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SPACE TELESCOPES “PLANETARY MONITORING” (PM) AND “ZVEZDNY (eng. STAR) PATROL” (ZP) FOR PLANETARY SCIENCE AND EXOPLANETS EXPLORATION

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ABSTRACT

"Mankind will not forever remain on Earth, but in the pursuit of light and space will first timidly emerge from the bounds of the atmosphere, and then advance until he has conquered the whole of circumsolar space"
(1911, K. Tsiolkovsky)

Solar System planetology requires a wide use of observing spectroscopy for surface geology to atmosphere climatology. A high-contrast imaging is required to study and to characterize extra-solar planetary systems among other faint astronomical targets observed in the vicinity of bright objects. Two middle class space telescopes projects aimed to observe Solar system planets by a long term monitoring via spectroscopy and polarimetry. Extra solar planets (exoplanets) engineering and scientific explorations are included in science program.

I. INTRODUCTION

The Space Research Institute of Russian Academy of Science (IKI RAS) currently develops two middle class space telescopes projects aimed to observe Solar system planets by a long term monitoring and aimed to study extra solar planets (exoplanets) via engineering and further scientific goals [1, 2].

(1) The Planetary Monitoring telescope is dedicated to the long-time continuous observation and the spectroscopic studies of the planets of Solar system to explore:

- Mars atmosphere, Dust storms, Meteorology (clouds), Water vapour distribution, Mars surface: seasonal variations, polar caps;
- Venussian atmosphere, Meteorology (clouds, lightning), Observing NIR transparency windows, Unknown UV absorber
- Jovian and Saturnian clouds
- Other planets and their satellites
- Comets
- Meteoroides and bolides phenomena on the planets
- Engineering tests to observe extrasolar planets and circumstellar discs via an imaging stellar coronagraph

A $10^6 \dots 10^{10}$ high-contrast stellar coronagraphy is required to image and to characterize extra-solar planetary systems among other faint astronomical targets observed in the vicinity of bright objects. Stellar coronagraphy becomes a rapidly evolving field with many enhanced alternatives to the classical Lyot coronagraph. In this list, an interfero-coronagraph (AIC) is an advanced technique because of its wide achromaticity and because of its leading spatial resolution specified as the IWA – inner working angle. We developed a common-path achromatic interfero-coronagraph CP-AIC to maintain an OPD trend in an AIC method. At next we proposed the tandem TCP-AIC to obtain a 10^{10} coronagraphic contrast at $0.8\lambda/D$ IWA by the ratio of planet to star separation to the stellar size at $0.01\lambda/D$ as considering the Earth-Sun pair [3, 4].

Perspective survey for exoplanets and for faint-contrast astronomical objects combines coronagraphy and spectroscopy to enable a material- and potential bio-markers recognition. A 0.6 meter space telescope is scheduled to monitor the planets spectral identities on the board of Russian Segment of ISS. Among the telescope instruments is a stellar coronagraph (CP-AIC) with a CCD camera observing in a visible wavelength range [5]. CP-AIC is co-linked with a low resolution spectrometer to identify the spectral characteristics of faint objects. Special efforts are made to correct a 0.6 meter telescope pointing error.

(2) A larger version with up to 1.5 .. 2 meter primary mirror diameter called “Zvezdnyi (engl. star) patrol” is tentatively scheduled for the launch in 2022 to L2 point on a Navigator automate platform. “Zvezdnyi patrol”

has the main goal to atmospheric characterization of cold exoplanets with spectral near IR instruments. Another goal is to measure more precisely the Solar system planets atmosphere components.

II. A 0.6 METER TELESCOPE “PLANETARY MONITORING” ON ISS RS

“Planetary monitoring” telescope has a 0.6 meter primary mirror diameter and it is planned aboard the ISS RS of Russian Segment (RS) of ISS. It is scheduled to be launched in 2018.

A PM telescope has a diffraction resolution better than the 0.25 seconds of arc in the optical wavelengths range of the near-UV, visible and near-infrared via photometric, spectral and polarimetric tools and platform guidance on board of the ISS outside sealed compartment. Telescope will observe planets and small bodies of the solar system and training the observation of exoplanets.

The “Planetary monitoring” telescope scientific goals devoted to explore not yet well studied questions on Mars (methane, ozone, dust and clouds, isotope ratio of HDO/H₂O), on Venus (UV absorber, night glow, atmosphere dynamics), icy and gaseous Solar system planets, Jovian moons, Lunar exosphere, comets, meteorites. This telescope aims also for engineering development of exoplanet study by stellar coronagraphy linked with a low resolution spectrometry.

