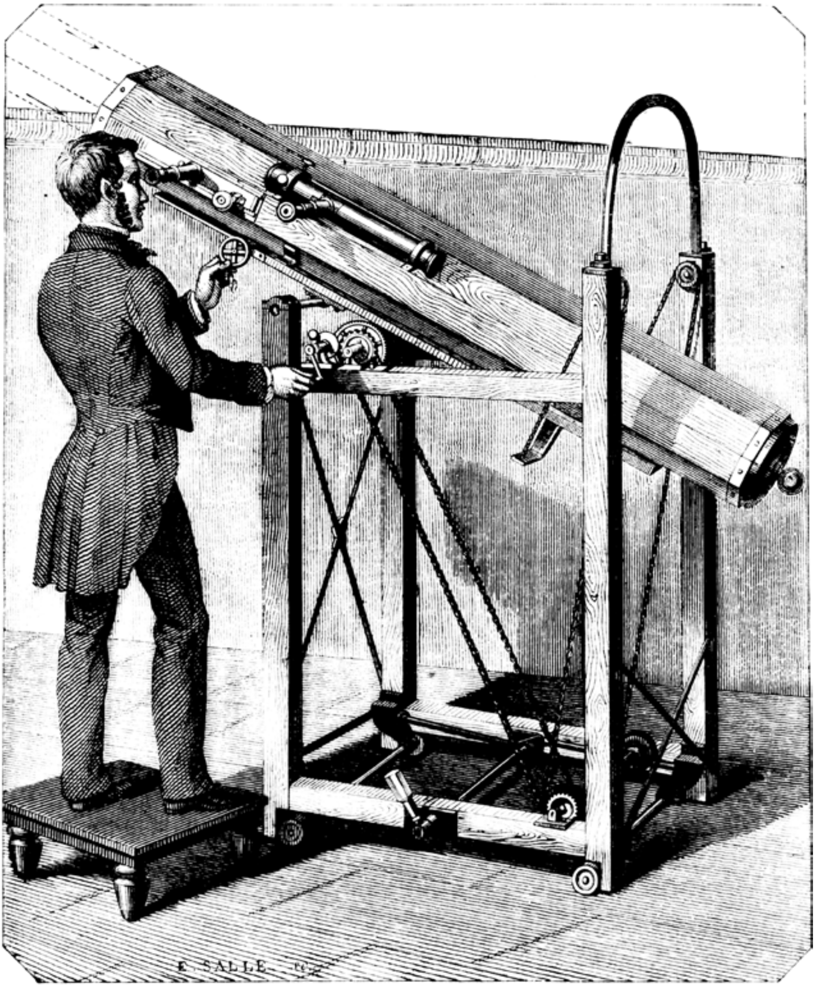
MUSÉE D'HISTOIRE DES SCIENCES
GENÈVE

Booklets of the Musée d'histoire des sciences n° 6

Observing the sky



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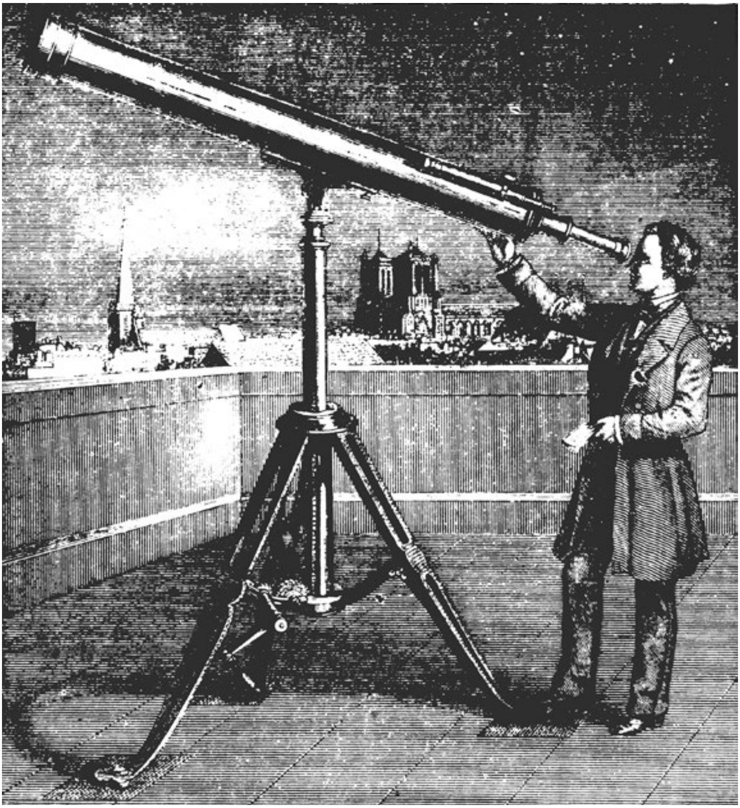
Cover : *Newton’s telescope*
Cours de physique, Ganot, Paris, 1866. Library of the Musée d’histoire des sciences

