Project Interim/Final Scientific Report

Project title: **Complex investigations of Solar System small bodies**

1. Scientific Excellence

The surfaces of the smallest planets and moons of the Solar system are covered with a large number of craters created by asteroids. Every day, Earth is bombarded with more than 100 tons of dust and millimeter-sized particles from space. About once a year, a two-meter sized asteroid hits Earth's atmosphere, often creating a bolide event as the friction of the Earth's atmosphere causes them to disintegrate - sometimes explosively. About every five-year Chelaybinsk type event take part.

During 2018 and 2019, asteroid monitoring and properties were performed at Baldone Astrophysical Observatory (BAO) on 123 nights. 2018-2019. The observations covered 755 square degrees of sky. 4,704 positions of 1,875 asteroids were measured and published in "The MINOR PLANET CIRCULARS/MINOR PLANETS AND COMETS SUPPLEMENT" (MPS)[1], The MINOR PLANET CIRCULARS/MINOR PLANETS AND COMETS (MPC)[1]. In addition, 24 new asteroids were discovered in BAO. For newly asteroids discovered in Baldone that have repeatedly oppositions to Earth were computed orbits and published in "The MINOR PLANET CIRCULARS/MINOR PLANETS AND COMETS ORBIT SUPPLEMENT" (MPO)[1], whose observations were insufficient to calculate good orbits have been published positions data in MPS (see Table1.). The Baldone Observatory plans its observations mainly in areas of the sky that other observers see as less perspective, at declinations greater than 50 degrees (see Fig. 1).

Table 1.1. Newly discovered asteroids during 2018-2019 in Baldone Astrophysical Observatory

Date	Discovered asteroids	Publication references	Observers
2018 Sep10–Oct6	2018 RG17; 2018 RH17 2018 TL9; 2018 TM9	MPC 107827, MPC 108759, MPC 109228, MPC 109684 , MPC 110175, MPC 110809, MPC 111864	I.Eglitis, I.Vilks, V.Eglite A.Sokolova
2018 Mar18 - Sep13	2018 FU25, 2018 FV25, 2018 GU6, 2018 GV6, 2018 GX8, 2018 GE3 2018 FL30, 2018 RW41	MPO 445214, MPO 445214 MPO 457150, MPO 448864 MPO 457150, MPO 445234 MPO 524182, MPO 524362	I.Eglītis, I.Vilks, V.Eglīte
2018 Oct 07 – Sep 26	2018 TF19, 2019 FU4, 2019 GJ8, 2019 GO8, 2019 GK8, 2019 GL8, 2019 GM8, 2019 GN8, 2019 FQ8, 2019 SN19 2019 SO29, 2019 SH61	MPS 1115042, MPS 986745 MPS 986762, MPS 986763 MPS 986763 MPS 986763 MPS 1115177, MPS 1115907 MPS 1115945, MPS 1116040	I.Eglitis, I.Vilks, V.Eglite, A.Bule, A.Sokolova

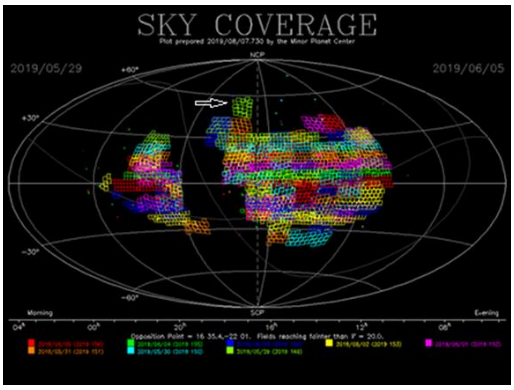


Fig. 1. Example of coverage of the sky in the time range 29.05.–05.06.2019. Observations conducted at BAO highlighted by an arrow.

Without monitoring asteroids the purpose of Project research was obtaining the light curves of two NEO's 2006 VB14=345705 and 1986 DA=6178 in order to determine their rotational period and corrected orbits. The first observation of the Aten-type asteroid 2006 VB14 in Baldone Observatory (BAO, code 069) was made on 2018-10-14.05185 (MPS 930858), when the distance between comet and Earth was 0.09 au. Results of observation in Baldone were published in Minor Planet Supplement (MPS), which consists of total results of 99 astrometric and 422 photometric observations using stations over all world, including BAO.

The first observation of Apollo-type asteroid 1986 DA was made on 2019-04-17.84924(MPS 991243),

[1] https://cgi.minorplanetcenter.net/iau/ECS/MPCArchive/MPCArchive_TBL.html.

when the distance between comet and Earth was 0.201 au. Results of observation in Baldone were published in MPS, which consists of total results of 33 astrometric and 130 photometric observations using stations all over the world, including BAO. Obtained results in Baldone Observatory are shown in Table 1. 2.

Table 1. 2. NEO asteroids observed at the BAO.

Object/Date	Number of CCD images	MPS reference	Observers, coordinate and brightness measurements
34705 = 2006 VB 14[2]			
14.10. – 01.12.2018	422	930858, 936549, 965727, 965728	I.Eglītis, V.Eglīte, A.Bule, A.Sokolova
6178=1986 DA[2]			
16.04. – 06.05.2019	130	991243, 992907, 994377, 996904	I.Eglītis, A.Bule, V.Eglite, A.Sokolova
533671 = 2014 LJ21			
07/08.05.2019	23		I.Eglītis, A.Bule
26724 = 2001 HU8			
22/23.09.2019	50	1050601	I.Eglītis, A.Bule, K.Nagainis
2583 = Fatyanov			
02.01. – 20.03.2020	259		I.Eglītis, A.Sokolova. V.Eglīte, A.Bule

Each sky region was observed at least three times each night. In order to reduce the images, flats, bias, and dark calibration images were taken each night. The program “MaxIm DL” was used to reduce and align the images. The flat-field images were taken against the twilight sky. The darks were exposed for the same time as the respective light images, two or three minutes for both asteroids. The red filter was used for observation. Position measurements were made with the help of “Astrometrica” and “Sky Sift”[3] programs. The brightness measurements are made with “MaxIm DL” or “MPO Canopus” programs.

