

# Future radio galaxy surveys



**Phil Bull**

**JPL/Caltech**

# Quick overview

- Radio telescopes are now becoming sensitive enough to perform surveys of  $10^7$ – $10^9$  galaxies out to high  $z$
- 2 main types of survey from the same datacube:
  - Continuum (no- $z$ )
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- **SKA1:**  $\sim 10^8$  galaxies,  $z < 5$  ( $\sim$ few  $\times 10^6$  spectra,  $z < 0.3$ )
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- Best-possible constraints on BAO/RSD from SKA2 (+competitive for weak lensing)
- Less clear-cut for SKA1, but interesting options (especially for synergistic science)

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## Cost and robustness

- Relatively simple and inexpensive... except for correlators
- Can simply add/move receivers to improve sensitivity
- Weather, day/night cycle not very important (at  $\sim 1$  GHz)

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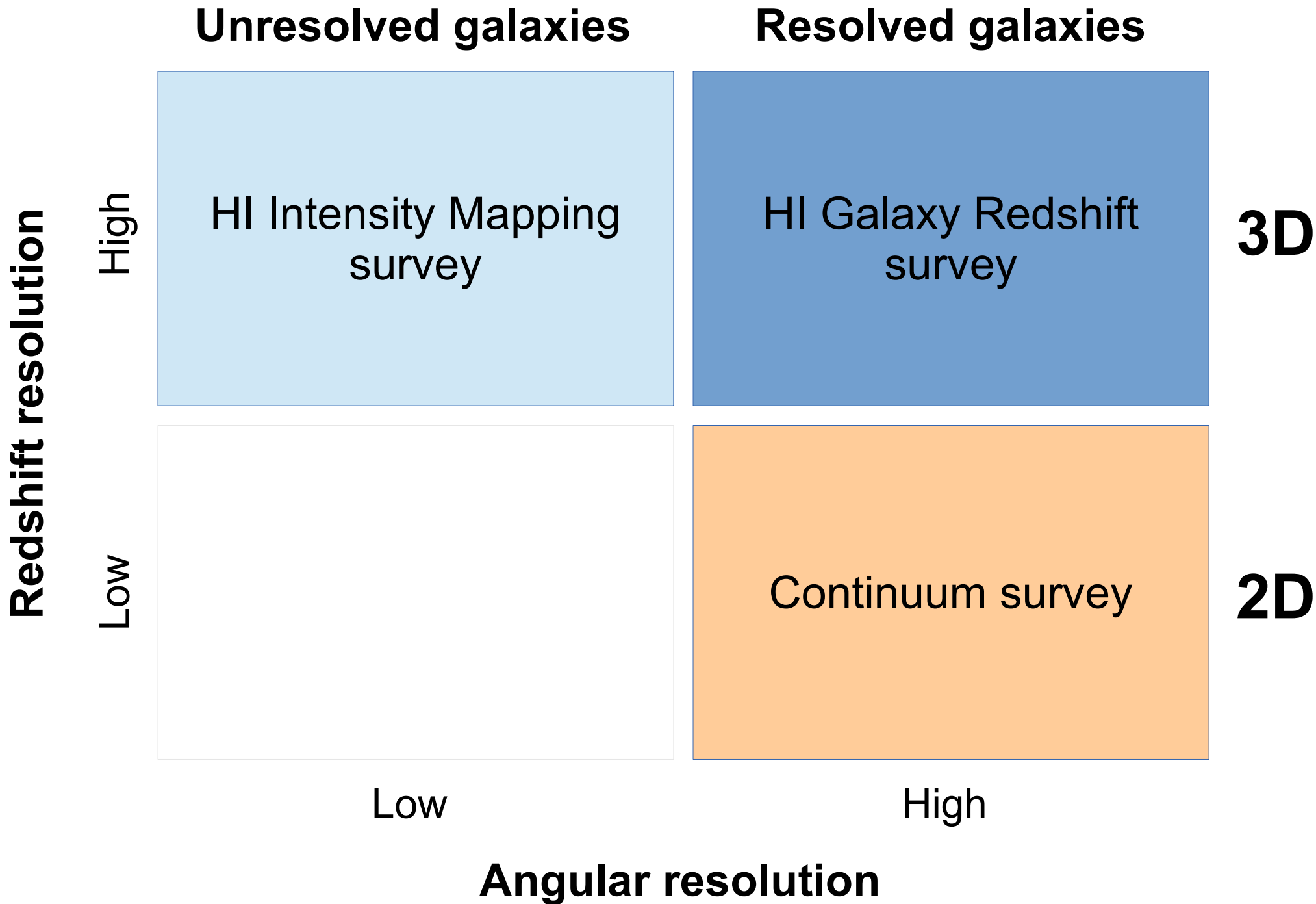
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## Spectral resolution

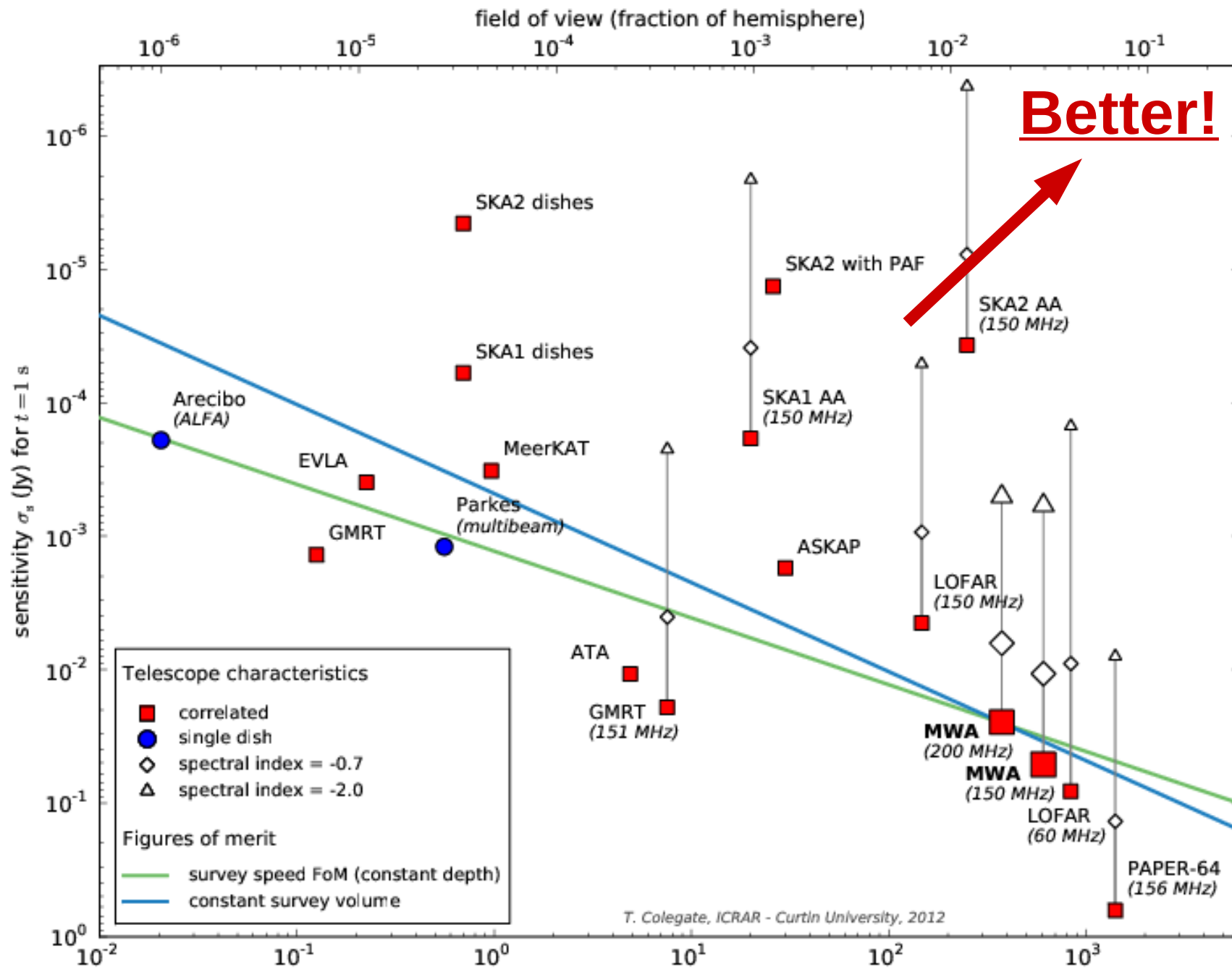
- Intrinsically high spectral resolution
- Choose spectral resolution on the fly, depending on target
- Neutral hydrogen 21cm line ( $< 1420$  MHz) is primary target





