The SKA radio telescope will cover an entire square kilometre of land and use the latest technology

XILOSTUDIOS/ISPO/CSIRO

SKA: the world's largest radio telescope

Ian Morison reports on the most advanced radio array ever to be designed

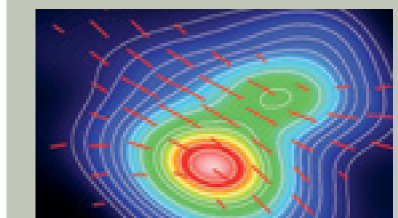
The Square Kilometre Array (SKA) will be the largest radio telescope ever built. With a collecting area of a million square metres – the equivalent of 127 dishes of 100m (328ft) in diameter – it will be able to observe the radio sky with a sensitivity over 30 times greater than any other radio telescope.

Work is just beginning on the SKA's detailed design and its inauguration is planned for 2015. An international team of astronomers, scientists, engineers and planners have worked closely on ►

What SKA will search for

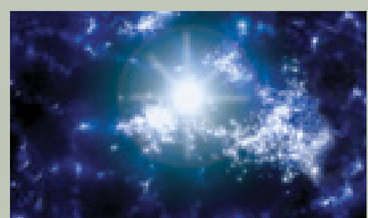
PULSARS
The SKA will discover thousands of pulsars, some of which are expected to be in orbit about black holes. By observing these pulsars, astronomers will be able to examine the limits of general relativity in regions of extremely curved spacetime. They'll be able to tell with high precision whether Einstein's theory is correct.

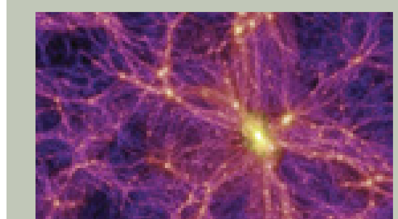
ALIEN LIFE
With a sensitivity 30 times greater than any previous radio telescope, the SKA will be capable of searching for, and imaging, planetary systems in formation. It could detect possible signals from other civilisations across the Galaxy, and maybe even the equivalent of television signals from planets in nearby star systems.



MAGNETIC FIELDS
Magnetic fields are an important component of space but, as yet, we know little about their origin and evolution. By mapping the effects of localised magnetism on a radio wave passing through a region of space, the SKA should be able to reveal the role that cosmic magnetism has played in the evolution of the Universe.

THE FIRST STARS
By observing the extremely redshifted hydrogen line, the SKA will be able to observe how the Universe lit up as primordial gas collapsed to form the first stars and galaxies. It may help us bridge the gap between the time when the Universe became transparent and the point at which the first galaxies appeared.

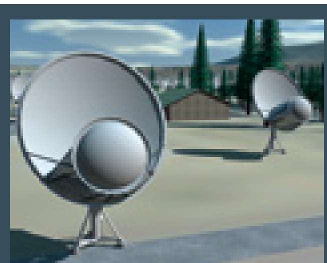




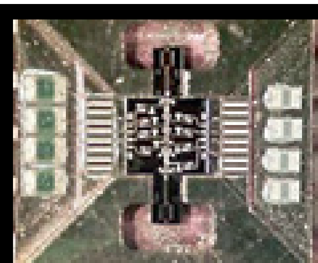
DARK MATTER AND DARK ENERGY
The SKA will have the sensitivity to detect a billion galaxies across the Universe. The resulting map should reveal the processes by which galaxies formed and grew. It will be possible to investigate the 'dark matter' that was instrumental in the formation of galaxies, and the mysterious 'dark energy' accelerating the expansion of the Universe.

SKA technology

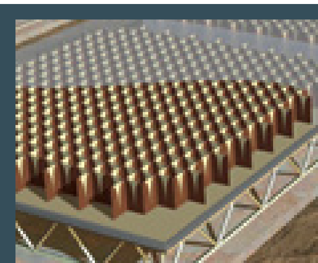
Development teams all over the world are collaborating to design the innovative, clever technologies that will be used in the SKA



In the USA, the Allen Telescope Array is pioneering the use of many small, cheap antennae in the place of single, giant telescopes. These dishes will form the foundation of the SKA's design.

