# アルマーの冒険 ALMAr

## ALMAr's Adventure 11
## Observing Jovian Radio Waves with Software Defined Radio (Part 1)

**Main Characters**


Nao Senri


ALMAr


Izayoi

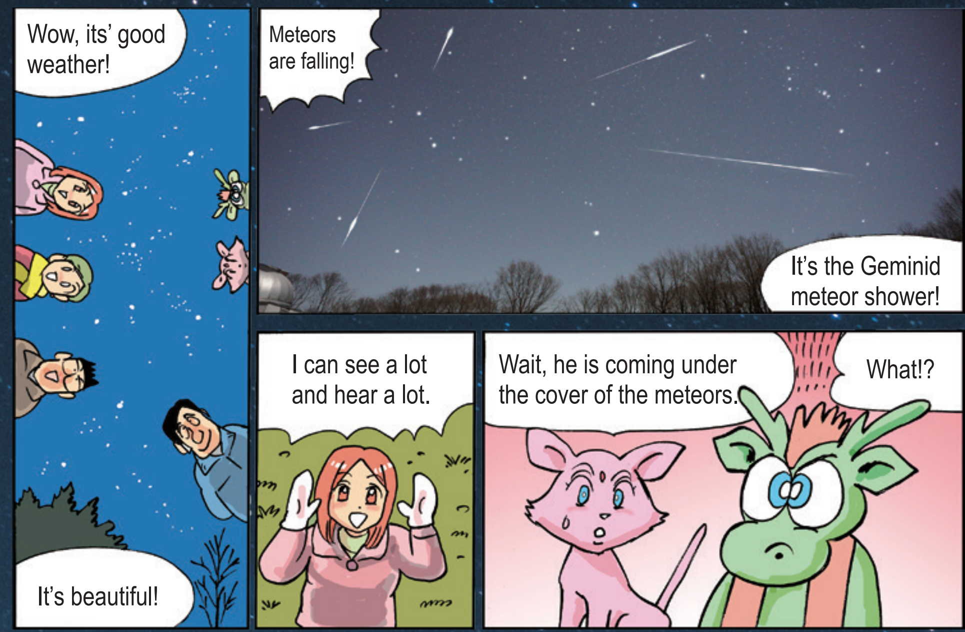
*Please refer to back issues for the Main Characters' profiles.

In the last issue of "ALMAr's Adventure" (Issue 10), we actually observed meteors using radio waves. However, we did not directly observe radio waves emitted by celestial bodies, but rather used radio waves transmitted from the ground for meteor observations. In addition, earlier we made two observations of solar radio waves ("ALMAr's Adventure," Issues 04 and 09), in both cases using mostly existing observational equipment.

Therefore, as in the preceding radio wave observations of meteors, we will now try to directly receive radio waves coming from various celestial bodies by building our own antennas and utilizing inexpensive receivers. As the first step, we will try to observe radio waves from Jupiter. We will build an observational device using a SDR (Software-Defined Radio) receiver similar to the one used for meteor radio wave observations, and aim to actually detect Jupiter's radio waves.

### ★ Summary up through Issue 10
### "Making a Software Defined Radio to Observe Meteors"

After successfully capturing radio waves from the Sun, the members of Soten "Deep Blue Sky" High School astronomy club chose meteors as their next observational target. They received reflections off of meteors of amateur radio waves being transmitted for that purpose. With the help of Dr. Warenabe (a relative of Nao's) at Kunitachi Observatory and others, they set up a dipole antenna, and the observation was a great success. However, that night, Izayoi sensed someone coming from space under the cover of the meteors! (Below: the last scene from Issue 10)

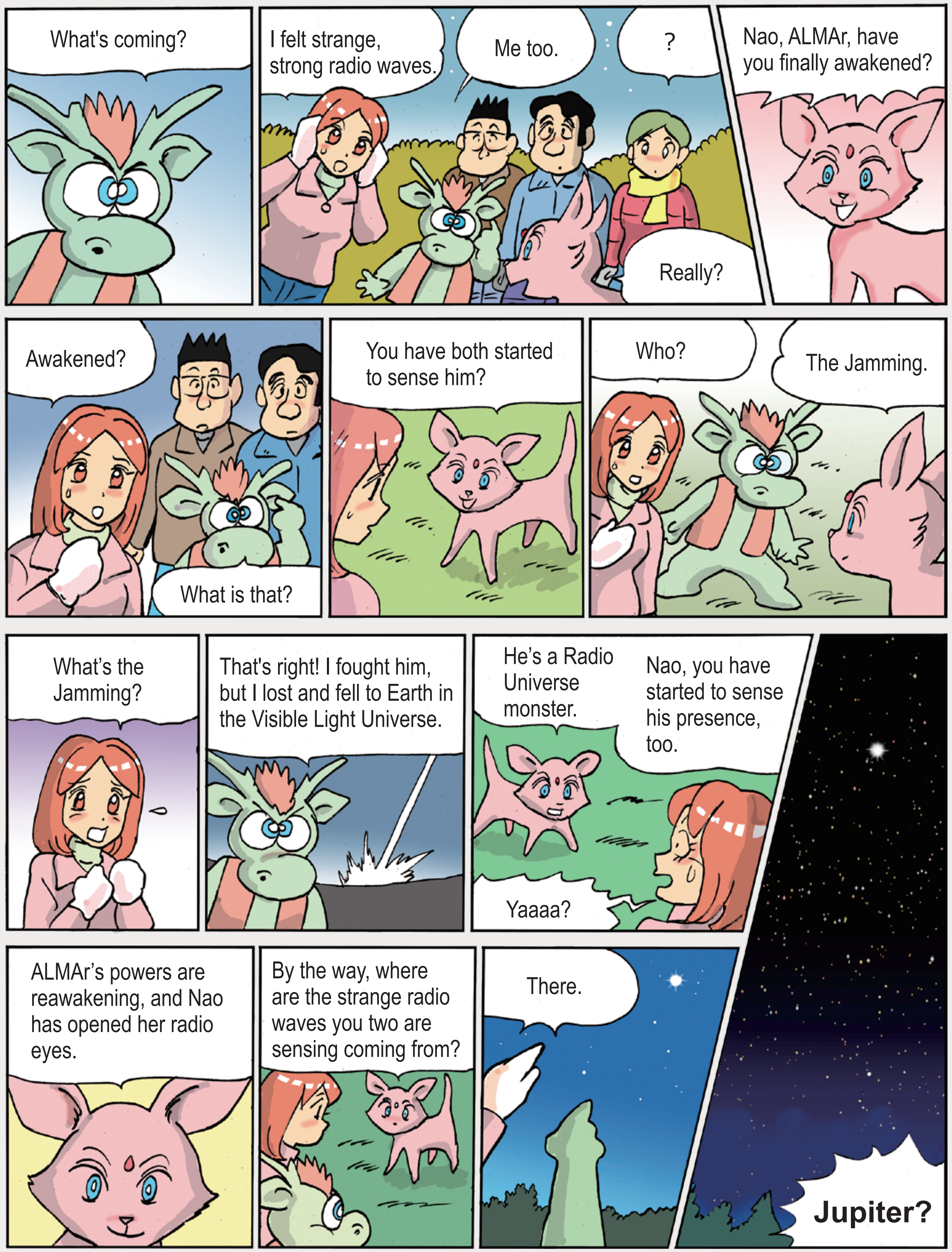



*Back issues of the ALMAr's Adventure radio astronomy Manga can be viewed at: https://www.nao.ac.jp/en/about-naoj/reports/naoj-news/almar/

**"ALMAr's Adventure" Production Unit**
Illustration: Ryuji Fujii
Photos, Story, Star Charts: Akira Kawamura
Supervision & Production Assistance: Atsushi Kumamoto, Fuminori Tsuchiya, Yasumasa Kasaba, Yuto Katoh (Tohoku University), Masato Ishiguro (NAOJ), Kenji Karasaki (Planetarium Works Co., LLC)
Editor in Chief: Hiroyuki Takata
Translation: Ramsey Lundock

In November 2022, we borrowed the premises of the University of Tokyo's Kiso Observatory to observe Jupiter's decameter waves. In the center of the image is Jupiter shining with a brightness of -2.7 magnitude.

