Research Article

Polina Levkina*, Nail Bakhtigaraev, Konstantin Martynyuk-Lototskyy, Sergey Velichko, Ilia Sokolov, Arkadii Bondar, Pavel Khorunzhiy, and Vadim Chazov

# Characteristics of small-sized space debris objects detected at the Terskol observatory in 2016-2017

https://doi.org/10.1515/astro-2018-0028
Received Nov 16, 2017; accepted May 08, 2018

**Abstract:** The study of near-Earth space includes the detection and investigation of an increasing number of space debris objects by ground-based optical telescopes. There is no natural cleansing of space in the geostationary region. The telescope Zeiss-2000 with a two-meter aperture of the Terskol observatory is the largest optical instrument regularly used for space debris investigations. One of the main purposes in «Astronomy in the Elbrus region» international program's boundaries is the detection and characterization of small fragments of debris, which are invisible for smaller telescopes. During observations on photometric nights we usually detect 4-5 unknown fragments of 17-21$^{st}$ star magnitude. In this article, we present orbital parameters and physical characteristics of several small-sized fragments of the space debris detected at the Terskol observatory in 2016-2017.

**Keywords:** space debris, optical observations, area-to-mass ratio, brightness variations

## 1 Introduction

In 2016-2017, on the complex of the Zeiss-2000 telescope of the observatory at the Terskol peak (Tarady 2016), seven observational sessions were held. Observations of artificial objects of technogenic origin on a geosynchronous orbit were made. Capabilities of the telescope with a two-meter aperture allow detecting and accompanying small-sized objects (10 cm and less) in the geostationary region. Zeiss-2000 is the largest instrument regularly used for space debris research at high orbits.

Main characteristics of the CCD camera on the Zeiss-2000: aperture – 2 m, focal length – 16 m, CCD size – 2084×2084 pixels, pixel size – 24×24 mkm, field of view ~12×12 arcmin, detection threshold on GEO – $22^m$.

Within the framework of the near-Earth space study using the Zeiss-2000 telescope complex the following problems are solved:

**Corresponding Author: Polina Levkina:** Institute of Astronomy of the Russian Academy of Sciences, 119017, Pyatnitskaya str., 48, Moscow, Russia; Email: ayvazovskaya@inasan.ru
**Nail Bakhtigaraev:** Institute of Astronomy of the Russian Academy of Sciences, 119017, Pyatnitskaya str., 48, Moscow, Russia; Email: nail@inasan.ru
**Konstantin Martynyuk-Lototskyy:** International Center for Astronomical, Medical and Ecological Research of the National Academy of Sciences of Ukraine, 03143, Akademika Zabolotnoho ave., 27, Kyiv, Ukraine; Email: langure@mail.ru
**Sergey Velichko:** Institute of Astronomy of Kharkiv National University, 61022, Sumska Str., 35, Kharkiv, Ukraine; International Center for Astronomical, Medical and Ecological Research of the National Academy of Sciences of Ukraine, 03143, Akademika Zabolotnoho ave., 27, Kyiv, Ukraine; Terskol branch of Institute of Astronomy of the Russian Academy of Sciences, 361605, MBS, Terskol village, Kabardino-Balkaria Republic, Russian Federation; Email: sergvelichko.sv@gmail.com
**Ilia Sokolov:** Terskol branch of Institute of Astronomy of the Russian Academy of Sciences, 361605, MBS, Terskol village, Kabardino-Balkaria Republic, Russian Federation; Email: ilia.v.sokolov@gmail.com
**Arkadii Bondar:** International Center for Astronomical, Medical and Ecological Research of the National Academy of Sciences of Ukraine, 03143, Akademika Zabolotnoho ave., 27, Kyiv, Ukraine; Email: arctur.ab@gmail.com
**Pavel Khorunzhiy:** Terskol branch of Institute of Astronomy of the Russian Academy of Sciences, 361605, MBS, Terskol village, Kabardino-Balkaria Republic, Russian Federation; Email: abyss-72@mail.ru
**Vadim Chazov:** Sternberg Astronomical Institute of Moscow State University, 119234, Universitetsky pr., 13, Moscow, Russia; Email: vadimchazov@yandex.ru

– detection and characterization of small-sized high-orbit fragments of space debris, hard-to-observe for telescopes with a smaller aperture,
– research of orbital and physical properties of space objects moving in the Earth's gravitational field,
– improvement of models of space objects and space debris movement.

Positional observations are carried out in short series for 2-3 minutes with a frame rate of about 10 seconds. The duration of exposure is chosen based on the object's brightness and the conditions of observations (sky background). Brightness measurements are carried out by long continuous series of 30-60 minutes and longer, depending on the characteristics of the change in brightness. The frame rate at the brightness measurements is 5-6 seconds.

