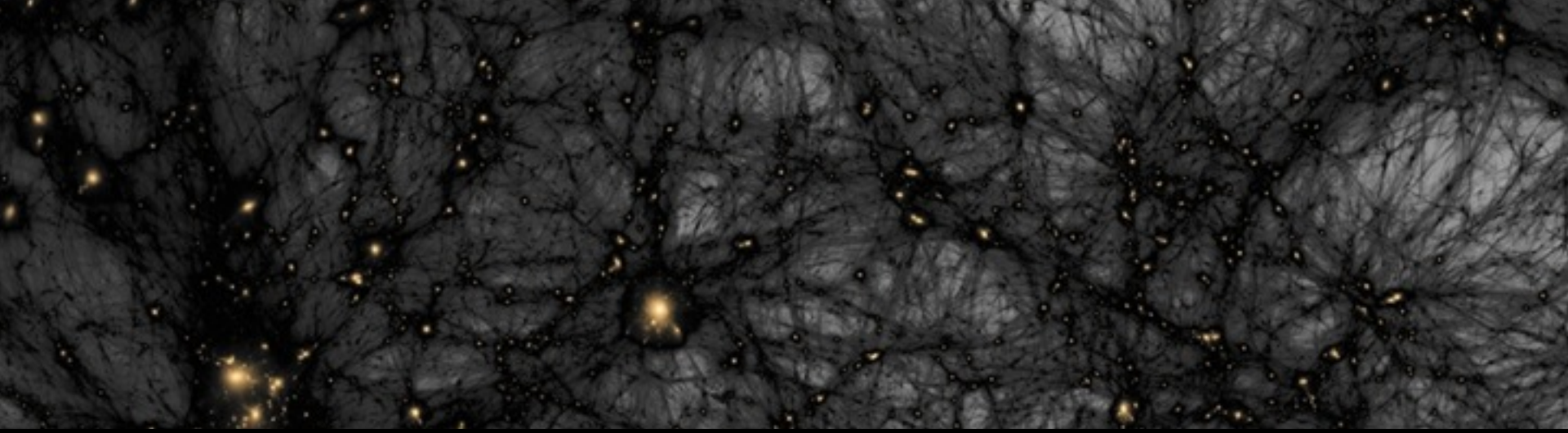


New frontiers in cosmology with SKA2 technologies

Alkistis Pourtsidou
ICG Portsmouth

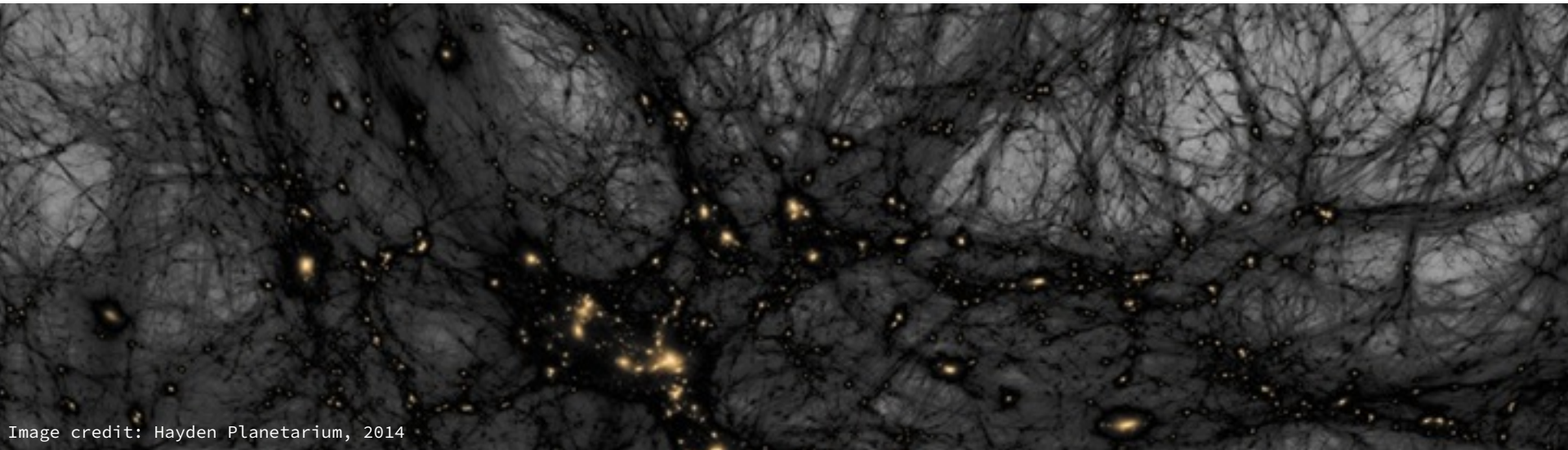


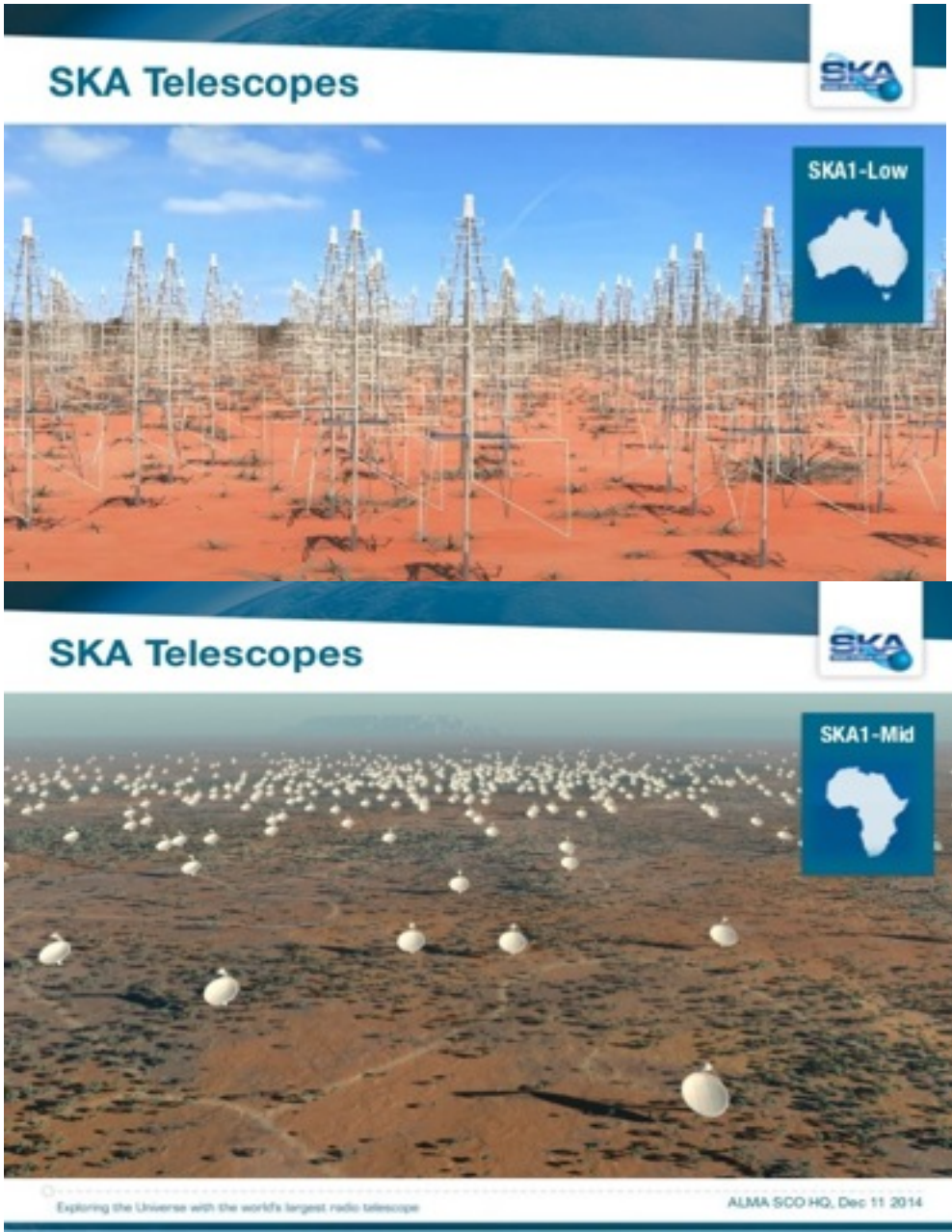
Image credit: Hayden Planetarium, 2014

PRECISION COSMOLOGY IN THE RADIO

- The SKA will kick off the "radio precision cosmology" era
- Competitive with optical (e.g. Euclid) at z<3
- Unique and transformational science at high redshifts (z>3)

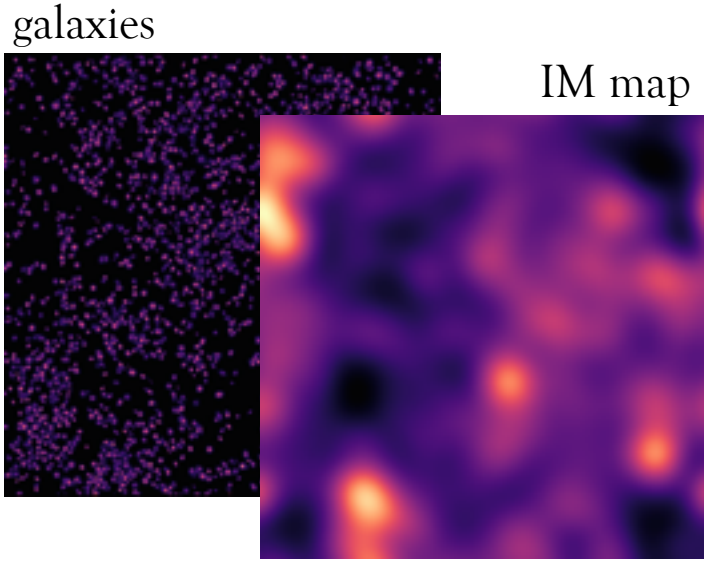
Precision radio cosmology

- Large sky "HI billion galaxy survey" with SKA2
- Intensity mapping
- New, transformative technologies!



THE INTENSITY MAPPING (IM) METHOD

[Battye et al 2004, Chang et al 2008, Peterson et al 2009, Seo et al 2010, …]



- HI galaxy detection hard
- Cosmological information is on large scales (beyond galaxy)
- Get intensity map of the HI 21cm emission line - like CMB but 3D!
- Excellent redshift resolution
- Challenge: Foregrounds

21cm IM surveys: GBT, BINGO, CHIME, HIRAX, MeerKLASS, SKA!

GOALS: Probe HI evolution, dark energy, gravity, inflation, …

Mid-frequency aperture arrays

- Frequencies 400-1500 MHz, dense AA, **e.g. EMBRACE pathfinder** [Torchinski et al 2016]
- Advantage wrt dishes: Very large FoV, multi-beams, very fast!
- Also great for IM, **e.g. MANTIS:** MFAA Transient and Intensity Mapping System [Cappellen et al 2016]

