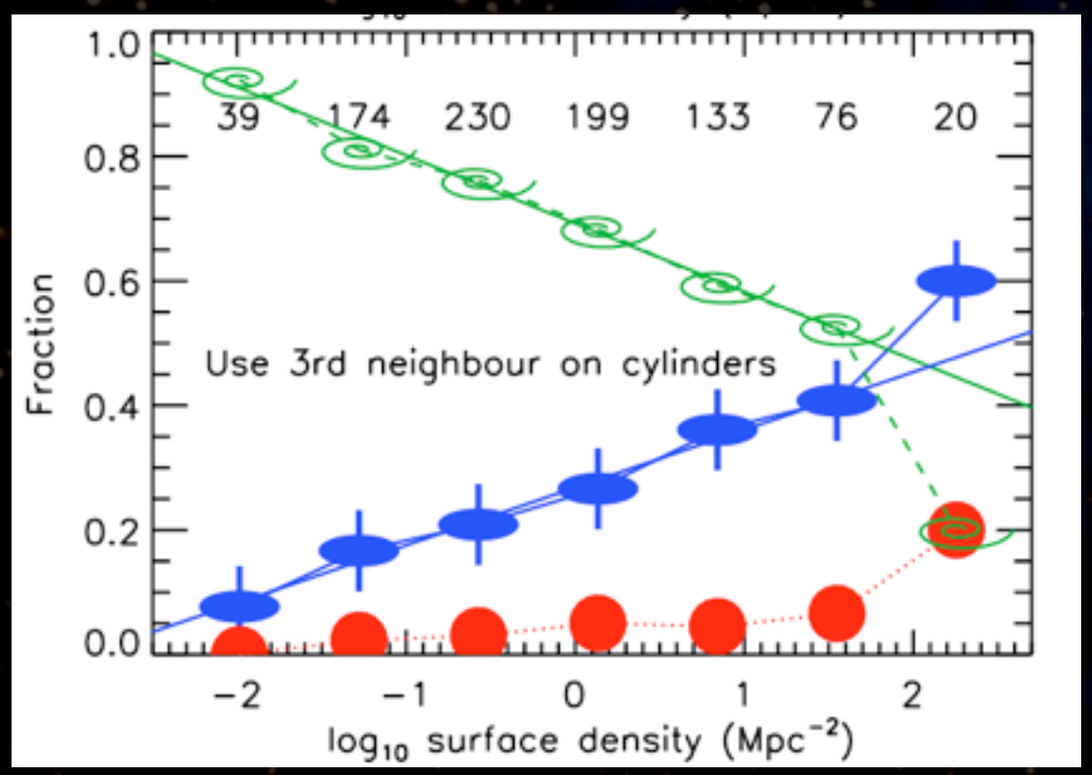
Why resolve galaxies?

- Morphology is key

low-density field

high-density field





morphology-density relation

Nearby galaxies

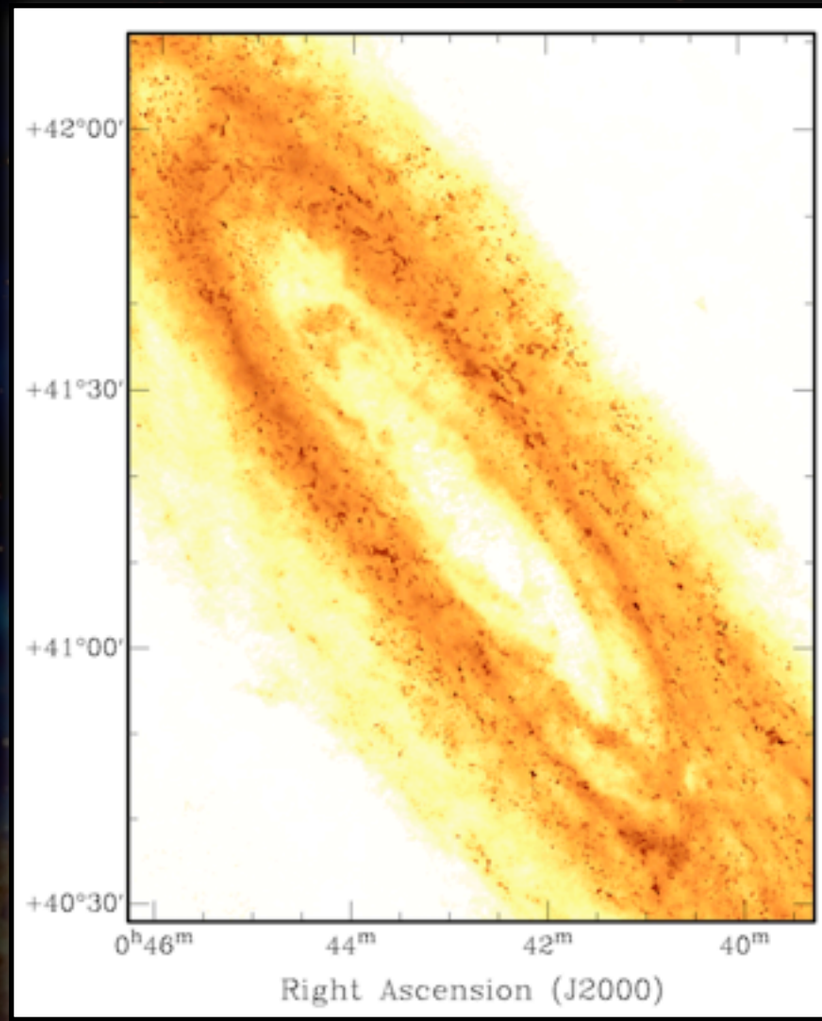
- THINGS: ISM at 500 pc resolution (EVLA B array 5”)
  most cited HI work of the last decade. big impact

- Need THINGS++: HI on scales smaller than 500 pc where statistical relations (KS-law) break down. Combine with ALMA!!!! Approach optical resolution

- Sensitivity of 6x EVLA would allow to work at 2 arcsec. Current baseline design does not deliver at this resolution.

- Need velocity resolution of 0.1 km s^{-1} over limited band width (10-20 MHz).

- Spectral zoom modes



Absorption

- One of the very few ways to study interaction of AGN with surrounding ISM at very small scales.