A brief introduction to astronomy and a presentation of some of the instruments from the first Geneva Observatory

This booklet introduces the reader to a few basic concepts of astronomy and present some of the instruments used to study the sky at the first Genevan Observatory, that are now housed in the Musée d'histoire des sciences.



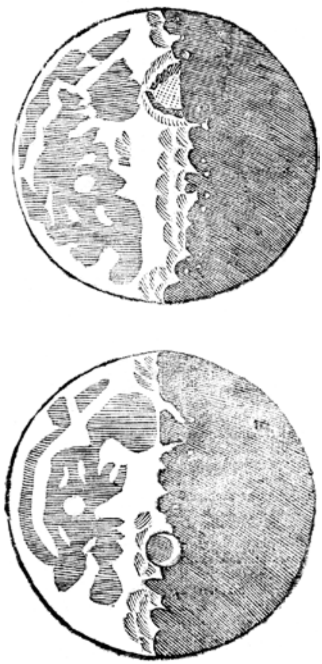
Astronomical telescope
Cours de physique, Ganot, Paris, 1866, Library of the Musée d'histoire des sciences

Galileo's telescope

The birth of modern astronomy

At the beginning of the 17th century, Dutch opticians invented the first telescope by mounting a corrective lens at each end of a tube, the length of which could be varied. The invention quickly spread through Europe. In 1609, in Padua, Italy, Galileo made his own telescope equipped with glass lenses which he had cut and polished himself. Rather than pointing his telescope to the earth, he raised it to the sky. In so doing, he made a series of discoveries which radically challenged the geocentric vision of the universe which prevailed at the time.

Galileo observed that the planet Jupiter is circled by four moons. He also noted that the appearance of Venus changes over time from a crescent to a full disc, as does the moon as it circles the earth. These two observations appeared to prove that other celestial bodies, namely Jupiter and the sun, around which Venus seemed to rotate, also had moons. Finally, by examining the moon, Galileo discovered that it was not as round and as smooth as had been thought. On the contrary, it appeared to be scattered with craters and steep ridges like many terrestrial landscapes.

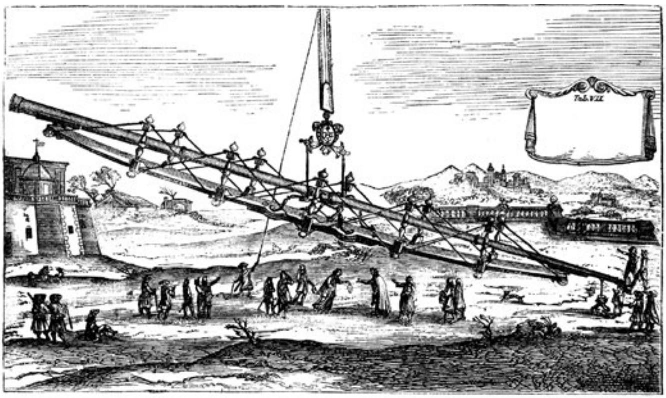


Drawings of the moon
Galileo, Sidereus Nuncius, Bologna, 1655
Library of the Musée d'histoire des sciences

Mirrors take the place of lenses

The astronomical telescopes available in the 17th century were difficult to use. While the stars were indeed magnified through the eyepiece, the image was often blurred and surrounded by a coloured halo. This was caused by light dispersion through the plain glass of the objective. In order to reduce distortion, makers were forced to construct tubes several metres long which were difficult to manipulate.

