COSMOLOGY WITH THE SKA

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(on behalf of the Cosmology SWG)
Stockholm, August 24, 2015

UNIVERSITY of the WESTERN CAPE
SKA AFRICA
SQUARE KILOMETRE ARRAY

Big questions in Cosmology

- Why is the expansion of the Universe accelerating? Dark energy? Modified gravity?
- What is the nature of the primordial Universe? Inflation? Is the primordial spectrum of perturbations non-Gaussian?
- Does the General Theory of Relativity really applies to cosmological scales, or does it needs modification?
- Is the Universe really isotropic and homogeneous? Is the Universe really flat? Is the Universe really expanding?
- SKA will not only measure cosmological parameters with more precision, but will answer fundamental questions in cosmology: needs a balance between “precision cosmology” and “discovery cosmology”

Science Review Panel priority cases

1. "Map the 3D matter distribution on the largest scales and deepest redshifts ever – in order to obtain transformational constraints on primordial non-Gaussianity and to perform the first tests of gravity on super-horizon scales."
   - **Require a large HI intensity mapping survey**
2. "Probe the initial conditions and the global features of the Universe through non-Gaussianity and the dipole in the matter distribution using high precision measurements of the angular correlation functions."
   - **Require a large continuum survey**

- Extra "headline" science: Map the distribution of HI on cosmological scales from z=20 to z=0 ("make a movie of the Universe!")

- SWG first goal: make sure that at least the two top cases are delivered by the SKA and try to achieve other Cosmology cases by taking advantage of other SKA surveys

SKA Cosmology chapters

- 21 chapters: SKA will be an extremely productive “Cosmology machine”!
- (72 Cosmology SWG members)

Session 2: Cosmology

Overview of Cosmology with the SKA
PoS(AASKA14)016 pdf *R. Maartens, F.B. Abdalla, M. Jarvis and M.G Santos*

Cosmology from HI galaxy surveys with the SKA
PoS(AASKA14)017 pdf *F.B. Abdalla, P. Bull, S. Camera, A. Benoit Levy, B. Joachimi, D. Kirk, H.R. Kloeckner, R. Maartens, A. Raccanelli, M.G Santos and G.B. Zhao*

Cosmology with SKA Radio Continuum Surveys
PoS(AASKA14)018 pdf *M. Jarvis, D. Bacon, C. Blake, M. Brown, S. Lindsay, A. Raccanelli, M. Santos and D.J. Schwarz*

Cosmology from a SKA HI intensity mapping survey
PoS(AASKA14)019 pdf *M. Santos, P. Bull, D. Alonso, S. Camera, P. Ferreira, G. Bernardi, R. Maartens, M. Viel, F. Villaescusa-Navarro, F.B. Abdalla, M. Jarvis, R.B. Metcalf, A. Pourtsidou and L. Wolz*

Cross correlation surveys with the Square Kilometre Array
PoS(AASKA14)020 pdf *D. Kirk, F.B. Abdalla, A. Benoit Levy, P. Bull and B. Joachimi*

HI galaxy simulations for the SKA: number counts and bias
PoS(AASKA14)021 pdf *M. Santos, D. Alonso, P. Bull, M.B. Silva and S. Yahya*

Weak gravitational lensing with the Square Kilometre Array
PoS(AASKA14)023 pdf *M. Brown, D. Bacon, S. Camera, I. Harrison, B. Joachimi, R.B. Metcalf, A. Pourtsidou, K. Takahashi, J. Zuntz, F.B. Abdalla, S. Bridle, M. Jarvis, T. Kitching, L. Miller and P. Patel*

Measuring baryon acoustic oscillations with future SKA surveys
PoS(AASKA14)024 pdf *P. Bull, S. Camera, A. Raccanelli, C. Blake, P. Ferreira, M. Santos and D.J. Schwarz*

Cosmology on the Largest Scales with the SKA
PoS(AASKA14)025 pdf *S. Camera, A. Raccanelli, P. Bull, D. Bertacca, X. Chen, P. Ferreira, M. Kunz, R. Maartens, Y. Mao, M. Santos, P.R. Shapiro, M. Viel and Y. Xu*

Real time cosmology - A direct measure of the expansion rate of the Universe with the SKA
PoS(AASKA14)027 pdf *H.R. Kloeckner, D. Obreschkow, C. Martins, A. Raccanelli, D. Champion, A.L. Roy, A. Lobanov, J. Wagner and R. Keller*

Weak Lensing Simulations for the SKA
PoS(AASKA14)030 pdf *P. Patel, I. Harrison, S. Makhathini, F.B. Abdalla, D. Bacon, M. Brown, M. Jarvis, O. Smirnov and I. Heywood*

Measuring redshift-space distortion with future SKA surveys
PoS(AASKA14)031 pdf *A. Raccanelli, P. Bull, S. Camera, C. Blake, P. Ferreira, R. Maartens, M. Santos, P. Bull, D. Bacon, O. Dore, P. Ferreira, M.G Santos, M. Viel and G.B. Zhao*

Testing foundations of modern cosmology with SKA all-sky surveys
PoS(AASKA14)032 pdf *D.J. Schwarz, D. Bacon, S. Chen, C. Clarkson, D. Huterer, M. Kunz, R. Maartens, A. Raccanelli, M. Rubart and J.L. Starck*

Topology of neutral hydrogen distribution with the Square Kilometre Array
PoS(AASKA14)033 pdf *Y. Wang, Y. Xu, F. Wu, X. Chen, X. Wang, J. Kim, C. Park, K.G. Lee and R. Cen*