# Chapter 11-1: The Radio Waves Sensed by the Awakened Nao came from Jupiter








## 1 Radio Waves from Jupiter Discovered by Chance

### Jupiter was the source of the noise captured during observations of the Crab Nebula

It is now known that radio waves, like light, are emitted by various celestial bodies. As mentioned in the history of radio astronomy (see "ALMAr's Adventure" No. 05), it started when Carl Jansky, a technician at Bell Labs in the U.S.A., accidentally captured radio waves coming from the center of the Galaxy in 1931. Subsequently, many celestial bodies emitting radio waves were discovered. In fact, the discovery of radio waves from Jupiter was also by chance.

In 1954, Bernard F. Burke and Kenneth L. Franklin, both of the Carnegie Institution of Washington, in Washington D.C., U.S.A., were using a radio telescope built on about 40 hectares (eight times the size of Tokyo Dome) of land in Seneca, Maryland to observe radio waves from the Crab Nebula in the constellation Taurus.

The radio telescope was called the "Mills Cross Array," an array of 66 dipole antennas* arranged in two rows in an "X" pattern spread over 624 m. The observation frequency was 22.2 MHz.

**Figure 01:** The antenna was designed by B. Y. Mills, an Australian radio astronomer, and Martin Ryle of England, who later won the Nobel Prize for aperture synthesis in interferometry. It was made of 66 pairs of wooden masts with wires strung across the tops of them. The total length of the wires used is said to have reached 8 km. The receiving equipment was mounted on an army surplus truck which was already on the site. Unfortunately, it has now been removed, neither the station nor the antenna remain. Credit: Carnegie Institution for Science Archives

During their observations, Burke and Franklin occasionally noticed noise that did not appear to be radio waves from the Crab Nebula. While searching for the cause, they noticed that while it wasn't every day, the noise appeared for one to two hours at approximately the same sidereal time (the time it takes the Earth to rotate once). So they theorized that the noise was not artificial radio waves, but originated from a celestial body. Further observations revealed that the noise actually appeared at slightly faster periodic intervals than sidereal time. Assuming the noise was coming from the cosmos, the source of the noise was moving from east to west on the celestial sphere. Just at that time, Jupiter was located near the Crab Nebula. Jupiter had reached a stationary point in the constellation Cancer in the middle of November 1954 and turned retrograde, moving westward on the celestial sphere from then until March of the following year. Burke and Franklin noticed that the temporal variation of the mysterious noise coincided with Jupiter's movement on the celestial sphere, and they determined that the noise was radio waves from Jupiter. This observation was the first confirmation of radio waves emitted by a planet.

After the paper was published in 1955, many radio astronomers reviewed their previous observations. Among them was C. A. Shain, an Australian radio astronomer who discovered what he believed to be previously unrecognized radio waves from Jupiter in 5 year old records. Astronomers were immediately convinced of the existence of radio waves coming from Jupiter.

However, this alone did not explain why Jupiter was emitting radio waves. Later, various hypotheses and detailed observations were made, and the cause was gradually clarified.

Incidentally, radio waves from Jupiter were later found to be in the frequency range of 10 to 40 MHz. The wavelength range is approximately 30 m to 7 m, which is roughly in the 10 m (decameter) range, and hence the name "Jovian DecAMetric radiation = Jovian DAM."

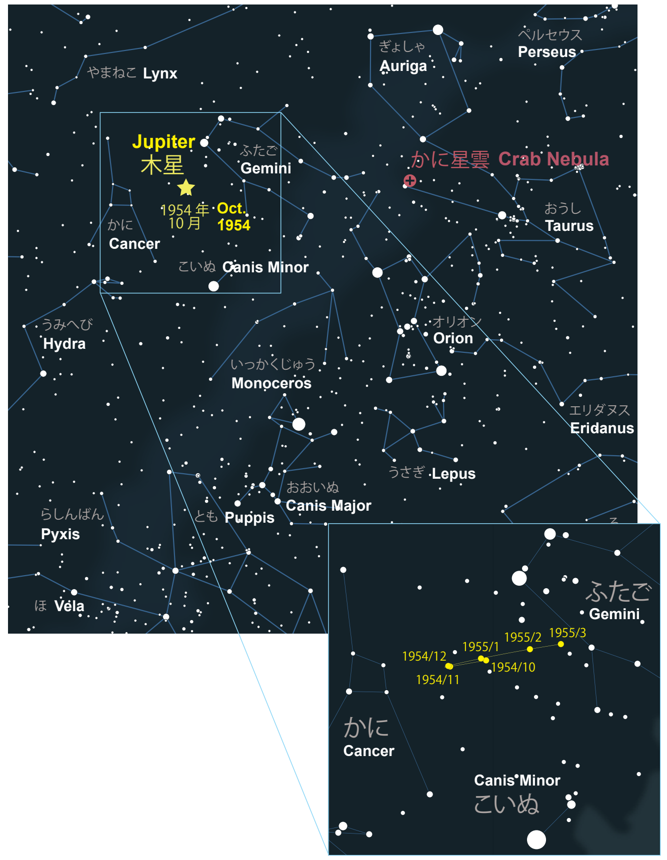
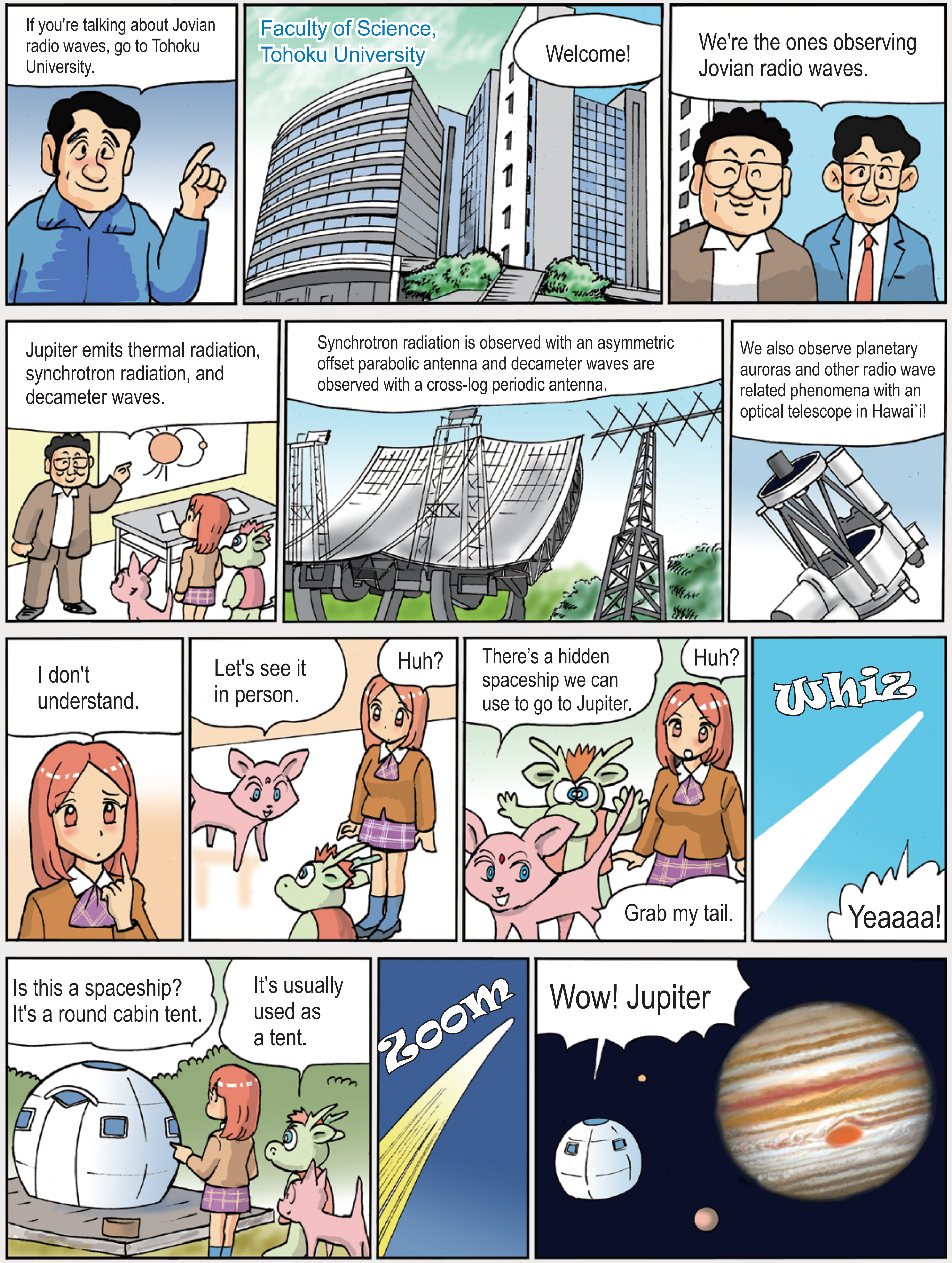