Scientists began to think about other techniques they might use for improving observations of the sky. In his 1611 work, Dioptrica, Johanes Kepler (1571-1630) suggested that one of the lenses could be replaced by a series of mirrors to avoid chromatic distortion. The first true reflecting telescope was constructed by Isaac Newton (1643-1727) and presented to the Royal Society in London in 1671. Barely 20 cm long, his instrument is fitted with a primary concave mirror and a second flat mirror set at 45° to the axis of the tube. The observer looks through the eye piece on the side of the tube.

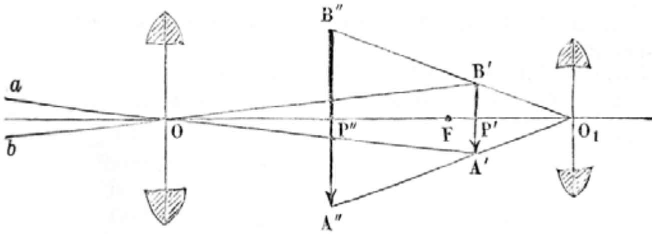


Large 17th century telescope
Astronomie populaire, Camille Flammarion, Paris, 1885
Library of the Musée d'histoire des sciences

Optics

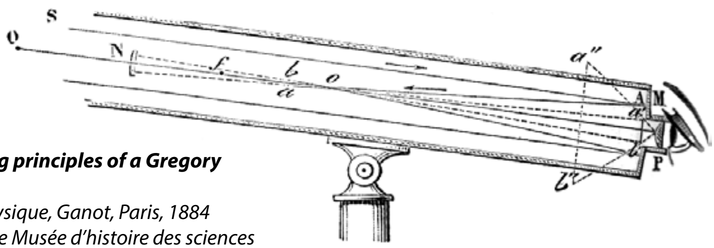
Refracting telescope and reflecting telescope

A schematic description of a refracting telescope : it consists of a closed tube equipped at each end with a glass lens (see sketch). The objective (O) collects the light emitted by the star and concentrates it as an image (A'B') which the eye piece (O) located close to the eye further magnifies into another image (A"B"). In telescopes used for terrestrial observation two other lenses are added to correct the image produced by the objective. Nowadays, lenses are usually made of several different types of glass to avoid the optical distortion resulting from chromatic aberration.



The working principles of a refracting telescope
Traité de physique, Ganot, Paris, 1884. Library of the Musée d'histoire des sciences

The reflecting telescope (a Gregory telescope is shown) is equipped with two mirrors. The first (M), mounted at the base of the tube next to the eye piece, receives light rays from the star and sends them to the second concave mirror (N) placed in the axis of the tube at the opposite end. The light, reflected a second time, returns towards the base of the tube where it forms an image (a'b') which is magnified by the eye piece (a"b").



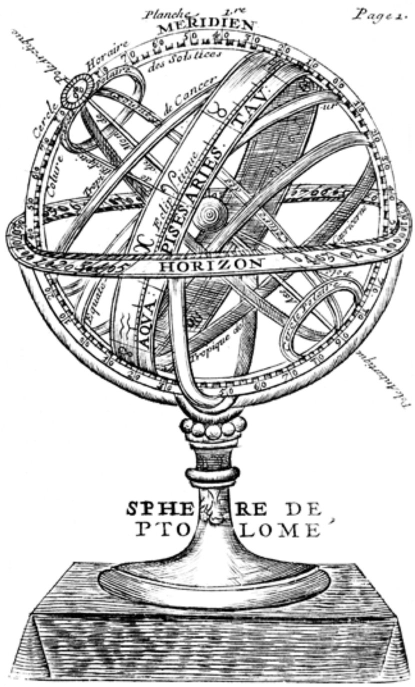
The working principles of a Gregory telescope
Traité de physique, Ganot, Paris, 1884
Library of the Musée d'histoire des sciences

Coordinates of a location

Positioning on the earth and in the sky

We can locate our position on the earth with the help of two geographical coordinates: latitude and longitude. **Latitude** indicates the angular distance (north or south) of a point from the terrestrial equator. **Longitude** describes the angular distance (east or west) between a point and the reference meridian. The reference meridian is an imaginary line joining the two poles and passing through Greenwich near London.

