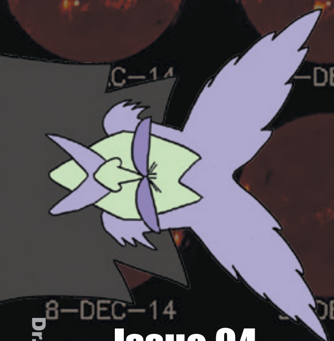
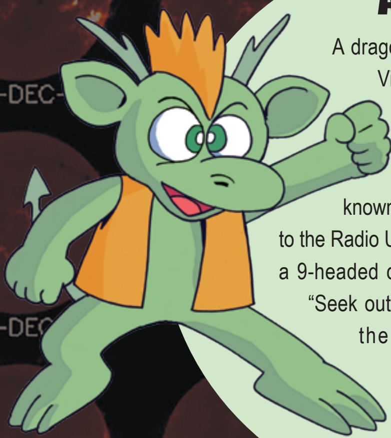
アルマーの冒険 ALMAr's Adventure



Dr. BS (Blackstone): Who is he really?

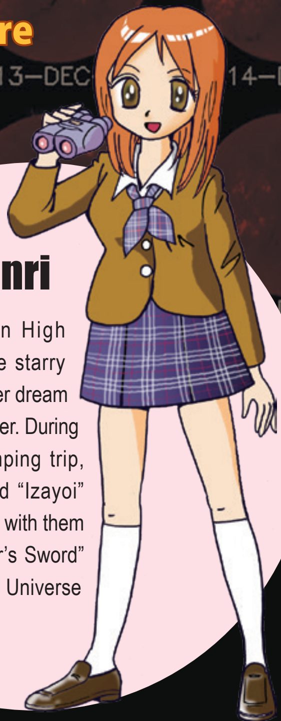
Issue 04
“Catching Radio Waves from Space!
Part 2: Solar Radio Waves”

In this 4th issue, we finally step into the world of radio astronomy and start actually receiving radio waves from celestial objects. The first celestial object we’ll observe is the Sun. Let’s try to catch radio waves from the Sun using a radio telescope made with a repurposed BS antenna.



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...

"ALMAr's Adventure" Production Unit
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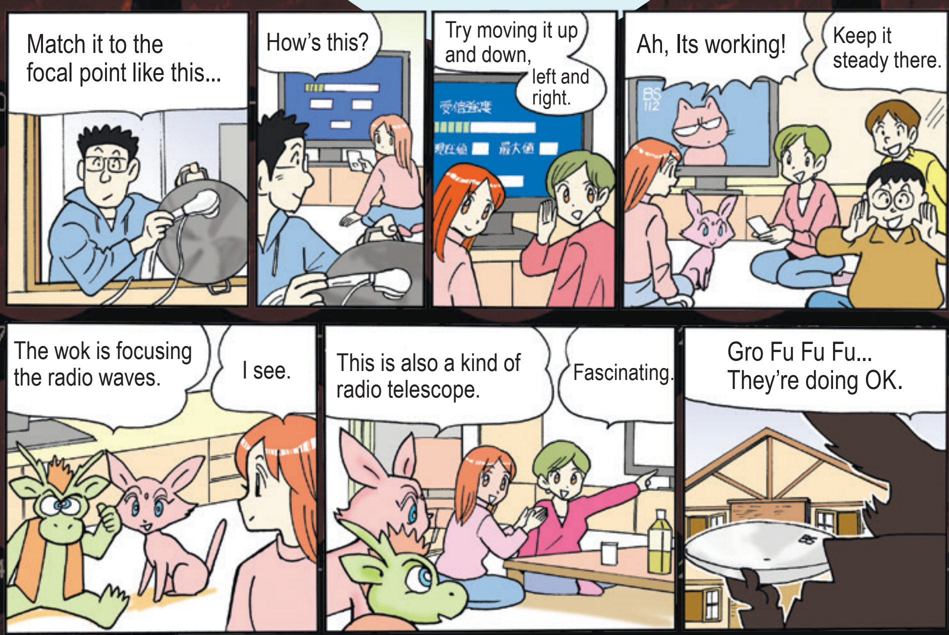
(NAOJ Professor Emeritus: Formerly ALMA Project Office)
Translation: Ramsey Lundock

