### Proposal form for research infrastructure project to be included in the Polish Roadmap for Research Infrastructures

<table>
<thead>
<tr>
<th>Title (name) of the proposed Research Infrastructure:</th>
<th>The 90m Radio Telescope of the National Centre for Radio Astronomy and Space Technology</th>
</tr>
</thead>
</table>
| Name and affiliation of the coordinator; the consortium members; name of the consortium: | Coordinator  
Nicolaus Copernicus University in Torun  

The consortium members:  
Gdansk University of Technology (technology coordinator)  
Space Research Centre PAS, Warsaw  
Military University of Technology, Warsaw  
Nicolaus Copernicus Astronomical Centre PAS, Warsaw  
Jagiellonian University, Cracow  
University of Zielona Góra  
University of Technology and Life Sciences, Bydgoszcz  
Institute of Bioorganic Chemistry, Supercomputing and Networking Centre, PAS  
+ 2 recent applications from  
Warsaw Technical University  
Institute of Applied Optics in Warsaw  

Name of the Consotium:  
The National Centre for Radio Astronomy and Space Technology. |

1: The overall rationale behind the proposed RI:

The goal of this project is to establish the National Centre for Radio Astronomy and Space technology (NCRST) devoted to carrying out scientific research and technology development in radio astronomy and space science based around a new, very large radio telescope of innovative design and with unique capabilities. The diameter of its fully steerable parabolic mirror would be around 90m – hence its working name is RT90+. Currently, only two fully-steerable antennas of comparable diameter exist in the world; they are located in Effelsberg (Germany) and Green Bank (USA). An instrument of this class located in Poland will therefore involve a huge technological and scientific leap forward for Polish astronomers and engineers, and highly attractive to international partners, since the proposed instrument will be exceptional for more than just its large size. Its most innovative feature will be an optical design capable of supporting state-of-the-art multi-pixel receivers - essentially “radio cameras” at the focus. Broad-band radio cameras capable of high time resolution parallel continuum and spectroscopic polarisation-sensitive observations simultaneously will dramatically increase the scientific potential of any radio telescope, but the combination with the huge collecting area of a 90-m diameter antenna will constitute a major new step in radio astronomy allowing previously impossible surveys of the radio sky to be carried out. These will complement the surveys being planned with other new telescopes across the electromagnetic spectrum. In addition to the sheer surveying speed, the homogeneity of the data will be greatly improved by allowing large areas of the sky to be covered in similar weather conditions and elevations, thus minimizing calibration uncertainties. Design studies for the next generation of multi-pixel radio cameras were successively conducted in the EC-funded FP5 and FP7 RadioNet projects FARADAY and APRICOT, in which Toruń Centre for Astronomy (TCfA) staff members worked with radio astronomers from the UK, Germany, Italy, the Netherlands, Spain and
The existing 32-m radio telescope of the TCfA – designed in Poland and commissioned in 1994 – remains in good health and is already operating first generation radio cameras at 30 GHz developed with the help of EC-funding in the FARADAY project which also involved TCfA scientists. The 32-m is already operated in a national-facility manner, providing free access to astronomers interested in radio observations. Similarly the RT90+ operated by NCR will be open to all astronomers through a system of research proposals. Observing time will be granted by a Program Committee based on the scientific merit of the proposals and the technical capabilities of RT90+.

In addition to its stand-alone capabilities the RT-90+ will also provide a dramatic enhancement to the European Very Long Baseline Interferometry Network (EVN). For 30 years, the TCfA has been an active member of the EVN which in terms of angular resolution, provides more detailed astronomical observations than those made with any other telescope in any wavelength domain. The extensive experience of the TCfA team meant that the TCfA was among those European radio observatories that pioneered a new technique of interferometric observations using of dedicated optical fibre links for very high-speed data transfer. The TCfA 32-m radio telescope provides observing services to the so-called "E-EVN" for about 25% of its time. The RT90+ will play a major role in the e-EVN which will be the most sensitive high resolution radio array in the world. The e-EVN has been officially recognized as a Square Kilometre Array (SKA) Pathfinder, hence it is in the main stream of ESFRI – Europe’s strategic infrastructure plan. The RT90+ telescope in the e-EVN will add an important northern extension to the SKA in South Africa, combining the highest available angular resolving power of the EVN with the extremely high sensitivity of SKA. The e-EVN and SKA combination will together be the most advanced radio astronomy facility for many decades into the future.

