PROSPECTIVE RECOVERY PLAN FOR UKRAINIAN ASTRONOMY

Ukrainian astronomy has a history of more than two hundred years and is one of the most internationally recognised branches of domestic science. Despite the full-scale armed aggression of Russia, the Ukrainian astronomical community has demonstrated resilience, preserving its scientific, educational, and international potential. This document provides a comprehensive overview of the current state of the field. It examines the institutional structure, human resources, scientific achievements of leading institutions, the impact of the war on infrastructure and personnel, and outlines strategic priorities for post-war recovery and further integration into the European Research Area.

Table of Contents

FOREWORD

This document was written under extraordinary circumstances. It was written while some of its authors heard explosions outside their windows, while observational stations stood mothballed or lay in ruins, while students received their education in bomb shelters, and while rockets attempted to strike the solar panels of an institute struggling to maintain even minimal electrical power for its operations. And at the same time — while Ukrainian astronomers were publishing papers in leading international journals, participating in international projects, delivering online lectures to hundreds of listeners, and opening the doors of observatories to children on Museum Night and Asteroid Day.

This contradiction is the very essence of the current state of Ukrainian astronomy.

Astronomy in Ukraine has deep roots and internationally verified competencies. The network of scientific institutions — the Main Astronomical Observatory of the NAS of Ukraine, the Radio Astronomy Institute of the NAS of Ukraine, the university observatories of Kharkiv, Kyiv, Odesa, and Lviv — still retains research potential even amidst total uncertainty. Ukraine holds unique globally significant competencies: the world's largest decametric radio telescope UTR-2, an internationally recognised cometary school, experience participating in major international projects, and strong traditions in astrometry, stellar physics, cosmology, and the physics and dynamics of small Solar System bodies. But these competencies are coupled with intensifying vulnerabilities. Personnel attrition has reached a critical level at certain institutions; the younger generation of scientists is dispersed between the front lines, abroad, and the civilian labour market. Part of the observational infrastructure has been destroyed or mothballed. Basic funding for fundamental science covers, at best, half of what is needed. Ukraine lost the Crimean observatory in 2014, and since 2022 has suffered new losses whose full scale is only beginning to be comprehended.

And despite all of this — science has not stopped. This in itself is a powerful argument in favour of systematic support. If Ukrainian astronomers have been able to preserve their competencies under conditions that would have simply halted most scientific systems in the world, then with proper support we are capable of far more. We see this support structured around four directions that form the backbone of this document. This structure is not arbitrary: it reflects four interdependent dimensions, without each of which long-term revival of the field is impossible. They are not listed in order of importance — they form a system in which a break in any link undermines the whole.

Direction 1: "Human Capital and Scientific Networks" is the starting point, because science cannot exist without people. Infrastructure can be rebuilt, instruments can be purchased, but scientific competencies accumulated over years, and trust between colleagues, cannot. If Ukraine loses the critical mass of researchers, no number of telescopes or grants will restore the field to working order. The transition from scattered personal contacts to institutional partnerships, the formation of a network for the diaspora, mentorship and joint educational programmes — these are not supplementary measures but the structural foundation without which everything else will have no one to implement it.

Direction 2: "Scientific and Research Infrastructure" is a prerequisite for scientific activity to take place at all — and to take place at a level competitive on the global stage. But the fundamental position of this document is that reconstruction is not synonymous with restoration. It is an opportunity to build better — focusing on areas where Ukraine has unique advantages, and on structures such as the Astronomical Data Centre, capable of becoming a platform for a wide range of research and people. That is why this direction begins not with a list of facilities to restore, but with the requirement to first define scientific priorities.

Direction 3: "Innovation and Economic Development" addresses the practical question that inevitably arises from taxpayers, the state, and business: why fund astronomy in a country recovering from a devastating war? The answer is that astronomy is not a peacetime luxury, but a generator of technologies and competencies without which development in IT, the defence industry, remote sensing, navigation, and a whole range of other sectors is impossible. Technology transfer, innovation hubs, entrepreneurial skills in scientists, astrotourism — these are not fantasies, but real pathways to making astronomy a visible component of economic recovery.

Direction 4: "Education and Public Engagement" is what ensures the long-term reproducibility of the entire system. The best researchers, the most modern infrastructure, and the most effective technology transfers are worth nothing if in ten years there is no new generation to take our place. Astronomy is a unique instrument for attracting young people to science — and therefore investment in astronomical education is investment in the STEM system as a whole, in technological sovereignty, and ultimately in national security. That is how this direction should be understood: not as "education for education's sake", but as a strategic priority at the state level.

Realistic Expectations from Implementation

Realistic expectations from the implementation of this document are neither modest nor inflated. They are specific.

In the short term — over the next two years — we expect: the launch of a network connecting Ukrainian astronomers with international partners; the establishment of the Ukrainian Astronomical Data Centre as a formal organisational unit; the first formal memoranda with EU universities and networks; the commencement of operation of the first mobile planetariums in the regions; the first steps towards ESA membership; the formulation of a scientific priorities document by the community itself.

In the medium term — by 2030 — we expect: the connection of Ukrainian radio astronomy systems to LOFAR and the VLBI network; the deployment of a meteor monitoring network covering the entire country; the opening of the first AstroHub; the launch of joint educational programmes and Industrial PhD schemes; the restoration of full research activity at key facilities; the training of 10+ certified GTTP/NASE trainers; stabilisation of human resources and the first signs of scientists returning.

In the long term — on a horizon of ten or more years — we expect: Ukraine among the full members of ESA; fully restored and modernised radio-astronomical and optical infrastructure; the first commercial spin-off astronomical start-up; a complete continuous educational vertical — from kindergarten to doctoral studies — with an astronomical component at every level; and — most importantly — a new generation of Ukrainian astronomers, who have returned or never left, engaged in science in Ukraine.

Conditions and Responsibilities

None of these expected changes will happen automatically. They require several interdependent conditions.

From Ukraine: a clear formulation of priorities by the scientific community itself — without which external support will be scattered and ineffective; reforms to working conditions and funding that make an academic career in astronomy attractive; political will to include science and education at the core of the post-war recovery strategy.

From the international community: a transition from sympathy to systematic partnership — formalised agreements, long-term programmes, membership in structures, and real resources; an understanding that supporting Ukraine in science is not humanitarian aid, but a strategic investment in the stability and development of an entire region; a willingness to listen to what Ukraine actually needs, rather than imposing ready-made solutions.

From the astronomical community itself: a readiness not merely to wait for recovery, but to actively shape it — through dialogue, self-organisation, learning new communication and entrepreneurship skills, and through constantly reminding society and the state of what astronomy is and why it matters.

This document is not a request for aid and not a list of problems awaiting someone to solve them. It is a strategic plan, developed by a community that knows its strengths, soberly assesses its limitations, and sets itself specific goals.

Ukrainian astronomy survived the annexation of Crimea and the loss of observatories. It is surviving the full-scale war with all its consequences for people, infrastructure, and finances. It continues to work. This resilience is not coincidence and not romanticism — it is the result of decades of accumulated scientific competencies, pedagogical tradition, and a human dedication to a cause that extends beyond any politics.

The sky above Ukraine is the same sky as above Leiden, Paris, Kyoto, or Chile. The questions Ukrainian astronomy asks — about the structure of the Universe, the nature of small Solar System bodies, cosmic radio emission, stellar evolution, and the large-scale structure of the Universe — are questions for all of humanity. The answers to them have no borders.

Therefore, the recovery and development of Ukrainian astronomy is not only Ukraine's affair. It is a contribution to the shared scientific knowledge that is one of the few truly universal values remaining in our divided world.

> *"Astronomy is useful because it raises us above ourselves; it is useful because it is grand; it is useful because it is beautiful. That is why I ask: which of us would not feel the poorer for never having seen the stars?" — Henri Poincaré*

CURRENT STATE OF UKRAINIAN ASTRONOMY: INSTITUTIONAL STRUCTURE, WARTIME CHALLENGES AND DEVELOPMENT PROSPECTS

1. Institutional Structure and Governance

As of 2026, astronomical science in Ukraine operates at two levels of governance. At the governmental level, the Ministry of Education and Science of Ukraine (MESU) supports the activities of astronomical departments and observatories at universities. The National Academy of Sciences of Ukraine (NASU) coordinates the work of leading academic institutes and observatories.

At the non-governmental level, the key coordinating role is played by the Ukrainian Astronomical Association (UAA), founded in 1991. The UAA serves as the national committee representing Ukraine in the International Astronomical Union (IAU) and the European Astronomical Society (EAS), and also participates in shaping strategic "roadmaps" for the development of the field.

An important milestone that defined the current configuration of the field was the occupation of the Autonomous Republic of Crimea in 2014. As a result, Ukraine lost key observational facilities: the Crimean Astrophysical Observatory, the RT-70 radio telescope in Yevpatoria, and laser ranging stations at Simeiz and Katsiveli. This led to a near-complete cessation of scientific cooperation with Russian institutions and necessitated a reorientation towards European and global partners. With the onset of Russia's full-scale invasion of Ukraine, the high-altitude observatory on Mt. Terskol was also lost, along with its main instrument — a 2-metre telescope.

2. Astronomical Institutions and Their Scientific Potential

Ukraine's network of astronomical institutions includes both academic institutes and university observatories, each with its own scientific specialisation and unique observational base.

2.1. Main Astronomical Observatory of the NAS of Ukraine (MAO NASU)

Founded in 1944 in Kyiv, MAO NASU is the leading multidisciplinary institution. Its scientific directions cover astrometry and space geodynamics, research on small Solar System bodies, heliophysics, stellar and galactic physics, galactic and extragalactic astronomy, cosmology, and astronomical instrumentation. The Observatory ranks 7th and 10th among Ukrainian scientific institutions by h-index in the Web of Science and Scopus databases, respectively.

Scientific structure: The MAO comprises 8 specialised departments and several laboratories covering the full spectrum of astronomical research: Department of Astrometry and Space Geodynamics; Department of Atmospheric Optics and Instrumentation; Department of Sub-stellar and Planetary Systems with a Laboratory of Solar System Small Body Physics; Department of Solar Physics; Department of Stellar and Galactic Physics; Department of Extragalactic Astronomy and Astroinformatics with a Laboratory of Large-Scale Structure of the Universe and a Laboratory of High-Energy Astrophysics; Scientific-Educational Department; Mykolaiv Astronomical Observatory (annexed in 2025).

Main instruments: Solar horizontal telescope ATsU-5, reflector AZT-2, laser ranging station "Kyiv-Holosiiv".