Summary up through the previous issue, Issue 03 “Catching Radio Waves from Space! Part 1: Broadcasting Satellites”

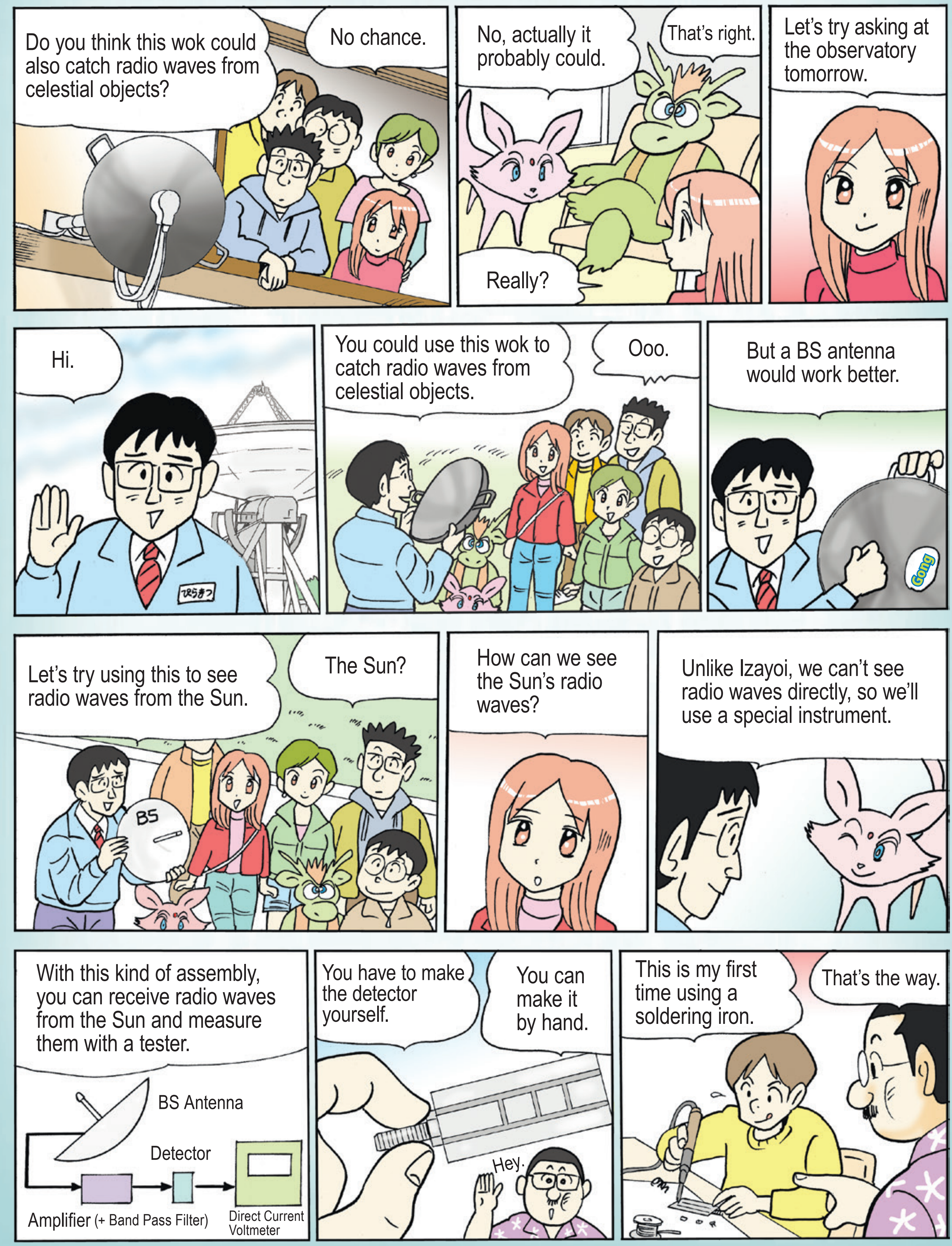
Nao, ALMAr (a dragon child), and Izayoi (a cat) met up with the members of the Soten “Deep Blue Sky” High School astronomy club and returned to the lodge. For some reason, the BS antenna was broken so they couldn’t watch Broadcasting Satellite (BS) television. Izayoi suspected that it was the work of Dr. Blackstone (Dr. BS). Nao and her friends went to Nobeyama Radio Observatory and studied methods for receiving radio waves. Based on this knowledge, they succeeded in using a wok as an antenna to catch BS signals. But Dr. Blackstone seems to have more nefarious schemes.