A Fourier transform was applied to determine the rotation period for both asteroids. Light curves were created also using MPO Canopus software.The rotation period 3.25 ± 0.02 h better fitted to our measurements for 2006 VB14. The period is in agreement with the earlier work of Skiff et al. 2012[4]. The sharp fall of brightness in phases 0.3 and 0.8 and the brightness peak in phase 0.1, indicate the possible presence of a crater and the bright surface area (frozen gas field or water) on the asteroid surface, respectively.

Afterward, the program “MPO Canopus v10.2.1.0”[5] was used to perform differential photometry on the reduced data. For each data set, five stars were used for brightness comparison to the asteroid. Aperture photometry using a differential photometry technique was done to determine the brightness of comparison stars and the asteroid. The errors in magnitude for stars and asteroids were found and plotted in a phase diagram. Relative magnitude (the difference between brightness and average day brightness of asteroid) versus rotational phase, to create a light curve. 339 brightness measurements of 2006 VB14 and 130 for 1986 DA were obtained using "g" GAIA magnitudes of more than 30 reference stars.

All orbital computations of the asteroid were made using the “OrbFit” software v.5.0.5 and v.5.0.6. In the last version the “NEODyS Team” introduced the error weighing model described by Veres et al. 2017[6]. We used the JPL DE431 Ephemerides with 17 perturbing massive asteroids as was described in Farnocchia[7].

[2] I.Eglitis, Investigation of NEO asteroids 2006 VB14 and 1986 DA, Odessa Astronomical Publications, 2019,32, 142-145

[3] Holvorcem P. http://sites.mpc.com.br/holvorcem/SkySift_presentation_Holvorcem_WSP2015.pdf

[4] Skiff B. A. et al. (2012) Minor Planet Bull. 39, 111

[5] Warner B. D. (2011) MPO Canopus software v10.2.1.0, http://www.minorplanetobserver.com/

[6] Vereš P., Farnocchia D., Chesley S. R., Chamberlin A. B., 2017, Icar, 296, 139

[7] Farnocchia D., Chesley S. R., Chamberlin A. B., Tholen D. J., 2015, Icar, 245, 94-111

Computed residual norm (RMS) equal to 0.381" for observations of asteroid 345705 (2006 VB14) using a totally of 1168 observations from which 1164 were selected. Similarly, for asteroid 6178 we have 1041 observations with 1039 selected with RMS=0.479". Due to the long observational arcs, about 12 years and 42 years, respectively, it was possible to compute the non-gravitational parameter A2. Table 3 presents starting orbital elements of the asteroids 345705 (2006 VB14) and 6178 (1986 DA) computed with the non-gravitational parameter A2. A negative value of A2 of asteroid 345705(2006 VB14) denotes that the mean semimajor axis drifts da/dt<0 and hence asteroid can be retrograde rotator, in contrary, the positive value of A2 of asteroid 6178(1986 DA) denotes that the mean semimajor axis drift da/dt>0 and hence asteroid can be a retrograde rotator. As seen the orbital elements have small errors and non-gravitational parameters A2 have typical values as for NEAs. Discussed results were presented in five international conferences[8][9][10][11][12] and will be published in two intended papers[13][14] .

Table 1.3. Initial nominal orbital elements of the asteroids 345705 and 6178: a denotes semimajor axis, e - eccentricity, angles i, Ω and ω refer to the Equinox J2000.0, M - mean anomaly. Epoch: JD2458800.5 TDB = 13 November 2019. Orbital elements are computed with the non-gravitational parameter A2.

a	e	I (deg)	Ώ (deg)	ω (deg)	M
345705 = 2006 VB14					
0.7669388731 6.2E-09	0.42123761 1.0E-07	31.024613 1.5E-05	258.7275473 2.8E-06	346.441171 1.7E-05	314.203021 3.3E-05
Orbital parameter: non-gravitational 2 A2=(–1.19±1.26)E-14 au/d^2					
6178 = 1986 DA					
2.82214597 2.1E-08	0.58180432312.2E-08	4.3052158 5.0E-06	64.636860 6.6E-05	127.386722 6.6E-05	39.4555013 3.8E-06
Orbital parameter: non-gravitational 2 A2=(+3.24±2.98)E-14 au/d^2					

For more than 35 years such an astronomical plate archive of photographic negatives, which have been obtained with the Baldone Schmidt telescope, is collected at the Astrophysical Observatory (IAU code 069) of the Institute of Astronomy, University of Latvia (IA UL). The first astronomical photos were obtained in January 1967. The photos cover the field of 19 square degrees, but the linear size of photoplates is 24x24 cm. For the stellar photometry the plates and light filters were used that provided a spectral sensitivity, close to the standard U, B, V system, the Becker's R- and Kron's I-magnitudes. The Baldone Schmidt archive contained 22000 plates. Classically the scientific interests of the Latvian astronomers in the field of stellar astronomy were directed mainly to carbon stars. Therefore, the majority of plates, both direct and spectral, obtained with the Baldone Schmidt telescope, cover the zone along the galactic equator, where the carbon stars are concentrated. Astronomical photos plates digitalization took place from 2012 to 2018. Digital scans processing is now underway to gain the position and brightness of all astronomical objects captured in the images. Alongside this process, the search for asteroids in reduced images has begun.

During the years 2018-2019 the 2,500 images were studied. In images with centers close to ecliptic more than 3000 asteroids were found. Interestingly, one third of the asteroids discovered have been observed for many years, even decades before their discovery date. The results of research were presented in two conferences and is published in paper

[8] UL 77 International Scientific conference, Riga, Latvia, 2.February 2019 (Annex 2)

[9] http://gamow.odessa.ua/wp-content/uploads/2019/09/Fin-2019-Gamow-Abstracts_.pdf

[10] https://drive.google.com/file/d/13vSAxFkLBBx76V0DBDy_DCPwvBlwdbde/view

[11] https://meetingorganizer.copernicus.org/EPSC-DPS2019/EPSC-DPS2019-732-5.pdf

[12] UL 78 International Scientific conference, Riga, Latvia, 2.February 2020 (Annex 2)

[13] M. Bleiders, A. Berzins., N. Jekabsons, V. Bezrukovs, K. Skirmante, Low-Cost L-band Receiving System Front-End for Irbene RT-32 Cassegrain Radio Telescope, 2019, Latvian journal of physics and technical sciences, No.3, DOI: 10.2478/lpts-2019-0019, https://sciendo.com/article/10.2478/lpts-2019-0019.

