

On a dark, cloudless night, at a distant location far away from the city lights, the starry sky can be seen in all its splendour (Fig. 1.1). It is easy to understand how these thousands of lights in the sky have affected people throughout the ages.

As long as human beings have existed, they have certainly wondered the sky. In the sky, ancient people saw figures related to religious myths and omens sent by the gods. However, already a couple of millennia ago the real astronomy started to evolve, separating itself from religions and astrological superstitions. People started to study the sky for its own sake.

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## 1.1 Celestial Objects

In the 17th century people started to realise that the Earth is not the centre of the Universe. About the same time emerged the current view that stars are celestial bodies similar to our Sun. They seem to be faint dots only due to their huge distances. We now know that the Sun and stars are hot glowing balls of gas, producing energy when fusion reactions convert hydrogen to helium and also to other heavier elements (Chap. 11).

Although stars actually move at enormous speeds, the sky does not seem to change even in thousands of years, due to the vast distances of the stars. In addition to the Sun and the Moon there are some other objects that move with respect to the stars. Since the antiquity, these moving objects have been called *planets*, from the Greek word meaning a wanderer.

The rapid motions of the planets reveal that they are much closer than the stars. Indeed they are objects orbiting the Sun. According to the current definition (Chap. 7) there are eight planets orbiting the Sun: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. In addition to these relatively big bodies a lot of different smaller objects move around the Sun: dwarf planets, asteroids, comets and meteoroids (Chap. 8). Most planets also have their own satellites or moons. Planets, moons and minor bodies do not produce light by nuclear fusion; instead they shine just by reflecting the sunlight.

At the centre of the solar system shines the Sun, producing energy by fusion reactions (Chap. 13). It is the nearest star, and studying its properties reveals also a lot about other stars.

A few thousand stars can be seen by the naked eye, but even a small telescope reveals millions of them. Based on their properties, stars can be divided into different categories. A great majority of them is *main-sequence stars*, like our Sun. Some of them, though, are much bigger, *giants* or *supergiants*, and some are much smaller, *white dwarfs*. Different stars are usually related to different evolutionary stages in the lives of stars. Many stars are *variable stars*, whose brightness varies with time.

Rather recently found objects are *compact stars*: *neutron stars* and *black holes* (Chap. 15). Their material is squeezed into such a compressed form and their gravitational field is so strong that Einstein's general theory of relativity must be used to describe their matter and space around them.

**Fig. 1.1** The starry sky in all its splendour can be seen only far away from the light pollution of cities. (Pekka Parviainen)



**Fig. 1.2** The Pleiades is one of the best-known open star clusters. The six brightest stars can easily be seen with the naked eye. Photographs reveal also interstellar gas reflecting the light of the stars. (NASA, ESA, AURA/Caltech, Palomar Observatory)



The Sun is a solitary star. Many stars appear in pairs, they are *binary stars*, orbiting around their common centre of mass (Chap. 10). Also systems of several stars are relatively common.

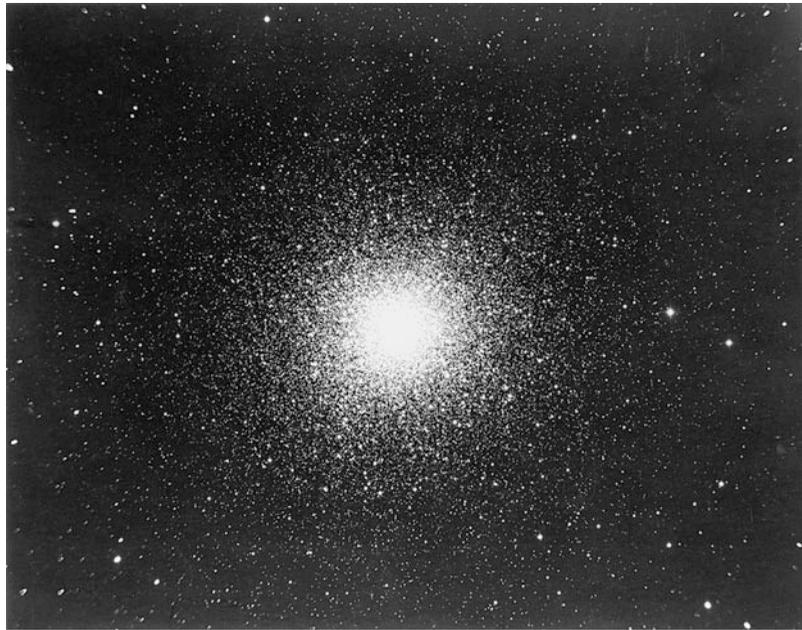
Bigger groups of stars are *star clusters* (Chap. 17). *Open clusters* (Fig. 1.2) usually contain a few tens or hundreds of stars, that were born in the same area, usually quite recently. Eventually the stars will diverge to their own paths.

