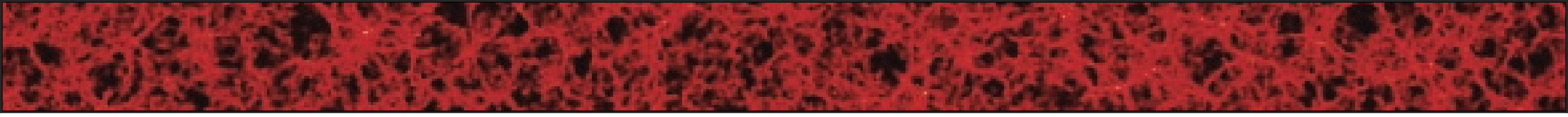


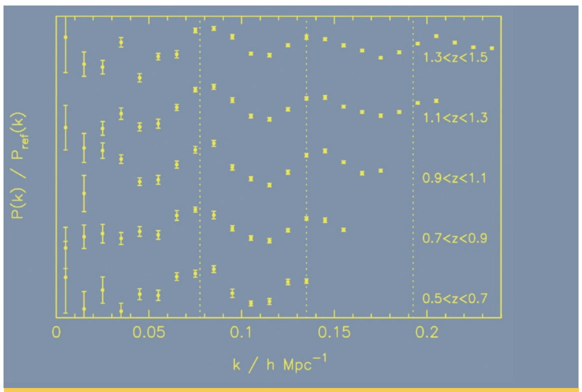
SKA Key Science Projects

The following projects have been identified by the radio astronomy community as being the key science drivers for the Square Kilometre Array

• The evolution of galaxies and cosmic large scale structure

What is the equation of state of dark energy? Does it change with cosmic time? How do galaxies assemble and evolve? With its wide field of view (>1 sq deg) the SKA will be able to map out the cosmic distribution of neutral hydrogen (HI) in the 21 cm line at cosmological distances that are almost entirely inaccessible to current instrumentation. This will enable revolutionary progress in the fields of galaxy evolution and large-scale structure.

An HI emission-line survey maps out galaxies independently of dust extinction, with one additional advantage: once the 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. This will allow us to chart the kinematics, merger history, and environment of ordinary galaxies as they evolve from redshifts z ~ 5 to the present.



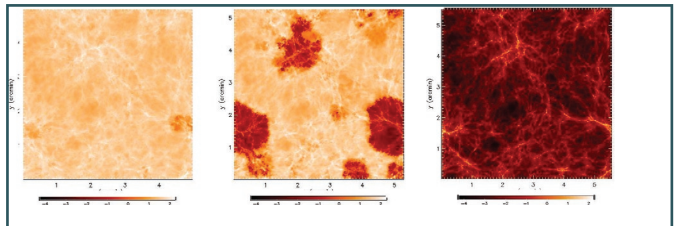
Simulation of baryonic oscillations in the power spectrum of the clustering of HI emission galaxies as a function of redshift. Credit: Chris Blake

With its wide field-of-view, the SKA could also survey the entire visible sky in a year of operation, locating a billion new HI emission galaxies over a vast volume stretching to redshift z=1.5. One of the cleanest methods of measuring dark energy in the Universe is by accurately delineating the small-amplitude "acoustic oscillations" in the power spectrum of the clustering of the HI emission galaxies. This baryonic signature has an identical physical origin to the acoustic peaks already identified in the Cosmic Microwave Background (CMB), which act as an accurate standard ruler for the experiment. Their recovery in the SKA HI survey, as a function of redshift (see figure), will permit an extremely accurate determination of the rate of evolution of the equation of state of dark energy with cosmic time.

• Probing the Dark Ages – the first black holes and stars

What happened during the epoch of reionization? The SKA has the ability to observe the very first black holes, stars and galaxies which shaped the development of the universe during the epoch of reionization.

High redshift quasars show evidence for a sharp rise in the neutral fraction of the intergalactic medium (IGM) at redshifts of ~6, implying that the epoch of reionization ends at this time. On the other hand, WMAP has found a surprisingly large electron scattering optical depth to the cosmic microwave background (CMB) radiation, implying that reionization began at redshifts of ~20.

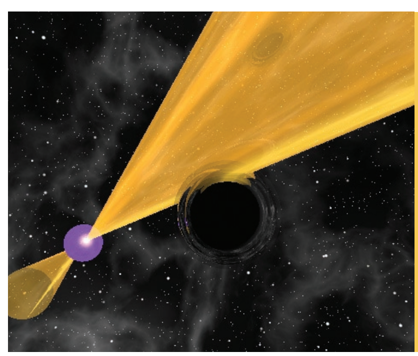


The panels in the figure show snapshot simulations of the HI universe evolving with time (from left to right). The dark regions correspond to highly ionized regions (such as those around protogalaxies) and the bright regions are dense, neutral pockets of gas. Credit: Steve Furlanetto et al 2004, Ap J

Due to the high Lya opacity, radio emission from the redshifted 21 cm line of neutral hydrogen provides the only observational window through which to observe this era directly. The SKA will provide detailed pictures of structure formation and reionization over a wide range of redshifts. Through multi-frequency observations, we can construct fully three-dimensional maps of neutral gas in the universe. Such maps are crucial for studying the time dependence of reionization.

Moreover, the SKA will have the sensitivity to pick out the continuum radio emission of the very first quasars and make high-resolution spectra of high-redshift radio sources e.g in HI and CO. In particular, HI spectra will yield detailed information about the early evolution of the cosmic web, the growth of ionized regions around protogalaxies, and even provide the only known direct way to observe, in absorption, "minihalos" or small clumps of dark matter and gas in the IGM that are predicted by many structure formation theories.

