Measurement of anomalous angle of deviation of light during Satellite Laser Ranging

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Abstract

In this article the effect of anomalous deviation of light during satellite laser ranging is described. It is shown that it is not caused by telescope's deformations. Specially for study of this effect the measurement and data processing procedure was developed. First measurements' results are presented.

Introduction

The SLR station "Katzively-1893" of the Crimean Laser Observatory ranges satellites with laser beam with small angular divergence (about 5 arcseconds). Thus, we need high pointing accuracy to receive response signal from ranged objects. We discovered that in order to obtain strong signal, we have to make an advance not only for the velocity aberration, but also for an unknown factor that we call "anomalous deviation of light" that is comparable with velocity aberration by value but, as a rule, different by direction. First manual mostly qualitative observations were conducted in years 2001, 2002, 2004 [Ignatenko et al. 2004]. With installation of CCD camera in mid 2007 attached to computer with proper software we increased quality and quantity of observations. This allowed us to determine more precisely the anomalous deviation of light from the preset direction in the field of view of the telescope subtracting velocity aberration from apparent deviation of satellite's image.

Equipment

Scheme of the optical part of the Katzively SLR station is shown on the Fig. 1.
Main optical axes and focuses of the 1 m TPL-1 telescope with alt-azimuthal mount, the PMT, and the Nd:YAG laser with output wavelength 532 nm are superposed by means of the optical matching system (OMS). The OMS permits to set and control direction of emission and divergence of the transmitted laser beam. All elements of the OMS are mounted on immobile part of the telescope. Hence, all optical alignments are long-term stable. During the full telescope's alignment the artificial star of the OMS is set in the conjugate focal plane of the telescope so that its center represents telescope's main optical axis. Then all adjustments are made respectively to this star. Tuning mirror 8 (Fig. 1) is placed into its operating location unambiguously due to its special mount.

To prove that anomalous deviation of light is not caused by thermal or mechanical deformations of the telescope we conducted the following experiment: on the shutter of the dome two high-quality retroreflectors were set. The rotating mirror 7 (Fig. 1) is partially transparent (~ 1%). Through it and guide 6 we observed laser radiation reflected from corner cubes and passed twice through the telescope. While we rotated the dome and moved the shutter up and down imitating change of angular coordinates, the center of the reflected spot never deviated from projection of the main telescope's optical axis onto the field of view more than on 2 arcseconds.

Specially for measurement of anomalous angle of deviation of light the CCD camera was installed onto the telescope's main guide and calibrated by pairs of stars with known angular distance between them. Inequality of horizontal and vertical scales of the camera images also was taken into account. We have written a special program (in C++) that stores camera images on PC hard disk when station's measuring equipment detects laser pulse reflected from the satellite. Also we have modified standard software in order to calculate the projection of the satellite's velocity aberration onto the telescope's focal plane. Post-processing software for detection of the satellite image center and computation of the anomalous deviation was written too (in MATLAB).

