Research Activities in Korea Astronomy and Space Science Institute

Korea Astronomy and Space Science Institute (KASI)

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Korea Astronomy and Space Science Institute (KASI) was established in 1974 as the national astronomical observatory. KASI has been contributing to the development of Korean astronomy and playing an underpinning role in the advancement of astronomical science and technology (http://www.kasi.re.kr).

KASI is a government funded research institute and at present, has 77 research and 55 supporting staff. The institute maintains several optical and radio observatories and GPS stations in Korea and overseas. The main research goals of the institute are the following: (1) investigating major topics in astronomy and space science, (2) constructing observing systems for astronomy and space science and developing the required key technologies, (3) establishing the better forecast system to prevent natural disaster, and (4) distributing and popularizing the achievements to the Korean public society.

The comprehensive research activities of KASI will be described based on our research facilities, especially focusing on the optical and radio astronomy and space science. The present ongoing research projects and future research plans of the KASI are also reviewed briefly in the following sections.

1. OPTICAL ASTRONOMY
1.1. Current Research Facilities
After the foundation of Korea national astronomical observatory in 1974, it is said that the modern history of Korean astronomy started with the 61 cm Sobaeksan Optical Astronomy Observatory (SOAO) telescope in 1978. Initially this telescope was used much for the training of students and for the initial astronomical researches in Korea. It is still being used for active researches especially in the studies of eclipsing binaries, pulsating stars, and variable stars (http://soao.kasi.re.kr).

In 1996, 1.8 m telescope was installed at Bohyunsan Optical Astronomy Observatory (BOAO) located at Mt. Bohyun in the south eastern part of Korea, which has been used for modern observational research (http://boao.kasi.re.kr). This telescope has three major components: (1) CCD camera with a field of view of 11.7′ × 11.7′ (2,048 pixels × 2,048 pixels), which is being replaced by a new 4,096 pixels × 4,096 pixels CCD, (2) BOES (BOAO Optical Echelle Spectrograph) which is a fiber-fed spectrograph equipped with iodine cell for precise radial velocity measurement. It can cover an optical wavelength range of 3,600 Å ~ 10,200 Å in one CCD frame of 2,048 pixels × 4,096 pixels (pixel size of 15 μm), and (3) KASI near-infrared camera system (InSb 512 pixels × 512 pixels; filters are J, H, Ks, L, H2, & H3+) which can cover a near-infrared wavelength band of 1 ~ 5 μm with a field of view of 3.3′ × 3.3′. Fig. 1 is the picture of the 1.8 m telescope and Fig. 2 is the sample of Korean 10,000 Won bill, on the back of which the 1.8 m telescope is printed.

Another 1 m telescope was installed in 2003 at Mt. Lemmon Optical Astronomy Observatory (LOAO) located at Mt. Lemmon near Tucson, Arizona, USA (http://loao.kasi.re.kr). The telescope is operated remotely from the main KASI building in Daejeon, Korea via internet. LOAO has more than 200 clear nights per year. The time difference of 16 hours between Korea and Tucson makes it useful for longer coverage of light curves of variable stars.

1.2. The Ongoing Projects
Two major projects in optical astronomy have been started in 2009. These are...
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Korean Giant Magellan Telescope (K-GMT) project and Korean Microlensing Telescope Network (KMTNet).

K-GMT is a ten year project (2009 ~ 2018), participating in the GMT project as a 10% partner and developing both Korean science programs and Korean technologies related in astronomical telescopes. The GMT is an innovative 25 m telescope composed of seven 8.4 m-diameter mirrors (one mirror in on-axis and surrounding six mirrors in off-axis, see Fig. 3), which can produce images ten times sharper than those from the Hubble Space Telescope using adaptive optics techniques. This can be used to probe to far fainter levels than possible with today’s largest ground-based telescopes. The GMT will be located at Las Campanas observatory in the Andes Mountains of Chile and is scheduled to complete around 2019. GMT is a multi-purpose telescope operating in the visible and infrared wavelength bands of 320 nm ~ 25 μm, and will produce an unobstructed field of view not less than 20′ in diameter. In near future, it can be a crucial tool for investigating many questions at the forefront of astrophysical research such as (1) understanding planet formation outside the solar system, (2) determining the nature of dark matter and dark energy, (3) understanding stellar populations and the origin of the chemical elements, (4) probing the mysterious black holes, (5) understanding the formation of galaxies, and (6) detecting the first light photons and the reionization processes of the Universe. Current partners of the GMT projects include KASI, Carnegie Institution for Science, Harvard University, the Smithsonian Institution, Texas A&M University, the University of Arizona, the University of Texas at Austin, Australian National University and Astronomy Australia Limited.

