Preface

The international workshop, entitled "Japan Square Kilometer Array (SKA) International Workshop 2010 - Revealing the Universe with Wide-band cm-Wavelength Observations" was held at National Astronomical Observatory of Japan (NAOJ), Mitaka, Tokyo on 4-5 November 2010, and was hosted by the Japan SKA consortium. With the success of the Japan SKA workshop held at NAOJ as well in November 2008, this workshop was organized with the anticipation from the participation of the international radio astronomy community. The idea behind this workshop is to bring together scientists and engineers from different communities at one place and discuss how scientists and engineers in Japan will be able to contribute to SKA.

The workshop became a meeting place of observers, theorists, engineers, and people from industry as well as young and senior people. The workshop attendance included 98 participants with having 12 attendants from overseas, and they discussed intensively about the science cases and technical developments which are undergoing inside or outside Japan.

The oral presentation time was devoted to 17 invited talks covering the current status of the pathfinders of MeerKAT and ASKAP, the status of Korean participation to SKA, VERA, SKA science and project overviews, star-formation, cosmic magnetic field, pulsar, high-z galaxy, spectral-line survey, contributions from the Japanese industry group, engineering aspects, and the economic impact of SKA. The scientific and technical talks were arranged both on the first and second day. International schemes and discussion on the general international collaboration were focused in the last sessions of the second day. Fourteen posters were displayed during the workshop period. The workshop provided participants great opportunities for discussing future aspects of SKA collaboration of Japan and the international SKA community. We believe that many of the participants enjoyed a life in Japan during the early winter period.

The success of the workshop owed many people who helped providing the logistics and organizing the scientific program. Many thanks go to the Science Organizing Committee and the Local Organizing Committee. We thank the really local staff, Motoki Kino, Kotaro Niinuma, and Akiyo Komori for their extensive help to the workshop.

We acknowledge the support provided by National Astronomical Observatory of Japan and the Foundation for Promotion of Astronomy.

Yoshiaki Hagiwara
Keitaro Takahashi
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Hiroyuki Nakanishi
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Work Shop Program

11/4 (Thu)
Session 1: SKA overview (Chair: Noriyuki Kawaguchi).
9:00--9:10 Opening Remarks (Hiroyuki Nakanishi).
9:10--9:50 Joseph Lazio (JPL):
The Science of the Square Kilometre Array.
9:50--10:30 Steve Rawlings (Oxford):
Overview of the Square Kilometre Array.
10:30--11:00 coffee

Session 2: SKA Pathfinder (1) (Chair: Joseph Lazio).
11:00--11:40 John Bunton (CSIRO):
The Australian SKA Pathfinder: ASKAP.
11:40--12:20 Jasper Horrell (South African SKA Project Office):
MeerKAT Overview: An Engineering and Technical Focus.
12:20--13:50 photo & lunch

Session 3: SKA Pathfinder (2) (Chair: Peter Dewdney).
14:20--14:50 Kristian Zarb Adami (Oxford):
NlogN vs. N^2 Imaging Processes.
14:50--15:20 Minho Choi (KASI):
Status of Korean Participation in the SKA Project.
15:20--15:50 coffee

Session 4: Science (1) (Chair: Yoshiaki Sofue).
15:50--16:20 Ryohei Kawabe (NAOJ): Collaboration with ALMA.
16:20--16:50 Keitaro Takahashi (Nagoya University):
Origin and Evolution of Cosmic Magnetic Fields.
16:50--17:10 Takuya Akahori (Chungnam National University):
Exploring Faraday Rotation Measure due to the Intergalactic Magnetic Field with the Square Kilometer Array.
17:10--17:30 Lisa Harvey-Smith (CSIRO): Studying magnetic fields using Faraday rotation of polarized extragalactic sources: Future prospects with ASKAP and the SKA.
17:30--17:40 break
17:40--18:10 discussion (1).
18:30--20:00 banquet
11/5 (Fri)

**Session 5:** Technology toward SKA (Chair: Steve Rawlings).
9:00--9:30 Noriyuki Kawaguchi (NAOJ):
   Technical Interests on the SKA.
9:30--10:00 Peter Dewdney (SPDO):
   SKA update and engineering opportunities /ideas.
10:00--10:30 Philip Diamond (CSIRO):
   The potential socio-economic impact of the SKA.
10:30--11:00 coffee

**Session 6:** SKA Industry (Chair: Hiroyuki Nakanishi).
11:00--11:30 Toshiki Kumazawa (TOYO Corporation):
   SKA-Japan industry.
11:30--12:00 Carole Jackson (CSIRO):
   Engaging industry-the Australian SKA experience so far.
12:00--12:20 Tomoharu Kurayama (Kagoshima University):
   Variable-Step Frequency Integration in the Decade/Century-Band Imaging.
12:20--13:50 lunch
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**Session 7:** Science (2) (Chair: Philip Edwards).
13:50--14:20 Hiroshi Imai (Kagoshima University):
   Astrometry from VERA to SKA.
14:20--14:50 Osamu Kameya (NAOJ): Pulsar study using the SKA.
14:50--15:20 Satoshi Yamamoto (The University of Tokyo):
   Spectral line survey.
15:20--15:50 coffee

**Session 8:** Science (3) (Chair: Ryohei Kawabe).
15:50--16:20 Tsutomu Takeuchi (Nagoya University):
   Physics of the Formation and Evolution of Galaxies:
   Report from the High-z Working Group.
16:20--16:50 Motoki Kino (NAOJ): AGN science with SKA.
16:50--17:20 Kazuyuki Omukai (Kyoto University):
   Probing the first star formation by 21-cm line.
17:20--17:50 discussion (2).
17:50--18:00 Concluding Remarks (Ryohei Kawabe)
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The ASKAP Survey Science Projects.

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Kenichi Harada (ELECS INDUSTORY CO., LTD.)
8GHz Sampling A-D Converter.

Takayuki Hayashi (The University of Tokyo)
Multi-wavelength polarimetry of radio-loud broad absorption quasars.

Tomoya Hirota (NAOJ)
VLBI Observations of Galactic radio sources.

Takahiro Iwata (ISAS/J AXA)
The roadmap of LLFAST: The Lunar Low Frequency Astronomy Telescope, and its implication of collaborations with SKA.

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Yoshiaki Sofue (Meisei University)
  Galactic Magnetic Field and its Origin.

Kazuhiro Takefuji (NICT)
  Applications of the Next Generation A/D sampler ADS3000+ for VLBI2010.

Hideki Ujihara (NICT)
  Simulation of wideband feed.
Section 1

ORAL PRESENTATION
SCIENCE WITH THE SQUARE KILOMETRE ARRAY

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Abstract

The Square Kilometre Array (SKA) is the centimeter- and meter-wavelength telescope for the 21st Century. Its Key Science Projects are (a) The end of the Dark Ages, involving searches for an HI signature and the first metal-rich systems; (b) Testing theories of gravitation using an array of pulsars to search for gravitational waves and relativistic binaries to probe the strong-field regime; (c) Observations of HI to a redshift z ≈ 2 from which to study the evolution of galaxies and dark energy; (d) Astrobiology including planetary formation within protoplanetary disks; and (e) The origin and evolution of cosmic magnetism, both within the Galaxy and in intergalactic space. The SKA will operate over the wavelength range of at least 1.2 cm to 4 m (70 MHz to 25 GHz), providing milliarcsecond resolution at the shortest wavelengths.

1 Introduction

In the latter half of the 20th Century, we discovered unimagined sources and phenomena. Observations at radio wavelengths laid the foundation for many discoveries, including non-thermal emission mechanism, active galaxies, the cosmic microwave background (CMB), pulsars, gravitational lensing, and extrasolar planets. In the 21st Century, we seek to understand the Universe that we inhabit.

Under development by an international consortium, the Square Kilometre Array (SKA) is a centimeter- and meter-wavelength telescope envisioned as being one of a suite of multi-wavelength facilities for the 21st Century. Its original motivation was as a “hydrogen array,” a telescope sensitive enough to detect the 21-cm HI line from a Milky Way-like galaxy at a redshift of order unity. Since then, the international community has developed a set of Key Science Programs that are intended to address a much broader range of fundamental questions in astronomy, physics, and astrobiology [1,2]. In the spirit of the European Astronet Roadmap and the U.S. New Worlds, New Horizons Decadal Survey, we shall discuss the key science in two broad categories, “origins” and “fundamental physics,” recognizing that the divisions between these two categories is, at times, indistinct.
2 Key Science: Origins

One of the motivations for observing the Universe is that it can answer fundamental questions about how we originated, questions that have been posed since the beginning of humanity.

2.1 The Dark Ages, Cosmic Dawn, and the Epoch of Reionization

At a redshift around 1100, the Universe became largely neutral as protons and electrons combined to form the first hydrogen atoms, while today the Universe is largely ionized. Observations of the highest redshift quasars and analysis of the Wilkinson Microwave Anisotropy Probe (WMAP) observations indicate that stars were forming, and Reionization was underway, by redshifts \( z \approx 6-15 \). These redshifts are so large that only observations at wavelengths longer than 1 \( \mu \text{m} \) are useful, and the SKA will play a key role in probing these epochs.

As the first stars and accreting black holes begin to illuminate their surroundings, they should ionize and heat the surrounding H I in the intergalactic medium (IGM). Its excitation (spin temperature) will decouple from the temperature of the CMB, and a complex, time-dependent patchwork of (highly redshifted) H I emission or absorption against the CMB is predicted. At \( z \lesssim 10 \), the (redshifted) H I line should appear in emission as the gas is being heated to the point of starting to reionize, while at higher redshifts, the signal should switch into absorption, as the gas remains colder than the CMB. The goal of the SKA is to detect this highly-redshifted H I emission and absorption, which in turn will constrain the formation of the first structures.

Further, carbon monoxide (CO) has been detected in some of the most distant radio-loud quasars. The presence of "metals" at \( z \approx 6 \) is problematic, as the time scale for these elements to be produced in the first stars and then distributed is uncomfortably close to the age of the Universe at that time. The shorter-wavelength capabilities (\( \sim 1.5 \) cm) of the SKA will be used to conduct even more sensitive searches for CO emission from distant, radio-loud objects and constrain the time scales on which the first stars would have had to form, fuse these elements, then disperse them back to the surrounding medium.

2.2 Galaxy Formation and Evolution

The original focus of the SKA was observations of the 21-cm H I line from galaxies, and such observations remain a significant focus of the SKA Science Case. Neutral hydrogen is the raw material from which stars form. The peak of the star formation rate in the Universe occurred at \( z \sim 1-2 \). The SKA will be able to probe the evolution of H I to this crucial point in the assembly of galaxies.

Although the star formation rate in the Universe peaks at \( z \sim 1-2 \), the density of H I appears to be relatively constant until relatively recently. Moreover, most galaxies contain insufficient amounts of gas to power their star formation for a Hubble time. These observations suggest that galaxies are able to tap a reservoir(s) of gas in order to power their star formation. This reservoir might be the IGM, from hot gas condensing onto galaxies or delivered through "cold accretion" streams, or it might be in the form of mergers or both. The very deepest observations often show extended H I halos around galaxies or low column density clouds in their neighborhoods, and it is well known that the H I gas is often an indicator of potential merger activity in groups of galaxies. However, the current generation of observations is not sufficiently deep to provide definitive answers to the question of the balance between accretion and mergers in the galactic gas budget.
2.3 Astrobiology: The Cradle of Life

The current picture of planetary assembly, supported by considerable evidence from our solar system and young stars in star formation regions, is that it begins in a disk composed of dust and gas. The initial dust grain size is probably sub-micron, comparable to that for interstellar dust particles. Within the proto-planetary disk, the dust grains begin to “stick” together. As they do so, they decouple from the gas and begin to interact gravitationally. The dust grains accrete, first forming “pebbles,” then “boulders,” and finally planetesimals. Probing the disk when pebbles are forming and accumulating into boulders requires observations at wavelengths comparable to the size of the particles (≈ 1 cm). With its high frequency capabilities, the SKA will be positioned uniquely to probe the assembly of planets. Moreover, it is planned for the SKA to be able to obtain milliarcsecond resolution. At the distance of nearby star forming regions (≈ 150 pc), 1 AU subtends an angle of approximately 7 mas. Thus, the SKA will be able to resolve the inner portions of proto-planetary disks. For a solar-mass star, the orbital period at a distance of 1 AU is 1 yr, so the SKA may even make “movies” of planet formation.

In addition, a number of large (> 10 atom) prebiotic molecules are being discovered in interstellar space. Typical transition frequencies for these molecules are 1–20 GHz, with larger molecules having transitions at lower frequencies. The SKA will search for these prebiotic molecules and explore the extent of organic chemistry and the precursors of life in interstellar space.

3 Key Science: Fundamental Physics

A second motivation for astronomy is that it can motivate or provide tests of theories of fundamental physics. For instance, observations of gravitational lensing by the Sun provided key early support for Einstein’s General Theory of Relativity (GR), which now finds widespread use, such as in the Global Positioning System (GPS).

3.1 Strong Field Tests of Gravity using Pulsars and Black Holes

Observations of the pulsar PSR B1913+16 have already provided an indirect detection of the gravitational radiation predicted in GR (and the 1993 Nobel Prize in Physics). The Galaxy should contain systems capable of providing even more stringent tests, and the sensitivity of the SKA will be such that it will detect a significant fraction of the 20,000 rotation-powered radio pulsars within the Galaxy that are beamed in our direction.

Models of the Galactic pulsar population predict that there should be at least one pulsar-black hole binary in the Galaxy. As a black hole is the most compact object that should exist, the regular pulsations from a pulsar (“clock”) in its environment would provide stringent tests of GR. At a basic level, the pulsar timing will reveal the properties of the black hole companion, such as its mass and angular momentum, in a manner similar to how timing observations have measured the mass of both components in double neutron star systems. Higher order tests of GR can also be conducted, such as of the “no-hair” theorem that predicts that a black hole is described entirely by its mass, angular momentum, and electric charge, and which also predicts a simple relation between its angular momentum and quadrupole moment. Further, the supermassive black hole in the Galactic center should contain a number of pulsars in orbit about it, pulsars that have escaped detection because current instruments do not have sufficient sensitivity at the frequencies (> 10 GHz) required to mitigate the severe interstellar scattering effects along the line of sight.
The SKA is expected to discover millisecond pulsars across the sky. With their exquisite timing stability, this network of millisecond pulsars (pulsar timing array) can serve as a many-armed gravitational wave detector, searching for timing distortions due to the passage of very low frequency gravitational waves ($\sim nHz$). Generally, cosmic sources are expected to produce a spectrum of gravitational waves, and the SKA pulsar timing array will probe a regime in which gravitational waves may be produced by binary supermassive black holes resulting from galactic mergers, cosmic strings, or during the initial inflationary epoch of the Universe.

3.2 The Origin and Evolution of Cosmic Magnetism

Electromagnetism is one of the most accurate physical theories, and it is clear that magnetic fields fill in clusters and interstellar space, affect the evolution of galaxies, contribute significantly to the total pressure of interstellar gas, are essential for the onset of star formation, and control the density and distribution of cosmic rays in the interstellar medium. Nonetheless, fairly basic questions remain about the origin and evolution of cosmic magnetic fields. A radio wave propagating through a magnetized plasma undergoes Faraday rotation, providing the SKA with a unique probe on cosmic magnetic fields. The SKA will be able to form a grid of Faraday rotation measures, with a typical separation of about $90^\circ$ between lines of sight.

With this grid, a detailed picture of the Galactic magnetic field will be produced, and similar measurements will be used to probe the fields in nearby galaxies. Such a detailed model for galactic magnetic fields in turn can discriminate between various origins for magnetic fields in galaxies, whether the fields are in some sense primordial or were generated at later times by a dynamo action (e.g., $\alpha-\Omega$ dynamo).

For nearby clusters of galaxies, the rotation measure grid will be sufficiently dense to probe the field within the clusters themselves, in contrast to the current situation in which only properties averaged over many clusters can be determined. A detailed view of the magnetic field structure within clusters will in turn allow probes of the interaction between magnetic fields and the hot, X-ray emitting gas as well as the interplay between “heating” mechanisms for a cluster (e.g., mergers, radio jets from active galactic nuclei near the center of clusters) and the cooling provided by the X-ray emission.

Finally, with the deepest SKA observations, magnetic field measurements at high redshift ($z > 2$) will be possible. Complementing those in nearby galaxies, observations of distant galaxies may trace directly the enhancement of the magnetic field by a dynamo (or illustrate that a dynamo is not responsible for its origin).

3.3 Cosmology and Dark Energy

The HI emission from galaxies can be used to study the galaxies themselves, or it can be used to identify test masses from which one can conduct cosmological observations. If the SKA can observe the HI emission from galaxies out to a redshift of order unity over much of the sky ($\sim 2\pi$ sr), it will survey a significant volume of the Universe ($\sim 100$ Gpc$^3$). Within this volume should be more than one billion galaxies, from which the galaxy power spectrum as a function of redshift can be determined. At the time of recombination, acoustic oscillations in the intergalactic plasma should have been “frozen in.” These baryon acoustic oscillations are detected today in the galaxy power spectrum, and they serve as a standard ruler. Importantly, the SKA’s sensitivity should be such that they can be determined as a function of redshift. The SKA experiment will determine the change in the apparent angular size of these acoustic oscillations as a function of redshift. When combined with measurements of the size of these oscillations seen in the CMB, one can obtain a measure of the cosmic evolution of the Universe. In particular, the influence of
dark energy from the time of the formation of the CMB to \( z \sim 1 \) can be probed, thereby constraining the equation of state of the Universe. Crucially, the accuracy of measurements of this sort depends upon the total number of objects detected. The large sample size of the SKA surveys will provide unparalleled precision.

