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Light and its usefulness in astronomy

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ABSTRACT

Light has numerous uses in several areas of research and this work aims to show the importance of its usefulness particularly in the field of astronomy. Initially, humanity had a way of measuring celestial objects and with technological advancement and in-depth studies of light itself, its ability to transmit data is observed, which are key factors for analyzing and controlling the dynamics of the universe and its constituent elements. The work emphasizes the structure of light in terms of its spectrum, as well as favoring astronomy in data collection through the use of tools, such as optical fibers and spectroscopy.

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1. INTRODUCTION

Humanity has always raised questions about nature and social relations. This search is due to the curiosity to collect information and through them control the possible events and develop improvements in the conduct of social interactions, such as in the preparation of food, instruments for various works, always seeking favor for society.

As this survey of questions was initially due to the functioning of natural phenomena and this through the observations of nature, such as the sky, the Sun and the stars, then astronomy is considered the oldest science, due to this search for the mysteries of the Universe in its early days.

The years pass and the search for knowledge makes a natural requirement for modernization of observation instruments, where light becomes not only an object to be studied, but also an extremely useful tool for the measurement and detection of celestial objects, as well as for the development of humanity directly, by the use of medicine and industry.

This work aims to show the use of light especially in the context of astronomy and its fundamental aspects, such as the use of x-ray, gamma ray, microwave, infrared, optical fibers, among others. The astronomical concepts and the relationship of the works of Brazilian astronomers with the use of these tools will be presented.

2. A LITTLE BIT OF HISTORY

The human being has been investigating space, with the first observations of eclipses. Through observation of space, the Egyptians invented a calendar (considered the first historical of mankind) based on the movement of celestial bodies, around 4,000 BC. Every search for knowledge is based on some interest and the objective of these Egyptians at this stage was the occupation of the banks of the Nile River [1].

According to Milone et al. (2018), the Babylonians were one of the first peoples to record the five planets visible to the naked eye, being Mercury, Venus, Mars, Jupiter and Saturn. At that time they believed in gods, heroes and associated their animals with the observed stars. They tried to understand the will of their gods by looking at the stars in heaven. The constellations were figurative representations of the gods, animals, and objects, where we see this example in the Zodiac.

Around 190 BC and 120 BC, the Greeks also made their contribution to the works of apparent magnitude. It was a kind of scale to divide stars visible to the naked eye into six magnitudes, *with* m ranging from 1 to 6 which is the visible range. The smaller the magnitude, the greater the brightness of the star in the night sky and for each magnitude value, the brightness of the next degree is doubled, following a logarithmic scale. There were no photodetectors and spectroscopy at the time, so rudimentaryness was eventually popularized by Ptolomy, with a possible belief of its originality to Hipparchus.

Over time, spectroscopy develops which according to Santiago (2012), the stars are very distant from the Earth and are similar to the Sun, varying with mass, temperature and size. According to Kragh (1999), science has discovered several celestial objects, such as the Milky Way, expansion of the Universe, the Model of the Big Bang by Cosmology, through studies with cosmic background radiation, Hubble's Law and cosmological abundance of elements [1].

3. THE ELECTROMAGNETIC SPECTRUM AND ITS USE ASTRONOMY

There are several ways to obtain information in astronomy, through neutrinos, múons, gravitational waves, but naturally it is obtained by the analysis of light and the electromagnetic spectrum. In the part of the infrared spectrum, radiation with a wavelength greater than red light is observed, being important in the study of cold objects for the emission of visible light, such as circumstrelar discs and planets. The details of the infrared spectrum, causes some molecules to radiate, allowing sidereal chemical analysis, existence of water in comets and young stars in molecular clouds.

Simply, the Sun and stars produce and emit electromagnetic radiation at their various wavelengths. In the case of visible light (400 nm to 700 nm), known as optical astronomy, the oldest form of astronomical works was hand-drawings of optical images and in most of the twentieth century the images began to be used by photographic equipment [1].

Light is the essence of the tools used by astronomers because it presents us with phenomena and carries information of the effects. Light is present in various activities of society, and we observe its refraction, reflection, interference and diffraction. In more laboratory cases, we observed the photoelectric effect.

