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Synchronous Tests of Laser Active ARTEMIS Satellite at Different Ground Stations

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Abstract—**In July 2001, the geostationary satellite ARTEMIS with laser communication terminal OPALE on board was launched. Successful laser communication sessions were performed between ARTEMIS and low Earth orbiting (LEO) satellite SPOT-4. Regular laser communication experiments between the Optical Ground Station (OGS) of ESA and ARTEMIS were also performed. The laser communication sessions were successfully established between LEO satellite KIRARI and ARTEMIS. A laser communication link between LEO satellites with the data rate of 5.625 Gbps (5100 km distance) was established by the TESAT Spacecom in 2008. First laser communication experiments between the LADEE spacecraft at the lunar orbit and Earth OGS with a rate of 622 Mbps were realized in October 2013.**

The amount of information sent from telecommunication satellites located at the geostationary orbit is constantly increasing. There is a certain demand in high speed laser link data transmission between ground stations and satellites. For some LEO satellites, the direct transmission of information to a ground station is required. To reduce the influence of atmosphere, some of ground stations located in different climatic regions are needed. The Main Astronomical Observatory of Ukraine (MAO) have developed a compact laser communication system named LACES (Laser Atmospheric and Communicational Experiments with Satellites) using the Cassegrain focus of its 0.7 m telescope. The laser link between the LACES terminal of MAO and the OPALE terminal of ARTEMIS was established. During the pointing, OPALE terminal performs the beacon laser scanning of the territory where a MAO ground station is located. Several experimental observations of OPALE beacon laser scanning by ground stations located in different regions of Ukraine took place in 2012-2013 years. During the sessions, laser beacon peaks from OPALE were detected by the stations in Kyiv, Mykolaiv (500 km from Kyiv), Yevpatoriya (800 km from Kyiv), Odesa, and other stations. Selected results of the experiments are presented in the report.

Keywords — optical ground station; synchronous; satellites; laser; observations

I. INTRODUCTION

Free space laser communication systems have some advantages in comparison with radio frequency communication systems. First of all, laser communication systems have a much higher carrier frequency (up to hundreds of THz) and, as the result, higher communication rates up to N×10 Gbps per each communication channel.

Laser communication systems also have advantages in space where do not exist the atmosphere turbulence. From April 2003 till January 2008, 1789 laser communication sessions with total duration of 378 hours had been performed between ARTEMIS and the SPOT-4 satellite with data rates of 50 Mbps and pulse position modulation. Laser communication experiments in different atmosphere conditions between ESA's OGS and ARTEMIS were also performed [1-6].

n 2006, the LEO satellite KIRARI (OICETS) with a laser communication terminal on board had launched by Japanese Space Agency. The bidirectional laser communication links (50 Mbps and 2 Mbps) were successfully established between KIRARI and ARTEMIS. Successful laser communication experiments between KIRARI and OGS were performed also [7-10].

In 2008, the German Space Agency (DLR) and the Tesat-Spacecom had produced their laser communication terminals that use BPSK (binary phase shift keying) modulation. They succeeded to establish laser communication links between LEO satellites TerraSAR-X and NFIRE achieving data transfer rates of 5.6 Gbps at the distance of 5,100 km. ESA is now developing its European Data Relay Satellite (EDRS) system. It will use laser communication technology to transmit data from LEO satellites to the geostationary satellites EDRS-A and EDRS-C with data rates of 1.8 Gbps at the distances up to 45000km. The improved Tesat-Spacecom laser communication terminal is planned to be used. [11-13].

In October 2013, NASA had demonstrated the possibility of data transmitting between the Lunar orbit LADEE spacecraft and the OGS located in different regions with a rate of 622 Mbps at distance up to 239,000 miles. Two simultaneous laser channels and pulsed position modulation were used. The tests also performed of providing continuous measurements of the distance by same laser beams from the Earth to the LADEE spacecraft with an accuracy of less than 10 mm.

The amount of information from telecommunication satellites in GEO constantly increases and there is a demand in high rate information transmitted from the ground, in particular, by laser link via atmosphere. For example the Inmarsat 5-F1 at 63 E position has 89 Ka-band beams. The satellite has down link communications speeds to 50 Mbit per second by Ka-band beam. For maximum realization of this traffic the high communication speeds from ground to satellite is necessary.

