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ASTRONOMICAL OBSERVATORIES

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16. Abstract

The pamphlet discusses the layout and equipment of astronomical observatories, the oldest scientific institutions of human society. The example of leading observatories of the USSR allows the reader to familiarize himself with both their modern counterparts, as well as the goals and problems on which astronomers are presently working.

The book is aimed at a broad range of readers.

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Introduction

Often my new acquaintances, discovering that I am an astronomer, will ask: "Well then, let's see the sky in your telescope!" On hearing such a request, I am always somewhat confounded. There is a natural interest in the studies of the stars, nebulae, galaxies, quasars and other celestial objects, a knowledge of the laws of formation and evolution of the Universe, analysis of the multiplicity of forms of matter and the phenomena which occur in it, in a word, everything concerned with astronomy. But it is not so easy to satisfy the thirst of the curious.

On the one hand, it is a technically difficult task. Today astronomers seldom look at the sky with the naked eye. The eye is too weak and limited in its capacity as a receiver of light. Astronomical observations, all of which come back to gathering electromagnetic radiation from celestial objects, are done with more sensitive and specialized receivers of radiation than the human eye. These may be photoelectric receivers, television equipment and so on. About 30% of all observations are done through photography.

But even in those rare cases when visual observation is done, i.e. with the unaided eye, the view is hardly impressive - usually only one or two stars are visible. Therefore, to "show the sky" we must either rig up a special visual apparatus or employ auxiliary telescopes or guides. But even the guides of large telescopes are now photoelectric.

On the other hand, the sky is far from always clear. Quite

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[*] Numbers in the margin indicate pagination in the foreign text.

often, it is overcast, and not only one, but several nights in a row. And the program of observations of the astronomers is interrupted. They wait impatiently until it "clears". Every minute counts and, as they say, "there isn't enough sky". And so often, even in the dead of night, all it takes is the sky to clear suddenly for the astronomers to rise from bed and begin observation. In many cases they do not even go to bed, but watch the entire night allocated to their observational program.

The objects of astronomical observations and their research methods are quite diverse. But one thing unites all astronomers. That is their instrument, the telescope. These are quite unique and of interest in their own right. And these the astronomers are quite ready to display to the curious, insofar as can be done during the day or the off time.

Each telescope is a high precision, complicated instrument, combining an optical system and a mechanical mounting. Various receivers of radiation and the required auxiliary equipment are attached to it. Working with astronomical instruments requires appropriate forms of management. Such managing institutions are the astronomical observatories. These, their specifics, the problems on which astronomers are working and the instruments they are using, will form the subject of this pamphlet.

A Little History

Lost in the remote past... Astronomy has always attended mankind. The rising and setting of the Sun determined the rhythm of life, which is the biological rhythm of man. The round of existence of the cattle-raising nations was set by the phases of the Moon, that of agricultural peoples by the seasons of the year. It was in fact practical concerns, especially orientation in time and in space, which stimulated the rise of astronomical knowledge.[1]

The Megalithic structures of Stonehenge, a remarkable observatory-cum-temple (Fig. 1) in the southwest English plains, have survived from the Stone Age. It took a long time to build: the erection of this ring-shaped structure was begun by the people of the Stone Age, but completed by people of the Bronze Age. The time for the construction spans 2800-1600 B.C.

Its main part is a ring roughly 30 m in diameter of vertically erect stone pillars weighing about 25 t. Inside the ring there were five stone arches of blocks weighing about 50 t: two stones served as props, a third spanned them at the top. The ring of stone pillars was bordered by a circular trench of almost 100 m diameter, surrounded by embankments, as well as several intermediate rings marked by small stones or ground craters. At the outside, 30 m beyond the bank, on the axis of the horseshoe, there is a "heel" stone, surrounded by a small trench. It is thought to have been a reference, lining up with sunrise of the summer solstice.

Stonehenge was both a temple and a prototype of the astronomical observatory. Narrow openings in the stone arches, not even large enough to fit the head, served as sights which strictly fixed the bearing from the center of the structure onto various points of the horizon and points of rising and

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[1] Here is an example. Several years ago the Novosibirsk archeologist V. Ye. Larichev, excavating a settlement of the Paleolithic near Achinsk, found a staff with a ring of wooly mammoth tusk. Both the staff and the ring were covered with spiraling snakelike bands, small recesses and an intricate network of patterns. Studies of the staff revealed that its images constitute an astronomical calendar - a peculiar calculating device for counting the years and even predicting eclipses. This staff belonged to people who lived in Siberia 18,000 years ago. As Larichev writes: "The significance and combinatorial analysis of the remarkable numbers which they knew about are the highest compliment to the intellectual and artistic abilities of the ancient Siberians" (Larichev, V. Ye., Peshchernyye charodei [Magicians of the Caves], Novosibirsk, 1980, p. 220).

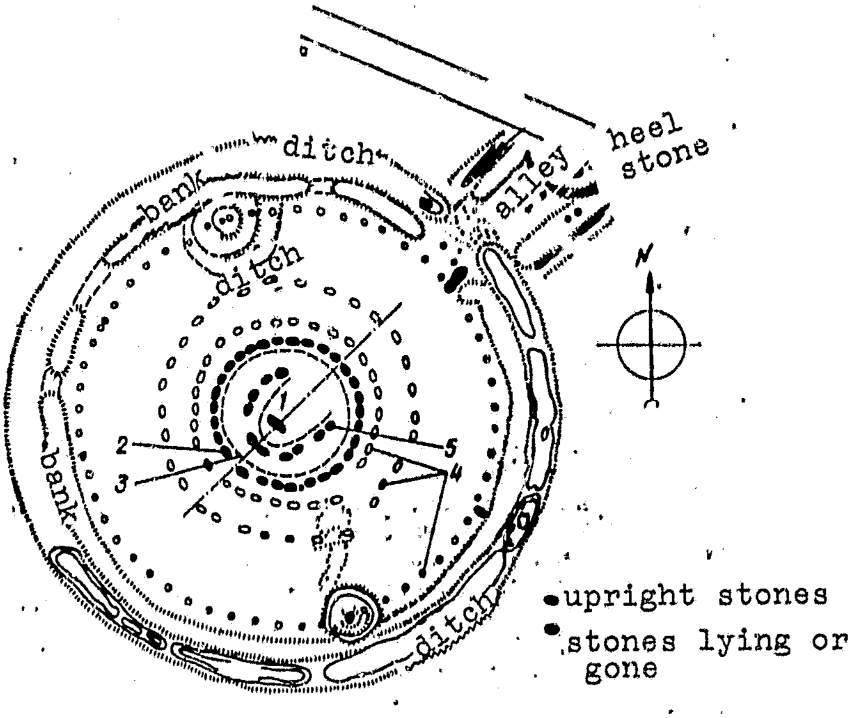

Fig. 1. Diagram of the Stonehenge works: 1 - central so-called "altar" stone, 4.8 x 1 x 0.5 m; 2 - main ring of pillars; 3 - inner ring of small "blue" stones; 4 - intermediate rings of craters: the inner of diameter 40 m (30 craters), middle of diameter 53.4 m (also 30 craters) and outer ring, opened by Aubry, with diameter of 88 m (56 craters); 5 - horseshoe of largest stones.

setting of the Sun and Moon. The ancient observers determined and predicted the arrival of the summer and winter solstice, the spring and autumn equinox and, perhaps, the times of lunar and solar eclipses.

The need to establish a connection between certain astronomical phenomena and everyday earthly events was especially important for thp agricultural nations of the ancient world - Egypt and the Near East. The serious scientific development of astronomy is largely associated with the accomplishments of the ancient Greeks, especially the representatives of the Alexandrian School.

The city of Alexandria was founded in 332 B.C. The Ptolemies, the rulers of Egypt, fostered the sciences and poetry and assisted in the construction of a temple of the muses - the Museion of Alexandria, a sort of academy of sciences with munificent library, for which this institution became famous. Its name (museion - museum) became a common noun. At the museum of Alexandria the world's first scientific astronomical observatory was created with which the names of all the prominent astronomers of the subsequent five centuries, beginning with Aristarchos of Samos, are more or less connected.

After the fall of the Roman Empire and the spread of Christianity, the development of science came to a halt in Europe. The Alexandrian library and museum were destroyed. For nearly a millenium, Western Europe fell into the gloom of the middle ages. In contrast, in the East, in the Arabian world, the sciences including astronomy underwent further development. In the VIII-X centuries, the Arabs translated nearly all the works of the ancient Greek astronomers. Large observatories were constructed at Bagdad, Damascus and several other cities.

On the territory of our country, in the outskirts of Samarkand, the remains of the observatory of Ulugbek are preserved. The grandson of Timur, ruler of the vast region of Maverannakhra with its capital at Samarkand, and after 1447 ruler as well of all the extensive domain of Timur, Muhammed Taragai Ulugbek, availing himself of the perquisites of power, attracted to Samarkand the leading scientists, astronomers and mathematicians. In 1430 (according to others 1424) he built the largest astronomical observatory of the time, a round tower almost 50 m in diameter, having three stories and an observation platform on top. Through the entire tower, embedded in the ground, along the meridian was situated the chief astronomical instrument of that time - a stone quadrant (others say a sextant), consisting of two marble-faced arcs with a stairway between them. It is believed this gigantic instrument was used to determine the angle of inclination of the ecliptic to the equator, for observations of the Sun, Moon and planets.

In 1449 the eldest son of Ulugbek, Abd-al-Latif, abetted by the reactionary clergy, treacherously slew Ulugbek as an "apostate from Islam" and took power. Religious fanatics plundered and destroyed the observatory.[1] Only manuscripts were rescued by Ulugbek's savants.

European observatories of the XVII and XVIII century. In the second half of the XVII and early XVIII century, State scientific observatories began to be founded in rapid succession in Europe. The major geographical discoveries, and the nautical and land voyages, required a more exact determination of the size of the globe, and new methods of determining time and coordinates on land and on water. But the only more or less reliable means of determining geographical position was determination of latitude and longitude (introduced by the ancient Greek astronomer Hipparchus) from astronomical observations. Yet such determinations required a knowledge of the pointlike celestial coordinates of the stars, planets and Moon, and use of appropriate catalogues and tables. It was also necessary to be able to determine and keep accurate time.

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[1] Only in 1908 did the Russian archeologist V. M. Vyatkin find its remains, while in 1948 it was excavated and partially restored by the efforts of V. A. Shishkin. The remaining portion of the observatory is an unique architectural and historical monument, carefully preserved by the government. Alongside the observatory, a museum of Ulugbek has now been created.

And so from the second half of the XVII century in Europe, mainly on the initiative of the leading scientists, state astronomical observatories came to be built.[1] Thus, in France, on the initiative of the astronomer J. Piccard, the "Sun King" Louis XIV advanced sums for construction of the Paris observatory (the construction was begun in 1667 and continued until 1671). A magnificent building was put up, resembling a castle, with observation platforms on top. At the Paris observatory many diverse astronomical observations were performed: four satellites of Saturn and the dark line in its ring (the so-called "fissure of Cassini") were discovered, while the Danish astronomer O. Roemer, invited to work at the Paris observatory, proved the finite speed of light (from observations of eclipses of the satellites of Jupiter) and estimated its value. Not less and possibly more famous for the Paris observatory was the diversified work on determining the precise positions of the stars, as well as the dimensions of the Earth.

During these same years in England a royal commission headed by J. (G.?) Flemstead was petitioning for the creation of an observatory in order to develop a rational method of fixing longitude by determining the exact positions of the stars and Moon. Soon thereafter the king signed an edict founding the observatory, to be kept at government expense, while J. Flemstead was nominated its director with title of "Royal Astronomer". The observatory began to function in 1676 in the London suburb of Greenwich. J. Flemstead acquired some of the instruments at his own cost, some were donated by wealthy benefactors.

The chief merit of the observatory was the compilation of a star catalogue, the first in a series of many Greenwich catalogues now covering nearly 300 years. The importance of this

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[1] The first of these was the observatory of Copenhagen (built from 1637 through 1656), although it burned down in 1728.

fundamental contribution to astronomy is confirmed by the fact that the meridian passing through the Greenwich observatory is taken as the zero longitude, while the mean solar time of this meridian is taken as the International Time.

On account of the great illumination produced by London, in 1954 the Greenwich observatory was moved to a rural locality, 70 km southeast of London. The administrative headquarters and laboratories were lodged in the venerable castle of Hearstmonso, whose name became that of the new observatory.

After the founding of the Paris and Greenwich observatories, many European nations began to build state observatories. But along with these serious scientific organizations, private and sometimes quite amateur observatories appeared, confronting other more modest tasks. The amateur observer did not need to take accurate readings. All that was needed was attentive and regular examination of the starry sky. Even so, not everyone succeeded. But several of those who began as amateurs finished as professionals and provided an important contribution to the development of astronomy.

One of these was Charles Messier who, entering the employment of the astronomer J. Delille as copyist, gained access to a small refractor when the latter returned from St. Petersburg. Observing the sky in search of comets, Messier discovered 14 comets in 40 years. His observatory was in the turret of his Paris dwelling. In the course of his observations he also discovered 103 nebulous objects (68 of these for the first time) and in 1781 published a catalogue of these, so others would not confuse them with comets.

William Herschel, by profession a musician, became in time an outstanding observational astronomer and optician. In 1773 he built a giant reflector with mirror diameter of 122 cm and focal distance of roughly 12 m (the mirror weighed about 2 t). But his major observations were done with reflectors having mirror diameters of 30 cm, or later 47.5 cm (with focal distance 6 m). Being an optician, he made a new advance in telescope construction, although his telescopes were set up on a troublesome azimuth mounting, with poor aiming and no clockwork. But Herschel was little concerned with star coordinates. He was more interested in the pattern of the Universe's structure.

At his home observatory in Sloe, near Windsor palace, he discovered that the majority of the nebulae from the list of Messier could be resolved into stars - they were stellar clusters. To Herschel belongs the discovery of a new class of nebulae, named by him the planetary nebulae. He discovered more than 800 binary and multiple stars, showing that several of them form physical systems.

An even larger, but equally awkward reflector was built by W. Parsons, bearing the title of Lord Ross, on his estate Byor Castle in Ireland. His reflector had a mirror diameter of 182 cm and focal distance 15.6 m. With its help, Parsons discovered many details of the structure of nebulae, including the spiral structure of several of them. He studied the Great Nebula in Orion and observed several details of the surfaces of the planets.[1]

The St. Petersburg astronomical observatory. The conquest of the immense territories of Siberia, the Far North, and the maritime voyages of the pomors in the XVI-XVIII centuries,

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[1] The famous astronomer O. V. Struve, son of the founder and afterwards himself the director of the Pulkovo observatory, visited Byor Castle in 1844 and 1850. He marveled at the "enormous accumulation of light at the focus" and the details which could be discerned, although noting that the image precision left something to be desired. He also concluded that such an instrument would only be second-rate for the Pulkovo observatory.

wherein our ancestors displayed great energy and skill, were impossible without astronomical knowledge. In 1690 at Kholmogory on the Northern Dvina, near Arkhangel'sk, Russia's first astronomical observatory is founded by A. A. Lyubimov (the archbishop of Kholmogory) to meet the needs of navigation of the pomors.