  Important for role of AGN feedback in galaxy evolution

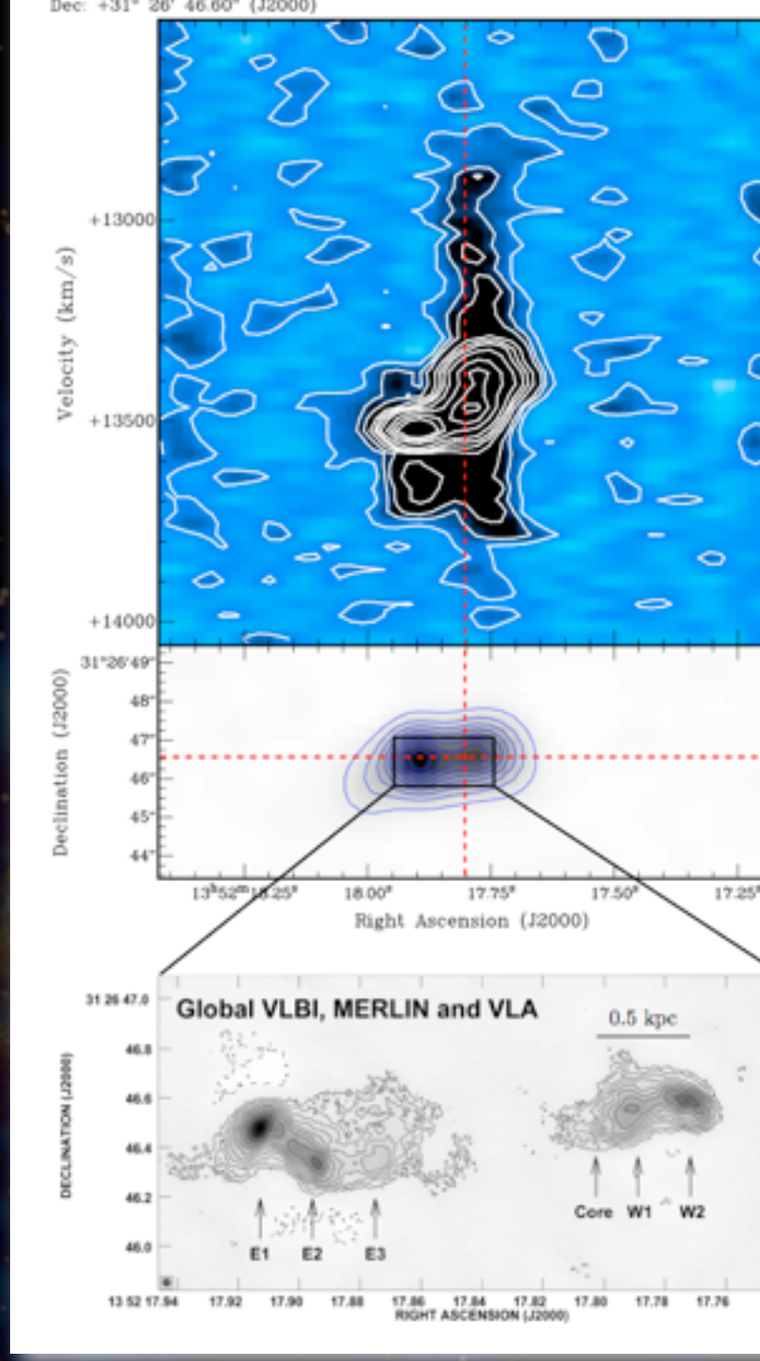
- Locate where the absorption occurs,
  the higher the spatial resolution, the better.

- **Baseline Design: spectral dynamic range TBD**
  Current limits on spectral dynamic range are ~ few x 10^4
  so SKA1-Mid needs >10^5, SKA1-Survey >few x 10^4

- The Good: much better performance at higher redshift

- The Bad: Current limits: ~1 arcsec with EVLA
  BD: SKA1-Mid highest resolution ~ 0.5” at z = 0 at sensitivity slightly better than EVLA

- Should go to higher resolution : ~0.1-0.2 arcsec
  (at good sensitivity)



Fast AGN driven HI outflow in 3C293 EVLA A-array

(Mahony+ 2013)

Simulations of SKA1

SKA1-Mid: for the science we would like to do, it has the wrong resolution
best sensitivity at ~10” , not at 3”
At the resolution we want to work, it is less sensitive than it could be (only 3x EVLA)

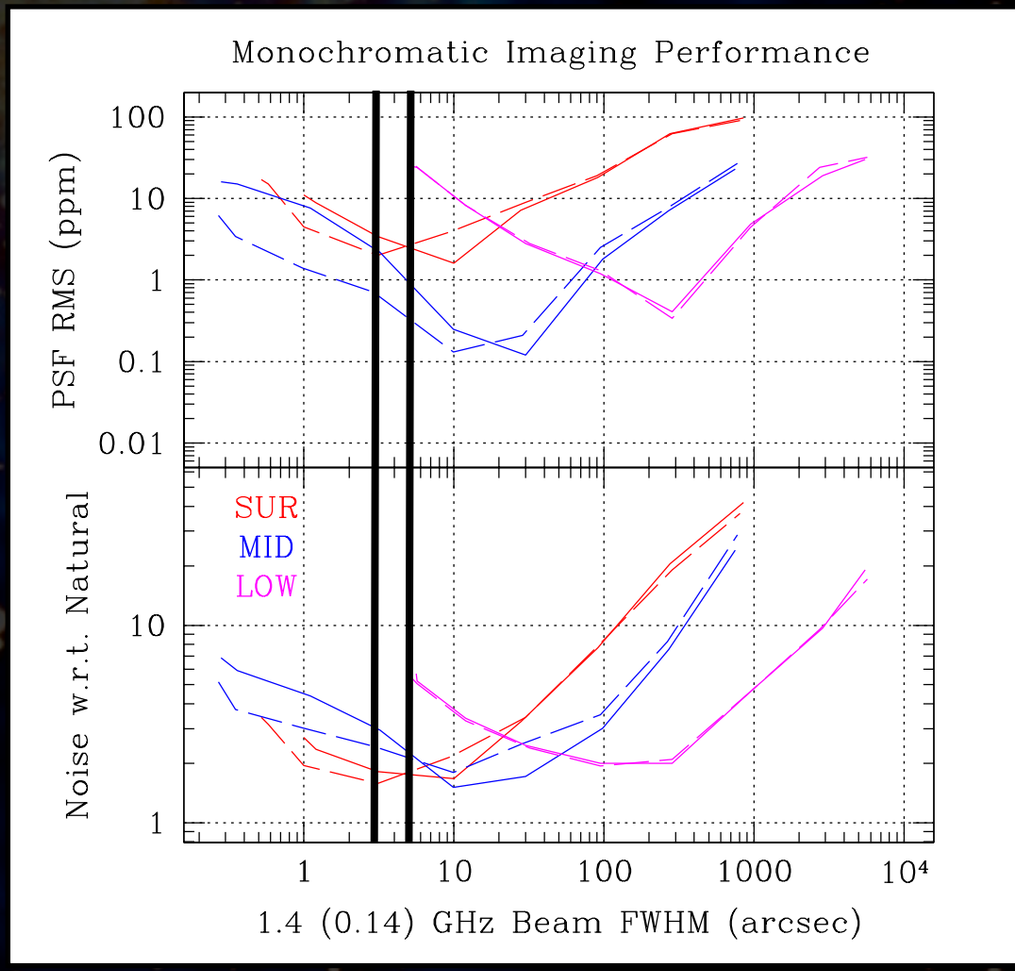
at highest resolution (~ 0.5”) SKA1-Mid sensitivity is only modestly better than EVLA

Optimum performance of SKA1-Mid should shift to higher resolution
2nd generation array is better, but can still be improved

SKA1-Survey:

Better match between sensitivity and resolution
but beam shapes should be improved

