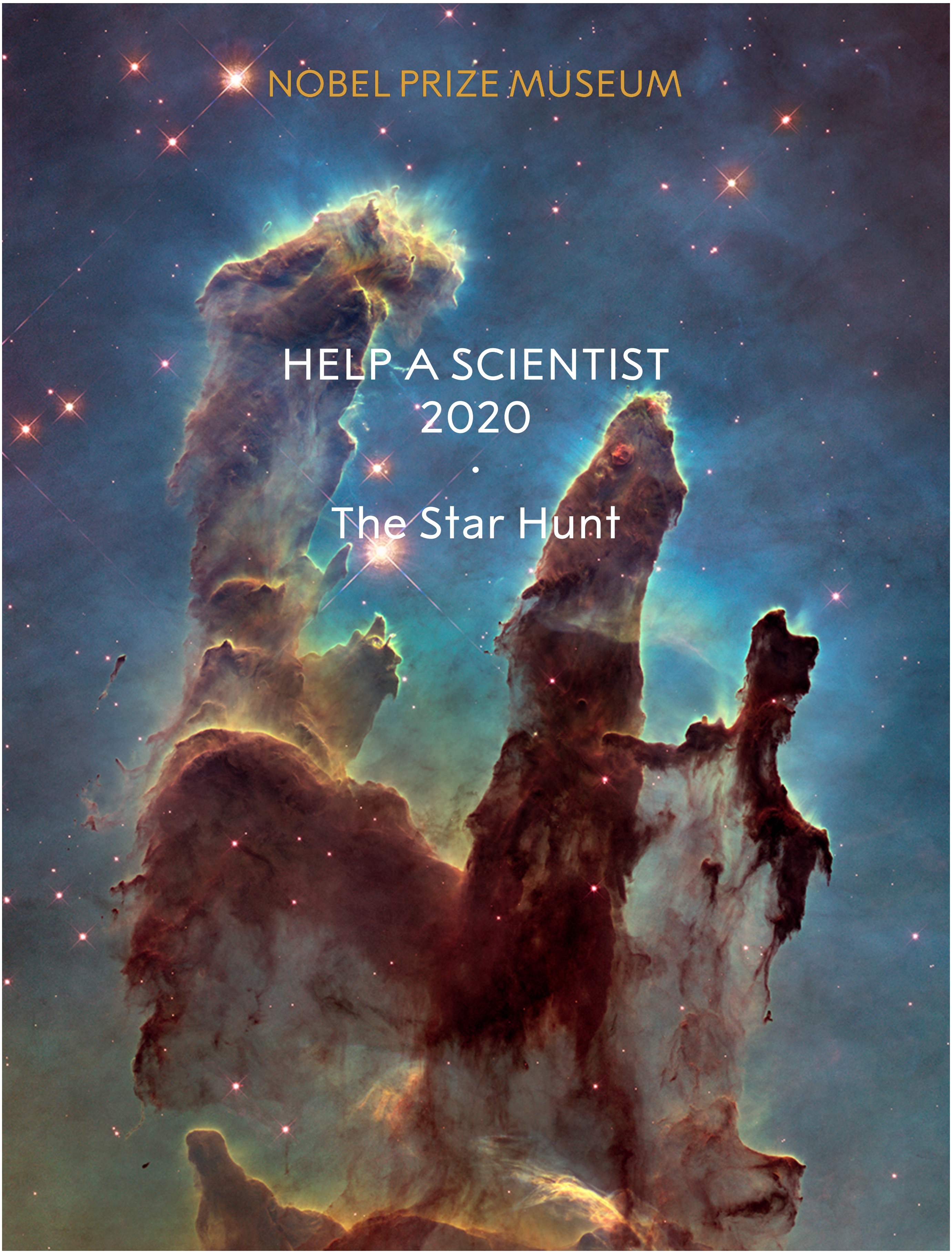
NOBEL PRIZE MUSEUM



HELP A SCIENTIST 2020

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The Star Hunt

Swedish Foundation for Strategic Research

CHALMERS

Box 2245, 103 16 Stockholm
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https://nobelprizemuseum.se/en/education/stjarnjakten/
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Content

Welcome to *Help a Scientist 2020*!

The aim of the Help a Scientist project is to give students in Swedish schools the opportunity to try out genuine scientific research. The students gain a deeper understanding of what a research project can involve, and at the same time scientists receive help with their research. The hope is that together, we can contribute a small but significant piece of the puzzle in a large research project. Help a Scientist is a project under the auspices of Nobel Prize Museum in Stockholm. It is funded by the Swedish Foundation for Strategic Research.

We are in the midst of an era of change. In many cases changes will bring improvements, but they will also confront us with a number of challenges. What is required to enable all of us to live a good life in our world? Research is one tool. In order for us to find new solutions we need people who are creative and persistent, and who love to solve problems. We need people who dare to think in ways no one previously thought and go where no one has gone before – who insist on continuing their search when others have given up and are strongly determined to stand by their convictions. These people are the heroes of our future – scientists! For more information on earlier Help a Scientist projects, go online to https://nobelprizemuseum.se/en/education/earlier-projects/

Help a Scientist 2020 – The Star Hunt

What?

In this year's project, The Star Hunt, scientists (in this case, astronomers) need help in finding and identifying stars that are being born from dusty interstellar clouds in our galaxy. Their aim is to answer questions such as: Do these stars – especially the massive ones – form alone, as twins or perhaps together in large clusters?

How?

Students will use the web-based WorldWide Telescope (WWT) platform to study astronomical images of space clouds made of gases and dust (small particles), where new stars are formed in our galaxy. By superimposing images taken at different wavelengths, the students will be able to help us identify the number of newly formed stars and possible supernova explosions. The scientists will provide background on this research and instructions for analysing the images. The students' analysis will take place using input from the researchers and also based on their own initiatives.

Why?

By studying images that show light radiation of different wavelengths, we will be able to understand the chemical environment around stars that are born in our galaxy. Aided by this information, we can study various phenomena related to the birth of stars, such as space dust and supernova explosions.
These studies can provide important information about the environment and composition of star-forming space clouds in the Milky Way, and thus about the overall life cycle of stars. Researchers do not yet have a complete understanding of this. Students will be able to

contribute important basic information, which will also help us better understand the origins of our own sun and its planets.

Poster competition

Working in two-person teams, the students will then produce scientific posters describing their work and their results. Of all the posters (about 15 per class of 30 students), each class will select one poster that will represent their school and will be entered in a poster competition.

PLEASE NOTE: You may want to let more than one class at the same school participate in the project, but keep in mind that you can only submit one poster per school to the poster competition. The approximately 25 posters will be shown to three different jurys:

- Jury 1 consists of three popular science journalists will select a winner from a holistic perspective (scientific content, graphic design and presentation technique). The students behind the winning poster will receive SEK 5,000 for their class fund and another price that will be announced later.

- Jury 2 consists of the three scientists will select the best poster from a scientific perspective. The people behind the winning poster will be invited for a study visit to the scientists at Chalmers and will receive SEK 2,000 for their class fund.

- Jury 3 consists of the students themselves! The student selects the winner of The Prize of Schools. The students behind the winning poster will be invited for a study visit to our Scientific Expert for the Help a Scientist project, Pernilla Wittung Stafshede at Chalmers and SEK 2,000 for their class fund.

Closing conference

On February 12. 2021 there will be a concluding conference at Nobel Prize Museum, where one teacher and two students per school are welcome. The conference will consist of lectures and a report on the results by the three scientists. All posters that were entered in the poster competition (one per school) will be displayed at the museum, and the students will briefly present their poster.

The working group for the Star Hunt consists of:

· *Jonathan Tan*, Professor at the Department of Space, Earth and Environment, Astronomy and Plasma Physics, Galactic Astronomy, Chalmers University of Technology in Gothenburg, Sweden.
· *Giuliana Cosentino*, Cosmic Origin Postdoctoral Fellow, Department of Space, Earth and Environment, Astronomy and Plasma Physics, Chalmers University of Technology in Gothenburg, Sweden.
· *Rubén Fedriani*, Postdoctoral Fellow, Department of Space, Earth and Environment, Astronomy and Plasma Physics, Chalmers University of Technology in Gothenburg, Sweden.
· *Pernilla Wittung Stafshede*, Professor, Department biology and biological engineering, Chalmers, Scientific Expert for the Help a Scientist project.
· *Paulina Wittung Åman*, Museum Educator at Nobel Prize Museum and Pedagogical Director of the project.
· *Pia Johansson*, Event Manager, Nobel Prize Museum.
• *Anna Johanna Lindqvist Forsberg,* Project Manager, Nobel Prize Museum.

We have also started a closed Facebook group for teachers called “The Star Hunt” – feel free to join it! Its purpose is to enable you as teachers to exchange experiences with each other, reach out to me with any questions and comments, and post pictures from the work of your class.

Help a Scientist is funded by the Swedish Foundation for Strategic Research. If you are curious about the other projects that they finance, go to their English-language website: https://strategiska.se/en/

We hope that The Star Hunt will be a stimulating experience, and we once again welcome you warmly to the project!

The Star Hunt project group

Important dates, workflow

September
Week 37
September 10 - Test before start-up 16-16.45
September 11 - Start-up (digital) 13–17

Week 38–40
September 14 – October 2 - background Theory
25/9 – Star date 1 (Exercise 1)

October
Week 41–43
Work on research assignment 1
Deadline: Exercise 1 **October 23**

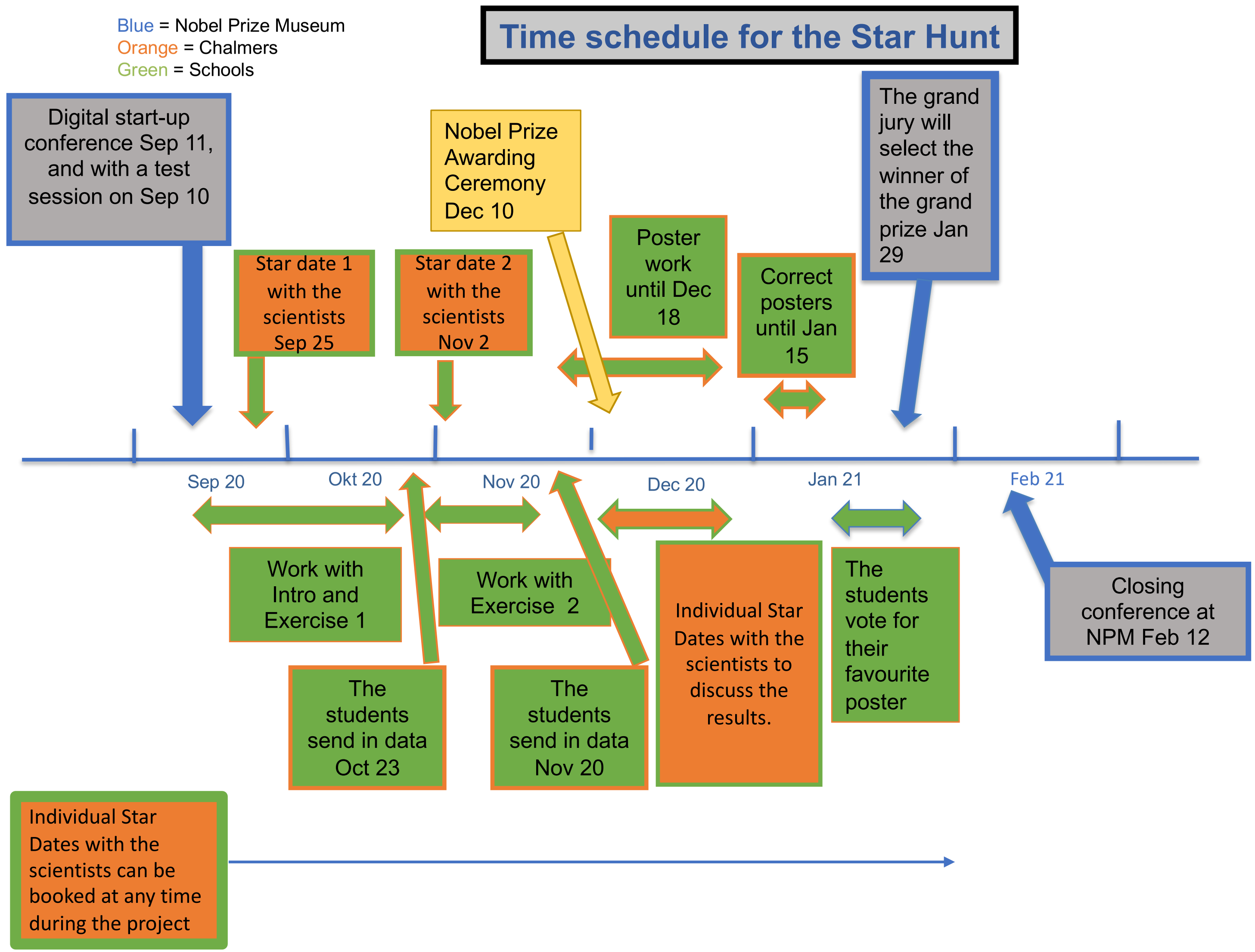
November
Week 45–47
November 2 - Star date 2 (Exercise 2)
Work on research assignment 2
Deadline: Exercise 2 **November 20**

November/December
Week 48–51
Work with the posters
Deadline: Send in poster **December 18**

January
Week 2
Deadline: Send in correct poster **January 15**

January/February
Week 4–5
Classes vote on posters **(January 20–29)**

February
Week 10
February 12 - Closing Conference


Time schedule for the Star Hunt
Blue = Nobel Prize Museum
Orange = Chalmers
Green = Schools
Digital start-up conference Sep 11, and with a test session on Sep 10
Star date 1 with the scientists Sep 25
Star date 2 with the scientists Nov 2
Nobel Prize Awarding Ceremony Dec 10
Poster work until Dec 18
Correct posters until Jan 15
The grand jury will select the winner of the grand prize Jan 29
Sep 20
Okt 20
Nov 20
Dec 20
Jan 21
Feb 21
Work with Intro and Exercise 1
Work with Exercise 2
The students send in data Oct 23
The students send in data Nov 20
Individual Star Dates with the scientists to discuss the results.
The students vote for their favourite poster
Closing conference at NPM Feb 12
Individual Star Dates with the scientists can be booked at any time during the project

Background Information for the Star Hunt

In the Star Hunt we are going to carry out astronomical research to explore how new stars are being born in our Galaxy, also known as the Milky Way. We will first learn a little about the history of astronomy, how we study the Universe using telescopes to analyse light we receive from space and the importance of the formation of stars for the evolution of our Galaxy and for producing other planetary environments that may be suitable for life.

History of Astronomy and the Map of the Sky

Since ancient times, humans have been staring at the sky and wondering about the nature of celestial objects, from the brightest like our Sun and Moon to the thousands of stars visible in the night sky. The study of all these celestial objects is called Astronomy. At first the objects in the sky were attributed special powers and worshiped as gods and goddesses. For example, the Ancient Greeks identified shapes in the apparently fixed distribution of stars in the night sky that they related to heroes and characters of their mythology. One example is Orion the Hunter. Many of the constellations we use to find our way around the night sky are inherited from these early times. Although we now know that stars are actually orbiting in our Galaxy, they do not appear to move much from year to year or century to century. They thus appear to define a fixed pattern of shapes scattered around us in all directions. This pattern of stars defines the Celestial Sphere, which is basically our "Map of the Sky" (see Figure 1.1a). The Celestial Sphere is divided into 88 constellations, so that any location in the sky belongs to a constellation.

In Astronomy, it is essential to know where things are in the Celestial Sphere, so now astronomers have agreed on the Equatorial Coordinate System (see Figure 1.1b). Two coordinates specify the position in the sky, Right ascension (RA) and Declination (DEC), similar to how longitude and latitude are used to specify a location on the surface of the Earth. To measure RA and DEC, astronomers slice the Celestial Sphere, vertically into semicircles between the celestial poles and horizontally into parallels, similarly to what is done with the Earth's surface. The parallel that corresponds to DEC angle 0 degrees is called the Equator, while the RA of 0 deg is measured at the Vernal Equinox. RA measures eastwards on the celestial sphere from the vernal equinox and is like longitude on the Earth. DEC measures north and south on the celestial sphere with respect to the equator, and is like latitude on the Earth. Here we will measure RA and DEC in degrees, arcminutes (60 arcminutes in each degree) and arcseconds (60 arcseconds in each arcminute). Recall there are 360 degrees around a full circle!

An important and useful star to recognise is Polaris, which is very close to the North Celestial Pole (see Fig. 1.1a). Thus, if you were standing at the North Pole on the Earth, Polaris would be directly overhead. What is the value of DEC of Polaris? Does this make sense to you? Locating Polaris in the sky is very useful, since that tells you which direction is North. One way to find Polaris is to follow the line of two bright stars in Ursa Major (the Great Bear) (see dotted line in Fig. 1.1a).

The winter night sky looks different from the summer night sky because the night side of the Earth, i.e., away from the Sun, is pointing to the opposite side of the Celestial Sphere

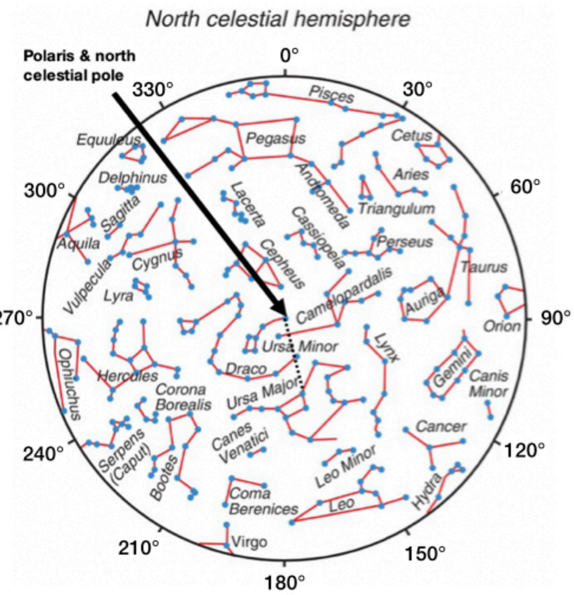
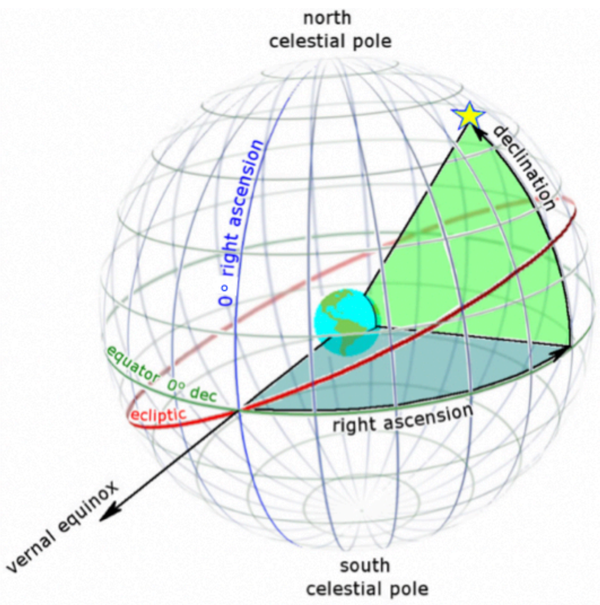
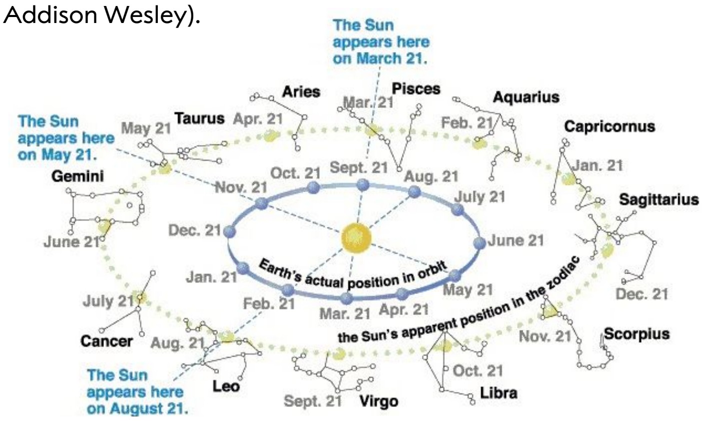


Figure 1.1: (a) Left: The constellations of the North Celestial Hemisphere (credit: A Question & Answer Guide to Astronomy, CUP, Christian & Roy). The star Polaris is marked with the arrow. Polaris is close to the North Celestial Pole, i.e., the direction directly above the Earth's North Pole. **(b) Bottom Left:** This figure summarises the components of the celestial sphere. Two angles, right ascension (RA) and declination (DEC), are used to specify a position on the celestial sphere, which tells us the direction in which to locate an object. Since the Earth is spinning on its axis from West to East, if we look up at the sky it appears that the whole celestial sphere is spinning around us in the opposite direction. This causes celestial objects, including the Sun, to appear to rise up out of the East and arc across the sky and then set in the West. Note, the stars are also rising and setting! At any given time of the year, the Sun is at a particular location in the Celestial Sphere. But because the Earth orbits the Sun, this direction changes: over the course of 1 year, the direction sweeps around a full circle, called the Ecliptic. **(c) Bottom Right:** Representation of the Earth going around the Sun and how the Sun's position in the Celestial Sphere as viewed from the Earth changes over the course of a year. The Sun appears to move on a Great Circle called the Ecliptic, which crosses through 12 constellations (credit: Addison Wesley).





compared to 6 months earlier (see Figure 1.1c). Look up at the sky in the day time. You can't see stars because the Sun makes the sky bright, but there are stars there in that part of the Celestial Sphere! Six months from now, if you look up on a clear night, you would see these stars. At any given time the Sun is at a particular location in the Celestial Sphere. In fact, over the course of a whole year, the Sun appears to move along a "great circle" around the Celestial Sphere, which we call the Ecliptic. The ecliptic crosses 12 constellations, known as the Zodiacal constellations and maybe familiar to you from Astrology. By the way, never confuse a modern Astronomer with an Astrologer - the Astronomer will get very upset, since there is no scientific basis for Astrology… it is nonsense!

Fun fact: The Babylonian calendar was based on motions of the Sun and Moon through the sky. The calendar consisted of 12 months, like the one we use today, but their names were...slightly different! However, each month based on the changing phases of the Moon takes 29.5 days and so 12 months is less than 1 full year of the Earth going around the Sun. So extra "intercalary" months were often needed, otherwise a "summer" month or a "crop planting" month would have eventually been in the wrong season! :-)

Objects in our Solar System, like the Sun, but also Earth's Moon and the planets, appear to move through the fixed pattern of stars of the Celestial Sphere. Ancient astronomers noted there were 7 objects they could see that moved: the Sun, the Moon, Mercury, Venus, Mars, Jupiter and Saturn. This is why we have the 7 days of the week, of course! The other planets Uranus & Neptune are too faint to see with the naked eye and were not discovered yet - if they had been we might have had 9 days in the week! Many early civilisations, such as the Babylonians, used the motion of the Sun through the Celestial Sphere to predict seasons and that of the Moon to build up calendars. This was crucial for planning agriculture activities, on which their civilizations depended.

Throughout history, men and women devoted themselves to the study of celestial objects, making important discoveries such as the concept of the Earth being a sphere (and not a flat disk!), the idea that all the planets in our Solar System orbit around the Sun, the nature of other stars and galaxies, and eventually the Big Bang theory for the beginning of the Universe. (For a timeline of observational discoveries in Astronomy see https://en.wikipedia.org/wiki/Timeline_of_astronomy). Indeed by finding and explaining patterns in the sky, Astronomy helped develop the Scientific Method and it can be regarded as the oldest science. It is also remarkable that early astronomers had no telescopes at their disposal to make their discoveries. Indeed, it was only in 1609 (as we will see later) that the first telescope was used to study celestial objects.

Nowadays, we have built an incredible number of telescopes and instruments that allow us not just to study the planets of our solar system, but to look at other solar systems in our Galaxy and the light from stars in other galaxies far across space, emitted long ago when the Universe was young. Below, we will learn how astronomers carry on their day-to-day work to better understand the nature of celestial objects. Astronomers are trying to answer some big questions, like: Where did the Sun and Earth and all the other solar systems come from? How was our Galaxy born and how will it change ("evolve") through time? Are we alone in the Universe?

All you need is light!

Stars are very far away. The closest star to us, Proxima Centauri, is located at a distance that is about 270 000 times that between the Earth and the Sun. This means that even traveling at the fastest speed possible, the speed of light = 300 000 km s^{-1}, it would take just over 4 years to travel to Proxima Centauri. This "light travel time" is used by astronomers to describe the distance to an object: we say Proxima Centauri is just over 4 light years away. Note, it takes light just over 8 minutes to reach us from the Sun (calculate how many years is 270 000 × 8 minutes as a check). That means when we look at the Sun we are seeing it as it was 8 minutes ago. When we look at Proxima Centauri, we are seeing it as it was more than 4 years ago. The further away we look, the further back in time we are probing. So astronomers are not only explorers, but also historians!

