Whitepaper
Dark Energy Experiments with the Square Kilometer Array

For the International SKA Project:
Including the Australian, Canadian, European, and US SKA Consortia and Other Partners
http://www.skatelescope.org

Prepared by
C.A. Blake (University of British Columbia), S. Rawlings (University of Oxford), S.L. Bridle (University College London), F.B. Abdalla (University of Oxford)
June 15, 2005

Submitted by
J. M. Cordes (Cornell University)

The US SKA Consortium:
Chair: Professor Yervant Terzian (Cornell University)
California Institute of Technology and the Jet Propulsion Laboratory
Cornell University and the National Astronomy and Ionosphere Center
Harvard University and the Smithsonian Astrophysical Observatory
Massachusetts Institute of Technology and the Haystack Observatory
National Radio Astronomy Observatory
University of New Mexico
Naval Research Laboratory
SETI Institute
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University of Wisconsin
Virginia Polytechnic Institute and State University

ABSTRACT

One of five key science projects for the Square Kilometer Array (SKA) is precision measurements of the equation-of-state of dark energy. The unparalleled sensitivity of the SKA, combined with its extremely large instantaneous field of view (the design goal is 200 deg^2 at 0.7 GHz), permits ground-breaking cosmic surveys. Reasonable models indicate that, in a year of operation, the SKA can map $\sim 10^9$ HI galaxies across the entire visible sky to redshift $z \approx 1.5$, providing the premier measurement of the clustering power spectrum: accurately delineating acoustic oscillations and the 'turnover'. In addition, a radio continuum survey will quantify the cosmic shear distortion of $\sim 10^{10}$ galaxies with a precisely-known point-spread function, determining the power spectrum of the dark matter and its growth as a function of cosmic epoch. These experiments will provide exquisite information on the properties of dark energy. Furthermore, additional cosmological constraints will follow from the late-time Integrated Sachs Wolfe effect, and precise geometrical measurements of the distance scale using strong gravitational lensing and studies of extragalactic water masers.

1. Why the SKA is a revolutionary concept capable of transformational science

In order to study the properties of dark energy we require experiments with precision exceeding the current state-of-the-art by an order of magnitude. For example, a large-scale structure survey should map a volume exceeding what is possible today by a factor $\gtrsim 100$. The SKA can achieve these goals by mapping a significant fraction of the observable cosmos.

The SKA provides a two order of magnitude increase in collecting area over existing radio telescopes. This advance is transformational because for radio telescopes the sensitivity gain is proportional to collecting area A, not $\sqrt{A}$ as is the case for optical telescopes observing galaxies (in other words, radio telescopes have a 'grasp' of $A^2 \times FOV$, not the $A \times FOV$ familiar for optical telescopes, where FOV is the instantaneous field-of-view imaged). This means that, unlike previous radio telescopes, an SKA survey will be dominated by the 'normal' high-redshift galaxies familiar from optical surveys; the SKA can, in just a few hours exposure, detect these galaxies to $z \sim 3$ in HI and to $z > 10$ in the radio continuum.

Moreover, the technology chosen for the telescope design should allow the SKA to look in many directions at once without loss of sensitivity ('multi-fielding') which can be utilized either to dramatically increase the instantaneous FOV or to allow many rare objects (e.g. massive clusters or extragalactic water masers) to be targetted simultaneously. The goal for the SKA design is a field of view of 200 deg^2 at 0.7 GHz, exceeding what is possible for an optical telescope by a factor of 100: the SKA can survey *all the available volume* by studying the whole visible sky.

2. Baseline Proposal

The following baseline surveys are achievable once the SKA is operational in about 2015:

- By about 2016, an 'all-hemisphere' (20,000 deg^2) SKA HI survey containing $\sim 10^9$ galaxies to a 5σ HI mass limit $\sim 5 \times 10^9$ M$_\odot$ out to $z \sim 1.5$ (Abdalla & Rawlings 2005). This redshift survey would increase the cosmic volume, and also the number of $\sim L_*$ objects surveyed, by a factor ~ 1000 over current state-of-the-art optical surveys like the 2-degree-Field Galaxy Redshift Survey (2dFGRS) and the Sloan Digital Sky Survey (SDSS).
- By about 2020, an 'all-hemisphere' (20,000 deg^2) SKA weak lensing experiment with very high image quality (better than 0.1 arcsec resolution), high source surface density ($\gg 100$ arcmin^{-2}) and the possibility of precise redshift tomography at least for $z < 1.5$ through the HI survey data. The 'point spread function' is precisely known; it is simply the Fourier transform of the interferometer baseline distribution.
- By about 2020, deep (and because of the multi-fielding capability of the SKA, potentially simultaneous) targetted observations of large samples ($\gg 100$) of objects enabling precise measurements of geometric distance via a variety of techniques. One of the most promising techniques is deep HI follow-up of the most massive clusters, for which strong gravitational lensing effects can be measured in redshift slices behind each massive lens, providing entirely geometric measures of distance out to very high redshift (e.g. Jain & Taylor 2003). Another outstanding prospect is extremely accurate measurements of the distance scale locally (i.e. $\sim 1\%$ precision for H_0) by finding, mapping and monitoring water maser sources in the accretion discs around super-massive black holes (Greenhill 2004).
- Also through 2015–2020, the ability to do 'pixel-by-pixel' correlations of SKA, CMB temperature and CMB polarization maps to make definitive measures of the late-time ISW effect and hence gain independent constraints on dark energy.

