Annex 9
to the Contract on the implementation and funding of fundamental and applied research project
(August 31.2018, No.lzp-2018/1-0401)

Project 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 takes part.

During Autumn 2018 till Autumn 2021, asteroid monitoring and properties were performed at Baldone Astrophysical Observatory (BAO) on 233 nights. The observations covered 1370 square degrees of sky. 9309 positions of 4550 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 (so far, the results of 2021 have not been published by the MPC) 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 Table1.1). 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.

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

Discovered asteroids	Publication references
2018 RG17; 2018 RH17 2018 TL9; 2018 TM9	MPC 107827, MPC 108759, MPC 109228, MPC 109684 , MPC 110175, MPC 110809, MPC 111864
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
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

Without monitoring asteroids the purpose of Project research was to obtain the light curves of NEO 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 overall world, including BAO.

Apollo-type asteroid 1986 DA was observed on 2019-04-17.84924(MPS 991243), when the distance between comet and Earth was 0.201 au. Results of measurements were published in AAT[2] , which consists of total results of 33 astrometric and 130 photometric observations using data from Observatories overall the world, including BAO.

Each sky region was observed for at least three-five nights. In order to process 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 dark images were exposed for the same time as the respective light images, two or three minutes for all asteroids. The red filter was used for observation. Position measurements were made with the help of “Astrometrica”, the new genesis of the

[1] https://www.minorplanetcenter.net/mpec/RecentMPECs.html
[2] K. Skirmante et.al, Astron. and Astroph. Trans., 2020, Vol 29, p.179-188 https://www.degruyter.com/document/doi/10.1515/astro-2020-0017/html

program "CoLiTec" ("Lemur"[3]) and "Sky Sift"[4] programs. The brightness measurements are made with "MaxIm DL" or program "Lemur". The program 'Lemur" was used to perform differential photometry on the reduced data. For each data set, more than 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 in GAIA G(RP) passband.

A standardized methodology is used to process the luminosity curves to eliminate differences in observations over time. Data from all series of observations are reduced to a single epoch, usually to the first series of observations. First, the difference in receiving the light signal due to the different distances is ruled out.

$$t = (JD_i - JD_0) - \Delta R/c,$$

where JD is Julian's day of i series to zero series and ΔR is the distance difference till observer.

For brightness, two adjustments are made to change all measurements to the first series of observations. The adjustment for distance changes is observed in the following way:

$$\Delta m = -2.5log(\frac{R_i^2}{R_0^2}\frac{D_i^2}{D_0^2}),$$

where R is distance till observer and D is distance till the Sun for i series to zero series.
In turn, the effect of the phase is corrected with subsequent reduction:

$$\Delta m = (Ph_i - Ph_0)p,$$

where Ph are phases and p is a slope coefficient in the phase diagram.

After these corrections, a Fourier transform was applied to determine the rotation period of asteroids. Light curves were created using the Python program 'Fourier series_0.9-1.1' created at Baldone observatory.

$$V_r = A_0 + \sum_{i=1}^{n} B_n \sin\left(\frac{2\pi i}{P}t\right) + \sum_{i=1}^{n} C_n \cos\left(\frac{2\pi i}{P}t\right),$$

where V_r is the apparent magnitude or relative magnitude, A_0, B_n, C_n are Fourier constants, P is the period and t is time in Julian days.

The rotation period 3.25 ± 0.02 h better fitted to our measurements for NEA 2006 VB14. The period is in agreement with the earlier work of Skiff et al. 2012[5]. 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. From 2020 Baldone Observatory is a member of the International Asteroid Warning Network[6] and took part in discovering, monitoring and physically characterizing the potentially hazardous NEO population (for example Apophis campaign). Obtained results for other NEO observed in BAO are given in Table 1. 2.

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

Object	Number of CCD images	Observers, possitions and brightness measurements	Obtained period of rotation (hours)
34705 = 2006 VB 14[7,2]	422	I.Eglītis. V.Eglīte. A.Bule. A.Sokolova	3.25±0.02
6178=1986 DA[7,2]	130	I.Eglītis. A.Bule. V.Eglīte. A.Sokolova	3.12±0.02
9450=1998 BT1[8]	91	I.Eglītis. V.Eglīte. A.Bule. K.Nagainis	9.245±0.012
24298=1999 XC221[8]	119	I.Eglītis.V.Eglīte. A.Sokolova. K.Nagainis	11.940±0.032
19562=1999 JM81[8]	208	I.Eglītis. V.Eglīte. A.Bule. K.Nagainis	9.343±0.011
558307=2015 AS45[8]	65	I.Eglītis. A.Sokolova. K.Nagainis	105.7±0.3
8081=1998 DD[8]	74	I.Eglītis. K.Nagainis. A.Bule. A.Sokolova	2.561 or 4.913±0.032
1994 GF10=Nr15808[9]	122	I.Eglītis. V.Eglīte. K.Nagainis	19.92±0.02
307984=2004 OV13[8]	77	I.Eglītis. V.Eglīte. K.Nagainis	15.36±0.03

[3] http://www.neoastrosoft.com/download_en/
[4] Holvorcem P. http://sites.mpc.com.br/holvorcem/SkySift_presentation_Holvorcem_WSP2015.pdf
[5] Skiff B. A. et al. (2012) Minor Planet Bull. 39, 111
[6] https://iawn.net/about/members.shtml
[7] I. Wlodarczyk, K. Černis, and I. Eglitis, Observational data and orbits of the asteroids discovered at the Baldone observatory in 2015–2018, Open Astronomy, 2020, Vol 29, Issue 1, p.179-188 https://www.degruyter.com/document/doi/10.1515/astro-2020-0017/html
[8] I.Eglitis et.al, Astronomical and Astrophysical Transactions, 2022 in press (pdf in Annex 2)
[9] I.Eglitis et.al, Dynamics of some NEO asteroids, International conference MAO-200, http://www.nao.nikolaev.ua/MAO-200/abstract.html

1994 GF10=Nr15808[8]	122	I.Eglītis, V.Eglīte, K.Nagainis	19.92±0.02
506459=2002 AL14[8]	45	I.Eglītis, V.Eglīte, K.Nagainis	2.398±0.024

