Chapter 2
Astronomers and Time

Astronomers of the past few decades have above all been the authors of discoveries that have revolutionised our vision of the Universe. They have developed instruments and used them to observe the sky, measuring quantities that were accessible to them such as the temperature of a medium, the energy of particles, or the chemical composition of a gas. They have developed models which provide a consistent picture of these measurements, then used their models to predict new properties of the given objects, and so on and so forth. The whole of modern astrophysics is characterised by this way of doing things, which already goes back to ancient times. It is the essence of the scientific method, applied to observation of the sky.

Until the beginning of the seventeenth century, all instruments used the naked eye as the only optical and detecting system, in the first place to measure angles. What was studied was the place of the Earth in the Solar System and in the Cosmos, and models of this Cosmos, called cosmogonies. These observations took a great step forward with the construction of Tycho Brahe's great observatory on the island of Hven in the strait between Denmark and Sweden, or the Jaipur observatory in India. Then Galileo turned his refracting telescope to view the Moon, the Sun, and Jupiter, opening the way to a closer analysis of the nature of celestial bodies. However, this kind of research would long remain a minor role for astronomers. Until recently, their main activity was to measure time, on the scale of seasons and years, and then on ever shorter scales of days, hours, minutes, and finally seconds and fractions thereof.

Time, Apparent Motion of the Heavenly Bodies, and Mechanics

Going back as far as records can go, humans have used the apparent motions of the heavenly bodies to measure time go by. The Sun, the Moon, and the stars provide the only points of reference for gauging the passage of time without having at least

© Springer International Publishing AG 2017

T.J.-L. Courvoisier, *From Stars to States*, SpringerBriefs in Astronomy,
DOI 10.1007/978-3-319-59232-9_2

some elementary knowledge of the laws of physics. Celestial objects that can be perceived by their visible emissions are stable enough to be used to this end. In a world where observation of the sky was done in the X-ray region of the spectrum, where objects constantly change in intensity and sometimes even disappear, it would probably be impossible to use the observed changes to take stock of passing time.

Other regularities than the celestial motions, such as the regular swing of a pendulum or the vibration of a crystal, or indeed atomic transitions, cannot be exploited to measure time without a solid grounding in the phenomena which govern such systems, an understanding that we have only acquired relatively recently.[1] The oscillations of pendulums were not understood by savants until around 1600, and it was only then that their motions could be used to measure time in clocks, indeed, in pendulum clocks. Later, crystal vibrations replaced mechanical ones in most modern watches. And in recent decades, it has been possible to control oscillations associated with atomic transitions well enough to use them as the basis for time measurement in our own society.

The Seasons

There would be no way to follow the cycle of the seasons without recognising the apparent motion of the Sun during the year. Every day at noon it gets higher in the sky as winter and spring go by, but then comes back down little by little during the summer and autumn, at least in the northern hemisphere (but the opposite in the southern hemisphere). The first monuments erected by humans and which have remained to this day, standing stones set in place long before the advent of writing, like the Standing Stones of Stenness (Fig. 2.1) in the Orkneys or Stonehenge in England, were sometimes aligned with certain important moments of the astronomical year, such as the winter solstice at the time of their construction. So it was skywatchers, astronomers of a sort, who presided over the construction of these monuments, which could then be used to determine the seasonal cycles throughout the year.

Determining the direction of the winter solstice in the British Isles during prehistoric times would certainly have taken years of painstaking observations, memorising positions and reporting the results from one year to the next. Once the geographical direction of the solstice had been determined, it would probably still have been necessary to convince the community that it was worth setting up monuments along this axis, as this construction would have represented a considerable work load for such societies. Today we would say that it represented a significant fraction of the community's gross domestic product. If we judge by the difficulty we have in convincing our own authorities of the need for our work, the

[1]We have made no mention of the hourglass and the clepsydra.

Fig. 2.1 Standing Stones of Stenness on the main island of the Orkneys. *Source* S. Kessler © https://drinkvicariously.files.wordpress.com/2013/08/dsc05015.jpg

task of persuasion required by our ancestors to obtain such a result must have been forbidding!

Once erected and aligned, these monuments could be used to measure time during the year. This was a crucial source of information for the practice of agriculture. Indeed, in order to plant seeds in the right season, it was essential to follow time on a monthly scale. Meteorological time is not a reliable indicator for this, as we all know. It was observation of the sky, the Sun, or the stars, the work of astronomers, which allowed prehistoric societies to develop agriculture. The ability to measure time during the year was essential for the development of civilisation, and it is one of astronomy's contributions to human development.

