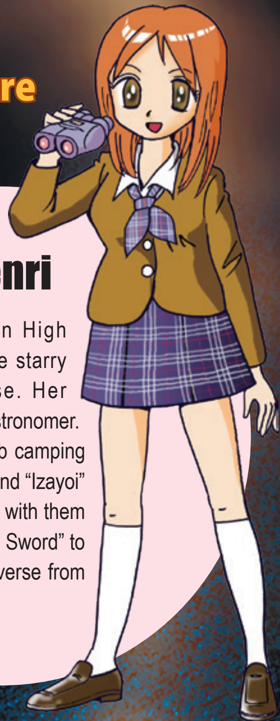
アルマーの冒険 ALMAr

ALMAr's Adventure

Issue 03
"Catching Radio Waves from Space! Part 1: Broadcasting Satellites"

Among the many types of radio waves around us, this 3rd installment introduces the types and characteristics of radio waves coming from space. Let's learn about radio astronomy. Additionally, let's try an experiment using a wok to catch television signal radio waves broadcast by artificial satellites.



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.

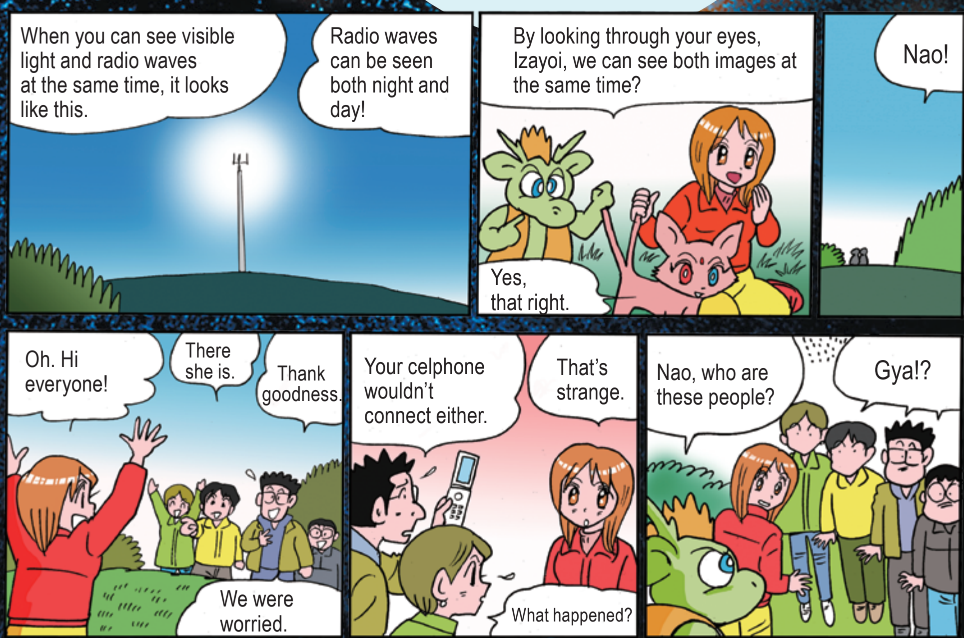
Izayoi

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...

"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 Ishigro
(NAOJ Professor Emeritus: Formerly ALMA Project Office)
Translation: Ramsey Lundock

Summary up through the previous issue, Issue 02 "See the Light, See the Radio Waves"

