# PROJECT STRUVE

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ABSTRACT

We present the current status of the space astrometry and photometry project STRUVE which is being designed at the Pulkovo Observatory (Russia) in cooperation with other Russian space institutes in order to extend the Hipparcos reference system. This project will include about 20 million stars down to $V = 19.5$ mag. The proper motions of the Hipparcos stars are to be determined with the mean accuracy of about 0.1 mas/yr. The mean accuracy of star positions in the output catalogue is expected to be better than 0.6 mas. A properly designed micrometer will give the possibility of observing all objects on the sky down to $V = 14$ mag.

Key words: space astrometry; future projects.

## 1. INTRODUCTION

The space astrometry and photometry project Struve (Yershov et al. 1995) is being designed at the Pulkovo Observatory in cooperation with other Russian space institutes. It is expected that launch will be before 2010 and a mission duration of at least 36 months is planned.

The main objective is to extend, at the milliarcsecond accuracy level, the Hipparcos reference system to more faint objects, including quasars, and to get a second epoch for the Hipparcos stars. Project Struve along with the recently suggested project DIVA (Bastian et al. 1997) will fill the intermediate position between Hipparcos and microarcsecond astrometry. In contrast with DIVA, we propose a far more extensive astrometric and photometric survey.

We expect that the Struve Catalogue will contain about 20 million stars (the density is about 500 stars per square degree). A sky survey will be complete down to $V = 14$ mag (about 15 million stars), while selected objects down to $V = 19.5$ mag will be observed within a special part of the program. The proper motions of the Hipparcos stars would be determined with an accuracy of about 0.1 mas/yr. The mean accuracy of star positions in the output catalogue is expected to be 0.6 mas which could be achieved by proper design of the satellite (symmetry, smooth rotation, etc.), optics and the micrometer. A properly designed micrometer (with CCD arrays, special processors for image processing and compressing the data flux to the ground station) will give the possibility of observing all objects on the sky down to a definite limiting magnitude.

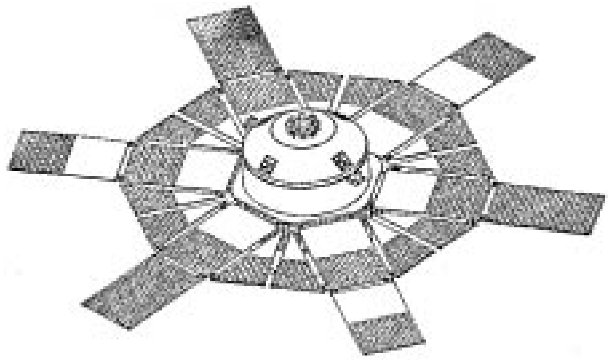

*Figure 1. The Struve satellite.*

## 2. TECHNICAL DESIGN

The satellite (Figure 1) has a cylindrical volume for instruments of 3 m diameter and about 2 m height, with solar panels of 3 m length. The mass is about 2500 kg. The satellite will be in a geostationary orbit. The scanning law is analogous to the Hipparcos one, with a similar Sun direction and a rotation rate of 150 arcsec/s. The satellite is being designed to rotate very smoothly in order to minimize observation errors.

Wide arcs on the sky along the scan direction will be measured by combining separate fields on the sky into one telescope. The basic measuring angle will be formed by a special beam combiner placed in front of the telescope. Two different basic angles (62 and 74 degrees) and two telescopes are planned to be used on board the Struve satellite, as this reduces systematic errors of observations (Makarov 1992). Both telescopes are to be folded inside a limited volume of the satellite (a cylinder of 3 m diameter and 1.5 m height).

