SKA Continuum Science & Technical Requirements

Inputs:

- SKA Continuum Science Team: Monthly Telecons
- Science Assessment Workshop: 9-11 Sept. 2013 at SKAO
  Team + Experts + SKA Office

Scopes:

✓ Identify critical science driven technical requirements for SKA1
✓Discuss possible SKA1 BD changes required by key science cases
✓Make recommendations and prioritize change requirements, if needed
✓Indicate pathway to SKA2

Caveat: on-going work (here focus on MID/SUR)

variety of science areas addressed by continuum surveys - need to focus
…..BUT can attract large communities (not only radio)

Astronomy Landscape in SKA Era

Pre-SKA (2015+):

- SKA precursors/pathfinders (1% SKA): LOFAR, JVLA, eMERLIN, ASKAP, Meerkat,…

  ➔SKA1 need to make significant scientific advance over pathfinders

SKA1 (2020+):

- JWST: sub-arcsec mid IR imaging + spectroscopy of z>5 galaxies
- Euclid: 15k deg^2 HST image (0.2”) in optical and near IR, L* galaxies up to z=3, 0.7<z<2
- LSST: 18k deg^2 ugrizy (r<27.5; i<26.8; z<26.1), 4 Billion galaxies, <z>~1.2, photo-z up to z~4

SKA2 (2025+)

- ELT: VLBI-like optical/MIR images + spectroscopy, internal dynamics of galaxies up to z~4, spectroscopy of z>7 galaxies

Science Requirements – MID/SUR

Science Case	Depth (uJy/b rms)	Frequency (GHz)	Area (deg2)	Type of area	Resolution (arcsec)	Comment
SF+ AGN: Deep	0.05	1	10s	Deep Fields	0.5	5 M_Θ/yr z<1.5 50 M_Θ/yr z<5
		10-30			10x better	Resolve SF/AGN cores
SF+AGN: Wide	1	1	5k – 15k	Euclid/DES	1-2	5 M_Θ/yr z<0.5
Diffuse/ clusters	1-3	0.4-1	~0.1-20k	1000-10^5 clusters	1-2	SKA Low not useful
~~Galactic~~	~~1~~	~~1-3~~	~~2x270~~	~~Galactic Plane~~	~~1-2~~	~~>5 GHz~~
~~Cosmology/ Weak lensing~~	~~1 0.3~~	~~1 1~~	~~20,000 5,000~~	~~All-sky wide~~	~~2 0.5~~	~~ISW, CM, .. [LSST, etc]~~
Strong Lensing	1	1-3	20,000	All-sky	0.2-0.3	10x better res.
Magnetism	1-2 <0.1	>1 >1	20,000 20	All-sky Pointed	1 0.5	Wide Deep
Local Galaxies	1-2	1-2	25	200 pointed	1	Stepping stone
Rare/Legacy	1	~1.4	20,000	All-sky	1	+HI

Based on Nick's table

SKA 1 Continuum Surveys – mid frequency

Topics	Rms (μJy/b)	Area (deg2)	Resolution (“)	Freq. (GHz)	Science
Tier 1 (All sky)	1	20-30k	2	~1	**Cosmology tests** Low-z gal/AGN Cluster/diffuse Magnetism Galactic studies Legacy/Rare
Tier 2 (Wide)	0.34	5k	0.5	~1	**Weak lensing** Galaxy/AGN Cluster/diffuse Magnetism Galactic studies Strong lensing
Tier 3 (Deep)	0.05	10s	0.5	~1	**Complete census of SFRD(z),** SFG/AGN evolution, SF/AGN interplay

Tier 1 (all-sky): Science drivers & Specs

Science Drivers:

Power spectrum+ISW+CM, legacy/rare, cluster/diffuse, magnetism, galactic science, local Universe

Frequency: ~1.4GHz (not critical): find best trade off between SS & resolution

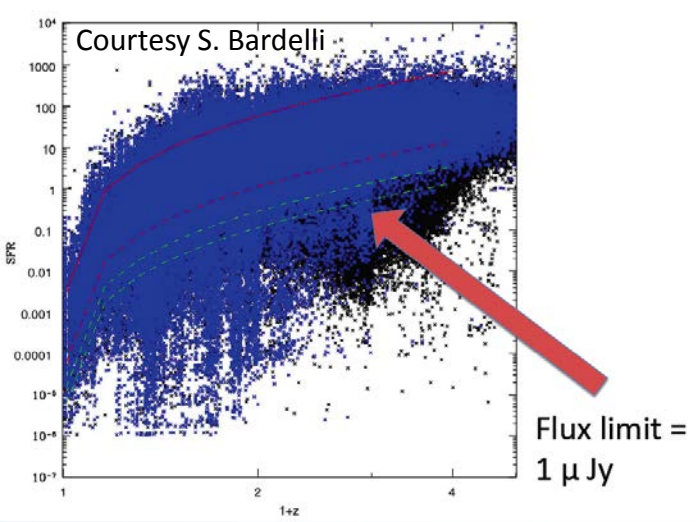
<1.4 GHz → synergy with HI survey

Area: 31,000 deg^2 /3π steradians (cosmology)

≥15/18k (to exploit synergy w Euclid/LSST)

Sensitivity: ~1 μJy/b → L* gals to z~0.5 (SFR~5 M_{sun}/y)

- suitable source density
- synergy w Euclid
- factor 10 deeper than ASKAP-EMU



Resolution: ~2”

