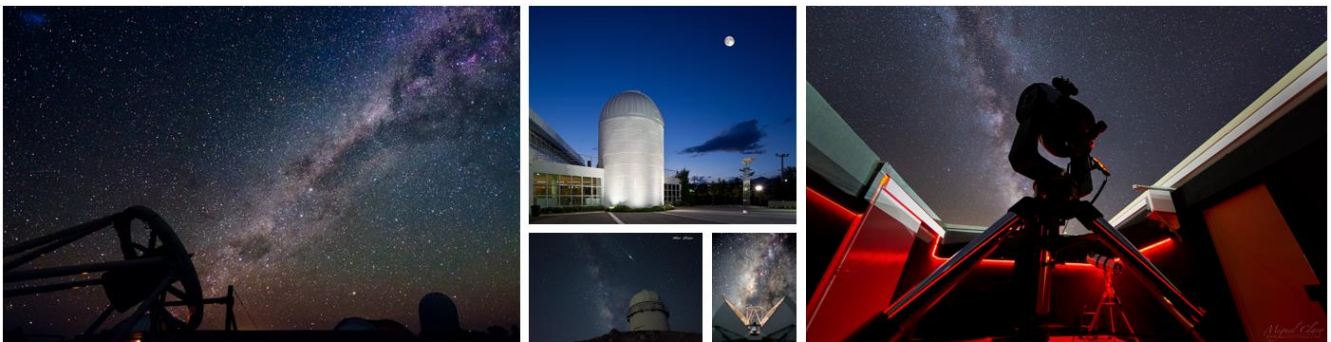


Light is more than meets the eye

Georgios Klimis - Greece

Utilizing Robotic Telescopes in Education



General Info

Short description: This activity emphasizes the importance of the invisible part of the electromagnetic spectrum, as a means of investigating the cosmic structure and evolution. Students will learn the phenomena hidden behind emissions of various wavelength bands, focusing in the near-infrared part of the spectrum, since, besides visible light, it's the only one that can be exploited by ground robotic optical telescopes. Images of galaxies and nebulae, obtained both in visible as well as infrared light, will be processed and put under investigation with the purpose of interpreting the differences and the mechanisms behind them.

Key Terms: Electromagnetic Spectrum, Radiation, Wavelength-Temperature relation.

Educational Context

Ages: 15-18

Prerequisites: Light propagation properties, Radiation Wavelength Bands, Emission and Absorption Spectra, Spectral Redshift and Reddening.

Level of Difficulty: Medium.

Duration: 8-10 hrs.

Connection with Greek Curricula: The activity can be implemented in the 11th grade General Physics class, where students learn about the properties of electromagnetic radiation, absorption and emission spectra and their role in discovering and establishing the atomic structure as we know it.

Educational Objectives

Cognitive: Discover the importance of light analysis beyond what our eyes perceive, as the main means of studying the majority of astronomical phenomena.

Affective: The satisfaction of students becoming, for a short period of time, real astronomers, controlling a telescope and taking images which will be processed and interpreted, acknowledging this way the scientific practice and methodology.

Psychomotor: To be able to create colored astronomical images.



Provoking curiosity and asking questions

- Is Light all our eyes can see, or is there invisible Light as well?
- If there is radiation beyond visible light, could it be perceived otherwise?
- You have all heard of X-ray medical equipment and “night-vision” devices. Do they relate to invisible light?
- Do you know what infrared radiation is and where it originates from?
- What if you were told that you all use infrared emitters and detectors, daily. Would you believe it?

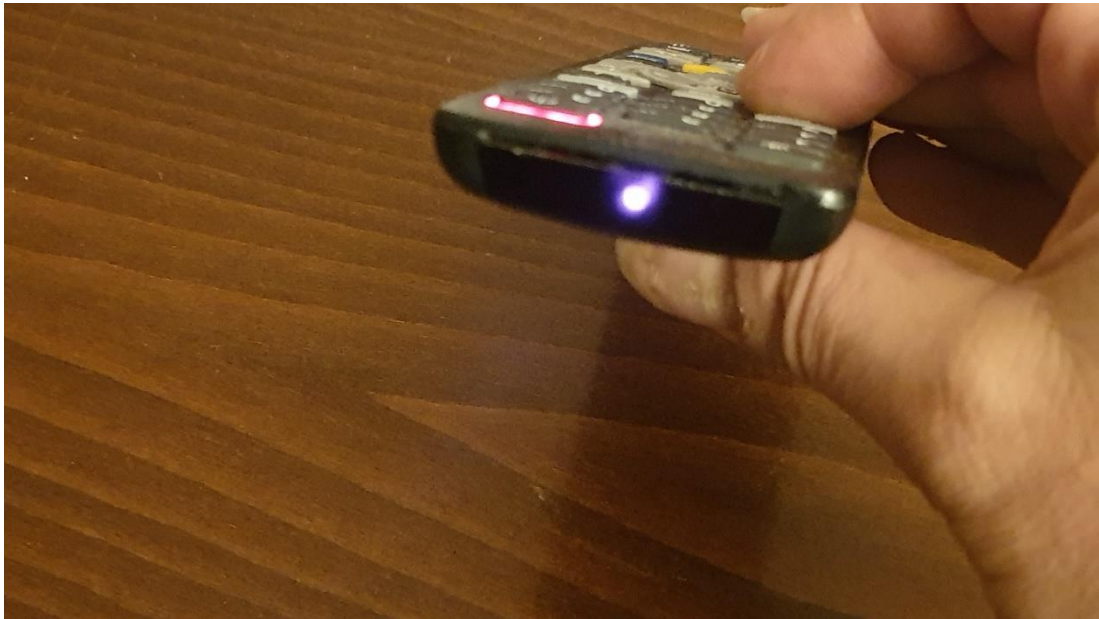


Fig.1: Remote controls emit infrared radiation, invisible to our eyes. Almost all cell phone cameras can detect infrared light. This increases their efficiency under low light conditions.

The Electromagnetic Spectrum

Radio waves, microwaves, x-rays, gamma rays, and the spectrum of visible colors are all really the same thing - electromagnetic energy. The differences are their wavelengths. Radio waves are long, measuring as much as hundreds of meters between peaks. Gamma ray wavelengths are extremely short, as little as trillionths of a meter. A photon of shorter-wavelength light packs more energy than a photon of longer-wavelength light.