Up to now we consider two scenarios how to mount the “Planetary monitoring” telescope.

Scenario 1. The main concept is the PM telescope delivery to RS ISS by the unmanned cargo resupply spacecraft Progress, then through the pressurized (living) compartment, the telescope will be manually transported and then will be mounted on the external surface of the ISS RS (YRM) by the astronauts. Remotely controlled two-axis guiding platform will have the pointing accuracy of $\pm 5'$ (angular min), Fig. 1.

The PM telescope mass is no more than 100 kg required from the guiding platform load capability. The telescope pointing error is controlled and is compensated by a low mass secondary mirror tilt on a hexapod driver. Science instruments container includes a field imager with FOV over the 20° to simultaneously fix the platform guiding error, Fig. 2.

Scenario 2. Additional concept is the PM telescope being delivered to the ISS by the unmanned cargo resupply spacecraft Progress, then the astronauts prepare the specialized starting container inside or outside the cargo spacecraft Progress of that developed for the removal in a higher circular orbit to launch the PM telescope spacecraft. The later is similar to the micro-satellite Chibis [6]. The PM Orbital Observatory mission intends to use the a low cost small satellite platform developed by the Dauria Aerospace® - Russian private company and reuses the Progress to elevate the observatory orbit [7]. The Progress launches four times per year to provide supplies and scientific instruments to the ISS. The Progress is capable of raising the height of the orbit for the piggyback scientific missions; therefore, the implementation of the Orbital Observatory mission is considered not just as a development of a successful science mission so it is most importantly developing an affordable and frequent flight opportunities for space sciences research in Russia and worldwide, Fig. 3. In the scenario 2., the characteristics of a PM telescope mission are foreseen as summarized in the Table 1.

A PM telescope includes 5 science instruments:

- IR: 1000..2400 nm high-resolution spectrometer $R > 10000$;
- Visible photometer camera with filters wheel;
- UV-VIS Fourier spectrometer;
- UV-VIS Spectropolarimeter;
- Stellar coronagraph linked with spectrometer.

III. A 1.5 .. 2 METER TELESCOPE “ZVEZDNYI (eng. STAR) PATROL” [8]

The “Planetary monitoring” telescope will have its larger version with up to a 1.5 .. 2 meter primary mirror diameter. That mission called “Zvezdnyi (engl. star) patrol” and is tentatively scheduled for the launch in 2022 to the L2 point on a Navigator automate platform. “Zvezdnyi patrol” has the main goal to atmospheric characterization of cold exoplanets with spectral near IR instruments. Another goal is to measure more precisely the Solar system planets atmosphere components.

High-contrast imaging is currently the only available technique for the study of the thermo-dynamical and compositional properties of exoplanets in long-period orbits, comparable to the range from Venus to Jupiter.

This project is a stellar coronagraph-equipped space telescope dedicated to the spectro-polarimetric analysis of gaseous and icy giant planets as well as super-Earths at visible and near IR wavelengths. So far, studies for high-contrast imaging instruments have mainly focused on technical feasibility because of the challenging planet/star flux ratio of $10e-8$ – $10e-10$ required at short separations (200 mas or so) to image cold exoplanets. The main interest of “Zvezdnyi patrol” instruments, namely the analysis of planet atmospheric/surface properties, has remained largely unexplored till now.

