

# Astronomy beyond the visible

**Beatriz García, Ricardo Moreno**

International Astronomical Union, National Technological University (Mendoza, Argentina), Retamar School (Madrid, Spain)

## Summary

Celestial objects radiate in many wavelengths of the electromagnetic spectrum, but the human eye only distinguishes a very small part: the visible region.

There are ways to demonstrate the existence of these forms of electromagnetic radiation that we do not see through simple experiments. In this presentation, you will be introduced to observations beyond what is observable with a telescope that can be used in a primary or secondary school.

## Goals

This activity aims to show certain phenomena beyond what may be observable with amateur telescopes, such as the existence of:

- Celestial bodies that emit electromagnetic energy that our eye can not detect. Astronomers are interested in these other wavelengths because visible radiation alone does not offer a complete picture of the Universe.
- Visible emissions in the regions of radio waves, infrared, ultraviolet, microwave and X-rays.

## Electromagnetic spectrum

Electromagnetic waves cover a wide range of frequencies or wavelengths and can be classified by their main source of production. The classification does not have precise boundaries. The set of all wavelengths is called the electromagnetic spectrum.

Figure 1 shows the different regions of the spectrum with its various regions. It indicates the size between wave crests (wavelength  $\lambda$ ) and some objects of these sizes: atoms, flies, mountains ... to get an idea of the waves' sizes. In the same figure we can appreciate how we "see" the Sun and Saturn if observed them at wavelengths that our eyes can not detect. These photographs were made with special detectors sensitive to these wavelengths.

In the Universe, there is material that is much lower temperatures than the stars, for example, clouds of interstellar material. These clouds do not emit visible radiation, but can be detected at long wavelengths such as infrared, microwaves and radio waves. Observing the Universe in all regions of the electromagnetic spectrum, which astronomers call "multi-wavelength observation", gives us a much clearer picture of its structure, temperature and energy and

make more realistic models related to their evolution.

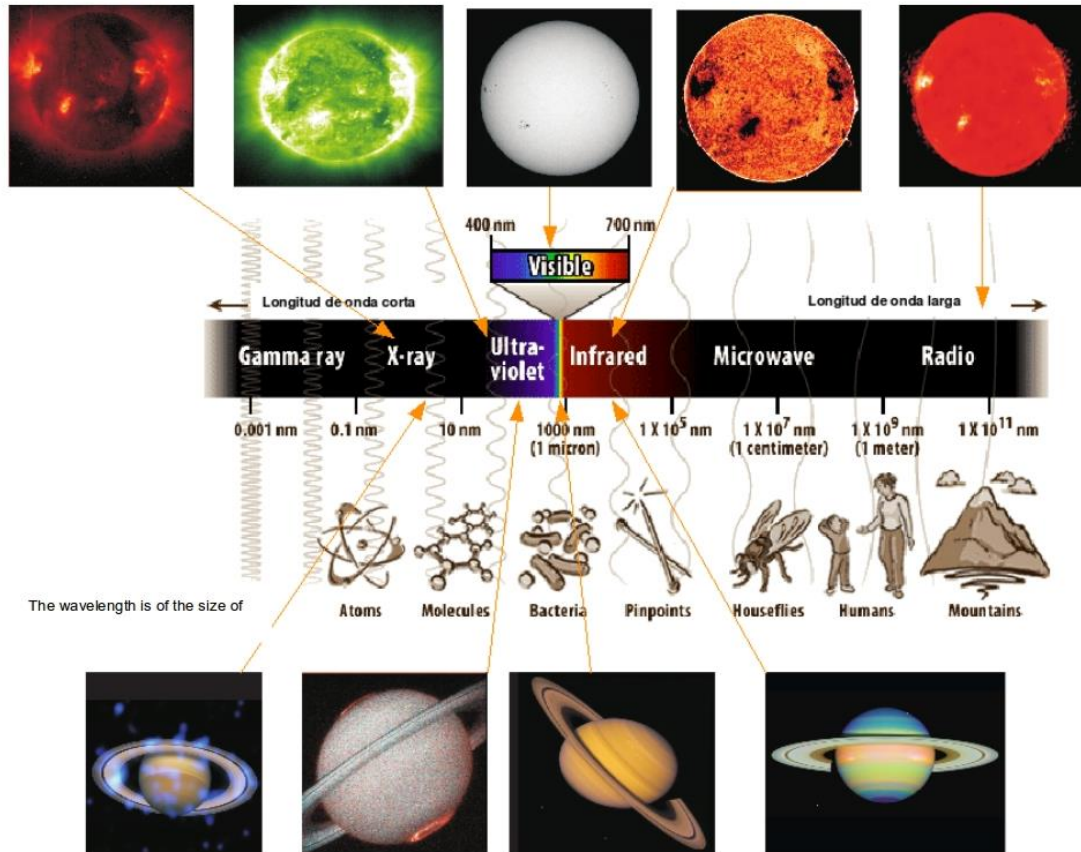


Fig. 1: Electromagnetic spectrum, with objects the size of these waves. The Sun (above) and Saturn (bottom) observed at different wavelengths (colors are simulated).



