Soraryuden: Legend of the Sky Dragon, Episode IV

アルマーの冒険 ALMAr

ALMAr's Adventure

Prologue
"Messenger from the Radio Universe"

The expansive Universe...

Since ancient times we have developed astronomy to solve the various mysteries lurking 'out there.' For a long time astronomy progressed through observations of "the Universe that can be seen with the eye" in other words, visible light. But in the first half of the 20th century, it became possible to observe many other kinds of electromagnetic waves, first and foremost radio waves. One after another, new visions of the Universe which had been invisible to the eye were revealed. Astronomy took a big step forward. These results can be referred to as "Discovering the Universe at Multi-Wavelengths." And now a high quality radio telescope is being constructed in the Atacama Desert of Chile. The National Astronomical Observatory of Japan is also participating in this international project, known as "ALMA." What will ALMA see? What does the Universe look like when seen in radio waves? To answer these questions let's start our adventure with ALMAr, the dragon from the Radio Universe, and his friends.

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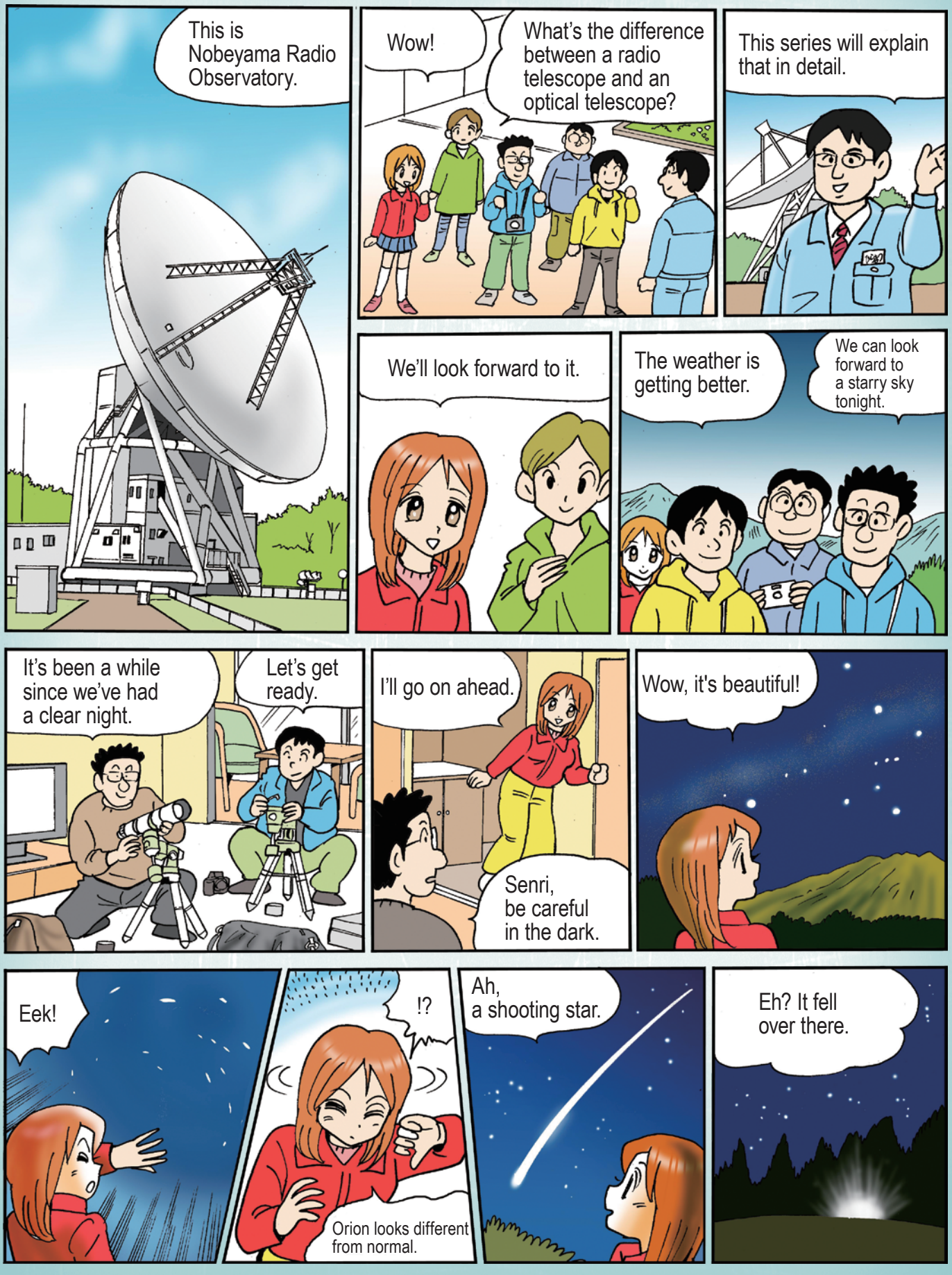
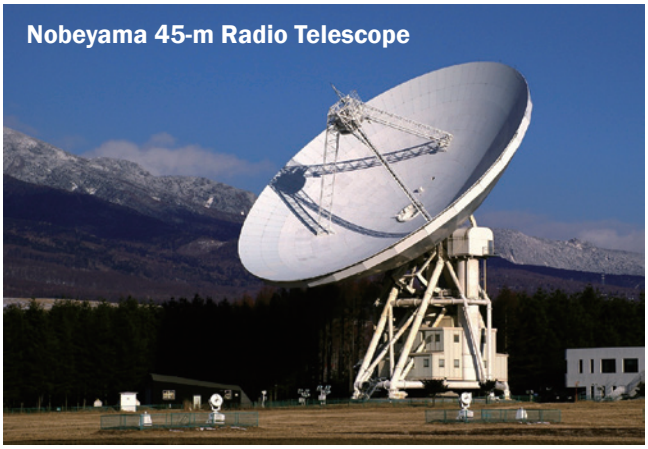
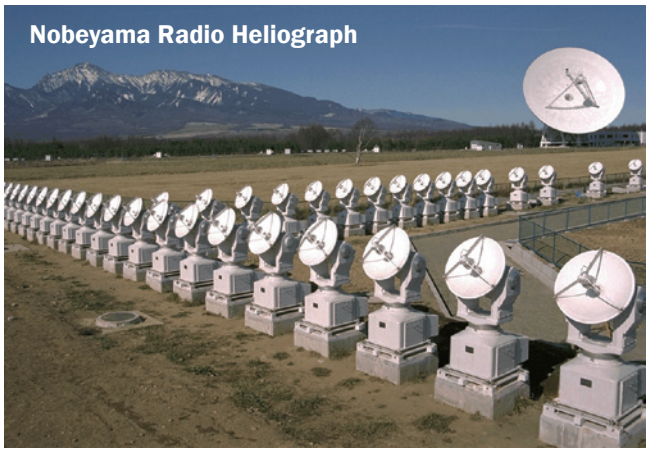
Chapter 1: A Night in the Nobeyama Highlands