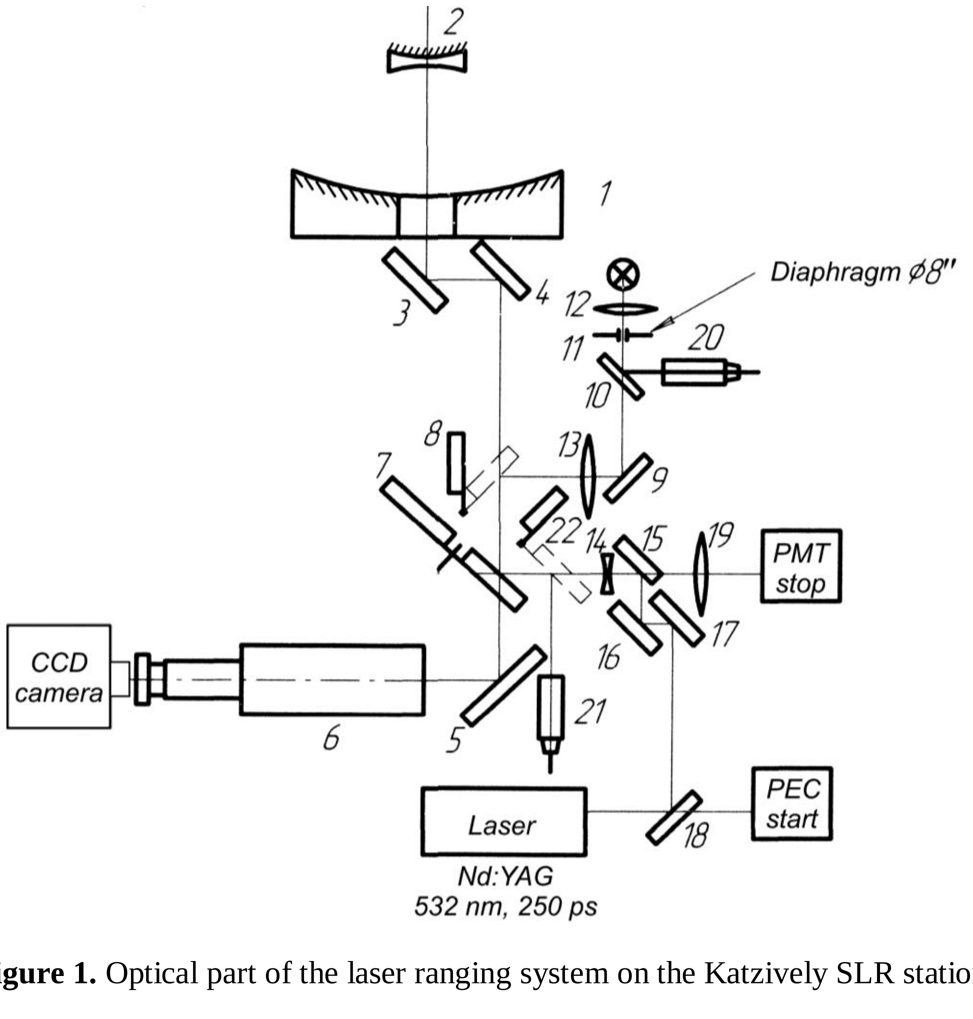

Figure 1. Optical part of the laser ranging system on the Katzively SLR station

i) TPL-1 telescope:
1 – primary mirror; 2 – secondary mirror; 3, 4, 5 – diagonal mirrors;
6 – main guide with chromatic aberrations compensator and image intensifier;

ii) Optical matching system:
7 – rotating mirror; 8, 22 – tuning switch mirrors; 13, 14, 19 – matching lenses;
9, 15..18 – mirrors; 10, 11, 12, 20 – artificial star; 20, 21 – oculars

Measurement and data processing procedure

During our observations laser radiation was directed along the telescope's main optical axis, divergence was 5 – 8 arcseconds. We checked it before each night, when observations were conducted, and corrected in case of need. At the same time the artificial star's image was captured and a virtual guide mark was placed on the monitoring computer's screen.

Throughout the satellite's passage operator corrected telescope's pointing in order to obtain strong response signal from satellite's retroreflectors. At moments, when we received echoes, video frames were stored on the PC.
While postprocessing of the obtained images we determined positions of the projection of the telescope's main optical axis onto the focal plane (from pictures of the artificial star) – point A on Fig. 2, and of the satellite's center – point B – in Cartesian coordinate system bounded to the telescope's focal plane. To remove outliers in determination of the satellite's position we used median filtering and sliding average by each coordinate. Then we found the sequence of vectors $\mathbf{AB}$ of the observed deviation of the satellite. For the corresponding instants we calculated the vectors of the satellite's velocity aberration $\mathbf{AC} = 2\mathbf{v}/c$, where c denotes the speed of light and $\mathbf{v}$ is for projection of the satellite's velocity onto the field of view of the telescope. In addition, the direction of the vector $\mathbf{AC}$ was controlled by sequence of frames with the same star passing through the telescope's field of view. So, the vector of anomalous deviation of light was computed as $\mathbf{CB} = \mathbf{AB} + (-\mathbf{AC})$.

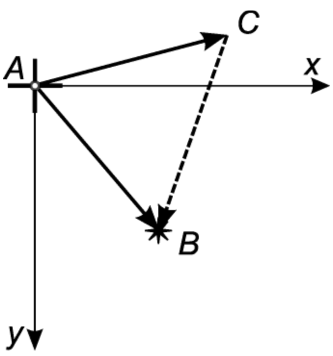

Figure 2. Computation of the anomalous deviation of light

Results

From March until November 2007 using described hereinbefore procedure we observed near a hundred passes of various satellites. We processed only those passes which satisfied the following criteria: the number of signal points was greater than 100 (operating laser rate is 3 Hz), the satellite's image was not too bright and its diameter was less than 8 arcseconds (this allowed to avoid image intensifier's afterglow and determine the image center more precisely), the duration of the pass was long enough (5 – 12 minutes for LEO, 15 – 30 minutes for LAGEOS, 30 – 60 minutes for HEO), the atmospheric conditions permitted to obtain more or less uniform sequence of signal points, the satellite's elevation was greater than 20° above horizon for LEO and exceeded 30° for LAGEOS and HEO.

