PUBLIC AND SCIENTIFIC TIME AT PARIS OBSERVATORY : EVOLUTION OVER THREE CENTURIES

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ABSTRACT. When the *Académie Royale des sciences* is created in 1666, and the following year the Observatoire Royal, by Louis the XIVth, several improvements had appeared during the past millenium. Time and determinations by sundials, between sunrise and sunset had led to intervals of twelve unequal hours and to a special reference, the time the shadow was the shortest one, later known as to represent the meridian line. The two aspects of time were also seen : - the date as an instant of time ; - the duration between two dates.

1. WHAT IS TIME ?

What is behind the expression "the measure of time" ? A quantity which indeed cannot be measured. In 1858 Le Verrier (1811-1877) had written : *"Bien que nous ne puissions savoir ce qu'est en lui-même le temps, nous concevons néanmoins qu'on peut, par la répétition de phénomènes identiques, s'assurer de l'égalité de certains intervalles de temps"*. Almost one century later, in 1949, Danjon (1890-1967) could write : *"On n'a rien fait quand on a dit que c'est* [il s'agit de la durée] *l'intervalle de temps compris entre deux instants, puisque cette affirmation reporte le problème sur le mot temps. Mais l'expérience permet d'atteindre une certaine quantité susceptible d'une représentation numérique à laquelle on donne le nom de temps"*. Fortunately, as written by Le Verrier, there are periodical phenomena leading to a certain estimation of time: the rotation of the Earth around the Polar Star, its revolution around the Sun.

Another related problem concerns the necessity of maps to travel from one place to another one. In that case, latitude is easily obtained from the altitude of the Polar Star but for longitude, related to the rotation of the Earth, it needs time determinations. In any case time, whatever it is, needs to be determined and to be kept with the best possible accuracy. In the past sundials could give it at about a minute and various types of clepsydra, sand-glass, hour candles could keep it in between.

The major evolution of clocks which appeared in the bell-towers, as early as during the 13th century, will come with Huygens (1629-1695), in the Low Countries by 1655. He introduced a pendulum leading to pendulum clocks, later to be named regulators. While old clocks could vary of one hour per day, the new ones will be able to keep the second over 24 hours.

Due to the quality of his clocks, Huygens was invited by the Sun-King to come to Paris and he stayed in France from 1666 to 1681/82. From good clocks for time, the longitude problem appeared to be possibly solved for cartography.

2. TIME BY THE END OF THE 17th CENTURY

The 17th century will be, for astronomy and related fields in general, for time in particular, a very decisive one. On the other hand, mural sectors will be equipped with refractors, themselves having filar micrometers, after the works by Auzout (1622-1691) and Picard (1620-1682). Murals are installed, at the Paris Observatory, along its thick meridian walls. Clocks, designed, under Huygens, in Paris by the horologer Thuret (Figure 1), are placed in their vicinity and they can beat the half-second allowing time to be recorded at about a quarter of a second.

In 1668, the French astronomers had to check Cassini's table allowing to predict eclipses of the nowadays named galilean satellites of Jupiter. Due to their quality Cassini (1625-1712), from Bologna, was invited to come to Paris where he arrived in spring 1669, the Observatoire Royal being under construction. In 1673 he decided to stay in France. In 1669, Picard designed three new instruments, a sector with a short limb for zenith observations, a portable quadrant with two refractors for azimuth measurements, a level equipped with a refractor. This year and the following one, he worked on the measurement of a meridian arc centered on the Paris Observatory latitude. From its length he could deduce the circumference, the diameter and the radius of the Earth with a very high accuracy for the time.

Between 1671 and 1672, Picard experienced the method of determination of longitude in using eclipses of Jupiter satellites and good pendulum clocks. He went to Danemark where he received the help of young Roemer (1644-1710) with whom he came back to France in 1672. The corresponding observations were made in Paris, by Cassini. In 1676, Picard began to use the eclipses of the galilean satellites for longitude determination along the French coasts. He was working with La Hire (1640-1718) determining the timings by clocks, Cassini doing the same from the Observatory meridian line. The corresponding map, including this meridian for the first time, was presented to the Academy in 1682, and published in 1693.

Astronomy, which will give birth to astrometry, geodesy, topography, cartography and other related domains, had gained powerful instruments, introduced new methods and obtained fundamental results. The astronomers had obtained accurate positions of celestial bodies; they were able to perform terrestrial astro-geodetic measurements; they had proved the value of the pendulum clocks, given the data concerning the figure of the Earth, established a reference for local time determinations and, more generally, for longitude campaigns.

