Hemisferium

THE ASTROLABE

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www.hemisferium.es
Madrid, 2006

The Astrolabe

A Little History

The name "astrolabe" comes from the Greek word *astro*, meaning star, and *labio*, "that which searches," so it could be translated as "star searcher." Nonetheless, this complex instrument has many other applications.

The first manifestation of the astrolabe was as a simple vertical graphometer whose sole purpose was measuring altitudes (of the Sun or stars to calculate the time and position). Later it became a representation of the celestial sphere, meant to answer more complicated questions, and began its triumphant career when, by taking a planar or planispheric form, its surface could easily provide the answers to problems involving the rising or setting of bodies and other issues related to the horizon in a specific place.

It became more complex by the inclusion of calculation tables, more or less superimposed, whose number was limited only by the need to avoid excessive confusion on the astrolabe's plates. In short, the apparatus incorporated in the limited space of its plates the mysteries of astronomy, celestial mechanics, chronologic ephemerid and trigonometry, including, as required, curves related to the Cabala and Astrology, eventually constituting a calculation machine and a true *vademecum* where the astronomer and the mariner found the information that today is provided by nautical ephemerid, logarithmic tables and the sextant.

The first news we can find about the development of the astrolabe concerns the Center for Investigations in Alexandria. The astronomer Hipparchus (150 B.C.) designed the first planispheric astrolabe using the theory of stereographic projection.

Claudius Ptolemy, in 140 A.D. in his book *Almagest*, developed an instrument called *astrolabon organon*, very similar to a spherical armillary or star seeker in terms of ecliptic coordinates. Other important texts about the astrolabe were written by John (530 A.D.) of the Alexandria School, and by Severus (650 A.D.). The work of the Arab erudite Masha-Alla Albategnius (850 A.D.) is outstanding for the influence it had over European scientists in subsequent centuries.

With the reconquest of Toledo by the Catholic Monarchs, the way was open for new science in Europe. During the 13th century, Alfonso X The Wise of Castile created the Toledo School of Translators, where numerous Islamic works were translated and became the basis for creating new astronomic tables.

In Europe, the astrolabe became the vital tool for astronomers, astrologers and surveyors until the end of the 17th century, when it was replaced by more precise instruments. In the Arab world its use continued until the 19th century.

Parts of the Astrolabe

1. *Mater*: brass disk with a rim or limb, used to hold the plates and the rete.
2. Plate or *tympanum*: plaque engraved with the coordinates of the celestial sphere (almucantars); it includes the zenith, horizon, altitude lines, azimuth, equator and the tropics of Cancer and Capricorn. It corresponds to 50.5° of latitude (fig. 1).
3. *Rete*: an astral map where the central axis marks the position of the pole star; the path of the Sun is shown on the ecliptic circle, which is divided into twelve zodiac signs (fig. 2).
4. Rule: Situated over the rete, it is used to align the date on the ecliptic circle with the correct time on the hourly circle.
5. *Alidade*: Its vanes are used to line up with the scale on the back of the astrolabe or mater (fig. 3).
6. Back of the *mater*: All the observations and measurements are made on the back of the mater; the graduated circle around it is called the *limb* (fig. 4).

Uses of the Astrolabe

The possible calculations with an astrolabe, according to Claudius, are more than one hundred. Here we offer the essential ones that may interest the fan of these instruments. We will demonstrate their precision and we will observe how simply and elegantly it solves astronomic problems based on spherical trigonometry.

