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Technical report 4

Collection of Capabilities and Assets in Slovakia related to SWE frameworks

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Version		
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1) Introduction

This is Technical report 4 (TR-4) - Collection of Capabilities and Assets in Slovakia related to Space Weather (SWE) frameworks document that contains a list of Slovak entities and assets that specialize in activities related to the ESA Space Safety Programme's frameworks Space Weather (SWE) and Lagrange mission. This document is a compilation of information to be used as input for TN1 - Collection of Capabilities and Assets in Slovakia related to the ESA Space Safety Programme.

2) Applicable and reference documents

2.1) Applicable documents

[AD-1]	SLOVAKIA NATIONAL SPACE SAFETY PROGRAMME (S2P) STUDY - EXPRO PLUS, ref. ESA-S2P-MGT-SOW-0001 – Statement of Work
[AD-2]	SK_AD03 Slovakia National Space Safety Programme (S2P) Study Proposal no. AD03-SK-S2P, 20.08.2021
[AD-3]	SK_AD03 Slovakia National Space Safety Programme (S2P) Study – ESA Contract No. 4000136251/21/D/AP – Minutes of Meeting, 14.10.2021

2.2) Reference documents

[RD-1]	International Space Weather Initiative (ISWI) in Slovakia web page, http://stara.suh.sk/id/iswi/iswi_SK-en.htm

3) Scope of SWE activities in Slovakia

The research related to space weather (SWE) has one of the longest history among other space research topics in Slovakia. Even more, one of the most important person in national history - Milan Rastislav Štefánik participated also in research of the Sun (Millochau & Stefánik, 1906). Based on this heritage, SWE research is still an important part of space science in Slovakia. In recent years, the SWE-related activities in Slovakia have focused on the following studies. Here we provide the scope according to the SWE expertize topics within ESA.

3.1) Solar Weather

Activities and studies in Slovakia related to Solar Weather topic as it is defined at ESA portal https://swe.ssa.esa.int/solar-weather:

- Studies of solar physics by analysis of data from ground-based and space-based missions: Rušin et al. (1990), Kučera et al. (1990), Rybanský, et al. (2003), Rybák et al. (2004), Dzifčáková et al. (2008), Mackovjak et al. (2014), Dudík et al. (2015), Schwartz et al. (2015), Gömöry et al. (2016), Gömöry et al. (2017), Koza et al. (2017), Koza et al. (2019), Schwartz et al. (2019), and etc.

- Development of instruments for ground-based observations of solar disk and corona in VIS and IR spectral lines by the coronagraph at the Lomnicky Stit Observatory (LSO) (Kučera et al.,2016, Malherbe et al., 2021). Observations of solar prominences and solar corona in emission spectral lines with the coronagraph at LSO (González Manrique et al., 2020).

- Study of solar activity during solar cycles: routine observations of solar photosphere and chromosphere at Slovak Central Observatory Hurbanovo, detection of solar radio bursts, detection of spectral continuum level, publication of Modified Coronal Index (MCI, https://suh.sk/online-data/modifikovany-koronalny-index) and Modified Homogeneous Data Set (MHDS, https://suh.sk/online-data/modifikovany-homogenny-rad) of solar corona intensity (derived from LSO measurements until 2008, derived from space-based measurements since 2010 - Lukáč and Rybanský, 2010; Dorotovič et al., 2014). Own methods for automatic identification of solar activity (Barata et al., 2018) study of north-south asymmetry of solar activity (Gonçalves et al., 2014). Study of differential rotation of the solar corona: own methods for automatic detection of coronal bright points based on SDO/AIA measurements to determine rotation velocity that is dependent on heliographic latitude (Lorenc et al., 2012; Shahamatnia et al., 2016; Dorotovič et al.: 2018; Dorotovič et al.: 2019)

- Observations of solar photosphere and chromosphere at public observatories - Hurbanovo, Prešov, Rimavská Sobota, Hlohovec, and etc. Publishing of annual Bulletin of the Solar observations in Slovakia by Astronomical Observatory in Prešov - observations' coordinator (https://astropresov.sk/na-stiahnutie/bulletin-o-pozorovani-slnka-na-slovensku), actual relative sunspot number (http://raf.astropresov.sk), basic daily patrol observations of sunspots (https://astropresov.sk/astro-info/archiv-slnka) and solar activity weekly forecast (https://astropresov.sk/astro-info/tyzdenna-predpoved-slnecnej-a-geomagnetickej-aktivity) from Roztoky Observatory.

References:

- Barata, T., et al.: 2018, Astronomy and Computing, 24, 70
- Dorotovič, I., et al.: 2014, Solar Physics, 289, 7, 2697
- Dorotovič, I., et al.: 2018, Astronomy and Computing, 25, 168
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- Gömöry, P., et al.: 2017, Astronomy & Astrophysics, 602, 8
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- Koza, J., et al.: 2019, The Astrophysical Journal, 885, 2, 13
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- Mackovjak, Š., et al.: 2014, Astronomy & Astrophysics, 564, A130, 12
- Malherbe, J., et al.: 2021, Experimental Astronomy, in press
- Millochau, G., and Stefánik, M.: 1906, Astrophysical Journal, vol. 24, p.42
- Rušin, V., et al.: 1990, Solar Physics, 128, 1, 261
- Rybak, J., et al.: 2004, Astronomy and Astrophysics, 420, 1141
- Rybanský, M., et al.: 2003, Solar Physics, 217, 1, 109
- Schwartz, P., et al.: 2015, The Astrophysical Journal, 807, 1, 9
- Schwartz, P., et al.: 2019, Astronomy & Astrophysics, 631, 12
- Shahamatnia, E., et al.: 2016, J. Space Weather and Space Climate, 6, A16

3.2) Heliospheric Weather

Activities and studies in Slovakia related to Heliospheric Weather topic as it is defined at ESA portal https://swe.ssa.esa.int/heliospheric-weather:

- Study of plasma and energetic particles in space environment of Earth, Moon and planets by participation on development of particle detectors and energetic neutral atom imagers for space missions: Active, Coronas-I, Coronas-F, Interball, Spectrum-R(Radioastron), Double Star, BepiColombo, JUICE.

References:

- Baláž, J.: 2002, Nuclear Instruments and Meth. in Physics Research A, 481, 1, 323
- Baláž, J.: 2010, Contributions of the Astro. obs. Skalnate pleso, 40, 3, 182
- Baláž, J., et al.: 2013, Cosmic Research, 51, 2, 90 ,
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- Orsini, S., et al.: 2021, Space Science Reviews, 217, 1, 11
- Zelenyi, L., et al.: 2015, Solar System Research, 49, 7, 580

3.3) Space Radiation

Activities and studies in Slovakia related to Space Radiation topic as it is defined at ESA portal https://swe.ssa.esa.int/space-radiation:

- Long-term observations of space radiation and fundamental research of space weather conditions via measurement of neutron component of secondary cosmic rays by continuous measurements at high altitude Lomnicky Stit Observatory (LSO) since 1958: Kudela et al. (2000), Kudela et al. (2005), Kudela & Langer (2009). Contribution to international Neutron Monitor Database (https://www.nmdb.eu) and Space Environmental Viewing and Analysis Network (SEVAN, http://crd.yerphi.am/SEVAN_Data).

- Studies of theoretical models of cosmic rays propagation and distribution in magnetosphere and heliosphere focused on complex model development to describe data from space experiments (Bobik et al., 2012), and development of methods to numerical (Bobik et al., 2016), and analytical (Bobik et al., 2021) solution of Parker's equation.

- Studies of radiation protection of aircrew and spacecrew from cosmic rays (development and design of radiation shielding, metrology and measurement of radiation protection quantities in mixed fields): Kubančák et al. (2013), Kubančák et al. (2014), Ambrožová et al. (2017), Kubančák et al. (2019)

- Research of high energy particle fields induced during the lightstorms and related radiation protection tasks.

