International Square Kilometre Array Newsletter

Volume 1

February 2000

Greetings. This is the first newsletter of the International Square Kilometre Array project.� The SKA project has enjoyed rapid development on the international front in the past year.� An international SKA Steering Committee (ISSC) has been established, with representation from the 7 countries that are signatories to the Memorandum of Understanding for Research and Development (Australia, Canada, China, India, The Netherlands, the U.K., and the USA).� The mandate of the ISSC includes to provide international oversight and a coordinating body, to establish agreed goals and timelines for the SKA project, to organize a joint international technical and scientific proposal for the SKA and, to this end, to establish and oversee working groups as necessary.�� The ISSC meets twice per year.� The inaugural meeting was held in Dwingeloo in February 1999.� A second meeting occurred in Toronto in August.� The third gathering will take place in Munich at the end of March.

The first steps are being taken to establish a European SKA Consortium to coordinate the efforts in Europe. This is being done in the context of an EU-funded Infrastructure Cooperation Network in Radio Astronomy.���

Another area of very significant progress in the past year has been the continued organisation of national projects within the participating countries.� This first newsletter is devoted to reports of activities from correspondents in MOU countries.� Efforts around the world focus on exploration of innovative technologies to: a) bring to bear modern advances in digital processing, telecommunications, and RF devices to develop more powerful radio telescope concepts for the SKA, and b) allow construction of a square kilometre of collecting area at reasonable cost.�� As you will read, a number of novel ideas are being studied in parallel.� As an international project, we are working toward a goal to converge on a specific technical proposal for the SKA by 2005.�

A significant event in the march toward a technical proposal will be the upcoming workshop at Jodrell Bank from 3-5 August.� This workshop, �Technical Pathways to the Square Kilometre Array�, will bring together the various groups involved in technical studies for three days to compare notes, identify key outstanding problems and develop collaborative R&D projects.� One important outcome will be a plan to establish an international infrastructure of task groups to oversee and coordinate efforts in key areas. Workshop information and registration can be found by following the links at http://www.jb.man.ac.uk/ska.

More information on the SKA project can be found at http://www.ras.ucalgary.ca/SKA.

Russ Taylor, The Editor
International SKA Consortium

News From Australia

Australian SKA involvement was boosted recently with the establishment of a formal CSIRO seed research program aimed primarily at contributing more extensively to the international SKA scientific and technical effort.� The program will also broaden interest in the SKA within the Australian research and industrial sectors, and promote the new telescope via media and outreach activities.� While fairly modest - $A1.5M over 3 years - the program will fund a number of postdoctoral and postgraduate positions in areas where the Australian contribution is likely to be especially valuable.� Established activities in the fields of antenna design, interference mitigation and site characterization have been absorbed into the new program.� The expectation is that, over the next few years, further funding will become available, both to CSIRO and other players in the SKA arena.� This will support construction of astronomical demonstrator systems to be evaluated in international technology trials.� Most importantly, it is expected that a national SKA Steering Committee will begin operating in Australia in the next few months, establishing a body for co-ordinating the CSIRO and other efforts.

There has already been quite a bit of progress in technical and related areas.� To help disseminate information effectively, we have set up a "working documents" link from our ATNF web page at http://www.atnf.csiro.au/SKA/ .� While Australian workers have been active in the antenna area over the past couple of years, the most engaging recent work has centred on the preliminary evaluation of the Luneburg Lens (LL) as an SKA element.� While much work remains, especially in relation to lens materials and fabrication, the LL is certainly a solution that offers true multi-beaming and preserves full sensitivity (no projection effects) over all look angles.� In the coming year we plan to refine the electromagnetic modelling of the LL and to look at ways of fabricating these 3-D antennas more economically.� Regardless of the ultimate success of the LL in the SKA context, the concept certainly forces us to think about the scientific drivers and costs associated with full-sensitivity multi-beaming.