Since stars are so far away, astronomers cannot carry out experiments in the same way as a chemist would to study a new substance in a laboratory. Hence, astronomers need to find a way to study objects from huge distances. Light is the answer! The light coming from a celestial object carries with it information that can tell us what it is made of, how massive and big it is, what its temperature is and much, much more. To study the light emitted by very distant and faint celestial objects (galaxies, stars, planets, etc.), astronomers need to build special instruments, called telescopes. In the next Sections, we will learn how astronomers use light to study objects in space and what kind of telescopes they need.

The different kinds of light

Before we discuss telescopes, it is important to explain that there are different kinds of light. Light can be thought of as either a stream of tiny packages of energy, called photons, or as a wave of electric and magnetic force fields. Admiring the different colours of flowers or in a beautiful sunset is possible because objects emit different types of light that is caught by our eyes and processed by our brains. If you imagine light as a wave, the different colours that we see correspond to waves of different lengths. As an example or another kind of wave, when you shake a piece of rope, you create waves that are shorter when you shake very fast or longer when you shake slowly. This is the same for light: a short wave would appear to us as violet or blue, while a longer wave would appear to us as orange or red. However, the different visible colours are not the only types of light that exist: there are many more that our eyes are not equipped to detect. All the different types of light together form what is called the Electromagnetic Spectrum (see Figure 1.2).

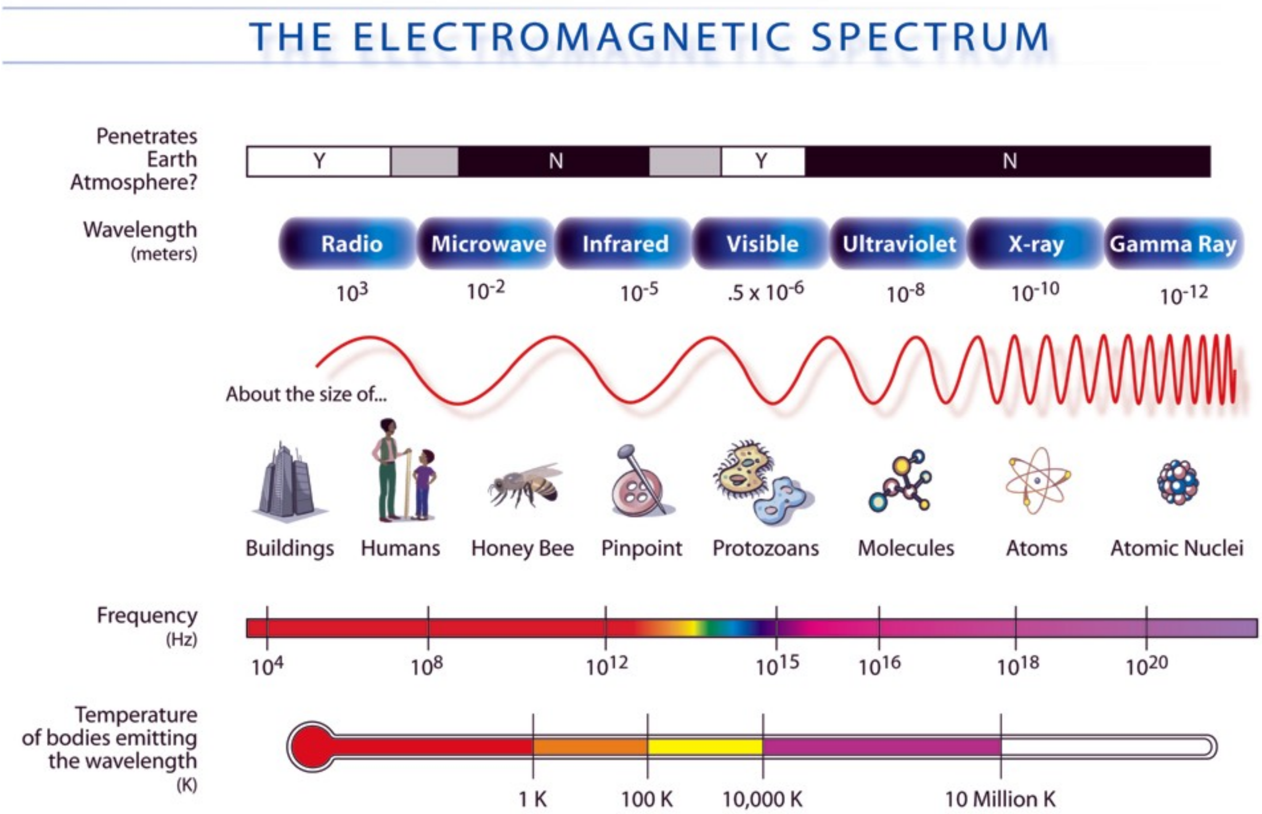


Figure 1.2: The electromagnetic spectrum (credit: NASA)

To classify all kinds of light, scientists measure the length of the waves, this is called the wavelength! The wavelength indicates how long or short a light wave is and it is defined as the distance between two neighbouring crests (or troughs) in the wave. Wavelength is indicated by astronomers with the Greek letter λ. Waves that have shorter wavelengths carry more energy. Gamma-rays are the most energetic light-waves known and their wavelength is smaller than an atom. In space, they can be produced when a very massive star explodes. X-rays, like those used by doctors to check bones, are a little bit longer. Then comes ultraviolet (UV) and next the visible band of light from blue to red. Infra-red (IR) waves are longer still, followed by microwaves, which may have cooked your dinner. Finally radio waves have the longest wavelengths - they could be as big as a football field, or a mountain or a planet... there is no limit!

As we said, our eyes are only able to detect a small portion of the electromagnetic spectrum: so-called visible light. The visible light corresponds to the colours from red to violet that we are very used to. However, many times all or some of these colours reach our eyes mixed together and appear to us as white, for example the kind of light emitted by the lamp on your desk. Such white light can be separated into its constituent colours. If you look outside your window after a very rainy day, you may spot these separation process in the sky in the form of a rainbow. The physical process responsible for the separation (or dispersion) of the visible light into its colours is called refraction (see Figure 1.3).

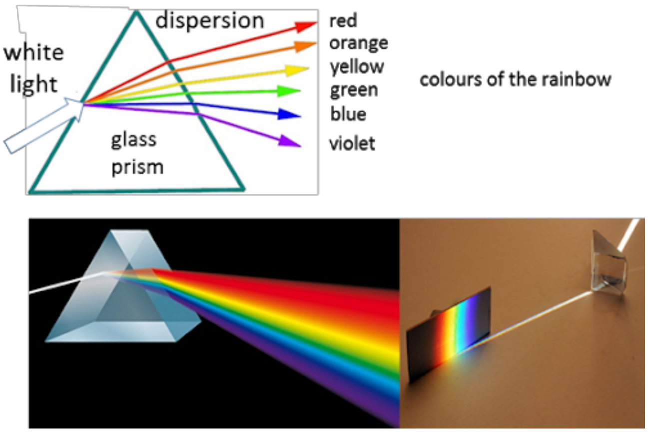


Figure 1.3: White light is split into its component colours by refracting through a glass prism (credit: PNGImage).

Let us now follow the journey of white light through a piece of glass shaped as a prism. The white light is composed of different colours, each of them with its own wavelength. When entering the prism, each colour travels along a different direction and hence will be separated from the other colour components. In this way, the light that exits the prism is no longer white and all the colours can be identified! This effect can happen when light travels from one kind of substance (like the air) to another (like glass or water). Note that light waves, unlike sound waves, can also travel through the vacuum of space, which is crucial for astronomy!

How to use light to study an object

Scientists use light to investigate the nature of a multitude of objects. Astronomers use the light emitted by celestial objects to study their distances, sizes, temperatures, chemical compositions, and more. Doctors use light to look under the skin of a human body. Chemists investigate light coming from chemical mixtures to identify the substances in the mixture. How is all this possible? When white light is shone into a chemical element, i.e., the element is irradiated, some of the colours will be absorbed and blocked by the element. For example, if you irradiate Hydrogen (the simplest of the chemical elements) with white light, some particular blue, indigo, cyan and red components of the light will be blocked. Hence, when the light coming out from the Hydrogen is passed through a prism, it will appear mostly with the full spectrum, but with some dark "absorption lines". This is what scientists call an absorption spectrum. In a similar way, if you warm up a chemical element or spark it with electricity, it can start to emit some light. In the Hydrogen example, if the light emitted is passed through a prism, only a few different colours will appear and these are the same that are absorbed in the earlier example! The colour components emitted by a chemical element make up what scientists call an emission spectrum (see Figure 1.4).

Both the absorption and emission spectrum are unique for each chemical element. They represent the equivalent of chemical fingerprints, that can be used to identify the chemical composition of an object. By studying emission and absorption spectra, astronomers can find out what a star or planet is made of.

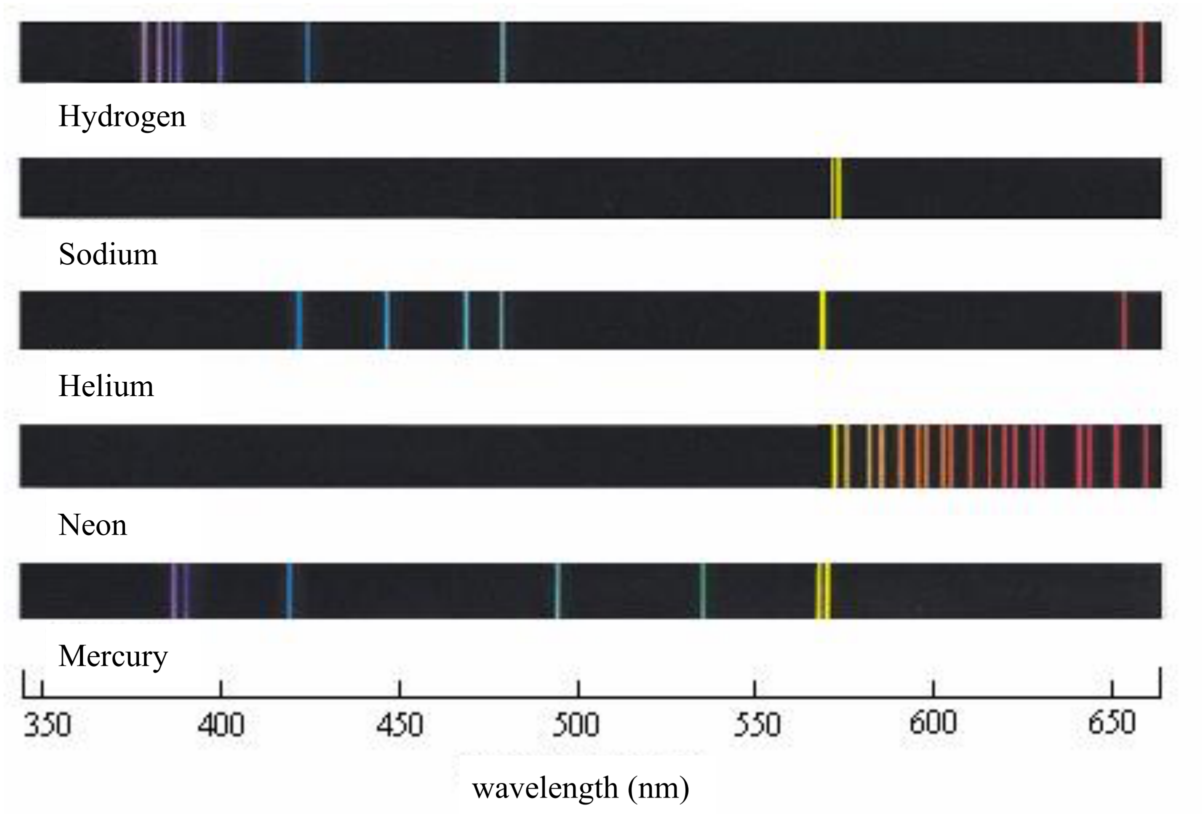


Figure 1.4: Emission lines from different chemical elements. By detecting the wavelengths of emission (and absorption) lines in the light from celestial objects, astronomers determine what they are made of. In fact, Helium was first discovered in the light from the Sun and hence its name (from the Greek Helios for Sun; credit: AS Chemistry Revision Guide)!

Fun fact: The energy carried by light waves can be very dangerous for the human skin. The UV light that our Sun emits is responsible for causing sunburn if you spend too much time outdoors on a very sunny day. However, if exposed to it with moderation, UV light helps your body to produce vitamin D that makes you happy :-)

Also the main colour emitted by a star is a good indication of its temperature: blue objects tend to be hotter; red objects cooler (see bottom row of Figure 1.2). Objects that are cooler than stars, like planets, emit mostly in the infrared. And very cold clouds of gas and dust in interstellar space that we will meet later emit mostly at even longer wavelengths in the infrared or even microwave parts of the spectrum.

By characterising the light from a star, astronomers can also estimate its size and its mass, i.e., how much matter it contains. It turns out that there are a wide variety of stars, some much larger, more massive and more luminous than our Sun, and some much smaller, of lower-mass, and less luminous. Why there is this variety is still not fully understood. In our project we will be looking at regions that are forming some of the most massive, largest and most luminous stars to try and help answer this question.

Build your own spectroscope

Scientists studying the light emitted or transmitted by an object (a star, a planet, a lamp, a molecule, a bacterium etc.) need to build instruments that allow them to easily separate the light into its component colours. One way to do this is with a prism. Another is with an instrument called a spectroscope. A spectroscope is an instrument that directs some light into a narrow slit and then disperses it into its component colours. This is simple enough that you can build your own! Find the instructions on the webpage http://cosmicorigins.space/starhunt.

Fun fact: In the case of a rainbow, the light travels from the air to the rain water drops. By entering and exiting these drops the white light is refracted and the rainbow appears. Sadly enough, refraction cannot make the pot of gold appear as well :-)

To each light its own telescope

As we have seen, there are different types of light and that seen by our eyes is only a small part of the electromagnetic spectrum (see Figure 1.2). Other types of light, such as infrared or ultraviolet, are also emitted by celestial objects but cannot be seen by our eyes. Some objects in space do not emit visible light at all and can only be studied by the light that they emit at infrared, ultraviolet or other wavelengths, like X-rays. Hence, how do astronomers study these objects without seeing them? The answer is to build special detectors that are able to sense such “invisible light” that objects emit. These detectors are placed within telescopes that focus the light to the detector, thus magnifying and concentrating the light, which allows faint objects to be seen in fine detail.

In 1609, Galileo Galilei, the Italian astronomer and physicist, was the first person to use a telescope to study celestial objects. A telescope is used to collect the light from an object and to focus it toward a point to produce a bigger, brighter image of it.

The main purpose of telescopes is to make distant objects appear bigger and brighter so that their study is easier, since many more details can be seen. How exactly a telescope focusses and detects light depends on the type of light being observed. For example, telescopes that collect radio waves work in a way similar to modern optical telescopes by reflecting the waves with a curved mirror to concentrate them to a detector. However, the materials used in the mirror are very different. For X-ray telescopes, because X-rays are very penetrating, it is very difficult to have them bounce off mirrors, so special materials (including gold foil!) and mirror designs need to be used. Hence, each type of light needs to have its own telescope! Some different examples of telescopes and the wavelengths they observe at are shown in Figure 1.5.

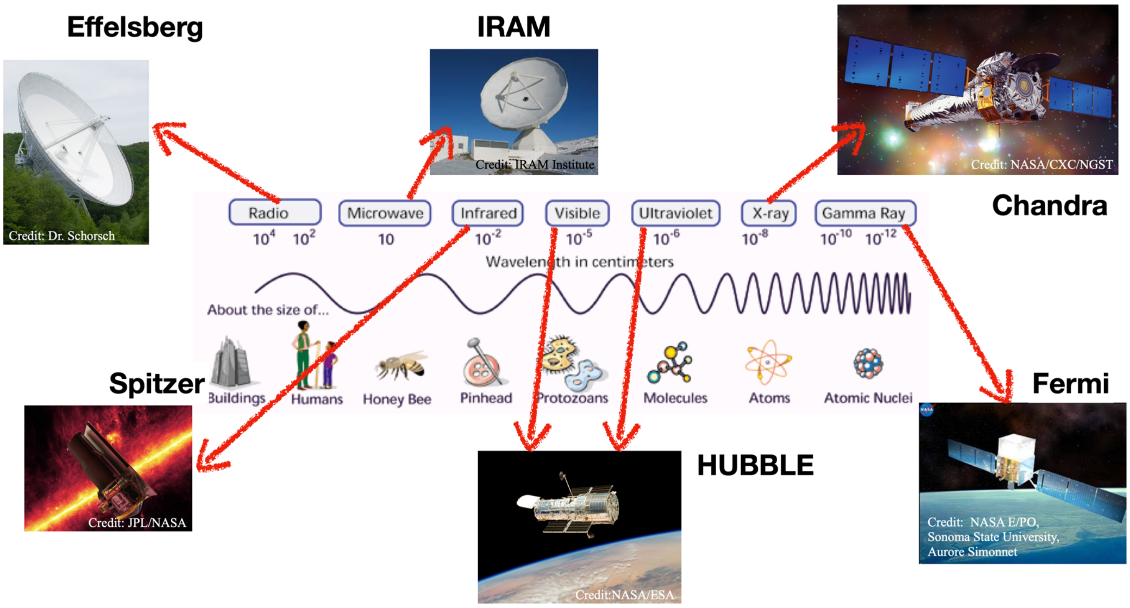


Figure 1.5: Examples of different telescopes and the wavelengths they observe (credit: The Electromagnetic Spectrum Google Sites).

As you may have noticed from Figure 1.5, some telescopes are located on the Earth while some others are sent to space and are orbiting around our planet. The reason why not all telescopes can be placed on the Earth is due to our planet's atmosphere. The atmosphere is a set of gaseous layers surrounding our planet. The molecules that compose the atmosphere block many kinds of light, like gamma-rays, X-rays, ultraviolet, and most infrared wavelengths (see Figure 1.6). Hence telescopes built to collect these types of light often need to be sent above the atmosphere. In particular, gamma-rays, X-rays and ultraviolet rays are blocked by the upper atmosphere, so telescopes need to be in space. One of the most famous X-ray telescopes orbiting our planet is called Chandra. This telescope was sent to space in July 1999 (last year it turned 20!) with the aim to observe the most energetic regions of the sky, like the remnants of exploded stars.

Infrared light is blocked much closer to the Earth (around 5 to 30 km from the planet surface, including by clouds of water vapour) and hence it can be observed either from space or from telescopes built on high mountains or even placed on airplanes that fly about 10 km above the Earth's surface. One famous telescope observing infrared emission from space is called Spitzer, in honour of the astronomer, Lyman Spitzer, that first proposed to send telescopes into space. The Spitzer Telescope was launched in 2003 and only recently in Jan. 2020 has stopped sending us back infrared images of the sky.

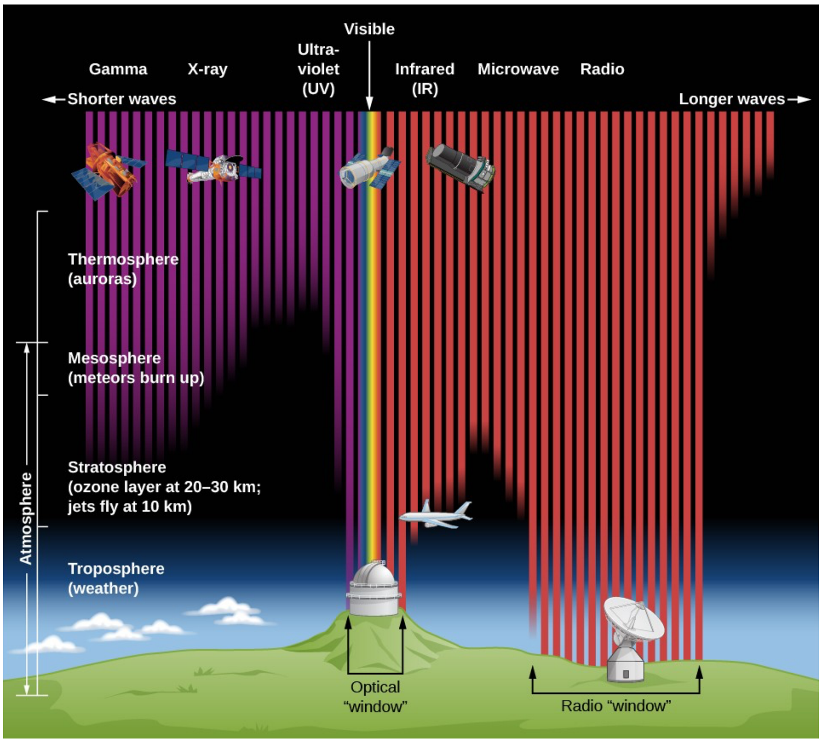


Figure 1.6: The penetration of different wavelengths of light through the Earth's atmosphere. Only visible and radio wavelengths easily make it all the way down to the ground! (Credit: Chandra Mission and Space Telescope Science Institute)

Finally, visible and radio light are not blocked very much by the atmosphere and hence telescopes aimed to detect these kinds of light can stay on the ground. Of course, it is easier to build bigger telescopes that collect more light if they are situated on Earth. However, the water vapour that is present in the atmosphere and the light pollution and radio interference coming from big cities can impact the functioning of these telescopes. For example, you may end up observing the light emitted by your neighbor's house instead of the light coming from a star! Hence, these telescopes are usually built in very isolated places, especially at the top of high mountains to try and be above most of the clouds.

Some examples of telescopes include the following. The biggest radio telescope built so far is called ALMA and is composed of more that 60 smaller telescopes all placed on a plateau high in the Atacama Desert in Chile at an altitude of 5000 m. One of the biggest optical telescopes is also in the mountains in Chile and is called the Very Large Telescope (VLT) run by the European Southern Observatory (ESO) of which Sweden is a member country so that scientists working in Sweden have access. One of the most iconic telescopes is the Hubble Space Telescope (HST), which has produced some of the most astonishing images in almost every field of astronomy. For example, Figure 1.7 shows the Carina Star Forming region where many thousands of stars are being born.

Fun fact: Galileo did not invent the telescope. His true genius was to point such an instrument to the sky and systematically report what he observed! Among the several discoveries made by Galileo with his telescope are the first observations of the "phases" of Venus (i.e., it can appear as a crescent, half-circle or full circle, just like the Moon) and the first observations of Jupiter's four largest moons (Io, Europa, Ganymede, and Callisto).

Figure 1.7: The Carina Nebula observed by the Hubble Space Telescope (HST) at optical wavelengths. Thick clouds of gas and dust are revealed at these wavelengths, which cannot penetrate any further. Image Credit: ESA/NASA.

The importance of studying stars and how they form

As we discussed earlier, astronomers use the light emitted by stars and other objects in space to study their composition, size, mass, temperature and, more generally, the laws of physics they obey. But why is this important? What is it that astronomers are trying to learn? Some of the big questions we are trying to answer are: How do galaxies, stars and planets form and evolve? How did our own Galaxy (the Milky Way), our own star (the Sun) and our own planet (the Earth) form and how are they evolving? Are they special compared to other galaxies, stars and planets? What are the main chemical ingredients needed to form life? How did these end up on our planet? What else was needed for life to originate on the Earth? How common is life in our Galaxy and other galaxies?

Fun fact: The ALMA telescope is located so high that astronomers need to pass a medical test for altitude sickness before being allowed to go up there and in any case they are not allowed to spend more that two weeks at the telescope site. At such a height, your body spends so much energy only to keep you at the usual temperature of 37 degrees that you can eat all the chocolate you want....without feeling guilty about it!

On the Earth, the main source of energy that provides sustenance to most forms of life comes from our Sun. Astronomers and biologists think that life will generally needed a planetary environment similar to that of the Earth, i.e., with a solid surface crust rather than being a gas giant planet like Jupiter or Saturn. All life on Earth uses liquid water (H_2O), so water will need to be present on the planet and the temperature will need to be in a range that allows water to be in liquid form, rather than as ice or as steam (This temperature range is 0°C to 100°C in the Celsius scale or 273 K to 373 K in the Kelvin scale). The planet will also need a protective atmosphere of gases. The surface temperature of the planet will be set by the light it receives from its host star, which means a planet cannot be too close or too far from its star. This defines a "habitable zone" around the star in which planets need to be if they are to host life. Stars that are more massive than our Sun are also more luminous (they emit more light energy), so their habitable zones are larger. Stars that have less mass than our Sun are less luminous (they emit less light energy), so their habitable zones are smaller. The star should also be able to shine for long enough so that life can form and evolve. It took about 4 billion years for life on Earth to reach the point of having more complicated multicellular organisms. So complex, intelligent life forms may need their host stars to exist for at least 1 billion years or so. As we will see below, not all stars live this long.