References:

- Ambrožová, I., et al.: 2017, Radiation Measurements, 106, 262
- Bobík, P., et al.: 2012, The Astrophysical Journal, 745, 2, 21
- Bobík, P., et al.: 2016, JGR: Space Physics, 121, 5, 3920
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- Kubančák, J., et al.: 2019, Radiation Protection Dosimetry, 186, 2, 211
- Kudela, K., et al.: 2000, Space Science Reviews, v. 93, Issue 1/2, p. 153
- Kudela, K., et al.: 2005, Advances in Space Research, 36, 12, 2368
- Kudela, K., Langer, R.: 2009, Advances in Space Research, 44, 10, 1166

3.4) Ionospheric Weather

Activities and studies in Slovakia related to Ionospheric Weather topic as it is defined at ESA portal https://swe.ssa.esa.int/ionospheric-weather:

- The airglow acts as a display of processes in the thermosphere-ionosphere system. By detection of the airglow intensities, it is possible to monitor the variations of constituents' densities in various altitudes. For this purpose, AMON (Airglow MONitor) program has been established in Slovakia (Mackovjak et al., 2019). The program consists of measurements by a multi-wavelength all-sky airglow camera, a high sensitive photometer, spectrometer, and a GNSS receiver for the detection of ionospheric parameters. To study the sources of detected variations, there have been employed advanced Machine Learning techniques to extract required information from publicly available space weather and atmospheric data: Mackovjak et al. (2021a), Mackovjak et al. (2021b), Maslej-Krešňáková et al. (2021), Amrich et al. (2021)

References:

- Amrich, S., et al.: 2021, Journal of Instrumentation, 16,12
- Mackovjak, Š., et al.: 2019, Nuclear Inst. and Methods in Physics Research A, 922, 150
- Mackovjak, Š., et al.: 2021a, JGR: Space Physics, 126, 3
- Mackovjak, Š., et al.: 2021b, Monthly Notices of the Royal Astro. Society, 508, 3, 3111
- Maslej-Krešňáková, V., et al.: 2021, Earth and Space Science, 8, 11

3.5) Geomagnetic Conditions

Activities and studies in Slovakia related to Geomagnetic conditions topic as it is defined at ESA portal https://swe.ssa.esa.int/geomagnetic-conditions:

- Direct observations of the geomagnetic storms cover a period of more than 180 years, and they include the most intense magnetic storms known to date, which were observed in the 19th century. A comparison with recent intense events, for which data on coronal mass ejections, solar wind and interplanetary magnetic field are available, may help to improve our understanding of the mechanisms of extreme storms that pose a risk to terrestrial environment. In papers (Hejda et al., 2021a; Hejda et al., 2021b; Valach et al., 2019), it was processed and data was made available from the historical observatory Prague/Clementinum from 1839 to 1917. It was pointed out in them e.g. to the extreme events of September 3, 1839 and November 17, 1848. It was also tried to contribute to a better understanding of the relationship between geomagnetic activity and solar wind and interplanetary magnetic field parameters by modelling the indices Dst (Revallo et al., 2014) and C9 (Valach et al., 2014).

References:

- Hejda, P., et al.: 2021, Geoscience Data Journal, in press
- Hejda, P., et al.: 2021, Annales Geophysicae, 39, 439
- Revallo, M., et al.: 2014, Journal of Atmospheric and Solar-Terrestrial Physics, 110, 9
- Valach, F., et al.: 2014, Advances in Space Research, 53, 4, 589
- Valach, F., et al.: 2019, Journal of Space Weather and Space Climate, 9, A11

4) Identified SWE Assets

This section summarizes the list of Slovak SWE assets. The assets review has been conducted by using [RD-1], available peer-reviewed literature, proceedings papers and online sources. For each sensor its operator and/or owner has been identified. The main technical parameters, capabilities and location have been summarized.

Table 4.1: List of Slovak assets in space weather framework (according domains presented in Section 3).

NAME	TECHNOLOGY	OPERATOR	COUNTRY	Location	LON [deg]	LAT [deg]	ALT [m]
Coronographs	Telescopes for solar corona observations	AI SAS	SK	Lomnicky stit	20.2131	49.1951	2634
CoMP-S	Spectropolarimeter for solar corona and prominences	AI SAS	SK	Lomnicky stit	20.2131	49.1951	2634
Solar telescopes	Telescopes for solar atmosphere observations	SUH	SK	Hurbanovo	18.1911	47.8734	114
Solar telescopes	Telescopes for solar atmosphere observations	AOP	SK	Prešov	21.2563	48.9997	282
Solar telescopes	Telescopes for solar atmosphere observations	AOR	SK	Rimavská Sobota	20.0051	48.3742	218
Space R&D	Laboratory infrastructure for Space R&D	IEP SAS	SK	Košice	21.2609	48.7060	203
Neutron Monitor	Detectors of secondary cosmic rays	IEP SAS	SK	Lomnicky stit	20.2131	49.1951	2634
SEVAN	Detectors of secondary cosmic rays	IEP SAS	SK	Lomnicky stit	20.2131	49.1951	2634
AMON-ES, AMON-net	Detectors of thermosphere-ionosphere	IEP SAS	SK	Kolonicke sedlo	22.2737	48.9347	448
INTERMAGNET	Detectors of the Earth's magnetic field	ESI SAS	SK	Hurbanovo	18.1911	47.8734	114

4.1) Dual Coronographs & CoMP-S

The first 20/300 cm ZEISS coronagraph was installed at Lomnicky Stit Observatory (LSO) in 1962 (Lexa, 1963). First regular observations of the H-alpha prominences started in 1962 and observations of the emission lines, originating in the solar corona, in 1964. In 1970 the identical coronagraph was installed at the same mount. Today, the observatory ranks among just few existing ground-based observatories worldwide which systematically observe emission spectral lines of the solar corona (Figure 4.1.1).

Researchers working at the Lomnicky Peak Observatory have prepared two long-term data sets of the solar coronal activity. "The Homogeneous Data Set of the Green Coronal Emission Line Intensities" is compiled from the data of all coronal stations over the world since 1939 including the Lomnicky Stit Observatory. "The Green Coronal Index" is prepared on the base of the previous data set for the Sun-as-a-star. In recent years, these data sets (https://suh.sk/online-data) have been maintained using measurements of the AIA instrument onboard the SDO satellite by the staff of the Slovak Central Observatory in Hurbanovo (Slovakia). "The Catalogue of the Solar H alpha Prominences'' has been prepared using measurements performed at the Lomnicky Stit

Observatory itself. Since 2009 it has been extended using observations performed by the Kanzelhohe Observatory for solar and environmental research (Austria, https://www.kso.ac.at).

Figure 4.1.1 – Solar coronograph at Lomnicky Stit Observatory, Slovakia. (Photo: AI SAS archive)

Technical details of the dual coronographs:

- a Lyot type instrument with some ZEISS inventions
- single objective lens: aperture = 196 mm, focus = ~3 m
- diffraction limited from 530 to 1100 nm by changing position of the objective lens over a range of 80 mm
- spatial resolution: 0.67” at 530 nm, 0.82” at 656 nm, 1.36” at 1083 nm
- secondary optics with a Lyot stop, final diameter of the solar image = ~4 cm
- field of view: 1.02-1.84 of the solar radius
- post-focus instrument rotation around the optical axis and radial shift away from it
- photoelectric pointing

In years 2011 and 2016, new instruments - Coronal Multi-Channel Polarimeter (CoMP-S) and Solar Chromospheric Detector (SCD) - developed by the staff of the HAO/NCAR (Boulder, CO, USA, https://www2.hao.ucar.edu) have been installed at the coronagraphs (Kučera et al., 2010).

Technical details of the CoMP-S (Figure 4.1.2):

- based on the CoMP instrument (Tomczyk et al., 2008)
- tunable Lyot filter + Stokes polarimeter
- VIS and near IR ranges from 500 to 1100 nm – list of the selected emission lines:
  - corona: Fe XIV 530.3, Ca XV 569.5, Fe X 637.5, Fe XI 789.2, Fe XIII 1074.7, and Fe XIII 1079.8 nm
  - prominences: He I 587.6, H I 656.3, Ca II 854.2, He I 1083.0 nm
- FoV ~750” x ~550”
- bandpass FWHM: 0.028 - 0.13 nm (530 - 1083nm)

- polarimetric signal using @ FLC linear polarizers
- subtraction of the scattered light (continuum signal) from the emission line images (continuum + emission signal)
- VIS detectors: 2 ANDOR Neo sCMOS cameras
    - 2560 x 2160 6.5µm pixels, 60% QE (500 nm)
    - readout: 16bit, 50 frames per second, 1 electrons readout noise
    - 0.33 arcsec/pixel at 656.3 nm
- IR detectors: 2 Goodrich GA1280J cameras
    - InGaAs imager, 1280 x 1024 15 µm pixels, sensitivity 950-1650 nm, QE > 65 %,
    - dynamic range up to 900:1
    - readout: 12bit output, 30 Hz full frame rate
    - 0.78 arcsec/pixel at 1083 nm
- Data: example is presented in Figure 4.1.3.

