GMN Outreach Project

Module Astronomy

27.2.2024

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The Global Meteor Network

What you will find in this module

In this module, you will find some basics of astronomy and the means of observation. Firstly, you will learn about optics and telescopes, don't forget that every camera contains some optics called lens. The second topic in this module is meteor science as that is what our cameras care for, meteors and meteorites. And we calculate where they came from and we try to find the parent body. You will learn how to navigate in the night sky, so you'll be able to find what you are looking for among thousands of stars.

What are you going to learn?

Introduction to optics and telescopes

In this topic, you will learn about the most commonly used telescope designs, how their internal optics are assembled, and the pros and cons of each telescope type. You will learn how to calculate the focal ratio of a telescope, how to calculate the magnification of a telescope/eyepiece combination and how you can change the focal length and focal ratio of telescopes using Barlow lenses and focal reducers. Finally, you will learn about the different basic telescope mounts and the importance of choosing the correct mount for your needs, including the pros and cons of Altitude-Azimuth and equatorial mounts.

Meteor science

In the Meteor science topic, you will learn all about meteors. You start with our Solar system and what it contains focusing on which small bodies are the source of meteors. Then you will learn what they consist of, how they burn, and what they produce in our atmosphere. The last will be meteor showers and fireballs. In the end, you will find references, a list of meteor showers whose parent body is known and a glossary.

Navigating the night sky

The night sky fascinates mankind from the dawn of mankind, it is sown with the stars. Depending on the light pollution of your area you can see thousands of stars in the night sky, so how to find what you are looking for? In this topic, you will learn about constellations, asterisms, the motion of the night sky, solstices, the moon and its phases and orbit, planets and finally how to navigate in the night sky with and use stars and constellations.

Who prepared the module

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Introduction to optics and telescopes

In this topic you will learn about the most commonly used telescope designs, how their internal optics are assembled, and the pros and cons of each telescope type. You will learn how to calculate the focal ratio of a telescope, how to calculate the magnification of a telescope/eyepiece combination and how you can change the focal length and focal ratio of telescopes using Barlow lenses and focal reducers. Finally, you will learn about the different basic telescope mounts and the importance of choosing the correct mount for your needs, including the pros and cons of Altitude-Azimuth (commonly referred to as Alt-Az) and equatorial mounts.

Introduction

When you first start to do observational astronomy, binoculars offer many advantages; they are lightweight, easy to use and they help you to learn and navigate the night sky. However, there are many benefits to upgrading to a telescope:

- Greater magnification
- Changing eyepieces is simpler, allowing you to observe at different magnifications
- Different telescopes are better for different objects so you can customize more easily
- You can easily mount a telescope onto a tracking mount that has Go To functionality
- Telescopes are easier for astrophotography

The telescope was invented in 1608 with the invention often credited to Hans Lippershey, a spectacle maker from The Netherlands, although Janssen and Metius also claimed to have independently made the discovery. Galileo improved this first telescope design and used it for astronomical observing. These early models were refracting telescopes, but Isaac Newton is credited with building the first reflecting telescope in 1668. Telescopes have continued to evolve since then and there is now a huge variety of different telescope designs available.

Basic telescope types we will cover are:

- Refractor
- Newtonian Reflector
- Classical Cassegrain
- Ritchie-Chretien (RC)

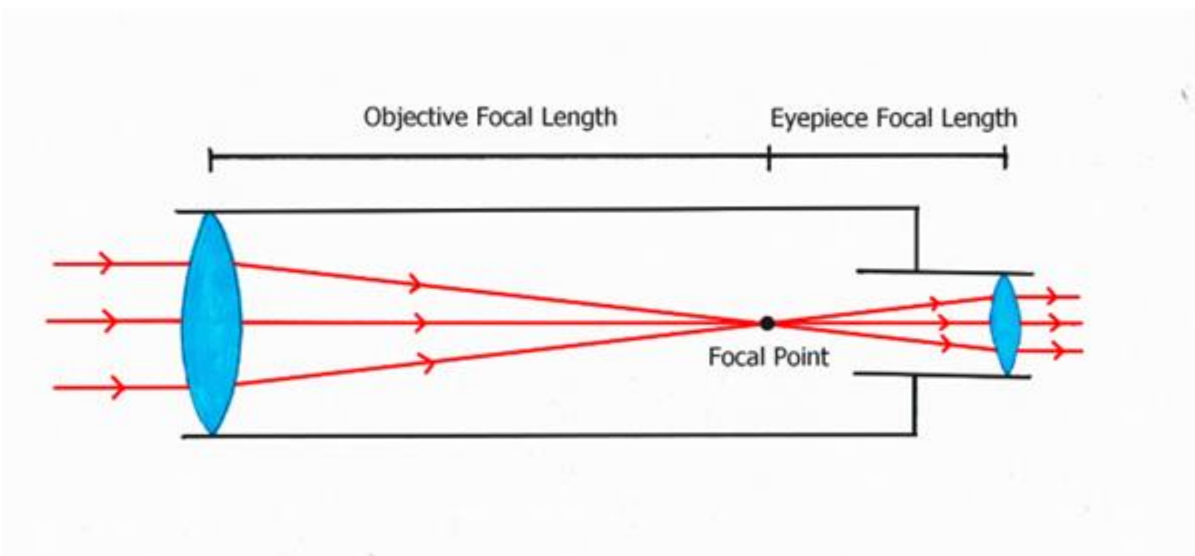
- Schmidt-Cassegrain (SCT)

Refractors

Achromatic Refractors

The simplest refractor design has a concaved glass lens – known as a dioptric - at one end, and this brings the parallel beams of light to focal point somewhere inside the telescope tube. This design is known as an achromatic refractor. The distance between the lens at the end of the tube and the focal point is the focal length of the telescope.

A concave glass lens in the eyepiece at the other end then brings those light beams back to parallel so your eye can observe them. Because the beams of light cross over at the focal point, the image you see in the eye piece will be upside down. The distance from the focal point to the eyepiece lens is the eyepiece focal length.

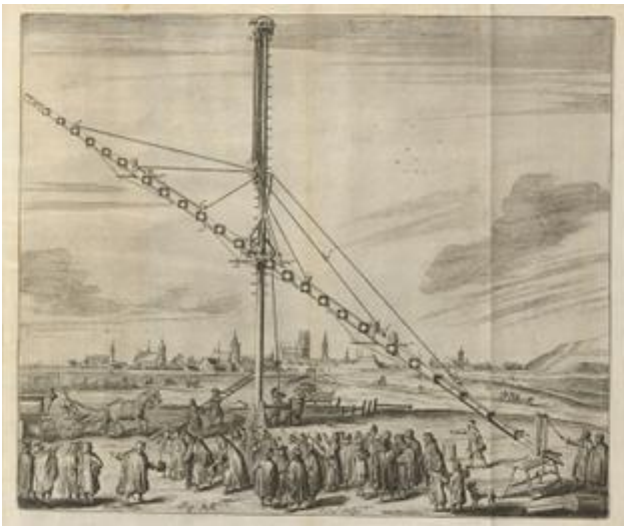


The problem with this simple design is that the three primary colours of light do not focus at exactly the same spot, so objects viewed through the telescope will have colour fringes around them. This is called chromatic aberration and it will show up on photographs as bluish-purple haloes around the stars or coloured fringes around the edge of the Moon.

These can be reduced to an extent by photography post-processing, so if all you have access to is an achromatic refractor, please just use it!

Two photos of Messier 31 The Andromeda Galaxy. The upper photo was taken with an achromatic refractor which suffers from chromatic aberration so the stars all have blue haloes. The bottom photo was taken with an apochromatic refractor, which has corrective lenses that remove this effect

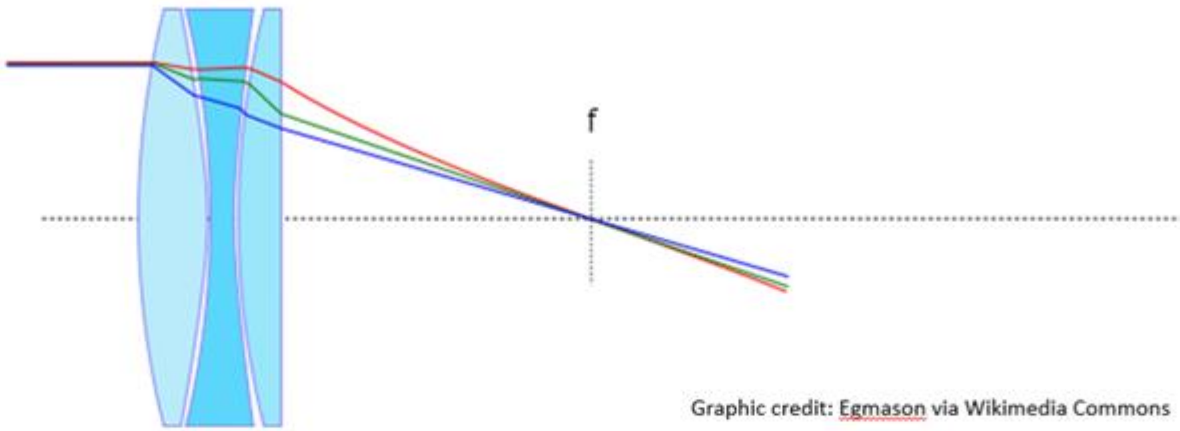
One way that early astronomers tried to counter chromatic aberration was to make refractors with very long focal lengths. The telescope that Giovanni Cassini discovered Saturn's moon Rhea which had a focal length of 35 feet / 11 metres, and many vintage refractors required large telescope domes to house them. An extreme example belonged to Johannes Hevelius, who built a telescope with a focal length of 150 feet / 46 metres, and it was so long that it needed support masts to prevent the long tubes from flexing or collapsing altogether!



Engraved illustration of the 46 metre / 150 foot focal length refractor made by Johannes Hevelius circa 1673. Credit Houghton Library, Harvard University

Apochromatic Refractors

Modern refractors utilise extra-low dispersion (ED) materials and sandwich two or three lenses together which results in all three wavelengths of light reaching focus at the focal point, so this removes chromatic aberration. Refractors with two lenses are called doublets, those with three lenses are called triplets. Doublets and triplets are quite a lot more expensive than traditional non-ED refractors because of higher production costs, but they are a much better option for astrophotography.



Most refractors intended for visual astronomy will have a diagonal prism at the eyepiece end that bounces the light up by 90 degrees. This allows for more comfortable observing without having to strain your neck, especially when observing objects that are high in the sky.

Comparison of visual astronomy using a refractor with and without a diagonal.
It is much more ergonomic to do visual observing with a diagonal in place.

<u>Advantages of Refractors:</u>

- They give a wide field of view which is ideal for larger objects, especially when imaging large nebulae
- They are low maintenance
- They are very portable, especially the modern short-tube refractors
- Apochromatic doublets/triplets give excellent results for imaging
- No star spikes when imaging because there are no obstructions in the design

<u>Disadvantages of Refractors:</u>

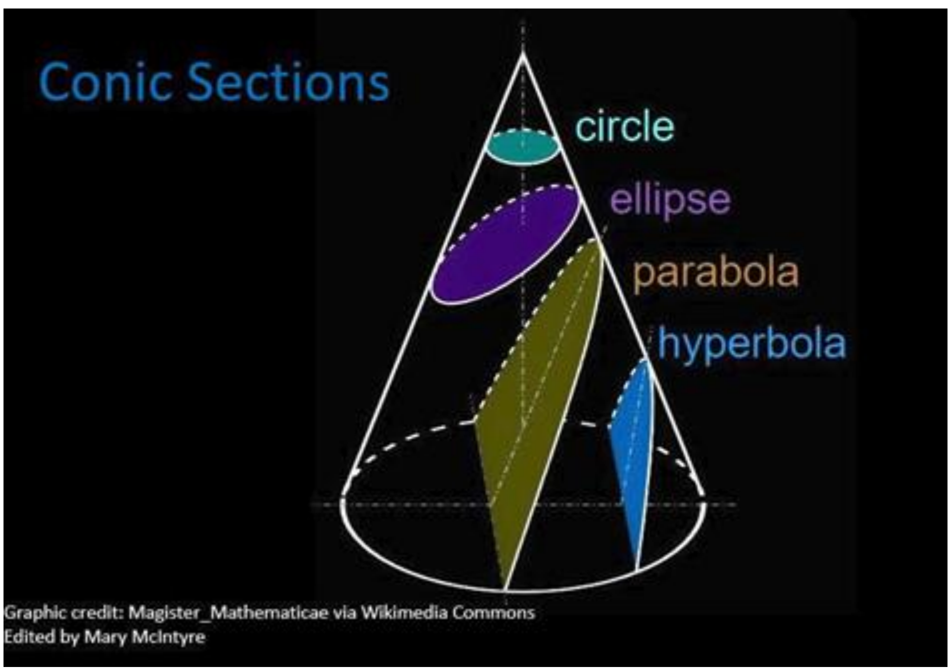
- Larger aperture refractors need extremely long tubes

- The aperture is limited to 100cm because the weight of the glass causes distortion to the lens
- Apochromatic refractors are heavier than achromatic refractors

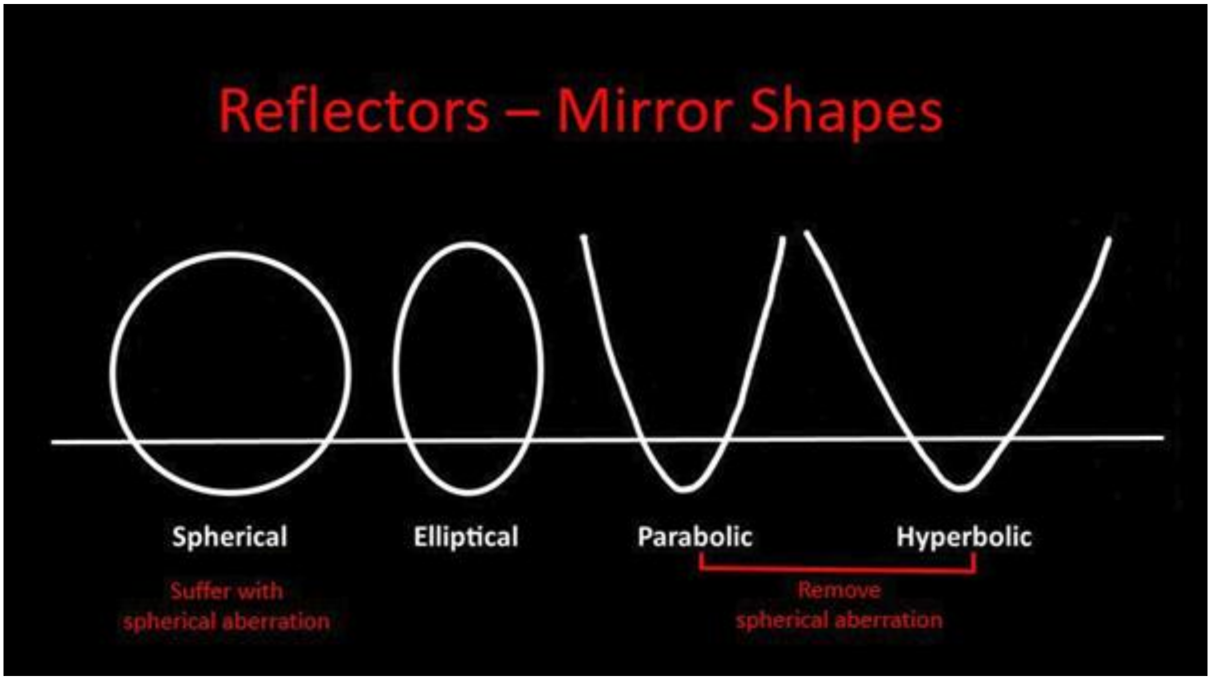
Reflectors

All reflecting telescopes contain mirrors, and are sometimes called catoptric telescopes. Photons of light enter the telescope tube and are then reflected off the primary mirror at the bottom of the tube. The primary mirror will focus the light so it then hits a much smaller secondary mirror which then sends the light to the eyepiece.

Primary mirrors can be a variety of different shapes; spherical, elliptical, parabolic or hyperbolic. These shapes are described as "conic sections". If you imagine a solid cone and you take slices through it at different angles, the resulting shapes will be one of the conic sections just described.



The shape of mirrors is more subtle than this, but the exaggerated diagrams below help to show you the basic profile.

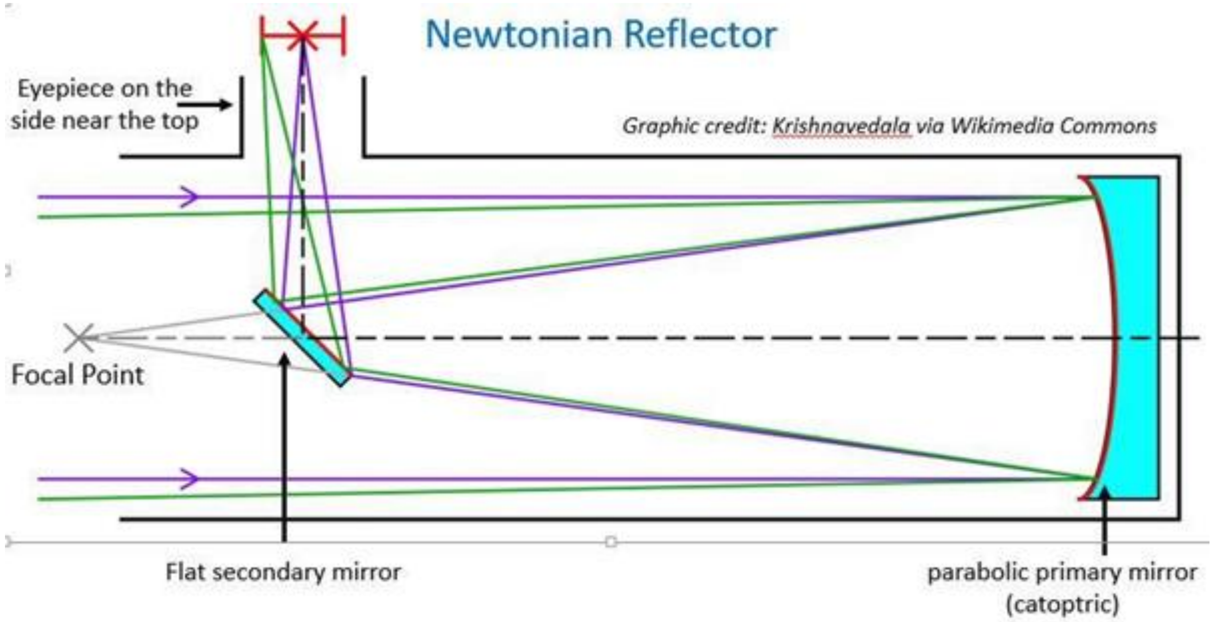


The mirrors are carefully ground from glass blanks into these shapes. By far the easiest and therefore most economical mirror to make is a spherical mirror, but these suffer with spherical aberration. This is caused by some light rays not focusing in exactly the same place and this leads to a fuzzy image. Parabolic and hyperbolic mirrors do not suffer with spherical aberration.

Secondary mirrors are much smaller than the primary mirror and they can be a variety of different shapes.

Newtonian Reflector

The simplest design of catoptric telescope is a Newtonian reflector named after Sir Isaac Newton who constructed the first model in 1668. The primary mirror is parabolic, and the diameter if this mirror is the aperture of the telescope. The focal length is the distance from the primary mirror to the focal point, which is actually located beyond the secondary mirror. The secondary mirror is flat and is held in place in the middle of the top end of the tube by a cross-shaped truss called the spider. The secondary mirror catches the light rays before they reach the focal point and directs them up into the eyepiece, which is located on the side of the telescope tube, somewhere near the top.



Advantages of Newtonian Reflectors:

- Because only one surface needs to be accurately polished, you can get the largest aperture for your budget
- There is no light lost due to absorption by glass lenses
- There are no glass lenses therefore no chromatic aberration issues

Disadvantages of Newtonian Reflectors:

- Because of the open tube, the telescope needs time to adjust to ambient temperature before use, otherwise the warmer air currents inside the tube can affect the telescope performance
- The spider assembly obscures some of the light so bright stars have diffraction spikes and ring flares (some people think this is actually an advantage!)
- Some stars may be “coma” shaped around the edges, but a coma corrector can fix this
- These telescopes need regular collimation to keep the images sharp
- The open tube design means the mirror can get dirty
- The larger the aperture is the longer the tube will be, so you may need a ladder to look through the eyepiece
- Many Newtonians need a 2x Barlow lens in place to achieve focus when a camera is attached. This adds contrast and works well for lunar and planetary imaging, but every doubling of magnification halves the amount of light hitting the camera so it’s

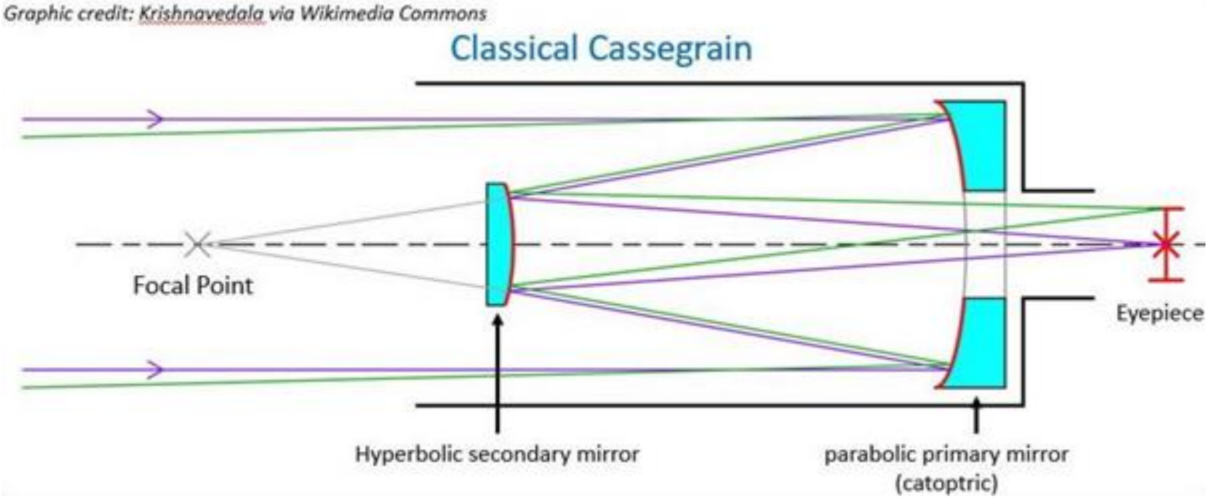
not ideal for faint deep sky object imaging. However, larger apertures can have good enough light gathering that you can get away with it

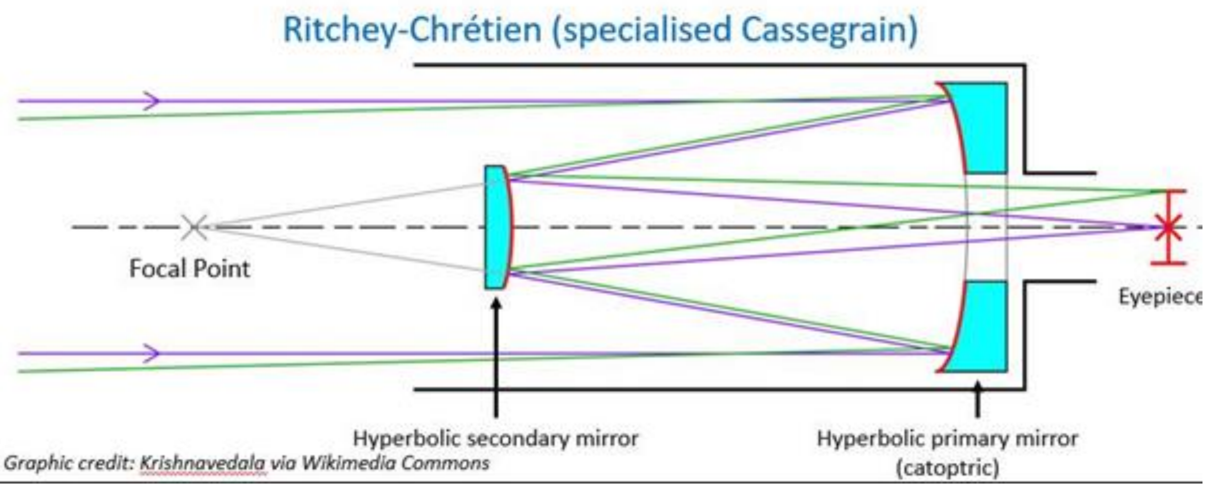
Classical Cassegrain and Ritchie-Chretien

Classical Cassegrain telescopes are a type of reflecting telescope that utilizes a so called "folded mirror" design. Like a Newtonian, these telescopes have an open tube with a parabolic primary mirror. The big difference is that the primary mirror has hole in the centre. The secondary mirror is hyperbolic and is held in place by a spider, and the light is reflected off the secondary mirror and back down through the hole in the primary mirror and to the eyepiece which is located on the back of the tube. This focal point of these telescopes is a long way outside of the tube, so the design packs a long focal length telescope into a short tube design.

Ritchie-Chretien (RC) telescopes are a type of specialised Cassegrain. Their design is very similar to the classical Cassegrain but the primary mirror is hyperbolic.

Graphic credit: Krishnavedala via Wikimedia Commons





Graphic credit: Krishnavedala via Wikimedia Commons

<u>Advantages of Classical Cassegrain and Ritchie-Chretien telescopes:</u>

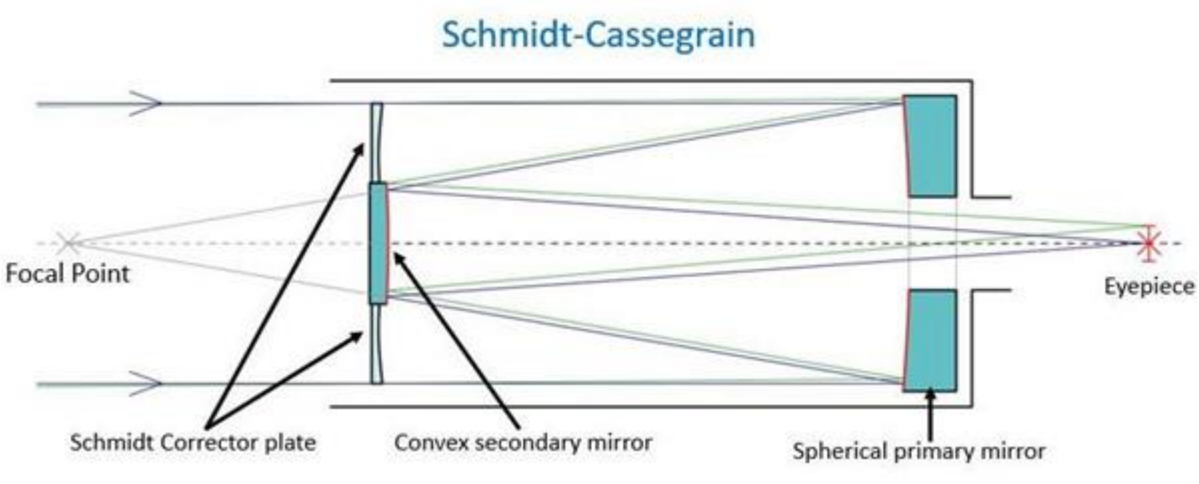
- The "folded mirror" fits a very long focal length telescope into a short tube
- Ritchie-Chretien telescopes are completely free of spherical and coma aberration
- Almost all professional telescopes these days are Ritchie-Chretien

<u>Disadvantages of Classical Cassegrain and Ritchie-Chretien telescopes:</u>

- The open tube design means the mirror can get dirty
- Because of the open tube, the telescope needs time to adjust to ambient temperature before use, otherwise the warmer air currents inside the tube can affect the telescope performance
- Regular collimation is required
- The spider assembly obscures the incoming light, leading to star spikes
- Most telescopes of this design are optimised for imaging rather than visual astronomy

Schmidt-Cassegrain Telescopes

Schmidt-Cassegrain telescopes (SCTs) are referred to as "Catadioptric" because they use both curved mirrors (catoptric) and lenses (dioptric). Like the classical Cassegrain and RC telescopes, they utilize a folded mirror design in a short tube. The primary mirror is spherical and it has a hole in the centre. They have a secondary mirror which is convex and this reflects the light back through the hole and to the eyepiece at the back of the telescope. Spherical primary mirrors suffer with spherical aberration but the front of the telescope is fitted with a transparent corrector plate that corrects the light on its way into the telescope and corrects the aberration. The secondary mirror is located in the centre of this corrector plate so there is no spider required.



Graphic credit: Griffenjbs via Wikimedia Commons

Advantages of SCTs:

- No spider means there is no obstruction of light on the way into the telescope and therefore no star spikes or lens flare effects
- Spherical mirrors are much easier and cheaper to manufacture so you can get a large aperture for a reasonable price
- The secondary mirror acts as a field flattener
- The corrector plate means the inside of the telescope is sealed and this keeps the primary mirror clean

Disadvantages of SCTs:

- Focussing is achieved by moving the entire mirror
- These telescopes can suffer from “mirror flop” when slewing
- They require regular collimation

Understanding Technical Specifications of a Telescope

The focal ratio or f/number of a telescope is a measure of how fast the telescope gathers light. This is calculated by dividing the focal length by the aperture

<u>Example 1:</u>

A telescope with a focal length of 1,000mm and aperture of 200mm

1,000 / 200 = f/5

<u>Example 2:</u>

A telescope with a focal length of 3,190mm and aperture of 356mm

3,190 / 356 = f/11

A lower f/number is better for imaging faint deep sky objects that require a lot of light gathering, the lower the f/number the ‘faster’ the telescope but a higher f/number has better contrast and is better for imaging bright objects like the Moon and planets.

It is possible to change the focal length of your telescope. A magnifying Barlow lens can increase the focal length, for example a 2x Barlow will increase an f/5 telescope to f/10; a 3x Barlow will increase an f/5 to f/15 and so on.

Conversely, a focal reducer will reduce the f/number of your telescope. For example a 0.5x reducer will change an f/15 telescope to f/7.5; a 0.7 reducer will change an f/15 to f/10.5.

