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SUB-MILLIARCSECOND ACCURACY WITH THE STRUVE ASTROMETRIC SATELLITE

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ABSTRACT

The Struve astrometric satellite which is being developed at Pulkovo Observatory in cooperation with Krasnoyarsk Institute of Applied Mechanics, S.I.Vavilov's State Optical Institute and some others space instrumentation institutes, will produce observations of a second epoch for the Hipparcos stars. The project is devoted to maintaining the Hipparcos coordinate system as well as extending it to a density of $\approx$ 100 stars per square degree. Possibilities of submilliarcsecond accuracy of observations with single aperture on-board telescopes are discussed. Requirements to the optical scheme and to the dynamic properties of the spacecraft are formulated. CCD and microchannel plates are discussed as a focal assembly detectors.

Key Words : space astrometry, Hipparcos, Struve

I. INTRODUCTION

Essential improvement of the fundamental coordinate system is expected in 1997, with completion of the Hipparcos satellite data reduction. Two high precision catalogues of positions and proper motions of stars will be published soon by ESA with mean accuracy of 2 milliarcsecond (mas) for 118000 Hipparcos stars and 30 mas for about 10^6 Tycho stars.

In order to maintain the accuracy of the Hipparcos reference system, second epoch observations are need. Various proposals exist in different countries to launch second epoch astrometric satellites. One of the most ambitious projects is a small astrometric interferometer (GAIA) with the stated accuracy of about 30 microarcsecond of positions and proper motions of stars in its output catalogue (Lindegren & Perryman, 1995).

A future Russian astrometric satellite (named Struve) is supposed to be launched within the next decade, and it is aimed at increasing the projected density of the reference system representation up to about 100 stars per square degree of the celestial sphere, that is $\approx 4.1 \cdot 10^6$ stars in the output catalogue (Yershov *et al.*, 1995).

The Struve satellite will use single telescopes, rather than interferometric systems. However, using modern optical techniques and advanced photodetectors one may achieve submilliarcsecond accuracy of star positions in the output catalogue.

II. OPTICAL PARAMETERS

Two optical parameters are of great importance for achieving high accuracy of image location: the diffraction limited size of the image and the number of detected photons. For the initial design of the Struve on-board telescopes (40-cm semi-circular aperture) one may expect approximately 20000 visual photons from a 14 mag. star during its transit over the field of view (24 seconds for one-square-degree field of view, while the rotation of the satellite is 10 turns per day).

Taking into account the fact that the dispersion of photons within the star image is approximately 100 mas (the radius of the Airy disk is 300 mas for visual wavelengths), one may calculate the potential accuracy of the image location being 0.7 mas. However, the error of a single transit observation is estimated 5-10 times larger (4-7 mas) due to optical aberrations, imperfectnesses and insufficient resolution of the detector, instability of the spacecraft dynamics, temperature gradients inside the instrument etc. This error is expected to be reduced in the output catalogue down to $\approx 0.6 - 1.0$ mas by multiple observations of each object during the 2.5-year period of the work.

III. STABILITY

New techniques developed at the S.I.Vavilov State Optical Institute (St.Petersburg), allow the increase of the entrance pupils of the on-board telescopes up to 61 cm while keeping the mass and size of the Struve payload close to those of the initial variant of the project (the spacecraft has been designed by the Krasnoyarsk Institute of the Applied Mechanics, and the weight of the astrometric instrument must not exceed 800 kg). SiC was chosen for the optical elements; this keeps the instrumental parameters very stable.

It is very important that the focal length of the telescopes and also the basic measuring angle be very stable (at least during one 2.4 hours revolution of the satellite). The principle of an elementary measurement is similar to that of the Hipparcos satellite: while star images of two different parts of the sky pass through one combined field of view, the image detector measures separations between these stars.

The scale of the image and the value of the basic angle must be known in order to calculate real angular distances between stars. Any changes of scale and of basic angle will influence the accuracy of observations.

Analysis of the Struve optical design shows the focal length of the on-board telescopes must be retained within 0.2 mm range near the normal position in order to keep optical aberrations at the diffraction limit level. At the same time, the submilliarcsecond accuracy of observations implies stronger restrictions on the focal length stability, namely 0.1 mm on the time scales of 2.4 hours.

With 61 cm apertures one may estimate that the theoretical accuracy of one 24-second observation would be 0.2 mas. Therefore, the practically achievable accuracy is about 1 mas for a single transit and 0.15 mas for the output catalogue (about 50 transits during 2.5-year period of observations).

IV. ACCUMULATION AND INSTANT DETECTION

When using a CCD as the image detector which accumulates photoelectrons during all the transit time and with the 1 mas accuracy of a single observation, no vibrations of the spacecraft which exceed 0.1 mas displacements of the image, with frequencies higher than $0.2s^{-1}$ are acceptable.

A mosaic of 4 by 4 or 5 by 5 CCDs could be placed at the focus of the telescope, and the accumulation time would not exceed 5 seconds. This implies very strong limitations on the rotational stability of the spacecraft, about 0.00002 %. This is practically impossible to satisfy, and special devices should be used in order to measure the velocity of the image displacement and to adjust the clocking pattern of the CCD.

With a panoramic photon-counting detector, such as a microchannel plate (MCP) or, for example, a superconducting tunnel junction array detector, which is may be available during the next decade (Perryman et al., 1992) the basic integration time will not exceed 30 ms, that is, one pixel crossing time. In this case, the required stability of the spacecraft will be only 0.002 %, which is quite possible to satisfy.

MCPs with opaque photocathodes (for example, CsI) could be used as photodetectors (Yershov, 1995*b*). They have high quantum efficiency in the UV spectral range (comparable with quantum efficiency of CCDs for the visual wavelengths). Using the UV spectral range reduces dispersion of photons down to 20 – 40 milliarcsecond level. Thus, the accuracy of observations could even be increased to a few tens of microarcseconds.

The satellite is designed to have a very symmetrical shape, and the center of solar light pressure will be controlled in order to coinside with the center of mass of the satellite. In addition, no moving devices will be placed on board. Therefore, the satellite rotation will be very smooth, and submilliarcsecond accuracy of observations becomes achievable.

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