アルマの冒険
ALMAr
ALMAr's Adventure

Issue 05
"The History of Radio Astronomy"

Up until now, we have introduced the methods for observing celestial objects with radio waves and conducted experiments to do things like actually catch radio waves from the Sun. But what exactly are radio waves? In this issue, let's examine the true nature of radio waves and the beginning of radio astronomy.

"ALMAr's Adventure" Production Unit
Illustration: Ryuji Fujii
Story: Akira Kawamura (Hoshinotechosha "Starbook Company")
Supervision: Masaaki Hiramatsu (NAOJ Chile Observatory)
Editor in Chief: Hiroyuki Takata
Design: Maki Kubo
Special Guest: Masato Ishiguro (NAOJ Professor Emeritus: Formerly ALMA Project Office)
Translation: Ramsey Lundock

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

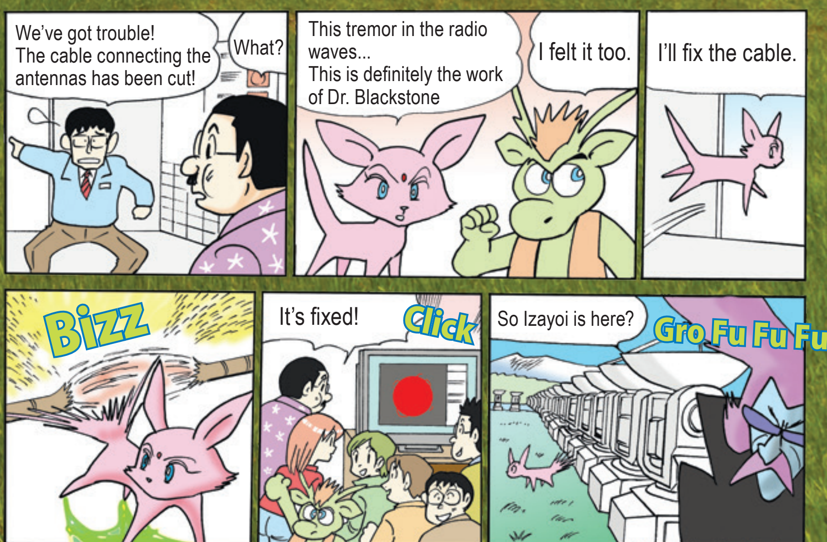
A dragon-child who came to the Visible Light Universe from the Radio Universe. He passed out after being showered by mysterious radio interference known as "Jamming" which poses a threat to the Radio Universe. While he was unconscious, a 9-headed dragon appeared to him and said, "Seek out Grand ALMAr's 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 04 "Catching Radio Waves from Space! Part 2: Solar Radio Waves"

