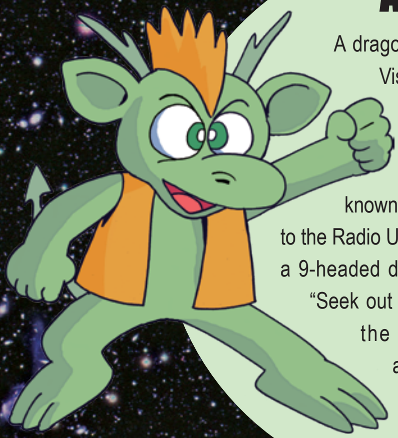
アルマーの冒険 ALMAr

ALMAr's Adventure

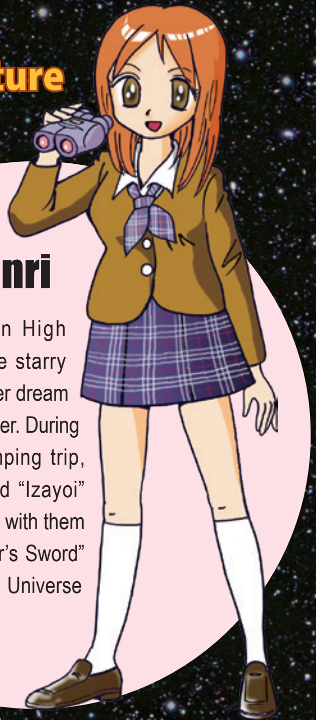
Issue 02
"See the Light, See the Radio Waves"

This 2nd installment explains the topic of "Seeing the Universe" while reviewing Issue 01. Let's compare the similarities and differences of "the Universe seen by the eye" (visible light) and "the Universe seen by radio telescopes" (radio waves) while thinking about what it means to 'see.'



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.



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.

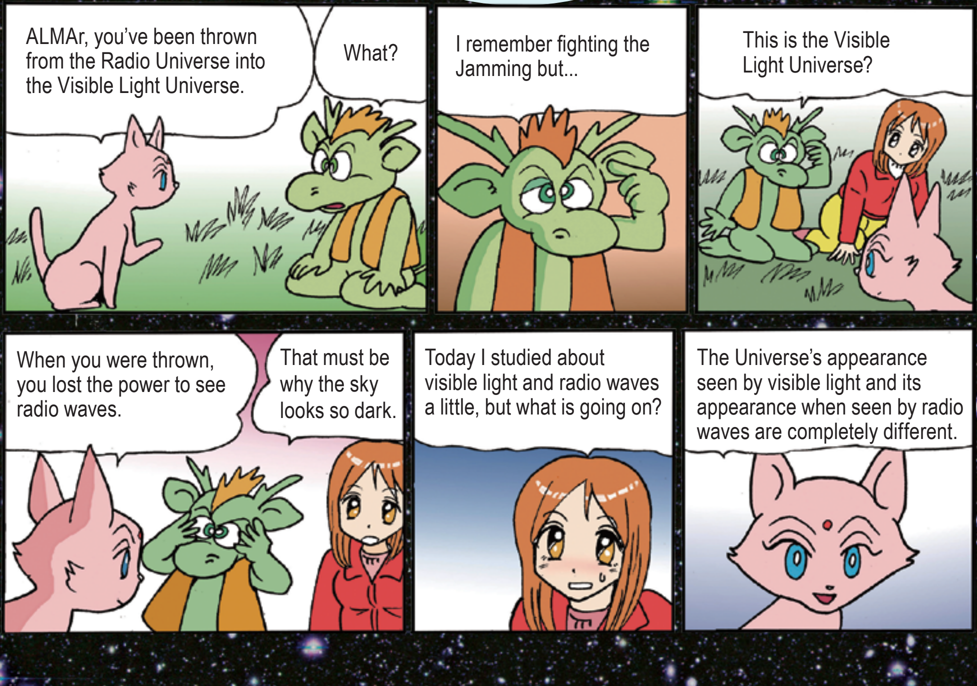
Izayoi

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...

Produced by "ALMAr's Adventure" Production Unit
Illustration: Ryuji Fujii
Dialog: Shoken Hiramatsu
Editor in Chief: Hiroyuki Takata
Design: Maki Kubo
Translation: Ramsey Lundock

Previous Issue, Issue 01 "Messenger from the Radio Universe"

Members of Soten "Deep Blue Sky" High School's astronomy club used Golden Week vacation to hold a training camp in the Nobeyama highlands, which are known for wonderful stargazing. During the day, they visited NAOJ Nobeyama Radio Observatory and toured the radio telescopes. As the evening darkened, a sky full of stars appeared.... Nao Senri, a club member who went out ahead of everyone else, looked up at that starry sky and saw a falling star land nearby. Investigating she found ALMAr, a dragon-child from the "Radio Universe." Then a mysterious, knowledgeable cat appeared.