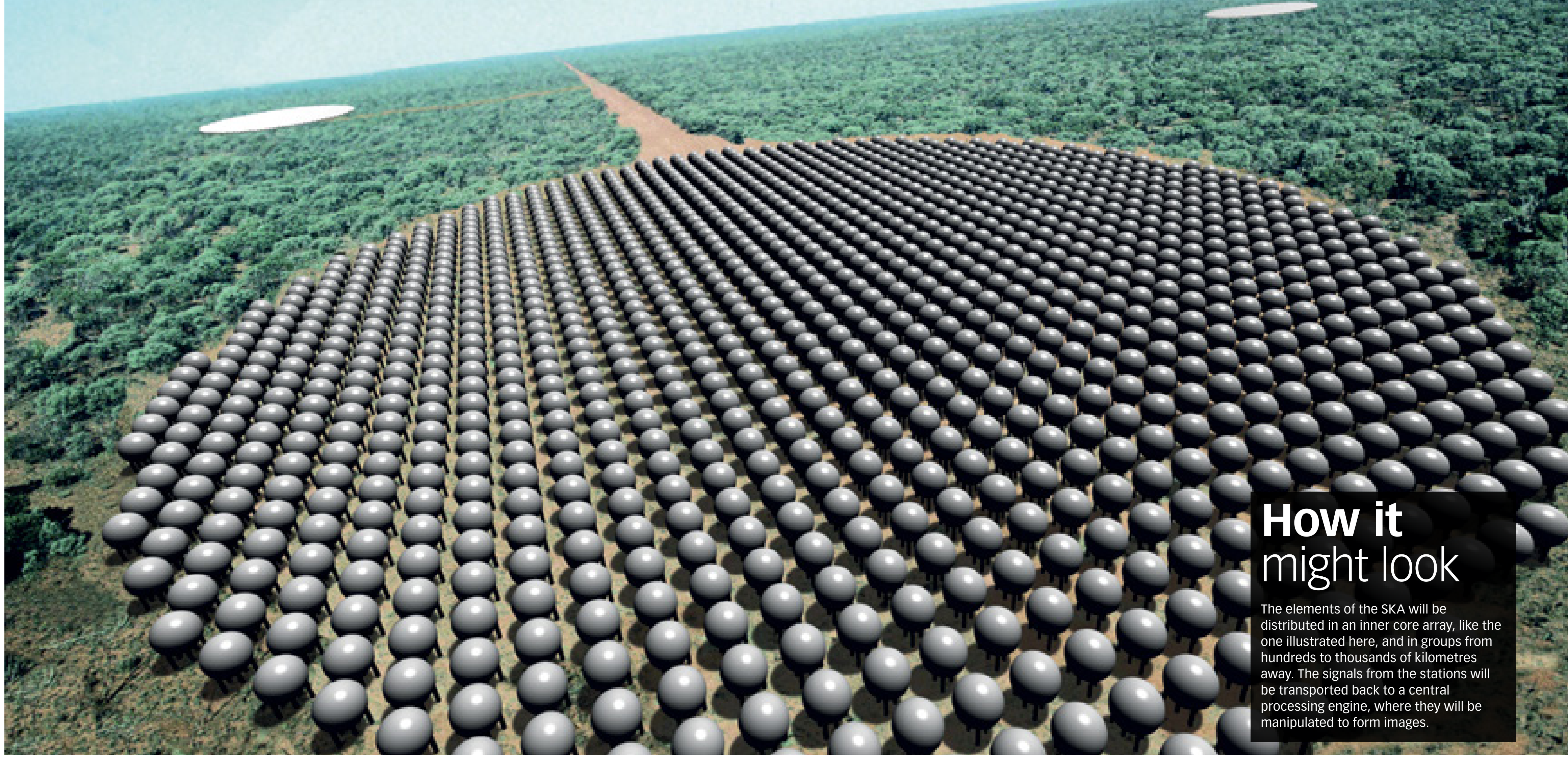


Engineers in the Netherlands are collaborating with IBM to develop customised data processors that have the low intrinsic noise needed to detect weak radio signals from the distant Universe.



UK scientists and engineers are helping to develop 'phased arrays' of tiny antennae that will enable astronomers to keep watch for transient events occurring anywhere in the sky.

NASA/JPL-CALTECH X3; BEN SIMONS/VISLAB SYDNEY; MAX PLANCK INSTITUTE; GIRART/RAO/MARRONE; ISAAC GARY; XILOSTUDIOS/ISPO/CSIRO



How it might look

The elements of the SKA will be distributed in an inner core array, like the one illustrated here, and in groups from hundreds to thousands of kilometres away. The signals from the stations will be transported back to a central processing engine, where they will be manipulated to form images.

► the project, which will represent more than a decade of exciting developments in radio astronomy.

