THE STUDY OF EARTH'S ATMOSPHERIC EXTINCTION EFFECT ON ASTRONOMICAL OBSERVATION: THEORETICAL MODEL VERSUS OBSERVATION

By

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PHYSICS

The undersigned hereby certify that they have read and recommend to the College of Natural Sciences for acceptance a thesis entitled "**The study of Earth's Atmospheric Extinction Effect on Astronomical Observation: Theoretical Model versus Observation**" by **Ebise Niguse** in partial fulfillment of the requirements for the degree of **Master of Science in Physics(Astrophysics)**.

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To my father Niguse Amossa and my mother Tshehay Gelata

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Abstract

Currently the science of astronomy for the study of origins and evolutions is greatly advancing both theoretically and observationally. However, there are a number of works for further developments. For example, the data extracted on earth is highly extinct due to stellar winds, background radiations and planetary atmospheres. So motivated by this astrophysical relevant issue we were interested to study on the effect of atmospheric extinction on astronomical photometry and spectroscopy theoretically. The standard Plancks black body radiation law was used for perfect (non-extinct) radiation. To see the effect of earth's atmosphere we assumed an exponential atmosphere that obeys the Beer-Bouguet-Lambert law of the optical depth equation. The results are in agreement with observational works and the standard theories. However, this work is limited to high approximations.

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Introduction

I. Background of the study and literature review

Throughout history humans have looked to the sky to navigate the vast oceans, to decide when to plant their crops and to answer questions of where we came from and how we got here. It is a discipline that opens our eyes, gives context to our place in the Universe and that can reshape how we see the world [11]. The first systematic observation of the sky was considered to be carried out by the Chinese as early as the 14th century BC [21] while the concept of stellar magnitudes is at least as old as Ptolemy's Almagest (ca. 137 AD). Ptolemy's catalogue was based, or largely borrowed (with an incorrect value for precession) from the star catalogue of Hipparchus; as early as the second century B.C. The literature on Ptolemys star catalogue is quite extensive [12], Hipparchus divided the visible stars into six classes according to their apparent brightness [8], stars were ranked from 1 to 6 with 1 being the brightest and 6 being the dimmest (you can already see a problem that a higher number means a dimmer star).

Instead of changing this system, modern astronomy has simply slapped a mathematical underpinning to the magnitude scale. We do so by requiring that a difference in five magnitudes corresponds to a star having a flux that is precisely 100 times greater. Mathematically, we compare the magnitudes to the fluxes [12].

In 1610 Galileo published the first telescopic observations showing that the Milky Way consists of numerous stars. By the time Galileo was observing the heavens with a small refractor at the beginning of the 17th century, the Chinese had been recording celestial phenomena for nearly 3000 years [19]. Many of those observations are of use to modern astronomers.

Traditional eye based estimation of stellar brightness is usually thought to be doing very well at 10% accuracy [5]. There are many variables of large amplitude where data of this accuracy are still useful, particularly when coverage is extensive, so that observations can be averaged [19]

While these early observations are of course important, in order to study stars systematically we must be able to make quantitative measurements to obtain their basic properties. Only quantitative measurements can form the nucleus of a theoretical understanding and against which model predictions can be tested. Detailed knowledge of celestial visibility is required to extract the maximum information out of visual astronomical observations.

Observational astronomy becomes science only when answer the basic properties of star quantitatively: How far away is that object? How much energy does it emit? How hot is it? what about its motion? [26]

Modern astronomers study stars by measuring and analyzing the light they radiate. Most of what we know about astronomical sources comes from measuring their spectral energy distributions (collect and analyze the electromagnetic radiation these objects emit into space). The only means for investigating distant stars, nebulae, and galaxies is to collect and analyze the electromagnetic radiation these objects emit into space [26].

The goal of the observational astronomer is to make measurements of electromagnetic radiation from celestial objects with as much detail, or finest resolution possible. The perfect astronomical observing system would tell us the amount of wave length, from the entire sky in arbitrarily small angle slice. Such a system does not exist [6].

Ground- based astronomical observations are affected by the earth's atmosphere. If the space between the radiation source and observer is not completely empty, the passage of light through a medium (or atmosphere) is affected. The earth's atmosphere allows only small fraction of all wave lengths of electromagnetic radiation to penetrate. For accurate result it is important to estimate the amount of light being blocked on its path to Earth [25].medskip
Global strategy of observational astronomy requires exact knowledge of properties of Earth's atmosphere. Light from astronomical object is scattered and absorbed by air molecules and aerosols and this cause a significant loss of flux, intensity depending on the wave length and weather conditions. In order to overcome this problem, astronomers have developed plenty of tools which is measuring extinction [25]. It is the absorption and scattering of electromagnetic radiation by aerosols and molecules between an emitting astronomical object and the observer.

However, most of this radiation is absorbed or distorted by the atmosphere before it can reach a ground-based telescope, only visible light and some radio waves, infrared, and ultraviolet light survive the passage from space to the ground. This limited amount of radiation has provided astronomers enough information to estimate the general shape and size of the universe and categorize its basic components [17]. On the other hand the advancement of both science and technology has given the opportunity for achieving high-precision photometric measurements in upcoming multiband sky surveys. PanSTARRS (Panoramic Survey Telescope and Rapid Response System) and LSST (Large Synoptic Survey Telescope) motivates a comprehensive assessment of the limitations of ground-based CCD (charge-coupled device) photometry. The science goals for future ground-based all-sky surveys, pose stringent requirements on the stability and uniformity of photometric measurements [6], [10].

The first astronomy practiced was optical astronomy and measuring star brightness is an ancient idea. Up to Galileo Galilei (1609), the most important means of observation in astronomy was the human eye. But Over the centuries, astronomers have developed the capability of their instruments to give them greater power to detect and measure astronomical sources. Modern astronomy began in the renaissance with the observations of Tycho Brahe and Galileo and the theoretical work of Kepler and Newton.

At the beginning of the 17th century telescope was invented in Holland and in 1609 Galileo Galilei made his first astronomical observations with this new instrument. The progress of our knowledge of the sky may be traced through a series of major discoveries which often follow the development of new technologies such as the telescope, computers, and space observatories [3].

Astronomy is now carried out across the entire electromagnetic spectrum from the radio to the gamma ray. Astronomers use more precise tools to obtain the calculation [3]. But the natural and artificial environments restrict the development of astronomy and challenge its advances. It is convenient to describe the environmental challenges through the techniques that are used to make the measurements: optical, radio, etc [9].

Earths atmosphere is an incredibly important fluid that supports life on Earth. We are actually physically connected because we constantly share and recycle air molecules through our lungs. Although the atmosphere of the Earth is very important for life, it does cause systematic observational uncertainties significant for ground-based astronomical observations. [9].

The theory of atmospheric extinction was developed only when the knowledge of the precise magnitudes of the stars became of interest, and again the extinction at low altitude was not important. The basic physics of atmospheric extinction was first presented by Pierre Bouguer in 1729 [22].

Photometry can be said to have started with measurements on the sun and the moon by Pierre Bouguer (1729) and by Johann Heinrich Lambert (1760). Systematic work on stars began only after Norman Pogson had defined stellar magnitudes (1850) [19].

Processes that attenuate(extinction)light as it propagates through the atmosphere include absorption and scattering (Rayleigh) by molecular constituents (O_2, O_3, water vapor, and trace elements), scattering (Mie) by airborne macroscopic particulate aerosols with physical dimensions comparable to the wavelength of visible light, and shadowing by ice crystals and water droplets in clouds[6]. Analysis and correction for this component of atmospheric extinction requires special care(the fitting model for atmospheric transmittance of light). But the state-of-the-art of measurement science and calibration technology has now developed in precision and field applicability to the point where we must look at the column of atmosphere through which light travels to our telescopes to realize the precision and accuracy now required for astrophysical measurements[9] since extinction depend on transparency, elevation of the observer, and the zenith angle, the angle from the zenith to ones line of sight. Therefore, looking vertically, the zenith angle is 0^o, and is 90^o at the horizon.

Astronomers who specialize in photometry need to compensate for atmospheric extinction: the reduction in a celestial object's apparent brightness when its light passes through the atmosphere. Parrao and Schuster [23] in 2003 points out that precise atmospheric extinction determinations are needed not only for stellar photometry but also for any sort of photometry, spectroscopy, spectrophotometry and imaging. whenever accurate, absolute and well-calibrated photometric measurements are required for the derivation of physical parameters in the studies of galaxies, nebulae, planets, and so forth. Precise determinations of the atmospheric extinction ultimately determine the scientific value of the telescope data .

Within the next decade a suite of observatory class instruments directly measuring Earths atmosphere and telescope throughput will enable routine, probably accurate photometric measurements to sub - 1% accuracy [7], often achieving the fundamental photon noise limit. Examples of requirements for precise and accurate photometry for research ranging from stars to dark energy are described.

The extraterrestrial extinction is not taken into account in this study, because it is not important for atmospheric attenuation and is not discussed herein.

II. Statement of the problem

Ground-based astronomical observations are affected by the Earths atmosphere. Light from astronomical objects is scattered and absorbed by air molecules and aerosols. This extinction effect can cause a significant loss of flux, depending on the wavelength and weather conditions. The signal of the targeted object is further deteriorated by background radiation, which is caused by light from other astronomical radiation sources scattered into the line of sight and emission originating from the atmosphere itself.

Research Questions

- How Earth's atmosphere affects spectral energy distribution of astronomical object?
- How do we determine the standard (exo-atmospheric) photometry of astronomical object?
- How the component of earth's atmosphere reduces the flux/Luminosity of star?
- What can astronomers do to capture(compensate) the missing electromagnetic radiation for study?

III. Objectives

General Objective

To study earth's atmospheric extinction effect on astronomical observation: Theoretical model versus observation.

Specific Objectives

- To derive relevant observable parameters that enter in the extinction effect of observation.
- To er derive spectral energy distribution radiation law with and without extinction.

- To see the effect of seeing/airmass.
- To analyze the effect of atmospheric depth on astronomical photometry and spectroscopy.

IV. Methodology

Planck's radiation law is being used to derive relevant parameters like brightness magnitudes (such as apparent, absolute, bolometric magnitudes), and other observable parameters. The atmospheric extinction is being considered by assuming an exponential atmosphere. Then the optical thickness related to extinction is an exponential one, where the Beer-Bouguer-Lambert law is considered. The analytically derived equations are used to generate numerical data computationally using MATHEMATICA to analysis.

The outline of the work is as follows;

In chapter one we introduced some basic tools of astronomical observations and parameters. In chapter two we discuss the black-body radiation phenomena, which is of primary importance in thermal radiation theory and practice and the fundamental law of radiation of such system. The quantitative black-body radiation laws and their corollaries are addressed in detail for later use. In chapter three we derive the relevant equations for the appropriate astronomically observable parameters. In chapter four we discuss our results. Finally, in chapter five we give our summary and conclusion.

Chapter 1

Basic Tools and Parameters In Astronomical Observation

Introduction

History of astronomy is, history of the science that studies all celestial object in the universe. The field of astronomy have developed from simple observation (by eye) about the movement of sun and moon in to sophisticated theories nature of the universe. Celestial measurements reaching back 3000 years or more carried out in many cultures world wide [3].

Observational astronomy is the practice of observing celestial object by using telescope and other astronomical tools and focused on getting data, in contrast with theoretical astrophysics which is mainly concerned with finding out the measurable implication of physical model.

As a science, the study of astronomy is somewhat hindered in that direct experiments with the properties of the distant universe are not possible. However, this is partly compensated by the fact that astronomers have a vast number of visible examples of stellar phenomena that can be examined. This allows for observational data to be plotted on graphs, and general trends recorded.

Theoretical astronomy is the use of analytical model of physics and chemistry to describe astronomical objects and astronomical phenomenon. Then astronomy includes observation and theories about celestial objects [3].

Astronomical objects send enormous range of electromagnetic radiation and are known through the radiation they emit. Astronomers learn about astronomical objects by observing the energy that they emit in the form of electromagnetic radiation which travel through out the universe in the form of waves or photons that can range from gamma rays, which have extremely short wave lengths, to visible light to radio waves , which are very long. The whole range of these different wave lengths makes up electromagnetic spectrum. Since Earth's atmosphere complicates studies by absorbing many wave length's of the electromagnetic spectrum, astronomers study EMR by using deferent techniques for different wave lengths[24].

Earth's atmosphere is a great impediment in many kind of astronomy. At some frequencies the radiation can penetrate the atmosphere and ground- based observations are feasible but at other frequencies the atmosphere is opaque and observations must be carried out above earth's atmosphere. Space missions can overcome this limitation as will ground-based adaptive optics systems that are now coming into operation [5].

1.1 Basic Tools

There are three basic components of a modern system for measuring radiation from astronomical sources: the telescopes, the wavelength-sorting device, and the detectors.

