Japanese Astronomy

Astronomy in Japan has made rapid progress in the last two decades, placing Japan among the leaders in the field. Not only mm wave and x-ray astronomy since the 1980s but also the optical and infrared, gravitational wave and neutrino astronomy are now at the highest level in these fields. Astronomers are preparing ambitious future plans in both ground-based and space-borne astronomy, in spite of the many challenges that basic science in Japan faces.

Historical view of Japanese astronomy

Historically, astronomical research in Japan contributed little to the human understanding of the universe before World War II. In the Meiji era (1868–1912), Japan started introducing science and technology to catch up with the Western world. The government established faculties of engineering in universities as one of the earliest of such attempts in the world. However, most of the systematic and organized activities of basic sciences, including astronomy, started only after World War II.

The Norikura Solar Corona Observatory, started in 1950, and the OKAYAMA ASTROPHYSICAL OBSERVATORY with a 188 cm optical telescope (1960) of Tokyo Astronomical Observatory (TAO) and other observatories produced only a few observational results of the highest quality during the period of the 1950s to 1970s. However, these observatories established a foundation for observational astronomy in Japan. The TAO was then with the University of Tokyo and reorganized in 1988 as an interuniversity research institute, the NATIONAL ASTRONOMICAL OBSERVATORY, JAPAN (NAOJ). The progress in theoretical research in Japan, on the other hand, was remarkable in this period. The brilliant works by Chushiro Hayashi on the early universe, stellar structure and origin of the solar system, Yoshihide Kozai in celestial mechanics and Satio Hayakawa in high-energy astrophysics were among memorable contributions to the theoretical astronomy and astrophysics of humankind. In particular, the systematic works on the formation of stars and the solar system by C Hayashi and his group had built a firm foundation in the field.

In the 1960s small but extensive attempts started in radio, x-ray and infrared astronomy in Japan and grew rapidly throughout in the 1970s. It was in the 1980s that those efforts were rewarded with remarkable scientific and technological results.

Developments in radio astronomy

Solar radio observations in Japan started in the 1950s. The development of solar microwave interferometers by Haruo Tanaka was among the earliest in the field. The millimeter wave observations in Japan started in 1970 with a 6 m diameter telescope at Mitaka constructed by Kenji Akabane, Masaki Morimoto and their group. Their efforts led TAO to establish the NOBEYAMA RADIO OBSERVATORY (NRO) in 1982 with two top-level mm wave telescopes, the 45 m diameter telescope (the world's largest mm wave telescope until now) and the mm wave interferometer composed of five (a sixth added later) 10 m antennas with 570 m baseline. Norio Kaifu, Masato Ishiguro and their group led the construction and work on related developments such as high-precision antennas, acousto-optical radio spectrometer, Fourier correlation radio spectrometer, high-sensitivity SIS mixer receivers, closely cooperating with engineers from Japanese industries. Since its establishment the Nobeyama mm wave telescopes have been providing rich scientific results: detection of many exotic new molecules in interstellar clouds, protoplanetary disks, evidence of supermassive black holes in galactic nuclei, to name a few, making Japan one of the leading countries in radio astronomy.

Recently (1998) NRO succeeded in linking the 45 m telescope with the array of six 10 m diameter antennas for a seven-element mm wave interferometer called RAINBOW. It will be the most sensitive mm wave interferometer for the time before the planned international project ALMA (mentioned below). Another facility of NRO is a radioheliograph, completed in 1992 under the leadership of Shinzo Enome. The 84-element array of 80 cm diameter parabolas yields high-resolution radio images of the sun every second.

NRO and Mizusawa Astrogeodesy Observatory of NAOJ had started the VLBI observations with other Japanese institutes and organized a domestic VLBI network (J-Net). In 1997 the VLBI group led by Hisashi Hirabayashi and his group launched the world's first space VLBI satellite HARUKA as a collaboration among ISAS, NAOJ and overseas institutes. The launched 8 m diameter antenna is orbiting around the Earth to link with radio telescopes worldwide to form a 30 000 km aperture radio telescope (VSOP). It was an engineering and logistical challenge, and recently VSOP has produced clear images of many energetic galactic nuclei with extremely high resolution of 0.1–1 marcsec, approaching a linear size about 100 times that of supermassive black holes.