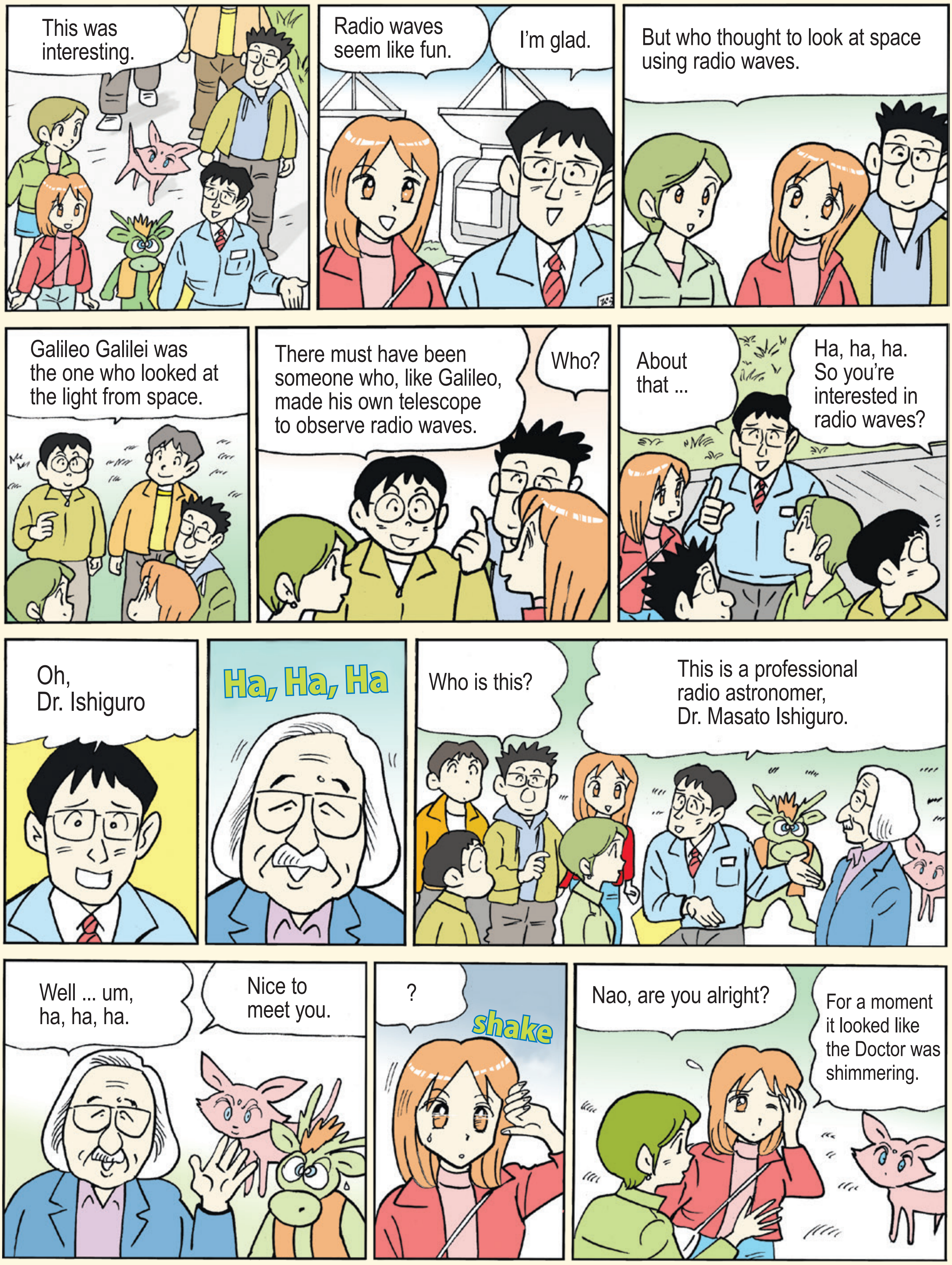
Nao Senri and the other members of the Soten "Deep Blue Sky" High School astronomy club used a wok to receive BS satellite signals. And with the help of Nobeyama Radio Observatory staff, they conducted an experiment using a wok to observe solar radio waves. Right after that, an anomaly developed in the Nobeyama Solar Radio Observatory Radioheliograph. As part of a plot, Dr. Blackstone had cut a cable, making it impossible to receive the image of the Sun. But thanks to Izayoi's intervention, operations were safely restored. Who is this Dr. Blackstone shadowing Nao and her friends?



Radio Observation Professional

Chapter 5-1: Dr. Ishiguro Appears

After touring the Nobeyama Radioheliograph which captures images of the solar radio waves, Nao and her friends meet someone unexpectedly on the way back.



The Mechanism of Producing Radio Waves

Up until now we've learned about the nature and characteristics of radio waves, but how are radio waves actually produced?

•Electricity, Electric Fields, Magnetic Fields, and Electromagnetic Waves

The idea that radio waves are a variety of electromagnetic waves with wavelengths longer than (visible) light has been introduced repeatedly (refer to ALMA's Adventure issues 01~04). However, the existence of radio waves, which can't be seen like visible light, has not been obvious all along. Radio waves were discovered only about 130 years ago, in the latter half of the 19th century.
Referring to the history of the discovery of radio waves, we'll produce radio waves through a simple experiment and verify their existence. Although many methods for producing radio waves have been discovered (refer to Page 08), the simplest is to run electrical current through a wire.

In junior high school science class, we conduct an experiment where we hold a compass close to an electrical wire, run an electrical current through the wire, and watch the point of the compass move. When an electrical current flows, an "electrical field" produces a "magnetic field." The term "magnetic field" refers to the region around a magnet where the force which attracts iron filings is active. Based on this phenomenon, the relation between the electrical current and the magnetic field generated around it is given by "Ampere's Law" ★01.

In science classes we also learn an experiment involving moving a bar magnet through a coil of electrical wire to produce an electrical current in the coil. The magnetic field changes due to the motion of the bar magnet and this is what produces the electrical current. This phenomenon is known as "Faraday's Law" ★02.

From these 2 experiments we can see that there is a back and forth relationship between an "electric field" and a "magnetic field." From investigating this relationship more deeply, an idea including a method of transmission known as "electromagnetic waves" was theorized (Figure 1, for more details refer to Page 05). Therefore to produce radio waves, which are a kind of electromagnetic waves, we should create an electric/magnetic field by running an electrical current through a wire.

In the case of radio and television broadcasting stations, base stations for smart-phones, etc., electrical current flows and stops very rapidly in a cycle (this is known as very high frequency current ★03), and the required radio waves are released from an antenna.

