CESAR Scientific Challenge

In Search of our Origins

Understanding the origin of stars with ESA and ESO scientific archival data

Student guide

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Your Scientific Challenge

Searching for our origins…

The search for planets around stars other than the Sun, called "exoplanets", has been one of the hot topics in Astronomy in the last decades. As of today, around 4700 exoplanets have been confirmed[1] in our galaxy, out of which 3500 are planetary systems, including 790 are multiple-star systems. If our galaxy contains between 100-400 thousand million stars and 2 thousand million galaxies have been detected in the observable Universe, imagine how many exoplanets can possibly exist orbiting around those stars!

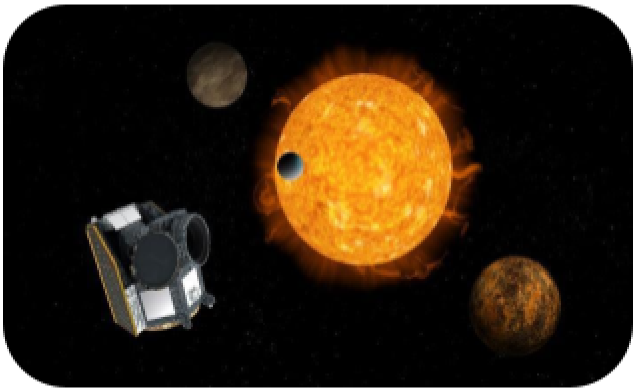


***Figure 1**: Artist impression of CHEOPS (Credit: ESA)*

European Space Agency (ESA) missions like CoRoT, CHEOPS or GAIA have been contributing to this search for exoplanets since 2006, together with NASA missions Kepler and TESS.

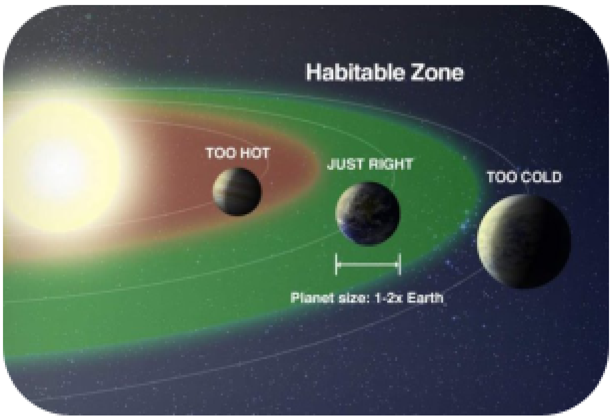


***Figure 2:** Habitable Zone (Credit: Astrobiology, NASA)*

A further contribution comes from the ESA/NASA space mission Hubble as well as telescopes on Earth such as GTC and antennas like ALMA.

In order to understand whether these exoplanets could be anything like our Earth, we also have to study the star they are orbiting.

[1] http://exoplanet.eu/catalog/

Just like the Sun in our case, stars play a crucial role in the evolution of planets and the possibility of hosting life. If we search for life in terms of liquid water detection on the planet's surface, we will arrive at the definition of a planet in the habitable zone, shown in Figure 2.

Throughout this activity you will enter the fascinating field of how and where stars form. There are still many mysteries around the formation of stars... **If you want to help scientists at ESA to solve this challenge, we will be one step closer in the search of our own origins.**

Phase 0

In order to put into context, we recommend to watch these **videos:**

- This is ESA (10 min)
- ESAC: ESA's A window on the Universe (3 min)
- Presentation to ESA/ESAC/CESAR (6 min)
- Here there is another complementary set of videos.

We recommend **working in teams** of (4-6) people, with a clear role in their team, assigned per profession. You will fill Table 1 for the coming Challenge with a name for their Team and the name of the team members after having agreed among themselves on their role in the team.

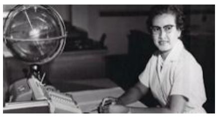
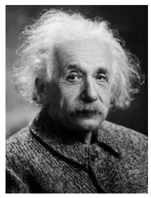
Challenge ID			**Team number (1-6):**	
Names				
Profession	**Mathematician/ Software engineer**	**Astrophysics**	**Engineer**	**Biologist**
Roles	Lead the correctness of the calculations	Lead the use of the virtual telescope ESASky and the understanding of their celestial objects.	In charge of finding the optimum strategy agreed among the team members and its correct execution.	Lead the more detailed research about the scientific understanding of the energetic processes and composition of the celestial objects.
Reference **(female)**	Katherine Johnson 	Vera Rubin 	Samantha Cristoforetti 	Marie Curie 
(male)	Steve Wozniak 	Matt Taylor 	Pedro Duque 	Albert Einstein 

Table 0: *Write down the Identification of your Challenge (an unique number), the Number of your Team (1-6) and the name of the team members, one of them with a clear role (and assigned tasks), all needed.*

Note: The documentation makes use of the International System of Units.

Phase 1

Activity 1: Glossary

In order to study how and where stars form, you should be familiar with the vocabulary used by astrophysicists. Match each key word with its definition.

Key word	Definition
Star	Area of science that studies the hidden secrets of the Universe beyond our atmosphere.
Gas	Electromagnetic radiation. It is still around us even when it's dark.
Heat	Clouds within galaxies made of cold gas and dust. Nurseries of the stars.
Galaxy	Amount of energy transferred between objects with different temperatures.
Planet	Self-luminous ball of gas held together by gravity.
Hydrogen	Round object orbiting the Sun with a clear orbit.
Interstellar cloud(s)	Highest point in the sky, at 90º above the observer.
Zenith	Recurring succession of events.
Light	Huge group of stars, solar systems, gas and dust, all held together by gravity. The Milky Way is an example.
Cycle	Ball of gas, soon to become a star.
Astronomy	Substance which takes up the space between stars in galaxies.
Protostar	One of the four fundamental states of matter. Will expand and fill the whole container it is in.
Interstellar medium	An element in chemistry with symbol H. The most abundant chemical substance in the Universe. Exists naturally as molecular hydrogen (H2).

Activity 2: Measurements in Astronomy

Activity 2.1: Positions

To study an object in the sky, you first need to know its location. The position of any celestial objects is expressed using two dimensional coordinates, just like you would use coordinates on Earth (see Figure 3).

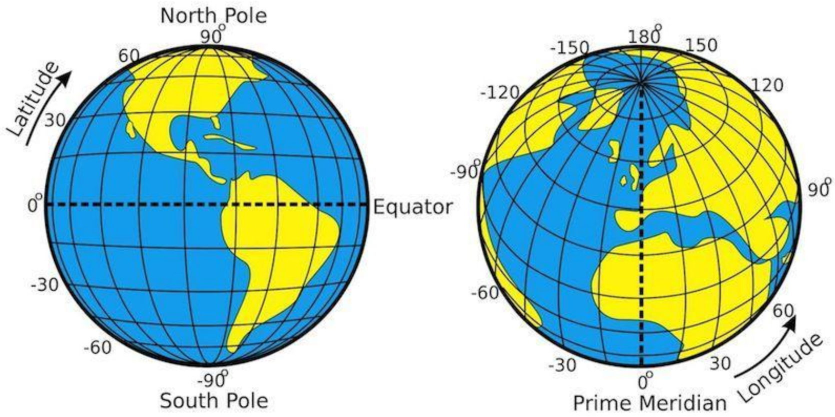
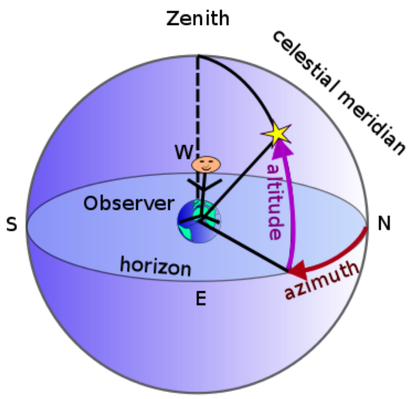


Figure 3: *Latitude and longitude (Credit: Wikipedia)*

The coordinate systems usually used in astronomy as: the **horizon** and **the equatorial coordinates.** The main difference is that horizon coordinates depend on the location of the observer and the equatorial coordinates don't. Visit this [web] and/or watch this [CESAR video] for clarification (in Spanish).



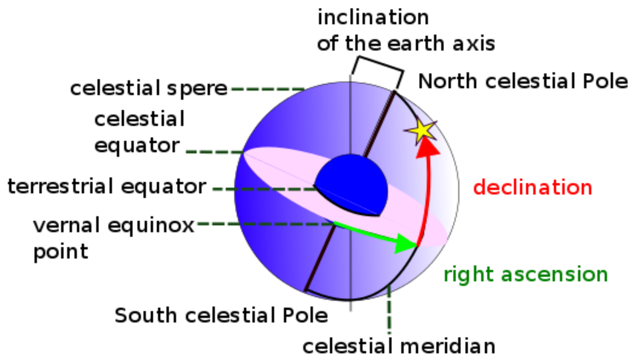


Figure 4*: Horizon coordinates. (Credit:Aurge.org)*

Figure 5*: Equatorial coordinates. (Credit: Aurge.org)*

Horizon coordinates

These coordinates consist of altitude (alt) and azimuth (az). They are also called local coordinates, which means they are given with respect to the observer. Take a look at the Figure 6.

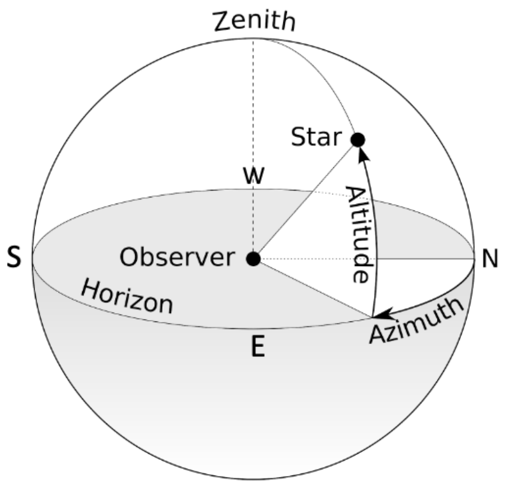


Figure 6: *Horizon coordinates (Credit: Wikipedia)*

Imagine you are at the "Observer" point looking at the star.

- **The altitude** is the angle measured above the horizon. This can range from 0° (at the horizon) to 90° (just above your head, at the **zenith**).
- **The azimuth** corresponds to the angle on the horizontal plane, starting from the geographical North towards the East, until reaching your position.

Since these coordinates depend on the observer's position on Earth, an observer looking at the same star from somewhere else will have different altitude and azimuth coordinates.

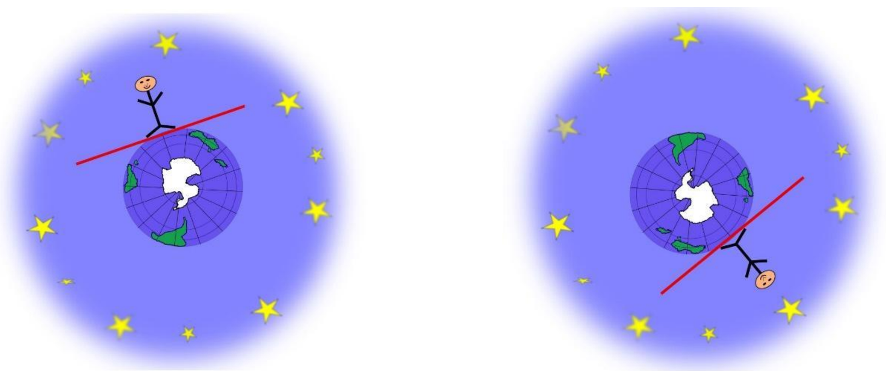


Figure 7*: Horizon coordinates. (Credit:Aurge.org)*

Equatorial coordinates

The equatorial coordinates are right ascension (RA) and declination (DEC). They are independent of the observer position and are therefore called global coordinates.

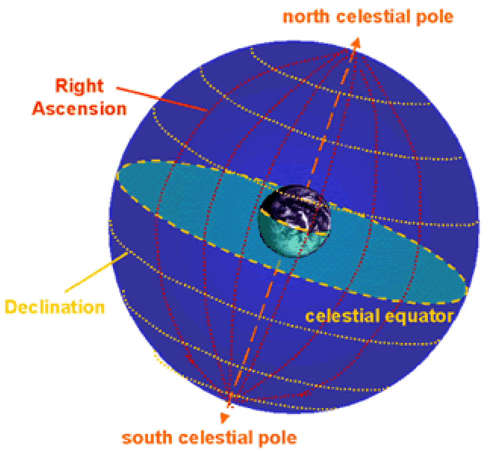


Figure 8: *Celestial sphere (Credit: COSMOS)*

Imagine placing the Earth inside a huge sphere, what we call a celestial sphere. If you extend the Earth's equator plane all the way up to this sphere, we obtain the celestial equator plane.

For simplicity, we consider every celestial object to be projected onto this celestial sphere, thereby are able to determine the position.

Just like on Earth, the celestial sphere has *longitude* and *latitude* lines.

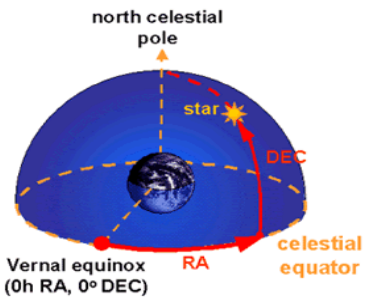


Figure 9: *Equatorial coordinate system. (Credit: COSMOS)*

- **Right ascension (RA)** can be compared to longitude on Earth. It is measured in *hours, minutes* and *seconds.* The reference position (RA=0) is the **vernal equinox[2].** Note: Since the Earth rotates 360º on its axis in 24h, one hour corresponds to 15º.
- **Declination (DEC)** can be compared to latitude on Earth. It is measured in *degrees, arcminutes* and *arcseconds*. The reference plane is the **celestial equator**, and the values are positive when the object lies north.

[2] The vernal equinox is the location where we can find the Sun on the 21rst of March, which matches with the beginning of the spring in the Northern Hemisphere (video 1, video 2)

Sometimes astronomical catalogues give the RA and DEC coordinates entirely in degrees. It is therefore useful to know how to convert between units.

To convert Right Ascension in hours, minutes and seconds into degrees use Equation 1:

$$(h + \frac{min}{60} + \frac{sec}{3600}) \times 15$$

(Equation 1)

To convert Declination in degrees, arcminutes, arcseconds into degrees use Equation 2:

$$(d + \frac{arcmin}{60} + \frac{arcsec}{3600})$$

(Equation 2)

Note: When declination is negative, the arcminutes and arcseconds are too!

Activity 2.1.1: Conversion between hh:mm:ss and degrees:arcminutes:arcseconds to degrees

A star has the following RA (h,m,s) and DEC (degrees, arcmin, arcsec) coordinates:

(RA, DEC) = (10h 43m 56s, -59°33′00″)

Convert these coordinates to degrees.

Activity 2.2: Distances

There are various methods to measure the distance to celestial objects. These methods are represented in the "cosmic ladder", shown in Figure 10. Each method of measurements is based on the values obtained from the previous method.

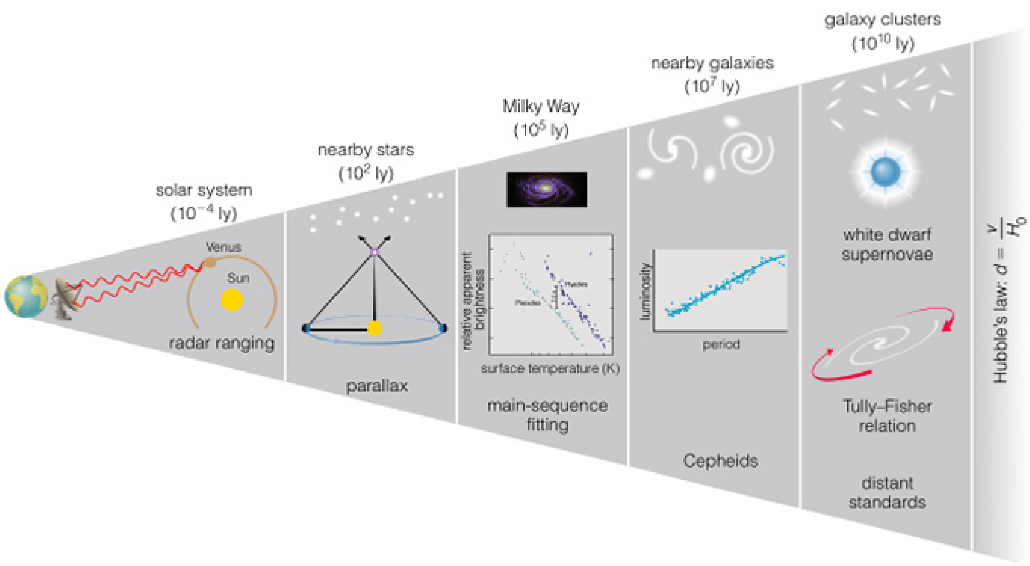


Figure 10: Cosmic ladder (Credit: ScienceWISE)

Before measuring any distances, it is important to have the units clear.
For distances within the Solar System astronomers use the
astronomical unit (AU).

1 AU corresponds to the average distance from Earth to the Sun and is equal to $1.5\times10^{8}\ km$.

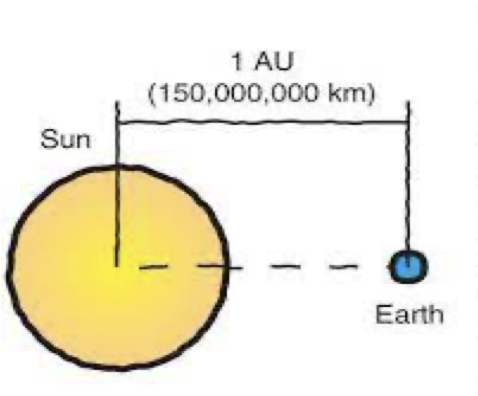


Figure 11: *Astronomical Unit.*

(Credit: NASA)

Another unit of distance is the **light year (ly)**, used in Figure 10.

A light year is the **distance light travels in a year**.

Now that units are clear, here is a short description of each method used to measure distances within the following ranges in the Universe:

- d1 (within the Solar System, $d < 10^{-4} ly$)
- d2 (nearby stars, $d < 10^{2} ly$)
- d3 (within our galaxy, $d < 10^{5} ly$)
- d4 (nearby galaxies, $d < 10^{7} ly$)
- d5 (galaxy clusters, $d < 10^{10} ly$)

Method 1: radar ranging

For measurements within the Solar System ($10^{-4} ly$). It works by sending a radio wave from Earth towards the object of interest in the Solar System, and recording the time it takes for the wave to return.

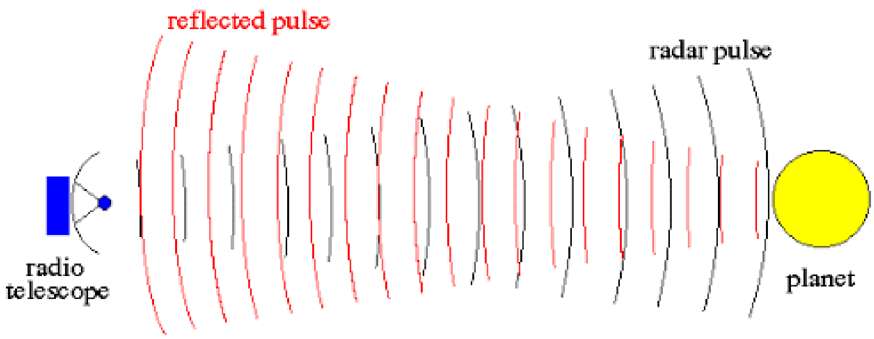


Figure 12: *Radar ranging (Credit: http://abyss.uoregon.edu/~js/ast123/lectures/lec13.html)*

Method 2: stellar parallax

To measured distances to nearby stars ($d < 10^{2} ly$). This method makes use of the parallax effect. In order to understand how this works, take a look at Figure 13 and try it yourself.

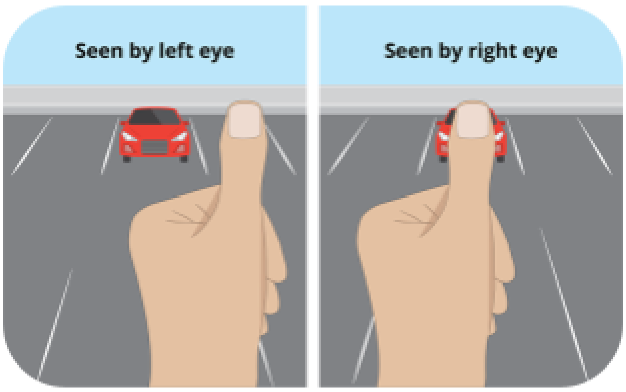


Figure 13*: Example of the parallax effect (Credit: http://blog.cupix.com/)*

ACTION: Hold your thumb up in front of you, as shown in Figure 13, as far away from your body as possible (with a comfortable posture).

Observe the object, in this case the car, positioned in front of you, with respect to the position of your thumb. Close one eye and repeat this. Next close the other eye instead, always leaving one eye open.

Explain what you see:

This is what we call the “parallax effect”. By measuring the apparent shift in position of an object (thumb) with respect to the background, arising from the fact that the object was observed from two different positions (equal to the separation between eyes or larger) one can calculate the distance to the object. This method is used to measure the distance to nearby stars, and is therefore called “**stellar parallax”.**

Figure 14 shows the observation of a nearby star with respect to the background. In January, the star appears to be positioned at the far right in relation to the background stars, whilst the same observation in July shows the star at the far left.

The combination of both observations gives an estimate of the apparent shift in position of the star.

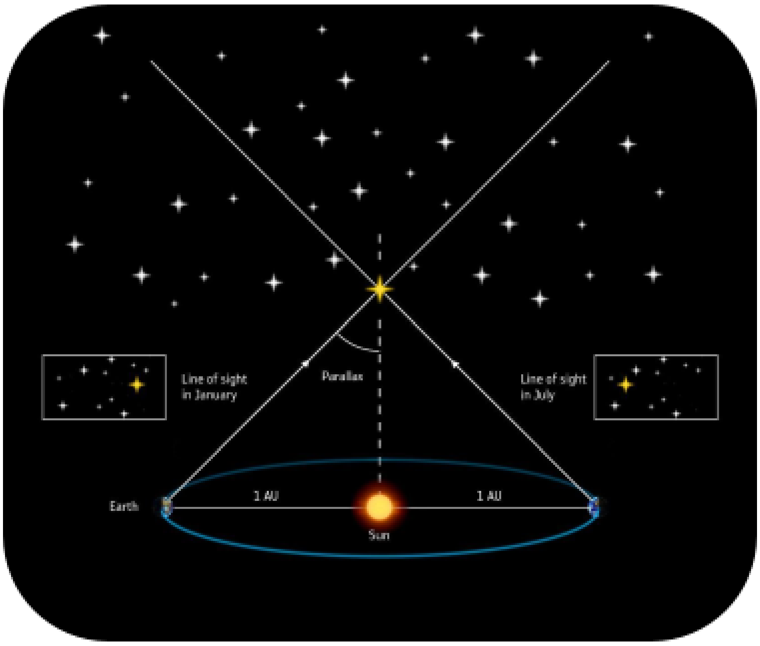


Figure 14: Definition of stellar parallax (Credit: Gaia/ESA/ATG medialab)

To measure the parallax distance “D” to the star, one needs a known “baseline length”. In this case, the orbital radius of Earth around the Sun, 1 AU, is used as baseline, as shown in Figure 14. The *half-angular shift (parallax angle)* between the star and the background combined with the baseline is then used to calculate the distance.

$$tan(P) = \frac{1\,AU}{D} \quad \text{(Equation 3)}$$

where P is the stellar parallax and d is the distance between Earth and the star.

The unit used for distance which arises from using the parallax method is the parsec.

(The word parsec comes from *par*allax of one arc*sec*ond).

1 parsec is the distance to an object, at which Earth’s orbital radius subtends a parallax angle P of one arcsecond (1/3600th of a degree).

A parsec is equal to 3.26 light years.

Method 3: Main sequence fitting

For distances within our galaxy ($d < 10^5 ly$).

To understand this method, we first explain how astrophysicists use a H-R diagram and identify the main sequence phase on it.

In a H-R diagram, like the one shown in Figure 15, the values of the intrinsic brightness of the objects are plotted on the y-axis and on the value of the surface temperature of stars on the x-axis. The H-R or Hetzsprung-Russel diagram is named after its creators.

The main sequence is the evolutionary phase of a star in which its core burns 4 atoms of hydrogen producing 1 atom of helium. In general it is the most stable phase of the stars, although the most massive stars leave this phase much earlier than the less massive ones.
We can see the different evolutionary steps of stars in an H-R diagram.

The distance measurement method compares the position on the H-R diagram for a set of stars of common origin (called a star cluster) whose distance is known, with that of another star cluster of unknown distance.

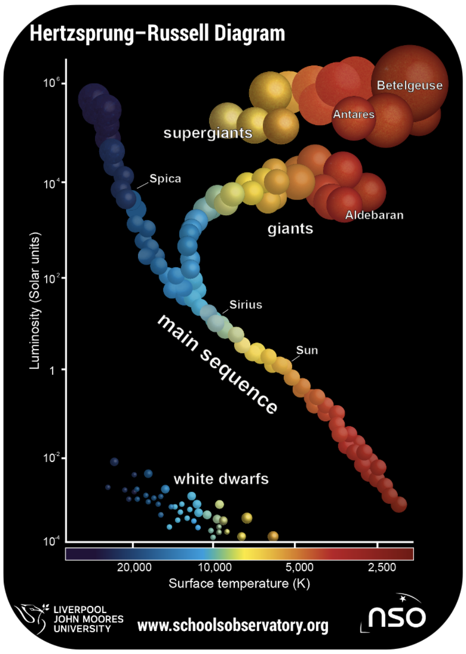


Figure 15: *H-R diagram (Credit: National Schools' Observatory)*

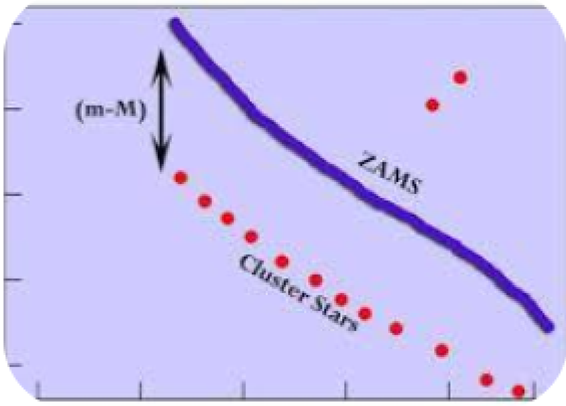


Figure 16: *Difference between the apparent brightness measured for an object (m) and its intrinsic brightness (M) used to calculate distance. ZAMS stands for "Zero Age Main Sequence", which indicates the initial point in which stars begin to burn hydrogen in their cores, starting their life as stars. (Credit: birmingham.ac.uk, link)*

Method 4: Measurement of distances employing cepheid variables

For nearby galaxies ($d < 10^7 ly$).

Cepheid stars are a type of very luminous star that expands and contracts periodically, varying in brightness. Their brightness sequence is well known. These stars were discovered by astronomer Henrietta Swan Leavitt in 1912. Leavitt discovered and catalogued variable stars and deduced that those of greater luminosity have longer periods, which led her to establish the relationship between both parameters. This discovery revolutionized the way of observing the Universe and led to important findings, such as Hubble's law.

***Figure 17**: Henrietta Swan Leavitt (Credit: wikipedia)*

This method consists in comparing the brightness of a variable cepheid within a nearby galaxy, to the known, intrinsic brightness of a similar star. The difference in brightness allows us to determine the distance to this nearby galaxy.

Method 5: Distance measurements from the Tully-Fisher relation

To measure distance to galaxy clusters ($d < 10^{10} al$).

The **Tully-Fisher** relation relates the luminosity of galaxies to their rotation speed. The larger the galaxy, the faster it rotates. If one knows the velocity, one can find the luminosity and, as with Cepheid stars, deduce the distance.

Method 6: Calculating distances from Hubble's law

This method is used to measure distances to distant galaxies. It consists of measuring the velocity at which galaxies move away and thus estimate their distance. Hubble's Law relates the velocity (v) at which galaxies move away to the distance at which they are located (D) and the Hubble constant (H_0).

$$v = H_0 D \qquad \text{(Equation 4)}$$

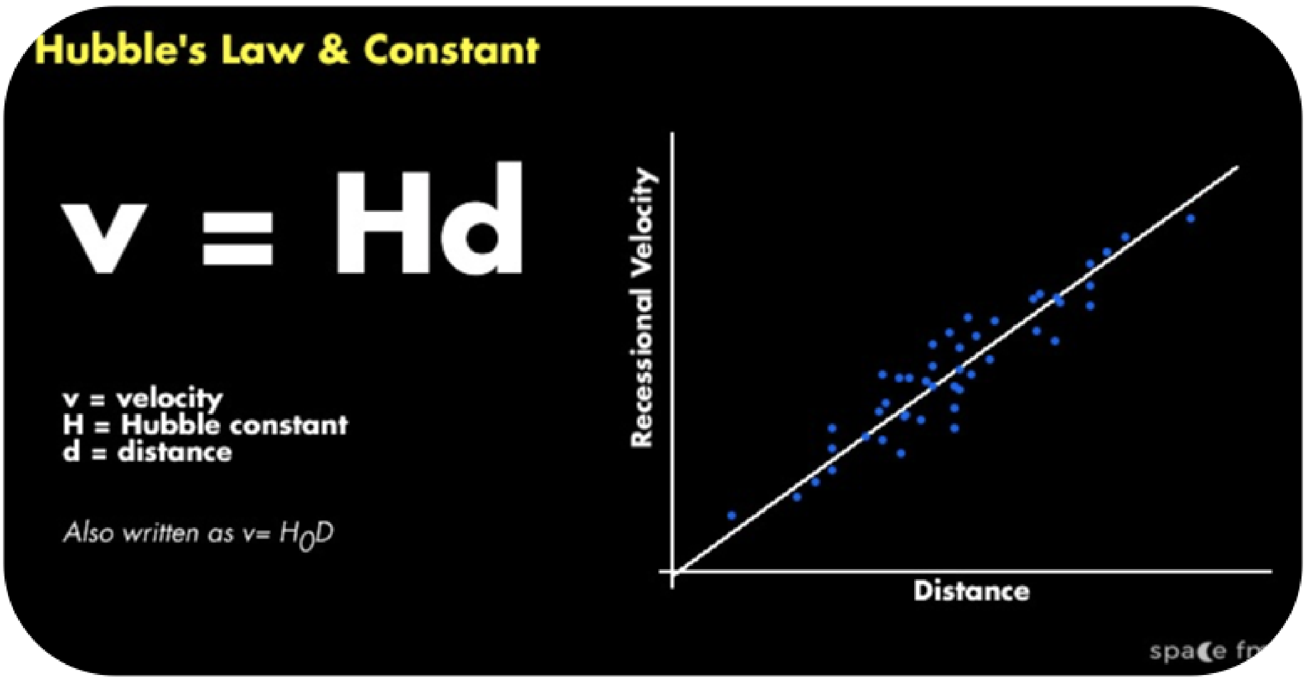


***Figure 18**: Hubble's law (Credit: Space FM)*

Activity 2.2.1: Conversion between units of length (longitude)

1. Using the trigonometric relation between parallax and distance, answer the following question:

   At what distance (D), in astronomical units (AU), will an object at 1 parsec be?

2. Convert 1 light year (ly) into kms:

Hint 1:

1 year = 365 days

1 day = 24 h

1h = 60 min

1 minute = 60 seconds

Hint 2: Light travels at $3 \times 10^5 \frac{km}{s}$

3. Use what you have learnt about the different astronomical distance units to calculate how far the following objects are from Earth. What units make sense for each object in Table 1?

Object	Astronomical units (AU)	Light years (ly)	Parsec (pc)
Jupiter		0.00008175	
Sun			0.000004848
Proxima Centauri	268142.2		
Orion Nebula			412
Eagle Nebula		7000	
Carina Nebula		7500	
Andromeda		2 500 000	

Table 1: *Calculating distances.*

4. Why does using different units depending on the object or region of the sky make sense?

5. What units would you use to quote distances within the Solar System?

6. What units would you use to quote distances to a stellar cluster?

Activity 2.3: Sizes

Having found the distance to the Sun, the Orion and Carina Nebula etc in Activity 2.2.1, we can now find **how big these objects or regions on the sky are**.

The size of an object in astronomy is given as the **"angular diameter"** as seen from Earth, instead of their actual sizes. To understand this better, take a look at Figure 19, which shows an observer looking at the Moon. The Moon is at a distance *D* from the observer. The *actual diameter* of the Moon is *d* and the *angular diameter* for the observer is δ.

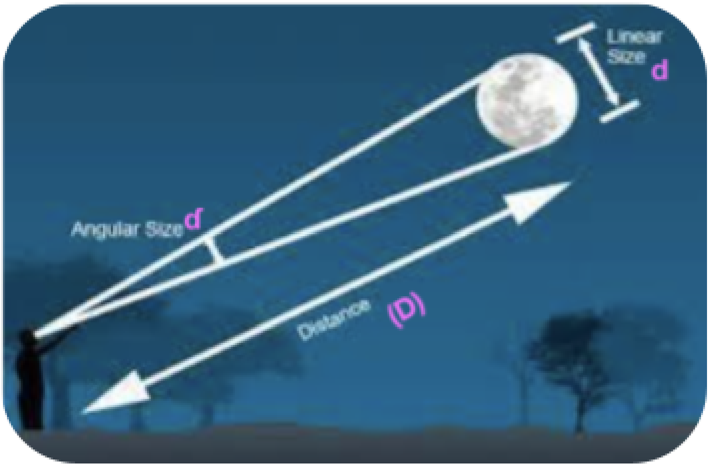


Figure 19: *Representation of angular and actual (linear) sizes (Credit: https://lonewolfonline.net)*

Looking at Figure 19, and with your understanding of trigonometry, you can relate the angular size, δ, the linear size (or actual size), d, and the distance to the object (the Moon in this case) D, as follows:

$$tan\,\delta = \frac{d}{D}$$ (Equation 5)

The angles we are dealing with are usually very small so we can make use of the *small angle approximation*:

$$tan\,\delta \approx \delta$$ (Equation 6)

where δ is in radians.

In astronomy, angles are usually given in arcseconds, so to transform radians to arcseconds we should take into account that:

- ✔ 2 π rad = 360 °
- ✔ 1 ° = 60' = 3600 arcseconds

Therefore to express δ in arcseconds, we should use Equation 7:

$$\delta\,(arcseconds) = \frac{3600''}{1º} \times \frac{360º}{2\pi\, rad} \times \frac{d}{D} = 206265'' \times \frac{d}{D}$$ (Equation 7)

1. Calculate the Sun's actual size, with the following information:
    a. The Sun's angular diameter is: $\delta = 0.5º$
    b. The mean distance between the Sun and Earth is: D=150 000 000 km

WARNING: Never look at the Sun with the naked eye.

Activity 2.3.1: Estimating angular sizes with your hands

Did you know that by holding your hand out as shown in Figure 20 and 21, you can estimate the angular diameter of objects?

Figure 20: *Measuring angular sizes (Credit: https://www.exploratorium.edu/)*

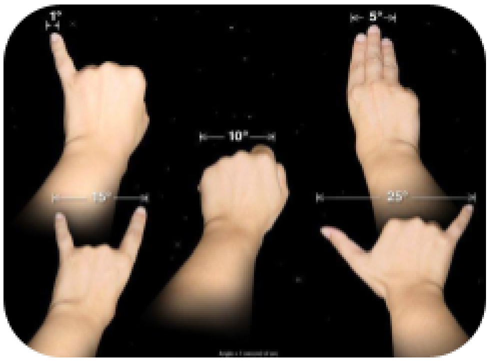


Figure 21: *Estimation of angular diameters (Credit: www.daviddarling.info)*

Tonight, try to measure the Moon's angular size in degrees. Repeat this exercise during a month and check your answers.

Activity 2.4: Magnitudes

Astronomers use the concept of **magnitude** to express how bright a celestial object is. Magnitude is just a number, but it is counterintuitive; **the lower the magnitude of a star, the brighter it is!**

Note: The very, very bright objects even have negative magnitudes!

The distance to an object plays a role in how bright it looks to us. Imagine two identical flashlights shining at you, one from 1 m away and another from 20 m away. The former will of course look brighter to you even though they are the same. This also happens with stars.

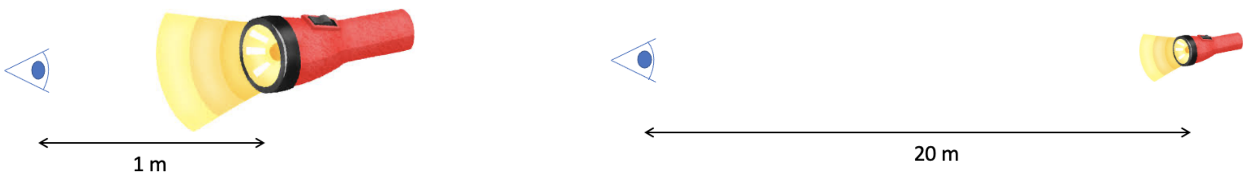


Figure 22: Lightbulb (Credit: Shutterstock)

To avoid this distance factor, astronomers use **apparent magnitude**.

The **apparent magnitude** of an object is how bright the object appears to be in the night sky as seen from Earth.

Hipparchus of Nicaea was a Greek astronomer, 2000 years ago, who classified stars in terms of how bright they appeared in the sky and grouped them into six categories. The brightest stars had magnitude 1 and the faintest, magnitude 6.

Figure 23: *Representation of Hipparchus de Nicea (Credit: https:// cienciaes.com)*

Today, the method has changed slightly, and we know that between the "1st" and "6th magnitude" stars there is a **factor of 100 in brightness**.

That means, between each interval in magnitude, brightness decreases by a factor of $\sqrt[5]{100}$ or 2.512. A magnitude 1 object will be 2.512 times brighter than a magnitude 2 object and 2.512^2 times brighter than a magnitude 3 object.

This can be summarized by Equation 8,

$$m = -2.5\,log\,F + const \qquad \text{(Equation 8)}$$

where F is the object's brightness.

With this new method, objects can also have negative magnitudes. Such objects are even brighter than Hipparcus' original "1st magnitude" stars.

Therefore, the apparent magnitude does not necessarily describe how bright the object actually is. Figure 24 and 25 show the example of the Sun and Vega, the fifth brightest star in the night sky. The Sun has a much lower apparent magnitude and therefore appears to be many times brighter than Vega, when actually Vega is 57 times brighter than the Sun. The problem is it's just further away.

The Sun, apparent magnitude = -27

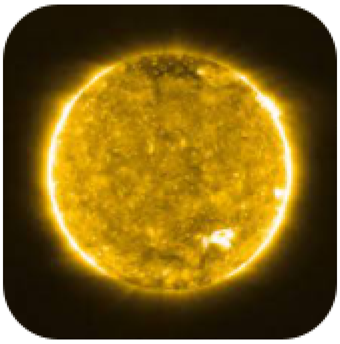


Figure 24: *Image of the Sun (Credit: ESA/SOLO)*

Vega, apparent magnitude = 0.03

Figure 25: *Image of Vega (Credit: Wikipedia)*

Activity 2.4.1: Filters

As you saw in Activity 2.4, magnitudes are used to express how bright objects are. Telescopes provide magnitude data by looking at stars through different **filters**.

Imagine a star emitting in the visible range (like our Sun). Without a filter, this emission will appear white. However if we were to use a telescope's red filter, the filter would block light of all colours except red.

The magnitude of that star, measured through the telescope with this filter will therefore be the *red-band magnitude*.

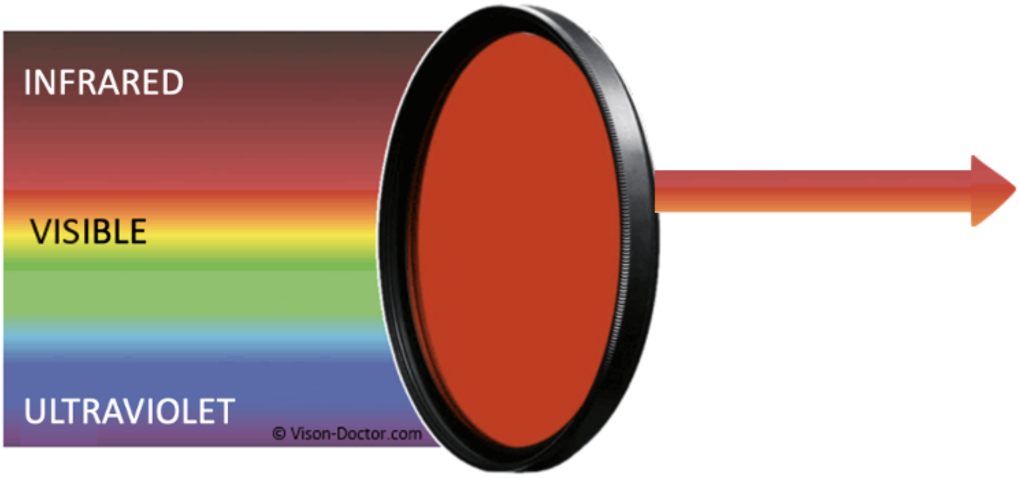


Figure 26: *Red-filter (Credit: VisonDoctor.com)*

Telescopes also measure magnitudes with green (g), ultraviolet (u), and infrared (i) and many more filters, such as H-alpha.

Whenever we give a magnitude value, we must specify what filter it corresponds to.

Activity 2.5: Colour

Activity 2.5.1: What colour are stars?

You may have noticed when looking up at the night sky, that not all stars appear to have the same colour, and that is correct!

Some stars look red, others blue, yellow… due to their different emission temperatures, see Figure 28.

Figure 27: *Trails in the night sky of Teide (Credit: Daniel López)*

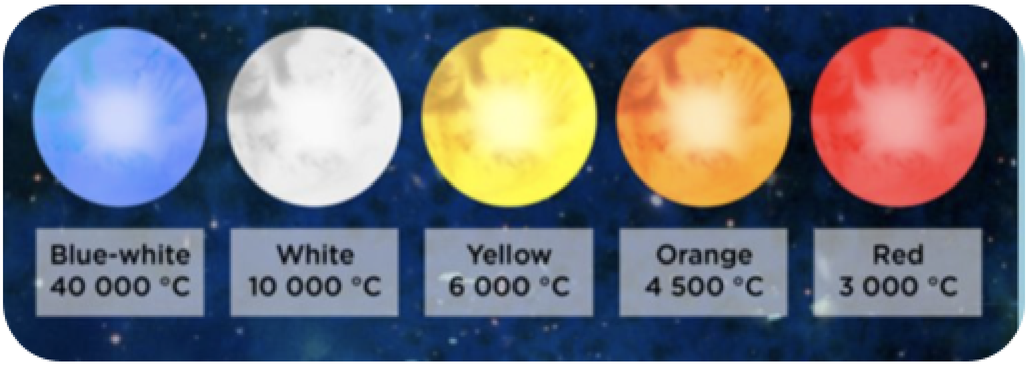


Figure 28*: Different coloured stars. (Credit: http://www.mstworkbooks.co.za/natural-sciences/gr9/gr9-eb-05.html)*

The colour of stars we see depends on the peak wavelength at which they are emitting (emission peak).

The energy distribution of a body can be compared to that of a black body. In this way one derived the effective temperature of it.

In Activity 5.2 you will be able to learn about these concepts in more depth using a simulator.

If you want to experiment how different we may see the colour of the stars, take a look at this CESAR Scientific Case about "What are the colours of the stars?".

The problem with colour is that what might appear blue to you, might appear less blue to someone else. To solve this issue, astronomers came up with a precise definition for colour, one that everyone agrees on and which can be compared.

Activity 2.5.2: Colour in astronomy

In Astronomy, **colour is the difference between two magnitudes**.

Comparing the magnitude of an object observed with a red filter to the magnitude observed with a blue filter, we will find out whether that object emits more in a redder or bluer band. (Note: remember from Activity 2.4, that the brighter the object, the lower its magnitude).

Subtracting these magnitudes from each other gives you the colour of the celestial object.

Figure 29 shows the Sloan filters from which you may obtain the following colours:

(u-g) colour	(r-i) colour
(g-r) colour	(i-z) colour

where (u) is ultraviolet, (g) is green, (r) is red, (i) is infrared and (z) is far infrared. If the (u-g)>0, the magnitude in the u band is larger than in the g band. This means the object is greener (given it is emitting at a longer wavelength).

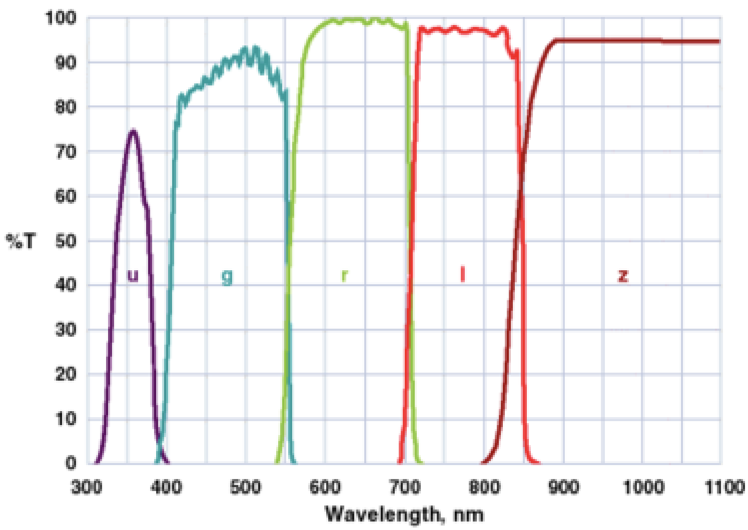


***Figure 29**: Sloan filters of the instrument MegaCam in the CFHT telescope. (Credit: cfht.hawaii.edu)*

1. Compare the *(g-r) colour* of the Sun and the star Vega. What does the result tell you about the emission of the Sun and Vega in the g and r magnitude band?

The Sun
(g-r) = 0.44

Figure 30: Image of the Sun (Credit: ESA/SOLO)

Vega
(g-r) = -0.25

Figure 31: Image of Vega (Credit: Wikipedia)

2. Compare the *(u-g) colour* of the Sun and the star Vega. What does the result tell you about their emission in the u and g magnitude band?

The Sun
(u-g) = 1.43

Vega
(u-g) = 1.02

Activity 2.5.3: Colour-colour diagrams

As one can deduce from the name, this type of diagram compares many colours of an object (or many) at the same time.

1. Go back to [Activity 2.5.2](#) and note the (u-g) and (g-r) colours of the Sun and the star Vega. Plot these onto this colour-colour diagram:

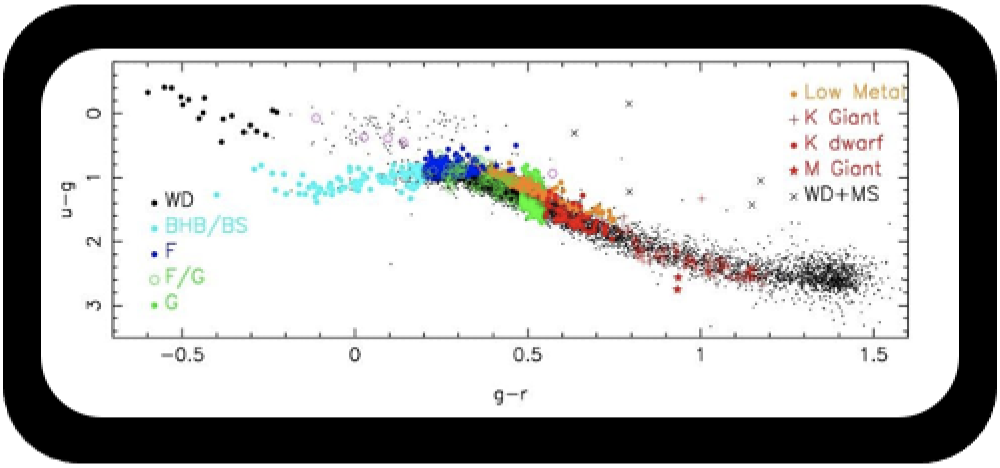


***Figure 32**: Example of a colour-colour diagram from the Sloan Digital Sky Survey (Credit: SDSS)*

2. Reading Figure 32, what type of stars are the Sun and Vega categorized as?

Activity 3: How much do you know about how stars form?