Fig. 2: The center of our Milky Way Galaxy imaged at different wavelengths

Figure 2 shows the center of our Milky Way Galaxy imaged by Spitzer space telescopes (infrared), Hubble (in visible) and Chandra (X-ray). In each of these we observed objects and details that are not visible in other wavelengths.

## Activity 1: Building a Spectrometer

The white light from a bulb with a filament is composed of all colors while the light from bulbs that are gas (fluorescent tubes, energy-saving lamps, or street lamps) is composed of only certain colors. If we separate the colors of light, we obtain its spectrum, which in the case of gases consists of a set of colored lines. Each type of gas has its own spectrum, which is the "barcode" of the compounds in the gas. If we look with a spectroscope at the light of a distant galaxy, the lines characteristic of hydrogen and other gases are displaced toward the red (known as a "redshift"), with a greater displacement the farther away the galaxy is.

With strong scissors, cut pieces from a CD or DVD (figure 3a) that does not have a label. If you use a DVD, separate the upper layer from the bottom in the cut piece of plastic (you may need the scissors or a screwdriver to help) and you will have prepared the diffraction grating. If you use a CD, there is only one layer of plastic, and you must detach the metal layer with care. A craft knife or razor blade will be helpful.

Make a photocopy of the template in figure 4. If you do it at A3 size, it will be more accurate. Cut out the template, including the white part, the curved section, and make a thin slit in the flap with the scale. You do not need to cut out the scale. Assemble the box, putting the black on the inside, and paste the flaps. In the hole left by the curved section, paste the piece of CD or DVD.

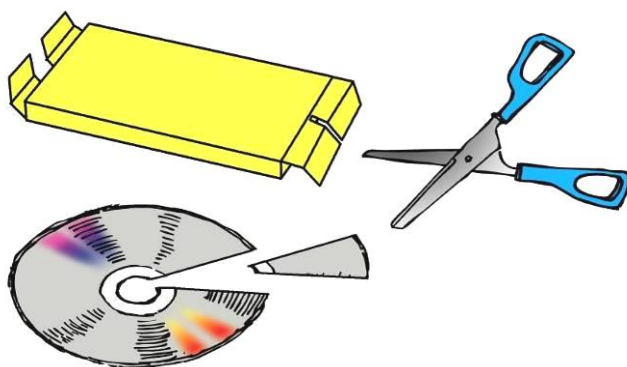


Fig. 3a: Material that you will need: DVD, scissors and paper box.



Fig. 3b: Removing the metal layer of the CD, with tape.

Look through the piece of DVD and aim the slit of the box (not the scale) at a low energy lamp or a fluorescent tube (figure 11). You should see the emission lines from the gases in the bulbs on the scale. If you do not see at first, move the slit back and forth until the lines appear. The scale is labeled in hundreds of nanometers, ie, the mark 5 shows 500 nm ( $500 \times 10^{-9}$  m). The narrower the slit is, the more accurately you can measure the wavelength of the lines.



Fig. 4: Looking at a fluorescent lamp.

