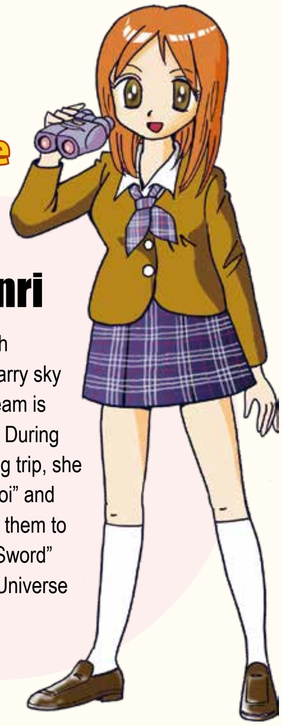
アルマーの冒険 ALMAr ALMAr's Adventure

Issue 06 "The History of Radio Astronomy 02"

The previous issue explained how Jansky discovered radio waves coming from space by accident, and how Reber had conducted the first astronomical observations using radio waves. This time, we trace the development of Japanese radio astronomy.

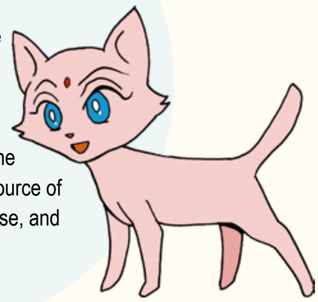


Nao Senri

A Junior at Souten High School. She loves the starry sky and the Universe. Her dream is to become an astronomer. During an astronomy club camping trip, she meets "ALMAr" and "Izayoi" and starts an adventure with them to find "Grand ALMAr's Sword" to save the Radio Universe from danger.

ALMAr

A dragon-child who came to the Visible Light Universe from the Radio Universe. He passed out after being showered by mysterious radio interference known as "Jamming" which poses a threat to the Radio Universe. While he was unconscious, a 9-headed dragon appeared to him and said, "Seek out Grand ALMAr's Sword to protect the Radio Universe." When he awoke, he was in a grassy field in the Nobeyama highlands.

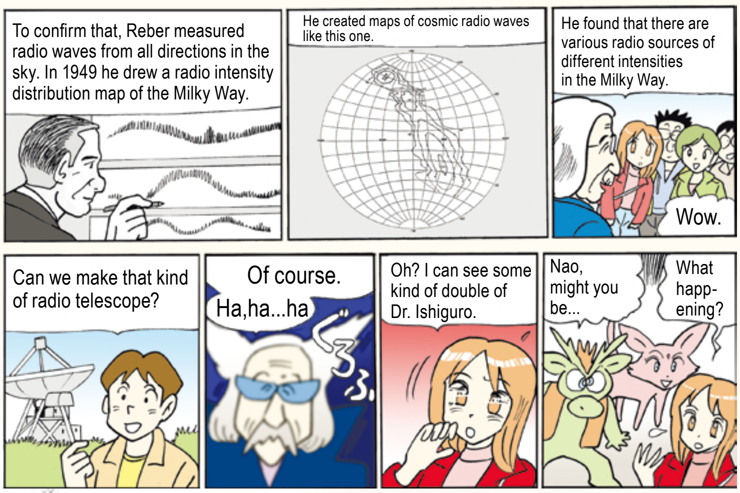


Izayoi

A mysterious female cat who appeared in front of Nao and ALAMr. She has the special ability to see both the Visible Light World and the Radio World. She possesses a rich knowledge of both the Radio Universe and the Visible Light Universe. Somehow she knows about ALMAr's past, the source of the danger to the Radio Universe, and Grand ALMAr's Sword...