1. How many stars do you think are in the Universe? Take a guess!

2. Before starting to read about star formation, take a guess on what “ingredients” may be necessary to form a star!

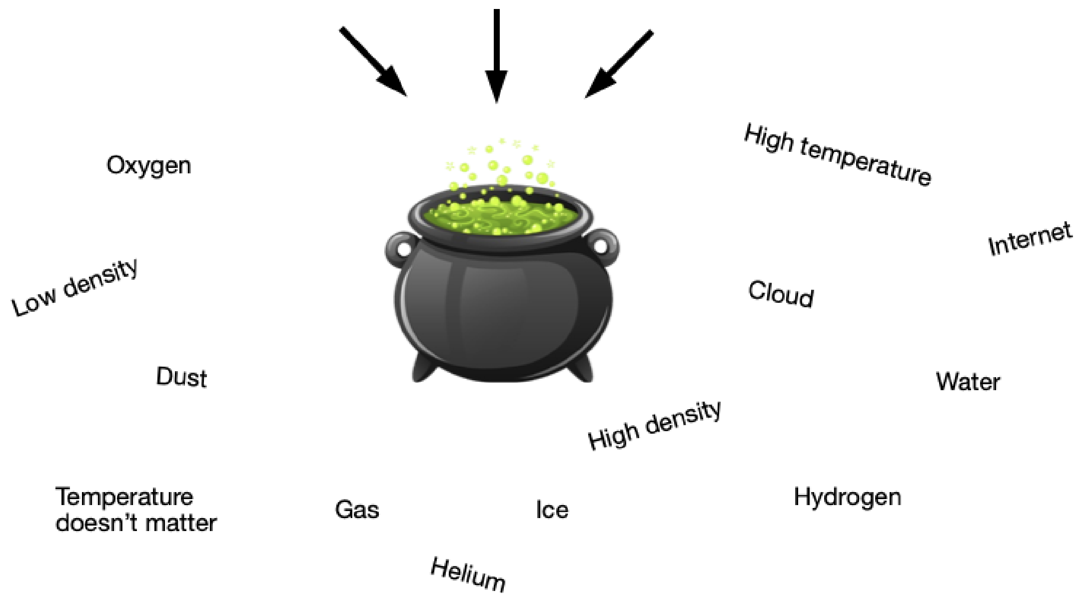
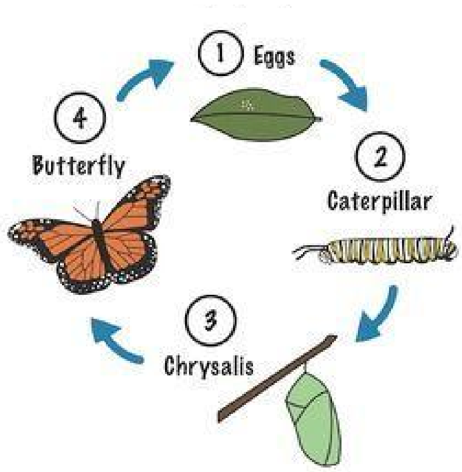


Figure 33: *Cauldron (Credit: ClipArt)*



Stars have life cycles just like the life cycle of a butterfly. You will soon find out all the details!

Figure 34: *Butterfly cycle (Credit: Pinterest)*

3. The star formation process can be divided into phases as shown in the road cartoon in Figure 35. Order the images (a-e) in Figure 36, from the initial evolutionary stage of the star to the latest one of formation:

Figure 35: *Overview of the steps of star formation (Credit: adapted Freepik)*

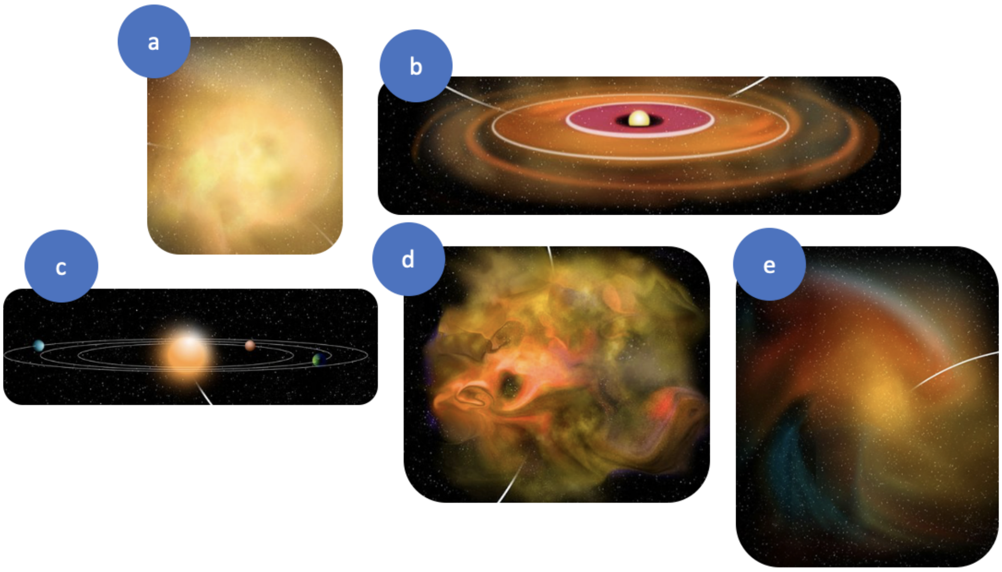


Figure 36: *Basic steps of star formation (Credit: ESO Supernova)*

4. Watch this video to get the hints about the star formation processes.

Activity 4: Star formation in detail

Have a look at Figure 37, where the various stages of the star formation process (that you watched in the previous video) are represented.

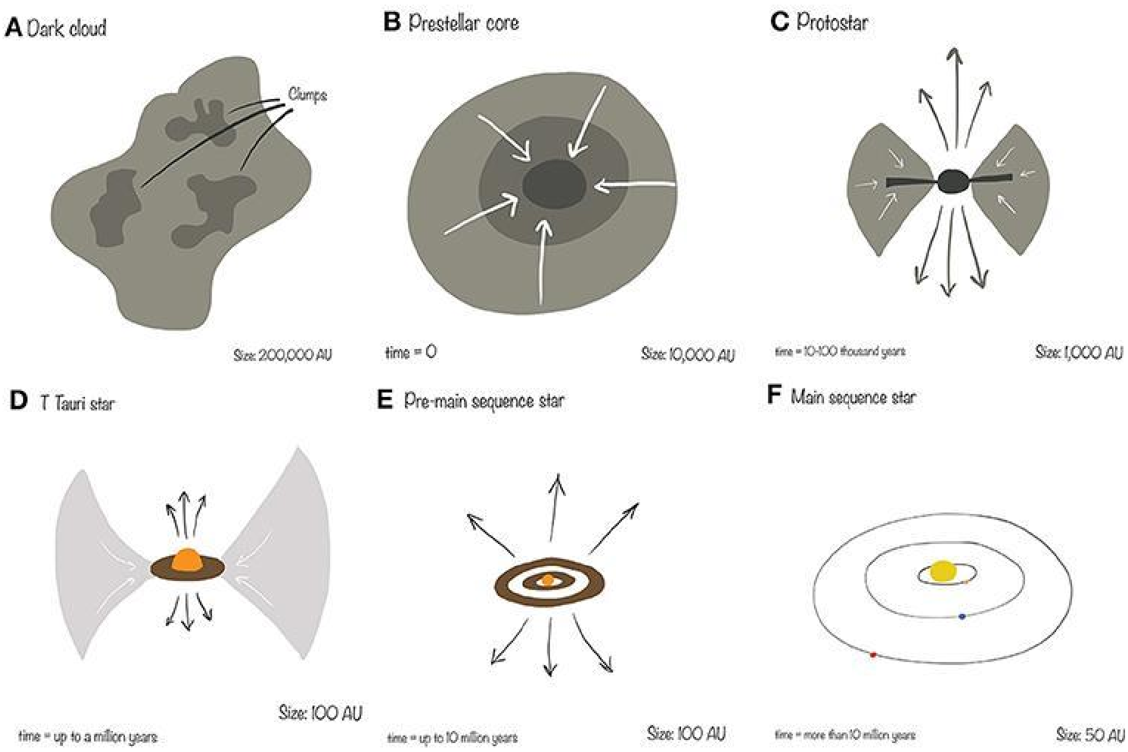


Figure 37: *Overview of the steps of star formation. (Credit: https://kids.frontiersin.org/)*

1. Explain in your own words what you understand about the different star formation stages.

Here are the evolutionary phases that take place in the star formation process more in detail.

Before the star formation begins …

PHASE 1: The molecular clouds

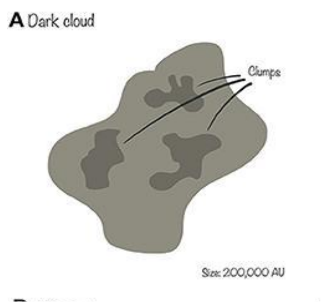


Figure 38: Molecular cloud. (Credit: https://kids.frontiersin.org/)

As we saw in Activity 1, the **interstellar medium** (**ISM**) is the matter and radiation that occupies the space between the star systems in a galaxy… Most of the mass of the interstellar medium (as gas, dust and cosmic rays) is contained in regions called **molecular clouds.** Molecular cloud are composed primarily of hydrogen molecules and helium atoms and can contain more mass than 100 000 times the Sun. You can fit our entire Solar System 10 000 times in a cloud!

Figure 39: The Orion Nebula (Credit: Wikipedia)

There are bright and dark clouds (also called nebulae). Bright nebulae can be further split into two types: emission and reflection nebulae. Emission nebulae absorb photons and re-emits them at longer wavelengths, while the reflection nebulae just reflects nearby light.

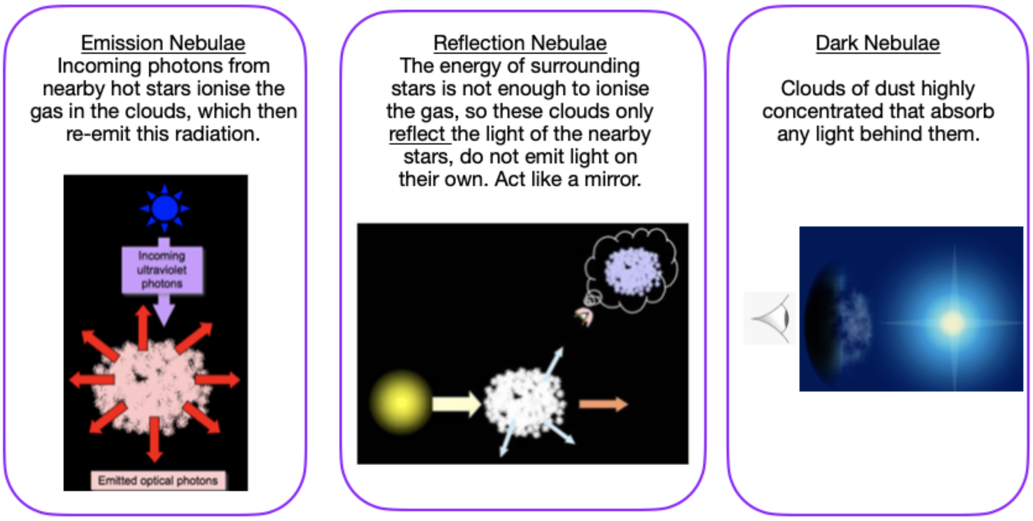


Figure 40: *Emission, Reflection and Dark Nebulae (Credit: COSMOS and adapted from glyphweb)*

PHASE 2: From clouds to filaments

The material in the **molecular clouds** moves around constantly in every direction. You can compare this material to stars in a busy city. In regions where matter is most concentrated (like in a traffic jam), **filament structures** form.

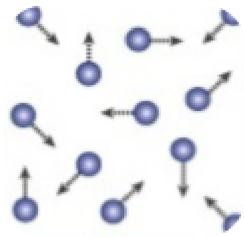


Figure 41: *Particle movement in clouds. (Credit: https://www.sciencelearn.orgy)*

Figure 42*: Traffic jam (Credit: Rabinky Art)*

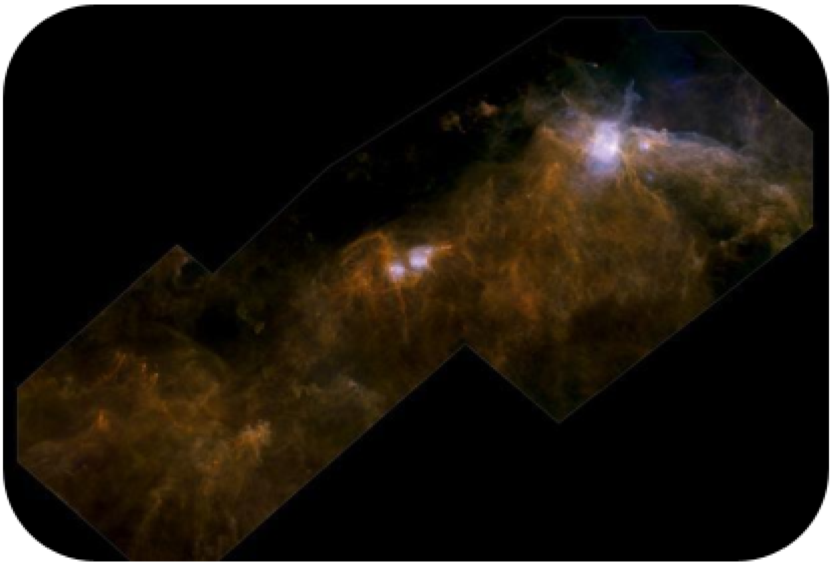


Figure 43: *Star-forming region Orion B (Credit: ESA/Herschel/NASA/JPL-Caltech, link)*

PHASE 3: From filaments to clumps

Within these filaments, matter starts to pile up, producing very dense regions. A point is reached in which the gravitational force of these regions is so strong, it takes over, becoming the dominating force, and these regions fragment into warm **clumps** as shown in Figure 44.

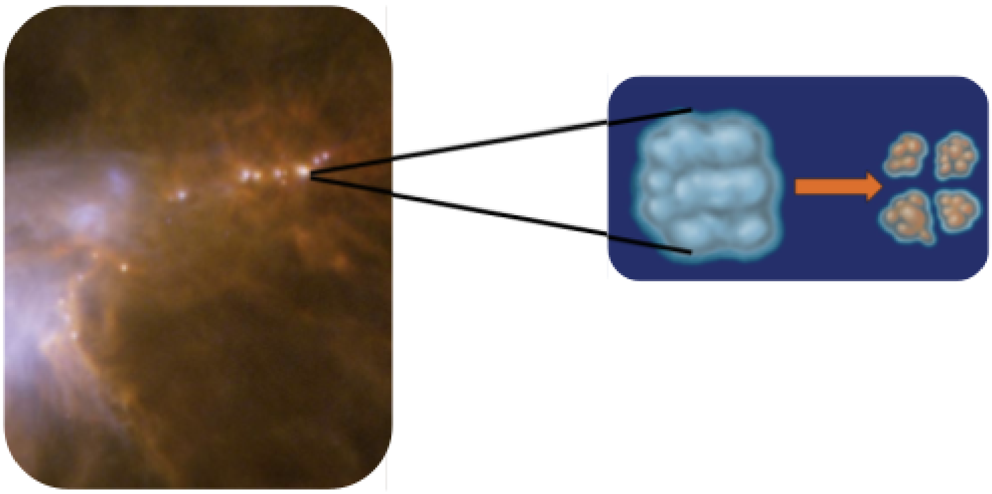


Figure 41*: Clump fragments (right image: Credit: Adapted version of the Star-forming region Orion B (Copyright: ESA/Herschel/NASA/JPL-Caltech, left image Credit: 2014 Pearson Education, Inc)*

These clumps are so dense that they collapse over their own gravity, as shown in Figure 45 and 46. During the collapse, clumps accumulate more and more matter from the surrounding cloud.

Figure 45: Building collapsing (Credit: Builders Enquiry)

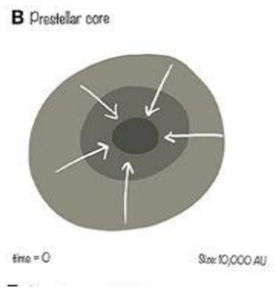


Figure 46: prestellar core gravitational collapse (Credit: https://kids.frontiersin.org/)

Once the star formation begins ...

PHASE 4: From clumps to cores

The movement of particles within the clump causes it to spin. The collapsing occurs quicker in the denser, center region, which leads to even more material (mostly molecular hydrogen) to be driven towards the center. As more and more material concentrates in the middle, the clump spins faster and faster (just like when a ballerina brings in her arms to spin quicker). This phenomenon is called **conservation of angular momentum**.

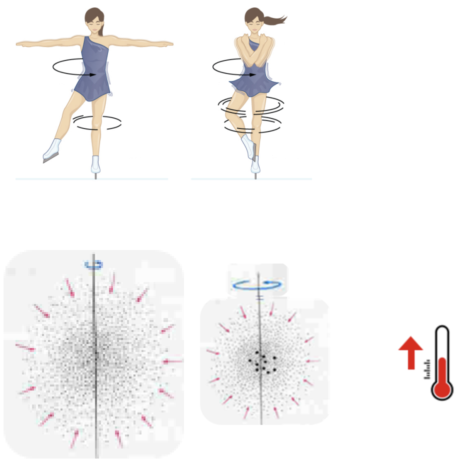


Figure 47: Top: Conservation of angular momentum (Credit: Lumen Learning). Bottom: Clump gets denser, hotter, and spins faster as material concentrated in the centre.

The increasing density raises the temperature, forming a hot centre that is so dense, it is referred to as a **core.** Once this core reaches a temperature of 30 000K, it is called a **pre-stellar core.**

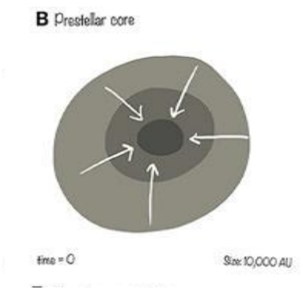


Figure 48: *Prestellar core gravitational collapse (Credit: https://kids.frontiersin.org/)*

PHASE 5: From cores to protostars

The core has been accumulating material from the surroundings, becoming denser and rotating faster whilst collapsing. A gravitationally collapsing sphere surrounded by material creates a flattened spinning disk (just like the ballerina's tutu behaves when she turns). This flattened disk is called an **accretion disk**.

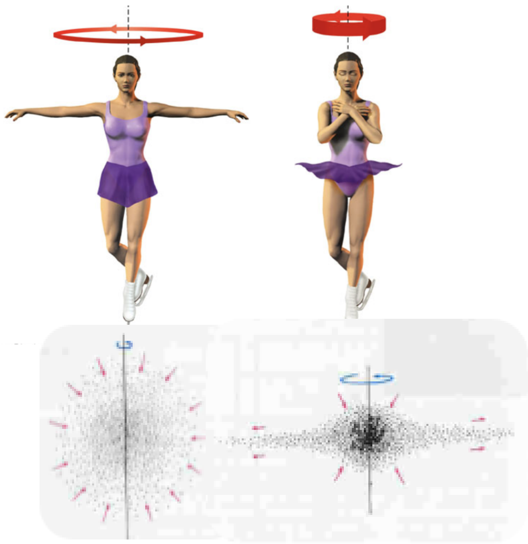


Figure 49: *Top: The ballerina's tutu is lifted, parallel to the floor while she turns (Credit: link). Bottom: Material around core being flattened into a disk.*

The pre-stellar core is now known as a **protostar** and the accretion disk will be essential for its evolution. The protostar grows from the material that falls in from the disk moving inwards towards its surface. This acquisition of material is called **accretion**.

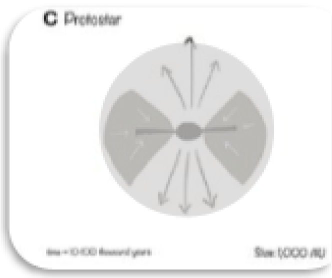


Figure 50*: Prestellar core gravitational collapse (Credit: https://kids.frontiersin.org/)*

Watch this video about accretion disks and see what other types of objects do have accretion disks, apart from the protostars.

Stars that form at the same time within a molecular cloud form group called **stellar cluster**. If these stars are young, the cluster is known as an **open cluster**, whilst if they are evolved, older stars, they belong to a **globular cluster**. Stars within the same cluster will all be at the same distance from Earth, be of the same age and have the same chemical composition at the beginning. The difference between the stars is their mass. Protostars with a higher mass will evolve faster than their lower mass neighbours. This will differentiate them and will result in the classification of stars into different types, defining their position in the H-R diagram as seen in Activity 2.2.

PHASE 6: From protostars to classical T Tauri stars

During the **first 100 000 years** star formation takes place inside cocoons of gas and dust. The details of this process are hidden for the naked eye (in the visible), however one can detect the protostar's emission from the absorbed and then re-radiated emission at longer wavelengths by the material in the envelope.

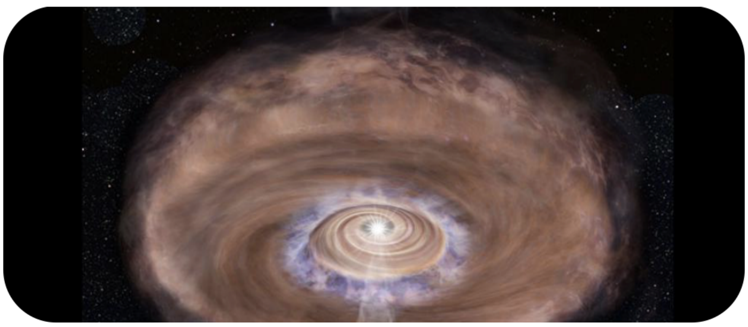


Figure 51*: Representation of view through the envelope surrounding the protostar during the first 100 000 years. (Credit: https://www.sciencemag.org/news/2014/02/close-look-young-star-finds-chemical-surprise)*

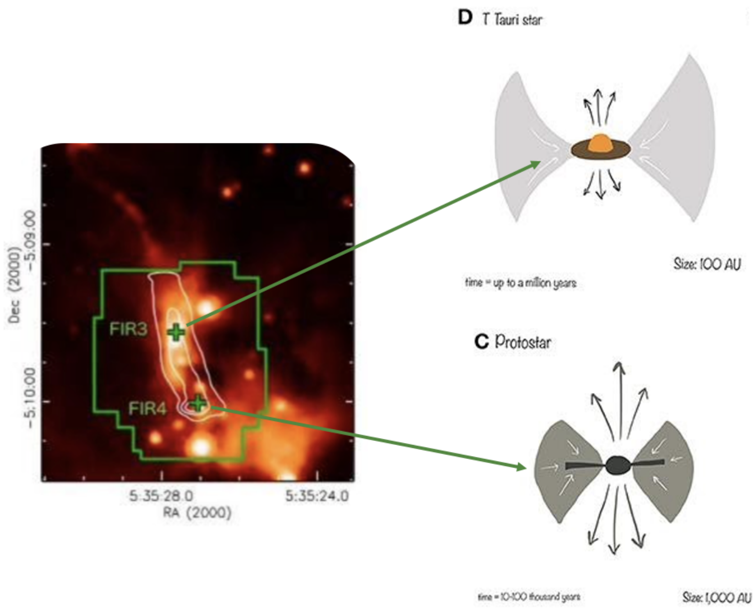


Figure 48*: Left: Two protostars detected by ESA/Herschel in the Orion star forming region. FIR4 is still a cocoon while FIR3 has a visible jet (Credit: B.González-García et al, A&A 2016, 596,26, ESA/Herschel and the HOPS Team). Right: Tauri star and prestellar core gravitational collapse (Credit: https://kids.frontiersin.org/)*

After 100 000 years, the gas and dust surrounding the protostar disappears. The gas and dust settles onto the accretion disk or is ejected in jets or outwards in both directions perpendicular to the accretion disk, following the magnetic field lines (called bipolar jets). This allows the conservation of angular momentum. For the first time the envelope surrounding the protostar is lifted and the protostar can be seen for the very first time.

PHASE 7: From classical T Tauri to weak line T Tauri stars

After several million years, the reservoir of material in the accretion disk is running low, and the accretion onto the star slows down, which weakens its emission and gives name to this stage: **weak line T Tauri stars**.

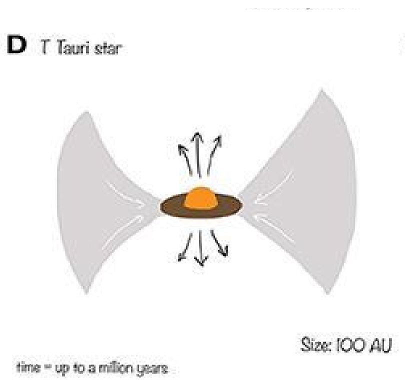


Figure 53: *T Tauri star (Credit: https://kids.frontiersin.org/)*

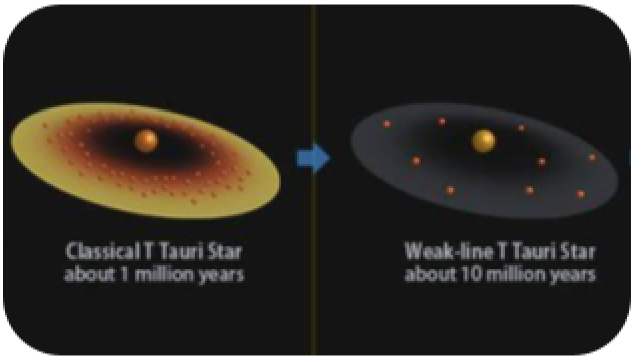


Figure 54: *Weak line T Tauri star (Credit: Adapted version of https://exoplanet.mtk.nao.ac.jp/eng/seeds)*

PHASE 8: From planetary debris disk to planetary disk

The disk becomes what is called a **debris disk**, and the remaining clumps of matter within the disk start to agglomerate together forming larger and larger bodies (just like when you make a snowball), called **planetesimals.** These clumps increase in size, attracting surrounding material and forming what will eventually become a **planetary system** (disk) like the Solar System (with planets).

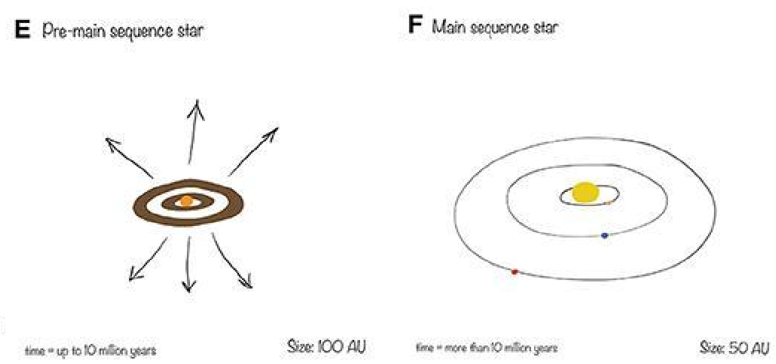
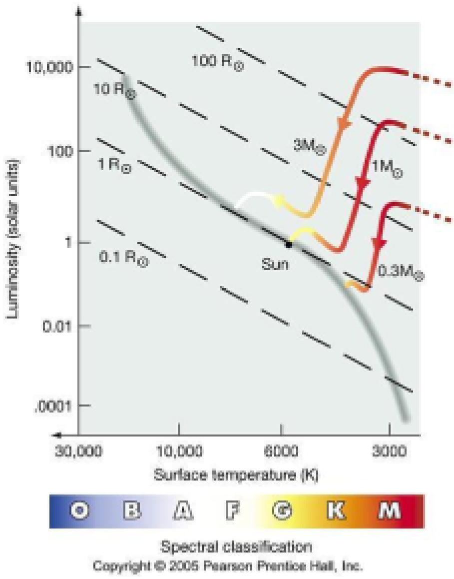


Figure 55: *Planetary system. (Credit: link)*

PHASE 9: From protostar to star

Whilst the debris disk becomes a planetary disk, the protostar continues to contract and heat up in what is called the pre-main sequence star.



As shown in Figure 56, depending on the initial mass of the protostar (in solar masses) the star at the main sequence phase will have a specific size, luminosity (brightness per area) and surface temperature.

The protostar achieves the main sequence phase when its core reaches enough temperature to **ignite hydrogen.** At this point in time, **the protostar has become a star.**

Figure 56: *H-R diagram (Credit: stackexchange.com , link)*

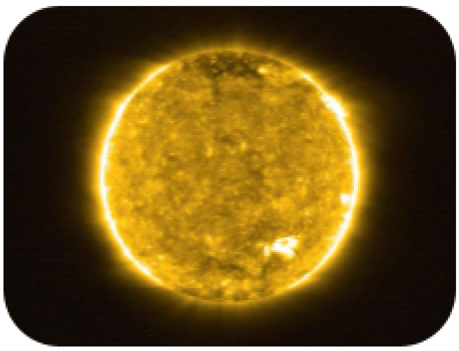


Figure 57: *Image of the Sun collected by the ESA misión Solar Orbiter (Credit: kyandtelescope.org)*

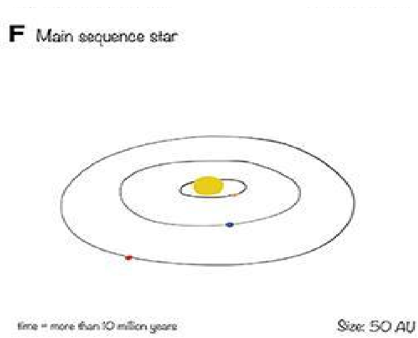


Figure 58: *Young stellar system (Credit: SPITZER)*

Now that you have read about the star formation steps in more detail, review your initial answer about how star formation occurs in Activity 3.

Activity 5: Light from stars

Activity 5.1: Electromagnetic radiation

Light is defined as **electromagnetic radiation** composed of oscillating electric and magnetic fields, in phase, forming a 90° angle, and moving perpendicular to the direction in which the light ray is moving.

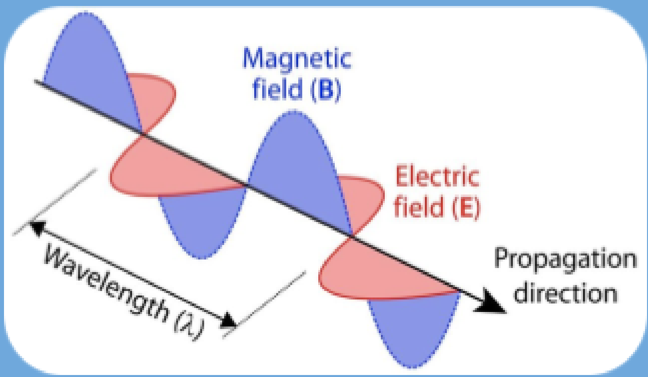


***Figure 59**: Electromagnetic fields (Credits: researchgate)*

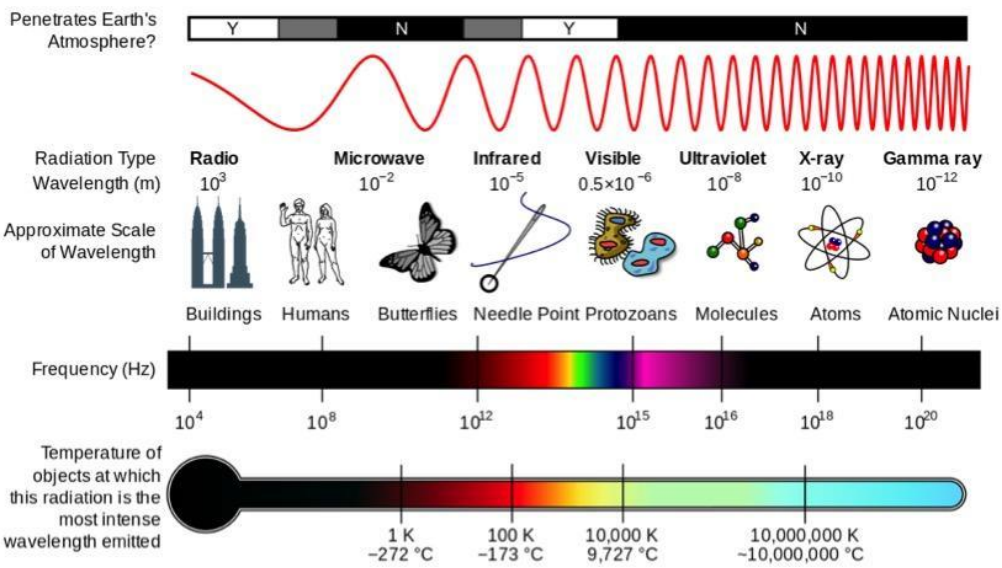


***Figure 60:** Properties of the electromagnetic spectrum. (Credit: Wikimedia Commons)*

The electromagnetic spectrum includes, from longer to shorter wavelengths: radio waves, microwaves, infrared, visible light, ultraviolet, X-rays and gamma rays. The length of these wavelengths are compared with recognizable objects for us in Figure 60.

Human eyes can only see light in a small range, called visible light. However some animals can also see in the ultraviolet (some birds) and in the infrared range (nocturnal animals).

With the aid of Figure 60, test your knowledge about electromagnetic radiation by filling the gaps:

1. Microwaves, gamma rays, and radio waves are some types of ________ ________.
2. Light is composed of _________ electric and _________ fields perpendicular to the direction of propagation of light.
3. _________ waves have the longest wavelength.
4. Gamma rays have the highest ____________.
5. The human eye can only see ________ light.

Different wavelengths provide us with various characteristics of the emitting objects.

Activity 5.2: Spectral Energy Distribution (SED)

Warm things emit light, you included!

Similarly, stars emit at different wavelengths depending on their temperature and energy.

***Figure 61**: Infrared emission (Credit: Wikipedia)*

By plotting the energy we receive from a star as a function of wavelength, we can find out in what wavelength range it is mostly emitting. Comparing its distribution with a **blackbody**[3] **spectrum** we can infer the peak temperature of the star, see Figure 62.

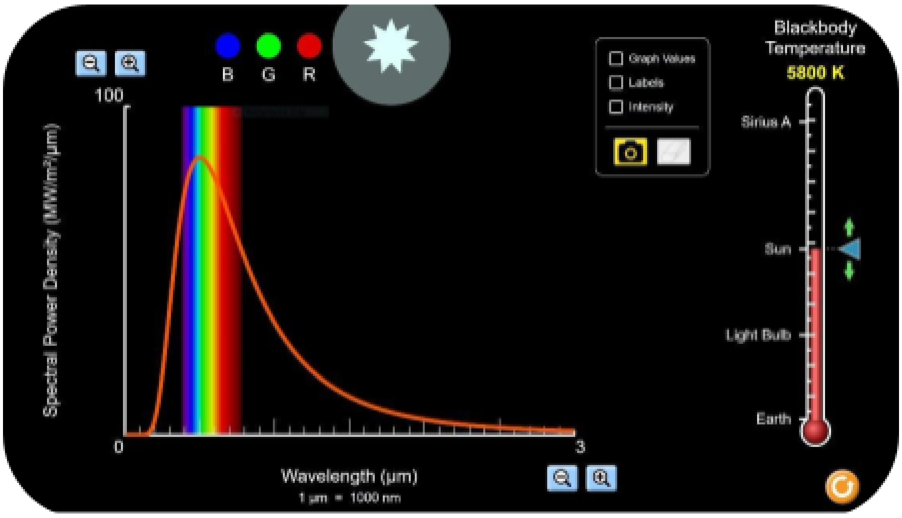


Figure 62*: Blackbody simulator (Credit: het.colourado.edu)*

Play around with this [blackbody spectrum simulator] and explain what you see when you select the light bulb, the Sun and Sirius A as emitting objects.

(Tip: You can zoom in and out on either axis to see the distribution clearer)

For a Light bulb:
For the Sun:
For Sirius A:

[3] https://en.wikipedia.org/wiki/Black_body

The distribution of energy of an object plotted as a function on wavelength is called its **Spectral Energy Distribution (SED).** Figure 63 shows the SED of the Sun as well as the SED of a Sun-like star compared to that of a brown dwarf.

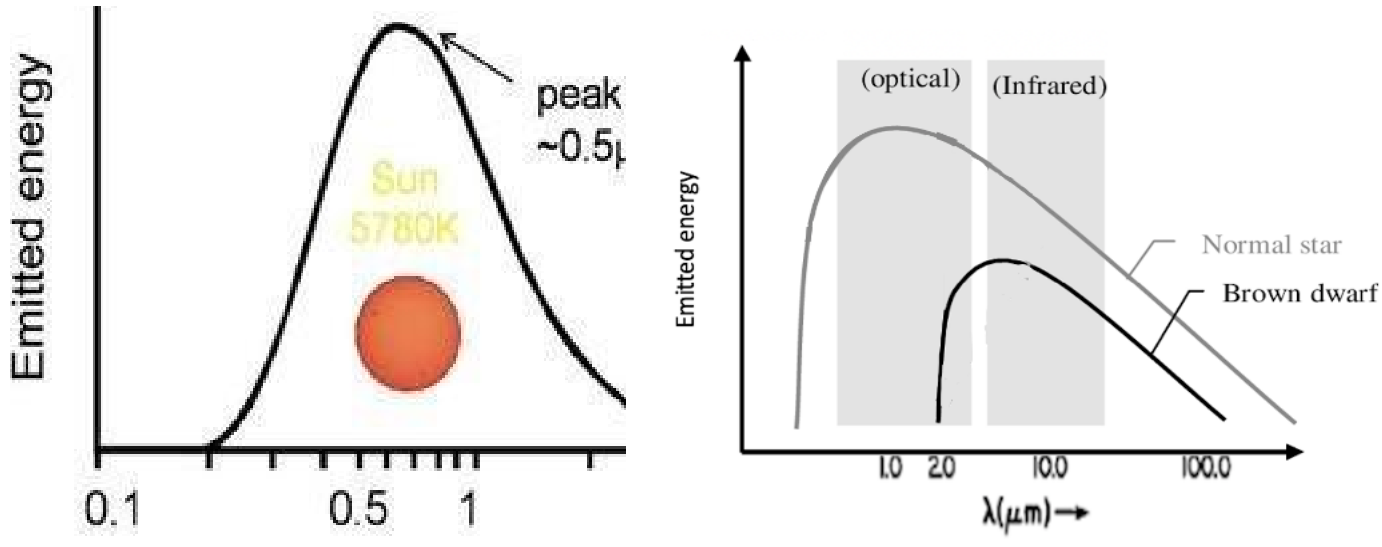


Figure 63: SED of the Sun (left) and SED of a Sun-like star compared to a brown dwarf (right). (Credit: Science Journal. 8. S113-S121. 10.2481/dsj.IGY-018.)

By looking at Figure 63, answer the following questions:

1. What type of electromagnetic radiation is the Sun mainly emitting in?

2. What type of electromagnetic radiation is a brown dwarf mainly emitting in?

Note: A brown dwarf is called a failed star because it never reaches hydrogen fusion. The reason behind this is the brown dwarf's initial mass is insufficient for gravity to result in a core temperature high enough to fuse hydrogen.

Activity 5.3: What can we learn about forming stars from their light?

A forming star will be radiating energy as well as the surrounding disk. Each energy-radiating component of the system (protostar, disk, envelope) will occupy a certain region in the SED depending on the wavelength it is emitting in. This is shown in Figure 64.

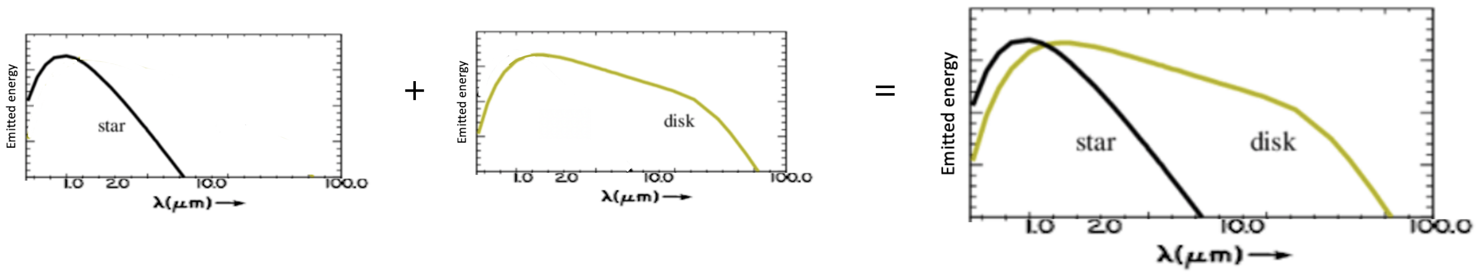


Figure 59: *Examples of SED (Credit: Zadelhoff, G.-J. (2002). Shaping disks; A radiative transfer and gas abundance study of circumstellar matter.)*

As the disk evolves and runs out of material, its contribution will decrease until only the star is emitting energy (like in the Sun). From the star and disk contribution on the SED, we are able to tell in what stage of the formation process the star is in.

Star formation SEDs are classified into four classes depending on their emission profile.

Each class corresponds to an evolutionary stage within the star formation process.

- Class 0: earliest stage of star formation, no clear contribution of the disk or star,
- Class I: the particles in the disk absorb light from the protostar and re-emit it at longer wavelengths (infrared excess). The protostar's contribution to the SED is barely noticeable at this stage,
- Class II: the protostar becomes visible in the optical, there is also infrared excess emission from the disk. This is the classical T Tauri stage,
- Class III: the disk is running out of material, the SED is mostly dominated by the protostar and the contribution of the disk is very weak. This is the weak-line T Tauri stage.

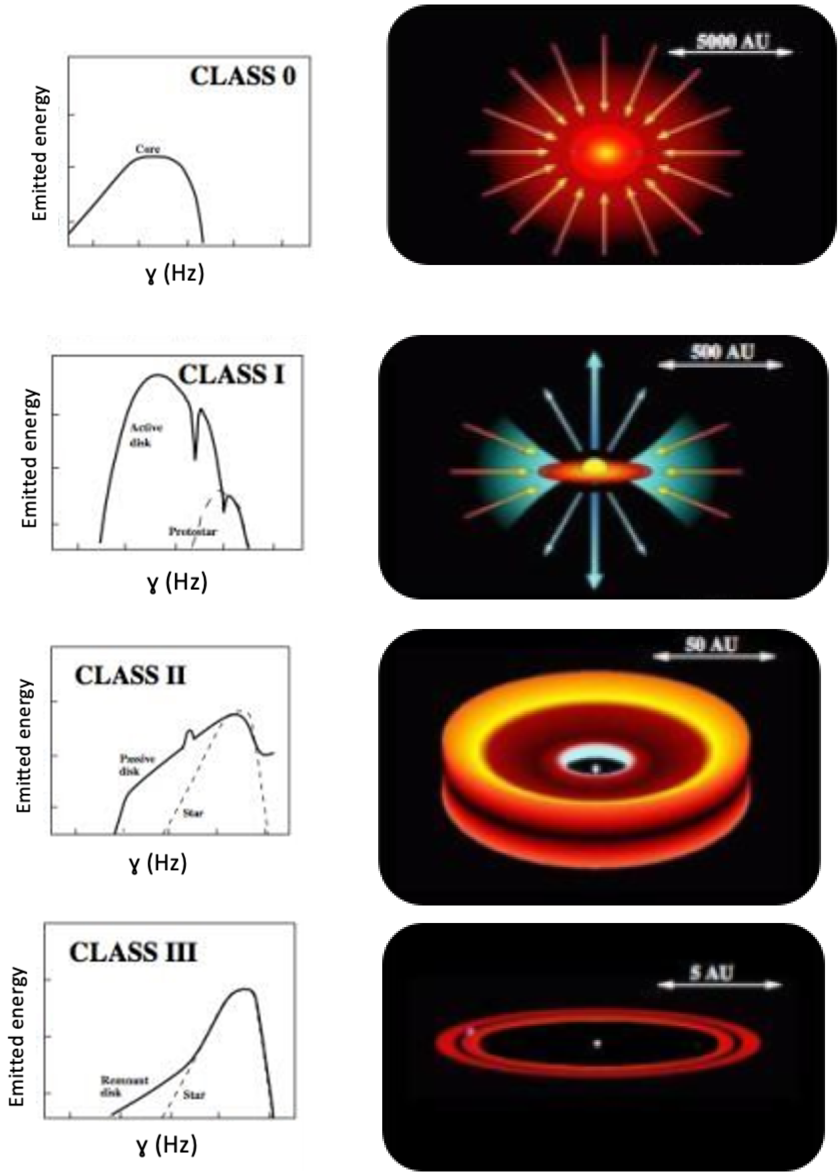


***Figure 65**: Describing and classifying the evolution of a protostar. (Credit: Harvard astronomy, link)*

1. Review Activity 4 and Figure 37 where star formation processes are described.
2. Compose and match the SEDs of classes I, II and III by:
    a. Taking a star and a disk contribution to form the complete SED from Table 2.
    b. Matching the SED you built to the corresponding SED in Table 3.

Hint 1: For step 2.b, bear in mind that SEDs are presented as a function of wavelength (λ) in Table 2 and as a function of frequency (ɣ) in Figure 65 (and Table 3). (**ɣ = c/ λ, where c is the speed of light**)

Hint 2: Remember, with time, the material in the disk runs out, the energy re-emitted from the disk is reduced and the star's energy dominates the SED.

Star contribution **Disk contribution**

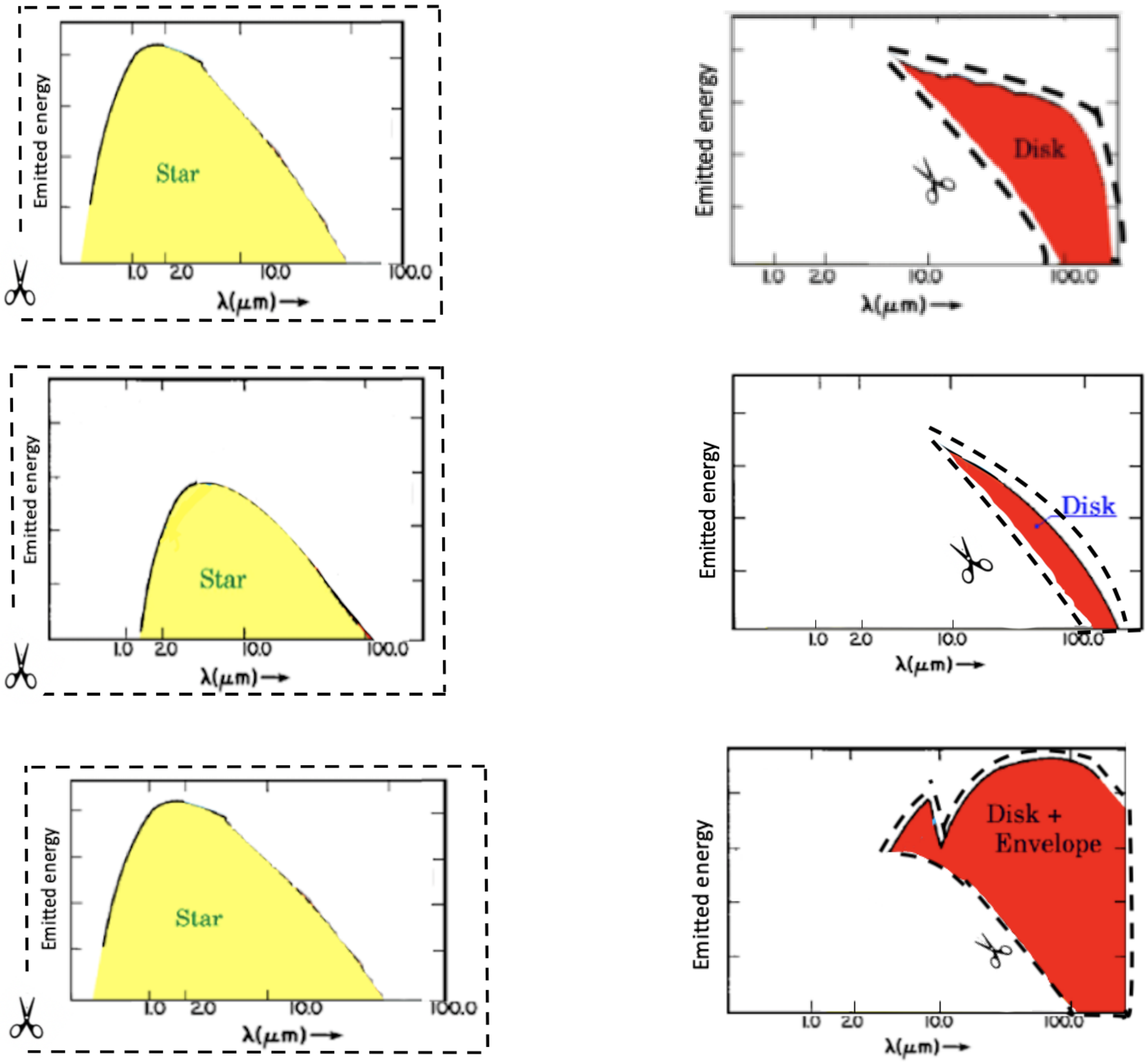


Table 2: Disassembled SEDs into star and disk contribution (Credit: Preibisch 2020)

Insert your solution obtained with Table 2 here:

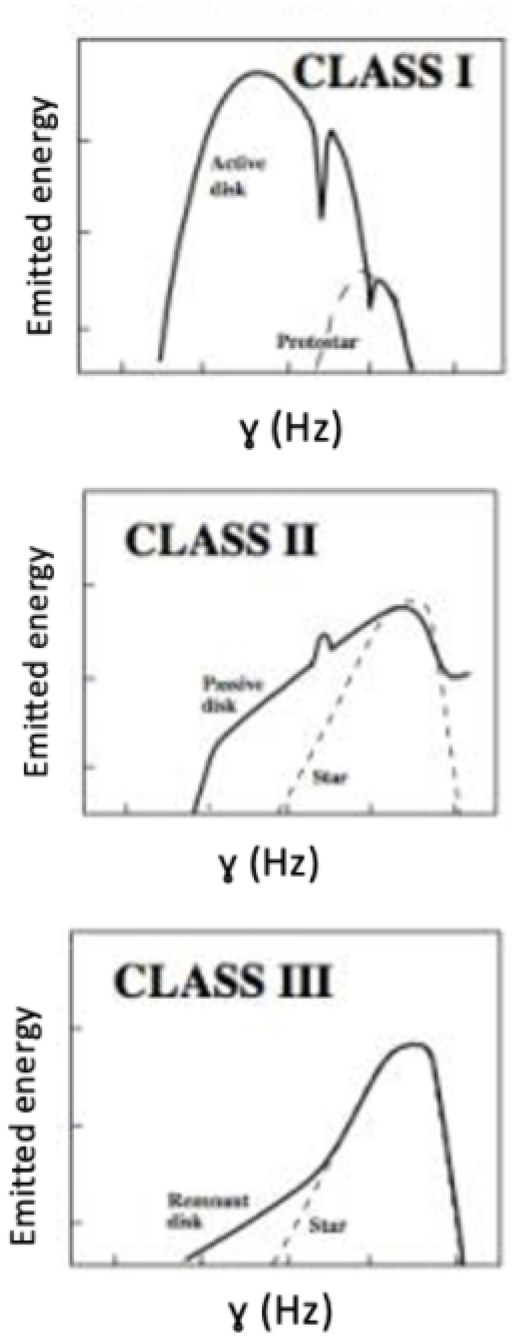


Table 3: SED classes (Credit: Harvard astronomy, link)

Activity 6: How do astrophysicists detect star formation?