# Survey telescopes

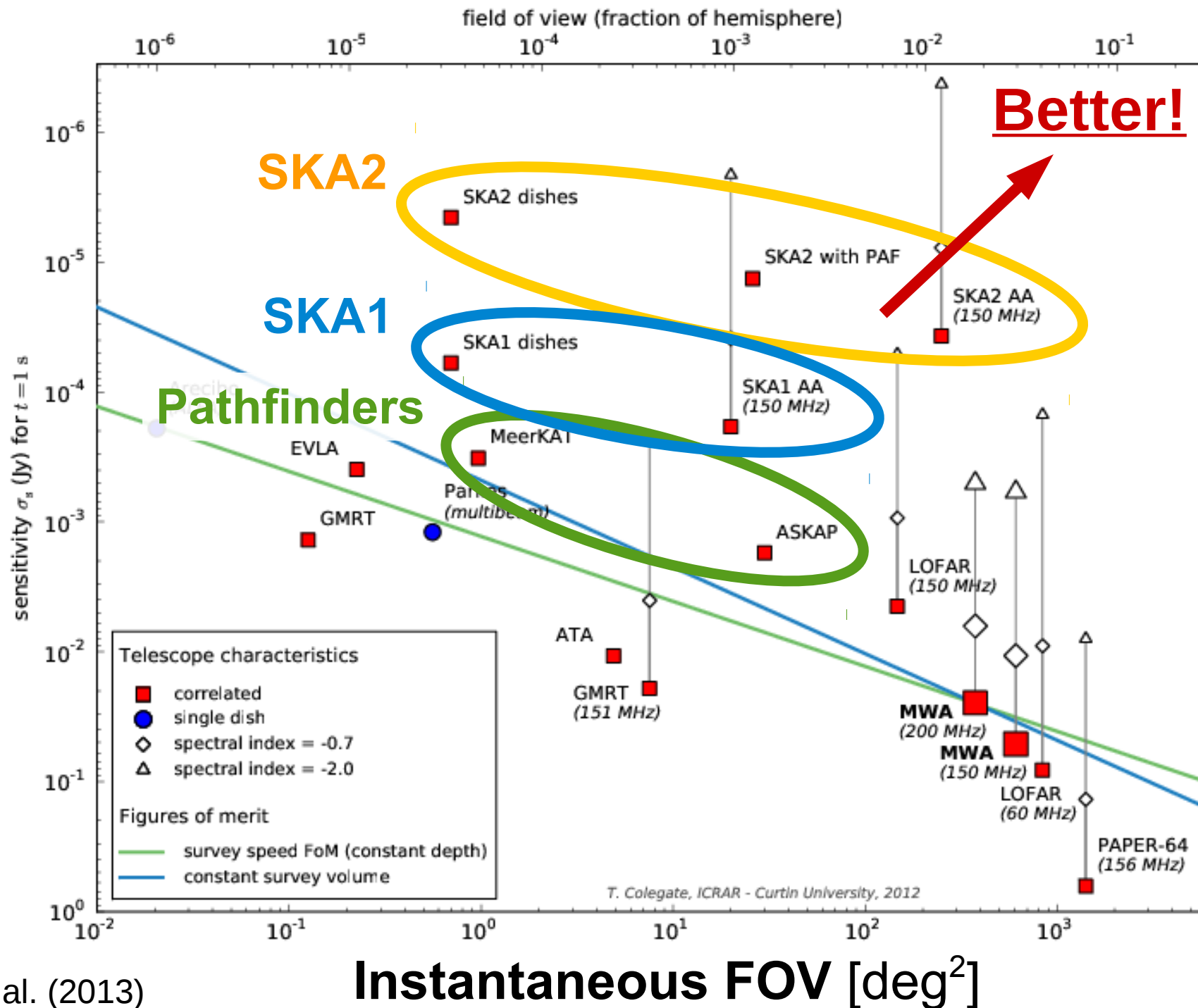
Point source sensitivity



Instantaneous FOV [deg<sup>2</sup>]

# Survey telescopes

Point source sensitivity



# Timeline

**ASKAP, MeerKAT:** already built. Planned surveys:

- **MIGHTEE:** MeerKAT deep continuum survey
- **LADUMA:** MeerKAT deep HI survey
- **EMU:** ASKAP continuum, 75% of sky,  $10 \mu\text{Jy}/\text{beam}$ ,  $z < 1$
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**SKA1:**

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**SKA2:**

- 2017–2020: Detailed design
- 2019–2021: Seek funding
- 2022–2027: Construction
- ~2030: Surveys available

# SKA1-MID

Conventional dish array with single-pixel feeds **in S. Africa**

- $\sim 200 \times 15\text{m}$  dishes with balanced core + spiral arm layout
- 5 bands, covering 350 MHz – 14 GHz
  - Band 1: 350-1050 MHz
  - Band 2: 950-1760 MHz
- Includes MeerKAT
- Low  $T_{\text{inst}} \sim 24\text{ K}$
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## SKA2

- 10–20 times more sensitive
- Not yet defined!



