STARLIGHT

FLEMING-MAURY-CANNON CLASSIFICATIONS
HERTZSPRUNG-RUSSELL DIAGRAM

SYNTHESIS ABOUT STARS LIGHT

IRINA RABEJA

CONTENT

STARS LIGHT

STARS BRIGHTNESS

LIGHT SPECTRUM

MODERN ASTRONOMY BEGINS…

STARS LIGHT

“The friendly gloss of stars on the night sky hides not only the Unknown but also the immense variety of the stars that often wander as double, triple and even quadruple, are either small as our Earth or big as our solar system, with an oscillating luminosity since they regularly expand and contract.
And although the life of the stars is measured in billions years, they age also and ultimately die or simply cool down until their gloss is weaker and goes off or contrary collapse and explode in a powerful fireball.
But still while the old pass new stars are born.”

Our Earth is only a very small part of what we call the "universe" commonly defined as the totality of everything that exists.

The word "universe" is derived from the Latin word *universum,* which connects *uni* (one) with *versum* (rolled/rotated), used in the sense everything rolled/rotated as one or everything combined into one.

The universe was perceived by people from ancestral times as the sky with stars visible at night by their spot.

The starlight is the only thing that comes from or is given by universe to us.

But today only from the starlight the astronomers have knowledge about the *chemical composition* of the stars and other attributes like *surface temperature, age, absolute magnitude, luminosity, diameter, mass, volume, density, distance from Earth, velocity, speed of rotation, magnetic field.* And that happened by observing and analysing only two unmistakeable/distinctive properties of the stars:

* *brightness* (study originated in antiquity by Hipparchus)

* *spectrum* (study done first time by Joseph von Fraunhofer)

They have opened the door to universe.

STARS BRIGHTNESS

Around the year 120 BC the Greek astronomers divided the stars visible to the naked eye into 6 classes function of their *brightness* B, from the brightest stars of class 1 to the faintest stars of class 6 at the limit of human visual perception. The brightness was measured in *magnitude(s)*, class 1 having magnitude 1, class 2 having magnitude 2… class 6 with magnitude 6. Each class had twice the brightness of the following class, a total range of 6 magnitudes in logarithmic scale.

Originated by **Hipparchus,** this method was popularized by **Ptolemy** in his *Almagest*, a second century ancient Greek mathematical and astronomical treatise on the complex motions of the stars and planetary paths, its geocentric model accepted as dogma for more than 12 hundred years until Copernicus.

Norman Robert Pogson (1829-1891) formalized the system in 1856 year by defining a typical first class star (of magnitude 1) as a star that is 100 times brighter than a typical sixth class star (of magnitude 6), a magnitude 1 star being 2.512 times brighter than a magnitude 2 star, which is 2.512 times brighter than a magnitude 3 star and so on, where:

$2.512 = \sqrt[5]{100}$ = Pogson's Ratio

The modern astronomy has kept in principle the same system, however is not limited to 6 magnitudes or only visible light, the scale has become enlarged (extended) to the extreme faint sky objects on one direction and on the other direction to the brightest heavenly bodies whose magnitudes are negative as Sirius (–1.4) full Moon (–12.74) or Sun (–26.74).

The Hubble Space Telescope has located stars with brightness of magnitude +30 to +31 at visible wavelength and Keck telescopes have located similarly faint stars in infrared. However those magnitudes do not show the real light radiation of the star; they express a combination of the real spread of light of a star and its distance from Earth, for example a faint star would appear brighter at a shorter distance from Earth or the closest star to us, Sun, will appear a dot of light at enough farther distance. What is observed from Earth is the *apparent brightness* B_m measured in *apparent magnitude(s)* marked m, see FIG1.

As measure for the real spread of light of a star, the astronomers defined the *absolute brightness* B_M measured in *absolute magnitude(s)* marked M, see FIG 2.

That is the brightness of the same star situated at a standard distance of 10 *parsecs* from Earth, examples: *Sirius (1.4)* or *Sun (4.8)*.

Parsec (pc) is a unit of length meaning ***par**allax of one arc **sec**ond.*

1pc=31×10^{12} km=206,265 AU~3.26 light-years

Parallax is the angular difference in the star apparent positions observed from opposite sides of Earth's orbit.

Knowing the distance D (in parsecs) between a star and Earth and the *apparent brightness* $\mathbf{B_m}$ of that star it is possible to calculate the *absolute brightness* $\mathbf{B_M}$ of that star with the formula:

$$\mathbf{B_M} = 5 + \mathbf{B_m} - 5(\log D)$$

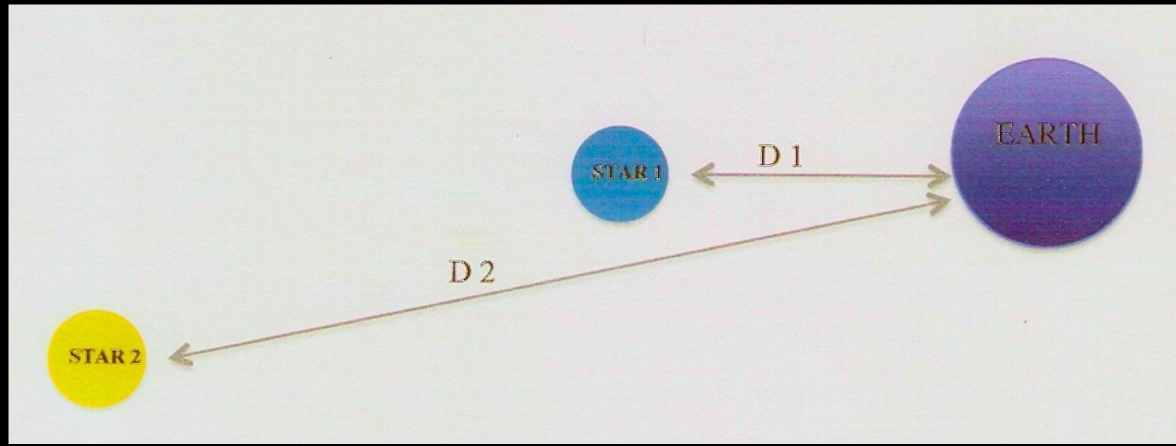


FIG 1 APPARENT BRIGHTNESS B_m

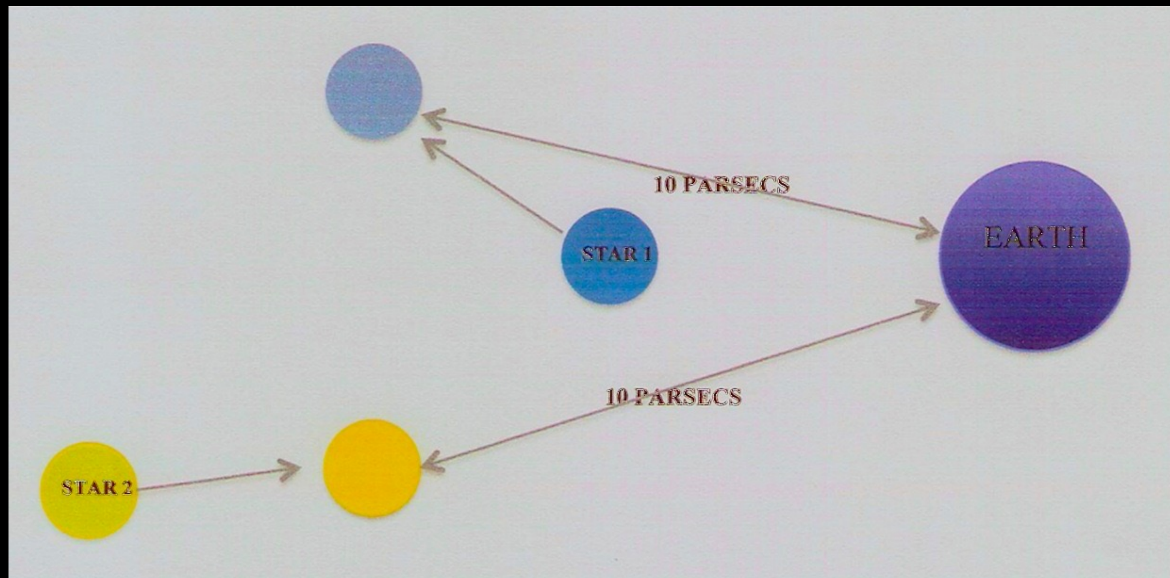


FIG 2 ABSOLUTE BRIGHTNESS B_M (at 10pc)

To express scientifically the amount of electromagnetic energy radiated per unit of time by star (the power output of a star) it is used the term *luminosity* marked **L**. Considering the luminosity of Sun as unit of measurement $L_{sun}=1$, the luminosity of any star can be obtained by knowing its absolute brightness $\mathbf{B_M}$ with the formula:

$$\mathbf{L} = 10^{-0.4\,(\mathbf{BM} - 4.8)}$$

Based on the Stefan-Boltzman law the luminosity of a star can be expressed as a function of its radius R and its surface temperature T: $L = 4\,\pi\,R^2\,\sigma\,T^4$

Higher the temperature and bigger the surface greater the energy flow in consequence the luminosity.