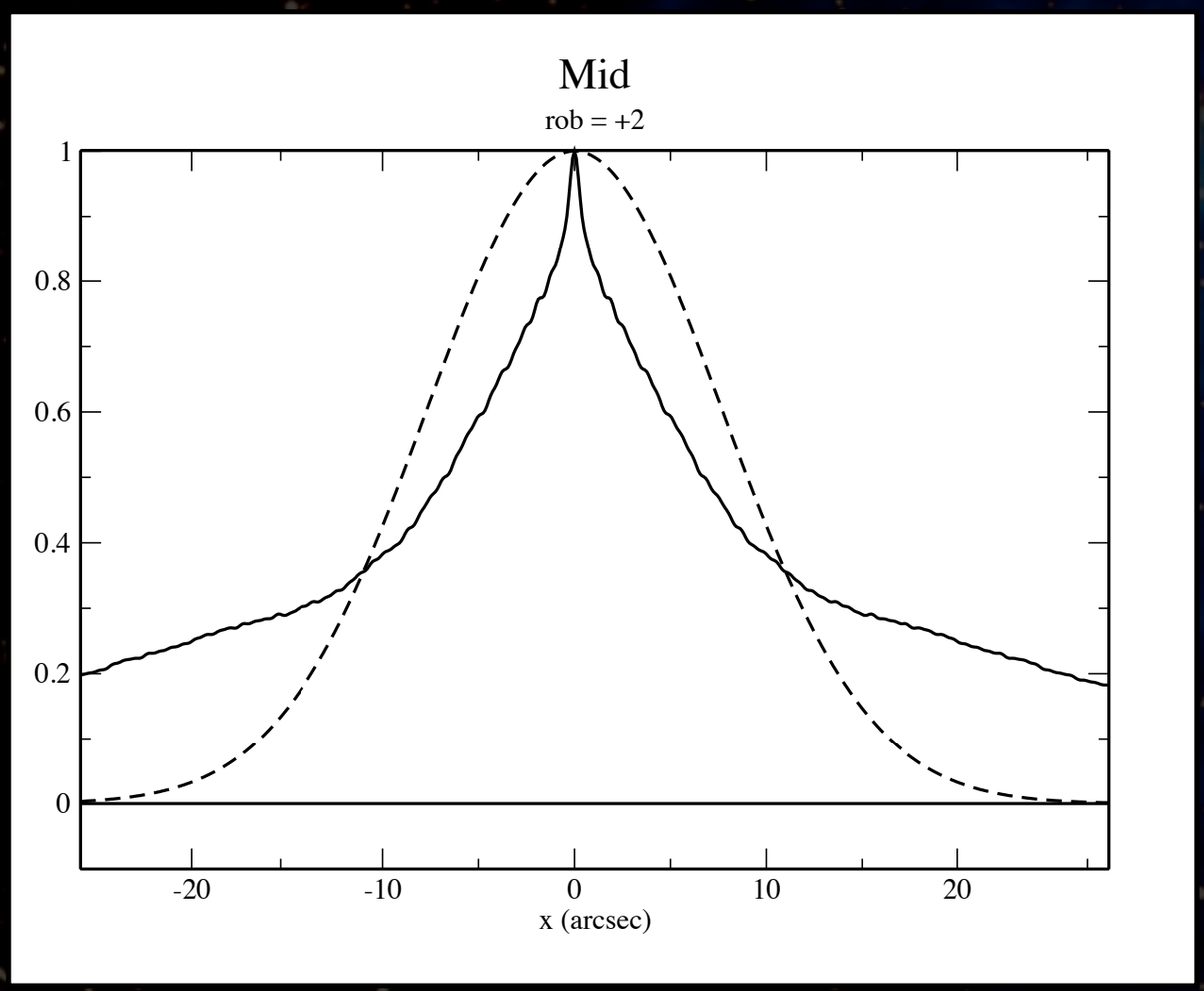
The wrong way around:
SKA1-Survey is less sensitive but higher resolution!



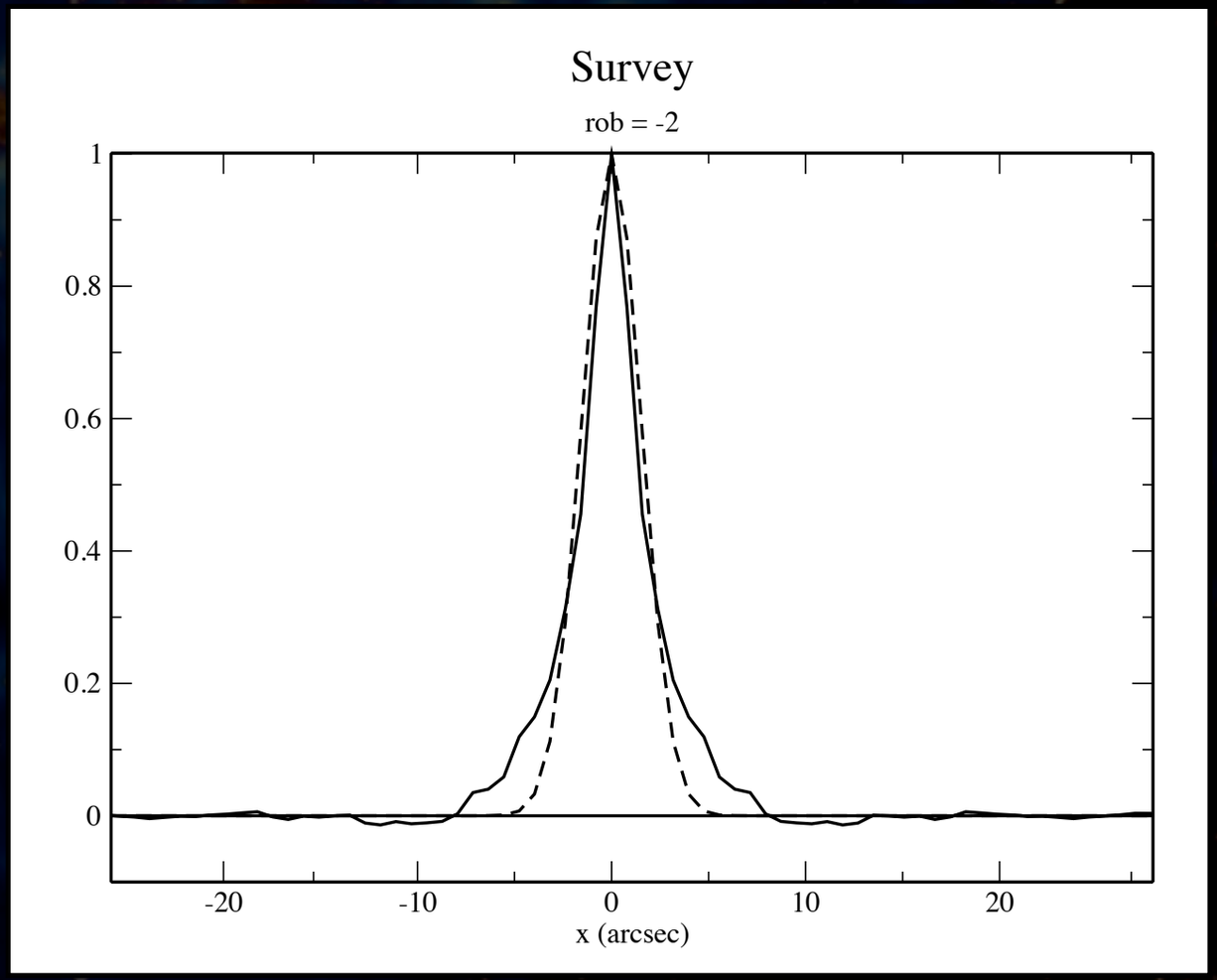
- Should also consider beam shape,

  SKA1-Mid: acceptable beams only for robust <-1: normally we work at rob ~ 0 so we lose sensitivity

- SKA1-Survey: acceptable beams only for robust < 0.5 AND tapering: do not get the full resolution