The background images are Radio images taken by Nobeyama Solar Radio Observatory’s Nobeyama Radioheliograph in December 2014 and January 2015. Observations can be conducted every day regardless of weather.

Chapter 4-1: Let's Catch Radio Waves from the Sun with a BS Antenna

Nao and her friends used a wok to catch BS signals. By chance could they use it to catch other radio waves from space?



Characteristics of Radio Waves from Celestial Objects, Let’s try to Detect Radio Waves Emitted by the Sun

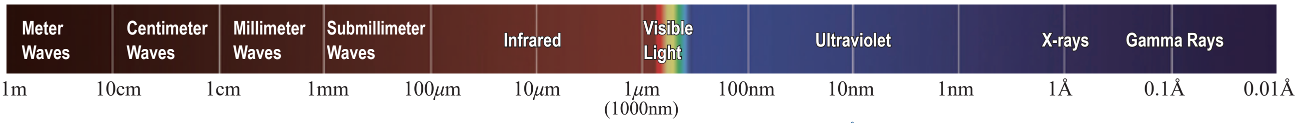


Figure 01) Chart of wavelengths used in astronomical observations (“μm” indicates micrometers, “nm” indicates nanometers, “Å” indicates angstroms)

•The Differences between Radio Waves from Celestial Objects and Radio Waves from Artificial Satellites

After you’ve received BS signals coming from outside of Earth (please refer to ALMAr’s Adventure Issue 03), next let’s try to catch radio waves from an actual celestial object. There are many kinds of objects in space. But to start with, let’s observe radio waves from the most familiar object: the Sun.

The Sun shines brightly thanks to nuclear fusion reactions. This (visible) light is so dazzlingly bright that on Earth you can’t stand to look directly at it. But the Sun is also emitting many other wavelengths of electromagnetic waves. Solar astronomers observe at many wavelengths of electromagnetic waves, not just visible light (Figure 02).

The Sun can be observed during the day. If it’s fair weather, anybody can quickly determine where the Sun is in the sky. Also, it is comparatively close to the Earth, so the radio waves arriving at Earth from the Sun are far stronger than those radio waves coming from distant objects. So the Sun is the easiest object to observe.

By the way, what are the differences between radio waves coming from celestial objects (the Sun for example) and artificial radio waves? One of the biggest differences is that artificial radio waves used for broadcasting and communications are transmitted at specific frequencies. (Please refer to Issue 03 for the relation between frequency and wavelength.) In contrast, celestial objects emit radio waves with a wide range of wavelengths. (Not just radio waves, there is a wide range of many types of electromagnetic waves: Figure 01.)

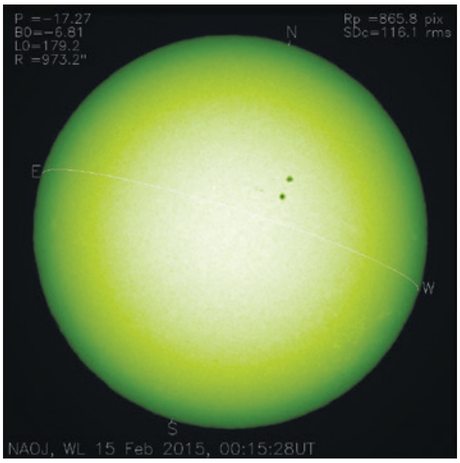
In the satellite broadcasts which we caught in Issue 03 for example, each broadcasting station uses a frequency around 12 GHz (25 mm wavelength). The frequency of NHK BS1 is 11.99600 GHz. Likewise GPS, which determines your positional information like elevation, latitude, and longitude, uses a number of set radio wave frequencies (1575.42 MHz, 1227.6 MHz, etc.) As these examples of artificial radio waves show, unless the frequencies and strengths of the radio waves for each use are decided beforehand, it wouldn’t be possible to single out the radio waves you want; all the radio waves would interfere with each other, making them unusable.