*Globular cluster* (Fig. 1.3), on the other hand, may contain hundreds of thousands or millions of stars, which are usually very old.

The interstellar space corresponds pretty well to our idea about a perfect vacuum. However, it is not totally empty but contains *interstellar matter*, mainly hydrogen and helium, but also minute amounts of heavier elements, molecules and dust (Chap. 16). The interstellar medium does not fill the space as a uniform mist, but forms huge clouds (Fig. 1.4).

New stars are born by condensing from the interstellar matter. When the density, pressure and temperature of the condensing cloud have risen high enough, fusion reactions start and a new star

**Fig. 1.3** The globular cluster M13 in the Hercules constellation contains over a million stars. The cluster can even be seen with the naked eye as a small nebulous spot. (Palomar Observatory)



begins to radiate the energy released in the reactions (Chap. 12). After millions or billions of years the energy resources will be exhausted. The evolution then depends on the mass of the star. The smallest stars just cool down and fade away, but more massive ones either eject part of their mass back to space as *planetary nebula* or explode as *supernovas*. Thus matter converted by the nuclear reactions of the stars is mixed with the interstellar matter.

All stars visible as separate objects to the naked eye or with binoculars belong to the *Milky Way* (Fig. 1.5, Chap. 18). The Milky Way is a system containing a couple of billion stars, a *galaxy* (Figs. 1.6 and 1.7, Chap. 19). It takes about 100,000 years to travel across the Milky Way with the speed of light.

Milky Way is not the only galaxy, but just one of very many similar systems. Galaxies are the basic building blocks of the Universe. They do not spread out evenly but form small *galaxy groups*, bigger *galaxy clusters* and even bigger *superclusters*.

Galaxies are observed close to the edge of the visible universe. Nuclei of some galaxies are seen as *quasars*; the most distant of them have radiated the light we detect now when the age of the Universe was only one tenth of the current value.

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## 1.2 The Role of Astronomy

Already a long time ago man was interested in celestial phenomena. Several bone carvings made by the *Cro-Magnon men* as early as 30,000 years ago have been found, possibly recording Lunar phases. In that case these calendars would be the oldest astronomical documents, predating the skill of writing by some 25,000 years.

Agriculture required a good knowledge of the seasons. Religious rituals and prognostication were based on the locations of the celestial bodies. Thus time reckoning became more and more accurate, and people learned to calculate the movements of celestial bodies in advance.

During the rapid development of seafaring, when voyages extended farther and farther from home ports, position determination presented a problem for which astronomy offered a practical solution. Solving these problems of navigation were the most important tasks of astronomy in the 17th and 18th centuries, when the first precise tables on the movements of the planets and on other celestial phenomena were published. The basis for these developments was the discovery of the laws governing the motions of the planets by *Copernicus*, *Tycho Brahe*, *Kepler*, *Galilei* and *Newton*.