NRO, with its large mm wave telescopes, was the first top-level observational facility Japan had for astronomy. In the field of mm wave and sub-mm wave astronomy, university groups are now undertaking a number of small but excellent projects: a 4 m diameter mm wave telescope of Nagoya University (located at Las Campanas, Chile), a 60 cm CO molecular line mapping telescope of the University of Tokyo (La Silla, Chile), a 1.2 m remote-operation sub-mm carbon atom line survey telescope of the University of Tokyo (atop Mt Fuji) etc, yielding a large amount of observational data for specific scientific subjects.

Developments in x-ray astronomy

HAKUCHO, the first Japanese x-ray satellite, was launched in 1979 by the INSTITUTE OF SPACE AND ASTRONAUTICAL SCIENCE (ISAS) under the leadership of Minoru Oda. Subsequent series of ISAS x-ray satellites, TENMA (1983), GINGA (1989) and ASUKA (1993) under the leadership of Yasuo Tanaka and his group, with their rich scientific results made Japanese x-ray astronomy one of the most productive in the world. Since the early identification of the x-ray source Sco-X1 with an evolved star using the balloon-borne x-ray telescope and the Okayama 188 cm telescope, efforts by ISAS and groups in universities in parallel with developments in space engineering have revealed the physics of dying stars and their energetic activities. ASUKA is a relatively small satellite (420 kg) but is actively continuing x-ray spectroscopic observations of various objects from star formation sites to clusters of galaxies in the very distant universe.

Solar x-ray observations have also been made by a successful collaboration of x-ray astronomy at ISAS and traditional solar physics at TAO/NAOJ. YOKO, launched in 1991 following the first Japanese solar x-ray satellite HINOTORI (1981), has been providing a tremendous number of x-ray images of the Sun and contributed to understanding of the physical process of energetic solar flares (project leaders: Yoshiaki Ogawara and Yutaka Uchida).

Recently ISAS developed the M-V rocket with a payload capability much higher than that of previous L-series rockets. The first launch of M-V was celebrated by the success of HARUKA/VSOP mentioned earlier. By using M-V, new astronomical projects such as Astro-E, IRIS and Solar-B are being promoted. Astro-E is a 1650 kg mass satellite with very high x-ray spectroscopic and imaging capabilities, to be launched in early 2000. Solar-B, a next-generation HINOTORI, is a 50 cm aperture optical solar telescope slated for 2004. IRIS is described below.

Developments in optical and IR astronomy

An 8.2 m aperture optical and IR telescope 'Subaru' atop Mauna Kea, Hawaii, started its test observations in early 1999 and will be opened to the astronomical community in late 2000. It is one of the new-generation telescopes with a large active-support primary mirror housed in a turbulence-suppressed cylindrical enclosure and has seven observational instruments that cover ultraviolet to mid-infrared ranges. Its high performance was demonstrated by stellar images with a full width at half-maximum of 0.2 arcsec and a number of spectacular scientific results through the test observation period. The construction of the SUBARU TELESCOPE, led by Keiichi Kodaira and later by Norio Kaifu and their group, started in 1991 as a 9 yr project of optical and IR astronomers of Japan.

