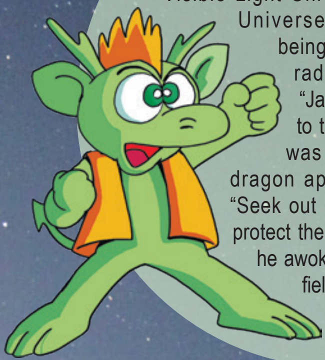
アルマーの冒険 ALMAr's Adventure

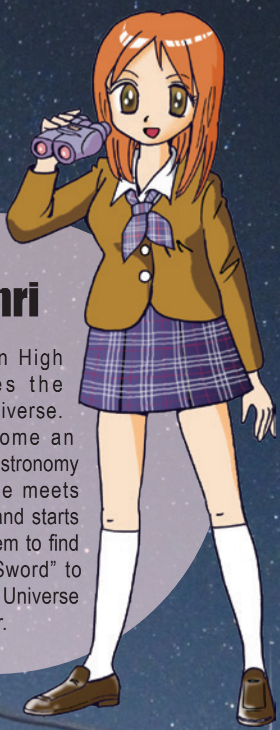
Issue 10
"Making a Software Defined Radio to Observe Meteors"

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...

★ Summary up through Issue 09
"Solar Radio Observations with a Hand-Made Parabolic Antenna"

Inspired by students at Nagano Prefecture Komagane Technical High School, the Soten "Deep Blue Sky" High School astronomy club members gathered materials at a DIY store to build a parabola antenna for solar radio observations under Mr. Shinolar's instruction. They pointed the antenna to the Sun and successfully received solar radio waves, but was that part of Dr. BS's plot to draw Nao into the Radio Universe?
(Top: the last scene from Issue 09)

Background Photo: Geminid meteors appearing behind a dipole antenna. This image is a collage of meteor images taken at different times and thus does not ensure scientific accuracy.

1. How Does a Meteor Light Up? What are the Geminids?

In this issue of ALMAr's Adventure we try to make meteor radio observations.
First, let's explain our observational targets: meteors and meteor showers.

What is a Meteor?

A dazzling light flares up in the night sky, streaking past and disappearing in the blink of an eye. This is a shooting star, a tiny piece of interplanetary debris entering Earth's atmosphere and lighting up. Shooting stars are called "meteors" in astronomy, but this term refers to the astronomical phenomena rather than the plunging objects themselves.

Meteors are caused by interplanetary dust particles (referred to below as "dust particles" or just "particles") ranging in size from grains of sand to several centimeters in diameter. Despite being so small, these particles are celestial bodies moving in their own orbits around the Sun. When a particle's orbit crosses that of Earth and both objects happen to arrive at the same point at the same time, they will collide.

The velocity of a dust particle can reach up to about 40 km/s. (If it traveled any faster, it would be flung out of the Solar System.) Given that Earth orbits the Sun at about 30 km/s, if Earth and the dust particle collide head-on, the relative velocity of the dust particle measured from Earth is the sum of the two velocities: 70 km/s, which is equal to 250,000 km/h. At this velocity, traveling from Earth to the Moon would only take about one and a half hours.

Although I used the word "collide" above, Earth is surrounded by the atmosphere through which the particle must travel. In fact, the particle's velocity is so fast that the air molecules in front of it have no time to get out of the way and are thus compressed, resulting in adiabatic compression that raises the air temperature. This is the same process by which an air pump gets warm when air is pumped into a bicycle tire. In meteor science this process is also known as "convective aerodynamic heating."

Around the dust particle, a shock layer forms, where the air density, pressure, and temperature fluctuate dramatically. If the dust particle travels faster than 10 km/s, the temperature of the shock layer can soar above tens of thousands or even a hundred thousand degrees. At these high temperatures, oxygen and nitrogen molecules in the shock layer dissociate into individual atoms. The high temperatures and pressures also strip electrons from these atoms to make plasma, a state of matter where the constituent atoms are separated into ions and electrons. This plasma emits electromagnetic waves and heats the dust particle even more through a process called "radiation heating," just like a microwave oven heats food.

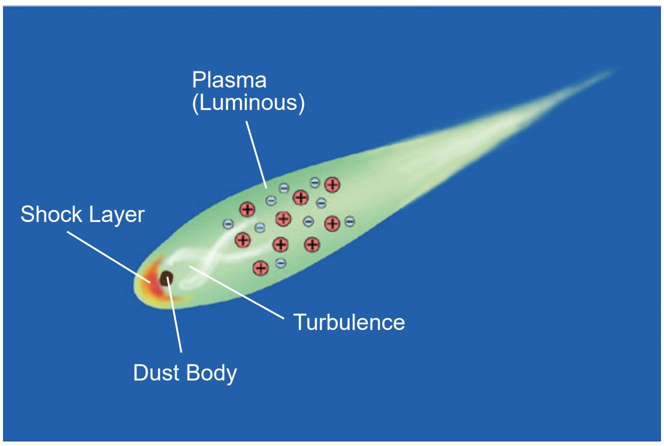


Figure 01: Schematic diagram of a dust particle hurtling through the atmosphere and colliding with the air molecules. The compressed air molecules in front of the particle form a high-temperature and high-pressure shock layer of plasma, which vaporizes the particle's solid compounds, turning them into plasma as well. The ionized molecules create turbulence at the rear of the particle and scatter violently, colliding with the surrounding air. Excited by these collisions, the elements in the air emit light in specific emission lines when they return to their ground states.

Through radiation heating, the solid components of the dust particle are explosively vaporized and collide with the surrounding air. The impact caused by this collision excites both the escaping gas atoms and the air. When atoms are excited, they can jump from their most stable "ground states" to higher energy states and eventually release energy in the form of light before returning to their stable states. In other words, the flash of a meteor is a manifestation of a dust particle's kinetic energy transformed into light (radiation energy) through complex interactions with the surrounding air (Figure 01).

The light emissions observed when an excited atom returns to its ground state have specific wavelengths, collectively called the emission line spectrum, based on the element, the type of atom. Familiar examples where emission line spectra can be seen are the colored flames of fireworks. The light of a meteor is mainly composed of various emission line spectra (Figure 02).

As a side note, meteors glow at altitudes between 80 and 120 km.

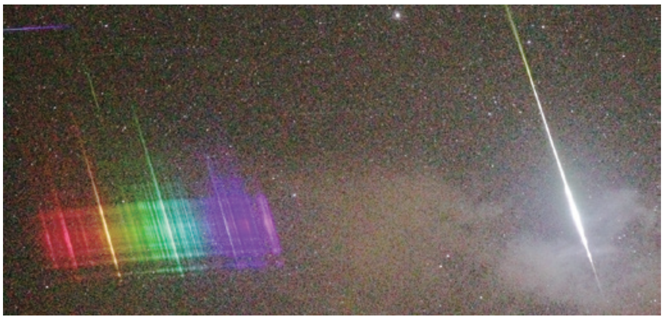


Figure 02: Meteor spectrum obtained by splitting the light of a Perseid meteor. The violet emission lines on the right side of the spectrum are attributed to magnesium and calcium; bright green lines are attributed to magnesium; bright orange lines to sodium, and red lines to oxygen and nitrogen. The isolated portion of a green emission line faintly visible on the upper side is the oxygen forbidden line. The spectrum of a dust particle can tell us what elements it contained.

What is a meteor shower?

Where do the dust particles that cause meteors come from? Dust particles in outer space are so small and dim that they cannot be detected directly from the ground at optical and radio wavelengths. It is this elusive nature that makes it difficult to predict when and where meteors will occur. However, there are some known instances where swarms of meteors appear at about the same times every year, and these events are called meteor showers.

In fact, all the meteors in meteor showers originate from comets, bodies traveling across the celestial sphere with long tails extending from their faint heads. Their characteristic shapes gave rise to the Japanese name "suisei," which literally means "broom star." Comets are also famously described as dirty snowballs, because the main body, the nucleus, is composed of a mixture of water ice, dust, and volatiles. As a comet approaches the Sun, its icy body begins to melt and evaporate, releasing gas and dust. It is this dust that provides a source of dust particles that will eventually become meteors.

Over time, cometary dust particles drift away from the original comets and end up in orbits similar to those of the comets, creating dust trails composed of huge amounts of dust. Because a comet continually changes its orbit due to the gravitational pull from other celestial bodies, every approach to the Sun creates a new dust trail with a slightly different orbit. This means that a comet that has made repeated approaches to the Sun has a bundle of many dust trails along its orbital path.

If one such dust trail intersects Earth's orbit, then when Earth passes through the intersection, many dust particles strike Earth en masse. This is how a meteor shower occurs. Because the date and time when Earth crosses the orbit of a particular comet change little from year to year, every meteor shower occurs at about the same period every year (Figure 03 / Table 01). The comet that ejected the dust particles responsible for a particular meteor shower is called the "parent body" of that meteor shower.

Because the dust particles that cause a particular meteor shower intersect Earth's orbit at a fixed angle, all of them strike Earth from the same direction. This means that these dust particles enter Earth's atmosphere parallel to each other, which in turn means that the paths of the meteors seen from the ground can be traced back to effectively a single point in the sky, known as the radiant point. Meteor showers take their names, such as the Leonids or eta Aquarids, from the constellations where their radiant points are located.

Of course, there are many meteors not associated with any meteor shower. These meteors are called "sporadic" meteors, and might have originated from long-lost comets or dust particles produced by asteroid collisions.

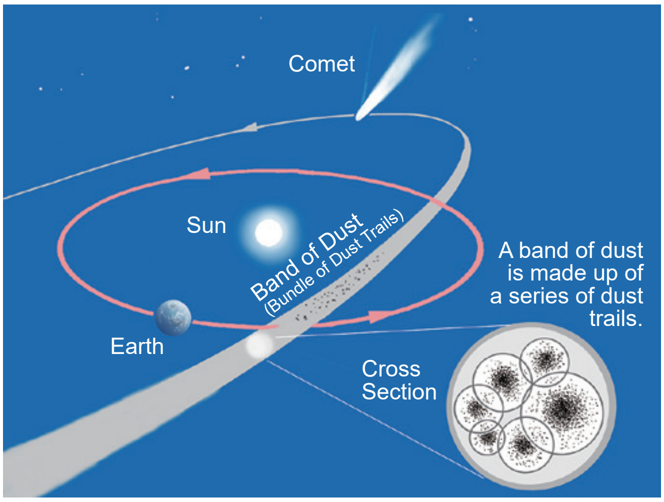


Figure 03: Schematic diagram of a comet intersecting Earth's orbit. On each close approach to the Sun, the comet ejects a large amount of dust, which eventually evolves into a dust trail. Comets that have made multiple close approaches to the Sun have many dust trails with slightly different orbits that overlap to form dust bands near their orbits. Because dust particles drift away from their parent body over time, comets that have been active for a very long period are thought to have trails which are fused together and indistinguishable from one another. As Earth revolves around the Sun once a year, it passes through these dust trails around the same day each year if the orbits of the comets and Earth cross.