Table 1.3. Results for Main belt asteroids observed at the BAO

Object	Number of CCD images	Observers, possitions and brightness measurements	Obtained period of rotation (hours)
1642=1951 RU[8]	77	I.Eglītis, A.Bule, V.Eglīte, A.Sokolova	6.125±0.019
2583=1975 XA3*[8]	155	I.Eglītis, A.Bule, V.Eglīte, A.Sokolova	6.142±0.022
2890=1978 SY7[8]	48	I.Eglītis, V.Eglīte, A.Bule, K.Nagainis	1.505±0.019
5425=1984 SA1[8]	42	I.Eglītis, A.Bule, V.Eglīte, A.Sokolova	2.635±0.022
12349=1993 GO[7]	82	I.Eglītis, V.Eglīte, A.Bule, K.Nagainis	15.710±0.019
11508=1990 TF13[8]	135	I.Eglītis, A.Bule, V.Eglīte, A.Sokolova	3.057h±0.015
18869=1999 TU222[8]	86	I.Eglītis, V.Eglīte, K.Nagainis	17.72±0.03
42724=1998 QJ76[8]	119	I.Eglītis, V.Eglīte, K.Nagainis	8.503±0.025

*asteroid has a satellite

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[10]. We used the JPL DE431 Ephemerides with 17 perturbing massive asteroids as was described in Farnocchia[11].

Computed residual norm (RMS) equal to 0.381" for observations of asteroid 345705 (2006 VB14) using a total 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 1.3 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, on the 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[12],[13],[14],[15],[16] and will be published in one intended papers[17] .

For more than 35 years such an astronomical plate archive of photographic negatives, which have been obtained with the Baldone Schmidt telescope, been 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 photo-plates 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.

[10] Vereš P., Farnocchia D., Chesley S. R., Chamberlin A. B., 2017, Icar, 296, 139
[11] Farnocchia D., Chesley S. R., Chamberlin A. B., Tholen D. J., 2015, Icar, 245, 94-111
[12] UL 77 International Scientific conference, Riga, Latvia, 2.February 2019 (Annex 5)
[13] http://gamow.odessa.ua/wp-content/uploads/2019/09/Fin-2019-Gamow-Abstracts_.pdf
[14] https://drive.google.com/file/d/13vSAxFkLBBx76V0DBDy_DCPwvBlwdbde/view
[15] https://meetingorganizer.copernicus.org/EPSC-DPS2019/EPSC-DPS2019-732-5.pdf
[16] UL 78 International Scientific conference, Riga, Latvia, 2.February 2020 (Annex 5)
[17] I. Wlodarczyk, K. Černis, and I. Eglitis, Observational data and orbits of the asteroids discovered at the Baldone observatory in 2015–2018, Open Astronomy, https://www.degruyter.com/document/doi/10.1515/astro-2020-0017/html

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 2018-2021, 1760 images were studied. In images with centers close to the ecliptic, more than 1700 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 the research were published in papers[18],[19],[20] and presented in conferences[21]. Two programs were made – one is made for employees in the Institute of Astronomy of the University of Latvia for more engaging work to understand input and output better. The program can do the following - give clear instructions on how to use the NASA webpage (used to get the coordinates for asteroids from archive) and give information to copy in there, autocorrects the values from NASA page, displays the info of archive file and finds the needed asteroid, finds similar objects and after that can show the location of all them graphically either in decimal degrees or hexagonal degrees.

The other program automatizes all the above except for graphical interpretation, so no human interaction is needed. With this program, we found on Baldone Schmidt archive plates more than 100 asteroids were not yet identified. Results presented in conference[21].

Comets are guests from far away-outer areas of the Solar system 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 possibly 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 – sweep the evaporated material and dust back in a long dust tail. A second tail: the plasma tail, is formed due to ionized gas from the comet coma. Comets can be observed in optical frequency band, as well as in 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's 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.

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. 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)[22]. To observe cometary OH maser emission, 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 a new secondary focus front-end. Results of this activity were published in a paper[23].

To evaluate the potential of the Irbene RT-32 radio telescope to detect cometary OH masers, two assessments must be taken into account - the sensitivity of the Irbene RT-32 radio telescope in the 1.6 GHz band[24] and the potential emission or absorption from the cometary OH maser during the observation[25]. To summarise the results of cometary OH maser observations, the typical cometary OH maser flux density is around 0.01-0.05 Jy, although the flux density of the bright cometary OH maser could reach 0.5 Jy.

The one activity of the research was to determine the lowest possible level of the detection using VIRAC radio telescope 1.6 GHz receiving system and using implemented data processing methods, with the

[18] **I.Eglitis**, S. Shatokhina , O. Yizhakevych , Yu. Protsyuk , V. Andruk, Asteroid search results for digitized astroplates of 1.2m telescope in Baldone, Odessa Astronomical Publ., 2019, 32, 189 – 191, http://oap.onu.edu.ua/article/view/181599/185108

[19] I.Eglitis, Asteroids exploration with Baldone Schmidt telescope, Odessa Astronomical Publications, 2018, 31, 204 – 207, http://oap.onu.edu.ua/article/view/144438/148862

[20] Shatokhina, S. V. ; Yizhakevych, O. M. ; Protsyuk, Yu. I. ; Kazantseva, L. V. search by orcid ; Pakuliak, L. K. ; **Eglitis, I**. ; Relke, H. ; Yuldoshev, Q. X. ; Mullo-Abdolov, A. Sh. ; Andruk, V. M. On the "Solar System Bodies" Astroplate Project of the Ukrainian Virtual Observatory http://oap.onu.edu.ua/article/view/181732

[21] See Annex 1 International scientific conferences to participate in: At the "6th Gamow International Conference 2019, presentations N4, N5, N6, and UL 78 coference presaentation N10, and BAASP conference 2021 presentation N14.

[22] D. Despois, et al. 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.

[23] M. Bleiders, et al., 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.

[24] K.Skirmante, et al. Observations of weak galactic OH masers in 1.6 GHz frequency band using Irbene RT32 radio telescope, Space Science and Technology. Article submitted and will be published in the middle of 2022.