Many different types of radio telescope have been successful, but large steerable paraboloids have stood the test of time because their performance can be continuously enhanced as a result of advances in instrumentation and in signal-processing techniques. RT90+ will constitute a major step beyond previous international experience in two ways. First the proposed parabolic antenna design is novel. Second, from the outset, RT90+ will be designed to accommodate a suite of very large “radio cameras”; it will be the first large radio telescope in the world so to do. With many pixels observed simultaneously it becomes possible to survey previously impossibly large areas of the sky in reasonable observing times even though the individual pixel size of a large telescope is small. These new surveys will open new windows on the Universe, from the constituents of our Milky Way to new types of distant active galaxies and unexpected transient events in the radio sky.

The ambition for RT90+ is to add new discoveries to those already made with radio telescopes which have transformed our view of the universe: quasars and radio galaxies; superluminal motion; the evolution of the Universe; pulsars; astrophysical masers and molecular lines; dark matter in galaxies; the Cosmic Microwave Background Radiation. Radio telescopes have been so successful because radio waves also penetrate dust and gas which absorbs and scatters radiation in most other wavebands allowing us to explore the universe in unique ways: by the study of the first photons that were able to travel freely without being rapidly absorbed after the Big Bang; the basic element hydrogen via the 21cm line; magnetic fields via polarisation imaging and pulsars the most accurate clocks in the universe. Radio observations also reveal matter in different phases: synchrotron radiation from high energy electrons in magnetic fields, maser emission from molecules, bremsstrahlung from ionized plasmas, and coherent emission associated with stellar flares, pulsars and Jovian bursts. It is perhaps not surprising that Nobel prizes have been awarded on four separate occasions to radio astronomers.

In summary the RT90+ project is based on the recognition of the exciting new astronomical opportunities awaiting a large radio telescope outfitted with state-of-the-art radio cameras to multiply its collecting area, and hence its sky-surveying capability by up to 100-fold. No existing paraboloidal radio telescope has been designed to accommodate such cameras as a principal requirement. There is thus an opportunity for Poland to be the first to build a telescope which will take advantage of the rapidly developing multi-pixel receiver technologies to make observations of
the radio sky which will form part of the astronomical legacy of the 21st century. To complement this astronomical vision the design, construction and operation of the RT90+ will develop new capabilities in Polish engineering and data management. Finally, but not least, RT90+ with specialized laboratories and gathering human potential in technology development will become a national flagship facility and will provide a focus for inspiring a new generation of Polish students to take up technical and scientific study.

2: The proposed ownership and operational structure (e.g. single sited, distributed, network, anticipated working life); proposed organisational arrangements (e.g. management model, relations between consortium members, etc.); proposed legal structure; proposed localisation(s):

The over-riding idea of this project is to combine efforts of all Polish radio astronomers and create a national institution that will coordinate scientific research and the development of new instruments. The initial focus for this new institution is to build a new radio telescope that will dramatically improve research capabilities in Poland and in Europe as a whole. The diameter of this new instrument, a crucial parameter for any radio telescope, should be at least 90m. Moreover, the instrument should be fully steerable. Only two comparable antennas exist (100m at Effelsberg, Germany and 100m at Green Bank, USA). The unique RT90+, located in Poland, will provide a giant leap forward for Polish scientists, and will also raise the efficiency of the whole EVN, doubling the sensitivity of the network at some frequencies. It can be expected, therefore, that the National Centre for Radio Astronomy (NCR) will become one of the leading institutions in the EVN.

Based on the decades-long track-records of the Jodrell Bank 76m in the UK the 64m Parkes dish in Australia, and the Effelsberg 100m one can be confident that the lifetime of the RT90+ as a stand-alone research instrument will be at least 40 years, if it is regularly refurbished. The RT90+ will also remain a vital element in the EVN, with its role depending on the scientific demands and strategy of the EVN. In the 2020s and beyond this will increasingly include working with the SKA in South Africa and across Africa.

Initially, the proposed instrument will be used and maintained by a consortium of Polish institutes and Universities coordinated by the Copernicus University in Torun. In the future it should have an independent status as a national centre for research in radio astronomy.

The Consortium agreement “The National Centre for Radio Astronomy and Space Technology” which aims application for funds to build 90m class telescope and to effectively operate the new instrument has been accepted and signed by all 9 members (in November 2012).