In the last decade, an incredible number of planets (more than 4000!) orbiting stars similar to our Sun have been discovered. These planets are known as exoplanets and are located outside our Solar System. Some exoplanets are rocky and similar to our Earth, while others are like Jupiter and are mainly made up of gas. These exoplanets orbit around a host star and some of them are at the right distances to be in their star's habitable zone.

Thus we can see that the existence of life depends on stars and planetary systems. We think planets form almost at the same time as their host star. So to understand the birth of habitable planetary environments and how common they are in the Universe, we need to understand the overall process of star and planet formation, along with the evolution of the stars and planets after they are born.

To best understand star formation, astronomers try and observe stars in our Galaxy that are currently being born (we call these protostars) or have just recently formed (we call these young stellar objects - YSOs). As we will see in the next section, we now know that star formation happens when gravity compresses clouds of gas and dust that are in interstellar space. However, it can be very difficult to directly detect the light coming from a forming star. This is because they are usually very far away, or because they are forming in groups, called stellar clusters, that makes it challenging to separate out the individual protostars and YSOs. The presence of gas and dust tends to block the optical light from the forming stars, so usually other wavelengths of light, like infrared and radio, are needed to penetrate into the clouds.

Astronomers need to study not only the protostars and YSOs, but also the clouds of interstellar gas and dust from which these stars are forming. This interstellar gas is mostly composed of the simplest, lowest mass chemical element, Hydrogen, which has symbol H. Next most abundant is Helium (symbol He), which is the second lightest element, but there is only 1 He for every 10 H. Then all the other "heavy elements", like Carbon (C), Oxygen (O), Silicon (Si), Iron (Fe), are much less abundant. At most they are present at a level of about 1 atom per 10 000 Hydrogens! Adding all the mass of these heavy elements together makes up about 2% of the total, which is dominated by H. Of this 2%, about half is in the form of gas, while the other half is in the form of small dust grains, containing C, Fe and "silicates" with Si and O. The Sun and other stars have the same composition as this interstellar gas, while Jupiter is also mostly made of H. The Earth on the other hand is mostly made of the heavy elements that are found in dust grains. This information gives us clues about how stars and planets form.

The particular clouds that form stars are known as molecular clouds. The name is due to the fact that the Hydrogen they contain is in the form of molecules with two H atoms bonded together (we write this as H_2). The heavy elements in the gas can also be in the form of molecules. Some of these are quite simple like carbon monoxide (CO) and water (H_2O), while others are more complicated such as methanol (CH_3OH) or C60 (60 atoms of Carbon all chained together!). One important finding is that many of the molecules we think are important and necessary for life on Earth, including building blocks of amino acids from which proteins are made, have been observed in molecular clouds and so will be available to other forming planetary systems. Many amino acids have also been found in comets, asteroids and meteorites in our Solar System, which are thought to be remnant material from the formation of the Sun and the planets. Hence, studying stars and the molecular clouds in which they are born can also help us to understand our own history and the processes that enabled life on Earth.

Fun fact: More that 150 different molecules have been detected in space, for a complete list have a look at this webpage https://cdms.astro.uni-koeln.de/classic/molecules. Have you noticed that salt (NaCl) is in the list?

In the next section, we will see what astronomers have learned so far about the "lives" of stars, including how we think they are born and how they eventually die.

Star Formation and the Stellar Life Cycle

Stars are not eternal. They are born at a particular time and then go through several phases during their life and then eventually die in various ways depending on the initial mass of the star. Astronomers refer to this evolutionary path as the stellar life cycle.

Although, stars are very hot and bright objects in space (especially compared to planets), they are born in the coldest and darkest regions of our Galaxy: the molecular clouds introduced in the last section. Molecular clouds are among the coldest regions known in the Universe. They can have temperatures lower than -250°C (note, the coldest one can reach is -273°C, which is known as "absolute zero" or 0 K in the Kelvin scale of temperature). Since the temperature is so low, some of the molecules in the cloud freeze and produce a layer of ice on the interstellar dust grains that are mixed in with the cloud.

Molecular clouds are quite dense compared to other regions of space (the "interstellar medium" - ISM) in our Galaxy: 1 cm^3 of volume of a molecular cloud often contains more than 1000 H_2 molecules. This means there is also a relatively high concentration of dust grains in molecular clouds and these grains tend to absorb visible light, especially shorter, "bluer" wavelengths (this is the similar to the reason why a sunset appears red, since the blue light has been more absorbed and scattered by particles in our atmosphere). Thus molecular clouds often appear as dark holes in the night sky since they block the light from background stars (see Figure 1.8).

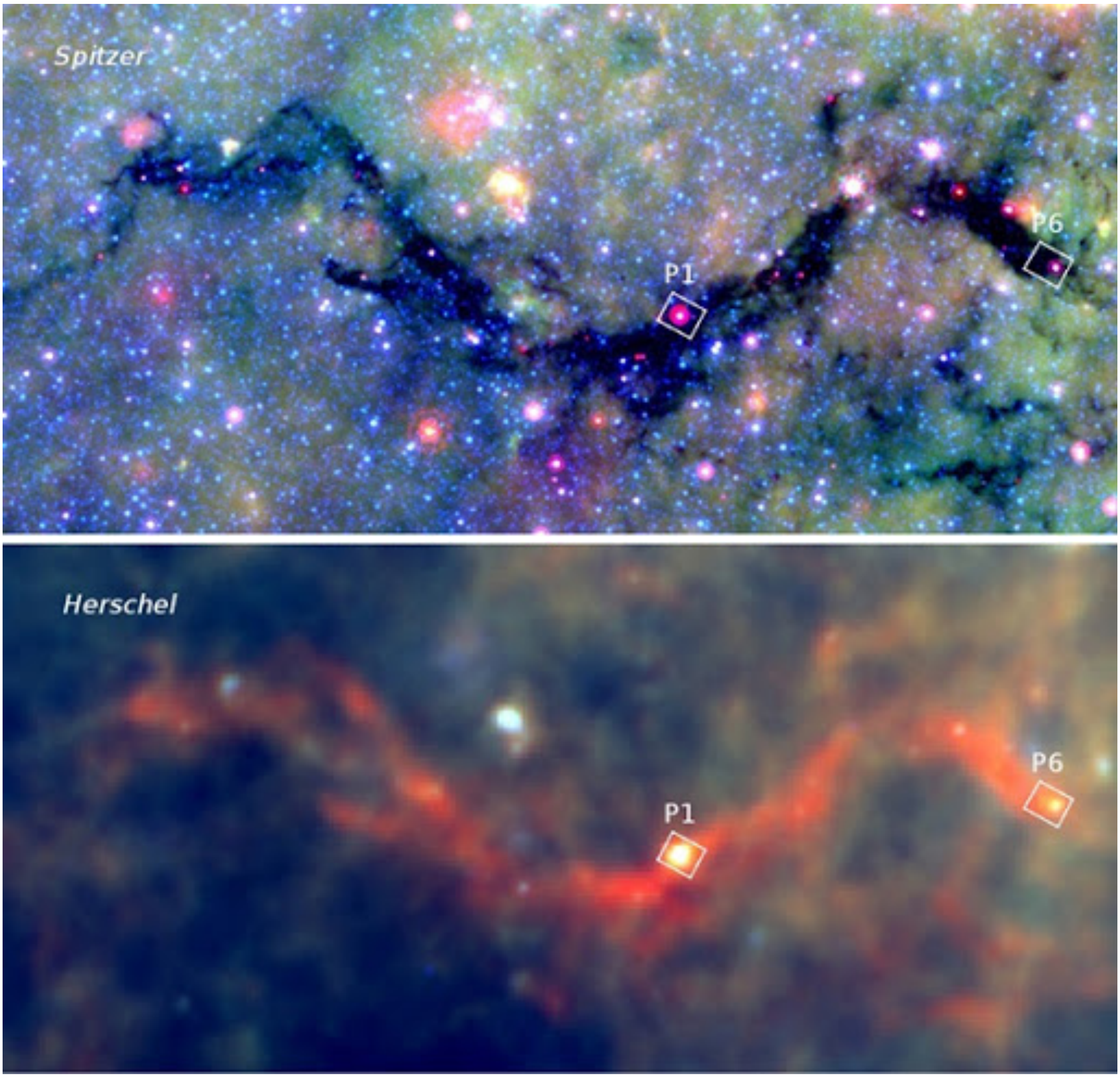


Figure 1.8: An example of a dense interstellar molecular cloud, known as "The Snake". The top image is taken with the Spitzer Space Telescope at quite short infrared wavelengths. The Snake is so dense and contains so much dust that these infrared wavelengths are absorbed by the cloud and we see it appear as a dark shadow. Objects like The Snake are known as "Infrared Dark Clouds" (IRDCs) and we will be studying them as examples of clouds that are just beginning to form stars inside, like the "P1" and "P6" objects that have been marked. The bottom image shows the same region of the sky, but now viewed at longer infrared wavelengths with the Herschel Space Telescope. See how The Snake now glows bright because its cold dust is emitting strongly at these wavelengths (credit: Jean-Charles Cuillandre).

However, molecular clouds also emit their own light. Since their temperature is so low, they can only emit light waves that have very long wavelengths and that carry very little amounts of energy. Hence, molecular clouds emit radio waves, microwaves and very long infrared waves. When telescopes observing at these wavelengths are pointed toward molecular clouds, they see the clouds glowing in this radiation (see Figure 1.8).

At some point, certain parts of molecular clouds start to become denser and denser. In Figure 1.8, examples of these regions are indicated as P1 and P6. The material accumulated in such spots begins to fall under its own weight. Astronomers call these condensations of gas and dust protostellar cores. The energy of gravity is liberated to heat up the gas and dust and the protostellar core begins to shine brighter and brighter and at shorter and shorter wavelengths.

At the centre of a protostellar core is a protostar. This is an object which is no longer contracting very quickly since it has become very hot and with a high pressure inside and this pressure pushes back against gravity. In this sense, protostars are like normal stars, such as our Sun. However, there are important differences. Protostars are still surrounded by lots of dense gas and dust, which are falling to join the protostar: we say that the protostar is "accreting" mass. How this accretion happens is still very uncertain. One reason for this is because protostars have so much gas and dust around them, the light they emit from their surfaces is almost completely blocked and we mostly see only the longer wavelength light from the surrounding dust. So it is hard to see what is really happening inside a protostellar core.

Astronomers think (i.e., they make a hypothesis) that the gas and dust falling onto the protostar will first start to spin quickly and settle into an orbiting disk, called an Accretion Disk. The reason for this is a law of physics called the Conservation of Angular Momentum. The Angular Momentum of an object is related to its size multiplied by its rate of spin. If an object is already spinning, then if it contracts and get smaller then it has to spin faster. You can experience conservation of angular momentum for yourself if you set yourself spinning (it is easier on ice!) with your arms out and then quickly bring your arms in close to your body... you will spin faster! Eventually the spinning is so fast that the material around a protostar settles into an almost circular orbit. One clue that our Sun formed from an accretion disk is that the planets all orbit on nearly circular orbits lined up in nearly the same plane and all going in the same direction around the Sun. We hypothesise that the planets of the Solar System formed from the Sun's remnant accretion disk of gas and dust.

Once material is in circular orbit in an accretion disk, how does it end up reaching the central protostar? We do not yet know the answer! One possibility is that the gas reaching the protostar has to lose its angular momentum by giving it to other matter, which is then ejected out to large distances from the top and bottom surfaces of the accretion disk. This process may require magnetic fields, which are also spinning with the disk, and these then cause the "protostellar outflows" to become collimated into two powerful jets. If you look closely at Fig. 1.7, there is at least one clear example of collimated jets emerging from opposite sides of a protostellar core. Can you see them?

Although astronomers have an idea of how protostars form from molecular clouds, there are still many unanswered questions. We do not know why stars are born with the masses that they have, which can range from 10 times smaller to >100 times greater than than of the Sun. About half of the stars we see in the sky are actually binary stars, i.e., a pair of stars orbiting around each other, unlike our Sun, which is a single star. We do not know why this is. While our Sun is now single, we think it was originally formed in large cluster with many other sibling stars. We can see young clusters forming in our Galaxy, but we do not know why this is so, or why most stars in these clusters eventually escape, like our Sun did, to orbit freely in our Galaxy. By studying protostars and recently formed, young stars, we aim to answer these and other questions. In the Star Hunt, we hope you can help us in this research!

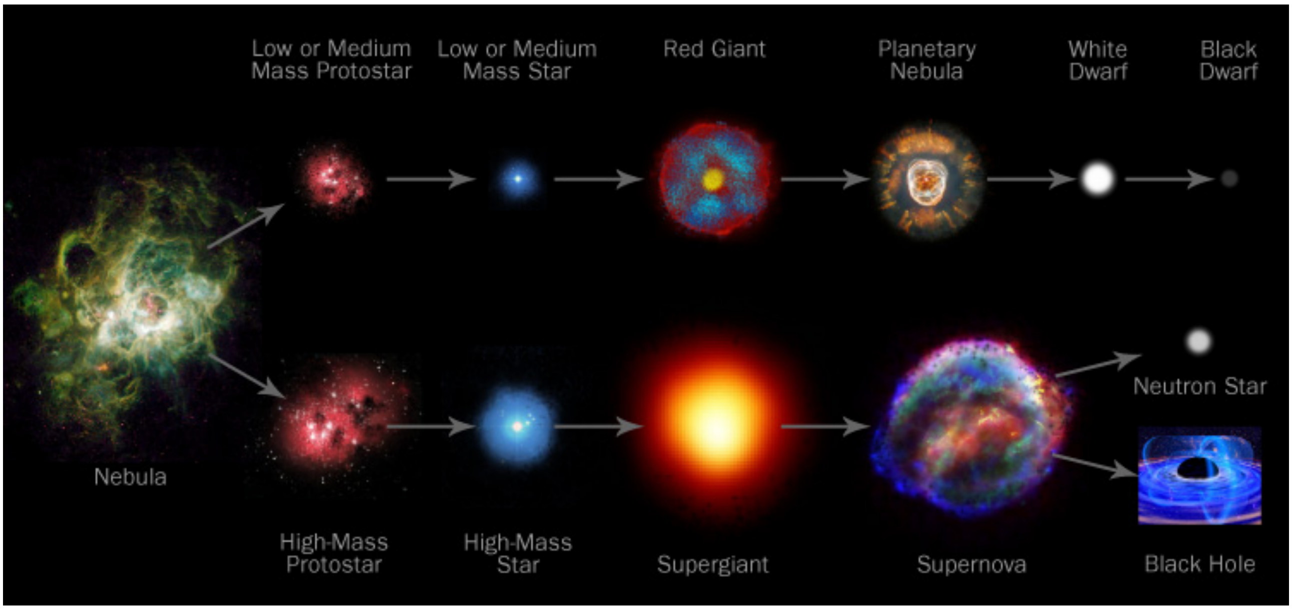


Figure 1.9: The Life Cycle of lower-mass (top row) and higher-mass (bottom row) stars. (Credit: American Board Website)

Somehow star formation from molecular clouds, probably involving accretion disks, outflowing jets, heated dust and star clusters, leads to young stars with a wide range of masses and with many in binary systems. The stars themselves then undergo the process of stellar evolution, to complete their life cycle, eventually dying in different ways, some quite violent.

The basic idea is that stars need to keep supporting themselves against gravity, so they need to keep their pressures high in their centres. But this requires energy. At first the energy comes from gravity as the protostars and most young stars slowly contract. The temperatures at the centre eventually reach a very high level of 10 000 000 K, which is hot enough for the process of nuclear fusion of Hydrogen into Helium to occur. Note, the surface of the star is much cooler: for the Sun it is "only" 6 000 K, while for higher-mass stars it can be 30 000 K. These are very hot temperatures compared to planets, but far too cool for fusion, which only happens deep inside the stars.

The H in the core of a star is the fuel that provides the energy they need to resist gravity and while they are fusing this H, we say that the stars are in their main sequence part of their life cycle. This is the longest phase of a star's life, lasting about 90% of the total. However, the total lifetime depends sensitively on the mass of the star. For a star like our Sun, which is in the middle of its main sequence phase, this lifetime is about 10 billion years. Scientists estimate that the Sun was born 4.6 billion years ago. However, a star that is 10 times the mass of the Sun has much stronger gravity so needs to fuse its Hydrogen at a much faster rate. This means it runs out of H after only about 10 million years. Conversely, stars 10 times lower in mass that the Sun fuse their H much more slowly, so remain in the main sequence phase for about a 1000 billion = 1 trillion years!

"Fun" fact: Currently, the Sun is in the middle of its main sequence stage. In about 5 billion years from now it will become a red giant and expand to engulf Mercury and Venus. Earth's oceans will boil and we will need to leave!

Once a star has run out of H in its core, the core starts contracting and reaches even hotter temperatures of 100 000 000 K, which is hot enough to fuse He into heavier elements like Carbon and Oxygen. During this phase, both low-mass and high-mass stars end up swelling to become very large. Our Sun will become what is called a "Red Giant", while high-mass stars, e.g., those with more than 8 times the mass of the Sun, become "Supergiants". For low-mass stars, the outer layers of the red giant are eventually flung out into space creating an object known as a "Planetary Nebula" (note, this name is misleading as it has nothing to do with planets!). The dense, hot core of the low-mass star, mostly made of C, O and some He, is left behind as a "White Dwarf". This white dwarf slowly radiates its energy into space and cools down so its color changes to red and eventually infrared so it would be invisible to the eye. It is then called a "Black Dwarf". This "evolutionary sequence" or "life cycle" for low-mass stars is shown in the top row of Figure 1.9.

Stars with more than 8 times the mass of our Sun, known as "high-mass stars" have very high luminosities and temperatures. At their surface they produce a lot of ultraviolet light and stellar winds, which sweep-up the interstellar gas into a surrounding shell or "wind blown bubble". The temperatures in the core are also very high and are capable of fusing elements up to iron, which is the most stable element. No more energy can be obtained, so the iron core builds up until eventually it becomes unstable and collapses very quickly (in a fraction of a second!) to a very dense object. This typically results in an extremely high density "Neutron Star", which has more than the mass of the Sun concentrated within a sphere of radius of 10 km (like the size of city!). However, occasionally, in the cores of the most massive stars, an even denser object forms. It has such strong gravity that nothing, not even light, can escape. These objects are known as "Black Holes". So much energy is released when a neutron star or black hole is created that the rest of the high-mass star is blown out into space in a "Supernova Explosion". The material flung out in a supernova contains a lot of heavy elements, like carbon, oxygen, iron, etc., which sweep-up and mix with the interstellar gas and can also make a shell, like a bubble, which we call a "Supernova Remnant". It is possible that wind blown bubbles and supernova remnants even trigger the birth of new stars in their dense shells, creating a "Cycle of Star Formation". Finally, consider this: most of the material of the Earth, including the calcium in your bones and the iron in your blood, was once forged in the centre of a star and then released into space in supernova explosions. That is an amazing thought!

Fun fact: The most massive star known so far is RMC136a1, with a mass about 300 times greater than our Sun. RMC136a1 is not in our Galaxy but it is located in the Large Magellanic Cloud, a small galaxy that is a satellite of the Milky Way

What we Astronomers want your help with

The big question we are researching is: how do stars form? To collect more information about this process we need to understand the environment in which forming stars are embedded. In the project **The Star Hunt** we need your help to find new stars that are being born from dusty interstellar clouds in our Galaxy. We want your help to understand whether these stars form alone, as twins or clustered together in great broods. We want to know about the surrounding environments of the clouds and to discover if there are clusters of stars already formed that are hidden in the dusty centres of the clouds. In the next sections we will discover together how astronomers investigate the formation process of stars and how you can help us to know more about it.

The Star Hunt Research Project

The World Wide Telescope

The World Wide Telescope (hereafter WWT[1]) is an example of those tools that astronomers use to locate and study celestial objects in the sky. In this section, we will understand how WWT works and how we can use it to extract all the information we need. By the end of the section, we will be able to:

- Start and explore the WWT webpage: get the tool started and use all its functionalities such as *StarHunt Targets, Explore, Search, Imagery, View and Look at.*
- Navigate the sky: find constellations, planets and stars but also specific objects by typing their celestial coordinates. This exercise can also be extended to real sky observing, where you should be able to locate the North Celestial Pole (Polaris) and bright constellations. If your target celestial objects are visible above the horizon, then you can try and locate these also (but they will generally not be visible to the naked eye).
- Travel through time! See how the night sky changes as the time goes forward...or back!
- Explore the sky at different wavelengths: how the night sky changes when looking at different kinds of light it emits.
- Measure Distances: use the scientific tools such as the *Bullseye* and the *Distance from Target panel.*

Thanks to *Peter Williams* (Harvard-Smithsonian Center for Astrophysics and American Astronomical Society) who is working with the scientists to adapt the WorldWide Telescope for this project.

By the end of the section, you will be a WWT master, ready... steady... go!

[1] www.worldwidetelescope.org/home

What is it?

The WWT is a project developed by the American Astronomical Society (AAS[2]) to enable the seamless visualization and sharing of scientific data among scientists and the general public. For the *Star Hunt* project we have added a few extra features to carry out the exciting quest of *hunting stars* that we are about to explain!

How to use it?

The WWT can be used through the web in any device, although we recommend using it on a laptop or tablet with Google Chrome. We have tested using a MacBook Pro and an iPad using Google Chrome. It can be accessed by just typing the following url in the web browser:

http://starhunt.worldwidetelescope.org/

Traveling through the Universe has never been so easy! To move around just click and drag using your mouse or moving with your finger in the tablet. Zooming-in or out is also as easy as using your mouse wheel to scroll down or up on a laptop or using your fingers on the tablet, as you do on a phone.

There are several tools that you can use to explore the Universe in the WWT. Its use is very intuitive, and you can explore as much as you like! There are several tabs in the upper and lower parts of the window that are explained below (see Fig. 2.1):

- **StarHunt Targets:** The sources that will be studied are listed here.
- **Explore:** Images of the Cosmos, from our own Solar System to Star Forming Regions in the Milky Way to Galaxies far far away.
- **Guided Tours:** Enjoy guided tours lead by expert astronomers revealing the secrets of the Universe.
- **Search:** Type the coordinates of your favorite astronomical object and press Go to explore its surroundings (see bottom panel of Fig. 2.1).
- **View:** Travel into the Future or into the Past! In the view tab you can control the time to study how the night sky changes.
- **Look at:** 3D features of planets, the Moon, and more!
- **Imagery:** Observe the Milky Way at different wavelengths to reveal its different components!

The tools specifically developed for this project can be found in the StarHunt tab and the StarHunt layer manager (see Fig. 2.2):

- **Targets:** Here the *molecular clouds* and the *high-mass protostars* that will be used in the Star Hunt are shown. You can go directly to the target position by just clicking on it.

[2] https://aas.org/

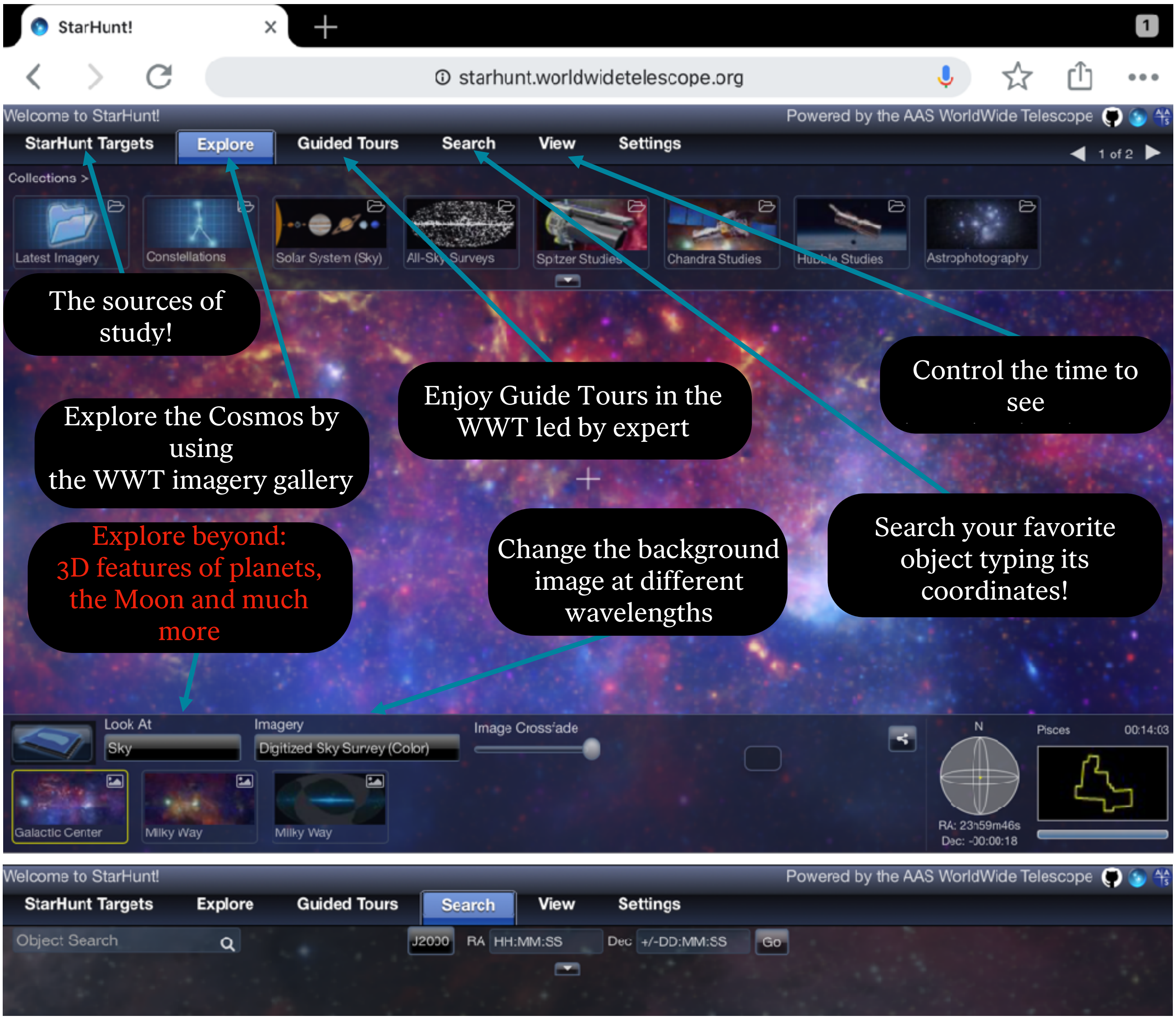


Figure 2.1: *Top:* Home page for the *Star Hunt* web client application as seen in an iPad using Google Chrome. *Bottom:* The Search tab where the coordinates of the objects can be written.

