# SPACE DEBRIS OBSERVATIONS WITH THE NEW EQUIPMENT ON THE SAYAN OBSERVATORY

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Experimental equipment at the Sayan mountain observatory, operated by the Institute of Solar Terrestrial physics, provides the opportunity for detection of moving objects up to 22 (R) magnitude in the tracking mode with the 1.7 meter AZT33 telescope. For measuring of spectral brightness the CCD UBVRI photometer and low resolution spectrometer have been used. An auxiliary telescope with the main parabolic mirror of diameter 500 mm is also used for the debris searching. In the past years, the secondary mirror of the telescope has been replaced by a three-lens pre- focal corrector that provides the 2.2° field of view and $19^m$ limit magnitude. Orbital parameters and optical characteristics of the faint objects have been evaluated. We discuss the methods and apparatus for moving objects investigations. The results of observations are also presented. Statistical estimations of an opportunity for the application of these metrical and photometrical characteristics for identification and cataloguing of the faint space debris are submitted. Today we are facing the problem of predicting the positions of small-sized space debris. Over a short time interval the orbital characteristics of these objects can vary considerably, consequently the correlation between their orbital elements can be very low. A measurement of the optical characteristics is an additional, but incomplete way for small objects identification. We layout plans for the more complex measurements of orbital parameters with the help of two telescopes simultaneously on the long arcs. The future plans for wide-field optical systems and for a high-speed sky survey are discussed.

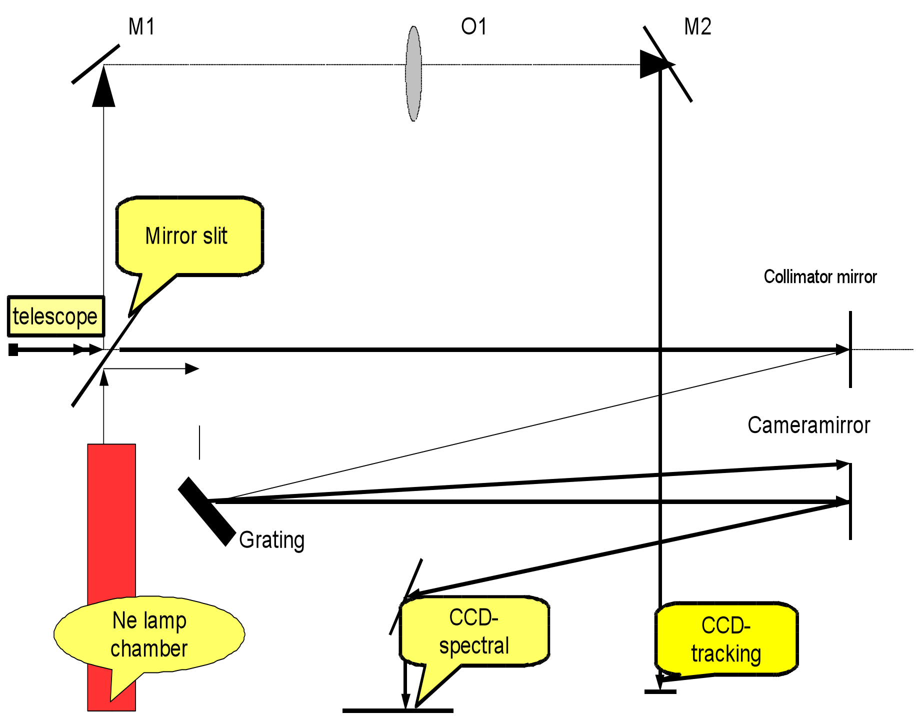
## 1. The telescopes and observational techniques

The observations of the small sized debris at high altitude orbits are conducted at the Sayan mountain observatory by several instruments and methods. Current hardware for metrical and spectrophotometrical faint object study consists of:

- A searching optical system based on a 0.5 meter cassegranian telescope AZT 14. AST14 cassegrenian telescope with the main parabolic mirror of diameter 500 mm originally had a field of view about 20 arc min on diameter 40 mm. In the latter, the secondary mirror had been replaced by a three-lens prefocal corrector that provides the 2.2° field of view diameter and $19^m$ limiting magnitude at the 60-second exposure (Fig. 1) with a front illuminated CCD detector KAF 4301.