Mid Natural

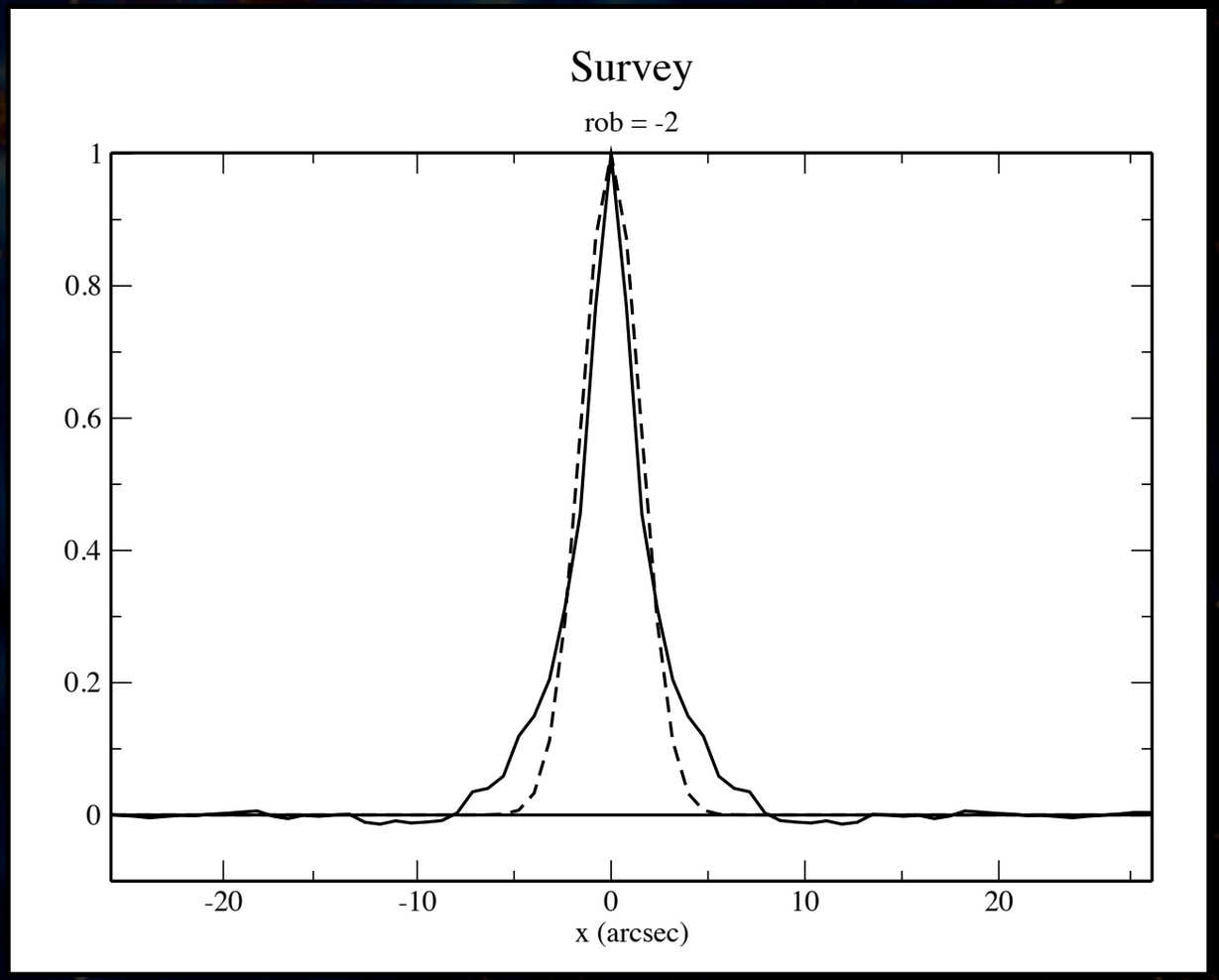


Survey Uniform

- Should also consider beam shape,

  SKA1-Mid: acceptable beams only for robust <-1: normally we work at rob ~ 0 so we lose sensitivity

- SKA1-Survey: acceptable beams only for robust < 0.5 AND tapering: do not get the full resolution



Survey Uniform

- Should also consider beam shape,

  SKA1-Mid: acceptable beams only for robust <-1: normally we work at rob ~ 0 so we lose sensitivity