We have learnt about the different steps of star formation and how to read an SED of a forming star. The next step is to learn how to differentiate between forming and already existing stars. When astrophysicists look for star forming regions, they try to detect the radiation coming from the prootstars and their disks. In particular they search in three electromagnetic emission ranges. These emissions are known as “star formation tracers”.

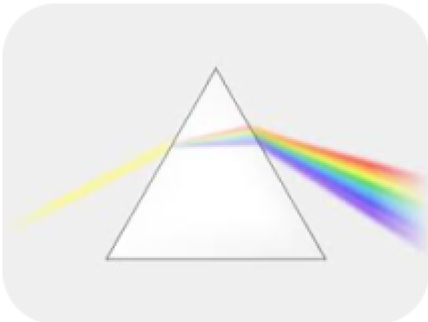


Figure 66: *Light dispersion (Credit: Wikipedia)*

These star formation tracers are: Halpha detection in the visible, with specific characteristics, excess of infrared, and X-ray emission.

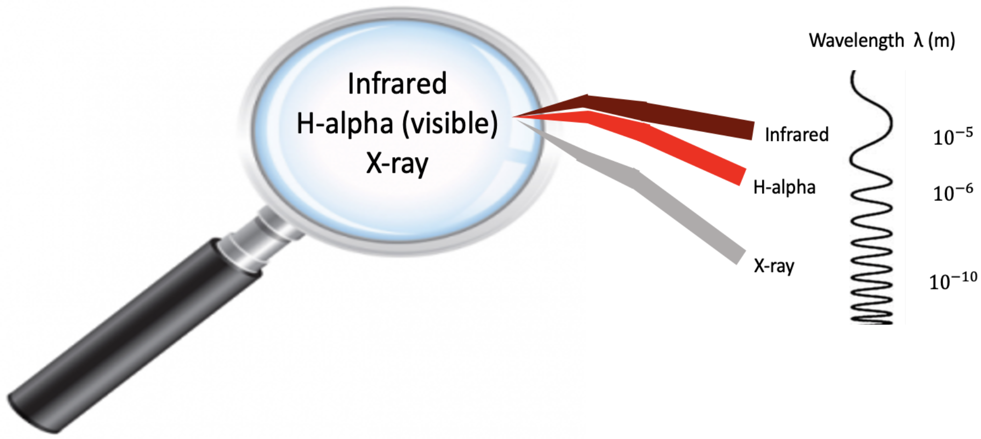


Figure 67: *Magnifying glass (Credit: CanStockFoto)*

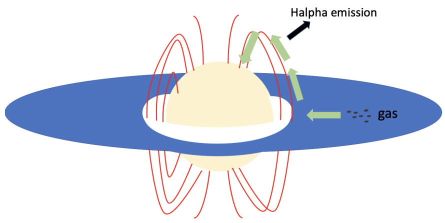
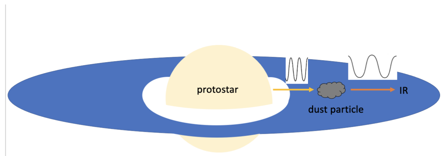
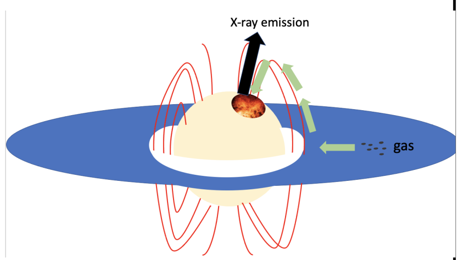
Detection method	**Explanation**	**Image**	**Wavelength**
Halpha emission	This occurs when accreted material falls onto the protostellar surface, channelled by the stellar strong magnetic field which accelerates the gas and leads to Halpha emission. When an electron is recombined with a hydrogen atom and falls from level 3 to level 2, it emits Halpha.		$656 \times 10^{-9} m$
Infrared excess	Infrared excess is caused by the dust particles in the accretion disk which absorb light from the central protostar and re-emit it at longer wavelengths. The detection of infrared excess is a well known tracer for the presence of a circumstellar disk.		$800 - 2500 \times 10^{-9}$
X-ray emission	The X-ray emission results from accretion shocks as well as from gas on the protostellar surface being heated to such high temperatures, it emits in X-ray.		$0.5 - 2.5 \times 10^{-10}$

Table 4*: Star formation tracers*

Identify the region in the spectrum corresponding to infrared, Halpha, and X-ray emission and label these on Figure 68.

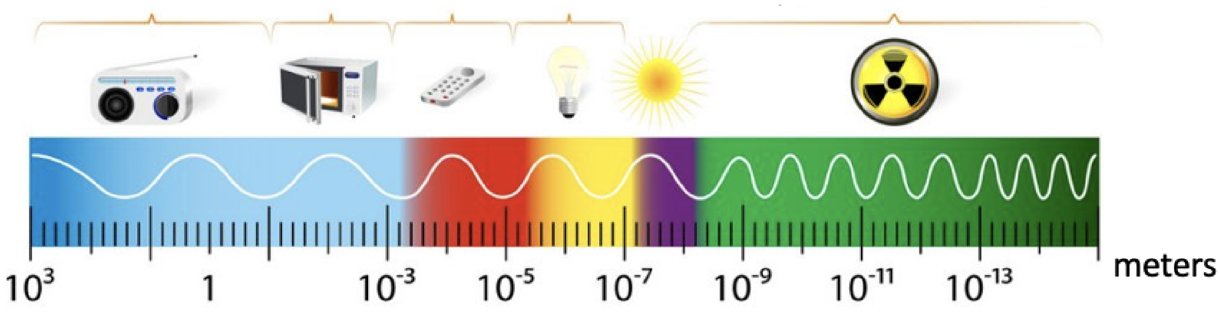


Figure 68: *Electromagnetic spectrum showing wavelength in meters (Credit: VectorStock)*

Figure 69, shows the percentage of light being absorbed by the atmosphere depending on the wavelength. An opacity of 100% means the atmosphere is blocking light from entering Earth.

Look at Figure 69 and think about whether the wavelengths used to study star formation can be detected from Earth or one needs to observe from outer space?

Hint: the emission ranges for star formation detection are visible, infrared and X-rays.

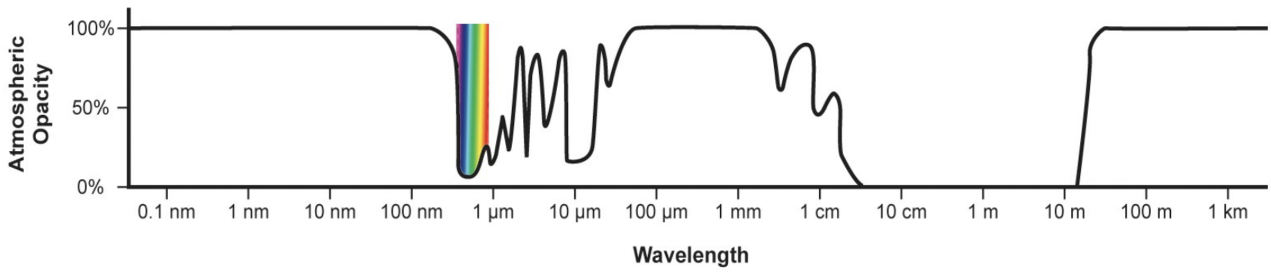
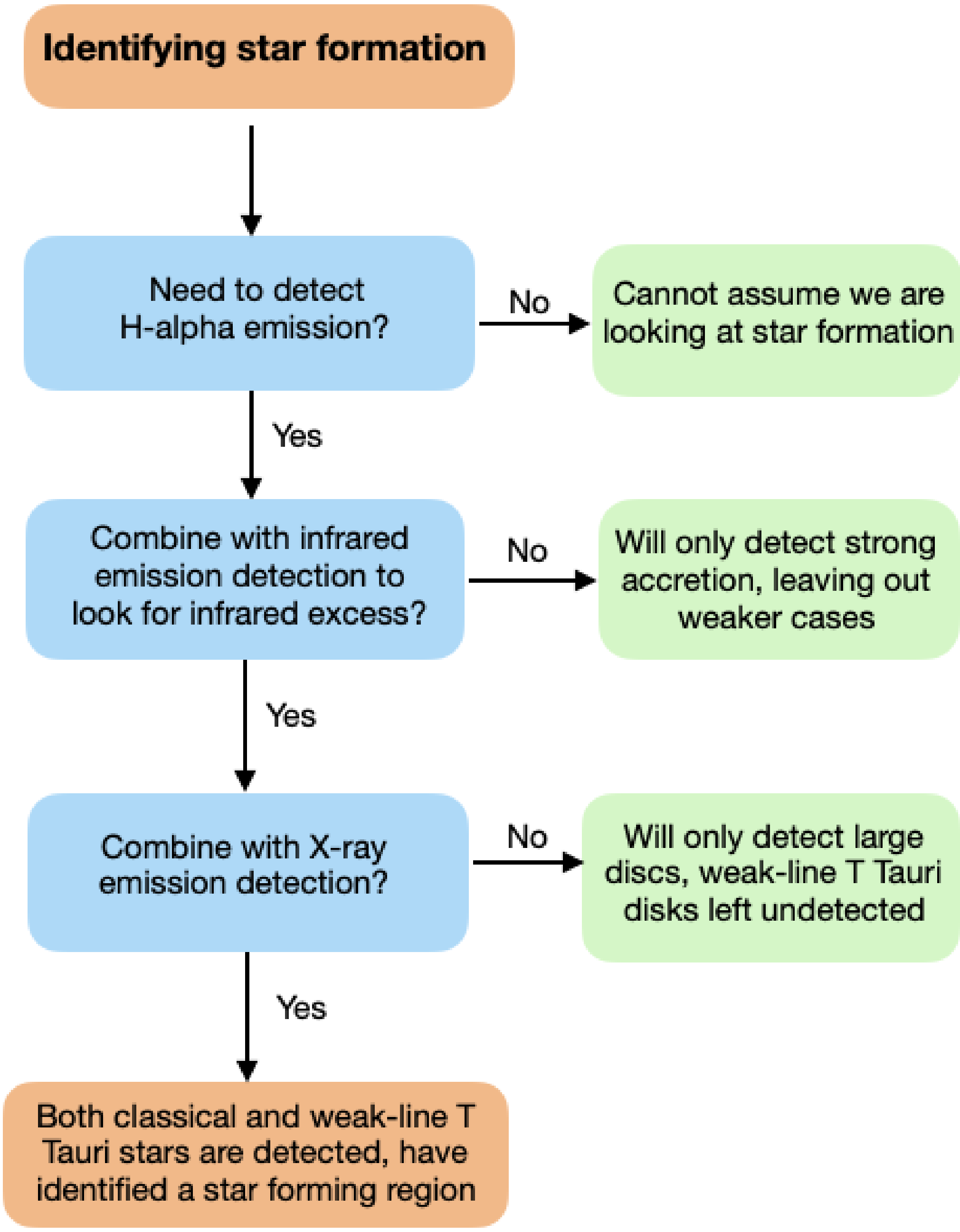


Figure 69: *Atmospheric opacity (Credit: NASA)*

Each star formation tracer is not enough alone, one needs to combine the three to obtain a reliable result. The following chart shows why:



Activity 6.1: Halpha emission

Halpha emission occurs in hydrogen, which has the atomic symbol H. Hydrogen is the most simple atom in the entire Universe, made up of one proton forming the nucleus and one orbiting one electron. Here is a simple version of the hydrogen atom:

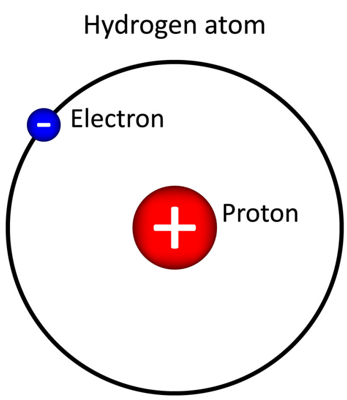


Figure 70: *Hydrogen atom (Credit: VectorStock)*

Imagine our electron finds itself in orbit 2. Then the hydrogen atom interacts with surrounding light. This incoming light meets the electron and gives it a small present (some energy!). The electron very happily accepts the present and absorbs the energy, this makes it jump out of its orbit, leaving the hydrogen atom.
Hydrogen is now said to be **ionized** and is called HII (pronounced H-two).

We can think about the hydrogen atom as a "solar system" where the Sun is the nucleus and the electron is the planet orbiting around it. The electron may orbit the nucleus at various orbits and these orbits are each given a number and have an energy assigned.

After some time, the atom recaptures the electron. The electron enters the atom and may stop at different orbits before it returns to its original one. In this case our electron returns to the atom and stops for a while at level 3.

Nature tends to a state of equilibrium, or low energy, therefore the electron will move from orbit 3 to orbit 2. This transition leads to the emission of a photon (i.e. energy in the form of light), as shown in Figure 71.

The light emitted has a wavelength of **656 nm**. This emission is called Halpha emission and corresponds to **red** light.

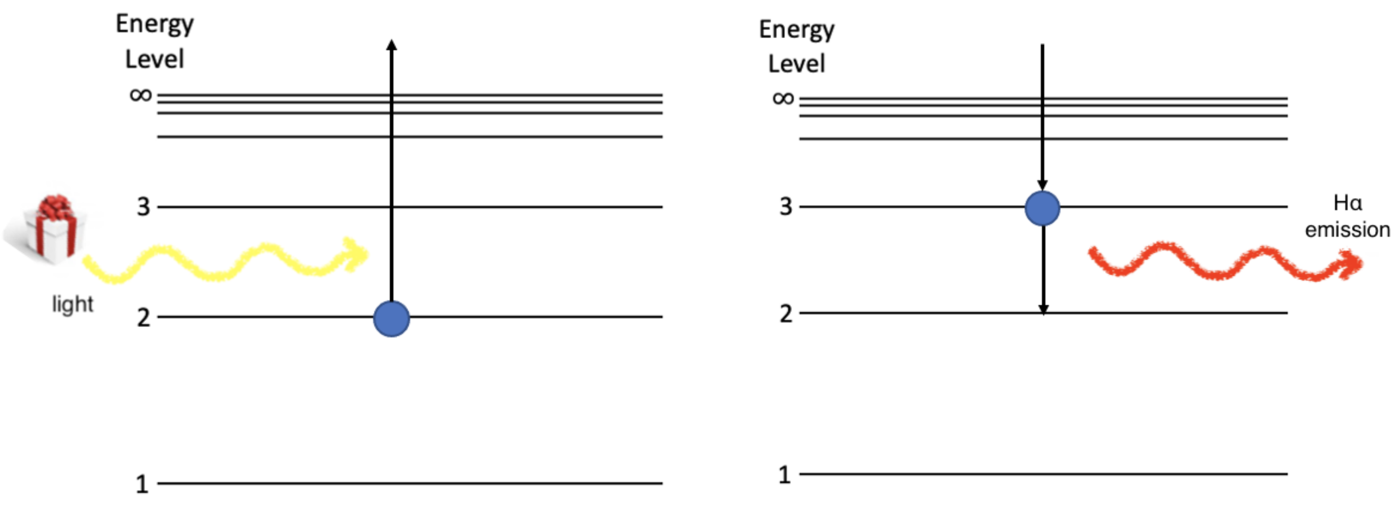


Figure 71: *Absorption and emission of light leading to Halpha emission*

Remember, we are in the visible region of the electromagnetic spectrum when we talk about Hα emission.

The process of absorption and emission leading to Halpha emission can be detected in the hydrogen absorption and emission spectrum (Figure 72).

An **absorption spectrum** is produced by shining white light (composed of all visible wavelengths) through an emitter across a colder medium (gas). The energies (or wavelengths) absorbed by the atoms will show up as a black gaps on the spectrum. The photons with these energies have been absorbed and therefore do not show.

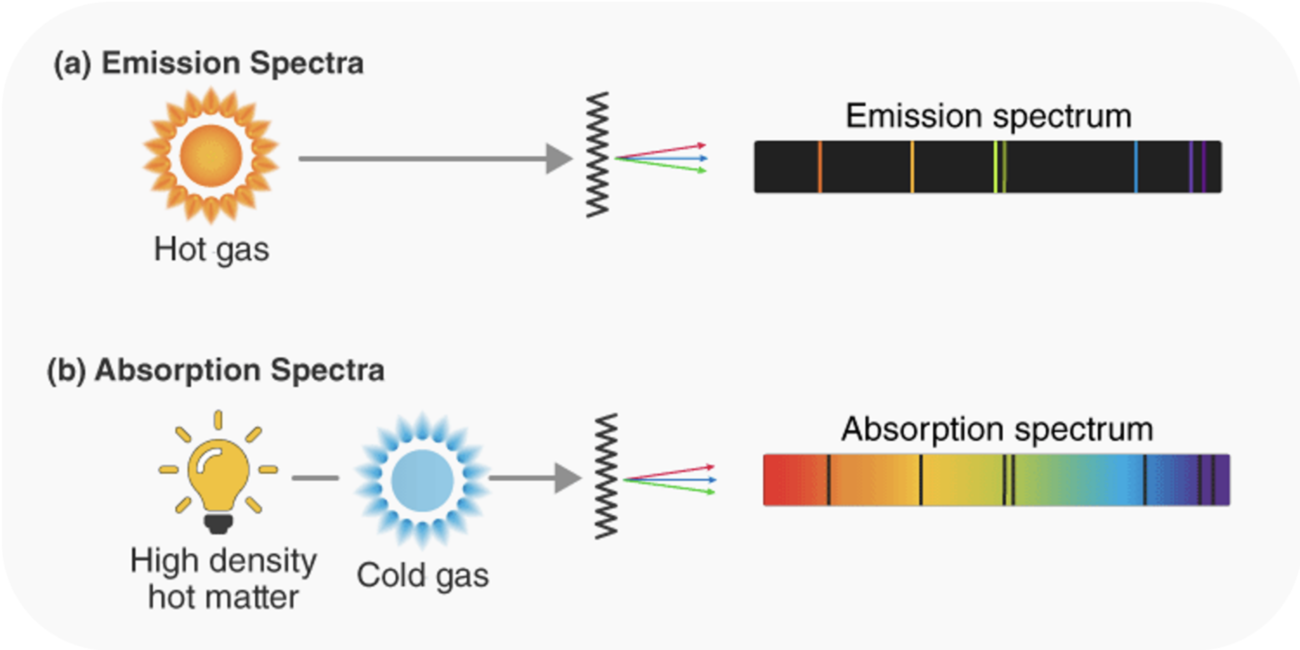


***Figure 72**: Emission and absorption spectrum when passing through hot and cold gas. (Credit: Byjus)*

***Figure 73:** Hydrogen absorption spectrum (Credit: Siyavula)*

When light from an emitter passes through hot gas, electrons become excited. When these return to a lower energy state, they emit light, leading to emission lines.

***Figure 68:** Hydrogen emission spectrum (Credit: Siyavula)*

Figure 75 shows the Sun's absorption spectrum. Notice any similarities with the one of hydrogen (look at Figure 74)?

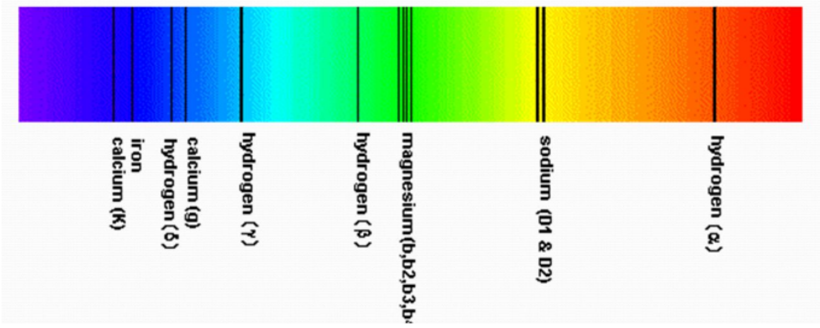


***Figure 75**: Solar spectrum (Credit: Studying the Sun, Charlie Fagg.)*

That's right! The Sun also absorbs in the Halpha wavelength!

The Halpha wavelength can be calculated thanks to the Danish physicist Niels Bohr, who came up with the idea of treating the hydrogen atom as a planetary model and developed an equation to calculate the wavelength of the emission originating from the movement of electrons between orbits.

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \qquad \text{(Equation 8)}$$

R_H is the Rydberg constant and is equal to $1.097 \times 10^7 m^{-1}$, n_f is the final orbit the electron falls to (in the case of Halpha, it is equal to 2) and n_i is the initial orbit from which the electron falls (in the case of Halpha, it is equal to 3).

1. Use equation 6 to calculate the wavelength of Halpha emission.

Read through Table 4 to remember what leads to Halpha emission in star formation.

The intensity of the Halpha emission can be obtained from photometry (extraction of the detected flux or magnitude of an object from the photons collected by the CCDs of an instrument with a Halpha filter), as we have seen in the VST catalog.
Another method of measuring the intensity of the Halpha line (or any other transition line of another chemical element) is from its emission lines.

Spectral lines are the result of passing light from an object through a slit or diffraction grating, called a spectrograph.

You can check out different spectrographs by clicking on this link and reading Section 3.3.

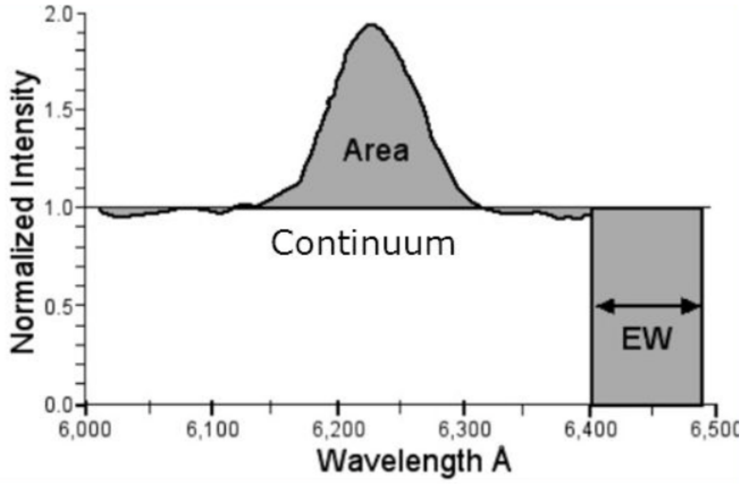


Figure 76: *Equivalent width (Credit: Hopkins Phoenix Observatory)*

The size of spectral lines indicates the strength of the emission and is measured as a function of equivalent width (EW).

The equivalent width of an emission line measures the area below the curve and is approximated as a rectangle, as shown in Figure 76.

When you don't have an emission spectrum, but rather have catalogue photometric data like we do, one can use the photometric equivalent width, which also measures the strength of an emission.

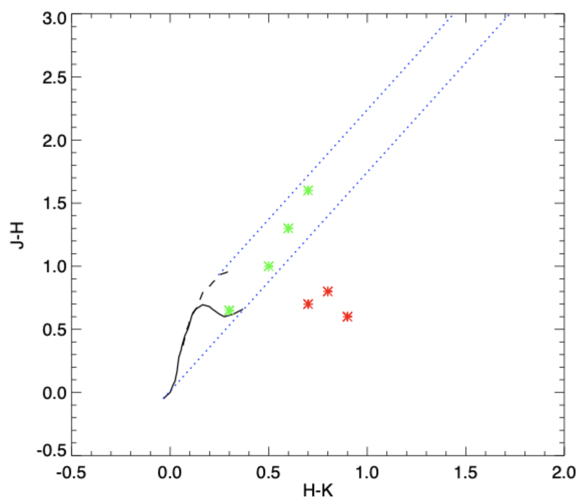
The photometric equivalent width is given as

$$EW_{H\alpha} = W \times [1 - 10^{0.4\times(r-H\alpha)_{excess}}]$$ (Equation 9)

where $EW_{H\alpha}$ represents the equivalent width, W is the width of the filter being used and $(r - H_{\alpha})_{excess}$ is the excess of colour.

Activity 6.2: Infrared emission

Take a look at Table 4 to remind yourself about why infrared excess occurs in star formation. Infrared emission appears on the SED and tells astronomers the disk is present.



By plotting colour-colour diagrams, astronomers can study the excess infrared emission originating from the disk. Such a plot is shown in Figure 77, where the three different infrared wavelength bands called J,H,K have been used to compute colour.

Figure 77: *Colour-colour diagram (Credit: Preibisch)*

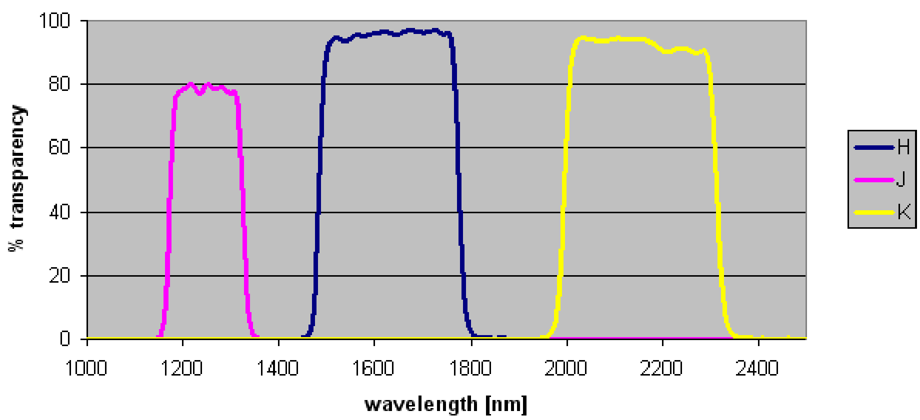


Figure 78*: Wavelength ranges for J,H,K filters (Credit: http://www.rem.inaf.it/remir.html)*

Take a look at Figure 77. As we previously saw in Activity 2.5.2, infrared excess would arise if:

(J-H)> 0, (H-K)>0

Full grown stars with no accretion disk, show no infrared excess (green symbols) and occupy a very specific region in the plot which can be delimited by the dotted lines. Every object that falls to the right of this limiting region,

(H-K)>0, H>K

is considered to show infrared excess (red symbols). This is because objects to the right have a smaller K value (and are therefore brighter in the K band). Since the K band has the longest wavelength it can be thought as being “more in the infrared”. Therefore these objects have an “excess” of infrared emission.

Note: Remember, the lower the magnitude, the brighter the object emits in that wavelength.

Activity 6.3: X-ray emission

Similar to our Sun, protostars have magnetic field lines. With the rotation of the protostar, these lines get tangled, just like when you twist a rubber band many times. This entanglement creates loops, which interact with the gas on the protostar’s surface and heats the gas up to millions of degrees.

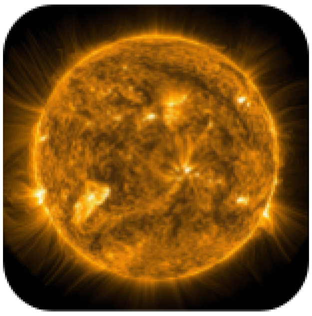
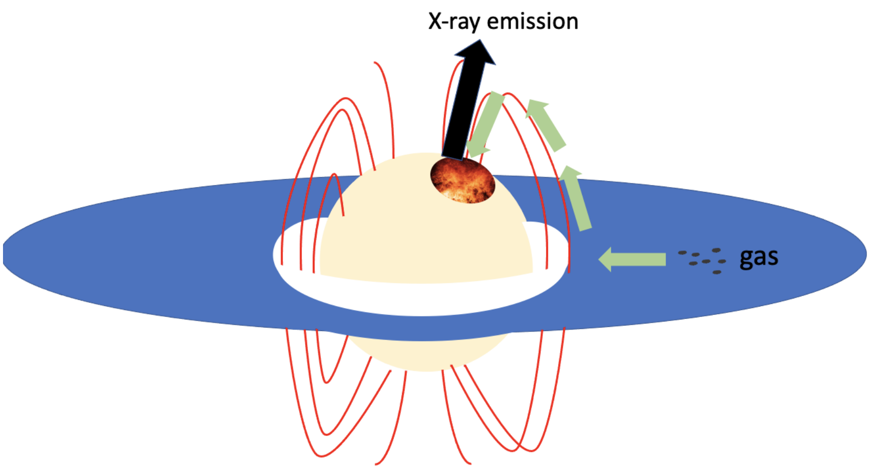


Figure 79: Sun's magnetic map (Credit: Solar Orbiter)

Check out this video to understand the process better.

X-ray emission is also found to originate from **accretion shocks** but at a smaller scale compared to the X-ray from the magnetic activity.



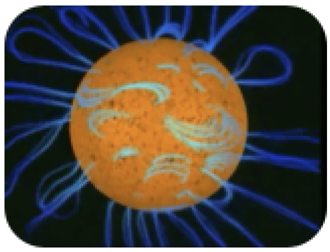


Figure 81: *Magnetic Loops on protostar surface (Credit: link)*

Figure 80: *X-ray emission in protostars through accretion*

We have learnt how to identify star forming candidates from their Halpha, infrared excess and X-ray emission.

However you must take care because other objects in the Universe also emit this type of emissions and may be wrongly classified as forming stars. For example: Black holes are also surrounded by an accretion disk and emit X-rays, as well as emitting in the infrared or visible parts of the spectrum.

Activity 7: Star formation exploration

The European Space Agency has a wide variety of scientific missions studying the Universe and contributing greatly to the international scientific community. One of the topics explored by ESA is star formation, seen in Activity 6. In this Scientific Case we will use data from three important ESA missions related to star formation: XMM-Newton, GAIA, and Herschel.

Activity 7.1: Star formation exploration by the European Space Agency

Mission: XMM-Newton

Observational range: $1 - 120 \times 10^{-10} m$

The name of this space mission is composed of two factors. "XMM" stands for X-ray Multi-Mirror. "Newton" is in honour of the great physicist and mathematician Sir Isaac Newton. It was launched by the vehicle Ariane 5 and placed into orbit in 1999. It is currently fully operational. The Earth's atmosphere blocks X-rays (thankfully) so the only way to detect them is by having detectors in space. XMM is the largest, scientific satellite ever built in Europe ($\sim 11\,m \times 16\,m$) and helps scientists unravel the secrets of our Universe at very high temperatures (millions of degrees). For example, how galaxies form, how black holes interact with their environment or how star formation occurs. For this purpose, it carries 7 scientific instruments on board (camaras, X-ray spectra, radiation meter, and an optical-UV monitor).

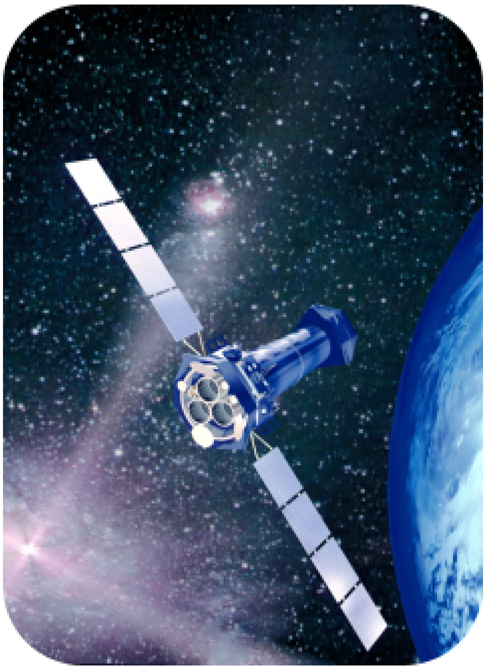


***Figure 82**: XMM-Newton (Credit: ESA)*

Want to learn more? Check out this video!

Mission: GAIA

Observational range: $330 - 1050 \times 10^{-9} m$

GAIA is an European Space Agency satellite observing the sky. This satellite is capable of identifying 10^{9} more stars than its predecessor, Hipparcos. It identifies the distance to these objects (parallax method studied in

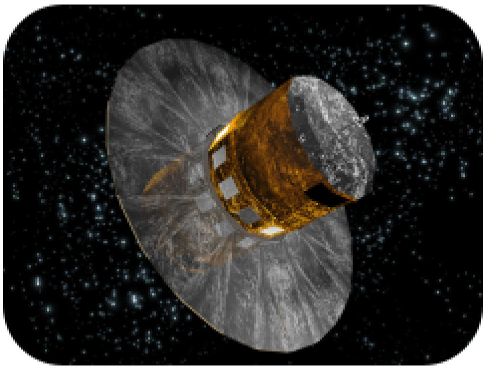


***Figure 83:** GAIA (Credit: ESA)*

Activity 2.2), their position, radial velocity, and photometry… Studying the variation in position of stars and other celestial objects allows us to understand their trajectories and in some cases their origin as well as to identify "sister stars", with the same chemical composition and of the same age, which have dispersed throughout the galaxy (for example: sister stars to our Sun). Check out this video to learn more about GAIA!

Figure 84: *Stellar trayectory*

The dotted lines you observed on Figure 84 emerging from the sources detected by GAIA show their trajectories, at 90º to the vision line between us and them.

Mission: Herschel

Observational range: $55 - 672 \times 10^{-6} m$

Figure 85: *Herschel (Credit: ESA)*

The Herschel Space Observatory, operated by the European Space Agency, has been the space telescope with the largest main mirror (D = 3.5 m) put in orbit. Since infrared observatories need to be refrigerated, their life expectancy will depend on how the refrigerating liquid conserves its properties. For Herschel, the satellite operated from 2009 until 2013. It's aim was to study the coldest and most distant objects in the Universe as well as in our galaxy, with main focus on star and galaxy formation and interaction with the interstellar medium. Herschel was sensitive to the radiation from the cold dust in molecular clouds and was therefore able to image these regions, known as "stellar nurseries".

Check out this video to learn more!

Here are the various ESA missions. You can look at the full sized image under this link.

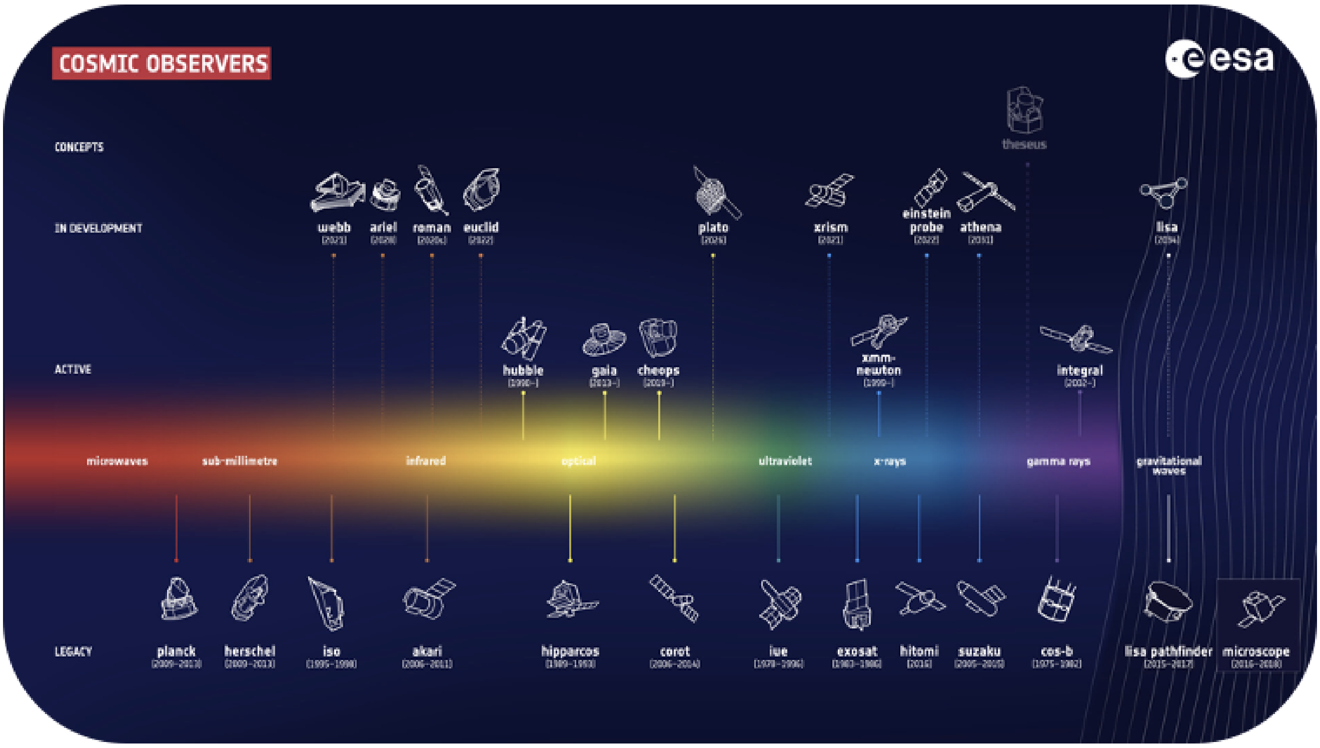


Figure 86: *ESA missions (Credit: ESA)*

Collaboration between space agencies over the world helps scientific research move faster. Researchers usually make use of data obtained through various missions. In this Scientific Challenge you will use data from other space agencies like the European Southern Observatory (ESO) combined with ESA data to reach our goal: explore star formation.

Activity 7.2: Star formation exploration by ground based observatories

Mission: 2MASS
Observation range: $1.25 - 2.17 \times 10^{-6} m$

2MASS, which stands for 2 Micron (=micrometer) All Sky Survey. The data obtained was the result of a collaboration between many American organizations, including NASA (1997-2001). By using two telescopes, observing in the infrared, one in the northern hemisphere (United States) and one in the southern hemisphere (Chile).

2MASS mapped more than 300 million objects in the near-infrared. The catalogue included brown dwarfs, low mass stars, galaxies, and stellar nurseries where stars form.

The spectral range used was the J,H and K band (review Activity 6.2) which have the following wavelengths:

Band	Main wavelength ($\times 10^{-6}\ m$)
J	1.25
H	1.65
K	2.17

***Table 5**: 2MASS bands*

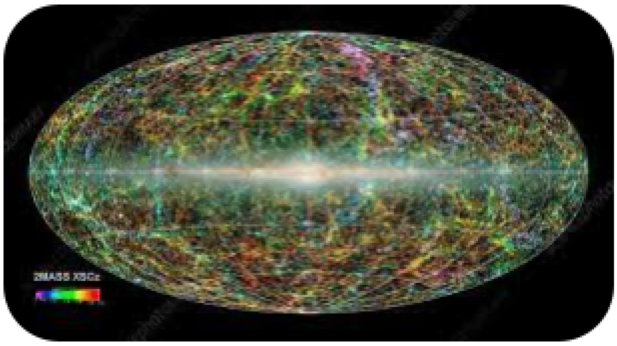


***Figure 87**: 2MASS survey (Credit: Caltech)*

Mission: VLT and VST

Observational range: $300 - 1100 \times 10^{-9} m$

VLT stands for Very Large Telescope. It is on the observatories run by the European Southern Observatory and is located in Chile (Paranal). It is composed of 4 telescopes, with 8 meters of diameter, with the most advanced instrumentation in the visible range. Each telescope has an angular resolution of 50 milliarcseconds (like seeing a DVD held by an astronaut at the International Space Station!).

When all 4 telescopes work at the same time, they can reach a resolution of up to 2 milliarcseconds. The VLT is responsible for many breakthroughs such as obtaining the first image of an exoplanet or the study of how stars behave around a massive black hole. The array of telescopes started working in 1999.

Since 2011, these four telescopes have been supported by another telescope called VST, which stands for the Very large Survey Telescope. This 2.6 m in diameter telescope is used to map regions in the sky and produce surveys and stellar maps.

The sensitivity of this telescope's camera allows the study of young stars in the process of accreting as well as finding out more about molecular clouds.

The VST camera has 5 filters which are used to measure magnitudes and study colour of objects (see Activity 2.5.2 about colour) in 5 different bands:

Band	Main wavelength ($\times 10^{-9}\ m$)
Ultraviolet (u)	354.3
Green (g)	477.0
Red (r)	623.1
H-alpha	658.8
Near Infrared (i)	762.5

***Table 6**: VST bands*

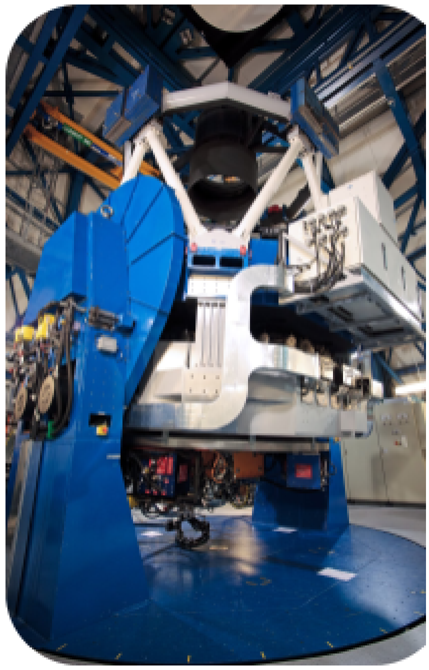


***Figure 88:** VST (Credit: ESO)*

Check out this video to learn more!

Science works through collaborations between scientists and missions. The scientific data from the European Space Agency are accessible through the free, scientific portal called ESASky. This portal allows scientists and astrophysics amateurs to access this data, as well as use it for educational and scientific communication resources.

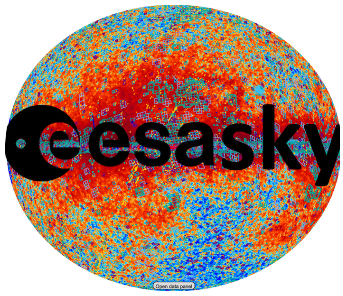


Figure 89: *ESASky (Credit: ESDC)*

ESASky gives access to scientific data from ESA scientific, spatial missions and step by step will contain data from Earth observatories from 2MASS or ESO.

Phase 2

Activity 8: What have you learned so far?

Answer this quiz to evaluate your learning.

Activity 9: News

AstroESFM
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hydrogen burning. The contracting phase is called pre-main sequence. If the stars have a mass smaller than 2M. is called a TTauri while is a Herbig Ae/Be if the mass is between 2 & 8 M.
In the image the premain sequence star HBC1 by ESA/Hubble

AstroESFM @AstroEsfm · 2 Aug
#Mistymonday
When the protostars have blown away most of its envelope it might become visible although the hydrogen burning in its core has not yet starts. No more mass will be accreted. On the contrary, it will contract until the temperature inside get the value to ignite the

1 1 2

Phase 3

Your mission

We have seen the different steps needed for a star to form. We learnt that

- A protostar accretes material from its surrounding accretion disk until the disk runs out of most of its material
- The disk from which the protostar feeds provides material for roughly 1 to 10 million years
- During the main phase of accretion the protostar is known as a classical T Tauri star. The accretion process can be detected as Hαemission.
- After that, the disk is depleted and the protostar becomes a weak line T Tauri.

The mystery is that astronomers have found Hα emission from protostars that are 30 million years old, that no longer have an accretion disk. But how is that possible? This observation seems to contradict the theory, and when such contradictions occur in science, the only way to find an explanation is to conduct our own research!

Your mission is to help us understand what is happening. Through the following activities, you will look for classical T Tauri stars in Trumpler 14 and try to find out whether your observations agree with the ones by the astronomers or with the theory we have learnt.

Activity 10: The Carina Nebula

In this Scientific Challenge we will be researching a particular region in the sky, the Carina Nebula. Read the following passages about this region and extract as much information as you can find! Summarize your findings in the space below the 4 texts.

Activity 10.1: The Carina Nebula bibliography

This Nebula is filled with baby stars like our Sun

Jade Boyd-Rice

1 INTRODUCTION

A new study of one of the most active star-forming regions in the galactic neighbourhood is helping astronomers better understand the processes that may have contributed to the formation of the sun 4.5 billion years ago. "Most stars form in giant molecular clouds, regions where the density of matter is sufficient for hydrogen atoms to pair up and form H2 molecules," said Patrick Hartigan, professor of physics and astronomy at Rice and lead author of the new study. "The Carina Nebula is an ideal place to observe how this happens because there are dozens of examples of forming stars at various stages of development." The Carina Nebula spans more than 100 light-years and is visible to the naked eye as a bright glowing patch in the Milky Way for observers in the Southern Hemisphere. In addition to thousands of stars similar in mass to the sun, Carina contains more than 70 O-type stars, each with a mass between 15 and 150 times that of the sun. Young stars with a disk are present at the centre of globules. The entire evaporation process takes about a million years, and astronomers believe it is an essential aspect in the creation of solar systems like our own, Hartigan said.

The Carina star-formation region is about 7,500 light-years from Earth, about five times farther away than the Orion Nebula, which is visible in the northern hemisphere but is only about one-tenth the size of the Carina Nebula.

New images of Carina show multiple examples of each of the different stages of cloud destruction.

"There is huge variety in Carina, in part because it is so large," Hartigan said. "It spans more than a degree on a side, which means that it covers more of the sky than four full moons. In addition, Carina is young enough to have a great deal of ongoing star formation. But it is also old enough that the most massive stars have cleared away enough material to reveal a dizzying array of globules and pillars."

In the new survey, Hartigan and colleagues used the National Optical Astronomy Observatory's Extremely Wide-Field Infrared Imager and its Mosaic camera to photograph the entire Carina region from the four-meter telescope at Cerro Tololo in northern Chile. Both the optical and near-infrared imagers use large-format detectors to obtain high-resolution shots of wide swaths of the sky. Each of the images isolates a specific wavelength of infrared or optical light. By looking at these wavelengths separately and in composite, Hartigan and colleagues were able to penetrate Carina's nebular dust. Hartigan said the new images reveal details about the underlying physics of the region.

"Our images are sharper and deeper than previous ones, and they provide the best snapshot so far of a star-formation region at one point in time," he said.

Note: A globule is a concentration of dust

This extract was adapted from the original article published on Futurity, which you can read [here](#).

A Census of the Carina Nebula – II. Energy Budget and Global Properties of the Nebulosity

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[1] Astronomy Department, University of California, 601 Campbell Hall, Berkeley, CA 94720, USA
[2] Australia Telescope National Facility, CSIRO, PO Box 76, Epping, NSW 1710, Australia

1 INTRODUCTION

The Carina Nebula (NGC 3372) is the nearest massive star-forming region that satisfies three criteria which distinguish it from other Galactic giant HII regions: (1) it harbours the most extreme grouping of massive stars within a few kpc of the Sun, including ~70 O stars initially (some, like η Carinae (η Car), have now moved off the main sequence) that are in the process of creating a giant superbubble; (2) it is young enough that active star formation is still ongoing within a few parsecs of these massive stars and (3) unlike any comparable massive cluster in our Galaxy, our sightline to it suffers little interstellar extinction, allowing it to be studied across the electromagnetic spectrum and not just at infrared (IR) and radio wavelengths.

This last point is critical, because it offers the potential to construct a relatively complete picture of the massive star-forming environment and the stellar content.The first two indicate that Carina is our nearest suitable analogue of more extreme regions like 30 Doradus (30 Dor). Finally, unlike many Galactic regions, the distance to Carina (2.3 kpc) is known to within a few per cent from the expansion parallax of η Car's circumstellar nebula so that the properties one derives are reliable.

Carina is an ideal laboratory for comprehensive multiwavelength studies of an environment much like that where our own Solar system may have formed, where young protoplanetary discs will be bombarded by supernova (SN) ejecta. It also represents the early stages of the birth of an OB association, and it is an environment where this young OB association is triggering the birth of a second generation of stars as they destroy their own natal giant molecular cloud.

Note:
An H II region is a gas cloud containing a large amount of ionized hydrogen (H II) - hence the name. Massive stars form in these regions.

Interstellar extinction is the dimming of light from stars due to absorption by the surrounding dust.

An OB association is a type of stellar association (or star cluster) formed by stars of spectral type O and B (they are the most luminous and hottest).

This extract was adapted from the original paper which you can read here.

Imaging study of NGC 3372, the Carina nebula – II. Evidence of activity in the complex Trumpler 14/Car I photodissociation region

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Accepted 2005 December 16. Received 2005 December 16; in original form 2005 October 27

1 INTRODUCTION

The Great Carina nebula is not only one of the greatest celestial spectacles of the Southern skies but also a very important natural laboratory for studying the birth and evolution of the brightest and most massive stars in the Galaxy. In this huge H II region, dozens of O–B0-type stars produce a large ultraviolet (UV) radiation field which, together with strong stellar winds, interact heavily with the material in its parental giant molecular cloud.

The nebula extends more than four square degrees on the sky and, as a result of the evidently complex mass motions, it presents peculiar morphologies at all scales. These include clumps, filaments, arcs, and all sorts of chemical, kinematical and density inhomogeneities..

There is mounting observational evidence that the process of massive star formation has been active for several million years and has not ceased. Recent observations of the nebula indicate that massive stars are being born in several regions within molecular condensations, located mainly to the SE and NW of the cluster Trumpler 16 (Tr 16), whose most famous member is η Carinae. It is becoming evident that the new generations of stars now being born are the result of the momentum inserted into the medium by the large-scale winds and UV radiation from the 'older' generations of stars.