>1.8” needed to detect most T~1 K face-on SFGs (dominant source population)

<4” needed for reliable optical id with LSST (r_{AB}~27.5); <2” for HUDF (r_{AB}~29.5)

Dynamic Range: ~10^6 (70 dB), assuming we mask all sources ≥ 1 Jy (2500-3000 RS)

Tier 2 (wide): Science drivers & Specs

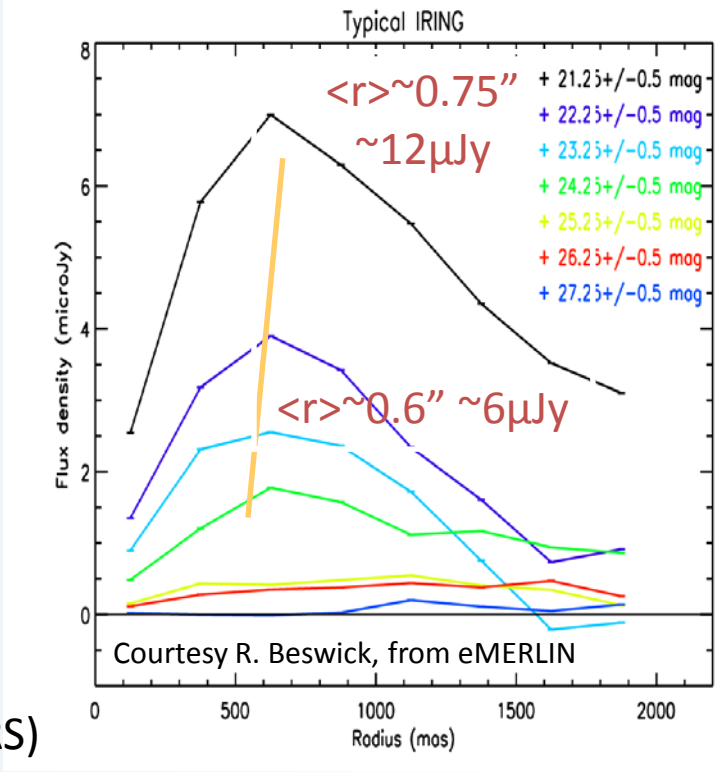
Science Drivers: **Weak lensing** (synergy w Euclid/LSST to beat systematics), strong lensing, resolved SF in local gals (<500 pc at z<0.05), etc…

Frequency: ~1.4GHz (not critical): find best trade off between SS & resolution
<1.4 GHz → synergy with HI survey

Area: 5000 deg^2 (pilot ~ 1000 deg^2)

Resolution: 0.5" (≤ typical galaxy size for WL)
resolve SF in local gals

Sensitivity: 0.5 μJy/source or 0.34 μJy/b rms
→ 5 RS (≥10σ) per arcmin^2 needed source density
[factor 10 deeper than Meerkat Wide]
→ Minimize beam pedestals and sidelobes
(ideally scale-free array)



Dynamic Range: ~10^6 (70 dB), masking all ≥ 1 Jy (400 RS)

Systematics under control [<N$^{-0.5}$ Poisson fluctuations in source numbers]
stable beam, flux calibration <1% at 5-10σ, …

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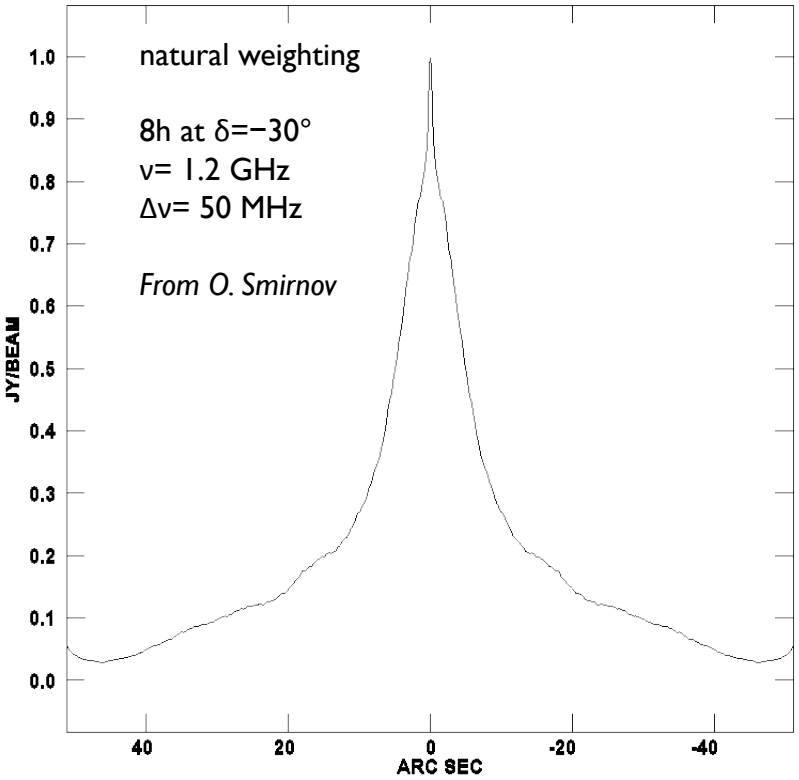

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stable beam, flux calibration <1% at 5-10σ, …