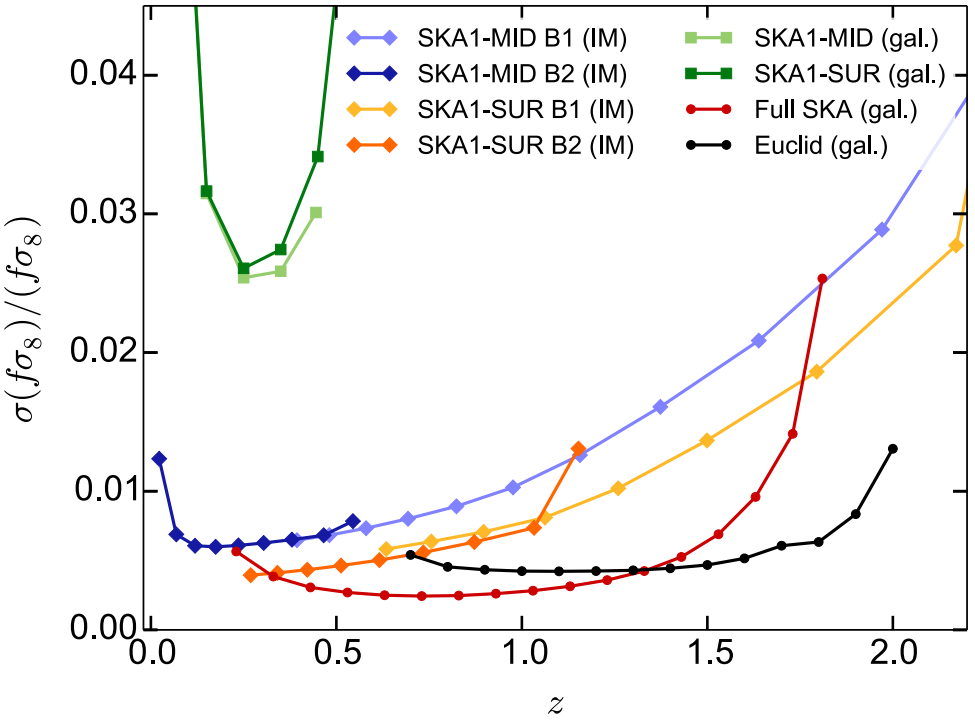
Phased array feeds & wide-band single-pixel feeds

- Dishes with single beam wide-band feed systems (1-10 GHz)
- PAFs at intermediate frequencies (0.3-1 GHz) extending the FoV, **e.g. ASKAP**

COSMOLOGY WITH THE SKA

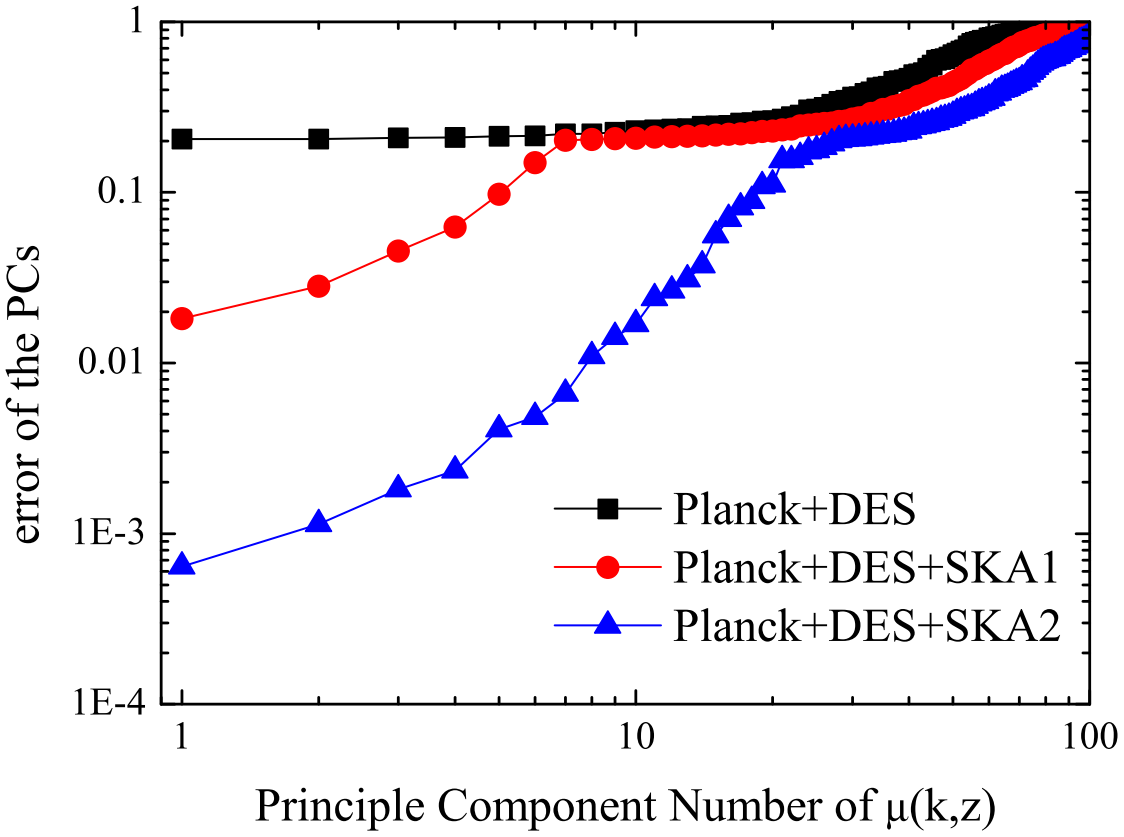
- **SKA1-Mid:** 200 dishes, can do precision cosmology using IM / same for **ASKAP**
- BAOs, RSDs, weak lensing, primordial non-gaussianity, GR tests, ...
- **SKA2-Mid:** 10x SKA1 sensitivity, orders of magnitude in speed
- MFAA is great for both "billion galaxy survey" and intensity mapping (out to z=2-3)
- FoV is key

dark energy



[SKA Science Book, Santos et al]

