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Science with the Australian Square Kilometre Array Pathfinder

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Abstract: The future of centimetre and metre-wave astronomy lies with the Square Kilometre Array (SKA), a telescope under development by a consortium of 17 countries that will be 50 times more sensitive than any existing radio facility. Most of the key science for the SKA will be addressed through large-area imaging of the Universe at frequencies from a few hundred MHz to a few GHz. The Australian SKA Pathfinder (ASKAP) is a technology demonstrator aimed in the mid-frequency range, and achieves instantaneous wide-area imaging through the development and deployment of phased-array feed systems on parabolic reflectors. The large field-of-view makes ASKAP an unprecedented synoptic telescope that will make substantial advances in SKA key

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science. ASKAP will be located at the Murchison Radio Observatory in inland Western Australia, one of the most radio-quiet locations on the Earth and one of two sites selected by the international community as a potential location for the SKA. In this paper, we outline an ambitious science program for ASKAP, examining key science such as understanding the evolution, formation and population of galaxies including our own, understanding the magnetic Universe, revealing the transient radio sky and searching for gravitational waves.

Keyword: telescopes

1 Introduction

The Australian SKA Pathfinder (ASKAP) is a next-generation radio telescope on the strategic pathway towards the staged development of the Square Kilometre Array (SKA). The ASKAP project is international in scope and includes partners in Australia, Canada, the Netherlands and South Africa. This paper, which concentrates on the science made possible with ASKAP was written jointly between Australian and Canadian research scientists following a collaborative agreement signed between CSIRO and the National Research Council of Canada.

ASKAP has three main goals:

- to carry out world-class, ground breaking observations directly relevant to the SKA Key Science Projects;
- to demonstrate and prototype technologies for the mid-frequency SKA, including field-of-view enhancement by focal-plane phased-arrays on new-technology 12-m class parabolic reflectors;
- to establish a site for radio astronomy in Western Australia where observations can be carried out free from the harmful effects of radio interference.

Following international science meetings held in April 2005 and March 2007, seven main science themes have been identified for ASKAP. These are extragalactic HI science, continuum science, polarisation science, Galactic and Magellanic science, VLBI science, pulsar science and the radio transient sky. In this paper, we first give a general science overview, then outline the system parameters for ASKAP, before allocating a section to a summary of each science theme. A larger, and more complete, version of the science case for ASKAP will be published elsewhere.

1.1 ASKAP and SKA Science

The SKA will impact a wide range of science from fundamental physics to cosmology and astrobiology. The SKA Science Case 'Science with the Square Kilometre Array' (Carilli & Rawlings 2004) identifies compelling questions that will be addressed as key science by the SKA:

- understanding the cradle of life by imaging the environments of the formation of earth-like planets, the precursors to biological molecules, and carrying out an ultra-sensitive search for evidence of extra-terrestrial intelligence;
- carrying out fundamental tests of the theory of gravity by using radio waves to measure the strong space-time warp of pulsars and black holes and timing of arrays of pulsars over large areas of the sky to detect long-wavelength gravitational waves propagating through the Galaxy;
- tracing the origin and evolution of cosmic magnetism by measuring the properties of polarised radio waves from galaxies over cosmic history;
- charting the cosmic evolution of galaxies and large-scale structure, the cosmological properties of the universe and dark energy, the imaging of atomic hydrogen emission from galaxies and the cosmic web from the present to time of the first galaxies; and
- probing the dark ages and the epoch of reionisation of the Universe when the first compact sources of energy emerged.

The technological innovation of ASKAP and the unique radio-quiet location in Western Australia will enable a powerful synoptic survey instrument that will make substantial advances in SKA technologies and on three of the SKA key science projects: the origin and evolution of cosmic magnetism, the evolution of galaxies and large scale structure, and strong field tests of gravity. The headline science goals for ASKAP are:

- The detection of a million galaxies in atomic hydrogen emission across 80% of the sky out to a redshift of 0.2 to understand galaxy formation and gas evolution in the nearby Universe.
- The detection of synchrotron radiation from 60 million galaxies to determine the evolution, formation and population of galaxies across cosmic time and enabling key cosmological tests.
- The detection of polarised radiation from over 500 000 galaxies, allowing a grid of rotation measures at $10'$ to explore the evolution of magnetic fields in galaxies over cosmic time.
- The understanding of the evolution of the interstellar medium of our own Galaxy and the processes that drive its chemical and physical evolution.
- The characterisation of the radio transient sky through detection and monitoring of transient sources such as gamma ray bursts, radio supernovae and intra-day variables.
- The discovery and timing of up to 1000 new radio pulsars to find exotic objects and to pursue the direct detection of gravitational waves.
- The high-resolution imaging of intense, energetic phenomena through improvements in the Australian and global Very Long Baseline networks.

Table 1. System parameters for ASKAP

Parameter	Symbol	Strawman	Expansion
Number of dishes	N	30	45
Dish diameter (m)		12	12
Dish area (m^2)	A	113	113
Total collecting area (m^2)		3393	5089
Aperture efficiency	ϵ_a	0.8	0.8
System temperature (K)	T	50	35
Number of beams		30	30
Field-of-view (deg^2)	F	30	30
Frequency range (MHz)		700–1800	700–1800
Instantaneous bandwidth (MHz)	B	300	300
Maximum number of channels		16 000	16 000
Maximum baseline (m)		2000	400, 8000

1.2 System Parameters

Table 1 gives the ASKAP system parameters. The first column gives the parameter with the second column listing the symbol used in the equations in this section. The strawman (or base model) parameters for ASKAP are given in the third column of Table 1 and these strawman assumptions have been used throughout this paper. Likely upgrade or expansion paths include the addition of further dishes and/or the cooling of the focal plane array elements to provide a lower system temperature. Parameters for this expansion path are listed in the fourth column of Table 1.

ASKAP is designed to be a fast survey telescope. A key metric in this sense is the survey speed expressed in the number of square degrees per hour that the sky can be surveyed to a given sensitivity. Survey speeds and sensitivity for an interferometer like ASKAP have been derived elsewhere (e.g. Johnston & Gray 2006) and the full derivation will not be shown here. To summarise, the time, t, required to reach a given sensitivity limit for point sources, σ_s, is

$$t = \left(\frac{2kT}{AN\epsilon_a\epsilon_c}\right)^2 \frac{1}{\sigma_s^2 B n_p} \tag{1}$$

where B is the bandwidth (Hz), n_p the number of polarisations, A is the collecting area of a single element (m^2), N is the number of elements and ϵ_a and ϵ_c represent dish and correlator efficiencies. The system temperature is T with k being the Boltzmann constant. The number of square degrees per second that can be surveyed to this sensitivity limit is

$$SS_s = FBn_p\left(\frac{AN\epsilon_a\epsilon_c\sigma_s}{2kT}\right)^2 \tag{2}$$

where F is the field of view in square degrees. The surface brightness temperature survey speed is given by

$$SS_t = FBn_p\left(\frac{\epsilon_c\sigma_t}{T}\right)^2 f^2\epsilon_s^{-2} \tag{3}$$

where now σ_t denotes the sensitivity limit in K and f relates to the filling factor of the array via

$$f = \frac{A\epsilon_a N\Omega\epsilon_s}{\lambda^2} \tag{4}$$

Here, ϵ_s is a ‘synthesised aperture efficiency’ which is related to the weighting of the visibilities and is always ≤ 1.

There is interplay between these parameters when trying to maximise the survey speed for a given expenditure. For the majority of the science that will be considered here, the value of SS_s and SS_t are critical parameters, although the instantaneous sensitivity is also important, especially for pulsar science. Although these equations are useful, they are not the entire story. For example, the effects of good (u,v) coverage on the image quality and dynamic range do not appear in the equations. Furthermore, one should also not neglect the total bandwidth available for a spectral line survey. If the total bandwidth (or velocity coverage) is insufficient to cover the required bandwidth (velocity range) of a given survey, the survey speed suffers as a result of having to repeat the same sky with a different frequency setting.

