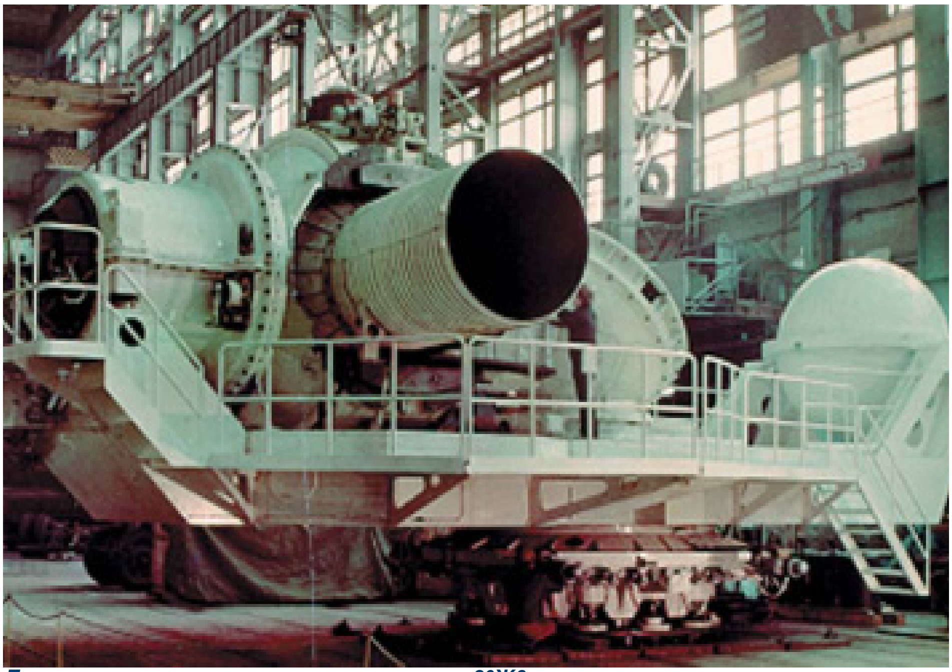
LASER-OPTICAL FACILITIES OF SPACE DEBRIS MONITORING



Телескопическая система оптического локатора 30Ж6.
Telescopic system of the 30Zh6 optical radar.

The problem of near-Earth space environment (NESE) contamination by man-made objects has become very pressing for recent 5-10 years. Currently the number of man-made objects on orbits, i.e. so-called space debris is so large that one has to square up to the real danger of expensive spacecraft's damage from eventual collisions with man-made orbital particles or even bigger fragments.

This problem is gaining special relevancy within provision of manned orbital stations' safety. The dimensions of such space platforms are very large, which renders their collision with objects or space debris large fragments rather possible. The probability of collision with space debris fragments increases due to long terms of orbital stations' active existence equaling decades by now. In some cases even a single impact of one of such fragments can disable an orbital station.

Space debris, being, mainly, the product of human activity, features heterogeneous composition. Its largest components are represented by passive spacecraft, i.e. the spacecraft that ceased their existence. Besides, there is functional debris pulled out off orbital stations in the run of their normal operation. One of the general reasons for space debris' appearance in the near-Earth space environment is spacecraft explosions. These explosions produce flinders part of which fall on Earth and burn down, and the rest remain on orbits. The scope of the whole orbital population increases year by year, which is determined by such factors as new spacecraft launches and explosions of old "space vehicles" into fragments. The reasons for these explosions are various. Sometimes they are scheduled and carried out upon commands from the Earth, and sometimes there are unintended blow-ups. But at any rate a spacecraft explosion produces a lot of fragments.

Nowadays there are about 10,000 large fragments on near-Earth orbits. These are the fragments supervised and traced by the ground facilities, having 10-cm cross-section size. But, along with these fragments, there is a large group of smaller unobserved elements. Thus, the number of fractions featuring cross-section sizes from 1 to 10 cm is estimated at 35,000, though there are also more pessimistic evaluation: up to 70,000 and even over 100,000. The number of smaller elements with size lower than 1 cm makes about 3.5 million.

Therefore a kind of a cloud cover of space debris fractions has shaped in the near-Earth space environment, and it constitutes a considerable part of the environment. Active spacecraft, including manned ones, operate within this "cloud", incurring danger, even though potential, of fragments' destructive effect. Since space debris is accumulated on orbits related to more intensive employment, one should expect facing higher risk of its interaction with higher concentration of fragments and elements in these areas.

Nowadays there are no guaranteed methods of spacecraft's protection from collisions with space debris elements. That is why the approach concerning information provision of flight safety, i.e. the approach based on near-Earth space environment's monitoring for the purpose of determination of more secure orbits free of space debris, is considered to the most efficient.