An alternate approach to dark energy studies with \( \text{H} \, \text{i} \) is intensity mapping. The relevant scale for BAOs is about 150 Mpc, much larger than the size of an individual galaxy, or even a group of galaxies. Thus, rather than attempting to resolve individual galaxies, intensity mapping seeks to detect the integrated emission from galaxies. Once the integrated emission is detected, however, the approach to BAO studies of dark energy is conceptually similar in that the objective is to detect BAOs via a power spectral analysis of the \( \text{H} \, \text{i} \) emission.

4 SKA Precursors, Pathfinders, and Phase 1

One of the original motivations for the SKA Key Science Programs was that they provide a qualitative improvement on existing radio wavelength observations. To reach this objective, however, will require a solid observational foundation or “science pathfinding” using existing and under-construction telescopes, and this science foundation is being laid with observations at telescopes around the world. The observational programs being conducted are diverse, but span the entire SKA Science Case. Further, it is likely that there will be a “positive feedback loop” between the SKA Science Case and the on-going programs. Just as the SKA Science Case has helped to influence some of the current observational programs being conducted, the results of these observational programs will influence the evolution of the SKA Science Case, as surveys push to deeper fields and larger sky expanses.

One of the key strengths of an interferometer is that it degrades gracefully as receptors are removed from operation. Conversely, an interferometer can begin science operations well before it has reached its full complement of receptors. Such is the notion of the SKA Phase 1: Rather than waiting for the construction of the full SKA to be completed, significant science results can be produced when the array has only a fraction of its full complement of receptors. A notional value for the scale of SKA Phase 1 is that it would be 10% of the capability of the SKA. Key scientific motivations for SKA Phase 1 are two aspects of the full SKA Science Case, namely, studies of \( \text{H} \, \text{i} \) over cosmic time, particularly observations of \( \text{H} \, \text{i} \) during the Epoch of Reionization, and fundamental physics as probed by pulsar observations, particularly detecting gravitational waves.

Between the on-going science programs at existing and near-future telescopes, and the science that they will motivate first in SKA Phase 1 and then in the SKA itself, radio wavelength observations are poised to continue their impressive record of helping us understand the Universe in which we live.

Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

References


ASKAP: Australian SKA Pathfinder

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Abstract

ASKAP is a radio telescope being built at the proposed Australian SKA site: the Murchison Radio Observatory (MRO). It consists of 36 12m parabolic reflector with a 188 element phased array feed at the focus. Over its operating frequency range of 0.7 to 1.8GHz the phased array gives ASKAP a field of view which is 30 times larger than a dish with a single feed at the focus. The phased array feed will give ASKAP an observing speed that is more than an order of magnitude greater than any existing telescope.

The extra challenges posed by this telescope are the development of the novel chequerboard phase array, transporting the 188 signals from the phased array to downconverters and digitisers and then the beamforming of this data. To do this ASKAP has a compute capacity of 2 Petaops/s and an optical network transporting 100Tb/s.

1 Introduction

The mainstay of radioastronomy for many years has been a dish with a single feed and for many of those years improved performance was obtained by reducing the system temperature of the receiving system. For example the Parkes dish built in 1961 is still a very productive radiotelescope. However, receiver performance has reached the limits of what is possible. This leaves two main areas for improvement in telescope performance: collecting area and field of view. Increasing collecting area is obtained by building more dishes, such as in the SKA, or through innovation on unique sites such as is demonstrated by FAST. At CSIRO we have been exploring the possibility of increasing field of view. The simplest method is to add multiple feeds to a single dish (Parkes Multibeam)[1] and with ASKAP [2] the next step is being taken by using a phased array feed at the focus of a dish which increases the field of view by a factor of ~30.

2 ASKAP

ASKAP is being built on the Australian site proposed for the SKA, the other site is in South Africa. As shown in Figure 1 it is approximate 300km NW of the the city of Geraldton on the Boolardy pastoral station. The station is in the Murchison shire which has an area greater than the Netherlands and a total population that is less than 160. The low population density gives the site very
low levels of radio frequency interference. The correlation data generated at Boolardy is set to the Pawsey High Performance Computing Centre in Perth for processing. ASKAP is laying a 42 fibre link to the Geraldton Support facility on from there it will go on dark fibre provided by the NBN link to Perth, WA.

![Location in Western Australia and Fibre links to Perth.](image)

The specification for the ASKAP radiotelescope are given in Table 1. The 36 dishes have an area comparable to that of a single 72m reflector. But with higher spatial resolution and a larger field of view.

<table>
<thead>
<tr>
<th>Table 1: ASKAP specifications and properties</th>
</tr>
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<tbody>
<tr>
<td>Number of dishes</td>
</tr>
<tr>
<td>Dish diameter</td>
</tr>
<tr>
<td>Max baseline</td>
</tr>
<tr>
<td>Resolution</td>
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<tr>
<td>Sensitivity</td>
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<td>Field of View</td>
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<td>Speed</td>
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<td>Processed Bandwidth</td>
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<tr>
<td>Channels</td>
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<td>Focal Plane Phased Array</td>
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</tbody>
</table>

Compared to a single 72m dish a single beam on ASKAP has 36 times the field of view. This is increased by a further factor of 30 times more by the installation of phased array feed at the focus of the dish. This will make ASKAP the fastest HI survey instrument when it is built. Compared to NVSS/SUMMS it will go 40 times deeper at 6 times the spatial resolution resolution. This has attracted considerable interest, which has now been reduced to 10 Survey Science Programs [3] these Proceedings.
Figure 2: Three axis ASKAP dish and chequerboard phased array feed (left).

3 ASKAP dish and Phased Array Feed

The phased array feed is a chequerboard design, illustrated in Figure 2, and collects energy from a $1\text{m}^2$ area at the focus. As the focal length is 6m this corresponds to a field of view $\sim 6^\circ$ across. To utilise this field of view the data from the phased array feed is processed to generate 36 dual polarisation beams. In its simplest form each beam corresponds to a conjugate match to the fields on the focal plane for a point source illumination.

The 12m dish has an altitude over azimuth mount. With this mount the feed would rotate relative to source during an observation. This is not a significant problem with a single beam instrument but with a multibeam instrument such as ASKAP all but one of the beams rotates on the sky. In ASKAP this problem is solved by adding a third axis of rotation. The whole dish surface, quadrupod and phased array feed can rotate, Figure 2. This enables the beams generated by the phased array feed to be kept fixed on the sky. A second benefit of this is that sidelobes, which may contain interfering sources, also stay fixed on the sky. This enables imaging software to process such sources as if they are in the field of view. This feature will significantly enhance the dynamic range of ASKAP.

4 Signal Processing

With 188 signals, each 0.3GHz wide, the total bandwidth being generated by each antenna is 56.4GHz. At the antenna the 700-1800MHz RF signals are transported to the pedestal, downconverted to a 400-700MHz IF, and digitised. After this each signal is passed through a filterbank with a 1MHz frequency resolution and this data is transported to the central site on 192 10Gb/s optical fibres, Figure 2. Transportation of the signal from the PAF to the ADC are a major challenge for ASKAP. For the SKA more advanced methods are needed such as RF over Fibre and direct sampling of the RF at the focus. The last requires low cost, low power digitiser capable of sampling at GHz rates.

At the central site a cross connect brings data from all signal from the PAF together in the digital beamformer. The beamformer is based on Field Pro-
grammable Gate Arrays (FPGAs) and each FPGA processes 5MHz of bandwidth. Also calculated in the same FPGA is the Array Covariance Matrix (ACM) and correlation between reference signal and signals transmitted from the surface of the dish. These correlations are used to calibrate the phased array and calculate the optimum weights for beamforming.

After beamforming on the 1MHz channels a final filter bank is used to bring the data to an 18.5kHz frequency resolution. This gives 16,416 frequency channels across the 300MHz bandwidth of ASKAP. The corresponding beams and frequency channels are correlated to generate full Stokes parameters. The total compute load in the beamformers and correlator is ~2Peta op/s. With 5 second integration times in the correlator the data generated at the central site is ~200Gb/s, which is considerably less than the 70Tb/s generated at the antennas and 25Tb/s going to the correlator.

The correlator data is sent via optical link to Geraldton and on to the Pawsey Centre in Perth. Here each 5 second integration generates a 30 square degree continuum image for real time calibration. For high fidelity continuum images and spectral cubes hours to days worth of data is used. Even so for 30" resolution spectral cubes ~1Tbyte of data will be generated in real time each day.

5 Conclusion

ASKAP is a SKA precursor telescope being built on one of the candidate SKA sites. It demonstrate phased array feed technology as a way of increasing field of view and survey speed. The processing involved in doing this is ~2Peta operation/s which is a major cost. By the time of the SKA advances in digital processing will bring this cost down to an acceptable level.

References


MeerKAT Overview: An Engineering and Technical Focus

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Abstract

After briefly providing the context of the SKA South Africa Project, we focus on the engineering and technical aspects of the MeerKAT Radio Telescope, South Africa’s SKA pathfinder instrument being constructed at the SKA SA candidate site. This includes the MeerKAT specifications, major science projects, development of the site, the KAT-7 engineering and science testbed and the various technologies employed in the development of the instruments.

1 Introduction

The SKA South Africa Project has three major components: (i) the SKA site bid - SA and Australia are the two shortlisted core sites; (ii) MeerKAT, an SKA precursor telescope; and (iii) Youth Into Science, a large skills development and training programme. An exciting recent addition to this list is (iv) a new development of an Africa VLBI array. We focus here mostly on (ii), the MeerKAT, a 64-element dish-based interferometer, intended to be a world class facility and the most sensitive Southern Hemisphere telescope at cm wavelengths. The current status:

- The SKA SA Project has three main centers: Cape Town (engineering and science); Johannesburg (business, infrastructure and site bid); and the Karoo site (where the telescopes are).
- About 75 people are now directly employed on the project (growing) plus several major industry partners.
- The MeerKAT (and SKA candidate) Karoo site is operational after a major infrastructure development. The site lies in the Northern Cape region of SA in a radio quiet reserve protected by government legislation. Access from the major centers is by road or a weekly flight. Accommodation and workshops are available on site. The radio astronomy reserve also currently hosts the PAPER experiment and the Southern C-BASS dish.
- A 7-dish engineering and science testbed for MeerKAT, known as KAT-7, has been constructed on the site and is now in steady operation. Full remote operations will commence from Jan 2011 from the Cape Town control room. Three of the 7 dishes are now running cold cryo systems and another 2 have warm cryos with all 7 on cold cryos by end of March 2011. The system has already undergone much single dish commissioning, and also produced several interferometric images and even VLBI fringes! Pulsar monitoring and transient detection activities are expected to start up in 2011.
• The Karoo site is now powered from the country’s electrical grid (with diesel backup power) following the construction of an 80 km power line from the site to the nearest town of Carnarvon. The power line also carries a fibre optic cable which will provide the high speed data connection to Cape Town.

• A MeerKAT Concept Design Review was held in 2010 with the outcome that MeerKAT will be constructed from 64 x 13.5 m offset Gregorian antennas. The unblocked apertures provide a number of technical performance advantages over prime focus designs and are in alignment with the SKA mid-band design.

• 2010 also saw the Time Allocation Committee evaluate the MeerKAT large survey project proposals.

So, in general, by any standards, things are going well. The major success factors to date have been: an excellent, well protected, accessible and workable RFI-quiet site; continued strong top-level political and funding support; and a large pool of innovative and talented people from which to draw.

2 MeerKAT Specifications and Phasing

MeerKAT is being built to the follow major specifications:

• 64 dishes, offset Gregorian design, 13.5 m effective diameter, 1 mm rms surface, 15 arcsec pointing accuracy (with approx 5 arcsec tracking consistency)

• Frequency range from 0.59 to 14.5 GHz with 65k frequency channels (spread over 4 tunable sub-bands)

• L-band sensitivity: $Ae/Tsys = 220$ m$^2/K$

The phasing is as follows:

<table>
<thead>
<tr>
<th>Estimated completion</th>
<th>Phase I</th>
<th>Phase II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2016</td>
<td>2018</td>
</tr>
<tr>
<td>Frequency bands (GHz)</td>
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<td>0.59 - 1.1</td>
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<td></td>
<td></td>
<td>8 - 14.5</td>
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<td>RF bandwidth (GHz)</td>
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<td>Sampling frequency (Gbps)</td>
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<tr>
<td>Processed bandwidth (GHz)</td>
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</tr>
<tr>
<td>Maximum baseline (km)</td>
<td>8</td>
<td>8/60 (unfunded)</td>
</tr>
</tbody>
</table>

3 MeerKAT Science

During 2010, more than 500 scientists organized into more than 20 proposals, responded to a call for proposals for MeerKAT large survey projects. An internationally constituted Time Allocation Committee evaluated the proposals with the following outcomes and allocations. Priority 1 were:

• Radio Pulsar Timing (7860 hours)

• Deep III Field (5000 hours)

The priority 2 proposals were:

• MESMER: Search for Molecules in the EOR (6500 hours)

• MeerKAT Absorption Line Survey (4000 hours)
• MONGOOSE: Deep Observations of Targeted Nearby Galaxies (6000 hours)
• TRAPUM: Transients and Pulsars with MeerKAT (3080 hours)
• MeerKAT HI Survey of Fornax (2450 hours)
• MeerGAL: MeerKAT High Frequency Galactic Plane Survey (3300 hours)
• MIGHTEE: Deep Continuum Survey (approx 1950 hours)
• ThunderKAT: Hunt for Dynamic and Explosive Radio Transients with MeerKAT (3000 hours)

VLBI will also be supported and the potential for SETI explored. This constitutes 70% of the time allocation for the first few years of operation of the telescope. The remainder is allocated for smaller PI proposals (25%) and director’s time (5%).

4 Subsystems

The MeerKAT team has worked closely with a number of major contractors in the design and construction of KAT-7. This trend is expected to continue for MeerKAT. Major telescope contractors to date include BAE and MMS (antenna/dish structures), EMSS (feeds and cryos), Tellumat and ETSE (RF stages), and TFZ (cooling systems).

In-house teams include, project management, infrastructure, site operations, commissioning, system engineering, antenna design, RF, software (control and monitor and science processing), and digital back-end (correlator and beamformer).

The antennas for KAT-7 are 12 m prime-focus, single-piece composite reflectors which were molded on site using a vacuum infusion process. Pedestals are steel, constructed off site, but assembled on site. KAT-7 feeds are optimized for 1200 - 1950 MHz operation and were designed and modelled using the sophisticated FEKO software. The cryos use Stirling cycle coolers.

Several RF stages are used on KAT-7 including RF-over-fibre transmission to a central downconverter. This is expected to be replaced with direct digitization at the antennas for MeerKAT following the low noise amplifier at the feed.

The KAT-7 and MeerKAT correlators are based on the ROACH designs as part of the CASPER collaboration. The in-house digital back-end team is playing a key role in the design and production of ROACH technology which is now being used throughout the world.

Control and monitor software has also been developed in-house and is largely Python-based. This provides a powerful and flexible scripting interface for engineering and commissioning activities as well as a platform for higher level tools. The science processing area covers both imaging and non-imaging systems. For imaging, the team is starting to work closely with developers of existing packages (CASA and MoToEes). For the non-imaging systems, some generic building blocks are being developed for time domain processing and recording which will allow for exploration of a range of areas (pulsars, transients, VLBI recording, raw data recording, SETI, etc). GPU technology is being increasingly employed within the science processing systems.

SKA SA, a business unit of the National Research Foundation, is funded by the Department of Science and Technology and is a team effort. This paper reports on the work of almost the full technical team (including subcontractors) and the author, in presenting the brief summary, fully acknowledges the contributions of his colleagues and is very grateful to be part of such an effort.
Figure 1: Two of seven KAT-7 single-piece, composite dishes showing backing structure.

Figure 2: From the air, KAT-7 at the Karoo site.
LOFAR: Science with a single LOFAR station

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Abstract

The Low Frequency Array (LOFAR) is a phased array with wide-field, multi-beamforming technology using many dipoles operating over the frequency range 10–240 MHz. LOFAR is transitioning from construction to its commissioning and operations phase. This paper briefly summarizes LOFAR and shows some recent results from a single LOFAR station. The success of LOFAR will be important to the low band of the SKA given the potential technological overlaps.

1 Introduction

Several projects using wide-field, multi-beamforming technology with many low cost dipoles are ongoing, including the Low Frequency Array (LOFAR: 10–240 MHz), the Murchison Widefield Array (MWA: 80–300 MHz), and the Long Wavelength Array (LWA: 10–88 MHz). They will explore the relatively unexplored low-frequency sky and may reveal yet unknown phenomena. LOFAR has produced exciting images with dynamic ranges already reaching 10,000 to 1.\(^1\) In § 2 we briefly describe LOFAR, and in § 3 we show some results from an individual LOFAR station using the Effelsberg LOFAR station (Fig. 1).

2 The Low Frequency Array

LOFAR was originally designed and constructed by ASTRON as an array in the Netherlands with baselines up to 100 km. Its capabilities are geared to key science projects on Deep Extragalactic Surveys, Transient Radio Phenomena and Pulsars, the Epoch of Reionization, High Energy Cosmic Rays, Cosmic Magnetism, and Solar Physics and Space Weather. Now, the International LOFAR Telescope, mostly constructed by the end of 2010, and to be completed in 2011, has 40 stations in the Netherlands, plus at least 5 stations funded in Germany, and 1 each in France, Sweden, and the United Kingdom, that provide additional sensitivity and angular resolution on baselines extending to more than 1000 km. Future additions are envisaged. LOFAR is comprised of two different types of dipoles (Fig. 2), with

\(^{1}\) http://www.lofar.org
Figure 1: The first international LOFAR station in Effelsberg, Germany. The 96 low band dipole antennas (10–80 MHz) are (nearly) randomly distributed within a 60 m diameter circle (foreground) to minimize sidelobes. The 96 high band tiles (110–240 MHz) each consists of 4 × 4 dipole antennas (background). The photo was taken by James M Anderson from the Effelsberg 100 m telescope. Copyright: Max Planck Institute for Radio Astronomy (Bonn)

observing ranges of 10–80 MHz (low-band antennas, LBAs) and 110–240 MHz (high-band antennas, HBAs). A LOFAR station consists of 48/96 LBA dipoles and 48/96 HBA “tiles”, each tile consisting of sixteen dipole antennas in a 4 × 4 configuration. The data are correlated for imaging or summed for beamforming in a Blue Gene/P supercomputer in Groningen, the Netherlands. However, LOFAR stations can be also used in a local mode, in which the data do not go to Groningen, but instead to a PC cluster attached to the LOFAR station.