Interference mitigation (IM) activities continue to have a high profile and there have been a number of recent experiments involving the AT Compact Array and the Parkes multi-beam HI receiver.� These have been useful in extending work on post-correlation IM algorithms and in providing real data (astronomical and interference) for our software radio telescope project.� This project uses digitally recorded outputs of individual antennas, allowing development, refinement and assessment of coherent processing (e.g. adaptive beamforming) algorithms; data are also available to other workers and a number of AT data sets are already in use around the world.

A recent highlight was the two-day E. & F. White IM Conference held in Sydney.� About 40 people attended the conference and many participated in the preceding DSP course taught by Fred Harris from San Diego State University.� Fred is well known in the software radio field and, together with Steve Ellingson from Ohio State University, and local speakers, led an enthusiastic and profitable workshop dealing with IM themes in an SKA context.� Material from the conference is available via links from our SKA web site - as is additional discussion material from the 'intmit' international e-mail forum.

Site characterization has also been a major activity, with the government of the state of Western Australia being especially enthusiastic in its support of site-related activities.� The main aim of our work is to provide insight into the requirements for SKA sites and the processes necessary for site selection.� The general principles being established will be applicable to SKA site definition wherever the telescope is eventually built. �However, the project is yielding information about representative potential Australian sites, including (shortly) actual RFI measurements to complement our hitherto predicative studies based on the Australian Communications Authority database.� We have also begun a related project examining possible methods of zonal protection for SKA sites, again with an emphasis on general issues.

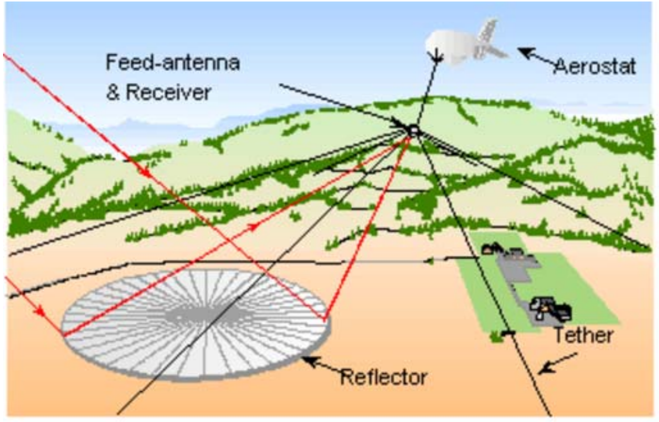
A particularly pleasing aspect of the CSIRO program is the way it is already fostering ties with the University community and with international collaborators.� Examples include projects such as the University of Sydney work on fibre-optic link design and integral photonic signal processing.� In the coming year the number of collaborations will be increased, most notably in the areas of digital signal processing and MMIC-based receivers for the SKA.� As well as the technology projects, we also have active groups building on previous science and systems work by ATNF and University of Sydney workers; these studies relate in the short-term to configuration and imaging performance studies of representative SKA designs.

Peter Hall, SKA Program Leader, Australia Telescope National Facility

News from Canada

In Canada, there has been progress on several fronts in developing the Large Adaptive Reflector (LAR) for the SKA. Since this is an unusual concept, a thumbnail sketch is required for the news to make sense. The

LAR consists of three main components:



The LAR Concept.

1. A large parabolic reflector, nominally 200 m in diameter, with limited shape adjustment. Incoming rays, shown in red in Figure 1, are reflected to the feed antenna, which is at the focus of the paraboloid.

2. The focal package that contains the feed-antenna and a receiver system to amplify the signal collected at the focus. The focal package is held in place by a system of taut winch-driven tethers.

3. An aerostat, a large helium balloon, which provides the lifting force needed to support the focal package and to tension the tethers.