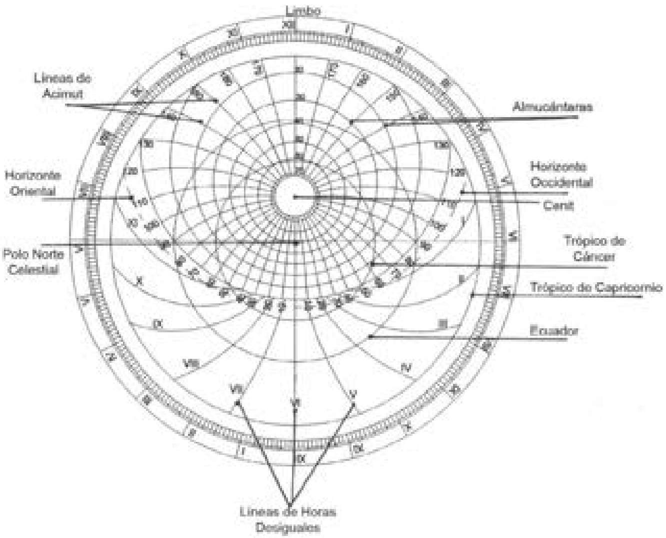

Fig. 1: Plate or Tympanum

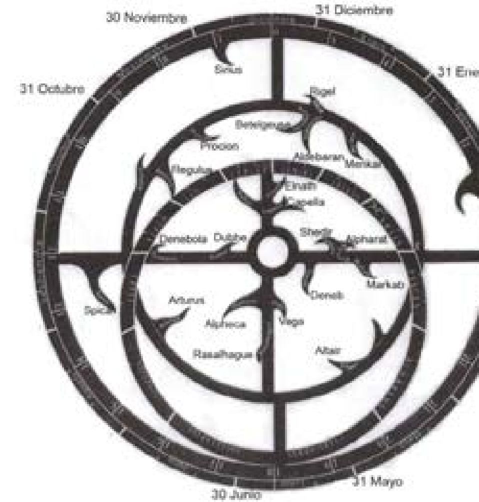

Fig. 2: Rete

Fig. 3: Vanes of the Alidade

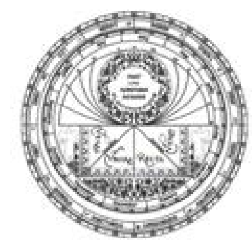

Fig. 4: Back of the Mater

General Uses

The plate represents the local coordinates of altitude **h** and azimuth **Az** for the place of the observer, for which reason there will be as many different plates as latitudes, although it is possible, without great error, to use plates with a difference of a half degree more or less than the actual latitude, while the rete shows us the celestial coordinates, representing the stars in their position in the celestial dome (right ascension **AR** and declination **δ**) by means of pointers in various shapes on antique instruments. Considering the stars fixed (at least over a very long period), we consider their AR and **δ** constant, and so the rete is adaptable to all latitudes, that is, it is interchangeable and can be used on any planar astrolabe, whatever the lines on its plate, and thus is universal. As the Earth rotates from west to east, we can see these stars rotate from east to west clockwise. This apparent movement is the one made by the rete of the astrolabe, shifting the Sun, the stars and other bodies from the eastern horizon to the south, finally setting at the western horizon.

To intuitively present the projection of the celestial sphere with respect to the horizon, turn the astrolabe so that the holder or *throne* is facing south. This way the east will be to the left of the observer, the west to the right and the meridian (XII line) in the center.

On the back of the astrolabe, as shown on figure 4, is a calendar that, using the alidade, converts months and days to degrees of a sign of the zodiac, thus giving the exact situation of the Sun on the ecliptic.

If the rule is located over the point in at which the Sun is found on the ecliptic, the astrolabe will answer all possible questions during day and night, and the rule will act like the hour hand on a conventional clock; the hours are marked on the limb or rim of the mater, such that XII mark close to the throne corresponds to solar 12 or noon, and the XII opposite to 24 hours or midnight.

The rete is imprinted with marks for the right ascension AR and the rule with the declination scale **δ**. In the following examples, we will used the values of φ = 51.5°, λ = 0m 20s, and the day of the observation, unless otherwise indicated, will be August 17. Obviously, any day of the year and any time (day or night) can be used. The instrument can also be used to obtain a variety astronomical data without having to go outside.

The Astrolabe Set for Use

We set the astrolabe to be used for the night of August 17. For that, we line up the star Arcturus with the alidade sighting vanes on the back of astrolabe. Since we get an altitude of 20° on the east side, we must raise the pointer that represents Arcturus (α of Boötis) over the 20° almucantar on the right part of the plate and place the rule over the 24° mark (Leo) on the ecliptic that corresponds to the position of the Sun on this day.

Now, the astrolabe is ready to answer your questions: in this arrangement, the celestial dome is exactly represented by the conjunction of the astrolabe's rete and plate. The first data that we can find are:

- The declination of the Sun. The rule, which is over the 24° Leo point on the ecliptic, indicates: **δ** = 13° 20'.
- The declination of a star. Putting the rule over the pointer for Arcturus we get: **δ** = 19°.