[25] K. Skirmante and G. Jasmonts Evaluation of cometary OH masers emissions in 1.6 GHz frequency band, Astronomical and Astrophysical Transactions. Article submitted and will be published in the middle of 2022.

aim to successfully detect cometary OH masers which are weak in the radio frequency range. Obtained results were published in scientific papers[24],[26]. Theoretical estimations of the overall radio telescope 1.6 GHz system were done and it shows the possibility to detect weak objects if the integration time is large enough, but it was necessary to prove the estimations using observations[27]. It should be noted that the radiation of comets has a tendency to decrease, for example, the comet OH brightness usually fades very fast, and the comets are not the best choice for the proof of estimated calculations.

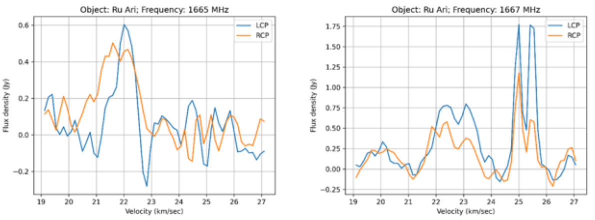

Fig. 7. Object - OH/IR star Ru Ari. Frequency - 1665 MHz (Left side) and 1667 MHz (Right side). Polarisation - Left circular polarisation (in blue) and right circular polarisation (in orange).

That's why the multiple interstellar OH maser observations were carried out and the choice of targets was done evaluating the target brightness level. For example, the targets with flux densities around 0.3 Jy and 2 Jy were chosen to simulate bright cometary OH maser with flux density ~0.5 Jy. To check RT-32 readiness level for weak object observations the observations of variable star R LMi, OH/IR star Ru Ari (spectrum shown in Fig. 7), variable star U Aur, OH/IR star OH 138.0 +7.2, variable star V524 Cas were carried out. All obtained results are summarized in Table 1.4.

Table 1.4 lists the observed objects and their parameters. The first four columns include the source name, source type and J2000 equatorial coordinates. In column No. 5 the observation lines are shown. Column No. 6 contains the flux density at the total intensity peak or peaks (if the spectrum consists of multiple parts), together with the noise level (1σ). The penultimate column hours needed for detection ~3σ or ~2σ for weaker objects. The last column gives the velocity of peak flux density.

Table 1.4. Obtained results of weak OH masers observations using RT-32 and 1.6 GHz receiver

Name	*Type*	*RA*	*Dec*	*Line (MHz)*	*Flux density peak/s (RMS level) in Jy*	*Hours needed for detection with ~3σ*	*V(LSR), km/s*
R LMi	Variable Star of Mira Cet type	09 45 34.28	34 30 42.83	1665 1667	3.22 and 1.95 (0.12) 2.92 and 2.16 (0.12)	2h 2h	-4.01, 4.22 -4.14 and 4.63
Ru Ari	OH/IR star	02 44 45.50	12 19 02.89	1665 1667	0.60 (0.3) 1.76 and 0.78 (0.5)	12h (2σ) 6h and 10h	22 25.00, 22.25
U Aur	Variable Star of Mira Cet type	05 42 09.06	32 02 23.58	1665 1667	0.43 (0.2) 0.28 (0.2)	22h (2σ) 22h (2σ)	3.47 3.03
OH 138.0 +7.2	OH/IR star	03 25 08.40	65 32 07.06	1665 1667	no detection (0.3) 1.72 and 0.6 (0.3)	16 h observed 6h and 16h	- -46.15, -27.63
V524 Cas	Variable Star of Mira Cet type	00 46 00.13	69 10 53.63	1665 1667	no detection no detection	26 h observed 26 h observed	- -

The results from the first observations of variable Star of Mira Cet type R LMi showed successful detection in both frequencies and R LMi was chosen as a calibrator target for other observations as well. The characteristics of the spectrums and the obtained velocities were compared with results from scientific publications[28],[29],[30] and maser.db[31] page. The obtained results have been verified and are considered correct[32].

Based on processed observation data and the corresponding results, it is concluded that practically the sensitivity level is 6.7 times larger than estimation in the theoretical model. This can be explained by unstable receiver activity during the long observations, where system temperature is changing stochastically. For example, to detect targets with the flux density ~ 0.4 Jy, more than 22 hours are needed, for ~0.04 Jy detection - more than 300 hours are needed, which is cost-ineffective to use radio telescopes for the observations of cometary OH maser.

[26] K. Skirmante, et al. Observations of astronomical objects using radio (Irbene RT-32 telescope) and optical (Baldone Schmidt) methods, Astronomical and Astrophysical Transactions,Issue 1, Vol. 32, p. 13-22, doi:10.17184/eac.4392
[27] K. Skirmante, et al. Observations of astronomical objects using radio (Irbene RT-32 telescope) and optical (Baldone Schmidt) methods, Astronomical and Astrophysical Transactions,Issue 1, Vol. 32, p. 13-22, doi:10.17184/eac.4392
[28] B. M. Lewis, Main - line OH observations of the Arecibo set of OH/IR stars, The Astrophysical journal supplement series, 109:489È515, 1997
[29] John D. Fix and Joel M. Weisberg, A low-detection limit search for OH emission from the infrared stars, The Astrophysical Journal, 220:836-840, 1978 March 15
[30] P. Wolak, et al. Polarization properties of OH masers in AGB and post-AGB stars, A&A 537, A5 (2012) DOI: 10.1051/0004-6361/201117263
[31] Andrej M. Sobolev et al. Database of molecular masers and variable stars, RAA 2019 Vol. 19 No. 3, (8pp) doi: 10.1088/1674–4527/19/3/34
[32] More detail information about reuslts can be found in paper[24]

During the project, the determination of the cometary OH maser flux density regards on previous optical and radiofrequency observation was carried out and obtained results were published in the scientific paper[25]. In the research, analysis of the results published in scientific papers and reports, Nançay radio telescope database site[33] were carried out to evaluate the potential flux density level of the cometary OH maser. For the next research stage, large amounts of comet observations in the optical spectral range were collected from the Comet Observation database (COBS)[34] and Minor Planet Center (MPC)[35] databases. In the study, the linkage model of the radio and optical observations' results was developed with the main goal of identifying the relationship between the cometary OH maser emission in a 1.6GHz frequency band and the optical brightness. Also, the comet's orbital parameters were included in the developed model. As the 18 cm spectral line is affected by solar radiation, comet distance to Sun and Earth needs to be included in the prediction model. Student V.Smits (bachelor study program "Computer Sciences") was involved in the data collection using his developed program and the bachelor thesis was supervised by project researcher K.Skirmante, thus involving bachelor students in astronomical research.

