STEREOSCOPIC PRINCIPLE IN SPACE OBSERVATORY

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The scientific team (ST) of the Interplanetary Solar Stereoscopic Observatory (ISSO) has got the financial support to finalize the scientific determination study with the aim to investigate the full potential of the stereoscopic idea and technical possibilities to realize the space stereoscope. The stereoscopic principle will work with optimal effectiveness in space under conditions of the stable stereoscopic base during the whole time interval of the experiment. The main conclusion of the ST up to now is that the ISSO may be created as the observatory with the flexible program, being able to support the extended solar physics investigations and the star investigations for stellar astronomy and astrophysics, being especially effective in the 3D astrometric monitoring of the motion of Solar System bodies, including near-Earth asteroids.

INTRODUCTION

The scientific program of the project under development is directed, firstly, to ensuring of comprehensive investigations of three-dimensional phenomena both in the fine structure of the solar atmosphere and in solar geo-effective interactions with their evolution during at least one helio-cycle (11 years). At the starting study [6–8] it was realized that only the observations from essentially different two directions will supply the necessary space and time resolution and singularity of the long-live monitoring of the solar phenomena. The instruments in the Earth's vicinity, space and ground-based, are reasonable to use as the third fundamental direction.

The second part of investigation is the extended program of the 3D measurements in the Solar System based on the stereoscopic principle. The dynamical stability of the spacecrafts motion in the vicinity of the librational points L_4 and L_5 (Fig. 1) was investigated by the high-precision numerical integration of differential equations of the motion. The numerical theory of the both spacecrafts motion was constructed and tested. We use the differential equations of the barycentric motion of the spacecrafts as well as the Sun, major planets, and the Moon in the form of the well-known Einstein–Infeld–Hoffman relativistic equations [5].

The result of this integration serves as the keystone in the choice of the ISSO configuration and spacecrafts navigation.

CONCEPTION OF THE MEASUREMENTS

Our approach is schematically shown in Fig. 1. As any real observatory, the ISSO could be designed with the wide flexible program, and can be realized as the mono or constellation of spacecrafts in vicinities of both trigonal centres SSEMB (system of the Sun – "Earth–Moon Baricentre").

In any case, it is planned that the measurements are performing in the coordinate system of the high-precision astrometric catalogue and software packages placed on both spacecrafts (SC) that will enable one to solve, in the autonomous mode, the following problems: 1) the calculation of the ephemeris positions of the Earth, Moon, major planets and their satellites, asteroids and comets having orbits based on the DE/LE numerical ephemerides; 2) access to the star catalogue data and calculation of astrographic coordinates and brightness of stars over the whole sky; 3) the numerical theory of the motion of zero mass bodies (both SC are considered as the zero-mass bodies in three-body problem of celestial mechanics) in the vicinities of the libration's centres in the SSEMB. This scheme assumes the advanced aboard processor with conformed operating system and timing system. Celestial sphere aboard is presented by the modern catalogue in the ICRS with the star density

