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M. S. Chubey, G. I. Eroshkin, V. V. Pashkevich

SPACE STEREOSCOPIC OBSERVATORY PROJECT

Abstract. The Interplanetary Solar Stereoscopic Observatory (ISSO) is designed for the long-time series of the Sun and the Solar system bodies observations. The basic principle is stereoscope with the stable base, that is planned to be realized by inserting two identically equipped spacecrafts (SC) into the vicinity of the triangular Lagrange's libration points of the "Sun – barycenter of the Earth and Moon" system. The scientific program in the project may include two sets of experiments related to the solar-terrestrial physics and to celestial mechanics, stellar astronomy and astrophysics respectively. The coordinate frame in the project is planned to be presented by FK6 system (catalogues ICRS, Hipparcos, Tycho-2). The accuracy of the angular measurements is planned to be reached the milliarcsecond level. The main conception and solution for the problem of the base stability is presented.

1. Introduction

The stereoscopic vision with the base of $\sim$ 6–7 cm had been the first natural basic ground of the human evolution in its 3-D geometric adaptation in the world. Just this is the principle that lies in the origin of all scale systems in the modern astronomy as well. The maximum usage of the principle is possible in the stable stereoscopic mode of the astronomical observations.

The creation of the Interplanetary Solar Stereoscopic Observatory (ISSO) was proposed by Grigoriev V. M., [1]. Extended scientific objectives and programs are described in [2].

It appears that the stereoscopic mode with the baseline equal to $a\sqrt{3}$ (a is astronomical unit) is suitable for the Sun activity processes 3-D monitoring, for receiving the 3-D measurement series for the Solar system bodies and star positions during the ISSO's lifetime. The extended investigation of the planetary aberration, based on observations of major planets and their satellites, minor planets and the direct distance determinations for all planets and the Kuiper's belt objects and the simple and quick way to create their orbits, and the principally new direct determination of the star parallaxes — all these topics are the main parts of the project [3].

2. Conception of the measurements

Our approach is schematically shown on the Fig. 1.

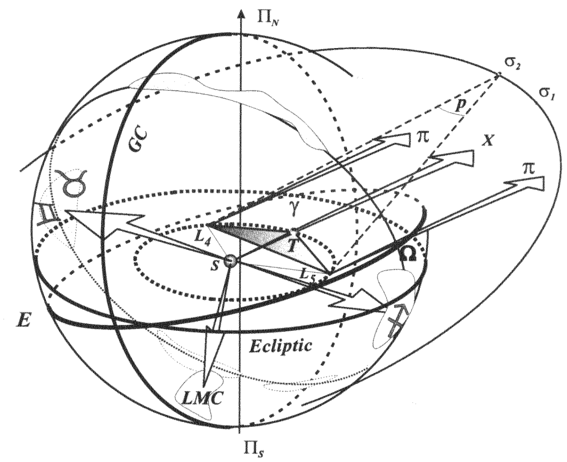

Fig. 1. Observational situation on celestial sphere: Π_N and Π_S – poles of ecliptic, $E\Omega$ – plane of celestial equator, Ω – the node of the Galaxy plane on equator, γ – point of the vernal equinox. L_4, L_5 are the triangular libration centers in the system "Sun — Earth and Moon barycenter" as the vertices of the equilateral triangles STL_4, STL_5 with the site equal to astronomical unite a. The star parallaxes are optional to observe in a direction of a great circle $\Pi_N GC \Pi_S$, with the $L_4 L_5$ continuation as poles. The microlensing events are the most probable on the directions of a center and anti-center of Galaxy marked by their zodiac signs, and also in the direction on Magellanic Clouds LMC. The Solar System bodies' observations σ_1, σ_2 are carried out in opposite side to the Sun S symmetrically to the great circle $\Pi_N GC \Pi_S$ as determinations of the parallax angle p and the 2-D object positions on the stellar background. The perspective arrows π mark the best direction of both instruments for the star parallaxes determination which are parallel to X – the Sun - Earth direction.

It is supposed, that the measurements are performed in the coordinate system of the high-precision astrometric catalogue FK6 and the following software is on both spacecraft boards, running in the autonomous mode:

1) The software package for the calculation of positions of the Earth, Moon, major planets and their satellites, asteroids having orbits in the system of theories DE403/LE403 ([4]) or later versions;

2) The catalogue and software for the calculations of the astrographic star positions and their brightness over the whole sky;

3) The numerical theory of the motion of two zero mass bodies in the vicinities of the triangular libration points in the system "the Sun – the Earth+Moon barycenter";

4) The advanced onboard processor with a conformed operating system and timing system.

The celestial sphere is represented by the modern catalogue (Tycho-2, Hipparcos, ICRS). The DE403/LE403 ephemerides are to be used as the references link for this navigation. Accuracy of this frame is near to $0''.002$ almost in all directions.