Cosmology with galaxy clusters: studying the Dark Ages and the Epoch of Reionization in the SKA era
PoS(AASKA14)034 pdf *S. Colafrancesco, P. Marchegiani and M.S. Emritte*

Foreground Subtraction in Intensity Mapping with the SKA
PoS(AASKA14)035 pdf *L. Wolz, F.B. Abdalla, D. Alonso, C. Blake, P. Bull, T.C. Chang, P. Ferreira, C.Y. Kuo, M. Santos and J.R. Shaw*

Model-independent constraints on dark energy and modified gravity with the SKA
PoS(AASKA14)165 pdf *G. Zhao, D. Bacon, R. Maartens, M. Santos and A. Raccanelli*

Stacking of SKA data: comparing uv-plane and and image-plane stacking
PoS(AASKA14)168 pdf *K.K. Knudsen, L. Lindroos, W.H.T. Vlemmings, J.E. Conway and I. Marti-Vidal*

- http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=215#session-2107

SKA Cosmology in the media…

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SKA – Cutting-edge Astronomy in SA

11 February 2015, 15:00 Share:

Scientists from around the world are lining up to participate in the world's biggest science experiment, South Africa's Square Kilometre Array. Hidden deep in the Karoo, SKA will enable us to look back to the origin of life and answer questions we haven't even thought o yet.

The massive Square Kilometre Array (SKA) telescope, to be built in a collaboration between Australia and South Africa, will allow scientists to look far back into the history of the cosmos and give more detail than ever before on how the universe has evolved and how stars and galaxies formed. It will also ultimately allow for the plotting of a 3D map of the universe.

CAPE TIMES

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SKA telescope poised to map history of the universe

January 21 2015 at 07:01am

Staff Writer

THE Square Kilometre Array (SKA) telescope in the

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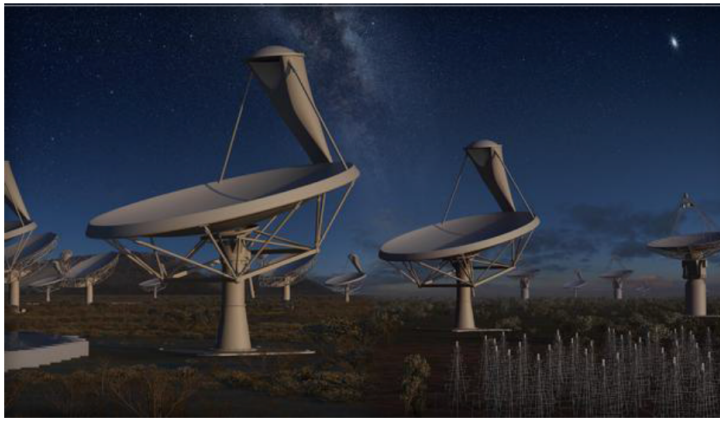
How South African scientists plan to map the universe, yes really

By **MICHAEL CASEY** / **CBS NEWS** / *February 6, 2015, 12:06 PM*

Team sets out to map universe, unraveling its mysteries along the way



An artist rendering of the Square Kilometer Array, which will be the largest telescope ever built and tasked with mapping the universe. / **SKA ORGANISATION**

4 Comments / Shares / Tweets / Stumble / Email Mor

It is one thing to draw up a map of the United States or even Earth.

But the entire universe?

