“Dioscuri Center of Excellence in Astrophysics”

1. Research institution data (name and address): Faculty of Physics, Astronomy, and Informatics, Nicolaus Copernicus University (NCU), Grudziądzka 5/7, 87-100 Toruń

2. Type of research institution:
   1) <u>basic organizational unit of higher education institution</u>

3. Head of the institution: prof. dr hab. Andrzej Tretyn, Rector

4. Contact information of designated person(s) for applicants and NCN: first and last name, position, e-mail address, phone number, correspondence address):

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5. Research discipline in which strong international position of the institution ensures establishing a Dioscuri Centre (select one out of 25 listed disciplines):

   Natural Sciences and Technology

   <u>Astronomy and space research</u>

6. Description of important research achievements from the selected discipline from the last 5 years including a list of the most important publications, patents, other (up to one page in A4 format)

The key aim of creating the Dioscuri Center of Excellence in Astrophysics in Toruń is to qualitatively improve the scientific potential by bringing new strong interdisciplinary expertise in research fields encompassing **exoplanets, astrochemistry** (incl. **quantum chemistry**), and **high-precision spectroscopy**, all of them being the hallmarks of the Torun research environment.

1) **Exoplanets**: Following the Alex Wolszczan discovery of the first planets outside our Solar System in 1992, the exoplanets continue to be one of the most important research fields in Toruń. The group led by Andrzej Niedzielski discovered 22 new planetary systems using high-precision spectrographs at Hobby Eberly Telescope in Texas (HRS) and the Telescopio Nazionale Galileo telescope in La Palma (HARPS-N). The Pennsylvania-Toruń Planet Search is one of the largest planet search projects based on the radial velocity technique, and the largest one focused on planetary systems around evolved stars. Complementary world-class numerical studies of planetary system dynamics, stability, and evolution are developed and successfully implemented by the group of K. Goździewski and C. Migaszewski.

2) **Astrochemistry**: The formation of stars and planets is investigated using astrochemistry (M. Szymczak. A. Bartkiewicz, A. Karska) and hydrodynamical simulations (M. Hanasz). The observations have been made using the in-house 32-m radiotelescope working in the Very Long Baseline Interferometry network, and the suite of ESO, ESA, and NASA instruments (i.e. APEX, Herschel, SOFIA). Among the most important results is the discovery and explanation of peculiar maser emission in a high-mass star forming region, where variable emission from water masers is detected interchangeably with the emission in methanol. The radiotelescope in Toruń benefits from the advancements in constructing optical atomic clocks as the frequency (or time) reference. In particular, one of the most accurate time standards in Poland is currently a system of two such clocks assembled from ultracold Sr atoms in the optical lattice. These devices, developed at the Faculty, open up new possibilities in the field of ultra-high resolution spectroscopy and allow – among others - the determination of experimental constraints on dark matter detection (P. Wcislo).

In close connection with the astrochemical observations, theoretical methods suitable for describing interactions and dynamics of small and medium-size molecular systems have been developed. Of particular importance to this project is the knowledge of interactions between H_2 molecule and open-shell molecules, which – when combined with collision dynamic calculations - is essential for astrochemistry. The collaboration between P. Zuchowski and the experimental group of E. Narevicius (Weizmann Institute) has yielded the most accurate prediction of scattering cross-sections for the collisions of helium atom and hydrogen molecule, as well as the first ever observation of low-energy shape resonances in such collisions.

3) **High-precision spectroscopy**: A. Niedzielski and P. Maslowski are involved in the construction of High Resolution Spectrograph (HIRES) for the Extremely Large Telescope (ELT). This includes the development of high-accuracy calibration system for the spectrograph, that will enable both the most precise measurements of the Doppler shifts and the research on exoplanets' atmospheres. Additionally, the broadband, high-resolution comb-based spectroscopy and comb-references cavity-ringdown spectroscopy allow for high quality measurements of astrophysically relevant molecular species in the laboratory conditions.

These are the most important achievements in the context of the Dioscuri proposal as they form an excellent platform for carrying out internationally competitive research program by the newly established group.