Eyepieces

For visual astronomy there are huge numbers of different eyepieces available. An eyepiece will take the image from the telescope and magnify it. The eyepieces come in different focal lengths, for example 6mm, 10mm, 15mm, 20mm and so on. The shorter the focal length of the eyepiece, the more magnification you get. You can also use Barlow lenses to even further magnify the view, but remember that more magnification equals less light getting through to your eye so if you’re looking at an object with low surface brightness, more magnification is not always better.

To calculate the magnification you’re getting with a telescope and eyepiece combination, you divide the focal length of the telescope by the focal length of the eyepiece.

Example 1:

Telescope focal length 1,200mm + 20mm eyepiece

1,200 / 20 = 60 x magnification

Example 2:

Telescope focal length 1,200mm + 6mm eyepiece

1,200 / 6 = 200x magnification

Telescope Mounts

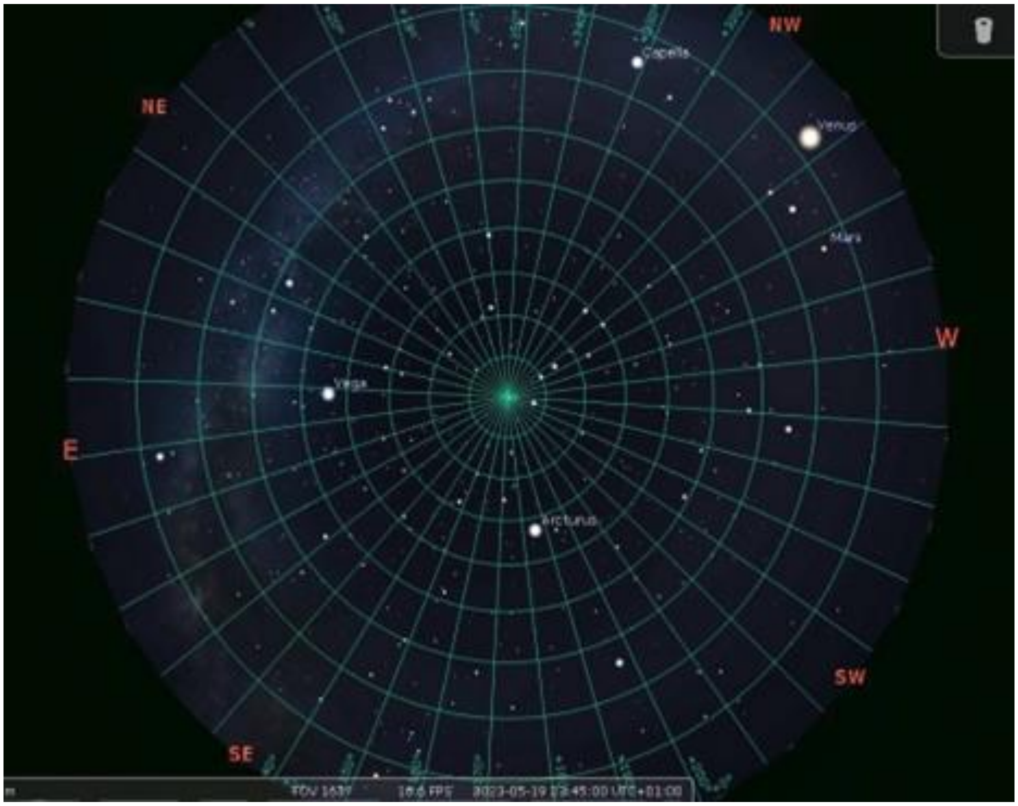
There are three main types of telescope mount:

- Dobsonian
- AltAz
- Equatorial

Before we look at these mounts in turn, it's important to understand the two different types of celestial coordinate system that are used. In both cases the entire sky is broken up into a grid system, but the two are very different.

Altitude – Azimuth (Alt-Az):

This grid system covers the whole sky with its centre at the zenith – i.e. the point directly above your head.

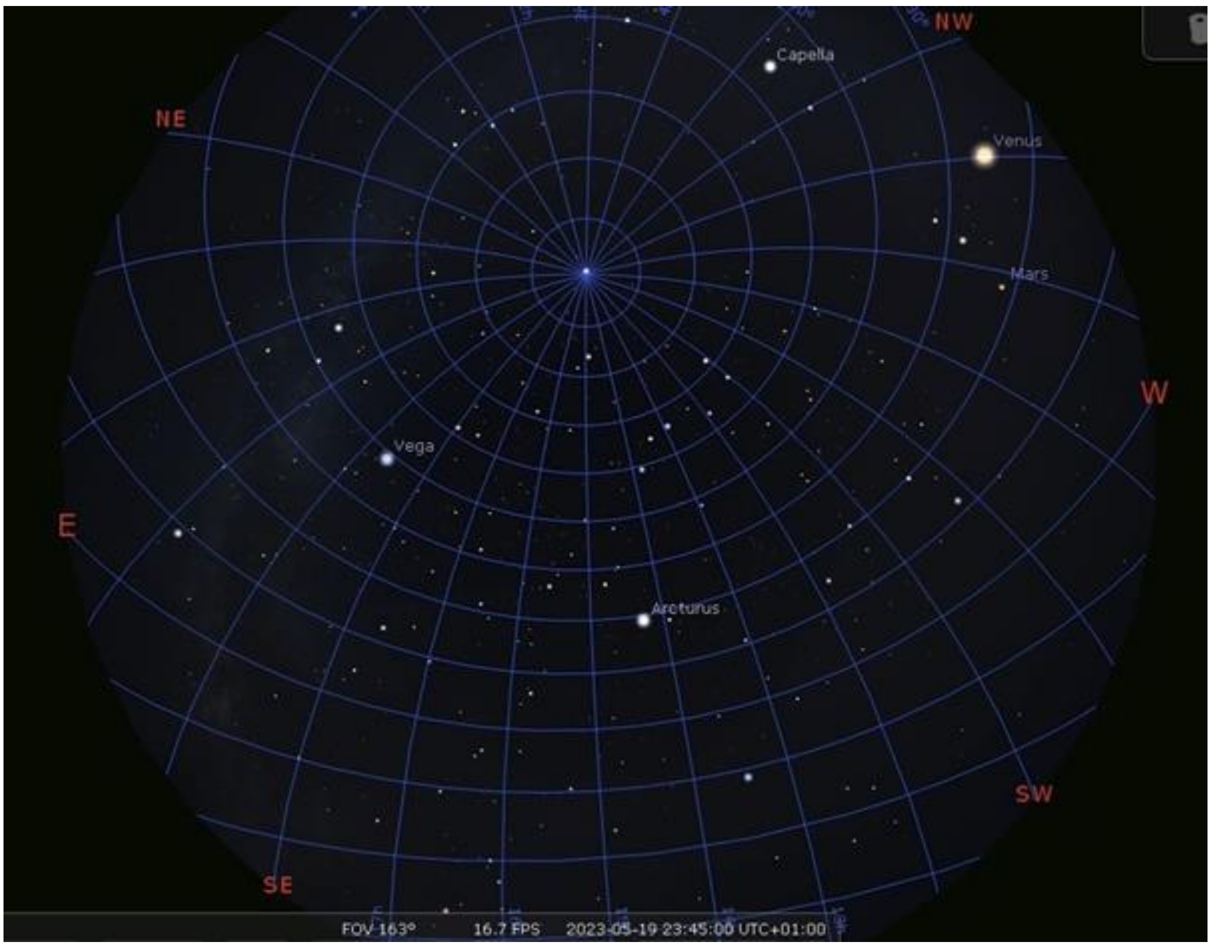


The image above was created using Stellarium. From the centre point at the zenith there are concentric rings that move outwards, with straight lines extending down to the horizon.

- The altitude value tells you how far above the horizon an object is, with a value between 0 degrees (at the horizon) and 90 degrees (at the zenith)
- The azimuth value tells you far around the sky from North an object is. The value range is 360 degrees of the full circle. North is 0 degrees, East is 90 degrees, South is 180 degrees and west is 270 degrees
- This grid system is specific to the observer’s location, so celestial objects viewed from different locations at the same time will have different Alt-Az coordinates
- The grid is also fixed at your location, so as the Earth rotates and we see the apparent rotation of the sky, celestial objects are constantly changing their coordinates
- Dobsonian and other Alt-Az telescope mounts track along this grid system, so the mount does a basic left-right, up-down movement. However, the movement of the sky does not follow this grid, so long exposure photographs will have the stars trailing in a circular pattern. This is known as “field rotation”

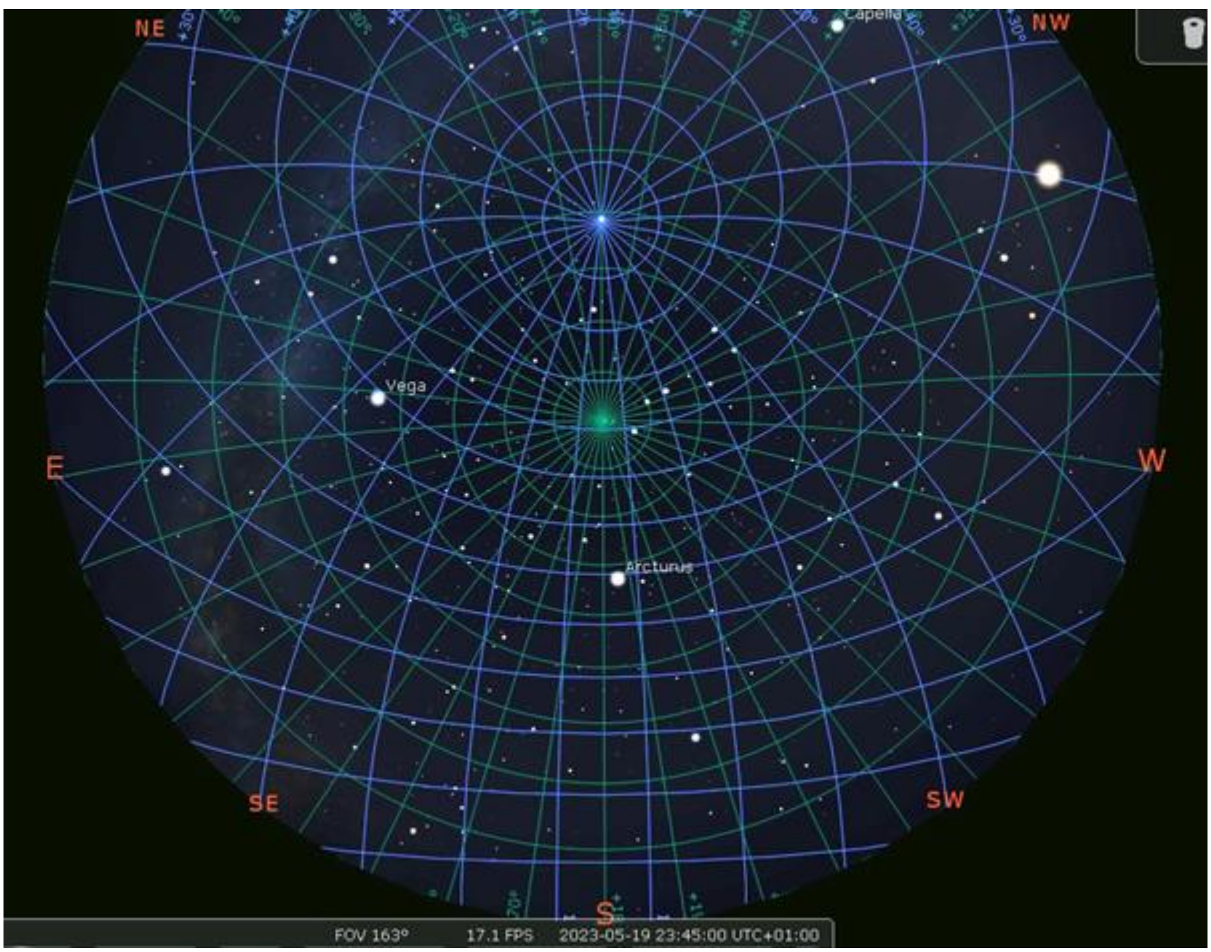
Equatorial (EQ):

In the equatorial system the entire sky is broken up into a grid system whose centre is above the North Celestial pole. This means that the centre of the grid system will be roughly in the position of Polaris the Pole Star, the altitude of which is dependent on your latitude. If you live at 52 degrees latitude, Polaris is located 52 degrees above the horizon. If you live at 48 degrees latitude, Polaris is 48 degrees above the horizon, and so on. In the southern hemisphere there is no bright pole star. The nearest star to the South Celestial Pole is sigma Octantis and the sky appears to rotate around that star. If you live at latitude 30 degrees south, then sigma Octantis is always 30 degrees above the horizon. The two measurements are Right Ascension (RA) and Declination (Dec).



The image above is from Stellarium and shows the EQ grid from 52 degrees latitude.

- The Declination is a measure of the angle of an object relative to the celestial equator, so the North celestial pole is +90 degrees, the celestial equator is 0 degrees and the south celestial pole is – 90 degrees
- Right Ascension is a measure of the angular distance eastwards from the vernal equinox. It is measured in sidereal hours, minutes and seconds. This method measures the time it takes for a celestial object to complete one full rotation of the celestial equator as Earth rotates
- In one hour, objects move 15 degrees of RA, in 24 hours they move 360 degrees
- This grid system is fixed on the sky, so the RA and Dec values of fixed celestial objects do not change; the RA and Dec of a star is the same regardless of where you observe it from
- As the Earth rotates the entire grid system moves across the sky so the RA and Dec values remain constant. Equatorial telescope mounts accurately track along this grid



For comparison, here are the AltAz and EQ grid systems from 52 degrees latitude overlaid together. An AltAz mount will track the green lines, but the stars are actually moving with the blue lines, which an EQ mount will track

Dobsonian

- Dobsonian set ups are available in a huge range of sizes, with most telescope shops offering from 3” up to 20” diameter mirrors
- The telescope tube is usually a Newtonian reflector
- Sometimes the tube is solid, sometimes truss rods
- They are quick and easy to set up and use, and give best bang for buck in terms of what size you can get for the money
- They were originally always sold as manually operated systems and you push and tilt the telescope manually, but they’re now also available with computerised tracking and GoTo capability
- Dobsonian mounts are AltAz so even if you have a computerised tracking version, they are not ideal for long exposure photography. However, you can still use them for imaging brighter objects that don’t require very long exposure times. Indeed, if you have a large aperture Dobsonian, it collects light so fast that you may be able to image some fainter objects with a shorter exposure. There are plenty of people around the world who do astrophotography through a Dobsonian telescope

Basic 3" tabletop Dobsonian compared to a larger computerised 10" version

The Dumbbell Nebula, Sinus Iridum, Jupiter, Saturn and Mars imaged using a 10" Dobsonian by Mary McIntyre

Tripod mounted AltAz

- These mounts sit on tripod and are most commonly used for refractor telescopes
- They are available as static mounts or with computerised tracking and GoTo function
- They are significantly less expensive than EQ mounts
- No complex set up required and no counterweights are used so they're lightweight and portable and great for outreach
- Many can run on batteries and are controlled from a mobile phone app
- They track in AltAz so they will suffer from field rotation on longer exposures when imaging but you can do shorter exposures of brighter objects and get good results
- You can buy a wedge to modify it to track in EQ rather than AltAz

Skywatcher AZGTi – an AltAz mount with a 102mm refractor. Photo by Mary McIntyre

A 60 second exposure of The Pleiades taken with a tracking AltAz mount by Mary McIntyre.

The stars are showing field rotation

Equatorial mounts

- EQ mounts are tripod mounted. The polar axis is aligned to point at the north celestial pole if you are in the northern hemisphere, or the south celestial pole if you are in the southern hemisphere.
- They need to be aligned on 3 bright stars before use. They take longer to set up and the set-up has to be accurate, but once done, the mount's movement will track the stars perfectly
- They utilise counterweights to balance the telescope
- Bigger telescopes will need a bigger mount that can take the weight
- Available as manual or computerised with GoTo capability
- They are more expensive than other mounts but with care it will last you many years
- If you're serious about astrophotography of deep sky objects, an EQ mount is essential
- If imaging very faint objects that require exposure times of longer than 3 minutes, it's helpful to utilise autoguiding which will feed tracking corrections back to the mount and it will track even more precisely

Example of an EQ5 Pro tracking mount with a 70mm refractor. Photo by Mary McIntyre

When choosing a mount you need to consider the following:

- What do you want to use it for? For casual observing you can use something more budget friendly but if you want to get into serious astrophotography you'll need a computerised EQ mount
- What is your budget? Always go for the best mount you can afford and it should last you for many years
- Storage – how much space will it take up? Will it be secure there?
- Weight – you will need to carry it in and out storage to use it so chose something that won't cause you injuries
- As a beginner it's tempting to opt for a fully computerized, GoTo mount, but you still need to know the names and positions of the brighter stars in order to align it
- If you observe from home and have the space, you can install a permanent pier. This considerably reduces the set up time because the mount remains in situ and

polar aligned. You can keep it dry using an upside bin clipped onto a plinth or you can buy heavy duty waterproof covers. All you need to do before use it attach the telescope and do the 3 star alignment.

- If you have a large Dobsonian telescope, it can be helpful to store it in its own little shed

Using a dustbin to weatherproof an EQ mount on a permanent pier. Photo by Mary McIntyre.

Small storage shed to house a Dobsonian telescope. Make sure your shed is locked and alarmed! Photo by Mary McIntyre

Meteor science

In the Meteor science topic, you will learn all about meteors. You start with our Solar system and what it contains focused on which small bodies are the sources of meteors. Then you will learn about what they are made of, how they burn up and what they produce in our atmosphere. Lastly you will learn about meteor showers and fireballs. At the end you will find a list of references for further reading, a list of meteor showers for which the parent body is known and a glossary.

The Solar System

Definitions

The planet Earth on which we live is part of the Solar System, which is made up of the Sun, eight major planets, many dwarf planets, and millions of small bodies left over from its formation, and which includes the comets and asteroids. It is useful to consider the definitions of these various bodies, as agreed at the 26th General Assembly of the IAU on 24 August 2006:

(1) A planet is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (c) has cleared the neighbourhood around its orbit.

(2) A "dwarf planet" is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, (c) has not cleared the neighbourhood around its orbit, and (d) is not a satellite.

(3) All other objects, except satellites, orbiting the Sun shall be referred to collectively as "Small Solar System Bodies".

Formation of the solar system (as it relates to meteor astronomy)

Every day several hundred tonnes of particles enter Earth's atmosphere, where they burn up and become visible as meteors, also popularly known as 'shooting stars'. These are not stars at all as the popular name suggests, but are the debris left over from the formation of the solar system itself. The Solar System was formed around 5 bio years ago after a star-forming event from a **Giant Molecular Cloud (GMC)**. Giant Molecular Clouds are the nurseries where new stars are born. Most of the matter we can see in the Milky Way galaxy is in the form of stars. Between the stars, the inter-stellar medium (ISM) comprises mainly hydrogen and elements synthesised in stars, which have long since depleted their fuel and returned their remnants to the ISM. Most of the material in the ISM is unseen, but occasionally clouds may be visible as bright emission or reflection nebula, or dark nebulae. A good example of a Giant Molecular Cloud where new stars are being born is the Eagle Nebula (Messier 16).

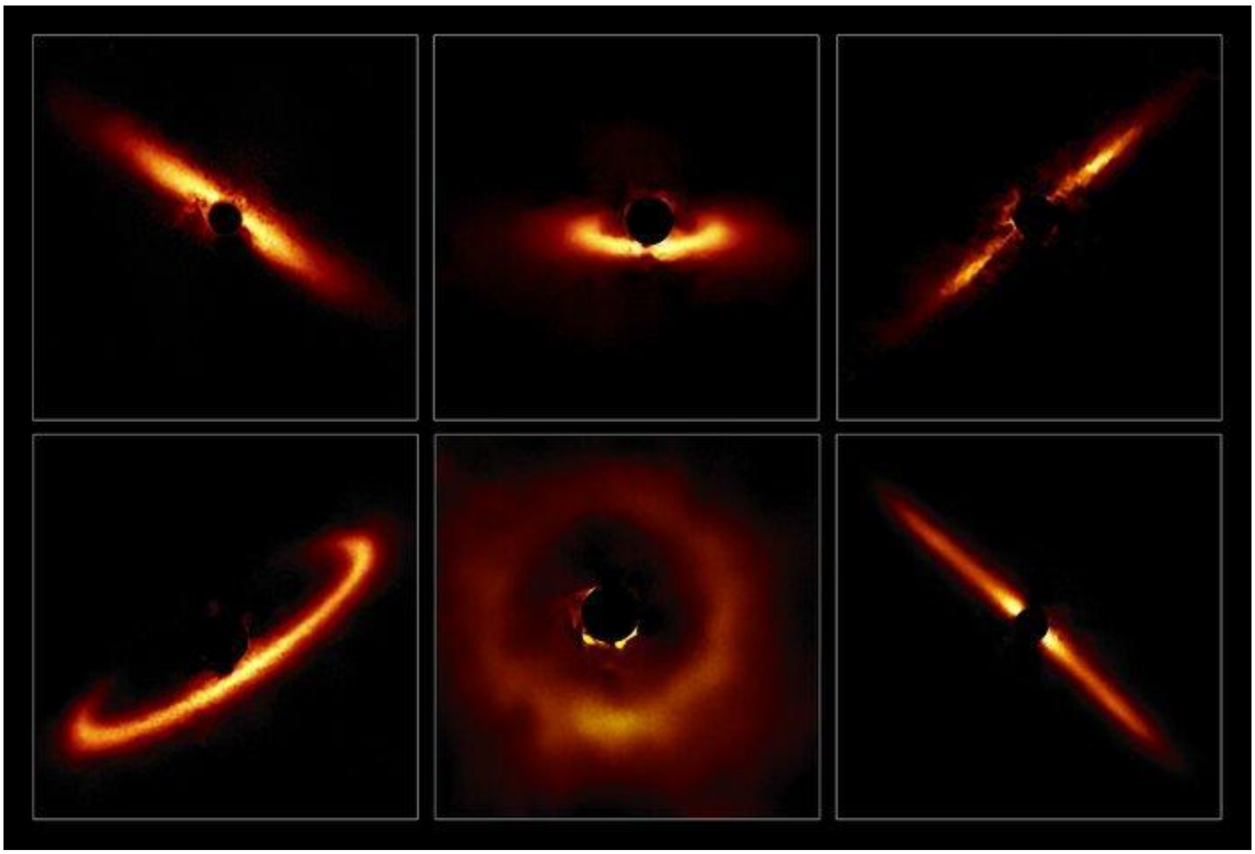
Star forming region in the Eagle Nebula. On the left is an image taken by the Hubble Space Telescope, and on the right is an image taken by the James Webb Space Telescope. Credit NASA.

Giant Molecular Clouds are mainly made up of gas and dust. Most of the gas is in the form of molecular hydrogen (H_2) and helium (He), formed in the early universe. Seeing that this dust is responsible for what we see as meteors, it is important to understand how it was formed. Dust particles are synthesised in stars, either during the lifetime of the star in the normal process of nuclear reactions, or during the cataclysmic phases towards the ends of their lifecycle when stars become novae or supernovae. Supernovae scatter dust particles into the ISM, where the dust is incorporated into newly formed solar systems.

Since the materials making up GMCs are not of uniform density, clumps of gas and dust in the cloud begin to collapse and under the influence of gravity begin to accrete material to form a protostar. As the mass of the protostar increases, so too the temperature increases until a point where nuclear reactions begin, converting hydrogen to helium through the process of nuclear fusion, and the star 'switches on'. Material surrounding the new star is spun into a disk surrounding the star, and is termed a **proto-planetary disk (or "proplyd")**.

Protoplanetary disks (Proplyds) in the Orion Nebula. Image credit NASA/ESA and L. Ricci (ESO)

New planets may form from the cooling disk of gas and dust. Material left over from the formation of the new star and its planets forms a remnant disk surrounding the new solar system. The disk around the star beta Pictoris was the first evidence for the existence of **circumstellar disks**. Now disks have been found surrounding many more stars, all of which are the remnants from the formation of solar systems around those stars. These disks comprise the dust particles we see as meteors.



Circumstellar disks surrounding their parent stars. International Gemini Observatory/NOIRLab/NSF/AURA/T. Esposito (UC Berkeley)

General Structure of the Solar System

Our own solar system comprises the Sun, eight main planets and their moons, dwarf planets, asteroids and comets. The Sun is the single star in our Solar System, and all other bodies rotate around the Sun in orbits which have the Sun as one focal point of their orbit. We will get to understand more about different types of orbits and their characteristics later. The main planets in order of distance from the Sun are shown in Table 1:

Planet	Mean distance from the Sun in km	Mean distance from the Sun in au.
Mercury	57,900,000	0.39
Venus	108,200,000	0.72
Earth	149,600,000	1.00
Mars	227,900,000	1.52
Jupiter	778,600,000	5.20
Saturn	1,433,500,000	9.54
Uranus	2,872,500,000	19.2
Neptune	4,495,100,000	30.06

Table 1 Distances of the main planets from the Sun

Source https://www.jpl.nasa.gov/edu/pdfs/scaless_reference.pdf

When working with the Solar System, distances expressed in kilometres or even millions of kilometres become cumbersome, and so are normally quoted in **astronomical units**, abbreviated to au, which is the unit of length representing the mean distance of the Earth from the Sun, approximately 150 million km. The official definition of 1 au adopted by the IAU at the XXVIIIth General Assembly (IAU 2012 Resolution B2) is a conventional unit of length equal to 149 597 870 700 m exactly *. Therefore, the mean distance from the Sun to the Earth is 1.00 au, and the distances of other Solar System bodies can be quoted on the same basis.

* Source: Measuring the Universe, The IAU and astronomical units, https://www.iau.org/public/themes/measuring/

When looking at the distances in au, astronomers realised there was a reasonable relationship between the distance of the planets from the Sun and the expression:

$$a = 0.4 + 0.3 \cdot 2^n$$

where a is the semi-major distance of the planet from the Sun. This is known as the Titius-Bode Law, or sometimes simply as Bode's Law. Substituting for n, (with n = 0, 1, 2...7) gives the sequence 0.4, 0.7, 1.0, 1.6, 2.8, 5.2, 10.0, 19.6 and 38.8. This sequence is in reasonable agreement with the distances of the planets in au, except there is a gap, with no planet coinciding with 2.8, i.e. between the distances of Mars and Jupiter. Accordingly, a search began for the missing planet around 2.8 au, which resulted in the discovery of the first asteroid on 1 January 1801. The asteroid 1 Ceres orbits the Sun at a mean distance of 2.8 au. After the initial discovery, more and more asteroids were discovered orbiting the Sun between the orbits of Mars and Jupiter; these are known as Main Belt Asteroids.

In 1950 Jan Oort first postulated the existence of a vast reservoir of comets at the edge of the Solar System, extending from about 50,000 au to about 100-200,000 au from the Sun, now referred to as the **Oort Cloud**. Evidence for the existence of a spherical cloud was based on the random inclination of the orbits of long period comets, which do not necessarily align with the ecliptic plane. Comets are mixtures of frozen gases, with dust grains embedded, the true material left over from the formation of the Solar System, and the dust particles from comets are the primary source of the meteors we observe.

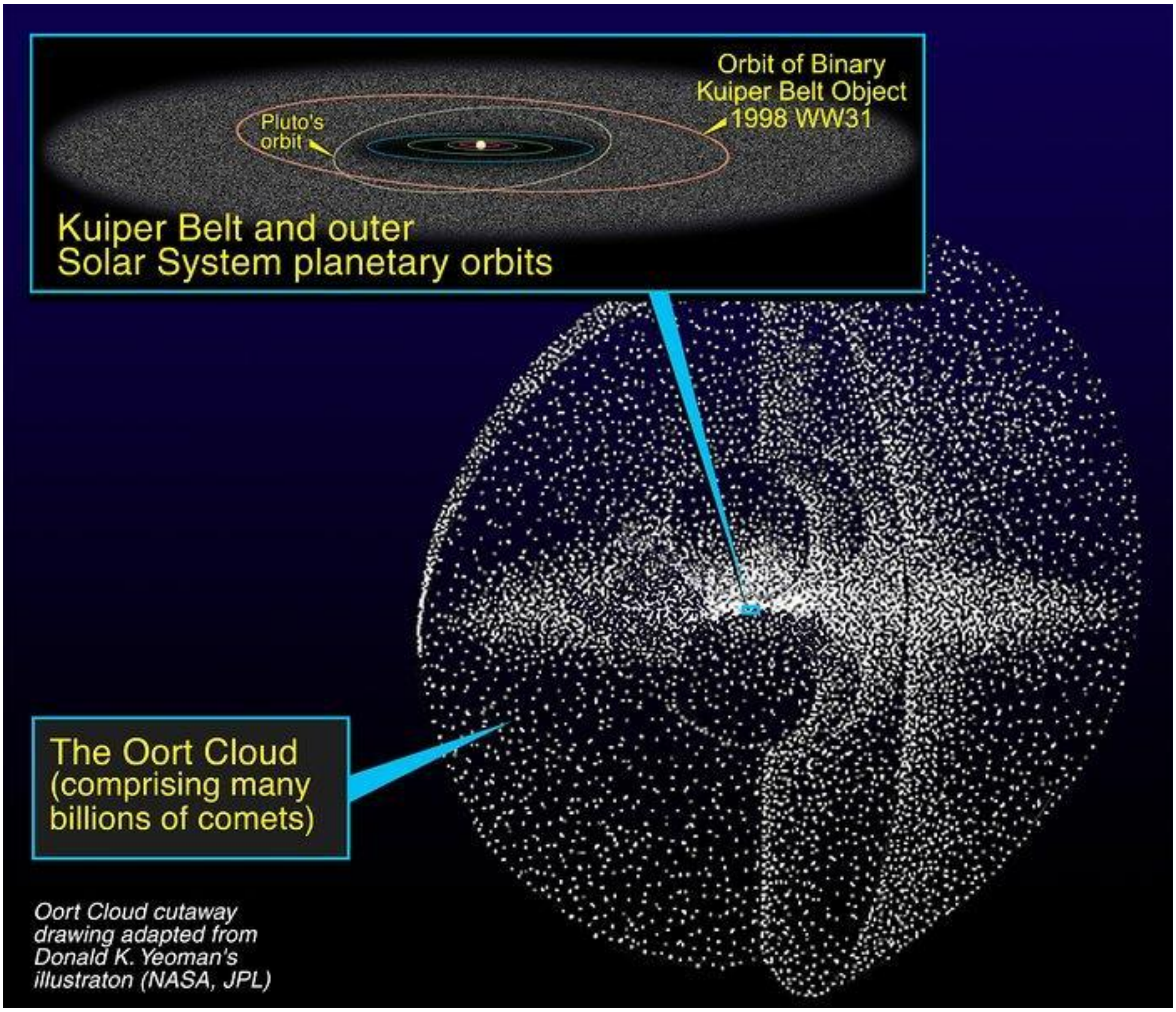
In 1951 Gerard Kuiper proposed a second source of comets, and suggested a ring of icy material must exist in the plane of the Solar System, with its inner edge just outside the orbits of Neptune and Pluto at about 30-40 au. In 1992 the discovery of a body 1992 QB1 in a nearly circular orbit at 41 au was the first evidence for the existence of the **Kuiper Belt**. Since then several thousand Kuiper Belt Objects, also known as Trans-Neptunian objects have been discovered. The Trans-Neptunian Objects are minor planets that orbit the sun at a distance greater than 30 au from the Sun.