In antiquity, several scientists raised questions about the properties of light and whether it would have an undulating or corpuscular nature. Isaac Newton (1643-1727) publishes works on light and one of them on the phenomenon of colors, where he considers the decomposition of light in various colors when passing through a prism, stating that light consisted of parts, using terms such as "particles of light" and "tiny bodies".[2].

Figure 1. Refraction of light through a prism [2]

The corpuscular theory of light was consistent during the 17th century. The result obtained by Fresnel and Young showed that light exhibited constructive and destructive interference which led to the Wave theory of Light, that is, light was constituted by vibrations (oscillations of electric and magnetic fields). In reality, light in a given phenomenon exhibits corpuscular and in another, undulating nature. In this case, theories are not exclusionary, but complementary [2].

Astronomy also uses light as a unit of distance, calling it the light-year, due to the need to measure the treatment of large distances between the stars. This measure is standardized in astronomy due to the correspondence of the distance traveled by the light particle over a period of one year. Light year is unit distance, not time unit. The particle of light travels a trajectory in a shorter time. Any other particle would travel the same trajectory in a longer time [3].

Light has a propagation speed and in vacuum it arrives at approximately c = 299,792,458 m/s. It is a universal constant and of absolute value. And how can we analyze this kind of propagation? For example, in non-homogeneous media and in the case of astronomy, we can highlight Atmospheric Turbulence.

When we look at the stars in the night sky, we notice a tremor, as if they were blinking. This reality is actually due to atmospheric turbulence, wind currents, variations in air refraction index, pressure and density fluctuations and with this the light trajectory becomes unstable, hindering observations of distant celestial bodies, and it is necessary to use satellites such as Hubble [2].

In the case of electromagnetic spectrum, its use is fundamental in astronomy studies and this spectrum is nothing more than electrical and magnetic vibrations. For example, with radio waves at certain frequencies coming out of antennas and propagating in space, this in sound waves and likewise the frequency of electromagnetic waves varies. The figure below shows the frequency ranges and the associated wave type [4].

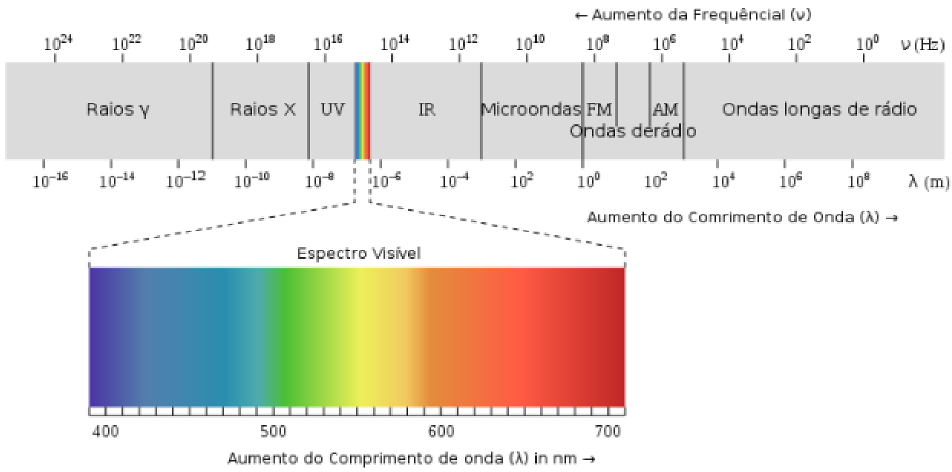

Figure 2. The electromagnetic spectrum [4]

In the case of celestial objects, most of them have wide frequency ranges. The higher the temperature, the more energy is emitted per unit area and there will be a more displacement to the blue, being the maximum of the spectrum. We can look at this in stefan-boltzmann's relationship.

$$Total\ energy = \sigma T^4 \quad (1)$$

And Wien's law

$$\lambda_{max} = \frac{2898}{T} \mu m \quad (2)$$

Bein σ stefan's constant and T given in degrees K. Through Wien's law as the temperature decreases, it shifts to longer wavelengths, where the importance of studying exoplanets that are planets around other stars is observed.