Therefore the interest is to compare the influence of atmosphere conditions on laser communication at different atmosphere regions. ESA’s OGS uses the Coude focus of a 1m telescope located at the altitude of 2400 m above sea level while Main Astronomical Observatory of Ukraine (MAO) uses the Cassegrain focus of a 0.7 m telescope at the altitude of 190 m above sea level. In 2002, MAO had started the development of a ground laser communication system for the 0.7m AZT-2 telescope. Comparative investigations of atmosphere turbulence at ESA’s OGS and MAO telescope was performed [14-15]. MAO developed a compact laser communication system called LACES (Laser Atmosphere and Communication Experiments with Satellites). The work was supported by the National Space Agency of Ukraine and by ESA. Laser experiments between MAO and ARTEMIS were performed. Laser link between LACES terminal of AZT-2 telescope and OPALE terminal of ARTEMIS was achieved. Laser beams from the satellite were detected in cloudy conditions. The laser beacon from the OPALE terminal could be seen through clouds. Also, the anomalous atmosphere refraction at low altitudes above the horizon was observed [16-20].

For mitigate of influence of the atmospheric conditions on ground-to-space and space-to-ground laser communication, the network of OGS in different atmosphere Tests of Laser Active ARTEMIS Satellite

A. The Alliance of Optical Facilities of Ukraine

Different optical ground stations for observation of the satellites are in the world. Some optical ground telescopes (OGT) that would be possible to use for observations and investigations of the satellites are in Ukraine also. The alliance “UMOS” (from Ukrainian acronym: УМОС) of Ukrainian institutional research observatories and optical facilities of State Space Agency was founded in 2012 for near-Earth space research and the studies of motions of selected space objects. The positions of the UMOS telescopes at Ukraine are presented on Figure 1.

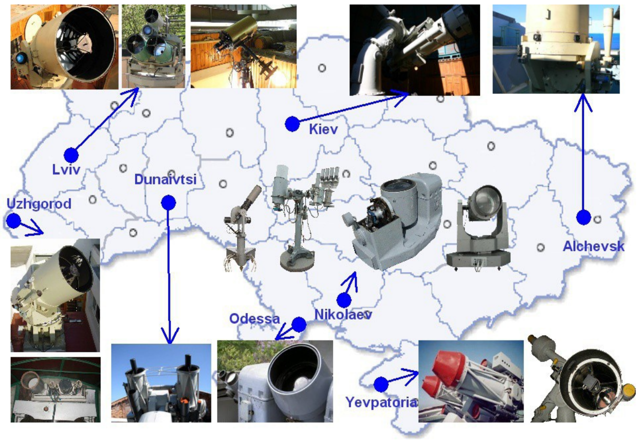


Figure 1. The positions of UMOS telescopes at Ukraine

Since the establishment of the network, or even earlier, the series of research were conducted, with results earned positive feedbacks from customers, namely State Space Agency and partners from abroad. In particular, since 2012 the UMOS (some of the observatories since 2005) has conducted maintenance the first circuits after launching into orbit with Dnepr rockets to identify and/or refine orbits of space objects, for example RapidEye, EgyptSat-1, CryoSat-2, Sich-2.

Since 2010 the photometric observations and analysis of 5 satellites with tumbling motion were made. Two abnormal launch cases detected - Express-AM4 (5,775 kg mass at altitude of 1,000 km), Phobos-Grunt (13,200 kg mass on the low reference orbit of 250 km); as well as three accidents of satellite malfunction, when the appropriate control centre has lost the connection - CBERS-2B (1,450 kg at altitude of 780 km), EgyptSat-1 (160 kg at altitude of 670 km), Sich-2 (170 kg at altitude of 670 km). All these satellites, except Phobos-Grunt, are non-resolved objects, thus photometry has been the only source of in-orbit status information.

Every member of the UMOS is developing by applying modern and novel theoretical, software and hardware solutions. Associates are welcome for collaboration.

