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SOME ASPECTS ON THE EVOLUTION OF ASTRONOMY

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Abstract

We show some aspects of the Astronomy evolution in general, and on its research and measurement tools. We present the Earth from an astronomical and geodetic point of view, the celestial sphere and astronomical coordinate systems. The conclusion is that the evolution of Astronomy has been marked by different moments from the beginning of humanity, about 30,000 years ago, until today.

Keywords: science, astronomy, astronomical coordinate systems

1. Introduction

If on a dark, cloudless night we look from a distant location, far away from the city lights, the starry sky can be seen in its splendour and beauty. Thus it is easy to understand how these thousands of lights in the sky have fascinated and also intrigued humanity throughout its existence. The Sun, which was worshiped by various religions and cultures over time and that in essence is necessary to all forms of life, and the Moon, governing the night sky while continuously changing its phases, are the most visible object in the sky. When it comes to the stars they seem to stay fixed in the sky, although it seems to be rather an optical illusion. The planets, which are relatively bright objects, move with respect to the stars around the Sun and around their axes.

The phenomena in the starry sky aroused people' interest since long time ago. The *Cro Magnon* people made bone engravings 30,000 years ago, which may depict the phases of the Moon. These discoveries took astronomy, as a science, from the start of our civilization until today, to great heights. These calendars, made in ancient times, are the oldest astronomical documents, 25,000 years older than the writing itself.

In order to get good crops and to have a more accurate prediction, agriculture requires a good knowledge of the seasons, their determination being borne by Astronomy. Religious rituals and omens in ancient times, in different cultures and religions that have existed over time, were and are based on the location of celestial bodies, in the infinite universe of knowledge [1].

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Considering all the things mentioned above, the calculation of time became increasingly more accurate, and people learned to calculate in advance the movements of celestial bodies, drawing up calendars of various types, most of which are influenced by the position of the stars, the Sun and Moon and the Earth's position in relation to them.

Over the centuries civilization has developed and part of its development came from the maritime sector, especially when sea routes expanded and were increasingly longer and ships travelled farther from their ports [2]. This issue, namely the location of the ship, represented a big problem at a certain time. Determining the position and distances thereof was a problem for which astronomy provided a practical solution which then solved many other problems over time, both in sea and land transport. Among other problems that Astronomy solved or attempted to solve were those concerning navigation, which were its most important tasks in the 17th and 18th centuries when the first accurate tables were published on the movements of planets and other celestial phenomena observed in the sky, only that now these observations were made with modern tools of observation, measurement and determination. These developments were made possible after the laws governing planetary motions were discovered by Copernicus, Tycho Brahe, Kepler, Galilei and Newton.

More than any other science, the research in the vast field of Astronomy changed the way one sees the world, from geocentric and anthropocentric concepts to a modern point of view of a vast universe compared to which man and Earth play an insignificant role. With the help of Astronomy people could see and conceive the real scale of the nature surrounding us. Without it people would not be able to comprehend the infinite size of the Universe of which they are a part of.

Today, modern Astronomy is a fundamental science that has grown because people have come to wonder how the planets move, where the Earth fits in the universe, within our galaxy called the Milky Way and in our solar system, motivated by human curiosity and the ancestral desire to know more about nature and the Universe. Astronomy, together with Astrophysics and Geodesic astronomy, has had and has a key role in the formation of a scientific picture of the world in which we live and in which we operate daily, throughout the period it has been perceived as a science. ‘A scientific view of the world’ is a model of the Universe based on astronomical observations, theories thoroughly tested in time and a logical reasoning based on tried and tested formulas, tangible and verifiable. In Astronomy, as in general, observations are always a final test of a model created by man that meets reality in a greater or lesser extent. In reality, if the astronomical model which was designed is not consistent with observations - in particular and in general - it must be changed, and this process should not be limited by concepts or philosophical, political or religious beliefs, or otherwise.

