# HI Galaxy Science with SKA1

Erwin de Blok (ASTRON, NL) on behalf of
The HI Science Working Group

# SKA1 HI Science Priorities

- Resolved HI kinematics and morphology of ~$10^{10}$ $M_\odot$ mass **galaxies out to z~0.8**
- High spatial resolution studies of the **ISM in the nearby Universe**.
- Multi-resolution imaging studies of the **ISM in our Galaxy**
- **HI absorption studies** out to the highest redshifts.
- The gaseous interface and accretion physics between **galaxies and the IGM**

## SKA1 science goals

| Science Goal | SWG | Objective | SWG Rank |
|---|---|---|---|
| 1 | *CD/EoR* | Physics of the early universe IGM - I. Imaging | 1/3 |
| 2 | *CD/EoR* | Physics of the early universe IGM - II. Power spectrum | 2/3 |
| 3 | *CD/EoR* | Physics of the early universe IGM - III. HI absorption line spectra (21cm forest) | 3/3 |
| 4 | *Pulsars* | Reveal pulsar population and MSPs for gravity tests and Gravitational Wave detection | 1/3 |
| 5 | *Pulsars* | High precision timing for testing gravity and GW detection | 1/3 |
| 6 | *Pulsars* | Characterising the pulsar population | 2/3 |
| 7 | *Pulsars* | Finding and using (Millisecond) Pulsars in Globular Clusters and External Galaxies | 2/3 |
| 8 | *Pulsars* | Finding pulsars in the Galactic Centre | 2/3 |
| 9 | *Pulsars* | Astrometric measurements of pulsars to enable improved tests of GR | 2/3 |
| 10 | *Pulsars* | Mapping the pulsar beam | 3/3 |
| 11 | *Pulsars* | Understanding pulsars and their environments through their interactions | 3/3 |
| 12 | *Pulsars* | Mapping the Galactic Structure | 3/3 |
| 13 | *HI* | Resolved HI kinematics and morphology of ~10^10 M_sol mass galaxies out to z~0.8 | 1/5 |
| 14 | *HI* | High spatial resolution studies of the ISM in the nearby Universe. | 2/5 |
| 15 | *HI* | Multi-resolution mapping studies of the ISM in our Galaxy | 3/5 |
| 16 | *HI* | HI absorption studies out to the highest redshifts. | 4/5 |
| 17 | *HI* | The gaseous interface and accretion physics between galaxies and the IGM | 5/5 |
| 18 | *Transients* | Solve missing baryon problem at z~2 and determine the Dark Energy Equation of State | =1/4 |
| 19 | *Transients* | Accessing New Physics using Ultra-Luminous Cosmic Explosions | =1/4 |
| 20 | *Transients* | Galaxy growth through measurements of Black Hole accretion, growth and feedback | 3/4 |
| 21 | *Transients* | Detect the Electromagnetic Counterparts to Gravitational Wave Events | 4/4 |
| 22 | *Cradle of Life* | Map dust grain growth in the terrestrial planet forming zones at a distance of 100 pc | 1/5 |
| 23 | *Cradle of Life* | Characterise exo-planet magnetic fields and rotational periods | 2/5 |
| 24 | *Cradle of Life* | Survey all nearby (~100 pc) stars for radio emission from technological civilizations. | 3/5 |
| 25 | *Cradle of Life* | The detection of pre-biotic molecules in pre-stellar cores at distance of 100 pc. | 4/5 |
| 26 | *Cradle of Life* | Mapping of the sub-structure and dynamics of nearby clusters using maser emission. | 5/5 |
| 27 | *Magnetism* | The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields | 1/5 |
| 28 | *Magnetism* | Determine origin, maintenance and amplification of magnetic fields at high redshifts - I. | 2/5 |
| 29 | *Magnetism* | Detection of polarised emission in Cosmic Web filaments | 3/5 |
| 30 | *Magnetism* | Determine origin, maintenance and amplification of magnetic fields at high redshifts - II. | 4/5 |
| 31 | *Magnetism* | Intrinsic properties of polarised sources | 5/5 |
| 32 | *Cosmology* | Constraints on primordial non-Gaussianity and tests of gravity on super-horizon scales. | 1/5 |
| 33 | *Cosmology* | Angular correlation functions to probe non-Gaussianity and the matter dipole | 2/5 |
| 34 | *Cosmology* | Map the dark Universe with a completely new kind of weak lensing survey - in the radio. | 3/5 |
| 35 | *Cosmology* | Dark energy & GR via power spectrum, BAO, redshift-space distortions and topology. | 4/5 |
| 36 | *Cosmology* | Test dark energy & general relativity with fore-runner of the 'billion galaxy' survey. | 5/5 |
| 37 | *Continuum* | Measure the Star formation history of the Universe (SFHU) - I. Non-thermal processes | 1/8 |
| 38 | *Continuum* | Measure the Star formation history of the Universe (SFHU) - II. Thermal processes | 2/8 |
| 39 | *Continuum* | Probe the role of black holes in galaxy evolution - I. | 3/8 |
| 40 | *Continuum* | Probe the role of black holes in galaxy evolution - II. | 4/8 |
| 41 | *Continuum* | Probe cosmic rays and magnetic fields in ICM and cosmic filaments. | 5/8 |
| 42 | *Continuum* | Study the detailed astrophysics of star-formation and accretion processes - I. | 6/8 |
| 43 | *Continuum* | Probing dark matter and the high redshift Universe with strong gravitational lensing. | 7/8 |
| 44 | *Continuum* | Legacy/Serendipity/Rare. | 8/8 |

**Table 1. Collated list of science goals. Within each science area, the entries are ordered in the rank provided by the SWG Chairs. The eight different groups of SWG contributions are listed in the Table in an arbitrary sequence.**

**Braun et al, 2014,**
**SKA1 Science Priority Outcomes**

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- Multi-resolution imaging studies of the **ISM in our Galaxy**

- **HI absorption studies** out to the highest redshifts.

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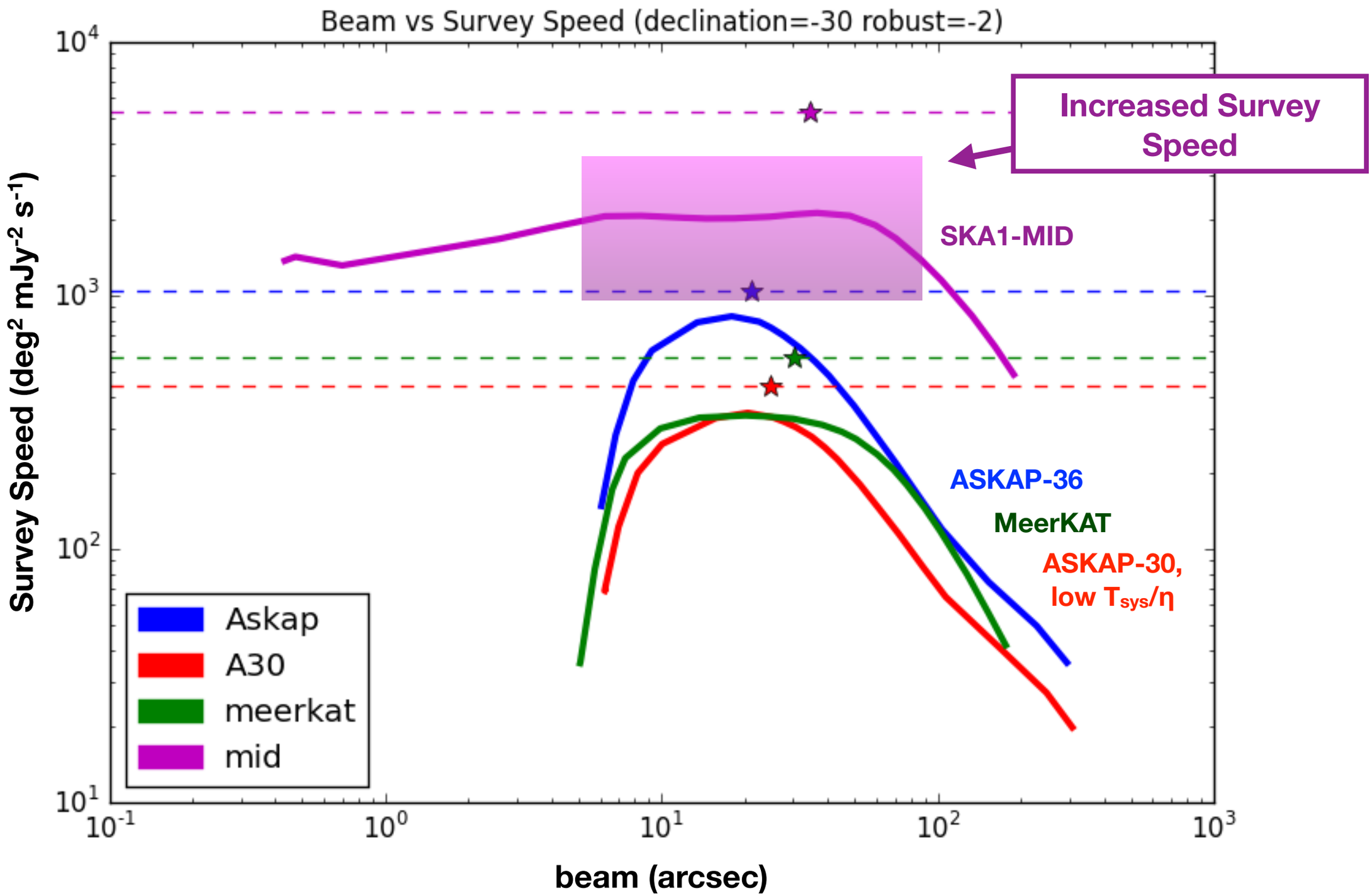
| 33 | *Cosmology* | Angular correlation functions to probe non-Gaussianity and the matter dipole | 2/5 |
| 37 + 38 | *Continuum* | Star formation history of the Universe (SFHU) – I+II. Non-thermal & Thermal processes | 1+2/8 |