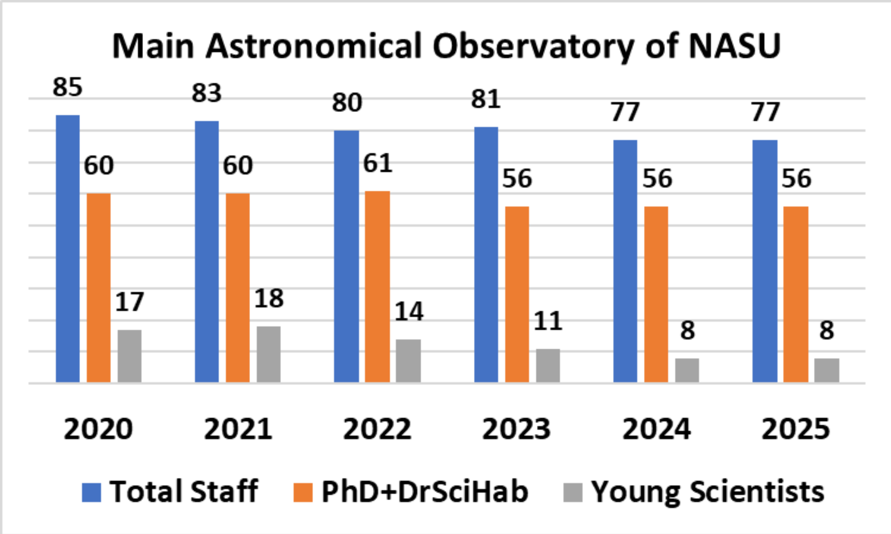

Figure 1 Dynamics of the personnel composition of MAO NASU for 2020-2025

2.2. Institute of Radio Astronomy of the NAS of Ukraine (IRA NASU)

Founded in 1985 on the basis of the Radio Astronomy Division of the Institute of Radio Physics and Electronics, IRA NASU is the leading organisation in the field of radio astronomy in Ukraine. The Institute is the custodian of unique objects of National Heritage: the world's largest decametric radio telescope UTR-2 with the URAN interferometer system, and the Complex for Electromagnetic Study of the Environment. Primary scientific directions include radio astronomy of the Universe, remote sensing of Solar System objects, and the development of radio telescopes and radio-technical systems. The Institute has four scientific schools, including those in theoretical radio physics and low-frequency radio astronomy.

Scientific structure: Department of Decametric Radio Astronomy; Department of Radio Astronomy of the Sun and Solar System; Department of Planetary Physics and Space Radio Physics; Department of Millimetre Radio Astronomy; Department of Space Radio Physics; Department of Remote Sensing and Antenna Technology; Department of Theoretical Radio Physics.

Main instruments: Decametric telescopes UTR-2 and telescope systems GURT and URAN; RT-32.

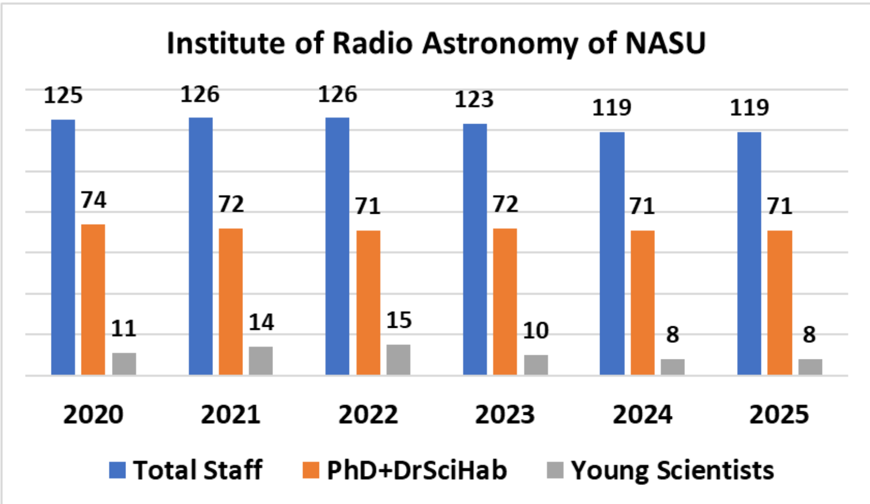

Figure 2. Dynamics of the personnel composition of IRA NASU for 2020-2025

2.3. International Centre for Astronomical and Medico-Ecological Research of the NAS of Ukraine (ICAMER)

Established in 1992 jointly by the National Academy of Sciences of Ukraine, the Russian Academy of Sciences (at the time), and the Cabinet of Ministers of Ukraine, ICAMER is a unique high-altitude scientific institution. The Centre specialises in conducting comprehensive research in astrophysics, high-energy physics, the interstellar medium, small Solar System bodies, rapidly variable objects (cosmic transients, gamma-ray bursts), machine learning for astrophysical classification tasks, and medico-biological research under high-altitude conditions and adaptation of the human body to extreme environments. The Centre's main base is located on the peak of Terskol (Elbrus region), which provides one of the best astroclimates in Europe for optical observations. The Centre has scientific schools in precision spectroscopy and space biology.

Structure: The Centre comprises scientific departments of astrophysics and medico-ecological research, and a high-altitude observational base with developed life-support infrastructure.

Main instruments: Zeiss-2000, Zeiss-600 telescopes, Small Horizontal Solar Telescope, high-resolution spectrometers, climatic and barochambers.

Note: Annexed by Russia.

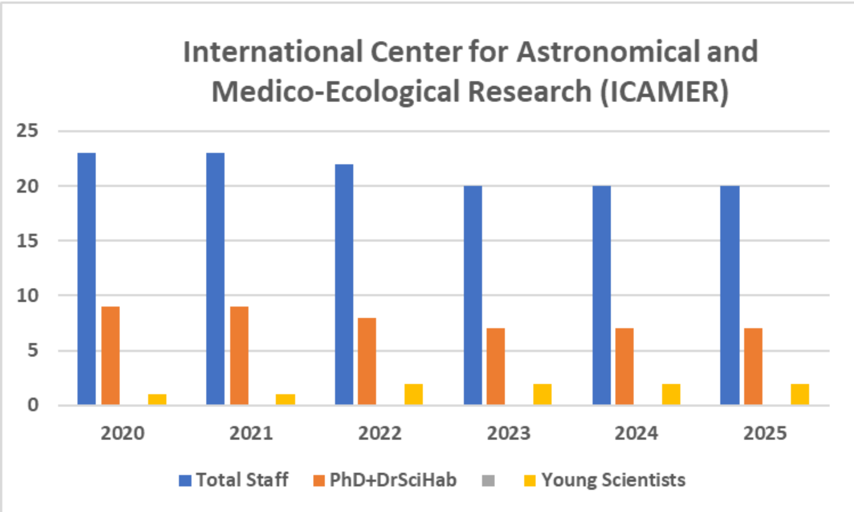

Figure 3. Dynamics of the personnel composition of ICAMER for 2020-2025

2.4. Astronomical Observatory and Department of Astronomy and Space Physics, Taras Shevchenko National University of Kyiv (TShNUK)

The Astronomical Observatory of TShNUK, founded in 1845, is one of the oldest scientific centres. Its primary research directions include relativistic gravity and cosmology, high-energy astrophysics, solar physics, astrometry and small Solar System bodies, and research on the atmosphere and ionosphere. In 2021, the Horizontal Solar Telescope (HST) of the observatory received the status of National Heritage. The University has been a full member of the Cherenkov Telescope Array Observatory (CTAO) consortium since 2015, though after 2025 its membership is at risk due to financial constraints. As of 2025 the university holds grants: HORIZON-INFRA-2023-SERV-01, Project 101131928 — ACME; "The Cohesion Problem and Activity of Distant Comets" (BL 298/32-1) — DFG; two NSFU projects and 7 state budget research topics.

The Department of Astronomy and Space Physics trains specialists in the following educational programmes: Bachelor's in "Astronomy", Master's in "Astrophysics", and doctoral (PhD) in "Physics and Astronomy". Scientific research covers a wide range of directions from atmospheric physics to extragalactic astronomy.

Main instruments: AZT-8 and AZT-14 reflectors; horizontal solar telescope; meteor complexes.
Two suburban observational stations in the villages of Lisnyki and Pylypovichy.

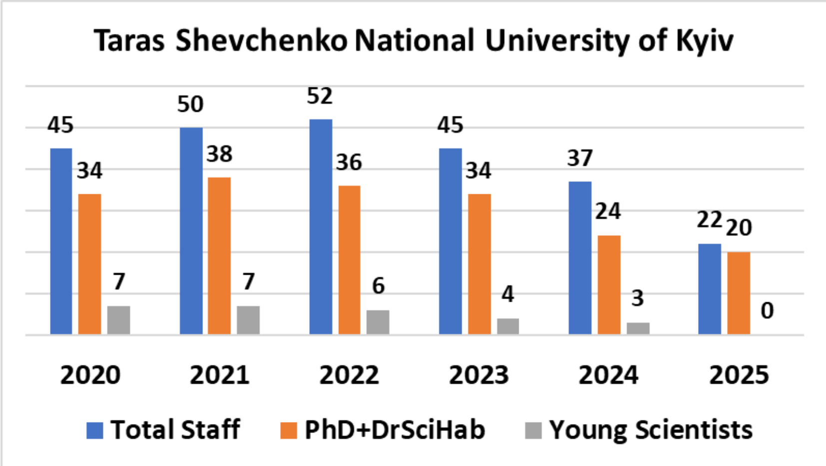

Figure 4. Dynamics of the personnel composition of TShNUK for 2020-2025

2.5. Research Institute of Astronomy and Department of Astronomy and Space Informatics, V.N. Karazin Kharkiv National University (KhNU)

The Kharkiv astronomical school, founded in 1804, has deep historical traditions. The Research Institute of Astronomy (RIA) and the Department of Astronomy and Space Informatics specialise in research on the composition and structure of the surfaces of the Moon and planets, physical and dynamic properties of asteroids and comets, astrometry and kinematics of the Galaxy from Gaia mission data, detection of mineral deposits on the Moon by new methods of observational astronomy based on machine learning, and application of artificial intelligence technologies for analysing large arrays of spectrophotometric observations. Among the key achievements of recent years: participation in the scientific team of the NASA DART mission (2022) and the first polarimetric orbital experiment DANURI (Korea), and the publication of the monograph "Optics of the Moon" (Elsevier, 2025). The "Coherent Optical Image Processor" (since 1999) is an object of National Heritage.

Main instruments: AZT-8 telescope, AFR-2 solar telescope, spectrophotometric complex.
Suburban observational station in the village of Chuhuiv.