3 Science with an individual LOFAR station

LOFAR can do interesting science even with a single station. Each station can output beamformed, time-series data from up to more than 200 separate beam directions, with an aggregate bandwidth of up to 48 MHz. Each beam has a relatively large field of view, with the FWHM of an individual beam ranging from 1.7 degrees at 240 MHz to 11 degrees at 30 MHz for international stations. Each station is also capable of simultaneously correlating the signals from all receiving elements, allowing all-sky images to be produced. These features make LOFAR stations ideal tools to search for radio transients in the beamformed and correlated data. A group of LOFAR station users is commissioning the single-station observing mode to enable these and additional scientific uses for individual stations.

3.1 Pulsars

Pulsars are generally weak radio sources. However, LOFAR can easily detect pulsars with just a single station as pulsars have steep power-law spectra [1]. We have

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2 The international stations outside the Netherlands have 96 elements per array.
detected pulsars with the Effelsberg LOFAR station, including PSR B0329+54, which has the characteristic of mode switching [2]. The pulsar profile, analyzed with the PRESTO software suite, is clearly visible in Fig. 3. The pulsar intensity is displayed as a function of observing time, with a 1 hour integrated pulse profile. Data acquisition was done using the ARTEMIS backend (see acknowledgment).

3.2 All sky monitor for radio transients

An individual station can also be used as an array for synthesis mapping, while it simultaneously works as part of the international LOFAR array. The beam size of each dipole in a station covers almost all of the visible hemisphere, allowing the station to work as an all-sky monitoring telescope. The station correlator produces the correlation products of all dipoles for one narrow-band frequency channel per second. Fig. 4 shows an all-sky image constructed from a 60 s integration at a frequency of 123.4 MHz using the Effelsberg LOFAR station, in which Cyg A, Cas A, and our Galaxy are clearly visible [3]. This mode can be used for monitoring the entire visible sky for radio transients.

Acknowledgment. ARTEMIS, the software package and hardware used for acquiring LOFAR stand-alone mode data for our pulsar observations, was created by the University of Oxford (Karastergiou et al. in preparation). The software to produce the all-sky image in Fig. 4 was written by JMA. LOFAR, the Low Frequency Array designed and constructed by ASTRON, has facilities in several countries, that are owned by various parties (each with their own funding sources), and that are collectively operated by the International LOFAR Telescope (ILT) foundation under a joint scientific policy.

References


3 http://www.cv.nrao.edu/~sransom/presto
Figure 3: A diagnostic plot from the PRESTO pulsar software suite, which shows the clear detection of the pulsar PSR B0329+54. The top grayscale shows the intensity of emission as a function of time and pulse phase. On the right, the integrated emission as a function of phase is shown. The bottom plot shows the signal to noise as a function of time.

Figure 4: All-sky image at 123.4 MHz with 60 seconds integration time, above Effelsberg, Germany, on November 10, 2009 [3]. Cygnus A (near the center), Cassiopeia A (upper left), and the Galaxy (from bottom to upper-left) are visible. Copyright: Max Planck Institute for Radio Astronomy (Bonn)
Status of Korean Participation in the SKA Project

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Abstract

In this short report, I summarize the status of radio astronomy projects in Korea and give a report on the status of various efforts in Korea in relation to the Square Kilometre Array project. I also make brief comments on the SKA-related activities in Korea expected in the near future.

1 Introduction

Korea has three radio telescopes in operation for astronomical research. All of them are designed for observations in the millimeter band. Most of the radio astronomers are working in the Korea Astronomy and Space Science Institute (KASI), and several belong to the universities.

The Taeduk Radio Astronomy Observatory (TRAO) of KASI has been operating a single-dish telescope since 1987. The TRAO 14 m telescope is now equipped with a 3 mm multibeam receiver array system. The Seoul Radio Astronomy Observatory (SRAO) of Seoul National University has been operating a single-dish telescope since 2001. The SRAO 6 m telescope has receivers for observations in the 1 mm and 3 mm bands.

The Korean VLBI Network (KVN) of KASI is under construction. KVN is a three-element VLBI system with 21 m antennas and 310–480 km baselines [1]. The construction of antennas was completed recently (Figure 1). The receiver system is designed for simultaneous observations in the 22, 44, 86, and 129 GHz bands. The 22/44 GHz receivers were installed in 2009, and KVN antennas are currently used for astronomical observations in the single-dish mode at these lower frequency bands. Fringes were acquired at these bands, and 22/43 GHz simultaneous phase referencing tests are under way. VLBI test observations with KVN and VERA of NAOJ at 22/43 GHz bands were recently performed successfully. In addition to operations of KVN alone, joint operations with VERA have been tested with a goal to form East Asian VLBI Network. The 86/129 GHz receivers are to be completed by 2011. KVN is expected to perform regular VLBI observations from 2012.

The construction of Korea-Japan Joint VLBI Correlator (KJJVC) was completed recently. It contains 16 stations (8 Mark5B, 4 VERA2000+DMS-24, and 4 K5) and 16 raw VLBI data buffers. The data archive system has a capacity of 100 TB. KJJVC will be hosted by East Asian VLBI Network Correlation Center that will be constructed in a few years at the KASI headquarter in Daejeon, Korea.

As the construction phase of KVN is getting close to completion, the radio astronomy community of Korea are considering several possibilities for the major project of near future. The Square Kilometre Array (SKA) is obviously one of them.
2 Korean Participation in the SKA Project

In recent years KASI has become more and more active in participating in large-scale astronomical projects. For example, KASI recently joined the Giant Magellan Telescope project, which is helping the KASI staffs getting more familiar with large-scale international collaboration projects. The Radio Division and the International Center for Astrophysics (iCAP) of KASI is planning to perform a feasibility study for post-KVN projects, and SKA is considered one of the major possibilities. In addition, the Korean government has recognized the need to participate in large-scale international projects. The National Research Facilities and Equipment Center (a coordinating agency in the government) recently compiled the National Roadmap for Large-scale Research Facilities, and SKA is listed in the wish list.

In an effort to get actively involved in the SKA project, KASI is participating in the PrepSKA project as a collaboration program through the EU-FP7. One of the major efforts contributed by KASI is the development of software correlator. KASI is also participating in the RadioNet project through the EU-FP7 collaboration. The Korean participation in PrepSKA and RadioNet is funded by the National Research Foundation of Korea. In addition, KASI formally joined the SKA Science and Engineering Committee as a regular member, as of 2010 September.

Several astronomers in Korea are working on scientific projects closely related to the scientific goals of SKA. For example, a team of scientists led by D. Ryu is studying the structure of cosmological magnetic fields and participating in the Polarization Sky Survey of the Universe’s Magnetism with the Australian Square Kilometre Array Pathfinder [2, 3].

To stimulate the discussions on SKA in the Korean astronomy community, iCAP
hosted SKA-Korea Workshop on 2010 August 20. Several speakers reviewed the status of the SKA project and various efforts being carried out in the community. More than fifty scientists and engineers participated in the workshop and expressed their interests in SKA. Scientific goals of special interest among Korean astronomers include the large-scale structure of magnetic fields, evolution of galaxy clusters, the nature of dark matter, and the epoch of reionization. All the participants agreed that SKA is a good opportunity for both scientists and engineers.

3 Future Prospects

The SKA-Korea Workshop confirmed that there are good motivations in the community, and it is encouraging that SKA is listed in the National Roadmap. To make a more concrete plan for the participation in the SKA project, SKA Science/Engineering Working Groups are being organized, and they will push for further involvements in the SKA project. Korean astronomers hope to make significant contributions to SKA and are very interested in collaborations among East Asian countries.

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References


Study of Cosmic Magnetic Fields with SKA

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Abstract

In this article, we report the activity of SKA-JP sub-Science Working Group on Cosmic Magnetism. We are studying various topics concerning cosmic magnetic fields, such as galaxies, clusters of galaxies, large scale structure and cosmological fields. SKA will become a very effective tool to probe these magnetic fields.

1 Introduction

It is well known that astronomical objects such as galaxies and galaxy clusters have their own magnetic fields. It is conventional to consider these magnetic fields are amplified and maintained by dynamo process, but dynamo cannot generate magnetic fields from zero and requires the seed fields. The origin of the seed fields is one of the biggest problems in modern astrophysics and cosmology. On the other hand, we have only upper bounds on cosmological magnetic fields, which are not associated with any specific object and fill the whole universe. If primordial magnetic fields existed, they not only act as the seed fields but could have affected the formation of first stars and galaxies.

Our group, SKA-JP sub-Science Working Group on Cosmic Magnetism, consists of 11 researchers. We are discussing what we can learn about cosmic magnetic fields with SKA, especially focusing on its wideband observation. In this article, we report the activity of our group.

2 Activity of Our Group

2.1 galaxy

The large scale structure of the magnetic field in a spiral galaxy has been an unresolved problem in astrophysics. The magnetic field lines in spiral galaxies show spiral structures, whose pitch angles are almost the same as those of the optical spiral arms. The strength of the large scale field is estimated to be $\sim$ several $\times 10^{-6}$ G, which is comparable to the random magnetic field. The structures of the magnetic field are classified by the symmetry. Some galaxies show the axisymmetric (ASS) or ring structures, others show the biaxymmetric (BSS) structure in which the field lines go into the disk from one side and go out from the opposite side. Mixed structures are also seen in some galaxies.

There are two competing ideas to explain the large scale structure of the magnetic fields in spiral galaxies. One is the dynamo theory and another is the primordial field theory. The advantage of the primordial field theory is that BSS field
is naturally produced from the nearly uniform field by the differential rotation of the galaxy. [1] proposed the idea that the several types of the magnetic field (not only BSS, but ASS, ring, and vertical near the centre) can be produced from the large scale primordial field (Fig. 1). They also carried out MHD numerical simulation and nearly confirmed the idea. They found that the initial magnetic field was amplified due to magnetorotational instability even if the turbulent diffusion is effectively working.

2.2 galaxy cluster and large scale structure

Intergalactic magnetic field, IGMF, causes interesting astrophysical phenomena such as the particle acceleration and synchrotron radiation through accretion shocks induced by the structure formation, and affects temperature substructure in galaxy clusters suppressing electron thermal conduction to the direction perpendicular to the magnetic field. It also may play an important role in star and galaxy formations, and deflects ultra high energy cosmic rays. Therefore, understanding the origin and nature of the IGMF is essential to know histories of various astronomical objects in the universe.

In the shock waves, it is expected that the Biermann battery effect generates the magnetic fields. In addition, the shock also produces vorticity, and the vorticity cascading stretches magnetic field lines then amplifies the magnetic field strength. This is so-called the turbulent dynamo. Amplification of the IGMF by the turbulent dynamo has been estimated. According to the estimations, the volume average of the IGMF strength and the coherence length in filaments are expected to be \( B \sim 10 \text{ nG} \) and \( B \sim \text{a few } \times 10^2 \text{ kpc} \), respectively. However, it is hard to carry out a full cosmological simulation of MHD turbulence, because we have to correctly calculate the dissipation of magnetic fields to handle MHD turbulence, which require unrealistic number of grid points in the simulation. Thus they apply an empirical model of the turbulent dynamo to the cosmological hydrodynamic simulations so far. Fig. 2 shows the RM map due to the IGMF [2]. The root mean square value of RM is expected to be \( \sim 1 \text{ rad m}^{-2} \) in filaments, which is too small to measure by current observational facilities, but could be possible by the SKA.
2.3 cosmology

A lot of mechanisms to generate primordial cosmological magnetic fields have been proposed so far. Among them are cosmological models concerned with inflation and phase transition in early universe, and astrophysical models concerned with reionization [3] and protogalaxy formation. They produce cosmological fields whose amplitudes are estimated to be of order $10^{-25} - 10^{-15}$ Gauss. Although there are many uncertainties in the predictions, this amplitude is considered to be sufficient for seed magnetic fields.

In [4, 5], we have shown that primordial density fluctuations can naturally generate magnetic fields. Before the recombination, the universe was filled with high-temperature and high-density plasma composed of photons, electrons and protons which were tightly coupled through Thomson and Coulomb scatterings. However, the motion of electron fluid was more easily dragged by that of photon fluid because electrons are much lighter than protons. Thus the difference in motion between electron and proton fluids, namely electric current, was generated and then magnetic field was induced. This model is based on cosmological perturbation theory which has been well established both theoretically and observationally through the studies of CMB anisotropies and structure formation. Thus it suffers essentially no ambiguity in predicting the amplitude and spectrum of magnetic field. This is a significant advantage compared with other generation mechanisms. Because the magnetic fields and the anisotropies of cosmic microwave background have the same origin, their distributions are correlated. Fig. 3 plots the predicted spectrum of magnetic fields generated by this mechanism. As a result, it was shown that our universe is filled with magnetic fields of order $10^{-15}$ Gauss at the recombination which is strong enough to act as the seed magnetic field of galactic magnetic fields.

To distinguish between various generation models observationally, it is very important to predict the spectrum and distribution of magnetic fields for each model.
Figure 3: Spectrum of magnetic fields at the recombination generated from density fluctuations [5]. Two contributions and their sum are plotted. Here the horizontal axis and the vertical axis are the coherence length and the amplitude of magnetic field of the scale, respectively.

3 Summary

In this article, we reported our activity on cosmic magnetic fields toward SKA. Our research field covers, besides topics mentioned above, astrophysical jets and supernova remnants [6]. SKA observation, through Faraday rotation survey and synchrotron radiation, will allow us to probe the origin of cosmic magnetic fields.

References

Exploring Faraday RM due to the IGMF with SKA

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Abstract
The nature and origin of the intergalactic magnetic field (IGMF) are outstanding problems of cosmology, yet they are not well understood. The Square Kilometer Array (SKA) will explore the IGMF in filaments of galaxies through observations of Faraday rotation measure (RM). In this proceeding, we briefly summarize our theoretical studies of RMs through filaments in which we newly used a model of the IGMF based on the MHD turbulence simulations. For instance, the root mean square (rms) value of RMs through filaments for the present-day local universe is estimated to be $\sim 1$ rad m$^{-2}$, and which can reach $\sim$several rad m$^{-2}$ when we integrate up to a redshift of $z=5$ and when we account for the redshift distribution of background radio sources against which RMs are to be measured. We also mention the galactic foreground RM, and demonstrate how we can remove it, using a filtering technique.

1 Introduction

Intergalactic space is though to be filled with the magneto-ionic medium. RMs of order hundreds rad m$^{-2}$ have been reported from the observations of Faraday rotation of polarized light from background radio sources through galaxy clusters [1, 2]. Typical strength and coherence length of the IGMF in galaxy clusters are estimated to be $\sim 1-10$ $\mu$G and $\sim 1-10$ kpc, respectively. RMs through the large-scale structure also have been discussed [3, 4, 5]. For instance, all-sky survey indicates that the extragalactic contribution of the width of the RM distribution is $\sigma_{\text{RM, RG}} \sim 6$ rad m$^{-2}$ [6]. However, the measurement error is still $\sigma_{\text{err, RM}} \sim 10$ rad m$^{-2}$. The origin and nature of the IGMF are thus not yet known well, which will be explored with SKA and upcoming SKA pathfinders (e.g., ASKAP, MeerKAT, LOFAR).

It was suggested that the IGMF was produced as a consequence of the amplification of weak seed fields of any origins through the stretching of field lines in turbulence in the large-scale structure of the universe; this scenario has been studied with cosmological structure formation simulations and MHD turbulence simulations [9, 10]. Some evidences that the IGMF follows a Kolmogorov-like power spectrum were discovered in galaxy clusters [7, 8], implying the existence of turbulence flow motion of the ionized medium and turbulence amplification of the IGMF.

2 Model

To investigate the RM in the large-scale structure of the universe, we used structure formation simulations for a concordance $\Lambda$CDM universe, and employed a turbulence dynamo model for the IGMF based on the simulations of incompressible MHD turbulence [9, 10]. In this model, the IGMF is estimated with local eddy turnover number and the turbulent energy density. For the direction of the IGMF, we used
that of the passive fields from the simulations for cosmological structure formation. As seed magnetic fields, we took the ones generated through the Biermann battery mechanism at cosmological shocks. See [9, 11] for details.

We first calculated the RM of the present-day local universe, by integrating the RM up to $100 \, h^{-1} \, \text{Mpc}$ (a computational box size) for the data output at $z = 0$, then extended it by integrating the RM up to $z = 5$, taking account of redshift evolution of the large-scale structure and considering distribution of radio sources. For the redshift of sources, we employed the redshift probability distribution function of the radio galaxies (FR I and II) which are detectable by SKA [12].

Faraday RM for a background source at a given redshift $z_s$ is given by

$$\text{RM} \, (\text{rad} \, \text{m}^{-2}) = 8.12 \times 10^5 \int_0^{l_s(z_s)} (1 + z)^{-2} n_e(z) B_l(z) dl(z),$$

(1)

where $n_e$ is the thermal electron density ($\text{cm}^{-3}$), $B_l$ the line-of-sight strength of the IGMF ($\mu$G), $t$ the propagating path (Mpc), and $l_s$ is the path length up to the source.

