

Astronomy beyond the visible

Beatriz García, Ricardo Moreno, Rosa M. Ros

International Astronomical Union, National Technological University (Mendoza, Argentina), Retamar School (Madrid, Spain), Technical University of Catalonia (Barcelona, 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:

- Gravitational lenses
- 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.

Gravitational lenses

Light always follows the shortest possible path between two points. But if a mass is present, then space is curved and the shortest possible path is a curve as seen in figure 1a. This idea is not difficult for students. We can easily show it on a terrestrial globe (figure 1c). Obviously they can understand that on the surface of the Earth the distance between two points always follows a curve.



Fig. 1a and 1b: If the space is curved, the shortest path between two points is a curve.



Fig. 1c: The shortest path above the terrestrial surface is not a straight line.

In general, we can imagine a gravitational lens as an ordinary lens, but in which the deflection of light is produced by a large mass that is in the path of the light, called deflector (figure 2a).

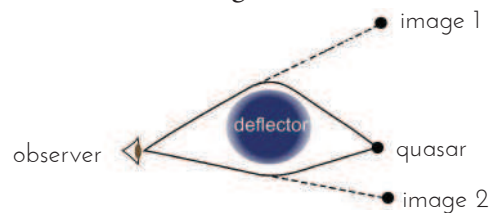


Fig. 2a: The observer sees two images, because it appears as though the light is coming from two different places.



Fig. 2b: Picture of the double quasar Q0957+561 image. The deflector is the galaxy close to the B component.

Gravitational lenses produce a curvature in the beams of light that are emitted by astronomical objects. If these objects are point sources (stars or quasars), they appear to be in a different place from where they actually are, or sometimes even multiple images of the object are produced (figure 2b). If the emitting objects are extended (e.g., galaxies), the images appear distorted as bright arcs (figures 3a, 3b and 3c).

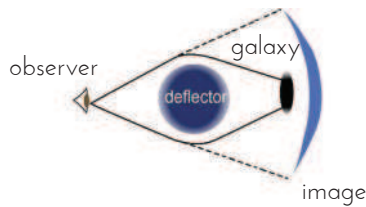


Fig. 3a: If the body diverted is an extended object, the images obtained are a set of bright arcs or a complete ring.

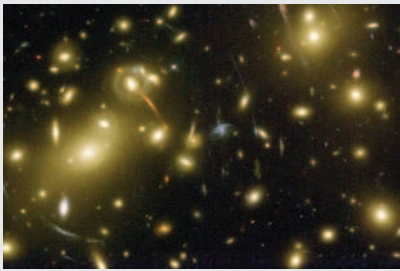


Fig. 3b: Giant luminous arcs formed by the galaxy cluster Abell 2218.

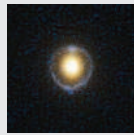


Fig. 3c: Complete ring of a galaxy behind the deflector.

Activity 1: Simulation of gravitational lens with a glass of wine

We can simulate a gravitational lens using a glass of wine. This allows you to “show” how matter can introduce distortions in the images observed.

It is easy to see that this simulation leads to the “distortion of space” that is observed. Simply place the glass on graph paper and look through the white wine (or apple juice). We see the distortion of the graph lines (figures 4a and 4b).



Fig. 4a and 4b: We only can see the distortion of the graph paper if the glass is full.

Now let’s simulate the Einstein ring or multiple images. Take a flashlight, place it on the other side of a glass full of red wine or juice and observe the ray of light passing through it.

Looking at the ray of light, we move it from right to left and from top to bottom. We note that the light produces images repeatedly and in some cases some arches. This is a consequence of the glass acting as a lens that distorts the light trajectory. In particular, we can sometimes see an amorphous figure, or a bright

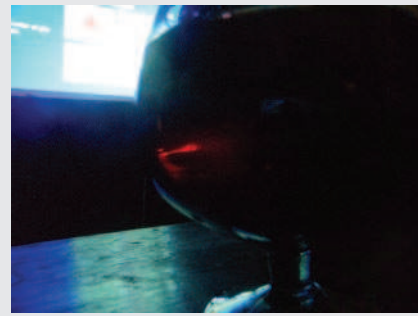


Fig. 5a: The flashlight beam is distorted as an arc between two bright red spots, Fig. 5b: like an amorphous rectangle, and Fig. 5c: the Einstein cross.

red dot, four red dots or a red bow between points (figures 5a, 5b and 5c).