Initially, the official position of the Church, as a representative of a new religion and of the Romans, which expanded to the point of prevalence, was quite cautious about Science in general, simply because it was a product of the ancient pagan world. With all these reasons for distrust and suspicion, Astronomy was essential, since a Church (religious) calendar had to be designed to determine the holy days of Christians, especially the date of Easter. This was a good reason why the great sages and bishops studied Astronomy and through this knowledge they got closer to the cosmology and cosmogony of the Old Testament. In fact, in order to reconcile the astronomical views of their time with the cosmogony described in the Book of Genesis, they wrote treaties on the six-day Creation (Peri Hexahemerou or On Hexameron), which became the short spiritual texts of the 4th century AD [3, 4].

As Th. Nikolaidis writes, "the most important texts were the 'Homilies to the Six-day Creation' by Saint Basil the Great and those by his brother, Saint Gregory of Nyssa, treatises that exerted an especially strong influence, not only in the East but also in the West" [5].

2. Modern astronomy at short

Nowadays, modern Astronomy is exploring the whole Universe and its various forms of matter and energy through different branches within it, some of which are: Geodetic Astronomy, Astrophysics, Astrometry, Stellar Astronomy, Galactic Astronomy, Extragalactic Astronomy, Cosmology, Stellar Evolution, Formation and Evolution of Galaxies, the Emergence and Evolution of the Solar System, Star Formation, Planetary Science. Astronomers in general, through various branches of astronomy, study the contents of the universe, starting with elementary particles and molecules (with masses of 10^{-30} kg) to the largest clusters of galaxies (with masses of 10^{50} kg).

Astronomy can be divided into different branches in several ways, as shown above; also, another division can be made, depending on the research methods or research objects of various aspects of the universe which are investigated.

The Earth, the planet on which we live and conduct our daily activities, is of great interest to Astronomy, for many reasons. The vast majority of astronomical observations must be made through the atmosphere, and the phenomena of the upper atmosphere and magnetosphere reflect the state of the interplanetary space at the time of observations. Among other aspects, the Earth is therefore the most important object of comparison for planetary scientists in the studies, theories and models they design and must empirically verify.

The Earth's natural satellite, namely the Moon, is still studied by modern astronomical methods, although in the last century, astronauts and spacecrafts have visited its surface and brought samples back to Earth. For the majority of astronomers, but especially for amateurs, the Moon is an interesting object from several points of view and is easily observed without tools or specialist astronomical instruments.

In the study of planets in the Solar System, the situation in the 1980s was the same as in the Moon's exploration 20 years earlier, i.e. in the early 1960s, and a number of surfaces of planets and their satellites were mapped by spacecraft or their satellites and space ships landed on Mars and Venus. This type of exploration added a lot to our knowledge of the conditions on other planets. With all this, continuous monitoring of planets can only be done on Earth, and many bodies in the solar system are still waiting for their space ship in order to be explored and - why not - colonized in the near or distant future.

In the Milky Way Galaxy, of which we are a part, the Solar System is ruled by the Sun, which produces energy in its core through nuclear fusion and has temperatures of over 6,000 degrees Kelvin. The Sun is the closest star to Earth and as such, its study helps to understand the conditions on the other stars. There are thousands of stars that can be seen with the naked eye, but even a small telescope reveals millions of them. When using professional telescopes the amount of stars is much higher. Stars that are subject to observation by astronomers and other scientists can be classified according to the characteristics observed. The majority of these stars are like the Sun, which is a medium sized star, and we call them main sequence stars. However, some stars are much larger (giant or supergiant stars), and some are much smaller (dwarf stars). Different types of stars represent different stages of stellar evolution in the solar system and the universe in general. Most stars are components of binary or multiple systems; many are variables: their brilliance is not constant.

Nowadays, among the newest objects studied by astronomers, are compact stars: they are represented by neutron stars and black holes. In these compact stars, matter is so compressed and the gravitational field so powerful that we use Einstein’s theory of relativity to describe matter and space.

As a representation and image, stars are like bright dots in a seemingly empty space, that is, nevertheless, part of the universe. However, interstellar space is not empty but contains large clouds of atoms, molecules, elementary particles and dust. An amount of new material is injected into interstellar space by exploding stars that erupt over time while in other places new stars are formed by contracting interstellar clouds.

Most of the stars are not evenly distributed in space and in the universe, but form concentrations, groups of stars. These consist of stars born near each other, and in some cases, stars that remained together for billions of years, as if completely ignoring time, which is relentless.

