# 1

# Observations

## 1.1 The definition of 'observation'

Astronomy is a natural science and as such is based upon observation. If one were to try to define the term 'observation', one would be led to say that an observation is the detection of a signal, carried out by somebody at a given place and a given time, with a particular instrument and for a particular purpose.

Such a definition is rather broad and could also apply, for instance, to the measurement of one's own body temperature. To use the term in a strictly astronomical sense, one must qualify the nature of the signal detected: it must be either electromagnetic radiation or a high energy particle from an extraterrestrial object. This applies to all astronomical observations, except the sampling of lunar soil and meteorites that have landed on the Earth, which can be analysed in laboratories. The only contact the astronomer has with the object of study is, then, through an electromagnetic signal or high-energy particles from an extraterrestrial object.

Astronomical observations differ from observations in physics and chemistry because, in astronomy, the place of observation and the date must be carefully specified. In chemistry this is unimportant in general.

We have still to add the very general requirement that an observation is only usable if it is documented. However, this applies to all sciences, not only to astronomy.

Let us next illustrate our definition with some examples. We start with Hipparchos (*c*. 150 BC), who observed the simultaneous rising and setting of pairs of stars on the sky. He observed visually, helped with a celestial globe, on which he marked the positions of his pairs of stars. He described his observations in *Comment on the Phenomena of Aratos and Eudoxus*.

Chinese annals describe the visibility of many solar eclipses at the times of kings of different dynasties. The observations were carried out visually by astronomers and a description of the cities where they were made was given in the Annals. These observations constitute, even today, important checks for the theory of the Earth's motion.

The fall of a shooting star is an observation if we are told when and where it was seen, which part of the sky was transversed and how long the phenomenon lasted.

A photographic plate taken with a camera having an objective prism provides the spectra of several hundreds or thousands of stars. If we are told which was the instrument used, the objective prism angle, the photographic emulsion, the dispersion of the prism, the place and date of observation and the exposure time, we consider this to be an astronomical observation.

If a satellite measures the X-ray flux emitted by a source in the sky, it only qualifies as an 'observation' if a (very) large number of parameters is specified – the position of the satellite, the description and specification of the detector used, the signal measured, the time and duration and the location of the source in the sky.

All the preceding examples insist on certain aspects of the definition given already. Let us examine now in some detail the different elements included in the definition.[1]

(a) Detection of an electromagnetic signal or of high energy radiation. We have remarked already that this becomes a rule for all astronomy of objects beyond the Moon. If we consider that, perhaps in the next decades, we will get soil samples from other bodies in the solar system, we may generalize and say that this condition will describe essentially all 'non-solar-system' astronomy. From here onwards, we shall use the word 'astronomy' in the sense of being 'non-solar-system' astronomy. A segregation of solar system astronomy from the rest seems reasonable in the 1980s when the methods used differ increasingly, the literature on solar system bodies has grown enormously and astronomers are increasingly specialized in either one or other of the two fields.

(b) Made for a particular purpose. An underlying purpose distinguishes making an observation from casually 'looking at the sky', as we all do from time to time. It is one of the most important factors that needs to be specified in order to make the observation properly. The purpose determines the technique used for carrying out the observation and puts it in its context. For instance, if somebody determines the geographical latitude by means of observations, one should know if the observations were carried out for land-surveying purposes, or for determining the position of an observatory, or for studies of the polar motion. If one does not know the purpose but only the resulting latitude, one may run into trouble: was it an approximate result obtained by a surveyor, expressed to more significant figures than were actually measured? Was it an eighteenth-century determination carried out by an astronomer?

Notice also that observations can be made for a certain purpose and used later for a completely different one. Messier (1781), for instance, was interested in comets and his list of objects was set up to avoid confusion with comets. For us it is the first long list of non-stellar objects. Similarly, Flamsteed measured the positions of stars and included also some observations of a planet, not recognized as such by him; these are the earliest observations of Uranus.

Supernovae and novae, called 'guest stars', were observed by Chinese, Korean and Japanese astronomers to predict the destinies of their kings, but today they are irreplaceable records for the study of supernovae and novae.

(c) Made by somebody. This is an important element of the observation, which goes with the documentation. It constitutes a recognition of intellectual property, like, for instance, the name of the discoverer of a comet or a variable star. By providing a name, an indication is given of the approximate epoch and, perhaps, even of the place at which the observations were made. The mention of the epoch also furnishes an indication of the possible techniques used. If other observations by the same scientist are known, it provides in addition a 'quality mark'.