Tier 3 (deep): Science drivers & Specs

Science Drivers: **SFRD(z)**, BH Accretion History, AGN/SF interplay

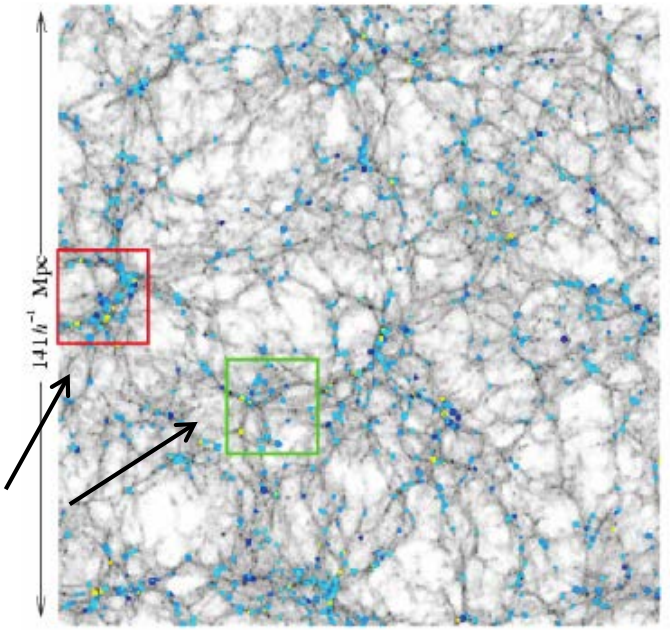
Frequency: ~1.4GHz (not critical): find best trade off between SS & resolution
<1.4 GHz → synergy with HI survey

Area: 30 deg^2 (≥10 deg^2) beat cosmic variance/probe different environments

Resolution: ~0.5" (few kpc resolution to separate bulge/disk)