Time and Organisation of Society

Determining the seasonal cycle is a central problem for agriculture, but it is still not accurate enough to arrange a meeting somewhere, a key aspect of social organisation. To do that, we need to be able to measure the passage of time during the day. Even there, it is down to astronomy to take up the main part of the challenge. Diurnal time is determined by following the Earth's rotation about its own axis.

And this is measured from the Earth's surface by observing the transit of stars at the meridian, that is, the plane specified by the axis of rotation of the Earth and the position of the observer. The time required for one rotation of the Earth about its axis, the day, is given by the time between two consecutive transits of the same star at the same place. The Sun itself crosses the meridian every day. This is the definition of noon. But in one day, the Earth has moved a certain distance on its orbit around the Sun, in fact, something like one degree (about 1/365 of the Earth's yearly journey around the Sun). Viewed from the Earth, the Sun has thus moved through the same angle relative to the stars. The lapse of time between two consecutive noons, called the solar day, is thus not the same as the lapse of time between two transits of the meridian by a distant star, the so-called astronomical day. These details had to be gradually understood and taken into account to be able to provide accurate timekeeping in a given community and thus facilitate its organisation.

Astronomers invented the instruments needed for their observations using the technology of the day. They then carried out the necessary observations night after night for centuries, in all those communities that considered a mastery of time important for their internal organisation. The effort involved in this work represents one of astronomy's central contributions to modern life, even if this particular contribution has become much less important in recent decades. To judge by the mandates given by the authorities to their observatories over the last few centuries, in many towns of varying size, time measurement came high on the list of an astronomer's duties. The latest advances in astrophysical understanding were a secondary activity in these observatories, at least until the middle of the twentieth century.

Just communicating time to a given population is another problem that needs to be solved. While the local astronomer may know, for example, that it is noon at his observatory, he can hardly set off on foot or on horseback to tell the mayor or some other authority that it is noon. It would no longer be noon by the time he arrived. Since sound travels at about 300 m/s, sound signals were not accurate enough to carry information about time, for example, to meet the needs of ocean navigation. The city of Athens, and others too, got round this problem in the nineteenth century by using a visual signal. The observatory determined noon and lowered a ball down a mast placed on the roof of the observatory at exactly this time (Fig. 2.2). The mast was visible from the cathedral, so the bellringer could accurately sound the bells and hence inform the whole population of the time every day. The delays due to the propagation of sound are short enough not to pose any problem for the purposes of everyday life, since nobody needs to meet their appointments with an accuracy of seconds. But the same is not true for navigation.

For several centuries and up to relatively recently, observatories were predominantly there to serve their communities through the provision of high quality time measurement. For example, the observatory in Besançon (France) was founded in the 1870s, but it was not set up so that astronomers could contribute to an understanding of the Cosmos. The aim was rather to support the local clockmaking industry which found itself at a certain disadvantage with respect to its competitors

Fig. 2.2 The Athens observatory, founded in 1842 to provide time to the city. Every day at noon, a ball was lowered on the mast. *Source* Fingalo, Published under the Creative Commons Attribution-Share Alike 2.0 Germany license. https://commons.wikimedia.org/wiki/File:07Athen_Observatorium1.jpg

in Geneva and Neuchâtel, for the latter had their own chronometric observatories. In Geneva, the observatory carried out precise measurements on chronometers made in the region up until the 1960s.

From the middle of the last century, technology exploiting vibrations of quartz crystals, then another making use of atomic transitions, gradually replaced mechanical clocks and watches, providing more accurate and more economical timekeepers than astronomical observations on timescales of the order of days. But atomic time nevertheless remains linked to astronomical time, since the gradual slowing of the Earth's rotation due to friction induced by tidal effects is regularly compensated by adding intercalary seconds to civil time so that it remains in phase with astronomical time.

Time and Navigation

The measurement of time and the measurement of position on the Earth's surface are closely related. Time is given by the transits of celestial bodies across the meridian, and the meridian is given by the position of the observer. The difference in longitude between two points on the Earth is determined by measuring the time difference between the passage of a star across the meridian at each of the points. Moreover, the height of the Sun above the horizon at midday, a measurement used to establish the observer's latitude, depends not only on the position of the observer, but also on the day when the measurement is made. So knowledge of the relative position of two points on the Earth depends, like the measurement of time, on astronomical measurements.

Such knowledge underlies all geographic cartography, and it also underlies all navigation when there are no recognised visual points of reference, and in particular, when crossing the oceans. The navigator measures progress by regularly determining the ship's position relative to the Sun and stars and referring to a pre-established map.