To describe the position of stars in the sky, astronomers use the analogous equatorial coordinate system founded on the ancient geocentric vision of the world in which the sky is seen as a transparent sphere turning around a fixed point (the Polar star), the interior surface of which is encrusted with stars. The angle between the direction of a star on the sphere and the celestial equator (the projection of the terrestrial equator onto the celestial sphere) is called the **declination** (equivalent to terrestrial latitude). Equivalent to the Earth's longitude, right ascension defines the angular distance between the star and a celestial meridian of reference passing through the vernal point (the intersection between the ecliptic, the plane containing the Earth's orbit around the Sun and the celestial equator).

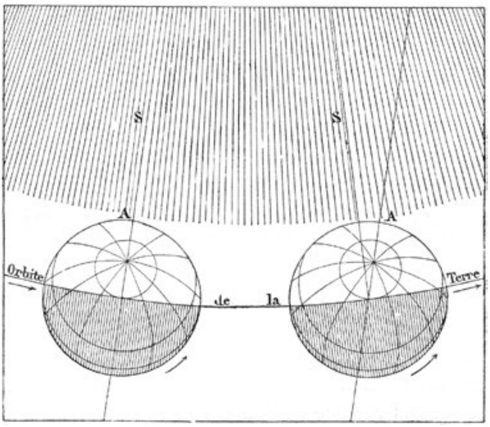


The Ptolemaic sphere, a geocentric universe
L'usage des globes céleste et terrestre et des sphères, Bion, Paris, 1717, Bibliothèque de Genève

Sun time and star time

Our daily life is based on a 24-hour day, that is, the duration between two consecutive middays, or the time taken by the sun to apparently make one full passage around the earth. In reality, however, it is the earth which rotates and it does so irregularly. It accelerates and decelerates with such frequency that a solar day is rarely equal to 24 hours (see page 12). Astronomers prefer to use the sidereal day, which is much more precise and regular. The sidereal day is defined by the time interval separating two transits from the vernal point (the intersection of the celestial equator and the ecliptic) to the meridian of the place of observation on Earth, which is invariably 23 hours, 56 minutes and 4 seconds.

That 4-minute difference between the solar and sidereal day is explained by the fact that the earth rotates on itself but also around the sun. The diagram below showing the earth in orbit around the sun explains this. To the left, it is midday at the terrestrial meridian (A) which directly faces the sun's light (S). The following day, after a complete rotation of the earth, (A) is no longer directly facing the sun which appears to have retreated. This is because of the movement of the earth on its orbit. In order to be midday again at (A), the earth must turn for about another 4 minutes.



The difference between the length of a day and the time taken to complete one rotation of the earth
Astronomie populaire, Camille Flammarion, Paris, 1885
Library of the Musée d'histoire des sciences

Observatories for sailors

Towards the end of the 17th century the first large-scale astronomical observatories were built in Europe, notably in Paris, France and in Greenwich, England. Their construction was partly motivated by an urgent need : the problem of measuring longitude at sea. At the time, ships could not calculate their location with precision because they were not able to determine their longitude. This lead to great loss of both ships and human lives.

Astronomers embarked on a review of phenomena which were easy to observe from the bridge of a ship : eclipses of Jupiter's moons, the position of the moon in relation to certain prominent stars, etc. They then produced ephemerides, tables showing the hours at which selected events occur in relation to a given reference point (Paris for the French, London for the English). By noting the local time at which the events occurred and comparing them with the reference hours in the tables, sailors were finally able to calculate the longitude of their position. This long and laborious method of navigation did not survive a major technological invention of the 18th century, the marine chronometer, which enabled sailors to know the time of their home port at all times during their voyage, making it much easier to deduce their position in longitude.

