Reference systems in astronomy and radio astronomy

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It is useful to summarize some information about reference systems, and the units of measurement used in astronomy, essential notions in order to go with safety in the study of the cosmos. The news will be reduced to the essentials, in amounts just enough to frame the observational data in the correct dimensional fields. More and more precise details can be found in the specialist astronomical literature.
We define the astronomical unit (AU), the average distance Earth-Sun, about 150 · 106 km, while the distance traveled in a year by an electromagnetic wave that propagates in a vacuum is defined Light-Year. We have:

$$1 \text{ PARSEC} = 3.26 \text{ LIGHT-YEAR}$$
$$1 \text{ pc} = 3.26 \text{ LY}.$$

The relations between the units of measurement of astronomical distances are summarized in the following table:

• **Astronomical-Unit (AU):**	$1.496 \cdot 10^8$ Km		
• **Light-Year (LY):**	$9.460 \cdot 10^{12}$ Km	0.307 pc	$6.324 \cdot 10^4$ AU
• **Parsec (pc):**	$3.086 \cdot 10^{13}$ Km	3.262 LY	$2.063 \cdot 10^5$ AU

The Earth travels in a year, around the Sun, orbit on a plane inclined at 23 °, 27' than the terrestrial equator: seen from Earth, the Sun covers an apparent annual orbit named ecliptic, which cuts the celestial equator in two places, the spring equinoctial point (or first point of Aries γ - March 21) and the autumnal equinoctial point (or first point of Libra - September 23). The ecliptic is the imaginary circle on the celestial sphere formed by the intersection between it and the Earth's orbit.
It is well-known as the geographic coordinates of a location on Earth are defined by the system of meridians and parallels. Meridians are great circles passing through the geographic poles, the parallels are circles perpendicular to the axis of rotation (the maximum among these is the equator). We have:

- *Latitude* φ: measured by the arc of the meridian between the equator and the place considered (counting from 0 ° at the equator, up to 90 ° to the north pole, from 0 ° to -90 ° at the equator to the south pole);

- *Longitude* λ: the arc of the equator between the intersections of the equator with the meridian of the place and the prime meridian of Greenwich reference (0 ° longitude).

The Earth's rotation around its axis causes the apparent daily motion of the stars move from east to west: only the north and south celestial poles, the extension of the axis of rotation of the earth, do not take part in this motion. The North Star, being only 0.9 ° from the north celestial pole, along a circle just discernible to the naked eye. The angular distance of the north celestial pole (also called polar height) from the north point on the horizon is equal to the geographical latitude φ: in a location at latitude φ = 44 °, even the north celestial pole is 44 ° above the horizon . The zenith is the highest point on the celestial sphere directly above the observer and perpendicular to the horizon, while the nadir is the point diametrically opposite the zenith. We define the projection of the celestial equator on the Earth celestial equator: it descends below the horizon to the west and re-emerges to the east, south and reaches the maximum height above the horizon (culmination). It is called the meridian circle passing through the southern point on the horizon to the zenith, the north point and the nadir.

A terrestrial observer may use different coordinate systems to determine the position of the stars on the celestial sphere. The most useful are the high system-azimuth and the equatorial.

- *Azimuthal High-System* of coordinates (a, h), in which the reference plane is the ideal one that passes through the point of the observer, and is parallel to the horizon. The poles are the zenith and the nadir and the great circle which passes through the north, the south and the zenith is the meridian. We have:
  a = azimuth, horizontal angular distance [degrees] between the south point on the horizon and the perpendicular passing through the star;
  h = height (*elevation*), angular distance [degrees] of a star from the horizon (it is equal to 90 ° for a star at the zenith).

Is called hour circle the circle that connects a star with the zenith and perpendicular to the horizon. In this reference system the coordinates of a celestial object vary continuously during the day due to the Earth's rotation. Despite this, it is convenient for the frames of the large telescopes and antennas for radio telescopes, as structurally simple to build (the system must move with respect to two axes, one horizontal and one vertical).