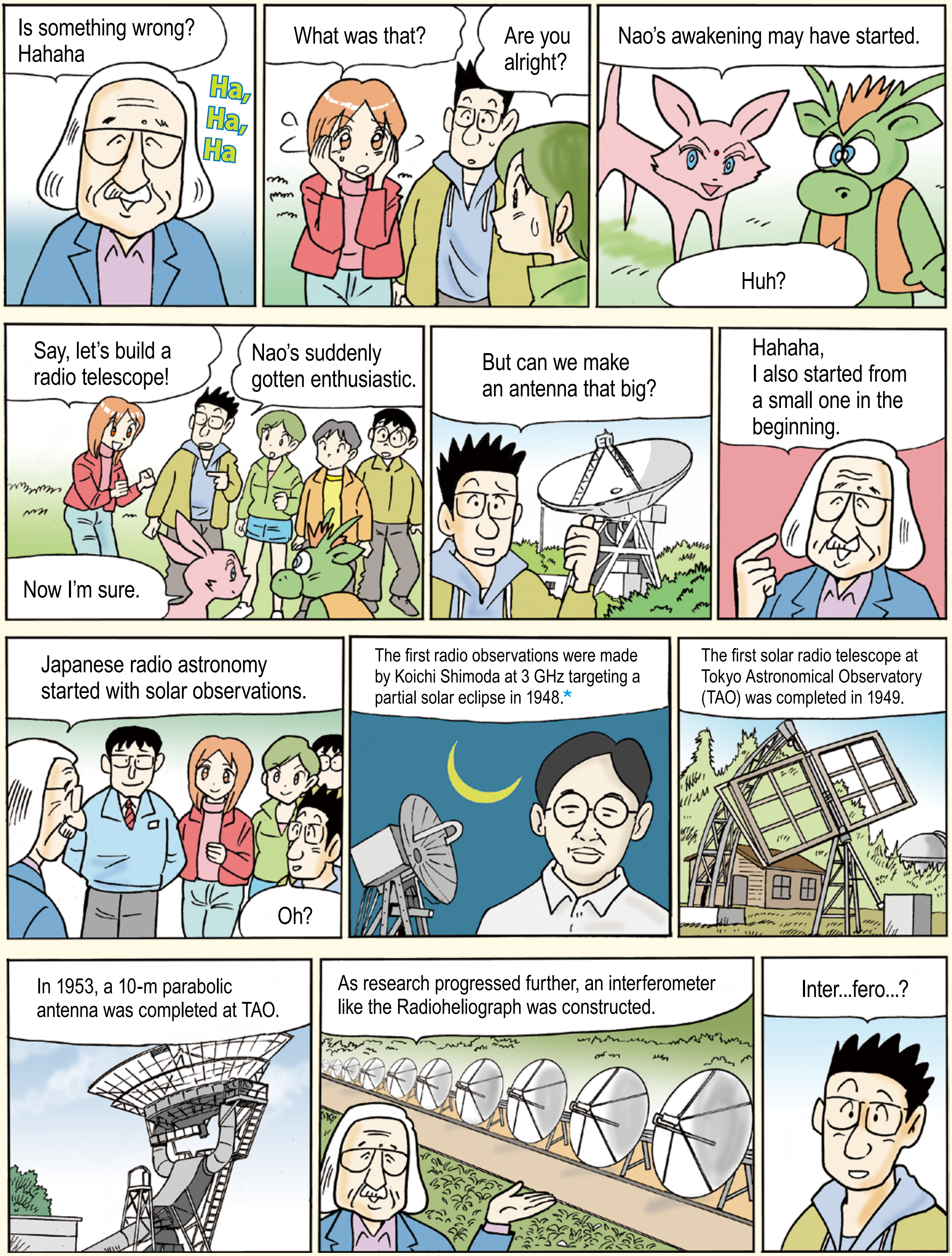
★ Summary up through the previous issue, Issue 05 "The History of Radio Astronomy"

After a tour of the Nobeyama Solar Radio Observatory Radioheliograph, Nao Senri and the other members of the Soten "Deep Blue Sky" High School astronomy club met Dr. Masato Ishiguro, a famous radio astronomer. Dr. Ishiguro talked about how cosmic radio waves were discovered by accident and how after that observations using a radio telescope started. Then suddenly it looked to Nao like there was another person superimposed over Dr. Ishiguro. Izayoi realized that Nao's powers are awakening.



Front Page Photo: Various radio telescopes located in Tokyo Astronomical Observatory in the 1960's. The cross-shaped antenna on the left is the rhombic antenna spectrograph. The large parabola visible in the center is the 10-m Equatorial Solar Radio Telescope. The small parabolas lined up on the right are the 8 antennas of 1.2 m diameter forming the 17 GHz transit (fixed direction) style interferometer.

Chapter 6-1: Japanese Radio Astronomy started from Solar Observations



*References
1) Masato Ishiguro et al., HIGHLIGHTING THE HISTORY OF JAPANESE RADIO ASTRONOMY. 1: AN INTRODUCTION, Journal of Astronomical History and Heritage, 15(3), 213-231 (2012).
2) Koichi Shimoda, et al., HIGHLIGHTING THE HISTORY OF JAPANESE RADIO ASTRONOMY. 2: KOICHI SHIMODA AND THE 1948 SOLAR ECLIPSE, Journal of Astronomical History and Heritage, 16(2), 98-106 (2013).

The Dawn of Japanese Radio Astronomy

As an attempt at radio astronomy, observations of the Sun started in Japan. This was right after the end of World War II.

• Japanese Radio Astronomy Started with the Sun

During World War II, the English physicist James Hey was involved in developing radar technology to detect rockets flying from Germany. He noticed that when the radar detection direction was pointed near the Sun, the noise increased. This led to the discovery of solar radio waves. Solar radio waves were affecting the radar.

Figure 01: 1949, the beginning of 200 MHz intensity observations. Eight dipole antennas were arrayed on the approximately 5 m x 2.5 m wooden frame. It seems the equatorial mount was repurposed from one used in an optical telescope.