# SKA1 Capabilities



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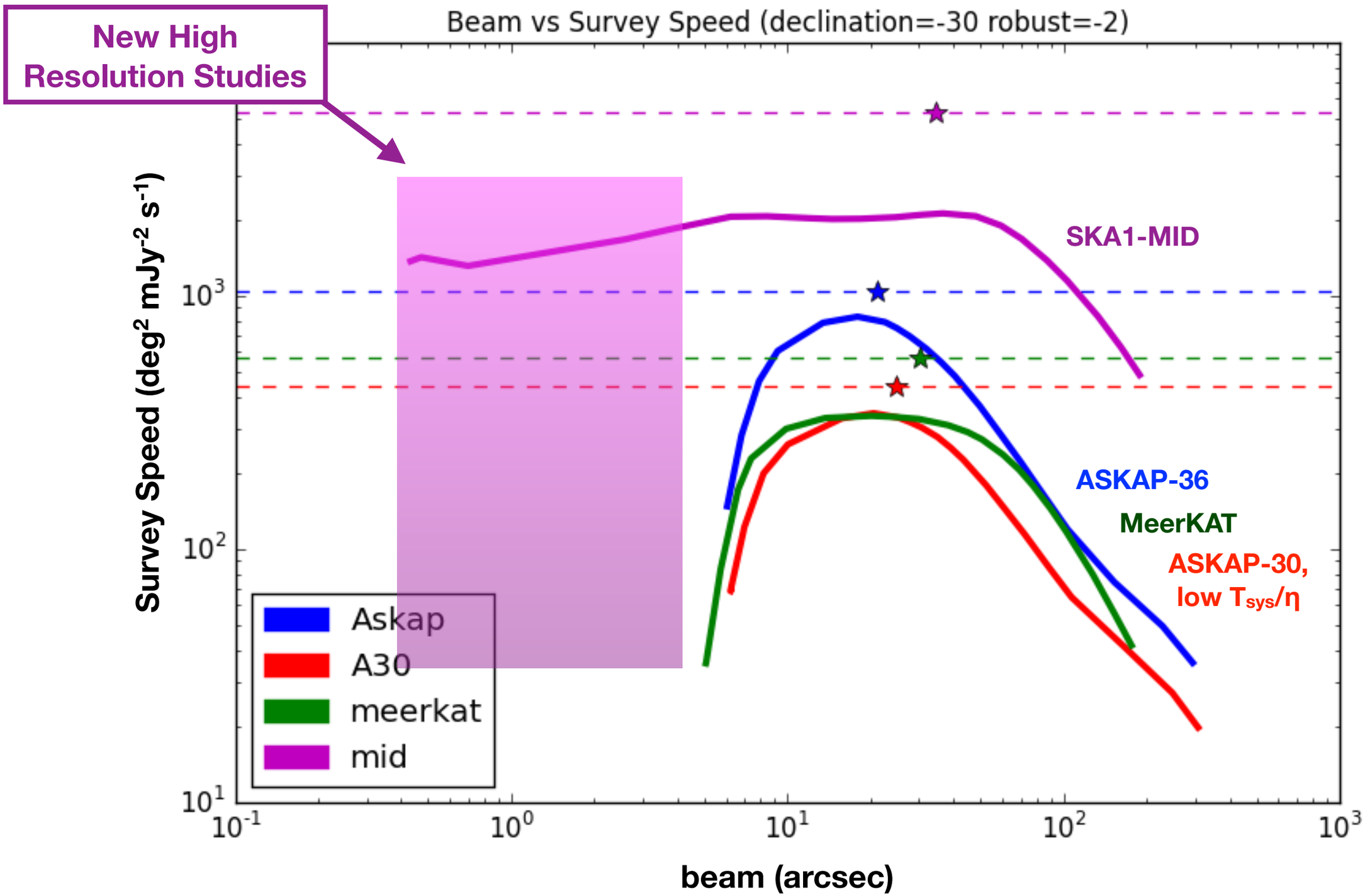
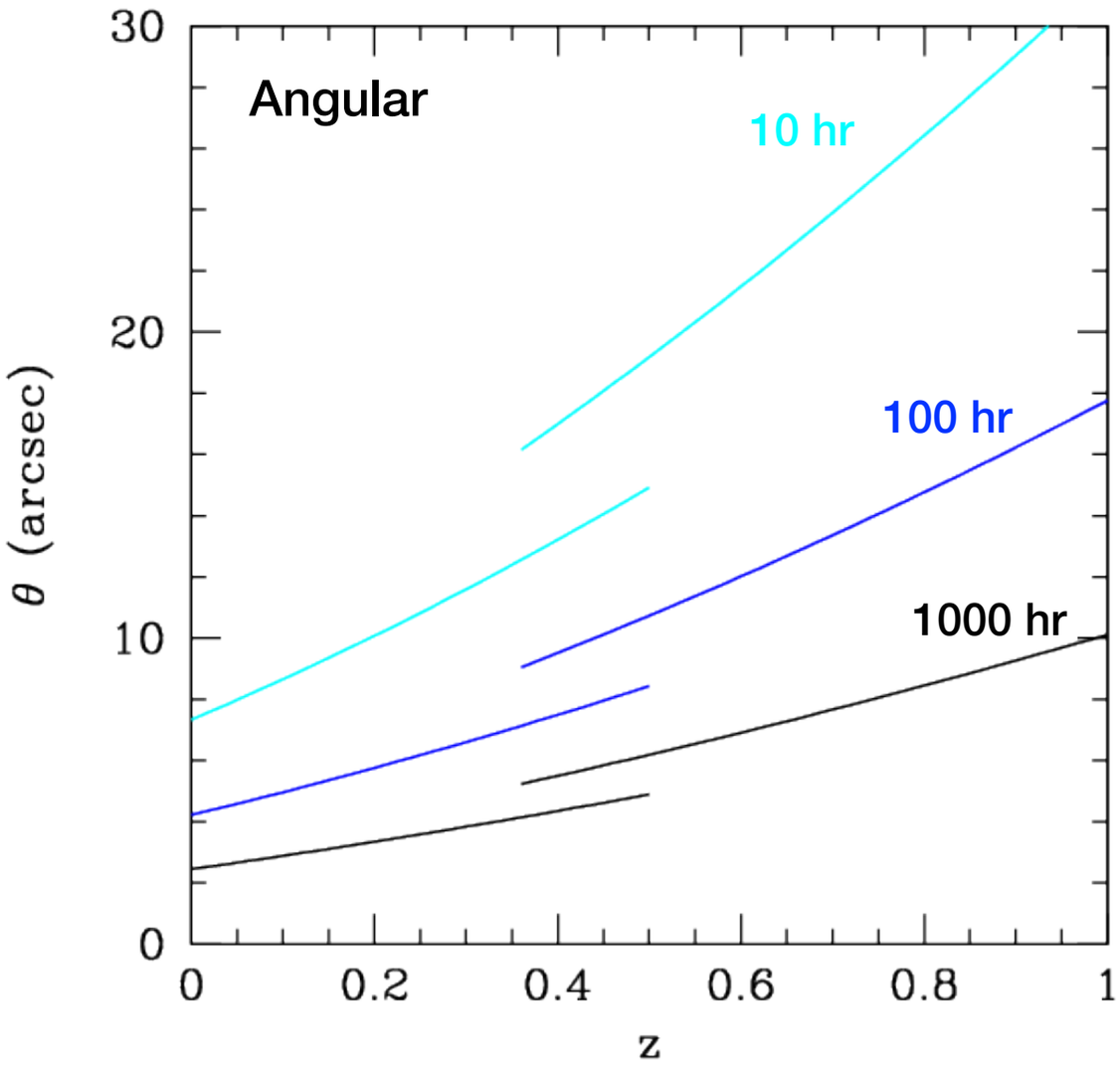
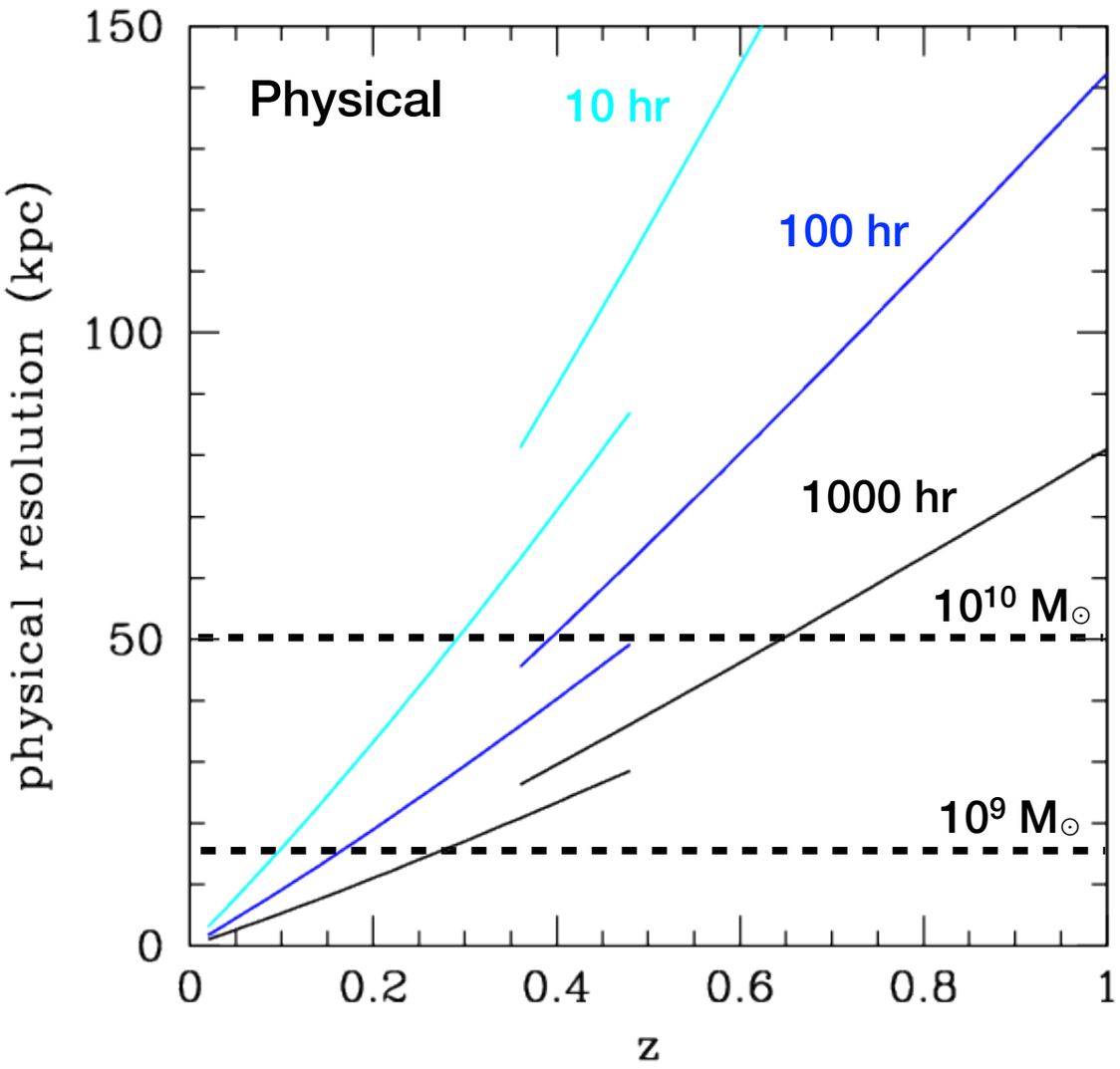