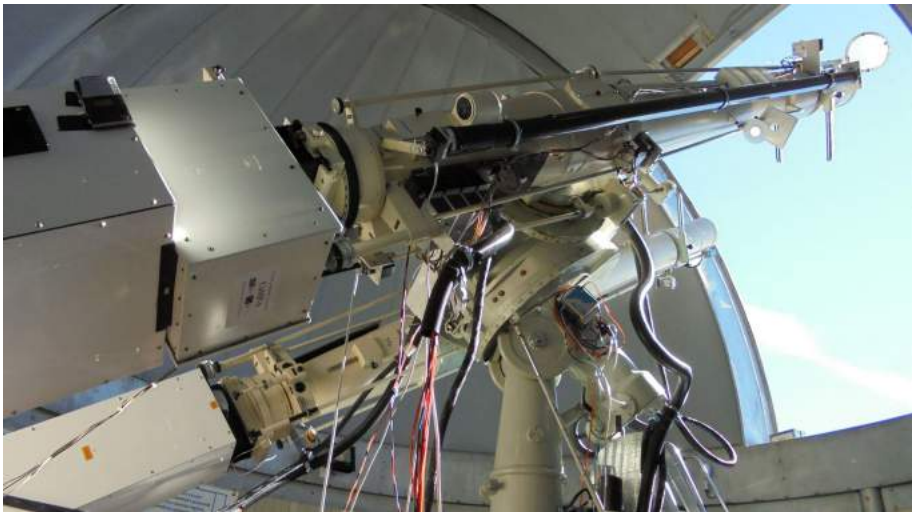

Figure 4.1.2 – CoMP-S installed on coronagraph at Lomnicky Stit Observatory, Slovakia. (Photo: AI SAS archive)

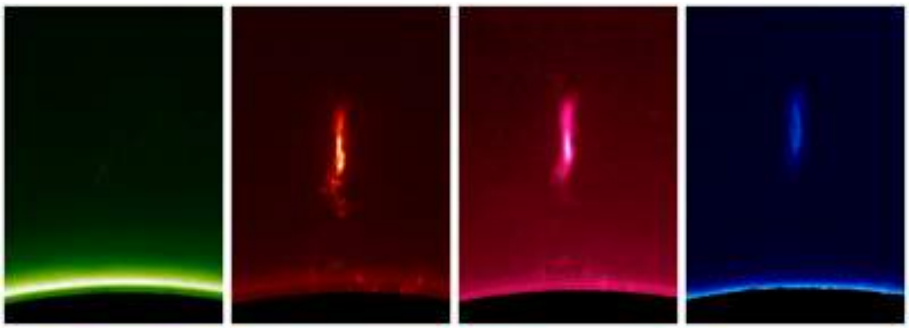

Figure 4.1.3 Example of CoMP-S observation at LSO. An eruptive prominence, observed on 2014/03/10 above the southeast limb of the Sun sequentially in 4 spectral lines: He I 587 nm , H I 656 nm, Ca II 854 nm, and He I 1083 nm (08:15:59-08:25:17 UT). (Photo: AI SAS archive)

References:

- Lexa, J.: 1963, Bulletin of the Astronomical Institute of Czechoslovakia, 14, 107
- Kucera, A., et al.: 2010, Contrib. Astron. Obs. Skalnate Pleso 40, 135
- Tomczyk et al., 2008, Solar Physics, 247, 411

4.2) Solar telescopes at public observatories

Regular observations of the solar atmosphere have a long tradition in Slovakia. Many public observatories and astronomical amateurs contribute to the regular records of solar activity and also use these observations for educational and public outreach activities.

Solar telescopes at Slovak central observatory in Hurbanovo (SUH)

- Coudé refractor telescope (15/225 cm)
  - Description: Optical observation of sunspots in photosphere
  - Data: https://suh.sk/online-data/protokoly-pozorovani-sln-fotosfery
- LUNT telescope with H-alpha filter (8/54 cm)
  - Description: Photographic observation of chromosphere and prominences
  - Data: https://suh.sk/obs/aktivita/aktivita.htm
- Spectrometer CALLISTO
  - Description: Radio solar spectrometer (45 – 800 MHz). Component of international network: http://www.e-callisto.org
  - Data: http://soleil.i4ds.ch/solarradio/callistoQuicklooks
- Spectrometer Ocean Optics HR4000 and horizontal solar telescope (50/3500 cm)
  - Description: Measurements of solar continuum in VIS spectral band with the aim to detect solar flares
  - Data: available on demand

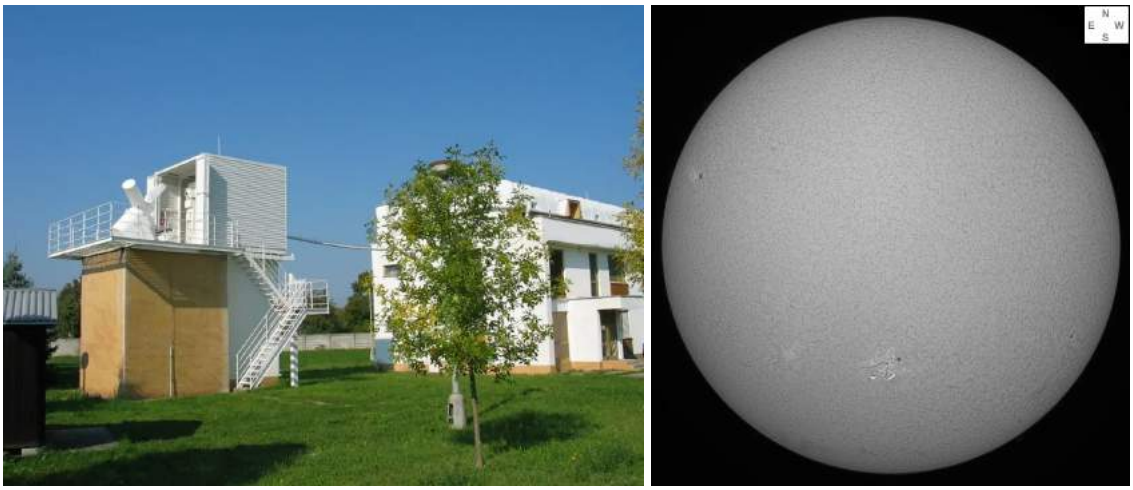

Figure 4.2.1 – Solar telescopes at Slovak Central Observatory in Hurbanovo, Slovakia. Left: Premisses of horizontal solar telescope. Right: Example of solar chromosphere image from 2021/10/28. (Photos: SUH archive)

Solar telescopes at Astronomical Observatory in Prešov (AOP)

- Coudé refractor telescope (15/225 cm)
  - Description: Optical observation of sunspots in photosphere
  - Data: https://astropresov.sk/astro-info/archiv-slnka/ archive for years 1947 - 2013
- Refractor telescope ZEISS - KEPLER (10/100 cm)
  - Description: Optical observation of solar photosphere
- Telescope MEADE ACF (30.4/243.8 cm)
  - Description: Optical observation of solar photosphere
- LUNT telescope with H-alpha filter (8/56 cm)
  - Description: Photographic observation of chromosphere and prominences

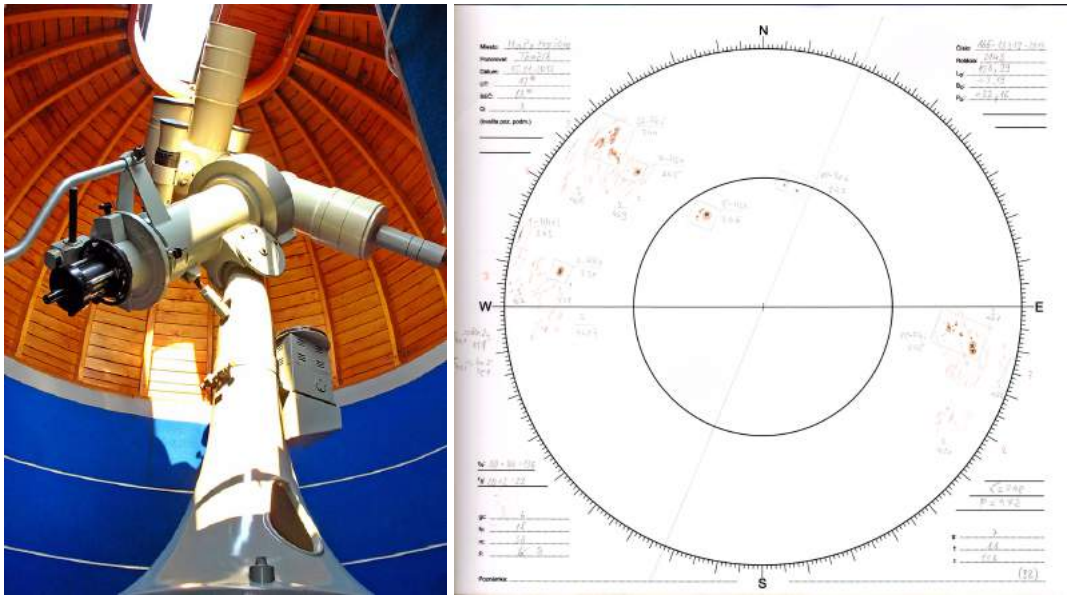

Figure 4.2.2 – Solar telescopes at Astronomical Observatory in Prešov, Slovakia. Bottom view of telescopes. Right: Example of solar photosphere drawing from 2013/11/12. (Photos: AOP archive)