Astronomy is now carried out across the entire electromagnetic spectrum from radio to the gamma ray as well as cosmic ray,neutrinos,and gravitational waves. Observational astronomy may be divided according to the observed region of the electromagnetic spectrum (fig.11). Some parts of the spectrum can be observed from the Earth's surface by different tools such as optical telescope, radio telescope, and Infrared telescope(for shorter infrared wave length) while other parts are only observable from either high altitudes or outside the Earth's atmosphere by using Gamma ray telescope, X-ray telescope, and Ultraviolet telescope [3]. Fig. 1.1 shows the bands of

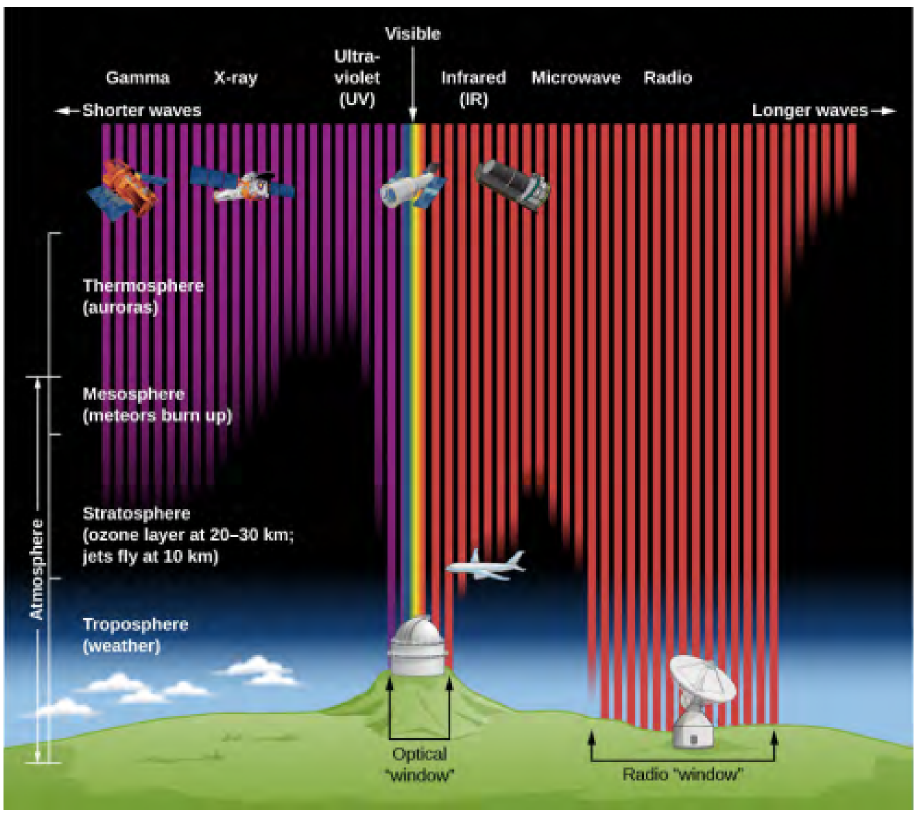

Figure 1.1: Radiation and Earth's Atmosphere [Source, Astronomy, Senior Contributing Authors, page 154)]

the electromagnetic spectrum and how well Earths atmosphere transmits them. Note that high-frequency waves from space do not make it to the surface and must therefore be observed from space.

1.2 Basic Parameters In Astronomical Observation

The measurement of the brightness of radiating objects in the sky is astronomical photometry, is a technique of astronomy concerned with measuring the flux, or intensity of an astronomical object's electromagnetic radiation and when we deal mainly with, centers around which a region of the electromagnetic spectrum to which the human eye is sensitive is optical photometry [5]. The quantitative measurement of the basic properties of stars and galaxies came from observing the electromagnetic radiation they emit for earth's atmosphere is nearly transparent around the range of visible light and some infrared (IR), while the other is the radio window long wave lengths.

UVB Photometry

Stellar photometry come in to use in 1861 as a means of measuring colors. This technique measured the magnitude of a star at specific frequency ranges, allowing determination of the overall color, and there fore temperature of a star. In the year 1950 H.J. Johnson and Morgan developed UVB photometric system. By 1951 an internationally standardized system of UBV-magnitudes (Ultraviolet-Blue-Visual) was adopted [16].

These bands have been chosen in such a way that (B-V) and (U-B) are zero for A0 stars and surface temperature of such star is 10,000 K. Note that U, V and B magnitudes are apparent magnitudes. Their corresponding absolute magnitudes are M_U,

M_V and M_B.

Photoelectric photometry using the CCD is now frequently used to make observations through telescope. These sensitive instruments can be designed to view in parts of the spectrum that are individual photons, and can be designed to view in parts of the spectrum that are invisible to the eyes [16].

Spectroscopy stellar spectroscopy is the fundamental tool for investigating the natures of stars and is central to our understanding of modern astronomy and astrophysics. Spectroscopy is the study of what kinds of light we see from an object. It is a measure of the quantity of each color of light (or more specifically, the amount of each wavelength of light). It is a powerful tool in astronomy and most of what we know in astronomy is a result of spectroscopy: it can reveal the temperature, velocity and composition of an object as well as be used to infer mass, distance and many other pieces of information. Spectroscopy is done at all wavelengths of the electromagnetic spectrum, from radio waves to gamma rays [18].

1.2.1 Magnitude

As the magnitudes were introduced by the Greek astronomer Hipparchus 130 BC, the modern magnitude system has its origin in the ancient Greek. Magnitude is a number that measures the brightness of a star or galaxy. In magnitude, higher numbers correspond to fainter objects, lower numbers to brighter objects; the very brightest objects have negative magnitudes. The Hipparchus arranged the visible stars in to six brightness rank, and he called the first rank the brightest and were ranked as six the faintest. The ranks were called magnitude [8].

When modern astronomers talented to make more exact measurement of the brightness of stars, they understood that, Hipparchus magnitude scale was roughly logarithmic. This system remains intact to this day, though with some modification. In steady of changing Hipparchus magnitude system, modern astronomer has added precision to the magnitude scale that a difference in five magnitudes corresponds to star having precisely a flux (f) of 100 times greater [12], were f is the energy flux going through the area per unit time.

Accordingly in 1856 the Oxford astronomer Norman R. Pogson proposed that mathematical scale of stellar magnitudes with the difference of five magnitudes be exactly defined as a brightness ratio of 100 to 1. That means a first magnitude star is 100 times as brighter than a 6th-magnitude star or conversely, a 6th-magnitude star is 100 times dimmer than a 1st-magnitude star. One magnitude thus corresponds to a brightness difference of exactly the fifth root of 100 (the logarithm of which equals 0.4) or very close to 2.512 a value known as the Pogson ratio. This implies that a star of magnitude m is 2.512 times as bright as a star of magnitude m +1 [13].

The magnitude logarithmic scale is setup still in use today. Enough it to say that the our sensory organs and the brain perceive stimuli (such as light, sound, and taste) proportional to the logarithm of the stimulus. This is known as the Weber-Fechner psychophysical law [14].

Now, magnitudes are quantified by a logarithmic equation, So defined modern magnitude scale where the ratio of flux of two stars corresponds to their magnitude difference according to:

$$\frac{F_1}{F_2} = 2.512^{m_2 - m_1} \tag{1.2.1}$$

Where F_1 and F_2, respectively represent,the recorded flux and m_1 and m_2 the corresponding magnitude. This leads to the formula

$$m = -2.512logF + c \tag{1.2.2}$$

This expression is often referred to as pogson's formula, and the coefficient (-2.5) is the Pogson scale, C is an arbitrarily choosen constant.

$$\frac{F_1}{F_2} = 100^{\frac{(m_1-m_2)}{5}} = 10^{\frac{(m_1-m_2)}{2.5}} \tag{1.2.3}$$

or

$$m_1 - m_2 = -2.5log\frac{F_1}{F_2}. \tag{1.2.4}$$

this equation is the fundamental equation needed to define and deal with magnitudes. The most common use of magnitudes is for expressing the apparent brightness of stars to give a definite number for a magnitude of a star, instead of just the magnitude difference between pairs of stars, we must pick a starting place, or zero point, for the magnitude system. To oversimplify some what we pick the star Vega, and say it has magnitude of 0.00. Then the magnitude of any other star is simply related to the flux ratio of that star and Vega as follows:

$$m_1 = -2.5log10\frac{f_1}{f_{vega}}$$

The magnitude of Vega does not appear, because it is defined to be 0.00. These magnitudes are called apparent magnitudes, because they are related to the flux of the star, or how bright the star appears to us [4].

Astronomers use two different magnitudes, Apparent (m) and Absolute (M) magnitude.

1.2.2 Apparent Magnitude

Apparent magnitude is the brightness of an object as it appears to be. The brightness of a star in physical units is its flux which has the units of Watts per square meter in MKS. In terms of the magnitude system, the flux is described as an apparent magnitude. However, astronomers almost never use flux to describe brightness of objects, they use magnitude. It depends on how far away the object is from the observer (like an objects flux). The brighter an object appears, the lower its magnitude value (e.i., inverse relation ship). It is simply a measure of the apparent flux density of the star as measured from earth [8]. The basic formula has been given already as eqn (1.2.4).

1.2.3 Absolute Magnitude(M)

Absolute magnitude is a concept that was invented after apparent magnitude when astronomers needed a way to compare the intrinsic, or absolute brightness of celestial objects. Astronomers use this magnitudes which stars are truly bright and which are truly faints because distance is no longer variable. Therefore, it reflects the intrinsic amount of light out put by the source and never changes (like an objects luminosity). It is apparent magnitude that an observer would measure at a distance of d = 10 pc from the source and that the source (in the absence of light loss in the intervening space) would have if situated at this distance 10 parsec (32ly). It is a measure of flux at 10 pc away from earth [8]. A light-year is the distance light travels in one year about 6 trillion miles, or 10 trillion kilometers. $1pc = 206,265AU = 3.08 * 10^{16}m$. Absolute magnitude (M) then satisfies:

$$m - M = 5log\frac{d}{10pc} \tag{1.2.5}$$

$$m = M + 5log\frac{d}{10pc} \tag{1.2.6}$$

where, m is for apparent magnitude, d is the distance from the source to earth.

Magnitudes for stars range in practise from about -10 to +17,but the possible range of values is theoretically unlimited. Example, Sun has an absolute magnitude of 4.2, Sirius has an absolute magnitude of 1.47, Betelgeuse has an absolute magnitude -5.14.

Clearly there must be a relationship between m, M and d and this can be derived from the inverse square law if we neglect any dimming of a star that might occur due to interstellar absorption (i.e. fog). Assuming that the only factor causing a star to dim as it moves away from us is the geometric effect of spreading its light over an increasingly large sphere, can be written as $f = \frac{L}{4\pi d^2}$ where L is the luminosity of the star, d is its distance and f is its flux measured at Earth. This is a statement of the inverse square law for light, that the flux of an object changes as the inverse square of its distance. By using the definition of absolute magnitude employing the magnitude $m - M = -2.5 \log \frac{f}{f(at10pc)}$ we can determine the additive term of apparent magnitude.

$$\frac{f}{f(at10pc)} = \frac{10^2}{d^2}$$

$$\Delta m = 5 \log_{10} d - 5 \tag{1.2.7}$$

where, Δm is distance modules.

1.2.4 Visual magnitude

In daylight the human eye is most sensitive to radiation with a wavelength of about 550 nm, the sensitivity decreasing towards red (longer wavelengths) and violet (shorter wavelengths). The magnitude corresponding to the sensitivity of the eye is called the visual magnitude Mv.

1.2.5 Photographic magnitude

Brightness of star measured photographically: the magnitude of a star determined by measuring its size on a photographic plate. Depending on the color of the star, photographic magnitude and visual magnitude can differ because the eye and standard photographic plates have different color sensitivities. Photographic plates are usually most sensitive at blue and violet wavelengths, but they are also able to register radiation not visible to the human eye. Photographic magnitudes can be measured with photographic plates sensitive to other region of the electromagnetic spectrum.

1.2.6 Bolometric magnitude and Bolometric correction

The bolometric magnitude is a measure of the energy spectral flux density (W m-2 Hz-1) integrated over the entire appropriate frequency band(integrated over all wavelengths. It is a measure of the bolometric flux density F (W/m^2) magnitude of a star.

Bolometric magnitudes go beyond the restriction of magnitude at some particular wavelength, or range of wavelengths, and refer to the total power of the source and includes those unabsorbed due to an instrumental pass-band, the earth's atmospheric absorption and extinction by interstellar dust. It is based upon the total energy flux in and near the optical band (IR, optical, UV). The distribution of radiation from a star approximates a black-body spectrum with superimposed absorption lines; it peaks in the visible range for many stars and falls toward zero.

The electromagnetic radiation that astronomical objects emit are varies with wave lengths. To measure all the electromagnetic radiation, we must have observe at all wave lengths from gamma ray (the shortest wave lengths) to radio wave (the longest wave length). The object must be observed by ground based telescope (for earth's atmosphere is transparent) and space based telescope (for earth's atmosphere is opaque). This is not trivial to determine because some regions of the spectrum are absorbed by the atmosphere (for example) and theoretical models are used to determine correction for the effects.

The Bolometric correction is the correction applied to a magnitude (apparent or absolute) to get the bolometric value. Then the bolometric correction BC_x is defined as

$$m_{bol} = m_x + BC_x, \tag{1.2.8}$$

where x is stands for the particular pass bands.

$$M_{bol} = M_V + BC_v \tag{1.2.9}$$

where the subscript V refers to the V or Visual pass-band (a yellow-green filter) of the UBV or UBVRI photometric systems, and BC is the bolometric correction which is determined as a function of temperature or spectral type.

The BC_v bolometric correction zero point was derived by assuming for the sun $M_{bol} = 4.74$ and $M_v = 4.81$ from the observed $V = -26.76$ mag. Thus we assigned visual bolometric correction BC_v of -0.07 mag for the solar model. The bolometric correction is then the quantity that must be added to the visual magnitude to obtain the bolometric one. By definition, the bolometric correction is zero for radiation of solar type stars (or, more precisely, stars of the spectral class F5).[28]

$$BC = m_{bol} - V = M_{Bol} - M_V \tag{1.2.10}$$

1.2.7 Absolute Bolometric Magnitude and Luminosity

The absolute bolometric magnitude is a direct measure of the bolometric luminosity of a star. It is the energy output integrated over the ultraviolet, visual, and Infrared as fitting for the temperature of the star. The bolometric magnitude M_{bol} of an arbitrary star is related to luminosity L as :

$$M_{bol} - M_{bol,\odot} = -2.5 log \frac{L}{L_{\odot}} \tag{1.2.11}$$

$$M_{bol} = -2.5 log \frac{L}{L_{\odot}} + 4.74 \tag{1.2.12}$$

Where, $L_{\odot} = 3.845 \times 10^{26}$ $M_{bol,\odot} = 4.74$. To define the zero point of the absolute bolometric magnitude scale by specifying that a radiation source with absolute bolometric magnitude $M_{Bol} = 0$ mag has a radiative luminosity of exactly;

$$L_0 = 3.0128 * 10^{28} W$$

1.2.8 Luminosity

Luminosity is an expression of true brightness of an object how much radiation is emitted per second. It is also a measure of the radiative power of a source, and relates to the entire output, and thus can be directly connected with absolute bolometric magnitude. The most basic stellar property we can think of measuring is its luminosity and one of the basic direct observable quantities for star. It depends where star is in its evolutionary sequence (the effective temperature), size of a star and extinction. One of the basic direct observable quantities for star [15]. As the radius increases, the surface area will also increase, and the constant luminosity has more surface area to illuminate, leading to a decrease in observed brightness. Measuring luminosity means deriving accurate measurements, for each of these components and without which an accurate luminosity figure remains elusive.

