BASICS OF ASTRONOMY

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June 2020

1 INTRODUCTION

Astronomy is one of the most comprehensive and challenging science.It consist of observational and theoretical astronomy.Observational astronomy is a division of astronomy that is concerned with recording data about the observable universe, in contrast with theoretical astronomy, which is mainly concerned with calculating the measurable implications of physical models.

Theoretical astronomy is the use of the analytical models of physics and chemistry to describe astronomical objects and astronomical phenomena.

Topics studied by theoretical astronomers include:
1.Stellar Dynamics and Evolution
2.Galaxy Formation
3.Large-scale structure of matter in the Universe
4.General Relativity and Physical Cosmology
It is an exciting field requiring a strong grip in maths and physics but most importantly astronomy.
I will try to cover all of them to the best of my ability in the material provided online.

Let's take a brief look on the other interesting aspect of it. Observational astronomy is a division of astronomy that is concerned with recording data about the observable universe.This field uses sensitive equipment which study the different properties of celestial bodies. The information is later used to understand and form theories.

The sub-parts of observational astronomy are:

1. Optical astronomy is the part of astronomy that uses optical instruments to observe light from near-infrared to near-ultraviolet wavelengths. Visible-light astronomy, using wavelengths detectable with the human eyes falls in the middle of this spectrum.

2. Infrared astronomy deals with the detection and analysis of infrared radiation . The most common tool is the reflecting telescope, but with a detector sensitive to infrared wavelengths. Space telescopes are used at certain wavelengths where the atmosphere is opaque, or to eliminate noise (thermal radiation from the atmosphere).

3. Radio astronomy detects radiation of millimetre to decametre wavelength. The receivers are similar to those used in radio broadcast transmission but much more sensitive.

4. High-energy astronomy includes X-ray astronomy, gamma-ray astronomy, and extreme UV astronomy.

5.Occultation astronomy is the observation of the instant one celestial object occults or eclipses another. Multi-chord asteroid occultation observations measure the profile of the asteroid to the kilometre level.

2 TOPICS TO STUDY

1. Luminosity,Age,Mass,Temperature

2. Stellar Spectra and Spectral Lines

3. Photometry

4. Stellar coordinates

5.Distance: parallax, apparent and absolute magnitudes

6.The Hertzsprung-Russell Diagram and spectral classification

2.1 Parallax

Parallax is the displacement in the apparent position of an object viewed along two different line of sights. It is the procedure of effectively measuring the distance to any stellar object. Let us discuss four different types of parallax.

Dynamical Parallax
Photometric Parallax
Spectroscopic Parallax
Stellar Parallax

Dynamical Parallax - An estimate of the parallax of a visual binary for which the period and semimajor axis have been obtained. The semimajor axis in astronomical units is derived from Kepler's third law by assuming a value for the total mass of the system based on the stars' spectral types.

Photometric Parallax - The distance of a star as inferred from its position on the lower main sequence, where colour and absolute magnitude are tightly correlated by the colour–magnitude relation. If the colour is known, the absolute magnitude may be inferred. The difference between the apparent magnitude, m, and the absolute magnitude, M, is related to the parallax, , in seconds of arc by the formula

$$log\pi = 0.2(M - m - 5) \quad (1)$$

Spectroscopic Parallax - The spectroscopic parallax technique can be applied to any main sequence star for which a spectrum can be recorded. The method depends on the star being sufficiently bright to provide a measurable spectrum. One must measure the apparent magnitude of the star and know the spectral type of the star. If the star lies on the main sequence, as determined by its luminosity class, the spectral type of the star provides a good estimate of the star's absolute magnitude.

Stellar Parallax - At this point we will be only using the triangulation method of this parallax.