In the northern part of the Carina nebula, the stellar population is dominated by the three clusters: Tr 14 and Tr 16, near the brightest part of NGC 3372, and Tr 15, a less rich stellar cluster now free of dense ambient material. The stellar population in this region has been widely studied photometrically and spectroscopically in the optical for the last three decades supplemented at near-IR wavelengths. The most extensive proper motion study of the region is that of Cudworth, Martin & DeGioia-Eastwood (1993) who provided membership probabilities for nearly 600 stars in the field of Tr 14 and Tr 16. In spite of all this work, the fundamental parameters that characterize the Tr 14 and Tr 16 clusters, such as the interstellar, or more precisely, the reddening and thus, distances and ages, are still subject to controversy.

Near-IR *JHK* aperture photometry of more than 200 of the visually brightest stars in Cr 228, Tr 14, Tr 15 and Tr 16 was reported by Tapia et al. (1988) who compared their *JHK* with available *UBVRI* colours of all stars in their sample. These authors concluded that the interstellar extinction towards the cluster Tr 15, in the northern end of the Great Carina nebula, is identical to the Galactic average from 0.33 to 2.5 μm. This is not surprising, as the environment around this cluster is devoid of nebular or obscuring material.

Note:
An H II region is a gas cloud containing a large amount of ionized hydrogen (H II) - hence the name. Massive stars form in these regions.

This extract was adapted from the original paper which you can read here.

The Carina Nebula and Gum 31 molecular complex – I. Molecular gas distribution, column densities, and dust temperatures

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Accepted 2015 November 23. Received 2015 November 23; in original form 2015 September 28

1 INTRODUCTION

The Carina Nebula Complex (NGC 3372, hereafter CNC) is the Southern hemisphere's largest and brightest nebula. Located at 2.3 kpc away, it provides a laboratory to study ongoing star formation in the vicinity of some of the most massive stars known, including our Galaxy's most luminous star, Eta Carinae (η Car). Across the entire CNC there are more than 65 O stars and several hundred protostars making it a rich environment to study the interplay between clustered star formation, massive star feedback, and triggered star formation. Two young stellar clusters, Trumpler 14 and Trumpler 16, dominate the central region and the CNC is home to three high-mass-loss Wolf–Rayet stars. For comparison, Orion nebula is dominated by just a single O-type star.

Until the mid-1990s, the prevailing view was that the CNC was an evolved star-forming region, with a few remnant gas clouds that had been shredded by the energy input from the massive stars.

In recent years, and with the new wide-field, high-resolution images at X-ray, optical, and IR wavelengths, this view has changed dramatically. We now recognize that the CNC is a hotbed of active star formation, with a reservoir of quiescent molecular gas where new bursts of star formation may one day occur. The stunning images from *HST* and *Spitzer* reveal numerous gigantic pillars of dust (sometimes called 'elephant trunks' because of their morphology), situated around the periphery of the ionized nebula associated with η Car and which point towards the central massive star clusters. Star formation appears to have been triggered recently in these pillars, as there are hundreds of protostars of ages ~105 yr, possibly formed as a result of the impact of winds from the massive stars on the dust clouds.

The region also shows extended, diffuse X-ray emission which may be from a previous supernova. If so, the supernova's expanding blast wave could have triggered the new generation of star formation, but this also raises an intriguing question as to the location of the precursor star.

This extract was adapted from the original paper which you can read here.

Write down everything you know about the Carina Nebula:

Activity 10.2: The Trumpler 14 region

Having read through the extracts above, you have probably noticed a specific region being mentioned several times, and that is Trumpler 14 (Tr 14). It is one of the youngest known star clusters and is known to be an active region of star formation within the Carina Nebula. The coordinates for Trumpler 14 are RA: 10h 43m 55.92s and DEC: -59º32'60.00''. Throughout this Scientific Challenge, we will focus on finding stars in the process of formation within this famous cluster.

***Figure 90**: Trumpler 14.*

(Credit:https://hubblesite.org/image/3693/news)

Activity 11: Inspecting star formation regions

PHASE 1 of star formation involves **molecular clouds**, also called star nurseries. Here you will get a chance to explore different clouds, enjoy!

Activity 11.1: Get familiar with clouds on ESASky

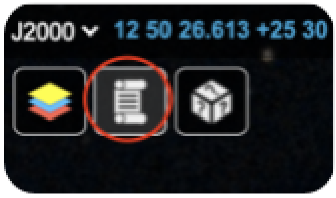
PROCEDURE IN INSTRUCTIONS:

1. Click on this link to enter ESASky: https://sky.esa.int
2. Select the explorer mode
3. Click on the parchment icon.
4. Click on the target list.
5. Select the bright nebulae or dark nebulae from the list
6. Click around on any nebula you want, a spectacular image of each one you click will appear
7. Each object includes some extra information. Take some time to explore around!

PROCEDURE IN IMAGES:

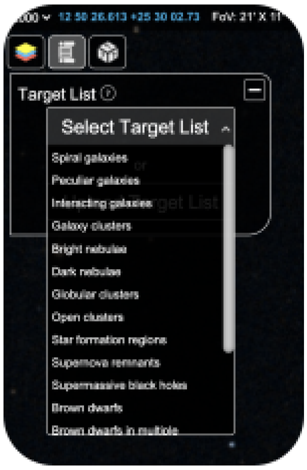
2.

3.



4.

5.



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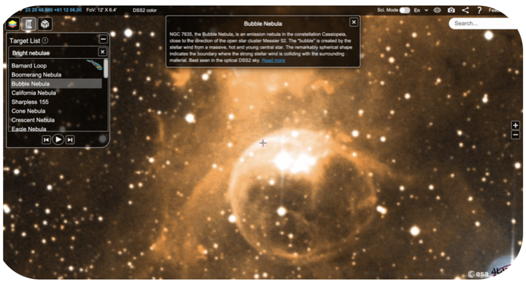

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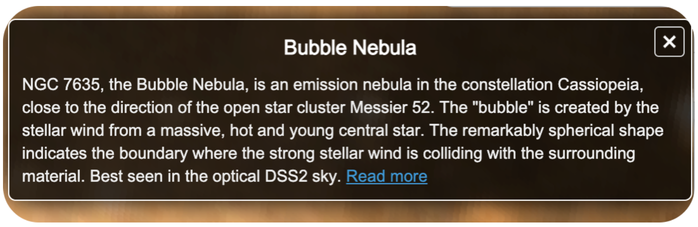
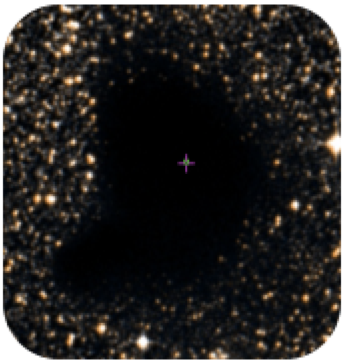


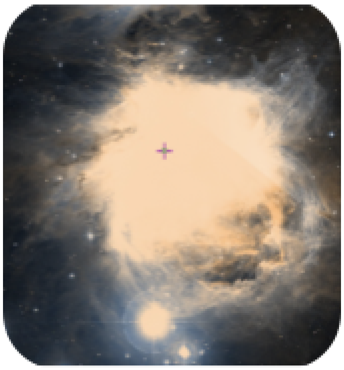
Activity 11.2: Classification of nebulae

Since reflection and emission nebulae are usually observed together, we are going to treat them as one single category; bright nebulae.

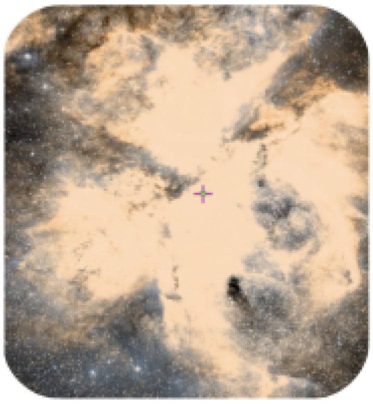
Can you tell whether the following nebulae are bright or dark? Write a B or a D next to each one.

a) 

b) 



c)



d)

***Figure 91**: Various nebulae from ESASky (Credit: ESASky)*

Try to recognize the nebulae on Figure 91 in the list of bright and dark nebulae created on ESASky and annotate their names and coordinates in Table 6. Write down the RA, DEC central coordinates for each nebula. Look for the nebulae on ESASky and write down the name of each cloud. Review [Activity 2.1](#) to refresh the concepts of RA and DEC if you need to.

Name of the nebula	Central coordinates

***Table 6**: ESASky nebulae*

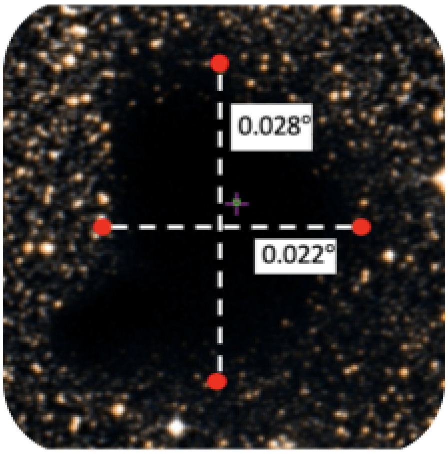
Remember you can always access ESASky and look for a region in the sky in the search box on the right hand side, searching for their coordinates or technical name (on the AladinLite database).

Note: Write on google the name of your object and AladinLite will show you the result

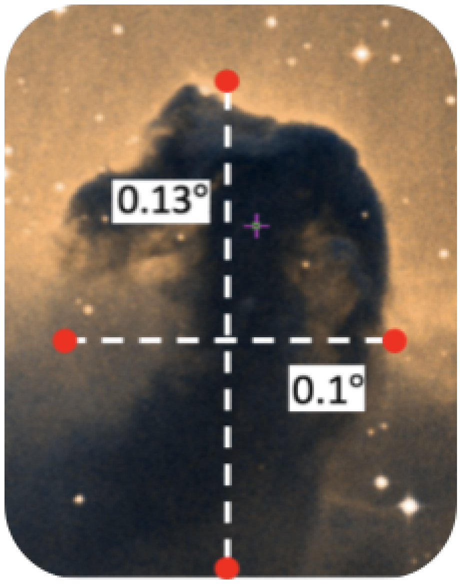
Activity 11.3: Calculating sizes of non-circular objects

The sizes of these nebulae are given below. Since these regions are not circular, the sizes are given as a height and width.

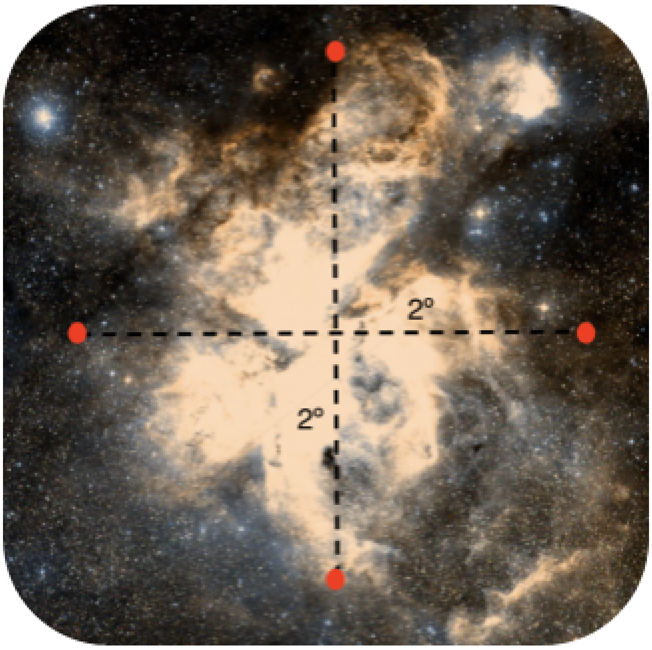
Barnard 68 (500 ly away)



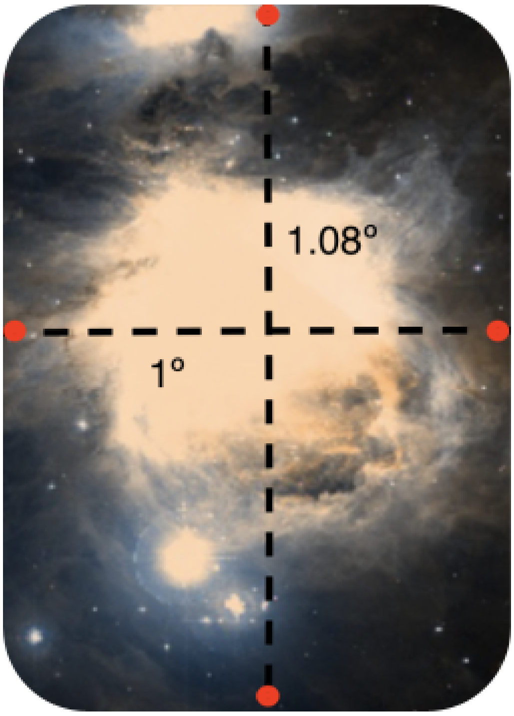
Horsehead nebula (1500 ly away)



Carina (7500 ly away)



Orion (1334 ly away)



1. Each team picks a nebula.

Options:

- Barnard 68
- Horsehead nebula
- Carina
- Orion

2. Given the angular diameters and the distances to these, calculate their sizes in kilometers.
3. Instead of kilometers, what units would be more appropriate for these sizes?

For Barnard 68:   For Horsehead nebula: For Carina: For Orion:

Activity 11.4: Downloading astronomical images from ESASky

Activity 11.4.1: Download SAOImage DS9

1. Access the following link to download SAOImage DS9 depending on your computer:
    - MacOSX: link
    - Windows: link
    - Linux: link

Having inspected the above nebulae, we are now going to focus on the Carina Nebula, more specifically in Trumpler 14. To do this we will use Herschel images from ESASky of this region and the astronomical program SAOImage DS9, an astronomical imaging and data visualization tool. Here are the steps to do so:

PROCEDURE IN INSTRUCTIONS:

1. Click on this link to enter ESASky: https://sky.esa.int
   and select the **science mode**.
2. On the right-hand corner you will see a search bar. Introduce the name of "Trumpler 14" or the central coordinates.
3. Zoom out clicking the - sign 3 times.
4. Click the "available images" icon, on the upper-left hand side, which resembles a galaxy, which says "examine the images in this region".
5. Select the "Herschel (far infrared to submillimeter)" block.

6. You should get regions drawn in the background with the names of the observations in the catalogue. The size of the square indicates the number of images available for that region in said catalogue.
7. Select the observation with the “ObsId:1342211615” and the “Target Name: Carina Nebula Complex-1” with the instrument “PACS”.
8. Visualize said image by clicking on the magnifying glass symbol
9. Download the image by clicking on the left-hand side button (a downwards pointing arrow)
10. You should obtain a compressed file (with .tar format) in your downloads folder.
11. Open this file and you will get a folder. Open this folder to see the **two** documents inside it.
12.
    a. If you have a Windows computer, you may open these types of compressed files with a program called 7ZIP. This will decompress the tar files into fits.gz and from fits.gz to fits.
    b. If you have a Mac or Linux computer, click on the tar file and it will decompress automatically into fits.gz files. By double clicking on these, you will obtain the fits format required.

    The names of the files to visualize on SAOImage DS9 are:

    - hpacs_25HPPJSMAPB_blue_1043_m5925_00_v1.0_1471643665627.fits
    - hpacs_25HPPJSMAPR_1043_m5925_00_v1.0_1471643689343.fits

13. For simplicity, rename the files in order to find them easily later on:
    - Trumpler14_blue.fits
    - Trumpler14_red.fits
14. Open the SAOImage DS9 program to visualize your images. To do so, on the main menu, follow the following steps:

    File → Open as → Mosaic Segment WCS → (name of your file)

    Trumpler14_blue.fits

15. Select the following parameters for a better visualization of the image:
    - "Zoom" = "Fit"
    - "colour" = "bb"
    - "scale" = "sqrt" & "zscale"
16. You can define the parameters more in detail on the visualization scale in the following way:

    "Scale" → "Scale parameters"

    Adjust the parameters:

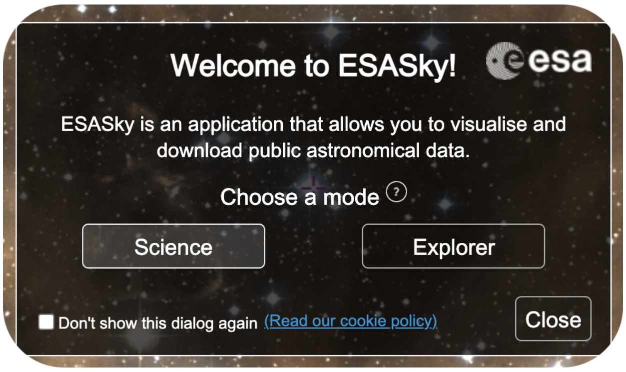
    low = 0

    max = 10

    and click on "Apply"
17. Repeat this for the file named Trumpler14_red.fits

PROCEDURE IN IMAGES:

1.



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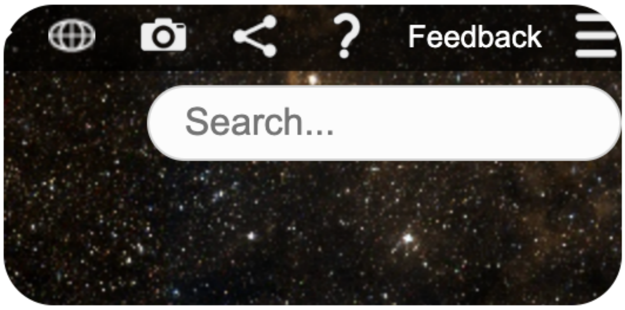

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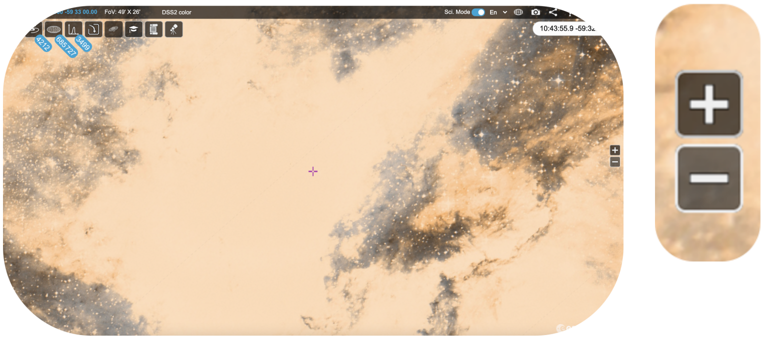
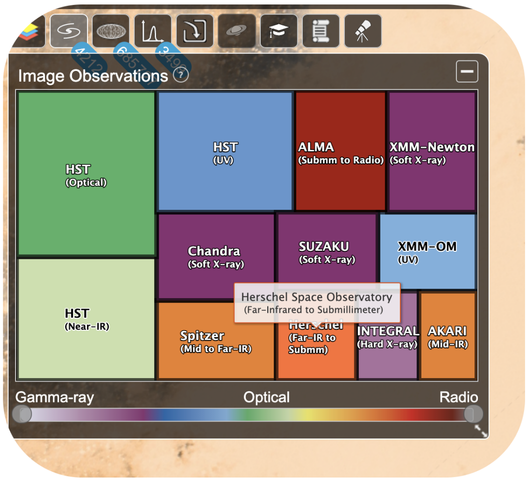


4.

5.



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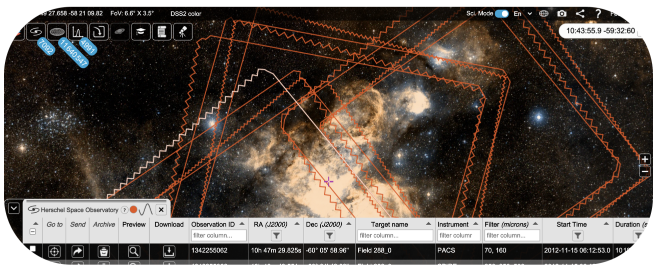

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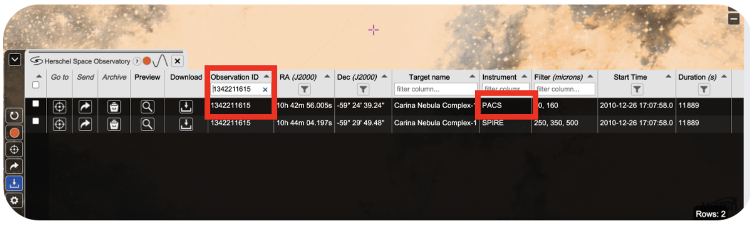

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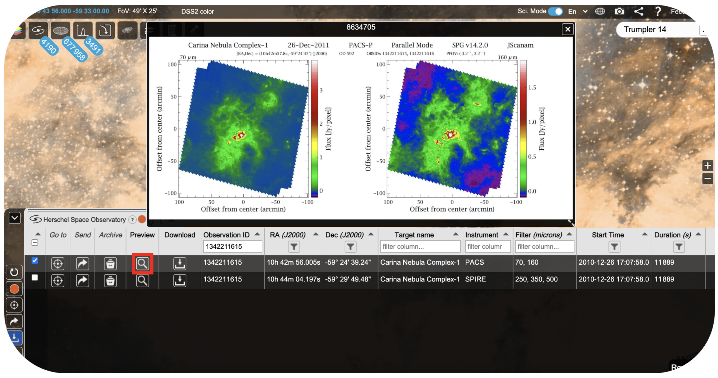

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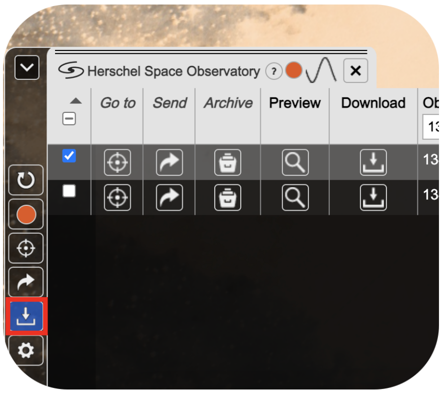

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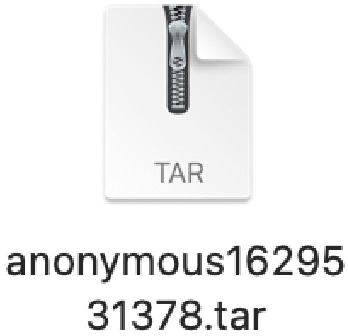

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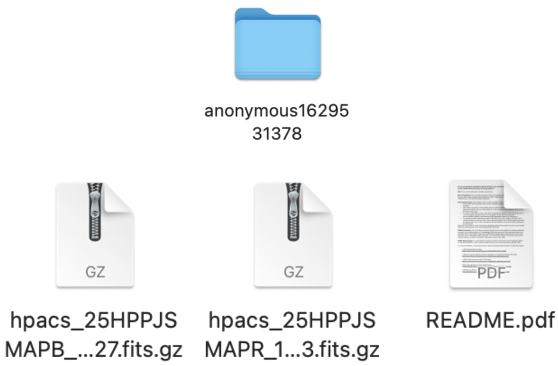

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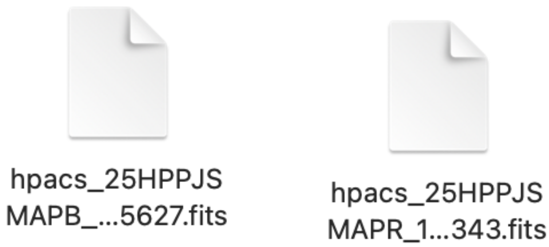
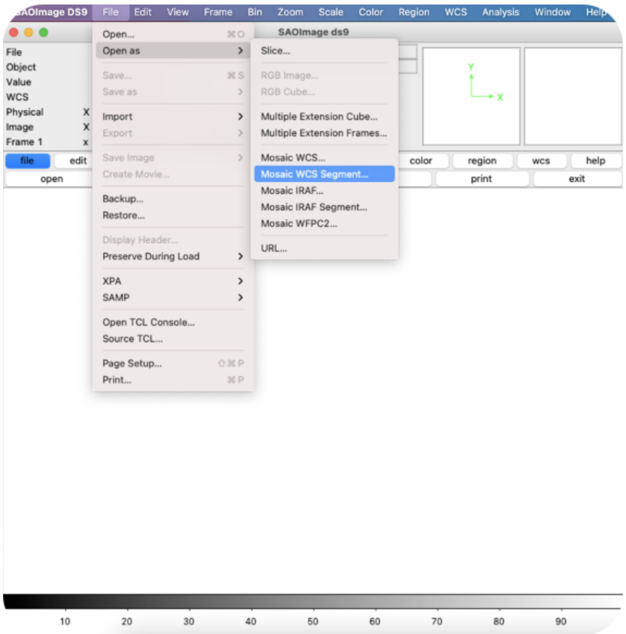
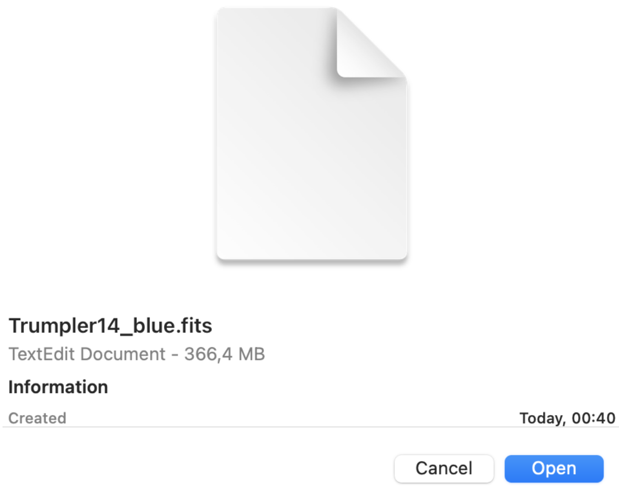


13.

14.




Trumpler14_blue.fits
TextEdit Document - 366,4 MB
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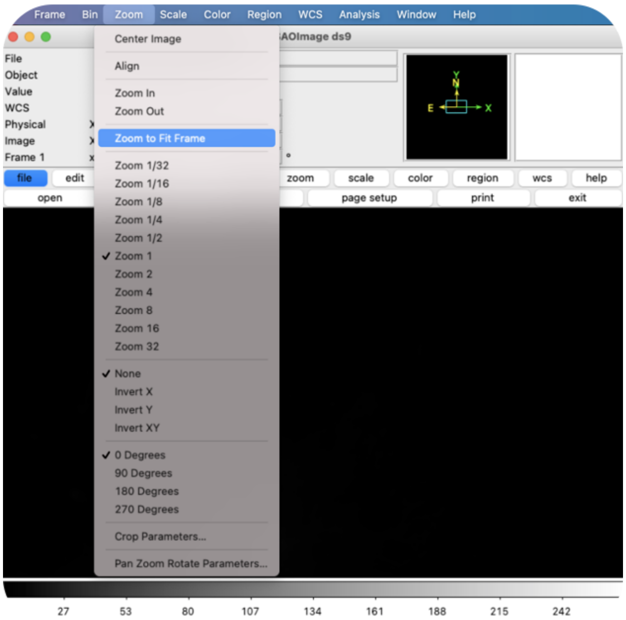
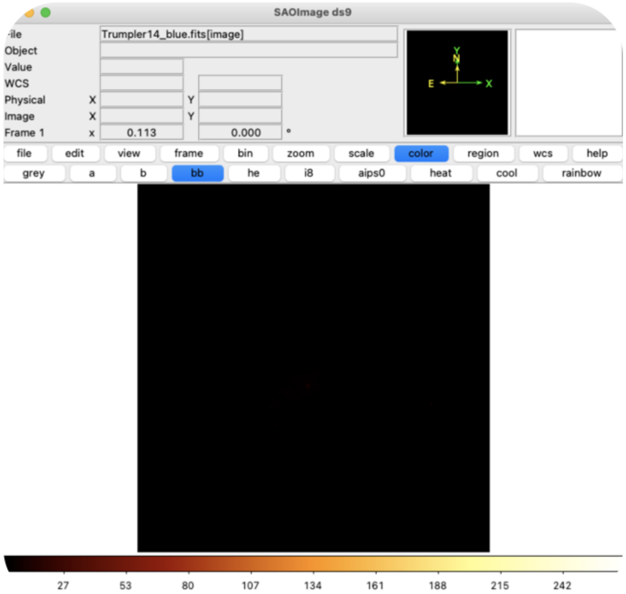
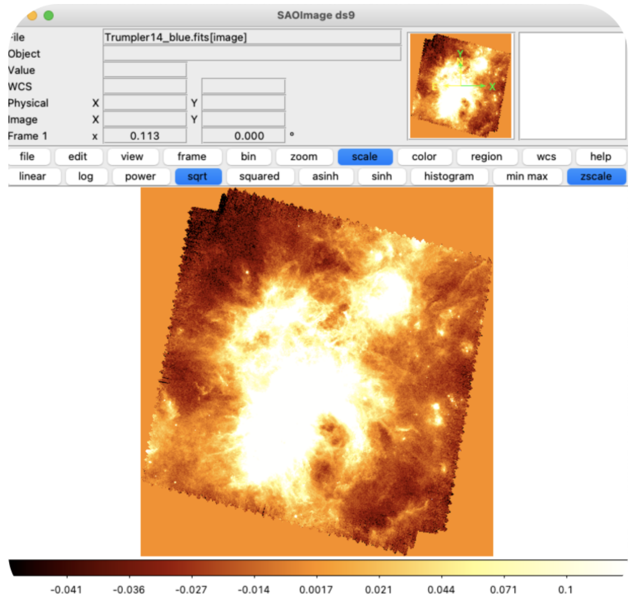
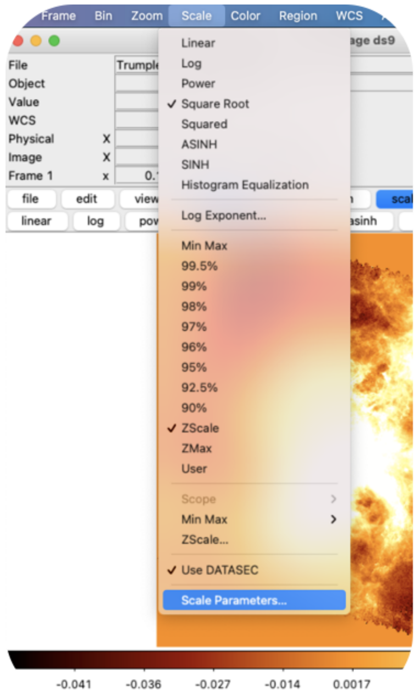
15.

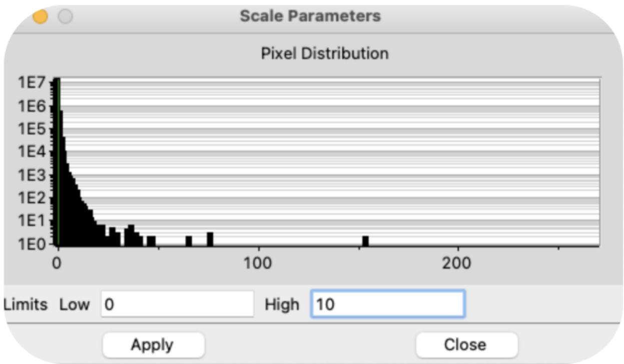






16.





The image you will obtain is a Herschel, far infrared image (micrometers) showing the density of clouds in Trumpler 14.

1. Can you identify the region where the material is the most dense?

Activity 11.5: RGB Images

Now that you are more familiar with working with astronomical images, you can go a step further.

You have probably seen spectacular colourful images of objects in space but these colours are usually “not real”, but rather enhanced for visualization purposes..

Astronomical images are taken with telescope detectors such as CCDs (Charged Couple Device) and appear in black and white. However, when the CCD is used together with a colour filter, the image obtained enhances that specific colour, like in Figure 92.

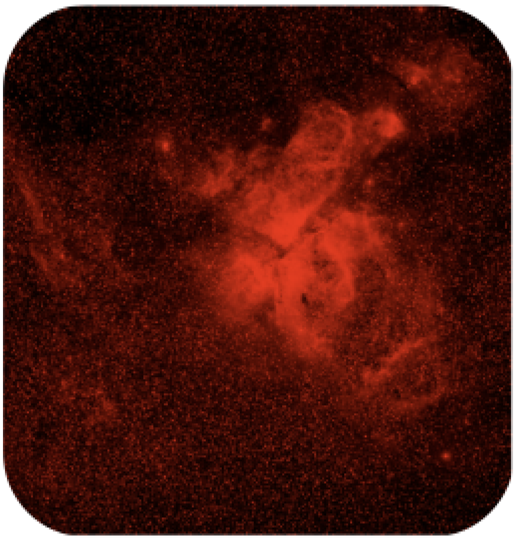


Figure 92: Red band image of Carina Nebula from the Digitized Sky Survey

By combining the same image, taken in different filter bands, one can obtain a coloured image. The combined image receives the name of RGB Image, from the combination of red, blue and green.

The RGB model correlates very well to how humans perceive colour through the receptors in our eyes, which are sensitive to red, green and blue wavelengths.

Figure 93 shows the image taken for the three bands, which combined together form an image with colour close to the “true colour” we would perceive is produced, Figure 94.

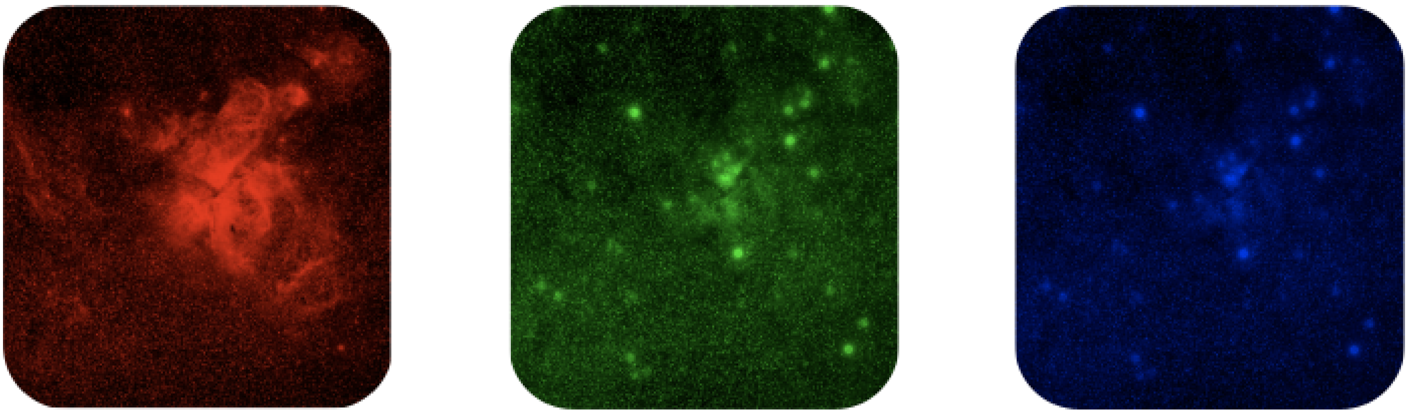


Figure 93: Red, green and blue band images of Carina Nebula from the Digitized Sky Survey

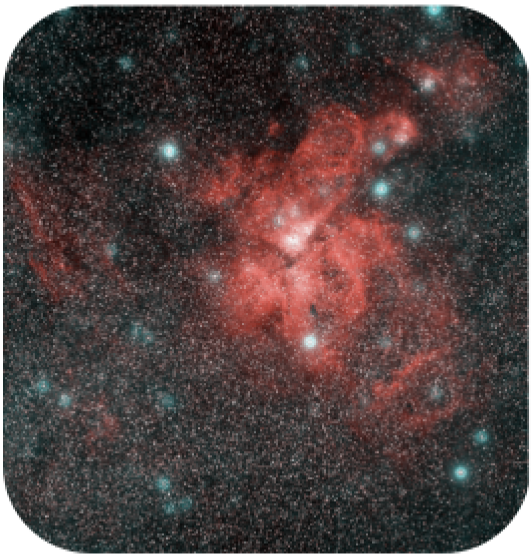


Figure 94: RGB Image of Carina Nebula

Follow the procedure in steps and images.

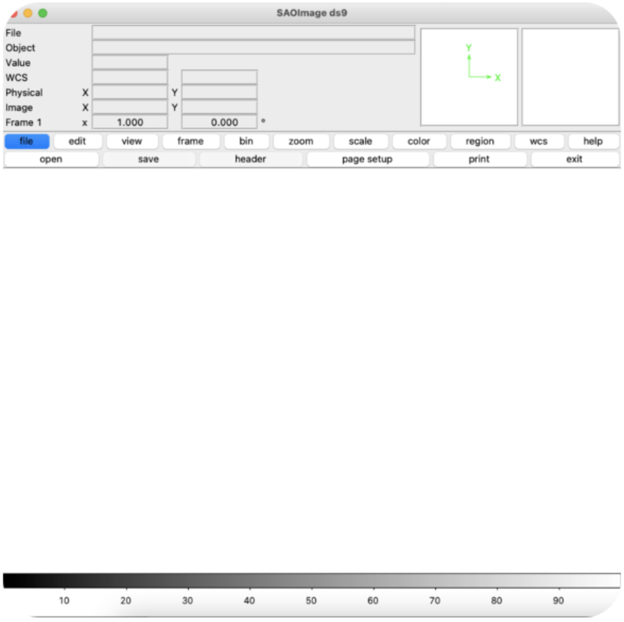
PROCEDURE IN INSTRUCTIONS:

Download the three files from this link named “dss-verywide-r.fits”, “dss-verywide-g.fits” and “dss-verywide-b.fits”.

1. Open SAOImage DS9.
2. Click on “Frame” → “New Frame RGB”.
3. A window called RGB will open, select the “Red” entry.
4. Click on “File” → “Open as” → “Mosaic WCS Segment”.
5. Upload the “dss-verywide-r.fits” by selecting it and clicking “Open”.
6. Click “Ok”.
7. You should an image like on step 7 on the image procedure below.
8. Click on “Zoom” → “Zoom fit” to obtain the whole image.
9. Next select “Frame” → “RGB” → “Green”.
10. Repeat Steps 5 and 6, loading the file called “dss-verywide-g.fits” file and you will obtain an image of the red and green images on top of each other.
11. Select “Frame” → “RGB” → “Blue”.
12. Repeat Step 11 and upload the file called “dss-verywide-b.fits”.

PROCEDURE IN IMAGES:

1.



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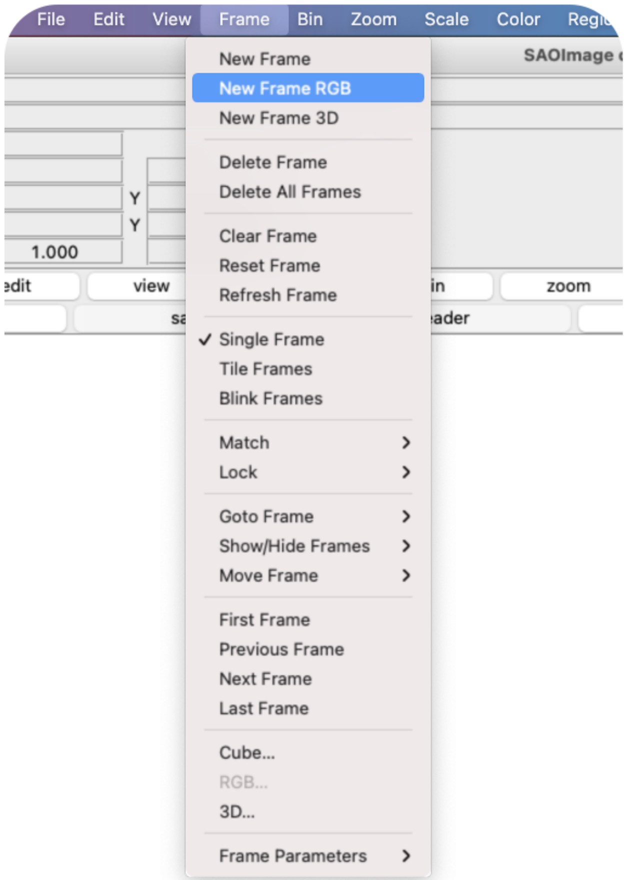
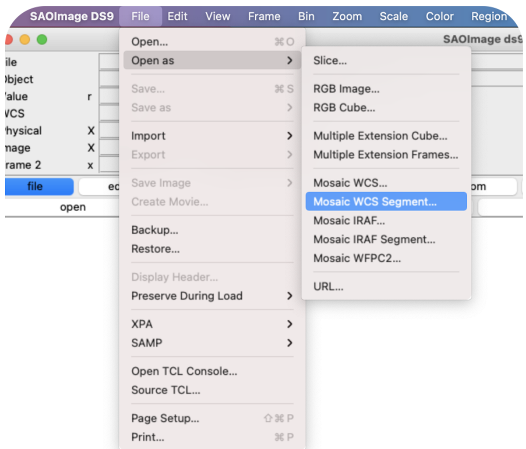
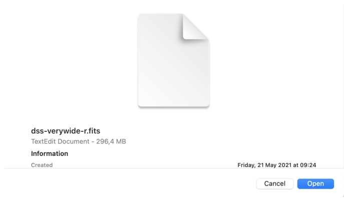


3.

4.



5.



dss-verywide-r.fits
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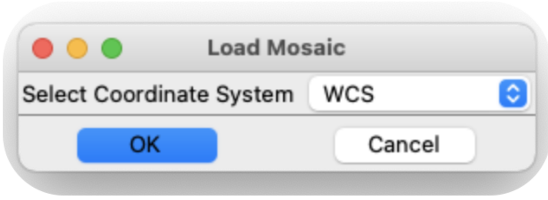
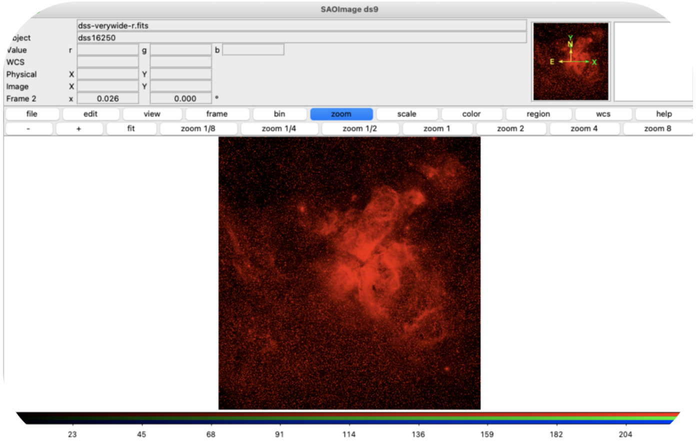
Information
Created
Friday, 21 May 2021 at 09:24
Cancel
Open

6.



Load Mosaic
Select Coordinate System
WCS
OK
Cancel

7.



SAOImage ds9
dss-verywide-r.fits
dss16250
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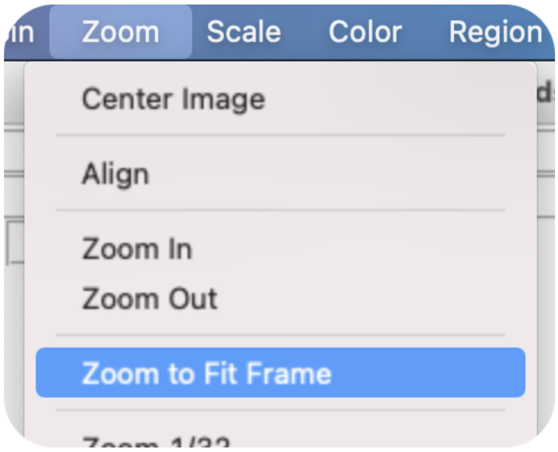
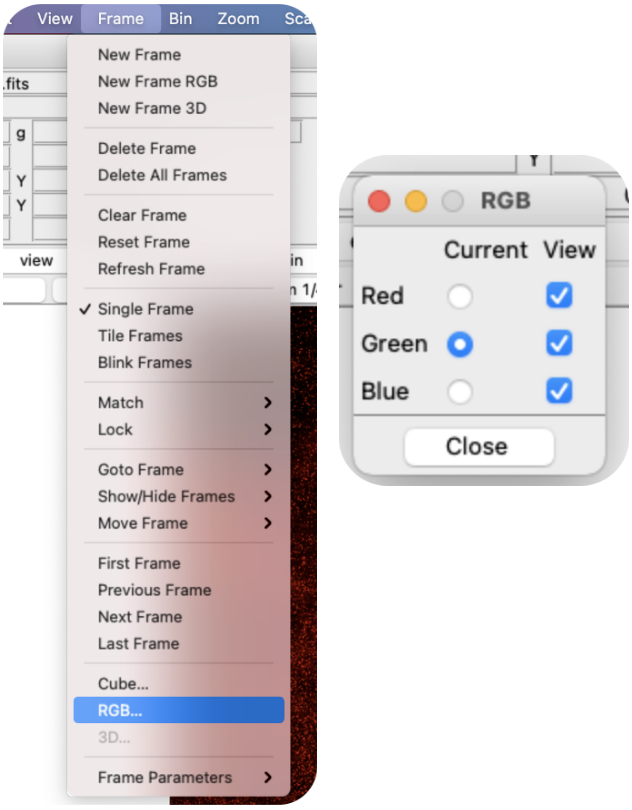
scale
color
region
wcs
help
fit
zoom 1/8
zoom 1/4
zoom 1/2
zoom 1
zoom 2
zoom 4
zoom 8
23
45
68
91
114
136
159
182
204

8.



Zoom
Scale
Color
Region
Center Image
Align
Zoom In
Zoom Out
Zoom to Fit Frame

9.

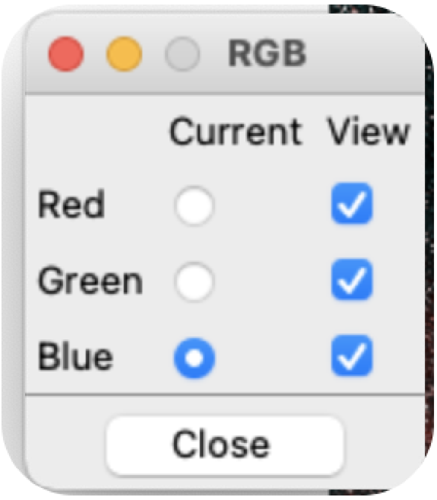


View
Frame
Bin
Zoom
New Frame
New Frame RGB
New Frame 3D
Delete Frame
Delete All Frames
Clear Frame
Reset Frame
Refresh Frame
Single Frame
Tile Frames
Blink Frames
Match
Lock
Goto Frame
Show/Hide Frames
Move Frame
First Frame
Previous Frame
Next Frame
Last Frame
Cube...
RGB...
3D...
Frame Parameters
RGB
Current
View
Red
Green
Blue
Close

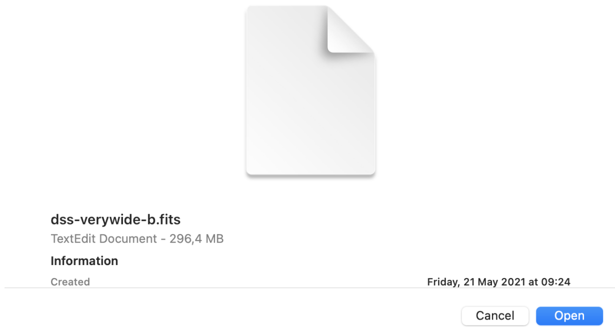
10.

Edit
View
Frame
Bin
Zoom
Scale
Color
Open...
Open as
Save...
Save as
Import
Export
Save Image
Create Movie...
Backup...
Restore...
Display Header...
Preserve During Load
XPA
SAMP
Open TCL Console...
Source TCL...
Page Setup...
Print...
Slice...
RGB Image...
RGB Cube...
Multiple Extension Cube...
Multiple Extension Frames...
Mosaic WCS...
Mosaic WCS Segment...
Mosaic IRAF...
Mosaic IRAF Segment...
Mosaic WFPC2...
URL...
dss-verywide-g.fits
TextEdit Document - 296,4 MB
Information
Created
Friday, 21 May 2021 at 09:24
Cancel
Open

11.



12.



1. Once you have obtained the RGB Image, from the coordinates for Trumpler 14, draw a circle where you think it is located… To help you with this, you can plot a coordinate grid by clicking on "Analysis" and "Coordinate Grid"
2. To check your results, plot a circle showing Trumpler 14 following these steps:
    1. Download the file called "Trumpler14.reg" onto your computer.
    2. Back in SAOImage DS9, click "Region" → "Load regions" and select the region for Trumpler 14 you have just downloaded and click "open"

Did you get Trumpler 14's location correct?

Activity 11.6: Inspection with DS9

Now that we have identified Trumpler 14, let's take a look at a few sources in that region.

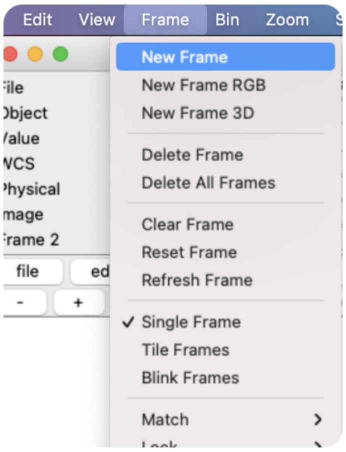
PROCEDURE IN INSTRUCTIONS:

1. Download the file "XMM2.vot" onto your computer. This is an example of a catalogue, which we will work with in Activity 12.
2. On DS9 click "Frame" → "New Frame".
3. We are now going to upload an image directly from SAOImage DS9 by clicking "Analysis" → "Image Servers" → "ESO-DSS I/II" or "DSS(ESO)" (depending on the version you have installed)
4. In the pop-up window write "Trumpler 14" for the Object entry and click "Retrieve".
5. Click "Zoom" → "Zoom Fit".
6. You will have probably obtained a black and white image. You can change the colour by clicking "colour" → "bb".
7. Go onto "Analysis" → "Catalog Tool", you will get a new pop-up window.
8. At the very top click "File" → "Load".
9. Select the file "XMM2.vot" you have downloaded and click "open". The file is a catalogue containing 20 sources, whose positions are shown as green circles.