Fig. 1 The prime focus corrector and CCD established at the top of AZT 14 telescope.

- The 1.7 m Richey-Chretien telescope with a field of view of 10′ and the limiting magnitude of $22^m$ at the 60-second exposure has a restricted possibility for finding new objects, and is usually applied for the follow-up orbit measurements and spectrophotometrical study. AZT 33 hardware is made of two main subassemblies. First, the focal reducer (FR) which accepts the image of the f/20, 170 cm Richi-Chretien telescope and transfers it onto CCD (1Kx1K, 16 mkm pixel size device, named ISD 017, produced by plant “Electron”, St-Petersburg) is suitable for detection of small-sized debris with good determined orbital parameters. The CCD photometer has been used for measuring of spectral brightness. Commonly used UBVRI filters and low dispersion grism are located in the gear (worm)-driven filter wheel just before the CCD. In the multicolor photometrical mode, which is more adequate for faint objects, the measurements are executed consequently with exposure times chosen by the observer. A second one, we have taken SBIG self guided spectrograph (SGS) with the ST-8 CCD 8 camera [www.sbig.com] as a starting point for our investigation. These devises allow to observe the object that is viewed on the tracking CCD, simultaneously with the slit. The spectra is recorded by the imaging CCD, oriented long ways so the spectra falls across 765 pixels, with a height of about 10 pixels for point sources. The grating, 150 rulings/ mm gives a dispersion of 4.3 angstroms per pixel and allows to capture the wavelength range from 3800 to 7500 A with a blue rejected glass filter, and from 6000A to 10000 A with a red one. The resolution is about 8 A, when a normal width slit is applied. In low resolution mode the slit width is approximately equal to the star diameter, and typically is 150 – 200 mkm. By this means certain pixels of the CCD have been illuminated by 70-90, an area of the spectrum which is more than one order narrow of the halfwidth of a color filter in the photometer. The exposure time required to record a spectrum in a seeing limited mode is (3-5 times) longer than in photometrical measurements. The moving object is manually maneuvered onto the slit using the telescope control system and held there using the ephemerides tracking capabilities of the telescope drivers during a long exposure. The spectrometer and CCD are controlled by MicroPC units, which are attached in Cassegrenian focus and connected with the telescope LAN. The overall view of the spectrometer onto the telescope is shown in figure 2.




- Fig.2 A general layout of the spectrometer for the AZT 33 telescope.

Both of these instruments have been operated by a universal control system. The telescope control systems and its mechanical drivers, electronics and software units enable an object tracking along an ephemeris, and make possible to detect the small-sized objects as faint as sky background permit. As it takes place, both telescopes can be available for joint, or their own observational, programs. The master computers of both telescopes are located in the same control room. This provides a cross-telescopes interaction and a direct communication among telescope operators. The additional equipment – the all-sky camera and the weather monitor are used for monitoring of the clouds and seeing conditions. The overall layout of the instruments interaction is shown on the figure 3.