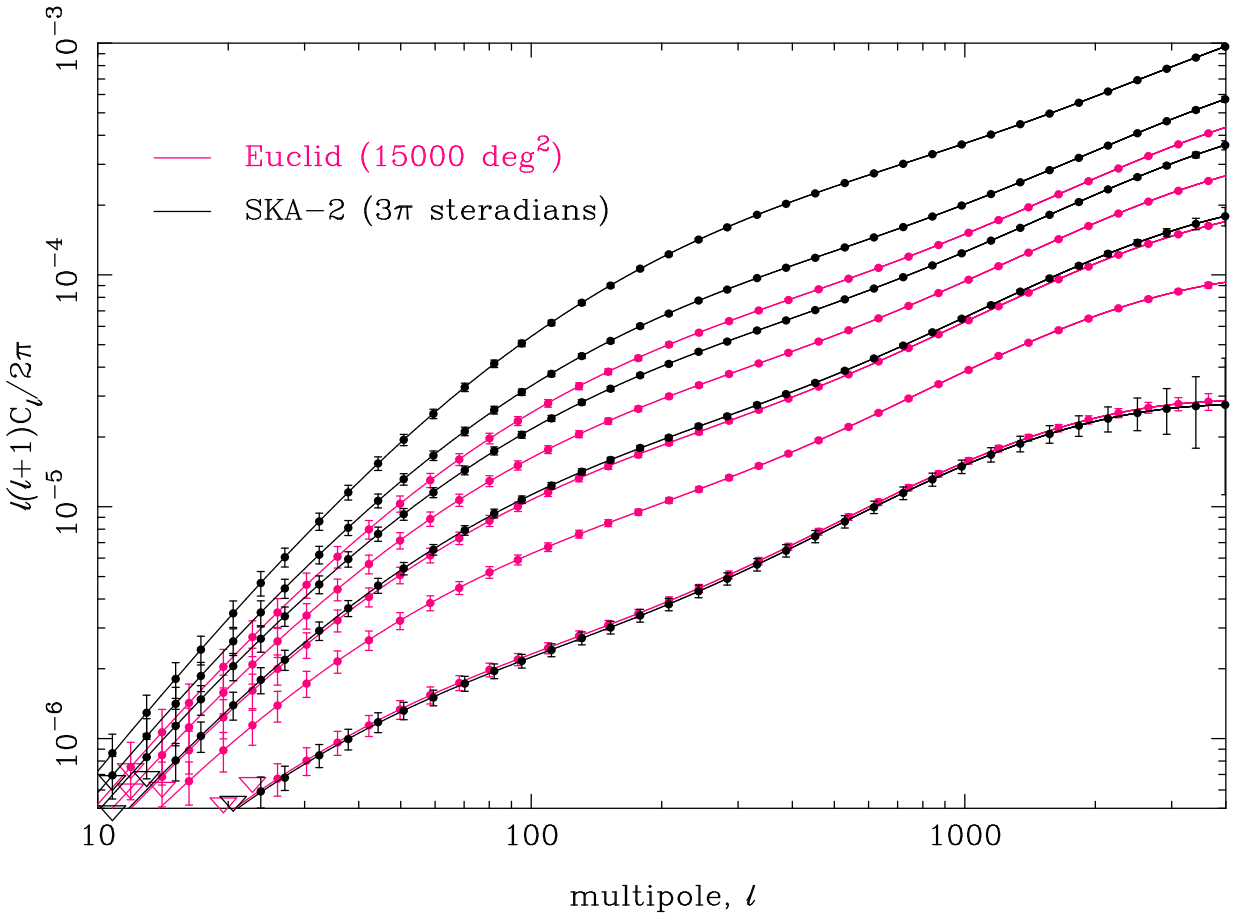
modified gravity



[SKA Science Book, Zhao et al]

COSMOLOGY WITH THE SKA

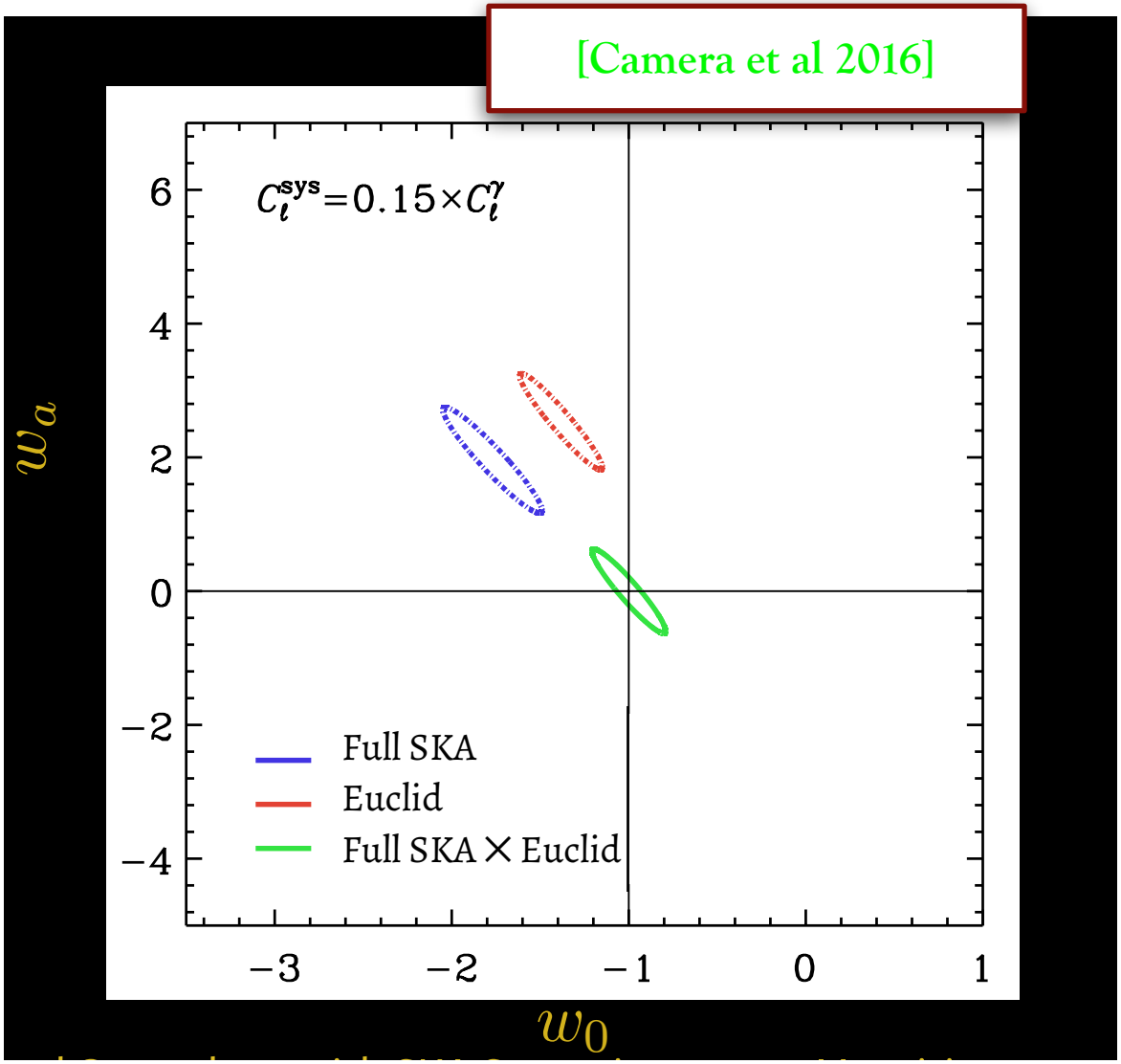
weak lensing



[SKA Science Book, Brown et al]