List of participants:

- Research Institute “Mykolaiv Astronomical Observatory”, (RI MAO, Mykolaiv).
- Astronomical Observatory of Ivan Franko National University of Lviv, (AO IFNUL, Lviv).
- Research Institute “Astronomical Observatory” of Odessa National University, (RI AO ONU, Odessa).
- Space Research Laboratory of Uzhhorod National University, (SRL UzNU, Uzhhorod).
- Main Astronomical Observatory of National Academy of Sciences of Ukraine (MAO NASU, Kyiv).
- National Space Devices Control and Test Center, State

Space Agency of Ukraine (NSDC-TC SSAU, Yevpatoriya).

- Center of the Special Information Receiving and Processing and the Navigating Field Control, State Space Agency of Ukraine (CSIRP NFC SSAU, Dunaivtsi).
- State Inter-institutional Center “Orion” of Donbass State Technical University (SIC DSTU, Alchevs’k).

The main telescope data and positions of UMOS are presented in Table 1.

TABLE I. TELESCOPE DATA OF UMOS

Location	Telescope	Objective D, [m]	λ [°]	φ [°]	h (м)
MAO, Kyiv	AZT-2	0.7	30.49673	50.36417	190
RI MAO, Mykolaiv	KT-50	0.5	31,96662	46,96661	73
AO ONU, Odessa	KT-50	0.5	30.75564	46.47778	56
AO NUL, Lviv	LD-2	1.0	23,95420	49,91753	361
SRL UzNU Uzhhorod	TPL-1M	1.0	22,45380	48,56360	273
SIC Orion, DSTU Alchevs’k	TPL-1M	1.0	38,90616	48,45728	140
NSDC-TS SSAU, Yevpatoriya	AZT-28 AZT-8	0.23 0.7	33.16403	45.21975	47
CSIRP NFC SSAU Dunaivtsi	AZT-28	0.5	26.72000	48.84831	36

Some telescopes of UMOS were participated in photometry of laser active satellite ARTEMIS.

B. Tests of Laser Active ARTEMIS Satellite

OPALE communication terminal on-board of ARTEMIS has laser beacon beam of 750 μ radian divergence and laser communication beam of 7.5 μ radian divergence. Before the session the ARTEMIS perform precise pointing on the position of ground station according of its coordinate. At start of the session the OPALE terminal start the beacon scanning by spiraled moving as it presented on Figure 2.

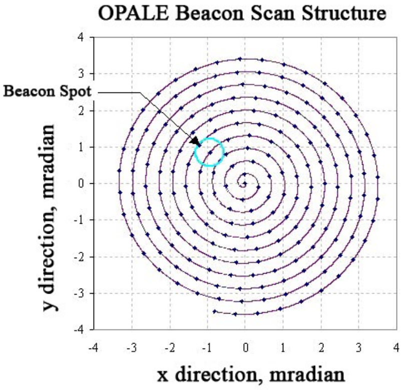


Figure 2. Spiral scanning of laser beacon of OPALE. (ESA)

ARTEMIS satellite was pointed to position of MAO at coordinate: λ = 30.49673 ° E , φ = 50.36417 ° N , h = 190 m. The maximum deviation of beacon spiral scanning from pointed position is approximately 3.5–3.7 mradians. For inclined distance of 38100 km to the satellite the diameter of ground spot from the OPALE beacon laser is approximately 29 km. Ordinary OPALE beacon perform two scans of OGS during the session.

The typical photometry of the laser beacon at position of MAO is presented on Figure 3.

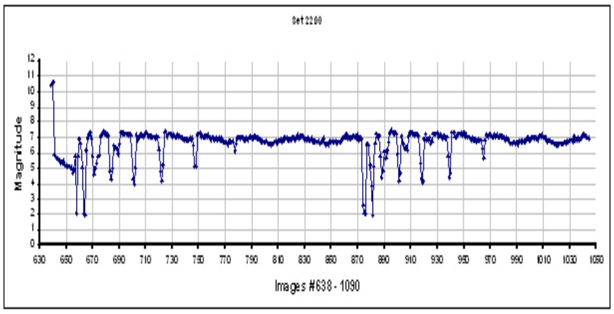


Figure 3. Photometry of the OPALE beacon. 0.7 m AZT-2 telescope MAO. Photometry of laser active ARTEMIS satellite during first and second scans. 452 images. Exposition 0.05 s. Cycle 0.75 s.