- **StarHunt:** Here is where all important features are:
  1. *Crosshairs:* The Crosshairs are used for positioning the part of the sky of interest.

     You can create a marker by clicking [Create Marker Here] to highlight a special feature you find or to mark the location of a star in the surroundings, once a Target has been loaded (see above).

     In this part of the window one has useful information such as 'Distance from target: value arcsec' and 'Angle from target: value deg'. This tells us the distance and the angle from the center of the Bullseye and the position of the Crosshairs, which brings us to the next item. You can also create a coordinate marker by clicking on [Create Coordinate Marker]. You can then retrieve the coordinates of the coordinate markers by clicking [Report Coordinates]

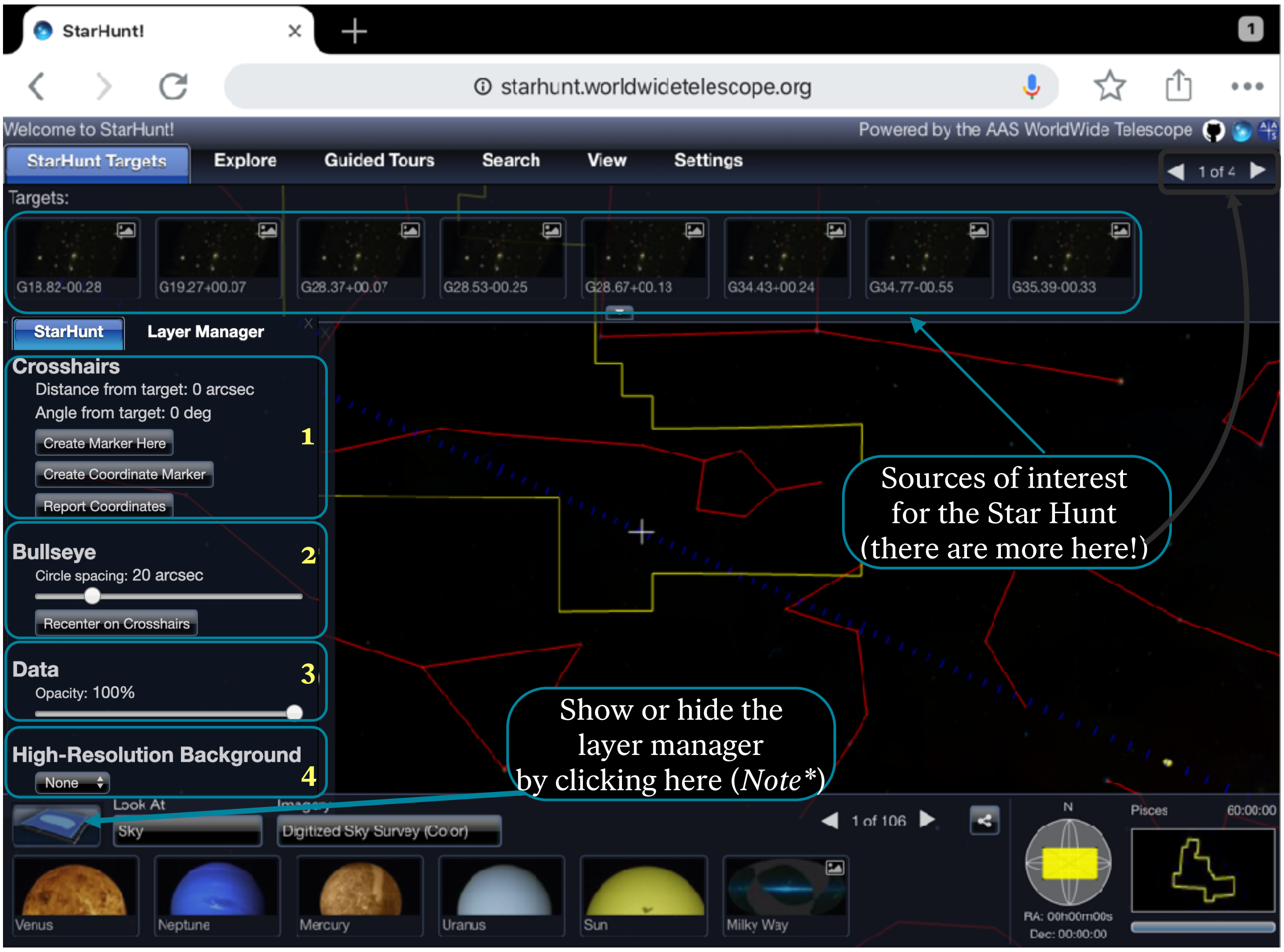


Figure 2.2: The Star Hunt Tab and the Star Hunt Layer Manager as seen in an iPad using Google Chrome. The various components are highlighted (see text for an explanation). *Note**: see that in Figure 2.1 the layer manager is hidden to show the entire window.

2. *Bullseye:* With this tool, you can measure distances to interesting features or other stars. You can also measure the angle between two sources (see Fig. 2.3). You can change the circle spacing from 1 arcsec to 100 arcsec, with a default value of 20 arcsec. To help you with your measurements, there are 10 concentric circles as well as 12 sectors that divide the circle in portions of 30 degrees, like a cake! This means that every circle is separated by 20 arcsec in the default case, with the smallest circle is 20 arcsec in radius and the biggest is 200 arcsec (=20 arcsec x 10 circles). In the scrollbar 

one can set the circle spacing. This is useful if you are dealing with large or small scales.

   Also, with the button 

you can recenter the Bullseye to the current position of the Crosshairs.

3. *Data:* Here is where you control the scientific data that has been loaded in the Targets tab. In the scrollbar 

you can control the opacity of the image to explore the region and discover peculiarities that you find interesting.

4. *High-Resolution Background:* You can choose between None and 2MASS to load a high-resolution image at infrared wavelengths, or not, of the region that you are working on. As in the case of Data, an opacity scrollbar will appear where you can set the transparency of the high resolution image.

In Figure 2.3 are shown two screenshots illustrating the Bullseye tool. In astronomy, we measure the so-called Positions Angles (PA) from top to left, i.e., counter clockwise (note that in math the angles are measured from top to right, i.e., clockwise). You may have also noticed that we have written half of the angles with positive numbers (from 1 to 180 degrees) and half with negative numbers (from -179 to 0 degrees). It is important to note that it is exactly the same to write, for example, PA = -120 degrees or PA = 240 degrees.

In Figure 2.3, two different scales are shown for the same region, G35.2-0.74N. In the top panel, we have selected a circle spacing of 7 arcsec. This means that the first circle has a size of 7 arcsec, the second 14 arcsec, the third 21 arcsec, and so on. We have highlighted the smallest (7 arcsec, green), the fifth (35 arcsec, blue) and the tenth circle (70 arcsec, red). Likewise, we have also highlighted the angles for these specific lines, i.e., 30 degrees (blue), -60 degrees (red), and -90 degrees (green). We have placed a marker coinciding with the blue distance and angle, i.e., 35 arcsec and 30 degrees, which is measured from the center of the bullseye.

In the bottom panel, we have re-centered the bullseye to another position and increased the circle spacing to 20 arcsec to demonstrate different scenarios. In this case the smallest (green), the fifth (blue) and the tenth circle (red), correspond with 20, 100, and 200 arcsec, respectively. Now the position of the marker is 202 arcsec at an angle of 20 degrees (Warning! We have not moved the marker but the bullseye, the distance and angle are measured from the center of the bullseye!).

Now we know the basics about the WWT, we are ready to embark ourselves into the *Star Hunt* spaceship.

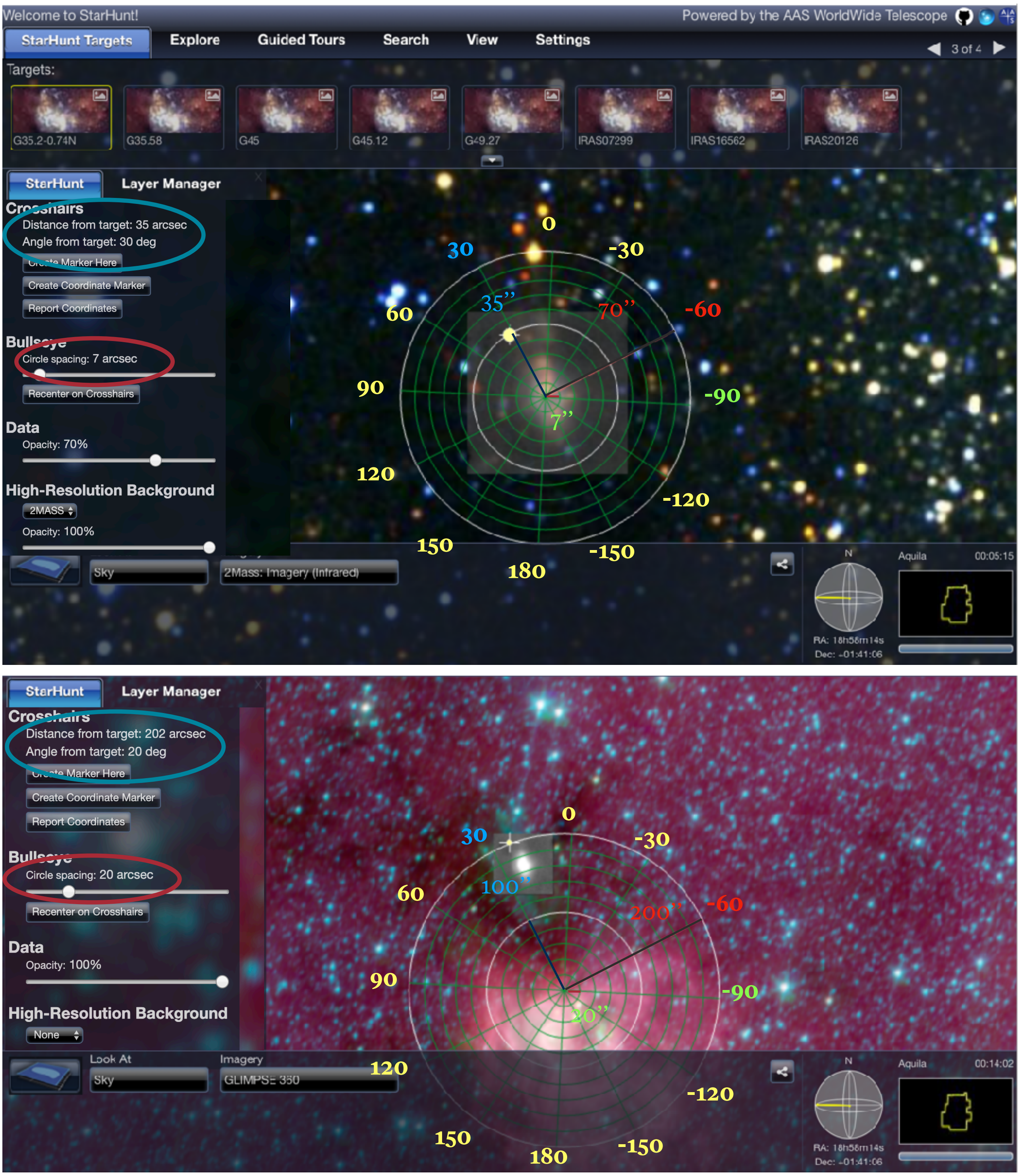


Figure 2.3: Demonstration of the *marker* and *bullseye* tool. Note that we have changed the background Imagery survey (2MASS and GLIMPSE). The marker is shown as a yellow dot. Its distance and angle from the center of the bullseye is highlighted in the upper left corner of both panels.

The Star Hunt in Practice

Two main and complementary exercises will be carried out in the Star Hunt project. These assignments will involve, on the one hand molecular clouds (in particular Infrared Dark Clouds - IRDCs) and on the other hand high-mass protostars (the “SOMA sources”). Since the spatial scales are different in these astronomical objects, we will be focused on investigating different features around each type of object.

Each pair of students will have two objects, one molecular cloud (IRDC) and one high-mass protostar (SOMA). They will work together to carry out the two following exercises. We have set a very simple way of distributing the molecular clouds and high-mass protostars: Assuming that there is a class of 30 students, teams will be numbered from 1 to 15. Then, team#1 will get IRDC#1 and SOMA#1, team#2 will get IRDC#2 and SOMA#2, and so on until team#15 that will get IRDC#15 and SOMA#15. Tables A1 and A2 list the team number and the associated IRDC and SOMA target, respectively. In the unlikely case that your class has more that 17 teams, fell free to assign to team 18 the same sources as team 1. Alternatively, you can have fewer groups of three students.

The guidelines for the various exercises and tasks are given below with the expected requirements, but you have the freedom to explore beyond these.

Sharing is caring

Before we start the explanation of the exercises, it is important to explain how we are going to input and collect the data. For this purpose, we have created an online spreadsheet that you can find at this link:

https://docs.google.com/spreadsheets/d/1wE6QcB2EISp097ephO40w4Dri2VUJz9BIPIz6FiRjhI/edit?usp=sharing

When you click at the link above, you will find a Google Sheets called **The Star Hunt tables**. By default, you will not be able to modify this table (because it has view permission only!), but you can copy it to your local Google account. This is easy to do by clicking **File - Make a Copy (**make sure that you are logged in to your Google account!). Now, you should have full access to the tables with all the tabs and you can write in the cells.

If you do **not** have a Google account, you can very easily create one at the following link:

https://accounts.google.com/signup/v2/webcreateaccount?flowName=GlifWebSignIn&flowEntry=SignUp.

Alternatively, you can ask your teacher if there are temporary accounts (or maybe a school account?) you can use. It is important that you have an available Google Account!

Let us explain what is inside this table. The beginning of the table is shown in Figure 3.1. This table consists of five different tabs called filaments, bubbles, stars/circles, stars/sectors, and screenshots. Each of these tabs corresponds to an Exercise and Task explained below (note that they are set-up in the same order as the exercises appear). In each tab, we have added descriptive information of what is expected to be inputted in each table. In the spreadsheet table you will be able to input the data we are asking very quickly and make calculations using the formulae provided. Also, a very important aspect of using these tables is that you can make graphs very easily using the tools that the spreadsheet offers. Besides these, you can upload the screenshots you will be taking during the exercises to the tab screenshots. **You can use all this information to create your poster that will enter the competition to be the best one with exciting prizes!**

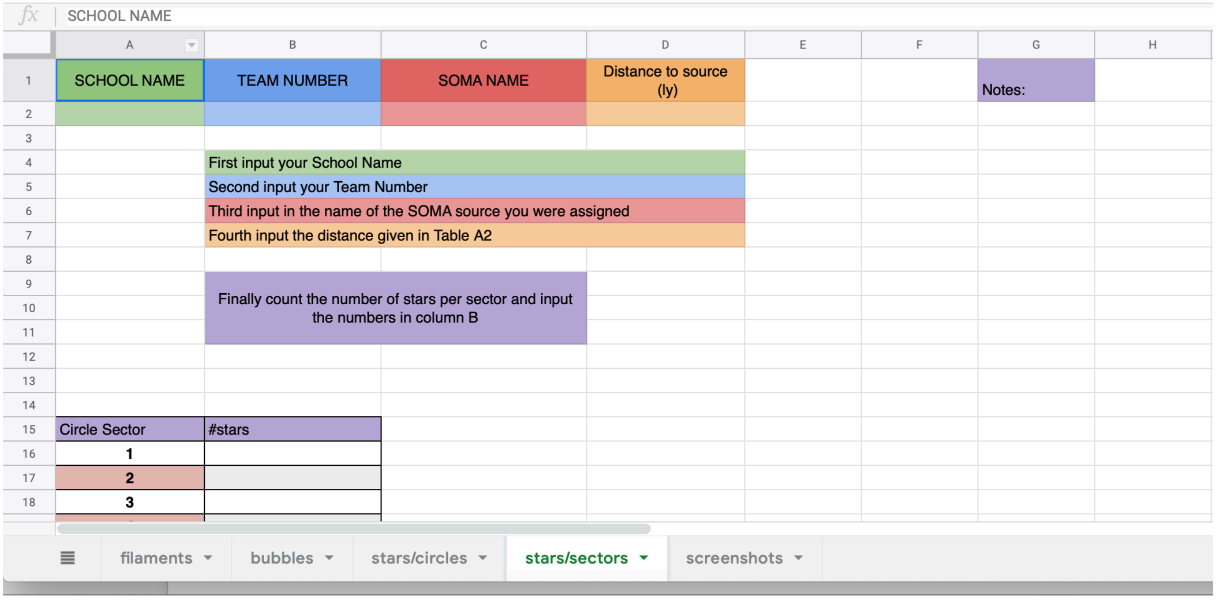


Figure 3.1: Example of the first tab of the tables prepared for the Star Hunt Project.

How to send us the completed tables

As the title of the section states, sharing is caring, which is particularly important in science. After completing the two exercises, explained below, you will have a few beautiful tables, graphs and screenshots that we are looking forward to analysing for our research. Only by sharing your results with other scientists we can all work together to unveil the mysteries of the Universe.

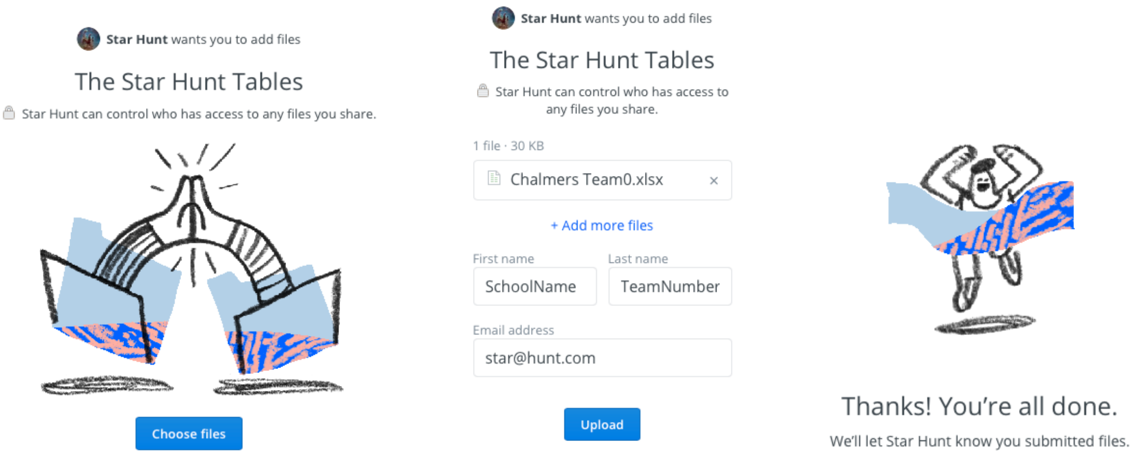


Figure 3.2: Left: File Request link to send the collected data. **Middle:** Form to be completed to send files to the astronomers. **Right:** Confirmation message that you successfully submitted the data.

To make things easy, we have set a *files request* link where you can send us all this information:

https://www.dropbox.com/request/LmJ7VMOahJ6J6LORQKyX

When clicking in the previous link you should see what shown in Figure 3.2.
By the end of the two exercises you will have an online table with several tabs that hold very important information for us. To send us your results you need to download the final file with your exercise done by clicking on **File -> Download -> Microsoft Excel (.xlsx)** and then upload it using the DropBox link. To help us to organise all the files, we ask you to name the file with your school name and your team number. For example, if my school is Chalmers and my team number is 0, the file would be called `Chalmers Team0.xlsx`, as you can see in Figure 3.2 middle panel. In the form, you will be asked for First name, Last name, and Email address; please write your school name in the first name box, team number in the last name box, and star@hunt.com in the email address box. Finally, you should see something like the **right panel** of Figure 3.2. We received your files, let's do science together!

If this seems complicated, don't worry, we will repeat and specify this information in each exercise; this is just to introduce you how we are going to proceed with the data collection.

Exercise 1: The Environments of Star-Forming Molecular Clouds

Now that WWT has no secrets for you, we are ready to explore, investigate and unveil the sky! In this Exercise 1, we astronomers need *your* help to study objects in the sky that are known as *Molecular Clouds* and the area of the sky around them. In the following section:

- We will locate the molecular cloud.
- We will investigate the molecular cloud by looking at the *Infrared* emission coming from the area of the sky in which the object is located.
- We will thus investigate the surroundings of the cloud. In particular, in **Task A** we will look for dark filaments in and around the molecular cloud. In **Optional Task**, we will look for bright bubbles around the molecular cloud. We will use the WWT tool *Markers* and *Bullseye* to identify their location, extension and distance from the cloud. How many features can you find?

Why are we doing this?

We will begin our quest by looking at very big portion of the sky, where we can see the biggest objects. As you probably already know, our Earth and Sun are part of a much bigger structure, our Galaxy, called the Milky Way (see Figure 3.3).

Astronomers have estimated that the Milky Way contains about 100 billion stars and that there are also large quantities of gas (mostly Hydrogen and Helium) between the stars - the “Interstellar Medium”. Mixed in with the gas is dust, i.e., very small particles made of Carbon and Silicon that can also be covered up by a layer of water ice mixed with other molecules like CO and CO_2. This gas and dust are the reservoir of material from which new stars are formed.

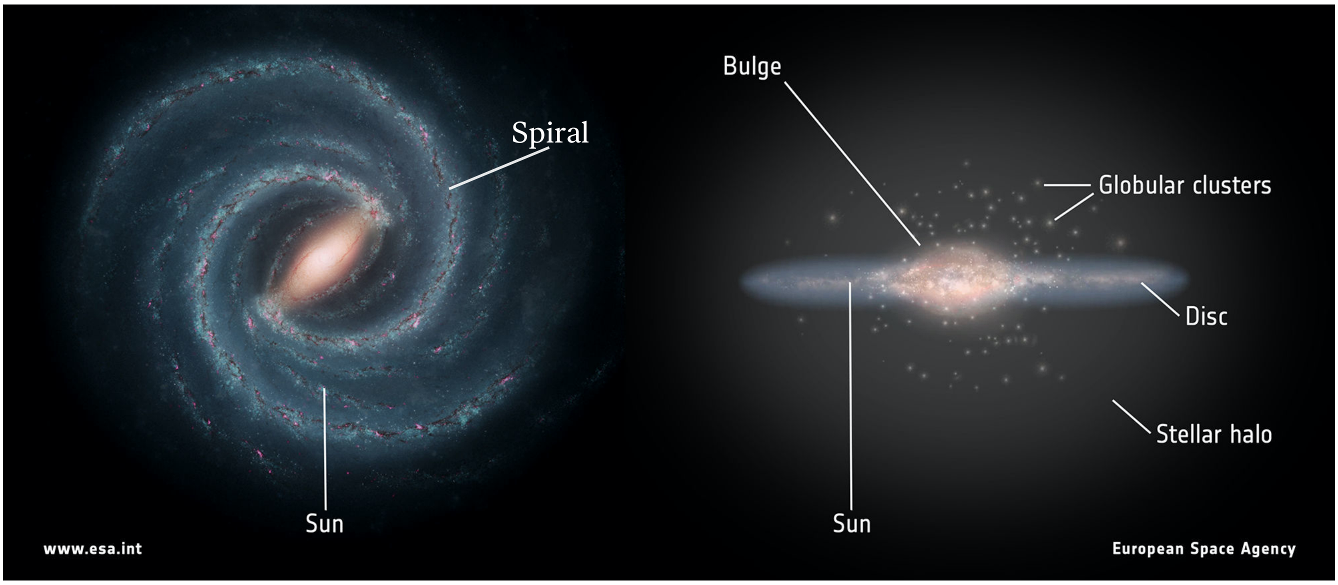


Figure 3.3: Left: Top-down view of the Milky Way showing the plane of the Galaxy with its spiral arms. **Right:** Side-on view of the Milky Way showing the thin disk of the Galaxy, its bulge, halo and the location of the globular clusters. In both views the location of our Sun, almost at the edge of the disk, is indicated.