The Oort Cloud and the Kuiper Belt

The Oort Cloud is a nearly spherical cloud consisting of perhaps 0.5-1 million icy cometary nuclei. It was formed due to scattering of planetesimals by the giant planets early in the Solar System's history and was completely formed about 1 billion years after the planets formed from the protoplanetary nebula. Actual comets which form the cloud have not been detected directly, but its existence is inferred due to the distribution of comets with inclinations of their orbits outside the ecliptic plane, as well as the fact that most new long period comets have aphelion distances of several thousand au.

The Kuiper Belt, originally predicted by Gerard Kuiper as a disk of planetesimals left over from the formation of the planets, which according to Morbidelli and Brown (2004) 'that preserved the pristine conditions of the protoplanetary disk', is most certainly the remnant population of the proto-planetary disk. The Kuiper Belt extends from about 30-50 au and includes three distinct populations:

- The classical Kuiper Belt – consists of objects outside the orbit of Neptune, and show no interactions (resonance) with that planet. Their orbits are in the same plane as the ecliptic, inclinations generally below 5° with a few outliers, and their orbits are of low eccentricity.
- The Scattered Disk – consists of objects which have been perturbed into highly eccentric orbits, with perihelia around 30-50 au but aphelia outside 1000 au.
- The Resonant Population – consists of objects which interact with Neptune in mean-motion resonances. For example, those in 2:3 resonance are termed Plutinos after the largest member of the group Pluto.



Schematic diagram of the structure of the Solar system.

Credit NASA/ESA and A. Feild (Space Telescope Science Institute)

Our knowledge of the Kuiper Belt is still in its infancy but is growing as more and more objects in the region are discovered. However, the Oort Cloud and Kuiper Belt are accepted as the reservoirs from which the comets originate, and which in turn are the source objects from which most of the meteors originate.

Small bodies in the solar system – comets and asteroids

The material left over from the formation of the solar system, and which did not coalesce to form the main planets and their moons, are the small bodies of the solar system. They comprise the dwarf planets, asteroids and comets.

To recap,

> A "dwarf planet" is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, (c) has not cleared the neighbourhood around its orbit, and (d) is not a satellite.

Since the dwarf planets orbit the Sun at great distance from the Earth and are not in Earth-crossing orbits, they are of no relevance to the field of meteor science.

> All other objects, except satellites, orbiting the Sun shall be referred to collectively as "Small Solar System Bodies".

All other objects include the comets and asteroids, and since these can approach Earth or be in an Earth-crossing orbit, both are of interest as potential sources of meteors.

<u>Asteroids</u>

The vast majority of known asteroids are located between the orbits of Mars and Jupiter and are known as Main Belt Asteroids. In addition, there are many other classes of asteroid known which are not Main Belt asteroids. There is a family of asteroids known as Trojans, which share Jupiter's orbit, and orbit either ahead of or behind Jupiter in 1:1 resonance with the planet. Similarly, the Hilda family orbit in a 3:2 resonance with Jupiter, on the opposite side to Jupiter in its orbit. Of importance to meteors are the asteroids which come close to, or actually cross Earth's orbit. Such asteroids are known as **Potentially Hazardous Asteroids** (PHAs) and include the Amor, Apollo, and Aten families. Since their orbits can bring them into proximity with Earth, they are also known as Near Earth Asteroids (NEAs).

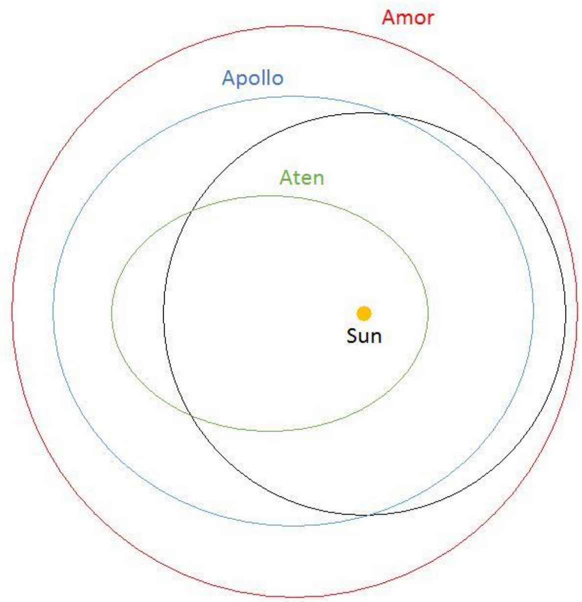


Diagram showing orbits of the Amor, Apollo and Aten families of Near-Earth Asteroids. The orbit of the Earth is shown in black. Apollo and Aten asteroids are able to cross Earth's orbit. Amor asteroids can pass close by but do not cross Earth's orbit.

The NEAs may be classified into three families (Bottke et al 2002):

- Apollo asteroids, with $a \geq 1.0$ and $q \leq 1.017$ AU, having orbits larger than the Earth's but their perihelion distances are inside the Earth's orbit at their aphelia. These asteroids are earth crossers with the capability of impacting the earth and may also be referred to as potentially hazardous asteroids (PHAs). Known examples are 1866 Sisyphus, 69230 Hermes, 4179 Toutatis, 25143 Itokawa, and 3200 Phaethon.
- Aten asteroids have $a < 1.0$ AU and $Q \geq 0.983$ AU, having orbits smaller than earths but their aphelion distances are outside earth's orbit. They are also earth crossers and therefore capable of impacting the earth. There are currently around twenty known members of the Aten family including the now well-known example 99942 Apophis.
- Amor asteroids having perihelion distance $1.017 < q \leq 1.3$ AU. This means that even when the asteroid is at perihelion and the Earth is at aphelion, the orbits do not intersect, but the asteroid can make a close approach to earth's orbit. The most well-known example is 433 Eros.

All three types of NEAs may be responsible for meteors if they have associated meteor streams which come close to Earth's orbit.

Comets

Located at the outer extremes of the Solar System, comets are the frozen remains from the formation of the Solar system itself. They generally travel on highly eccentric orbits, with periods ranging from a few years to several thousand years. Comets are broadly classified by the time taken to orbit the Sun:

- **Long period comets**, which have orbital periods longer than 200 years, or
- **Short period comets**, which have orbital periods shorter than 200 years.

Most long period comets probably originate in the Oort Cloud, and have a large distribution in the inclination of their orbits, which are not necessarily close to the plane of the ecliptic. Comets with small inclinations to the plane of the ecliptic are also known as Ecliptic Comets. The short period Ecliptic Comets, that is with period P less than 200 years, can be sub-divided into two groups:

- **Jupiter Family Comets**, which have orbital periods shorter than 20 years, and distance at their farthest from the Sun less than 7.4 au ($a < 7.4$ au).
- **Halley-type Comets**, which have orbital periods more than 20 years but less than 200 years, and distance at their farthest from the Sun more than 7.4 au but less than 34.2 au ($7.4 \leq a \leq 34$ au).

During their passage around the Sun, both long and short period comets can be responsible for meteor showers if their orbits intersect with the orbit of the Earth.

Nomenclature of asteroids and comets

The naming procedure for asteroids is as follows:

- Newly discovered asteroids are given a provisional designation based on the year of discovery, two letters, which are followed, if necessary, by further digits.
- Once the orbit is known precisely and the asteroid has been observed at four or more oppositions, the asteroid is given a permanent number designation.
- Once the asteroid has a permanent number designation, the discoverer is invited to suggest a permanent name for the asteroid.

Example: an asteroid was discovered by astronomer Tom Gehrels on 18 October 1977. It received the provisional designation 1977 UB. Subsequently the asteroid received the number designation 2060. Tom Gehrels suggested the name Chiron. The asteroid is now known as 2060 Chiron.

The naming procedure for comets is as follows:

- Newly discovered comets are given a prefix, depending on the type of comet:
    - P/ for a periodic comet.
    - C/ for a comet that is not periodic.
    - X/ for a comet for which a meaningful orbit cannot be computed.
    - D/ for a periodic comet that no longer exists or is deemed to have disappeared.
    - I/ for all interstellar objects, whether comets or asteroids.
- The prefix is followed by the year of discovery
- An uppercase letter identifying the half-month of observation during that year (A for first half of January, B for second half and so on).
- A number representing the order of discovery within that half month.
- A name, comprising the discovery team, or if discovered by individuals, up to three independent discoverers.

Examples: a 19th magnitude object with a coma was discovered on 3 January 2021 by Gregory Leonard at Mount Lemmon Observatory. It was the first comet discovered in 2021 and received the designation Comet C/2021 A1 (Leonard). On the same date, a 15th magnitude comet was discovered by the NEOWISE satellite and received the designation Comet C/2021 A2 (NEOWISE). The sixteenth comet discovered in 2021 was by David Rankin on 11 February, and as the first comet discovered in the first half of February it received the designation

Comet C/2021 C1 (Rankin). Note that in the names, only the first letter of the individual discoverer is capitalised, but in the case of discoveries by specific instruments or satellites, the acronym is capitalised.

Short period comets that have been observed at two perihelia are designated separately by a number followed by an uppercase letter P. So, for example, comet Halley is designated 1P/Halley, and comet Encke as 2P/Encke. The name follows immediately after the forward slash, without a space. The number of named short period comets currently is 460 (Yoshida, April 2023).

If a new object is discovered and appears without a coma it is designated as an asteroid. Some objects initially designated as asteroids can later be designated as comets if they are shown to be active and produce a coma.

Example: a comet was discovered on 19 November 1949 by astronomers Wilson and Harrington at Palomar Observatory and named comet Wilson-Harrington. It was subsequently lost as its orbit could not be accurately determined. An asteroid was discovered on 15 November 1979 by astronomer Eleanor Helin, also at Palomar Observatory, and given the designation 1979 VA, and subsequently asteroid 4015. With more accurate orbit determination it is now known that comet Wilson-Harrington and asteroid 4015 are the same object, now known to be an active Apollo asteroid and carries both designations as asteroid 4015 (Wilson-Harrington) and comet 107P/Wilson-Harrington.

Comets and asteroids as parent bodies of meteors

Every day, tonnes of small particles enter Earth's atmosphere. These particles are mainly the dust left behind by comets as they pass around the Sun, or less frequently are fragments of asteroids lifted off the surface, or ejected in Earth crossing orbits during collisions between small bodies in the Solar system. Estimates of the actual amount of dust that enters the atmosphere as meteors vary (Plane 2017), but may amount to several hundred tonnes per day. So, if meteors can have either a comet or an asteroid as their parent body, what is the difference and how does that possibly affect meteors from these different parent bodies? Broadly speaking, the main difference is that asteroids are rocky, while comets are icy.

Comets are made up of frozen gases (ices) in which are embedded solid particles. The most prevalent ices in comet nuclei comprise water, carbon monoxide and carbon dioxide. While far from the sun, the comet exists as a frozen nucleus. As it approaches the sun in its orbit, the constituents come under the influence of solar radiation, melting and sublimating the frozen materials at the surface and releasing gases and dust grains to form a coma around the nucleus. These particles are released both from the surface of the nucleus, and from the interior of the nucleus during jetting events as hot spots on the nucleus move in and out of sunlight as the nucleus rotates.

Image of dust tails in Comet C/2006 P1 (McNaught). Credit Simon Walsh.

The distribution of dust particles from the nucleus of a comet was well seen in the dust tail of Comet C/2006 P1 (McNaught). The tail shows series of bands of particles emitted from the nucleus at the same time, which are termed synchronic bands, or **synchrones**. Ejected particles also have different ejection velocities relative to the motion of the nucleus, as well as different particle sizes. Smaller particles are swept more rapidly away from the nucleus under the effects of the solar wind, leading to a gradation of particle sizes in the individual synchrones. Lines connecting particles of the same size are called **syndynes**.

Further factors will influence the density and distribution of this laid down stream, and depend on the composition of the comet, the physical morphology of the comet's nucleus, the geometry of its orbit relative to the sun, the degree of solar activity at the time of apparition, and the activity of jets as they move in and out of sunlight. Initially, this laid down stream probably remains localised in the orbit of the comet, both radially and longitudinally. If the earth were to intersect the stream, still but a compact swarm, any resultant meteor shower activity would be of short duration, and intense if the earth passes near the centre of the swarm. The rate profile of the alpha Monocerotids is probably a good example. Over a long period of time, the meteors begin to diffuse away from the centre path of the orbit and become spread out along the orbit, until eventually they form a complete loop. The shower now becomes visible each year, and the meteor shower becomes an annual shower. Gradually, the dispersed stream becomes broader and visible for perhaps several weeks. The maximum also becomes broader, lasting maybe a few nights, and less intense, with rates of only a few meteors per hour. The Taurids are a good example. Eventually the stream becomes so dispersed that the activity is visible over a wide period, with no discernible maximum, and the rates may be difficult to detect above the sporadic background. In fact it has been suggested (Hughes 1991) that 20% of the meteors observed as sporadic are no more than the drizzle of these highly dispersed meteor streams, and that many such low rate meteor showers should be in existence.

The formation of meteor streams from asteroids is less clear. Asteroids are rocky bodies, and by their definition do not show existence of activity to form a coma. Nevertheless, there is a growing list of meteor streams which have asteroids as parent bodies, inferred by the similarity of their orbits. Therefore, the asteroids must have been capable of leaving debris behind at some stage, in order for a meteoroid stream to exist. It is possible that some asteroids responsible for meteor streams may be extinct comets, and that the volatiles have been depleted by its many trips around the sun. It is also possible for asteroids to release dust grains into space, lifted off the surface as the asteroid spins around its axis, particularly when the asteroid is closest to the sun and the spin rate is accelerated by **Yarkovsky effects**.

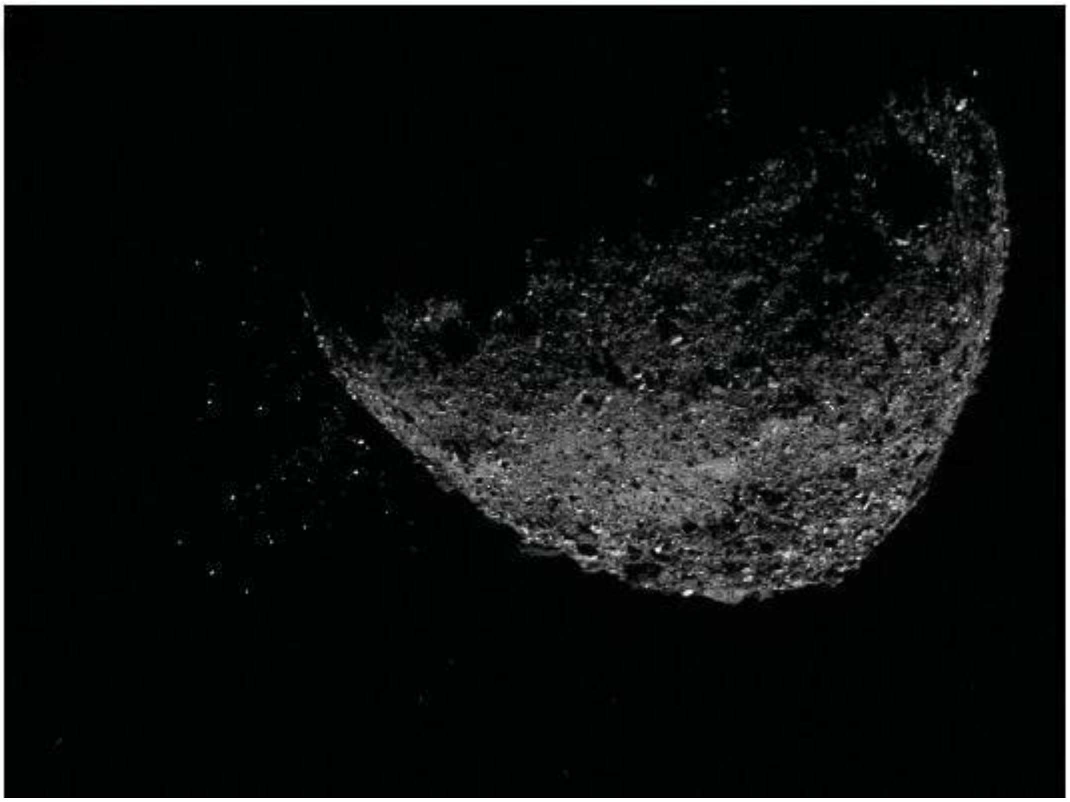


Image of dust particles being ejected from asteroid 101955 Bennu on 6 January 2019, from images taken by the NavCam 1 imager aboard NASA's OSIRIS-REx spacecraft.

Credit: NASA/Goddard/University of Arizona/Lockheed Martin Full Image Details

One such asteroid which has been observed to be ejecting particles into space is 101955 Bennu. The asteroid was the target of the OSIRIS-Rex space probe, which showed plumes of dust emitted from the surface of the asteroid on several occasions. Asteroid 101955 Bennu is an Apollo type asteroid, and it is predicted the particles may form a meteor shower at Earth in the future.

The composition of cometary dust

The common conception of meteors is that they are caused by particles about the size of a grain of sand. Nowadays, with sample collection from high altitude aircraft and with probes having visited several comets and sampled the dust, we have a better understanding of how the particles responsible for meteors are made up.

Composition of cometary dust has been inferred by several methods:

- Spectroscopy of comets using ground-based telescopes.
- Collection of inter-planetary dust particles from the stratosphere by high altitude aircraft.
- Direct sampling during flyby of space probes.

Spectroscopy shows the main components of cometary dust to be silicates of the metals iron (Fe) and magnesium (Mg), typical of the minerals olivine, pyroxene, forsterite and enstatite.

Olivine	$(Mg,Fe)_2SiO_4$
Pyroxene	$(Mg,Fe)SiO_3$
Forsterite	Mg_2SiO_4
Enstatite	$MgSiO_3$

The first attempts to collect particles of an extra-terrestrial origin were by high altitude aircraft during the 1970s. These particles were thought to be a mixture of dust from comets, asteroids and interstellar sources, and were named Brownlee particles after Donald E Brownlee who studied the particles.

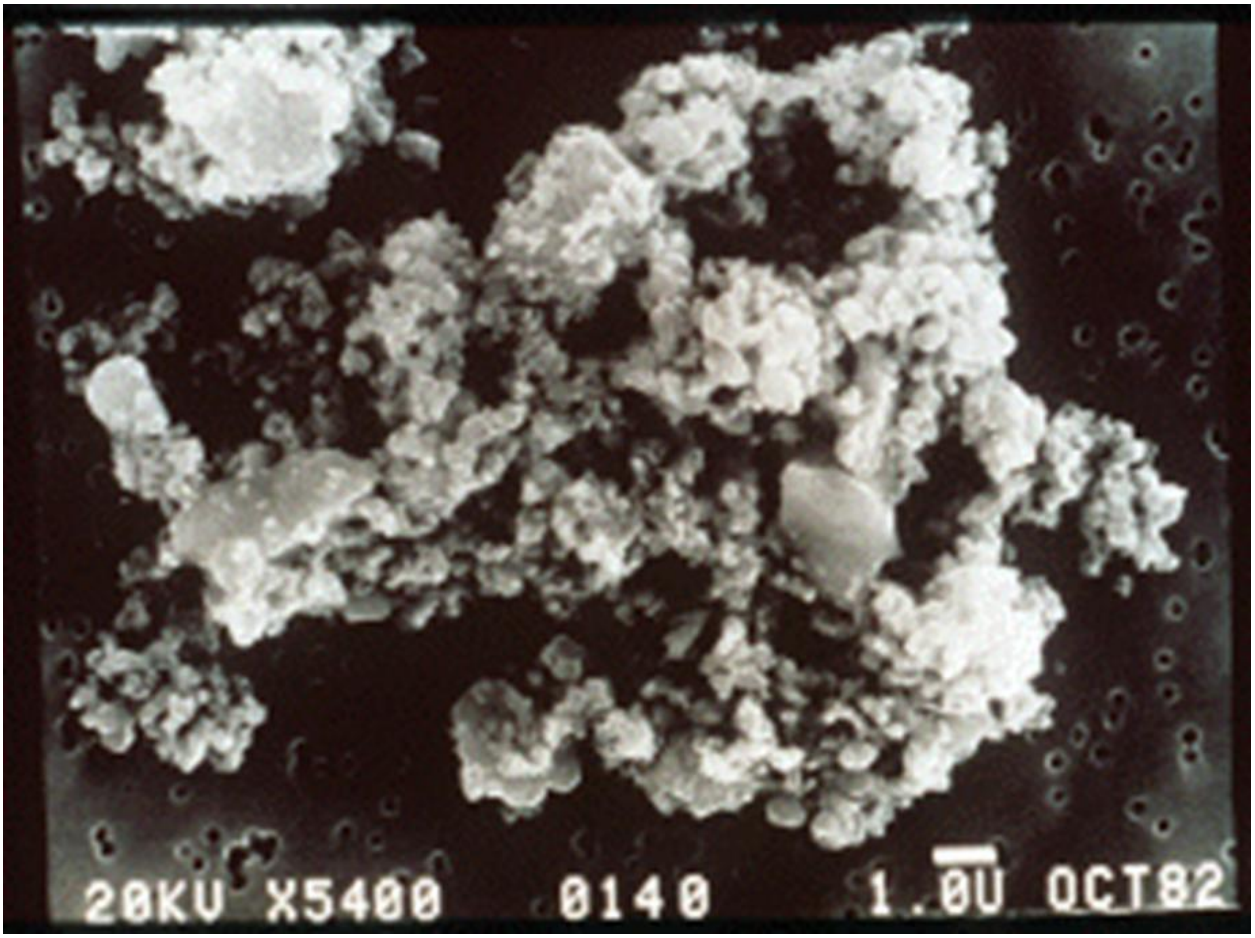


Image of a Brownlee particle. Credit JPL

Analysis of Brownlee particles shows them to be (Flynn et al 1978) largely **chondritic**, containing the elements calcium (Ca), magnesium (Mg), iron (Fe), aluminium (Al), silicon (Si), as well as sulphur (S) and nickel (Ni).

During the most recent return of Comet 1P/Halley, several spacecraft were sent to rendezvous with the comet to study its composition in more detail. The Giotto probe made a close flyby of the comet's nucleus of less than 600 km on 14 March 1986, and the Vega 1 and 2 probes imaged the comet and determined the composition by mass spectrometry. During its flyby the Giotto probe was impacted by more than 12,000 particles, which were mainly smaller than expected. The largest weighed an estimated 1 gram and was large enough to knock the spacecraft out of alignment for some hours.

(see https://www.esa.int/Science_Exploration/Space_Science/Giotto_overview)

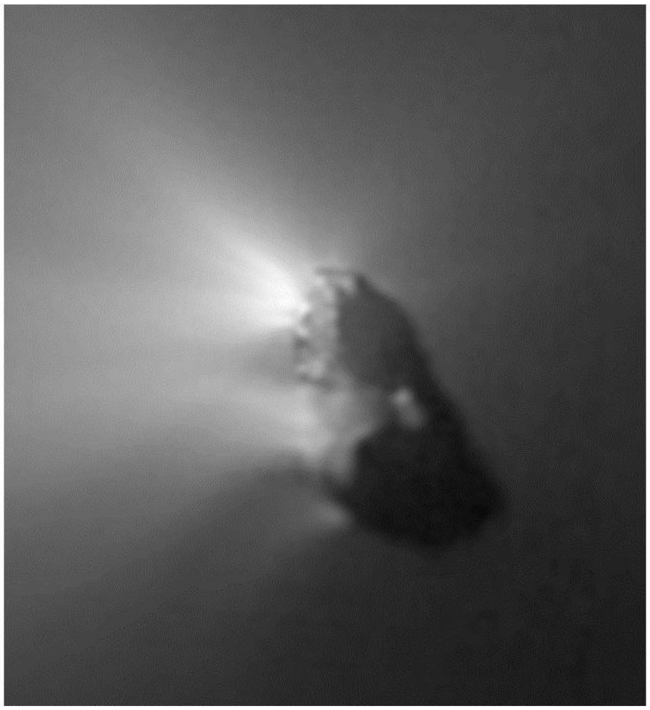
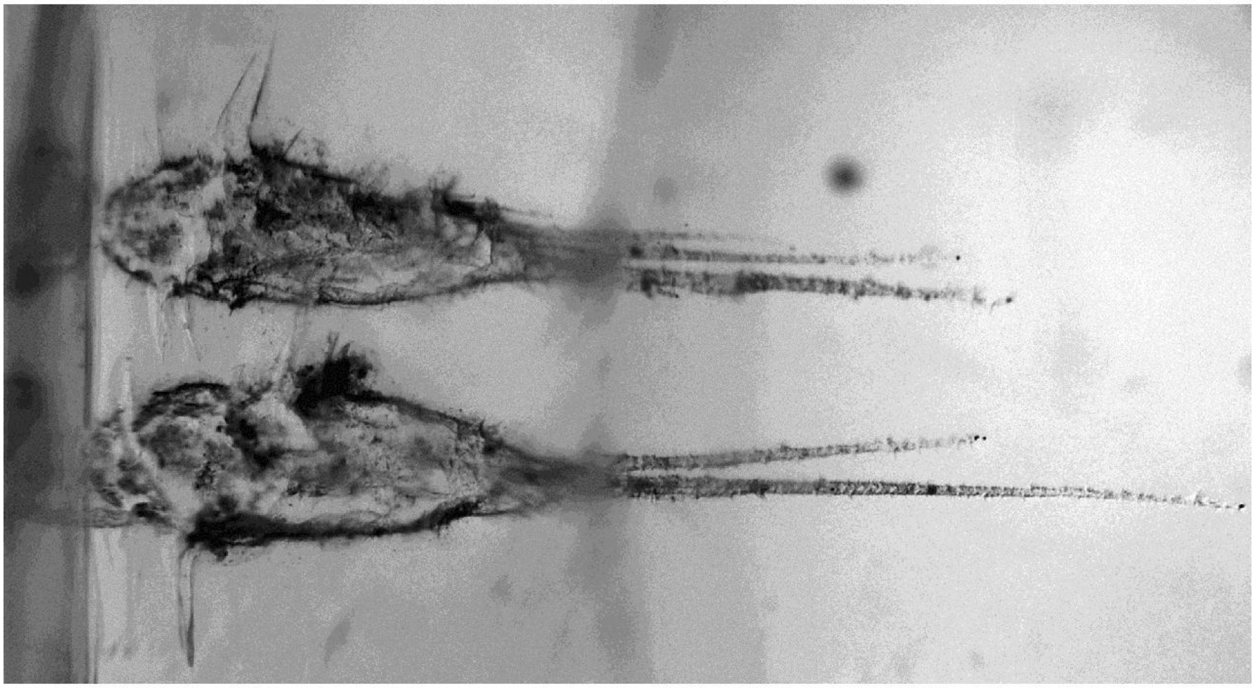


Image of jets from nucleus of Comet 1P/Halley taken by the Giotto spacecraft's Halley Multicolor Camera. These jets emit gas and dust into the space around the comet's orbit. Credit ESA HMC.

Particles from Comet 1P/Halley were found to be a combination of rock-forming elements calcium (Ca), magnesium (Mg), iron (Fe) and silicon (Si), as well as a complex organic solid containing carbon (C), hydrogen (H), oxygen (O) and nitrogen (N), referred to simply as 'CHON'. From a meteor point of view, understanding this comet is important as it is the parent body of two meteor streams, the eta Aquariids in May, and the Orionids in October each year.

An opportunity to study the composition of comet dust came more recently, when the Stardust probe rendezvoused with Comet 81P/Wild.



Particles returned by the Stardust probe from Comet 81P/Wild. The particles were collected in a low density glass medium called aerogel, in which the particles seen at right formed tadpole-shaped tracks. Image credit: NASA/JPL-Caltech/University of Washington.

The probe made a flyby of the comet in 2004 and returned samples to Earth. Analysis shows the particles from Comet 81P/Wild to be:

- Silicates of the elements Mg and Fe (olivine, pyroxene, forsterite)
- Glass (silica) with embedded metal sulphides (GEMS)
- Complex organics based on C, H, O and N (CHON), aliphatic hydrocarbons, and organic nitrogen compounds, including two with biologically active nitrogen (N).

The second comet to be directly sampled and analysed was Comet 67P/Churyumov-Gerasimenko. It was visited by the Rosetta probe which sampled dust from the comet during the period 10 April to 27 May 2015, at distances between 91 km and 321 km from the comet's nucleus.