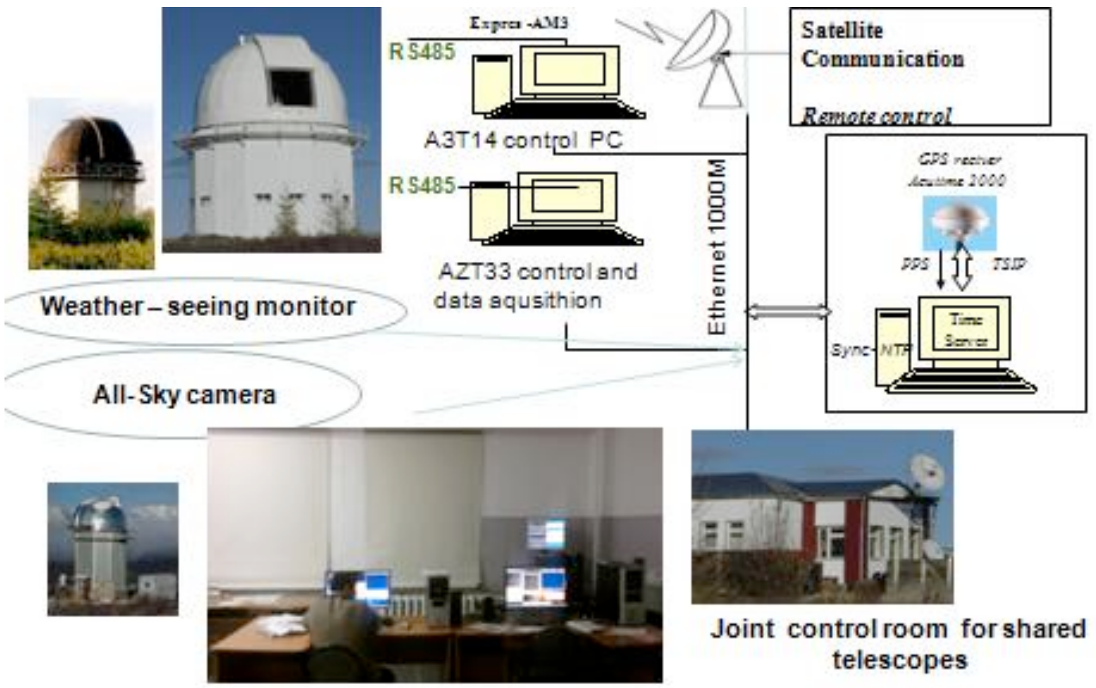



Fig. 3 The layout of the instruments interaction at the Sayan Observatory hardware for the satellites observations.

## Observation results

### Metrical observations

The advanced telescope AZT 33 was applied to small sized debris detection, orbit determination, and spectrophotometrical measurements. Fig.4 illustrates the brightness distribution of objects which were observed in the geostationary ring since autumn 2006 with the AZT 33 and AZT 14 telescopes. The faintest objects observed at AZT 33 had magnitudes 21.5 (V). The magnitudes were estimated relative to stars in the FOV with the help of the USNO B star catalog. One can estimate a size of an object, based on a diffuse sphere assumption, as 10 cm with an accuracy 30% or less.

Observations of faint objects, as usual, have been performed in the tracking mode in which a telescope moves as predicted by the ephemeris. But the precision of an ephemeris prediction for this type space objects is not high, resulting in point blurring and errors in the magnitude estimates.

