



Status of Pathfinder Telescopes and Design Studies

**Edited by Colin Greenwood,
International SKA Project Office**

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1. Introduction

Institutions participating in the SKA are now designing and building prototype systems, and design decisions for the full SKA will be based on the technologies demonstrated by these pathfinder telescopes and design studies. Many different technological solutions will be selected and integrated into the final instrument. This document provides a summary of the status of the SKA prototypes, pathfinder telescopes, design studies and other SKA-related R&D work, and has been generated from information provided by these projects.

The purpose of this document is to provide background information for the 'Preliminary Specifications for the Square Kilometre Array' report, first issued as a discussion document on 10 September 2007.

2. Design Studies

2.1. SKA Preparatory Phase (*PrepSKA*)

PrepSKA is a 4 year project, supported by EU funding of €5.5 M for the first 3 years (first call). The project is scheduled to commence in April 2008 and has the principle objectives to:

- Produce a deployment plan for the full SKA, and a detailed costed system design for Phase 1 of the SKA;
- Further characterise the two candidate SKA sites in Southern Africa and Australia and to analyse the various risks associated with locating the SKA at each of the sites;
- Develop options for viable models of governance and the legal framework for the SKA during its construction and operational phases;
- Develop options for how the SKA should approach procurement and how it should involve industry in such a global project;
- Investigate all aspects of the financial model required to ensure the construction, operation and, ultimately, the decommissioning of the SKA;
- Integrate all of the activities, reports and outputs of the various working groups to form an SKA implementation plan.

PrepSKA is a global endeavour to explore the appropriate legal, policy and technical framework required for the SKA. The EU-supported work packages are:

- WP1 Management of the contract
- WP2 Technical activity: SKA Design
- WP3 Support activity: SKA sites
- WP4 Support activity: SKA Governance
- WP5 Support activity: SKA procurement and industrial involvement
- WP6 Support activity: Developing the funding model for the SKA
- WP7 Coordination activity: Production of final report and SKA implementation plan

WP2 is the principle technical work package and has been organised as a program covering system design and prototyping activities. Prototyping projects have been defined for each of the major SKA sub-systems in an arrangement mirroring that of the established international SKA engineering development structure. Specific objectives of WP2 are to produce:

- A costed top-level design for the SKA, and a detailed system design for SKA Phase 1;
- Advanced prototype SKA sub-systems specified in the course of (a), the sub-systems being based on technology development in current regional Pathfinders and Design Studies;
- Base technologies for SKA Phase 1 and critical wide field-of-view design technology extensions; and

- An Initial Verification System (IVS) which brings together the most advanced SKA Phase 1 technology components and demonstrates the functionality, cost effectiveness and manufacturability of the adopted SKA Phase 1 design.

In developing a costed top-level design, WP2 will build on technology developments being undertaken within the suite of international SKA Pathfinder telescopes and Design Studies, as well as other radio astronomical and industrial developments. The expenditure on SKA-related R&D around the world will be ~ €150 M from 2006-2010. The Design Studies are SKADS (FP6, Europe) and TDP (USA); the Pathfinders are the MeerKAT (South Africa), ASKAP (Australia, Canada), ATA (USA), e-MERLIN (UK), EVLA (USA), LOFAR (Netherlands, Germany), APERTIF (Netherlands), MWA (USA, Australia), and LWA (USA).

WP2 will be carried out by a Central Design Integration Team (CDIT), embedded within the SPDO and hosted at the University of Manchester. This team will integrate all of the diverse strands of technology development from around the world to deliver the outputs of WP2.

2.2. Square Kilometre Array Design Studies (SKADS)

SKADS, which commenced in July 2005, is a 4 year international program to investigate and develop technologies for the SKA. The SKADS consortium (including participants from 9 EU countries, South Africa, Canada and Australia) is carrying out a detailed investigation of the scientific- and cost-effectiveness of the SKA concept, and is developing technologies which will enable the instrument to be built at an affordable cost. For further information about SKADS, see <http://www.skads-eu.org>.

SKADS focuses on the frequency range 100MHz to 1500MHz, which is the low and mid-range for SKA. A key element of this part of the design is the use of phased arrays in which many small antennas act together to collect the incoming radio waves. The signals from the individual antennas are electronically delayed and combined such that the telescope can point in a given direction without making any mechanical adjustments. By multiplying the signals and combining them in different ways, the telescope can observe in multiple directions simultaneously. This will give the telescope an unprecedented ability to observe a large part of the sky at once and allow more than one group of astronomers to use the telescope for independent measurements.

SKADS comprises the following work packages:

- DS1: management of SKADS
- DS2: Science and Astronomical Data Simulation
- DS3: The network and its output data
- DS4: Technical foundations and enabling technologies
- DS5: Aperture array demonstrator (EMBRACE)
- DS6: Cylindrical Concept demonstrator
- DS7: Assessment of work and critical reviews
- DS8: Overall system design and preliminary SKA plan.

In terms of identifying a cost-effective design for the SKA, it is recognised that the cost per square metre of collecting area be 5-10 times less than current radio arrays; also, more than one collector technology will be required to cover the range of frequencies from 0.1 to 25 GHz. The SKADS costing team, led by the University of Cambridge, is developing a SKADS cost model based on experiences from current pathfinder telescopes, and in particular from the LOFAR and e-MERLIN projects where accurate cost data is available. The final cost model will be capable of modelling different SKA configurations, and determining their costs. By combining the SKADS cost model with the project's sky and telescope simulations, the aim is to design the SKA with required performance at an affordable price.

SKADS aims to prove the technical feasibility of the phased aperture array concept by building and testing prototypes. Three demonstrators are under construction: BEST, EMBRACE, and 2-PAD.

2.2.1. The Basic Element for SKA Training (BEST)

The BEST comprises 3 test beds on part of the large Northern Cross Radio telescope in Medicina, Italy. The BEST will test electronic sub-systems, adaptive beamforming, multibeaming and RFI mitigation / excision algorithms.

The effectiveness of electronic multi-beaming must be tested rigorously, and this involves electronically creating multiple pixels within the field-of-view of a single parabolic reflector. "Adaptive beam forming" will also be studied, which involves combining signals from separate receivers with the proper weighting in order to create a beam of a chosen shape in a given pointing direction. Finally, algorithms for mitigating, and possibly eliminating, the effects of man-made radio frequency interference are being developed and tested. All these concepts will be verified on the BEST before being utilised by the European EMBRACE demonstrator.

2.2.2. Electronic Multi-Beam Radio Astronomy (EMBRACE)

EMBRACE) is the world's first large-scale demonstrator for the aperture-plane phased-array concept. The main objectives of EMBRACE are to demonstrate the technical and scientific potential of the aperture array concept using a low cost phased array station with the essential Square Kilometre Array (SKA) functionality in combination with the Westerbork Synthesis array.