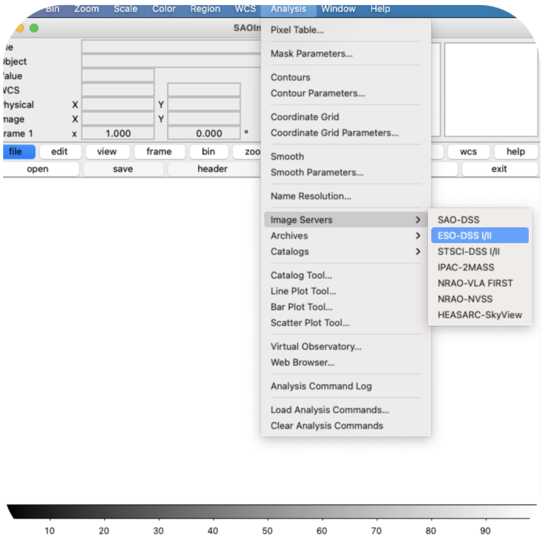
PROCEDURE IN IMAGES:

1.

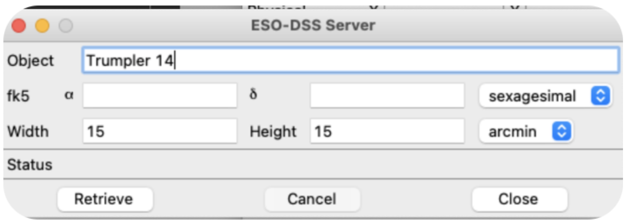
2.



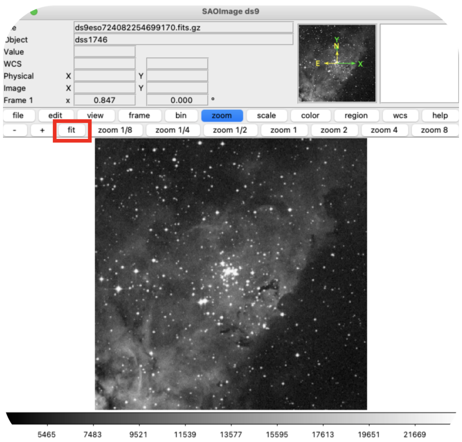
3.



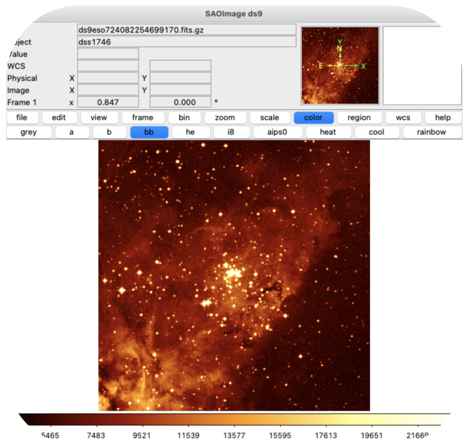
4.



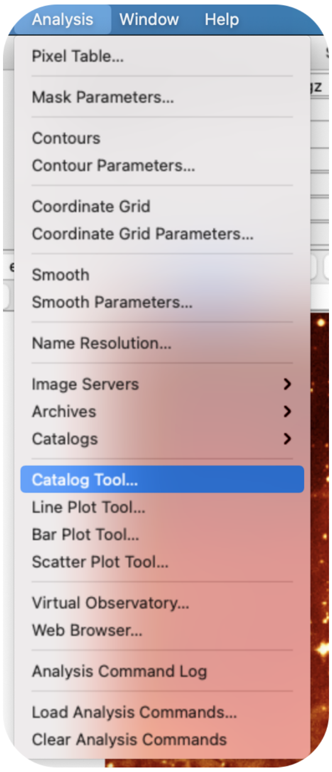
5.



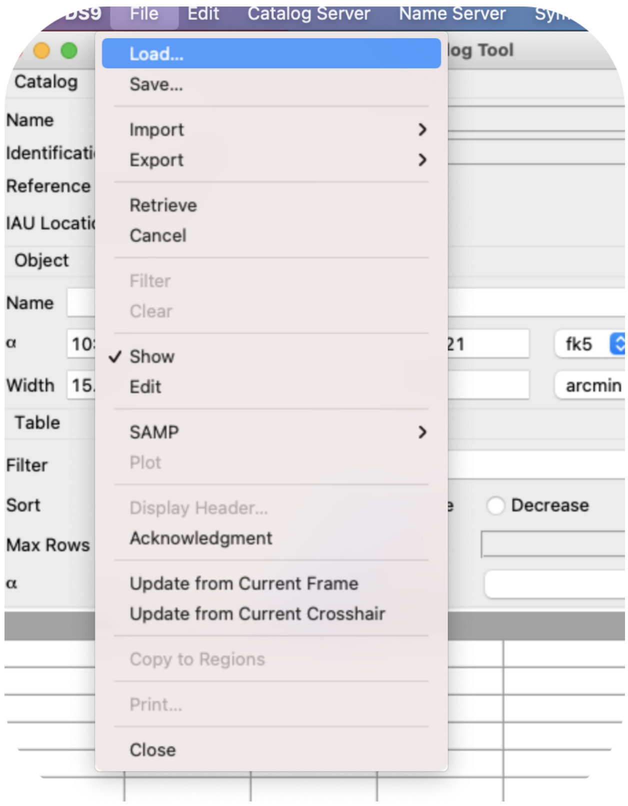
6.



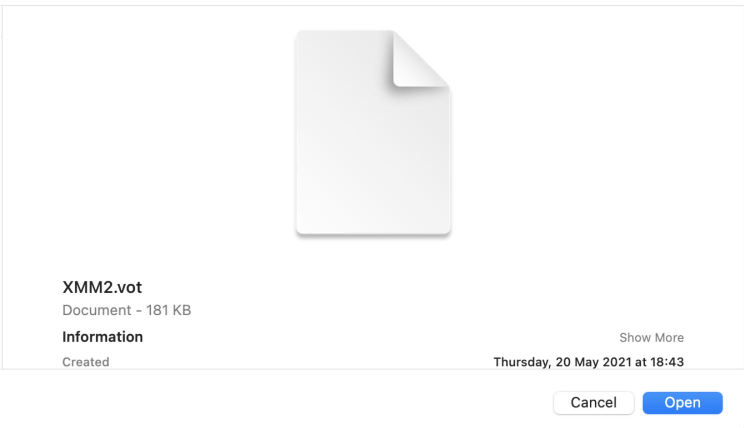
7.


Analysis
Window
Help
Pixel Table...
Mask Parameters...
Contours
Contour Parameters...
Coordinate Grid
Coordinate Grid Parameters...
Smooth
Smooth Parameters...
Name Resolution...
Image Servers
Archives
Catalogs
Catalog Tool...
Line Plot Tool...
Bar Plot Tool...
Scatter Plot Tool...
Virtual Observatory...
Web Browser...
Analysis Command Log
Load Analysis Commands...
Clear Analysis Commands

8.


File
Edit
Catalog Server
Name Server
Load...
Save...
Import
Export
Retrieve
Cancel
Filter
Clear
Show
Edit
SAMP
Plot
Display Header...
Acknowledgment
Update from Current Frame
Update from Current Crosshair
Copy to Regions
Print...
Close
Catalog
Name
Reference
Object
Name
Width
Table
Filter
Sort
Max Rows
fk5
arcmin
Decrease

9.


XMM2.vot
Document - 181 KB
Information
Show More
Created
Thursday, 20 May 2021 at 18:43
Cancel
Open

Answer the following questions:

1. Can you identify the source that is best centred? Write down the coordinates of this source. You can read off the RA and DEC in the fk5 entry displayed on the screen on SAOImage DS9.

2. The coordinates are in hh:mm:ss and degrees, arc minutes, arcseconds. Convert these into degrees. Review Activity 2.1 to remind yourself on how to do this:

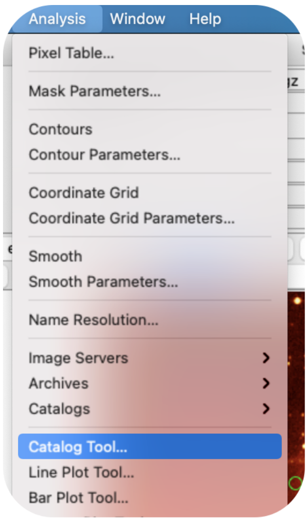
3. Once you know the position of source X, the next information we want is it's catalogue name. To find this, follow the procedure instructions and images:

PROCEDURE IN INSTRUCTIONS:

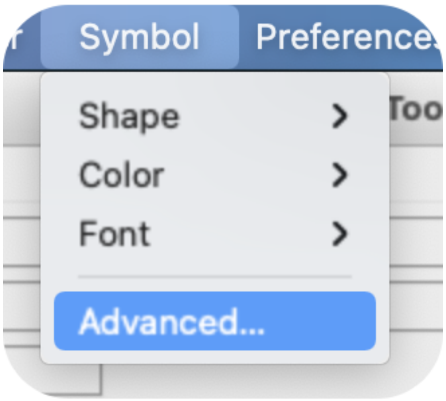
1. Open the "Catalog tool" on SAOIMage DS9, which you obtained when you uploaded the "XMM2.vot" catalogue.
2. Click on "Symbol" → "advanced".
3. In the "Text" entry, write the name of the column containing the sources' names: $iauname (this is the name of the source given by the IAU, International Astronomical Union).
4. You should now see the names plotted over your sources. Zoom in onto the well-centred source you found and write down its name next to the coordinates you found.

PROCEDURE IN IMAGES:

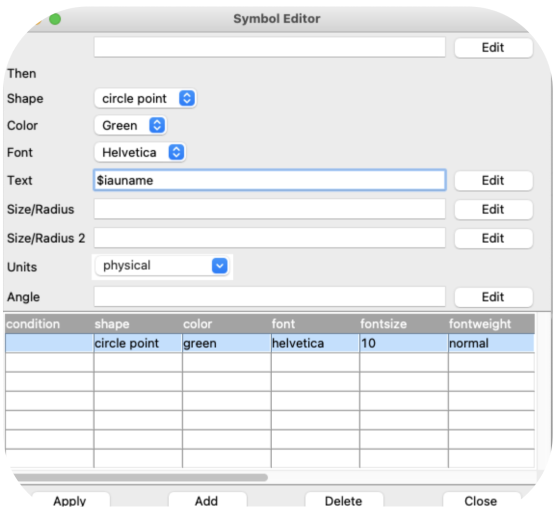
1.



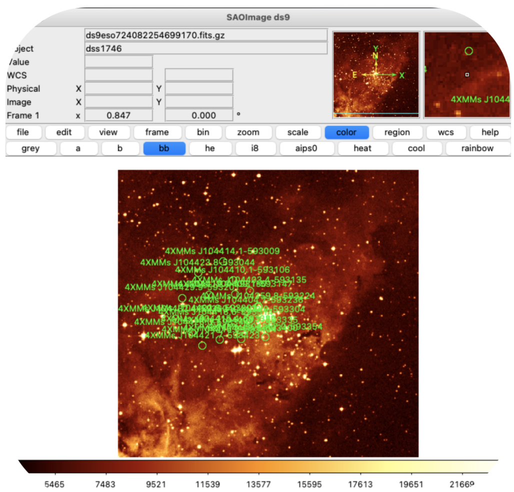
2.



3.



4.



Name of the source:

Activity 12: Handling catalogues

We will now download astronomical catalogues from ESASky, to look for classical T Tauri stars. These catalogues are: XMM-Newton, 2MASS and GAIA. We will also use VST data from the ESO Archive.

Activity 12.1: Downloading catalogues from ESASky

Follow these steps to download the 2MASS catalogue:

PROCEDURE IN INSTRUCTIONS:

1. Click on this link to enter ESASky: https://sky.esa.int
2. Select the science mode
3. On the right-hand corner you will see a search bar
4. Introduce the name "Trumpler 14" as shown in the Step 4 of "Procedure in Images"
5. Zoom out by clicking on the '-' symbol 5 times
6. Once Trumpler 14 is located, move your mouse to the left-hand side of the screen and click the filters icon
7. Select the "Optical" option and "DSS2 colour" filter
8. You should now see an optical image of the Carina Nebula with the cross indicating the position of Trumpler 14. (Note: If you move the image around, the cross will be displaced too and you will have to conduct the search again)
9. Zoom in again by clicking the '+' sign 2 times
10. The next step is to explore the catalogue data available for this region by clicking on the icon for catalogues, shaped as an ellipse. You should then get all the available catalogues displayed
11. Click the 2MASS square

12. An empty tab should open and the background will be displayed as a grid of yellow lines

13. Click on the square with the cross in it, and click “load data”

14. The data you have just loaded will appear in a new tab and the position of the sources are shown on the image.

15. Drag the tabs down, for better visibility of the image

16. Select the grid on the left of the one you have just selected. Once again click on “load data”. A new tab will appear.

17. You should now have both squares containing the sources found by 2MASS and two extra tabs with the corresponding catalogues. You should have 918 rows in the first catalogue and 706 in the second one. Each row corresponds to a source. You can check this on the bottom, right-hand corner

18. Click on the first catalogue, select all the sources by ticking the first column, as shown in image 18

19. Click on the download icon

20. Click on VOTable, the catalogue will start downloading onto your computer. Do not close ESASky

21. Repeat steps 18-20 with the second catalogue

22. Repeat step 13-20 for the two upper and lower squares

23. On your downloads folder you will get all the files

24. Rename the files, give them significant names such as “2MASS1”, “2MASS2”, etc. and make sure to check the ending of the file from “.vot” to “.fits”. You are now ready to work with the 2MASS catalogues on TopCat.

25. Downloading the XMM catalogue is very similar. From where you left ESASky, click again on the catalogues icon to get the available catalogues displayed.

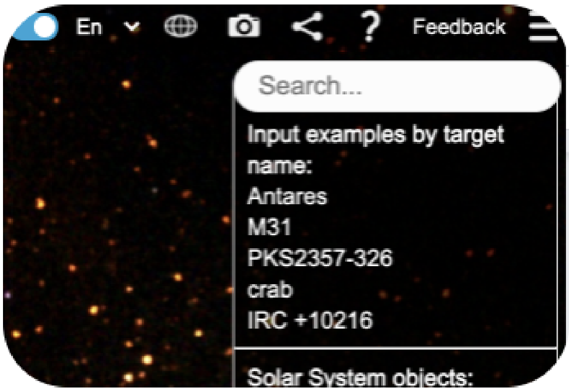
26. Select the 4XMM-DR10 catalogue.

27. Again, you will get the sources detected by XMM shown in purple squares this time. Click on the downloading button again and download the table as a VOTable. Once the file is downloaded onto your computer, rename it as “XMM” and change the ending to .fits so that your file is called “XMM.fits”.

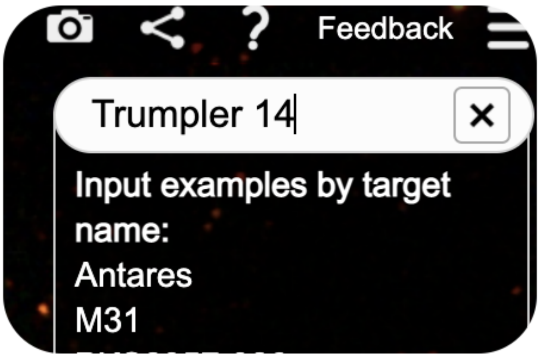
PROCEDURE IN IMAGES:

2.

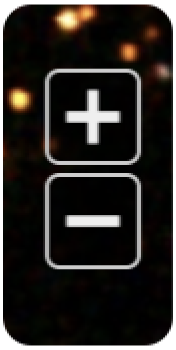
3.



4.



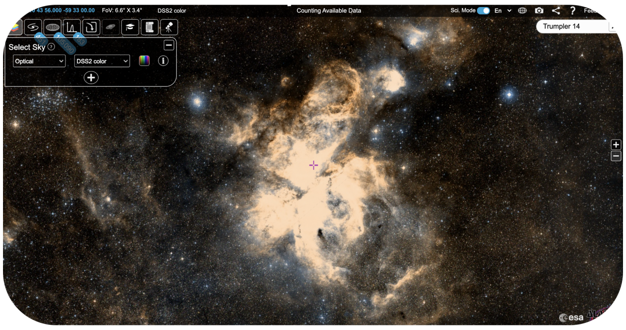
5.



6.

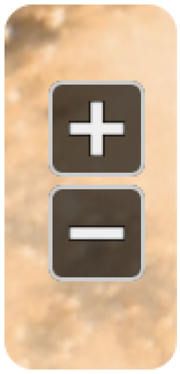
7.

8.

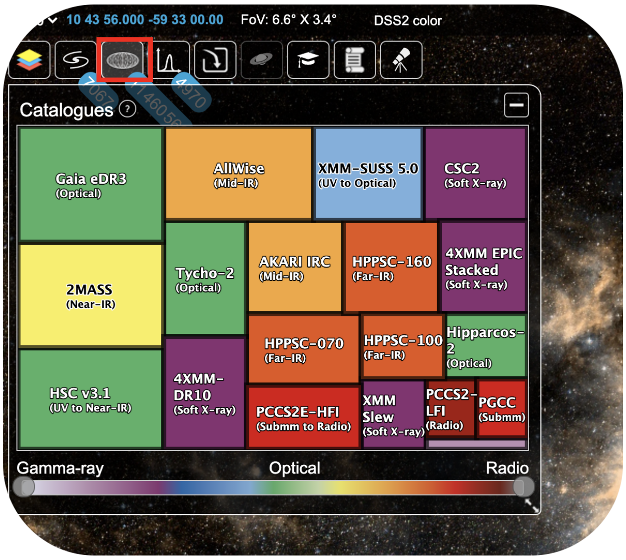


DSS2 color
Counting Available Data
Trumpler 14
Select Sky
Optical
DSS2 color

9.

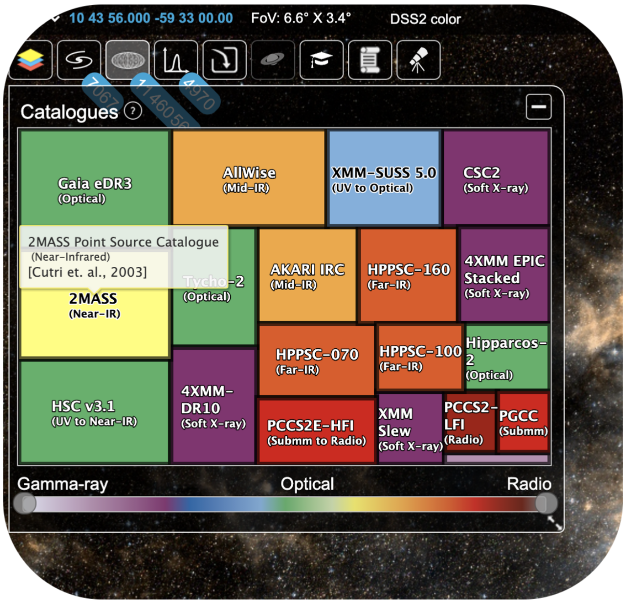


10.



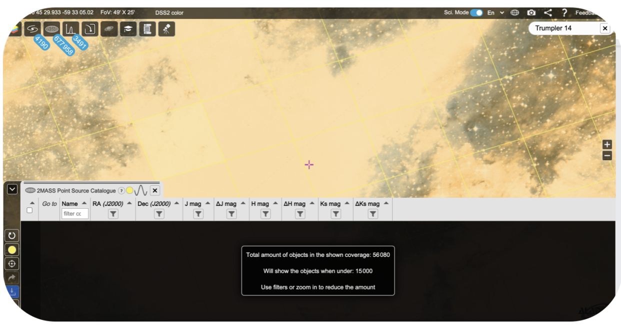
10 43 56.000 -59 33 00.00
FoV: 6.6° X 3.4°
DSS2 color
Catalogues
Gaia eDR3 (Optical)
AllWise (Mid-IR)
XMM-SUSS 5.0 (UV to Optical)
CSC2 (Soft X-ray)
2MASS (Near-IR)
Tycho-2 (Optical)
AKARI IRC (Mid-IR)
HPPSC-160 (Far-IR)
4XMM EPIC Stacked (Soft X-ray)
HPPSC-070 (Far-IR)
HPPSC-100 (Far-IR)
Hipparcos-2 (Optical)
HSC v3.1 (UV to Near-IR)
4XMM-DR10 (Soft X-ray)
PCCS2E-HFI (Submm to Radio)
XMM Slew (Soft X-ray)
PCCS2-LFI (Radio)
PGCC (Submm)
Gamma-ray
Optical
Radio

11.



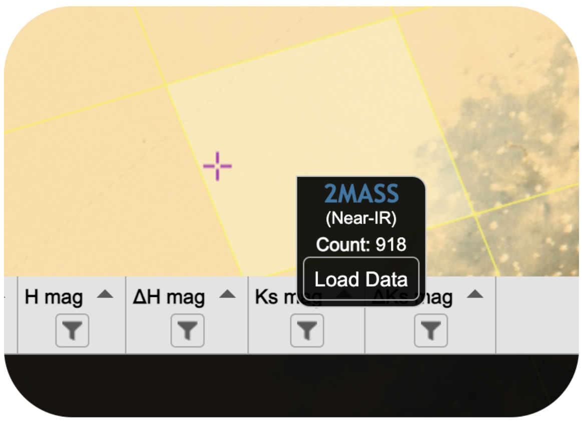
10 43 56.000 -59 33 00.00
FoV: 6.6° X 3.4°
DSS2 color
Catalogues
Gaia eDR3 (Optical)
AllWise (Mid-IR)
XMM-SUSS 5.0 (UV to Optical)
CSC2 (Soft X-ray)
2MASS Point Source Catalogue
(Near-Infrared)
[Cutri et. al., 2003]
2MASS (Near-IR)
Tycho-2 (Optical)
AKARI IRC (Mid-IR)
HPPSC-160 (Far-IR)
4XMM EPIC Stacked (Soft X-ray)
HPPSC-070 (Far-IR)
HPPSC-100 (Far-IR)
Hipparcos-2 (Optical)
HSC v3.1 (UV to Near-IR)
4XMM-DR10 (Soft X-ray)
PCCS2E-HFI (Submm to Radio)
XMM Slew (Soft X-ray)
PCCS2-LFI (Radio)
PGCC (Submm)
Gamma-ray
Optical
Radio

12.



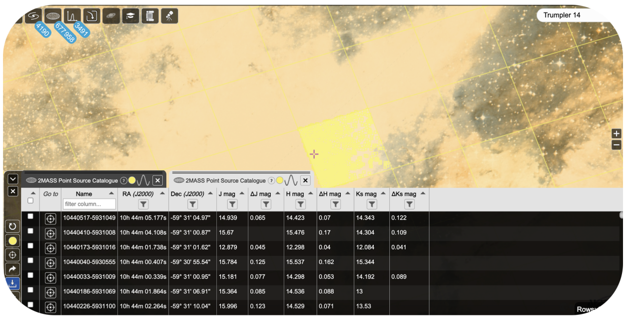
DSS2 color
Trumpler 14
2MASS Point Source Catalogue

13.

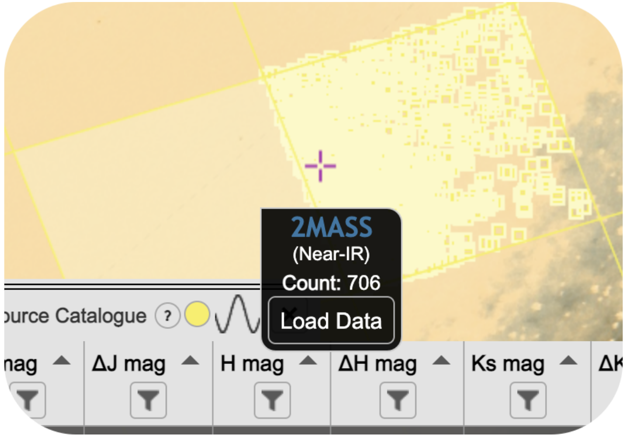


2MASS
(Near-IR)
Count: 918
Load Data
H mag
ΔH mag

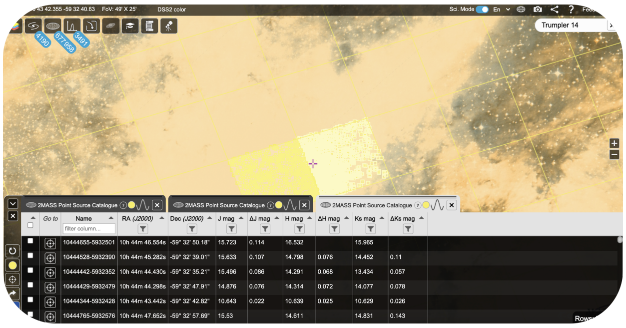
14.



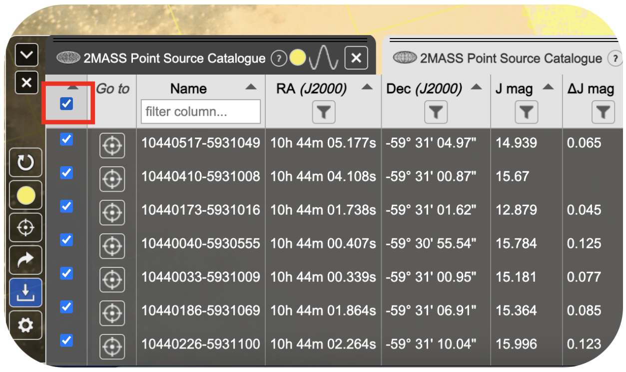
16.



17.



18.

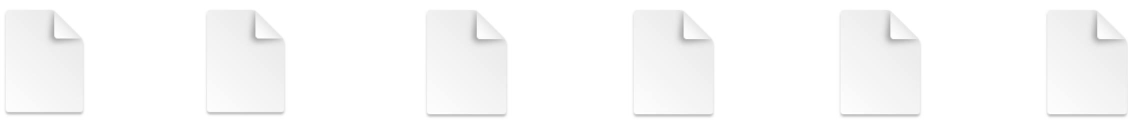


19.

20.

22.

24.

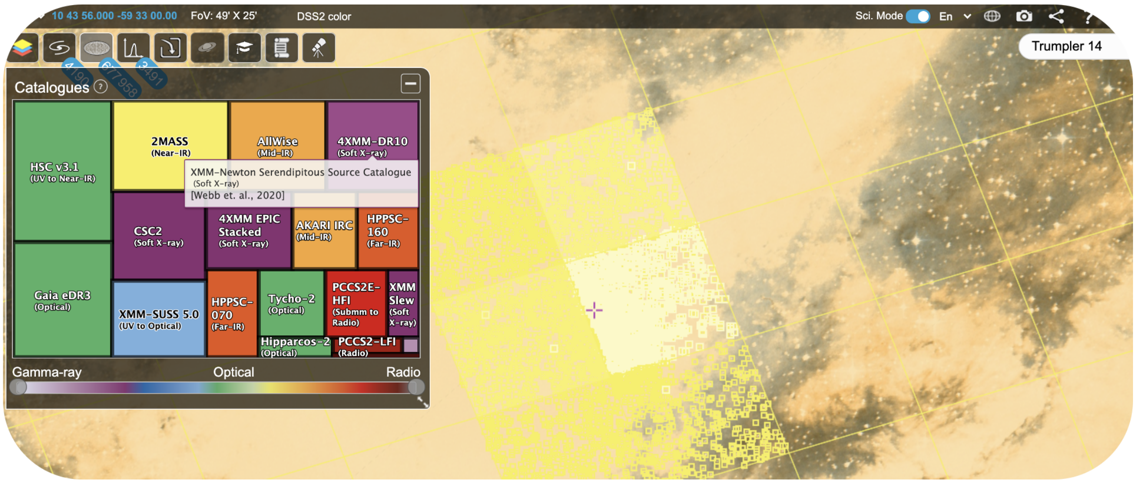


2MASS1.fits 2MASS2.fits 2MASS3.fits 2MASS4.fits 2MASS5.fits 2MASS6.fits

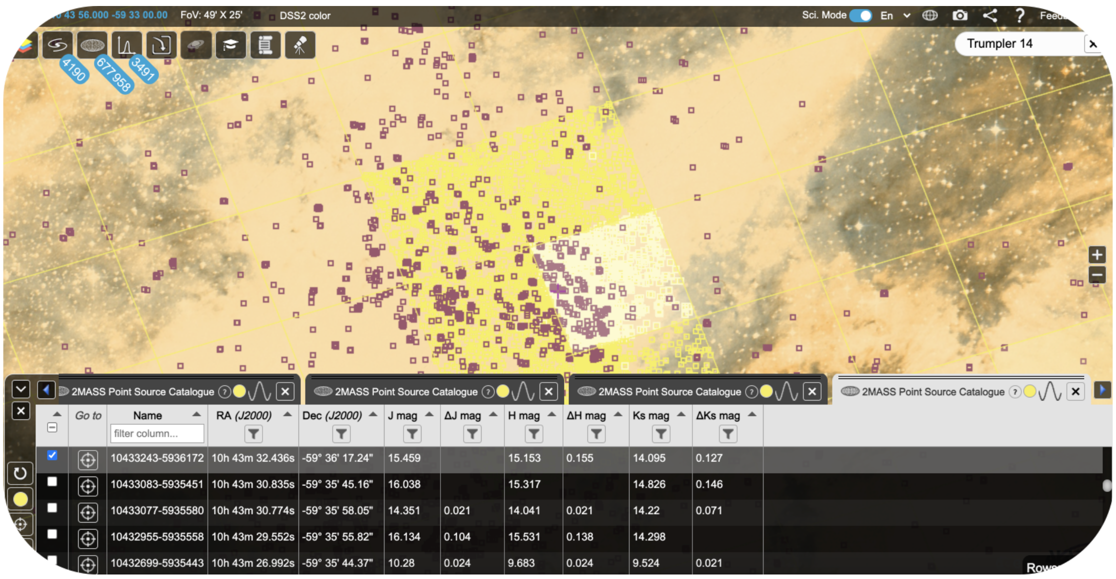
25.


10 43 56.000 -59 33 00.00
FoV: 49' X 25'
DSS2 color
Catalogues
HSC v3.1 (UV to Near-IR)
2MASS (Near-IR)
AllWise (Mid-IR)
4XMM-DR10 (Soft X-ray)
CSC2 (Soft X-ray)
4XMM EPIC Stacked (Soft X-ray)
AKARI IRC (Mid-IR)
HPPSC-160 (Far-IR)
Gaia eDR3 (Optical)
XMM-SUSS 5.0 (UV to Optical)
HPPSC-070 (Far-IR)
Tycho-2 (Optical)
PCCS2E-HFI (Submm to Radio)
XMM Slew (Soft X-ray)
Hipparcos-2 (Optical)
PCCS2-LFI (Radio)
Gamma-ray
Optical
Radio

26.


10 43 56.000 -59 33 00.00
FoV: 49' X 25'
DSS2 color
Sci. Mode
En
Trumpler 14
Catalogues
XMM-Newton Serendipitous Source Catalogue (Soft X-ray) [Webb et. al., 2020]
Gamma-ray
Optical
Radio

27.


FoV: 49' X 25'
DSS2 color
Sci. Mode
En
Trumpler 14
2MASS Point Source Catalogue
Go to
Name
RA (J2000)
Dec (J2000)
J mag
ΔJ mag
H mag
ΔH mag
Ks mag
ΔKs mag
filter column...
10433243-5936172 10h 43m 32.436s -59° 36' 17.24" 15.459 15.153 0.155 14.095 0.127
10433083-5935451 10h 43m 30.835s -59° 35' 45.16" 16.038 15.317 14.826 0.146
10433077-5935580 10h 43m 30.774s -59° 35' 58.05" 14.351 0.021 14.041 0.021 14.22 0.071
10432955-5935558 10h 43m 29.552s -59° 35' 55.82" 16.134 0.104 15.531 0.138 14.298
10432699-5935443 10h 43m 26.992s -59° 35' 44.37" 10.28 0.024 9.683 0.024 9.524 0.021

Activity 12.2: Handling catalogues in TopCat

Use the result obtained in Activity 12.1. If you have not completed this Activity, use the file in the link.

Activity 12.2.1: Download TopCat

1. Access the TopCat web: star.bris.ac.uk/~mb/topcat
2. Chose the "Standalone-Full.tar" version and download it onto your computer

TopCat is a program used to analyse and manipulate catalogues and is used in astronomy due to its power in handling very large datasets

Activity 12.2.2: Concatenating tables

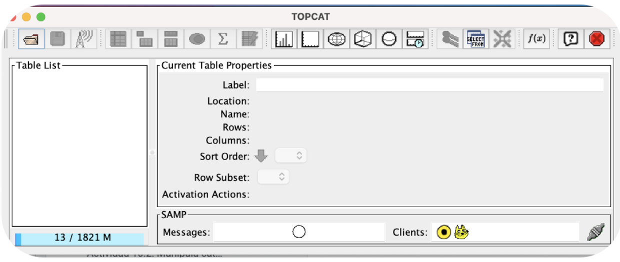
We have downloaded **six** 2MASS tables, which we want to later treat as a single catalogue. In TopCat you can concatenate tables together. Follow these steps to concatenate your 2MASS catalogues:

PROCEDURE IN INSTRUCTIONS:

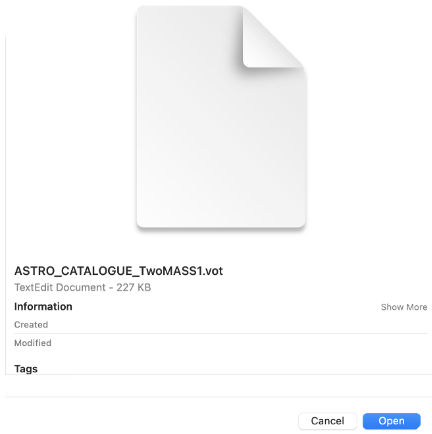
1. Launch TopCat
2. Click on the folder symbol and then on "System Browser". Select all the files and click on "Open".
3. Once you have the catalogues on TopCat click on "Joins" → "Concatenate Tables"
4. For the "Base Table" select the first catalogue "2MASS1.fits" and for the "Appended Table" use the second catalogue, "2MASS2.fits"
5. Click on "Concatenate". The joint table will save onto TopCat under the name "concat(1+2)"
6. Repeat the concatenation between the new table "concat(1+2)" and the third 2MASS catalogue, "2MASS3.fits".
7. Repeat this process, always concatenating the last table you produce with the next 2MASS catalogue. You will finally get a final catalogue with 4420 sources.
8. Save the final catalogue as "2MASStotal.fits"

PROCEDURE IN IMAGES:

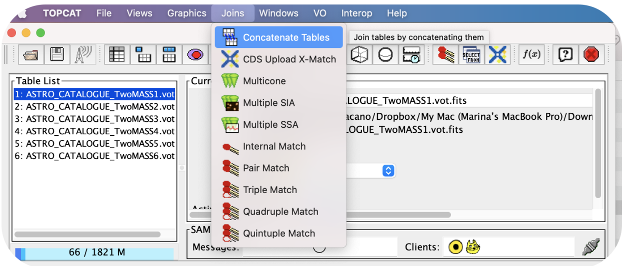
1.



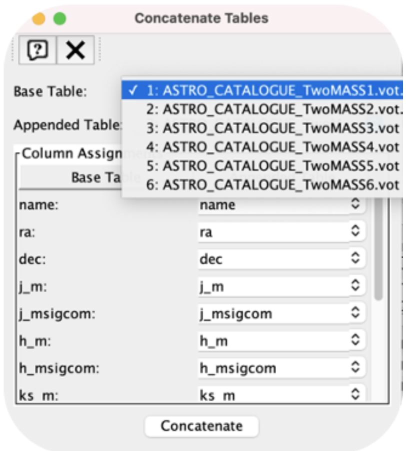
2.

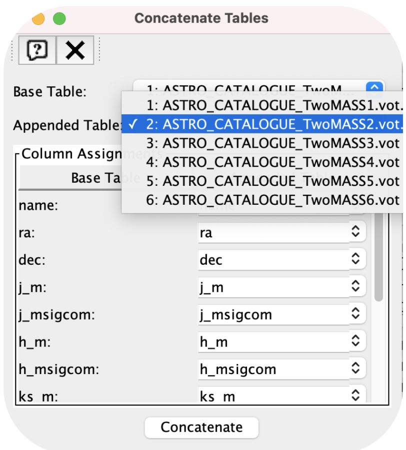


3.

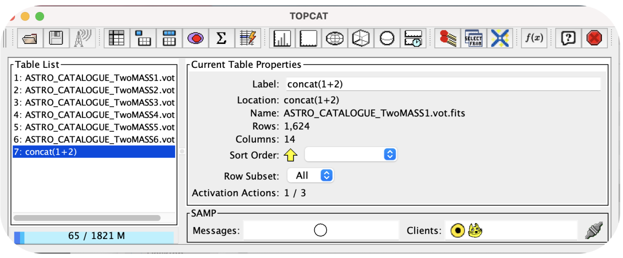


4.

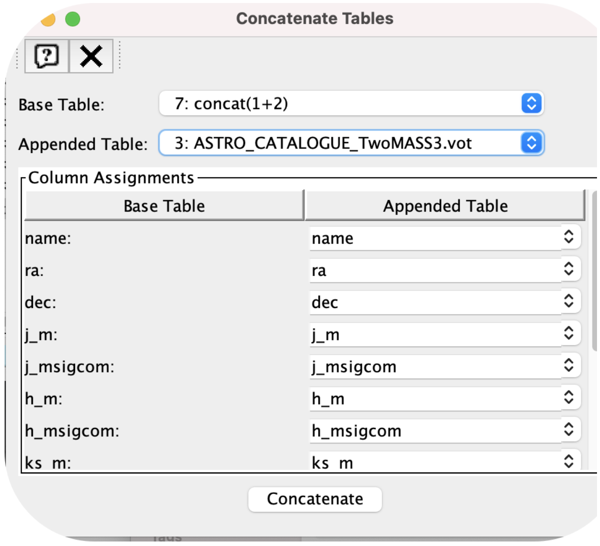




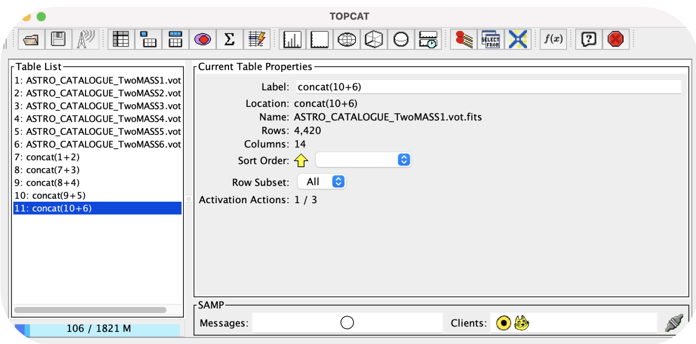
5.


TOPCAT
Table List
1: ASTRO_CATALOGUE_TwoMASS1.vot
2: ASTRO_CATALOGUE_TwoMASS2.vot
3: ASTRO_CATALOGUE_TwoMASS3.vot
4: ASTRO_CATALOGUE_TwoMASS4.vot
5: ASTRO_CATALOGUE_TwoMASS5.vot
6: ASTRO_CATALOGUE_TwoMASS6.vot
7: concat(1+2)
Current Table Properties
Label: concat(1+2)
Location: concat(1+2)
Name: ASTRO_CATALOGUE_TwoMASS1.vot.fits
Rows: 1,624
Columns: 14
Sort Order:
Row Subset: All
Activation Actions: 1 / 3
SAMP
Messages:
Clients:
65 / 1821 M

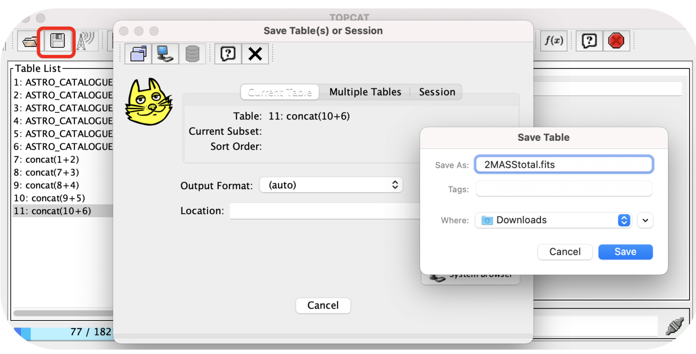
6.


Concatenate Tables
Base Table: 7: concat(1+2)
Appended Table: 3: ASTRO_CATALOGUE_TwoMASS3.vot
Column Assignments
Base Table
Appended Table
name: name
ra: ra
dec: dec
j_m: j_m
j_msigcom: j_msigcom
h_m: h_m
h_msigcom: h_msigcom
ks_m: ks_m
Concatenate

7.


TOPCAT
Table List
1: ASTRO_CATALOGUE_TwoMASS1.vot
2: ASTRO_CATALOGUE_TwoMASS2.vot
3: ASTRO_CATALOGUE_TwoMASS3.vot
4: ASTRO_CATALOGUE_TwoMASS4.vot
5: ASTRO_CATALOGUE_TwoMASS5.vot
6: ASTRO_CATALOGUE_TwoMASS6.vot
7: concat(1+2)
8: concat(7+3)
9: concat(8+4)
10: concat(9+5)
11: concat(10+6)
Current Table Properties
Label: concat(10+6)
Location: concat(10+6)
Name: ASTRO_CATALOGUE_TwoMASS1.vot.fits
Rows: 4,420
Columns: 14
Sort Order:
Row Subset: All
Activation Actions: 1 / 3
SAMP
Messages:
Clients:
106 / 1821 M

8.


TOPCAT
Save Table(s) or Session
Table List
1: ASTRO_CATALOGUE
2: ASTRO_CATALOGUE
3: ASTRO_CATALOGUE
4: ASTRO_CATALOGUE
5: ASTRO_CATALOGUE
6: ASTRO_CATALOGUE
7: concat(1+2)
8: concat(7+3)
9: concat(8+4)
10: concat(9+5)
11: concat(10+6)
Multiple Tables
Session
Table: 11: concat(10+6)
Current Subset:
Sort Order:
Output Format: (auto)
Location:
Cancel
Save Table
Save As: 2MASStotal.fits
Tags:
Where: Downloads
Cancel
Save
77 / 182

Activity 12.3: Selecting classical T Tauri stars in Trumpler 14

The first selection of our possible classical T Tauri stars will entail checking whether they are in the main phase of accretion. As we know, these objects emit Halpha emission, hence we will use the VST catalogue.

The VST catalogue for the Trumpler 14 region contains 30964 sources, but not all contain magnitude values. Download the catalog named “VST_initial” from this link and open it on Google Sheet. You will obtain a table with the objects and their data in columns.

Each object will contain the following information in the columns:

- IAUNAME: name assigned to the source by the international Astronomical Union (IAU), using the vphas+coordinates nomenclature
- RA2000: Right ascension in units J2000
- DEC2000: Declination in units J2000
- UAPERMAG3: magnitude in u filter
- UAPERMAG3ERR: error in the magnitude measurement in u filter
- UCLASS: classification of the object, in terms of its morphology in the u band, see classification on Table 7
- GAPERMAG3: magnitude in g filter
- GAPERMAG3ERR: error in the magnitude measurement in g filter
- GCLASS: classification of the object, in terms of its morphology in the g band, see classification on Table 7
- RAPERMAG3: magnitude in r filter
- RAPERMAG3ERR: error in the magnitude measurement in r filter
- RCLASS: classification of the object, in terms of its morphology in the r band, see classification on Table 7
- R2APERMAG3: magnitude in the second r filter

- R2APERMAG3ERR: error in the magnitude measurement in second r filter
- R2CLASS: classification of the object, in terms of its morphology in the second r band, see classification on Table 7
- IAPERMAG3: magnitude in i filter
- IAPERMAG3ERR: error in the magnitude measurement in i filter
- ICLASS: classification of the object, in terms of its morphology in the i band, see classification on Table 7
- HAVPHASAPERMAG3: magnitude in Halpha filter
- HAVPHASAPERMAG33ERR: error in the magnitude measurement in Halpha filter
- HAVPHASCLASS: classification of the object, in terms of its morphology in the Halpha band, see classification on Table 7

Every time a measurement is taken in science, it has a margin of error.

Table 7 shows the decoding of the VST catalog classes. The columns containing the "classes" can have the following values. Depending on the value, the object in question is probably a star, a galaxy or just noise

CLASS VALUE	OBJECT CLASSIFIED AS...
0	noise
1	galaxy
-1	star
-2	probably a star
-3	probably a galaxy
-9	saturated

Table 7: *Classes in the VST catalog*

If you were to get a UCLASS = 0 for a source, then that means that source has been classified by previous studies as being noise (i.e. not interesting for us).

As described in [Activity 11.5], the measurements recorded on this catalogue are taken by CCDs which are photon detectors. Each photon arriving at the CCD generates an electron which is registered as an "event". CCDs are divided into small squares (known as pixels), sensitive to light. "UAVERAGECONF" or "GAVERAGECONF" describes the probability that a pixel has detected incoming light correctly and the measurement can be trusted.

Activity 12.3.1: Selection criteria

For our first selection of classical T Tauri stars we will select the sources which meet these requirements:

- ✔ Magnitudes r (RAPERMAG3) and r2 (R2APERMAG3) (magnitudes with both r filters) > 13.0 mag. This way we prevent any excessively bright objects from saturating the detector.
- ✔ the error < 0.1 mag in bands g (GAPERMAG3ERR), r (RAPERMAG3ERR), r2 (R2APERMAG3ERR), i (IAPERMAG3ERR) and Halpha (HAVPHASAPERMAG3ERR)
- ✔ classified as como *stars* in bands g and i (GCLASS = ICLASS = -1)
- ✔ classified as *stars* or *probably stars* in bands r and r2 (RCLASS and R2CLASS with values -1 or -2)
- ✔ classified as *stars, probably stars* or *galaxies* in bands Halpha and u (HAVPHASCLASS and UCLASS equal to values 1, -1 or -2)
- ✔ pixel confidence > 90.0 in u, g, r, r2, i (UAVERAGECONF, GAVERAGECONF, RAVERAGECONF, R2AVERAGECONF, iAVERAGECONF > 90.0%)
- ✔ pixel confidence > 95.0 in band Halpha (HAVPHASAVERAGECONF > 95.0%)

Activity 12.3.1.1: Using Google Sheets

(Link to video tutorial)

Copy the VST catalogue into Google Sheets. Go through each of the columns in the list above and filter out the sources that do not meet the criteria stated. To do so, follow the procedure in instructions or images.

PROCEDURE IN INSTRUCTIONS:

1. Open the “VST_initial.csv” file in Google Sheet
2. Select the first row containing the names of each column
3. Click on the menu on “View” → “Freeze” → “1 row”
4. Search the column “RAPERMAG3· and select it completely by right clicking on the letter assigned to that column, in this case it should be the letter Q
5. Select the option “Sort sheet A → Z”. This will sort the column in ascending order. You will see many of the values are below 13.0. These are the ones we will be getting rid of
6. Click on the upper left corner of the table to select it completely. The whole table will be highlighted
7. Click on the filtering icon. The table will appear green and a filtering symbol will appear next to each column’s name
8. To do the filtering, click on this symbol for the specific column you are interested in. For instance, let's filter the column “R2APERMAG3”. We want values to be above 13.0
    8.1. Click on the filtering symbol for column “R2APERMAG3”
    8.2. In the drop-down menu select the option “Filter by condition”
    8.3. Select the option “Greater than” → write 13.0 → click on “OK”
    8.4. Repeat steps 8.1 to 8.3 for the rest of the selection criteria, taking into account whether the criteria requires the “Greater than” or “Less than” option

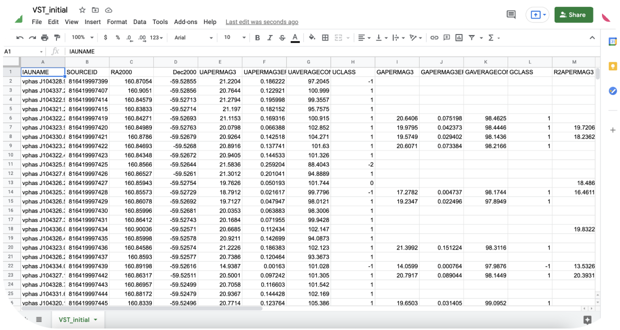
8.5. For the criteria on “classes” seen on Table 8, click on the filtering symbol of a column

8.5.1. Select the option “Filter by values”

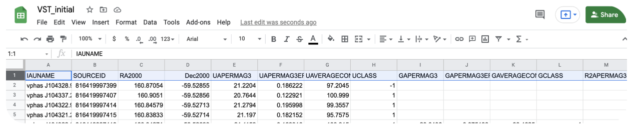
8.5.2. Select only those values you wish to maintain

PROCEDURE IN IMAGES:

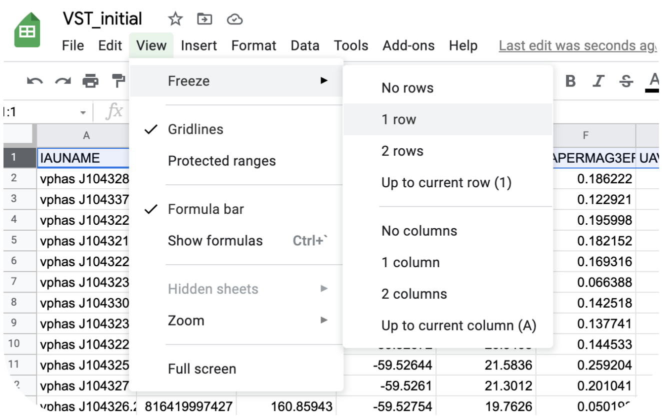
1.



