

THE STARS

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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 ability to distinguish colors: only the brightest stars are sufficiently luminous to show their 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 (surface temperature of about 2500 K) are red while the hottest (surface temperature of about 50000 K) are blue.

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 1 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 one seen by naked eye. Increasing the magnitude the stars appear fainter. Now,

Spectral type	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

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 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 of one of magnitude 1, but 100 times less luminous.

Astronomers measure luminosity with the *absolute magnitude*, that is the apparent magnitude the star would have if it is at 10 parsec (about 33 light years) from us. Of course, we have to determine the distance of the star to measure absolute magnitudes.

3 Stellarium

Stellarium is a software that allows people to use their home computer as a virtual planetarium. It will calculate 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 in 3D, very close to what you see with naked eye, binoculars or telescope.

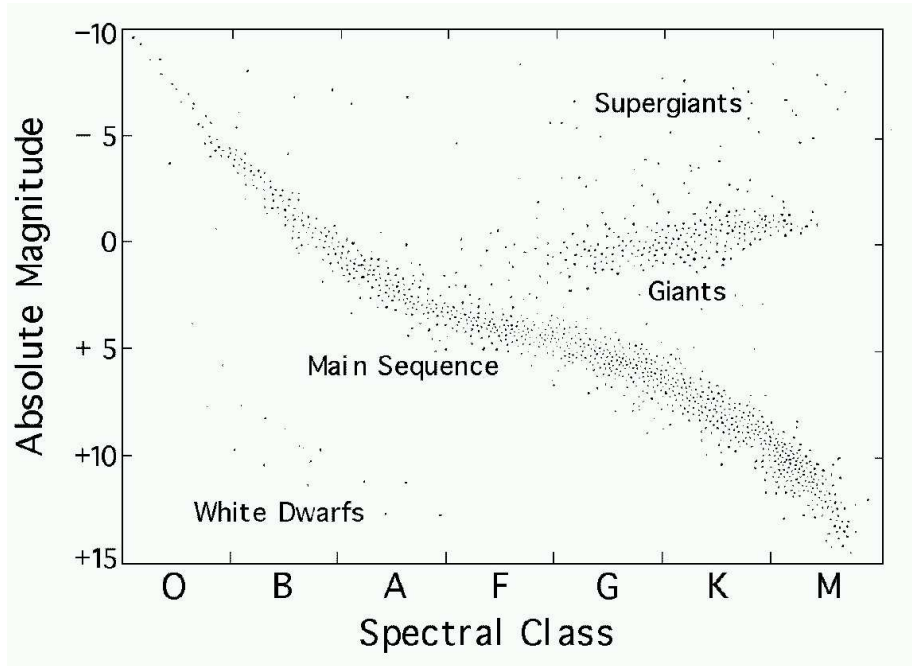
Stellarium provides astronomical data (coordinates, magnitudes, distances, etc.) for celestial objects you see on the screen.

You can download Stellarium from the website <http://www.stellarium.org>.

4 Hertzsprung-Russel diagram

The Hertzsprung-Russel (HR) diagram shows absolute magnitude of stars versus their color. In this diagram stars occupy only few regions, most of them 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 in the next page).



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.

H-R 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 Russel did at the beginning of the XX century.

Hertzsprung and Russel 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 stars and all the informations appear on the upper left corner. Look at the spectral type and absolute magnitude, we will use them to build our HR diagram.

Stellar evolution

Stars are huge spheres of gas (if the planet Earth is a ping pong ball, a medium size star is a hot-air balloon). Stars produce energy by nuclear fusion that occur in the core, mainly composed by hydrogen. The fusion of four atoms of hydrogen into one of helium is the main process. A star pass most of its life in a steady phase, corresponding to the main sequence of the HR diagram, in which it burns the hydrogen of the nucleus. Stars have different masses and therefore different mounts of nuclear fuels, such hydrogen. 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 then nucleus, transformed completely into helium. The star now burns helium in the nucleus and hydrogen in a shell surrounding the nucleus. The star starts to expand and becomes a red giant. Giant stars are very big and relatively cool stars, 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 or can 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 exploded as supernovae and/or collapse in a black hole.

EXERCISES

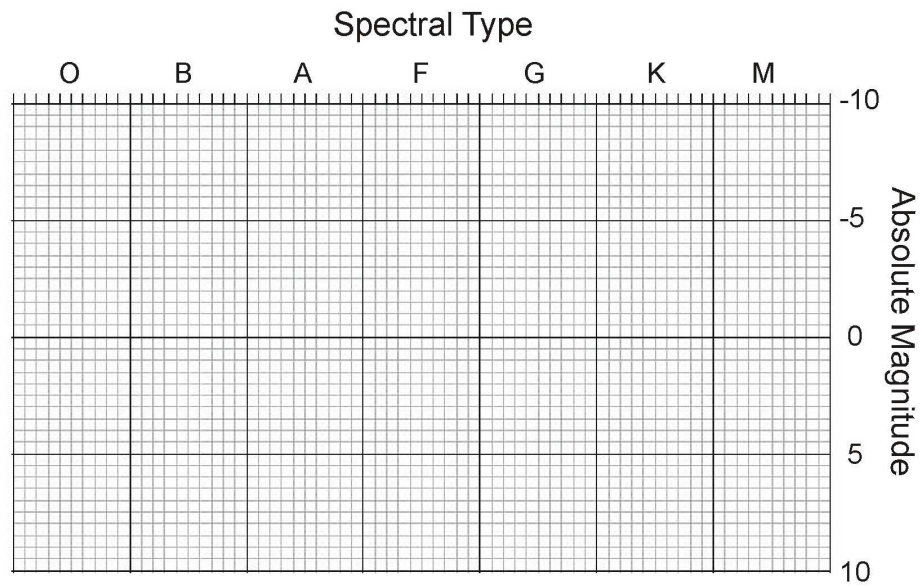
▷ Exercise 1

Activity: 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 and constellation.

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

▷ Exercise 2

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



SOLUTIONS

▷ Exercise 1

Activity: 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 and constellation.

Star	Absolute magnitude	Spectral type	Constellation
Sun	4.8	4.8	–
Sirius	1.4	A1	Canis Major
Rigel Kent	4.4	G2	Centaurus
Arcturus	0.2	K2	Bootes
Vega	0.6	A0	Lyra
Capella	0.4	M1	Auriga
Procyon	2.6	F5	Canis Minor
Achernar	-1.3	B3	Eridanus
Betelgeuse	-7.2	M2	Orion
Hadar	-4.4	B1	Centaurus
Acrux	-4.6	B0.5	Crux
Altair	2.3	A7	Aquila
Aldebaran	-0.3	K5	Taurus
Antares	-5.2	M1	Scorpius
Spica	-3.2	B1	Virgo
Pollux	0.7	K0	Gemini
Fomalhaut	2.0	A3	Piscis Austrinus
Mimosa	-4.7	B0.5	Crux
Regulus	-0.3	B7	Leo
Adhara	-4.8	B2	Canis Major
Castor	0.5	A2	Gemini
Gacrux	-1.2	M4	Crux
Shaula	-3.5	B1.5	Scorpius

▷ Exercise 2

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