Peter I, who did much to advance science and the arts in Russia, was also interested in astronomy. During his European journey he visited the observatories of Greenwich and Copenhagen, and after returning to Moscow in 1701 he organized a "school for the ingenius arts of mathematics and navigation" in the fortress of Sukharev. An astronomical observatory was installed in one of the upper stories of the Sukharev fortress, and astronomy was taught at the navigation school.

In 1725 the Astronomical Observatory of the St. Petersburg Academy of Sciences was set up in three stories of the tower of the Academy of Sciences building on Vasil'yev island (at present the Kunstkamera building). M. V. Lomonosov played a tremendous part in furtherance of geographical explorations and the development of astronomy in Russia. In 1762 he designed and built his own reflector telescope, and initiated many geographical expeditions to chart the territory of Russia, sometimes to the most remote corners. Under the charge of S. Ya. Rumovskiy, director of the Petersburg Observatory in 1763-1803, geographical expeditions were organized to compile Russia's first "Catalogue of Astronomical Coordinates" of geographical sites.

In the early XIX century, other observatories were founded in Russia: the naval observatory of Nikolayev, university observatories at Vil'no and Derpt (now Tartu). In 1831 Moscow observatory was built.

The founding of Pulkovo observatory. By the early XIX century it was clear that the Petersburg observatory could no longer assure the requisite accuracy and required workload. The construction of another large observatory was seriously debated. This was built from the designs of its founder and first director V. Ya. Struve, previously director of the astronomical observatory of Derpt. The reputation of Struve was earned by predicting the development of astronomy, selecting or designing such instruments, choosing such collaborators, and organizing the observations in such manner that in no more than 30 years after its founding Pulkovo observatory became famous as the "astronomical capital of the world".

The site of the observatory was chosen in the Pulkovo hills (75 m above sea level), 19 km south of the center of /1
St. Petersburg. And even though the infelicitous location of the observatory (proximity to a large city, bright summer nights) was apparent to its founders, it was realized that the Pulkovo hills are the most convenient site in the district. The observatory building was designed by the architect A. P. Bryullov, brother of the artist K. P. Bryullov. The architecture of the building stressed the astronomical function of the structure. It was oriented from east to west, with the main facade facing north, to the city. It consists of three towers with domes in which the telescopes are lodged. The main instruments are installed in meridian rooms, joining the central tower to the eastern and western.

Two-story buildings with living quarters and laboratories have been added onto the observatory at the east and west. To the north of the observatory toward the city runs a straight highway, oriented along the center of the observatory and directed due north, as though a physical embodiment of the "Pulkovo meridian". The observatory was situated in a shady park. Trees shadowed the buildings and produced an improved astronomical microclimate.

Rational design and clearly specified function, dictated by Struve, are a characteristic feature of the astronomical instruments of Pulkovo observatory.[1] This helped place the observatory at the head of all the rest. The work of several generations of Pulkovo astronomers resulted in the renowned Pulkovo catalogues of fundamental stars, whose positions are determined with highest accuracy. These catalogues formed the basis of all subsequent fundamental catalogues and were much more reliable and accurate than those of Greenwich, Leipzig or Leyden.

The Pulkovo instrument fleet was continually expanded and improved. The Pulkovo astronomers jealously watched for any new astronomical instrument novelty. As soon as a new generation of refractors appeared, the largest in the world was instantly commissioned at Pulkovo, a 76-cm (30") refractor, installed in 1885. In 1893 the observatory obtained a so-called normal astrograph, inaugurating the age of precision photographic observations. Even in the period of Soviet power the observatory was equipped with a large solar spectrograph (1924) and several years later with a wide-angle zone astrograph, used to compile a photographic catalogue of northern stars down to the 11-th magnitude in the zone of declination from +70° to the North Pole.

Affiliates of Pulkovo observatory were successfully developed in the south of the USSR - at Nikolayev and Simeiz. But we shall return to the later history of Pulkovo observatory somewhat below.

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[1] We can give a striking example. Two instruments of Pulkovo observatory -- a large transit instrument and large vertical circle (naturally modernized and furnished with modern radiation receivers and [spectrometers?] - still operate today, no less accurate than the similar modern instruments. More than 140 years of uninterrupted good service is an extraordinary "lifetime" for a technical instrument or machine?

Astronomical Instruments

Principal characteristics of the telescope. It is only possible to study distant celestial objects by one method - collecting and analyzing their emission. It is precisely for this purpose that the telescope is used. We shall mainly discuss the classical, optical telescopes, which gather rays in the optical range. But specialized telescopes exist for working with ultraviolet and infrared rays, radio, gamma, and X-rays.

Usually when we speak of an optical telescope we are referring to its *optical section*. But in order to gather light, the telescope must also be pointed at a given site of the sky and the given bearing maintained throughout the observation. For this we need an appropriate mechanical structure and mechanisms for fast and precision tracking, as the astronomers call them. The structure should be rigid, so the mutual arrangement of the optical parts is not affected, while the motion should be smooth and uniform, to prevent image jerking in the field of vision. Such a mechanical structure with motion mechanisms is known as the *telescope mount*. Finally, the collected light must be received and analyzed, using *radiation receivers*.

The telescope can only be formed from all three elements together. They should all be of identical high quality. If one of them is poor, the whole telescope will be worthless.

Whatever the optical layout of the telescope, it is characterized by several principal parameters. The first of these is the *diameter of the entry aperture* D: for lens telescopes this is the diameter of the free aperture of the objective lenses, while for mirror types it is the diameter of the main telescope mirror. The larger D, the more light the telescope can gather. Indeed, it is often designated by the diameter of the inlet aperture: the 65-cm large astrograph of the Pulkovo observatory (the modern one - the older one was 76-cm), the 2-m reflector of Shemakhinsk observatory, the 5-m reflector of the Mount Palomar observatory, and the world's largest 6-m Soviet telescope.

The distances to the stars, as compared with the dimensions of man and his instruments, are so large that they can be taken as infinite, and the pencil of beams leaving them as parallel. Such a pencil of lightbeams, arriving at the main telescope mirror, is gathered into a point known as the *main focus* and denoted F. The distance f from the apex of the main mirror to the point F is the *focal distance* of the main mirror. If the telescope has additional optical elements (secondary mirrors or lenses), we speak of the equivalent focal distance of the optical system f'. In other words, f' is the focal distance which would obtain if the main mirror collected the incident beams at the same angle as they are in fact gathered by all the optical elements jointly.

No optical system can be ideal. Distortions get into the image from an actual optical system. These are generally termed *aberrations* of the optical system. Along the optical axis the aberrations are negligible, but rapidly increase away from it. It is precisely the aberrations which restrict the field of operation in the focal plane, where the images approach the ideal and can be measured. The size of such field is known as the *visual field* of the telescope and denoted 2β.

Ordinarily a telescope's visual field is not large. For the majority of reflectors it is 12-20' in diameter. Only in the widest-angle astrographs does it reach 6°. Granted, specialized short-focus cameras have a broader field, but the short focus and certain other drawbacks render such cameras unsuited to the majority of astronomical chores.

The ratio between the diameter and the focal distance A is known as the relative aperture of the telescope.[1] The potential capabilities of a telescope are characterized by its penetrability, expressed by the brightness of the weakest object observable with the given telescope. This depends on the lens diameter, but also the manufacturing quality of the optics, the tranquility and transparency of the atmosphere, the brightness of the background sky, the losses of light in the telescope optics, and such factors not always strictly accountable. Therefore the penetrability can only be approximated.

The penetrability differs for pointlike objects (stars) and extended objects (various nebulae). For extended objects the luminosity of the image is proportional to the aperture ratio, and the stronger the telescope the dimmer the nebulae which it can pick up. The strongest telescopes used to observe feeble nebulae have A = 1:2, 1:1.5 and even 1:1.

For stars which ideally give pointlike images, the image area is not important, and the penetrability in this case is expressed by the limit of the star magnitude accessible to the telescope.

When D is increased, not only does the stellar magnitude limit increase, but also the resolution of the telescope is improved, i.e. the capacity to distinguish two close and almost merging stars.

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[1] Sometimes A is known as the telescope's aperture ratio, but this is inexact. The aperture ratio is the amount of light that a telescope can create in the focal plane. Disregarding the losses of light in the optical system, the aperture ratio is proportional to A^2. This is obvious, since the amount of light collected by the telescope is proportional to the area of the lens, i.e. the square of the diameter of the inlet opening D^2, and is distributed over the image area, i.e. inverse to f^2.

Refractors, reflectors and mirror-lens telescopes. Telescopes are divided by optical layout into refractors, whose optical system consists solely of lenses, reflectors, including only optical mirror elements, and combined mirror-lens systems, otherwise known as catadioptric telescopes. The choice of a particular optical layout depends on the problems confronting the observer.

In the past century, for many decades refractors possessed considerable advantages. They produced the best image, had the broadest visual field and, especially important, their image quality did not depend on the direction of the telescope tube. But even by the end of the last century refractors had reached the limit of their capabilities.[1] Lens objectives are more expensive than mirror types, and hard to manufacture. The lens is fastened in a mount only about its perimeter, and therefore large lenses begin to buckle under their own weight when the telescope is tilted (leading to increased aberration).

The development of astrophysics, on its part, requires ever more powerful telescopes with ever greater penetrability. As far back as the turn of the XIX century, huge reflectors were created: the 90-cm at Licks observatory and the 1.5-m at the Mount Wilson observatory. Their mirrors were made of glass, having a parabolic shape, while the relative apertures are 1:4 or 1:5. Somewhat later, in 1917, a 2.5-m reflector was built for the Mount Wilson observatory. In all, prior to 1940 there were 12 reflectors built with diameter of 1 m or more, including the 1-m reflector started in construction at Simeiz (USSR) in 1926. Reflectors are being constantly improved, and today they have almost totally supplanted reflectors.

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[1] The largest refractor, whose double lens objective has a diameter of 102 cm, focal distance 19 m and A = 1:19, was installed at Yerkes observatory, USA in 1897. Today refractors are no longer being built with objectives whose diameter is larger than 65 cm.

The most simple optical layout of a reflector has one main mirror, gathering beams at a main focus, where a receiver is placed. The basic optical layouts are shown in Fig. 2, although others also exist, about which we shall also say something. The Cassegrain layout was developed into the Ritchie-Chretien. But in this layout the main and secondary mirrors have complicated shape, as a rule hyperbolic. This complex shape substantially enlarges the field of good images, attaining 1° at diameter. Along with the advantages, reflectors have certain drawbacks, mainly occasioned by mirror aberrations.

Mirror-lens optical systems, or catadioptric telescopes, form a separate class of telescopes with lenses serving to correct the aberrations intrinsic to the main mirror. In this case the lenses are known as lens compensators. The use of compensators can increase the aperture ratio and visual field of the telescope, and sometimes enables a shorter telescope tube. The most common mirror-lens telescope systems are those of Schmidt and Maksutov.

In 1932 B. Schmidt published a description of his own telescope, in which a correction lens of complicated shape was mounted at a distance equaling twice the focal distance in a pencil of parallel beams arriving on the main mirror. This corrected practically all aberrations of the main mirror and enabled a powerful wide-angle instrument. A certain drawback of the telescopes of the Schmidt system (as well as the Maksutov) is the fact that their focal field is not planar, but spherical. As a consequence, either the photographic plate must be bent into spherical form, or an extra correction lens must be mounted in front of the plate, rectifying the field but restricting its dimensions.

The largest telescope of the Schmidt system is installed at the Tautenburg observatory (GDR). It has a correction lens

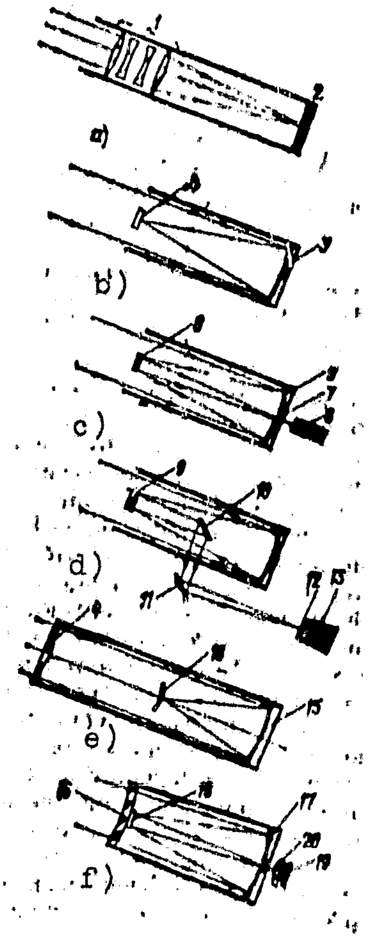

Fig. 2. Optical layouts of telescopes: a - refractor telescope; 4-lens objective (1) collects a parallel pencil of beams in the focal plane (2) where a receiver of radiation (photographic plate) is placed; b - reflector telescope; parallel pencil of beams is incident on the main mirror (3) and gathered at the main focus (4), where a radiation receiver (usually photographic plate) is placed; c - Cassegrain layout; a parallel pencil of beams reflected from the main mirror (5) arrives at the secondary convex mirror (6), is reversed, passing through the aperture (7) at the center of the main mirror, and collected at the "focus of Cassegrain" where is a receiver of radiation (PEM-optoelectronic transducer, spectrograph camera or photographic plate) (8); d - kude layout; a convergent pencil of beams reflected from a secondary convex mirror is led outside the telescope tube (across the polar axis) by means of plane mirrors (10,11) and collected at the kude focus (12), where is an immovable receiver (13) of radiation

(usually a spectrograph camera with high dispersion); e - mirror-lens system of Schmidt; a parallel pencil of beams passing through a correction plate (14) is reflected from the main mirror (15) and gathered on a curved focal surface (16), where there is a photographic plate; f - system of Maksutov; a parallel pencil of beams refracted by the meniscus (16) is slightly enlarged and reflected from the main mirror (17) and the secondary convex mirror (18), and is collected at the Cassegrain focus (19), where a radiation receiver (photographic plate) is mounted. In front of the focal plane is a field rectifying correction lens (20).

diameter 1.37 cm, a main mirror diameter 2 m, A = 1:3, a visual field 5°. The second largest is the "Large Schmidt" telescope installed at the Mount Palomar observatory, whose correction lens diameter is 122 cm, main mirror diameter 183 cm, A = 1:2.5 and visual field 6.6°. This instrument was used to produce a detailed sky atlas, known as the Palomar survey, which contains stars down to stellar magnitude +21.1.