Difficulties with authorship occur frequently and I quote a few. First of all, if the observations are of the routine type, they may have been carried out not by the astronomer himself but by one of his assistants and/or students. If a discovery results, who is to be regarded as its finder? (This happened, for instance, with the discovery of pulsars.) The observation may be made by several people, like in the case when somebody takes a plate, somebody else examines it and finds a suspected object and a third person measures it and discovers that it is a lost comet. Who is the 'observer'? Or the observation may be carried out automatically (see Chapter 2); the observation may then be associated with the astronomer who proposed that it be made.

It is clear that the usefulness of knowing the name of the observer diminishes with the passing of time. Except historians, most astronomers would be satisfied by knowing that they are dealing with a 'fifteenth-century observation'. Thus, observations are to be regarded like the stone blocks of the cathedral of Strasbourg – each one is important and is the personal work of somebody but, once put into its place in the building, it loses its individuality.

(d) Carried out at a given place and at a given time. The recording of these is a fundamental requirement for any observation and their absence practically eliminates the observation from further use in a science in which everything is variable with time. Although astrometrists are usually specific on these details, astrophysicists have become 'sinners' and it is seen nowadays, in quite fashionable journals, that 'photoelectric observations in the uvby system were carried out (with a precision of a few millimagnitudes) in 1987'. Some years later, nobody is able to provide the exact dates of observations because the records were destroyed, the author moved to another place or is engaged in other research. The observations are thus useless, for example, for investigating time variations. Authors reply to such criticism that journals do not want observing dates (because it takes space) but they forget that, for instance, data banks are there for just such purposes. (This will be discussed in Chapters 9 and 10.) Observing places are also often omitted under the assumption that they say little about the observations; what is forgotten is that they are often the last hope for anybody looking for more details – an oldtimer of the observatory may still be able to provide details on the reduction of data one is interested in, or log books may be found in some drawer.

(e) Made with a technique that has to be described in detail. This is a self-evident condition for observations to be useful. If we are told that something was observed but not how it was done, we are in the positions of historians who try to deduce or guess from data how they were obtained.

It goes without saying that the techniques should be described in detail, keeping in mind that observations are preserved for future users and, sometimes, for uses other than the original ones. A few examples may be appropriate, although we shall consider this in more detail in Chapter 3.

Photoelectric observers from 1920 to 1950, for instance, described their photometers in detail but usually did not provide the average wavelength of the photocell–filter combination; in other cases they did not use filters at all. The result is frustrating: we have the observation of a flux with 1% precision but we are ignorant of the wavelength at which it was measured! Unhappily, most photoelectric photometry done before 1950 was of this kind.

Other observers describe their photographic material as Panchromatic Super X, but forget to say to what wavelength range that corresponds. If the manufacturer of the material is not indicated, the lack of wavelength specification may prevent further use of the observations. Similar remarks apply to descriptions like 'the plates were taken with the Mt. Apple telescope at Hollywood with the 10-inch objective prism'. It would eliminate a lot of literature searching if the plate dispersion and the wavelength range of the spectra had been indicated.

This rapid overview shows that complete documentation is required to make an observation fully usable. This is a seemingly obvious point and I think that we are all convinced that we have satisfied it. What we often do not realize is that many details that seem obvious to us *now* (so that it is unnecessary for them to be written down) will not be obvious at all for next generation of astronomers. It is just the non-mention of the obvious that complicates things.[2]

From the preceding discussion it is clear that an observation must fulfil a number of conditions to be usable. Not all of these conditions are equally important in all cases but if some are absent the observation loses some value and may become partially or totally useless. Since all astronomy is based upon observations, this means that we are 'building on sand'.

## 1.2 Planning observations

We turn now to the practical aspects of observing. We start by noticing that observations are usually carried out at places called observatories; we shall deal with them in Chapter 2. Secondly, we notice that one rarely makes just one observation; usually, a whole series of observations of similar type are carried out. This is called an 'observation programme'. Because any observation requires instruments (e.g. a telescope), auxiliary equipment (e.g. a spectrograph), assistance from other persons (e.g. an engineer or a night assistant), transport to and from the observatory, lodging after the night is over etc., it is clear that an observation programme must be planned very carefully in advance. For ground-based observations this means typically six months beforehand, whereas, for space experiments, the planning period may extend to six *years*. Excepted from such provision are those happy (few) astronomers who have an instrument available for their own use, which may happen when one uses an instrument not much needed otherwise or the prototype of a new instrument, or one is the owner of the telescope. For the remaining 98% or so of astronomers, observations must be carefully planned long in advance.