Ordinary we observed two or three bright picks when beacon passes near the position of the OGS. The planning of sessions with ARTEMIS are performed at week advance and difficult exact predict the weather conditions before of programming the OPALE terminal. During of laser experiments with ARTEMIS on 12-15 November 2012 period the weather conditions was unstable in Kyiv and decision was to use different OGS in Ukraine for observations of laser beacon signals also.

Main photometry of active laser beacon was performed at sessions on 12 and 14, 15 November. On 12 November the photometry of active laser beacon performed by Mykolaiv and Yevpatoriya telescopes, on 14 November – Lviv, Uzhhorod telescopes and on 15 November – Mykolaiv, Yevpatoriya, Odessa, Lviv, Uzhhorod, Kyiv telescopes.

Some results of synchronous photometry of laser active beacon of ARTEMIS on 15 November 2012 are presented:

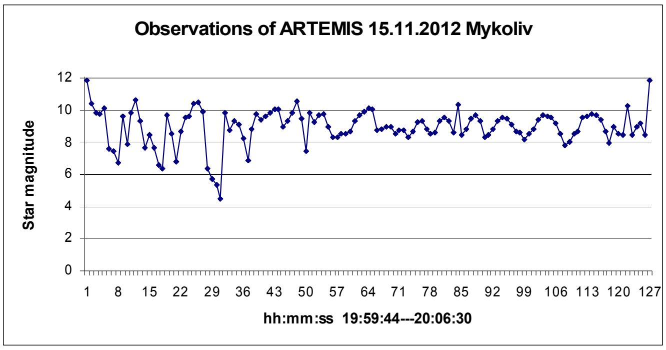


Figure 4. Observations of ARTEMIS on 15 November 2012 at 19:59:44 – 20:06:30 UTC at Mykolaiv

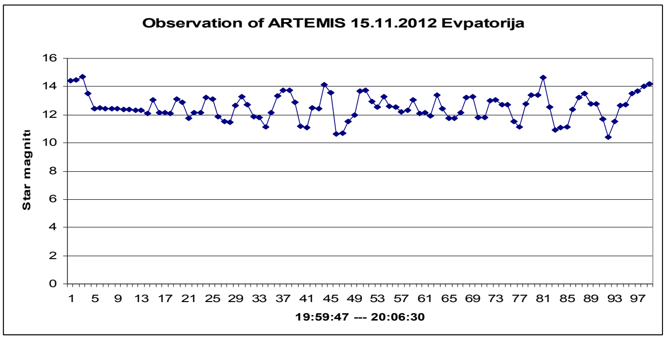


Figure 5. Observations of ARTEMIS on 15 November 2012 at 19:59:47– 20:06:30 UTC at Yevpatoria

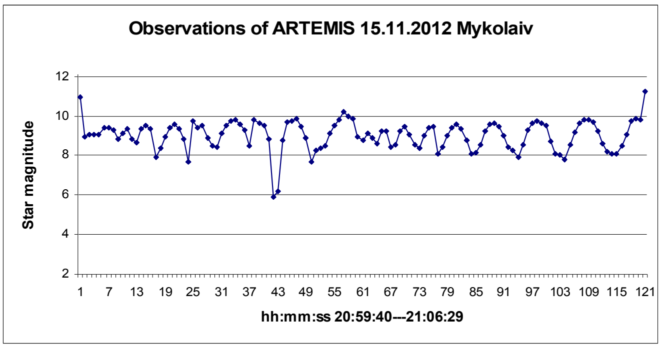


Figure 6. Observations of ARTEMIS on 15 November 2012 at 20:59:40– 21:06:29 UTC at Mykolaiv

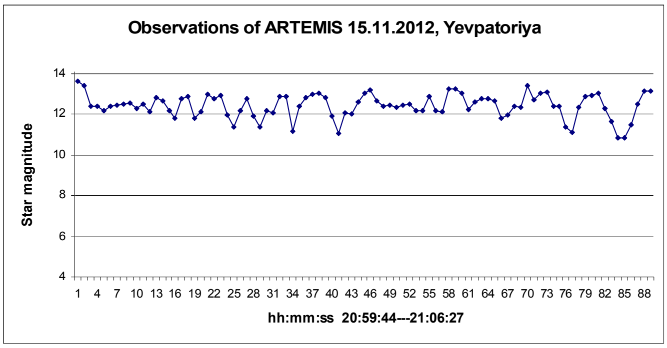


Figure 7. Observations of ARTEMIS on 15 November 2012 at 20:59:44 – 21:06:27 UTC at Yevpatoria