Records show that in Japan on May 9, 1948, only 3 years after the end of World War II, the physicist Koichi Shimoda observed 3 GHz radio waves during a partial solar eclipse. In the following year, 1949, a radio telescope for solar radio observations was constructed, at Tokyo Astronomical Observatory (the predecessor of the modern National Astronomical Observatory of Japan) located in Mitaka City Tokyo. Takeo Hatanaka began observations of the Sun at 200 MHz using an array of dipole antennas in cooperation with the Radio Research Laboratories (a precursor of the modern National Institute of Information and Communications Technology) (Figure 01). At about the same time, a group at Osaka University led by Minoru Oda and Tatsuo Takakura conducted solar radio wave observations at 3300 MHz. And at Nagoya University, the Research Institute of Atmospherics was established in Toyokawa City, Aichi Prefecture and a group led by Haruo Tanaka observed solar radio waves in the microwave region starting from the beginning of the 1950's. This group used a 2.5-m parabolic antenna (Figure 02).

At Tokyo Astronomical Observatory (TAO), observations at 3 GHz were undertaken using a 2-m parabolic antenna completed in 1952, and then an equatorial fork mount style 10-m parabolic antenna was completed in 1953 (Figure 03).

The first multi-antenna radio interferometer in Japan was erected in 1953 at the Research Institute of Atmospherics. Five parabolic antennas with diameters of 1.5 m were aligned and began observing the Sun at 4 GHz. Furthermore, the largest-scale interferometer systems in the world at 9.4 and 3.75 GHZ were constructed with 100 antennas in total and were operated over an extended period.

• Observation Diversification and Consolidation of Solar Radio Research Institutions

From the 1950's to the 1960's, the observed wavelength bands expanded and the observation techniques also diversified into interferometry and polarimetry. Due to this combination, antennas of various sizes and configurations continued to be constructed. Researchers anticipated being able to create high angular resolution images of the solar disk with interferometers and resolve the solar magnetic field through polarimetry.

Figure 02: 1951, the 2.5-m antenna of the Research Institute of Atmospherics (Toyokawa, Toyohashi City) and Haruo Tanaka.

Figure 03: 1953, the start of 3 GHz observations using a 10-m parabolic antenna in Mitaka (refer to the front page as well).

Figure 04: 1970, the start of observations at 17 GHz and 160 MHz from Nobeyama.

At the Research Institute of Atmospherics in 1969, a total of 50 parabolic antennas were arranged in a "T" shaped array to begin observations at 9.4 GHz. In addition, the Nobeyama Solar Radio Observatory (Minamimaki, Nobeyama Prefecture) was established and started observations with 17 GHz and 160 MHz interferometers in 1970. At 17 GHz, twelve 1.2-m parabolic antennas were deployed. And at 160 MHz, eight 6-m and three 8-m antennas were arrayed from east to west and six 6-m antennas were arranged north to south (Figure 04).

Furthermore, to support the field of cosmic radio wave observations, the Nobeyama Radio Observatory was established in 1982 and then the Nobeyama 45-m Radio Telescope and the the Nobeyama Millimeter Array with six 10-m parabolic antennas were completed in succession, making Nobeyama one of the premier locations for radio astronomy.

In 1988 the National Astronomical Observatory of Japan (NAOJ) was established, and the relevant positions, including the Solar Radio Division of the Research Institute of Atmospherics were transferred to NAOJ. Thus the two large research institutes advancing Japanese solar radio research were merged.

Figure 05: 1992, completion of the Radioheliograph.and Haruo Tanaka.