3. Dynamical aspects of the motion of Spacecrafts in the vicinity of the librational points L_4 and L_5 and the choice of initial conditions of movement

The equations of the orbital motion of the zero-mass spacecrafts are solved simultaneously with the equations of the orbital-rotational motion of the major bodies of the Solar system. The geometric sense of the coordinate frame and introduced variables are shown on Fig. 2. The differential equations of the barycentric motion of spacecrafts as well as those of the Sun, major planets, and the Moon are the well-known Einstein-Infeld-Hoffman relativistic equations:

$$
\begin{aligned}
\ddot{\bar{R}}_i = &\sum_{j\neq i} Gm_j \frac{\bar{R}_j-\bar{R}_i}{{\Delta_{ij}}^3}\left\{1-\frac{1}{c^2}\left[\dot{\bar{R}}_i^{\,2}-2\left(\dot{\bar{R}}_i-\dot{\bar{R}}_j\right)^2+\frac{3}{2}\left(\frac{\bar{R}_j-\bar{R}_i}{\Delta_{ij}}\cdot\dot{\bar{R}}_j\right)^2\right.\right.\\
&\left.\left.+4\sum_{k\neq i}\frac{Gm_k}{\Delta_{ik}}+\sum_{k\neq j}\frac{Gm_k}{\Delta_{jk}}-\frac{1}{2}(\bar{R}_j-\bar{R}_i)\cdot\ddot{\bar{R}}_j\right]\right\}\\
&-\frac{1}{c^2}\sum_{j\neq i} Gm_j\left(\dot{\bar{R}}_j-\dot{\bar{R}}_i\right)\left[\frac{\bar{R}_j-\bar{R}_i}{{\Delta_{ij}}^3}\cdot\left(3\dot{\bar{R}}_j-4\dot{\bar{R}}_i\right)\right]\\
&+\frac{1}{c^2}\sum_{j\neq i} Gm_j\,\ddot{\bar{R}}_j\cdot\frac{7}{2\Delta_{ij}},
\end{aligned}
\tag{1}
$$

where $\bar{R}_i = \bar{R}_i\,(x_i, y_i, z_i)$ is the barycentric radius-vector of the body with the mass m_i; here and further dots over the letters mean the differentiation with respect to time; G is the square of the Gaussian gravitational constant; $\Delta_{ij}^2 = (\bar{R}_j - \bar{R}_i) \cdot (\bar{R}_j - \bar{R}_i)$; the point between the vectors means their scalar product; c is the light velocity; $i,\ j = 1, 2, 3, \ldots, N$, where N is the number of the Solar system bodies in the problem.

The right hand sides of equations (1) are completed by the terms representing the body-body gravitational interaction, as well as the tidal interaction in the Earth-Moon system. Equations (1) are also completed by the differential equations of the rotation of the Moon. The differential equations of the orbital-rotational motion are those of the mathematical model of the DE403/LE403 ephemerides.

Figure 2 represents the coordinate system of the modelling problem. The initial conditions of the motion of the spacecrafts in the projection to the coordinate axes are determined by the initial conditions of the orbital motion of the Earth–Moon barycenter:

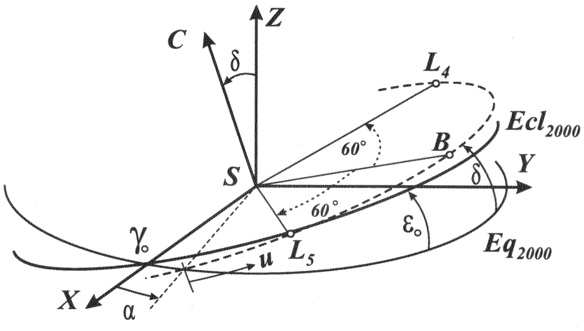

Fig. 2 The coordinate system in the model.

$$\left.\begin{aligned} x_L - x_S &= r_{BS}[\cos\alpha\cos(u \pm 60°) - \sin\alpha\sin(u \pm 60°)\cos\delta], \\ y_L - y_S &= r_{BS}[\sin\alpha\cos(u \pm 60°) + \cos\alpha\sin(u \pm 60°)\cos\delta], \\ z_L - z_S &= r_{BS}[\sin(u \pm 60°)\sin\delta], \end{aligned}\right\} \qquad (2)$$

$$\left.\begin{aligned}
\dot{x}_L - \dot{x}_S &= \dot{r}_{BS}\frac{x_L - x_S}{r_{BS}} - \dot{\alpha}(y_L - y_S) + \dot{\delta}\sin\alpha(z_L - z_S)\\
&-\dot{u}r_{BS}\left[\cos\alpha\sin(u \pm 60^o) + \sin\alpha\cos(u \pm 60^o)\cos\delta\right],\\
\dot{y}_L - \dot{y}_S &= \dot{r}_{BS}\frac{y_L - y_S}{r_{BS}} + \dot{\alpha}(x_L - x_S) - \dot{\delta}\cos\alpha(z_L - z_S)\\
&-\dot{u}r_{BS}\left[\sin\alpha\sin(u \pm 60^o) + \cos\alpha\cos(u \pm 60^o)\cos\delta\right],\\
\dot{z}_L - \dot{z}_S &= \dot{r}_{BS}\frac{z_L - z_S}{r_{BS}} + \dot{\delta}r_{BS}\sin(u \pm 60^o)\cos\delta\\
&+\dot{u}r_{BS}\cos(u \pm 60^o)\sin\delta,
\end{aligned}\right\} \quad (3)$$

where α is the right ascension of the "Earth–Moon barycenter" orbit node, δ is the orbital inclination, u is the orbital longitude, r_{BS} is the modulus of the vector $\bar{r}_{BS} = \bar{r}_{BS}\,(x_B - x_s, y_B - y_s, z_B - z_s)$.