Publications:

- "Tracking Advanced Planetary Systems (TAPAS) with HARPS-N." Niedzielski, A., Astron. Astrophys., 10.1051/0004-6361/201424399, 10.1051/0004-6361/201527869, 10.1051/0004-6361/201628417
- "A resonant chain of four transiting, sub-Neptune planets", incl. Migaszewski, C., 2016, *Nature* 533, 509
- "Experimental constraint on dark matter detection with optical atomic clocks" Wcisło, P., 2016, *Nature Astronomy* 1, 9, 10.1038/s41550-016-0009
- "Directly probing anisotropy in atom-molecule collisions in quantum scattering resonances" incl. Żuchowski, P. 2017, *Nature Physics* 13, 35, 10.1038/NPHYS3904
- "EELT-HIRES the high-resolution spectrograph for the E-ELT", incl. P. Masłowski, A. Niedzielski, 2016, Proc. SPIE 9908, 990823 10.1117/12.2231653

7. List of no more than 3 important research projects from the selected discipline awarded in national and international calls to the institution in the last 5 years (title, name of PI, source of funding, amount of funding):

1) "An optical-infrared high resolution spectrograph for the E-ELT (E-ELT HIRES)", coordinator of the Polish contribution: A. Niedzielski, European Southern Observatory, 150 000€ granted for phase A

A consortium composed of about 30 institutes and organizations from 12 countries performs a phase A study for ELT-HIRES – high resolution, broadband spectrometer to be operated on the European Extremely Large Telescope in Chile. In the study, the top science cases that HIRES should address are carefully identified. These will then drive a baseline design which will allow not only to address the top science cases and match the cost cap but also provide easy operation and maintenance. The proposed instrument is conceived to be very versatile, capable of pursuing a multitude of science cases , but with the focus on outstanding science cases which can only be achieved through high spectral resolution with the photon collecting area provided by the ELT, which includes Exoplanets (characterization of planetary atmospheres and the detection of life signatures, exoplanets debris), Star and planet formation (Protoplanetary disks), Stellar physics, chemistry and astro-archaeology (3D structure of stellar atmospheres, solar twins, stellar magnetic fields, isotope ratios and nucleosynthesis for the earliest and the latest stages of stellar evolution, chemical enrichment in the local group, extremely low metallicity stars, resolved stellar populations in extragalactic star clusters), Galaxy formation (Population III stars, reionization, intergalactic medium, massive galaxies evolution, supermassive black holes), and Fundamental Physics and Cosmology.

2) "Optical clocks with 1e-18 uncertainty", M. Zawada, Horizon 2020 / EMPIR, 2 M€ total, 200 000€ NCU share, 2016-2019 (3 years)

The main aim of this project is to develop world-leading optical atomic clocks across Europe, which will support a future redefinition of the SI second and underpin international timescales. The target is to be able to determine the rate at which the clocks run to within a systematic uncertainty of 1 part in 10^{18} after just a few hours of statistical averaging. In the fundamental physics community 1×10^{-18} optical clocks will allow laboratory tests of variation of fundamental constants, searches for dark matter and tests of Lorentz Invariance – all at unprecedented levels. Proposed space-based missions looking to test Einstein's theory of General Relativity are also dependent on high performance clocks in the ground stations. The Radio Astronomy community is currently upgrading to more precise timing signals for each antenna site in Very Long Baseline Interferometry as this enables increased resolution in the observations. For the geodesy community, the use of 1×10^{-18} clocks will allow changes in gravity potential to be resolved that are equivalent to 1 cm changes in height, enabling the clocks to be used in applications including alignment of national height systems, oil and gas surveying, and monitoring environmental changes such as melting of the polar ice caps and volcanic processes that take place before an eruption.

3) "Planets of other suns", A. Niedzielski, Polish National Science Center, 494 400 PLN, 2016-2019 (3 years)

The Pennsylvania-Toruń Planet Search is one of the largest planet search projects based on the radial velocity technique, and the largest one focused on planetary systems around evolved stars. The main aim of the project is the discovery and analysis of new planetary systems as well as their evolutionary changes due to the star-planet interactions. Systematic observations of radial velocities are performed for a large group of stars with Hobby Eberly Telescope in Texas (HRS) and the Telescopio Nazionale Galileo telescope in La Palma (HARPS-N). Periodic changes in radial velocities of the star can be interpreted as signatures of planets. So far, more than 20 planetary systems have been discovered and, as part of this project, the follow-up observations with 2-4 m class telescopes are obtained.

8. Description of the available laboratory and office space for Dioscuri Centre (up to one page in A4 format):

The research infrastructure includes the Astronomical Observatory in Piwnice near Toruń, with the largest Polish radiotelescope (32 m) as well as numerous physical and photonics laboratories in the Faculty of Physics, Astronomy, and Informatics in Toruń. Those laboratories are not only well suited for measurements of the atomic and molecular species relevant for astrophysics, but also are fully capable of developing high-end astronomical instrumentation.

The Faculty of Physics, Astronomy and Informatics runs experimental laboratories in the fields of physics, chemistry and biophysics, which includes the laboratories of Center of Quantum Optics and National Laboratory of Atomic, Molecular and Optical Physics. Altogether, **more than 130 scientists and 66 PhD students are working in 18 laboratories (in 83 offices with over 2360 sqm of total laboratory space)**, most of them equipped with air-conditioning and temperature control.