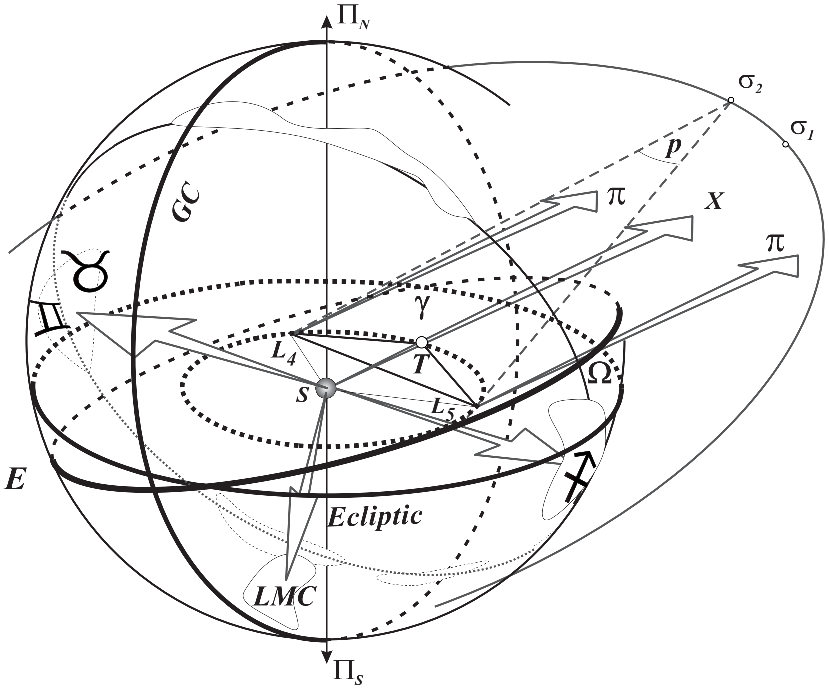

Figure 1. Observational situation and overview programs. Π_N and Π_S denote poles of ecliptic, E_q is the plane of celestial equator, Ω is the node of the Galaxy plane on equator, γ is the point of the vernal equinox, L_4 and L_5 denote the triangular libration's centres in the SSEMB as the vertices of the equilateral triangles STL_4 and STL_5 with the sites equal to astronomical unit a. Stereoscopic system consists of three bases: $B = L_4L_5 = a\sqrt{3}, B_4 = L_4T = a, B_5 = L_5T = a$. Triangle L_4L_5T is rotating around the Sun S with an annual period as a quasi-solid body. The Sun is accessible for an observation from three directions spread at the angles 60° over the whole lifetime in almost stable and homogeneous conditions. The double stars and stellar astronomy tasks are optional to observe in a direction of the great circle $\Pi_N GC \Pi_S$, with the L_4L_5 continuation as the poles. The microlensing events are most probable in the directions to the centre and anti-centre of Galaxy marked by their zodiac signs, and in the direction to Magellanic Clouds (LMC). The Solar System bodies' σ_1, σ_2 observations, as determinations of the parallax angle p and the 2D object positions on the celestial sphere, are carried out in opposite side to the Sun S symmetrically to the great circle $\Pi_N GC \Pi_S$ which play the role of the classic "meridian" of the ISSO. The perspective arrows mark the best sphere sector for the star parallaxes determination, X denotes the Sun–Earth direction

sufficient for the CCD-registration. The DE405/LE405 numerical ephemeris is to be used as the reference link for this navigation. The accuracy of this frame is near to $0.002''$ in all directions.

SCIENTIFIC PROGRAM OF ISSO

Stereoscopic observations with a high spatial resolution will be effective for the solution of the most actual problems in solar physics, that were outlined in [1, 6, 8].

Apart from determination of the three-dimensional distribution and dynamics of hot and cold loops in the corona, separation of inner motions in the loop from the motion of the loop as a whole, loop-loop interaction mechanism, and a detailed picture of magnetic field line reconnection, determination of the 3D-structure of the velocity field, determination of the 3D-picture of the appearance and development of solar flares, the main time will be used to stereoscopic observations of appearance and development of coronal mass ejection (CMEs) and the form and trajectory determination of CMEs in the corona and interplanetary space, and of the acceleration mechanism. The advantage of this CMEs monitoring in the stereo mode consists of the early detection of the phenomena evidence at the east solar limb.

By analyzing the phase relationships of global oscillations from two (or three – with observations from the ground) directions, it becomes possible to identify acoustic non-radial oscillation modes which are important for the helio-seismology, for the study of internal rotation and internal magnetic fields, as well as gravitational oscillations having at the surface a predominantly horizontal velocity component. Stereo observations will improve the accuracy of determination of frequencies, lifetime and amplitude of individual acoustic oscillation

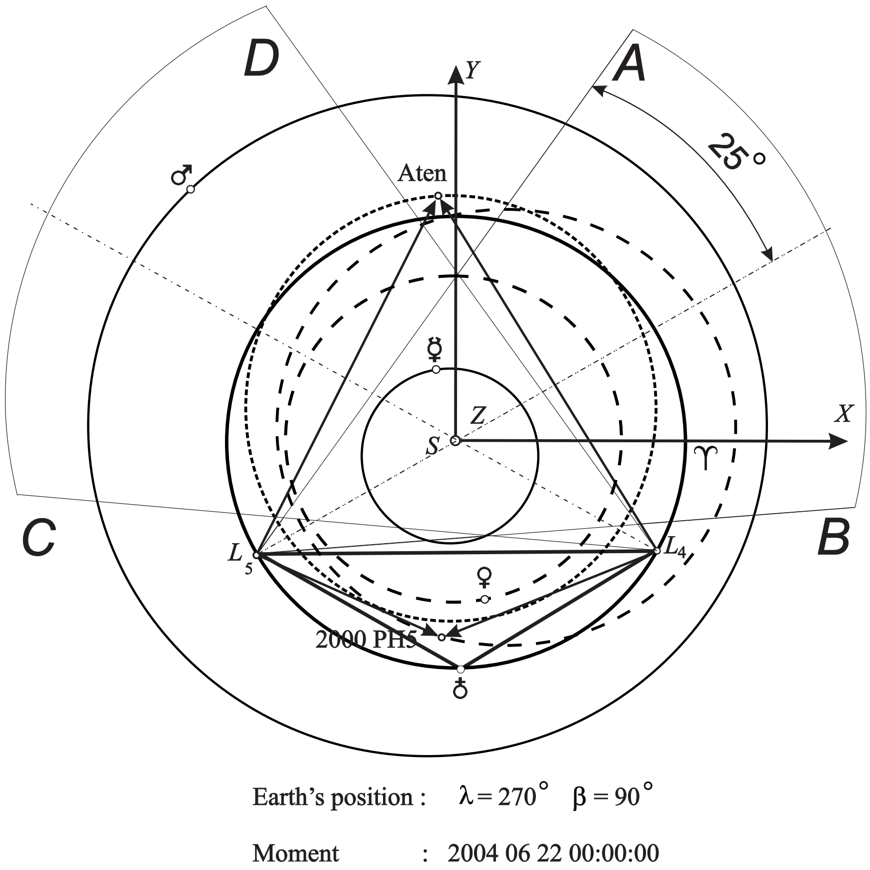

Figure 2. Control of the space area, where the NEAs are moving. Both spacecrafts enable one to observe the area near to the Earth's orbit as the separate existent instruments in the directions out of cones AB and CD with the vertexes in L_5 and L_4, respectively, each with the angular radius 25° – the inescapable angular distance to the Sun's direction to avoid the light-striking of the astrographs. An observation of the body out of both cones is possible in a very stereoscopic mode, as it is shown for the real dispositions of two NEAs – 2062 Aten and 54509 2000 PH5 – for June 22, 2004

