FUNDAMENTAL ASTROMETRY - A LOOK THROUGH THE PAST

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Introduction

In view of the immense importance for all fields of astronomy and adjoining sciences, as well as for its application, the fundamental astrometry has striven during its very long history to continuously enhance the accuracy of the stellar positions on one hand, and to include in catalogs as many stars as possible on the other. Up till the middle of the last century one had to deal on the whole with bright stars, mainly those visible with the nacked eye, for they were used in the studies of the motion of bodies of the solar system and in the determination of the geographic coordinates. With the growing needs of the stellar astronomy, the rapid development of which took place since, a strong requirement was felt not only for ever more precise positions of these stars but for their proper motions as well. In more recent times such requirement was set out by many applied sciences, and at present by astronautics too.

To achieve these ends the fundamental astrometry has steadily been creating more and more precise observational instruments, had contrived better and better observational and computing methods of elaborating catalogs, looking at the same time for new ways of more accurate determination of fundamental astronomical constants, whose accuracy is essential for that of stellar positions.

In consequence the fundamental astrometry is disposing nowadays of a vast fund of stellar catalogs, which, with respect to the methods of their composition, might be classified as **observational** and **computed** ones. The former in their turn might be divided into **absolute** and **relative** (visual and pfotographic), and the latter into **derived** and **fundamental** in dependence upon whether they represent a new system or are related to some of the already existing fundamental systems. Finally, with respect to cellestial bodies whose positions or other characteristics they give, the catalogs can be classified as **general**, if they comprise positions (frequently apparent magnitudes and spectral types, as well as reduction constants) of the „ordinary" stars, and **special**, comprehending binaries, variable stars, stellar clusters, nebulae, paralaxes, radial velocities, photometric and spectrometric quantities etc.

In the present brief monograph we shall try, in conformity with the above stated endeavours, to lay out in a condensed form the development of instruments, accessories and observational methods of the fundamental astrometry from the most ancient times up to the present, and to give a survey of the principal stellar catalogs of the same period along with their basic characteristics and purposes.

A survey of the development of instruments of the fundamental astrometry

Antiquity. Modern astronomy has evolved from the ancient Greek astronomy. Europe acquired astronomy during Crusade and more particularly later, during Renaissance, Arabian scholars being the transmitters. Ancient Greek astronomy in its turn, according to the ancient historical records, has been transplanted there from Egypt, whereto it had expanded from Assyria and Babylon, then bordering countries, about the year 2000 B.C..It seems that the passage from the qualitative observations of celestial bodies to the **measurements** of their position has taken place as early as about 3000 B.C..According to the above mentioned historical records the first astronomical instrument used universally, alike in China, in India and Mesopotamia and later on in Egypt and Greece, was **gnomon**, a pointy stick fixed onto a leveled horizonthal soil. Greek astronomers got acquainted with the gnomon through Thales's disciple Anaximandros (611-545 BC). The merit for the development of practical astronomy in the ancient Greece at that time rests with Eudoxos of Knidos (409-356 BC.) and Aristotle (384-322 BC).

Gnomon subsequently developed into **solar clock**, which maintained itself in Europe untill the New Age, although the orientation and the position of its dial varied with the time. This clock, besides **sand clock**, and later on **water clock - clepsydra**, invented by Ktesibios about 27 BC, served for time determination, as the positions of celestal objects were changing as funcion of time. Hence every measurement of the position of luminaries needed time recording, performable only with clocks as precise as possible.

Aristarhos of Samos (around 310-230 BC) put the gnomon inside a bowl with the engraved horizonthal circles, thus obtaining a **movable gnomon** or **scaphion** for measuring horizonthal coordinates. The first relatively accurate measurement of the Earth's size is known to have been carried out by Eartostenes (276-174 BC) in the second century BC just using the gnomon.

But the development of gnomon proceeded in another direction as well. At first it was provided with a „scale-rule" on its stick, later with a two-sight lever-diopter, through which cellestial bodies could be pointed at. The instrument was further developed by Heron of Alexandria (about 100 BC.), preserving that form until it was replaced by the telescope. The „scale-rule" enabled the altitudes of the observed luminaries to be read by means of its lower bar, while the angle between the vertical plane containing line of vision and meridian plane defined its azimuth. Thus a new instrument was created - „parallactical rule". In the Middle Ages, and particularly early in the New Age, it developed into **movable quadrant**, by means of which accurate, - for those times - results could be obtained, but more about it later.

It soon became apparent to the ancient Greeks that besides measurement of horizonthal coordinates, ecliptical and equatorial coordinates were also necessary. They got therefore to construct new instruments for measuring these coordinates. It was at that time that began the composition of first stellar catalogs in ecliptical coordinates.

Right from the beginning of Alexandrian school of astronomy (third century B.C.) a new instrument appeared: **armilla**. The basic concept of its construction, most probably, has also been taken over from Mesopotamia. Its final form has been preserved from the times of Arabs and, without changes, has been in use in Europe as late as seventeenth century. It consisted of a system of divided rings materializing basic reference circles of the celestial sphere. Cercles, representing the horizon, the meridian of the observing site and the celestial equator were fixed, whereas the one corresponding to the declination circle of the star could rotate around the polar axis untill its diameter with the sights (diopter), its alidade, was pointed at the celestial object under observation. This type of armilla furnished directly the hour angle and the declination of the star and for this reason it was called **equatorial armilla**. Were the time of the measurement also recorded by means of a sand-clock or water-clock, the passage over from the hour angle to the right ascensions, then to ecliptical coordinates, could easily be performed. A similar circle system - **zodiacal armilla** - served for direct measurement of ecliptical coordinates. It was by use of this instrument that Alexandrian astronomers Timocharis and Aristillus, in the forth century B.C, made one of the first stellar catalogs.

Unfortunately it is not known to us what kind of instrument has been used by Aristarchus for the determination of distances of the Sun and Moon and their true sizes.

A testimony is at hand, left over in Ptolemy's „Almagest", that Hipparchus of Nicea (about 162-126 B.C.), the greatest astronomer-practician of the Alexandrian school and the entire antiquity, had constructed **equatorial ring**, and that he, by noting the time of passage of its projection from elipse into a stright line, had determined, in 146 B.C., the time of equinoxes and thence the lenth of the tropical year. From the same source we learn that Hipparchus, upon completing his education and work in Alexandrian scool, had travelled to Syracusa and Babylon, where he made some observations and that, finally, he constructed in Rhodes an observatory of his own, reported to have been well equiped.

Among quite a number of astronomical discoveries, made by this Alexandrian or taken ober by him from Babylon, we are most interested in a new instrument, the **astrolabe**, constructed by himself. The instrument was perfected particularly by Arabs and Mongolians, who made ample use of it at observatories and also in the field works. It was in fact a divided circle, the verticality of which was secured by having it suspended. By means of a plumb line the circle could easily be turned in such a way that its zero division mark corresponded to the horizon or the zenith. Its metal, movable diameter-alidade - fitted at its ends by sights (diopter), was directed towards the luminary under observation and its altitude or zenith distance was directly read on the circle. At the inner side of the circle Hipparchus engraved, besides horizontal, an equatorial net of coordinates of appropriate projection. It was therefore easy to pass from the measured horizontal to equatorial coordinates of the observed heavenly body. Later on he engraved ecliptical instead of equatorial coordinates. It is with this latter instrument that is connected the elaboration of the renowned Hipparchus's catalog of 850 stars and the discovery of the precession.

In concluding this chapter let us mention one of the great Alexandrians of the late epoch – Claudius Ptolemaeus (second century A.D.), famous for his great compendium of all astronomical knowledge of the antiquity – „Almagest" as it was named by Arabians. In our days it is a precious source of information on ancient discoveries, in addition to the scanty documents of the epoch. He is not known to have himself constructed any new instrument, but he made use of all instruments referred to above, both for his catalog and for his many works in the field of fundamental astrometry (refraction etc).