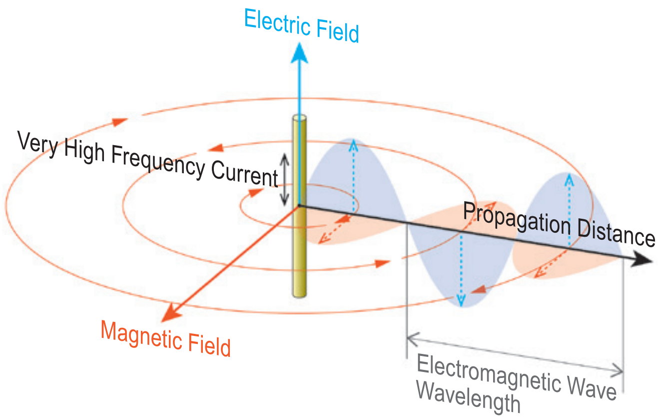


Figure 01) Radio is a phenomenon transmitting oscillations (changes with time) in electric fields and magnetic fields as a wave. If electrical current flows cyclically through a wire, the magnetic field changes continuously. As shown in the figure, the wave travels through space as the electrical field creates a magnetic field orthogonal to itself and the magnetic field creates an orthogonal electrical field.

★01 Andre-Marie Ampere (1775~1836) was a French physicist and mathematician. He discovered Ampere's Law. Sixty years before the discovery of the electron, he had a large influence on 19th century physics through his ideas such as, "Magnetic phenomena are caused by many microscopic particles carrying electricity moving within electrical leads."

★02 Michael Faraday (1791~1867) was an English scientist and physicist. Although he had no specialized training, with innate curiosity and tenacity he conducted many experiments related to electricity and magnetism. He is remembered for discovering the law of electromagnetic induction among other things. He also made many lasting contributions to the field of chemistry. More than a few people consider him the greatest scientist of the 19th century.

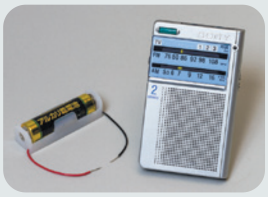
★03 Of the smartphones indispensable to modern life, many models use radio waves with frequencies above 1 GHz (Gigahertz). Frequency indicates the number of wave cycles repeated within a set time (please refer to ALMAr's Adventure Issue 03, Page 03). Radio uses units know as Hertz (Hz), this indicates the number of waves in 1 second. To produce 1 GHz radio waves it is necessary to generate a very high frequency electrical current by turning the switch on and off 1,000,000,000 times a second. Of course a physical switch couldn't function quickly enough, so very high frequency current is produced via electronic circuits.

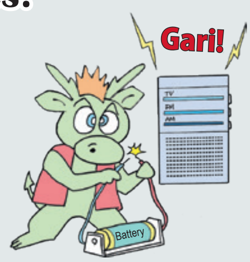
Dr. Masato Ishiguro

The world famous radio astronomer Dr. Masato Ishiguro, a radio interferometry professional, is the father of millimeter wave interferometry, through the six 10-m antennas at Nobeyama Radio Observatory. His endeavors to develop radio astronomy include serving as the Japan Project Leader for the ALMA collaboration between Japan, America, and Europe through the inception, planning, and construction phases. Currently he is functioning as a professor emeritus of the National Astronomical Observatory of Japan (NAOJ).

Experiment 4 Let's Try Making Radio Waves!

Turn on an AM radio, and tune it to a frequency between stations. You should be able to hear a "Zaaa" noise coming from the speakers. Then, next to the radio tap together the ends of 2 pieces of copper wire attached to the plus and minus ends of a dry cell battery (1.5 volt). In the instant that the wires touch, a "Gari!" sound should come from the speakers. The instant that the copper wires touch (or separate), the electrical current starts (stops) and changes the electric field, thereby producing radio waves.