In contrast, radio waves from celestial objects come in a wide range of wavelengths (frequencies). Each wavelength of radio waves is produced by different conditions and phenomena in the object. (Refer to ALMAr’s Adventure Issue 02.) So, radio astronomy attempts to clarify the mysteries of the Universe by conducting precision observations narrowing in on the wavelengths corresponding to the characteristics of the target object or phenomenon and determining the physical mechanisms which give rise to them.

• To Receive Radio Waves from the Sun

So now at last, let’s take on the challenge of receiving solar radio waves. In Issue 03 we explained that there are different types of antennas based on the frequencies (wavelengths) to be received. So what kind of antenna should we use for receiving solar radio waves? As described earlier, the Sun emits a wide range of radio wavelengths. So this time, instead of the wok we used to receive BS signals in Issue 03, let’s use an authentic BS antenna as is to catch solar radio waves. Using a ‘small, familiar radio telescope’ known as a BS antenna, we can receive 12 GHz (25 mm wavelength) solar radio waves.

The Solar Flare Telescope during observations.



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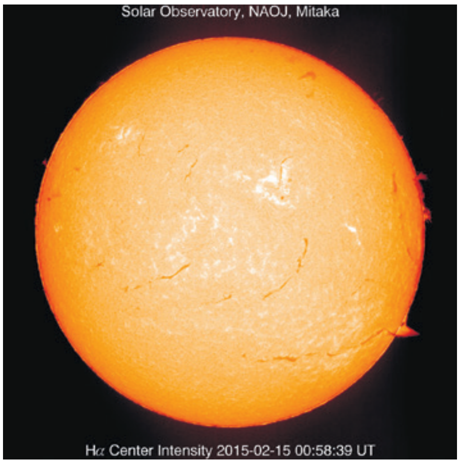

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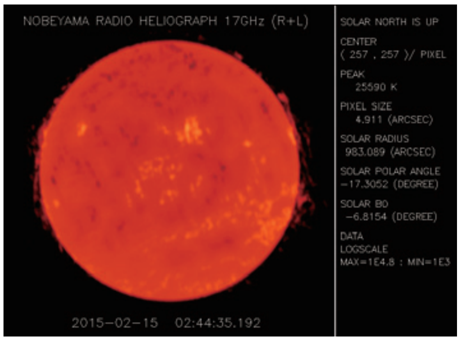

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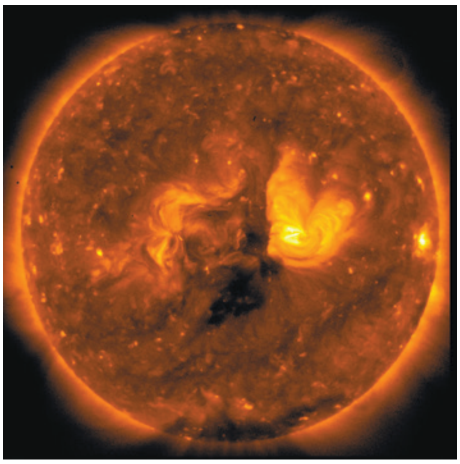


d

Figure 02) Many different wavelengths of electromagnetic radiation are emitted by the Sun. Of course there is visible light. On the short side of that, we can observe ultraviolet and X-rays. To the long side we can observe infrared and radio. Here we introduce (false color) images of the Sun taken in the various wavelengths observed by NAOJ.

a) Visible (white) light observed by the NAOJ Solar Observatory Sunspot Telescope.
b) Image of Hα line emissions (656.3 nm, redder than visible light) observed by the NAOJ Solar Observatory Solar Flare Telescope.
c) Radio image (17 GHz, approximately 17.6 mm wavelength) taken by the Nobeyama Radioheliograph at Nobeyama Solar Radio Observatory.
d) X-Ray image taken by the X-Ray Telescope onboard the solar observation satellite HINODE.