Figure 04: Composite image of the 2009 Geminids meteor shower. This image was created by stacking multiple exposures containing meteors that were captured over an extended period during the night of maximum, highlighting the position of the radiant point. Because the altitude of the radiant point changes over time, this image does not ensure the scientific reproducibility of the brightness and other properties, but clearly shows how meteors shoot outward from the radiant point. Although it is called the radiant "point," it does not converge to a single point for one reason or another but has a certain finite size.

The Strange Geminids

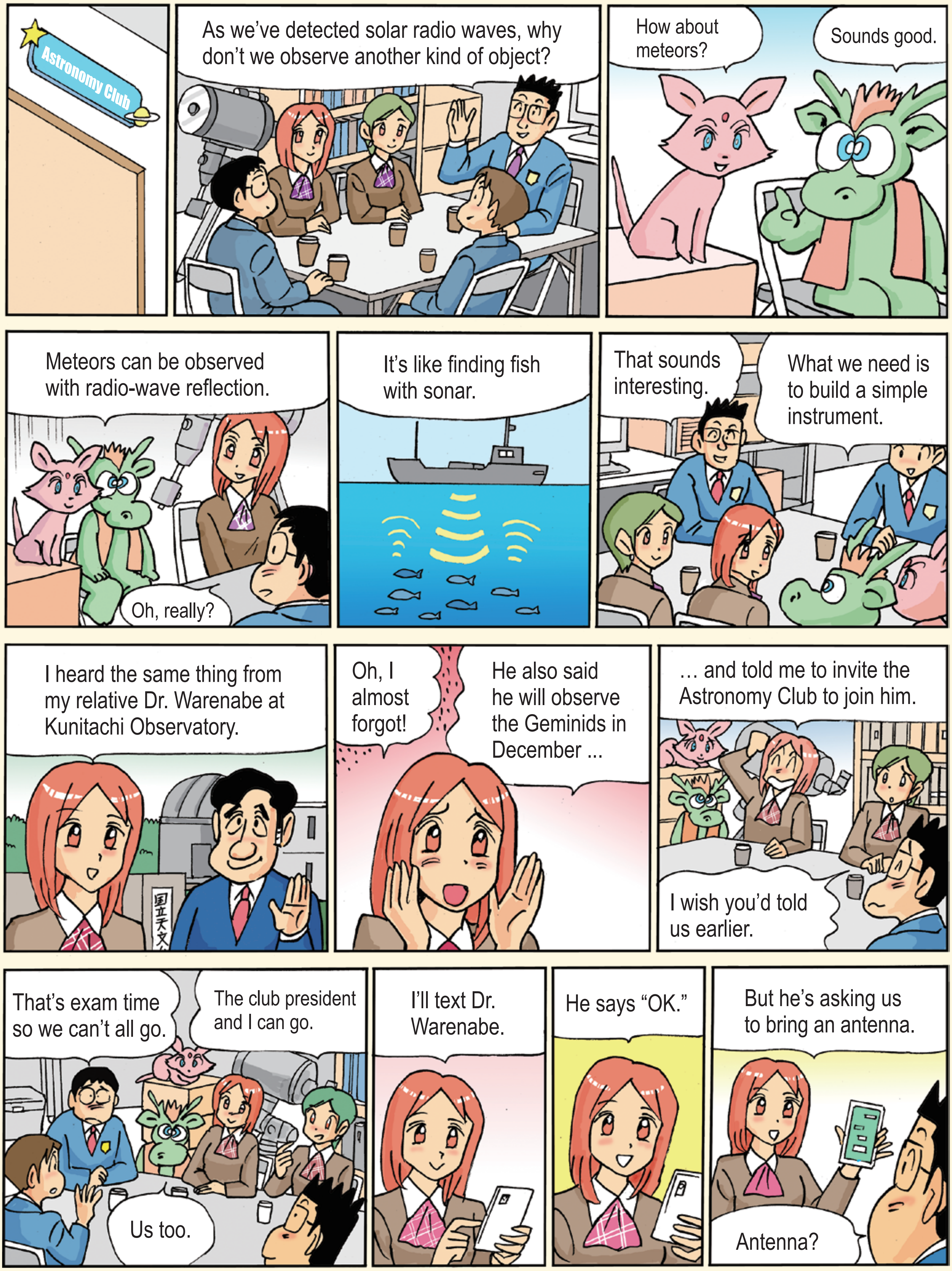
The Geminids, the meteor shower we tried to observe this time, have their radiant point near Castor, the alpha star of the winter constellation Gemini. Peaking around December 14 every year, the Geminids are known as one of the most prolific meteor showers. Seen from Japan, their radiant point rises near the zenith, allowing a single observer to spot approximately 45 meteors per hour under optimal conditions without interference from the moonlight (Figure 04).

As explained earlier, the dust particles that produce meteor showers are thought to have cometary origins. The case of the Geminids, however, is a bit peculiar: their parent body is believed to be the asteroid (3200) Phaethon. In fact, growing evidence now suggests that Phaethon, which is thought to be an asteroid, ejects material just as comets do during its close approaches to the Sun. These findings have made some scientists suspect that Phaethon was once a comet but has lost almost all its volatiles. In order to reveal the secrets of Phaethon, a Japanese project is underway to send a probe to this mysterious asteroid. (See page 12.)

Meteor Shower	Activity Period	Maximum Date	Number Per Hour During the Peak
Quadrantids	December 28–January 12	January 4	45
April Lyrids	April 16–April 25	April 22	10
eta Aquariids	April 19–May 28	May 6	5
Southern delta Aquariids	July 12–August 23	July 30	3
Perseids	July 17–August 24	August 13	40
October Draconids (Giacobinids)	October 6–October 10	October 8	5
Southern Taurids	September 10–November 20	October 10	2
Orionids	October 2–November 7	October 21	5
Northern Taurids	October 20–December 10	November 12	2
Leonids	November 6–November 30	November 18	5
Geminids	December 4–December 17	December 14	45

Table 01: List of major meteor showers. Meteors associated with a particular shower can be spotted during its activity period, but there are also cases where almost no meteors will appear at the predicted time. Each meteor shower is expected to be most active during the days around its maximum. The rightmost column shows how many meteors you can expect to see in an hour during the night of maximum activity under optimal conditions, where observations are made in an open space without any interference from the moonlight and city lights. (This table was created based on: https://www.nao.ac.jp/astro/basic/major-meteor-shower.html)

Chapter 10-1: Meteor Observations with Radio-Wave Reflection?



2. Detecting Meteors from Reflection of Terrestrial Radio Waves

Receiving very high frequency signals reflected by meteors' ionized columns

Preliminary knowledge for performing meteor radio observations

When you hear the term "radio observation," you may think that you need to receive radio waves emitted from the target objects, as we did in the solar observations in the previous issue. However, that is not the case when it comes to meteor radio observations. Meteors may emit radio waves (see the boxed item on page 15); however traditional meteor radio observations aim to receive radio waves broadcast from the ground and reflected by meteors flying through Earth's atmosphere (Figure 05).

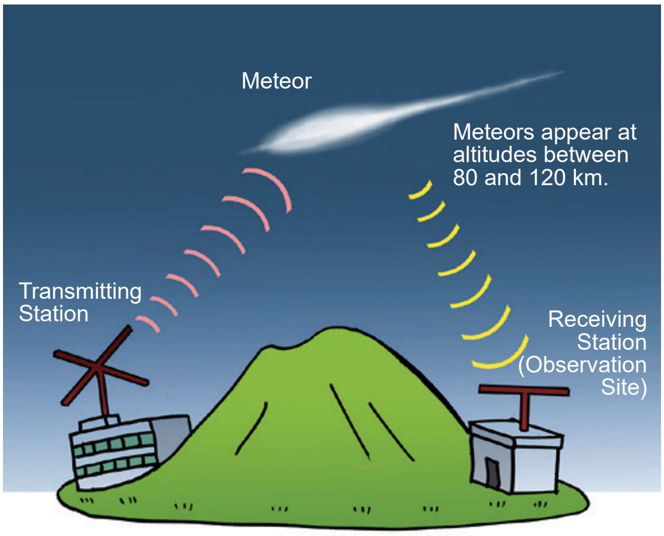


Figure 05: There are two methods to observe radio waves reflected from objects. The one in which the transmitting and the receiving antennas are placed at the same site to detect reflected radio waves is called the back scattering method. This method is used in air traffic control and weather radar. The meteor radio observations explained here incorporate the other method, called the forward scattering method, in which the transmitting and the receiving antennas are placed at separate sites.

Lighting up the night sky in the way described on page 02, meteors leave behind persistent trails of ionized material. These trails, known as ionized columns, can reflect radio waves in the very high frequency (VHF) range (30 to 300 MHz) used for FM radio and television broadcasting. Strictly speaking, therefore, the radio waves that meteor observations aim to receive are the reflections from the ion columns, not from meteors themselves, but for the sake of convenience, here I will refer to them as reflections from meteors.

Meteors used to be observed by receiving radio waves from distant FM radio stations. When meteors appear, distant radio stations normally out of range can be heard for just a moment. Since the 1990s, the Ham-band Radio Observation (HRO) method has been used in observations performed in collaboration with amateur radio operators in the 50 MHz band, known as the amateur radio 6 m band. More recently, other observational methods have been introduced, such as the FM Radio Observation (FRO) method, another method using radio waves from FM radio stations, and the VHF omni-directional radio range Observation (VRO) method, which uses radio wave emissions from air navigation systems. Each of these methods has its pros and cons. Here, let me explain the HRO method, a currently popular method for detecting meteors.

Since the late 1990s, thanks to the efforts of Kimio Maegawa at the National Institute of Technology, Fukui College (NIT-Fukui), radio signals for HRO have been transmitted at 53.750 MHz from the college's amateur radio club (call sign: JA9YDB). The radio signals currently available for HRO in Japan include a 53.755 MHz signal (JH9YYA), transmitted from Fukui Prefectural University's amateur meteor radio observation club, and 50.017 MHz signal (JA6YBR), transmitted by the alumni association of the University of Miyazaki's radio club.

The idea of the HRO method is to detect meteors by converting meteors' radio signals into sounds to detect. This method requires an antenna and a receiver. In the past, relatively expensive amateur radio transceivers were used, and even dedicated receivers were developed. Recently, however, the advent of Software Defined Radio (SDR), a computer-based radio module, has enabled us to develop less expensive alternatives.