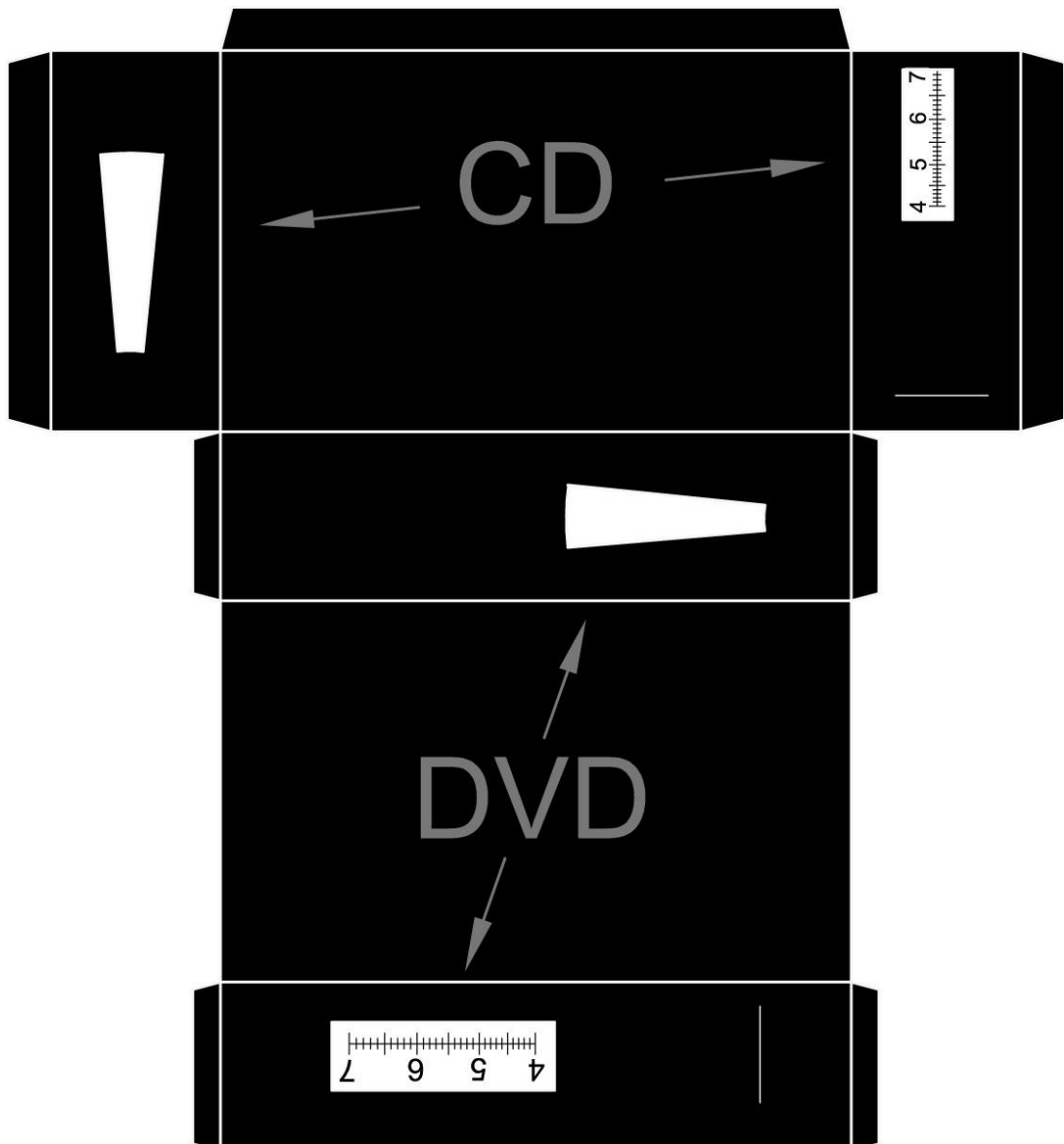


Fig. 5. Template for the spectrometer.

You can also make the box with cardboard, but if you do, you will need cut out the space for the scale and paste a paper copy over it so you will be able to see through the scale.

You can observe street lamps; both the orange (sodium) and white (mercury vapor) will work. Traditional incandescent bulbs produce a continuous spectrum.

Younger students can decompose the light and make a rainbow. Use a water hose with diffuser, and put the Sun behind (figure 6).



Fig. 6: Younger students can decompose the light into a rainbow

## The infrared

The infrared region of the electromagnetic spectrum was discovered by William Herschel (the discoverer of the planet Uranus) in 1800 using a prism and a thermometer. He obtained a spectrum by passing the white sunlight through a prism and placed several thermometers, one in the blue region, another in the red one (both colors detected by the eye) and a third thermometer placed beyond red, immediately thereafter. With a fourth thermometer measured the temperature of the environment and found that the temperature that registered the thermometer in the area "below" the red (hence the name "infra" red) was greater than that of the environment.

Herschel did other experiments with "heat rays" (as he called them) that existed beyond the red region of the spectrum showing that they were reflected, refracted, absorbed and transmitted just like visible light. These "heat rays" were later called infrared rays or infrared radiation. These discoveries were followed by others that resulted in several technological applications.

The bodies found at low temperature do not emit in the visible region of the spectrum, but in longer lengths so that the energy released is lower. For example, our body and animals emit infrared radiation that we can not detect with the unaided eye but which is perceived as heat emitted by the body. All objects that are at a certain temperature emit infrared (figures 6 and 7). Night vision goggles allow one to detect this radiation that eye can not.