Within the limited range our eyes can perceive, we interpret different wavelengths as colors, from violet (about 400 nanometers) to red (about 700 nanometers). Light with wavelengths just shorter than violet is known as "ultraviolet" (UV). We can't see it but our skin responds to it. That's the portion of sunlight we're trying to block when we wear

sunscreen.

The part of the spectrum with wavelengths just longer than red is called "infrared" (IR). Like UV light, IR light is invisible to the naked eye. But we can feel it as heat, and we can see it with the aid of technology.

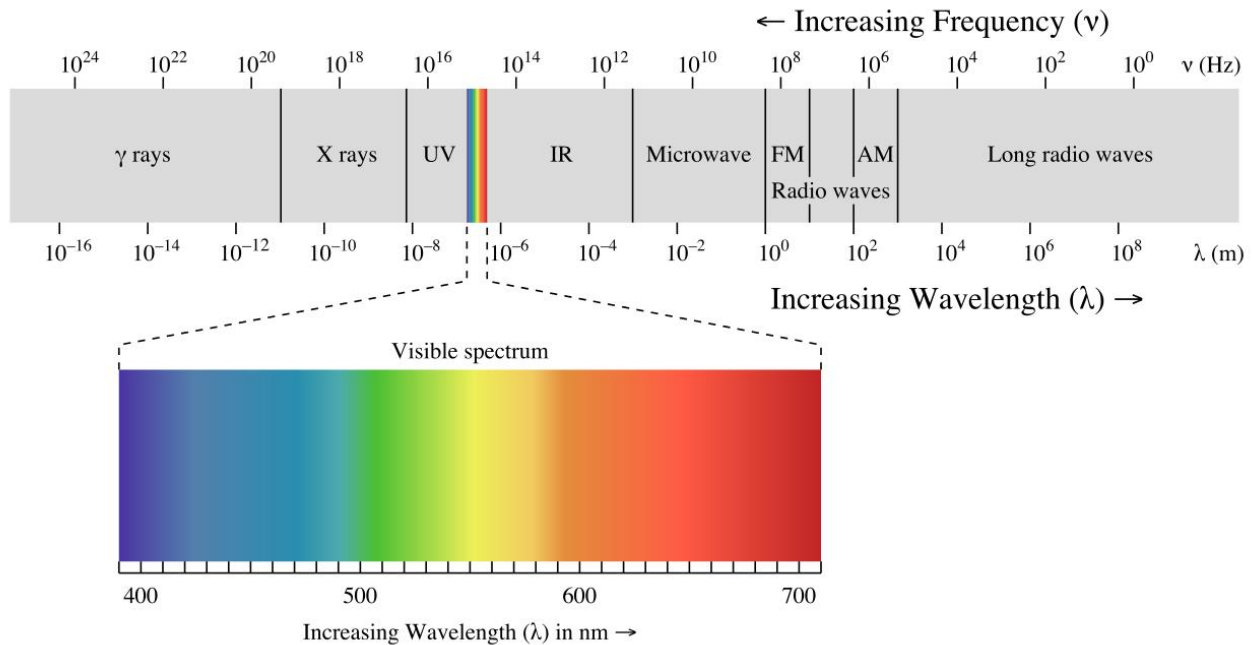


Fig. 2: The electromagnetic Spectrum and its Bands.

Astronomers analyze light in order to study the Universe. Telescopes collect light, and the data collected by telescopes allows astronomers to learn about specific celestial objects, and to develop better theories about the past, present and future of the Universe. By combining observations at different wavelengths, we can develop a more complete picture of the structure, composition and behavior of celestial objects than the visible wavelengths alone could ever show. The nature of the light that an object emits depends on its **temperature**.

Radiation and Temperature

Some astronomical objects emit mostly infrared radiation, others mostly visible light, and still others mostly ultraviolet radiation. What determines the type of electromagnetic radiation emitted by the Sun, stars, and other dense astronomical objects? The answer often turns out to be their *temperature*.



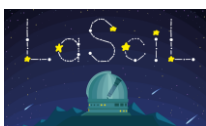
At the microscopic level, everything in nature is in motion. A solid is composed of molecules and atoms in continuous vibration: they move back and forth in place, but their motion is much too small for our eyes to make out. A gas consists of atoms and/or molecules that are flying about freely at high speed, continually bumping into one another and bombarding the surrounding matter. The hotter the solid or gas, the more rapid the motion of its molecules or atoms. The temperature of something is thus a measure of the average motion energy of the particles that make it up.

This motion at the microscopic level is responsible for much of the electromagnetic radiation on Earth and in the universe. As atoms and molecules move about and collide, or vibrate in place, their electrons give off electromagnetic radiation. The characteristics of this radiation are determined by the temperature of those atoms and molecules. In a hot material, for example, the individual particles vibrate in place or move rapidly from collisions, so the emitted waves are, on average, more energetic. Higher energy waves have a higher frequency. In very cool material, the particles have low-energy atomic and molecular motions, generating lower-energy waves.

Types of Electromagnetic Radiation

Type of Radiation	Wavelength Range (nm)	Radiated by Objects at This Temperature	Typical Sources
Gamma rays	Less than 0.01	More than 10^8 K	Produced in nuclear reactions; require very high-energy processes
X-rays	0.01–20	10^6 – 10^8 K	Gas in clusters of galaxies, supernova remnants, solar corona
Ultraviolet	20–400	10^4 – 10^6 K	Supernova remnants, very hot stars
Visible	400–700	10^3 – 10^4 K	Stars
Infrared	10^3 – 10^6	10 – 10^3 K	Cool clouds of dust and gas, planets, moons
Microwave	10^6 – 10^9	Less than 10 K	Active galaxies, pulsars, cosmic background radiation
Radio	More than 10^9	Less than 10 K	Supernova remnants, pulsars, cold gas

Table 1: Wavelength-Temperature relation of typical celestial sources.



Why is infrared radiation important to astronomy?