**Figure 02:** A star map depicting 1954-1955, when Burke and Franklin were investigating the mysterious noise. Jupiter can be seen near the constellation Cancer, which itself is near the constellation Tauru where the Crab Nebula is located. The enlarged star map shows the position of Jupiter on the first day of each month. Jupiter moved about 10 degrees westward on the celestial sphere between December 1954 and March 1955.

* **Dipole antenna:**
An antenna consisting of two symmetrically deployed straight elements (conductors), each 1/4 the length of the target wavelength, attached to the end (feed point) of a cable (coaxial cable) to guide radio waves. Because of its simple structure, it is easy to make one yourself.

# Chapter 11-2: A Quick Flight to Jupiter to Investigate Anomalies There




## 2 What are Jovian decameter waves?

### Detailed observations of Jupiter in visible light and radio waves to determine the nature of its mysterious radio waves

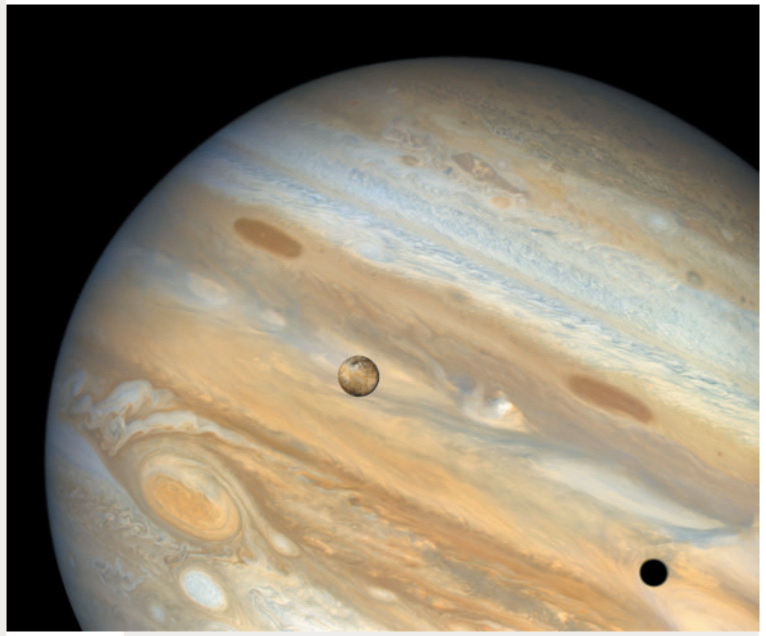


**Figure 03:** Jupiter, the fifth planet of the Solar System, is the largest of the Solar System's planets, with a diameter approximately 11 times that of Earth. It is a gas giant planet composed mainly of hydrogen and helium, and from Earth, even small astronomy telescopes can see stripes and a large red spot on its surface. These patterns are mainly caused by clouds of ammonia crystals and other substances. This image shows Jupiter and its satellite Io, photographed from a distance of about 1 million kilometers by the Voyager 1 planetary probe in 1979. Io casts a shadow on the surface of Jupiter.
Credit: NASA/Jet Propulsion Laboratory/Ian Regan

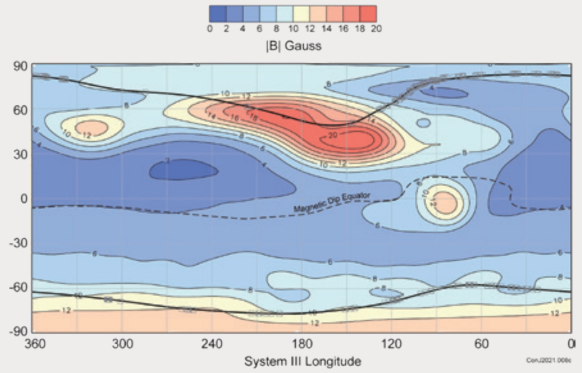



**Figure 04:** Contour map of the strength (in gauss) of Jupiter's magnetic field at its surface based on latitude and longitude. The contours were created from observational data from the Jupiter probe Juno. Blue areas indicate weak magnetic fields and red areas indicate strong magnetic fields. A considerable difference can be seen.
Citation from Connerney et al. (2022) Fig. 5.

Astronomers were convinced of the existence of Jupiter's decameter waves from their observations, and continued to record the wavelengths and intensities of the radio waves and the time of observation in order to further determine the mechanism of radio emission. Optical observations were also made at the same time. From the ground, the cloud patterns on Jupiter's surface can be observed using optical telescopes. Comparing the positions of these patterns with the radio wave intensity observations, they found that there was a correlation. Latitude and longitude are used to indicate positions on Earth, and on Jupiter latitude and longitude can also be determined nominally based on its surface patterns. The longitude in the center of the face of Jupiter as seen from Earth is called the central meridian longitude, and radio waves vary in intensity according to that central meridian longitude.

Also, Jupiter's decameter waves had right-handed circular polarization. Polarization describes the orientation of the oscillation of the electromagnetic waves. A radio wave is a phenomenon in which oscillations (changes in time) of the electric and magnetic fields are transmitted as a wave. Circular polarization is a state in which the electric field is rotating around the direction of propagation.

From polarimetry observations, we can draw information about the radio source and the state of space between Jupiter and Earth. As one of the causes of polarization, it was predicted that magnetic fields are involved in the generation of Jupiter's decameter waves. From this, it was suggested that magnetic fields may exist on Jupiter.

Today, direct probes by spacecraft and other means have confirmed the existence of magnetic fields around Jupiter. The origin of a planet's magnetic field is thought to be primarily inside the planet. Earth also has a magnetic field, but it is stronger or weaker depending on the location. There are several theories as to the cause, but the details are unknown. It is natural to assume that, like Earth's magnetic field, Jupiter's magnetic field also has stronger and weaker areas and that the periodic changes in the strength of decameter waves is caused by the rotation of the magnetic fields.

However, long-term observations of Jupiter's decameter waves have also revealed a discrepancy between radio intensity and central meridian longitude. The cloud pattern on Jupiter's surface itself changes with time, and there are slight differences in rotation period between the equatorial and polar regions. Thus differences in the rotational speed of Jupiter's interior and the rotation speed of the cloud tops were also revealed by radio wave observations.

In addition, they found something interesting in the observational data. Even at the same central meridian longitude, Jovian decameter waves showed a large variation in intensity, and that variation was periodic. The cause was Jupiter's satellite Io. The combination of a particular Jovian central meridian longitude and Io's phase (or orbital position) causes Jupiter's decameter waves to emit particularly strongly on a periodic basis. Jupiter has many satellites, but Io's orbit lies within the strong magnetic field lines of Jupiter's magnetic field.