The telescope is pointed by moving the focal package with the tethers, and simultaneously adjusting the shape of the reflector with actuators so that the feed is always located at the focus of the parabolic reflector. Since there is no compromise in the shape, the telescope has the same properties as a standard parabolic telescope of offset design. The long focal length affords the possibility of a large number of feeds, and hence a large number of beams on the sky in a cluster around the main pointing direction. The goal is to provide about 100 beams at decimeter wavelengths. More information on the LAR can be found at http://www.drao.nrc.ca/science/ska.

Because of the wide variety of technologies required and the interplay between science and engineering, the LAR can be realized only through a multidisciplinary approach, involving groups from engineering departments in universities, many of whom had never worked on instrumentation for astronomy before. Encouraging university-based engineers to participate in R&D toward a major, new astronomy project is a new development in Canada.

These groups carried out a Phase-A study of the feasibility of the LAR, funded by the National Research Council of Canada. The motivation was to find at least one feasible conceptual solution for each critical component of the LAR. The results are encouraging. Each of the individual "sub-studies" indicates that the LAR is a feasible design. Also, the cost per unit collecting area is estimated to be an order of magnitude less than for traditional large parabolic reflector designs.

Highlights of the Phase A work are: early progress in a theoretical understanding of the means for ensuring aerostat stability; a concept for large actuators whose cost is insensitive to actuator stroke; a study of the use of differential GPS methods for measuring the position of the focal point; a successful demonstration of a design to accurately measure the distance to the focus, while at the same time transmitting a Local Oscillator signal; the development of inexpensive photogrammetry techniques for determining the shape of the reflector; a series of conceptual designs for feeds; some early theoretical and experimental work on the control of the focal position; a project to develop small, efficient cyro-cooling devices for receivers; a fully engineered structure for the reflector and its panels.

More recently, new work has begun on the structural design of the focal package. This will be a complex component. Although its cost may be high, it is averaged over about 30000 m^2 of collecting area. A series of studies on the design of the feed have been carried out, and it is now apparent that the best design is a phased array system at decimetre wavelengths. This will require the development of very small, cooled receivers (for decimetre and cm wavelengths), and a complex combining network. Preliminary ideas on how to accomplish this are being fleshed out in more detail. The potential wavelength coverage will depend upon the accuracy of the surface for short wavelengths, and on the size of the feed at long wavelengths. It appears to be feasible to operate the LAR from about 100 MHz to 22 GHz, although not with a single focal package.

In the near future, more detailed work on the control of the innovative actuator design used to control the reflector surface elements, and a study of how to achieve the dynamic range needed for the SKA using LAR antennas will be carried out.
It is now necessary to establish the detailed performance and cost of two critical components of the LAR in field and laboratory tests, the actuated reflector and the tethered aerostat system. These cannot be satisfactorily understood and perfected through paper and computer models alone. This will require the construction of scaled field models for a) an actuated section of the LAR reflector and b) a fully controlled multi-tethered aerostat.

The schedule of this follow-on work on the LAR will depend heavily on funding. Funding to carry out these field tests has been applied for from two different funding organizations.� Recently Canadian astronomers have undertaken a national initiative to articulate and fund development programs for facilities in the next decade.� Continued development of the LAR is a high priority element of that program, for which funds are expected in 2001.

Peter Dewdney, National Research Council of Canada

News from China

One way to realize the SKA is to construct a spherical reflector array of about 30 individual unit telescopes, each roughly 200 m diameter. As the first step, the FAST (Five-hundred-meter Aperture Spherical Telescope) acting as a pilot of the SKA has been proposed in China.

FAST is not simply a copy of the existing Arecibo telescope. It has a number of innovations. Firstly, the main spherical reflector will fit a paraboloid of revolution in real time by actuated active control, enabling the realization of broad bandwidth and full polarization capability using a standard feed design. Secondly, a feed support system, which integrates optical, mechanical and electronic technologies, will effectively reduce the cost of the support structure and control system.� With an overall diameter of 500 m and radius of its spherical surface of 300 m, FAST will be the world's largest single dish.