The famous Soviet optician D. D. Maksutov proposed, in order to correct for aberrations of the main mirror (not a parabolic, but simply a spherical mirror), that a concavoconvex lens (meniscus) be mounted close to the main focus. A meniscus telescope is characterized by simple optical fabrication (since all the surfaces are spherical) and a shorter tube than the similar version of the Schmidt system. Such telescopes have been installed in several observatories of our country. They are produced by the Leningrad Optics and Mechanics Union (LOMO). The largest telescope of the Maksutov system is installed at the Abastumani observatory. It has a meniscus diameter of 70 cm, a main mirror diameter of 100 cm, A = 1:3 and visual field 4°50'.

Telescope mountings. Have you ever had occasion to look at a star through powerful binoculars? If so, then you know that the star does not stand still, but trembles continually. No matter how strong and firm your arms holding the binoculars to your eyes, they always shake slightly and the star describes an intricate broken line in the visual field. This is not so noticeable when viewing ground objects, as the observer's attention is absorbed in the opening panorama, while a star is a point, and this point travels continually across a dark field. Therefore, when observing the stars we must place the binoculars on some kind of stand.

For this very reason a telescope also needs a stand. Of course, the matter is more complex, for a telescope weighs hundreds of kilograms, or more likely many tons. Moreover, such a stand should allow the telescope to be aimed at the most diverse points of the sky, and maintaining a given telescope bearing with high precision. For its part, the Earth continuously revolves on its axis, which is manifested in the daily motion of the stars across the sky. Consequently, the stand should also compensate for this daily motion of the stars, maintaining the telescope's direction in space with an accuracy down to hundredths of an angular second.

Thus, the telescope stand has a rather complicated structure and is known as the telescope mount. This is placed on a massive iron column and consists of two axes, corresponding to the two axes of spatial coordinates, and has a clockwork movement mechanism. The mount may be extremely diverse in structure, although a number of its elements have the same function.

A telescope weighs hundreds of kilograms, sometimes even many tons, and yet its motion should be smooth, with minimum friction. Such motion is achieved if the given system turns with respect to the center of gravity. Therefore the telescope tube is secured to the axle in a way that balances the objective and ocular ends. When the tube is arranged at one end of the axle, a counterweight is placed at the other. The weight of the moving parts (tube, axle and counterweight), in turn, is equalized relative to the common center of turn. And even though this increases the weight of the mount by nearly 4 times above the weight of the tube, all the movements of the instrument are greatly facilitated, and a small synchro motor is sufficient to turn a many ton machine.

The simplest is an azimuth mount, corresponding to an azimuth system of coordinates (Fig. 3a). One of its axes is vertical, the other horizontal. Such a mount is used for small theodolites and certain astronomical instruments. This mount is troublesome in that, to compensate for the daily revolution of the Earth, the tube of the instrument must be turned simultaneously about the horizontal and the vertical axes, at different speed.

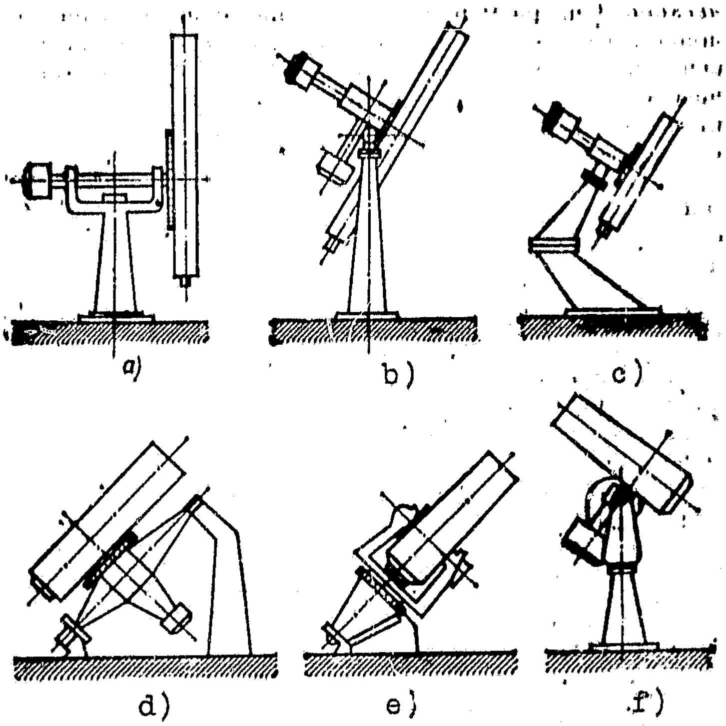

Fig. 3. Telescope mounts: a - azimuth with vertical and horizontal axles; b - parallax (equatorial), with polar axis and declination axis, German type (with straight column); c - parallax, German type, with broken column; d - parallax, English type; e - parallax, fork type; f - triaxial for satellite cameras.

This defect is eliminated by a parallax (or equatorial) mount (Fig. 3b), having a polar axis (parallel to the axis of revolution of the Earth) and a declination axis, perpendicular to this. After the telescope is positioned along the declination axis and aimed at a star, the instrument need only be turned about the polar axis by using a clockwork mechanism at constant speed, corresponding to the speed of the Earth's revolution.

For small telescopes a parallax mount with straight column is most common. This mount is usually called the German mount: last century it was often used by designers of German companies. But if the telescope tube is long, and the column is tall, then the tube will brush against the column in certain positions (cf. Fig. 3b), resulting in mechanical damage to the telescope and, in addition, impossibility of viewing certain sky regions. In this case the column is tilted, and its upper part is used as a sleeve for the polar axle. The result is a German mount with broken column (Fig. 3c).

Another version of the parallax mount is the so-called English mount (Fig. 3d). This has a polar axle resting on two supports: northern (top) and southern (bottom). The polar axle is longer and more firm.

Powerful telescopes, mainly reflectors with diameter of 1 m or more, are extremely heavy. An effort is made to lighten the structure of their mount by making it symmetrical, with no counterweight. Such, for example, is the fork mount (Fig. 3e). The polar axle of this terminates in a bifurcation, between the two arms of which the telescope is aligned along the center of the short declination axle. In this mount, the fork must be very massive, to increase the rigidity.

More complicated mounts are used in telescopes for observation of artificial Earth satellites. Besides the usual two axles (vertical and horizontal, or polar and declination), they also have a third axle, directed at the pole of orbit of the satellite (Fig. 3f). This is called in fact the orbital axle.

The telescope turret. The telescope and its auxiliary systems are installed in a special building - the turret, protecting it against wind and rain. Many of the past observatories were accommodated either in small separate pavilions or simply in a room if there was a large enough window or opening hatch. And even today for simplicity we sometimes resort to such lightweight pavilions for small instruments. At any rate, the telescope is placed on a stable, firm foundation, and the temperature in the room where the telescope is installed should equal the outer air temperature, to avoid air currents around the telescope, resulting in flicker of the images of the observed stars. These conditions specify the form of the astronomical turret (Fig. 4).

In the center of the turret is a massive pillar, the base of the telescope. The pillar is embedded in the ground and rests either on a rock foundation or on bedrock. A column is set up on this, as well as the particular telescope mount, elevated by the pillar so that the telescope has a free vantage in all directions of the horizon. The walls of the turret are embedded in the ground to the same depth as the pillar beneath the telescope. This is done so that microseismic vibrations or shaking of the soil by passing transportation vehicles are shielded by the walls of the turret and do not reach the telescope pillar. As a rule, the turret has a round shape. It is just such symmetrical structure which best accords with uniform temperature distribution in all parts of the turret. Inside the turret, at a level allowing the telescope to sight on the zenith, and allowing the observer to conveniently approach the telescope eyepiece, is the floor of the turret. To prevent the shocks produced by the steps of the observer from reaching the

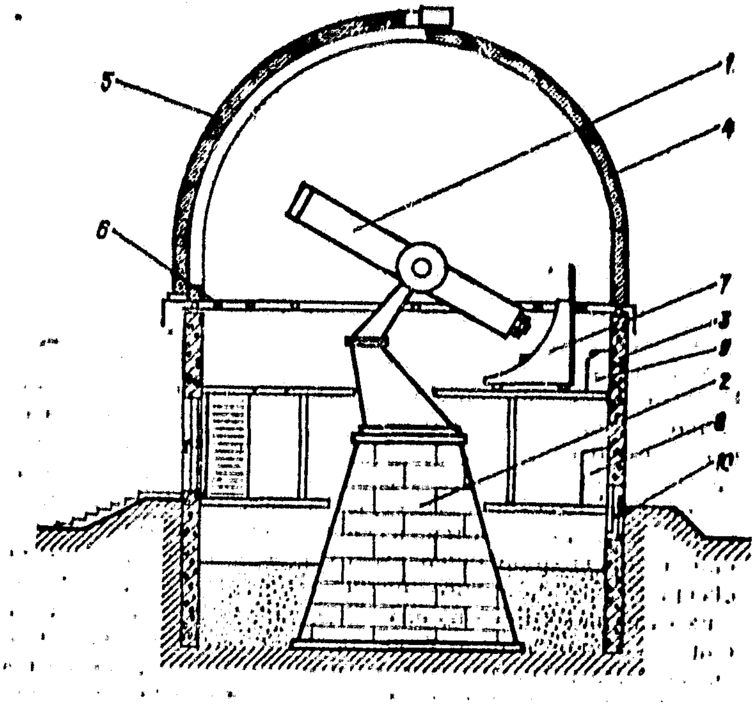

Fig. 4. A telescope turret: 1 - telescope; 2 - stone pillar, base of telescope; 3 - walls of turret; 4 - revolving dome; 5 - opening hatch of dome; 6 - roller track for the revolving dome; 7 - movable cart for the observer; 8 and 9 - power supply and control equipment for the turret and the telescope; 10 - ventilation ducts.

telescope and causing the image to shake, the floor of the turret rests against the walls and is nowhere in contact with either the pillar or the telescope column.

When the telescope is aimed at a star near the horizon, it is quite difficult for the observer to reach the eyepiece. Therefore either a portable stairway rolling over the floor of the turret or a special lift cart is provided in the turret. A rising floor is installed in the turrets of long-focus refractors.

To avoid air turbulence and other undesirable temperature effects, natural and artificial ventilation is installed in the turrets. The dome of large telescopes has two layers, with an air flushing between the outer and inner cladding, and heat insulating cushions between these. The largest telescopes are lodged in turrets with air conditioning units. At the outside the turret is often clad in metal louvers, protecting the stone walls of the turret from direct heating by the Sun. The turret is painted in either shiny aluminum or white, taking up the least heat radiation. The best paint is considered to be titanium white, with good reflection of visible and infrared. And in good time before the observations it is mandatory to open the hatches of the turret and air it out. In small turrets, 40-60 min are sufficient; for larger ones, at least 2 h. But the turret of the 6-m reflector of BTA is constantly air conditioned at the temperature of the outside air.

Light receivers. The role of the telescope is to gather the incident radiation from the object of observation. The gathered light must be registered and analyzed: determination of the direction of the incoming light and its composition, i.e. the physical nature of the emitting object. All of these, including the diverse characteristics of the radiation, are recorded and analyzed by means of radiation receivers. All of these are based on either the direct action of light quanta on the recording medium or the interaction between quanta and a photocathode, which forms an interim electronic image.

The first receiver of light was the human eye. Laboratory research has established that, for a visual perception to arise, it is necessary for about 33 light quanta per 0.1 s to arrive at the necessary spot at the base of the eye. However the eye is not a very sensitive or precise receiver of light. The most widely used light receiver is a photographic emulsion, either in the form of photographic plates or films. Plates better convey the correspondence between the various parts of the image and are easier to store over time. But the photographic laboratories are not always able to cast the necessary varieties of photoemulsion on glass, and therefore it is often necessary to use wide-format films.

It is assumed that a photographic plate of 35 x 35 cm holds about $2 \cdot 10^8$ light-sensitive grains, i.e. some $2 \cdot 10^8$ individual elementary receivers of radiation, and each in addition with appreciable gradation of darkness density. Thus the photoemulsion has remained the most useful receiver of light.

Experience shows that 9 out of 10 light quanta incident on a photoemulsion are reflected or transmitted by it, and only one quantum hits a light-sensitive grain. To form a nucleus of the latent image, made visible after developing, it is necessary for about 10 quanta of light to hit the sensitive grain. Thus, to form a single nucleus of the latent image requires 100 light quanta, i.e. the photoemulsion has a 1% quantum efficiency.

But even so the quantum efficiency of photoemulsions does not suit the astronomers, and they are seeking ways of enhancing the sensitivity. Processes of hypersensitization of the photoemulsion make use of direct pre-heating or flushing of the plates in a stream of nitrogen or hydrogen.

Photographic portraits of the sky are further convenient in their ease of storage. The older observatories have "glass libraries" - repositories of sky photographs gathered over many decades of observation. They hold tens of thousands of negatives. The importance of such information stores is hard to overvalue.

Heat receivers absorb the incident radiation and convert it to heat. They include bolometers, whose electric resistance increases upon heating (sensitivity down to 10^{-14} W); thermocells, in which the heating of a junction of two heterogeneous metals produces an electromotive force (sensitivity down to 10^{-10} W); heat radiometers, acoustic or pneumatic detectors, whose sensitivity matches that of the best thermocells, although they work in a longer wave spectral region. The heat receivers employed in the infrared portion of the spectrum also include liquid crystals, which change color upon heating.

A <u>television receiver</u> consists of a television transmitter tube, mounted at the telescope focus, as well as video amplifiers, power supply, regulators, a communication channel and a receiving television tube or kinescope. The transmitter tube resolves the image into rows, and the rows into elements (video signals), which are amplified by the video amplifier, sent to the laboratory, and either form an image on the kinescope screen by means of a sweep layout, or are recorded on magnetic tape, or are put into computer. A television monitor is convenient because the illumination intensity in the image is amplified on the kinescope by 10^5-10^8 times in relation to the image brightness at the telescope focus. But for determining the mutual positions and brightness of the objects of the observation, it is less accurate than the usual methods.

<u>Photoelectric light receivers</u> are based on the photoeffect: when light is incident on a metal cathode, electrons are emitted in the direction of the positively-charged electrode (and may be accelerated and focused by electromagnetic field). This produces a photocurrent, proportional to the amount of incident light. Photoelectric receivers are extremely diverse in layout. They include both photocells, and photomultipliers (PEM), and photoresistors, and photodiodes, and image converter tubes (ICT). The most common have become the PEM and ICT.