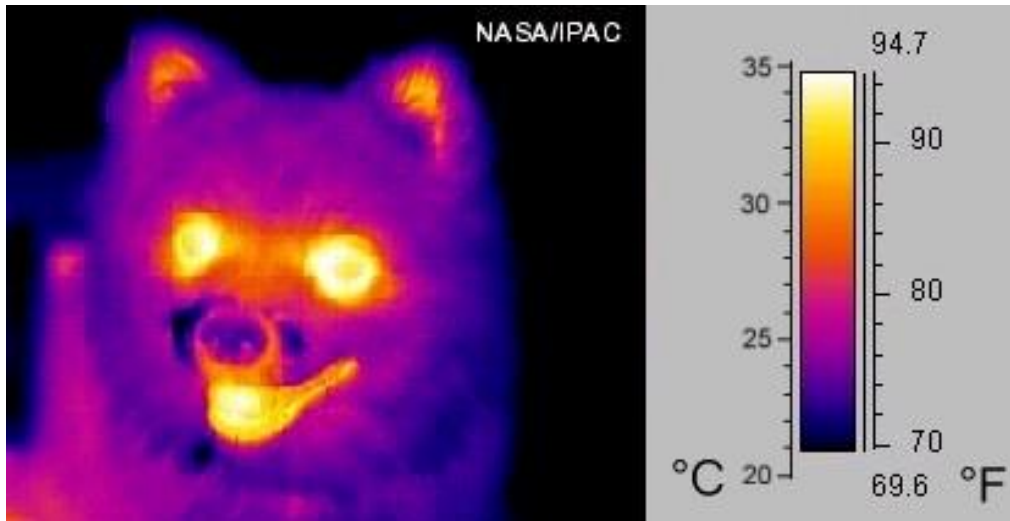


Fig. 7: Infrared photo. We distinguish hotter to cooler areas.

## Activity 2: Herschel Experiment in the IR band

The goal is to repeat the experiment of 1800, by which the famous astronomer Sir William Herschel discovered a form of radiation other than visible light. We will need a glass prism, four thermometers, black permanent marker ink, scissors, tape, a cardboard box and a white sheet. We put tape on the bulbs of thermometers and paint with black marker to absorb heat better.

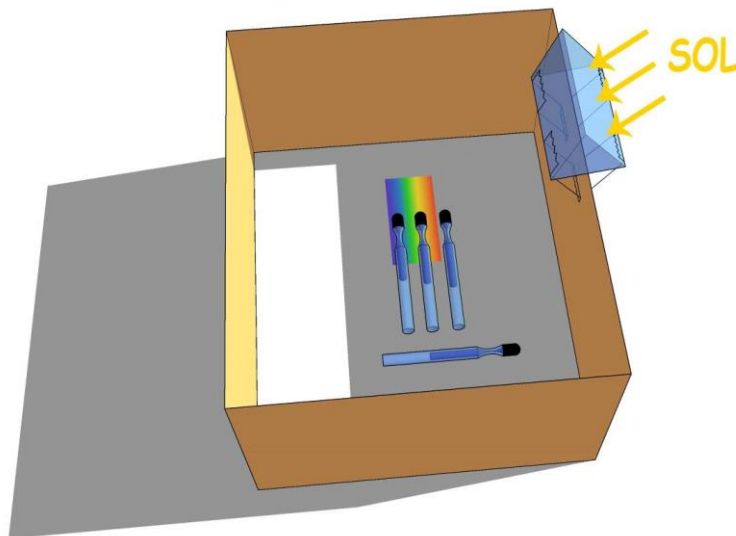


Fig. 8: Herschel device. The three thermometers in the spectrum mark higher temperature than the environment.

The experiment should be performed outdoors, in a VERY sunny. If windy, the experience can be inside, provided you have a window where the sunlight enters directly. Place a white sheet at the bottom of the carton box. The prism is placed carefully on the top edge of the box, so that it is the side of the Sun. Inside the box should be everything or almost everything in

shadow (figures 8 to 9c). Rotate the prism carefully until a spectrum appears as wide as possible on the sheet at the bottom of the box.

After securing the prism with the tape in that position, place the three thermometers in the light spectrum, so that each bulb is in one color: one in the blue region, the other in the yellow and the third a little more beyond the visible red region. It should help see the graduated scale, not to move the thermometer when we take action. (figures 15 to 16c).



Fig.9a: Placing the three thermometers, with the black bulb, and the spectrum in the shadow part.

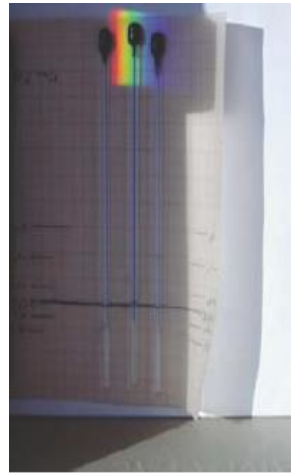


Fig.9b: Thermometers in blue, in yellow and in red right after.