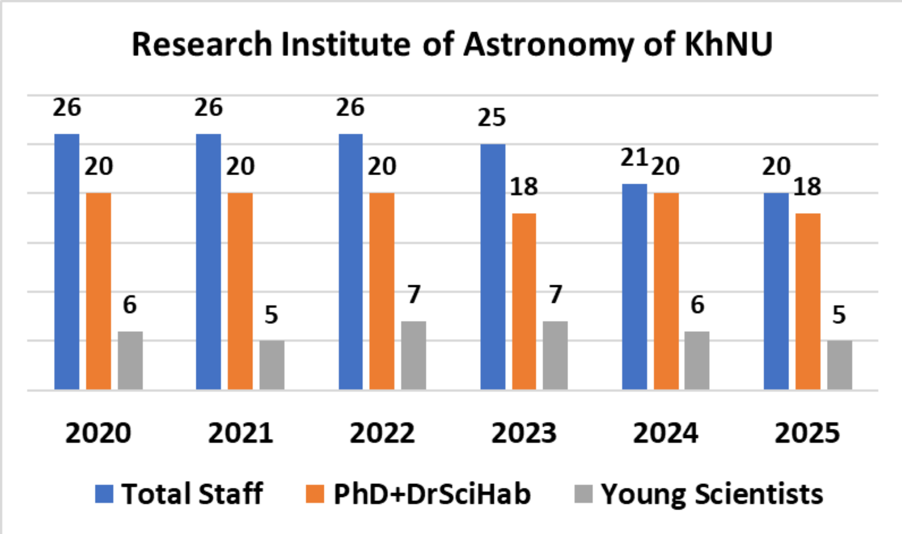

Figure 5. Dynamics of the personnel composition of KhNU for 2020-2025

2.6. Astronomical Observatory and Department of Physics and Astronomy, I.I. Mechnikov Odesa National University (ONU)

Founded in 1871, the Odesa Observatory is a candidate for the UNESCO World Heritage List; in 2023 it was inscribed in the International List of Cultural Property under Enhanced Protection. It holds a unique collection of over 110,000 astrographic negatives (the "Glassware"), which is being partially digitised within the Ukrainian Virtual Observatory framework. Scientific research focuses on stellar and galactic physics, cosmological models in multidimensional space-time, photometry and astrometry of artificial celestial bodies, and meteor astronomy.

The Department of Physics and Astronomy, founded in 1865, is one of the oldest departments at ONU. It trains students at all three educational levels.

Main instruments: OMT-800 and AZT-3 telescopes, fast alt-azimuth KT-50 for near-Earth space monitoring, Schmidt telescope, and others. Two suburban observational stations in the villages of Mayaky and Kryzhanivka.

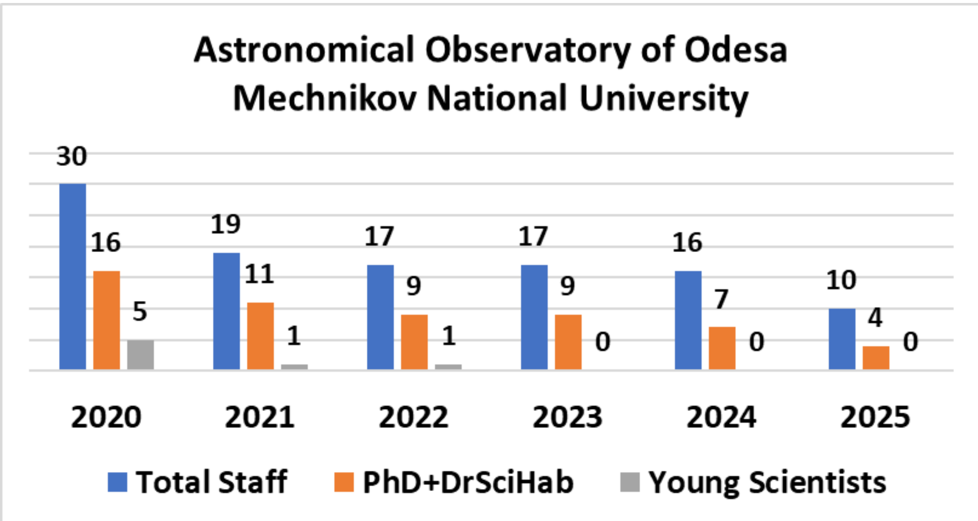

Figure 6. Dynamics of the personnel composition of ONU for 2020-2025

2.7. Astronomical Observatory and Department of Astrophysics, Ivan Franko National University of Lviv (IFNUL)

Founded in 1771, the IFNUL Observatory is one of the oldest in Ukraine. Primary research directions cover cosmology, high-energy astrophysics, solar physics, physics of variable stars, and near-Earth space research. The Observatory is a member of CTAO and the International Laser Ranging Service (ILRS). In 2025, a new Bachelor's programme "Astrophysics and Space Physics" was opened at the Faculty of Physics, with a significant Space Situational Awareness (SSA) component.

Main instruments: AZT-14 telescope, Horizontal Solar Telescope, chromospheric-photospheric AFR-2 telescope, laser rangefinder. Suburban observational station in the village of Bryukhovychi.

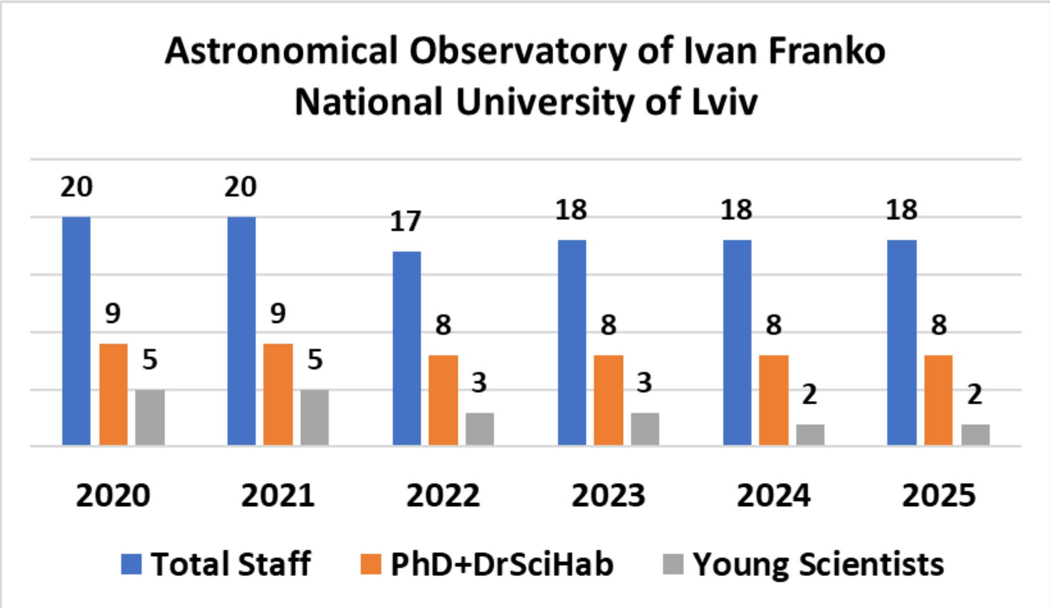

Figure 7. Dynamics of the personnel composition of IFNUL for 2020-2025

2.8. Mykolaiv Astronomical Observatory (Branch of MAO NAS of Ukraine)

The Mykolaiv Astronomical Observatory is one of the oldest observatories in Eastern Europe, founded in 1821. It is included in the Tentative List of UNESCO World Heritage Sites from Ukraine as an integral historical-cultural heritage territory. For over 200 years, the observatory has been engaged in observations and research on the motion of stars and Solar System bodies, and since the beginning of the space age in 1957, its main scientific directions have included optical and radio observations and determination of orbital parameters of artificial objects in near-Earth orbits.

Main instruments: In the optical range — 6 automated telescopes created at the observatory, one of which, the "Axial Meridian Circle", has the status of National Heritage, and a network of 6 meteor cameras deployed in the southern region of Ukraine; in the radio range — a network of 6 stations for synchronous reception of satellite television signals, a network of 7 stations for observing radio meteors in the 80–110 MHz range and at 143.05 MHz, and a Doppler satellite observation station with radio beacons (430–440 MHz).

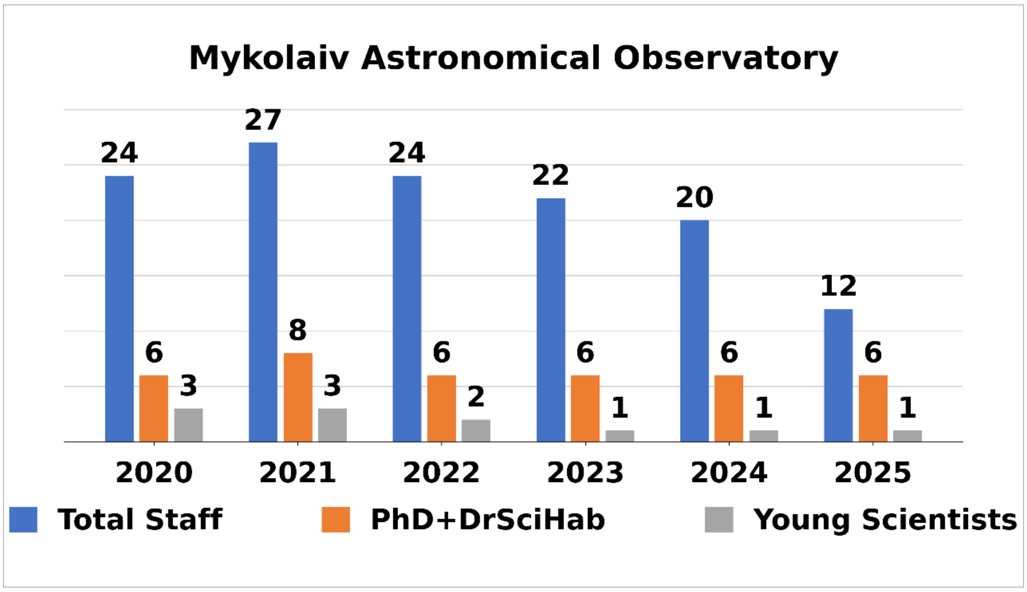

Figure 8. Dynamics of the personnel composition of Mykolaiv Astronomical Observatory for 2020-2025

2.9. Department of Higher Geodesy and Astronomy and Astronomical Observatory, Lviv Polytechnic National University (LPNU)

Established in 1871, the Department of Higher Geodesy and Astronomy at LPNU is one of the oldest scientific-educational institutions in its field in Ukraine. The department is the custodian of rich historical traditions and unique objects, including the only 19th-century Astronomical Observatory in Lviv, built in 1877, and suburban observational stations in the village of Shatsk and the town of Berezhany. Primary scientific directions span fundamental and applied research at the intersection of disciplines: from the theory of the Earth's figure and the creation of reference systems to space geodesy, satellite monitoring, and research on polar regions (including an active GNSS station at the Antarctic station "Academician Vernadsky").

Main instruments: GNSS station (since 2001), digital meteorological station, educational optical telescope, meteor activity monitoring station in the radio range. GNSS station installed in Antarctica (Vernadsky).

2.10. Department of Mathematics, Physics and Astronomy, Odesa National Maritime University (ONMU)

This department is an important centre for variable star research, continuing the scientific school of variable star researcher Volodymyr Platonovych Tsesevych (1907–1983), and for developing methods of statistically optimal analysis of time series with the non-uniform sampling characteristic of most astronomical surveys. The department maintains close scientific ties with the Astronomical Observatory of ONU and the Main Astronomical Observatory of NASU, and develops international cooperation (USA, Canada, Korea, Slovakia, Czech Republic, Poland, Germany, France, and others).

2.11. B.L. Kashcheyev Radio Astronomy Research Laboratory, Kharkiv National University of Radio Electronics (NURE)

The Laboratory, whose history dates to 1954, is a unique centre for meteor radar research. Its scientific output includes foundational monographs on meteor astronomy and catalogues of meteor orbits. In 2025, the laboratory gained membership in the Alliance of Historical Observatories.