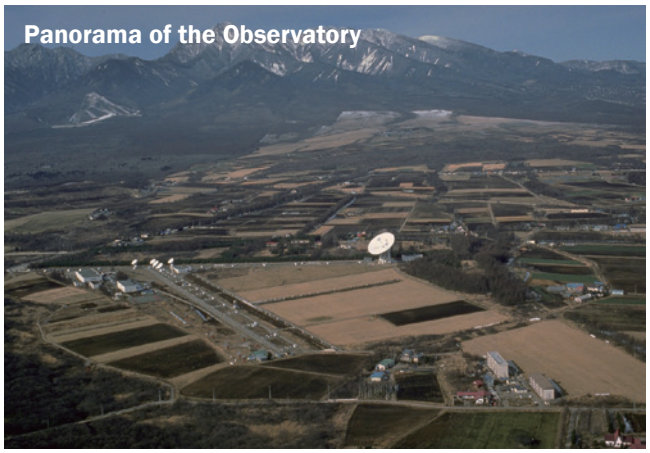
The members of Soten "Deep Blue Sky" High School's astronomy club have come for a training camp in the Nobeyama highlands, a location famous for stargazing. They visited the National Astronomical Observatory of Japan's Nobeyama Radio Observatory. This is the story of that night.



Astronomical Observatories Studying Radio Waves
~ NAOJ Nobeyama Radio Observatory and Nobeyama Solar Radio Observatory







NAOJ Nobeyama Radio Observatory and Nobeyama Solar Radio Observatory are located in the Nobeyama highlands at the foot of Yatsugatake (the Yatsugatake mountain range can be seen in the background of the lower right picture.) Various radio telescopes like the Nobeyama 45-m Radio Telescope (upper left), Nobeyama Millimeter Array (Upper right) and the Nobeyama Radio Heliograph have been gathered together forming a Mecca of Japanese Radio Astronomy. The facilities are open for visiting.

At this observatory spreading out at the base of the Yatsugatake Mountains, various parabolic antennas, large and small, operate night and day to seek out new views of the Universe. The Nobeyama 45-m Radio Telescope boasts the largest diameter in the world among telescopes that can catch radio waves with wavelengths out to 3 mm. The Nobeyama Millimeter Array acts as a single antenna by using a computer to combine the radio waves received by six 10-m antennas. The Nobeyama Radio Heliograph consists of 84 antennas arranged in a T-shape to film videos of vigorous solar activity at radio-wavelengths. In addition, the polarimeter composed of 8 parabolic antennas is used to elucidate the nature of long period solar cycles through over 50 years of accumulated data.

Radio astronomy started from accidentally catching radio waves from space during the development of wireless technology which began in the 1930s. It is a relatively young field of study compared to visible light observations of heavenly objects which have been used since ancient times to set calendars and which have made great advances since the invention of the telescope in the 17th Century. Radio wave observations at Nobeyama started in 1969 with the establishment of the Nobeyama Solar Radio Observatory. The Nobeyama 45-m Radio Telescope started observations in 1981. The Nobeyama Millimeter Array started observations the next year. In this way, Nobeyama quickly became one of the world's leading radio observatories. Now, 30 years later VERA, comprised of radio telescopes established throughout Japan to map the structure of the Galaxy, and ALMA, under construction in Chile and set to start observations soon, have inherited trained personnel and technological advances from Nobeyama, continuing the quest to explore the mysteries of the Universe.

So what does the Universe revealed by radio waves look like? To start with, what does it mean to "See the Universe with radio waves?" And why are there so many parabolic antennas arrayed?
Let's start our journey exploring the Radio Universe with Nao Senri.

I came for a tour of Nobeyama Radio Observatory. The winter here in Nobeyama is very cold, but in addition to there being few artificial radio waves it is also very dry, making it ideal for radio observations. I had thought we could only observe the Universe at night, but here at Nobeyama Radio Observatory, observations continue around the clock. I was surprised to hear that observations continue even when it is cloudy or raining. The Sun, distant stars, and black holes in the centers of even more distant galaxies all emit radio waves. They told us that we learn about various phenomena in Universe, not just through light visible to our eyes, but also through radio waves. I was worried that rain would collect or snow would pile up in the large parabolic antenna. But the antenna has gaps so that the rain doesn't collect. If snow piles up, they point the antenna towards the Sun to melt it. It is surprisingly low-tech, but it's all been carefully thought out.

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.

Chapter 2: Messenger from the Radio Universe

Thinking that "a shooting star has landed!" Nao rushes to the landing site and meets some kind of dragon-child. The creature calls itself "ALMAr." What is going on?

Let's compare the Milky Way seen by Light and the Milky Way seen by Radio Waves.

