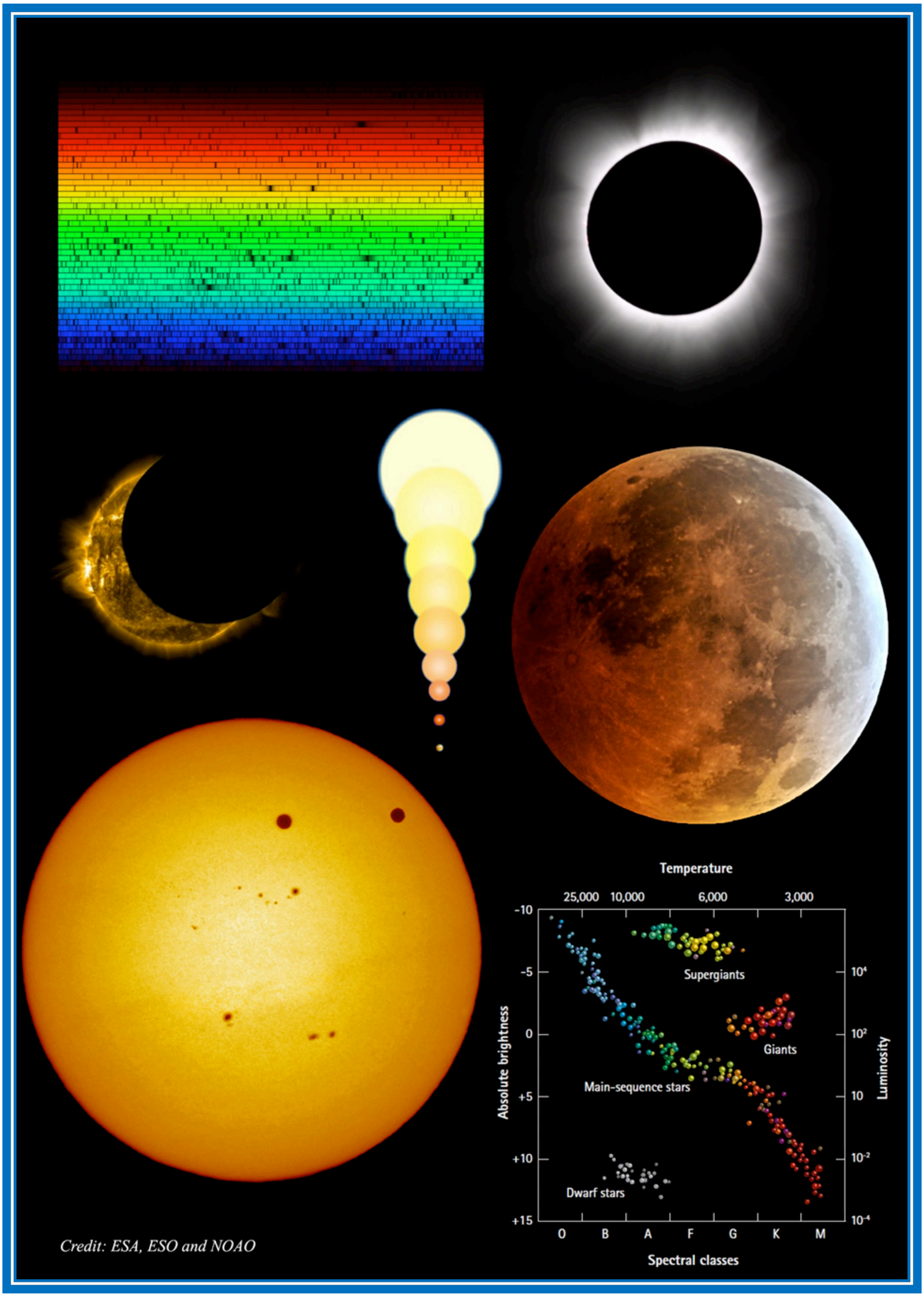
# CESAR BOOKLET

General Understanding of Eclipses and Stars




*Credit: ESA, ESO and NOAO*

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## Solar eclipse –Partial, annular and total eclipse

When we think about an eclipse, we talk about an event in astronomy that happens when a body is “covered” and its light is not visible to our eyes for a moment. This can occur either by an object having another body that crosses between the viewer and it, or the body crossing into the shadow of a different body. An eclipse includes either the shadow of our natural satellite or the Moon that crosses the surface of the Earth. But is also includes a solar eclipse or a lunar eclipse, that is when the Moon moves into the shadow of the Earth. However, an eclipse does not include only these three astronomical bodies. It can also refer to occasions outside the Earth-Moon system. For example, it can refer to another moon in the solar system that passes its planet’s shadow or a moon crossing into the shadow of another moon. These are also eclipses.