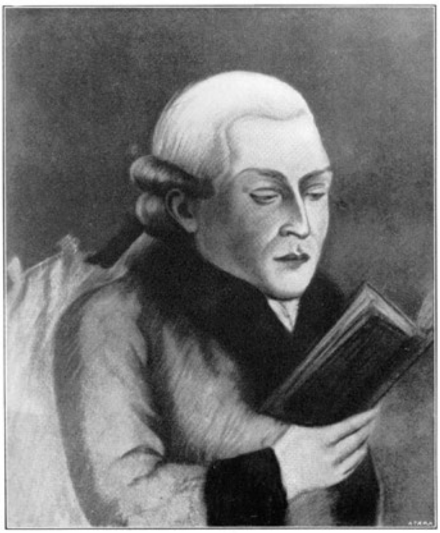
Sailor using a sextant
The applications of Physical Forces, Guillemin, London, 1877
Library of the Musée d'histoire des sciences

The distance between the earth and the sun

Mallet and the transit of Venus

Born in 1740 in Geneva, Jacques-André Mallet, the founder of the Geneva Observatory, studied mathematics in Geneva and then in Basel where he was a student of Daniel Bernoulli. In 1765 he travelled to England and France and became a friend of Jérôme de Lalande (1732-1807) and Nevil Maskelyne (1732-1811) who introduced him to astronomy. On the recommendation of Lalande and the Swiss mathematician Léonhard Euler (1707-1783), then a member of the Imperial Academy of Sciences in St Petersburg, he took part in the observations of the transit of Venus on 3 June 1769. This extremely rare event mobilised scholars worldwide. According to the calculations of the great astronomer Halley in 1716, the time taken for the passage of Venus across the sun from different terrestrial observation points, should lead to the accurate determination of the earth-sun distance, the fundamental unit of measurement of the solar system.

Commissioned by Catherine II of Russia and the St Petersburg Academy of Sciences, Mallet left Geneva in 1768 to observe the transit in Russian Lapland in the company of his friend and colleague, Jean-Louis Pictet. The expedition was dogged by bad luck: Pictet's observations were washed out by rain while Mallet only saw part of the event because of cloud cover. Fortunately, the 150 other astronomers spread over 77 observation spots on the Earth would be luckier. Their measurements gave a value very close to the 149,597,871 km officially validated today.



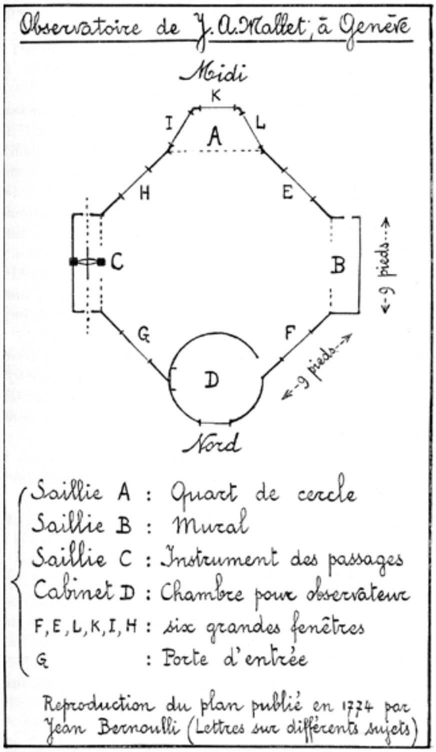
Jacques André Mallet (1740-1790)
Collection of the Musée d'histoire des sciences

The first observatory

Back in Geneva, Mallet, with a new-found reputation following his expedition to Russian Lapland, obtained permission from the authorities to build an observatory at his own expense, on condition that he supply the city's watchmakers with an acurate time signal. The octagonal observatory was built on the St-Antoine bastion, in the south-east of the city. Mallet installed his own instruments some of which are on display at the Musée d'histoire des sciences. He spent the rest of his life examining the sky and sending his observations to the Academies of Science in Paris and London of which he had become a correspondent. Mallet died at the end of 1790.