International cooperation is maintained with the Astronomical Institute of the Czech Academy of Sciences.

Main instruments: The Meteor Automated Radar System (MARS), on which unique astronomical meteor experiments of global significance have been conducted. The MARS astronomical instrument, as part of the Balakliya Multipurpose Geophysical Complex for research on the atmosphere and meteor matter influx (village of Vilkhuvatka, Balakliya district, Kharkiv region), is included in the list of objects constituting the National Heritage of Ukraine. MARS has been partially damaged and generally requires technological modernisation.

3. Impact of the Full-Scale Invasion on the Astronomical Field

Russia's full-scale invasion in February 2022 caused unprecedented losses for Ukrainian astronomy, which can be classified across several dimensions.

3.1. Personnel Losses and Forced Displacement

According to data from the Ukrainian Astronomical Association, the total number of scientific personnel in astronomical institutions has decreased by 12–44% depending on the institution. The situation regarding young scientists is most critical: their proportion has decreased by 41% compared to the pre-war period. At TSHNUK, four staff members serve in the Armed Forces of Ukraine. At RAI NASU, despite a general staff reduction of 12.3%, 94.4% of scientists were retained, demonstrating the prioritisation of preserving intellectual capacity. As of 2025, up to 20% of researchers from Kharkiv remain abroad, and half of students are also in forced displacement.

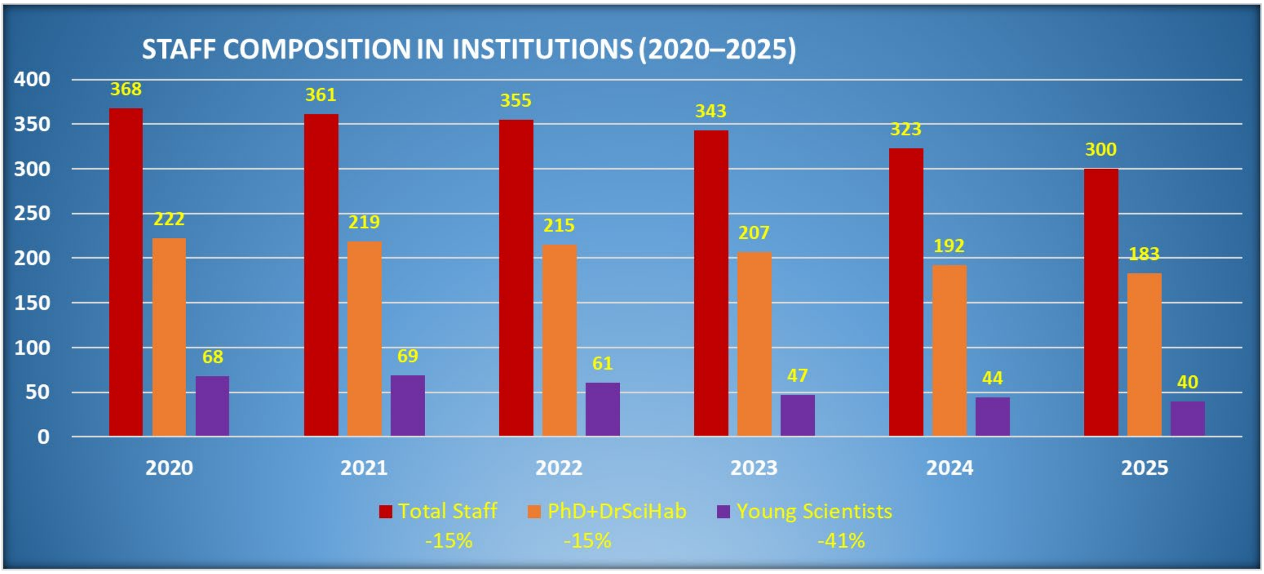

Figure 9. Dynamics of the personnel composition of Ukrainian institutions for 2020-2025

3.2. Infrastructure Destruction and Material-Technical Losses

The observational infrastructure of the Kharkiv region suffered the greatest losses. The Chuhuiv observational station of KhNU found itself in the combat zone: the CCD cameras of the AZT-8 and Baker-Schmidt telescopes were destroyed, and five television cameras of the meteor patrol were stolen. The Braude Observatory of RAI NASU (location of the UTR-2 radio telescope) was occupied for six months in 2022. Of the 17 buildings on the observatory grounds, 16 suffered significant damage; servers and computer equipment were looted. Several dozen of the 2,040 UTR-2 antennas were damaged.

In early 2026, the blast wave from an enemy drone damaged the buildings of the Astronomical Observatory in Odesa (Shevchenko Park). Glass was blown out and frames were significantly damaged on 84 windows; the roof of the Space Research Division building and several storage facilities was destroyed; dozens of doors were damaged. The main building of the observatory — an architectural monument of the 19th century — also suffered damage. The dome of the Cook telescope (1886) and the pavilion of the Repsold Meridian Circle telescope (19th century) were partially damaged. The observational station of the Odesa Observatory in the village of Mayaky, which houses the famous collection of astrographic plates, has been mothballed for an indefinite period due to its location in a high-risk zone.

The observational base of the Department of Higher Geodesy and Astronomy at LPNU also suffered significant losses due to power outages and window damage resulting from a nearby enemy missile strike.

3.3. Financial Constraints

As of 2025, all institutions report a critical reduction in baseline funding. Under martial law, the state has significantly reduced support for fundamental research. Budget funding at TSHNUK fell from UAH 9.15 million in 2020 to UAH 5.5 million in 2024; National Heritage object funding was cut from UAH 0.49 million to UAH 0.15 million. At KhNU, similar figures decreased from UAH 7.42 million to UAH 5.57 million (state budget) and from UAH 0.735 million to UAH 0.350 million (National Heritage). MAO NASU records a salary fund deficit of up to 50%. To fill the gaps, institutions attract competitive funding from the National Research Foundation of Ukraine (NRFU), MESU, and international programmes (EURIZON, ALLEA, PAUSE, DFG, grants from the Polish and American academies of sciences, Czech Academy of Sciences grants).

3.4. Energy Instability

Regular strikes on energy infrastructure have compelled institutions to resort to autonomous power supply. Kharkiv University installed a 21.6 kW solar power station (received as a donation from the Exil-VHS consortium). The Lviv Observatory uses a petrol generator; TSHNUK provided laboratories with uninterruptible power supplies. The LPNU Astronomical Observatory uses a generator installed at the main LPNU building, which provides an uninterruptible power supply to the observatory laboratory.

3.5. Educational Process

Part of classes at TSHNUK took place in bomb shelters. A general decline in student enrolment is a worrying trend: the number of applicants to astronomical specialisations at TSHNUK fell from 98 in 2020 to 46 in 2024. At the same time, Lviv University recorded growing interest in the new "Astrophysics and Space Physics" programme — the first intake consisted of 16 students, the highest figure at the Faculty of Physics.

Part of classes at LPNU took place in bomb shelters and online, and new educational programmes were opened: "Earth Sciences: Geoconsulting and Earth Monitoring" at Bachelor's level (15 students in 2024, 19 students in 2025) and Master's level, as well as a Bachelor's in Geoanalytics (interdisciplinary) (2025) in Earth Sciences/Computer Science.

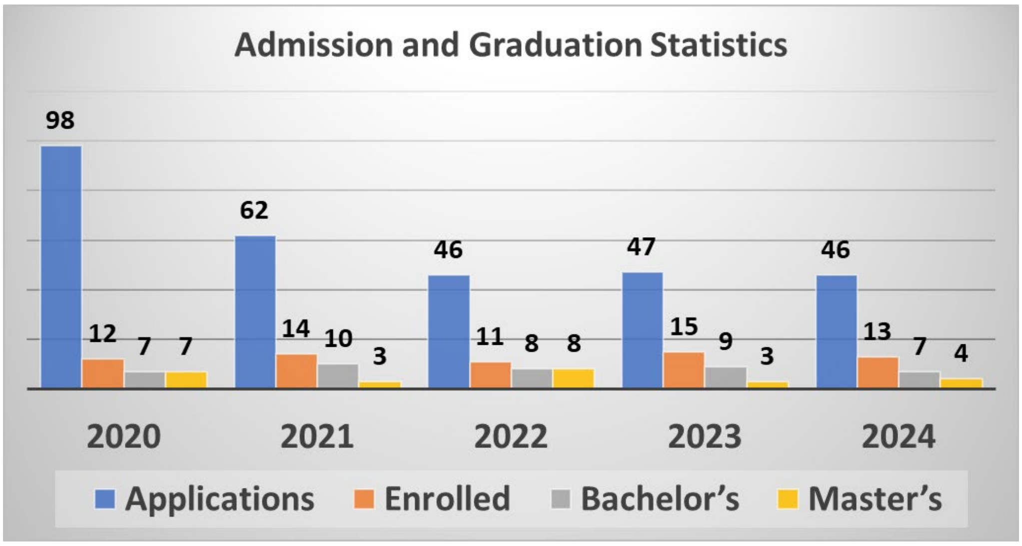

Figure 10. Dynamics of enrolment and graduation indicators in the speciality "Astronomy" at TShNUK in 2020-2024

4. Scientific Activity and International Cooperation under Wartime Conditions

Despite extremely difficult conditions, Ukrainian astronomers have not only continued their scientific work but demonstrate high international achievements.

4.1. Publication Activity

During 2020–2025, Ukrainian astronomers published over 800 scientific papers, of which more than 250 are indexed in Scopus and Web of Science. Among the most cited works are publications by Ukrainian scientists within the CTAO and LISA consortia, as well as studies on asteroid physics and the chemical evolution of the Galaxy.

4.2. International Cooperation

International support and integration remain the key mechanisms for preserving the field's potential. Leading institutions are members of international consortia:

- CTAO (TSHNUK, IFNUL)
- LISA (MAO NAS, TSHNUK)
- LOFAR and NenuFAR (RAI NASU in cooperation with the Paris Observatory)
- EUROPLANET and ChETEC-INFRA (ONU)
- EISCAT (RAI NASU)

At IFNUL, leading foreign specialists are regularly invited to give lectures under the international "visiting professor" programme. Students also actively participate in various international academic mobility programmes such as double degrees, Erasmus+, NAWA, etc.

Ukrainian scientists hold leading positions in international organisations: Iryna Belska (KhNU) is Vice-President of Division F of the IAU (Planetary Systems and Astrobiology); Yurii Shkuratov (KhNU) is a member of the IAU Working Group on Lunar Nomenclature; Ivan Slyusarev (KhNU) participates in the IAU Thematic Commission on Small Body Nomenclature; Iryna Vavilova is an adviser to the European Astronomical Society; Ivan Andronov is the National Outreach Coordinator for Ukraine in the International Astronomical Union.

