**STUDY MATERIAL** 

# INDO-AMERICAN COLLEGE

Department of physics M.Thirunavukkarasu

2020-2021

Cheyyar - 604 407, Tamil Nadu, India

# Astrophysics

Study Material for B.Sc Physics students as per the Thiruvalluvar university syllabus

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M.THIRUNAVUKKARASU

M.Sc., M.Phil.,B.Ed. Assistant Professor of Physics, Indo-American College, Cheyyar.

#### **SYLLABUS - ASTROPHYSICS**

#### **UNIT – I: ASTRONOMICAL INSTRUMENTS**

Optical telescope - reflecting telescope - types of reflecting telescope - advantages of reflecting telescopes - radio telescope - astronomical spectrographs - photographic photometry - photoelectric spectrometry- detectors and image processing.

#### UNIT – II: SPACE

Introduction – Hubble's Law – Big bang theory – Shape of Universe – Expanding universe in space – Galaxies – Types of Galaxies – Spiral, Elliptical and Irregular Galaxies – Clusters of Galaxies – Milky Way – Quasars.

#### UNIT – III: STARS

Birth of Stars – Colour and Age – Life of Stars – Red giant stars – With dwarf star – Neutron Star – Black hole – Supernovae – Constellations - Zodiac.

#### **UNIT – IV: SOLAR SYSTEM**

Introduction – Sun – Structure of Sun – Nuclear reactions in sun – Sun spot and solar flares – Earth – Structure of earth – Atmosphere – Moon and its structure – Inner planets – Outer planets – Asteroids – Meteors – Meteorites - Comets.

#### **UNIT – V: SPACE DISTANCE, UNITS AND CO-ORDINATES**

Cislunar space – Translunar space – Inter planetary distance – Interesteller space – Inter galactic space – Light Year – Astronomical Unit – Astronomical Map. Astronomical Systems – Astronomical co-ordinates – Celestial Sphere – Celestial Equators – Celestial Poles - Celestic.

# **UNIT – I: ASTRONOMICAL INSTRUMENTS**

# **Learning Objectives**

- > Principle of working with construction and type of Optical telescopes.
- Working Principle with construction of reflecting telescopes and its advantages.
- Description of Radio telescope.
- Spectrum analysis Techniques used in Astronomical spectrographs for Astronomical objects
- Photographic photometry used to obtained light intensity of stars or other astronomical objects as imaged on a photographic film.
- > Detection and Process of imaging for astronomical objects.

# **UNIT – I: ASTRONOMICAL INSTRUMENTS**

#### Introduction

Astronomical instrumentations are the tools used to observe astronomical objects and phenomena that occur in space. These can include both Earth based and satellite-borne telescopes. High precision optical components such as mirrors and lenses at all wavelengths in the electromagnetic spectrum are crucial to the development of these devices. If you look at the sky when we are in night time, there seem to be number of stars up there. In reality, only about 9000 stars are visible to the unaided eye. The light from most stars is so weak that by the time it reaches Earth, it cannot be detected by the human eye.

In this unit, we describe the tools astronomers use to extend their vision into space. We have learned almost everything we know about the universe from studying electromagnetic radiation, as discussed in the unit on Radiation and Spectra. In the twentieth century, our exploration of space made it possible to detect electromagnetic radiation at all wavelengths, from gamma rays to radio waves. The different wavelengths carry different kinds of information, and the appearance of any given object often depends on the wavelength at which the observations are made.

#### **1.1 Optical telescopes**

Optical telescopes have undergone several changes since their invention in the late sixteenth century. All telescopes gather light from a large area and bring it to a common focus. But the way they focus the light varies with design. There are three primary types of optical telescope:

- 1. *Refracting telescope*, which use lenses (dioptrics)
- 2. *Reflecting telescope*, which use mirrors (catoptrics)
- 3. *Catadioptric telescopes*, which combine lenses and mirrors







#### **General components of Optical Telescope:**

The main parts of which any telescope consists with are the following:

• *Primary lens* (for refracting telescopes):

Which is the main component of a device. Bigger the lens, more light a telescope can gather and fainter objects can be viewed.