modes, based on analyzing the velocity field almost throughout the 5/6 of the Sun's surface.

Such monitoring combined with measurements of interplanetary parameters (solar wind velocity, interplanetary magnetic field, and particle energy and composition) makes some questions of predicting the "weather in space" evident and makes it possible to switch over from prediction to warning. The observations of the east apparatus of the ISSO (in the point L_5, Fig. 2) must enable one to build the bridge from the prognosis to the warning of dangerous phenomena of the solar activity. Namely, this possibility will be the leading idea to settle the Lagrangian libration points by the research complexes in the incoming future.

The choice of the adequate aboards equipment is outlined shortly in [8]. Investigations are in progress on the basis of the up-to-date experience and methods in the solar physics.

The full downlink from ISSO is estimated to reach 6.5 GB per day in solar physics part of the program. The same order of downlink is expectable from astrographs, in astronomical part of the program.

The astronomical possibilities of the experiment as the additional or freestanding potential of the project, in our opinion, present the fundamental interest also, especially in verifying by observations of those facts and appearances, the uncertainty of which is not yet eliminated from the analysis of the ground-based data.

Particularly, it concerns the microlensing phenomena, for singular monitoring of which in the stereoscopic mode and with space distribution of the ISSO instruments [1, 2, 6], including and combining with the ground-based observational support, can supply the crucial verifying observational material. Modelling of the stereo measurements [3, 4] shows their effectiveness in the construction of the new opened body's orbits.

Triangulation or 3D-position vector measurements of Solar System bodies, monitoring of the whole space area where the near-Earth asteroids (NEA) are moving, Fig. 2, are planned as the main part of the astronomical program, where the stereoscopic mode gains an advantage over the one-directional classic observations.

It is evident that the alternative (to classical one) system of parallaxes π of near stars can be gained by the direct triangulation in stereoscopic mode ($\Delta x_i = B\pi$, B being the stereoscopic base), taking the advantage especially for the double and multiple star measurements.

To reach this level, it is offered to use the astrographs with the limiting magnitudes $\approx 21^m$–22^m and the diffraction quality of images in the field of view with angular diameter $\approx 1°$ as a basic instrument. The interferometric optics for the mission is being studied as well, since its usage supplies the highest resolution in principle.

INSTALLING AND AUTONOMOUS NAVIGATION REMOTE CONTROL

The ISSO spacecrafts installation and exploitation in far space, during a long period, is not possible without a perfect aboard navigation system. Such system is designed as two-channel instrument [1] with the help of which it is possible to determine the navigational directions with the singular observation accuracy $\sigma_1 = 0.02''$. The short series of the observations permits one to reduce the error to $\sigma_s = 0.005''$, *i.e.,* to the error $\sigma_r = 3.75$ km at a distance of $1a$. Since the control of heliocentric motion is possible only relatively to Solar System bodies' directions, then the problem of extending the dynamical brightness diapason arises. The usage of two-channel instrument permits one to measure bright images of planets and faint stars in the CCD-system of registration with approximately the same accuracy. In our modelling we used the new catalogue UCAC2 [`http://ad.usno.navy.mil/ucac/`]. First results show that series of 25 observations with the weekly interval, by the unfolded navigation instrument, permits us to control the disturbed heliocentric orbit with accuracies $\sigma_r \simeq 2 - 5$ km in radius-vector and $\sigma_{angl} \simeq 0.02'' - 0.02''$ in angular motion, depending on the geocentric distance to the spacecraft. The booster timing at the final forming of orbits near the targeted Lagrangian centres requires the accuracy $\varepsilon_t \simeq 3.5$ s in command impulse time for deceleration or acceleration. Proposed system permits one to get almost two orders more accurate timing.

CONCLUSION

It is impossible to give a wide overview of the stereoscopic projects in a short paper. But comparing with the other stereo projects, we consider that observations will be more valuable, under all other equal terms, if they are performed in stable conditions of a long-live space observatory. In our opinion, an experiment of such type is necessary to master the space with particular properties in vicinity of the Lagrangian libration centres L_4 and L_5 of the SSEMB. The stability of librational motion of "zero-mass" bodies in these areas presents the interest for fundamental experiments, which is similar to the interest towards the geostationary orbit area, that was densely settled by researching complexes already at the end of the 20th century.

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