4.3. Grant Support

Ukrainian astronomers actively attract international funding. Among the key grants:

- Project HORIZON-INFRA-2023-SERV-01 ACME (Astrophysical Center for Multimessenger studies in Europe) — participation of RAI NASU, TSHNUK
- Czech Academy of Sciences grants for NURE (2023–2026)
- DFG grants for TSHNUK (project BL 298/32-1 "The Cohesion Problem and Activity of Distant Comets")
- US Army Research Office grants (RIA KhNU)
- National Research Foundation of Ukraine projects for all institutions
- EURIZON (MAO NASU)

5. Strategic Priorities and Post-War Recovery Plans

In June 2025, an international meeting "Recovery Plan for Ukrainian Astronomy" was held at Leiden University (Netherlands), organised jointly with the IAU European Regional Office of Astronomy for Development (IAU-EROAD). Based on the results of the meeting, the following key priorities were outlined:

5.1. Infrastructure Recovery

- RAI NASU: primary task — restoration and modernisation of the UTR-2 radio telescope, development of the GURT radio telescope, restoration of observations at the RT-32 telescope. A UTR-2 restoration and modernisation project was prepared in early 2026.
- MAO NASU: acquisition of a 1-metre optical telescope.
- KhNU: restoration of the Chuhuiv observational station, provision of access to remotely controlled telescopes for student practice.
- ONU: implementation of the Southern Ukrainian Astronomical Observatory (UASO) project with installation of a new 1.5-metre telescope in the village of Mayaky.
- TSHNUK: continued modernisation of AZT-8 and AZT-14 telescopes; creation of an Astrobiology Centre jointly with the University of Edinburgh; restoration of the observational station in the village of Pylypovichy (within 1–3 years); creation of the "Ecosphere" collective use centre (Celestron telescope + meteor patrol); provision of internet connectivity for the station; modernisation of the horizontal solar telescope for observations under international scientific programmes.
- IFNUL: creation of an 80-cm automated Ritchey-Chrétien telescope with remote control.
- MAO (Mykolaiv): completion of the restoration of the mobile optical complex "MOBITEL".
- LPNU: Reconstruction of the Astronomical Observatory and Space Monitoring Laboratory; modernisation of current equipment (educational telescope, server computing centre, modern software); restoration of historical equipment, preservation of unique books from the astronomical library, digitisation of unique astronomical books.

5.2. Digital Infrastructure Development

Priority areas include the development of the Ukrainian Astronomical Data Centre (UADC) and integration into the European Open Science Cloud (EOSC). This will ensure the preservation of and open access to unique observational data, such as the digitised "Glassware" collection of the Odesa Observatory.

5.3. Human Capital and Education

- Development of new educational programmes in astrophysics and Space Situational Awareness (MAO, IFNUL, TSHNUK, LPNU).
- Involvement of students in international academic mobility programmes (Erasmus+).
- Creation of a fund to support Ukrainian astronomers' participation in IAU, EAS, and COSPAR congresses.
- Development of mentorship programmes between Ukrainian students and foreign scientists.
- Participation in international academic cooperation, training, co-teaching, joint scientific research, experience exchange in education, staff exchange.

5.4. Integration into European Structures

Key tasks include: active participation in multilateral Horizon Europe projects and EU-Ukraine programmes, RIFF; expansion of participation in bilateral projects, including ESO, USA, Canada; restoration of Ukraine's full membership in CTAO after 2025. Another important direction is the creation of joint international laboratories (in particular between RAI NASU and the Polish Academy of Sciences in the field of geospace research).

6. Conclusions

Ukrainian astronomy is going through one of the most difficult periods in its more than two-hundred-year history. The destruction of infrastructure, the outflow of personnel, chronic underfunding, and the daily danger faced by scientists have created unprecedented challenges. These challenges can be divided into: global challenges caused by the war, which we cannot influence but can plan for post-war development (Recovery Plan with the participation of international partners and national programmes); national challenges caused by the outflow of young personnel, reduction in baseline funding, unsuccessful reforms to secondary education; and local challenges caused by the destruction of electricity and heating networks, etc.

At the same time, the Ukrainian astronomical community has demonstrated resilience:

- Observations continue, including at partially restored facilities (UTR-2, GURT, AZT-8 in Lisnyki, KT-50 in Odesa, the ShAK telescope complex in Mykolaiv).
- Publication activity remains at a high level, and participation in international consortia ensures integration into the global scientific space. The possibility of free publications for Ukrainian scientists in international journals MNRAS, A&A, and others has been a major source of support.
- Despite declining enrolment at some universities, new educational programmes demonstrate the existence of demand for astronomical education.
- International support in the form of grants, academic mobility programmes, access to observational bases of foreign institutions, and institutional cooperation is becoming an important resource for ensuring the stability and development of astronomy in Ukraine.

Strategic Vision: Two Periods

Period I: During Martial Law

- The primary problem is the preservation of the personnel composition of Ukrainian astronomical institutions. The data show that this composition has decreased by more than 50%. A particular concern is the small proportion of young scientists.
- With the help of international programmes, sponsors, and the Ukrainian astronomical community, to focus on restoring damaged astronomical infrastructure: the observational station of the RIA of KhNU in Chuhuiv, the AO ONU and its observational station in the village of Mayaky.
- To concentrate human and financial resources on restoring individual elements of the URAN radio interferometric system and initiating the commissioning of individual elements of the GURT system.
- Involving astronomical institutions in tasks of economic development and national security, in particular near-Earth space monitoring.
- Support for education and outreach.

Period II: After the Cessation of Martial Law

- To approach the Government of Ukraine regarding the future functioning of the observational bases in Crimea (CrAO) and the high-altitude observatory on Mt. Terskol (ICAMER).
- To concentrate all international and national resources on restoring the URAN decametric telescope network.
- To become a member of LOFAR 2.0.
- Development of public-private partnership to create a powerful observational base for participation in international research programmes.

PROSPECTS FOR THE DEVELOPMENT OF UKRAINIAN ASTRONOMY

The long-term prospects for the recovery and development of domestic astronomy are structured around four interrelated directions: human capital and scientific networks; scientific and research infrastructure; innovation and economic development through astronomy; education and public engagement.

Direction 1. Human Capital and Scientific Networks

Human capital is the most valuable and simultaneously the most vulnerable resource of Ukrainian astronomy. The outflow of scientists and students, the rupture of established communication ties, and limited access to international funding — these challenges require a systemic response that goes beyond individual ad hoc arrangements and shifts the relationship between Ukraine and the global astronomical community into the realm of sustainable institutional partnerships.

1.1. Key Challenges

The full-scale invasion exacerbated problems that had been accumulating in Ukrainian astronomy since 2014. The field faces the following systemic challenges for human capital:

- Outflow of students and researchers from the academic environment in Ukraine amid uncertainty, generating the risk of an irreversible loss of an entire generation of scientists;
- Weakness of communication channels for informing the scientific community about funding opportunities and project participation — both in Ukraine and among the diaspora;
- Limited access to long-term projects and prospective funding, reducing the attractiveness of an academic career;
- Difficulties and legal restrictions regarding research trips, which effectively exclude part of researchers from in-person academic exchange.

1.2. From Ad Hoc Arrangements to Institutional Partnerships

One of the key strategic tasks necessary for the sustainable development of the field is the transition from current arrangements between individual scientists to formalised, long-term, and mutually beneficial partnerships between institutions.

First, existing informal schemes must be formalised in the form of official agreements. This concerns primarily access to scientific journals: open access agreements and coverage of article processing charges (APCs), already in place in a number of countries for institutions with special status, could significantly reduce the financial burden on Ukrainian research teams.

Second, a priority task is the formalised joining or expanded participation of Ukraine in leading international research networks and structures — ESA, ESO, SKAO, LOFAR, CTAO, and others. Each of these opens access not only to unique observational capacities, but also to a wide range of international contacts and resources.

Currently, what is important is:

- to formulate a review of priority scientific networks and justification for joining each of them;
- to outline the unique competencies and "niches" of domestic astronomy that are in demand in the context of international cooperation.

1.3. Ukrainian Researcher Network

A critically important task is the creation of an open infrastructure for connecting Ukrainian astronomers — in Ukraine and abroad — with their potential international partners. Today this communication takes place mainly through personal contacts and informal channels, making it impossible to systematically utilise the collective potential of the diaspora.

The proposed network should serve as a platform for: sharing information about funding opportunities and joint project participation; finding partners and co-supervisors; coordinating efforts in representing the Ukrainian astronomical community internationally. The specific form of the platform — a dedicated website, Slack workspace, mailing list, or a combination — should be determined based on a survey of the community itself.

> **Important:** Conduct a survey among students and scientific personnel — both in Ukraine and abroad — regarding interest in such a network and preferences for communication formats.

1.4. Online Seminars and Scientific Visibility

A series of regular online seminars presenting the results of Ukrainian astronomers is one of the most accessible and effective tools for increasing the visibility of domestic science in Europe and worldwide. This format does not require physical travel and can attract a wide audience in Ukraine and abroad. It also enables foreign colleagues to systematically familiarise themselves with the scientific competencies and achievements of Ukrainian research groups — a necessary precondition for moving from one-off invitations to long-term cooperation.

1.5. Bilateral Mentorship Programmes

Mentorship programmes occupy a special place in the system of human capital support. A bilateral model covering two complementary streams is recommended:

- *Ukrainian students and postgraduate students — foreign mentors:* international researchers from among leading specialists provide scientific guidance, help build networks, and familiarise mentees with the research culture of leading institutions.
- *Foreign students and young researchers — Ukrainian mentors:* experienced Ukrainian scientists share unique methodological competencies; participation in joint projects with Ukrainian teams creates mutual interest and trust.

In both formats, the emphasis should be on practical skills in building scientific networks — the ability to establish and maintain academic ties, without which any mobility remains a short-lived episode rather than the beginning of sustainable cooperation.

1.6. Joint Educational Programmes

The development of joint academic programmes — from individual courses to full joint degrees — is one of the most effective mechanisms for long-term consolidation of inter-institutional ties. First examples already exist: partnership programmes between Lodz University of Technology and Lviv University demonstrate the practical feasibility of this model.

Promising formats include:

- Joint Bachelor's and Master's programmes (distance or with internships);
- Research projects conducted by students in Ukraine under joint supervision of Ukrainian and foreign scientific advisors;
- Joint PhD and postdoctoral research schemes.

1.7. Participation in Leading International Forums

Active presence at the annual meetings of the European Astronomical Society (EAS) is an important communication channel with the broad international community. The organisation of a special session dedicated to Europe-Ukraine astronomical cooperation would provide an opportunity to present the current state and needs of domestic astronomy and to facilitate the establishment of new partnerships.

1.8. Schools, Exchanges, and Financial Support for Mobility

The number of young scientists in Ukraine decreases every year, creating serious challenges for the development of astronomy and space engineering. At the same time, there is a gap between astronomy students and scientific institutions: many students are insufficiently aware of modern astronomical research conducted in Ukrainian observatories, NASU institutes, and universities. Under these conditions, summer and winter schools are a classic and proven instrument for introducing young researchers to new scientific directions and expanding their scientific networks. Positive examples — Astroschool 2024–2026, organised at MAO NASU — demonstrate that even under martial law such events are achievable. Lecturers from scientific institutions and universities of Ukraine, as well as foreign specialists, are involved. Due to constant blackouts, the school is held in a fully in-person format to ensure continuous communication.