## 3 Result

The left panel of Figure 1 shows an example of the RM map for $(28 \, h^{-1} \, \text{Mpc})^2$ area in logarithmic scale. RMs trace the large-scale distribution of matter, and we see two clusters of galaxies and a filamentary structure containing several groups of galaxies. RMs through clusters, groups, and filaments are roughly $\sim 100$, $\sim 10$, and $\sim 1$ rad m$^{-2}$, respectively. The right panel of Figure 1 shows the distributions of RMs as well as other quantities along the LOSs through filaments. There are many reversals of the IGMF depending on the coherence length (a few to several hundreds kpc in filaments, shorter than the depth of filaments), which would cause a random walk process on the induction of the RM along the LOS. However, we found that the resulting RM is dominated by the contribution from the density peak along the LOS.

To quantify RMs through filaments, we calculated the rms value of RMs for $512^2 \times 3 \times 16$ (projected grid zones $\times$ directions $\times$ runs) LOSs. Through filaments
Figure 2: (Left) Rms values of RMs calculated along the way of integration up to $z = 5$. Gray solid, solid, gray dashed, and dashed lines show the results of CLS, TM7, TS8, and TS0 runs, respectively. (Right) Two dimensional power spectra of RMs integrated up to $z = 0.05$, 0.3, and 5.0 (from thin to thick) for TM7 run.

(with the X-ray emissivity weighted average temperature $10^5$ K < $T_X$ < $10^7$ K), the rms value is $\sim$ 1.4 rad m$^{-2}$. This agrees well with the value predicted with the mean strength and coherence length of the IGMP in filaments [10].

The left panel of Figure 2 shows the integrated rms value of RMs, where an average of 200 stacking calculations are shown and each calculation covers 200 deg$^2$ RM sky. In order to estimate RMs through filaments, we considered several different criterions for subtracting RMs through galaxy clusters from the RM map. In the integration of the RM along LOS, if we exclude any computational grids within 1 Mpc from the X-ray brightness peak of the halos that have $T_X > 2$ keV in their central parts ($< 0.5$ Mpc), we obtain $\sim$ 10 rad m$^{-2}$ (CLS). More simply, if we exclude any grids with the gas temperature higher that $10^7$ K, we obtain $\sim$ 7 rad m$^{-2}$ (TM7). Or, if we rule out the pixels which satisfy $T_X > 10^7$ K and the 2–10 keV X-ray surface brightness $S_X > 10^{-8}$ erg s$^{-1}$ cm$^{-2}$ sr$^{-1}$ (the current detection limit) in the integrated RM, we obtain $\sim$ 7 rad m$^{-2}$ (TS8). If we adopt $10^{-10}$ erg s$^{-1}$ cm$^{-2}$ sr$^{-1}$ as the future detection limit, we obtain $\sim$ 6 rad m$^{-2}$ (TS0). In all the cases, the integrated RM is derived mostly from the RM in $z < 1$ and is saturated at $z \sim 3$, because the integration is terminated mostly at $z \sim 3$ according to a decrease of observable radio galaxies, and an arrival light to a given wave band have experienced smaller rotation of polarization angle depending on $(1 + z)^{-2}$.

To see the characteristic scale of RMs through filaments, we calculated the two-dimensional power spectrum of RMs (the right panel of Fig. 2). We found that the power spectrum up to low redshift peaks at $\sim 1^\circ$. As we extend the integration toward higher redshift, the small-scale power increases, since an apparent size of the RM structure of filaments is getting smaller. Eventually, the power spectrum up to $z = 5$ peaks at $\sim 0.24^\circ$.

Finally, the galactic RM is expected to be a serious contamination for detecting the RM through filaments, since its amplitude is larger than that through filaments [3, 4, 5]. One of the possible methodologies to remove the contamination would be a high-pass filter. Figure 3 demonstrates the reconstruction of the RM map using the fast-Fourier and fast-wavelet transformations (FFT and FWT, respectively). To the original RM map (Fig. 3a), we added a model galactic RM which has the rms value of 5 rad m$^{-2}$ and the Kolmogorov power spectrum peaked at a few degrees
Figure 3: (a) RM map of the present-day local universe. (b) Noise-included RM map. (c) Reconstructed map by FFT. (d) Reconstructed map by FWT.

scale (Fig. 3b); RMs through filaments is hidden by the foreground noise. However, since the power spectrum of RMs through filaments peaks at sub-degree scale, the FFT and FWT high-pass filters can selectively remove the galactic RM, cutting the large-scale power in $k$-space, and make RMs through filaments visible (Figs. 3c and 3d).

4 Concluding Remarks

We predict that the RM through filaments would be $\sim 1$ to several rad m$^{-2}$, while the RM through galaxy clusters has been observed to be hundreds rad m$^{-2}$. Therefore, the large-scale structure should exhibit a wide range of the RM. We note that high-frequency observations should be suitable for large RMs in galaxy clusters, preventing $\pi\sigma$ ambiguity. On the other hand, low-frequency observations, which are expected with SKA and SKA pathfinders, would have an advantage for measuring small RMs in filaments.

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The Square Kilometre Array: Update and Engineering Opportunities

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Abstract

The Square Kilometre Array (SKA) will be the next generation radio telescope for the cm/m band, built to further the understanding of the most important phenomena in the Universe. The SKA is now making the transition from an early formative stage to a well-defined design. This paper briefly sketches the technical aspects of the SKA telescope system, showing the flow from antennas to images and other scientifically useful outputs.

The scientific importance of the Square Kilometre Array (SKA), as the next-generation radio telescope for cm/m wave astronomy, is well understood. Its science programme is a combination of unique science, that only radio astronomy can provide, and complementary science, supporting telescopes operating in other parts of the electromagnetic spectrum.

To achieve the transformational goals of the science program, especially those related to early Universe studies, the SKA will have to be much more sensitive than the current generation of radio telescopes. A more complete description is provided in Dewdney et al. 2009[1]. In brief it will:

- have up to 1 million m² of antenna collecting area distributed in an array configuration more than 3000 km in extent;
- operate at frequencies from 70 MHz to 10 GHz utilizing two or more detector technologies;
- provide high-resolution spectral line “cubes”, high dynamic range images, pulsar search and timing capabilities, and transient detection.

The telescope will have approximately fifty times the sensitivity of world best radio interferometers, and up to a million times survey speed (capability of mapping a large area of sky to a minimum flux level).

Figure 1 is a system diagram of the SKA, showing the main telescope components. An artists’ concept view of the antenna arrays is shown in Figure 2, and the configuration of the antenna arrays on the ground is shown in Figure 3. These three figures together illustrate the system from several perspectives:

- Several different antenna technologies are needed to cover the large range of frequencies needed for the SKA and to provide its high survey speed. The low and mid frequencies use aperture arrays, arrays of many small (wavelength-sized) antennas. The outputs of these antennas are connected to digital beamformers, which are capable of forming many beams on the sky at once. At
Figure 1: The SKA system block diagram.

The sparse aperture arrays (top pictorial) are shown as arrays of “droopy dipoles”, one for each polarization. The diagram shows a close-up of one of the stations and another station in the distance.

At higher frequencies (middle pictorial) the dense aperture arrays are closely packed elemental antennas arranged as “tiles”. As for the sparse aperture arrays, the arrays are arranged into stations.

The size of the dense aperture arrays stations has not been finally determined, but is likely to be ~60 m diameter.

The bottom pictorial shows an array of parabolic antennas (dishes). These will not be arranged into stations, except at baselines longer than ~180 km. The dishes can be equipped with either phased array feeds or wide-band single-pixel feeds, or both types. Each dish is ~15 m in diameter.

Figure 2: An artists’ concept of the SKA antenna technologies.
Figure 3: A representative array configuration for the inner part of the SKA.

the high frequencies, more traditional reflector antennas are used. At these frequencies, where the sky is very “cold”, cryogenically cooled receivers are used to reduce noise.

- The potential for high survey speed is enabled by wide-field technologies. Because they can form many beams at once, the aperture arrays are inherently capable of wide-field observations. A similar array technology, phased array feeds, can be used at the focus of dishes to increase their field-of-view by more than an order of magnitude.

- The array configuration (Figure 3) shows a dense “core” for each of the antenna technologies, merging into “spiral arms” at distances of about 10 km from the central area. The result is dense coverage of the synthetic aperture plane (u-v plane) near its center, and exponentially decreasing coverage with distance away from the core. This provides a “scale-free” array configuration, for which the point response function is approximately invariant with resolution.

- A very large network will be needed to connect the antennas to the signal processing facility (see Figure 1), which will process signals for both imaging science, where correlation is needed, and non-imaging science, where time-domain signals such as pulsars will be processed.

- The science computing facility (Figure 1) is expected to be a super-computer, which will not be located on the SKA site, but rather in a large city several hundred kilometers from the signal processing facility.

- Data products (images, pulsar data, source catalogues, etc) will be sent over
Figure 4: A representative signal path for the dish array.

global networks to regional science centers. This will enable people located anywhere to use the telescope and obtain their science results.

Figure 4 illustrates the components of the signal path for the dish array. Under each block in Figure 4 is a list of devices or design areas. These represent opportunities at the technical and engineering level for international astronomy organizations to contribute to the SKA system.

Update: The SKA system design is being coordinated by the SKA Program Development Office (SPDO), currently located in the UK at the University of Manchester. The SPDO and collaborators recently completed a Concept Design Review at the SKA system level. Plans are now being made to proceed to the next phase of the project. Similar concept reviews are planned for each of the major sub-systems, which are themselves very large projects. This work is enabled by a large global group of contributing organizations, which are involved in R&D, design and evaluation.

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References

The Status of the SKA Industry Japan Forum

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Abstract

As the Japanese SKA industry consortium, the SKAIJ (SKA Industry Japan) kicked off the industry meeting call for NAOJ and Japan SKA consortium on September 2009. The 9 companies came together to the consortium and began to discuss the contribution to SKA program.

1 Introduction

The SKA industrial consortiums are starting up activity in the SKA program in the world. It was kicked off in calling from NAOJ and Japan SKA consortium in September, 2009 the activity of the industrial consortium in Japan, and the SKA Industry Japan (SKAIJ) started in December, 2009. Nine excellent enterprise companies of Japan were concentrated in July, 2010, and the contribution of Japan and the examination of the system that was able to achieve it began. The main activity with SKAIJ has the following;

- Exchange latest technologies
- Dispute the sub-system specifications with the Japan SKA Consortium
- Experimental trial and evaluation of the system performance

We have held the meeting once every 1.5 months. Each SKAIJ participating company is doing the experimental tests and the verifications.

We aim at the development of the sub-system cover from mid-frequency-band to high-band from the proposal from NAOJ and Japan SKA consortium and our knowledge / the experiences. We are developing a new technology that doesn’t use the down converter from mid-band to high-band from an existing technology that uses the down converter. We propose the wideband direct sampling digital receiver and feed from mid-band to high-band. We were able to call the technology “Wideband Homodyne Frontend”, and to have foreseen the proposed the sub-system that digitalizes data within the 3–20 GHz frequency range.

As the key future ;

- Frequency coverage
  - SKA mid-band to SKA semi-high-band feed
  - 3–20 GHz → Goal for decade band!
Figure 1: Potential sub-system: It becomes the sub-system of the wideband direct sampling digital receiver and feed in 2–10 GHz. The two signals of orthogonal linear polarizations is sampled at high speed digital data.

- Integrated receiver
  - Low power and cooling wide band LNA
  - High frequency and wide band ADC
- Ultra high speed gigabit data transmission
- Digital beam forming
  - 100 instantaneous beams and 2 polarizations

2 Proposal from SKAIJ

In our existing technology, the sub-system that we proposed can receive the two signals of orthogonal linear polarizations and be sampled directly by the bandwidth of 4 GHz. The sub-system is located in the prime focus or Cassegrain/Gregorian structure of the individual dish antennas. Fig 1 is a block diagram of the potential sub-system that can be achieved by our existing technologies. The main performance of the potential sub-system:

- 2–10 GHz Wideband Single Pixel Feed (Orthogonal 2 linear polarizations)
- Tsys = 100 K cooling receiver
- 8 Gbps ultra high speed A/D sampler
- 10GbE data transmission

Our new developments and future directions has the following item, and we try to examine the challenging sub-system proposes to the SKA program shown in Fig 2.

The main performance of the challenging sub-system:

- SKA semi-high-band feeds → Phased array
Figure 2: Challenging sub-system: It will become the sub-system of the wide-band direct sampling digital receiver and feed in 3–20 GHz. The phased array with the two signals of orthogonal linear polarizations is sampled at high speed digital data.

- 3–20 GHz
- 100 instantaneous beams × 2 polarizations

- LNA with Cryogenic cooling
  - Low power consumption
  - Cryogenic cooling

- Whole analog section or individual LNA
  - Wideband

- A/D converter
  - Analog frequency: ~20 GHz
  - Sampling rate: ~16 Gbps / 3 bits

3 Experimental test and verification

The experimental tests and the verifications that we executed have the following.

- Ultra high speed InP HBT 3bit sampler
- Trial model of wideband feed
- Trial model of A/D converter package
As for us SKAIJ, the challenge to advanced sub-system will be enforceable by these results of the experiment.

As for these experimental tests and verifications, the Advanced Instrumentation Program decision in 2016 is scheduled that it completes, and the result is announced in a lot of workshops.

4 Conclusion

The goal at which we SKAIJ aim is as follows:

- Frequency coverage
  - RF band : 3–20 GHz
  - Bandwidth : 8 GHz (16 Gbps nyquist)
- Phased array feed per antenna
  - Number of beams : 100 instantaneous beams
  - Polarization : Horizontal and Vertical
- Low noise amplifiers
  - Amplifier noise temperature : $T_{sys} = 30\text{ K}$
  - Cooling temperature : $20\text{ K}$ cooling
  - Number of LNAs : 200 ea. per antenna

We expect that some improvements are generated by many experimental tests and the verifications in the future.

A lot of discussions of NAOJ and Japan SKA consortium will be done, and we think and verify the contribution of Japan of the best. We come into international events to get development status and new technologies, and we come out with the development status and test results.
Engaging Industry with the SKA: the Australian ASKAP Experience

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Abstract
CSIRO Astronomy and Space Science has developed a policy to engage industry to deliver components of ASKAP and develop technologies for SKA. There are 3 broad modes of industry engagement within the ASKAP Theme - (i) as suppliers, (ii) R&D partners and (iii) to provide an external industry voice to Government for on-going support of all Australian and New-Zealand SKA effort (anzeka [1]). This paper describes some of our strategies, successes and lessons learnt.

1 Introduction

Major scientific endeavors excite industry as they provide ‘grand challenges’ and visibility to a range of industry sectors. Projects like the Australian SKA Pathfinder (ASKAP) (Bunton, these proceedings and DeBoer et al 2009[2]) and the SKA (Rawlings, these proceedings) must balance cost and risk whilst also maintaining realistic expectations with industry regarding SKA outcomes and future contract certainty.

The key challenge for radio astronomy is that its driving specifications are far removed from the core business of any single commercial industry. Communications, IT and defence can be considered ‘adjacent industries’ but notably all rely on mass production and/or significant investment in very early phase R&D to anchor risky technologies. The particular demands of radio astronomy (e.g. extreme dynamic range, sensitivity and astronomers’ willingness to adopt leading-edge, non-standard new technologies) can appear foreign to normal commercial concerns of cost control, reliability and operability.

To avoid cost-loading of technology risks into the project budget, projects like ASKAP are usually delivered and managed by a Government entity, where the risk is implicitly understood, if not explicitly funded. Two of many options for SKA are that it may choose to follow a similar path to ASKAP or could contract to a single ‘system integrator’ company; if the second option is adopted the company will necessarily front-load the risk costs to the project and then rigorously manage them to deliver strictly to contract.
2 ASKAP industry strategy

The ASKAP project commenced its industry engagement strategy with the 'SKA Technologies Roadmap' which set out options for each sub-system of an SKA pathfinder, assessed the technology maturity and presented an outline plan for how each of these would be delivered. The last part is particularly important for industry relations as ASKAP’s core technology - the phased array feed (PAF) - is designed, developed and tested in-house. The Roadmap clearly stated CSIRO’s intention to deliver ASKAP such that there was no overall ‘system integrator’ contract available to industry.

The Roadmap has since evolved into the 'Industry Opportunities Register' (IOR) which is freely available on-line and updated regularly. The IOR enables business to identify opportunities and plan for their potential involvement. IORs are common for large Government defence-type systems to provide an overview of project status, particularly to provide information on the major upcoming procurement and/or R&D opportunities.

3 The Australiasian SKA Industry Consortium

The Australiasian SKA Industry Consortium (ASKAIC) is a self-funding body comprising a number of major system integrator companies, many of which are multi-nationals, industry associations and Government agencies who have an agreed common goal to promote the Australian-New Zealand SKA effort over the long term (ASKAIC [4]). ASKAIC members pay an annual subscription to fund its activities, promote and part-fund national and international SKA events and support a professional chair-convener.

The ASKAIC group meets at least four times per year around Australia and New Zealand. ASKAIC members support and facilitate engagement by all Australian-based companies - large and small - with SKA-related efforts through their own networks of suppliers. ASKAIC provides a forum for direct contact with the ‘active’ SKA-related projects like ASKAP as well as opportunities to provide tactical industry-focused advice to Government, particularly regarding SKA procurement, IP management and organizational options in an trusted and informed manner.

Individual company members of ASKAIC have provided valuable advice to ASKAP, particularly regarding best-practice for management of complex projects, system integration and system engineering. The relationship between ASKAIC and the ASKAP project has matured so that communications are regular and at a level of usefulness. ASKAP conveys key updates to industry stakeholders via the quarterly ASKAP Technical Update and industry e-news alerts (see www.ska.gov.au/industry).