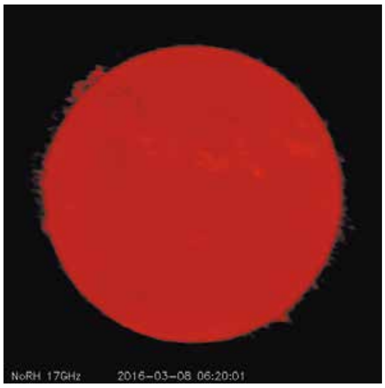
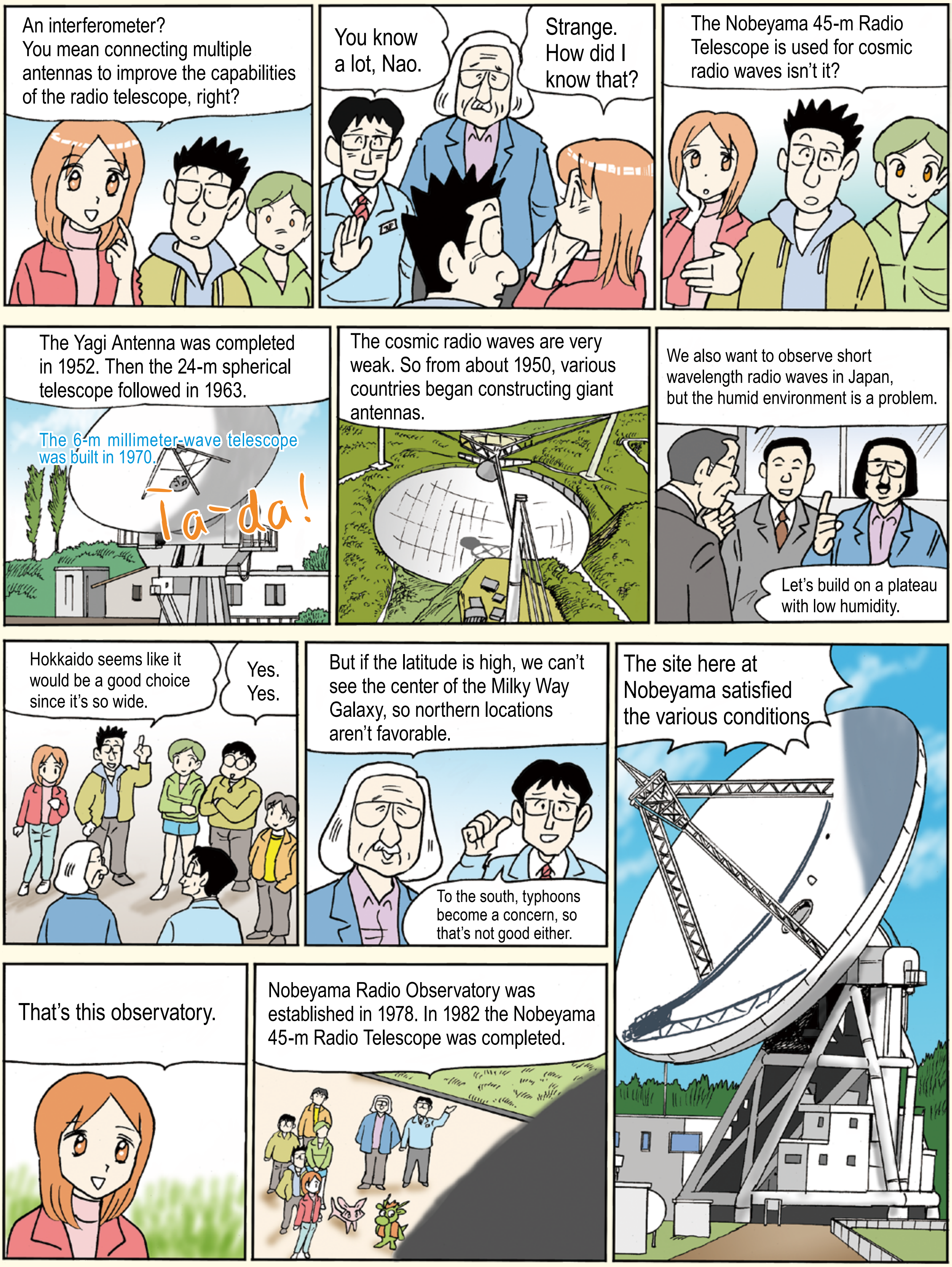


Figure 06: An image of the solar disk taken by the Radioheliograph.

Many of the antennas established at the Research Institute of Atmospherics were also relocated from Toyokawa to Nobeyama Radio Observatory. With the antennas transferred from Toyokawa added to the polarimeter antennas to observe explosive phenomena on the solar surface (bursts) and others already observing 3 frequency bands in Nobeyama, all told 7 frequency bands could be monitored simultaneously. In addition the Radioheliograph, an interferometer dedicated to solar observations composed of 84 parabolic antennas 80 cm in diameter arranged in a "T" shape, was completed in 1992 (Figure 05). The Radioheliograph can produce high-angular-resolution images of the surface of the Sun via radio waves in almost real time, making it a world-class system (Figure 06).

In this manner, Japanese observations of the Sun via radio waves steadily accumulated successes. In 2015, Nobeyama Solar Radio Observatory's mission concluded, but the polarimeter antennas were transferred to Nobeyama Radio Observatory and the Radioheliograph was taken over by an international consortium led by Nagoya University's Solar-Terrestrial Environment Laboratory (now the Institute for Space-Earth Environmental Research), so that they continue to conduct observations of the Sun. [Update: The Radioheliograph ceased operation in 2020.]

Chapter 6-2: Observing Cosmic Radio Waves with Giant Parabolic Antennas



World Leading Cosmic Radio Wave Observations at Millimeter Wavelengths

A 45-m Radio Telescope and a Millimeter Array were Constructed in Nobeyama
with the Slogan “Let’s build the largest telescope in the world!” and a variety of discoveries have followed.

• A New Frontier that Other Nations Couldn’t Explore, Japan’s Cosmic Radio Wave Observations Advanced into Millimeter Waves

Because there is a variety of observational targets and their radio waves are weak compared to the Sun, the study of cosmic radio waves was somewhat delayed after the start of solar radio observations.