# Survey specifications


SKA1 hardware specs more or less fixed, but survey specs likely to change (through “KSP” process)

- Simultaneous HI and continuum observations

- Tiered strategy likely:

<b>All-sky:</b>	<b>30,000 deg<sup>2</sup></b>	(2.0” PSF, 2 $\mu$ Jy/beam)
Wide:	5,000 deg <sup>2</sup>	(0.5” PSF, 0.3 $\mu$ Jy/beam)
Deep:	30 deg <sup>2</sup>	(0.5” PSF, 0.04 $\mu$ Jy/beam)

@ 1–2 GHz





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Wide:            5,000 deg<sup>2</sup>            (0.5” PSF, 0.3  $\mu$ Jy/beam)

Deep:            30 deg<sup>2</sup>                (0.5” PSF, 0.04  $\mu$ Jy/beam)

- Total  $\sim$ 10k hour surveys (2–3 yrs); max. 5k likely in 1 tier

- Which band gets the big surveys?

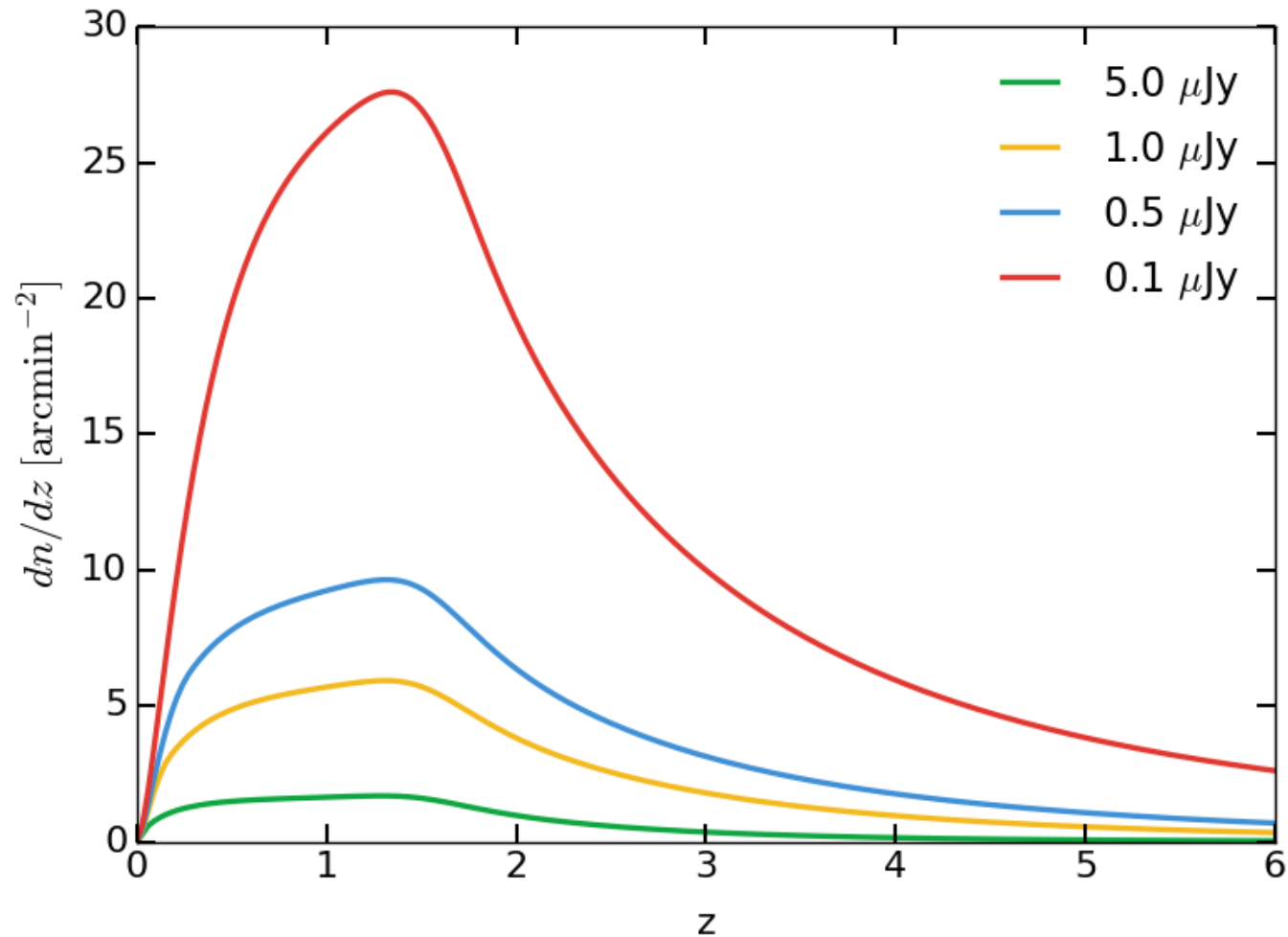
Likely Band 2 (0.95 – 1.7 GHz), good for continuum

Restricts HI survey to  $z < 0.49$  (OK given MID sensitivity)

# Continuum number density

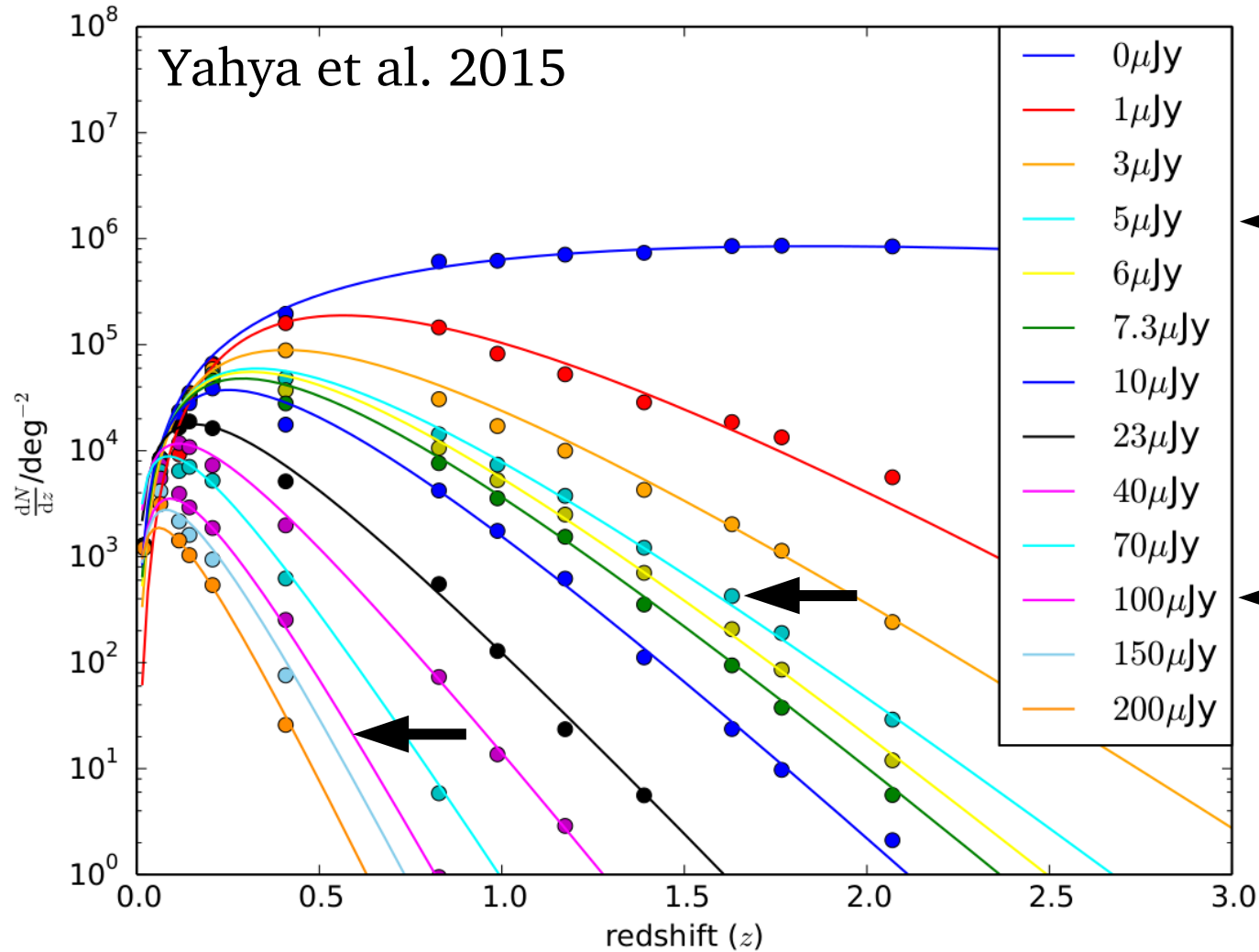
Detect  $\sim 10^8 / 10^9$  galaxies with SKA1/2