First results are already visible: after the first school, partners supported a student start-up for the creation of a polarimeter (APISAT); participants of the school subsequently made more deliberate choices of internship venues and future scientific work. Also in 2026, an increase in the number of postgraduate students at MAO NASU was observed.

Financial support for academic mobility — covering costs of conference participation and research visits — is critically important, since the very absence of such opportunities is what forces researchers to sever ties with the world community. Among potential sources, the possibility of directing part of Russia's frozen assets towards supporting Ukraine's scientific capacity as a directly affected country is being discussed. In parallel, it is necessary to systematise and make more accessible information on existing funding mechanisms: Erasmus+, Marie Skłodowska-Curie Actions, EAS, IAU, COSPAR, EURIZON, ALLEA grants.

1.9. Long-Term Actions (2026–2030)

- Secure institutional access for Ukraine to selected international networks (ESO, SKAO, LOFAR, CTAO, etc.) — in accordance with community priorities and available funding.
- Broader involvement and state support for a postdoctoral system at institutions in Ukraine.
- Search for and consolidation of funding sources for membership fees and participation.
- Prepare recommendations for the Ministry of Education and Science of Ukraine on reforms necessary for preserving human capital in astronomy: working conditions, salary levels and

career paths in academia; mechanisms for supporting the return of scientists after the end of the war; incentives for attracting young people to academic careers in astronomy.

- Implement sustainable bilateral mentorship formats, joint educational programmes, and postdoctoral support.

Priority scientific directions: near-Earth astronomy including security-relevant research; astrometry, space geodynamics and Earth rotation; satellite geodesy and geoinformation technologies; solar physics and solar-terrestrial relations; physics of planets, small Solar System bodies and exoplanets; Earth atmospheric physics; stellar physics and interstellar medium; galactic astronomy with emphasis on numerical modelling and 3D kinematics; large-scale structure of the Universe; high-energy astrophysics; astronomical instrumentation; modern astroinformation technologies; history of astronomy, modern methodology of teaching astronomy, preservation of scientific heritage and popularisation of astronomical knowledge.

Direction 2. Scientific and Research Infrastructure

The recovery and modernisation of astronomical infrastructure is a prerequisite for Ukraine to maintain and strengthen its role in world astronomy. The scale of the damage inflicted is significant: destroyed or mothballed observational stations, destroyed or stolen equipment, the interruption of long-term observational programmes. At the same time, Ukraine has strong grounds for optimism: a powerful tradition in radio astronomy and optical observations, internationally recognised expertise in polarimetry, modelling, software, space plasma physics and high-energy astrophysics, and significant unrealised potential in a number of promising directions.

The fundamental methodological principle of this direction is the sequence of priorities: before making decisions on the reconstruction of particular facilities, the community must clearly define the scientific questions that this infrastructure should answer. Simply restoring what existed before the war — without reconsidering functions and capabilities — is neither expedient nor strategically justified. Reconstruction is an opportunity not only to restore, but to improve qualitatively.

2.1. Defining Scientific Priorities as the Basis for Reconstruction

Any decision on the restoration or development of infrastructure must derive from a clear understanding of the key scientific questions this infrastructure is intended to address. Therefore, the first and necessary step is to conduct a broad internal dialogue within the Ukrainian astronomical community in order to define such priorities — across radio astronomy, optical astronomy, and theoretical research.

The result of this dialogue should be a document outlining the key scientific questions for which Ukraine can make a significant contribution to pan-European research programmes. This document will serve as a guide for international partners seeking to provide targeted financial or technical support.

Strategic leadership and regular updating of these priorities can naturally be assumed by the Ukrainian Astronomical Association (UAA) in coordination with NASU institutions and MESU. A structured approach to strategy is especially important in decision-making on participation in large international missions and infrastructure projects.

> **Important:** Conduct regular meetings of representatives of different generations of astronomers in order to identify key scientific questions in each field of astronomy. Expand membership of Ukrainian scientists in international scientific consortia, in particular: for optical astronomy, membership in LSST (Vera Rubin Observatory); for radio astronomy, entry into LOFAR 2.0, the European VLBI Network (EVN); participation in European Space Agency projects (LISA, EINSTEIN); development of interdisciplinary centres — astrobiology, astrochemistry, exoplanets — and participation in corresponding networks.

2.2. Radio Astronomy: Reconstruction and Integration into European Networks

Ukraine has unique radio astronomical assets: the world's largest decametric radio telescope UTR-2, the URAN interferometer system, the new GURT telescope, and the RT-32 radio telescope (Zolochiv, Lviv region). Together they form a potential that no other country possesses in the corresponding frequency range.

Full reconstruction of large facilities such as UTR-2 is a long-term task costing likely millions of euros. However, within the coming years a phased restoration of individual subsystems — electronic units, buildings, signal reception and recording equipment — is possible, which does not bind the future reconstruction to a specific scientific profile and preserves flexibility for long-term reconceptualisation of facilities' functions.

In parallel, on a horizon of one to five years, a more important short-term prospect is being realised: the connection of existing Ukrainian antenna systems to European low-frequency radio networks — in particular LOFAR (Netherlands) and the VLBI network. This requires relatively modest investments in interfacing equipment from the European partners' side, but gives Ukraine immediate access to global research programmes and restores scientific activity even before the completion of large-scale reconstruction.

> **Important:** The Ukrainian radio astronomy community should hold a meeting to discuss specific pathways for integrating Ukraine's various radio astronomical facilities and institutional capacities into European networks of low-frequency and interferometric radio astronomy. This meeting should define scientific questions, financial and technical requirements, and possible funding sources. Involvement of European researchers is critically important.

2.3. Optical Astronomy: Expanding Capabilities and New Directions

Ukraine has significant experience and a distinct international reputation in optical astronomy, particularly in the following fields: polarimetry and light scattering modelling (RIA KhNU, MAO NAS), research on small Solar System bodies, photometry and astrometry of satellites and space debris (TSHNUK, AO ONU, MAO), and solar physics and solar activity. These competencies are competitive advantages in demand in the context of current and future space missions.

One of the most promising directions is the coordination of ground-based telescopic observations with planetary missions and the conduct of monitoring observations of celestial objects. In the coming years, the number of small missions studying space debris, small bodies, and near-Earth asteroids will increase substantially; optical ground-based analysis of the objects under study is becoming an integral part of such missions. Ukraine is capable of developing its optical capacities precisely in this direction, aligning them with ESA and EU research priorities.

A separate, concrete, and realisable in the short term initiative is the development of a meteor observation network. Despite its vast geographical area, Ukraine is practically absent from systematic and continuous meteor monitoring — which is a significant gap both for Europe and for global efforts in this area. A first grant for starting this work has already been received. Development of the meteor observation network does not require large telescopic infrastructure, and with relatively modest investments from Europe, Ukraine could assume a leading role in instrument development and expand global coverage.

> **Important:** The Ukrainian optical astronomy community should hold a meeting to specifically discuss how existing optical facilities and institutional competencies can be integrated into European networks, in particular to support space missions. The group should also consider the construction of a ~1.5 m telescope specifically intended for support of planetary missions and related observational programmes. Europe should support the development of the Ukrainian meteor monitoring network.

2.4. Broad Spectrum of Astrophysical Expertise

Alongside radio astronomy and optics, Ukraine has documented competencies in a number of other fields that open opportunities for participation in broader international programmes. These include:

development of scientific instruments for space missions (MAO NASU); scientific software for gamma-ray astronomy (CTAO, with the participation of TSHNUK, IMME NASU, MAO NASU); numerical simulations using supercomputers; extragalactic astronomy; small Solar System bodies; near-Earth space and atmospheric physics. Each of these fields deserves separate consideration as a possible direction for short- and medium-term projects involving foreign partners.

2.5. Creation of the Ukrainian Astronomical Data Centre

Among all proposals for infrastructure reconstruction, the most rapidly realisable and simultaneously the most systemically important is the creation of the Ukrainian Astronomical Data Centre (UADC). This idea deserves priority attention for several reasons.

First, the centre can be created in a very short time: it is sufficient to identify the host institution, form the core team and basic computational infrastructure — and the centre as an organisational unit begins to function. Physical scale and technical capacities will grow gradually as funding is attracted.

Second, Ukraine already has components from which such a centre can grow: the Laboratory of High Energy Physics and Astrophysics of TSHNUK, the Collective Use Centre for Scientific Equipment, the Ukrainian Virtual Observatory (UkrVO, MAO NAS), and widely recognised competencies in software development and IT.

Third, by its purpose, UADC goes far beyond being "just a data repository". It can perform the following functions:

- A hub for theoretical astronomy and modelling, integrated into the cloud computing resources of European clusters;
- A link between radio astronomical, optical, and gamma-astronomical data and corresponding theoretical programmes;
- A repository and resource for the systematic digitisation, curation, and research use of unique archives — in particular the 110,000+ astrographic negatives of the Odesa Observatory and the collections of MAO NAS and TSHNUK;
- A platform for engaging young Ukrainian astronomers in a wide range of research projects — from radio astronomy to optics and gamma-ray astronomy — within a unified scientific environment.

Finally, UADC can become a point of integration into the European Open Science Cloud (EOSC) and the MMODA platform, already being discussed in the context of UkrVO, providing Ukraine with a full presence in the pan-European scientific data infrastructure.

> **Important:** Ukraine should urgently begin the process of establishing the Ukrainian Astronomical Data Centre. It is necessary to identify a host institution; form a working group to define priorities and funding sources; attract support from European scientific data centres. The centre as a formal unit can be announced within the coming months, enabling immediate commencement of funding applications.

2.6. Long-Term Facilities and Large-Scale Infrastructure

In parallel with addressing immediate tasks, an ambitious long-term perspective must be outlined now. Identifying large infrastructure aspirations not only provides a strategic guide, but also gives structure to short- and medium-term decisions (for example, UADC can develop with a view to supporting future large facilities).

Among the potential long-term goals:

- *Next-generation low-frequency radio astronomy station* — reconstruction and modernisation of UTR-2 or construction of a new facility with expanded capabilities exceeding the pre-war level.
- *~1.5 m class optical telescope* for support of ESA planetary missions — in particular JUICE and future small body missions.
- *Next-generation laser rangefinder* — long-range communication using laser downlink, an increasing requirement for precision geodesy and satellite missions.
- *Extensive meteor monitoring network* — Ukraine forming a significant segment of the global meteor observation network, using its own developed instrumentation.
- *Mobile telescopes* — conducting seasonal observations of stars, asteroids, near-Earth orbit objects in favourable astroclimatic conditions, and urgent observational programmes.
- *Network for photometric monitoring of artificial Earth satellites* (optical and radio ranges) — forming one's own network of high-speed photometric observations of artificial Earth satellites and space debris can open the direction of instantaneous determination of their rotational parameters.

Important: The Ukrainian astronomical community should hold a dedicated brainstorming session on large-scale infrastructure ambitions on a horizon of 10–30 or more years. These ideas may be revised as scientific priorities evolve, but formulating them today will help define the development trajectory and provide reference points for current projects — including UADC.