Mallet's successor, the Geneva physicist Marc-Auguste Pictet, extended the activities of the Observatory to include chronometry and meteorology. In particular, he contributed to the establishment of the meteorological station at the Grand Saint-Bernard, where measurements were taken by the monks of the hospice.

By 1830, the observatory was in a dilapidated state and was demolished and reconstructed a few hundred metres away opposite the present Musée d'art et d'histoire. After modernisation, it was moved to its current location in Sauverny in the north of the canton in 1966.



The plan of the first Observatory
Lettres sur différents sujets, Bernoulli, Berlin, 1777
Bibliothèque de Genève

Apparent midday and mean midday
Solar time and mechanical time

By the end of the 18th century, clocks had become precise enough to show that the length of a solar day (based on the apparent movement of the sun in the sky) varied over a year and that it rarely equalled 24 hours. However, until the beginning of the 19th century, the only way of adjusting watches and clocks was based on observation of the sun's passage over the local meridian at the real solar mid-day. As the length of time between successive real mid-days fluctuated, watches and clocks had to be adjusted daily.

To help the watchmakers, Mallet improved the sundial on the south side of the cathedral, which until then had only shown true noon. He drew a mean time curve a figure of eight, representing the 365 bright points of the Sun's mean noon throughout the year. Watchmakers could now set their watches according to mean noon rather than true noon.

Solar time was definitively abandoned in Geneva on 15 April 1821, the date on which official mean time came into operation and all of the city's clocks were adjusted to it.

Sundial providing Sun's mean noon installed by Mallet on the south façade of the cathedral
End of the 19th century
Collection CIG / Bibliothèque de Genève

Mapping the sky

Mallet and his assistant, the physicist Marc-Auguste Pictet, purchased most of the Observatory's instruments in England, a country renowned for the quality of its scientific instruments. Acquired in 1771, the meridian telescope is one of the essential instruments of a chronometric observatory (as the one in Geneva was). It is used to observe the precise moment of meridian passage of some fundamental stars. The telescope is mounted on an east-west horizontal axis and is movable only in the plane of the meridian (north-south line).

This 5-foot telescope was delivered to Geneva in 1771. It was installed on two massive limestone pillars in the Observatory. Originally, the telescope's magnification was 48x, rising to 70x in 1791.

Meridian telescope
MHS 829
Steel, brass, glass, Sisson, London, around 1770

Astronomical clock and second counter

The beat of passing time

To determine the position of a star passing along the meridian, Mallet and Pictet needed to be able to determine its declination and right ascension. Declination could be measured using the meridian telescope mentioned earlier (see p. 13), or with a quadrant, a type of telescope fitted with a graduated sector that has now unfortunately disappeared.

The right ascension, or celestial longitude was obtained using the sidereal time provided by a reference clock at the time of passage. Since observations are made at night and the clock face is not visible, the observer needs a second counter, synchronised with the clock, which beats the minutes and seconds audibly and distinctly in order to deduce the precise moment of passage.

Astronomical clock
MHS 1991
Steel, wood, brass, glass, Shelton, London, 1775

Second counter
MHS 198
Steel, wood, enamel, brass, Lepaute, Paris, 1771

Fixing the latitude of Geneva

Between 1825 and 1828, Alfred Gautier (1793-1881), astronomer and director of the Geneva Observatory, carried out a series of measurements of the height of the Polar Star to determine Geneva's latitude even more precisely. To do this, he used a new instrument, a repeating circle supplied in 1819 by the Parisian manufacturer Henry Gambey.

A kind of graduated circle fitted with an astronomical telescope, this instrument was designed to repeat measurements several times without returning to zero, in order to divide reading and graduation errors by the number of observations.

After more than 3338 measurements, Gautier obtained a latitude of 46°11'59.4". This latitude was re-measured between 1842 and 1844 by Emile Plantamour (1815-1882), Gautier's successor as the head of the Observatory, who found a value of 46°11'58.84".