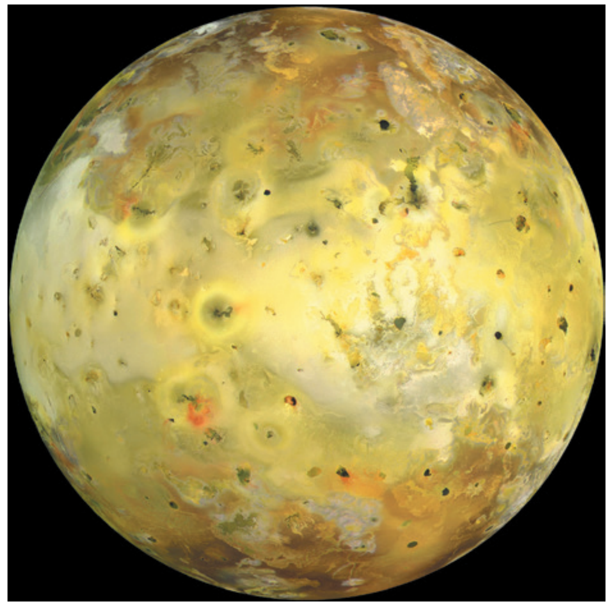


**Figure 05:** Image of Jupiter's closest satellite, Io, taken by NASA's Galileo probe in 1999. The image was taken at multiple wavelengths and adjusted to colors similar to what would be seen with the naked eye, but with further color enhancement. The blackish areas are volcanic craters, and much of the surface is covered primarily with sulfur and sulfuric compounds, giving it a yellowish tint.
Credit: NASA/JPL/University of Arizona

# Chapter 11-3: The Jamming Wreaks Havoc on Jupiter's Radio Waves and Earth is in Danger!


## 3 Jovian Decameter Wave Generation Mechanism

### Strong radio waves are periodically generated by electric currents between the satellite Io and Jupiter's ionosphere (magnetic field lines)?

Jupiter's satellite Io is a celestial body slightly larger than Earth's Moon. Io is unusual among Solar System satellites in that it has volcanoes. Io orbits relatively close to Jupiter, and Jupiter's powerful tidal forces generate heat in Io's interior, causing the material inside to erupt. Even though they are called volcanoes, volcanoes on Io are different from those on Earth. The ejecta is composed mainly of sulfur and sulfur dioxide gases, but also contains sodium, potassium, and chlorine. Most of the ejecta is ejected into space, where it is ionized into separate ions and electrons, becoming a plasma. This ionization is caused mainly by ultraviolet radiation from the Sun. This plasma is then distributed around Io's orbit like a floating ring around Jupiter. We call this the "Io Torus."

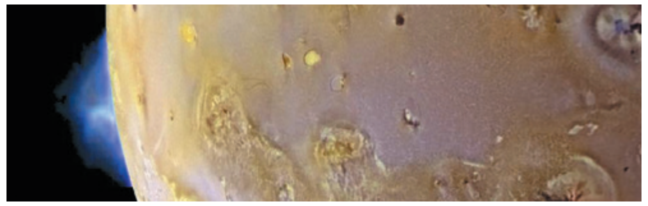


**Figure 06:** An eruption on Io as captured by the Jupiter probe Galileo. Volcanic activity eruptions are known as plumes. Here Io plumes are sending material high up into space. Credit: NASA/JPL/University of Arizona

Within this torus, Io orbits Jupiter cloaked in a thin atmosphere composed of its own volcanic ejecta. This atmosphere is electrically conductive because the material is in a plasma state. Therefore, if we think of Jupiter and its magnetic field as a magnet, as Io moves through Jupiter's magnetic field (actually, Jupiter's rotation period is shorter than Io's orbital period, so the magnetic field lines overtake Io), we can understand that an electric current is generated. In a generator that uses a magnet and a coil of wires, turning the magnet inside the coil causes an electric current to flow through the wires of the coil, so Io's atmosphere (plasma) and Jupiter's magnetic field are truly a giant generator.

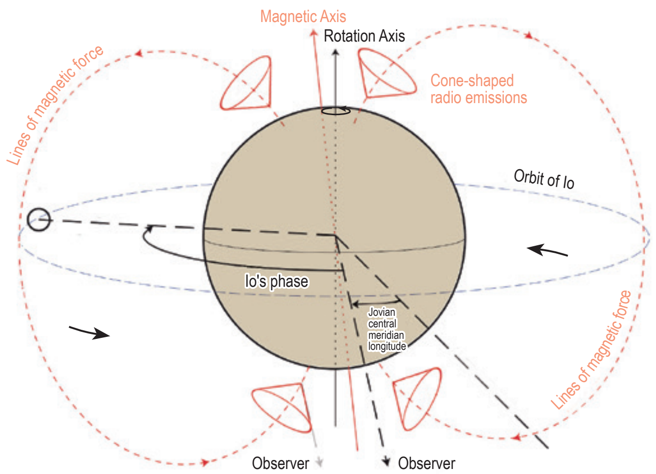



**Figure 07:** Schematic figure of the decameter wave generation mechanism on Jupiter. Jupiter's rotational period is shorter than Io's orbital period, so an electromotive force is generated when magnetic field lines overtake Io and its associated plasma, creating a current circuit between Io and the Jovian ionosphere via the magnetic field lines. Ions accelerated along the magnetic field lines are thought to generate auroras in the ionosphere, and electrons emit radio waves in cone shaped areas. Even at higher latitudes than Io's effects, radio waves are emitted by electrons accelerated along the magnetic field lines due to current circuits between the magnetic field lines and the more distant magnetosphere (see Figure 11), but these emissions are weaker than those associated with Io.
Cited and partially modified from Louis, C. K., et al, ExPRES: an Exoplanetary and Planetary Radio Emissions Simulator, A&A, 627 (2019) A30, Fig. 2.

Thus, conditions are created for electric currents to flow along the Jovian magnetic field lines connecting Io and Jupiter's ionosphere. The electrons accelerated along the magnetic field lines are thought to emit radio waves as they travel along the field lines in a spiral motion. This mechanism of radio wave generation is called "cyclotron radiation." *

Unfortunately, the generation mechanism of Jupiter's decameter waves is not fully understood, but it is now known that decameter waves are emitted from relatively close to Jupiter's poles where the magnetic field lines intersect with the ionosphere. Radio waves are emitted in the shape of an upside-down cone, like an open umbrella, and Jupiter's decameter waves can be received only when the straight line between the vertex of the cone and Earth falls within the cone.

The frequency of Jupiter's decameter waves observable on Earth is approximately 18 MHz to 40 MHz. The frequency of Jupiter's decameter waves can be used as an indicator of the strength of Jupiter's magnetic field, since the frequency of radio waves generated by cyclotron radiation depends on the strength of the magnetic field.

#### Jupiter's Auroras and the Io Footprint

On Jupiter, as on Earth, auroras can be seen in the polar regions. Although the principle of how Earth's auroras are generated is not fully understood, they are thought to mainly be the result of a complex process in which plasma (charged particles) from the solar wind is accelerated along the magnetic field lines of Earth's magnetic field and collides with Earth's atmosphere, thereby exciting atmospheric molecules which then emit light when they return to their energy ground state. The basic generation mechanism of Jupiter's auroras is believed to be similar to Earth's. Auroras extend across a wide range of wavelengths, from X-rays to ultraviolet, visible light, and infrared.

Interestingly, a particularly bright luminous area appears near where the magnetic field lines passing near Io intersect with Jupiter's atmosphere (the ionosphere). This area is called the "Io Footprint." The Jovian decameter waves are believed to be emitted from the vicinity of the Io Footprint.

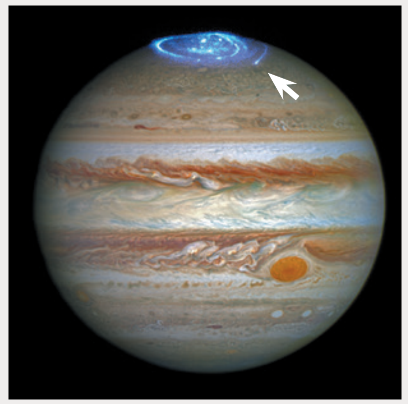


**Figure 08:** Aurora and "Io Footprint" (arrow) in Jupiter's polar regions
Credit: NASA, ESA, and J. Nichols (University of Leicester); Acknowledgment: A. Simon (NASA/GSFC) and the OPAL team

* Most of the radio waves flying through space can be classified into three types: thermal radiation, synchrotron radiation, and emission lines. Jupiter emits its strongest radio waves due to cyclotron radiation. Both synchrotron and cyclotron radiation are due to electrons moving in a spiral along magnetic field lines, but synchrotron radiation is due to electrons with much higher energy (near the speed of light).