We can also simulate the gravitational lens looking through the glass foot of the wine glass. If we put the foot of the glass on a graph paper and look through it, we can see the deformation of the grid (figure 6).

Moving the foot of the glass slowly from right to left above an object, (e.g., a red circle about 3 cm), we can reproduce the shapes observed through gravitational lenses (figure 7).

Moving the foot of the glass slowly from right to left



Fig. 6: Grid deformation.



Fig. 7a, 7b and 7c: The glass foot can simulate various shapes made by gravitational lenses: arc segments, images of points, and Einstein rings.

above an object, (e.g., a red circle about 3 cm), we can reproduce the shapes observed through gravitational lenses (figures 7a, 7b and 7c).

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 8a shows the different regions of the spectrum with its various regions. It indicates the size between wave crests (wavelength λ 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 Jupiter if observed them at wavelengths that our eyes can not detect. These photographs are 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.

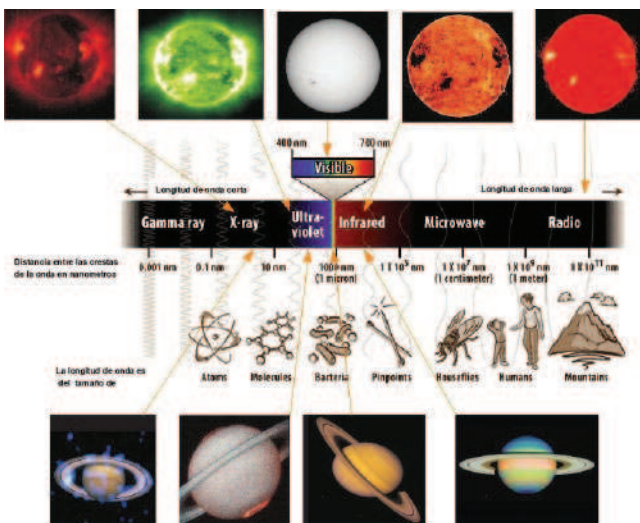


Fig. 8: Electromagnetic spectrum, with objects the size of these waves. The Sun (above) and Saturn (bottom) observed at different wavelengths (colors are simulated).

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.

Figure 9 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.

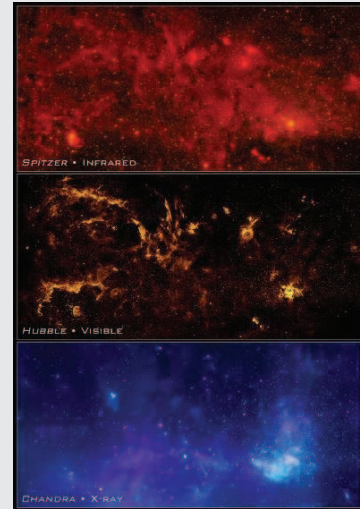


Fig. 9: The center of our Milky Way Galaxy imaged at different wavelengths.

Activity 2: 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 10a) 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 11. 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.

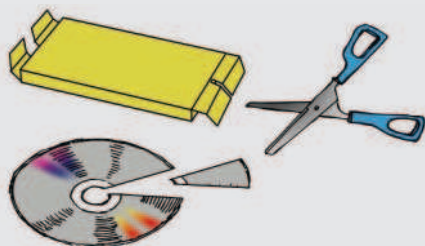


Fig. 10a: Material that you will need: DVD, scissors and paper box.



Fig. 10b: 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 10). 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 ($500 \cdot 10^{-9}$ m). The narrower the slit is, the more accurately you can measure the wavelength of the lines.

You can also make the box with cardboard, but if you do, you will need cut out the space for the scale and



Fig. 11: Looking at a fluorescent lamp.

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 to you (figure 13).



Fig. 13: Younger students can decompose the light into a rainbow.

What is 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.