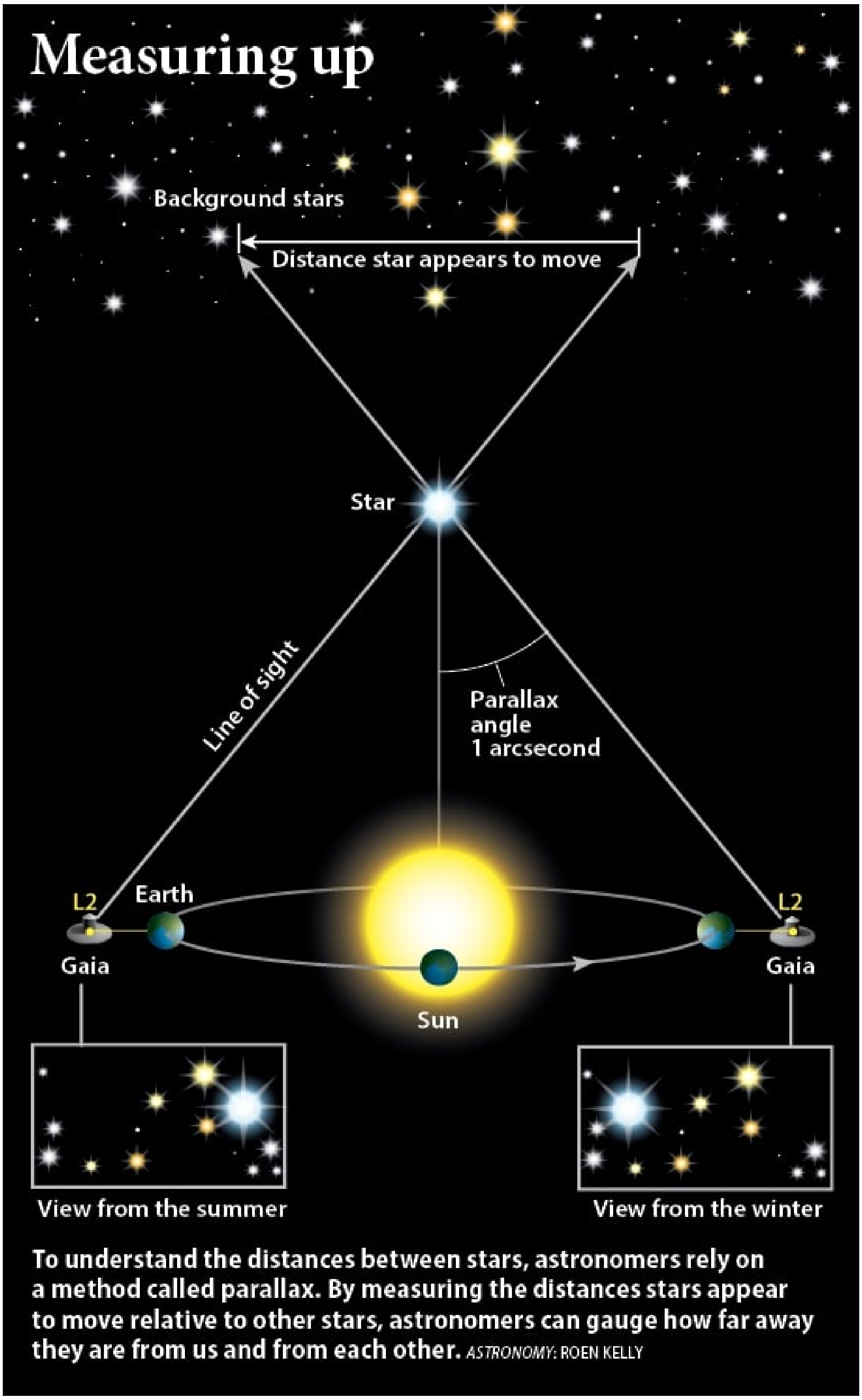

Figure 1: Stellar Parallax.
(Source : Astronomy Magazine)

$$1\ AU = 1.49 \times 10^{11} m \qquad 1\ parsec = 3.08 \times 10^{16} m \tag{2}$$

$$tan\theta = \frac{d}{r} \tag{3}$$

2.2 Luminosity

Stellar Luminosity or in this case luminosity is the total output energy of a star per unit time.In simpler terms it is the power of a star.The power output across all wavelengths is called as bolometric magnitude.