# 4 Three Types of Jovian Radio Wave Emissions and Radio Waves from Other Planets

## Radio waves from Jupiter other than decameter waves and current planetary radio observations

Later observations have shown that Jupiter also emits radio waves other than decameter waves. One type is thermal radiation from its surface clouds. Objects emit thermal electromagnetic waves based on their temperature. The temperature of Jupiter's clouds is about 130 K (about -140 °C). The radio waves from Jupiter due to this thermal radiation are around 20 GHz, which is roughly consistent with the theoretical value expected for 130 K blackbody radiation.

Another type is related to areas around Jupiter known as radiation belts, where very energetic particles are trapped by the magnetic field. It is also known that electrons emit radio waves from these regions by a mechanism called synchrotron radiation.

Synchrotron radiation is mainly radio waves emitted when high-energy electrons, with speeds close to the speed of light, are captured by a magnetic field. The frequency of synchrotron radiation is higher than that of radio waves emitted by cyclotron radiation, ranging from several hundred MHz to several GHz.

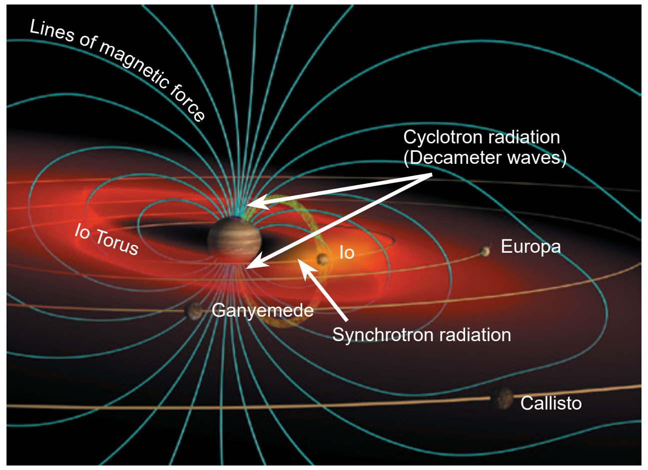



**Figure 09:** This figure schematically illustrates Jupiter's magnetic field and the orbits of its four major satellites, as well as the Io Torus and the electrons flowing along magnetic field lines from it. Decameter waves are emitted from the ionosphere near Jupiter's poles, and radio waves from synchrotron radiation are emitted from the radiation belt further inward than Io's orbit. Wikimedia Commons (https://commons.wikimedia.org/wiki/File: Citation from Jupiter_magnetosphere_schematic.jpg).

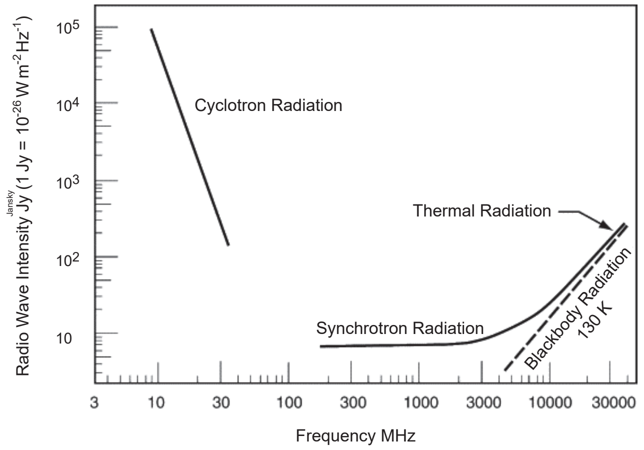



**Figure 10:** Radio waves emitted from Jupiter are spread over different frequency bands depending on the radiation process. There are three types of Jovian radio waves: thermal radiation from the surface, synchrotron radiation from the radiation belts, and cyclotron radiation from the Io Torus and magnetic fields. A simple comparison of radio wave intensities shows that the strongest observed radiation is cyclotron radiation.
Mark S. Marley, Jonathan J. Fortney, in Encyclopedia of the Solar System (Second Edition), 2007 (https://www.sciencedirect.com/topics/physics-and -astronomy/jupiter)
Citation from Fig. 11.

In fact, Earth also has a radiation belt called the Van Allen Belt, named after its discoverer. Because Jupiter's magnetic field is much stronger than Earth's, radio waves are emitted due to strong synchrotron radiation. Of course, radio waves are also generated in the magnetosphere on Earth. However, because they reflect off the ionosphere, it is difficult to observe such radio waves. Jupiter's decameter waves were the first time that the existence of radio waves from a planet other than thermal radiation was recognized.

Another method of observing planets with radio waves involves the absorption lines of the atmosphere. In radio waves due to atmospheric thermal radiation, certain specific frequencies of radio waves are absorbed, depending on the molecules contained in the atmosphere, and these absorption lines can be observed. Radio waves make it possible to indirectly determine the substances present in the atmosphere.

### Planetary Magnetic Fields

On Earth, we can determine the directions north and south by using a magnetic compass. This is because the Earth has a magnetic field similar to that of a bar magnet. Although the generation mechanism of the Earth's magnetic field is not fully understood, it is believed that the molten metals (mainly iron and nickel, which are conductive) that make up the outer core inside the Earth generate convection currents due to heat and mass transfer, and that the Earth's rotation also adds to the convection currents, creating a magnetic field inside the outer core. This magnetic field generation mechanism is called the "Dynamo theory." Although it is a complex mechanism, the rotation of the Earth has the greatest influence on the magnetic field, and the poles of the magnetic field are located relatively close to the poles of the Earth's rotation axis.

Jupiter's interior is believed to be filled primarily with conductive liquid metallic hydrogen, which seems to generate a magnetic field through a process similar to that seen on Earth. However, the strength of the magnetic field is 20,000 times stronger than that of Earth. The strong magnetic field creates a high-energy radiation belt, so when sending probes to Jupiter, measures must be taken to ensure that onboard equipment is not affected.

Other than Earth and Jupiter, the planets with magnetic fields are Mercury, Saturn, Uranus, and Neptune. Mars and Venus have no magnetic fields, but probe observations indicate that Mars once had a magnetic field.

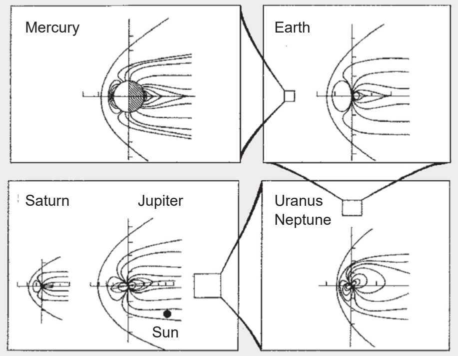



**Figure 11:** The area within a planet's magnetic field is called its magnetosphere. This figure shows the relative sizes of the magnetosphere for each planet. You can clearly see how strong Jupiter's magnetic field is. For some reason, the magnetic poles of Uranus and Neptune are tilted away from the axis of rotation.
Modified from Andrew J. Coates, The Solar System in the next millennium (https://www.researchgate.net/publication/243688353_The_Solar_System_in_the_next_millennium#pf12) Fig. 4

### Japan's Solar Planetary Atmosphere Research Telescope (SPART)

One example of Japanese observations of absorption lines in radio waves from planetary atmospheres comes from the Solar Planetary Atmosphere Research Telescope (SPART) of the Radio Astronomy Laboratory of Osaka Prefecture University. After the Nobeyama Millimeter Array at NAOJ Nobeyama Radio Observatory was discontinued, one of the six 10 m aperture parabolic antennas that made up the interferometer was refurbished and used as the world's first ground-based millimeter wave telescope dedicated to planetary atmosphere observations. Although the project has already been terminated, it still contributes to long-term monitoring of seasonal changes in the atmospheric composition of Venus and Mars, as well as changes caused by solar activity, by taking advantage of the fact that certain components of the atmosphere absorb radio waves.