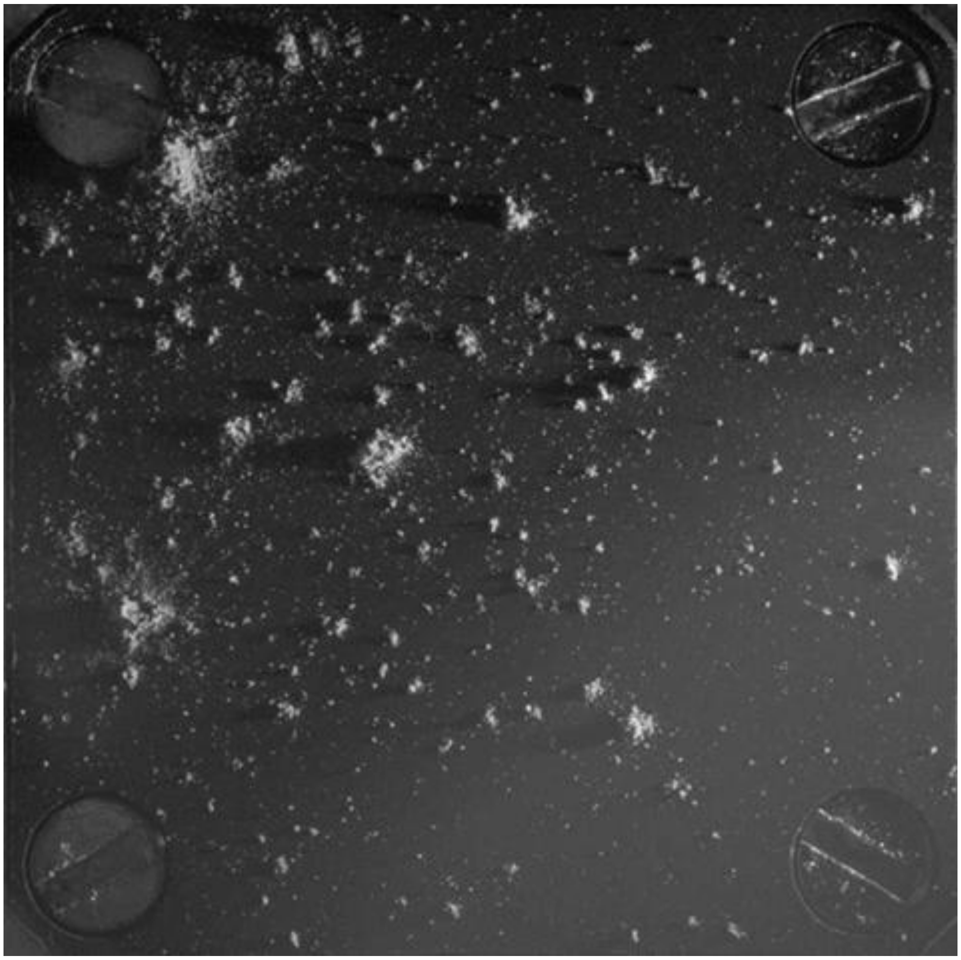


Image of dust from Comet 67P/Churyumov-Gerasimenko and analysed by the COSIMA instrument on the Rosetta spacecraft. The screw heads are 1.5 mm in diameter.

Credit ESA/ROSETTA/MPS FOR COSIMA TEAM MPS/CSNSM/UNIBW/ TUORLA/IWF/IAS/ESA/BUW/MPE/LPC2E/LCM/FMI/UTU/LISA/UOFC/VH&S

Analysis by the probe's onboard mass spectrometer shows the particles from Comet 67P/Churyumov-Gerasimenko to be on average 55% non-hydrated mineral silicates and 45% organics, and with the mineral composition 5.5% silicon (Si), 1.6% iron (Fe), 0.6% magnesium (Mg) and smaller amounts of sodium (Na), calcium (Ca) and aluminium (Al).

These particles then are typically what we see as meteors if the Earth crosses the orbit of the meteor stream left behind by a comet.

The composition of asteroidal dust

Given that asteroids originate from different regions of the solar system, their composition may be expected to depend on the source region from where they come and the degree to which they have come under the influence of radiation from the Sun. Composition of asteroidal dust has been inferred by:

- Spectroscopy using Earth-based telescopes.
- Analysis of meteorites collected from Earth's surface.
- Flybys from space probes

Spectroscopy has been used to classify asteroids into different Classes depending on the characteristics of their surface spectra. The three main classes, C, S and M-types, account for most of the asteroids, with C-type (carbonaceous) which account for more than 75 percent of all known asteroids, and S-type (silicaceous) which account for about a further 17 percent of all known asteroids (https://nssdc.gsfc.nasa.gov/planetary/text/asteroids.txt). The compositions of these three asteroid classes are shown in Table 2 (Zellner 1979).

Asteroid type	Mineralogy	Composition, meteorite analogues
C	Silicates plus carbon	Carbonaceous chondrites, olivine, pyroxene
S	Silicates plus metal	Stony irons, metallic iron mixed with iron and magnesium silicates
M	Metal plus silicates	Nickel-irons, enstatite chondrites

Table 2 Main types of asteroid and their compositions

An interesting case that falls outside these classes is that of asteroid 3200 Phaethon, which is the parent body of the Geminids meteor shower seen each year during mid-December. The asteroid is an Apollo-type, and it reaches perihelion every 1.43 years at the very small perihelion distance of only 0.14 AU. Such a small perihelion distance brings the asteroid in close proximity of the sun on a regular basis, leading to intense heating of the minerals at the asteroids surface. This causes so-called 'Space Weathering' in which the properties of the surface dust may be modified. It was found (Jewitt, Li and Agarwal 2013) that the asteroid develops a dust tail when near to the Sun, leading to the conclusion that Phaethon is a rock comet, producing dust due to thermal decomposition and fracture of hydrated minerals and their ejection into the path of the asteroid. In a recent study (Zhang et al 2023) the SOHO satellite detected a tail from sodium (Na), which indicates there is still much to be learned from the particles emitted from asteroids. Whatever the composition, it is these particles we see as meteors every December as we pass through the stream left behind by Phaethon.

SOHO images of sodium tail from asteroid 3200 Phaethon. Credit: ESA/NASA/Qicheng Zhang

Most meteorites found on Earth have their origin on asteroids. Therefore, analysis of meteorites can be correlated with spectra of asteroids, and a broad body of data of meteorite compositions exists. Previously meteorites were broadly classified into three types depending on their composition: stony, iron or stony-irons. However, modern classification schemes have been developed which rather take into account the formation location in the early Solar System. On this basis meteorites are classified as :

- Chondrites (undifferentiated, unmelted)
- Primitive achondrites (undifferentiated, part-melted)
- Achondrites (differentiated, melted)

Differentiated meteorites are those that originate from melted asteroids, and where the material has undergone physical and chemical changes during the solidification process. Undifferentiated meteorites are those that have not undergone melting and solidification processes, and have a composition similar to the Sun's **photosphere**.

The major determining factor amounts to the presence or not of **chondrules**, which are spherical globules of minerals found in many meteorites. The chondrites are divided into 15 groups (8 carbonaceous chondrites, 3 ordinary chondrites, 2 enstatite chondrites, and the R and K chondrites). Carbonaceous chondrites comprise mainly iron (Fe) and magnesium (Mg) silicates, including olivine, pyroxene and plagioclase, as well as iron sulphide (FeS) and smaller amounts of aluminium (Al), calcium (Ca) and sodium (Na). Enstatite chondrites (stony-irons) contain iron (Fe) and nickel (Ni) in metallic form. (see https://faculty.uml.edu/Nelson_Eby/87.201/material.htm)

There is a growing number of asteroids which have been visited by space probes. Many of these have been analysed spectroscopically, and in a couple of cases samples have been taken from the surface and returned to Earth for analysis. In June 2010 the Hayabusa spacecraft returned samples from the S-type asteroid 25143 Itokawa and in December 2020 the Hayabusa 2 spacecraft returned samples from the surface of asteroid 162173 Ryugu. Analysis shows Itokawa to be similar to an ordinary chondrite, with majors of magnesium (Mg) and iron (Fe) silicates[1]. Analysis of dust from Ryugu shows it to be like CI-type carbonaceous chondrites, which have elemental abundances very similar to that of the Sun.

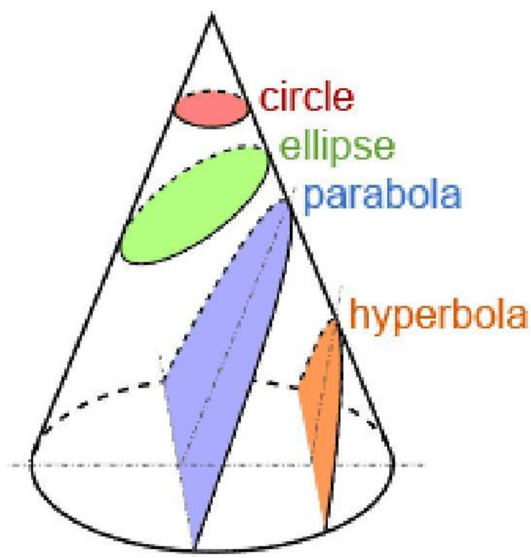
[1 https://solarsystem.nasa.gov/asteroids-comets-and-meteors/asteroids/25143-itokawa/in-depth/]

Another asteroid imaged and sampled by a spacecraft is the Apollo-type asteroid 101955 Bennu. The asteroid was the target of the OSIRIS-REx probe which launched on 8 September 2016, and arrived at Bennu on 3 December 2018. Shortly after arrival the spacecraft captured images of solid particles ejected from the surface of the asteroid. Subsequently, the probe collected samples from the asteroid using its Touch-And-Go Sample Acquisition Mechanism (TAGSAM), and which were returned to Earth for analysis, scheduled to arrive on 24 September 2023. Since Bennu can come close to Earth's orbit the dust particles seen emanating from the asteroid may be visible in the future as a meteor shower.

Introduction to orbits of comets and asteroids

All bodies in the solar system, except the natural satellites, revolve around the Sun in orbits which can be described by one of the **conic sections**. There are four sections of a cone:

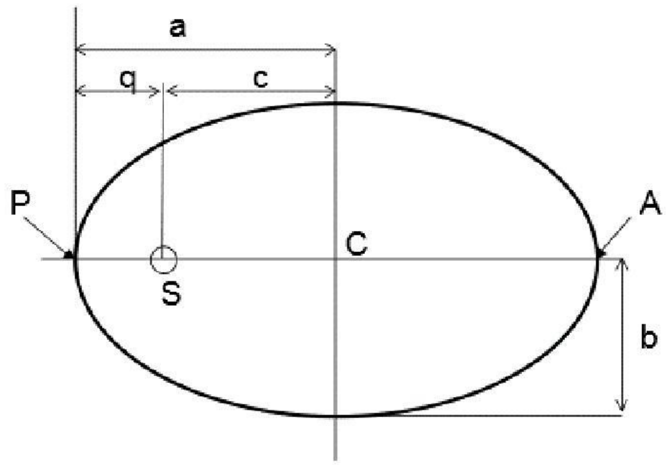
- Circle
- Ellipse
- Parabola
- Hyperbola



Sections of a cone, diagram from Conic section facts for kids,

Kiddle encyclopedia, content is available under CC BY-SA 3.0

There are no truly circular orbits in the Solar System, and only a few bodies on hyperbolic orbits have been found. Most comets and asteroids orbit the Sun on curved paths which may be elliptical or parabolic. The shape of the orbit can be described by parameters known as orbital elements.



Parameters of an elliptical orbit

By way of example consider the shape of the orbit of a comet with reference to the above diagram. All distances are given in astronomical units (au). S is the position of the sun and is at one of the two focal points of the ellipse. C is the centre of the ellipse. P is the perihelion point, where the comet is at its closest to the Sun in its orbit. A is the aphelion point, where the comet is at its farthest from the sun in its orbit. The moment in time when the comet is at perihelion is designated as T, expressed as ephemeris time (replaced by barycentric dynamical time, TDB, since 1984). Also, q is the perihelion distance, a is the semi-major axis, b is the semi-minor axis and c is the distance from the sun to the centre of the orbit. Now, the shape of the orbit is described by the eccentricity, designated e, such that:

$$e = \sqrt{\frac{a2 - b2}{a}}$$

or also $e = \frac{c}{a}$

If e is equal to 0 then the orbit is circular (c=0 and hence e=0). If e is equal to 1 the orbit is parabolic. For all values of e between 0 and 1 the orbit is elliptical.

The perihelion distance is designated as q and is defined as:

$$q = a \cdot (1 - e)$$

With this we have thus defined three of the six orbital elements:

T = perihelion date and time

q = perihelion distance

e = eccentricity of the orbit

Having defined the shape of the orbit we now need to define its orientation in space. The first parameter is the inclination of the orbit relative to the plane of the orbit of the earth around the sun (the ecliptic plane). The second parameter is the argument of perihelion and the third is the longitude of the ascending node. Consider the orbit shown superimposed on the ecliptic plane (the grey-shaded plane):

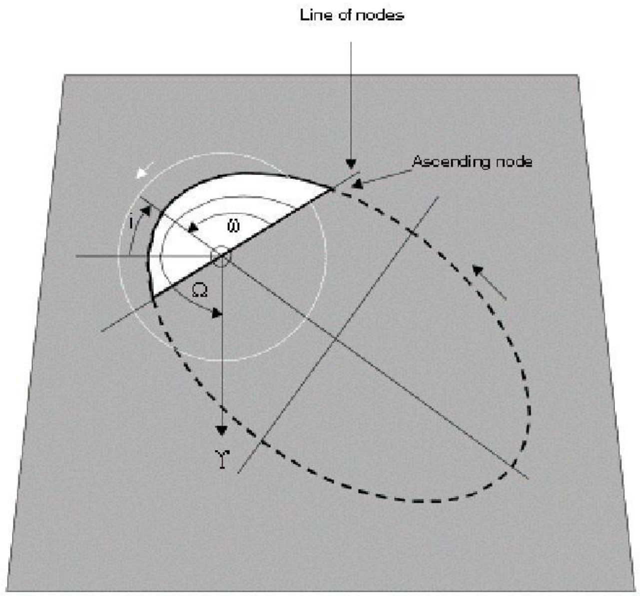


Diagram of elliptical orbit relative to the ecliptic plane

The orbit of the Earth is shown as a solid white line. The plane of the orbit is shown in grey, with the **vernal equinox** (0° celestial longitude) at the bottom. In this diagram the hypothetical object approaches from below the ecliptic plane in the direction of the arrow. The angle between the orbital plane of the comet and the ecliptic plane is termed the inclination, designated i. The sector of the orbit showed with a dotted line indicates the comet is below the ecliptic plane, while the solid sector shown in white is where the comet is above the ecliptic plane. The point at which the comet crosses the ecliptic plane is known as the ascending node, and the angle between this point measured eastwards from the vernal equinox is termed the longitude of the ascending node, designated Ω. Finally, we need to define the position of the perihelion point in space, which is termed the argument of perihelion, designated ω, and is the angle between the direction of the ascending node and the perihelion point, measured in the direction of motion of the comet. In figure y we have defined the remaining three orbital elements that describe the comets orbit:

i = inclination of the orbit

ω = argument of perihelion

Ω = longitude of ascending node

Since these three parameters are determinant on the precession of the Earth's orbit, they are quoted with the Epoch of measurement. By inputting the six orbital elements into certain planetarium software programs, you can determine the exact position of the comet at any point in time.

When considering the orbit of planetary bodies, it is customary to replace T, the time and date of perihelion, with the Mean anomaly, which is the angular distance of the body measured from its perihelion to its current position in its orbit, measured in the direction of motion of the body.

The six elements used to define the orbit of a comet are: eccentricity, perihelion distance, time of perihelion passage, inclination, longitude of the ascending node, and argument of perihelion.

The six Keplerian elements used to define the orbit of an asteroid are: eccentricity, semimajor axis, mean anomaly, inclination, longitude of the ascending node, and argument of perihelion.

https://ssd.jpl.nasa.gov/faq.html#a02

These elements are known as **osculating elements**, which describe the orbit in the absence of perturbations which might affect the orbit.

The science of meteors

Definition of terms

In order to clarify the terminology relating to meteor astronomy, and seeing that the 'basic definitions in meteoric astronomy' adopted at the IAU General Assembly in 1961 no longer corresponded to the current state of knowledge, Commission F1 of the IAU on 30 April 2017 approved a number of definitions, including inter-alia the following related specifically to meteors (the full text of the definitions can be found on the Commission F1 webpage):

Meteor - is the light and associated physical phenomena (heat, shock, ionization), which result from the high speed entry of a solid object from space into a gaseous atmosphere.

Meteoroid - is a solid natural object of a size roughly between 30 μm and 1m moving in, or coming from, interplanetary space.

Meteorite - is any natural solid object that survived the meteor phase in a gaseous atmosphere without being completely vaporized.

Meteor train - is light or ionization left along the trajectory of the meteor after the meteor has passed.

Meteoroid stream - is a group of meteoroids which have similar orbits and a common origin.

Meteor shower - is a group of meteors produced by meteoroids of the same meteoroid stream.

In the remarks to the term 'meteor'; A meteor brighter than absolute (distance of 100 km) visual magnitude –4 is termed a bolide or a fireball. A meteor brighter than absolute visual magnitude –17 is also called a superbolide.

The Earth's atmosphere

As we saw previously, the definition of a meteor 'is the light and associated physical phenomena (heat, shock, ionization), which result from the high speed entry of a solid object from space into a gaseous atmosphere. In our case meteor processes take place in the Earth's atmosphere, and therefore it is useful to understand the medium in which these processes take place. The atmosphere comprises five layers as shown in this diagram:

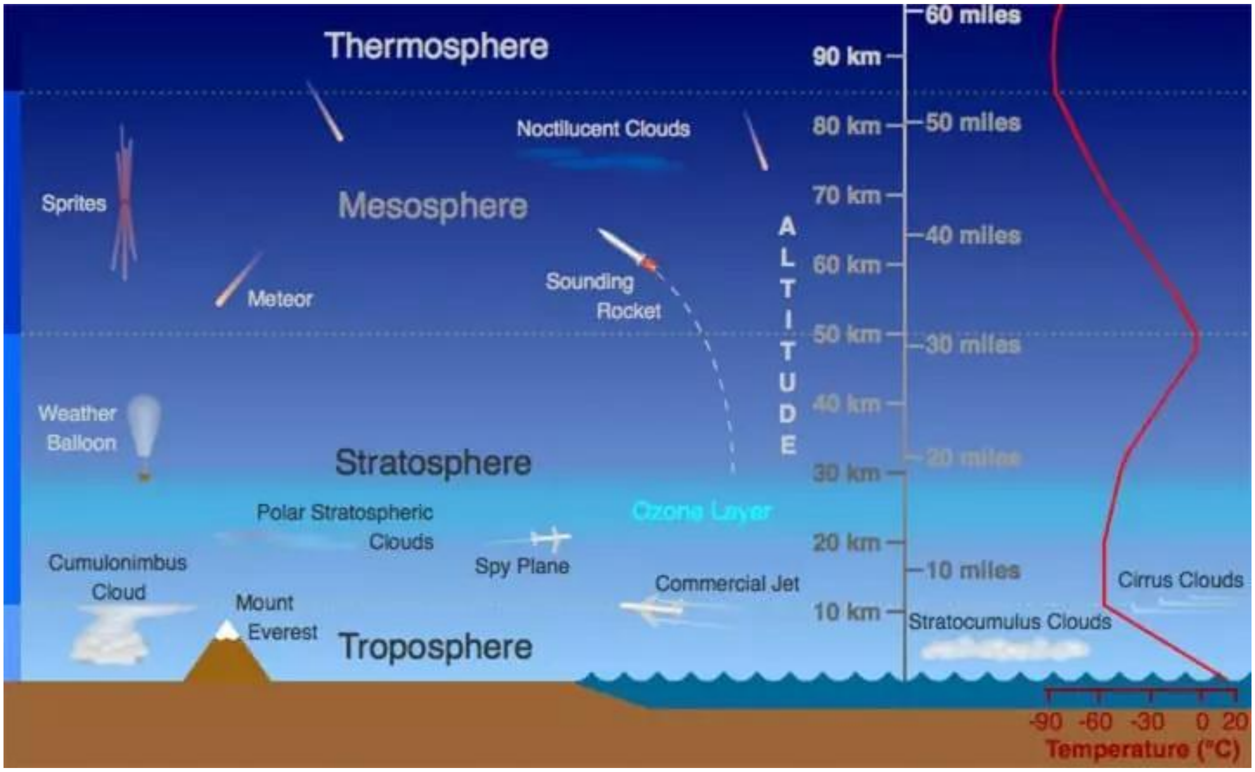


Figure showing layers of the atmosphere and their altitude regions.

Credit Randy Russell, UCAR, & UCLA

From the ground upwards the layers are:

https://www.nasa.gov/mission_pages/sunearth/science/atmosphere-layers2.html

https://www.noaa.gov/jetstream/atmosphere/layers-of-atmosphere

- Troposphere – which extends from the Earth's surface to an altitude of about 8 km at Earth's poles, and 14 km at the Equator. The Troposphere is the region where most of Earth's weather occurs. Temperature ranges from about 20°C at the bottom of the layer to -55°C at the top of the layer.
- Stratosphere – extends to about 50 km above the Earth's surface and includes the ozone layer. Temperature varies from -55°C to 0°C.
- Mesosphere – extends to about 85 km, and includes the parts of the atmosphere in which meteor phenomena occur. Temperature varies from 0°C to -90°C.

- Thermosphere – extends from about 85 km to 600 km above the Earth's surface. Meteor phenomena start to occur in the lower Thermosphere. The layer is also the region where the **aurora** occurs. Temperature varies from -90°C to >1000-2000°C
- Ionosphere – is a region extending from about 48 km to outer space, and therefore includes the Mesosphere and Thermosphere. It is made up of charged particles and enables radio communications.

Earth's atmosphere is made up of the following elements (**molar percentage**):

- Nitrogen 78.08%
- Oxygen 20.95%
- All others <1%

This composition includes all layers up to and including the Mesosphere, and remains fairly consistent due to turbulence and mixing. However, the temperature, pressure and density change on moving to higher altitudes. (see https://study.com/learn/lesson/mesosphere-temperature-composition.html).

The Meteor phenomenon

In the preceding parts of this chapter, we considered the nature of particles from comets and asteroids travelling through space (meteoroids), and the nature of the atmosphere. Recall that the definition of a meteor 'is the light and associated physical phenomena (heat, shock, ionization), which result from the high-speed entry of a solid object from space into a gaseous atmosphere.' So, what we see as a meteor is the result of the passage of particles from comets or asteroids through the Earth's atmosphere.

The first comprehensive explanations of the meteor phenomenon were by Opik in 1958, and by Bronshten in 1983. This understanding has been expanded since, but in general (Ceplecha et al 1998) the result of a high speed entry of a meteoroid into the atmosphere results in four types of phenomena, which are dependent on the mass and velocity of the meteoroid:

- Meteors

- Fireballs, bolides and meteorites
- Explosive impacts
- Meteoric dust particles

The first two will concern us here. The third, explosive impacts are caused by very large bodies and are rare phenomena, while the fourth, meteoric dust particles are small and are slowed down to the extent their kinetic energy is too low and do not result in producing meteors that can be detected by eye or by camera.

The particles that produce the meteor phenomena we are interested in enter the atmosphere with speeds ranging from 11 km/sec at their slowest, to 72 km/sec at the fastest. That speed is determined by two factors; the velocity of the meteoroid itself before it enters the atmosphere and the angle it enters the atmosphere relative to the Earth.

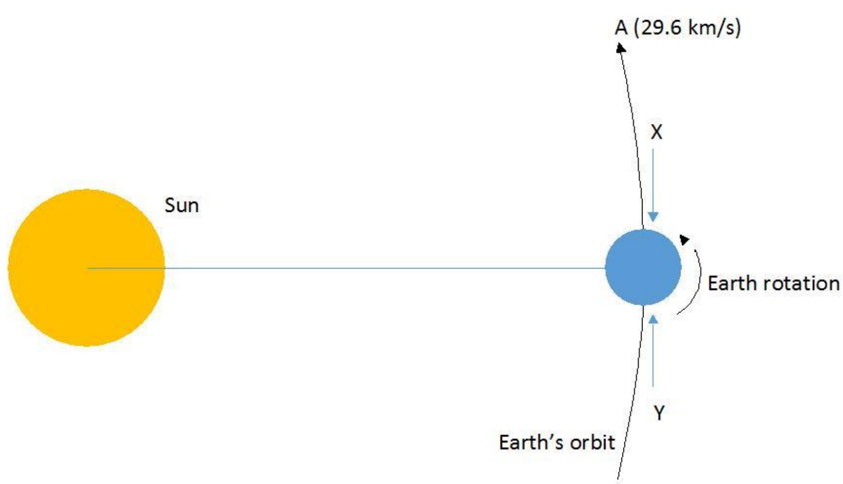


Diagram showing speed, geocentric velocity, apex of the Earth's way (A)

Consider the motion of the Earth and meteoroid shown in the diagram. The Earth travels at a velocity of 29.6 km/s in direction of A, the apex of the Earth's way. The meteoroid shown travelling on path X is travelling with velocity 41 km/s, but it enters the atmosphere with a combined velocity of 29.6 + 41 = 70.6 km/s. This velocity relative to the Earth is called the geocentric velocity. This scenario is typical for the Leonid meteor shower, caused by particles from comet 55P/Tempel-Tuttle, and the meteors appear very fast moving.

If the same particle were travelling at velocity 41 km/s, but from direction Y, it would have to catch up with the Earth which is moving in the same direction as the particle. The particle would enter the atmosphere with geocentric velocity 41 – 29.6 = 11.4 km/s, and such meteors would appear to be very slow moving.

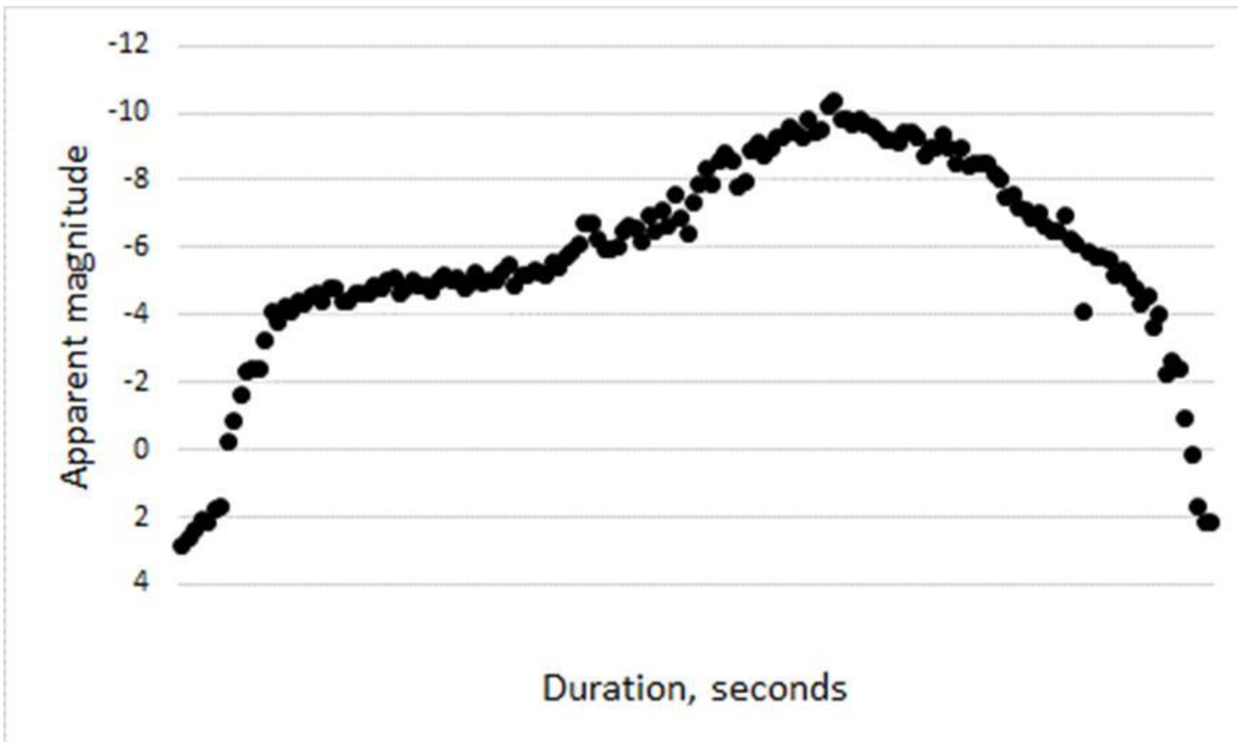
Now, consider again the particle approaching the Earth from direction X. At around 300 km altitude it starts to encounter atmospheric molecules and due to collisional interactions begins to heat up. This is the preheating phase of the meteoroid, but the particle has not yet become a meteor.

As the heated particle descends to lower altitudes, around 100-120 km, the particle encounters higher densities of air, resulting in more frequent collisions and as a result is heated above its melting point. The particle may fragment, and once the temperature reaches around 2500 K, the particle begins to evaporate. This process of melting, fragmentation and evaporation is called **ablation**. At the same time, kinetic energy is converted into electromagnetic radiation, including visible light, and the phenomenon becomes a meteor.

During the ablation phase the particle decelerates and loses kinetic energy. If the particle is small enough its evaporation results in conversion to a vapour. However, if the particle is large enough, it may survive the ablation phase, but the residual kinetic energy is insufficient to produce light, and the particle enters the phase called dark-flight. It is no longer visible as a meteor, but the surviving particle may then reach the ground, when it becomes a meteorite.

Light production and colour from meteors

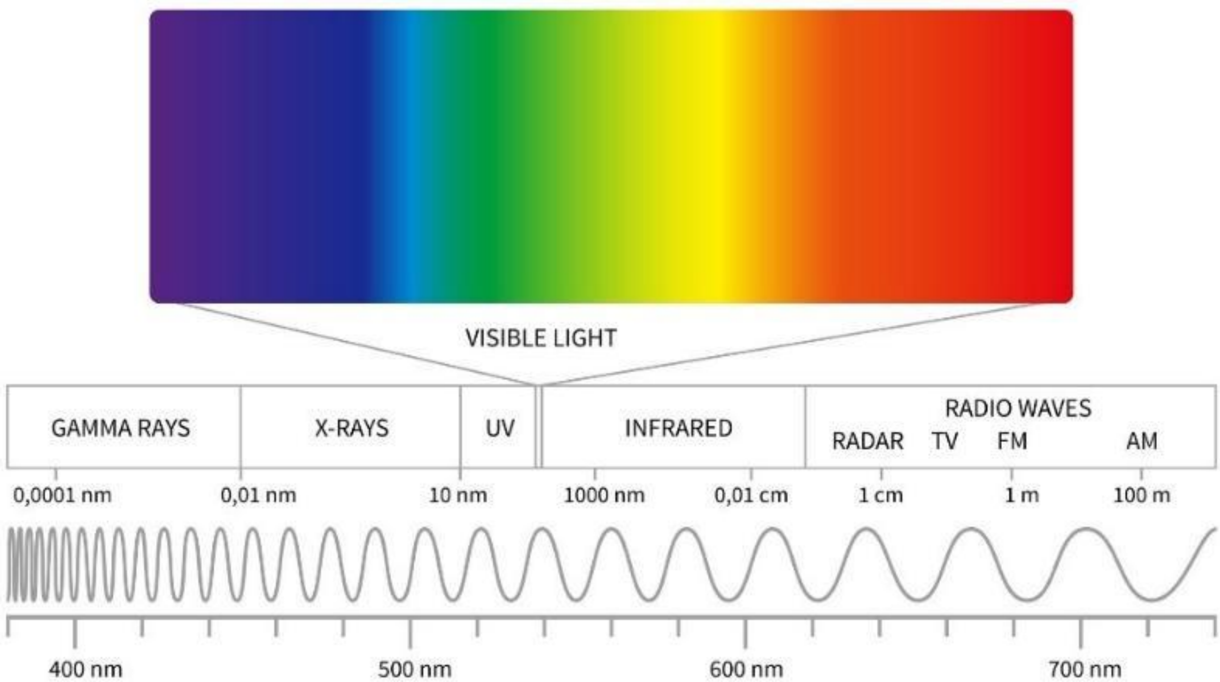
Travelling at such speeds, kinetic energy is converted into **electromagnetic radiation** (heat and light) due to collisions between the meteoroid and air molecules. These collisions cause ionisation of the air molecules, which are raised to a higher energy level, and radiate the energy as light when they return to the ground state. It is this streak of light that we call a meteor. The brightness of the meteor is dependant primarily on the mass and velocity of the particle, and the fraction of kinetic energy converted to radiation can be calculated using the formula for **luminous efficiency**, designated by the Greek letter tau (τ). However, the light emitted is not constant along the entire path of the meteor, but starts out faint as ablation begins, brightening to a maximum and then fading again. The brightness of a meteor can be plotted to give a light curve.