3. Precursor experiments

Clearly, substantial new cosmological surveys will have been completed before the SKA commences operation. These experiments will doubtless provide valuable advances and perhaps succeed in detecting a deviation in dark energy properties from a simple cosmological constant. But even in this case, we believe that surveys of the scale provided by the SKA will be required to delineate the new model.

In terms of large-scale structure, it will be difficult for a ground-based optical redshift survey to cover more than 1000 $\deg^2$ owing to the restricted field-of-view of optical spectrographs. As regards cosmic shear, there is no planned experiment that can deliver the combination possible with the SKA: all-sky coverage, superb image quality, very high source density, precisely-known point spread function, and source redshift information.

In both cases, the SKA data would result in an improvement in precision compared to intervening surveys of a factor of a few, corresponding roughly to the gain of these precursor experiments with respect to today's state-of-the-art.

4. Dark Energy Experiments with the SKA

We quantify here some specific experiments which represent our best guess as to the key dark energy studies possible with the SKA.

4.1. Experiment I: Large-scale structure and acoustic oscillations

The SKA will map out the cosmic distribution of neutral hydrogen by detecting the HI 21cm transition at cosmological distances that are almost entirely inaccessible to current instrumentation. Once an HI emission galaxy has been located on the sky, the observed wavelength of the emission line automatically provides an accurate redshift, locating the object's position in the three-dimensional cosmic web.

Reasonable models (see Abdalla & Rawlings 2005) indicate that the SKA can survey the entire visible sky in a year of operation, locating $\sim 10^9$ HI emission galaxies over a volume stretching to redshift $z \approx 1.5$ with sufficient number density that clustering statistics are limited by cosmic variance, not by shot noise. In comparison, planned next-generation optical redshift surveys will only cover $\sim 1000 \deg^2$.

The resulting HI redshift survey yields an improvement in power spectrum precision of between one and two orders of magnitude compared to the current state-of-the-art (Figure 1). In addition, the SKA clustering map traces modes on large scales beyond the power spectrum turnover (i.e. on scales $k < 0.02\,h\,\mathrm{Mpc}^{-1}$) that are entirely inaccessible to local redshift surveys. The precise determination of the power spectrum on large scales can be compared with the predictions of inflationary models, testing for effects such as departures of the primordial power spectrum $P_{\rm prim}(k)$ from a pure power-law. The narrow window function in k-space (resulting from the vast cosmic volume probed by the SKA) implies that any sharp features in $P_{\rm prim}(k)$ are not smoothed out and may be detected in a manner not possible using the CMB. It has been suggested that the intriguing outliers in the CMB temperature power spectrum measured by the WMAP satellite (at $\ell \sim 30$ and $\ell \sim 200$) could be due to unknown physics on scales smaller than the Planck length, which are imprinted during inflation (e.g. Martin & Ringeval 2004).

Moreover, the power spectrum of galaxies on large scales ($\gtrsim 30$ Mpc) should contain a series of small-amplitude *acoustic oscillations* of identical physical origin to those seen in the CMB. These features result from oscillations of the photon-baryon fluid before recombination, and encode a characteristic scale – the *sound horizon at recombination* – accurately determined by CMB observations. This scale can act as a *standard ruler* (Eisenstein 2002). Its recovery from a galaxy redshift survey depends on the assumed cosmological parameters, particularly the dark energy model, and thus constrains that model over a range of redshifts (Blake & Glazebrook 2003; Seo & Eisenstein 2003).

The application of this cosmological test does not depend on the overall shape of the power spectrum, which can be divided out using a smooth fit, but only on the residual oscillatory signature of the acoustic peaks. Hence the method is relatively insensitive to smooth broad-band tilts in $P(k)$ induced by such effects as a running spectral index, redshift-space distortions, and complex biasing schemes. In the absence of major systematic effects, constraints on the dark energy model are limited almost entirely by how much cosmic volume one can survey, rendering this an ideal experiment for the SKA, which can map the HI galaxy distribution out to $z \approx 1.5$ (where three acoustic peaks lie in the linear regime).

