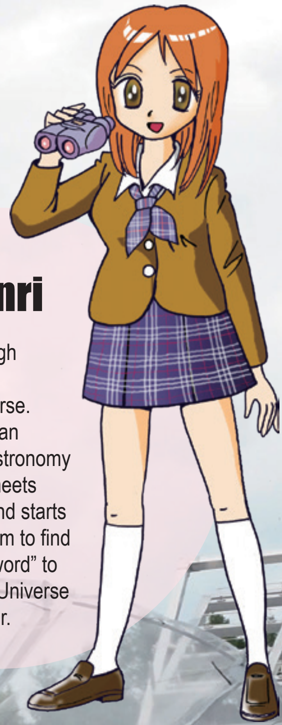
アルマーの冒険 ALMAr's Adventure

Issue 09
“Solar Radio Observations with a Hand-Made Parabolic Antenna”



Nao Senri

A Junior at Souten High School. She loves the starry sky and the Universe. Her dream is to become an astronomer. During an astronomy club camping trip, she meets “ALMAr” and “Izayoi” and starts an adventure with them to find “Grand ALMAr’s Sword” to save the Radio Universe from danger.

ALMAr

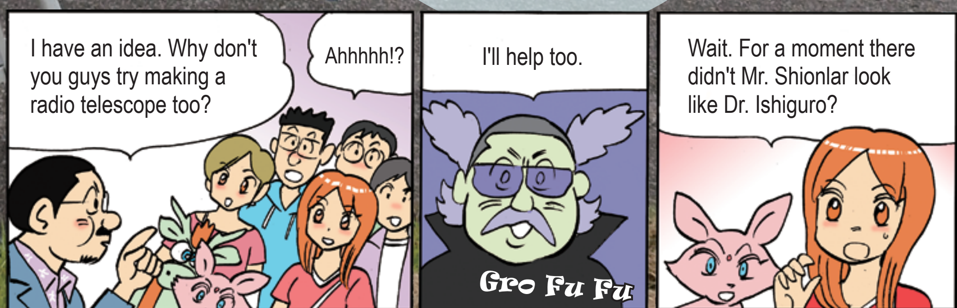
A dragon-child who came to the Visible Light Universe from the Radio Universe. He passed out after being showered by mysterious radio interference known as “Jamming” which poses a threat to the Radio Universe. While he was unconscious, a 9-headed dragon appeared to him and said, “Seek out Grand ALMAr’s Sword to protect the Radio Universe.” When he awoke, he was in a grassy field in the Nobeyama highlands.

