dustry (MITI) is planning to organize a large-scale project in this field and to invest $200 million over the next 10 years. The Institute of Physical and Chemical Research (RIKEN), of the Science and Technology Agency (STA), is also organizing another project, although not on such a grand scale. Some private companies have also begun to move forward. For example, recent newspaper articles indicated that NEC Corporation has succeeded in creating bits with a diameter of 10 nm on a film of amorphous vanadium oxide with an STM tip. Such a report is encouraging for research on the material processing at the smallest scales.

REFERENCES AND NOTES

1. G. Binnig and H. Rohrer, *Helvetica Phys. Acta* **55**, 762 (1982); *Surf. Sci.* **126**, 236 (1983).
2. R. S. Becker, J. A. Golovchenko, B. S. Swartzentruber, *Nature* **325**, 419 (1987).
3. D. M. Eigler and E. K. Schweizer, *ibid.* **344**, 524 (1990); D. M. Eigler, C. P. Lutz, W. E. Rudge, *ibid.* **352**, 600 (1991).
4. S. Hosoki, S. Hosaka, T. Hasegawa, *Appl. Surf. Sci.*, in press.
5. A. Kobayashi, F. Grey, M. Aono, *Kagaku-Kogyo* (*Chemical Industry*) **28**, 944 (1991); M. Aono, A. Kobayashi, H. Uchida, H. Nejoh, E. Nomura, *J. Crystallog. Soc. Jpn.* **33**, 158 (1991).
6. A. Kobayashi, F. Grey, M. Aono, in preparation.
7. D.-H. Huang, H. Uchida, M. Aono, *Jpn. J. Appl. Phys.*, in press.
8. M. Iwatsuki, S. Kitamura, A. Mogami, *Proceedings of the XIIth International Congress for Electron Microscopy* (San Francisco Press, San Francisco, 1990), p. 322.
9. Y. Utsugi, *Nature* **347**, 747 (1990); *Nanotechnology*, in press.
10. H. Nejoh, *Nature* **353**, 640 (1991); ______ and M. Aono, *Mod. Phys. Lett.* **B6**, 187 (1992).
11. I.-W. Lyo and P. Avouris, *Science* **253**, 173 (1991); ______, B. Schubert, R. Hoffmann, *J. Phys. Chem.* **94**, 4400 (1990).
12. H. J. Mamin, paper presented at the Engineering Foundation Conference on Atomic & Nanoscale Modification of Materials, Ventura, CA, August 1992.

Astronomy in Japan

Yasuo Tanaka

For a long time, the Japanese astronomy community has remained small relative to the physics community, while the latter has steadily expanded. International activities, in particular, have been limited to individual scientists rather than larger institutional groups. A radical change in this trend has occurred over the last 20 years. During this time, radio astronomy and x-ray astronomy have grown strongly. These new fields, including the still newer field of neutrino astronomy, have prompted an internationalization of Japanese astronomy.

A major advance in Japanese radio astronomy took place when a 45-m telescope was completed in 1982 at the Nobeyama Radio Observatory (NRO), about 100 km west of Tokyo. At present, the NRO belongs to the National Astronomy Observatory (NAO), an interuniversity institute. Six 10-m telescopes to constitute a mm-wave interferometer were also installed. This 45-m dish facility is still the largest mm-wave telescope in the world, and it is widely used by international observers.

Among the many objectives addressed by these telescopes, the following are two examples of the major achievements. Star-forming regions have been extensively investigated, and important results about the nature of protostars have been obtained. Innovative acousto-optical spectrometers (*1*) at Nobeyama played a powerful role in the discovery of numerous molecular species in the interstellar clouds, some of which do not exist on the Earth. In addition to the Nobeyama Observatory, a Nagoya University group built its own mm-wave telescopes and is actively conducting investigations, including sky mapping in the wavelength of a carbon monoxide line.

Japanese radio astronomers are not content with their present success, and they have ambitious plans for the future. A large mm-wave interferometer array (LMA) and an extension to submillimeter astronomy would be their next steps, in addition to the space very long baseline interferometry (VLBI) project currently in preparation (see below).