Most of the light in the Universe is in infrared and longer wavelengths. There are three basic reasons for this:

1. It is cold out there.

Many of the celestial objects are far too cold to radiate in optical or shorter wavelengths. However, even at temperatures far below the coldest spots on Earth, they do radiate at far-infrared and submillimeter wavelengths. To understand how stars form and evolve, we need to understand their raw materials - the cold atoms and molecules that populate interstellar space. Analyzing their spectra enables scientists to determine the temperature, density, luminosity, composition, magnetic fields, and dynamics of the chemicals and their environments.

In our own solar system, cold objects such as comets, asteroids, and the planets themselves reveal most of their characteristics by infrared light.

Brown dwarfs, protostars, dusty disks around young stars, and planets in other star systems are all too cold to radiate in the optical range, but shine at infrared wavelengths.

2. It is dusty out there.

A number of things of great interest to astronomy are hidden within or behind vast clouds of gas and dust. In the early stages of their formation, stars and planets are concealed by them. So are the enormously powerful cores of active galaxies, the center of our own Milky Way, and most of the early Universe.

Our view is blocked in visible light because the dust grains are about the same size as optical wavelengths, about one micron or less, and so are very effective at scattering or absorbing that light. On the other hand, longer infrared wavelengths manage to propagate through the dust. And the longer the wavelength, the thicker the layer of dust they can penetrate. So, far-IR and submillimeter radiation can move freely through the Universe, unobstructed by dust.

The visible and ultraviolet light that the dust absorbs warms the grains just enough for them to reradiate the light at infrared wavelengths. Thus, in addition to allowing infrared light to pass through, the dust itself radiates at that range of wavelengths. And by analyzing the dust's radiation, scientists can deduce information about the optical sources hidden behind.



3. The Universe is expanding.

The Universe is expanding and galaxies outside our own local group are traveling away from us. The more distant they are, the faster they are receding. As they speed away, the wavelengths of the radiation they emit are shifted towards longer values, with the amount of this “redshift” depending on their velocities. Light that starts out at optical wavelengths may be stretched into the infrared.

This radiation, holds clues to many mysteries from the beginning of everything, the first stars and galaxies in the early universe, after the big bang. Observation of these early days in the universe’s history will shed light on perplexing questions of dark matter and energy, black holes, galaxy evolution over time, what the first stars were like, and how we arrived at the universe we experience today.

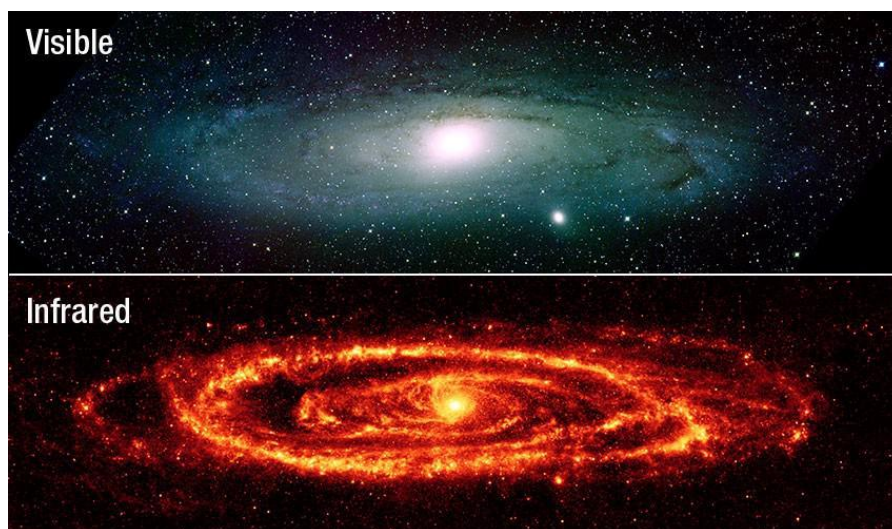


Fig. 3: Andromeda galaxy in visible and IR

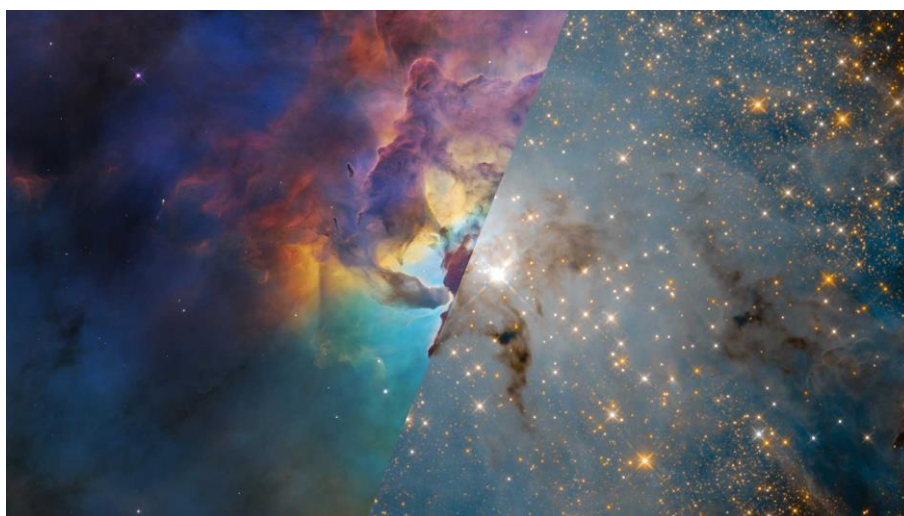


Fig. 4: Lagoon nebula in visible and IR.

Observational Limitations

The Universe sends us light at all wavelengths of the electromagnetic spectrum. However, most of this light does not reach us at ground level here on Earth. Why? Because we have an atmosphere which blocks out many types of radiation while letting other types through. Fortunately for life on Earth, our atmosphere blocks out harmful, high-energy radiation like X-rays, gamma rays and most of the ultraviolet rays. It also blocks out most infrared radiation, as well as very low energy radio waves. On the other hand, our atmosphere lets visible light, most radio waves, and small wavelength ranges of infrared light through, allowing astronomers to view the Universe at these wavelengths.

Most of the infrared light coming to us from the Universe is absorbed by water vapor and carbon dioxide in the Earth's atmosphere. Only in a few narrow wavelength ranges, infrared light can make it through (at least partially) to a ground based infrared telescope. The main limitation on infrared sensitivity from ground-based telescopes is that water vapor in the Earth's atmosphere absorbs a significant amount of infrared radiation. For this reason, most infrared telescopes are built in very dry places at high altitudes (above most of the water vapor in the atmosphere). Suitable locations on Earth include the Mauna Kea Observatory, situated at 4205 meters above sea level; the Atacama Large Millimeter Array (ALMA), at 5000 m in Chile; and high-altitude ice desert regions, such as Dome C in Antarctica.