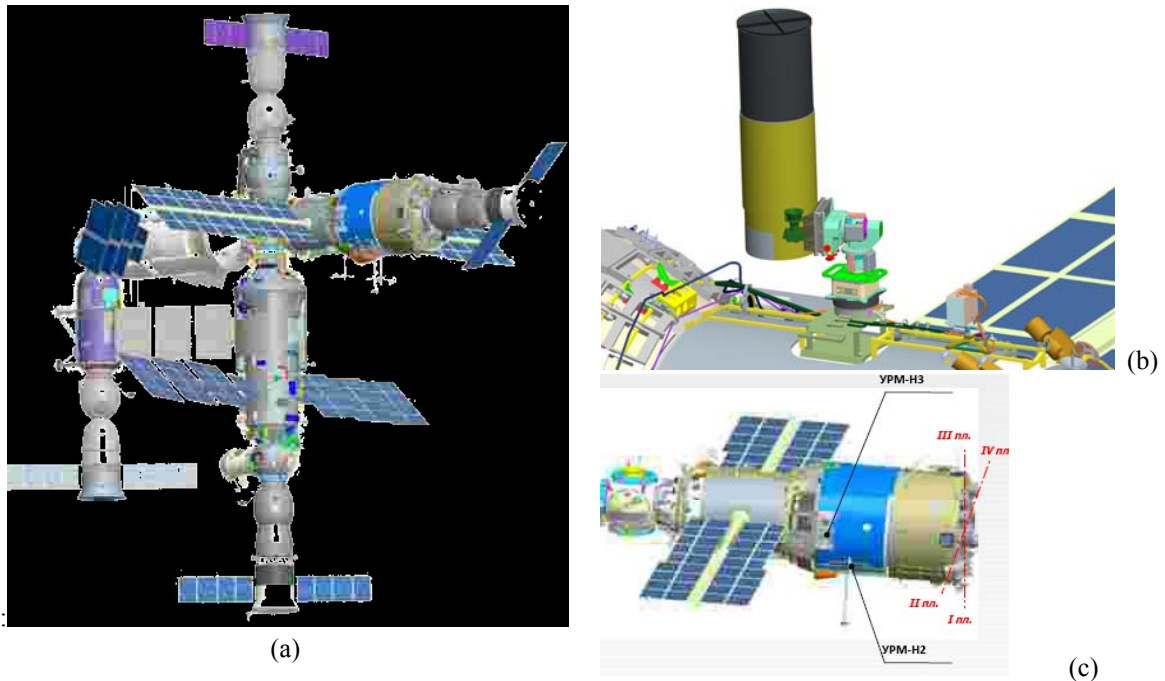


Fig. 1. PM telescope mounting on the external surface of the ISS RS (URM). (a) – ISS structure, (b) – PM

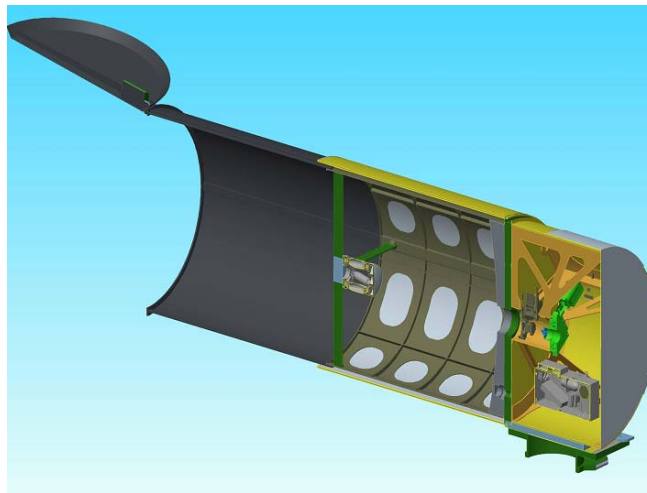
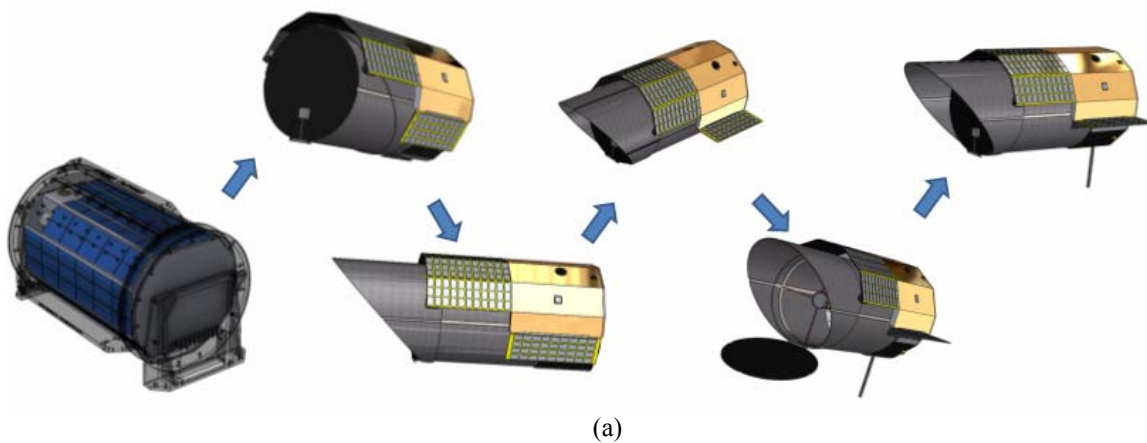
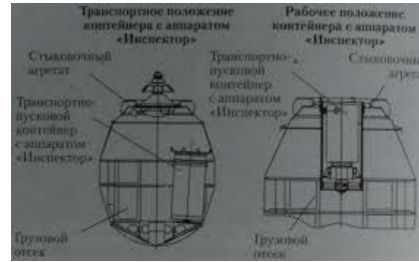


Fig. 2. PM telescope sectional view with the secondary mirror on hexapod platform and with science instrument compartment.