In Table 2 we list values of the sensitivity and survey speed for different ‘typical’ surveys for both the strawman and the expansion parameters. The first entry gives a continuum survey where the entire 300 MHz of bandwidth is exploited and a desired $1-\sigma$ sensitivity of 100 μJy is required. The second entry gives a spectral line survey, with the third line listing a surface brightness survey needing to reach a $1-\sigma$ limit of 1 K over 5 kHz channel under the assumption of a $1'$ resolution. The final row lists the time necessary to reach $1-\sigma$ of 1 mJy across a 1 MHz bandwidth to a point source at the centre of the field. The expansion option for ASKAP offers a factor of almost 5 improvement over the strawman design.

1.3 Comparison with Other Instruments

The large field-of-view makes ASKAP an unprecedented synoptic radio telescope, achieving survey speeds not available with any other telescope. ASKAP will routinely image very large areas of the sky to sensitivities only achievable with current instruments over very small areas.

The survey speed of ASKAP exceeds that of the Parkes 20-cm multibeam receiver, the Very Large Array (VLA) and the Giant Metre Wave Telescope (GMRT) by more than an order of magnitude for spectral line surveys in the GHz band. In continuum, ASKAP can survey the sky some 50 times faster than the NVSS survey carried out by the VLA over a decade ago (Condon et al. 1998).

As an interferometer ASKAP provides low-frequency imaging not otherwise available at the other major southern hemisphere interferometric array, the Australia Telescope Compact Array (ATCA). For single pointings it exceeds the ATCA sensitivity at 1400 MHz and will also have better resolution and surface brightness sensitivity. In terms of survey speed however, it gains by large factors for both line, continuum and surface brightness sensitivity and will be comparable to other planned facilities such

Table 2. Sensitivity and survey speeds for ASKAP

Parameter	Strawman	Expansion	
Continuum survey speed (300 MHz, 100 μJy)	250	1150	deg^2/hr
Line survey speed (100 kHz, 5 mJy)	209	960	deg^2/hr
Surface brightness survey speed (5 kHz, 1 K, 1′)	18	83	deg^2/hr
Point source sensitivity (1 MHz, 1 mJy)	1290	280	sec

as the Karoo Array Telescope (KAT) in South Africa, the Allen Telescope Array (ATA; Deboer et al. 2004) in the USA and APERTIF in the Netherlands.

The survey speeds of ASKAP (with the strawman parameters), the ATA and APERTIF are almost identical although achieved in different ways. The ATA achieves its survey speed through a large number of small dishes each with a single pixel feed. APERTIF will have a focal plane array system on larger dishes. The presence of telescopes with similar survey speed in the northern hemisphere makes for excellent complementarity to ASKAP.

1.4 Configuration of ASKAP

A number of science projects (pulsar surveys, Galactic HI, low surface brightness mapping) require a highly compact array configuration in order to increase the surface brightness survey speed (see equations 3 and 4). On the other hand science such as continuum and transients require long baselines both to overcome the effects of confusion and to obtain accurate positions for identification at other wavelengths. In the middle is the extragalactic HI survey which needs moderate resolution to avoid over-resolving the sources. With a total of only 30 dishes it is difficult to achieve all these requirements simultaneously.

It is envisaged that three array configurations will be available ranging from a very compact configuration (maximum baseline $\lesssim 400$ m) through a medium compact configuration (maximum baseline $\sim$2 km) to an extended configuration (maximum baseline $\sim$8 km). Configuration changes would occur by physically moving the antennas and would happen only infrequently.

A design study is currently underway to determine exact antenna positions for different configurations given the science case and the constraints of the local site topology and terrain.

1.5 Location of ASKAP

The central core of ASKAP will be located at the Murchison Radio Observatory in inland Western Australia, one of the most radio-quiet locations on the Earth and one of the sites selected by the international community as a potential location for the SKA. The approximate geographical coordinates of the site are longitude 116.5 east and latitude 26.7 south. The southern latitude of ASKAP implies that the Galactic Centre will transit overhead and the Magellanic Clouds will be prominent objects of study. At least 30 000 square degrees of sky will be visible to ASKAP. The choice of site ensures that ASKAP will be largely free of the harmful effects of radio interference currently plaguing the present generation of telescopes, especially at frequencies around 1 GHz and below. Being able to obtain a high continuous bandwidth at low frequencies is critical to much of the science described in this document.

1.6 ASKAP Timeline

In early 2008, the ASKAP test bed antenna will be installed at the site of the Parkes radio telescope to allow testing of the focal plane array and beamforming systems. Following this, the goal is to have the first six antennas of ASKAP on-site in Western Australia in early 2010. Over the subsequent two years the remainder of the antennas would be deployed, with commissioning of the final system expected to take place in 2012.

2 Extragalactic HI Science

Understanding how galaxies form and evolve is one of the key astrophysical problems for the 21st century. Since neutral hydrogen (HI) is a fundamental component in the formation of galaxies, being able to observe and model this component is important in achieving a deeper understanding of galaxy formation. At any given time we expect that the amount of neutral hydrogen in a galaxy will be determined by the competing rates at which HI is depleted (mostly by star formation) and replenished (mostly by accretion of cold gas from its surroundings). Understanding how the abundance and distribution of HI in the Universe evolves with redshift therefore provides us with important insights into the physical processes that drive the growth of galaxies and is a powerful test of theoretical galaxy formation models (e.g. Baugh et al. 2004).

The cosmic HI mass density $\Omega_{\rm HI}$ provides a convenient measure of the abundance of HI at a given epoch. Estimates of $\Omega_{\rm HI}$ at high redshifts ($z \gtrsim 1.5$) can be deduced from QSO absorption-line systems in general and damped Lyman-α (DLA) systems in particular. DLA systems contain the bulk of HI at high redshifts and imply that $\Omega_{\rm HI} \simeq 10^{-3}$ (e.g. Péroux et al. 2003; Prochaska & Herbert-Fort 2004; Rao et al. 2006). At low-to-intermediate redshifts, however, the only known way to measure $\Omega_{\rm HI}$ accurately is by means of large-scale HI 21-cm surveys.

This has been possible at $z \lesssim 0.04$ using the HI Parkes All-Sky Survey HIPASS (Koribalski et al. 2004; Meyer et al. 2004), which mapped the distribution of HI in the nearby Universe that is observable from the Parkes radio telescope. HIPASS data have allowed accurate measurement of the local HI mass function (HIMF) and $\Omega_{\rm HI}$ of galaxies (Zwaan et al. 2003, 2005). However, few measurements of the HIMF and $\Omega_{\rm HI}$ using HI 21-cm emission have been possible over the redshift range $0.04 \lesssim z \lesssim 1$ because of insufficient sensitivity of current-generation radio telescopes (though see e.g. Verheijen et al. 2007). In the simulations that follow, it is therefore assumed that the HIMF does not evolve with redshift. This assumption is conservative and any evolution in the HIMF will likely result in the detection of a greater number of HI galaxies.

Widefield HI surveys using the next generation radio telescopes such as ASKAP and ultimately the SKA will allow unprecedented insights into the evolution of the abundance and distribution of HI with cosmic time, and its consequences for the cosmic star formation, the structure of galaxies and the Intergalactic Medium. ASKAP excels as a survey telescope as it will be able to spend long periods of time integrating on large areas of sky, resulting in the detection of large numbers of galaxies. Two compelling HI surveys are:

- A shallow hemispheric HI survey lasting a year. This would result in the detection of over 600 000 galaxies, or two orders of magnitude greater than HIPASS. The typical survey depth would be $z \sim 0.05$ with massive galaxies detected out to $z \sim 0.15$ (see Figure 1).
- A deep survey covering a single pointing, also lasting a year. Although this would only detect 100 000 galaxies in the example of a non-evolving HIMF shown in Figure 2, the typical depth would be $z \sim 0.2$ with massive galaxies detected out to $z \sim 0.7$.

The results from this survey will provide powerful tests of theoretical galaxy formation models and improve our understanding of the physical processes that shaped the galaxy population over the last ∼7 Gyr.