To establish a correlation between the radio emission/ absorption and the optical brightness, data were merged based on the values of each day. A total of 362 observations were found in both collections - radio and optical. Fig. 8 shows the correlation between comet visual magnitude and radio flux density using the Pearson correlation coefficient (r)[36].

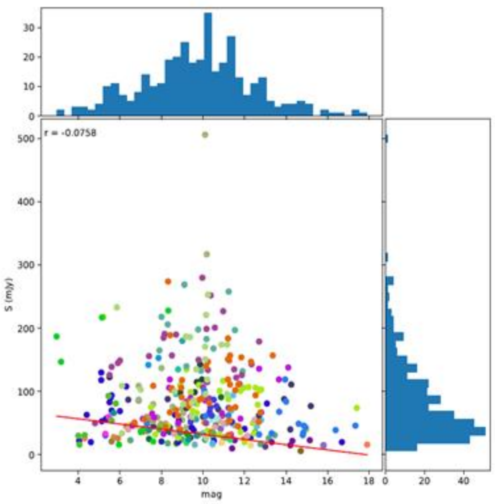

Fig. 8. In the middle - optical magnitude correlation to radio flux density using optical and radio observation data and calculated Pearson correlation coefficient; in the top - the distribution of the comets by its visual brightness in mag.; in the right - the distribution of the comets by its radio flux density in mJy.

In Fig. 8 each comet is colored differently. The absolute values of the flux densities were used in the correlation since in this case, it is not important to separate cometary OH maser emission and absorption. The Pearson correlation coefficient (r) indicates the linear relationship between two variables, in this case, the coefficient is r = -0.0758. The coefficient indicates a weak linear correlation between the observed comet visible magnitude and radio flux density at 1.6 GHz frequency. The obtained result is appropriate because low magnitude values of the observed magnitudes (brighter comet) do not necessarily guarantee strong OH maser activity in the radiofrequency band as it is shown in Fig. 8. In the research, the correlation between radio flux density in 1.6 GHz and OH production models were made and the Haser-Equivalent[37] and 1986A OH[38] production models were chosen in the analysis. In cases where the Haser-Equivalent model did not converge, zero values were assumed and these observations were ignored.

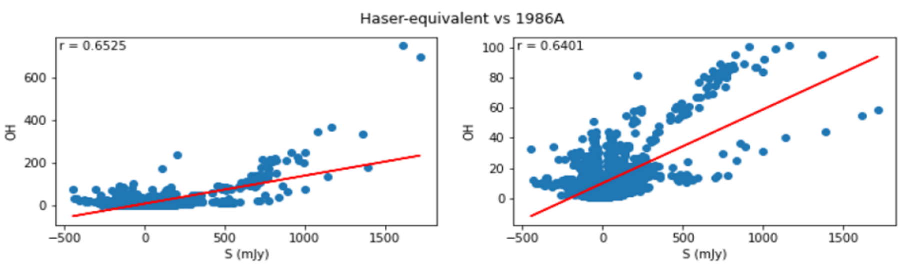

Fig. 9. Radio observation flux density correlation to OH production rate models - Haser-Equivalent and 1986A.

Observations with high radio background noise also were ignored, for example, the observation of comet 22P/Kopff on 1996-04-26, when flux density value reached about 2000 mJy, due to radio source background contamination of M17 (ionized hydrogen cloud region in Sagittarius). Fig. 9 shows the

[33] J. Crovisier et al. Observations at Nancay of the oh 18-cm lines in comets. The database. Observations made from 1982 to 1999. Astronomy and Astrophysics, v.393, p.1053-1064 (2002), 2002.
[34] J.Warell, et al. The COBS comet database: Observer tools and case study. In European Planetary Science Congress, pages EPSC2018–644, September 2018.
[35] Brian G. Marsden. The Minor Planet Center. Celestial Mechanics, 22(1):63–71, July 1980.
[36] L.M. Surhone, et al. Pearson Product-Moment Correlation Coefficient. Betascript Publishing, 2010.
[37] M. R. Combi, et al. Neutral cometary atmospheres. I - an average random walk model for photodissociation in comets. , 237:633–640, April 1980.
[38] F. P. Schloerb, et al.. OH Radio Observations of Comet p/ Halley. , 187:469, November 1987.

correlation between flux density and OH production and their patterns. It can be observed that despite the fact that the Haser-Equivalent model production rate is much higher than the 1986A model, both OH production models have a similar linear correlation with flux densities obtained from observations (r=0.6525 and r=0.6401) using the Pearson correlation method.

In the research, a neural network prototype was used for the prediction of the next day's visual brightness value of a comet based on observations from previous days, as well as other values that characterize the comet. To build the model, data from MPC and COBS was supplemented with data from NASA's HORIZONS JPL database using the Astroquery library. The data layer of the Neural Network model consisted of a collection of MPC and COBS observation results and the comet's distances to the Sun and Earth in AU values. To ensure that the neural network was not affected by rare and very strong comet outbursts, observations that had the difference between the first and third day's more than five magnitudes were filtered out before the neural model training. In the final model training, the model data layer included 5607 three-day comet data from 1011 different comets. The Keras library[39] was used to train the neural network model. To solve the regression problem with multiple sequential inputs, a neural network consisting of two LSTM network layers was created combined with Dropout and Dense layers. After model training, 581 test data were used for the model, where the model predicted the next day's value with an average error of approx. 0.65 magnitudes. This can be explained by a large number of small outbursts in the data sets, which cannot be accurately modeled based on the comet's distance to the Earth and Sun. If all outbursts were cut out of the model training data-set, the model could be more linear and the error decreases, but at the same time, the outburst prediction would not be acceptable for further usage.