Izayoi

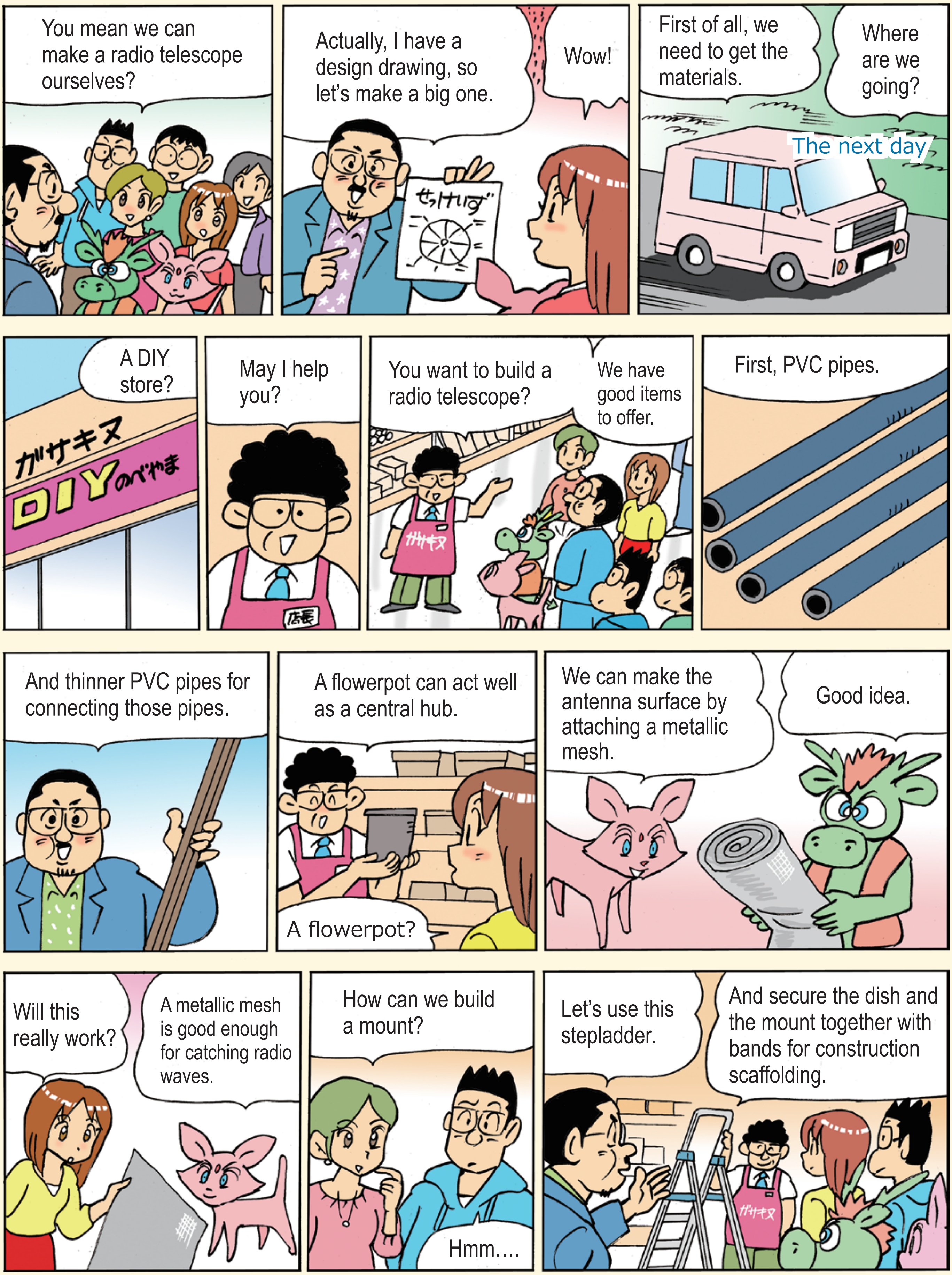
A mysterious female cat who appeared in front of Nao and ALAMr. She has the special ability to see both the Visible Light World and the Radio World. She possesses a rich knowledge of both the Radio Universe and the Visible Light Universe. Somehow she knows about ALMAr’s past, the source of the danger to the Radio Universe, and Grand ALMAr’s Sword...

★Summary up through the previous Issue, Issue 08 “The Solar Radio Interferometer being Built by High School Students”

Led by Mr. Shinolar of Nobeyama Radio Observatory, the Soten “Deep Blue Sky” High School astronomy club members visited Nagano Prefecture Komagane Technical High School. There they saw a parabolic antenna for observing solar radio waves and a solar radio wave interferometer under construction, both of which were built by the high school students. Later, Mr. Shinolar suggested that the club members build a parabolic antenna, but Nao and Izayoi started to sense a mysterious force driving him.
(Right: the last scene from Issue 08)



Chapter 9-1: Let's Find Radio Telescope Materials at a DIY Store



The Legendary 4-m, or Actually 3-m, Parabola Reborn!

The restoration project for Dr. Ishiguro's hand-made parabolic antenna starts

Two Big Searches in the Nobeyama Radio Observatory Warehouse

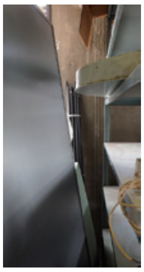
In the summer of 2018, the "Almar's Adventure" production staff were in the NINS Exhibit Room warehouse (formerly the Interferometer Building) at Nobeyama Radio Observatory, diving deep into a pile of supplies looking for the missing parts of a 4-m parabolic antenna.

That 4-m parabolic antenna was the one used in the NHK TV program "Welcome Back Graduates" (aired from 1998 to 2016). In this program, famous people from various fields returned to the schools they had attended and explained the importance of their own work while interacting with students at their alma maters. Dr. BS (Dr. Masato Ishiguro) made an appearance on this program in 2003. He remembered that at that time he assembled a parabolic antenna with the students to help deepen their understanding of radio astronomy and observed solar radio waves with a wavelength of about 21 cm (in the 1400 MHz band).