ASKAP will provide useful cosmological measurements, but the detection of the so-called baryonic acoustic oscillations will probably only be possible on small spatial scales with the all-sky survey. This will preclude the investigation of dark energy studies at higher redshift in a manner competitive with future and ongoing optical surveys such as 'WiggleZ' (Glazebrook et al. 2007). The leading sources of systematic error for baryon oscillation surveys are the poorly-modelled effects of redshift-space distortions, halo bias and the non-linear growth of structure. These processes all modify the underlying linear power spectrum which encodes the baryon oscillation signature, hampering our cosmological measurements. ASKAP can make inroads into this problem and pave the way for future SKA surveys by precisely measuring the clustering properties of HI galaxies over a range of redshifts and through measuring the HIMF with unprecedented accuracy, including how this function varies with redshift (to $z \sim 0.7$) and environment.

3 Continuum Science

Understanding the formation and evolution of galaxies and active galactic nuclei (AGN) as a function of cosmic time is a key science driver for next-generation telescopes at all wavebands. Today's instruments already give profound insights into the galaxy population at high redshifts, and a number of current surveys are asking questions such as: When did most stars form? How do AGN influence star formation? What is the spatial distribution of evolved galaxies, starbursts, and AGN at $0.5 < z < 3$? Are massive black holes a cause or a consequence of galaxy formation?

However, most of these surveys are primarily at optical and infra-red wavelengths, and can be significantly misled by dust extinction. A survey with ASKAP will be able to determine how galaxies formed and evolved through cosmic time, by penetrating the heavy dust extinction which is found in AGN at all redshifts, and studying the star formation activity and AGN buried within. An ASKAP survey, with baselines out to ∼8 km (5″ resolution) can survey the entire southern sky to a flux limit of ∼50 μJy beam^{-1} in one year, a limit which is currently being reached only in tiny parts of the sky (e.g. in the HDF-N and HDF-S deep fields). Such a survey is likely to have the enormous impact that the NVSS (Condon et al. 1998) has had over the past decade, but at a factors of 50 better in sensitivity and 9 in angular resolution.

With a 5σ flux density limit of 50 μJy beam^{-1}, typical starburst galaxies, with star formation rates (SFRs) around 100 $M_\odot$ yr^{-1}, will be detectable to $z \sim 2$. The most extreme starbursts, with SFRs of a few 1000 $M_\odot$ yr^{-1}, will be visible well into the epoch of reionisation ($z \sim 6$–10) if indeed they existed then. Ordinary disk galaxies like the Milky Way, with SFRs of only a few $M_\odot$ yr^{-1}, will be visible to $z \sim 0.3$. A confusion limited sky survey with the 8 km baseline configuration, obtained in addition to a compact configuration for the HI survey, will make the star forming galaxy population accessible as never before. It will allow unprecedented exploration into how star formation in galaxies evolves with time, and how it depends on galaxy mass, galaxy environment, past star formation history, interaction/merger history, and more.

Another important factor to consider is distinguishing the star forming population from the AGN population. At flux densities $\lesssim$1 mJy starburst galaxies start to become a major component of the 1.4 GHz source counts, dominating below 0.5 mJy or so (Hopkins et al. 2000; Jackson 2005). Recent measurements, though, suggest that there may still be a significant proportion of low-luminosity AGN (Simpson et al. 2006) even at these levels. By 0.1 mJy, existing AGN evolutionary models imply that starburst galaxies should be dominant, although normal star forming galaxies are not expected to dominate the counts until levels below ∼1 μJy are reached (Windhorst et al. 1999; Hopkins et al. 2000).

There is an inevitable degeneracy between luminosity and redshift inherent in flux limited samples of classical (active) radio galaxies. This arises because only the most powerful sources are detected at the largest redshifts. In order to explore the physics of radio galaxies, and especially their evolution, large samples of radio galaxies of comparable luminosity across cosmic time are required.

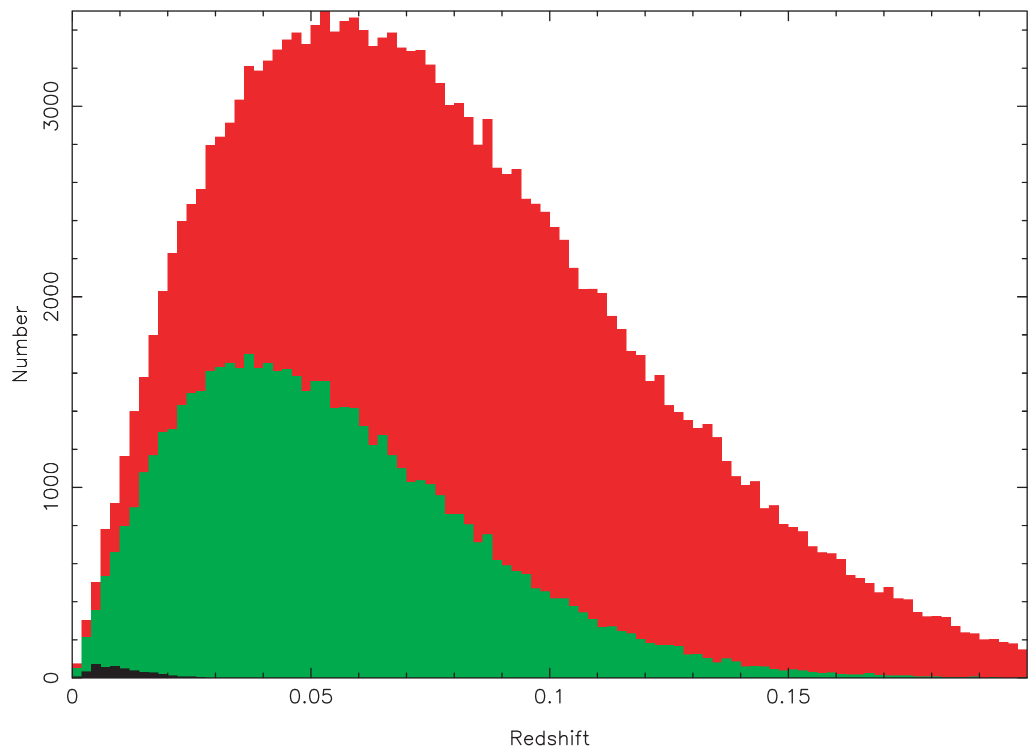

Figure 1 Number of galaxies above 5σ as a function of redshift bin for a shallow ASKAP HI survey lasting a year, covering the southern hemisphere, compared with HIPASS HICAT (Meyer et al. 2004; black histogram). The simulation assumes the Zwaan et al. (2005) HIMF with no evolution, and a bivariate relation between HI mass and velocity width. The simulations further assume a compact ASKAP configuration — the number of detections sharply reduces for angular resolutions below $1'$. The number of predicted detections is $\sim 1.8 \times 10^6$ and $\sim 0.6 \times 10^6$ for the expansion (red histogram) and strawman (green histogram) options.