Middle Ages. The Christianity, once raised to the status of state religion of the Roman Empire, under which came also Alexandria, rendered impossible the work of ancient pagan scientists. The „Museum" was destroyed and its library burnt by the religious fanatics. Religious authors spread the teaching about the Earth being a flat disc and a conception of the universe not corresponding even to that which prevailed several thousands years before. The young Arabian people, in the course of their conquerings of the North of Africa, captured also Alexandria in 642. Driven by their desire to acquire knowledge, Arabians learned what in Aleaxandria was to be learned, collecting the sunk into oblivion ancient Hellenistic scripts and set to their translation into Arabian. Harun al-Rashid founded in Baghdad a high school, libreries and an astronomical observatory, at which famous astronomers were active: Al-Ferghani, Al-Battani and later on Abu'l Wefa, a Persian. Al-Battani erected an observatory in Damascus. His observations enabled him to deduce the motion of the apsides line of the Sun's apparent path. Abu'l Wefa discovered the variation of the Moon's motion. The two astronomers developed spherical trigonometry almost to its present form. On the hill Alioref, near Cairo, Arabians erected another reputed observatory at which Ibn Yunis (died in 1008) made his observations. They founded also high schools, libraries and astronomical observatories in the towns of Arabian Spain.

At the close of the eleventh century, peoples of Western Europe unenlightened and captivated by their faith, set upon the bicentennial Crusade. In this way they came in touch with the advanced Arabians. Italians have already had contacts with them in Sicily, and first among Europeans realized how much there was to be learned from their manuscripts. They therefore undertook to translate these writings into Latin and in this way Europe came to be acquinted with the works of ancient astronomers. Ptolemaus's Alamgest played thereby a decisive role, so it happened that geocentic system was imposed to Europe, which anyhow was in good harmony with existing religious doctrines which, only Copernicus was able to get rid of. But it was how true resutls of Arabian measurements and observations, as well as the construction of their astronomical instruments came to be known to Europe. These were the already described ancient instruments, only somewhat perfected. The perfection consisted mainly in the introduction of substantially larger circles than those constructed in the antiquity, securing a higher precision. It was further realized that complete circles were often unnecessary but only their sectors. Thus came into use large sextants and quadrants at the Arabian observatories but also at the Mongolian ones in the Central

Asia, notably of that in Samarcand, where Thamerlan's grandson, astronomer Ulugh Beg (1394-1449) made measurements with two large quadrants.

Johan Müller Regiomontanus (1346-1476) is the builder of the first observatory in Christian Europe. His ephemeris have played an important role in the development of the oversee navigation.

Renaissance. The fall of Constantinople in 1453 caused througs of refugees to rush into Italy, whither they broght ancient Greek manuscripts. This had for consequence an intensifying of the already strong interest for them, while the art of printing, already developed, contributed to the multiplying and wide distribution of the translations of these writings. As early as 1491 Crakow university disposed of its own observatory. In that year Nicolas Copernicus (1473-1543), the great reformer of astronomy, took up his studies. In 1496 Copernicus stayed in Bologna, where Da Novarra was making his astronomical observations. There Copernicus, a great future theoretician, learned the art of observation. Upon returning to his homeland he made observations with **triquetrum**, a kind of parallactic scale rule, from the tower of Frombork as well as with other instruments intended to check his system of universe.

In the period of Renaissance Europe witnessed the construction of first observatories on its soil as well as first systematic observations, but these were still confined to the courts and were associated to the art of astrology. The last step on the ladder of the ancient and medieval astronomical practice, before a new era with the Galileo's telescope set in, is certainly represented by the activity of the great Danish astronomer Tycho Brahe (1546-1601), who received his education at the universities in Wittenberg and Rostock. Back in his country, he arranged a small observatory at the home of his uncle. The observation by him of a nova in the constellation of Cassiopeia made his fame spread widely, so much so that the Danish king Frederic II ordered the erection of a great observatory in the island Hveen -„Uraniaborg"- with the provision, however, its prime purpose to be making horoscopes for himself and members of his family. Tycho began his work at the observatory in 1580. He purchased large-scale instruments of all kinds, ranging from armillas and scale rules of anclient times to those most modern - for those times-constructed by Purbach, e.g. quadrants. Some instruments were constructed by Tycho himself: great sextant, circular quadrant, movable quadrant and great mural quadrant.

Tycho's **circular quadrant** had a 9 feet radius and circular division down to 10'. The craftsmen of those times were able to secure an accuracy of 0.1 mm of the division, which amounted to an accuracy of about 10" in the coordinates measured. This accuracy excelled that obtained by Tycho himself in measuring stellar coordinates by nacked eye, which attained about 1'. But the latter was, in its turn, superior to what was characteristic of measurements prior to his. This accuracy was high enough for Kepler to derive from these data laws of planetary motions. The observation consisted in directing the diopter upon the star. Alidade with the diopter pointed to the heavenly body on one hand, and the plumb line on the other, determined on the quadrant absolute value of the zenith distance, while the plane of the quadrant, with respect to the meridian, defined the azimuth of the star observed.

The movable circular sector, most frequently **movable quadrant**, was still in use as late as eighteenth century. Unlike fixed quadrant, the circular arc of the movable quadrant could turn, along with the instrument as a whole, around a horizontal axis, the indicator - a plumb line - protected against air circulation by a veneer, being stationary. The setting on the celestial object was performed by the outermost radius, whose ends were provided with sights (diopters), so the movable alidade could be done away with. The instrument was transferabe. By means of it latitude could be determined with an accuracy up to a few hundred meters while the time was determinable within two or three seconds margin.

Upon similar principle rested also small portable instruments for angle measuring - **arbalestrilla** and **english quadrant**, used by seamen. They were the forerunner of the Newton's mirror sextant, still in use even nowadays.

Tycho's **mural quadrant** was constructed of polished stone and comprised a complete circular quadrant ten feet in radius. To each minute od arc of its graduation corresponded a 1mm interval. This was a very stable instrument in the meridian plane, affording an estimation of the star altitude by means of a movable diopter up to $0'.5$.

The registration of time of observation at that epoch was performed by means of a **clock with weight and a regulator**, a tool originating also from the Arabian possesed countries. Its motion was maintained by the weight, whose accelerated motion was bracked by a regulator, a relatively uniform motion of the clock being the final result. The rotation of the Earth - that „celestial clock" - was thereby followed in the best possible way.

With the diopter of the quadrant, fixed in the meridian, directed upon a star, the observer registered the time of its transit over meridian, whence the right ascension could easily be deduced, while the star's altitude, readable on the quadrant's circular division, allowed the determination of its declination.

Tycho introduced into practice devices permitting estimation of even smaller portion of the graduated circle divisions. In addition to a 90° graduation on the main, outer quadrant arc, he installed an array of concentric circular arcs with 89, 84, 79, 72... portions graduation. With the celestial body pointed at by alidade, the observer had to look what division mark, and from which side of the divided arc, was nearest to the alidade indicator. If it was for instanse 29th division of the 46 divisions arc, then the measured angle was 29/46 divisions of the quadrant. This procedure of reading very small portions of the circular graduation was invented by the Portugeese Nonius in 1542. But Brahe soon discarded this system of circle reading and adopted the system of transversals.

The method of **transversals** rested upon a simpler, decimal system and permitted angle estimation up to a tenth part of a circular division. Instead of one circular arc on the outer quadrant ring, there were two concentric arcs, both divided into 90 equal divisions, each division mark of the outer arc being connected with the preceeding one on the inner arc by a transversal. The portion of the alidade between the two concentric arcs was divided, like a scale rule, into ten equal divisions. With the celestial body pointed at and the alidade fixed, all that was necessary was to read the nearest lesser division mark on the inner arc, and the tenths of minute on the ruler where it cut the transversal joining the nearest larger division mark on the outer arc. Sometimes the transversals themselves, instead of scale rules,were divided into ten parts.

However useful and ingenious the idea of transversals might have been, they still required a precise division, while the checking of the main division was not possible. This disanvantage was removed by Vernier's device of 1631, bearing his name, which is often called nonius. Nevertheless, the transversals did not disappear untill eigteenth century. **Vernier** enabled the precision up to one arc minute in the angle measuring, i.e. in the star coordinates to rise up to 10" or 0'.1. Such a precision in the setting of instruments on stars could not be achieved by the nacked eye, so it was natural to apply telescopes, then just invented, for the measuring of coordinates of the heavenly bodies. With them a new era in the observational astronomy broke in.

