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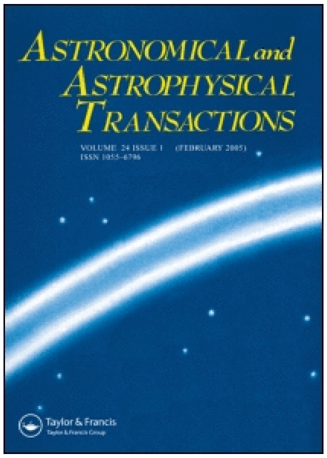

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NEAR-EARTH OBSERVATIONS BY WIDELY SEPARATED TELESCOPES

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We suggest the idea of a total-sky survey at the International Space Station by four small wide-angle telescopes with polarization filters and charge-coupled device arrays separated several metres from one another. The video information processing will be carried out by a real-time multiprocessor system on board the station. This experiment would allow us to observe the sunlit space debris and meteoroids of centrimetre size with estimations of their distances and velocities at distances up to 20 km from the station and to investigate the interplanetary and interstellar medium by making polarization sky maps and detecting the weak-contrast features on them.

Keywords: International Space Station; Space debris; Meteoroids; Polarization sky maps

1 INTRODUCTION

The investigations of the sky background that basically consists of zodiacal light are difficult to conduct on the ground because of the contribution of light from other sources and zodiacal light itself (Bernstein et al., 2002) scattered in the atmosphere. The translucent high-latitude cirri found by Infrared Astronomical Satellite (IRAS) were observed in the visual region by Cawson et al. (1986). Since the scattered light is sufficiently polarized, these features are better to search for on polarization sky maps. The space experiment with a polarization sky survey using wide-angle telescopes and charge-coupled device (CCD) arrays would allow us to investigate the distribution and properties of interplanetary dust and the size, shape and orientation of dust particles.

Another problem related to prolonged polarization background mapping is the possibility of discovering and investigating supernova echoes. Polarized spots with several years's variability should be observable (Maslov, 2000) around the locations of supernovae that were observed several centuries ago. Observations of these spots would give the information about the interstellar medium of our Galaxy. A search for these objects with non-polarized light was conducted by Van den Bergh (1966) with photographic plates and provided a nega-

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tive result, but using modern technique and image-processing methods allows us to move forwards with respect to this question.

Radar stations under space control are regularly watching for several thousand spacecraft and their fragments of sizes more than 20 cm. The smallest particles were recorded by the collisions with film screens (Long Duration Exposure Facility satellite) and spacecraft surfaces. However, experimental data about the medium-sized (about 1 cm) particles that are most dangerous for spacecraft are almost absent.

2 EXPERIMENT DESCRIPTION

The choice of the International Space Station (ISS) for this experiment was made for three reasons.

(i) Monitoring the near-Earth medium near the ISS orbit allows us to estimate the statistical parameters and to watch for bodies dangerous to the station without additional assumptions about their spatial distribution.
(ii) The size of the ISS allows us to separate the telescopes sufficiently for triangulation measurements.
(iii) Installation of devices on the often-visited station simplifies the changes in the data-processing program.

The main three goals of the experiment are as follows.

(i) To investigate distribution and properties of dust in the Solar System and Galaxy.
(ii) To obtain data about space debris and meteoroid particles of centimetre size near the ISS orbit.
(iii) To discover and observe asteroids, comets and variable stars.

The idea of the experiment is the following. Four small telescopes with an approximately 8° field of view installed on the ISS, watching in the same direction and observing the sky by using the continuous station rotation with an angular velocity of about $4^\circ\,\mathrm{min}^{-1}$. The information processing of CCD images is being carried out by on-board computers in real-time mode.

The comparison of light sources coordinates with the stars catalogue allows us to determine the exact orientation of the telescopes, to find unknown sources and to measure their position. The difference in these positions measured on different telescopes allows us to determine the distance to the object.

The reasons for using four telescopes are the following.