[14] I. Wlodarczyk, K. Černis, and I. Eglitis, Observational data and orbits of the asteroids discovered at the Baldone observatory in 2015–2018, Open Astronomy,

Comets are guests from far away-outer areas of the Solar system in opposite to asteroids. In contrast to asteroids, comets are more light objects - snowballs of frozen gases, rock and dust - estimated size of a few kilometers or larger. When a comet comes close to the Sun, it heats up and spews dust and gases into a giant glowing head larger than most planets. The dust and gases form a tail that stretches away from the sun for millions of kilometers. Comets possible have brought water and organic compounds -- the building blocks of life -- through collisions with Earth and other bodies in our Solar system. To study the comet's nucleus and environment it is important to observe how it changes as it approaches the Sun. As the comet begins to heat up and the ice transforms directly from a solid to a vapor, the dust particles embedded inside are released. Sunlight and the stream of charged particles flowing from the Sun – the solar wind – sweeps the evaporated material and dust back in a long dust tail. A second tail: the plasma tail, is formed due to ionised gas from the comet coma. Comets can be observed in optical frequency band, as well as radio frequency band using radio methods - single dish mode and VLBI. Both methods - optical and radio - supplement each other, different aspects of underlying physical phenomena can be seen in detail only at particular wavelengths. From the security point of view optical systems are not effective in all weather conditions and they are not able to detect objects, approaching the Earth from the Sun direction. It can be achieved by radio observations, for example to observe comets' OH masers at 1.6 GHz frequency, however not all comets' OH masers are so bright in radio frequencies to detect them. Observations of comets are possible with the best available accuracy when optical and radio methods are combined.

Activities and results related to comets observations in radio frequencies:

There are four known (1612.231, 1665.402, 1667.359 and 1720.530 MHz) hyperfine transitions of OH at 18 cm wavelength which have been used for 40 years, to observe comets. In 1973, the OH molecule in comet Kahoutek[15] was observed with Nancay 30 meter telescope. The 18 cm line is the result of an excitation from resonance fluorescence, whereby molecules absorb solar radiation and then reradiate the energy. The OH molecule absorbs the UV solar photons and cascades back to the ground state Lambda doublet, where the relative populations of the upper and lower levels strongly depend upon the heliocentric radial velocity (the Swings effect)[16].

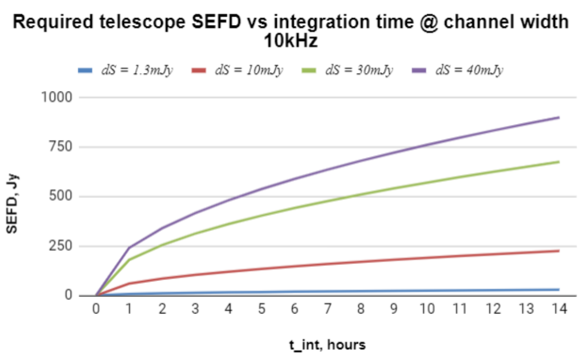


Fig. 2: Simulated Irbene RT-32 telescope sensitivity requirements for comet observation in single dish mode

The results of comets observations in 1.6 GHz frequency band made by other astronomers[17] [18] [19] - show that the typical peak source flux densities of the comet are in the range of 4 to 40 mJy. Weakness of the radio signal is the main challenging factor. Assuming that the detection threshold is 3σ, at least 1.3 to 13 mJy noise floor is required.

Developed flux detection threshold estimation model which is related to noise floor *dS* vs *integration* shows that the detection of the source with the flux density below 40 mJy is possible by radio telescope RT-32 complex if bandwidth spectral channel bandwidth is small and integration time is large (see Fig.2.).

15 B. E. Turner. Detection of OH at 18-CENTIMETER Wavelength in Comet Kohoutek (1973f). Astrophysical Journal, 189:L137–L139, May 1974.

16 D. Despois, E. Gerard, J. Crovisier, and I. Kazes. The OH radical in comets - Observation and analysis of the hyperfine microwave transitions at 1667 MHz and 1665 MHz. Astronomy and Astrophysics, 99:320–340, June 1981.

17 Jacques Crovisier, Pierre Colom, Nicolas Biver, Dominique Bockel´eeMorvan, and J´er´emie Boissier. Observations of the 18-cm OH lines of Comet 103P/Hartley 2 at Nan¸cay in support to the EPOXI and Herschel missions. Icarus, 222(2):679–683, Feb 2013.

18 A. J. Lovell, E. S. Howell, F. P. Schloerb, B. M. Lewis, and A. A. Hine.Arecibo observations of the 18 cm OH lines of six comets. In Barbara Warmbein, editor, Asteroids, Comets, and Meteors: ACM 2002, volume 500 of ESA Special Publication, pages 681–684, Nov 2002.

19 A. E. Volvach, A. A. Berezhnoi, L. N. Volvach, I. D. Strepka, and E. A. Volvach. Observations of oh maser lines at an 18-cm wavelength in 9p/temper1 and lulin c/2007 n3 comets with rt-22 at the crimean astrophysical observatory. Bulletin of the Crimean Astrophysical Observatory, 107(1):122–124, Jun 2011.