Chapter 2-1: The tip of the Antenna is Shining!

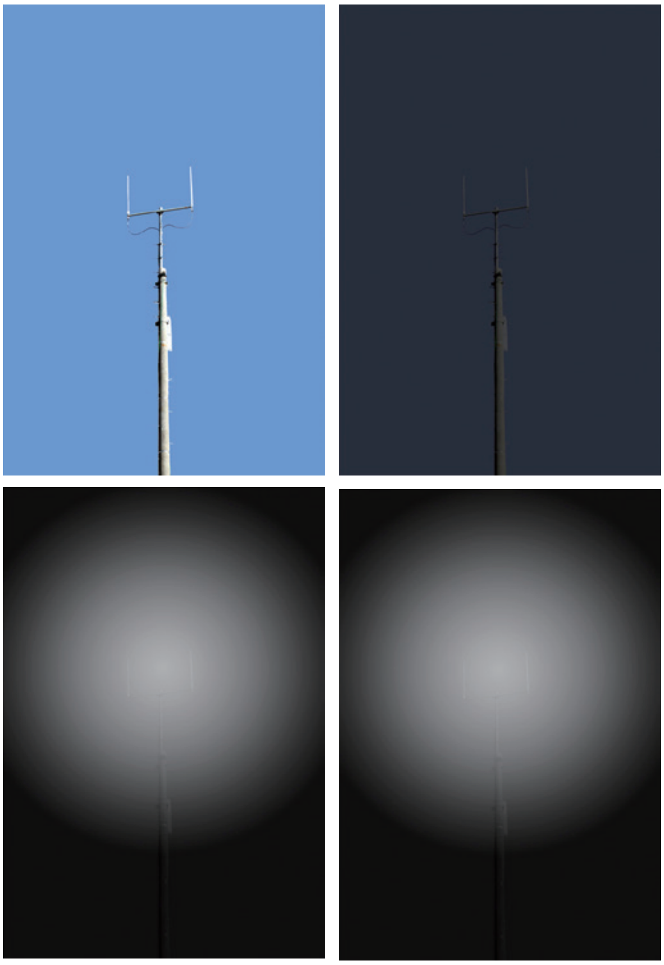
When Nao holds "Izayoi's" tail and looks at a celphone base station antenna...

A Way to “See the Universe in Radio Waves” - Observing the Direction and Strength of Radio Waves

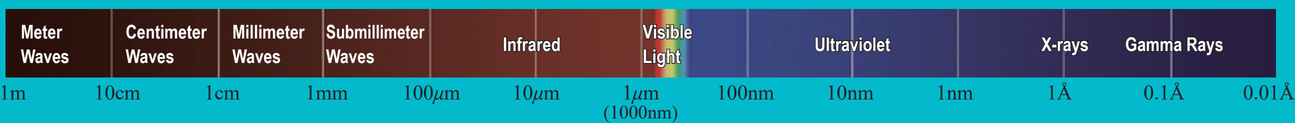
In preparation to think about what it means “to observe the Universe with radio waves,” or “to take pictures of celestial objects with radio waves,” let’s think about how we perceive the scenery in front of our eyes. The way we can see things like this “ALMAr’s Adventure” comic book or radio towers, like the one in the pictures to right, is that light from sunlight or an artificial light source reflects from the object and reaches our eyes. This light is converted into an electrical signal by the photoreceptor cells in the retina at the back of the eye. This signal is conducted to the brain by nerves. This is how we perceive ‘seeing objects.’ If the amount of light entering our eyes is large, we experience it as “bright.” If the amount of light is small, we perceive it as “dim.” Also, which wavelengths of light come in strongly determines the color we experience.

Radio waves must also be entering our eyes, but the photoreceptors can’t change them into electrical signals. For this reason, we can’t “see” radio waves. Instead, humans can create instruments to detect radio waves. Using those instruments, we can determine which direction radio waves are coming from and how strong they are. For example a celphone, a celphone base station, and the tip of Tokyo Tower emit strong radio waves. If we use the same terminology as visible light, we can say that these objects appear “bright (in radio waves).” We can make a “radio photograph” by determining which direction radio waves are coming from and how strong they are and turning that information into a picture.

Of course this isn’t limited to just radio waves. We can do the same thing with other signals the eye can’t see, like X-rays, ultraviolet radiation, infrared radiation, or neutrinos. By making observational instruments suited to each and examining “which direction electromagnetic waves (or particles) are coming from and how intense they are” we can investigate what kinds of objects are emitting what kinds of electromagnetic waves (or particles.) Thanks to astronomers producing various instruments in this manner, we can see many phenomena in the Universe that can’t be perceived by the unaided human eye.