In fact, we had been discussing the idea of building our own radio telescope and catching radio waves from celestial objects. That was when Dr. Ishiguro brought us the good news that the whole set of the antenna parts should have been kept intact. Seeing a photo from the episode where he appeared, we recognized that the antenna he built was an impressive parabolic antenna with a metallic mesh mirror.

So instead of building an original one from scratch, we decided to experience the process from reassembling that parabolic antenna to receiving solar radio waves. Thus, the restoration project for the legendary 4-m parabolic antenna started.

With two separate searches in the warehouse, we found the antenna parts one by one, and by referring to the remaining photos of the completed parabolic antenna, we were able to complete all the major parts.



(left) We caught a glimpse of a bundle of pipes behind a pile of machines and supplies. Wait, that's the frame of the parabola, "Jackpot!"

(middle) For starters we laid out the parts we found. Nobeyama's public relations staff member Kenzo Kinugasa was a great help. Thank you!

(right) The project writer and photojournalist Kawamura discovered the last parts by chance. Why were only these parts wrapped in paper and placed (dropped?) away from the rest of the parts?

Then in the summer of 2019, we were finally ready for the assembly work. Borrowing a workshop at Nobeyama Radio Observatory, we started assembling the antenna. However, as the shape of the parabolic antenna appeared, we noticed something odd: it looked smaller than expected. According to Dr. Ishiguro, the diameter should be 4 m, but each PVC pipe making up the curve of the dish was obviously shorter than the average human height. "Perhaps, the aperture might actually be 3 m. Hmm, I thought that I had used 1.8-m pipes, which might have made me believe that the aperture was 4 m," said Dr. Ishiguro. In this way, the "Almar's Adventure" production staff were set to restore the legendary 4-m, or actually 3-m, parabolic antenna.

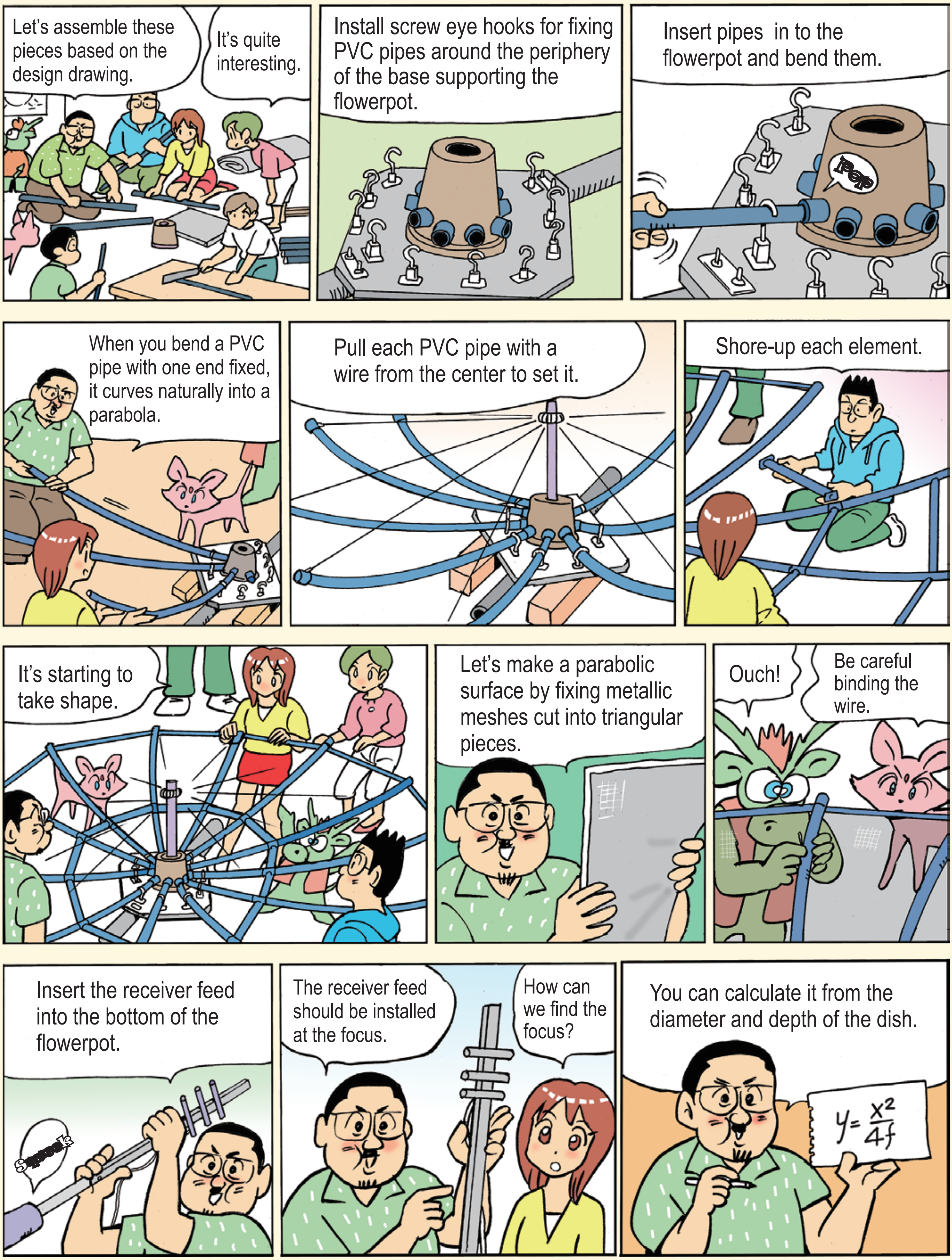
Dr. Ishiguro's hand-made parabolic antenna used in "Welcome Back Graduates."