For two stars of luminosity L_1 and L_2 their luminosity ratio is function of their radius square ratio and the fourth power of their temperature ratio:

$$L_1 / L_2 = 4 \pi \sigma R^2{}_1 T^4{}_1 / 4 \pi \sigma R^2{}_2 T^4{}_2$$

$$L_1 / L_2 = R^2{}_1 T^4{}_1 / R^2{}_2 T^4{}_2$$

Our Sun has a luminosity of 3.84×10^{26} W (Js^{-1}) and a radius of 695 500 km.

In astronomical calculations it is often more convenient to consider Sun as unit of measurement for stars by stating:

Unit for luminosity of stars L_{sun}

Unit for radius of stars R_{sun}

Unit for mass of stars μ_{sun}

Any other stars are compared with Sun.

The radius **R** of a star can be evaluated when it is in the previous relation with Sun by knowing its temperature T and luminosity **L**:

$$\mathbf{R} = (T^2_{sun}/T^2)\sqrt{\mathbf{L}}$$

Analysing the luminosity and the mass for different stars, was found that the luminosity of a star is bigger when its provision of energy is bigger meaning its mass is bigger. Resulted the relation between mass μ and luminosity L, mass-luminosity formula: $L = \mu^{3.5}$

In consequence the *mass* **μ** of a star can be obtained knowing the luminosity **L** of that star:

$$\boldsymbol{\mu} = \sqrt[3.5]{\mathbf{L}}$$

So, from the observed or apparent brightness of a star $\mathbf{B}_m$ it is possible to calculate for that star:

- absolute brightness $\mathbf{B_M} = 5 + \mathbf{B}_m - 5(\log D)$
- luminosity $\mathbf{L} = 10^{-0.4(\mathbf{BM} - 4.78)}$
- radius $\mathbf{R} = (T^2_{sun} / T^2)\sqrt{\mathbf{L}}$
- mass $\boldsymbol{\mu} = \sqrt[3.5]{\mathbf{L}}$

LIGHT SPECTRUM

The light began to reveal its secrets in the year 1666 when the genial English mathematician and Nature scientist, Isaac Newton, directed a ray from Sun through a prism and saw that on the wall of his room appeared the colours of rainbow.
To name the multicolour band that appeared like by magic on the wall of room, Newton took from Latin language the word **spectrum** *meaning "ghost appearance" or "phantom".*
The prism decomposed the light in a row of colours entering lightly one in another from red, through orange, yellow, green and blue to violet.

Isaac Newton proved, what other thinkers agreed before, that the white light unifies in itself all the colours of the rainbow.
The set of main colours in spectrum are shown in FIG 3.
In 1900 years researchers studied in laboratory the spectrum of the light coming from the flame of different glowing burning gases, found bright lines of different colours and called them spectral lines of the *emissions spectrum* see FIG 4. The researchers also found dark lines in the colours of spectra of Sun and other stars and called them the spectral lines of the *absorptions spectrum*, see FIG 5.
The many dark lines in spectra have a chemical origin and their observations and analyses led to the discovery of the code of *cosmic chemistry.*
The astronomers have developed a method to identify the chemical elements that generate the dark lines in spectrum by comparing carefully the spectrum of the star light with the spectrum of different burning gases light obtained in laboratory.

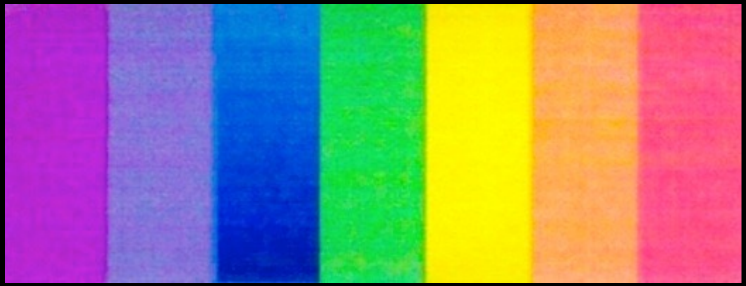


FIG 3 Continuous Spectrum Colours

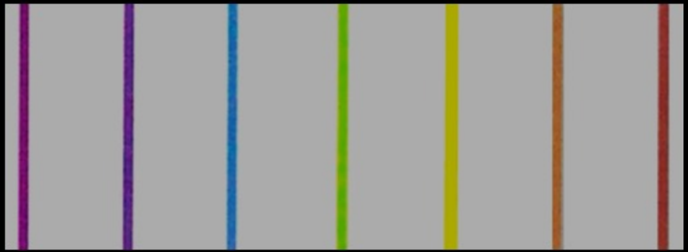


FIG 4 Emissions Spectrum

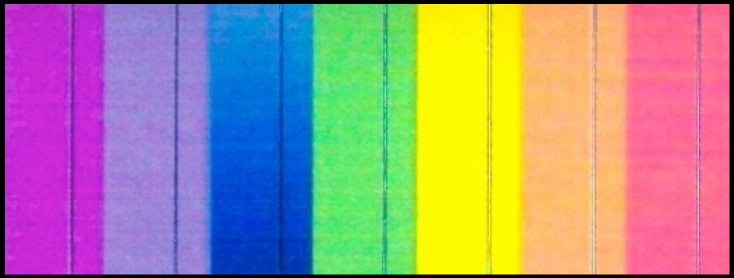


FIG 5 Absorptions Spectrum

The colours in spectrum are visible electromagnetic radiations with wavelengths from 380nm to 750nm, see FIG 6.

In 1900 year **Max Planck (1858-1947)**, a German physicist, theorized that the electromagnetic radiation is emitted by a hot body in certain quantities, quanta.

The light quanta are the photons.

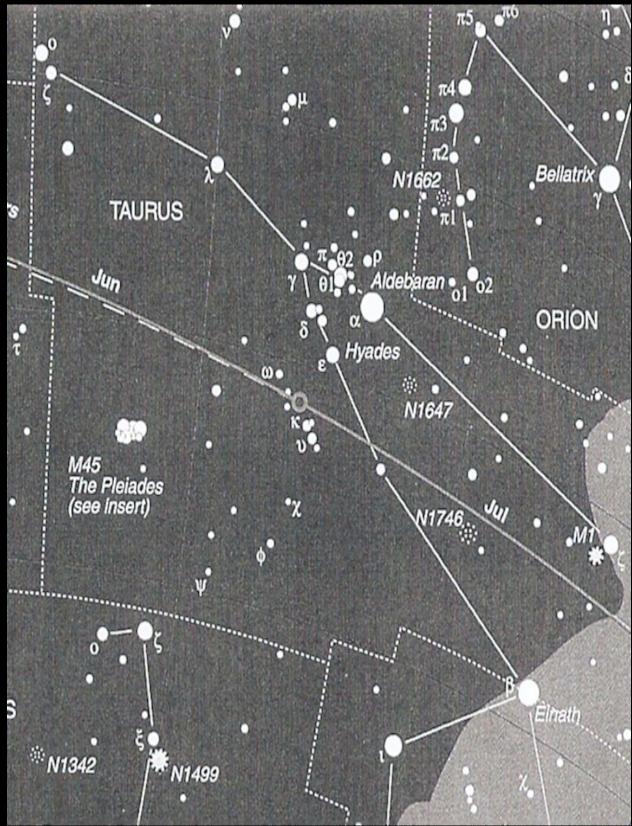
A spectral line is a bright line or a dark line in an otherwise uniform and continuous spectrum, resulting from an excess or a deficiency of photons in a narrow frequency range, compared with the nearby frequencies.

FIG 6 THE STARLIGHT SPECTRUM
WITH COLOURS WAVELENGTHS

The system of classification for stars based on the presence and strength of various types of absorption lines in their spectrum is called the *spectral type*.