So, to conclude it all, shadows are the main reasons for eclipses and it does not have to be linked to just our planet, Moon and Sun. More about this will be discussed further on.

Let us start with a solar eclipse. When the Moon passes in front of the Sun and casting a shadow on the Earth (referred as an occultation), a solar eclipse is occurring. **Keep in mind to never look at the Sun directly, even if it is during an eclipse. The light from it can damage your eyes, even if its light is blocked.**

Maybe you are asking yourself, why not during an eclipse? The answer is: Throughout an eclipse, the visible (white) light is blocked, but the UV (ultra violet) light that the Sun emits is not since it has a wavelength that is more unsafe for our eyes.

First of all, when we look at the Sun during daytime, our eyes get irritated and we turn our heads away. But when viewing an eclipse, we get a great dose of UV light, but we do not feel that uncomfortable feeling. Second, when we look at something bright, our pupil narrows. The narrowing of it protects our eye from potential damage by not receiving too much light. As an eclipse occurs, the sky becomes darker which widens our pupils. This allows a lot more of the harmful UV light to enter inside our eyes, harming our photoreceptors and it in turn harms our retina. The photoreceptors are the structures in our eyes that permit the detection of incoming light. In other words, photoreceptor damage results in decreased vision.

As the distance from the Earth to the Sun is around 400 times the distance of the Moon, and the diameter of the Sun is around 400 times the Moon’s, the Sun and the Moon as observed from us seem to be roughly the same size. This only happens when the Moon passes between the Sun and the Earth, and when the Moon is partially or fully blocking (or occulting) the Sun. This can only happen at new Moon that is when the Sun and the Moon are in conjunction from our point of view. There are three different types of solar eclipses:

### i. Partial solar eclipse

A partial solar eclipse happens when only the partial shadow (penumbra) falls down the surface of Earth. When this occurs, a portion of the Sun always stays in view. Frequently the penumbra shadow gives just a glimpse to our planet over the Polar regions; in cases like that, places that are distant from the poles but still in the zone of the penumbra will maybe not see more than a small piece of the Sun unseen by the Moon.

In a unlike situation, the observers that are located inside a couple of thousand kilometers of the pathway of a total eclipse will see a partial one. The near as you are to the path of a total eclipse (totality), the larger the obscuration of the Sun (*solar obscuration)*. For example, if you are located just outside the path of the total eclipse, you will see the Sun fade to a narrow semi-circular disk, then increase up again as the shadow passes by.

### ii. Annular solar eclipse

This type of eclipse happens when the distance to the Moon is close to its limit for the umbra to reach Earth.

Often, an annular solar eclipse starts because the top of the umbra falls just short of making contact with the Earth. After that, it develops to a total eclipse since the roundedness of the Earth spreads up and intercepts the shadow top near the middle of the path, then lastly it returns back to annular to the end of the trail. Since the Moon seems to pass right in front of the Sun, total, annular and hybrid eclipses are also named "central" eclipses to differentiate them from eclipses that are only partial.

### iii. Total solar eclipse

The outermost region of the Sun, named the corona, illuminates like a halo around the Moon through a total solar eclipse. Eclipses like that occur when a new Moon crosses in front of the Sun. They do not occur often, only about once a year, since the sloping orbits of the Moon, Earth, and the Sun make their alignment (another word for this in astronomy is **syzygy**) rare.

The special thing about a total eclipse is that the observer can see the corona of the Sun and it is the only time it can be seen from us.