If we could look at our Galaxy from the outside, it would look like the pictures shown in Figure 3.3, which shows top-down (left) and side-on (right) views. As shown in Figure 3.3, the Milky Way has the form of a disk, called the *Galactic disk*, that about 2,000 light-years thick and 200,000 light-years wide. The plane on which the disk lies is called *Galactic plane*.

The Galactic disk spins around its center, where astronomers believe a black hole 4 million times more massive than our Sun is located. The central part of the Milky Way has the shape of a thick bar, called the *Galactic bulge.* The bulge, is surrounded by a stellar halo, including star clusters called *globular clusters.*

As we can see from Figure 3.3, the Sun is located in the Galactic disk, about 27,000 light-years from the center. It takes about 200 million years for the Sun to complete an orbit all the way around! Looking with more attention to Figure 3.3, we see that the Galactic plane is not uniform. It shows some more concentrated regions that have the shape of spirals. These features are called *spiral arms.*

The gas and dust in the Milky Way are not evenly distributed. In some regions of the Galaxy there are less than a couple of atoms per volume of 1 cubic cm (cm^3): these regions are known as the *diffuse interstellar medium.* In other regions, gas and dust form much denser condensations in which the amount of molecules per cm^3 is high enough to form new stars. Astronomers call these regions *molecular clouds.*

Molecular clouds are among the densest regions of the interstellar medium in our Galaxy and they are usually very cold, with temperatures that can be as low as -260 °C. Astronomers usually refer to molecular clouds as stellar nurseries because it is in those regions that stars form. Stars at very early stages in their evolution have been seen in molecular clouds, indicating that indeed that is the place in which they form. However, astronomers do not have a precise idea of how the formation of stars is started in such clouds. Hence, ***if we want to understand how stars form, we need to study molecular clouds and their surrounding environments.***

The problem of how stars form has been investigated by astronomers for many years and several ideas have been proposed and are currently been tested by observing protostars, young stars and molecular clouds. Something that the astronomers agree on is that to form a star you need to compress the gas and dust in the Milky Way: molecular clouds are regions in which this compression has already happened. But how can/does this happen? One possibility is that as gas orbits around the disk it becomes compressed when entering the spiral arms or as they collide with other clouds. If these theories are correct, we should see some indication of the compression in the shape and orientation of molecular clouds that align with the Galactic disk. In **Task A**, you are going to test this idea by analysing the molecular cloud structures in and around a very dense, compressed region, known as an Infrared Dark Cloud.

The natural orbital motion of clouds around the Galaxy is not the only way in which gas and dust can be compressed. For example, when a very massive star dies it will violently explode as supernova and it will produce a bubble of very fast travelling material. If this supernova bubble hits a molecular cloud it further compresses it, making the formation of new stars possible. Another kind of bubble also exists around a massive star before it dies as a supernova. While still shining, the star creates a bubble of very hot gas, called an HII region, that can also compress the gas around it and initiate the formation of new stars. Finally, there are strong winds from massive stars, which can also sweep up surrounding gas into shells that look like bubbles. Hence, ***it is important to look for bubbles near molecular clouds to understand if they are the reason that gas was compressed, and the***

cloud was created. Whatever is the nature of a bubble, they usually appear as very bright objects when we look at them in Infrared light. In **Optional Task** of this Exercise 1, you will look for bubbles around the molecular clouds you have been assigned. By doing this, you will help us test the idea that bubbles are important ingredients in the recipe to form new stars.

But first things first.... let's see what our molecular clouds look like!

Task A: The Filament Hunt

We first need to locate our molecular clouds in the sky. We are going to guide you step by step and to do so we have selected as example the molecular cloud G34.77-0.55.

In order to locate the cloud in the sky, we follow these steps:

1. Open the web client by typing http://starhunt.worldwidetelescope.org/ in the Google Chrome browser of your laptop or tablet.

2. Make sure that the default background Imagery is selected, i.e., *Digitized Sky Survey (Color)*.

3. Go to **StarHunt Targets** Tab and upload *your team's molecular cloud* by clicking on its name. In the case of the example G34.77-0.55 (Figure 2.4).

4. Explore the region: Do you see anything at the location of your cloud? Zoom-in. Now?

5. Select in the **Imagery** Tab the *GLIMPSE 360* image of the sky

6. Explore again: What do you see now? Zoom-in and -out. Can you tell where your source is and what it looks like?

7. Go to **Data** and change the **Opacity** using the scrollbar. Can you say if your source corresponds to any dark feature in the sky?

8. Adjust the **Opacity**, at the level you decide, so that both your cloud and the *GLIMPSE 360* image are visible

After following all the steps below, you should see something like in Figure 3.4.

Now that we know what a dense molecular cloud looks like.... let's look in more detail at the filamentary structures around the cloud: these may give us clues about where the cloud came from!

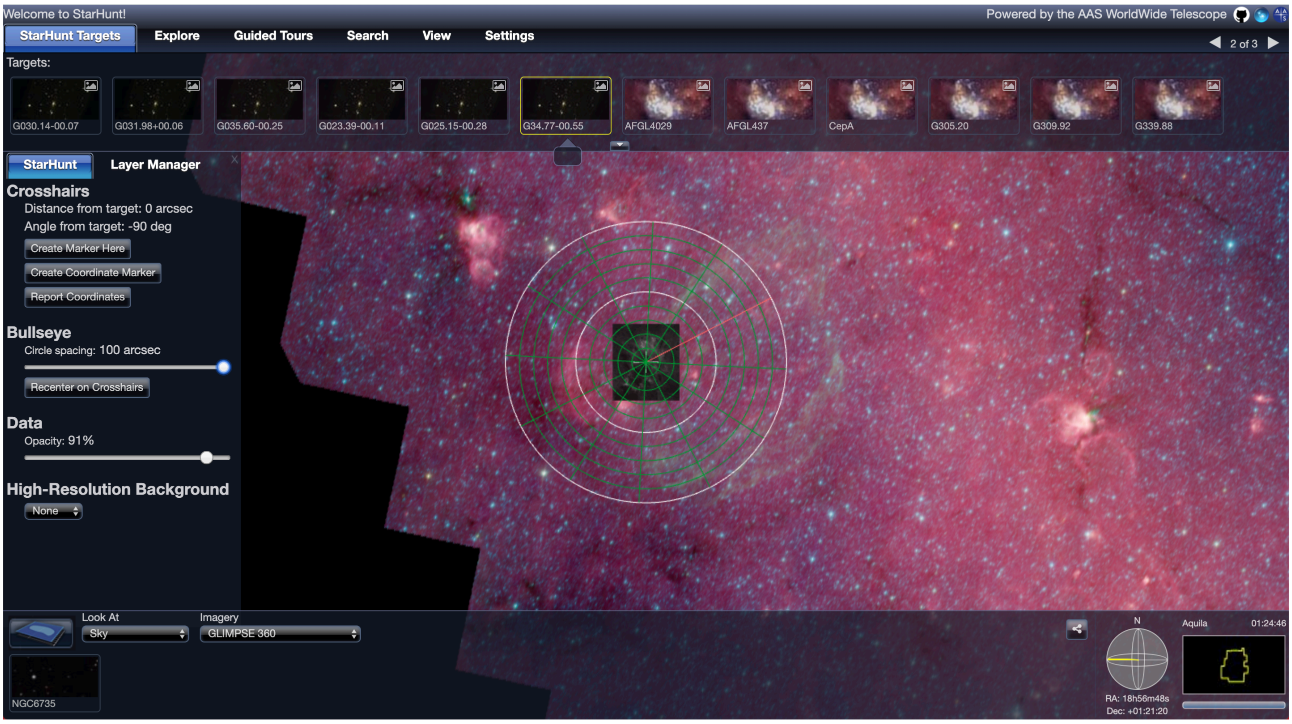


Figure 3.4: The molecular cloud G034.77-00.55 overplayed on the GLIMPSE image in WWT. The bullseye is centered at the location of the cloud and it is extended to its maximum radius possible.

One of the first astronomers to identify a molecular cloud in the sky was Sir William Herschel together with his sister Caroline in the XVIII century. While looking at the night sky, he realized that some parts of the sky were full of stars, while others seemed almost empty, like "holes" in the sky. Molecular clouds are indeed so dense that they can block all the optical light coming from the stars located behind them, giving the illusion that there are very few stars in that direction. If we look at the sky at a different wavelength of Infrared light, we can still see the same effect, but less pronounced, since Infrared can penetrate deeper through the clouds. Still, the densest parts of molecular clouds still appear as dark regions in the sky. Many molecular clouds have a long, thin appearance, and we will refer to these as *dark filaments*. ***A filament is something that is quite long compared to its width. We will see that when we search to find dark filaments we will approximate their shapes to be like simple straight lines.***

A:1 Finding filaments

As part of this task, we are asking you to identify, in the GLIMPSE image, any dark filaments located in the nearby area around your molecular cloud.

The GLIMPSE image is of Infrared light emitted from space. Astronomers have collected a series of such images also at many other wavelengths: in visible light, e.g., the DSS image; in X-rays, e.g., the RASS image, etc. These different images are useful as objects do not generally emit all the same light! Hence, a particular object may be visible at one wavelength, but not in another! Think, for example, of the molecular cloud you are working with. In the GLIMPSE (Infrared) image it appears dark, but if you observe the same molecular cloud in the RASS X-ray image....it does not appear at all! In Figure 3.5, we show a summary of the images in WWT and their wavelengths.

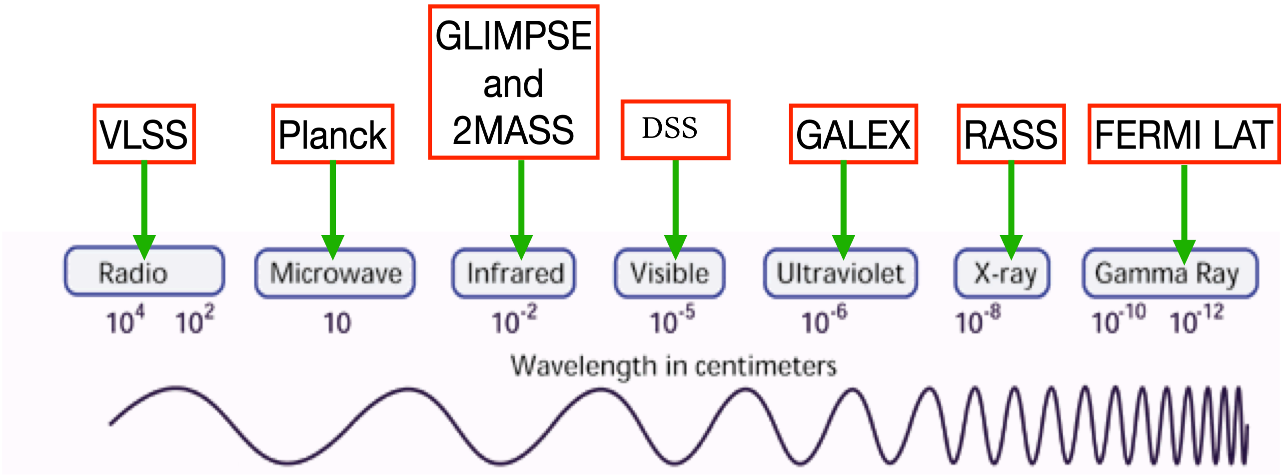


Figure 3.5: Name of the Images loaded in WWT for each wavelength.

Dark filaments are seen as shadows, in the GLIMPSE image, because the dense material of the cloud blocks the Infrared light coming from space. They can be either linked or isolated from the molecular cloud you have been assigned. Finally, although they are called dark filaments, they can have quite different levels of contrast, i.e., they can be very dark or just have the hint of a shadow.

Now that you know what to look for.... let's hunt for the filaments!

The video at the link http://cosmicorigins.space/starhunt will show you an example of how to look for dark filaments around the molecular cloud G034.77-00.55. ***What we are asking you to do*** is to identify the dark filaments around your cloud and to provide us with information about them, especially the start and end coordinates of the filament. We ask you to fill in a table that looks like the one below. This and the other tables that we will use in this task, are in the sheet "filaments".

Table 1				
RA (deg)	DEC (deg)	Angle to Galactic Plane(°)	Angular Size, α(")	Physical Size, s (light years)
284,5470	1,3987	122,8	24508,33	
284,8770	1,4123			

How many filaments can you find?

In order to fill in the online table we will follow the steps below:

9. Extend the radius of the bullseye to its maximum size

10. Can you see any dark feature in the area identified by the bullseye?

11. For every dark feature that you see, now put *coordinate markers* to mark the beginning and end of the filament. ***Here we are approximating the various dark features by describing them as simple filaments, i.e., line segments. If you see a long, curved filament, you can describe it with a series of separate line segments that are counted as different filaments in the table. Remember some filaments may only appear as faint shadows, so look carefully!***

12. Use the *Report Coordinates* button to copy and paste the markers coordinates into the online table.

13. Use the *Create Marker Here* button to draw the shape of the filament connecting the two red *coordinate markers* (see Figure 3.6).

14. Use your laptop/tablet/iPad to take a screenshot with you best creation! (add these screenshots in the tab screenshot of your table)

When you copy the filament coordinates into Table 1, some numbers will appear in column 3 and 4. This is because we have pre-inserted some formulae into these columns. The physical meaning of these automatically calculated quantities will be discussed later.

If you have followed all the steps, you should have a lot of structures like the one reported in Figure 3.6 for cloud G034.77-00.55. In this link http://cosmicorigins.space/starhunt you will find video examples to help guide you through the exercise.

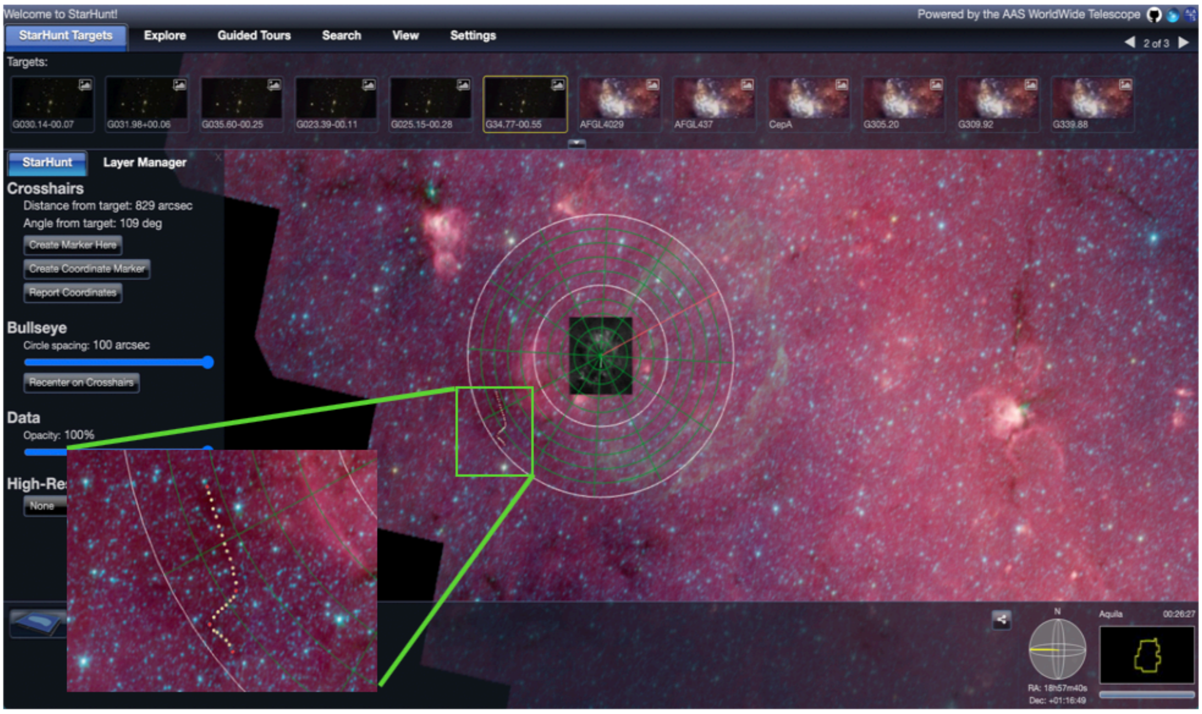


Figure 3.6: Example of a dark feature identification around the molecular cloud G034.77-00.55. The start and end position of the filaments are indicated by red markers, while the shape of the filament is indicated by the yellow markers. The complicated shape of the dark features has been approximated by multiple straight lines.

Your scientific point of view.

Now that we have identified all the filaments around the molecular clouds, let's do science!

As we discussed before, it is important to understand how dark filaments are connected to each other, if they have all the same orientation, what is their shape, if they are very dark or only faint shadows. In this task we want to answer all these questions.

As you learned in the *Research methodology* section, scientists use the *scientific method* to validate or discard their theories. The first step to apply the scientific method is to make a hypothesis, i.e., a statement to prove or discard basing on the evidence brought up by the data. In this task, our hypothesis is the following:

Hypothesis:
Dark filaments are oriented preferentially along the direction of the Galactic plane

We are now going to use our data to see whether the hypothesis is true or false.

In order to test our hypothesis, we first need to identify the direction of the Galactic plane. If you have no idea what the Galactic plane direction is, try to:

15. Zoom out the GLIMPSE image as much as you can. Do you see the stripe that is the GLIMPSE image? The longest dimension in the of the GLIMPSE image is the Galactic plane direction (see Figure 3.7).

16. ***To which angle of the bullseye does the Galactic plane direction correspond?*** In order to answer this question, slightly zoom in again in the GLIMPSE image, as shown in Figure 3.8.

The Galactic plane direction corresponds to the 30° angle direction in the bullseye. Now that we have defined the Galactic plane direction, we want to see how many of our identified filaments have orientations that are similar to this.

In Table 1 of the "filaments" spreadsheet you have reported the coordinates of the starting and ending point of the filaments. As you may have noticed, when you typed in the two sets of coordinates a number appeared in the third column of the table. This is because we have inserted a formula that uses the start and end coordinates of the filament to calculate the angle that it makes with the direction of the Galactic plane.

Hence, we have calculated for each filament the corresponding angle. Now let us draw some conclusions by looking at these angles. When a filament has an angle of 0° or 180°, it means that its direction is parallel to that of the Galactic plane. Alternatively, if the filament has an angle of 90°, it is oriented perpendicularly with respect to the Galactic plane. How many filaments have angles in the range between 0° and 15°? How many filaments in the range between 75° and 90°?

17. For each angle range reported in Table 2 below, count the number of filaments showing position angle, θ, in that range. This Table corresponds to Table 2 in the "filaments" spreadsheet.

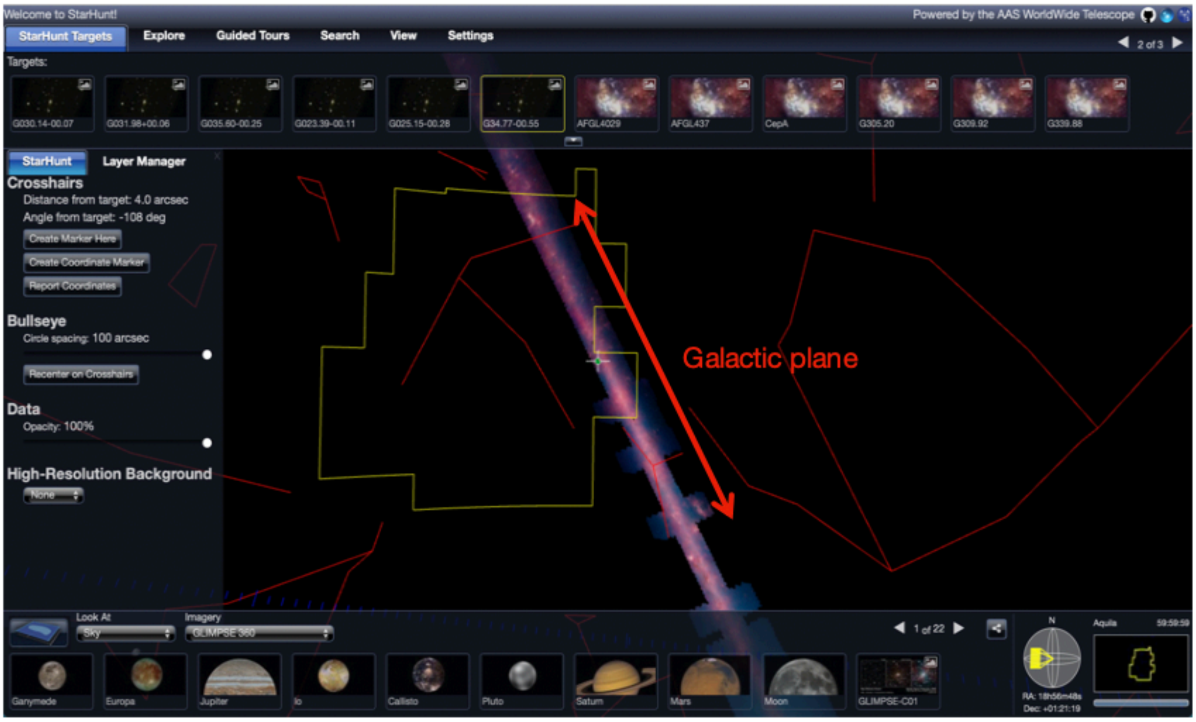


Figure 3.7: GLIMPSE image in WWT zoomed out to the maximum possible. The longest direction of the GLIMPSE image correspond to the direction of the Galactic plane, as indicated by the red arrow.

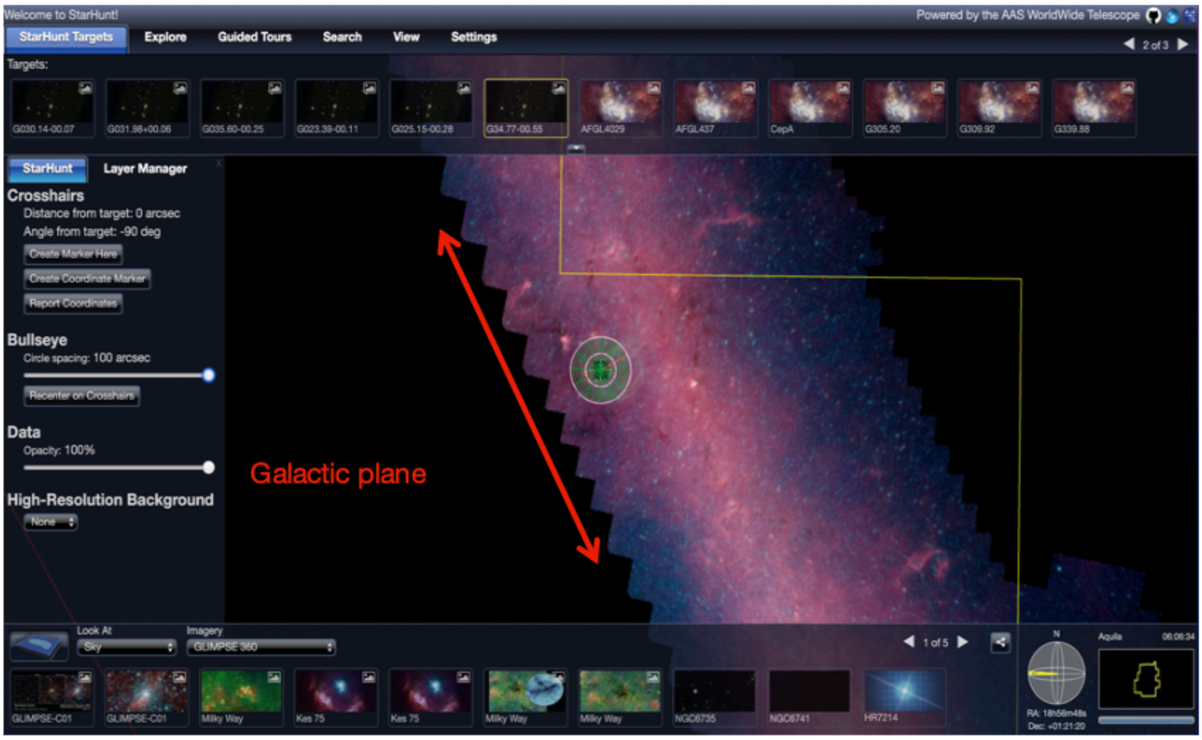


Figure 3.8: Direction of the Galactic plane with respect to the bullseye angle reference.