The Astronomical Observatory facility is highly flexible with spacious offices. For the exclusive use of the new Dioscuri Center, the Principal Investigator will be offered 8 **furnished offices with total space of approx. 200 sqm as well as laboratory space (45 sqm) and 3 offices in the Institute of Physics**, if required by the research program.

The short-term collaborators and visitors can use any of 5 hotel rooms available in the Observatory as well as 2 visitors' offices in the Institute of Physics. The experimental laboratories in the Faculty are fully supported by mechanical workshop, and the team of ten electronic engineers and a chemist. Also, two equipped chemical rooms are available. The software and computer network support is provided by both local network engineer as well as the University Informatics Center.

Additionally, the Observatory operates a computer cluster HYDRA, which is available for data reduction, time consuming numerical simulations (currently more than 128 CPU cores) and for data storage (180 TB of disk space). The computer resources are available for the staff, students and visitors of the Centre.

The Center of Quantum Optics in our Faculty possesses computer cluster with about 20 computing nodes (more then 800 CPU cores), equipped with up to 256 GB of RAM memory as well as a few TB of disc space each - totally more than 100 TB of disk space. Additionally, there are also 4 graphical workstations, stereo-glasses.

For more sophisticated tasks, free access to the computational cluster with 10 000 CPU cores is available in the Center for Modern Interdisciplinary Technologies in Toruń. Moreover, 5 supercomputing centers in Poland offer computing power on grants basis.

9. List of the available scientific equipment for Dioscuri Centre:

The Faculty of Physics, Astronomy and Informatics carries out high-end multidisciplinary research in various fields related to astronomy and physics. As the candidate is expected to introduce broad, multidisciplinary research program, the world class equipment of the Institute of Physics will be available on the collaborative basis, which includes the following:

a) **Astronomical Observatory**:

1. **32 m radiotelescope**

   The telescope is equipped with L-band (21-18 cm), C-band (6 cm), M-band (5 cm), K-band (1.3 cm), and Ka-band OCRA-p (1 cm) receivers and autocorrelation spectrograph and VLBI/e-VLBI terminal. The instrument is used to determine precise distances to astronomical objects, study jets from radiogalaxies, and map methanol and water maser emission from high-mass protostars.

2. **0.9 m Cassegrain-Schmidt telescope**

   The telescope is equipped with a low resolution spectrograph, high resolution Echelle spectrograph, and a CCD camera. Previous research focused on spectroscopy of symbiotic binary systems and other variable stars, as well as photometry of open clusters and planet transits.

3. **0.6 m Cassegrain telescope**

The telescope is equipped with a CCD camera and is used for photometric observations of variable stars and planet transits.

b) **Institute of Physics**:

Optical atomic clocks laboratory (in the National Laboratory of Atomic, Molecular and Optical Physics):

1. **Optical Lattice Sr clocks**

   The system consists of:

   - Two systems of optical lattice clocks based on Sr atoms,
   - Ultra stable lasers allowing Hz-resolution optical spectroscopy,
   - Optical frequency comb providing bridge between optical and radio frequencies
   - Access point for frequency stabilized fiber network connecting frequency standards of Space Research Center PAN in Borowiec near Poznań, Central Office of Measures in Warsaw, National Laboratory FAMO in Toruń, and Center for Astronomy UMK in Piwnice.

   This system can deliver to other laboratories very high accuracy time/frequency reference reaching the relative precision of 10^{-16}. They were used as frequency reference for radiotelescope in Piwnice for VLBI measurements (Krehlik et al. 2017, A&A 603, A48). The Sr clocks were already successfully used for dark matter research (Wcislo et al. 2016, Nature Astronomy 1, 9). The optical frequency comb used in this laboratory can deliver low-phase noise optical frequency reference in the whole range from 0.5 to 2 µm, so it can be used for ultra-precise spectroscopy experiments in any other laboratory in the Institute.

Molecular spectroscopy laboratory (in the National Laboratory of Atomic, Molecular and Optical Physics):

2. **Two ultra-precise systems for cavity enhanced spectroscopy of gaseous samples at low absorption level (down to 10^{-12} cm^{-1}).**

   Operating wavelength range 1.46-1.63 µm and 690 nm, thermal control of the sample within 10 m°C in the range from 15 to 70 °C. They are linked to optical frequency combs referenced to the primary frequency standards that provide sub-kHz accuracy of the frequency axis.

   They use three independent cavity enhanced techniques to measure absorption and dispersion: cavity ring-down, cavity mode-width and purely frequency based one-dimensional cavity-mode dispersion spectroscopies. This enables measurement high-accuracy spectra of weakly absorbing gaseous samples, providing reference spectroscopic data for atmospheric research and exoplanets research, detection of trace gases, spectroscopic measurement of temperature and pressure, study of molecular collision dynamics, experimental verification of molecular potential energy surfaces and quantum electrodynamics.