Solar telescopes at Astronomical Observatory in Rimavská Sobota (AOR)

- Refractor telescope (16/245 cm)
  - Description: Photographic observation of photosphere (CCD MR285C) in continuum (537 nm) and Ca II K spectral line (393 nm)
  - Data: http://astrors.sk/slnko.html
- Coudé refractor telescope (15/225 cm)
  - Description: Optical observation of sunspots in photosphere
- LUNT telescope with H-alpha filter (8/54 cm)
  - Description: Photographic observation of chromosphere and prominences

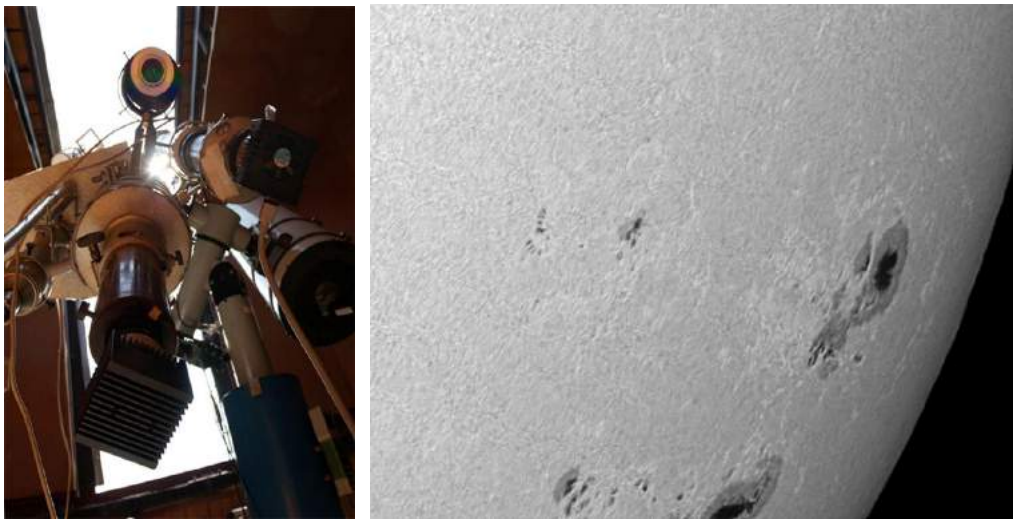

Figure 4.2.3 – Solar telescopes at Astronomical Observatory in Rimavská Sobota, Slovakia. Left: Bottom view of telescopes. Right: Example of solar photosphere image from 2014/06/13. (Photos: AOR archive)

4.3) Space R&D infrastructure

Space R&D infrastructure is located at the Department of Space Physics (DSP) IEP SAS at Bulharska 2, Kosice, Slovakia. The infrastructure consists of the specialized space engineering laboratories for electronics and mechanical design, construction and testing (PCB prototype manufacturing in CNC machine, soldering, thermal-vacuum testing, physical calibration/clean room, vibration testing, EMC testing), software development (workstations with software for electronics CAD - Altium designer, mechanical 3D design - SolidWorks, development tools for many microcontrollers and FPGA platforms), measuring instruments (high-speed multi-channel mixed signal oscilloscopes, signal generators, high speed counters, precision multimeters, laboratory power supplies, high voltage power supply etc.). Mechanical laboratory is fully equipped for mechanical manufacturing (manual milling and drilling machines, lathes etc.).

Technical details of the SPACEVAC - Space Environment Simulator:

- Bell chamber 150L with multi-feedthrough system
- Temperature controlled copper base, diameter 450mm
- Temperature controlled radiation shroud
- Dry Scroll pump Varian SH-110
- Turbomolecular pump Varian – V301 Navigator
- Gate valve VAT DN 63-400
- Vacuum gauge Pfeiffer TPG 261+ PKR251 full range
- Temperature monitoring and logging system COMET MS5D (max 16 channels)
- Temperature sensors PT1000
- Temperature control system IS 002
- Feedthrough adapters (32pin + 32pin + 4 HV pins on bottom, 9pin on top bell)
- Vacuum at +25°C (empty chamber) 1×10^{-7} mbar
- Heatig: Electrical, Cooling: LN2
- Temperature test range: from - 100°C to +160°C

Figure 4.3.1 – Space environment simulator at Department of Space Physics in Košice, Slovakia. Left: The view of thermal-vacuum components. Right: Detail of detection and operation components. (Photos: IEP SAS archive)

Technical details of the Vibration Test System (Bruel & Kjear / LDS):

- Shaker: V780
- Power amplifier: HPA-K 5kVA /D-class
- Control system: Laser USB, Control software: LAS-200
- Acceleration sensors: IEPE 100mV/g (4pc)
- Action force (sinus peak): 5100 N, Action force (random-rms): 4200 N
- Action velocity (sinus peak): 1,9 m/s
- Action acceleration (sinus peak): 1050 m/s^2, Action acceleration (random-rms): 480 m/s^2
- Frequency range: DC – 4000 Hz
- Resolution of the control system: 24 bit
- Interface to control computer: USB 2.0

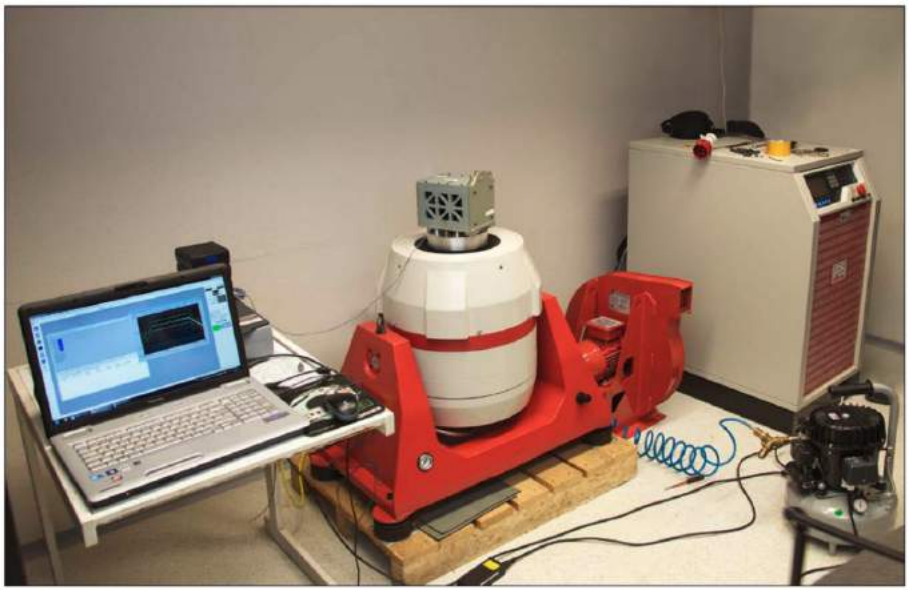

Figure 4.3.2 – Vibration test system at Department of Space Physics in Košice, Slovakia. (Photo: IEP SAS archive)