On the Fig. 3, 4 the results for two LAGEOS-1 passes are shown. On the Fig. 3A, 4A the vector diagrams represent the change with time of the measured apparent deviation $\mathbf{AB}$ (curve number 1 on the figures), the vector opposite to velocity aberration $\mathbf{CA} = (-\mathbf{AC})$ (2), and the anomalous deviation $\mathbf{CB}$ (3) in the telescope's field of view. The arrows indicate the beginning of the observations. Angular scale is in degrees; absolute values are in arcseconds. On the Fig. 3B, 4B the time dependency of the absolute values of the vectors $\mathbf{AB}$ (1), (2) and $\mathbf{CB}$ (3) is plotted. We would like to note that there is a several months' interval between shown on these two figures observations. It is clear that the directions of the vector $\mathbf{CB}$ differ for different epochs.

On the Fig. 5 the maximal absolute values of the anomalous deviation of light **CB** for each processed pass of the LAGEOS-2 and Beacon-C satellites are presented. One can see the seasonal dependency of the investigated effect.

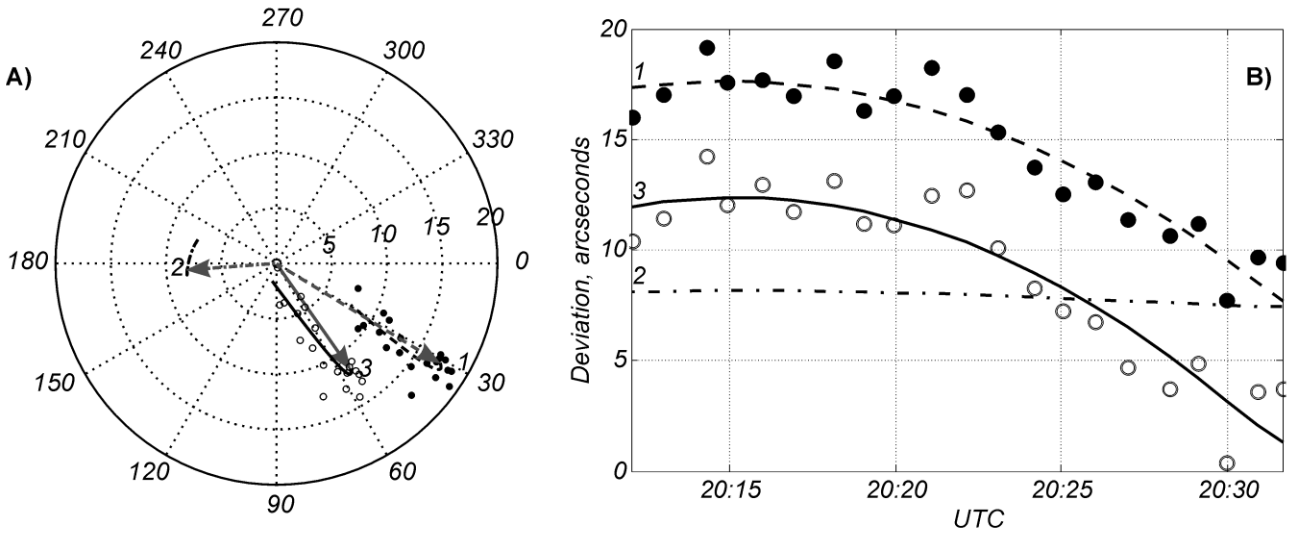

Figure 3. Satellite LAGEOS-1 March 20, 2007

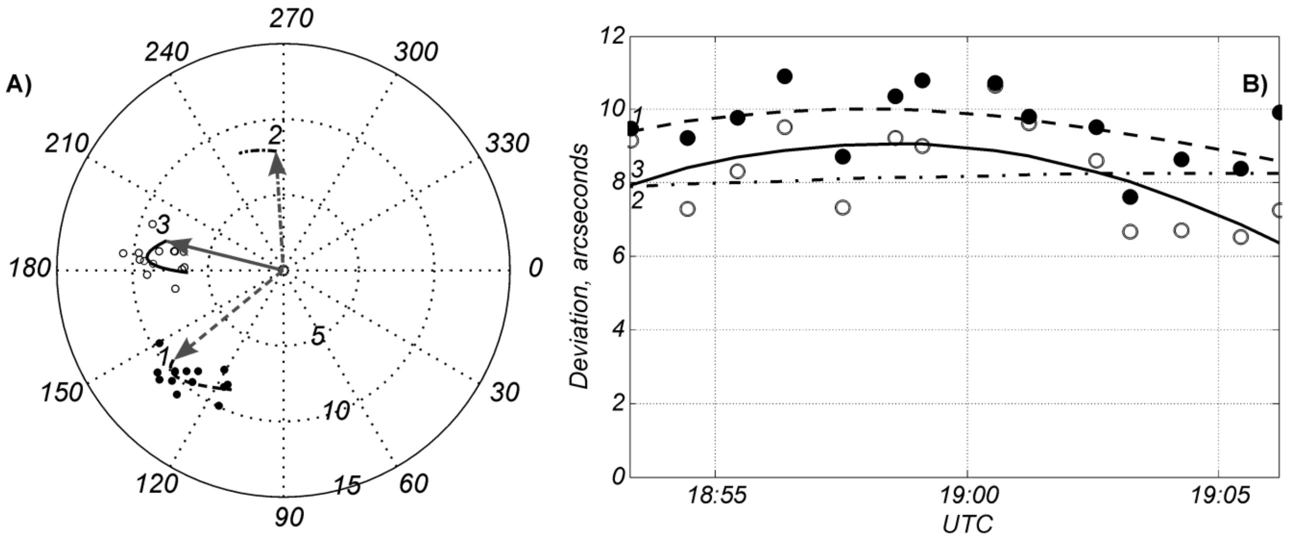

Figure 4. Satellite LAGEOS-1 July 28, 2007