To measure total luminosity, assuming that no light is absorbed during its journey out side of the shell i.e at $r > R$ and by neglecting any effect (relativistic effect) then the inverse square law for the energy flux is cogent.

$$F = \frac{L}{A} \tag{1.2.13}$$

$$F = \frac{L}{4\pi r^2} \tag{1.2.14}$$

Where $A = 4\pi r^2$ is the surface area of the illuminated sphere with radius r and r is the distance from the observer to the light source,F is flux density

$$\Longrightarrow L = 4\pi r^2 F \tag{1.2.15}$$

The inverse square law for energy flux out side of the star at a distance $r > R$ is $F\alpha\frac{1}{r^2}$, where R is radius of star. The total luminosity of star is the product of surface area and the radiation emitted per area.

$$L = A\sigma T^4 \tag{1.2.16}$$

(assuming the star is a black body).

$$L = 4\pi R^2 \sigma T^4 \tag{1.2.17}$$

where σ is the Stefan-Boltzmann constant

1.2.9 Intensity

Specific intensity is the energy per unit area normal to the direction of radiation, per unit solid angle, per unit time, per unit wave length (or frequency). The intensity including all possible frequencies is called the total intensity I, and is obtained by integrating I_ν over all frequencies.

1.2.10 Flux and flux density

More important quantities from the observational point of view are the energy flux and the flux density (Fv, F). The flux density gives the power of radiation per unit area. Observing radiation of a source means measuring the energy collected by the detector during some period of time, which equals the flux density integrated over the radiation-collecting area of the instrument and the time interval about the total flux density. Flux is just the average of intensity over all directions.

1.2.11 Color, Temperature and Luminosity of stars

Temperature is one of the most basic quantities in physics and astrophysics. The color of a star is primarily a function of its effective temperature. The frequencies of detected photons may be an indicator of the temperature of the originating bodies. For example, photons from the sun at optical frequencies tell us that the surface layers of the sun have temperature of 6000 K (kelvin). The luminosity and temperature of stars are often deduced from observed broad band colors and magnitudes. Empirical color-temperature relations and color-bolometric magnitude corrections are normally used to transform observed standard magnitudes and colors to temperature and luminosity. Careful measurement of star's light spectrum gives about its temperature.

1.2.12 Color Temperature

The color temperature Tc is derived from broadband UBV photometry, the measurement of fluxes in the U, B, and V bands, under the assumption that the observed object has a black-body spectrum. The relative flux densities in these bands are a measure of the color of the objet. The color temperature of a light source is determined by comparing its chromaticity with a theoretical, heated black-body radiator. The temperature (in k) at which the heated black-body radiator matches the color of the light source is that source's color temperature. From Wiens displacement law, we get the color temperature, $T = constant/\lambda_{max}$. It shows for which wavelength radiation has its maximal intensity and hence which color the star appears to have.

1.2.13 Color index

One way to classify stars or galaxies is by the ratio of the flux at one wavelength to the flux at another wavelength and this ratio is a strong function of temperature [2]. Flux usually is measured through color filters as, U,B or V filters. Flux through e.g., B filter is called B magnitude written m_B.

A color index is the ratio of fluxes in two color bands for the same star or the difference between the apparent magnitudes of a star in two different spectral region [5]. The color index that is used very often is the U-B index and B -V changes with temperature. Hot star has negative color index and the cooler star has positive color index. That is, hot star tend to be brighter in the blue part of the spectrum that in the visual or red part of the spectrum and for such stars, $B < V$. Cooler stars are brighter in the visual band pass than in the blue band pass so $V < B$. There fore, it convey useful information about a star's spectrum and temperature. Thus by measuring the ratio of fluxes, we can learn about the temperature of the star or galaxy (there are empirical correction terms to account for the non-ideal black body behavior of stars and galaxies).

The standard wavebands for optical astronomy are U, B, and V and all are in the broadband UBV system approximately 100 nanometers wide for each filter. U stands for ultraviolet and is centered at 365 nm, B stands for blue and is centered at 440 nm and V stands for visual and is centered at 550 nm [2]. For example the B filter passes only light from about 3900nm to 4900nm. The difference between magnitudes in a pair of this wavebands tells about the temperature, or color, of the star and it is called color index(or colors)and it measure the slope of the spectral energy distribution(SED) between bands 1 and 2.

To measure the index, one observes the magnitude of an object successively through two different filters such as U and B or B and V where U is sensitive to UV rays, B is sensitive to blue light and V is sensitive to visible light.

$$U - B \quad \alpha \quad -log\frac{F_U}{F_B} \tag{1.2.18}$$

$$B - V \quad \alpha \quad -log\frac{F_B}{F_V} \tag{1.2.19}$$

are color indices of stars.

$$m_B - m_V = B - V = -2.5log10\frac{F_V}{F_B} + constant \tag{1.2.20}$$

where

$$m_{\lambda_1} - m_{\lambda_2} = -2.5log\frac{F_{\lambda_2}}{F_{\lambda_2}} \tag{1.2.21}$$

The constant appears in the above equation is a function of the zero points of the two band (where we define the zero point of the color system).You might think that if $B - V = 0.00$, $f_B = f_V$. But this is not how the color system is defined. Historically, astronomers picked a set of stars of spectral class A (including Vega) and defined the average color of these stars to have all colors equal to 0.00. For an A star, f_B is not equal to f_V, so that a non-zero constant is needed in equation to make the color come out to 0.00. Thus, the $B - V$ color of Vega is 0.00, the B- V color of the Sun, redder than Vega, is about 0.63. The $B - V$ colors of the hottest (bluest) stars are about-0.3. The color of Betelgeuse, the very red star marking one of the shoulders of Orion, is about $B - V = 1.54$.

Example: Color Indices and Bolometric Corrections Sirius, the brightest-appearing star in the sky, has U, B, and V magnitudes of $m_U = -1.47$, $m_B = -1.43$, and $m_V = -1.44$. Thus for Sirius,

$$U - B = -1.47 - (-1.43) = -0.04 \tag{1.2.22}$$

$$and B - V = -1.43 - (-1.44) = 0.01 \tag{1.2.23}$$

The bolometric correction for Sirius is $BC = -0.09$, so its apparent bolometric magnitude is

$$m_{bol} = m_V + BC = -1.44 + (-0.09) = -1.53$$

[30]

Chapter 2

Black Body Radiation

2.1 Introduction

The influence of blackbody radiation has been great on both theory and technology since physicists begun to explore such radiation. The features of blackbody radiation have been applied in many fields, such as, cosmic microwave background radiation, temperature measurements of astrophysical object, color temperature, infrared temperature etc [19]. A blackbody is an object which is a perfect absorber (absorbs at all wavelengths) and a perfect emitter (emits at all wavelengths) and does not reflect any light from its surface. An object is called a blackbody if its surface re-emits all radiation that it absorbs thus it radiates continues emission. The continuum emission radiated is described by only one parameter, the objects temperature.

Stars are fairly well approximated radiate in a similar fashion to a blackbody, with surface temperatures ranging from 6000 K (M dwarfs) to 40,000 K (O type) and this is why we want to deal with blackbody radiation. All normal (byronic) matter emits electromagnetic radiation when it has a temperature above absolute zero and conversely all normal matter absorbs electromagnetic radiation to some degree. knowing blackbody radiation is used to know astrophysical information derived from the EM spectrum [3]. since the study of astronomy is somewhat hindered in that direct experiments with the properties of the astronomical object or not possible.

2.2 Radiation and Temperature

Some astronomical objects emit mostly infrared radiation, others mostly visible light, and others mostly ultraviolet radiation. The type of electromagnetic radiation emitted by the Sun, stars, and other dense astronomical objects determines obviously their temperature.

At the microscopic level, everything in nature is in motion; the temperature of something is thus a measure of the average motion energy of the particles that make it up. This motion is responsible for much of the electromagnetic radiation on Earth and in the universe. As atoms and molecules move about and collide, or vibrate in place, their electrons give off electromagnetic radiation. The characteristics of this radiation are determined by the temperature of those atoms and molecules.

Since electromagnetic radiation is the only source which we use to get information about astronomical object (distant universe), it is of high importance in astrophysics to know the processes which produce this kind of radiation, so thermal radiation(black body radiation) is the one. It is the thermal motion of atoms produces electro- magnetic radiation at all wavelengths [5].

Then, to understand the relationship between temperature and electromagnetic radiation, in more quantitative detail, to study and understand the spectra of radiation emitted by a physical object or a body in thermal equilibrium maintained at temperature T; we imagine this an idealized model (black-body radiation). This is commonly pictured as a cavity or empty bottle (box) in which waves (photons) are bouncing back and forth between walls at a certain temperature defining the temperature of the cavity. The bottle has a little peephole through which radiation is escaping to be observed. As it absorbs energy it heats up and re-radiates the energy as electromagnetic radiation until absorption and radiation are in balance [29]. It has a specific spectrum and intensity that depends only on the body's temperature.

The continuous spectrum produced by a black body is distinctive and can be shown

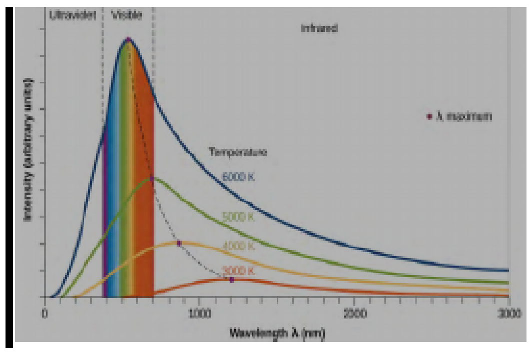

Figure 2.1: Continuous spectrum of black body radiation [Source, AST1100 Lecture Notes 6 Electromagnetic radiation]

as an intensity plot of intensity against emitted wavelength (fig 2.1). This plot is called the black body curve or the Planck curve, after the German physicist Max Planck (1900) who first postulated that electromagnetic radiation was quantized [29].

Wien's displacement law states that the black body radiation curve for different temperature peaks at a wavelength that is inversely proportional to the temperature. The shift of that peak is a direct consequence of the Planck radiation law, which describes the spectral brightness of black body radiation as a function of wavelength at any given temperature.

The spectrum of a black body given by Planck's law is continuous in the UV to NIR and also for the star and their spectrum spectrum peaks at a wavelength that depends on the temperature, so that cool objects radiate with a peak in the infrared, while hot objects glow in colors that range from red through yellow to blue as the object's temperature increases [3].

2.2.1 Spectra

Electromagnetic spectrum refers to the full range of all frequencies of electromagnetic radiation and also to the characteristics distribution of electromagnetic radiation emitted by the particular object. The spectral distribution of electromagnetic radiation from a celestial object can reveal much about the physical processes taking place at the object. By obtaining and analyzing the spectrum from a distant we can identify what type of object it is and determine a wealth of characteristics for the object.

Three general types of spectra were now known, a continuous spectrum and two

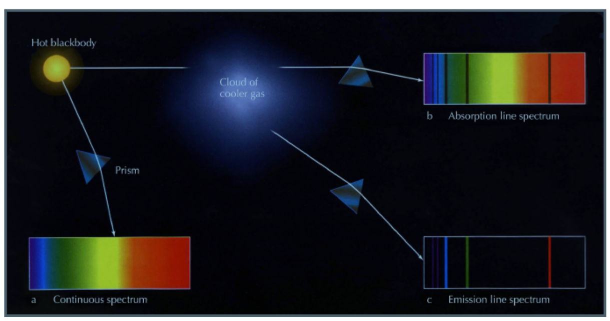

Figure 2.2: Spectral formation [Source, Figure: www.nthu.edu.tw]

types of line spectra.

- A continuous spectrum - showing all the component colors of the rainbow, and the overall hill-shaped spectrum of electromagnetic radiation emitted by a black body by thermal emission [5]. Such a spectrum contains no lines because light of all colors is present in it.

- Absorption spectrum - dark-line spectra like the solar spectrum and those from stars or continuous spectrum, but with the flux of certain frequencies reduced because something absorbed them between the source and Earth. The dark lines correspond to wavelengths of light where the energy of photons at that wavelength matches the difference in energy between two energy levels in some atom or molecule in the stellar atmosphere. If you looked at the source of the continuous spectrum (light bulb, core of a star) through a spectrograph, it would have the familiar Blackbody spectrum, with a dark line where the light had been absorbed. This is an absorption line.

- Emission spectrum - bright-line spectra as emitted from gas discharge tubes and some nebulae. An emission spectrum looks very different rather than a continuous spectrum, we see emission at specific wavelengths. Because it can only emit those same wavelengths that it can absorb, and those wavelengths will depend on the atoms comprising the gas [3].

Spectral lines arise from atoms or molecules undergoing transitions between two energy states differing in energy by ΔE and it is an excess (emission) or deficiency (absorbtion) of radiation at a specific frequency relative to nearby frequencies. While an emission line adds light of a particular wavelength, an absorption line subtracts light of a particular wavelength. They provide powerful diagnostics of the regions that form the line. The formation of spectral lines is quantified with the radiation transfer equation. Its solution for different conditions gives insight to the formation of both absorption and emission lines. An absorption line can be diagnosed by superposed lie upon a continuum spectrum. An emission line may or may not be superposed upon a continuum spectrum [3]

2.3 Plank's law

The idea of light in the form of energy quanta [29] of size $h\nu$ was introduced by Planck to explain the radiation energy B(T) emitted by a black body as a function of frequency (wave length) and temperature T, per unit frequency, surface area, viewing solid angle and time.

