THE STARS

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Within this use case you discover the basic observational parameters of stars, color and magnitude. These observational parameters are counterparts of the main physical parameters temperature and luminosity. By selecting stars on the sky you build the Herzsprung-Russell diagram that shows the relation between color and magnitude, a milestone in the history of our understanding of how stars work and evolve.

If used in the classroom, the meaning of temperature, color and luminosity should be explained before performing the use case. It is required to draw coordinate points on a diagram. The level of the UC is intermediate.

1 Introduction

Stars have different colors and luminosities. Following this tutorial we will learn what star luminosity and color are, and which information about stellar evolution we can obtain from them.

2 Stars: magnitude and color

Looking at the sky with naked eye most stars appear of the same color. We see stars shine of white light because the human eye, in low luminosity, loses its capability to distinguish colors: only the brightest stars are sufficiently luminous to show their real color. Looking at the sky with a binocular or a telescope we see that stars have colors and that these colors can be put in a sequence: from blue to white, yellow, orange and red.
Astronomers use spectra to study the color of stars. A spectrum forms when light passes, for example, through a prism. The prism splits light in a “rainbow” that astronomers use to determine the color of a star. Thanks to the laws of physics, astronomers have understood that different colors correspond to different surface temperatures. The coldest stars, with a surface temperature of about 2500 K, are red while the hottest, with a surface temperature of about 50000 K, are blue. Kelvin measurement unit (K) is the International System unit of temperature: T (K) = T (°C) + 273,15.

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For simplicity astronomers divide the sequence of colors into 7 main spectral types, indicated by the letters O, B, A, F, G, K, M. Each class is further subdivided into 10 subclasses indicated by a number from 0 to 9, in order to have a more precise definition of the spectral class. For example A0 indicates the hottest stars in the A class and A9 indicates the coolest.
The apparent luminosity of a star depends on distance from us, temperature and radius. Astronomers measure apparent luminosity in *apparent magnitude*: magnitude is a luminosity scale used to compare stars. First astronomers gave magnitude 1 to the brightest star of the sky and magnitude 6 to the faintest ones seen by naked eye. With telescopes, we can see stars fainter than magnitude 6, so the actual scale of magnitude extends over these values. There are also stars brighter than magnitude 1: for example Vega has magnitude 0 and the Sun has magnitude -27.
The magnitudes are logarithmic because the human eye senses brightness logarithmically, so an increase of 5 magnitudes corresponds to a decrease in luminosity of a factor 100: a star of magnitude 6 is not 5 times less luminous than one of magnitude 1, but 100 times less luminous.
Astronomers measure luminosity with the *absolute magnitude*, that is the apparent magnitude a star would have if it were at 10 parsec (about 33 light years) from us. We have to determine the distance of the star to compute its absolute magnitude.

Spectral Class	Temperature	Color
O	30000 - 60000 K	blue
B	10000 - 30000 K	blue - white
A	7500 - 10000 K	white
F	6000 - 7500 K	white - yellow
G	5000 - 6000 K	yellow
K	3500 - 5000 K	orange
M	2000 - 3500 K	red

3 Stellarium

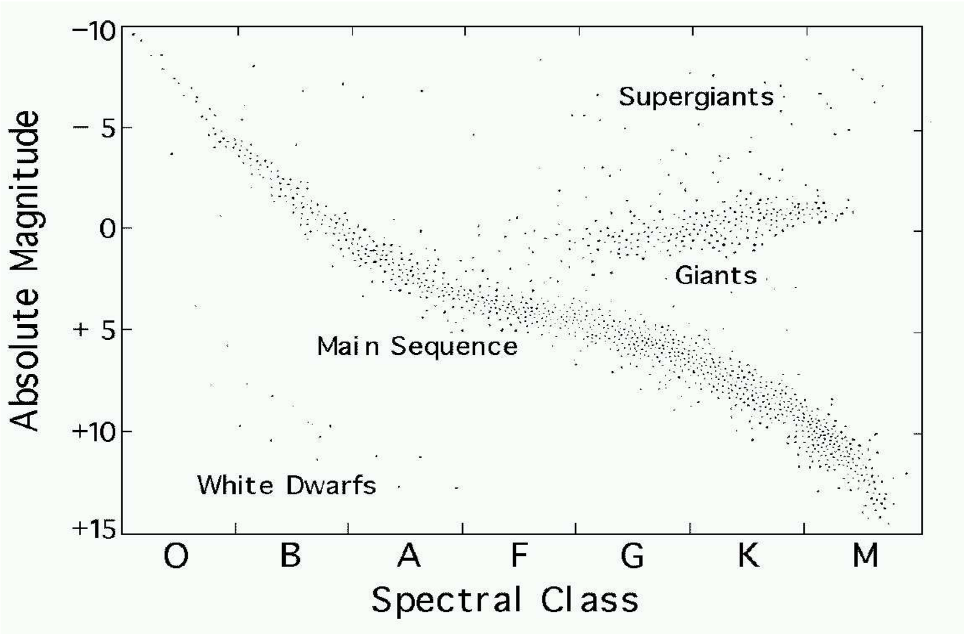
Stellarium is a free software that transforms a home computer in a planetarium. It calculates the positions of Sun and Moon, planets and stars, and draws the sky how it would be seen from an observer anywhere on the Earth and at any epoch. Stellarium can also draw the constellations and simulate astronomical phenomena such as meteor showers and solar or lunar eclipses.
Stellarium may be used as an educational tool for kids of all ages, as an observational aid for amateur astronomers wishing to plan an observing night, or simply to explore the sky (it is fun!). Stellarium shows a realistic sky, very close to what you see with naked eye, binoculars or telescope. Stellarium gives astronomical data (coordinates, magnitude, distance, etc.) of most of the celestial objects visualized on the screen.
You can freely download Stellarium from our site http://vo-for-education.oats.inaf.it or from http://www.stellarium.org.