T~1 K → res>0.4"

Sensitivity: 0.05 μJy/b rms
→ LIRGs up to z~6 (50 M_{sun}/yr at z~5
[10x deeper than Meerkat/JVLA/eMERLIN]

Dynamic Range: ~10^6 (70 dB), trying to avoid sources ≥ 1 Jy (1 RS/10 deg^2)



Courtesy E. Murphy

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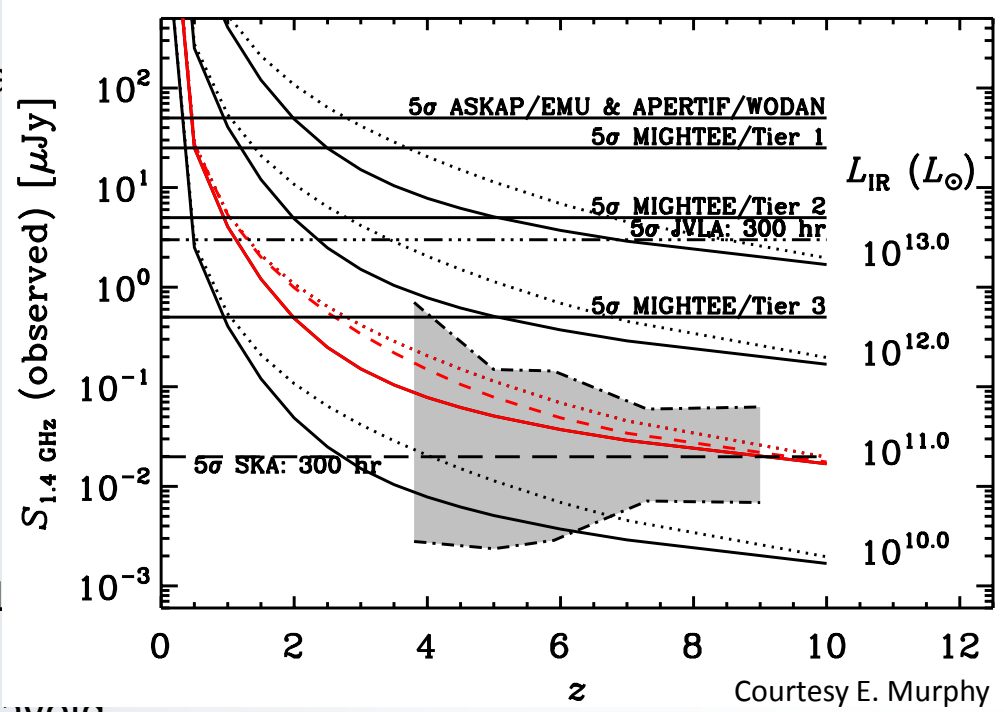
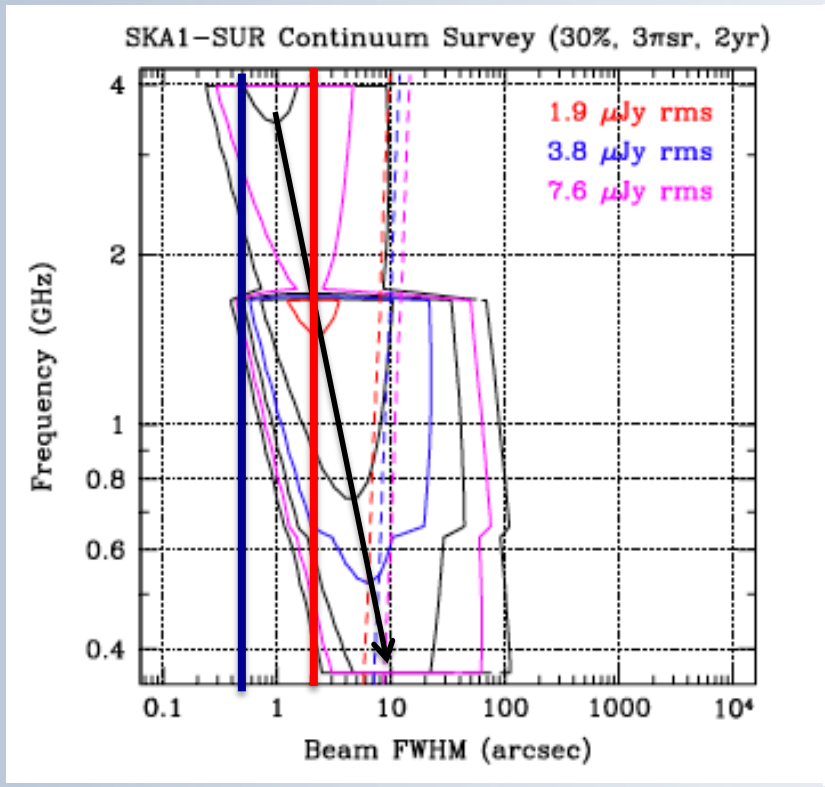
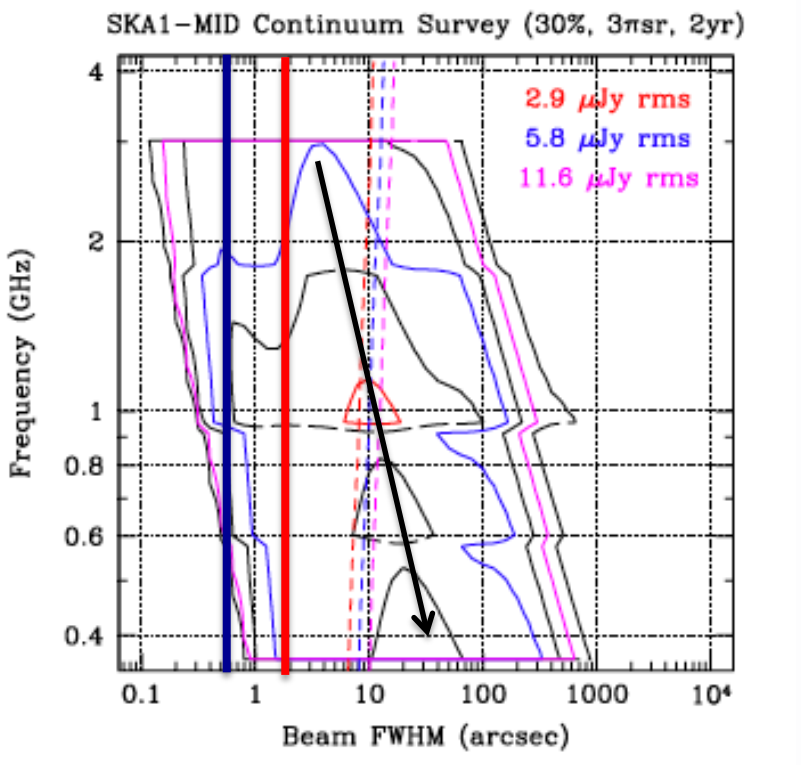