Laboratory for ultra-fast and ultra-precise spectroscopy

3. **Broadband optical spectrometers and calibration units with-record setting optical resolution based on frequency combs**

   The system consists of two optical frequency combs, with the reference to radio frequency standard or optical atomic clock in KL FAMO, covering the range in 0.7-2 µm window and 3-5 µm window It also includes filtering cavities, electronics and spectrum-shaping components for development and testing the astrocombs and various strategies for calibration of astronomical spectrographs (in a way similar to HARPS telescope and proposed for HIRES) The spectral detection uses Fourier transform spectrometer and Virtual Imaged Phase Array spectrometer for broadband, optical frequency comb-based measurements of the molecular species (both simple and large, in wide range)with frequency resolution up to 1 kHz (3e-8 wavenumber). It also allows time-domain pump-probe measurements.

Ultra cold atoms Laboratory (in the National Laboratory of Atomic, Molecular and Optical Physics):

4. **The laser and trapping system for Hg and Rb atoms**

   It includes the state of art laser system for generation of ultra-violet radiation near 254 nm with two stage frequency doubling technique, as well as the magneto-optical trap for simultaneous trapping and cooling of Hg and Rb atoms. Upgraded from the Rb Bose-Einstein Condensate (BEC) experimental setup it can be used for study of ultra-cold collisions and chemistry of Hg and Rb atoms (Witkowski et al. 2017, Opt.Express 25, 3165). It can provide ultra-precise spectroscopic information about atomic interaction at nm scale for testing possible non-Newtonian gravitation and other models going beyond Standard Model. System can be used for study of photoionization of Rb atoms. It is also designed to investigate photoassociation and control interactions by optical Feshbach resonances in Hg-Hg and Hg-Rb systems.

Single Photon Applications Laboratory (in the National Laboratory of Atomic, Molecular and Optical Physics):

5. **Single-Photon detection setup**

   The laboratory is equipped with a selection of single photon detectors including silicon and InGaAs/InP single photon avalanche diodes, the superconducting nanowire detectors and prototypical detector arrays. Those combined with a precise electronics allow for time resolved measurements with a timing jitter as low as 20 ps in a spectral range from 300 nm to 2400 nm. The system can be used for testing and implementation of a long distance fiber based quantum communication protocols for future use in the satellite communication, time resolved measurements of decays in color centers in diamonds, or characterization of entangled photon pair sources.

Molecular Ion Laboratory (in the National Laboratory of Atomic, Molecular and Optical Physics):

6. **Molecular Ion spectroscopy in Paul trap**

   The laboratory operates linear Paul trap with complete optical setup for Ca ions trapping and sources of electron and molecular beams. This setup can be used for research of the ionization process of atoms and molecules due to the collisions with electrons (measurements of the cross-sections) or as a result of interaction with electromagnetic radiation. Furthermore, it allows research on the ion – neutral atom/molecule interactions (charge-transfer collisions, chemical reactions of single atoms/molecules) or on the ion's interactions with electrons (elastic collisions, further ionization or dissociation of atomic or molecular ions). The system can be extended for the research on quantum computing on trapped Ca ions.

Laboratory of Optical Manipulation and Detection of Nanostructures

7. **Experimental setups for Spectroscopy of Nanostructures Group**
   Several home-made fluorescence microscopes (confocal, wide-field, dark-field) with variety of excitation and detection options, high spatial resolution of 300 nm, steady-state and time-resolved capabilities. These experimental setups can be flexibly adjusted to match almost any need in regard to studying fluorescence properties of nanostructures, including hybrid nanostructures. The samples can be studied in solution, as layers, in real-time, etc.

8. **Chemistry lab suitable for synthesis of nanostructures and preparation of samples**

Atomic Force Microscopy Laboratory

9. **Atomic force microscope AFM – model Agilent 5500 and inverted fluorescence microscope model Nikon Eclipse Ti-E**

The two microscopes can be used either separately or as an integrated system, since their optical and mechanical construction allows for simultaneous optical and AFM image acquisition of a given sample. The AFM instrument is equipped with two scanners: 90(x)90(y)x8(z) micrometers and 9(x)9(y)x2(z) micrometers. Measurements can be performed in gaseous and liquid environments, under the temperature controlled conditions. The instrumentation available in the Atomic Force Microscopy Lab may be used to investigate the topography of surfaces in contact and non-contact modes, allowing to perform various types of mapping e.g. mapping of magnetic and electrostatic forces, electric conductivity and surface potential. It can be applied to studies of broad class of materials including, among others, solid state surfaces and various nanostructures as well as fragile biological systems, such as single biomolecules, single living cells, tissue fragments or even small organs (e.g. an eyeball). Various types of measurements are possible, for instance: force- distance curves for single molecules, imaging and investigation of mechanical properties of living cells and their interaction with surfaces (adhesion).