As the analysis shows, each comet is unique and there could be a strong cometary OH maser emission in comets that are not so bright in the optical frequency band. It is worth continuing comet observations in the 1.6 GHz frequency band, although the overall sensitivity level of RT-32 needs to be improved, for example, 1) to install a new cryogenic 1.6 GHz frequency LS band receiver (design internal report is included in Annex 5[40], but development process will start in the middle of 2022); 2) to use more effective data processing algorithms, for example, usage of Karhunen–Loeve Transform[41] for detection and RFI identification, isolation in the weak cometary OH maser signal processing workflow.

To estimate the OH production rate of the comet, the sub-activity related to 67P/Churyumov–Gerasimenko cometary images processing was carried out. The aim of sub-activity was to calculate the optical brightness of comet 67P using images created by the Rosetta probe's OSIRIS sensor. In the determination, the orbital model was created for the comet and Rosetta probe and processed image results were combined with comet and probe position in the coordinate system. Image processing activities were - using the image processing methods, to cut out the comet from the image and to calculate the flow of the OH maser emission. Multiple segmentation methods were used, for example, Boundary-based segmentation method, Region-based segmentation method, Watershed segmentation method, Flood fill segmentation method for the image processing of 67P comet.

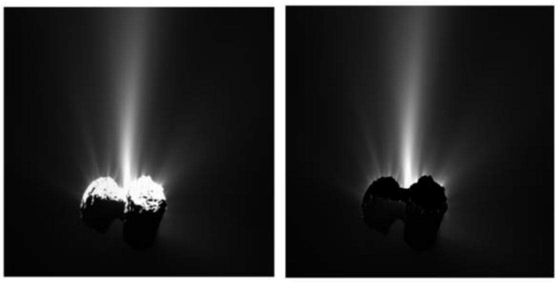

Fig. 10. Optical brightness determination using Rosetta probes OSIRIS sensor images of 67P/Churyumov–Gerasimenko comet. Left side: Original image from OSIRIS; Right side: Result image after the segmentation where detected only OH maser flow.

Overall 530 images were processed (an example is shown in Fig. 10). Obtained results were consistent with the optical observations, but the OSIRIS images can be used only to calculate the optical brightness of a specific comet and results were not used for further studies. Student E.Riekstins (bachelor study program "Computer Sciences") was involved in the OSIRIS image processing and the bachelor thesis was supervised by project researcher K.Skirmante, thus involving bachelor students in astronomical research.

During the project, the potential usage of new processing methods were investigated, to process weak signal data. One of the prospective processing method of signal processing is Karhunen-Loève transform which could be used to replace the Fast Fourier Transform (FFT). During the project, the KLT method was investigated and implemented on an existing knowledge base. Student G.Jasmonts of the master

[39] Francois Chollet, et al.. Keras. https://keras.io, 2015.
[40] Internal technical report of design LS band receiver_eng.
[41] C. Maccone. Advantages of Karhunen Loeve transform over fast Fourier transform for planetary radar and space debris detection. Acta Astronautica, 60(8-9):775–779, April 2007.

study program “Computer Sciences” was involved in the implementation of the KLT algorithm, to study and program the KLT algorithm in his study course project (supervised by project researcher K.Skirmante), thus ensuring knowledge transfer and increasing student knowledge capacity.

KLT is related to popular methods such as Singular Value Decomposition (SVD)[42] and Principal Component Analysis (PCA)[43], but with far fewer applications. The biggest reason for the less frequent use of KLT is the algorithmic execution time, which is often $O(N^2)$ time complexity, which is not optimal in Big data processing, for example, where 1Mb/s data production rate is handled. The main question was pointed out in the KLT research - What is the benefit of using KLT compared to FFT? KLT provides the ability to extract weak signals from background noise better than FFT. In several examples, the FFT algorithm was unable to detect signal from the noise with SNR= -23 dB, even though the KLT could. KLT decomposes the signal into components, from which only a few can be selected, and then reconstructs the signal. KLT can be used for time-independent random functions, which allows multiple non-sequential radio astronomy datasets to be processed.

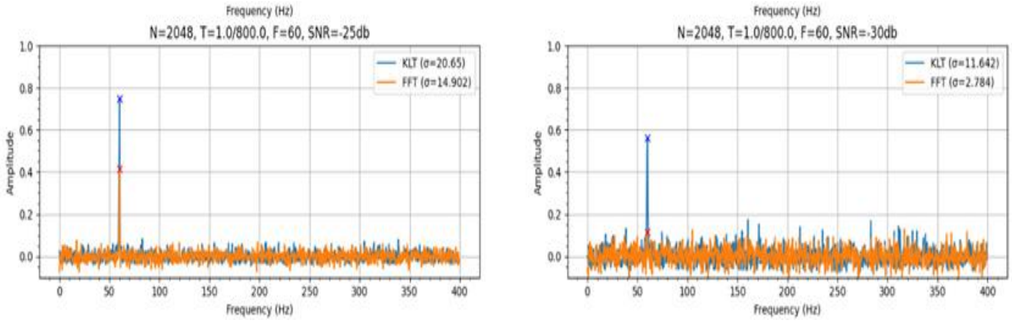

Fig. 11. Spectrum of the multiple signal with different noise level: in orange - result obtained with only FFT; in blue - result obtained with KLT for the noise removal and FFT for the spectrum creation. Raw signal: generated signal in 60Hz frequency.

The first practical experiment has been done using the base implementation of the KLT to test KLT effectiveness on a generated signal and the results were promising. The difference between only FFT usage and KLT and FFT usage are shown in Fig. 11 using generated 60Hz signal with different SNR level, but in summary, KLT detection level was -39db, but FFT only -25db.

During Autumn 2018, Autumn 2019 and the 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 the 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. Ionized gas and dust tails were singled out on Baldone Schmidt telescope CCD images[44].

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 at the night. As a 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) was in February and March 2020. B V R magnitudes and position measurements of the comet were made in three nights.

