V. V. Nesterov, A. A. Ovchinnikov, A. M. Cherepashchuk, E. K. Sheffer. *Problems of space astrometry.* Project LOMONOSOV. Information obtained from observations of celestial objects contains their position (assigned by directions to the source of electromagnetic radiation), and photometric and spectral characteristics in various radiation ranges. All these pieces of information are functions of time: the position changes due to the proper motions and parallaxes of stars, and their brightness and color are frequently variable.

The collection of this information and its study is the main task of astronomy, as it has been since its origin, and the materials collected by astronomers are compiled in catalogs. The use of a catalog with practical and scientific goals always involves the extrapolation of the information contained in catalogs. The accuracy of catalogs inevitably declines over time. Today's accuracy of several tenths of a second may in 10–20 years become an error of seconds.

Over a century of work in classical astrometry shows that it is fundamentally impossible to achieve mass measurements from the surface of the Earth with an accuracy better than 0.10″. An increase in accuracy is limited by local fluctuations of the atmosphere, insufficient stability of the directions chosen to assign zero points, and the technical imperfection of measurement instruments functioning in gravity. It should be stressed that increasing the number of observations virtually does not lead to an increase in the accuracy of the result once some limit is reached. Polaris has been observed thousands of times over the last 300 years, but its coordinates are, as before, known only with an accuracy of several hundredths of an arc second.

The goal of Project LOMONOSOV is the creation of a highly-accurate coordinate system for the entire sky, which would remain in effect for a sufficiently long period of time (30–50 years), providing a solution to a wide range of fundamental and practical problems. This goal is achieved as the result of comprehensive work based on a space experiment, that is, the organization of stellar observations with a telescope installed on board on Earth satellite.

The program of observations of the LOMONOSOV experiment includes:

—all stars up to 10.0 stellar magnitudes, in all about 400,000, providing for the presence of about 10 stars in a quadratic degree of the sphere;

—selected weaker stars (up to 13.0 stellar magnitudes), about 8000 in number (these stars were already chosen for the HIPPARCOS program of the European Space Agency; they are of special interest for astrophysics and stellar astronomy);

—about 30 of the brightest sources of extragalactic radiation;

—about 40 bodies of the solar system (large and small planets).

The fundamental scientific importance of the results of Project LOMONOSOV should be examined in two aspects: the creation of a coordinate system for scientific and practical purposes, and obtaining information for the development of astronomy.

1. The coordinate system. Absolute proper motions will be obtained for a 100 times more stars and for many hundreds of times more weak stars than in stellar catalogs comparable in quality (FK5) and with 5–10 times more accuracy than in catalogs which are comparable in volume, AGK3 and SAO. To achieve these results from Earth would require about 100 years of work.

The absolute positions will be obtained with an accuracy 10–30 times greater than in FK5. This is generally unattainable for terrestrial observations (the atmosphere limits the achievable accuracy). However, the most important improvement of current data is the achievement of uniform accuracy over the entire celestial sphere, in particular, the elimination of different systems in the northern and southern hemispheres, which is inevitable for terrestrial observations.

An absolute coordinate system will be obtained by linking the stars of the system with the sources of extragalactic radiation, whose positions are measured using radio interferometry, and from joint observations of stars and bodies of the solar system. The observations of the parameters of Earth's rotation by classical optical methods in the LOMONOSOV system of coordinates and the use of radio interferometry will make it possible to compare these two systems. Thus, the Project LOMONOSOV catalog will become a representative of the best absolute system of coordinates obtainable at present.

With an absolute coordinate system, it will be possible to:

—establish the link between a dynamic reference system (planets, the Moon) and an absolute geometric system;

—study non-gravitational effects on the motion of the Moon and relativistic effects for other bodies of the solar system;

—establish a reference system to measure precession of the Earth's axis, which is extremely sensitive to the properties of the internal structure of the Earth;

—establish a reference system to study the secular motion of the Earth's poles, which is linked with the shifting of lithospheric plates and variations in the Earth's moments of inertia;

—establish a reference system to study secular effects in the movement of the planets and refinement of their masses.

2. Astrophysics and stellar astronomy. At present there

is information on the parallaxes of about 10,000 stars, mainly in the northern hemisphere. Of these stars, only 5 percent have relative errors of less than 10 percent. Project LOMONOSOV will make it possible to measure the parallaxes of tens and hundreds of thousands of stars with an absolute accuracy of 0".001–0".002, and to determine the distance to these stars, which will greatly increase the volume of studied space (to 1000 parsecs).

a) The absolute luminosities of stars. It will be possible to determine the trigonometric parallaxes of individual members of stellar clusters, in particular, the Hyades, which will significantly improve our information on the distance to this cluster, which is a starting point for establishing the scale of distances in the universe.

b) Luminosity calibration. For the first time, measurements will be made of the parallaxes of B-stars of the main sequence of the Hertzsprung-Russell diagram, as well as the K and M class giants. Their luminosities will also be determined. The parallaxes of *F* and *G* stars of the main sequence (about 15,000 closer than 75 parsecs, and brighter than 11 stellar magnitudes) may be used to study the dependence of their luminosity on chemical content.

c) Stellar masses. The number of binary systems in which the mass of the stars will be determined with an accuracy better than 15 percent will increase by about a factor of 10.

d) Kinematics and dynamics of the galaxy. The accuracy of the determination of the Oort constants A, and especially B, will increase significantly. The latter constant has been measured only from the proper motions of stars.

e) Study of individual objects. Measurements of the proper motions will make it possible to determine the spatial velocities of many objects and their orbits in the galaxy, and back extrapolation will make it possible to obtain the location of sources of star formation by moving 500 million years back in time.