**Fig. 1.4** The North America nebula in the constellation of Cygnus is a large cloud of interstellar gas. The nebula appears brighter than the background because the radiation from the nearby stars makes it shine. The nebula is,

however, very faint and difficult to observe visually. The brightest star *on the right* is  $\alpha$  Cygni or Deneb. (Photo M. Poutanen and H. Virtanen)

Astronomical research has changed man's view of the world from geocentric, anthropocentric conceptions to the modern view of a vast universe where man and the Earth play an insignificant role. Astronomy has taught us the real scale of the nature surrounding us.

Modern astronomy is fundamental science, motivated mainly by man's curiosity, his wish to know more about Nature and the Universe. Astronomy has a central role in forming a scientific view of the world. "A scientific view of the world" means a model of the universe based on observations, thoroughly tested theories and logical reasoning. Observations are always the ultimate test of a model: if the model does not fit the observations, it has to be changed, and this

process must not be limited by any philosophical, political or religious conceptions or beliefs.

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### 1.3 Astronomical Objects of Research

Modern astronomy explores the whole Universe and its different forms of matter and energy. Astronomy can be divided into different branches in several ways, based e.g. on the object of research or the method used.

The Earth (Fig. 1.10) is of interest to astronomy for many reasons. Nearly all observations must be made through the atmosphere (Fig. 1.9), and the phenomena of the upper atmosphere and magnetosphere reflect the state of interplanetary

**Fig. 1.5** The Milky Way appears as a nebulous band stretching across the sky. A telescope reveals that it consists of myriads of stars as observed already by Galileo Galilei 400 years ago. The Milky Way is a flat disclike stellar system. Our solar system is close to the plane of the disc, and looking in the direction of the plane we see a lot of stars. But if we look away from the disc the stellar density is much lower. The disc contains also unevenly distributed interstellar gas and dust, which obscures the view in some directions. Near the lower edge of the picture the Milky Way seems to split into two branches because the distant stars are behind the intervening obscuring matter. (Pekka Parviainen)



space. The Earth is also the most important object of comparison for planetologists.

The Moon is still studied by astronomical methods, although spacecraft and astronauts have visited its surface and brought samples back to the Earth. To amateur astronomers, the Moon is an easy and interesting object for observations.

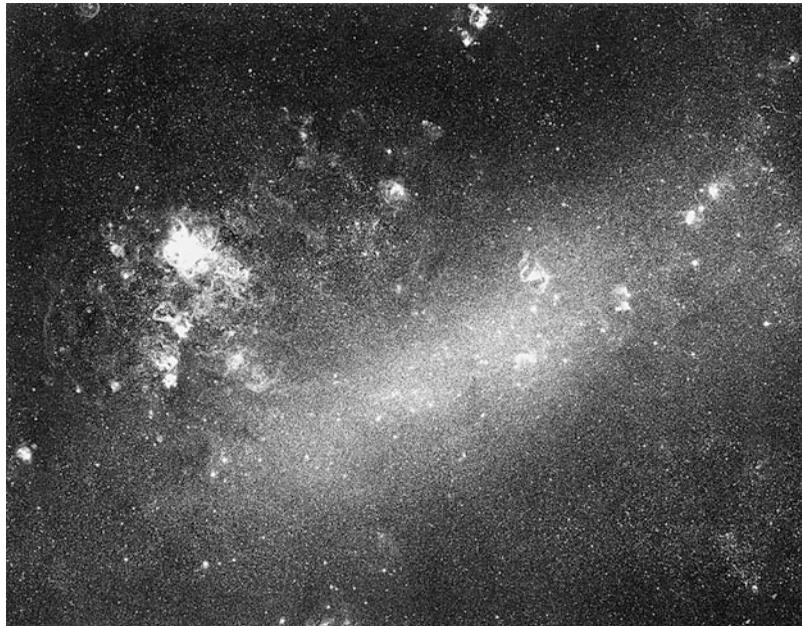
Space probes have already studied all planets, many of their satellites, some asteroids and

comets. The most distant planets, Uranus and Neptune, have been observed only by fly-bys, but all the other ones also by orbiters. Spacecraft have softlanded on Mars, Venus, Saturn's moon Titan and some minor bodies. Exploration by such probes has tremendously added to our knowledge about the conditions of these objects. Continuous monitoring of the planets, however, can still only be made from the Earth, and many small bodies of the solar system still await their spacecraft.