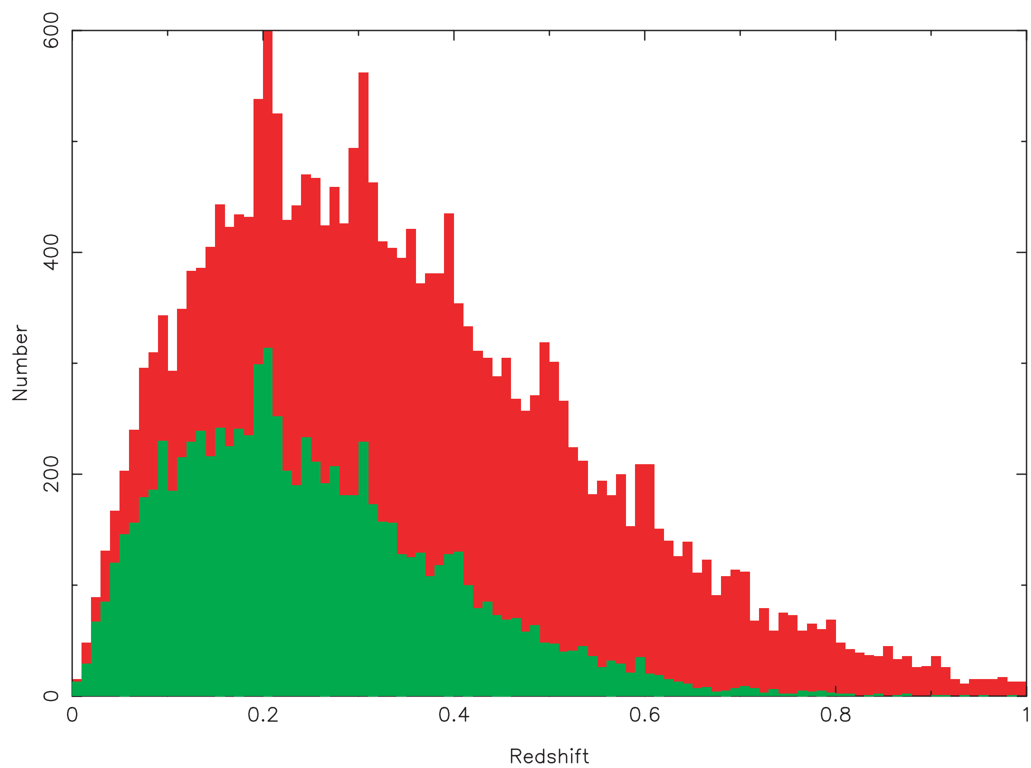

Figure 2 Number of galaxies above 5σ as a function of redshift bin for a deep ASKAP HI survey lasting a year, covering a single pointing. The simulation is similar to that for the all-sky survey and assumes a non-evolving HIMF. The number of predicted detections is $\sim$226 000 for the expansion option (red histogram) and $\sim$99 000 for the strawman option (green histogram). There is less dependence on angular resolution than for the shallow all-sky survey. Standard cosmology is assumed (flat Universe, $H_0 = 75\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, $\Omega_\mathrm{m} = 0.3$, $\Omega_\Lambda = 0.7$).

At present, we are still unable to say much about the global population of radio galaxies at $z \gtrsim 0.5$ because the faint source counts are so limited.

The results of the proposed ASKAP confusion limited survey, coupled with optical spectroscopic data from e.g. PanStarrs and the LSST, will generate samples from which luminosity functions can be determined for FRI and FRII galaxies as a function of z, as well as for the high-redshift radio galaxy population that are strikingly different to the canonical FRI and FRII morphologies we are used to observing at $z \lesssim 1$ (van Breugel et al. 1999). Note that ASKAP will be able to detect FRIs to $z \sim 4$ based on their luminosity alone, but only out to $z \sim 1.7$ based also on their morphology.

The resulting science should not be underestimated: radio galaxies represent the most massive galaxies at any redshift up to $z \sim 5.2$ (Rocca-Volmerange et al. 2004) and therefore represent our best chance to understand the formation and evolution of massive galaxies and their central supermassive black holes. In addition, they are likely also to provide the dominant source of energy in the universe, and possibly even provide the dominant source of magnetic fields.

It is worth emphasising that at $5''$ resolution, incompleteness becomes significant as emission extended on scales larger than this is resolved (see the discussion regarding the choice of angular resolution for the NVSS in Condon et al. 1998). However, this issue is likely to be less of a problem for ASKAP than for NVSS for two reasons. First, at the extremely faint flux densities of the proposed ASKAP survey, the source counts are dominated by distant star-forming galaxies with $\sim 1''$ angular sizes, rather than the larger and more powerful radio galaxies which dominate the source counts in NVSS. Second, a continuum all-sky survey with short baselines will be available as a by-product of the proposed HI sky survey. While this compact continuum survey will be confusion-limited, the data can be sensibly combined with the longer-baseline $5''$ resolution southern sky survey to create a complete *and* confusion-limited high-resolution sky survey. Furthermore, the low surface brightness survey will be sensitive to the diffuse emission from, for example, dying radio galaxies (Murgia et al. 2005) cluster haloes, relics and ghosts (e.g. Enßlin 1999; Feretti 2000; Enßlin & Gopal-Krishna 2001), 'fat double' FRI tails and plumes (Subrahmanyan et al. 2006), and perhaps even the Thomson scattered electrons off dark matter (Geller et al. 2000).

ASKAP may answer directly the question of whether dark energy exists at $z \sim 1$, and if so on what scale. A unique independent test of dark energy is to observe a correlation between CMB fluctuations and low-redshift large-scale structure (Crittenden & Turok 1996), the so-called late-time Integrated Sachs–Wolfe (ISW) effect. Such a correlation would only be seen if the CMB photons have been redshifted by the low-redshift structure as it collapses, and only occurs if the current expansion of the Universe is *not* matter dominated. Cross-correlation of the NVSS radio galaxies with the CMB anisotropies gave a tentative detection of the ISW effect, but at significance of only 2σ (Boughn & Crittenden 2004). A more recent analysis (Pietrobon et al. 2006) used WMAP3 data and powerful statistical techniques to exclude the null hypothesis at 99.7%. However an extremely deep survey with ASKAP can provide a far more stringent examination; this test has a much lower confusion limit than the traditional limit for source counts because we are looking for a statistical result on size scales of order the scales of the CMB anisotropies. Moreover, the deep ASKAP survey may also provide the ability to track the effect as a function of redshift.

4 Polarisation Science

One of the five key-science drivers for the SKA is to understand the origin and evolution of cosmic magnetism. The history of the Universe from the Big Bang to the present day is essentially a history of the assembly of gas into galaxies, and the transformation of this gas into stars and planets. While gravitation initiates and sustains these processes, it is magnetism which breaks gravity's symmetry and which provides the pathway to the non-thermal Universe. By enabling processes such as anisotropic pressure support, particle acceleration, and jet collimation, magnetism regulates the feedback that is vital for returning matter to the interstellar and intergalactic medium (Boulares & Cox 1990; Zweibel & Heiles 1997).

Prime observational approaches to this key science will include a deep survey of polarised emission from extragalactic sources (EGS) (Beck & Gaensler 2004), and of the diffuse polarised radiation from the Galaxy. These surveys will be extremely important in the study of Galactic magnetic fields, both within the Milky Way and in external galaxies. A key experiment with ASKAP will be to image the entire southern sky at 1.4 GHz to a $1-\sigma$ sensitivity of 10 μJy in full-Stokes continuum emission as described in section 3. The polarisation products from this survey would provide

- a deep census of the polarisation properties of galaxies as a function of redshift (secured through complementary HI or optical surveys),
- a dense grid of Faraday rotation measures to over 500 000 background radio sources.
- all-sky Faraday Rotation image of the three-dimensional structure of the diffuse magneto-ionic medium of the Galaxy.

The fractional polarisation, Π, of EGS is typically only a few percent, so the signal to noise ratio in polarised flux is always a factor ~ 50 below the signal to noise ratio in total intensity. This has limited investigations of the polarisation properties of EGS to the bright ($\gtrsim 80$ mJy) radio source population, dominated by powerful, radio loud AGN. There are some indications from these bright sources that at least fainter steep-spectrum radio sources are more highly polarised (Mesa et al. 2002; Tucci et al. 2004), up to a median Π of $\sim 1.8\%$ in the flux density range

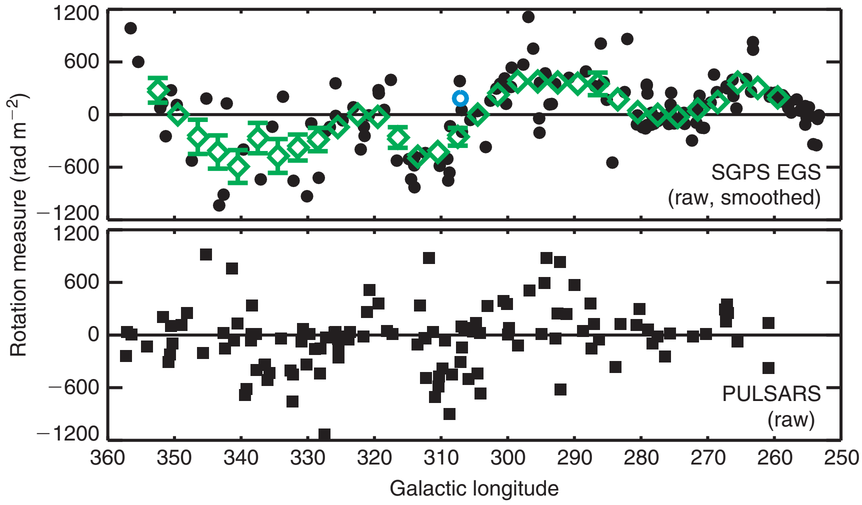

Figure 3 RM vs Galactic longitude for EGS and pulsar RMs in the Southern Galactic Plane Survey (SGPS; Brown et al. 2007). Top panel: Circles represent individual RMs of EGS while open diamonds represent these data boxcar-averaged (smoothed) over 9° in longitude with a step size of 3°. Where symbol size permits, the error bars are the standard error of the mean. The single open circle at $l = 307°$ represents the only EGS in this region prior to the SGPS. Bottom panel: squares represent individual pulsars with known RMs in the SGPS region. The oscillations seen in the data reveal the orientation of the large-scale magnetic field in the spiral arms and interarm regions.