- SKA1: Assume  $< 0.5 \mu\text{Jy}$  (at 1 GHz) over 5,000  $\text{deg}^2$
- SKA2: Assume  $< 0.1 \mu\text{Jy}$  over 30,000  $\text{deg}^2$



Based on Wilman et al. (2008) sims (code by D. Alonso)

# HI number density

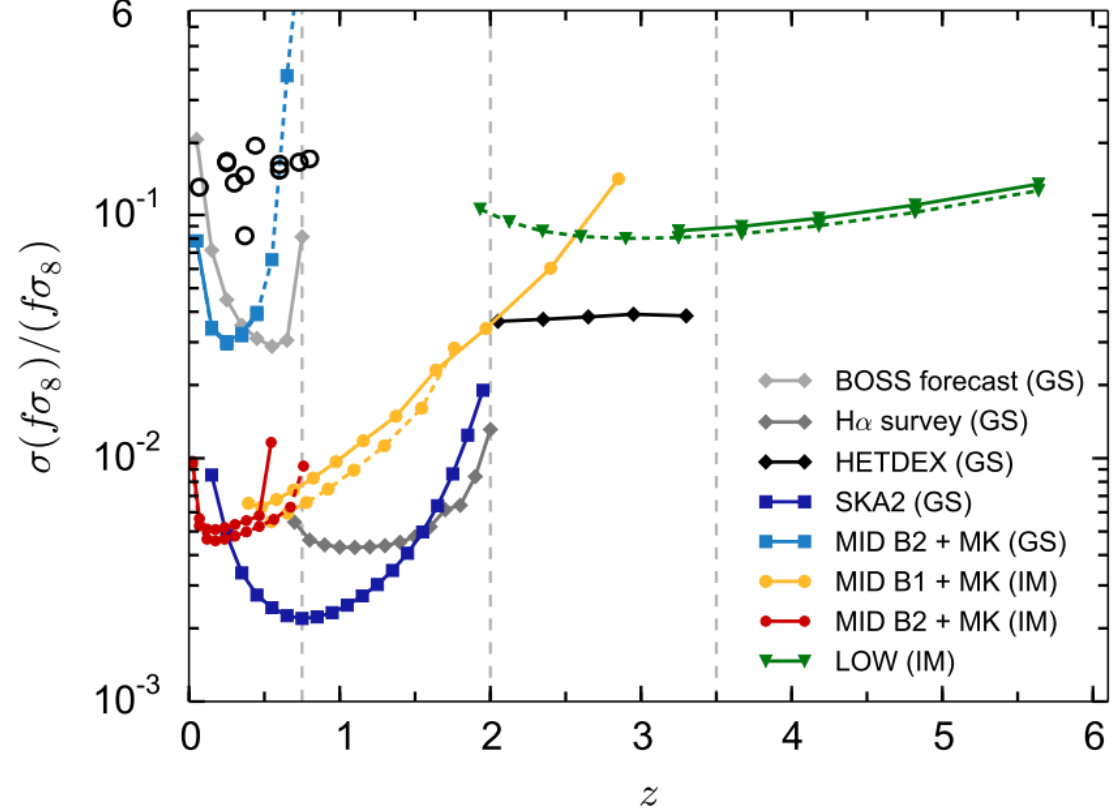
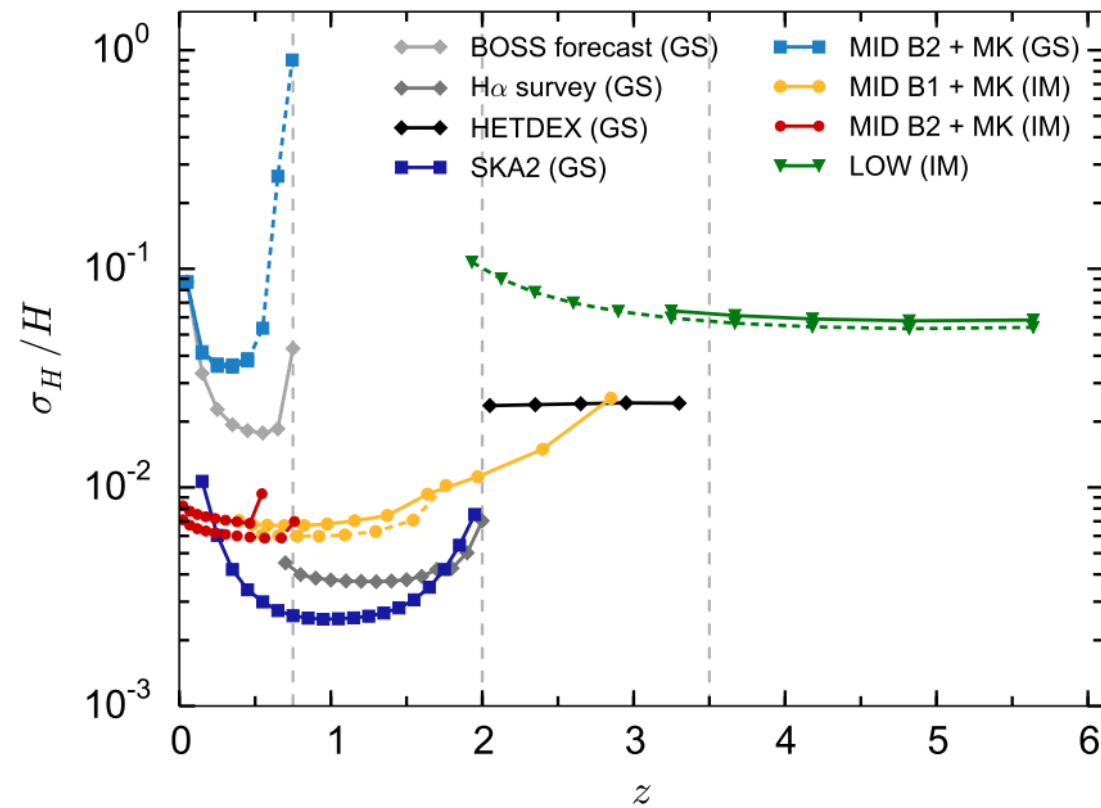