**Fig. 1.6** The galaxy M31 in the Andromeda constellation is a star system resembling our own Milky Way. Stars and interstellar matter concentrate in spiral arms. The shape of M31 is a round, flat disc, but due to the oblique view it looks oval. In good conditions the centre of the galaxy can be seen even with the naked eye as a faint nebulous spot. M31 has two small elliptic neighbour galaxies seen here as bright ellipses. M32 is below the centre of M31 and M110 towards northeast from the centre. North is up. *The dots* are stars of the Milky Way. (Bill Schoening, Vanessa Harvey/REU program/NOAO/AURA/NSF)



**Fig. 1.7** In addition to the big galaxies like the Milky Way there are numerous much smaller dwarf galaxies, which are often irregular in shape. One of them is the Large Magellanic Cloud, our nearest neighbour galaxy. It is easily seen with the naked eye, but it is close to the southern pole of the sky. (NOAO/Cerro Tololo Inter-American Observatory)



**Fig. 1.8** The deep-field picture of the Hubble space telescope is a combination of several images exposed altogether over 11 days. The picture shows several distant galaxies that are the most distant ones known. When we are looking far to space we are also looking far to the past since the light proceeds at a finite speed. Thus many of the galaxies in the picture are also among the oldest known objects. When we compare them with the objects in our neighbourhood we can deduce how the galaxies evolved during billions of years. (NASA)



**Fig. 1.9** Although space probes and satellites have gathered remarkable new information, a great majority of astronomical observations is still Earth-based. The most important observatories are usually located at high altitudes far from densely populated areas. One such observatory is on Mt Paranal in Chile, which houses the European VLT telescopes. (Photo ESO)



An astronomer can also specialise in studying several different fields like the Sun, different kinds of stars, star clusters, the Milky Way or galaxies (Fig. 1.11).

The largest object of research is the whole Universe. Earlier this field, *cosmology*, belonged to theologians and philosophers, but in the 20th century it became an object of physical theories

and eventually of concrete astronomical observations.

*Spherical astronomy* is an old field of astronomy studying the coordinate systems of the celestial sphere and apparent positions and motions of the celestial objects. Until the 17th century astronomy was mainly spherical astronomy.

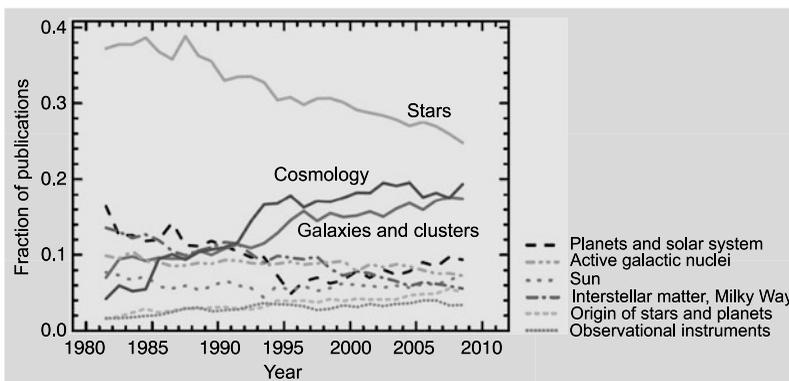
When Isaac Newton published the fundamental laws of mechanics in 1687 in his *Principia mathematica*, the motions of celestial objects got a physical explanation. That was the beginning of *celestial mechanics*, studying the motions from the planets of the Solar System and satellites orbiting the Earth to distant galaxies and galaxy clusters.

Halfway the 19th century it was found out how spectra can reveal physical properties of celestial objects. This was the beginning of *astrophysics*, studying the physical phenomena of the stars. Results from astrophysics are utilised particularly in the research of the Sun, stars and interstellar matter.