It has been realized that the right terrain, such as the karst formations of Guizhou Province in south-western China, would be critical to a successful implementation of an Arecibo-style spherical reflector. A database of about 400 karst depressions in Pingtang and Puding counties in the province has been set up. Due to the remoteness of this region and terrain shielding, the monitoring results on radio interference look quite promising.

A State Standard, Protection Criterion for the Radio Astronomy Service has been worked out. Recently we made proposals for designating a radio quiet zone (RQZ) in Guizhou province for a potential site of the FAST. The Guizhou regional Bureau of Radio Management agreed to work and collaborate on designating a RQZ as soon as the final site for the FAST is chosen and the FAST project approved as a National Megascience Project of China. The Guizhou provincial government would like to make a plan to develop their radio industry and communications in a modest scope. We have re-started the site monitoring on radio interference environment since January 1999, and believe that a protected RQZ in Guizhou would make it an ideal location for an international radio astronomical facility, and would establish the FAST site as a natural SKA location.

This FAST project has now become a key project in the Chinese Academy of Sciences, and has also been supported by the Ministry of Science and Technology of China. A formal laboratory, namely the Large Radio Telescope (or FAST) Lab., was formed in the newly established National Astronomical Observatories in China. Dr. Nan Rendong is the chief. The FAST Lab. has contracted 2 years' of R&D on the FAST project with the universities of Xidian, Tsinghua, Tongji etc., institutes of Remote Sensing Application, Radio Measurement, Systems Science, Mechanics etc., and Nanjing Astronomical Instruments Research Center since May 1999.

The IAU Colloquium 182 will be hosted by the FAST Lab. at the FAST site from April 17 to 21, 2000.

Bo Peng, FAST Laboratory

News from India

At the National Centre of Radio Astrophysics of the Tata Institute of Fundamental Research we have developed a new design of a 12 m parabolic dish, which is likely to have much lower cost per sq. m than the GMRT dishes. A detailed dynamic and static analysis has been done and drawings have been developed. The design minimizes not only material but also the labour involved. The Raman Research Institute has agreed to fabricate a prototype dish over the next year, or earlier. We hope to present results of this work at the Jodrell workshop. For the surface of this 12-metre prototype dish we are planning to use stainless steel wire mesh of size 6mmX6mmx0.55 mm, which should allow us to work at much higher frequencies than the GMRT 45 m antennas.� A preliminary study has also been completed for a 25-metre dish.

Govind Swarup, Tata Institute of Fundamental Research

News From the Netherlands

The Netherlands Foundation for Research in Astronomy (NFRA/ASTRON) made the decision early on in the development of the Square Kilometer Array to focus on the phased array approach. A radio telescope built on that principle has no moving parts: tracking and beamforming are done electronically. In addition, the development of such a telescope can profit from the extremely fast technological progress in the areas of micro-electronics, signal processing and computing. This in contrast to the development of telescopes along more conventional lines, that have to face the fact that the cost of building and erecting large steel structures is not decreasing with time.

The task of developing a concept that is both technically feasible and economically sound is being tackled at NFRA through a series of demonstrators (AAD, OSMA and THEA) that show increasing complexity, numbers of elements and levels of integration. In addition, independent research lines are ongoing to further develop competence in specific fields; in many cases through close cooperation with research groups at technical universities in the Netherlands and elsewhere.

The second half of 1999 saw the conclusion of the final phase of the One Square Meter Array (OSMA).� After the Adaptive Antenna Demonstrator (AAD) OSMA is the second system developed at NFRA. OSMA is a planar phased-array receive-only antenna with a mixed analogue and digital adaptive beamforming architecture.