100–200 mJy and even higher for sources below 100 mJy (Taylor et al. 2007).

ASKAP will revolutionise this field by providing larger samples of polarised sources, to much fainter flux densities than currently possible. At a sensitivity level of 10 μJy, ASKAP will begin to reveal the polarisation of radio sources as faint as a few mJy, where star forming galaxies begin to contribute measurably to the total radio source counts (Windhorst 2003). Models of the integrated polarised emission from disk galaxies, based on magnetic field strengths and geometries, in conjunction with analysis of the integrated polarisation of nearby disk galaxies, will provide a theoretical basis for analysis of the magnetic properties of the large sample of distant star-forming galaxies that will be observed by ASKAP (Stil et al. in prep). Idealised models suggest that the Π distribution of a large sample of randomly oriented disks has a minimum at $\Pi = 0$. The presence of such a minimum in the distribution depends on the importance of Faraday depolarisation and the importance of poloidal magnetic fields in the halo of these galaxies. We can measure this minimum by including the lowest-order antisymmetric deviations from a Gaussian in our Monte-Carlo analysis of a sufficiently large number of galaxies (Taylor et al. 2007). The projected large frequency coverage of ASKAP will allow us to distinguish between highly frequency-dependent Faraday depolarisation, and magnetic field structure that should not change with observing frequency. As we consider integrated quantities, our analysis will not be affected by variation of resolution with frequency.

The Milky Way and many other nearby spiral galaxies all show well-organised, large-scale magnetic fields (Beck et al. 1996), for which the dynamo mechanism is the favoured explanation (Ruzmaikin et al. 1988). However, dynamos are not yet well understood and still face theoretical difficulties, especially in light of recent results which show that field amplification in galaxies can be extremely rapid (Gaensler et al. 2005). Our own Milky Way is an excellent test-bed to better study the underlying physical processes, because a huge ensemble of background Faraday rotation measures (RMs) can be used to probe its three-dimensional magnetic field structure. RMs from both pulsars and EGS should be used in such studies. Until recently (Brown et al. 2003, 2007) there had been comparatively few EGS RMs available, while studies utilising pulsar RMs alone have been limited both by the comparatively sparse sampling of pulsars on the sky and by uncertainties in pulsar distances. As a result, mapping the three-dimensional magnetic field distribution has been difficult, especially in complicated regions.

Broadly speaking, the Milky Way's magnetic field has two components: a large-scale, coherent, magnetic field, tied to the overall structure of the spiral arms, disk and halo, and a small-scale, fluctuating field which traces supernova remnants (SNRs), HII regions, and diffuse turbulence in the ionised ISM (Ruzmaikin et al. 1988). One method of separating the smooth and fluctuating components of the magnetic field is to average the RM data from EGS into intervals of ~20 deg^2 as shown in Figure 3. Such an analysis begins to beautifully reveal the overall structure associated with field reversals and spiral arms. However, ASKAP can greatly improve current RM yields, providing a source density over the entire sky of ~20 RMs per deg^2. With such a data-set, we can successfully distinguish between the behaviours of the smooth and fluctuating components of the field (at a signal-to-noise ratio of ~4–5) down to a resolution of ~1 deg^2. One square degree turns out not to be some arbitrary scale, but represents an approximate dividing line between the sizes of individual SNRs and HII regions, and the larger scale structure of spiral arms, super-bubbles and fountains. Polarimetry with ASKAP will thus provide our first complete view of the magnetic geometry of the Milky Way, on scales ranging from sub-parsec turbulence up to the global structure of the disc and spiral arms.

5 Galactic and Magellanic Science

The renaissance of observational studies of the Milky Way and Magellanic System over the past decade has raised new and profound questions about the evolution of the interstellar medium (ISM). The community has transitioned from studying small-scale aspects of the ISM to a more comprehensive approach, which seeks to combine information about a variety of ISM phases with information about magnetic fields. With ASKAP we can make significant and unique inroads into understanding the evolution of the ISM and through that the evolution of the Milky Way. These are crucial steps along the path to understanding the evolution of galaxies.

Galaxy evolution is one of the great puzzles in current astrophysics, incorporating how galaxies assemble and evolve from the beginning of the universe to the present day. Unfortunately, our knowledge of the fundamental processes of galaxy evolution is blocked because we do not understand the evolutionary cycle of interstellar matter in our own Galaxy. We know that the life cycle of the Milky Way involves a constant process of stars ejecting matter and energy into the interstellar mix, from which new stars then condense. Somehow matter makes the transition from hot, ionised stellar by-products to become the cold molecular clouds from which stars are formed. The circulation of matter between the Galaxy's disk and its surrounding halo further complicates this cycle. ISM studies in our Galaxy probe the evolutionary cycle with sensitivity and resolution unattainable in external galaxies; it is only in the Milky Way that we can observe the evolution of the interstellar medium on scales ranging from sub-parsec to kiloparsecs. Furthermore, the evolution of the Galaxy is controlled by the Galactic and local magnetic fields, yet these components are largely unknown. The Milky Way is thus an ideal laboratory for studying galaxy evolution.

In recent years there has been a renaissance in Galactic ISM surveys. This has largely been driven by advances with the Canadian and Southern Galactic Plane Surveys, which used a combination of single antenna and aperture synthesis telescopes to map the Galactic plane in HI and polarised continuum emission at an unprecedented resolution of $\sim 1'$. These results can be combined with a number of Galactic Plane surveys at comparable or better resolution in ^{12}CO (Clemens et al. 1988), ^{13}CO (Jackson et al. 2006) and the *Spitzer* GLIMPSE survey of infrared emission. These surveys have revealed structure on all size scales, a remarkable agreement between ISM phases, and a wide variety of new polarisation structures.

The Milky Way and Magellanic System, because of their very large sky coverage, can only be observed in survey mode. An all-sky Galactic HI survey with ASKAP would build on current surveys to provide a full census of all HI associated with the Milky Way and the Magellanic System at arcmin resolution. We therefore propose a 1 year survey to a brightness temperature sensitivity limit of $\sim$100 mK over a $\sim 2'$ synthesised beam using the very compact configuration. An additional consideration for this survey is the need to include single dish data for sensitivity to structure on the largest scales. Fortunately the Galactic All-Sky Survey already exists with comparable sensitivity and spectral resolution to the proposed survey and can be combined with the ASKAP survey. The survey would provide essential information about the physical and thermal structure of high velocity clouds and their interaction with the halo, the role and origin of halo cloudlets and the physical structure of the Magellanic Stream and Leading Arm.

One of the key science drivers for the SKA is understanding the magnetic universe. For the Milky Way, rotation measures of extragalactic point sources will yield information about the line of sight averaged magnetic field weighted to regions of ionised gas. To fully understand the Galactic field and its effect on the evolution of the Galaxy we propose two surveys, (a) an all-sky survey of the polarisation state of the diffuse emission to provide data for detailed study of the magneto-ionic medium (MIM), and (b) a survey of Zeeman splitting of the HI line to provide in situ magnetic field measurements.

The appearance of the polarised sky is dominated by Faraday rotation. Existing data permit this conclusion about the MIM, but are entirely inadequate for unravelling its detailed physical characteristics. The surveys that exist are of very poor angular resolution or provide only interferometric data without complementary single-antenna data, and hence miss important information on broad structure. Wideband, multi-channel imaging of the diffuse polarised emission promises to provide significant new data on the MIM through the technique of Faraday rotation synthesis (Brentjens & de Bruyn 2005). Such a survey with ASKAP will allow identification of RM features with known objects (stars and various kinds of stellar-wind bubbles, SNRs, low-density envelopes of HII regions, ionised skins on the outside of molecular clouds), and promises to give information on the turbulent structure of the MIM. The latter outcome will shed light on the role of magnetic fields in the turbulent cascade of energy from large to small scales. Such a survey will also give measures of field strength in many regions. Most polarisation surveys have focused on the Galactic disk, and the ASKAP survey will give important new information on the disk-halo transition and on conditions high above the Galactic plane.