- The right ascension of the Sun. The rule indicates 9h 49m for this day.
- The right ascension of a star. With the rule over the point that represents Arcturus, its end indicates 14h 14m on the AR scale of the rete.
- The angular hour of a star. Since Arcturus is on the 20° almucantar, the rule placed over it will indicate Vh 20m on the peripheral limb of the mater, counting from XII hours.
- The angular hour of the Sun, solar time. Placing the end of the rule on 24 Leo, it indicates IXh 50m or 21h 50m official time.
- Sidereal time at this moment. Since this is equal to the sum of the right ascension of the Sun and its angular time, t Hs = 9h 50m + 9h 49m = 19h 40m. The sidereal time is counted starting from the meridian or from XII hours on the astrolabe. The sign of the gamma point γ (0° Aries) indicates on the peripheral limb the number of hours and minutes counted backwards, that is, clockwise, from the XII mark.
- Unequal hours of the Sun. We see that it just passed the III mark for the unequal night hour.
- Some positions of the stars. Right away, we see that Spica has set and has an altitude of -11°, ending in the nautical twilight. That Capella (α of Auriga) is circumpolar, that is, it neither rises nor sets. We see that Vega (α of Lyra) has culminated; it now transits over the superior meridian and is found at an altitude of 71° and an azimuth of 40° SW. That Altair (α of Aquila) has an altitude h = 48° and an azimuth of 5° SE very close to culminating. That Deneb (α of Cygnus) is at an altitude h = 79° and an azimuth of Az = 70° SE. We selected these three stars because they form the "summer triangle", the most representative example of the sky in summer months in the northern hemisphere.

A. Examples of the use of the Sun

The time we use is the true solar without any kind of correction for longitude, the Time Equation or for daylight savings time.

Nomenclature

Hs, angular hour of the sun or **He** of a fixed star; **t**, time in hours; **δ**, declination of the Sun or of a fixed star; **A**, 180-Az; **Az**, azimuth from the south: / (SE southeast, SW southwest); **λ**, ecliptic or terrestrial longitude; **φ**, latitude or place of use; **A.Rs**, Right Ascension of the Sun; **A.Re**, AR of a star; **ε**, angle of the ecliptic with the celestial equator at 23.44°; **ω**, auxiliary angle; **h**, altitude of the sun or a fixed star; **γ**, Aries point (point where the ecliptic crosses with the celestial equator, origin of the A.R and the point indicated by sidereal time); **α**, first magnitude star in a constellation and **β**, second magnitude; **T. E.**, time equation; **A.M.** antemeridian; **P.M.**, postmeridian; **U.T.**, Universal Time; and **t Hs**, sidereal time.

A.1. Calculate Dawn or Sunrise

The day chosen for this calculation is August 17. On the zodiacal calendar on the back, this day corresponds to 24° Leo. We mark 24° Leo with the rule over the ecliptic circle and we turn both until this point touches the eastern edge of the horizon. The end of the rule will point to 4h 50m solar time.

The official time for this place whose longitude is 0° 05' West equals 20sg, thus: Official time = true solar time + λ difference in longitude (west) + Time Equation + 1h (daylight savings time). The ET value is 4m 05s for this time (5 A.M.). So the official time is: 5h 54m 25s.

A.2. Hours of Sunshine (from the Dawn until Nightfall)

This procedure is the same as for sunrise, but in this case using the time for twilight; 21h 35m - 2h 25m = 19h 10m. The double of Hs as already calculated yields: 2 x 9h 35m = 19h 10m.

A.3. Finding the Time when Know the Altitude of the Sun

The altitude can be known from the back of the astrolabe, suspending it from its holder so that a sunray passes through the two vanes. Observe this indirectly, that is, allow the sunray to pass through the small hole in the anterior vane until it is projected over the second small hole in the posterior vane, but **never look at the Sun through the vanes** because it can cause eye damage. The alidade will point to the altitude of the Sun in degrees on the peripheral limb.

Assuming that the solar altitude, obtained on the afternoon of August 17, to be 30º, now we want to know the solar time. We proceed as usual, with the astrolabe set for use with the Sun on 24º Leo of the ecliptic; we put the edge of the rule over this point, then we turn the rete and rule together until the point falls over the almucantar of 30º in the right or west zone of the astrolabe. The rule will point to IIIh 50m P.M. on the peripheral limb or 15h 50m.

This is the classic example shown in almost all books and the most common use in antiquity. It is said that during the Islamic invasion, conquest and domination of the Iberian Peninsula, Arab leaders had astrolabe experts accompany them on their incursions as inestimable assistants to carry out their strategies.

B. Nightime Chronometer

The astrolabe can tell us the time not just during the day using our star, Sol, but by taking on the role of a **Nocturlabe** and allowing us to know the solar hour by taking readings of the stars, even if they are not circumpolar (one overtakes the other), and though its use is strictly local, unlike the nocturlabe which can be used universally.