New Era. About 1580 the telescope with lenses - **the refractor** - was invented. Giambattista della Porta (1538-1615) is often credited with that invention but no definite evidence is at hand. In 1609 Galileo (1564-1642) constructed his model and was the first to use it in the observation of clestial bodies. Important discoveries he was able to make with it stroke a decisive blow upon the geocentric world system. In 1611 Kepler (1571-1630) invented a new type of refractor wich, with some modifications, is still in use even yet. As early as 1616 Scheiner (1575-1650) supplanted diopter by telescope on his circular sector, whose axis he inclined so that it coincided with the direction of the celestial pole, thus getting the first **equatorial**.

J. Picard (1620-1684) was the first to apply a refractor with a reticule for precise angle measurements, in 1669, in combination with a circular quadrant. It was the instrument he used in his renowned determinations of the Earth's size.

In England W. Gascoigne invented, in 1640, **the micrometer**, developed afterwards by Towlew and Hook.

In 1660 Thévenot invented the level, substituting it for plumb line as means for determination of vertical direction on the circular sectors.

Quite independently of the English, Picard's closest associate A.Auzoût constructed, in 1666, a **micrometer**, whose movable system of wires could be driven by a screw. The amount of the linear motion of the wires in the field of view coud be read on the divided screw's head in angular units. O. Roemer (1644-1710) fitted in the micrometer, in 1672, a spring serving to **remove the lost motion** of the screw. With this the micrometer received the pattern we know nowadays. Thus measurement of tiny angular intervals and differences in coordinates could be measured in the eighteenth century, for which special differential observational methods were devised. By applying refractor, micrometer and level to the circular sectors they developed into present-day astrometric instruments.

C. Huygens (1626-1695) demonstrated that defects of the lens are diminished with the reduction of their curvature, viz. with the increase of its focal lenth. This caused in the seventeenth century the racing towards ever longer refractors. Notorious in this respect is Hevelius' tubeless refractor 49 feet long. In 1699 Huygens discovered the method of abolishing spherical aberation by **combining lenses**, with the result that shorter but optically better refractors emerged. The diameter of the lenses grew ever larger with the time with the purpose to allow the amount of light received to be as great as possible, thus making possible the observation of ever fainter and remoter celestial objects. In 1656 Huygens enriched the practical astronomy by his invention of the **pendulum precision clock** which, perfected by Riefler and Short,survided all through until, in our time, **quarz** and **atomic clocks** came into use.

Picard installed circular sector, fitted with level and refractor with reticule, in the meridian plane, thus creating the first **transit** and **meridian instrument**. The first mural sector with refractor, well known to history, was that of La Hire, installed in 1683 in the western tower of Paris observatory. In the eighteenth century these instruments became important tool for the astrometric precision measurements, developed with the time into present - day transit and meridian instruments.

Shortly after Greenwich observatory was founded in 1675, its first director J. Flamsteed (1646-1719) managed to supply it, mostly from his own resources, by a **mural sector** of a 135° arc, -arcus meridiomalis- fitted with Picard's reticule and Roemer's micrometer, modern, compared with the standards of that time. But on account of its other defects its errors in right ascension amounted to 8^{s}.

Instead of the instruments of this kind Roemer constructed, in 1690, his well known **meridian instrument - Machina Domestica.** But this instrument was also shortlived, ceding its place, in the eighteenth century, to the meridian instruments reminiscent of those existing nowadays.

J.D. Cassini (1625-1712) supplied Paris observatory with paralactic refractors to which he attached **precision circles** and **automatic clock driving**. Roemer constructed in 1690, in Danemark, an instrument of this kind, calling it Machina Aequatorea, while Famsteed secured two equatorial sectors for the Greenwich observatory. While working with his collaborators with these instruments he conceived the first exact method of determination of the vernal point position. In his **Historia Coelestis Britanica** he presents, in addition to numerous Sun and Moon observations, of which use has been made, among others, by Newton, the first catalog of 3000 stars whose accuracy excelled that of Tycho's catalog, attainig, according to Bessel, 10".

In 1704 Roemer constructed two instruments for fundamental astrometry, regarded as prototypes of the present-day classical instruments. One of them is the **meridian circle - Rota Meridiana,** marked by its stability and complete cicle attached to the telescope, read by two microscopes. Side by side with it was a **large transit instrument**, installed in the first vertical. Perfectly suited to right ascension determination these instruments could not compete with the murai sectors in the determination of declinations, so both instruments were operative at the observatories until the close of the eighteenth century. In England meridian instruments were manufactured by great techicians Graham and Bird. In the middle of the eighteenth century Le Monnier and La Caille for the Paris observatory and Halley for the Greenwich observatory procured these instruments, which subsequently rapidly spread over to all other observatories. At the close of the eighteenth and early in the nineteenth century there appeared larger meridian instruments of the present-day design, thanks to the English mechanics Ramsden and Troughton, German Reichenbach and Repsold and French Gambey.

After the death of Flamsteed the directorship of the Greenwich observatory was entrusted to Halley (1656-1742), fames by his works in the theory of comets, catalog of the southern stars and the method of determination of solar parallax from the transit of Venus over the Sun. With the new instruments Halley determined accutate positions of Sirius, Procyon, Arcturus and other fixed stars and discovered, by comparing them with the positions from Ptolemy's catalog, **proper motion of stars**. Halley's successor Bradley (1692-1762) was first to apply the method **eye and ear** in the observations with the meridian instruments, rising therewith the precision up to one tenth of the second of time.

Alongside with meridian instruments Graham constructed **zenith sector**, with a 3.8 cm apperture and a $12^{o}.5$ arc, a forerunner of modern zenith-tubes. It was adjusted to measurements of zenith distances of the stars using an old method of the **outer screw**. According to this method the instrument is placed in the meridian plane and the plumb line made to coincide with one of the sector's marks, whereupon the observer brought the star onto the wire cross-section, slightly shifting the instrument by means of a screw by a fraction of one part of the sector. That fraction was read on the screw's head and was added to the sector reading, corresponding to the original plumb line position. The positions, determined by Bradley with this instrument, differed from those computed, according to Lalande, by 1".5, thus Bradley performed his measurements with a precision of 0.02 mm.

With this instrument Bradley discovered, in 1725, from the deviations of the star γ Draconis, the phenomenon of annual aberation and in 1748, from the measured variations in precession, the phenomenon of astronomical nutation. After his death two volumes of his observations were published in 1798 and 1805. Bessel's famous catalog of over 3000 stars – Fundamenta Astronomiae – from 1818, is based on these observations, whose proverbial accuracy is due as much to the observer and his methods, as to the technical level of instruments of that time. Bradley's positions differed from the real ones, according to Bessel, by 4" in declination and by 15" in right ascension.

Tobias Mayer (1723-1762), director of Göttingen observatory, who acquired his fame by accurate observations of the Moon and the discovery of its librations, realized that there was no need to attain a perfect adjustment of a meridian circle to the meridian plane, but that instead the effect of the instrumental constants shoud be eliminated. It is to him that we owe the formula for the **reduction of meridian observation**, found otherwise quite independently by R. Boshcović (1711-1787), the founder of the Brera observatory near Milano, and also, in a differen form, by Bessel und Hansen. Thus were crowned Tycho's attempts as well as Bradley's unremitting endeavours to have astronomical observations treated according to strictly scientifical procedure.

The precision observations required images freed from the chromatic aberation and refractors of shorter focal lenth, which could better be adapted to circular sectors and circles, in order to reduce their flexion and other defects as much as possible. The question of achromatic objectives thus ripened. It was moved from standstill in 1747 by L. Euler (1707-1783). He maintained the human eye to be an achromatic system and established that this was a result of the human eye being composed of several transparent substances of different refractive indices. English optician J. Dollond, deffending at first Newton's viewpoint that the color dispersion was inavoidable, convinced himself by experiments that chromatic aberation could substantially be reduced by combining lenses of different refractive indices, and in

1758 he submitted to the Royal Society a communication about the construction of an **achromatic objective** made of a combination of crown-flint glasses. Later on it came to light that an amateur astronomer C. M. Hall had also, through experiments, arrived at the construction of achromatic telescopes and that similar researches were carried out by R.Boshcovićin Brera.