A:2 Counting filaments

By grouping together, the data as we have done in Table 2, we have produced what is called a distribution. Table 2 tells us how many of the filaments we have found have a certain orientation.

However, it can be difficult to find patterns or peculiarity in the distribution just by looking at the table. Hence, scientists make use of graphs to better visualize their results. The graph we are going to produce to visualize our distribution is called histogram. You can easily make a histogram in the online spreadsheet, by following few steps as below:

Table 2

Angle Range	Number of Filaments
0°;15°	
15°;30°	
30°;45°	
45°;60°	
60°;75°	
75°;90°	
90°;105°	
105°;120°	
120°;135°	
135°;150°	
150°;165°	
165°;180°	

18. In the spreadsheet, select column 1 and 2 of Table 2.

19. Click on **Insert -> Chart**

20. Make sure to select the Column **Chart**

Your histogram should look something like the one in Figure 3.9 (but not necessarily with this shape).

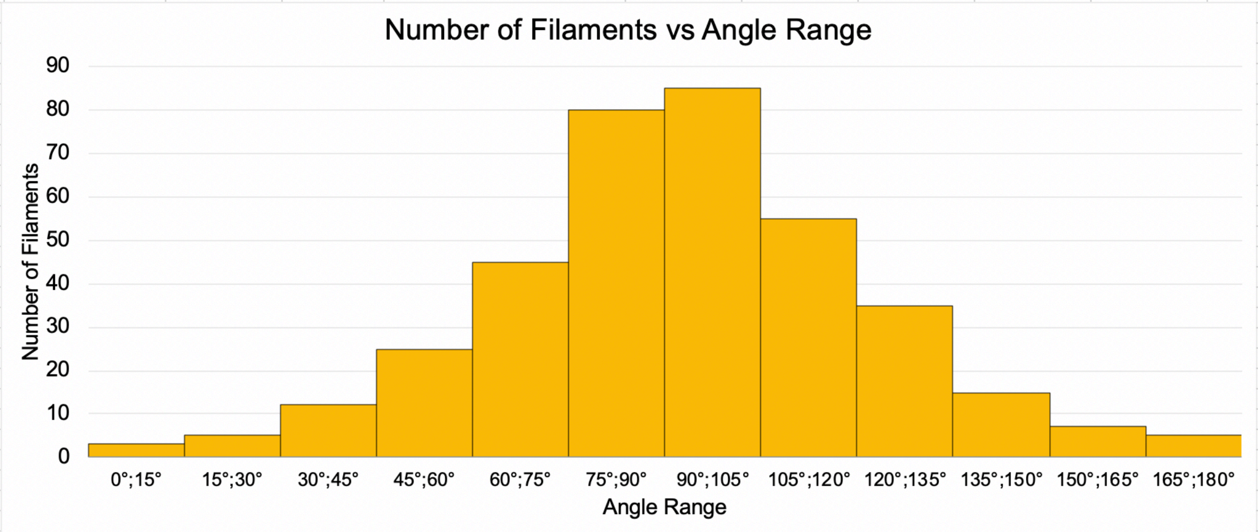


Figure 3.9: Histogram built from the data distribution in Table 2. Each yellow bar represents the number of filaments having this range of angles with respect to the direction of the Galactic plane.

By looking at the histogram you just created, ***do you think that the hypothesis we formulated earlier in our task is true or false? Are there preferred angles for the orientation of the filaments? If so, how do such angles compare to the direction of the Galactic plane?***

Let us know your thoughts about this by leaving a note in the dedicated space in the "filament" spreadsheet.

There are many other questions that we can ask about dark filaments. For example, how long are the filaments? Let us now try to answer this question. Like we did for column 3 of Table 1, we have added a formula in column 4 to calculate the size of a filaments by using its start and end coordinates. The numbers in columns 4 report the length of a filaments in arcseconds i.e., the *angular size* of a filament.

A:3 How long are the filaments?

Angular size (α) is very important for astronomers, since this is what we measure directly in the sky. However, it is more important to know the actual, true **physical size (s)** (that is in km or light years) of an object. To convert from angular size to physical size, we need to know how far the object is from us.

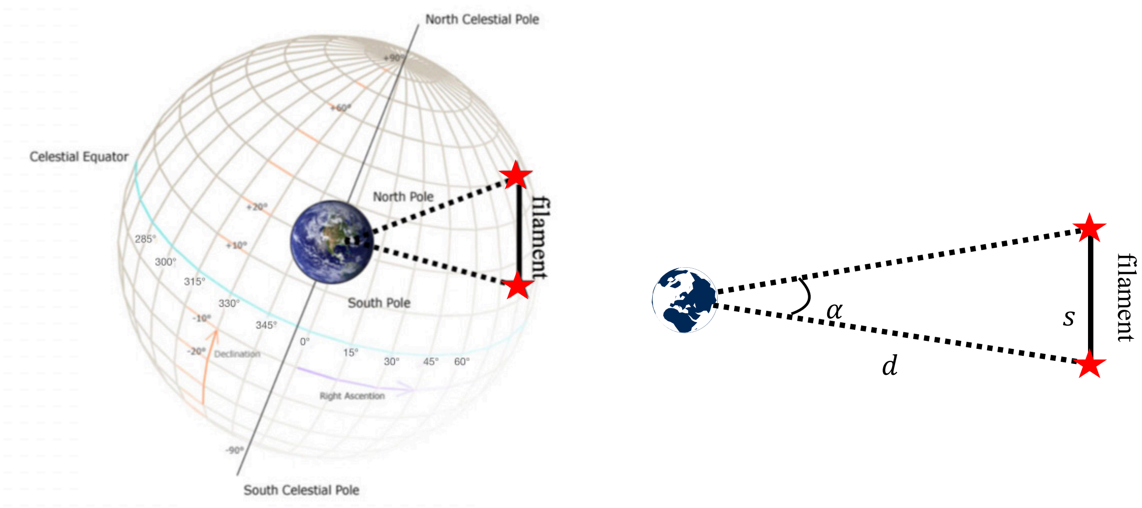


Figure 3.10: Left: The Celestial Sphere with the Earth at its centre. The Celestial Equator and North Celestial Pole are indicated. The red stars indicate the ends of a filament on the Celestial Sphere. Image Credit: Lone Wolf online. **Right:** Sketch of the triangle formed by the end of the filament and the Earth. The angular size α, the physical size *s* and the distance between the filament and the Earth, *d*, are shown.

If you look at a full Moon, you see it has a certain angular size, which is about half a degree (0.5 degrees = 30 arcminutes = 1800 arcseconds). The Sun has an angular size, which, by chance, happens to also be 0.5 degrees (this is why the Moon almost exactly covers the Sun during a total solar eclipse). However, the Sun is of course much bigger than the Moon (about 400 times bigger, in fact!). The reason that the Sun and the Moon can have the same angular size is because the Sun is much further away than the Moon... in fact, the Sun is 400 times further away!

There is a basic formula that connects angular size, physical size and distance:

$$\alpha = \frac{s}{d}$$

We can rearrange this to be:

$$s = \alpha \times d$$

Now we can understand the case of the Moon and the Sun. They have the same value of angular size, α, so we can see that if the Sun's distance, d, is 400 times greater, then its size, s, must also be 400 times greater.

When using this formula for the true physical size, s, we need to be careful about the units of α and d. For the distances, since the clouds are located very, very far away from Earth, we will use light years as our unit of measurement. A light year (ly) is the distance travelled by light in one year, which corresponds to 9,460,730,472,580 km, so almost 10,000,000,000,000 km, i.e., about 1 followed by 13 zeroes! We can also write this as 1E13 km. By the way, the closest star to Earth is called Proxima Centauri and is located at 4.3 ly away. The distance of the cloud G034.77-00.55 from Earth is 9458 light years! The distances to all the clouds being studied in The Star Hunt are given in Table A1: so you should look up the distance to the particular cloud you are studying.

Now, you may know that the units on one side of an equation need to be the same as those on the other side - they need to balance! As for distance, we will also use light years for the unit of the size of the filaments. This means that the angular size, α, needs to have no units! The kinds of angles that have no units are called "radians". There are 2 π radians in a full circle. So 2 π radians = 360°. Recall that we have measured angular size in arcseconds. So we now need to convert arcseconds to radians.

$$2\pi \text{ radians} = 360^\circ = 360 \times 60 \times 60'' = 1.296 \times 10^6 \text{ arcseconds}$$

So

$$1 \text{ arcsecond} = (2\pi / 1.296 \times 10^6) \text{ radians} = 4.85 \times 10^{-6} \text{ radians}$$

So our final formula for true, physical size s measured in light years is:

$$s = (4.85 \times 10^{-6}) \times \alpha \text{ (arcseconds)} \times d \text{ (light years)} \qquad (1)$$

Let's look at the biggest filament in cloud G034.77-00.55 as an example. It has angular size, α, of 170 arcseconds. And recall this cloud is 9458 light years away. So what is the size of this filament? If we enter the numbers in the formula we get: $s = 4.85 \times 10^{-6} \times 170 \times 9458 =$ 7.8 light years long!

Make a note of this formula. You will need it in this and all the other tasks of the exercise 1 and 2 to convert any angular size to physical size.

21. ***Calculate the physical size of all the filaments you have identified using equation (1).*** Doing the calculation one by one can be quite tiring. In order to make it simpler, why don't you try to insert the formula into columns 5 of Table 1 in the spreadsheet? This is similar to what we astronomers have done for you in columns 3 and 4 (hint: you will use cell D2 and the equation above together with the sizes reported in arcsec in column D).

What we astronomers will learn from your analysis in Task A?

When a new dark feature in the sky is located, astronomers want to know as much as possible about it. With your analysis, you are helping us to collect important information on the filaments you just found. By putting together the data from all the teams and all the schools, we will study the orientation of filaments, not just in a single portion of the sky but across the whole Galactic plane. We will identify how many filaments there are, on average, around a molecular cloud and we will investigate the different sizes that a filament can have. This will test different hypotheses of the processes that control the formation of molecular clouds and thus, ultimately, the formation of all the stars in the Universe!

We will discuss more with you and show you what you have helped us to achieve in a face-to-face session during The Star Hunt!

Optional Task: The Bubble Hunt

As we discussed before, the environment in which molecular clouds are located can be very crowded. Not just dark filaments, but also bright objects, often appearing as round bubbles or parts of bubbles, can be easily identified near molecular clouds. These bright objects usually correspond either to sites where stars are already shining or to relics of stars that have recently died and left behind the remnants of explosions, known as supernovas. We will refer to all these objects as *Galactic bubbles.* It is important for us astronomers to identify these bubbles to see if they are influencing the molecular clouds. For example, there is a theory of *Triggered Star Formation*, in which new molecular clouds are formed by being swept up by expanding bubbles. And since the bubbles can trace the presence of already formed stars, this is another reason to find them, so we can learn about how exactly stars are forming from the clouds. For example, is the center of a bubble sitting on a filament?

If you have time to spare, help us find bubbles around the molecular cloud you have been assigned!

In this link http://cosmicorigins.space/starhunt will show you how to look for bubbles around the example molecular cloud G034.77-00.55. ***What we are asking you to do*** is to identify bright features in the sky and to provide us with a list of such objects. Remember! "Bubbles" may not appear necessarily as complete circles, but also as arc-like features!
In this task, we will fill in a table that looks like the one below:

Table 3

RA (deg)	DEC (deg)	Angular Radius (arcsec)	Physical Radius (ly)

You can find this table in the "bubble" spreadsheet.

In our hunt of bubbles, we will follow the steps below:

22. Extend the radius of the bullseye to its maximum.

23. Can you see any bubble (or bright part of a circle) in the area identified by the bullseye?

24. For every bubble you see put a *coordinate marker* at its center.

25. Click on *report Coordinates*, copy the markers coordinate and paste them into the online table.

26. By using the button *Create Marker Here*, trace the shape of the bubble you have identified.

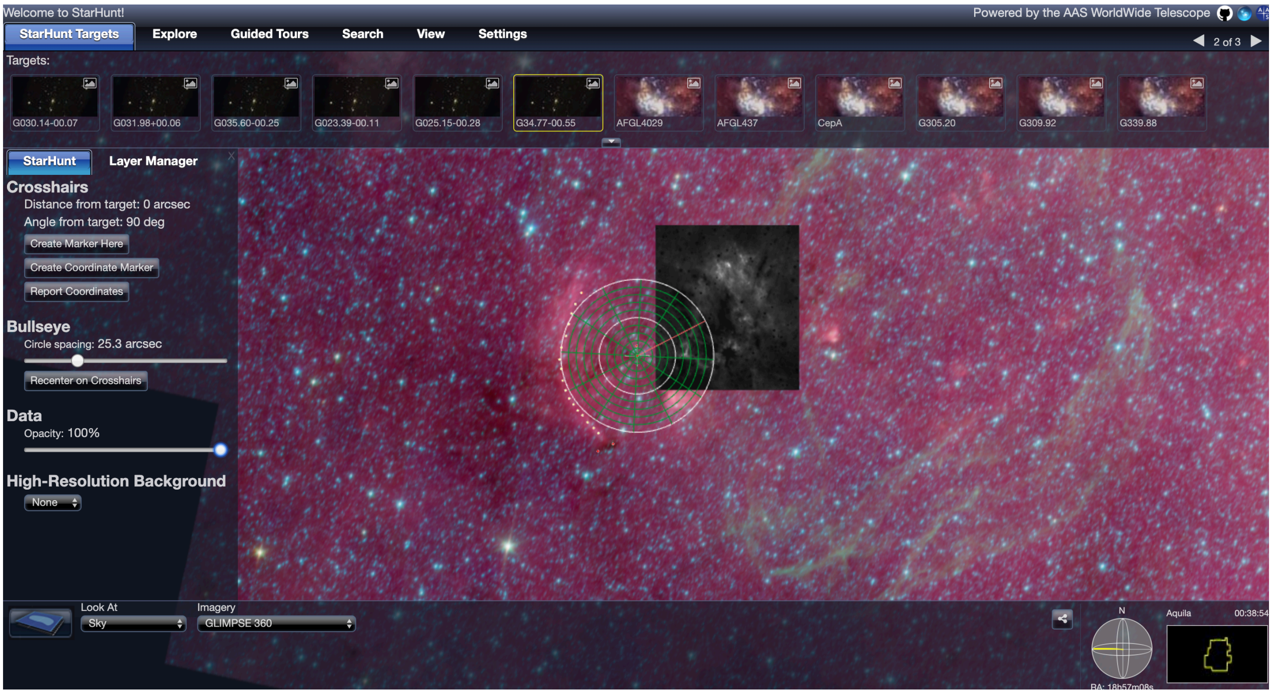


Figure 3.11: Example of bubble identification around the molecular cloud G034.77-00.55. The bullseye is located at the center of the bubble and extended to a radius corresponding to that of the bubble. The shape of the bubble is indicated by yellow markers.

27. This is the right moment to take a good snapshot! (remember to add it to the tab *screenshots*)

28. Move the cross-hair at the center of one of the bubbles.

29. Click in *Recenter on Crosshairs*, resize the Bullseye so that you can measure the Angular Radius of the bubble in arcseconds. Calculate the Physical Radius from the Angular Radius using the same equation (1) and method you used in Task A. Do this for all the identified bubbles.

By following all these steps, you should see something similar to what shown in Figure 3.11.

Your scientific point of view.

As we discussed before, we need to look for Galactic bubbles around molecular clouds to test the idea that these may have helped to form the molecular cloud (and thus maybe new generations of stars) by sweeping up material during their expansion. Again, we need to formulate a hypothesis and to perform some scientific analysis that will proof or discard it.

Hypothesis:
Galactic bubbles are bright structures produced by luminous stars or supernova explosions from recently deceased stars that may have helped to form the molecular cloud and new generations of stars.

The first step of our analysis is to understand the nature of bubbles you have identified, i.e., we want to understand if there are stars at the centre of the bubble.

30. Change your background to the 2 micron image by clicking in High-Resolution Background and choose 2MASS.

31. Are there any bright point sources near the bubble center? If yes, it is likely that these are luminous stars that have made the bubble by their winds or radiation. If there is a cluster of stars in the center, then it could also be that the bubble was produced by a supernova explosion from one of the cluster members, which has now disappeared. If there are no obvious point sources, then the bubble could be a supernova from a single, lone massive star, since destroyed.

32. To see if the bubble is a supernova, explore how it looks in the X-rays using the RASS: ROSAT All Sky Survey (X-ray). Supernova remnants tend to shine brightly at X-ray wavelengths!

33. Leave your answers to these questions and any other observations you wish to comment on in the dedicated space in the 'bubbles" spreadsheet.

Finally, we want to understand if the bubbles have helped to form new stars. In order to do this, we need to understand how the position of the bubbles in the sky relates to the position of the filaments we found in **Task A**. The best way to do this is to compare the picture you produced in **task A** with those you just produced in **optional task**.

34. Try to put these images side by side. Are bubbles far away from the filaments? In this case, the bubble probably has had no influence on the filament. Does any filament line up with the rim of the bubble? In this case maybe the filament has been produced by bubble expansion that has swept up gas of the interstellar medium. Is the center of the bubble aligned with any filaments? (you may need to look on larger scales around the bubble, since the bubble could have destroyed the nearby parts of the filament). If so, then this bubble likely was produced by a star or stars that formed from the filament. If such a case is a supernova, then that is very interesting, since we know it takes at least 3 million years for a supernova to result once a massive star is formed… this would tell us the filament is at least 3 million years old! Leave us your notes about your observations and conclusions from this investigation in the online table.

By looking at the results of your analysis, ***do you think the hypothesis is true or false***? Tell us your point of view in the dedicated space of the "bubbles" spreadsheet and motivate your answer.

What we astronomers will learn from your analysis in the Optional Task?

With your analysis, you are helping us to better understand the environment of molecular clouds across the Galactic plane. We will put together the data you send us with those of other schools and we will use them to study:

- ★ How many molecular clouds are close to a supernova remnant? Are there examples where the supernova remnant appears to have formed the molecular cloud? Or are there examples of molecular clouds that formed a star, which then later exploded as a supernova remnant?
- ★ How many sites of massive young or forming stars are around a molecular cloud?

★ What is on average the distance of a bubble from a molecular cloud?
★ How big are Galactic bubbles? Do they have similar sizes or a wide range?

We will discuss these questions and we will show you what you have helped us to achieve in a face-to-face session during The Star Hunt!

End of Exercise 1

Now that you have completed the Exercise 1, you are free to send us the results you have got so far. If you decide to do so, please name the file with the name of your school followed by the number of your team and Exercise1 at the end of the file name

Exercise 2: The Birth of Massive Stars

Now that we know everything about molecular clouds and their surrounding environments, we are ready to take a closer look. The most important thing about molecular clouds is that they are stellar nurseries. Every star forms within a molecular cloud. In Exercise 1 we looked at the clouds on large scales to gain an idea of how conditions arose to form the clouds and the stars. Now, in Exercise 2, we will look closely at places inside molecular clouds where very massive stars are still forming - we call them massive “protostars”. We want to better understand, for example, if these important, powerful massive protostars are forming in isolation or in groups of star families, called stellar clusters.

In this section:

- We will look at finding a forming star (a “protostar”) in the sky and we will study this object by looking at the different wavelengths of light that it emits.
- By using the WWT tools such as *Bullseye* and *Markers,* we will take a census of how many other stars are located around the protostar.
- We will use the numbers and positions of the stars to study the “distribution of stars” around the protostar: how many stars are very close to your massive protostar? Is the distribution of stars concentrated around the massive protostar? If so, this can give us a clue about what conditions are needed to form massive stars.
- Finally, we will learn how to assess how uncertain our measurements are: this is called error analysis. Scientists uses it to understand how reliable a measurement is.

Why are we doing this?

As mentioned in the introduction, stars are formed by the accretion (gathering) of gas from a collapsing gas core, via a spinning accretion disk, onto a central protostar. As the protostar gains material from the disk, it also produces violent jets, i.e., ejections of material from both surfaces of the disk, which we think are collimated by magnetic fields into narrow jets. In Figure 3.12 we can see one of the jets from a protostar in reddish colours, however the disk (and the opposite jet on the other side) is hidden by all the gas and dust in the collapsing gas core.

In this exercise we want to understand how the environment surrounding a protostar affects its formation. In particular, we want to understand how many stars there are around massive protostars and how these are distributed. This information will allow us to test different ideas about how massive stars form. For example, can massive stars form in isolation or do they always need a surrounding cluster of lower-mass stars, like our Sun, which help feed them gas from the molecular cloud? This is important for a general understanding of the evolution of our Galaxy and Universe, since massive stars make most of the heavy elements that are needed by life! We would also like to know how common it is for low-mass stars, like our Sun, to be close to massive stars at their birth. There is some evidence our own Sun was in such a position - how special is the Sun?

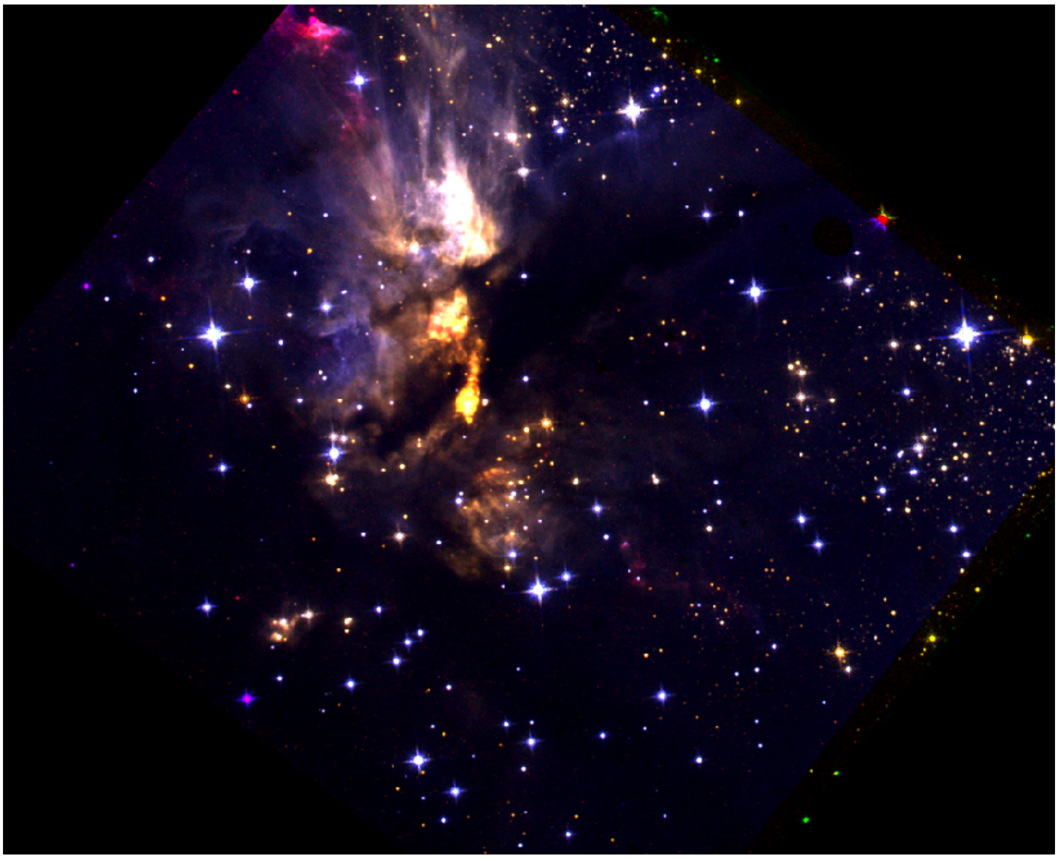


Figure 3.12: Hubble Space Telescope (HST) image of the high-mass star forming region G35.2-0.74N. During the process of star formation, protostars blast their surroundings with powerful jets and outflows that are seen in this image in bright colors. These jets move at more than 500 km s^{-1} and are the first way that stars begin to destroy the molecular cloud from which they were born.

Task B - Searching for Stars

For the example of this exercise we use the high-mass protostar G35.2-0.74N, which so far has gathered about 10 times the mass of our Sun and whose distance is 7175 light years (ly). In Figure 3.12 we show the stellar nursery where this object is forming. In this exercise, we will also introduce some simple mathematical concepts such as area, density, making graphs, and calculating measurement errors. We will start in a similar way as in Exercise 1, exploring the surroundings by following these steps:

1. Open the web client by typing http://starhunt.worldwidetelescope.org/ in the Google Chrome browser of your laptop or tablet.