Chapter 4-2: Solar Radio Wave Observations Start with Handmade Electronics

A detector is necessary for a radio telescope made from a BS antenna. Let's make it ourselves!

Experiment 3 Let's Catch Solar Radio Waves

In Experiment 02 from ALMAr's Adventure 03, you used things like a wok in place of a BS Antenna to collected radio waves from broadcasting satellites and watch BS broadcasts. This time we will use a BS antenna as is for an experiment to see if we can catch radio waves from the Sun. Many wavelengths of radio waves reach us from the Sun; among those, 12 GHz frequency radio waves can be received with a BS antenna. Which isn't to say that you can see an image of the Sun on the TV. The radio waves coming from the Sun are converted to a voltage and that result can be measured as a numerical value with a tester. Compared to the experiment catching BS signals with a wok, this time requires some electronics knowledge and skill; but you can proceed with this experiment by investigating on your own or asking a science teacher at a school or science museum.

• The Adviser for this Experiment •

The adviser for Experiment 03 is Noriyuki Shinohara from Nobeyama Solar Radio Observatory. (He joined Nobeyama Radio Observatory starting from April.)

Please inquire with Shinohara for the details of Experiment 03, such as how to make the circuit and how to obtain the electrical parts.

Contact Information:
Shinohara.noriyuki@nao.ac.jp

STEP 01 What to Prepare

To observe solar radio waves with a BS antenna, you'll need a "BS antenna (one including a converter)," "amplifier," "band pass filter," "detector," and a "tester (direct current voltmeter)."

Conceptual diagram of a BS solar radio telescope. The radio waves collected by the antenna are high frequency, so they are changed into a low frequency signal by the (frequency) converter to make them easier to handle. A converter is integrated into commercial BS antennas. The converted signal is still weak, so next it is passed through the "amplifier (booster)." Next the signal passes through the "band pass filter" and the "detector." Finally, the voltage produced by the detector is measured by the tester. The voltage measured by the tester is proportional to the strength of the radio waves.

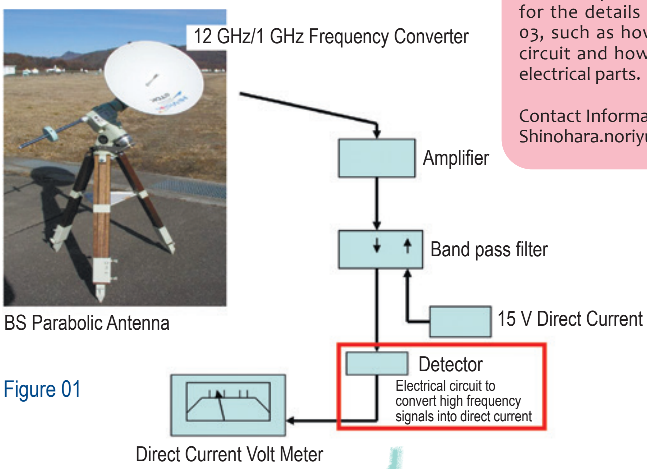


Figure 01

STEP 02 Making the Detector

You can use commercially available parts for the BS antenna, amplifier, band pass filter, and tester. But you can't buy the detector. The detector is a specialized device for converting the magnitude of the wave signal into an easy-to-measure direct-current signal. The structure is straightforward. It's not difficult to make it yourself if you have the necessary electrical components and simple electronics tools. (Note 01)

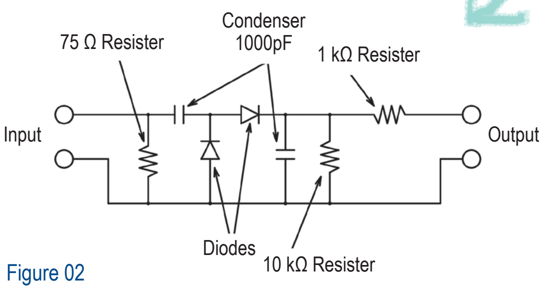


Figure 02

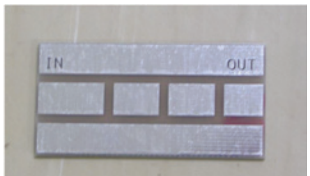


Figure 03

Figure 02 is the electrical diagram for the detector. First make the substrate (Figure 03) and solder each of the components to it.