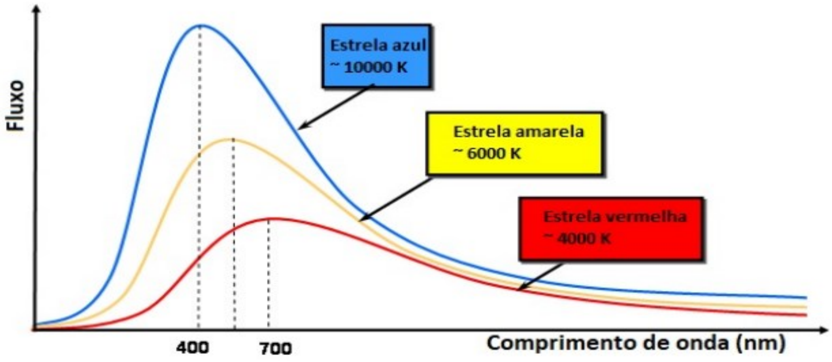

Figure 3. The approximate electromagnetic spectrum of stars at different temperatures [4]

The energy emitted by the exoplanet and the star differs from six in the order of magnitude and the temperatures are very low of the planets, in the case of Earth around 300 K. This discrepancy favors in some cases in the possibility of observing a planet, in infrared analysis work [4].

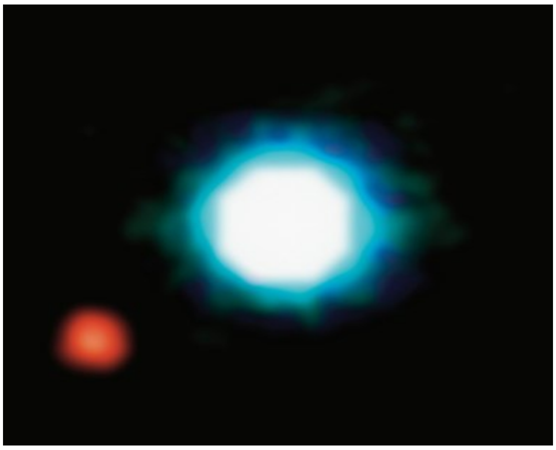
Figure 4. The first directly imaged exoplanet, in the star 2M1207, with the exoplanet 2M1207b (redder) near [4]

In a didactic way, we can explore the stars and black bodies, relate the frequency of the spectral power density peak of the stars with their visible colors.

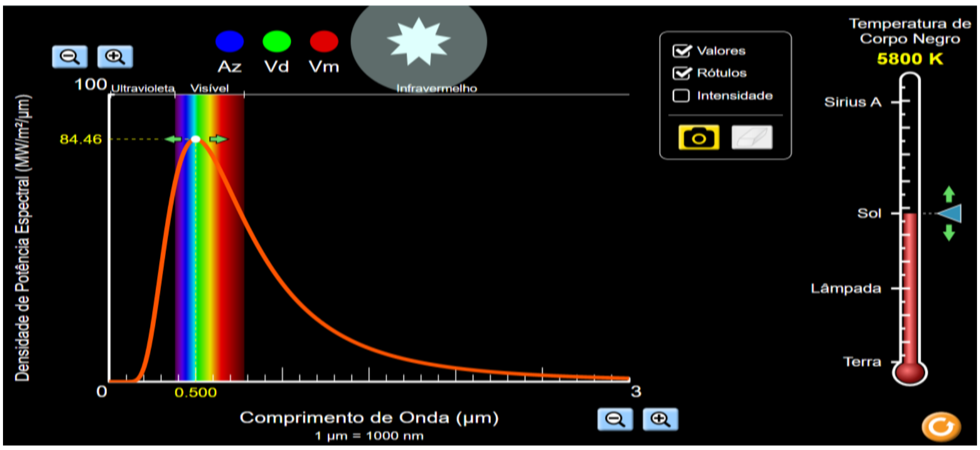

Figure 5. Ratio of spectral power density and wavelength of the Sun [5]