• Strong field tests of gravity using pulsars and black holes



Artist's impression of a pulsar-black hole binary expected to be discovered by the SKA. Credit: Michael Kramer.

Is Einstein's Theory of General Relativity correct in the strong field limit? Is the cosmos filled with a gravitational wave background? It has been proposed that the ultimate theory of the Universe will involve the unification of general relativity with quantum mechanics. We can expect that this theory of "quantum gravity" produces somewhat different predictions than general relativity. But how can we measure such deviations?

Tests in the solar system are made under "weak-field" conditions. "Strong-field" tests have only been possible using pulsars, which provide some of the most stringent tests ever made. Pulsars are the most precise natural clocks known in the universe - as precise as the best atomic clocks on Earth.

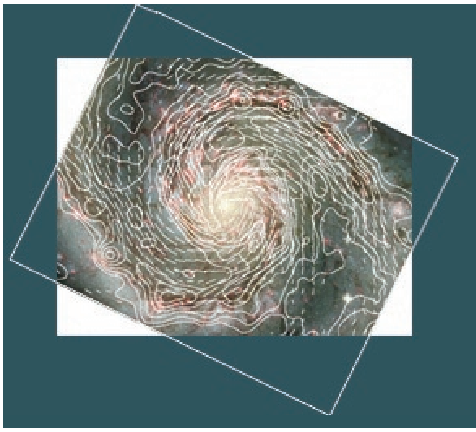
Through its sensitivity, sky and frequency coverage, the SKA offers the possibility of probing this strong-field realm of gravitational physics by finding and timing pulsars. The SKA is expected to discover - besides extragalactic pulsars - a very large fraction of the pulsars in the Galaxy, resulting in 10,000 to 20,000 pulsars, including the discovery of more than 1,000 millisecond pulsars.

In order to test general relativity further, we need to find a pulsar around a black hole or even one in orbit around the super-massive black hole in the centre of the Galaxy.
General relativity makes clear predictions about the nature of a black hole. Observations with the SKA will be able to measure these properties and hence provide the ultimate test for general relativity.

When timed to very high precision (< 100 ns), the array of millisecond pulsars will act as the multiple arms of a cosmic gravitational wave detector. This "device", with the SKA at its heart, will be sensitive to the elusive nano-Hertz gravitational waves from the birth of the Universe in the Big Bang – a unique opportunity.

• The origin and evolution of Cosmic Magnetism

Is the overall Universe magnetic? If so, has the Universe's magnetism affected the way in which individual stars and galaxies form? And ultimately, where has all this magnetism come from?



M51 radio continuum emission (contours) and magnetic field (vectors) at 5 GHz from VLA and Effelsberg data overlaid onto an HST image. Credit: Andrew Fletcher and Rainer Beck

Cosmic magnetism spans an enormous range in its strength, varying by a factor of 10^{20} between the weak magnetic fields in interstellar space and the extreme magnetism found on the surface of collapsed stars. Because these cosmic magnetic fields are all-pervasive, they play a vital role in controlling how celestial sources form, age, and evolve. Radio is the key, in many areas even the only, wavelength to study this cosmic magnetism.

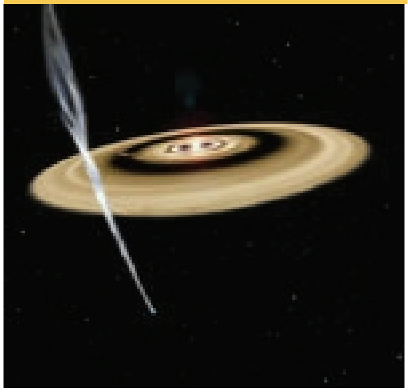
If we point the SKA at any part of the sky, we will be able to detect the radio emission from thousands of distant faint galaxies. These galaxies will be so closely spaced that we also can use their polarized radio emission as it travels through and is modified by magnetized interstellar and intergalactic space (Faraday rotation) to make detailed studies of the magnetic field throughout the universe. Combined with images of polarised synchrotron emission, three-dimensional maps of the magnetic field in the Milky Way, nearby galaxies, and galaxy clusters can be derived.

Moreover, all of "empty" intergalactic space may be magnetized, as part of the "cosmic web" structure. This field has not yet been detected, but its role as the likely seed for dynamos in galaxies and clusters places considerable importance on its discovery.

• Cradle of life

Are there Earth-like planets around other stars? Do they host intelligent life? By observing the process of planet building in the dusty disks that form around young stars, the SKA will be able to tell us how Earth-like planets are formed. It may be the only instrument capable of imaging, with the angular resolution required, the thermal emission from dust in the inner regions of disks where Earth-like planets are likely to be located. In addition, the SKA offers the possibility of detecting radio transmissions that would provide evidence for intelligent life among the stars.

An artist's impression of a dusty protoplanetary disk around a young star with gaps where planets may be forming (and a comet). Credit: David Aguilar and David Wilner



If placed at 500 light years distance, our own Solar System would be about 1 arcsecond across , so observations at milli-arcsecond angular resolution are very important to zoom in on planetary gaps. The SKA will have this resolution.

At the SKA's highest frequencies, it will be able to image the thermal emission from dust in the "habitable zone" around other stars in unprecedented detail. This will allow identification of features in disks related to planet formation, e.g. nearly empty gaps and spiral waves, and track the evolution of these features and identify rapid gravitational instabilities.

Moreover, the telescope will be so sensitive that it will be able to detect signals comparable in strength to television transmitters operating on planets around the closest stars to the Sun. So, the SKA will be able to search for "leakage" signals from other civilizations in a much larger volume than has been possible so far.