The EMBRACE project, led by ASTRON, will consist of two systems: one at Westerbork in the Netherlands, with a collecting area of 300 m² and one in Nançay, France with a collecting area of 100 m². Each will cover a frequency range from 500 - 1500 MHz and provide multiple beams within $\pm 45^\circ$ of the zenith.

The collecting area of the EMBRACE systems comprises a large number of antenna tiles, each of area ~ 1 m². All processing is done at the back-end using an analogue link (low cost co-axial solution) from the aperture array. The analogue link from the tiles to the back-end processing simplifies the tile design and totally decouples the antenna from the receiver. This reduces EMC related problems in general, since the local oscillator and clock signals now have to be distributed in the back-end cabinet only.

The down-conversion and digitisation is also carried out in the back-end cabinet. For the down-conversion and for the distribution of the control and power to the antenna tiles, the Control and Downconverter (CDC) will be developed by the EMBRACE project. For the digitisation and digital processing, a LOFAR station will be re-used with minor adaptations. The LOFAR Station Control Unit will be updated so that the tile phase shifters, LO generators, etc which will be added by the EMBRACE system can be controlled within the same environment.

The signals from the 64 elementary radiating elements from each tile are amplified and initial RF analogue beam-forming will be applied. Due to the limitations imposed by the use of phase shift control with large instantaneous bandwidth requirements, a tile has been re-configured into quadrants. The outputs of these quadrants can then be combined with time-delay lines directly to increase the instantaneous bandwidth as desired. There is an option for an additional time delay per tile should there be a need to increase the requirement on instantaneous bandwidth even further.

EMBRACE specifications are shown in Table 1.

Table 1. EMBRACE specifications

Parameter	Specification
Frequency range of receiver chain:	400 MHz - 1550 MHz.
Polarization:	Single polarisation
Physical collecting area	$\approx 300 \text{ m}^2$
Aperture efficiency:	>0.80
Electronic scan range:	Full hemispherical
T_{sys} :	$<100 \text{ K @ } 1\text{GHz}$ (aim for 50 K)
Antenna element phase control accuracy:	3 or 4 bit
Instantaneous bandwidth:	40 MHz
Dynamic range A/D converter:	60 dB
Number of independently tuned FOVs (RF beams):	2
Number of digital beams:	8, of 20 MHz per FoV

EMBRACE has no moving parts; the planar array is steered electronically to allow multiple independent Fields of Views (FoV). Such a flexible system offers the prospect of supporting many users to carry out separate astronomical programmes at the same time.

2.2.3. Dual Polarisation All Digital (2-PAD)

The ultimate capability of an aperture-plan phased-array is realised with 2-PAD aperture array tile, a project led by the University of Manchester. This concept exploits digital signal processing technology to the fullest extent. The signal from the sky is sampled immediately after reception at the antenna element, and from then on, only digital electronics are used. This concept promises unprecedented flexibility and performance for a telescope, limited only by the computer power and speed of data transfer. The challenges are to limit the power consumption and to achieve the required data rates at an affordable cost. However, the fully digital solution provides the maximum possibility for simultaneous observing, very wide bandwidths, precise calibration for the best possible beam, tailoring of the field-of-view at different frequencies for specific science, and post-observation analysis of transient signals.

A technology demonstration system is being built as part of SKADS at Manchester's Jodrell Bank Observatory. It will demonstrate solutions to the challenges of an all digital array: processing power, cost and the prevention of interference from the processing system. The 2-PAD technology would be a major step for the SKA, to be a "software telescope", limited only by computer processing power.

2.3. US Technology Development Project (TDP)

In June 2007, the US SKA Consortium (17 institutions) was informed that it would be awarded \$12M by the National Science Foundation for a "Technology Development Project for the Large-N/small-d Square Kilometre Array Concept". Funding will commence in November 2007. The TDP proposal was submitted by Cornell University on behalf of the US SKA Consortium, and includes work done across the US and international collaborators. The TDP takes specific note of the European FP7 preparatory phase proposal, and states that the US TDP is the "mechanism for US participation in the international design effort". The funding is for four years for end-to-end development, costing and preliminary design. It will be managed at Cornell University.

The primary work package in the TDP is "Antennas, Feeds and Receivers," which includes a study of antenna manufacturing methods, development of wideband feeds (WBFs) and receivers, studies of

cryogenics, identification of optimal optical designs for the antenna for a range of feed types, including the WBFs developed under the TDP along with PAFs developed elsewhere around the world. Antenna diameters in the 6 to 15m range will be considered. One of the hardware deliverables is a fully outfitted, optimized SKA antenna.

A secondary work package is “Calibration and Processing,” that includes consideration of algorithms for dealing with the full range of imaging, spectroscopic and time-domain science applications.

Included in the study is an analysis of the cost/performance as a function of operating frequency to help define the technical constraints on the upper limit of the mid-frequency range of the SKA. The scope of the proposal is to span the current SKA Reference Design up to an engineering design for construction of Phase I of the SKA in 2012.

The TDP’s goals are the same as PrepSKA’s and the two projects can be viewed as one. The TDP includes explicit interactions with the Australian, Canadian, and South African SKA efforts, particularly in the Antennas, Feeds and Receivers work package.

3. SKA Prototypes

3.1. Australian SKA Pathfinder (ASKAP)

The Australian SKA Pathfinder (ASKAP) is a collaborative project to demonstrate the use of phased array feeds (PAF) and beamforming on parabolic dishes in the Mid-West region of Western Australia (WA) as well as continental baselines. The location is being developed as the Murchison Radio Observatory (MRO) with robust developmental and RFI protections. The area is one of the two short-listed SKA areas. Recently the Australian Communications and Media Authority (ACMA) has released a Radiocommunication Assignment and Licensing Instruction (RALI), enacting a stringent radio-quiet zone in the area. The coordination zone extends out to 260 km, with the restriction zone extending to 150 km.

The Australian Government has funded the development of ASKAP at a budget of over A\$100M over the next five years. The ASKAP collaboration includes the Hertzberg Institute for Astrophysics’ (HIA) Dominion Radio Astrophysical Observatory (DRAO), the Netherlands Foundation for Research in Astronomy (ASTRON), and the KAT project for software in a program called CONvergent Radio Astronomy Demonstrator (CONRAD). The Murchison Widefield Array (MWA) is a collaborative instrument also to be sited at the MRO. Other associated projects include the Precision Array Probing the Epoch of Reionisation (PAPER; University of California, NRAO, University of Virginia), and the Cosmic Reionisation Experiment. (CoRE; ATNF).