3. 18th CENTURY INSTRUMENTS, METHODS AND RESULTS

Using a vertical sector, similar to the one designed by Picard, Bradley (1693-1762), the third *Astronomer Royal* at Greenwich Observatory (established in 1675) published, in 1728, the discovery of aberration and two decades later nutation. The first phenomenon could confirm the discovery of Roemer concerning the velocity of light. The second will affect the celestial pole.

Portable quadrants will not change so much. But, by the end of the century, astronomers had large mural quadrants for determination of time and meridian observations of celestial bodies. While the portable quadrants were made by the French Langlois (ca 1730/1750), the Paris Observatory was equipped with a mural one made by the British maker Bird (1709-1776). It was installed on the east side of the Observatory at about 35 meters from the meridian of reference. They had at their disposal clocks made by the horlogers Julien Leroy (1686-1759) and Berthoud (1729-1807). They had improved their pendulum part in using two different metallic pieces and one, from Berthoud (Figure 2), is still in the collections of the Paris Observatory.

The astronomers from Paris Observatory, upon request of Colbert, Louis the XIVth, later Louis the XVth, were asked to develop geodesy in view of a general map of France. They established a reference for longitude (the Paris Observatory meridian line, from the northern to the southern border), and a reference for latitude perpendicular to the reference meridian at the latitude of the building. The issued map, achieved in 1790, is - one can assume - the first one,

at the level of a country, established under a scientific cartographic method. By the end of the century appeared small portable transit instruments for field observations.

For the public, and before his departure from the Observatory in 1793, Cassini IV (1748-1845) submitted the proposal to fire a canon, from its upper level, every day at noon. But in case it could affect the building the project was abandoned.

4. 19th CENTURY EVOLUTION

Due to the improvements in the mechanical domain, larger instruments could be built. Under the influence of Arago (1786-1853), a large east wing is built, around 1835, to house three new ones : - a meridian circle for declination measurements ; - a transit instrument for right ascension and time determinations ; - a meridian circle to perform both types of observations (Figure 3).

Their regulators, under the form of two clocks, one for mean solar time, the other for sidereal time are placed in the same room close to the instruments due to the method of the time (ear and eye) being used. As soon as electricity was available, such clocks were equipped with a new design to insure a better regularity. To give profit to the public of accurate time determinations, Arago had in mind to install a Chappe (1763-1805) telegraph on the Observatory. With the electricity he moved to the use of the electric telegraph.

But what time will be given to the public ? According to Arago, in Paris - from 1816 - the clocks had to be settled upon the one given by the Paris Observatory meridian. While, in the past, public clocks gave the local solar time, from 1839, they had to give the mean local solar time, in using the *Annuaire du Bureau des longitudes*, created in 1795. By 1881 and during the following years, mean solar time of Paris was provided to the main harbors beginning with Le Havre, Rouen and others ; later on came the main towns under the influence of the railway.

A decision studied in Roma in 1883, was taken in 1884 in Washington, to divide the Earth into 24 time zones, referred to Greenwich meridian; it was not immediately adopted in France. By the end of the century, with the discovery of wireless, the very first time signals were sent, from Hamburg in Germany, in 1899. A few years earlier a phenomenon, suspected by Picard but not yet found in the observations, was discovered, in the US by Chandler (1846-1913) : the 1.2 periodical motion of the pole which will play an important role during the following century.

At Paris Observatory, the clocks were still installed in the vicinity of the time measurement instruments. From 1891, time was unified in France, being the mean solar time of the Paris Observatory meridian of reference.

5. UNIFICATION OF TIME DURING THE 20th CENTURY

Ferrié (1868-1932) to become later general, took into consideration what is called in French TSF (*Télégraphie Sans Fil*). In cooperation with Paris Observatory, he set-up a laboratory at the bottom of the Eiffel Tower. He had in mind to sent time signals from its very high summit. Poincaré (1854-1912), then president of the *Bureau des longitudes*, was affected by the delay which had occurred due to the flood of the river Seine in January 1910. Fortunately he could show, to the the French government, the equipment in June and, in November, the very first efficient time signals could be sent up to 5 000 kilometers. Accurate values of time were sent, from Paris Observatory to the tower, every day at given hours.

The following year, 1911, France decided to adopt the time zone system referenced to Greenwich. An international conference was held in Paris, upon invitation launched by the *Bureau des longitudes*, in 1912. It was decided to consider the general unification of time at the international level and to create some special bureau to take care of it. But World War I stopped the projects.

During the war Baillaud (1848-1934), then director of the Observatory, and Bigourdan (1851-

1932) succeeded in pursuing some sort of continuation of the project. When the International Astronomical Union was created, in 1919, the *Bureau des longitudes* took this opportunity to propose the creation of a time commission and what was named *Bureau International de l'Heure* (BIH). From the beginning of the century new clocks under constant temperature and pressure were designed. At Paris Observatory they were installed in the basement at minus 27 meters from the courtyard level (temperature stable between 12°5 and 13°), in thick metallic cylindars in which a very low pressure is obtained (Figure 4). Bips issued from the clocks were send to the time division, later to the BIH.