***Figure 1:*** *Partial Solar eclipse*

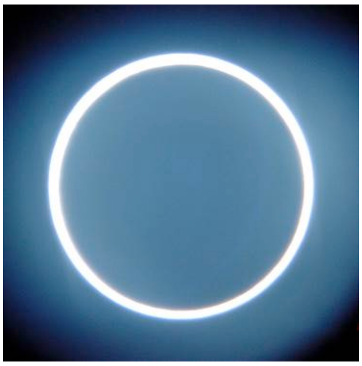


***Figure 2:*** *Annular Solar Eclipse*

***Figure 3:*** *Total Solar Eclipse*

*Credit: all three pictures are from ESA*

## Lunar eclipse

When shadow of the Earth blocks the light from the Sun, a lunar eclipse happens. There are three different types of lunar eclipses: total, partial and penumbra, and these differ from each other. *(More about the types will be described below).*

The most eye-catching eclipse is the total lunar eclipse, in which the shadow of the Earth completely covers the Moon. Depending on your location, an eclipse can differ. In some locations, a total eclipse can be seen. At the same time, in a different place, a partial can be seen. Some can observe one during the Moon rise, and others during a Moon set. It all depends on where you are. This is due to the orbit that our Moon is having around the Earth. As our planet is a globe, the Moon is not in the exact same place from every single position on Earth.

You can relate this to the difference between night and day around the globe. For example, when it is night in Europe, it is morning in the other side of the Earth. When the Moon is waxing crescent or waxing gibbous, it is waning crescent or waxing gibbous in a different location.

First of all, a lunar eclipse only occur when it is full, that is at full Moon. A total eclipse can only happen when the Earth, the Sun and the Moon are perfectly aligned. If it is not, then a partial lunar eclipse can be seen, or even nothing at all. This is due to the Moon's orbit around Earth. Because of its orbit around Earth that lies in a slightly different plane than Earth's orbit around our Sun. A flawless alignment for an eclipse does not happen at every full Moon. A total one develops over time, mostly some hours for the whole event.

An eclipse works mainly in the following way: During a lunar eclipse, the Earth casts two shadows that fall on the Moon. The full and dark shadow is called the umbra. The penumbra is a partial external shadow. The Moon is crossing these two shadows in different phases. The initial and final stages, when the Moon is in the penumbral shadow, are not so obvious. That is why the greatest part of an eclipse is through the middle of the occasion, which is when the Moon is in the umbral shadow. As mentioned, there are different types of lunar eclipses. Here are the descriptions in each of them:

### i. Partial lunar eclipse

An eclipse can also be partial. But even a total lunar eclipse goes over a partial phase on both side of totality. The reason is that the Moon is orbiting around the Earth. During the partial phase, the Earth, Moon and Sun are not quite perfectly lined up, and the shadow of the Earth seems to be on one side of the Moon.

### ii. Penumbral lunar eclipse

Here, the Moon is instead in the penumbral shadow of the Earth (the outer that is dim). This type of eclipse is not easy to notice, so it is important to know when and in what time this event occurs.

### iii. Total lunar eclipse

During a total eclipse, the umbral shadow of the Earth falls on the Moon. It will not entirely vanish, but it will be cast in a peculiar darkness that makes it easy.

Some of the light that the Sun is emitting passes through the atmosphere of the Earth, which scatters and refracts (bents), and then refocus on the Moon. This in turn leads to a faint glow even through totality. Let us say that you were standing on the Moon as a substitute, watching at the Sun when it is aligned with the Earth. At that moment, you would see the black disk of our planet blocking the entire Sun. You would also see a circle of reflected light shining around the edges of Earth. That light is the light that falls on the Moon through a total eclipse.

One particularly thing that is noticeable is that the Moon might turn coppery or red in color through the total portion of an eclipse. This is because while the Moon is in total shadow, some light from the Sun passes through the atmosphere of the Earth and is then refracted toward the Moon. Although other colors in the spectrum are scattered and blocked by Earth's atmosphere, the red light have a tendency to make it through more effortless.