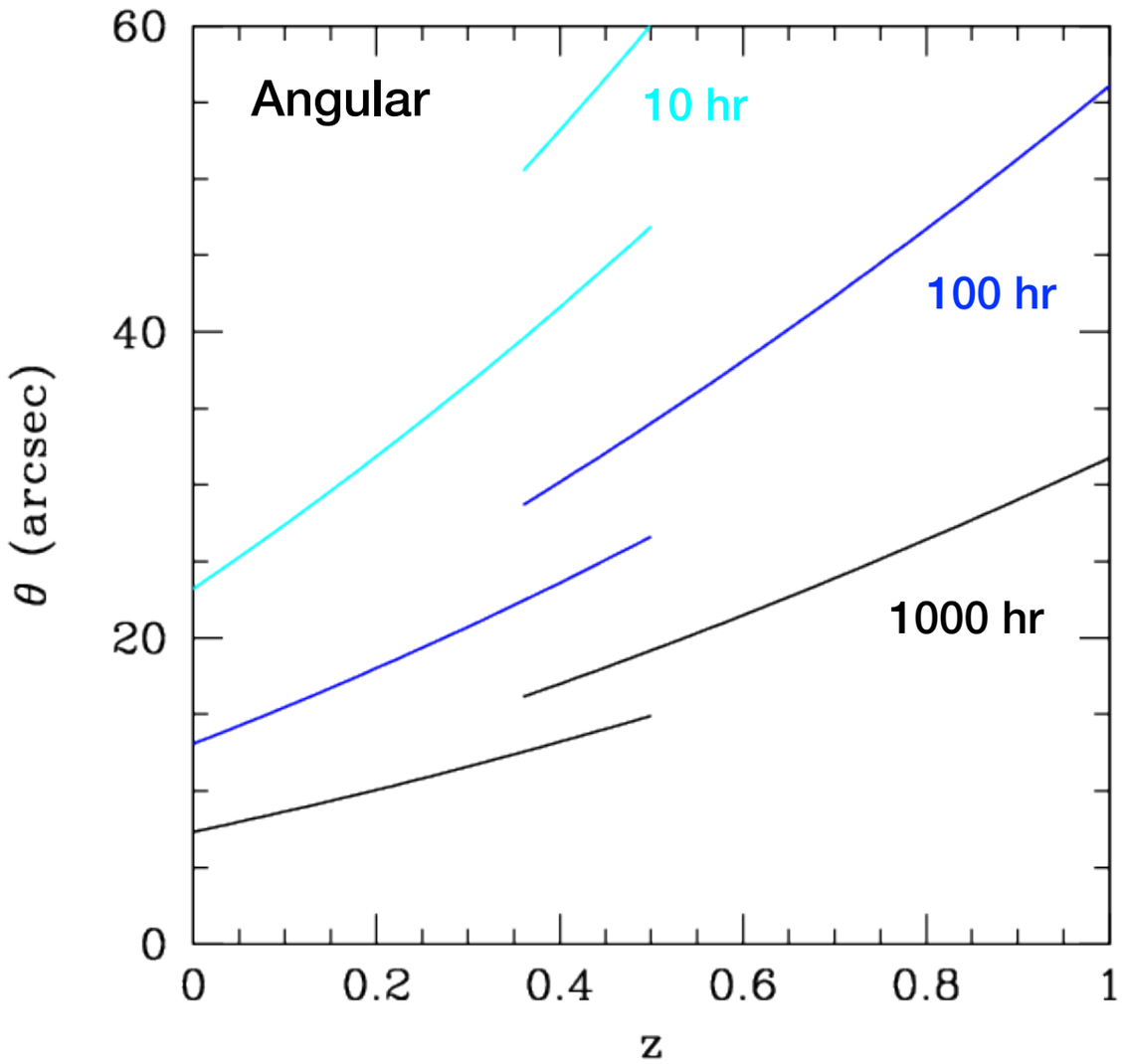
# SKA1 Surveys: Resolution @ $10^{20}$ cm$^{-2}$