The Earth's atmosphere causes another problem for infrared astronomers. The atmosphere itself radiates strongly in the infrared, often putting out more infrared light than the object in space being observed. This atmospheric infrared emission peaks at a wavelength of about 10 microns.

Another way of doing infrared astronomy is by the use of airborne observatories, such as SOFIA (Stratospheric Observatory for Infrared Astronomy) and the Kuiper Airborne Observatory. By flying at high altitude (in the stratosphere), there is less water vapor between the telescope and objects in space, leading to a smaller IR absorption of the atmosphere.



Fig. 5: SOFIA airborne observatory

From the table below, you can see that only a few of the infrared "windows" have both high sky transparency and low sky emission. These infrared windows are mainly at infrared wavelengths below 4 microns.



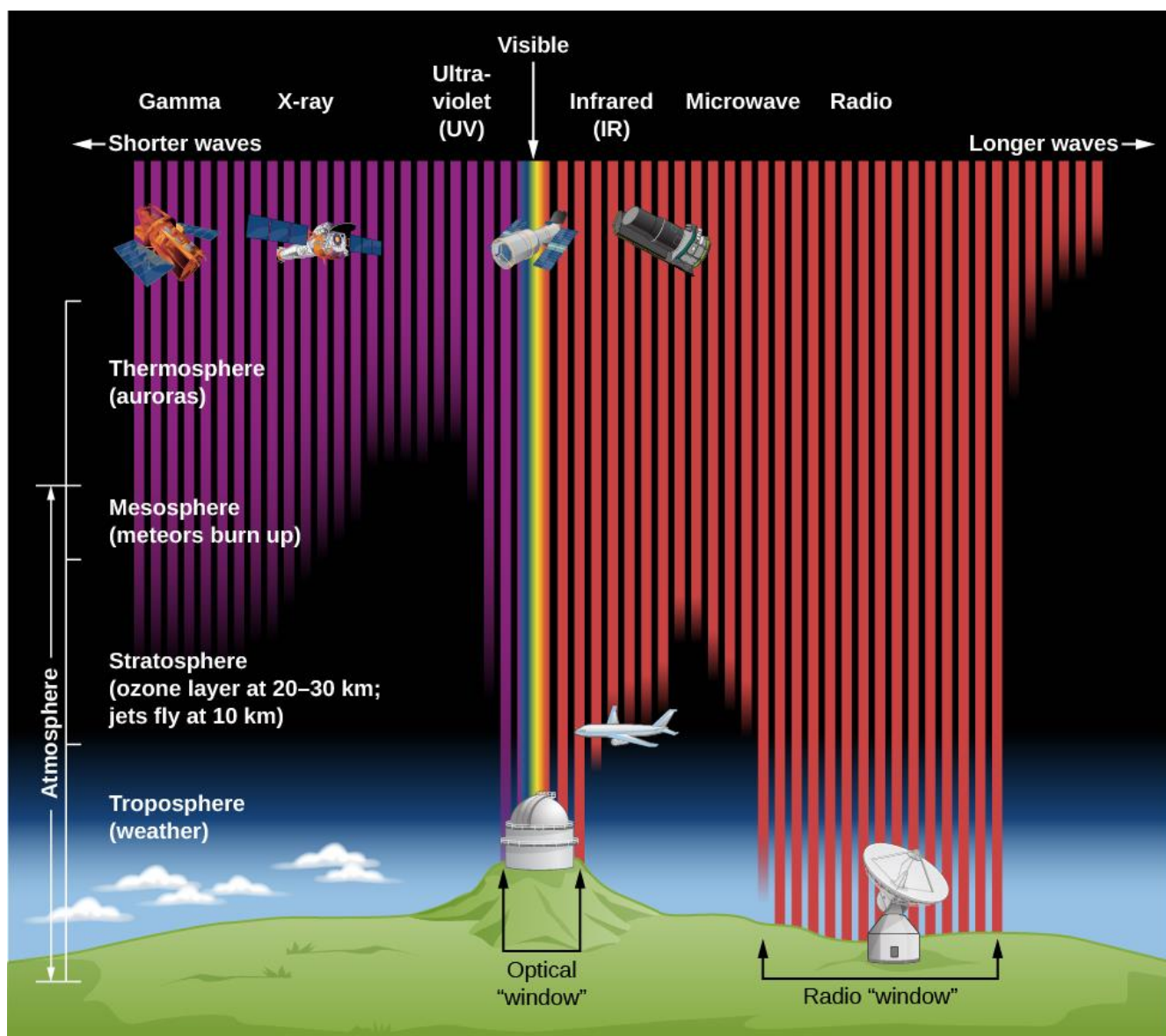


Fig. 6: Electromagnetic “windows” of Earth’s atmosphere.

Finally, it is obvious that infrared astronomy is best served by space telescopes. Infrared surveys of the universe have been successfully carried out by space telescopes such as the [Herschel Space Observatory](#), and the [Spitzer Space Telescope](#), launched in 2009 and 2003 respectively. [James Webb Space Telescope](#) (JWST), the successor of [Hubble Space Telescope](#), is optimized for infrared observation and has already provided astronomers with excellent IR images.

For the purposes of the present activity, the visual images obtained with LCO telescopes could be compared with IR images from the above space telescopes, in case the LCO near-IR images are either difficult to obtain or process.

Planning and Investigation

- LCO Robotic Telescope Observation Planning Steps

Las Cumbres Observatory (LCO) is a global telescope network consisting of two 2-metre telescopes, thirteen 1-metre telescopes, and ten 0.4-metre telescopes.

Requests on the LCO network do not identify specific sites or telescopes – instead, you choose which telescope aperture class or size (e.g., 0.4 m telescope) to use. LCO's scheduling software assigns each observation request to the best telescope available, and reassigns it to the next available telescope if the initial attempt fails (due to weather or technical problems).

To access the LCO telescopes one has to be a registered user. Registration is free in the following link: <https://observe.lco.global/accounts/register>.

