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NEW SOVIET CAMERAS FOR PHOTOGRAPHIC OBSERVATIONS OF ARTIFICIAL HEAVENLY BODIES

By: A.G. Masevich and A.M. Lozinskiy

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The VAU camera was created in Moscow. ~~It~~ is equipped with an "Astrodar" lens. The effective aperture is 500 mm. The focal length is 700 mm and the diameter of the main mirror is 1070 mm. It differs basically from the American Baker-Nunn camera by its parallactic mounting which allows recording reference stars in the shape of dots in the immediate vicinity of the satellite's image, simultaneously with the chopped trail images of bright stars. This makes it possible to take into consideration practically the entire deformation of the film.

At the present time the Soviet Union and other socialist countries have a network of stations equipped with modern cameras for tracking heavenly bodies, which make it possible to solve serious problems of geophysics and geodesy.

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(Novyye Sovetskiye kamery dlya fotonablyudeniy iskusstvennykh nebesnykh tel)

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NEW SOVIET CAMERAS FOR PHOTOGRAPHIC OBSERVATIONS OF ARTIFICIAL HEAVENLY BODIES

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Candidate of Physical-Mathematical Sciences
A.M. Lozinskiy

To solve a number of scientific problems of geophysics and geodesy, observations of satellite motions are necessary. One of the most reliable indicators characterizing the orbit evolution of an artificial heavenly body is a photograph of the satellite's trail on the background of a starry sky, indicating the moment of time for particular points of the trail. The rapid visible motion of a satellite across the sky (as compared against natural heavenly bodies) requires very precise registration of the observation time and special shutters controlled by the clocks of the Time Service which make it possible to mark the moments of their opening and closing with an accuracy to several milliseconds. The available astronomic telescopes do not have such devices, because only approximate time-markings are needed in the ordinary astronomic observations. The rapid motion of satellites creates still one more additional difficulty: the effective time of exposure of a moving object is very short, and for a majority of the existing satellites it is equal to hundredths of a second. This means that the trail of many insufficiently bright satellites is simply not visible on the film. To increase the exposure it is necessary that the telescope or its plate holder follow the satellite.

In addition, astronomic telescopes, as a rule, are rather "awkward"; before the observations they are preliminarily aimed at the section of the sky being studied. They do not have devices for moving them in all directions with the speed required for tracking the satellites, and they can only follow the slow daily movement of the firmament.

To photograph satellites it is necessary to develop special cameras and to modify the existing telescopes.

Modified aerophoto cameras were used in the Soviet Union and other countries after the launching of the first artificial satellite. Special shutters of various types provided a break in the satellite's trail on the film, and the moment of this break was registered with great accuracy. Also created were special satellite cameras which take into account all the motion peculiarities of an artificial cosmic body. The best known is the American camera "Baker-Nunn" (1957). This is a camera of the Schmidt system with a 51 cm lens diameter and the same focal length, i.e., its relative aperture is equal to one. The camera has a triaxial mounting, which makes it possible to track a satellite along an arc of great circle with speeds from 0 to 2 degr/sec. Its field of view is 30° x 5°; the scale on the film is 1" - 2.46 microns. A shutter located in front of the focal plane permits breaking of the stars' (or satellite's) trails. An additional shutter regulates the beginning of the exposure. Quartz clocks with an accuracy to 0.001 sec are used for time-marking.

Large series of exact photographic observations of satellites from numerous stations, obtained during the last ten years, as well as synchronous observations according to a special program carried out from several stations, have made it possible to solve a number of important problems of geodesy and geophysics. This pertains to investigations of the density of the atmosphere and its periodical fluctuations caused by the activity of the sun, determinations of higher-order coefficients of the potential of the earth's gravity, and accuracy improvements in the positions of the observation stations on the earth's surface. Thus, satellite geodesy has originated, with its considerable advantages over terrestrial geodesy, such as: the possibility to establish geodetic ties over great distances (up to 6000 - 7000 km), comparative speed and low cost of creation of a geodetic network, and others.

Work in this field of science and improvement of the already obtained results are being continued. The launching in recent years of special geodetic satellites ("Geos") equipped with impulse flashes has increased considerably the accuracy of photographic observations, since they have made it possible to fully eliminate the error caused by the inaccuracy of registering the time of the observation.