In the second half of the eighteenth century Clairaut (1713-1765) published his well known memoirs about the **methods of removal of various lenses defects,** and D'Alambert (1717-1783) his conception of the **correction for chromatic aberation through regulation of destances between objective lenses.** But the manufacturing of long-focused refractors had already been stoped, being superceded by the production of refractors of modern design, which were much more suitable for the circles. The telescopes with reticules having become considerably shorter, a transition from sectors to smaller but comlete circles took place, but these obviously required a substantially more precise division. It was then that Chulnes (1714-1769) constructed the fist **machine for precise circle division,** with an accuracy up to 2 to 3 second of arc. The transversals gave gradually their place up to verniers, and from 1768 on they were completely supplanted by microscopes. Right from the beginning the alidades on the circles were provided with two microscopes for elimination of the eccenticity of the circles divisions. Soon afterwards observations in two positions of the instrument began to be practicised, wherewith the effects of the systematic errors, depending on clamp position, began to be accounted for..

Besides classical method of outer screw, applied throughout in the determination of absolute stellar coordinates, Liouville's **method of inner screw,** proposed as early as 1712, was spreading ever more thanks to the use of micrometer. It differs from the former method only in that the star observed is set upon, with the instrument installed in right position indicated by the plumb line on the sector's graduation by means of the movable wire operated through micrometer's screw, whose motion is readable on its head. This motion is then added to the reading on the sector's division, marked by the plumb line. This method developed in the nineteenth century into the **method of micrometer measurement** of differential coordinates, which resulted in the first great stellar catalogs of differential star positions.

N. Maskelyne (1732-1811), Bradley's and Bliss's successor at the Greenweech observatory, is the first to reveal personal observational errors in the star transits over meridian, whereas F. W. Bessel (1784-1846) established their first laws and methods of determination.

A particular prominence in the making of precision instruments for great state observatories, built in all great Europeen countries, was won at that time by Adams, Troughton and Ramsden in England and Passement in France.

In the second half of the nineteenth century the meridian circles were further improved and received finally their modern design. In this a considerable part was played by G. B. Airy (1801-1892), author of one of the most ingenious methods of determination of pivot errors, in use to our days.

With the secret of the personal error revealed by Bessel, astronomers strived to remove it. The conviction prevailed that this was attainable by superceding the method eye-ear by the method of registering transits by the Morse's clue. This attempt dates from 1844 and is connected with the determination of longitude in North America. As early as 1850 W.C. Bond (1789-1859), the founder of the Harvard observatory, made the first **registering chronograph** for recording the time of transits. Before long it was realized that the personal error remained unchanged even so. In 1861 C. Brauns got the idea of **following the star by a travelling wire** insted of registering its transits over fixed threads, whereof Repsold's construction in 1890 of the **impersonal micrometer** was not far away.

Modern Era. Current efforts are going in two directions: by the construction of impersonal astrolabe an avoidance of the systematic errors inherent in the meridian instrument and observer is aimed at. Another aproach in the same direction is the objectivization of observation by the use of photo-cell as well as the construction of special instruments for the fundamental astrometry. Efforts have also been made to achieve time keeping as precise as possible. In consequence first quartz clocks and in most recent years atom clocks are being constructed. On the other hand endeavours are made to enhanc to the accuracy of registration by using modern electronic equipment: electronic chronograph, impulse counter and automatization of the entire observational procedure.In this way the results of measurements are registered directly on the punched cards or tape-recorders, and are immediately ready to put them into pre-programmed electronic computer capable of delivering final results in a matter of a few minutes, an operation which until recently, when the reduction of the observations was carried out by simple electric machines, required a long time to be performed.

Reference will be made here to only some of the instruments, constructed after the Second World War, which already have found their regular use at observatories and have raised the accuracy by a whole order of magnitude in comparison with the classical instruments we hitherto have spoken about. True, we must state at once that the precision of time keeping and registering of observation is far ahead of the precision of the observations themselves. For instance the precision of the daily rate of modern quartz clocks is of the order of 10^{-4}s, that of the atomic clocks even 10^{-6}s, whereas the precision of the observations with modern instruments does not yet attain 10^{3}s.

Let us mention first, in a chronological order, the use of photo-cell instead od the observer's eye for the observation of the star transits with the transit instrument. The purpose of this was the elimination from the observations not only of accidental, but of the personal errors of the observer as well. Following the attempts of Ferrier, Hugo and Mesnier in Paris in 1924, Dickert in Germany in the same year and B. Strömgren in Kopenhagen in 1925, N.N. Pavlov of Pulkovo observatory succeded, by using a photo-cell multiplier and a suitable amplifier, to register stars down to 7^{m}. Notwithstanding great efforts protracted over many years, the accuracy of the observations did not exceed $0^{s}02$ in regard of systematic errors, an amount characteristic of the classic observations. An experimental proof was thus obtained that the chief source of errors was not the observer, but the instrument and the pavilion and in particular the variable and asymetrical temeperature influence exercised upon the instrument by its surroundings and observer. After having taken various measures to effectuate protection of the instrument against the temperature influnieces and having even installed the instrument so as to have its objective outside pavilion, keeping at the same time its constants as near zero as possible, the accuracy of the clock correction out of 10 transits reached $\pm 0^s004$. A similar result has been achieved with the large modern photographic zenith-tubes. The principle of photoelectrical registration has been applied with success to some meridian instruments, coupled with many other adaptations. We cite as examples the instruments in Hamburg (now in Perth) and Bordeaux.

Proceeding from the idea of Claude and Driencourt, brought forward as early as 1900, Danjon constructed, in 1950, an **impersonal astrolabe** using dual Wolaston's prisme. In moving this prisme in the focal plane of the objective by way of a steering wheel, by hand or a synchronous motor, parallel with the optical axis, Danjon made possible the coincidence of two star images to be extended over 10 to 20 seconds, otherwise an instantaneous occurence with the classical astrolabes. The prisme displacement, i.e. the revolving of the steering wheel, is registered on the chronograph, and out of a great number of contacts a mean time of star transit over the almucantar $z=30^o$ is obtained with high accuracy and moreover, free from certain systematic errors. It appeared that the clock correction from one sole series was obtainable with an accuracy of $\pm\ 0^s008$ while that of latitude with an accuracy of $\pm 0''.07$. Coordinates of a star, observed during a year, can be obtained with an accuracy of $0''.01$, an entire order of magnitude above that obtainable from more-observations with the classical fundamental instruments. That is the reason why Danjon's astrolabe is increasingly being used for catalog observations.

In concluding let us dedicate a few words to some of the prototypes of new fundamental instruments, not entering into their description, construction details nor the way of observation.

We certainly have to refer here to Danjon's **horizontal transit instrument**, Zverev's **photographic vertical circle** as well as to **horizontal meridian cicles** of Atkinson and Suharev. Photographic vertical circle is in regular use, Suharev's horizontal meridian circle is only partly in use, while the rest of them is still in a preparatory stage. Common feature of all horizontal instruments consits in that, the light rays from the star, in this or another way, are conducted into telescope's horizontaly fixed tube, whereby some of the systematic errors, connected with the classical instruments, are avoided.

A totally new instrumental technics, as well as the prospects of the fundamental astrometry, will be dealt with in another paper of this monograph: „Fundamental astrometry - its present state and prospects".