As a result of the new funding and collaborations, ASKAP targets to incorporate:

- an array of up to 45 ~12-meter antennas equipped with phased array feeds and digital beamformers
- studies of cooled phased array feeds, along with continued investigation of “room-temperature” performance;
- a remote array station in western New South Wales linked to the WA core via fibre-optic infrastructure;
- key infrastructure and developmental controls to demonstrate the viability of the site for the SKA, including radio-quiet zone controls and optical fibre appropriate for the SKA;
- support facilities in Geraldton (the nearest major town, located 315 km from the MRO by road). This is the termination point of the fibre-optic cable

3.1.1. ASKAP Telescope

The ASKAP Telescope is under construction as a significant, science-capable array to demonstrate the use of phased array feeds on reflector antennas. The approach is to provide a flexible

environment to provide the best opportunity to demonstrate PAF performance and inform SKA decisions on wide field-of-view high dynamic range imaging. Given the increase in funding, the program has expanded rapidly through the xNTD and MIRA projects to become ASKAP.

The ASKAP core at the MRO is being built with the target specifications shown in Table 2.

Table 2. Specifications of the ASKAP core at the MRO

Parameter	Specification
Antennas	45 x ~ 12 m.
	Each antenna equipped with a ~10x10 dual-polarization phased array feed ("smart feed", including studies on coupling with other feeds for other bands)
System temperature	35K (Goal, possibly cooled)
Frequency range	0.7 – 1.8 GHz
Instantaneous bandwidth	300 MHz
Field-of-View	30 square degree
Baselines	Compact array with baselines < 8km
Correlator	Located at the MRO, with high-bandwidth fibre link for processing and archiving at a data centre is either Geraldton or Perth.
	Full cross-correlation of all beams from all antennas.
Operations	Six-antenna system to be operational in 2010 [to begin detailed studies of the system and provide some degree of input to the full array build-out]

A remote station in NSW will be developed to examine continental baselines in this context. The exact form and placement of the NSW station is dependent on negotiations currently underway.

The ASKAP telescope parameters are aimed at addressed the following Key Science Projects of the SKA:

- strong field tests of gravity using pulsars and black holes
- the origin and evolution of cosmic magnetism
- galactic evolution, cosmology and dark energy

Thus the science goals of ASKAP include:

- understanding the evolution of the gaseous component of the nearby universe
- determining the evolution, formation and population of galaxies throughout cosmic time
- understanding the interstellar medium of our own Galaxy and the generation and maintenance of its magnetic fields
- revealing the nature of the transient radio sky
- discovering and timing up to 1000 radio pulsars, and
- providing a vital element of the VLBI network

Although only about 1% of the collecting area of the full SKA specifications, ASKAP will be a front-line scientific instrument in its own right which attacks ground-breaking science questions directly relevant to the SKA.

For further information about ASKAP/MRO, see <http://www.atnf.csiro.au/projects/askap> and <http://www.ska.gov.au>.

3.1.2. Murchison Widefield Array (MWA)

The MWA is an international collaboration between the US, Australia and Indian institutions to build a wide-field low-frequency dipole array, comprising 512 16-element tiles operating in the frequency range of 80 – 300 MHz. It is being built in the Murchison Radio Observatory and relies on the extreme radio-quiet provided by the very remote site.

The central goal of the MWA is to measure the signature of the epoch of reionisation by using a compact ultra-wide field-of-view array of dipoles. Each 16-element tile of dipoles features an analog beamformer and digitizer, with summed beams being fed back to the correlator.

Key specifications of the MWA are shown in Table 3.

Table 3. MWA specifications

Parameter	Specification
Number tiles	512
Dual-dipoles/tile	16
Max baseline	1.5 km
Frequency	80 – 300 MHz
FOV	170 - 1900 deg ²
Bandwidth	32 MHz
Resolution	8 kHz
Channels	4000

The MWA will tackle one of the SKA key science projects: probing the dark ages. The instrument will detect the red-shifted emission from the epoch of reionisation, the era when the first stars and galaxies formed in the universe. Other specific sciences goals for the MWA are: continuous monitoring for possible coronal mass ejections from the sun and detecting transients.

For further information about MWA, see <http://www.haystack.mit.edu/ast/arrays/mwa>.

3.2. Karoo Array Telescope (KAT) / MeerKAT

The Karoo Array Telescope (KAT), a 1% SKA technology demonstrator, is currently under construction in the Northern Cape province of South Africa, near one of the proposed sites for the core of the SKA. It will have 1% to 2% of the survey capacity of the SKA and so will be a world-class research instrument in its own right. KAT will demonstrate wide-field techniques using small dishes (15m). A high-speed fibre-optic link will connect the KAT to the Centre for High-Performance Computing (CHPC) in Cape Town. The KAT is scheduled to be fully operational by 2010. It will be a working, integrated instrument with an aperture of at least 3,000m² ($A_{\text{eff}}/T_{\text{sys}} > 50$) and at least 10 steerable beams in 40 square degrees field of view.

The first step in the development of the KAT antenna is to design and construct a prototype (MeerKAT) at the Hartebeesthoek Radio Astronomy Observatory (HartRAO) by the end of 2007. This will make it possible to validate the mechanical design of an antenna for the KAT before starting with the production phase in the Northern Cape, thereby minimizing project risk. The lessons learned from MeerKAT will be incorporated into an updated design when the full array of 20 antennas is constructed.

The prototype will make it possible to conduct sensitivity tests of some of the key KAT science experiments. This will help the engineers to assess the suitability of critical elements of the KAT system design and will enable early testing of the telescope operational and science software chain.

Linking the prototype antenna to the existing HartRAO antenna will help build competence in interferometry and provide a test bed for evaluation of the KAT feed technology. This includes characterisation of the beam pattern, pointing and tracking accuracy, self-generated radio frequency interference (RFI), calibration and polarisation performance. The antenna will be designed to allow for tests of both horn cluster feeds and development of focal plane array feeds (FPAs), in collaboration with international partners. Table 4 summarises the technical specifications of the prototype antenna.