In Figure 2 we display simulated power spectra for a survey covering 20,000 $\deg^2$, divided into redshift slices. The standard ruler provided by the acoustic oscillations may be applied separately to the tangential and radial components of the power spectrum, resulting in independent measurements of the co-ordinate distance $x(z)$ to each redshift slice and its rate of change $x'(z) \equiv dx/dz$, respectively.[1] We fitted these simulated measurements of $x(z)$ and $x'(z)$ over a series of redshift slices, assuming a dark energy model

[1] The actual quantities determined by the experiment are the ratio of x and x' to the sound horizon s at recombination (which determines the characteristic spatial scale of the acoustic oscillations). The value of s is determined by CMB observations, via $\Omega_{\rm m}h^2$ and $\Omega_{\rm b}h^2$.

$w(z) = w_0 + w_1 z$. Figure 3 illustrates the accuracy of recovery of (w_0, w_1) assuming a fiducial cosmology $(-0.9, 0)$, demonstrating that in this case we can dismiss a cosmological constant model $(-1, 0)$ with high significance. The accuracy of our prior knowledge of $\Omega_{\rm m}$ and h affects the tightness of the dark energy constraints. These parameters must be known to standard deviations $\sigma(\Omega_{\rm m}) = 0.01$ and $\sigma(h) = 0.01$ if these uncertainties are not to dominate the overall error in (w_0, w_1). These demands are not unrealistic on the SKA timescale: SKA observations of masers in the vicinity of black holes will determine h to $\sim 1\%$ accuracy (Greenhill 2004) and CMB data from the Planck satellite will fix $\Omega_{\rm m} h^2$ to a similar precision (Balbi et al. 2003).

Ground-based experiments plan to survey the acoustic peaks before $\sim$ 2015. However, the limited field-of-view of optical spectrographs will restrict such surveys to $\lesssim 1000$ deg^2, deriving constraints on (w_0, w_1) that are several times poorer than the 20,000 deg^2 SKA survey (the error bars roughly scale as $1/\sqrt{f_{\rm sky}}$). If these precursor experiments detected any deviation from Einstein's cosmological constant, the SKA will be required for a precise delineation of the new model.

4.2. Experiment II: Weak Gravitational Lensing

The cosmic web imprints a coherent shape distortion in the distribution of distant galaxies. This 'cosmic shear' is a powerful probe of dark energy, which controls both the angular diameter distances intrinsic to the lens equation (e.g. the source-lens distance) and the redshift evolution of the mass fluctuations producing the lensing. A successful cosmic shear survey has three leading design requirements: very high image quality for reliable shape measurements, a high source surface density ($\gtrsim 100$ arcmin^{-2}) to limit statistical noise, and a wide survey area to reduce cosmic variance. Each of these demands is delivered superbly by an SKA radio continuum survey (Schneider 1999).

The leading systematic for ground-based optical cosmic shear experiments is the difficulty in quantifying systematic variations in the point-spread function, due to inevitable changes in the atmospheric seeing and telescope properties with position and time. The psf determination is accomplished by observing stars in the field (of which there are a limited number density). In comparison, the point-spread function of a radio telescope is well-determined and stable (being simply derived from the interferometer baseline distribution, i.e. the synthesized beam). In addition, the planned SKA angular resolution (≈ 0.05 arcsec at 1.4 GHz) vastly improves upon that obtainable over wide fields from the ground.

Space-based optical cosmic shear surveys may also exist by the time the SKA is available. However, these surveys will not be capable of surveying a full hemisphere to a depth exceeding 100 sources arcmin^{-2} and will hence be dwarfed by an SKA all-sky continuum survey. The fraction of sky $f_{\rm sky}$ mapped is directly related to the precision of the shear power spectrum measurement via a factor $1/\sqrt{f_{\rm sky}}$.

An SKA continuum survey will achieve sensitivities of ~ 30 nJy in a 4-hour pointing, far exceeding depths attained by contemporary radio surveys. In order to simulate the results of an SKA cosmic shear experiment, we must assume a model for the radio source populations at these unprecedented flux densities. We generated this model from a combination of two populations: starburst galaxies and quiescent spiral disks (we ignore for now the Active Galactic Nuclei which dominate at the highest flux densities but which have too low surface density to contribute significantly to the weak lensing signal at SKA sensitivities). We extrapolated local radio luminosity functions for these two populations (Sadler et al. 2002) as a function of redshift using a Press-Schechter-based approach, and folded in a prescription for the physical sizes of each population. Full details of these models will be published elsewhere (Abdalla et al., in prep.).