KMTNet is also a ten year project (2009 ~ 2018) to build a network of three 2 m-class telescopes with a field of view of 2° × 2° (with mosaic CCDs having pixels size of 20K × 20K). The telescopes will be installed at the three southern hemisphere continents (Africa, Oceania, and South America), which can give full 24-hours coverage on any celestial object. The goals of the KMTNet are to discover earth-mass class extra-solar planets from ground-based observation, a huge number of extra-solar planets in wide mass range, and a huge number of variable stars.

2. RADIO ASTRONOMY
2.1. The Korean VLBI Network
Korean VLBI Network (KVN) is the only VLBI facility in Korea. It consists of three 21 m radio telescopes, which are located in Seoul (Yonsei Univ.), Ulsan (Univ. of Ulsan), and Jeju island (Tamna Univ.), and produce an effective spatial resolution equivalent to that of an 500 km radio telescope. Compared to American and European VLBI networks such as VLBA and EVN, the size of KVN is still small. In order to overcome this shortcoming, KASI is developing innovative multi-frequency band receiver systems with which we will be able to make simultaneous VLBI observations at four different frequencies: 22 GHz, 43 GHz, 86 GHz, and 129 GHz. Since millimeter-wave VLBI (mm-VLBI) is still in the developing stages around the world, we expect that KVN will play an important role in promoting mm-VLBI research activities. In addition, KVN will be often operated in combination with Japanese and Chinese VLBI networks to form so-called East Asian VLBI Network (EAVN), which is expected to be comparable to VLBA and EVN in spatial resolution, sensitivity, and imaging fidelity. KVN will provide opportunities to study the formation and death processes of stars, the structure and dynamics of our own Galaxy, the nature of active galactic nuclei and so on at milli-arcsecond resolutions. KVN can be also utilized to precisely detect tectonic movements in the Korean peninsula. KASI is building the Korea-Japan joint VLBI correlator, as well, in collaboration with the national astronomical observatory of Japan.

The first set of 22/43 GHz receivers was installed at the KVN Yosei telescope in 2008 August. The first fringes were detected in the VLBI test observations with the Japanese VLBI network VERA at both frequencies. KVN Yosei telescope is operational as a single dish. The VLBI test observations are being carried out to evaluate and to improve the performance. Second and third sets of 22/43 GHz receivers will be installed on the other telescopes within the end of 2009. All KVN telescopes will be equipped with 22/43/86/129 GHz receivers in 2011. As the world-first dedicated mm-VLBI network, KVN will make KASI take an-

Fig. 3: An artist’s drawing of the 25 m Giant Magellan Telescope.
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2.2. KVN Sites
Three KVN observatory sites have been selected among many competitors. Table 1 presents the locations, while Table 2 lists the baseline lengths, ranging between 300 km and 500 km. The antenna constructions were finished at all three sites in 2008. Fig. 4 shows an example of the u-v coverage and the synthesized beam for the combination of three KVN antennas and TRAO 14 m radio telescope located at KASI headquarters in Daejeon. In future, these four antennas will be connected using the optical fiber networks both for the real-time unmanned operations and for “online” operations (e-VLBI).