For an amateur or a professional carrying out observations with adequate equipment or even with the naked eye, the highest concentration of stars in the sky is the Milky Way, the galaxy to which we belong. The Milky Way is a massive star system, a galaxy consisting of over 200 billion stars. All the stars visible to the naked eye belong to the Milky Way. Light passes through our galaxy in 100,000 years.

Our galaxy, namely the Milky Way, is not the only galaxy out there, but one of countless other galaxies. Galaxies often form clusters of galaxies, and these groups can be brought together in super-clusters of galaxies. Galaxies are seen at all distances that can be observed by us, especially if we use high power telescopes. In the most remote places we see quasars, knowing that the light of more distant quasars that we see now was in fact emitted when the Universe was a tenth of its present age.

In Astronomy, the largest object studied by astronomers is represented by everything that exists in the entire Universe. In the beginning, Cosmology was reserved for philosophers and theologians and over time - especially today - has become the subject of physical theories and concrete astronomical observations.

Among the many branches of research, spherical and positional, astronomy studies the celestial sphere coordinate system, their changes and the apparent position of celestial bodies in the sky. Celestial mechanics studies the motion of bodies in our solar system: stars systems, galaxies and clusters of galaxies in the universe, which is infinite. Astrophysics deals with the physical properties of celestial bodies, using methods of modern physics, combined with new theories in various related fields. Astrophysics has a central place in almost all branches of Astronomy, as it helps decipher and verify the numerous theories in Astronomy in general.

3. Earth seen from an astronomical and geodetic point of view

A position on the Earth is usually given by two spherical coordinates (although in some calculations rectangular or other coordinates may be more convenient). If necessary, a third coordinate, e. g. the distance from the centre can also be used.

The reference plane is the equatorial plane, perpendicular to the rotation axis and intersecting the surface of the Earth along the equator. Small circles parallel to the equator are called parallels of latitude. Semicircles from pole to pole are meridians. The geographical longitude is the angle between the meridian and the zero meridian passing through Greenwich Observatory. We shall use positive values for longitudes east of Greenwich and negative values west of Greenwich. Sign convention, however, varies, and negative longitudes are not used in maps; so it is usually better to say explicitly whether the longitude is east or west of Greenwich [6]. The latitude is usually supposed to mean the geographical latitude, which is the angle between the plumb line and the equatorial plane. The latitude is positive in the northern hemisphere and negative in the southern one. The geographical latitude can be determined by astronomical observations [6].

The altitude of the celestial pole measured from the horizon equals the geographical latitude. (The celestial pole is the intersection of the rotation axis of the Earth and the infinitely distant celestial sphere) [7-9].

Because the Earth is rotating, it is slightly flattened. The exact shape is rather complicated, but for most purposes it can by approximated by an oblate spheroid, the short axis of which coincides with the rotation axis. In 1979 the International Union of Geodesy and Geophysics (IUGG) adopted the Geodetic Reference System 1980 (GRS-80), which is used when global reference frames fixed to the Earth are defined. The GRS-80 reference ellipsoid has the following dimensions:

- equatorial radius $a = 6{,}378{,}137$ m,
- polar radius $b = 6{,}356{,}752$ m,
- flattening $f = (a-b)/a = 1/298.25722210$

The shape defined by the surface of the oceans, called the geoid, differs from this spheroid at most by about 100 m. The angle between the equator and the normal to the ellipsoid approximating the true Earth is called the geodetic latitude. Because the surface of a liquid (like an ocean) is perpendicular to the plumb line, the geodetic and geographical latitudes are practically the same.

4. The celestial sphere used in Astronomy

When we look at the starry sky, it appears to us like a spherical cap that is supported all around by the horizon and on which we can see the stars projected according to the directions of the visual rays that are joined to the eye of the person who makes the observation. The sphere that includes this cap was named local celestial sphere, frequently called topocentric sphere or direction sphere in astronomy.

Since the distances to the stars are great, constellations appear to us as having the same geometric shape regardless of where we are on the globe or if visibility is hindered by the horizon. Moreover, the same issue happens regardless of the position of Earth in its orbit around the Sun, and regardless of the calendar date on which the observations are carried out. We can generalize that the observation directions of the stars remain parallel to each other at any moment during the observation. In reality, we shall see that because of several astronomical phenomena that are inevitable, the parallel nature of the visual rays' directions to the stars is only an approximation, but one which has practical utility.