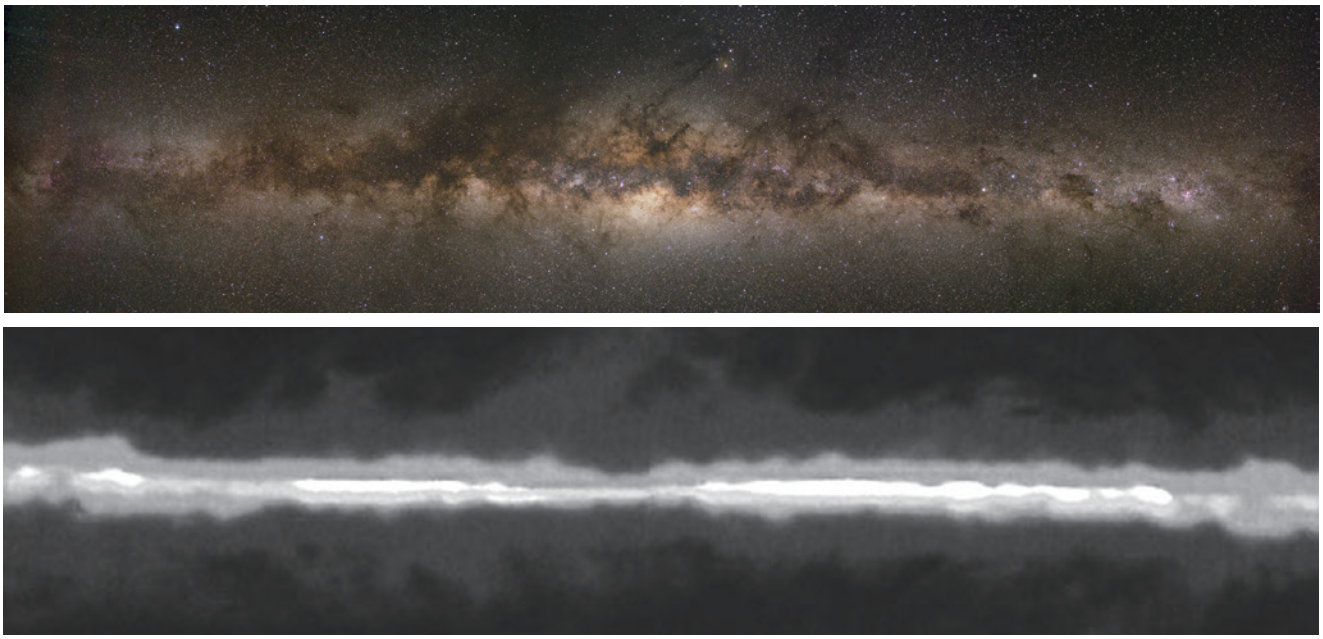


Figure 1) The Milky Way seen by light (upper) and the Milky Way seen by radio waves (lower). In the Milky Way seen by light, the dark stripe (Dark Rift) shows where the Milky Way's light has been blocked. In contrast, the Dark Rift appears bright when seen in radio waves. (Upper image: Tetsuo Hasegawa /Lower image: NRAO)

The Universe seen by radio waves appears different from the Universe seen by the light which our eyes can see. Above, Figure 1 shows the appearances of the Milky Way seen by light (upper) and as seen by radio waves (lower). The stripe stretching out horizontally can be seen in both of them, but its appearance is different. In the Milky Way seen by light, a black part can be seen between the numerous stars. In the Milky Way seen by radio waves, this dark band appears bright instead.

To start with, what do we mean by "to see?" What do we mean by "bright?" We experience the illumination from the Sun or a lamp as "bright." But this is because when lots of light from the Sun or a lamp enters our eyes, the retina at the back of the eye senses it. The retina doesn't react to radio waves. For example, telephone towers or celphones which are emitting strong radio waves do not appear bright to us. But if we use an instrument we can investigate where strong radio waves are coming from. If we do this, we understand that the laptop computers and celphones carried by many people and the celphone base stations and television towers located in towns all emit strong radio waves. Can you envision a scene where "objects emitting strong radio waves sparkle dazzlingly?" If you glance at outer space, many stars shine brightly in the light visible to the eye. If we take a device which can see radio waves from outer space, in other words a radio telescope, and turn it towards the sky, we can investigate celestial objects emitting strong radio waves. This is radio astronomy.

Returning to the above pictures of the Milky Way, the parts which appear bright in visible light and radio waves are different. In other words, light and radio waves see different aspects of the Universe. Actually visible light and radio waves are both "electromagnetic waves." The differences in their properties come from differences in their wavelengths.