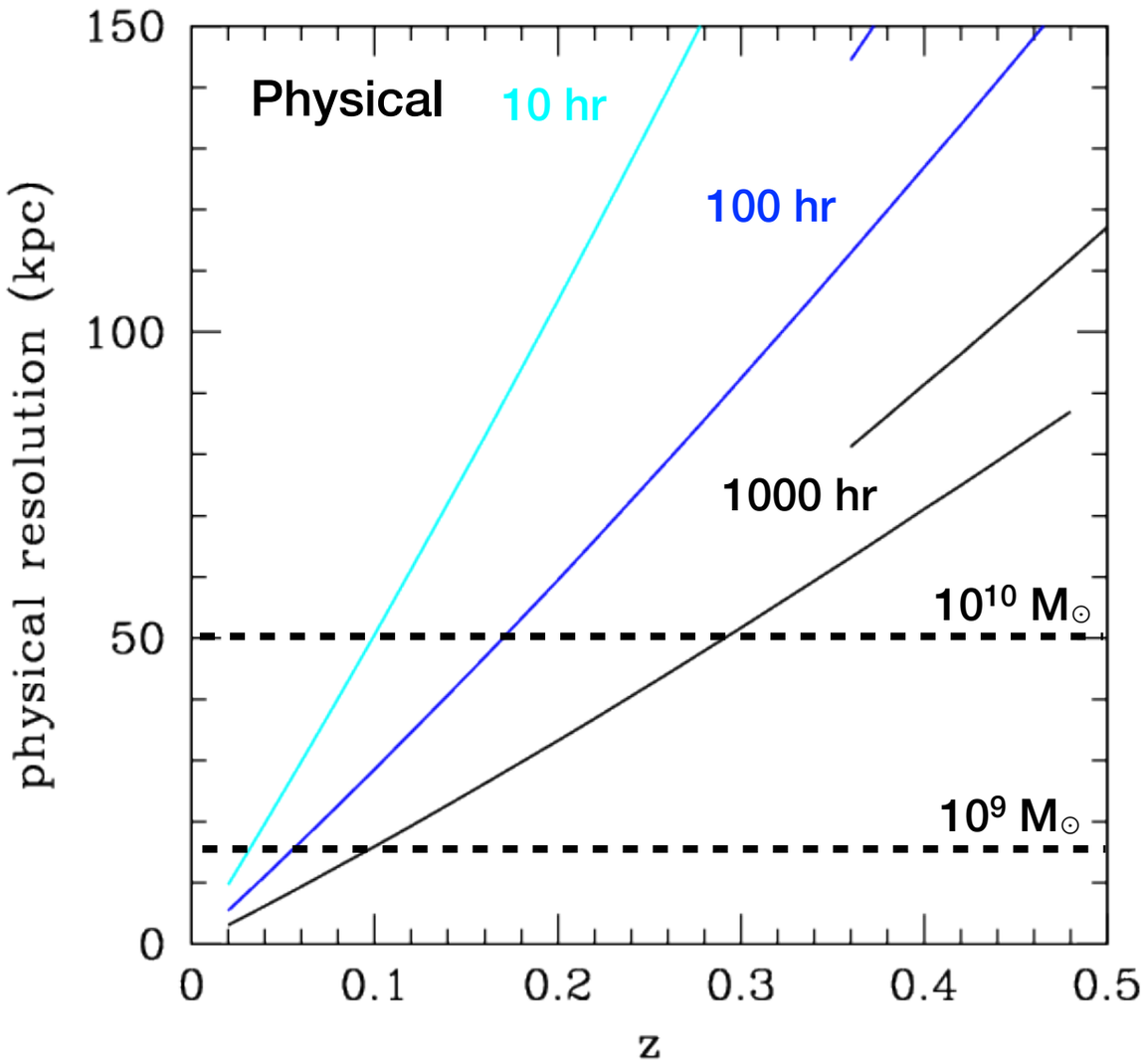



- **Resolve** galaxies over large redshift range
- Study role of mergers, feedback, local environment
- carry out detailed studies of galaxy kinematics & angular momentum
- high resolution studies of ISM in nearby galaxies (< 100 pc)

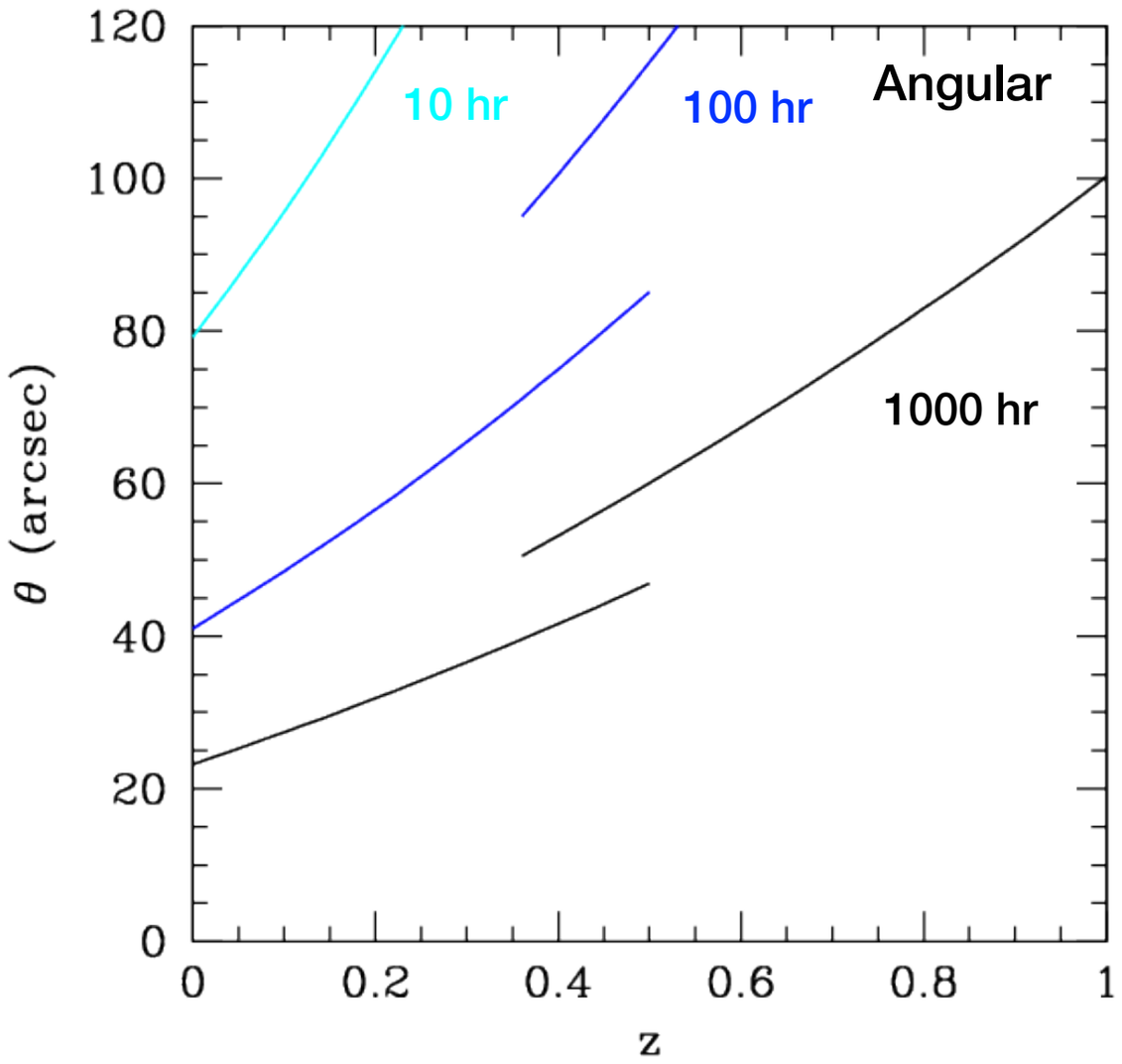
# SKA1 Surveys: Resolution @ $10^{19}$ cm$^{-2}$

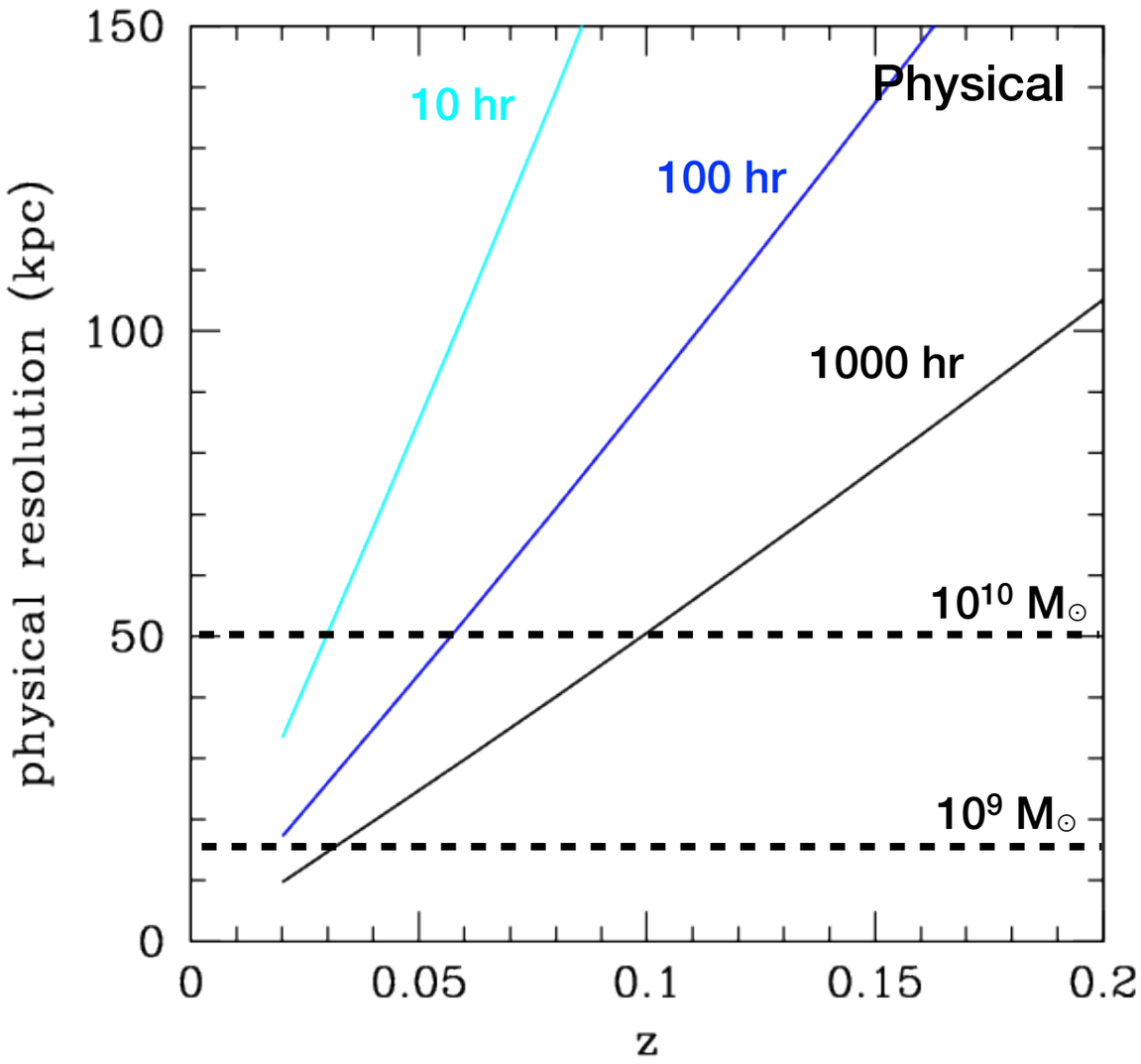



- HALOGAS type studies beyond local Universe
- understand how galaxies acquire their gas: role of environment/accretion