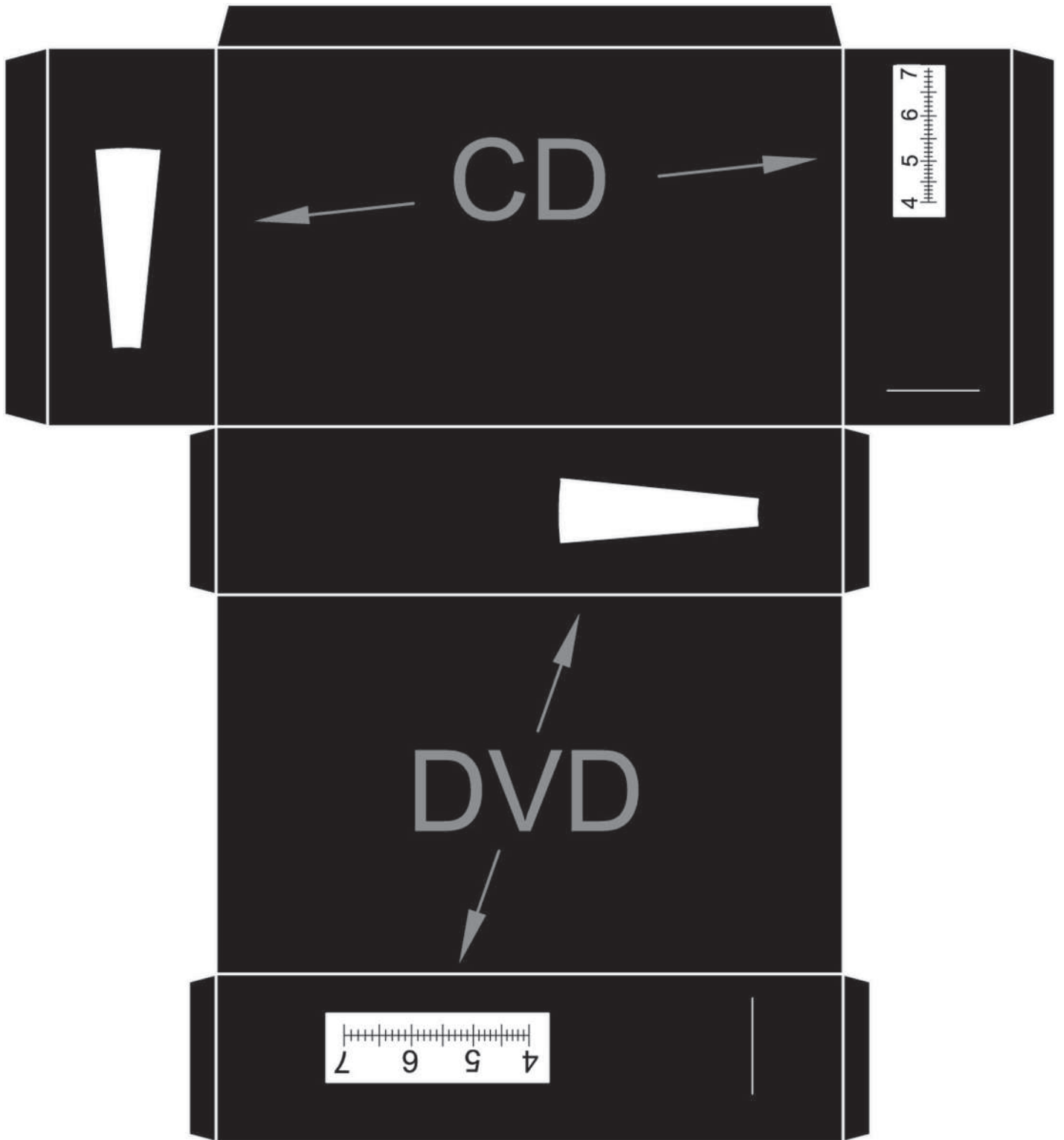


Fig. 12: Template for the spectrometer.

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 13 and 14). Night vision goggles allow one to detect this radiation that eye can not.

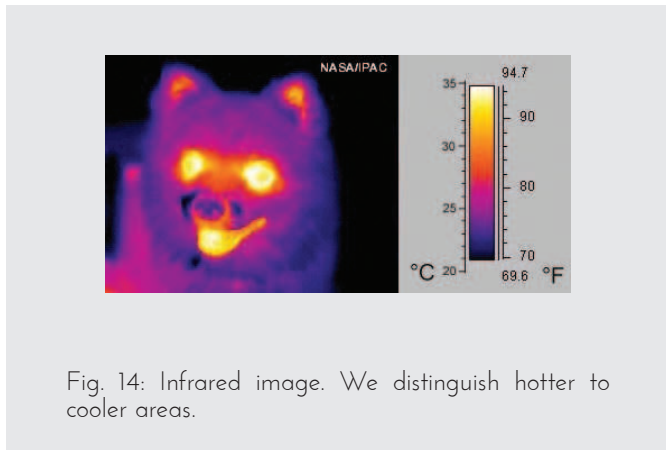


Fig. 14: Infrared image. We distinguish hotter to cooler areas.