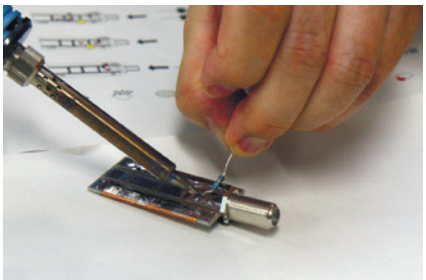


Figure 04) Careful Soldering

Figure 05) The Completed Circuit Board (Note 01)

Figure 06) A BS antenna on an equatorial style mount

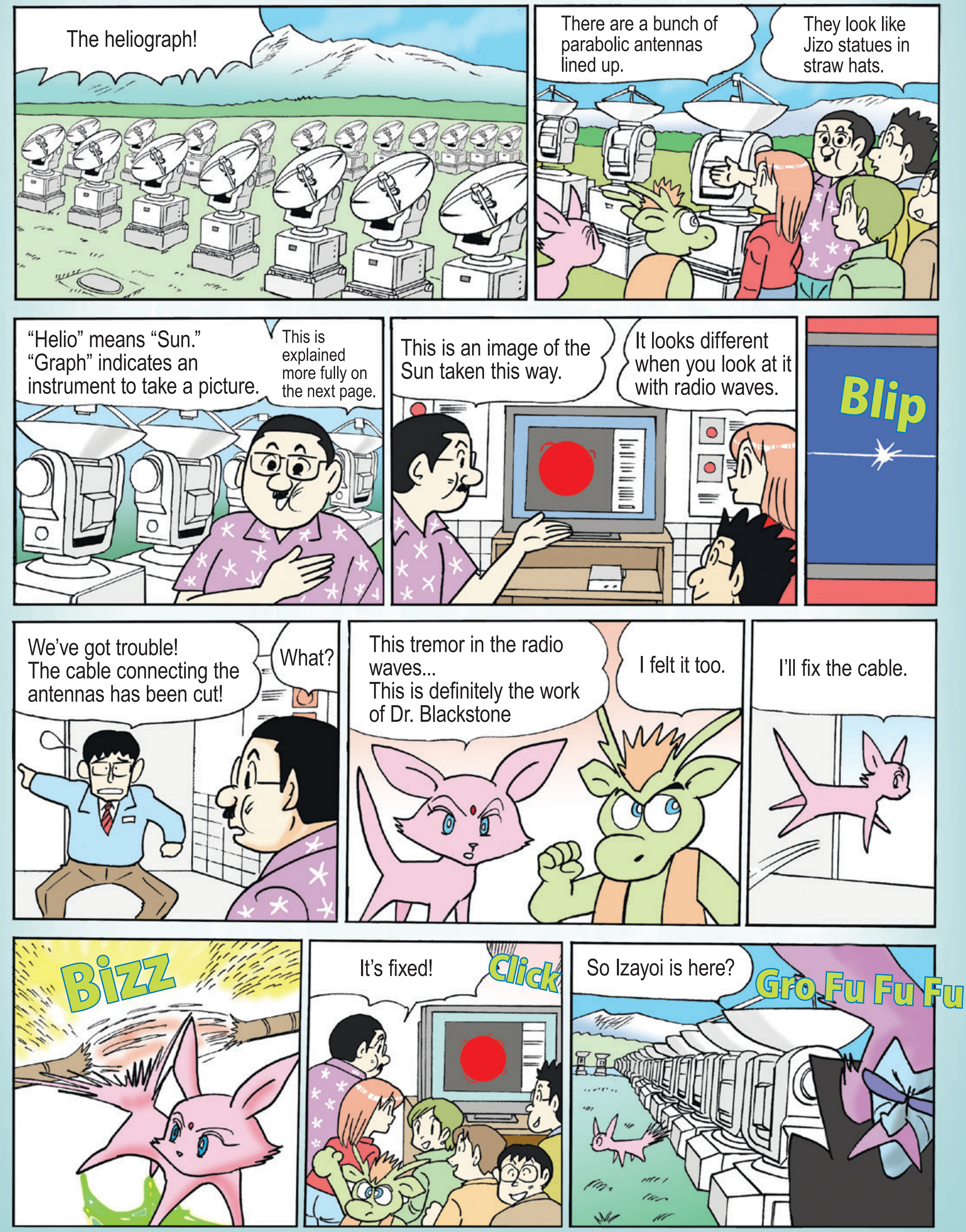
STEP 03 Setting up the Equipment

After making the detector, connect the components to complete the "solar radio telescope." Reception will be easiest if you arrange it so that the BS antenna can track the Sun. For this reason, it's best to use an equatorial style mount. After completing the mounting, you can start observing solar radio waves.

NOTE 1) Before trying observations, you can test whether or not your detector is finished and ready to detect solar radio waves. The test is called "linearity." You can discuss this with a science teacher at a school or science museum

Chapter 4-3: There are so Many Parabolic Antennas! The Heliograph is an Interferometer.

TheNobeyama Radioheliograph observes solar activity through radio waves every day. Suddenly, the image disappears. Is someone up to no-good again?



↑ The heliograph’s observational data is transmitted by fiber optics, not a metallic electrical line. In this interferometer, the time delays due to the observed radio waves arriving at each antenna at slightly different times must be measured with extreme accuracy. (Please refer to page 08.) So fiber optic cables which are insensitive to things like temperature changes are used.

STEP 04 Measuring Solar Radio Waves

First, point the BS antenna at several spots in the sky far away from the Sun and measure the values with the tester. This is observing the conditions at normal locations in the sky (in space!) where there aren't 12 GHz radio sources. After recording these values, next point the BS antenna towards the Sun and measure the value with the tester. If you get a value higher than for the normal sky, you're measuring solar radio waves. When you're fine-tuning the BS antenna pointing, the BS antenna is aimed directly at the Sun when the highest value is measured.

Figure 07) First we measured while pointing at spots far from the Sun. At this time, the tester's readout was "0.598 volts."

Figures 08 & 09) Then the value went up to a maximum of "0.869 volts" when pointing at the Sun. We've caught radio waves from the Sun.

STEP 05 (Advanced Course)