Table 4. MeerKAT antenna specifications

Parameter	MeerKAT Specification
Pointing Accuracy (deg)	0.04
Surface Accuracy (mm rms)	4
Frequency Range (MHz)	700 - 1700
Wind (Operational) km/h	20
Wind (Marginal Operation) km/h	36
Wind (Survival) km/h	160
Azimuth Rotation speed (deg/s)	1
Azimuth speed (deg/s)	0.5
Diameter	15
F/D	0.5
Lowest Natural Frequency (Hz)	3
Feed Mass (kg)	200
Feed Displacement (mm) - any direction	2
Feed Rotation (deg) any axis	0.02

For further information about the KAT, see <http://www.kat.ac.za>

3.2.1. Phased Experimental Demonstrator (PED)

PED is a test radio telescope interferometer currently under construction by the KAT project at The South African Astronomical Observatory (SAAO). PED will comprise 6 x 2.5m diameter steerable satellite TV dishes arranged as an interferometer and 1 x 3.5m diameter satellite TV dish with fixed pointing for drift-scan experiments. PED has a narrow bandwidth (4 MHz), centered around the HI radio astronomy line at 1420 MHz.

The main goals of PED are to serve as a test bed for KAT/MeerKAT in the development of the software systems for monitor and control, remote operations, basic scheduling, basic tied array and interferometric imaging processing, and RFI mitigation.

In March 2007, PED achieved 'first light', i.e. the receive chain and dish drive electronics were connected for the first time and a scan across the sun was performed. This was later followed by a longer spectral integration on, and off, the galactic plane in order to detect the neutral hydrogen radio signal. Since 'first light', the team has focused on development of the site infrastructure and work towards more automated end-to-end single dish experiments, to be followed by interferometric experiments with the 6-dish array later in the year.

3.3. Low Frequency Array (LOFAR)

LOFAR is a generic Wide Area Sensor Network for astronomy, geophysics and precision agriculture applications. It comprises an array of simple antennas. The electronic signals from these antennas are digitised, transported to a central digital processor, and combined in software to emulate a conventional dish antenna. The cost is dominated by the cost of electronics instead of steel, becoming cheaper with time and allowing increasingly large telescopes to be built. Originally, it was planned to have 15,000 antenna spread out over an area of ultimately 350 km in diameter, in the full original LOFAR design. However, since funding is limited and recent developments on a European level, LOFAR will be realised in several phases and will reach beyond its initial design.

The LOFAR project has gone through a re-scope process after concluding that the expected in-cash co-financing to complete the originally planned (77 station) lay-out could not be secured at this time. It is the ambition of LOFAR to secure funding at a later stage to realise the original scope. In the re-scope process which took place from July to September 2007, a LOFAR Phase 1 configuration was defined which consists of a geographically compact Core area (located in the northern Netherlands province of Drenthe) with about 20 core stations in addition to about 20 Remote Stations. Each Remote Station will be equipped with 48 high band antenna tiles, each tile consisting of 4x4 high band antenna elements, 96 low band antennas and several auxiliary systems, e.g. for weather monitoring and GPS time/position measurements. In the Core area, with 2km diameter, there will initially be about 20 stations equally equipped as the remote stations, ie. 96 low band antenna stations and 48 high band antenna tiles divided equally over 2 fields some 100 m apart. The maximum baseline between stations in the Phase 1 configuration is envisaged to be roughly 100km. Data transport requirements are in the range of many terabit/s and the processing power needed is tens of teraflop/s.

The low band antenna will be optimised for the 30-80 MHz range. The High Band antenna will be optimised for the 120-240 MHz range. The FM band is suppressed in the antenna Low Noise Amplifiers and in the receiver for both antennas to minimize intermodulation products from FM transmitters. The 96 low band antennas consist of two 48 antenna configurations optimised for the low and high part of the low band antenna band (10-80 MHz). Only 48 low band antenna can be used at a time. Additional sensors for geophysics, infrasound will also be placed at (some of) the astronomical stations.

Remote stations will be connected by 10 GbE technology to the Central Processing systems. The sensor data will be dominated by the astronomical antennas (2 Gb/s, being the equivalent of a single dual-polarized beam over 32 MHz, so 1 beam x 32 MHz or 8 beams x 4 MHz etc). The input section of the Central Processor is dimensioned such that up to 100 stations can be accommodated simultaneously. The processing capacity is matched to the proposed scenario for Epoch of Reionisation observations. Full Tied Array beamforming will be supported. Transient detection will be supported (probably using large collections of low-bandwidth beams). Buffering of the full sampled bandwidth and limited triggering (primarily Ultra High Energy Cosmic Ray detection) will be available at station level.

The first LOFAR core station (CS1) was constructed in the fields of Exloo in the North-East of the Netherlands during the summer of 2006. 96 low band antennas have been distributed over 4 station locations; 48 antennas were placed in a central field and 16 each were distributed over 3 stations around the central station - yielding baselines of up to 450 metres. The set-up was chosen to enable not only performance tests of a single station at full bandwidth but also the emulation of LOFAR with 24 micro-stations at reduced bandwidth. CS1 went on-line at the beginning of October 2006. Since then, data has flowed to the BlueGene-based correlator in Groningen and is being processed, stored and analysed. Images of increasing quality have been produced and have demonstrated the potential of LOFAR. There are also 6 high band antenna tiles in the fields to test the other type of antennas. Although these tests are not as far as the low band antenna tests, the LOFAR project is preparing for the roll-out phase which will start in the end of 2007.

Over the last years, an enthusiastic European community has formed with the goal to extend LOFAR beyond its original scope and prepare to provide LOFAR with baselines of up to 1000 km establishing E(uropean)-LOFAR which will make high resolution low frequency radio science possible. There are efforts in Germany, the UK, France, Italy, Sweden, Poland and Austria/Ukraine to place stations within their countries and connect them via high speed internet links to the central processing facility. These very remote stations will consist of 96 low band antennas and 96 high band antennas.

In fact, the first international LOFAR station (IS GE-1) is being built in the direct neighbourhood of the 100 m Effelsberg radio telescope in a collaboration between ASTRON and the Max-Planck-Institut für Radioastronomie (MPIfR). The costs of the station are borne by the Max Planck Society. In Effelsberg, 96 low band antennas have been placed already and are functioning well. The LOFAR project prepares in collaboration with the MPIfR for the first long baseline correlation and expects the first fringes before the end of 2007.

The European community has secured money for three more stations in Germany, i.e. close to Potsdam, Munich and Tautenburg, for one station in France in Nançay and one station in the UK. The European community is not only adding hardware in form of astronomical stations to the LOFAR project but it also adds new scientific perspectives. Recently, two new international German led key science projects were formed which complement the Netherlands led key science projects (Transients, Surveys, the Epoch of Reionisation and Cosmic Rays). The new key science projects are 'Solar science and space weather' and 'Cosmic Magnetism'.

LOFAR is designed to see objects so far away that their radio signals were emitted just after the Big Bang. One expects in fact to be able to detect the very first objects. LOFAR will also provide unique insights into magnetic storms on the Sun and the solar wind, and how they affect the climate on Earth. Table 5 summarises the technical specifications of LOFAR.