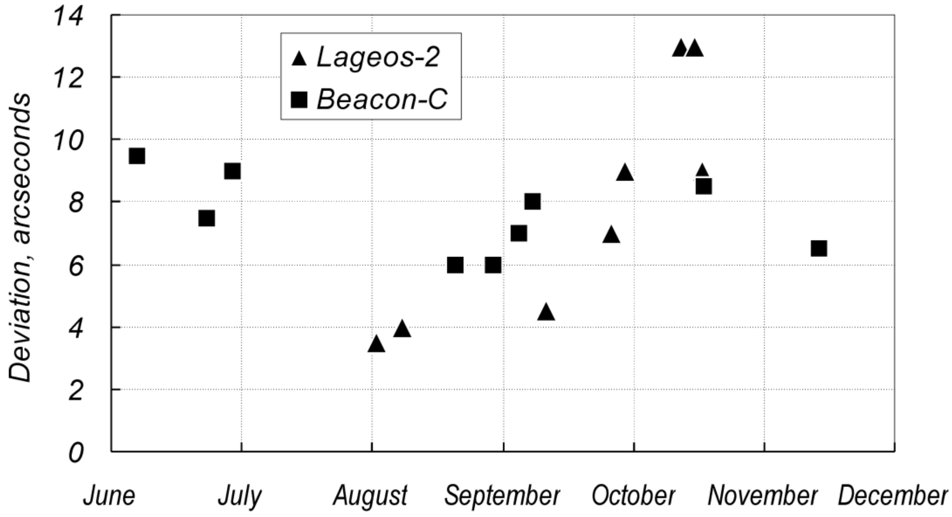

Figure 5. Seasonal dependency of the maximal absolute values of projections onto the telescope's focal plane of the anomalous deviation of light

Conclusion

Automation of measurements allowed us to improve quality and to increase quantity of observations as compared with ones held in 2004 and earlier. The method of automatic registration of anomalous deviation of light and data processing was developed.

First results indicate that the anomalous deviation of light attains 10 – 12 arcseconds and is comparable with velocity aberration by value but different in direction. The observed effect is seasonally dependent.

Further processing of obtained results needed. We are going to make an attempt to combine a 3D-vector of anomalous deviation from its different projections onto the telescope's field of view.

It is possible that observed anomalous deviation of light could be explained by motion of luminiferous medium in the near-Earth space relatively to the optical ranger.

Reference

Ignatenko Yu., Tryapitsyn V., Ignatenko I., *Determination of Speed Aberration While Laser Location of Earth Artificial Satellites*, Journal of Automation and Information Sciences, vol. 36, issue 4, 2004.