Courtesy E. Murphy

Continuum All Sky/Wide Surveys: SUR vs. MID



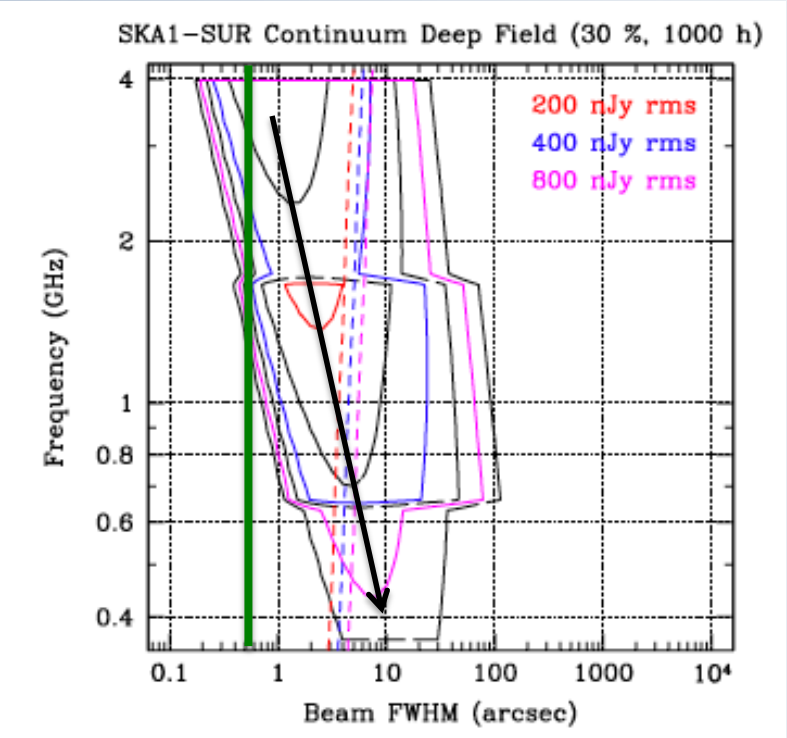


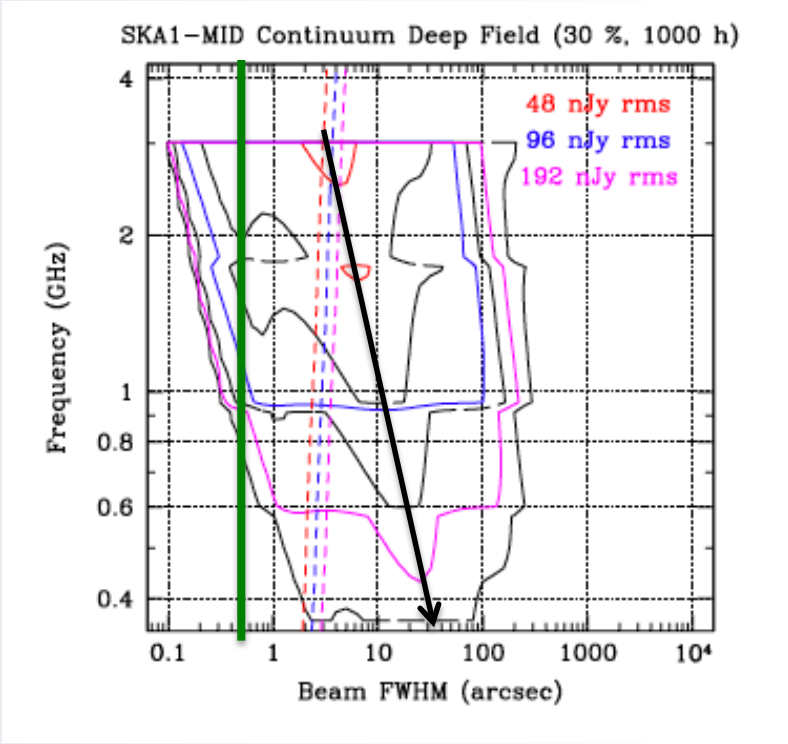
Courtesy
R. Braun
Oct., 2013

★Tier 1 – All Sky: 1 μJy/b rms all sky survey at 2" resolution
- SUR → ~2 μJy at ~1.7 GHz in 2 years → 2x deeper
- MID → ~3.5 μJy at ~1 GHz in 2 years → >3x deeper

★Tier 2 – Wide: 0.34 μJy/b rms over 5000 sq. degr. (1/6 all sky) at 0.5" resolution
- SUR → ~3 μJy/b at ~1.7 GHz in 2 years → 9x deeper
- MID → ~1.6 μJy/b at ~1 GHz in 2 years → >5x deeper