Laboratory for Computational Modeling

10. DELL Linux computational cluster

Contains 11 servers (ca. 500 CPU cores) coupled by fast Infiniband network, >10 Tb HD memory, DAT tape robotic backup. It includes also 4 graphical workstations, stereo-glasses. State-of-the art software for molecular modelling (NAMD, GROMOS, AMBER, MOIL, VMD, Pymol) and quantum chemical modeling (Quantum Expresso, Gaussian, Gauss-view). Can be used to perform large scale quantum chemical calculations of geometry, electronic structure and electronic/vibrational spectra of mid-size molecules. Our scientists have vast experience in modeling protein and DNA dynamics and structure. and are prepared for basic bioinformatics analysis and homology protein structure modelling. The main research is on molecular foundations of optogenetics and application of quantum chemistry in biomedical problems.

Optical Coherence Tomography (OCT) Laboratory

11. Spectral Optical Coherence Tomography (SOCT) system for ophthalmic applications with eye tracking

SOCT imaging system with eye tracking based on scanning laser ophthalmoscope images. The system is combined with transcranial Doppler USG for simultaneous monitoring of retinal and brain blood flow. The main application of the device is to provide high resolution images of retinal vasculature in vivo in human eyes combined with high quality cross-sectional images of human retina. It can be used for search of new biomarkers for early detection of civilization diseases such as diabetes or hypertension.

12. Spectral Optical Coherence Microscope (SOCM) system for biomedical and material studies

High resolution SOCT imaging system for basic research in development of new imaging modalities based on SOCT. It can be used for studies on spectroscopic contrast in biomedical applications or for development of speckle free SOCT imaging.

13. Spectral Optical Coherence Microscope for rodent brain imaging with ischemic stroke induction

A system for observing structures and dynamic processes in the brains of living rodents. The system is designed for basic ischemic stroke research and allows simultaneous development of stroke by photochemical clotting of cerebral vessels and imaging of the effect of blood flow restriction on the structure of brain tissue. Spatial resolution of the order of microns allows to count individual neurons.

14. Spectral Optical Coherence Microscope for single cell examinations

SOCT system combined with inverted microscope that allows you to visualize intracellular structures in three dimensions without the use of fluorescent dyes. The technique uses the concept of optical microscopy OCM and allows to observe the dynamics of intracellular processes with micrometer spatial resolution and time resolution in seconds. It can be used to find biomarkers for assessment of developmental potential of cells.

15. Optic system for psychophysical double-vision studies

Dual-photon vision is based on the perception of near-infrared (900-1100 nm) infrared laser radiation based on the double-photon absorption in human photoreceptors. Infrared beams are perceived as having approximately half the wavelength of the applied beam. The system measures the sensitivity thresholds of the human eye for a short-pulse (250 fs) laser beam with a central wavelength of 1040 nm and its second harmonic: 520 nm. A pair of optically-coupled optically-coupled galvanometric scanners allows for the generation of a stimulus of any shape. The position of the subject's eye during the measurement is controlled by infrared recording of the pupil image in the focal plane of the last lens of the excitation path. The system is also equipped with a white broad-spectrum LED that allows a strong stimulation of the large area of the retina in the short-term (bleaching) and measurement of adaptation curves to darkness based on both stimuli: visible and infrared. In the near future, it will be possible to record a retinal image during a scan with a built-in laser scanning ophthalmoscope working with a tunable beam (700-980 nm).

16. Swept source OCT (SS-OCT) system for biomedical and industrial applications

The system uses frequency swept laser engine operating at the central wavelength of 1310 nm and the sweep rate of 50 000 A-scans/second allowing for deep penetration into the object and the axial resolution of the cross-sectional images of 8 um. The acquisition National Instruments system with the bandwidth of 250 MSPS and FPGA card enables real-time preview of the internal structure of the semi-transparent objects. The system can be used for high-speed in vivo imaging of the anterior segment of the eye as well as in material science for determination of topography and micro-structures.

17. Air-puff SS-OCT system for determination of viscoelastic properties of the tissues

The SS-OCT can be equipped with frequency swept light source operated at 1310 nm or 1050 nm with the imaging speed 50 kA-scans/s and 30 kA-scans/s, respectively. The OCT interface has been integrated with the air-puff chamber from commercial tonometer (XPert NCT; Reichert Inc., USA) for mechanic stimulation of the eye by generation of the short air pulse. The available depth range of the air-puff SS-OCT instrument is 9 mm or 28 mm in the air, which enables visualization of the dynamics of the anterior segment or the entire eye during mechanic stimulation. The set-up can be used to determine visco-elastic properties of the tissues in vivo as well as ex-vivo. Different excitation mechanisms can be incorporated into existing system to extract response of the object to particular spatio-temporal stimulus.