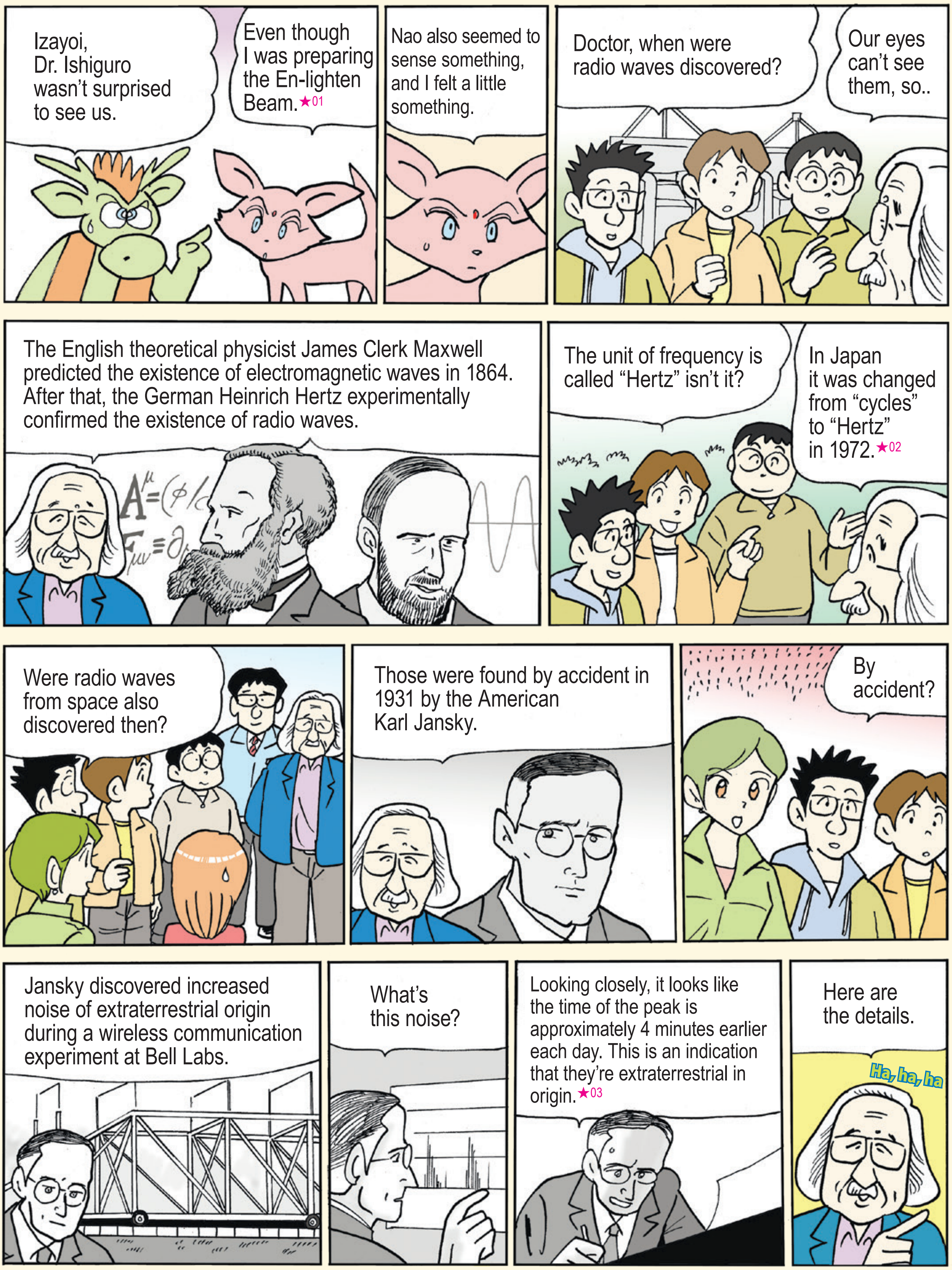




If you leave the two copper wires attached to the ends of the battery connected, it's what's known as a "short." There is the danger that the wires and the battery will overheat. In the experiment, take care to connect the ends of the copper wires for just an instant.

Chapter 5-2: Chance Radio Waves from Space
~Dr. Ishiguro's Special Lecture, Part 1~

Dr. Ishiguro doesn't need the En-lighten Beam. A special lecture about the discovery of radio waves and radio waves coming from space begins.



★01 What is the En-lighten Beam? A mysterious beam of light emitted by Izayoi. When it shines on someone, he accepts the existence of Izayoi and Almar without question.

★02 Japan used cycles as the unit of frequency, but in 1960 the General Conference on Weights and Measures adopted hertz as the international unit. Japan changed units in 1972.

The Discovery of Radio Waves and Cosmic Radio Waves

The existence of radio waves was predicted by 19th century scientists and confirmed experimentally. In addition, from the cosmos...

•Maxwell Predicted the Existence of Radio Waves

Before radio waves were actually discovered, there was a man who predicted their existence: the English theoretical physicist James Clerk Maxwell (Figure 02). Starting from Michael Faraday's theory of electromagnetic fields (refer to Page 03) known at that time, Maxwell derived his equations in 1864.

$$\mathrm{div}\vec{D} = \rho$$

・When a charge (density) (ρ) exists, an electric field (electric flux density) (D) is produced such that it diverges (div).

$$\mathrm{rot}\vec{E} + \partial\vec{B}/\partial t = 0$$

・A time change ($\partial/\partial t$) of the magnetic flux density (B) produces an electric field with a clockwise curl (-rot).

$$\mathrm{div}\vec{B} = 0$$

・Magnetic monopoles do not exist. (The magnetic flux density doesn't have divergence (div = 0)).

$$\mathrm{rot}\vec{H} - \partial\vec{D}/\partial t = \vec{i}$$

・Time changes ($\partial/\partial t$) in the current (i) and the electric field (electric flux density) (D) produce a counter-clockwise (rot) magnetic field (H).