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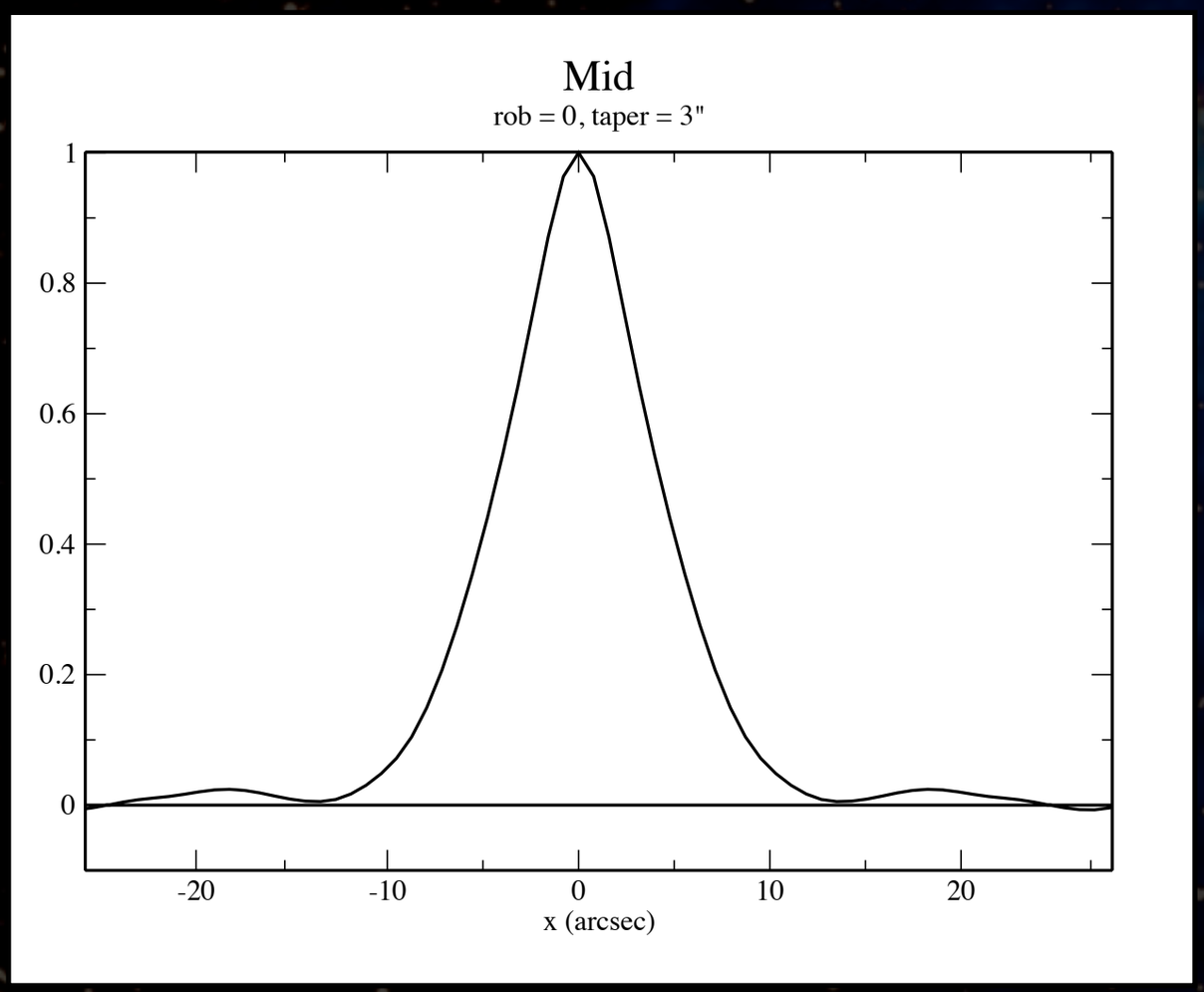
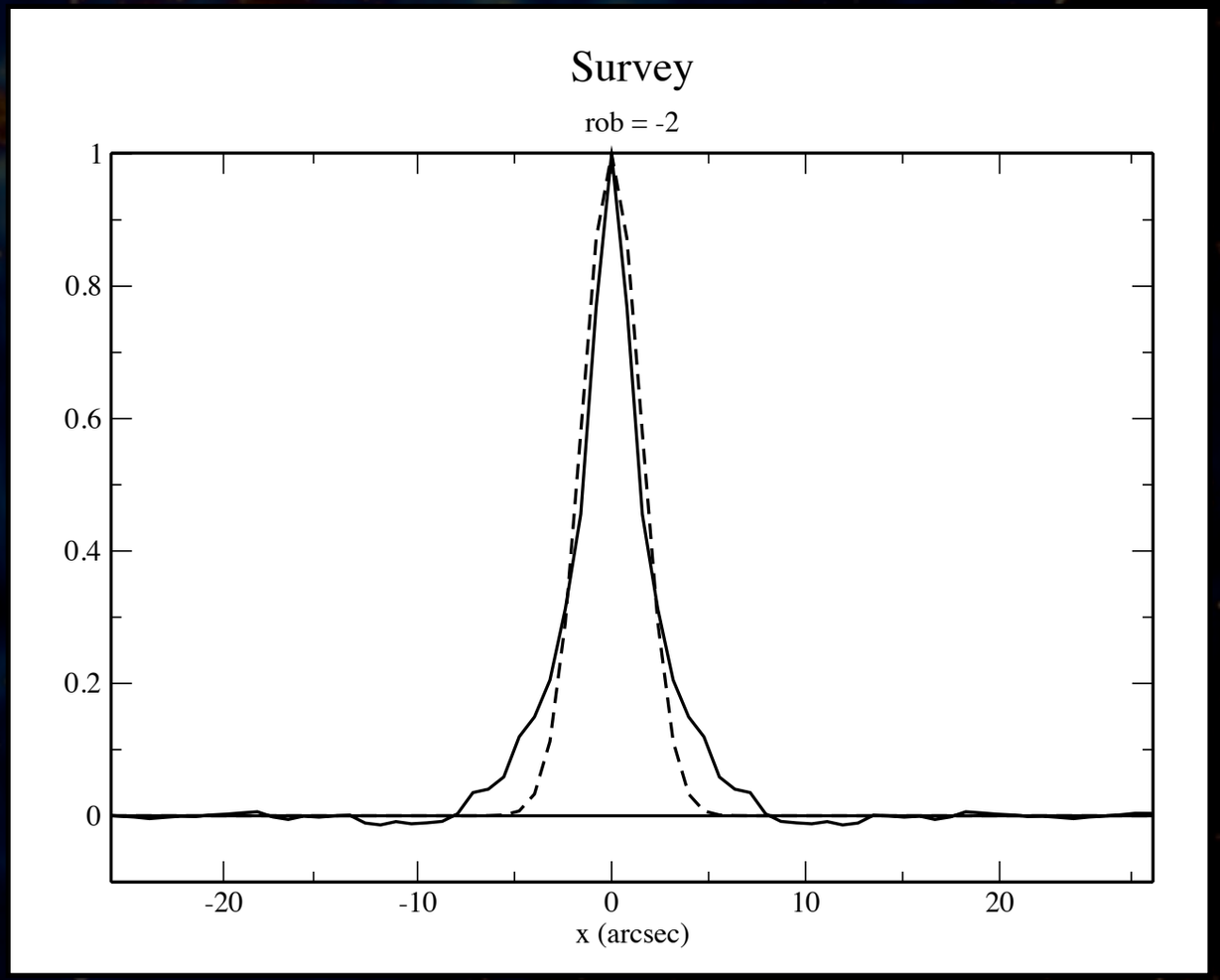
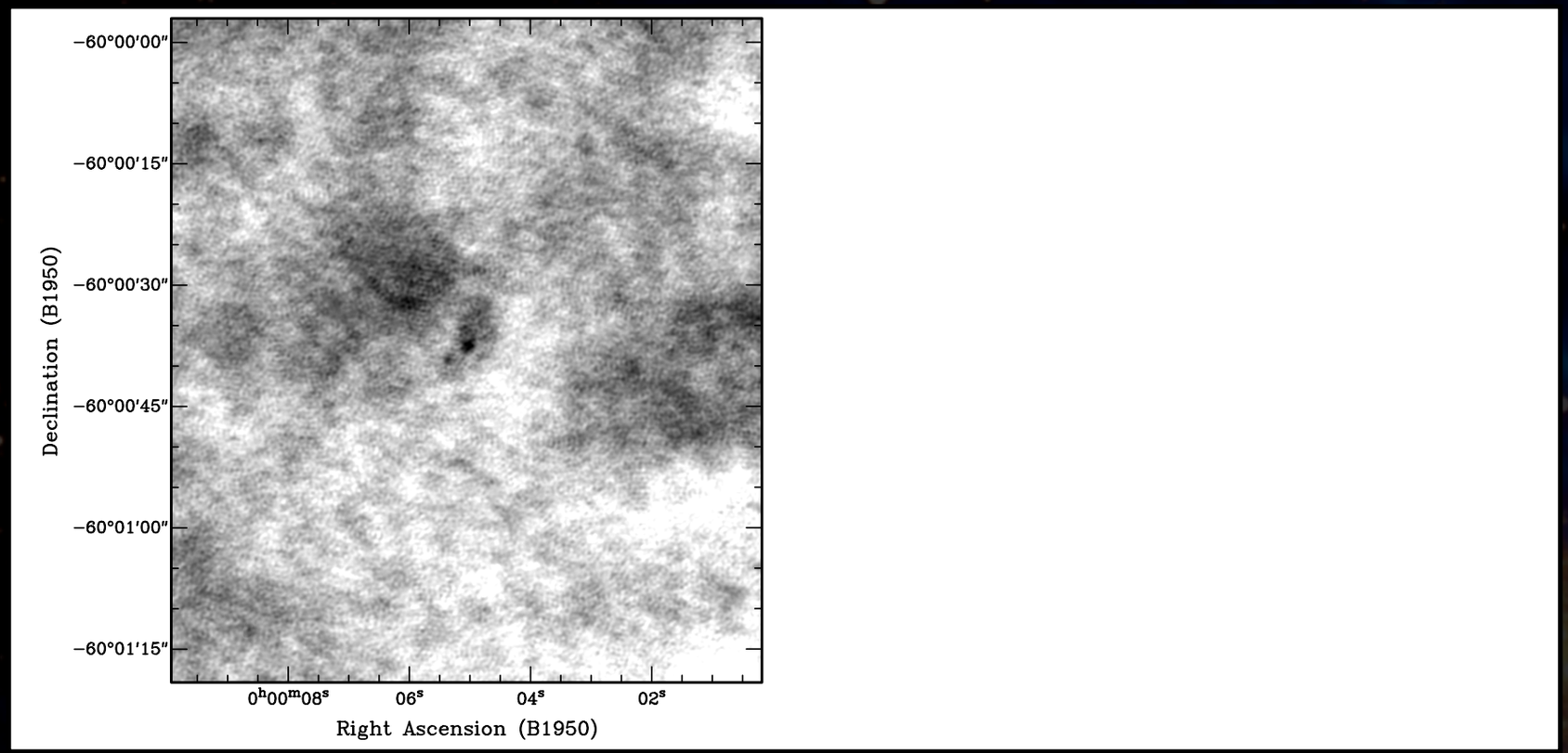