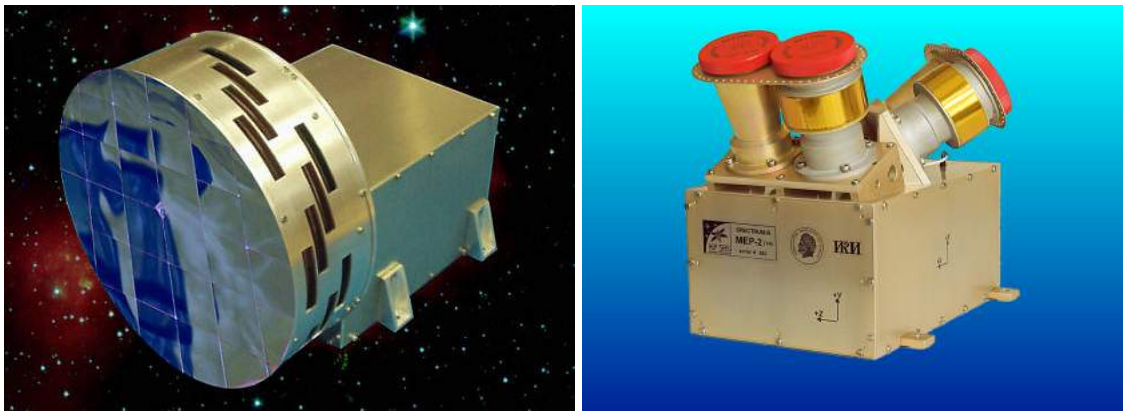

Figure 4.3.3 – Examples of space-based instruments developed and constructed at DSP in Košice, Slovakia. Left: NUADU imager was developed specifically for operation on board of the TC-2 probe in the frame of the European - Chinese magnetospheric mission Double Star. Right: MEP-2 (Monitor of Energetic Particles) developed for Spectrum-R / Radioastron mission. It provided long-term (9 years of operation in space) registrations of energy spectra and time variations of the energetic particle flux. (Photo: IEP SAS archive)

4.4) Neutron monitor & SEVAN

Measurements of the cosmic ray intensity by neutron monitor on Lomnicky Stit Observatory commenced in January 1958 as part of the Czechoslovak scientific program associated with the International Geophysical Year (Dubinský et al., 1960). This monitor was subsequently replaced in December 1981 by an 8-tube NM64 installed in the small house on the roof of the main building at LSO. The average counting rate of the NM is now ~ 1.6×10^6 counts per hour. At each of these changes, both monitors were kept in concurrent operation for several months so that the recorded cosmic ray intensity could be normalized back to the initial measurements in 1958. The increasing

statistical accuracy from December 1981 allowed to observe short time variations. Thus, from 1982 5 min data and from 1984 1 min data resolution are available. The description of the existing measurements can be found in Kudela et al. (2009). Checking of the simultaneous temporal profile in 4 sections by 2 tubes is done routinely. In addition, the barometric pressure is measured automatically and pressure corrected data are constructed. From 2001 the data are routinely available on the web (http://neutronmonitor.ta3.sk) where past 6 hours of 1 min data, past 24 hours of 5 min and past 30 days of hourly cosmic ray intensity can be found both in graphical and digital data format. The data are continuously updated. The construction of the NM 64 instrument is presented in Figure 4.4.1. Cutoff rigidity is ~ 4 GV. The changes due to the external geomagnetic field are presented in Bobik et al. (2001). The neutron monitor is a component of the international network of neutron monitors. All the details are available at https://www.nmdb.eu.

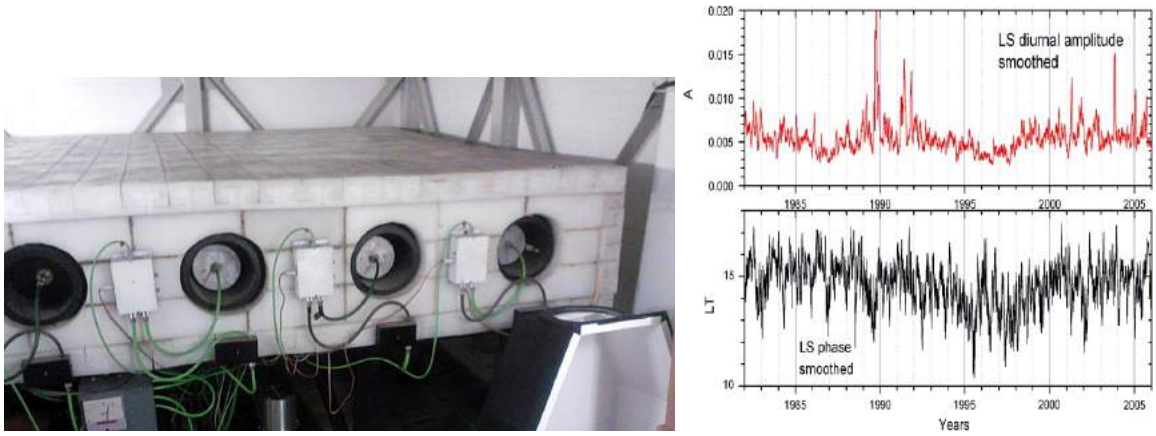

Figure 4.4.1 – Neutron monitor at Lomnicky stit observatory, Slovakia. Left: There are 8 proportional counters of the type SNM-15 used for measurements of secondary cosmic rays (Photo: IEP SAS archive). Right: The amplitude and phase of diurnal variations of cosmic ray intensity observed at LSO in the period 1982 - 2006 (Kudela et al., 2009).

SEVAN (Space Environmental Viewing and Analysis Network) instrument of the international network has been operated at LSO since 2014. The SEVAN network consists of hybrid detectors registering charged and neutral components of secondary cosmic rays. The network detects changing fluxes of different species of secondary cosmic rays at different altitudes and latitudes, thus turning into a powerful integrated device used to explore solar modulation effects. To facilitate SEVAN network creation, Cosmic Ray Division (CRD) of the Yerevan Physics Institute designs the basic SEVAN particle detector module, front-end electronics and advanced data acquisition system (ADAS). The CRD provides scintillator slabs, photomultipliers, electronics and ADS to the host institutions. The host institution provides a steel frame of the detector, lead filter and scintillator housings. Host institutions also are responsible for providing SEVAN detectors with uninterruptible Internet connection and electricity. CRD provides multivariate data visualization and analysis tools. The on-line data from all 7 operating SEVAN sites are posted on-line and could be downloaded from ADEI (http://crd.yerphi.am/ADEI).

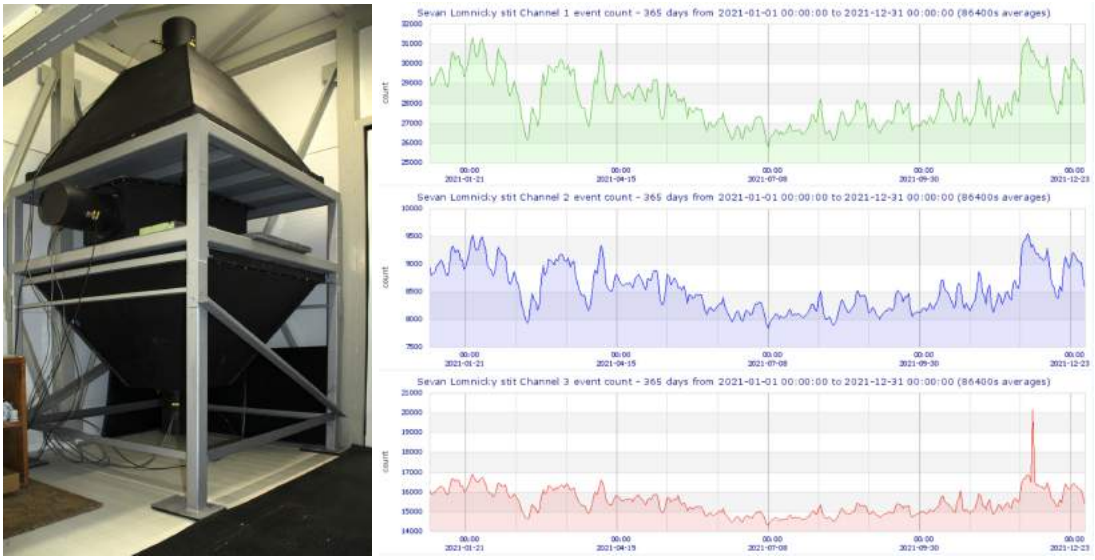

Figure 4.4.2 – SEVAN instrument at Lomnicky stit observatory, Slovakia. Left: The detail of the detectors' construction (Photo: IEP SAS archive). Right: The count rate of secondary cosmic rays observed at LSO in 3 channels within the year 2021 (http://data.space.saske.sk).

References:

- Bobik, P., et al.: 2001, Proc. 27th ICRC, 10, 4056
- Dubinský, J., et al.: 1960, Matematicko-fyzikalny casopis SAV, X, 4, 247
- Kudela, K., Langer, R.: 2009, Advances in Space Research, 44, 10, 1166

4.5) AMON-ES & AMON-net

Airglow Monitor - Extended Station (AMON-ES) has been established at the Astronomical Observatory on Kolonica Saddle (AOK) in 2019. The main goal of AMON-ES construction was to obtain wider understanding of airglow variation that is observed by AMON (Airglow MONitor) photometers and to get clear recognition which variation is caused by airglow dynamics and which is caused by troposphere and astronomical background effects. It was also built to allow comparison of airglow measurements with the ionospheric measurements by using GNSS signals. All the obtained results are needed for the development process of the network of airglow photometers: AMON-net. All the data are available on demand and will be available online, soon. Documentation and data examples can be found at: https://github.com/space-lab-sk/amon-es.