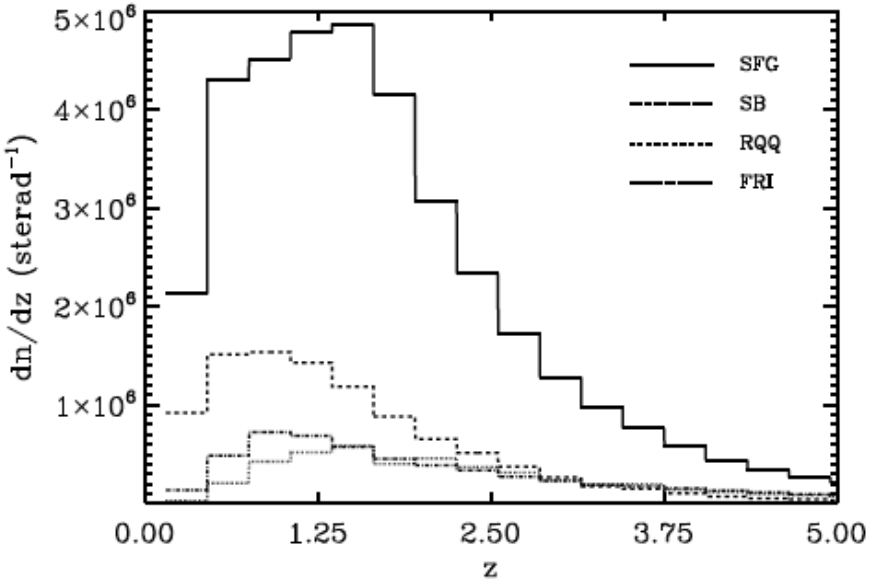
SKA Cosmology KSPs

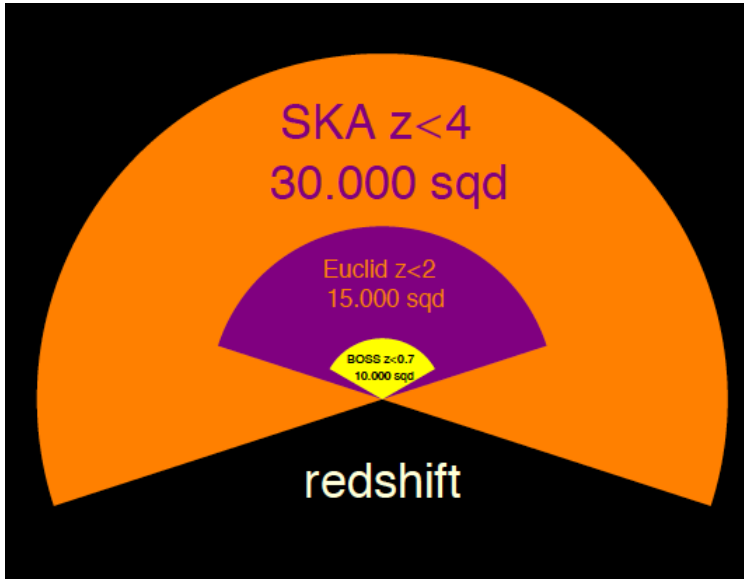
- Current ideas:
  - Distinction between KSPs and telescope surveys
  - KSPs should revolve around major data analysis/calibration efforts, with requirements for large focused teams ("like an experiment using the SKA facility")
  - More focused scientific products should become work packages within a KSP
  - Great effort should be put on obtaining commensality both in terms of surveys and human resources – this will provide huge savings later on…
  - 5 Cosmology KSPs are "on the table" at the moment as a starting point for discussions (for SKA1) ->

Ongoing discussions on the wiki: http://skacosmology.pbworks.com

KSP: Cosmology with a continuum survey

- Should produce the largest catalogue of galaxies ever, over the all sky
- ~ 5x10^8 galaxies, ~ 1 uJy rms (SKA1 should detect ~ 20 times more galaxies than pathfinders with better resolution)
- "Full" sky survey ~ 30,000 deg^2
- Will need about 10,000 hours
- ~0.5 arcsec resolution in order to identify FR galaxies

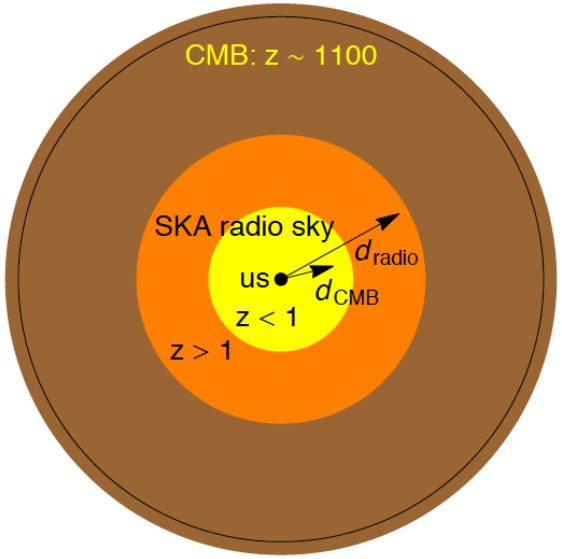




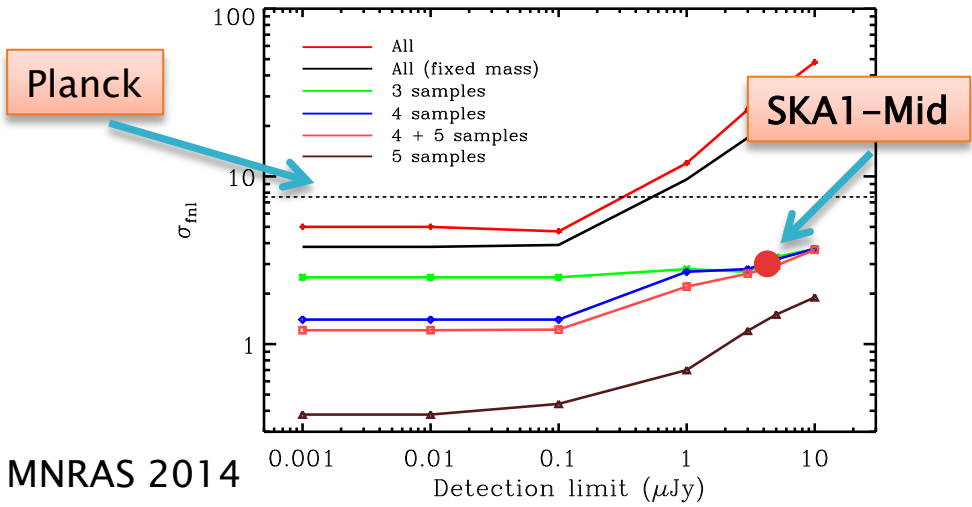
See summary in Jarvis et al., arXiv:1501.03825v1

KSP: Cosmology with a continuum survey

- Outputs:
  - Constrain dark energy and modified gravity through correlation with photometric surveys and the CMB (ISW)
  - Tests of isotropy (CMB anomalies?)
  - Test if the cosmological dipole (with radio-galaxies) is the same as the CMB one
  - Constrain primordial non-Gaussianity/inflation