Mid Rob = 0



Survey Uniform

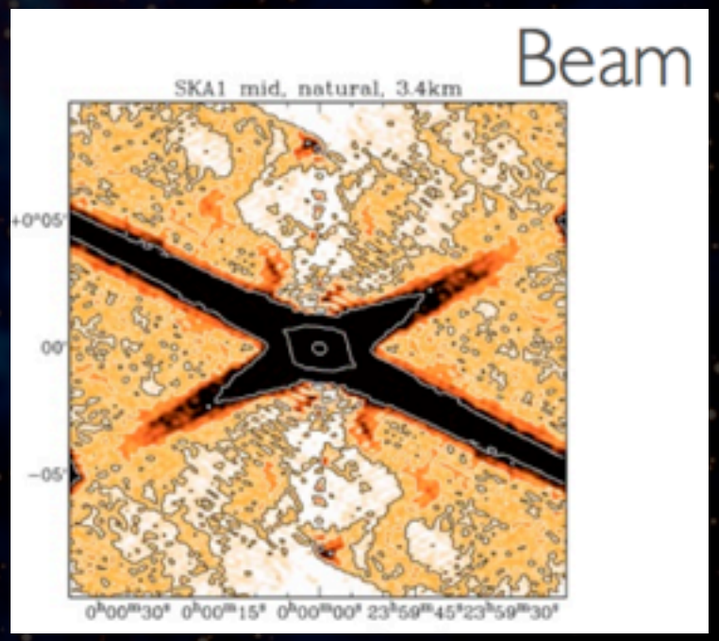
Other issues



Noise structure

Also here robust < -1

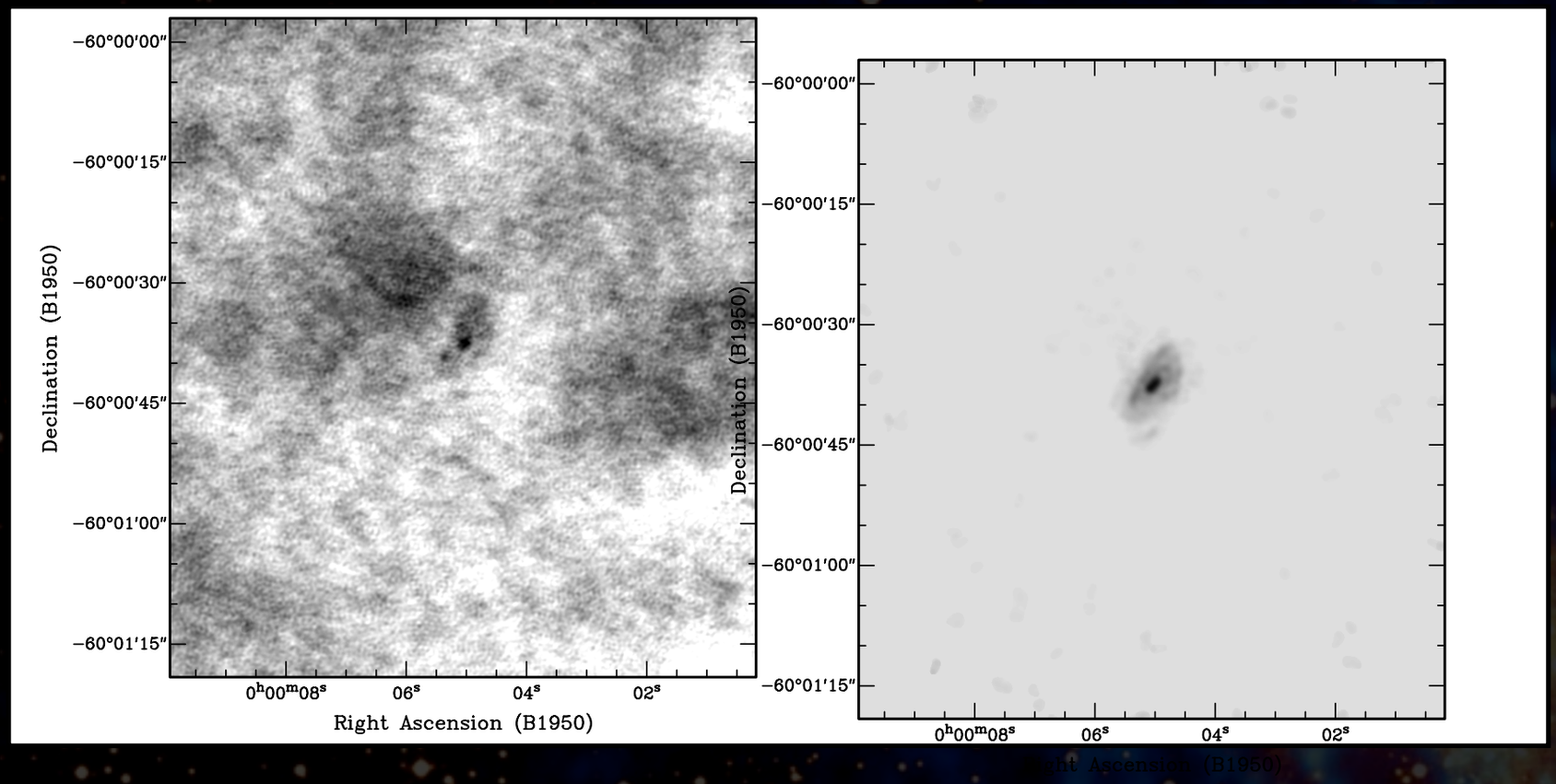
SKA1-Mid natural beam at dec=0



Many famous survey fields are at the equator

Imaging at dec = 0 is important

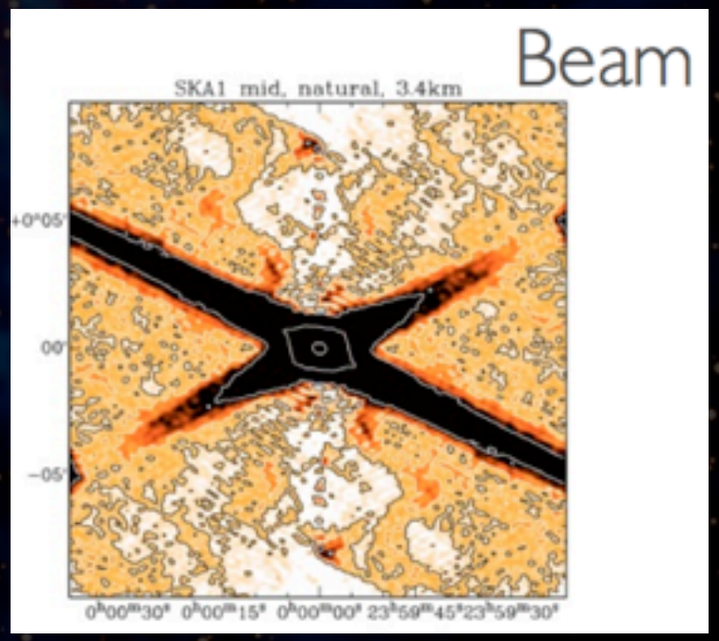
Other issues



Noise structure

Also here robust < -1

SKA1-Mid natural beam at dec=0



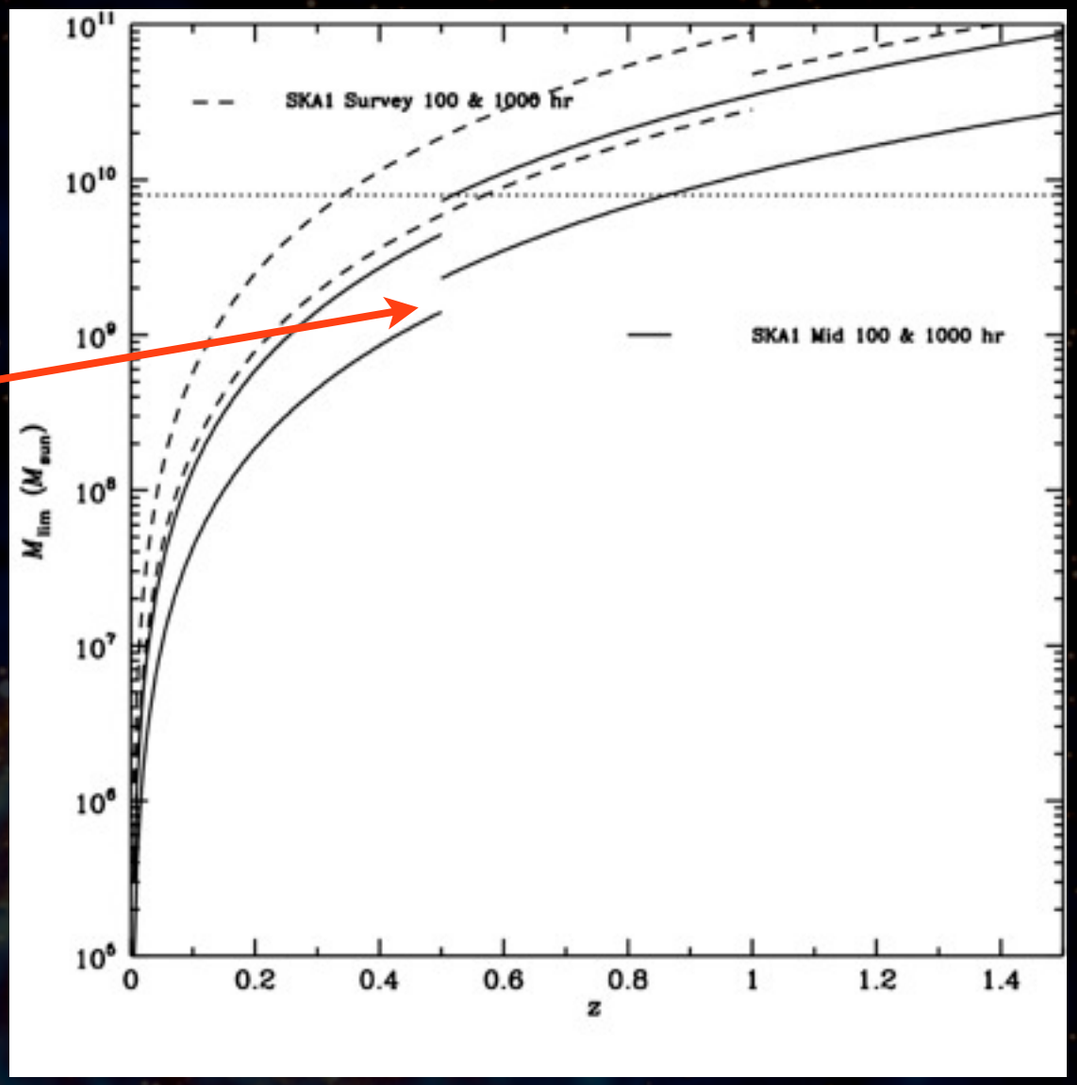
Many famous survey fields are at the equator