This implies that one must plan what to study, how and when; in other words, one must plan one's research well in advance of making the observations one needs. Let us add that careful planning does not guarantee that one will be able to carry out the programme because, in a similar way, many colleagues also plan to observe with the same telescope. In the ensuing competition, the best proposer usually wins; we shall see in the next chapter how the competition is decided in practice by the 'programme committee'. It is clear that one increases the chance of succeeding if the purpose of the observing programme is well-founded (i.e. it is clear why one wants to observe), if the proposal contains a reasonable request for observing a limited number of objects (since, if the programme is too extended, it will collide with more programmes than if it is short) and if one provides a clear explanation of why one needs a specific combination of telescope and auxiliary equipment.[3]

What kinds of programmes can be proposed? In general, there are two extreme types: the survey type and the individual, monographic type. We call 'survey type' all those programmes in which the emphasis is put on the observation of a large number of objects with the same technique, and 'monographic type' the one in which the concern is for one (or a few) objects to be studied in detail. Because of the number of objectives involved, it is clear that one might also speak of long-term programmes and of short programmes – although a long series of monographic-type programmes may constitute a future long-term programme. The terms 'long' and 'short' refer in this context more to what one writes in the proposal asking for observing time than to the long-term philosophy. It is clear that the two types of programmes have different objectives. In a survey programme one is more interested in the statistical aspects of the objects, such as distribution in space, average properties, correlation between parameters and so on. To know the distribution of B-type stars on the sky, or that of galaxies in space, for example, it is clear that one must study as many objects as possible, even when one does this only for a part of the sky. It is also the only way of picking out interesting objects, or to find out what is a 'typical' (i.e. average) object of the type one is studying.

The drawback of survey programmes is that they demand much time for their execution. Since telescope time is often at a premium, programme committees tend not to be overenthusiastic with such proposals. This is often justified on the ground that surveys tend to produce fewer papers per year than monographic studies. We shall discuss in Chapter 12 how to evaluate publications; here we observe simply that the impact of surveys is often much greater than that of monographic papers. In favour of monographic studies one can say that the newest instrumentation may be used to study one (or a few) parameters of one object. One may thus expect real progress or new insights, which is the best reason for such studies. One examines, you might say a small section of the universe with a magnifying glass. To safeguard against excessive optimism, let us formulate two reservations. The first concerns the selection of the object: one should make sure by all conceivable means that one is dealing with an average (typical) object; otherwise we might learn much about an interesting object but not very much about the whole class of objects. (Consider, for instance, if extraterrestrials decided to study mankind and considered as 'average' either a man named Johann Sebastian Bach or another called Gengis Khan.) The second reservation concerns the use of new instrumentation: usually one underestimates the investment of time that goes into the making of a new instrument and getting it to work properly. For instance, in space astronomy, the time for development may well be of the order of five years or more.

We have already said that monographic studies demand less observing time (which makes them popular with programme committees) and generally produce more papers per unit of observing time than survey programmes. We have emphasized the differences between the types of programme one may carry out, because the choice may well influence the scientist's life for many years. It is clear that a careful choice must be made.

Usually, the young astronomer is not concerned with such choices because thesis work is made under the supervision of a senior scientist who directs the student. Since postgraduate work is usually connected with thesis work, the necessity of choice may come up only years later, when, for instance, the astronomer wants (or has), to re-orient his research.

We may add two more considerations to 'planning'. First of all, one must also consider the available observational facilities.

The variety of instruments and equipment available to an astronomer in an industrialized country should not obscure the fact that such good fortune is not shared by all astronomers in all countries, nor at all times. Western Europe, for instance, had no modern telescopes until the 1950s and was therefore rather backward in observational astrophysics; Latin American astronomers today do not all have access to modern instruments. It is important to consider such limitations from the start. The astronomy one may do in one's lifetime often does not depend so much on one's own wishes as on what the society that support us provides us with.