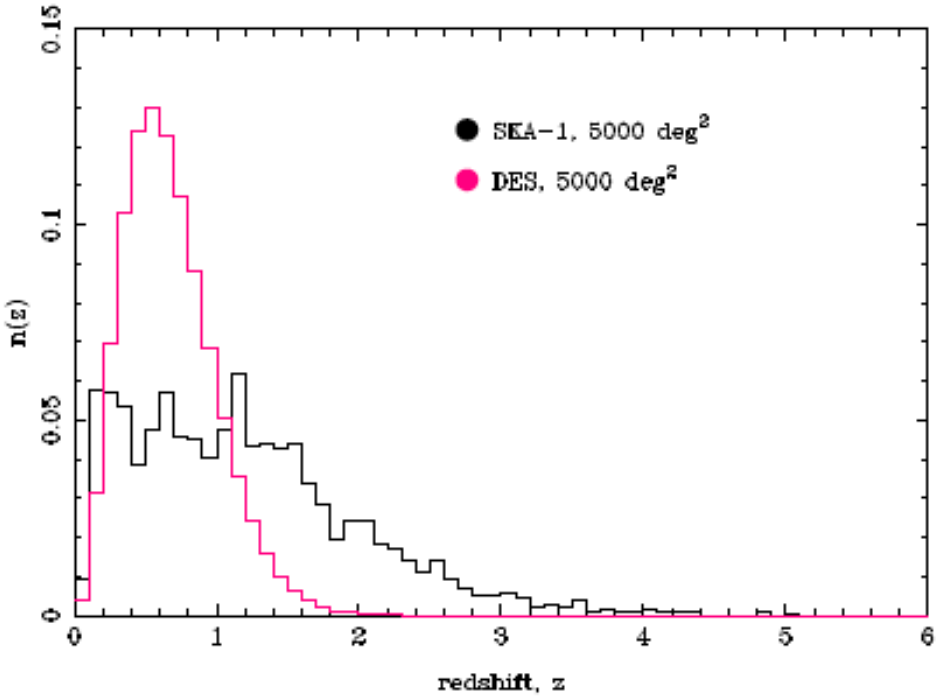
D. J. Schwarz, et al., PoS(AASKA15), SKA chapters, 2015



Ferramacho et. al, MNRAS 2014

KSP: Galaxy weak lensing survey

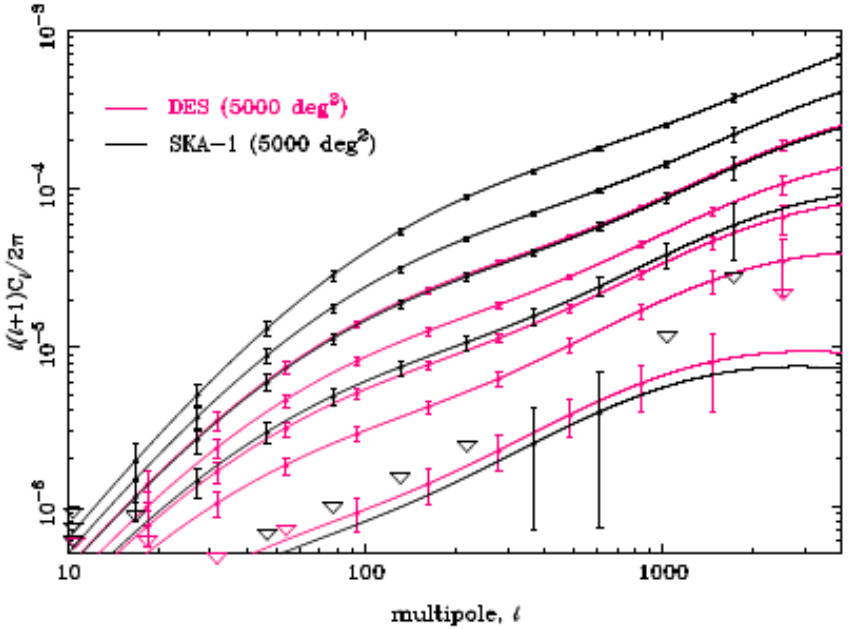
- The largest weak lensing survey ever done in the radio
- Highly complementary to optical surveys
- Crucial to set the path for SKA2
- Need ~ 3 (usable) galaxies per arcmin^2 (at least)
- ~ 5,000 deg^2
- ~ 0.5 arcsec resolution (or equivalent uv coverage for shape measurements)
- KSP or Work package within Cosmology continuum KSP?

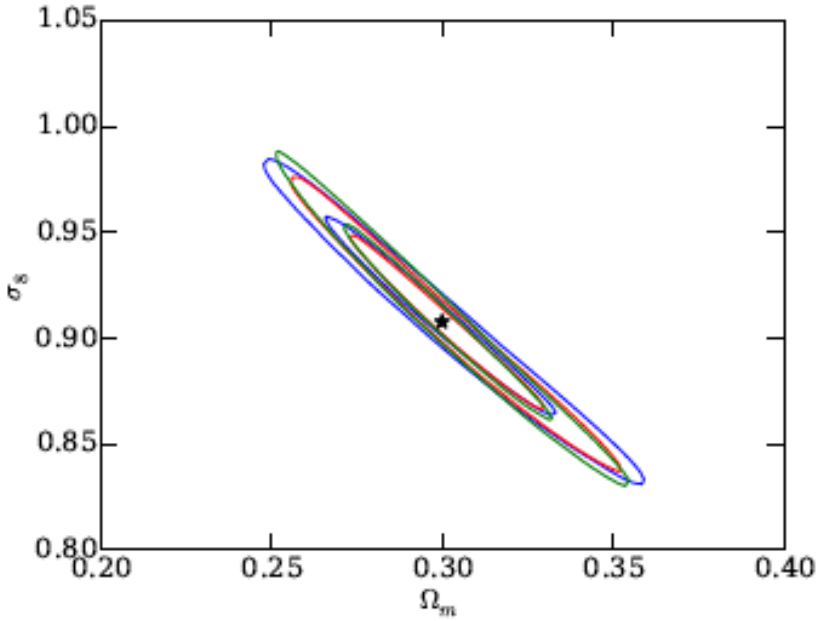


See: Brown et al., PoS(AASKA14)023

KSP: Galaxy weak lensing survey

- Can probe higher redshifts
- Synergies with optical to reduce systematics
- Unique Advantage in radio: polarization and rotation velocity as indicators of intrinsic alignment
- Not competitive with Euclid expectations but will provide different approach and prepare for SKA2 – "piggy-back" on other survey?