Repeating circle
MHS 85
Steel, brass, glass, Gambey, Paris, around 1818

The Observatory, the time keeper

At the Geneva Observatory, as at other observatories in the world, clocks have always been part of the basic equipment along with telescopes. Some of them measured sidereal time, that is the time according to the apparent movement of stars in the sky, which is necessary for pinpointing the position of a star in the celestial sphere. Other clocks calibrated with the mean time (the time shown on watches) supplied the reference hour to the public and particularly to clock and watch makers who could thus check the accuracy of their timepieces.

One of the Observatory's tasks was to contribute to the development of Genevan precision watch making, a pillar of the local economy. From 1842, the Observatory made available a depot for monitoring precision clocks and watches. Their performance was compared with a reference clock. Competitions were organised to identify the most accurate pieces produced.

22

1^{er} prix. Chronomètre n° 64025 : MM. J.-M. BADOLLET & C^{e}. Régleur : M. F. VIDONNE

Température.	Date. 1872	État du chronomètre sur le temps moyen.	Marche diurne.	Variation.	Température.	Date. 1872	État du chronomètre sur le temps moyen.	Marche diurne.	Variation.
		Plat.					**Pendu.**	(suite)	
°		s	s	s	°		s	s	s
+19,9	Sept. 2	-1^m 4,0			+14,8	Sept. 27	-0^m 56,2	+0,5	+0,1
20,0	3	4,3	−0,3	+1,0	14,8	28	55,6	+0,6	−0,7
20,5	4	3,6	+0,7	0,0	15,6	29	55,7	−0,1	+0,3
21,4	5	2,9	+0,7	−0,1	16,7	30	55,5	+0,2	−0,2
22,1	6	2,3	+0,6	+0,1	17,0	Octob. 1	55,5	0,0	+0,4
22,5	7	1,6	+0,7	−0,1	17,6	2	55,1	+0,4	
22,6	8	1,0	+0,6	−0,1	+17,85				
22,5	9	0,5	+0,5	0,0			**Plat.**		
22,5	10	0,0	+0,5	−0,2					
22,5	11	-0^m 59,7	+0,3	+0,2	+17,2	3	-0^m 55,4		
22,2	12	59,2	+0,5	−0,2	16,9	4	55,6	−0,2	0,0
22,4	13	58,9	+0,3	0,0	15,7	5	55,8	−0,2	0,0
22,4	14	58,6	+0,3	0,0	15,2	6	56,0	−0,2	0,0
22,3	15	58,3	+0,3	−0,6	14,2	7	56,2	−0,2	0,0
22,7	16	58,6	−0,3		13,9	8	56,4	−0,2	
+21,90					+15,52				
		Pendu.							
+22,0	17	-0^m 59,3			+31,52		**Étuve.**	−1,0	
21,8	18	59,4	−0,1	0,0	13,9	9	-0^m 57,4		
22,2	19	59,5	−0,1	0,0	13,6	10	57,6	−0,2	−0,3
20,8	20	59,6	−0,1	+0,5	13,2	11	58,1	−0,5	−0,1
19,4	21	59,2	+0,4	+0,8	13,0	12	58,7	−0,6	+0,5
17,5	22	58,0	+1,2	−0,7	12,4	13	58,8	−0,1	−0,5
16,5	23	57,5	+0,5	−0,4	12,0	14	59,4	−0,6	−1,3
16,5	24	57,4	+0,1	+0,4	10,8	15	-1^m 1,3	−1,9	+0,4
16,7	25	56,9	+0,5	−0,3	10,2	16	2,8	−1,5	
15,7	26	56,7	+0,2	+0,3	+12,39				

1^{re} période du 2 au 16 septembre 1872, température +21,90 plat. Marche moyenne +0ˢ,39
2^{me} » du 17 sept. au 2 octob. » » 17,85 pendu. » +0,28
3^{me} » du 3 au 8 octobre » » 15,52 plat. » −0,20
4^{me} » du 8 au 9 octobre » étuve 31,52 plat. » −1,00
5^{me} » du 9 au 16 octobre » température 12,39 plat. » −0,77