4 ASKAP experience - procurements

Early in the ASKAP project time line it was established that ASKAP would offer full, fair and internationally-open opportunities for all of its major procurements. The proposed procurements are described in the IOR and a companion 'Australian Industry Participation Plan' sets out how Australian-based compa-
nies will be fairly treated within the international tender processes to supply goods and services to ASKAP.

One of the largest single contracts for ASKAP is the antenna contract. The project team spent more than 2 years talking with commercial antenna vendors in the SATCOM business to obtain background information on antenna design options, manufacturing techniques and likely cost of 12-m class X-band (10 GHz) antennas. These early discussions recognized ASKAP’s requirement to buy antennas which were close to ‘off-the-shelf’ designs; unusual or non-standard antennas would be costly both in time and budget - both of which are highly constrained for ASKAP.

A full and open international tender process was concluded during the first half of 2009, with the 54th Research Institute of the China Electronics Technology Group (CETC54) winning the contract to design and deliver 36 ASKAP antennas. The ASKAP antennas are about 85% of a CETC54 standard antenna design and 15% bespoke. The bespoke aspects of the antenna are the third axis, termed the ‘polarisation axis’ to rotate the entire dish structure (and hence stabilise the sidelobe response) and maintain a constant parallactic angle at the PAF, and the requirement for RFI-quiet control systems components. The first antenna was delivered in January 2010 and a further five have been built at the new ASKAP site during October 2010. The remaining thirty ASKAP dishes will be built on site during 2011 and at this stage all is on schedule and budget.

The ASKAP antenna contract is an excellent example of how radio astronomy can buy value-for-money infrastructure from companies like CETC54 who have proven product lines and ability to deliver. The key lesson from this procurement was the necessity for an experienced and professional team to lead the entire tender process, including the derivation of the detailed technical specification, design and build statements of work and the tender contract well ahead of the open tender process. The relationship between CSIRO and CETC54 is excellent and highly productive, and one which is actively maintained by both parties.

5 ASKAP experience - R&D

ASKAP is designed to exploit a novel phased array feed (PAF) receiver system to provide a wide field of view radio telescope. ASKAP’s front-end receiver systems are being built from discrete components to allow absolute flexibility in their performance characteristics and also allow the PAF to be built within the ASKAP delivery timescale.

There is a potential, and very attractive, design improvement for both PAF and aperture array receivers for SKA in the form of highly-integrated ‘system on chip’ (SOC) components to replace complex and large-sized discrete systems. A proof-of-concept SOC was developed in-house at CSIRO (Jackson et al 2010 [3]), and based on this promising research we have entered into a joint R&D project with Silanna (formerly Saphicon Semiconductor), a privately-owned Australian CMOS design and fabrication company, to develop a low-cost, highly integrated SOC with SKA-like performance. It is planned that this R&D will demonstrate SKA-like performance mid-2012 in an ASKAP type PAF, although the chip itself is not critical to the delivery of ASKAP.
This is an example of successful industry engagement for SKA through collaboration. We attribute its ongoing success to a number of factors: (1) an earlier small-scale R&D project established the relationship between CSIRO and Silanna, and built trust between the parties, (2) The R&D detailed technical specification was agreed early on and the total work package scoped, (3) the expert engineers met upfront to avoid endless discussions on 'what we might do' and (4) that we have maintained honest dialogue of where this technology may fit regarding SKA: expectations from both sides are realistic.

6 ASKAP experience - lessons and the SKA

As ASKAP is a live project, maintaining its successful track-record of industry engagement is an on-going task. Many of the ASKAP project team have had to gain new skills and adapt to the required level of rigour when dealing with industry. Rigour is required both to ensure that we provide documented, traceable and detailed technical briefs in a timely manner, as well as ensuring that full and fair approaches to market are made in a way which meet all legal and probity concerns.

The ASKAP industry engagement activities continue to require an investment of time and resources to deliver to time and budget. Moreover, pre-dating ASKAP itself, between 2005 and 2007 a small CSIRO engineering team toured Australia presenting 10 half-day workshops on potential SKA technologies to inform a wide industry base. These workshops were open to all and free to attend. Each separate workshop attracted an audience of around 100 attendees, and the participants continue to receive updates from the project. The events identified a number of companies with SKA-related capabilities and established some short, very early-phase collaborations on SKA-related R&D which subsequently benefited the ASKAP project itself.

Radio astronomy projects like ASKAP have to continually resist the temptation to believe it might be 'easier to do it all in house' rather than invest in meaningful industry engagement: As can be seen from the ASKAP experience, we can show that done successfully, it provides significant benefit to the project and some lessons for the much larger SKA project.

References

Variable-Step Frequency Integration in the
Decade/Century-Band Imaging

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Abstract

In decade/century-band imaging, we have a problem in the frequency integration. In order to minimize this problem, variable-step frequency integration $\Delta\nu \propto 1/\nu$ is proposed, where $\Delta\nu$ is the integration step, $\nu$ is the frequency. From a simple simulation, synthesized beams and images of the variable-step frequency integration become more sharp than those of constant-step frequency integration.

1 Introduction

Frequency integrations are very important. In order to detect faint continuum sources, we need frequency integrations. Frequency integrations are important in the data reduction because they save the computer resources, such as hard disks and CPU time. We should integrate data in the frequency domain as much as possible.

In the synthesis imagings, source images are the Fourier transforms of visibilities, which is the observables on the uv plane. Fourier transforms are linear, so we can integrate data both image and visibility domains. In current analyses, the frequency integrations are carried out by averaging all frequency points of each time and each baseline.

However, in the decade/century-band imaging, the loci on the uv plane is so wide. The values of $u$ and $v$ are the projected components of baseline vector divided by the observing wavelengths. Even at a time and for a baseline, $u$ and $v$ varies with observing frequencies. In the case of decade/century-band observations, the $u$ and $v$ at the lowest frequency can be ten/hundred times as large as those at the highest frequency. We can no more integrate the frequency points with the current method. Decade/century-band imagings limit the range of frequency integrations.

2 Variable-Step Frequency Integration

Here, I propose the variable frequency integration step $\Delta\nu$ which is inversely proportional to the frequency $\nu$. That is, $\Delta\nu \propto 1/\nu$.

In the imaging process, we normally carry out the gridding of data in order to use the Fast Fourier Transform (FFT). FFT requires that the data must be assigned to a regular, rectangular matrix. If the integrated points spaced with the constant separations on the uv plane, the effects of frequency integration becomes small.

$(u, v)$ change with the earth's spin. The loci are ellipses if we can observe the source for twenty-four hours. The length of these ellipses for two frequencies $\nu_1$
and $\nu_2$ have the ratio of $\nu_1 : \nu_2$. When the width of these two frequencies are $\Delta \nu_1$ and $\Delta \nu_2$, the areas of these two loci on $uv$ plane have the ratio of $\nu_1 \Delta \nu_1 : \nu_2 \Delta \nu_2$. Thus, when we carry out the frequency integration as $\nu \Delta \nu = \text{constant}$, that is, $\Delta \nu \propto 1/\nu$, the distribution of integrated points becomes more uniform, so the resultant image becomes more sharp, comparing with the case of the uniform-step frequency integration.

3 Simple Simulation

I carried out a very simple simulation to evaluate my variable-step frequency integration. Figure 1 shows the array configuration for this simulation. Observing frequency is 1–10 GHz, duration is 10 hour, and the time intervals of correlator outputs is 48 seconds. Simulations were done for two frequency integration methods, the constant-step integration and the variable-step integration. The sampled points of these integrations are shown in Figure 2. In the constant-step integration, $\Delta \nu = 0.5$ GHz. In the variable-step integration, $\nu_{n+1} = (2.3/\nu_n) + \nu_n$, where $\nu_n$ is the nth sampled point. This means $\Delta \nu = 2.3/\nu$.

Figure 3 shows the $uv$ coverages and synthesized beams of this configuration. When we compare the $uv$ coverages for all baselines (c and d), the visibility points of the variable-step frequency integration (d) distribute wider and more uniform than those of the uniform-step frequency integration (c). When we sample these points with $1024 \times 1024 = 1048576$ grids, 462382 grids (44%) are sampled in the case of constant-step frequency integration while 758383 grids (72%) are sampled in the case of variable-step frequency integration. When we compare synthesized beams (c and f), the main beam of variable-step frequency integration becomes narrower than that of the constant-step frequency integration because we sample many points at distant area on $uv$ plane in the case of variable-step frequency integration. The first sidelobe of variable-step frequency integration is slightly higher than that of constant-step frequency integration because the number of visibilities drops rapidly at the edge of visibility distribution in the case of variable-step frequency integration.

Figure 4 shows the models and the resultant images of simulations.
Figure 2: Sampled points of frequency integrations for the simulation. The simulated integrations are two, constant-step integration of $\Delta \nu = 0.5$ GHz (above) and the variable-step integration of $\nu_{n+1} = (2.3/\nu_n) + \nu_n$, where $\nu_n$ is the $n$th sampled point (below).

Figure 3: (a, b) uv coverages for one baseline. (c, d) uv coverages for all baselines. (e, f) Normalized synthesized beam. (a, c, e) are those of the uniform-step frequency integration. (b, d, f) are those of the variable-step frequency integration.
Figure 4: Simple simulation. (b) and (c) are the resultant images with constant-step and variable-step frequency integrations of the model image shown at (a), respectively. (e) and (f) are also the resultant images of the model image shown at (d). The flux scale of the resultant images (b, c, e and f) are not normalized.

This simulation was done in the following procedure: (1) Making model visibilities with Fourier transform of model image. (2) For the grids covered by $(u, v)$ loci, the visibility values are remained. Otherwise, visibility values set to zero. (3) Getting the resultant (observed) images by inverse Fourier transform of these visibilities. The model and resultant images have $1024 \times 1024$ pixels, but Figure 4 shows a part of whole image.

When we compare (a), (b) and (c) of Figure 4, we can see the difference of sidelobes. In the case of constant-step integration (b), we can see dark belt from the top-left to the below-right of the source. We can not see it in (a) and (c). From (d), (e) and (f), we can find the image is sharp in the case of variable-step frequency integration (f) comparing with the constant-step case (e).

4 Summary

The new type of frequency integration is proposed for decade/century-band imaging. Its frequency steps $\Delta \nu$ are set as $\Delta \nu \propto 1/\nu$. From the simple simulation, we have found that the sampled points of variable-step frequency integration distribute more uniformly on $uv$ plane than those of constant-step integration, and that the synthesized beams and images of variable-step integration become more sharp than those of constant-step integration.
Astrometry from VERA to SKA

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Abstract

Here we summarize the progress of current VLBI astrometric projects such as those conducted with VERA, EVN, and VLBA and discuss possible feasibility of and expectation to astrometry with SKA, capable of a wide band receiving system and a wide field-of-view. We also list the challenging issues towards SKA on the basis of our current experiences.

1 Introduction — Current VLBI Astrometry —

10 \mu as-level astrometry is achievable with the current VLBI arrays such as the VLBI Exploration of Radio Astrometry (VERA), the Very Long Baseline Array (VLBA), the European VLBI Network (EVN), and the Australia's Long Baseline Array (LBA). OH, H$_2$O, CH$_3$OH, SiO masers as well as non-thermal continuum emission. These astrometric observations enable to measure trigonometric parallaxes and to directly determine source distances as far as \sim 10 kpc with accuracies empirically of \sim 3D[kpc]$^{\alpha}$ % (\alpha \sim 0.8). Some of the astrometric results are summarized in the paper \cite{5}. The VERA team has established key projects to conduct the astrometry towards \sim 500 H$_2$O maser sources. The National Radio Astronomy Observatory (NRAO) accepted several large astrometric VLBA projects such as BeSSeL (Bar and Spiral Structure Legacy Survey), Gould's Belt Survey, and PSRPI (Pulsar \pi Program). These projects can measure trigonometric parallaxes of \sim 2000 Galactic sources, in total, harboring H$_2$O, CH$_3$OH masers, non-thermal sources associated with young stellar objects and pulsars. Including other astrometric VLBI projects, a large variety of compact radio sources should become the astrometric targets, enable to map the structure of the Milky Way Galaxy and to contribute to understanding important issues in astrophysics such as cosmology and extrasolar planet search as well as stellar evolution.

However, the efficiency of the astrometry and the number of the astrometric targets are still limited. For example, VERA can perform high precision astrometry for source pairs with a separation of 0\degree.5–2\degree.2. In order to increase
Table 1: Specification of current VLBI array and the SKA expectation.

<table>
<thead>
<tr>
<th></th>
<th>VERA</th>
<th>VLBA</th>
<th>SKA (expectation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dishes [m]</td>
<td>4×20</td>
<td>10×25</td>
<td>5000×15×4</td>
</tr>
<tr>
<td>Total aperture [m²]</td>
<td>630³</td>
<td>2950³</td>
<td>500 000⁴</td>
</tr>
<tr>
<td>Baseline SEFD [Jy]</td>
<td>1760</td>
<td>500</td>
<td>940⁵, 17⁶</td>
</tr>
<tr>
<td>Baseline SEFD [Jy]</td>
<td>250⁸</td>
<td>130⁸</td>
<td>2.4⁹, 0.34¹⁰⁵</td>
</tr>
<tr>
<td>Baseline length [km]</td>
<td>2 300</td>
<td>8 600</td>
<td>~3 000</td>
</tr>
<tr>
<td>Number of baselines</td>
<td>6</td>
<td>45</td>
<td>50¹¹, 600¹²</td>
</tr>
<tr>
<td>Maser astrometry [µas]</td>
<td>~20 (~10)</td>
<td>~20 (~1)</td>
<td>~10 (~0.02)</td>
</tr>
<tr>
<td>Continuum astrometry [µas]</td>
<td>~20 (~70)</td>
<td>~20 (~5)</td>
<td>~10 (~0.025)</td>
</tr>
<tr>
<td>Bandwidth [GHz]</td>
<td>0.256</td>
<td>0.512</td>
<td>8.0</td>
</tr>
</tbody>
</table>

¹Assuming an 1° field-of-view, an effective aperture of 100 m² at 1 GHz.
²Total effective aperture. ³At the 22 GHz band.
⁴At the 10 GHz band. Assuming 50% available effective collecting area.
⁵For an element antenna pair. ⁶For a station pair.
⁷With a larger telescope or "core" in SKA. ⁸For baseline with GBT.
⁹For an element antenna–core baseline. ¹⁰For a station–core baseline.
¹¹Only core–stations. ¹²Among stations.
¹³The accuracy is empirically valid for the source with a flux density shown in the brackets (in Jy).
¹⁴The accuracy is empirically valid for the source with a flux density shown in the brackets (in mJy).
¹⁵Bandwidth for astrometry.

The number of astrometric targets, higher sensitivity by increasing a signal receiving bandwidth is required, but invalid for line spectrum sources such as masers. A larger aperture achieved with SKA is an ultimate approach. Note that the super-synthesis using Earth’s rotation gives constraint on astrometric efficiency. Multi-element VLBI facilities larger than VLBA is also required.

2 Possible Astrometry with SKA

Table 1 summarizes the accuracy of current VLBI astrometry and that expected in SKA astrometry. The latter is calculated on the basis of announced specification of SKA, i.e., 15-m dish antennas, 50% effective collecting area in the central “core”, and a possible bandwidth of 8 GHz. Because the sources with a flux density 1–2 orders of magnitude lower become the astrometric targets and wide fields of view ~1° are valid thanks to lower frequency bands, the number of the future astrometric targets will dramatically increases. Taking into account these consideration, the following directions are expected in the future astrometry with SKA.

- Astrometry for thermal sources
  Thermal continuum emission from high brightness stars such as OB stars
(T_b ≥ 10^5 K) may be detectable with SKA, enabling to conduct 10 μas-level astrometry and measurement of trigonometric parallaxes of these stars. Even for lower brightness stars such as M-type red giants, 10 μas-level astrometry may be possible. The latter astrometry enables to determine only proper motions of the stars, but their maser emission still enable to measure the trigonometric parallaxes. It is also important because they are widely distributed in the whole Galaxy, including the Galactic plane with heavy interstellar extinction and the Galactic halo.

- Wide-field astrometry
  High accuracy astrometry in in-beam, multi-beam observations is more frequently possible. Figure 1 shows the histogram of reference source candidate at the 8-GHz band. From the slope of histogram at 100 mJy ≤ S_ν ≤ 3 Jy, it is expected that there are ~30 000 reference sources with a flux density higher than 1 mJy. In such a case, every target source for astrometry has at least one reference source within 0°.7 from the target. In the case of wide-field astrometry, multi-field delay tracking in correlation should be possible. Actually the DiFX software correlator installed in LBA and VLBA may be the prototype of this capability. Wide-field capability in astrometry is quite important to compensate the limited number of astrometric targets when taking into account the massive optical astrometry via GAIA. Furthermore, it should enable to conduct projects similar to "blind" surveys that monitor positions of many radio sources in order to detect "micro-lensing" events (10⁻³ stars in 10 μas level towards LMC, [4]). Astrometry towards high galactic latitude (|b| > 10°) and the Galactic bulge and halo may be possible.

- Deep space astrometry
  The main targets of radio astrometry are within the Milky Way Galaxy. Sources in the Magellanic Clouds (LMC, SMC) should also be the targets with SKA. The annual parallax (π ≃ 20 μas) should be detectable with the combination of SKA’s high sensitivity and high angular resolution achieved in the Earth-scale or space VLBI. Proper motions of galaxies in the Local Group (D ≤ 10 Mpc) in a level of 10 μas yr⁻¹ are also detectable, dependent on available time baseline (≤10 yr). Compact radio emission from the central massive blackholes should be the position references of the galaxies.