Some of the most prominent catalogs - a historical sketch

Antiquity. The first stellar catalog of which a record has been preserved is that of the Cinese astronomers Han Hun and Shi Shen, given in ecliptical coordinates, derived from the observations made between 360 and 350 B.C..It comprised 800 stars, 120 of them with accurate coordinates. It appears from the ancient records preserved that stellar catalogs were compiled by Eudoxos of Cnidus in the forth century B.C., Aristyllus and Timocharis in the same century and Hipparchus of Nicea in the second century B.C., all being Alexandrian astronomers. By comparing the positions of the same stars of his catalog with those of the catalog of Aristyllus and Timocharis, Hipparchus discovered precession. But none of these catalogs is preserved. The first catalog preserved is that of C. Ptolemy of the second century A.D., contained in „Almagest" which has had many editions. It comprises positions of 1026 stars. It has been a matter of long controversy whether it was but a copy of Hipparchus's catalog, reduced to another equinox, or it was compiled from Ptolemy's own observations. The dispute has been cleared in Ptolemy's favour. The catalog, along with the entire Almagest, was translated from Arabian into Latin by Gerhardo of Cremona in 1175, subsequently to be retranslated into many European laguages. It is through Gerhardo's edition, in all appearance, that Copernicus entered the realm of astronomy.

Middle Ages. After Alexandrian school had been ruined, the astronomical activity was continued throughout the whole Middle Ages by the Arabians. Quite independently, astronomy was developing during the same period with Persians and Mongolin peoples of the Central Asia, experiencing finally in Western Europe late in the Middle Ages, thanks to Arabian trasfer, its renovation, bursting into full brilliance during Renaissance.

Down to the fifteenth century Arabians have used Ptolemy's catalog and „Almagest", such as they were, translated from ancient Greek. Persian astronomer Al Sûfi compiled in the tenth century his significant catalog of 1018 stars, which too was accepted by Arabians. It is by way of this catalog that Arabian names of stars and constellations were transmitted to us. Al Sûfi retained Ptolemy's stars, but he made a re-estimation of their apparent magnitudes and remeasuring of the positions of many of them, removing thereby a number of errors he had revealed. In the opinion of Schjellerup, who translated it into French, and also Knobel, this work is of great value. Andromeda Nebula is registered therein and the variability noted of a star, later to receive the designation Lalande 25086.

In 1483 there appeared in Western Europe a catalog, known under the title „Tabulae Alphonsinae", of the astronomer Alphons X, king of Castilia, which in fact is nothing else but Ptolemy's catalog reduced to the thirtheenth century, containing 1022 stars.

Tamerlan's grandson, astronomer Ulugh Beg, founder of the great observatory in Samarkand, composed a catalog, renowned at the time, with 1018 stars for the equinox 1437.0. A critical review of it was given by E.B. Knobel, from which it appeared that its author has restrained himself to Ptolemy's stars, an occurence going on until the early Renaissance, with the remark, however, that he made position determinations of his own for 700 stars, accepting apparent magnitude as given by Al Sûfi.

Renaissance. Assotiated with the renascence of astronomy on the basis of „Almagest" are the names: G. Purbach, B. Walter, J. Regiomontanus, J. Schoener, P. Apianus, G.Frisius, C.Huyghens and others, but its highest level was reached with Tycho Brahe, Copernicus, Galileo, Kepler and Newton. Frisius was the first to indicate, in his work „De usu globi astronomici", that longitudes could best and in the simplest way be determined by using clocks, a method appropriate to raise the precision of the position deternimation of places on the Earth's surface as well as that of the positions of celestial bodies. His disciple Johanes Stadius, a professor at Sorbone, edited a number of ephemeris and astronomical tables, through which Tycho Brahe acquired his astronomical knowledge. But new catalogs were missing until Copernicus's work „De revolutionibus orbium coelestium" in 1543 cast its dazzling light upon the scientific world. It has been edited many times and translated into almost all European languages. It contains also a stellar catalog with positions of 1025 stars in ecliptical coordinates. According to Tycno's statement, in his well known work „Astronomiae instauratae Progymnasmata" this catalog too is in fact that of Ptolemy, reduced to the year 1543 by applying precession. Copernicus also used Ptolemy's method of relating star positions to the Sun, with the Moon as an intermediary body. In this way he determined most cautiously the position of α Arietis, situated close by equinox point, relating the positions of other stars to it.

The method of Hipparchus and Ptolemy was further developed by Regiomontanus, the founder of Nuremberg observatory, by introducing Venus instead of Moon, that planet being more suitable for accurate observations. This is stated by Regiomontanus himself in his work „Scripta".

The occurence of a nova in 1572 and of some comets made Tyho realize the need for a new catalog with a more homogeneous distribution of stars and their more accurate positions. With this objective in mind he procured his instruments and installed them at the Uraniborg observatory where he, with his assisants, completed a giant's work of position determination of a large number of stars, Sun, Moon and large planets. It can be said that he was the founder of the fundamental astronomy in Europe of the New Age.

In 1582 he started measurements, with his instrument „sextans trigonometricus" with a 1.70 m radius, of the angular distances Venus-Sun, as well as their altitudes and often their azimuths, while their declinations and meridian altitudes were measured with armillas. After the sunset he measured angular distances of Venus from a few zodiacal stars, along with the declinations of the latter. From the right ascensions of the Sun and zodiacal stars, and using Sun's tabular positions, he derived absolute right ascensions of zodiacal stars, while their declinations were determined directly. All positions were related to the star α Arietis, the position of which he managed to determine with an amazing accuracy of $\pm 15''$.Absolute positions of nine fundamental and twelwe supplement stars, referred to α Arietis, were derived by Tycho with an accuracy of $\pm 25''$.One should not overlook the fact that the refarction values at that time were known only poorly and that the discovery of nutation by Bradley still lay far in the future. He found a very good value of the constant of precession -50" per year. He made also estimation of the apparent magnitudes but there he was not so successfull.

Tycho's catalog, as part of the above cited work, went to press in 1589 in Uraniborg, but its printing was finished in 1602 in Prague, after Tycho's death. It contains positions of 777 stars for the end of 1600. There were several more editions of Tycho's catalog, either as part of „Progymnama" or as separate volumes. Kepler incorporated it in his renowned „Tabulae Rudolphinae" in 1627 and Flamsteed in his „Historia coelestis" in 1725, but it was also published in the „Memoirs of the Royal Astronomical Society", Vol.113. in 1843 and also in the work of Tycho's assistant C.S.

Longomontanus „Astronomia danica" in 1622. It appeared also in Tycho's „Opera Omnia".

It should be added that Tycho, his death aproaching, had rather hastily determined positions of some supplementar stars, obviously motivated by the wish to match the number of stars in the Prolemy's catalog. So the number of his stars rose to 1005, but while the accuracy in the first part attained l', that in the second is considerably lower both with regard to accidental as well as to systematic errors. For this reason neither Kepler nor Longomontanus did include this second part of stars in their catalogs.

It is not only by its accuracy that Tycho's catalog marked a turning point in astronomy. Thanks to that very accuracy he finally proved the nonexistence of the so called „trepidation" of equinoxes, a misconception held by astronomers for thousends of years preceeding. He demonstrated that the precessional motion was uniform and established its amount.

Following Tycho's catalog there appeared the work of J. Bayer „Uranometria" in eight volumes (from 1603 to 1723) occupying a prominent place in the history of fundamental astrometry by being the first to introduce the desingantions of stars by Greek letters, maintained to our days, instead of old clumsy description of stars positions in constellations. Not to be overlooked is A. Picolhomini's atlas „De sphera" published in 1568, where such designations already appeared while the constellations omens are omitted. This atlas is significant also because the constellations in it, unlike previous atlases, are for the first time given such as they appear to the observer, that is, observed from inside the celestial sphere and not from ouside. But this atlas sank into oblivion until it was republished by Bayer.

Wilhelm IV von Hesse, who erected the observatory in Kassel, aided by C. Rothman and S.J. Bürgi, made extensive observations of the Sun, Moon, planets and stars from 1561 until 1592. But the catalog of 1032 stars appeared in 1666, after his death, entitled „Historia Coelestia", to have afterwards three more editions. Positions of 378 stars from his catalogs were included by Hevelius in his catalog, while 368 of themare found in Flamsteed's renowned „Historia coelestis Britanica". J.B.Riccioli published in 1665, as part of his work „Astronomia Reformata" a catalog of 1440 stars on the basis of his own observations but using also observations of Grimaldi and all previous catalogs. He is the first astronomer to have made observations of this kind with telescope.