(a)



(b)

Fig. 3. Free flyer scenario of PM telescope.

- (a) – Specialized starting container
in a higher orbit to launch the PM telescope spacecraft,
(b) – Specialized starting container inside the Progress cargo spacecraft.

Table 1. Specifications of PM observatory on autonomous platform.

Mass	~ 180 kg
Energy consumption	110 W
Overall dimensions (mm)	
The width in the transport position	~ 710
The width in the working position	~ 1115
Transport height	1200
Working height	1750
Mission definition	Observation and monitoring of the solar system planets and exoplanets.
Deliver to the ISS	Delivery is made by cargo container "Progress"
Operation with the spacecraft on the RS ISS are produced by crew of station	Calibration and launch checkout.
Excretion apparatus on operational orbit	Excretion is performed by using cargo container "Progress" by separating the unit from the cargo launch container.
Working orbit	~ 500 km incl = 51,6 °
UBAT Field of View (half coded)	From 0.001 sec till 60 sec

IV. STELLAR CORONAGRAPH

In astronomical observations, extrasolar planets have a total brightness that is lower than the brightness of a star by 6–10 orders of magnitude, depending on the wavelength range, respectively, from the infrared (IR) to the visible. In Bracewell's method [9], a long-baseline interferometer increases the resolution using two telescopes: in this interferometer, the light from the background on-axis source (star) has a phase shift by π radians and interferes in antiphase. At the same time, the light from the off-axis source (planet) interferes with another phase difference, so that the off-axis source is attenuated only slightly and has a signal level sufficient for photo-detection. In recent years, various optical devices have been proposed to attenuate the background signal of the on-axis source. These include phase and focal masks, entrance pupil apodization, delay lines, achromatic phase-shifting devices, and their combinations. A nulling interferometer that directly solves the problem of stellar coronagraphy has been considered as a device that removes the background light through an achromatic phase delay by π radians.

Lab. tests presented in Fig. 4: (a) image obtained when only the off-axis source was switched on electrically; its pair image was observed at the two interferometer outputs: the bright one at the top and the nulled one at the bottom. Intensity approximately equal to a quarter of the total power of the off-axis source corresponds to each element of the pair and these elements are symmetric relative to the optical axis of the interferometer. To visualize the nulling contrast, the intensity of the off-axis source was set to be three orders of magnitude lower than that of the on-axis one. Fig. 4 (b) shows the image when only the on-axis white-light source, the collimated *white* light from a halogen lamp, was switched on electrically. The intensity of the on-axis source and the exposure time of the CCD camera were chosen so as not to exceed the dynamic range of the CCD camera until saturation. In the upper half of the field of view, in the region of the bright output, the light from the on-axis

source roughly corresponds to the initial energy. At the bottom of the field of view, we see a weak level of the residual signal the non-nulled on-axis source. To experimentally measure the nulling contrast NC, Fig. 4 (c) shows equal (in size) images of the bright and nulled fields. Fig. 4 (d) presents the image when the on-axis and off-axis sources were switched on simultaneously. In the upper region, the bright field of the on-axis source completely overwhelms the light from the faint off-axis source in intensity. At the same time, in the lower region of the field of view, the nulled field of the on-axis source is fairly attenuated and adds only a slight background to the off-axis source. The exposure time of the CCD camera, about 4 s, shows that the nulling interferometer is mechanically stable. Photo of a common-path interfero-coronagraph block is shown in Fig 4.