2.3. KVN 21 m Antennas
The KVN antennas are shaping Cassegrain antennas with a diameter of 21 m. They were built in between 2006 September and 2008 September. Fig. 5 exhibits three KVN sites with the 21 m antennas. The surface accuracies of the primary reflectors are ≤ 150 μm rms and aperture efficiencies about 50%, 70%, 70% at 22 GHz, 43 GHz, 100 GHz, respectively with a pointing accuracy of each antenna estimated to be better than 4" rms. The maximum slewing speed is 3°/sec in both azimuthal and elevation angle with an acceleration of 3°/sec². This high slewing speed ensures weak source detection via “fast position switching phase referencing.”

2.4. KVN Receiver Systems
For the KVN front-ends, several cryogenic HEMT receivers will be installed at the Cassegrain focus for 2/8 GHz, 22 GHz, 43 GHz, & 86 GHz and SIS receiver for 129 GHz operations. The 2/8 GHz receivers will mainly be used for geodetic observations, whereas the others for astronomical purposes. The 22/43 GHz receivers are installed first to set up the antennas and for the initial VLBI observations. The 86/129 GHz receivers will be installed by 2011. Full polarization observation mode will be supported at 22 GHz, 43 GHz, 86 GHz, and 129 GHz.

For KVN, which is designed for mm-VLBI, we adopt an innovative multi-chan-

Table 1: Site locations of KVN and TRAO.

<table>
<thead>
<tr>
<th>KVN site</th>
<th>Longitude (East)</th>
<th>Latitude (North)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yonsei (Seoul)</td>
<td>126° 56' 35&quot;</td>
<td>37° 33' 44&quot;</td>
</tr>
<tr>
<td>Ulsan (Ulsan)</td>
<td>129° 15' 04&quot;</td>
<td>35° 32' 33&quot;</td>
</tr>
<tr>
<td>Tamna (Jeju)</td>
<td>126° 27' 43&quot;</td>
<td>33° 17' 18&quot;</td>
</tr>
<tr>
<td>TRAO (Daejeon)</td>
<td>127° 22' 19&quot;</td>
<td>36° 23' 53&quot;</td>
</tr>
</tbody>
</table>

Table 2: Baselines of KVN sites and 14 m TRAO telescope in units of km.

<table>
<thead>
<tr>
<th>KVN site</th>
<th>Yonsei (Seoul)</th>
<th>Ulsan (Ulsan)</th>
<th>Tamna (Jeju)</th>
<th>TRAO (Daejeon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yonsei (Seoul)</td>
<td>–</td>
<td>305.2</td>
<td>477.7</td>
<td>135.1</td>
</tr>
<tr>
<td>Ulsan (Ulsan)</td>
<td>305.2</td>
<td>–</td>
<td>358.5</td>
<td>194.2</td>
</tr>
<tr>
<td>Tamna (Jeju)</td>
<td>477.7</td>
<td>358.5</td>
<td>–</td>
<td>356.0</td>
</tr>
<tr>
<td>TRAO (Daejeon)</td>
<td>135.1</td>
<td>194.2</td>
<td>356.0</td>
<td>–</td>
</tr>
</tbody>
</table>

Fig. 4: Example u-v coverage (left) and synthesized beam (right) of KVN plus TRAO 14 m telescope for a source with a declination of 60°.
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Fig. 5: Three KVN 21 m radio telescopes.

Fig. 6: Schematic diagram of KVN quasi-optics (left) and receiver plate of KVN Yonsei telescope (right). Only 22/43 GHz receivers are currently installed.

2.5. KVN DAS and MK5 Recorder
The KVN Data Acquisition System (DAS) has been developed and installed at all stations in 2008. For our multi-channel receiver system, we employ four high-speed samplers operated at 1 Gbps. These four data streams of 2 Gbps are transported via optical fibers to the operation building, and then distributed among sixteen finite-impulse-response digital filters. With these filters, we can choose a passband (whose center frequency is arbitrarily programmable in the input bandwidth) and then resample the filtered data at 2 bits per sample. These resampled data streams are then formatted and sent to the recorder. The digital spectrometers are deployed for single-dish observation of total-power and polarization.