Let us close this survey of Renaissance era with the last astronomer to have made catalogs from observations with the naked eye. It was Johan Hevelius (1611-1687) of Danzig, where he built an observatory of his own, providing it with a whole arsenal of large instruments. The description of these instruments is found in his work „Machina Coelestis" Vol.1, issued in 1673 and Vol.2 in 1679.

Hevelius, in his determinations of star positions, made use of an azimuthal quadrant 1.39 m in radius, with 10" divisions, and a large sextant of 1.67 radius. It is noteworthy that Halley, one of the first astronomers to apply telescope for catalog purposes, had carried his sextant with telescope to Danzig in order to have its observational results compared with those obtained by Hevelius. It appeared that Halley's observations were of lower accuracy.

In Heveius's posthumously published work „Prodromus Astronomiae" in 1690 two star catalogs appeared, containing also positions of stars observed by his predecessors. In addition to ecliptical coordinates characteristic of old catalogs, equatorial coordinates are also given. The first catalog, entitled „Catalog Maior" contains 1563 stars, while the second, entitled „Catalog minor", 1540 stars. The former is reduced to the beginnig of 1600 and the latter, after being supplemented by Halley's catalog of the southern sky, to the end of 1700. The first Hevelius's catalog was included by Flamsteed in his „Historia coelestis Britanica", published in 1725, and also in „Memoirs of the Royal astronomical Society", Vol.13, 1843.

Hevelius included in his first catalog new constellations: Sextant, Scutum, Lacerta, Vulpecula, Canes Venatici, Leo Minor and Lynx. Attached to it is Hevelius's well known sky atlas „Johanis Hevelii Firmamentum Sobiescianum, sive Uranographia" in which fine figures of constellations, as seen from outside, are displayed but B ayer's designations of stars by letters is abandoned.

New Era. Observations with the naked eye and sextant, in conformity with the method of measuring angular distances of stars from the Sun, with the Moon and Venus as intermediary bodies, have practically disappeared, with Hevelius, from serious astronomical work. There were, besides, many discoveries and perfections of the instruments, we referred to in the foregoing presentation. As a result, the accuracy of catalogs was also increasing. The beginning of the new era is marked by the first director of Greenwich observatory John Flamsteed (1646-1719). The working conditions prevailing at that observatory at the time were more than delicate, an example being the fact that Flamsteed had to procure instruments for his own money. Pressed by Halley he felt compelled to publish his important catalog „Historiae coelestis libri duo" in 1712, even though all necessary works were not yet properly finished. This is the first modern stelar catalog. It contains 2682 stars in equatorial and ecliptical coordinates for the equinox 1690.0. But soon Flamsteed himself burnt three quarters of the printed copies dissatisfied with the quality. Finally there appeared, in full splendeur, in 1725, his completed work in three volumes under the title „Historia coelestis Britanica, tribus voluminibus contenta", printed in London. The catalog contains positions of 2935 stars in both coordinate systems down to 8th apparent brightness for the end of 1689.

But falling ill he failed to include in the catalog all the stars observed, and moreover, he had many mistakes committed, e.g. some minor planets, comets and even the large planet, Uranus, were mistaken for ordinary stars. These errors have been corrected by Caroline Herschel in a new, enlarged edition of Flamsteed's catalog in 1798, containing 591 star missed in the author's edition. But the most complete edition of Flamsteed's catalog we owe to F. Bailly, published in London in 1835-37, containig 3310 stars numbered in the present-day fashion, i.e. in order of growing right ascensions. Bailly supplemented it also with Flamsteed's autobiography, his correspondence and a list of his unpublished works.

Flamsteed initiated also the work on a stellar atlas, based on his catalog, but this great undertaking could only be concluded after his death and was published in 1729 under the title „Atlas coelestis by the late Rev. Mr. John Flamsteed, Londini, 1729". Besides two editions in England, it had two editions, in an abrevited form, in

France and two more in Germany.

E. Halley, about whose contributions, including his catalog of the southern sky, an account has above been given, was succeded as director of the Greenwich observatory by James Bradley, who won fame by his discovery of aberation and works started concerning nutation. He was, since 1718, member of the Royal Society and a professor at Oxford University since 1721.

Immediately upon his appointment Bradley devoted himself with ardor to the observation of Flamsteed stars. Two stages of these observations might be distinguished: the first from 1742 until 1750 and the seconf from 1750 until 1762. During the first stage the observations were carried out by the old but reconstructed instruments -quadrant and a modified transit instrument. The second stage is marked by the use of new instruments - zenith sector constructed after hid design and Bird's large quadrant and large meridian instrument. During the second stage alone he collected 60 000 observations, known afterwards by their high precision. While Flamsteed and Halley contented themselves with an accuracy of one second, Bradley strove to attain half and even one third of the second. He did not live to see his observations published, still less to have catalogs composed upon them. This was done by reputed astronomers who succeded him. These catalogs are at present considered as the oldest catalogs of high accuracy, sometimes utilized even to our days.

After a brief directorship of Bliss, the Greenwich observatory was headed since 1765 by Nevil Maskelyne who immediately started the publication of Nautical Almanac. With his 36 reference stars: γ Pegs, α Arie, α Ceti, α Taur, α Auri, β Orio, β Taur, α Orio, α CMai, α Gemi, α CMin, β Gemi, α Hydr, α Leon, β Leon, β Virg, α Virg, α Boot, α^1 Libr, α^2 Libr, α CBor, α Serp, α Scor, α Herc, α Ophi, α Lyra, γ Aquil, α Aquil, β Aquil, α^1 Capr, α^2 Capr, α Cygn, α Aquar, α Pisc, α Pegs, α Andr he laid foundation for great future differential as well as fundamental catalogs. Most of his observations carried out in the periods 1765-1772, 1779-1785 and 1803-1807 were published by him in „Greenwich Observations 1851, App.II".Right ascensions were referred to that adopted for α Aquil,to which he applied corretions for aberation, precession and nutation and, since 1776, for proper motion. Maskelyne's catalog is also published in „Zach, Tabulae Aberationis et Nutationis, Gotta 1806". All his observations were edited by the Royal Society under the title „Astronomical Observations made at the Royal Qbservatory at Greenwich, from MDCCLXV to MDCCLXXV by the Rev. Nevil Maskelyne, MDCCLXXVI-MDCCXI".

In France in the eighteenth century Jérome de Lalande (1732-1907) acquired reputation in his earliest youth by his determination of the Moon's parallax at the B erlin observatory which won him, in his nineteenth, the membership of the Berlin Academy whose president was Mopertius. Lalande is also noted for other numerous works, including his Bibliography of astronomy and his voluminous excellent textbook of astronomy, afterwards re-edited and translated several times. He held also the post of the astronomer of the French Academy and was for many years editor of „Connaissance des Temps", a professor of the renowned Collège de France at whose observatory he took active part during 46 years. But his most important work is connected with his great stellar catalog for which he, aided by his collaborators, made observations since 1799 at the observatory of Ecole de Guerre. Most prominent feature of the catalog is its great number of stars, over 40 000, faint stars down to ninth magnitude inclusuve, whose positions were determined for the first time. It was published in 1801 under the title „Histoire céleste française". The observations were made with the Bird's mural circle of 7.5 feet and, since 1798, with the meridian circle of 3.5 inch aperture. The deficiency of the catalog are stars observed only once. It happened to Lalande too to mistake some of the minor planets and even, later to be discovered, Neptun for stars. This catalog was not only regarded as the greatest but also as the best of its time, this especially after it was edited, revised and completed by later observations at the Paris observatory, headed in succession by Mouchez, Tisserand, Loewy, Baillaud, Deslandres and Esclangon, in 6 volumes under the title „Catalogue de l'Observatoire de Paris, Toulouse, 1928-1933". Totalling 400 000 observations extended over 60 years, the catalog has been reduced portion by pòrtion to different equinoxes: observations from 1837 to 1853 to the equinox 1845.0, those from 1845 to 1867 to the equinox 1860.0, from 1868 to 1881 to 1875.0 and those from 1882 until 1889 to 1890.0.