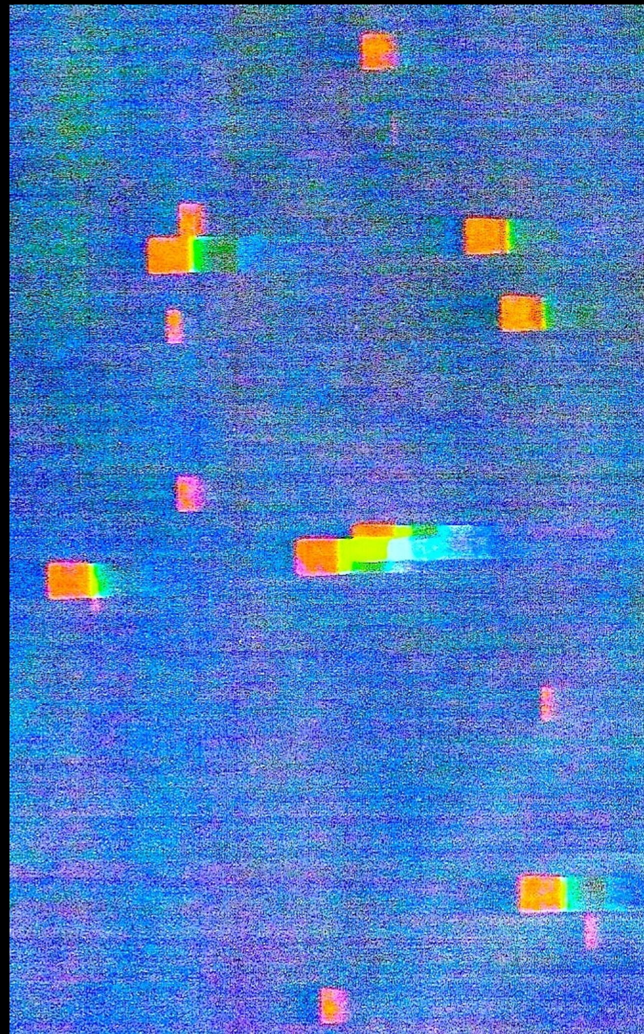
The large-angle telescopes of the astronomical observatories equipped with special prisms can take hundreds of star-spectrums simultaneously as photo images, see the photo with spectra of stars from the star cluster *Hyades* in FIG 7.

The Hyades (Greek Ὑάδες also known as Mellote 25 / Collinder 50/ Caldwell 41) is the nearest open cluster to the Solar System (151 light years) consisting of a roughly spherical group of 300-400 stars of same place of origin, chemical content, age, motion through space.
From the observers on Earth, the Hyades Cluster appears in the constellation Taurus.



STAR CLUSTER *HYADES*

FIG 7



SPECTRA OF STARS
FROM CLUSTER *HYADES*

The study of the spectrum of the light coming from a star gives us an abundance of information about that star like:

1. The relative position of the spectral lines gives information about the *chemical composition* of the external gaseous layer of the star, because the spectral lines of a specific element or molecule always occur at same wavelengths and for this reason we are able to identify which element or molecule is causing the spectral lines.

2. The chemical composition of a star indicates the star *age*. If a star contains a high percentage of elements other than hydrogen and helium, it is relatively young. Older stars contain few of these other elements. Our own star is middle-aged compared to other stars.

3. The *surface temperature* of a star can be estimated by studying its spectrum because the temperature determines the type and the number of present absorption spectral lines. Few lines will indicate a hot star, and many lines will indicate a cool star.

The surface temperature of a star is also indicated by its colour.
Blue stars are generally hotter, with temperatures around 50,000 K. Red stars are cooler at less 3,500 K. Our star, Sun, which is yellow, has a surface temperature around 5,500 K.

4. The intensity of certain spectral lines is a measure for the *absolute magnitude* of that star because the intensity of spectral lines show the abundance of respective elements in the light source, statistical correlations showing that the measured spectral line intensity is a function of the weight of material vaporised, more material more brilliant the star.

5. The *luminosity*

6. If the temperature and the luminosity of star are known can be simply calculated its *diameter,* the star diameters varying between few 100 million kilometres for the supergiants as *Betelgeuse* and few thousand kilometres for white dwarfs as *Sirius B*.

7. From the luminosity it is possible to obtain (extract) the *mass* because they are in relationship, bigger the mass higher the luminosity.
The masses of the stars do not vary too much, they are between tenth and ten times the mass of Sun.

8. Through the diameter of a star it is known its *volume* both having a big range of oscillation.

9. The *density* varies also correspondingly from hundred of thousandth of water density for giants to hundred of thousand times water density for white dwarfs and for neutron stars is even higher.

10. The spectral determination of the luminosity of a star allows us to determine its *distance from Earth* since ***Lambert Departure Law*** says that there is a double distance to a light-cell if its brightness becomes half, so it is possible to calculate how far is a star by knowing the absolute brightness in comparison to the apparent brightness.

11. The *velocity* (speed at which the star is moving relative to Earth) can be determined by taking the **Doppler Effect** into consideration. The Doppler Effect is a change in wavelength of the light relative to the observer. If the lines on a star's spectrum are shifted towards the red end of the spectrum, this means that the star is moving away from Earth. If the lines are shifted towards the blue end of the spectrum, the star is moving towards Earth. The velocity is indicated by the amount that the lines shift: a large shift indicates a greater speed.

12. The degree of extension of the spectral lines is a measure for the *speed of rotation* of a star around its axis. The rotation of a star causes the atoms on its surface to advance, retreat, or remain at a constant distance. This causes "smudges" on the spectrum, either towards the blue end or the red end. By measuring the width of these smudges, the scientists can determine the speed of rotation of a star.

13. The split of the spectral lines shows a strong *magnetic field.*

MODERN ASTRONOMY BEGINS…

The German poet Johann Wolfgang von Goethe (1749-1832) said in year 1790: "The idea of white light being composed of colored lights is quite inconceivable, mere twaddle, admirable for children in a go-cart."
The French philosopher Auguste Comte (1798-1857) was quoted as saying: "There are some things of which the human race must remain forever in ignorance, for example the chemical constitution of the heavenly bodies."
What is cited above was the essence of a general opinion.
When in the 19th century the scientists deciphered and proved the code of light, namely that the light coming from stars gives us information about the stars composition, they opened the gate to universe.
Since then for astronomers was accessible information contained in the light of stars and began an era like never before in science, when the scientists analysed, registered, classified hundreds of stars and on that

was created the basis for progress to the theory of the stars realized in the 20th century.
Almost all what is known today about different aspects of the stars is based on *Spectroscopy*, the analysis of light, but also of other radiations.

Isaac Newton (1642-1727) the genial English physicist, mathematician, astronomer, natural philosopher, alchemist and theologian of the 17th century placed himself near the earlier thinkers as the French Rene Descartes (1596-1650) proving that the white light unifies in itself all the colours of the rainbow.

William Wollaston (1766-1828) an English chemist, discovered in 1802 year that the Sun light does not form perfect spectrum, the spectrum is slashed by dark lines.

Josef von Fraunhofer (1789-1826) a young German optician in 1806 year seeking the best lens for telescope and other devices began the experiment of spectroscopy, the study of spectra, including the position and intensity of emission and absorption lines. In 1814 year he made one of the earliest studies of the absorption lines.

He installed a telescope in a dark room where he let the light fall through a narrow hole in the window blind, put a prism in the front of telescope and observed through the ocular that the resulting spectrum has a multitude of vertical, strong and weak dark lines, some appearing even perfectly black.

Those fine strips will be known in one day by any physics student as the *Fraunhofer Absorption Lines*.