Antenna Specifications / Materials (original)

Basic Design: 3-m diameter parabolic antenna / Manual altazimuth mount
Antenna Frame: PVC pipes (steel-wire tension construction)
Hub for PVC pipes at the parabolic reflector center: Plastic flowerpot
Parabolic Surface: Stainless mesh (for screen doors)
Receiver Feed: 5-element Yagi-Uda antenna (3-elements at the time of restoration)
Receiver Feed Base: Telescopic rod of a floor cleaning mop
Center Frequency: 1420 MHz (The Japanese Radio Act designates the 1400-1427 MHz band as a guard band to protect observations of the 21-cm line of hydrogen.)
Mount: Altazimuth mount made out of a 3-step aluminum stepladder
Vertically Movable Element / A steel pipe + clamps
Horizontally Rotating Element / None (manual rotation)

A parabolic antenna signed and presented by the elementary school students with whom he built a radio telescope in an episode of "Welcome Back Graduates" that aired in 2003. "The students are now in their late twenties. It is fun to imagine that the experience of building the telescope might have made some of them pursue related careers," says Dr. Ishiguro.

Chapter 9-2: Putting PVC Pipes Under Tension to Transform Them into an Antenna Frame



★For more details, refer to Page 07.

Unpacking All Parts and Starting the Assembling Work

Assembling a parabolic antenna while learning its structure

Obtaining a set of materials at a DIY store

A parabolic (or parabola) antenna working as a radio telescope can be broken down into several components based on their functions: the parabolic mirror designed to focus radio waves, the receiver for detecting radio waves, and the mount. Here, we provide a somewhat detailed look at each component and how it works as part of a radio telescope, while assembling Dr. Ishiguro's 3-m parabolic antenna.

By the way, the 3-m parabolic antenna restored this time was built on Dr. Ishiguro's concept of "consisting as much as possible of parts that can be purchased from any DIY store." So, each of its components was crafted in an ingenious manner based on easy-to-purchase materials. If you want to build your own parabolic antenna, this antenna will serve as a useful example.

Perhaps the most conspicuous component of a parabolic antenna is its parabolic mirror, a circular, dish-shaped structure curved inward to focus radio waves. The term "parabola" refers to a curve that represents the trajectory of a projectile, and its shape can be expressed as the following equation:

$$y = a x^2$$

01 After borrowing a corner of Nobeyama Radio Observatory's workshop, we started assembling the parabolic antenna. Dr. BS was almost moved to tears when he saw the antenna for the first time in 15 years. For starter we laid out all the unearthed parts on the floor and took a commemorative photo.