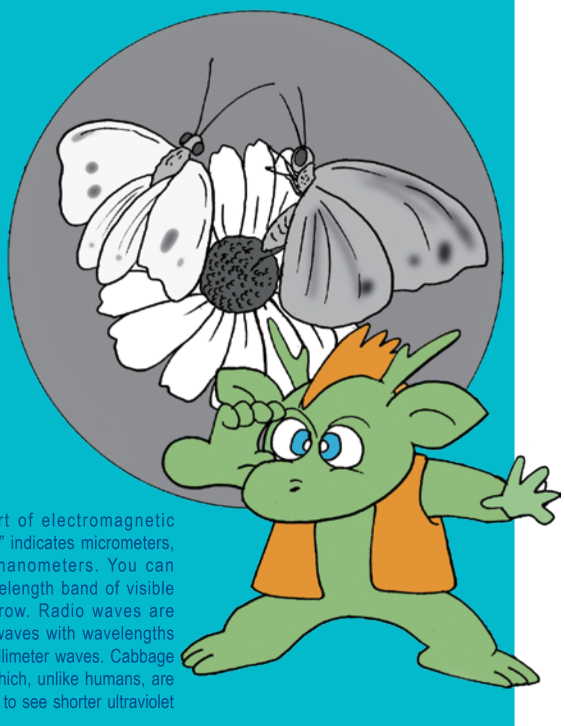
A celphone base station antenna seen in visible light (upper left: daytime, upper right: nighttime) and seen in radio waves (lower left: daytime, lower right: nighttime, artist’s renditions). The antenna can be seen in visible light during the day, but at night there’s no sunlight so it can’t be seen. In contrast, if we look at the radio waves, an antenna emitting radio waves appears “bright” regardless of day and night.



A Human’s Eye, a Cabbage White Butterfly’s Eye, or an ET’s Eye?

The wavelengths of light the human eye can perceive are about 400 nm to 800 nm. This covers the wavelength range of electromagnetic waves emitted most strongly by the Sun. Also, ultraviolet radiation can damage cells since it is high energy, and infrared radiation causes water molecules to vibrate, producing heat. It can’t be coincidence that the human eye has evolved to sense the wavelength range between ultraviolet and infrared. But how far to either side of visible light the eye can see depends on the species. For example, when cabbage white butterflies (Pieris rapae) are illuminated by ultraviolet radiation, the brightness of the males’ wings and the females’ wings are very different. So we think that cabbage white butterflies can see into the ultraviolet and use this to distinguish the males from the females.