The LCO network is used by thousands of astronomers, communicators, educators and students around the world. To ensure telescope time is used efficiently, it's essential that users take the time to adequately prepare before scheduling observations. The steps below will help you do this:

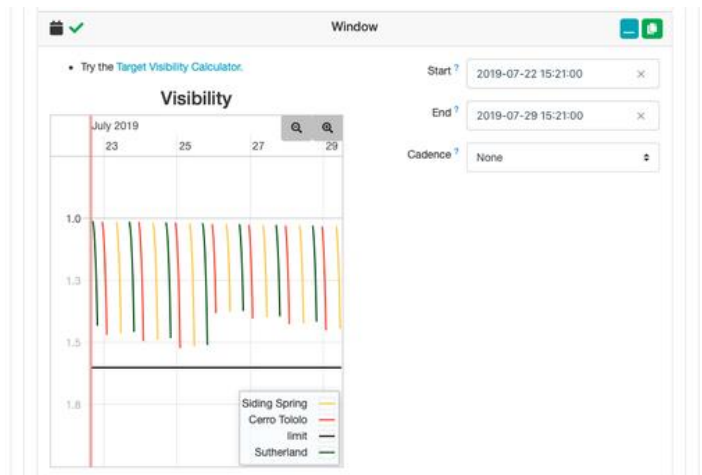
Step 1: *Define your Observation Window* – Select the time period within which you'd like your observations taken. We recommend a minimum length of one week. Enter the time window on your Observation Planning Sheet if you are using one.

Step 2: *Select a visible object* – In Stellarium, set the date and time to when your Observation window will start. Set the location to match the location of one of your potential chosen telescopes (e.g. if you wanted to use a 1m telescope, choose one of the locations where there is a 1m telescope).

Stellarium will now display the sky that will be visible from your chosen observatory location during your time window. Search for a selection of deep sky objects, ideally, that are located at least 30 degrees above the horizon. To see more information on each object, click on it in Stellarium. This will pop up information such as its angular size, magnitude, name, type and coordinates. Enter any relevant information for each potential object on your Observation Planning Sheet if you are using one.



LCO Visibility Plot: When scheduling your observations on the LCO queue, after you have defined your time window, a plot will appear showing the visibility of your target object at each observatory location during this period. Each site is coded with a different colour and visibility is shown as the change in air-mass (essentially, the amount of atmosphere through which light from the object must travel) of the object over time.)



Step 3: Check object dimensions – The area of sky visible through a telescope at any one time is called its ‘Field of View’ (FOV). When choosing your object, keep in mind the field of view of the camera aboard your selected LCO telescopes. Information about the cameras and telescope size can be found in the table below.

Telescope class (size)	Camera (instrument) name	Field of View (arcmin)
2 metre	MuSCAT3	9.1 x 9.1
2 metre	Spectral	10 x 10
1 metre	Sinistro	26 x 26
0.4 metre	SBIG 6303	29 x 19

Table 2: The dimensions of your object(s) can be found by clicking on the object in Stellarium.

Step 4: Select a suitable exposure time - The exposure time is how long the telescope shutters stay open to collect light from your object. A suitable exposure time must be selected: if the exposure time is not long enough, the object will appear too faint, while over-exposure leads to saturation and loss of detail.

Suitable exposure times can be found by looking at previous observations of your object in the LCO archive and seeing which ones gave good results:

- Go to <https://archive.lco.global/>
- Enter the name of your object in the Point field.
- Set the date range to “All time” using the calendar at the top of the left menu.
- Set the Telescope field to match the size of the telescope you will be using.
- You will see the exposure times (Exp. Time) for any listed observations and can look at the images to see which are under/overexposed or just right.



Step 5: *Select suitable filters* – Each telescope class has different filter sets available. If you are just interested in making a colour image then we recommend you take an image with the red, green and blue filters (N.B. the MuSCAT3 camera on FTN has fixed filters and takes an image using all filters at the same time, so on this telescope you cannot choose a filter).

Telescope class (size)	Camera (instrument) name	Filters options
2 metre	MuSCAT3	SDSS g,r,i,z (fixed)
2 metre	Spectral	18
1 metre	Sinistro	21
0.4 metre	SBIG 6303	9

Step 6: *Schedule your observations* – once you know what telescope size, object, exposure time and filter you plan to use, you are ready to go onto the LCO observing portal and schedule your observations.

- How to download your images from LCO

1. Log into the LCO portal with your username and password

LC Observing Portal

Home Submit Observation Manage Proposals Planning Tools Help

Login

Observing Portal

This is your access point to Las Cumbres Observatory's global network of telescopes. Registered users can:

- Submit proposals and manage the membership of their research teams.
- Compose, save, and submit observing requests.
- Check the status of submitted requests, and download data from completed observations.

Register an Account

Login

Quick Navigation

- Submit Observation
- Manage Proposals

Need more information?

Check out the [help page](#).

Telescope availability history

This chart shows the percent of operational science time for each telescope over the last 4 days. View the [detailed operational status](#).

Telescope	-4 days	-3 days	-2 days	-1 day	Today
Siding Spring 0.4m A	19	94	38	62	
Siding Spring 0.4m B	19	94	38	62	



2. After you login, you will see a list of your submitted requests. Click on a Request.

G Klimis George_63 FTPEPO2014A-004	✓ COMPLETED 2023-03-24 05:17:26	1	0	0	1	Sutherland 1m 1	16	100	57	0
G Klimis George_63 FTPEPO2014A-004	✓ COMPLETED 2023-03-23 20:50:33	1	0	0	1	Sutherland 1m 2	16	100	57	0
G Klimis George_63 FTPEPO2014A-004	✓ COMPLETED 2023-03-23 20:55:37	1	0	0	1	Sutherland 1m 3	16	100	57	0
G Klimis George_63 FTPEPO2014A-004	✓ COMPLETED 2023-03-23 20:23:03	1	0	0	1	McDonald 0.4m A 1	79	89	100	99
						McDonald 1m 1	79	89	100	99

3. Click on Data.
4. To download a colour image, click on 'View colour image' and then right click on the image that appears to save it as a jpg file.
5. To download the separate B, V and R files so you can create your own colour image, select the files with "Reduction" level, "reduced" and click "Download Selected".