A dedicated amateur radio antenna is preferred if you put a high priority on sensitivity, but a dipole antenna is still practical enough for experimental observations even though it has quite a simple structure. Here, I will show you how to build a dipole antenna and how an SDR system works in a real observation setting.

A conventional radio collects radio waves with an antenna, selects a specific frequency with an analog tuning circuit, extracts the signal with a detector, and interpret the signal as sounds with an output device. In an SDR, by contrast, following the tuning circuit the signal is digitized, and parts of the functions and interfaces are implemented in computer software. Furthermore, technological advancement has enabled all the necessary elements to be integrated into a compact device called a USB dongle (Figures 06 and 07). Priced at only about 4,000 yen, this device works with dedicated freeware by connecting to a PC via USB.

Figure 06: Our SDR dongle of choice was the NESDR SMArt v4 SDR produced by Nooelec, which we purchased online for about 4,000 yen. Among the various types of SDR available, the products we recommend are ones equipped with temperature compensated crystal oscillators (TCXO), which can suppress the fluctuation of the receiving frequency caused by changing temperatures. Because our SDR dongle had an SMA antenna connector (male) and our antenna used an F-type connector (female), we also purchased a conversion adapter (for approximately 400 yen).

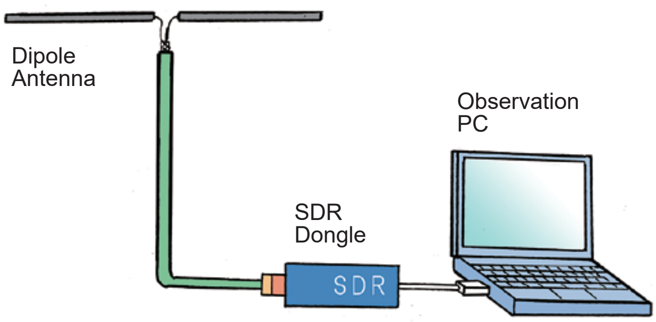
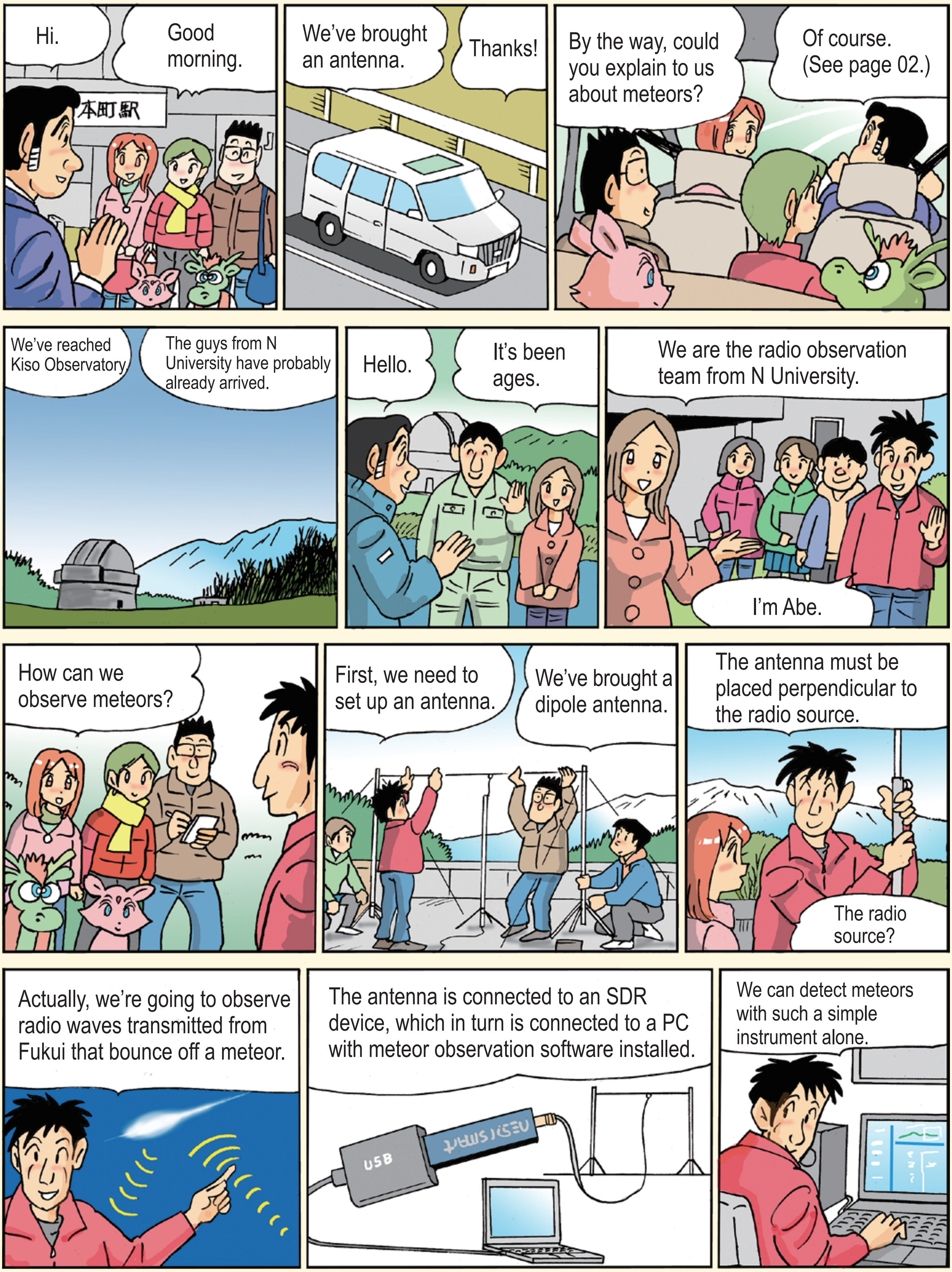


Figure 07: Our system for meteor radio observations was quite simple, consisting only of an antenna, a coaxial cable, an SDR dongle, and a PC. The PC was of course configured with freeware to run the SDR. Additionally, we also used another piece of freeware dedicated to meteor observations, which is available online.

Chapter 10-2: Setting up a DIY Antenna for Observations



3. Gathering the Parts and Starting to Build the Antenna

Building a dipole, the simplest and most basic type of antenna

Using an ordinary power cable as material for an antenna

Here, I explain the antenna that we used for our observations. Instead of purchasing a commercially available one, such as a Yagi-Uda antenna that can work in 50 MHz, we chose to build a simple dipole antenna as the receiving antenna. Being the most basic type of antenna, a dipole antenna consists of two elements (conductors) aligned in a straight line. Because of their simple structure, dipole antennas are widely used as DIY amateur radio antennas. The overall length of our antenna was designed to be equal to one-half of the target wavelength (1/2 wavelength), with the length of each element equal to one-half of the antenna length (1/4 wavelength).

The main materials for the dipole antenna included a vinyl parallel cord commonly used at home as an AC 100 V extension cord, which was separated into individual strands to make the elements. To relay the radio waves to the SDR dongle, we used a coaxial cable designed for a BS/CS broadcasting antenna. Coaxial cables come in several varieties; the one we used had an impedance, one of the cable properties, measuring 75 ohms. An F-type connector was to be attached to one end of the coaxial cable to connect the SDR dongle. Every one of these materials can be purchased at a DIY store. The total cost amounted to only around 2,000 yen even though the cable we purchased was 10 m long.

Assuming that our observations use 53.755 MHz radio waves transmitted by Fukui Prefectural University's amateur meteor radio observation club, our target wavelength is 5,577 mm. As explained earlier, the length of each element should be one-quarter of the target wavelength, in this case 1,394 mm, but in fact, it needs to be a bit shorter. This is because radio waves, which travel in a vacuum at the speed of light, slow down a bit when they travel through the elements. How much a given element needs to be shortened is represented by the shortening rate. This figure, usually ranging from 95 to 98%, is difficult to calculate and usually determined by measuring the properties of the antenna. This time, however, there were no measuring instruments available and the antenna was able to be redesigned if any issues arose, the figure was assumed to be 96%, making the length of each element 1,338 mm.

The parallel cord for making these elements was cut to the right length with a soldering margin of about 15 mm taken into account. The elements were then soldered directly to the one end of the cable where the insulation was stripped off. To the opposite end of the coaxial cable, a connector called an F-type connector was attached.

We completed the elements by covering the soldered part with vinyl tape for insulation and waterproofing (Figure 08).

What is antenna impedance?

In direct current, the opposition to electric current is measured by the "resistance value," represented by the unit ohm (Ω). However, a signal passing as a wave through an antenna is an alternating current and its flow can be impeded by several factors. One of these factors is impedance, which is also expressed in the unit ohm (Ω). When radio waves are input from an antenna to a receiver, a large variation in impedance between the two components increases the signal loss. To avoid this problem, you need to match the impedances of the coaxial cable running from the antenna and the input terminal attached to the receiver.

The connection between the elements and the coaxial cable is called the feed point. When the elements are aligned in a straight line, the impedance of the feed point is 73 ohms. Normally, the feed point needs a mechanism to match impedance; however, such kind of mechanism was omitted from our dipole antenna because the impedance errors were negligible.

① Materials
A: Vinyl parallel cord used for a 100 V extension cord at home, desingated as VFF 1.25. A cable length of 3 m will suffice. Priced at around 700 yen per 5 m. B: Coaxial cable (S-5C-FB) for receiving BS/CS broadcasting. One rated as 75 Ω will work. The cable length needs to be long enough to reach from the antenna to the USB tuner. Priced at around 1,000 yen per 10 m. C: F-type connector for a 5C coaxial cable (FP-5A). Priced at around 100 yen. D: Vinyl insulation tape. Used to insulate and waterproof the soldered connections of the vinyl parallel code antenna and the coaxial cable. Priced at around 100 yen.

② Preparing to attach the connector

③ Attaching the connector
Attach the F-type connector to one end of the coaxial cable.

④ Preparing to solder the elements (part 1)
Strip the other end of the coaxial cable so that the elements can be soldered.