Using these population models, we simulated radio skies as a function of SKA integration time and angular resolution. Following the method of Massey et al. (2004), we then employed standard shape-estimation software (Kaiser, Squires & Broadhurst 1995) to recover the shear dispersion per galaxy arising from intrinsic shapes and from measurement errors (σ_γ) together with the surface density of 'usable galaxies' (n_g) after cuts for objects that are unresolved or faint. The values achieved, $\sigma_\gamma \approx 0.2$ and $n_g \sim 500$ arcmin^{-2}, are comparable to deep space-based optical surveys (Massey et al. 2004) whilst covering a substantially larger survey area. Figure 4 illustrates the measurement accuracy of the *cosmic shear angular power spectrum* using these data.[2]

The resulting measurements of the dark energy model can be estimated using the Fisher matrix methodology (e.g. Refregier et al. 2004). Figure 5 illustrates joint constraints on (w_0, w_1) using the shear power spectrum up to $\ell = 10^5$. The analysis requires models for both the *source redshift distribution* (which can be readily inferred from a deep HI emission-line survey of a sub-area of the sky) and the *linear theory mass power*

[2] We note that it is also possible to analyze a radio cosmic shear survey directly in the *uv*-plane (Chang & Refregier 2002).

spectrum (e.g. calculated using CMBFAST; Seljak & Zaldarriaga 1996) corrected for non-linear effects in accordance with the prescription of e.g. Smith et al. (2003).

The power of this experiment may be increased by splitting the lensed galaxies into two broad redshift bins (Refregier et al. 2004). This is readily, if roughly, accomplished by separating the radio continuum sources into two groups determined by detection (or absence) in the HI emission-line survey of Experiment I. A potential residual systematic error may lie in *intrinsic alignments* of galaxy disks (owing to structure formation processes) which may masquerade as coherent shear signal. For example, some starburst galaxies may exist in pairs, forming merging disk systems. Taking an extremely cautious approach, we assume for now that starburst galaxies would not be used in the cosmic shear analysis. This reduces the surface density by a factor of two, but the SKA still yields a vast improvement in dark energy constraints compared to future space-based surveys.

4.3. Experiment III: The Local Distance Scale (H_0) from water masers

As noted above, converting cosmic distance measurements to dark energy constraints requires knowledge of at least the parameters $\Omega_{\rm m}$ and H_0. CMB observations (via the Planck satellite) deliver an exquisite measure of the degenerate combination $\Omega_{\rm m} H_0^2$. The SKA enables a similarly accurate determination of H_0, the local distance scale.

Current 10-per-cent-accuracy estimates of H_0 are obtained via measurements of 'standard candles' that are limited by intrinsic scatter and systematic errors. Even the best estimate is calibrated using the controversial distance to a single and possibly unrepresentative (metal-poor) galaxy, the LMC. The SKA is likely to play a central role in improving this situation (Greenhill 2004).

Moving to a 1-per-cent level of accuracy for the measurement of H_0 requires a new method which yields reliable *geometric* distances to galaxies, and which, to order to probe a representative local volume, reaches to reasonable redshifts. The SKA can achieve this by finding, mapping, and monitoring water maser sources within (roughly edge-on) accretion disks at sub-parsec radii from supermassive black holes out to distances of a few hundred Mpc. Although only a fraction of masers turn out to be relatively simple dynamical systems suited to detailed modelling, a very large number of masers will be discovered and the absolute number of suitable objects will be orders of magnitude greater than today. The result will be a catalogue of systems with well-measured black hole masses, disk geometries, orientations, and mappings between angular and physical sizes.

Amongst the compelling features of this method are: (i) evidence from the remarkable study of NGC4258 (Herrnstein et al. 1999; Humphreys et al. 2004) that the method works well in practice; (ii) relatively few sources of systematic uncertainty given highly constrained models for the most suitable systems; and (iii) the expectation of uncorrelated uncertainties in individual distance measurements that should ensure that accuracy on H_0 increases as $\sqrt{N}$, where, to get to the required 1-per-cent level of accuracy, N need only be a few hundred out of the many thousands of extragalactic water maser systems that will be discovered by the SKA.

5. Cosmology beyond dark energy

Even if precise measurements of the dark energy parameters detect no deviation from a cosmological constant, the cosmic surveys provided by the SKA could well result in breakthrough discoveries, especially when combined with Planck measurements of the CMB:

- The combination of Planck and SKA data will enable a precise mapping of the late-time ISW effect, and could potentially be used to establish the clustering properties of dark energy (e.g. Weller & Lewis 2003).
- The precise measurements of clustering modes on large scales provided by the SKA will measure the form of the primordial power spectrum as a function of scale, constraining inflationary models. The combination of SKA and CMB datasets will help isolate the tensor (gravitational wave) contribution to the CMB power spectrum.
- It is commonly assumed that the primordial perturbations are in energy density (adiabatic), but more general models add in perturbations in entropy density (isocurvature) which, being spatially homogeneous in energy density, leave no perturbation in spatial curvature. Bucher et al. (2004) have shown that the existence of such modes cannot be ruled out by current datasets. The CMB/SKA surveys will powerfully discriminate between such models, again testing inflationary theories.