CROSS-CORRELATIONS

Less systematics to worry about: **the cosmic shear case**



SKA INTENSITY MAPPING

- **Important requirements for MFAA:** Short baselines < 5 m to probe the large scales, compact core, big volume
- Constraints competitive with Stage IV optical

[Bull et al 2015]

$$\Omega_K = 0.0 \pm 0.0014$$

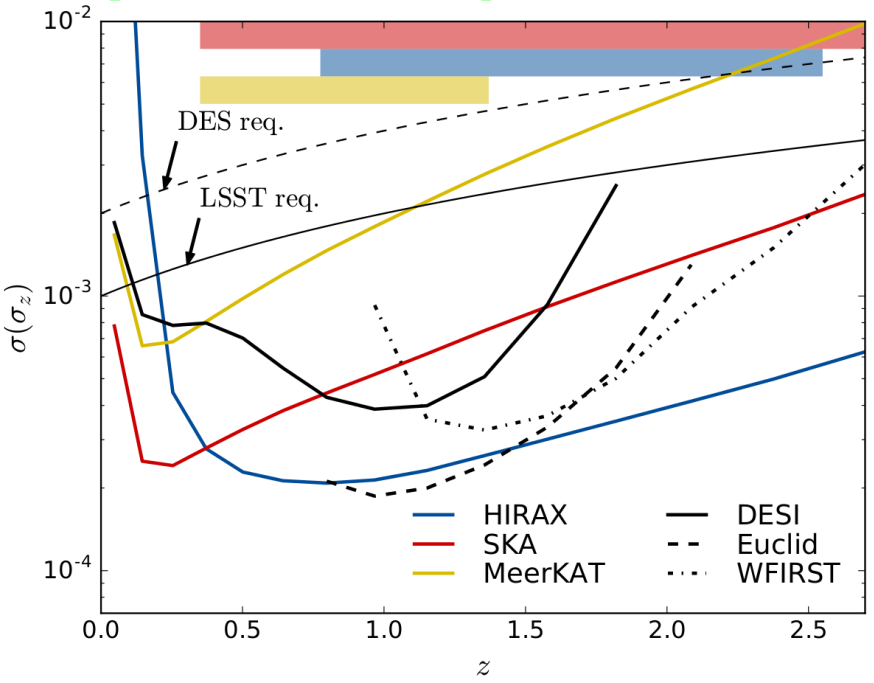
$$\Omega_{DE} = 0.684 \pm 0.009$$

$$\gamma = 0.55 \pm 0.03$$

$$w_0 = -1.0 \pm 0.06$$

- IM also great for **photo-z calibration**
- This would be a great science case in synergy with DES and LSST

[Alonso et al 2017]



SKA INTENSITY MAPPING

PAFs: In "single-dish" mode they greatly increase the signal-to-noise ratio

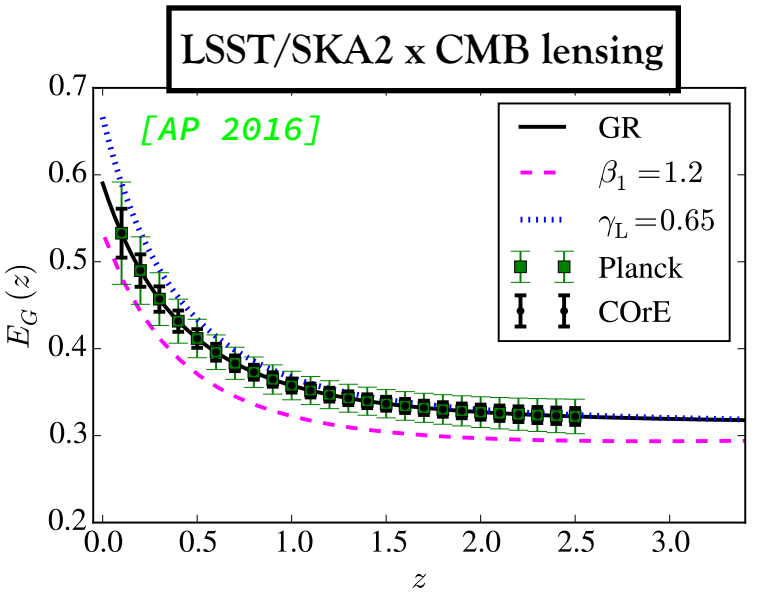
$$P_{\rm N} \propto \frac{1}{N_{\rm d} N_{\rm b} t_{\rm tot}}$$

- E.g. **SKA1-SUR-like** survey can beat Stage IV optical galaxy surveys on DE constraints via BAOs and RSDs measurements
- Ultra-large scales, high sensitivity at high z → $f_{\rm NL}$
- Relativistic corrections
- Spatial curvature
- Isotropy tests
- Multiple tracers (more later)