Its operating frequency ranges from 1.5 to 3 GHz. The linearly polarized array consists of an 8x8 element active region surrounded by two rows of passive elements (144 in total). The figure shows OSMA in NFRA�s anechoic room. As shown here OSMA uses bow-tie elements with an integrated balun printed on a low-cost substrate.�

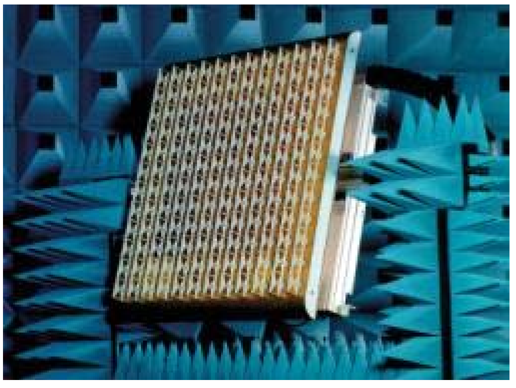


Figure 1: OSMA in NFRA�s Anechoic Room

The beamforming hierarchy consists of two stages: in a first RF beamformer stage, groups of four elements are combined (64 in and 16 out). These 16 outputs are connected to either a 16-channel adaptive digital beamforming (ADBF) unit or a second stage 16- channel RF beamforming unit.

A detailed description of results obtained with OSMA can be found through the NFRA web pages (http://www.nfra.nl/ska/archive). A short summary is given here:

- **Antenna** - Measurements with the bow-tie elements show that the array can be used over a 3:1 bandwidth with an average scan loss smaller than 1dB for scan angles less than 50 degrees w.r.t. broadside.
- **Calibration** - A novel calibration procedure (referred to as Multi-Element Phase-toggle or MEP) was developed to allow groups of elements to be calibrated simultaneously using FFT signal processing techniques. The calibration technique is required for the correction of all amplitude and phase errors that occur in the analogue beamforming structure of the OSMA system.
- **RFI suppression with deterministic RF nulling -** Spatial nulling was done through using both the analogue and digital beamformer stages. Null depths of up to �43 dB w.r.t. main beam were achieved. Compared with the sidelobe level of the original beam the signal-to-interferer ratio has been improved by more than 30dB.
- **RFI suppression with adaptive digital nulling -** The adaptive digital beamformer allows unknown and/or moving interfering sources to be suppressed.

In addition to the list above, encouraging results have also been obtained in many other instances. In the future OSMA will be moved to a new, second anechoic room at NFRA to be used as a development and test platform.

The experience gained with OSMA has had a profound impact on the design of the Thousand Element Array (THEA), the third stage of NFRA�s demonstrator programme. THEA consists of 1024 receiving antenna elements, and will be used as an outdoor phased-array system to detect (known) radio sources in the frequency band ranging from 600 to 1700 MHz in the presence of a number of strong RF Interfering (RFI) signals.� The 1024 elements are connected to a novel mixed RF/digital beamforming architecture that produces 32 beams simultaneously.

Compared with conventional radio telescope designs THEA has the following new features:

- Multi-beam operation � THEA will have 32 digital beams available simultaneously, clustered in two groups of 16 beams. Each group of beams can be directed to any point on the sky without loss of sensitivity.
- Adaptive nulling � The signals from interfering sources (including those from crossing satellites) can be suppressed using a real-time adaptive digital beamformer.
- Interference monitoring � A real-time map of the interfering sources can be made.
- Re-configurability by using sub-array units � THEA is built up of 16 tiles (each with 64 elements). These tiles can be moved around on an outdoor platform to allow experiments with e.g. sparse random arrays. In addition, THEA could be set up as a two-antenna interferometer.

This year will be devoted to the development of the individual THEA tiles. The array is due to be completed next year. Once again, full details � including a system description of THEA � can be found at the NFRA web site.

Parallel research paths that are being pursued include the following:

- Investigation of interference mitigation strategies � filtering in both the temporal, frequency and spatial domain. The Westerbork Synthesis Radio Telescope (WSRT) is being used as a test bed for many of these techniques.
- Development of end-to-end simulation tools for the next generation of radio telescopes.
- Application of photonic techniques � in particular in the development of beamformers.