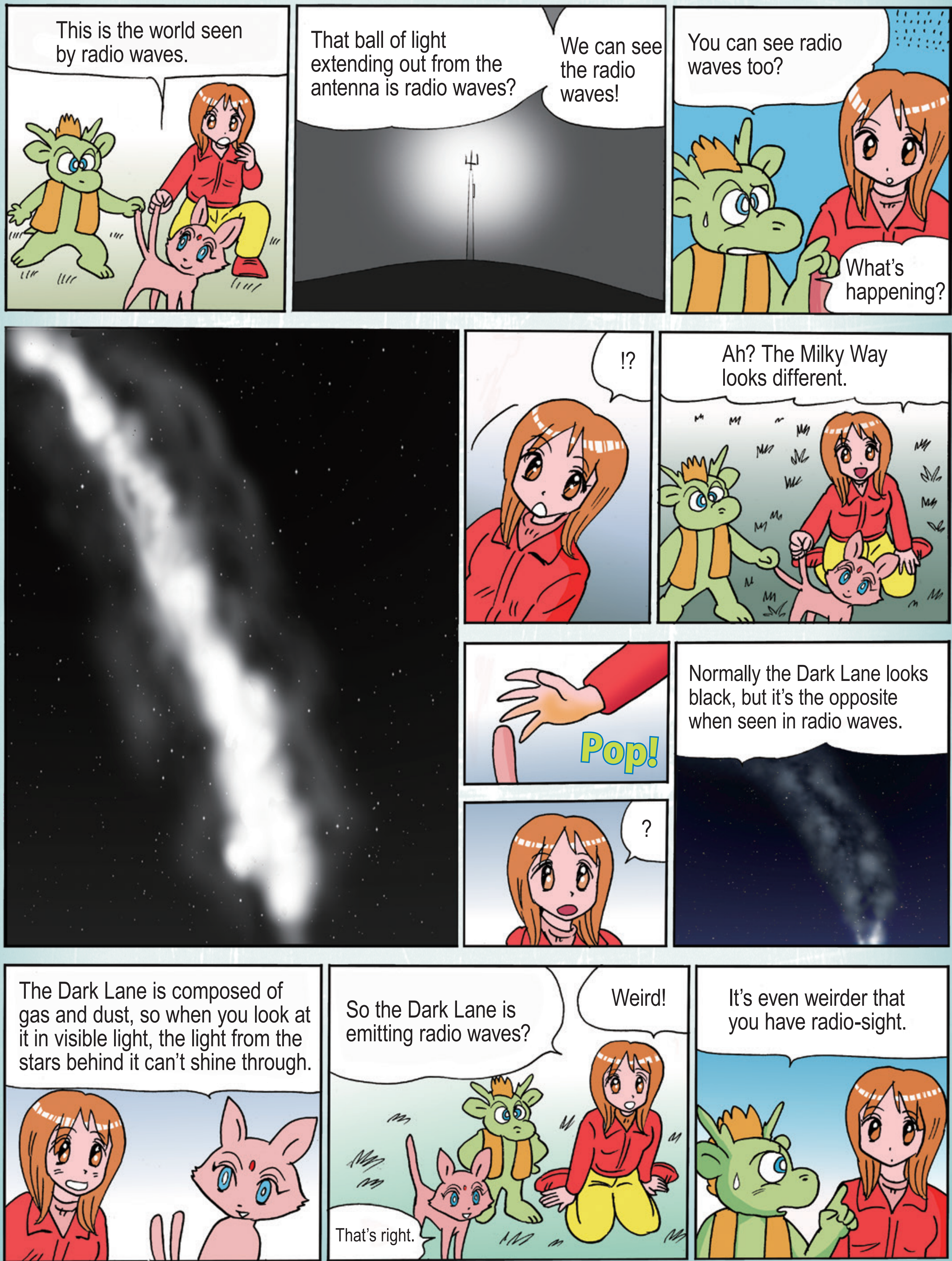
So for example, if the Sun’s temperature was lower, infrared radiation would be stronger than visible light. If this was the case, then what wavelengths of electromagnetic waves would the eyes of creatures living on Earth be able to sense? On the other hand, what would have happened if the Sun was hotter making the ultraviolet stronger? When thinking about what kinds of sensory organs the life forms which might be living on extra-solar planets would have, it is important to consider which wavelengths of electromagnetic waves the central star emits strongly.



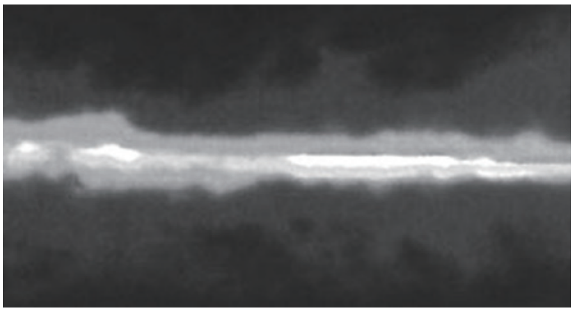
Above is a chart of electromagnetic wavelengths. “μm” indicates micrometers, “nm” indicates nanometers. You can see that the wavelength band of visible light is very narrow. Radio waves are electromagnetic waves with wavelengths longer than submillimeter waves. Cabbage white butterflies which, unlike humans, are thought to be able to see shorter ultraviolet wavelengths.

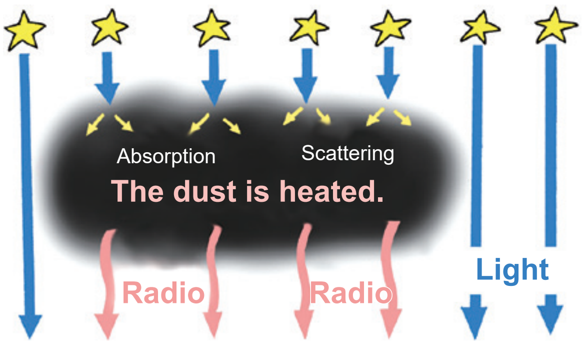
Chapter 2-2: The Light and Shadow of the Milky Way Appear Reversed!

Why do the shape of "the Milky Way Seen in Visible Light" and the shape of "the Milky Way Seen in Radio Waves" differ?