Light curve of bright fireball seen over Western Cape of South Africa, 6 August 2023 (Cooper 2023)

In addition to the rise and fall in brightness, the light curve may show flares as the meteor disrupts or fragments during its passage. Very bright fireballs may show a sharp terminal burst as the meteoroid explodes, and such a fireball is called a bolide.

To the human eye, the perceived colour of a meteor is subjective, and varies from one observer to another. However, from a physics standpoint the colour can be accurately determined by measuring the intensity of light emitted at different wavelengths within the **electromagnetic spectrum**. The electromagnetic spectrum is the distribution of electromagnetic radiation according to frequency or wavelength of the radiation, ranging from high energy, high frequency, low wavelength gamma rays, through x-rays, ultra-violet (UV), visible light, Infra-red (IR), microwave, to low energy, low frequency, long wavelength radio waves.

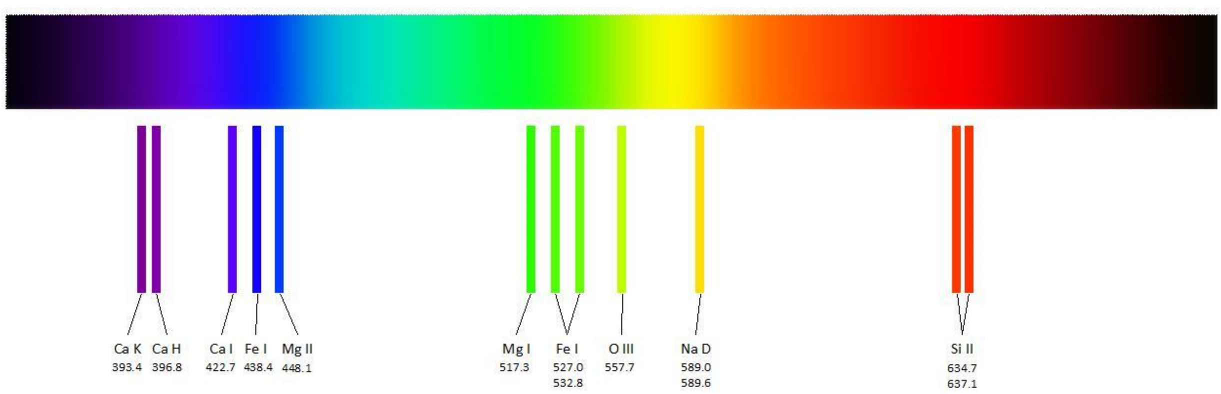


Regions of the electromagnetic spectrum, showing visible region from 400 nm (blue) to 700 nm (red)

Image courtesy of Gamma Scientific at https://gamma-sci.com/2021/07/02/electromagnetic-spectrum-101-radio-microwave-and-infrared/

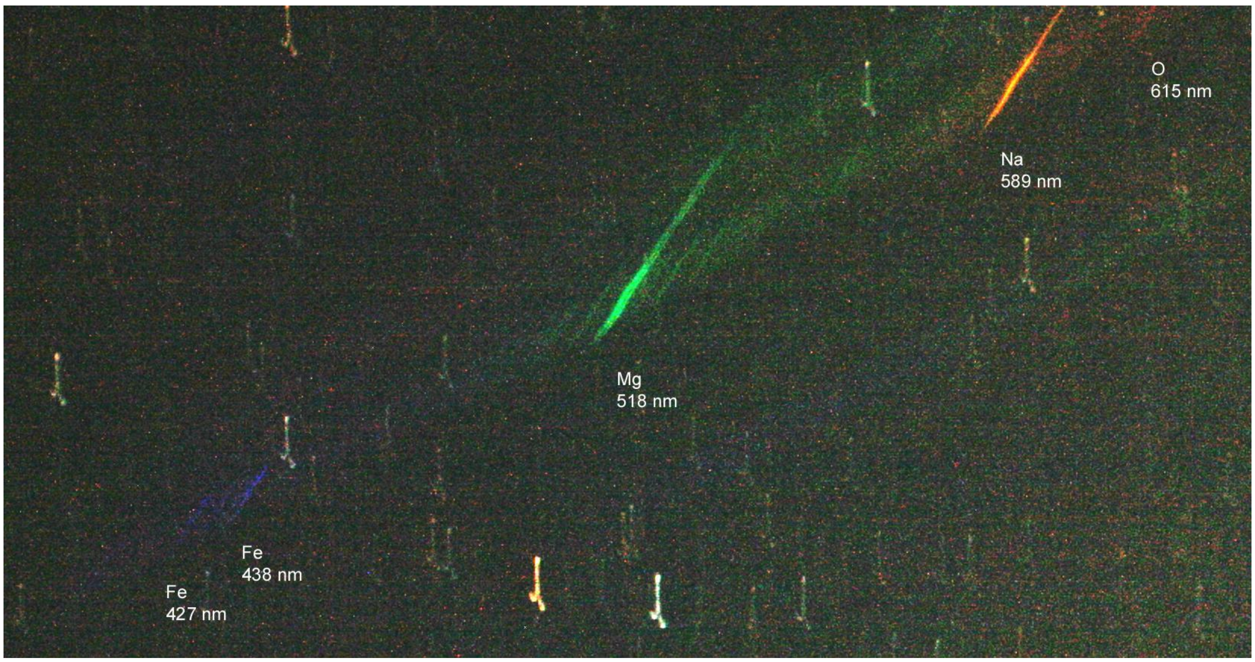
When talking about light emitted from meteors we are principally concerned with visible light extending from about 400 nm at the blue end of the spectrum to 700 nm at the red end of the spectrum.

The colour of light from meteors emanates from two sources, either from light emitted by the meteoroid itself, or by light emitted by air molecules. Firstly, light is emitted due to excitation of metals, which emit light on return to their ground state. Typical colours emitted by meteors (Rendtel 1993) are blue-violet from calcium and magnesium, yellow-green from sodium and iron, and red from silicon. The brightest emission lines in meteor spectra are normally the H and K lines from calcium. Secondly, very energetic processes during entry of the meteoroid into the atmosphere cause excitation of atmospheric gas molecules, which then radiate light in the visible region, for example green from oxygen and red from nitrogen. Persistent green trains from meteors have been shown to be due to the excitation of atomic oxygen at 557.7 nm (Evans 2003), and this emission is enhanced by the presence of sodium in the meteor (Beech 1987). The light emitted by the meteor ultimately depends on which process predominates, extinction effects due to altitude, and the length of the path, as the meteor loses kinetic energy and descends in altitude.



Prominent emission lines from atoms present in meteors, as well as atmospheric oxygen and nitrogen, and their colours. The colours depicted for the different species were created using the app at https://academo.org/demos/wavelength-to-colour-relationship/.

The colours of the strongest emission lines from meteors are shown in the diagram above. To the naked eye, most meteors may appear white, especially fainter meteors. The human eye detects light using two types of receptors; **rods and cones**. Rods function at low light levels (scotopic vision), while cones take over at high light levels, and are responsible for our ability to see colour (**photopic vision**). If the intensity of the light is too low to stimulate the cone receptors, then we see objects such as meteors as white. For brighter meteors, and especially fireballs, there may be sufficient light to stimulate the cone receptors, and depending on the wavelengths of light emitted the meteor may be perceived as coloured.

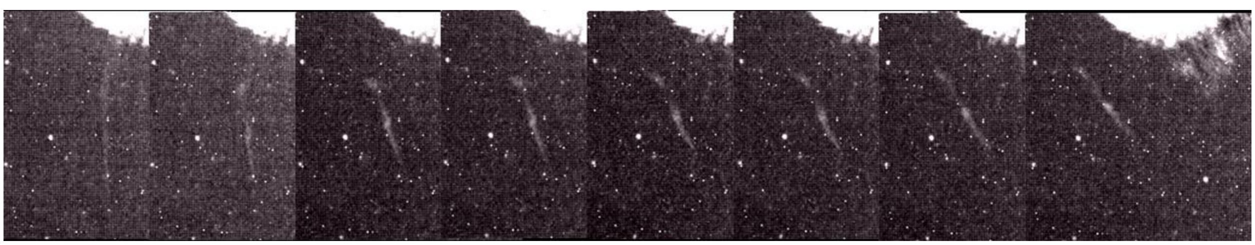


Spectrum of a meteor showing prominent lines of iron, magnesium and sodium
Picture from Starship Asterisk APOD and General Astronomy Discussion Forum*
at https://asterisk.apod.com/viewtopic.php?t=34693.

The light detected from a meteor can be analysed by passing it through a spectrograph, which uses a grating to split the light into its component colours and records a spectrum. By comparing the emission lines in the spectrum of the meteor to a library of spectral lines, the composition of the meteor can be determined.

Meteor trains and wakes

After the passage of a bright meteor through the atmosphere, a trail may be visible for some time afterwards. These trails are known as trains or wakes, and the nature of the trail and how long it is visible after the passage of the meteor depends on how it was formed. The IAU definition of a meteor train is light or ionization left along the trajectory of the meteor after the meteor has passed. During the description of the meteor phenomenon we saw that atoms are raised to an excited state, and radiate light as they return to their ground state. The process of returning to the ground state may in some circumstances not be instantaneous, but may take from a fraction of a second to a few seconds, during which time light is radiated after the particle responsible for the meteor has passed. The resultant glow is called a meteor train. In the case of larger particles which fragment during their flight, smaller particles may be left behind as the larger particle ablates, and as they decelerate they leave a luminous glow behind the head of the meteor. This glow is called a meteor wake. Finally, the IAU also defines meteoric smoke as solid matter that has condensed in a gaseous atmosphere from material vaporized during the meteor phase. The meteor smoke may be visible for some minutes after the passage of the meteor, and may be seen to drift under the influence if high altitude winds.



Meteoric smoke from a bright fireball observed by Marc Watts, South Africa, on 9 November 2021. After the passage of the fireball, a persistent smoke trail was visible for several minutes. Notice how the smoke drifts under the influence of high altitude winds. The last image on the right was taken 8 minutes after the passage of the fireball.

Meteor showers

Shower meteors versus sporadic meteors.

If you gaze at the sky during most times of the year, you are likely to see perhaps a handful of meteors during the period of an hour or so. These meteors are mainly isolated particles travelling through space, and we refer to them as sporadic meteors. At certain times of the year there appear to be more meteors visible. Why? These are the meteor showers, as the Earth crosses the orbits of particles left behind by comets and asteroids as they orbit the Sun. If the path of the meteor cannot be traced back to a known radiant, then the meteor is said to be sporadic. Many of these sporadic meteors are probably isolated particles, but most of these in reality were probably once members of a meteor shower that has long since dispersed, so that now only the occasional meteor appears randomly, so that determining its origin is not possible. In addition, there are probably many meteor showers formed by low-mass comets which produce fewer particles, so that the rate of meteors from the stream is so low as to be hardly detectable. Rather than calling them meteor showers, meteor astronomer David Hughes referred to these as 'meteor drizzle'.

Meteor showers occur as the Earth crosses the orbit of a comet or asteroid that has made at least one passage around the Sun and left dust particles in its orbit. So how many meteor showers are there? There are about a dozen well known meteor showers, many of which have been studied since ancient times, and which produce a reliable display of meteors every year. The most well-known meteor showers are shown in Table 3.

Meteor shower	Maximum date and (visibility)	Rate/hour ZHR	Parent comet or asteroid
Quadrantids	Jan 3/4 (Dec 26-Jan16)	120	Asteroid 2003 EH
Lyrids	Apr 22/23 (Apr 15-29)	18	Comet C/1861 G1 (Thatcher)
eta-Aquariids	May 5/6 (Apr 15-May 27)	50	Comet 1P/Halley
Southern delta-Aquariids	July 30/31 (Jul 18-Aug 21)	25	Comet 96P/Machholz?
Perseids	Aug 12-13 (July 14-Sep 1)	100	Comet 109P/Swift-Tuttle

Orionids	Oct 21/22 (Sep 26-Nov 22)	20	Comet 1P/Halley
Taurids	Nov 5/6 (Sep 23-Dec 8)	5	Comet 2P/Encke
Leonids	Nov 17/18 (Nov 3-Dec 2)	15*	Comet 55P/Tempel-Tuttle
Geminids	Dec 13/14 (Nov 19-Dec 24)	150	Asteroid 3200 Phaethon

*Table 3 Annual meteor shower activity. Data from IMO Meteor Calendar 2024. *Note the Leonids show storm activity coinciding with the return of Comet 55P/Tempel-Tuttle to the Sun on its 33-year orbit, which next occurs in 2034.*

Table 3 gives the meteor shower's activity period, its rate of meteors per hour at maximum, and the known parent body from which the particles came. The activity that can be expected from a given meteor shower is given by its rate. The simplest way to express the rate would be to observe for 60 minutes and count the number of shower meteors. The rate per hour would then simply be: Rate = n/t, where n is the number of shower meteors and t is the time in hours. However, this method says nothing about the conditions under which the observations were made, the altitude of the radiant, the reduction in visibility of sky due to obstructions or clouds, or the proficiency of the observer. Therefore, it is normal to determine the **Zenithal Hourly Rate (ZHR)** which is the rate that would be expected if the radiant was in the **zenith** and under clear, dark skies where magnitude 6.5 stars are visible to the eye.

In addition to the annual showers, there are many showers which remain dormant each year, but occasionally or even periodically show outbursts in activity. More details about these and other meteor showers can be found in the Meteor Shower Workbook 2014, Edited by Juergen Rendtel and available at: https://www.imo.net/resources/free-meteor-books/.

Observers in these two locations would see differing numbers of meteors from the same meteor shower. The observer on the left with dark skies will see more meteors than the observer on the right with light polluted skies. Image from Sky and Telescope, AAS Sky Publishing, LLC.

Finally, there is a growing number of meteor showers that produce very low activity, some are annual and others show outbursts, but always generally with low activity which make them difficult to detect by visual observations alone. These include the showers we referred to recently as meteor drizzle. These showers are ideally suited to observation with cameras such as those used in the GMN Outreach Project, which are able to determine the radiant of the meteors and their orbits.

You can get a good idea of meteor activity as picked up on any night by GMN cameras by visiting this page: https://globalmeteornetwork.org/flux/

How many meteor showers are there?

Regarding the number of meteor showers, the International Meteor Organisation (IMO) maintains a working list of meteor showers requiring observation. Currently there are 44 meteor showers on the list requiring observation.

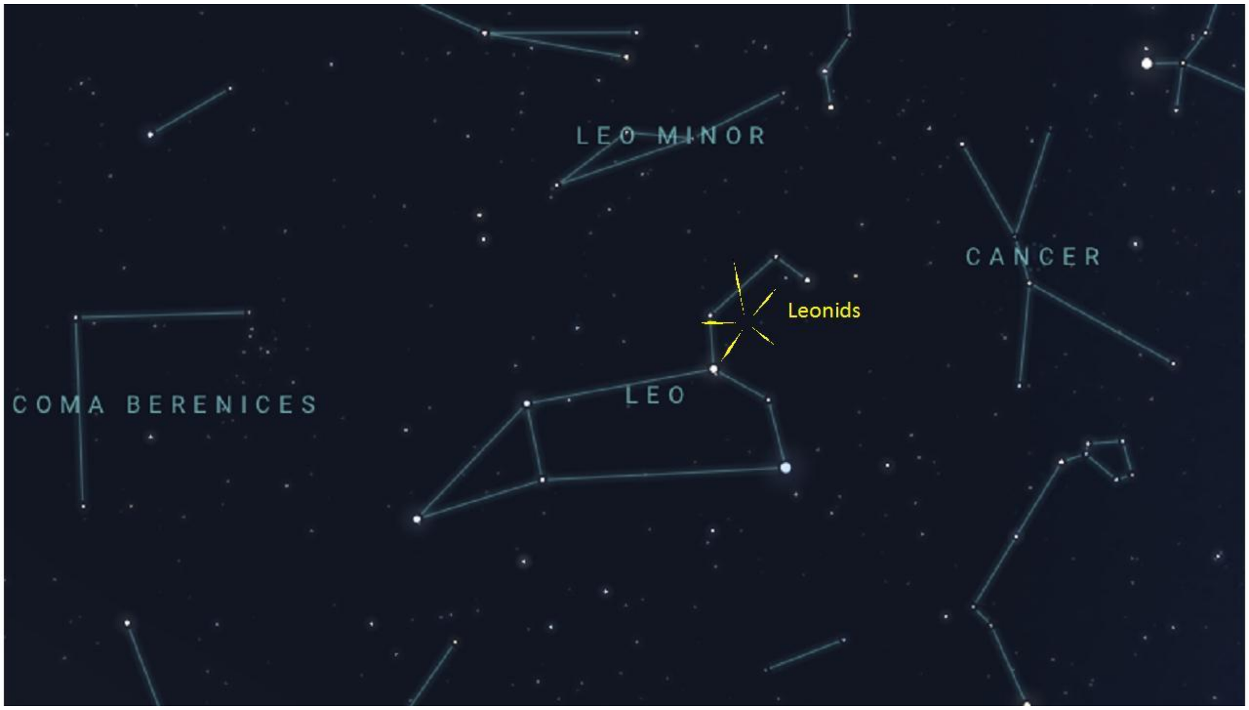
The official catalogue of meteor showers is maintained by the Meteor Data Centre (MDC) of the International Astronomical Union (IAU). This catalogue identifies meteor showers by giving them a name, three letter shower code and shower number. The MDC currently lists 795 meteor showers of which 659 meteor showers are on its working list, including all the confirmed known meteor showers, whether they are annual or have only been observed on a few occasions in the past. New meteor showers are being discovered all the time, many of these with GMN cameras such as those you will be using in the GMN Outreach Project. What is sure is that each and every one of these meteor showers resulted from the crossing of the orbit of a comet or asteroid with Earth's orbit in the past. If the comet is periodic and returns to the Sun's environment in the future, the orbits may intersect again and if the two bodies are in the right places at the right time, an impact of the body with Earth is possible. Therefore, meteor showers are useful indicators of the possibility of impacts from potentially hazardous comets and asteroids.

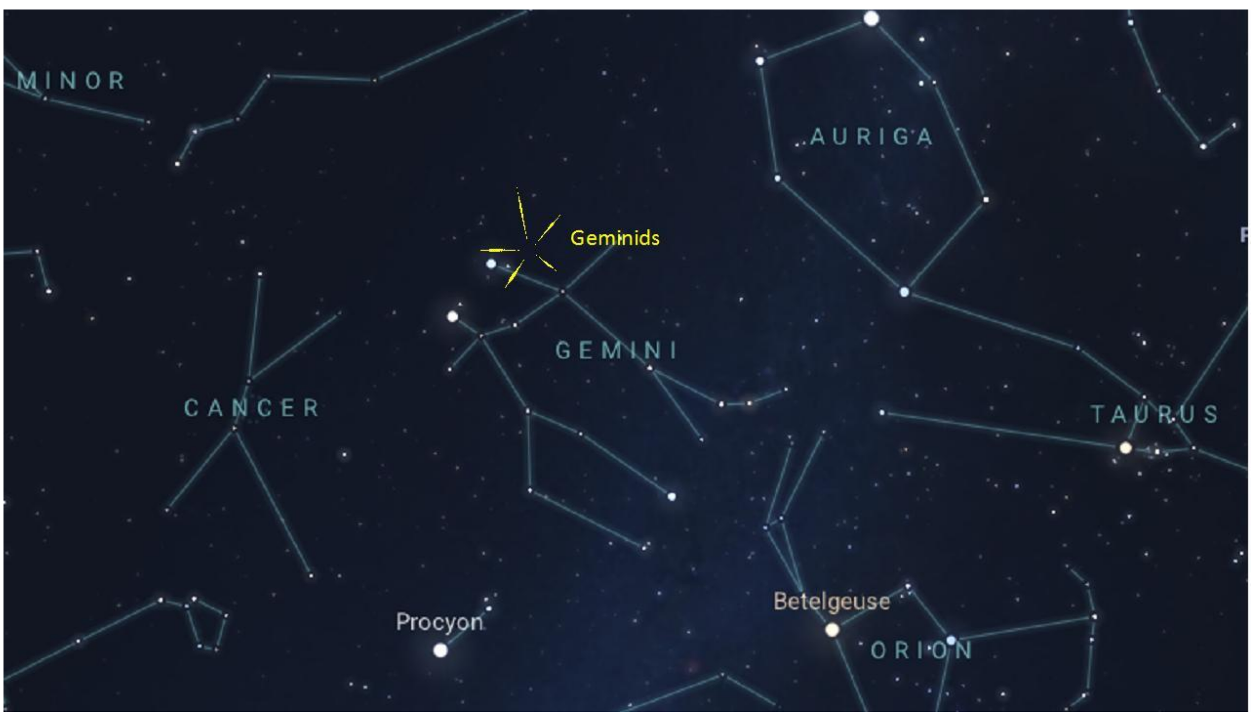
Meteor showers with known parent bodies

A list of meteor showers with known parent bodies is given at the end of this module. Of the nearly 800 meteor showers in the MDC list, less than 50 have known parent bodies. That means that there are still more than 750 meteor showers from potentially hazardous comets or asteroids that have not been identified as yet. Determining the orbital details of meteor showers is another important function of the cameras used in the GMN Outreach Project. Once the orbital details have been determined, they can be compared to the orbital details of all the known comets, and any similarities can be identified. When there is a close similarity between the two orbital details, the link can be made between the parent comet or asteroid and the daughter meteor shower.

Nomenclature of meteor showers

Historically, meteor showers were named after the constellation in which the radiant is to be found; so for example, the last three months of the year see three of the most well-known meteor showers active.





Radiant position of the Orionids, Leonids and Geminids, which all get their name from the constellation from which the meteors appear to radiate. Charts produced using Stellarium Web (stellarium-web.org)

Firstly, a meteor shower has been observed since ancient times, which reach their maximum about 22 October each year. Meteors appear to radiate from the constellation of Orion, and are referred to as the Orionids. Today we know that the Orionids are debris left behind by comet 1P/Halley, but rather than taking their name from the comet, they are named after the constellation from where they appear to emanate.

A few weeks later another meteor shower reaches its peak, usually in the early hours of 17/18 November. Meteors appear to radiate from the constellation of Leo, and the meteor shower is known as the Leonids. The Leonids have historically undergone a number of prolific outbursts or ‘meteor storms’, for example in 1833, when on the night of November 12/13 the rate reached between 50,000-150,000 per hour (14-42 per second). Only after the Leonid storms of 1799, 1833 and 1866, and the discovery of comet 55P/Tempel-Tuttle was it realised that the orbits of the Leonid meteors bore a striking resemblance to that of the comet, and that the outbursts coincided with the return of the comet to perihelion in its 33 year orbit. The next return of the parent comet to perihelion is in 2032, when higher rates of Leonids may again be visible.

Visualisation by Adolph Vollmy of the 1833 Leonid storm.

The year's most reliable meteor activity occurs in mid-December each year, with the debris from asteroid 3200 Phaethon resulting in the Geminid meteor shower from the constellation of Gemini.

During the late 20th century, there was an increase in the number of meteor showers discovered, and with the increasing number of cameras trained on the sky recording meteors, the rate of discovery of new meteor showers continues to grow at a faster pace. We have already seen that there are 659 meteor showers on the IAU working list, but there are only 88 constellations in the sky. So, it is not possible to call every meteor shower after the constellation from which the meteors appear to emanate. For this reason, the name of the constellation remains, but the nearest bright star is added which is closest to the radiant, or in some cases the month may be used with the constellation name. For example, at the same time as the Orionids are active in mid to late October, another meteor shower is active, albeit with lower rates per hour, from the nearby constellation of Gemini. Since there is already a Geminids meteor shower, the shower active in October is called the epsilon-Geminids since the radiant is very close to the star epsilon (ε) in the constellation of Gemini.

Radiant position of the epsilon-Geminids, close to the star epsilon Geminorum

Another example of a constellation from which more than one meteor shower emanates is Aquarius. Two well-known showers originate from within its boundaries, and to avoid any confusion they are named after the closest star to the radiant. So we have the eta-Aquariids in May, and the delta-Aquariids in July.

The Greek alphabet

Due to the continuing discovery of new meteor showers, the International Astronomical Union (IAU) approved new rules for naming new meteor showers from August 2022. The names of any meteor showers assigned before this date remain unchanged. The new rules follow a two-stage approach to naming new meteor showers, the first stage immediately after discovery of a new shower, and the second stage after the shower has been observed on subsequent occasions so that its existence is proved. See https://www.ta3.sk/IAUC22DB/MDC2022/Dokumenty/shower_nomenclature.php.

First stage – a new meteor shower submitted to the Meteor Data Centre (MDC) is given a provisional designation only (not a name) based on the date of submission. It is assigned by the MDC according to the following schema:

- a prefix M,
- the year of discovery (4-digit number) followed by a hyphen,
- an uppercase letter identifying the half-month of observation during that year; A for the first half of January, B for the second half, and so on,
- a number representing the order of the shower submission to the MDC within that half month.

Examples: the first shower submitted to the MDC within the first half of January 2024 would be designated as M2024-A1. A new shower discovered in the second half of August 2022 was given the designation M2022-Q1.

Second stage – a meteor shower, which has become well confirmed (its regular activity, origin, etc.) and meets the required criteria for established status, will be given a final designation according to the following schema:

- a prefix M followed by a hyphen,
- the IAU MDC numerical code (a number issued sequentially by the MDC)
- a name (the discoverer will be invited to propose a unique name for their shower; all proposed names will be judged by the Working Group on Meteor Shower Nomenclature of the IAU.)

The final shower designation and the name will be officially approved by the IAU.

Example: the meteor shower which was given the designation M2022-Q1 in the first stage was confirmed by video observations. It was then given the name 18-Aquariids, shower number 1212. Since the orbits of the observed meteors could be determined, the parent body was possibly confirmed as Comet 45P/Honda-Mrkos-Pajdusakova based on similarity of the orbits of the meteors and the comet.

The IAU MDC list of meteor showers

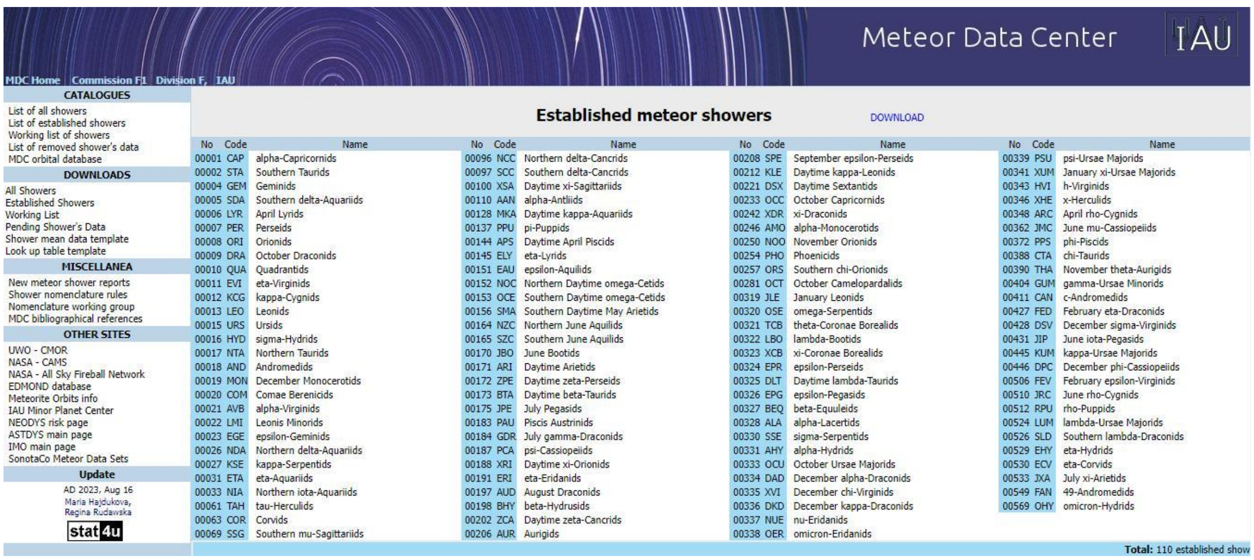
The official catalogue of all meteor showers is maintained by the Meteor Data Centre of the International Astronomical Union (IAU), which can be found at

https://www.iaumeteordatacenter.org/

The Meteor Data Center (MDC) provides databases of:

- all meteor showers (SD), the discovery of which has been published
- meteoroid orbits (MO) and other parameters about the individual meteors.