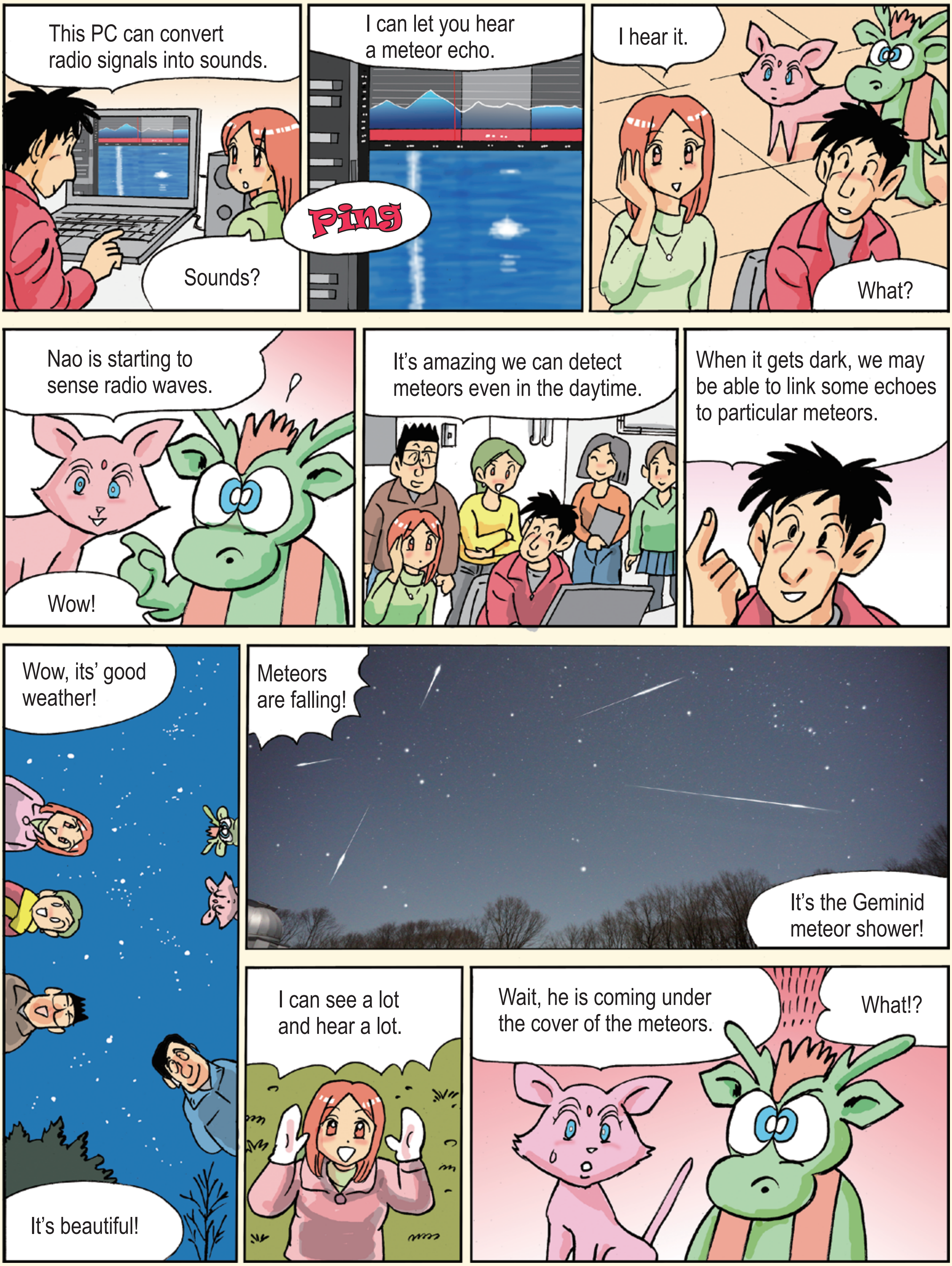
⑤ Preparing to solder the elements (part 2)
Cut the vinyl parallel cord into two pieces, each measuring 1,338 + 15 mm, and separate them into individual strands, with 15 mm of insulation stripped from one end of each strand.

⑥ Soldering the elements
Solder the elements to the coaxial cable.

⑦ Completion
Complete the dipole antenna by insulating and waterproofing the soldered connections with vinyl tape.

Figure 08: Step by step instructions for making a dipole antenna.

Chapter 10-3: Recording Meteor Echoes by Converting Radio Signals into Sounds



4. Actual Observations of the Gemnid Meteors

Placing the antenna on the rooftop of Kiso Observatory's airglow observation building

Geminid meteor echoes we ended up catching

After several test runs, we decided to perform actual observations targeting the Geminids, using the system consisting of our DIY dipole antenna and SDR. Thankfully, the University of Tokyo Kiso Observatory, located in Kiso Town, Nagano Prefecture, offered us help: they lent us an observation site, an airglow observation building on the premises. In this way, we were able to perform meteor observations over three nights around the peak day, from December 11 to 14, 2021, during which the Geminids were expected to be most frequent.

We successfully placed the dipole antenna on the rooftop of the single-story airglow observation building, but the antenna elements, made up of flexible cables, need to be pulled taut and straight in the air. Thus, we stretched a thin vinyl rope between two stands for photography flashes that we happened to have on hand, and along this rope, we fixed the elements with vinyl tape so that no bending would occur. Nevertheless, without any additional support, the weight of the coaxial cable would have caused the vinyl rope to sag and consequently lower the feed point, so we used another stand to support the feed point (Figure 09).

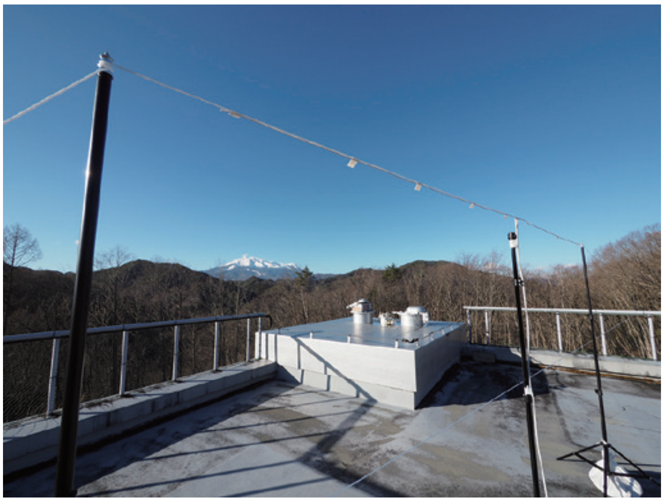


Figure 09: Our DIY dipole antenna for observing meteors placed on the roof top of Kiso Observatory's airglow observation building. The snow-covered mountain in the background is Mount Kiso Ontake. The direction in which the antenna should be aimed was determined by referring to the following website (Japanese language only) for the Geospatial Information Authority of Japan (https://vldb.gsi.go.jp/sokuchi/surveycalc/surveycalc/bl2stf.html). The latitude and longitude coordinates of Fukui Prefectural University and Kiso Observatory were obtained from Google Maps. The direction of Fukui Prefectural University seen from Kiso Observatory is a little over 286 degrees clockwise from due North (that is, approximately 16 degrees northward from due West) and the distance is about 126 km.

Incidentally, a dipole antenna cannot receive radio signals from all directions with equal sensitivity. Its reception pattern is directional, a dipole antenna is insensitive to the direction along the line of its elements. For this reason, our antenna was placed with its elements horizontal to the ground and perpendicular to the transmitting station, Fukui Prefectural University.

Nighttime temperatures in the Kiso region in December can drop far lower than the lowest safe operating temperature of our laptop computer for running SDR software. The laptop was thus kept indoors, connected through a 15-m USB repeater to the SDR dongle, which in turn was connected to the free end of the 10-m coaxial cable (Figure 10).

Our laptop ran Windows 10. When it comes to SDR software, we chose a piece of freeware called SDRSharp, which can run on Windows, macOS, or Linux (Figure 11).

SDRSharp can operate in several receiving modes, such as the AM and Wide FM (WFM) modes. In radio meteor observations, you need to select the Upper Side Band (USB) mode, an operating mode for amateur radio. You may expect that the center frequency on SDRSharp would be tuned to 53.755 MHz to match the frequency of radio waves transmitted from Fukui Prefectural University, but actually a slightly lower frequency needs to be used. This is because when the USB mode detects a signal with an off-center frequency, that signal is converted into a sound signal with a frequency equal to the difference between the center and off-center frequencies and then output from the PC speakers (Figure 12).

Figure 10: The coaxial cable extending from the dipole antenna was connected to the SDR dongle which in turn was connected to the USB repeater running through a window into our room downstairs. In some cases, noise from a PC can affect the SDR dongle; thus, the SDR dongle sometimes works better when spaced by a hub or repeater than when connected directly to the PC's USB port.

This time, we tuned the center frequency to 53.754 MHz, so that when we received a 53.755-MHz signal reflected from a meteor, we would hear a sound

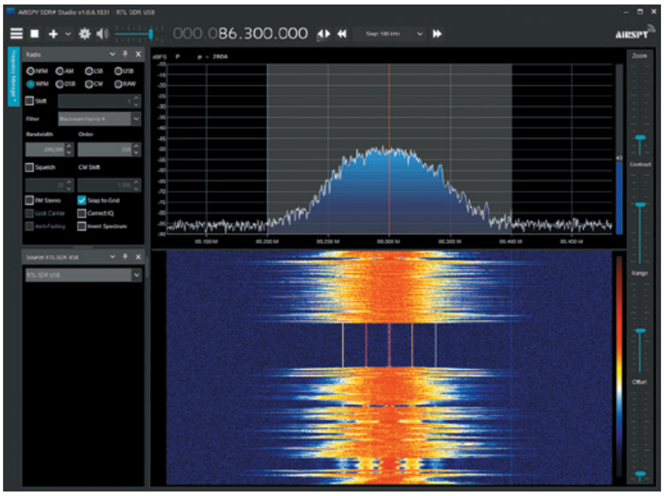


Figure 11: Although a bit of work needs to be done, such as installing the driver for the SDR dongle, some useful websites will provide you with installation tips. There also are some published books on SDR. Above all, you will not be able to learn how to use an SDR if no radio signal is received. What we recommend is to practice by connecting your SDR to a home television antenna and receiving signals from a nearby FM radio station. The image above shows a screenshot of SDRSharp receiving FM radio waves. The panel on the left is the configuration panel. The panel on the upper right, the "spectrum panel," displays a graph with frequency on the horizontal axis and signal intensity on the vertical axis. The panel on the lower right is the "waterfall panel." With time on the vertical axis and frequency on the horizontal axis, this graph displays in real time the signal intensities of the upper right spectrum panel indicated in different colors and flowing from top to bottom.

Figure 12: To listen for meteors, external speakers were set up and connected to the PC's headphone jack. When a meteor appears, these speakers give off a short or long echo to let us know its appearance.