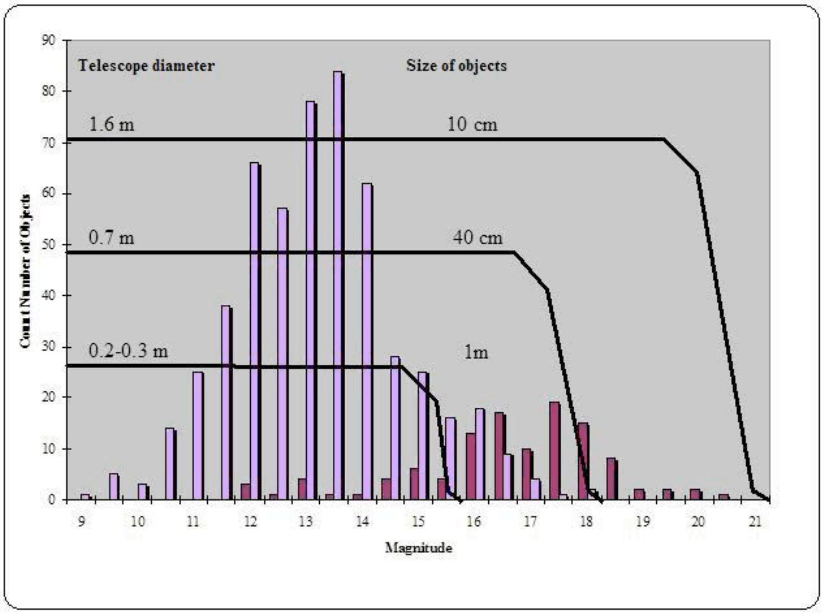



Fig. 4 The brightness distribution of the objects observed in the geostationary ring with the AZT 33 and AZT 14 telescopes.

The figure 5 presents a sky map at the J 2000 epoch in which the positions of all the faint (≥ 16-th mag.) objects were observed on the sky with our two telescopes are drawn. This map clearly demonstrates that the major portion of the faint objects is plotted near orbits of Ekran 2 and Transtage IV objects, which had been destroyed in the past.

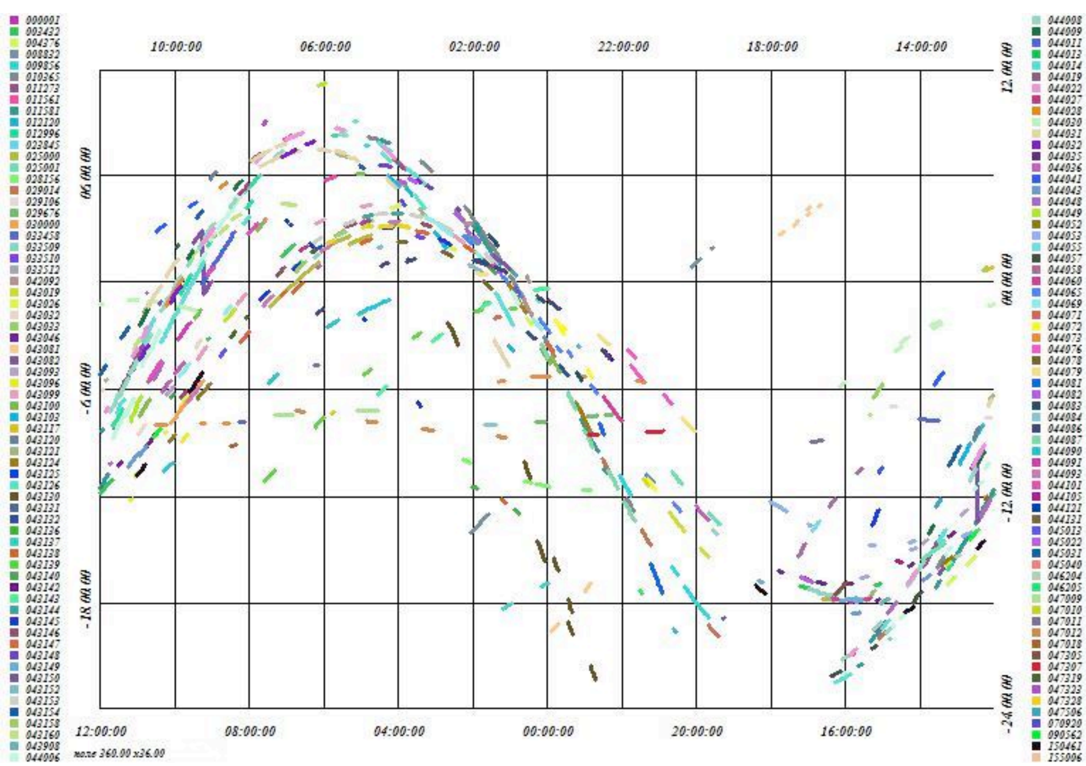



Fig.5 Sky map in the J 2000 epoch on which the positions of all the faint (≥ 16-th mag.) objects observed at Sayan Observatory are drawn.