The Low Frequency Array (LOFAR)

The goal of LOFAR is to open a new, high-resolution window on the electromagnetic spectrum from ~10�150 MHz (corresponding to wavelengths of 30�2 m). This portion of the spectrum has been poorly explored because ionospheric structure has prevented conventional interferometry on baselines longer than 5 km, limiting imaging to coarse angular resolution and low sensitivity. Development of ionospheric phasecompensation techniques on the 74 MHz VLA receiving system now make it possible to explore this spectral region with the unprecedented imaging power of LOFAR.

With a total of about 10,000 dual polarization receptors, an effective collecting area of more than 1 km^2 is obtained at a frequency of 10 MHz. The use of advanced phased array technology with digital beamforming results in a multi-beam capability of up to 64 simultaneous independent beams. This feature is new to radio telescopes and will make it a flexible and versatile instrument that can be used by different observers at the same time. LOFAR is being developed by NFRA in partnership with scientists and engineers at the Naval Research Laboratory (NRL) and also at the US National Radio Astronomy Observatory (NRAO).

Astronomically, LOFAR will be a powerful instrument for exploring the Universe for coherent emission processes, for delineating the interaction between nonthermal emitting plasmas and thermal absorbing gas, and for differentiating between self-absorption processes.� Steep-spectrum objects and processes that will be targets of LOFAR include: (1) High-redshift radio galaxies and quasars; (2) Shocks driven by infalling matter in clusters of galaxies; (3) The distribution and spectrum of the Galactic cosmic-ray electron gas; (4) Pulsars in the Milky Way and in external galaxies; and (5) Radio emission from extrasolar planets. LOFAR may also be capable of detecting the signature of the reionization of the Universe.

LOFAR hardware and software will be a key stepping stone to the development of the advanced digital signal processing technology required for the Square Kilometre Array. In addition, the proposed telescope will be the ideal receiver for bi-static solar radar systems designed to image Earthward bound Coronal Mass Ejections for geomagnetic storm prediction. Finally, LOFAR will enable high spatial- and temporal-resolution studies of both natural and artificially-produced ionospheric structures.

More details on LOFAR will be available shortly through the NFRA web pages (http://www.nfra.nl).

Michiel van Haarlem, Netherlands Foundation for Research in Astronomy

New from The United Kingdom

The Director of Jodrell Bank, Andrew Lyne, intends to sign the International SKA MOU for the March 2000 SKA meeting in Munich. In addition a small 'SKA Focus Group' has been set up at JBO, under the chairmanship of Alan Pedlar, to oversee JBO involvement with the SKA. A preliminary Jodrell SKA web page has been set up at http://www.jb.man.ac.uk/ska to give further information on SKA and related activity at JBO

Towards the end of 1999 the Particle Physics and Astronomy Research Council set up a 'Visions Panel' to produce a document outlining the a long term (10-15 year) science goals for UK astrophysics. Thanks to our representations SKA has been included in this document.

At present our main research initiative of relevance to SKA is in the area of using optical fibres to bring back broad-band signals for correlation. The applications of this research will also benefit MERLIN & ALMA. Last year an Optical Fibres Laboratory was set up from a JREI grant (in Collaboration with British Telecomm) of ~250K UK pounds (~$400). The laboratory contains optical fibre test equipment, light wave component analysers etc., and is also used by the laser/photonics group in the department of Physics. The project is led by Ralph Spencer and we have also appointed an EC funded optical fibres engineer - Brian Smith- who will be making a preliminary engineering design of fibre optics links up to 3000km in extent. Further research funding in this area is expected to be obtained shortly as part of the UK contribution to the ALMA project. Unfortunately a bid to the EC framework 5 to fund a prototype ~200km optical fibre link between Jodrell and the MERLIN 32m antenna at Cambridge was not successful - however the bid was highly rated and other funding sources will be approached to ensure this project goes ahead as soon as possible.