The proposed experiment, in general terms, may be reduced to the following.

A Cassegrain telescope will be installed on a spacecraft. The telescope will have an equivalent focal length of 50 m, with main mirror diameter of 1 m, a focus of 4 m, and an anaberrational field of vision of 6 arc minutes or 90 mm. The system of aperture mirrors gathers into one field of vision the images of two stars (or more accurately, two portions of the celestial sphere), which are separated in space by an angular distance of about 90°. Using their mutual position the aperture mirrors should create a highly stable standard angle, and measurements made during the experiment will be subject to the difference of the true angular separation between the stars from the value of the standard.

It has been proposed that a CCD matrix be used as the receiving recording device. The CCD would consist of 800×800 elements. The linear size of each element is 15×15 μm, which corresponds to 0.06". Analysis of the signals of the matrix using special digital algorithms makes it possible to find the distance between stars in the field of vision with an accuracy of up to 0.3 μm, which is about 0".001.

The strategy for carrying out the experiment is holding the position of the equipment, which is pointed to a chosen star near to the anitisolar point (conventionally called the standard star) with subsequent rotations relative to this direction and measurements of the distances from the standard star to all others 90° away from it (conventionally called program stars). Then the spacecraft will point to another standard star, and measurements will be made of the distance from it to another set of program stars. While the spacecraft is being quieted down, photometric measurements will be made of program stars, and spectrophotometric measurements are proposed for the standard stars.

The main requirement on the spacecraft is the ability to rapidly reorient with subsequent triaxial stabilization.

The choice of the spacecraft orbit is subject to the need to minimize various noises: light noise from the Earth and Moon have forced the choice of a high-apogee orbit. Noise from the radiation bands of Earth on the CCD matrix forces moving the apogee to beyond 80,000 km. One must also consider the desirability of a larger ratio of the spacecraft's position in a useful part of the orbit to the time it spends near the pericenter. Thus, one can speak of a 48-hour orbit with an apogee of about 120,000 km. The inclination of the orbital plane to the plane of the ecliptic should be 50–60°, which would make it possible to reduce the seasonal effect of the magnetospheric tail, which would create additional noise in the CCD matrices.

To execute optimally the set of observations of the space experiment one must calculate all angles of rotation of the spacecraft beforehand, that is, one must have an ordered list of all stars of the future catalog with approximate coordinates (the so-called initial catalog). Compilation of this catalog is an important and labor intensive task which is being carried out on the basis of materials of photographic observations of Soviet observatories in both hemispheres, as well as the data of the "Karty Neba" [Sky Maps] astrographical catalogs.

Planning of the space experiment and its optimization are directly linked with the initial catalog, and are necessary for: 1) the choice of the maximum number of independent measurements in a minimal experiment execution time; 2) obtaining the best possible conditional system of equations of the final stage of establishing the coordinates from measured distances. The deduction of the final catalog is reduced to the solution by one means or another of a system of linear equations, each of which links the data of a specific measurement with 10 unknowns (five for each of the stars). The matrix of the normal system has a dimension ($5 \times$ the number of stars in the program) and since only relative angular measurements are examined, there is a rank 6 defect which corresponds to the unknown rotation of the system of coordinates and its changes in time.

The system of normal equations may be solved using several different methods, for example, iteration methods. Another method is the two-stage solution. In this case one must choose a limited number of stars (10,000–40,000) which have sufficiently well known coordinates from the best astrometric catalogs, and consider only those equations which link them. As a result, one can find a solution which equates the set of coordinates of these stars within themselves with zero-points corresponding to the system of initially chosen coordinates. The coordinates of the remaining stars of the program of the experiment will be determined from their differences from the coordinates of the stars of the first stage.

The final stage of the deduction of the system of coordinates, the resultant absolute system, is obtained by linking it

with various systems of physical bodies. This will be complete when Project LOMONOSOV is completed.

Making massive astrometric and photometric measurements using a telescope installed on a spacecraft is also being planned for the HIPPARCOS project, which has been in development since 1975 by the European Space Agency. Their program includes about 100,000 specially chosen stars with a brightness of up to 13 stellar magnitudes. Each of them should be observed 60–80 times with an accuracy of one observation of about 0".01. The main equipment of the spacecraft is a Schmidt system telescope with a focal length of 140 cm and a diameter of the entry pupil of 29 cm. Homogeneous coverage of the sky is obtained by rotating scanning of the sky, and the photoelectric method is used for measurements.

In Projects LOMONOSOV and HIPPARCOS different methods of surveying the celestial sphere are used, and fundamentally different methods of recording the positions of stars in the focal plane are used. Both projects, without a doubt, will supplement each other. There is the possibility of determining and excluding possible errors in the methods, thus increasing the confidence of the obtained scientific data. This task requires the coordination of the efforts of Soviet scientists and specialists with their West European colleagues.

Translated by C. Gallant