List of optical observations of comets at BAO 2018-2020 (Comet name, Observations date, Number of images, Observers, Processing**): 1) 38P/Stephan-Oterma**, 2018 01.12, 1, I.Eglitis, Brightness measurements A.Bule; **2)Africano (C/2018 W2)**, 30.11.2018, 3, I.Eglitis, Position measurements K.Cernis; **3)Borisov (2I/2019 Q4)**, 25.09.2019 - 27.10.2019, 51, I.Eglitis, V.Eglite, Brightness measurements of the comet and its tail, K.Nagainis; **4) C/2017 T2**, 24.02.2020 - 14.03.2020, 16, I.Eglitis, V.Eglite, Brightness measurements of the comet and its tail A.Bule, A.Sokolova, K.Nagainis;**5)Atlas (C/2019 Y4)**, 19.03.2020, 12, I.Eglitis, V.Eglite, Position and brightness measurements A.Bule, A.Sokolova, K.Nagainis.

[42] Golub, Gene H.; Kahan, William (1965). Calculating the singular values and pseudo-inverse of a matrix. Journal of the Society for Industrial and Applied Mathematics, Series B: Numerical Analysis. 2 (2): 205–224
[43] A. Maćkiewicz, W.Ratajczak, Principal components analysis (PCA), Computers & Geosciences Volume 19, Issue 3, March 1993, Pages 303-342
[44] Press reliese https://www.lu.lv/par-mums/lu-mediji/zinas/zina/t/51610/

List of radio observations of comets at Irbene 2018-2021 (comet name, observation date, year, duration in h): **1) Africano (C/2018 W2)**, Sep 11-12, 2019, 8h; **2) C/2017 T2 (PANSTARRS)**, Oct 16–21, 2019, 40h; **3)C/2018 N2 (ASASSN)**, Jan 18, 2020, 8h; **4) C/2017 T2 (PANSTARRS)**, Jan 24, 25, 26, 2020, 60h; **5) Atlas (C/2019 Y4)**, Mar 15-30, 2021, 120h; **6) C/2020 F8 (SWAN)**, May 5 - 29, 2020, 110h; **7) C/2020 F3 (NEOWISE)**, Jul 6 - Sept 21, 2020, 427h; **8) C/2021 A1 (Leonard)**, Dec 3-21, 2021, 35h; **8) 29P/Schwassmann-Wachmann**, Nov 11-15, 2021, 20h (observation of the comet cloud in 6.035GHz).

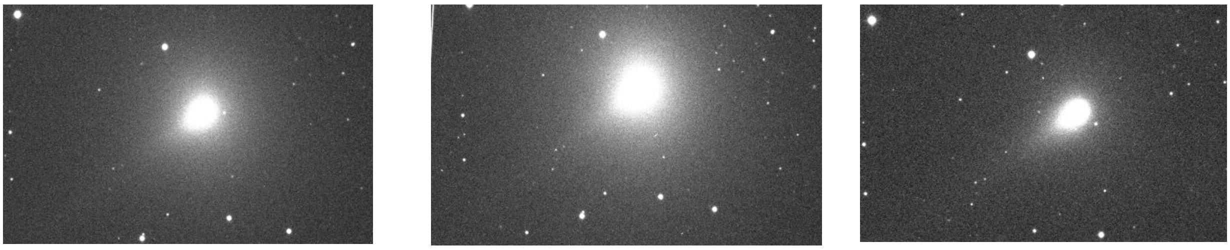

Fig. 12. Atlas comet images in B, V and R passbands at 19.03.2020 obtained at BAO with 120 sec exposure.

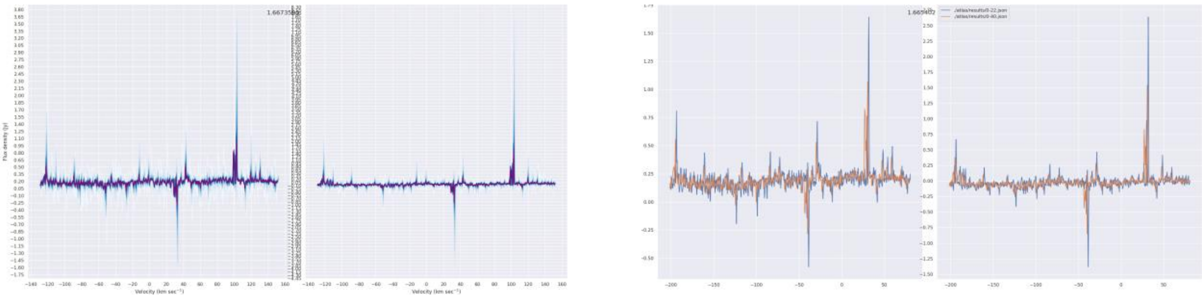

Fig. 13. First results of the Atlas comet obtained at VIRAC. Left and Right circular polarisations (LCP and RCP) of comet ATLAS spectra from 19.03.2020 and 20.03.2020 observations.

2. Impact

2.1. The project's scientific results

Table 2.1. Results Impact indicator of results	Number	
	Intended	Completed
1. Scientific publications		
1.1. Scientific publications (SCOPUS, WoSCC and/or ERIH +)	7**	8*
1.2. Other anonymously reviewed scientific publications	3	5*
1.3. Reviewed scientific monographs	0	0
1.4. Data scientific publications	0	11**
2. Establishment of intellectual property rights (patents, registered varieties of species etc.)	0	0
3. International scientific conferences to participate in or organize	11	17**

* see in Annex 1, ** see in Annex 2

2.2. Opportunities for research development

During the implementation of the 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 the Forward scatter radar method.

Table 2.2.

No.	Collaborating institution/organization, country	Type of collaboration	Result	Period

1.	Institute of Theoretical Physics and Astronomy of Vilnius University, Lithuania	Asteroid position measurements	139 new asteroids	From 2008 until now
2.	Main Observatory of Kiev, National Academy of Sciences of Ukraine	Digitized astro plate processing.	Common publications	From 2015 until now
3.	Nikolev Observatory of National Academy of Sciences of Ukraine	Digitized astro plate processing.	Common publications	From 2015 until now
4.	Chorzow Astronomical Observatory, Poland	Asteroid orbits calculation	Common publications	From 2010 until now
5.	Torun Radio Astronomy Observatory, Poland	Collaboration radio observations with Torun VLBI station in	Experimence exchange, common publications	From 2018 until now
6.	Institute Radio Astronomy of NAS of Ukraine, Kharkiv, Ukraine	Collaboration with Zolochiv RT-32 in radio observations,	Experimence exchange, common publications	From 2005 until now
7.	The Radiophysical Research Institute (NIRFI), Nizhny Novgorod, Russia	Collaborative observations, staff exchange	Experience exchange, common publications	From 2005 until now
8.	Odessa Astronomical Observatory, Odessa, Ukraine	Collaborative observations, staff exchange	Experience exchange. Common publications	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 a 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 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 2.3.