When we think of a radio telescope, images of large instruments such as the recently upgraded Lovell Telescope at Jodrell Bank (now in its 50th year) spring to mind. However, future radio telescopes will be very different.

Recent technological advancements mean that the same collecting area

▲ The SKA site must be sparsely populated and free from radio interference

as the giant (and very expensive) individual radio telescopes can be achieved more cheaply using many small antennae. And this is what matters where sensitivity is concerned: when the antennae's individual signals are combined together in powerful computing systems, they can surpass the capabilities of any single radio telescopes currently in use.

Although each dish must have its own receiver and associated electronics, meaning far more electronics are required, their cost is falling rapidly. Optical fibres can easily bring the signals together. "Steel is being replaced by silicon," says Jill Tarter, head of the SETI Institute, which is building the Allen Telescope Array (ATA) in California.

The use of many small dishes has another useful property: many small antennae can observe signals from a wider region of sky. A single, large antenna can only observe signals from a very small region of the sky at one time. This is called its beamwidth: a 120m (40ft) dish only encompasses an area about one quarter the size of the Moon. By contrast, the 6x7m (40x23ft) ATA dishes are able to observe an area of sky over four times the diameter of the Moon. The signals from each individual antenna are synchronised to form one small beam, making up the equivalent of a large antenna. These signals can then be combined in slightly different ways to give a second beam, a third and so on. At relatively little extra cost, telescopes like the ATA and the SKA will be able to provide multiple beams on the sky, allowing several observing programmes to be carried out simultaneously.

Reasons for radio observing

But why observe the Universe using radio telescopes? One reason is that some very interesting objects, such as pulsars (the spinning remnants of massive stars) can usually only be detected in the radio part of the electromagnetic spectrum.

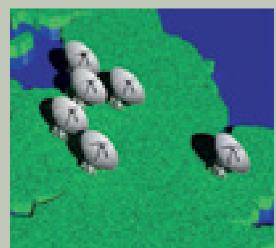
Not only are pulsars interesting in their own right, but they enable us to probe the matter between stars and investigate how physics works under extreme conditions. Recently, the study of a double pulsar produced the most precise confirmation of Einstein's theory of gravity ever, showing his theory to be at least 99.95 per cent right.

Another good reason to use radio telescopes is that they allow us to see much more than just light, owing to the longer wavelength of radio waves ►

▼ The 350 dishes of the ATA radio array in California form the equivalent of one 120m dish

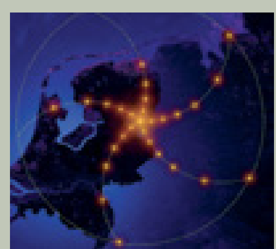
Other radio telescope arrays

ATA
The Allen Telescope Array is being commissioned in northern California and will link together up to 350 dishes of 7x6m (23x20ft) in diameter. In its SETI role, this innovative design will enable many target stars to be observed simultaneously.



e-MERLIN
The Extended Multi-Element Radio Linked Interferometer Network is Britain's own 217km (135 mile) diameter array. Following upgrades to its optical fibres, by 2008 its sensitivity will increase nearly 30 times to make it the world's most sensitive radio telescope.

ALMA
The Atacama Large Millimetre Array is situated high in the Chilean Andes. It will comprise 50 dishes, 12m (39ft) wide and will observe the Universe at wavelengths 1,000 times longer than light. It will be able to see through dust and study the rich chemistry of the Universe.



LOFAR
The Low Frequency Array of 15,000 simple antennae is due to be operational in 2008. The signals are digitised, transported to a central processor and combined in a powerful computer, making what is, essentially, a 'software' radio telescope.

EVLA
The Enhanced Very Large Array's 27 antennae of 25m (82ft) diameter span 36km (22 miles) of the plains of New Mexico. It's having a similar upgrade to e-MERLIN and, when completed in 2012, will take over the title of the world's most sensitive radio telescope.