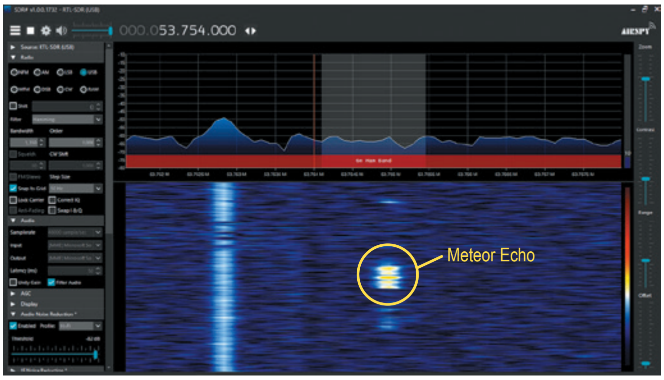


Figure 13: SDRSharp screen just after receiving a meteor echo. The red vertical line on the spectrum panel marks the 53.754-MHz receiving frequency. The yellow "blob" on the waterfall panel visible around 53.755 MHz, a frequency 1,000 kHz above the receiving frequency, represents a meteor echo. The white band running vertically around 53.753 MHz indicates the noise during the meteor observations, which might have been caused by radio waves broadcast from somewhere else nearby. To eliminate as much noise occurring during reception as possible, the width of the frequency band (bandwidth) for signal reception was narrowed down to 1,350 kHz, and the received signals were further processed with noise reduction.

with the 1-kHz difference frequency. The average human can hear frequencies between 20 and 20,000 Hz, whereas the frequency of the human voice ranges from 100 to 1,000 Hz. In other words, this tuning allows us to hear the detection of a meteor as a slightly high-pitched sound, which is called a meteor echo. A short one sounds like a "ping," whereas a long one, called a long echo, sounds like a "beep" (Figure 13).

Obtaining data through a combination of SDRSharp and MROFFT

When it comes to HRO meteor radio observations, there is yet another useful and necessary piece of software. Although SDRSharp does allow us to know when a meteor is detected from the sound, counting their number, for instance, still requires us to keep listening and wait for meteors to appear, and once an echo is detected, we need to record the time and sound characteristics.

Because we were planning to perform observations with a PC, it was reasonable to use software that can detect meteor echoes and record them automatically. For a fairly long time in Japan, HROFFT, a piece of freeware for Windows, and the equivalent MROFFT, have been some of the most popular among such kinds of software. Because HROFFT is not easily available online, MROFFT (Japanese language only) was selected for our observations. (https://www.nap.jp/michi/meteor/mrofft/index.html)

By applying the Fourier transform to sound data, MROFFT can generate a real-time graph with the sound frequency spectrum on the vertical axis, time on the horizontal axis, and each spectral component colored based on the intensity. The screenshot is automatically saved as image data every ten minutes.

Originally, HROFFT and MROFFT were intended for analog sound transmission, in which the sound output from a radio device was connected to the microphone input (or the LINE input) on a PC. In our SDR observations, by contrast, both SDRSharp and MROFFT were running on the same PC, allowing us to input sound from SDRSharp to MROFFT by using the stereo mixer, a built-in utility of Windows 10 (Figure 14).

Figure 14: The stereo mixer needs to be enabled to transmit sounds from SDRSharp to MROFFT inside a PC.

In a PC, sound signals are transmitted from SDRSharp to MROFFT at the maximum power level. Consequently, the sound from SDRSharp would have come out of our laptop's built-in speakers at the highest volume, bothering us all the time with loud noises as well as meteors echoes, unless the laptop was connected to an external speaker set with a volume control knob (Figure 12 on page 09).

In this way, we were able to observe the Geminids for three nights. The meteors were expected to peak at 4 p.m. on December 14 (JST), and approximately 120 meteor echoes were detected between 1 and 2 a.m., during which the radiant point culminated near the zenith that day. The point worth noting is that this number only includes definite meteor echoes because of the noisy screen of MROFFT (Figure 15).

Along with the radio observations, we also performed optical observations with digital photography, we think we observed some of the same meteors at both radio and optical wavelengths (Figure 16).

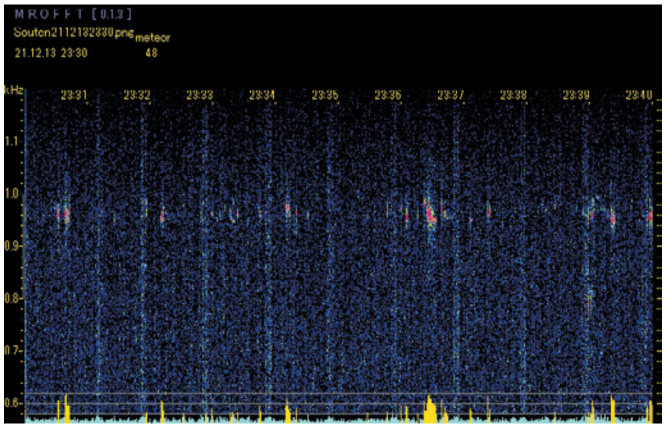


Figure 15: MORFFT data around the peak of the Geminids and at the time when the radiant point was rising near the zenith. The areas highlighted in red indicate echoes resulting from strong radio waves. During a 10-minute period, dozens of echoes were detected.

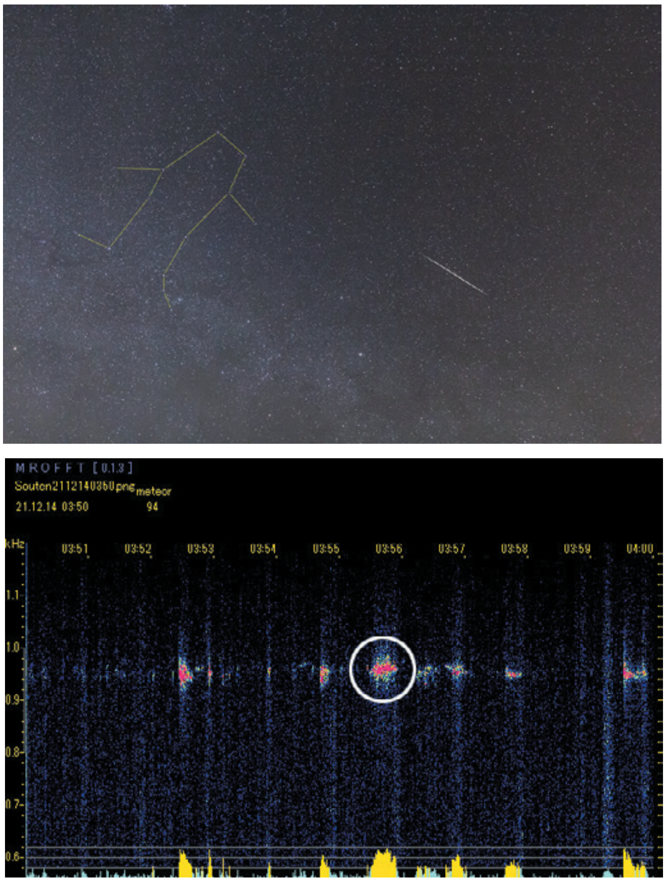


Figure 16: Presumably the same meteor was detected independently in both optical observations with a digital camera (top) and radio observations (bottom). Its identity was confirmed through the time of appearance. There were many meteors captured only by the camera but not in radio waves, or vice versa.

Our observational data were later provided to the observational team of Dr. Shinsuke Abe, an associate professor at Nihon University's College of Science and Technology, who is primarily involved in optical observations at Kiso Observatory. We have no idea whether our data are of sufficient quality to yield something meaningful, but we are curious to see what the results will be.

5. Pros and Cons of Detecting Meteors by Radio Observations

Meteors can occur not just in the nighttime sky but also in the bright daylight sky

The greatest advantage of meteor radio observations is the ability to detect meteors regardless of the weather, be it cloudy or rainy, or even in sunny skies during the day (Figure 17).

In fact, there are many meteor showers only observable during the day (Table 02). Since 2009, the International Astronomical Union (IAU) has designated a total of 112 meteor showers, of which 14 are referred to as daytime meteor showers.

Having their radiant points near the Sun, these meteor showers are either completely invisible during the night or, at best, optically observable only during the twilight with the naked eye or through photography. However, these elusive meteor showers are observable in radio waves.

Of course, radio observations are far from perfect and have many shortcomings. Our observations with the HRO method, for example, were not able to survey the entire sky all at once because of the directivity of our dipole antenna. Additionally, we cannot so far obtain the optical characteristics of a meteor from the intensity and duration of its echo. Even if an echo is successfully detected, we cannot tell whether that echo is from a meteor belonging to a particular shower or from a sporadic meteor, let alone locate the point on the celestial sphere at which the meteor appeared. Noise poses another big problem (Figures 18 & 19). During our observations, a sudden rise in the noise level sometimes made meteor observation impossible. This may be analogous to how optical observations are vulnerable to inclement weather.

In addition to observation methods that use the forward scatter of radio waves, such as the HRO method, there are other, more active observation methods that focus on backscatter. For example, meteor observations at the Shigaraki MU Observatory of the Kyoto University Research Institute for Sustainable Humanosphere use the Middle and Upper atmosphere (MU) radar (see page 14). By emitting radio signals toward a meteor and receiving the reflections, this large-scale system, known as a phased array, can determine the meteor's point of origin and velocity. Other observations for detecting meteors using radio signals have been carried out around the world.

Meteor Shower	Maximum Date
Daytime xi Sagittariids	January 25
Daytime kappa Aquariids	March 21
Daytime April Piscids	April 23
Northern Daytime omega Cetids	May 9
Southern Daytime omega Cetids	May 9
Southern Daytime May Arietids	May 14
Daytime Arietids	June 8
Daytime zeta Perseids	June 10
Daytime lambda Taurids	June 17
Daytime beta Taurids	June 29
Daytime xi Orionids	July 25
Daytime zeta Cancrids	August 20
Daytime kappa Leonids	September 24
Daytime Sextantids	September 28

Table 02: List of daytime meteor showers and their maximum dates.

Nevertheless, radio observations alone cannot obtain all of the electromagnetic properties, particularly optical ones. Future meteor research will advance through collaboration between radio and optical (including ultraviolet, visible, and infrared) observations.

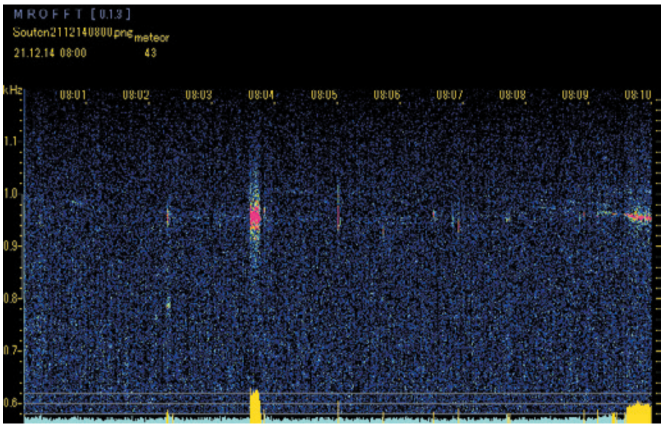


Figure 17: A meteor echo detected early in the morning after sunrise. The ability to perform observations even during the day is a great advantage.