G Klimis

RequestGroup # 1667860

State ✓ COMPLETED	Updated 2023-03-24 05:17:26	Submitted 2023-03-23 09:03:37	Proposal FTPEPO2014A-004	Submitter George_63	IPP 1.050000	Type NORMAL	
Sub-requests / #3181500							

# 3181500	✓ COMPLETED	
⌚ Duration: 437 seconds	📄 Acceptability Threshold: 90%	View in API Download
📷 Instrument: 1.0 meter Sinistro	📅 2023-03-24 05:17:26	

- Details
- Scheduling
- Visibility
- Data**

Click a row in the data table to preview the file below. Click preview for a larger version.

Download Selected **Download All**



<input type="checkbox"/>	filename	DATE_OBS	filter	obstype	Reduction
<input type="checkbox"/>	elp1m008-fa05-20230323-0115-e00.fits.fz	2023-03-24 05:12:12	I	EXPOSE	raw
<input checked="" type="checkbox"/>	elp1m008-fa05-20230323-0115-e91.fits.fz	2023-03-24 05:12:12	I	EXPOSE	reduced

Showing 1 to 2 of 2 rows



2014-01-01
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Proposal ?
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Object ?

Observation Type
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Reduction Level
All ▼

See documentation on

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<input checked="" type="radio"/>	zip download (with uncompressed fits files)	-20230323-0440- 2023-03-24 05:12:58	FTPEP02014A-004	M81	air	GUIDE	10.0	Raw
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<input checked="" type="checkbox"/>	elp1m008-ef08-20230323-0435-g00	2023-03-24 05:11:58	FTPEP02014A-004	M81	air	GUIDE	10.0	Raw

• Image Processing

This guide will show you how to create beautiful color images using free software that can be downloaded from the Internet.

Observations produced by the LCO telescopes will be available to you as a special type of file known as Flexible Image Transport System or FITS files (e.g., tfn1m001-fa11-20230321-0059-e91.fits). FITS files are more than just image files, at the start of every FITS file is a header section, which contains important information about the image, such as the number of pixels, the date the image was taken, the telescope it was taken with, the exposure time and much more. You will need to install special software to view and edit your FITS files. An example of free FITS editing software available on the internet is [FITS Liberator](#).

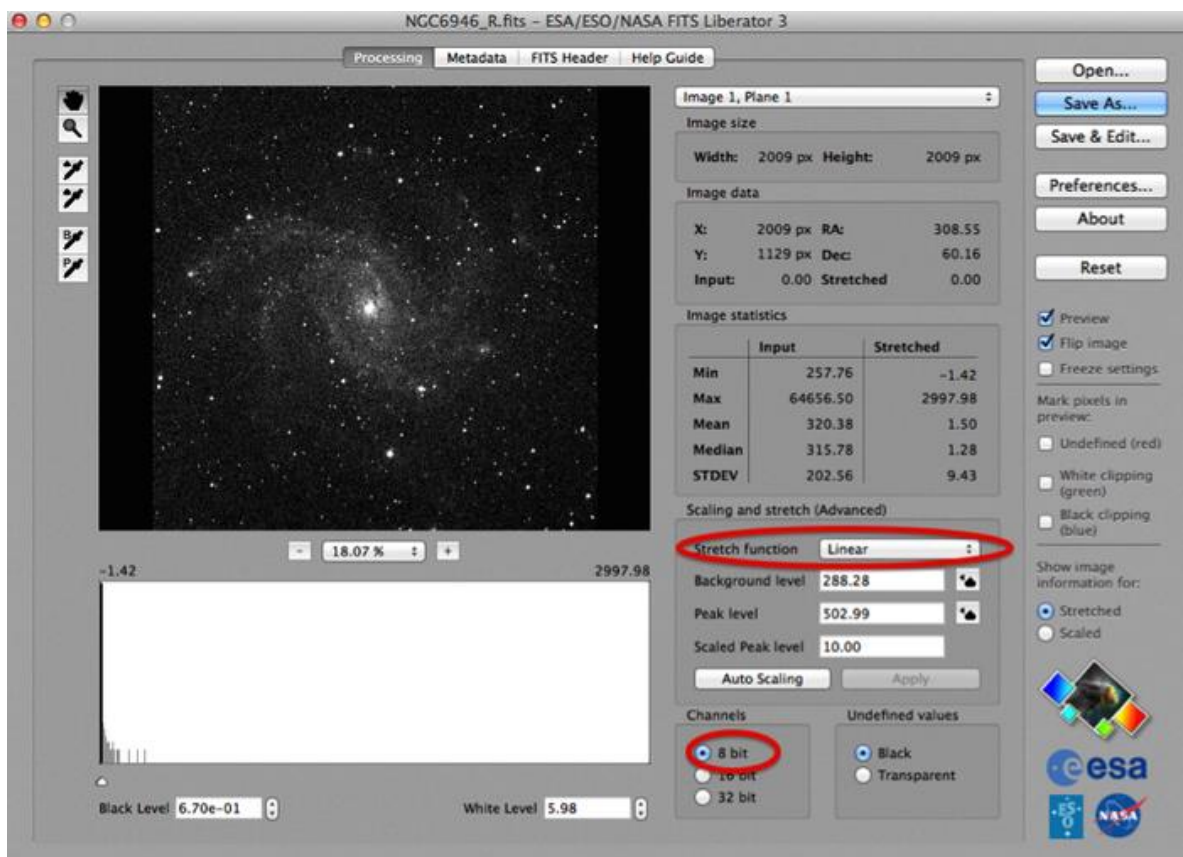
Color images of space are created by combining three separate black and white observations; one taken with a green filter, one with a blue filter and one with a red filter. Red, green and blue are three primary colors that can simulate a full spectrum of visible light to the human eye. It can be done easily using **GIMP**, an image editing software that can be downloaded for free ([GIMP website](#)) from the Internet and used on Mac or Windows computers.



Preparing your Images

Before opening GIMP, you need to prepare your images so you achieve the best quality possible.

- Begin by launching your FITS editing software and open your three FITS files by going to **File > Open**.
- Set the **white** and **black** level sliders in the histogram graph to give a good amount of contrast without too much black or too much saturation.
- You can experiment with the different Stretch functions to enhance fainter parts of the image. Different stretch functions produce different results with each image so play around and see what works. You're aiming to make the background as black as possible while maintaining the detail of the object in the image.