# SKA1 Surveys: Resolution @ $10^{18}$ cm$^{-2}$



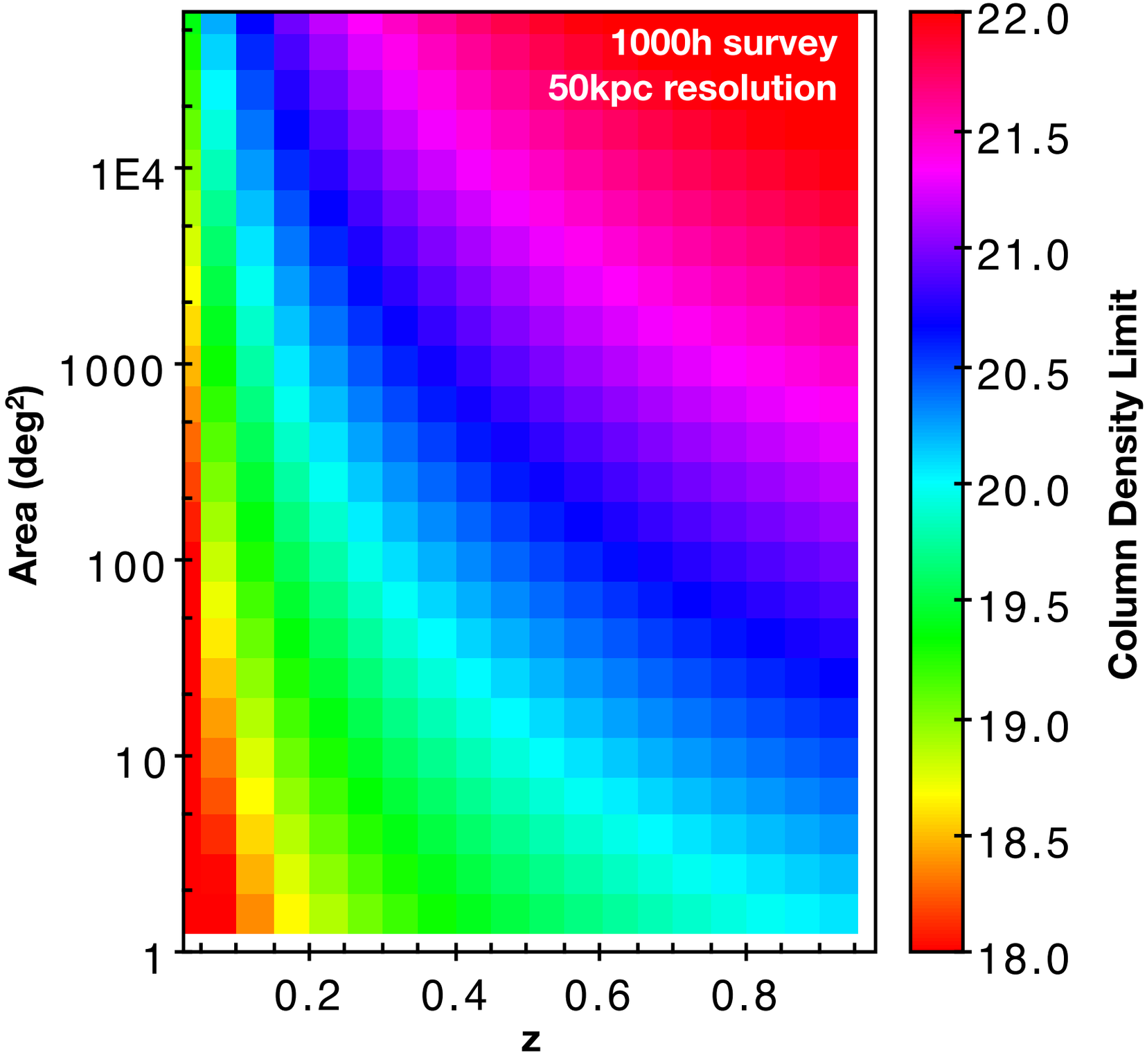




- New studies of the disk-halo-IGM interface

# What Kind of Surveys To Do?

**Requirements**

- Want to observe HI down to at least galactic scales
- SKA observation time is limited (~1000h KSPs)
- Time+beam+z+area sets column density limit
- Need $n_{HI} > 10^{20}$



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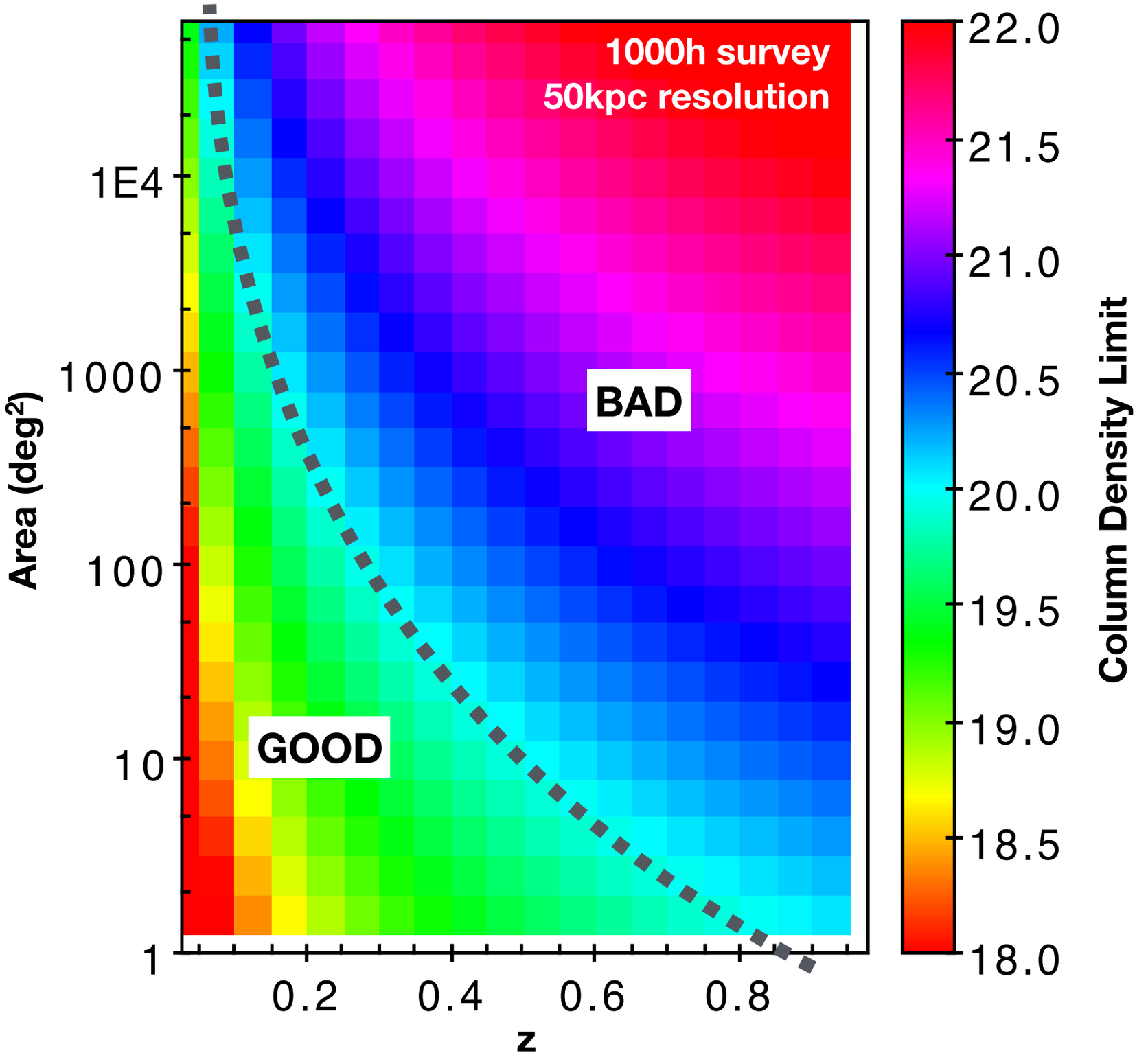