Experience of Japanese optical astronomers has been mostly limited to the Okayama 188 cm telescope built in 1960 and the Kiso 105 cm Schmidt camera built in 1974. Infrared astronomers studied through the pioneering construction of the Agematsu 1 m IR telescope (1973) and observations with overseas telescopes led by Haruyuki Okuda and Shuji Sato. To build an engineering and technical basis for optical and infrared astronomy, the Advanced Technology Center was established at Mitaka campus of NAOJ headquarters. Close cooperation with university groups and industries was also organized for preparation, basic design and construction of the telescope and observing instruments. To overcome the lack of middle- to small-size modern telescopes and poor weather conditions in Japan, a 2 m IR telescope atop Haleakala, Hawaii, and a 1.2 m IR telescope in South Africa are being constructed by the University of Tokyo and by Nagoya University, respectively. Japan had never established a permanent governmental scientific facility abroad before the Subaru. NAOJ being a government organization, much effort was needed to overcome this hurdle and finally in 1997 the Subaru Telescope Facility was formally established in Big Island, Hawaii. Further progress toward internationalization is definitely needed for Japanese science and its future.

The Subaru Telescope, equipped with adaptive optics and versatile observational instruments, together with other new-generation telescopes such as VLT and GEMINI will embark on new frontiers including direct observations of extra-solar-system planets, detection of many small icy planetesimals orbiting beyond Pluto, observations of mysterious galactic nuclei, dark matter, distant clusters of galaxies and the youngest celestial bodies in the expanding universe.

Developments in other fields of astronomy and astrophysics

Recent major developments of experimental research in astrophysics in Japan include neutrino and gravitational wave astronomy. Kamiokande's neutrino detection from supernova SN1987A opened a new field of neutrino astrophysics. The Kamiokande (Kamioka, Japan) is a Cherenkov light detector initially built to detect proton decay (led by Masatoshi Koshiba and Yoji Totsuka). Because of the importance of neutrino observations, the Cosmic Ray Institute (CRI, University of Tokyo) constructed SUPER-KAMIOKANDE which is 10 times larger than Kamiokande with 50 kt of pure water in a tank 39 m in diameter and 41 m high, at the Kamioka site, 1 km underground. It confirmed the finite mass of the neutrino recently.

TAMA-300 is a Japanese pilot project in gravitational astronomy led by Yoshihide Kozai and joint groups of NAOJ and other institutes. The 300 m long L-shaped interferometer of TAMA-300 at Mitaka started operation in 1999. Its high sensitivity would make TAMA-300 able to detect gravitational waves for the first time, if they have fortunate events such as that for Kamiokande. As 3–4 km scale gravitational telescopes, LIGO of USA and VIRGO of France–Italy are to be commissioned within a few years; the Japanese gravitational telescope group is working on a further upgrade of TAMA-300.

AGASA, a large-aperture high-energy cosmic ray detector of CRI, is in operation at Akeno, Yamanashi, Japan. It aims to detect cosmic rays with extremely high energy ($>10^{20}$ eV) and identify their origin, which is still unknown.

Theoretical studies in Japan have kept their high level through the 1950s to the 1990s. The extensive studies of atmospheres of low-temperature stars by Takashi Tsuji, the discovery of a mathematical solution for a rotating black hole by Akira Tominaga and Fumitaka Sato, the inflationary universe theory of Katsuhiko Sato and the theory of supernova explosions of Daiichiro Sugimoto and Kenichi Nomoto are examples of prominent contributions among many active theoretical studies in Japan. The availability of powerful computers is also providing a strong basis for theoretical work in Japan.

Future plans

Encouraged by this remarkable progress, Japanese astronomers are discussing their ambitious future facilities. An immediate project of Japanese ground-based astronomy is LMSA, which was originally planned as a Japanese large mm and sub-mm array consisting of 50 antennas each 10 m in diameter aimed at a wide range of study from planetary formation to cosmology. In 1994 LMSA was recognized as the next national project strongly supported by the astronomical community of Japan and the search for a site started in parallel in Chilean dry plateaux. The 4800 m elevation Pampa La Bola near the Atacama desert was selected as the best site. At present radio astronomers of Japan, USA and Europe are intensively discussing the consolidation of their similar projects: LMSA, MMA (USA) and LMA (Europe). The unified world array, ALMA, will be a challenging mm and sub-mm wave telescope with 100-element antennas and 10 km maximum baseline. Such an interferometer would enable humankind to obtain high-quality images of a variety of cosmic phenomena with spatial resolution of 0.01 arcsec. Compared with the current highest angular resolution of 0.1 arcsec of the Hubble Space Telescope and new-generation optical–IR telescopes, the images will be ten times sharper. The ALMA project will be an equally shared triple cooperation by Japan, USA and European countries with a total cost of the order of 1 billion dollars. Astronomers wish to start the operation before 2010.