Table 5. LOFAR specifications

Parameter	Specification
No. of stations / elements	Phase 1: Compact Core ~20 stations / ~3000 elements Remote stations ~ 20 stations / ~3000 elements E-LOFAR: ~+15 very remote stations / ~+3000
Frequency range	30-80 MHz 120-240 MHz.
Polarisation	2
Bandwidth	32 MHz
Spectral Resolution	1kHz
No. of beams	1 beam of 32 MHz up to 8 beams of 4MHz
Start date	Core station 1: Fall 2006 IS-GE01 Effelsberg: Spring 2007 Completion: 2009

For further information about LOFAR, see <http://www.lofar.org>.

4. SKA Pathfinders

4.1. Allen Telescope Array (ATA)

The ATA, known formerly as the One Hectare Telescope, or 1hT, is a joint effort by the SETI Institute and the University of California, Berkeley. It is being built at the existing Hat Creek Observatory, run by the Radio Astronomy Lab at Berkeley, and located in the Cascades just north of Lassen Peak, CA.

The ATA is a centimeter-wave array that pioneers the Large-Number Small-Diameter (LNSD) concept of building radio telescopes. The ATA has four primary advantages for scientific studies over all major radio telescopes built to date: (i) wide field-of-view i.e. 2.45° at $\lambda = 21\text{cm}$, (ii) complete instantaneous frequency coverage from 0.5 to 11.2 GHz, (iii) multiple simultaneous backends and (iv) active interference mitigation. The instantaneous area of sky imaged is 17x that of the VLA. Active interference mitigation will make it possible to observe at frequencies of many terrestrial radio emitters.

The ATA will ultimately comprise 350 dishes (6.1m in diameter) and will make possible large, deep radio surveys that were not previously feasible. The pseudo-random arrangement of the telescopes on the ground places all of the telescopes well inside a 1 km circle, carefully located to provide a very high quality beam. The large number of antennas provides unprecedented control of unwanted sensitivity outside the primary beam.

The ATA is being constructed in 4 stages, the ATA-42, ATA-98, ATA-206, and ATA-350; each number representing the number of dishes in the array at a given time. By building the new telescope as an array, many areas on the sky can be studied at once. In addition, it is easy to expand an array by merely connecting more dishes into the system.

The design involves an off-centre reflector assembly to minimise the chance of terrestrial signals bouncing off the antenna structures and causing interference. A secondary mirror has been incorporated into the design to bounce incoming radio signals collected by the large (6.1m diameter) primary reflector back to the feed horn, where they are amplified and then sent to the control buildings. By introducing a secondary mirror and a surrounding shroud, the antenna is less likely to pick up noisy radiation from the (relatively hot) ground surrounding the telescope.

The key design specifications of the ATA are shown in Table 6.

Table 6. ATA design specification

Parameter	Specification
No. of elements	350
Element diameter	6.1 m
Total geometric collecting area	10 229 m ²
Frequency	0.5-11.2 GHz
Aperture efficiency	60%
Effective area	6,137 m ²
System temp.	42 K
$A_{\text{eff}}/T_{\text{sys}}$	146 m ² /K
Effective diameter	700 m
No. of beams	16 dual polarization
FoV	0.07-40 deg ² (5 deg ² at 1.42 GHz)

Key science projects to be conducted initially will include:

- Determining the HI content of galaxies over three quarters of the sky,
- Classifying 250, 000 extragalactic radio sources as active galactic nuclei or starburst galaxies,
- Exploring the transient sky,
- Surveying 1,000,000 stars for extraterrestrial signals with enough sensitivity to detect an Arecibo radar out to 300 pc within the range of 1-10 GHz,
- Surveying the 4×10^{10} stars of the inner Galactic Plane near the frequency of 1420 MHz for very powerful transmitters
- Measuring the magnetic fields in the Milky Way and other Local Group Galaxies,
- Detecting the gravity-wave background from massive black holes through pulsar timing, and
- Measuring molecular cloud and star formation properties using new molecular tracers.

For further information about ATA, see <http://ral.berkeley.edu/ata/>

4.2. *APERture Tile In Focus (APERTIF)*

The APERTIF system being developed for the Westerbork Synthesis Radio Telescope (WSRT) to demonstrate the feasibility of using Focal plane Array technologies to improve the capabilities of reflector telescopes. By replacing the current single receiver of each WSRT dish by an array of receivers, the field of view of the WSRT is increased by more than an order of magnitude. This will allow imaging the sky at high spatial resolution at high sensitivity, enabling completely new strategies for radio astronomical research.

APERTIF aims to increase the FoV and bandwidth of the (WSRT) by using Focal Plane Arrays and all digital beamforming. It comprises 14 x 25m telescopes and is planned to become operational in 2010.

Science that will be enabled by APERTIF includes:

- HI
 - all sky: HI in "all" normal spirals out to $z = 0.08$; absorption out to $z = 0.2$ (10^7 sources)
 - deep: gas in Sloan galaxies
 - very deep: gas in galaxies at $z = 0.2$
 - Cosmic Web: down to column densities below 10^{17} cm^{-2}
 - very nearby: smallest galaxies
- Continuum
 - star forming galaxies at $z = 0.5-2$
 - RM grid
 - Halos in nearby galaxies
- Pulsars: all pulsars out to 10 kpc.

Target specifications for APERTIF project are shown in Table 7.

Table 7. Target specifications for APERTIF

Parameter	APERTIF Target
Collecting area	14 x 25 m 6900 m ²
A _{eff}	75%
T _{sys}	50 K
A _{eff} /T _{sys}	100 m ² /K (all telescopes)
Bandwidth	300 MHz
Beams	25 dual polarised beams (50 in total).
Frequency range	850-1750 MHz
FoV (@21 cm)	8 deg ²
Initial operation	2010

4.2.1. DIGITAL Early Stage Tile In Focus (DIGESTIF)

The DIGESTIF system is a digital FPA demonstrator that has been installed in one of the WSRT dishes and is an important milestone towards the application of APERTIF.

The objective of DIGESTIF is to test and evaluate beam forming, calibration and imaging of focal plane arrays. A 112 element dual polarised Vivaldi array is mounted in one of the fourteen 25 m WSRT telescopes. After amplification, 60 analog signals are transported to the backend, which is located in a shielded cabin next to the telescope. The RF signals are down-converted and digitized by 60 receiver units. The receivers sample at 80 MHz using 12 bit ADCs. The raw digital data is stored into RAM buffers and further processed offline. This setup offers an enormous flexibility since the weighting factors with which the elements of the array are combined are applied afterwards. This allows optimisation of the beamformer weights in software without re-measuring. First light was achieved in September 2007. DIGESTIF characteristics are summarised in Table 8.