Were you able to catch radio waves from the Sun? Actually, based on that observational data, with a little more work, you can calculate the temperature of the Sun. We'll introduce that observational method in the next installment.

•Nobeyama Solar Radio Observatory

Nobeyama Solar Radio Observatory and NAOJ's Nobeyama Radio Observatory are located in the Nobeyama highlands in Nagano Prefecture. The Nobeyama 45-m Radio Telescope and the Nobeyama Millimeter Array, composed of 6 antennas with 10 m diameters, belong to Nobeyama Radio Observatory. The 8 parabolic Polarimeter antennas and the Nobeyama Radioheliograph, employing 84 antennas with 80 cm diameters, are part of Nobeyama Solar Radio Observatory.

To investigate the state of solar activity, the Polarimeter observes the strengths and orientations (known as polarizations) of 7 frequencies of radio waves coming from the full solar disk. The 3.75 GHz frequency observations have continued for over 60 years, accumulating valuable data for the study of changes in solar activity over long time periods.

The Nobeyama Radioheliograph is also a radio telescope specializing in solar observations. Its 84 parabolic antennas are arranged in a "T" shape 490 m from east to west and 220 m from north to south. By combining the receiver data obtained by these antennas, it acts like a single giant virtual antenna. Mechanisms like this, combining multiple antennas, are called radio interferometers. Actually, the Nobeyama Radioheliograph obtains images of the solar disk with a resolution equivalent to that of an antenna with a 330 m diameter. Moreover, through high-speed digital data processing, it can generate images of the Sun at up to 20 frames per second. (Please refer to page 03, Figure 02c.) Therefore it is also possible to precisely record rapidly changing phenomena in high time resolution.

Figure 10) The Nobeyama Radioheliograph in Nobeyama Solar Radio Observatory. The large parabolic antenna in the background is the Nobeyama 45-m Radio Telescope of Nobeyama Radio Observatory.

•The Principle of a Radio Interferometry

In the case of radio interferometers, "interference" is a physics term describing the phenomenon where 2 (or more) waves meet and strengthen and/or weaken each other. Since radio waves are a type of wave, interference occurs when 2 waves meet.