On a good observation night, using the telescope Zeiss-2000, 3-4 new, previously unobserved objects are detected. In order to determine the initial orbit and make a motion-satisfying prediction for the next night, new objects are observed from the moment of detection on a continuous arc from 40 minutes and longer. High-accuracy observations on the arc in 1 hour can confidently detect the object on the next night, while the inaccuracy of the prediction does not exceed 20 arcmin.

## 2 Characteristics of detected objects

Object 91133 (number in the catalog of the Keldysh Institute for Applied Mathematics) was opened on April 5, 2016 and was observed for 10 nights. A total of 1319 positions were measured. Figure 1 and Figure 2 show the brightness estimates on April 5 and 7, respectively.

On the light curve obtained on a two-hour time interval, three condensations of points in different brightness values are clearly visible. This indicates a complex shape of the object and rapid axial rotation – the brightness of the object changes to 4 star magnitudes for one minute.

According to measurements, the orbital parameters of 91133 object were obtained for the epoch of observations:

Date: 07.04.2016. UTC = 20h 28m 59.7s,
$a$ = 18964.5 km,
$e$ = 0.65010,
$i$ = 7.047°,
$\Omega$ = 112.427°,
$A/m$ = 0.038 m$^2$/kg.

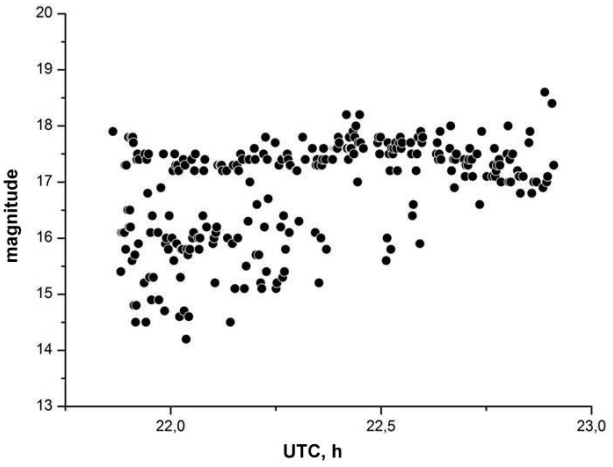


**Figure 1.** Brightness variations of 91133 object, April 5, 2016.

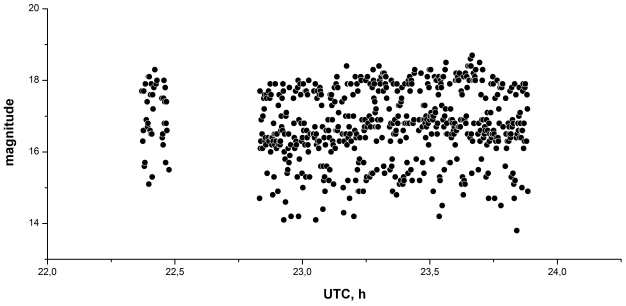


**Figure 2.** Brightness variations of 91133 object, April 7, 2016.

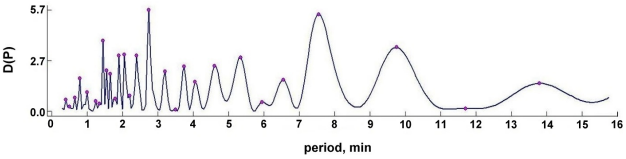


**Figure 3.** Periodogram for 91133 object, April 5, 2016.

On the hourly time interval, period of the brightness variation of the object 91133 was estimated to be ~ 7.5 minutes. Figure 3 shows the periodogram of the object.

According to the measurements of another object, 99981, detected on Zeiss-2000 in March 2017, it was assigned a number 91689 in the dynamic catalog, and the evolution of the orbital parameters was calculated. Figure 4 shows the brightness and the phase curve for 352 measurements on March 8, 2017. The interval of measurements is 1 hour. The amplitude of the brightness variation of this object is about 7 star magnitudes.

At the epoch of observations, the following orbital parameters of the object were obtained:

Date: 06.03.2017. UTC = 16h 53m 01.0s,
$a$ = 22102.0 km,

$e = 0.69908$,
$i = 23.523°$,
$A/m = 0.005$ m$^2$/kg.

Parameters of motion of the objects and prediction of evolution were calculated using numerical-analytical theory of satellite motion (Bakhtigaraev 2005).

The prediction for the evolution of the orbital elements of object 91689 (see Figure 5) from the moment of detection on April 2018 showed a decrease in the semi-major axis and inclination of orbit, as well as an increase in the mean motion. The object accelerates in its motion and belongs to the objects on a highly elliptical orbit. The ballistic coefficient is 0.005 m$^2$/kg. The period of change in eccentricity is 14 days and is due to the influence of the Moon. Reversal of the perigee of the orbit occurs with a period of 300 days, which is due to the oblateness of the Earth.