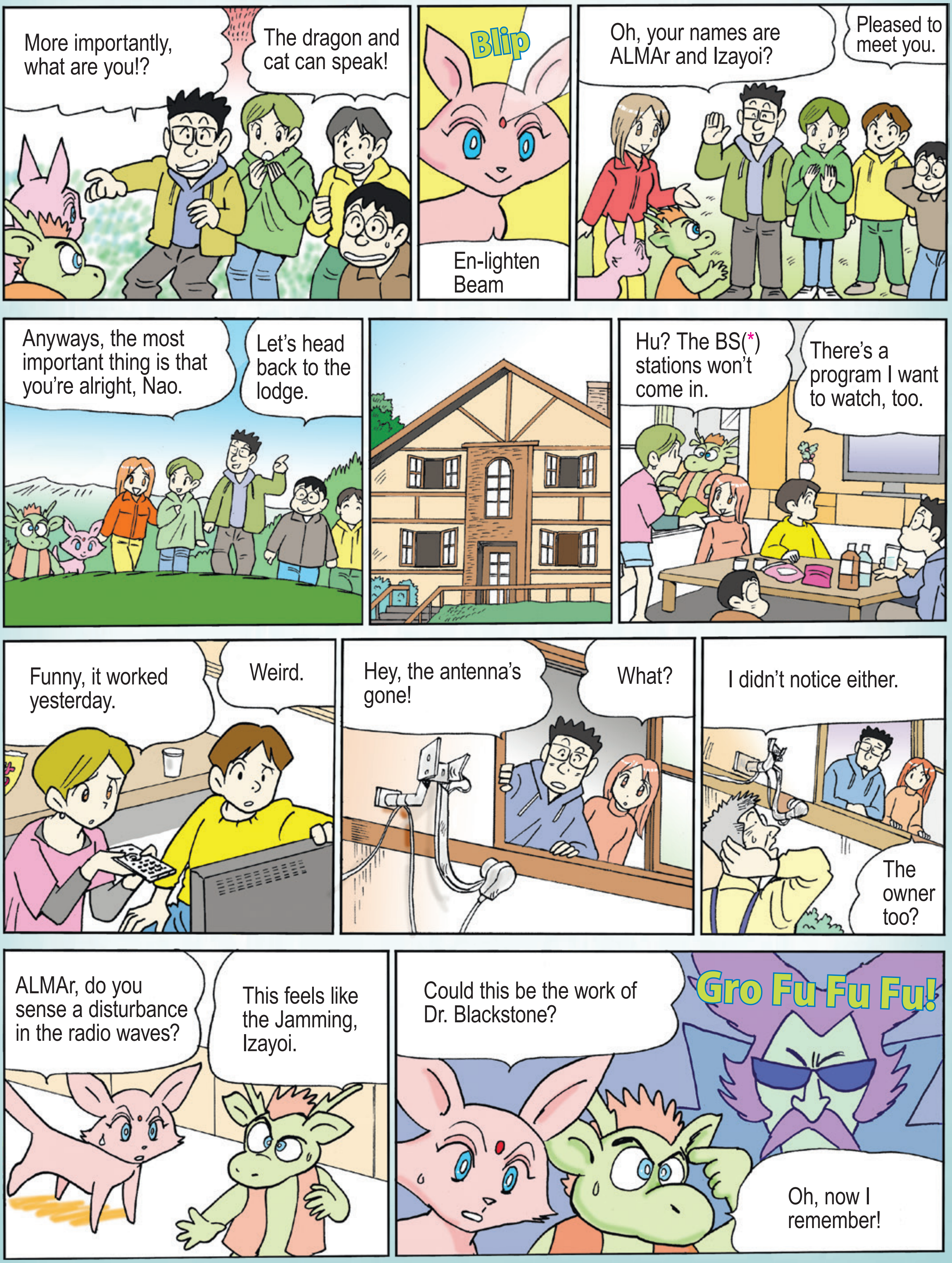
One night during a training camp in the Nobeyama highlands, Nao Senri, a member of the Soten "Deep Blue Sky" High School astronomy club, met ALMAr, a dragon child, and Izayoi, a knowledgeable cat. They said that they were flung from the Radio Universe into the Visible Light Universe. They seem to have radio-sight, the ability to see the world of radio waves. Nao can also see the world of radio waves when she holds Izayoi's tail. She learned that there are differences between when the world is seen with visible light and when it is seen with radio waves. Now morning has come and the other astronomy club members have found Nao and her friends.