2.7. ESA Membership and Other Key International Organisations

Full membership of Ukraine in the European Space Agency (ESA) is a systemic change that would open fundamentally new possibilities. ESA membership will allow Ukrainian scientists to: become Principal Investigators of missions; participate in the development of scientific instruments for spacecraft; propose and initiate new astronomical and planetary missions; obtain direct access to data from all active ESA missions. The flexible structure of financial obligations — in particular through participation in optional programmes — means that Ukraine is not obliged to make significant contributions from day one, but can already gain substantial benefits.

At the same time, participation in a number of other structures should be more actively developed. Ukraine's existing participation in CTAO requires clarification and strengthening. Associate membership or observer status from Ukraine in ESO and SKA should be considered. The existing, rather fragmented access to software, databases, and networks — which could become one of the functions of UADC — requires systematisation.

Important: Ukraine should strive for full membership in ESA. A working group should be formed to prepare the rationale for ESA membership, identify projects in which Ukraine can participate immediately, and formulate an appeal to Ukrainian state bodies. A separate working group should be formed to systematically analyse all astronomical networks and consortia (SKA, CTAO, La Palma, LOFAR, etc.), determine Ukraine's current status in each, the desired level of participation, and specific steps to strengthen this participation.

2.8. Interdisciplinary Astronomy

Astronomy in Ukraine has developed ties with related sciences that open additional opportunities for international cooperation. One of the most promising examples is astrobiology: the TSHNUK Centre for Astrobiology in partnership with the University of Edinburgh, and the participation of Ukrainian scientists in the European Astrobiology Network Association (EANA). Similar synergies exist in astrochemistry, chemical evolution of galaxies, exoplanet research, and planetary sciences.

The development of these interdisciplinary directions not only expands the thematic scope of domestic science, but also opens additional funding and partnership channels through organisations and programmes beyond purely astronomical structures.

2.9. Preservation and Use of Astronomical Cultural Heritage

Ukraine is the custodian of exceptional astronomical cultural heritage: ancient architectural ensembles of observatories (some of which are under state protection and included in the UNESCO Tentative List), unique collections of 19th–20th century scientific instruments, rare library and archival holdings, including over 110,000 astrographic plates in the Odesa Observatory, the AO TSHNUK collection, and the MAO library.

However, treating cultural heritage purely as a "past preservation task" is a mistake. Restored and preserved facilities can perform entirely practical functions for modern science:

- Libraries and archives of analogue observational data are irreplaceable for long-term studies of the variability of stars, comets, small bodies, and solar activity;
- UADC can assume responsibility for the digitisation, curation, and scientific use of these collections;
- Observatory buildings and structures can serve as offices and laboratories for scientific personnel;
- Demonstrably restored facilities can become centres of education and outreach — directly supporting state and public recognition of astronomy and attracting new generations to science.

Important: A working group should be created to study, inventory, and prioritise objects of astronomical cultural and historical heritage of Ukraine. The group should consider: mechanisms for preservation and restoration using European funding; possibilities for using archives and libraries in modern research; the potential of individual facilities as outreach and science popularisation centres across the country.

Direction 3. Innovation and Economic Development through Astronomy

3.1. Astronomy as a Driver of Innovation

Astronomy is not only a fundamental science about the structure of the Universe. Throughout its modern history, it has generated technological innovations reaching far beyond scientific laboratories. Wireless internet (Wi-Fi) grew from radio astronomical research; digital cameras owe their birth to CCD matrices developed for telescopes; image processing algorithms that underpin modern medical diagnostics were refined through astronomical data processing. These examples are not exceptions, but a pattern.

For Ukraine, which will eventually enter a recovery phase, this opens a strategic opportunity: to transform the existing scientific potential in astronomy into a catalyst for technological and economic development. Ukraine already has documented competencies in key technological fields — instrument development, software, data processing, remote sensing, plasma physics. The task is to build systematic bridges between astronomy and the market, which are currently almost non-existent.

3.2. Technology Sectors: Where Astronomy Meets the Market

3.2.1. Optical Astronomy: Detectors, Photonics, Security

The development and manufacture of detectors and sensors is a natural extension of the experience accumulated in optical observatories. The Kharkiv RIA has its own Laboratory of Astronomical Optics and extensive experience manufacturing optical components; TSHNUK and MAO NAS have expertise in developing polarimetric apparatus. This experience is directly relevant for markets such as medical imaging, industrial quality control, and security systems.

Optical computing and laser systems are acquiring strategic significance in the context of quantum computing and communications development. MAO NAS competencies in satellite laser ranging (SLR) are a specific example of technological potential awaiting commercial application. In parallel, systems for optical observation of artificial satellites and space debris (Space Situational Awareness — SSA), developed at TSHNUK, AO ONU, IFNUL, MAO NASU, MAO, are directly commercially and defence-relevant given the growing intensity of near-Earth space use.

3.2.2. Radio Astronomy: Apparatus, GNSS, and Security

RAI NAS and Kharkiv University hold unique competencies in developing low-frequency radio apparatus, antenna systems, and radio signal processing systems. By-products of these developments find application in telecommunications, navigation, and interference detection systems. The MARS meteor radar system at NURE is a vivid example of technology of astronomical origin serving the practical task of near-Earth space monitoring.

MAO NAS competencies in GNSS measurements (Global Navigation Satellite System) are directly market-relevant: precision navigation, geodesy, monitoring of Earth crust deformations and critical infrastructure — all these are sectors with real demand, in which university astrometry and geodynamics have a competitive advantage.

3.2.3. Space Technologies and Remote Sensing

Ukraine has significant but insufficiently realised potential in the field of small satellites and satellite technologies — taking into account both the traditions of the rocket and space industry and astronomical competencies in spectroscopy and photometry. The planned Aerosol-UA satellite (MAO NAS) is a specific example of active or in-progress missions.

Earth Remote Sensing (ERS) is one of the fastest-growing markets in Europe, especially in the context of the ESA Copernicus Programme. Ukraine, with its vast agricultural land areas and need for monitoring the consequences of war (soil degradation, contamination, infrastructure destruction), is simultaneously a potential provider and an extremely relevant consumer of ERS services. Competencies in atmospheric physics (TSHNUK, MAO NAS), including in relation to climate change, complement this direction.

3.2.4. Data Science, Artificial Intelligence, and Quantum Computing

Astronomy is a natural testing ground for big data processing methods and machine learning: the Gaia catalogue with 1.8 billion stellar positions, LOFAR data, CTAO streams — all these are arrays requiring advanced analytical approaches. Ukrainian astronomers already have experience working with such data, in particular at MAO NAS (Gaia data analysis, extragalactic astroinformatics) and TSHNUK (UkrVO, VIRGO.UA).

Software development is a recognised competitive advantage of Ukraine: the IT sector is one of the leading export sectors of the economy. The synergy between astronomical computing and the commercial IT industry is direct and untapped. The direction of quantum computing applied to problems of physical system modelling, observation scheduling optimisation, and cryptography is also promising.

3.3. Technology Transfer and Innovation Ecosystem

The key structural problem is that systematic intermediaries between scientific institutions and the market are virtually absent in Ukraine. While in leading EU universities, technology transfer offices (TTOs) are a standard element of infrastructure, at most Ukrainian universities and institutions such offices either nominally exist or are entirely absent.

The first practical step is the strengthening, and where necessary creation, of TTOs at key institutions (TSHNUK, KhNU, ONU, IFNUL) for astronomical and related technologies. In parallel, a systematic inventory of current astronomical projects for hidden commercial potential is necessary: every method, algorithm, or instrument developed for a scientific task is potentially a spin-off candidate.

The next step is the formation of AstroHubs — physical or hybrid incubator spaces where researchers, student-entrepreneurs, and business mentors can jointly develop ideas from laboratory prototype to market product. Successful examples to emulate are ESA BIC (Business Incubation Centre) and Space Hub Graz in Austria. Linking AstroHub to UADC (Direction 2) creates a natural synergistic effect.

3.4. Human Resources Development: Entrepreneurs from Science

Building entrepreneurial skills in scientists is a systemic task that requires embedding corresponding components in educational programmes. Bachelor's, Master's, and PhD students should have access to courses on the fundamentals of entrepreneurship, intellectual property protection, writing technology proposals, and the commercialisation of research results.

Particularly promising are dual PhD programmes where research is conducted in partnership with an industrial enterprise: the student receives an academic degree and practical experience working in industry, while the company gains access to advanced competencies and the opportunity to build a long-term connection with the university. Models to follow include CIFRE programmes (France), Industrial Doctorates (UK), and analogous schemes under Marie Skłodowska-Curie Industrial Fellowships.

3.5. Other Economic Development Strategies

3.5.1. Astrotourism

Astrotourism is one of the fastest-growing segments of the global tourism market. Dark skies, unique nature, mid-latitudes with a relatively clean atmosphere, and a network of observatories with rich history — all these are competitive advantages that Ukraine has not yet exploited. The Odesa Astronomical Observatory (UNESCO monument), MAO in Kyiv, the TSHNUK Astronomical Museum, and the Chuhuiv station of KhNU are potential nodes of such a network. Astrotourism does not require large-scale investments at the start: combining the efforts of observatories, local communities, and tour operators with minimal branding can yield first results in the short term.

3.5.2. Services for Other Industries

A number of astronomical competencies can be directly monetised as services: processing and analysis of large data arrays (for the agricultural sector, ecology, etc.); positional astrometry and chronometry (for telecommunications and navigation); software and algorithm development for image processing (for medicine, industrial automation); consultancy in atmospheric optics (for aviation and communication systems). These services can be provided both directly by university departments and through spin-offs.

3.5.3. Public-Private Partnership and STEM Investment

Systematic involvement of private business in funding astronomical R&D is a necessary complement to state and grant funding. This involves developing legal and financial mechanisms in science — tax incentives for companies investing in university research; corporate scholarships and internships; joint laboratories in the "university + business" format. International experience demonstrates that such partnerships are mutually beneficial: companies gain access to advanced competencies and qualified personnel, while universities gain resources and real research challenges.

3.6. Best Practice Examples and Benchmarks

When developing an innovation and technology transfer strategy, it is advisable to draw on proven models, adapting them to Ukrainian realities:

- **ESA BIC (Business Incubation Centre)** – a network of over 20 incubators in ESA member states that has already supported more than 1,000 startup companies. A similar structure, contingent on Ukraine's future ESA membership, could serve as a direct vector for the commercialisation of astronomical technologies.
- **Space Hub Graz (Austria)** – a university-industry hub model with a clear focus on space technologies and their transfer into adjacent markets.
- **United Kingdom (UKRI, Catapult Network)** – a network of technology centres (Catapults) linked to universities and oriented toward specific market sectors, including the Satellite Applications Catapult.

- **Poland (NCBR – National Centre for Research and Development)** – a successful model of state-funded R&D with a strong technology transfer component, from which Ukraine can directly borrow instruments and mechanisms.
- **ESA Participatory Science Platform** – citizen science and broad public engagement with astronomical data as an intermediary link between science and society.