Continuum Deep Fields: SUR vs. MID



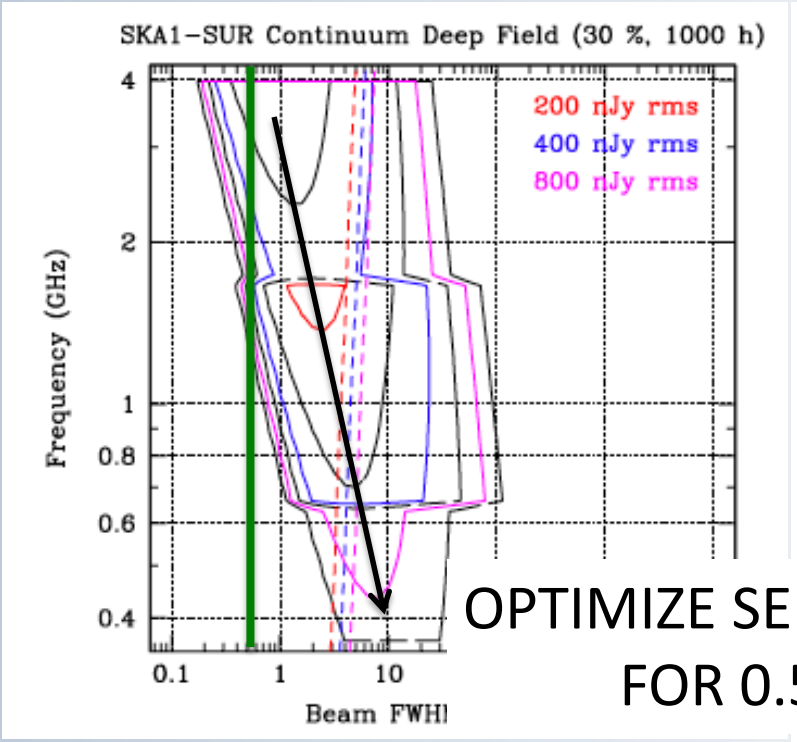


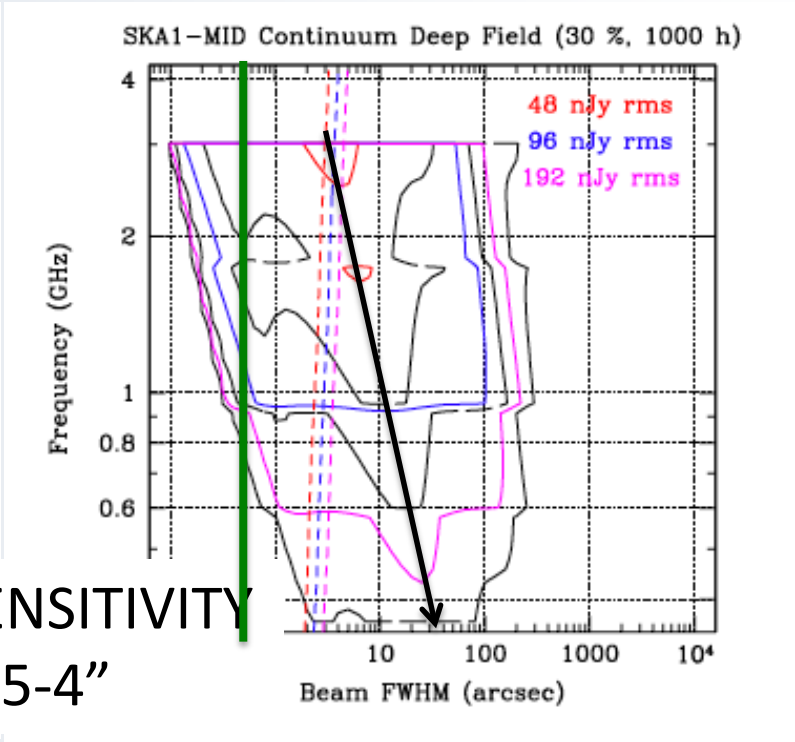
Courtesy
R. Braun
Oct., 2013

SUR has a better match between sensitivity and resolution performance than MID
MID more competitive at <1" resolution

★Tier 3 – Deep Field: 50 nJy/b rms over 30 sq. degr. at 0.5" resolution
•SUR → ~400 nJy at 1.7 GHz in 1000 hr → >8x deeper (1 pointing)
•MID → ~70 nJy at ~1.4 GHz in 1000 hr → 1.2 deeper x 30 pointings (1 sq. deg. FoV)

Continuum Deep Fields: SUR vs. MID





OPTIMIZE SENSITIVITY FOR 0.5-4”

Courtesy R. Braun Oct., 2013

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Recommendations 1

SKA1: Mid frequency facility (MID and/or SUR) should:

a) **have optimal sensitivity at 0.5”-4” at ~1 GHz**

the resolution and PSF quality we need comes at the expenses of a factor 2 sensitivity

➔ explore array configuration changes with more sensitivity on longer antennas (serious issue for MID, but SUR sub-optimal as well)

a) provide DR ~ $10^{6:}$ + excellent control of systematics➔ “high quality” telescope
- polarization purity 0.1% (synergy w magnetism)
- Pointing accuracy [high performance dishes]
- cal. flux errors <1% at S/N~5-10
- Stable PSF vs time/position
- Low PSF ellipticity (0.1)
- very accurate modeling of PSF

b) reach thermal noise over >90% area

➔ keep confusion noise (beam pedestals/sidelobes) under control
nearly Gaussian PSF at “natural” resolution? Scale free array ?
need more simulations

d) Dish accuracy for 20-30 GHz operations (help with DR, interesting science for SKA2)