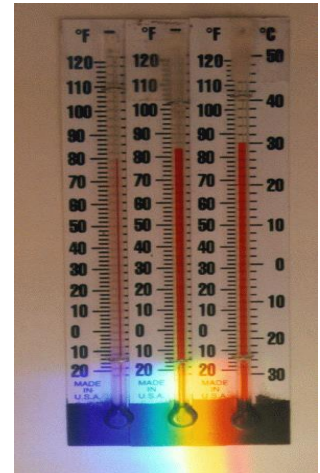


Fig.9c: An example of the measures in 3 minutes. (www.spitzer.caltech.edu)

Temperatures take five minutes to reach their final values. We record temperatures every minute in the table (see Table 1) for each of the three regions of the spectrum and the environment. We must not move thermometers from their positions in the spectrum or block their light.

The thermometer in the yellow (figure 16c) should show a temperature somewhat higher than in the blue, and the one that is near the red should show a temperature still slightly higher, so it is logical that in the thermometer next to the red arrives some kind of radiation from the Sun, invisible to our eyes.

	Thermometer nº 1 in the blue	Thermometer nº 2 in the yellow	Thermometer nº 3 beyond red	Thermometer nº 4 in shadow
After 1 minute				
After 2 minutes				
After 3 minutes				
After 4 minutes				
After 5 minutes				

Table 1: Table of the data

### Activity 3: Detection of the IR with a modern technological tool

If we want to detect the IR with modern technological tools, probably the first thing that comes to mind are the night sights, prepared to see the infrared emitted by our bodies. But that is not a remedy available to anyone. Consider a more economical and easy to get device.

Remote controls we use to turn on the TV, the stereo, or the microwave use infrared (do not use those that also have a red bulb). Will be there an easy way to see that non-visible radiation and it suddenly becomes detectable?

For that we must seek a detector sensitive to IR. There is a major technological product, which is due to development of the study of light in Astronomy, called CCD (as the initials of its name: Charged Coupled Device). This device can capture and collect photons over a determined period of time, so that we can detect objects that emit or reflect light. The CCD is more sensitive in the red region and, in some cases their efficiency range covers the near IR. Any modern camera or camcorder has a CCD for image acquisition. This enables taking pictures in conditions of very low level of illumination. The simplest arrangement, of everyday use, which has a modern camera and therefore a CCD detector, is the mobile phone.



Fig. 10a: Remote activated naked eye.



Fig. 10b Remote activated by mobile phone.

Looking at the remote control with our eyes directly, we don't notice any difference between on and off, as in figure 10a. But if we take the photo with the same mobile phone, and remote control activated (figure 10b) ... Surprise! The device that uses the control to send the signal that turns on the television or other electronic equipment is an infrared light that our eye does not see but the phone camera does. The color of this light is false.



## Activity 4. Detection of the infrared light of a bulb

Most of the bodies of the sky emit many wavelengths. If between them and us there is dust or gas, some wavelengths can be blocked, but not others. For example, dust in the center of our galaxy prevents us from seeing the intense visible light produced by the concentration of millions of stars there. If however the dust is transparent to infrared light that gets through it and reach us. The same applies to other dark dust clouds in our galaxy (figures 11a and 11b).



Fig. 11a: Cloud of dust in the visible region

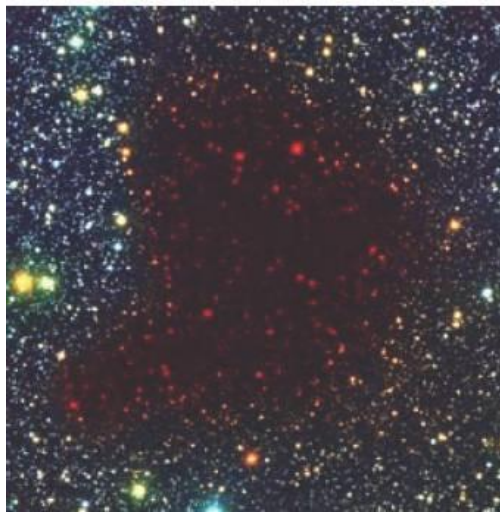


Fig. 11b: By overlaying the infrared vision

In the emissions from an incandescent filament bulb, most energy is emitted in the visible region, but also emits in the infrared. Infrared radiation can pass through things that are opaque in the visible.