Background image: ALMA (ESO/NAOJ/NRAO), Visible light image: the NASA/ESA Hubble Space Telescope

Chapter 3-1: Dr. Blackstone Appears!

The group returns to the lodge, but the TV doesn't show satellite broadcasts. C..could this mean...



* Broadcasting Satellite

Not just Celestial Objects! Familiar Radio Waves from Space

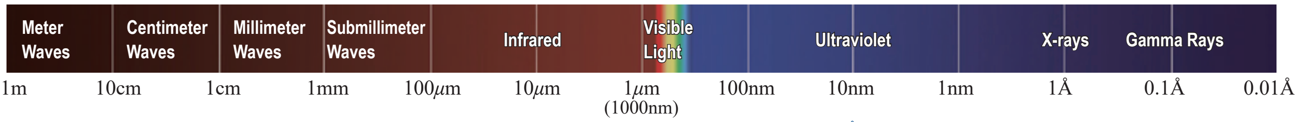


Figure 01) Chart of wavelengths used in astronomical observations ("μm" indicates micrometers, "nm" indicates nanometers, "Å" indicates angstroms)

Radio waves are electromagnetic waves with wavelengths from roughly 0.1 mm to 10 km. (See Table 01 below). In addition to radio waves, electromagnetic waves can be classified, based on their wavelengths, as infrared, visible light, X-rays, gamma rays, etc. (See Figure 01, above.)As we explained before, if we comprehensively observe the many electromagnetic waves coming from space with numerous "eyes for different wavelengths," we can better understand the mysteries of the Universe.

Among these many wavelengths, observing radio waves coming from space is known as radio astronomy. In addition to natural radio waves, the world around us is also inundated with artificial radio waves used by many of the machines indispensable to daily life: radio stations, TV, transceivers, celphones, wireless internet, etc. Almost all of these radio waves are ground based, but radio waves are also coming from artificial satellites outside of Earth: Broadcasting Satellites (BS), Communications Satellites (CS), GPS, satellite telephones, weather satellites, etc. The radio waves coming from space aren't just from celestial objects.

Devices using radio waves from artificial satellites include things which have become extremely common as of late, for example GPS (Global Positioning System). We can navigate by using a celphone, smartphone, or car navigation system to compare this GPS radio signal to map information. A GPS unit receives radio signals from numerous artificial satellites orbiting about 20,000 km above the Earth. This allows it to acquire time and location information on the ground. (See Figure 02.)

It's not a radio signals which ordinary people can access directly but, weather satellites use radio waves to send the pictures they've taken of Earth's surface. The "Himawari 8" weather satellite currently (2015) in operation travels in an orbit matched to the rotation of the Earth to stay directly above the Equator at 140 East Longitude at an altitude of approximately 36,000 km, in order to continuously observe the area around Japan. Satellites which always appear in the same location as viewed from the surface of the Earth are known as geostationary.

Among radio waves related to artificial satellites, one type which is used by many people is of course BS (Broadcasting Satellite) signals. The satellites sending BS signals are geostationary Broadcasting Satellites 36,000 km above the equator. Ground based transmission stations send radio signals up to the Broadcasting Satellites which process the signal back into radio waves and send it back down to the Earth. Lately, round plate-like parabolic antennas known as BS antennas can be seen attached to the roof or veranda of almost every home.

Figure 02) The Quasi-Zenith Satellite Michibiki is a Japanese test satellite. (Image: JAXA)