Many interesting phenomena emitting thermal radiation follow approximately the theoretical curve of a black body radiation. To determine the temperature and other properties of such body Planck's law becomes a source of information about them. Planck's law gives the spectral distribution of electromagnetic emission for a black body at a given temperature. Here our main objective is to derive Planck's radiation formula because Planck's radiation function plays an important role as the only source function in the radiative transfer equation when a non-scattering medium is in local thermodynamic equilibrium so that a beam of monochromatic intensity passing trough the medium will undergo absorption and emission processes simultaneously [29, 1].

The Planck function is derived in the frequency domain using the method of oscillators. To derive the form of a black-body spectrum we need to apply some elementary quantum mechanics and to know the number density of photon states for a given energy level and the average energy of each state, using Boltzmann formula.

Planck postulated that atoms oscillating in the walls of the cavity have discrete energies given by $E = nh\nu$. The energy level of a harmonic oscillator are equally spaced by $\Delta E = E_{n+1} - E_n = h\nu$, $E_n = nh\nu$ for n = 0,1,2,3,.... , where n is integer (quantum number), h is Planck's constant, ν is frequency and ΔE is quantum of energy emitted when an atom changes its energy state.

For energy of a mode E_n, there are n photons in the mode. Each photon has an energy equal to $h\nu$, the energy of a mode is quantized. To obtain the probability n photons P(n) in the mode of frequency, we start from the definition temperature Boltzmann factors (According to statistical mechanics, when local thermodynamic equilibrium (LTE) holds in the material, the state populations will obey a Boltzmann distribution proportional to $e^{\frac{-E}{kT}}$). Where E is the state energy, T is temperature, and k is Boltzmanns constant.

$$P(E_n) = Ae^{\frac{-En}{kT}} \tag{2.3.1}$$

A is normalizing constant

$$\sum_{n=0}^{\infty} P(E_n) = A \sum_{n=0}^{\infty} e \frac{-nh\nu}{kT} = 1 \tag{2.3.2}$$

The sum of all the probabilities must be 1. Using the fact that: $\sum x^n = 1 + x + x^2 + x^3 + x^4 ... = \frac{1}{1-x}, x = e^{\frac{-h\nu}{kT}}$, therefore, $A = 1 - x = 1 - e^{\frac{-h\nu}{kT}}$,

$$P(E_n) = (1 - e^{\frac{-h\nu}{kT}})e^{\frac{-E_n}{kT}} or P(n) = (1 - e^{\frac{-h\nu}{kT}})e^{\frac{-nh\nu}{kT}}, \tag{2.3.3}$$

For the expression of probability P(n) there are n photons in at the temperature T.

$$< n >= \sum_{n=0}^{\infty} nP(n) = (1 - e^{\frac{-h\nu}{kT}}) \sum_{n=0}^{\infty} ne^{\frac{-nh\nu}{kT}}, \tag{2.3.4}$$

$$\sum_{n=0}^{\infty} ne^{\frac{-nh\nu}{kT}} = \sum_{n=0}^{\infty} ne^{-\alpha n},$$

where $\alpha = \frac{h\nu}{kT}$

$$\sum_{n=0}^{\infty} n e^{-\alpha n} = -\frac{\partial}{\partial \alpha} \sum_{n=0}^{\infty} e^{-\alpha n}$$

$$= \frac{\partial}{\partial \alpha}\left(\frac{1}{1-e^{-\alpha}}\right) = \frac{-\partial}{\partial \alpha}\left(\frac{1}{1-e^{-\alpha}}\right) = \frac{e^{-\alpha}}{(1-e^{-\alpha})^2} \tag{2.3.5}$$

$$< n > \; = \; \frac{e^{\frac{-h\nu}{kT}}}{1 - e^{\frac{-h\nu}{kT}}} \tag{2.3.6}$$

$$< n > \; = \; \frac{1}{e^{\frac{h\nu}{kT}} - 1} \tag{2.3.7}$$

or

$$< n >= \frac{1}{e^{\frac{hc}{\lambda kT}} - 1} \tag{2.3.8}$$

Eqn(2.3.8) is the thermal average distribution of photons plank's distribution. Multiplying this number by energy per photon ($h\nu$), it gives the mean thermal energy.

$$< E_n >= h\nu < n >= \frac{h\nu}{e^{\frac{h\nu}{kT}} - 1}, \tag{2.3.9}$$

or

$$< E >= \frac{\frac{hc}{\lambda}}{e^{\frac{hc}{\lambda kT}} - 1}. \tag{2.3.10}$$

This equation is the average energy per mode or quantum is the energy of the quantum times the probability that it will be occupied.

2.3.1 The Planck Spectral Energy Distribution in Terms of Frequency and wavelength Domain

To show this we need the number of modes of oscillation of electromagnetic wave in a cavity in the frequency interval ν to $\nu + d\nu$ per unit volume. consider a one-dimensional box of side L and in equilibrium only standing waves are possible, and these will have nodes at the ends.$X = 0, L$.

$$\frac{L}{\lambda} = \frac{n_x}{2}, n_x = 1, 2, 3, .. \tag{2.3.11}$$

$$n_y = \frac{2L}{\lambda}, n_y = 1, 2, 3, ...n_z = \frac{2L}{\lambda}, n_z = 1, 2, 3, ... \tag{2.3.12}$$

Where λ is wave length. In 3D, each triplet of integers (posetive) (n_x, n_y, n_z) correspond to a possible mode of standing wave inside the cavity. To find the number of modes with frequency between ν and $\nu + d\nu$, look at fig 2.3 an array of points. Each

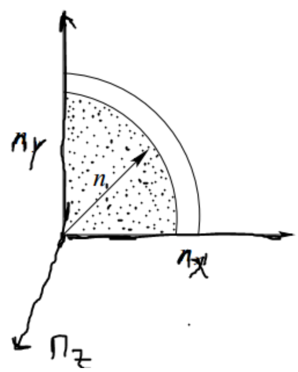

Figure 2.3: An array of points in acavity

cube has side $\frac{c}{2L}$. Each point in this space, (n_x, n_y, n_z), represents a mode and each points represent two mode and are distributed uniformly in this space. So there are two modes per unit volume of n-space. $\lambda = \frac{c}{\nu} \Longrightarrow \nu = \frac{n_x c}{2L}$. There are two independent polarizations possible for photons. By noting that $n = (n_x^2 + n_y^2 + n_z^2)^{\frac{1}{2}}$ is the radius of sphere in n-space. Actually the number of triplets of positive integers is equivalent to the volume of one octant of the space (one-eight of the spherical shell) whose thickness is dn. Then the number of modes that lie between n and n + dn is equal to the number of n-space points inside the spherical shell times two. The volume of spherical shell of radius n and dn is $4\pi n^2 dn$ and so the number of modes in the octant is $2(\frac{1}{8})4\pi n^2 dn$. The factor 2 comes from two possible states of polarization for each standing wave. If we convert the result interms of frequency,

$$n = \frac{2L}{\lambda} = \frac{2L\nu}{c}, dn = \frac{2L}{c} d\nu$$

$$The number of modes in the octant = (\frac{\pi 4L^2\nu^2}{c^2})(\frac{2L}{c})d\nu$$

Let $N(\nu)d\nu$ represent the number of standing waves in the cavity in [$\nu, \nu + d\nu$], then we get the result

$$N(\nu)d\nu = \frac{8\pi L^3\nu^2}{c^3} d\nu \tag{2.3.13}$$

$$N(\nu)d\nu = \frac{8\pi V\nu^2}{c^3} d\nu \tag{2.3.14}$$

L^3 has been replaced by V of the cavity and equation 2.3.14 is the number of modes of oscillation in the frequency interval ν to $\nu + d\nu$. Thus, per unit volume, the number of states is

$$N(\nu)d\nu = \frac{8\pi\nu^2}{c^3} d\nu \tag{2.3.15}$$

The factor $4\pi\nu^2 d\nu$ is the volume of thin spherical shell.

When the system is in thermal equilibrium each mode of oscillation will attain the same energy $\bar{E}$. There fore, the energy density of radiation per unit frequency interval per unit volume is, multiplying the number of mode of standing wave whose frequency lies between ν and $\nu + d\nu$ (eqn 2.3.14) by average energy (eqn 2.3.10) and divide by the volume of cavity. $U(\nu)d\nu$ is the energy per unit volume between ν and $\nu + d\nu$ is, expressed in terms of either frequency or wavelength:

$$du = u(\nu)d\nu = \frac{(N(\nu)d\nu)\bar{E}}{V^3} \tag{2.3.16}$$

$$u(\nu)d\nu = (\frac{8\pi\nu^2}{c^3})\frac{h\nu}{e^{\frac{h\nu}{kT}}-1}d\nu \tag{2.3.17}$$

$$u(\nu)d\nu = (\frac{8\pi h\nu^3 d\nu}{c^3})\frac{1}{e^{\frac{h\nu}{kT}}-1} \tag{2.3.18}$$

Eqn.(2.3.18) is the monochromatic (or spectral) energy density of Planck. To find the dependence of the total energy density of radiation U up on temperature, integrating this over all frequencies or wavelengths.

$$U = \int_0^\infty U(\nu)d\nu \tag{2.3.19}$$

$$U = \frac{8\pi h}{c^3}\int_0^\infty \frac{\nu^3 d\nu}{e^{\frac{h\nu}{kT}}-1}. \tag{2.3.20}$$

Change the variable to $x = \frac{h\nu}{kT}$, so $dx = \frac{h}{kT}d\nu$. Then,

$$U = \frac{8\pi h}{c^3}(\frac{kT}{h})^4\int_0^\infty \frac{x^3 dx}{e^x-1} \tag{2.3.21}$$

The integral is a standard integral, the value of which is
$\int_0^\infty \frac{x^3dx}{e^x-1} = \frac{\pi^4}{15}$

$$U = (\frac{8\pi^5 k^4}{15c^3h^3})T^4 \tag{2.3.22}$$

$$U = aT^4 \tag{2.3.23}$$

Eqn 2.3.23 is the total energy density of radiation where $a = \frac{8\pi^5 k^4}{15c^3h^3}$ is radiation constant. Specific intensity is generally related to the differential amount of radiant energy, dE, that crosses an area element, dA, in directions confined to differential solid angle $d\Omega$.

$$dE_\nu = B_\nu cos\theta dA d\nu d\Omega dt \tag{2.3.24}$$

B_ν is specific intensity of the radiation at the frequency ν in the direction of the solid angle $d\Omega$. Its dimension is $Wm^{-2}Hz^{-1}sr^{-1}$.

$$\frac{dE}{dV} = u_\nu d\nu = \frac{8\pi h\nu^3 d\nu}{c^3}\frac{1}{e^{\frac{h\nu}{kT}} - 1} \tag{2.3.25}$$

$$dE = \frac{8\pi h}{c^3}\frac{\nu^3}{e^{\frac{h\nu}{kT}} - 1} d\nu dv = B(\nu, T) cos\theta dA d\Omega dt d\nu \tag{2.3.26}$$

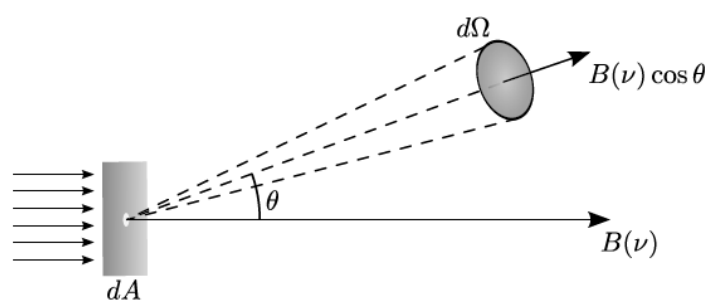

Figure 2.4: Intensity is the energy of radiation passing through area dA into a solid angle $d\Omega$ per time, per wavelength [Source, AST1100 Lecture Notes, page 6]

$$B(\nu, T) = \frac{8\pi\nu^3 hc dt dA d\nu}{c^3(e^{\frac{h\nu}{kT}} - 1) dA d\Omega dt d\nu} \tag{2.3.27}$$

where $V = cdtdA$ and $d\Omega = 4\pi$

The specific intensity for blackbody radiation - the Planck radiation law in terms of the frequency ν and temperature T, is

$$B(\nu, T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1} \tag{2.3.28}$$

Eqn. (2.3.28) is planck's function of spectral radiance in frequency ν domain [$Wm^{-2}Hz^{-1}sr^{-1}$] where $h = 6.626 * 10^{-34} Js$ and $k = 1.381 * 10^{-23} Jk^{-1}$ are the Planck and Boltzmann constants and $c = 3 * 10^8 m$ the speed of light. The planck's law as spectral radiance function in the wave length domain is;

$$B_\nu d\nu = -B_\lambda d\lambda \tag{2.3.29}$$

The minus sign indicates that the wave length decreases with increasing frequency. $c = \lambda\nu \Longrightarrow \nu = \frac{c}{\lambda}$,

$$\frac{d\nu}{d\lambda} = -\frac{c}{\lambda^2}, \tag{2.3.30}$$

$$B_\lambda = -B_\nu \frac{d\nu}{d\lambda} \tag{2.3.31}$$

$$B_\lambda = B_\nu(\frac{c}{\lambda^2}) \tag{2.3.32}$$

$$B(\nu, T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}} - 1} \tag{2.3.33}$$

The Stefan Boltzmann power law - The total intensity of radiation depends up on temperature and is proportional to the fourth power of temperature as $B \ \ \alpha \ \ T^4$. The total intensity can be found by using either of planck radiation law integrating over all frequencies or wave lengths eqn.(2.3.28 or 2.3.33) respectively.

$$B(T) = \int_0^\infty B(\nu, T) d\nu \tag{2.3.34}$$

$$B(T) = \frac{2h}{c^2}\int_0^\infty \frac{\nu^3}{e^{\frac{h\nu}{kT}}-1}d\nu \quad (2.3.35)$$