In 1966 a new determination of station coordinates and harmonics of the earth potential was carried out on the basis of photographic observations accomplished by a network of United States stations equipped with "Baker-Nunn" cameras, and the so-called "Standard Earth 1966" was created by the Smithsonian Observatory. To derive the geodetic parameters of the "Standard Earth" twelve stations were used; they were located in Spain, Argentina, on the Antilles Islands, in Peru, Florida, New Mexico, on the Hawaiian Islands, in India, Japan, Australia, Iran, and South Africa. About 160,000 observations were processed in this project. And in addition to purely geometric methods, the dynamic and orbital methods and various combinations of them were used also. A comparison of the results has shown that the accuracy in determining the coordinates of 12 stations of the net by different methods is approximately the same, ± 10 - 20 m.

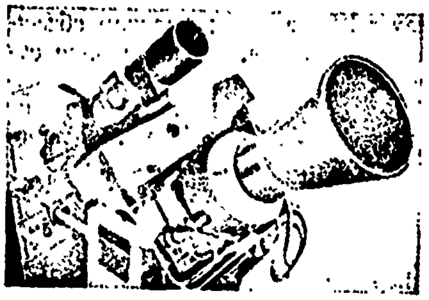
In some countries the satellites are observed with the aid of laser devices. These observations are of the utmost interest. First of all, the combination of data on the distance to the satellite, measured by laser location, and the data on the direction obtained by the tracking camera make it possible to determine at once all three satellite coordinates; secondly, the laser beam can illuminate the satellite for photographing when it is located in the earth's shadow, and, thirdly, with respect to the accuracy of distance determination, the laser system exceeds photographic and radio observations almost by one order.

In France the observations of French geodetic satellites are being successfully carried out with the aid of photography, radio and laser. Processing of the obtained data has shown, in particular, that such joint observations make it possible to construct, by the method of cosmic geodesy, the European net with an accuracy of 3" - 5" along the chord connecting any two stations, and 0".5 along the direction of this chord.

In the USSR, I.D. Zhongolovich has developed a unique geometric method for determining the position of the center of the earth's masses with the aid of synchronous photographic and laser observations of artificial earth satellites. This method does not require preliminary knowledge of the exact values of the orbit elements. He has also suggested the project of a world triangulation net with a minimum number of observation stations.

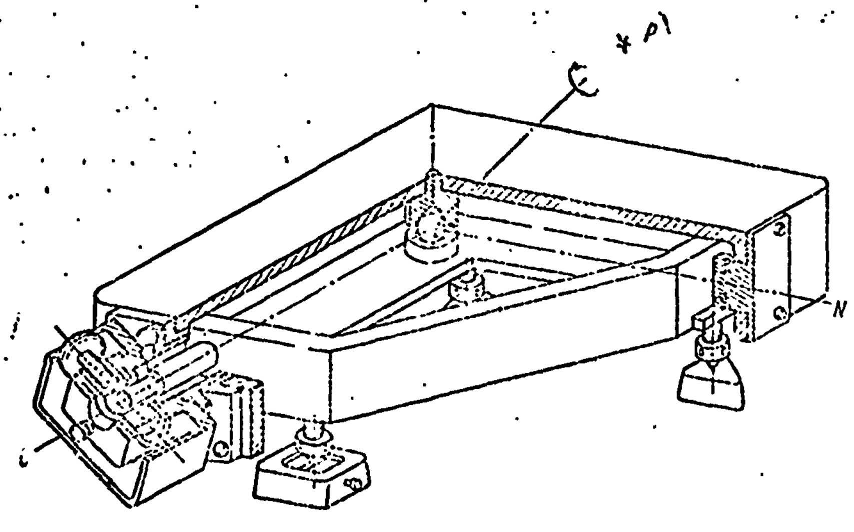
The basic idea of the project consists of constructing around the earth a closed spatial triangle net with the smallest number of vertexes, uniformly distributed over the earth's surface (12 stations at the vertexes of a right polyhedron-icosahedron). After final determination these points will play the role of reference points for work on condensing the space triangulation net, for connecting various geodetic systems to them, and also they will become the basis for appropriate conclusions on the form and dimensions of the earth. The project requires the launching of a special "high" satellite (12,000 km) with a polar circular orbit. Detailed computations of the elements of such a satellite, of the observation conditions and of the anticipated accuracy have been worked out.