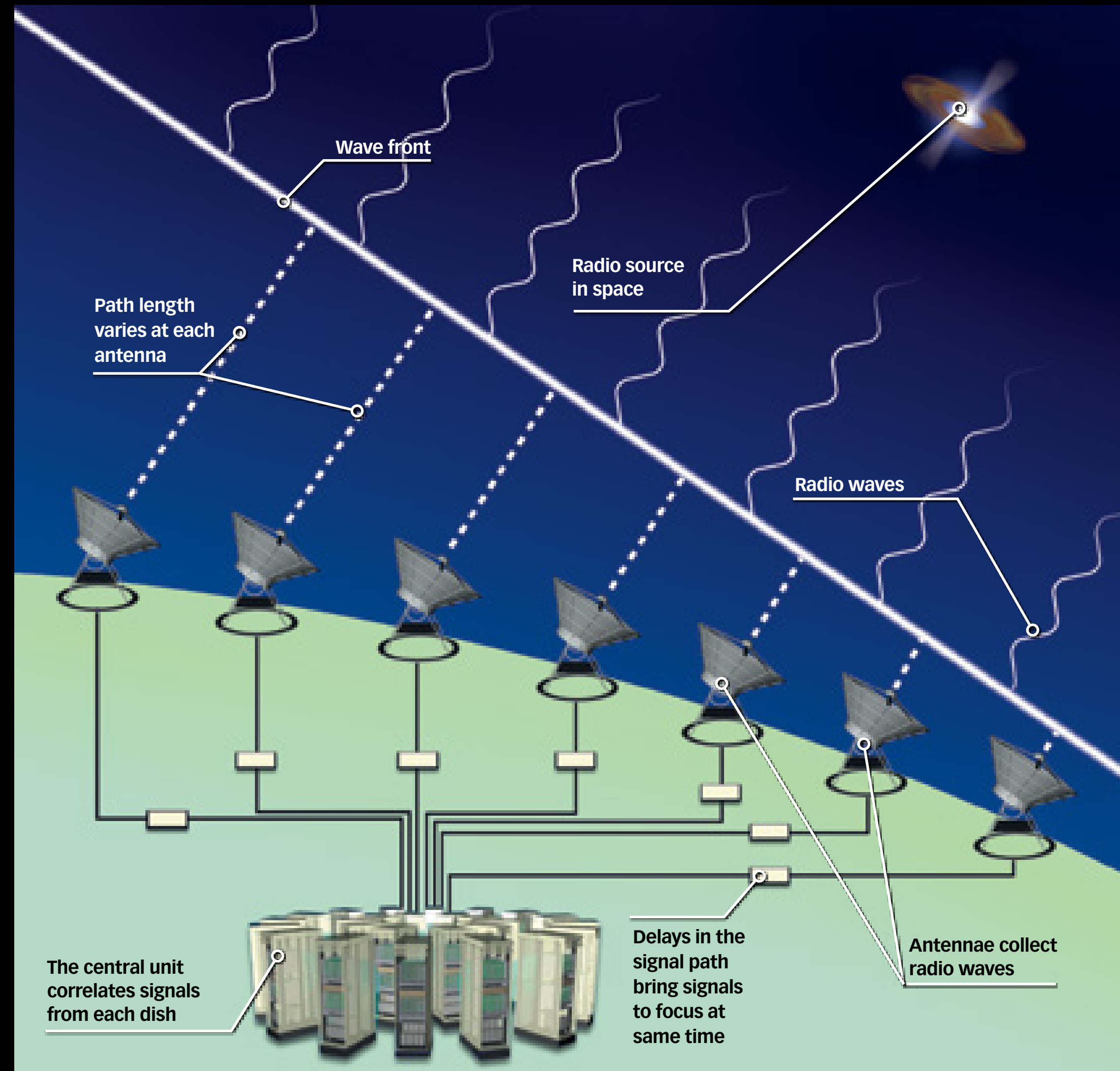
How it works

Interferometry is the name given to the method of combining signals from two or more antennae in an array to form a radio telescope of a much larger diameter.

An array's effective size is given by the largest separation of the antennae, and its sensitivity is determined by the antennae's total collecting area.

All the radio signals from the array will end up at a central focus point, or 'correlator'. It's critical that the total path length from the radio source to this correlator must be the same for all antennae for the correlator to act effectively as the focus of the distributed telescope. To this end, delays are inserted into the signal paths to bring the signals together simultaneously.

Because there are lots of pairs of antennae observing for up to 24 hours, enough information is gathered to make an 'image' of the radio source. For each second of time that the distributed telescope is observing, every pair of telescopes in the array provides a little information about the structure of the radio source. As the Earth rotates, the SKA's geometry changes and more information can be gleaned.



▸ compared to light waves. Radio waves pass through dust clouds unhindered and 'see' deep into the hearts of other galaxies. This means we can observe areas where matter is spiralling in towards supermassive black holes, releasing vast amounts of energy.