We are looking forward to hosting this workshop at Jodrell on the 3-5th August as part of the IAU 2000 meeting. See details elsewhere in the newsletter.

Alan Pedlar, Jodrell Bank Observatory, University of Manchester

News from the United States

The US SKA Consortium, which held its inaugural meeting in May 1999, now consists of the following ten members: California Institute of Technology, including JPL; Cornell University, including NAIC; Georgia Institute of Technology; Harvard-Smithsonian Center for Astrophysics; Massachusetts Institute of Technology, including Haystack Observatory; National Radio Astronomy Observatory; Ohio State University; the SETI Institute; the University of California Berkeley; and the University of Minnesota.� Representatives meet twice a year; the next meeting is in February.�

The US SKA Consortium is hosting its first scientific and technical meeting, open to the community and targeted toward US groups interested in SKA development and science.� It will take place at Arecibo Observatory on February 28 and 29, 2000.� Information on the meeting can be found at http://space.mit.edu/RADIO/arecibomeet.html.

The SKA design being examined by the US SKA Consortium is one with a large number (of order hundreds to one thousand) "stations" each consisting of a number of antenna elements.� This "Large-N" concept offers considerable advantages, including superb image fidelity and dynamic range, multibeaming, instantaneous imaging, improved interference suppression, flexibility, and expandability.� As described below, activities at the US SKA member institutions are being carried out that explore the large-N design.

The one-hectare telescope (1hT) is being designed and developed as a joint effort between the SETI Institute and the UC Berkeley Radio Astronomy Laboratory.� It will be built at the Hat Creek Observatory and will be used simultaneously for SETI and radio astronomical observations.� The 1hT will be an array of ~500-1000 small (3 to 5 m) parabolic antennas, operating from 500 MHz to 11 GHz, with a design goal for Aeff/Tsys of 170 sq m per Kelvin. Aggressive design, simulation, and manufacturing efforts have produced preliminary solutions for: low cost antennas and mounts, a wideband feed, a miniature InP MMIC LNA and cryogenic cooler, an RF/IF MMIC, thermally stable fibre, and an array configuration.� Efforts will now shift to finding an affordable solution for wideband, analog F/O transmitters and receivers.� A seven-element Rapid Prototyping Array made from commercial, modified, or in-house components will be dedicated on 8 April 2000 (the 40th anniversary of the start of the OZMA project), and will permit extensive experimentation with RFI excision and nulling algorithms, antenna control, and continuous calibration using GPS satellites.� Individuals from Georgia Tech, JPL, Sun Microsystems, NFRA, NAIC, and Ohio State University have been collaborating on the 1hT.

At MIT Haystack Observatory, large-N configuration studies are continuing together with consideration of signal processing requirements.� Development of a digital receiver design based on wireless communication technology is being investigated, which, with its low cost, stability, and robustness to interference, may be applicable to the SKA.� Funding is being sought to build a prototype array that will demonstrate the digital receiver, exercise interference suppression techniques, and carry out astronomical observations that achieve unprecedented sensitivity to diffuse line sources, giving experience in addressing one of the major SKA science goals.�

Haystack is participating in discussions of the design of LOFAR, and hosted a regional one-day workshop in January on LOFAR and the SKA.

At the National Radio Astronomy Observatory investigations of RFI suppression techniques, full-sampling array feed design and implementation, and simulations of the sub-mJy sky continue.� NRAO is also participating in the LOFAR design, and will host a LOFAR meeting in Charlottesville February 22-24.� At Ohio State an eight-element array operating at 200-400 MHz is being used to test new algorithms for RFI suppression, especially adaptive nulling.

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US SKA Consortium news and information can be found at http://space.mit.edu/RADIO/usska.html.

Jacqueline N. Hewitt
Chair, US Square Kilometer Array Consortium