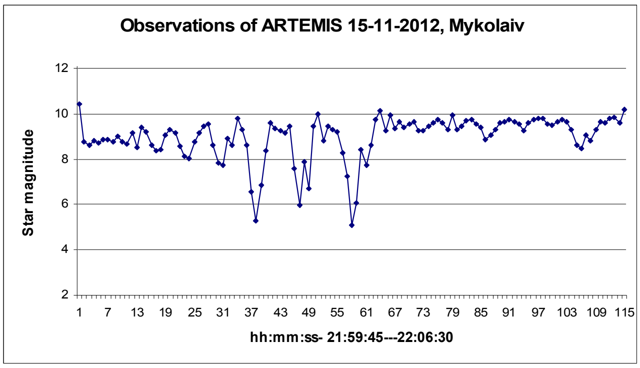


Figure 8. Observations of ARTEMIS on 15 November 2012 at 21:59:45 – 22:06:30 UTC at Mykolaiv

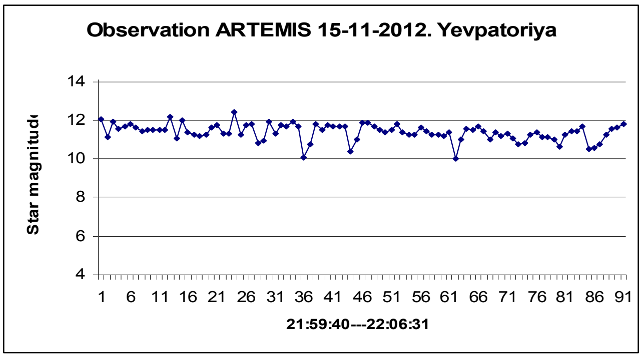


Figure 9. Observations of ARTEMIS on 15 November 2012 at 21:59:40 – 22:06:31 UTC at Yevpatoria

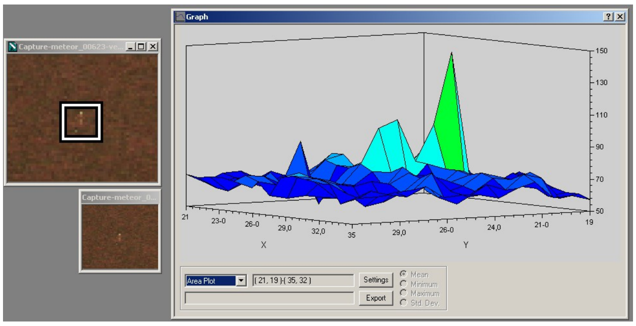
At Odessa observatory position the variations of brightness of ARTEMIS similar as Mylolaiv observatory was observed.

Some clouds conditions was at Lviv, Uzhgorod locations, some observations of the ARTEMIS satellite were performed and laser activity detected , but signals was low.

In Kyiv strong clouds was and pointing, tracking of the ARTEMIS was unsuccessful. But small signal from the laser beacon was recorded via clouds by pointing camera. The image ARTEMIS laser beacon via clouds was recorded by pointing CMOS camera on 15 November 2012 with exposition of 10 seconds. Start of the exposition was at 21:04:08 UTC. Small part of pointing camera image with laser beacon via clouds is presented on Figure 10.

Figure 10. ARTEMIS laser beacon via a clouds, exposition 10 s.

3D Image of ARTEMIS laser beacon via a cloud is presented on Figure 11. Anomaly laser scattering via clouds may be exist in this event also [21].



(21, 19)-(35, 32)

Figure 11. 3D Image of ARTEMIS laser beacon via a cloud

CONCLUSIONS

Synchronous observations of laser beacon of ARTEMIS satellite by optical ground telescopes (OGT) were performed. Six OGT synchronously obseved laser activity of the satellite. More amplitude of laser signals was observed at Mykolaiv, Yevpatoriya and Odessa OGT. This is example of minimisation of influence of a atmosphere weather conditions on space to ground communication. Time synchronisation of observations was perfomed from global navigation satellites. Synchronisation observations of laser pulses from the satellite by several OGT at different positions would open possibility of determine the distance to the satelite.

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