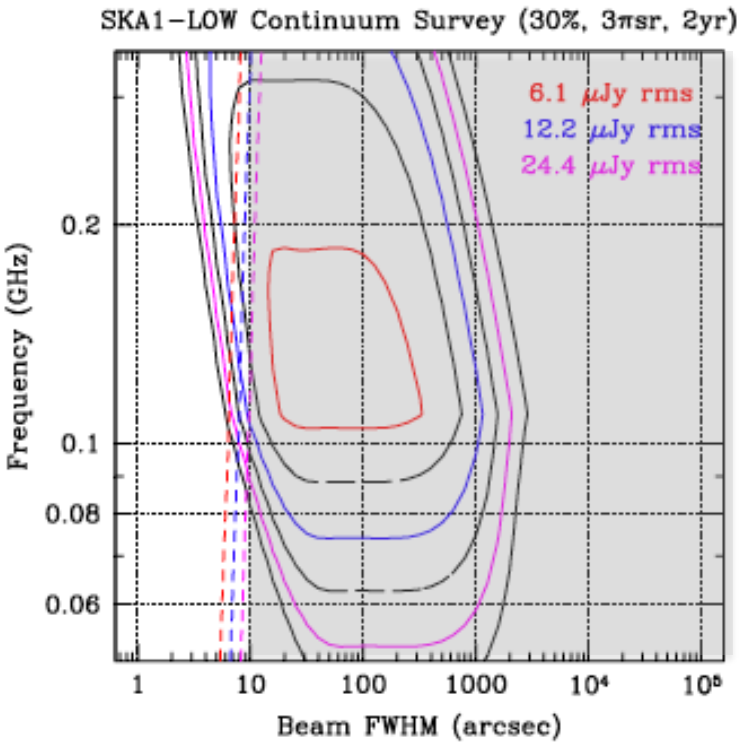
Recommendations 2

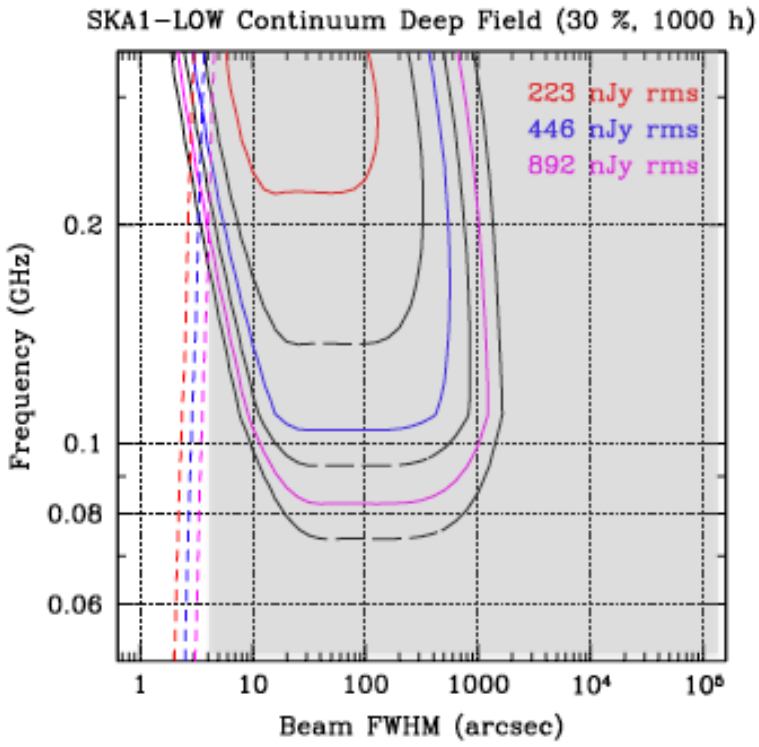
Path to SKA2 (mid frequencies):

- <0.1” resolution at 1 GHz (thermal noise limited) [ideally VLBI-like, see E-ELT]
  resolving SF in high-z galaxies SF/AGN interplay, weak/strong lensing

- >10 GHz capability (up to 20-30 GHz?)
  stellar studies – thermal emission in SFG at very high z, radio-FIR rest frame colors, synergy with ALMA (>30 GHz), spatially resolved (AU-scale) studies of proto-planetary disks, high-z low-J CO transitions, etc..

Continuum Survey Performance: SKA_LOW



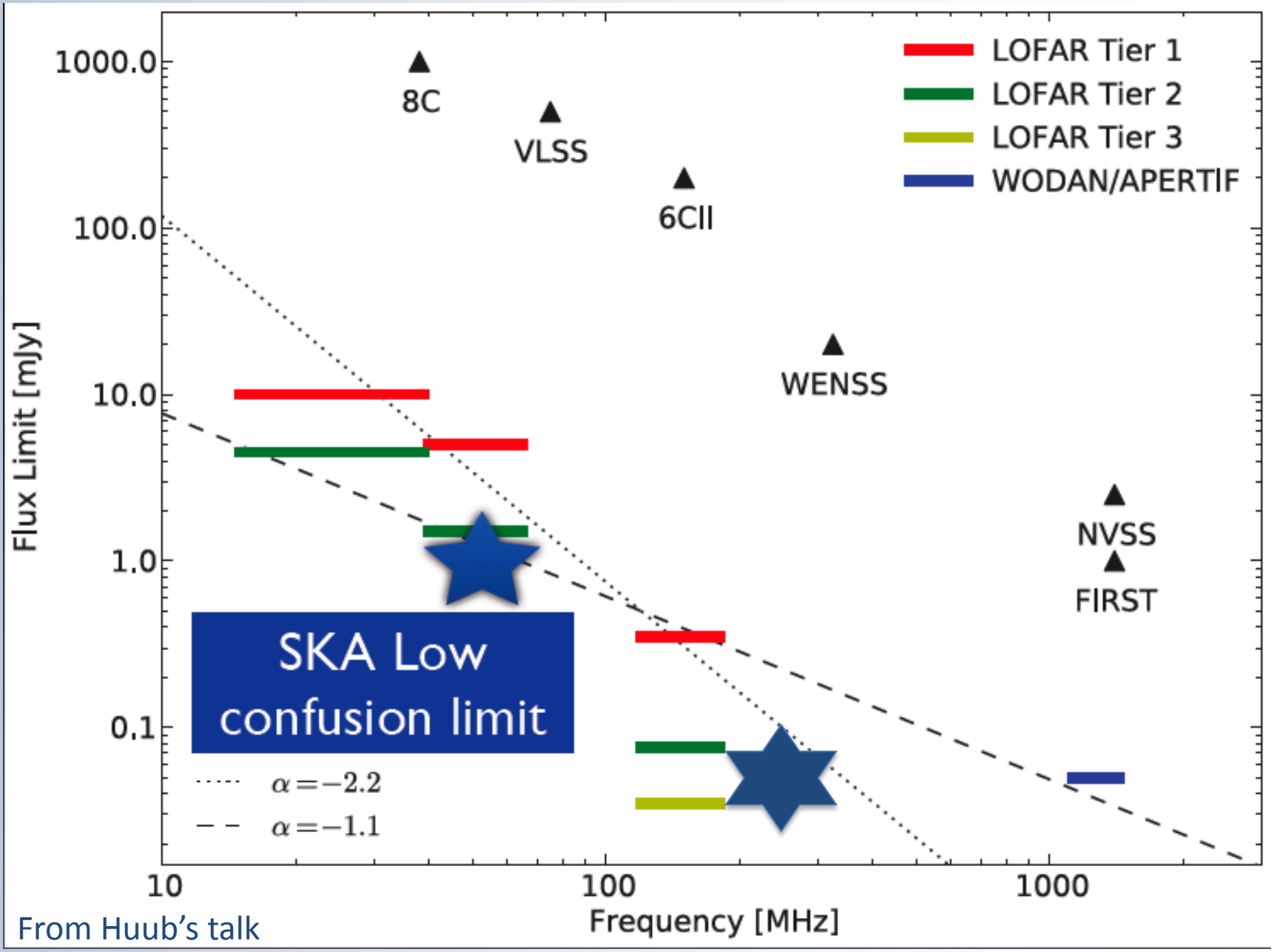


Courtesy
R. Braun
Oct. 2013

Confusion limited very quickly: ~10 μJy rms surveys only feasible at ν> 150 MHz
<1 μJy rms surveys only feasible at ν> 200 MHz