VERA (VLBI Exploration of Radio Astrometry) is a national plan for high-accuracy radio measurements of distances to stars throughout the Galaxy to obtain a '3D map' of the Galaxy for the first time. Mizusawa and the NRO VLBI group of NAOJ, collaborating with the University of Kagoshima and others, started the construction of VERA toward its operation within a few years, with possibilities of cooperation with Asian countries. A sensitive gravitational wave telescope with 3 km baseline is being planned by groups at the University of Tokyo, NAOJ and other institutes. If coordinated with LIGO and VIRGO, it will provide information on the direction of gravitational wave sources. The Telescope Array project, a plan to extend the aperture for detecting extremely high-energy cosmic rays to 60 times that of AGASA, is being promoted by CRI under collaboration with the University of Utah, Australian groups and other universities.

Space-borne astronomy is another major frontier for the future of Japanese astronomy. In addition to the above-mentioned plans Astro-E and Solar-B, ISAS will launch the IR Imaging Surveyor (IRIS) in 2003 as the first Japanese infrared astronomy satellite. It is a survey-type 70 cm aperture telescope cooled by a hybrid system of liquid helium and a refrigerator with high-sensitivity imaging arrays covering near-IR to far-IR wavelengths. The enormous amount of high-quality IRIS images would also be effectively used by combining them with the IR observations from Subaru and equivalent ground-based IR telescopes.

Even larger astronomical satellites using HII rockets developed by the NATIONAL SPACE DEVELOPMENT AGENCY (NASDA) are being discussed. SELENE, a lunar orbiting explorer for lunar science, will be launched in 2004 as the first attempt. A second version of SELENE including pilot astronomical observations from the lunar surface is under consideration. As an extension of the HII program, astronomers have been discussing extensively various plans for a Japanese space telescope. The H2L2 project is one such plan to launch a 3–4 m aperture cooled telescope to a Lagrange point for IR observations. The future of Japanese astronomy requires close and flexible cooperation among institutions such as NAOJ, ISAS, NASDA and CRI and universities.

Challenges Japanese astronomy is facing

Recent activities in astronomy and astrophysics, backed by a high level of industrial technology and economic power, have enabled Japan to advance and achieve considerably in this field of science. However, Japanese astronomy is still facing difficult situations compared with those in the USA and European countries.

The numbers of Japanese astronomers and related institutes are extremely low. They are concentrated at two institutes (NAOJ and ISAS) and four departments at universities (Universities of Tokyo, Kyoto, Nagoya and Tohoku). The number of the INTERNATIONAL ASTRONOMICAL UNION (IAU) members per million population of Japan is only 2 and Japan is ranked roughly the 24th among the IAU member nations. Compared with about a dozen of the top-rank countries, Japan is struggling to achieve the same level of astronomy with 1/4–1/5 as many astronomers. Although astronomy is one of the most popular subjects among university students, the number of faculty positions for astronomy is very low even now and for the majority of students astronomy courses are not available. Such a situation partially comes from the inflexible system of Japanese universities.

The operation of scientific organizations is also a subject for improvement. Employment, budget and accounting are tightly controlled by governmental regulations, which are often restrictive for scientific activities. It also causes difficulties in international cooperation or activities in different cultures and traditions of various countries. In 1998 the Japanese Parliament formally proposed an extensive reform of governmental organizations including national institutes, such as NAOJ and ISAS, and universities. The proposed plan includes possible improvements with respect to the difficulties

Japanese basic science is facing. The future of Japanese astronomy toward the 21st century will depend greatly on the outcome of this innovation.

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