2. Make sure that the default background Imagery is selected, i.e., *Digitized Sky Survey (Color)*.

3. Go to **StarHunt Targets** Tab and upload your SOMA source by clicking in its name. In the case of the example G35.2-0.74N. How does the source look now?

4. Explore the region: Do you see anything at the location of your source?

5. Select in the **Imagery** Tab the *GLIMPSE 360* image of the sky

6. Explore again: What do you see now? Can you tell where your source is and how it looks like? Describe the source. Is it point like? Is it elongated?

7. Go to **Data** and change the **Opacity** using the scrollbar.

8. Select *2MASS* in the **High-Resolution Background** Tab.

9. Adjust the **Opacity** so that both your source and the *GLIMPSE 360* or *2MASS* image are visible. Describe what you see and take a screenshot with your best creation! *(remember to upload for screenshots in the spreadsheet tab as explained in pages 6 and 7)*

If you remember from the introduction of the booklet, changing the background images from DSS (optical), to 2MASS (near-infrared), to GLIMPSE 360 (mid-infrared) what we are doing is to look at the star-forming region at longer and longer wavelengths. In this way, we can observe deeper and deeper in the cloud, which is obscured by gas and dust. What you do not see at one wavelength might be revealed at another wavelength!

Tip: If you see that the image sometimes goes completely black, adjust the zoom-out and you will recover the image. Sometimes the sky and the internet do not connect!

This exercise involves one main task and further analysis afterwards.

10. Locate the centre of the object (the WWT will take you to the centre when you click on your object in the **StarHunt Targets** Tab).

11. Place a red marker clicking *Create Coordinate Marker* to mark the central object.

12. Adjust the circle spacing to **10 arcsec** using the *Circle spacing* scrollbar (in this way you will have a total of 100 arcsec to work with).

13. Put opacity of the data to 0% using the *Opacity* scrollbar in **Data**.

14. Set **High-Resolution Background** to 2MASS with 100% its *Opacity* scrollbar.

15. Zoom-in and start counting stars! Make sure to look carefully at the images to be able to find even faint stars.

16. Place one yellow marker for each star clicking *Create Marker here* you see in the 2MASS image within the circles (see Fig. 3.13).

17. Once you are done, set the opacity of the High-Resolution Background to around 20%. In this way you can compare with the GLIMPSE image. Place makers in the stars that you have missed! (sometimes stars will appear more clearly in the longer wavelength GLIMPSE image)

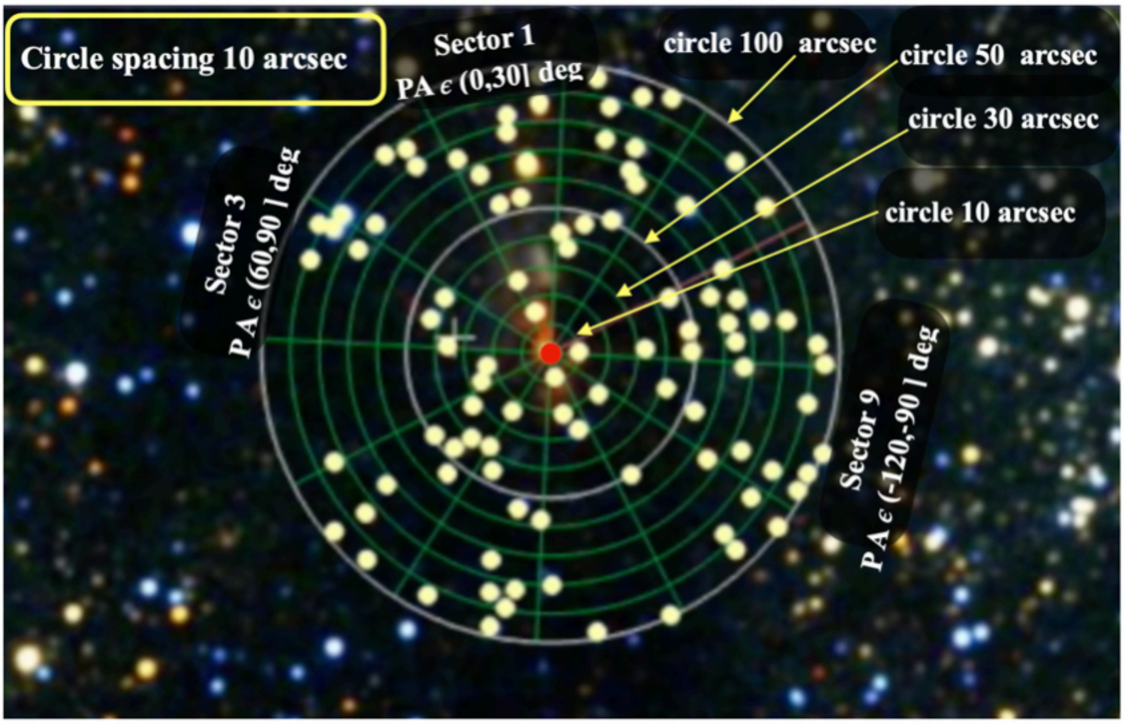


Figure 3.13: Bullseye centred in the star forming region G35.2-0.74N. The various sectors and circles are highlighted. Markers indicating the position of stars in the background image 2MASS are represented by yellow dots (note that the central dot is the massive protostar itself and is not included in the star counting).

Once we have hunted all stars in the region we defined, we are ready to fill in the tables and make the graphs. This information is crucial for the astronomers as they need to know the stellar density around high-mass protostars to test theories of formation. In this link http://cosmicorigins.space/starhunt you will find video examples that can help you to carry out the exercise.

B:1 Counting Stars in each Circle

First of all we need to identify the different circle radii (Circle Angular Radius from 10 to 100 arcsec) in the region we defined. For this, let's consider Figure 3.13. Since we set the spacing circle to 10 arcsec, we know that the smallest circle corresponds to an Angular Radius of 10 arcsec and the biggest to 100 arcsec (see Figure 2.3). This information is reported in column 1 of Table 4.

Next we need to convert from Angular Radius to Physical Radius for each circle. To do this we use equation (1) from Exercise 1 that is written below as well for convenience (see page 18 for more details). For the example of G35.2-0.74N, which is 7175 light years away, then the first circle has Angular Radius of 10 arcseconds and a Physical Radius of 0.35 light years. You should enter this information in Column 2 of Table 4 for each circle.

$$s = (4.85 \times 10^{-6}) \times \alpha \text{ (arcseconds)} \times d \text{ (light years)} \qquad (1)$$

Now it is time to test the first hypothesis of this exercise:

Hypothesis: Low-mass stars are clustered around massive protostars.

In simple terms, this means: are there more stars per unit area or volume close to the massive protostar compared to the typical levels in the region?

To test this, we now count the **number of stars** that are in **each circle**. Starting from the smallest, we see that in our example there are 2 stars (do not count the central massive protostar itself!). Then, in the second circle we count 1. We continue like this until the last circle, that we count 20 stars. We write down this information as has been done in the third column of Table 4. Then, we calculate the sum within each circle. For example, if we count 2 stars in the first circle and 1 star in the second circle, we know that the sum inside the second circle is 3 stars. Enter this in the Table 4 as the fourth column.

Tip: If a star lies in the middle of two circles (on top of a line) always count it as belonging in the smaller circle.

Now we need to calculate the area of each circle, which is given using basic geometry Area = πr^2. In the example of G35.2-0.74N, the innermost circle with radius of 0.35 light years has area 0.38 $(ly)^2$. See Table 4, below, for all the information on G35.2-0.74N.

Now we calculate the "stellar surface density" simply by dividing the sum of stars in a given circle by its area. Write down this information as the sixth column in the table. In the case of G35.2-0.74N's first circle, there were 2 stars inside an area of 0.38 $(ly)^2$, so the stellar surface density here is 5.26 stars per $(ly)^2$.

We are also interested in the number of stars per unit volume (also known as the "number density"). It is similar to what we did for the area, but now assuming the stars are distributed in a spherical volume. Recall that the volume of a sphere is Volume = $(4/3)\pi r^3$. Write this information in columns 7 and 8. In Table 4 we show a full example table where the number of stars per volume is evaluated. If you think about the actual distribution of stars in space, then consider what effects this could have on the accuracy of our estimate of number density (hint: what if some stars are simply in the foreground and aligned by chance with our region – what effect would this have on the estimate of the number density?).

Now, with all this information we can make several graphs. One that is very informative is to put in the X axis the circle size and in the Y axis the stellar surface density. In this way, we can detect if there is any overpopulated region next to the massive protostar and test our hypothesis. We show an example of graph in Figure 3.14. You can also plot the circle size against the stellar volume density. Can you tell if the proposed hypothesis above is true or false? You can make all these graphs very easily with your spreadsheet.

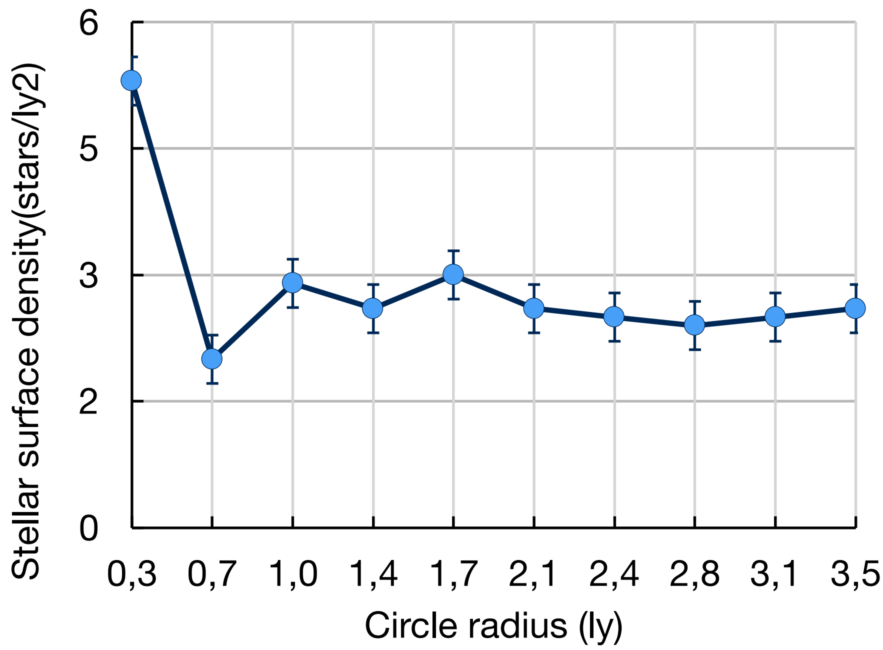


Figure 3.14: Graphical representation of the stellar surface number density per circle. Error bars indicate the counting (Poisson) error in the data (see Error Calculation section).

Table 4: Star Hunt summary example circles

Circle Angular Radius (θ) (arcsec)	Circle Physical Radius (r) (ly)	#stars	Sum	Area (πr^2) (ly^2)	Stellar surface density (stars/ly^2)	Volume $\left(\frac{4}{3}\pi r^3\right)$ (ly^3)	Stellar number density (stars/ly^3)
10	0,35	2	2	0,38	5,26	0,18	11,33
20	0,70	1	3	1,52	1,97	1,41	2,12
30	1,04	7	10	3,42	2,92	4,77	2,10
40	1,39	6	16	6,09	2,63	11,30	1,42
50	1,74	13	29	9,51	3,05	22,06	1,31
60	2,09	7	36	13,70	2,63	38,13	0,94
70	2,44	11	47	18,64	2,52	60,54	0,78
80	2,78	11	58	24,35	2,38	90,38	0,64
90	3,13	20	78	30,82	2,53	128,68	0,61
100	3,48	20	**98**	38,04	2,58	176,51	0,56

B: 2 Counting Stars in each Sector

Once we have counted how many stars are in each circle, we can test another important hypothesis:

Hypothesis:
There is a preferential direction of the stars surrounding the massive protostar.

This hypothesis is motivated by the formation mechanisms of massive protostars. We mentioned that during their formation, protostars blast their surroundings in certain directions with powerful jets, which can shape the environment. This could have several effects. For example, the jets could clear away dust and so make it easier to see stars in certain directions. If this is true, then we would notice more stars in directions that line up with those of the protostellar jets (at least the one that is on the side approaching us). This would then mean that there are actually lots of stars in other directions, but simply hidden by dust of the collapsing core. Alternatively, more stars in certain directions could be caused by the large scale cloud being elongated, like a filament, and the stars are forming preferentially at these locations. To test this idea, we would need to also look at the larger scale and see if there is a dark filament along these directions. Or the stars may be at random positions, without any preferred direction.

Circle Sector	#stars
1	11
2	5
3	7
4	4
5	11
6	9
7	6
8	7
9	11
10	12
11	3
12	12
TOTAL	**98**

Table 5: Star Hunt summary example sectors

To test this hypothesis, we will count **how many stars** are in **each sector**. For example, in *Sector 1* we have 11 stars, while in *Sector 11* we have 3 stars. We count the stars for each sector and write down the information in tabular form, in Table 5.

Hence, we will make a graph with the information of the table. For this, we take the X axis as the Sector number (from 1 to 12) and the Y axis as the numbers of stars (note all the sectors have the same area). An example of this graph is given in Figure 3.15. This information is of critical importance to astronomers to discern whether or not there is a preferential angle or position for stars in the stellar nursery. What would you say? Is there a preferential direction to have more or fewer stars?

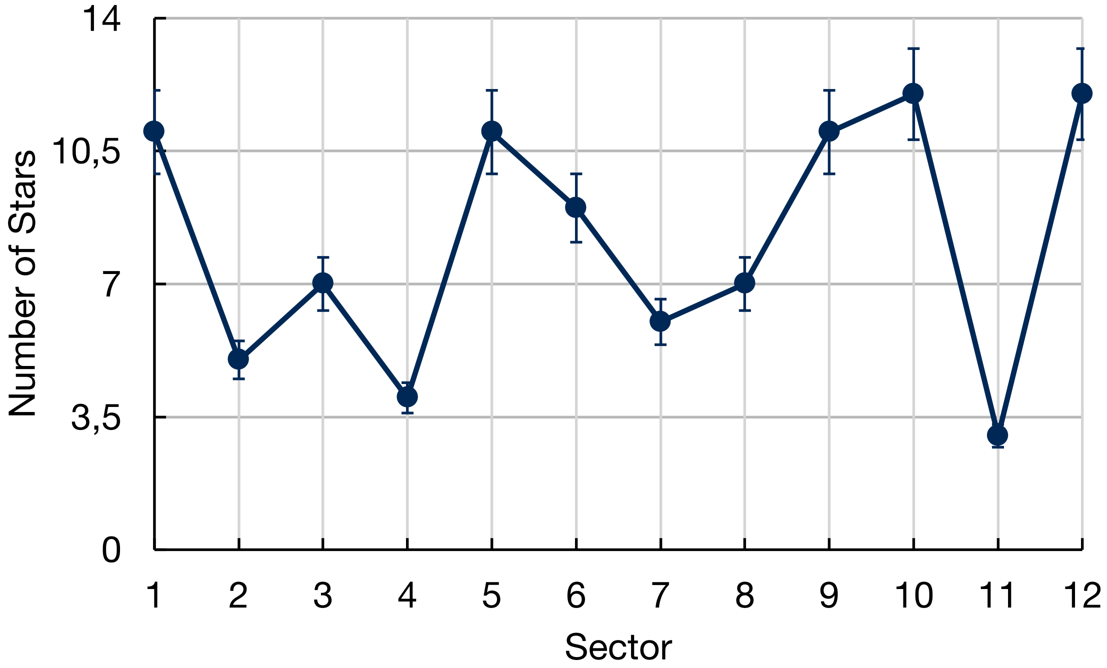


Figure 3.15: Graphical representation of the number of stars per sector. Error bars indicate the counting (Poisson) error in the data (see Error Calculation section).

Tip: Make sure that the total numbers in both tables (Table 4 and 5) coincide! In this example we have 98 stars in total.

To end with the exercise, do not forget to send us your table with all your graphs and screenshots (added to the table) as we explained in pages 33 and 34

Optional task: Error calculation and error bars

The simplest source of error considered in a given distribution is the so-called counting error, also known as Poisson error. It is given by simply the square root of the number of objects (stars) that you count. For example, if you count 100 stars you have a Poisson error of $\sqrt{100} = 10$. So your result is 100 ± 10. This means we were able to determine the stellar number (and thus surface density and number density) to an accuracy of 10 / 100 = 0.1 (i.e., 10%). But what if you only counted 3 stars? How certain can we be of our measurement?

If you have time, estimate the errors in your counting measurements of the numbers of stars in both the circles and sectors. The percentage error in these numbers will be the same percentage error in the surface densities and number densities of stars. We have plotted these error bars on our graphs. See if you can do the same! For more information about this, see the Extra Activities document at The Star Hunt web portal:

http://cosmicorigins.space/starhunt and/or we can discuss it during our interaction session!

What we astronomers will learn from your analysis?

These regions have not been seen before with the detail you have looked at them. With your help and effort, we will be in the position to discern whether a massive star is forming in an isolated way or is surrounded by a great swarm of lower mass stars. We will also learn if the stars align with the powerful jet or not. It will very interesting if the numbers of stars found by different teams and different schools are uniform or not! This will tell us how different teams might focus on different aspects of the same region. All given information is valuable, and we will use it with great care. Who knows if you are making the great discovery of the XXI century! Thank you very much!!!

Extra Activities for The Star Hunt

Maybe you would like to explore more?

We have prepared some extra activities that you can try help explore the Universe and better appreciate your research work so far. See the Extra Activities document at The Star Hunt web portal: http://cosmicorigins.space/starhunt

Research methodology

Introduction

Research is the activity of gaining new knowledge. In the context of scientific research, we aim to do this in a carefully-considered, orderly way, in particular by formulating hypotheses that are possible to test and thus prove or disprove whether they are correct. The research methods used, including gathering, analysis and interpretation of data, should be as objective as possible – free from preconceived notions and individual opinions. These methods must be structured, orderly and repeatable.

Scientific methods have been crucial for expanding our knowledge of the world and for the development of technology. These methods are basic tools that can help us solve problems and answer questions. Depending on the research field, scientific methods can look a little different. For example, there is are often differences between the methods in the social sciences, on the one hand, and in the natural sciences on the other. Even within the natural sciences, there can be important differences between, for example, physics and chemistry, where controlled, repeatable experimentation is usually possible, and astronomy and geology, where it may not be.

Scientific methods can be divided into:
Quantitative methods involve experiments, observations and measurements leading to gathering of quantitative data in order to test hypotheses. Natural science researchers are the main users of these methods, but some social science researchers also use them.
Qualitative methods that include recording descriptive observations of individual phenomena and events, which by their nature may not be able to yield quantitative measurements.
It is not unusual to combine several different scientific methods in a research study. Furthermore, research that combines knowledge and methods from different branches (disciplines) of science is called interdisciplinary.

There is also a difference between basic and applied research. The aim of basic research is to increase general knowledge in a given field. Applied research is instead more likely to be put into practice by an external party, such as a public authority, local government or company that can find answers to a specific problem with the help of a research effort. However, the boundary between basic and applied research is not distinct – basic research often leads to applied research, and vice versa.
The most important steps in the scientific method are asking a question, establishing a hypothesis about what you think the outcome will be, designing experiments that test this hypothesis, gathering experimental data, analysing the data and then – based on the conclusions you have drawn – accepting your hypothesis or creating a new one.

In scientific studies – for example when we calculate, observe and sort information – it is important to design the study so that it actually measures what it is supposed to measure. This may sound obvious, but is not always the case. Scientific methods, with all their different well-defined steps and demands for detailed reporting of methodology, analysis and results, have been developed precisely to be as independent as possible and to avoid errors and the possibility that the personal opinions of the researcher will colour the studies they conduct. However, things can be measured in different ways and can yield different answers, among other things depending on one's starting point and theory formulation. This is one reason why even researchers working on similar issues may arrive at different results and sometimes draw different conclusions. The tradition of questioning conclusions and the constant discussion by the research community of the results obtained then help achieve further progress in research efforts.

Another crucial aspect of scientific research is the recognition that there is always some uncertainty present. For example, there is always some degree of measurement error, which can include statistical/sampling/random errors (e.g., due to a small sample size or random noise fluctuations contaminating a measurement with no preferred direction) and systematic errors (e.g., due to contamination or bias in a sample that tends to act in one direction to give a misleading result). Thus one feature of scientific knowledge is that while "facts" can be established, e.g., after repeated experiments confirm a hypothesis, there always remains at least a small chance that the hypothesis is actually not correct and could be overturned by some future, better experiment that leads to a more accurate hypothesis or theory. However, this new theory would still need to be able to also explain all the previous experimental results. Thus, scientific theories need to be open to being falsified if contradictory data are found. In this way, the collection of scientific hypotheses and theories, which form the body of knowledge of a science are continually tested and improved.

The Star Hunt – this year's "Help a Scientist" project – is about studying the process of how stars are born from interstellar clouds in our Galaxy. The Star Hunt is categorised as basic scientific research. Students will explore their own assigned regions of interstellar clouds in our Galaxy. It will involve a combination of qualitative and quantitative scientific methods. By gathering and analysing data from many different star-forming regions, it will increase our knowledge of the environments around dense molecular gas clouds (for example, are they typically being affected by external influences, such as supernova explosions?) and around regions where very massive stars are forming (for example, do massive stars always form surrounded by a dense cluster of lower-mass stars and what are the properties of such clusters?). The students' results will contribute to increased human knowledge about our Galaxy and especially about the birth of new stars, which will ultimately help us to better understand the origins of our own sun and its planets.

The project is based on analysing images taken by various telescopes that are located on Earth or in space. The images will be provided via the web-based World Wide Telescope platform, which works together with the US National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) databases. The telescopes have different properties, such as measuring the light radiation from the interstellar clouds at different wavelengths, ranging from X-rays to radio waves. Depending on the wavelength analysed, different phenomena can be detected in the interstellar clouds.

Professor Jonathan Tan works at the Department of Space, Earth and Environment at Chalmers University of Technology in Gothenburg, Sweden, where he collaborates with postdoctoral researchers Dr. Giuliana Cosentino and Dr. Rubén Fedriani. Their research deals with the birth, life and death of stars, especially massive stars and star clusters. Massive stars, i.e., those with more than 8 times the mass of our Sun, die as supernovae. Supernova explosions generate many chemical compounds that are necessary for the creation of planets, and thus life. Their research is aimed at enabling us to better understand the life cycle of the stars, and thereby also how planets and life have emerged.

Below we will illustrate the work of the Star Hunt through the scientific method. We will use a pedagogical and somewhat simplified process-results diagram of the scientific method, consisting of hypothesis-experiment-results-analysis-conclusion. Next to each step is an explanatory text written by the Swedish National Agency for Education.

Question/Problem

When you start a scientific study, you start with a question. In the Star Hunt our overall question is: How are stars born?
In the first part of the project, we study dense molecular clouds that are expected to be the site of future star cluster formation. Here the overall question is: What processes are influencing the environment of the molecular clouds?
In the second part of the project, we study massive protostellar cores, which are locations where high-mass stars are currently forming. Here the overall question is: Does the birth of massive stars require the presence of a surrounding cluster of lower-mass stars?

This describes a specific problem or question that we want answers to. The description should be concise but still sufficient for someone who knows nothing about the problem to be able to understand. Remember to formulate it in such a way that it will be possible to discuss your results in the conclusion. / National Agency for Education

Formulate a hypothesis

When you come up with a question it is important to formulate a hypothesis, which is really just another way of asking the question, but you write it in such a way that you can test it.
In the first part of the project, our overall hypothesis is: dense molecular clouds are usually being impacted by surrounding external “feedback” processes from already formed stars, including wind-blown bubbles and supernova explosions. These feedback processes could have swept-up interstellar gas to form the dense molecular cloud. If the hypothesis is confirmed it could imply that the birth of new stars is triggered by previous generations of massive stars. Alternatively, if the clouds are seen to typically be relatively isolated from external feedback, then it could indicate that star formation results from processes related more to the evolution of molecular clouds themselves, rather than needing a feedback trigger.
In the second part of the project, our overall hypothesis is: massive protostars are always found at the centre of a dense cluster of lower-mass stars. This is a prediction of one theory of massive star formation proposed about 20 years ago, known as “Competitive Accretion”. An alternative theory, known as “Core Accretion” does not require that massive protostars have such a surrounding cluster.