Overseas, in the first half of the 1950’s, 20 meter class parabolic antennas began observations; and in the United States, United Kingdom, and Australia large radio telescope construction projects went forward. At this time in the world, new discoveries were coming one after another: the 21 cm emissions by hydrogen atoms, the confirmation that synchrotron radiation is one possible method of radio wave generation, etc.

In Japan plans for a fixed, spherical reflector, 200-m antenna were conceived. As a test for that antenna, Kenji Akabane et al. established a 24-m spherical reflector antenna inside TAO in 1963. This helped to advance observational instrument research and development, but unfortunately a giant antenna was not forthcoming (Figure 07).

Figure 07: 1970, the 6-m millimeter-wave radio telescope built in Mitaka. The fixed-mount 24-m radio telescope is visible in the background to the right.

In 1966, the “Large Radio Telescope Working Group” was established with the slogan "Let's build the largest telescope in the world!” and planning for a 45-m telescope and a millimeter array commenced. A parabolic antenna demanded a high surface accuracy but would enable observations of quasars, interstellar molecules, and star forming regions at millimeter waves, shorter than the wavelengths observed up until then. There were two trends in the field of radio astronomy at that time: capturing high resolution radio images via large-scale radio interferometers, and observation of shorter wavelengths with large antennas. But Japan chose to take on the challenge of millimeter wave observations for which there was little precedent, even overseas.

● Completion of the World’s Largest Millimeter-Wave Radio Telescope

Having set their sights on completing a large-scale radio telescope, Japanese astronomers worked to develop instruments and techniques for observations; for example they once borrowed a large parabolic communications antenna to conduct radio observations of the Milky Way. At the same time, they built radio telescopes that although small were specially designed to observe cosmic radio waves. There was a 6-m millimeter-wave telescope (Figure 07). This 6-m parabolic antenna was set up at TAO in Mitaka in 1970. At this time there were very few radio telescopes worldwide that could observe millimeter waves. Radio spectra observations by Masaki Morimoto, Norio Kaifu, and others with this 6-m millimeter-wave telescope discovered spectra from many interstellar molecules such as paraformaldehyde and methylamine.

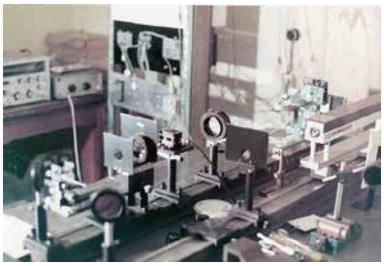


Figure 08: The 128 channel prototype for the first acousto-optical radiospectrometer in the world for cosmic radio waves (1976). It was used for observations on the 6-m millimeter-wave radio telescope and became the model for the Nobeyama 45-m Radio Telescope’s large-scale radio spectrometer.

Figure 09: The Nobeyama 45-m Radio Telescope during construction. Completed in 1982 (Current picture shown on the right).

Figure 10: (Left) The large acousto-optical radiospectrometer (AOS) for the Nobeyama 45-m Radio Telescope. 32,000 channels, maximum bandwidth 2 GHz. For 30 years after the start of observations, it yielded many discoveries as the largest radiospectrometer in the world. (Right) the new digital spectrometer now in use, SAM45.

In the plan for the large radio telescopes, more than astronomy research, many new technologies needed to be developed. For this reason, concurrent with the progress on the antenna body itself, advances were also made on the design of a pedestal to control the body with high accuracy and the development of high-sensitivity, low-noise receivers. Also Minamimaki Village, where the Nobeyama Solar Radio Observatory was already located, was chosen as the construction site. In 1978, Nobeyama Cosmic Radio Observatory (one of the precursors of Nobeyama Radio Observatory) was founded.

And in 1982 the 45-m Radio Telescope was finally completed (Figure 09). Thanks to new technologies for the giant antenna face to be maintained with high accuracy and the development of original high-accuracy receivers and a radio spectrometer, many important astronomical discoveries followed: observational confirmation of molecules floating in interstellar-space and a supermassive black hole, etc. (Figures 10, 11).