KASI participated in the Mark5 VLBI recorder development consortium. The KVN-Mark5B is designed to support VLBI standard interface specification fully. With this new recording system, not only the highly sensitive offline observation but also e-VLBI is possible. e-VLBI will ensure more reliable VLBI operation for astronomy, astrometry, geodesy, and space mission.

2.6. EAVN
As mentioned earlier, KVN will be often operated together with Japanese and Chinese VLBI networks to form EAVN. EAVN for 22 GHz will consist of 19 antennas scattered over 5,000 km, while EAVN for 43 GHz will comprise 9 antennas. In May 2009 the first fringes of EAVN for 22 GHz were successfully detected. Fig. 7 shows the results. Full-fledged observations using EAVN are expected to get under way in 2010.

3. SPACE SCIENCE
3.1. Space Geodesy
3.1.1. Researches
Space geodesy researches in KASI are based on space geodetic technologies like GPS, VLBI, SLR and Gravimeter. These are focused on the earth’s shape...
and its geodynamic changes, i.e., terrestrial reference frame and earth orientation parameters. These efforts are based on the three pillars of geodesy – geokinematics, earth rotation, and gravity field [Fig. 8]. KASI also works on the applications of space geodesy like an early warning system of natural hazard against bad weather, earthquakes, climate changes, ionospheric disturbance, etc. [Figs. 9, 10]. KASI has been carrying out several research projects related to the above topics. Among them “Development of an integration and application system of space

Fig. 7: First fringes of K-band EAVN (KVN Yonsei-VERA-CVN Sheshan).

Fig. 8: Three pillars of geodesy.  

Fig. 9: GPS troposphere monitoring.
geodetic techniques,” “Development of global navigation satellite system (GNSS) supplied techniques for weather forecast,” and “Development of continuous monitoring technologies for torrential rain, radio interference, and tectonic deformation based on GPS” are our major interest. The research can be KASI’s contributions to global earth observation system of systems (GEOSS) and global geodetic observing system (GGOS).

3.1.2. Applications
KASI has been operating its own GPS Network (KGN), which consists of nine domestic GPS stations [see Fig. 11]. KASI collects the KGN observation data and generates various products for scientific researches and their applications. Archived data and products are open to the public users through KGN data center. The KGN data are used for various science and engineering areas such as geodesy, surveying, and real-time high accuracy positioning. KASI is a leading R&D organization for the high precision GPS data processing and the real time practical GPS applications. KASI has developed the real-time kinematic and high accuracy differential GPS applications like real-time GPS data service via wireless communication network. Recently, KASI participates in the Korea multi-purpose satellite program (KOMPSAT-5) to extend its research areas to space based GPS applications [Fig. 12].

3.1.3. Infrastructures IGS GDC
KASI has been a member of international GNSS service (IGS) for more than 15 years. Based on the research activities and contributions to the IGS, KASI has been officially operating the IGS global data center (GDC) since the beginning of the 2006 [Fig. 13]. The KASI GDC is the first IGS GDC in the Asia-Oceania region, and the 4th in the world.

3.1.4. IVS Combination Center
KASI is also participating in international VLBI service as a combination center.
3.2. Solar and Space Weather
The sun is not as quiet as we see. It produces abrupt events namely solar flares and coronal mass ejections (CMEs). Solar flares release intense radiations in X-rays and radio waves. CMEs are billions of tons of gas moving into the interplanetary space. Usually, the earth’s magnetosphere deflects most of the solar wind and high-energy particles from the Sun. Sometimes, these solar activities change the earth’s magnetosphere significantly and cause high energy particles to reach the upper atmosphere of the earth directly and produce aurora. This environmental change of the space, the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere, is popularly known as “space weather” or “space environment.”

As civilization spreads into space, we rely on space-borne (e.g. satellites) technologies that are vulnerable to space weather. The effects of the space weather on modern technological system are of growing interest around the world.