Two optical schemes are undergoing design (Yershov

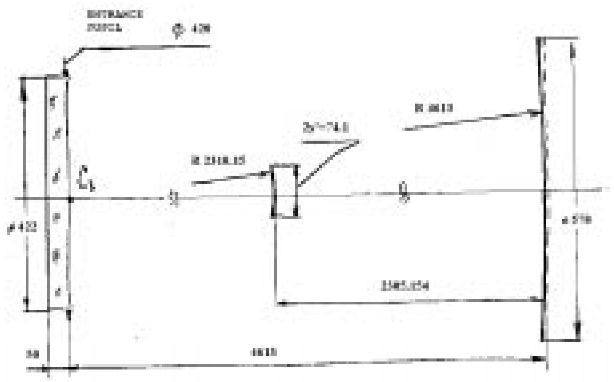

*Figure 2. Shortened Schmidt optics.*

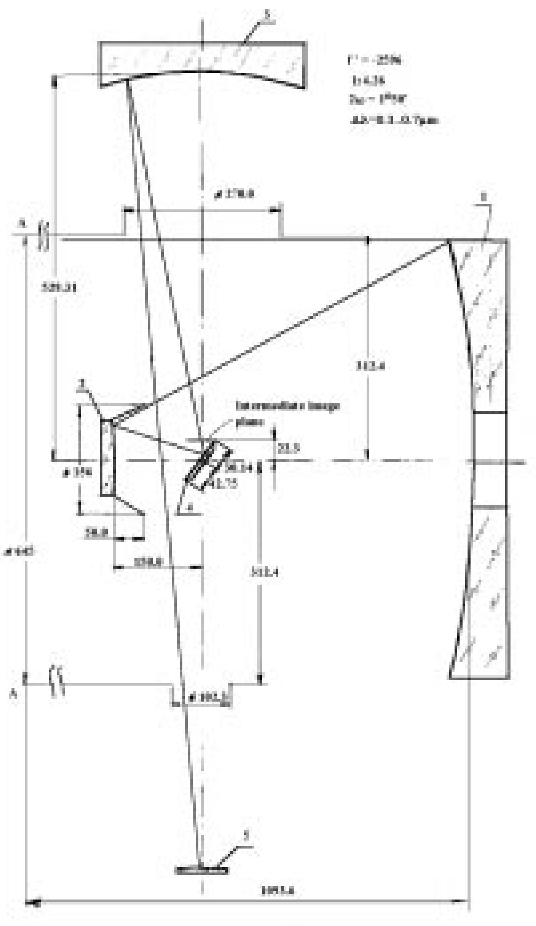

*Figure 3. Three-mirror objective.*

et al. 1997): a Schmidt optical scheme (Figure 2), and a three-mirror scheme (Figure 3). The main parameters for these schemes are summarized in Table 1. Two optical schemes of the Struve on-board telescopes provide close to diffraction-limited performance within more than a 1.5 degree field of view.

The focal surface of the Schmidt telescope is curved, and the CCDs are very difficult to fit on this surface.

*Table 1. Two options for the on-board telescope.*

| Characteristics | Schmidt | Three-mirror |
|---|---|---|
| Focal distance, m | 2.3 | 2.5 |
| Entrance pupil, mm | 420 | 610 |
| Image surface | Sphere | Plane |
| Sizes, m | D=2.6,H=1.66 | 2.6x0.6, H=1.1 |
| Mass, kg | 450-500 | 250-300 |

Some other optical systems with a flat focal surface (for example, Ritchey-Chrétien) gave no acceptable results, because they do not have symmetrical images within the necessary field of view.

Another disadvantage of the Schmidt telescope is that it is difficult to locate it within a compact space (the Schmidt plate must be located at double the focal length distance from the primary mirror and the diameter of the primary mirror is as large as the entrance pupil). That is why a three-mirror optical scheme has been also calculated for the Struve satellite.

The three-mirror telescope has a plane image surface. Moreover the second design, of approximately the same mass and of smaller size, gives the possibility of increasing the limiting magnitude of the instrument (down to 20–21 mag) because of its more than twice greater light collecting area.

Many telescope parameters will be included in the equations for the great-circle solution. Some of the optical parameters will be calibrated both on the ground and on board the spacecraft. Variation of scale could be measured with a special hologram placed on the surface of the primary mirror. This will focus the light emitted by illuminated marks at the focal plane of the telescope forming their images close to the original marks, by which it is possible to control the focal length. The same marks may be used to check distortion and chromaticity.