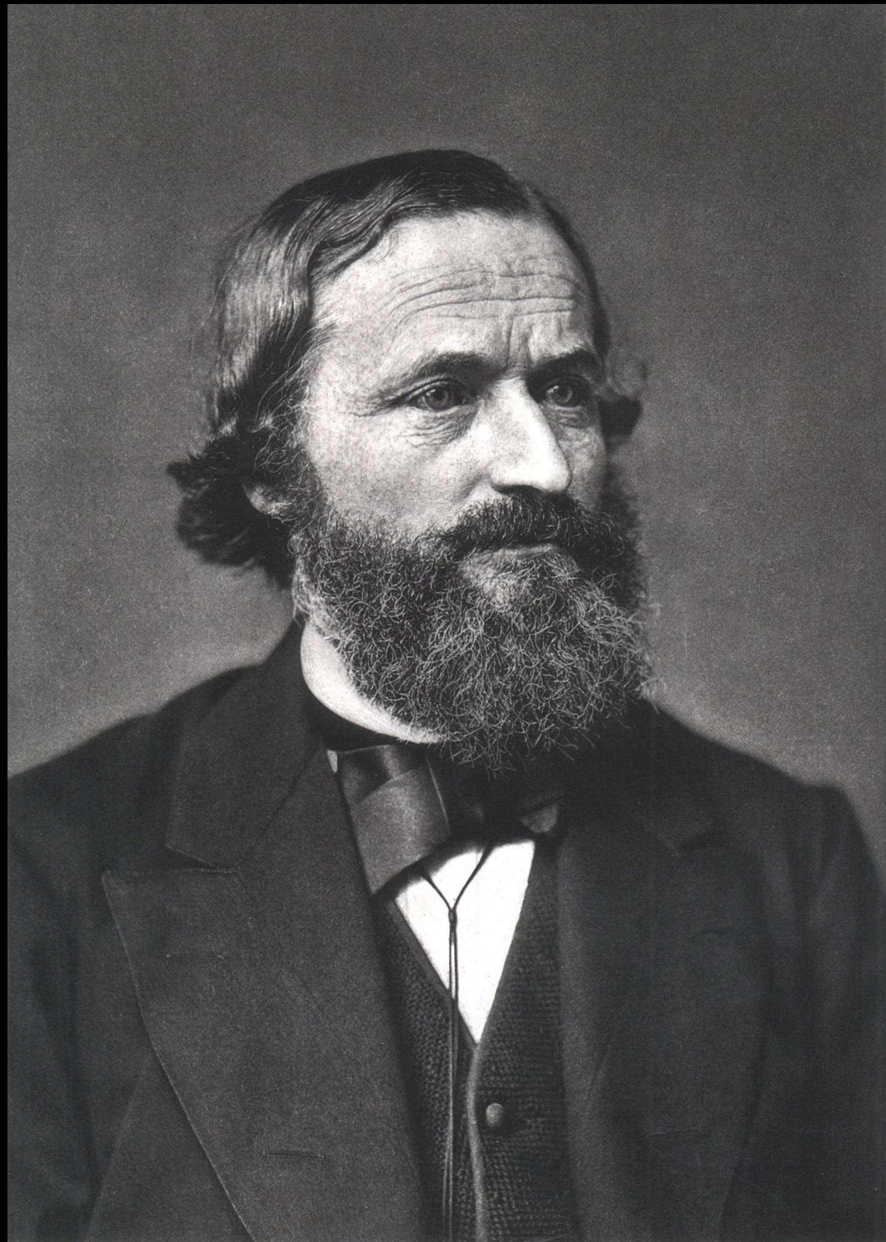
Then he directed the new instrument named the *spectroscope* to the Moon, Venus and Mars. The three spectra show the same order of lines like in the Sun spectrum and Fraunhofer deduced correctly that those heavenly bodies do not emanate their own light, they reflect the Sun light. When he directed his spectroscope to the Sirius and five other bright stars the spectral lines sample was for each star another and also different from the Sun sample, appearing that every star has its own spectrum sample, different each from other.

He discovered that the spectra of various stars have different black lines. He hypothesized that the dark lines were caused by the absence of certain wavelengths of light. Fraunhofer also invented a grate that gives a spectrum with much more detail than the prism.

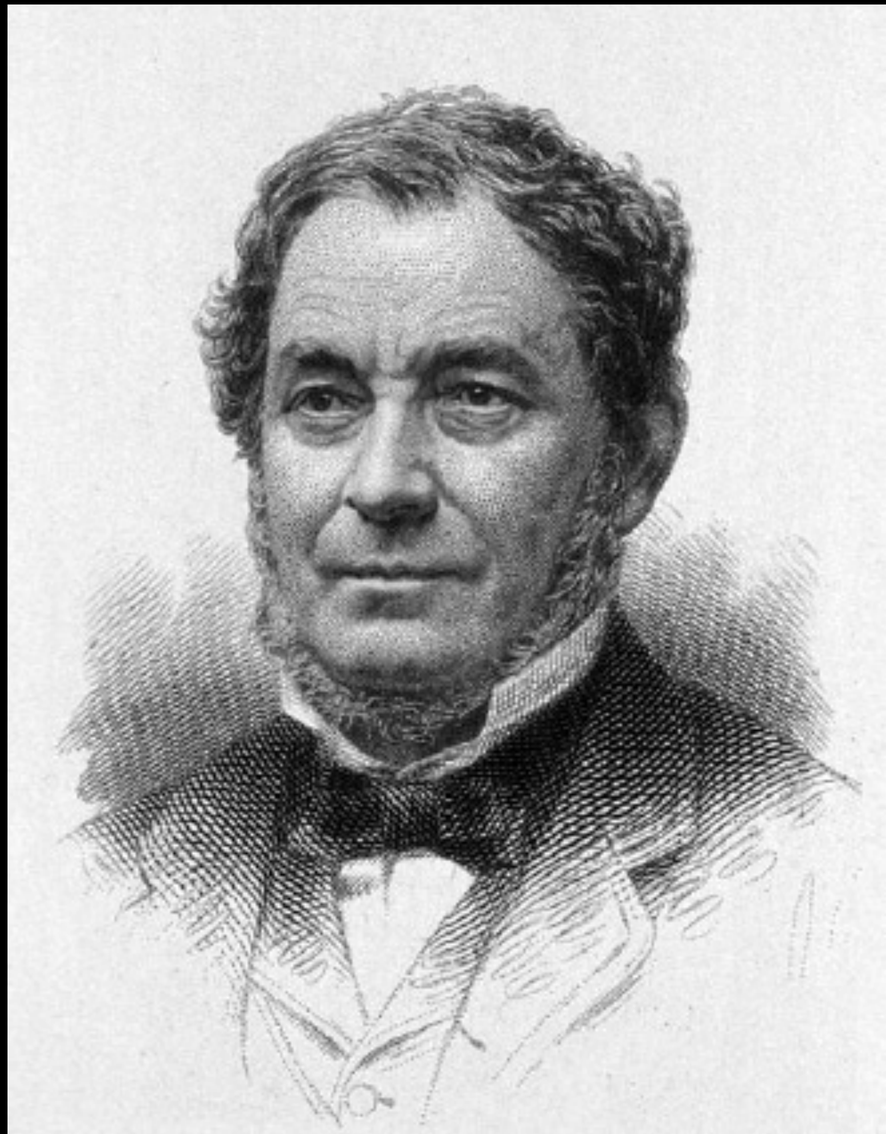
JOSEPH VON FRAUNHOFER

After Fraunhofer the scientists directed their search more on the bright than the dark spectral lines spending time more in laboratory than with the sky, work performed in many countries for three decades.

Gustav Kirchhoff (1824-1887) German physicist and **Robert Bunsen** (1811-1899) German chemist, did a deciding experiment in the year 1859 at the University of Heidelberg trying to identify chemical substances by their colour in the time of burning and directing the light from the burner through a spectroscope to better differentiation. So was proved that every chemical element when is burned as gas gives/shows an own typical sample (model) of bright *lines of emission* in its spectrum. Sodium, for example, delivers a pair of yellow lines that Fraunhofer observed in so many spectra because traces of this element are found in many substances. By spectral analysis, Bunsen and Kirchhoff determined the sample of the coloured emission lines for all then known elements. Parallel they studied the flames in the Sunlight. The *Fraunhofer Absorption Lines* of the Sunlight appear sharper and darker, obviously the gas taking more energy from the Sunlight than itself radiates.



GUSTAV KIRCHHOFF



ROBERT BUNSEN

Followed an astonishing conclusion:
light from the hot Sun or other stars passes through their colder atmosphere; there the gases, like sodium steam, absorb their characteristic colour from light and so appear in the spectrum of the light arriving on Earth the dark *Fraunhofer Lines*. On this basis they determined that in Sun atmosphere also there are big quantities of iron, calcium, magnesium, nickel and chrome. With the help of the new spectral analysis the astronomers began to collect (gather) plenty of new knowledge about the stars.

William Huggins (1824-1910) a rich Englishman was one of the most zealous astronomers.
He could publish in 1863 year with unique certainty:
"Although the stars differentiate themselves by the way they look, however all are built in the same way as our Sun and contain matter which at least partially coincides with the component elements of our solar system"
While men like Huggins revealed more and more star spectra other researchers developed more detailed systems to classify the spectral samples.
Soon was shown that the stars can be classified in more classes or categories based on their *brightness*, *colour* and *spectral difference,* those classes helping to see the degree of similarity of the stars.

Angelo Secchi (1818-1878) Italian, Jesuit and physicist, director of the Stars Department of Collegium Romanum in the course of five years examined the spectra of approximately 4000 stars overwhelming overlapped; however Secchi found enough similarity to classify them in four main spectral types function of their *colour,position, volume, number* and *darkness of the absorption lines* giving **first useful, advantageous classification of stars** in 1868 year.