$Definingx = \frac{h\nu}{kT}$ gives to

$$B(T) = \frac{2k^4}{c^2h^3}T^4\int_0^\infty \frac{x^3}{e^x-1}dx \quad (2.3.36)$$

$$B(T) = \frac{2\pi^4k^4}{15c^2h^3}(T^4) \quad (2.3.37)$$

$$B(T) = \beta T^4 \quad (2.3.38)$$

with $\beta = \frac{2\pi^4k^4}{15c^2h^3}$ Since the black body radiance may be considered as an example of isotropic radiance, the radiative flux density (F) also called the irradiance. Then flux density of F for isotropic radiation of intensity B is integrating eqn. (2.3.28) over all frequencies and all possible solid angles gives the energy flux F emitted per surface area A by a black body. Using that the angular interval consist of the solid angle $d\Omega = d\theta sin\theta d\phi = d\phi(dcos\theta)$ by taking in to account only the perpendicular area $A \perp = Acos\theta$ is visible.

$$F = \int_0^\infty d\nu \int d\Omega B_{(\nu)}cos\theta \quad (2.3.39)$$

$$\int d\Omega cos\theta = \int_0^{2\pi} d\phi \int_0^{\frac{\pi}{2}} d\theta sin\theta cos\theta = \pi \int_0^{\frac{\pi}{2}} d\theta sin2\theta = \pi \quad (2.3.40)$$

Now,

$$F = \pi\int_0^\infty B_\nu d\nu = \pi\int_0^\infty \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kt}}-1}d\nu \quad (2.3.41)$$

By using Eqn(2.35)

$$F(T) = \pi B(T) \quad (2.3.42)$$

Then insert Eqn(2.3.38) in to Eqn(2.3.42)

$$F(T) = \pi\beta(T^4) \tag{2.3.43}$$

$$\sigma = \pi\beta \tag{2.3.44}$$

$$F(T) \;\;=\;\; \sigma T^4 \tag{2.3.45}$$

in (Wm^{-2}; blackbody radiation) where $\sigma = \pi\beta = 5.67 * 10^{-8} Jm^{-2}s^{-1}k^{-4}$ is the Stefan-Boltzmann constant.

The flux radiated from the surface of a black body is related to the energy density as:

$$F_\nu = \frac{c}{4} u_\nu$$

or

$$F_\lambda = \frac{c}{4} u_\lambda$$

The flux (eqn.2.3.45) increases rapidly with temperature. A doubling of the temperature yields a power greater by a factor of 16.

Now the flux density in terms of frequency and wavelengths are

$$F_\nu = B_\nu \pi = \frac{2\pi h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{kT}} - 1} \tag{2.3.46}$$

$$F = B_\lambda \pi = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1} \tag{2.3.47}$$

From the Steffan-Boltzmann law we get a relation between the luminosity (L) and temperature of a star if the flux density on the surface is F.

$$L = 4\pi R^2 F \tag{2.3.48}$$

If the star is assumed to radiate like a black-body, then by substituting equation (2.3.45) in to (2.3.48)

$$L = 4\pi\sigma R^2 T^4 \tag{2.3.49}$$

(L is luminosity of spherical object, R is stellar radius.

By inserting eqn. (2.3.42) in to eqn. (1.2.4) (i.e the relation ship between magnitude and flux)

$$m_1 - m_2 = -2.5log\frac{\pi B_1}{\pi B_2} \tag{2.3.50}$$

$$\frac{B_{\lambda_1}}{B_{\lambda_2}} = \frac{\lambda_2^5}{\lambda_1^5} = \frac{e^{\frac{hc}{\lambda_2 kT}} - 1}{e^{\frac{hc}{\lambda_1 kT}} - 1} \tag{2.3.51}$$

The temperature T solved from this equation is a color temperature. Then eqn. (1.2.4)

$$m_1 - m_2 = -2.5log\left[(\frac{\lambda_2}{\lambda_1})^5\left(\frac{e^{\frac{hc}{\lambda_2 kT}}}{e^{\frac{hc}{\lambda_1 kT}}}\right)\right] \tag{2.3.52}$$

$$m_1 - m_2 = 12.5log(\frac{\lambda_1}{\lambda_2}) - 2.5\frac{hc}{kT\lambda_2} - \left(\frac{-2.5hc}{kT\lambda_1}\right)$$

$$m_1 - m_2 = 12.5log(\frac{\lambda_1}{\lambda_2}) + \frac{2.5hc}{kT}\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)loge \tag{2.3.53}$$

$$m_1 - m_2 = -2.5log(\frac{\nu_2}{\nu_1})^3 + \frac{h}{kT}(\nu_2 - \nu_1)loge$$

2.3.2 Effective Temperature

This temperature is the temperature that the object would have if it were a perfect blackbody. That is, the effective temperature of a star is the temperature of a black body that would emit the same total amount of electromagnetic radiation and with the same luminosity per surface area (F_{Bol}) as the star. It is defined according to the Stefan-Boltzmann law $F_{Bol} = \sigma T_{eff}^4$ that the total (bolometric) luminosity of a star is then $L = 4\pi\sigma R^2 T_{eff}^4$, where R is the star radius. It is the most important physical quantity often used as an estimate of a body's surface temperature when the body's emissivity curve (as function of wavelength) is not known.

$$T_{eff} = (\frac{L}{4\pi\sigma R^2)^{\frac{1}{4}}} \tag{2.3.54}$$

If the flux density at a distance r is

$$F^{'} = \frac{L}{4\pi r^2} = \frac{R^2}{r^2}F = (\frac{\alpha}{r2})^2\sigma T_{eff}^4 \tag{2.3.55}$$

where $\alpha = \frac{2R}{r}$ is the observed angular diameter of the star. For direct determination of the effective temperature, we must measure the total flux density and the angular diameter of the star. If we assume that at some wavelength λ the flux density $F_\lambda$on the surface of the star is calculated from planck's law, we get the brightness temperatureT_b In the isotropic case :

$$F_\lambda = \pi B_\lambda(T_b) \tag{2.3.56}$$

$$F_\lambda^{'} = \frac{R^2}{r^2}F_\lambda \tag{2.3.57}$$

$$F_\lambda^{'} = \left(\frac{\alpha}{2}\right)^2 \pi B_\lambda(T_b) \tag{2.3.58}$$

At low frequency and high temperatures, $h\nu << kT$

$$B_\nu = \frac{2\nu^2 kT}{c^2}$$

In radio astronomy, brightness temperature is used to express the intensity (or surface brightness) of the source. If the intensity at frequency $\nu is I_\nu$, the brightness temperature is

$$I_\nu = B_\nu(T_b) \tag{2.3.59}$$

$$T_b = \frac{c^2}{2k\nu^2} I_\nu \tag{2.3.60}$$

$$T_b = \frac{\lambda^2}{2k} I_\nu \tag{2.3.61}$$

Spectral radiance of black-body radiation is expressed by wavelength as:
$B_\lambda = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$

$$I_\lambda = B_\lambda T_b \tag{2.3.62}$$

For long-wave radiation $hc << kT$.

$$T_b = \frac{I_\lambda \lambda^5}{2hc^2} \frac{hc}{k\lambda} \tag{2.3.63}$$

$$T_b = \frac{I_\lambda \lambda^4}{2kc} \tag{2.3.64}$$

2.3.3 Limiting cases

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}}} \tag{2.3.65}$$

In the limit of high temperature or long wave lengths the term in the exponential becomes small and it is approximated with the Taylor polynomials first order term, and

$$e^{\frac{hc}{\lambda kT}} \approx 1 + \frac{hc}{\lambda kT}$$

So

$$\frac{1}{e^{\frac{hc}{\lambda kT}} - 1} \approx \frac{1}{\frac{hc}{\lambda kT}} = \frac{\lambda kT}{hc}$$

Then the Planck's black body formula reducing to

$$B_\lambda(T) = \frac{2ckT}{\lambda^4} \tag{2.3.66}$$

$$F = \frac{2ckT\pi}{\lambda^4} \tag{2.3.67}$$

In the limit of small frequencies i.e $h\nu << kT$

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1} \approx \frac{2h\nu^3}{c^2}\frac{kT}{h\nu}$$

(RayleighJeans law)

$$B_\nu(T) = \frac{2\nu^2 kT}{c^2} \tag{2.3.68}$$

$$F = \frac{2\pi\nu^2 kT}{c^2} \tag{2.3.69}$$

$$L = 4\pi R^2 \frac{2\pi\nu^2 kT}{c^2} \tag{2.3.70}$$

For energy per unit volume (energy density)

$$U(\nu, T) \approx \frac{4\pi}{c} B_\nu(T) \tag{2.3.71}$$

$$U(\nu, T) = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

$$U(\nu, T) \approx \frac{8\pi kT\nu^3}{c^3} \tag{2.3.72}$$

$$U(\lambda, T) = \frac{8\pi hc}{\lambda^5}\frac{1}{e^{hc}\lambda kT - 1}$$

$$U(\lambda, T) \approx \frac{8\pi kT}{\lambda^4} \tag{2.3.73}$$

2.3.4 Temperature brightness

Brightness temperature or radiance temperature is the temperature a black body in thermal equilibrium with its surroundings would have to be to duplicate the observed intensity of a grey body object at a frequency ν. This concept is used in radio astronomy. It characterizes radiation, and depending on the mechanism of radiation can differ considerably from the physical temperature of a radiating body.

Chapter 3

Extinction by Earth's Atmosphere On Spectral Energy Distribution of Astronomical Objects

In areal observations a number of effects can complicate the picture. The theoretical celestial brightness requires accurate models of many effects, among them atmospheric extinction is one. Since the first pointing of a telescope towards the sky by Galileo Galilei, the extinction properties of the atmosphere have hampered the astronomical observations made with the instruments placed on the Earths surface. Our knowledge of celestial objects must take into account absorption and scattering of photons as they travel to earth atmospheres [27].

As light propagates to us from its sources it experiences various opportunities to interact with material. As a result the flux of the observed object reduced. Attenuation causes the strength of the signal to drop off rapidly after travelling a few kilometres. Then to allow ground based observations the exact knowledge of properties of earth's atmosphere and correction for the effect is needed. Because the correction for optical atmospheric extinction is one of the crucial steps for achieving accurate spectrophotometry from the ground. In making these observations, we must also correct for the effect of the Earths atmosphere.

So generally my concern is the astrophysically uninteresting attenuation from the four hurdles faced by an astronomical photon and air mass. It is useful to define the mean-free path, l, for a photon and the related opacity and optical depth.

3.1 Optical Depth

The opacity of a material is a measure of its ability to absorb light. The dimensionless parameter, τ_ν describing the opacity or extinction at frequency ν. In particular, the infinitesimal increase in optical depth along a line of sight $d\tau_\nu$, is related to the infinitesimal path length dr according to.

$$dL = -\alpha L dr \tag{3.1.1}$$

$$d\tau = \alpha dr \tag{3.1.2}$$

Where α is the factor tells how effectively the medium can obscure radiation. It is called the opacity. Substitute eqn. (3.1.2) in to eqn. (3.1.1). Next integrate eqn. (3.1.3) from the source (where $L = L_0$ and r = 0).

$$dL = -d\tau L \tag{3.1.3}$$

$$\int_{L_0}^{L} \frac{dL}{L} = \int_{\tau_0}^{\tau} -d\tau \tag{3.1.4}$$

Opacity (extinction) reduces the flux of a source according to

$$L_{\nu,obs} = L_{\nu,0}\, e^{\tau_\nu} \tag{3.1.5}$$

Where τ is the optical thickness (depth) of the material between the source and the observer, depending on wavelength and cloud properties. Gas with $\tau_\lambda >> 1$ is optically thick and if $\tau_\lambda << 1$ the gas is optically thin. L, is the observed flux, $L_{\nu,0}$ is the unextincted flux(i.e., $\tau = 0$). The flux L falls off exponentially with increasing optical thickness. Empty space is perfectly transparent $\alpha = 0$ thus the optical thickness does not increase in empty space, and the flux remains constant.

The opacity can be due to one of four main physical processes (or a combination of them):

- Bound-bound transitions - these are the familiar transitions between different energy levels which cause absorption (or emission) lines at discrete wavelengths.

- Bound-free absorption - this is the process of photoionisation which will occur for all photon energies greater than ionisation potential of a given atomic energy level:

  bound $\longrightarrow$ unbound:ionisation

  unbound$\longrightarrow$bound:recombination

- Free-free absorption - a photon is absorbed by a free electron and an ion,free electron gains energy by absorbing a photon in the vicinity of an ion, or loses energy by emitting a photon which share the photons momentum and energy (continuum opacity). This is the inverse process of free-free emission (bremsstrahlung) in which a free electron is decelerated by the electric potential of an ion and, as a result, radiates.

- Electron scattering - this is the scattering of photons by free electrons without change of photon energy.

3.1.1 The Magnitude of The Extinction

Let F_0 be the flux density on the surface of a star and F_r the flux density at a distance r,

$$F_0 = \frac{L_0}{4\pi R^2} \tag{3.1.6}$$

$$L_0 = 4\pi R^2 F_0 \tag{3.1.7}$$

R is star radius

$$F_r = \frac{L}{4\pi r^2} \tag{3.1.8}$$

$$L = 4\pi r^2 F_r \tag{3.1.9}$$

by substitution $L = L_0 e^{-\tau}$

$$L_0 e^{-\tau} = 4\pi r^2 F_r \tag{3.1.10}$$

$$F_r = F_0 e^{-\tau} \frac{R^2}{r^2} \tag{3.1.11}$$

$$m - m_0 = -2.5 log \frac{F_\lambda r}{F_\lambda 0} = -2.5 log(\frac{R^2}{r^2}) e^{-\tau} = A_\lambda \tag{3.1.12}$$

m is the magnitude observed, m_0 is the intrinsic magnitude

$$A_\lambda = -2.5 \log(e^{-\tau_\lambda}) = \Delta m = m - m_0 = 1.086 \tau_\lambda \tag{3.1.13}$$

3.1.2 Atmospheric Extinction

Electromagnetic Radiation is attenuated by its passage through the atmosphere. At higher frequencies, atmospheric opacity is incompatible with ground based observation. Models for atmospheric extinction deal mainly with the wavelength dependence of the atmospheric extinction $k_{\lambda,z}$, is the sum of physical elementary components, either scattering or absorption. Rayleigh scattering on molecules, Mie(1908) scattering on aerosol, ozone and telluric (molecular) absorbtion and each of these has its own form of wavelength dependence, distribution with height, and variation with time. Atmospheric extinction is the scattering and absorption of electromagnetic radiation [27].