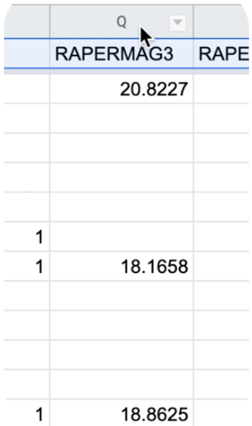
2.



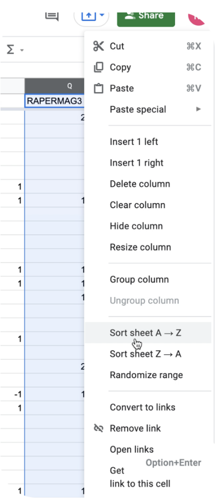
3.



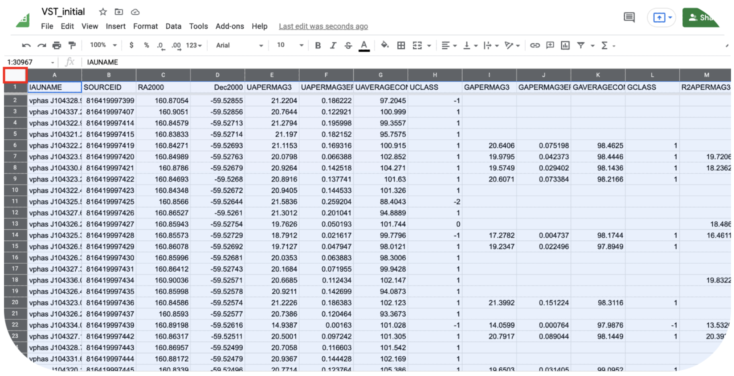
4.



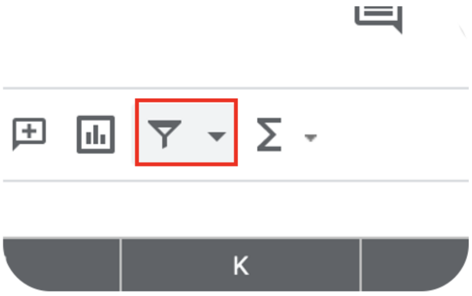
5.



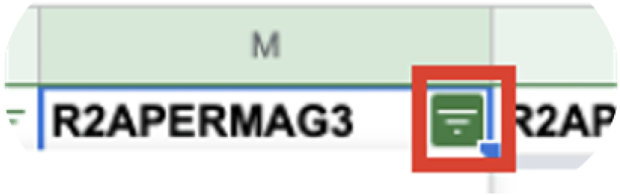
6.



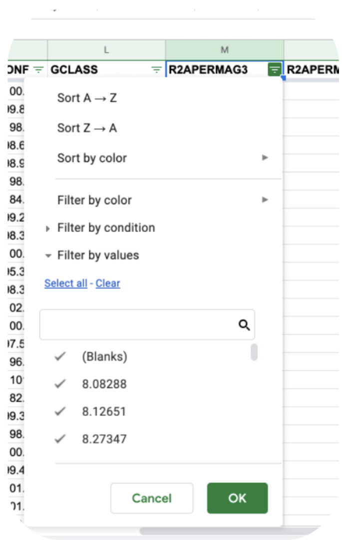
7.


K

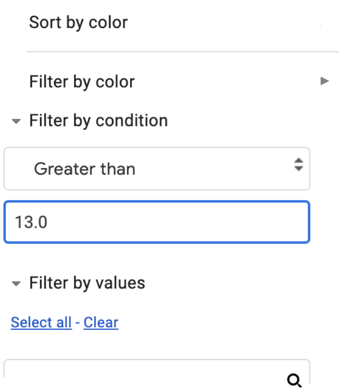
8.1.


M
R2APERMAG3

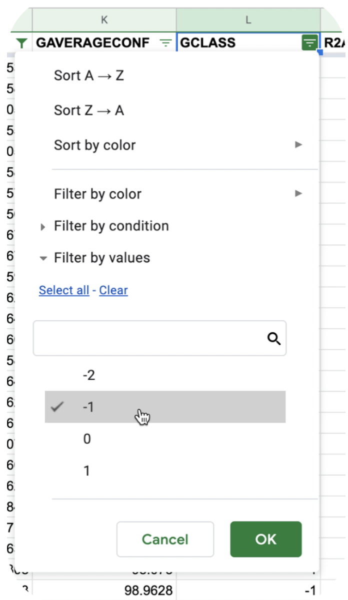
8.2.


GCLASS
R2APERMAG3
Sort A → Z
Sort Z → A
Sort by color
Filter by color
Filter by condition
Filter by values
Select all - Clear
(Blanks)
8.08288
8.12651
8.27347
Cancel
OK

8.3.


Sort by color
Filter by color
Filter by condition
Greater than
13.0
Filter by values
Select all - Clear

8.5.1


K
L
GAVERAGECONF
GCLASS
Sort A → Z
Sort Z → A
Sort by color
Filter by color
Filter by condition
Filter by values
Select all - Clear
-2
-1
0
1
Cancel
OK
98.9628

Activity 12.3.1.2: Using Excel

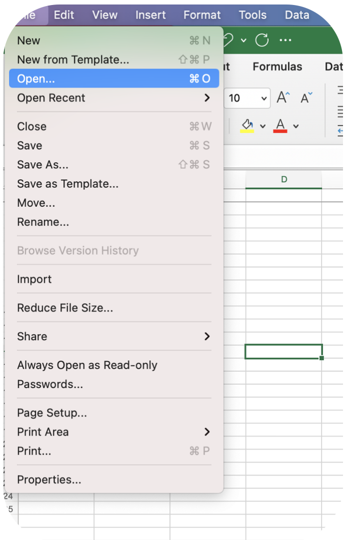
(Link to video tutorial)

PROCEDURE IN INSTRUCTIONS:

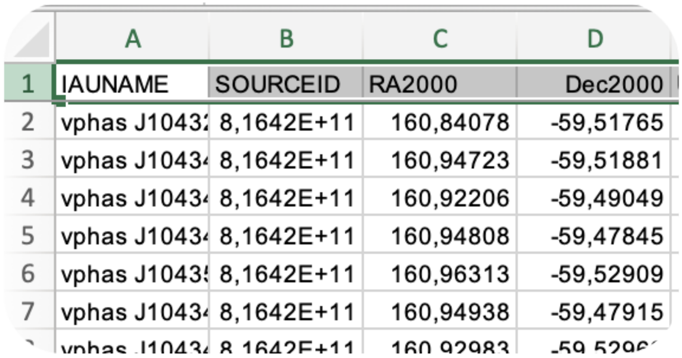
1. Download the VST_initial file onto your computer
2. Open the file in Excel by clicking on Open → selecting your file → open. You will obtain the complete table
3. Select the first row with the names of the columns
4. Click on “View” → ”Freeze Top Row”
5. Select the entire “R2APERMAG3” column and click on the filter symbol called “Sort & Filter“ → “Sort Smallest to Largest” → “Sort”
6. Select the entire table by clicking on the upper-left hand side corner
7. Again click on the filter symbol → “Filter”. Each column will have now have an downwards arrow on its side
   7.1. Click on the arrow of the “R2APERMAG” column
   7.2. Choose the option “Greater than” and write on the side 13,0. Then click on “Apply filter” and close the pop-up window
   7.3. Repeat this filtering for the rest of the properties taking into account whether the criteria requires the “Greater than” or “Less than” option
8. For the criteria on “classes” seen on Table 8, click on the filtering symbol of a column
   8.1. Select only those values you wish to maintain on the list displayed in the pop-up window

PROCEDURE IN IMAGES:

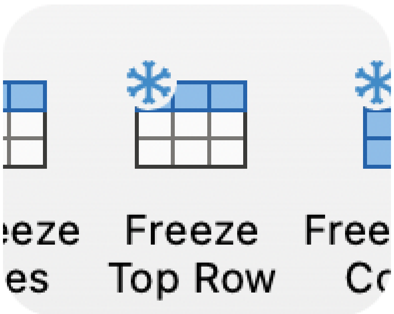
2.



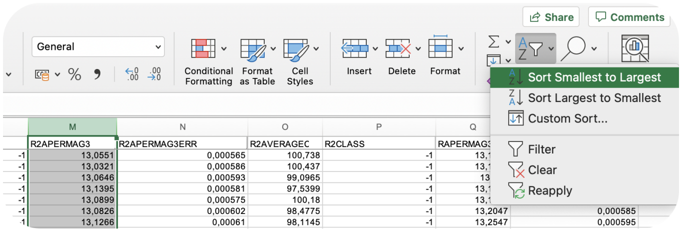
3.



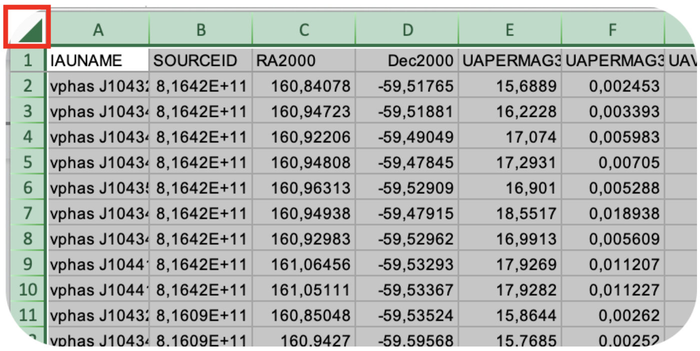
4.



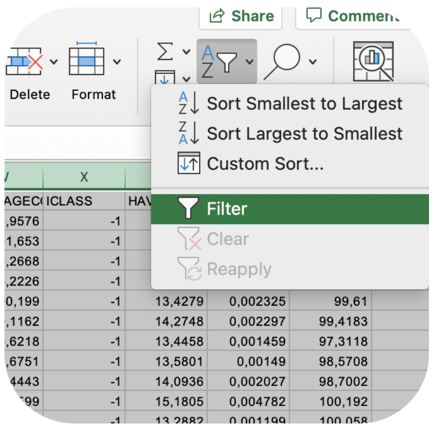
5.



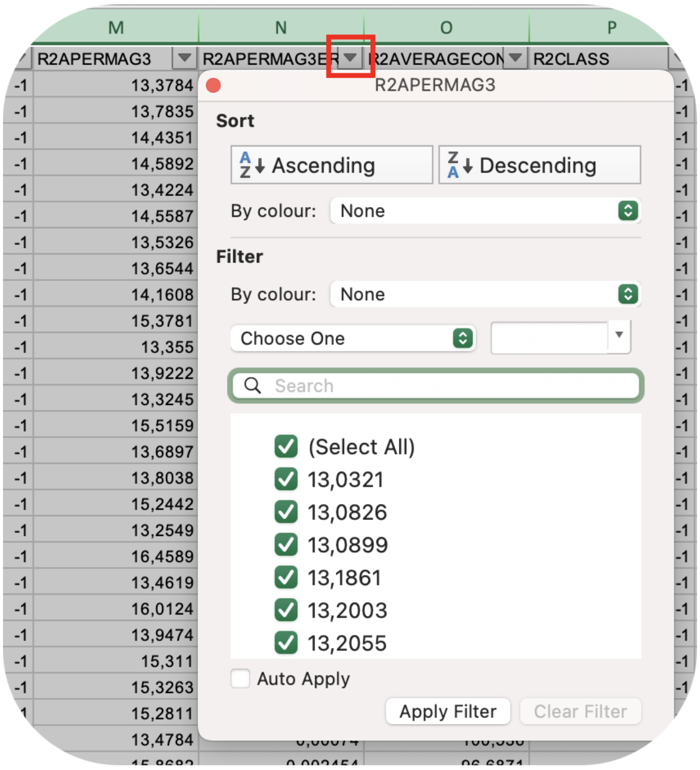
6.



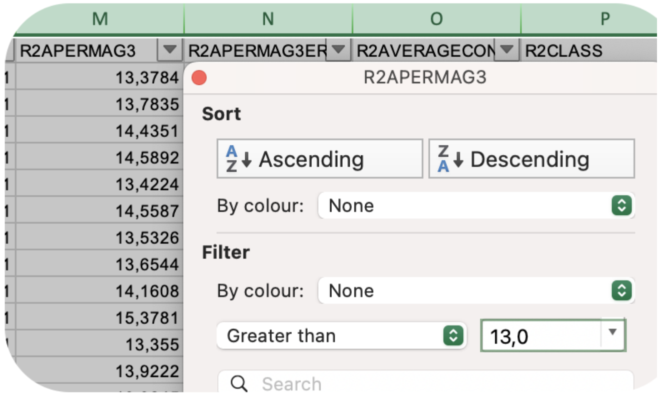
7.



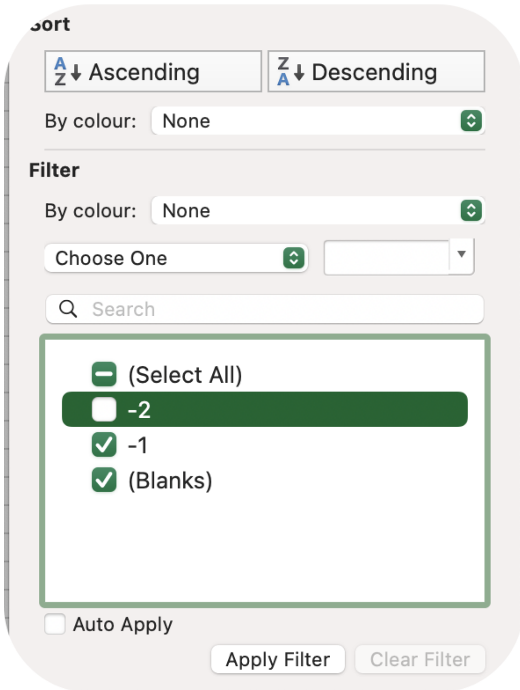
7.1


M
N
O
P
R2APERMAG3
R2APERMAG3ER
R2AVERAGECON
R2CLASS
13,3784
13,7835
14,4351
14,5892
13,4224
14,5587
13,5326
13,6544
14,1608
15,3781
13,355
13,9222
13,3245
15,5159
13,6897
13,8038
15,2442
13,2549
16,4589
13,4619
16,0124
13,9474
15,311
15,3263
15,2811
13,4784
R2APERMAG3
Sort
Ascending
Descending
By colour:
None
Filter
By colour:
None
Choose One
Search
(Select All)
13,0321
13,0826
13,0899
13,1861
13,2003
13,2055
Auto Apply
Apply Filter
Clear Filter

7.2


M
N
O
P
R2APERMAG3
R2APERMAG3ER
R2AVERAGECON
R2CLASS
13,3784
13,7835
14,4351
14,5892
13,4224
14,5587
13,5326
13,6544
14,1608
15,3781
13,355
13,9222
R2APERMAG3
Sort
Ascending
Descending
By colour:
None
Filter
By colour:
None
Greater than
13,0
Search

8.1


Sort
Ascending
Descending
By colour:
None
Filter
By colour:
None
Choose One
Search
(Select All)
-2
-1
(Blanks)
Auto Apply
Apply Filter
Clear Filter

Once you have filtered your sources, how many do you have remaining?

Save the file containing the sources which meet the selection criteria naming it candidates_final.

Activity 12.4: Construct colour-colour diagrams

Review Activity 2.5.3 to remind yourself about colour-colour diagrams.

We will be constructing a colour-colour diagram to plot the candidates which met the selection criteria in Activity 12.3.1. These are our candidates to TTauri stars for now.

To do so, follow the procedure on your Google Sheet final table you named "candidates_final" in Activity 12.3.1.

Activity 12.4.1: Using Google Sheets

(Link to video tutorial)

PROCEDURE IN INSTRUCTIONS:

1. Open the table named "candidates_final", select it, and copy and paste it entirely onto a new Google Sheets
2. Add two columns at the end of the table
3. Name these "R-I" and "R-Halpha" respectively
4. On the first empty row of column "R-I" write the expression =(AX-BY) where:
   - A = letter defining the column "RAPERMAG3"
   - X = number of the first empty row in column "R-I" (should be number 2)
   - B = letter defining the column "IAPERMAG3"

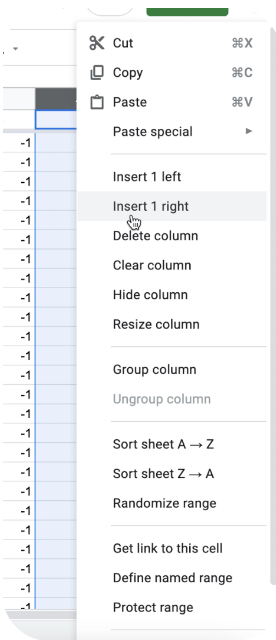
- Y = number of the first empty row (should be 2 again)
- It will then ask you whether you want to apply this expression for the rest of the column, click on accept

This is how the magnitude value from band i is subtracted from band r resulting in the (r-i) colour.

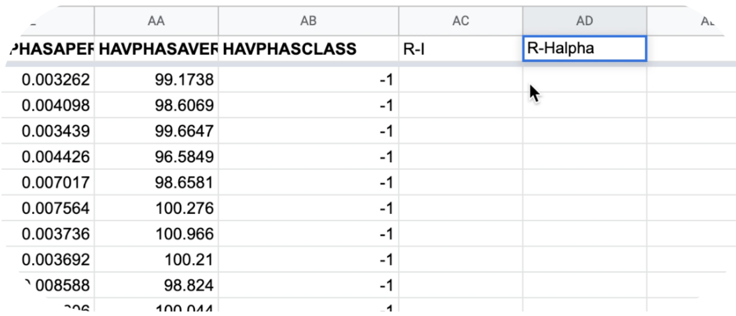
5. Repeat step 4 with the column “R-Halpha” to obtain the (r-Halpha) colour with the corresponding columns
6. Select both column you have created “R-I” and “R-Halpha”
7. Click on the plotting icon
8. In “format” select “Scatter plot” option
9. For the X axis, select the colour (r-i)
10. In the “Series” option, click on the three dots to the right of “R-I” and click on “Remove”. This set the Y axis to be the (r-Halpha) colour
11. Add the axes titles as well as the plot title by clicking on the plot menu on “Customize” → “Chart & Axis title” → fill in the “Title text” with the plot title → Instead of “Chart title” select “Horizontal axis title” and write R-I. Repeat this for the Y axis (vertical)
12. Click on “Series” → “Point size” and select the 2px option
13. You should obtain a colour colour diagram like on step 13 of the procedure in images

PROCEDURE IN IMAGES:

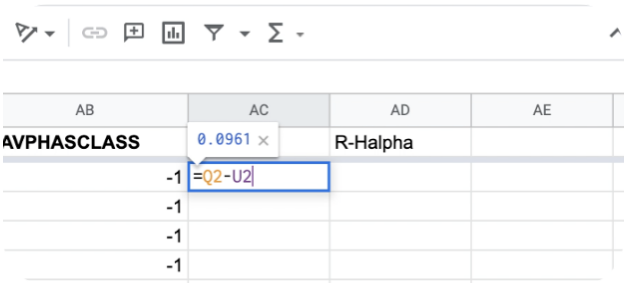
2.

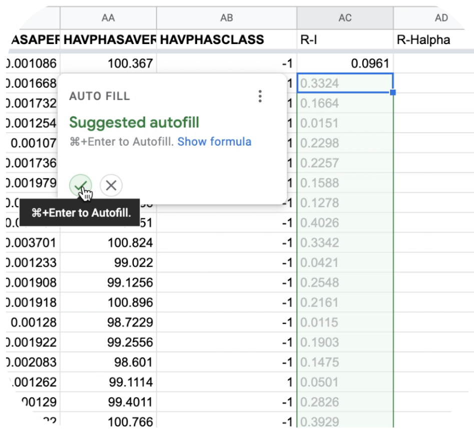


3.

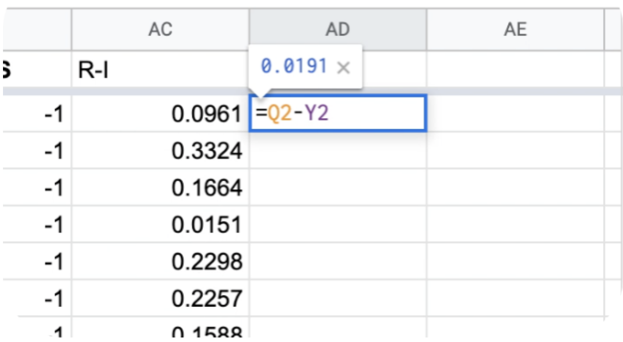


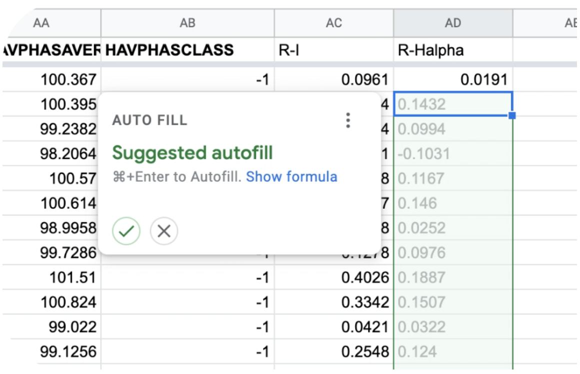
4.



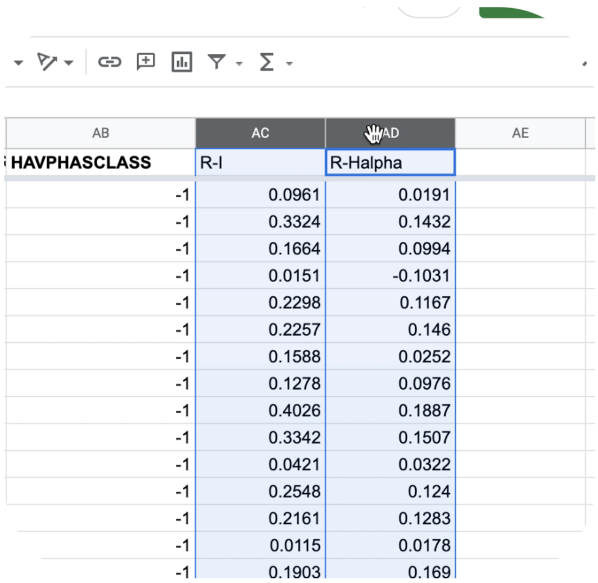


5.



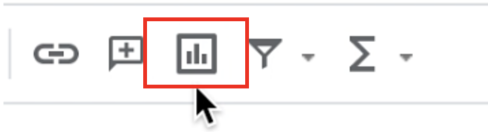


6.

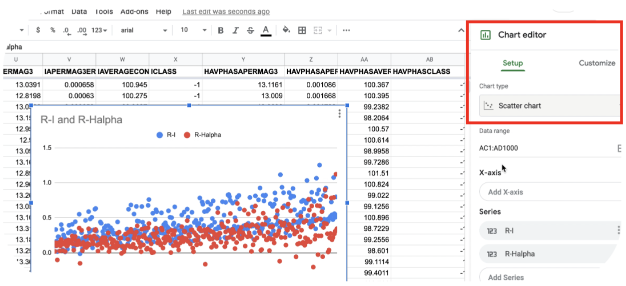


AB
AC
AD
AE
HAVPHASCLASS
R-I
R-Halpha
-1 0.0961 0.0191
-1 0.3324 0.1432
-1 0.1664 0.0994
-1 0.0151 -0.1031
-1 0.2298 0.1167
-1 0.2257 0.146
-1 0.1588 0.0252
-1 0.1278 0.0976
-1 0.4026 0.1887
-1 0.3342 0.1507
-1 0.0421 0.0322
-1 0.2548 0.124
-1 0.2161 0.1283
-1 0.0115 0.0178
-1 0.1903 0.169

7.



8.



R-I and R-Halpha
Chart editor
Setup
Customize
Scatter chart

9.

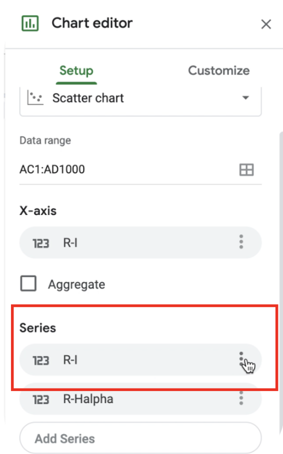


Chart editor
Setup
Customize
Scatter chart
Data range
AC1:AD1000
X-axis
R-I
Aggregate
Series
R-I
R-Halpha
Add Series

10.

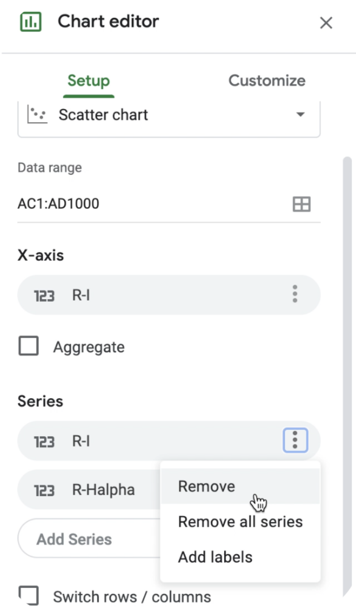


Chart editor
Setup
Customize
Scatter chart
Data range
AC1:AD1000
X-axis
R-I
Aggregate
Series
R-I
R-Halpha
Add Series
Remove
Remove all series
Add labels
Switch rows / columns

11.

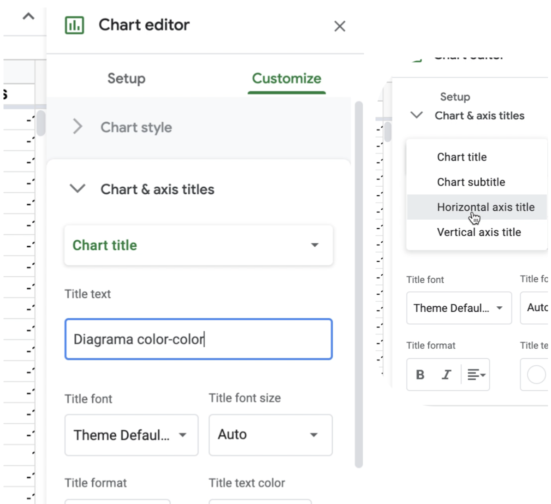


Chart editor
Setup
Customize
Chart style
Chart & axis titles
Chart title
Title text
Diagrama color-color
Title font
Title font size
Theme Defaul...
Auto
Title format
Title text color
Chart title
Chart subtitle
Horizontal axis title
Vertical axis title

12.

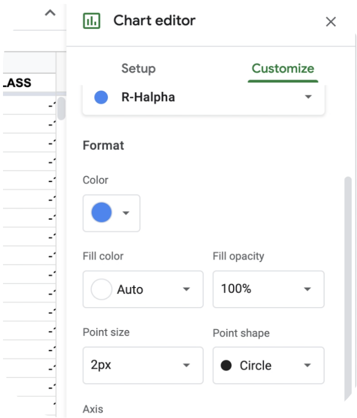
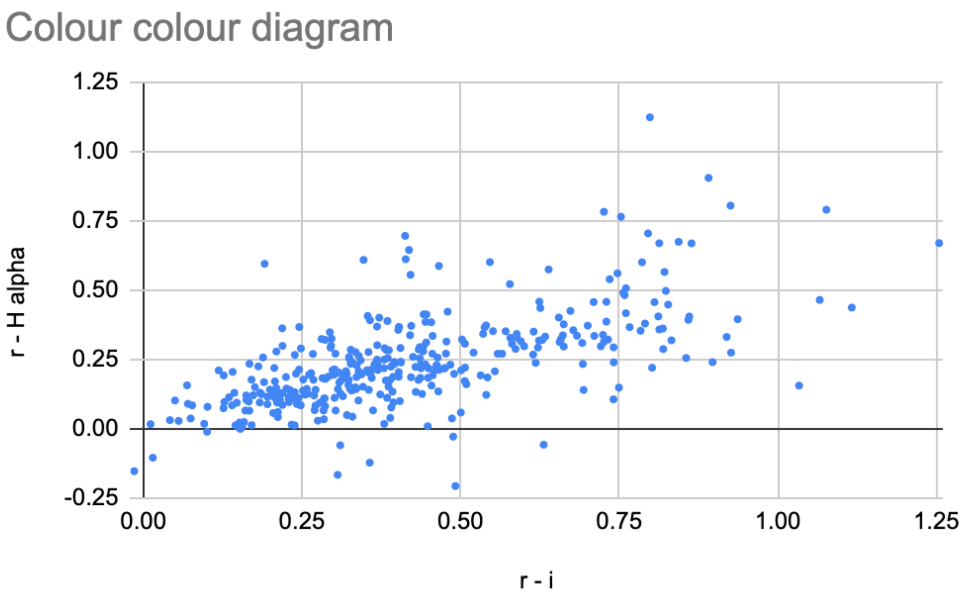


Chart editor
Setup
Customize
R-Halpha
Format
Color
Fill color
Fill opacity
Auto
100%
Point size
Point shape
2px
Circle
Axis

13.



Colour colour diagram
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
r - H alpha
0.00
0.25
0.50
0.75
1.00
1.25
r - i

Activity 12.4.2: Using Excel

(Link to video tutorial)

PROCEDURE IN INSTRUCTIONS:

1. Open the table named "candidates_final", select it, and copy and paste it entirely onto a new Excel sheet
2. Select the first row with the names of the columns
3. Click on "View" → "Freeze Top Row"
4. Add two columns at the end of the table
5. Name these "R-I" and "R-Halpha" respectively
6. On the first empty row of column "R-I" write the expression =(AX-BY) where:
    - A = letter defining the column "RAPERMAG3"
    - X = number of the first empty row in column "R-I" (should be number 2)
    - B = letter defining the column "IAPERMAG3"
    - Y = number of the first empty row (should be 2 again)
    - Click on the lower-right hand side corner of the box. This will apply the equation to the entire column

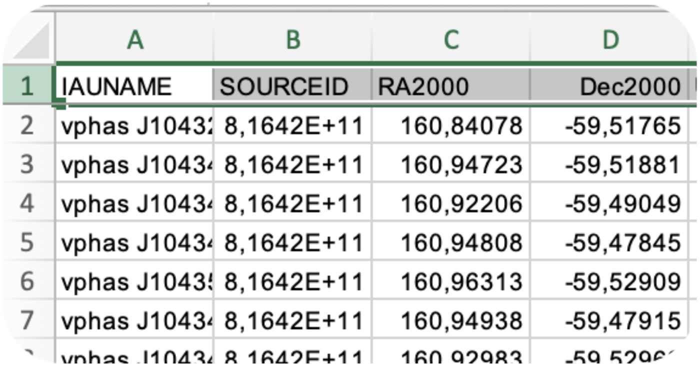
This is how the magnitude value from band i is subtracted from band r resulting in the (r-i) colour.

7. Repeat step 4 with the column "R-Halpha" to obtain the (r-Halpha) colour with the corresponding columns
8. Select both columns you have created "R-I" and "R-Halpha"
9. Click on "Insert" and on the scatter plot option select the first option
10. Double click on the title to change it
11. For the x and y axis titles click on "Add chart element" → "Axis titles" → "Primary horizontal" or "Primary vertical" and add the desired name

12. You should obtain a colour-colour diagram like the one shown in step 11 in the procedure in images

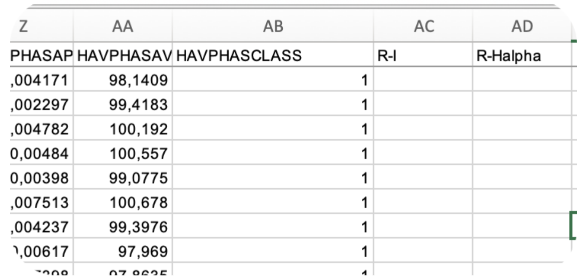
PROCEDURE IN IMAGES:

3.



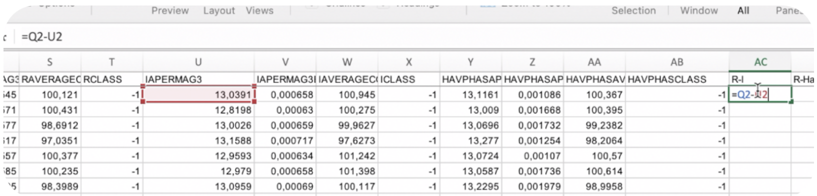
	A	B	C	D
1	IAUNAME	SOURCEID	RA2000	Dec2000
2	vphas J1043	8,1642E+11	160,84078	-59,51765
3	vphas J1043	8,1642E+11	160,94723	-59,51881
4	vphas J1043	8,1642E+11	160,92206	-59,49049
5	vphas J1043	8,1642E+11	160,94808	-59,47845
6	vphas J1043	8,1642E+11	160,96313	-59,52909
7	vphas J1043	8,1642E+11	160,94938	-59,47915

5.



Z	AA	AB	AC	AD
PHASAP	HAVPHASAV	HAVPHASCLASS	R-I	R-Halpha
,004171	98,1409	1		
,002297	99,4183	1		
,004782	100,192	1		
0,00484	100,557	1		
0,00398	99,0775	1		
,007513	100,678	1		
,004237	99,3976	1		
,00617	97,969	1		

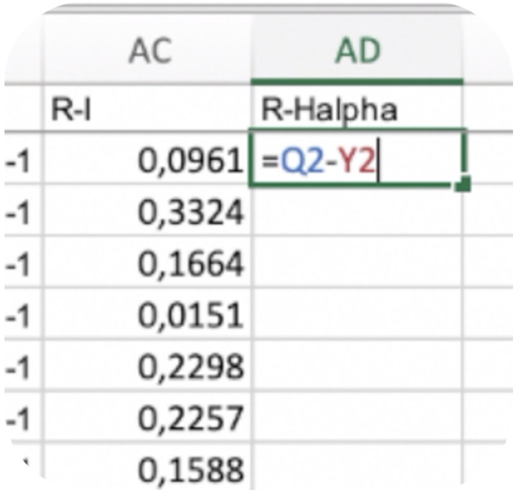
6.



=Q2-U2

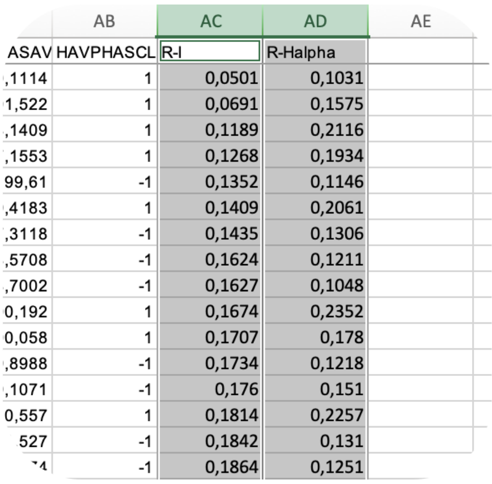
S	T	U	V	W	X	Y	Z	AA	AB	AC	
RAVERAGEC	RCLASS	IAPERMAG3	IAPERMAG3I	IAVERAGEC	ICLASS	HAVPHASAP	HAVPHASAP	HAVPHASAV	HAVPHASCLASS	R-I	R-Ha
100,121	-1	13,0391	0,000658	100,945	-1	13,1161	0,001086	100,367	-1	=Q2-U2	
100,431	-1	12,8198	0,00063	100,275	-1	13,009	0,001668	100,395	-1		
98,6912	-1	13,0026	0,000659	99,9627	-1	13,0696	0,001732	99,2382	-1		
97,0351	-1	13,1588	0,000717	97,6273	-1	13,277	0,001254	98,2064	-1		
100,377	-1	12,9593	0,000634	101,242	-1	13,0724	0,00107	100,57	-1		
100,235	-1	12,979	0,000658	101,398	-1	13,0587	0,001736	100,614	-1		
98,3989	-1	13,0959	0,00069	100,117	-1	13,2295	0,001979	98,9958	-1		

7.



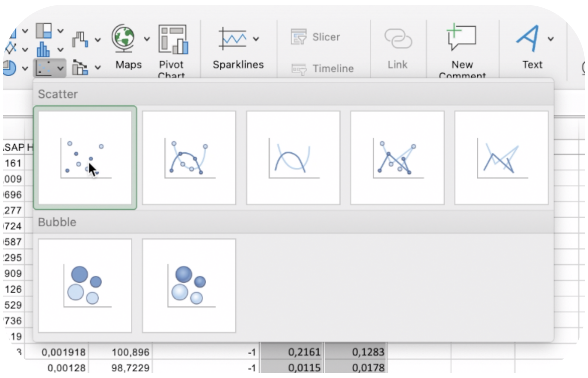
	AC	AD
	R-I	R-Halpha
-1	0,0961	=Q2-Y2
-1	0,3324	
-1	0,1664	
-1	0,0151	
-1	0,2298	
-1	0,2257	
	0,1588	

8.

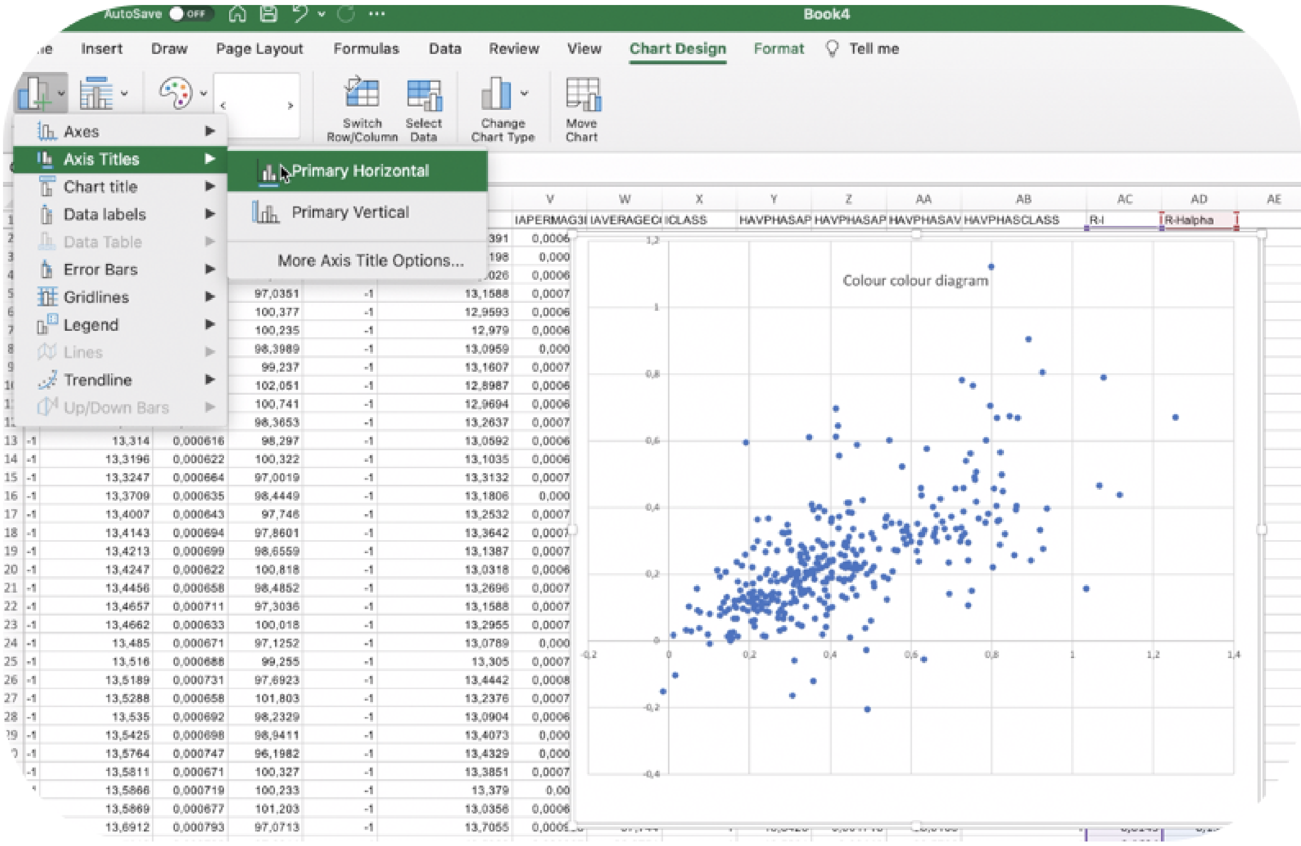


	AB	AC	AD	AE
ASAV	HAVPHASCL	R-I	R-Halpha	
,1114	1	0,0501	0,1031	
1,522	1	0,0691	0,1575	
,1409	1	0,1189	0,2116	
,1553	1	0,1268	0,1934	
99,61	-1	0,1352	0,1146	
,4183	1	0,1409	0,2061	
,3118	-1	0,1435	0,1306	
,5708	-1	0,1624	0,1211	
,7002	-1	0,1627	0,1048	
0,192	1	0,1674	0,2352	
0,058	1	0,1707	0,178	
,8988	-1	0,1734	0,1218	
,1071	-1	0,176	0,151	
0,557	1	0,1814	0,2257	
527	-1	0,1842	0,131	
	-1	0,1864	0,1251	

9.



11.


AutoSave
Book4
Insert
Draw
Page Layout
Formulas
Data
Review
View
Chart Design
Format
Tell me
Switch Row/Column
Select Data
Change Chart Type
Move Chart
Axes
Axis Titles
Chart title
Data labels
Data Table
Error Bars
Gridlines
Legend
Lines
Trendline
Up/Down Bars
Primary Horizontal
Primary Vertical
More Axis Title Options...
Colour colour diagram

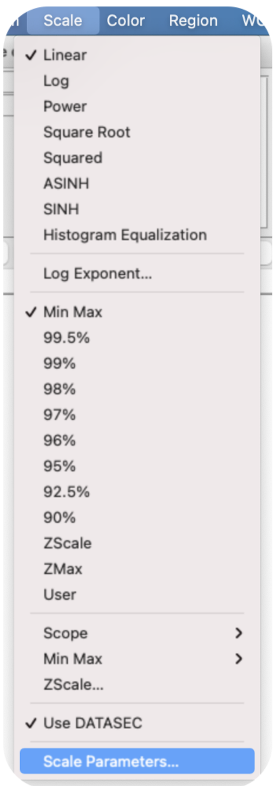
1. Check whether you get a plot like that on step 13 of the procedure with Google Sheets or 10 with Excel
2. Select the 4 sources you think have the strongest Halpha emission (Note: remember, the stronger the emission in a band, the lower its magnitude)
3. When you have selected these 4 sources, complete Table 8 with their coordinates (RA, DEC) and colour (r-Halpha). You can read this information from the Google Sheet table

(RA, DEC)	colour (r - Halpha)

***Table 8**: Four sources with strongest Halpha emission*

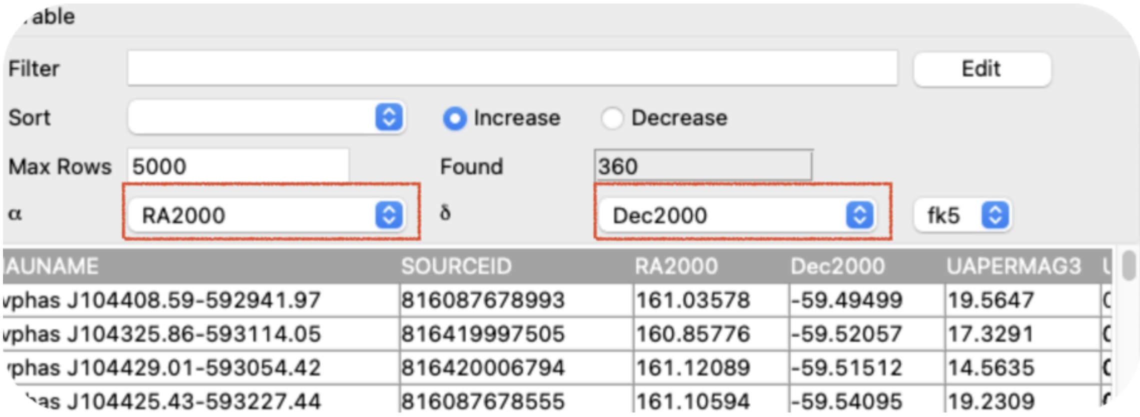
Activity 12.5: Identifying sources on the VST catalogue with SAOImage

1. Download the image “CarinaHalpha” onto your computer from from this link. This image is compressed
2. In order to be able to work with this image we must decompress it twice
    - If you have a Windows computer, you may make use of programs such as “72ZIP” to decompress the image
    - If you have a Mac computer, you can decompress the file by double clicking on it twice until you obtain a file with the .fits extension
3. On SAOImage DS9 click on “Frame” → “New frame”
4. Upload the Carina image. This image was taken by VST with a Halpha filter
5. On the menu click on “Zoom” and select the “Align” option to align the image
6. The color of the image should be black and white (option “greyscale”). You can change this by going onto “Scale” → “Scale parameters” and set the upper limit (“High”) to 1910 and “Apply”

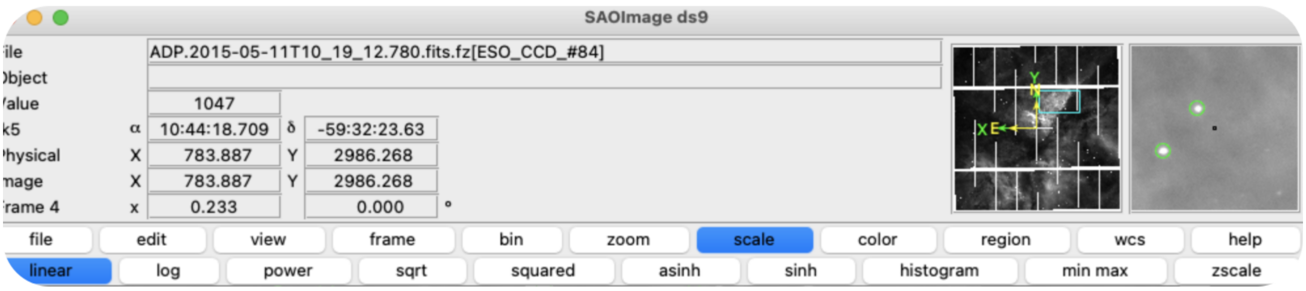


7. Again click on “Analysis” → “Catalog tool” and load the “candidates_final.VOT” (link to the file) catalogue with all your sources

8. Make sure you select RA2000 and Dec2000 for the entries α and δ. Ignore any possible error message you might get. This will plot the regions of the sources you filtered out onto the image.



9. Once the regions are plotted, click on "Analysis" → "Coordinate Grid". This will help you find the sources. Hovering over the sources will show you a zoomed-up image on the far right of the ds9 interface



Your task now is to identify the 4 sources you found to have the highest Halpha emission on this image. To do this, you should convert their coordinates from degrees to hours, minutes, seconds and degrees, arcminutes, arcseconds for RA and DEC respectively. Here is how to do that:

How to convert right ascension (RA) from degrees to (hh,mm,ss)	How to convert declination DEC from degrees to (degrees, arcminutes, arcseconds)
1. To divide the right ascension coordinate from degrees to hours, you can divide the number of degrees by 15 (Note: this is because 360 degrees are 24 hours) 2. You will obtain a decimal number of hours 2.1. The whole number will be the hours 2.2. The decimal part can be converted into minutes by multiplying by 60 (Note: 1 hour is 60 minutes) 2.3. The decimal part of the minutes you obtain can be converted into seconds by multiplying by 60 (Note: 1 minute is 60 seconds) Example: 161.85776° $\frac{161.85776}{15} = 10.7905173 \rightarrow$ 10 h $0.7905173 \times 60 = 47.43104 \rightarrow$ 47 min $0.43104 \times 60 = 275.8624 \rightarrow$ 25.8s 161.85776° = 10h 47m 25.8 s	1. Obtain a decimal number in degrees 1.1. The whole number gives you the degrees 1.2. The decimal part of the number in degrees can be converted into arcminutes by multiplying by 60 (Note: 1 degree is 60 arc minutes) 1.3. The decimal part of the arc minutes can be converted into arcseconds by multiplying by 60 (Note: 1 arc minute is 60 arc seconds) Example: -59.52057° -59° $0.52057 \times 60 = 31.2342 \rightarrow$ 31 arcmin $0.2342 \times 60 = 14.052 \rightarrow$ 14.052 arcsec

Fill in Table 9 with the necessary information on the 4 sources you found to have the strongest Halpha emission.

Sources	Colour (r - Halpha)	RA (degrees)	DEC (degrees)	RA (hh, mm, ss)	DEC (º, ’, ”)
A					
B					
C					
D					

Tabla 9: *Información on the four sources with strongest Halpha emission*

Activity 12.6: Fine-tuning the selection of classical T Tauri stars

Activity 12.6 is divided into three parts.

Activity 12.6.1: Part 1

We have conducted the first selection of possible classical T Tauri stars based on their magnitudes on the VST catalogue and have identified four of them on a Halpha image.

The next step to fine-tune our selection of prostars in the process of accretion is to look for a specific amount of Halpha emission. To do this we will use the colour-colour diagram you plotted on Activity 12.4. Sources with larger (r-Halpha) colour will have stronger Halpha emission (remember, a smaller magnitude means brighter object in that band).

The colour of stars follows a specific function, called the “reddening curve” or “extinction curve”.

Light extinction refers to the absorption of electromagnetic radiation coming from astronomical objects. The interstellar gas and dust between the object and the observer absorbs some of the light. In the visible, blue light is more affected by extinction than red light, resulting in objects appearing redder than normal. This is why this effect is also known as "interstellar reddening".