➔few arcsec resolution wide surveys at LOFAR deep fields limit

➔1 μJy rms deep fields (2-3" res) at >200 Mhz



From Huub's talk

SKA - Low Science Cases – Work in Progress

- First black holes
  - When/how/properties?
  - extreme spectrum sources
- Clusters
  - halo's/relics/accretion shocks/head tails
  - ultra steep spectrum emission/polarization
  - B?particle acceleration/gas heating/cluster formation
- Life cycle of AGN/accretion history
  - starting/giant/restarting phase
  - Peaked/steep spectrum/polarization
  - B?/Old electrons/Feedback mechanism? Start en end?
- Galaxies
  - warm neutral medium? spatially resolved absorption
  - out flow halos: feedback? spatially resolved steep spectrum emission/polarization
  - T=100-1000 K gas: recombination lines

Science: use unique diagnostic tools

From Huub's talk

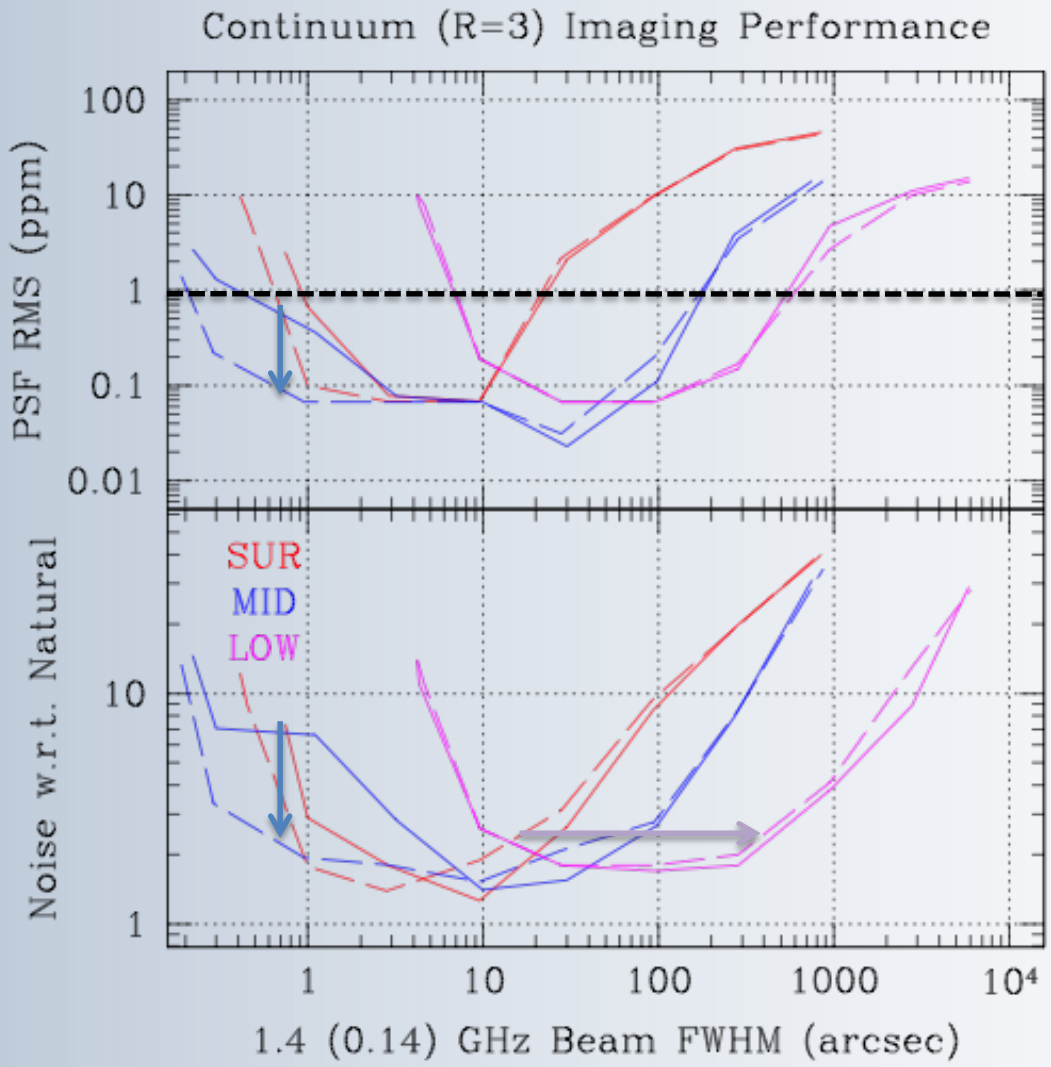
Recommendations 3
(work in progress)

SKA Low (phase 1 or 2?) should:

a) have higher resolution/longer baselines (1” resolution at ~100 MHz, thermal noise limited)

b) <50 MHz capability? - opens new spectral window / uncharted territory

Continuum Performance



BD

Generation 2

3x better noise below 1” res.

Courtesy R. Braun