3.7. SWOT Analysis: Astronomy and Innovation in Ukraine

Strategic planning for the development of astronomical innovations requires a qualitative assessment of existing strengths, limitations, and the external environment.

STRENGTHS (S)	WEAKNESSES (W)
• Strong tradition in radio and optical astronomy, polarimetry, small body physics Internationally recognised competency in software, IT, and computing • Network of universities and academic institutes with qualified personnel • Unique observational infrastructure (UTR-2, URAN, GURT) • Experience participating in international missions (NASA DART, DANURI, CTAO) Competitively low cost of observations and R&D	• Chronic underfunding of fundamental science • Personnel attrition and shortage of young researchers • Weak link between scientific institutions and business • Limited number of technology transfer offices at universities • Destroyed or mothballed part of observational infrastructure • Absence of systematic branding and communication of achievements
OPPORTUNITIES (O)	**THREATS (T)**
• Growing EU demand for remote sensing data, meteor monitoring, and SSA • Horizon Europe, EIC Accelerator, Erasmus+ as funding sources • ESA membership — access to missions and instrument development • Integration into EOSC, CTAO, SKAO, LOFAR • Post-war reconstruction — demand for STEM personnel, start-ups, defence-adjacent technologies • Growing astrotourism market in Ukraine and the diaspora	• Prolonged martial law and uncertainty regarding timelines for recovery • Competition from well-funded EU and US centres • Risk of irreversible brain drain of best personnel • Bureaucratic and legal barriers to research trips and international contracts • Instability of power supply and communications infrastructure

3.8. Expected Economic Impact and Contribution to Ukraine's Reconstruction

The implementation of this direction is capable of generating real economic effects at several levels. In the short term — preservation and attraction of STEM personnel in academic and technological sectors, formation of first start-ups and R&D contracts, development of services for ERS and SSA markets. In the medium term — diversification of funding sources for scientific institutions, growth in the R&D share of GDP, entry into EU markets with technologies of astronomical origin. In the long term — formation of a full-fledged innovation ecosystem where astronomy is one of the sectoral "anchors" pulling adjacent IT, instrumentation, and aerospace sectors.

Notably, the majority of the described steps do not require significant initial investments: competency inventory, formation of working groups, introduction of entrepreneurship courses, TTOs, negotiations with ESA and EIC — all this is realisable within existing budgets and with relatively modest external support. The transformation will begin when the scientific community recognises that research results have not only publication value, but also commercial value — and that the tools for this already exist.

Direction 4. Education and Public Engagement

4.1. Strategic Context

Astronomical education and science communication are not only instruments for science popularisation, but a fundamental driver of economic recovery, technological sovereignty, and national security of Ukraine. Astronomy serves as a natural "portal" to the physical sciences, engineering, mathematics, data science, biology, ecology, and space technologies. Modern astronomical research integrates artificial intelligence, high-performance computing, advanced materials, sensor technologies, and telecommunications. Therefore, investments in astronomical education directly translate into the training of personnel for high-technology industries, the defence sector, and the innovation economy.

4.2. Current State and Systemic Challenges

The full-scale war has inflicted critical damage on educational infrastructure: damaged observatories, planetariums, school laboratories, and museums. Despite this, a core of educators, club organisers, and science communicators has been preserved, demonstrating high adaptability, readiness for experimentation, and effective use of limited resources. At the same time, the system faces:

- Professional isolation and a deficit of international exchange;
- Absence of specialists in science communication, fundraising, and English-language project management;
- Unequal access to quality STEM resources between cities and rural/decentralised regions;
- A gap between the formal school curriculum and practice-oriented research;
- Loss of morale and a sense of disconnection from global scientific processes.

4.3. Priority Areas for Recovery and Development

4.3.1. Investment in Early Childhood Science Education

Research by Nobel laureate James Heckman demonstrates that investments in pre-school education yield the highest socio-economic returns. Priorities include: creation of Ukrainian-language popular science content (books, animation, interactive kits, TV programmes for ages 3–10); adaptation of international programmes such as UNAWE and Pale Blue Dot; introduction of elementary astronomical experiments in kindergartens and primary schools. This forms primary interest in understanding the world and lays the foundation for future STEM learning.

4.3.2. "Learning through Research" in School Education

The US National Academy of Sciences and leading educational institutes emphasise the effectiveness of an approach where students conduct their own observations, process real data, and participate in international citizen science initiatives (such as Globe at Night). It is necessary to integrate practice-oriented modules into school curricula in physics, geography, and informatics; provide schools with portable telescopes, spectrometers, and software for astronomical data analysis; and create a network of school weather stations and photometric observations.

4.3.3. Olympiad Movement and Youth Research Activities

All-Ukrainian Olympiads in astronomy and space physics (initiated in 2011 through the active work of astronomy enthusiasts who brought the issue to the level of MESU), and the activities of the Junior Academy of Sciences of Ukraine (JAS), are critically important channels for identifying, supporting, and retaining gifted young people in Ukraine. JAS traditionally provides a continuous trajectory from a school club to a university laboratory and a real scientific project. Prospects include:

- Financial and methodological strengthening of Olympiad programmes through the organisation of summer scientific schools, training camps, provision of access to modern problems and simulators;
- Integration with real research through involving Olympiad participants and JAS students in processing data from Ukrainian observatories, participation in international observation networks, and writing scientific publications under mentor guidance;
- Digital transformation through creation of a unified platform for registration, online training, access to observational archives, and preparation for international competitions (IOAA, IAAC, EUCYS, EuPhO);
- Support for astronomical, interdisciplinary, and STEM conferences and workshops at regional, inter-regional, and all-Ukrainian formats, where students and teachers/mentors could share research experience and educational projects (non-competitive!);
- Restoration and strengthening of the regional network through priority reinforcement of all extracurricular centres teaching and promoting astronomy (including JAS branches), especially in affected and decentralised regions, providing them with equipment, methodological support, project grants, and connections with leading scientific centres.

4.3.4. Planetariums, Astronomical Museums, and Extracurricular Education

Museums, planetariums, and community observatories serve as bridges between academic science and society, forming a culture of scientific literacy. Their restoration should include:

- Modernisation of exhibitions — updating content to reflect modern discoveries (exoplanets, dark matter, gravitational waves, next-generation space telescopes);
- Mobile infrastructure solutions — acquisition of portable planetariums and telescopic kits for regional centres and schools, with simultaneous training of local educators in their operation;
- Creation of a network of "astronomical hubs" — transforming museums and planetariums into active educational centres combining lectures, workshops, night observations, project activities, and volunteer initiatives;
- Outreach formats — systematic support for events such as "Astronomy Night", "Open Days", "Café Scientifique", science festivals, and astronomers' participation in media.

4.3.5. Professional Development of Teachers and International Integration

Without teacher training, sustainable recovery of the system is impossible. It is necessary to:

- Introduce large-scale professional development courses with emphasis on modern pedagogical methods, digital tools, working with real data, inclusive education, and psychological support for students during wartime/post-war periods;

- Integrate Ukrainian educators into proven international programmes: Galileo Teacher Training Programme, NASE (Network for Astronomy School Education), Shaw Symposium, Teaching Enquiry with Mysteries;
- Provide support for English-language communication, grant writing, and project management, as these skills are critical for breaking out of information isolation;
- Create a mentorship network between Ukrainian and European educators for experience exchange, joint webinars, and development of open educational resources (OER).

4.3.6. Engagement of the Diaspora, Business, and Formation of a Support Ecosystem

Ukrainian scientists and engineers abroad are a strategic resource for restoring educational potential. Their involvement encompasses:

- Virtual integration: lectures, mentorship programmes, joint online laboratories, assistance in finding educational resources and grant opportunities;
- Partnership with technology corporations, STEM businesses, and defence enterprises using astronomical technologies (sensors, AI, HPC, materials science, telecommunications);
- Creation of a coordination centre for communication and fundraising, bringing together schools, universities, state institutions, public organisations, and international astronomical structures (IAU, ESA, ESO, NOIRLab), ensuring transparency and effective resource allocation.

4.4. Implementation Mechanism: Positive Feedback Loop

Effective recovery is based on the cycle: networking → joint projects → grant attraction → expanding partnerships → boosting educator community morale → new initiatives. Overcoming professional isolation and integration into European educational networks not only provides resources, but also forms a sustainable ecosystem capable of self-development. The experience of Leiden University and NSF's NOIRLab demonstrates that a systemic combination of open data, teacher training, citizen science, and transparent public communication is the key to large-scale impact. Key is the transition from the "survival" of individual enthusiasts to institutionally supported, financially transparent, and internationally integrated educational infrastructure.

4.5. Conclusion

Astronomical education and public engagement is an investment in human capital, technological independence, and national resilience of Ukraine. As Carl Sagan — whose roots are connected to Ukraine — noted, a civilisation that depends on science but does not understand it is doomed to risk. By rebuilding educational infrastructure according to best global practices, preserving the Olympiad movement, developing the network of JAS, planetariums, and astronomical museums, Ukraine not only reclaims its scientific potential but also forms a new generation of scientists capable of integrating into the global technological ecosystem and ensuring the long-term development of the state.

CONCLUDING SECTION

This document is addressed not only to Ukrainian institutions and authorities. It is addressed to partners — universities, observatories, agencies, and scientific organisations that seek to understand how they can effectively support Ukrainian astronomy.

The most valuable support is not the kind that decides for Ukraine, but the kind that reinforces decisions Ukraine makes itself. This means: partnerships, not philanthropy; long-term agreements, not one-off gestures; inclusion in consortia and missions, not separate survival grants; a willingness to listen to what is needed, rather than imposing what is available.

Five Simple Starting Actions

Concretely, this might look like five simple actions to start:

- Funding of access for Ukrainian institutions to scientific journals and databases through open access agreements.
- Inclusion of Ukrainian groups in consortia of large missions and telescopic networks — CTAO, LOFAR, EVN, LSST, future ESA optical networks.
- Support for joint PhD and postdoctoral programmes, where young Ukrainian scientists have a real opportunity to return to Ukraine with new competencies.
- Joint organisation of training schools and educational programmes based on proven formats — GTTP, NASE, summer schools.
- Lobbying at ESA and Horizon Europe in favour of including Ukraine in relevant programmes.

Ukrainian astronomy is not asking for concessions. It is offering a partnership — based on real competencies and shared scientific questions. This is an arrangement where both sides receive something of value.

Recovery is not a one-time event. It is a process that requires attention, adjustment, and long-term commitment. Documents such as this one have meaning only when people ready to act stand behind them — and structures ready to sustain those actions over time.

Ukrainian astronomy has both resources: people who did not stop even during the most difficult months, and structures — the UAA, universities, academic institutes — that have preserved their institutional memory and organisational capacity. This is significant. It is already a sufficient foundation to begin.

The task of this document is not to describe an ideal final state, but to identify first steps, to make them obvious, and to provide arguments for those who will take these steps. If even one of the five simple actions is realised sooner because this document exists — it has already fulfilled its purpose.

The sky does not wait. And neither does Ukrainian astronomy.

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