The SOlar and Space weather research group (SOS) is actively involved in the front line research in the field of solar activity and space weather. Currently we are managing the SOlar Flare Telescope (SOFT), the solar spectroscopy telescope, the sunspot telescope, the solar radio spectrograph, magnetometer, the scintillation monitor, and the all-sky imager (see Fig. 14). We are observing sunspots since 1987 using the sunspot telescope. In 1995, the SOFT was installed at BOAO to observe solar activity through white light, H alpha, and vector magnetograms. We have also made spectroscopic observations using Coelostat-type solar spectroscopy telescope since 2002. Recognizing on these achievements, in the year 2001 the SOS was chosen as solar activity research laboratory (one of the National Research Laboratories) by the Ministry of Science and Technology Korea. Since then, we have developed solar full disk monitoring system which consists of H alpha full-disk and coronagraphic polarimeter.

In 2007, we initiated a new project to establish a Korean space weather prediction center for domestic satellites and communication systems. Scope of the project includes extension of ground observation system, construction of space weather database and networking, development of prediction models, and space weather studies. As a part of the project, the SOS has installed a magnetometer at BOAO for the space weather study and joined a global network of frequency-agile radio spectrometers which was constructed in collaboration with ETHZ, Switzerland. For study of ionosphere/upper atmosphere under the project, the SOS also installed an all-sky imager at BOAO and a scintillation monitor in KASI headquarters and is now constructing a VHF coherent scatter radar in the Korean Air Force region.

Since 2004, the SOS is performing a new project, which comprises the development of Korean Solar Radio Burst Locator (K-SRBL) and participating in the construction of 1.6 m New Solar Telescope (NST). Recently, through these projects, we are not only developing observational systems that can monitor solar activi-
ties, but also concentrating research on the more deeper issue of solar activity and the Sun-Earth connection.

3.3. Space Astronomy

Space era, initiated along with space ships, gave birth to space astronomy. Space astronomy changes the conventional concept of astronomy from ground observations to the space. Space observations indeed promise us an unprecedented understanding of the Universe, through the entire electromagnetic wavelength, without worries of the atmospheric extinction.

KASI space science research group was officially organized in 1997, to promote space astronomical research activities and to develop a payload system for the current Korean space program. Succeeding in the development of the low light level CCD camera and the X-ray detector for the Korean sounding rocket program, KASI constructed the Far-ultraviolet Imaging Spectrograph (FIMS) in collaboration with Korea Advanced Institute of Science and Technology (KAIST) and UC Berkeley. FIMS (also called as SPEAR), the first Korean-made space telescope, is the primary payload for the Science and Technology Satellite 1 (STSAT-1, Fig. 15 left) launched in September 2003. FIMS has conducted first-of-a-kind survey which successfully produced half-sky far-ultraviolet map that shows emission lines of hot gas ranging from tens of thousands to several million degrees Kelvin. Since KASI is concerned about design and construction of space payloads, the institute started to run its own laboratories and facilities for optical, ultraviolet, and near infrared astronomy.

Based on the technology obtained in developments of the KASI near infrared camera system on BOAO 1.8 m telescope and the infrared instruments for the Cosmic Infrared Background ExpeRiment (CIBER) sounding rocket program in collaboration with NASA and JAXA, the space astronomy research group in KASI is now developing the Multipurpose InfraRed Imaging System (MIRIS, Fig. 15 right) which is the main payload of STSAT-3. The MIRIS will produce imaging with a wide field of view (3.67° × 3.67°) with the wavelength coverage from 0.9 μm to 2 μm. To reduce a thermal noise, the telescope temperature will be cooled down to 200 K for space observation by radiative cooling. The main scientific purposes are to survey the Galactic plane in Paschen alpha (1.88 μm) emission line and to observe the Cosmic Infrared Background (CIB) in two wide bands (I and H bands). Paschen alpha survey will reveal the origin of warm ionized medium (WIM) which is a major component of the interstellar medium of the Milky Way. The structure information of WIM enables us to find the physical properties of interstellar turbulence related to star formation. In order to understand the origin of the first generation of massive stars (Population III stars) which caused the reionization of the universe, the MIRIS will observe the CIB for north ecliptic pole region in two wide bands. The large sky coverage (10° × 10°) can measure clearly the large-scale CIB fluctuation detected by the IRTS (InfraRed Telescope in Space) mission.