4 Hertzsprung-Russell diagram

In the Hertzsprung-Russell (HR) diagram absolute magnitudes of stars are plotted versus their color. In this diagram stars occupy well defined regions, with most stars lying in the *main sequence*, a roughly diagonal curve.
Astronomers have discovered that stars move on the diagram during their life, spending most of their life on the main sequence. The “life" of a star is called “evolution" (see the box on stellar evolution).
90 % of stars lie on the main sequence, with blue stars on the upper left corner of the sequence and red stars on the lower right corner. The Sun is located in the middle of the main sequence. In the diagram there are also stars that do not belong any more to the main sequence and are approaching the end of their life. For example giant and supergiant stars lie on the upper right section of the diagram because they have large luminosity but low temperature. The white dwarfs, that are very hot but small, lie in the lower left corner of the diagram.

Stellar evolution

Stars are big spheres of gas (if the planet Earth is a grain of sand, a medium size star is a ball of 1 meter diameter). Stars produce energy by nuclear fusion that occurs in the core, mainly composed by hydrogen. The fusion of four atoms of hydrogen into one of helium is the main process. The net energy of an helium atom is lower than the sum of the energies of 4 atoms of hydrogen, the excess energy is radiated as radiation. A star spends most of its life in a steady phase, corresponding to the main sequence of the HR diagram, during this phase it burns the hydrogen of the nucleus. Stars have different masses and therefore different amount of nuclear fuel. More massive stars have more fuel, therefore they radiate more energy and evolve more rapidly than small stars, which shine less. Massive stars evolve faster and belong for less time to the main sequence. Since stars are most likely to be found in the steady stage of hydrogen burning, the main sequence is richly populated.
The main sequence phase ends when the star finishes the hydrogen of the nucleus, transformed completely into helium. The star now burns helium in the nucleus and hydrogen in a shell surrounding it. The star starts to expand and becomes a red giant. Giant stars are very big and relatively cool, they radiate a large amount of energy and appear very luminous.
When the star finishes all kinds of nuclear fuel it can start to collapse and possibly explode, depending on its mass. If the star is massive it expels its outer layers which form a planetary nebula, while the hot core collapse in a white dwarf. More massive stars explode as supernovae and/or collapse in a black hole.



5 HR diagram with Stellarium

Open Stellarium and toggle off atmosphere and ground (buttons “Atmosphere" and “Ground"). Looking at the stars you note they have different colors and magnitudes. In order to understand what this features mean, we try to operate as Hertzsprung and Russell did at the beginning of the XX century.

Hertzsprung and Russell observed the most luminous stars, plotted their absolute magnitude versus spectral type and obtained the diagram. Today we can use the Virtual Observatory tools, so we do not need to perform astronomical observations during the night. We will observe in Stellarium the 25 brightest stars of the sky and then plot their spectral type versus absolute magnitude.

Click the search button on the left menu and enter the name of a star, for example Sirius. Stellarium moves to the star and all the information appears on the upper left corner. Look at the spectral type and absolute magnitude, we will use them to build our HR diagram.

Repeat this process for all the 25 stars and fill the plot with a point for each stars corresponding to its spectral class and magnitude. Now you have built your HR diagram, do you recognize any feature of the star evolution cycle?