E = Electric Field, H = Magnetic Field, D = Electric Flux Density, B = Magnetic Flux Density

These 4 equations look difficult at first glance, but Maxwell's Equations can describe all the behaviors of electric and magnetic fields. From these equations, the existence of light and other forms of electromagnetic waves, including radio waves, was predicted.

•Hertz Discovered Radio Waves

Heincich Rudolf Hertz (Figure 03), a professor of physics at the Karlsruhe Institute of Technology (Berlin, Germany), first proved the existence of radio waves in his home laboratory on November 1, 1886.

For the transmitter, Hertz used a device which discharged electricity into the air, producing a spark. And for the receiver he used 1 copper wire. The receiver copper wire was shaped so that there was a small gap between the 2 ends. Then he confirmed that when a spark was produced by electrical discharge on the transmitter, a spark also appeared across the small gap in the copper wire receiver. This meant that radio waves produced by the transmitter flew across the space between the transmitter and receiver, and arriving at the copper wire receiver caused electricity to flow through the copper wire, producing a spark across the gap.

After that techniques for sending and receiving radio waves were created; radiotelegraphy (dot-dash Morse Code) and voice transmitting radio were developed. Also, not just artificial sources, more and more radio waves were found coming from the natural world (most of these are received collectively as "noise" ★04).

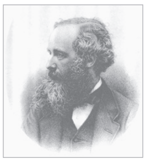


Figure 02: James Clerk Maxwell (1831~1879) was an English physicist. He introduced Maxwell's Equations based on Michael Faraday's electromagnetic induction, founding classical electrodynamics. He is also known for his observations of Saturn. (Photo credit: NRAO/AUI/NSF)

Figure 03 Heinrich Rudolf Hertz (1857~1894) was a Germany physicist. He proved for the first time the existence of the electromagnetic radiation predicted by Maxwell. He had interests in antenna development and meteorology; for example he designed a new type of hygrometer. He died young from disease at age 36. (Photo credit: NRAO/AUI/NSF)

•And Karl Jansky Discovered Extraterrestrial Radio Waves

As wireless telephones using radio waves began to spread, at the start of the 1930's trans-Atlantic calls were put into service. To offer better quality service, the telephone company began observations to study the conditions which caused noise that interfered with the signal. Karl G. Jansky (Figure 04), a researcher at Bell Labs in the U.S.A. noticed a strange noise (spurious signal) during observations in 1931. This noise he called a "hiss" wasn't that different from the noise produced continuously by the receiver itself.

Then from January 1932, he started observations of hiss noise at 20.5 MHz. The antenna was large, with a high sensitivity for short-wave. It was mounted on a circular rail allowing it to rotate 360 degrees horizontally (Figure 05). By observing as the antenna rotated, he found that the noise exhibited a peak, being stronger in a certain direction. What's more, the direction of that peak moved with time.

At that time, the direction of the largest noise peak was in exactly the same direction as the Sun, so Jansky thought that light from the Sun could be producing radio waves in the Earth's atmosphere. But as the days passed, the direction of the noise peak began to shift westward from the direction of the Sun. Jansky persevered in his observations and confirmed that after 1 year the direction of the noise peak and the direction to the Sun coincided again.

Figure 05: Jansky's antenna which discovered radio waves from space. (Photo credit: NRAO/AUI/NSF)

From this Jansky conjectured that the noise source was radio waves coming continuously from one direction outside of Earth. The problem was, where were they coming from? Jansky noticed that the assumed direction to the center of the Milky Way agreed with the movement of the direction of the noise. By accident, he had discovered extraterrestrial radio waves.

Figure 04: Karl Jansky (1905~1950) was an American physicist and radio engineer for a private company. In 1931 he noticed that radio waves were coming from a particular direction in the sky. This was the discovery that radio waves are coming from the direction of the center of the Milky Way. The unit modern radio astronomers use for radio flux density is named the "Jansky" in his honor. (Photo credit: NRAO/AUI/NSF)

★03 The Celestial Sphere exhibits diurnal motion due to Earth's rotation; 1 rotation takes approximately 23 hours and 56 minutes, 4 minutes less than 24 hours. Because this type of periodic variation was observed, it showed that the noise was coming from a location on the Celestial Sphere, i.e. outside of the Solar System.)

★04 All radio waves except artificial signals humans use for specific purposes are considered "noise." But for radio astronomers who observe radio waves from celestial objects, it is the artificial signals and sources other than what they want to observe that are considered "noise." The radio waves from celestial objects are extremely faint, so in order to actually detect and observe the signal of the target radio waves within lots of noise, a variety of ingenuity and accumulated know-how are needed.