The distribution of the faint debris on the sky is not stochastic. Some of these objects had been thrown into well delineation belts, as was predicted by Sochilina, et al. (2001) and Kiladze, et al. (1998).

## Multicolor and spectrophotometrical observation

The time series of the frames at the BVR filters were obtained. A time resolution in a series had been defined by the exposure time in the given filter. In an ordinary situation it was equal to 1 - 3 seconds for R and V filters, and 5-10 seconds for B filter as a compromise between a signal to noise ratio and a period of a brightening variation. The procedure was repeated at different phase angles during the visibility of objects. Observable debris objects have various mean brightness in the range from 14 to 18.5 magnitude, various colors (B-V) and brightness variations on the range 0.2 - 5 magnitudes. A photometrical accuracy can be estimated from some qualitatively reasons and was no more than 0.05 magnitudes. It is important to note that all bright objects, which were observed, have a strong variability. But, for objects fainter then 16-th magnitude the variability evidence is less clear. It will be the subject of a self-contained study. This paper discusses more general debris optical properties in conjunction with the apparatus and the applied methods. Phase curvers for GEO debris objects are not quite similar to those for intact objects. It follows from general considerations that debris have a more simple form than intact objects. The debris phase curves are determined by their dynamics, orientation and indicatrix. An orientation of a plate explains the unusual phase curve of 44014 debris, as it is shown on the figure 6.

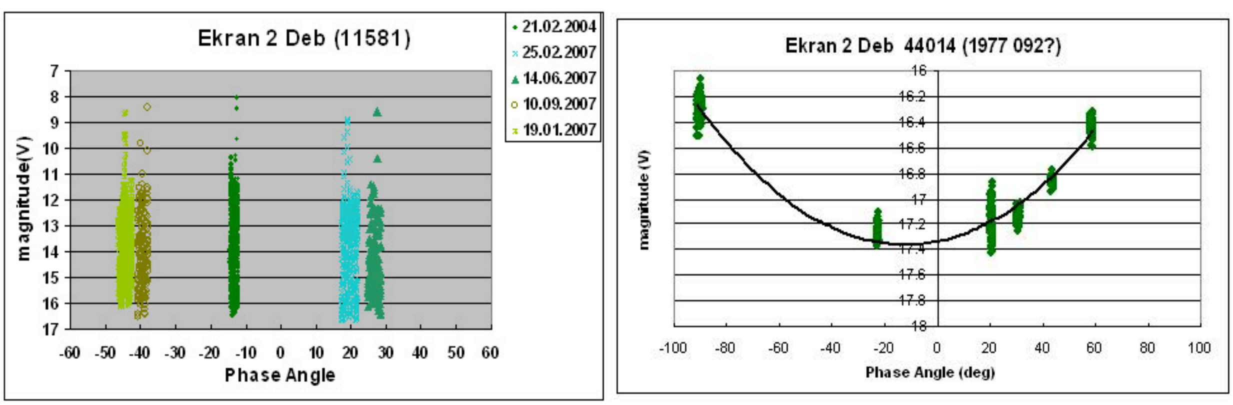



Fig. 6 The phase curves of two debris objects from Ekran 2 family.

At the same time rocking can explain the object variability. We have not touched on the variability of debris in this paper. We only point out that the variability of amplitudes and periods depend on a phase angle (figure 7).