No.	In cooperation with	Cooperation form and description	Result	Period
1.	ESA	European Space Agency Wavelets Course 2020 – education course	Published	2020
2.	ESA	International Space Science Institute (Bern) Expert, In-Space Resource Utilisation	A.Graps advisor for WG	2020-2021
3.	USA, Italy, Estonia, Finland, Sweden, Poland, Germany, France, Spain, Austria, Netherlands	ESA Comet Interceptor mission Science	A.Graps Team member of WG	2020-2030
4.	**UL**, Finnish Meteorological Institute, Tartu Observatory, EstSat/ EstCube, NewTime, Garage48, Baltics in Space, Institute of Environmental Solutions, **VIRAC**, Zinoo, Moletai Ethnocosmological Museum	ELLF v.1 Ecosystem (2019) project ELLF-v2 2020 second part of project	Project submittedbut not accepted	2019-2020
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	Team member A.Graps	2017-2020

		society, especially with young citizen scientists		
6.	ASIME	Consulting to Luxembourg Ministry of the Economy (now Luxembourg Space Agency) for ASIME concept on in-space asteroid utilisation	A.Graps Consulta-tions	2016-2018
7.	European Commission	Expert SME Space reviewer A.Graps	Expertise	2017 untill now
8.	CRAF ESF	The Committee on Radio Astronomy Frequencies (CRAF) is an Expert Committee hosted and administered by the European Science Foundation.	Expert from Latvia Vladislavs Bezrukovs	2018 untill now

2.4. Publicity and communication

During project time following publicity and communication activities were carried out by the project participants in which the results of the project were popularized: 4 posters at SPACE Tech Expo Europe in 2019 and 2021; 93 popular scientific lectures at Observatory Planetarium and Mini Planetarium for overall 2288 visitors; presentations for 1597 visitors at European Scientists nights 2018 and 2019; Sky demonstrations for 120 visitors; 11 presentations; 4 radio broadcasts; 3 TV broadcasts; 6 press release; 3 media interview; and project Web page (https://www.lu.lv/en/astr/projects/plate-digitization/). More detailed information about publicity and communication activities take in Table 2.4.

Table 2.4.in full text report.

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-cieminu-latvija-vares-verot-entuziasti?id=51513999 (Edžus Miķelsons, interview with I.Eglītis)	2019.Oct.02.
16.	Press release	Press release about project and activities https://www.virac.eu/petnieciba/projekti/projekts-pla	From Aug 2, 2018
17.	Poster at Bremen**	Space Tech Expo Europe, Bremen,Germany. K.Skirmante, M.Bleiders N. Jekabsons,V.l. Bezrukovs, A.Graps, Observations of OH maser comets in 1.6GHz frequency band: adaptation of the Irbene RT32 radio telescope and development of the data processing methods (poster).	19-21 November, 2019
18.	Poster at Bremen**	Space Tech Expo Europe, Bremen,Germany. Eglitis I., Bule A., Minders V., Eglite V., Asteroid monitoring at the Baldone Astrophysical Observatory	19-21.11. 2019
19.	Poster at Bremen**	Space Tech Expo Europe, Bremen_Graps_Asteroid_Mining	19-21.11. 2019
20.	Press release	Press release about uniq result obtained in VIRAC using RT32 radiotelescope http://virac.eu/pirmo-reizi-vsrc-vesture-tika-iegutstroksnu-videjais-limenis-zem-0-25-jy/	From Feb 10, 2020
20.	Presentation	At UL innovation day I.Eglitis. Video: https://www.youtube.com/watch?v=AmvV8PNLa-g	04.11.2020
21.	TV show	Latvian TV 1 TV show: "Mēs ar brāli kolosāli" (I.Eglitis). Video: https://www.youtube.com/watch?v=fVYfGb9YqTc	23.02.2020
22.	Press release	Press release about project and activities https://www.virac.eu/nosledzies-latvijas-zinatnes-padomes-granta-projekta-saules-sistemas-mazo-kermenu-kompleksie-petijumi-vidusposms	From April 16, 2020
23.	Presentation	V. Bezrukovs et.al., VSRC radio astronomical observations in 2021,JIV-ERIC consortium web meeting	28.04.2021
24.	TV show	Latvian TV 3 TV show: "Dzīvīte brivdienās"(I.Eglitis). Video: https://tv3play.skaties.lv/series/dzivite-brivdienas,serial-2560652/3maijs,episode-2560678	03.05.2020
25.	Popular-scientific article	K.Šķirmante, "Zvaigžņotā DEBESS" ("Starry Sky") Spring 2021(251) https://www.lu.lv/par-mums/lu-mediji/zurnali/zvaigznota-debess/	May 2021
26.	Press reliase	UL I.Eglitis The asteroid discovered at Baldone Observatory is given the name "Lapuska". https://www.lu.lv/par-mums/lu-mediji/zinas/zina/t/66657/ https://www.iau.org/static/publications/wgsbn-bulletins/wgsbn-bulletin-2101.pdf	19.06.2021
27.	Participation in media interview	V. Bezrukovs' interview. "Latvia's got personality: Astrophysicist Vladislavs Bezrukovs". https://eng.lsm.lv/article/features/features/latvias-got-personality-astrophysicist-vladislavs-bezrukovs.a414034/	24.07.2021
28.	Newspaper interview	Vl. Bezrukovs Newspaper "Ventspilnieks. Nr 35(222) 2021.17.09. https://www.virac.eu/izi-vsrc-astronomijas-un-astrofizikas-petnieks-vladislavs-bezrukovs-sniedzis-interviju-laikrakstam-ventspilnieks-lv	17.09.2021