- Astrometry for transient objects
  Thanks to multiple elements (≥50) and wide fields of view, quick mapping and astrometry of transient objects are possible soon after the alert without super-synthesis using the Earth’s rotation. Taking into account the importance of astrometry for source identification and the requirement of milliarcsecond-level astrometry for distant sources such as γ-ray bursts, the snapshot capability with SKA is quite unique. SETI should consider every time this kind of quick astrometry for true identification of the origin of ETI signal.
3 Challenging issues towards SKA

3.1 Data calibration and processing

Wide-angle astrometry is popular in an optical astrometric missions using a spacecraft such as HIPPARCOS. This is necessary to obtain high astrometric accuracy with maintaining the optical reference frame against its secular deformation. On the other hand, in grand-based astrometry, the atmospheric refraction makes the wide-angle astrometry difficult. However, such refraction should be measured and calibrated. If many reference sources are almost simultaneously observed, the atmospheric refraction can be precisely measured within a short time (<1 min) and subtracted from the raw data. Thus SKA astrometry should include such calibration scans.

At the same time, maintenance of radio reference frame (i.e., ICRF) should be regularly organized. The International VLBI Service (IVS) has conducted such systematic activity. The SKA stations also should join this activity. Many reference source candidates nearby the Galactic plane will be detected and compensate a large sky void in ICRF. However, their true properties (QSO?) should be identified in e.g., follow-up astrometry.

Furthermore, wide-field astrometry will create a huge size of image cubes and require a massive space in the computer hard disk. For example, multiscale gridding in the image cube synthesis should be taken into account. The development of automatic data processing pipeline for astrometry is quite crucial. In order to save the computer disk space, efficient processing in data correlation should be planned.
3.2 Construction and operation of high angular resolution network with SKA

SKA alone (≤3000 km) will have the angular resolution comparable or poor than that of VERA. In this situation, many radio sources with complicated, time-variable structures are unresolved, causing limited astrometric accuracy. A "global array" achieved with SKA and current VLBI array (VLBA, EVN, EAVN, APT) will provide higher angular resolution. However, the efficiency of astrometry may be significantly reduced because this array still needs the super-synthesis using the Earth's rotation unless enough large number of telescopes can participate the section astrometry at the same time. This may be difficult due to the geometrical reason. Operations of radio antennas on spacecrafts with SKA may compensate such a situation. Although the size of space antennas may be quite limited (≤20 m), a large aperture of SKA station can compensate the array sensitivity and enable to conduct astrometry towards extragalaxies including the Magellanic Clouds for which it is difficult with the current VLBI network. At moment, possible potential in astrometry in higher angular resolution should be further discussed and demonstrated.

3.3 Number of target sources after GAIA era

The size of target source number for SKA astrometry could be discussed from the view of scientific impact and the contributions from optical/infrared astrometric mission in the near future as follows.

- GAIA(2012~)[1]: \( \sigma \sim 24 \, \mu \text{as} \) for \( V < 15 \, \text{mag}, 10^8 \) stars
- SIM[6]\footnote{Recently it was announced that the SIM project is cancelled. See \url{http://planetquest.jpl.nasa.gov/SIM/projectNews}.}: \( \sigma \sim 4 \, \mu \text{as} \) in all sky, \( > 10^4 \) stars
- JASMIN(2020~)[3]: \( \sigma \sim 10 \, \mu \text{as} \) for \( K_W < 11 \, \text{mag}, \sim 10^5 \) stars

Even taking into account the transparent sky in radio emission, in which SKA can see radio sources beyond the Galactic center, \( \sim 10^5 \) sources, two orders of magnitude larger number than that in the whole current astrometric projects, should be the targets in SKA era. During 20 year operation, each source should be scanned, e.g., 5 times within \( \sim 2 \) years for measurement of its trigonometric parallax. Approximately 10 000 sources should be monitored every year, which requests astrometric measurements for \( \sim 100 \) sources everyday. This number may be still realistic if SKA is available for astrometry for 1 hour almost everyday and several sources can be scanned for 1-2 min at the same time.

4 What can we learn from SKA astrometry

It has been long discussed the importance of radio astrometry mainly for the following issues.
• The three-dimensional visualization of the distributions of stars, interstellar gas clumps, and galaxies, including exodic objects.

• The history of the Universe probed by these movements in the whole sky.

However, at microarcsecond-level astrometry, we will definitely meet the difficulty of accurate time-space measurements due to the intrinsic variations in source structures and the general relativistic effects such as gravitational lenses. In the current astrometry, they have been thought as errors in astrometry because of their unknown/unpredictable properties. In SKA era, they should be deeply studied and used for new probes to understand the Universe.

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[1] URL: http://www.esa.int/esaSC/120377_index_0_m.html


Pulsar study using the SKA

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Abstract
Pulsar is one of the important radio target sources of SKA. We can newly discover more than ten thousands pulsars which may cover the galactic plane. Collaboration with VLBI antennas in the world will produce many accurate trigonometric parallaxes and proper motions of these pulsars. The results may realize three dimensional distribution of pulsars and density distribution of interstellar medium in our Galaxy. Observations of shifts of pulsar timing may indicate exact evidence of propagation of gravitation wave.

1 Introduction
Pulsars are one of the important subjects which will be dramatically improved by SKA. In Japan, large number of radio astronomers are interested in higher radio frequency because of activity of Nobeyama 45m telescope and ALMA, but there are many astronomers who study pulsars in lower radio frequency. Pulsars are very important sources since its discovery in 1967 because it in the extreme strong physical conditions. Magnetic field is $10^8$–$10^{14}$ Gauss, the surface gravitation of them is $10^9$ times stronger than that of the earth. The voltage difference in magnetosphere is $10^{12}$ volts. When it rotates, two radiation beams appear in the strong magnetosphere. We can detect pulses when the beams come to us. Distribution of the period of pulsars shows that the period is between 0.1 sec and 3 sec, and some are between 0.001sec and 0.01 sec which are called millisecond pulsars. Dispersion in pulse arrival time exists along frequency and we can measure the dispersion measure from the phase delay along frequency (e.g. [1]). The schematic of period and period derivative or p dot shows that we can derive some time scale on pulsars from the ratio of period to p dot. It may reflect some period of activity continues. It is between one thousand years to several ten million years. And from period and period derivative, magnetic fields of pulsars are estimated. One Giga Gauss to $10^{14}$ Gauss (e.g. [1]). The distribution of pulsars on the galactic plane is determined by dispersion measure of pulsars. Many pulsars are distributed on the galactic plane (e.g. [2]). This is similar to that of water masers calculated by line of sight velocities and Galactic longitudes of them. The current sample of all known radio pulsars projected on to the galactic plane. There is a hint that pulsars are along the Galactic arms. However, number of pulsars is only several thousands, so pulsar survey itself
Figure 1: Position of pulsars and the mean values of electric density between the pulsars and the earth on the galactic plane [3]. Straight lines indicate a possible position of the arms which are added by Kameya.
is still very important in order to find enough sample of them to cover whole Galactic plane.

2 Recent research in pulsars

Because pulsar pulse is very stable, pulsar timing observations can derive interstellar scintillation between pulsars and the earth. Giant pulse for several ten sources are interesting for understand pulsar physical model. Astrometry by using VLBI is also important. Distribution of electron density in our Galaxy can be derived by the measurements of distance of pulsars. If the distance of pulsars is known, we can estimate interstellar ionized- gas density by using distant measure. Similarly, rotation measure can be derived by observations of pulsars. interstellar magnetic field strength along the line of sight can be measured by the ratio of rotation measure and distant measure.

Figure 1 shows an example of the position of pulsars based on the parallax measurement of pulsars by early work of Braken et al. [3]. Mean values of electron density of interstellar medium between the pulsars and the earth are calculated by distance measure and trigonometric distance of the pulsars.

Figure 2 indicates results of electron density distribution for recent all data. It seems that there are positions of high electric density (ne ≥ 0.02 cm−3) along the local arm, and three in the Perseus arm. The high electric density may have relationship between activities of star formation in arms: III regions and supernova remnants.
3 Scientific goals considering SKA with UWB

The future SKA observations of pulsars using ultra wide band receiving system are very important for next research in pulsars because of very high sensitivity. Unbiased pulsar survey for our Galaxy will discover more than 100000 pulsars which would distribute whole galactic plane. It is possible that many pulsars are found in globular clusters and some in extra galaxies. And some of the others would be some exotic sources. Pulsar timing observations are important for SKA for detection of gravitational wave etc. It might be a very important technique for future gravitational wave astronomy. VLBI with SKA telescopes in the world (Japan also) can derive proper motions and parallaxes of pulsars. Especially, interesting scientific targets are transverse velocity of pulsars in whole out galaxy. It would derive distribution of electric density and B everywhere in our Galaxy. Distance and proper motion measurements towards pulsars in globular clusters and in extra galaxies are also important to understand distance of globular clusters and extra galaxies and electric densities between them and the earth.

4 Summary

- SKA can discover pulsars whole in our Galaxy and may find some in extra-galaxies.
- SKA with UWB increases dramatically number of pulsars.
- Determination of distances of pulsars improve theoretical model of pulsars, density distribution of interstellar ionized gas.
- Pulsar timing observations are important for detection of gravitational wave etc.

This talk is based on the support of the Pulsar Sub Working Group.

References

Physics of the Formation and Evolution of Galaxies:
Report from the High-\textit{z} Working Group

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Abstract

We report the recent discussion in the SKA Japan high-\textit{z} working group. This time, we restricted our discussion to a frequency range of 1–15 GHz, which may be contributed from Japanese instrumentation group. Hence we first discuss plausible scientific topics of H$_2$O maser, NH$_3$ lines, HI line, CO lines, and the continuum radiation. Then, we move on to a subject of 21-cm line tomography, featuring the exploration of the non-Gaussianity of the initial matter distribution in the Universe.

1 Overview of the Working Group

The SKA Japan high-\textit{z} working group consists of twenty-two members (in the mailing list), from graduate students to senior researchers with wide range of expertise. The representative of the group is Hiroyuki HIRASHITA (ASIAA, Taiwan), and the core members are Tsutomu T. TAKEUCHI (Nagoya Univ.), Daisuke IONO (NAOJ), and Shinki OYABU (Nagoya Univ.).

The high-\textit{z} working group is open to anyone. If you would like to participate in this working group, we would kindly ask you to contact any of the core members.

2 Galaxy Evolution with a Wideband Receiver at 1–15 GHz

2.1 Possible Observations

In this section, we concentrate on a frequency range of 1–15 GHz, possibly contributed from Japanese instrumentation. In this frequency range, the following scientific themes are plausible: 1) H$_2$O maser: 22 GHz (\textit{z} > 0.5), 2) NH$_3$ lines: 23.7 GHz (\textit{z} > 0.5), 3) HI emission line: 1.4 GHz (\textit{z} < 0.4), 4) CO absorption lines: \textit{z} > 6.7, and 5) Continuum. Of course, under this restriction, some other possible important themes for lower frequencies are missing, e.g., the redshifted HI line [1.4/(1 + \textit{z}) GHz] for cosmology. We will discuss this topic in Section 3.

H$_2$O maser (22 GHz; \textit{z} > 0.5). Up to now, two detections at \textit{z} > 0.5 have been reported: SDSS J08043+3607 (at \textit{z} = 0.66: Barvainis & Antonucci 2005) and MG J0414+0534 (at \textit{z} = 2.64: Violette Impellizzeri et al. 2008). The latter
is a gravitationally lensed quasar with a magnification factor of 35, and its lens-corrected line luminosity is $10^4 L_\odot$. The hydrogen molecular gas density and the temperature are estimated to be $n(H_2) > 10^3 \text{cm}^{-3}$ and $T > 300$ K. These imply that this is associated with AGN environments (accretion disk or AGN jets), hence this observation will be useful to explore the physics of AGN and its evolution.

**NH$_3$ lines (23.7 GHz; $z > 0.5$)** As for NH$_3$, since the emission line is very weak, absorption may be easier to observe. An example for the detection of absorption for a lensed quasar at $z = 0.9$ (Henkel et al. 2008). If we obtain the level population of various rotational states, we can trace the excitation temperature of the interstellar medium (ISM). This will be an interesting viable way to explore the state of the ISM in high-$z$ galaxies.

**HI emission (21 cm; $z < 0.4$)** Here we discuss the so-called baryonic Tully-Fisher relation (BTF). The usual TF relation has a systematic difference in its logarithmic slope and a significant dispersion, both caused by the recent star formation and dust. Especially, the TF relation seemed to break down at lowest luminosity end. However, McGaugh et al. (2000) discovered that if we use the baryonic mass (sum of gas and stellar masses), the linearity can be restored. The BTF is an important empirical relation connecting the halo (dynamical) mass and baryon content, and it is especially important for very late-type galaxies (HI-dominated in baryonic content). Some ongoing HI survey project has investigated the BTF (e.g., HIPASS: Meyer et al. 2008) and reported a steeper slope than luminosity TF, but this might be still too shallow. Further, some recent works showed a possible downward deviation from a single power law. In the “extended” BTF, the slope becomes steeper from the largest (clusters of galaxies) to the smallest structures (dwarf spheroidal galaxies) (McGaugh et al. 2010). A possible effect of feedback is implied from this result. However, gaseous dwarfs are missing on this plot, and we need to explore this relation more extensively toward lower HI masses.

**CO absorption lines: $z > 6.7$** If the CO molecular absorption lines are sufficiently redshifted, we will have them at the frequency range we consider here. We discuss such absorption line observation in $\gamma$-ray burst afterglows. This will be a promising probe of physical and chemical conditions in high-$z$ ISM. Inoue, Omukai, & Ciardi (2007) discussed this and found that it is quite feasible, since the 1–15 GHz continuum flux density will be 0.1–1 mJy at $t_{\text{obs}} \sim 10$ days for $z = 5$–30.

**Continuum** The synchrotron radiation from supernova remnants is tightly related to the star formation activity. Frequency $\nu > 15/(1 + z)$ GHz is favorable to avoid f-f absorption in dense ($> 10^3 \text{cm}^{-3}$) regions. Hirashita (2010) discussed the FIR-radio correlation and pointed out a potentially interesting area occupied only by very young galaxies.

### 2.2 Requirement for the Instruments

According to these topics, we consider the requirement for the instruments. The H$_2$O maser peak is 3 mJy at $z = 2.64$ with lensing factor 35. This requires 0.1 mJy without lensing at similar redshifts. The NH$_3$ detectability is determined by the continuum level and S/N. If we assume continuum $\sim 1$ Jy for quasars and S/N = 100, we need 10 mJy. The HI emission observation down to HI mass of $10^2 M_\odot$ (i.e., baryonic mass of dSph) gives a flux level of $50 (M/10^3 M_\odot) (\nu/10 \text{ km s}^{-1}) \mu\text{Jy}$ for extended galaxies at 3 Mpc. The radio SED models suggest that absorption with $\tau \sim 1$ in a GRB can be observed with a $\mu$Jy-level detection limit. Murphy (2009)
pointed out that the cosmic ray electrons lose energy through inverse Compton scattering of the CMB, and nonthermal continuum is strongly suppressed at high-z. Considering this effect, to detect moderate LIRGs at \( z = 4-10 \), the detection limit of 10 nJy is required.

We mention some merits of the wide frequency range at the end of this section. For lines, the wideband allows us to trace the evolution along redshifts, and to determine the excitation temperature and density (e.g., CO(1-0) and CO(2-1)). For continuum, the biggest merit would be that the instrument can receive a larger number of photons. However, we should not that a special imaging technique to deal with a large dynamic range should also be developed.

3 Exploring Non-Gaussianity in the Primordial Perturbation with 21-cm Line Tomography

We now change the topic to the 21-line cosmology. Through the observations of the CMB and the large-scale structure, we can explore the nature of primordial fluctuations, and further, the physics of the early Universe. The amplitude of the fluctuation gives the information on the energy scale of inflation, the scale-dependence can restrict the functional form of the potential of inflaton, and the statistical properties enables us to examine if the standard inflation scenario would be correct.

Current observations predict that the primordial fluctuation has almost Gaussian statistics as expected from the linear perturbation theory. However, now the primordial non-Gaussianity is hitting the limelight of cosmologists (Komatsu & Spergel 2001, and many others). Non-Gaussianity is a very broad category and until recently no systematic way to investigate it was known, in spite of enormous theoretical effort made in 90's. The situation has dramatically changed by the introduction of the nonlinearity parameter, \( f_{NL} \). The primordial perturbation \( \Phi \) is described as

\[
\Phi(x) = \Phi_{\text{Gauss}}(x) + f_{NL} \left[ \Phi_{\text{Gauss}}(x)^2 - \langle \Phi_{\text{Gauss}}(x) \rangle^2 \right].
\]  

(1)

Non-zero \( f_{NL} \) gives (i) higher order contribution in the power spectrum (2-point correlation function) and (ii) leading order contribution in the bispectrum (3-point correlation function). The current observational limit from WMAP 7-year data is \(-10 < f_{NL} < 74 \) (central value \( \sim 40 \)). Future CMB observations like Planck are expected to give \( \Delta f_{NL} \approx 5 \). Theoretically, a single, slow-roll inflation model (standard inflation scenario) gives \( f_{NL} = O(0.01) \) (= order of slow-roll parameters), while a non-slow-roll model or multi-scalar model would suggest \( f_{NL} = O(0.1-1) \). So, if we establish this level of precision, we will be able to constrain the inflation scenario.