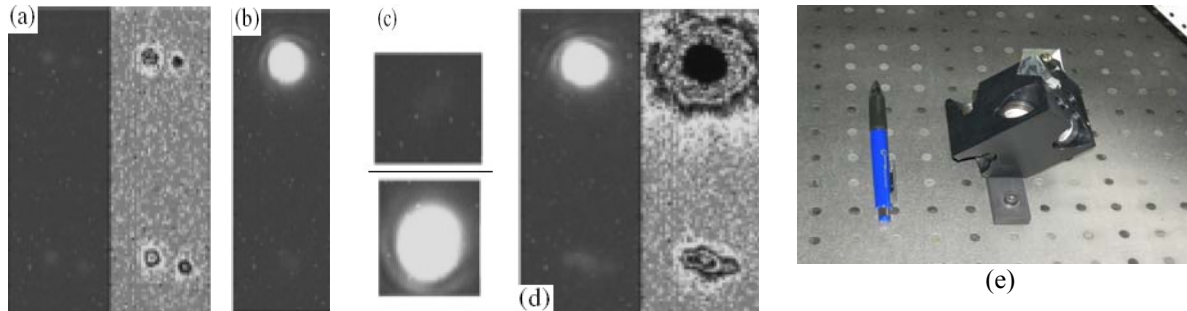


Fig. 4. Interfero-coronagraph lab. tests (a..d). CPAIC photo (e).

V. CONCLUSIONS

Two middle class space telescopes projects aimed to observe Solar system planets by a long term monitoring and aimed to study extra solar planets (exoplanets) via engineering and scientific goals are presented in available details.

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REFERENCES

- [1]. A. Vidmachenko, Yu. Ivanov, O. Monsar, I. Sinyavsky, M. Sosonkin, V. Kryukov, O. Korablev, V. Gnedykh, A. Tavrov. Spectrometer - polarimeter for the Joint Russian-Ukrainian Space Experiment "Planetary Monitoring" Aboard the International Space Station, 2010, 10-th Ukrainian conference for space explorations, Tech. Abst.
- [2]. A. Tavrov, V. Ananyeva, L. Ksanfomality, O. Korablev, D. Bisikalo, A. Kiselev, Orbital observatories for planetary and exoplanets exploration, Tech. abstr. Cospar conference. 7 Aug. 2014. Moscow.
- [3]. A. V. Tavrov, O. I. Korablev, A. V. Rodin, I. I. Vinogradov, A. Yu. Trokhimovsky, A. Yu. Ivanov, L.V. Ksanfomality, D. A. Orlov, Stellar coronagraph using the principle of achromatic null-interferometer, COSMIC RESEARCH, Vol. 49 Issue: 2 p. 99-109 (2011). DOI: 10.1134/S0010952511020109.
- [4]. H. Lammer, A. Hanslmeier, J. Schneider, I.K. Stateva, M. Barthelemy, A. Belu, D. Bisikalo, M. Bonavita, V. Eybl, V. Coude du Foresto, M. Fridlund, R. Dvorak, S. Eggl, J.-M. Griessmeier, M. Gudel, E. Gunther, W. Hausleitner, M. Holmstrom, E. Kallio, M.L. Khodachenko, A.A. Konovalenko, S. Krauss, L.V. Ksanfomality, Y.N. Kulikov, K. Kyslyakova, M. Leitzinger, R. Liseau, E. Lohinger, P. Odert, E. Palle, A. Reiners, I. Ribas, H.O. Rucker, N. Sarda, J. Seckbach, V.I. Shematovich, A. Sozzetti, A. Tavrov, M. Xiang-Gruss. Exoplanet status report: Observation, characterization and evolution of exoplanets and their host stars. SOLAR SYSTEM RESEARCH Vol. 44, Issue: 4, p. 290-310, (2010), DOI: 10.1134/S0038094610040039.
- [5]. A. Tavrov, O. Korablev, L. Ksanfomality, V. Gnedykh, A. Rodin, J. Nishikawa, M. Tamura, M. Takeda, T. Kurokawa, "A 400-3500 nm spectroscopy through a common-path interfero coronagraph instrument on 600 mm telescope on RS ISS". Int. Conf. "In the Spirit of Lyot 2010 Direct Detection of Exoplanets and Circumstellar Disks", Paris, October 25th to 29th, 2010, http://lyot2010.lesia.obspm.fr/abstract_212.html.
- [6]. http://chibis.cosmos.ru/fileadmin/fileupload/2009chibis-m_02.pdf

[7]. A. Tavrov, A. Kiselev, O. Korablev, D. Bisikalo, A. Markov, M. Kokorich, N. Vedenkin. Orbital Observatory for Planetary Science on Low Cost Autonomous Platform, Tech. abstr. Cospar conference. 7 Aug. 2014. Moscow.

[8]. <http://www.star-patrol.cosmos.ru/>

[9]. R. N. Bracewell, Nature (London) 274, 780 (1978).