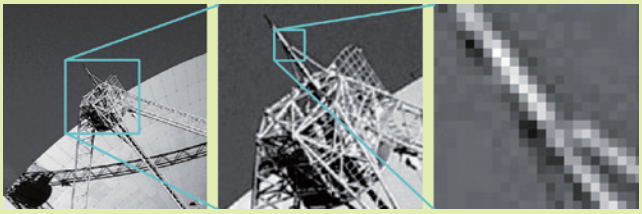


Figure 2) By expanding a monochrome photograph we can see that it is made of a collection of pixels. The principle of color photograph is the same: a collection of pixels showing the intensity of the light. The difference is that in a color photograph, 3 primary color pixels are combined into 1 set. By changing the intensities of those lights, various colors can be produced.

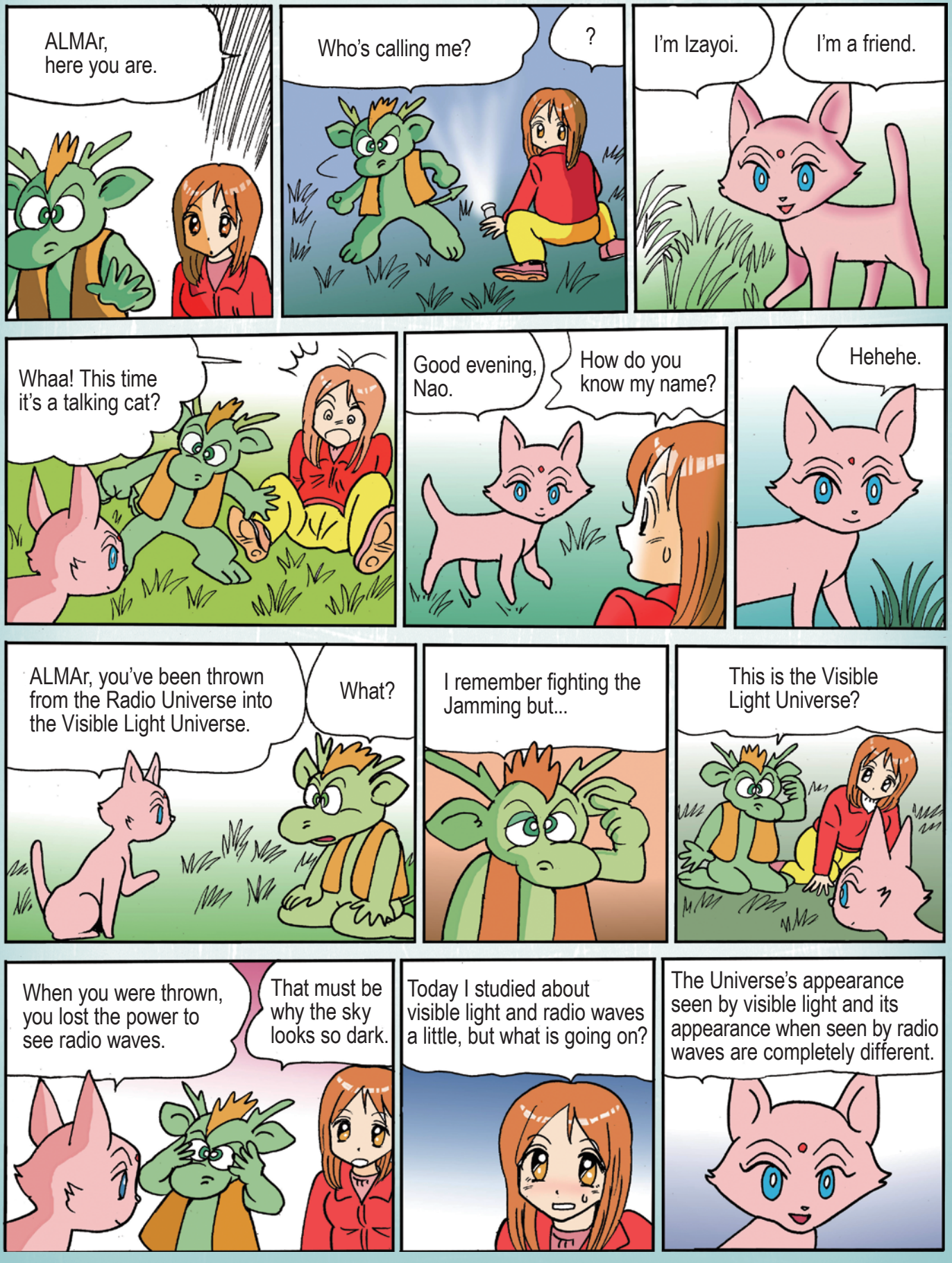
ALMAr

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.