Chapter 5-3: The Start of Radio Astronomy
~Dr. Ishiguro's Special Lecture, Part 2~

Radio Waves from the Milky Way were the first to be caught. Nao has a double vision of Dr. Ishiguro as he tells the story.

The Dawn of Radio Astronomy

It wasn't astronomers unacquainted with radio waves who understood the importance of Jansky's discovery, it was one radio engineer.

•Reber Conducted the First Celestial Object Observations using Radio Waves.

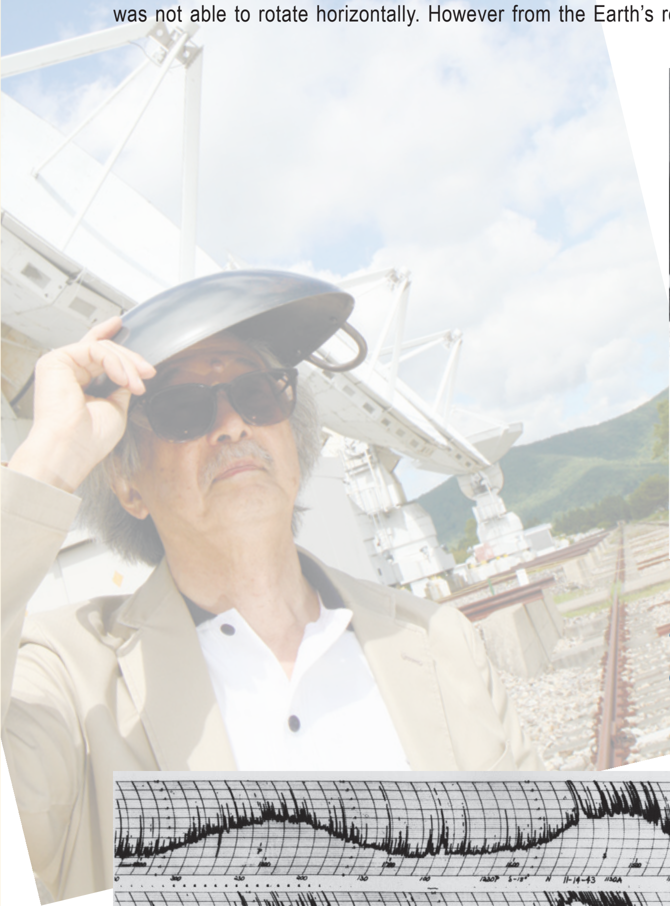
Jansky's finding that radio waves are coming from outer space was a major discovery. But astronomers of the time didn't show much interest. For astronomers who until then had conducted observations using only (visible) light, radio waves were a foreign topic. They didn't know what they should do.

Then a radio engineer, Grote Reber, came along. He made a 9.4 m parabolic antenna (Figure 06, Rigth) by himself, in the backyard of his house in Wheaton, Illinois and started observations of radio waves coming from space. That was in 1937. Reber knew of Jansky's discovery. He proposed making observations with radio waves to astronomers, but unfortunately his suggestions were not well received. So he decided to observe on his own and constructed a radio telescope.

The basic structure of Reber's telescope was constructed from wood. Of course the parabolic antenna surface was metal that reflects radio waves well. The elevation that the antenna pointed could be adjusted, but the entire structure was not able to rotate horizontally. However from the Earth's rotation, the observational targets exhibit diurnal motion, so that by just moving the antenna pointing up and down it is possible to observe most of the sky. Making the receiver was not that difficult for a radio engineer like Reber. He constructed the receiver from vacuum tubes, etc.

But at first he couldn't catch cosmic radio waves. Many things can generate radio waves (see Page 08), but Reber considered radio waves generated by heat. It was known that in general for thermally generated radio waves, the higher the frequency the stronger the radio waves are. So Reber started observations at 3,300 MHz, a frequency much higher than the 20.5 MHz used in Jansky's observations. But counterintuitively he couldn't receive many radio waves. So Reber continued observing while lowering the frequency. Finally at 160 MHz he detected radio waves. That was in 1939.

After that, Reber continued observing and drew a map of the celestial radio waves, or more correctly the radio wave intensity distribution (Figure 07). His map showed that the area of strong radio waves ran along the Milky Way, with the radio waves becoming strongest at the Galactic Center. This made clear the existence of Galactic radio waves. Radio astronomy had begun.