4^{me} période — $\frac{3^e + 5}{2}$ périodes ; différence tempér. +17°,57 ; différence de marche −0ˢ,515
Erreur de compensation à ± 1° ∓0ˢ,03

1^{re} période, marche réduite à +17°,0 plat. Marche moyenne +0,53
2^{me} » » » » » pendu. » +0,21
3^{me} » » » » » plat. » −0,24
5^{me} » » » » » plat. » −0,91
Marche moyenne, plat (périodes 1, 3 ,5) −0ˢ,31. Marche moyenne, pendu (période 2) +0ˢ,31
Différence de marche, pendu – plat + 0ˢ,62
» » » après et avant pendu − 0ˢ,77
» » » après et avant l'étuve − 0ˢ,57
Variation moyenne de marche du 2 septembre au 16 octobre ± 0ˢ,28

First prizes from 1876-1877
Coucours de chronométrie, Observatoire de Genève,1891
Library of the Musée d'histoire des sciences

Exoplanets and quasars

Installed at Sauverny, in the north of the Canton of Geneva in 1966, the Geneva Observatory has made a name for itself over recent years through its frequent discoveries of extrasolar planets. The first was identified in 1995 by Michel Mayor and Didier Queloz. This major discovery earned them the Nobel Prize in 2019. As a centre of excellence in this field, Geneva Observatory is also home to the operational centre of the new Swiss space telescope CHEOPS, launched at the end of 2019, which is dedicated to the study of exoplanets. Research at Sauverny also includes other areas of contemporary astrophysics such as the evolution of stars and galaxies, the study of quasars (nuclei of distant galaxies) and the development of measuring instruments for use on the earth or in space.

The two telescopes installed in the domes are now only used for teaching or for calibrating measuring instruments. All the data analysed at Sauverny comes from observatories in Chile, the Canaries, Provence and the Swiss Alps and from telescopes on satellites orbiting the earth, for example, the European Integral satellite observatory specialised in the spatial observation of gamma rays.

Cheops, the Swiss space telescope
Image: ESA/ ATG Medialab

Astronomy worldwide and in Geneva

Some key dates

1543 Copernicus publishes *De revolutionibus orbium coelestium* which puts forward the hypothesis of a heliocentric universe.

1609 Galileo is the first to point an astronomical telescope towards the sky.

1610 Publication of Sidereus Nuncius *(Celestial Messenger)* in which Galileo describes his astronomical observations offering many proofs of a heliocentric universe.

1667 Establishment of the Paris Observatory, the oldest in Europe.

1671 Newton presents the first telescope to the Royal Society in London.

1675 Establishment of Greenwich Observatory in London.

1769 The Geneva astronomers, Mallet and Pictet, observe the Venus transit from Russian Lapland.

1772 Establishment of the first Geneva Observatory by Mallet.

1830 Reconstruction and transfer of the Observatory within the Old Town.

1966 Move of the Observatory to Sauverny.

1995 Discovery of the first exoplanet by Michel Mayor and Didier Queloz of the Geneva Observatory.

2019 Nobel Prize in Astronomy awarded to Michel Mayor and Didier Queloz.
Launch of the Swiss space telescope CHEOPS, dedicated to studying exoplanets.

Further reading

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Booklets of the Musée d'histoire des sciences
The museum collections described in short thematic booklets

1. Under the skies of Mont Blanc
2. Once upon a time, there was electricity
3. Sun time
4. Seeing the infinitely small
5. Models of the universe
6. Observing the sky
7. The Pictet Cabinet
8. Jean-Daniel Colladon, Genevan scholar and industrialist
9. From foot to metre, from marc to kilo
10. The birth of modern meteorology
11. Vacuum tubes and light bulbs at the Musée d'histoire des sciences
12. The Villa Bartholoni

Downloads available at: http://institutions.ville-geneve.ch/fr/mhn/votre-visite/site-du-musee-dhistoire-des-sciences/parcours-permanent/

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