An interferometer is a device that uses this wave interference to dramatically improve the capabilities of a radio telescope. The actual principles behind an interferometer are fairly complex, but a general outline is explained as simply as possible on the next page.

Figure 11) The Polarimeter and Prof. Shibasaki Kiyoto of Nobeyama Radio Observatory.

What a Radio Interferometer Can Do• Part 1.
Accurately Determine the Location of a Celestial Object and Improve Resolution

You need at least 2 antennas to create a radio interferometer. First arrange the 2 antennas, Antenna A and Antenna B, with a distance separating them; point them both at the same celestial object and receive the radio waves coming from that object. In this arrangement, the distance from the object to each antenna is slightly different. Therefore the radio waves emitted by the object will arrive slightly later at the antenna which is farther away.

The waveforms of the radio waves from the object received by the 2 antennas are recorded as data.
For example, if we delay the data from the antenna closer to the object by a small amount of time, the waveforms line up; in other words ‘interference’ occurs. So we search for where the overlapping waves are the strongest. In this way, we can learn the time delay between the radio waves received by the 2 antennas (Figure 12). By doing this, we can determine the length of side C. If we’ve accurately measured the distance D between the antennas, then the angle E can be computed with extreme accuracy. Using this technique with sufficiently separated antennas, it becomes possible to distinguish between radio waves from 2 closely spaced sources. That is to say, we can attain high resolution.

With only 1 pair of antennas, we can only know the angle in 1 direction. But if we measure using multiple antennas arrayed in different positions, we can measure a celestial object’s position with higher accuracy.

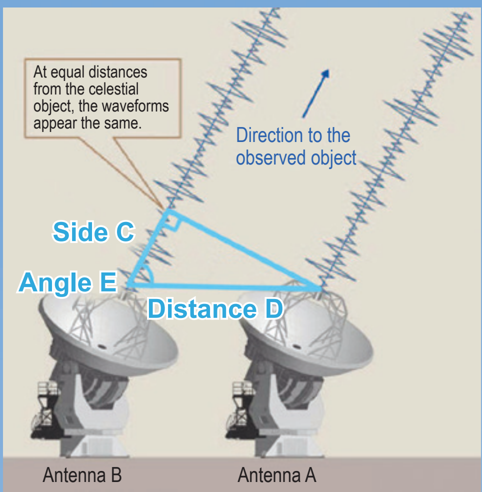


Figure 12) The Principle of a Radio Interferometer

What a Radio Interferometer Can Do•Part 2
Capture a 2 Dimensional Image of a Celestial Object

Another important feature of a radio interferometer is the ability to capture an image of a celestial object. By causing the celestial radio waves received simultaneously by 2 parabolic antennas set up at a distance to interfere, a striped pattern known as interference fringes appears. This pattern is known to be the “Fourier transform of the strength of the radio waves from a celestial object.”

“Fourier transform” is a type of mathematical analysis. Here we’ll omit the detailed explanation, but from this interference pattern it is possible to work backwards to determine the appearance of the celestial object. In other words, we can draw a picture of the object. Moreover, if there are more parabolic antennas arrayed over a wider area, then we can draw a clearer, high-accuracy, low-noise image of the object.

However, an interference fringe pattern can only be obtained by 2 antennas working as a pair. For this reason, when using many parabolic antennas, we make a series of many different pairs and observe the resulting interference patterns. Then based on all of those patterns, we conduct calculations to draw an image of the celestial object. A device known as a correlator fulfills this role. To improve correlator performance we need a computer with extremely high processing speed. One of the main differences between a radio interferometer and an optical telescope or a radio telescope observing with a single antenna, is that the interferometer requires not just a detection system composed of multiple antennas and receivers, but also a giant electronics system consisting of computers and software for high performance data processing to provide back-end support.

Special thanks to Kiyoto and Shinohara. Also shown are Hiramatsu (left) and Fujii (front).

ALMAr’s Adventure 04
Publication date: March 1, 2015
Published by: NAOJ, Public Relations Center, Publications Office
Production assistance: Nobeyama Radio Observatory

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