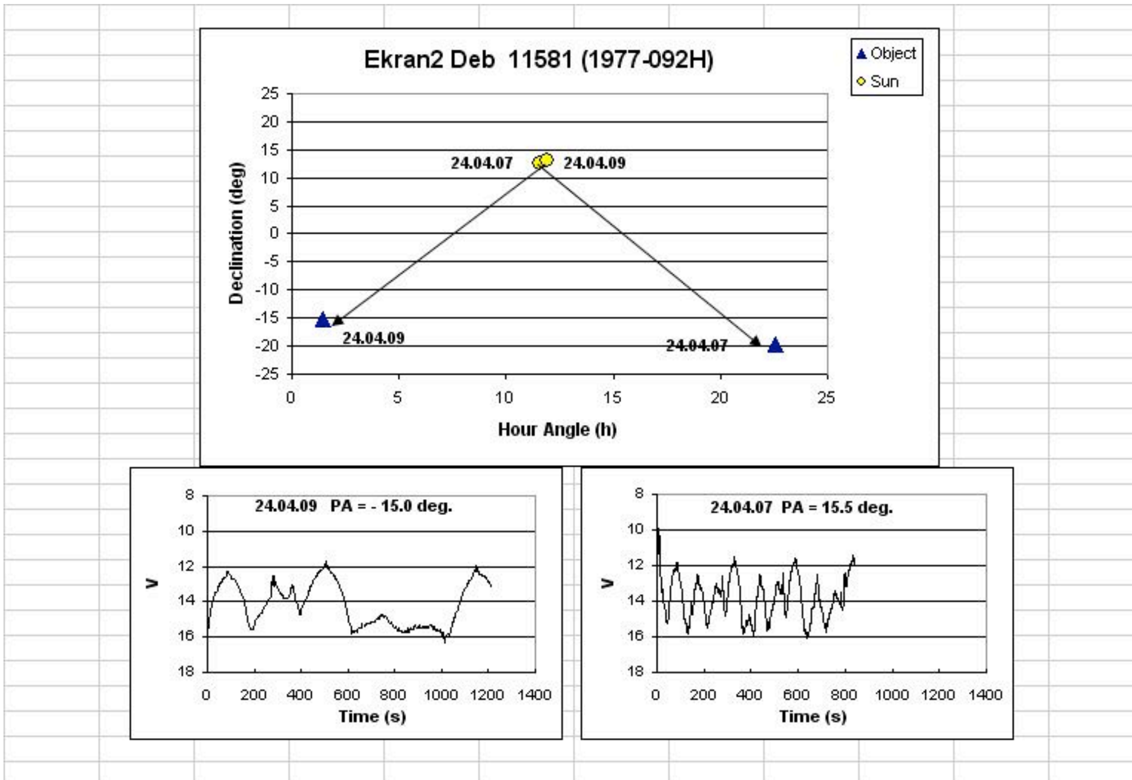



Fig.7 The different light curves for SSN 11581 debris at different positions of the object and Sun.

To obtain color indexes one must use curve differences from the adjacent filters. A spline interpolation of the row data was done to get the differences. To approximate the data averaging on the time intervals, more than the main periods of phase angle dependences of the mean magnitudes in different filters can be obtained. The photometrical properties of the debris observed in the Ekran 2 and Transtage IV tube were summarized. There are significantly different phase coefficients in the B and V filters for any samples of the small sized objects. It was established in multicolor debris observations that the colors of some objects, for example SSN 11581, are demonstrating short periods fluctuations. It will be a subject for a future stage of our work.

## Discussion and future plans

We conducted an analysis of the different methods for the simultaneous measurements in different spectral bands and concentrated on classic diffraction grating spectrometers. A low-resolution spectrometer at the advanced telescope, AZT 33, was applied to a spectrophotometrical study of an object's radiation. From the figures one can see an example of spectra of three different GEO objects. Spectroscopic data have been collected for a few satellites in a different mode of operation. In the picture the spectra of three different GEO satellites and comparison spectrum the β Sextanum star (B-V= -0.14) are shown. The spectra of the objects located near the same longitudes (about 100º E) show quite different spectral distribution. This example gives an idea of how spectra can be used for object identification. The other effect, that has been observed, is a different spectra behavior in the red part of spectrum, the so called “reddening effect“, quite different for the whole spacecraft and debris.