Zeeman splitting of the HI line can provide in situ magnetic field measurements throughout the Galactic disk (e.g. Heiles & Troland 2003, 2005). Ideally, one would like to measure the Zeeman splitting of the HI emitting gas at the tangent points for all longitudes between $-90°$ and $+90°$. A small, but significant latitude coverage of

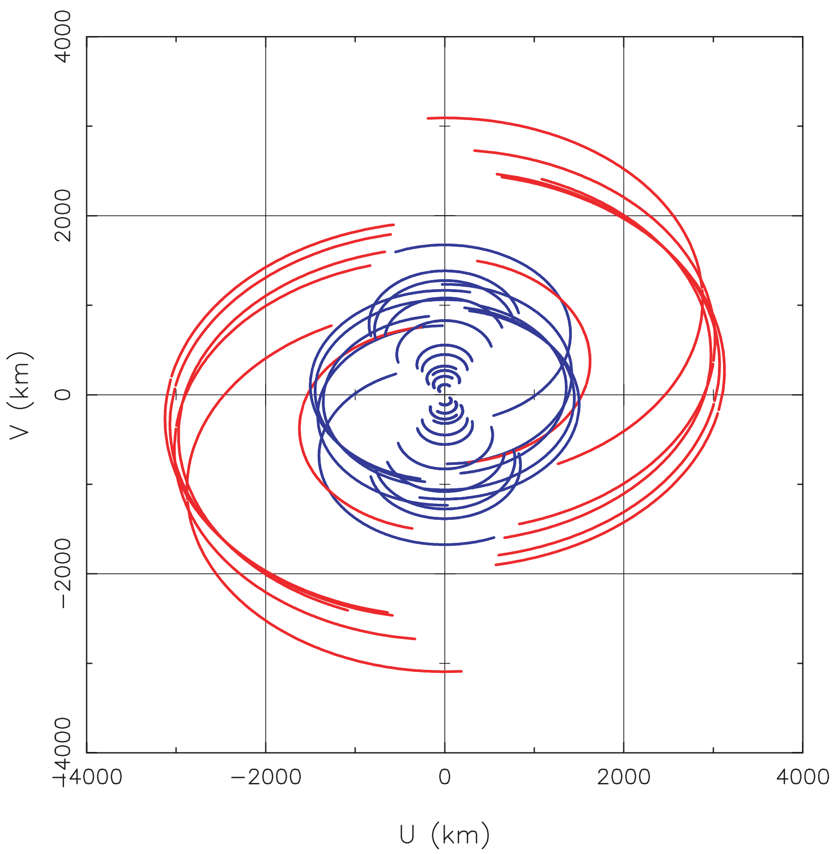

Figure 4 The (u,v) coverage of the current Australian VLBI array at 1.6 GHz (blue curves) and with the inclusion of ASKAP (blue and red curves combined). The improvements in the east-west component of the baseline distribution and in the extension of the maximum baseline length are significant.

$\sim 5°$ is needed to ensure that the measurements reflect the global Milky Way magnetic field, rather than being subject to individual clouds. We therefore propose an ASKAP survey of the area $270° \le l \le 45°$, $|b| \le 2.5°$: $\sim 700\,\mathrm{deg}^2$. For a typical magnetic field strength of $\sim 5\,\mu\mathrm{G}$ and a velocity width of $5\,\mathrm{km\,s^{-1}}$, we expect the amplitude of the Stokes V spectrum to be 70 mK. We require that the derivative of the line be very well sampled in velocity space, so for a typical derivative line width of $5\,\mathrm{km\,s^{-1}}$, we require $\Delta v \approx 0.25\,\mathrm{km\,s^{-1}}$ or $\Delta \nu \approx 1\,\mathrm{kHz}$. This survey requires a $1-\sigma$ sensitivity limit of $\sim 20\,\mathrm{mK}$ in each polarisation. In order to reach these low surface brightness limits we once again require that the telescope have a high filling factor. Because resolution is not a stringent demand on this project, an ultra-compact configuration with most of the collecting area inside a maximum baseline of ~ 200 m would be preferred. Measuring HI Zeeman in emission requires both low sensitivity limits and good polarisation properties of the telescope. With such a compact configuration ASKAP would be uniquely positioned to measure the magnetic field along the tangent point and contribute directly to constraining models for the Milky Way magnetic field.

6 VLBI Science

A number of scientific programs present themselves when considering the use of ASKAP as part of the Australian Long Baseline Array (LBA) and the global VLBI array. Better angular resolution at 1.4 GHz, better sensitivity, and better (u,v) coverage (see Figure 4) will aid standard VLBI observations of AGN, pulsars, and OH masers. An innovative additional capability for ASKAP is multibeaming. If this can be harnessed for VLBI in the form of multiple phased array beams, a number of wide-field survey observations become feasible.

In time, ASKAP should also become a part of the recently developed Australian e-VLBI network, currently called PAMHELA (see Figure 5). An interesting possibility is to not use ASKAP as part of the LBA, but use it as a source of trigger information for radio transients, as part of ASKAP survey work. These triggers could be transmitted to PAMHELA, and the candidate sources targeted at high angular resolution in rapid follow-up observations. The combination of ASKAP and PAMHELA would be unique and powerful. PAMHELA would add great scientific value to the low resolution detection of transients by ASKAP.

In the 1.4 GHz band, a number of VLBI science applications are possible, using ASKAP as an additional element in the LBA. Given the phased array field of view of approximately $5''$, the following observations could be usefully made:

- Active galactic nuclei (AGN) only require a narrow field of view. The addition of long, sensitive

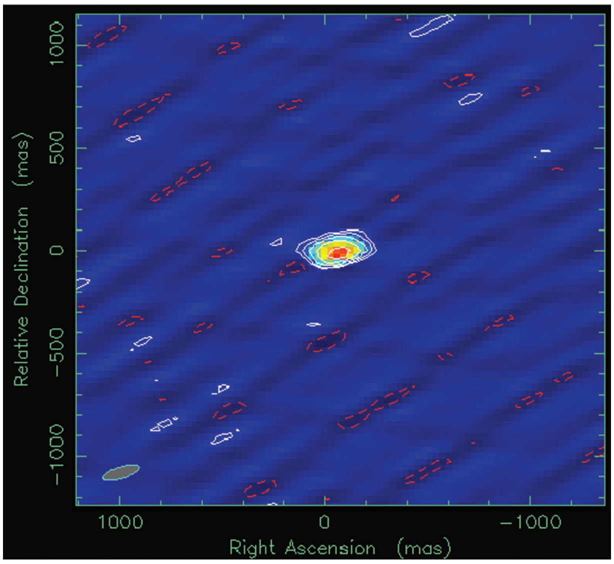

Figure 5 The PAMHELA image of Circinus X-1, the first Australian e-VLBI image of a transient radio source associated with a Galactic X-ray binary object (Phillips et al. 2007).

east-west baselines is critical for performing high dynamic range imaging of the often complex mas-scale jet radio sources. Further, use of ASKAP along with RadioAstron observations will be possible, examining AGN on the longest possible baselines to investigate brightness temperature limits in AGN.

- Pulsar proper motion and parallax observations benefit from good sensitivity on long baselines in order to do the best possible astrometry (e.g. Brisken et al. 2003). The relatively low frequency of ASKAP is optimal for pulsars. The combination of longer baselines and better sensitivity would allow the LBA to target a much wider range of pulsars for astrometry than is presently feasible.
- OH Maser observations benefit from good sensitivity on long baselines, important to resolve individual maser spots. Different maser species typically trace different parts of the star forming regions. Combining high-resolution OH imaging with observations of methanol and water masers, and the high velocity resolution dynamical information it is possible to image and interpret the three-dimensional distribution of masers in great detail, and in some cases to obtain proper motions and accurate distance estimates (e.g. Boboltz 2005).
- The detailed study of rare compact objects, such as supernovae seen at both optical and radio wavelengths (e.g. Bietenholz 2005).