**Figure 12:** Unit F of the millimeter wave interferometry array at Nobeyama Radio Observatory used by the Radio Astronomy Laboratory of Osaka Prefecture University. The millimeter wave array had used six 10-meter aperture parabolic antennas, but after the end of operation, only Unit F was refurbished for stand-alone use and continued to be utilized. The Nobeyama 45-m Radio Telescope can be seen in the background.

### Observations of Io's Atmosphere with ALMA

Io is known to have an atmosphere of sulfur monoxide and sulfur dioxide released from its volcanoes. Although this atmosphere is very thin (about one billionth of Earth's atmosphere), it was not known whether it is released directly from the volcanoes or if it is composed of material that had accumulated on the surface, and then was heated by sunlight and sublimated, and mixed into the atmosphere. A research team decided to use ALMA to observe Io's atmosphere before it entered Jupiter's shadow and again after it exited, because they believed that the atmosphere would freeze out as solids on Io's surface in Jupiter's shadow. With the high resolving power and sensitivity of ALMA, they succeeded for the first time in observing the sulfur dioxide and sulfur monoxide gases emanating from Io's volcanoes. Based on the observations, they estimated that 30-50% of Io's atmosphere is supplied directly by the volcanoes. ALMA also detected a new type of gas, potassium chloride, emanating from the volcanoes in areas where sulfur dioxide and sulfur monoxide were not detected. The team believes that this is evidence of an inhomogeneous magma composition inside Io.

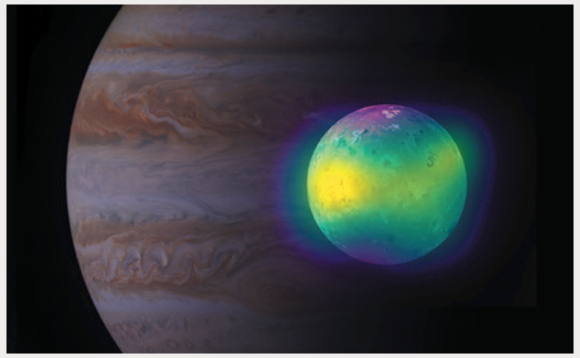


**Figure 13:** The blotchy yellow area is sulfur dioxide on Io as observed in radio waves by ALMA. The picture also combines images of Jupiter taken by the Cassini spacecraft and the surface of Io obtained by the Voyager 1 and Galileo spacecrafts.
Credit: ALMA (ESO/NAOJ/NRAO), I. de Pater et al; NRAO/AUI NSF, S. Dagnello; NASA/JPL/Space Science Institute

Io, shown above and to the right was observed by ALMA, a radio wave interferometer built in the Atacama Desert in Chile.
Antennas of the Morita Array (Atacama Compact Array) lined up at the ALMA Array Operations Site.
The closely spaced antennas are Japanese 7-m antennas, and a Japanese 12-m antenna stands in the right foreground.
Credit: ALMA (ESO/NAOJ/NRAO)

## 5 American Citizen Science Outreach "Radio JOVE"

### NASA-led Hands-on Educational Project Using Jovian Radio Waves

In the United States, a project called Radio JOVE (Jove is the Roman name for Jupiter), has been used for citizen science outreach since 1999. This is a hands-on educational project that allows students, teachers, and the general public to learn about radio astronomy by building radio telescopes and using radio telescopes in remote locations via the internet. More than 2,500 student groups and individuals have already participated in the project.

Radio JOVE participants can also talk back and forth on the network and collaborate through data sharing. The project is also supported by NASA Goddard Space Flight Center and other research and educational institutions, such as the University of Florida's Department of Astronomy and Middle Tennessee State University, as well as several companies.

In 2016, the scope of the Radio JOVE Project was expanded to include citizen science research in solar physics. Now the "Radio JOVE Project 2.0," collects data for Jupiter, the Sun, and the Milky Way Galaxy, as well as terrestrial emissions, and can be used to conduct scientific analysis and archiving.

The most important unique feature of the program is probably the inexpensive radio telescope kits provided to participants on a non-profit basis. Although the radio telescope is a simple configuration utilizing a simple dual dipole antenna and SDR as a receiver together with a PC, it is powerful enough to observe Jovian decameter radio waves. The software required for the observations is also provided, allowing anyone to experience radio astronomy observations. The initial receiver was an original design of soldered-together electronic components. However, now serious and meaningful observations are possible thanks to the advent of SDRs, which are inexpensive, have a wide wavelength range, high resolution in both wavelength and time, and above all, can acquire spectra.


**Figure 14:** Radio JOVE's website. Of course, the site is in English only, but recently web browsers have become more and more capable of translating, so it should not be too difficult to understand the content in other languages. The site contains a lot of information, from the discovery of Jovian decameter waves to modern observation methods.
https://radiojove.gsfc.nasa.gov/

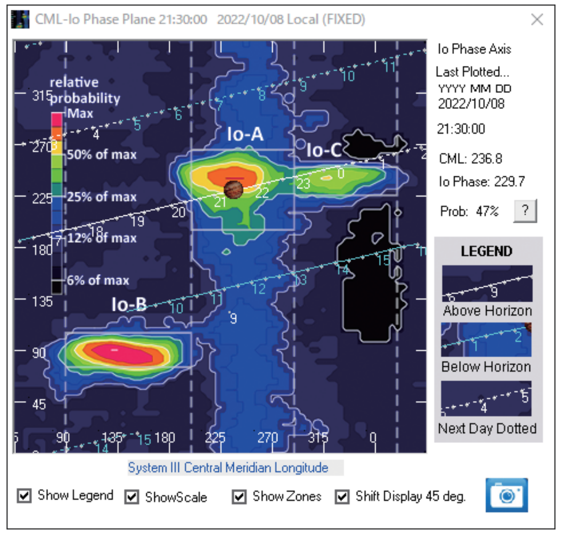



**Figure 15:** Radio-Jupiter Pro 3, available from Radio-Sky Publishing, is indispensable for planning observations of Jovian decameter waves. Based on Jupiter's central meridian longitude and Io's phase, it is possible to predict when strong decameter waves will be emitted.
https://radiosky.com/rjpro3ishere.html

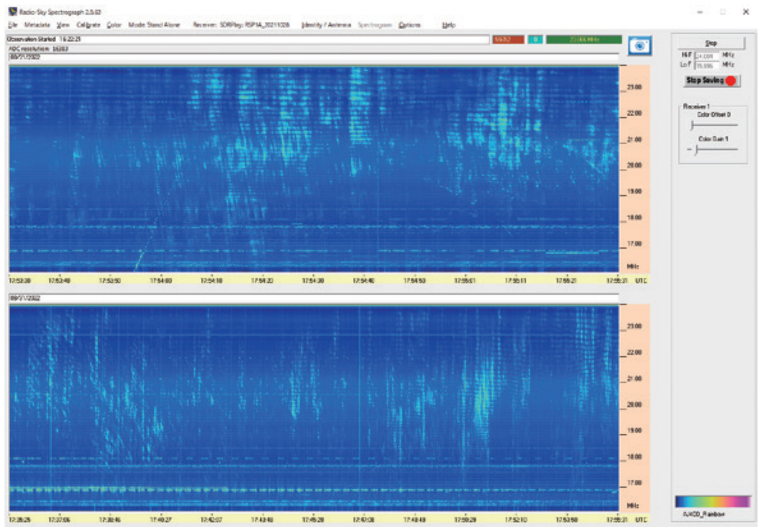


**Figure 16:** "Radio-Sky Spectrograph" is an internet-based strip chart recorder that uses analog-to-digital converters to collect data on a PC. Like "Radio-Jupiter Pro 3," it is provided by Radio-Sky Publishing. When used in conjunction with the SDR connection application, it can be used to observe a relatively broad spectrum of Jovian decameter waveforms.
https://www.radiosky.com/specdownload.html

In addition to the actual observation software, there is also free software that predicts Jupiter's decameter wave storms based on Jupiter's central meridian longitude and Io's phase, which can be used to complete the package.