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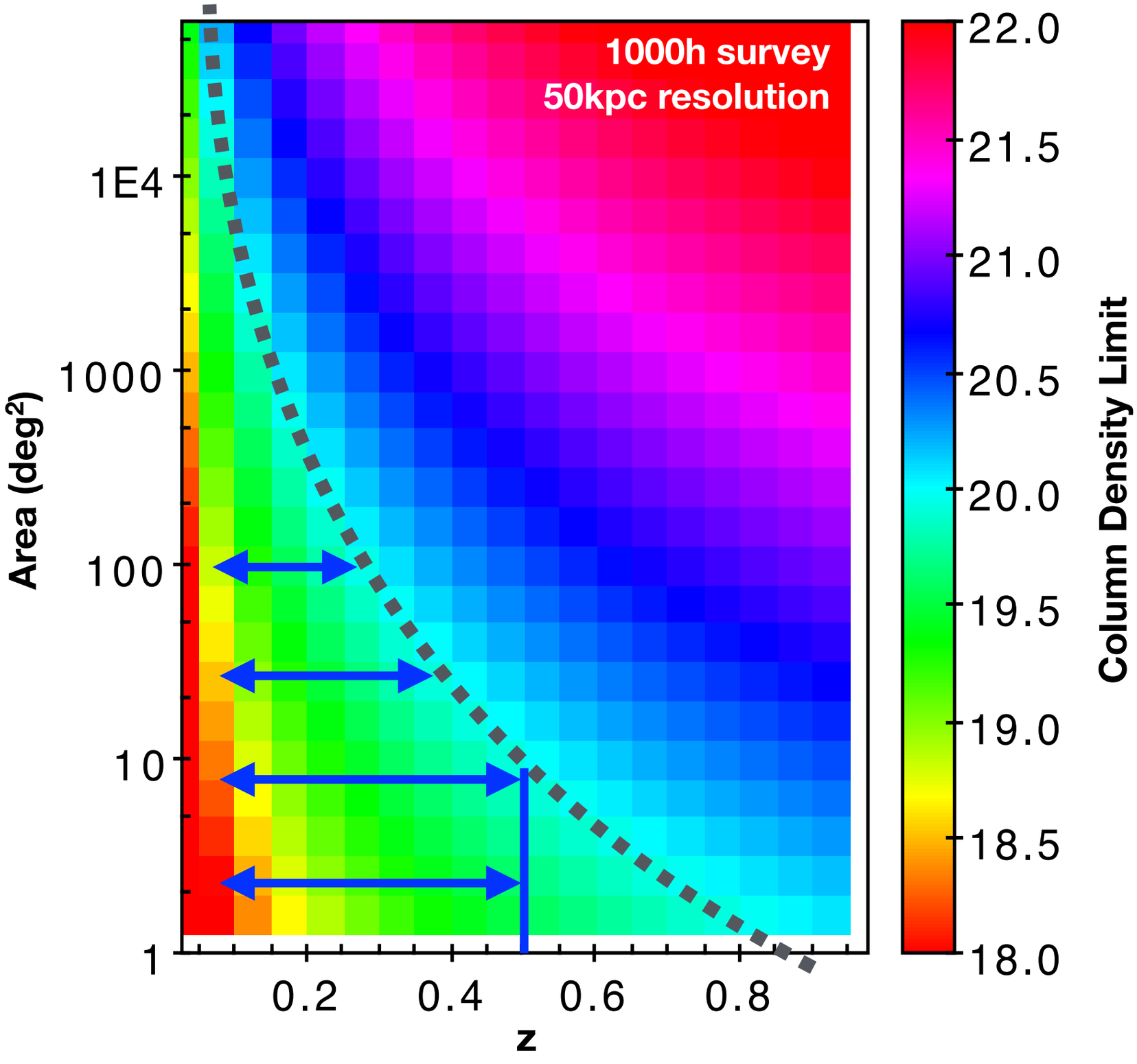
**Preferred Surveys**

- **band 2: ~10→100 deg$^2$**



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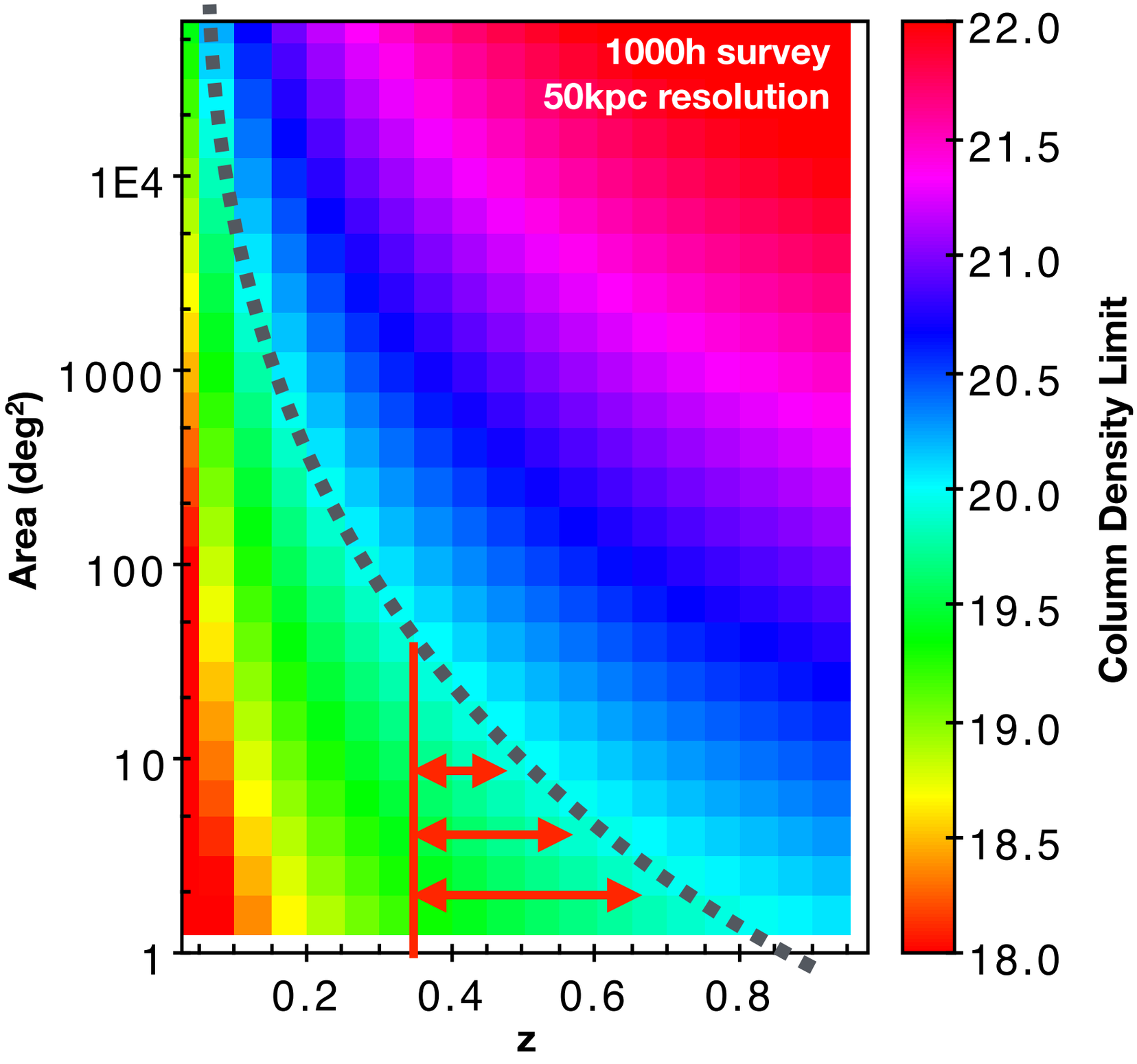
**Preferred Surveys**