From the results of multicolor photometrical observations and the light curve analyses of the non active geostationary spacecraft and faint debris, it is possible to deduce conclusions about a suspect object of destruction on the basis of orbit analyses. The fragments in the close neighborhood to the orbit of the Ekran 2 were investigated. An attempt of an identification of the 7 debris objects with the Ekran 2 design by using B-V color index was made. Amongst the Ekran 2 families objects there is objects 11581 that has the appearance of the solar panels. Its light curve demonstrates two bell-like details, approximately identical duration, but distinguished in amplitude of 1.5-2 magnitude. At the specific moments at the top of a smaller magnitude detail, a short mirror flash with an amplitude of 8 magnitude and strong blurring effect, has been observed. This kind of the light curve behavior is typical of a solar panel. Notably, no mirror flash and blurring effects are detected for Ekran 2 parental body. The other objects allocated along a "tube" of trajectories near Ekran 2 parental body do not demonstrate any sign of a mirror effect. There are much reddening objects with entirely diffuse indicatrix in comparison with average the color of space objects.

Today we face a problem of the prediction of small-sized space debris positions. On short time intervals the orbital characteristics of these objects vary so considerably, that correlation between their orbital elements is very low. In the future we plan to convoy these objects continuously with the help of a wide-field (WF) optical system for a high-speed sky survey. For this purpose a 1.6 meter diameter optical system with a field of view 2.8 degree is in development. The optical scheme of the WF is shown on fig. 8. Details of the construction of WF telescope AZT 33VM was discussed in the paper Denisenko, et al. in Optical Journal (2009).

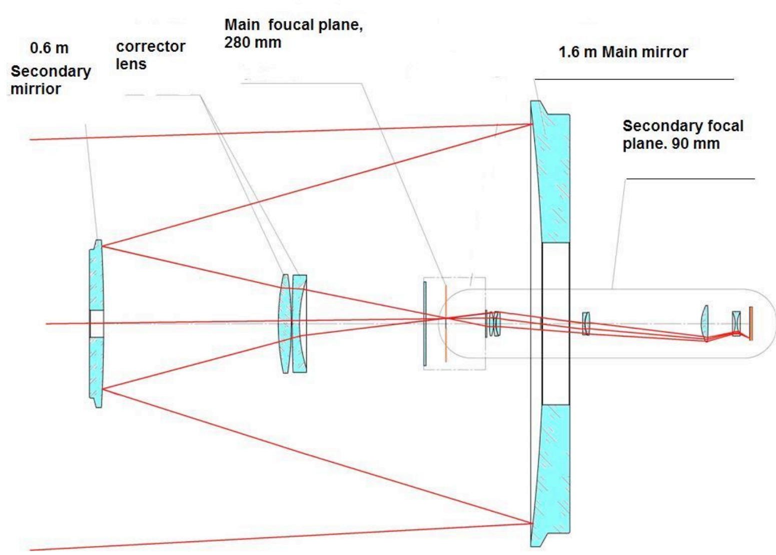



Fig.8 The optical scheme of the WF

## Conclusion

An advanced telescope, AZT 33, is applied to the small sized debris detection, orbit determination, and photometrical measurements. The equipment and methods for multicolor photometry of small sized moving debris are developed. The equipment and software of the telescope control system allow, by the use a predicted orbit, to make precision tracking of the object, and it is reliable to detect moving objects of 22 magnitude. The experimental equipment, at the Sayan mountain observatory of the Institute of Solar Terrestrial physics, provides the opportunity for detection of moving objects up to 22 (R) magnitudes in the tracking mode. For measuring of a spectral brightness the CCD photometer has been used. For simultaneous measurements in different spectral bands, a low dispersion slit spectrometer with custom CCD device was commissioned. These devises allow to observe the faint (18 mag) moving object spectra in the 0.4-1.0 mkm regions with low (70 - 100 A) resolution. High resolution mode and polarization measurements are also available. The preliminary spectral observation of GEO satellite, rocket bodies and other debris demonstrate its importance for object identification and determination of the space debris origin. In the near-term the ability for more careful finding, determining of the nature and cataloging, with high limited magnitude, accuracy and temporal resolution, with the WF telescope AZT 33VM will be established.

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