*Figure 4:* *Partial Lunar Eclipse*

*Figure 5:* *Annual Lunar Eclipse*

*Figure 6:* *Total Lunar Eclipse*

*Credit: ESA*

## Inner planet transits / planetary transits

A transit is basically a passage of a planet across the disk of its star, or in other words a celestial body that moves across the face of a larger one. This can often be seen when the body is between a planet and its host star. The observer, on a different planet, has to be behind the transiting planet to be able to see it pass. That is, any celestial body behind the observer's one cannot be seen. This is an obvious case. We can take the planet Mars for an example. We are not able to see it pass in front of the Sun since it is behind Earth. From our perspective, the only planetary transits we can see are those of Venus and Mercury. It is also worth to mention that planetary transits are much more uncommon than eclipses of the Sun by our Moon.

Normally, there are 13 transits of Mercury each century. The last one that we could see was in 2006, and the next one will be in the year of 2016. Transits of Venus, in comparison, usually happen in pairs with eight years splitting the two events, and then more than a century will pass before there's another pair. The most current are the transits of 2004 and 2012. The next pair will not be seen until 2117 and 2125.

Nowadays, a planetary transit has a different meaning. Astronomers are instead observing at transits beyond the Solar system, that is planetary transits of other stars in the Milky Way. The planets themselves are too far away and dark to be seen directly, so we cannot distinguish any details. On the other hand, if they transit their parent star, very slightly reducing its light, astronomers can infer their presence. Many space telescopes have been launched with a mission to find other planets beyond our solar system that is searching for exoplanets. Some examples are NASAs Kepler space telescope and ESAs COROT. Both of them have tracked thousands of stars and found many exoplanets. The ultimate goal is to track down planets with the size of the Earth, so called super-Earths. In particular, astronomers are interested in planets that orbit stars that are similar to ours in the so called "habitable zone", that is, at a distance that would make it probable for the existence of liquid water on their surface, theoretically making it possible for life to exist. That is the ultimate goal for any astronomer that is working with this.

### i. Mercury transit

Currently, all transits of Mercury fall within a number of days of May 08 and November 10. As the orbit of Mercury is inclined about seven degrees to the plane or Earth, it intersects the ecliptic at two nodes or points which cross the Sun every year on these specific dates. A transit will happen if Mercury passes through inferior conjunction at that time. The planet is close to aphelion through the May transits and is 12 arc-seconds across.

In contrast, through the November transits, Mercury is close to perihelion and displays a disk only 10 arc-seconds in width. On the other hand, the possibility of a transit occurring during May is reduced by a factor of nearly two. For example, May passages repeat only over 13 and 33 years, while November passages repeat at intervals of 7, 13, or 33 years.

The transits happening during May are less frequent than the ones in November because during a May transit, Mercury is near aphelion whereas during November, it is near perihelion. The transits through perihelion happen more often due to two effects: to start with, Mercury moves faster in its orbit at perihelion and can reach the transit node more rapidly. Secondly, at perihelion, Mercury is closer to the Sun and so has less **parallax.**

## ii. Venus transit

Venus is the second planet from the Sun, so its orbit is significantly larger than Mercury's. That is why this planet has transits are much rarer. A Venus passage are only probable through early and June when its orbital nodes pass across the Sun. Transits of Venus shows a noticeable array of relapse at intervals of 8, 121.5, 8 and 105.5 years. Since its seeming diameter is close to 1 arc-minute, it is just likely to see it without using any optical magnification as it passes the Sun. One should point out that a solar filter needs to be used during an observation.

During a transit, the planet can be seen from Earth as a small black dot or disk. The period of such a transit is typically measured in hours. The transit that occurred during 2012 lasted for 6 hours and 40 minutes. While Venus' diameter is more than 3 times that of the Moon, Venus seems smaller, and moves more slowly across the Sun. This is due to its distance to Earth compared with the one our Moon has.

Another fact to point out is that a Venus transit is amongst the rarest of expectable astronomical phenomena. They happen in a pattern that normally repeats every 243 years, with sets of transits eight years apart from each other. These are divided by long gaps of 105.5 and 121.5 years.

The orbit of Venus is inclined by 3.4° relative to the Earth's and typically seems to pass over (or under) the Sun at **inferior conjunction.** A transit happens when the planet reaches conjunction with the Sun near or at one of its nodes – the longitude where Venus passes through the ecliptic (or orbital plane) of the Earth- and looks like passing right across the Sun. Even though the Inclination (or leaning) amongst these two orbital planes is only 3.4°, Venus can be as far as 9.6 ° from the Sun when seen from the Earth at **inferior conjunction.** Since the **angular diameter** of the Sun is around half a degree, the planet might seem to pass below or above the Sun by more than 18 times the solar diameter during an ordinary conjunction.