It is not impossible to import the radio telescope kit provided by Radio JOVE from the U.S. to Japan, but unfortunately it is not very practical considering the shipping costs. So the ALMAr's Adventure Production Unit decided to build our own system modeled on the Radio Jove telescope kit. The SDR specified by Radio JOVE is made in the U.K., but it is carried by a distributor in Japan and can be purchased by mail order. Our antenna was assembled using materials that are relatively easily available in Japan. The construction of the observation system and the actual observation results will be introduced in the second part of this report.

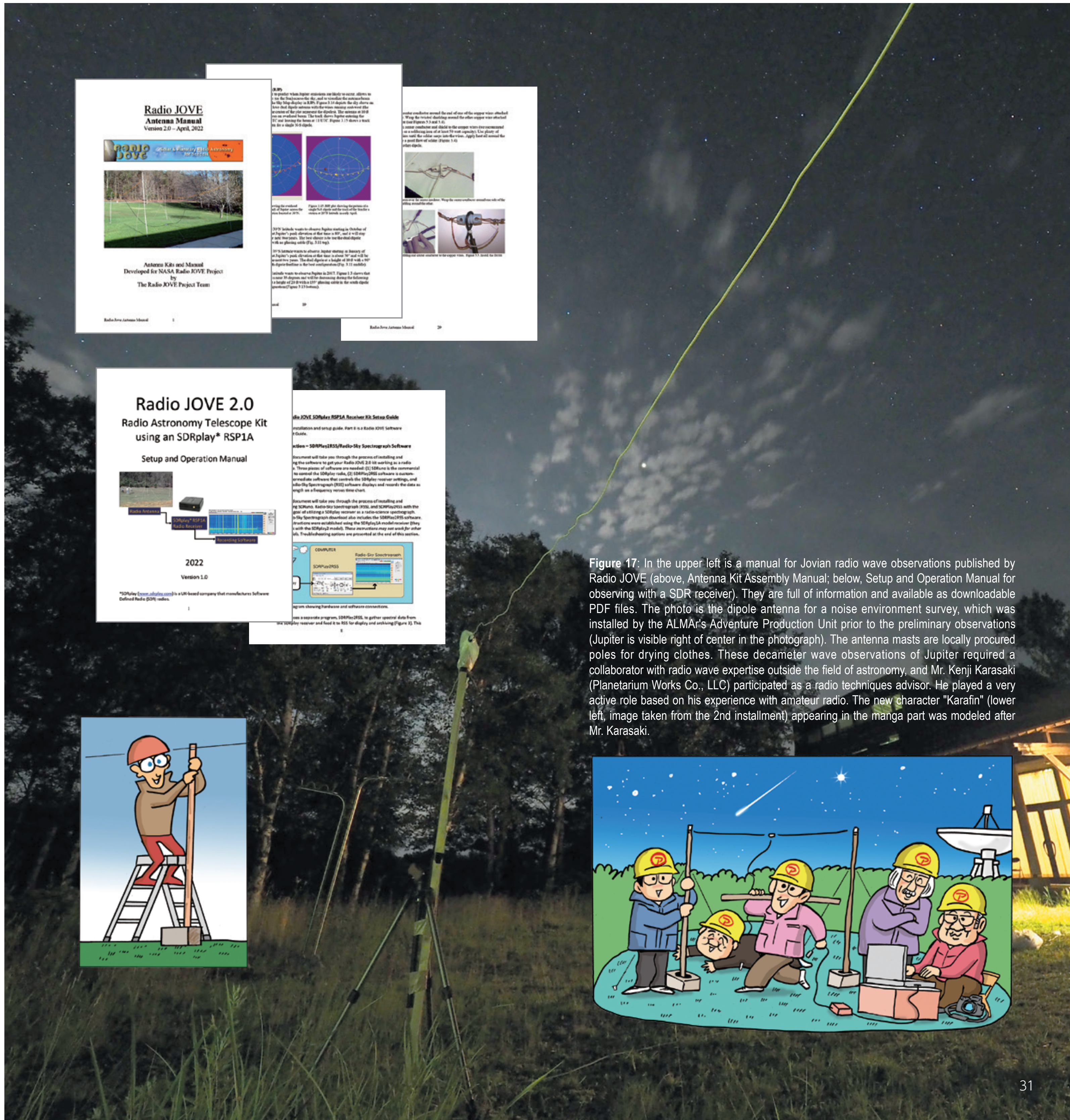



**Figure 17:** In the upper left is a manual for Jovian radio wave observations published by Radio JOVE (above, Antenna Kit Assembly Manual; below, Setup and Operation Manual for observing with a SDR receiver). They are full of information and available as downloadable PDF files. The photo is the dipole antenna for a noise environment survey, which was installed by the ALMAr's Adventure Production Unit prior to the preliminary observations (Jupiter is visible right of center in the photograph). The antenna masts are locally procured poles for drying clothes. These decameter wave observations of Jupiter required a collaborator with radio wave expertise outside the field of astronomy, and Mr. Kenji Karasaki (Planetarium Works Co., LLC) participated as a radio techniques advisor. He played a very active role based on his experience with amateur radio. The new character "Karafin" (lower left, image taken from the 2nd installment) appearing in the manga part was modeled after Mr. Karasaki.

# 6 A History of Japanese Experts in Jovian Radio Wave Observations

## A visit to Tohoku University, Graduate School of Science "Iitate Observatory,"

Jovian radio wave research in Japan has been conducted by Tohoku University, as well as by Koichiro Maeda (formerly of Hyogo Medical College), and Kazumasa Imai (Kochi National College of Technology). In particular, at Tohoku University which has been continuously observing Jovian radio waves since the 1970s, leading edge research is currently conducted in the Graduate School of Science Department of Geophysics/ Planetary Plasma and Atmospheric Research Center. Therefore, the ALMAr's Adventure Production Unit looked to the members of the Department of Geophysics/ Planetary Plasma and Atmospheric Research Center for cooperation and advice when conducting decameter wave observations of Jupiter.

Of the many astronomy observatories of the Planetary Plasma and Atmospheric Research Center, we visited the Iitate observatory, which is the center of planetary radio wave observations. Here, we will introduce the observatory and its research results.

The Iitate observatory is a facility built in the mountains of Iitate Village, Soma-gun, Fukushima Prefecture, about two hours drive from Sendai City, where the Tohoku University Graduate School of Science is located. Two facilities, the "Jupiter Galaxy Radio Observatory" and the "Optical and Radio Observatory," are located next to each other here.

The Jupiter Galaxy Radio Observatory observes decameter waves from Jupiter as well as from the Galaxy. In order to receive radio waves with higher sensitivity, nine cross-log periodic antennas have been installed in the forest, creating an interferometer system. This allows them to record the detailed behavior of Jovian decameter waves associated with Io, and to continue observations in order to reveal the full picture of faint radio wave sources unrelated to Io.

In addition, Tohoku University has facilities in Miyagi Prefecture to observe Jovian decameter waves: Yoneyama Observatory (Tome City), Kawatabi Observatory (Osaki City), and Zao Observatory (Zao Town, Katta-gun), and together with the Iitate observatory, they create a network of four long-distance interferometer stations. Using them together as an interferometer enables higher resolution, making it possible to determine which of Jupiter's poles is the source of the observed emissions.



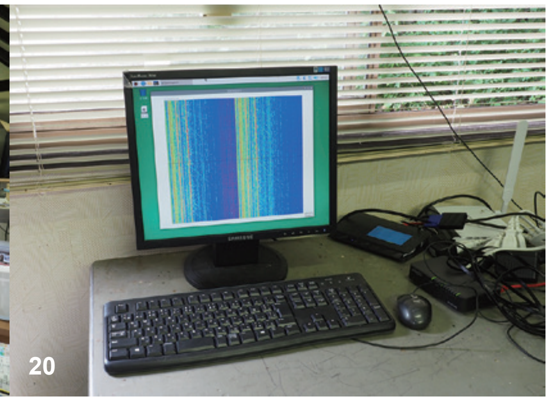



**Figure 18:** Nine shortwave (HF) antennas are arrayed in the Jupiter Galaxy Radio Observatory. Six of them are cross-log periodic antennas that monitor the intensity and polarization of radio waves from Jupiter. The observation frequencies range from 15 to 40 MHz.