This provides a little background on the problem/question and explains why you are conducting the study. Put the study in context. Tell us about the results of previous research. This explains to the reader why the area is interesting and how you can help increase our knowledge about it. / National Agency for Education

Method

Numerous images at different wavelengths of light of our samples of molecular clouds and massive protostars are available via the World Wide Telescope (WWT) tool. First we will learn to navigate the sky, i.e., the “Celestial Sphere” in the WWT.
We will then analyse the images of the regions containing the molecular clouds in a systematic way to assess if there are nearby wind-blown bubbles or supernova explosions. Indeed, the goal will be to identify the nearest such features to the clouds and quantitatively measure the distance between the objects and the size of the bubbles/supernova remnants. For identified bubbles and supernova remnants, their nature can be explored by examining images at different wavelengths.
For the study of the protostars, we will examine infrared images that are sensitive to the presence of young, lower-mass stars that may be in the vicinity. We will define a grid of annuli and sectors centred on the massive protostar. We will then measure the number of

these lower-mass stars as a function of distance from the massive protostar and at different angles. We will quantitatively assess the number of detected stars to estimate the total number density of sources.
For both parts of the project, we will consider possible sources of errors.

This describes the method of the study, and whether it is a quantitative and or qualitative method. Describe if you have performed control experiments. Describe what sources of error you can find. Describe materials and measuring equipment. If you have completed surveys or interviews, attach them. / National Agency for Education

Study

The study should follow the prescribed methods. There are various stages, where intermediate results are gathered and considered along the way to reaching a final conclusion.

Describe how you conducted the study. Feel free to include images and figures. / National Agency for Education

Results and analysis

Each student team should obtain some qualitative and quantitative results. Qualitative results will include a general description of features that they notice in the images. Quantitative results include distances and sizes of any bubbles and supernova remnants found and the number of low-mass surrounding stars around the massive protostars and their spatial distribution.
The researchers will compile the overall results from all the school classes and provide feedback that includes results from all regions of the Milky Way that were studied.

Here, measurement data are presented, for example in tables and charts. Qualitative data are reported by such methods as suitable quotes from interviews. If you have a lot of data, you can choose to report only what is relevant for analysis and conclusion. / National Agency for Education

Analysis/discussion of data

There will be analysis/discussion of data possible for each student team's project on their sources. They will interpret the images with guidance and support from the researchers. In particular, at least for these objects they will be able to address the validity of the original hypotheses. Sources of uncertainty should also be discussed.
The compilation of the entire sample of objects in each class will enable more general analysis and conclusions to be reached about how stars form at the molecular cloud scale and for massive stars. Thus, the student projects will make an important contribution to this research subject.

Describe in words what your results show. Conduct a discussion on your results and interpret them. How large and relevant are your sources of error? Do you need to study your question further? If so, how? What is the significance of your results and your conclusion? Discussion and question formulation are the most creative part of a scientific study. / National Agency for Education

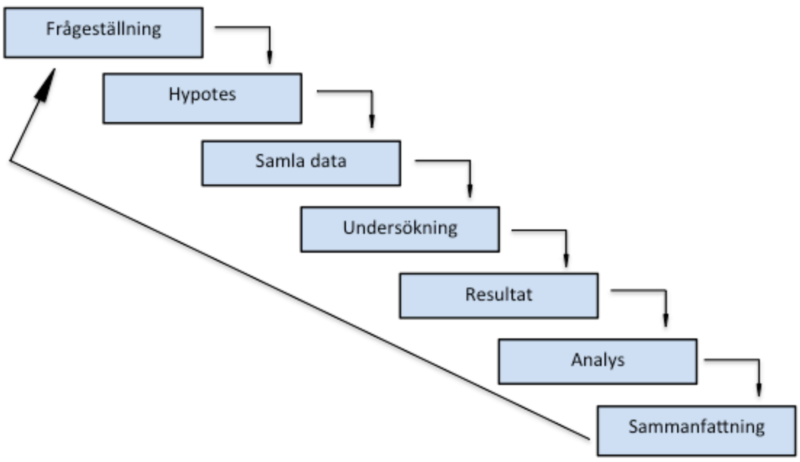
Conclusion

Here the students will summarise their results, especially in relation to the questions raised in the original hypotheses. The researchers will provide guidelines for the students' conclusions and will also examine whether these have led to new questions and ideas for future studies. The researchers will also evaluate whether they have received sufficient background data for a scientific article.

Must be brief. Summarise the outcome of your discussion. Remember to write in a way that answers the initial question. Be clear about whether your conclusions are reliable, considering your sources of error. Remember that people should be able to read your introduction and conclusion and get an idea of what you have studied. / National Agency for Education

Spreading knowledge

The students will distribute/display their posters at school, at Nobel Prize Museum and in various social settings. There can also be press releases to local newspapers, local radio stations and so on. The researchers will write a scientific article and present their results in the form of lectures or with the help of posters at conferences aimed at a scientific audience, but also in other relevant contexts where their results may be useful.



Question Hypothesis Gather data Research study Results Analysis Summary

References (in Swedish)

https://www.skolverket.se/download/18.6011fe501629fd150a292c8/1530883630960/Strukturen%20i%20en%20naturvetenskaplig%20rapport.pdf

Tips on more information about the scientific method

Examples of the various steps of the scientific method:

http://www.storyboardthat.com/sv/articles/e/vetenskaplig-metod

Examples related to the DNA molecule and Nobel Laureates:

http://www.storyboardthat.com/sv/storyboards/sv-examples/vetenskapliga-metoden-med-dna

Videos, Clearly thought + teacher's guide

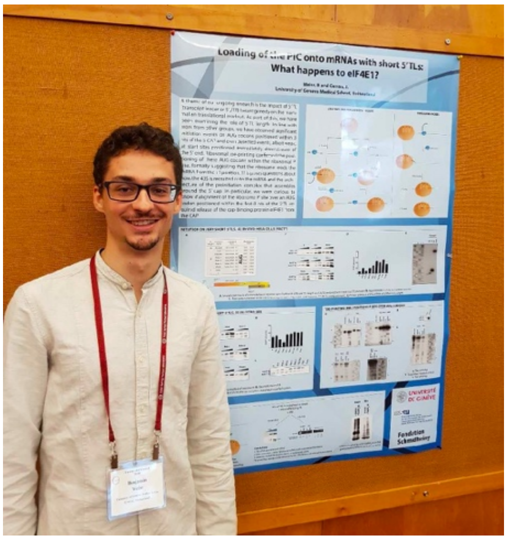
https://nobelprizemuseum.se/sv/skola/lararhandledningar/klartankt/

To communicate research results

When researchers have completed a series of experiments and obtained results that lead to new conclusions, they want to share this with other researchers and the outside world. In this way, research results are spread and can be used as a basis for other researchers to build upon.

Researchers spread their research results and conclusions via peer-reviewed articles that they publish in scientific journals. There are a number of subject-specific international journals of different prestige. It is important for researchers to publish their results. Researchers are assessed all the time, and one important aspect of this is how productive they are in terms of publishing results. If you publish several articles with important results, you also have a greater chance of getting further funding from research councils and attracting new students.

In principle, all scientific articles are written in English and include a number of figures showing the obtained experimental results. You should also include a detailed description of how the experiments were performed (so other researchers can repeat them) and a reference list of previous articles that form the background of the study. Everything you want to publish is first reviewed by other researchers (peer-review or referee-review) and you often have to rewrite and perform more experiments before the article is approved for publication. Sometimes the manuscript is rejected by the journal, and then you have to reconsider, do more experiments in order to improve the study, and then send a new version to another journal. Often, it takes about six months from when you submit an article to a journal until it is accepted, and an even longer time before it is finally printed. Today, many financiers demand that you purchase what is known as “Open Access” when you publish. This makes the article freely available to the public, and not only to subscribers of the journal.

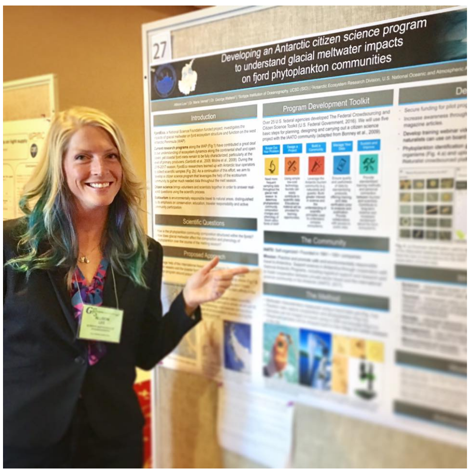


Another important way to share your results and get new ideas is to go to conferences. Conferences often have a theme, such as protein folding or renewable fuels, and can be small (from 50 participants) to huge (several thousand participants). These conferences are advertised far in advance so that researchers can plan their attendance and apply to give a lecture in the program. Usually a conference lasts for 3-5 days with a full schedule. The days are full of lectures where selected researchers explain their results in 20-30 minutes via a PowerPoint presentation. The language is English and there is usually time for question following each lecture, where the audience can ask questions. During some of the days, often in the afternoon or evening, conferences usually host so-called poster sessions.

A poster contains a short description of the researcher's study via text and images in an inviting and explanatory way. The researcher who made the poster should stand next to the poster during the session time and explain the research in more detail for other interested researchers passing by. At the same time the poster should be self-explanatory, and anyone should be able to read and understand the study even when the presenting researcher is not present. A schedule allows you to see when a presenter should stand at which posters. In this way, you can plan if you want to meet the researcher behind any particular poster.

All displayed posters are described in the conference program, where the schedule for all lectures is also stated. The program gives the title, the researchers name and a brief summary for each poster. Each poster has a number (so you can find it) and time (when the researcher should stand next to it). Conferences have many more posters than they have lecturers. Poster presentations is a way for a large number of researchers to present their results, and for less experienced researchers and students to show what they have done. Younger researchers are usually not invited as speakers to bigger conferences.

Poster sessions are often lively and enjoyable sessions with lots of people and lots of discussions and laughter. Often, the conference organizers offer drinks and snacks during the sessions. A poster prize is often awarded at the end of the conference when everyone has shown their posters. The prize is based on a combination of the design of the poster, the scientific results, and how well the person could explain the research. The posters are made on a large piece of paper that you roll up and bring with you in your suitcase. Nowadays, you can often bring the poster as a file on a USB-stick and print it at the conference, so you do not have to transport it. Researchers spread their research results and conclusions via peer-reviewed articles



Word List

A

Absolute Zero: it is the lowest temperature that it is possible to reach in nature. It corresponds to -273.17° Celsius.

Absorption spectrum: the electromagnetic radiation transmitted through a substance, showing dark lines due to absorption at specific wavelengths.

Accreting: A star is accreting when it is still forming by incorporating material from its surroundings, i.e., the molecular cloud in which it is born.

Accretion Disk: the material that is accreted by a star from its surroundings usually organises itself into a thin disk structure. The material orbits in circles within the disk, gradually spiralling inwards until finally falling onto the star.

ALMA: acronym for Atacama Large Millimetre/Sub-millimetre Array. It is a group of 60 radio telescopes located in the Atacama Desert and that are aligned to look at celestial objects. ALMA is a telescope observing millimetre and sub-millimetre wavelengths.

Angular Momentum: this is a physical quantity that an object has due to its rotation, mass and size. Angular momentum is conserved, so objects that become smaller (like collapsing gas clouds) spin faster (this is why an accretion disk usually forms during star formation).

Arcminute: a unit of angle equal to a 1/60th of a degree. Symbol: '

Arcsecond: a unit of angle equal to a 1/60th of an Arcminute and thus 1/3600th of a degree. Symbol: "

Astronomy: the branch of science that deals with the study of celestial objects, space, and the Universe as a whole.

Atmosphere: the envelope of gas surrounding a planet, such as the Earth, or other celestial object. Did you know that Saturn's moon Titan has a thick atmosphere?

Atom: smallest component of an element. It is consists of a nucleus made of protons and neutrons plus electrons moving around the nucleus.

B

Big Bang: the explosion from which the Universe was created about 14 billion years ago.

Binary stars: a system of two stars in which the stars orbit around their common centre of mass.

Black Dwarf: the final stage in the lifecycle of low-mass stars (similar to our Sun). They have run out of Hydrogen fuel for nuclear fusion in their centres and so gradually become cooler and cooler and fainter and fainter.

Black Holes: this is the final stage in the lifecycle of stars more massive than 30 times our Sun. Since the star is too massive, it collapses under the weight of its own gravity. Not even light can escape from the event horizon of a black hole. There are also supermassive black holes in the centre of most large galaxies, including our own. It is not yet known how these black holes are created!

C

Carbon: is a chemical element with the symbol C. It is crucial to form the organic molecules that are found in all living creatures.

Celestial objects: objects that are located in space.

Celestial Sphere: an imaginary sphere around the Earth, which can be considered a “Map of the Sky”. The different directions to celestial objects are plotted on this map, described by two angles (Right Ascension and Declination are the angles used in the Equatorial Coordinate system).

Chandra: Also known as Chandra X-ray Observatory, Chandra is a telescope orbiting the Earth, which observes the X-ray light coming from the Universe.

Conservation of Angular Momentum: It is a physical phenomenon for which an object will keep the same angular momentum: it stays with the same speed and spin axis if the size and mass does not change and as long as no torque is applied on the object.

Constellations: groups of stars in the sky that make apparent patterns on the Celestial Sphere, but are other wise not physically related, e.g., they can be a very different distances. The Celestial Sphere has been divided up into 88 different constellations that cover the whole sphere.

Cycle of Star Formation: stages of evolution that lead from a cloud of interstellar gas and dust to a newly formed star, followed by stellar evolution, the death of the star and return of some material back into space, enriched in heavier elements fused in the star. New stars keep forming from interstellar gas - the cycle goes around and around.

D

Declination: it is the angle between an object on the celestial sphere and the celestial equator. Together with Right Ascension, it is used to locate objects in the Celestial Sphere.

Degree: a unit of angular distance equal to a 1/360th of a full circle. Symbol:°

E

Ecliptic: The ecliptic is the path of that the Sun follow in the Celestial Sphere: over the course of one year it completes a full circle around. But this, of course, is really due to the Earth orbiting around the Sun.

Electromagnetic wave: waves, including visible light, infrared light, etc, that are created as a result of vibrations of electric and magnetic fields. These waves can travel through the vacuum of space and are the way by which astronomers learn most about the Universe. The Electromagnetic Spectrum describes the full collection of these waves ordered by their wavelength.

Emission spectrum: particular wavelengths of the electromagnetic spectrum that are emitted by chemical elements in hot gases.

Energy: it is a physical property that must be transferred to an object to be able to perform work on, or heat, the object. Energy is conserved, so it cannot be created or destroyed, just converted from one form to another.

Equatorial Coordinate System: it is a system used by astronomers to locate an object in the sky through its coordinates, two angles known as Right Ascension and Declination.

Exoplanet: it is a planet located outside our Solar System.

F

G

Gamma-ray: most energetic type of electromagnetic radiation, characterised by the shortest wavelength and highest frequency.

H

Habitable zone: a region of space where conditions are best for life to form. It is usually identified around stars to be the region where temperature allows water to be a liquid.

Heavy Elements: in Astronomy, elements heavier than Hydrogen and Helium are called heavy elements or “metals”.

Helium: chemical element with symbol He. It is the second most abundant element in the Universe.

Hubble Space Telescope: a well known telescope orbiting the Earth, observing in Ultraviolet, Visible and Infrared light.

Hydrogen: chemical element with the symbol H. It is the simplest and most abundant element in the Universe.

I

Infrared Radiation: light waves with wavelengths just longer than visible light.

Interstellar gas and dust: the material located in the space between stars. While the interstellar gas is mostly composed of H and He, interstellar dust consist of heavy elements, like Carbon, Iron, Silicates (of Silicon, Oxygen).

Iron: chemical element with symbol Fe. It is produced in the centres of massive stars.

J

Jets: ejection of material from the surfaces of accretion disks around forming stars. Usually become collimated, probably by magnetic fields.

K

Kelvin scale: standard temperature scale used in physics and astronomy. Zero degrees Kelvin is written as 0 K and defines Absolute Zero. Water freezes at 273 K.

L

Latitude: geographic coordinate that specifies the north–south position of a point on the Earth's surface. Analogous to Declination on the Celestial Sphere.

Light pollution: presence of artificial light in the environment that interferes with night sky observations.

Light travel time: time that the light takes to travel from a point to another.

Light years: unit of distance used by astronomers. It corresponds to the distance travelled by the light in one year, which is equal to 9.46 trillion kilometres.

Longitude: geographic coordinate that specifies the east–west position of a point on the Earth's surface. Analogous to Right Ascension on the Celestial Sphere.

Lyman Spitzer: Physicist and Astronomer (1914 - 1997). He is known for his studies of the Interstellar Medium and also for being the first astronomer to propose the possibility to have telescopes in space. The Spitzer Space Telescope, which observed in the Infrared, bears his name.

M

Magnetic fields: magnetic fields extend from a magnetised object, transmitting magnetic force and containing magnetic energy.

Main sequence star: any star that is fusing hydrogen in its core and has a stable balance of outward pressure from core nuclear fusion and gravitational forces pushing inward.

Microwaves: form of electromagnetic radiation with wavelengths ranging from about one millimetre to one meter.

Milky Way: it is the official name of our Galaxy. Part of the Milky Way is visible in the night sky and appear very bright. Hence, the ancient Greek compared it to the the maternal milk that the goddess Hera used to feed Hercules. Form this the name "Milky" Way.

Molecular cloud: region of the interstellar medium in which the Hydrogen gas is mostly in the form of molecules. These tend to be relatively dense and cold compared to other parts of space. Stars form from molecular clouds.

Molecule: group of two or more atoms bond together by electric forces, i.e., chemical bonds.

Moon: the only natural satellite of the Earth.

N

Neutron Star: it corresponds to the last stage in the lifecycle of stars with masses between about 8 and 30 times the mass of our Sun. Neutron stars are so dense that electrons and protons are crushed together forming neutrons. Hence, a neutron star is made almost entirely of neutrons.

Nuclear fusion: process in which atomic nuclei are fused together to form a nucleus of a heavier element. This is the main energy source of stars, especially fusing H to He in their centres when they are on the Main Sequence.

North Celestial pole: imaginary point on the Celestial Sphere directly above the Earth's North pole.

O

Oxygen: chemical element with symbol O. It is produced in the cores of massive stars.

P

Parallels: Imaginary horizontal slices on Earth or on the Celestial Sphere. Parallels are used to locate geographical positions on Earth on the Celestial Sphere. The equator is an example of a parallel.

Photons: “particles” of light, carrying energy depending on their “frequency”. This is an alternative way to describe the behaviour of light compared to electromagnetic waves.

Planetary Nebula: Last stage in the lifecycle of lower-mass stars (like our Sun). It consists of a white dwarf star surrounded by a cloud made up by the material ejected by the star in its previous life stage. Note, this has nothing to do with planets!

Polaris: is the bright star in constellation of Ursa Minor. It is very close to the north celestial pole, so is a useful navigational aid.

Prism: a wedge-shaped transparent body that causes incident light to be separated into its component colours upon exiting.

Protostars: still forming star, i.e., one that it is still in the process of accreting material.

Protostellar cores: condensation of interstellar gas and dust surrounding a protostar.

Protostellar outflows: violent ejecta of gas launched and swept up by a protostar during its formation. Similar to protostellar jets, but these outflows can include less collimated flows, as well as material swept up from the protostellar core.

Proxima Centauri: it is the star closest to our Sun, located about 4 light years away.

Q

R

Radio Wave: least energetic light characterised by long wavelengths.

Red Giant: Near final stage in the life cycle of a star, following the Main Sequence, characterised by the star having high luminosity and being swollen to very large size and having relatively cool surface temperatures.

Red Super Giant: Near final stage in the lifecycle of star at least 8 times more massive than our Sun, characterised by the star having extremely high luminosity and being swollen to enormous size and still having relatively cool surface temperatures.

Refraction: physical process by which a ray of light changes direction on entering a different medium, e.g., from air into water. Different wavelengths change direction by different amounts leading to separation of different colours, e.g., when crossing a prism.

Right Ascension: it is the angle between an object on the Celestial Sphere and the vernal equinox meridian. Together with Declination, it is used to locate objects in the sky.

S

Scientific method: procedure used by scientists to prove or disprove a theory.

Silicon: chemical element with symbol Si. It is one of the main constituents of interstellar dust.

Solar System: Ensemble of the Sun, planets and small objects such as comets and asteroids that orbit the Sun.

Spitzer Telescope: Telescope orbiting the Earth and observing the sky at Infrared wavelengths. The telescope has been retired in January 2020.

Stellar life cycle: ensemble of the stages that a star undergoes from when it is born until it “dies”, i.e., either exploding violently as massive stars do in Supernovae (leaving behind a neutron star or black hole), or ejecting its outer layers as a Planetary Nebula from lower mass stars (leaving behind a White Dwarf).

Sun: the star that is host to our Solar System.

Supernova Explosion: It is the explosion of a star more massive than about 8 times our Sun at the end of its life, in what is known as a Core Collapse Supernova. The star is not able to sustain nuclear fusion at its centre. The central iron core collapses, releasing a huge amount of gravitational energy that explodes the outer parts of the star and leaving behind either a neutron star or a black hole.

Supernova Remnant: a shell of material produced by a star exploding as a supernova. The shell is made of the external layers of the star that are ejected away at very high velocities during the explosion.

T

Telescope: instrument used to collect light from an object. In Astronomical context, typically is built to enhance the amount of light that is gathered to be able to detect faint objects and to be able to resolve fine details. There are telescopes designed to observe across the electromagnetic spectrum.

U

Ultraviolet: radiation of the electromagnetic spectrum. Abbreviated as UV, it is more energetic than visible light.

V

Vernal Equinox: the first meridian in the celestial sphere and used to measure Right Ascension coordinates.

Very Large Array: (VLA) it is a collection of 27 radio telescopes located in New Mexico, working together to collect light at centimetre-wavelengths from the sky.

Visible light: portion of the electromagnetic spectrum that can be seen by humans. It consists of all the colours from red to violet.

W

Wavelength: length of a light wave (from crest to crest, or trough to trough). Quantity used by astronomers to classify different kinds of light.

White Dwarf: Late stage in the life cycle of a lower-mass stars (similar to that of our Sun). It is the hot, exposed core of the star, mostly made of C, O and some He, left behind after the planetary nebula has occurred.

Wind blown bubble: shell of interstellar gas and dust swept up by stellar winds emitted by stars, typically seen around massive stars that have powerful winds.

X

X-ray: energetic radiation of the electromagnetic spectrum.

Y

Young stellar objects – YSOs: very newly formed stars that may still have some remnant material around them left over from formation.

Z

Appendix A - Teams and sources

Molecular Cloud Sources = Infrared Dark Clouds (IRDCs)

Table A1: IRDCs assigned to each team, along with distances to the IRDCs

Team	IRDC NAME	Distance (light years)
#1	G18.82-00.28	15655
#2	G19.27+00.07	7827
#3	G28.37+00.07	16307
#4	G28.53-00.25	18590
#5	G28.67+00.13	16633
#6	G34.43+00.24	12067
#7	G35.39-00.33	9458
#8	G38.95-00.47	8806
#9	G53.11+00.05	5870
#10	G023.60-0.09	3261
#11	G024.64+00.16	9784
#12	G024.94-00.15	26092
#13	G030.14-00.07	6523
#14	G031.98+00.06	16307
#15	G035.60-00.25	19569
#16	G023.39-00.11	22830
#17	G025.15-0.028	13046
#18	G034.77-00.55	9458

Massive Protostar Sources = SOMA Sources

Table A2: Massive Protostars assigned to each team, along with distances.

Team	SOMA Source	Distance (light years)
#1	AFGL4029	6523
#2	AFGL437	6523
#3	CepA	2283
#4	G305.20	13372
#5	G309.92	17938
#6	G339.88	6849
#7	G35.58	33268
#8	G45	27397
#9	G45.12	24135
#10	G49.27	18101
#11	IRAS16562	5544
#12	NGC7538	9785
#13	G25.40	9785
#14	G33.91	9785
#15	G30.76	9785
#16	G58.77	9785
#17	IRAS20343	9785
#18	G35.2-0.74N	7175

Earlier projects

Hundreds of school classes have been part of the Help a Scientist project since its start in 2011. You can read a bit about earlier years projects here:

Whole grains Hunt 2019

Young people's knowledge and attitude towards diet and health, especially wholegrains

Spider Hunt 2018

Drugs in our watercourses and in the food chain

Bee Hunt 2017

Bees, diet and gut bacteria

Music Hunt 2016

Creating music using software and interactive techniques inspired by evolutionary biology

App Hunt 2015

Exploring mobile contemporary and future everyday life; what form, content, sensors, size and network do we want?

DNA Hunt 2014

DNA and environment – genetic relationship between different species of herring in the Baltic Sea

Solar Hunt 2013

Energy and Solar cells – finding dyes that improve the photoelectrochemical solar cell

Gold Hunt 2012

Synthesizing new kinds of nano particles and nano materials

Medicine Hunt 2011

Antibiotic resistance - finding new bacteria from the actinomycetes group known to produce substances with antibiotic properties

NOBEL PRIZE MUSEUM