Consortium partners are:

**Nicolaus Copernicus University, Torun Centre for Astronomy (TCfA),** (main coordinator) Specialized in areas of: radio astronomy (galactic and extragalactic astronomy, cosmology), development of instrumentation, development of numerical methods, has high position in European radio astronomy. (NCU has been highly ranked, 6 of its 18 Faculties have category A, 11 category B, one A+)

**Gdansk University of Technology (GUoT)** (technology coordinator). Specialized in civil engineering, space technologies, application of space techniques, geotechnics, radio communication, computer modelling, applied informatics, (GUoT has also been highly ranked, 6 of its 9 Faculties has category A, 3 category B).

**Space Research Centre (SRC), Polish Academy of Science, Warsaw.** Specialized in space research, construction of space probes, physics of planetary system, geophysics, development and applications of new technologies, space communication, applied astronomy, (Category A+).

**Military University of Technology (MUoT)** in Warsaw. Specialized in radio communication, ground and space navigation, radio interferometry techniques, remote sensing, digital modelling of large structures, new materials and new technologies development,
Astronomical Observatory, Jagiellonian University (AO UJ), Cracow. Specialized in radio astronomy, studies of magnetic fields in the Universe, evolution of galaxies, polarimetry, large scale structures, surveys, well developed international co-operation. (Category A+)

Kepler Institute of Astronomy, University of Zielona Gora (IA UZ). Specialization in astrophysics of neutron stars – leading in Poland in pulsar observations, wide international co-operation in observations and theory. (Category (A+)

Nicolaus Copernicus Astronomical Centre (NCAC), Polish Academy of Science, Warsaw. The partnership is still being negotiated. Country leading specialists in theoretical and observational astrophysics, interested in the access to radio data from RT90 for pulsars, active galaxies and stars. (Category A+)

University of Technology and Life Sciences UTLS, Bydgoszcz. Specialised in mechanical engineering (materials and structures testing and evaluation, mechatronics, fatigue design, numerical simulation of static and dynamic phenomena), IC technology, control systems, digital signal processing, monitoring and measurements systems, civil engineering, geotechnics, urban planning, road communication systems planning, architecture, environmental protection, renewable sources of energy.

Institute of Biorganic Chemistry, Supercomputing and Networking Centre(PSCC), Polish Academy of Science. One of the leading Super Computer Centers in Poland, involved in software development for VLBI, and for virtual radio telescopes, provider of fibre optical wide band network for Poland (PIONIER), distributor of new computing technologies, and the access to state of the art computing facilities Very good international co-operation.

Poland has insufficient strength of scientific, technical and technological resources, to be able to actively participate in major international projects and challenging tasks of modern space research. The long-term purpose of this project is to build an infrastructure that fundamentally could change this unfavorable situation. Following the example of many research institutes in Western Europe and in the world we intend to build an unique addition to a worldwide research tool (RT90 +) and to create teams of highly skilled engineers and technicians prepared and able to actively participate in the mainstream of global research and technological development. The experience and performance of South Africa’s role in the Square Kilometre Array serves as an a fine example of what is possible.

Consortium members believe that it is worth investing in the development of national research infrastructure citing the National Centre for Radio Astronomy and Space Technology with a modern telescope of global importance. If Poland wants to possess the high-tech instrument designed for astronomical research and other complementary studies, the optimal solution is proposed by investment with the construction of a highly advanced radio telescope of large aperture and unique capabilities. Implementation of such instrument in the country will strengthen the economic potential of Polish companies and introduce new technologies to the standard of domestic enterprises.

The concept implemented within the framework of the National Centre for Radio Astronomy and Space Technology will radically change the negative trends of investment in large research instruments resulting in a reduction of the importance of engineering and technical teams. The radio telescope is important focus, but the basic idea is to build up around it, teams of engineers and technicians well-prepared and experienced, for which the taking of new jobs, particularly in the areas of space exploration, will be commonplace. Construction of the main center of these laboratories (GUoT campus) and sub-centers in other universities is primarily designed to serve the development of new technologies.

The Consortium Agreement (attached) describes in details structure of management and responsibilities of partners. Observations of the best working astronomical facilities imply that strong central management is usually very effective. The proposed RI operations should be governed by a Director with a high level of scientific and technical competence, who has the
responsibility and authority normally associated with the Institute Director, with central budget and technical control. Each consortium institution will delegate one representative for a CBD (Consortium Board of Directors, at the moment Board of Consortium Representatives) or SC (Steering Committee) and PC (Programme Committee). The structure of the Consortium is modelled on European regulation (EC) No. 1906/2006 by the European Parliament and of the Council of 18 Dec. 2006.