Collection of averaged stellar positions taken from all existing catalogs at that time was compiled and published in 1789 in England, under the title „A specimen of a General Astronomical Catalog". This was to be a precursor of fundamental catalogs.

Lalande's contemporary and disciple Guiseppe Piazzi (1746-1826) founded in 1786 the Palermo observatory and provided it, from Ramsden, with a large altazimuth with vertical circle 1.54 m in diameter and a chromatic telescope with 75 mm aperture (1:20) and was the first to apply microscopes for circle reading. The contingent of instruments included also a rather large transit instrument, so the new observatory was as predetermined for fundamental astrometry. It was just what Piazzi resolved to be his prime scientific task. Unlike Lalande he submitted to the principle of picking out a restricted number of stars, to have them observed as many times as possible in order to attain as high accuracy as possible. He commenced his observations in 1791, but it was only in 1972 that he set to them with all his fervor. Maskelyne stars, to which a number of other stars was added, were observed five nights in succession whereas the rest of stars were related to them. After ten years of persistent work there appeared his catalog of 6478 stars for the equinox 1800.0 entitled „Praeciporum Stellarum inerrantum positiones mediae.. Panorma, 1803". It excelled in accuracy all previous catalogs. Yet, the accurcy attained and the number of stars were not found satisfactory by Piazzi himself, who in 1814 published a new catalog of 7646 stars. This catalog was based on the observations of stars from the previous catalog, enlarged by 898 additional stars. The catalog was awarded a prize by the French Academy. This is one of the first catalogs which included proper motions too. It should be indicated that in elaborating the material he discovered large proper motion of the star 61 Cygni. While still working on his first catalog Piazzi discovered, on January 1, 1801, the first minor planet Ceres. All Piazzi's observations were collected and published in the period 1845-1849, and in 1855 a monograph of his catalogs was edited by Littrow, the director of Vienna observatory.

The activity in the fundamental astrometry should be recorded here of a contemporary of Lalande and Piazzi: Johan Bode (1747-1826). He was the editor, after the death of J.H. Lambert in 1777, of „Berliner Astronomisches Jahrbuch" and, since

1786, the director of the Berlin observatory. He is noted for his great stellar atlas „Uranographia sive Astrorum Descrptio viginti tabulis..., Berolini, 1801", as well as for his catalog „Allgemeine Beschreibung und Anweisung der Gestirne nebst Verzeichniss der Geraden Aufsteigung und Anweichung von 17 240 sternen, Doppelsternen, Nebelflecken und Sternhaufen für 1801.0, Berlin, 1801". The catalog is significant also because it is among the first to contain, besides stars, other celestial bodies, too. It is also one of the first general catalogs, although it includes 1250 stars not contained in any of the previous catalogs. In its compilation use has been made of the catalogs of Flamsteed, Hevelius, Mayer, La Caille, Messier, Mechain, Bradley, Darquier, Lalande, Herschel and others.

The most prominent place in the fundamental astrometry of the first half of the nineteenth century belongs to Friedrich Wilhelm Bessel, the founder of Königsberg observatory, famed, as already stated, for his reductions of Bradley's observations published in the form of first fundamental catalog entitled „Fundamenta Astronomiae" in 1818 and also for his important „Tabulae Regiomantanae" from 1830, intended for the reduction of stellar positions. With him rests the credit that Berlin Academy published the well known stellar maps from -15° to +15° declination which helped J. G. Galle on 28 September 1846 in his discovery of the planet Neptun on the basis of Leverrier's calculations. Besslel's observations of star positions, carried out from 1821 to 1833 in the declination zone -15° to +45° were published in the period 1822-1835 in the volumes VII to XVII of „Astronomische Beobachtungen... Königsberg". Two catalogs have been deduced from these observations by M. Weisse,the first comprising stars in the zone -15°to +15° declination, with positions of 31 085 stars down to 10th magnitude for the equinox 1825.0. It was published in St. Petersburg in 1846 by F. Struve as editor, under the title „Positiones mediae stellarum fixarum in zonis Regiomontanis a Besselio". The second catalog comprised the zone between +15° and +45° declination with 31 445 stars and was published in St. Petersburg in 1863 under an analogous title, with O. Struve as editor. The two catalogs are familliar in the astronomical literature by their designations W1 and W2.

Bessel's zones were extended up to +80° by his disciple Argelander who made his observations in Bonn.

A. Auwers issued, in 1903, a supplement to Bessel's catalogs on the basis of unpublished observations edited by the Prussian Academy of Sciences.

Notwithstanding high qualities of these catalogs, they still were affected by quite a number of errors. These were meticulously collected and published in an edition of the Prussian Academy of Sciences in 1909. This publication was later to play a very useful role in the composing of an all-inclusive collection of star positions „Geschichte der Fixsternhimmels" in 48 volumes, comprehending positions of stars contained in all catalogs from 1750 until 1900.

The fundamental observations with modern instruments of the Sun, Moon, planets and selected stars, whose accuracy surpassed all earlier, commenced at the Greenwich observatory in 1750. An advanced stage of observations at Paris observatory began in 1800. Pulkovo observatory, erected in 1839, soon became prominent through its important works in fundamental astrometry to such extent that S. Newcomb gave it the epithet „world astronomical metropolis". Before long works of this kind were started in Cape and Washington. The activity of these centres has been and continues to be of immense significance for the fundamental astrometry. Later on a number of important European observatories joined in.

In all these works one could clerly discern, with respect to their underlaying concept and methods applied, two astrometric schools: that of Greenwich and of Pulkovo. Greenwich won its unique place by very wide range of celestial bodies observed, in particular members of the solar system, and by centuries long continuity of observations. Pulkovo astrometric school is characterized by paying special attention to the investigation of instruments for accidental and systematic errors and it is thereby that high accuracy of its catalogs is explained. Among these the importance of absolute catalogs should particularly be stressed.

With the growing number of observatories working in the fundamental astrometry, and especially in view of the large number of stellar catalogs, the possibility was at hand in the last century to compose calculated, derived (general) catalogs which would integrate in themselves all the available material, eliminating thereby accidental and systematic errors from the final results to a maximum degree. Since the times of Bessel until our days many catalogs of this kind have been compiled and it is therefore impossible to present them all, so we are led to confine ourselves to only a few of the most important among them.

Let us first deal with fundamental catalogs. After Bessel the activity connected with the composing such catalogs is assotiated with the names of Newcomb, Auwers, L. and B. Boss.

In 1872 S. Newcomb (1835-1909) published a catalog of right ascensions of 32 equatorial stars (Designation N1), using data from 26 observational catalogs. The point of vernal equinox was determined from observations of the Sun from 1750 to 1869. The accuracy attained was so high that it left an impact upon the constructing of calculeted catalogs in the next half century. In 1898 there appeared his another catalog (N2) „Catalogue of Fundamental Stars for the epochs 1875 and 1900 reduced to Absolute System", based on 43 absolute catalogs, containing positions and proper motions of 1257 stars. This catalog was used in elaborating ephemeris of many almanacs (save Berliner Jahrbuch) from 1900 to 1927.

The series of Boss' catalogs was started in 1877 by the catalog of declinations of 500 stars „Declinations of Fixed Stars", produced by L. Boss (1846-1912). This catalog (B1) is based on 57 observational catalogs, 32 of which were used for constitution of the catalog's system. The next L. Boss's catalog (Bs) from 1898 contains coordinates of 178 stars of the southern hemisphere (from -20° declination to the south pole). In 1903 was published another L. Boss's catalog of 627 stars (B627) a kind of extention of N1 and B1 to a larger number of stars. The two catalogs, like previous ones, are marked by a limited number od stars contained, which prevented numerous astronomical problems to be studied (solar and planetary motions, determinations of various constants (precession etc), neither was their application in geodesy convenient. The need was therfore strongly felt for catalogs containing a larger number of stars. That is also the background of L. Boss's plan for the composition of a catalog with an extensive number of stars. It foundation is laid down by the „Preliminary General Catalogue of 6188 Stars" (PGC) published in 1910. It contains 1919 stars of the northern and 2111 star of the southern hemisphere brighter than 6^m as well as 2158 stars fainter than 6^m. It is based on 82 observational catalogs, using its proper system in addition to those of N1, B1, and B627. L. Boss could not complete his catalog, but fortunately the work after his death was assumed by his son B. Boss, born in 1880. The catalog was published in 1937 under the title „General Catalogue of 33 342 Stars" (GC), in use even nowadays. No fewer than 238 catalogs have been used for its composition.