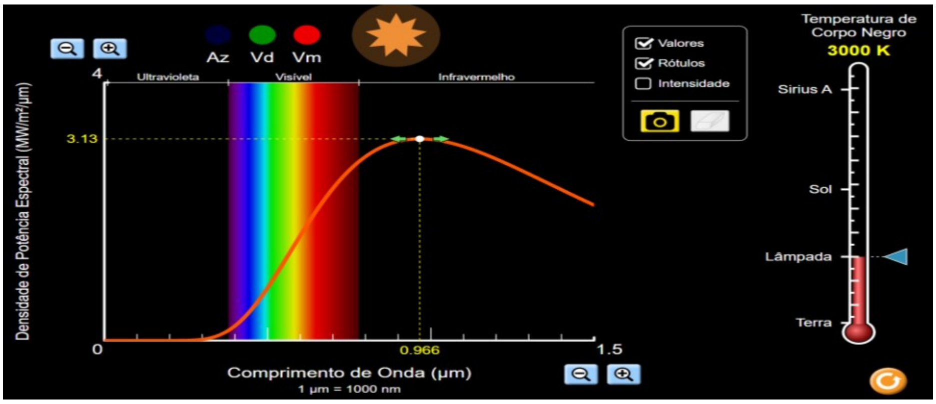

Figure 6. Ratio of spectral power density and lamp wavelength [5]

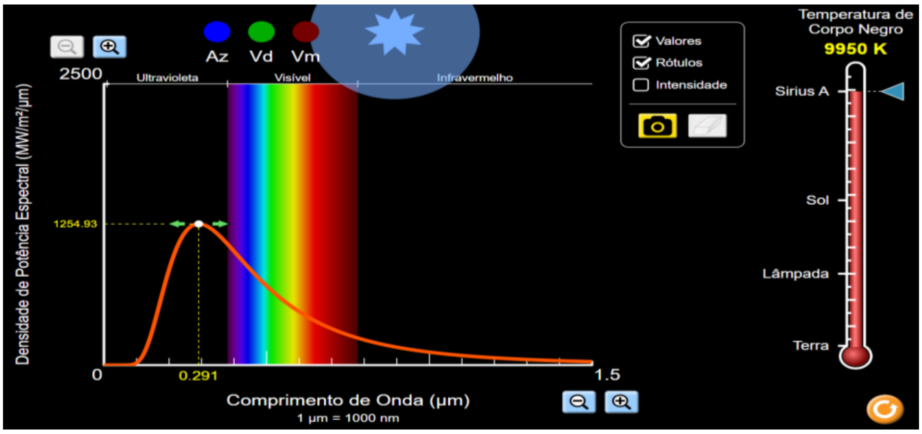

Figure 7. Relationship of spectral power density and wavelength of Sirius A [5]

In the case of the Sun, we have a surface temperature close to 5,800 K. Its spectral power density enters the visible range. In the case of the lamp, we have a temperature of 3,000 K and its spectral power density already enters the infrared range. And finally for the star Sirius A, with a temperature of 9,950 K, it enters the ultraviolet radiation range for its spectral power density. According to the virtual experiment, the temperature ranges from 3,700 K to 7,600 K for the visible range.

Continuing the electromagnetic spectrum, for the ultraviolet spectrum (10 nm to 320 nm), aims studies of the Earth's atmosphere into space, checking the thermal radiation and spectral emission lines of hot blue stars, known as (OB Star), being very bright. In this spectrum, blue stars are observed in other galaxies, planetary nebulae, active galaxy nuclei and supernova remnants, but there is a need for correction in the measurements of these objects due to absorption by interstellar dust.

In the x-ray range, celestial bodies such as clusters and elliptical galaxies, active nuclei, pulsars and supernovae that emit radiation at the wavelength of x-rays are observed. Observations are collected by balloons at high altitudes, rockets or spacecraft.

In the range of gamma rays, we have in its majority of sources the eruptions of these rays, being energetic explosions of distant galaxies, such as pulsars, candidates for black holes and neutron stars [1].

Another way to work with light in astronomy is through photometry which is the measure of light coming from an object. Although it can be observed in space, it is mostly obtained from the earth's surface.