Activity 3: 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.

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 15 to 16c). Rotate the prism carefully until a spectrum appears as wide as possible on the sheet at

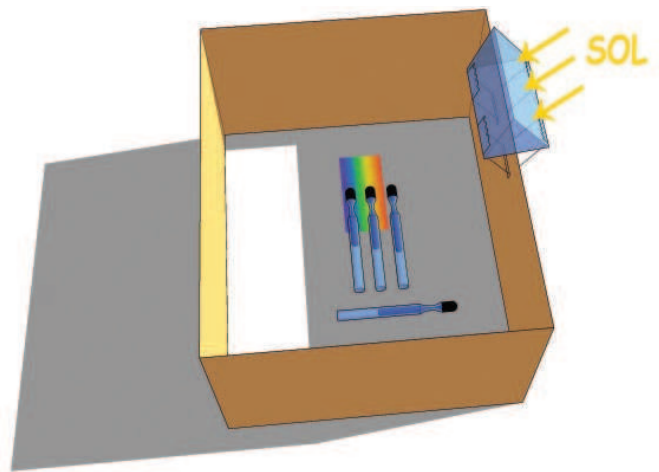


Fig. 15: Herschel device. The three thermometers in the spectrum mark higher temperature than the environment.

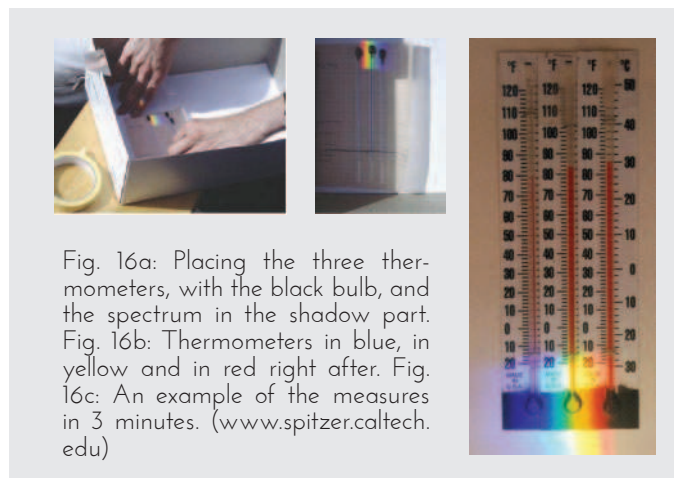


Fig. 16a: Placing the three thermometers, with the black bulb, and the spectrum in the shadow part. Fig. 16b: Thermometers in blue, in yellow and in red right after. Fig. 16c: An example of the measures in 3 minutes. (www.spitzer.caltech.edu)

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).

Temperatures take five minutes to reach their final values. We record temperatures every minute in the table for each of the three regions of the spectrum and the environment. We must not move thermometers from

	Thermometer n° 1 in the blue	Thermometer n° 2 in the yellow	Thermometer n° 3 beyond red	Thermometer n° 4 in shadow
After 1 minute				
After 2 minutes				
After 3 minutes				
After 4 minutes				
After 5 minutes				
After 5 minutes				

Tabla 1: Table of the data.

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.

Activity 4: 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 “see” 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.

Looking at the remote control with our eyes directly, we don't notice any difference between on and off, as



Fig. 17a: Remote activated naked eye. Fig. 17 b: Remote activated by mobile phone.

in figure 17a. But if we take the photo with the same mobile phone, and remote control activated (figure 17b) ... 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.

Activity 5. 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 18a and 18b).