(i) Using two or more telescopes separated several metres from one another provides the possibility of determining the distance to the particle.
(ii) The recording of the track of fast-moving object by two telescopes with opposite CCD regimes (‘exposure’ on the first and ‘reading’ on the second and vice versa) allows us to determine the angular velocity of the object.
(iii) Using different axis directions of the polarizing filters of the telescopes, we can measure the linear polarization on both point and extended sources.
(iv) The failure of one telescope to work does not cause sufficient change to worsen the quality of the information remaining, making the conduction of experiments still possible.

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(v) The accuracy of measurements is better; the probability of discovering space debris or meteoroids or observation of an unusual event (a short-time burst, for example) increases.
(vi) An extension of the observable sky area is possible.

The telescopes are installed in pairs on two platforms with a vertical (relative to Earth) axis of rotation. The telescopes are watching in one direction at an angle of about 30–60° to the zenith. The distance between platforms should be not less than 5 m. The platforms turn the telescopes to the required sky region not subject to emission from the Sun.

3 DESCRIPTION OF THE APPARATUS

The apparatus complex consists of two of the same devices. The mass of each is not more than 40 kg, the size is 940 mm × 550 mm × 550 mm, which makes their transfer and installation on the ISS possible.

The telescopes were developed at the Space Research Institute based on Star Sensor (Ziman, 1994) which is now successfully working on the geostationary communication satellite Yamal 100. The basic parameters of the telescopes are shown in Table I. The telescopes are able to work at angles down to 30° from the Sun and from the Earth horizon. Adding to the video information, they supply the parameters of each image orientation, which simplifies further information processing.

The information-processing-and-saving device is the special on-board computer being developed at the Space Research Institute. It consists of

(i) two processors of Intel 486 type with a frequency of 66 MHz,
(ii) an energy-independent flash memory not less than 8 Gbits and
(iii) special modules based on programmed logical matrices for fast image processing.

One such device can process information from two telescopes. If we use a second device for two telescopes, either it will be a reserve telescope or we shall have the possibility of processing debugging and comparison of programs. The basic way to pass the information to Earth and to edit programs is by copying using the ISS server and changeable information holders.

4 ALGORITHMS AND PRINCIPLES OF INFORMATION PROCESSING

The input information flux is the sky images made by four telescopes each second. This flux fills the memory of the comuters in several minutes, which is why information compression is necessary. It is better to do this in order to have complete astronomical data (such as maps,

TABLE I Characteristics of Telescopes.

Lens diameter	26 mm
Focal distance	58 mm
Visible area	$8^\circ \times 8^\circ$
Spectral range	0.5–1.0 μm
CCD format	512 × 512
Angular resolution	$1'$
Information reading period	1 s
Noise of reading	$100e^-$

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catalogues, light curves, etc.) at the output. The sources in the images can be classified as follows.

(i) By extension:
  (a) point sources: stars and star-like objects (for $1'$ resolution);
  (b) tracks: the trace as a straight line made by a moving object;
  (c) extended sources: the source with angular size from $1'$ to several degrees;
  (d) background: the source with angular size more than the visible area.
(ii) By time averaging:
  (a) model: given initially, with parameters correction during the experiment if necessary;
  (b) momentary: present in just one image;
  (c) current: present on the map obtained by the addition of images in a single sky survey near the source;
  (d) seasonal: present on the map obtained by the addition of images during several months of work (until the data passes to Earth).

The tracks and point source information will be saved in the catalogues, and the extended sources and background in the $2'$-resolution sky maps.

Finally, we shall obtain the following information:

(i) the last 200 sky images;
(ii) point-momentary-sources catalogue;
(iii) point-current-sources catalogue with variability data;
(iv) current sky map;
(v) tracks catalogue;
(vi) seasonal sky map;
(vii) current maps of some sky regions;
(viii) some sky images.

The apparatus model is given by the ‘dark image’, ‘flat-field image’ and point spread function (PSF) of a point source depending on the orbital declination where the survey was made.

The computer memory holds the background sky map and stars catalogue that are the sky model for a given spectral region. The deflections from this model are recording during the survey, which makes the search for new and variable sources easier. The model image is the sum of the background map and point sources taking into account of the PSF.