A second consideration one should always keep in mind in the planning stage is the amount of work it takes to obtain the data from the observations, i.e. the data reduction. This is often underestimated, with ensuing difficulties. The history of astronomy is full of projects that were too large for the time allowed and that were afterwards either abandoned or not fully carried out. It seems that each country has had its own 'white elephant'! The analysis of such cases is often very illuminating for the development of science, but falls (regrettably) outside the scope of the book.[4]

Before closing the chapter, we should mention a last point, which arises in monographic studies and is due to the technical progress that opened to astronomers a number of wavelength regions other than the visible one (350–670 nm). In succession, the radio, ultraviolet, infrared, X-ray and $\gamma$-ray regions became accessible, and so it became interesting and fruitful to study an object in different wavelength bands simultaneously so that time variations do not affect the intercomparison.[5]

The problem of how to arrange simultaneous observations from different observatories has no easy solution. A colloquium at Strasbourg, *Coordination of observational projects*, in late 1987, will deal with these problems and the reader is invited to consult the proceedings.[6]

One obvious conclusion is that a careful planning of observations well in advance is needed more than ever.

**Notes on Chapter 1**

1. Curiously, it is hard to find in the astronomical literature a definition of the term 'observation'. For observation and experiments in sciences see Ziman (1978). For a philosophical point of view, concerned specially with the observer, see Kutschmann (1986).
2. One of the first astronomers to call attention to the need for documenting observations carefully was Lacaille (1713–62) who wrote that . . . 'in the advanced state of astronomy, no-one could any longer be believed on his mere word', and that, in order to employ with confidence an observed position, it was necessary to have all details of the observation and all the elements of reduction.
3. Just to illustrate how important a programme proposal is nowadays, we may quote Heck and Egret (1987), who say, 'in fact, scientists are now complaining that writing a good observing proposal requires as much time, care and energy as a paper for a refereed journal'.
4. An example of a good programme that ran into difficulties when it came to the reduction of the material, is the *Carte du Ciel–Astrographic Catalogue* project. Started in the late 1880s, it was to photograph the whole sky, with similar instruments installed at different latitudes. A short exposure series was to be measured and reduced immediately – the so-called *Astrographic Catalogue* –

whereas the long-exposure series, the *Carte du Ciel*, was to be considered as a document usable by future generation of astronomers. This generous project, proposed by French astronomers, was a success with respect to observing, but turned into a painfully lengthy operation when it came to reductions. All measurements had to be done by eye, using hand-moved screws or rasters, and subsequent plate reduction had to be made by hand or by mechanical calculators driven manually. No wonder that it took over sixty years to complete the *Astrographic Catalogue* and that, for the two countries which were most involved with it (France and Australia), it turned out to be a crushing burden that left little time for other work. In retrospect, this was clearly due to faulty planning – the amount of reduction work was considerably underestimated. The reader may find more details in the proceedings of IAU Symposium No. 133, *Mapping the sky: past heritage and future directions*, which took place in June 1987 at Paris (Debarbat *et al.*, 1988).

5. Another reason for carrying out coordinated observations is the need to cover entire cycles of a given variable star. This clearly needs observations from places located at different geographic longitudes.
6. Another meeting on the same subject was called *Multiwavelength astrophysics*. Proceedings of both are to be published by Cambridge University Press.

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# 2

# Observatories

## 2.1 History

In Chapter 1 we used the term 'observatory' in the sense 'place where observations are made' without being specific. In this chapter we shall examine briefly the evolution of observing places over history and the current system for obtaining observations. This is an essential step for understanding how one makes the transition from observations to data. However, the reader should remember that this is not a book on the history of astronomy, so only a very sketchy outline of the subject is given.

The first groups to show systematical interest in phenomena happening in the sky were the priests of primitive societies. They observed the Sun, the Moon, the stars, the planets and also a wide range of meteorological phenomena like clouds, coloured sunrises or sunsets, lunar halos and storms. We can only speculate on their motivation: perhaps they were mostly interested in discovering the will of their gods as manifested through the phenomena observed.

We have, for instance, clay tablets from astronomers, priests of Uruk, 1650 BC, providing observed positions of Venus. Such reports extending over decades denote that an organization of observers and reporters of heavenly phenomena existed. Since the reports were made by priests and addressed to kings, it can be surmized that the observations were made from the ziggurats or the palaces. We know what the motives of these astronomers were: they observed to know and predict certain solar-system phenomena.

When Greek visitors brought this knowledge to Greece, the motivation changed. Since the Greek visitors were 'philosophers' (i.e. intellectuals) and not priests, they tried to understand nature. Thus, the search for celestial omens was neglected for some centuries. Greek astronomers observed at their own cost and, since no large instruments existed, observing was probably done from the astronomer's house.