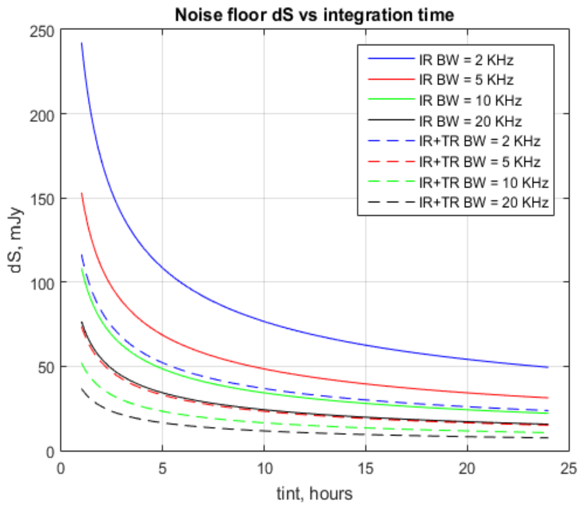


Fig.3. Achievable noise floor using Irbene RT-32 and Irbene-Torun interferometer vs. integration time and spectral resolution bandwidth

Regarding previous cooperation withTorun Observatory, Irbene-Torun interferometer usage was identified as a possible technique to detect weak OH masers on comets. Threshold estimation of *noise floor* using Irbene RT-32 and Irbene-Torun interferometer vs. *integration time* and spectral resolution bandwidth shows achievable possibility to successfully detect OH masers of the comets (see Fig.3.).

Models showed that comets' OH masers detection in radio bands is theoretically possible, but the RT-32 receiving system should be improved to obtain better results.

Significant work was invested to prepare the instrumentation of Irbene 32-meter antenna for spectral line observation at L band. This includes improvement of receiver system sensitivity at 1.665 and 1.667 GHz, by building and installing new secondary focus front-end. Results of this activity were published in a paper[20].

Then activities were devoted to implement and test Solar system object tracking capability in antenna software system. When receiving and tracking system tasks were finished, additional work was carried to optimize spectral line registration spectrometer for reliable and sensitive molecular line detection. Spectrometer software was supplemented with raw I-Q sample recording, necessary for data post-processing. This also involved change of spectrometer host computer and provision of 10 Gbit/s Ethernet connection between host and spectrometer for reliable high-speed data transfer. During first long duration (4 hours and more) observations an issue of narrowband radio frequency interference (RFI) was found, which made spectra line detection impossible. In Winter 2019/2020 careful investigation was carried out to find the RFI source. As a result, various equipment modules at receiver cabin were shielded, switching power supplies changed, and provision for remote turn-off of problematic equipment was implemented, which significantly reduced RFI levels at L band. Currently observation system functions are stable and regular large-integration-time observations of Solar system objects regularly performed.

To ensure the object tracking during the observations, the azimuth and elevation parameters of radio telescope RT-32 are passed to the Field System which is responsible for telescope movement. To provide this, the orbit determination model was developed and azimuth and elevation values were obtained at each minute in the observation. Model is based on T. van Flandern and K. Pulkkinen's paper "Low precision formulae for planetary positions"[21] and Kepler elements of the comet are passed as input parameters of the model.

Based on developed estimation models, the RT-32 receiver system upgrade and data processing activities were implemented in parallel mode. Data calibration and processing methods were necessary to filter out weak OH maser signals from radio astronomical data sets. For spectral data calibration, the frequency switching method[22] was integrated in the observation process. Data processing is implemented to collect data using long integration time, consequently the compensation of the Doppler shift was needed. For signal processing Fourier transforms and wavelet transforms were used.

To verify enhanced RT-32 sensitivity for weak object observations, the Mira variable star R LMi was selected as the test object, which was previously observed by Nancay Radio Astronomy Observatory, France[23]. In this research obtained results showed its spectral line at 1665 MHz with maximum 5 Jy and two local maximums (2 Jy and 1 Jy) at 1667 MHz spectral line. Multiple observations were carried out to detect

20 M. Bleiders, A. Berzins., N. Jekabsons, V. Bezrukovs, K. Skirmante, Low-Cost L-band Receiving System Front-End for Irbene RT-32 Cassegrain Radio Telescope, Latvian Journal of Physics and Technical Sciences, 2019, Vol.56, No.3, 50.-61.lpp.

21 van Flandern, T. C. & Pulkkinen, K. F.,Low-precision formulae for planetary positions, Astrophysical Journal Supplement Series, vol. 41, Nov. 1979, p. 391-411.

22 B. Winkel, A. Kraus, and U. Bach. Unbiased flux calibration methods for spectral-line radio observations. Astronomy and Astrophysics, 540:A140, Apr 2012.

23 G. M. Rudnitski, M. I. Pashchenko, and P. Colom. Polarization observations of circumstellar oh masers. Astronomy Reports, 54(5):400–417, May 2010.

the object R LMi with tuned Irbene RT-32 radio telescope receiver system. In April 16, 2019 a two hour observation session at 1667 MHz frequency band showed strong emission lines and unclear results in central frequency. Filtering with multiple wavelet families showed the best results with rbio1.5 wavelet and 0.5 threshold. Obtained results demonstrate small maximum at central frequency (see Fig. 4). On August 9, 2019 the second experiment session was organized where observation duration was 4 hours and frequency band was 1667 MHz. Strong emission line was detected and two maximum peaks (1.4 Jy and 1.1 Jy) were obtained using calibration algorithms, Fourier transforms and wavelet coif6 with threshold 0.5 (see Fig. 5)[24].

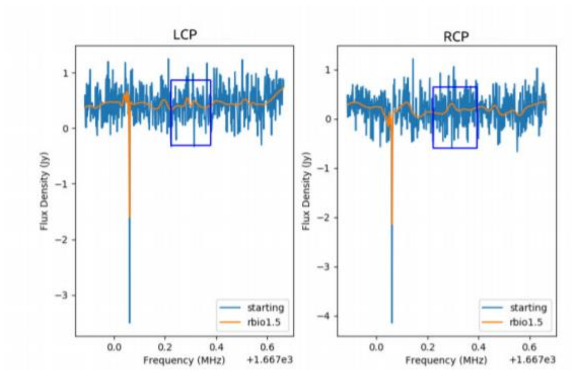


Fig. 4: Left and Right circular polarisations (LCP and RCP) of object R LMi were used on April 16, 2019. Spectre (line in blue) and rbio1.5 wavelet with threshold 0.5 (line in orange) are shown.