Japanese astronomy from space is relatively young but has been developing vigorously. The Institute of Space and Astronautical Science (ISAS), an interuniversity institute, is responsible for implementing space research programs for the Japanese space science community. Scientists from all over the country participate in the preparation, operation, and data processing in each ISAS mission. ISAS has developed its own launch vehicle, the Mu-rocket, of modest payload capability. With this tool, ISAS has maintained a regular launch pace of one mission per year. Although ISAS missions are modest in scale, we believe that regular opportunities are essential for healthy development and that modest missions can perform frontier research well if they are given unique capabilities. In the area of astronomy, ISAS has launched two solar physics satellites and three x-ray astronomy satellites so far.

With these satellites, x-ray astronomy in Japan achieved rapid growth after a late start. The first satellite, Hakucho (1979), was launched 10 years after the U.S. x-ray astronomy satellite UHURU, and was a small spinning satellite weighing less than 100 kg. The second, Tenma (1983), was several times more sensitive, and the third, Ginga (1987), was a real x-ray astronomy observatory at an international level, equipped with a 4000-cm^2 x-ray detector array (one of the largest of its kind) jointly developed with the U.K. scientists. Ginga was used for a great many observations of virtually all classes of astronomical objects, from nearby stars to distant quasars, during its orbital life of nearly five years.

Still fresh in our memory is supernova 1987A in the Large Magellanic Cloud, which occurred less than 3 weeks after the launch of Ginga. At that very moment, the Japanese neutrino detector in Kamioka (see below) detected a burst of neutrinos from the supernova (*2*). The detection of neutrinos from this supernova marks a turning point in the history of astronomy. We immediately began observation of the supernova with Ginga, and anxiously watched for x-rays emergent through the expanding debris. In late August, we confirmed the emission of x-rays from the supernova (*3*). Later analysis showed that x-rays had become visible already in July, several months earlier than theoretically predicted. This implied large-scale turbulence inside the bursting star. With these two observations, Japanese astronomy made leading contributions to the dramatic advance of supernova astrophysics.

Ginga yielded exciting results in other areas as well. Cyclotron resonance features were found in the spectra of gamma-ray bursts (*4*). The implied magnetic field of $\sim 2 \times 10^{12}$ Gauss strongly suggests a neutron-star origin of gamma-ray bursts. Several bright transients suspected to be black hole binaries were discovered (*5*). The detailed study of them gave us much better insight into the common properties of the black hole candidates. And many active galactic nuclei, including a number of quasars, were newly observed. Their time variabilities and wide-band spectra have been extensively studied.

At the same time Ginga demonstrated the increasing international involvement of overseas scientists in Japan. Nearly 50% of the time of Ginga has been made available to foreign investigators, mostly from the United Kingdom, the United States, and European countries. These international collaborations have stimulated young Japanese astronomers, and have established

The author is at the Institute of Space and Astronautical Science, Kanagawa 229, Japan.

good working relationships.

Imaging and spectroscopy become important as any field of astronomy matures, and x-ray astronomy is no exception. The fourth Japanese x-ray astronomy mission, Astro-D, is a high-sensitivity imaging and spectroscopy mission scheduled for launch in February 1993. With its larger telescope aperture and a wider energy band, 0.5 to 10 keV, Astro-D is a significant improvement in capability as compared to previous imaging missions such as the Einstein Observatory and ROSAT. This mission includes an extensive collaboration with the U.S. scientists. In particular, the x-ray telescopes and CCD imagers with high spectral resolution are jointly developed with the NASA/GSFC group and MIT group, respectively. After launch, much of the Astro-D observing time will be open to international observers.

As an advanced x-ray astronomy observatory, Astro-D will explore new frontiers of astronomy. In particular, this is the first time that x-ray spectroscopic studies will be performed. In fact, the characteristic x-ray lines and absorption edges are known to be present in the spectra of many galactic and extragalactic sources. More accurate measurements of these with Astro-D will deepen our insight into the nature of x-ray sources. Furthermore, with its high sensitivity, Astro-D should be able to reach the deepest universe, comparable to the range of large optical telescopes. Its observations might tell us what lies beyond quasars.

X-ray vision: Astro-D scheduled for launch in February 1993.

In the area of solar physics, the Yohkoh mission (1991), following Hinotori (1981), has been a great success [see the article by Acton *et al.* in this issue (6)]. Among other instruments on Yohkoh, a CCD soft x-ray telescope (collaboration with the Lockheed group in the United States) and a Fourier synthesis hard x-ray imager were flown for the first time. These instruments continuously send spectacular images of the x-ray sun with unprecedented quality and sampling (every 2 s during flaring). These images show vividly the complex configurations of the solar magnetic fields and their motions and the heating and ejection of plasma. The international team of scientists analyzing Yohkoh data believe that the high-energy imaging, together with spectroscopic and photometric data, is bringing revolutionary advances to solar physics research.