The Milky Way which Blocks Light and Emits Radio Waves – Radio Waves Emitted by the Low Temperature Interstellar Medium

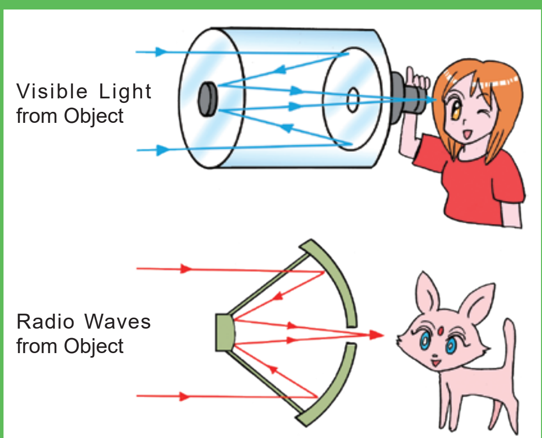




The figure to the left is a portion of the Milky Way seen in visible light (upper) and radio (21 cm wavelength radio waves emitted by water molecules) (middle). A black band runs horizontally through the middle of the visible light photo. But seen in radio waves, that portion has strong radio emissions and shows up as white in the image. The appearance of the Milky Way is a spiral galaxy seen from the inside. This spiral galaxy has a large collection of stars (called the Bulge) at its center, surrounded by a spiral disk of stars and interstellar medium (gas and dust). The part which is dark in visible light and bright in radio waves is where the interstellar medium contained in this spiral disk is distributed. In the interstellar medium dust, several micrometers in size, scatters and absorbs light well. So when interstellar medium is distributed in the foreground, it scatters and absorbs light from stars in the background, appearing as a dark belt. This is why it's called the Dark Lane. On the other hand, the dust grains, which absorb starlight, and the gas around them are heated only by this small amount of absorbed energy. In cold areas, the temperature is only about −260°C (absolute temperature 10 K). When the temperature is this low, an object can't emit visible light, but it can emit radio waves. In general, lots of energy is needed to produce electromagnetic waves with short wavelengths, but electromagnetic waves with long wavelengths can be produced even at low energies. The Sun is about 6000°C, hot enough to emit visible light. The −260°C interstellar medium can't produce visible light, but it can emit long wavelength radio waves. This is why the light and shadows appear reversed in visible and radio pictures taken of the same location (lower diagram on the left).

Also, the various molecules contained in the interstellar gas are known to emit radio waves at their characteristic frequencies. The exact radio frequency varies according to the composition. If the radio frequencies coming from a celestial object exactly match molecular emission frequencies measured in ground based laboratories, then we know that the observed object contains those molecules. So far, over 150 species of molecules have been found in interstellar space. There are also unusual molecules which can only exist in the low temperature, low density environment of space. There are many kinds of radio waves for which the kind of molecules producing them is unknown. By catching the radio waves which come to Earth from the Universe, we can analyze the composition of the target object.

The Milky Way seen by visible light (top) and by radio waves (middle). In the Milky Way seen by visible light, we know that the black stripe (Dark Lane) is where the Milky Way's light has been blocked. When seen by radio waves, the Dark Lane appears bright instead. (Upper image: Tetsuo Hasegawa /Lower image: NRAO) Below is a conceptual diagram.



The top left pictures is a small optical reflector telescope (21 cm mirror diameter). The top right picture is a radio telescope (12 m antenna). Their sizes are very different, but as can be seen in the diagram, both collect light or radio waves by reflecting them with 'mirrors.'