# BAO+RSD with HI

**SKA1:** HI luminosity function too steep; restricted to low  $z$

Interesting cosmology with resolved 21cm line? e.g. peculiar velocities.

PB (2016), based on S-cubed sims

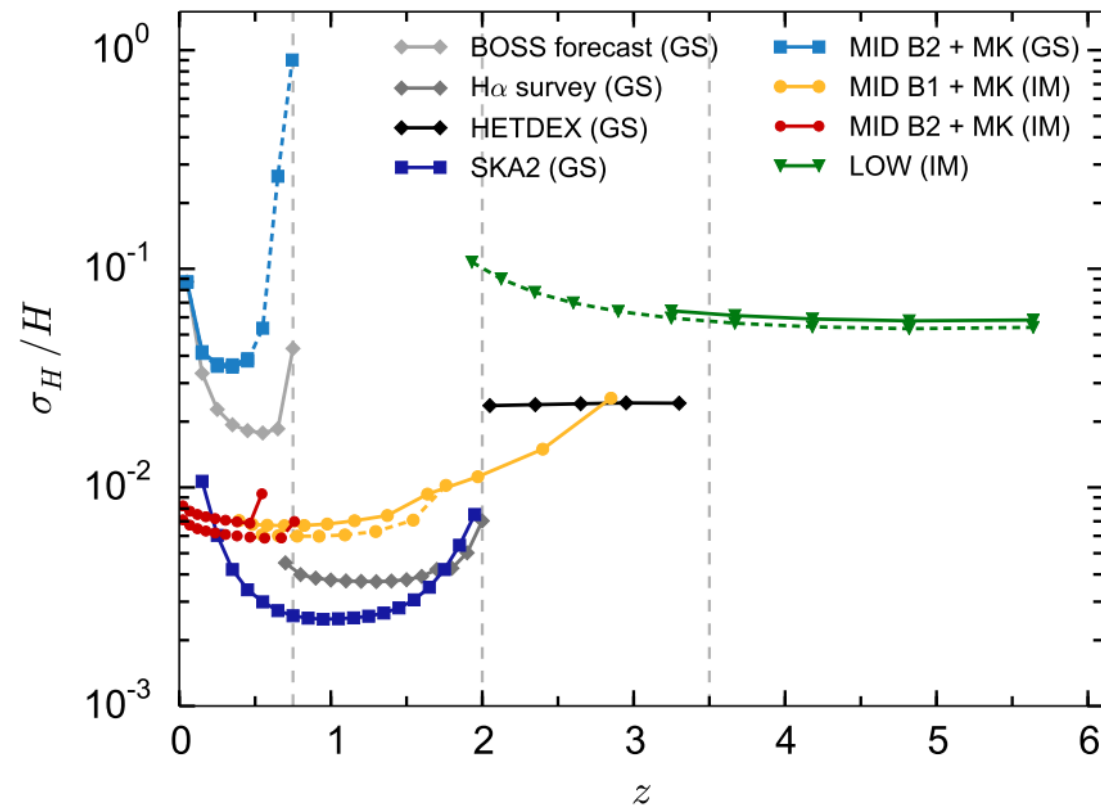


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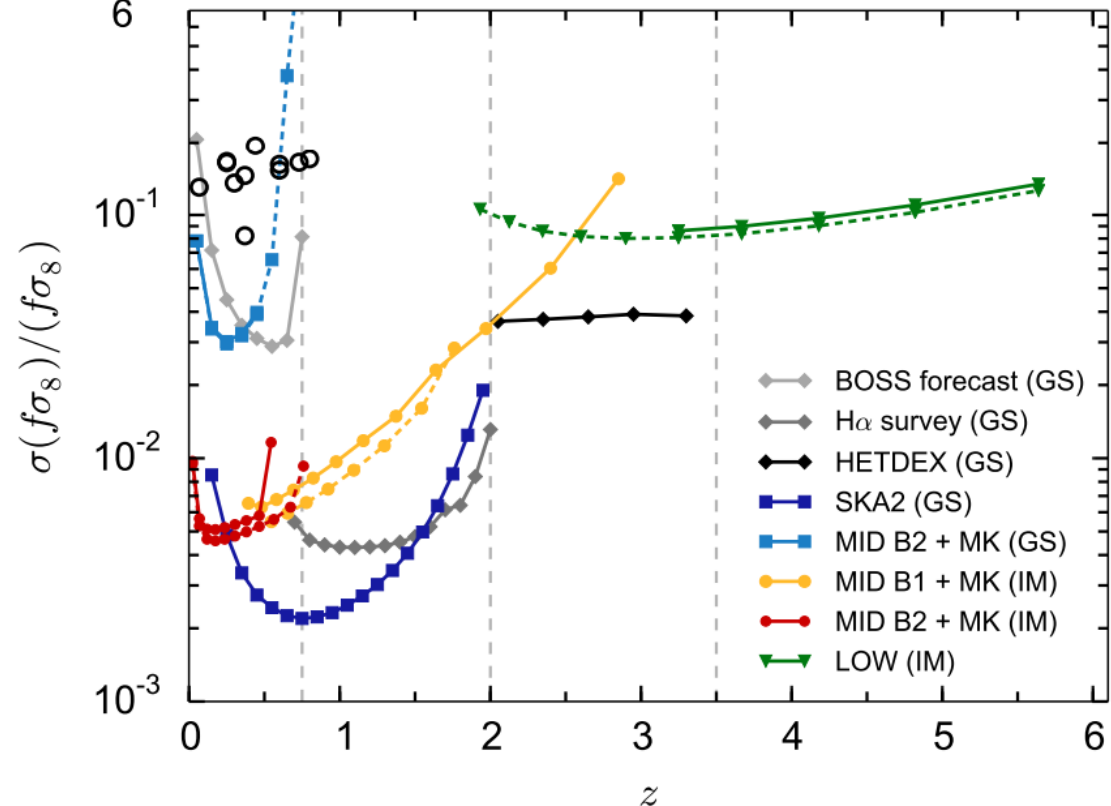
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**SKA2:** Sample variance limited BAO over  $0 < z < 1.5$ ,  $3/4$  sky