- *Equatorial system* of coordinates (δ, α), in which the reference plane is the ideal one that cuts the Earth's equator. The poles are the North Celestial Pole (NCP) and the south celestial pole (SCP), located respectively at the intersection of the Earth with the celestial sphere, on an imaginary surface at a great distance from the center of the Earth. The great circle passing through the poles and the zenith is the meridian circle. The coordinates are:

  δ = declination, angular distance [degrees] of a star from the celestial equator (positive for the stars to the north of this, negative for those in the south). The north and south celestial poles are respectively a declination of +90 ° and -90 °.
  α = right ascension (or RA: right angle) is the angle on the celestial equator (measured in hours, minutes and seconds, taking into account that 1h = 15 °, 1 ° = 4 minutes, 15 '= 1 minute, 1 '= 4 seconds) from the first point of Aries γ (spring equinox) to the hour circle passing through the star (it is the great circle that passes through the poles and the star).

The star catalogs show the positions of celestial objects in this coordinate system, since they do not depend on time (by the motion of the diurnal rotation of the Earth). In this reference the position of the "fixed stars" is always the same, the Sun and the Moon are moving objects, while a point that remains stationary in the equatorial system, moves with respect to a reference point on Earth, one turn once every 24 hours. Due to the slow motion of precession of the earth axis around the pole of the ecliptic occurs as a slow change in equatorial coordinates of a fixed object in the sky (one cycle every 26,000 years). For this reason it is necessary to specify the date (time) to which they relate the equatorial coordinates of an object. Specific references in this sense can be found in the "Explanatory Supplement to the Astronomical Ephemeris". Although the positions of celestial objects are nearly always specified in the celestial coordinates declination and right angle (δ, α), for instrumental purposes-observation is often convenient to convert these coordinates in azimuth and elevation (a, h). For an observer at a given geographic latitude, the following relationships conversion from (δ, α) to the (a, h):

$$\begin{cases} \sin h = \sin\varphi \sin\delta + \cos\varphi \cos\delta \cos\alpha \\ \cos h \cos\alpha = \sin\varphi \cos\delta \cos\alpha - \cos\varphi \sin\delta \\ \cos h \sin\alpha = \cos\delta \sin\alpha \end{cases}$$

and vice versa, by the system of coordinates (a, h) to that (δ, α)

$$\begin{cases} \sin\delta = \sin\varphi \sin h - \cos\varphi \cos h \cos\alpha \\ \cos\delta \cos\alpha = \cos\varphi \sin h + \sin\varphi \cos h \cos\alpha \\ \cos\delta \sin\alpha = \cos h \sin\alpha \end{cases}$$

When a star crosses the meridian, it says that it passes the meridian. Every day there are two transits: the one closest to the zenith is called upper culmination, the most far lower culmination. If both culminations occur above the horizon, the star is circumpolar, otherwise it is undetectable.
The time measured in astronomical observations and records data, as well as that reported in the tables and in the yearbooks, is the so-called Universal Time UT (Universal Time or GMT) which corresponds to the average in Western Europe at longitude 0 ° (of the Greenwich meridian). In Italy, for the solar time, add one hour to GMT time, two hours if it is in daylight saving time:

LOCAL TIME (not legal) TIME = GMT + 1
LOCAL TIME (legal) TIME = GMT + 2

Important are the relations between stellar magnitudes and brightness of celestial objects. In optical astronomy, the brightness of a star is measured in magnitude (mag) m, on a non-linear scale such that at decreasing brightness distribution, correspond increasing magnitude. The brightest stars have a magnitude of about 1, while the weaker ones (barely visible to the naked eye) are of a magnitude 6. The ratio of luminous fluxes of two celestial objects, whose brightness distribution differ by a magnitude, is equal to 2.512. The Sun, which appears bright from Earth, has a m = -26.74 visual magnitude, while that of the moon when it is in opposition is m = -12.73. The planets have magnitudes ranging from approximately m = -4 in the case of Venus m = +14 in the case of Pluto, when they are at maximum brightness. The human eye is able to detect differences in magnitude up to about 0.1.

If two stars have magnitudes m1 and m2, the ratio between the respective brightness l1 and l2 (that physically correspond to the power density of the luminous flux [W/m2]) is given by the formula of Pogson:

$$\log_{10}\left(\frac{l_1}{l_2}\right) = -0.4(m_1 - m_2)$$

As in radio power ratios are commonly expressed in dB, it is interesting to derive how many dB corresponds to 1 magnitude. Is obtained:

$$1 \text{ magnitude} = 10\cdot\log_{10}(2.512) = 4 \text{ dB.}$$

In the following table are compared reports in decibels and the magnitude.

Magnitude	**Decibels [dB]**
0.25	1
1	4
2	8
5	20
10	40
20	80
30	120

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