EXERCISES

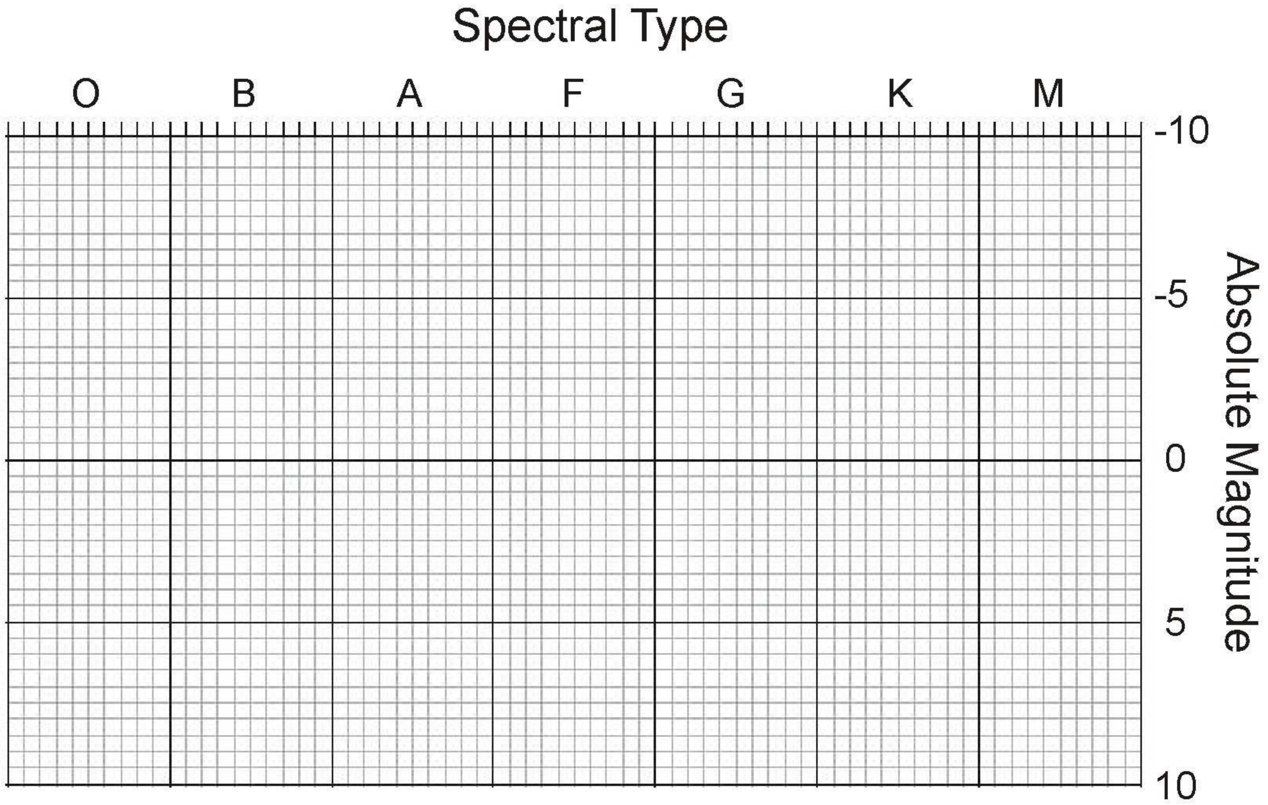
Exercise 1

In the table below there is the list of the brightest stars of the sky. Find them in Stellarium and fill the table with absolute magnitude, spectral type (write in the table only the first letter and first number indicated in stellarium, e.g. B3IV -> B3) and constellation.

Star	Absolute magnitude	Spectral Type	Constellation
Sun		G2	
Sirius			
Rigil Kent			
Arcturus			
Vega			
Capella			
Procyon			
Achernar			
Betelgeuse			
Hadar			
Acrux			
Altair			
Aldebaran			
Antares			
Spica			
Pollux			
Fomalhaut			
Mimosa			
Regulus			
Adhara			
Canopus			
Gacrux			
Shaula			
Rigel			
Deneb			

Exercise 2

Put each star of the previous exercise in the following empty HR diagram, according to its absolute magnitude and spectral type. Do you recognize any feature of the HR diagram?