Table 8. Summary of DIGESTIF specification

Parameter	Specification
Frequency range	1.0 – 1.7 GHz
Array size	80 x 80 cm
Dual linear polarization	Yes, Vivaldi elements
Number of elements	112
Instantaneous bandwidth	30 MHz
Number of receivers	60
Observation time	max 6.7 seconds per measurement
System temperature	100 K
Dish diameter	25 m

4.3. Canadian Research

In Canada, research is being concentrated in three areas in support of the SKA:

- (i) investigations into reducing the cost of concentrators through the use of advanced composite materials and fabrication techniques,
- (ii) increasing the field-of-view with phased-array feeds, and
- (iii) development of low-noise, ambient-temperature amplifier technologies.

Each of these developments have a direct impact on the survey-speed equation by increasing A_{eff} (because we can afford to buy more collecting area) and by increasing the field-of-view (or number of beams) with phased-array feeds (made possible with ambient temperature LNAs).

Recent developments include a collaboration with CSIRO on ASKAP and a tri-partate agreement with ASTRON and CSIRO on phase-array feed development.

4.3.1. Composite Applications for Radio Telescopes (CART)

Using composite materials (a sandwich structure consisting of two layers of resin impregnated high-strength fibres separated by a layer of foam) has the potential of allowing the production of light-weight stiff reflector antennas. It is commonly perceived that composite construction techniques are expensive because the materials are expensive. While it is true that materials such as carbon-fibre cloth is more expensive per kilogram than steel or aluminum, a much lower mass is required (because of the superior strength-to-weight ratio of advanced materials) resulting in a lower total cost.

At Dominion Radio Astrophysical Observatory (DRAO), a prototype 10-metre reflector antenna has been produced as part of a program called Composite Applications for Radio Telescopes (CART). This reflector has an f/D ratio of 0.45 in anticipation of use by phased-array feeds. This reflector was pulled off the mold in September 2007 and is currently undergoing surface measurement tests with an optical interferometer and microwave holography.

4.3.2. Phased-Array Feed Demonstrator (PHAD)

DRAO has constructed a demonstrator called Phased-Array Feed Demonstrator (PHAD). The purpose of this array is to explore the key issues of applying phased-array feeds to radio telescopes. This will be done through an incremental experimental approach beginning with measurements within an anechoic chamber and culminating with tests on a reflector antenna. The majority of testing will involve digitally recording data from all the array elements and beamforming off-line with a matrix language such as Octave or Matlab. This technique is powerful in comparison to a hardware beamformer because it permits diagnostics of all channels, encourages "what-if" experimentation, and allows archived data to be analysed anywhere, at any anytime. Once the array is understood and calibration and beamforming algorithms developed, then real-time beamforming can be implemented in the data collection system using on-board FPGAs.

PHAD has been implemented with off-the-shelf components where ever possible. Single-chip LNAs and receivers have been utilised to speed development. The data recording system is a commercial unit and has a Matlab-Simulink programming environment. Parameters of the system are summarised in Table 9.

Table 9. Summary of the PHAD system specification

Parameter	Specification
Number of elements	$9 \times 10 \times 2 = 180$
Number of polarizations	2
Frequency range	1--2 GHz
Bandwidth	4 MHz
Element spacing at f_{max}	$\lambda/2$
Number of receivers	180
Receiver temperature	$\sim 100\text{K}$
Beamformer inputs	180 (all elements)
Beamformer modes of operation	(i) off-line (data recording) (ii) real-time

The PHAD hardware is now complete and the test program has commenced. The first tests have been made in our near-field antenna range. The 10-metre CART dish will be used to test the system on the sky using both satellite sources and strong astronomical objects.

4.3.3. CMOS Low-Noise Amplifier development at the University of Calgary

More effort has been expended on the development of silicon CMOS than any other semiconductor process. As device geometry is reduced, the maximum frequency of CMOS transistors is increased. It has been shown that a side effect of this improvement is the reduction of transistor noise. Research at the University of Calgary has shown that, with current CMOS geometries of 90 nanometres, amplifier equivalent noise temperatures of ~14K can be achieved over a wide band at L-band frequencies. This is a significant result as it makes phased-array feeds much more feasible as it could make cryogenic cooling unnecessary. The work at the University of Calgary will continue by exploring noise temperature improvements by using smaller transistor geometries and by integration of the amplifier adjacent to array-element feed points.

4.4. Deep Space Network Array (DSNA)

The telecommunications link between the Earth and spacecraft engaged in solar system exploration includes the Deep Space Network (DSN). This network, consisting of large antennas located approximately equally spaced around the Earth, is responsible for the delivery of telemetry to scientists from a multiplicity of spacecraft currently on mission, as well as for those planned in the future. There is a cluster of antennas at each of the three longitudes that make up the DSN. Each cluster currently consists of one to three 34-m beam-waveguide antennas and one 70-m Cassegrainian antenna. These are located in the USA, Spain and Australia. Although the current DSN assets support existing mission scenarios, it has been suggested that future missions will desire both greatly increased data rates and higher capacity.

JPL and NASA are developing plans for the eventual replacement of the DSN 70-m antenna by 2015, with a prototype implementation starting in 2009. The size and number of antennas for this will be finalized as part of that activity. Array-based options are being considered, specifically the installation of 1200x12m parabolic reflector antennas, equally split across the existing DSN locations. A site at each longitude will occupy roughly 10-12 square kilometres including facilities.

Each antenna will operate simultaneously at both X-band (8 to 8.8 GHz) and Ka-band (31 to 38 GHz) and will be configured with radio frequency (RF) electronics, including the feeds, low-noise amplifiers, and frequency converters, as well as the appropriate servo controls and drives. The array also includes the signal transmission and signal processing to enable the system to track from between 1 and 16 different signals.

The concept of using arrays to increase the sensitivity is not new for radio telescopes or to the DSN. What is new about this concept is the cost goals that have been identified to complete a project capable of replacing the downlink capacity of the 70-m antennas. The concept leverages the advances made in electronics, such as monolithic microwave integrated circuits (MMICs), cryogenics, and, in particular, the inexpensive fabrication of smaller reflector antennas. The result is that duplication of the downlink capability of a 70-m antenna is expected to be achieved for 10-20% of the cost of the 70-m antenna.

4.5. EVN

The European VLBI Network (EVN) is the world's most sensitive VLBI array; it consists of 16 large radio telescopes in Europe and Asia. VLBI is limited both operationally and in sensitivity by current equipment; e-EVN is a proposal to transform the capabilities of the EVN through the use of fibre-optic connections from the telescopes to the EVN correlator at JIVE in the Netherlands. This upgrade will

result in a dramatic increase in sensitivity of the array and in its ability to respond quickly to targets of opportunity.