The improved measurements make it possible to solve ever more complicated and intricate scientific problems which only a few years ago seemed insolvable. In particular, this pertains to the identification of gravity disturbances caused by the displacement of masses in the earth's body as a result of lunar and solar tides from higher-order terms in the expansion of the earth potential; detection of



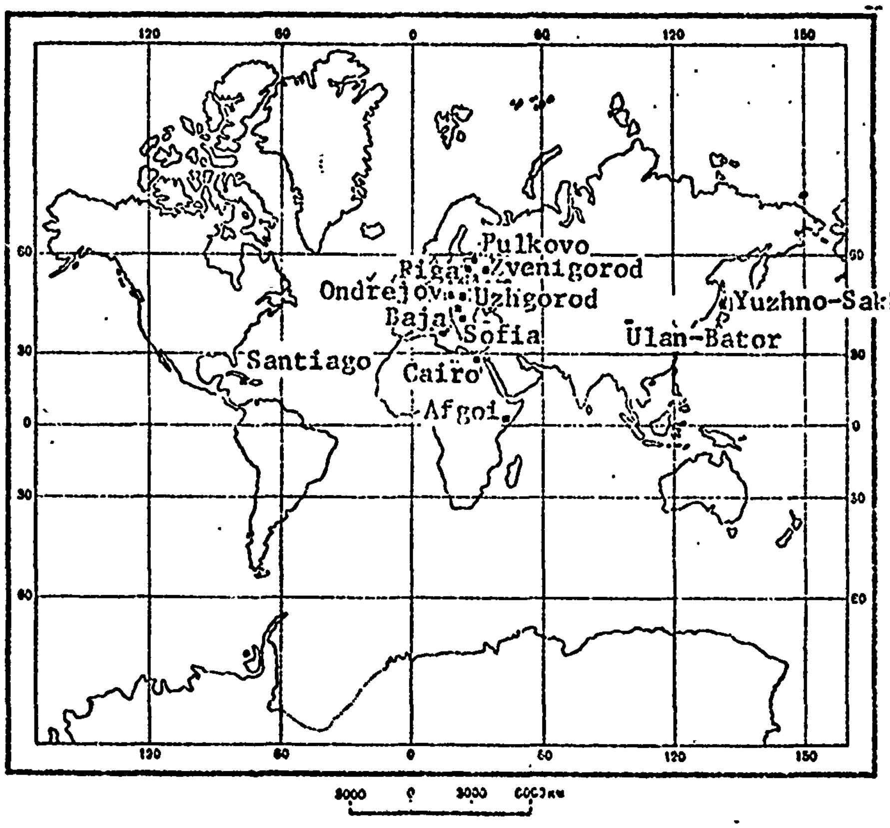
AFU-75 Camera

variations in the moment of the earth's inertia, connected with the irregularity of its rotation, and also seasonal re-distributions of atmospheric masses, from higher-order disturbances of the satellite orbits. Such investigations require the accuracy yielded by the laser devices. The measurement of horizontal movements of the earth's crust are within the possibility of laser observations. Of course, it should be remembered that more accurate investigations also require appropriately more complicated methods of processing.



Equatorial platform of the AFU-75 camera

The joint utilization of laser and photographic technology, as well as methods of photography of geodetic satellites, determine increased requirements for photographic instruments and for methods of processing of the obtained data. New large cameras for satellite tracking have been designed in various countries in recent years. Some of them have already been used in international programs of satellite geodesy for several years, others are still being installed. Below a description is given of new apparatus created in the Soviet Union.



Locations of AFU-75 cameras

In 1965, the AFU-75 camera was constructed at the Riga University station. It features a lens with a focal length of 736 mm, and d = 210 mm; a seven-lens "Uran-16" type objective d/f = 1:3.5, with a field of view of 10° x 14°. It uses 190 mm film. A telescope-guide is attached to the camera. The entire camera is set on a special equatorial platform, devised for observation of daily stellar motion in 2 - 3 minutes tracking. This construction is unique among all existing "satellite" cameras. The four-axial mount of the camer is designed for the tracking of artificial satellites along the arc of a small circle.