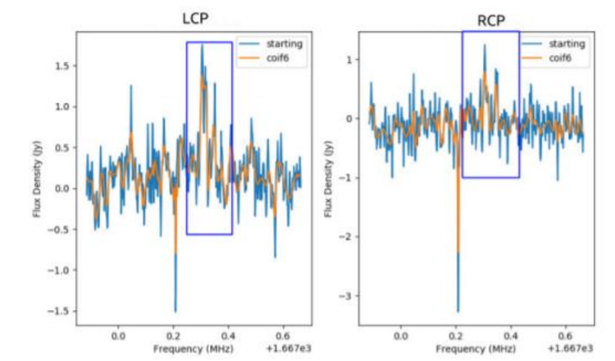
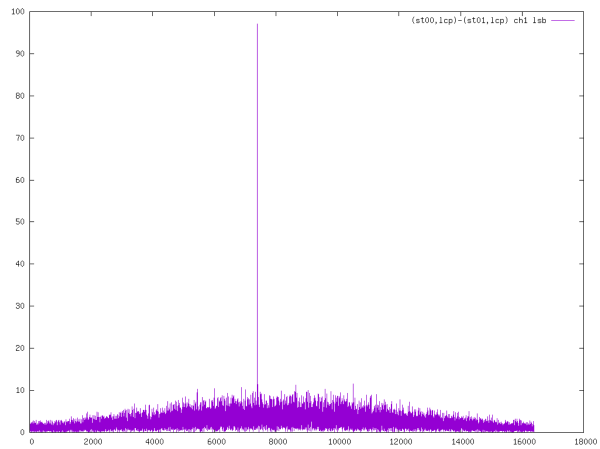


Fig. 5: Left and Right circular polarisations (LCP and RCP) of object R LMi were used on August 9, 2019. Spectre (line in blue) and coif6 wavelet with threshold 0.7 (line in orange) are shown.

L-band receiver tests using interferometer Irbene-Torun were organized on February 4, 2019, where observation frequency 1665 MHz (LCP and RCP) was used and observation objects - OH masers of galactic sources W3OH, 3C123, 3C84, W49N - were successfully detected. An example of some results of interferometer Irbene-Torun observations shown at Fig.6.



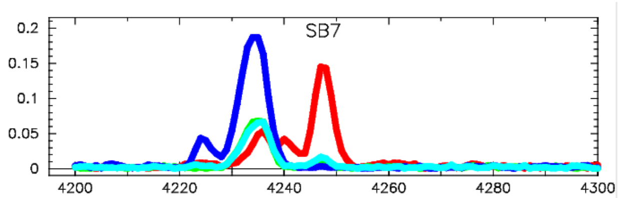


Fig.6. Cross-correlation functions for the baseline Irbene – Torun. Experiment date: 4 Feb 2019, frequency: 1660.49 MHz. Calibrator source 3C84 (left) and OH maser source W3(OH) (right). On the X axis - FFP points; on the Y axis - amplitude of the fringe function.

Although the observations using interferometer Irbene-Torun were successful, RFI of Torun station were large. It was decided that the first part of the Project implementation will be focused on observations in single mode and at the last year of Project implementation - usage of interferometer will be revised.

Table 1.4. Observations of comets at Irbene 2018-2020.

Comet name	**Observations date**	**Duration/integration (h, hours)**	**Observers**	**Comments**
Africano (C/2018 W2)	2019.Sep. 11 – 2019.Sep. 12	8	VIRAC team	No detection

24 K. Skirmante, I. Eglitis, N. Jekabsons, V. Bezrukovs, M. Bleiders, M. Nechaeva and G. Jasmonts, Observations of astronomical objects using radio (Irbene RT-32 telescope) and optical (Baldone Schmidt) methods, Astronomical and Astrophysical Transactions, vol.31, issue 4, 2020. https://drive.google.com/open?id=1RXjKaUz6p4nnSAxWOK6S_Gg13imDj_YV

C/2017 T2 (PANSTARRS)	2019.Oct. 16 – 2019.Oct. 21	40	VIRAC team	Unclear results
C/2018 N2 (ASASSN)	2020 Jan 18	8	VIRAC team	No detection
C/2017 T2 (PANSTARRS)	2020 Jan 24, 25, 26	20h x 3 days	VIRAC team	Data processing ongoing
Atlas (C/2019 Y4)	from March 15 till March 30	overall: 120h	VIRAC team	Data processing ongoing

<u>Activities and results related to comets observations in optical frequencies:</u>
During Autumn 2018, Autumn 2019 and beginning of 2020 at Baldone Astrophysical Observatory were observed five comets. In 2018 the first observed comet was the Africano C/2018 W2 using the Baldone Observatory optical telescope. However, this comet OH maser was not bright enough to detect it in radio range with VIRAC RT-32. Therefore, BAO did not continue to observe this comet in the optical range. In the Autumn - Winter of 2019 BAO observed two comets 38P/1980 L2 Stephan-Oterma and unusual visitor from far away space Borisov C/2019 Q4. Baldone made position and brightness measurements of both comets. Borisov comet was observed for five nights and the tail structure was studied. Ionised gas and dust tails were singled out on Baldone Schmidt telescope CCD images (see Fig. 7.).