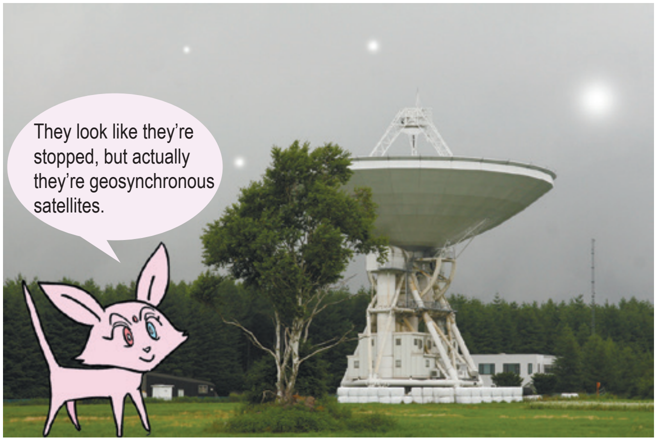


Figure 03) With radio-sight, the radio waves from satellites appear as bright stars, even during the day time and through clouds. (Please Refer to ALMAr's Adventure Issue 02.)

Radio telescopes employing parabolic antennas function the same way. You could say that BS antennas are small radio telescopes. (See page 05, Figure 04.)

The Various Types of Radio Waves and their Uses

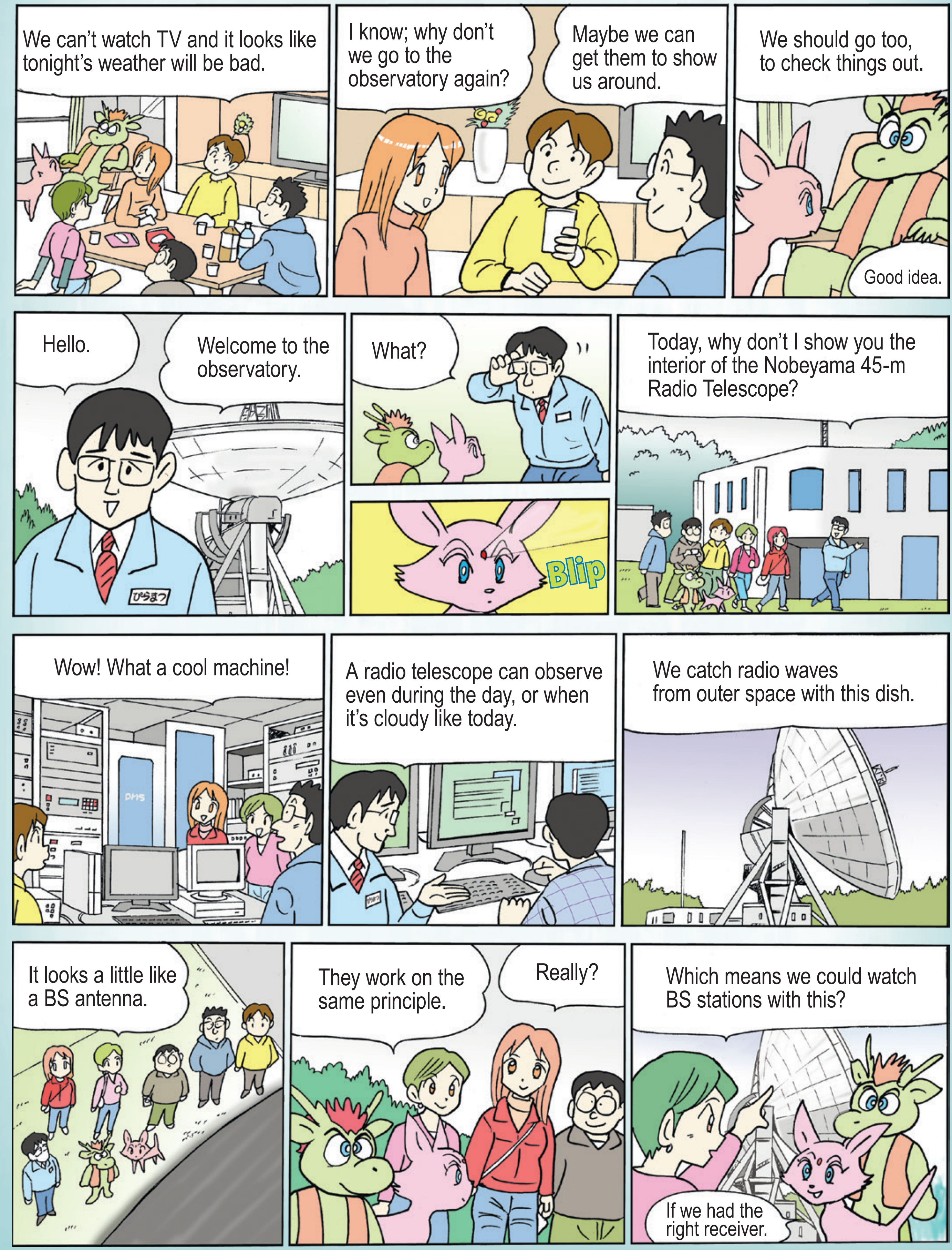
The kinds of radio waves are divided according to their wavelengths. Wavelength indicates the length of one cycle of the wave motion. The method to transmit radio waves and what they are used for change based on the wavelength. Each is used for a purpose suitable to the wavelength. Let's look at how the transmission methods differ. Also, there are cases where "frequency" units are used, as in radio stations. Frequency indicates how many wave cycles happen in 1 second.