When they hear the words "radio waves," most people think of things they can hear with their ears like radios or celphones. But actually, radio waves are related to light. If we use a device to catch radio waves, we can record their strengths and use them to "see." For example, if you continue to expand a picture taken with a digital camera, you can see that the picture is made from a collection of small points of light (pixels). In a monochrome picture, the brightness of each pixel indicates how strongly the light entered it (Figure 2). In other words, arranging many points measuring the strength of the light within a given area (the field of view) can be said to show us a monochrome photograph. Likewise, if we arrange many points measuring the strength of the radio waves within a field of view, we can take a "radio photograph" or a "radio movie." Using this principle radio astronomers can determine the characteristics of celestial objects by investigating how strongly various kinds of radio waves are coming from different kinds of places.

Chapter 3: The Two Universes

After the dragon-child "ALMAr," next "Izayoi" a talking cat appears.
Nao Senri is already confused but is further shocked when Izayoi reveals the true nature of ALMAr.



By Combining Images Taken with Light and Radio Waves, More of the Universe Becomes Visible

Figure 3) The constellation Orion seen in visible light (left panel), has been overlaid with the distribution of dark nebulae emitting strong radio waves (right panel). The color shifts from blue to red to show stronger radio emissions. (Radio image: University of Tokyo 60-cm Survey Telescope)

What are the concrete differences between the Universe seen by light and the Universe seen by radio waves? First, light and radio waves are both "electromagnetic waves." Because they're "waves," their features can be classified according to their wavelengths (the distance between one wave peak and the next). Light (light which can be seen by the human eye, hereafter referred to as "visible light") has wavelengths from about 400 to 800 nanometers. (A nanometer is 1 millionth of a millimeter.) The wavelengths of radio waves are much longer than this, more than several hundred mircometers. (A mircometer is 1 thousandth of a millimeter.) (Figure 4)

The locations emitting visible light and radio waves are also different. Visible light is emitted by stars like the Sun (hotter than tens-of-thousands of degrees) or parts of the gas drifting in space that have been illuminated by nearby stars and reached high temperatures. The stars shining in the night sky and the familiar nebulae seen in photographs from the Subaru Telescope or the Hubble Space Telescope are primarily these kinds of high temperature celestial objects. In contrast, radio waves are emitted by celestial objects which aren't very hot. Because the Milky Way's dark stripe (Dark Rift) seen on page 5 has an absolute temperature of 10 Kelvin (-263 Celsius) and is composed of extreme low temperature dust (small particulate matter) and gas, it can't emit visible light; but it can emit radio waves. The above image (Figure 3) shows the constellation Orion seen in visible light (left panel) and the same image overlaid with the distribution of dark nebulae emitting strong radio waves (right panel). By looking at the radio waves we can see that large amounts of matter are scattered in places where nothing can be seen in visible light. The distribution of young stars can be investigated with visible light. By comparing that to the distribution of dark nebulae observed via radio waves, we learned that actually stars are born in dark nebulae and as a star matures, its distance from the dark nebula increases. We can better understand the characteristics of celestial objects through the ability to see visible light and radio waves, electromagnetic waves of different wavelengths. By combining these, we can create even grander astronomy stories.

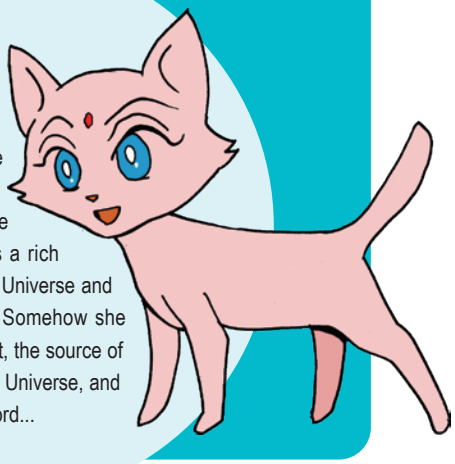
Figure 4) A chart of electromagnetic wavelengths. "μm" indicates micrometers. You can see that the wavelength band of visible light is very narrow.