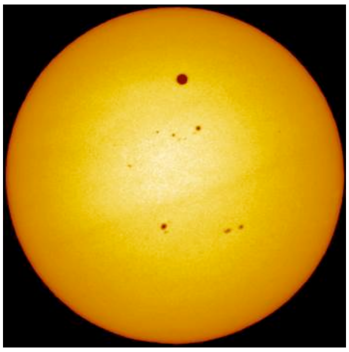


***Figure 7:*** *Venus transit during 5-6 June 2012*

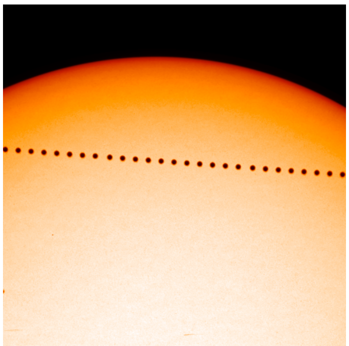


***Figure 8:*** *Mercury transit the corner of the Sun*

*Credit: ESA/NASA*

## Spectral class / Hertzprung-Russel diagram

The stars in the universe are divided into several spectral classes according to their decreasing effective temperature:

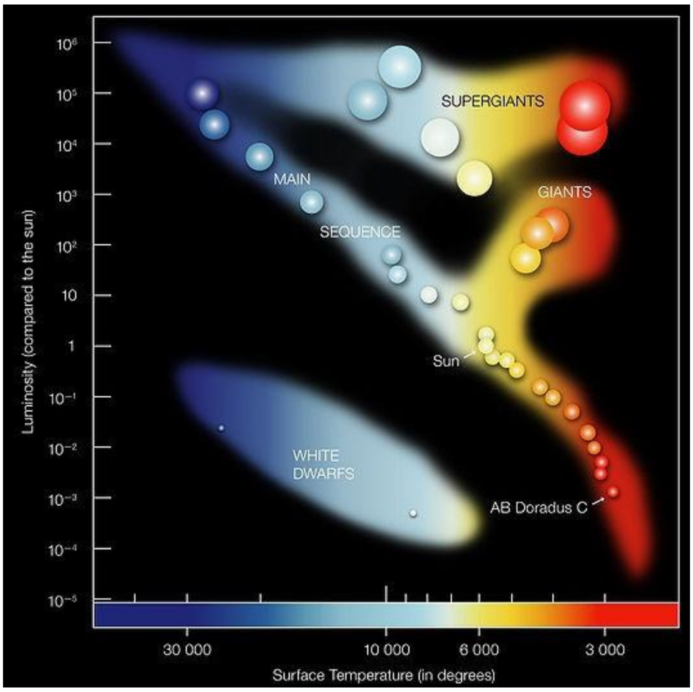
O, B, A, F, G, K, M, L, T…

Where the O stars are those with the highest temperature and the letter order indicates continuously colder stars up to the coldest M class. The arrangement has also another purpose, a presentation of their colors. **O** stars are called blue, **B** for blue-white, **G** for yellow, **K** for orange, and finally **M** stars for red. Each star starts their life in the main sequence and then evolves to different parts of the Hertzprung-Russel diagram. As mentioned in the overview (introduction), the Sun is a G-type main-sequence star (G2V). It is informally designated as a yellow dwarf, because its observable radiation is most intense in the yellow-green portion of the spectrum. Although its color is white, from the surface of the Earth it may appear yellow. This is because of **atmospheric scattering** of blue light. In the spectral class label, *G2* specifies its surface temperature of roughly 5778 K (5505 °C), and *V* indicates that the Sun, like the majority of the stars, is a main-sequence star, and thus generates its energy by nuclear fusion of hydrogen nuclei into helium.

When a star has been detected, plotting it on a Hertzprung-Russel (HR diagram) can give us more information about it.