A significant part of the ASKAP science case involves the rapid survey capability of the instrument and its ability to detect rapid transients in continuum emission. The types of transient that ASKAP will likely detect include Galactic X-ray binaries, gamma-ray bursts (GRB), flaring stellar systems, and possibly supernovae in nearby galaxies. A fuller description of transient searches with ASKAP follows in Section 8.

Both the new types of transients that ASKAP will likely discover, and the previously known types of transients are likely to involve objects of small angular size and varying structure such as X-ray binaries, GRBs, and supernovae. For all these objects, especially any newly discovered types of transients, therefore, VLBI observations will prove useful to elucidate the source structure and its evolution. Such VLBI observations will be particularly useful if the source is imaged while in an active state, and so the combination of ASKAP transient event detection with rapid-response PAMHELA observations should pay particularly high science dividends.

7 Pulsar Science

Almost 2000 radio pulsars have been discovered since the initial detection in Cambridge (Hewish et al. 1968). Pulsars have been used as tools to address some of the most fundamental questions in basic physics (allowing precision tests of general relativity, investigations into the equation of state of ultradense matter and the behaviour of matter and radiation in the highest magnetic fields known in the universe) and astrophysics (binary evolution, binary dynamics, the interstellar medium, globular cluster physics, supernova remnant astrophysics, the physics of relativistic winds and precision astrometry). Pulsars are also intrinsically interesting, being the result of core collapse supernovae and astonishing converters of mechanical energy of rotation into electromagnetic radiation, particles and magnetic fields. The study of pulsars themselves is important for constraining the overall population's properties and hence their origin, as well as understanding the mysterious pulsar emission mechanism.

Historically it has been common to carry out pulsar research using large single dish instruments. ASKAP will provide the transition from using large diameter single dishes to using large numbers of small antennas with wide field-of-view (FoV) capability as is likely in the final mid to high frequency SKA design. However, pulsar observations, especially searches, with ASKAP will present myriad computational challenges, some of which can be mitigated through specification choices. In particular, any large-scale survey with good sensitivity will be severely computationally limited, and the need to process every pixel independently ensures that the computational load becomes larger as the square of the maximum baseline length. It is therefore necessary that as many short baselines as possible be present in the configuration of ASKAP. For pulsar timing, there is no such requirement; any configuration is adequate.

We suggest a survey with ASKAP which occupies ~100 days of observing time and covers the 30 000 square degrees of visible sky. Each 30 square degree single pointing therefore is observed for ~150 min. Such a survey, with the strawman ASKAP parameters, would equal the sensitivity of the Parkes Multi-beam Pulsar Survey (but over a much larger area of sky) and would be 10 times more sensitive than the previous Parkes All-Sky Survey. Data recording requirements would force the survey to sample at a rate of only 5 or 10 ms; this would necessarily and unfortunately preclude sensitivity to millisecond pulsars.

Simulations (Lorimer; private communication) show that such a survey would detect 1600 pulsars with periods $\gtrsim$40 ms, about half of which would be new discoveries. Many of the new detections would be low-luminosity objects; a large sample of low-luminosity pulsars is important in defining pulsar birthrates and evolution. Furthermore, even though this proposed survey would not be sensitive to millisecond pulsars, many exotic objects have longer periods including the original binary pulsar PSR B1913+16 (Hulse & Taylor 1975), pulsars with high-mass companions and relativistic systems such as PSR J1141−6545 (Kaspi et al. 2000). It is likely that any pulsar companion to a black hole in the field of the galaxy would be slowly spinning and the survey described here might find such an object. Finally this survey would be sensitive to transients with pulse widths greater than 10 ms or so. The science case for detecting new pulsars is wide-ranging and includes:

- The ability to improve models of the pulsar population and hence determine birth rates and the Galactic distribution (e.g. Vranesevic et al. 2004).
- The discovery of unique objects, particularly highly relativistic binary systems including pulsar-black hole binary systems. Many unexpected discoveries will be made in future surveys.
- Mapping the electron density distribution and magnetic field of the Galaxy by combining rotation and dispersion measures with independent distance estimates (e.g. Cordes & Lazio 2002; Han et al. 2006).
- Understanding the pulse emission mechanism. As the number of known pulsars increases so does the variety in pulse profiles, polarisation and fluctuation properties. A more complete understanding of the pulse emission mechanism will only occur from the careful analysis of these properties for a large sample of pulsars at multiple observing frequencies (e.g. Karastergiou & Johnston 2006).
- Timing of these newly discovered pulsars will be more efficient with ASKAP than existing telescopes because the large FoV makes it possible to time multiple pulsars simultaneously.

One of the most exciting modern-day applications of pulsar timing is to combine data from multiple millisecond pulsars to form a global timing array (Foster & Backer 1990; Hobbs 2005). The aims of such a project are manyfold with the main goal of making a detection of the gravitational wave (GW) background at nano-Hertz frequencies. In brief, GW backgrounds are predicted to occur due to cosmological (e.g. due to inflation, cosmic strings or phase transitions), or astrophysical (e.g. due to coalescing massive black hole binary systems that result from the mergers of their host galaxies) processes (e.g. Maggiore 2000). The background is detected by looking for correlations between the timing residuals of pulsars that have a wide range of angular separations (Jenet et al. 2005). ASKAP will enhance the capabilities of a global pulsar timing array and demonstrate the possibility of high-precision pulsar timing on an SKA-type instrument.

High precision millisecond pulsar timing will also continue to undertake sensitive observations of relativistic effects in double-neutron-star systems which lead directly to stringent tests of relativistic gravity. ASKAP will have uniquely sensitive access to many of the binary pulsar systems discovered in the Parkes Multibeam surveys. Masses measured by ASKAP will add to the currently poor statistics of masses in pulsar–white-dwarf systems and finally allow a realistic investigation of mass dependencies on orbital period, companion type and evolutionary history.

8 The Transient Radio Sky

It has been the general trend in radio astronomy to move from dipole-like antennas towards parabolic dishes which have much larger forward gain at the expense of a much smaller field-of-view. Consequently, this severely limits the possibility of detecting (random) transient events and the transient sky in the radio is only poorly characterised. At the same time, many classes of objects are known to be variable radio sources including the Sun, the planets, cool stars, stellar binary systems, pulsars, supernovae (SN), gamma-ray bursts (GRBs) and active galactic nuclei (AGN).

The key to a successful transient instrument is to have high sensitivity, large field-of-view, good dynamic range and high resolution. ASKAP fulfills these criteria with its ability to achieve sub mJy sensitivity across the entire sky in a single day observing. Nearly all transients arise from point source objects; high resolution is ideal for obtaining accurate positions necessary for follow-up at other wavebands. It is important also that a wide range of timescales from seconds to months are covered by the transient detector. This implies a careful search strategy for uncovering rare objects. ASKAP will most likely suffer from a surfeit of transient and variable sources. This will pose challenges both for imaging and for determining which sources are most interesting and worthy of follow-up observations on other facilities.

The most interesting transient sources detected with ASKAP will undoubtedly be objects which we currently know nothing about. One of the advantages of an all-sky survey is that it is tailor-made for detecting the unknown. It has become clear recently that the radio sky contains many transient objects, the identification of which remain mysterious. For example, Hyman et al. (2005) discovered a bursting transient towards the Galactic Centre which lasted for only a few minutes but had a flux density in excess of 2 Jy. The bursts repeat at irregular intervals and the identification of this source remains unclear. Bower et al. (2007) examined archival VLA data of the same field spanning 22 years with observations approximately once per week. They detected 10 transient sources, at least six of which have no optical counterparts or quiescent radio emission. Bower et al. (2007) consider the classes of known transients and conclude that their sample is unlikely to be drawn from the known population. They estimate that at ASKAP sensitivity, approximately one transient source per square degree, with a duration of order a week, will be present at any given time.