Its apparent brightness or flux is the total energy received per second on each square meter (or square centimeter) of the observer's telescope.If a star shines with the same brightness in every direction we can use the very famous inverse-square law.

$$F = \frac{L}{4\pi d^2} \tag{4}$$

F is flux
d is distance to the star

A star is a blackbody therefore for calculating the luminosity we can use Stephan-Boltzman σ constant in an effective formula.

$L = 4\pi R^2 \sigma T^4$

R is the radius of the star
T is effective temperature(the temperature at which a black body with same radius emits the same energy).

Now as mentioned above different sections of observational astronomy are based upon the tapping of information in different wavelengths and frequencies. Therefore, we also determine the flux of a star in different wavelengths and frequencies.Flux per unit wavelength is defined as $F(\lambda)(\Delta\lambda)$ between λ and $\lambda + \Delta\lambda$.

On the other hand we have flux per unit frequency $F(\nu)(\Delta\nu)$ between ν and $\nu + \Delta\nu$.Radio astronomers measure flux w.r.t. frequency in Janskys.

$$1Jy = 10^{-26} Wm^{-2} Hz{-}1 \tag{5}$$

$$F = \int_0^\infty F d\nu = \int_0^\infty F d\lambda \tag{6}$$

2.3 Temperatures

Stars are complex bodies. But we can analyse some of their properties by adopting a model and in the case of temperature we adopt that of a black-body.

Now blackbody is a term we use for the relationship between an object's temperature and the wavelength emitted by it. A black body(BB) is an idealized object that absorbs all electromagnetic radiation it comes in contact with. It then emits thermal radiation in a continuous spectrum according to its temperature.

Stars behave like black bodies approximately.

Therefore the wavelength emitted by one star is different to other (if T differs) leading the stars to have such different colours.

Being a black body two laws will follow 1. Stephan-Boltzman Law 2. Wien Law

1. Stephan-Boltzman Law - This law describes how the power radiated by a BB is related to the temperature of it. It states that energy emitted per unit time per unit surface area is directly proportional to fourth power of temperature

$$P = \sigma \times T^4 \qquad \sigma = 5.67 \times 10^{-8} K^{-4} Wm^{-2} \tag{7}$$

Radiance - watts per square metre per steradian

$$L = (\sigma * T^4)/\pi \tag{8}$$

2. Wien law - Wien's law states that the black body curve of an object will peak at different temperatures for different wavelength. λ max = W/T (where W is a constant = 2.898×10^{-3} for T in kelvins and λ max in nm)

2.4 Mass and Age

The various stellar stages of a star is affected by age that effects the mass of the star creating end proucts as bizarre as black holes,neutron stars and white dwarfs. Well they may sound interesting but we will not discuss them in depth until we acquire the required mathematics and physics.

Here we will discuss in depth measures and theories taken in consideration to assign right quantitative values to both. Let's clear one thing the different parameters are derivable but only for limited stars. Stellar ages are critical to establish for investigations such as the time scales involved in the formation and long term evolution of planetary systems.

Astronomically speaking planets are a hell lot closer to one another in solar system than to stars in the universe.We measure the mass by taking up a COM b/w sun and a planet. Laws of Motion and Gravity from Newton and Kepler that relate orbital speeds and orbital sizes to the masses of objects in bound systems help.But for stars far away we use the method of binary systems and we are lucky that half of the stars are in binary or multiple systems.

Types of binary systems:
1. Optical Double : These are not actual binaries but appear to be so ,as they lie in the same line of sight.The stars are not gravitationally bound therefore we cannot determine the mass.

2. Visual Binary : The stars can be resolved independently and if the orbital period is not prohibitively long,it is possible to track down the motion of each star. Even the linear distance b/w two can be known if distance to the system is known.

3. Astometric Binary : There are many cases in which one star is significantly brighter than the other. So an indirect approach of is used (oscillating system)(velocity cannot be affected until an external force acts).

4. Eclipsing Binary : One star overshadowing the other happens when the orbital planes are along line of sight. One star may periodically pass another blocking out the light. Light curves reveal the presence and data also provides relative effective temperatures and radii of each star based on the depths of the light curve minima and lengths of the eclipses.