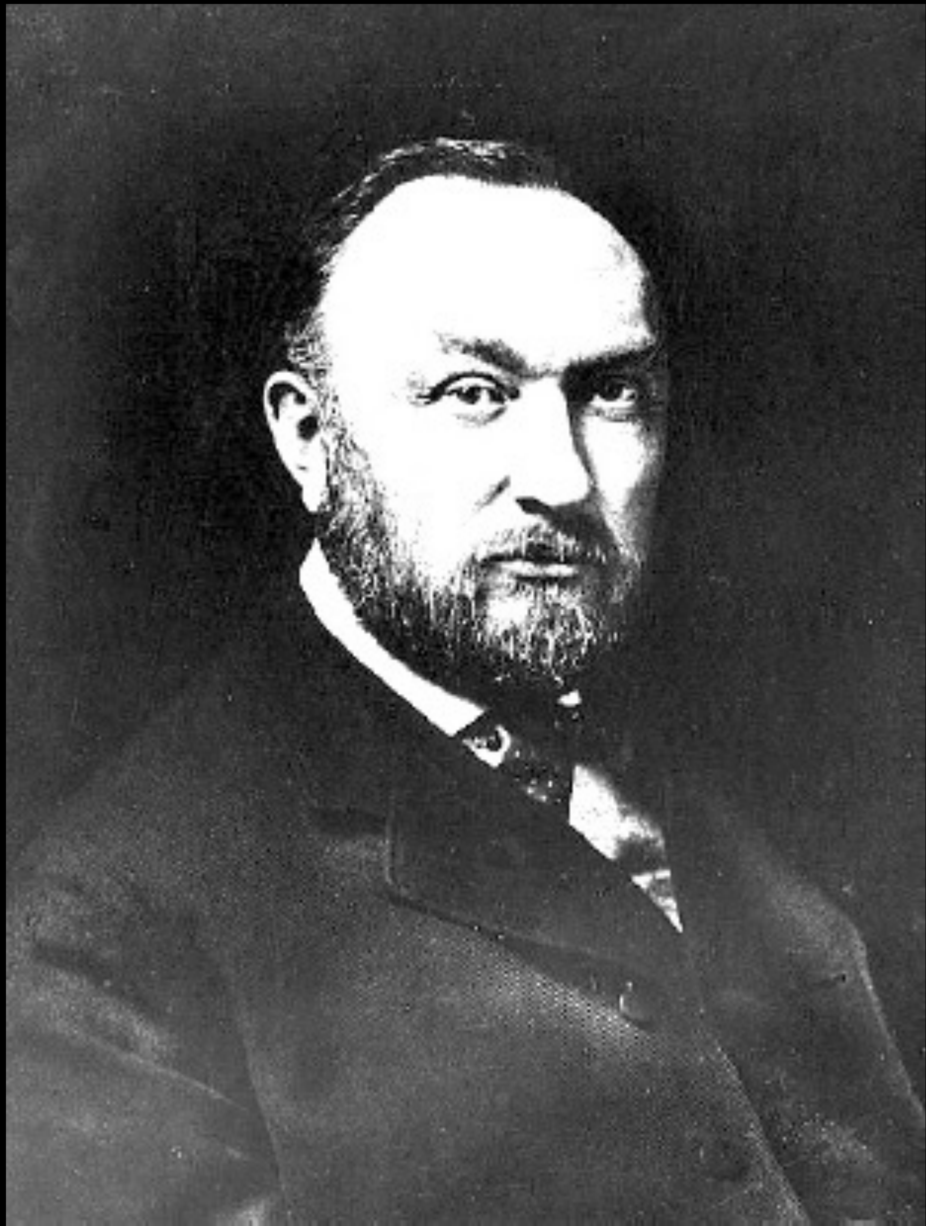
Henry Draper (1837-1882) a rich New York doctor and amateur astronomer was the first researcher to whom belong photographs of stars spectrums; already his father, also doctor and amateur astronomer, did the first photograph of Moon and one of the first photographs of the Sun spectrum.
In 1872 year Henry photographed the spectrum of the star Wega and went on to record the spectra of over eighty other stars using the *spectrograph*, basically a spectroscope gifted with camera.
Because of the sensitivity of the photo-plates towards the ultraviolet light the researchers could have pictures of the stars with so weak light that they are not observed with a telescope. And also they could notice radiations of wavelengths not visible for the human eye.

ANGELO SECCHI

HENRY DRAPER

In 1886 year his widow **Mary Anna Draper** set up a foundation in his honour; the aim of the foundation was to finance an ambitious programme for the spectrographic research and classification of the stars at Harvard College Observatory in Cambridge, Massachusetts, U.S.A. eventually published as the **Henry Draper Catalogue** ($400 000).

Edward C. Pickering (1846-1919) American astronomer and physicist, the director of Harvard College Observatory, had the idea of that project.
Pickering invented and equipped the large-angle telescope of the observatory with special objective prisms taking hundreds of star-spectra simultaneously on 20x25 cm size photo-plates like the photo with spectra of stars from the star cluster *Hyades* presented in FIG 7.
And to bring in order the plates that have gathered in the headquarters of the observatory at the outskirts of Cambridge, he employed a group of women.
After his opinion the women suit the best for tiring classifications and measurements.



EDUARD PICKERING

WOMEN COMPUTERS
AT HARVARD COLLEGE OBSERVATORY

FLEMING-MAURY-CANNON CLASSIFICATIONS

<u>**Williamina Fleming**</u> (1857-1911) immigrant Scottish teacher, Pickering's former housekeeper was the first leading assistant. Analysing photographic spectra which permitted fine divisions, the **Williamina Fleming project** together with **Pickering developed schema** extended and improved the old system of Secchi, which was based on the comparison of samples of spectral lines, assigning to the stars twelve types marked with letters *A–M* (without *J*), later completed with other types, *N O P Q R*, for new discovered stars or mixed spectra.

The first **Henry Draper Catalogue** was published in the year 1890, with 10,498 stars of the north half sky with a large fraction of work attributable to Fleming.

With the time, improved telescopes led to better wavelength resolution and some star types disappeared others merged.

The last **Fleming's Works** published under her name alone included her measurements of the apparent brightness of another 1400 stars as well as their spectral types.

Fleming examined all of the Harvard survey plates as soon as they were acquired, discovered 222 variable stars, 10 novae, and found in 1897 year the first spectrum of a meteor (published under Pickering's name).

Wlliamina Fleming was elected to honorary membership in the Royal Astronomical Society England.


WILLIAMINA FLEMING

Even before the first Draper Catalogue was published, Pickering had already identified other women to improve the Fleming-Pickering classification scheme for stellar spectra and put Antonia Maury to work on the stars of the Northern Hemisphere and Annie Jump Cannon to work on the stars of the Southern Hemisphere.

Antonia Maury (1866-1952) niece of Henry Draper, held in 1888 year the mandate for the second classification project; she was probably the most intellectually gifted of the three women. She studied at Vassar College , New York with professor **Maria Mitchell** and graduated in the year 1887 with honours in astronomy, physics and philosophy. She was the first female American astronomer. Although she had been employed to classify objective-prism spectra into a system defined by Pickering and Fleming, she set up her own system, which improved in two ways. First was a finer gradation by the temperature of stars; Maury was first to recognise that the temperature sequence must be O,B,A. Second she noticed that in some cases the spectral features were unusually hazy (her type low case b) and in other cases unusually sharp (her type low case c).

ANTONIA MAURY

These and other details that Maury recorded were regarded by Pickering as a waste of time, attributing them to the imperfection of instruments, and it was not until about 1907 year that Ejnar Hertzsprung who had independently discovered supergiants by another method, recognized the importance of Maury’s class c.
The own **Antonia Maury’s Catalogue** with the a, b, c characteristics and a variety of additional kinds of information including notes of composite spectra and emission lines, appeared in **Harvard College Annals** 1897.
Many of Maury’s b types were later recognized as rapid rotators, an interpretation she had herself suggested.
Maury was a pioneer in the investigation of spectroscopic binaries. Pickering had discovered the first of these, *Mizar*, from the doubling of its calcium K line in 1889. Maury found the second, *b Aurigae,* the same year and was the first to measure the orbital periods of both.
After 1892 year she was not longer formally employed by Harvard College Observatory but continued to analyse spectra, her work appearing periodically until 1935 year in the **Harvard Annals Bulletin**.
She was also a recognised ornithologist and naturalist.

Antonia Maury was the recipient of the Annie J. Cannon Prize of the American Astronomical Society.