Figure 6 shows a diagram of the minimum height of the flight of 91689 object, expressed in kilometers during a year. The first day on the diagram is March 6, 2017. The period of fluctuation of the minimum height of the orbit, equal to 14 days with amplitude of 2.5 km, is due to the influence of the Moon. The period of fluctuations in height equal to 300 days with amplitude of 30 km is due to the reversal of the perigee of the orbit.

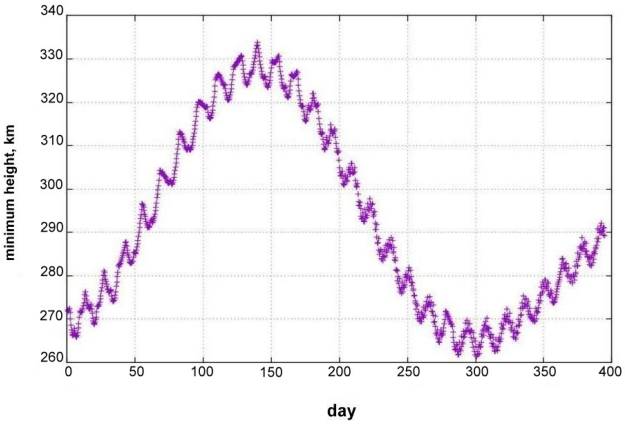


**Figure 6.** Minimum height for 91689 object.

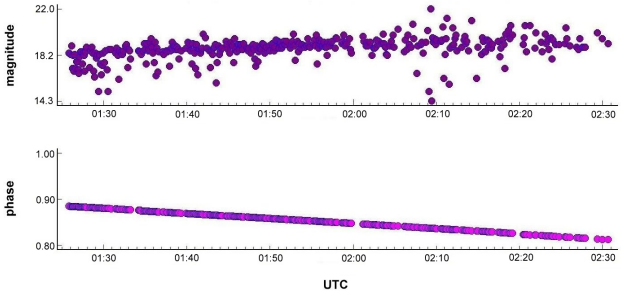


**Figure 4.** Brightness variations (top) and phase (bottom) diagram of 91689 object, March 8, 2017.

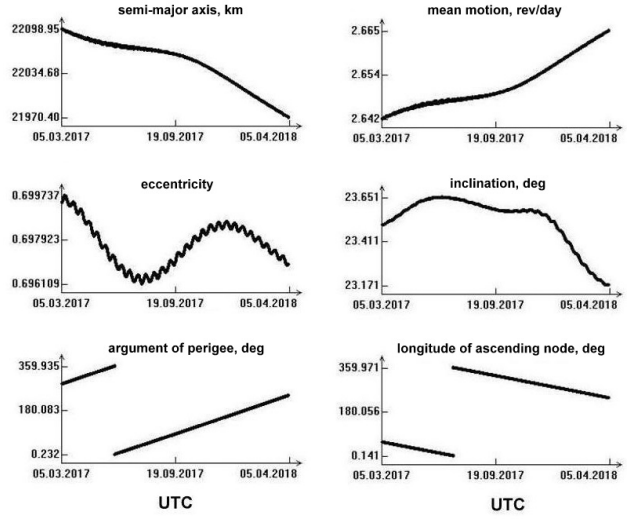


**Figure 5.** Orbital elements evolution of 91689 object.

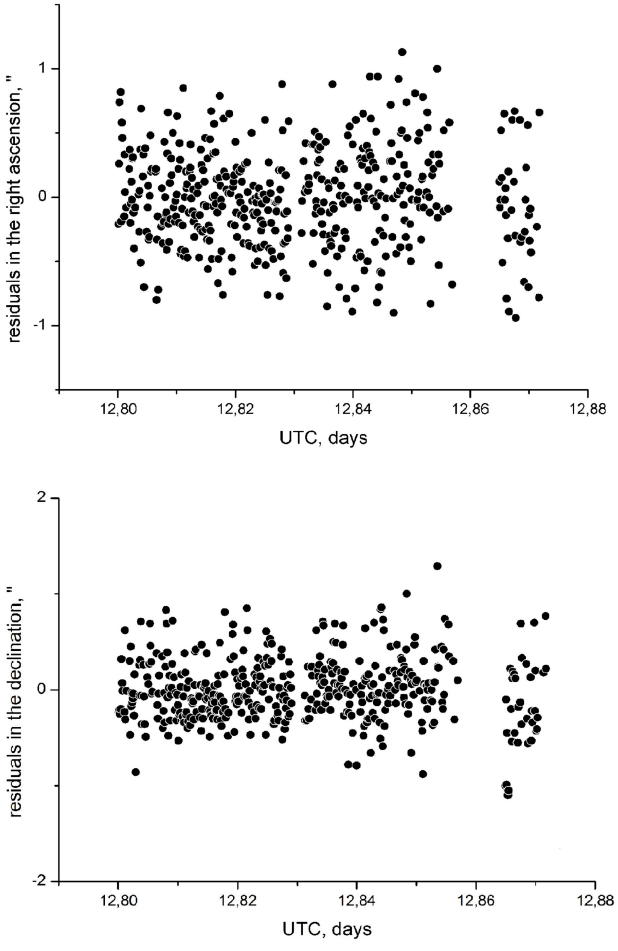


**Figure 7.** Residuals in the right ascension (top) and declination (bottom) in arcsec for 99995 object.

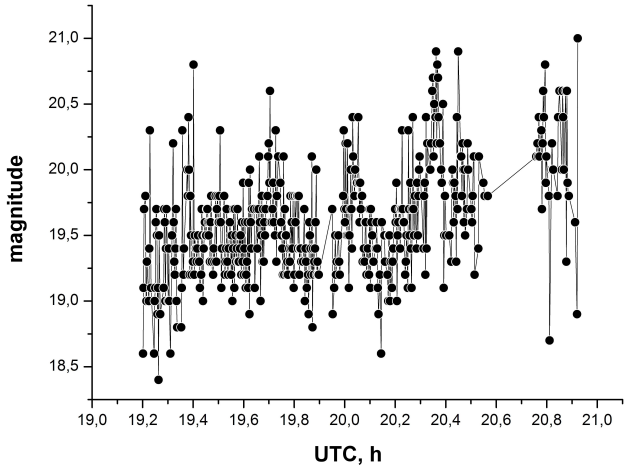


**Figure 8.** Brightness variations of 99995 object, August 12, 2017.

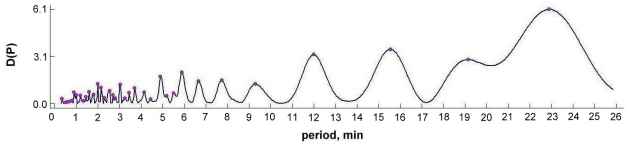


**Figure 9.** Periodogram for 99995 object, August 12, 2017.

In 2017, several space debris objects were discovered by the Zeiss-2000 telescope complex, which are fragments of the «Fregat» upper stage. Residuals in the right ascension and declination for one of such objects (a new, previously unobserved 99995 object) are shown in Figure 7 on the upper and lower graphs respectively.

Furthermore, on Figure 8, the brightness variations of the 99995 object on the night of August 12, 2017 is shown.

Figure 9 shows the assessment of the change in the brightness period of the 99995 object.

At the epoch of observations, the following orbital parameters of 99995 object were obtained:

Date: 13.08.2017. UTC = 21h 21m 50.6s,

$a$ = 41369.726 km,

$e$ = 0.002957,

$i$ = 0.845°,

$\Omega$ = 7.151°,

$A/m$ = 0.140 $m^2/kg$.

In the NORAD catalog (Hoots 1980), we found only one object with close orbital characteristics. This is object 41106 (2015-074B «Fregat R/B»). Most probably, the 99995 object with size less than 10 cm was formed when the spacecraft 2015-074B was launched. The «Fregat» launched of the satellite «Electro-L2» on December 11, 2015.

In the identification process, the most stable orbital elements were compared – the semimajor axis and the inclination of the orbit.

Differences from 41106 object: 77 km in the longitude of ascending node and 0.1° in the inclination with almost zero eccentricity. These parameters differ from the parameters of other catalogue objects by an order of value.

# 3 Conclusions

Objects detected during observations in 2016-2017 have large amplitudes of brightness variation. Almost all new objects are characterized by a high area-to-mass ratio. Amongst detected objects at least one object is the consequence of the launch of the «Fregat» upper stage.

# References

Yatskiv, Ya. S., Rykhlova, L. V., Taradiy, V. K. **2016**, *KPCB*, **32**(5), 213-217.

Bakhtigaraev, N.S., Levkina, P.A., Rykhlova, L.V., Sergeev, A.V., Taradiy, V.K., Karpov, N.V., Chazov, V.V. **2016**, *KPCB*, **32**, 5, 237-240.

Bakhtigaraev N.S., Levkina P.A., Rykhlova L.V., Chazov V.V., Sergeev A.V. and Karpov N.V. **2016**, *KPCB*, **32**, 5, 233-236.

Bakhtigaraev N.S., Levkina P.A. and Chazov V.V. **2016**, *SoSyR*, **50**, 2, 130-135.

Bakhtigaraev N. S., Chazov V. V. **2005**, *CosRe*, **43**(5), 369-372.

Hoots F.R., Roehrich R.L. **1980**, *Spacetrack Report No. 3*, http://celestrak.com/NORAD/documentation/.