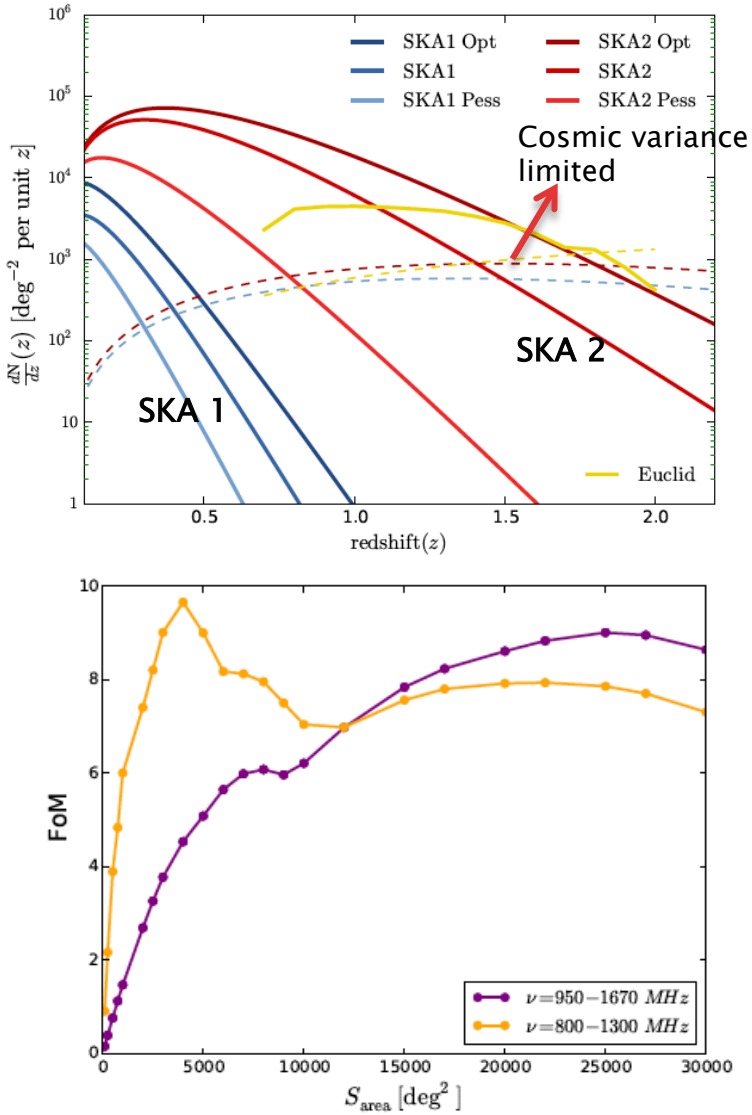




Red: 1-sigma/2-sigma constraints for 5,000 deg² (~ DES like)

KSP: Cosmology with a HI galaxy survey

- First cosmological survey with HI galaxies (10^7 galaxies!)
- Great probe for redshift space distortions
- Given SKA1 sensitivity, focus on redshifts $z < 0.8$
- Optimal survey area ~ 5,000 deg^2 (although 25,000 deg^2 can be acceptable)
- Propose new band2 definition in order to optimize HI science: 750 – 1450 MHz

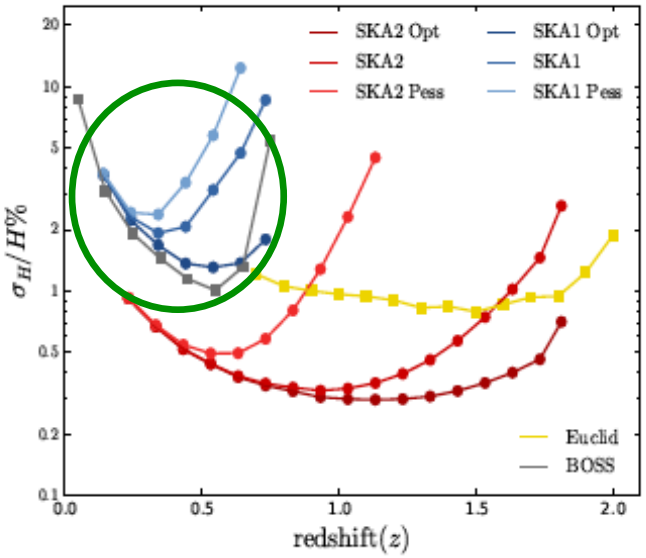


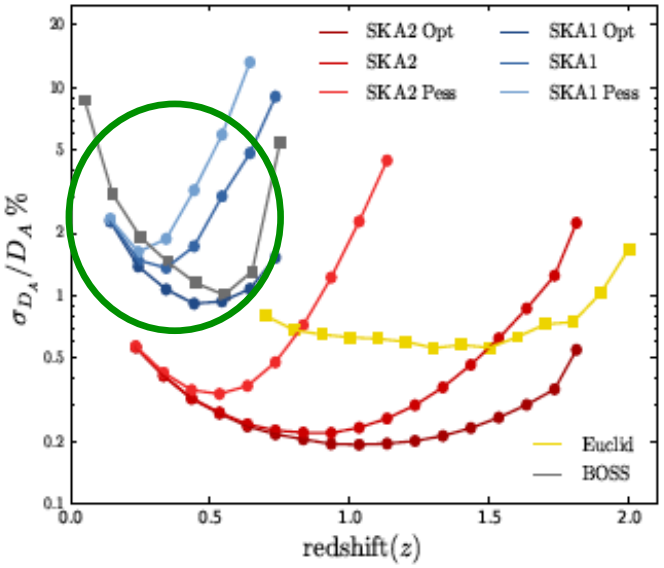
See summary in Abdalla et al., PoS(AASKA14)017