The connection on this graph is the following. The y-axis represents the relationship concerning the star's absolute luminosities or absolute magnitudes. Shortly, luminosity is the amount of energy a star radiates in one second. Absolute magnitude is the essential brightness of the star. The x-axis is concerning their effective temperature versus their spectral types or classifications. More about these features can be found below.

One thing that is necessary to know is that this graph doesn't give us any information about their distances or locations in the universe. By plotting its characteristics on a diagram it can further be compared with other stars. This can give a picture of how common different types of stars are.




As mentioned, by plotting the characteristics for an appropriate amount of stars the grouping can be revealed, by looking at their stellar properties.

***Figure 9:*** *The figure above is clearly showing us that the majority of stars are to be found on the main sequence, which is the line across the diagram following from the upper left to the lower right. The brightest and hottest stars is located at the upper left and the coldest and the faintest stars are in the lower right, following the visible curve in the middle. As can be seen, the giant branch is also well populated and many white dwarfs are plotted there.*
*But this is not just it; the diagram is even more sophisticated and bares more information.*

*Credit: ESO*

There are three main regions of the HR diagram and they are presented below:

**a.** The main sequence stars that are luminous and hot, to faint stars with a low temperature can (as mentioned earlier) controls the HR diagram. Here, stars spend approximately 90 % of their lives burning hydrogen (H) into helium (He). This event happens in their cores. The *Morgan-Keenan luminosity* class here is labeled V.

**b.** Supergiants and red giant stars, with the luminosity classes I through III, inhabit the region exceeding the main sequence. This reveals that they have high luminosities and low surface temperatures. According to the *Stefan Boltzmann law*, this means that the stars have great radius. Stars enter this evolutionary phase of their life once they have exhausted their hydrogen (H) fuel in their centers and started to burn helium (He) and other heavier elements.

**c.** The last evolutionary stage of low to transitional mass stars are the white dwarfs, and they are to be found in the bottom left of the diagram. The stars here have a very high temperature but they have low luminosities. This is due to their small sizes.

So, in conclusion, by plotting a HR diagram for either an open or globular cluster of stars, astronomers can estimate the age of the cluster, temperature of a star, where they are in their lives and so on.

## Spectral types – (The letters/ Harvard spectral classification)

**Class O:** In this class, you discover the relative rare stars. Class O includes luminous blue stars which also have very high temperatures on their surfaces. The temperature range between 25,000 K up to 50,000 K**.** Stars in this class have few absorption lines, weak Balmer lines and ionized helium lines in their spectra.

**Class B:** This is the first class with a high population. Stars in this type burn fiercely and are blue in their color. Their surface temperature is lying between 11,000 and 25,000 K. The spectrum has neutral hydrogen lines that are more noticeable than Balmer lines.

**Class A:** Stars classified as A-stars are those whose surface temperature lies approximately between 7,500 K and 11,000 K. They are known for their white color and the most known stars visible in the night sky belong to this classification. Here, the Balmer lines are the strongest.

**Class F:** F-type stars can be found between the A-type white stars and G-type yellow stars. They have a noticeably yellowish light. Occasionally, they ace called *Calcium stars…* The temperature of their surface is between 6,000 K and 7,500 K. The Balmer lines are weak, and many lines are including neutral metals.

**Class G:** It is worth knowing that as cooler a star becomes the more complex its chemistry tends to become. The stars in this class, with temperatures between 5,000 K and 6,000 K *have a spectrum that betrays the presence of 'metals'*. With metals we mean elements that are heavier than helium. Like above, the Balmer lines are weak, and the dominant lines are ionized calcium lines.

**Class K:** Stars in this group are infrequently denoted as Arcturian stars. This is due the brightest star of their number. With a surface temperature between 3,500 K and 3,500 K, it is sufficient low for simple molecules to form. These stars have also an orange color. Here, neutral metal lines are the most noticeable.

**Class M:** Class M stars have the coolest of the common star types, which are red stars. The surface temperature is very cool, approximately below 3,500 K. This allows more complex molecules to form. They have strong neutral metal lines and molecular bands.