Regarding the position of the stars and constellations, i.e. where they are on the celestial sphere, this position is continuously changing due to the Earth's rotation on its axis and its movement around the Sun. If we look at the stars on a clear night we see stars that pop up and then go down and stars that remain visible throughout the night. Another aspect is that an observer will also see that there are stars that readily cross the sky and stars which are slowly moving on the same sky. All changes in the position of the stars coming from daytime motion are different for their observers who are in different places on the globe. With this in mind it is possible to determine the position of the observer on Earth, position expressed by the astronomical coordinates (Φ, Λ) of the vertical of the place in the point it is located. The instruments used and the methods of observation, measurement and determination of these coordinates are the subject of practical Geodetic astronomy.

These clarifications made before are very important because the position of a star on the celestial sphere is given by the direction on which an observer sees it, the distance to the star being negligible compared to its position. Most times, in different situations, the radius of the celestial sphere can be considered infinite, and in other cases we can consider the celestial sphere as a unit radius.

The ancient Universe was confined within a finite spherical shell. The stars were fixed to this shell and thus were all equidistant from the Earth, which was at the centre of the spherical Universe. This simple model is still in many ways as useful as it was in antiquity: it helps us to easily understand the diurnal and annual motions of stars, and, more important, to predict these motions in a relatively simple way. Therefore we will assume for the time being that all the stars are located on the surface of an enormous sphere and that we are at its centre. Because the radius of this celestial sphere is practically infinite, we can neglect the effects due to the changing position of the observer, caused by the rotation and orbital motion of the Earth.

Since the distances of the stars are ignored, we need only two coordinates to specify their directions. Each coordinate frame has some fixed reference plane passing through the centre of the celestial sphere and dividing the sphere into two hemispheres along a great circle.

One of the coordinates indicates the angular distance from this reference plane. There is exactly one great circle going through the object and intersecting this plane perpendicularly; the second coordinate gives the angle between that point of intersection and some fixed direction.

5. Coordinate systems used in Astronomy

The position of the stars in the sky is defined by spherical coordinates calculated by astronomers from making observations, by means of specific instruments, from fixed points, represented by astronomical observatories. These coordinates are tabulated in the form of tables called ‘ephemerides’, annually made available to users for different purposes. They are necessary for geodetic astronomy work where, in order to determine the coordinates of the key points, stars are considered fixed points (known coordinates), relative to the celestial sphere (Table 1) [9, p. 55].

Table 1. Coordinate systems used in Astronomy.

Fundamental reference planes	**Polar axis of the fundamental planes**	**Reference directions (origin) in fundamental planes**	**Coordinate system**
the horizon of the location	the vertical of the location	the intersection of the horizon and meridian of the location	horizontal coordinate system
the celestial equator	Earth’s axis	the intersection of the celestial equator and the meridian of the location	zones coordinate system
		the intersection of the celestial equator and the celestial meridian of the vernal equinox	equatorial coordinate system
the ecliptic	polar axis of the ecliptic	the intersection of the ecliptic and the ecliptic meridian of the vernal point	ecliptic coordinate system

There is the possibility of adopting several reference planes and thus we can define various astronomical and geodetic coordinate systems, for example:
horizontal coordinate system, zones coordinate system, equatorial coordinate system and ecliptic coordinate system.

In the following we will present, one at a time, these systems of coordinates, determining for each the reference planes, type of coordinates, and also specific characteristics (Table 1).

A coordinate system is generally represented by three perpendicular axes and is defined by origin, a fundamental reference plane (plane XY), a reference direction in this plane (X-axis) and the positive part of this plane. One can use other planes or fundamental directions: for example, the Z-axis direction (normal to the plane XY), the pole of the XY plane or the X-axis can be defined as a line of intersection of two planes of reference [7; 8; 9, p. 55].