Maximising survey area is important for linear modes

Highly oversampled at low- $z$ ; great for RSDs/multi-tracer



# Continuum weak lensing

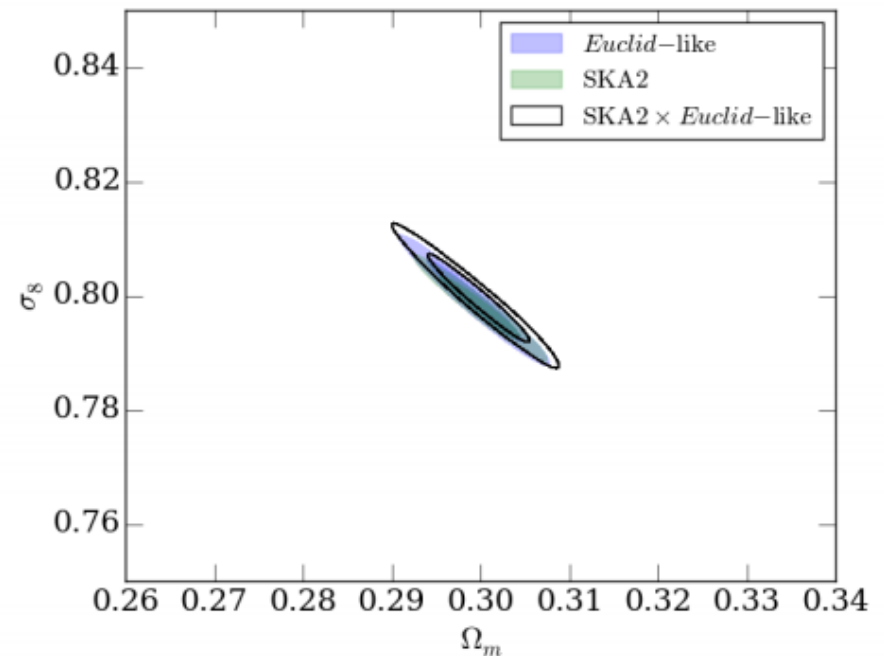
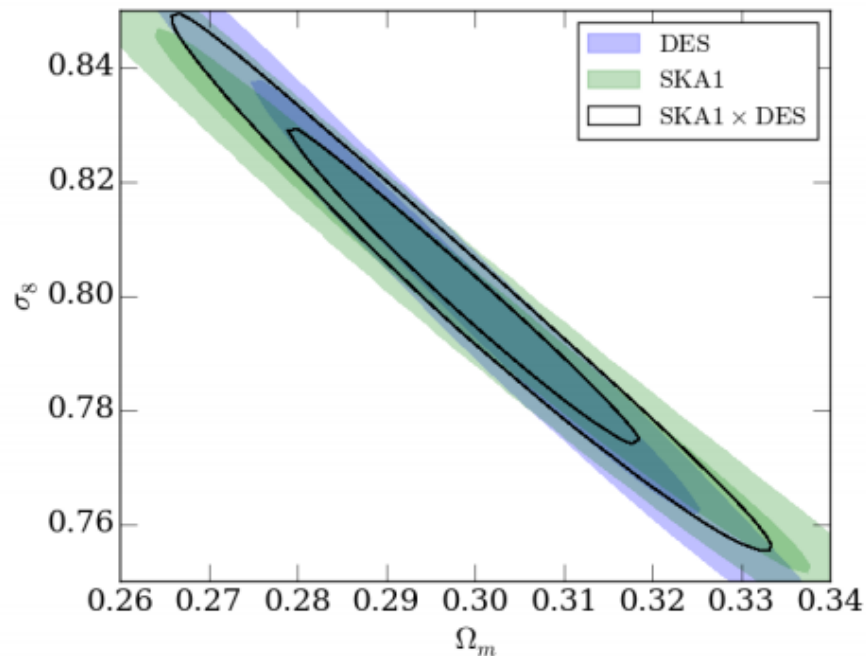
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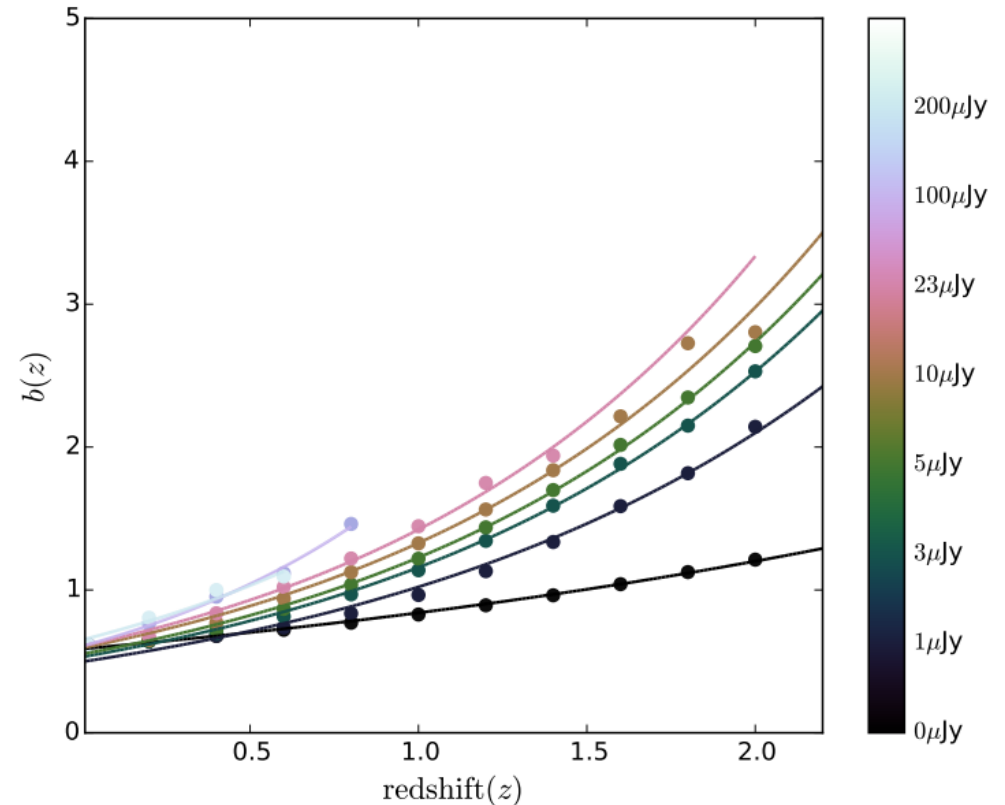
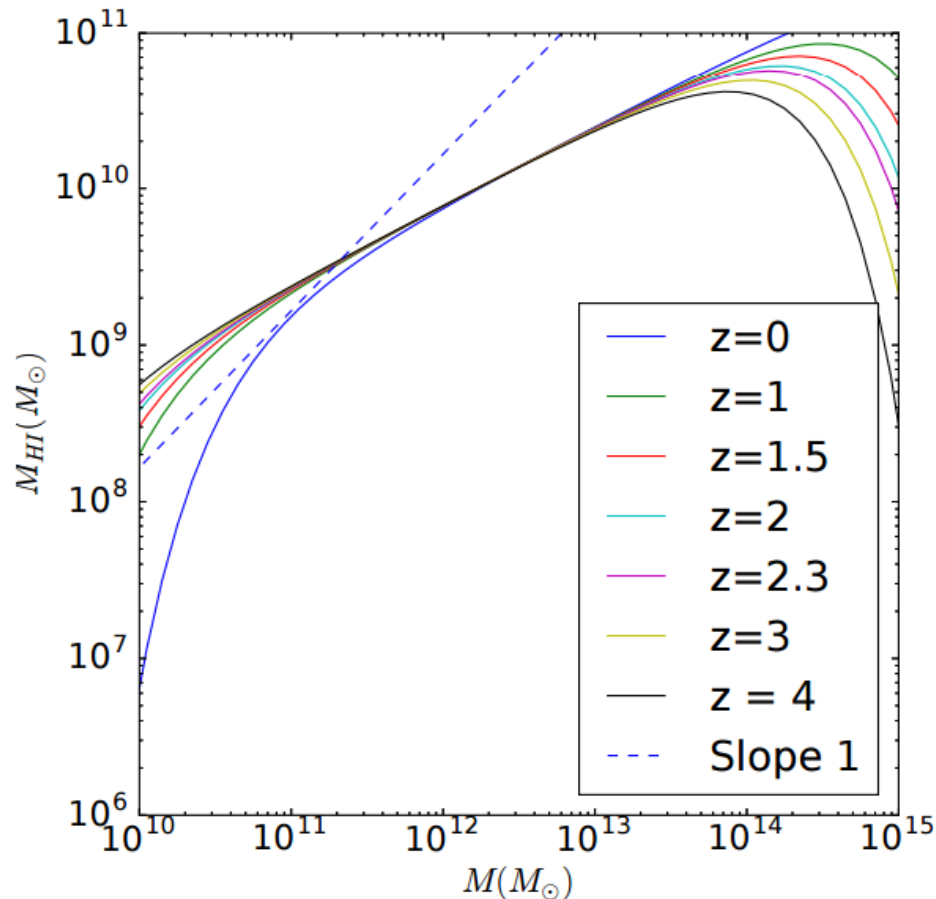
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- Weighted PSF with  $<1''$  FWHM
- No redshift info, but good overlap with CMB lensing kernel
- Raw performance: competitive with DES (but in  $\sim 2024$ )
- Synergies are more exciting: identify blends, IA