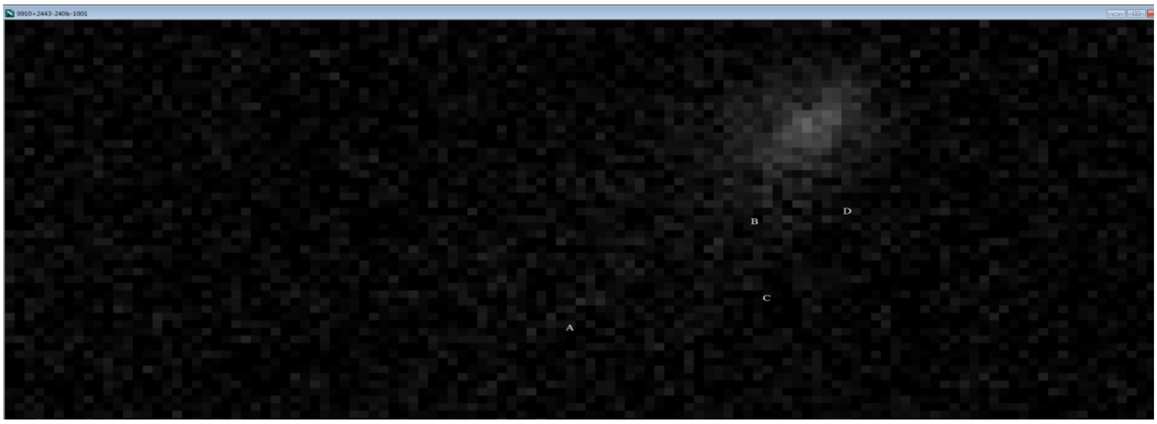


Fig. 7. C/2019 Borisov at 26 09.2019 exposition 120 sec. A –ionised gas tail, C dust tail.

Optical observations of space objects in the Winter of 2019/20 were very limited by the abnormally high number of cloudy nights, which resulted in average winter temperatures ranging from +1 to +4 C and day from +4 to +8 C. In result, the number of partly clear nights from November to mid of March did not exceed 12. Among which there were only 7 clear nights.

Parallel optical in B V R passbands and radio observations of comet C/2017 T2 (Panstarrs) were in February and March 2020. B V R magnitudes and position measurements of the comet were made in three nights. A summary of comet observations in optic is given in Table 1.4.

Table 1.5. Observations of comets at BAO 2018-2020.

Comet name	Observations date	Number of images	Observers	Processing
38P/Stephan-Oterma	2018 01.12	1	I.Eglitis	Brightness measurements A.Bule
Africano (C/2018 W2)[25]	30.11.2018	3	I.Eglitis	Position measurements K.Cernis
Borisov (2I/2019 Q4)	25.09.2019 - 27.10.2019	51	I.Eglitis, V.Eglite	Brightness measurements of comet and it tail, K.Nagainis

[25] I.Eglitis and 49 coautors, MPEC 2019-E73 : COMET C/2018 W2 (Africano) https://minorplanetcenter.net//iau/mpec/K19/K19E73.html

C/2017 T2[26]	24.02.2020 - 14.03.2020	16	I.Eglitis, V.Eglite	Brightness measurements of comet and it tail A.Bule, A.Sokolova, K.Nagainis
Atlas (C/2019 Y4)	19.03.2020	12	I.Eglitis, V.Eglite,	Position and brightness measurements A.Bule, A.Sokolova, K.Nagainis

Activities and results related to comets observations in optical and radio frequencies:

Successful parallel radio-optical observations are associated with possibly the brightest upcoming comet in the 2018-2021 period, Atlas C / 2019 Y4 (see Fig. 8 and Fig. 9.), which already has an integral magnitude brighter overall comets already observed during the project. The comet is still approaching the Sun and its brilliance will increase until May 31, 2020, when it comes closer position to the Sun. It is difficult to judge the brilliance of the comet by its rapprochement with the Sun. Both are possible as a history of comet observations show - it can become even brighter than in the cases of Hale-Bopp and Hyakutake comets, or become more dummy as expected - comets ISON 2013, Austin 1990. and Kohoutek 1974. The parallel radio – optical observations of comet Atlas began in March 2020.

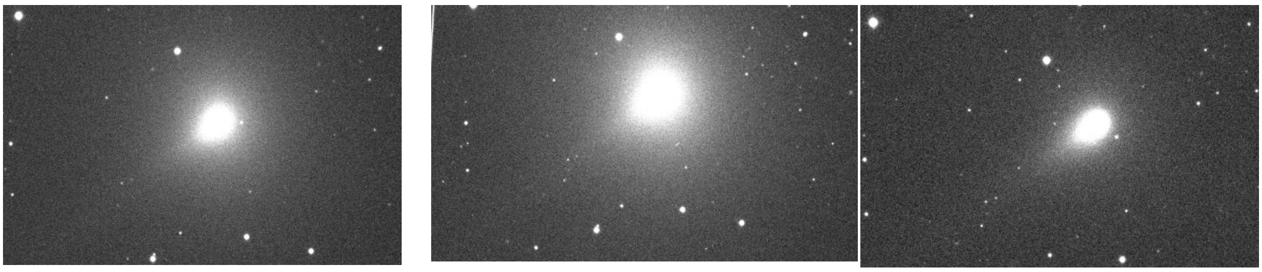


Fig. 8. Atlas comet images in B, V and R passbands at 19.03.2020 obtained at BAO with 120 sec exposure.

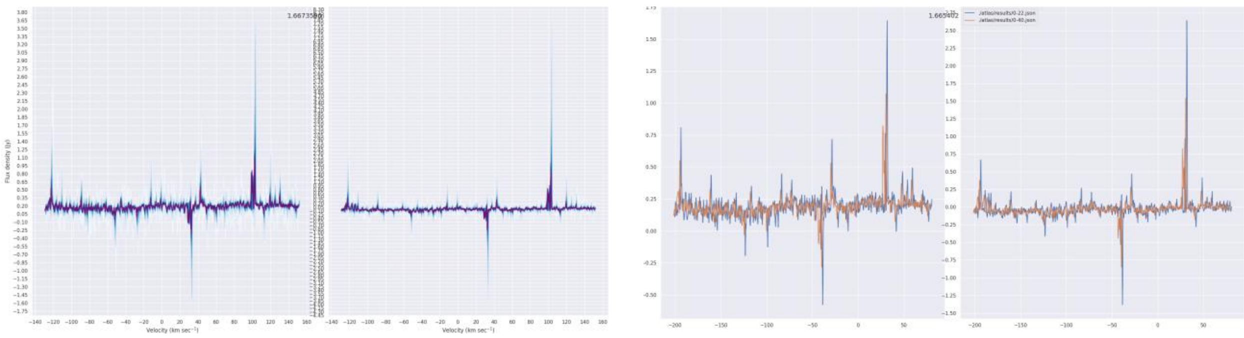


Fig. 9. First results of the Atlas comet obtained at VIRAC. Left and Right circular polarisations (LCP and RCP) of comet ATLAS spectra from 19.03.2020 and 20.03.2020 observations. Data processing is still ongoing.