There are many varieties of electromagnetic waves defined by their wavelengths. Even within radio waves, there are millimeter waves with wavelengths of several millimeters, submillimeter waves with shorter wavelengths, and meter waves with longer wavelengths. Millimeter waves and submillimeter waves with short wavelengths are radiated strongly by low temperature dust and interstellar gas. Radio waves with long wavelengths are emitted by things like plasma gas gushing out from a black hole at close to the speed of light. Even though they're both called radio waves, what we can see differs based on the wavelength.

In addition to visible light and radio waves, electromagnetic waves also include ultraviolet, infrared, x-rays, etc. By viewing the Universe at various wavelengths, we can observe the characteristic celestial objects of each wavelength (Figure 4). Multiwavelength astronomy, which observes various wavelength bands of electromagnetic waves, enables us to elucidate the multifaceted nature of space more richly by using radio waves to reveal a Universe which can't be seen by visible light.

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...



“Anyways, something interesting has started.”

“ALMAr” and “Izayoi” came from the Radio Universe. Nao Senri who met them by chance in the Nobeyama highlands has gotten mixed up in things as the radio astronomy quest for “Grand ALMAr’s Sword” gets ramped up. See you next time.

A Note about ALMAr’s Adventure

The title “ALMAr’s Adventure” is of course derived from the name of the ALMA project. (It is also a pun on “Elmer’s Adventure” the Japanese title of the children’s book “My Father’s Dragon.”)
Also, “Izayoi” is the name of the radio telescope (radio interferometer) which NAOJ is responsible for producing as part of the international ALMA project. To better understand “ALMAr’s Adventure,” here we introduce a little more detail about ALMA and Izayoi which lend their names to these characters.

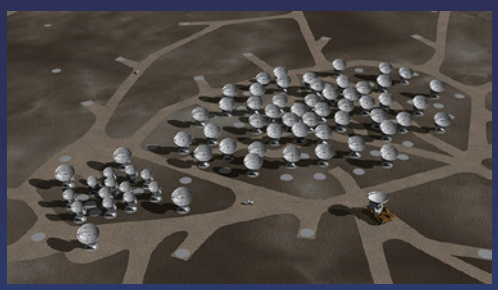
ALMA

ALMA is an international collaboration between East Asia (mainly Japan), the United States of America, Europe and Chile. A total of 66 antennas, including 54 high-accuracy 12-m antennas and 12 high-accuracy 7-m antennas are arrayed on a 5000 m elevation plateau in the Andes Mountains in Chile. These antennas operate as a single, super high-capability radio telescope. The official name “Atacama Large Millimeter/submillimeter Array” is abbreviated as “ALMA” which also means “soul” in Spanish, the official language of Chile. Construction started in 2003, after more than 20 years of preparation by world astronomers who “want to see farther, fainter celestial objects in greater detail.” Science observations are set to start in 2011.

ALMA is an interferometer capable of repositioning each antenna for observations.

Izayoi

Of the 66 ALMA antennas, Japan is responsible for building four 12-m antennas and twelve 7-m antennas. We call these 16 antennas the “Atacama Compact Array (ACA).” It was nicknamed “Izayoi” through a public completion (please refer to NAOJ News April 2010). Radio interferometers like ALMA, which connect multiple antennas to form a single telescope, excel at charting the detailed structure of astronomical objects. On the other hand, they have difficulty observing faint, extended objects. “Izayoi” was built to compensate for this weakness and accurately measure the radio wave intensities. We can make high resolution radio images by combining data from “Izayoi” and the fifty 12-m antennas to be provided by Europe and the United States of America. Izayoi is a beautiful classical Japanese word related to the number of antennas (the 16th day of the month in the traditional luni-solar calendar, also meaning to hesitate). We hope the harmonious spirt of this word conveys the image of an interferometer which will produce great observational results by combining multiple antennas.



“Izayoi” is the group of 16 antennas in the lower left.

ALMA Search

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The 8 ALMA antennas which have started test observations.
Photos, illustration of completed state: ALMA (ESO/NOAJ/NRAO)