Let us take a flashlight and a cloth of felt (figure 12a and 12b). This material is not particularly well-woven and blocks visible light. Let us in a dark room and light the flashlight. Then we cover it with the felt and prove that we not see its light. If not, put another layer of felt (you can double) or even a third. Do not put more than necessary, because the infrared radiation can also be blocked if there is too much material. In that room as dark as possible, if we observe with a camera on our mobile phone, which captures the infrared radiation, we see that it distinguishes the bulb (figures 12a and 12b).



Fig. 12a and 12b: Felt completely blocks visible light but not infrared.

## Activity 5: Constellation with infrared

In electronics stores or online, you may purchase infrared **LEDs**, similar to those used by remote controls TV, music devices, etc.. They are very cheap (about 0.2 euros or dollars). They operate with a stack of 3 or 9V batteries, or with a DC power supply. They are connected in parallel with a resistance between 100 and 500  $\Omega$ .

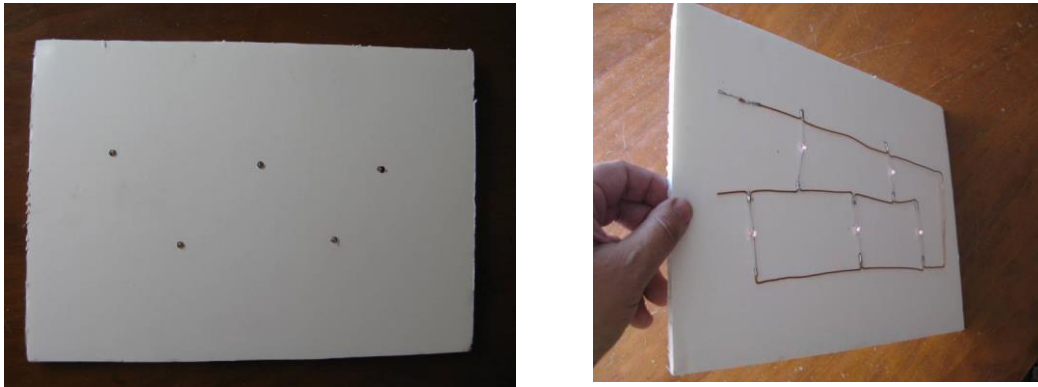


Fig. 13a and 13b: Cassiopea made with infrared leds. They are connected in parallel .

You can make a small circuit with multiple LEDs, forming a well-known constellation, for example Cassiopea (figures 13a and 13b), Orion, the Southern Cross or Ursa Major (depending on the constellations you see from the hemisphere in which you live). Observed with a phone camera, you can see it in the infrared.

## Activity 6. Constellation with remote controls

An easier demonstration than the previous one is to form a “constellation” using several infrared remote controls. If the remote controls are imaged in the dark with a digital camera, you can see the constellation (figures 14a and 14b).

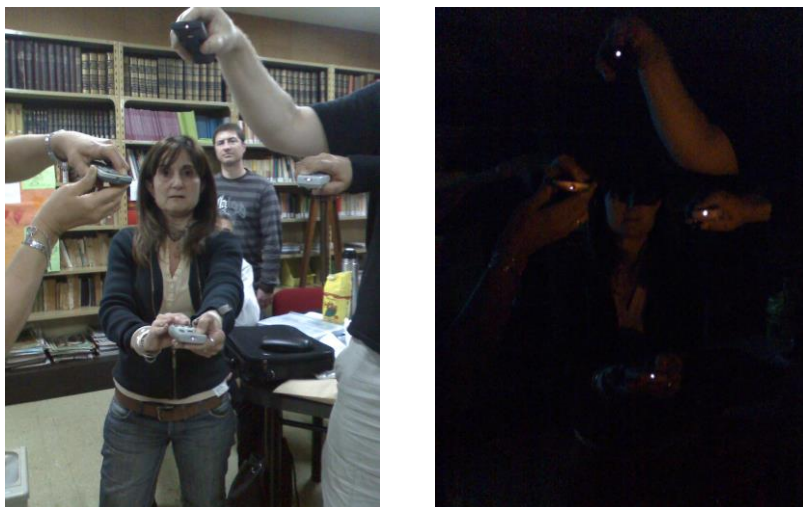


Fig. 14a and 14b: Making the Southern Cross constellation with remote controls

## Electromagnetic energy in the radio region

Electromagnetic radiation with wavelengths from meters to kilometers are called radio waves. They are used on commercial stations, but also reach us from space. These radiations show morphologies that other wavelengths do not (figures , 15a, 15b and 15c).