The front page is shown in the figure below:



Established meteor showers DOWNLOAD

No	Code	Name	No	Code	Name	No	Code	Name	No	Code	Name
00001	CAP	alpha-Capricornids	00096	NCC	Northern delta-Cancrids	00208	SPE	September epsilon-Perseids	00339	PSU	psi-Ursae Majorids
00002	STA	Southern Taurids	00097	SCC	Southern delta-Cancrids	00212	KLE	Daytime kappa-Leonids	00341	XUM	January xi-Ursae Majorids
00004	GEM	Geminids	00100	XSA	Daytime xi-Sagittariids	00221	DSX	Daytime Sextantids	00343	HVI	h-Virginids
00005	SDA	Southern delta-Aquariids	00110	AAN	alpha-Antliids	00233	OCC	October Capricornids	00346	XHE	x-Herculids
00006	LYR	April Lyrids	00128	MKA	Daytime kappa-Aquariids	00242	XDR	xi-Draconids	00348	ARC	April rho-Cygnids
00007	PER	Perseids	00137	PPU	pi-Puppids	00246	AMO	alpha-Monocerotids	00362	JMC	June mu-Cassiopeiids
00008	ORI	Orionids	00144	APS	Daytime April Piscids	00250	NOO	November Orionids	00372	PPS	phi-Piscids
00009	DRA	October Draconids	00145	ELY	eta-Lyrids	00254	PHO	Phoenicids	00388	CTA	chi-Taurids
00010	QUA	Quadrantids	00151	EAU	epsilon-Aquilids	00257	ORS	Southern chi-Orionids	00390	THA	November theta-Aurigids
00011	EVI	eta-Virginids	00152	NOC	Northern Daytime omega-Cetids	00281	OCT	October Camelopardalids	00404	GUM	gamma-Ursae Minorids
00012	KCG	kappa-Cygnids	00153	OCE	Southern Daytime omega-Cetids	00319	JLE	January Leonids	00411	CAN	c-Andromedids
00013	LEO	Leonids	00156	SMA	Southern Daytime May Arietids	00320	OSE	omega-Serpentids	00427	FED	February eta-Draconids
00015	URS	Ursids	00164	NZC	Northern June Aquilids	00321	TCB	theta-Coronae Borealids	00428	DSV	December sigma-Virginids
00016	HYD	sigma-Hydrids	00165	SZC	Southern June Aquilids	00322	LBO	lambda-Bootids	00431	JIP	June iota-Pegasids
00017	NTA	Northern Taurids	00170	JBO	June Bootids	00323	XCB	xi-Coronae Borealids	00445	KUM	kappa-Ursae Majorids
00018	AND	Andromedids	00171	ARI	Daytime Arietids	00324	EPR	epsilon-Perseids	00446	DPC	December phi-Cassiopeiids
00019	MON	December Monocerotids	00172	ZPE	Daytime zeta-Perseids	00325	DLT	Daytime lambda-Taurids	00506	FEV	February epsilon-Virginids
00020	COM	Comae Berenicids	00173	BTA	Daytime beta-Taurids	00326	EPG	epsilon-Pegasids	00510	JRC	June rho-Cygnids
00021	AVB	alpha-Virginids	00175	JPE	July Pegasids	00327	BEQ	beta-Equuleids	00512	RPU	rho-Puppids
00022	LMI	Leonis Minorids	00183	PAU	Piscis Austrinids	00328	ALA	alpha-Lacertids	00524	LUM	lambda-Ursae Majorids
00023	EGE	epsilon-Geminids	00184	GDR	July gamma-Draconids	00330	SSE	sigma-Serpentids	00526	SLD	Southern lambda-Draconids
00026	NDA	Northern delta-Aquariids	00187	PCA	psi-Cassiopeiids	00331	AHY	alpha-Hydrids	00529	EHY	eta-Hydrids
00027	KSE	kappa-Serpentids	00188	XRI	Daytime xi-Orionids	00333	OCU	October Ursae Majorids	00530	ECV	eta-Corvids
00031	ETA	eta-Aquariids	00191	ERI	eta-Eridanids	00334	DAD	December alpha-Draconids	00533	JXA	July xi-Arietids
00033	NIA	Northern iota-Aquariids	00197	AUD	August Draconids	00335	XVI	December chi-Virginids	00549	FAN	49-Andromedids
00061	TAH	tau-Herculids	00198	BHY	beta-Hydrusids	00336	DKD	December kappa-Draconids	00569	OHY	omicron-Hydrids
00063	COR	Corvids	00202	ZCA	Daytime zeta-Cancrids	00337	NUE	nu-Eridanids			
00069	SSG	Southern mu-Sagittariids	00206	AUR	Aurigids	00338	OER	omicron-Eridanids			

Total: 110 established show

The catalogues of meteor showers include a list of all meteor showers, totalling 931 showers as of October 2023. These are made up of the List of established showers, totalling 110 showers, and the Working list of showers, totalling 821 showers. In addition, there is a List of removed shower's data totalling 203 showers.

For each shower, the Lists give the IAU shower number, the three letter shower code, and the accepted name of the meteor shower. Clicking on an individual shower returns more details of the shower, including the position of the radiant, the nightly drift in the position of the radiant, the orbital details of the shower, and [if known] the parent body. Let's look at an example.

An established annual shower – the Geminids

The Geminids are shower number 004, shower code GEM, and are one of the most active meteor showers. Clicking on the entry for the Geminids brings up this page:

[00004] [GEM]					Name-designation: Geminids										Shower status - Established						Next	Previous	To the			
Activity	AdNo	Sl_b	Sl_e	Sl_a	RA	DE	dRA	dDE	V	LoR	SLoR	LaR	Theta	Phi	a	q	e	Peri	Node	Incl	N	T	A	O	R	References
				[deg]			[deg/day]		[km/s]			[deg]			[AU]	[AU]			[deg]							
annual	000	-		261.6	112.9	32.3			34.6	109.54	207.94	10.40	117.44	258.26		0.141	0.898	324.2	261.6	23.5	00051	P			1	Jopek et al., 2003
annual	002	-		262.2	113.8	32.3			34.6	110.30	208.10	10.52	117.59	258.11		0.140	0.897	324.4	262.2	23.9	00279	P			1	Jopek et al., 2003
2002/06	003	244	267	261.5	112.8	32.1	1.10	-0.17	35	109.48	207.98	10.19	117.50	258.49	1.416	0.136	0.904	324.6	261.3	24.0	04384	R				Brown et al., 2008
2007/08	004	245.6	279.4	261.4	112.8	32.3	0.90	-0.19	33.5	109.45	208.05	10.39	117.55	258.27							02510	T				SonotaCo, 2009
2002/08	005	240	273	261	112.5	32.1	1.12	-0.17	34.5	109.23	208.23	10.15	117.75	258.51	1.35	0.1373	0.898	324.95	261.0	23.2	10381	R				Brown et al., 2010
2010/13	006	243	262	262	113.5	32.3	1.15	-0.16	33.8	110.05	208.05	10.48	117.54	258.16	1.31	0.145	0.889	324.3	261.7	22.9	05103	T	M		1	Jenniskens et al., 2016
Parent body:		(3200) Phaethon																								
Notes:	the Phaeton Complex																									

On this page we can find all the current information about the shower. In the top line is the IAU shower number and code (4, GEM), followed by the accepted name (Geminids) and the shower status. Having been known for decades the Geminids is an Established meteor shower. The following lines give the known parameters of the shower as derived by various researchers, who are given in the References column. The parameters given are from left to right:

Activity	the observed activity of the stream
Sl_b	the ecliptic longitude of the Sun at the beginning of stream activity
Sl_e	the ecliptic longitude of the Sun at the end of stream activity
S.Lon	averaged value of the ecliptic longitude of the Sun
RA	averaged value of Right Ascension of the shower radiant
DE	averaged value of Declination of the shower radiant
dRA	radiant drift in Right Ascension (degrees RA per day)
dDE	radiant drift in Declination (degrees DE per day)
V	geocentric speed: before or after acceleration by Earth's gravity
LoR	averaged value of ecliptic longitude of the shower radiant
SLoR	averaged value of ecliptic sun-centred ecliptic longitude of the shower radiant
LaR	averaged value of ecliptic latitude of the shower radiant
Theta	averaged elongation of the shower anti-radiant from the Earth apex motion (Opik variable)
Phi	averaged angle between the plane containing the directions of the anti-radiant and the apex of the Earth orbital velocity, and the plane perpendicular to the ecliptic containing the apex of Earth motion (Opik variable)
a	semi-major axis
q	perihelion distance

e	eccentricity
Peri	argument of perihelion
Node	longitude of ascending node
Incl	inclination of the orbital plane
N	number of meteoroid orbits used for determining the average orbit
T	observation technique: C-CCD, P-photo, R-radar, T-TV, V-visual
A	averaging method: M - median values, A - arithmetic mean, L - by method of least squares, O - other method
O	origin of the stream: P - parent body ejection; C - collision; O - other origin
R	reliability estimation: 1 - yes; 0 if not; or space if not known

Table 4 Explanation of parameters for meteor showers in the Meteor Data Centre lists

Fireballs

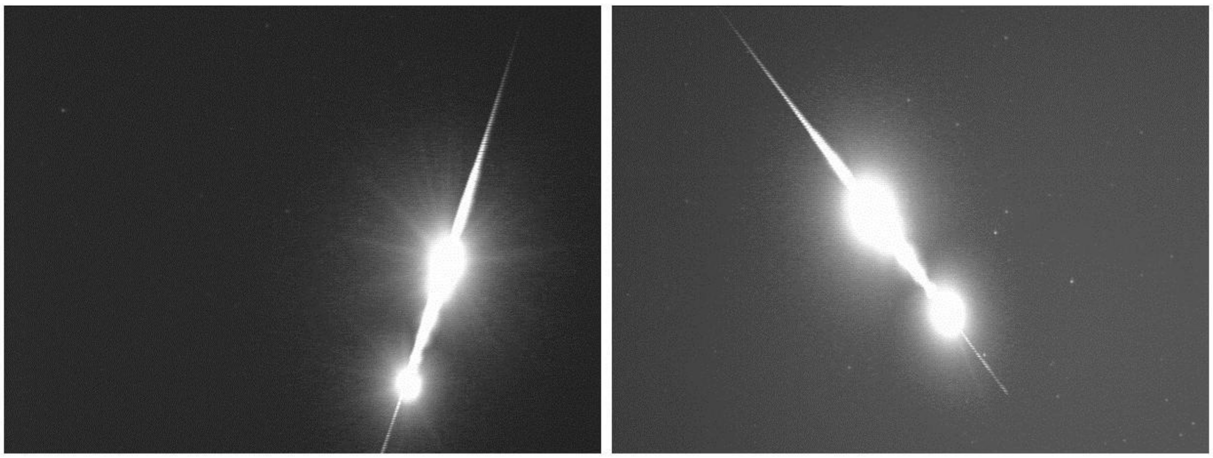
During the process of a night, many particles will enter Earth's atmosphere. Since many of these are very small, they result in faint meteors, which are too faint to be detected by visual means. Larger particle sizes result in brighter meteors, in the range of magnitudes from +5 to -4, and can be detected by eye or low light video cameras. Occasionally, a very bright meteor may appear of magnitude -4 or brighter; we call such events fireballs.

Definition of the term 'fireball'

The term fireball does not refer to a fiery ball of light, or a ball of light which appears to be on fire. What makes a meteor a fireball is entirely due to how bright the meteor appears. We have already seen from the IAU definitions that:

> A meteor brighter than absolute (distance of 100 km) visual magnitude –4 is termed a bolide or a fireball. A meteor brighter than absolute visual magnitude –17 is also called a superbolide.

So any meteor which is as bright or brighter than magnitude -4 is termed a fireball, irrespective of whether the particle comes from a comet or asteroid.



A bright meteor, called a fireball, captured on two meteor cameras situated about 75km apart. In such cases it is possible to triangulate the meteor to determine the orbit of the meteoroid that caused the fireball, and to determine the location of any meteorites if it reached the ground.

Sources of fireballs

The particles that we see as fireballs may come from a comet or an asteroid. Most meteors we see each night are the debris left behind by comets, but as we have seen there are a few meteor showers that have asteroids as parents, such as the Geminids from asteroid 3200 Phaethon for example. Particles from comets tend to be small and fragile, and break up easily as they enter the atmosphere. But there are a few meteor showers that are known to produce more frequent fireballs. These include the Taurids, remnants of comet 2P/Encke, and the Leonids from comet 55P/Tempel-Tuttle. Apart from these, many cometary fireballs are sporadic, solitary particles travelling in isolation. In any case, while cometary particles often produce fireballs, they almost always burn up completely and do not reach the ground as meteorites. Nevertheless, if a fireball is captured on video from more than one location, it is possible to determine the orbit of the meteoroid before it entered Earth's atmosphere and its trajectory through the atmosphere as it burned up.

Magnitude -8 Leonid fireball, a remnant of comet 55P/Tempel-Tuttle.

Photo: Copyright 1999 Arne Danielsen.

We have seen that asteroids are rocky bodies, and spacecraft flybys have sent back images of boulders strewn across their surfaces.

Surface of asteroid 101955 Bennu. NASA/Goddard/University of Arizona

Surface of Bennu seen during the TAGSAM sampling process which returned material from the surface of the asteroid to Earth for analysis. NASA/Goddard/University of Arizona

For example, asteroid 101955 Bennu was imaged by the OSIRIS-REx spacecraft, which showed it is a rubble-pile, made up of many rocks and debris formed during an impact with another body, and loosely held together by gravity. Smaller rocks and dust may be lifted off surface of asteroids, but collisions may produce fragments from a few millimetres to a few metres in diameter, which instead of remaining on the surface of the asteroid, may be ejected into space to follow their own orbits.

Fireballs that become meteorites

The particles from asteroids can be large enough to produce very bright fireballs, or bolides if they are seen to explode, and if they survive their passage they can deposit fragments on the Earth's surface as meteorites. As with cometary fireballs, video footage of asteroidal fireballs from two or more locations can be used to determine the pre-atmospheric orbit of the body, from which we can determine the location in the solar system from which the body originated, and most importantly the path through the atmosphere and location of the fall site for potential meteorites.

From the GMN webpage (https://globalmeteornetwork.org/scientific-mission/), one of the objectives of the Global Meteor Network is 'Observing meteorite-producing fireballs to increase the number of meteorites with known orbits', which helps us understand the source regions from where different meteorites originate. Techniques for using video camera detections to determine orbits and potential fall locations for meteorites are covered in a separate module.

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A List of meteor showers for which the parent body is known

Name	IAU No	Shower Code	Parent body
Quadrantids	10	QUA	Comet 96P/Machholz complex
β Tucanids	108	BTU	Asteroid (248590) 2006 CS
δ Pavonids	120	DPA	Comet C/1907 G1 Grigg-Mellish
Lyrids	6	LYR	Comet C/1861 G1 Thatcher
π Puppids	137	PPU	Comet 26P/Grigg-Skjellerup
η Aquariids	31	ETA	Comet 1P/Halley
η Lyrids	145	ELY	Comet C/1983 H1 Iras-Araki-Alcock
τ Herculids	61	TAH	Comet 73P/Schwassmann-Wachmann 3
June Boötids	170	JBO	Comet 7P/Pons-Winnecke
Daytime β Taurids	173	BTA	Asteroid 2004 TG10
α Capricornids	1	CAP	Comet 169P/NEAT
South δ Aquariids	5	SDA	Kracht Group of sun-grazing comets
ψ Casseiopeids	187	PCA	Asteroid 5496 (1973 NA)
Perseids	7	PER	Comet 109P/Swift-Tuttle
August δ Capricornids	199	ADC	Comet 45P/Honda-Mrkos- Pajdusakova
α Aurigids	206	AUR	Comet C/1911 N1 Kiess
Daytime κ Leonids	212	KLE	Comet C/1917 F1 Mellish
Daytime Sextantids	221	DSX	Asteroid 155140 (2005 UD)
Arids	1130	ARD	Comet 15P/Finlay
Orionids	8	ORI	Comet 1P/Halley
Leo Minorids	22	LMI	Comet C/1739 K1 Zanotti
October Capricornids	233	OCC	Comet D/1978 R1 Haneda-Campos
October Draconids	9	DRA	Comet 21P/Giacobini-Zinner
Leonids	13	LEO	Comet 55P/Tempel-Tuttle
Northern Taurids	17	NTA	Asteroid 2004 TG10
Southern Taurids	2	STA	Comet 2P/Encke
Andromedids	18	AND	Comet 3D/Biela
December Monocerotids	19	MON	Comet C/1917 F1 Mellish
Ursa Minorids	15	URS	Comet 8P Tuttle
Phoenicids	254	PHO	Comet 289P/Blanpain = 2003 WY25
Geminids	4	GEM	Asteroid 3200 Phaethon

Sources from Jenniskens 2023, Atlas of Earth’s Meteor Showers.

Glossary

Ablation – the process by which a particle travelling at high speed loses mass through interactions with constituents in the atmosphere. The result is a meteor.

Astronomical unit – the unit of length representing the mean distance of the Earth from the Sun, equal to 149 597 870 700 m exactly.

Cones – the photoreceptor cells in the eye which are responsible for us seeing colour. There are three types of cone cells, made up of 60% red-sensing, 30% green-sensing and 10% blue-sensing receptors (Ref: American Academy of Ophthalmology).

Conic sections – a figure formed by the intersection of a plane and a circular cone. Depending on the angle of the plane with respect to the cone, a conic section may be a circle, an ellipse, a parabola, or a hyperbola. Source Google English Languages, https://languages.oup.com/google-dictionary-en/

Chondrite – a stony meteorite containing small mineral granules (chondrules). Ref: Google English Languages.

Chondrule – a round granule found in a chondrite.

Circumstellar disk – a disc of dust, gas, asteroids and other objects that rotate around a star. Ref: ESA Wordbank at https://esahubble.org/wordbank/circumstellar-disc/.

Electromagnetic radiation – radiation including visible light, radio waves, gamma rays, and X-rays, in which electric and magnetic fields vary simultaneously. Ref: Google English Languages.

Electromagnetic spectrum – the range of wavelengths or frequencies over which electromagnetic radiation extends. Ref: Google English Languages.

Giant Molecular Cloud – vast cloud of gas and dust, sites of new star formation. Molecular clouds with mass greater than 100,000 Suns are known as Giant Molecular Clouds (GMCs). Ref Chandra X-Ray Observatory site at https://chandra.harvard.edu/edu/formal/stellar_ev/story/index2.html.

Interplanetary dust – all the particles, generally smaller than meteoroids, coming from interplanetary space are called interplanetary dust. (https://www.iau.org/public/themes/meteors_and_meteorites/)

It is possible to see this dust with the naked eye, visible as the Zodiacal Light which is a faint cone of light caused by sunlight scattered by the small dust particles. It can be seen from both the northern and southern hemispheres in the west after sunset during spring, and in the east before dawn during autumn, but seeing the light is faint it requires a dark sky to be visible. The dust is constantly being replenished by collisions in the asteroid belt.

Image of the Zodiacal Light, which is the faint cone of light extending diagonally up left from the horizon. Image credit to Mary McIntyre, taken from North

Oxfordshire, UK on 26th February 2022 with a Canon 1100D, Canon 10mm lens and is a stack of 9 x 25 second exposures

Kuiper Belt – circumstellar disc surrounding our Sun, material left over from the process of planet formation and comprising small bodies including Kuiper Belt Objects (KBOs) and Trans-Neptunian Objects (TNOs), as well as one source of comets.

Luminous efficiency – given by the Greek letter tau (τ) describes the fraction of the kinetic energy of a meteoroid which is converted into brightness. Ref: Drolshagen et al (2021), Astronomy and Astrophysics, 652, 29 pages.

Molar percentage – is the ratio between the amount of a constituent substance (expressed in moles) to the total amount of all constituents (also expressed in moles) x 100. Remember that the mole is the unit of measurement for the amount of substance, and is equal to $6.02214076 \times 10^{23}$ elementary units. This number is also referred to as the Avogadro number.

Oort Cloud - giant spherical shell of material surrounding and left over from the material which formed our solar system. Possibly contains trillions of small icy bodies, and source of the long period comets.

Osculating elements – describe the orbit that a solar system body would follow in the absence of the gravitational effects of other solar system bodies, such as the planets.

Photopic vision – is the vision of the eye when the object being observed is well lit. Conversely, scotopic vision is when the object is observed under low light conditions.

Photosphere – the visible surface of the Sun.

Potentially Hazardous Asteroids (PHAs) – are asteroids which can make a very close approach to the Earth, specifically with a minimum orbit intersection distance (MOID) below 0.05 au.

Proto-planetary disc (proplyd) – a circumstellar disc around newly formed stars. Ref: ESA Wordbank at https://esahubble.org/wordbank/circumstellar-disc/.

Rods – the photoreceptor cells in the eye which are responsible for us seeing different light levels. (Ref: American Academy of Ophthalmology).

SOHO satellite – the Solar & Heliospheric Observatory, is a satellite launched on 2 December 1995 to study the Sun.

Space weathering – refers to the changes in optical properties of the surface of an airless solar system body under the influence of the solar radiation and micrometeoroid impacts.

Spectroscopy – the branch of science concerned with the investigation and measurement of spectra produced when matter interacts with or emits electromagnetic radiation. Ref: Google English dictionary provided by Oxford Languages.

Synchrone – iso-lines in the dust tail of a comet connecting particles which were ejected from the nucleus of the comet at the same time.

Syndyne – iso-lines in the dust tail of a comet connecting particles of the same size. The tendency is for smaller particles to be carried away from the nucleus more quickly under the influence of solar radiation.

Vernal equinox – the ascending node of the ecliptic on the celestial equator, and when the apparent longitude of the Sun is 0°. The ecliptic is the mean plane of the Earth's orbit around the Sun. Therefore at the vernal equinox, the Sun is exactly on the celestial equator.

Yarkovsky effect – is a force acting on a rotating body due to absorption of sunlight and consequently radiating it as heat energy. The effect is to cause a change in the rotation rate of the body.

Zenith – the point in the sky or celestial sphere directly above an observer. Ref: Google English dictionary provided by Oxford Languages.

Zenithal Hourly Rate (ZHR) – the number of meteors that could be expected to be seen with the radiant of the meteor shower at the zenith and with magnitude 6.5 stars visible to the naked eye. The ZHR can be determined using the equation (1):

$$ZHR = \frac{\mathrm{N} \cdot \mathrm{F} \cdot r^{6.5-lm}}{T_{eff} \cdot \sin{(h)}} \qquad (1)$$

Where N is the number of shower meteors observed, F is a factor correcting for obscuration by clouds, trees etc., r is the population index, which is an indication of how bright meteors are from the shower and can be obtained from tables, h is the mean altitude of the radiant above horizon, LM is the limiting magnitude, or faintest star visible to the naked eye, and Teff is the observing time in hours corrected for breaks

But if you know the expected ZHR, how can you predict the number of meteors that would be visible from your location? We can transpose equation (1) to give N, which is the number of meteors that could be expected at the location and under the conditions of an observer.

$$N = \frac{ZHR \cdot T_{eff} \cdot \sin{(h)}}{F \cdot r^{6.5-lm}} \qquad (2)$$

For example, assuming for a hypothetical shower with r=3, expected activity of ZHR = 50 from your location, with the radiant of the shower (h) 30° above the horizon, you observe for 60 minutes in a clear sky without obstructions (F=1.0), and with magnitude 5.5 stars visible to the naked eye, substituting these values in to equation (2), you could expect to see N = 8 meteors per hour. If you were observing from town where only magnitude 5.0 stars were visible, you would only expect to see 6 meteors per hour.

Navigating the Night Sky

The night sky fascinates mankind from the dawn of mankind, it is sown with the stars. Depending on the light pollution of your area you can see thousands of stars in the night sky, so how to find what you are looking for? In this topic, you will learn about constellations, asterisms, the motion of the night sky, solstices, the moon and its phases and orbit, planets and finally how to navigate in the night sky with and use stars and constellations.

Constellations and Asterisms

People from all cultures around the world, dating right back into pre-history, divided the sky up into smaller named chunks and many civilisations linked the shapes and patterns of the stars with characters or objects that were important to their cultures, telling mythological stories about them. The groups of stars were called constellations and each culture had their own names and stories. In the modern day the sky has been officially broken up into patches a bit like the way a country is broken up into counties so the term constellation now refers to that entire patch of sky rather than just the bright star patterns. The names used were those chosen by the Greek/Roman cultures, for example Orion, Hercules, Taurus, Ursa Major and Ursa Minor are all constellations.

Prior to global travel, the Greek/Romans could only give names to the constellations that were visible from where they were located but later the southern hemisphere constellations were added. There are also a few in the northern hemisphere that added later because there was a patch of sky that contained no obvious, bright stars and had therefore been missed out. In 1922 the International Astronomical Union formally accepted the modern list of 88 constellations.

Orion, Taurus, The Pleiades, Auriga and Perseus in the evening western sky in April. Credit: Mary McIntyre

An asterism is the unofficial name given to a grouping of stars that is not a constellation. It could be a smaller group within a constellation such as the seven stars that make up The Plough/Big Dipper within Ursa Major, or a much larger group that spans several constellations such as the Summer Triangle. Some asterisms are only visible through binoculars such as The Coathanger, Eddie's Coaster or Kemble's Cascade. The crucial difference is that these names are informal and are not one of the official 88 constellations.

The Coathanger asterism in Vulpecula. Credit: Mary McIntyre

The Daily Motion of the Sky

If you observe the night sky for any length of time you will notice that the stars appear to be moving. What you're actually observing is not the stars themselves moving, but the Earth rotating on its axis. Like the Sun, Moon and planets, stars rise in the east and set in the west; this is because Earth is rotating towards the East.

A *day* is defined as the length of time it takes a planet to complete one full rotation on its axis; this includes day and night. Here on Earth one rotation takes 24 hours – or is it? If you measure Earth's rotation by timing how long it takes for the Sun to return to the same position then you will get 24 hours; this is a *solar day*. However, if you do it by measuring how long it takes a star to return to the same position, a day is slightly shorter – 23 hours 56 minutes 4.1 seconds to be exact – and this is a *sidereal day*.

The stars rising nearly four minutes earlier each day is the reason we have different constellations visible in some parts of our skies at different times of the year. The constellations that are only visible at certain times are called *seasonal constellations*. The constellations that are located around the celestial poles – i.e. the part of the sky directly above the north or south poles – are visible all year round, although they change their orientation. These are called *circumpolar constellations*. Long exposure star trails photographs show the stars around the celestial poles move in concentric circles around the poles, but further towards the celestial equator the stars appear to move in straight lines. The closer to the celestial pole you are, the less distance the stars appear to move in a given time period. In the northern hemisphere the star *Polaris*, also known as the *North Star* or *Pole Star* is located almost (but not quite!) at north celestial pole. This is why it was used by sailors for navigation. Because Polaris is located almost directly above the North Pole, its position in your sky from any one location will not change within your lifetime. The further south you go, the lower in the sky Polaris will be, so for example, if you are at the North Pole, Polaris will be directly above your head at 90 degrees, but at 52 degrees latitude, Polaris will be 52 degrees above your northern horizon. If you are at 46 degrees latitude then it will be 46 degrees above your northern horizon, and so on.

Long exposure star trails photos taken pointing in different directions, showing the different apparent movement of the stars. Credit: Mary McIntyre

As Earth spins on its axis, there is a slight wobble so the North Pole will slightly shift its position relative to the background stars. This is called precession and it takes about 26,000 years to complete one full cycle. Over this time period the stars at the north celestial pole gradually change, so it's just luck that we are observing at a time when Polaris is almost aligned with the poles.

Each 24 period on Earth is split into day and night, and the number of hours of daylight and night varies with the seasons. Seasons are the result of Earth being tilted on its axis by 23.5 degrees. During the summer months, the hemisphere that is titled towards the Sun will have more hours of daylight (and warmer weather!) than the hemisphere that is tilted away from the Sun.

Solstices and Equinoxes

The *winter solstice* is the day that has the shortest amount of daylight hours, the greatest amount of darkness and is when the Sun reaches its lowest point in the sky at noon. In the northern hemisphere the winter solstice is on 21st/22nd December. The northern hemisphere *summer solstice* is on 20th/21st June and is the day that has the longest amount of daylight hours, the shortest night and is when the Sun reaches its highest point in the sky at noon. In the southern hemisphere the seasons are the reverse of the northern hemisphere, so the summer solstice is on 21st/22nd December and the winter solstice is 20th/21st June.

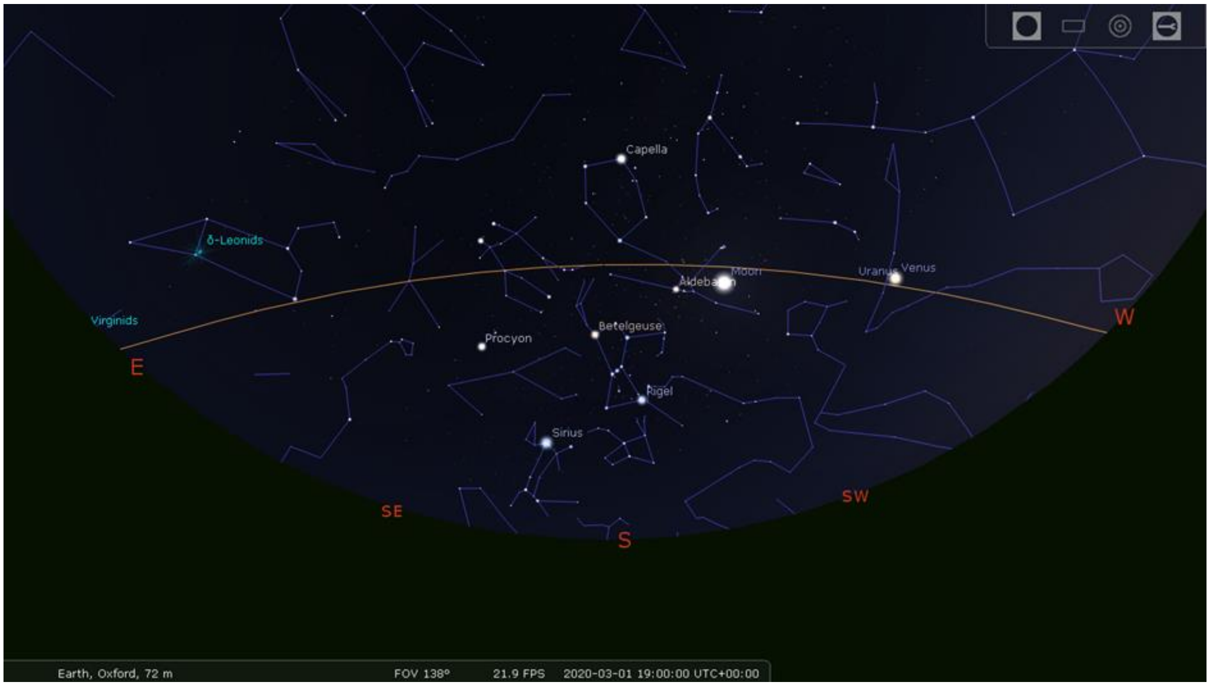
There are two days a year when there are equal amounts of day and night, and these are the *equinoxes.* The word equinox comes from the Latin word *aequus*, meaning "equal", and *nox*, meaning "night". The spring or *vernal equinox* is in the spring time, and the *autumn equinox* is, as the name suggests, in the autumn. The equinoxes occur around 20th March, which is the spring equinox in the northern hemisphere and autumn equinox in the southern hemisphere, and 23rd September which is the autumn equinox in the northern hemisphere and spring equinox in the southern hemisphere. The exact time and date varies because our calendar doesn't perfectly match up with the time it takes Earth to complete one orbit of the Sun. At the time of the equinox the Sun passes directly above the equator rather than north or south of it.