The AMON-ES consists of the following instruments (Figure 4.5):

- Airglow All-sky Camera: CCD G2-4000 with wish-eye lens, 5 filters for airglow emission in VIS spectral band
- GNSS receiver for measurements of ionospheric parameters: Septentrio PolaRxS and antenna Trimble Zephyr Geodetic Model 2 (loaned from ESA)
- AMON (Airglow Monitor): high-sensitive photometer for UV airglow measurements developed by IEP SAS (Mackovjak et al., 2019)
- TLE camera: autonomous camera for observation of Transient Luminous Events (Amrich et al., 2021)

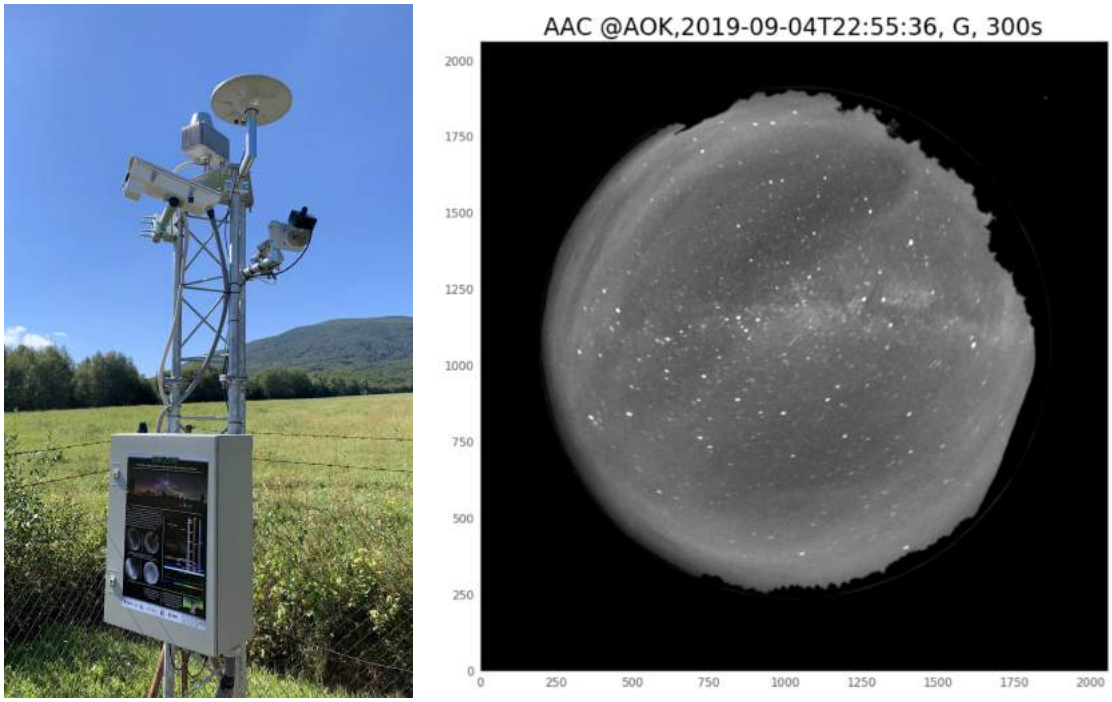

Figure 4.5 – AMON-ES at the Astronomical Observatory on Kolonica Saddle, Slovakia. Left: The AMON-ES instruments. Right: The allsky image of green airglow (557.7 nm). (Photos: IEP SAS archive)

References:

- Amrich, S., et al.: 2021, Journal of Instrumentation, 16,12
- Mackovjak, Š., et al.: 2019, Nuclear Inst. and Methods in Physics Research A, 922, 150

4.6) INTERMAGNET

The INTERMAGNET is a global, real-time, permanent geomagnetic observatory network, which is recognized as a key Earth observation system and which provides data that serves scientific research into the Earth, from its deep interior to space, and supports operational services benefiting society. The INTERMAGNET mission is to establish and maintain an organization with a worldwide membership drawn from institutes operating geomagnetic observatories that is dedicated to building a network of geomagnetic observatories supplying consistent data, with the geographical coverage, quality, and timeliness of delivery required to meet the evolving needs of research and applied science. More details can be found at https://intermagnet.github.io. The observatory at Hurbanovo joined the world-wide INTERMAGNET network in 1997.

Technical details of instruments in Hurbanovo within INTERMAGNET:

- DI-fluxgate magnetometer (type ELSEC 810, Zeiss Theo 015B)
- DI-fluxgate magnetometer (type LEMI 203)
- proton magnetometer (type PMG 1)
- Torsion photoelectric magnetometer (TPM) employing Bobrov-type quartz variometers
- Magson fluxgate magnetometer

5) Relevant SWE Entities

This section contains the list of identified Slovak entities (academia, industry, etc.) that are specialized, involved or have potential in Space Weather and Lagrange mission related activities.

The review of relevant entities has been conducted by using [RD-1], available peer-reviewed literature, proceedings papers, online sources, publicly available lists of research and development projects, and also by direct communication. Table 5.1 lists the identified entities with a short description of their capabilities and contact point information. More detailed information about each identified entity can be found in consecutive sections.

Table 5.1: List of Slovak entities in space weather framework.

Entity	HQ	Industry	Domains	Type of business	Website	Contact
Institute of Experimental Physics, Slovak Academy of Sciences (IEP SAS)	Košice, Slovakia	Academia, R&D institution, Observatory	SWE - Heliospheric Weather SWE - Space Radiation SWE - Ionospheric Weather	HW, SW, services, expertise	https://uef.saske.sk	Dr. Simon Mackovjak, mackovjak@saske.sk +421 55 792 2370
Astronomical Institute, Slovak Academy of Sciences (AI SAS)	Tatranská Lomnica, Slovakia	Academia, R&D institution, Observatory	SWE - Solar Weather	HW, SW, services, expertise	https://astro.sk	Dr. Ján Rybák, rybak@ta3.sk +421 52 787 9156
Slovak Central Observatory Hurbanovo (SUH)	Hurbanovo, Slovakia	Academia, Observatory	SWE - Solar Weather	services, expertise	www.suh.sk	Dr. Ivan Dorotovič, ivan.dorotovic@suh.sk, +421 35 245 1115
Earth Science Institute, Slovak Academy of Sciences (ESI SAS)	Bratislava, Slovakia	Academia, Observatory	SWE - Geomagnetic Conditions	services, expertise	http://www.geo.sav.sk	Dr. Fridrich Valach, fridrich@geomag.sk, +421 35 760 2211
Faculty of Mathematics, Physics and Informatics (FMPI)	Bratislava, Slovakia	Academia, University, Observatory	SWE - Geomagnetic Conditions	expertise	https://fmph.uniba.sk/	Dr. Tomáš Paulech, paulech@fmph.uniba.sk, +421 2 6029 5808
Astronomical Observatory Prešov (AOP)	Prešov, Slovakia	Observatory, Public outreach	SWE - Solar Weather	public outreach	https://astropresov.sk/	Mr. Ján Sadiv, sadiv@astropresov.sk
Astronomical Observatory Rimavská Sobota (AOR)	Rimavská Sobota, Slovakia	Observatory, Public outreach	SWE - Solar Weather	public outreach	http://www.astrors.sk	Dr. Pavol Rapavý, pavol.rapavy@gmail.com
Roztoky Observatory (RO)	Roztoky, Slovakia	Observatory, Public outreach	SWE - Solar Weather	public outreach	https://roztoky.space	Mr. Jozef Leško, astroroztoky@protonmail.ch
Astronomical Observatory Hlohovec (AOH)	Hlohovec, Slovakia	Observatory, Public outreach	SWE - Solar Weather	public outreach	http://hvezdaren.org	Mr. Ján Karlovský, jan.karlovsky@gmail.com
Faculty of Electrical Engineering and Informatics, Technical University of Košice	Košice, Slovakia	Academia, University, R&D institution,	SWE - Ionospheric Weather	SW, services, expertise	https://kkui.fei.tuke.sk	Assoc. Prof. Peter Butka, peter.butka@tuke.sk, +421 55 602 4280