When roughly 50-100 light quanta hit a PEM, a single photoelectron is formed and then accelerated and turned into a stream of electrons, photographically recorded by the observer or stored in computer. The light quanta arriving at the cathode of an ICT knock out photoelectrons which are focused by magnetic or electrostatic field and sent to the screen of the ICT with large magnification (on the order of 10^4-10^7), forming a magnified image of the observed object. The screen dimensions of good ICT have a diameter of about 40 mm and a resolution on the order of 40 lines per mm. Excellent results can be had by combining an ICT with backup recording equipment of television type or computer input.

A new type of ICT are the microchannel plates, consisting of a large number of fine tubes of poor-conducting glass. A photoelectron knocked out by light quanta is accelerated by electric field, hits the wall of the tube and knocks out secondary electrons, which in turn trigger a full scale avalanche at the output of the tube, thus creating a magnified image. Each such tube is a sort of solitary image, and the signal from it is recorded by photoemulsion, on a phosphor screen, or sent to computer. Such elementary radiation receivers can even be superior to photography, but only when recording images of low information content. They work well in those cases when images are studied that contain no more than 1000 elements. Chiefly, these are spectra. But they are greatly inferior to photography in observing broad fields with large number of stars.[1]

A detailed discussion on radiation receivers can be found in the special literature, e.g. the astrophysics textbooks. We

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[1] There are also electron cameras, in which photoelectrons act directly on an emulsion of photographic plates, being a sort of photographic ICT. The sensitivity is raised by roughly 10 times over ordinary photography, but both the photocathode and the photoemulsion should be in a vacuum. The difficulty here is that the photoemulsion adsorbs atmospheric gases prior to loading in the camera and once inside these gases are released, ruining the vacuum and "poisoning" the photocathode.

shall only add that the designs of the receivers are quite diverse and improvements are rapid. While telescopes as opticomechanical machines survive for several decades (the average "lifetime" of a telescope is considered to be 50 years), radiation receivers displace each other every 5 years.

Observational conditions. Astroclimate. Astronomers are far from indifferent to the climatic conditions under which the observatory functions. Foremost in desirability is a maximum number of clear nights and minimum number of cloudy. /2 Of course, if a cloudy night becomes clear for even 2 h, the astronomers will use this "window" and observe; as they say, a meteorologically cloudy night has become astronomically clear. It is obvious that there are much more astronomically clear than meteorologically clear nights. For example, for Pulkovo and Moscow the number of astronomically clear nights is from 70 to 100 per year, whereas the number of meteorologically clear (Table 1) is 32 and 30, respectively.

Table 1. Relation between meteorologically clear (N_m) and overcast (N_o) nights for several sites in the USSR (after the data of P. V. Shcheglov)

Stations	N_m	N_o	Stations	N_m	N_o
Pulkovo	32	177	Abastumani	85	98
Moscow	30	162	Alma-Ata	88	96
Crimea	73	93	Tashkent	142	90
Lower Arkhyz	78	108	Sanglok	128	99
Byurakan	83	121	Maydanak	145	80

But it is not enough to the astronomical observer for the sky to be free from clouds. It is further needed that it be free from haze, dust, with high transparency, untroubled star images, and low background illumination of the sky. The entirety of these and certain other factors constitutes the meaning of the astroclimate. For example, even if the number of meteorologically clear nights is almost the maximum of 142 for Tashkent, the overall dust burden, poor transparency, and high illumination make this place unfit for installation of large telescopes.

In order to search for areas with optimal astroclimate, special astronomical expeditions are outfitted. It has been established that loan peaks of 1000-2000 m, sufficiently remote from large cities and industrial complexes, in a locality with a large number of meteorologically clear nights, usually have the best astroclimatic conditions. Today observatories are no longer built near large cities. The aim is to move them to the mountains, in localities with optimal astroclimate. Recently the attention of astronomers has been drawn to the astroclimate conditions on the Canary and Hawaiian Islands and in the Southern Hemisphere, in the foothills of the Cordilleras.

In the Soviet Union the mountain regions of the Crimea, the Caucasus, Central Asia and Eastern Siberia come close to such conditions. In exploring the astroclimate, Soviet astronomers discovered two summits with exceptionally good astroclimate characteristics: Sanglok in Tadzhikistan and Maydanak in Uzbekistan. They are recommended for construction of observatories with large telescopes.

Radiotelescopes. These are used to determine the bearing of a radio source, the intensity and spectrum of its radio emission, the structure of extended sources, and in making radio surveys of the sky. The radiotelescope, as the optical telescope, consists of a radiation-gathering antenna, a mechanical mount enabling the telescope to be aimed at the necessary segment of the celestial sphere, and a receiver of radio waves - a half-wave dipole (or horn), which receives waves of the selected length.

The antennas of radiotelescopes are structurally diverse and gigantic in size. The form of the antenna is dictated by the range of wavelengths received by the antenna. Cup-shaped parabolic antennas with diameter of several dozen meters are established on azimuth mounts and can be directed to any portion of the visible hemisphere of the sky. The action of such antennas is analogous to that of a reflector telescope. Such, for example, is the RT-22 radiotelescope of the Crimean astrophysical observatory in the Goluboy gulf, near Simeiz, and the similar radiotelescope at Pushchino, near Moscow. Their parabolic antennas have diameters of 22 m and receive in the shortwave range. The largest radiotelescope of such type in the Soviet Union, the RT-70, has a parabolic antenna of 70 m diameter.

Larger radiotelescopes have fan-shaped antennas, consisting of a large number of individual reflecting mirrors, each controlled by its own mount and sending the incident radiation to a single common feed, which summates the radiation reflected by the group of such mirror reflectors. Such is the largest radiotelescope in the Soviet Union, RATAN-600, which shall be discussed more closely afterwards.

The antennas of large-size radiotelescopes are often fixed or limited in mobility. Changing the region of sky from which radio waves are received is done by repositioning the feed. The largest antennas used to receive long-wave radiation are constructed in the form of lattices of elementary receivers - dipoles or vibrators.

One drawback of radiotelescopes is the relatively low resolution. To enhance the resolution, radiointerferometers are used. These consist of two or more antennas, working in the same range of wavelengths, observing the same source at the same time, but separated by a distance known as the base of the radiointerferometer. This differs for the various radiointerferometers: from several meters to several thousand kilometers. In the latter case we talk of radiointerferometers with superlong base.

Depending on the length and direction of the base, radiointerferometers may attain a resolution down to 0.001" in ascertaining the dimensions and positional coordinates of a source, i.e. more accurate than optical astronomy.

Astronomical Observatories of the USSR

The function of observatories. The gathering of diversified observational material collected with the large telescopes built in the late XIX to early XX century (mainly reflectors) enabled astronomers to understand the structure of the Galaxy, determine the position of the solar system in it, and [[1]] determine the place of the Galaxy in the Universe. [However the power][2] of the telescopes built in the first half of the XX century did not suffice to penetrate far into the Metagalaxy. So it was until the middle XX century. The explosive development of physics in the postwar period, especially nuclear physics and the physics of elementary particles, provided a new and mighty stimulus to the development of astrophysics (astrophysics itself became a sort of experimental laboratory for nuclear physics). There was increased penetration of physical methods and methods of modern computer technology into astronomical investigations. And astronomical observatories became major scientific research organizations, numbering dozens or even hundreds of scientific personnel.

Modern astronomical observatories not only possess a stock of observational instruments, but also laboratories for pro-

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[1] Illegible text.

[2] Original almost illegible.

cessing and storage of the observational material, specialized metrology, computation and optical laboratories. It is mandatory for observatories to have well-equipped workshops, where new and unique (not mass produced) instruments and auxiliary apparatus are built. Practically all observatories have their own computer centers with one or more computer. And all of this influences the present mission of certain astronomical observatories, emphasizing their special significance as scientific institutions.

Perhaps the reader knows that the Pulkovo observatory is officially known as the Chief Astronomical Observatory of the USSR Academy of Sciences (GAO AN SSSR). But the observatory of Tashkent, with a history of more than a century, is today known as the Astronomical Institute of the Uzbek Academy of Sciences, the Observatory of Dushanbe is known as the Institute of Astrophysics of the Tadzhik Academy of Sciences, and so on. And these are essentially authentic scientific institutes, with a numerous staff, diverse laboratories, workshops, garages and administrative office. But since the source of astronomical knowledge is still observation (optical, radioastronomical and exo-atmospheric), all these institutes are generally speaking observatories.[1]

Astronomical observatories differ in the subjects they study, their instrument outfit, and even the number of workers.

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[1] The single exception is the Institute of Theoretical Astronomy of the USSR AS (ITA) in Leningrad. The ITA is involved in calculating the ephemerides of the stars, Sun and planet, publishing the "Astronomical Annual of the USSR" for the current and subsequent years - the major reference aid, containing exact positions of the stars, planets, Moon and Sun, data on rising and setting, eclipses, etc. Besides the "Astronomical Annual of the USSR", the ITA figures out and publishes "Tables of Star Cover by the Moon", the "Ephemerides of the Small Planets", and other tables needed by specialists.

The largest are administered by the Academy of Sciences of the USSR or the academies of science of the Union republics. Such, for example, are the Chief Astronomical Observatory of the Ukrainian AS, situated in the Goloseyevo forest near Kiev, or the Shemakhinsk astrophysical observatory of the Az AS, having one of the largest telescopes in the USSR, a 2-m reflector. Several solar or radioastronomical observatories belong to research institutes of adjacent fields: the solar observatories of the Institute of Earth Magnetism and Propagation of Radio Waves of the USSR AS (IZMIRAN) at Vatutinki near Moscow and the Institute of Earth Magnetism and Propagation of Radio Waves of the Siberian Division of the USSR AS (SibIZMIRAN) in the Eastern Sayan.

Fifteen universities of the USSR have their own astronomical observatories, handling both academic and scientific problems. Among them are such major observatories as the State Astronomical Institute im. Shternberg (GAISH) at Moscow State University im. Lomonosov, celebrating its 150th anniversary in 1981, and the astronomical observatory of Leningrad State University im. Zhdanov, which became 100 years old in 1980. The observatories of Khar'kov, Kazan', Kiev, Odessa, Ural (at Sverdlovsk), Riga, and several other universities are well known.

The conditions of observation at the older observatories near large cities are deteriorating continually. Thus new observatories are built in the mountains, away from major population centers, in areas with optimal astroclimate. Such are Abastumani observatory in Georgia, Byurakan observatory in Armenia, Gissar observatory in Tadzhikistan. The older observatories are constructing observation bases in such territories: Pulkovo in the mountains near Kislovodsk and at Ordubad, in Southern Azerbaydzhan, the GAISH in the Crimea and near Alma-Ata, the GAO AN USSR at Terskol in the Caucasus, etc.

There are now a total of about 50 scientific observatories functioning in the Soviet Union (Table 2) - academic, university and governmental. This number includes the branch divisions - the observational bases and stations. Furthermore, a number of observatories exist at the planetariums, pedagogical institutes and the All Union Astronomy and Geodesy Union (VAGO), which brings together amateur astronomers. These observatories are used for cultural, academic or amateur purposes.

Table 2. Main astronomical observatories of the USSR[1]

Name	Date of Foundation
Abastumani astrophysical observatory of the GRUZ. AS	1932
Astrophysical institute of the Kaz. AS	1942
(Alma-Ata observatory)	(1950)
Ashkhabad astrophysical laboratory of the TURK. AS	1946
Blagoveshchensk latitude station of the GAO AN SSSR	1959
Byurakan astrophysical observatory of the Arm. AS	1946
Solar observatory IZMIRAN at Vatutinki (near Moscow)	1960
Vil'nyuss astronomical observatory of Vil'nyuss State U. im. Kapsukas	1753 (1926)
Gissar astronomical observatory of the Tadzh. AS	1963
Chief astronomical observatory of the USSR AS (GAO AN SSSR) at Pulkovo	1839 (1954)
Chief astronomical observatory of the Uk. AS (GAO AN USSR) at Goloseyevo	1944
Institute of astrophysics of the Tadzh. AS (Dushanbe observatory)	1932 (1958)

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[1] In parentheses are the dates of modification or reorganization.

Table 2. Cont'd.

Name	Date of Foundation
Zvenigorod observational station of the Star Council of the USSR AS	1964
Special astrophysics observatory of the USSR AS (SAO) near Zelenchuk	1967
Radioastronomy station NIRFI at Zimenki, near Gor'kiy	1968
Astronomical observatory im. Engel'gardt at Kazan' State U. im. Ul'yanov-Lenin	1901
Kazan' municipal astronomical observatory of Kazan' State U. im. Ul'yanov-Lenin	1814
Astronomical observatory of Kiev State U. im. Shevchenko	1845
Kitab international latitude station im. Ulugbek	1930
Kislovodsk solar station of the GAO AN SSSR	1948
Crimean astrophysical observatory of the USSR AS (KrAO)	1950
Southern observations base of the GAISH in the Crimea	1958
Kourov astronomical observatory of Ural State U. im. Gor'kiy	1966
Astronomical observatory of Leningrad State U. im. Zhdanov	1881
Astronomical observatory of L'vov State U.	1907
State astronomical institute im. Shternberg (GAISH) at Moscow State U. im. Lomonosov (Moscow Observatory)	(1931, 1954)
Nikolayev branch of the GAO AN SSSR (Nikolayev astronomical observatory)	1827 (1912)
Astronomical observatory of Odessa State U. im. Mechnikov	1871
Poltava gravimetric observatory of the Ukr. AS	1926
Radioastronomical observatory of the FIAN at Pushchino	1957

Table 2. Cont'd.

Name	Date of Foundation
Riga astronomical observatory of the Latvian State U. im. Stuchka	1922
Riga astrophysical observatory of the Latv. AS	1960
Samarkand astronomical observatory (museum)	XV centur
Simeiz experimental station of the Star Council of the USSR AS	1908 (1975)
Tartu astronomical observatory im. Struve of the E. AS	1809 (1964)
Astronomical institute of the Uzb. AS (Tashkent astronomical observatory)	1873
Uzhgorod observational station for satellites	1957
Ussuri solar station SibIZMIRAN	1954
Astronomical observatory of Khar'kov State U. im. Gor'kiy	1808
Shemakhinsk astrophysical observatory of the Az. AS	1956

<u>The special astrophysical observatory (SAO)</u>. In the foothills of the Northern Caucasus, south of Cherkessk, where the forest-covered mountains become the magnificent summits of the Main Caucasian range, is located the Special Astrophysical Observatory of the USSR Academy of Sciences (SAO). If the observatory had been named after the locality, it might have been the Zelenchuk observatory, since the nearest populated point is the station of Zelenchuk. However it is differently named, for it has two gigantic instruments - the world's largest optical telescope BTA and the immense radiotelescope RATAN-600.