- When you are happy with the way the image looks, tick the 8-bit button and save your file. This is an important step; it will allow you to save your colored image as a JPG file when it's finished.
- Open the next image into FITS Liberator and repeat until all three images are edited, making sure you use approximately the same settings for each of your three images.

Adding Color to your Images

- Open GIMP and by selecting File→Open, open your three tif images.
- In order to be able to color the images you have to change their status from grey scale to RGB. To do that choose Image→Mode→RGB.
- Now you will create one image that includes all three images. Go to one of your images and select Edit→Copy and then Edit→Paste as→New image. Go to another filter and click Edit→Copy and go the new image you are creating and select Edit→Paste as→New layer. Do the same thing for the last filter. Now you can erase your initial images.
- Make sure your new image is on RGB mode.
- Now its time to color. On the right side of your screen you should see something like this:



By clicking on the eyes, you can appear or disappear a layer. Disappear two layers and keep only one, let's say the red one. Make sure to also click on the red filter image to select it. If you have selected it, it will appear like this (with a white frame):

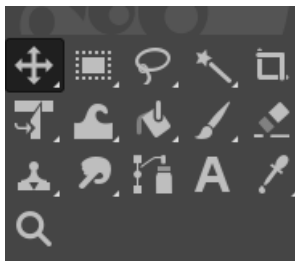


- Click on Color→Colorize... and paint your image pure red. The recommended values for **red**, **green**(visual) and **blue** colors are given in the following table and they can be set as presets for future use.



	Red	Green	Blue
Hue	0	120	240
Saturation	100	100	100
Lightness	-50	-50	-50

- To combine the layers, click on one of the layers and change the mode from normal to screen. The mode button is right above your layers at the right side of your screen. Do this for all three layers. Now you can see your final image!
- If your stars are not aligned you can move the layers by clicking in the move button at the top left side of your screen.



Here are some videos that might be helpful:

<https://www.youtube.com/watch?v=93fTrU2R1q4>

<https://www.youtube.com/watch?v=JZlmEkMHdSY>

Figure 7 shows the result of processing the RGB images of spiral galaxy M81, chosen for the present activity. Images were taken using the 1m aperture telescope, and the exposure time was 120 seconds.

Figure 8 is the result of merging three IR filters available with the 1m telescope: Bessell I at 798nm, Pan-STARRS Zs at 870nm and Pan-STARRS Y at 1004nm. The images were treated as an RGB set, hence the pseudo color of the final result.





M81 Blue

M81 Red

M81 Visual



M81 Colored

Fig. 7: M81 Galaxy RGB Images and the resulting colored image.