See Santos et al., PoS(AASKA14)017
Yahya et al., MNRAS, http://arxiv.org/abs/1412.4700

KSP: Cosmology with a HI galaxy survey

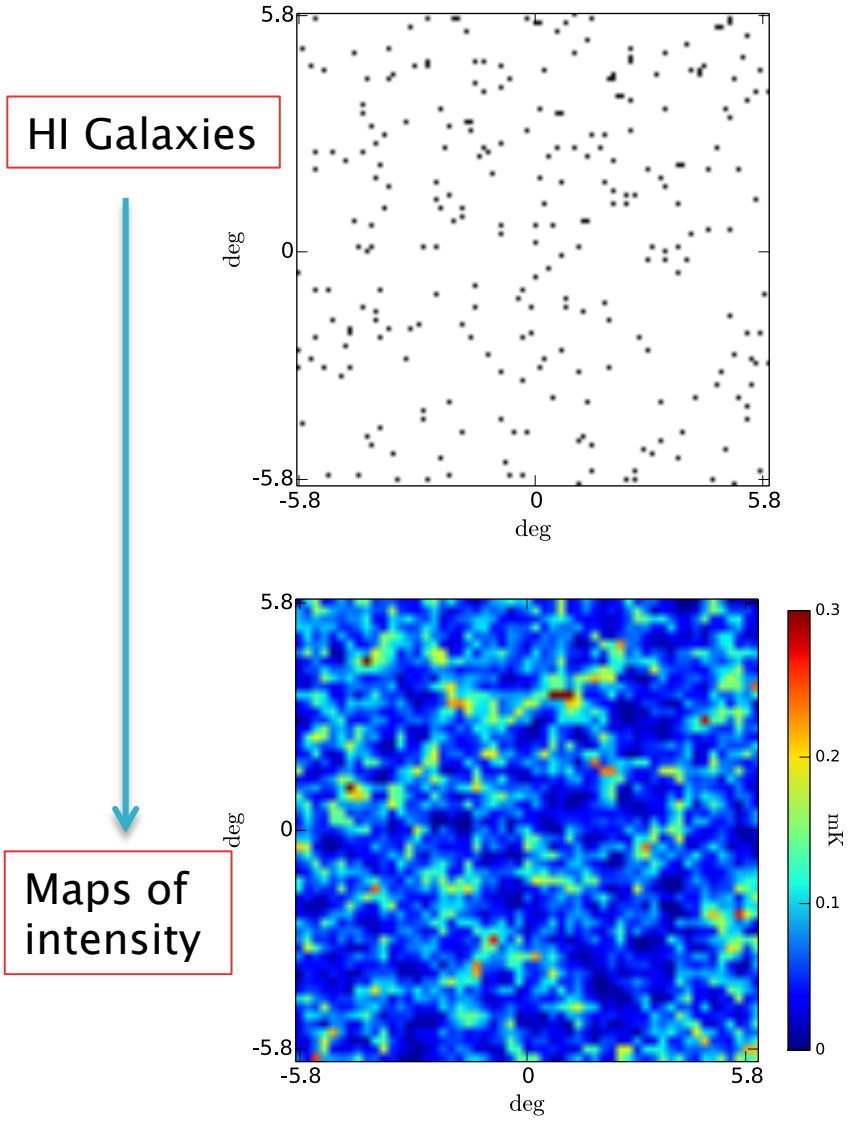
- Not competitive with Euclid. However, correlation with other wavelengths will provide important information
- Will provide a large catalogue of HI redshifts
- Will provide a peculiar velocity dataset (for Tully-Fisher)
- Will prepare for the key project in SKA2
- Might be done commensally with other KSP





KSP: HI intensity mapping

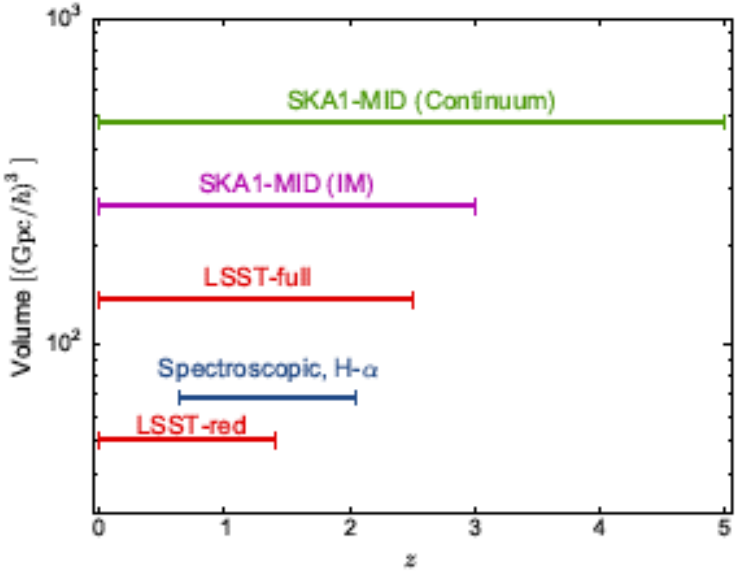
- Technique: use total intensity at each pointing as a function of frequency (no requirement to detect HI galaxies)
- Need calibrated dish auto-correlations to probe the required scales
- **Crucial for transformational cosmology with SKA1**
- "by-product": the hydrogen content of the Universe on large scales across cosmic time!
- 3 surveys under discussion:

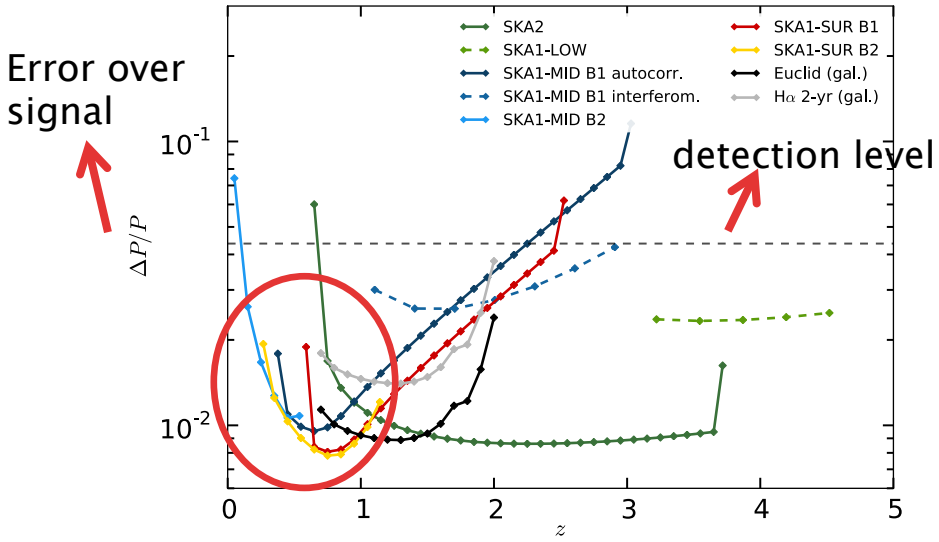


See summary in Santos et al., PoS(AASKA14)019

KSP: HI intensity mapping

- IM survey wish: $0 < z < 3$ (1.4 GHz – 0.35 GHz), 25,000 deg^2, T_{sys} ~ 20K – not possible, so:
- **Survey 1**:
  - Large ~ 25,000 deg^2
  - MID band2 – push again to higher z: 750 – 1450 MHz ($0 < z < 0.8$)
  - Commensal with continuum?
  - Need "on-the-fly" scanning strategy (see VLASS)
  - Highly complementary to Euclid
  - Will produce some of the best constraints on dark energy/ modified gravity parameters



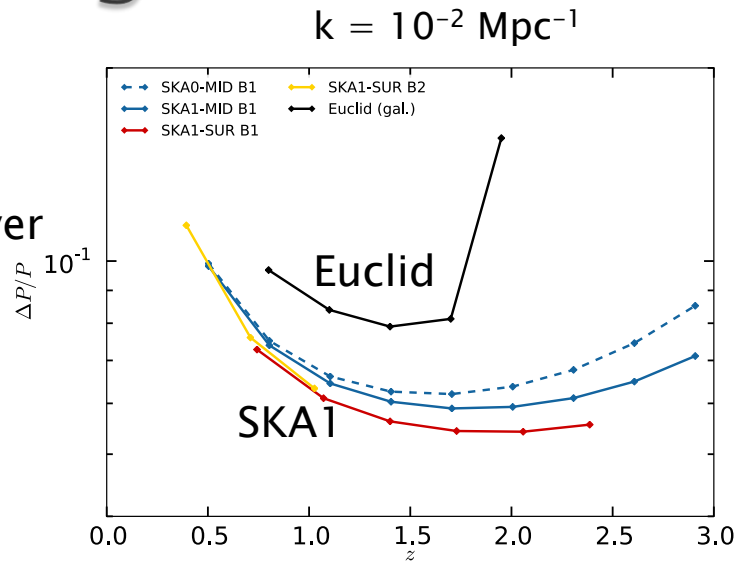


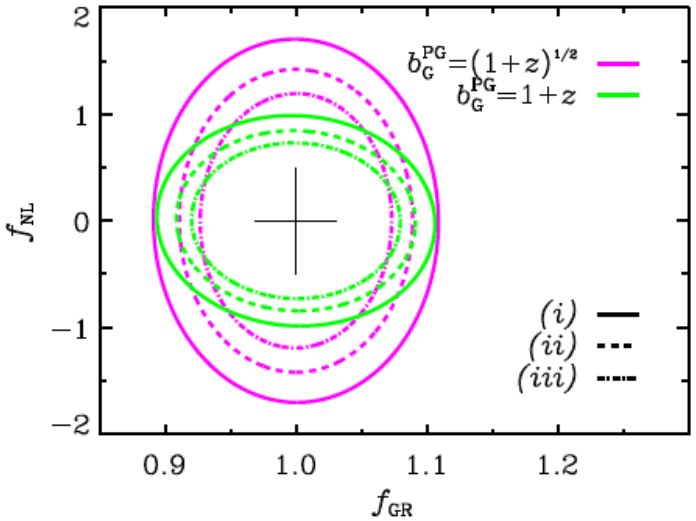
See Bull et al., PoS(AASKA14)024, Raccanelli et al., PoS(AASKA14)031

KSP: HI intensity mapping

- **Survey 2:**
  - Dish auto-correlations
  - Use MID band1 (current discussions going on – try to match LSST at least)
  - Large survey, ~ 20,000 deg2
  - Will provide "game changing" measurements of ultra-large scales – best constraints of primordial non-Gaussianity and detection of GR effects through cross-correlation with Euclid and LSST using the "Multi-tracer" technique
- **Survey 3:**
  - ~ 1,000 deg^2 survey with SKA-LOW (interferometer)
  - First detections of BAO at z>3
  - Make sure to close gap with MID HI detections