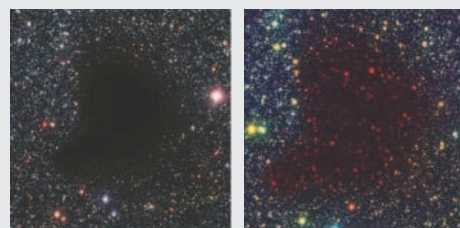


Fig. 18a: Cloud of dust in the visible region. Fig. 18b: By overlaying the infrared vision.

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 23). 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 19a and 19b).



Fig. 19a and 19b: Felt completely blocks visible light but not infrared.

Activity 6: 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 Ω .

You can make a small circuit with multiple LEDs, forming a well-known constellation, for example Casiopea (figures 20a and 20b), 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.

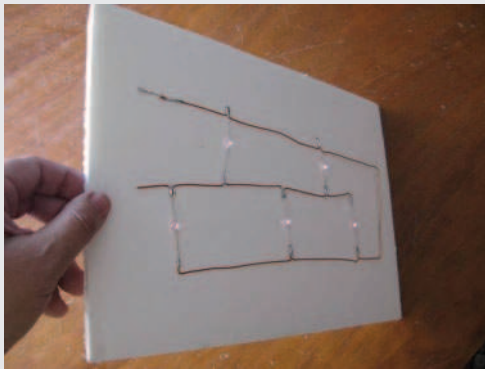
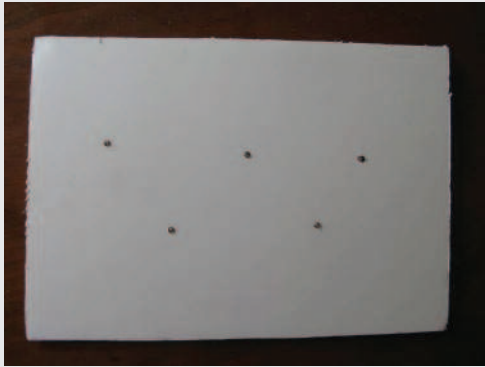


Fig. 20a and 20b: Casiopea made with infrared leds. They are connected in parallel .

Activity 7. 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 21a and 21b).



Fig. 21a and 21 b: Making the Southern Cross constellation with remote controls

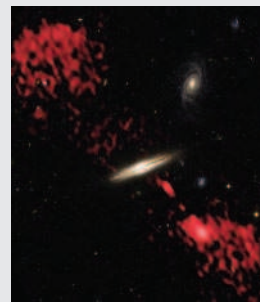


Fig. 22: This galaxy emits jets only detectable in radio (artificially colored red).

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. And they show morphologies that other wavelengths do not (figures 22, 23a and 23b).

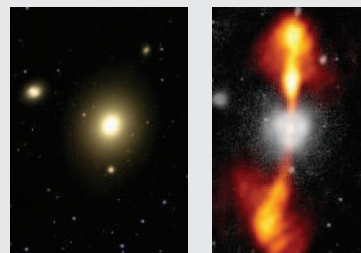


Fig. 23a: Photograph of the galaxy NGC 4261 in the visible. Fig. 23b: The same galaxy with the radio image superimposed. There are a few jets of matter artificially colored red.

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 8: 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 do this, 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 24).

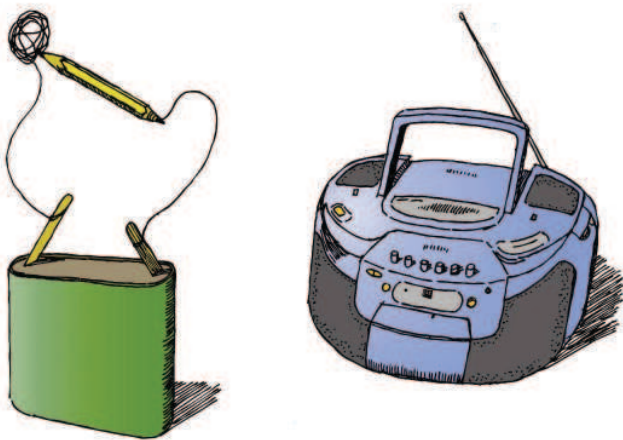


Fig. 24: Producing radio waves.

Turn on the radio and put it in the AM band (not FM). We hit the ball of wire with the free end of the pencil. 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.