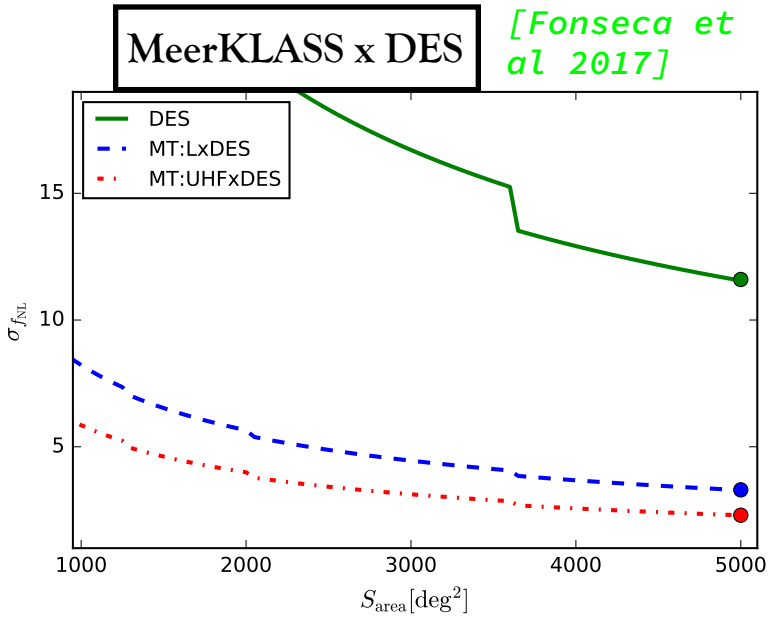
In interferometer mode they increase instantaneous FOV and smaller scales can be probed.

Cross-correlations & Multi-tracers

- Cross-correlate everything...
- Extremely useful for systematics mitigation
- Robust systematics-free constraints
- Multi-wavelength cosmological tests!
- Need large volume covered fast - new SKA technologies!



- Multi-tracers technique for large scales - no cosmic variance!
- Potentially revolutionising...
- Needs tracers with very different biases
- **Radio and optical communities need to work together on this!**

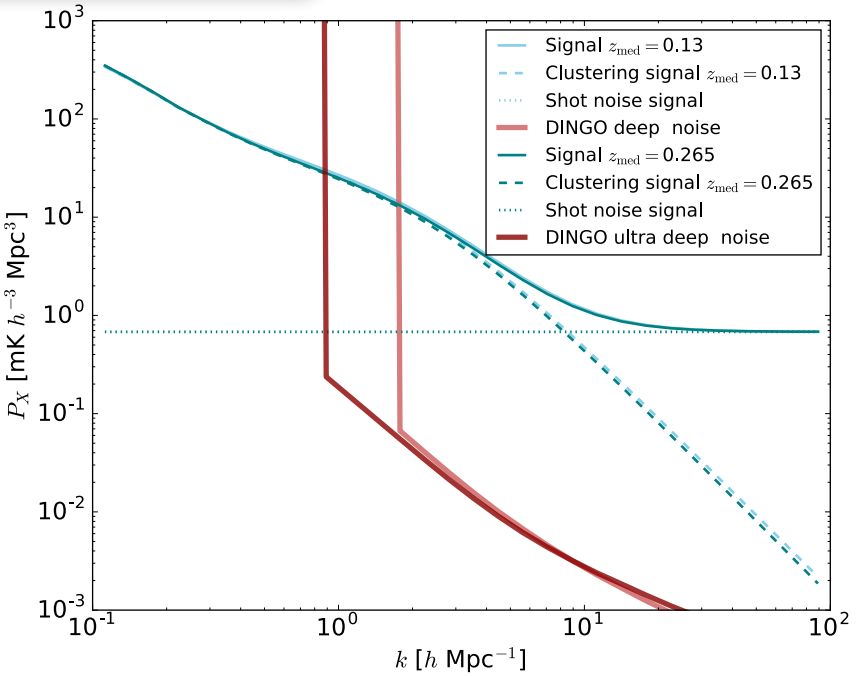


HI AND GALAXY EVOLUTION

- Cross-shot noise scales as average HI mass of gal sample $\frac{\overline{T}_{\mathrm{HI},g}}{n_g}$
- Probes the HI content of optical galaxies
- Constrain HI-SFR scaling relations for wide redshifts
- **Large FOV very important!**

ASKAP DINGO forecast

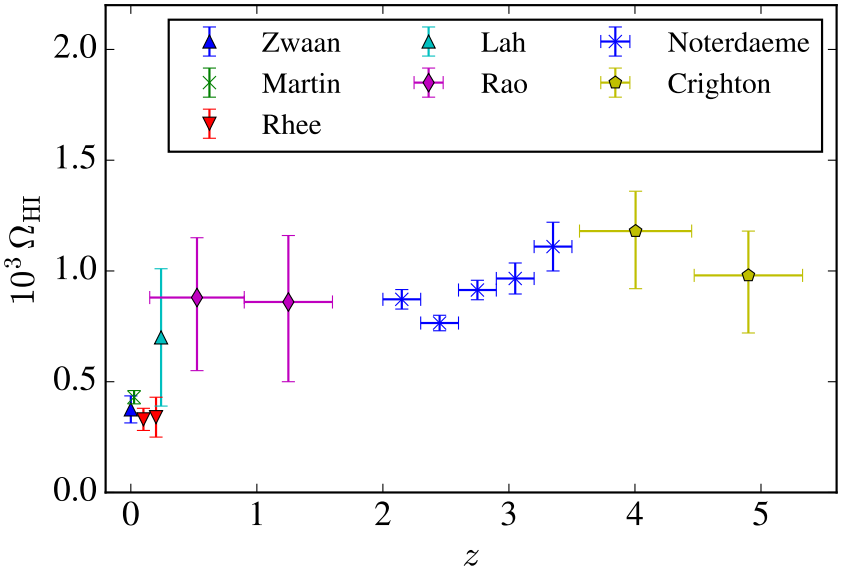
Wolz et al 2017; 1703.0826



HI AND GALAXY EVOLUTION

- **HI abundance and bias are currently poorly constrained**
- Important for galaxy evolution and cosmology alike!