5. Spectrum Binary : It is a system which cannot be resolved into separate light sources and the spectra is blended or superimposed, independent and discernible. The Doppler effect causes the spectral lines of a star to be shifted from their rest frame if the star has a radial velocity.The COM of stars move with constant velocity therefore the line of Star1 being blueshifted and

of Star2 being redshifted. In case the shifts are not significant (as in perpendicular orbital planes) then also we can detect if the fused spectra originates from the stars that have significantly different spectral features.

6. Spectroscopic Binary: In this a periodic shift in spectral lines will be observed. If one star is more luminous only one set of spectral line shift will be observed. It occurs in systems having orbital motion component along the LOS and short period.

Point to be noted that the classification is not mutually exclusive. It may happen a system is eclipsing as well as spectroscopic. Some may be more useful than others. Three types of star systems provide us with mass determination information: visual binaries,spectroscopic binaries(especially double-line) and eclipsing binaries.

2.5 Determining Mass

Let us discuss mass determination. Consider two stars with a center of mass and orbital plane being perpendicular to the LOS.

$$\frac{m1}{m2} = \frac{r2}{r1} = \frac{a2}{a1} \tag{9}$$

a2 and a1 are semi major axes of their respective eclipses
In terms of angular distance

$$\alpha 1 = \frac{a1}{d} \qquad \alpha 2 = \frac{a2}{d} \tag{10}$$

Therefore,

$$\frac{m1}{m2} = \frac{\alpha 2}{\alpha 2} \tag{11}$$

$$\nu = \frac{m1m2}{m1 + m2} r1 = \frac{-\mu r}{m1} r2 = \frac{\mu r}{m2} \tag{12}$$

$$r = \frac{a(1 - e^2)}{1 + ecos\theta} \tag{13}$$

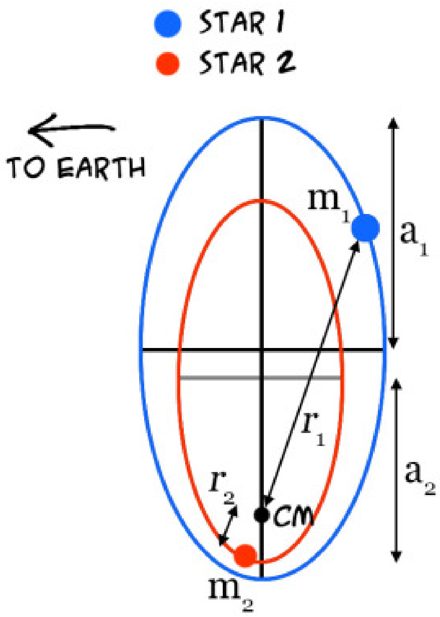

Figure 2: An image of total eclipsing and partial eclipsing binary. The smaller star is hotter.

(Reproduced from quantumredpill)

Clearly the minimum separation occurs when $\theta = 0$ and the denominator has its largest value, and the maximum occurs when $\theta = \pi$ and the denominator takes its minimum value. The semi-major axis is half of the total sum.

$$\frac{r(0)+r(\pi)}{2} = \frac{a(1-e^2}{2(1+e)} + \frac{a(1-e^2)}{2(1-e)} \tag{14}$$

which ultimately gives a = a1+a2

The orbital period is related to a by

$$P^2 = \frac{4\pi^2 a^3}{GM} \tag{15}$$

$$r1 = \frac{\nu r}{m1} = \frac{\nu a(1-e^2)}{1+ecos\theta} \qquad r2 = \frac{\nu r}{m2} = \frac{\nu a(1-e^2)}{1+ecos\theta} \tag{16}$$

If d is known - m1 and m2 can be individually known.
But is not as easy as perceived. Many of the stars are not oriented with their planes perpendicular to the LOS(Line of Sight) or they are not particularly perpendicular to LOS or lie in the plane of the sky.