Activity 9: Listening to the voice of Jupiter

Jupiter emits radio waves at various frequencies. Its provenance is unclear, but it seems they have to do with its magnetic field and interactions with its moon Io. The broadcast is in the frequency band from 18

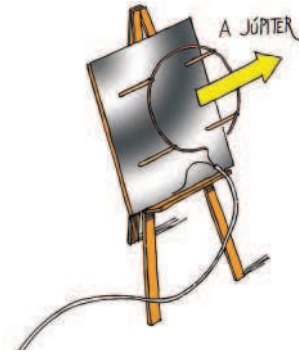


Fig. 25: Antenna to listen to Jupiter.

to 22 MHz, with a maximum at 21 MHz. These values are within the ability of many home receivers. You must have a Short Wave (SW) radio with sufficient range to reach these values.

Jupiter emissions are not continuous. Jupiter has three more or less equally spaced jets that rotate with the planet every ten hours. In addition, these jets are sometimes active and sometimes not, so we should arm ourselves with a good dose of patience.

To hear them take the shortwave radio. Situate the dial somewhere between 18 and 22 MHz where it has not much background noise, and wait. Emissions sound like ocean waves on a beach (or gusts of wind), that reach a frequency of about three per second or so. Its intensity grows up until a maximum that lasts a few minutes, or seconds sometimes, and then decays. Experience says that if you spend 20 minutes listening, you have 1 chance in 6 of hearing them. Of course, Jupiter must be above the horizon, but clouds will not interfere.

The radio antenna itself is adequate, although it is omnidirectional and will capture waves coming from all directions. If we want to improve listening, and also to ensure that the signal proceeds from Jupiter, we must build a directional antenna to replace the radio antenna. This is done as follows: we take 165 cm of copper wire, and make a circle with it, without closing it. We hold it with four sticks 30 cm long. Line a piece of wood of 60 x 60 cm on one side with aluminum foil. We attach to it the circle of copper held by the four sticks. We take a coaxial cable and split it so that we can connect the interior wire to the circle of copper, and the exterior wire to the aluminum. The other end connects to the radio so that you can listen to the output. Finally, we direct our new antenna toward Jupiter.

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 10: 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.

This 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 26). Thus it is proved that it is not a



Fig. 26: A note of 50 illuminated with UV light, shows small fluorescent strips marked here by arrows.



Fig. 27: Counterfeit Detector, which uses ultraviolet light.

simple photocopy of the note. This light is built into the counterfeit detection devices (figure 27). Many official cards have marks or signs that are visible only under UV 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 28).



Fig. 28: X-rays used in medicine.

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 29).



Fig. 29: Galaxy M81 with the core photographed in X-ray, suggesting the presence of a very massive black hole.

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. In the cosmos there are various sources (figure 30), and it is not unusual to detect occasional violent eruptions which emit a powerful blast of gamma rays for a few minutes or hours.

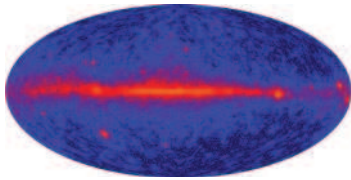


Fig. 30: Map of the Universe as seen by the "Fermi Gamma-ray Space Telescope". The center line is our galaxy.

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 31) and therapies to cure diseases like cancer.



Fig. 31: Bone scan with gamma of the human body.

At the end of the spectrum, with wavelengths even shorter than X-rays is gamma ray radiation. It is the most energetic radiation. In the cosmos there are various sources (figure 30), 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 31) and therapies to cure diseases like cancer.

Bibliography

Moreno, R, *Experimentos para todas las edades*, Ed. Rialp. Madrid, 2008.

Ros, R.M, "Experiments and exercises involving gravitational lenses", Proceedings 1st ESO-EAAE Astronomy Summer School, Barcelona, 2007.

Ros, R.M, "Gravitational lenses in the classroom", *Physics Education*, 43, 5, 506, 514, Oxford, 2008.

Internet sources

Spitzer Telescope, Educacion, California Intitute of Technology.

<http://www.spitzer.caltech.edu/espanol/edu/index.shtml>

Chandra X-ray Observatory

<http://chandra.harvard.edu/about/>

The Fermi Gamma-ray Space Telescope

<http://fermi.gsfc.nasa.gov/>

About gravitational lenses:

<http://www-ra.phys.utas.edu.au/~jlovell/simlens>

<http://leo.astronomy.cz/grlens/grl0.html>