Annie Jump Cannon (1863-1941) trained in physics and astronomy at Wellesley College and Radcliffe College, Massachusetts was Pickering's next assistant.
Appointed to the observatory staff in 1896 she spent her entire career there.
One of the most extensive efforts to classify the stars was Pickering's **Henry Draper Catalogue** which provides the positions, brightness and spectra of 225,300 stars.
An invaluable reference for astronomers covers the heavens from pole to pole for all stars brighter than the eighth magnitude, as well as many fainter stars and provides data on distances, distributions and motions.
Scientists investigating the colours, temperatures, sizes and compositions of stars frequently refer to the **Henry Draper Catalogue** for its spectral information.
The development of the catalogue was a colossal challenge with nearly a quarter of million stars to be classified. Pickering chose Annie Jump Cannon as principal investigator for the project.

In that capacity , she not only identified, recorded and indexed the data on the stars but also supervised the publication of all nine volumes in the year 1918.
Cannon personally examined every single one spectrum.
Cannon revised the symbols used for the spectral types and reordered the classes in a more specific and subtle terms of decreasing surface temperature classifying the stars function of their *colour* – from blue through white, yellow to red. The main classes of the spectrum had only the sequence O B A F G K M and the letters of the sequence had a decimal division that gave to system a new precision. Sun, for ex. has the spectral class G2.
She devised the Draper classification scheme which was used in her **own Catalogue of the Spectra of 1122 Stars** and adopted internationally.
The Henry Draper catalogue together with Annie Cannon classification system became standard works in astronomy.
Cannon's contribution in the field of spectroscopy was unsurpassed in quantity. Probably no other single observer in the history of science gathered so a great mass of data on a single system.

ANNIE JUMP CANNON

Cannon examined photographs of the stars near the South Celestial Pole for years and throughout her career she classified one-third of million stars and discovered more than 300 variable stars, 5 novae and many stars with peculiar spectra. Cannon believed that patience not genius was responsible for her success.

Cannon won many honors for her work:

- Henry Draper Medal - for notable investigations in astronomical physics
- William Cranch Bond Astronomer - for her distinguished service at Harvard College Observatory
- Ellen Richards Research Prize
- Doctor in Science degree - Oxford University first woman in 600 years history
- Doctor in Law - Wellesley College
- Honorary degree - University of Groningen, Netherlands
- Honorary degree - University of Delaware
- Honorary degree - Oglethorpe University
- Honorary degree - Mount Holyoke College
- Honorary Member - Royal Astronomical Society England
- A Moon crater was named in her honor

She endowed the **Annie j. Cannon Prize** of American Astronomical Society.

FLEMING-MAURY-CANNON CLASSIFICATIONS are the result of a wonderful work in describing and ordering hundreds of thousands stars performed by **Williamina Fleming, Antonia Maury, Annie Cannon**. **They built the backbone of the modern astronomy**. **Only by their work were found connections**, **relations between different features of stars**.

Those connections/relations were developed and revealed short after the turn of the 20th century, in a genial diagram by two astronomers from both sides of the Atlantic Ocean, independent one from another, the Danish Ejnar Hertzsprung and the American Henry Norris Russell. It was the **HERTZSPRUNG–RUSSELL DIAGRAM**. *It owes its creation / apparition first of all to the underestimated work of Antonia Maury*. To her was conspicuous that the relative width and darkness of some lines in spectrum come from stars of same colour and spectral class and for that she built the subgroups **a**,**b**,**c**. The **c** subgroup especially, waked the interest of the Danish astronomer Ejnar Hertzsprung.

HERTZSPRUNG-RUSSELL DIAGRAM

Ejnar Hertzsprung (1873-1967) was a Danish chemical engineer, who from the chemical process of photography came to star photography and from that to astronomy. From 1909 year he worked at the observatories of Gottingen, Potsdam, Leiden.

In 1905 and 1907 he published two papers both entitled "Zur Strahlung der Sterne" (On Radiation of Stars) in a journal for scientific photography, in which he had used stellar colours determined from his own work and distances estimated from proper motions to show that stellar brightness particularly for the cool stars came in two groups which he called "Riesen"-giants and "Zwerge"-dwarfs.

He concluded from his observations that the *luminosity* of a star is in relation with the *spectrum* and the *temperature* of that star, namely in the way that cold red stars in the same time have the lowest brightness.

Hertzsprung recognition of very bright supergiants in 1905 year served to validate the spectroscopic criterion ("c trait") identified by Antonia Maury and denied by Edward Pickering.

In 1908 he sent a letter to Harvard College Observatory informing Pickering about the new subgroups, hurrying him to consider his new subgroups in the Henry Draper classification. Pickering remained unimpressed.

KARL SCHWARZSCHILD & EJNAR HERTZSPRUNG

In 1911 year the Danish astronomer Ejnar Hertzsprung plotted the absolute magnitude of stars against their colour in what became known as colour-magnitude diagram for the Hyades star cluster; the most of the stars arranged themselves in a narrow band marked by Hertzsprung as *Main Sequence* with the bright, blue stars left and the dark, reddish stars right; the exception were the red giants which built an own group. Hertzsprung carry out astronomical work until about three years before his death, including determination of brightness of stars and their colours by photography, discovery of the variability of Polaris, study of Pleiades and Hyades clusters, estimation of the distance to the Large Magellanic Cloud and measurement for orbits of binary stars.

His work was recognized by:

- honorary degrees from Utrecht, Copenhagen, Paris
- Bruce Medal of Astronomical Society of Pacific
- Darwin Lectureship and Gold Medal of Royal Astronomical Society London
- Ole Romer medal awarded by city of Copenhagen

Henry Norris Russell (1877-1957) was an American astronomer with studies at Princeton University New Jersey U.S. and Cambridge University England. For his contribution to exploration and research of the universe was named “Decan of the American Astronomy”. Starting with his initial work at Cambridge University on the determination of stellar distances, Russell began to assemble data from different classes of stars observing that these data relate spectral type and absolute brightness.

Russell knew that the stars with the same temperature (which from spectrum is stated) give the same quantity of radiation per square kilometre of their surface and the American searched to find a relation between the temperature and the brightness of a star.

Also when a weaker and a brighter star at equal distance from Earth show the same temperature then must be the weaker star smaller than the brighter star.

Independently of Hertzsprung but using similar methods, Russell determined the distance from Earth for more stars and by that he could determine their absolute brightness.

HENRY NORRIS RUSSELL

Soon he concluded that were actually two general types of stars: giants and dwarfs.
In 1910 year the astrophysicist Karl Schwartzchild introduced him to Ejnar Hertzsprung.
In 1913 year Russell also represented the result of his research graphically for stars whose spectral classes were known and which were not in clusters but so nearly that their distances and thus their absolute brightness could be determined. He plotted the spectral classes of stars – sequence O B A F G K M from Harvard – which give also the colour and the temperature of the stars against their absolute magnitude.
His diagram also showed the distinction between the giants and main sequence stars like Hertzsprung's colour-magnitude diagram, looking like Hertzsprung's but rotated 90 degrees clockwise. The two diagrams have the same topography and collectively are known as the **Hertzsprung – Russell Diagram or H – R Diagram**.
By an accident of history an apparently independent parallel study of the relation between brightness and spectral type in the Pleiades star cluster was undertaken by **Hans Rosenberg** of Gottingen whose overlooked paper contained the first published H–R diagram in June 1910.

Until the apparition of the H-R diagram, the most astronomers assumed that the stars development follows the spectral sequence, namely each star begins hot and blue-white and ends cool and red, considerations possible thanks to the classification system developed by Antonia Maury, Annie Cannon and others from Harvard. Against, Russell proposed that both types of red stars giants and dwarfs, he and Hertzsprung found, represent the first respectively the last step in the life cycle of a star, each star beginning its presence as red giant of spectral class M, then contracts and heats itself, runs down the entire diagonal in H-R Diagram and ends as cold, red dwarf again in class M, conclusion known as premature. Russell was engaged in research work including eclipsing binaries and detailed analysis of Sun's spectrum. He postulated that most stars exhibit similar general combination of relative elemental abundances (dominated by hydrogen and helium) that became known as "Russell mixture".

Russell was an accomplished teacher and coauthor of **Astronomy** and author of **Solar System and Its Origin**, excellent text books which served as a guide for future research in astronomy and astrophysics.