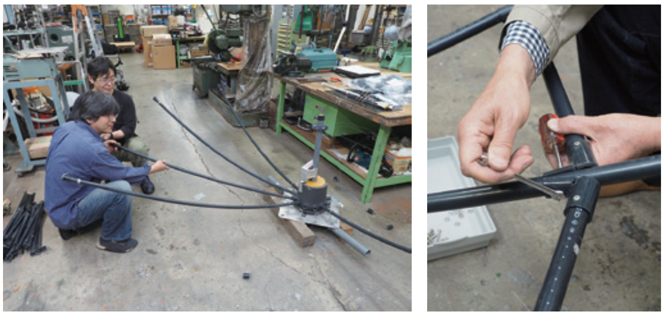
If you rotate this curve about the y axis, you will obtain a paraboloid, the shape of a parabolic mirror. Therefore, a "paraboloidal" mirror is a more accurate name for this component, but generally it is called just a "parabola" or a "parabolic" mirror.

02 The central element of the parabolic antenna is based on an aluminum plate onto which a plastic flowerpot is placed upside down. The steel pipe under the aluminum plate serves as the rotation axis, enabling adjustment of the elevation angle of the antenna. We fixed pipe fittings for PVC pipes around the circumference of the flowerpot and inserted one end of each of the PVC pipes constituting the dish frame into these fittings. By this point, we have already realized that the dish diameter is not 4 m but 3 m.

A parabolic mirror is also used as the primary mirror of a Newtonian reflecting telescope, a type of optical telescope, because of its ability to focus an incoming beam of parallel light rays at a single point, the focus. In just the same way, the parabolic mirror of a radio telescope can focus radio waves.

The frame of the 3-m parabolic antenna was made of PVC pipes. This is because if you bend a bar made of a homogeneous material with one of its ends fixed, the resulting shape can be approximated by a parabola. We made a hub out of a flowerpot to serve as the center of the radial frame of the parabolic mirror. One end of each of the twelve PVC pipes was attached to this hub so that all the pipes were arranged radially spaced at 30° to each other. Then we tied the other ends to thin steel wires and pulled them taunt until they were bent into curves. Adjacent pipes were connected to one another by two stay pipes, one at the periphery and the other at the middle, to reinforce the mirror surface.

For the material for the mirror surface, we used stainless mesh (fine metallic mesh for screen doors) because cutting and bending sheet metal is difficult. We made a paper pattern to cut the stainless mesh to fit into the twelve sectors of



03 The outer ends of the radially arranged pipes were pulled with steel wires toward the center, and these pipes were curved to form an approximate parabolic surface. A stay was inserted into the pipe fitting attached to the middle of each pipe to reinforce the structure. To fix each stay, holes were drilled into the pipe and the fitting, which were then bolted and tightened together.

the parabolic mirror and fixed these mesh pieces with thin steel wires to cover the gaps between the beams of the frame. By the way, how accurate does the surface of a radio telescope mirror need to be? The general rule is that the mirror must be accurate to within one-twentieth of the wavelength you want to observe. Because this time we planned to observe radio waves with a wavelength of about 21 cm, the mirror surface was allowed to have irregularities up to about 1 cm (although the actual mirror was a bit more irregular). With a smoother and more parabolic surface, the antenna becomes better able to collect radio waves, hence more sensitive.