4.6. e-Merlin

MERLIN, developed in the early 1980s, consists of 7 telescopes located across England and connected by narrow-band microwave links. It was designed to provide sub-arcsecond resolution at centimetre wavelengths to study in more detail the radio galaxies and quasars imaged by the Cambridge aperture synthesis arrays.

The e-MERLIN upgrade is a project that will replace the microwave links by fibre-optic cables, thus increasing the bandwidth by a factor of 100. This will result in an order of magnitude improvement in the sensitivity of the array. In addition, its frequency coverage will be extended at the higher frequencies, which will increase the effective imaging resolution for continuum sources by a factor of three. e-MERLIN design goals include:

- High sensitivity (~1 microJy in 12 hours)
- Upgraded receivers for high-resolution continuum imaging at 10 - 50 mas
- Wide field imaging as standard mode (10 arcmin at 1.4 GHz; 17k pixel square images)
- Simultaneous continuum and multi-line spectroscopy
- Almost complete uv-coverage using MFS
- Sub-milliarcsecond astrometric capability
- Dynamic scheduling and on-the-fly imaging

e-MERLIN will provide radio images with a resolution comparable with or better than the Hubble Space Telescope and the new generation of optical, IR and sub-mm telescopes. It will complement the VLBI networks, which can provide much higher resolution but with much lower surface brightness sensitivity. The uniqueness of the e-MERLIN instrument will continue to be its combination of high sensitivity and high resolution. It bridges the gap between the resolution regimes of VLBI and other connected element radio interferometers.

e-MERLIN will be a natural pathfinder for SKA. It will provide glimpses of the science achievable with nano-Jy sensitivity and will be crucial as a test-bed for many of the techniques required to build SKA. e-MERLIN is very similar in size to the proposed SKA core (albeit having < 1% of the collecting area) and so the techniques of wide-band data transfer over several hundreds of kilometres, RFI mitigation and remote operation of telescopes will be developed using the upgraded array.

The scientific goals of e-MERLIN are to study:

- Structure of galaxies detected at sub-mm wavelengths,
- Star-formation rate as a function of redshift,
- Imaging of thermal and non-thermal jets from young stellar objects (YSOs),
- Imaging of circumstellar dust disks and methanol masers around YSOs,
- Physics of mass ejection in novae, planetary nebulae and evolved stars,
- Physics of jets via matched resolution images, such as radio/optical movies of M87,
- GRB hosts through the measurement of star-formation rates,
- Cosmological parameters through deep observations of gravitational lenses, and
- Microlensing in high-redshift dark matter haloes.

For further information about e-MERLIN, see <http://www.merlin.ac.uk/e-merlin/>

4.7. **Expanded Very Large Array (EVLA)**

The Very Large Array (VLA) was built in the 1970s and comprises 27 x 25m diameter antennas. The goal of EVLA project is to improve most of the key observational capabilities of the VLA by at least an order of magnitude. Originally, the project was divided into two phases. The objective of Phase I is to improve the sensitivity, bandwidth, spectral resolution and frequency coverage of the existing 27 element array by the application of modern technologies. Funding was provided for Phase 1 and work has commenced on this phase, with completion due by 2012. The objective of Phase II was to increase the angular resolution of the existing VLA by adding additional array elements around New Mexico. A proposal for Phase II was submitted to the National Science Foundation (NSF) in April 2004 but, in December 2005, the NRAO was notified that the NSF was unable to support the proposal.

The basic plan of Phase I is to replace the electronics with modern systems, whilst retaining the antennas, array design and infrastructure. This strategy is highly cost-effective because the cost of new interferometric facilities is dominated by antenna and supporting infrastructure costs.

The EVLA Project will provide a radio telescope of unprecedented sensitivity, resolution, and imaging capability by modernizing and extending the existing Very Large Array. When completed, the EVLA will provide the following capabilities:

- Sensitivity: Continuum sensitivity improvement by up to a factor of 5 (below 10 GHz) to more than 20 (between 10 and 50 GHz).
- Frequency Accessibility: Operation at any frequency between 1.0 and 50 GHz,
- Spectral Capability: The WIDAR correlator will provide many frequency channels (minimum of 16,384, up to 262,144), process the wide bandwidths and provide frequency resolution better than 1 Hz if necessary.
- Resolution: Angular resolution up to 2000 / (frequency in GHz) milliarcseconds with tens of Kelvin brightness temperature sensitivity at full resolution.
- Low-Brightness Capability: Fast, high fidelity imaging of extended low-brightness emission with tens of arcsecond resolution and microKelvin brightness sensitivity.
- Imaging Capability: Spatial dynamic range greater than 10^6 , frequency dynamic range greater than 10^5 , image field of view greater than 10^9 with full spatial frequency sampling.
- Operations: Dynamic scheduling, based on weather, array configuration, and science requirements. "Default" images automatically produced, with all data products archived.

The scientific goals of the EVLA project are not based on any specific observations or projects. Rather, the goals are to provide astronomers a powerful and flexible instrument for research into all astrophysical phenomena which emit (or reflect) detectable radiation in the radio band. However, the design of the EVLA has been driven by the following broad science themes:

- Magnetic Universe - measure the strength and topology of the cosmic magnetic field.
- Obscured Universe - image young stars and massive black holes in dust enshrouded environments.
- Transient Universe - follow the rapid evolution of energetic phenomena.
- Evolving Universe - study the formation and evolution of stars, galaxies and AGN.

There is no specific formal connection between the EVLA (1.3% of a square km) and the SKA, but the EVLA project is a demonstrator for most technical issues for the SKA, including:

- Array operation
- Digital antennas systems
- Wideband multi-bit data transmission over long distance
- Management of massive, complex correlators

- Archiving
- Spatially-variant gain calibration
- Wide-field imaging including beam corrections and non-coplanar imaging.
- 'e2e' data management, and
- Exploring the sub-mJy sky.

For further information about the EVLA, see <http://www.aoc.nrao.edu/evla/>

4.8. Five-hundred-meter Aperture Spherical Telescope (FAST)

The FAST will be constructed in the karst landscape of Pingtang county, Guizhou Province in southwest China and will act as a pathfinder telescope for the SKA, demonstrating innovative technologies that could be incorporated into the full SKA instrument. The FAST will be the largest telescope in the world, with the radius of its spherical surface being 300m, and with an overall diameter of 500m. Its main spherical reflector will be composed of 4,600 panels and occupy an area as large as 25 football fields. Its observation capacity will be 10 times over that of the world's current biggest *steerable* radio telescope.