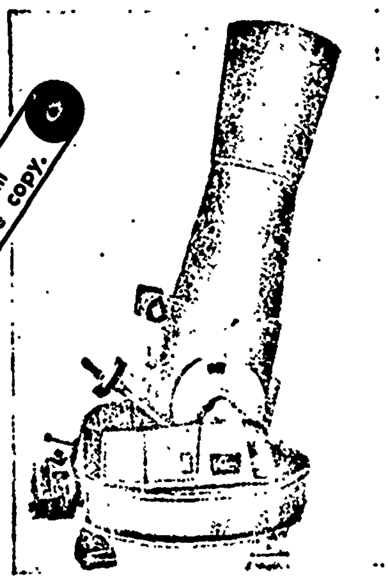
The camera makes it possible to photograph satellites from the 3rd to the 10th stellar magnitude. Objects not seen in the guide cannot be photographed. To photograph weak satellites a device is available which periodically moves the film behind the motion of the satellite's image. To photograph bright satellites (up to the 3rd stellar magnitude) a rotary shutter is used, which makes it possible to cause interruptions in the satellite's trail and to print the time marks on the picture. The camera can also photograph active satellites, i.e., satellites with a 15-million candle electronic flash from a distance of 3500 km.

The assembly is equipped with all the necessary instruments--in reality this is an independent observation station. It only requires a 220 volt and 2 kilowatt power line. Its total weight amounts to 350 kg. The tracking accuracy is 2.00" of arc, and a good observer can obtain even 1" of arc; the time recording accuracy is 1 millisecond.

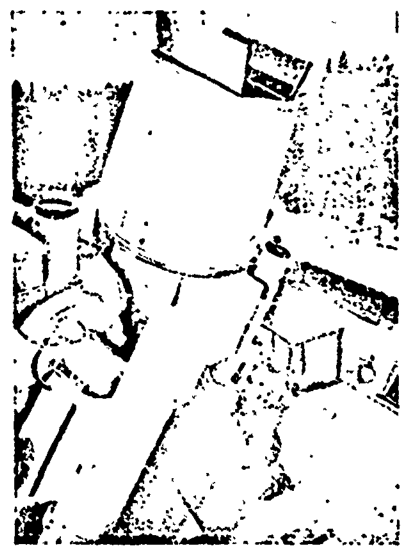
Thus, this is a universal, comparatively easily transportable camera, which possesses a number of undeniable advantages in comparison with other cameras having the same optical properties.

The AFU-75 cameras are used at Soviet stations in Riga, Uzhgorod, Zvenigorod and Yuzhno-Sakhalinsk. They are also installed in Ondřejov (Czechoslovakia), Sofia (Bulgaria), Ulan-Bator (Mongolia), Baja (Hungary), in Cuba, the United Arab Republic, Somaliland and Mirnyy (Antarctica). All these stations participate in international programs of satellite geodesy. In particular, at the end of 1968-beginning of 1969 the Soviet-African stations in the United Arab Republic and Somaliland and the stations located in the Soviet Union participated together with the stations of France, England, Greece, Spain and the United States in international observations of the "Pageos" satellite to establish geodetic connections Europe-Africa.

Beginning with 1967 the AFU-75 cameras installed at the Riga and Uzhgorod stations have been used regularly in the international studies connected with photographing the flashes of the "Geos" satellites in the program of the Smithsonian Observatory of the United States.