- Searches for non-Gaussianity in the statistics of the primordial fluctuation spectrum have, from CMB data alone, so far proven negative (Komatsu et al. 2003). The SKA 'all hemisphere' survey will detect large numbers of superclusters, the evolved counterparts of rare fluctuations in the quasi-linear regime, permitting sensitive independent tests of non-Gaussianity.
- As reviewed by Curran et al. (2004), there have been recent claims that the value of the fine structure constant α varies with cosmic epoch. Curran et al. demonstrate that SKA observations of redshifted radio absorption lines hold the key to confirming this remarkable result and to discovering changes in other physical constant (e.g. the ratio of electron and proton masses). Many theories unifying gravity with other fundamental forces predict such variations.
- The power spectrum derived from CMB results has some 'glitches' that have been interpreted as the signature of new physics on scales smaller than the Planck length, which were imprinted on $P(k)$ during inflation (e.g. Martin & Ringeval 2004). Precise large-scale measurements of $P(k)$ with the SKA will establish the reality and location of any glitches, and look for evidence of such new physics.
- Is the Universe precisely spatially flat? One explanation of the low quadrupole signal in the CMB is that the Universe has a small, but positive, curvature and a $P(k)$ which cuts off on this curvature scale (e.g. Efstathiou 2003). Precision cosmology led by the SKA could, for example, confirm that $w = -1$, and that the Universe is closed.

6. Project Strengths and Risks

The project's major strength is that more or less any design of the SKA with a 'decent' FOV of at least ~ 10 deg^2 will perform a transformational redshift survey quickly once it becomes operational in about 2015. The exact volume of this survey depends on the FOV achieved, but it is quite possible that an even more ambitious project to the baseline redshift survey outlined above might be realized: an all-sky survey to $z \sim 3$ containing more than $\sim 10^{10}$ galaxies.

An all-hemisphere weak lensing survey with the SKA provides interesting (but probably tractable) data volume/processing challenges. In SKA prototypes like LOFAR, FOV has to be compromised by 'phasing up' elements into 'stations' at relatively high-resolution/high-frequency, a limitation that can only be fully bypassed by correlating signals between each and every antenna pair. Uncertainties in the computing capabilities of 2020 are certainly a risk with this part of the project.

The mass function of HI-emitting galaxies has currently only been measured locally, so there is some uncertainty in our extrapolations of the number density of HI-emitting galaxies as a function of redshift. However, our models are guided by good constraints from optical damped-Lyman-α observations (Abdalla & Rawlings 2004). Actual high-redshift measurements will reduce some of the uncertainties in planning SKA HI surveys, and should be achieved by deep-field observations with SKA prototypes, as are planned for the potential SKA sites in Australia and South Africa.

7. Research and Development Timeline

The SKA timeline features an intensive research and development phase between 2005 and 2009, during which a site is chosen and a technology or technologies adopted. At the end of this process, it will be clear what values of FOV are achievable for the core of antennas, which will be constructed in the period 2012-2015. The full SKA (long baselines, all frequencies) will be available by around 2020.

The period 2009-2012 is set aside for detailed engineering design, fundraising and prototyping, possibly via the construction of an $\sim 10\%$ SKA proto-core. The technologies underlying most potential realizations of the SKA are proven, but R & D is required to determine the cost per square meter of collecting area of a given realization. The likely critical choice is between a true multi-fielding capability (pointing in several directions at once without loss of sensitivity), such as would be provided by a pure phased array system, and a hybrid system with a wide field of view provided by phased arrays at the focal planes of reflectors, which would lack true multi-fieilding capability. The R & D programme will study both the affordability of such designs alongside the cost/science trade-offs in the key science projects. The first scientific steps in this R & D programme are published in the book edited by Carilli & Rawlings (2004).