• *Primary mirror* (for reflecting telescopes):

Which carries the same role as the primary lens in a refracting telescope.

- *Eyepiece*, which magnifies the image.
- *Mounting*: which supports the tube, enabling it to be rotated.

# **Construction for primary type of optical telescope:**

#### **Refracting telescope**

The earliest telescopes like the ones Galilean telescope and also called **refracting telescope**. It consists of a long, narrow tube with a lens at the front end. Light which passes through the lens is bent, so that initially parallel rays meet near the bottom of the tube.

Refractors are easy to make and, when small, relatively inexpensive. Large telescopes of this sort become unwieldy. The largest refractor ever put to practical use is the Yerkes 40-inch instrument; its aperture (front lens) is 40 inches in diameter. The tube is a bit longer.



# **Reflecting telescope**

Reflecting telescopes the use mirrors instead of lenses to focus the light, the convex mirror is used to gather the light and reflect it back to a focal point to get the light out of the



telescope, and another mirror is used to direct the light to an eyepiece. It will be helps to astronomers see more clearly far-away objects in space. A mirror collects the light from the objects in space and to forming the image. Reflecting telescope can be much bigger and more powerful than refracting telescope.



#### **Catadioptric telescopes**

Catadioptrics are short, wide telescopes that use both mirrors and lenses. The use of both mirror and lens optics produces certain advantages in performance as well as in the manufacturing process. The term "catadioptric" results from two separate words: "catoptric" referring to an optical system which uses curved mirrors, and "dioptric" referring to one which uses lenses.



#### Principle of working and main parameters

The light from a source reaches the primary lens (or primary mirror), converging at a focal point of a system. Depending on the design, the light either enters the eyepiece (refractors) or is reflected outside a main tube towards the ocular lens (reflectors).

The angular resolution is defined by the diameter of the main lens or mirror, which is referred to as an aperture D, measured in millimeters. For the visible light this limit is described by the following formula:

$$\sin\alpha=\tfrac{138}{D}$$



Where  $\alpha$  is the limit resolution measured in arcseconds.

Each lens or mirror has their special feature known as focal length. If the focal length of the objective is F and the focal length of the eyepiece is f, then the magnification of the image produced by the optics is described by the following simple formula:

$$M = \frac{F}{f}$$

As mentioned before, the bigger the aperture, more light the optics can gather. More light enters the telescope, the fainter objects can be viewed.

Limiting magnitude of a telescope can be found according the following formula:

#### M L $\approx$ 7.2 + 5log d

Where d is the aperture diameter in millimeters.

Another important parameter of a telescope is the focal ratio. It is defined as the focal length of the objective divided by its diameter. The smaller the ratio, the "faster" the optical system is and the better and brighter image can be produced.

#### **1.2 Reflecting telescope**

Reflecting telescopes the use mirrors instead of lenses to focus the light, the convex mirror is used to gather the light and reflect it back to a focal point to get the light out of the telescope, and another mirror is used to direct the light to an eyepiece. It will be helps to astronomers see more clearly far-away objects in space. A mirror collects the light from the objects in space and to forming the image. Reflecting telescope can be much bigger and more powerful than refracting telescope.

#### **Types of reflecting telescope**

#### 1. Gregorian telescope

The Gregorian telescope, described by Scottish astronomer and mathematician James Gregory, employs a concave secondary mirror that reflects the image back through a hole in the primary mirror. This produces an upright image, useful for terrestrial observations. Some small spotting scopes are still built this way. There are several large

#### **Gregorian Reflector**





modern telescopes that use a Gregorian configuration such as the Vatican Advanced Technology Telescope, the Magellan telescopes, the Large Binocular Telescope, and the Giant Magellan Telescope.

#### 2. Newtonian telescope

The Newtonian telescope was the first successful reflecting telescope, completed by Isaac Newton. It usually has a paraboloid primary mirror but at focal ratios of f/8 or longer a spherical primary mirror can be sufficient for high visual resolution. A flat secondary mirror reflects the light to a focal plane at the side of the top of the telescope tube. It is one of the simplest and least expensive designs for a given size of primary, and is popular with amateur telescope makers as a home-build project.