We suggest the following processing sequence:

(i) Correct the output sky images using the ‘dark images’ and ‘flat-field images’.
(ii) Subtract the model image with the model point-sources brightness correction.
(iii) Make a photometric calibration by the model stars in the visible area.
(iv) Search for tracks and new point sources in images with the subtracted model and include in the tracks and point-momentary-sources catalogues.
(v) Create a current sky map with a size of about $10^\circ \times 10^\circ$ using the images with subtracted tracks and point momentary sources.
(vi) Search for weak tracks, stars and extended sources in the current map.
(vii) Obtain information about the brightness of sky regions from the current map including the seasonal map.

The seasonal map of the whole sky with $2'$ resolution requires a memory of about 200–300 MBytes for each telescope, if compression is not taken into account. The apparatus parameters and sky model are being corrected during the time of the experiment and changing after the data has been passed to Earth. Polarimetric and parallactic measurements are made on the basis of maps and catalogues obtained by different telescopes.

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5 EXPECTED RESULTS

The accuracy of a single position measurement of an object relative to the stars is $1'$. Since the stationary and slowly moving objects are being recorded about 100 times in one crossing of a visible area, the average-squared accuracy can reach $6''$. The same accuracy can be attained for track position measurement perpendicular to its direction, since this estimation is made by about 500 pixels.

The sensitivity of the telescopes (within S/N level equal to 1) will have a magnitude of about 10 for point objects. The accuracy of photometric measurements for bright star-like objects will be about 10%. The magnitude of the object present in all images obtained during a 2 min survey and the magnitude of the track can be estimated with an accuracy of 0.01–0.02.

The magnitude of space debris or meteoroid with albedo about 0.1 and size D, flying at the distance r with tangential velocity v_t can be estimated by using the Bagrov–Vygon (1998) formula

$$m_* = -31.1 + 2.5 \log\left(\frac{r^2}{D^2}\frac{v_t}{r}\frac{1}{\beta}\right), \tag{1}$$

where β is the angular size of one image pixel which is equal to about 3×10^{-4} rad. Corresponding to this formula, a fragment with size equal to 1 cm, flying at 20 km from ISS with velocity 40 km s^{-1} will be recorded by the telescopes as a track of magnitude 10, that is with an S/N ratio equal to 1. With decreasing velocity or distance, the S/N ratio will increase proportionally to these parameters.

If we increase the distance between the telescopes to 5–6 m, then the parallax of the fragment at a distance equal to 20 km will reach $1'$ and it will be possible to measure it with 10% uncertainty.

The angular velocity of slow-moving (from 0.001 to 1° s^{-1}) fragments can be measured by the displacement of the object in different images. Having measured the angle between the tracks recorded by CCD matrices of two telescopes (in 'exposure' and 'reading' regimes) we can determine the angular velocity of fast-moving (from 0.1 to 8000° s^{-1}) fragments. The velocity of a meteoroid equal to 40 km s^{-1} can be measured from a distance of 300 m.

Thus, the apparatus will be able to find and measure the brightness, angular velocity and distance and to estimate the size of all space debris and meteoroids larger than 1 cm, flying at distances from 1 to 20 km. If the flux of such fragments is dangerous because of possible collisions with the station once per 10 years, then they will be revealed by this apparatus complex several times per day.

Polarimetric observations will be conducted by the comparison of object brightnesses at four telescopes with different polaroid axes. For extended objects with size more than 1° it is possible to measure polarized light with intensity equal to 10^{-4} from the background (Sholomitskii et al., 1999), using a large number of pixels. Sky mapping prolonged for the several years would decrease this value for one more order and investigate the detailed features of Galactic background and zodiacal light variations.

6 CONCLUSION

The experiment would allow us to obtain the following:

(i) the distribution and scattering parameters of interplanetary and interstellar dust by prolonged regular polarimetric sky mapping;

(ii) statistical estimations of concentration, velocities and sizes of space debris and meteoroids near to the ISS orbit;
(iii) data about novae at early stages before they had been recorded by ground-based observatories (especially at small angular distances from the Sun) and statistical characteristics of bursting and variable stars.

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