# What are HI galaxies?

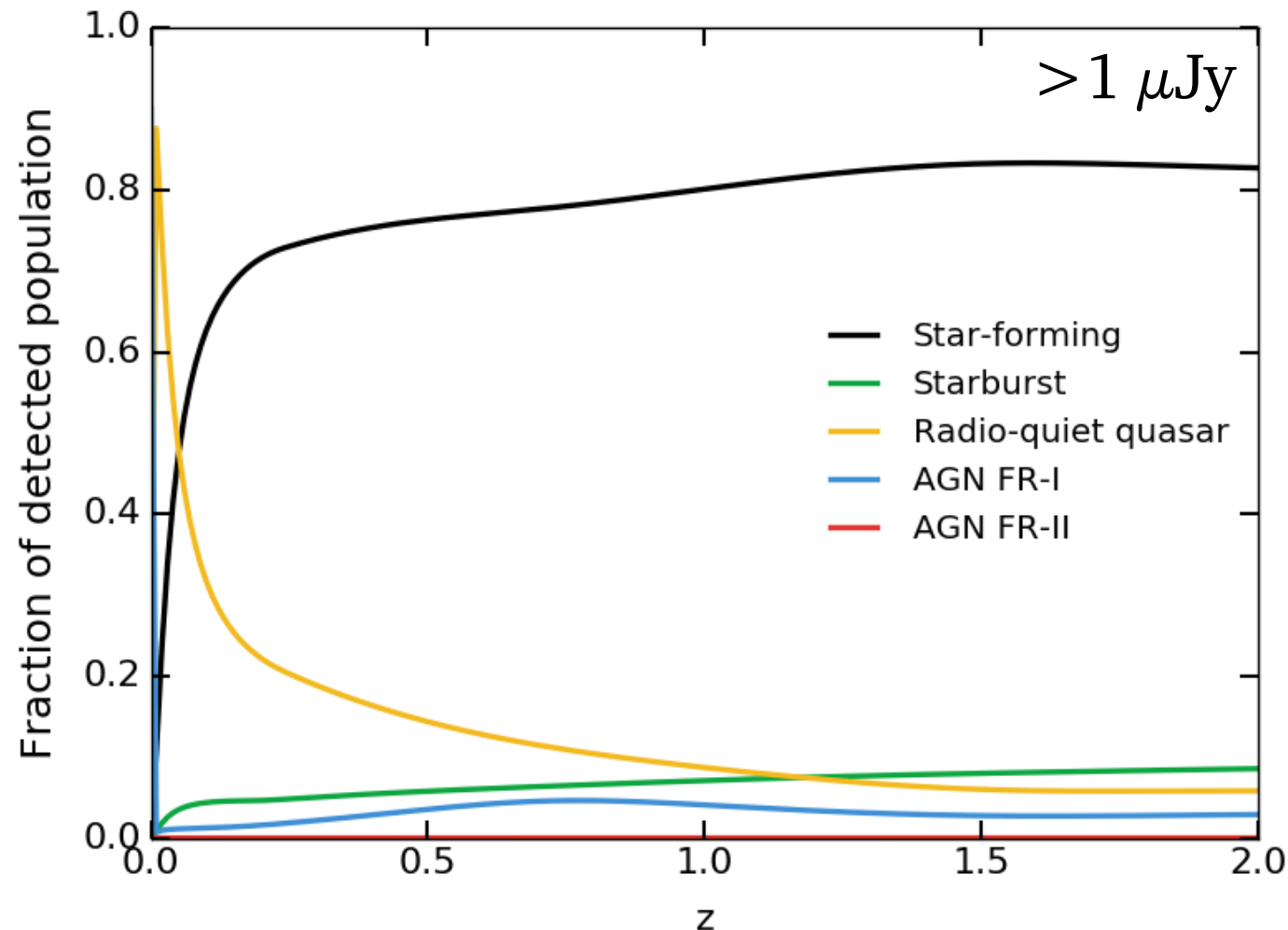
- Most galaxies have neutral hydrogen content  
→ Close to unbiased ( $b=1$ ) for low flux thresholds
- Significant uncertainty in HI evolution with  $z$  and halo mass