Alongside the laboratory building of the SAO have been constructed workshops, garages and residential buildings. All are situated in a shady picturesque gorge on the bank of the swift mountain stream Bol'shoy Zelenchuk and are known as the settlement of Nizhniy Arkhyz, to distinguish it from Verkhniy Arkhyz, a village in existence for several decades upstream. But the local inhabitants, as well as the astronomers themselves, affectionately call their settlement Bukovka or Bukovo, after the beeches growing on the slopes of the surrounding mountains. The exterior of the village has almost nothing to suggest the astronomical specialization of this institution. Only on the laboratory building are there two tiny turrets with small auxiliary telescopes. And it is even hard to see the stars from within the gorge. Yet precisely here, at Nizhniy Arkhyz, is the center of that scientific complex formed by the SAO. From here, astronomers sally forth to make observations with the BTA. It is here where they work on the acquired data and make preparations for further observation.

<u>BTA - Large Telescope Azimuthal</u>. Following the highway above Nizhniy Arkhyz, after 19 winding turns of the mountain road (and the highway is splendid here), the observers reach one of the summits of the foothills - the natural landmark of Semi Rodnikov [Seven Springs]. Here, at a height of 2070 m, is the world's largest optical telescope with main mirror diameter of 6.05 m. It is known as the "Large Azimuth Telescope", or BTA. The USSR Academy of Sciences created a special committee to allocate the work time at the BTA, consisting of representatives of the SAO and all the major observatories of the Soviet Union. This committee gathers and reviews requests from Soviet and foreign observatories and individual astronomers. It evaluates the significance and urgency of the requested programs. Visiting astronomers, including foreigners, are allotted 70% of the observation time, the SAO workers 30%.

The design project of this giant telescope was begun by a group of Pulkovo observatory, headed by the prominent optician and designer D. D. Maksutov. Later, after his death, the work on this telescope was conducted by another leader of the Soviet optico-mechanical industry, Lenin prize winner B. K. Ioannisiani. Involved in the project were a group of engineers and designers of the Leningrad Optics and Mechanical Union (LOMO) and many outstanding astronomers and opticians of the USSR.

The LOMO was the main builder of the BTA. But a whole series of factories and institutes of the USSR, including such major ones as the Kirov and Admiralty factories of Leningrad, took part in building the giant telescope. The glass blank for the mirror was cast at the optical glass factory of Lytkarino, near Moscow. An aluminum plating plant for the mirror was set up at Gor'kiy. Other factories of Moscow, Rostov on the Don, and other cities also participated. In token of this, at the approach to the BTA on the last segment of the road there is a sign: to Moscow 1890 km, to Leningrad 2620 km, to Rostov on the Don 540 km, to Gor'kiy 2190 km.

The preparatory work and installation of the necessary equipment alone took about three years. The molten glass body was transported along a gas-heated discharge chute and then along a platinum pipe, heated by hydrogen flame, to a mold for annealing and slow cooling. Two blanks were cast. The first of these, used for pilot production, was cooled rather fast - it was thought to require nine months for cooling. The blank did not stand such a cooling rate - the homogeneity of the body was disturbed, and it split into two roughly equal parts (which were used to manufacture auxiliary focusing mirrors).

The second or main blank, on the basis of the former experience, was cooled more slowly, at a rate of 0.03 K/h. Its cooling lasted for 2 years and 19 days. The resulting blank was first subjected to roughing to impart the given shape, which took 16.5 months and 15,000 carats of diamond tool. In the course of the machining, the weight of the blank was reduced by roughly 30 t. Later a third blank was cast.

In the polishing shop - a room with firm foundation and triple heat insulation - were installed a polishing machine and apparatus for studying the mirror. Only two people worked in the room - the breathing of a third would have altered the temperature conditions of the shop. In final form the mirror is 650 mm thick, 6050 mm in diameter, being a meniscus with surface of curvature radii equaling 48 m and, consequently, focal distance of 24 m. In its lower portion there are 60 round depressions to hold the relief bearings, situated in four concentric circles. A calculation shows that the relief system can preserve the surface shape of the mirror so that the deformations do not exceed 1/16 the wavelength of light.

The mirror was ready in June 1974, its final weight being 42 t. The mount of the mirror was made at the Admiralty factory of Leningrad. Shipping the mirror, like any other major telescope parts, was an unique transportation job. They were shipped by water, along the Volga and the Don to Rostov on the Don. Here powerful tractors hooked up to the platforms with the telescope parts and slowly, carefully hauled them to the mountains. It was summer and hot, the cargo was heavy, the asphalt melted beneath the tractor wheels. Thus, traveling along with them were road-building machines, continually sprinkling the platforms and the tractor wheels with water. They proceeded in this way for two days and 530 km to the station of Zelenchuk. After this, the mountainous segment of the highway began; the tractor rigs with trailers painstakingly climbed the steep turns of the road.

The design of the mount of the BTA was a complete novelty in the astronomical practice of the world. To appreciate the full complexity of the affair, let us recall that the second largest telescope in the world after the BTA, Mount Palomar, has a mirror diameter of 5 m, which is 1 m smaller than the BTA. The weight of the Mount Palomar mirror is 13 t, while its moving parts weigh about 500 t. How many times should the weight of the moving parts of the BTA be increased if its mirror weighs 42 t?

After considering various versions it was recognized that a large parallax mount would be very heavy, massive, and awkward in the engineering sense. It was proposed to use an alt-azimuth mount, one axis vertical, the other horizontal, with the instrument turning about these axes through the azimuth and the altitude. With such a mount, in order for the telescope to follow a star, the instrument must be turned about both axes simultaneously, through different angles of turn at different speed. Naturally, this is inconvenient. As far back as the XVIII century such mounting was rejected.[1] But that which was difficult and impractical in the XIX became the only acceptable solution in the latter half of the XX century.

The alt-azimuth mount is perfectly symmetrical. When turned about the vertical (azimuth) axis, the load on the vertical axis remains constant and evenly distributed. Tilting and buckling of the telescope tube occur only in one plane and depend solely on the altitude of the observed point. The mirror relief system is simplified, as is the balancing of the telescope. All of this simplifies and lightens the structure. The negative aspects of the alt-azimuth mount - simultaneous motion about two axes, nonuniform speeds of these motions, and

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[1] Incidentally, the very word "alt-azimuth" is treated by certain authors as "old-azimuth", deriving it from the German alt - "old". But in actuality the word comes from the Latin altum - "altitude", and the name of the mount should be understood as "altitude and azimuth".

rotation of the visual field - were able to be mastered by using a control computer and sufficiently fine movement mechanisms.

By using the alt-azimuth mount the weight of the moving parts of the BTA is 850 t, which is no more than 1.6 times larger than that of the Mount Palomar telescope. The manufacturing precision of the BTA assemblies (and it consists of 25,000 designated parts) and the finness of balance of the overall telescope are such that the movement of this apparatus is achieved by a motor of no more than 200 W.

Fig. 5 shows the layout of the BTA. It consists of a vertical support axis, carrying a horizontal platform of 12 m diameter, on which there rest two vertical columns 8 m high. At the top of the columns are the bearings of the horizontal axis, 2.2 m in diameter. At the outside of the columns, horizontal platforms for observers are secured. The vertical axis rests by its spherical surface (6.6 m in diameter), polished by the same machine as the main mirror, on six concave polished spherical bearings of the same radius. The entire weight of the telescope rests on these. In the gap between the spherical surface and the bearings, oil is supplied under high pressure, forming an intermediate film several hundredths of a millimeter thick. The several tons of bulk of the telescope float on this film of oil, as on a hydrostatic bearing.

The BTA can operate by two optical systems: at the major (primary) focus and in a Nesmith layout. At the primary focus the light losses are smallest, although the visual field free of aberration is no more than 2'. To enlarge the visual field, a two-lens compensator is placed in front of the main focus, augmenting the field to 13'. When observing at the main focus, the observer is in a special cabin known as the cup, with the major focus located just within this cup. Since the cabin is in the path of the pencil of beams incident on the main mirror, and the heat of the astronomer's own body in the cabin disturbs

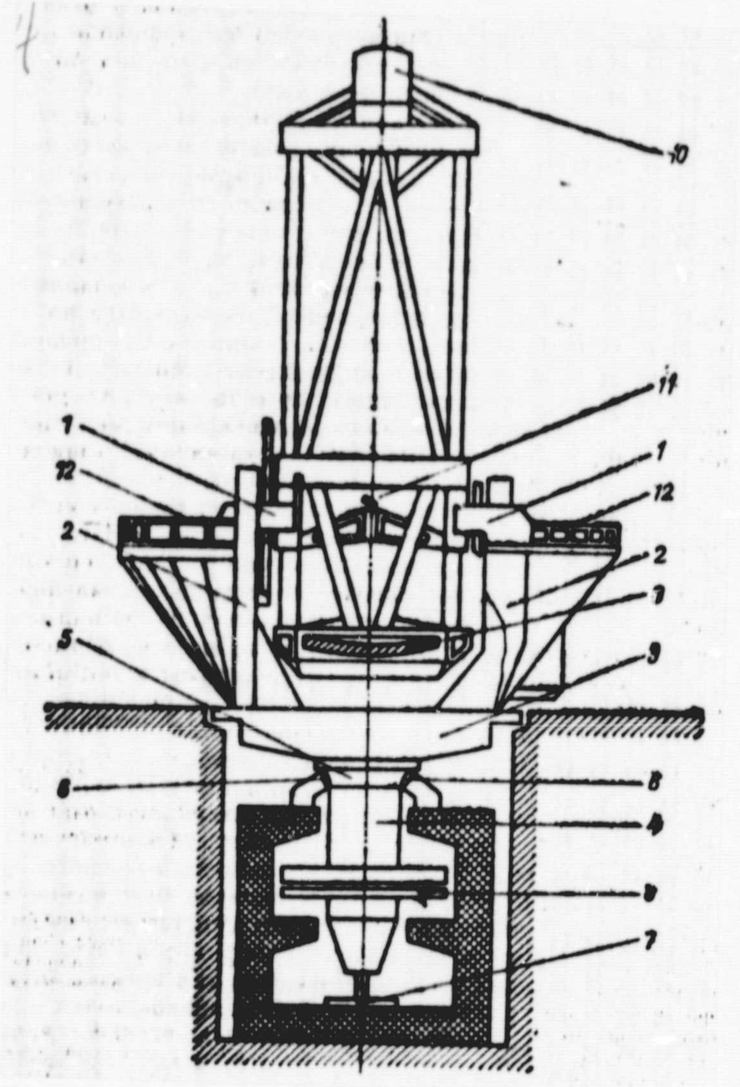

Fig. 5. Layout of the BTA: 1 - bearings dictating the direction of the horizontal axis; 2 - vertical columns carrying the horizontal axis and side observation platforms; 3 - main horizontal platform; 4 - vertical axis; 5 - ball bearing of vertical axis; 6 - hydrostatic bearings; 7 - base bearing and regulator of the direction of the vertical axis; 8 - gearing for turning the telescope about the vertical axis; 9 - main mirror; 10 - "cup" in which the observer is found when observing at the major focus; also lodges the lens correction system or a secondary convex mirror for observations by the Nesmith system; 11 - plane

mirror to direct the rays within the horizontal axis onto the observation platforms;
12 - side observation platforms on which fixed radiation receivers are placed.

the temperature field of the telescope, the cabin is enclosed at all sides after the observer gets in. The walls of the cabin at the inside have a heat insulating cover, and a ventilation system is supplied to the cabin to assure the necessary exchange of air for the observer.

The Nesmith system includes a secondary convex mirror, mounted in the lower portion of the cup to replace the lens correction system. The secondary mirror sends the beams back, where they encounter a small plane mirror in their path, which sends the rays to one of the observation platforms holding the reception equipment. In this layout the BTA has a focal distance of 180 m and relative aperture 1:30.

Studies by BTA observers revealed that its image quality is rather high: 61% of the light is concentrated in a spot of 0.5" diameter and 91% in a spot of 1". This indicates that the image quality is mainly governed by the tranquility of the atmosphere, and not the quality of the mirror. The new telescope enables observation of the stars by direct photography methods down to a stellar magnitude of 24.5, or 25 under specially favorable atmospheric conditions.

A special tower was constructed for the BTA telescope. We can get an idea of its size by noting that the distance from the main mirror to the cup where the primary focus is situated is in excess of 24 m (Fig. 6). The dome of the tower weighs about 1000 t, its diameter along the rolling circle is 44.2 m, and the working area of space beneath the dome is 3536 m^2. The entire volume beneath the dome should have an identical temperature equal to the outer air. Thus the BTA dome should be comprised of three layers of Duralumin panels with heat insulating liners. Not far from the BTA tower, just a little downhill, a ventilation plant has been built with a powerful air conditioner, capable of supplying air of identical temperature as the outside to the space beneath the dome year-round. This air is forced inside the cladding of the dome and aerates the space beneath the floor of the tower.

The hatch of the tower opens to a width of 11 m. It is covered by a visor, which is thrown across to the opposite side of the dome during the time of observations. The weight of this visor is 33 t.

The complicated control mechanisms of the BTA requires at night during observations the presence, besides the observer in the cup, of a team of engineers and attending personnel to monitor the working of the telescope mechanisms. It is therefore clear that every minute of use of the telescope is extremely valuable, and the work time should be strictly rational in use.

It remains to add that, since the opening of the BTA in 1977, interest scientific results have already been gathered, although it exceeds our subject to discuss them. The BTA mounting proved to be extremely successful. It will evidently form a part of practical telescope design for much time. Even now an English reflector of 4.2 m diameter is being built on a similar alt-azimuth mount, to be installed on the island of La Palma in the Canaries, and a telescope of 7.6 m diameter is being designed for Texas University in the USA.

<u>The radiotelescope RATAN-600</u>. Forty km to the north of Nizhniy Arkhyz, at the outskirts of Zelenchuk station, the largest radiotelescope in the USSR has been built, with a total antenna surface of more than 13,000 m^2. The diameter of the ring antenna is 600 m. This radioastronomical telescope of

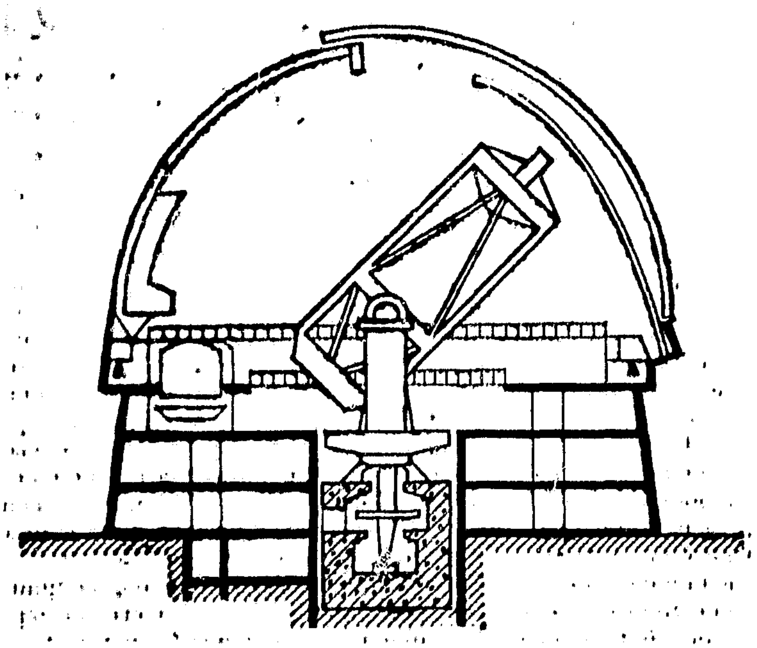

Fig. 6. Arrangement of the BTA in its tower.

the USSR Academy of Sciences (hence its acronym RATAN-600) began service in February 1977. It is part of the SAO, but in contrast with the BTA is located not on a mountain, but rather in a valley encircled by a gentle bend of the Caucasian foothills.