Table 1) Kinds of Radio Waves and their Primary Uses
(from the Ministry of Internal Affairs and Communications Radio Use Web Site)

Wavelength (Frequency)	Designation	Primary Uses
～10 km (30 kHz)	Very Low Frequency (VLF)	Submarine hunting
～1 km (300 kHz)	Low Frequency (LF)	Ship and aircraft beacons
～100 m (3 MHz)	Medium Frequency (MF)	AM radio/nautical radio/amateur radio
～10 m (30 MHz)	High Frequency (HF)	FM radio/fire department radio/police radio
～1 m (300 MHz)	Very High Frequency (VHF)	Celphones
～10 cm (3 GHz)	Ultra High Frequency (UHF)	TV (ground based broadcasts)/wireless LAN
～1 cm (30 GHz)	Super High Frequency (SHF)	Radio astronomy (Nobeyama 45-m Radio Telescope, etc.)/ broadcasting satellites/radar
～1 mm (300 GHz)	Extremely High Frequency (EHF)	Radio astronomy (Nobeyama 45-m Radio Telescope, ALMA, etc.)/communication satellites/radar
～0.1 mm (3 THz)	submillimeter waves	Radio astronomy (ALMA)

Chapter 3-2: A Giant Parabola! The Nobeyama 45-m Radio Telescope.

It seems that the Nobeyama 45-m Radio Telesope's structure is similar to a BS antenna.



Ways to see the Universe using Various Antennas and Parabolic Radio Telescopes which Receive Radio Waves

•A Varity of Antennas

There are a variety of techniques among the methods to receive radio waves. Devices to receive radio waves are called antennas (*Note 01). But there are many shapes: ones which extend and collapse along a straight line like radio antennas (rod antennas), ground-based-digital-TV antennas which look like fish bones (Yagi Antennas), and parabolic antennas which receive BS station broadcasts. Each shape is matched to the characteristics of the radio waves it receives (Figure 04). The 45-m parabolic antenna at Nobeyama Radio Observatory observes radio waves known as millimeter waves with wavelengths a couple of millimeters in length.

As was briefly explained in Issue 02, a radio parabolic antenna and an optical Cassegrain reflector telescope are in principle the same thing. The radio waves or visible light coming from a celestial object are extremely faint, so we use lenses or mirrors to collect and observe them. A parabolic antenna, which looks like a large plate, reflects and concentrates radio waves.

Figure 04) Various familiar receiver antennas. ① is an FM radio extendable/collapsible antenna (rod antenna). ② is a Yagi antenna for ground-based digital TV broadcasts. ③ is a parabolic antenna for BS signals. The receiver and converter are located at the tip of the arm.