In parallel with the Yohkoh mission, a large cm-wave radioheliograph, an interferometer consisting of 84 80-cm dishes, has been built at Nobeyama and recently began observations. This advanced facility with a spatial resolution of 10 arc sec and a time resolution of 50 msec will provide crucial diagnostic information of energetic solar phenomena complementary to the data obtained from Yohkoh.

Another challenging project is space radio interferometry, under preparation at ISAS in close cooperation with the radio astronomy community. Space-based interferometry has great potential for unlimited baseline length. The new mission, "VSOP" (VLBI space observatory project), will place an 8-m radio telescope in an elliptical orbit with an apogee of three earth radii using the first next-generation ISAS rocket, M-V, in the middle of this decade. NASA will provide dedicated ground stations for this mission. Virtually all large radio telescopes in the world will participate in this first space VLBI observatory. If this mission is successful, the scientific objectives are numerous, such as the structure of active galactic nuclei. It may lead to the opening of a new era in radio astronomy.

In 1983 a group of physicists constructed a major neutrino detector facility for the study of proton decay deep underground in Kamioka. Their interests have extended to neutrino astrophysics. The timely occurrence of SN1987A and the resulting neutrino burst detection at Kamioka had an enormous scientific impact (2). Without reservation, the entire world recognized this as the birth of neutrino astronomy. Another important result from the Kamioka neutrino detection experiment, "Kamiokande," is the measurement of the solar neutrino flux by use of its capability of determining the incident direction. This has turned out to be less than half of that predicted from the standard solar model, confirming the previous result of the Homestake Mine experiment (7). This discrepancy is a problem of outstanding importance to be clarified by future experiments.

The present Kamioka facility of the Institute for Cosmic Ray Research consists of 4500 m^3 of water as a target of neutrino interaction. A new "Super-Kamiokande" with ten times the water volume is presently under construction. This new facility will not only continue to push the limits for proton decay but will also expand the scope of neutrino astronomy significantly.

As compared to these newer fields of astronomy, optical astronomy in Japan has long been hampered by the lack of a large modern telescope. With a 1.88-m telescope still being the largest, astronomers have had to find opportunities for observation at larger telescopes abroad. After a number of preparatory steps since the late seventies, including the recent foundation of the NAO, Japanese optical astronomers decided to build a modern 8-m telescope at Mauna Kea, Hawaii. This will be the first time that a major observing facility will have been placed outside the country. The funding for this facility started last year. This telescope (named "Subaru," or Pleiades) will have wide infrared coverage and will incorporate new technologies, such as adaptive optics and state-of-the-art focal plane instruments. It will, therefore, become one of the more advanced telescopes in the world. When completed, it will allow the Japanese optical astronomy community, the largest subgroup, to make an enormous jump in capability.

Traditionally, astronomers have had an individualistic style of research. However, the trend in modern astronomical research resembles that in other big sciences. Astronomers in Japan are quickly adapting themselves to this trend, realizing the need for and power of cooperation. I notice remarkable changes in recent Japanese astronomy: intense multidisciplinary interactions are occurring among workers across all wavelength bands and involving the theoretical community. There is a steady increase of international cooperation, and, to our great encouragement, a steady increase in the number of graduate students in astronomy.

REFERENCES

1. N. Kaifu *et al.*, *NRO Rep. No. 3* (Nobeyama Radio Observatory, 1980); N. Kaifu, *NRO Rep. No. 4* (Nobeyama Radio Observatory, 1980).
2. K. Hirata *et al.*, *Phys. Rev. Lett.* **58**, 1490 (1987); *Phys. Rev. D* **38**, 448 (1988).
3. T. Dotani *et al.*, *Nature* **330**, 230 (1987).
4. T. Murakami *et al.*, *ibid.* **335**, 234 (1988).
5. Y. Tanaka, in *Proceedings of the Ginga Memorial Symposium* (Institute of Space and Astronautical Science, Kanagawa, Japan), p. 19.
6. L. Acton *et al.*, *Science* **258**, 618 (1992).
7. K. Hirata *et al.*, *Phys. Rev. D* **44**, 2241 (1992); K. Nakamura, in Proceedings of the 15th International Conference on Neutrino Physics and Astrophysics, *Nucl. Phys. B* (spec. suppl.) (1992).