The antenna of the RATAN-600 telescope is a reflector ring in the form of a wall of 895 rectangular aluminum mirrors, each 2 m wide and 7.4 m tall. At the rear of each mirror there are 276 bearings, securing it to a metal girder. These bearings can move. They turn the mirror, move it forwards or retract it, regulate the shape, imparting the necessary concavity. In this way, the mirror buckling caused by temperature changes or the cumulative effect of internal stresses is compensated. Each girder is mounted on a massive ferroconcrete base, assuring a stable mirror fixation. To use most fully the capabilities of the radiotelescope it is necessary for all 895 mirrors to function in coordination. This can only be done by using a control computer, altering the setting of all the mirrors in synchronization.

The radio emission gathered by the reflector antenna is sent to the feeds. These are in the form of mobile laboratories, which can travel along rails. A receiving antenna, or secondary feed, is mounted on the roof of each of the three such cars. This receives the radiation collected by the many mirrors of the antenna and reflects it to the primary feed - a horn, which is the input of the reception and mensuration equipment. Depending on the altitude angle of the observed region, the feed must be positioned at various points of the field (Fig. 7). For this, inside the ring formed by the antenna there are rail tracks along which the feed cars can travel from place to place, assuming the most rational position.

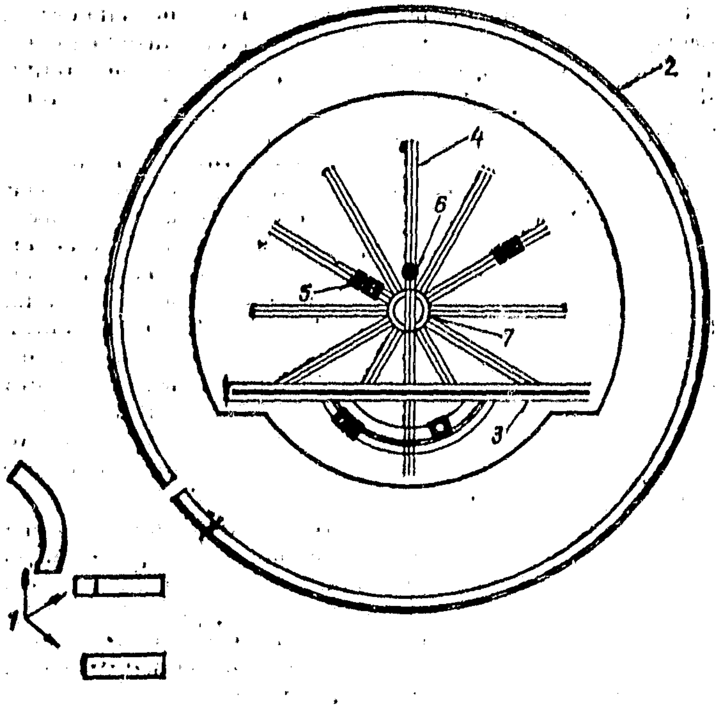

Fig. 7. Diagram of the RATAN-600 radiotelescope:
1 - laboratory buildings; 2 - reflector ring;
3 - straight feed; 4 - rails for movement of
feeds; 5 - feed cars; 6 - radio receiver;
7 - turntable.

Strictly speaking, RATAN-600 is an azimuth telescope. It can register the emission from a radio source passing through a given meridian or azimuth. The design of the radiotelescope enables observation of radio sources in the zone of declination from -40 to +90°, i.e. roughly 70% of the total surface of the celestial globe. In principle, it is possible to aim all 895 mirrors of the antenna at a single point of the sky, close to the zenith. But usually the RATAN-600 telescope is controlled so that, when the mirrors of one side of the ring are aimed at one point of the sky, the mirrors of the other part receive emission from another portion of sky. Thus, RATAN-600 can observe three regions of the sky in three different azimuth directions. Roughly a quarter of the telescope mirrors function in each of these.

The dimensions of the collecting surface of the antenna mirrors determine the quantity of received radiation. The effective area of the mirrors of each particular part of the radiotelescope amounts to several thousand square meters. RATAN-600 can receive radio emission with wavelengths of 8 mm to 30 cm. The information collected in the course of the observation is processed by computer, practically at the same time as the observations themselves. When the radio source passes through the azimuth of the feed, the computer figures out and prints its coordinates, intensity, and other parameters, and transcribes this data into the memory of the machine, for later use in more complete processing.

Observations with the radiotelescope are almost independent of atmospheric conditions. The large area of the reflector antenna and use of a special procedure dispenses with weather constraints, enabling observation both in cloudy weather and during the day.

Pulkovo observatory at the present day. From the very first days of World War II, Pulkovo observatory was subjected to fierce bombardment and artillery barrage. The enemy was not allowed to enter the territory of the observatory, but for more than 900 days the front passed in the immediate vicinity thereof. All its buildings were destroyed. The large 76-cm refractor, the normal astrograph, the horizontal solar telescope, and the major portion of the unique library were lost (only the objective lenses of the first two surviving). Only several medium sized instruments were saved, moved to Leningrad and stored in the basement of the Academy of Sciences building.

On 11 March 1945, when the war was still on, the decision was made to restore and expand Pulkovo observatory as the Chief Astronomical Observatory of the USSR Academy of Sciences (GAO AN SSSR). The observatory was restored to its classical form, as the massive stone foundations embedded in the ground and carrying the instruments before the war had been almost untouched, and it was possible to replace some meridian instruments in their former position. But prior to rebuilding the observatory, it was necessary to clear out the territory and its surroundings from mines and unexploded shells.

In 1947, when the reconstruction was in full swing, Professor A. A. Mikhaylov (member of the USSR AS since 1964) was nominated director of Pulkovo observatory. In the same year the first postwar astronomical observations were done with two instruments. The opening celebration of the restored Pulkovo observatory was held in 1954.

There is no sense in describing here all the telescopes of Pulkovo observatory. The meridian instruments were completely restored and even increased in number - new Soviet-manufactured instruments were created. The main building stands on the same foundations as before, while the center of the circular hall of the central tower continues to be the starting point of the Pulkovo meridian - the starting point of all astronomical-geodetic triangulation networks of the USSR. At present astronomical observations on wide-ranging scientific subjects are being conducted at Pulkovo. But in addition to the independent observations, the GAO AN SSSR is examining and working on astrometrical catalogues obtained from other observatories around the world. A Soviet branch of the Center for Astronomical Data is in existence at Pulkovo, working on analysis and dissemination of astrometrical data in the USSR and abroad.

Pulkovo has an active latitude facility and time facility. For these, new instruments have been introduced: the ZTL-180 zenith telescope, small transit instruments with photoelectric registration, and others. Great attention is paid to determining the fundamental constants of astronomy - the constants of precession, nutation, and aberration. On the suggestion of Mikhaylov, a polar tube was built - a fixed instrument for photographing a region of sky near the North Pole. Using this, regular observations have been carried out for more than a quarter century to determine these constants. Using modern knowledge as to the structure of the atmosphere as a basis, the famous Pulkovo tables of refraction have been updated and are getting ready for a new, fifth edition.

Regular photographic observations are carried out to determine the natural motions of the stars, to study the movement of the larger planets and their satellites, the small planets, binary stars, stars with dark (invisible) satellites, and other interesting objects. For this purpose, the normal astrograph has been restored and a new long-focus astrograph (65 cm in diameter, with focal distance 10.5 m) has been installed. The members of the observatory built a new and original structure of horizontal meridian circle of the L. A. Sukharev system.

The physics of the Sun and a solar study facility have an important place in the projects of the GAO AN SSSR. These are directed by corresponding member of the USSR AS, V. A. Krat. The observations are being done by a newly-built horizontal solar telescope and other devices. A considerable portion of the Sun observations is being done at the Mountain Astronomical Station near Kislovodsk. Pulkovo is one of three International Centers (USSR, USA and France) gathering all observations of the Sun and publishing a monthly bulletin "Sun Data".

At the GAO AN SSSR a division of radioastronomy has been organized. For this, a laboratory building has been constructed on the south slope of Pulkovo hill, and alongside there are several radiotelescopes, including a fan type of 90 reflector mirrors, situated along an arc of a paraboloid with chord diameter 120 m. At the focus of the paraboloid is a feed, connected by cable to the receiving equipment in the laboratory building. Observations are conducted at the meridian, while for altitude aiming the tilt of the reflector mirrors is appropriately altered and the feed is moved. The Pulkovo radiotelescope served as prototype for the already-described RATAN-600 radiotelescope.

Speaking of the GAO AN SSSR, we cannot fail to mention its department of astronomical instrument design, managed by D. D. Maksutov until his death in 1964. In this department, new astronomical instruments are being designed and built, both for the observatory itself, and for its branches and expeditions, while the members of the department develop recommendations and take part in the creation of many of the major telescopes of the USSR, including the BTA and RATAN-600.

As already noted, due to the proximity of a large city, as well as the bright nights, the conditions for observation at Pulkovo are far from ideal. Therefore the Pulkovo astronomers are trying to move their instruments to the south, in the mountains, where the astroclimate is better. For astrometrical observations at the marine observatory of Nikolayev, the Nikolayev division of the GAO AN SSSR has been created. In fact, this is a major modern observatory, specializing in astrometrical studies. As at Pulkovo, it has a large transit instrument, a vertical circle, a Repsold meridian circle (commissioned as early as V. Ya. Struve for the Pulkovo observatory, and transferred to Nikolayev after the war), a photographic zone astrograph, instruments for a standard time service, and several others. The Nikolayev observations are important supplements to Pulkovo and have been recognized internationally.

To study the revolution of the Earth, a latitude station has been constructed at Blagoveshchensk on the Amur, separated by approximately 90° longitude from Pulkovo. The ZTL-180 zenith telescope built by the LOMO is installed here. In the mountains of Transcaucasia, near Ordubad (Nakhichevanskaya Associated Republic), a permanent expedition of Pulkovo observatory is in operation, furnished with instruments for photographing the starry sky. On the mountain Shat Zhad Mas, 28 km from Kislovodsk, at a height of 2070 m, in a locality with astroclimate favorable to solar observations (as many as 337 observation days per year[1]), the Mountain Astronomical Station of the GAO AN SSSR has been built.

It is precisely in the mountains, where the scattered light is less and the sky is darker, that observation of the solar corona is facilitated. At the Mountain Astronomical Station of the GAO AN SSSR, a photoheliograph of the Maksutov system, a chromospheric-photospheric telescope, used to photograph the solar disk in the $H\alpha$ line and to make observations of the solar corona, two eclipse-outside coronographs, including the world's largest with an objective diameter of 53 cm (focal

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[1] Gnevyshev, M. N., "The Mountain Astronomical Station", Zemlya i Vselennaya, 3, 1979, p. 50.

distance 8 m), and other instruments, in particular a two-component radiointerferometer and two small radiotelescopes, have been installed.

The complex of instruments at the Mountain Astronomical Station renders possible observations of the Sun in the radio and optical ranges simultaneously. Since the radio emission of different wavelengths comes from different layers of the solar atmosphere, whereas optical facilities enable observation of the photosphere, the chromosphere, the protuberances and the corona, the observations at the Mountain Astronomical Station simultaneously cover the phenomena in all layers of the solar atmosphere. The work of this station is directed by M. N. Ghevyshev.

The Crimean Astrophysical Observatory of the USSR AS (KrAO). As far back as the end of the past century the inconvenience involved in observations at observatories close to large cities had become apparent, and the issue was debated of creating a new observatory in the south of the USSR. The site was chosen in the Crimea on the mountain Koshka, just above the resort of Simeiz. In 1908 a dual astrograph was built there with objectives 12 cm in diameter and a branch of Pulkovo observatory was opened. Regular observations of the small planets and variable stars were begun with this instrument.

After the October Revolution, Simeiz observatory began to expand quickly. The number of scientists increased: in 1925 G. A. Shayn and his wife P. F. Shayn arrived at the observatory. During this same time, Soviet diplomats, especially L. B. Krasin, managed to fill orders for scientific equipment from the capitalist nations, requisitioned by the Academy of Sciences from before the revolution, and new agreements were made. Among the other equipment from England there arrived a 102-cm telescope, the largest reflector of that time in the USSR. Under the direction of G. A. Shayn, it was installed at the Simeiz observatory. This reflector was equipped with a spectrograph, which was used to begin the study of the physical nature of stars, their chemical composition and the processes which take place in them.

In 1932 the observatory obtained a photoheliograph for photographing the Sun. Several years later a spectrohelioscope was installed - to study the surface of the Sun in the line of a certain chemical element. In this way, Simeiz observatory became involved in major work to study the Sun.

The modern instruments, up-to-date scientific subjects, and enthusiasm of the scientists made the Simeiz observatory the leading astrophysical observatory of the USSR. But the war began, and the observatory suffered great loss. Its buildings were burned, the laboratory equipment destroyed or evacuated. In retreating, the fascists shot up the main mirror of the 102-cm reflector with automatic weapons.

In 1945 a decision was made to restore Simeiz observatory and to situate it in a different more appropriate spot, with respect to astroclimate, and also to change it from a branch of Pulkovo observatory to an independent organization - the Crimean Astrophysical Observatory of the USSR Academy of Sciences (KrAO). After a series of astroclimatic studies, a new site was selected for the observatory in the mountains, 12 km to the east of Bakhchisaray (a little more than 30 km by highway), a bit further away from the heavily-lit cities of the southern shore of the Crimea - Sevastopol' and Simferopol'. Here, on a small flat elevation at a height of 600 m above sea level, construction began on the observatory and a scientific settlement, the so-called Scientific Village.