•How to make a Radio Image

But there is a big difference between radio observations and visible light observations. This is that for visible light, the image can be seen directly and be captured with film or a digital camera. But radio telescopes can't directly produce an image that people can see. What can be obtained directly by a single parabolic antenna are the measured values for the frequencies and strengths of the radio waves coming from the direction the antenna is pointing. (Please refer to Issue 01, page 05.) For this reason, special techniques are required to make the radio wave shape of a celestial object into an image which can be seen.

One technique is to move the antenna little by little, measuring the strengths of radio waves in slightly different directions. This data can be made into an image by connecting the points with equal radio strengths, like the isobars on a weather map. Another way to make an image is to designate different radio wave strengths with different colors, and array them like the pixels in a digital camera. One more way is to connect multiple antennas and observe by changing the configuration and distances between them. This method, known as "interferometry," synthesizes an image efficiently. (Please refer to page 08.)

•Radio Telescope Resolution and Sensitivity

In both radio telescopes and visible light telescopes, the level of fine detail in the target object which the telescope can discern is expressed by the resolution (angular resolution). Larger radio telescope antennas (or larger mirrors/lenses for optical telescopes) are needed to obtain higher resolutions. At the same time, larger telescopes can collect more visible light or radio waves to achieve higher sensitivities.

However the angular resolution is determined by the "wavelength divided by the aperture," and radio waves have very long wavelengths compared to visible light (please refer to page 03, Figure 01). So for millimeter waves for example, to obtain the same resolution as for visible light, you would need a parabolic antenna with a diameter hundreds of times larger than an optical telescope. This is why the Nobeyama 45-m Radio Telescope at the Nobeyama Radio Observatory has such a large diameter. To achieve even higher resolution, an even larger parabolic antenna is needed, but production becomes a difficulty. Interferometry is an excellent way to overcome this drawback and achieve high resolution. (Please refer to page 08.)

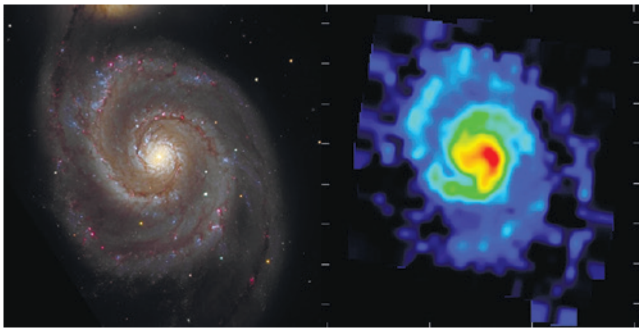


Figure 05) Galaxy M51 in the constellation Canes Venatici as seen by the Nobeyama 45-m Radio Telescope (right. On the left is the visible light image). The color shifts from blue to red to indicate stronger radio waves. (Visible light image: Jon and Bryan Rolfe/Adam Block/NOAO/AURA/NSF)

How to Determine the Resolution (Angular Resolution)

The resolution (angular resolution) of an optical telescope when observing by eye can be determined from the following empirical relation known as Dawes' limit:

-Resolution (arc sec) = 116 (arc sec)/telescope aperture (mm)

-For a 10 cm telescope, the resolution is 1.16 arcseconds.

-In contrast, the Nobeyama 45-m Radio Telescope's resolution for an observational wavelength of 3.5 mm is given by the following formula:

-Resolution (arc sec) = 1.22 x 57.3 x 3600 x wavelength(m)/aperture (m)

So the resolution becomes 19 arcseconds. We can see that even though the antenna's diameter is 450 times larger than a 10 cm optical telescope, it can't compete in terms of resolution. This shows that based on resolving power, it is extremely difficult in principle to precisely observe the Universe using radio waves.