We will assume i to be angle of inclination b/w the plane the orbit and the sky. Now as they will intersect at some point which lies in the line parallel to the minor axis forming a line of nodes. To be clear,a line consisting of points at which the orbit crosses the reference plane.

$\overline{\alpha 1} = \alpha 1 cosi$
$\overline{\alpha 2} = \alpha 2 cosi$

As already proved
$\frac{m1}{m2} = \frac{r2}{r1} = \frac{a2}{a1}$

$\frac{m1}{m2} = \frac{\alpha 2}{\alpha 1} = \frac{\alpha 2 cosi}{\alpha 1 cosi} = \frac{\overline{\alpha 2}}{\overline{\alpha 1}}$

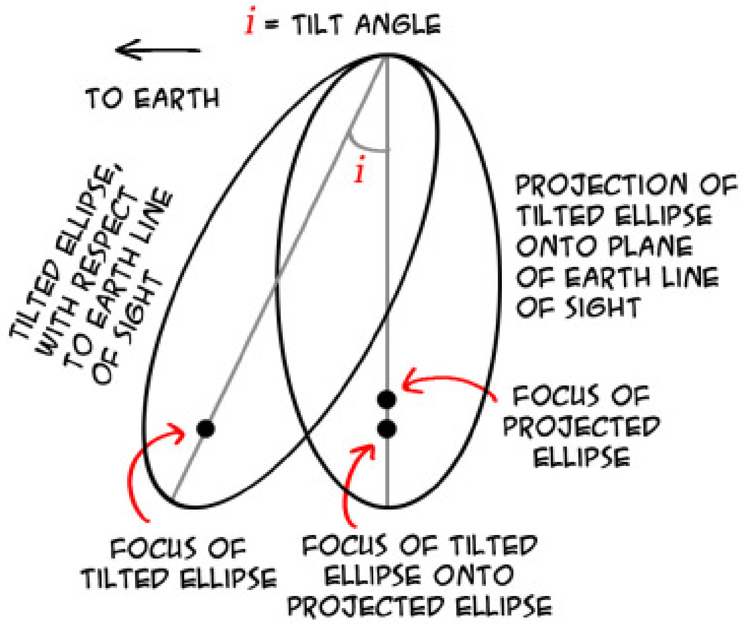

Figure 3: An image of total eclipsing and partial eclipsing binary. The smaller star is hotter.

(Reproduced from quantumredpill)

The following would be helpful if the distance to the system would be known. But if it is not we can always take the help of radial velocity, which give projections along the LOS. Visual binaries are the ones we used for digging mass info.

Several hundred visual pairs are known, but in most cases it has not yet been determined whether they are bound binary systems or chance superpositions. Many visual binaries have long orbital periods of several centuries or millennia and therefore have orbits which are uncertain or poorly known. For this reason, they only sample rather sparsely the HR diagram, with a strong bias towards the more common (and therefore more likely to occur in the solar vicinity) low mass stars. Fortunately, other types of binary stars help us expand the range of reliable stellar mass determinations.

But there are other properties which are important and eclipsing binaries and spectroscopic binaries here prove to be important.

2.5.1 Spectroscopic Binaries

The stars in this system are too far away to be resolved therefore we inspect the spectrum,which will be the superposition of two set of spectral features(which will be different if the stars of different spectral types). In doubled-line spectroscopic binaries,the absorption lines in the composite spectrum will be seen to move in wavelength, as each star moves in its orbit towards us and away from us. The maximum blueshift and redshift we measure within an orbit are lower limits to the true velocities because of the unknown inclination i.

$v1rmax = v1sini$
$v2rmax = v2sini$

Many of them have circular orbits as the timescales of tidal interactions which tend to circularise as the stellar lifetimes are large. When eccentricities are small orbital speed is essentially constant.
$v = \frac{2\pi a}{P}$
$\frac{m1}{m2} = \frac{v2rsini}{v1rsini} = \frac{v2r}{v1r}$

$a = a1 + a2 = \frac{P(v1+v2)}{2\pi}$

$m = m1 + m2 = \frac{P(v1+v2)^3}{2\pi G}$

$m = m1 + m2 = \frac{P(v1r+v2r)^3}{2\pi G sini^3}$

Since the inclination angle is generally unknown it is usually solved statistically. That is, we assume that the orbits are randomly inclined relative to our line of sight and use the integral average of $sini^3$ between 0 and 90 to deduce average mass of stars in a given luminosity or Teff class.