The extinction or reddening curve defines the limit to the (r-Halpha) colour of our classical T Tauri stars. Add this curve onto your colour colour diagram by using the data on the “reddening-curve” file. To do so follow the procedure:

Activity 12.6.1.1: Using Google Sheets

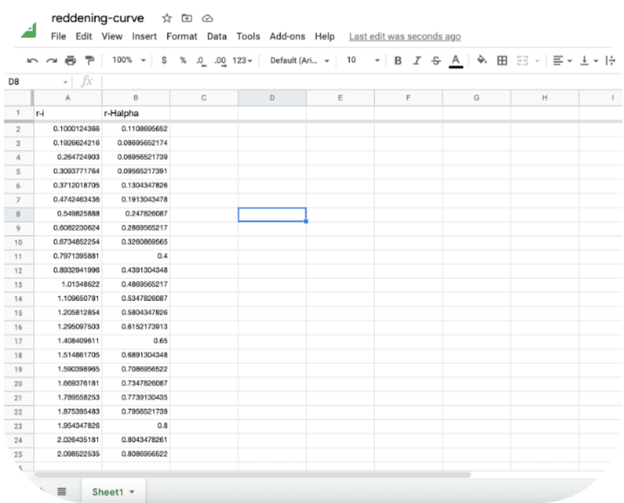
(Link to the video tutorial)

PROCEDURE IN INSTRUCTIONS:

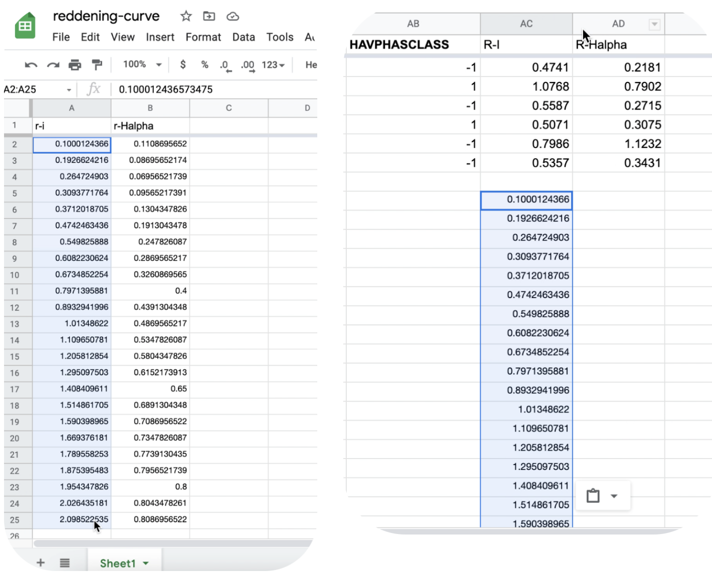
1. Open the file "reddening curve" on Google Sheets
2. Copy the column named r-i and paste it onto the end of your R-I column of the "candidates_final" table, leaving an empty row in between
3. Select the r-Halpha column on the "reddening curve" file and copy it onto a new column, to the right of your R-Halpha column on the "candidates_final" table. Name this new column "curve"
4. Select the three columns "R-I", "R-Halpha" and "curve"
5. Click on the plotting icon
6. Select the "Scatter plot" option
7. For the X axis select "R-I"
8. For the Y axis delete the series "R-I"
9. Custom the data points by click on "Customize" → "Series" → select R-Halpha → "Point Size": 2px → change R-Halpha for Data series 2 → "Point Shape": square
10. You should obtain a diagram like that on step 10 of the procedure in images

PROCEDURE IN IMAGES:

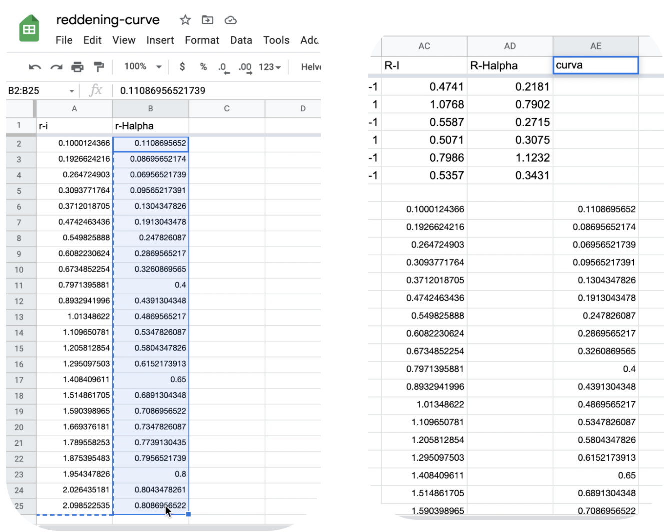
1.



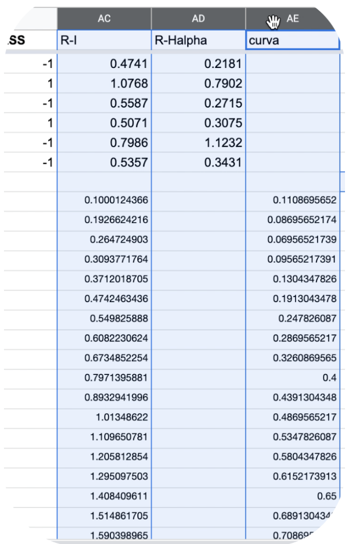
2.



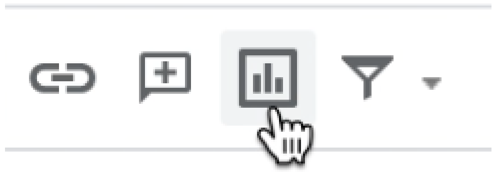
3.



4.



5.



6.

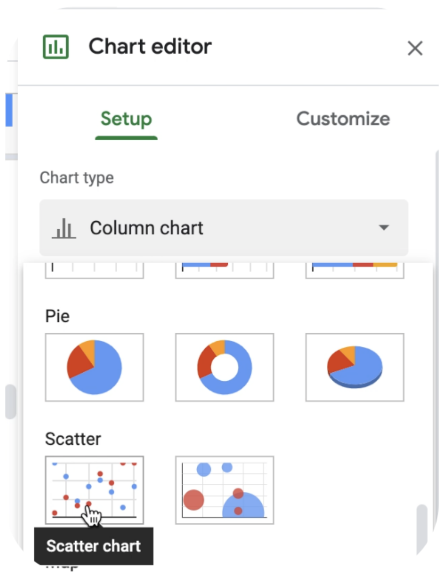
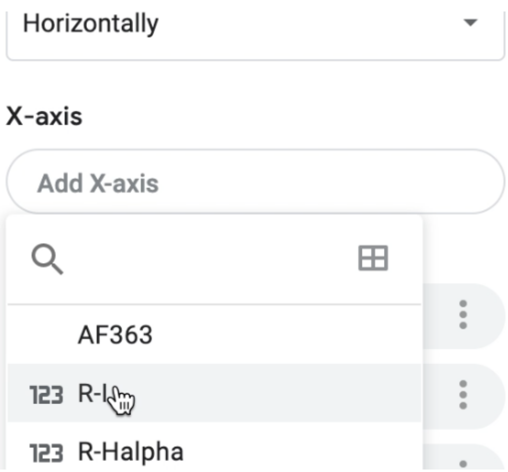
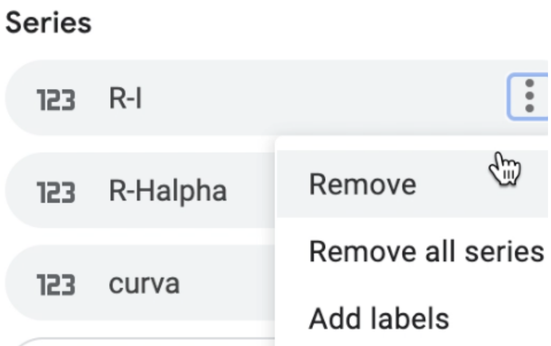


Chart editor
Setup
Customize
Chart type
Column chart
Pie
Scatter
Scatter chart

7.


Horizontally
X-axis
Add X-axis
AF363
123 R-I
123 R-Halpha

8.


Series
123 R-I
123 R-Halpha
123 curva
Remove
Remove all series
Add labels

9.

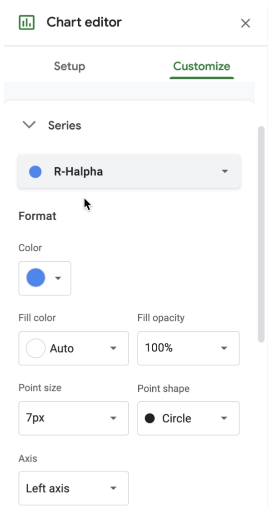
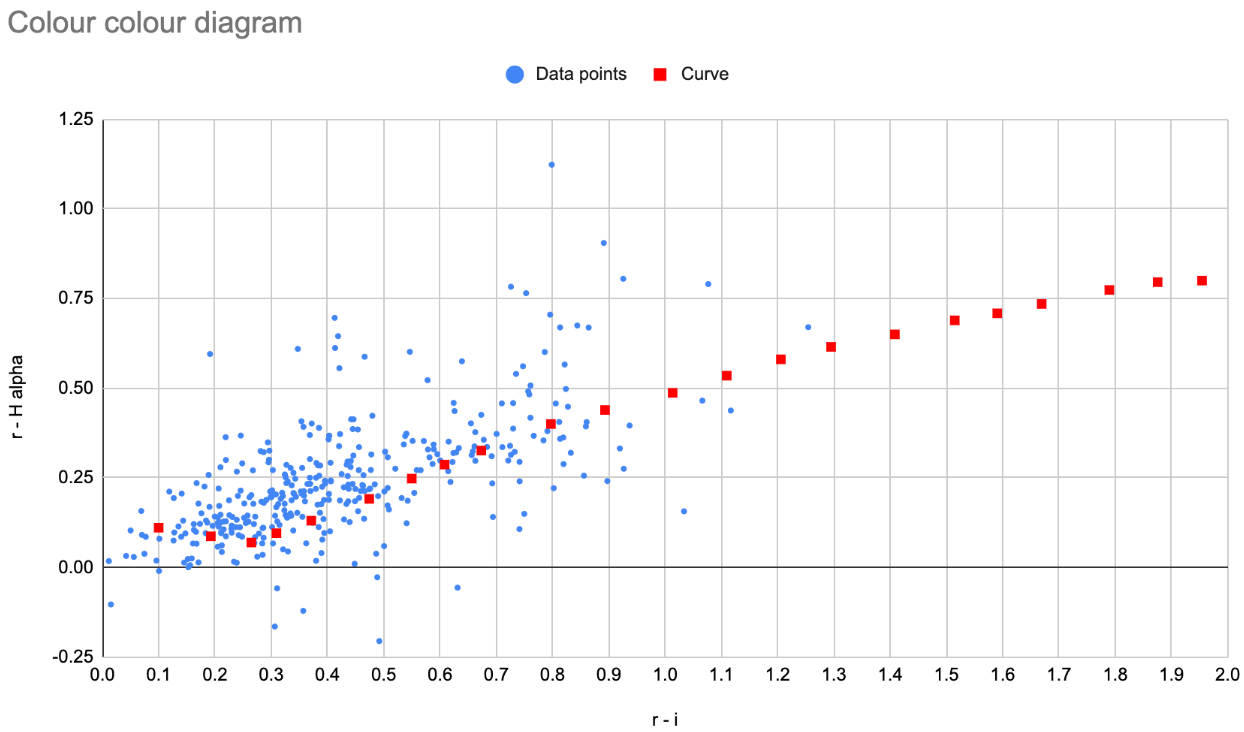


Chart editor
Setup
Customize
Series
R-Halpha
Format
Color
Fill color
Fill opacity
Auto
100%
Point size
Point shape
7px
Circle
Axis
Left axis

10.


Colour colour diagram
Data points
Curve
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
r - H alpha
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
r - i

Activity 12.6.1.2: Using Excel

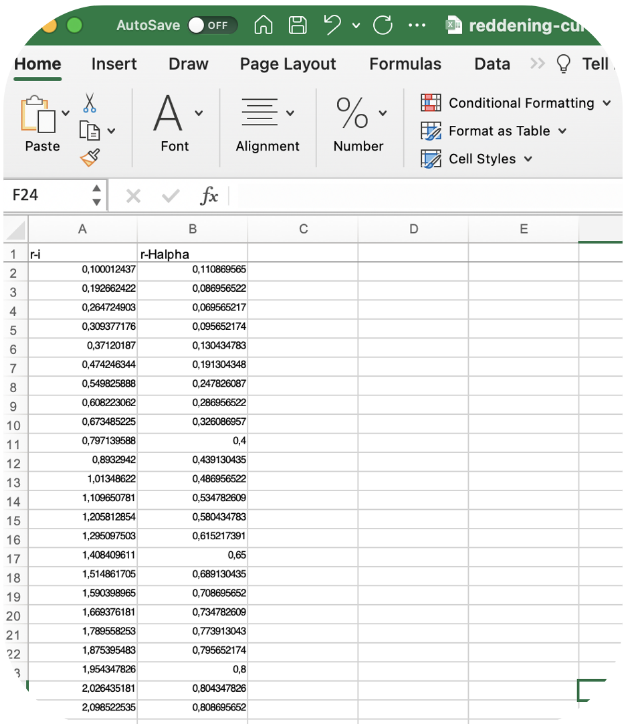
[(Link to the video tutorial)]()

PROCEDURE IN INSTRUCTIONS:

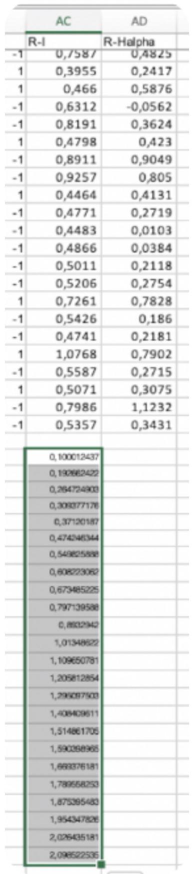
1. Download the "reddening_curve" file onto your computer and open with Excel
2. Copy the column named r-i and paste it onto the end of your R-I column of the "candidates_final" table, leaving an empty row in between
3. Select the r-Halpha column on the "reddening curve" file and copy it onto a new column, to the right of your R-Halpha column on the "candidates_final" table. Name this new column "curve"
4. Select the R-I and R-Halpha data of the sources (i.e. not the reddening curve data you have just added)
5. Click on "Insert" → and on the scatter plot option select the first option. You should obtain the r-Halpha versus r-i colour colour diagram
6. Click on "Select data"
7. On the pop-up window click on the "+" sign to add a new data series to your plot
   7.1. Click on the "x values" entry, then on your table click on the first r-i data box you have added from the reddening curve file and drag downwards to select the rest
   7.2. Go back to the pop-up window and click on "y values". Then for the y values select in the same way the data on your column called curve
   7.3. Click on "OK"
8. You should obtain the colour colour diagram with the reddening curve
9. To change the labels of the legend click again on "Select data"
   9.1. Select "Series1" and on the space write "Data points"
   9.2. Do the same for "Series2" and name it "curve"
10. You should obtain a diagram like on step 10 of the procedure in images

PROCEDURE IN IMAGES:

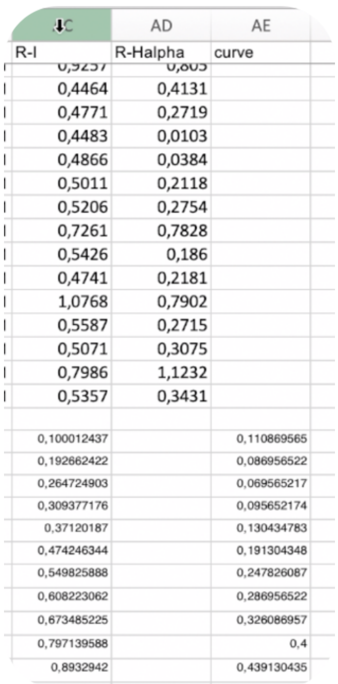
1.



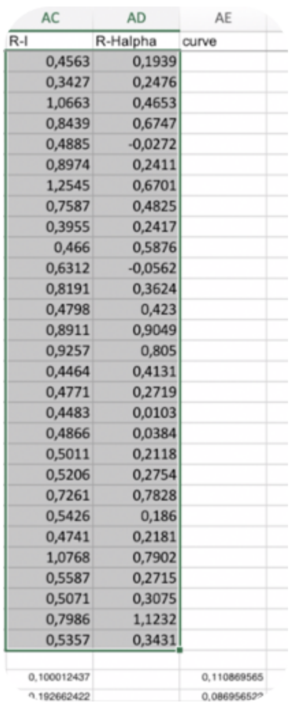
2.



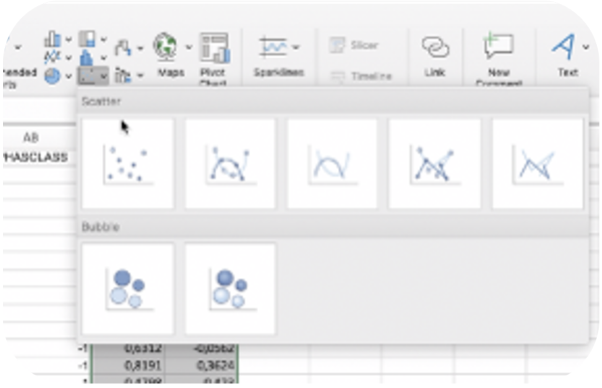
3.



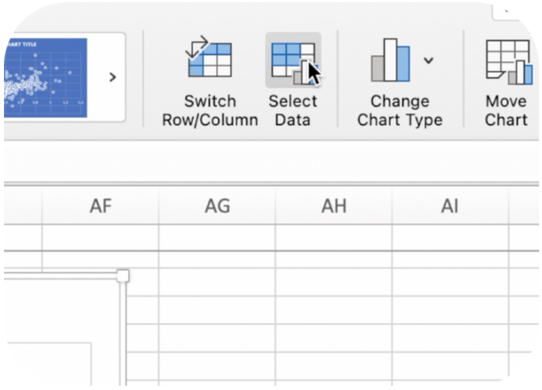
4.



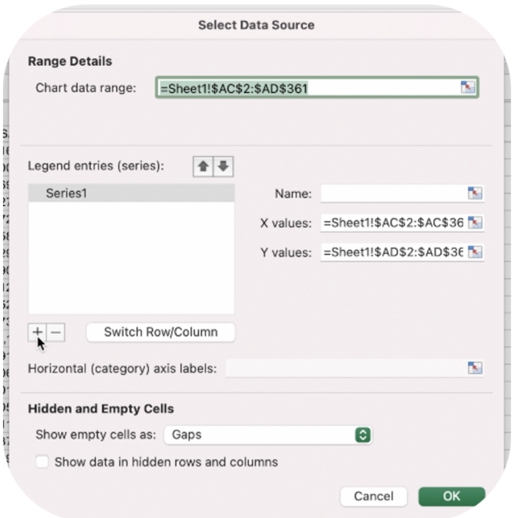
5.


Scatter
Bubble

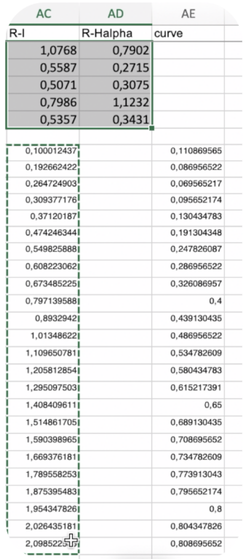
6.


Switch Row/Column
Select Data
Change Chart Type
Move Chart
AF
AG
AH
AI

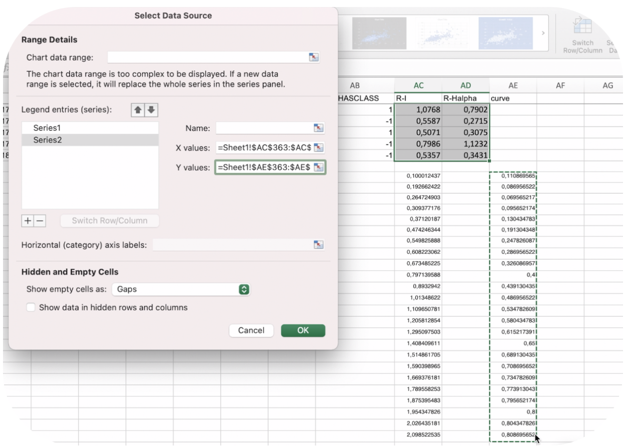
7.


Select Data Source
Range Details
Chart data range:
=Sheet1!$AC$2:$AD$361
Legend entries (series):
Series1
Name:
X values:
=Sheet1!$AC$2:$AC$36
Y values:
=Sheet1!$AD$2:$AD$36
Switch Row/Column
Horizontal (category) axis labels:
Hidden and Empty Cells
Show empty cells as:
Gaps
Show data in hidden rows and columns
Cancel
OK

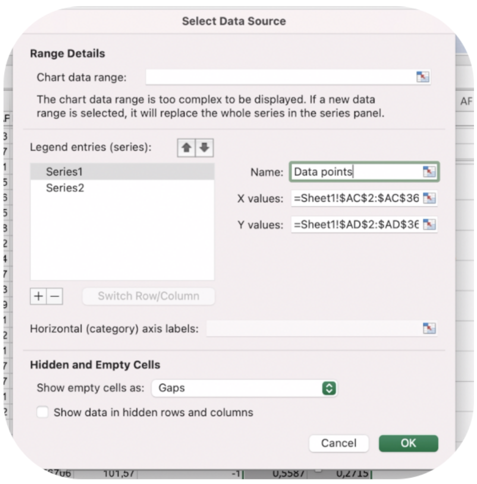
7.1


AC
AD
AE
R-I
R-Halpha
curve

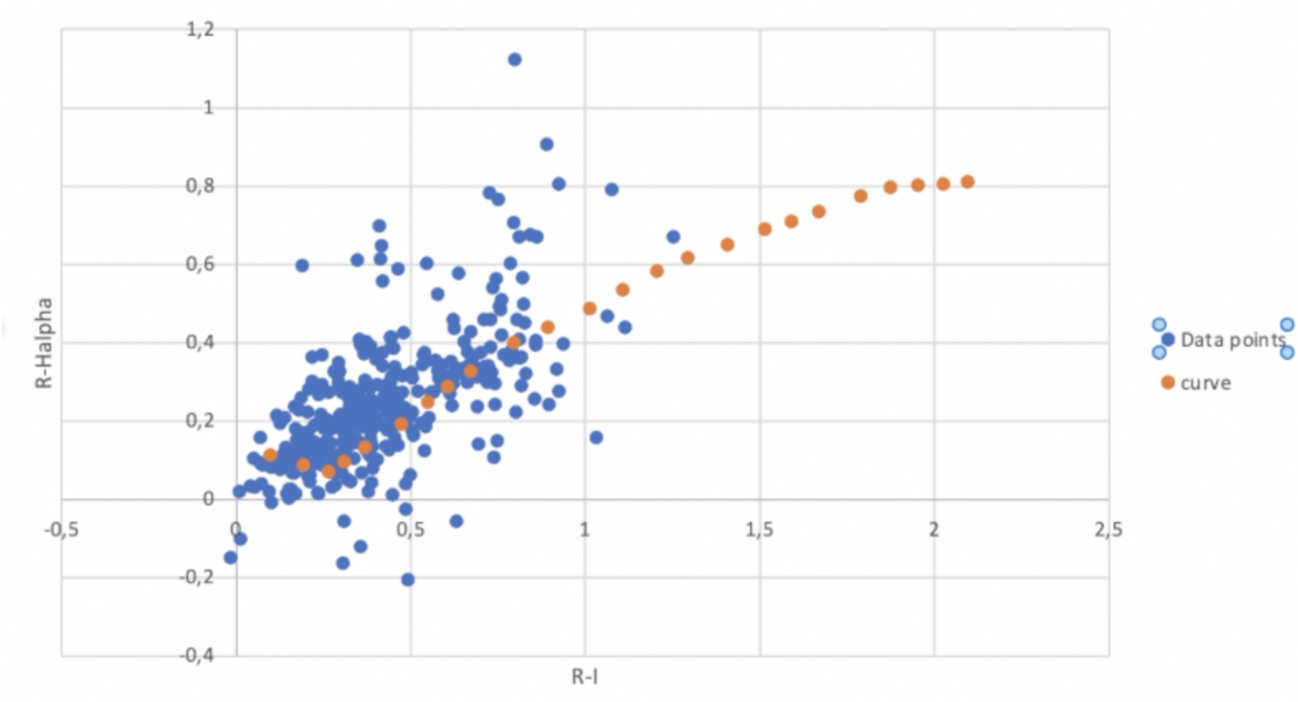
7.2


Select Data Source

9.1


Select Data Source
Range Details
Chart data range:
The chart data range is too complex to be displayed. If a new data range is selected, it will replace the whole series in the series panel.
Legend entries (series):
Series1
Series2
Name:
Data points
X values:
=Sheet1!$AC$2:$AC$36
Y values:
=Sheet1!$AD$2:$AD$36
Switch Row/Column
Horizontal (category) axis labels:
Hidden and Empty Cells
Show empty cells as:
Gaps
Show data in hidden rows and columns
Cancel
OK

10.



1,2
1
0,8
0,6
0,4
0,2
0
-0,2
-0,4
-0,5
0
0,5
1
1,5
2
2,5
R-Halpha
R-I
Data points
curve

The reddening curve defines a boundary for the (r-Halpha) colour of classical T Tauri stars. Any (r-Halpha) colour higher than this curve is called *(r-Halpha) excess* and is defined as:

$$(r - H\alpha)_{excess} = (r - H\alpha)_{observed} - (r - H\alpha)_{model} \quad \text{(Equation 10)}$$

where the (r-Halpha) colour observed is the measurements you have plotted on the colour-colour diagram (in blue dots) and the (r-Halpha) colour of the model is that expected from the curve (in red squares).

Activity 12.6.2: Part 2

1. Can you calculate the (r-Halpha) colour excess for the source with the highest emission in Halpha?

    1.1. What is the (r-Halpha) observed colour?

    1.2. What is the (r-Halpha) for the model?

    1.3. Subtract the model value from the observed value

Activity 12.6.2.1: Using Google Sheets

(Link to the video tutorial)

2. Calculate the excess for every source with a colour above the reddening curve. Hint: first filter out these sources
    2.1. If you look at the colour colour diagram you obtained, you will notice sources with (r-i) colour between 0.0 and 0.2 should have a (r-Halpha) colour > 0.1 in order to be positioned above the curve. We will using such conditions to select sources
    2.2. Open the "candidates_final.xls" table on Google Sheet
    2.3. Click on "Filter"
    2.4. The minimum point on the reddening curve has the following coordinates: (0.26, 0.069) meaning any sources with (r-Halpha) < 0.069 can be deleted. To do so click on the filtering symbol of the (R-Halpha) column and click on "Filter by condition" → "Greater than" and write 0.069
    2.5. Right click on the (R-I) column and click on "Sort column A → Z"
    2.6. For 0 < r-i < 0.2 select each row with r-Halpha<0.1, there should be 10 such rows and delete them by clicking on" Edit" → "delete selected rows"
    2.7. For 0.2 < r-i < 0.3 delete sources with r-Halpha <0.095 (6 sources)
    2.8. For 0.3 < r-i < 0.4 delete sources with r-Halpha <0.13, (8 sources)
    2.9. For 0.4 < r-i < 0.5 delete sources with r-Halpha <0.19, (10 sources)
    2.10. For 0.5 < r-i < 0.6 delete sources with r-Halpha <0.25, (8 sources)
    2.11. For 0.6 < r-i < 0.7 delete sources with r-Halpha <0.37, (17 sources)
    2.12. For 0.7 < r-i < 0.8 delete sources with r-Halpha <0.4, (14 sources)
    2.13. For 0.8 < r-i < 0.9 delete sources with r-Halpha <0.45, (11 sources)
    2.14. For 0.9 < r-i < 2.0 delete sources with r-Halpha <0.62, (6 sources)
    2.15. Copy this table onto a new Google Sheet. You should have 231 sources remaining.

2.16. Plot the colour colour diagram again with the remaining sources and the reddening curve. Every source you be positioned above the curve

2.17. Save this table and name it “candidates_final_R-Halpha.xls”

You should get the following graph:

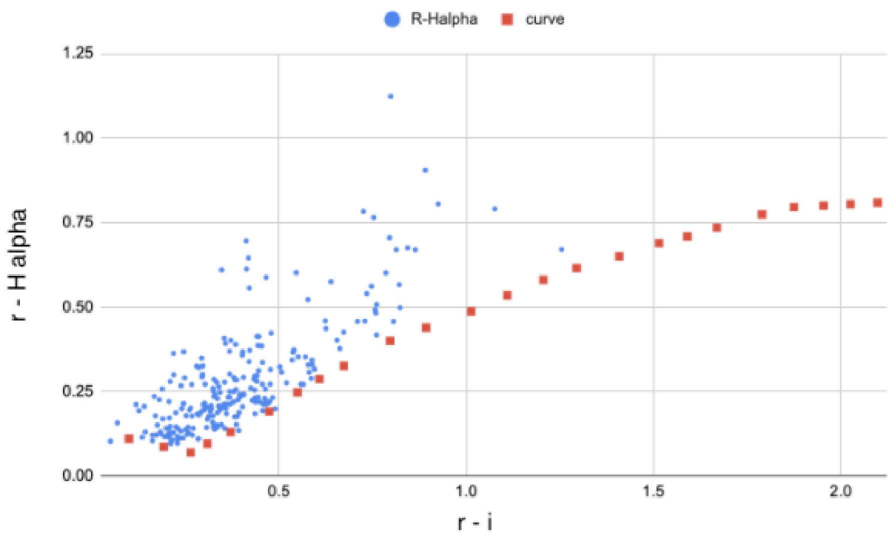


Figure 95)a): *Colour colour diagram of sources with (r-Halpha) colour above the reddening curve obtained with Google Sheets*

Activity 12.6.2.2: Using Excel

(Link to the video tutorial)

PROCEDURE IN INSTRUCTIONS:

1. Select the entire table by clicking on the upper-left hand side corner
2. If you look at the colour colour diagram you obtained before, you will notice sources with (r-i) colour between 0.0 and 0.2 should have a (r-Halpha) colour > 0.1 in order to be positioned above the curve. We will using such conditions to select sources
   - 2.1. Click on "Sort & Filter" → "Filter"
   - 2.2. The minimum point on the reddening curve has the following coordinates: (0.26, 0.069) meaning any sources with (r-Halpha) < 0.069 can be deleted. To do so select the (R-Halpha) column → click on the filtering arrow next to the name → Choose "Greater than" → write 0,069 → "Apply filter" → close the pop up window
   - 2.3. Select the (R-I) column and click on "Sort & Filter" → "Sort smallest to largest" → "Sort"
   - 2.4. For 0 < r-i < 0.2 select each row with r-Halpha<0.1, there should be 10 such rows and delete them by clicking on the drop-down arrow on "Delete" → "Delete Table Rows"
   - 2.5. For 0.2 < r-i < 0.3 delete sources with r-Halpha <0.095 (6 sources)
   - 2.6. For 0.3 < r-i < 0.4 delete sources with r-Halpha <0.13, (8 sources)
   - 2.7. For 0.4 < r-i < 0.5 delete sources with r-Halpha <0.19, (10 sources)
   - 2.8. For 0.5 < r-i < 0.6 delete sources with r-Halpha <0.25, (8 sources)
   - 2.9. For 0.6 < r-i < 0.7 delete sources with r-Halpha <0.37, (17 sources)
   - 2.10. For 0.7 < r-i < 0.8 delete sources with r-Halpha <0.4, (14 sources)
   - 2.11. For 0.8 < r-i < 0.9 delete sources with r-Halpha <0.45, (11 sources)
   - 2.12. For 0.9 < r-i < 2.0 delete sources with r-Halpha <0.62, (6 sources)

2.13. Copy this table onto a new Excel Sheet. You should have 231 sources remaining.

2.14. Plot the colour colour diagram again with the remaining sources and the reddening curve. Every source you be positioned above the curve

2.15. Save this table and name it "candidates_final_R-Halpha.xls"

You should get the following graph:

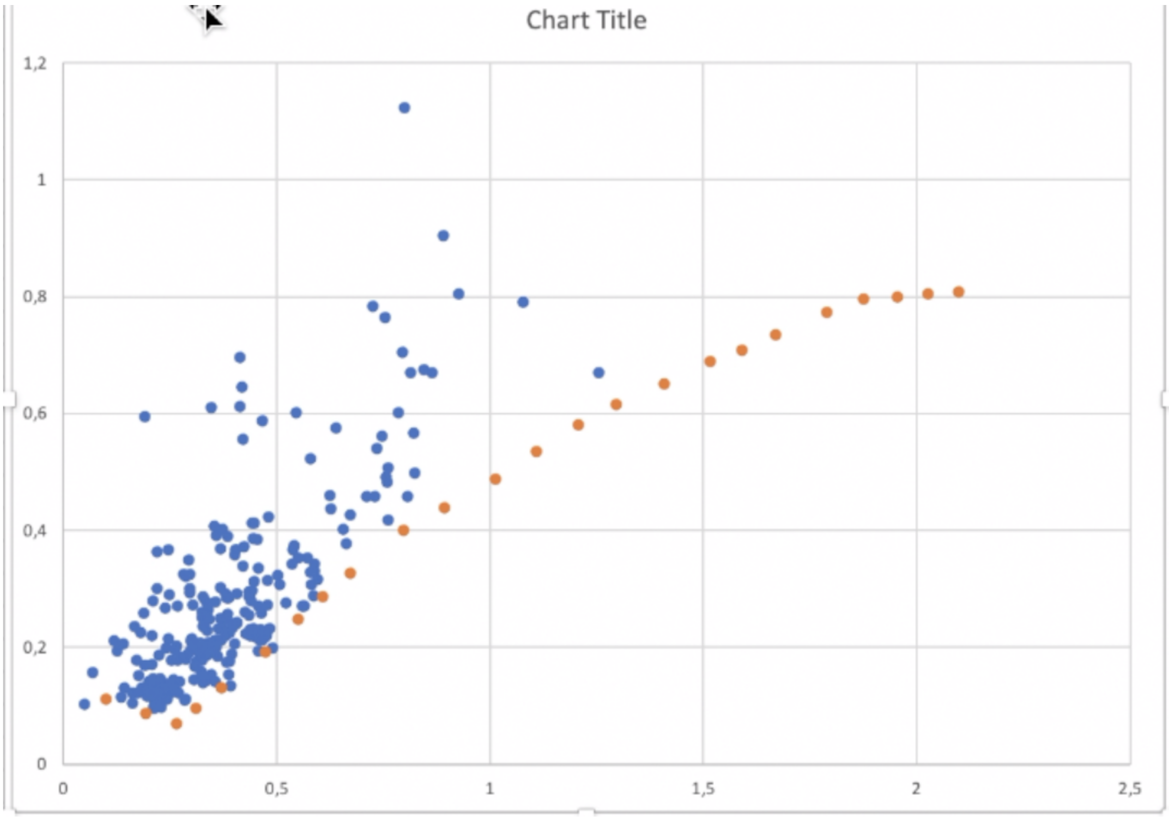
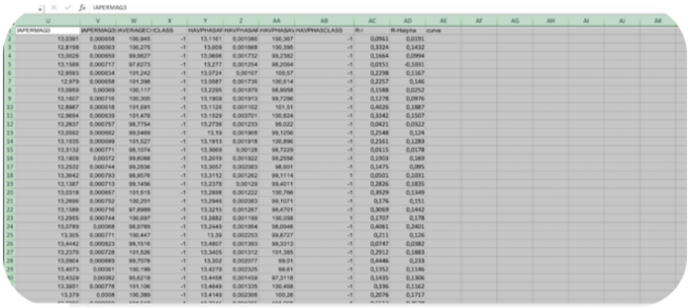


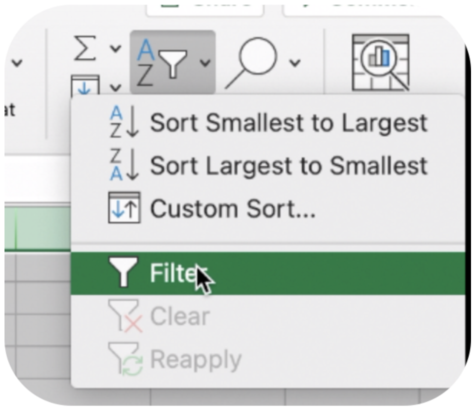
***Figure 95)b)**: Colour colour diagram of sources with (r-Halpha) colour above the reddening curve obtained with Excel*

PROCEDURE IN IMAGES:

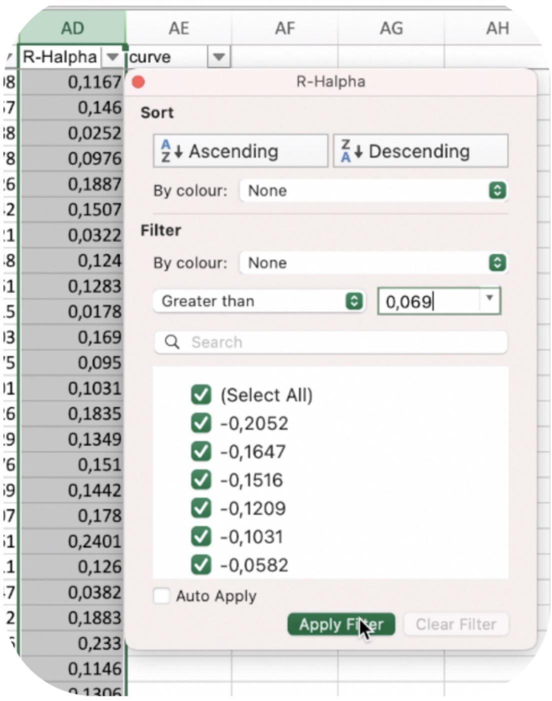
2.



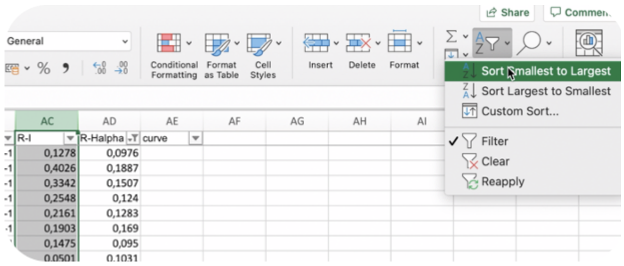
3.1



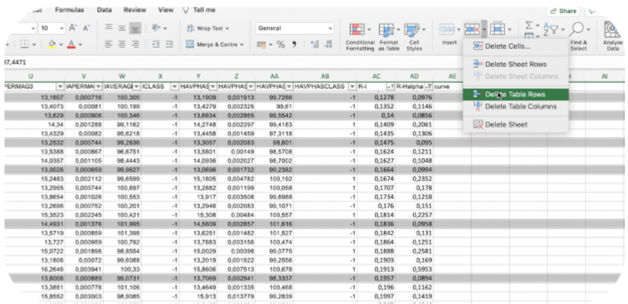
3.2



3.3



3.4



Activity 12.6.3: Part 3

Activity 12.6.3.1: Using Google Sheet

(Link to video tutorial)

1. Calculate the (r-Halpha) excess of sources taking into account their (r-i) colour. We will do so by dividing the reddening curve into piecewise functions with equations extracted from Figure 95:

   rc1 = (r - Halpha) - 0.1

   rc2 = (r - Halpha) - 0.095

   rc3 = (r - Halpha) - 0.13

   rc4 = (r - Halpha) - 0.19

   rc5 = (r - Halpha) - 0.25

   rc6 = (r - Halpha) - 0.37

   rc7 = (r - Halpha) - 0.4

   rc8 = (r - Halpha) - 0.45

   rc9 = (r - Halpha) - 0.62

   To do so, follow this procedure. (Note: when you see “ADX”, the X corresponds to the number of the row. For example, AD2 is column AD, row 2)

2. Take the Google Sheet file “candidates_final_R-Halpha.xls”

   2.1. We will focus on the (r-i) ranges and apply a criterion to each in new columns

   2.2. Add a new column at the end for range 0<(r-i)<0.2

   2.3. Write the rc1 function in box AF2. This function is (AD2-0.1).

   2.4. Drag this expression for the entire range 0<(r-i)<0.2

   2.5. Add a new column at the end for range 0.2<(r-i)<0.3

   2.6. Write the rc2 function in box AGX. This function is (ADX-0.095)

   2.7. Drag this expression for the entire range 0.2<(r-i)<0.3

   2.8. Add a new column at the end for range 0.3 < (r-i) < 0.4

   2.9. Write the rc3 function in box AHX. This function is (ADX-0.13)

   2.10. Drag this expression for the entire range 0.3 < (r-i) < 0.4

2.11. Add a new column at the end for range 0.4 < (r-i) < 0.5

2.12. Write the rc4 function in box AIX. This function is (ADX-0.19)

2.13. Drag this expression for the entire range 0.4 < (r-i) < 0.5

2.14. Add a new column at the end for range 0.5 < (r-i) < 0.6

2.15. Write the rc5 function in box AJX. This function is (ADX-0.25)

2.16. Drag this expression for the entire range 0.5 < (r-i) < 0.6

2.17. Add a new column at the end for range 0.6 < (r-i) < 0.7

2.18. Write the rc6 function in box AKX. This function is (ADX-0.37)

2.19. Drag this expression for the entire range 0.6 < (r-i) < 0.7

2.20. Add a new column at the end for range 0.7 < (r-i) < 0.8

2.21. Write the rc7 function in box ALX. This function is (ADX-0.4)

2.22. Drag this expression for the entire range 0.7 < (r-i) < 0.8

2.23. Add a new column at the end for range 0.8 < (r-i) < 0.9

2.24. Write the rc8 function in box AMX. This function is (ADX-0.45)

2.25. Drag this expression for the entire range 0.8 < (r-i) < 0.9

2.26. Add a new column at the end for range 0.9 < (r-i) < 2.0

2.27. Write the rc9 function in box ANX. This function is (ADX-0.62)

2.28. Drag this expression for the entire range 0.9 < (r-i) < 2.0

You should end up with a table similar to this one:

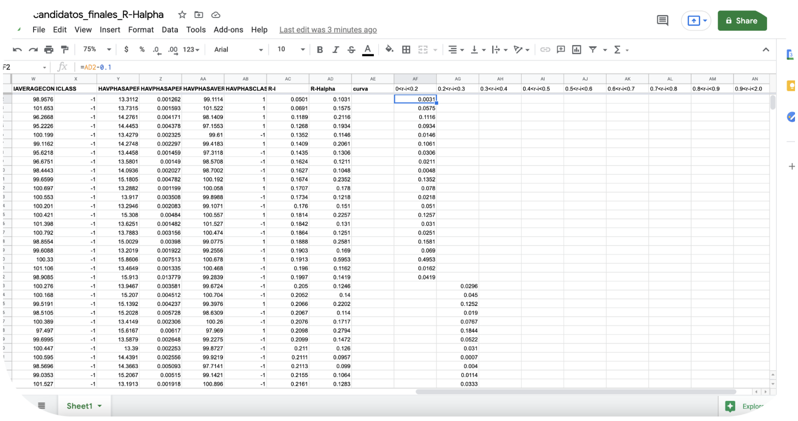


Figure 96: Table containing r-i colour to select candidates based on reddening curve

Activity 12.6.3.2: Using Excel

(Link to video tutorial)

1. Calculate the (r-Halpha) excess of sources taking into account their (r-i) colour. We will do so by dividing the reddening curve into piecewise functions with equations extracted from Figure 95:

   rc1 = (r - Halpha) - 0.1

   rc2 = (r - Halpha) - 0.095

   rc3 = (r - Halpha) - 0.13

   rc4 = (r - Halpha) - 0.19

   rc5 = (r - Halpha) - 0.25

   rc6 = (r - Halpha) - 0.37

   rc7 = (r - Halpha) - 0.4

   rc8 = (r - Halpha) - 0.45

   rc9 = (r - Halpha) - 0.62

   To do so, follow this procedure. (Note: when you see "ADX", the X corresponds to the number of the row. For example, AD2 is column AD, row 2)

2. Take the Excel sheet "candidates_final_R-Halpha.xls"

   2.1. We will focus on the (r-i) ranges and apply a criterion to each in new columns

   2.2. Add a new column at the end for range 0<(r-i)<0.2 by selecting the first empty column of the end of the tabla → "Insert" → "Insert Sheet Columns"

   2.3. Write the rc1 function in box AF2. This function is (AD2-0.1).

   2.4. Drag this expression for the entire range by clicking on the lower left hand side corner of the box and dragging downwards for 0<(r-i)<0.2

   2.5. Add a new column at the end for range 0.2<(r-i)<0.3

   2.6. Write the rc2 function in box AGX. This function is (ADX-0.095)

   2.7. Drag this expression for the entire range 0.2<(r-i)<0.3

   2.8. Add a new column at the end for range 0.3 < (r-i) < 0.4

   2.9. Write the rc3 function in box AHX. This function is (ADX-0.13)

2.10. Drag this expression for the entire range 0.3 < (r-i) < 0.4

2.11. Add a new column at the end for range 0.4 < (r-i) < 0.5

2.12. Write the rc4 function in box AIX. This function is (ADX-0.19)

2.13. Drag this expression for the entire range 0.4 < (r-i) < 0.5

2.14. Add a new column at the end for range 0.5 < (r-i) < 0.6

2.15. Write the rc5 function in box AJX. This function is (ADX-0.25)

2.16. Drag this expression for the entire range 0.5 < (r-i) < 0.6

2.17. Add a new column at the end for range 0.6 < (r-i) < 0.7

2.18. Write the rc6 function in box AKX. This function is (ADX-0.37)

2.19. Drag this expression for the entire range 0.6 < (r-i) < 0.7

2.20. Add a new column at the end for range 0.7 < (r-i) < 0.8

2.21. Write the rc7 function in box ALX. This function is (ADX-0.4)

2.22. Drag this expression for the entire range 0.7 < (r-i) < 0.8

2.23. Add a new column at the end for range 0.8 < (r-i) < 0.9

2.24. Write the rc8 function in box AMX. This function is (ADX-0.45)

2.25. Drag this expression for the entire range 0.8 < (r-i) < 0.9

2.26. Add a new column at the end for range 0.9 < (r-i) < 2.0

2.27. Write the rc9 function in box ANX. This function is (ADX-0.62)

2.28. Drag this expression for the entire range 0.9 < (r-i) < 2.0

The resulting values are the (r-Halpha)$_{excess}$ which we will now use to further tune the selection of classical T Tauri stars.

Activity 12.7: Fine tune the selection of classical TTauri stars with the Halpha Equivalent width emission line

By using the excess (r-Halpha) colour measured previously, we can compute each sources' equivalent width. Review the concept of equivalent width in Activity 6.1.

Activity 12.7.1: Using Google Sheet

(Link to video tutorial)

1. Calculate the Halpha line equivalent width for the following (r-i) intervals. To do so, follow this procedure:
    1.1. Take the Google Sheet file "candidates_final_r-Halpha.xls" and copy the table onto a new Google Sheet.
    1.2. Add a new column between columns AF and AG (see Figure 98) and call it EW
    1.3. For values 0<(r-i)<0.2, in the new column AG', in row AG'2, write the following expression (Note: in this case the Halpha filter had a width of $107\ Angstrom\ =\ 107\ \times 10^{-10} m$)

```
=107*(1-10^(0.4*AF2))
```

    1.4. Drag this equation for 0<(r-i)<0.2
    1.5. Add a new column between columns AH and AI
    1.6. For 0.2<(r-i)<0.3, in the new column AI, in the row where your values start, write the same equation. However, this time with AIX, where X is the number of the row.
    1.7. Repeat these steps with the next ranges in columns
    1.8. Save the table as "candidates_final_r-Halpha_excess_EW.xls"
2. Once you have the file containing the equivalent widths, we are going to filter sources again to identify classical TTauri stars. To do so follow this procedure:

2.1. For 0 < (r-i) < 0.8 the candidates will have to have EW < -10 Angstrom.

2.2. For 0.8 < (r-i) < 0.9 the candidates will have to have EW < -12 Angstrom.

2.3. For 0.9 < (r-i) < 2.0 the candidates will have to have EW < -25 Angstrom.

2.4. Delete any rows which do not meet this criteria

2.5. You should end up with 95 sources remaining

2.6. Your colour-colour diagram should now only show those sources which satisfy the EW boundary condition

2.7. Copy your data up until (and including) r-Halpha column onto a new spreadsheet

2.8. Download your file “candidates_final_r-Halpha_excess_EW” .csv format onto your computer by clicking on “File” → “Download” → “CSV”

Activity 12.7.2: Using Excel

(Link to video tutorial)

1. Calculate the Halpha line equivalent width for the following (r-i) intervals. To do so, follow this procedure:
   1.1. Take the Excel Sheet file "candidates_final_r-Halpha" and copy the table onto a new sheet.
   1.2. Add a new column between columns AF and AG by selection column AG → “Insert” → “Insert sheet columns” and call it EW
   1.3. For values 0<(r-i)<0.2, in the new column AG', in row AG'2, write the following expression (Note: in this case the Halpha filter had a width of $107\ Angstrom = 107 \times 10^{-10} m$)

```
=107*(1-10^(0,4*AF2))
```

   1.4. Drag this equation for 0<(r-i)<0.2
   1.5. Add a new column between columns AH and AI
   1.6. For 0.2<(r-i)<0.3, in the new column AI, in the row where your values start, write the same equation. However, this time with AIX, where X is the number of the row.
   1.7. Repeat these steps with the next ranges in columns
   1.8. Save the table as “candidates_final_r-Halpha_excess_EW”

2. Once you have the file containing the equivalent widths, we are going to filter sources again to identify classical TTauri stars. To do so follow this procedure:
   2.1. For 0 < (r-i) < 0.8 the candidates will have to have EW < -10 Angstrom.
   2.2. For 0.8 < (r-i) < 0.9 the candidates will have to have EW < -12 Angstrom.