How to Make Radio Waves into Numerical Data

How does a radio telescope observe the radio waves coming from a celestial object? In the Nobeyama 45-m Radio Telescope, the radio waves collected by the antenna are detected by a receiver. Actually, the radio signals are very weak, so they are strengthened by an amplifier. Also, there are a variety of wavelengths mixed into the signals coming from celestial objects. We need a machine to pick out only the particular wavelength of radio waves we want to observe. That device is known as a spectrometer. The Nobeyama 45-m Radio Telescope uses an acousto-optical spectrometer (an instrument for dividing radio waves by wavelength using a device to change the radio waves into ultrasonic waves) and a digital spectrometer (a device which performs a Fourier transform with a computer and conducts spectrography.)

(* Note 01) Among antennas there are many varieties: some of which emit radio waves (for example a celphone base station, please refer to ALMAr's Adventure Issue 02) and some of which receive radio waves. Let's investigate what kinds of antennas there are.

Chapter 3-3: A Small Parabola! A 30-cm Wok.

Our heroes are able to receive BS signals even without a specialized antenna!

Experiment 2 Watching BS Broadcasts with a Wok

This time let's try an experiment to actually catch radio waves coming from space. But it's difficult to detect radio waves from celestial objects right off, so let's try catching the BS signals coming from Broadcasting Satellites which were introduced on page 03. I can hear some people saying, "There's an official BS antenna attached to my house; I can watch BS channel programs anytime." But in this experiment, we'll try receiving BS signals with a wok, without using that professional antenna.

Note 02: You can also experience this experiment to catch BS signals using a wooden stand at events like NAOJ Mitaka Campus Open House Day.

STEP 01 What to Prepare

To watch BS broadcasts you'll need a "BS antenna," "receiver (converter)," "BS tuner" and a "television." Lately, TVs have internal BS tuners. Usually in professional BS antennas, the antenna and the receiver come as a set (please refer to page 05), but we'll remove the receiver and use just it. To make this experiment easier, secure the receiver to a stand prepared beforehand (Note 02). You could also use something like a large camera tripod.
we'll try receiving BS signals with a wok, without using that professional antenna.

Affix the receiver to a wooden stand.

STEP 02 Determine the Antenna Direction

You won't receive any radio waves unless the parabolic antenna is correctly pointed at a Broadcasting Satellite. The position (apparent direction and elevation) of the Broadcasting Satellite varies based on your geographical location (refer to the table on the right). Check the position data for your town ahead of time, and use a magnetic compass and protractor to get a general idea of the target area. If there is a BS antenna already installed nearby, then the satellite is in the direction which that antenna is pointing.

Check the position of the Broadcasting Satellite.

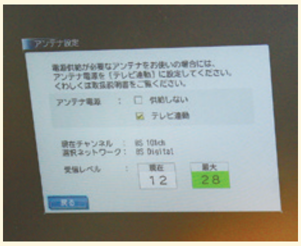
Broadcasting Satellite Position
(BS Antenna Orientation)*

	Height (Elevation)	Direction (azimuthal, clockwise from North)
Sapporo	31.2	221.7
Sendai	35.3	224.0
Tokyo	38.1	224.4
Niigata	36.6	222.1
Kanazawa	39.1	220.1
Nagoya	40.1	221.5
Osaka	41.4	220.2
Hiroshima	43.4	216.2
Kochi	43.5	218.2
Fukuoka	45.2	213.9
Kagoshima	47.0	215.6
Naha	53.6	215.8

*Taken from "Tips for Installing a BS•100°CS Antenna (satellite broadcasts)" by the Japan Electronics and Information Technology Industries Association.

STEP 03 Receive BS Signals

TVs with an internal BS tuner have the ability to measure the BS signal radio strength (signal level). While watching the numerical values or the meter, change the distance between the wok and the converter and the orientation of the wok little by little to search for the location where you receive the strongest signal. If you switch to the normal viewing screen, you'll be able to watch BS programs.



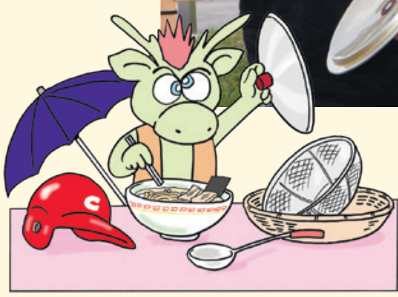
Check the signal level.