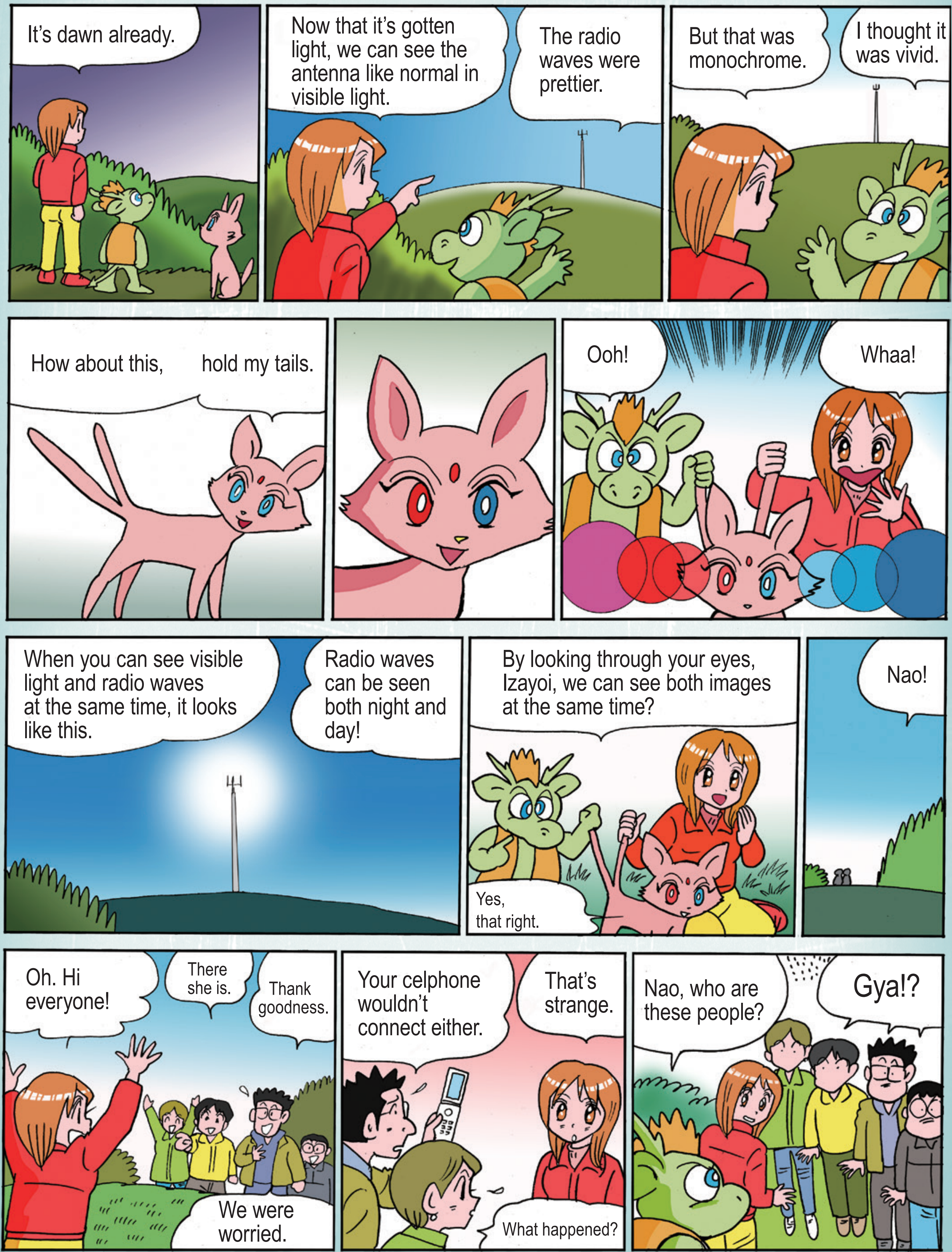
Optical Reflector Telescopes and Radio Telescopes work on the Same Principle

One of the main functions of a telescope is to collect as much of the faint electromagnetic waves coming from distant objects as possible. This ability is called light gathering power. The larger the telescope, the higher the performance which it can achieve is. In this regard, optical telescopes and radio telescopes are the same. A familiar instrument for gathering electromagnetic waves is a parabolic antenna used to watch satellite broadcasts. Artificial satellites broadcast strong radio waves, so antennas for home use are at most dozens of centimeters in size. On the other hand, there are many radio telescopes over 10 m in size.

Referring to the ray tracing diagrams on the left, you can see that an optical reflector telescope and a radio telescope (parabolic antenna) are both mechanisms to gather more light (radio waves) by reflecting them with similar parabolic mirrors (mirrors with parabolic surfaces). Making a large parabolic antenna from a single sheet is difficult, so multiple panels are arranged to form a large parabolic surface. For example, each of ALMA's 12 m antennas is composed of 205 square aluminum panels about 1 meter to a side. The Nobeyama 45-m Radio Telescope uses 600 panels. The primary mirror of the Subaru Telescope is an single-piece 8.2-meter mirror. But recently, large aperture optical telescopes have also started using the technique of arranging many segments to act as a single mirror. The Thirty Meter Telescope (TMT) proposed to be constructed in Hawai`i plans to use 492 segments 1.4 meters across.

Chapter 2-3: Seeing Light and Radio Waves Together...

As morning dawns, the antenna can be seen clearly. And by holding one of Izayoi's tails again...



To 'See,' Note the Differences in Wavelength – the Principle of Reflector Telescopes and the 'Mirror' Accuracy

Optical telescopes are placed in domes or enclosures to suppress interference from outside light. But in many cases the parabolic surface of a radio telescope can be seen from outside. So at a glance, they look like different designs. But the primary role of a telescope is to use a mirror to gather light or radio waves at a focus. As explained earlier, radio telescopes and (reflector) optical telescopes have similar structures.