18. Optical coherence microscope with photothermal stimulation

The setup is a modified fiber-optic interferometer with Fourier-domain detection configuration (Spectral OCT). The probe beam in the system is emitted by a Ti-Sa laser ($\Delta\lambda_{probe}$ ~ 140 nm, λ_{probe} = 800 nm), which provided high axial resolution (2 μm).The probe beam is focused on the object by a 20x Olympus microscope objective to achieve sufficient transverse resolution. The photothermal effect is obtained by illumination with a laser diode (λ_{pump} = 520 nm; the excitation power range 5 to 50 mW). Specific acquisition called dual optical lock-in scheme is applied. The set-up can be used in experiments with nanoparticles to provide ultrahigh-sensitive detection of nanoparticles via photothermal effect with high axial and transverse resolution.

19. Confocal microscope with vector optical beam and acousto-optic tunable lens

The illumination of that confocal microscope is a vectorial optical field that provides high resolution (small point spread function). Different types of the vector beams can be generated with spatial light modulator (digital micromirror device) and the vortex retarder. The application of high-speed acousto-optic tunable lens enables extension of the depth of focus and acquisition of sharp images of the biological objects. The system can be used in the microscopic imaging of the biological specimens.

Photothermal Methods and Luminescence Laboratory

20. Photopyroelectric (PPE) detection system

Universal, fully reconfigurable setup based on pyro effect with lock-in phase sensitive detection, pyroelectric detection is a technique, where a sample/detector system is excited with intensity modulated light. It allows to measure the thermal properties (thermal diffusivity, effusivity and conductivity) of both solids as well as fluids as a function of temperature. Depending on excitation the spectroscopy measurements are also possible. The advantage of this method is that it can be useful for samples where traditional transmission spectroscopy cannot be applied.

21. Modulated photothermal infrared radiometry (PTR) detection system:

The modulated photothermal infrared radiometry (PTR) is a noncontact method which is based on the measurement of the amplitude modulated infrared (IR) emission (2 μm – 12 μm) from the samples due to modulated heating by a diode laser. It allows to measure the thermal, infrared and recombination properties of the bulk and thin films samples as a function of temperature

Chair of Automation and Measuring Systems

22. The high-end software and hardware solutions for measurements and system control

The knowledge and experience on design and implementation of the systems based on microcontrollers and programmable logic devices. Original solutions for generation and measurements of time with increased precision and accuracy, for applications in industry, scientific measurements, electronic analyzers etc. The systems for digital control of multi-axis devices (3d-printers, plotters, precise laser cutting).

Materials Engineering Laboratory

23. X-Ray Diffractometer Siemens D5000

Diffractometer based on CuKλ (λ = 0,1542 nm) radiation, can beused for determination structural properties of various materials.

24. FT-IR Nicolet 8700 Spectrometer.

The IR absorption measurements can be performed using FT-IR Nicolet 8700 spectrometer in the range of 500-4000 cm^{-1}.

Optical Characterization Laboratory

25. Radio-, thermoluminescence and VUV spectrometer

The set-up includes UV and VUV lamps, rtg generator, the closed cycle helium refrigerator, monochromators, photomultiplier and high voltage power supply. The set-up is designed to measure thermoluminescence, photoluminescence and excitation spectra of broad bandgap materials activated with rare-earth ions for optoelectronic applications such as scintillators, phosphors and lasers.

26. Excited states spectroscopy set-up

The set-up includes argon laser and semiconductor lasers, 0,5 m spectrometer with a range of detectors, and the closed cycle helium refrigerator. Can be used to characterize luminescence (200 nm to 2,5 mm) of materials activated with transition metal and rare earth ions under excitation ranging from 300 to 1000 nm, including samples of these materials and optoelectronic components. The temperature range is from 4,5 to 350 K.

Laboratory for Luminescence Engineering

27. Set-up for excited states kinetics

The set-up includes nitrogen laser, dye laser, frequency dubler, closed cycle helium refrigerator and monochromator with detektor. It can be used to measure luminescence time profiles of materials activated with transition metal and rare earth ions with time resolution of 250 ps, with the excitation ranging from 210 nm to 1000 nm, for temperatures between 4,5 to 350 K.

28. Set-up for radio-, thermo-, and optically stimulated luminescence

The set-up is based on the rtg generator. It also includes the closed cycle helium refrigerator, monochromator equipped with a photomultiplier and high voltage power supply, and semiconductor lasers for two beam experiments..The system allows to to measure thermoluminescence and optically stimulated luminescence of broad bandgap materials activated with rare-earth ions for optoelectronic applications such as scintillators, phosphors and lasers.