- **band 2: ~10→100 deg$^2$**
- **band 1: SP→few deg$^2$**



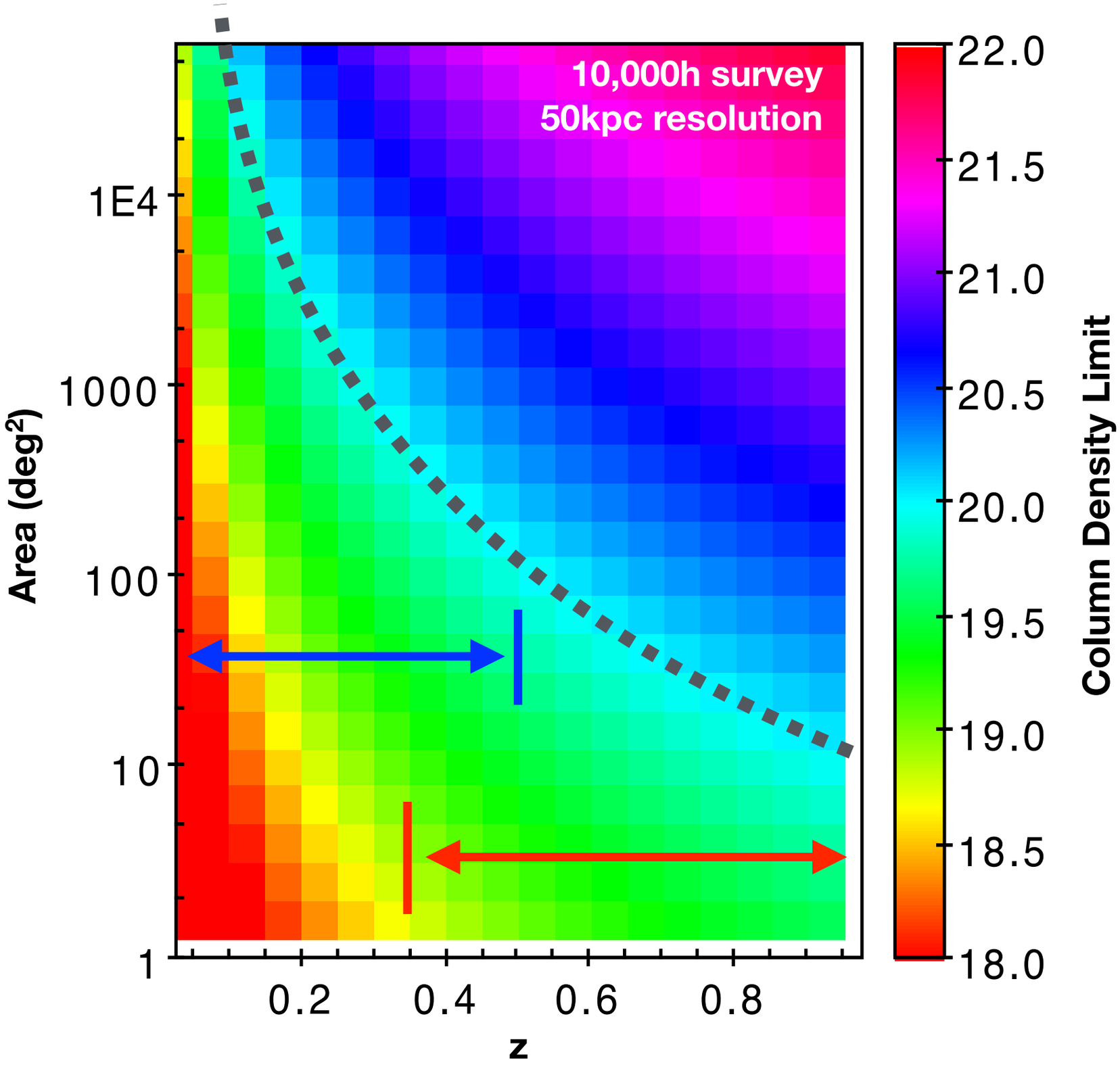
# What About Commensal 10,000 h?

**Requirements**

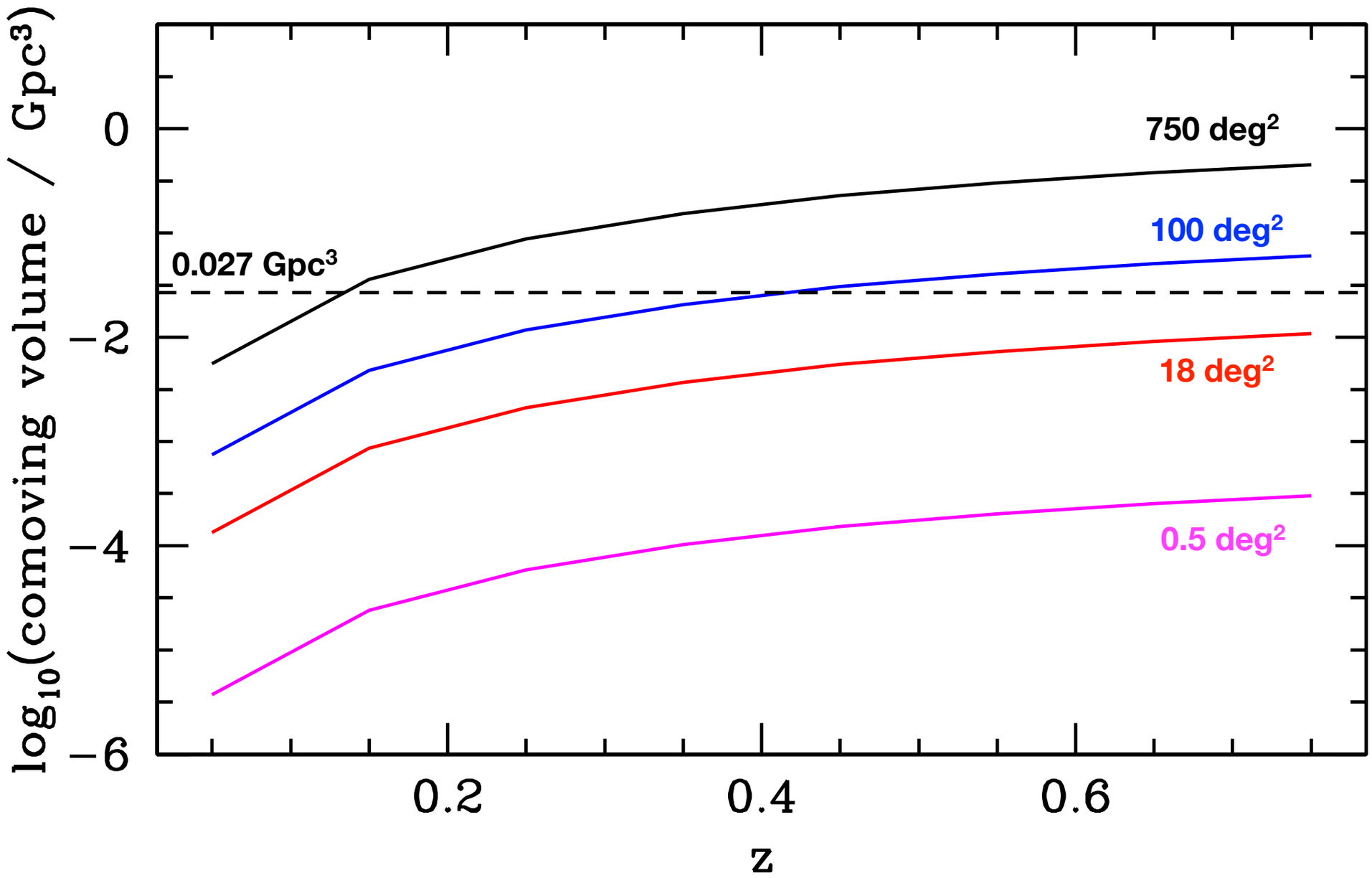
- Want to observe HI down to at least galactic scales
- SKA observation time is limited (~1000h KSPs)
- Time+beam+z+area sets column density limit
- Need $n_{HI} > 10^{20}$