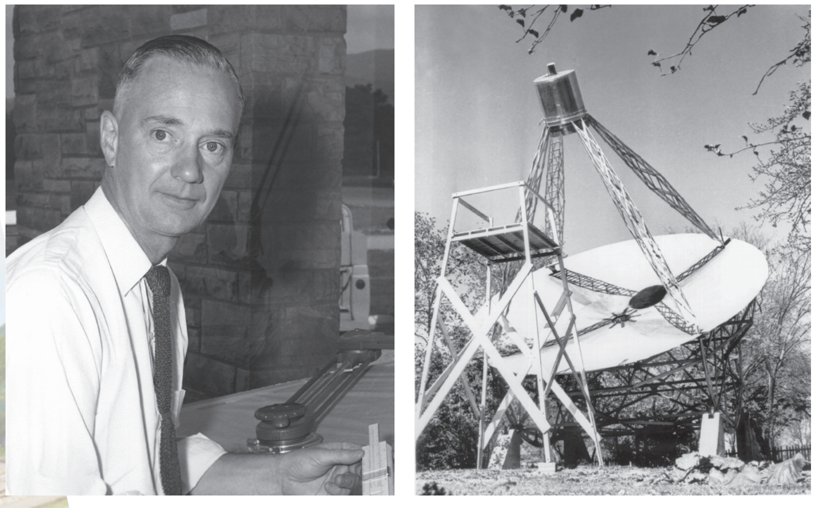


Figure 06: American radio engineer Grote Reber (1911~2002). He constructed a radio telescope (right) by himself and conducted continuous radio observations. He became a pioneer of radio astronomy through his achievements, including discovering many radio sources and making maps of radio wave intensities on the Celestial Sphere. By the way, Reber and Edwin Hubble, discoverer of the expansion of the Universe, graduated from the same high school; and Reber's mother had taught Hubble science. (Photo credits: NRAO/AUI/NSF)

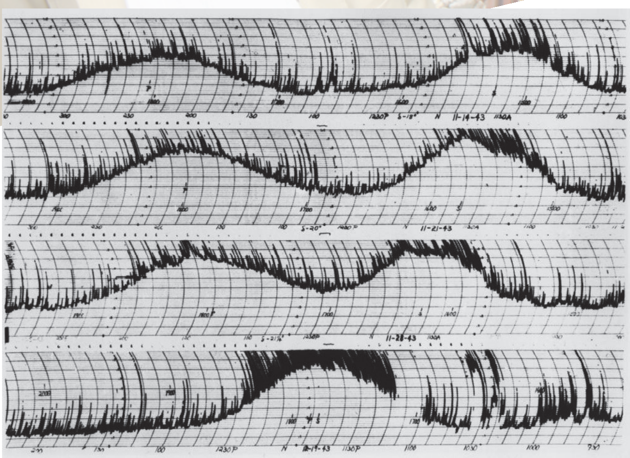
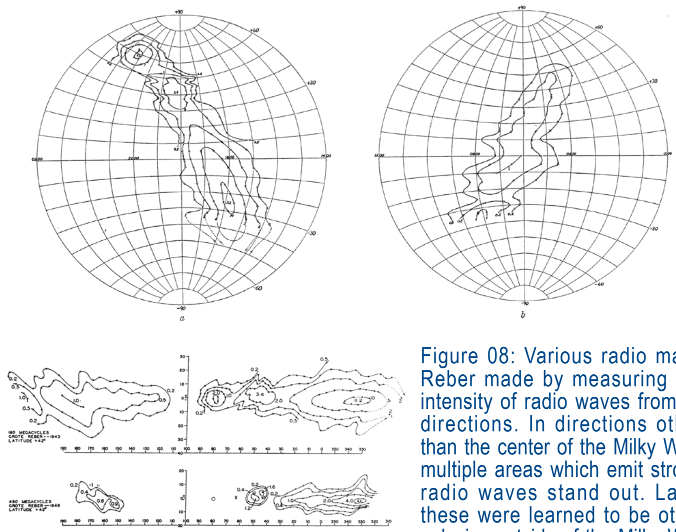


Figure 07: A chart of cosmic radio waves recorded by Reber (Note★). Reber observed with the antenna fixed to the ground, as time (i.e. the Earth's rotation = horizontal axis) progressed, changes in the intensity of the radio waves from space were recorded. The gentle (hill shaped) peaks on the chart are caused by radio waves from the Milky Way and the Sun. The thin stripe-like lines are noise from automobile engines.



Note★ From Grote Reber "Cosmic Static," The Astrophysical Journal, 100, 279 (11/1944).

Figure 08: Various radio maps Reber made by measuring the intensity of radio waves from all directions. In directions other than the center of the Milky Way, multiple areas which emit strong radio waves stand out. Later these were learned to be other galaxies outside of the Milky Way or supernova remnants. (Above Figure: Astrophysical Journal, Vol. 100 (1944), Figure to the left: NRAO/AUI/NSF)

There Are Many Varieties of Cosmic Radio Waves.