#### 3. Cassegrain telescope

The cassegrain telescope (sometimes called the "Classic Cassegrain") was first published design attributed to Laurent Cassegrain. It has a parabolic primary mirror, and a hyperbolic secondary mirror that reflects the light back down through a hole in the primary. The folding and diverging effect of the secondary mirror creates a telescope with a long focal length while having a short tube length.

# **Cassegrain Reflector**



#### Advantages

- Reflector telescopes not suffer by chromatic aberration because all wavelengths will reflect off the mirror in the same way.
- Support for the objective mirror is all along the back side so they can be made very big.



- Reflector telescopes are cheaper to make than refractors of the same size.
- Because light is reflecting off the objective, rather than passing through it, only one side of the reflector telescope's objective needs to be perfect.

# **1.3 Radio Telescopes**

Just as optical telescopes collect visible light, bring it to a focus, amplify it and make it available for analysis by various instruments, so do *radio telescopes* collect weak radio light waves, bring it to a focus, amplify it and make it available for analysis. We use radio telescopes to study naturally occurring radio light from stars, galaxies, black holes, and other astronomical objects. We can also use them to transmit and reflect radio light off of planetary bodies in our solar system. These specially-designed telescopes observe the longest wavelengths of light, ranging from 1 millimeter to over 10 meters long. For comparison, visible light waves are only a few hundred nanometers long, and a nanometer is only 1/10,000th the thickness of a piece of paper. In fact, we don't usually refer to radio light by its wavelength, but by its frequency.

Naturally occurring radio waves are extremely weak by the time they reach us from space. A cell phone signal is a billion billion times more powerful than the cosmic waves our telescopes detect.

Radio telescope is an astronomical instrument *consisting* of a *radio receiver* and an *antenna system* that is used to detect radio-frequency radiation emitted by extraterrestrial sources, these are mention in the below *figure*. Because radio wavelengths are much longer than those of visible light, radio telescopes must be very large in order to attain the resolution of optical telescopes.



Radio telescopes vary widely, but they all have two *basic components*: (1) *a large radio antenna and* (2) *a radiometer or radio receiver*. The sensitivity of a radio telescope, the ability to measure weak sources of radio emission-depends on the area and efficiency of the antenna, the



sensitivity of the radio receiver used to amplify and detect the signals, and the duration of the observation. For broadband continuum emission the sensitivity also depends on the receiver bandwidth. Because some astronomical radio sources are extremely weak, radio telescopes are usually very large and only the most sensitive radio receivers are used. Moreover, weak cosmic signals can be easily masked by terrestrial radio interference, and great effort is taken to protect radio telescopes from man-made interference

The most *familiar type of radio telescope* is the radio reflector consisting of a parabolic antenna-the so-called dish-which operates in the same manner as a television-satellite receiving antenna to focus the incoming radiation onto a small antenna referred to as the feed, a term that originated with antennas used for radar transmissions (see figure above). In a radio telescope the feed is typically a waveguide horn and is connected to a sensitive radio receiver. Cryogenically cooled solid-state amplifiers with very low internal noise are used to obtain the best possible sensitivity.

#### **1.4 Astronomical spectrographs**

Astronomical Spectroscopy is the study of astronomy using the techniques of spectroscopy to *measure the spectrum of electromagnetic radiation*, including visible light and radio, which radiates from stars and other celestial objects. It is used to analysis chemical composition, temperature, density, mass, distance, luminosity, and relative motion and many other physical properties objects such as planets, nebulae, galaxies, and active galactic nuclei.





A spectrograph is an instrument used to obtain and record an astronomical spectrum. The spectrograph splits or disperses the light from an object into its component wavelengths so that it can be recorded then analysed. The *schematic diagram* of a simple slit spectrogarps is shown bellow *figure*.