Navigating the Night Sky

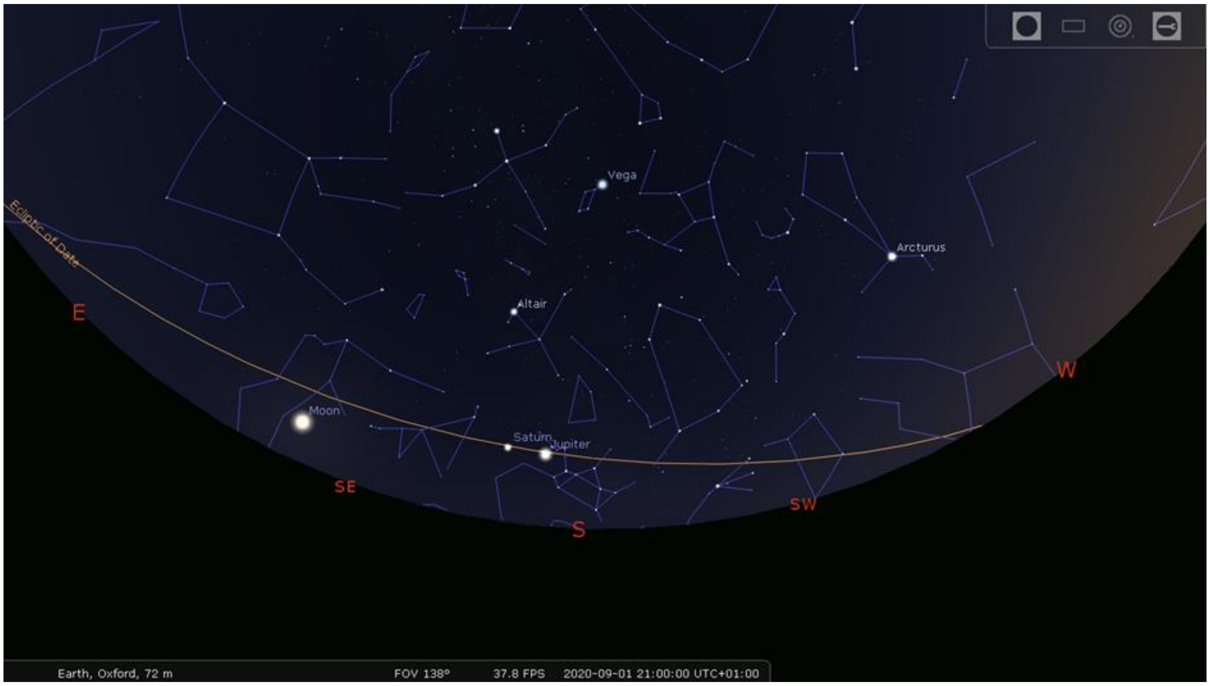
Although the sky was divided into constellations, a more accurate coordinate system was required to help people navigate the night sky so the entire sky was divided up into latitude and longitude coordinates. The point directly above the observer's head is called the *zenith*, and the point directly opposite from that, below the observer's feet, is the *nadir*.

As you may have already seen in the telescopes and mounts section, there are two celestial coordinate systems in place: the altitude-azimuth system is specific to the observer's location and the equatorial system is specific to the stars. For more details about the two systems, refer back to that section. If you are reading this text in the electronic form, click here to learn more about coordinate systems.

Because our solar system was formed from a flat disc of gas and dust, the planets all orbit the Sun in almost the same plane. As we observe the Sun, Moon, planets, dwarf planets and asteroids from Earth, we always see them moving along an imaginary line called the *ecliptic*. Because of the direction of Earth's rotation solar system bodies all rise in the east and set in the west, but the direction you see them *culminate* – i.e. reach their highest point in the sky – differs depending on whether you are in the northern or southern hemisphere. In the northern hemisphere, solar system bodies culminate the southern sky, so you will never see the Moon, Sun or planets in the north. In the southern hemisphere, these bodies still rise in the east and set in the west but they culminate in the northern sky. Because of Earth's axial tilt, at certain times of year the ecliptic is situated much higher in the sky than at others. The twelve constellations that lie along the path of the ecliptic are said to be part of *the zodiac*, and the constellation the Sun lies in on the date of your birth is said to be your zodiac sign, but these terms are mostly used in the world of astrology, not astronomy.



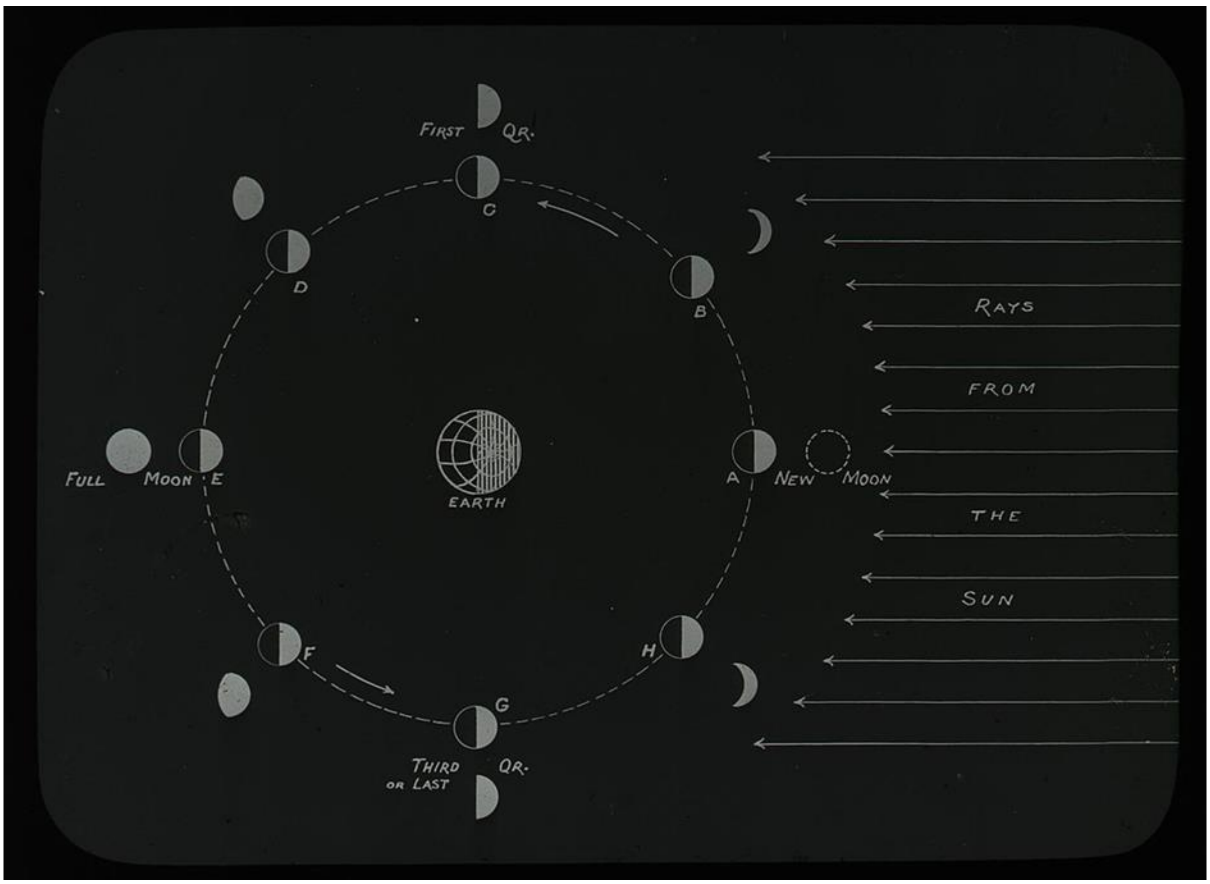
The line of the ecliptic in March from Oxford, UK. At this time of year, the ecliptic is high Created using Stellarium



The line of the ecliptic from Oxford, UK in September is much lower than it was in March. Created using Stellarium

Lunar Orbit and Phases

The Moon is in orbit around the Earth and it takes about 27.3 days to complete one orbit; this is *lunar sidereal month*. If you observe the Moon during that period, you will notice its appearance changes because it is moving through the *lunar phase cycle*, where it looks like a different percentage of the surface is being illuminated by the Sun as the Moon's position relative to the Sun changes each day. The lunar phase cycle takes about 29.5 days; this is a *synodic month*. If you think of the Moon as a spherical body, the Sun is always illuminating half of the sphere, but the amount of that illumination that we can see from Earth is dependent on where the Moon is in its orbit.



Phases of the Moon. Slide produced by the Province of Ontario Picture Bureau Community Archives, Public domain, via Wikimedia Commons

Moon phase graphic created from photos by Mary McIntyre

The lunar phases change from right to left

The right side is waxing, the left side is waning, the Full Moon is at the centre

The cycle begins with a New Moon which cannot be seen because there is no illumination. Over the next couple of weeks the amount of illumination increases day by day and the Moon is said to be *waxing*. After a New Moon there is a Waxing Crescent, First Quarter, Waxing Gibbous then two weeks later is a Full Moon. After Full Moon the amount of illumination decreases each day and the Moon is said to be *waning*. After a Full Moon is a Waning Gibbous, Last Quarter, Waning Crescent and then two weeks after Full Moon we are back to a New Moon again.

A Waxing Crescent Moon is visible in the western sky after sunset. Like other solar system bodies the Moon rises in the east and sets in the west, so when you see a Waxing Crescent Moon in the west in the evening, It will have actually risen several hours earlier but it can be difficult to spot in the daylight sky because of its proximity to the Sun, so it therefore becomes easier to see as the Sun sets. The Moon rises later each day so by First Quarter it is rising at around noon and setting at around midnight. A Full Moon rises as the Sun is setting and it remains visible all night long. Once you get to Last Quarter the Moon rises at around midnight and sets at around noon the following day, and a Waning Crescent rises in the east shortly before the Sun rises. Being a solar system body the Moon moves along the ecliptic but the height it reaches as it crosses the meridian can vary significantly during each cycle.

The other thing you will notice if you observe the Moon through a full cycle is that it always shows us the same face – the lunar *nearside*. This is because the Moon is *tidally locked* (also known as *synchronous orbit*) so the time it takes the Moon to make one complete spin on its axis is the same as the time it takes to complete one orbit of Earth; this means that a day on the Moon lasts 29.5 Earth days. The side we cannot see is the lunar *far side*, NOT the dark side as it is often referred to, because the far side gets just as much light as the lunar nearside does. Being tidally locked you would think that we could only ever see half of the lunar surface but we can actually see about 59% of it because various gravitational forces acting on the Moon cause it to wobble a bit. This is called *libration* and it allows us to catch a glimpse of features near the edges in the regions known as the *libration zone*.

Lunar Distance

The average distance between the Earth and the Moon is 384,400 km (238,855 miles) but because the Moon's orbit is oval rather than circular, at certain times each cycle the Moon is closer to Earth than others. When the Moon is at *apogee*, i.e. at its furthest point from the Earth, the Moon is about 405,696 km (252,088 miles) away, whereas when it is at *perigee*, i.e. at its closest approach to the Earth, it is only 363,104 km (225,623 miles) away. At its closest approach, the moon is about 14% bigger and 30% brighter than an apogee Moon so when Perigee coincides with a Full Moon, the press like to call it a "*supermoon*". The figures sound impressive but the Moon only takes up half a degree of sky so that increase is size and brightness will not be noticeable to the naked eye. However, through a telescope you may notice a difference in apparent diameter if you compare photos taken at apogee and perigee.

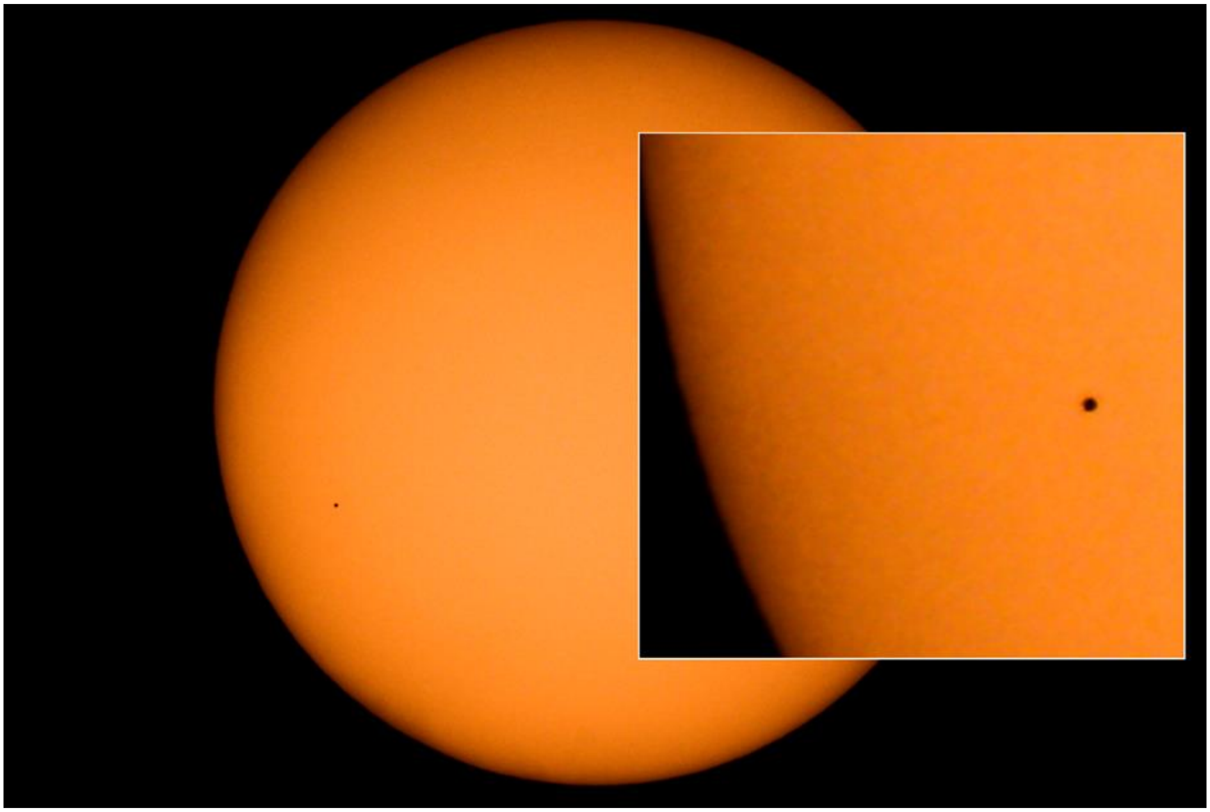
Comparison showing the size of an apogee Moon (left) compared to a perigee Moon (right) Credit: Marcoaliaslama, CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons

The Motion of the Planets

There are eight planets in the solar system, all in orbit around the Sun. From our vantage point here on Earth the planets do move along the ecliptic, but they do not follow the same motion as the stars. The unexpected ways these bodies moved earned them the name *planetai* – the Greek word for "wanderers" by early astronomers. When planets appear close together in the same part of the sky they are said to be in *conjunction;* although they look close together, in reality they are huge distances apart. Planets are often seen in conjunction with the Moon and with the constellations that lie along the ecliptic and sometimes a planet may actually disappear behind the Moon for a short time – this is called a lunar occultation of a planet.

Mars emerging from behind the Moon following a lunar occultation Credit: Mary McIntyre

Mercury and Venus are inner planets and therefore their orbits are closer to the Sun than Earth. When the planets pass behind the Sun they are said to be at *superior conjunction* and obviously we are not able to observe them at this time. The planet will then come out of superior conjunction and appear as an evening object until it reaches greatest eastern elongation. Once the planet passes greatest eastern elongation it once again moves towards the Sun but this time the planet passes in between the Earth and the Sun and into *inferior conjunction*, where once again they cannot be seen. Occasionally the inner planets line up perfectly with the Sun and we can see them transiting the solar disc. Mercury transits are more common and occur about 14 times per century but Venus transits are rarer with the last Venus transit taking place in June 2012 and next one not happening until 2117. Once the planet passes inferior conjunction it emerges a morning object until it reaches *greatest western elongation*.

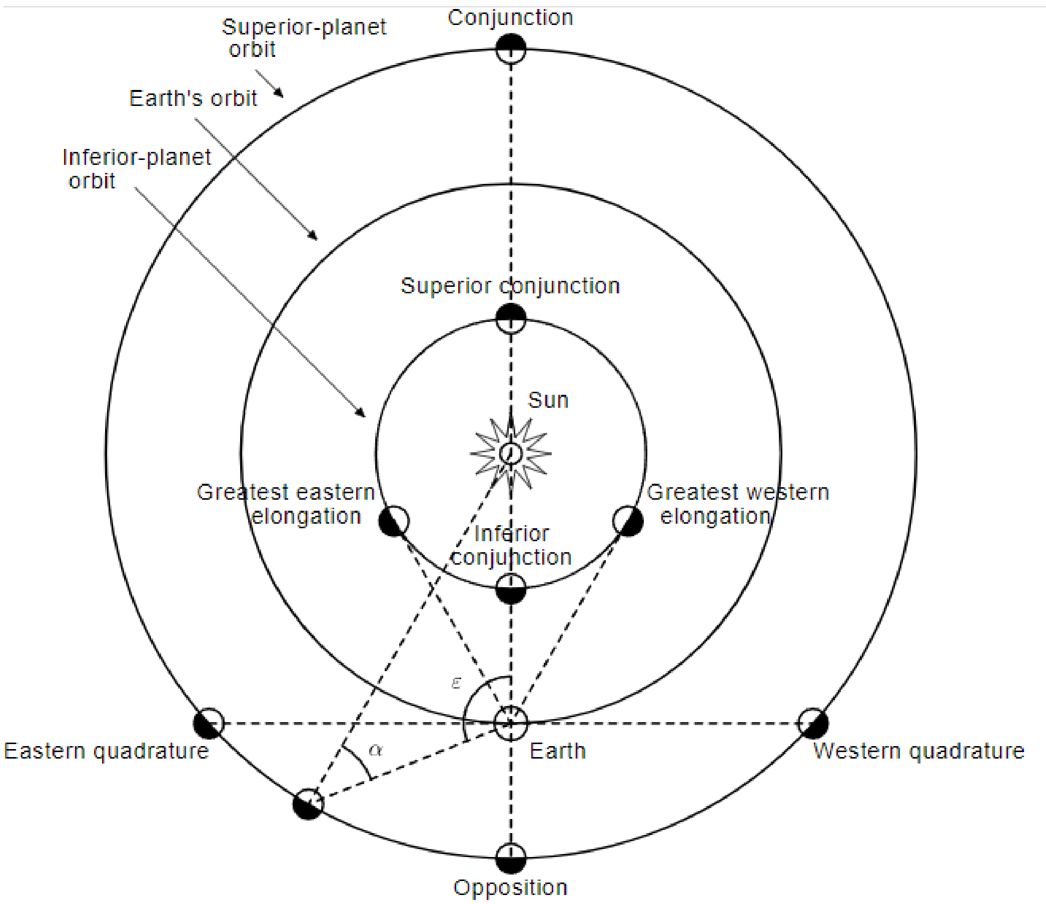


Mercury transiting the disc of the Sun. Image credit: Mary McIntyre

An inner planet's distance from the Sun at greatest eastern or western elongation is constrained by its own orbit, so Mercury can never lie that far from the Sun and is therefore usually seen in the twilight hours. Venus having a larger orbit means it can extend further east or west from the Sun than Mercury. If you have a telescope and you observe Mercury and Venus at different times during an orbit, you will notice that they both display phases in much the same way the Moon does, and the planets' apparent sizes will change as they moves closer and further away from Earth.

Mars, Jupiter, Saturn, Uranus and Neptune are the outer planets so it is not possible for them to pass in between Earth and the Sun to inferior conjunction. When these planets pass around the back of the Sun they are said to be at solar conjunction and we cannot observe them. The outer planets are best viewed when they reach *opposition*, so called because they're on the opposite side of the Earth to the Sun. During the month that a planet is at opposition, it is fully illuminated by sunlight so it appears at its biggest and brightest, and will be visible all night long. The apparent diameter of Mars can change dramatically during an apparition so it's always best to observe it at opposition. The location of the planets in our sky is also affected by our own movement along our orbit, so not all apparitions are as favourable for viewing as others.

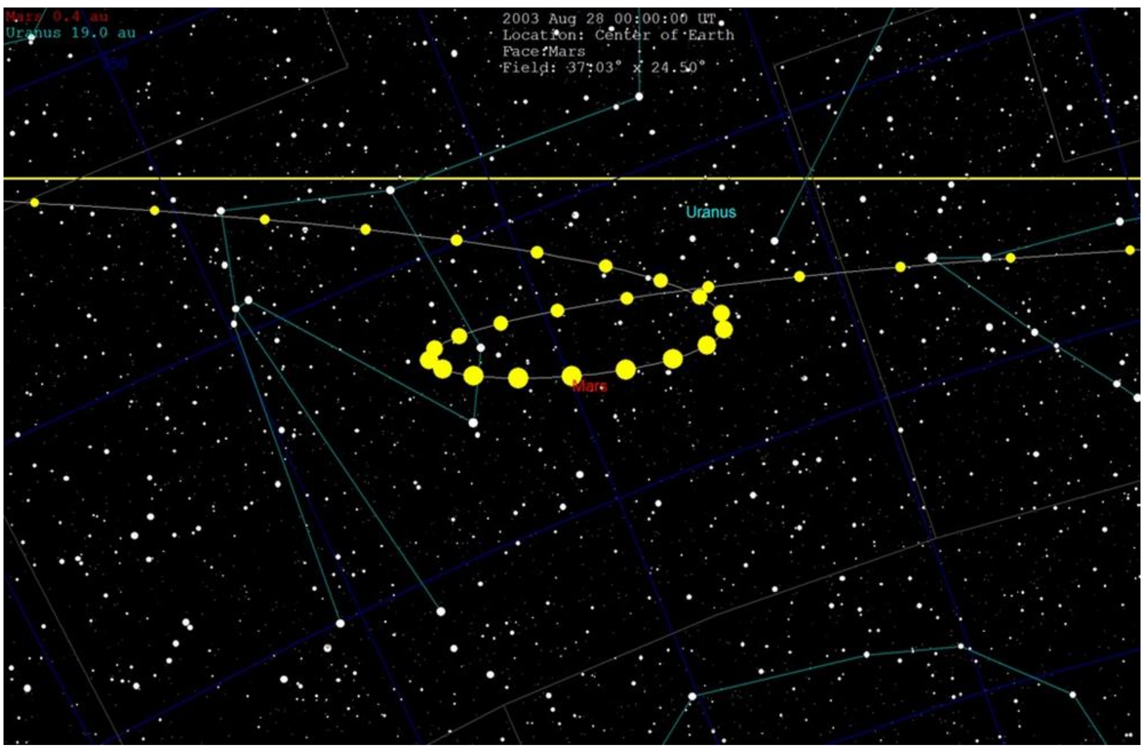
The further out from the Sun the planet is, the longer it takes to complete one orbit of the Sun. While Mars completes one solar orbit every 1.88 years, it takes Saturn 29.45 years and Neptune 164.79 years to do so, so these planets do not move as quickly against the background stars as the nearer planets do.



Positions of the inner planets at superior, inferior conjunction, greatest eastern elongation and greatest western elongation, and the outer planets at conjunction and opposition. Credit: Wmheric, CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons

Prograde and Retrograde Motion

When observing the planets over a number of days, most of the time the planets are moving further west each day like the stars do. This is when a planet is said to be in *prograde* motion. However, the planets are all travelling around in their orbits at different speeds; the closer to the Sun the orbit is, the faster the planet will move so there are times when a planet orbiting closer to the Sun will overtake one that is further away from the Sun and when viewed from Earth this can look like the planet slows down, comes to a stop then starts moving backwards. This is when a planet is said to be in *retrograde motion*. Of course the planets aren't actually moving backwards; it's purely a line of sight effect. Imagine sitting on motorway in busy traffic. If the traffic in your lane is moving slightly faster than an adjoining lane, it can make it look like the cars in the other lane are moving backwards. In reality all of the lanes of traffic are still moving forwards; they're just doing so at different speeds.



Movement of Mars during 2023 switching between prograde and retrograde motion Credit: Tomruen, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons

Using the Stars as Pointers

If you are new to stargazing it can be overwhelming trying to find your way around the night sky. However, if you start off with some of the brighter, more obvious star patterns, you can use them as signposts to find other constellations and even some deep sky objects. You can also use apps like Stellarium to see exactly which position the constellations will be each night from your location. If you are setting up a meteor camera you need to know some constellations in order to set up your plate par and calibrate the camera, but it's also fun to watch the night timelapse videos to see which constellations you can recognise.

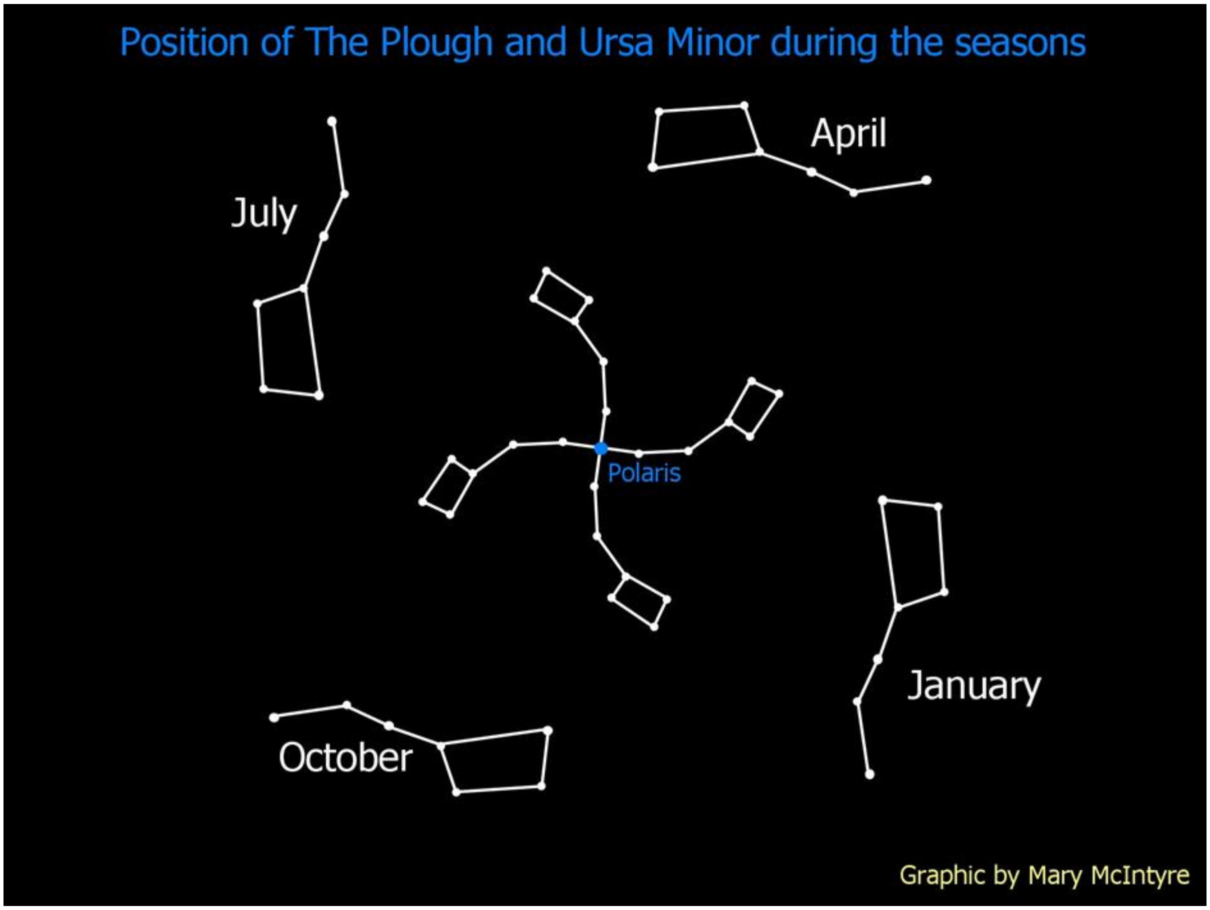
Some constellations are visible from your location all year round whereas others are seasonal because of the slight difference in length of the solar day compared to the sidereal day. The stars rise four minutes earlier each day and it's this small change that causes the seasonal variations.

Navigating the northern sky

Using The Plough to find Polaris and Ursa Minor

In the northern hemisphere we are fortunate to have a star very close to the north celestial pole; that star is called Polaris. Polaris is not a particularly bright star but it is easy to find if you use The Plough – an asterism made up of seven stars that are in the constellation Ursa Major (the Big Bear) – as a signpost.