# What are continuum galaxies?

- Mostly star-forming galaxies (synchrotron emission)
- Significant population of active galaxies (RQQs) at low  $z$
- Small fraction of AGN with jets, detectable out to high  $z$

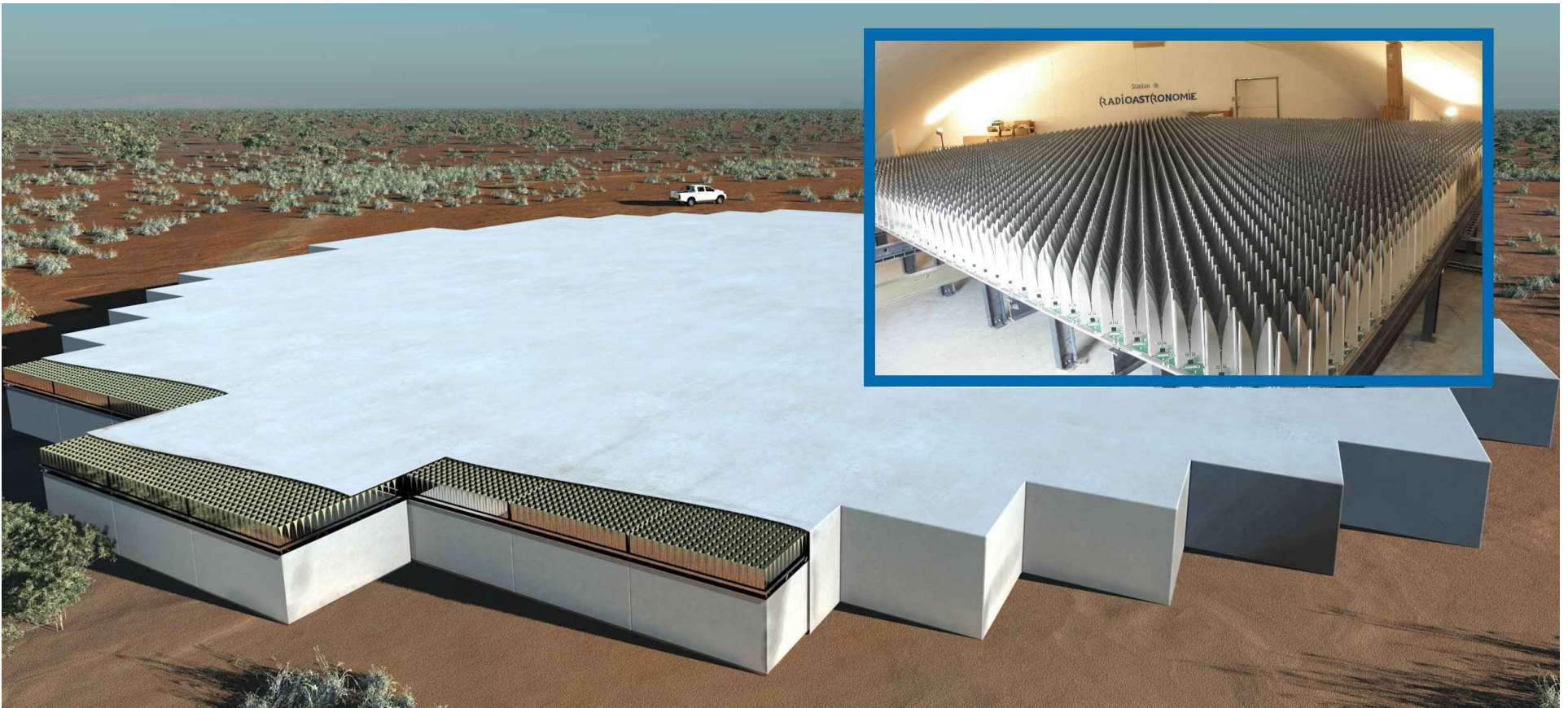


Based on Wilman et al. (2008) sims (code by D. Alonso)

# Technology: Aperture Arrays

SKA2 may move to an aperture array setup:

- Dense AA stations made of “Vivaldi” dual-pol. antennae
- Very large FOV, electronically steered
- Large effective area, passive cooling (high  $T_{\text{sys}}$ )



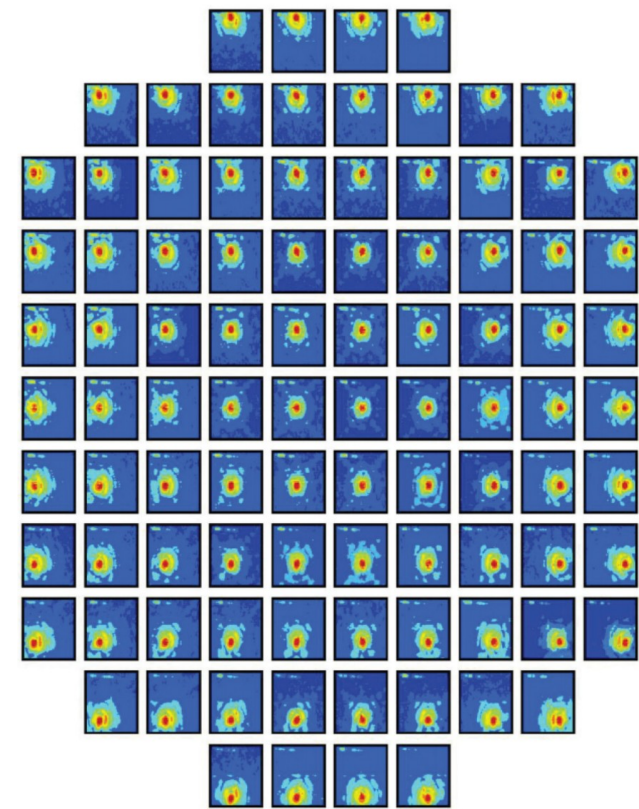
# Technology: Phased Array Feeds

Multi-pixel detectors installed at focus

- Multiple beams on sky → increase FOV of single dish
- Steerable dishes → control sidelobes, RFI, groundspill
- Currently being demonstrated on ASKAP



ATNF/ASKAP



A. Hotan/CSIRO

# Challenges

Lots of fun things to figure out/improve over the next 5 years:

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- Beam deconvolution (radio beams are more complex, but you have more control over them)
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- **RFI detection/rejection**
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- Cultural: historical radio methods not suitable for big survey programmes (e.g. CLEAN deconvolution)

# Summary

- The first truly large radio galaxy surveys are imminent
- $\sim 100\text{m}$  galaxies at  $z < 5$  possible with SKA1 continuum (but only  $\sim 5\text{m}$  spectra, at  $z < 0.3$ )
- $\sim 1$  billion *spectra* possible with SKA2 HI survey
- SKA1 + pathfinders are currently the only game in town for big, cosmological radio galaxy surveys
- SKA2 design begins next year – get ideas out there ASAP!