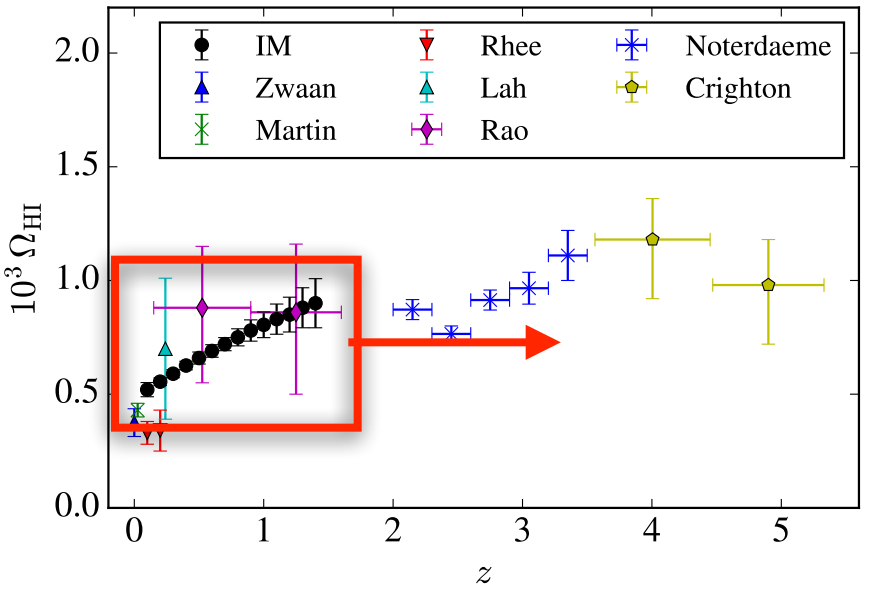
[AP 2017, c.f. Crighton et al 2015]



HI AND GALAXY EVOLUTION

- **HI abundance and bias are currently poorly constrained**
- Important for galaxy evolution and cosmology!
- Can get good constraints with SKA1 IM
- SKA2 unmatched!

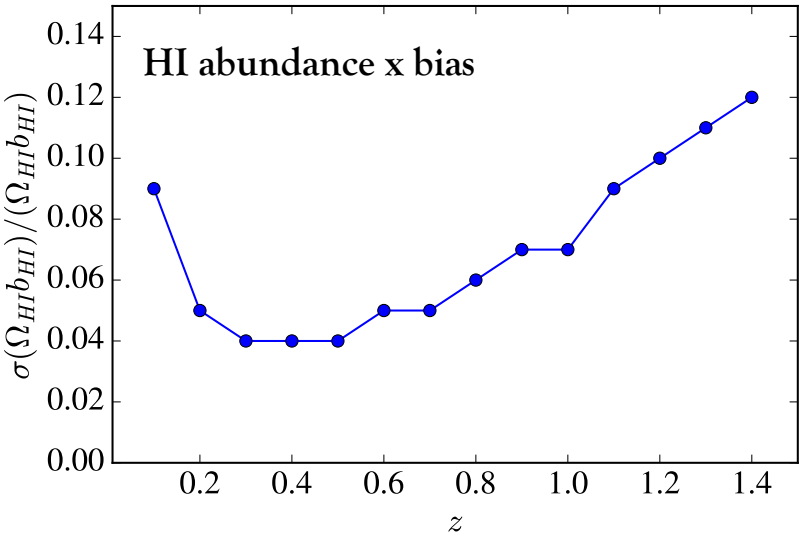
[AP et al 2016]



Radio continuum survey [see Jess' talk]

- Wide field, **high-resolution**, 3 billion galaxies!
- Star formation at high z
- Weak/Strong lensing, ISW effect
- Combine with HI gal/IM survey to get redshifts!

[SKA1 IM x DES] [AP et al 2016]