In 1863 F.W. Argelander (1799-1875) published his survey catalog „Bonner Durchmusterung" (BD), containing approximate coordinates of 324 188 stars (down to 9.5 app. magnitude) between -2^o and $+90^o$ declination. In this same year he founded Astronomische Gesellschaft (AG), a precursor of the International Astronomical Union. This organisation suggested a more accurate determination of the BD star positions. Thus came into being a whole array of fundamental and other catalogs, known by their common name AG catalogs, the latest result of which is the present fundamental catalog FK4. In connection with this work in the fundamental astrometry a scool has taken shape named after A. Auwers. Fundamental catalogs of this school might be cited here: „Fundamental -Catalog für Zonen-Beobachtungen am Nördlichen Himmel" (A.Auwers, 1789, the number of stars 539, designation FC); „Vorläufiger Fundamental-Catalog für die Südlichen Zonen der AG" (A. Auwers, 1889, the number of stars 303, designation A303); „Fundamental-Catalog für die Zonen-Beobachtungen am Südhimmel und südlicher Polar-Catalog für die Epoche 1900" (A.Auwers, 1897, the number of stars 499+24, designation As); „Neuer Fundamental-Catalog des BAJ (J. Peters, 1907, the number of stars 925, designation NFK); „Dritter Fundamental-Catalog des Berliner Astronomischen Jahrbuchs" (A.Koppf, 1937 and 1938, altogether 1535 stars, designation FK3), accepted in 1935 by the Interanational Astronomical Union as an international catalog. Following this decision all national almanacs since 1940 are based on the FK3 system; „Forth fundamental Catalogue" (Fricke W., Koppf A., 1963, the number of stars 1535, designation FK4). Another fundamental catalog in this series is currently being prepared with the designation FK5.

A fundamental catalog of W.S.Eichelberger „Positions and Proper Motions of 1504 Standard Stars for Equinox 1925" was published in1925, which differs from previous catalogs of this type in that its system was formed on the basis of only four absolute catalogs (two observed in Washington and two in Cape). It was adopted from the International Astronomical Union as international catalog for all astronomical alamanacs. English, American and French almanacs began using it since 1928.

H.R. Morgan published in 1952 „Catalogue of 5268 standard Stars based on Normal System N30", designated N30, based on 70 separate catalogs with equinoxes ranging from 1920.0 to 1950.0.

Of all these fundamental catalogs the use is curretly made, besides FK4 since 1963, of GC and N30. In the second part of this monograph a comparative analysis is presented of the accuracy of both catalogs.

All above cited catalogs are derived from observations made with many instruments at many observatories. But it is possible to derive a fundamental system of high accuracy from observations with one and the same instrument. These observations should be extended over a long period. A good example of this is offered by A.A. Nemiro, who derived two fundamental catalogs of right ascensions of the northern sky (Pu 1 and Pu 2), proceeding from nine absolute catalogs from 1845, 1865, 1885, 1892, 1905, 1915, 1925 and 1930, observed with the Pulkovo large transit instrument. The high accuracy of the two catalogs afforded deficiencies in the catalogs FK3, GC and N30 to be firmly established.

In the end let us dwell a little on other calculated catalogs, termed derived because they lack their own systems.

Mention has already been made of the activity of AG for the position determination of large number of stars according to the BD list. There are for the southern sky (from -23^{o} to 90^{o} declination) „Cordoba Durchmusterung" and Cape catalog CPD. The latter contains 454 875 stars between -19^{o} and -90^{o} declination. Only photographic technics could meet the requirements arising from producing catalogs of such a huge number of stars, and this in turn suposed the existence of reliable reference catalogs. In consequence fundamental catalogs were elaborated such as FC (for the stars between -10^{o} and $+90^{o}$), A303 (zone -2^{o} to -23^{o}), As (-20^{o} to -82^{o}) and afterwards general catalog NFK. Finally a series of photographic catalogs was produced with the designation AGK1, comprising stars between -23^{o} and $+90^{o}$ declination, in the system of FC. Late in the twenties of this century decision has been taken to work out a new catalog AGK2 in the FK3 system. To bring this about it was necessary to have the FK3 system extended to fainter stars, which resulted in the construction of a new derived catalog, designated AGK2A, containning 13 747 stars (between -4^{o} to $+90^{o}$ declination), with apparent magnitudes from 7.5 to 9.0. The International Astronomical Union decided, in 1955, on the elaboration of a new catalog – AGK3. To that end a new derived catalog was composed of the northern faint stars – AGK3R containing coordinates of 21 499 stars (-5^{o} to $+90^{o}$declination) in the FK4 system. In 1958 the IAU took the decision calling for the elaboration of a great photographic catalog of the southern sky. For this it was necessary first to compile a derived catalog of reference stars, whose designation is SRS (Southern Reference Stars) giving coordinates in the FK4 system. The work relating to this catalog is nearing its completion.

On the initiative and under the conduction of M.S.Zverev a wide activity is going on for the construction of a catalog of faint stars (KSZ), with positions of 15 355 stars,their magnitudes ranging from $7^{m}.5$ to $9^{m}.1$, and declinations from -30^{o} to $+90^{o}$. This very ambitious plan, to be completed in about twenty years from now, implies observations of stars, minor planets and point-like nebulae. KSZ will be related to the system of the fundamental catalog of faint stars (FKSZ), containing 945 stars. In 1958 a preliminary fundamental catalog of faint stars (PFKSZ1) was published, containing positions of 587 stars from -20^{o} to $+90^{o}$ declination, which is in fact a differential catalog in the FK3 system. The same catalog was subsequently transferred into the FK4 system, bearing the designation PFKSZ1'. The elaboration is currently in progress of PFKSZ2.

It should be remarked that AGK3R contains all stars of KSZ. It is to be hoped that KSZ will be extended over the southern sky by way of SRS.

The stars within the latitude zone -8^{o} to $+8^{o}$ are used in the observations of the Moon, planets and occultations of stars by the Moon. Hence the need for their positions to be known with the highest accuracy possible. It was evident that a special value was to be attributed to the observation of these so called zodiacal stars by meridian circles and the working out of corresponding derived catalogs. As a result we have „Catalog of 1098 Standard Clock and Zodiacal Stars" (S.Newcomb, 1890), „Catalog of Zodiacal Stars" (H.Hedrich, 1905, with 1607 stars), „Catalog of 3539 Zodiacal Stars (J. Robertson, 1940).

Catalog of the Smithsonian Astrophysical Observatory (SAO Star Catalogue) was published in 1966. The positions of 258 997 stars are given in the FK4 system.

It should be pointed out that at present time catalogs are produced not only with the classical meridian fundamental instruments. It appeared also that small transit instruments and Danjon's astrolabes were yielding very accurate observational data. Catalogs originating from these observations have already been published. We mention here the derived catalog of N.N. Pavlov, issued in 1961, based on the observations with the small transit instruments participating in the Soviet Time Service. B. Guinot was the first to derive a catalog (published in 1961) based on observations with astrolabe of the FK4 stars.

A very limited number of catalogs could be quoted here – we even omitted some of notoriety – but it is quite understandable that within this rather narrow space a complete presentation was impossible. As our Bibliography proves, the number of catalogs composed up to date is exceeding 2000. Each one of them constitues a brick, bigger or lesser, in the monumental edifice of the fundamental astrometry, whose corner-stones only we tried here to elucidate to whatever extent this was in our power.

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