The FAST's geometrical configuration will provide sky coverage of $> 40^\circ$ zenith angle. The simplified feed system will continuously cover most of the frequency range between 300 and 2000 MHz, with possible capability up to 5-8 GHz depending upon the cost.

Its main spherical reflector will allow both wide bandwidth and full polarisation capability while using standard feed design. In addition, its feed support system will integrate optical, mechanical and electronic technologies which will effectively reduce the cost of the support structure and control system.

Three outstanding features of the telescope are:

- i. siting of the telescope in limestone karst depressions,
- ii. active main reflector which corrects spherical aberration on the ground to achieve full polarization and a wide band without involving a complex feed system, and
- iii. light focus cabin driven by cables and servomechanism plus a parallel robot as secondary adjustable system to carry the most precise parts of the receivers.

The FAST will enable astronomers to address many science goals, for example, neutral hydrogen line surveying in distant galaxies out to very large redshifts, looking for the first shining star, detecting thousands of new pulsars, etc.

A prototype of the main reflector has been built and the design and testing of the feed support system is almost complete (July 2007). The FAST is scheduled to be completed by 2013.

For further information about the FAST, see <http://www.bao.ac.cn/english/home.asp>.

4.9. Giant Meter Radio Telescope (GMRT)

The GMRT (run by the National Centre for Radio Astrophysics, or NCRA) consists of 30 fully steerable parabolic dish antennas of 45 m diameter in western India about 100 km east of Mumbai. The antennas are arranged in a Y-shaped configuration covering an area equivalent to a 25 km diameter circle. The central square kilometre contains 14 antennas, randomly arranged, while the rest are distributed in three approximately equal arms. The antennas themselves do not have solid surfaces but instead the reflecting surface is made up of many thin wire "ropes". This works because at the long wavelengths we are using (21 cm and longer) the wires have the same effect as a solid surface. The use of wire instead of panels makes the telescopes lighter, cheaper and more stable in high winds.

GMRT has been operating since 2002 in the range 120 to 1450 MHz and is the largest synthesis radio telescope in the world at metre wavelengths.

For further information about the GMRT, see <http://www.gmrt.ncra.tifr.res.in>.

4.10. Long Wavelength Array (LWA)

The LWA will be a low-frequency radio telescope designed to produce high-sensitivity, high-resolution images in the frequency range of 10-88 MHz. This will be accomplished with large collecting area (approaching 1 square kilometre at its lowest frequencies) spread over an interferometric array with baselines up to at least 400 km, located mainly in the state of New Mexico. Current plans call for the start of operations in 2008. The basic specifications of LWA (as of January 2006) are shown in Table 10.

Table 10. Basic specifications of the LWA

Parameter	Required Specification	Desired Specification
Frequency Range	20 MHz to 80 MHz	10 MHz to 88 MHz
Angular Resolution	$\theta \leq [8, 2]''$	$\theta \leq [7, 1.4]''$
Largest Angular Scale at [20, 80] MHz	$LAS \geq [8, 2]^\circ$	$LAS \geq [16, 4]^\circ$
Baseline Range	100 m to 400 km	50 m to 600 km
Sensitivity at [20, 80] MHz	$\sigma \leq [1.0, 0.5]$	$\sigma \leq [0.5, 0.1]$
Collecting Area (m ²)	$A_e = 1 \times 10^6$	$A_e = 4 \times 10^6$
Dynamic Range [20, 80] MHz DR $\geq [1 \times 10^3, 2 \times 10^3]$	$DR \geq [2 \times 10^3, 8 \times 10^3]$	
Δv_{max} (per beam)	$\Delta v \geq 4$ MHz	$\Delta v \geq 8$ MHz
Δv_{min}	$\Delta v \leq 100$ Hz	$\Delta v \leq 10$ Hz
Temporal Resolution	$\Delta \tau = 10$ ms	$\Delta \tau \leq 0.1$ ms
Polarization	1 circular	full
Sky Coverage	$z \geq 40^\circ$	$z \geq 15^\circ$
Field of View at [20, 80] MHz	$= [8, 2]^\circ$	$\geq [16, 4]^\circ$
# of Beams	$= 4$ single pol.	≥ 4 single pol.
Configuration	2D array, $N = 53$ stations	2D array, $N \geq 53$
Mechanical Lifetime	≥ 15 years for potentially long lifetime	

Key Science Drivers of the LWA are:

- Acceleration of Relativistic Particles in:
- Cosmic Evolution & the High redshift Universe
- Plasma Astrophysics & Space Science
- Transient Universe

For further information about the LWA, see <http://lwa.unm.edu>.

4.10.1. Long Wavelength Demonstrator Array (LWDA)

The LWDA is a test bed for the development of the LWA - it is located on the VLA site. In particular, the LWDA provides a useful testbed for software development, including monitor and control and software correlation.

During May 2007, an LWA team set up an outlier antenna to work with the LWDA as an interferometer. The outlier is the second of the Big Blade antennas currently at the LWDA site (aka BB2) and is located approximately 300 metres east of the 16 element LWDA. The LWDA and outlier are remotely configurable between various modes, including with multiple beams, and a number of innovative science programs are being considered to take advantage of these capabilities. For example, a transient monitoring program, taking advantage of its all-sky field of view, is being undertaken.

4.11. SKA Molonglo Prototype (SKAMP)

SKAMP is a 1% technology demonstrator for a number of SKA technologies including correlators, digital signal transport, and dual polarisation feeds for cylindrical reflector antennas. The project uses the Molonglo Radio telescope in NSW, Australia as its underlying infrastructure, which provides a collecting area of 18,000m². SKAMP is being developed in three stages:

SKAMP 1 is now operational and provides a continuum digital correlator for all 88 single polarisation signals coming from the existing Molonglo Observatory Synthesis Telescope (MOST). This is the first demonstration of a full correlator on a cylindrical reflector and shows considerable improvement in calibration. Work is now underway to use the extra information available from the correlator to improve imaging quality.

SKAMP 2 will access the 352 RF signals coming from the current feed structure. These are down-converted and digitised at the antenna, with optical fibre connections to the correlator and the local oscillator. The correlator has full spectral line capabilities and demonstrates both an FX architecture as well as considerable power saving compared to earlier major instruments.

In SKAMP 3, a new dual polarisation feed structure will be installed to cover the frequency range 0.7 to 1.1GHz. Coupled with the SKAMP 2 correlator, this will be the first demonstration of dual polarisation on an aperture synthesis cylindrical reflector telescope.

For further information about SKAMP, see <http://www.physics.usyd.edu.au/astrop/ska/>.