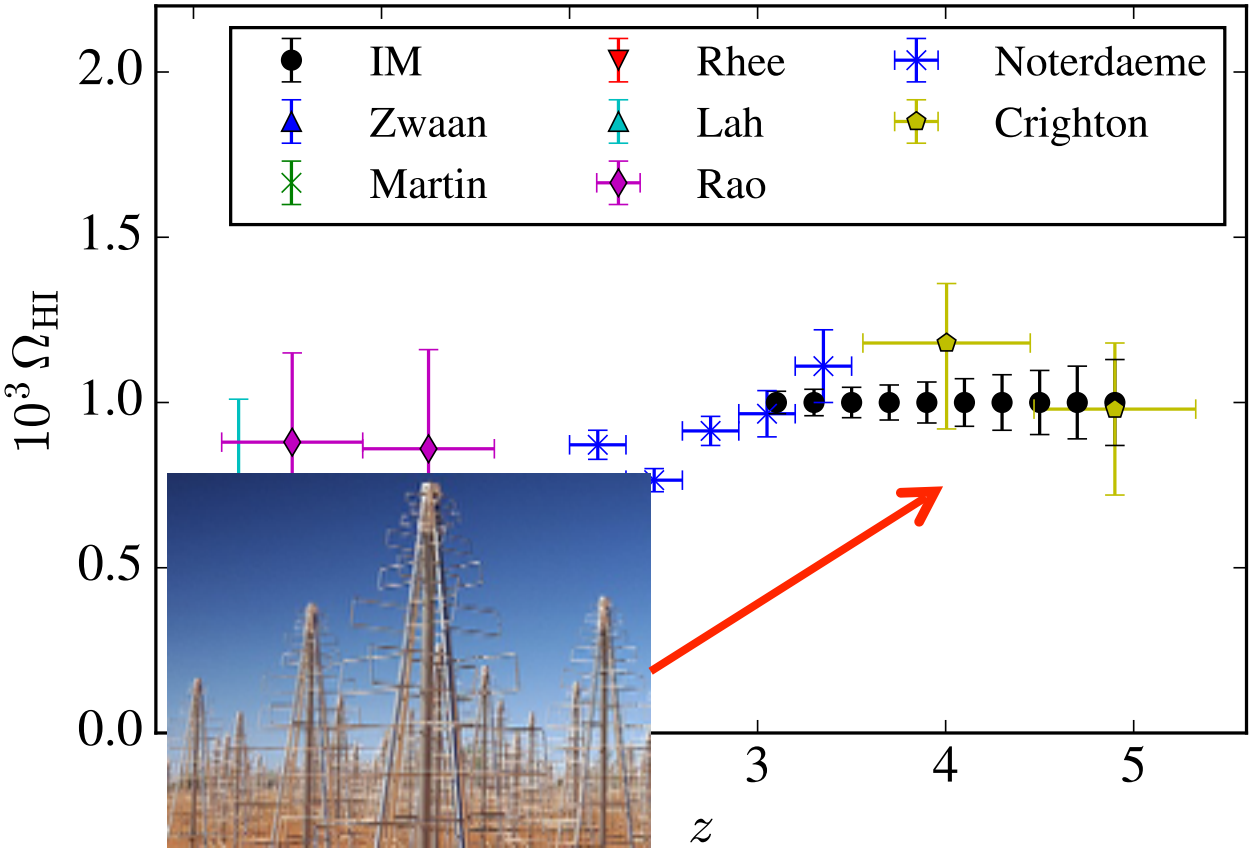


COSMOLOGY WITH SKA1-LOW

Intensity Mapping Survey with SKA1-Low at 3<z<5

[AP & Pritchard]

- Can get IM maps with SKA-Low at 200-350 MHz
- Use them to constrain HI and cosmology
- Synergies with SKA-Mid, BOSS Ly-α, ...
- **Large sky IM survey with SKA2-Low could do transformational neutrino science**

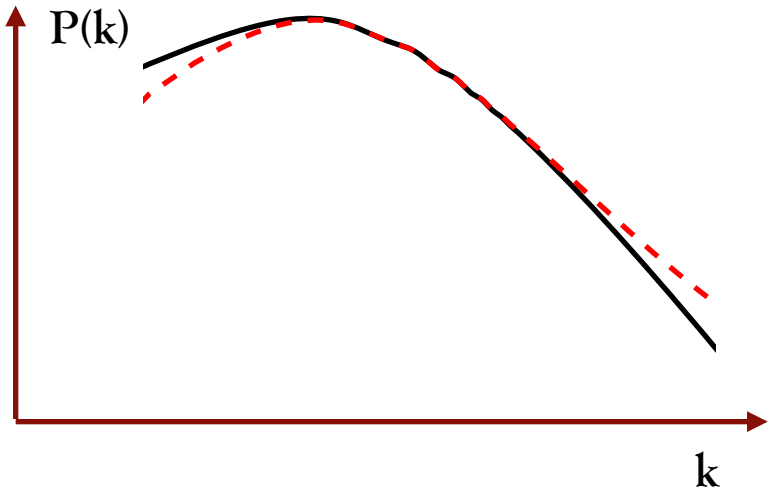


[Chapman, AP, Pritchard, Wolz 2017]

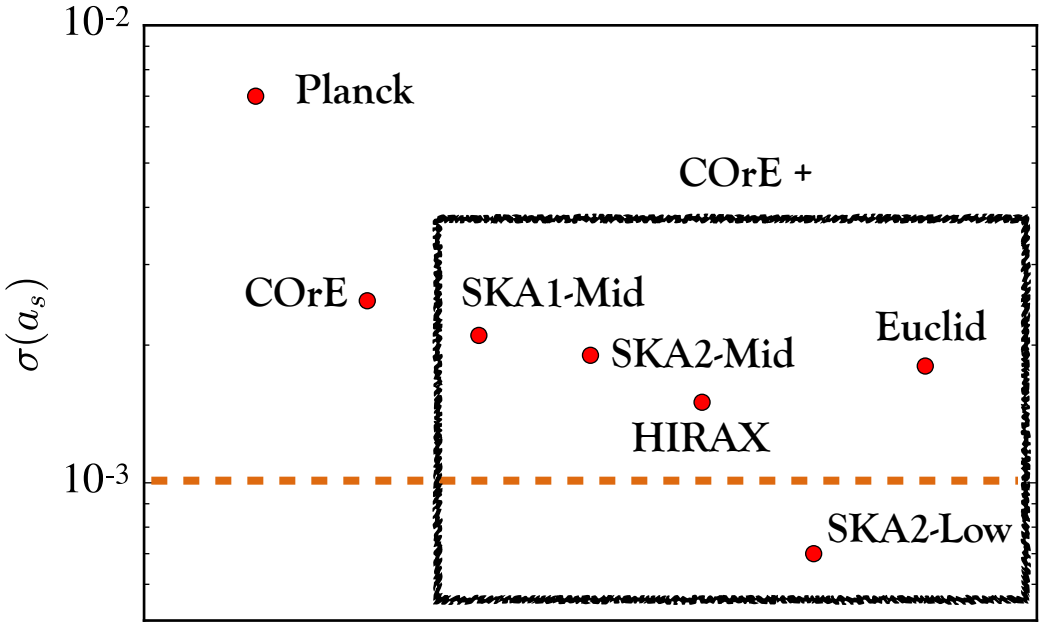
COSMOLOGY WITH SKA-LOW

Combine 21cm intensity mapping, optical galaxy, and CMB surveys, to constrain the inflationary parameters (n_s, α_s, β_s) *[AP arXiv:1612.05138]*

- Need to reach $\sigma(\alpha_s) < 0.001$



$$P_{\rm s}(k) = A_{\rm s}\left(\frac{k}{k_\star}\right)^{n_{\rm s}-1+\frac{1}{2}\alpha_{\rm s}\ln(k/k_\star)+\frac{1}{6}\beta_{\rm s}\ln^2(k/k_\star)}$$



CMB + high-z intensity mapping survey can severely constrain single-field inflation (via first running).
Also great for neutrino constraints!

OUTLOOK

- New technologies will revolutionise the capabilities of SKA for cosmology
- Large FoV is great!
- **Key large-scale cosmology cases:** Dark Energy, Gravity, Inflation (non-gaussianity), Neutrinos
- **Synergies with optical, mainly Euclid and LSST**
- **What about uniqueness?** SKA-Low - not just EoR, but also post-EoR ($3<z<6$) can result to transformational science!