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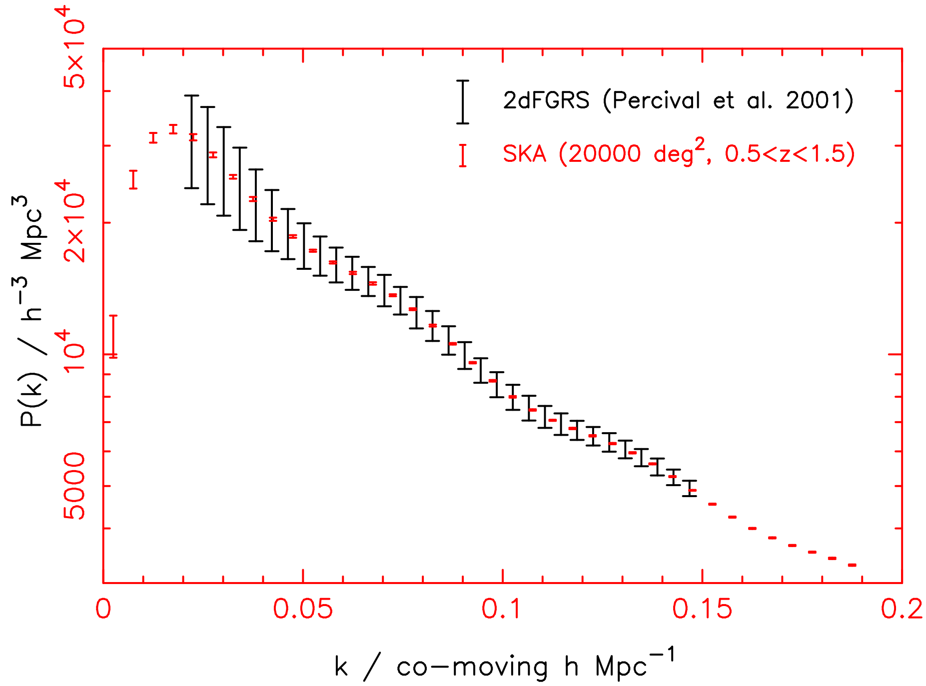

Fig. 1.— Simulated measurement of the galaxy clustering power spectrum by a 1-year SKA survey, compared to the 2dFGRS 100k data release (Percival et al. 2001). The measurements have been normalized to the same underlying power spectrum model, keeping the (1σ) fractional errors in each k-bin the same. For the SKA data, we assume that the redshift evolution of clustering may be divided out so that results from different redshift slices can be combined. We note that the 2dFGRS $P(k)$ data points are *heavily correlated* in this binning, whereas the SKA survey possesses a much narrower 'k-space window function' owing to the vastly greater cosmic volume probed, implying that the resulting $P(k)$ measurements are barely correlated. The SKA clustering data delineates the power spectrum turnover on large scales ($k < 0.02\,h$ Mpc^{-1}) and the acoustic oscillations, as a direct result of mapping a vastly greater cosmic volume V. The error in a power spectrum measurement in the cosmic-variance-limited regime scales as $1/\sqrt{V}$, and $V_{\rm SKA} \approx 500\,V_{\rm 2dF}$.