Imaging at dec = 0 is important

SKA1-Mid band selection

Baseline design features 5 bands (pp 15, 48):

Band 1	0.35–1.05	3:1
Band 2	0.95–1.76	1.85:1
Band 3	1.65–3.05	1.85:1
(Band 4	2.80–5.18	1.85:1)
(Band 5	4.60–13.8	3:1)



Break at z~0.5
In the middle of the interesting redshift range of SKA1-Mid

SKA1-Mid band selection

Baseline design features 5 bands (pp 15, 48):

Band 1	0.35–1.05	3:1	0.35–1.05
Band 2	0.95–1.76	1.85:1	0.77–1.43
Band 3	1.65–3.05	1.85:1	1.40–2.59
(Band 4	2.80–5.18	1.85:1)	2.54–4.70
(Band 5	4.60–13.8	3:1)	4.60–13.8

Shift bands to lower frequency

from z = 0.5 to z = 0.85 (HI)
from z = 0.16 to z = 1.16 (OH)
HI more important than OH

2 Gyr more look-back time
Increase cosmic volume by factor 5.3

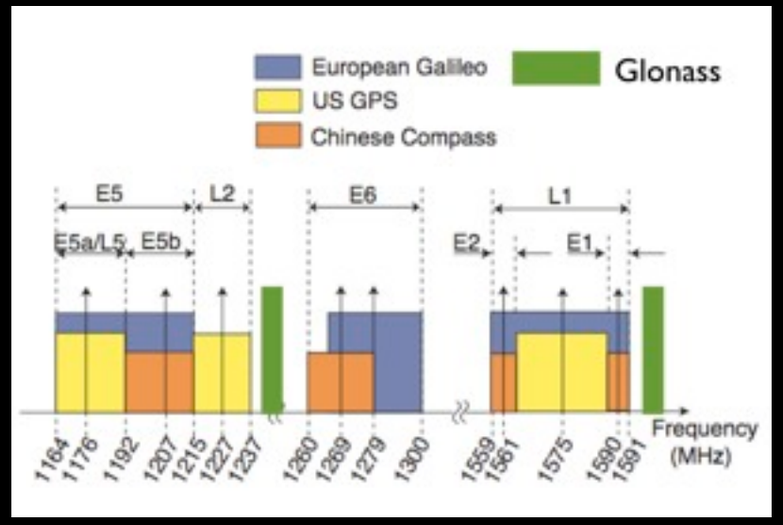
Strong RFI in 1450-1650 MHz, how much useful data there?

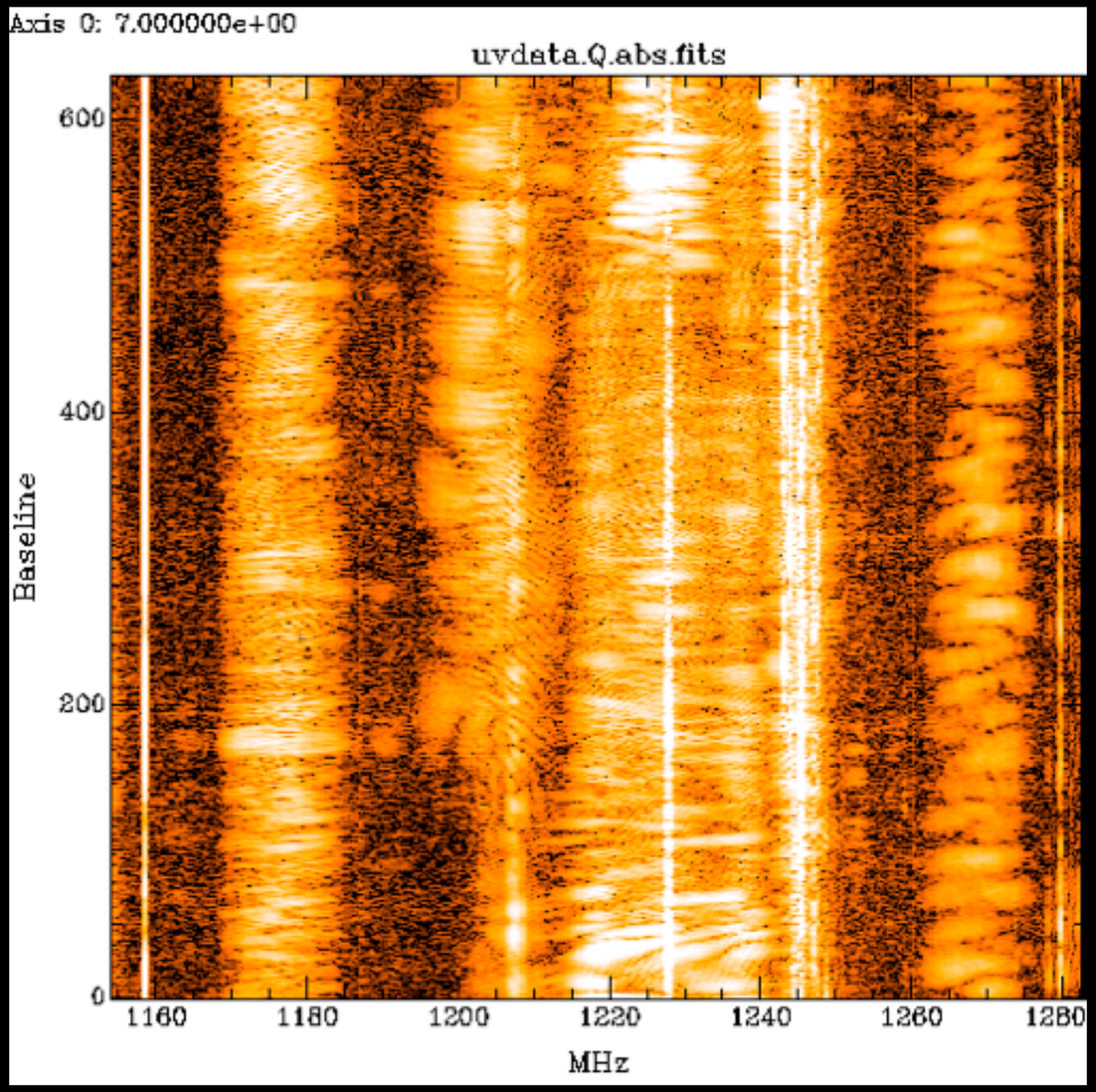
Possible survey strategy:
- Resolved HI up to z = 0.85 (band 2)
- Statistical high-z HI: $0.35 < z < 3$ (band 1)

RFI

In the ranges
1160-1300 MHz
and
1450-1600 MHz
there is very serious RFI.