As an example of transient sources, consider gamma-ray bursts (GRBs) which, in the gamma-ray band, occur approximately twice per day and are visible out to $z \gtrsim 6$. GRBs are almost certainly beamed in gamma-rays; this implies that we only detect some fraction of the total population. However, it may be possible to detect so-called orphan GRBs without the initial gamma-ray trigger by looking for variable radio sources. Levison et al. (2002) and Totani & Panaitescu (2002) show that several hundred radio afterglows of GRBs should be present in the sky at any one time above a level of 1 mJy. ASKAP could survey the sky to this level every day, providing a definitive test of these ideas.

Monitoring the variability in AGN is made possible by the wide FoV of ASKAP. A survey with ASKAP could cover the sky every day to a 5σ limit of 2 mJy, which would detect variability at the 2% level for 100 mJy sources and at the 20% level for 10 mJy sources on a daily basis. This is similar to levels achieved in the (targeted) MASIV survey (Lovell et al. 2003) which found that more than 50% of the AGN in their sample were variable. With 17 sources per square degree above 10 mJy in the sky, ASKAP would usefully survey some 350 000 AGN each day.

A small subset of these AGN show variability on timescales of less than a day, caused by interstellar scintillation; the intra-day variable (IDV) sources (Kedziora-Chudczer et al. 1997). IDVs are of astrophysical interest because the small angular sizes ($<50\,\mu$as) that they must possess in order to exhibit interstellar scintillation require them to have brightness temperatures near or, in many cases, several orders of magnitude in excess of the 10^{12} K inverse Compton limit for incoherent synchrotron radiation. The IDV phenomenon is observed to be highly intermittent in most sources. What fraction of IDVs are intermittent, and what is the duty cycle of their IDV? Is IDV intermittency source- or ISM-related? The brightening and fading of IDV in intermittent sources, which ASKAP could automatically measure in hundreds of thousands of objects, would then address the physics that causes the bright emission in the first place. IDVs may also provide the first *direct* detection of the ionised baryons in the IGM at $1 \lesssim z \lesssim 6$ through angular broadening induced by turbulence in the IGM. Hints of this are already present in the MASIV data (Lovell et al. 2007), where reduced variability is seen for sources with $z \gtrsim 2$.

Extreme Scattering Events (ESEs) are a type of transient in which the flux variations are not intrinsic to the source but are caused by variations in refraction along the line-of-sight (Fiedler et al. 1987b; Romani et al. 1987). In other words ESEs are a lensing phenomenon; not gravitational lensing, but refraction of radio waves in ionised gas. It has long been recognised that the lenses which cause ESEs must be Galactic, probably within a few kiloparsecs, but in the 20 years since the phenomenon was discovered no satisfactory physical model has emerged. In part this is a reflection of the difficulty of explaining the existing data using established ideas about the interstellar medium. Recently, however, Walker (2007) has suggested that the lenses must be associated with neutral, self-gravitating gas clouds and may be the source of the Galaxy's dark matter. Very little new data on the phenomenon has been obtained since the early work of Fiedler et al. (1987a, 1994) and the field has stagnated. The all-sky monitoring capability of ASKAP will address this problem in a comprehensive way.

The origin of the ultra high energy (UHE) cosmic rays (CR), which have energies extending up to at least 2×10^{20} eV, is currently unknown and determining the origin of these particles will have important astrophysical implications. A key to untangling the origin of the UHE CR will be direct detection of UHE neutrinos. A promising method for the detection of UHE neutrinos is the Lunar Čherenkov technique, which utilises Earth-based radio telescopes to detect the coherent Čherenkov radiation (Dagkesamanskii & Zheleznykh 1989) emitted when a UHE neutrino interacts in the outer layers of the Moon (Hankins et al. 1996; James et al. 2007).

Lunar Čherenkov emission produces a linearly polarised, broadband pulse with sub-nanosecond duration (e.g. Alvarez-Muñiz et al. 2003, 2006). In past experiments, false triggering (due to interference) has proved to be the limiting sensitivity, against which both multi-antenna coincidence (Gorham et al. 2004) and the characteristic ionospheric dispersion signature accross a large bandwidth (James et al. 2007) have provided powerful discriminants. The low interference environment of ASKAP means that we expect the trigger thresholds — and hence sensitivity — to be limited only by random noise statistics. However, there are many technical challenges in detecting sub-nanosecond pulses. ASKAP will serve as the first test-bed of nanosecond pulse technology which can be directly scaled to the SKA, though the possibility of a first detection should not be ruled out. The predicted sky coverage to UHE neutrinos for ASKAP is shown in Figure 6. This includes interesting regions where existing limits are weak.

9 Summary

ASKAP is a key step on the strategic pathway towards the SKA. The goals of ASKAP are to carry out world-class, ground breaking observations, to demonstrate and prototype technologies for the mid-frequency SKA and to establish a site for radio astronomy in Western Australia where observations can be carried out free from the harmful effects of radio interference.

In this paper we have outlined the main science themes to be tackled by ASKAP, themes which derive from the major issues confronting astrophysics today such as understanding the evolution, formation and population of galaxies including our own, understanding the magnetic

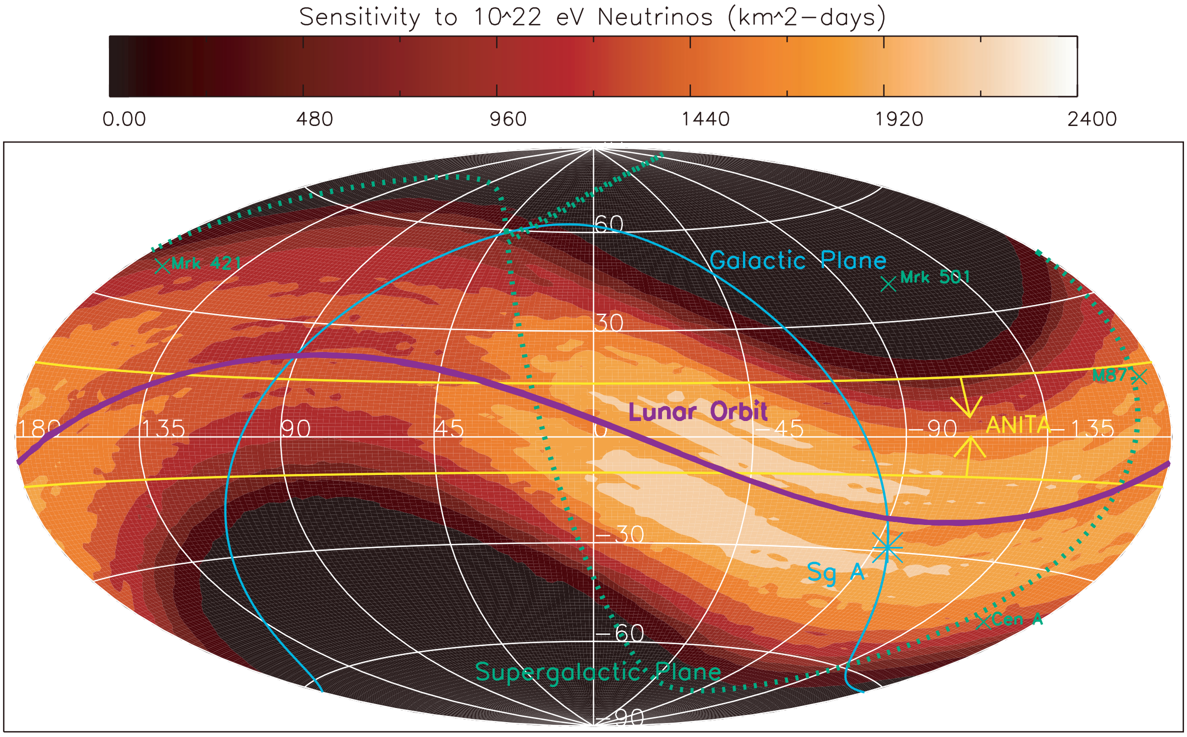

Figure 6 Likely sensitivity (km^2-days) to 10^{22} eV neutrinos ASKAP in celestial coordinates for one month's observations (40% duty cycle). A frequency band of 0.7–1 GHz is assumed. The sky coverage is much broader than for ANITA Antarctic ice balloon experiment (Miocinovic et al. 2005).

Universe, the nature of the transient radio sky and the direct detection of gravitational waves.

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