GlobalLogic Slovakia s.r.o.	Košice, Slovakia	IT company	SWE - Ionospheric Weather	SW, services	https://www.globallogic.com/sk/	Mr. Tibor Radačovský, tibor.radacovsky@globallogic.com
SPACE::LAB startup	Košice, Slovakia	Startup	SWE - Ionospheric Weather	SW, services	https://spaceoffice.sk/space-incubator/	Mr. Matej Varga, mvarga@saske.sk
Q-Products a.s.	Bratislava, Slovakia	Company	SWE - Heliospheric Weather	HW, services	https://www.qproducts.sk	Mr. František György, fero.gyorgy@qproducts.sk
CTRL s.r.o.	Košice, Slovakia	Company	SWE - Heliospheric Weather	HW, services	http://www.ctrl1.eu	Mr. Cristian Stratyinski cristian.stratyinski@ctrl1.eu

5.1) Institute of Experimental Physics, Slovak Academy of Sciences (IEP SAS)

IEP SAS is a research institution that is focused on fundamental research in space physics, condensed matter physics, sub-nuclear physics, and biophysics, employing ~100 scientific researchers (~80 FTEs). The research output is ~150 current content publications with ~1000 citations per year (Web of Science database, excluded big collaborations citations). The IEP was established in 1969 and it is located in Košice, Slovakia. The Department of Space Physics (DSP) is one of ten IEP departments where SWE research is conducted. DSP focuses on physical processes in the near-Earth's space, space weather, solar wind interactions in interplanetary space, airglow, thermosphere-ionosphere system, and low energy cosmic rays. DSP has a long history in space research and development, starting with ground-based cosmic rays measurements on Lomnicky peak observatory since approx. 1950. The Neutron monitor was introduced to service in the frame of the International geophysical year 1957/58 and operates continuously to present (Figure 5.1).

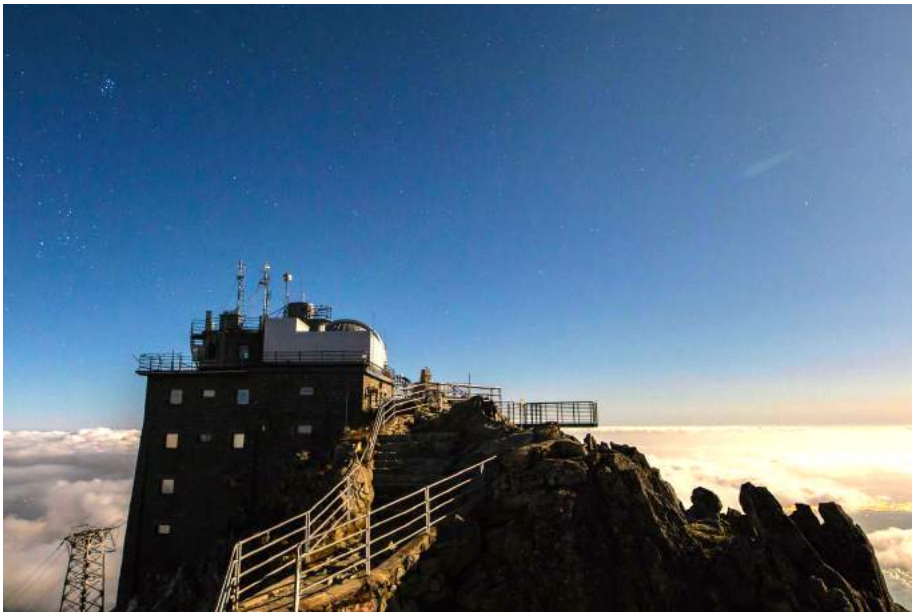

Figure 5.1 – Lomnicky Stit Observatory at altitude 2,634 m in High Tatras, Slovakia. (Photo: IEP SAS archive)

DSP joined space flight activities in 1970 in the frame of Russian Intercosmos programme, later contributed also to the ESA programme (space missions: DoubleStar, Rosetta, BepiColombo, JUICE) within the frame of various bilateral cooperations. In the JEM-EUSO collaboration, DSP represents

the Slovak participation. Strong cooperation relationships have been established with the key institutes of the mission including RIKEN (Japan), University of Tuebingen (Germany), University of Geneva (Switzerland), University of Turin (Italy), University of Alcala (Spain), National Centre for Nuclear Research (Poland), Colorado School of Mines (USA) etc. For more information about IEP SAS refer to: https://uef.saske.sk.

5.2) Astronomical Institute, Slovak Academy of Sciences (AI SAS)

AI SAS is located in Tatranská Lomnica in the High Tatras region in Slovakia. It operates three observatories in Stara Lesna, Skalnate Pleso (Figure 5.2), and on Lomnicky Stit. AI SAS consists of three scientific departments. The SWE related research is conducted in the Solar Physics Department (SPD). SPD research is focused mainly on the magnetism, dynamics and variability of the solar atmosphere. There are several research areas under investigation. A) study of the solar photosphere and chromosphere and active events in them, using modern spectro-polarimetric, spectroscopic and photometric observations acquired with top level solar telescopes base at the Canary Islands (GREGOR, VTT, SST, THEMIS), and with space-borne satellites under own joint observing proposals. B) study of the solar corona and structures in it (prominences, coronal holes, coronal condensations) and Sun-Earth relations using data acquired with modern infrastructure at our Lomnicky Peak Observatory, with space-borne satellites and from VSO – Virtual Solar Observatory (unique access to data from space- and ground-based observations of the Sun) and using data from solar total eclipses observations. C) study of evolution of fast and very powerful events in the solar atmosphere (flares, coronal mass ejections, active prominences, jets) using multiple observations from ground based and space-borne instruments. For more information about AI SAS refer to: https://astro.sk.

Figure 5.2 – Skalnate Pleso Observatory at altitude 1,786 m in High Tatras, Slovakia. (Photo: AI SAS archive)

5.3) Slovak Central Observatory in Hurbanovo (SUH)

SUH was established in Hurbanovo in 1871. Nowadays, it performs and coordinates observational and scientific research activities of Slovak observatories in the field of solar physics, interplanetary matter, variable stars and eventually other specializations. It solves its own research tasks in the field of solar physics and radio meteors. SUH participates in scientific research work of other institutions at national and international level, organizes and coordinates national and international events, performs consulting for institutions and individuals whose activities are related to scientific observational and research mission of the department. It raises direct contacts with other legal entities and natural persons in Slovakia and abroad with a purpose of astronomical information exchange, scientific stays, organisation of expeditions, and etc. For more information about SUH refer to: www.suh.sk.

Figure 5.3 – Slovak Central Observatory in Hurbanovo, Slovakia. (Photo: SUH archive)

5.4) Earth Science Institute, Slovak Academy of sciences (ESI SAS)

ESI SAS explores and investigates geodynamic evolution of the Earth, its rock composition, evolution of ecosystems, climate and seawater chemistry, and interpretation of geophysical fields and seismicity. It uses modern approaches and methods and advanced instrumental facilities. ESI SAS consists of two, Geological and Geophysical research divisions, which descend from the formerly independent Geological and Geophysical institutes of the Slovak Academy of Sciences, both founded in 1953. The research related to SWE is conducted at the Department of Geomagnetism (DGM). The research performed at the DGM includes: A) Study of the generation of the planetary magnetic field. Here the research is focused on the magnetohydrodynamic processes in the liquid Earth's core and on the phase transitions in the Earth's core. B) Magnetometry, magnetotellurics and paleomagnetism, which enable exploring complex geological structures by physical methods. This research is predominantly oriented to the territory of Slovakia and its

surroundings. C) Physics of the Solar–Terrestrial relationships. Here the research is focused on modelling the geomagnetic activity associated with various phenomena that take place in the interplanetary space. DGM runs the Geomagnetic Observatory ESI SAS at Hurbanovo. The international code of the observatory is HRB. The observatory is responsible for continuous recording of the elements of the geomagnetic field as well as for the regular evaluation of the observed geomagnetic activity. Since 1997, the Hurbanovo Geomagnetic Observatory has been a member of INTERMAGNET, the global network of observatories. Within the scope of the observatory is also the determination of the distribution of the geomagnetic field over the territory of Slovakia. Apart from scientific research, these data are utilized for navigation purposes, especially for aviation practice. For more information about ESI SAS refer to: http://www.geo.sav.sk.