Regarding the functioning of photometry, there is a magnitude of a radiation field called monochromatic specific intensity. So, considering the spherical surface, we will have the solid angle that is the sector of a sphere in the ratio between the area element of the surface of the sphere and be radius squared [6].

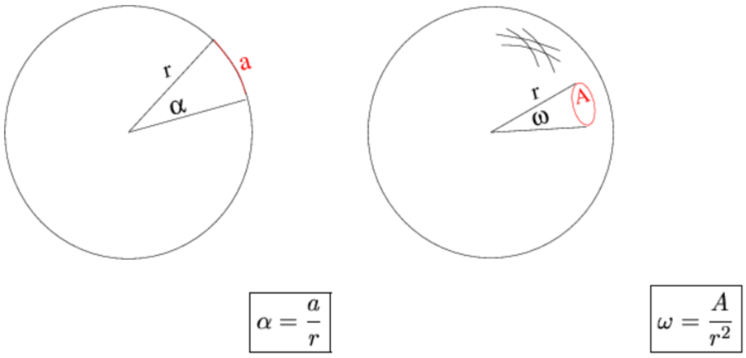

Figure 8. Solid angle in relation to the surface of the sphere [6]

The solid angle unit is the esferorradian (sr). The largest flat angle is the one that fills the entire circumference of the circle and is worth 2π radians. Already for the solid angle that fills the entire surface area of the sphere and is worth 4π esferorradians (sr).

In the case of the emission of light by an isotropic source (emitted in all directions), there will be an expansion of spherical shape, as if emitting through the center, where the radius increases as light propagates and the energy per unit of time and per unit of solid angle that crosses the unit of area of the source is called specific intensity $I_{\perp}$. When considering the emission of energy in a frequency range, we call it specific monochrome intensity$I_{\nu\perp}$. And in general, the energy propagates in anisotropic way, but is dependent only on the angle of propagation and the normal of the area. The intensities are of the

$$I_{\perp} = \frac{dE}{dtdAd\omega} \tag{3}$$

$$I_{\nu\perp} = \frac{dE}{dtdAd\omega d\nu} \tag{4}$$

$$I_{\nu} = \frac{dEcos\theta}{dtdAd\omega d\nu} \tag{5}$$

In general, the specific intensity would not depend on the distance from the issuing source, with no radiation sources along the target line. The specific intensity integrated across the spectrum of frequencies is in the

$$I = \int_{0}^{\infty} I_{\nu}\, d\nu \tag{6}$$

The flow is also an interesting amount, as it relates the energy per unit area and per unit of time when arriving at the detector. It is the net amount of radiant energy crossing the unit area, per unit of time. And the flow integrated into the frequency spectrum is the way.

$$F = \int_{0}^{\infty} F_{\nu}\, d\nu = \int_{0}^{\infty} F_{\lambda}\, d\lambda \tag{7}$$

The flow of radiation falls with the square of the distance and the spherical surface is in the

$$F(R) = \frac{L}{4\pi R^2} \tag{8}$$

L being the luminosity that is the total energy emitted per second in all directions [6].

And how is data transmitted in astronomers' work? One of the ways is with the use of optical fibers, used in the transmission of the internet, telephone, television, networks, radio etc. Optical fibers are transparent filaments with the ability to reflect light inside at various times. These filaments are flexible material worked from glass or plastic fibers for the propagation of light. They have a high refraction rate, with transparent layer coating, so that the phenomenon of total internal reflection of light occurs. They are generally used for data transmission, image collection of hard-to-reach places and sensors [7].

