OJC «RPC «Precision Systems and Instruments», Moscow, Russia

A. Alexandrov, V. Shargorodskiy

On the possibility to create a prototype of laser system for space debris movement control on the basis of the 3-meter telescope.

2012

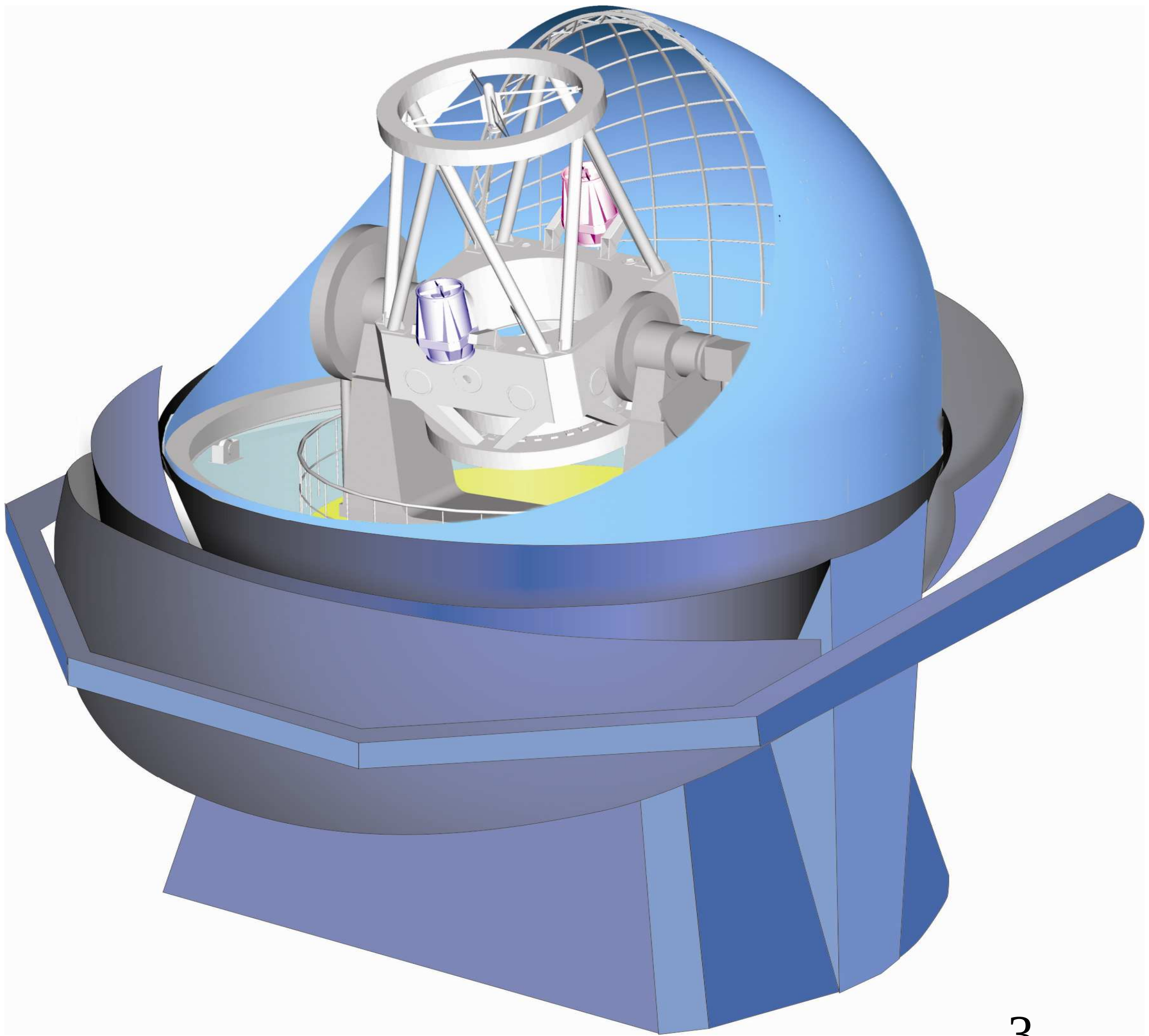
Problem of Orbital Debris Removal

Urgency of the problem of elimination of space debris (SD) today is as evident as ways of its solution are not. Laser methods of solution of this problem occupy a prominent place among the options considered.

Large number of theoretical works, which are devoted to laser method of impact on SD, consider light pressure and material removal (evaporation, ablation) for thrust generation. We believe, it is time to consider the possibilities for experimental verification of the laser method. (Laser ablation is the process of removing material from a solid surface due to laser spark).

For understandable economic reasons, the creation of demonstration system is reasonable with the use of existing instruments or ones being created now. We have considered the possibility of using of three-meter telescope for the system prototype to control the movement of debris.

Model of the large 2nd stage telescope of the Altay optical-laser center with the main mirror of 312 cm



Selection of an impact method

Considering peculiarities of laser radiation pressure method and the laser evaporation of the material method, we have excluded these methods from the list of the suitable options for thrust generation on SD.