**Slit:** The slit is a narrow rectangular aperture that is placed in the focal plane of the telescope. The slit has two main functions as a means of isolating the region of interest on the sky; only light falling on the slit may enter the spectrograph, as shown in figure

**Collimator:** To modifing the light from the sorce an angle  $\phi$  for suitable for given diffraction and this will add an additional phase shift to the light emerging from each gap between the grating lines by using bellow equation,

#### $n\lambda = d(\sin\theta + \sin\phi)$

**Grating:** The grating splits the light into its component wavelengths. A common example of a diffraction grating is a Diffraction gratings are more efficient than prisms they disperse the light into a colourful spectrum.

**Camera:** The role of the camera is to collect the spectrally-dispersed beams from the grating, which are still collimated, and make them converge so that the spectrum is imaged onto the detector.

**Detector:** The dispersed light is ultimately imaged by the spectrograph onto the detector, forming a spectrum, as shown in the bottom-left panel of above *figure*.

#### **1.5 Photographic photometry**

Photographic photometry is a measure of the *relative light intensity of a star or other astronomical object* as imaged on a photographic film emulsion with a camera attached to a telescope. An object's apparent photographic magnitude depends on its intrinsic luminosity, its distance and any extinction of light by interstellar matter existing along the line of sight to the observer.

The methods used to perform photometry depend on the wavelength regine under study. At its most basic, photometry is conducted by gathering light and passing it through specialized photometric optical bandpass filters, and then capturing and recording the light energy with a photosensitive instrument.

**Absolute photometry:** To perform absolute photometry one must correct for differences between the effective passband through which an object is observed and the passband used to define the standard photometric system.



**Relative photometry:** To perform relative photometry, one compares the instrument magnitude of the object to a known comparison object, and then corrects the measurements for spatial variations in the sensitivity of the instrument and the atmospheric extinction. This is often in addition to correcting for their temporal variations, particularly when the objects being compared are too far apart on the sky to be observed simultaneously. When doing the calibration from an image that contains both the target and comparison objects in close proximity, and using a photometric filter that matches the catalog magnitude of the comparison object most of the measurement variations decrease to null.

**Differential photometry**: Photometry is also used in the observation of variable stars, by various techniques such as, differential photometry that simultaneously measuring the brightness of a target object and nearby stars in the starfield or relative photometry by comparing the brightness of the target object to stars with known fixed magnitudes.

**Surface photometry:** The technique of surface photometry can also be used with extended objects like planets, comets, nebulae or galaxies that measures the apparent magnitude in terms of magnitudes per square arcsecond. Knowing the area of the object and the average intensity of light across the astronomical object determines the surface brightness in terms of magnitudes per square arcsecond, while integrating the total light of the extended object can then calculate brightness in terms of its total magnitude, energy output or luminosity per unit surface area.

#### **Application:**

- Photometric measurements can be combined with the inverse-square law to determine the *luminosity of an object if its distance* can be determined, or its distance if its luminosity is known.
- physical properties of an object, such as its *temperature or chemical composition*, may also be determined via broad or narrow-band spectrophotometry.
- Photometry is also used to study the *light variations of objects* such as variable stars, minor planets, active galactic nuclei and supernovae, or to detect transiting extrasolar planets.
- Determine the *orbital period and the radii* of the members of an eclipsing binary star system, the rotation period of a minor planet or a star, or the total energy output of supernovae.

# **1.6 Photoelectric spectrometry**

Photoelectron spectrometry is an instrument that measure the *kinetic energy of photoelectrons* to determine the binding energy, intensity and angular distributions of these electrons and use the information obtained to examine the electronic structure of objects. This technique used in astronomy that is concerned with measuring the flux or intensity of *light radiated by astronomical objects*.



Photoelectron spectrometry (PES) is the energy measurements of photoelectrons emitted from any of objects used by the *photoelectric effect*. Depending on the source of ionization energy, PES can be divided accordingly in the regions of Electro magnetic radiations. The source of radiation for any of astronomical objects like planets, comets, nebulae or galaxies that measures the apparent magnitude.