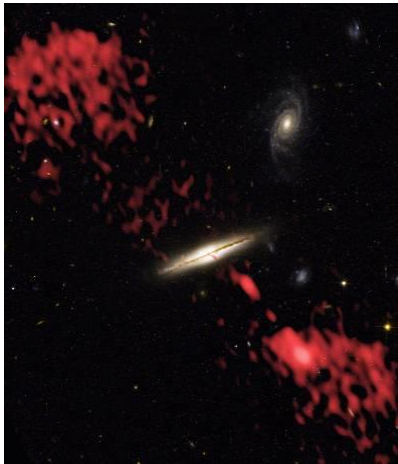


Fig. 15a: This galaxy emits jets only detectable in radio (artificially colored red).

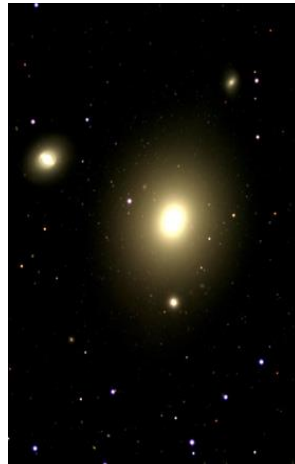


Fig. 15b: Photograph of the galaxy NGC 4261 in the visible.

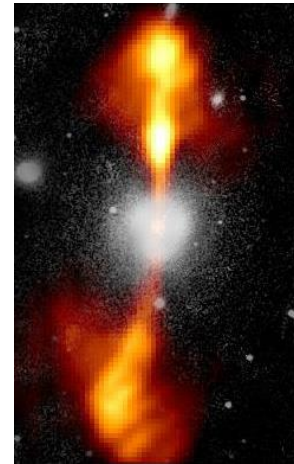


Fig. 15 c: The same galaxy with the radio image superimposed. There are a few jets of matter artificially colored red.

In the Universe there are many strong radio sources such as the center of our galaxy, neutron stars in rapid rotation, or even some planets like Jupiter.

### Activity 7: Producing radio waves

When you open and close an electric circuit, there are radio waves, similar to commercial broadcasting. You can capture them in a radio in the AM band, and transform them into sound, which is another type of waves. The power of these radio emissions decreases when the receptor moves away. Radio waves can pass through obstacles and even walls.

To perform the experiment, we take two pieces of wire about 20 cm each one. We removed the plastic at the two ends of one of the pieces. In the another cable, also remove the plastic at one end and leave about 10 cm with plastic; remove the plastic in the rest. In the end where there is plenty of bare wire, make him a ball. Plug the other end to a terminal of a battery of 9V. We use a pencil with a tip at each end. We will use the graphite to make a source of radio radiation. On one end connect the tip to the first piece of wire, securing it with tape. The other end is connected to the second terminal of the battery (figure 16).

Turn on the radio and put it in the AM band (not FM). We hit with the free end of the pencil to the ball of wire. We move the line of the radio until you can hear on the radio that we are tapping the ball. We can try to move away the radio, to put obstacles of cardboard, wood, etc.

We can also take the radio to another room and see if you hear or not. Take into account that the electromagnetic energy is transformed first into electric energy and after in sound.



Fig. 16: Producing radio waves.

## Ultraviolet Light

The ultraviolet photons have more energy than those of normal visible light. This allows this radiation, in high doses, to destroy chemical bonds of organic molecules, so that is deadly to life. In fact it is used to sterilize surgical equipment.

The Sun emits this radiation, but fortunately our atmosphere (particularly ozone) filters the most of it, and some is beneficial for life. This radiation is what makes our skin tan (although too much can cause skin cancer), is absorbed by plants for photosynthesis, and so on. But if the ozone layer decreases its thickness, Earth would receive too high a dose and cancer-type diseases would increase.

## Activity 8: Black light (UV)

There are bulbs called black light that emit mostly in UV and are often used to support the growth of plants in greenhouses or in areas with little sunlight. The glass of these lamps is often almost black, and emits only a bit of dark blue visible light. Some synthetic fabrics white shirts (especially shirts washed with "whitening agents" fluoresce with this light and reflect it in a bright purple. That's why this type of lighting is used in some discos, where white tissues turn aglimmer.

property is also used to manufacture the paper of many currency notes: examine the small strips of fluorescent material which are visible when illuminated by UV light (figure 17). Thus it is proved that it is not a simple photocopy of the note. This light is built into the counterfeit detection devices (figure 18). Many official cards have marks or signs that are visible only under UV light.



Fig. 17: A note of 50 € illuminated with UV light, shows small fluorescent strips marked here by arrows.



Fig. 18: Counterfeit Detector, which uses ultraviolet light

## X-Ray

More energetic than UV is the X-ray radiation. It is used in medicine in the radiographs and other forms of diagnostic radiology (figure 19a).