Error over signal

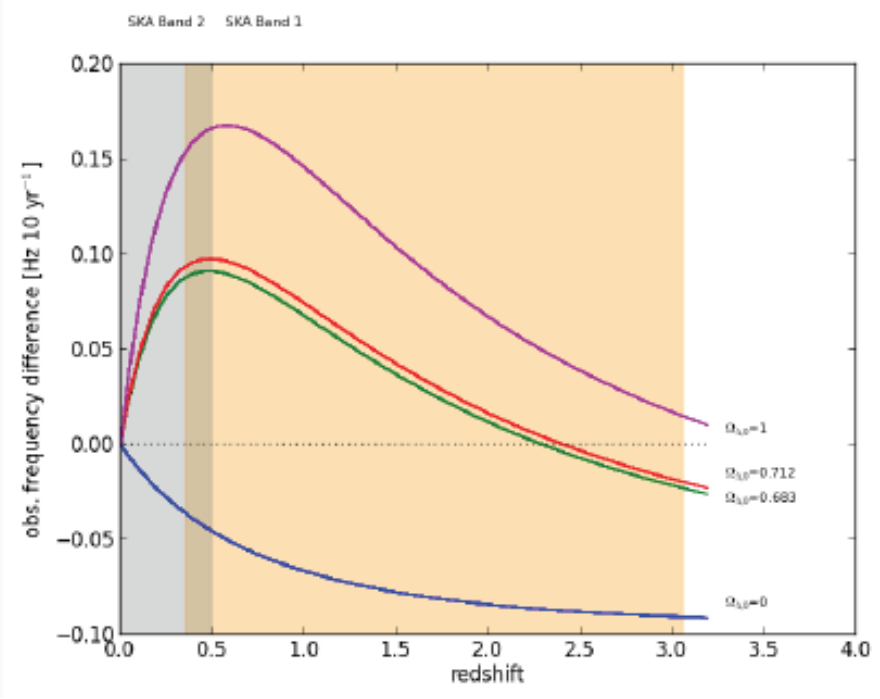


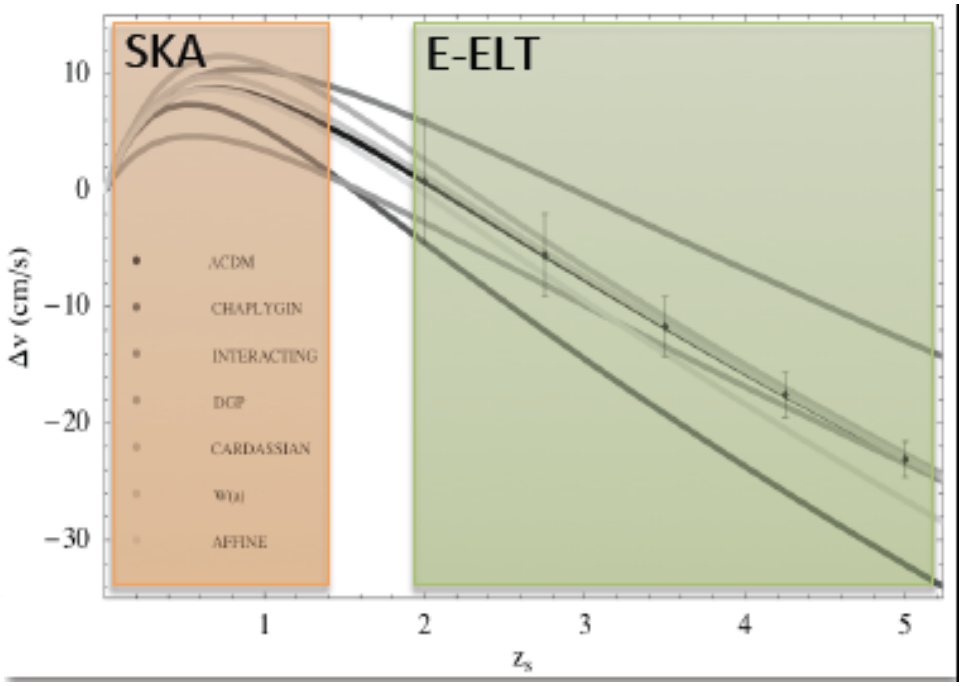


See Fonseca et al., http://arxiv.org/abs/1507.04605, Alonso et al., http://arxiv.org/abs/1507.03550

KSP: Real time cosmology – redshift drifts

- Measure change in z over time of a HI galaxy in order to derive H(z)
- Mostly a SKA2 KSP but a focused team and initial tests with SKA1 will be important to check the feasibility and experimental requirements
- Very different calibration requirements from other KSPs…





Summary

- Main surveys and internal commensality between Cosmology KSPs:
  - ~25,000 deg^2 survey in band2 (lowered to ~ 750 MHz) for a continuum survey and a HI intensity mapping survey
  - ~ 5,000 deg^2 survey in band2 for a HI galaxy survey and Weak lensing (issues with spectral resolution requirements…)
  - ~ 20,000 deg^2 survey in band1 (possibly with more sensitivity and bottom frequency at 430 MHz – **tbd**) for a HI intensity mapping survey and cross-correlations with LSST/Euclid
  - ~ 1,000 deg^2 survey with SKA-LOW to probe the post-reionization Universe on cosmological scales (need SKA-LOW up to ~ 450 MHz)
- **Note**: this assumes band2 will be deployed first and that the continuum surveys should be done in band2…