A new meridian instrument had been installed in a special building of the park and two small more modern transit instruments took place in two other ones. After World War I a new instrument appeared, the Claude (1858-1938) and Driencourt (1858-1940) prismatic astrolabe, able to provide data for the simultaneous determination of time and latitude. The bips af all theses instruments were registered through printing chronometers up to the hundredth of the second. After World War II a new instrument, issued by Danjon from the Claude and Driencourt model, was set up in the park in October 1952. More efficient printing chronometers were installed in order to register the bips up to the thousandth of the second, and, in the eighties, more electronics was introduced. Time was given at ± 0,005 second. Observations with this last instrument were stopped, in Paris, on 1987 December 31, new instruments being used for time and latitude determinations.

Meanwhile, by 1930, came quartz clocks and, in 1937, seasonal irregularities of the rotation of the Earth were discovered in Berlin and, in Paris, with Stoyko (1894-1976). For time scales, this new phenomenon had to be taken into account together with the effect of the polar motion. The comparison of clocks scales from various observatories was made under the leadership of the BIH and an international scale was established. In 1985 the time part of the BIH was moved to the Bureau International des Poids et Mesures and, from 1988 January the first, was created the International Earth Rotation Service (IERS).

On the other hand, in 1955, in Great Britain, atomic clocks were designed that were so successful that they can provide time scales independent from the irregularities of the Earth rotation. In 1967, the atomic second replaced the astronomical one based, after the rotation of the Earth (UT), on its revolution (ET). Whatever is the origin of the second, official time is still given to the public, in France, by the Paris Observatory through the speaking or talking clocks, taking benefit of the evolution of time during the 20th century having been created and put into service on 1933.

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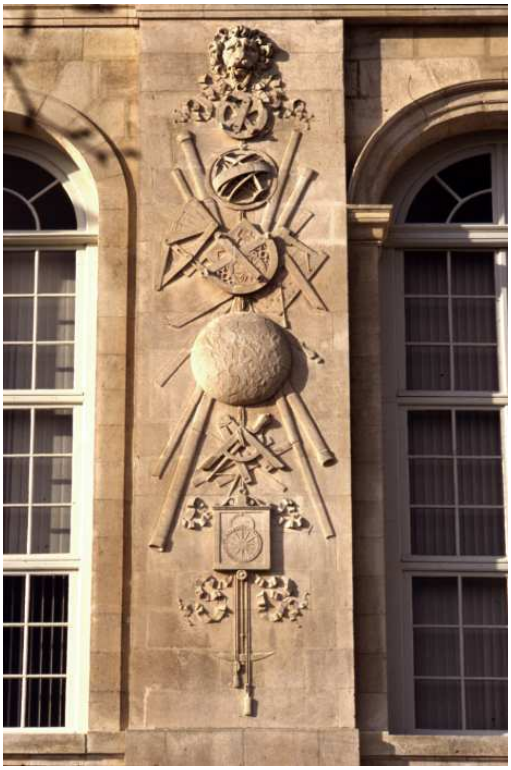

Figure 1: Thuret's clock represented on the southern facade of the Paris Observatory.

Figure 2: A Berthoud's reflactor, the oldest clock still preserved in the collections of Paris Observatory.

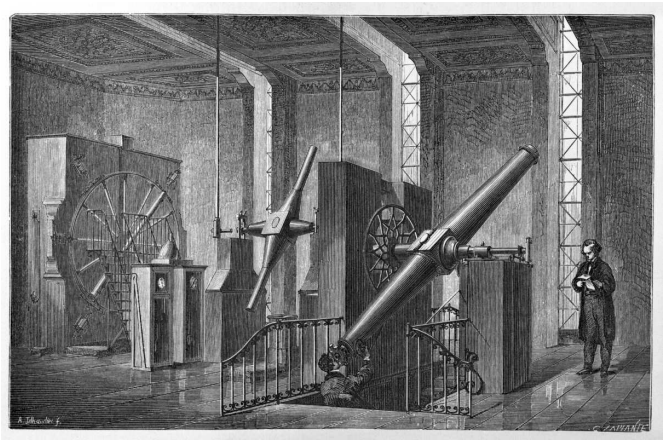

Figure 3: The meridian room as installed when Arago was "directeur des observations" at Paris Observatory.

Figure 4: A fundamental clock installed, by the beginning of the 20th century, in the basement of the Paris Observatory.