The most promising observational tool to explore this issue is the redshifted 21-cm line (\( z = 100-30 \) corresponds to 14–47 MHz). The brightness temperature is defined as \( T_l(n, \nu) = (T_l - T_{\text{CMB}}) \tau(n, \nu)/(1 + z) \), where \( T_l \) is the spin temperature of HI and \( \tau(n, \nu) \) is optical depth for the hyperfine transition. It is known that the fluctuation in the brightness temperature \( T_l \) is related to the primordial fluctuation (Loeb & Zaldarriaga 2004). Thus, the bispectrum (Fourier transformed 3-point correlation) of the CMB brightness temperature map can be used to estimate \( f_{NL} \) efficiently (Cooray 2006). If we assume the bandwidth: 1 MHz, frequency: 14–45 MHz (\( z \sim 100-30 \)) and \( \ell_{\text{max}} \sim 10^5 \), optimistic prediction gives \( \Delta f_{NL} \sim 0.01 \). In contrast, Planck will constrain \( \Delta f_{NL} \approx 5 \). This difference comes from the fact that the 21-cm tomography provides 3-D information, while the CMB gives only projected information (Fig. 1). Hence, the 21-cm line tomography works as a promising
Figure 1: Comparison between the 21-cm line tomography and the CMB analysis.

method to determine $f_{\text{NL}}$. If we achieve $\Delta f_{\text{NL}} \sim 0.01$, we can distinguish inflation models finely and constrain plausible scenarios. However, we should note that many realistic problems remain to be solved. Integrated effort from observational and theoretical side is needed.

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AGN science with SKA

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Abstract

We present the key science cases discussed in SKA-Japan AGN sub-WG.  
Using SKA, we explore open issues on jets which current VLBIs cannot assess  
and search for radio emissions from radio-quiet AGNs /galaxies.

1 Introduction

It is well established that AGN jets carry away some fractions of the available  
accretion power in the form of a collimated beam \cite{1}. However, the formation  
mechanism of AGN jets is a long-standing problem in astrophysics\cite{14}. Thanks to  
the high-spatial resolution observations, it is now widely accepted that the most  
galaxies have their central supermassive black holes (SMBHs)\cite{10}. However, the  
formation of SMBHs is still open question. We here report the main science cases  
which we have discussed in SKA-Japan AGN sub-WG to tackle these un-resolved  
problems of AGNs.

2 AGN Outflow

In this section, we report the main science cases discussed in the SKA Japan AGN  
outflow group. The cases shown here cover not only the area to be explored at  
the low-band but also include the ones to be done at the mid- and high-bands.

2.1 Cocoons

In AGN cocoons, electrons with higher energy cool down by synchrotron loss faster  
than those with lower energy. Therefore, to measure a matter distribution correctly,  
the low-band observation is crucial. For this reason, we pay attention to the SKA  
observations of AGN cocoons at the low-band. Knowing the real shape of cocoons  
is essential for the estimate of the true total power of jets \cite{9,4}. The low-band  
observation straightforwardly connect with for the cocoon study. Furthermore, we  
shortly add to a comment on hot spots in cocoons. Lazio et al. \textit{(2006)}\cite{12}  
indicated spectral flattening and turnover at $\sim 100$ MHz for the spots in Cygnus A.
However the spot sizes are smaller than the VLA beam sizes at the above frequencies. Therefore, the SKA low-band observation is essential for determining real low-energy-cutoff frequencies in hot spot spectra.

2.2 Fine structure in kpc scale knots

A higher resolution observation of jet termination shocks and knots structures allows us to explore energy dissipation and electron acceleration processes in FR I and II radio galaxies. However, it is difficult to obtain images of fine structures inside kpc scale hot spots/knots with VLBI because they tend to be resolved out. So far, only a few observations have succeeded to obtain them [19]. Recently, we investigate the fine structure inside the knot 1 in the quasar 3C380 by using the VLBA archive data (Koyama et al. in prep). The compact (∼ 100 pc) bright region has been detected in the knot 1 (Figure 1). It could be connected with the site of electron acceleration. As the continued research from the above one, we propose the SKA observations of kpc scale knots at mid-/high-band.

2.3 Evolutionary track of jets

In order to reveal the long-term evolution of jets in AGNs, we examine the dynamical evolution of variously-sized radio galaxies [i.e., compact symmetric objects (CSOs), medium-size symmetric objects (MSOs), and FR IIIs]. By comparing the observed shape of cocoons with a theoretical model, Kawakatu et al. (2008) [6] indicate that the advance speed of hot spots and lobes inevitably show the deceleration phase (CSO-MSO phase) and the acceleration phase (MSO-FR II phase). However, there is a gap between VLA and VLBIs in terms of spacial resolution and sensitivity and a typical size and brightness of the key population MSO fit in the range in between VLA and VLBA. Therefore, MSOs are not sufficiently studied in spite of their importance. The SKA high band observation may fill the gap.

2.4 Mapping velocity fields of jets

The current observational status of kinematics in extragalactic radio sources by MOJAVE has been presented in https://www.physics.purdue.edu/astro/mojave/. Its current observational status is represented in the papers[8]. On the contrary to the pc scale jets, little is known about the velocity of kpc scale jets apart from some exceptions. The high-band observation of SKA could constrain on it.

2.5 Radio emission from “radio quiet” AGNs

SKA will enable us to detect radio emission from sources currently termed as “radio quiet” AGNs. Jackson (2004)[5] showed the simulated sky images to be obtained by SKA including the three population of sources, namely FR I, FR II, and star-forming galaxies. Radio emission from radio weak sources, for example narrow line Seyfert 1 galaxies[3], could be of interest in SKA era.

3 AGN Inflow

In this section, we present the main science cases discussed in the SKA Japan AGN inflow group.
3.1 Imaging accretion disk-corona

In Seyfert galaxies and quasars, an accretion disk emits a huge amount of radiation. Above and below the disk, a corona, which is an optically-thin hot gas, radiates X-ray emission. So far, the disk-corona is investigated via only X-ray luminosity, spectrum and their time variability. Here, we note that the wavelength range of SKA is a powerful window to detect and take images of the corona in nearby Seyfert 1 galaxies. Although the corona is optically-thin in X-ray (the Thomson optical thickness $\sim 1$), it is optically-thick in radio due to cyclotron-synchrotron self-absorption[18, 11]. Based on the gas density, temperature and height of the corona[7], we estimate that the corona is optically-thick below 20GHz. The brightness temperature at low frequencies thus equals to the coronal electron temperature, i.e., $\sim 10^9$K.

3.2 Quest for deeply buried AGNs in ULIRGs

Ultraluminous infrared galaxies (ULIRGs) radiate quasar-like large luminosities ($L > 10^{12} L_\odot$) as infrared dust emission, and thus possess extremely powerful energy sources hidden behind dust[16]. Since this ULIRG population contributes importantly to the cosmic infrared radiation density at high-redshift[2], distinguishing whether ULIRGs are dominated by starburst activity or AGN activity is also energetically important, is closely coupled to clarifying the connection between star formation and SMBH mass growth in the dust-obscured galaxy population of the early universe. To probe AGNs deeply buried in ULIRG's cores, observations in the high-frequency radio regime ($>6$ GHz) are particularly effective, because (1) extinction effects are negligible, and (3) thanks to the long-baseline interferometric technique, highest-spatial-resolution is achievable in the radio and so can be used to distinguish between AGNs and starbursts. Using currently available VLBI networks, high-spatial-resolution radio observations of ULIRGs have been performed, but limited to low-frequency range ($<2$ GHz), where free-free absorption effects are large [13]. For this reason, putative buried AGNs could be missed in a substantial fraction of ULIRGs. Thus, SKA, with its high sensitivity at 6–25 GHz and high-spatial-resolution ($<0.001'$), will be the most powerful, unique instrument to investigate deeply buried AGNs in ULIRG's cores.
3.3 Quest for faint AGNs in BCDs

Blue compact dwarf galaxies (BCDs) host a compact and ongoing star formation activity in metal-poor and gas-rich environments [17]. According to X-ray observations, there is no clear evidence of bright AGNs in BCDs [20]. However, some BCDs may harbor faint AGNs associated with intermediate mass black holes. We here propose that the spectral index at radio band can be a key to quest faint AGNs, because there is a significant difference between the spectral index of faint AGNs and starbursts. The current radio observations is hard to detect faint AGNs because of the lack of the spatial resolution and and sensitivity. Thus, SKA mid-band observations could be powerful to search the faint AGNs in BCDs.

4 Summary

We report the key science cases discussed in SKA-Japan AGN sub-WG. By utilizing the advantages of SKA's VLBI-order spatial resolution and micro-Jy order sensitivity, we explore un-resolved issues on jets which current VLBIs are not able to assess, and search for radio emissions from the accretion-disk corona, ULIRGs and BCDs.

References

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Summary of Discussion

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Abstract

In this workshop, we had 30-minutes discussion session on each day. Here, we summarize what we discussed and concluded in these sessions. Through the discussion, we got a consensus that the keyword of “Wideband” is suitable to Japanese SKA community. For the next step, we will need deeper discussions about detailed system requirement from the science side, and more activities in engineering. In order to promote SKA-related activity in Japan, we would like to have more members who can do actual works and more international collaboration.

1 First day’s discussion

The items we raised for the first day’s discussion were (1) the key science and engineering for the Japanese community, and (2) what contribution we can do, and what Japanese contribution is expected by the international SKA community.

1.1 Key Science and Key Engineering

First, we discussed what we should define as Japanese key science and engineering. The previous Japanese SKA workshop was held in November 2008, and its title was “Combination of Science and Engineering for the SKA”. At that time, the keyword of “wideband receiving” system was recognized as a promising engineering development. Therefore, we set the title of the SKA-Japan Workshop 2010 “Revealing the Universe with Wide-band cm-Wavelength Observation”, and we have been discussed what science can be carried out with a wideband receiver system since the beginning of 2010.

In this workshop the most of the talks focus on the keyword of wideband. Consequently we found that it was a challenging and ultimate goal in terms of engineering, and that new attractive science could be possible with such a wideband receiver system.

Through the discussion session, we got a consensus that “wideband” must be a good keyword to encourage people in both science and engineering sides.

1.2 Japanese Contribution

There was a question from the Japanese researchers; what Japanese contribution is expected by the international SKA community? In order to contribute efficiently
to the international SKA project, Japanese researchers wanted to know what contribution was necessary for the SKA development.

However, the comment for this question was that the important thing was what we Japanese researchers wanted to do with the SKA, but not what we were expected to do for the SKA.

Since the SKA project is evolving rapidly particularly these years, it is important to synchronize our activity with the international SKA timeline. There are a lot of works related to the SKA such as ASKAP, MeerKAT, LOFAR, SKADS etc. Such projects welcome new collaborators from international community including Japan. It would be important for us to get involved into the international collaboration from the early stage. And such international collaborations can be a first step for an actual contribution.

2 Second day’s discussion

In the second day’s discussion, we discussed what we should do for the next step. Through the workshop we learned the followings:

(1) There are a lot of seeds (the pathfinder/precursor projects welcoming new collaborator from overseas, science activities by Japanese researchers etc), which can lead us to get involved into the SKA project.
(2) Though science is discussed intensively, detailed requirement for technical development is not obvious yet.
(3) There are interests on SKA from international community, Japanese industries, as well as domestic science community, which are enough pressures for the next step.

Considering these things, what we have to do will be as follows.

(1) to make more international collaborations
(2) to propose detailed system requirement from the science side and to have more activities in engineering
(3) to get more members actually working together

In order to achieve these objectives, we have to strengthen our Japanese SKA team. First, we would like to welcome new more members to the SKA-Japan core team.

We also need deep discussions on the requirements. Concerning science which Japanese researchers are interested in, there was a comment that some preferences were expressed for science topics that can be achieved with higher band of the SKA. We would like to have deeper discussion in upcoming telecons and face-to-face meetings in the annual meetings of the Astronomical Society of Japan and host a special session of SKA in the annual meeting at some point in near future.

After this workshop, we would have to host workshops constantly to share idea and information related to the SKA with international community. Recently, the East Asian region is regarded as potential partner by the international SKA community. Considering geographical distances, it will be necessary in the future to form East Asian SKA community. Hence, we hope to host East Asian and/or domestic workshop next year, and all participants from the international community are welcome.
SKA-JAPAN WORKSHOP

Yoshiaki Hagiwara with Meercat, Masaya Kuniyoshi, and Takuya Akahori

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Section 2

POSTER PRESENTATION
The ASKAP Survey Science Projects

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Abstract
The Australian SKA Pathfinder (ASKAP) is currently under construction in Western Australia. ASKAP's wide bandwidth (300 MHz) and large field of view (30 deg²) make it well suited to large surveys in the 700-1800 MHz band. The ten Survey Science Projects are outlined in this paper.

1 Introduction

The Australian SKA Pathfinder (ASKAP) will be an array of thirty-six 12 m diameter antennas using a novel three-axis design, with a maximum baseline of 6 km, and operating in the 700-1800 MHz range. ASKAP, which will be both a world-leading radio telescope in its own right and an important testbed for the SKA, is described in more detail in Bunton (these proceedings). ASKAP's wide field-of-view, large spectral bandwidth, excellent (u,v) coverage, southern hemisphere location and radio quiet site will make it an unprecedented survey telescope (Johnston et al. 2007, 2008). During ASKAP's first five years of operation at least 75% of its time will be used for large (> 1500 hr) Survey Science Projects (SSPs) designed to make use of the telescope's unique capabilities. Ten science projects (http://www.atnf.csiro.au/projects/askap/ssps.html) were selected in September 2009 for further study, representing 363 investigators from 131 institutions. Detailed design studies are underway, and contributions from new team members from Japan would be welcome!

2 The ASKAP Survey Science Projects

2.1 EMU

The Evolutionary Map of the Universe (EMU) will undertake a deep continuum survey to explore large-scale structure and trace the evolution of star-forming galaxies and massive black holes over the history of the universe.

2.2 WALLABY

The Widefield ASKAP L-Band Legacy All-Sky Blind Survey (WALLABY) is a blind survey of extragalactic neutral hydrogen, that aims to survey 75% of the sky and detect up to 500,000 galaxies.

2.3 FLASH

The First Large Absorption Survey in H I (FLASH) is a blind absorption-line survey of background radio continuum sources, to study the neutral gas content of galaxies in the redshift range 0.5< z <1.0.
2.4 GASKAP
The Galactic ASKAP Spectral Line Survey (GASKAP) will study Galactic and Magellanic HI and OH masers, including structures in the gas distribution that trace the effects of stellar winds and supernova explosions (Dickey et al. 2010).

2.5 POSSUM
The Polarization Sky Survey of the Universe’s Magnetism (POSSUM) will result in the production of a Rotation Measure grid across the sky, enabling studies of magnetic field generation in galaxies and clusters, and a census of magnetic fields as a function of redshift.

2.6 VAST
The ASKAP Survey for Variables and Slow Transients (VAST) will search for transients with timescales greater than 5 seconds, to study flare stars, intermittent pulsars, X-ray binaries, intra-day variables, and other sources.

2.7 CRAFT
The Commensal Real-time ASKAP Fast Transients survey (CRAFT) is a complementary search for transients with timescales less than 5 seconds, to study the most energetic and brightest single events in the universe (Macquart et al. 2010).

2.8 DINGO
Deep Investigations of Neutral Gas Origins (DINGO) will study the evolution of HI in the local universe, 0 < z < 0.5, to study the HI mass function and halo occupation distribution function.

2.9 VLBI
The VLBI Survey Science Project is designed to meet the Long Baseline Specifications for the SKA. The first ASKAP antenna has already participated in Long Baseline Array observations with a single pixel feed (Tzioumis et al. 2010).

2.10 COAST
Compact Objects with ASKAP: Surveys and Timing (COAST) is a project to undertake both blind searches for pulsars, and also undertake tests of General Relativity and other theories of strong gravity using precision pulsar timing of known pulsars.

References
Astrobiology and Circular Polarimetry of the Star-Forming Region using IRSF telescope in South Africa Astronomical Observatory

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Abstract

An image of circular polarization (CP) in the core of the Orion nebula is reported. IRSF 1.4m telescope is used for polarimetry, which is located at Sutherland, South Africa Astronomical Observatory. The results reveal that the CP extends over a region about 400 times the size of the solar system. If our solar system formed in a massive star-forming region like the Orion nebula and was irradiated by CP, then enantiomeric excesses could have been induced in the parent bodies of the meteorites. These would be delivered to Earth, and could then have played a role in the development of homochirality on Earth.

1 Introduction

The biomolecular homochirality, whose origin is a longstanding mystery, refers to the phenomenon that terrestrial living material consists almost exclusively of one enantiomer, left-handed amino acids and right-handed sugars (see review by Fukue 2010 [1] and references therein). The detection of enantiomeric excesses in meteorites is consistent with the hypothesis that life on Earth was seeded by the delivery of organics from outer space. Enantiomeric excesses can be produced by circularly polarized light through asymmetric photochemistry.

2 Observation

Fukue et al. (2010) [2] have used the IRSF 1.4m telescope for near-infrared observation of star-forming regions (see also Fukue et al. 2009 [3]). This telescope is located at Sutherland, South Africa Astronomical Observatory. The near-infrared polarimeter SIRPOL is set up on the IRSF telescope, for linear and circular polarimetry. The SIRIUS camera works at three near-infrared bands ($J_-$-, $H_-$-, $K_s$-bands) simultaneously.

3 Result and Discussion

Fukue et al. (2010) [2] have observed the core of the Orion nebula by imaging circular polarimetry. Figure 1 shows the degree of CP of the Orion star-forming region in $K_s$-band (2.14μm). The CP appears around the massive star-forming region, the BN/KL region. The bright regions extended from the left to the right
express left-handed CP, where the electric vector of light is rotated anticlockwise. The bright regions extended from the top to the bottom express right-handed CP. The degree ranges from 17% (left-handed CP) to -5% (right-handed CP).

In astrobiological view, if our solar system formed in a massive star-forming region (like the Orion nebula) and was irradiated by CP, then enantiomeric excesses could have been induced in the parent bodies of the meteorites. These would be delivered to Earth, and could then have played a role in the development of homochirality on Earth.

We thank the National Astronomical Observatory of Japan for the image in Figure 1.

References


Multi-frequency polarimetry of radio-loud BAL quasars

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Abstract

We conducted multi-frequency polarimetry for radio-loud broad absorption line (BAL) quasars using VLBA. Their flat spectra, one-sided jet and relatively high degree of polarization indicates that they are blazars.