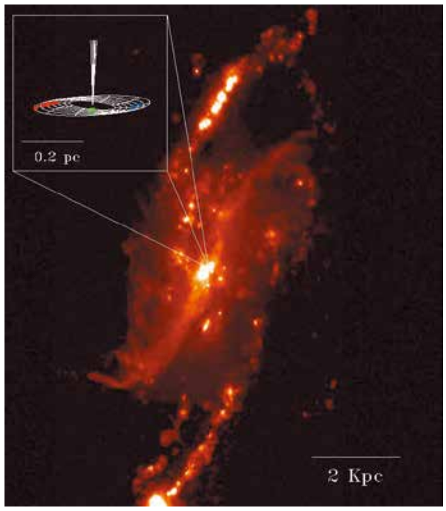
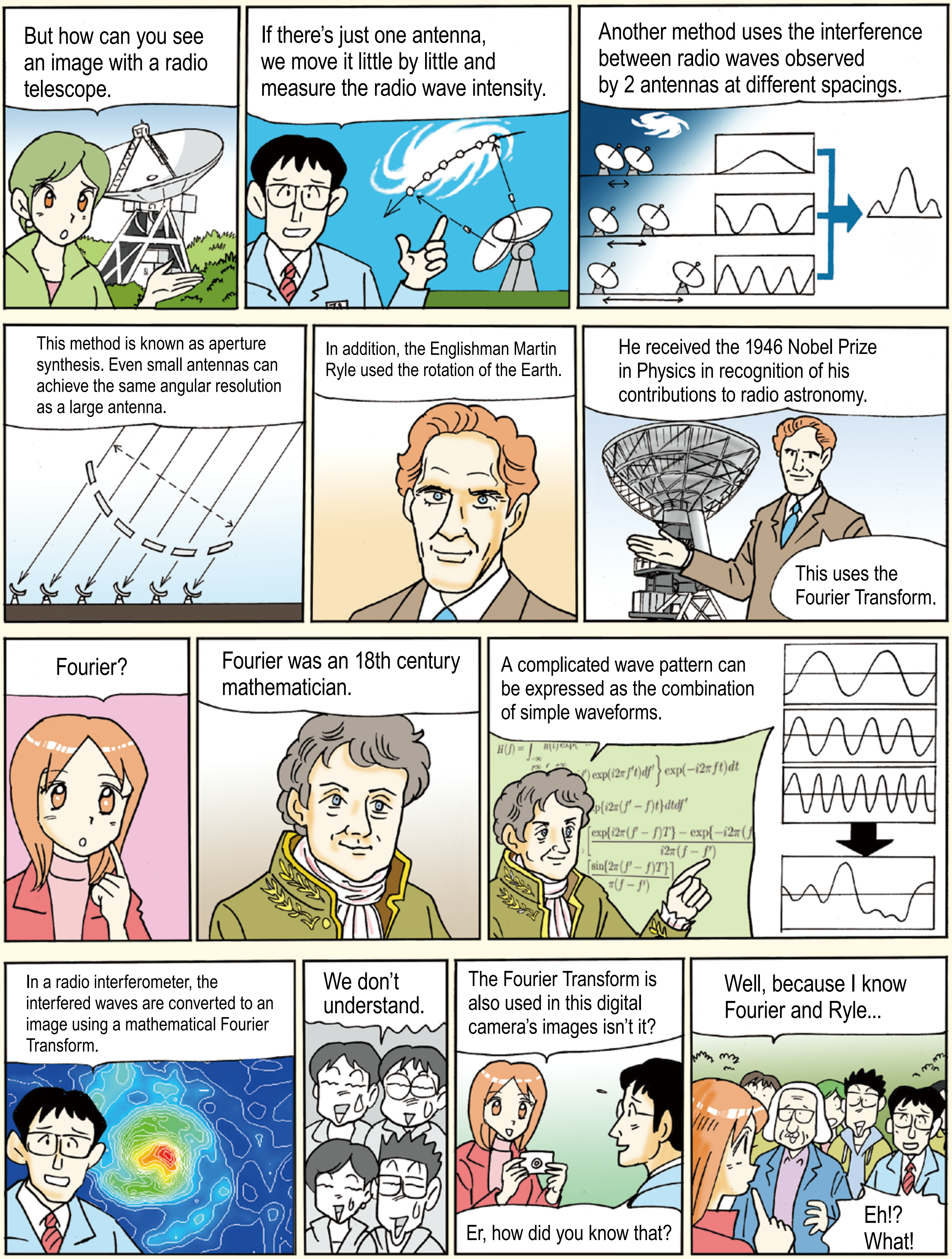


Figure 11: An extremely high-speed (3.6 million km/h) water maser (22 GHz) coming from the center of galaxy M106 was discovered in observations by Naomasa Nakai (now at Kwansei Gakuin University) using the 45-m radio telescope. Later, this was interpreted as the first evidence for a supermassive black hole in the galactic nucleus. This black hole is thought to be 39 million solar masses. A maser is radio waves with the same properties (coherence) as laser light.

Chapter 6-3: How to Make a Picture of a Celestial Object with Radio Waves



Interferometers Overcome the Shortcomings of Radio Telescopes

Building interferometers that can observe the finer details of celestial objects, even in millimeter waves.
What's more, and interferometer using an artificial satellite was achieved.

● Undertaking Millimeter-Wave Interferometers that can Observe Cosmic Radio Waves

At Nobeyama, a plan advanced to build a millimeter-wave interferometer with 10-m antennas concurrently with the 45-m radio telescope. Five (and later six) 10-m parabolic antennas moved along rails hundreds of meters long to conduct observations. Masato Ishikuro and Koichiro Morita, solar radio interferometer experts, moved to Nobeyama from the Research Institute of Atmospherics for the construction (Figure 12).