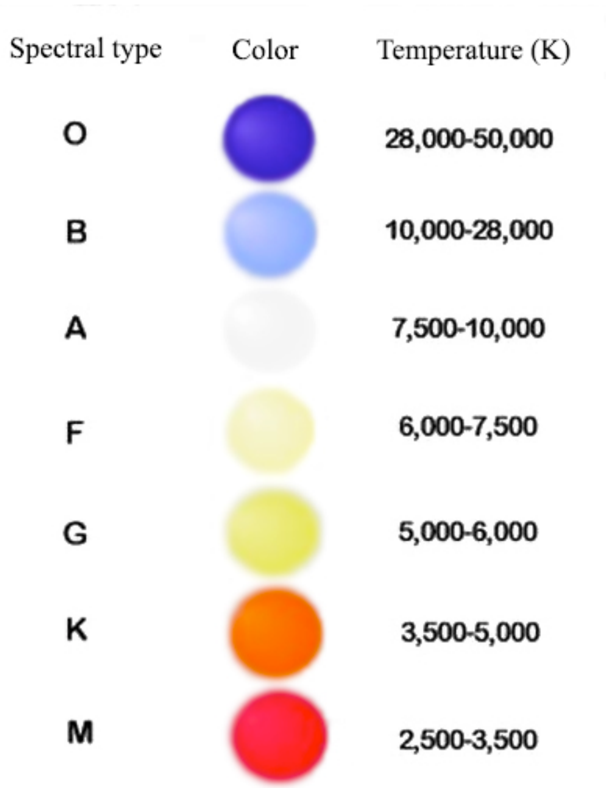



***Figure 10:*** *The figure above shows the previous classification and indicates the temperature range.*

## Luminosity classes description – Roman letters

**I:** In this group, Supergiants can be found. These are very luminous and massive, and are typically nearing the end of their lifecycle. I stars are sub classified as Ia or Ib, where Ia is signifying the most luminous stars in the group.

**II:** Bright giants are grouped here. This is a quite rare group of giant stars that are nearly luminous. These can be thousand times more luminous than our Sun, or even more.

**III:** In this collection, "Normal giants" can be found. Stars in this collection are frequently a hundred times more luminous than the Sun, and noticeably more gigantic.

**IV:** Categorized in this group are Sub giants. Even yet they are much more luminous and gigantic than the Earth's Sun, these are small compared to the real giants.

**V:** Here, in this class, are the dwarfs. These are a very frequent class of main sequence stars. Their mass and luminosity is often associated with that of the Sun.

**VI and VII:** These classes entitle white dwarfs and sub dwarfs. It should be known that they are not now in common use, but are built-in here for completeness.

## Morgan-Keenan luminosity classes

When classifying a star, the primary thing to do is to determine its temperature. A specific classification, also called the *Harvard spectral classification scheme*, gives every star a spectral type. This can further be separated into 10 sub-classes which depend on the absorption features obtainable in their spectrum. As mentioned, our Sun has a temperature of about 5700 Kelvin and its classification is G2.

Yet, this scheme does not entirely define the star as it cannot manage to separate between stars that have the identical temperature but luminosities that are different. This leads to a problem when it deals with distinguishing between main sequence stars (dwarfs), giant stars and supergiant stars. That is why the Morgan-Keenan luminosity class (MKK or MK) was established and is used.

Roman numbers between I and V is also used to simplify the classification. The numbers **I**, **II**, **III**, **IV** and **V**, is expressing the width of specific absorption lines in the spectrum of the star. The "**I**" stand for supergiant stars, III simply for giants and the V for either dwarfs or main sequence stars. Currently, class I stars have been divided into **Ia-O**, **Ia** and **Ib,** and classes **VI** and **D** has been added. VI stands for sub-dwarfs and D for white dwarfs.

The original Harvard classification is appended to the MK luminosity class to fully describe an observed star. Our Sun is, as mentioned, a main sequence G2 star. Therefore, its complete classification is G2V. In words, the Sun might be interpreted as a yellow, 2/10 towards the orange main sequence star. The brightest star on the night sky, Sirius, is a type A1V star

The current star classification system has a spectrum letter that is improved by a number from **0** to **9** specifying tenths of the series between two star classes. For an example, an A5 is five tenths (5/10) between A0 and F0, but A2 is two tenths (2/10) of the full range from A0 to F0.

## References