The first of these methods allows to apply a pressure force to space debris object, comparable to action of «solar wind» and, in our opinion, has small practical interest.

Evaporation of a material due to the laser heating, discussed in a number of works, can lead to unpredictable results due to possible rotation of irradiated object.

Influence of short powerful pulses on the object that can provide ablation of the space debris material, will allow to obtain the appreciable thrust which acts, as a rule, along laser radiation. Its threshold level is the basic drawback of this method. Depending on a kind of a material of space debris, the threshold density of the pulse power, necessary for ablation, lies within $10^6 \ldots 10^8$ W/cm^2.

Key problems

For the solution of a problem of the directed change of momentum and, accordingly, change of movement parameters of space debris objects it is necessary to solve some key problems.

First, to develop technologies for detection and identification of space debris objects.

Second, to generate powerful laser radiation with high axial light intensity and close-to-diffraction divergence.

Third, to refine targeting technology and delivery of powerful laser radiation through turbulent atmosphere to irradiated object without appreciable increase in divergence with accuracy in the order of an arc second.

The first of these tasks is already being implemented.

Let us consider two last ones in detail.

Choice of type of the laser

The threshold character of ablation practically unambiguously restricts the choice of illumination source to solid-state lasers.

This type of laser has a wide band gain for generating short pulses and is well-established technologically. The best candidates for a demonstration facility are lasers using glass and crystals with neodymium, and ytterbium fiber lasers with large-diameter fiber (up to 300 μm).

Leader in the design and manufacture of fiber lasers is IPG company, which announced lasers with an output power of 50 kW with a reasonable divergence of the output radiation at wavelength of λ = 1,04 ... 1.08 μm.

In addition, our corporation together with the Institute of Laser Physics (St. Petersburg) is considering the development and use of a laser with a coherent phasing of 18 channels, with the following main characteristics:

Laser characteristics

Wavelength of radiation, μm	1064.
Energy of pulse (Σ 18 channels), J	50-60.
Frequency of pulses, Hz	100-300.
Average power, kW	6-15.
Pulse length, ns	10.
Pulse power, GW	5-6.

Divergence of radiation in the central spot of the far-field region of the phased aperture is not more than two diffraction angles.

Laser pumping - pulse light-emitting diodes.

Continuous work time– not less than 3 minutes.

The quoted above laser parameters were used for computation of numerical estimations.

Problem of light transmission

The basic problem of light transmission is optical inhomogeneity of turbulent atmosphere which for example can be illustrated by the following values, typical for the Altay`s optical-laser center, located on a free-standing hill with height 636 m above sea level:

Good conditions – 1 ″. 5 ($\mathbf{r_0}$, =9.3 cm);

Average conditions – 3 ″. 0 ($\mathbf{r_0}$, =4.7 cm);

Where $\mathbf{r_0}$ – Fried parameter at wavelength 0.55 μm.

It is evident, that even in good conditions the beamwidth of laser light will have value within 1 ″ … 2 ″ and will substantially exceed diffractive limit ~0.07 ″ for the wavelength 1.06 μm.