Figure 5.4 – Geomagnetic observatory in Hurbanovo, Slovakia. (Photo: ESI SAS archive)

5.5) Faculty of Mathematics, Physics and Informatics, Comenius University (FMPI)

Figure 5.5 – Astronomical and Geophysical Observatory Modra, Slovakia. (Photo: FMPI archive)

Astronomical and Geophysical Observatory (AGO), located in Modra under the Little Carpathian Mountains, was established in 1992 as a scientific facility of the Faculty of Mathematics, Physics and Informatics of the Comenius University in Bratislava. Its main goal is to provide practical education for students of astronomy and astrophysics as well as to perform scientific research in these areas with main focus on the interplanetary matter. AGO cooperates intensively with a number of institutions and partners both Slovak and foreign. Besides the interplanetary matter it has also participated in measurements of geomagnetic conditions. Specifically, they perform observations of Transient Luminous Events (TLEs) by AMOS system, paleomagnetic measurements, Schumann's resonances measurements, and seismographic measurements. For more information about FMPI refer to: https://fmph.uniba.sk/ .

5.6) Public Observatories

There are 17 public observatories in Slovakia. The list with the basic information of observatories is available at: https://suh.sk/images/zakony/Zoznam_hvezdarni_a_planetarii.html. Their locations are presented on map in Figure 5.6 (red dots). They are focused mainly on public outreach and educational activities. However, most of them also perform basic observations of the solar atmosphere. These observations are coordinated by the Astronomical Observatory in Prešov. It provides continuous recording and evaluation of the state of the solar photosphere and publication of the annual Bulletin of the Solar observations in Slovakia.

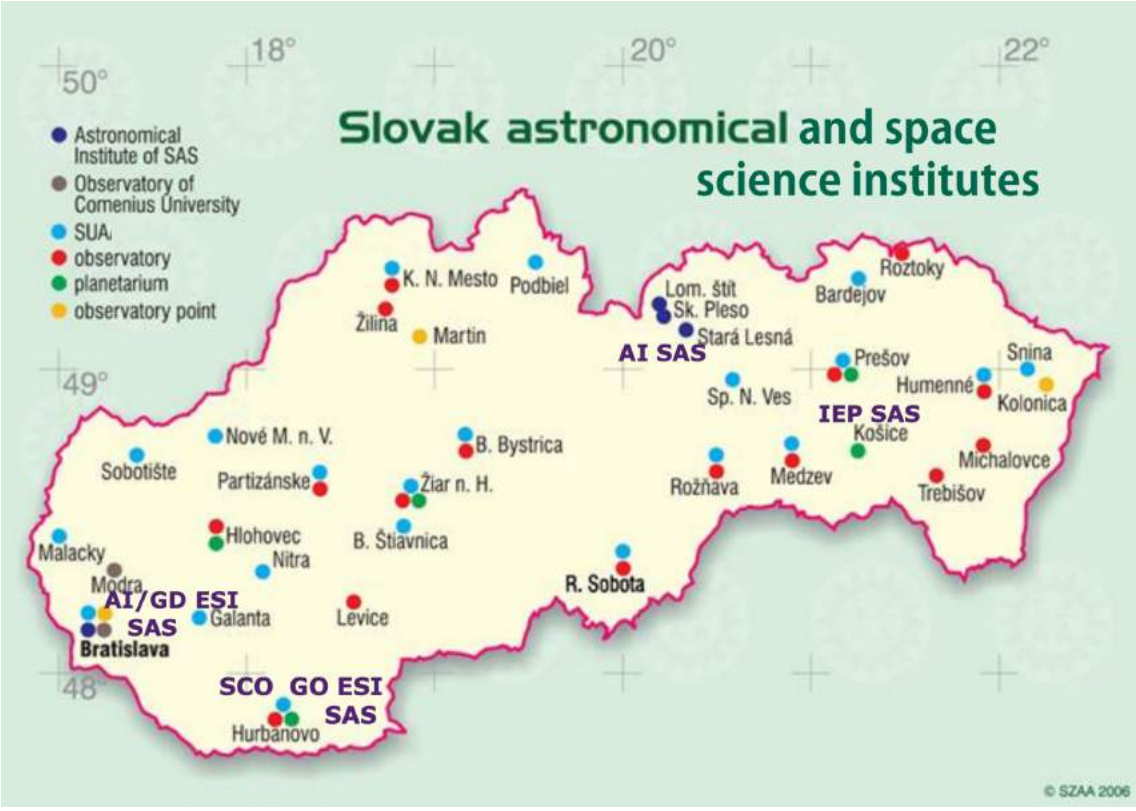

Figure 5.6 – Map of Slovak astronomical institutes, space science institutes and public observatories in Slovakia. (Source: http://stara.suh.sk/id/iswi/ISWIinSlovakia2008-2017.pdf)

5.7) Potential new players

5.7.1) Technical University of Košice

Technical University of Košice was established in 1952 and at present it is the second largest technical university in Slovakia, one of the leading academic institutions in eastern Slovakia with more than 10,000 students and 700 scientific and teaching staff members. The Faculty of Electrical Engineering and Informatics (FEI) is one of the largest faculties. The Department of Cybernetics and Artificial Intelligence has a strong record in computer science and applied research in the area of artificial intelligence, machine learning, data/text mining, knowledge engineering, with more than 150 national and international projects in the domains like industry, medicine, business, e-government, and also support of science research process (e.g. collaboration in CERN ALICE experiment). Within the department, the Data Science Group members have extensive experience in more than 30 national and international projects, with participation in more than 10 EU FP or H2020 R&D projects and collaboration with partners from more than 20 countries. They also started new collaborations recently towards the domains of space/geo data processing and support of their decision processing using machine/deep learning approaches. Here, the influential support at the start was provided by COST actions. Thanks to these actions and provided contacts even outside the networks, they were able to start other interesting collaborations in application of machine learning for space weather data with IEP SAS. This includes segmentation of events in solar corona, data-driven modeling of airglow intensities, automated analysis of radio spectrograms for lighting detection related to lower ionosphere, and prediction of ionospheric disturbances within ESA/PECS project ASPIS. For more information refer to: https://kkui.fei.tuke.sk.

5.7.2) GlobalLogic

GlobalLogic is a leader in digital engineering. We help brands across the globe design and build innovative products, platforms, and digital experiences for the modern world. By integrating experience design, complex engineering, and data expertise—we help our clients imagine what's possible, and accelerate their transition into tomorrow's digital businesses. Headquartered in Silicon Valley, GlobalLogic operates design studios and engineering centers around the world, extending our deep expertise to customers in the automotive, communications, financial services, healthcare and life sciences, manufacturing, media and entertainment, semiconductor, and technology industries. GlobalLogic is a Hitachi Group Company operating under Hitachi, Ltd. (TSE: 6501) which contributes to a sustainable society with a higher quality of life by driving innovation through data and technology as the Social Innovation Business. For more information refer to: https://www.globallogic.com/sk/.

5.7.3) SPACE::LAB startup

SPACE::LAB startup is an early-stage team engaged in the Slovak Space Incubator program connected directly to the Institute of Experimental Physics, Slovak Academy of Sciences (IEP SAS) in Košice. Its aim is to provide digital solutions by advanced machine learning techniques in the

domain of space weather. Based on the extensive know-how of IEP SAS and state-of-the-art technologies it is developing data-driven services for science & technology customers. For more information refer to: https://spaceoffice.sk/space-incubator/.

5.7.4) Q-PRODUCTS a.s.

Q-PRODUCTS Industrial Computers - Tailor made products to suit customer's requirements.
We have developed and produced ruggedized computers and displays since 1993. The company is located in Bratislava, Slovakia, EU and lead by its founder Ing.František György. More than 15 years of experience, wide cooperation with engineers from technical institutes and research companies in combination with cost-effective development and production allowed us to bring high-level professionall ruggedized products to market at competitive prices. Own measurements and test equipment in the hands of high educated engineers guarantee the promised quality. We are proud to tell that more than 70% of our employees have graduated from technical universities at the highest at the Master‘s Level. And more – we enjoy our own challenge. Let us introduce our technologies: A) Distribution division - industrial computers, displays, components for building technology computers, professional waterproof boxes and lights Peli. More info you can see on www.peli.sk. B) Production division - precize CNC milling, CNC bending, laser marking and engraving, 3D CAD/CAM engineering, tailor made production, prototyping. For more information refer to: https://www.qproducts.sk/about-us/.

5.7.5) CTRL s.r.o.

Company CTRL Ltd. was founded in 2010 and is ranked among small businesses. The intention of founding the company was building and deploying the electronic products with latest technologies and methods in the field of so called cyber-physical systems, which include mostly electronics, communication components and system approach with focus on the control. Since the beginning of the market, the company works closely with academic and scientific institutions, participates in the laboratories to develop new electronic equipment and new methods in the field of advanced control algorithms. In recent years, the products of the company are active in the sophisticated fields of cybernetics, artificial intelligence, robotics and measurement in practise. The Company participating and support in the frame of space and universe research projects of European Space Agency (ESA). For more information refer to: http://www.ctrl1.eu/.