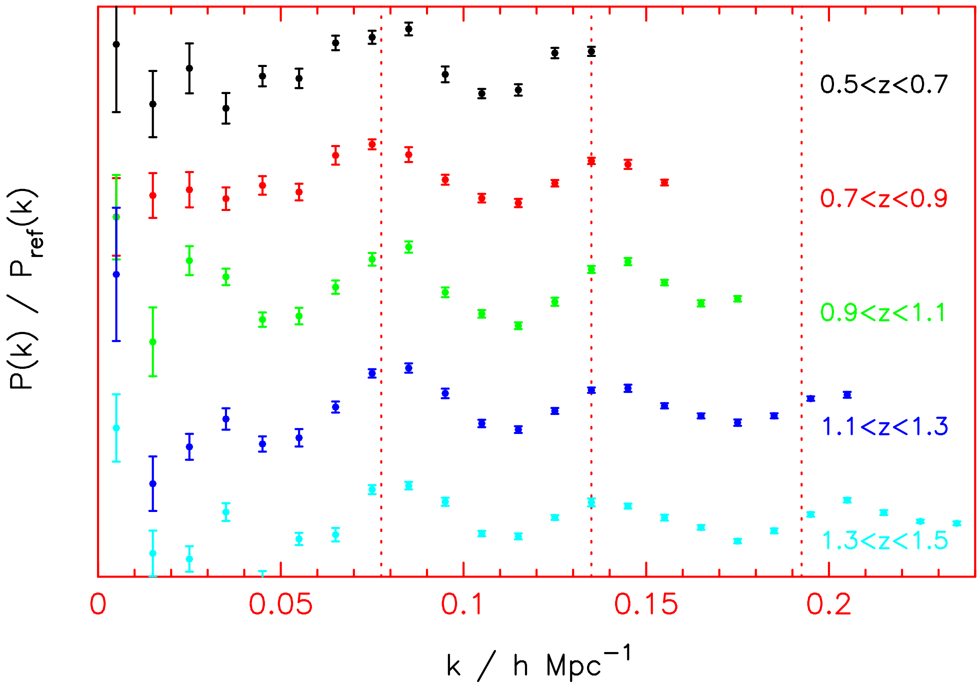

FIG. 2.— Simulated galaxy power spectra for an SKA survey of 20,000 $\deg^2$, analyzed in redshift slices of width $\Delta z = 0.2$. Each power spectrum is divided by a smooth polynomial fit, revealing the sinusoidal imprint of acoustic oscillations, and is shifted along the y-axis for clarity. As redshift increases, the linear regime extends to smaller physical scales (larger values of k), unveiling more peaks. The acoustic oscillation 'wavelength' may be used as a standard ruler. This is illustrated by the Figure: the true dark energy model is $w = -1$, but the observer has incorrectly assumed $w = -0.8$ when constructing the power spectra, and consequently the recovered acoustic scale disagrees with that observed in the CMB (represented by the vertical dotted lines).

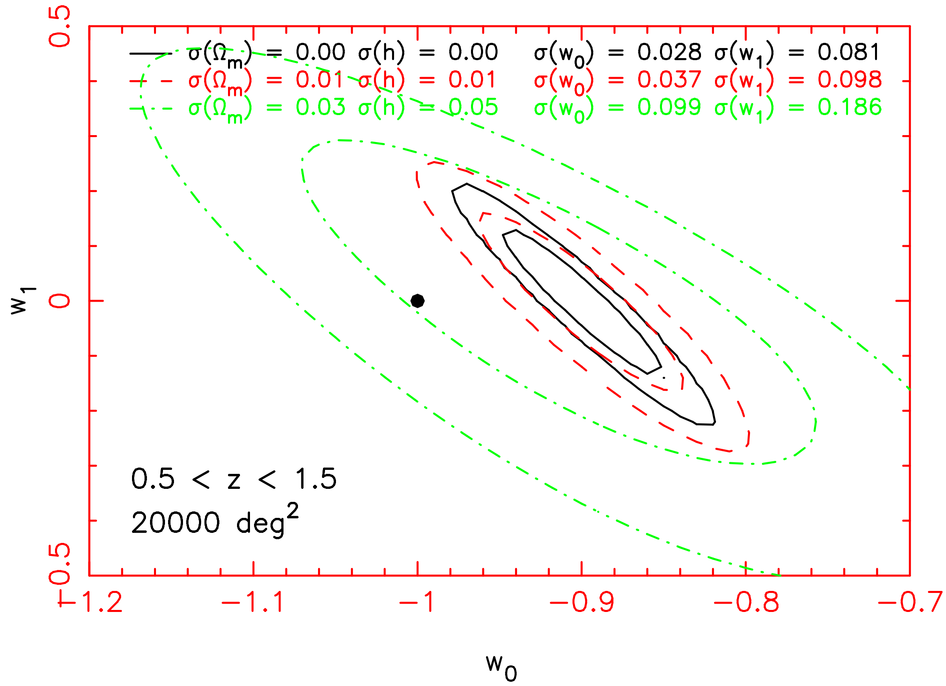

Fig. 3.— Constraints on a dark energy model $w(z) = w_0 + w_1 z$ achievable by an SKA survey of the acoustic peaks, illustrated by sets of (68%, 95%) contours corresponding to different assumed priors. The solid contours correspond to perfect knowledge $\Omega_m = 0.3$ and $h = 0.7$. For the dashed contours we impose Gaussian priors with standard deviations $\sigma(\Omega_m) = 0.01$ and $\sigma(h) = 0.01$, which are not unrealistic in the SKA epoch. In each of these two cases we are able to distinguish a fiducial model $(w_0, w_1) = (-0.9, 0)$ from a cosmological constant (marked by the solid circle). Weaker Gaussian priors $\sigma(\Omega_m) = 0.03$ and $\sigma(h) = 0.05$ (the dot-dashed contours) are inadequate for this purpose. Note that there remains a residual degeneracy in the (w_0, w_1) plane because at a given redshift, approximately the same cosmology can be obtained by increasing w_0 and decreasing w_1. This degeneracy is partially broken by measurements across a range of redshift slices (and by the independent determinations of x and x' for each redshift).