Will get worse,
if we really want to use this band,
we have to go beyond flagging

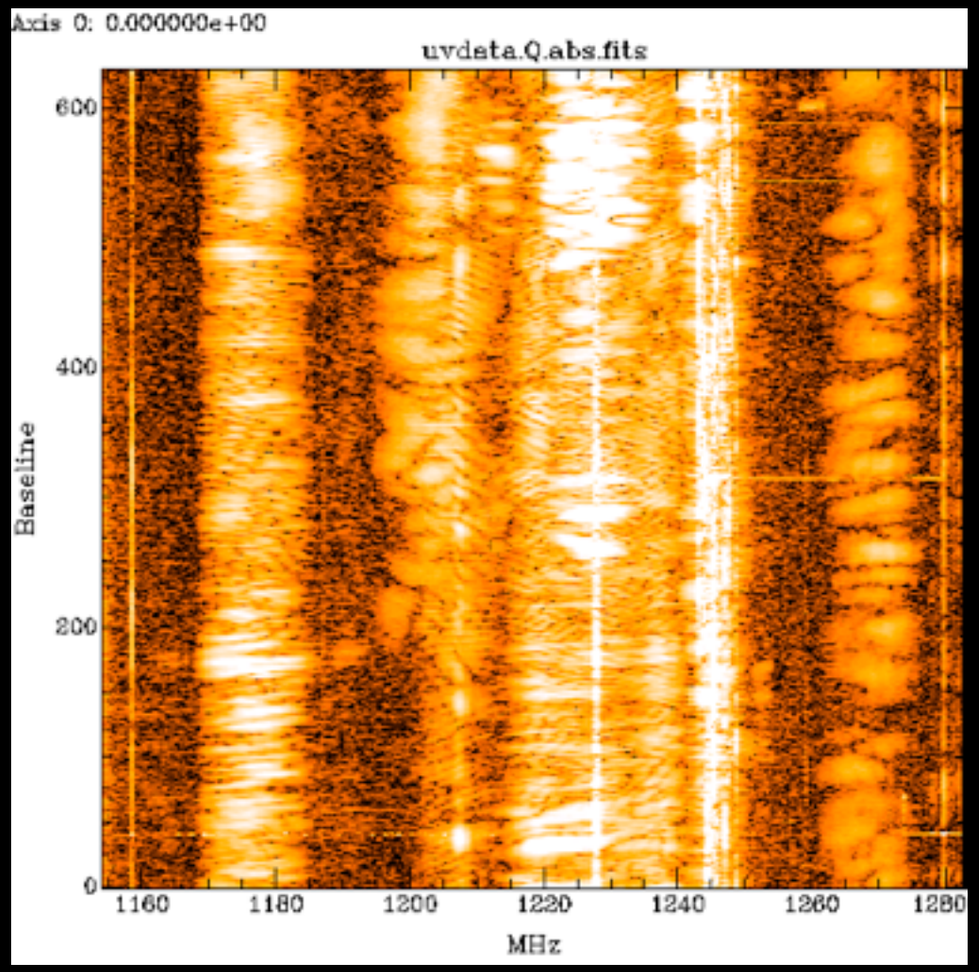




+ INMARSAT, IRIDIUM etc
Very significant loss of data.
Not WSRT specific!!!

RFI

- The WG is concerned that RFI mitigation (passive or active) does not appear prominently in the current baseline design. Methods for the passive (e.g. flagging) and active (adaptive nulling) mitigation of RFI need to be pursued by the SKA design team (and others).
- The WG is concerned about the lack of availability, accessibility and usability of basic RFI data for the SKA sites.
- RFI meeting Sydney June 2013:
  There are concerns that the SKA Office's RFI data does not reflect "real-world" experience with existing telescopes. Experience with a number of telescopes (JVLA, WSRT, Parkes, ATCA, Arecibo) appears to show higher levels of satellite RFI than is evident in the site data. Why?



Other issues

Archives

The success of the large HI surveys will to a large extent depend on the availability of the data through open access archives.

Such archives should be seen as integral part of the telescope and should be considered in the BD.

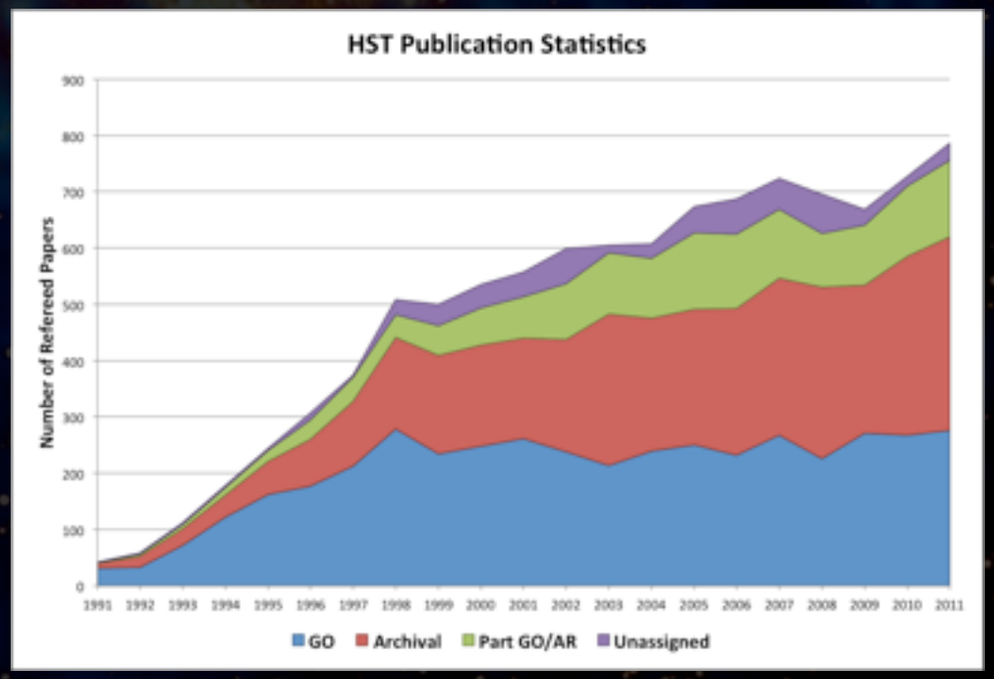
The data resulting from large surveys (HI and otherwise) should be public very shortly (or even immediately) after the data have been taken and validated.

The Science Working Groups should be involved in discussions about Science Policy.

Large vs small projects

SKA1 should not only focus on large surveys.
Survey teams should not (think they) own the sky.

Need plenty of time for smaller projects.
More flexible and more competition



Other issues

- VLBI
  For very high-resolution follow up work of detections of HI absorption, good VLBI capabilities are important

- Transition of MeerKat to SKA1-Mid and ASKAP to SKA1-Survey
  - Provide clarity soon on impact on planned surveys

Summary

- Optimum performance of SKA1-Mid should shift to higher resolution.
  Unresolved studies will be done with current telescopes and with pathfinders
  Better uv coverage for better beams
- Better uv coverage for long baselines for SKA1-Survey to get better beams
- Move Band 2 down to match deep HI surveys
- Methods for the passive (e.g. flagging) and active (adaptive nulling) mitigation of RFI need to be pursued by the SKA design team (and others).
- RFI data should become available
- The data resulting from large surveys (HI and otherwise) should be public very shortly (or even immediately) after the data have been taken and validated.
- SKA1 should not only focus on large surveys.