It is only since the 1990s that we have been able to determine our exact location by receiving signals generated by satellites in orbit around the Earth, satellites belonging to the American GPS system and the European Galileo system (still under development), or other satellite systems. The knowledge we have of a given location through a global positioning system depends in turn on the knowledge we have of the orbits of the satellites and their progress along these orbits. These quantities can be measured geometrically from points whose positions on Earth are precisely known. However, the latter positions must be determined independently, and this is done by making astronomical measurements. Consequently, as for the measurement of time, the most up-to-date positioning technology is firmly grounded on astronomical basics.

Progress in cartography and navigation has been based on the work of astronomers ever since they have been able to make accurate enough measurements of the positions of celestial bodies to determine positions more precisely than by simply keeping records of one's journey. Knowledge of geography and navigation is also a central issue in managing and defending a territory, or indeed in taking over a "new" territory. It is essential for governments and the military, who have financed, sometimes begrudgingly, the work needed to set these systems up, and have often placed the results under the seal of secrecy.

Time and Ritual

The time measured by motions of celestial bodies is also the time used to schedule religious ceremonies. Ramadan lasts one lunar month and ends when the Moon is once again visible after a New Moon. Easter is celebrated on the first Sunday following the first Full Moon after the spring equinox. The algorithm determining this date may seem a little imprecise, and this has indeed led to some controversy, and differences between the dates of Easter in the Western and Orthodox Churches. Once again, it is astronomers who set the schedule for the religious life of a community.

Regular celestial events provide points of reference on the calendar to plan festivals and other celebrations, while unexpected celestial events, such as the appearance of comets, have also played a role in communities who endow them with premonitory meaning, often treating them as bad omens. As a matter of fact, cometary trajectories are just as predictable as planetary orbits, but since they spend most of their time a very long way from the Sun, invisible to us at such distances even with our most impressive telescopes, comets give the impression of coming mysteriously from nowhere. Their appearances were long interpreted as signs announcing important events. Likewise for eclipses, alignments causing the Sun to disappear momentarily behind the Moon. These were considered as omens of various kinds until it became possible to predict them with perfect accuracy using the tools of celestial mechanics.

The close relationship between astronomy and time measurement is not only found in the Judeo-Christian, then Western society. The regularity of daily and annual apparent motions in the sky is a universal observation, like all scientific measurements. For example, the Aborigines in Australia named their seasons, of which there were six, after stars which appeared in the sky at the beginning of each season.[2]

Chinese astronomers made a close link between the apparent motions of celestial objects, the calendar, and political power. Since the number of days in the year isn't a whole number, and likewise the number of lunar months in the year, calendars must be regularly adjusted. We do this by adding a day every four years, at the end of February, thus defining what we call a leap year. A smaller correction must still

[2]Norris R.P. and Hamacher D.W., Proceedings IAU symposium 260, D. Valls-Gabaud and A. Boksenberg, eds, p. 40.

be made by omitting one leap year every hundred years. Chinese calendars lost their original relationship with the seasons over the decades and had to be readjusted from time to time. Such adjustments were carried out at moments of important political change. A new beginning in the calendar would thus be associated with a new administrative period.[3]

Astronomy in the Service of Society

The ability to measure time and determine one's location were of great importance for agriculture, the organisation of society, and navigation. State authority of whatever form and wherever it might be thus depended on astronomers carrying out several of their key missions. This privileged role of astronomers in state and societal organisation still gives astronomers a position of eminence in the hierarchy of the United Kingdom, under the title of Astronomer Royal. The fact that the astronomical knowledge we have acquired over recent decades is more closely related to the physics of cosmic objects than to the measurement of time for societal purposes means that this position, or its counterpart in other nations, is now merely a matter of prestige, no longer actually endowed with real power as it used to be.

Astronomers have thus provided a very real service for the public good and the governments they have worked for over the centuries and millennia. This service was a key resource for the functioning and development of collectivities up until the second half of the twentieth century. The work done in this respect very largely dominated all the other activities of most other astronomers. The acquisition of knowledge which has since become the central activity of the astronomical community is also a form of service to humanity, although now more abstract. Human culture has grown richer throughout the history of humanity, and continues to do so, through knowledge acquired by our understanding of the sky and the objects we discover there.

[3]X. Sun, Proceedings IAU symposium 260, D. Valls-Gabaud and A. Boksenberg, eds, p. 98.

Springer

http://www.springer.com/978-3-319-59231-2

From Stars to States
A Manifest for Science in Society
Courvoisier, T.
2017, XVI, 67 p. 15 illus., 11 illus. in color. With
Translated from the French original Des Etoiles aux
Etats - Manifeste pour une gouvernance à l'écoute de
la science., Softcover
ISBN: 978-3-319-59231-2