Figure 12: The Nobeyama Millimeter Array which began observations in 1982.

Even worldwide, interferometers had only been able to achieve observations at wavelengths longer than 2 cm. The millimeter-wave interferometer project targeting much shorter wavelengths was ambitious for Japan. It started observations a few months after the 45-m radio telescope. This telescope also produced many results, such as observations of protoplanetary disks which are the sites of planet formation. In addition, when combined with the 45-m radio telescope to form a 7 antenna array, it could achieve high accuracy observations as a "rainbow interferometer."

Nobeyama Radio Observatory started out like this over 30 years ago, and has produced a variety of results. Continuing improvements have been made to the 45-m radio telescope, to this day it is active on the forefront of millimeter wave observations. Operation of the millimeter-wave interferometer has concluded, but its mission is being continued by the grander-scale radio interferometer ALMA (Figure 14).

Figure 13: The Karl Jansky VLA (Very Large Array), shown here during observations, is composed of 27 antennas with diameters of 25 m each, arranged in a "Y" pattern.*

Figure 14: With 66 antennas having diameters of 12 m or 7 m, ALMA, of which Japan is a member, has the world's best performance among radio interferometers observing at millimeter and submillimeter wavelengths.

● VLBI using a Space-borne Antenna as an Element

In radio interferometry, the farther the 2 antennas are separated, the higher the resolution with which the shapes of celestial objects can be imaged. It would be impossible to connect the antennas directly with cables over global distances. So a method was designed to make maximum use of the fact that radio is a wave phenomenon. In this method, the waves are recorded as digital data and brought together. This method of constructing a radio interferometer from antennas very distant from each other is known as Very Long Baseline Interferometry (VLBI).

*Photo credit: NRAO/AUI/NSF

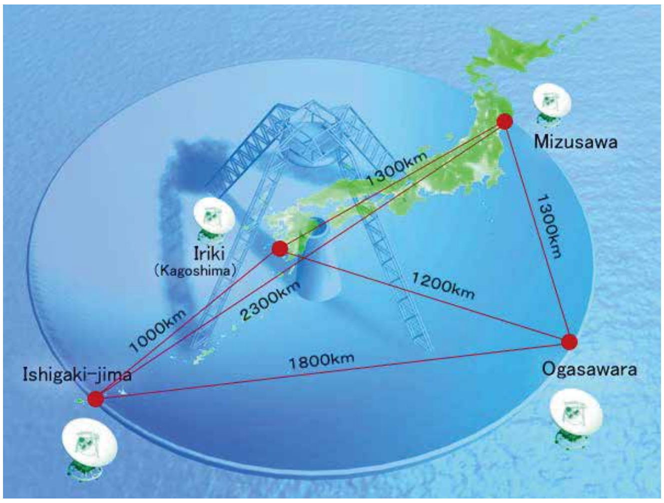


Figure 15: With antennas located at 4 locations across Japan, VERA obtains a resolution equivalent to a 2300 km diameter telescope. VERA is a project to obtain a 3-dimensional map of the Milky Way.

Of course, in order to cause the radio waves coming from the celestial objects to interfere, the data need to have been taken at the same time. Therefore, they are syncronized with atomic clocks which keep time extremely accurately. The time change of the radio waves is converted to an electronic signal and recorded as data.

Since there's no limitation on the distance, NAOJ uses 20-m parabolic antennas placed in 4 locations, Mizusawa (Iwate), Ogasawara (Tokyo), Iriki (Kagoshima), and Ishigaki Island (Okinawa), for the VERA (VLBI Exploration of Radio Astrometry) Project to map the 3-dimensional structure of the Galaxy (Figure 15). In addition, observations are conducted through the Japanese VLBI Network through cooperation with research institutions, primarily universities. Collaborative international test observations have also started to in order to realize a radio telescope with a diameter of 6000 km through the East Asia VLBI Network, a cooperation between radio telescopes in East Asia.

VLBI is not limited to ground-based antennas. It is also possible to launch antennas into space to form a radio interferometer. Japan launched the world-class, leading-edge satellite "HALCA" in 1997. As HALCA orbited around the Earth, it performed observations as the 30,000 km diameter radio telescope VSOP, in combination with multiple antennas around the world (Figure 16).