2. Impact

2.1. The project's scientific results

Table No. 2.1

Impact indicator of results	Number	
	Intended	Completed
1. Scientific publications		
1.1. Scientific publications (SCOPUS, WoSCC and/or ERIH +)	2**	2*
1.2. Other anonymously reviewed scientific publications	2	5*

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1.3. Reviewed scientific monographs	0	0
1.4. Data scientific publications	0	20
2. Establishment of intellectual property rights (patents, registered varieties of species etc.)	0	0
3. International scientific conferences to participate in or organize	4	13***

* see in Annex 1, ** see in Annex 2,
***see in Annex 1 and https://drive.google.com/drive/folders/1TGiZo4e336icEgJl7QtdnN5v0zFb8tWJ

2.2. Opportunities for research development

During the implementation of Project, obtained competence provided an opportunity to create a project proposal “The application of the forward scatter radar method for the detection of space objects”(Nr. lzp-2020/1-0239) which is related to asteroids and comets detection using Forward scatter radar method.

Table No. 2.2

No.	Collaborating institution/organization, country	Type of collaboration	Period
1.	Institute of Theoretical Physics and Astronomy of Vilnius University, Lithuania	Asteroid position measurements	From 2009 until now
2.	Main Observatory of Kiev, National Academy of Sciences of Ukraine	Digitized astro plate processing and common publications.	From 2015 until now
3.	Nikolev Observatory of National Academy of Sciences of Ukraine	Digitized astro plate processing.	From 2015 until now
4.	Chorzow Astronomical Observatory, Poland	Asteroid orbits calculation	From 2010 until now
5.	Torun Radio Astronomy Observatory, Poland	Collaboration observations with Torun VLBI station in Irbene-Torun interferometer	From 2018 until now

2.3. Socio-economic impact of results

Project results clarifying the nature of the Solar System and its small bodies will have direct impact on developing the priority research field in Latvia – physical sciences, particularly astronomy and radio astronomy. The technical solutions and software developments developed during the Project will be useful anywhere where it is necessary to deal with receiving and processing of weak signals and large amounts of data. So they will promote the Research Priority Area "Technologies, materials and system engineering for increased added value products and processes, and cybersecurity".

Table No. 2.3

No.	**In cooperation with**	**Cooperation form and description**	**Period**
1.	ESA	European Space Agency Wavelets Course 2020 – education course	2020
2.	ESA	International Space Science Institute (Bern) Expert Advisor for Working Group, In-Space Resource Utilisation	2020-2021
3.	USA, Italy, Estonia, Finland, Sweden, Poland, Germany, France, Spain, Austria, Netherlands	ESA Comet Interceptor mission Science Team member – working group	2020-2030
4.	**UL**, Finnish Meteorological Institute, Tartu Observatory, EstSat/ EstCube, NewTime, Garage48, Baltics in Space, Institute of	ELLF v.1 Ecosystem (2019) project ELLF-v2 2020 second part of project	2019-2020

	Environmental Solutions, **VIRAC**, Zinoo, Moletai Ethnocosmological Museum		
5.	Baltics in Space (Estonia, Latvia, and Lithuania)	Non-profit organization of the Baltic States organizes the steps to build a Baltic-wide eco-system of space and climate change educated society, especially with young citizen scientists	2017-2020
6.	ASIME	Consulting to Luxembourg Ministry of the Economy (now Luxembourg Space Agency) for ASIME concept on in-space asteroid utilisation	2016-2018
7	European Commission	Expert SME Space reviewer A.Graps	2017 untill now

2.4. Publicity and communication

Table No. 2.4

No.	**Activity (e.g. in the media)**	**Short description (cooperating party, target audience, website, if any, etc.)**	**Period**
1.	Presentation	An attractive presentation at the BAO,On the European Scientists' night (presented by I.Eglītis, V.Eglīte). About 300 visitors	2018.Sept.28.
2.	Presentation	An attractive presentation at the BAO, On the European Scientists' night (presented by I.Eglītis, V.Eglīte) 497 visitors	2019.Sept.27.
3.	Presentation	Presentation "Meteorites and their detection" at University of Latvia (Riga, Raina 19.), on the European Scientists' night (I.Vilks). About 800 visitors.	2018.Sept.28.
4.	Presentation	Presentation "How telescope works" at UL (Riga, Jelgavas 3), on the European Scientists' night (I.Vilks). About 500 visitors.	2019.Sept.27.
5.	Popularscientific lectures*	Popular scientific lectures about astronomy including project progress report at BAO Planetarium (V.Eglite, R.Eglitis). 56 lectures1430 visitors	3.11.2018 - 29.06.2019
6.	Popularscientific lectures	Popular scientific lectures about astronomy at UL Mini planetarium (presented by I.Vilks). Overall 37 lectures 858 visitors.	2018.Aug.- 2019.Dec
7.	Demonstrations	Demonstrations at the UL Astronomical Tower (presented by I.Vilks). Every Monday and Thursday, overall 120 visitors	2018.Oct. – 2019.Mar.
8.	Radio broadcast	Radio broadcast "Asteroid "Latvija"(presented by I.Vilks)	2018, Aug.
9.	TV broadcast	TV broadcast "Mars Rover Opportunity" (presented by I.Vilks)	2019, Febr.
10.	Radio broadcast	Radio broadcast "Solar System news " at Latvian radio 4 (I.Vilks)	2019, July
11.	Radio broadcast	Radio broadcast "Moon exploration" at Baltcom radio (I.Vilks)	2019, Sept.
12.	Public discussion	Public discussion about Mars colonization at Riga Technical University(presented by I.Vilks)	2019.Sep.19
13.	Press release	Press release about comet Borisov (C/2019 Q4) observation in Baldone Observatory. https://www.lu.lv/par-mums/lu-mediji/zinas/zina/t/51610/ (prepared by I.Eglītis)	2019.Oct.01
14.	Radio broadcast	Performance on radio in program "Nākotnes pietura" LR2 (Latvijas Radio 2) about asteroids observation in BAO (presented by I.Eglitis)	2019.Oct.09.