**Figure 19+20**: Inside the building where cables from each antenna are brought together, receivers and PCs are installed to record radio wave spectra. The observational data are available on the internet.
http://ariel.gp.tohoku.ac.jp/~jupiter/

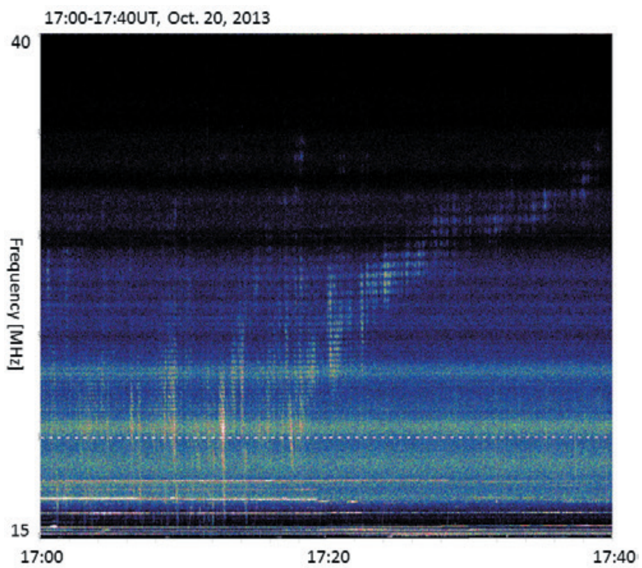
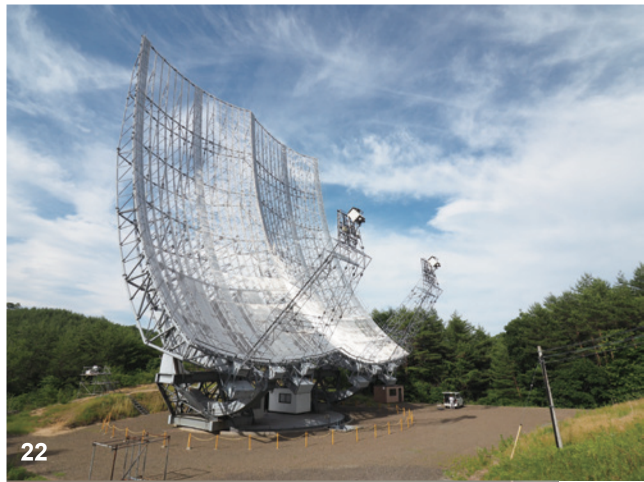


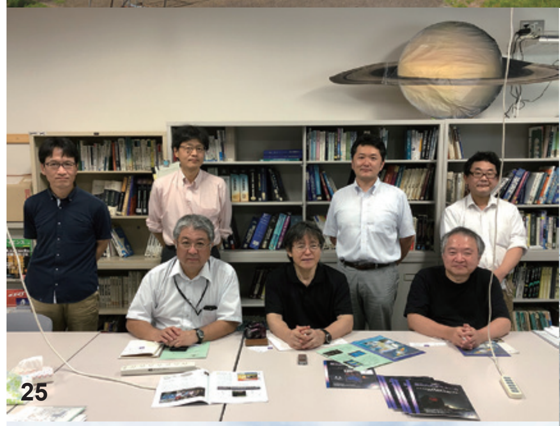

**Figure 21:** Example observation data. This is an image of a radio storm called Io-B in the Jovian decameter waves. The distinctive feature of this storm is that its frequency changes in an arc shape.

The Optical and Radio Observatory houses a large asymmetric offset parabolic planetary radio telescope with two surfaces, each measuring 31 m x 16.5 m for a total aperture area of over 1000 square meters. This telescope is currently observing radio waves emitted from high-energy electrons in Jupiter's radiation belts (synchrotron radiation). It also observes radio bursts emitted by accelerating plasma in the corona layer of the Sun's atmosphere. By analyzing the changes in radio wave intensity and spectra obtained from the observations, the acceleration and transport processes of plasma particles around Jupiter and the Sun are being elucidated.

In addition, Tohoku University has started activities, mainly led by graduate students, to make a Jovian radio observations based outreach program for citizen science, following the model of Radio JOVE in the United States. In addition, Tohoku University is also working in cooperation with other universities to encourage more people to become interested in and understand the "planetary sphere" of each planet, including Earth, through the experience of observing Jovian decameter waves.







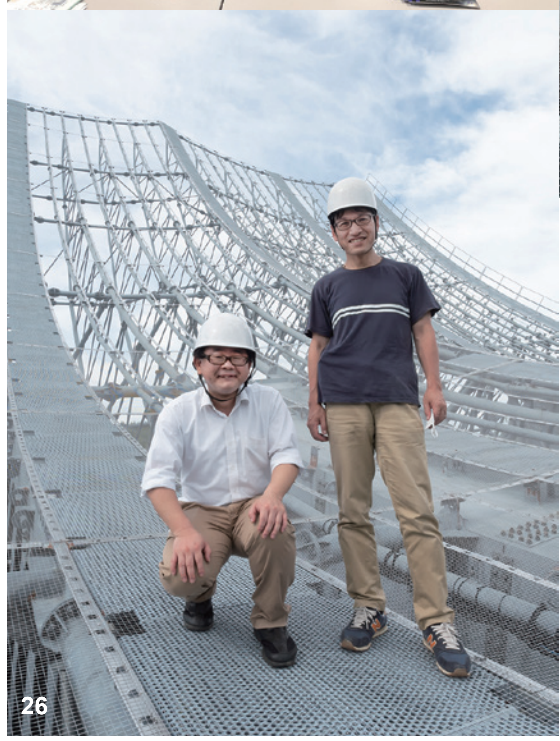



**Figure 22:** The main instrument of the Optical and Radio Observatory is a planetary radio telescope with unusually shaped asymmetric offset parabolic antennas (two antennas, each 31 m × 16.5 m). It observes radio waves emitted from high-energy electrons in Jupiter's radiation belts (synchrotron radiation) and is used to elucidate the acceleration and transport processes of radiation belt particles based on changes in radio wave intensity and spectrum.

**Figure 23+24:** The Iitate observatory is located on a forest road off Prefectural Road Route 315. Unfortunately, the observatory is not open for public visits, and the antennas of the facility cannot be seen from the road. Along the forest road are power poles, which were installed to supply electricity to the observatory (there are no houses or facilities along the forest road), and they are marked with plates that reads "Jupiter Line" in Japanese.

**Figure 25:** We received a lecture on Jovian radio waves at Tohoku University's Aobayama Campus in Sendai City, Japan. The photograph shows Associate Professor Fuminori Tsuchiya (Planetary Plasma and Atmospheric Research Center), Professor Yasumasa Kasaba (Planetary Plasma and Atmospheric Research Center), Professor Yuto Katoh (Department of Geophysics), Associate Professor Atsushi Kumamoto (Department of Geophysics) in the back row from left to right, and three members of the ALMAr's Adventure Production Unit in the front row.

**Figure 26:** Associate Professor Fuminori Tsuchiya (right photograph) and Associate Professor Atsushi Kumamoto (left photograph) showed us around the Iitate observatory. (Photograph courtesy of Tohoku University)

**Figure 27:** Special Guest, Professor Emeritus Masato Ishiguro (second from left) of the National Astronomical Observatory of Japan, joined the visit to the Iitate observatory.

**Next Issue:**

In order to receive Jovian decameter waves, we will finally build an antenna and try to observe Jupiter using SDR and a PC. Will it be able to detect radio waves from Jupiter? See you again next issue.