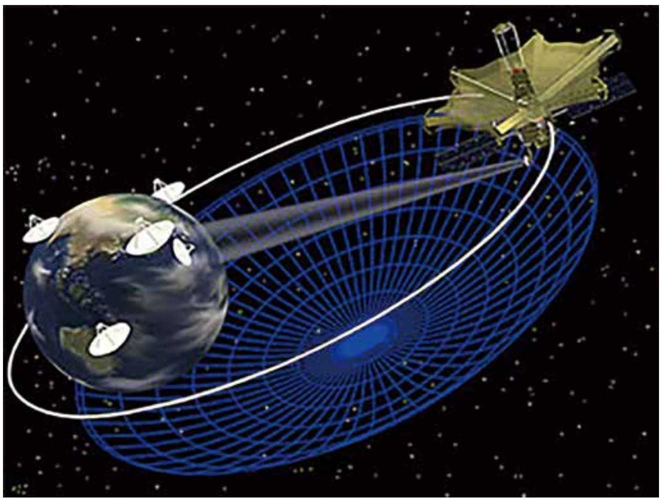


Figure 16: The radio observations satellite "HALCA" launched in 1997 combined with ground-based antennas formed an interferometer equivalent to a 30,000 km antenna.

● Nurturing Future Radio Astronomers

Japanese radio astronomers shouldn't forget the existence of universities nurturing the next generation of radio astronomers. In addition to the University of Tokyo which has studied radio astronomy since the beginning, now Ibaraki University, Gifu University, Yamaguchi University, and Kagoshima University have large radio telescopes, forming the Japanese VLBI Network (JVN). They also have astronomy related curriculum. In addition, Nagoya University independently established its own 4-m millimeter-wave telescope in the Chilean highlands, and is producing many research results with it. Also, WASEDA University has established 8 antennas with 20 m spherical surfaces and a single 30-m spherical antenna in Nasu to conduct pulsar research. There are also many universities which don't have their own observational equipment, but actively pursue research using radio telescopes operated by NAOJ or others.

Figure 17: Kagoshima University 6-m Radio Telescope. This was the 6-m millimeter-wave radio telescope located in Mitaka Campus (Figure 07, see also image below). It was relocated to Kagoshima in 1970. In 2018 it retired and returned to Mitaka.

Sojiro Norizuki, the Man who made over 350 Radio Telescopes

To observe celestial objects in radio waves, first you need to construct radio telescopes. At first radio telescopes were handmade by astronomers or researchers, but that wasn't feasible as radio telescopes got larger. In truth, there was a man who built many radio telescopes and supported the astronomers at the dawn of Japanese radio astronomy: Sojiro Norizuki, who managed an ironworks in Yaizu City, Shizuoka Prefecture.

Norizuki was born in Wada Village (modern Yaizu City) in Shizuoka Prefecture in 1912. When he graduated from what was high school at that time (now junior-high school), he worked as a blacksmith's apprentice. After that he joined an ironworks, and at age 25 started his own company Norizuki Ironworks (later renamed Norizuki Technical Factory).

In 1949, Norizuki started construction of the first Japanese equatorial-mount radio telescope at the request of the Research Institute of Atmospherics, Nagoya University. The 2.5-m parabolic antenna was delivered two years later, in 1951. After that, he supplied many radio telescopes for not just the Research Institute of Atmospherics, but also for NAOJ and other Japanese research organizations. There is an anecdote that when Japan started to seriously pursue radio astronomy, the international community thought that Japan could not produce high accuracy antennas, so as they saw the Research Institute of Atmospherics erect one antenna after another, a rumor started among overseas researchers that "the Research Institute of Atmospherics must have a secret factory."

The radio telescopes Norizuki made were not just high accuracy and high quality, but also low cost, so many radio astronomers placed orders with him. Amazingly, he made over 350 telescopes in total including large and small ones.

Eventually, he also tried his hand at manufacturing large optical telescopes as well. Regrettably, he passed away in 1995 at age 83. But even now radio telescopes manufactured by Norizuki are active in locations throughout Japan.

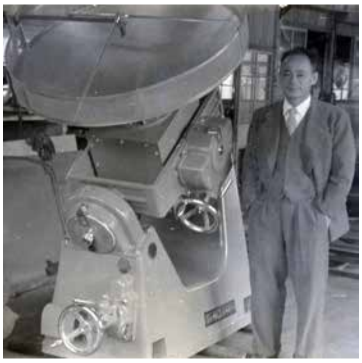


Figure 18: Sojiro Norizuki, shown together with a radio telescope paid for by TAO (now NAOJ). Image courtesy of Discovery Park Yaizu.

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https://www.nao.ac.jp/en/about-naoj/reports/naoj-news/almar/

Back Page Photo: Tokyo Astronomical Observatory circa the 1970's. In the foreground is the newly constructed 6-m millimeter-wave cosmic radio-wave telescope. In the background on the right is a radio telescope with its 24-m spherical mirror fixed to the ground. In the distance at the center of the photo, part of the antenna of the 10-m Equatorial Solar Radio Telescope can be seen.

* For more details please refer to Archive Office Newsletter # 52, August 15, 2008 (in Japanese).
http://prc.nao.ac.jp/prc_arc/arc_news/arc_news052.pdf