SOLUTIONS

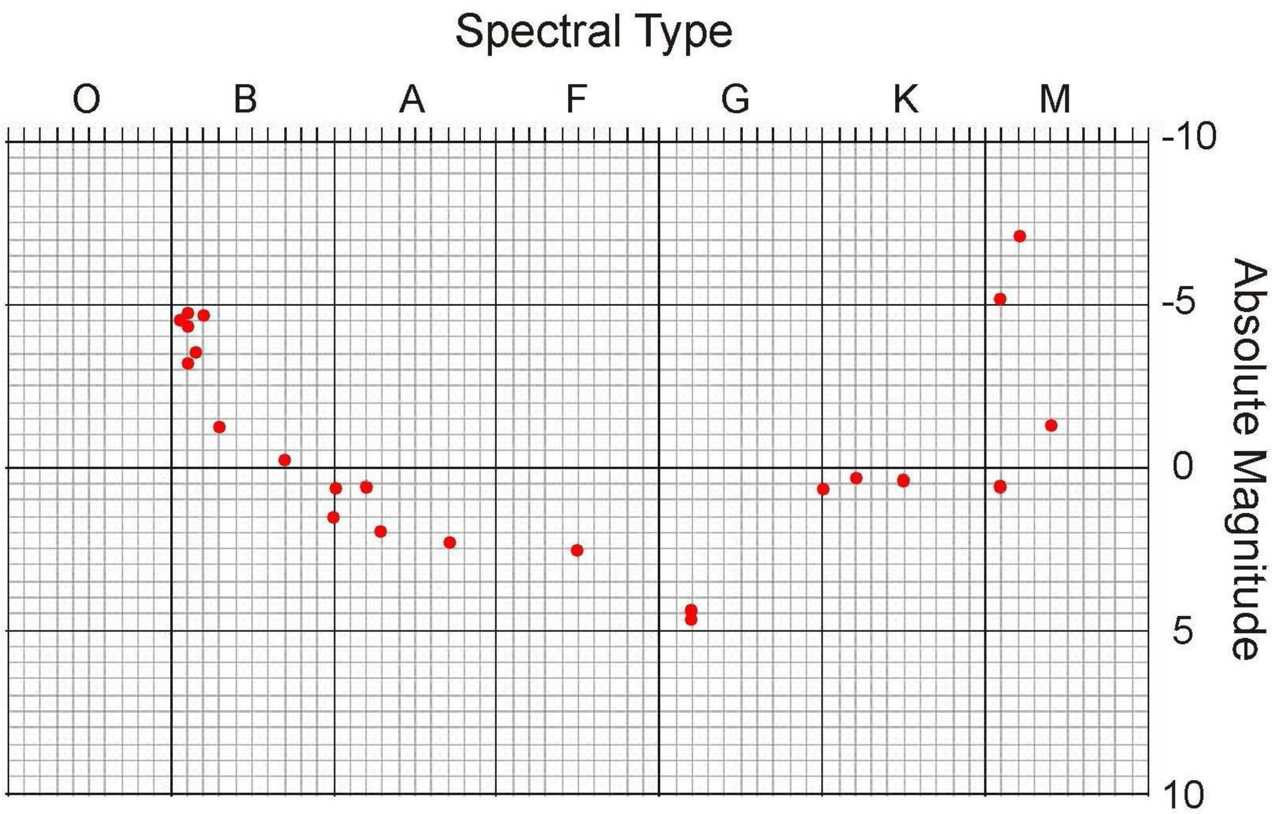
Exercise 1

In the table below there is the list of the brightest stars of the sky. Find them in Stellarium and fill the table with absolute magnitude (write in the table only the first letter and first number indicated in stellarium, e.g. B3IV -> B3), spectral type and constellation.

Star	Absolute magnitude	Spectral type	Constellation
Sun	4.83	G2	
Sirius	1.44	A0	Canis Major
Rigil Kent	4.45	G2	Centaurus
Arcturus	-0.11	K0	Bootes
Vega	0.57	A1	Lyra
Capella	-0.54	G1	Auriga
Procyon	2.68	F5	Canis Minor
Achernar	-2.70	B6	Eridanus
Betelgeuse	-5.47	M4	Orion
Hadar	-5.48	B1	Centaurus
Acrux	-3.71	B0.5	Crux
Altair	2.20	A7	Aquila
Aldebaran	-0.70	K5	Taurus
Antares	-5.10	M1.5	Scorpius
Spica	-3.47	B1	Virgo
Pollux	1.07	G9	Gemini
Fomalhaut	1.72	A4	Piscis Austrinus
Mimosa	-3.92	B1	Crux
Regulus	-0.58	B8	Leo
Adhara	-3.97	B1	Canis Major
Canopus	-5.53	A9	Carina
Gacrux	-0.62	M3.5	Crux
Shaula	-4.62	B1.5	Scorpius
Rigel	-6.96	B8	Orion
Deneb	-6.93	A2	Cygnus

Exercise 2

Put each star of the previous exercise in the following empty HR diagram, according to its absolute magnitude and spectral type. Do you recognize any feature of the HR diagram?



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