Astronomy can be divided into different branches also by the wavelengths used. We can talk about radio, infrared, optical, ultraviolet, X-ray or gamma-ray astronomy, depending on the wavelength used in the observations.

Astronomers study also particles coming from the space, like neutrinos and cosmic rays. Grav-

**Fig. 1.10** The Earth as seen from the Moon. Thanks to spaceflights we have seen clearly the planetary status of the Earth. The picture was taken by the Japanese Kaguya lunar orbiter in 2007. Currently the Moon is the only celestial object outside the Earth visited by human beings, on the Apollo flights in 1969–1972. (JAXA)



**Fig. 1.11** Astronomy in the change. Although the numbers of astronomical articles have increased in all subfields in the last few decades, the relative proportions have changed. Cosmology and galaxies are the greatest winners whereas the share of stellar research has decreased. The

graph illustrates the relative numbers of articles in different fields of astronomy in the most influential journals in 1981–2009. (Adapted from the *New Worlds, New Horizons in Astronomy and Astrophysics*, 2010, p. 120.) Published by the US National Science Academy

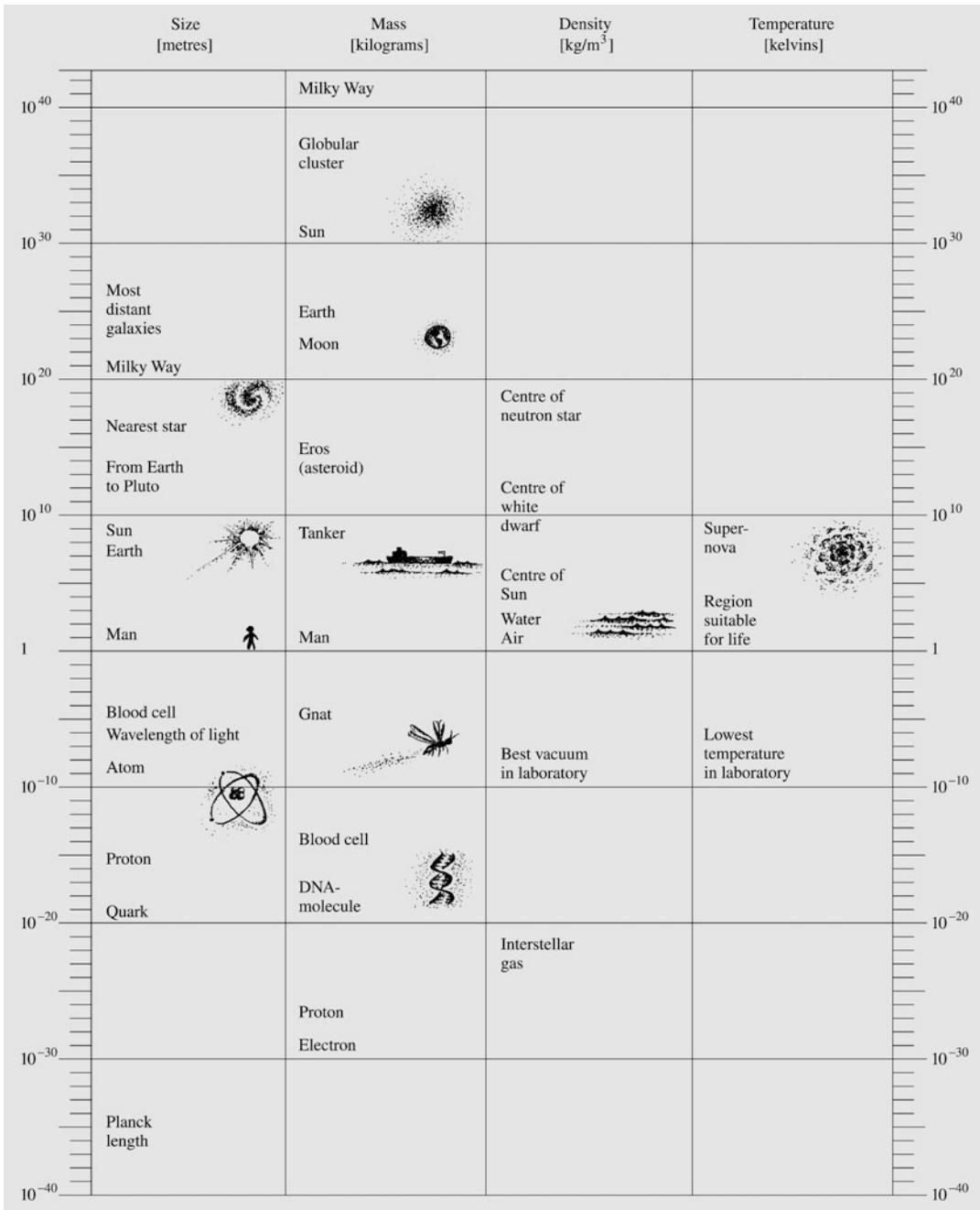


Fig. 1.12 The dimensions of the Universe

itational waves are the most recent object of research.

Astronomy and *space research* may seem to be related, although they are quite different things. Space research includes all activi-

ties in the space, but only a minor fraction of that is astronomical research. Space research is mainly commercial services, like communication, weather observations, navigation, remote sensing and environmental control, and also mil-

itary reconnaissance. *Space astronomy* is a field of astronomy that utilises observations made by satellites and space probes.

## 1.4 The Scale of the Universe

The masses and sizes of astronomical objects are usually enormously large. But to understand their properties, the smallest parts of matter, molecules, atoms and elementary particles, must be studied. The densities, temperatures and magnetic fields in the Universe vary within much larger limits than can be reached in laboratories on the Earth (Fig. 1.12).