Each field of view is planned to be filled with a mosaic of relatively small CCDs (28 detectors with sizes $13 \times 15$ mm$^2$ each). 20 CCDs will be covered with colour filters (with a different number of filters for different spectral bands) in order to implement photometry of stars in the Vilnius 7-band photometric system (Straizys 1992). This photometric system with its $W, P, X, Y, Z, S, V$ bands appears to be optimal for the survey because it provides sufficient information for classification of objects and determination of their physical properties and chemical composition.

Each CCD array with square $16 \times 16$ $\mu m^2$ pixels will have a rigid adjustable base. The precision of the adjustment is about 4 $\mu m$, and is restricted mainly by the CCD flat surface which does not fit strictly the curvature of the telescope focal surface.

The data rate will be up to 90 Mbit/s, if all pixels are read out and transmitted to the ground. This number can be reduced to several Mbit/s or, better still, to 300–500 kbit/s by on-board data processing.

*Table 2. Mean errors of Struve photometry (spectral type AO V) for a mission duration of 36 months.*

| V mag | W | P | X | Y | Z | V | S | Wide band |
|---|---|---|---|---|---|---|---|---|
| 11 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | <0.001 |
| 12 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | <0.001 |
| 13 | 0.002 | 0.002 | 0.001 | 0.002 | 0.002 | 0.002 | 0.003 | <0.001 |
| 14 | 0.003 | 0.003 | 0.002 | 0.002 | 0.003 | 0.003 | 0.004 | <0.001 |
| 15 | 0.005 | 0.005 | 0.004 | 0.004 | 0.005 | 0.004 | 0.006 | 0.001 |
| 16 | 0.009 | 0.008 | 0.006 | 0.006 | 0.008 | 0.007 | 0.010 | 0.001 |
| 17 | 0.016 | 0.013 | 0.010 | 0.011 | 0.014 | 0.011 | 0.017 | 0.001 |
| 18 | 0.033 | 0.026 | 0.018 | 0.019 | 0.025 | 0.021 | 0.033 | 0.002 |
| 19 | 0.073 | 0.055 | 0.037 | 0.036 | 0.051 | 0.040 | 0.070 | 0.004 |
| 20 | 0.172 | 0.128 | 0.082 | 0.078 | 0.113 | 0.088 | 0.162 | 0.007 |
| 21 | 0.422 | 0.310 | 0.196 | 0.182 | 0.268 | 0.207 | 0.390 | 0.015 |

## 3. PERFORMANCE

The integration time is about 7 s for each CCD working in the Time Delay Integration (TDI) mode. In total, each transit lasts 35 s, and simulations show that a limiting magnitude of $V = 18$ mag is achievable in the Vilnius photometric bands, with $V = 22$ mag in the wide band. Simulations show that the accuracy of the CCD observations will be $\leq 0.7$ mas for the coordinates of a 14 mag star image, $\leq 7.0$ mas for the coordinates of a star with $V = 18$ mag (Table 3), $\leq 4$ mmag and $\leq 35$ mmag for Vilnius system photometry of 14 and 18 mag stars respectively (Table 2).

*Table 3. The predicted astrometric accuracies of star coordinates in the Output Catalogue.*

| V mag | rms errors (mas) |
|---|---|
| 8 | 0.1 |
| 10 | 0.1 |
| 12 | 0.3 |
| 14 | 0.7 |
| 16 | 1.8 |
| 18 | 6.8 |

## 4. CURRENT WORK

At present we are concentrating our work on the following lines of investigation:

- the modeling of observations by space telescopes and the software development for the future astrometric and photometric data reduction;
- the design of several new optical schemes (for example with the plane focal surface);
- the preparation of the on-board pilot-catalogue for attitude determination and for calibration;
- the dynamic modeling of the spacecraft.

## 5. SUMMARY

The Struve project will provide an extensive survey of 20 million objects down to $V = 19.5$ mag with the mean astrometric accuracy of coordinates about 0.6 mas, and 7-band photometry with an accuracy of several millimagnitudes. This project will be able to take up the intermediate position between Hipparcos and the future microarcsecond astrometry projects.

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