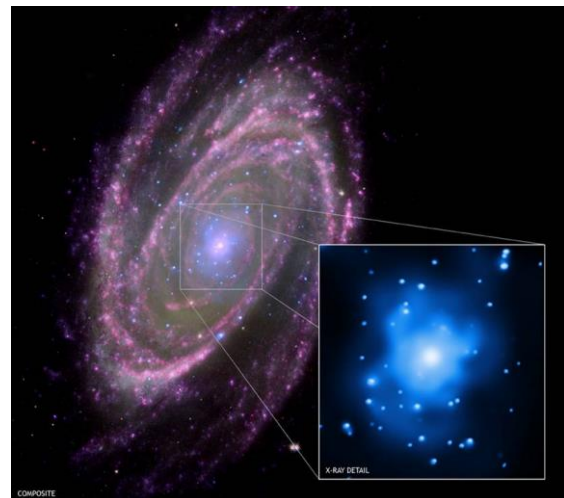


Fig. 19a: X-rays used in medicine. Fig. 19b: Galaxy M81 with the core photographed in X-ray, suggesting the presence of a very massive black hole

In the cosmos, X-rays are characteristic of very energetic events and objects: black holes, quasars, supernovae, etc.. The Chandra space telescope's mission is the detection and monitoring of these objects (figure 19b).

## Gamma Rays

At the end of the spectrum, with wavelengths even shorter than X-rays is gamma ray radiation. It is the most energetic radiation and it is produced when matter (an electron) find antimatter (a positron). In the cosmos there are various sources (figure 20a), and it is not

unusual to detect occasional violent eruptions which emit a powerful blast of gamma rays for a few minutes or hours.

As they are so short, the problem is to detect them and define their exact location to know what object is producing the radiation. Objects such as Active Galactic Nuclei, pulsars, and supernovae have been identified as gamma ray sources.

On Earth, this radiation is emitted by most of the radioactive elements. Like the X-rays, they are used both in medical imaging (figure 20b) and therapies to cure diseases like cancer.

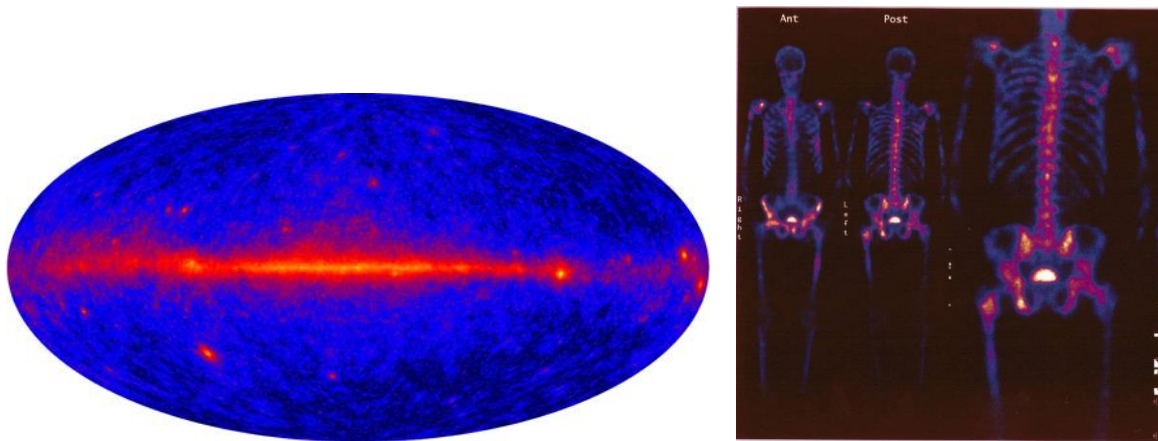


Fig. 20a: Map of the Universe as seen by the "Fermi Gamma-ray Space Telescope". The center line is our galaxy. Fig. 20b: Bone scan with gamma of the human body

## Bibliography

- Mignone, C., Barnes, R., More than meets the eye: how space telescopes see beyond the rainbow, Science in the School, Eiro Forum, 2014
- Moreno, R, *Experimentos para todas las edades*, Ed. Rialp. Madrid 2008.

## Internet sources

- Spitzer Telescope, Educacion, California Intitute of Technology. <http://www.spitzer.caltech.edu/espanol/edu/index.shtml>
- [http://www.scienceinschool.org/2014/issue29/EM\\_Astronomy](http://www.scienceinschool.org/2014/issue29/EM_Astronomy)
- <https://www.khanacademy.org/science/cosmology-and-astronomy/universe-scale-topic/light-fundamental-forces/v/introduction-to-light>
- Chandra X-ray Observatory <http://chandra.harvard.edu/about/>
- The Fermi Gamma-ray Space Telescope <http://fermi.gsfc.nasa.gov/>