At the new observatory a broad front of astrophysical research was developed, continuing and elaborating the work begun at Simeiz.[1] The Crimean Astrophysical Observatory received a numerous stock of first-class instruments. The first to be installed was a 40-cm dual astrograph, used for diversified astrometric and star-astronomical observations, but mainly search and discovery of small planets and comets. Moreover, replacing that lost in the war was a Zeiss reflector with mirror diameter 122 cm. This was used to continue the studies of physical processes in the atmospheres of stars, begun as far back as Simeiz. A 63-cm wide-aperture camera, a 50-cm telescope of the Maksutov system, an eclipse-outside coronograph and a number of other telescopes were installed.

Somewhat later, in 1954, a turret solar telescope (BST) was placed in service, equipped with diversified receiving gear for studying the spectra of the surface of the Sun. To investigate more closely the influence of the Sun on processes in the atmosphere of Earth, an instrument complex was created for studying the atmosphere and ionosphere and for registering changes in the Earth's magnetic field.

In 1952, A. B. Severnyy became director of the KrAO (member of the USSR AS since 1968). On his initiative, the BST was built. In the 1970s, the BST was modernized. Thus, new mirrors of sitall were installed: the 120 cm diameter coelostat mirror, an additional 110 cm diameter plane mirror and a 100 cm diameter main concave mirror. The mirrors were fabricated in the optical workshops of the KrAO. The resolution of the BST was increased: it is now possible to distinguish details of 0.3", which corresponds to 200 km on the surface of the Sun. It was necessary to raise the tower of the BST by 10 m: after the reconstruction its height was 25 m. /5

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[1] At the site of the old observatory of Simeiz there has now been opened up the Simeiz Experimental Station of the Astronomical Council of the USSR AS, furnished with five small instruments for observing artificial Earth satellites. A new reflector with mirror diameter 1 m is being installed at the station.

In 1961 a mirror telescope in honor of G. A. Shayn (ZTSH) with mirror 2.6 m in diameter, made by the LOMO union, was installed at the observatory. At that time, this was the largest telescope in the USSR and in Europe. And even today, along with the 6-m telescope of the BTA and another 2.6-m telescope of the Byurakan observatory, it belongs to a trio of the largest telescopes of the USSR, for which the observation time is allocated by a special committee of the USSR Academy of Sciences.

Radioastronomy has been developed at the KrAO, especially through study of the radio emission of the Sun, conducted jointly with optical observations at the BST. A large radiotelescope has been built, its site chosen on the shore of the Black Sea in the Goluboy gulf, to the west of Mount Koshka. South of the observation platform is the open sea (where radio interference is less); to the north, east and west the platform is shielded by the Crimean mountains. It is here that the RT-22 large radiotelescope has been set up, with parabolic antenna in the form of a cup, 22 m in diameter, on an azimuth mounting. In contrast with the RATAN-600 radiotelescope and the large Pulkovo radiotelescope, the RT-22 can be aimed at any point of the sky with a control computer and can track the object of observation for a lengthy time (aiming precision about 15").

The RT-22 radiotelescope has become a powerful means of radioastronomic research. It often works in tandem with the RT-22 radiotelescope of identical design and size at Pushchino, near Moscow. These together form a radiointerferometer with superlong base, having a resolution of radioastronomic observations down to 0.002" at a wavelength of 1.35 cm.

At the KrAO, regular searches for small planets and determination of their position are continued by tradition.

This work is directed by N. S. Chernykh. Each year, more than 2000 positions of various small planets are determined. In the decade from 1965 through 1974 alone there were 35 new planetoids discovered at the KrAO, each given a name and number. The share of the observatory in such discoveries is about 40% of the total of planetoids discovered in the entire world. A comet has also been discovered here, named the Smirnova-Chernykh in honor of its discoverers.

The State Astronomy Institute im. Shternberg (GAISH). In Moscow, in the Lenin mountains not far from the altitude building of MGU in the depth of a shady park is a 3-story structure with four astronomy towers on the roof. Scattered nearby in the park are nine turrets and pavilions for various astronomical instruments. This is in fact the GAISH - the astronomical observatory of Moscow State University im. Lomonosov.

The Moscow observatory was built in 1831 in the outskirts of Moscow in the region of Presnya. In the early XX century, this was a rather well-furnished astronomical institution with meridian circle, long-focus astrograph, wide-angle equatorial camera and several smaller instruments. At the observatory, meridian and photography determinations of star positions, search and study of variable stars, and investigation of binary stars were carried out.

From 1887 through 1920 P. K. Shternberg worked at the observatory (director since 1916). He was a leading scientist and revolutionary. In 1931, when three Moscow astronomical institutions were combined at the Moscow observatory, his name was bestowed upon the unified astronomical institute, which came to be called the State Astronomical Institute im. Shternberg (GAISH).

In 1954, along with construction of the altitude building of MGU, a building complex was built for the GAISH; it received new instruments, the first large telescopes made after the war by the optico-mechanical factory of Leningrad (now the LOMO). In the Lenin mountains, a meridian circle, the ZTL-180 zenith telescope, the AFR-1 wide-angle astrograph (diameter 23 cm, focal distance 2.3 m), the AZT-2 parabolic reflector with mirror diameter 70 cm, a telescope of the Maksutov system with meniscus diameter 50 cm and mirror diameter 70 cm, a horizontal and a turret-type solar telescope, and a number of other smaller instruments, as well as auxiliary equipment, were set up.

At first the new building of the GAISH was on the outskirts of Moscow, but after the rapid growth of the city it was soon surrounded by high buildings and broad, brightly-lit prospects. It became hard to conduct astrophysical observations, and as far back as 1957 a permanent mountain station of the GAISH was organized at a height of 3000 m, 50 km from Alma-Ata, where solar and spectral instruments were installed.

In 1958 in the Crimea the Southern Observation Station of the GAISH began to operate, located on the same summit as the KrAO, near the village Prokhladnoye. The station is a well-equipped astronomical observatory with 125-cm reflector, made at the LOMO, two 60-cm reflectors from the nationalized enterprise Carl Zeiss Jena of the GDR, a meniscus Maksutov telescope, and a 40-cm wide-angle astrograph, transferred from Moscow.

In addition, the GAISH is constructing a new observations base in the mountains of Central Asia at a height of 2500 m on the mountain Maydanak, where the astroclimate is the best in the USSR according to Moscow astronomers.

The GAISH is characterized by a close interrelation between scientific work and the learning process at the astronomy department of MGU. Three faculties work alongside the science departments: astrophysics, stellar astronomy and astrometry, celestial mechanics and gravimetry. The director of the GAISH, Professor Ye. P. Aksenov, is also chief of the astronomy department. The teachers of the astronomy department take part in the scientific work of the institute, while the scientists actively participate in the teaching process. Each year the astronomy department graduates about 25 young astronomers Also studying here are roughly 30 graduate students, including some from abroad.

On the whole, the GAISH is a wide-ranging astronomical institute, its projects covering almost all areas of modern astronomy, from classical fundamental astrometry and celestial mechanics to theoretical astrophysics and cosmology. In many areas of science, such as exogalactic astronomy and the investigation of nonstationary objects and the structure of our galaxy, the GAISH has one of the leading positions in the USSR.

The Chief Astronomical Observatory of the UkAS. Even during the war, in June 1944, a new structure of the Ukrainian Academy of Sciences was approved, where it was intended to create the Chief Astronomical Observatory (GAO AN USSR). A place for it was set aside on the southern outskirts of Kiev, in the Goloseyevo forest, 5-6 km west of the Dnepr. Around the observatory there stretches a protective park zone more than 1 km in radius.

The main thrust of the activities of the observatory was considered to be astrometry, although in time the GAO AN USSR became an institute with highly diversified concerns. Here studies are conducted on the rotation of the Earth by methods of astrometry and space geodesy (the GAO AN USSR is the coordinating agency for the problem "Study of the Earth's Rotation" in the USSR) and work is done on fundamental and photographic astronomy; the physics of the Sun and that of the Moon and planets is studied. An important area is experimental astrophysics - the study of variable stars and novae, the physics of galactic complexes. The director of the observatory since 1975 is corresponding member of the UkAS Ya. S. Yatskiv.

The observatory has a triple long-focus astrograph[1], a 40-cm wide-angle astrograph, whose photographic field of vision is 8 x 8°; a large vertical circle; horizontal lunar and solar telescopes; the AFR-2 chromosphere-photosphere telescope, the 70-cm AZT-2 reflector telescope, and a series of telescopes of smaller size.

In 1970, construction was begun on the Mountain Observation Base of the GAO AN USSR. It was originally supposed to be built in the Carpathians, but after a number of expeditions exploring the astroclimate, with members of the GAISH taking part, the site of the base was chosen to be a platform (3100 m high) on the peak Terskol, not far from El'brus. The astroclimate of Terskol is in no way inferior to that of the SAO, while in atmospheric transparency and low relative humidity is even superior. The conditions at Terskol are especially favorable for observations in the infrared.

As early as 1971 the AZT-14 telescope (diameter 48 cm, focal distance 7.5 m) was set up on Terskol for observations of variable stars. Later the reflectors AT-40 (diameter 40 cm) and AT-80 (diameter 80 cm) with spectrophotometer for the near

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[1] Originally it had two objectives: a photographic 40 cm in diameter with focal distance 5.5 m, enabling photographs of the sky of 2.5 x 2.5°, and a somewhat smaller visual one. Later, in 1970, the nationalized company Carl Zeiss Jena (GDR) built a new photovisual objective, 38 cm in diameter with focal distance 5.5 m. All three objectives rest on a common mount.

infrared, built in cooperation with the astronomical observatory of Odessa University) and several telescopes of smaller diameter were set up. The development of the observation base at Terskol is increasing in pace. It is intended to install a 2-m reflector of the nationalized company Carl Zeiss Jena, a large horizontal solar telescope, a 1-m reflector, and construction of a laboratory building and cableway.

As at other major observatories, a department of astronomical instrument construction exists at the GAO AN USSR. It functions in cooperation with the astronomical observatory of Odessa University. It is here where the reflectors AT-40 and AT-80 were built. New reflectors of about 1 m diameter and a number of astrophysical instruments, including the URAN-4 radiotelescope, consisting of 126 vibrators (it will be erected on the territory of Odessa observatory) are being designed and built.

In Kiev there is yet another astronomical observatory, managed by Kiev University. It was founded in 1945, but a discussion of it would exceed the bounds of our book.

<u>The Abastumani Astrophysical Observatory</u>. The Abastumani Astrophysical Observatory of the Georgian Academy of Sciences is situated 200 km west of Tbilisi on the picturesque spurs of the Adzharo-Imeretinsk range, 10 km south of Zekarskiy pass, on the mountain Kanobili (1650 m above sea level). It was founded in 1932 through active cooperation of Leningrad astronomers and was first located at the resort settlement of Abastumani. Here photographic and photoelectric observations of variable and binary stars were conducted. In 1937 the observatory was moved up to the mountain of Kanobili, an area distinguished by excellent astroclimate, with calm and transparent atmosphere. It became the first Soviet observatory situated in the mountains. From the day of its foundation, /5

the scientific chief and director of the observatory has been Ye. K. Kharadze, a specialist in the field of stellar astronomy, corresponding member of the USSR AS, and president of the Georgian Academy of Sciences.

The first instrument at the observatory was a 33-cm reflector - the first in Soviet optical instrument construction. In 1937 a long-focus refractor (objective diameter 40 cm, focal distance 7 m) with two photographic cameras enabling sky pictures with visual field 10 x 13° on 18 x 24 cm plates, was installed at the observatory. The cameras have objective prisms which can be used for pictures of star spectra. As of 1937, the 33-cm reflector has been working in combination with the first Soviet stellar electrophotometer.

In the postwar years, the observatory was greatly enlarged and received new powerful telescopes. In 1955, a 70-cm telescope of the Maksutov system (meniscus diameter 70 cm, mirror diameter 97.5 cm, focal distance 210 cm) was installed. The telescope is furnished with an objective prism with deflection angle of 8°; this can produce spectra of stars down to the 13th magnitude.

In 1970 a 125-cm reflector specially designed for electrophotometric work with fully automated measurement processes was installed at the observatory. The latest addition to the instrument arsenal of the observatory was a 40-cm dual astrograph of Carl Zeiss Jena. This is used for both stellar astronomy and astrometrical determination of star and planetoid positions.

The main research of the observatory is devoted to study of the structure of the Galaxy by classification of spectra, colorimetry, and counting of stars in selected directions. Studies are also conducted in the field of stellar dynamics, observation of variable and nonstationary stars. Extensive catalogues of stellar quantities and parameters of the color, spectra and luminosity of stars are being compiled at the observatory. Broad use is made of the methods of electrophotometry and spectrophotometry. Several comets, planetoids and hundreds of so-called emission stars have been discovered.

Systematic studies of the Sun have been conducted since the foundation of the observatory. For this, it is equipped with a horizontal solar telescope, a photoheliograph and a chromosphere-photosphere telescope. These instruments have a large assortment of accessory equipment, including interference polarization filters. This instrument complex sustains a regular solar service and study of active solar regions. Many year studies of the upper atmospheric layers of Earth are also carried out at the observatory.

The Byurakan Astrophysical Observatory. At Yerevan University since 1933 a modest academic astronomical observatory has been in operation. In 1943 the Academy of Sciences of the Armenian republic was organized, in which the Yerevan observatory was incorporated. The scope of the scientific work of the observatory is now almost entirely aimed at solving current problems of astrophysics. But the capabilities of the Yerevan observatory, situated within a major city, did not allow astrophysical observations. And as far back as 1944 the Academy of Sciences proposed construction of a new astrophysical observatory. The creator of the observatory and its irreplaceable director is the member of the USSR AS, V. A. Ambartsumyan, president of the Armenian Academy of Sciences.

The search began for locations with favorable atmospheric conditions. Naturally the astronomers looked to the mountains, where 35 km from Yerevan on the southern slope of the mountain Aragats near the village of Byurakan (about 1500 m altitude) in

1946 construction of the future observatory began. After the village, the observatory became known as the Byurakan Astrophysical Observatory.

In its first years the observatory obtained several small telescopes. In 1954 the largest of these was installed - a Schmidt telescope with correction lens and mirror diameter 53 cm and focal distance 1.8 m.

An important area of work of the new observatory came to be the study of stars at equal stages of evolution. This area was founded in 1947, when V. A. Ambartsumyan demonstrated that stellar associations contain relative young stars and are centers of star formation. Observations of exploding stars using a 53-cm Schmidt camera have proved to be extremely prolific. In general, the subject of research on exploding stars, as well as the so-called Herbig-Aro objects, became for many years a major project of the observatory. While polarimetry observations of stars led to the discovery in 1949 of natural polarization of starlight.