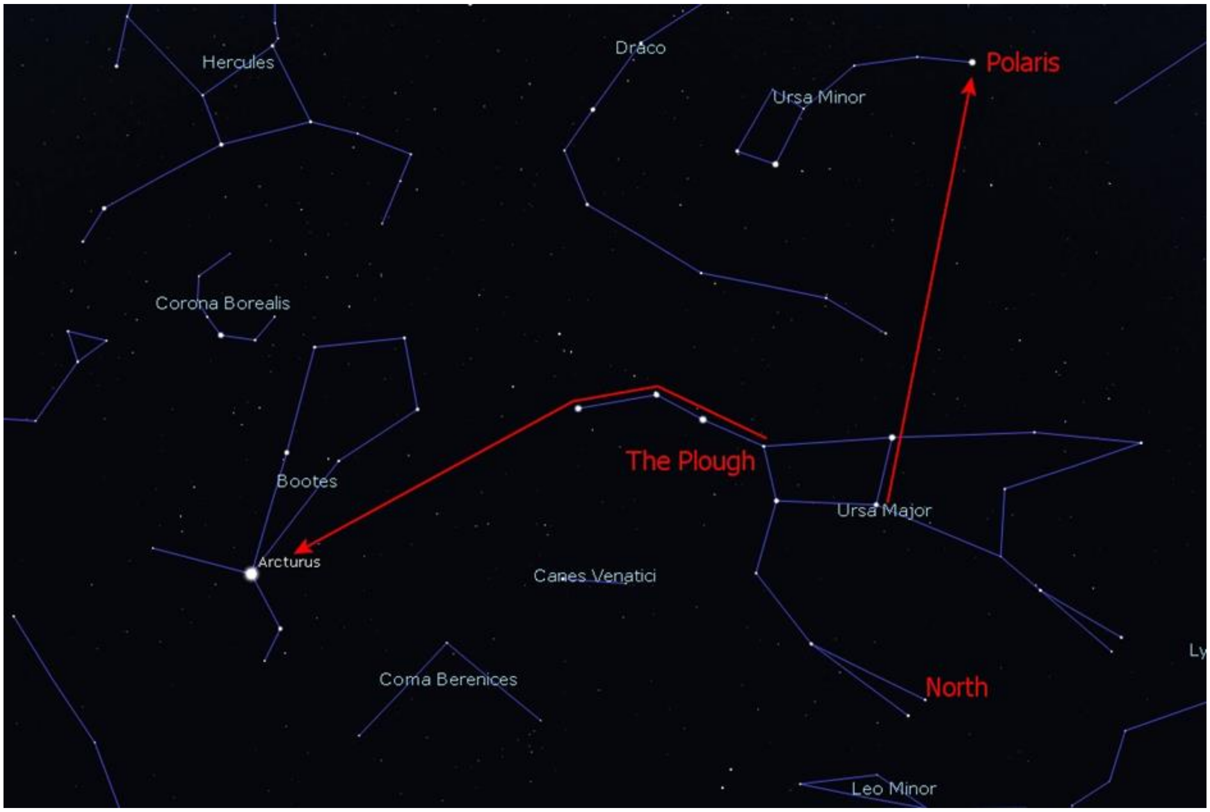
The Plough (also known as the Big Dipper) is located in the northern sky and is circumpolar from the UK; that means it's visible all year round, but it changes position throughout the seasons as you can see in the picture below.



The Plough can be used to locate Polaris. Follow an imaginary line from the two stars on the outer edge of the bowl and the next star you can see with the naked eye is Polaris. Polaris will not move within our lifetime so you only need to learn this once! Polaris is the end star in a constellation that looks like a smaller version of the Plough; this is Ursa Minor (also known as the Little Bear).

Using The Plough to find Boötes

Between mid-February and mid-October, The Plough can be used to locate the bright, red giant star Arcturus. It has a diameter 25 times greater than our Sun and it has an obvious reddish orange colour. If you follow the "handle" of The Plough and continue the line downwards, it points straight at Arcturus which lies at the bottom point of the kite-shaped constellation of Boötes the Herdsman.



Using The Plough to find Polaris and Arcturus Graphic created by Mary McIntyre using Stellarium

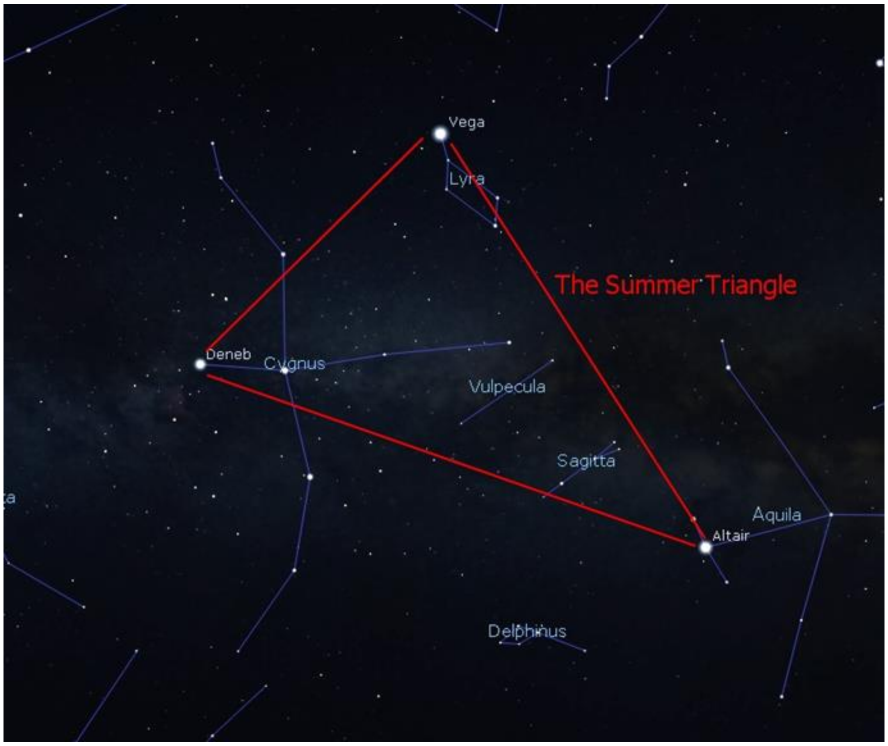
Using Cassiopeia to find the Andromeda Galaxy and the Square of Pegasus

Located 2.5 million light years away, Messier 31 the Andromeda Galaxy is the most distant object visible to the naked eye (from a dark sky location). On photographs the galaxy has the same diameter as six Full Moons but to the naked eye you can only see the bright central region. Although technically visible all year round from the UK, it is best viewed during autumn when it's at its highest. To find the Andromeda Galaxy, first look for Cassiopeia, a W-shaped circumpolar constellation in the northern sky. Look at the right hand "V" of the W-shape and Imagine the bottom point is an arrow; follow the line down about three times further than the height of the V and the galaxy lies there. You will only be able to see it with the naked eye if your eyes are dark adapted and it will be a tiny grey smudge, but that light has taken 2.5 million years to reach your eyes! Once you've found the Andromeda galaxy, look to its lower right to see the four stars that make up the huge Square of Pegasus.

Using Cassiopeia to find the Andromeda Galaxy and Square of Pegasus Graphic created by Mary McIntyre using Stellarium

The Summer Triangle and the Milky Way

The Summer Triangle is actually visible from April to October but is at its highest in the southern sky during the summer months. It is made up of Vega (in Lyra the Harp), Deneb (in Cygnus the swan) and Altair (in Aquila the Eagle). Cygnus and Aquila lie within the plane of the Milky Way, which you will easily see from a dark sky location.



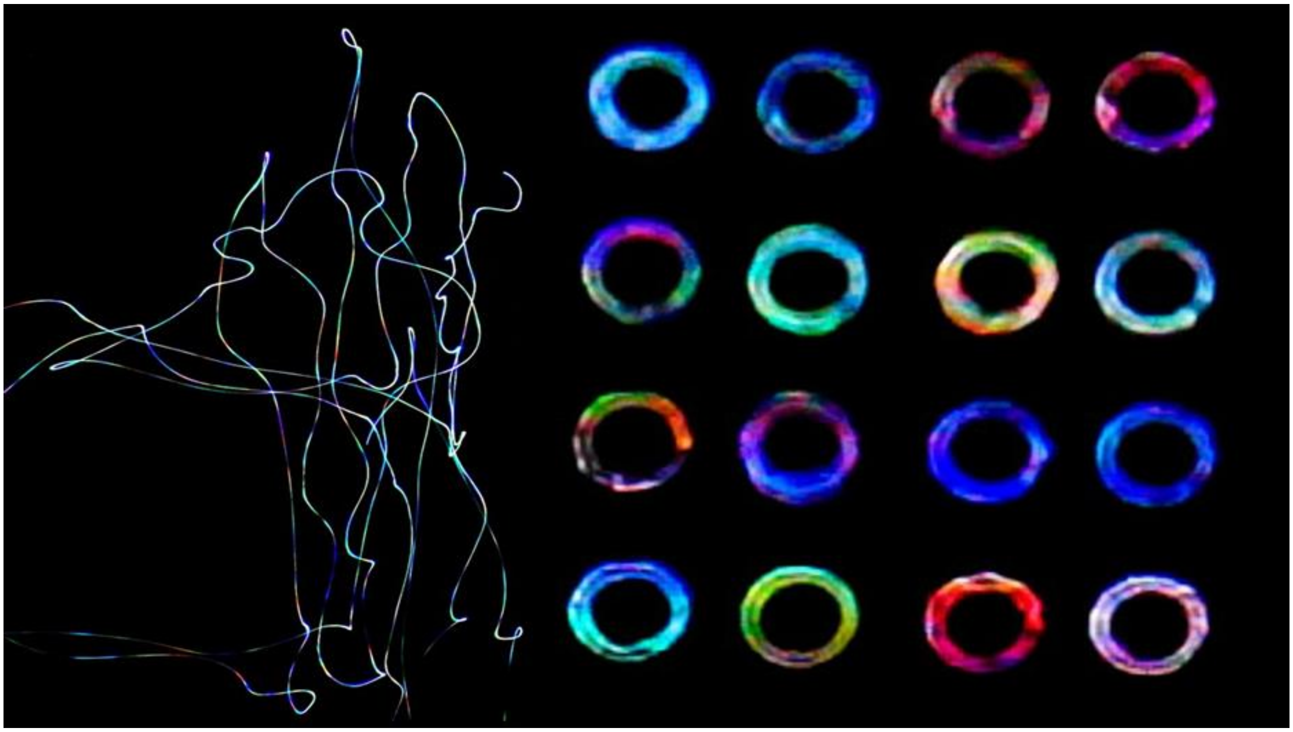
The Summer Triangle. Graphic created by Mary McIntyre using Stellarium

Using Orion to Find Sirius, Taurus and the Pleiades

Orion the hunter is one of the most recognisable winter constellations that is at its best from October to January. Orion looks a bit like an old fashioned egg timer. At the top left corner is the red giant star Betelgeuse (nearly 700 times larger than the Sun) and on the bottom right corner is the blue giant star Rigel (79 times larger than the Sun). The colour difference between them is very noticeable. The stars below Orion's belt form his sword; the middle star is actually Messier 42 the Orion Nebula, one of the only nebulae visible with the naked eye.

Orion’s Sword and the Orion Nebula as it would look through large binoculars
Image credit: Mary McIntyre

The stars of Orion’s Belt point down at Sirius the Dog Star. Sirius is a bright star that’s about 1.7 times larger than the Sun. It rapidly twinkles with flashes of different colours which show up really well in photos like the one shown below by Mary McIntyre.

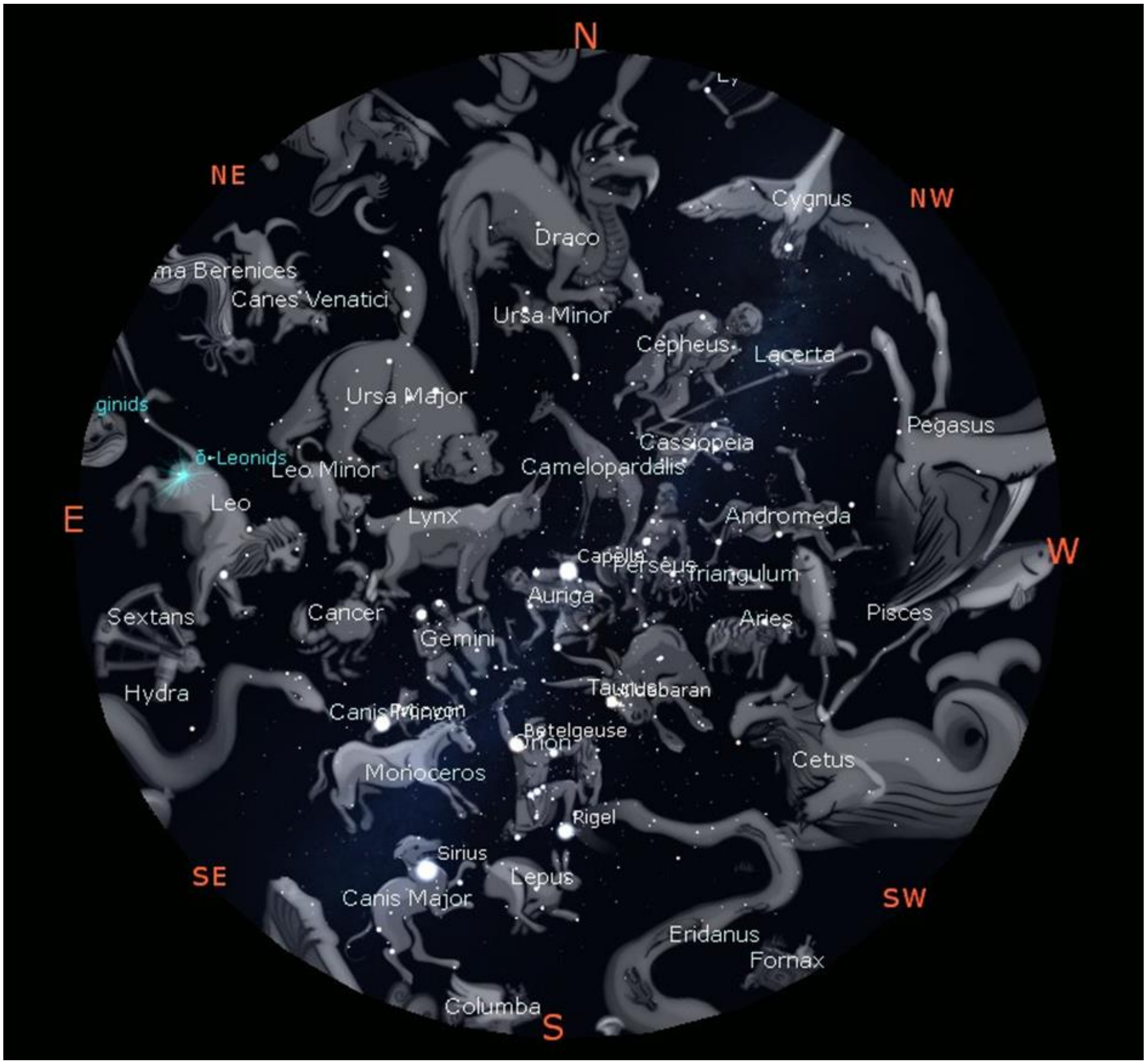


Left – a long exposure photograph of Sirius while the camera was deliberated wobbled shows colourful trails of light. Right – a series of close up out of focus photos of Sirius which show a huge range of colours. Credit: Mary McIntyre

The belt stars point upwards at the red giant star Aldebaran which is part of Taurus the Bull. It has a diameter 40 times bigger than our Sun. Continuing that line even further, you will come to The Pleiades, also known as the Seven Sisters. This little star cluster is gorgeous, and through binoculars you can really see the blue colour of these young, hot stars.

Using Orion's Belt to find Sirius, Taurus and The Pleiades. Graphic created using Stellarium

Once you have become familiar with these bright star patterns you can use them to locate some of the fainter constellations and you will soon be able to find your way around the whole night sky.



Graphic showing constellation art in Stellarium

Navigating the southern sky

The seasonal constellations seen in the southern sky of the northern hemisphere are also visible from the southern hemisphere but will appear upside down and they transit the northern sky. Most of the northern hemisphere circumpolar constellations are not visible from the southern hemisphere but southern hemisphere observers have their own set of circumpolar constellations that rotate around the south celestial pole. It's worth noting that all of the solar system bodies that travel along the ecliptic will also appear upside down when viewed from the southern hemisphere.

The Southern Cross

The most recognisable constellation in the southern hemisphere is the Southern Cross, also known by its official name as Crux Australis, or simply Crux. It is the smallest in size by area of the 88 constellations in the sky, but seeing as the five main stars that make up the constellation are fairly bright it is easy to find towards the southern sky. The Southern Cross is a useful constellation for navigation, and points towards the South Celestial Pole, and can also be used as a clock to tell the time depending on the time of year. You can find a useful exercise on using the Southern Cross to tell the time in the Tasks and Games section on our webpage. The brightest star in the constellation is alpha Crucis, also known as Acrux, and is the thirteenth brightest star in the sky.

Three Crosses and the Pointers

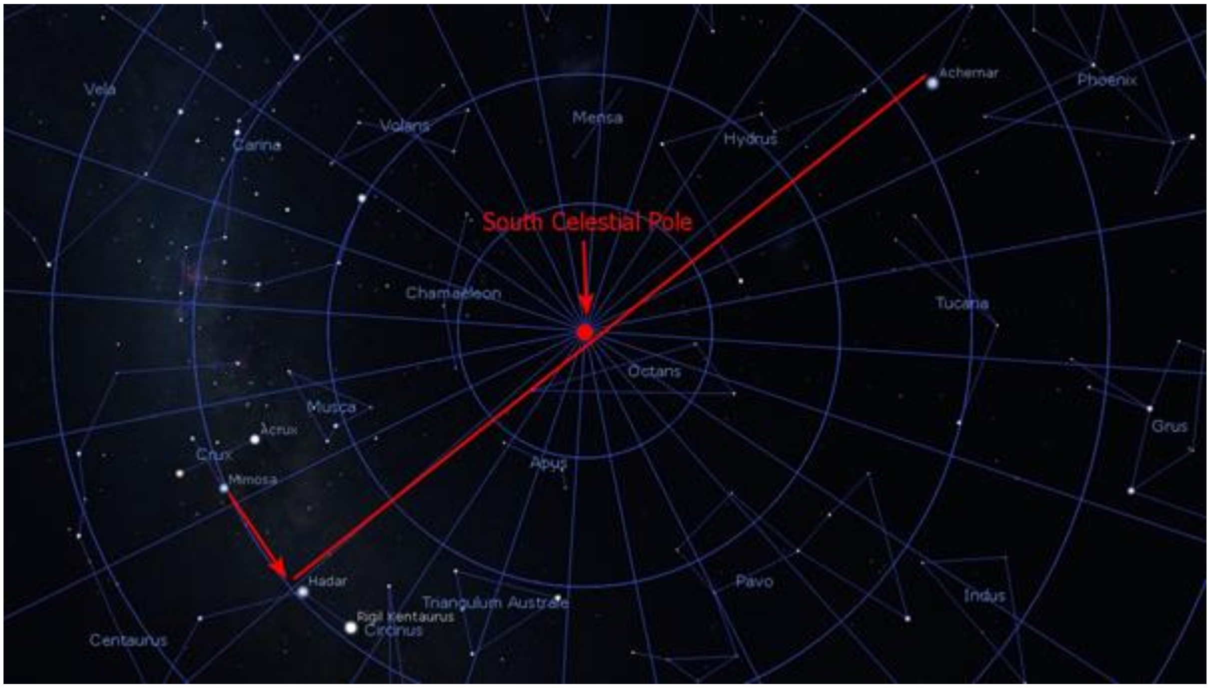
Once you have located the Southern Cross, you will notice two other Crosses nearby. Just to the west of the Southern Cross is the Diamond Cross, and continuing further you will come to the False Cross.

Looking towards south reveals the three Crosses in the southern sky, the Southern Cross, the Diamond Cross and the False Cross. Two bright stars, The Pointers, point to the Southern Cross. Graphic created using Stellarium

Both Crosses are larger than the Southern Cross, and often are mistaken for the Southern Cross. So how do you tell which one is the real Southern Cross? The answer is simple; to the east of the Southern Cross, you will find two bright stars in the constellation of Centaurus, known as Rigel Kentaurus (alpha Centauri) and Hadar (beta Centauri). Drawing a line through the two stars points in the direction of the Southern Cross, and for this very reason they are known as The Pointers. The other two Crosses, the Diamond Cross and the False Cross do not have bright stars pointing to them, and so it is easy to identify the Southern Cross as the only cross that has two bright Pointers.

Finding the South Celestial Pole

There is no obvious bright star close to the South Celestial Pole but it lies half way between the bright stars Hadar in Centaurus and Achernar, the brightest star in Eridanus. The irregular triangular shaped constellation of Octans lies nearby, so if you are trying to photograph circumpolar star trails from the southern hemisphere, aim to have Octans near the centre of your field of view and you will easily have the celestial pole in the shot.

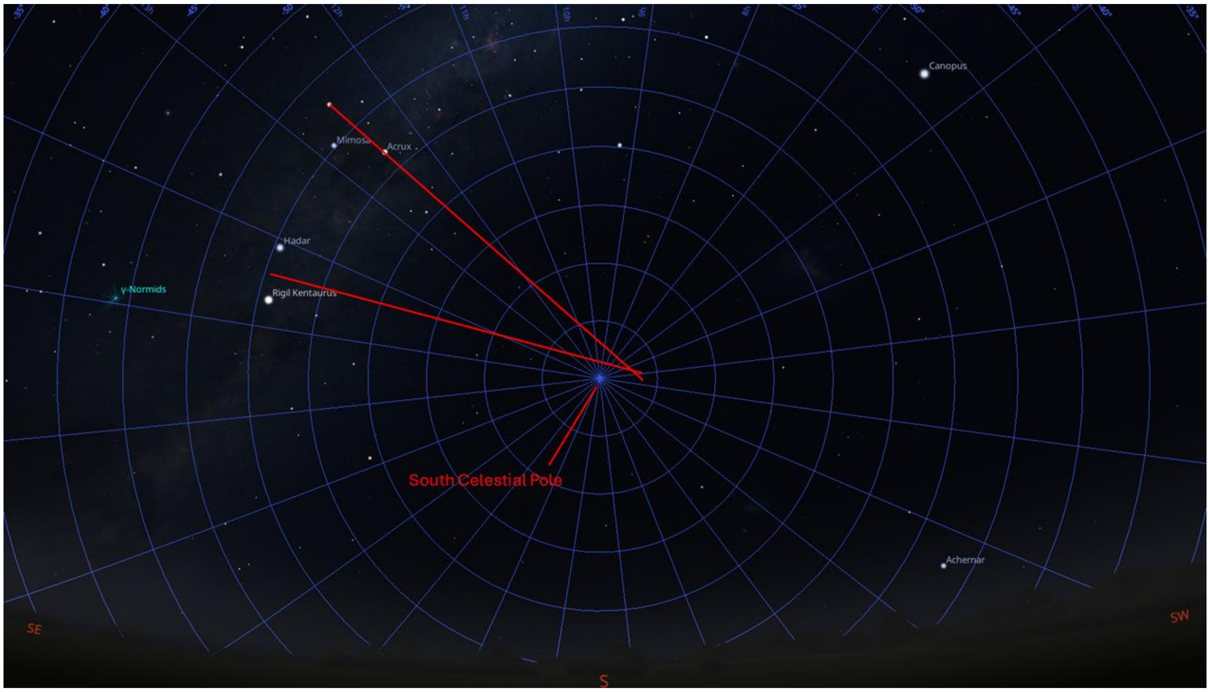


One way to locate the South Celestial Pole is to draw a line between the bright stars Hadar (the fainter of The Pointers) and Achernar. The Pole is in the middle of this line. Graphic created using Stellarium

But since Hadar and Achernar are on opposite sides of the South Celestial Pole, they are often not above the horizon at the same time. A very convenient way of orienting yourself and finding the direction of south is to use the Southern Cross and The Pointers.

First, take the long axis of the Southern Cross, and extend a line in the direction of Acrux, the brightest star in the Cross. Second, find the Pointers, and extend a line perpendicular to the line between the two stars, and in the same direction as the first line. Where these two lines intersect is close enough to the South Celestial Pole to orient yourself in the night sky.

Unlike in the northern hemisphere, where the prominent naked eye star Polaris is close to the North Celestial Pole, the closest star to the South Celestial Pole is sigma Octantis, which is just visible to the naked eye, but only if you have a dark sky.



A convenient method of finding the South Celestial Pole using The Pointers and the Southern Cross. Graphic created using Stellarium

Locating the two brightest stars in the sky, Sirius and Canopus

Continuing our journey from The Pointers westwards along the Milky Way, and to the southwest of the False Cross lies the bright star Canopus, the brightest star in the constellation Carina, and the second brightest star in the sky. Canopus is an important star for spacecraft guiding due to its brightness and its location away from the plane of the ecliptic.

Moving from the three crosses towards the west brings us to the brightest stars in the sky, Sirius and Canopus, and the constellation of Orion. Graphic created using Stellarium

Continuing towards the northwest we find Sirius, the brightest star in the sky, and on to Procyon. Below these bright stars is the constellation of Orion, which sits high in the sky during the southern summer months.

Using Orion to Find Sirius, Aldebaran and Procyon

Orion is one of the constellations that looks upside down in the southern hemisphere compared to how it appears in the northern hemisphere, but we can still use it to locate other stars and constellations. If you find the three stars of Orion's Belt and follow the line down towards the lower left, it points to Aldebaran in Taurus. Continue that line down to find M45 the Pleiades. If you follow the line of the belt stars towards the upper right, it points to Sirius in the constellation of Canis Major. Next, locate the red giant star Betelgeuse on the bottom corner of Orion and look to the right to find Procyon in the small constellation of Canis Minor.

The familiar constellation of Orion and the three stars in Orion's Belt point to Sirius, the brightest star in the sky, and to Taurus the Bull and the Pleiades star cluster. Graphic created using Stellarium

To locate Orion's Sword, look upwards and slightly right of the central belt star and you will see a row of three faint stars. The central "star" of this row is M42 the Orion Nebula. In indigenous Australian Mythology Orion is actually Djulpan the Canoe.

Finding the Large and Small Magellanic Clouds

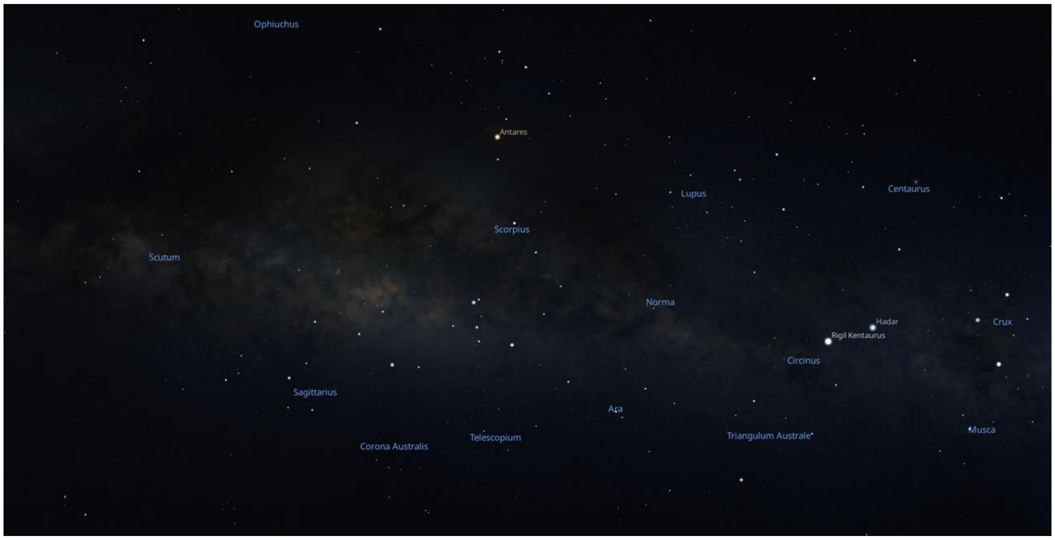
Two "must see" jewels of the southern hemisphere sky are the Large and Small Magellanic Clouds (LMC and SMC), two satellite galaxies which are easily visible to the naked eye from a dark sky location. They lie equidistant either side of the star gamma Hydri. In a dark sky the Magellanic Clouds may be more obvious than some of the stars, so you can use them to locate nearby constellations. The LMC lies close to the isosceles triangle at the tail of

Dorado, and the SMC lies about a quarter of the way from beta Hydri and the tail of Tucana.

To the south of the three crosses, you will find the Large and Small Magellanic Clouds, satellite galaxies of the Milky Way. Graphic created using Stellarium

Locating Scorpius and Sagittarius, and the heart of the Milky Way

Starting from the Southern Cross and the Pointers and moving in the opposite direction towards east we find the constellation of Scorpius, the Scorpion. It is one of the constellations that really looks like its name. The brightest star in Scorpius is Antares, which is a red giant star, the name meaning 'rival of Ares (or Mars)' due to the similarity of the colour to the red planet.



Viewing the centre of the Milky Way, moving from The Pointers and the Southern Cross. Graphic created using Stellarium

Scorpius sits with its tail, or sting, in a rich part of the Milky Way. To its east is the sprawling constellation of Sagittarius, the Archer, though you will find it difficult to visualise such from the pattern of stars. To most of us the main body of Sagittarius looks like a teapot.

Locating the centre of the Milky Way, just off the spout of the Teapot asterism in Sagittarius. Graphic created using Stellarium

The Teapot is also a convenient asterism to use to locate the centre of the Milky Way galaxy, shown here by the red cross. The centre of the Milky Way is high above our heads in the southern hemisphere during the winter months, and looks spectacular under a dark sky. It is made up of countless stars, open star clusters, globular star clusters, bright nebulae and dark dust clouds seen in silhouette against the stary background.

The Milky Way in all its glory, seen high in the sky from the southern hemisphere during winter evenings. Graphic created using Stellarium

Looking towards the centre of the Milky Way in Sagittarius. Scorpius with Antares are above right. You can clearly make out the central bulge in our galaxy, with the spiral arms extending either side. The vast number of stars and bright gaseous nebulae are crossed by dark bands of dust which block out the light from behind them.

Using Scorpius to find Libra, Boötes and Two Crowns

At the base of the tail of Scorpius lies the stars Sargas and Girtab. If you follow that line downwards it points to Kaus Australis in Sagittarius. Within Sagittarius is the asterism the "Teapot and Teaspoon" although from the southern hemisphere the teapot is usually on its side or upside down. To the side of Sagittarius lies Corona Australis – the Southern Crown.

Going back to the claw of Scorpius, the three stars in the fan shape point towards the three brightest stars of Libra, which is a pretty faint constellation. If you follow the line from Antares and along the bottom star of the fan and head slightly downwards, it points towards the red giant star Arcturus, the brightest star in Boötes. Boötes has a distinctive kite shape, and just off to one side of the widest part of the kite is Corona Borealis – the Northern Crown. The brightest star in this constellation is Alphecca.

The constellation of Scorpius can be used to locate the northern and southern crowns, Corona Borealis and Corona Australis. Graphic created using Stellarium

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