**Preferred Surveys**

- band 2: ~10→100 deg$^2$
- band 1: ~1→10 deg$^2$



# SKA1 Survey Design: Volume

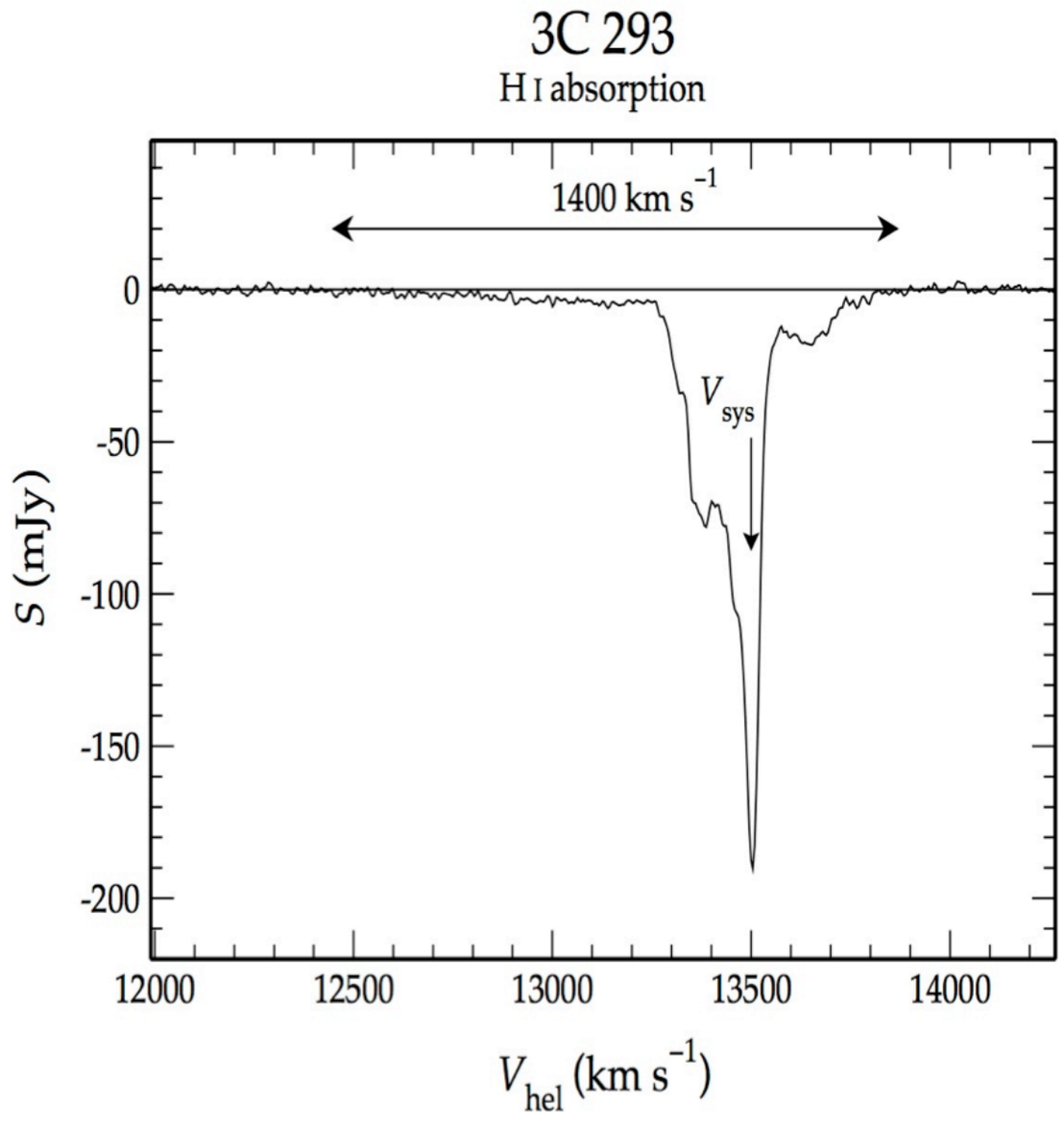


# HI at High-z: Absorption Studies

- HI 21-cm absorption spectroscopy provides a unique probe of cold neutral gas in normal and active galaxies *from redshift z > 6 to the present day*.

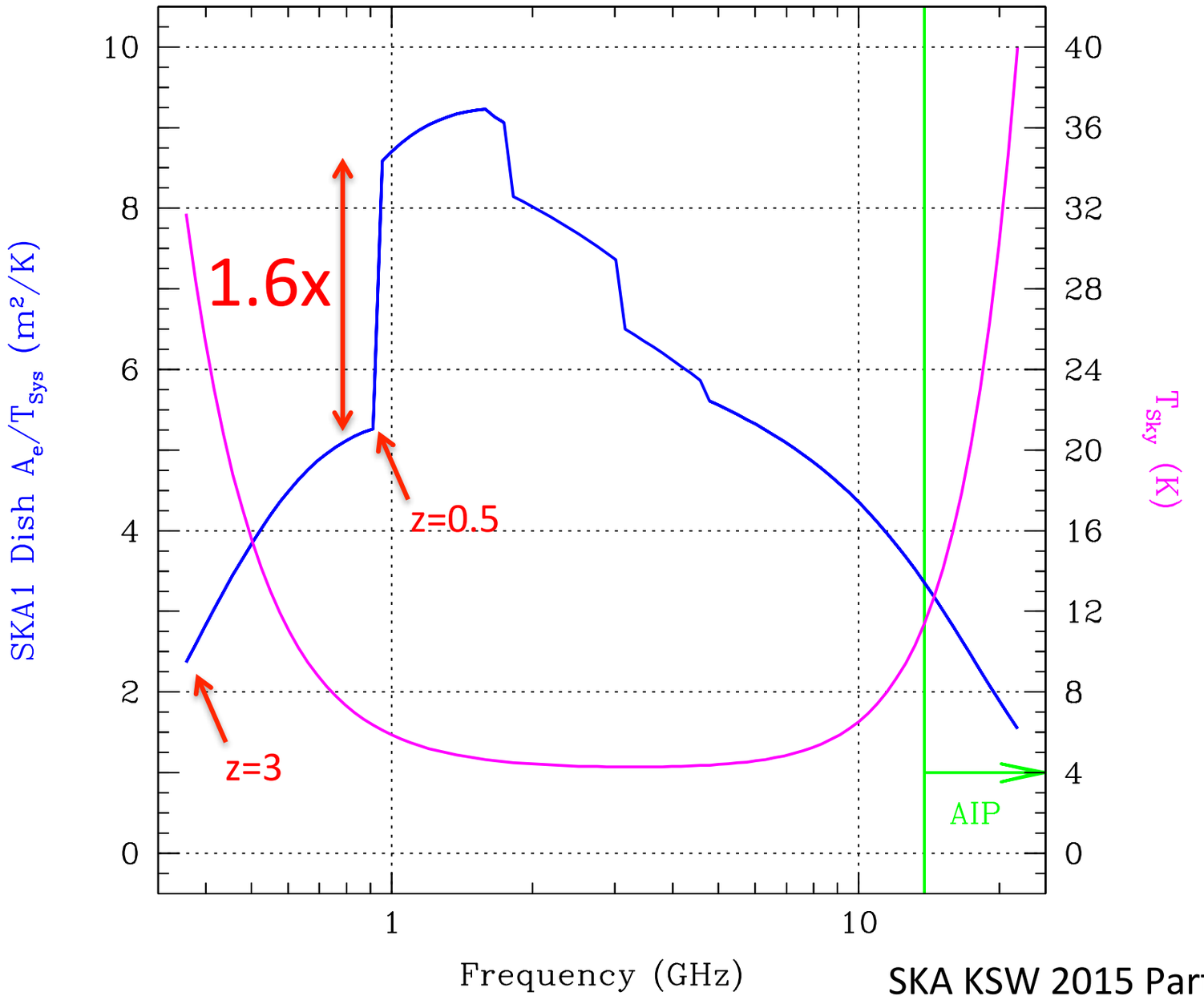
- Associated HI 21cm absorption → content of individual galaxies, structure of the central regions and the feeding and feedback of AGN.

- Intervening HI 21cm absorption → constrain the evolution of cold gas in normal galaxies over more than 12 billion years of cosmic time.




**Morganti et al, 2015, PoS, AASKA14, 134**

# SKA1-mid dish sensitivity




SKA KSW 2015 Participant Files

| | Baseline | ECP |
|---|---|---|
| Band 1 | 350 – 1050 MHz (z=0.35-3) | 450 – 825 MHz (z=0.7-2.1) |
| Band 2 | 950 – 1760 MHz (z<0.5) | 795 – 1470 MHz (z<0.8) |

# Possible SKA1 Surveys

**Minimum Requirements**

5 yr x 8000 h x 75% = 30000 h

| Survey | Area ($deg^2$) | Freq MHz | HI Resolution | <z> ($z_{lim}$) | T (hrs) |
|---|---|---|---|---|---|
| **Medium wide** | 400 | 950-1420 | 10" | 0.1 (0.3) | 2000 |
| **Medium deep** | 20 | 950-1420 | 5" | 0.2 (0.5) | 2000 |
| **Deep** | 1 pointing | 600-1050 | 2" | 0.5 (1) | 3000 |
| **Targeted ISM** | 30 targets | 1400-1420 | 3"-30" | 0.002 (0.01) | 3000 |
| **Targeted Accretion** | 30 targets | 1400-1420 | 30"-1" | 0.002 (0.01) | 3000 |
| **Galaxy/MS** | 500 | 1418-1422 | 10"-1' | 0 (0) | 4.500 |
| **Galaxy Abs** | (5000) | 1418-1422 | 2" | 0 (0) | (10.000) |
| **Absorption** | 1000+ | 350-1050 | 2" | 1 (3) | 1,000+ |
| | 1000 | 200-350 | 10" | 4 (6) | 1.000 |

**Updated from Staveley-Smith & Oosterloo, 2015, PoS, AASKA14, 167**

# Possible Commensal SKA1 Surveys

## Minimum Requirements

| Survey | Area ($deg^2$) | Freq MHz | T (hrs) | Magnetism | Cosmology/ EoR | Continuum |
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| **Deep** | 1 pointing | 600-1050 | 3000 | | | |
| **Targeted (ISM)** | 30 targets | 1400-1420 | 3000 | | | |
| **Targeted (Accr)** | (30 targets) | 1400-1420 | (3000) | | | |
| **Galaxy/MS** | 500 | 1418-1422 | 4500 | | | |
| **Galaxy Abs** | (5000) | 1418-1422 | (10000) | | | |
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() = commensal values

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| | 1000 | 200-350 | 1.000 | | fully commensal 5000 deg2 absorption survey | |

and commensal with medium-wide HI band 2

# Resourcing etc

- **Discussions on this still ongoing**
- **Much activity already with Pathfinders/Precursors**
- **Increased science contact with Office**
- **SKA SDP contacts**
- **Experience gained with**
  - source finders
  - calibration pipelines
  - archiving
  - re-processing
  - simulations
  - …

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