Radio telescopes can also detect the Cosmic Microwave Background (CMB). Over billions of years, our Universe has expanded in size, and the wavelength of the radiation within it has lengthened by a similar ratio. Imagine wavy lines drawn on the surface of a balloon lengthening as it is inflated. When the Universe became transparent about 380,000 years after the Big Bang, it was filled with yellow-orange light. But, since then, the Universe has expanded by about 1,000 times more, with the wavelength of the radiation increasing accordingly. This CMB radiation is now no longer visible light, but lies in the long-wavelength infrared and short-wavelength ultraviolet part of the electromagnetic spectrum.

To make such observations, working elements of the SKA will be distributed in an inner core and also in 'stations' of receiving elements. These will be located in spiral patterns from a few hundred metres to several thousand kilometres away from the central core. This design will provide high sensitivity and produce high-resolution images.

In addition, a 'phased array' of antenna elements will be located at the heart of the SKA's central core. These dishes will act like a radio fish-eye lens capable of continuously watching the whole of the sky for radio flashes from transient events.

So where should the SKA be built? The chosen site must be large enough, it should be sparsely populated – to minimise radio frequency interference – and in a location from which the SKA can observe the central regions of the Galaxy. The second two of these criteria indicate a site in the southern hemisphere, where the population density is lower and the Galactic centre comes high overhead.

Two sites are currently shortlisted: one in the centre of the northern cape of South Africa, extending into neighbouring African countries; the other in the plains of Western Australia, extending across to New Zealand. Site surveys to measure the levels of radio interference and investigate conditions in the local ionosphere, which affect low-frequency observations, are currently being carried out, and a final decision will be made before 2010.

SKA potential

Radio astronomy has a remarkable track record of discovery: quasars, pulsars, the CMB, complex molecules in space, gravitational lenses and the existence of gravitational waves. Whenever a new instrument has been commissioned whose capabilities greatly exceed any existing instrument, not only has it extended our current knowledge, it has often led to the discovery of new and exciting phenomena.

With radio telescopes like the ATA, e-MERLIN, ALMA, LOFAR and the EVLA coming on stream in the next few years, radio astronomy certainly has an exciting future – a future that will take a massive leap forward with the construction of the SKA. ✪

[FIND OUT MORE]

Square Kilometre Array:
www.skatelescope.org
Low Frequency Array:
www.lofar.org
e-MERLIN:
www.merlin.ac.uk/e-merlin

The expert

Prof Peter Wilkinson reveals all

How did the concept of the SKA arise?
In 1985, I visited the VLA in New Mexico and was shown a picture of a nearby galaxy imaged in the radio emission from atomic hydrogen. Due to the weakness of the diffuse hydrogen emission the resolution was only one tenth that of a ground-based optical telescope. It was obvious that to produce a radio image of comparable quality we would require 100 times the collecting area of the VLA – about one square kilometre.

Other radio astronomers in the Netherlands were thinking along the same lines, but with less ambitious plans. In 1991, I became aware of the progress being made on the Giant Metre Wave Radio Telescope in India, which provided a collecting area one sixteenth of a square kilometre at relatively low cost. After a further 15 years of planning and innovation, the world's astronomers have convinced themselves that, by working together, they really can build such an instrument. And now national funding agencies seem prepared to be convinced.

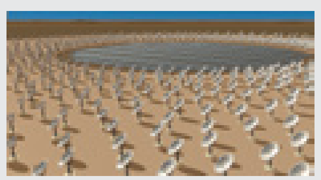
What is the UK's involvement?
The UK has been at the forefront of the planning and politics of the SKA since 1991, and will play a major role in its development phase. My colleague at Manchester, Prof Phil Diamond, and I are working with Prof Steve Rawlings at Oxford and Dr Paul Alexander at Cambridge to design a new type of 'aperture array' where the beams are formed electronically, rather than via the curved metal surfaces of a radio dish.

We are working closely with our Dutch counterparts, who have long espoused the idea of a telescope with no moving parts. The great advantage of this kind of phased array is that it enables widely separated areas of the sky to be observed simultaneously, meaning several groups of astronomers working in parallel. After all, the best way to make new discoveries is to allow as many clever people to use the SKA as possible.

Prof Peter Wilkinson of Jodrell Bank Observatory is the principal investigator for the UK SKA Development Study.

[TIMELINE]

January 1991
SKA concept first proposed



August 2000
Signing of the SKA International Memorandum of understanding at the IAU General Assembly in Manchester

September 2006
South Africa and Australia chosen as possible sites for the SKA

2011
Construction of the SKA will begin at the chosen site

2014
With 10 per cent of the collecting area operational, the first science can begin

2020
The full SKA will be operational

1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020