1 Introduction

Broad-absorption line (BAL) quasars show absorption troughs of broad resonance line in their rest-UV spectra. Usually, AGN outflow due to accretion disk are ascribed as the cause of their BAL features because their velocities are extremely high (sometimes up to $\sim 0.1c$). For a statistically homogeneous quasar sample from SDSS DR5, the fraction of BAL quasar is approximately 14\%\cite{3}. Though there is still no consensus about the origin of BAL quasar, two plausible explanations are advocated, orientation scheme and evolution scheme.

Adherents of orientation scheme insist that almost all of the quasars have BAL region and we can detect BAL features only when we observe these quasars from some viewing angles, especially edge-on. It is based on support in optical spectropolarimetric observations\cite{1}. The other scheme to explain BAL quasars, evolution scheme, ascribes the ratio of BAL to non-BAL quasars to duration of time when quasars possess the BAL region. Recent radio observations have revealed many BAL quasars are also the gigahertz peaked-spectrum (GPS) and compact steep spectrum (CSS) sources\cite{2}. These sources seem to be young sources due to their compact structures and they may evolve to large size radio sources\cite{4}, so that, when we take evolution schemes, it seems natural to think quasars have their BAL features during young age.

2 Observation and Result

Our VLBA observation for four radio-loud BAL quasars at L, C and X-band was carried out on Jun 25, 2010. Every object was observed at five frequencies (1.6, 4.6, 5.1, 8.1 and 8.6 GHz) with three to four scans, where each scan corresponds to integration of 5 minutes. We used two channels of 8 MHz bandwidth at 1.6 GHz and single channel at the other frequency.

Fig. 1 shows the total intensity maps and polarization features of J0928+444 and J1018+053 at 5.1 GHz and 8.6 GHz, respectively. They show one-sided jet, relatively high degree of polarization (a few percent to total intensity flux) and flat
core spectra. These are typical features of blazars which are thought to be AGN whose black holes aim their jets almost directly at Earth. It supports previous study on radio-loud BAL quasars which claim the existence of pole-on outflow.

3 Towards SKA

Though blazar scenario is convincing explanation, we cannot rule out the possibility of young radio sources which suffer inhomogeneous free-free absorption as described in Tingay et al. [5]. To confirm them and find the free-free absorber and Faraday rotation in BAL outflows, high-resolution and high-sensitivity observation at wide range of frequency are needed. Therefore, BAL quasars which host compact radio sources could be target of SKA.

This work has made use of the facility (VLBA) of the NRAO of USA, administered by the Association of Universities and funded by the American National Science Foundation. This work was partially supported by a Grant-in-Aid for Scientific Research (C: 21540250, A. D.) from the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT).

References


Figure 1: VLBA image of flat-spectrum BAL quasars observed on June 25, 2010. EVPA calibration is not yet done. (a) J0928+444 at 5.1 GHz. Contour levels are (1, 2, 4, 8, · · · ) × 1.5 mJy beam−1 and the peak flux density of stokes I is 172.7 mJy beam−1. (b) J1018+053 at 8.6 GHz. Contour levels are (1, 2, 4, 8, · · · ) × 2.1 mJy beam−1 and the peak flux density of stokes I is 352.8 mJy beam−1.
Expectation for SKA as a powerful system for Jupiter’s inner magnetosphere investigations

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Abstract

Jupiter’s synchrotron radiation (JSR) is generated by the relativistic electrons trapped in its radiation belt. Variation of JSR is, therefore, an important probe to investigate source and loss processes of the relativistic electrons in the deep inner magnetosphere where in-situ measurements can hardly be made. Recent observations have revealed existence of short-term JSR variations at a time scale of several days to weeks, which infer some global electro-magnetic activities. Now is the time to investigate details of variation characteristics and their causalities by more precise radio observations. SKA is one of the most powerful and attractive radio instruments for the purposes.

1 Introduction: Jupiter’s synchrotron radiation

It is well known that there is the huge radiation belt near Jupiter (JRB), whose relativistic electron’s intensity is larger than that of the earth by more than 3 orders of magnitude at the same L(McIlwain)-shell. The relativistic electrons generate synchrotron emissions (JSR) in the intense magnetic field of the JRB. JSR has been thought to be stable for a long time except for long-term variations in the time scale of several years. However, recent observations have revealed existence of short-term variations in the time scale of several days to weeks[1, 2, 3]. The short-term variations imply fast global changes of relativistic particles in the deep inner magnetosphere. The major characteristics of JSR are summarized as follows;
1) Source region: Locating within several planetary radii from Jupiter’s center. main source is around the equator from about 1.5 planetary radii and sub-sources are around the polar regions on the magnetic fields of L≈3 (e.g.[4]).
2) Total flux variation: More than 20% variation in the time scale of several years showing some correlation with solar wind properties[5]. More than several tens % variations in the time scale of days to weeks, which are larger in lower frequencies and show some correlation with solar UV/EUV variations (e.g.[6]).

2 Subjects in future study: Expectation for SKA

One of the important subjects of the future JSR studies is investigations on causalities of its variations. The energy range of relativistic electrons contributing to JSR is several MeV to several tens MeV in main, which are considered to be acquired by the radial diffusion process. The diffusion time scale is estimated to be more than a year from the outer to inner magnetospheres[7], which might correspond to that for the long-term variation, but not for the short-term one. On the other hand,
expected electron loss time scales due to major processes, such as absorptions by satellites and rings, coulomb interaction with Jupiter's atmosphere and synchrotron radiation are expected to be at least several tens days (e.g. [9]), which are also improbable as the causalities of the short-term variations. The plausible candidates are proposed to be temporal and/or localized enhanced radial diffusion brought by solar UV/EUV variations[1], and/or fast inward transport of high energy electrons just like injection as the source processes. While as the loss processes, electron absorption near Jupiter by (unidentified) dust and/or pitch angle scattering around the equatorial regions by some wave-particle interactions are proposed. Based on a numerical simulation, Sicard et al. 2004[10] suggested that the JSR total flux from the main and sub radiation regions is nearly the same as that from the outer regions where the diffusion rate is much larger than the inner regions. This implies that the outer JSR source regions where we cannot make quantitative observations at the moment due to their small radio flux density may have a key which causes the JSR short-term variation.

In order to assess the above mentioned candidates, it would be important to make more radio observations with higher sensitivity and spatial resolution in wider frequency range, which enable us to evaluate where and how the electrons are accelerated, transported and decelerated by losing their energies (see Figure 1). As an ideal tool realizing such investigations, we have great expectations for SKA whose capabilities, such as sensitivity, angular resolution and frequency coverage, are just matches for characteristics of JSR.

References

Simultaneous observations of radio and Xray pulses from the Crab pulsar: Kashima-Suzaku collaboration

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Abstract

We attempt simultaneous observations of radio and Xray pulses from the Crab pulsar, to study the correlation, if any, between giant radio pulses and hard Xray pulses. From the first trial observation, we have obtained an estimation for the observation time needed to establish the statistical significance of the correlation (or non-correlation).

Among the radio pulses emitted by the Crab pulsar, there are ultra strong pulses, called giant radio pulses (GRPs). The origin of GRPs is a long-standing enigma from the very discovery of this pulsar [1]. A recent progress in the study of Crab GRPs is a discovery of a 3\% correlation between radio and optical pulses [2]. Since the current upper limit for the pulse-to-pulse Xray variability is ~7\% [3], some 3\%-level correlation between GRPs and Xray pulses has not been excluded. Targeting the Crab pulsar we made on 6 April 2010 radio observations at 1.4GHz with the NICT Kashima 34m parabolic antenna [4], as well as hard Xray observations (15-70 keV) with the Suzaku HXD detector [5]. Figure 1a shows the profile of normal radio pulses accumulated over 8.75 hours, where we have excluded the contribution of GRPs.\footnote{We first de-disperse the raw antenna voltage data with the dispersion measure \textit{DM} of 56.835 pc cm\textsuperscript{-3}, take 10 \textmu sec average of the square-detected data, and then define main-phase GRPs as those having the peaks of the \textit{SNR}s (signal to noise ratios) >5 and the timings within \pm 300 \textmu sec from the main pulse phase. The number of thus defined GRPs is 5006, which is \sim 0.5\% of the total radio pulses during the observation period.} Figure 1b shows the Xray pulse profile obtained simultaneously with the radio pulses, reproducing the well-known double-peaked shape.

We now concentrate on the correlation study between the GRPs and Xray pulses. At the GRP peak timing in Figure 2b (shown by an arrow) the peak Xray intensity is 24.4\pm 3.4 photons \textup{s}\textsuperscript{-1}, while the normal Xray intensity at the main peak is 20.8\pm 0.4 photons \textup{s}\textsuperscript{-1} (Here both intensities are after the Crab nebula background.}
Figure 1: (a) The profile of Crab's normal radio pulses accumulated over 8.75 hours, where we have repeated three cycles to make the periodic structure easier to see. With the phase angle set 0° at the main-pulse peak, the interpulse peak appears at the phase angle ~ 145°. The vertical axis is in an arbitrary unit, with 1600 corresponding to ~ 1.1 kJy. (b) The X-ray pulse profile obtained simultaneously with the normal radio pulses. Both radio and X-ray signals are binned into 3° boxes.

Figure 2: (a) The GRP radio profile for the phase angle from -540° to +540° (from the pre-GRP period to the post-GRP period) accumulated over 5006 GRPs, where the center 0° is set at the GRP peak timing. (b) The X-ray pulse profile (red) accumulated at the GRP timing. The normal pulse shape (black) from Figure 1b is overlaid.

While the former peak intensity is slightly higher than the latter, their difference is of the order of one sigma and not statistically significant. To prove the GRP-X-ray correlation, if any, we need the data accumulation over 35 hours for the two sigma significance, and over 80 hours for the three sigma significance.

References
HI-selected Galaxies As a probe of Quasar Absorption Systems

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Abstract

We investigate a link between the local galaxy population and the quasar absorption systems by drawing a detailed comparison between the properties of the HI-selected galaxies detected by blind radio surveys and the HI absorption systems (DLAs and sub-DLAs).

We find that DLA galaxies contribute primarily to the population of local HI galaxies at \( M(HI) > 10^8 M_\odot \) detected in the radio observations. By contrast, in the low-mass range which is an observable range of the SKA, sub-DLA systems replace DLA galaxies as the dominant population. This result indicates that the SKA would reveal the nature of HI absorption systems and also provide an unique probe of galaxy formation processes.

1 Introduction

The quasar/GRB absorption systems provide us with a unique probe of galaxy formation and evolution processes. In particular, the HI absorption systems have been investigated extensively to place stringent constraint on the physical condition of the galactic gas. However, the origin of the HI absorption systems such as damped Ly\( \alpha \) absorption (DLA) systems \( N(HI) > 10^{20.3} \text{ cm}^{-2} \) and sub-DLA systems \( (10^{20.3} > N(HI) > 10^{19} \text{ cm}^{-2}) \), are still unclear because the optical counterparts are handful. For a purpose to revealing the origin of HI absorption systems, we focus on the radio properties of HI-emission galaxies detected in blind radio surveys \([4],[5]\), and investigate a link between the HI emission galaxies and the HI absorption systems.

2 Result and Discussion

We employ a semi-analytic model for galaxy formation which incorporates basic processes of galaxy formation (e.g., merging process and SN feedback) (for details in [1], [2]).

We find that the number fractions of DLAs relative to galaxies are almost unity at \( M_{HI} > 10^8 M_\odot \) at redshift \( z = 0 \) [3], which suggests a trend that gaseous disks of galaxies have HI column densities as high as those in DLA systems. The HI-selected
galaxies at $M_{\text{HI}} > 10^8 M_\odot$ correspond to DLA hosts. By contrast, in the low-mass range $M_{\text{HI}} < 10^8 M_\odot$, a small amount of HI gas of the less massive systems does not produce high enough HI column densities to detect as DLAs. Therefore, at the low-mass end, sub-DLAs with the HI column densities lower than those of DLAs become a dominant population instead of DLAs.

For exploring the origin of HI absorption systems, we focus on the radio properties (e.g., the HI mass and the size). In Figure 1(a), we present a contour map for HI mass $M_{\text{HI}}$ vs the cross section $\sigma$ of DLA galaxies for our model. We find that the cross sections correlate strongly to the HI masses, which is entirely consistent with the observations of a blind radio survey [4]. In Figure 1(b), we show a contour map for $M_{\text{HI}}$ vs $\sigma$ of sub-DLA galaxies which is the dominant population at $M_{\text{HI}} < 10^8 M_\odot$. Similarly to the DLA galaxies, sub-DLA galaxies show a strong correlation between $M_{\text{HI}}$ and $\sigma$. This result suggests that the SKA observation will provide an opportunity for exploring the less-massive and compact systems as the sub-DLA galaxies (the mean disk-size $4h^{-1} \text{kpc}$) which contribute significantly to the population of HI-selected galaxies at $M_{\text{HI}} < 10^8 M_\odot$.

On the basis of the SKA observation, the galaxy population ($M_{\text{HI}} < 10^8 M_\odot$) selected homogeneously by both emission and absorption lines would place stringent constraints on key processes of galaxy formation and evolution.

References

Primordial Origin of Composite Magnetic Configurations in Spiral Galaxies

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Abstract

Observations indicate composite magnetic fields in galaxy disks, comprising S (BSS), A (ASS), R (Ring), GPR (Gal. plane reversal) in disks, and V (Vertical) in the center. These are explained as the fossil of large scale primordial field wound up during galaxy formation, and are well reproduced by MHD simulations. SKA High-resolution and sensitive Faraday RM mapping will clarify the detailed S, A, R, GPR and V field configurations, which gives constraints on the seed cosmological magnetic field.

1 Introduction

Figure 1 shows observed magnetic configurations in near spiral galaxies and that in the Galactic Center. Fields in the disk are mostly bisymmetric spiral (BSS=S or ASS=A) or ring (R). The central fields are vertical (V) to the galactic plane. These different configurations often co-exist in the same galaxy.

![Fig. 1: Observed S, A, R and V magnetic configurations in nearby galaxies and V field in the Galactic Center. See the literature in Sofue et al. (2010)](image)

![Fig. 2: Hypothetical scenario of galactic magnetic field from uniform, tilted cosmological field (Sofue et al. (2010).)](image)
Fig. 3: MHD simulation of magnetic field evolution in a disk galaxy (Sofue et al. (2010)).

2 Primordial Origin Hypothesis

Figure 2 illustrates the origin of magnetic topology in spiral galaxies. Tilted uniform field is wound up into a rotating gas disk, forming an S, A or R fields in the disk. ASS field shows reversal with respect to the galactic plane (GPR). The vertical component is accumulated to the center to form twisted V field. Ring field is created from reconnection of a part of the spiral, stimulated by mode-1 asymmetry in the initial field.

3 Result of MHD Simulation

Figure 3 shows the result of MHD simulations. The gas is rotating in a disk potential (Sofue et al 2010). In several rotations, S (BSS), A with GPR, and central V fields are indeed created. R field is not created, because no mode-1 asymmetry exists in the initial condition, which would be a subject for the future.

4 SKA Faraday-RM Synthesis for Galactic Magnetic Field Origin

High-resolution RM mapping of nearby spiral galaxies is crucial to understand the magnetic field origin. Detailed comparison of the observations with MHD simulations may used to clarify the primordial magnetic condition in spiral galaxies.

References

Simulations of Wideband Feeds

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Abstract

Numerical simulations of wide band feed antennas, Tapered Slot Antenna, double-ridged and quad-ridged horns, are carried out with RF module in a FEM software, COMSOL Multiphysics ver.3.5a. Far field patterns become sharp as increasing frequency or aperture size, generally. Ridged horns are suitable for the element of phased array feed for beam forming, because of lower mutual coupling than TSA. Maximum physical memory size is 64GB for a model antenna with surrounding air and PML sections in the simulations, thus simulations were not done for arrays yet.

1 Tapered Slot Antenna (TSA)

Dimensions are based on TSAs designed by Kouzuma (Kagoshima Univ.). Substrate size is $W \times L \times H = 100 \times 150 \times 1.6 \text{mm}$, $\varepsilon_r = 4.6$. Siderobes are large in lower frequency and beams are not axial symmetric. This model antenna size is too small for 2.0GHz, however, larger antennas needs more memories.

2 Double Ridged Horn

Dimensions are based on SCHWARZBECK BBIIA9120A. $W \times H = 285 \times 238 \times 190 \text{mm}$ This was modeled with a lumped port in the ridges, instead of actual port of

Figure 1: Power flow of a TSA. $f=1.5 \text{GHz}, 10.0 \text{GHz}$. Outer circle is air and PML.
coaxial-waveguide transformer. Also, elongated flare horns are simulated for beam shaping which are Case 2 (L+150mm), case 3 (L+300mm), in same flare angles without ridges in elongated section. Rectangle aperture is not suitable for packing to the focal plane array, however we can study for beam shaping by this simple model.

![Diagrams showing E and H plane beam patterns of a double ridged horn with 300mm flare elongation (case 3).](image)

3 Quad Ridged horns

Dimensions are WxHxL=300x300x320mm, this is just a numerical model with dual polarization capable and square aperture. Models are not well converged yet. Maximum error is estimated 0.15 in some frequencies. Beam patterns are reasonable, however, power levels are too low. Port model must be improved, because distance of ridges near the port may be too wide.

4 Result and Tasks

The beam patterns of TSA varies in frequency, thus, we have to use TSA as some kind of array elements to control the beam width for the aperture efficiency of the radio telescope. Moreover, shielded boundary is needed to avoid mutual couplings to surroundings. TSA still needs carefully study to be used as a feed element.

Ridged horns are naturally shielded, however simulations model must be developed for optimization, especially for dual-polarization frontend.
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