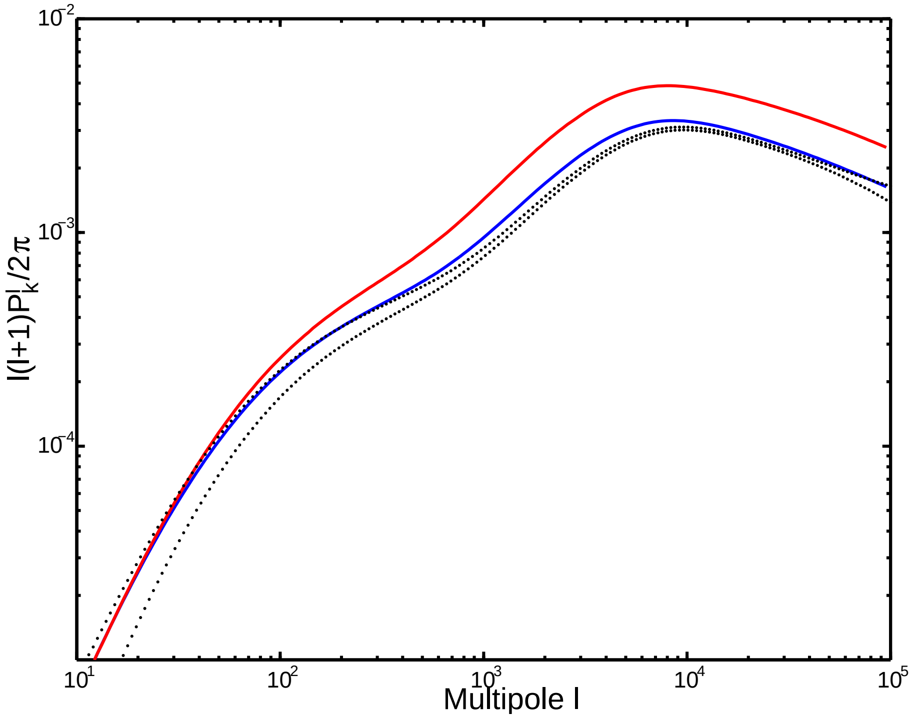

FIG. 4.— The cosmic shear angular power spectrum measured from a simulated SKA radio continuum survey. The upper (red) curve is for a model with $\Omega_{\rm m} = 0.25$ and $w_{\rm cons} = -0.9$; the lower (blue) curve is for $\Omega_{\rm m} = 0.3$ and $w_{\rm cons} = -1$; the dotted lines show the $\pm 1\sigma$ range for $\Omega_{\rm m} = 0.3$ and $w_{\rm cons} = -0.9$. We assume that the survey contains a surface density of usable galaxies $n_g = 200$ arcmin^{-2} and covers one hemisphere ($f_{\rm sky} = 0.5$).

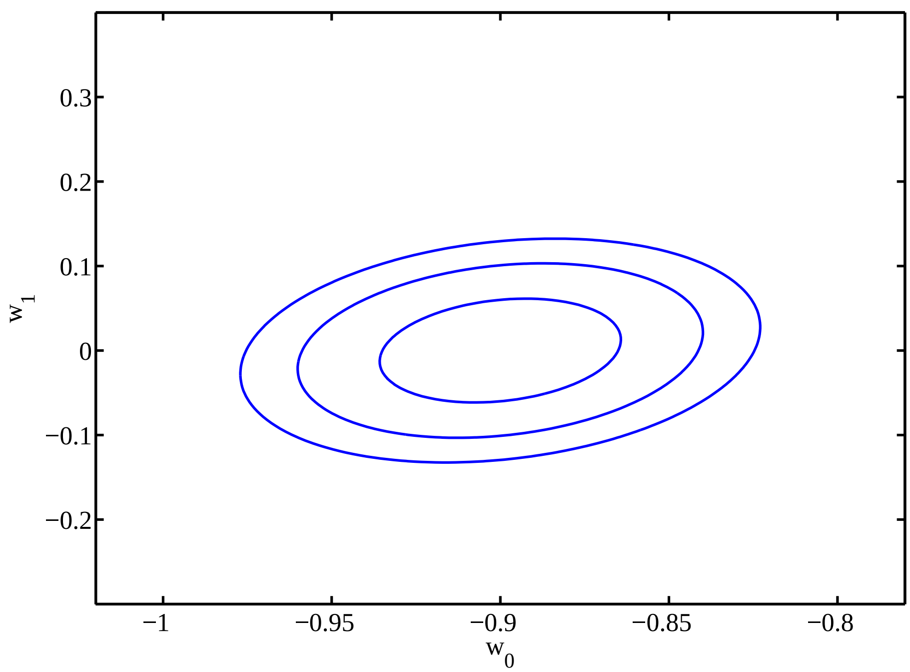

FIG. 5.— (68%, 95%, 99%) likelihood contours for a dark energy model $w(z) = w_0 + w_1 z$ from an SKA cosmic shear survey over a hemisphere, assuming 200 usable galaxies per square arcminute. We marginalize over the other cosmological parameters ($\Omega_{\rm m}$, $\Omega_{\rm b}$, h, n_s). These contours are conservative because no redshift information per galaxy has been included.