Quantum Photonics Laboratory

29. Systemt of high power CW lasers with special optical frequency and beam intensity modulation

Main laser - tunable Ti:Sapphire ring laser with a 7-Watt low noise DPSSL pumping unit - supported by two diode lasers, all with optical frequency locking control elements. AOM-based multiple-beam modulation system providing optical frequency shifts with additional control of phase relationships among independently controlled beams. Spatial light modulator can be also used to generate beams of special transverse modes.System can be used as a source of light in 700-1000nm range for any ultrahigh-resolution spectroscopy in continuous-wave and moderate speed modulation regimes. Especially, it facilitates studies of coherent interactions of resonant light with atoms and molecules involving multiple independently but phase-consistently controlled laser fields e.g. EIT.

30. Heating system for optical samples at 400 K optimized for low magnetic field experiments

Special heating system with a multi-layer cylindrical magnetic shield and compensation/test field coils. Apart from highly reduced ambient fields influence, most of possible internal sources of unwanted magnetic field are eliminated by use of hot air as the heating medium (volumetric flow). Temperature inside the sample compartment is precisely controlled (resolution 0.1K and fluctuations below 0.01K rms) with a PID controller. System can be used in measurements of transmission of magnetically sensitive media requiring only paraxial optical access and precise control of temperature and magnetic field (in limited range: up to 1mT transient and 0.1mT continuous).

LumDoz Laboratory

31. **Thermoluminsecence measurement system Risø TL/OSL reader (model TL/OSL-DA-20)**

    It allows up to 48 samples to be individually heated to any temperature between room temperature and 700°C, to be individually excited by the beta radiation and to be optically stimulated by various light sources. The stimulated luminescence is measured by a light detection system comprised of a photomultiplier tube and suitable detection filters. The system enables measurement of thermoluminescence and optically stimulated luminescence, especially in the dosimetric applications and material research.

Gamma Laboratory

32. **Gamma radiation spectrometry system (Canberra)**

    It is equipped with the germanium detector – *HPGe:* GX4018 of the relative efficiency of 40%,resolution 1.8 keV (FWHM) at 1.33MeV and measurement range to 2.1 MeV. Detector is installed in the passive shied that enables measurements of the activities on the level of natural background radiation. System can be used to precisely determine the concentration of the radionuclides in the solid samples.

Non-invasive examination of heritage objects in Structural Research Laboratory (co-affiliated with Institute of Physics and Structural Research Laboratory in the Centre for Modern Interdisciplinary Technologies, Nicolaus Copernicus University in Torun):

33. **Ultra-high resolution Optical Coherence Tomography (OCT) system**

    Developed in the Insitute of Physics, uses as a light source a set of coupled superluminescence diodes (version for in-situ examinations) or a femtosecond laser (FUSION XBB-300, from Femtolasers GmbH, version for examinations in the laboratory). It has been designed specifically for examination of objects of cultural heritage, especially in the place of their storage. The axial resolution of the instrument is 2.1 µm (in varnish). The device allows a determination of the internal structure of the examined object at the depth accessible for the infrared light from the range of 700 -900 nm. It was utilised for examination (by invitation of the curators) of many objects of art, including such famous paintings as „Adoration of the Magi" by Leonardo da Vinci, „Vase with Sunflowers" by Vincent van Gogh, „Last Judgment" by Hans Memling as well as stained glass, ceramics, paintings on reverse side of glass. It can be used also for monitoring of some restoration treatments, e.g. supporting safe removal of unwanted varnishes.

34. **Commercial set-up for Laser Induced Breakdown Spectroscopy (LIBS) micro-analyses (Echelle Spectrometer ESA 4000 from LLA Instruments GmbH)**

    Equipped with Nd:YAG laser generating at 1064, 532, 266 nm (ULTRA from Quantel), echelle-type spectrograph with image intensifier and a camera (Kodak KAF-1001). In our laboratory the instrument has been adapted to interoperate with the OCT tomograph. The device provides precise in-depth profiles of elemental composition of the object examined.

35. **Scanning MA-XRF spectrograph (M6 JetStream from Bruker AXS Microanalysis GmbH)**

    Designed for generating maps of distribution of elements of atomic numbers not lower than 16 (sulphur) from the surface up to 700 x 550 mm, with rhodium (Rh) cathode equipped with a micro-capillary lens focusing X-rays at the object to the diameter from 0,05 mm to 0,65 mm and with a SDD detector. Objects can be examined both in horizontal and vertical positions. As for the application to examination of objects of cultural heritage, it permits identification of pigments supporting dating, authentication and attribution as well as localisation and identification of past restoration attempts. It is mostly used for examination of easel paintings on canvas and wooden panels, illuminated manuscripts, maps, and old prints.