29.	Participation in media interview	Video and text broadcast. Vladislavs Bezrukovs www.apollo.lv new portal, video and text interview in Latvian. https://www.apollo.lv/7345857/mistiskais-irbenes-lokators-saule-un-melnie-caurumi-saruna-ar-ventspils-starptautiska-radioastronomijas-centra-vadoso-petnieku-vladislavu-bezrukovu	27.09.2021
30.	Press reliase	Noslēgušās zinātniskās aktivitātes Latvijas Zinātnes Padomes granta projektā "Saules sistēmas mazo ķermeņu kompleksie pētījumi" https://www.virac.eu/noslegusas-zinatniskas-aktivitates-latvijas-zinatnes-padomes-granta-projekta-saules-sistemas-mazo-kermenu-kompleksie-petijumi	29.09.2021
31.	Poeter at Bremen**	Space Tech Expo Europe, Bremen,Germany. Eglitis I., Nagainis K., Eglite V., Sokolova A., Bule A : " Astrophysical observatory in Baldone (code 069)" 069)" November 2021)	16.-18.11.2021
32.	Publik talk	Virtual dinner with scientists. Deep Sensing - Ecologies of the Post-Soviet Military Industries. RIXC gallery, Lenču street 2, Riga and virtually live Zoom / FB.	10.12.2021
33.	Presentation	Vl. Bezrukovs et al.,"Overview about radio astronomical observations and related science projects in VIRAC in 2021", Annual Conference of the Ventspils University of Applied Science.	16.12.2021
34	Presentation	Review of radio astronomical observations and related VIRAC scientific projects in 2021, JIV-ERIC consortium web meeting	22.12.2021
35.	Project Web page	Complex Investigations of solar system small bodies, https://www.lu.lv/en/astr/projects/plate-digitization/	Aug. 2018 – Dec. 2021

*Registration lists of visitors Annex 3, if needs photos of groups, connect with ilgmars.eglitis@lu.lv
**PPT in Annex 5

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 2.4. 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"	Sup. - A.L.Grapa, cons.- N.Jekabsons	In progress
2.	M.Bleiders	Doctoral thesis "Compact L-band receiving system for applications in Cassegrain-type radio telescopes".		In progress
3.	V.Bezrukovs	Doctoral thesis "Multi-wavelength VLBI polarization analysis of a complete sample of BL Lac objects".		In progress
4.	F.Kamiševs	Bachelor thesis "Development of radio astronomical data processing software of real-time correlation, filtering and data visualization modules"	Sup.K.Skirmante	June 2019, VeUAS[45]
5.	G.Jasmonts	Bachelor thesis "Weak radio astronomical object data processing, calibration, filtration and result analysis"	Sup. K.Skirmante	June 2020, VUAS
6	V.Eglite	Bachelor thesis "Guided tours for development of 5th grade cognitive activity in science lessons".	J.Bogdanova, DU[46]	2019, DU

[45] VeUAS – Ventspils University of Applied Sciences, where VIRAC is a research department
[46] DU - Daugavpils University

7.	V.Eglite	Master thesis" Opportunities for Improving Personnel Management at the Observatory of Astrophysics of the University of Latvia in the Conditions of Change."	A.Korniseva Daugavpils University	In progress from 2021
8.	A.Bule	Bachelor thesis "Monitoring of new carbon stars in the Milky Way"	Sup. I.Eglitis	2019, UL
9.	A.Sokolova	Bachelor thesis "Spectrophotometric investigations of carbon stars in the Milky Way"	Sup. I.Eglitis	2018, UL
10.	K.Nagainis	Bachelor thesis "Astrometry and photometry of asteroids in the Baldone Schmidt Telescope Archive Database"	Sup. I.Eglitis	In progress from 2020
11.	E.Riekstins	Bachelor thesis "Determination of optical brightness of comet 67P/Churyumov- Gerasimenko by processing Rosetta OSIRIS data"	Sup. K.Skirmante	June 2021, VeUAS
12.	V.Smits	Bachelor thesis "Development of a prototype linking a comet's OH molecule production rate and the orbital model"	Sup. K.Skirmante	June 2021, VeUAS

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 during the Project implementation:

1) The radio telescope RT-32 receiving system is not sensitive enough to detect weak OH masers of comets. Impact – medium. Solution: The radio telescope RT-32 receiving system was upgraded.
2) Covid-19 pandemic and its restrictions (for example, home working) during the implementation of Project. Impact – High. Solution: 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) 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. Impact – Medium. Solution: 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 the UL IA research team Dmitrijs Spakovs dropped out of physics study's and was therefore replaced by BSc physic's students Anna Bule (female) and K.Nagainis.

Project executor K. Skirmante is a PhD student at the University of Latvia in the study program "Physics, astronomy and mechanics" where her dissertation work "Radio Detection of OH lines of Solar System planetary small bodies" relates to Project goals and activities. She was involved in the 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 result presentation in international conferences. She was consulted by scientists 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 -K. Nagainis - was involved in the subject of asteroid and comet research. Also, student K.Nagainis was involved in brightness measurements of comet Borisov (2I/2019 Q4) and its tail, students A.Bule, A.Sokolova, K.Nagainis were involved in brightness measurements of comet C/2017 T and its tail, students A.Bule, A.Sokolova, K.Nagainis were involved in position and brightness measurements of comet Atlas (C/2019 Y4). Multiple students (G.Jasmonts, E.Riekstins, V.Smits) developed their bachelor thesis and course project related to Project themes related to radio astronomical data processing, thus ensuring knowledge transfer and increasing students' knowledge capacity in astronomy.

During the project, BAO has developed several programs for digital scan analysis and CCD image analysis, which greatly expands the scope of both research and applications. For example, the 'Fourier series_0.9-1.1' program is successfully used in an ESA project "Satellite and space debris photometry capability development for SLR station Riga" to analyze the luminosity curves of satellites and space debris.

The results of the project allowed us to write six projects for the Latvian Science Council, to participate in the development of the Horizon Europa Twinning project "Boosting Progress on New

Applications of SLR and Other Technologies for Effective and Sustainable Contribution to Space Situational Awareness".

More detailed report is published in Project Web page: https://www.lu.lv/en/astr/projects/plate-digitization/