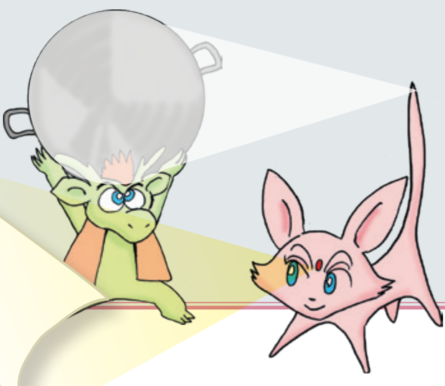
Switch to the regular viewing screen while holding the wok in a location where the signal is strong. When the image appears, try moving the position of the wok slightly and watch how the image changes.

STEP 04 Can this be an Antenna?

Well, were you able to catch radio waves from outer space using a wok? People who answered "yes," can think about the reasons why a wok is able to catch radio waves. Next, try using various other kinds of antennas to see if they can also catch the BS signal radio waves. You should be able to test the reasons you came up with.

Try using a metal pot lid.





Dr. BS: Masato Ishigro (NAOJ Professor Emeritus: Formerly Director of ALMA Project Office)

The Nobeyama 45-m Radio Telescope Opened Millimeter Wave Astronomy ALMA will Open Submillimeter Wave Astronomy

Astronomy's history with optical telescopes started over 400 years ago with Galileo Galilee. In contrast, the history of radio astronomy has yet to reach 100 years. Japanese radio astronomy started with observations of solar radio waves by the Tokyo Astronomical Observatory (now NAOJ). That was around 1947. Cosmic radio wave studies started with millimeter wave observations using a 6 m diameter parabolic antenna in 1970. Even internationally, millimeter wave observations had only recently started, so Japan was standing on the same starting line as everyone else. And in 1982, a 45 m diameter radio telescope with the world's highest performance was completed at Nobeyama Radio Observatory. Through its observations, it has led world radio astronomy, achieving many results which opened new doors for millimeter wave astronomy such as clarification of the various properties of molecular clouds, discovery of many interstellar molecules, and the discovery of a super-massive black hole in the center of spiral galaxy NGC 4258.

Nobeyama Campus has developed into a world-class center for radio astronomy through the addition of the Nobeyama Solar Radio Observatory (scheduled to be introduced next time in ALMAr's Adventure 04) located on the same premises and focusing on observations using a distinctive radio telescope known as the Nobeyama Millimeter Array composed of 5 (and later 6) parabolic antennas with 10 m diameters. Based on the successes from Nobeyama, Japanese radio astronomers started considering ideas for construction of an every higher performance radio telescope. That was an ambitious project to observe submillimeter waves which are shorter than millimeter waves. As can be seen from Figure 01 on page 03, submillimeter waves are the electromagnetic waves with the shortest wavelengths within the radio region (shorter than this moves into the infrared region). A telescope to observe these demands extremely advanced techniques. After that, the construction of a submillimeter telescope was also proposed overseas. An international collaboration between Japan, Europe, and the United States of America planned to build the world's largest, highest sensitivity radio telescope capable of observing millimeter and submillimeter waves. This became "ALMA" which was constructed in the Atacama Desert in Chile, South America and which has finally started full observations. It is a radio interferometer with 66 parabolic antennas (54 with 12 m diameters and 12 with 7 m diameters). It has already achieved unprecedented resolution and sensitivity and is now continuing with various kinds of observations. For information about the current status of ALMA, please refer to February's issue.

The Nobeyama 45-m Radio Telescope and Red Mountain (highest peak of the Yatsugatake Range; Altitude 2899 m)

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

ALMA which has started full science observations and Volcán Licancabur (center, rear; Altitude 5916 m)
[Photo: Clem & Adri Bacri-Normier (wingsforscience.com) /ESO]