B.1. What Time Will It Be When Arcturus (α of Boötis) Has an Altitude h = 20º in the West?

You can look at it directly with the alidade since there is no danger of blindness. For August 17 the AR of the Sun at this time is 9h 49m. This is easy to determine; it involves placing the pointer for the star Arcturus over the 20º almucantar on the right-hand or western part of the astrolabe. When the rete is set over this point, slide the rule until it reaches the position of 24º Leo. It will point on the limb hourly scale to IXh 50m in the afternoon (21h 50m).

We can also ask if Arcturus is visible at this time? The astrolabe gives the answer immediately, since the Sun at 24º Leo is already determined to be below the twilight line. We know that the astronomic evening twilight on this day ends at 21h 35m, so Arcturus has been visible for 15 minutes.

C. Problems Involving the Azimuth

Note: The origin of the azimuth and its numeration is the object of controversy. Astronomers, navigators and sundial users establish a specific ori-

E.1. Calculate the height of a tree knowing the longitude of its shadow
On August 17 at 10 solar hours, the shadow of a tree is 20 meters. You have seen in previous examples how to obtain the altitude of the Sun on this day and time, which is 45º. Put the alidade on the back at 45º, and its border will cross the *umbra recta* in the 10th division on its decimal scale.

Based on the resemblance of real triangles with those on the scale, you can write; altitude/20 = 10/10, therefor; height = 20 mts. = 20 m. Calculation: You can calculate it using the tangent of the measured angle. Height = 20 tan 45º = 20 m.

Use of the Astrolabe: Temporal Hours

It is traditional to include among the lines traced on the plate the line of the temporal or unequal hours. However, on the back there is a scale — also traditional — for converting equal hours into temporal hours for universal use. In ancient times, the length of each day was divided into 12 equal parts and each one represented a temporal hour. Logically, the length varied according to the season, being longer when the period of sunshine is longer (summer) and shorter as we approach the winter solstice, which is why they are called unequal. This arrangement of time was very practical for the completion of ordinary daily tasks.

Having read this brief prologue, we see that on the lower part of the astrolabe, below the horizon, appear the so-called temporal hours and numbers with the Roman numerals I, II, III…

The ingenuity of astrolabe makers is made clear by the fact that they refrained from placing these marks on the visible part, above the horizon, because they would get confused with the circles for height (almucantars) and for azimuths. They realized that the period of sunshine for any day was exactly equal to the length of the night opposite the Sun on the ecliptic, or, the equivalent in more modern terms, for a day in which the declination has the same absolute value but a different sign; if the day in question has a $+\delta = +13º30$, as in the case of the previous examples, August 17, 24º Leo, its opposite on the ecliptic (see the back) is February 13, $-\delta = -13º30$, 24º Aquarius.

Based on that premise, the double conversion of equal hours into unequal, or vice versa, is easy. For example, we want to know on that day, what is the unequal hour for 9h 30m (official time) or 8h 25m true solar time. We put both the rule and 24º Leo together (the place of the Sun on August 17) and move the rule to the mark on the scale for 8h 25m, and in this situation, the other end of the rule gives us the ecliptic of 24º Aquarius (February 13) **antisolar point**, and it is exactly on the III hour temporal time. Inversely, if we want to know what the equal hour is, at IV temporal we must move the antisolar point 14º Aquarius (February 13) over the IV and then put the rule in place. The opposite end of the rule will point on the limb to 9h 35m.

Conversion Scale

In the *Back* it appears the abacus for the conversion of equal hours in unequal with universal character based on the peak altitude of the Sun.

How do we use this scale and for what purpose? According to the rules put forward by Saint Benedict for prayer times (canonical hours), at the III hour it was the custom to say Mass. To know by the Sun the time that corresponded to the III (third) hour, a monk would use an astrolabe. He would put the point we determined in the previous example on the alidade over the III hour; the alidade would be over the 34º mark on the peripheral limb. He would suspend the astrolabe, and when a sunray entered through the first vane and coincided with the second hole on the second vane, it was the III hour, and he would sound a bell to advise the faithful that the religious act was beginning.

In summary, we can admire and are captivated by the harmony and elegance of this marvelous medieval calculating machine, an exceptional simulator of celestial mechanics, which in one plane represents the entire sky. It is a clear exponent of genius and mathematical rigor and deserves the title that Leybourg very properly gave it as "the mathematical jewel."

Note:
For more information consult *Documentation* in www.hemisferium.es.