3.1.3 Scattering

Scattering can be broadly defined as the redirection of radiation out of the original direction of propagation, usually due to interactions with molecules and particles(non-homogeneity).

Rayleigh scattering (1871) is molecular scattering. Occurs when the diameter of the molecules and particles are many times smaller than the wavelength of the incident EMR. The molecular scattering in the visible and near infrared primarily caused by air particles i.e. O_2 and N_2 molecules. The amount of scattering is inversely related to the fourth power of the radiation's wavelength ($I \, \alpha \, \frac{1}{\lambda^4}$) that means causes shorter wavelengths (violet, blue) of energy to be scattered much more than longer wavelengths and it is the dominant scattering mechanism in the upper atmosphere [27]. The fact that the sky appears blue during the day is because of this phenomenon. The Rayleigh scattering component of the extinction is reliably calculated as a function of wavelength, altitude, and the index of refraction. The attenuation due to Rayleigh scattering thus depends on the pressure of the atmosphere along the line of sight.

Mei Scattering - takes place when there are essentially spherical particles present in the atmosphere with diameters approximately equal to the wavelength of radiation.

Dust, pollen, smoke and water vapor are common causes of Mie scattering which tends to affect longer wavelengths.

Both of them are elastic scattering, the wavelength (frequency) of the scattered light is the same as the incident light (Rayleigh and Mie scattering).

3.1.4 Absorption

The process whereby the intensity of a beam of electromagnetic radiation is attenuated in passing through a material medium by conversion of the energy of the radiation to an equivalent amount of energy which appears within the medium; the radiant energy is converted into heat or some other form of molecular energy.

Different molecules in the atmosphere absorbing energy (EMR) at various wavelengths. The most important sources of telluric (molecular) absorption are molecular oxygen and ozone. Absorption of $UV - V_{visible}$ light in the atmosphere is mainly dominated by these two atmospheric gases corresponding to the largest photo absorption cross sections and water, which absorbs strongly in the infrared. The other minor atmospheric species are optically thin to UV-Vis radiations. The regions below 320nm and above 870nm are especially affected, due to strong O_3 and H_2O absorption, respectively. Molecules produce discrete absorption lines and bands. Atmosphere is as an absorbing slab. The opacity of ozone is responsible for the total loss of atmospheric transmission below 300nm [27].

During the absorption process a photon is destroyed and its energy transferred to the molecule, leading sometime to subsequent emission Wavelength Species. They produce discrete absorption features that can be very troublesome in certain wavelength ranges. The features can be quite strong and/or variable.

3.1.5 Refraction

More than two centuries ago Laplace established that for an atmosphere with spherical symmetry whose density decreases exponentially with height, the logarithm for the intensity of incoming light from any heavenly body is proportional to its refraction divided by the cosine of its apparent elevation angle. Most, if not all, theories of atmospheric refraction are based on the model of a stratified spherical envelope of air, concentric with the earth, the strata being thin shells of refractive index n. In the simplest model there is only one homogeneous shell of constant refractive index n_o, but in the more realistic approach n decreases gradually with height y.

Refraction deviate the apparent direction of a star chromatically that means in a wavelength-dependent way, from its true direction. When light passes at an angle through a transparent medium of different layers of air, it is bent by slightly different angles. The material in the atmosphere causes the photons to change direction slightly at an angle because of this the direction of an object differers from the original position (in the absence of an atmosphere) by an amount depending on the atmospheric conditions along the line of sight and the angle by which the light is bent is determined by the index of refraction of the material [3, 4, 27].

Because of refraction varies with atmospheric pressure and temperature,it is very difficult to predict accurately. However, an approximation good enough for most practical purposes is easily derived. If the object is not too far from the zenith, the atmosphere between the object and the observer can be approximated by a stack of parallel planar layers,each of which has a certain index of refraction n_i, outside the atmosphere, n=1. For example, all of the atmospheric models we incorporate in our refractive signal analysis assume a static, homogeneous, two-layer (troposphere and stratosphere) atmosphere. We define astronomical refraction, r, to be the angular

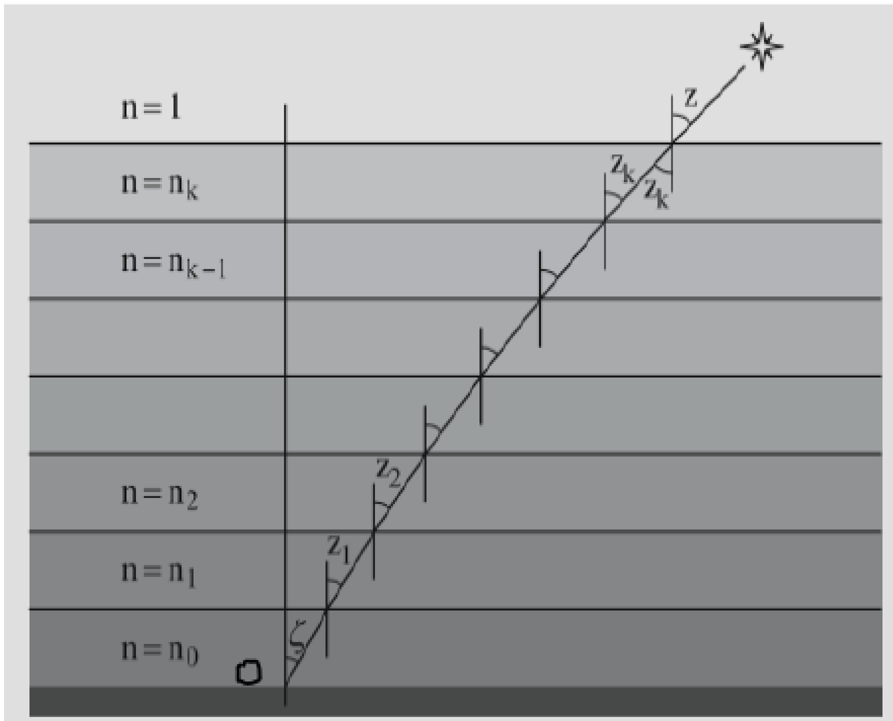

Figure 3.1: Refraction of alight ray traveling through the atmosphere [Source, (Fundamental Astronomy 5th edition, page 24)]

amount that the object is displaced by the refraction of the Earth's atmosphere: Let the true zenith distance be z and the apparent one ζ. Using fig. 3.1 we obtain the following equations for the boundaries of the successive layers: Initially, we assume a single homogeneous layer of refractive index n. The observer is at O; the observed zenith distance of an object is $sinz_0$. Applying the sine law of refraction at the refracting upper surface gives: Let $\zeta = z_0$

$$nsin(z_1) = sin(z_2) \tag{3.1.14}$$

But because all the verticals are parallel in this model, the angles z_0 and z_1 are equal; so

$$nsin(z_0) = sin(z_2) \tag{3.1.15}$$

This can be extended to a second layer, and then to a third. The product $(n_i sinz_i)$ at every horizontal interface remains equal to the sine of the zenith distance at the top of the whole stack, where n = 1 exactly; in particular, $nsinz_0$ at the bottom remains equal to sin(z) at the top of the stack. It is as though there were only the bottom layer, of index n. The refraction, R, is the difference of the angles z_0 and z_2 is

$$R = z_2 - z_0. \tag{3.1.16}$$

$$z_2 = arcsin(nsinz_0). \tag{3.1.17}$$

the exact expression for the refraction R in the plane-parallel model is

$$R = arcsin(nsinz0) - z_0. \tag{3.1.18}$$

By approximation

$$z_2 = z_0 + R. \tag{3.1.19}$$

The trigonometric identity for the sine of a sum of angles:

$$sinz_2 = sinz_0 cosR + cosz_0 sinR. \tag{3.1.20}$$

putting $sinR \sim R$, and $cosR \sim 1$,

$$sinz_2 = sinz_0 + Rcosz_0 \tag{3.1.21}$$

Insert this expression for $sinz_2$ back into the refraction-law

$$nsinz_0 = sinz_0 + Rcosz_0; \tag{3.1.22}$$

and solving for R gives

$$Rcosz_0 = (n-1)sinz_0,$$

$$R = (n-1)tanz_0 \tag{3.1.23}$$

This equation is the flat-Earth approximation for the refraction. It is proportional to the refractivity at the observer, and the tangent of the apparent (refracted) zenith distance.

When the altitude is over 15^o, we can use an approximate formula

$$R = \frac{P}{273+T}0.00452^o tan(90^o - a), \tag{3.1.24}$$

where a is the altitude in degrees, T temperature in degrees Celsius, and P the atmospheric pressure in hectopascals.

At lower altitudes the curvature of the atmosphere must be taken into account and an approximate formula for the refraction is then

$$R = \frac{P}{273+T}\frac{0.1594 + 0.0196a + 0.00002a^2}{1 + 0.505a + 0.0845a^2} \tag{3.1.25}$$

3.2 Atmospheric Window

The Earths atmosphere has always acted as a screen between the observer and the rest of the Universe. Atmospheric windows is then spectral regions where observation is possible from surface of the earth and refer to Radio Window, Infrared Window, Optical Window

- **Visible range window**

  $0.4\mu m$ - $0.7\mu m$,

Extinction in optical only 10-15 percent and transmit UV and visible: 0.30 - 0.75 μm atmosphere becomes opaque below 300 nm (due to ozone layer at altitude of 20-30 km).

- **Longwave window** 8 - 12μm NIR (0.8-1.35 μm) partial absorption due to water vapor and oxygen
- Beyond 1.35 μmabsorption bands Beyond 25 μm atmosphere is completely opaque up to $\lambda$of a few mm
- The radio window cover a range from a few cm to a few tens of meters

3.3 Atmospheric emission

Daytime, scattering of sunlight prevents observations in visible and near infrared and nighttime scattering of moonlight + fluorescence (air-glow)

- Emission of spectral line in NIR due to radiative de-excitation of atoms and radicals (OH^-) in the upper atmosphere (100 km)
- Above 2.3μm, atmospheric radiation is dominated by thermal emission
- Beyond 2μm, thermal emission from telescope also becomes important.

Atmospheric emission generally fluctuates in time (movement of invisible clouds of water vapor, variable excitation of fluorescence during the night, ionospheric winds, and so on), and the frequencies are rather high ($f \sim 0.110 Hz$)

3.4 Radiative Transfer

When observing an astronomical source through a cloud of matter which lies along the line of sight absorb the radiation from the source, scatter it or in fact emit further radiation. Each of these will change the sources apparent intensity. Radiative transfer is the combined effect of absorbtion and emission of electromagnetic radiation.

3.4.1 Absorbtion

Consider scant cloud of perfectly absorbing spheres of cross section σ_ν and number density n, as the beam of area dA propagates a distance ds into the cloud it encounters a total absorbing cross-section of $n\sigma_\nu ds$: We expect that a fraction of $\sigma_\nu nds$ of the beam to be observed.

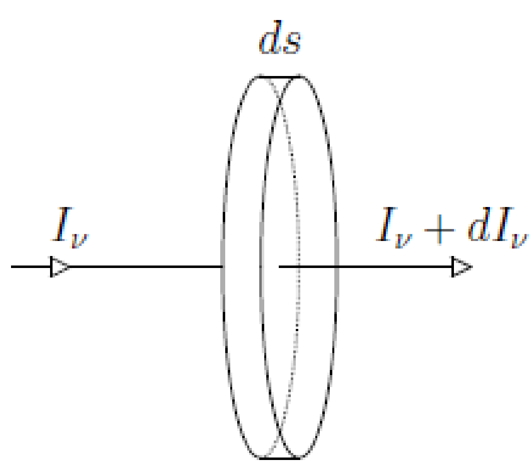

Figure 3.2: Absorption of Radiation Through's Earth Atmosphere [Source, Fundamental Stellar Parameters
]

$$dI_\nu = -n\sigma I_\nu ds = -k_\nu I_\nu ds \tag{3.4.1}$$

where $k_\nu[cm^{-1}]$: absorption coefficient as the fractional loss of intensity per unit length (represents radiation taken out of the beam by absorption) and microscopically, $k = n\sigma_\nu$

Over a distance s :

$$\int_0^s \frac{dI_\nu}{I_\nu} = -\int_0^s k_\nu ds = -\tau_\nu, d\tau = k_\nu ds \tag{3.4.2}$$

$$\tau_\nu(s) = \int_0^s k_\nu(s)ds$$

The beam intensity that survives passage through a uniform absorbing medium decreases exponentially with distance traveled as:

$$I_\nu(s) = I_{\nu(0)}e^{-\tau_\nu} \tag{3.4.3}$$

By convention, $\tau = 0$ at top of atmosphere and increases inwards. Then infinitesimal energy absorbed is

$$dE_\nu^a = dI_\nu^a cos\theta dAd\Omega dtd\nu \tag{3.4.4}$$

$$dE_\nu^a = k_\nu cos\theta dAd\Omega dtd\nu ds \tag{3.4.5}$$

K_ν is the opacity as a function of frequency.