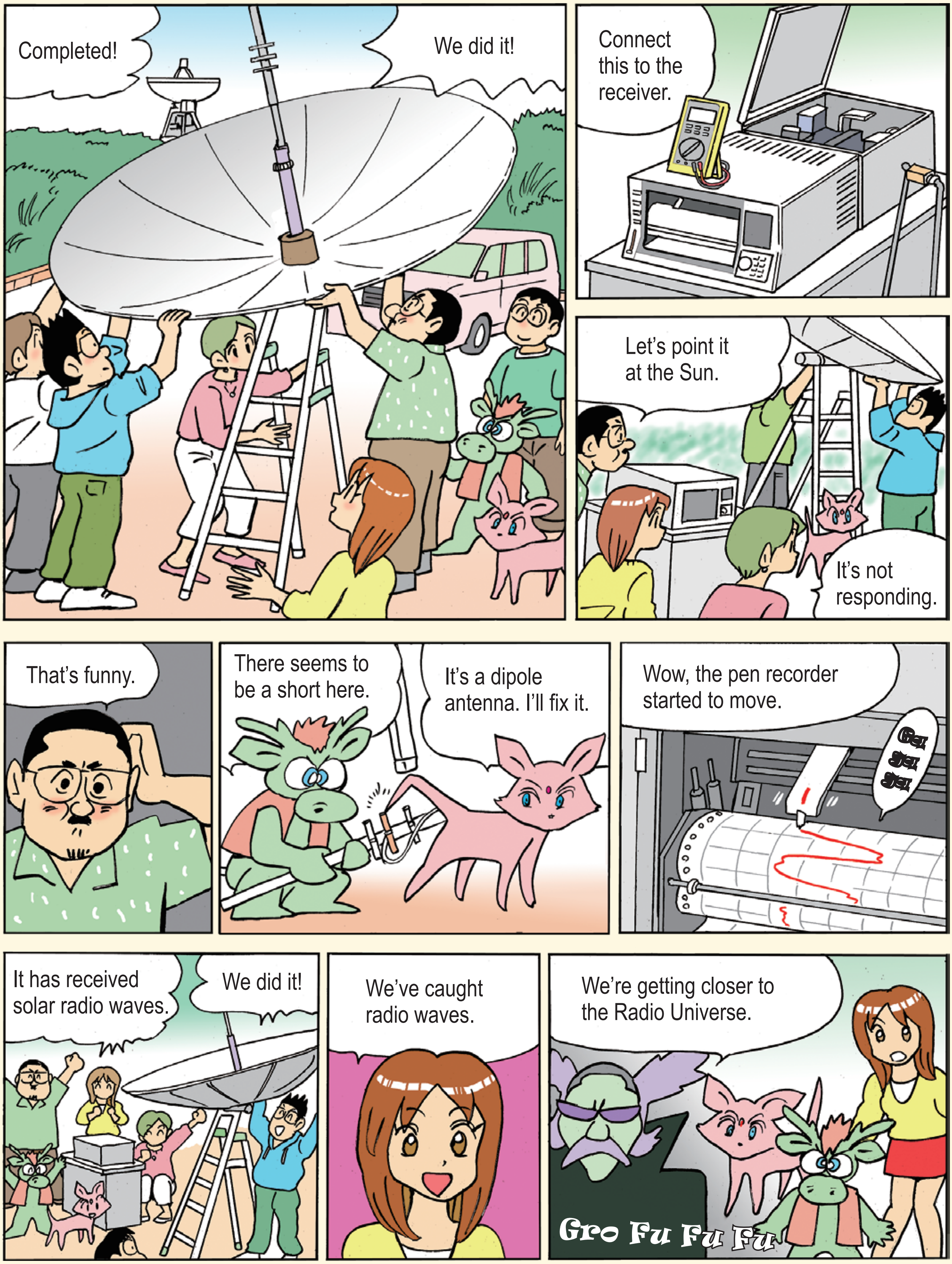
04 The dish frame started to take shape. But one problem arose here: we found that the completed frame would not be able to pass through the workshop door. Anyway, we decided to complete the frame and then disassemble part of it to carry it out of the workshop.

You may be concerned about radio waves passing through the mesh surface, but as in the case of surface irregularities, it does not matter if the surface has small holes upto about 1 cm in diameter.

05 This aluminum stepladder looks like nothing special. You may expect that it would be used for pruning garden trees, but surprisingly, it is able to serve as a mount for a parabolic antenna.

06 Dr. Ishiguro bolting a square piece of wood to the top of the stepladder. The clamps attached to the wood piece serve as the bearings for the steel pipe that acts as the rotation axis. Now we are ready to mount the dish frame. The elevation angle is adjustable by using a threaded rod (a long screw) as a support.

Chapter 9-3: Solar Radio Waves Move the Pen Recorder!



The Pivotal Element for Receiving Solar Radio Waves is...a Set of Metal Bars?

The basic receiver feed and signal processing are at the core of capturing radio waves

The basic receiver feed and signal processing are at the core of capturing radio waves

Although the parabolic mirror does focus radio waves, what actually captures these waves is the small receiver feed installed at that focus. This 3-m parabolic antenna has a receiver feed made from copper pipes. Each copper pipe measures about 10 cm in length, corresponding to about half of our observation wavelength (1/2 wavelength). We placed three copper pipes on a square aluminum pipe at about 5-cm intervals, a quarter of our observation wavelength. Of course, these copper pipes and the square aluminum pipe were electrically insulated. The copper pipe placed in the middle was connected to the receiver to serve as an antenna in a very real sense. Among the three copper pipes, the one closest to the dish is to direct radio waves, hence called a director, whereas the one farthest from the dish is to reflect escaping radio waves back toward the dish to improve the reception efficiency, hence called a reflector (Figure 04). In fact, this type of antenna, known as a "Yagi-Uda antenna," is a basic design for a high-sensitive antenna and is also used for television antennas.