On the basis of the information acquired, more contaminated heights and orbits are determined, and the catalogue is compiled. As a result, the full control of space environment is achieved, which permits to take timely measures regarding protection of spacecraft from space debris, including fragments' destruction, as well as provision of flight safety for unmanned and piloted spacecraft through orbit adjustment, for instance.

The wide scatter of space debris elements' dimensions (from centimeters to hundred meters) and ranges to them (from hundreds of meters to several thousands of kilometers) speak for the necessity of the above-mentioned tasks' complex solution with compulsory implementation of laser-optical facilities providing high angular resolution of reception under application of appropriate atmospheric compensation methods. It is necessary to mark that implementation of laser-optical systems with high angular resolution rate incident to them results in the necessity for application of a more complicated system of near-Earth space environment supervision in the run of space debris elements' searching, and also employment of methods for detection, path tracing and parameter evaluation of orbits containing space debris fragments. However, the enterprise already possesses technical solutions and means developed during creation of the first country's laser radar LE-1 in the early 80's.

Generally, employment of traditional optical means (telescopes) for space environment monitoring encounters a number of difficulties.

Firstly, this task's solution is impossible without creation of wide-aperture telescopes on the basis of large-size optics. In fact it seems possible to perceive elements of about 1-meter size at a distance of up to 10^3 kilometers with a telescope of 1-meter diameter. At the same time such equipment can not cope with tasks concerning imaging of objects featuring size of ≈(0.1-1.0) m and less at distances of ≈10^4 km.

Telescope systems with aperture D > 10 m are required for fulfillment of such tasks. Creation of such systems employing large-size diffraction optics seems to be a very expensive and, evidently, unmanageable task. Expenses for manufacturing of optical elements grow in D3 way, the requirements for metal framework and optics control increase. But, even in case of coping with all the above-mentioned difficulties, one will face the influence of atmospheric surface layer's optical heterogeneity, which sidelines capabilities of traditional systems. Application of adjustable optics for correction of atmospheric distortion during observation of dynamic objects seems to be inefficient and, maybe, technically impossible in change-over for large-diameter telescopes (D≥10m).

The "SPA Astrophysica" FSUE's long-term experience of development and creation of laser-optical space environment monitoring systems (SEMS), including the only SEMS optical radar 30Zh6 on the Euro-Asian continent, prove that further increase of resolution and penetration capability is related to pass-over to aperture synthesis optical systems. Application of such systems provides:

- decrease of large telescope's weight without using new and more expensive materials and frames due to reduction of width of separate sub-aperture's mirrors;

- decrease of cost and time necessary for manufacturing of an optical radar system featuring high angular resolution;

- possibility of simultaneous detection of many objects.

There are three basic configuration concepts of aperture synthesis systems. However, according to the analysis of production and operation problems, only the concept of telescopes' matrix on separate mountings is capable of providing necessary resolution of space debris fragments. Achievement of high angular resolution in separate telescopes' matrixes is based on combination of pre-detection dynamic processing of light radar signal's field, which is necessary in space-temporal aperture synthesis, and after-detection statistical processing of images captured in matrix, which is necessary in synthesis of space-frequency content of object's intensity recoverable distribution.

The aperture synthesis optical technology constitutes the basis of the ground space debris monitoring system's processing channel. Along with it, two more channels must be integrated into the system: the channel of image demodulation on the basis of the technology involving image background's processing and the channel of image processing on the basis of parallel architecture of computing facilities' interfacing and program-algorithmic support of captured photo images' digital correlation processing.

In particular, the analysis of probable types of optical image (photo, CCD and TV) detectors displays that the preferable variant of detector channel's configuration is a scanned raster pattern's TV detector on the basis of superkremnecon with an IIT-type image amplifier which operation in the image's photon counting mode provides necessary penetrating capability of an optical system.

The practical implementation of the space debris monitoring optical system is related to development and creation of a number of materials, devices and technologies on which the "SPA Astrophysica" FSUE has accumulated considerable scientific-technical back-log, and these are the following:

- new design materials and covers for telescopes and mirrors;

- new configuration of wind-directed telescopes' matrix;

- lightened mirrors featuring diameter of 3-5 meters with required profiles and curvature radiuses of high-accuracy high incurvature;

- laser interferometers and range sensors for high-accuracy measurement of optical path length;

- automated systems of monitoring and control of matrix optical elements' position, which provide their guidance and phasing adjustment;

- detector counting photons in a parallel action image, optical and IR high-sensitivity wave bands, large amplitude range, low resolution and photons' large number;

- algorithms and means of real-scale images processing;

- observed object's identification algorithms invariant with respect to offsets, scales and object's image angle.