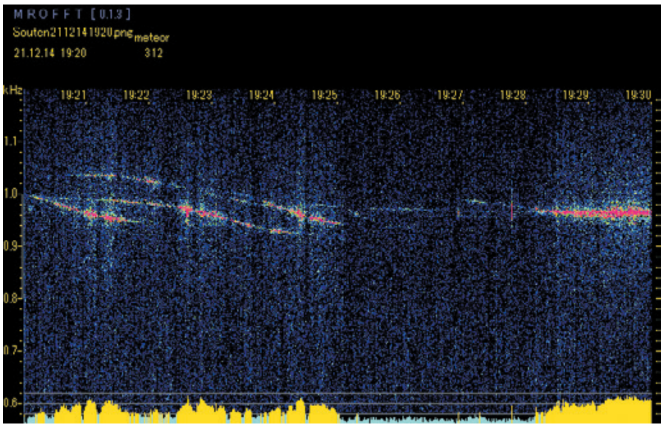


Figure 18: The lines running obliquely indicate signals reflected from an aircraft. Too much aircraft noise would mask meteor echoes, making them unobservable.

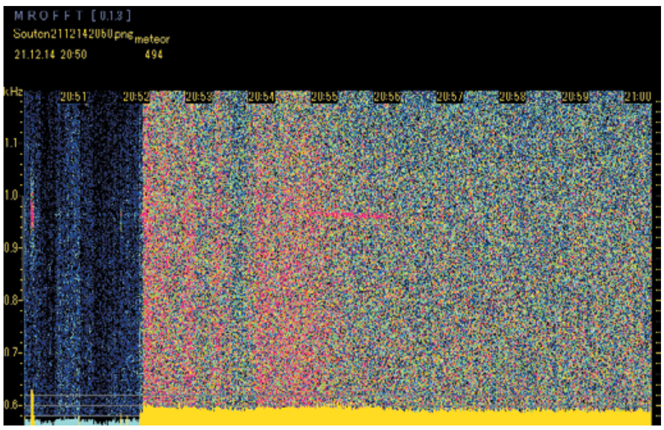


Figure 19: A sudden rise in the noise level interrupted our observations. Why it happened is still unknown. We coped with this problem by turning down the output gain on SDRSharp.

6. The DESTINY+ Mission: Unraveling the Origin of the Geminids

A flyby mission to the asteroid Phaethon scheduled for 2028

Based on their dust orbits, most meteor showers are known to be associated with comets, but there are some that are believed to have originated from asteroids. Among such meteor showers of asteroidal origin, the Geminids are particularly well known, and their parent body is believed to be the asteroid (3200) Phaethon.

Phaethon revolves around the Sun about once every 1.43 years in an elongated elliptical orbit tilted from the ecliptic plane. Its perihelion, the closest point in its orbit to the Sun, is at about 0.14 AU (one-seventh of the Sun-to-Earth distance) from the Sun, well inside the orbit of Mercury. Phaethon sometimes comes close to Earth, hence it is recognized as a near-Earth asteroid (Figure 20).

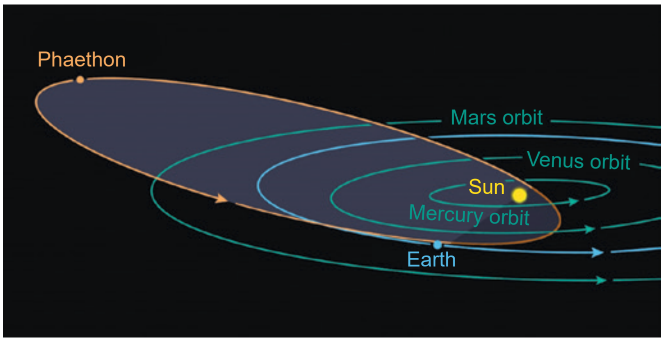


Figure 20: Phaethon has a distinctive, elongated orbit like that of a comet. For the dust of the Geminids to reach Earth, Phaethon's orbit needs to intersect that of Earth.

When Phaethon was discovered in 1983, its orbit led to the suspicion that this asteroid is the parent body of the Geminids. Because all meteor showers were once believed to originate from comets, some scientists claimed that Phaethon must be an extinct comet or comet-asteroid transition object that has shed all its volatiles and dust. Follow-up observations confirmed that Phaethon ejects dust only when it comes close to the Sun, probably because its surface is heated and evaporated by the intense solar radiation. Phaethon is thus currently categorized as an active asteroid. As just described, Phaethon is rather unusual for an asteroid.

To reveal the true nature of this mysterious asteroid, a flyby mission to Phaethon, called DESTINY+ (Demonstration and Experiment of Space Technology for INterplanetary voYage with Phaethon fLyby and dUst Science), is underway (Figure 21). This project is currently on track with the satellite development undertaken by the Japan Aerospace Exploration Agency (JAXA) and the preliminary research and instrument development led by Chiba Institute of Technology.

Before launching the spacecraft, detailed observations from the ground must be carried out to collect various information about the target object. The ground observations of Phaethon are led by Dr. Fumi Yoshida affiliated with the University of Occupational and Environmental Health, Japan, and Chiba Institute of Technology, with whom we had an interview:

"Phaethon has a particularly dark surface among asteroids," said Dr. Yoshida. "Its spectrum is similar to those of celestial bodies and meteorites containing carbon and organic matter, suggesting that Phaethon is also carbon rich. It is from this asteroid that the dust particles falling on Earth as the Geminids originate."

In fact, in addition to meteors, 40,000 metric tons of interplanetary dust originating from various sources are estimated to fall on Earth every year. Dust particles that do not have enough mass to light up the sky as meteors can be collected in the stratosphere or on the ground. The analysis of these minuscule particles suggests that interplanetary dust contains a significant amount of carbon and organic matter. Because organic matter is an essential part of life as we know it, interplanetary dust might have played an important role in the emergence of life on Earth. It is therefore meaningful to observe and study Phaethon and interplanetary dust in space (Figure 22).

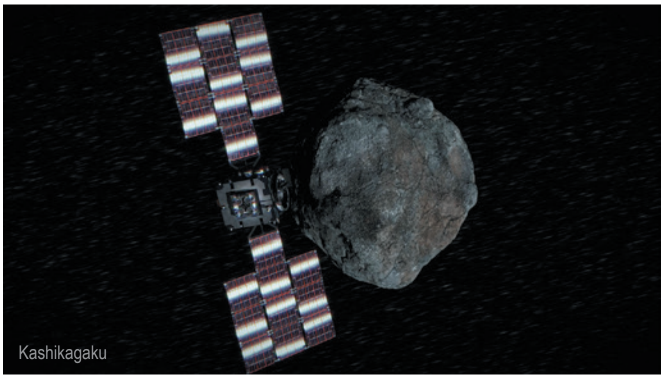


Figure 21: Artist's impression of the DESTINY+ spacecraft making a flyby of Phaethon. The size of the actual Phaethon is about 6 km in diameter, and the distance between the two objects is set to about 500 km. (Credit: JAXA/Kashikagaku)

"The DESTINY+ spacecraft is designed to carry three onboard scientific instruments: the Telescopic Camera for Phaethon (TCAP), the Multiband Camera for Phaethon (MCAP), and the DESTINY+ Dust Analyzer (DDA), each of which is currently under development," said Dr. Yoshida.

TCAP is designed to photograph the surface of Phaethon while the spacecraft passes near the asteroid at a velocity of 36 km/s. MCAP is for spectroscopic observations to measure the matter distribution on the surface of Phaethon. DDA is an instrument designed to collect dust particles in space and analyze their chemical composition, mass, speed, and other properties in situ.
"Because the spacecraft is just to hurtle past Phaethon at a closest approach distance of about 500 km, photographing the surface requires the camera to be preprogrammed with the right exposure time. To determine the right exposure, we need to measure the albedo of Phaethon, which cannot be obtained from the brightness alone; we also need to know the diameter and shape. That made us try to determine Phaethon's shape by observing stellar occultations caused by the asteroid."

Asteroid stellar occultation observations measure the length of time during which an asteroid passes in front of a star and blocks its light. The shadow cast by an asteroid blocking a star creates a band pattern on Earth's surface much like the path of totality, along which a solar eclipse appears as a total eclipse. Observing the asteroid from multiple sites in this band enables us to estimate the asteroid's shape.
"Because we need many observation points, we are currently making observations in cooperation with many amateurs. The flyby is still years away, so if you are interested, why not get involved in our occultation observations?"

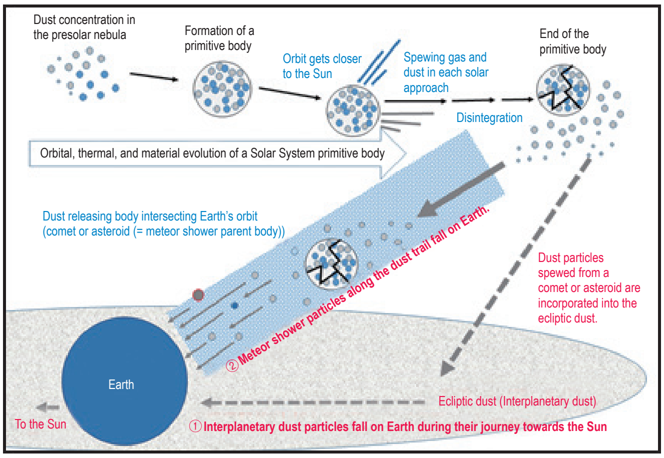


Figure 22: Dust particles come to Earth in two ways. One relates to primitive bodies formed in the early Solar System, which eventually disintegrate into dust (ecliptic dust) particles which are pulled toward the Sun. During that journey, some of the dust particles fall on Earth (noted as ① in the figure). The other relates to dust trails left behind by comets and asteroids and intersecting Earth's orbit (noted as ② in the figure). (This image is courtesy of PERC at Chiba Institute of Technology.)

7. Locating Meteors with the Improved HRO Method

Observation system combining a radar and a radio interferometer

Due to various limitations, our radio observations using the HRO method cannot detect all the meteor echoes coming from the sky, let alone locate where in the sky the meteors associated with the detected echoes appeared.

To overcome these downsides, improved detection systems that can locate where meteors appeared in the sky through various methods are being developed at Kochi University of Technology as part of student research. We interviewed Prof. Masayuki Yamamoto at the University's Schools of Systems Engineering, who supervises students involved in the research. "One solution is to use radio interferometry," said Prof. Yamamoto. "This is a technique in which the differences in the arrival times of individual signals are translated into phase differences to calculate the directions from which the received signals arrived (Figure 23)."