Problem of light transmission

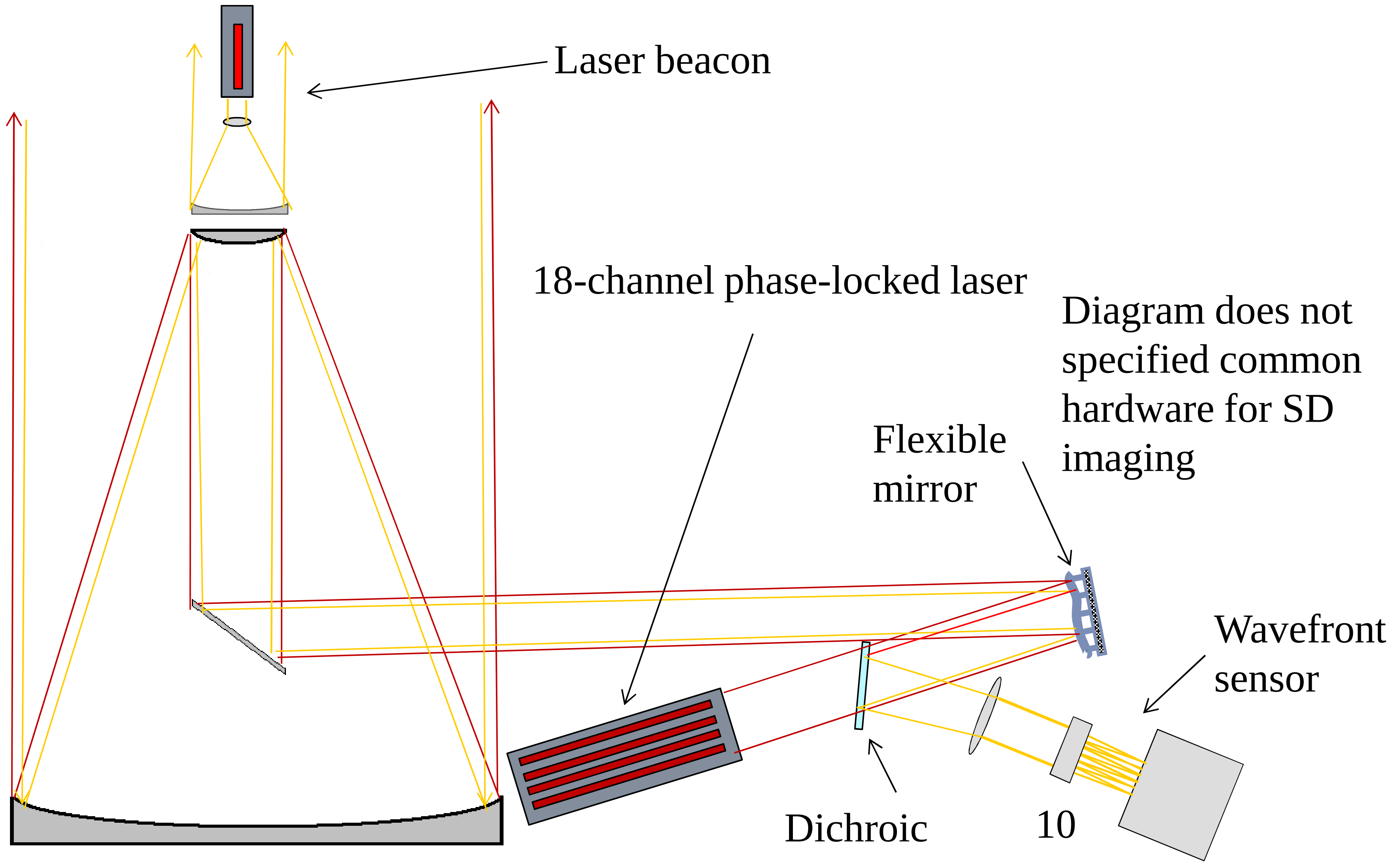
Compensation of atmospheric turbulence is possible by methods of linear and non-linear adaptive optics. The use of nonlinear optical laser illumination concentration presented at a conference in the report of employees of IAP I.A.Gorbunov and O.V.Kulagin (Institute of Applied Physics, Russian Academy of Sciences, N.Novgorod, Russia).

We have considered the possibility of application of the linear adaptive optics because high initial quality laser beam, provided by phase-locked aperture, allows to compensate effectively for phase distortions of wave front related to turbulence of atmosphere.

We have done engineering evaluation of the feasibility of demonstration experiment using a transmitting-receiving adaptive optical system (AOS).

For the operation of the wavefront sensor it is convenient to use solar light reflected from the space object.

Simplified scheme of demonstration experiment



Problem of light transmission

Since not all the debris objects have sufficient brightness, it is necessary to create an artificial laser start ("laser beacon") as a part of 3-m telescope system to ensure work of transmitting adaptive system with a "weak" space object and to support efficient operation of the wavefront distortion sensor.

For the operation of the adaptive system, we considered the use of a sodium laser star with average power 100W. With good agreement of the used laser spectrum and Doppler absorption spectrum of the sodium atoms, one can obtain $\sim 1.5 \times 10^4$ photon/cm^2 at the entrance aperture of the 3-m telescope at a zenith angle of 45 °.

For AOS, working for reception and transmission with 469 control channels and radial-ring structure of zones location, the flow of photons is $\sim 2 \cdot 10^6$ photons /s for each control channel. Such a flow of photons of the reference source will allow to build AOS with feedback time constant below 1 ms.

Problem of light transmission

In our numerical evaluation we have estimated the errors of wavefront spatial approximation with flexible mirror surface, wavefront sensor noise errors, time- dependent error of the phase conjugation, associated with a rapid change in the position of the object relative to atmospheric irregularities .

As a result, with good conditions of the experiment (and we can choose time of experiment) for the laser with the above characteristics on the slate range 400 km we can expect to receive the pulse power density of ~ $3 \cdot 10^6$ W/cm^2. This value is close to the lower range of the ablation threshold power. Therefore, for a demonstration experiment we have to use a special target coated with a material with low threshold for ablation.

The spot size of exposure in the experiment will be approximately 40 cm.

Expected results of the experiment

Preparation and carrying out of demonstration experiment will allow:

• to refine coupling of a powerful laser with a large-size satellite telescope, including the use of adaptive optics and optical radiation transport, formation of the exit pupil, etc.;

• to gain practical experience in the application of artificial reference source ("laser star") for high-accuracy formation and alignment of the laser radiation on the space object in the conditions of turbulent atmosphere;

• to refine a full operating cycle for space debris object, starting with its detection and identification and ending with control of changes of its vector of motion.

Finally, and most importantly, a successful experiment will pave the way for broad support for this important space development and technology path at national and international levels.