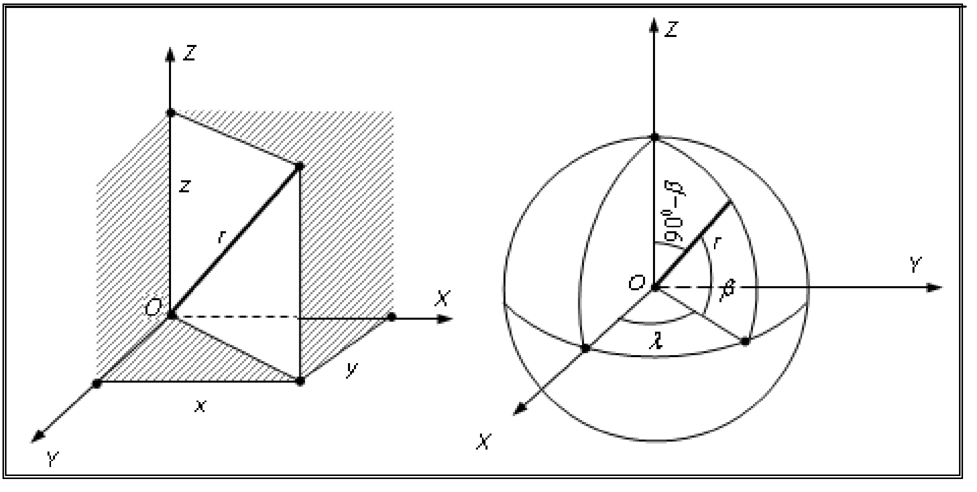

Figure 1. Rectangular coordinate systems.

Figure 2. Spherical coordinate systems.

Vector *r* from the origin to the object, also called position vector, can be represented by its rectangular coordinates (x, y, z), the projections of vector *r* on the three axes (Fig. 3.1). Also, the position vector *r* can be represented by spherical coordinates (Fig. 3.2) in which direction is defined by the longitude angle λ in the reference plane XY and the latitude angle β in the reference plane (sometimes the polar angle $90^0-\beta$ or the complement of the latitude angle are used; the prefix 'co' can be added to the name, in this case - colatitudine). These angles are called and have different symbols in the coordinate systems specific to astronomy. Geometric coordinate transformations between different astronomical coordinate systems and correcting physical effects can be made using the techniques of spherical trigonometry or vector and matrix algebra [7, p. 38; 8, p. 23; 9, p. 55].

The concept of celestial sphere is common for explanations, sphere arcs representing the angles between directions. The centre of the sphere can be positioned at various locations, but in most cases illustrates the origin of the coordinate system (reference trihedral). Also, when an object represented on the sphere changes its radial distance from the centre of the coordinate system, these changes need to be incorporated in the mathematical calculating models [7, p. 42; 8, p. 27; 9].

6. Conclusions

Astronomy is the science that has always fascinated personalities in the field of religion, Philosophy and Science as well. Astronomy has solved a number of problems that people have had ever since ancient times.

Religion needed Astronomy to clearly record the course of various important days for religious holidays. During history Science needed Astronomy to solve problems that had to be solved in scientific terms.

This paper presents Astronomy over time until today, finally presenting the coordinate systems that are indispensable to today's sciences: Space geodesy (GPS), Geographic Information Systems (GIS), sea, air and naval transportation, astronautics and other fields.

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We show some aspects of the Astronomy evolution in general, and on its research and measurement tools. We present the Earth from an astronomical and geodetic point of view, the celestial sphere and astronomical coordinate systems. The conclusion is that the evolution of Astronomy has been marked by different moments from the beginning of humanity, about 30,000 years ago, until today. Do you want to read the rest of this article? Request full-text. Figure 2: Modern Astronomy Stellar Evolution. Modern astronomy relies on the fusion of hydrogen to helium, the process observed within the photosphere (the outer layers of a star). This process starts out with a bangâ€”a supernovaâ€”which forms a blue giant star, that gradually cools down, moves down the Main Sequence, and burns out due to lack of hydrogen fuel.Â The most important aspect of the stellar evolutionary system that we are considering is the death of a starâ€”the supernova. In the Reciprocal System, it comes in two varieties, both of which are observed by modern astronomers. The first occurs when the star reaches its thermal limit, and explodes as a â€œType Iâ€ supernova.