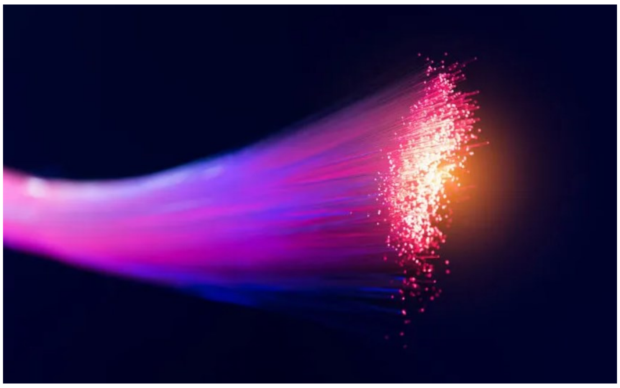

Figure 9. Light can be propagated inside optical fibers thanks to the optical properties of its core [7]

In general fiber optic cables have the transmission capacity between 10 to 40 Gbits/s. Depending on the application is required a length of more than 7,000 km, with the capacity to transmit 10^{15} bits/s. The most common material in its construction is silica (silicon oxide) SiO_2. But it depends on the type of application [7].

Due to the work of astronomers with the use of optical fibers in their relevance in data transmission, Brazil has been looking at several university and research institutes in its usefulness. Telescopes of the National Observatory, Technological Institute of Aeronautics (ITA), the radio telescope in Atibaia, São Paulo and the National Laboratory of Astrophysics (LNA), develop this type of work.

The LNA serves as national secretariat of the Gemini and SOAR consortia. The Gemini observatory consists of two telescopes approximately 8 meters in diameter in each hemisphere, covering all regions of the sky. The northern hemisphere telescope is located on top of an inactive volcano in Hawaii and the southern one is in Chile. The work is carried out mainly with optical and infrared instruments, with the capture of images, spectroscopy techniques, allowing the chemical analysis of the stars and mapping of the elements in the Universe. Correct the distortion of the light of the stars through the turbulence of the air.

In the case of the Southern Astrophysical Research Telescope (SOAR), it has a diameter of 4.2 meters, located in Cerro Pachón, Chile, near the Gemini. Brazilian astronomers work with optical fiber spectrographs with the ability to generate 1,300 spectra simultaneously. Brazil produced STELES, a spectrograph capable of detecting ultraviolet radiation, with high resolution [8].

All the works mentioned involve electromagnetic radiation. And another way to work for astronomers is through cosmic rays, particles that are detected from very distant origin st. of Earth, like neutrinos, being the second most abundant particle in the Universe, losing to the photon. It is not easy to detect neutrinos due to the absence of electrical charge, very small mass and almost no interaction with other particles. Astronomers use special underground laboratories and usually neutrinos originate from the Sun and supernovae [1].

Cosmic rays are classified as primary and secondary. The primary ones are incidents at the top of the Earth's atmosphere, being charged and stable particles. The secondary ones are produced by interactions of primary cosmic rays with interstellar gas. To detect cosmic rays, we can in space or on Earth, but considering the magnetic stiffness of the Earth [9].

With the advancement of science, studies of the spectrum of light and radiation have become important tools, as they favor various sectors of society. In this case, for example, cosmic background radiation, Alpher and Herman in 1948 began to make the first observations. In 1960, Zel'dovich and Dicke rediscovered the theory of cosmic background in microwaves. But what interests for the study of this type of radiation?

In the Big Bang model, the Universe was initially extremely hot and dense, so from the instability of atoms. Atoms were constantly bombarded by energetic particles, consequently tearing the electrons out of their structure. There was constantly chemical reaction with the hydrogen element, interacting with the photon, resulting in electron and proton, in the process of ionization of the form:

$$H + \gamma \leftrightarrow p + e^- \quad (9)$$

With the expansion of the Universe, there is a decrease in temperature and reduction of the average energy of the particles and resulting in the difficulty of photons to pull electrons. This means that through this model, the ionization energy of the hydrogen atom is associated with a background of light in the Universe [10].

4. FINAL CONSIDERATIONS

Astronomy develops very important works through light. We observed some examples of its use, such as the use of optical fibers, because it favors the rapid and high quality of information in its reception of data, in radioactive bands, because through the spectrum, astronomers can identify and analyze the structure of the stars and their composition.

The particle of light provides especially for astronomy information, where it observes not only the stars, but also analysis of the expansion of the Universe. The treatment of light reveals since antiquity the interest in various issues of Science and naturally leads us to the improvement of techniques of detection and modernization of equipment, improving the quality of images, data, controlling the dynamics and evolution of the stars.

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