All photoelectron spectrometers must have *three components*. The first is an excitation source used to irradiate the sample into releasing electrons. The second is an electron energy analyzer which will disperse the emitted photoelectrons according to their respective kinetic energy. Lastly, a detector. In addition, the spectrometer needs to have a high vacuum environment, which will prevent the electrons from being scattered by gas particles. These various components in photoelectron spectrometers are available in many different forms, which are discussed within the module on Photoelectron Spectroscopy: Application. A block diagram of a basic PE spectrometer is listed below:



#### 1.7 Detectors and image processing

#### (a) Detectors

In Photographic photometry, the Detectors can be used to detect the light photons from the any of astromomical objects. There are many detectors can used in the morden world but the human eye is an amazing thing of the "natural" detecter of visible photons is the retina of the human eye. The eye is sensitive to only a small part of EM radiation wavelengths. The wavelength range of sensitivity is slightly dependent on whether the eye is observing in bright light conditions (photopic) or under very low light level conditions ("dark adapted" or scotopic).

**1. Photographic Emulsions**: The *first technological advance in astronomical detectors* was the photographic emulsion. Photographic emulsions can make a permanent record of astronomical objects imaged by telescopes. However, photographic emulsions are not a very good photometric devices for astronomy because of several drawbacks. photographic emulsions only record a small fraction (around 1%) of the photons that hit the emulsion. Because of the analog (rather than digital) nature of the image record on an emulsion, it is difficult to make quantitative measurements of star brightnesses.



The figure below a magnified cross-section of a color negative film exposed to white light and then processed. White light passes through the film to form blue light, which activates the blue-sensitive layer on the color print paper to create yellow dye.



2. Photomultiplier tube (PMT): The *first modern detecter* in this sense is the photomultiplier tube (or PMT). A PMT consists of an evacuated glass tube, on one end of which is deposited a film of a material (such as indium antimonide) called a photocathode. This material has the property that when it is struck by a photon, an electron is often liberated from the material. Each electron liberated from the cathode is directed away from the cathode by an electric field, and is amplified into a pulse of electrons by a series of metal plates (called dynodes) and an accelerating electric field in the tube.

The fraction of the photons which hit the cathode that are actually detected by the PMT is set by the 20% fraction of photons that hit the cathode that liberate an electron. So the efficiency of observing is much higher for a PMT than for the best photographic emulsion.

**3. CCDs (Charge Coupled Devices):** The *detector of choice for optical astronomy* is now the CCD (charge coupled device). The CCD has many advantages- it is a linear, photon counting device which records a large fraction of the photons that fall on it. It is far better than a PMT because it can record a two dimensional image- i. e. there is positional information.

A CCD is a light sensitive silicon "chip" which is electrically divided into a large number of independent pieces called pixels (for "picture elements). Present day CCDs have 512 x 512 (262144) to at least 4096 x 4096 (16,777,216) individual pixels, and are from about 0.5 cm to 10 cm in linear size (typical sizes of each pixel are 10 to 30 micron square). For astronomical use, we use the CCD as a device to measure how much light falls on each pixel. The output is a digital image, consisting of a matrix of numbers, one per pixel, each number being related to the amount of light that falls on that pixel. Of course, one of the beauties of the CCD is that the



image, coming out in a digital form, is readily manipulated, measured, and analyzed by computer.



#### (b) Image Processing

*Image processing* is a method to perform some operations on an image, in order to get an enhanced image or to extract some useful information from it. It is a type of signal processing in which input is an image and output may be image or characteristics associated with that image. Nowadays, image processing is among rapidly growing technologies. It forms core research area in Astrophysics within engineering and computer science disciplines too.

There are two types of methods used for image processing namely, *analogue and digital* image processing. Analogue image processing can be used for the hard copies like printouts and photographs. *Digital image processing* techniques help in manipulation of the digital images by using computers. The three general phases that all types of data have to undergo while using digital technique are pre-processing, enhancement, and display, information extraction.

Image processing basically includes the following three steps:

- Importing the image via image acquisition tools
- Analysing and manipulating the image
- Output in which result can be altered image or report that is based on image analysis.

Image processing is a *general name for using a computer to manipulate images* or make measurements of something on the image. Scientific image processing programs are usually more concerned with making some sort of quantitative measurement of something on the image. There are a number of image processing programs available that are tailored to astronomical images. No matter which program we use, there are some basic ideas and concepts of image processing as applied to astronomical CCD images.