The greatest natural density met on the Earth is  $22,500 \text{ kg m}^{-3}$  (osmium), while in neutron stars densities of the order of  $10^{18} \text{ kg m}^{-3}$  are possible. The density in the best vacuum achieved on the Earth is only  $10^{-9} \text{ kg m}^{-3}$ , but in interstellar space the density of the gas may be  $10^{-21} \text{ kg m}^{-3}$  or even less. Modern accelerators can give particles energies of the order of  $10^{13}$  electron volts (eV). Cosmic rays coming from the sky may have energies of over  $10^{20}$  eV.

It has taken man a long time to grasp the vast dimensions of space. Already *Hipparchos* in the second century B.C. obtained a reasonably correct value for the distance of the Moon. The scale of the solar system was established together with the heliocentric system in the 17th century. In the old geocentric system the distances of planets did not affect their apparent motions and could

be chosen arbitrarily. In the heliocentric system this is no more possible. Thus the distances of the Solar System were known reasonably well as early as in the 15th century. Also serious attempts to determine stellar distances were made, but the first successful measurements were made only in the 1830's, and decent estimates for the distances to the galaxies were obtained only in the 1920's.

We can get some kind of picture of the distances involved (Fig. 1.4) by considering the time required for light to travel from a source to the retina of the human eye. It takes 8 minutes for light to travel from the Sun,  $5\frac{1}{2}$  hours from Neptune and 4 years from the nearest star. We cannot see the centre of the Milky Way, but the many globular clusters around the Milky Way are at approximately similar distances. It takes about 20,000 years for the light from the globular cluster of Fig. 1.5 to reach the Earth. It takes 150,000 years to travel the distance from the nearest galaxy, the Magellanic Cloud seen on the southern sky (Fig. 1.7). The photons that we see now started their voyage when Neanderthal Man lived on the Earth. The light coming from the *Andromeda Galaxy* (Fig. 1.6) in the northern sky originated 2 million years ago. Around the same time the first actual human using tools, *Homo habilis*, appeared. The most distant objects known, the quasars, are so far away that their radiation, seen on the Earth now, was emitted long before the Sun or the Earth were born (Fig. 1.8).