3.4.2 Radiative Emission

Suppose the slab of material also emits radiation at a certain rate. An excited atom can return to its ground state through two distinct mechanisms: (i). the atom emits energy spontaneously; (ii). it is stimulated into emission by the presence of electromagnetic radiation. It tells us how much radiation energy the gas emits per unit time

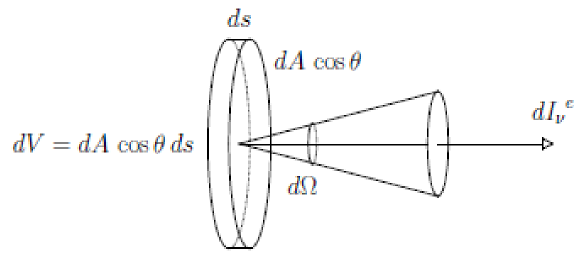

Figure 3.3: Emission of Radiation [Source, Fundamental Stellar Parameters]

per unit volume per unit solid angle per unit frequency. Energy radiated into $d\Omega$ by $dAcos\theta$ due to emission processes in dV :

$$dE^e_\nu = dI^e_\nu dAcos\theta d\Omega d\nu dt$$

$$dE^e_\nu = \epsilon_\nu dAd\Omega cos\theta d\nu dtds$$

$$dE^e_\nu = \epsilon_\nu dV d\Omega d\nu dt \tag{3.4.6}$$

ϵ is defined as the emission coefficient (represents radiation put into the beam by emission) and has dimensions $[ergcm^3sr^{-1}Hz^{-1}s^1]$

3.5 The Radiative Transfer Equation

A full radiative transfer calculation gives the specific intensity received at the ground for any given wavelength. Here scattering processes is ignored. If we combine absorption and emission together.

$$dE^{abs}_\nu = dI^{abs}_\nu dAcos\theta d\Omega dtd\nu = -k_\nu I_\nu cos\theta dAdtd\nu ds$$

$$dE^e_\nu = dI^e_\nu dAd\Omega dtd\nu = \epsilon_\nu cos\theta dAd\Omega dtd\nu ds$$

$$dE_\nu^a + dE_\nu^e = (dI_\nu^a + dI_\nu^e)dAcos\theta d\Omega d\nu dt \tag{3.5.1}$$

$$dE_\nu^a + dE_\nu^e = (-k_\nu I_\nu + \epsilon_\nu)dAcos\theta d\Omega d\nu dtds \tag{3.5.2}$$

$$dI_\nu = (dI_\nu^a + dI_\nu^e) = (-k_\nu I_\nu + \epsilon)ds \tag{3.5.3}$$

$$\frac{dI_\nu}{ds} = -k_\nu I_\nu + \epsilon_\nu \tag{3.5.4}$$

Eqn (3.5.5) is the differential equation(the equation of radiative transfer) describing the flow of radiation through matter.

The equation of radiative transfer also can be written in the form of

$$\frac{dI_\nu}{d\tau_\nu} = -I_\nu + s_\nu \tag{3.5.5}$$

Where $s_\nu = \frac{\epsilon_\nu}{k_\nu}$ is defined as a source function and has units of specific intensity. Multiplying eqn. (3.5.5) both side with e^{τ_ν} we obtain $\frac{d\bar{I}_\nu}{d\tau_\nu} = \bar{s}_\nu$

where $\tilde{I}_\nu = I_\nu e^{\tau_\nu} and \tilde{s}_\nu = s_\nu e^{\tau_\nu}$

The above differential equation can be written as

$$\int_{I_{\nu,0}}^{I_\nu} d\tilde{I}_\nu = \int_0^{\tau_\nu} \tilde{s}_\nu \tau_\nu$$

Using that $\tilde{I}_{\nu,0} = I_{\nu,0}e^0 = I_{\nu,0}$ the solution to the simple integral equation is

$$I_\nu = I_{\nu,0}e^{-\tau_\nu} + \int_0^{\tau_\nu} s_\nu(\tau_\nu^{'})e^-(\tau_\nu - \tau_\nu^{'})d\tau_\nu^{'} \tag{3.5.6}$$

where $\tau_\nu$is the total optical depth along the line of sight (through the cloud). Eqn. (3.5.6) is the formal solution, which, under the simplifying assumption that the source function is constant along the line of sight reduces to

$$I_\nu = I_{\nu,0}e^{-\tau_\nu} + S_\nu(1 - e^{-\tau_\nu}) \tag{3.5.7}$$

Eqn. (3.5.7) is the emergent intensity , the first term expresses the attenuation of the background signal, the second term expresses the incident intensity attenuated by the total optical depth (the added signal due to the emission from the cloud), while the third term describes the clouds self-absorption.

Consider a number of different cases.

• If no cloud

There is no absorption ($k_\nu = 0$) or emission($\epsilon = 0$) other than the emission from the background source. Thus $\frac{dI_\nu}{ds} = 0 \Longrightarrow I_\nu = I_{\nu,0}$

•Absorption Only

The cloud absorbs background radiation, but does not emit $\epsilon_{\nu=S_\nu} = 0 \Longrightarrow \frac{dI_\nu}{d\tau_\nu} = -I_\nu \Longrightarrow I_\nu = I_{\nu,0}e^{\tau\nu}$

• Emission Only

The cloud does not absorb($k_\nu = 0$) but does emit we have $\frac{dI_\nu}{ds} = \epsilon_\nu$

$$I_\nu = I_{\nu,0} + \int_0^l \epsilon_\nu ds$$

• If Cloud in Thermal Equilibrium

That means specified by a single temperature T(kinetic temperature is equal to radiation temperature). Since in a system in thermal equilibrium there can be no net transport of energy, we have that

$$\frac{dI_\nu}{ds} = -k_\nu dI_\nu + \epsilon_\nu = 0$$

$\Longrightarrow I_\nu = \frac{\epsilon_\nu}{k_\nu} = S_\nu$

3.6 Air Mass

Air mass X is the path length that the light from a source must travel through the Earth's atmosphere to get to the observatory, relative to that for a source at the zenith (X = 1 at Z = 0) where Z is the zenith angle. When we look straight up, our line of sight passes through exactly 1 air mass. However, when we look at some angle z (the complementary angle to the altitude a) from the vertical, our line of sight passes through more than 1 air mass. For stars that appear away from the zenith, the light will pass through a path length of air that is X air masses thick [27]. The airmass $m(90° - \text{el})$, ranges from 1 at zenith (el = 90°) to about 40 at the horizon (el = 0°), and τ_0 is the optical depth at the zenith. For different zenith angles, the optical depth τ has to be modified for the airmass $m(90° - \text{el})$.

The dimming of a beam of light entering the atmosphere depends on how much air is traversed by the beam. Air mass is measure of how much air of the atmosphere is in the line of sight between the telescope and the kind of vacuum higher then, 20km [20].

The measurement of dimming can be broken into two components : the first is a geometrical term (X) which is a function of the star's apparent zenith distance (Z), and the second, a meteorological term which varies with time and place. For altitudes well above the horizon(atmosphere is plane stratified and horizontal), a good approximation standard formula for the air mass (in Astronomy) is one divided by the cosine of the zenith angle (secz)z is star's angle relative to the zenith [20].

$$airmass = \frac{1}{cosz}(= secz) \tag{3.6.1}$$

This equation indicates the airmass for a flat Earth would be simply X=sec(Z). This is an excellent approximation for all observations far away from the horizon.

For large zenith angles $z > 60^0$ one should use a more accurate formula. However, photometric measurements for large zenith angles are difficult and should be avoided. Because When the star gets low towards the horizon, the starlight passes through many air masses and appears greatly dimmed. The extinction at low altitude was not important. For stars 5^o above the horizon ($Z = 85^o$, X = 10.3), the star appears 2.3 mag fainter than if it was at zenith. For the extreme case of a star on the horizon ($Z = 90^o$ so X=40) and k = 0.25 mag/airmass, the observed magnitude is about 10 mag fainter than V, which is to say that stars at the horizon are always too faint to be visible. We compute corrections to this formula assuming a finite earth radius and

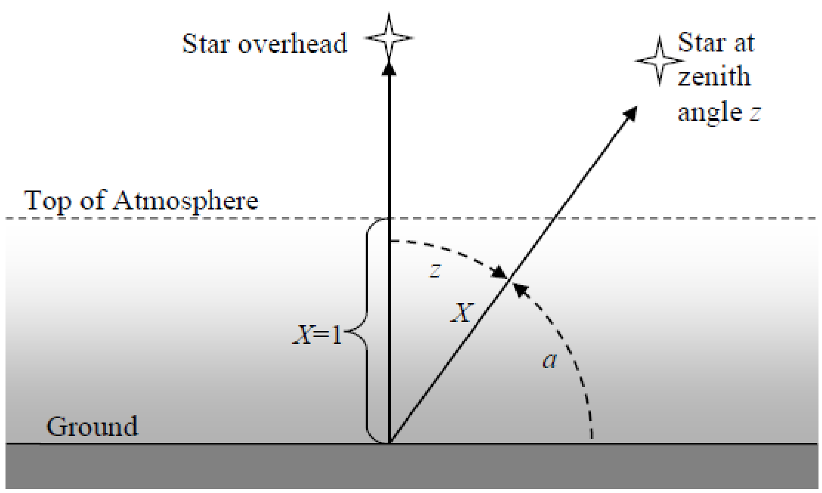

Figure 3.4: Sketch of the air mass X traversed by starlight over head, and at the zenith angle z = 90 - a where a is the altitude angle [source, Phys 322 Observational Astronomy Lab 6 NJIT (Prof. Gary) Spring 2017, page 4]

an exponential scale height. Let $\rho(h)$ be the density of air at altitude h above the telescope; the areal density is given by integration along the direction of the light ray.

$$A[\rho] = \int \rho(h)dx \tag{3.6.2}$$

$$x = \frac{h}{cosz}, dx = \frac{dh}{cosz} \tag{3.6.3}$$

$$a = \frac{A[\rho](z)}{A[\rho](0)} = \frac{\int \rho(h)\frac{dh}{cosz}}{\int \rho(h)\frac{dh}{cos0}} = \frac{1}{cosz} \tag{3.6.4}$$

this is the standard expression, this result is independent of the structure of the density function$\rho(h)$

In the limit of observing near the horizon, $z \longrightarrow 90^0$ the value becomes infinite, indicating that the view through the telescope never leaves the atmosphere.

3.6.1 Extinction Coefficient

The haziness of the atmosphere is quantified by a parameter called the extinction coefficient, k, with units of magnitudes lost per airmass. The wavelength dependence of the atmospheric extinction is the sum of physical elementary components. Several different physical effects contribute to continuous extinction and each of these effects is characterized by a different effective scale height, so that their mixture will change with altitude. These include Rayleigh scattering close to 8.2 kilometers [27], which for the stratospheric ozone is roughly 20 kilometers, and Mei (aerosol) for aerosol scattering the scale height varies substantially with a typical value of 1.5 kilometers or H_2O molecular absorption. For wavelength regions which are partially transparent, the atmospheric transmission will depend on the zenith angle of the observation, as when we look at larger zenith angles we are looking through a greater thickness of atmosphere and looking straight up (at the zenith) the minimum possible path length through the atmosphere.

The $secant\theta$ air mass formula strictly applies only in an in finite flat slab i.e. significant only for lines of sight near the horizon (approaching 90 degrees. Because of the atmosphere is curved (due to the curvature of the Earth), the $secant\theta$ air mass is not exactly $secant\theta$ but the deference between the real air mass. The density is the same at deferent places at the same altitude above sea level. The amount of such extinction is lowest at the sky's zenith and maximum near the horizon.

To reach a star's greatest celestial altitude requires the optimal hour of the day, the star's local meridian, a favorable declination (i.e. similar to the observer's latitude) and the point in the seasons the earth's annual cycle in axial tilt are key. K is simply the ratio of f_{inc} and f_{obs} at the zenith, expressed in magnitudes :

$$K = 2.5log(\frac{f_{inc}}{f_{obs(\theta=0)}}) \tag{3.6.5}$$

Air-mass dependency of atmospheric extinction; Extinction is approximated by multiplying the standard atmospheric extinction curve (plotted against each wavelength) by the mean air mass calculated over the duration of the observation. A dry atmosphere reduces infrared extinction significantly. About one sixth of the amount of perpendicularly incident light is extinguished in the visible domain. Clearly, if the light has to pass through a larger path in the Earth's atmosphere, more light will be scattered/absorbed; hence one expects the least amount of absorption directly overhead (zenith), increasing as one looks down towards the horizon. It can vary from night to night, it is better to measure on good night to get accurate photometry. Since the extinction coefficient is wavelength dependent, so it need a separate number for each filter. The extinction stars (standard stars) should be observed at air masses corresponding to the range in air mass of the program objects [26](a range of not less than 0.5 magnitudes in extinction is suggested) so that a good air mass correction can be determined and applied to the data.

To derive the extinction coefficients plot the instrumental magnitudes obtained as a function of the air mass. A straight line should provide a good fit to the data points. The slope will be the extinction coefficient, K, and intercept with the Y-axis the magnitude outside the atmosphere. Repeat for each filter and for each standard with sufficient number of points [26]. The total extinction coefficient will be the sum of the various components. That means, the total loss in brightness will be given by :

$$m_{inst} = m_0 + KX \Longrightarrow \Delta m = KX, X = sec\theta \tag{3.6.6}$$

$$K = K_{scattering} + K_{absorption} \tag{3.6.7}$$

$$K = K_{Relaigh} + K_{ozone} + K_{Arosol}$$

will represents the dimming towards the zenith.

$$\triangle m = K_R x_g(8.2km) + K_{oz}X_L(20km) + K_{aro}X_{aro}(1.5km) \tag{3.6.8}$$

Equation 3.6.6 is valid for positions away from the horizon and while Equation 3.6.8 is valid anywhere, yet is required near the horizon for accurate answers with X is the same for both equation for $\theta = 0 - 60$ degree. To avoid complexity we use eqn 3.6.6.