Along with the presented variant of space debris monitoring optical system's creation, the enterprise is engaged with development of other options and technologies. The latest results of research work carried out by the "SPA Astrophysica" FSUE and the P.N.Lebedev Physics institute of RAS (PI of RAS) testify that there is a real feasibility of achieving an image of objects having 0.1 m in size at a distance of $\approx 10^4$ km without using large-size optics, and at the same time the distortion effect of atmospheric surface layers does not impact the image quality.

Such an approach is based on object's image acquisition on its speckle structure through detection of temporary intensity shift of superweak laser emission, received from an observed object, in a number of points determined by the task with further diffractive images' regeneration and their analysis through results processing by a computer.

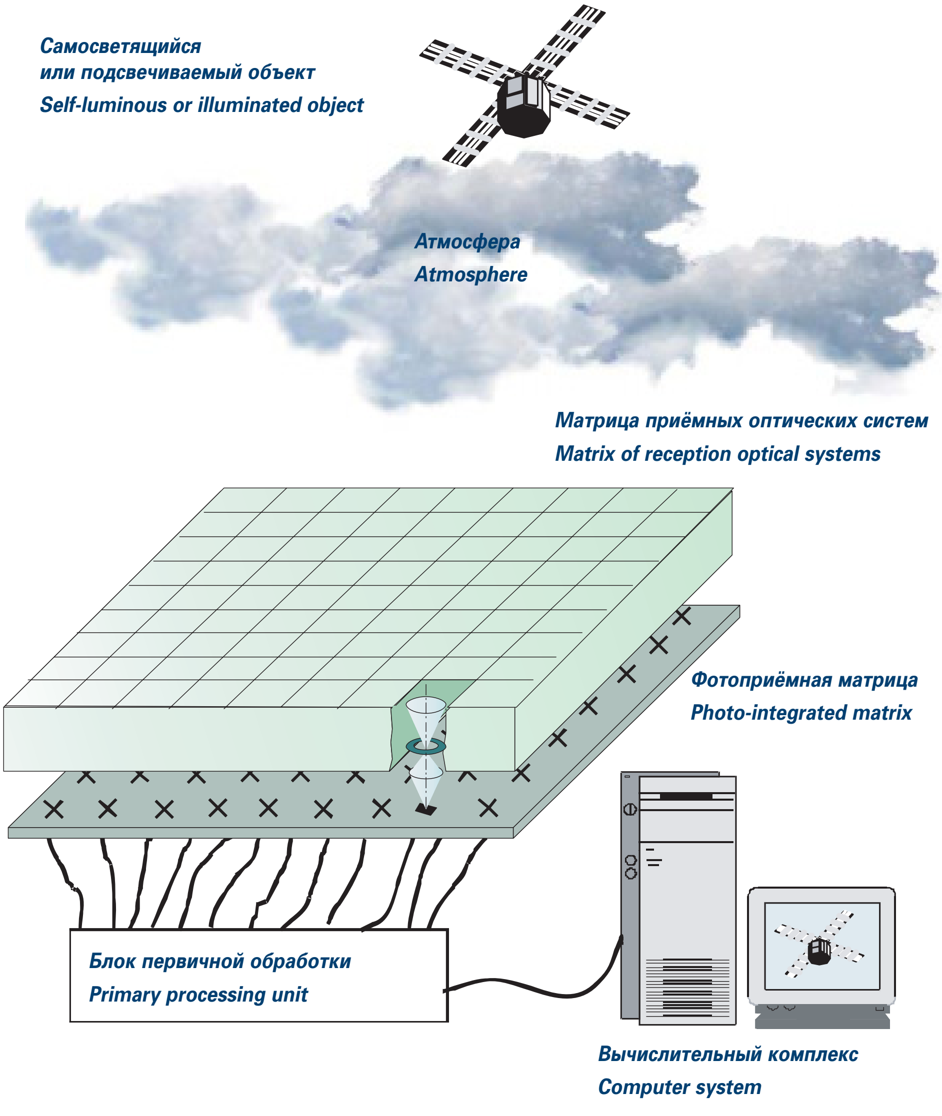
In order to create such systems, some basic research is to be executed on the following problems:

- reception and amplification of laser signals, including images, on the basis of induced scattering methods;

- imaging (image regeneration) of remote small-size objects with diffraction resolution, their analysis and identification through processing of optical fields and images;

- creation of high-dimension reception optical systems' matrixes and efficient methods of space surveillance and objects' tracking.

It is important to note that development of technologies, necessary for creation of efficient space debris monitoring systems, has been conducted within the framework of other specific projects at the enterprise, and creation of the system itself requires considerable financial assets.



Телескоп интенсивностей сверхвысокого разрешения.
Superresolution intensity telescope.