*M81 I**M81 Zs**M81 Y**Fig. 8: M81 IR I+Zs+Y filters*

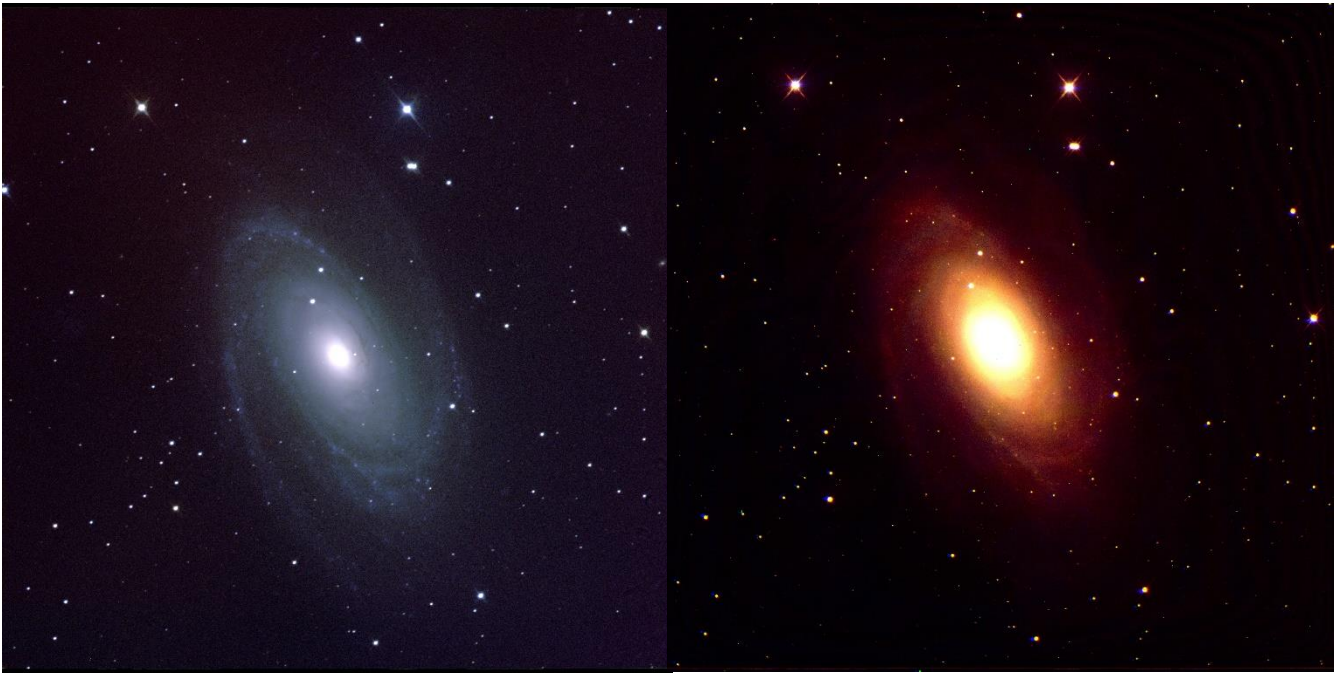


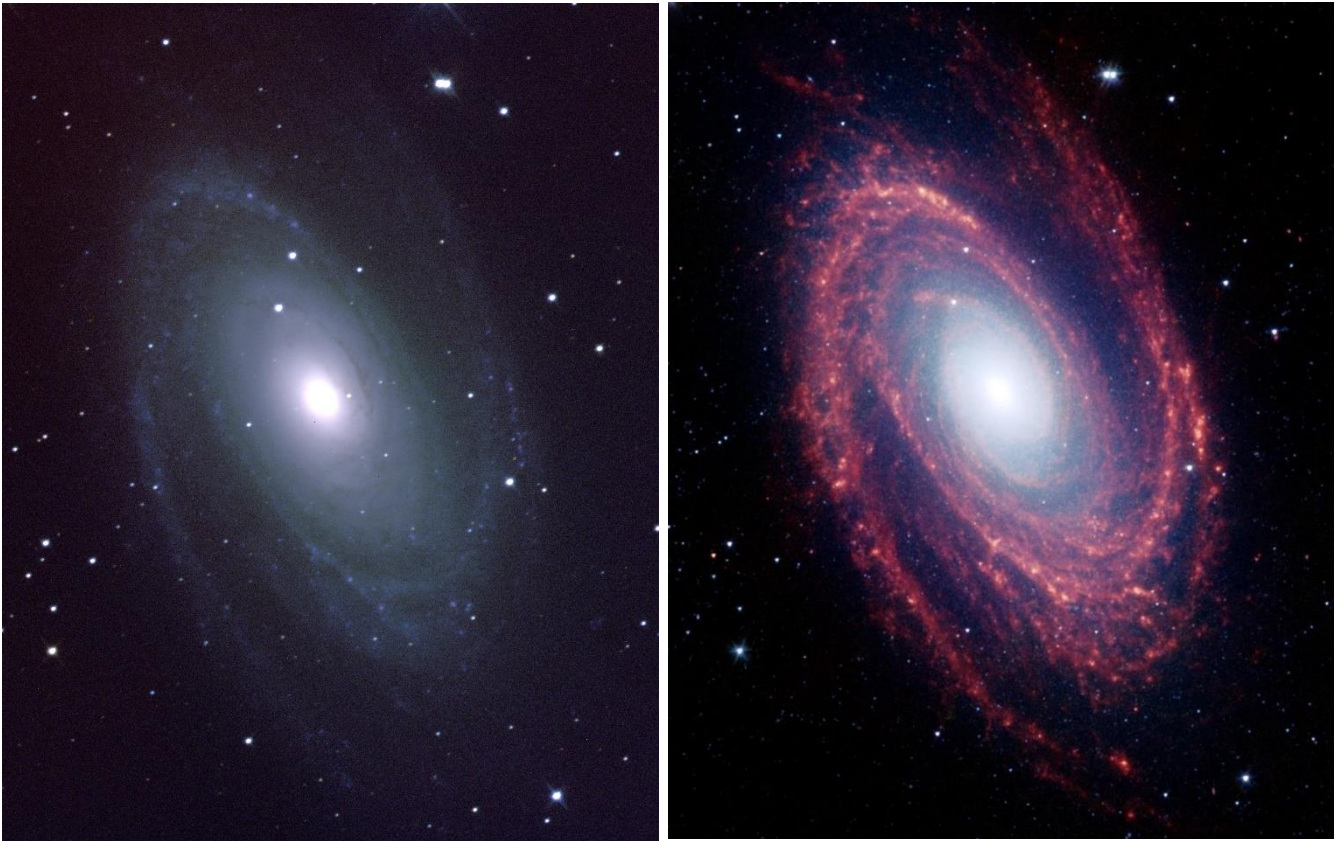
Fig. 9: Spitzer image of M81.

As you may see, the near-infrared image, exhibits no major differences from the visual image. This is due to the limitations posed by earth's atmosphere.

Images from space telescopes on the other hand, such as the one in Fig. 9, present great results capturing longer infrared wavelengths, with higher resolution. Hence, it would be easier to investigate the differences between the LCO visual image and the Spitzer infrared one.

Interpretation-Conclusion-Evaluation

Let us compare the following images of M81 Galaxy.



- Can you describe the differences in detail?
 - Which image provides a more detailed view of the galaxy's structure?
- Can you explain the difference in color between the core and the spiral arms?
 - The spiral arms seem to be dominated by infrared light. Why is that?

Located in the northern constellation of Ursa Major (Big Dipper), this galaxy is easily visible through binoculars or a small telescope. M81 is located at a distance of 12 million light-years from Earth.

Because of its proximity, M81 provides astronomers with an enticing opportunity to study the anatomy of a spiral galaxy in detail. The unprecedented spatial resolution and sensitivity of Spitzer at infrared wavelengths show a clear separation between the several key constituents of the galaxy: the old stars, the interstellar dust heated by star formation activity, and the embedded sites of massive star formation.

The infrared images also permit quantitative measurements of the galaxy's overall dust content, as well as the rate at which new stars are being formed.

The infrared image was obtained by Spitzer's infrared array camera. It is a four-color composite of invisible light, showing emissions from wavelengths of 3.6 microns (blue), 4.5 microns (green), 5.8 microns (yellow) and 8.0 microns (red).

Winding outward from the bluish-white central bulge of the galaxy, where old stars predominate and there is little dust, the grand spiral arms are dominated by infrared emission from dust. Dust in the galaxy is bathed by ultraviolet and visible light from the surrounding stars. Upon absorbing an ultraviolet or visible-light photon, a dust grain is heated and re-emits the energy at longer infrared wavelengths. The dust particles, composed of silicates (which are chemically similar to beach sand) and polycyclic aromatic hydrocarbons, trace the gas distribution in the galaxy. The well-mixed gas (which is best detected at radio wavelengths) and dust provide a reservoir of raw materials for future star formation.

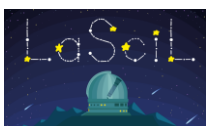
The infrared-bright clumpy knots within the spiral arms denote where massive stars are being born in giant H II (ionized hydrogen) regions. The 8-micron emission traces the regions of active star formation in the galaxy. Studying the locations of these regions with respect to the overall mass distribution and other constituents of the galaxy (e.g., gas) will help identify the conditions and processes needed for star formation. With the Spitzer observations, this information comes to us without complications from absorption by cold dust in the galaxy, which makes interpretation of visible-light features uncertain.

Summing up we have learned:

- That invisible light is crucial in our understanding of the Universe.
 - How to take astronomical images using robotic telescopes.
 - How to process and compose these images.
 - How to work like astronomers do.

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