15.	Participation in media interview	Publication in popular portal Delfi "Komēta nāk' – tālo zvaigžņu ciemiņu Latvijā varēs vērot entuziasti"https://www.delfi.lv/campus/raksti/kometa-nak-talo-zvaigznu-ciemiņu-latvija-vares-verot-entuziasti?id=51513999 (Edžus Miķelsons, interview with I.Eglītis)	2019.Oct.02.
16.	Press release	Press release about project and activities http://virac.eu/petnieciba/projekti/pla/	From Aug 2, 2018
17.	Press release	Press release about uniq result obtained in VIRAC using RT32 radiotelescope http://virac.eu/pirmo-reizi-vsrc-vesture-tika-ieguts-troksnu-videjais-limenis-zem-0-25-jy/	From Feb 10, 2020
18.	Press release	Press release about project and activities http://virac.eu/apstiprinats-vea-fundamentalo-un-lietisko-petijumu-projekta-pieteikums-2/	From Aug 2, 2018
19.	Press release	Press release about project and activities https://venta.lv/zinatne/istenotie-projekti/#valsts-finansetie-projekti	From Aug 2, 2018
20	Web page	On the website of the Institute of Astronomy of the University of Latvia in English, https://www.lu.lv/astr/projects/	From 2018 Aug.

*Registration lists of visitors Annex 3, if needs photos of groups, connect with ilgmars.eglitis@lu.lv

2.5. Contribution to the capacity building of the project's scientific team, including the students, as well as to the improvement of the study environment

Table No. 2.5

Doctoral, master's and bachelor theses supervised or provided with advice from the principal investigator or the lead participants within the framework of this project (if the theses have been defended, indicate this in the last column of the table, also specifying the date and the promotional council)

No.	**Author**	**Title**	**Supervisor and consultant**	**Defence**
1.	K.Skirmante	Doctoral thesis "Radio Detection of OH lines of Solar System planetary small bodies"	Supervisor - A.L.Grapa, consultant - N.Jekabsons	In progress
2.	F.Kamiševs	Bachelor thesis "Development of radio astronomical data processing software of real-time correlation, filtering and data visualization modules"	Supervisor K.Skirmante	2019 June
3.	G.Jasmonts	Bachelor thesis "Weak radio astronomical object data processing, calibration, filtration and result analysis"	Supervisor K.Skirmante	In progress
4	V.Eglite	Bachelor thesis "Guided tours for development of 5th grade cognitive activity in science lessons".	J.Bogdanova Daugavpils University	In progress
5	A.Bule	Bachelor thesis "Monitoring of new carbon stars in the Milky Way"	Supervisor I.Eglitis	Defenced at 2019 at UL, continue Master thesis
6	A.Sokolova	Bachelor thesis "Spectrphotometric investigations of carbon stars in the Milky Way"	Supervisor I.Eglitis	Defenced at 2018 at UL, continue Master thesis
7	K.Nagainis	Bachelor thesis "Astrometry and photometry of asteroids in the Baldone Schmidt Telescope Archive Database"	Supervisor I.Eglitis	In progress

3. Implementation
In the implementation of the Project it was identified that the RT-32 receiver system needed to upgrade. Data processing methods were developed independently on test objects (galactic OH masers) when the RT-32 receiver system was upgraded. New risks were identified. Please see Table 3.1.

Table 3.1. Risk assessment

No.	Risk	Risk description	Asses-sment		Risk prevention/reduction measures
			Proba-bility	Impact	
1.	Imple-men-tation	The radio telescope RT-32 receiving system is not sensitive enough to detect weak OH masers of comets.	High	Medium	The radio telescope RT-32 receiving system was upgraded and sensitivity is enough. In case RT-32 will fail, it is possible to continue observations using the radio telescope from collaborating observatories like Torun (Poland), Noto (Italy).
2	Imple-men-tation	Covid-19 pandemic and it restrictions (for example, home working) during the implementation of Project	High	Medium	Irbene radio telescopes, UL AI and HPC facilities can be managed and used remotely. VIRAC and UL AI employees have been provided with access from home to work computers using VPN (Virtual private network).
3.	Imple-men-tation	Nor should we forget the technical problems of adjusting the technique to the observation of the weak object in radio range, or of the Baldone Schmidt telescope's problems with the possible failure of heavily worn telescope control electronics	Medium	Medium	To overcome this problem, it is necessary to involve an old generation specialist in electronics prevention activities in BAO. Reconstruction/renewal of some Telescope control units. Close cooperation in observations and processing of data with colleagues from Lithuania and Ukraine.

No changes in the research team were made in VIRAC. At UL IA research team Dmitrijs Spakovs dropped out of physics study's and was therefore replaced by a BSc physic's student Anna Bule (female) .

Project executor Karina Skirmante is PhD student in University of Latvia in study program "Physics, astronomy and mechanics" where her dissertation work "Radio Detection of OH lines of Solar System planetary small bodies" relates with Project goal and activities. She was involved in development of the orbit determination model, organizing observations of test objects and comets, development of the processing methods related to wavelet transform usage, as well scientific article preparation and results presentation in international conferences. She was consulted by scientifics from UL AI (I.Eglītis, A.Graps) and VeUAS VIRAC (N.Jekabsons and M.Nechaeva).

In the Project theme BSc student of University of Latvia -Kristers Nagainis - was involved on the subject of asteroid and comet research. Also student K.Nagainis was involved in brightness measurements of comet Borisov (2I/2019 Q4) and it tail, students A.Bule, A.Sokolova, K.Nagainis were involved in brightness measurements of comet C/2017 T and it tail, students A.Bule, A.Sokolova, K.Nagainis were involved in position and brightness measurements of comet Atlas (C/2019 Y4).