In parallel with the optical observations, beginning in 1951 radioastronomic research came to be developed. Using two radiointerferometers, observations were made of discrete radio sources at wavelengths 4.2 and 1.5 m. The receivers and antennas for the radiotelescopes were built in the laboratory of the observatory. Methods were developed for accumulating weak radio signals, allowing a considerable increase in the penetrability of the radiotelescopes. As a result, it became possible to observe such weak radio sources as had previously been detected only with the largest radiotelescopes.

By 1956 construction of the first stage of the observatory was completed. The building complex of the observatory - a main laboratory building which also contained a conference hall, library and administrative quarters, observation towers, an inn for visiting astronomers - was designed by the architect S. A. Safaryan. The buildings were constructed of rose tuff and are maintained in the national style. The observatory was officially opened on 19 September 1956.

Since then the instrument arsenal of the Byurakan observatory has been amplified more than once. Radiotelescopes allowing observation of radio sources in a broad range of wavelength have been built and put in service. Some of the radiotelescopes have been installed at the radioastronomy base of Saravande (above the village of Byurakan). In 1960 the largest Schmidt telescope in the USSR and one of the largest in the world was put in service, with a correction lens diameter of 1 m, equipped with three of the world's largest objective prisms. The great penetrating range of this telescope, excellent image quality and large visual field conferred a primacy on the Byurakan astronomers in a number of investigations of the physics and morphology of the galaxies. It was proved that trapezoid and chain type configurations prevail in galactic systems. Observations supporting nonstationary phenomena in exo-galactic objects have received special attention. Compact blue galaxies with unusually strong ultraviolet emission have been discovered. More than 100 objects of this class have been found in observations with the Schmidt telescope of Byurakan observatory.

In October 1976 an even larger telescope, with mirror diameter 2.6 m, was put in service. It is an analog of the ZTSH (and also built at the LOMO). This telescope is one of the three largest telescopes of the USSR (along with the 6-m telescope of the SAO and the ZTSH telescope of the KrAO). The observation time is allocated by a special committee of the USSR Academy of Sciences.

Conclusion

The number of astronomical observatories both in the world and in the USSR is constantly growing. Several of these have moved to a new situation with better observing conditions, others have built themselves branches or observation bases. The total number of astronomical scientific observatories in the entire world (omitting amateurs) is currently in excess of 500, while 90% of these are in the Northern Hemisphere.

The natural question is what will the telescopes of the near future be like? What new design projects, what new concepts will be incorporated in astronomy, say, by the year 2000? What will the astronomical observatories be like?

The telescope is an instrument with a long life. The existing telescopes have not yet used up their capacities. It may therefore be supposed that the majority of large telescopes now operating will continue to do so in the year 2000, although some of them may be moved to a new and more favorable site. Before the end of the century several more large telescopes will be built in the USSR and new, improved radiation receivers will be developed, with capabilities approaching the theoretical limit.

New ways of using the telescopes are also intended, particularly deployment in outer space, beyond the limits of the Earth's atmosphere, which will open broad prospects for astronomical research. Projects are now in development for injecting into Earth orbit a 2-meter optical telescope in the mid-1980s, and it has been calculated that this will provide a gain of five stellar magnitudes over similar observations from Earth. Even so, the main areas of astronomical observation outside the atmosphere will not be optical, but studies in the ultraviolet, X-ray and gamma ranges.

But space investigations will not fully replace terrestrial observations. Owing to their accessibility, simplicity and proven qualities, ground optical observations will remain a highly effective means of exploring the universe. Nor has the development of terrestrial astronomical engineering reached its limit. The construction of observatories in the mountains, in a locality with optimal astroclimate, enhances the labor productivity of the astronomers. There is talk of creating in the early XXI century a telescope with mirror diameter of 20-25 m. Its total surface will be roughly 20 times larger than that of the largest current telescopes.

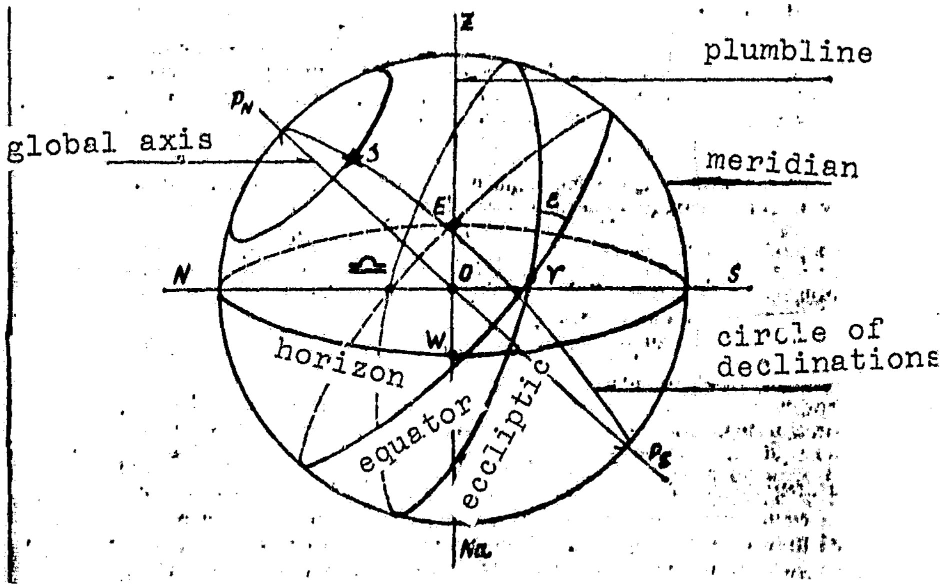
It is not yet clear whether its mirror will be made of a single block or a large number of individual mirrors - both alternatives are under study. But it is more likely that prior to this telescopes with diameter of 8-10 m will be built. A telescope project of Texas University has also been published with "superthin" mirror, 7.6 m in diameter and 10 cm thick, its shape sustained by the action of numerous mechanical bearings.

But it is considered more promising to build multi-mirror telescopes. These are a set of 4, 6, 12 or larger number of individual telescopes, each independently aimed at the object of observation, and the information from each telescope is summated in computer. Thus, even the 25-meter telescope can likewise be constituted (such alternatives are being examined) of 108 telescopes 2.4 m in diameter or 72 telescopes 3 m in diameter or 16 telescopes 6.25 m in diameter. Multi-mirror telescopes, just as the so-called mosaic telescopes, are much cheaper and, most important, are easier to make than those of identical size with mirrors of a single block of glass. The future apparently lies with these telescopes.

The Amateur Astronomer's Corner

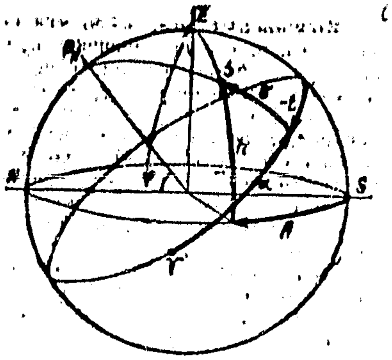
How to Find a Star in the Sky

In astronomy spherical coordinate systems are adopted to indicate the position of an object (such as a star) on the celestial sphere. There are several such systems. Each is specified by a reference plane and a point on the plane that is the origin of coordinates. The system in fact is named after the reference plane. When the reference plane is chosen to be the ecliptic, it is an ecliptic coordinate system; when the reference plane is the plane of the galaxy, it is a galactic coordinate system, and so on. Most often the horizontal and the equatorial systems are used.



Major circles and points on the celestial globe.

For the future discussion it is helpful to familiarize oneself with several lines and points on the celestial sphere. The plane passing through the North Pole P_N, the star ξ and the South Pole P_S forms on the celestial sphere the circle of declinations of the given star. The circle of declinations, passing through the poles of the globe, the zenith of the observation spot z and the nadir point Na, is known as the meridian (the meridian, of course, of the observation site, since at each point on the surface of the Earth the direction of a plumbline is unique). The meridian intersects the horizon at two points - the north point N (closest to the North Pole) and the opposite (along the diameter) south point S. The points of east E and west W are equidistant along the horizon from the points N and S. In its daily motion, the star rises in the eastern part of the horizon, crosses the meridian (culminates), then descends and sets in the western part of the horizon.



Spherical coordinate systems: azimuth system - azimuth A and height h; equatorial system - right ascension α (or clock angle t) and declination δ.

On the celestial sphere there are many interesting and important points associated with a particular celestial phenomenon. We shall mention two more of these - the points of intersection of the equator and the ecliptic. That point where the Sun passes from the Southern to the Northern Hemisphere is known as the point of spring equinox, or simply the point of spring, and is denoted by the symbol for the constellation Aries. The other is known as the point of autumn equinox, or the point of autumn, and is designated by the symbol of Libra (shown in the figure). These characters retain their meaning, even though today the point of spring equinox is now in the Crab constellation while the point of autumn equinox is in Virgo.

In a horizontal coordinate system the reference plane is the plane of the horizon, while the reference point is the point of the south. One coordinate is counted off along the circle of altitude from the horizon to the star and designated h. Another is counted off along the arc of the horizon from the base of the circle of altitude to the point of the south. It is known as the azimuth of the star and denoted by A. In astronomy, the azimuth is counted from 0 to 360°, the count running from the point of the south through the west. The horizontal system is convenient in that it clearly indicates the position of the star on the vault of the sky. Knowing h and A, the observer understands at once the conditions of visibility in which the star is found: high or low above the horizon, in the north or south. But a drawback of this spherical coordinate system is the fact that the coordinates change constantly from the daily revolution of the celestial sphere. Therefore, in dealing with horizontal coordinates, it is mandatory to specify the moment of time to which they refer.

The equatorial system of spherical coordinates is free from this defect. Its reference plane is the plane of the celestial equator, while the major point on it is the point of spring equinox. One coordinate is counted off along the circle of declination, from the equator to the star. This is the declination δ. It is counted off from 0 to +90° to the North Pole and from 0 to -90° to the South. The second coordinate, or right ascension α, is counted off along the arc of the equator from the point of spring equinox to the base of the circle of declination, counterclockwise from 0 to 360°, or from 0 to 24 h (in units of time). The right ascension and declination are almost independent of time, uniquely characterizing the position of the given object among the stars, but have little to say as to the conditions of visibility on the vault of the sky at a given time.

The coordinates of the stars vary little in time. In fact, there are only two reasons for change in these coordinates - the natural motion of the star and certain phenomena connected with change in the coordinate grid on the celestial sphere. The latter is mainly due to precession and nutation of the Earth's axis, resulting in change in position of the poles and points of spring and autumn equinox. All these changes are easy to figure out - the appropriate formulas are found in any catalogue of positions for each star. As to the natural motions of the stars, they are small in general and for the majority are ignored in practice.

Hence, if we know the coordinates of a star we can always find it in the sky. But what accuracy is required? If we only need to find it in order to then determine, let us say, the spectral class, or analyze the variability of its luminosity, it is most often sufficient to know the coordinates with an accuracy down to 0.1 min for the right ascension and 1' for the declination. It is not necessary to allow for any other subtle effects, only properly account for the precession and nutation, and even this not always. Indeed, the coordinates of the star can be taken from any catalogue at all. For example, the "Astronomical Annual of the USSR" (ed. V. K. Abalakin) publishes, among others, the precise coordinates of 685 stars with a precision down to 0.001 s for the right ascension and 0.01" for declination, as well as a series of tables necessary for astronomical observation. However in the majority of cases such high precision (especially for amateur observations) is not needed, and sometimes is even a hindrance. It is therefore more convenient for amateur astronomers to use the "Astronomical Calendar", published by the All

Union Astronomy and Geodesy Society (VAGO).

The "Astronomical Calendar" consists of two parts - Permanent and Variable (annual). The permanent part (Astronomicheskiy kalendar', Permanent Part, 7th ed., Nauka, Moscow, 1981) is a reference work on all the main topics which may come up in amateur astronomy. It contains the basic concepts of general astronomy, spherical and theoretical astronomies, astrophysics, describes astronomical instruments and the methods of using them and imparts instruction on all the basic types of amateur astronomy observations and their mathematics. The main section contains 37 tables on all the branches of observational astronomy whose data do not depend on time, including a catalogue of all stars brighter than magnitude 4.5. This catalogue gives the name of the star, its magnitude, the spectral class, the right ascension (with accuracy of 0.1 s) and declination (with accuracy 1"), their annual changes due to precession, parallax, the natural annual motions, the radiation speed, the color index and galactic coordinates (with accuracy of 1°). For almost every star information is given as to variability, multiplicity or physical peculiarities.

The "Astronomical Calendar" was founded in 1895 at Nizhniy Novgorod (now Gor'kiy) by a group of amateur astronomers. Its publications attracted many of the outstanding astronomers of the USSR. Since then, 86 editions of the Variable part and 7 editions of the Permanent part have appeared. The result is a useful reference work, for consultation by not only amateur astronomers, but also professionals. The Variable part (e.g. Astronomicheskiy kalendar'/Yezhegodnik, Nauka, Moscow, 1963) consists of two sections, the first giving the ephemerides (the majority calculated from data of the "Astronomical Annual of the USSR"), while the second presents supplements which publish articles on current topics of modern astronomy.

Contrary to the stars, the planets, Sun and Moon change their positions in the sky each day and, moreover, with irregularity. For this reason ephemerides are used - tables of the positions of the planets, Sun and Moon for a series of consecutive moments of time. The ephemerides are computed by the ITA AN SSSR and published in the "Astronomical Annual of the USSR". The intervals of consecutive moments of time are chosen to enable interpolation of the data given in the tables to any interim time, without loss of precision.

The "Astronomical Calendar" first gives the ephemerides of the Sun and Moon. For the Sun it indicates in hours and minutes the rising and setting (for 0 h global time) the azimuths of the points of rising and setting (in angular degrees), the equatorial coordinates and declination, the Julian dates, the time equation, the star time at Greenwich midnight, and several other data. For the Moon, the times of rising, culmination and setting, the azimuth of the points of rising and setting, the equatorial coordinates and the visible angular radius. Also given are data on the phases of the Moon, the conjunctions between the planets and the Moon, and the positions of the Moon in orbit.

All this information for each calendar date is presented for 0 h global time, i.e. Greenwich midnight, while the data on rising and setting are given for a latitude of 56°. For other moments of time and points lying on another latitude or longitude, the appropriate conversion of the ephemerides must be done. To avoid confusing the reader or computational errors, all the tables are furnished with circumstantial "explanations of the ephemerides", which distinctly tell how to do such conversions, giving the necessary formulas and examples.

For the planets their coordinates are published - the right ascension (with accuracy of 0.1 min) and declination (with accuracy 1'), moments of rising, upper culmination and setting (with accuracy 1 min), the azimuth of the points of rising and setting (with accuracy 1°), the angular diameter of the visible disk, the phase and stellar magnitude of the planet. To use the tables more easily, they are prefaced with a verbal description of the conditions of visibility of the planets in the particular year.