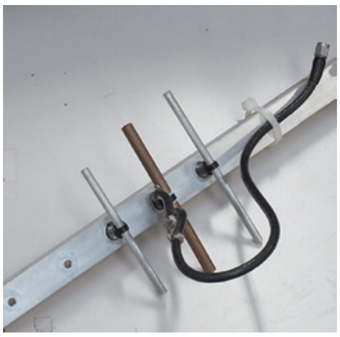
By installing this Yagi-Uda antenna at the focus of the parabolic mirror, we finally completed the antenna. The position of the focus was calculated from the depth of the parabolic mirror.

In this way, we managed to build the antenna itself. However, it was beyond us to build our own receiver system to convert a received radio signal into an electric voltage, a form which we can visually understand. Even purchasing parts for the system at a DIY store is difficult. So this time, we relied on Mr. Shinolar (Noriyuki Shinohara) for building a receiver. In fact, he had discussed the system to be used with Dr. Ishiguro beforehand and amazingly even repaired the dipole antenna, which had somehow shorted out.

01 First, we prepared the mirror surface. All the team members worked together to attach the metallic mesh.

02 Diligent work to stack two sheets of wire mesh and binding them together to the PVC pipe frame with thin wires.

03 The parabolic surface was completed, and the receiver feed was finally ready to be installed, but then a problem arose: Dr. Ishiguro had forgotten the position of the focus. However, by solving a simple equation, we were able to derive the distance from the dish bottom to the focus.



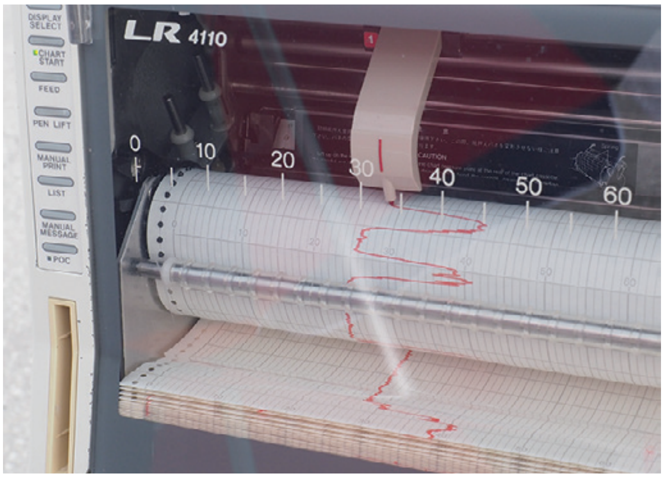
04 The receiver feed takes advantage of the Yagi-Uda antenna style. The trick is to make the dipole antenna slightly shorter than a half wavelength, with the director a bit shorter and the reflector a bit longer than the dipole antenna. (Of course, there is a theoretical reason for this.)

Thanks to his device, we were able to achieve our goal. Although the day we attempted solar radio observations was cloudy, we waited until a moment when the Sun appeared from behind the clouds. During a short interval of fair weather, we pointed our antenna to the Sun and successfully received solar radio waves with a wavelength of about 21 cm.

05 The parabolic antenna has been completed!

06 (left) Another problem arose. The antenna did not respond to radio waves. "What's wrong?" Dr. Ishiguro peering into the switchbox containing a circuit for processing signals.

07 (right) A short circuit in the dipole antenna turned out to be the cause of the malfunction. Once the problem was identified, removing it was a piece of cake. Shinohara's soldering skills fixed the antenna immediately.



08 By pointing the parabolic antenna at the Sun and then in another direction, we confirmed that the pen attached to the pen recorder reacted based on the direction. (The more the pen moves to the right, the stronger the received radio waves are.) We have definitely received solar radio waves.