Russell received recognition from more organizations:

- Gold Medal - Royal Astronomical Society England
- Henry Draper Medal - US National Academy of Sciences
- Rumford Prize - American Academy of Arts and Sciences
- Bruce Gold Medal - Astronomical Society of Pacific

Hertzsprung–Russell Diagram is one of the most useful / powerful plots in astrophysics. Its usefulness comes from how it illustrates the many different types of stars in one glance and is remarkable in how it essentially creates a graphical way to represent the stellar complexities in one simple plot.

The Hertzsprung–Russell Diagram is a graph displaying the characteristics of any star. It provides essential clues for the evolution of stars and has been a valuable tool in determining the distances of those stars beyond the reach of parallax measurements.

Accurately, the horizontal axis should display the effective temperature / colour / spectral classes of stars and the vertical axis should display the luminosity / brightness of stars.

In surface temperature the range is from 2,200 K to 60,000 K, in colour the range is from bluest through white, yellow to red and in spectral classes the range is seven - O B A F G K M - easy to remember by the phrase: "Oh, Be A Fine Guy/Girl: Kiss Me."

In luminosity the range is $(10^{-5}...10^{6})L_{sun}$ and in absolute brightness the total range is 27M [(+19..–8)M].

The brightest stars appear at top of the H-R diagram, the vertical axis having the most negative value of B at top.

The outcome is not a random scattering of points, the stars populating very specific regions of the diagram and that gives clues about their physical nature and their stage of evolution.

Computer models can reveal how the luminosity and the surface temperature of a star change as it evolves.

Equal of what stars are plotted in a H-R diagram, see version of FIG 8, it shows that the stars are not distributed uniformly but concentrated manly in four regions:

1. A band well populated (~90% of stars) running diagonally from high luminosity, hot surface temperatures to low luminosity, cool surface temperatures, named *Main Sequence* (most stars of Sun size)

2. A very high luminosity region scarcely populated at top of diagram with extremely large stars, called *Supergiants*

3. A region with stars of luminosities between those of the supergiants and those of the main sequence stars, termed *Giants* (stars of Earth orbit size)

4. A region with stars, small but hot, termed *White Dwarfs* (stars of Earth size)

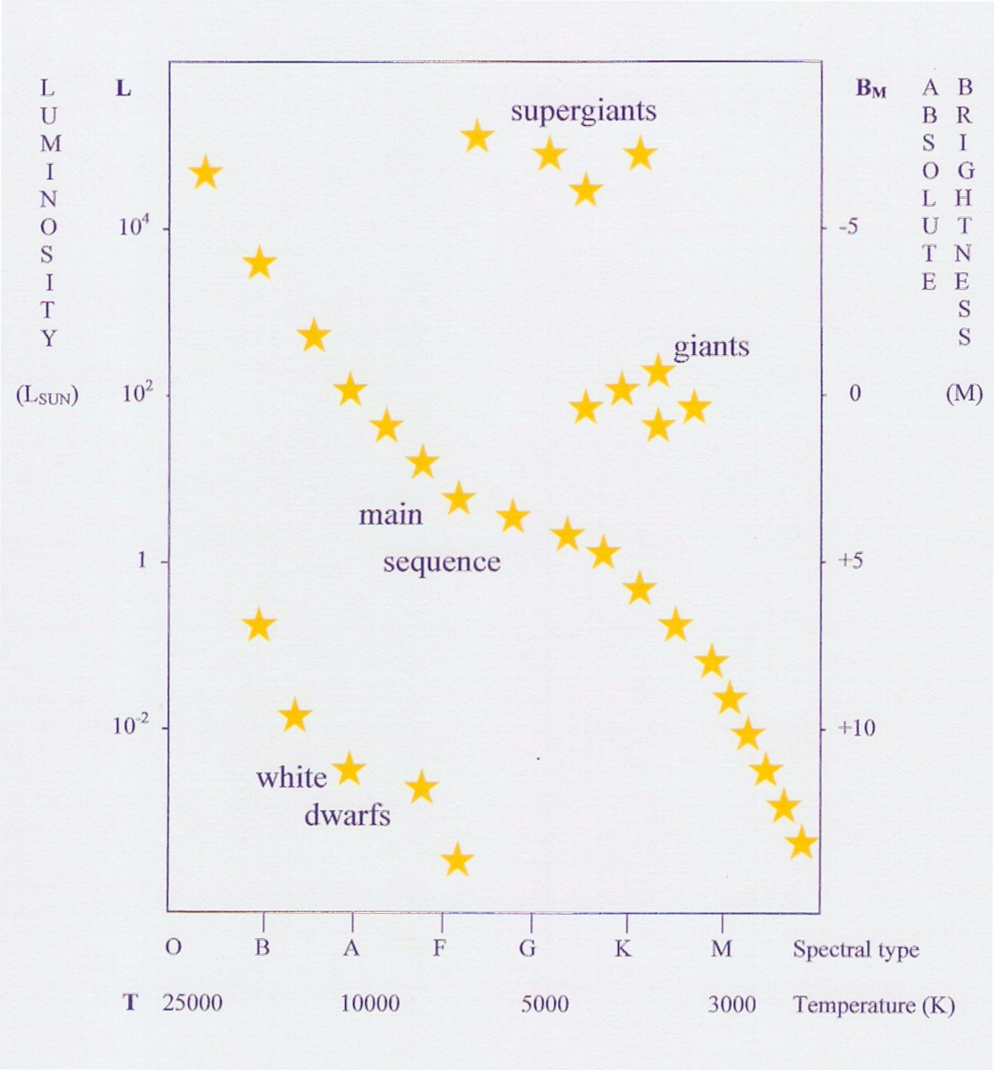


FIG 8 H-R DIAGRAM

The modern theorists say that is hard to believe that the stars travel the main sequence, but they have a place depending on their mass. The mass decides also when a star leaves the main row. The stars which are rich in mass are also hot and very bright corresponding to the blue colour and the pattern of their spectral lines are the O and B stars. In their centre has place the fusion process of high delivering energy. In the course of their storm-like development they use fast their matter, leave the main sequence and swell up in giants and supergiants building groups in the right upper corner of diagram. Massive stars can end their lives in *Supernova* explosions, which leave behind *Neutron Stars* or *Black Holes*; as they are detected at non-visible wavelengths they are not represented on the H-R diagram. The yellow stars of middle mass like our Sun belong to the middle part of the main sequence, are colder and less bright then O and B stars, consume their matter slower and remain milliards of years on the main sequence before they swell up in giants, finally contracting in white dwarfs. The stars which remain on the main sequence, are cold, weak lighting M stars, red dwarfs, with small mass which use their fuel sparingly, their estimated life spans longer than the estimated age of the universe.

The H-R Diagram version from FIG 9 illustrates that for the stars on the *main sequence*, the diameter hangs together with the temperature and the luminosity.
The hot, luminous, blue stars upper-left are also the biggest; the massive, bright, yellow stars like our Sun are accordingly smaller; and the cool, faint, red stars are the smallest bodies, the dwarfs of the main sequence; the statistics show that stars fainter than Sun are far more numerous than those brighter than Sun.
However a minority of stars *off* the main sequence, has high temperature but small diameter and low brightness; they are the *white dwarfs*, in general hotter than Sun but having a small surface light much weaker; vice versa are red *giants* and many *supergiants* mostly not hotter than Sun but millions times brighter because their diameter rises up to 1000 times above that of Sun.