In singled line spectroscopic as the spectrum of only one star is observed we assume three options:

1. The star is very much fainter
2. The other body maybe a neutron star or black hole
3. Otherwise, it may be a planet making velocity amplitudes in ms^{-1}

v2r cannot be measured therefore we resort to the mass ratio

$m = m1 + m2 = \frac{P(v1r+v2r)^3}{2\pi G sini^3}$

$v2r = \frac{v1rm1}{m2}$
$m1 + m2 = \frac{P(v1r)^3}{2\pi G(sini)^3}(1 + \frac{m1}{m2})^3$

$\frac{m2^3 sini^3}{(m1+m2)^2} = \frac{Pv1r^3}{(2\pi G)}$

This is the mass function which provides the lower limit of to the mass m1.

2.5.2 Eclipsing Binaries

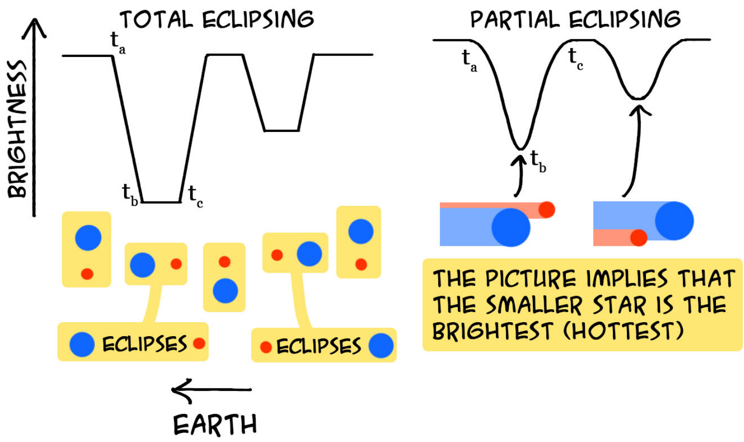

Figure 4: An image of total eclipsing and partial eclipsing binary. The smaller star is hotter.
(Reproduced from quantumredpill)

The first diagram is total eclipsing and second is partial eclipsing. As can be seen the minima is constant in total eclipsing and in partial it changes.

t_a is the point of first contact(not literally but seen from so far away looks like that)
t_b is the point of minimum light
$v = v_s + v_l$ - both are relative velocities of the smaller star and larger star.

$$r_s = \frac{v(t_b - t_a)}{2} \qquad r_l = \frac{v(t_c - t_a)}{2} \tag{17}$$

$$r_l = \frac{v(t_c - t_b)}{2} + r_s \tag{18}$$

The light curve of eclipsing binaries gives information not only on the radii of the two stars but also on the ratio of their effective temperatures. $L = 4\pi R^2 \sigma T^4$; as when an area πR^2 is eclipsed from the system, the drop in flux will be different depending on whether the hotter star of the two is in front or behind the cooler one. Assuming for simplicity a uniform flux across the stellar disk, we have:

$$B_o = A\pi(r_l^2 F_{rl} + r_s^2 F_{rs}) \tag{19}$$

where F is the radiative surface flux, F0 is the measured flux when there is no eclipse, and A is a proportionality constant to account for the fact that we register only a fraction of the flux emitted (due to distance, intervening absorption and limited efficiency of the instrumentation). The deeper, or primary, minimum in the light curve occurs when the hotter star is eclipsed by the cooler one.

$$B_p = A\pi(r_l^2 F_{rl}) \tag{20}$$

It is the amount of light detected during primary minimum.

$$B_s = A\pi((r_l^2 - r_s^2)F_{rl}) + A\pi r_s^2 F_{rs} \tag{21}$$

It is the amount of light detected during secondary minimum.