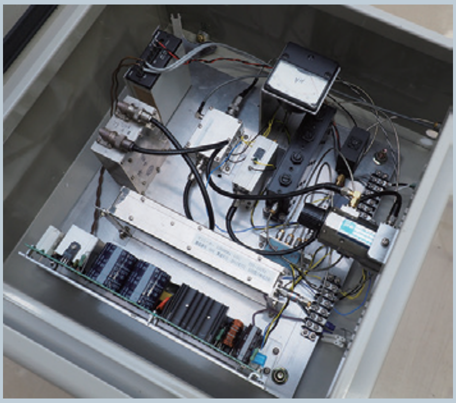
The focus position of the completed parabolic antenna (the distance from the dish bottom to the receiver: f) can be calculated by using the following equation.

$$y = \frac{x^2}{4f}$$

y: height of the parabolic surface above the base at a point x radial distance from the dish center

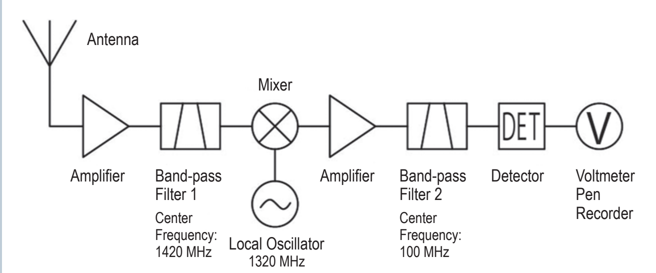
Composition of the 3-m Parabolic Antenna Receiver

A receiver is a device that amplifies a weak radio signal received by an antenna and generates a direct current voltage proportional to the radio intensity. This time we asked Mr. Shinohara to build a receiver for the 3-m parabolic antenna. Here, let us provide a brief explanation on how a signal received by the antenna is processed, along with descriptions of the necessary receiver components. Almost all the receiver components are encased in a metal switchbox (shield case) (Figure 01).



01 The metal switchbox housing a switchboard and other equipment is packed with electronics designed to convert a radio signal to an electric voltage.

First, a radio signal received by the antenna travels through the coaxial cable and reaches an amplifier, where this signal is boosted. The amplified signal is then fed into band-pass filter 1, and only the frequency components around 1420 MHz are allowed to pass through the filter. After filtering, the signal is sent to the mixer. Because a high frequency signal is difficult to process directly, this 1420 MHz signal is mixed with a 1320 MHz signal from a local oscillator and converted to a signal with the difference frequency of 100 MHz. If the input contains a frequency component at 1220 MHz, this component will also be converted to a 100 MHz signal, which is indistinguishable from the one generated from the 1420 MHz signal. Therefore, the band-pass filter 1 is necessary to remove this unwanted frequency component. The mixer output is then boosted by a second amplifier and fed into band-pass filter 2, which allows only the frequency components around 100 MHz to pass through and reach the detector. The detector converts the radio signal to a direct current voltage proportional to the radio intensity, and the signal strength is expressed in visible form for the first time by the voltmeter and the pen recorder (Figure 02).



02 A block diagram showing the composition of the receiver.

About the 21-cm line

This time we observed radio waves with frequencies around 1420 MHz. Our Earth is continuously showered with radio waves (emission line) of 1420.4 MHz frequency and 21.1 cm wavelength emitted by hydrogen atoms in space, and this hydrogen line is known as the 21-cm line. The radio waves from hydrogen are so important in astronomy that emitting artificial radio waves at frequencies ranging from 1400 to 1427 MHz is prohibited by law. Therefore, this frequency band experiences less interference from artificial radio sources. Note that what we observed this time was part of the Sun's continuum spectrum and not the 21-cm line itself.

Angular resolution of a parabolic antenna

Angular resolution is a measure of how well an observational device can distinguish small details of an object, and that of a parabolic radio telescope can be approximated by the following equation.

$\theta \simeq 1.2\,\lambda/D$

(θ: angular resolution (radian); λ: wavelength; D: antenna diameter)

If we assume that the diameter is 3 m and the wavelength is 21 cm (0.21 m), the equation is 1.2 × 0.21 ÷ 3 = 0.084 radian $\simeq$ 5°, meaning that the angular resolution is about 5° when a 3-m parabolic antenna observes radio waves at 21-cm wavelength.

Because the Sun's apparent diameter is about 0.5°, we can safely say that radio waves from the Sun are easy to capture even if the antenna's direction is a little off from straight at the Sun.

The receiver being carefully checked by Dr. Ishiguro and Mr. Shinohara. They look like they're having great fun immersed in their own little world.

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