The word *pixel* can refer to an area of *silicon on a CCD* or to one tiny piece of the picture. A CCD is a collection of pixels arranged in rows and columns, and a picture the CCD produces is an array of pixels arranged in rows and columns. Each pixel in the image is represented by a number that is related to the amount of light that fell on each pixel on the CCD. Pixels on the CCD have a finite size. The area of sky imaged on each pixel also has a finite angular size, set by the (linear) size of the pixel on the CCD and the plate scale of the telescope. A typical CCD has square pixels with sides of length 24 microns (s =  $2.4 \ 10^{-5}$  m). On a 4 meter, f/2.7 telescope, with a focal length of f = 10.8 meters, each pixel subtends an angle of  $\Theta$  = s/f or 2.22E–6 radians, or about 0.46 arcsec.

A CCD image can be thought of as a 2 *dimensional array* of numbers. We specify a single pixel with an x and y value from the origin. Instead of x and y, we often refer to rows and columns. The origin is (usually) at the lower left corner of the image. Rows run parallel to the floor, and columns perpendicular to the rows. In x,y notation, a row is all the pixels with the same y value, and a column all the pixels with the same x value.

The brightness of each pixel is stored as a number. The size of the computer file representing the image depends on the type of number used to store the image. A raw image, the image as read out of the CCD, is often stored in an integer number format. Such images are often stored as 2 byte (or 16 bit) integers. Thus, the *value of each pixel* can only take on one of 216 = 65536 different values. (This "discreteness" is not a problem at this stage, because the output of the CCDs is in this integer form.)





Thus, an integer image from a  $1024 \times 1024$  CCD will require  $1024 \times 1024 \times 2 = 2,097,152$  bytes (or 2MB) of storage. The same size image in real format will require twice as much storage (4 MB). A night of observing can produce hundreds of images- you can see why astronomers are always looking for bigger and faster hard disks and tape backup units.

The above block diagram classification. Preprocessing steps include image selection from the acquired stack, automated image alignment to adjust for translation, and image segmentation. Clas- sification steps include the computation of parameter values within each image segment and application of the network to select the usable image regions.

Computer files of images usually contain some header information (with info like when and where the picures was taken), but the space taken up by the header information is usually trivial compared to the space taken up by the pixel data.

# **Review questions**

# **Section** A

- 1. Define astronomical optical telescope.
- 2. What is resolution of telescope?
- 3. What are the reflecting telescopes and give its type?
- 4. What is radio telescope?
- 5. Give the components of astronomical spectrographs.
- 6. What is the purpose of using Photographic photometry in astronomical spectrometry?
- 7. Define photoelectric spectrometry.
- 8. What are the detectors used in astronomical spectrometry?
- 9. What do you mean by CCD's detector?
- 10. What do you understand by image processing?

# Section B

- 1. Explain the reflecting telescope with its types and give the advantages.
- 2. Describe the Radio telescope.
- 3. Explain working with contraction of astronomical spectrograph.
- 4. Write the note on photoelectric spectrometry.
- 5. Explain methods of various photographic photometries.



# **Section C**

- 1. Explain the construction and working of optical telescopes and also explain about various parameters associated with them.
- 2. Describe the detectors with process of imaging of astronomical spectrograph.

# **E-References:** (click the link to open)

https://youtu.be/rotRWyzQAng https://youtu.be/v1RWyzQAng https://youtu.be/jAFrlzOtz-Y https://youtu.be/iAFrlzOtz-Y https://youtu.be/Igmx4WW-8K8 https://youtu.be/Igmx4WW-8K8 https://youtu.be/pxC6F7bK8CU https://youtu.be/Bx0SMevn-0c https://youtu.be/OI3plvLhVcc https://youtu.be/OI3plvLhVcc https://youtu.be/OI5IEG2woA0 https://youtu.be/Y8JIB\_Ona60 https://youtu.be/\_djfA0ermCM https://youtu.be/\_djfA0ermCM