$$\frac{B_o - B_p}{B_o - B_s} = \frac{T_s^4}{T_o^4} \tag{22}$$

2.6 Photometry

Usually in astronomical data you will come across columns named as U-B, B-V and U-V. These are filters used in astronomy for collecting data in a given. Apparent magnitudes m1 and m2 of two stars with fluxes F1 and F2. Apparent brightness of a star is measured as apparent magnitude - which is how bright is a star at a standard distance of 10 parsecs.
Bigger the apparent magnitude, dimmer the star(it can also be negative)

$$m1 - m2 = -2.5\log_{10}(F1/F2) \tag{23}$$

Instead of inspecting the whole spectrum we inspect it within a broad range of wavelength. At far-ultraviolet wavelengths below 912 A, even small amounts of hydrogen gas between us and the star absorb much of its light. Earth's atmosphere blocks out light at wavelengths below 3000 A, or longer than a few microns. In addition to the light pollution, the night sky itself emits light.

The standard filter bandpasses each specified by the fraction of light $0 \leq T(\lambda) \leq 1$ that it transmits at wavelength λ. When all the light is passed T = 1 or if no light gets through T = 0(at the particular wavelength).

$$F_{BP} = \int_0^\infty T_{BP}(\lambda)F_\lambda(\lambda)\Delta\lambda = F_\lambda(\lambda_e ff)\Delta\lambda \tag{24}$$

2.7 Hertzsprung Russell diagram

The periodic table was a breakthrough in chemistry for better understanding of elements and their properties. Going in the same path the Hertzsprung Russell diagram is used in astronomy for studying the evolutionary tracks of stars. It boasts of 2 axes or sometimes 3. In the case of 2 - we have temperature and luminosity. Otherwise ,we add a third axis of absolute magnitude. The trend that seeped out of classifying data in the way was that stars are not scattered randomly. Instead, they were found to be restricted to a few regions. The regions consist of white dwarfs, red dwarfs, blue to red supergiants,etc.

They form distinctive sequences. This can be understood in the context of the stellar evolution models, and used to test them.

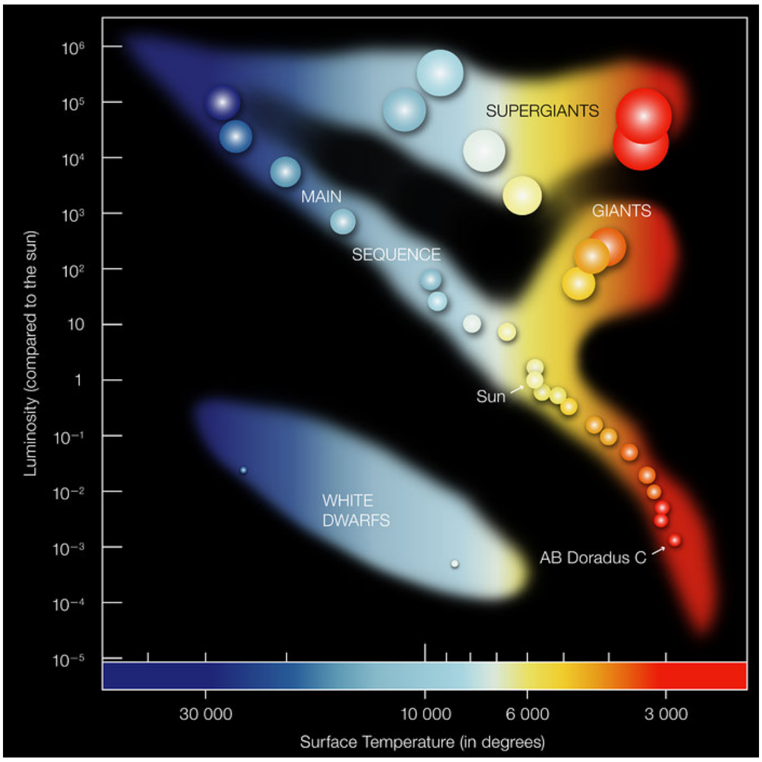

Figure 5: A Hertzsprung Russell diagram clearly depicting well defined regions.

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