10. List of the additional benefits that the Institution declares to provide for Dioscuri Centre (i.e.: additional funds, personal benefits, other) (up to one in page A4 format):

The University will offer a **permanent position for the Principal Investigator** once the funding for the Dioscuri Centre is finished (5 or 10 years). On top of the **300 000€/ year** grant from the National Science Center and Max Planck Gesellschaft, our institution will offer **25 000€ / year** (obligatory as part of the proposal) as well as additional **60 000€ / year** (equipment, materials for the staff of the Center) and the salary for the experienced, English-speaking secretary. The total funding during 5 years is almost 2 M€.

The successful **Principal Investigator** will have the **strong institutional support** in all activities related to the Dioscuri Center, e.g. in preparing additional grant proposals and their ultimate evaluation reports. The main Polish funding agencies are the National Science Center, the Ministry of Science and Higher Education, the National Center for Research and Development, and the Foundation for Polish Science. These institutions offer several grant programs dedicated for scientists at all career levels. For example, the Maestro program of the National Science Center provides funding for experienced scientists for 5 years up about 0.5-1 M€ covering the costs of computers and laboratory equipment, salaries for group members, and travel expenses. Similarly, the program TEAM by the Foundation for Polish Science offer up to 1 M€ grants for 3 years. Additionally, our Rector's grants for up to 50 000 PLN are accessible for employees upon successful application.

The Nicolaus Copernicus University will also offer a **low-cost credit for up to 70 000 PLN** as well as a **low-rent apartment in Toruń**, which could be used either by the **Principal Investigator** or by any of the group members. We also recognize the need to provide **family support** to the Dioscuri Center leader. We will do our best to offer a job in the University to the life partner of the successful applicant, as well as assist in getting a place in the nursery, kindergarden, and / or high school run by our University. In fact, the high school run in close collaboration with our University is ranked as the best high school in the entire country and is located close to the Torun city center (http://www.gimakad.torun.pl/).

The Dioscuri Center in Toruń has also a strong support of the President of the city of Toruń and the Marshal's Office of the Kujawsko-Pomorskie province.

11. Other information about internationalization of the scientific institution, foreign scientists employed at the institution, availability of the English language seminars etc. (up to one page in A4 format):

The Faculty of Physics, Astronomy and Informatics is the **top faculty in the Nicolaus Copernicus University** in Toruń, which is ranked as 5th best university in Poland. The Faculty itself is ranked as the 5th best among the faculties of physics of all higher education institutions. We are recognised for **excellence both in research and education**. We successfully acquire about 30% of research grant money of the entire University, which makes us the 2nd most efficient physics department in Poland (after the University of Warsaw). Our flagship faculties: physics, astronomy, and technical physics are all ranked 3rd in Poland.

Our Faculty maintains a **widespread international collaboration in research and education**. The 32 m radiotelescope works as part of the VLBI and EVN networks, consisting of a few tens of institutions around the globe. The atomic optical clock is developed in collaboration with 14 institutions from Europe, North America, and South Korea. In total, we are currently involved in about 40 international research project in collaboration with ~130 foreign institutions from about 40 countries.

Our international collaboration is enhanced by the **Polish membership in the European Southern Observatory (ESO) and the European Space Agency (ESA)**. Our astronomers are members of scientific committees and evaluation panels (e.g. OPC at ESO), as well as instrument development teams in these organisations (e.g. HIRES at E-ELT). The space industry in Poland also highly benefits from our participation at ESO/ESA.

In 2012-2016 we had about **200 foreign visitors** in our Faculty including trainees and visiting professors. Currently, in our academic staff we have 8 people from abroad.

Seminars in the Observatory and in the Institute of Physics are held in English whenever we have visitors from abroad. The list of topics of the recent seminars can be found here:
http://www.fizyka.umk.pl/fizyka/?q=node/76

As part of the European Union, our Faculty benefits from EU student and PhD student exchange programs, e.g. Erasmus, and our diploma are valid in all member states. While the number of international students is still a rather small fraction of undergraduate students (~5%), during the last academic year the number of PhD students from abroad, including trainees, was roughly 50% of all PhD students. We are active partners in international programs for staff and student exchange in astronomy: **RadioNET and Opticon**.

We are currently actively attracting international students and PhD students to consider our Faculty. For example, this year we initiated a 4-week summer program for students - the **Toruń Astrophysics / Physics Summer program**, TAPS 2017 (http://www.ca.umk.pl/taps2017/). Among the applicants, more than 60% were international students from Croatia, Ukraine, Canada, India etc.