Of course optical telescopes and radio telescopes have differences as well. The biggest difference is in the surface accuracy. In order to reflect electromagnetic waves cleanly, the mirror surface roughness must be small compared to the wavelength of the electromagnetic waves (less than 5~10 % of the wavelength). In the case of the Subaru Telescope which can observe visible and infrared light, the shortest observable wavelength is 370 nm (1 nm is one-billionth of 1 meter) and the mirror surface accuracy is 12 nm. On the other hand, for ALMA the shortest observable wavelength is 320 μm (1 μm is one-millionth of 1 meter) and the mirror surface accuracy is 25 μm. The observable wavelengths of the Subaru Telescope and ALMA differ by a factor of 1000, so the required surface accuracies also differ by a factor of 1000. When observing even longer wavelength radio waves, for example the 21 cm radio waves emitted by hydrogen atoms, surface roughness (or holes) on the order of 1 cm don't cause problems. Actually, some of the radio telescopes which observe long wavelength radio waves have mirror surfaces made from wire mesh with many small holes. These don't look like mirrors to the human eye; but for long wavelength radio waves, it doesn't matter if there are holes significantly smaller than the wavelength. Even a wire mesh makes a fine mirror (Figure 1).

For the same observational target, the way to observe it changes based on the wavelength. If we had 2 types of eyes a "visible light eye" and a "radio wave eye" like Izayoi in this comic, during the day, a celphone tower would look like this conceptual image (Figure 2).

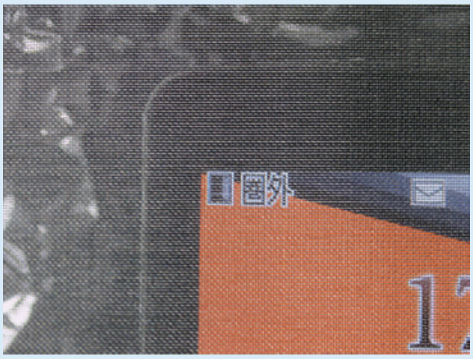
Figure 1) A picture of the 70-600 MHz Radiospectrograph at Nobeyama Radio Observatory used to observe the Sun until 1994. It observed long wavelength radio waves, so it used a metallic mesh parabolic antenna surface. The blue sky in the background shows through it. Unlike the Milky Way's dark stripe, this mirror allows visible light to pass through it and reflects long wavelengths (radio waves).

Figure 2) Conceptual image of how a celphone tower would appear during the day if viewed in both visible and radio waves. It is a compilation of the image of the antenna seen by visible light and the image of the antenna seen by radio waves. We can see both the nature of the antenna as a radio source, which can't be seen by visible light alone, and the blue sky, which can't be seen by radio waves alone. Please compare this to its appearance in the pictures on page 3. This is one example where more complete information can be obtained when observing an object at multiple wavelengths.

Experiment 1 Changing a Celphone to 'No Service'

A celphone is a familiar object which can send and receive radio waves. The wavelength depends on the carrier, but is between 15 cm to 35 cm (800 MHz to 2 GHz frequency). In urban areas, there are many celphone base station antennas, like the one which appears in the comic. Certainly some of the readers have seen them. If you go far away from the base stations or into the interior of a substantial building, the radio waves can't reach the celphone. The celphone displays a 'no service' message.