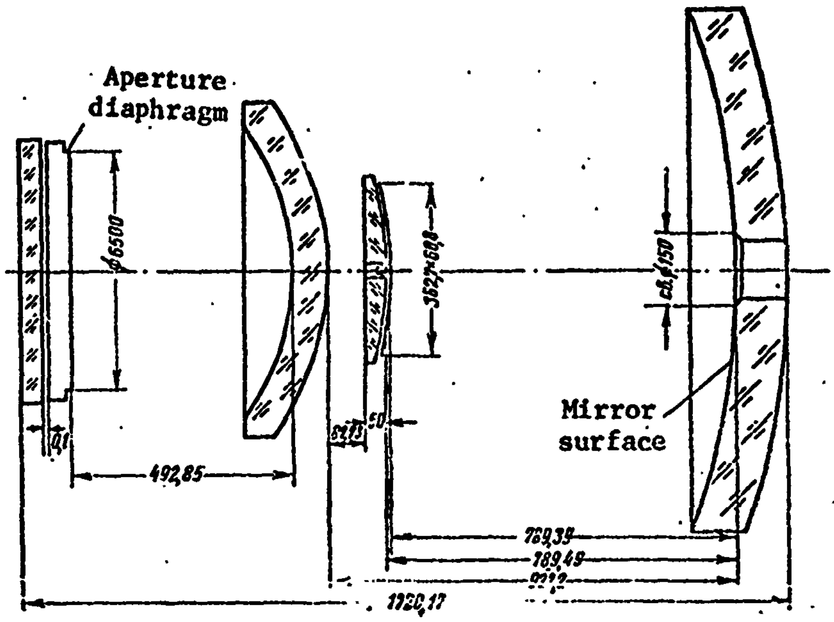


FAS Camera



VAU Camera

The FAS camera was constructed in 1969, also at the Riga University station. It is intended for taking pictures of active satellites. It is also set up on an equatorial platform, with the same working principle as that of the AFU-75. The camera is mounted on the platform biaxially.



Schematic of the "Astrodar" lens

The FAS camera features a mirror lens system. The main mirror is a spherical mirror, d = 300 mm. The focal length is 480 mm, d/f = 1:1.9. The photographing is done at the main focus on plates or film measuring 6.5 x 9 cm. The field of view is 7° x 10°.

The control accuracy determinations from computation of the locations of stars and comparison with the catalog coordinates yielded results of discrepancies from 1".5 to 3".0. The same accuracy as that of the AFU-75 with different focal lengths is explained by the fact that the images of stars on the FAS pictures are considerably clearer due to good optics, and this decreases the measurement errors.

At the end of 1969, FAS cameras were installed at the stations of Riga, Zvenigorod, Uzhgorod, Pulkovo and Yuzhno-Sakhalinsk.

The VAU camera, presently the largest satellite camera in the world, was created in Moscow. The camera is equipped with an "Astrodar" lens, designed as long ago as 1958 by D.D. Maksutov and M.A. Sosnina of the Pulkovo Observatory. The effective aperture is 500 mm. The focal length is 700 mm, and the diameter of the main mirror is 1070 mm. The camera has two shutters: a rotating shutter, which serves to obtain an intermittent image of the trail of reference stars or bright satellites and has a system for registering the correct time; a flicker shutter, for limiting the number of chopped trail images. The camera uses 70 mm film, and the size of the negative is 60 x 360 mm.

The camera's mounting is triaxial parallactic, which, unlike a biaxial equatorial mounting, makes it possible not only to aim the camera at any point of the sky where a satellite is located, but also to trace its motion in any direction from this point. Depending upon the brightness and the velocity of the satellite's movement on the celestial sphere, one of four photographic procedures is selected: the first one is used in taking pictures of weak satellites having high velocity; the second-for bright satellites which may not be tracked with the camera; the third-for weak, slow satellites, and the fourth-in tracking space probes.

The VAU differs basically from the American Baker-Nunn camera by its parallactic mounting which allows recording reference stars in the shape of dots in the immediate vicinity of the satellite's image, simultaneously with the chopped trail images of bright stars. This makes it possible to take into consideration practically the entire deformation of the film.

The first VAU camera has already been installed at the station of the Astronomic Council of the Academy of Sciences of the USSR in Zvenigorod, where it is currently being tested. Two more such cameras are to be installed in Tadzhikistan and Armenia in 197[illegible].

Thus, at the present the Soviet Union and other socialist countries have already a network of stations equipped with modern cameras for tracking heavenly bodies, which make it possible to solve serious problems of geophysics and geodesy. The introduction of the largest VAU sets will permit a considerable increase in the volume of information on the evolution of orbits of remote artificial objects in the near future.