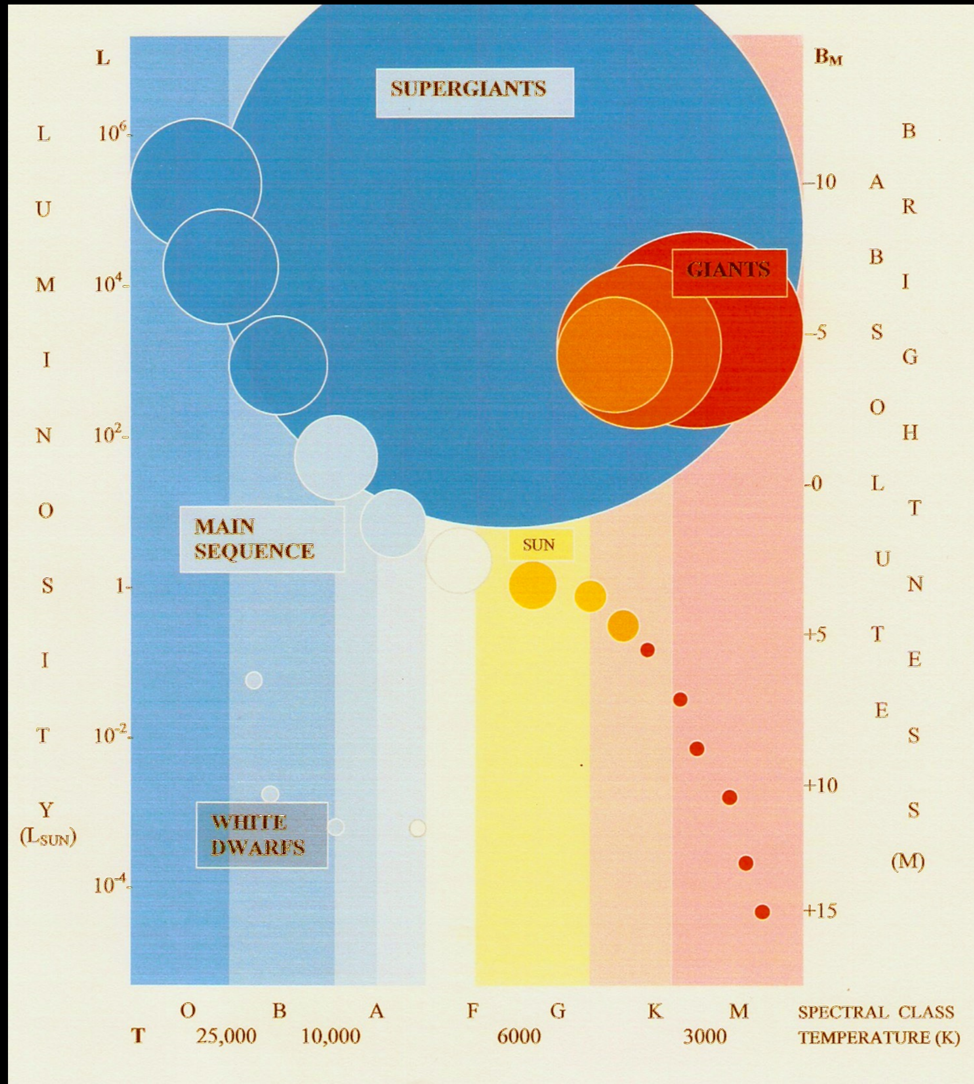


FIG 9 H-R DIAGRAM

The H-R Diagram for 20 brightest stars in the sky and a few fainter, nearby stars (such as Barnard's star and Kapteyn's star) is given in FIG 10 .

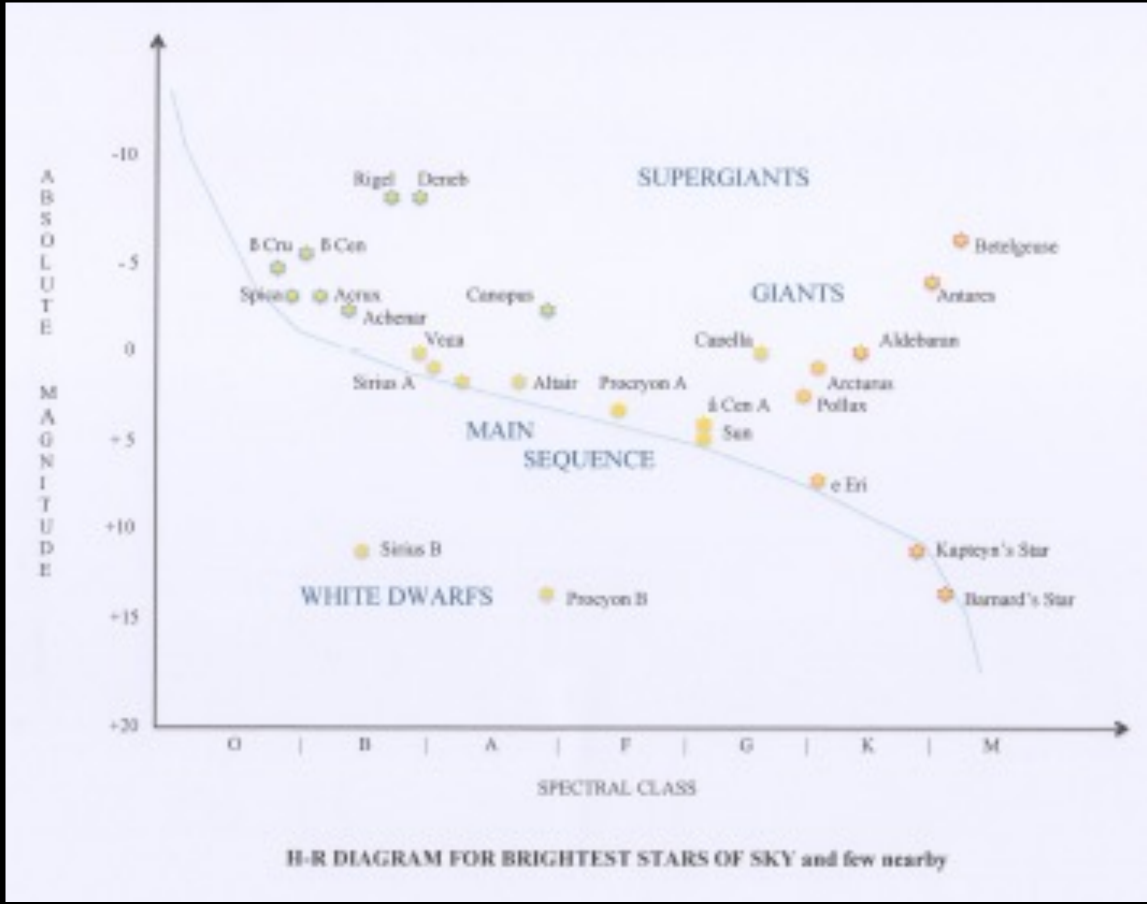


FIG 10 H-R DIAGRAM

STARS OF MAIN SEQUENCE

PROPERTIES

COLOR	CLASS	MASS $\mu_{sun}=1$	RADIUS $R_{sun}=1$	TEMPERATURE K	MAIN LINES
bluest	O	20 - 100	12 - 25	40 000	ionized He
bluish	B	4 - 20	4 - 12	18 000	neutral He neutral H
blue-white	A	2 - 4	1.5 - 4	10 000	neutral H
white	F	1.05 - 2	1.1 - 1.5	7 000	neutral H ionized Ca
yellow-white	G	0.8 - 1.05	0.85 - 1.1	5 500	neutral H very ionized Ca
orange	K	0.5 - 0.8	0.6 - 0.85	4 000	neutral metals (Ca Fe) ionized Ca
red	M	0.08 - 0.5	0.1 - 0.6	3 000	molecules neutral metals

REFERENCIES

- REISE DURCH DAS UNIVERSUM - VON DER REDAKTION DER TIME-LIFE BUCHER AMSTERDAM
- MEDIA RELEASE INFORMATION - CSIRO
- ASTRONOMY 2011 AUSTRALIA
- THE PHYSICS FACTBOOK
- THE DATA BOOK OF ASTRONOMY - PATRICK MOORE
- A TO Z OF SCIENTISTS IN SPACE AND ASTRONOMY - DEBORAH TODD, JOSEPH A. ANGELO JR.
- ENCYCLOPEDIA OF ASTRONOMY AND ASTROPHYSICS - PAUL MURDIN
- PHILIP'S ASTRONOMY ENCYCLOPEDIA - PATRICK MOORE
- THE ILLUSTRATE ENCICLOPEDIA OF THE UNIVERSE - IAN RIDPATH
- HISTORY OF ASTRONOMY - AN ENCICLOPEDIA - JOHN LANKFORD
- BIOGRAPHICAL ENCICLOPEDIA OF ASTRONOMERS - THOMAS HOCKEY
- THE SAO ENCYCLOPEDIA OF ASTRONOMY
- THE FACTA ON FILE - DICTIONARY OF ASTRONOMY - JOHN DAINTITH & WILLIAM GOULD
- THE ENCICLOPEDIA OF SCIENCE
- WIKIPEDIA

- H–R DIAGRAMS:

RICHARD POWELL - STARS PLOTTED FROM HIPPARCOS AND GLIESE CATALOGUES,
A. FRAKNOI & D. MORRISON & S. WOLFF - VOYAGES THROUGH THE UNIVERSE, C.J. PETERSON

- PHOTOGRAPHS:

AIP EMILIO SEGRE VISUAL ARCHIVES, DORRITT HOFFLEIT YALE UNIVERSITY OBSERVATORY,
MARGARET RUSSELL EDMONSON COLLECTION, AMERICAN INSTITUTE OF PHYSICS, SKY GUIDES,
WIKIMEDIA COMMONS, HERMANN KNIERIEM AFW, ARCHIV KUNST UND GESCHICHTE BERLIN