As we learned in Experiment 04 “Let’s Try Making Radio Waves!”, artificial radio waves can be made easily from the flow of electrical current (the movement of electrons). So what kinds of radio sources are there in the natural world? Among familiar natural phenomena, there’s lightening. Lightening is the discharge (electron movement) of large scale static electricity. When listening to AM radio, a “Gari” noise can be heard at the same time as the lightening flash is seen. It’s not entirely natural, but in a dry location in winter, the static electricity generated as you put on or take off cloths also produces radio waves at the same time as the small “Pachi. Pachi.” electrical discharge accompanying the light and sound. In both cases the flow of electrical current produces radio waves. Outside of these produced by electrical current, in space there are various other radio generation sources. Radio waves from the objects observed by modern radio astronomy are classified into 3 categories based on differences in the generation methods: 1. thermal radiation 2. synchrotron radiation 3. spectral lines of atoms and molecules.

1. Thermal Radiation (lower left figure)

Physical matter with a temperature emit radio waves. The higher the temperature of the matter, the stronger the emissions. Radio waves are released from our bodies, from the Earth, and from distant celestial objects or gas, in accordance with the temperature of each. Emissions from bodies in a thermally stable state (thermal equilibrium) are called thermal radiation. Emissions from an ideal object (a black body) are called black body radiation. In addition, the emissions produced when electrons flying through a space are deflected by the electromagnetic potential of charged particles are called “Bremsstrahlung radiation” or “free-free emissions;” because the emissions change based on the (thermal) motions of the electrons, these are also included in thermal radiation.

2. Synchrotron radiation (lower center figure)

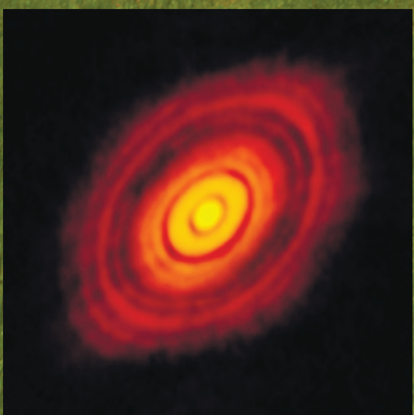
Radiation produced by electrons deflected while flying through a magnetic field at relativistic speeds (speeds near the speed of light) is known as synchrotron radiation. These radio waves have no relation to heat, so they are called non-thermal radio waves. The radio waves received by Jansky and Reber were from synchrotron radiation. Magnetic fields cause various effects, so observations of synchrotron radiation fulfill an important role in understanding the magnetic fields of celestial objects.

3. Spectral Lines of Atoms and Molecules (lower right figure)

Thermal radiation and synchrotron radiation emit electromagnetic waves over wide frequency bands. In contrast, emissions released only at set frequencies are known as spectral lines. When the electrons contained within atoms or molecules loose energy for some reason, radiation is produced with a wavelength corresponding to that energy. The larger the energy difference, the higher the frequency of the emitted radiation. These energy differences are determined by the species of atom or molecule. When we receive particular frequencies of radio waves from an area, we can learn the composition and energy state of the material which exists there.

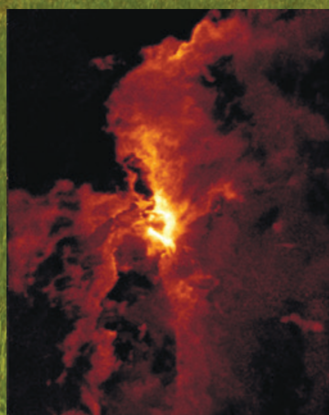
ALMAr’s Adventure 05
Publication date: September 1, 2015
Published by: NAOJ, Public Relations Center, Publications Office
Production assistance: Nobeyama Radio Observatory

Back issues of ALMAr’s Adventure can be viewed at
https://www.nao.ac.jp/en/about-naoj/reports/naoj-news/almar/



1. Example of an object observed via thermal radiation: “protoplanetary disk of HL Tau” as observed by ALMA. Thermal radiation emitted by dust is captured. [ALMA (ESO/NAOJ/NRAO)]

2. Example of an object observed via synchrotron radiation: Hercules A. Radiation emitted by jets shooting out from the center of a galaxy is captured. [NASA, ESA, S. Baum and C. O'Dea (RIT), R. Perley and W. Cotton (NRAO/AUI/NSF), and the Hubble Heritage Team (STScI/AURA)]



3. Example of an object observed via the spectra of atoms and molecules:The area around the Orion Nebula observed by the Nobeyama 45-m Radio Telescope. Radio waves emitted by carbon monoxide molecules are captured.

★The background picture shows the Nobeyama 45-m Radio Telescope (on the right edge of the front cover) and the 10-m antennas of the Nobeyama Millimeter Array at Nobeyama Radio Observatory.