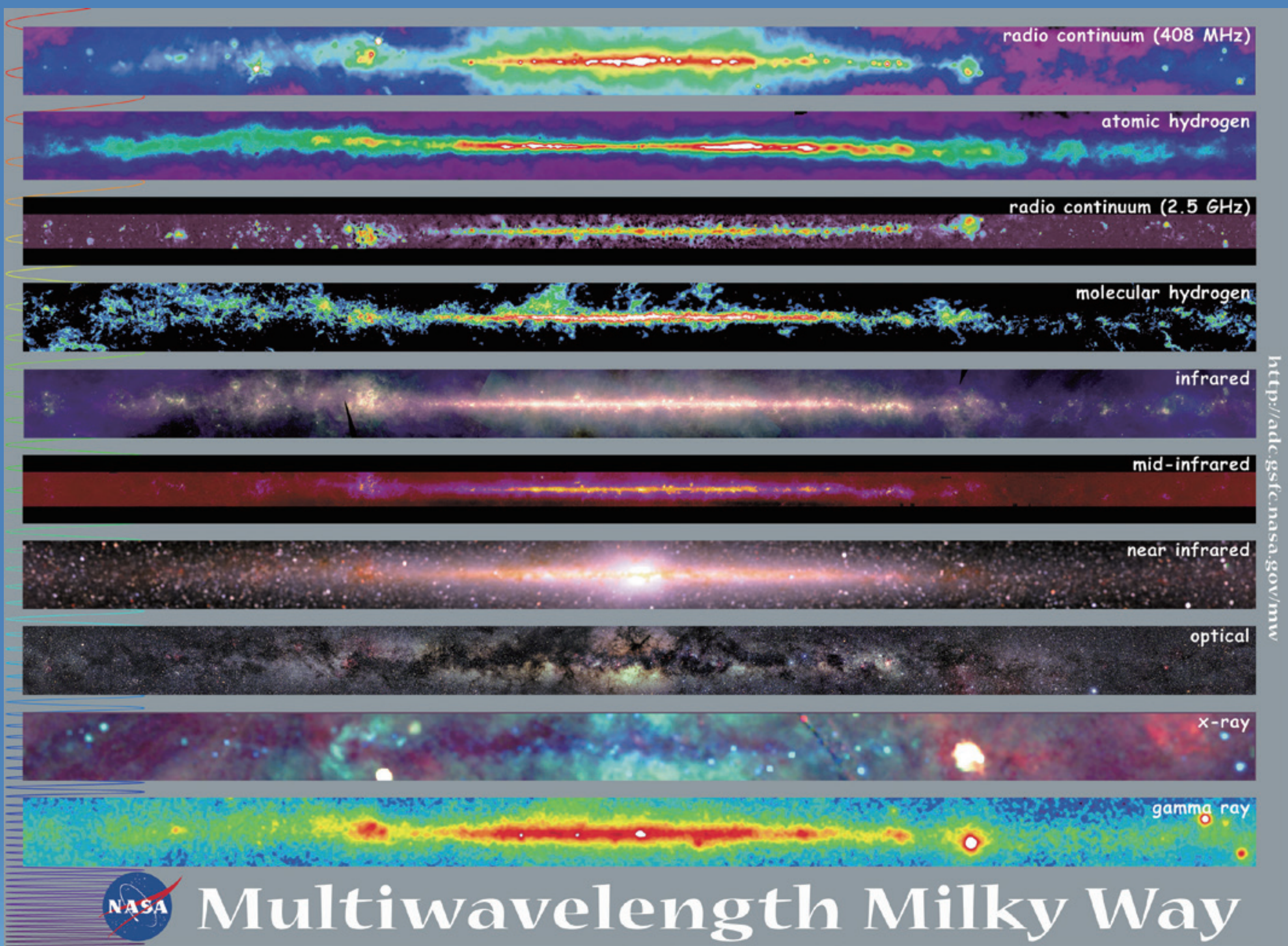
If you interrupt the radio waves, you can easily make this kind of 'no service zone.' For example, if you wrap a celphone in wire mesh or aluminum foil, it will lose service. This is because the radio waves from the base station are reflected by wire mesh/aluminum foil and can't reach the phone. Like the wire mesh parabolic antenna, it looks full of holes to the human eye, but radio waves can't pass through it.

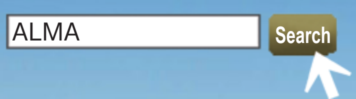


Place a celphone on top of a spread out sheet of aluminum foil, cover it with a fine stainless steel mesh with holes on the order of 0.1 mm, close the aluminum foil completely around all sides and the celphone will lose service. Light can pass through, but radio waves can't. You can find stainless steel mesh at a hardware store.

… And the Eyes We Have to See the Universe Aren't Limited to Just "Visible Light" and "Radio Waves"

ALMAr's Adventure primarily introduces the Universe observed by radio waves. But more than just radio waves and visible light are coming from space. There are also infrared radiation, ultraviolet radiation, X-rays, gamma rays, neutrinos, and occasional gravitational waves. Just like the images of the Universe seen by radio waves and visible light differ, we see various distinct images of the Universe when we observe it with particles or other wavelengths of electromagnetic radiation. Below are images of the Milky Way taken at various wavelengths of electromagnetic radiation. In each image the center of the Milky Way is in the middle. The 3rd from the bottom is the familiar visible light image. Please compare this to the other images. For example, there is a bright object on the right side of the bottom 2 images (X-rays and gamma rays). This is the Vela supernova ruminant. The X-rays emitted by extreme high temperature gas, at tens-of-millions-of-degrees, and gamma rays produced when electrons and photons collide appear bright. This object can't be seen in visible or infrared light. But 2.5 GHz and 408 MHz radio waves from this location appear bright. We can understand the state of the magnetic field lines inside the supernova remnant by analyzing these radio waves in detail. In this way, by observing the same object at various wavelengths, we can understand the physical phenomena occurring inside the object. By constructing various telescopes to catch information that the human eye can't perceive, humanity opened new windows to the Universe.





Inquiries:
Masaaki Hiramatsu (ALMA Project Office) : hiramatsu.masaaki@nao.ac.jp
Hiroyuki Takata (Public Relations Center, Publications Office) : hiroyuki.takata@nao.ac.jp

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The 22 ALMA antennas which have started Early Science Observations
Image Credit: ALMA (ESO/NAOJ/NRAO)