As the result of the numerical solution of the indicated system of the differential equations we receive the orbital-rotational motions of the major bodies of the Solar system, very close to the DE200/LE200 ephemerides, and dynamically consistent to this ephemerides motion of the spacecrafts. On Figs. 3, 4 we present the zero mass body's motion in the polar coordinate system near both libration centers. The general control of our integration is presented on Fig. 5.

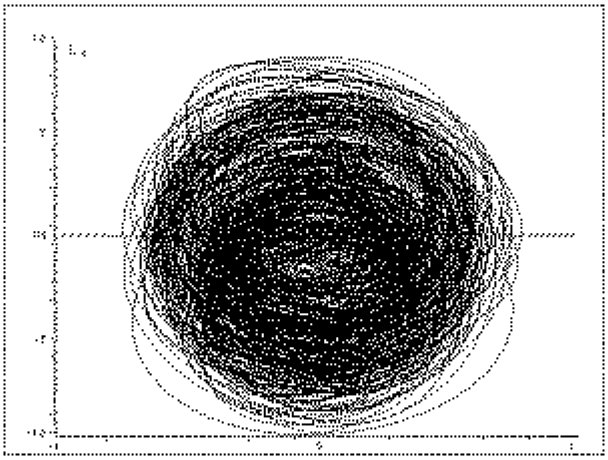

Fig. 3. Orbital libration of the orbit spacecraft in vicinity of L_4 point at the time interval 1969 – 2070 years.

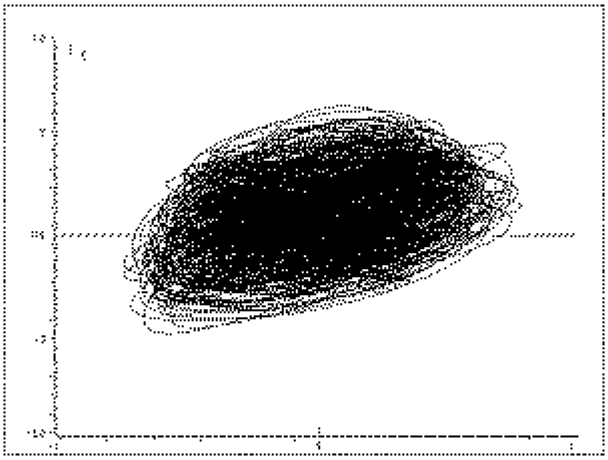

Fig. 4. Orbital libration of the spacecraft in vicinity of L_5 point at the time interval 1969 – 2070 years.

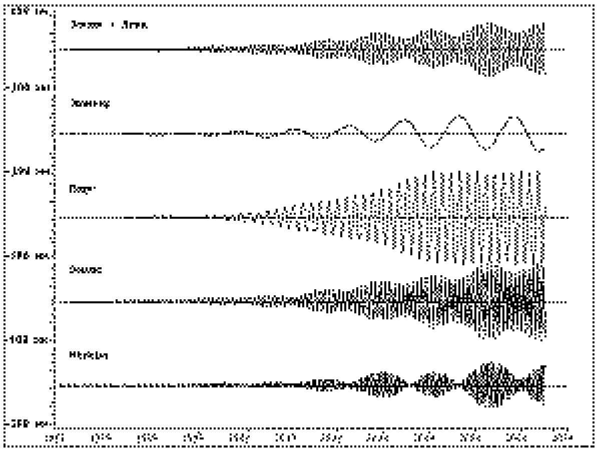

Fig. 5. Comparison of the positions of the Solar system bodies, received in the result of the integration, and the DE200/LE200 Ephemeris.

4. Discussion and conclusion

Evaluations presented on Figs. 3–5 approve our assurance in the possibility to create the space stereoscopic observatory with the stable triplet bases: $L_4L_5 = a\sqrt{3}, L_4T = a, L_5T = a$, (Fig. 1). The main technical problem consists in the installation of both spacecrafts into the vicinity of the librational centers: there are no massive bodies there and the very "inserting" must be performed inside the "empty" space – the strictly defined point on the orbit of the Earth. We have a solution of this problem [3] consisting in the special device and the autonomous navigation procedure. Our approving procedure confirms the possibility to realize the series of the experiments in the XXIth century during the long time, in which the librational centers will be used with the same necessity as, for example, the geostationary orbit was settled in the XXth century by the communicative and research satellites.

References

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Pulkovo astronomical observatory
E-mail: E-mail: mchubey@gao.spb.ru

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