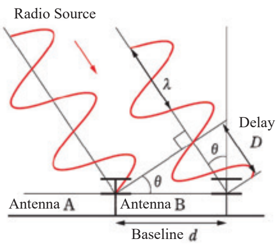


Figure 23. Measuring the phase difference enables us to know which direction the radio waves come from. This is the same principle on which ALMA works.

Comparing signals received by two antennas and determining the phase differences allow us to estimate the directions from which those signals arrived. This is the same technique used by ALMA to measure the precise locations of celestial radio sources. Kochi University of Technology's system incorporates the HRO method intended to observe radio signals transmitted by the amateur radio club at the NIT, Fukui College, and the amateur meteor radio observation club at Fukui Prefectural University. Equipped with three antennas, this system started observations in 2005. Initially, one antenna was placed at the center and two other antennas were placed along the east-west axis and north-south axis to calculate the direction of the radio waves from the phase difference obtained from each antenna pair.

In 2009, the system was upgraded to five antennas arrayed in an eccentric cross shape to improve the accuracy. The new system uses crossed Yagi-Uda antennas, which have advantages in both the directivity and sensitivity of reception (Figure 24).

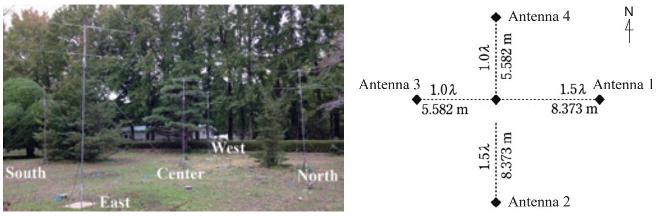


Figure 24: Five crossed Yagi-Uda antennas arranged in a cross shape, with one at the center and the other four to the north, south, east, and west. If the trios of antennas in the east-west and south-north rows were evenly spaced, the phase difference between the central antenna and the antenna at each end of the row would be equal. To better identify the direction of the received signal, the distances between the central antenna and one of each opposing pair was set to be equal to the target wavelength (1.0λ), and the distances to the other side of the pair was set to 1.5 times the length of the target wavelength (1.5λ).

In actual observations in conjunction with optical observations with a highly sensitive video camera, this system reportedly achieved an 80 percent agreement on meteor echoes with sufficient intensity and durations of at least 4-second, within an error range of 10 degrees.

"Because in previous student studies using radio interferometry an interferometer could determine the directions of meteors but couldn't measure the distances to those meteors, we devised a method in which an interferometer works together with a radar system that transmits radio signals and receives the backscatter."

One of his students, Takumi Sato, became interested in radio techniques through his bachelor's study. He earned an amateur radio operator license and got involved in the development of a system combining a radio interferometer and a backscatter radar for his master's thesis, in which he could use his expertise and experiences. Unfortunately, time restrictions did not allow him to produce sufficient observational results.

"Our research to date has been advanced by students working on research papers. One thing I regret is that the graduation of the students who wrote the papers would lead to the suspension of the research itself unless other interested students come to join the laboratory."

If you are a Junior high or high school student and want to study radio waves and meteors in the future, Kochi University of Technology may be the right choice for you.

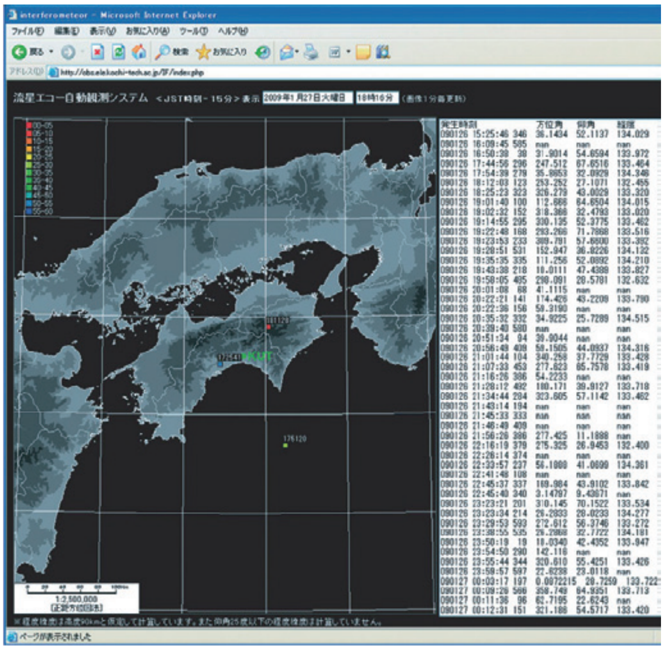
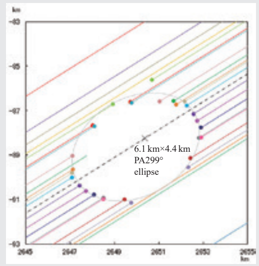


Figure 25: An example screenshot of a meteor echo auto observation system. The times and locations of meteors detected in the past hour are indicated on the map and also shown in the column on the right as text data.

Let's Participate in Occultation Observations!

When it comes to the one-time-chance of photographing during an asteroid flyby, preliminary investigations are indispensable to avoid over and under exposure. Even though the brightness can be measured from the ground, calculating the right surface albedo requires the actual size to be known. Unfortunately, asteroids are so small that they cannot be spatially resolved from the ground to determine their sizes and shapes.



Elliptical fit to the chords of a stellar occultation by Phaethon, with the long axis measuring 6.1 km and the short axis measuring 4.4 km. The observational data were summarized by Tsutomu Hayamizu at the Saga City Hoshizora Astronomy Center.

Instead, we use stellar occultations to measure the sizes of asteroids from the ground. When an asteroid passes in front of a star, the asteroid blocks the light from the star and casts a shadow on the ground, much like the Moon blocking the sunlight during a solar eclipse. As the asteroid's velocity on the celestial sphere is known, measuring as precisely as possible the time during which the asteroid is blocking a star from many locations allows us to reconstruct the shape of the asteroid's shadow.

This is also the case with Phaethon, whose shape and size have been estimated through observations of stellar occultations. On October 4, 2021, a joint team of professional and amateur astronomers tried to observe a stellar occultation by Phaethon at 36 locations in Japan, and among them, 18 locations actually observed the occultation. These observations produced an excellent depiction of Phaethon's shape. Many opportunities remain to observe Phaethon's stellar occultations before the DESTINY+ spacecraft makes its flyby. If you are interested, we would encourage you to participate in the observations.

★ More details on how to observe an occultation can be found on the following website: https://fumi-yoshida.wixsite.com/occultation-ws (Japanese language only)

Figure 24: From T. Sato, "Development of a meteor-radar observation tool by using forward-scattering method and a trial of simultaneous observation with 5 channel meteor radio interferometer," a master's thesis at Kochi University of Technology in 2021 (in Japanese)
Figures 23 & 25: From M. Yamamoto & K. Noguchi, "Automatic Direction-finding System of Measuring Meteor Plasma Echoes by Forward-scattering Radio Waves," The journal of the Institute of Electronics, Information and Communication Engineers, Vol.94, No.10, 2011 (in Japanese)

8. Observing Meteors with a Combination of Radio and Optical Observations

The amount of interplanetary dust falling on Earth is estimated to be 1 metric ton a day

The University of Tokyo's Kiso Observatory, which helped us carry out our radio observations, has been conducting its own meteor observations. Kiso Observatory's major instrument is a 105-cm aperture Schmidt telescope that offers sharp images and a wide field of view (Figure 26). Built in 1974, this telescope was initially used with photographic plates measuring 35.6 x 35.6 cm with each side covering a field of view of 6 degrees. It has been involved in various observations such as searching for new celestial objects. Now that the world has entered the age of electronic image sensors, the telescope is now equipped with a new instrument, Tomo-e Gozen, integrating the latest technology.

Figure 26: With a 105-cm aperture and 330-cm focal length, Kiso Observatory's Schmidt telescope is the world's fourth largest of its kind and offers a particularly bright field of view. This telescope can now work in a fully remote setting and has been conducting automated observations with Tomo-e Gozen.

At the core of the instrument is a high-sensitive camera in which 84 CMOS image sensors are arranged in a mosaic-like pattern (Figure 27). As each of the image sensors covers a field of view almost equal to the apparent size of the full Moon, Tomo-e Gozen can capture an area of about 84 times the size of the full Moon in a single exposure. Additionally, this instrument has integrated videography into astronomy observations, where still photography has long been the standard practice. Videography allows us to capture celestial phenomena changing on short timescales, which are otherwise difficult to observe.

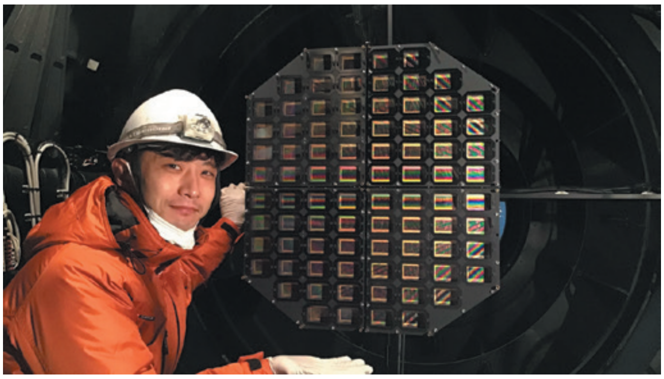


Figure 27: Tomo-e Gozen's imaging system consisting of 84 CMOS sensors.

There is a published study that carried out unique meteor observations by combining this new instrument with radio observations. We interviewed the study's primary author, Dr. Ryou Ohsawa, a Project Assistant Professor at the University of Tokyo's Institute of Astronomy. He told us that he became involved in the development of Tomo-e Gozen while studying interstellar dust.

"Now that the new instrument Tomo-e Gozen has been completed, it is destined to give rise to new observational methods making use of its advantages, which in turn should produce new scientific achievements," said Dr. Ohsawa. "So, we decided to observe interplanetary dust particles, or meteors, as an entirely new kind of observation. In fact, Tomo-e Gozen can detect meteors as dim as 10th magnitude, which cannot be seen with the unaided eye."

This is why he initiated a completely new style of observation, one that combines radio and optical observations using the MU Radar at Kyoto University's Shigaraki MU Observatory.

The MU Radar is a large phased-array radar designed mainly to observe the middle to upper atmosphere 10–500 km above the ground (Figure 28). It consists of 475 crossed Yagi-Uda antennas placed in a circular area 103 m in diameter, and each antenna can transmit signals in a given direction in phase. Additionally, it can also collect reflected signals (Figure 29).