If a star's light beam of flux F passes through a thickness of material dX with τ

$$dF = -F\tau dX \tag{3.6.9}$$

$$\frac{dF}{F} = -\tau dX$$

$$\int \frac{dF}{F} = \int -\tau dX \tag{3.6.10}$$

$$\ln \frac{F}{F_0} = -\tau X$$

$$\frac{F}{F_0} = e^{-\tau X} \tag{3.6.11}$$

$$log\frac{F}{F_0} = -\tau X loge \tag{3.6.12}$$

$$m_{ins} - m_0 = KX = -2.5log\frac{F}{F_0} = 2.5\tau X loge \tag{3.6.13}$$

From eqn(3.1.13)

$$m_{ins} - m_0 = KX = -2.5log\frac{F}{F_0} = 2.5\tau X loge = A_\lambda = 1.086\tau_\lambda \tag{3.6.14}$$

Pigson's formula

$$m - m_0 = -2.512log\frac{I}{I_0}$$

The apparent intensity of a star viewed through the atmosphere is given by the expression

$$I = I_0 10^{\frac{-\triangle m}{2.5}} \tag{3.6.15}$$

The equation becomes

$$I = I_0 e^{-\tau \sec\theta} \tag{3.6.16}$$

this equation is due to Lambert

Equation 3.6.14 is the combination of Lamber's and Pgson's formula. Beerlambert is only for a flat earth and a flat atmosphere and fails at the horizon.

Chapter 4

Result and Discussion

4.1 Influence of Earth's Atmosphere on Astronomical Object's Spectra

We wish to study the influence of earth's atmosphere on the spectral energy distribution of astronomical objects by comparing observational result with theoretical. The flux of an astronomical object measured on earth needs to be corrected for effects.
A completely uniform, in thermal equilibrium at temperature T that in thermal equilibrium the photons have to follow a particular distribution, called the Planck function according to fig(4.1)

Planck Spectrum(Exoatmospheric intensity).

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$$

The intensity clearly doesn't vary from point to point so $\frac{dI}{d\tau} = 0$, and we have $I = S = B_{\nu,T}$. This means that we know the radiation intensity and the source function for a uniform medium and in general when the gas is in thermal equilibrium with radiation.The source function to be the planck function, and temperature T is

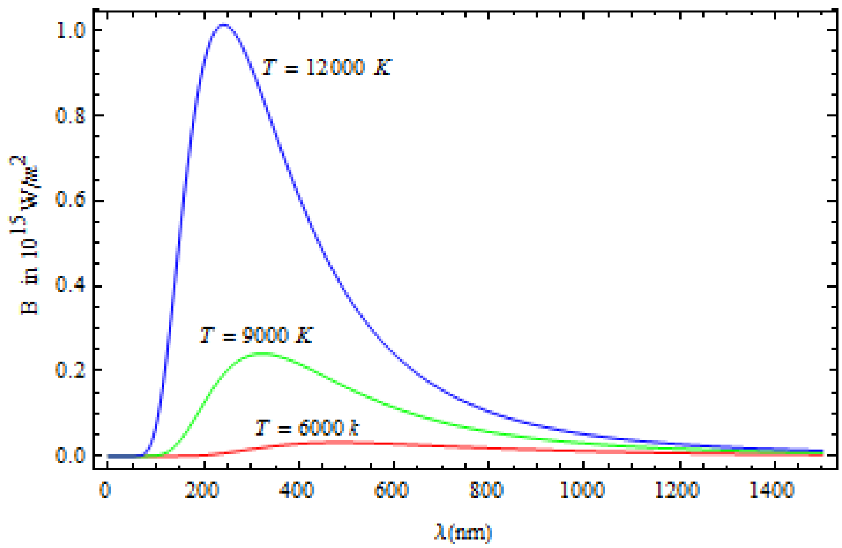

Figure 4.1: Intensity with out atmospheric extinction with varying temperature (Exoatmospheric intensity)

constant as discussed in section three. Then the above figure shows that the continues spectrum of stars above the earth's atmosphere since stars radiates approximately as black bodies which is depend only on one parameters i.e. temperature. The higher temperature of an astronomical object the higher spectral energy distribution.

Correction for the effects - With simple formal radiative transfer frame work we have developed sofar we can already study and understand how spectroscopic emission features and absorption features are formed and a spectral feature in the observed intensity. Mathematically, we have extincted intensity or the observed intensity is as next equation.

$$I = I_0 e^{-\tau sec\theta} \tag{4.1.1}$$

or

$$B_{\lambda,T} = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1} e^{-\tau sec\theta} \tag{4.1.2}$$

To find the radiation intercepted by a real detector at an Earth-based observatory we have been used to generate a numerical data computationally using MATIMATICA. The results are displayed according to the following figure. This exponential attenuation is why common objects appear to have sharp edges the light getting through medium falls of exponentially fast. The exponential term defines a scale over which radiation is attenuate. In the below graph we keep temperature and optical depth

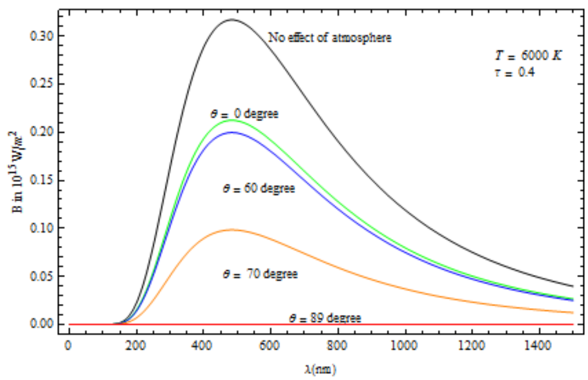

Figure 4.2: Effect of Air Mass on Intensity

constant, by varying line of sight. We change air mass where the over all curve is at exoatmospheric(no effect of atmosphere).

As we can see from the graph, the light we receive from an object was different than the light that was sent. This spectral plot indicates the distinction between the light that was sent by the star versus the light that we see and measure.

The spectral energy distribution falls off exponentially as the line of sight increases(air mass)

- When viewed through different atmospheric paths, the extinction effect will not be identical as determined (fig 4.1) the extinction in each direction.

- The longer the atmospheric path, the greater the loss of light(energy).

- The lower the elevation of the line of sight, the longer the atmospheric path(air mass), and hence the greater the effect of atmospheric extinction.
- The area under the graph decreases with increases the path length and nearly diminished when approaches to horizon.

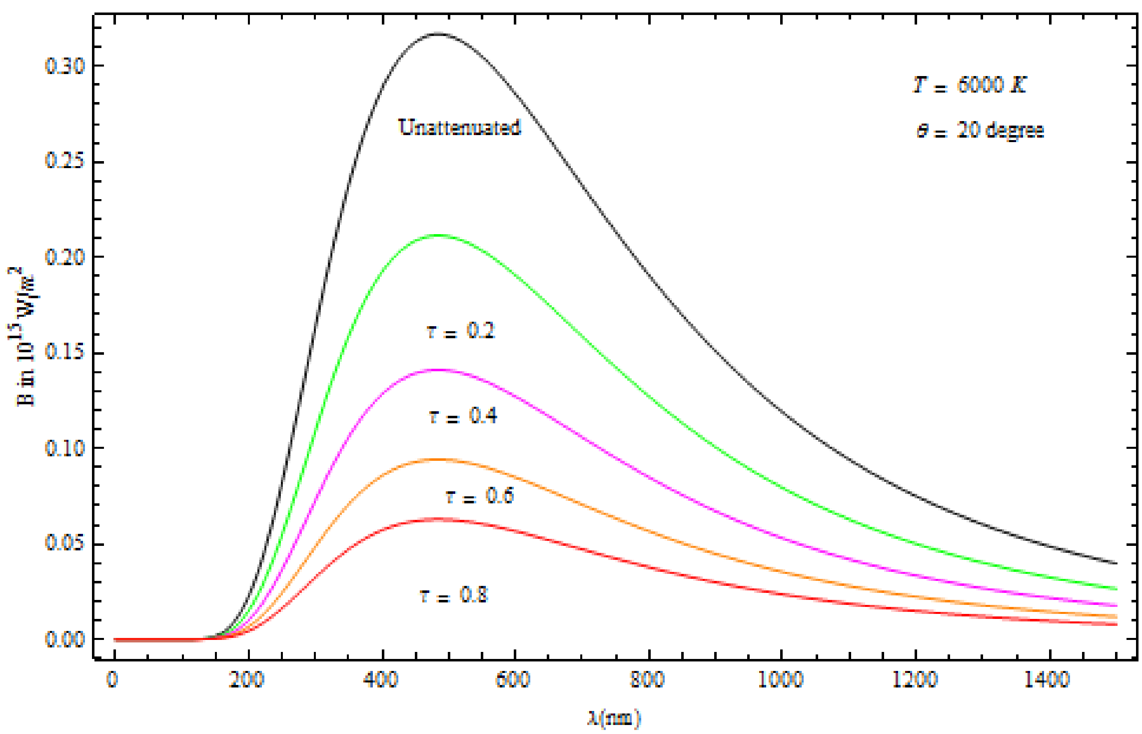

Figure 4.3: Effect of Atmospheric Depth on Intensity)

We keep temperature and air mass constant and change optical depth (τ).

- The large optical depth of the atmosphere is the more it reduces intensity. of air increases with decreasing altitude
- The spectral energy is decreasing as one looks down towards the horizon.
- The more material in the medium the more reduction of energy.

Generally when viewed through different atmospheric paths, the extinction effect will not be identical. As altitude decreases the amount of the component of earth's atmosphere increases and more flux/Luminosity reduced and star's spectra distorted more, the intensity clearly does vary from point to point.

2. Magnitude

i). Using the relative apparent magnitude relation we derive the excess magnitude created in the atmospheric extinction. The excess in magnitude is now a function of the airmass at which the object is observed and is given by,

$$\triangle m = KX = 2.5\tau \sec\theta \log e \tag{4.1.3}$$

This is the excess magnitude created in by atmospheric extinction.

ii. **The excess magnitude in the bolometric magnitude**

$$\Delta M = 2.5log\tau \sec\theta \log e \tag{4.1.4}$$

In magnitude, higher numbers correspond to faintest objects, lower numbers to brighter objects as in review literature. As depth increase the excess magnitude increase as well as line of sight. Then dimming of astronomical bright object increase as the optical depth increase as well a length of path of light through atmosphere increases. As dimming increases energy of astronomical object decreases as expected (fig.4.4).

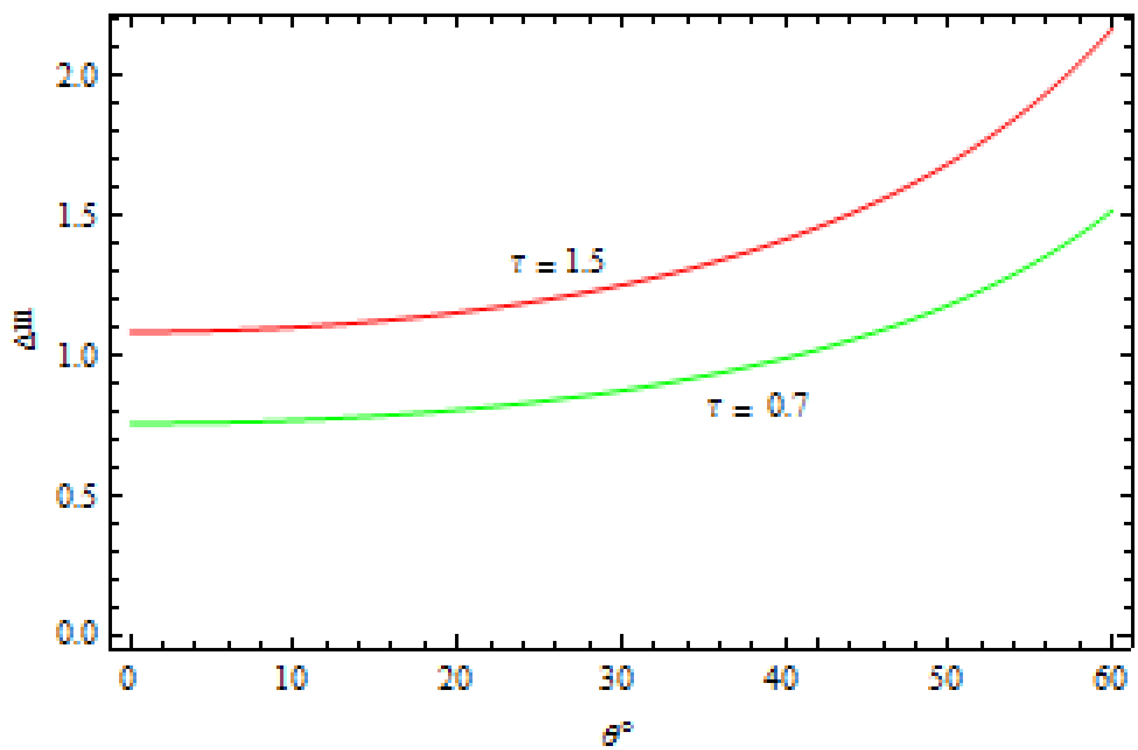

Figure 4.4: Atmospheric extinction on magnitudes

Chapter 5

Summary and Conclusion

In this study we have considered atmospheric extinction in astronomical observation. First we have derived theoretical equation of planck's radiation law which is star's spectrum approximated with it at outer atmosphere or unextincted stars spectrum. In the approach used here to determine the effect of atmosphere on star's image or spectral energy distribution, we used Plancks radiation law the only source function in the radiative transfer equation by ignoring scattering. The medium is in local thermodynamic equilibrium so that a beam of monochromatic intensity passing trough the medium undergo absorption and emission processes simultaneously. It is assumed that the Earth's atmosphere system is uniform in its horizontal temperature distribution and is a plane over each area of consideration. Generally, from the result observation of spectral energy distribution of astronomical object observation is affected by different factors like atmospheric extinction such as Absorption atmospheric emission, clouds, concentration of air particles in the atmosphere, dust particles in the air, air mass and motion of the air. This extinction reduces the electromagnetic radiation that coming from the object to the earth. It is important to make observation repeatedly rather than observing ones, in different time in a place clear medium(

with no dust in air, no cloud) and more or less no motion of air as well as at high altitude and small zenith angle to decrease air mass by considering plane parallel atmosphere.

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