2.3. For 0.9 < (r-i) < 2.0 the candidates will have to have EW < -25 Angstrom.

2.4. Delete any rows which do not meet this criteria by selecting them and then clicking on “Delete” → “Delete Table Rows”

2.5. You should end up with 95 sources remaining

2.6. As shown in Activity 12.6 Part 2, plot the colour colour diagram for the remaining sources

2.7. Copy your data up until (and including) r-Halpha column onto a new spreadsheet and save as .CSV format

The sources you have just selected are considered to be emitting Halpha strongly enough to be accreting.

You should obtain the following graph:

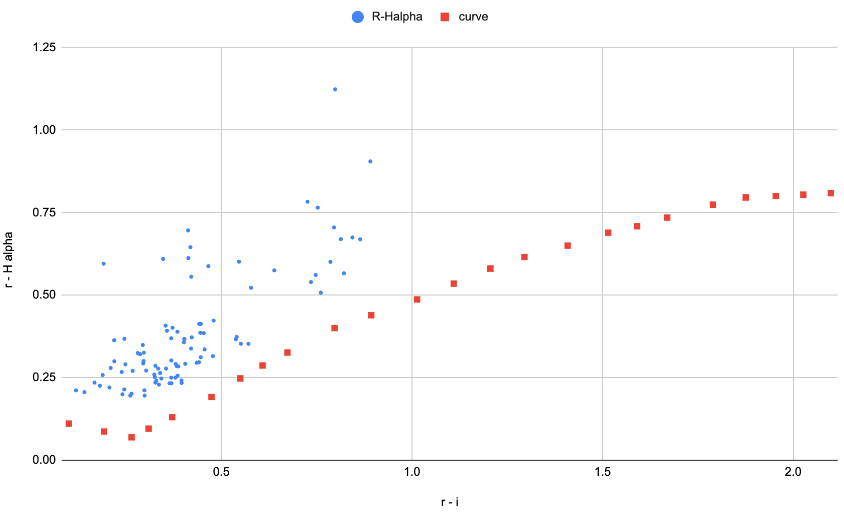


Figure 97*: Selection of TTauri candidates based on their equivalent width*

		Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
	AVPHASAPEF	HAVPHASAPEF	HAVPHASAVEF	HAVPHASCLAS	R-I	R-Halpha	curve	0-0.2	EW	0.2-0.3	EW	0.3-0.4		0.4-0.5		0.5-0.6		0.6-0.7		0.7-0.8
[illegible]	17.2335	0.024288	98.3433	1	0.3427	0.2476						0.1176	-12.24049704							
-1	17.4825	0.030463	100.752	1	0.3955	0.2417						0.1117	-11.59428953							
-1	13.6863	0.002906	100.35	-1	0.3293	0.2403						0.1103	-11.44146695							
-1	14.8324	0.003439	99.6647	-1	0.327	0.2353						0.1053	-10.89727784							
-1	16.1819	0.010122	101.554	-1	0.3959	0.2342						0.1042	-10.77789218							
-1	15.9473	0.021291	100.472	-1	0.3693	0.2332						0.1032	-10.66946468							
-1	14.9788	0.008966	100.687	-1	0.3644	0.233						0.103	-10.64779116							
-1	16.0896	0.009364	101.44	-1	0.3364	0.2291						0.0991	-10.22595452							
-1	16.6297	0.021442	97.3401	1	0.2459	0.3678				0.2728	-30.56367761									
-1	15.8525	0.007398	97.8635	1	0.219	0.3632				0.2682	-29.9820867									
-1	14.5765	0.00628	100.008	1	0.2941	0.3489				0.2539	-28.18975397									
-1	15.1073	0.004116	98.4293	1	0.2968	0.3257				0.2307	-25.33166526									
-1	14.8129	0.007732	99.6923	-1	0.2811	0.3246				0.2296	-25.19766299									
-1	13.4036	0.002268	99.5332	-1	0.2867	0.3215				0.2265	-24.82074983									
-1	15.0732	0.009654	100.018	-1	0.2961	0.3005				0.2055	-22.29560948									
-1	14.3839	0.002671	100.327	1	0.2195	0.2997				0.2047	-22.20037604									
-1	14.1759	0.002209	101.383	1	0.2952	0.2933				0.1983	-21.44102943									
-1	15.8066	0.007247	98.9465	1	0.2485	0.2904				0.1954	-21.09842136									
-1	15.6167	0.00617	97.969	1	0.2098	0.2794				0.1844	-19.80716046									
-1	14.3487	0.0024	100.247	-1	0.2674	0.2708				0.1758	-18.80670204									
-1	14.3473	0.002703	101.674	1	0.2389	0.2673				0.1723	-18.40180212									
-1	15.1392	0.004237	99.3976	1	0.2066	0.2202				0.1252	-13.07809178									
-1	13.9419	0.002489	99.0121	1	0.2456	0.2144				0.1194	-12.4383452									
-1	16.0351	0.008838	99.3645	1	0.2983	0.2117				0.1167	-12.1416959									
-1	15.1456	0.004053	97.7156	1	0.2646	0.2017				0.1067	-11.04939827									
-1	16.0018	0.008448	100.145	1	0.2408	0.1996				0.1046	-10.82129116									
-1	14.0809	0.004004	98.1654	-1	0.2989	0.1959				0.1009	-10.42046807									
-1	16.5915	0.013921	98.145	-1	0.2614	0.1957				0.1007	-10.39883242									
-1	15.8606	0.007513	100.678	1	0.1913	0.5953		0.4953	-61.85105468											
-1	15.0029	0.00398	99.0775	1	0.1888	0.2581		0.1581	-16.77239017											
-1	15.1805	0.004782	100.192	1	0.1674	0.2352		0.1352	-14.18916068											
-1	15.308	0.00484	100.557	1	0.1814	0.2257		0.1257	-13.13340251											
	14.2761	0.004171	98.1409	1	0.1189	0.2116		0.1116	-11.5833671											
	14.2748	0.002297	99.4183	1	0.1409	0.2061		0.1061	-10.98417978											

Figure 98*: Table on Google Sheets to filter candidates based on their equivalent width*

Activity 12.8: Compare the contributions from the optical, infrared and X-rays for candidates to classical TTauri stars (data from VST, 2MASS and XMM-Newton) for the Trumpler 14 region

Make use of the result obtained in Activity 12.7. If you have not completed this Activity, make use of the file in this link.

Through Activity 12.3 to 12.7 we have filtered a catalog containing 30964 sources to one containing 95 candidates, which meet the requirements of a CTTauri in terms of their Halpha emission, a sign of accretion.

As mentioned in Activity 6, the identification of CTTauri stars requires an excess of infrared (caused by the material in the accretion disk) and the emission of X-rays (caused by the accretion process).

We therefore have to find out which and how many of these 95 candidates really are CTTauri candidates. To do so we will be "matching" the catalog containing these Halpha emitting candidates (VST catalog) with an infrared catalog (2MASS) and an X-ray one (XMM-Newton). The match will check for similar coordinates (RA, DEC) shared between the three catalogs with a margin of error.

This matching process will be conducted with a software used by astronomers called TopCat. Follow the procedure in instructions or images:

PROCEDURE IN INSTRUCTIONS:

1. Retrieve the "candidates_final_r-Halpha_excess_EW" file in CSV format
2. Download TopCat onto your computer
   2.1. Access the web and download the adequate option for your computer (Topcat-full.jar)

2.2. Double click on the downloaded file and TopCat will install onto your computer. You are ready to proceed

3. Open TopCat
4. Load your “candidates_final_r-Halpha_excess_EW.csv” file you obtained in Activity 12.7. To do so on TopCat:
    4.1. Go onto the main menu and click on “File” → “Load table”
    4.2. Search for the CSV file on your computer and load it
5. Repeat step 3, selecting the “auto” format and load the “2MASStotal.fits” catalog obtained in Activity 12.2.2 from the 6 regions on Trumpler 14 selected in ESASky

You should now have two catalogues available on TopCat as shown in the procedure in images.

6. Click on the matching symbol and you will get a pop-up window
7. Select the catalogues you want to match, allowing an error between positions of 1.0 arcsec
    7.1. Select “candidates_final_r-Halpha_excess_EW.csv” as Table 1 and the “2MASStotal.fits” catalog as Table 2
    7.2. For the max error write down the value of 1.0 arcsec and click “Go”

You will obtain a new pop-up window specifying the number of matches found between both catalogues. A third catalog containing the matches will automatically show on your TopCat under the name “match(x,y)”

8. Click on “OK”
9. Select the matches catalog and click on the plotting icon. You will plot the (J-H) vs. (H-Ks) colour colour diagram to find out how many sources show infrared excess.
10. In the pop-up window you will see SOURCEID has been selected by default as the X axis and RA2000 for the Y axis. We will change this to obtain the colour colour diagram

10.1. Delete the SOURCEID on the X axis and instead write the expression “h_m-ks_m”

10.2. Delete the RA2000 on the Y axis and instead write the expression “j_m-h_m”

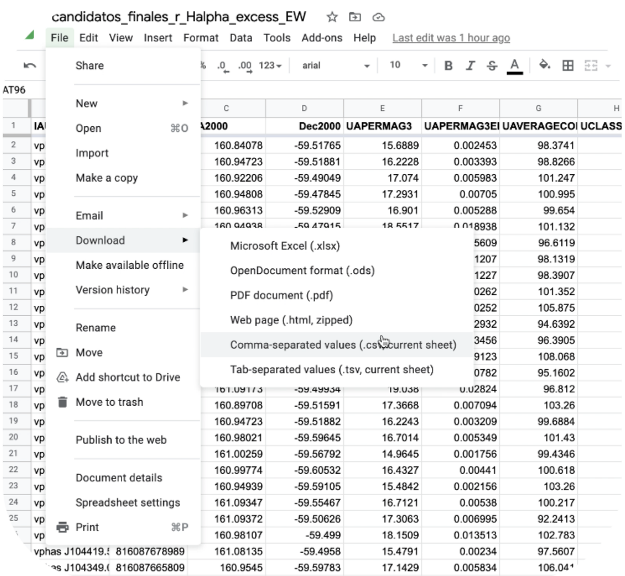
11. Click on “Form” and reduce the size of the dots to 2

12. Next draw the boundary curve after which sources are considered to show IR excess. This is done by selecting the line plotting symbol and writing down the expression 1.86*x - 0.12, x being the independent variable. Click enter to obtain the results

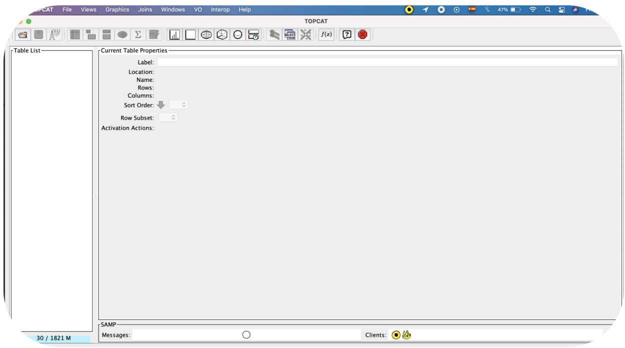
13. Save the plot to your computer by clicking on the “save” symbol

PROCEDURE IN IMAGES:

1.

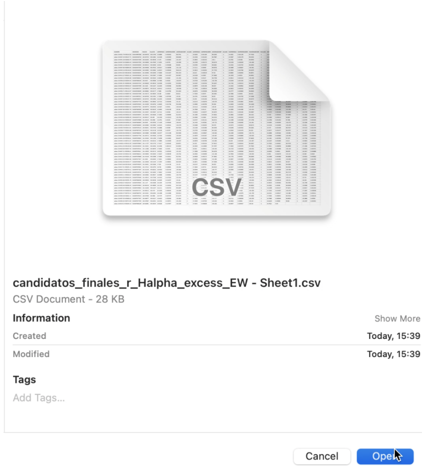


3.

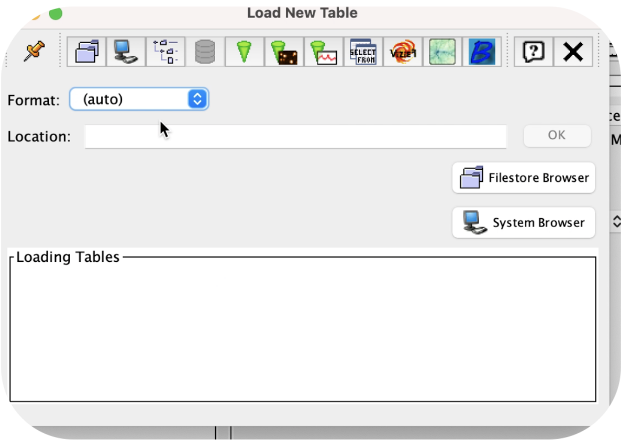


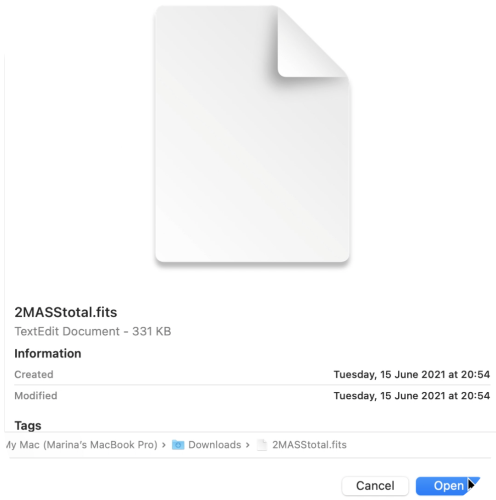
4.1

4.2


CSV
candidatos_finales_r_Halpha_excess_EW - Sheet1.csv
CSV Document - 28 KB
Information
Show More
Created
Today, 15:39
Modified
Today, 15:39
Tags
Add Tags...
Cancel
Open

5.


Load New Table
Format:
(auto)
Location:
OK
Filestore Browser
System Browser
Loading Tables


2MASStotal.fits
TextEdit Document - 331 KB
Information
Created
Tuesday, 15 June 2021 at 20:54
Modified
Tuesday, 15 June 2021 at 20:54
Tags
Downloads
2MASStotal.fits
Cancel
Open

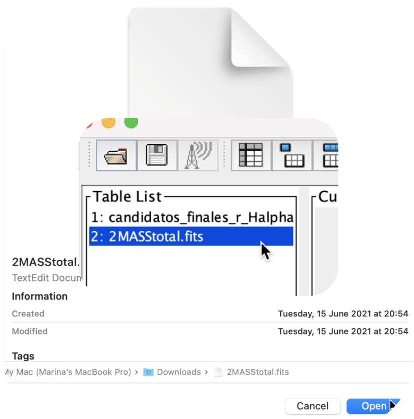
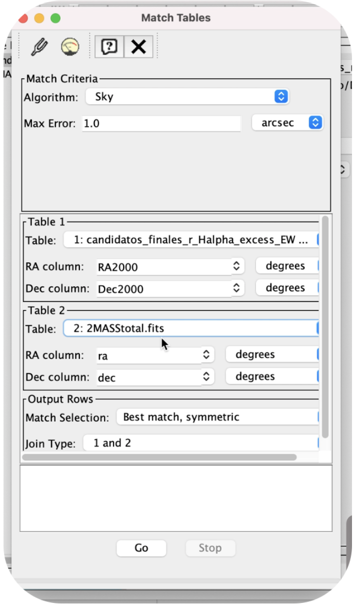


Table List
1: candidatos_finales_r_Halpha
2: 2MASStotal.fits
Information
Created
Tuesday, 15 June 2021 at 20:54
Modified
Tuesday, 15 June 2021 at 20:54
Tags
Cancel
Open

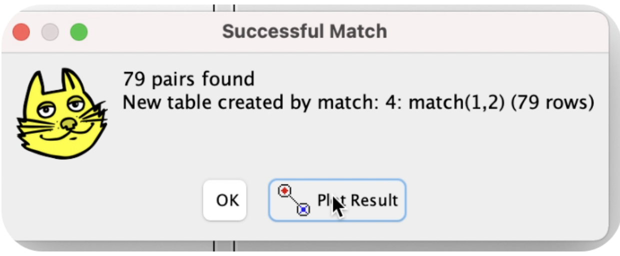
6.


TOPCAT

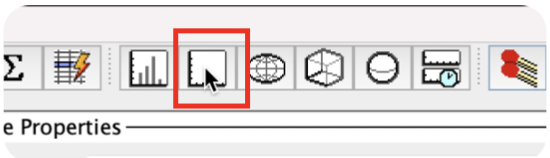
7.


Match Tables
Match Criteria
Algorithm: Sky
Max Error: 1.0 arcsec
Table 1
Table: 1: candidatos_finales_r_Halpha_excess_EW ...
RA column: RA2000 degrees
Dec column: Dec2000 degrees
Table 2
Table: 2: 2MASStotal.fits
RA column: ra degrees
Dec column: dec degrees
Output Rows
Match Selection: Best match, symmetric
Join Type: 1 and 2
Go
Stop

8.

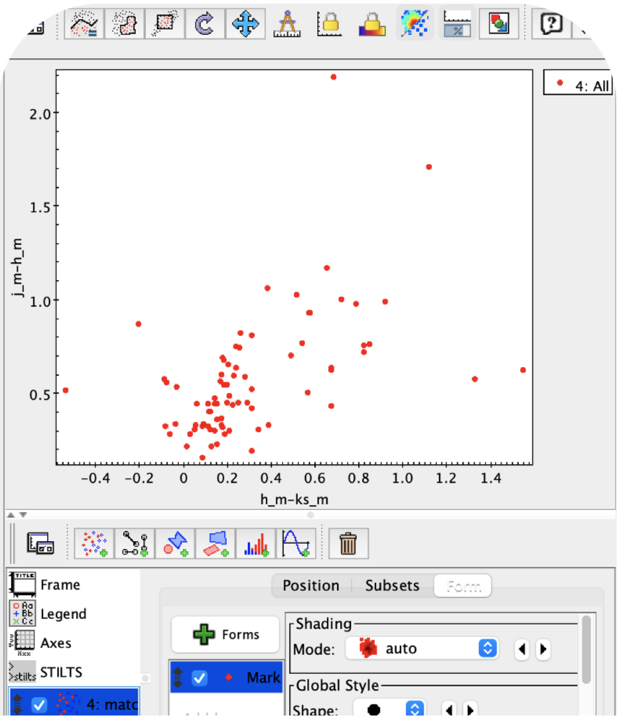

Successful Match
79 pairs found
New table created by match: 4: match(1,2) (79 rows)
OK
Plot Result

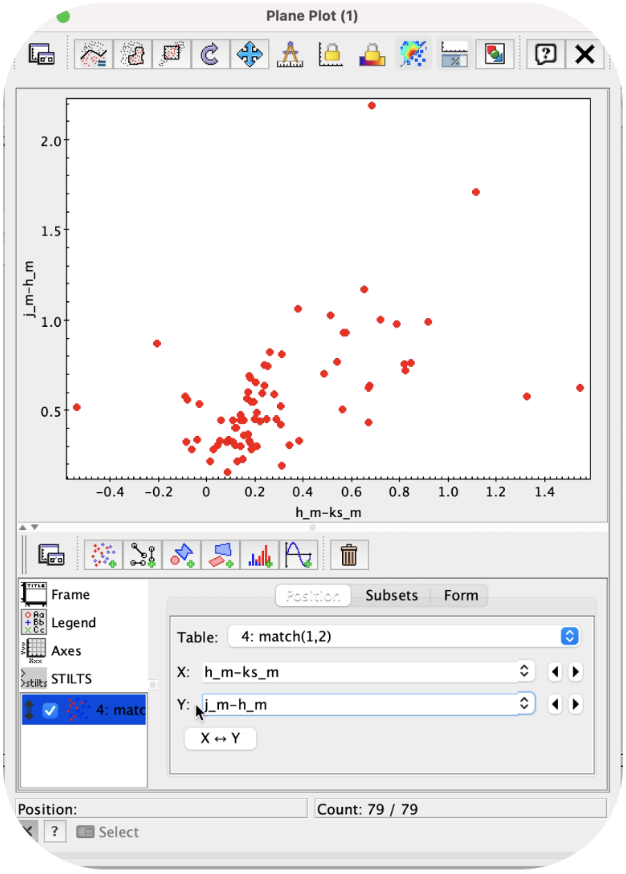
9.


e Properties

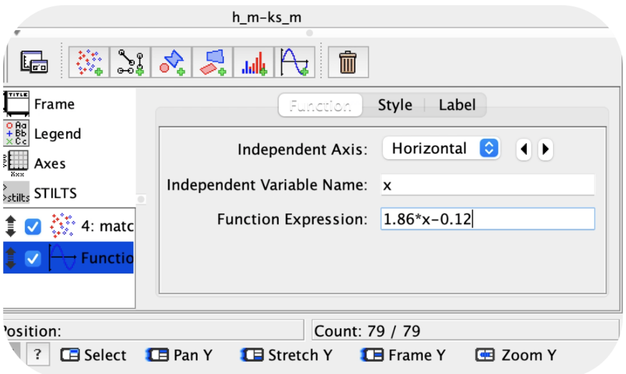
10.

11.

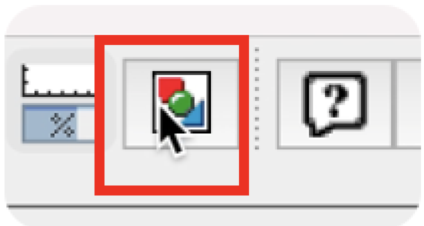

4: All
j_m-h_m
h_m-ks_m
Frame
Legend
Axes
STILTS
Position
Subsets
Forms
Shading
Mode: auto
Global Style
Shape:



12.



13.



How many of the sources show infrared excess?

Activity 12.8.1: Matching between the resulting catalog from VST & 2MASS with the XMM-Newton for the Trumpler 14 region

Video tutorial: link

Use the result obtained in Activity 12.8. If you have not completed this Activity, make use of the file in this link.

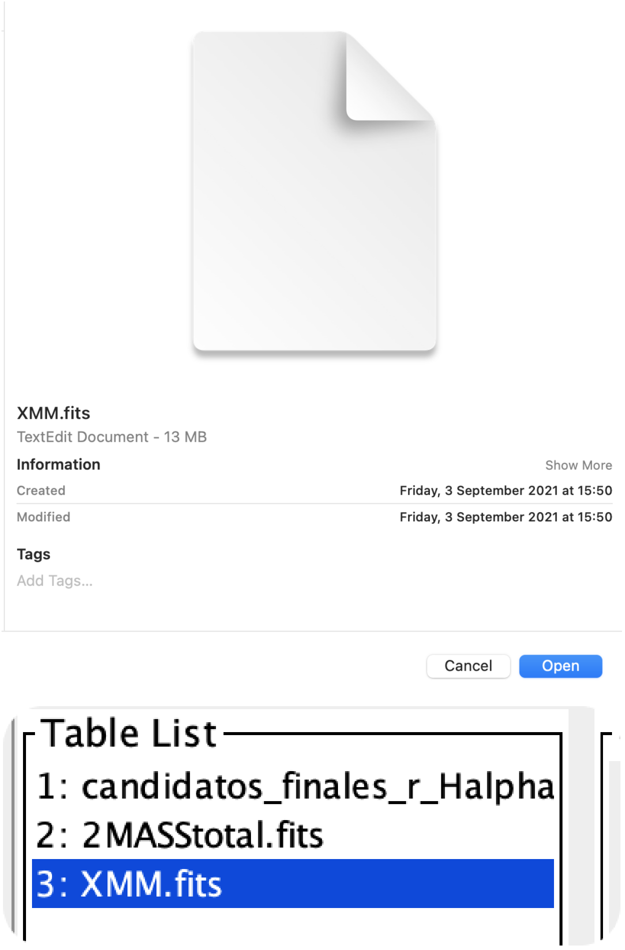
In Activity 12.8 we conducted the matching between catalogs offering information on Halpha emission (VST) and on infrared excess (2MASS).
In this Activity we will fine tune our selection of classical T Tauri candidates selection only sources which emit in X-rays.

PROCEDURE IN INSTRUCTIONS:

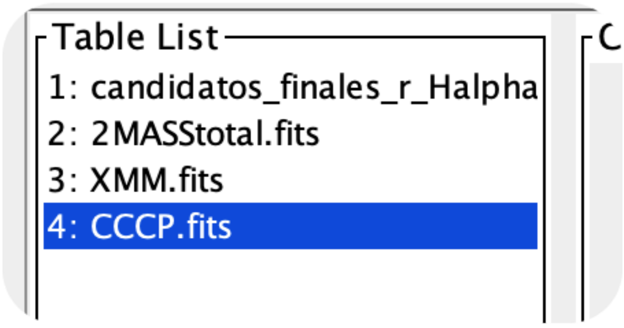
1. Load the “XMM.fits” file you obtained in Activity 12.1 from the XMM-Newton sources in Trumpler 14, on ESASky
2. Download the “CCCP.fits” file. This catalog is from the Chandra Carina Complex Project, carried out by Chandra, a NASA mission searching X-rays- The catalog contains sources in the Carina Nebula which have been found to emit X-rays and will add additional information onto your XMM catalog
3. Use TopCat to concatenate both catalogues (using the Joins option we saw in Activity 12.2.2) “CCCP.fits” and “XMM.fits”. Make sure to select RA and DEC as shown in image 3 on the procedure in images. Load both catalogs on TopCat using the “auto” format. The result between the concatenation is saved as “concat(x+y)”
4. Repeat steps 4 to 7 of Activity 10.8 together with the resulting matched catalog from said activity “match(a,b)” and the X-ray catalog “concat(x+y)”. This time use 2.0 arc seconds for the error between matches

PROCEDURE IN IMAGES:

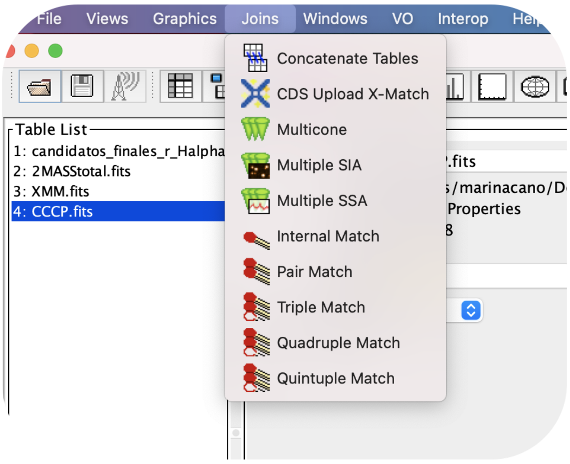
1.

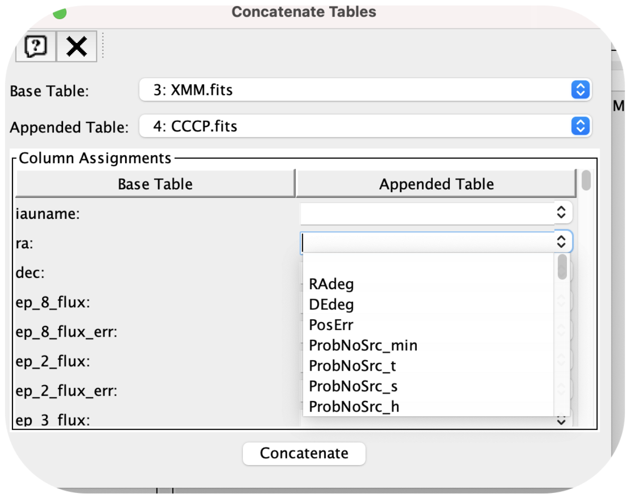


2.

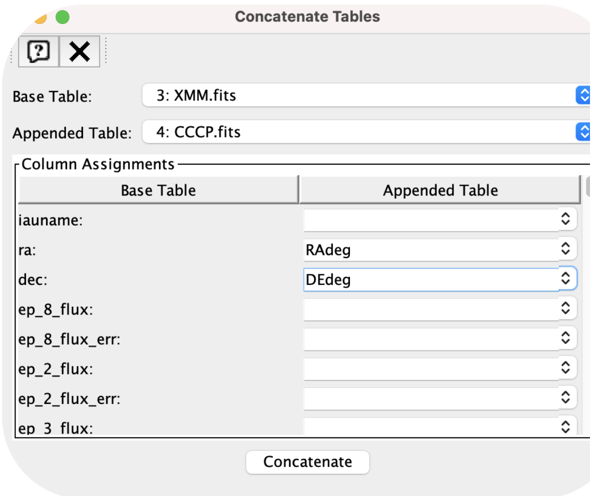


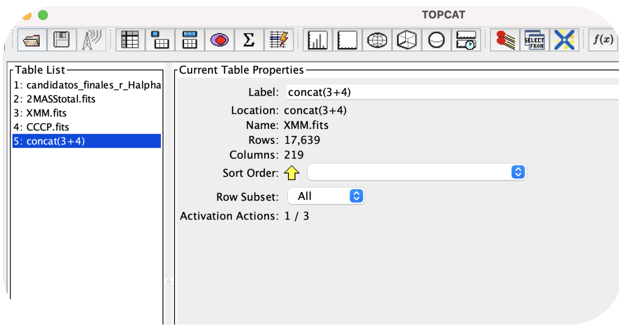
3.





4.





The final number of objects is the list of candidates with Halpha emission, infrared and X-ray. How many matches are there?

Plot the colour colour diagram again.

How many of the sources show infrared excess?

The next step is to check how many of these sources are at a reasonable distance to belong to the Carina Nebula. This will indicate the final sample of possible classical T Tauri stars.

To do so, the next and final step is to match our final catalog with GAIA.

Activity 13: Check whether your candidates are within the Carina Nebula (data from GAIA)

The number of matches will tell you how many sources in Trumpler 14 are emitting in Halpha, have an infrared counterpart and are also classified as X-ray sources. However, for this last match, you will also have to check which of these sources show infrared excess.

To do this, go onto ESASky and download the GAIA catalog for the Trumpler 14 region and repeat the matching on TopCat as explained in previous Activities.

Follow the procedure in instructions and/or images.

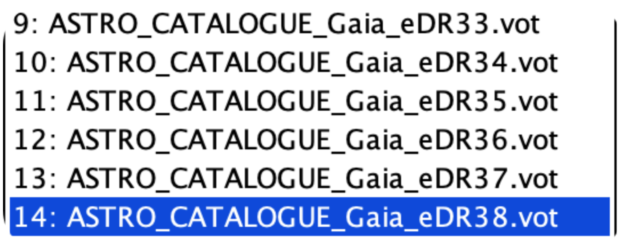
PROCEDURE IN INSTRUCTIONS:

1. Repeat steps 1 to 10 of the procedure on Activity 12.1, only in this case you want the GAIAeDR3(optical) catalogue. Download the same six regions as for 2MASS and save in VOT format

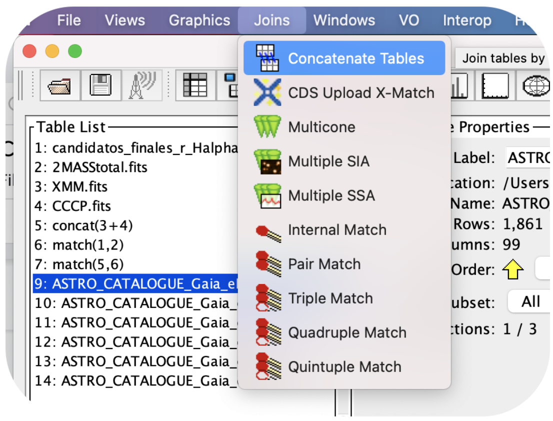
2. Repeat steps 1 to 3 of the procedure on Activity 12.2.2 and merge these catalogues on TopCat. [You should have a final sample of 7646 GAIA sources].
3. Repeat steps 6 to 7 of the procedure on Activity 12.8 and do a match between the candidates & 2MASS & XMMtotal catalogue with that of GAIA for a 1.0 arcsecond error.

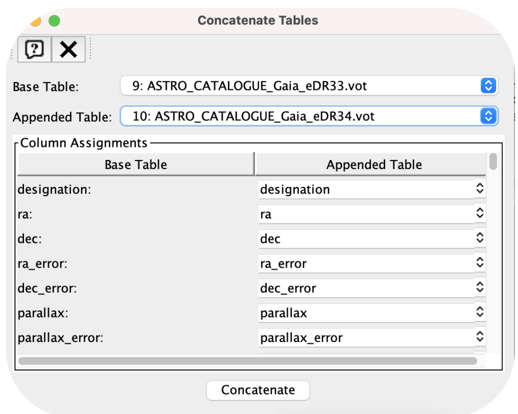
PROCEDURE IN IMAGES:

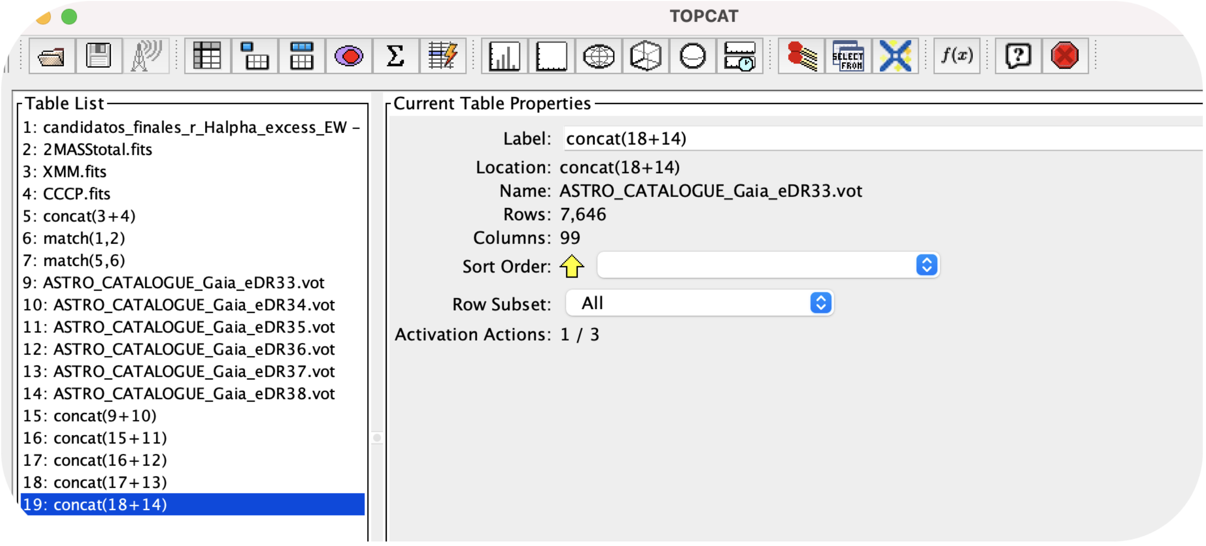
1.



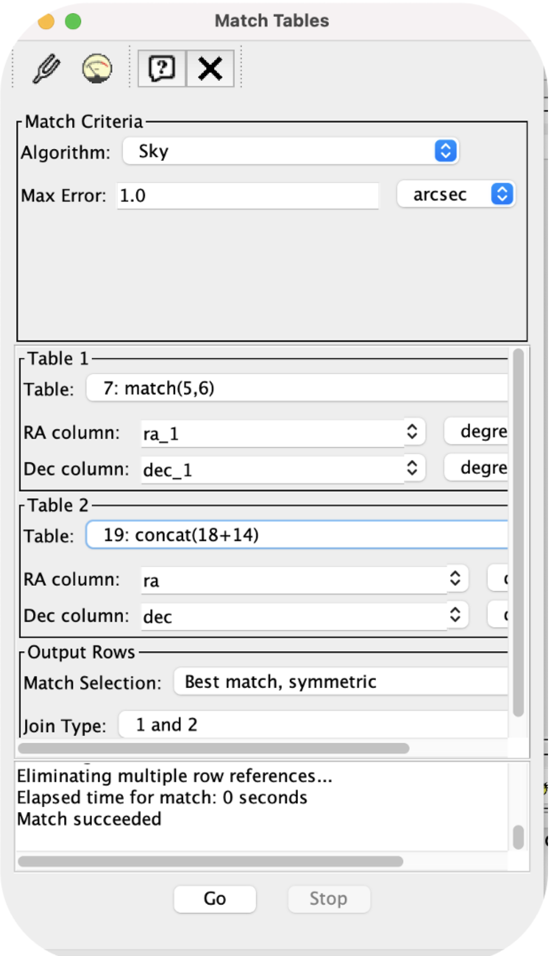
2.







3.



How many matches do you obtain?

Plot the (J-H) vs (H-Ks) colour colour diagram with the limiting function (y = 1.86x - 0.12 to identify how many of these sources display infrared excess.

Just from looking at the plot, how many do you see have infrared excess?

Now that we know how many of the sources show Hα emission, have infrared excess and are detected in the X-ray, we need to calculate the distance to these sources by using the data provided by GAIA.

You will now calculate how far these sources are from Earth to inspect whether they are actually in Trumpler 14 (and in the Carina Nebula) or not. In order to find out whether a source is within a nebula, astronomers estimate the distance to each source via their parallax and compare it to the estimated distance to the entire nebula. Those stars with a similar distance as the one estimated for the cloud have a high chance of actually belonging to it, and those that do not are probably just in the field of view.
GAIA provides such parallax measurements which you will now use.

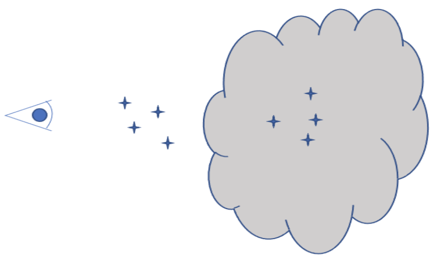
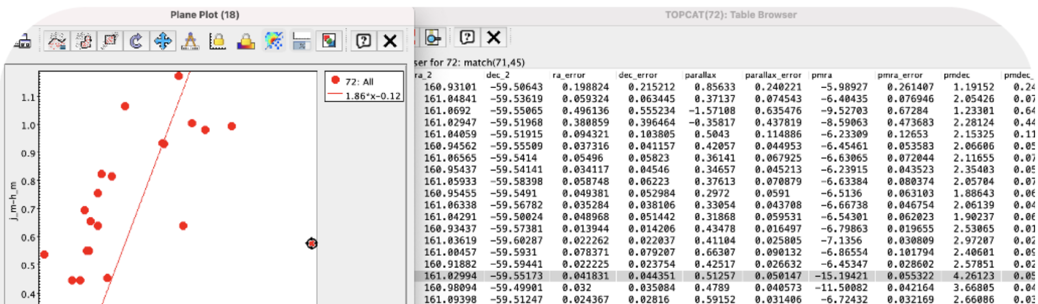


Figure 99: Foreground stars in the field of view between the observer on Earth and a molecular cloud.

Take a look at the final catalogue you have obtained and inspect the parallax (given in milliarcseconds (mas)) of the 7 sources you have found to show infrared excess.
Tip: By selecting the different data points you will be able to obtain the corresponding row on the catalogue.



Out of the 7 sources, two may be disregarded due to their parallax. Can you identify these two? Remember parallax is a measure for distance!

This means we are left with 5 sources of interest.

Write down the parallaxes of these 5 sources:

To calculate the distance to these sources, convert from milliarcseconds to pc.

Hint 1: Convert milliarcseconds to arcseconds

Hint 2: Remind yourself of the definition of a parsec in Activity 2.2

Stars in the Carina Nebula are expected to lie between **2200 pc** and **2800 pc**.

From your results, how many sources do you think are classical T Tauri stars within the Carina Nebula?

Write down their source ID, RA, DEC, J mag, Ks mag, H mag, r mag, Halpha mag, i mag and distance, and identify them on the (J-H) vs (H-K) and (r-Hα) vs (r-i) colour-colour diagrams you plotted previously.

FEATURES		

***Table 10**: Information on the final candidates*

Activity 14: Visualize the sources with SIMBAD/Aladin Lite

Now that you have identified your two potential classical T Tauri stars within Trumpler 14, in the Carina Nebula, you can check whether these objects have already been identified before in previous studies. To do this go onto SIMBAD, an astronomical database, following this link:http://simbad.u-strasbg.fr/simbad/sim-fcoo.

Enter the coordinates of the sources without the comma separation and with a defined radius of 2 arcseconds, as shown in Figure 100.

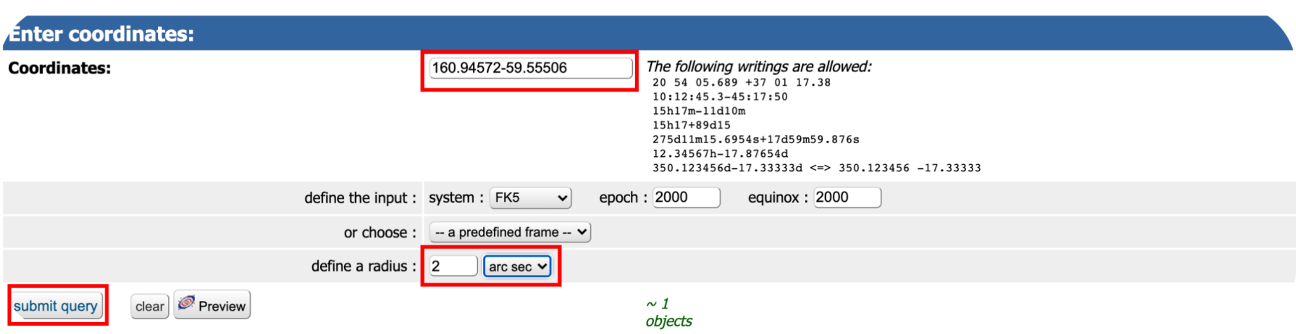


Figure 100: Search of Source 1 on SIMBAD

Once you have searched your source, you can visualize it on the right-hand side (thanks to AladinLite) , selecting the 2MASS option and zooming in with your mouse.

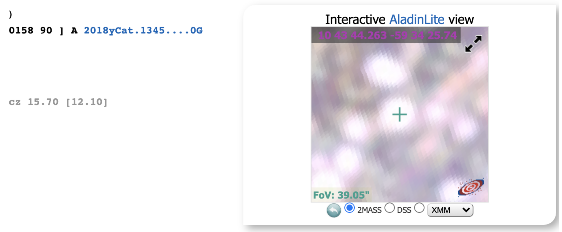


Figura 101: Visualización de fuentes en SIMBAD con la opción 2MASS.

SIMBAD will provide the following information about a source:

Figura 102: Information obtained on SIMBAD

as well as:

- the names assigned to a source under the section “Identifiers”
- the scientific publications on the source, under “References”

1. What information can you obtain about the final candidates? Fill in the spaces below:

<u>Source 1</u> Name: Classification: Parallax: Magnitude in R band: R-I colour:	AladinLite image:

<u>Source 2</u> Name: Classification: Parallax: Magnitude in B band: B-V colour:	AladinLite image:

2. Search for these sources on ESASky, obtain an image of them and paste it here. Review how to use ESASky on [Activity 11.1](). Si te acuerdas:
   2.1. Search the sources via their coordinates, without writing the coma
   2.2. Change the filter on ESASky to "Near infrared"

Source 1: Source 2:

3. Name a study or publication conducted about these sources by writing down the title of the publication and the date. To do so follow the procedure

PROCEDURE IN INSTRUCTIONS:

   3.1. Once you have located your source, zoom in for better a view

3.2. Click on the hat symbol and you will see sources appearing in publications appear with a circle

3.3. Click on your source

3.4. This will show the publicational on the first column, the authors in the second column, the journal in which it was published in the third and the date in the last column

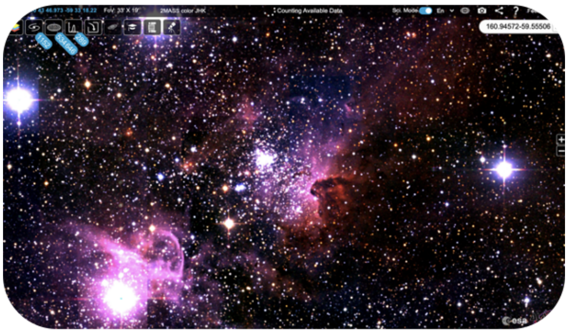
3.5. Fill in Table 11 with the information about your sources

Source	Title of publication	Date
1		
2		

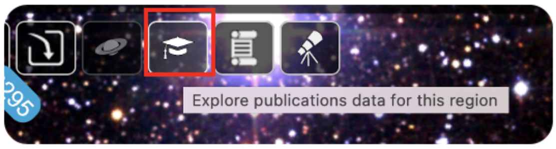
Table 11*: Publications featuring sources 1 and 2, information retrieved from ESASky*

PROCEDURE IN IMAGES:

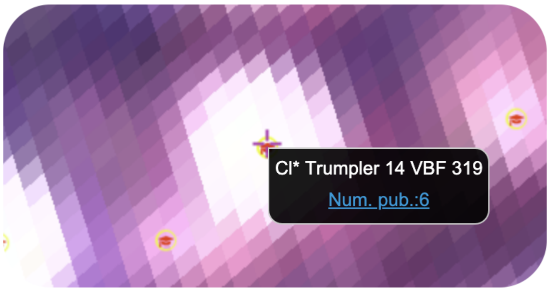
3.1.



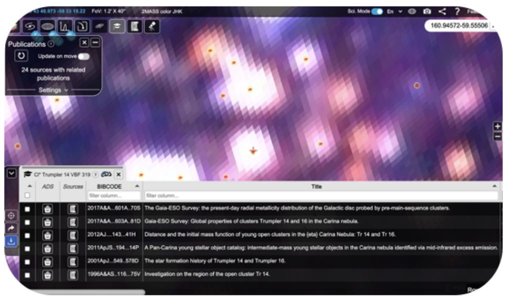
3.2.



3.3.



3.4.



Phase 4

Activity 15: Write a scientific publication

Once you have completed your research, it is now time to explain your method and results obtained. To do this, write up your findings in the format of a scientific paper, just like a researcher would do.

Title: It should contain summary information about your research. At the same time, it should be a title that catches the attention of those who read it.

Team members: Write the names of the team members in this format: ***Last Name, First Name***

Summary:

Summarizes the objective of this research, the results obtained and how this study contributes to the scientific community.

Introduction:

Introduce basic concepts of your study. Explain the type of object you are looking for (stars in the process of formation) and the region you are investigating (Trumpler 14, inside the Carina nebula).

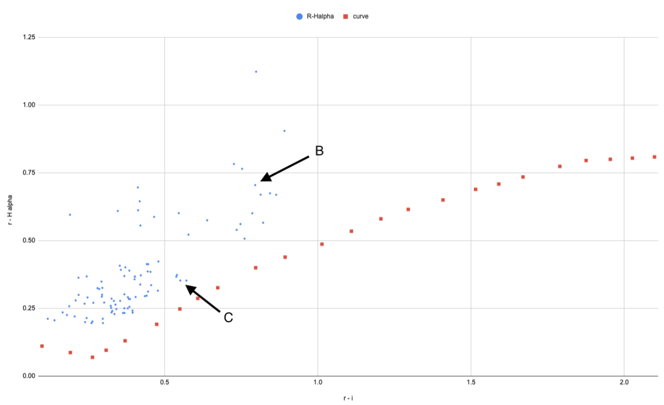
Observations:

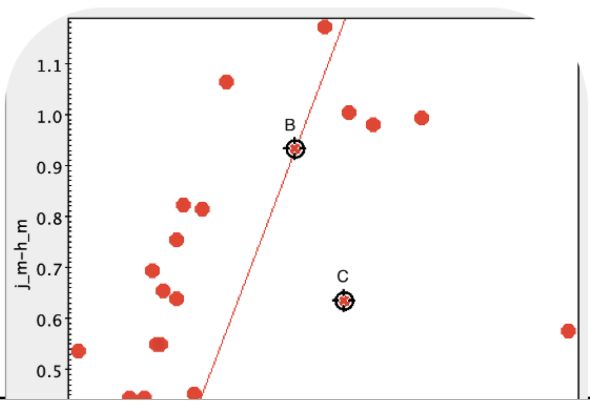
In this section describe the type of data you are going to use for your research, including the sources of these data. The idea is that anyone reading this publication will be able to reproduce your work later.

Analysis of the data:

Explain the results you have obtained and the procedure to reach them.

Relevant graphics which should definitely be included in this section are:





P.S: don't forget to write captions for the figures!

Conclusion:

Explain the conclusions you draw from your results.

Bibliografía:

Make reference to any material you may have used for information such as web pages, scientific publications, etc.

Title:

Team members:

Summary:

Introduction:

Observations:

Analysis of data:

Conclusions:

Bibliography:

Congratulations!

- **You have completed the Scientific Challenge!**
- **Tell us your story!**

Think about your experience with your team and teacher and complete these Activities.

Activity 16: Congratulations! You have achieved your goal

- **In teams**: complete this quiz to check your understanding of this Scientific Challenge
- **With your teacher**: give us feedback

Activity 17: Present your results

Students should create a final product (an A0 poster in pdf, using powerpoint for example) and explaining what they have learned in the different phases of the Scientific Challenge.

This poster is the ticket to participate in the International *CESAR Adventures* contest.

Links

LINKS FOR PHASE 0:

https://kids.britannica.com/kids/article/Katherine-Johnson/628677

https://www.nytimes.com/2016/12/27/science/vera-rubin-astronomist-who-made-the-case-for-dark-matter-dies-at-88.html

https://www.esa.int/kids/en/learn/Life_in_Space/Astronauts/Samantha_Cristoforetti

https://es.wikipedia.org/wiki/Marie_Curie

https://es.wikipedia.org/wiki/Steve_Wozniak

https://www.famousbirthdays.com/people/matt-taylor-scientist.html

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