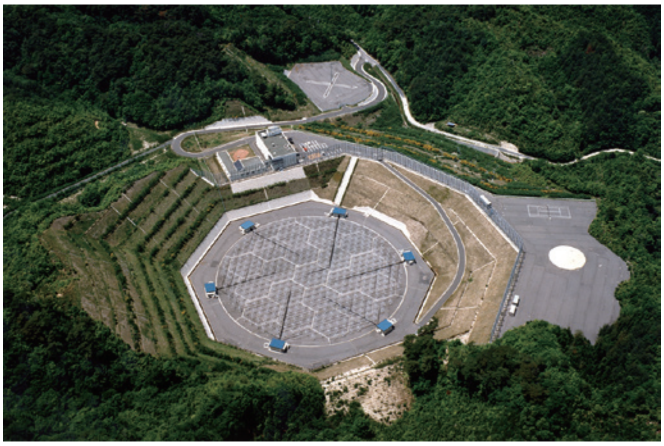


Figure 28: An array of 475 antennas arranged in a circular area 103 m in diameter. The MU Radar can not only transmit signals in phase to a give direction, but also change the direction of the signals 2,500 times a second.

Figure 29: The crossed Yagi-Uda antennas arrayed on the ground; equipped with a small transmitter-receiver module, each one can transmit and receive radio signals. Although the MU Radar was originally intended to observe the spatial structure of high-altitude winds and atmospheric turbulence, it can also observe meteors because meteors (or more correctly their head plasma) in the atmosphere reflect radio waves with frequencies that the MU Radar covers.

The MU Radar has long been used to observe radio reflections from meteors. The technique the MU Radar uses is called "meteor head echo observation" because it aims to observe radio waves reflected by meteor head plasma. This technique can not only measure the altitude and azimuth where a meteor appeared, but also its velocity and distance from the observer. Additionally, the intensity of the radio reflections allows us to determine the meteor's radar cross-section, the size of the meteors' plasma. Nevertheless, the MU Radar alone cannot measure the brightness of meteors.

This is where Tomo-e Gozen comes into play. The idea is to point the Schmidt telescope to an area of the sky that the MU Radar can cover. Once a meteor appears, its brightness can be measured by Tomo-e Gozen, and its velocity and the size of its plasma by the MU Radar.

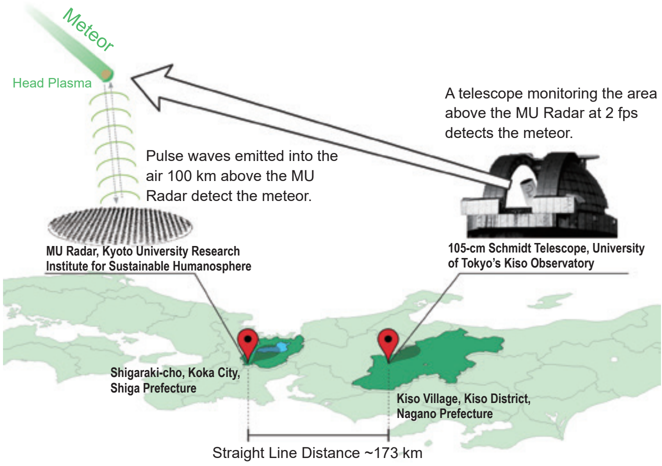
Because the brightness of a meteor can be expressed as a function of its dust mass and velocity, once a meteor's brightness and velocity are known, its dust mass can be calculated. In other words, when optical and radio observation data are combined, we can obtain a correlation equation for estimating the dust mass from the radar cross-section of a meteor measured by the MU Radar.

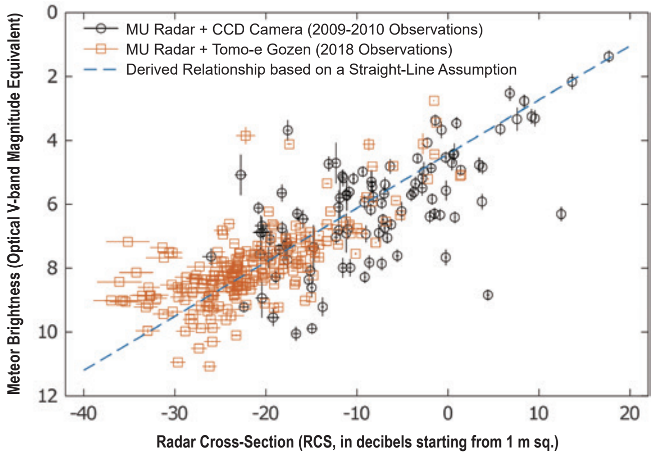
In fact, a research group led by Dr. Ohsawa was able to detect 228 sporadic meteors (meteors that do not belong to any shower) during a four-day period from April 18 to 21, 2018. By combining the data with those from 103 simultaneous observations conducted from 2009 to 2010 with the MU Radar and a highly sensitive CCD camera, the group investigated the relationship between meteors' radar cross-section and optical brightness. The group found that this relationship can be approximated by a single equation for 10th magnitude or brighter meteors.

By applying this equation to the meteor head echo data observed by the MU Radar from 2009 to 2015, the group estimated the amount of dust particles falling on Earth as meteors to be about a metric ton a day (Figure 30).

In the Solar System, comets and asteroids constantly produce interplanetary dust. Most dust particles floating near Earth's orbit are thought to weigh between 0.001 mg and 10 mg, but the particles' low densities have made them difficult to observe directly. The meteors detected by Dr. Ohsawa's group using the MU Radar were found to be caused by dust particles weighing between 0.01 mg and 1 g, providing some insights into the proportions of the masses of near-Earth dust particles.

By combining radio and optical techniques, future observations of the near-Earth interplanetary dust will help us better understand the activities of small Solar System bodies and the evolution of minute particles.





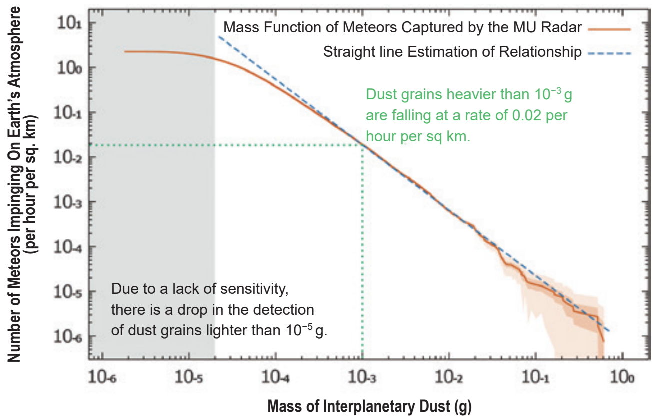


Figure 30:
(Top) A conceptual diagram of simultaneous observations with Kiso Observatory and the MU Radar. While the MU Radar observes a meteor 100 km above the ground, Tomo-e Gozen, located 173 km away, monitors the same region of the atmosphere as the MU Radar.

(Middle) Simultaneous observations with Tomo-e Gozen and the MU Radar revealed that 2nd to 10th magnitude meteors have a linear relationship between the optical brightness and radar cross-section.

(Bottom) A graph showing the numbers of meteors (interplanetary dust particles) falling on Earth as meteors versus their mass, based on the observation results from the MU Radar. Lighter dust particles are more abundant, and that relationship can be approximated by a straight line. These data may not include all the light dust particles because of the lack of sufficient sensitivity.

Features of Meteor Radio Observations —How Do They Differ from ALMA Observations?

This time, we performed radio observations of meteors, but this is a very different style of observation than is used in ALMA observations. The first difference to note is that, unlike radio-wave-emitting objects, meteors do not emit radio waves but instead reflect artificial radio waves, and these reflections are what we detect in meteor radio observations. Additionally, meteor radio observations don't detect faint radio waves from distant objects located many light-years away, but instead much closer phenomena occurring within Earth's atmosphere. Moreover, the observers can freely configure the parameters for observations, such as radio frequency and intensity, based on their own convenience (transmitting radio waves sometimes requires a license however).

The HRO meteor radio observation method uses signals transmitted by volunteers. In contrast, the MU Radar can not only handle transmission and reception with each antenna, but also match the phases of the signals and transmit them in any direction.

Yet another difference is that meteors are not fixed bodies but are unpredictable as to when and where they will occur. This unpredictable nature makes it impossible to produce radio images by pointing a massive array of dishes at a single object, the way ALMA does. The five-element radio interferometer of Kochi University of Technology, which works on basically the same principle as ALMA, can determine the phase differences between signals received by each pair of antennas, thereby locating the radio sources. However, ALMA goes even further by employing a technique called aperture synthesis: it can produce images of celestial bodies by using a computer, called a correlator, to crunch data from many antenna pairs pointed in different directions and placed at different distances apart.

Recently, the LOw Frequency ARray (LOFAR), a radio interferometer in the Netherlands, made news with the successful radio imaging of meteor trails. The images show clear meteor trails even though the authors state that it remains unclear whether the meteors were emitting radio waves or reflecting terrestrial signals. Future developments in this field will push meteor radio observations to a new level.

Image Credits: Figures 26, 27 University of Tokyo's Kiso Observatory; Figures 28, 29 Kyoto University Research Institute for Sustainable Humanosphere; Figure 30 School of Science, The University of Tokyo (Source paper: Ohsawa et al. 2020 P&SS, 194, 10511)

After Experiencing Observations with a DIY Antenna and an SDR Dongle

This time, through crash-course study and trial and error, the ALMAr's Adventure Production Unit attempted meteor radio observations. The HRO method once required an expensive amateur radio system. We carried out a hands-on experiment to determine whether an inexpensive SDR dongle would be practical enough to observe meteors. We still have a very long way to go to build an interferometer like ALMA, but we've gotten a little closer.

Figure 31: On the same days as our observations, the observation team led by Dr. Shinsuke Abe (the second person from the right), an associate professor at Nihon University's College of Science and Technology, also stayed at Kiso Observatory to perform optical observations of the Geminids. We had a fruitful exchange of ideas and information. Our radio observation data were later provided to the observation team. What will be the results from our data?

Figure 32: Our meteor radio observations would not have been possible without the help of the staff of Kiso Observatory. Even though the nighttime temperatures outside dropped below freezing, the staff kindly offered us warm rooms and bedding, as well as delicious meals three times a day. We took a commemorative photo with Observatory Director Naoto Kobayashi (middle) and staff member Yuki Mori (the second person from the left), with the enclosure of the Schmidt telescope in the background.

Next Issue

The next issue will be on the theme "Receiving Jovian Radio Emissions," where we will build a long dipole antenna to pick up radio waves with longer wavelengths. In the science corner, we will explain various scientific findings about planets. Don't miss it.

"ALMAr's Adventure" Production Unit

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Background Image: A bolide (a bright meteor) falling behind the enclosure of the 105-cm Schmidt telescope at the University of Tokyo's Kiso Observatory, where we conducted radio observations of the Geminid meteor shower. The image was taken on the night of December 14, 2021, during which many meteors appeared.

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