The telescope will be localized in “Bory Tucholskie” 60 km North of Torun. The major facilities will be build or expanded at University of Nicolaus Copernicus in Torun - (NCRST), Gdansk University of Technology – NCSIE (National Centre for Space Engineering), University of Zielona Góra and University of Technology and Life Sciences – specialized laboratories.

The coordination centre of The National Radio Astronomy and Space Technology will be located at Torun Centre for Astronomy in Piwnice (Radio Astronomy Department of TCfA) and in Gdansk University of Technology (technology development, specialized education and space engineering part of NCRST).

At each partner site there will be dedicated laboratory to use the telescope for the particular research interest and to develop their own advanced technology centers.

Data archive and off line processing will be performed at Gdansk and Poznan Super Computer Centers on a remote request issued from any partner locations.

3: The technical concept (e.g. use of existing buildings or construction of new facilities, acquisition of new scientific instrumentation, acquisition of new service equipment, time scale to the start of operations); technical feasibility / technical challenges; time schedule with clearly marked milestones (including preparation and implementation stages of the investment, i.e. preparation of documentation, fulfillment of administration procedures, including environmental impact assessment and building permits, public procurement, beginning and completion of project tasks):

We aim to build a fully-steerable parabolic antenna with a diameter >90m, capable of working in the range of 0.5-22 GHz which will serve Polish and European astronomers as a major new world-class astronomical facility for decades hence. Requirements that will push the state-of-the-art in mechanical, radio and software engineering include:

- a large dish design having unique optics, to provide high sensitivity combined with a large field-of-view
- a novel construction “new technology antenna” based on the use of large scale hydraulic actuators controlled by a sophisticated computer control system enabling pointing and tracking precision to high precision.
- a suite of multipixel receiver arrays with advanced ultra broad-band digital back-ends to cover the frequency range from 0.5 to 22GHz simultaneously
- software and “big data” management techniques to deal with large real-time data volumes and off-line reductions producing huge archive quality data sets for world-wide access long into future.

In the initial stage of project realization we will be based on the existing facilities of Radio Department TCfA. These include buildings and instrumentation used on and with the 32m antenna. It is important to note that since the optics of the 32m are quite similar to those of the RT90+ all the existing cryogenic receivers and digital spectrometric backends can be used on RT90+ without modification. Thus the RT90 can start astronomical operation immediately after the construction work is finished. It is estimated that after three years the final set of instrumentation including radio cameras will be ready for the use.

Detailed design studies for the next generation of multi-pixel radio cameras has very recently been completed in an EC-funded FP7 research project “APRICOT” in which Torun Observatory staff worked with leading radio astronomy groups in the UK, Germany, Italy and Spain. The APRICOT
philosophy has been to derive the design requirements and prototype critical elements of general-purpose radio cameras capable of polarisation-sensitive broad-band continuum and spectroscopic observations with choices made at the flick of a switch. Such cameras will dramatically increase the scientific potential of radio telescopes. In addition to sheer surveying speed, they will greatly improve data homogeneity by allowing large areas to be covered in similar weather conditions and elevations, thus minimizing calibration uncertainties. And with no need to change receivers for different types of observations all-purpose radio cameras will enhance operational efficiency and access for users. The RT90+ concept has benefitted enormously from the European radioastronomy technology base established in APRICOT. Appropriate back-ends for spectroscopic and pulsar surveys are already operational for the current generation of receivers – and for the next generation systems they are being developed within another EC FP7 funded radioastronomy R&D program (UNIBOARD). These type of technological advance is currently being tested at Polish Institutes - MUoT, GUoT, IoAO, who are members of the Consortium.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value/type</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical system</td>
<td>Cassegrain</td>
<td>Richie-Chretien</td>
</tr>
<tr>
<td>Diameter of the main reflector D</td>
<td>&gt;90 m</td>
<td>Axis simmetrical hyperbolic</td>
</tr>
<tr>
<td>Focal length of main reflector f</td>
<td>&gt;31.5m</td>
<td></td>
</tr>
<tr>
<td>Aperture f/D</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>Diameter of subreflector d</td>
<td>&gt;9 m</td>
<td>Hyperboloid</td>
</tr>
<tr>
<td>Effective focal length F</td>
<td>&gt;273 m</td>
<td></td>
</tr>
<tr>
<td>Focal plane above vertex</td>
<td>3 m (5)</td>
<td>Above the surface</td>
</tr>
<tr>
<td>Precision of the surface</td>
<td>0.5 mm</td>
<td>RMS</td>
</tr>
<tr>
<td>Range of movement in elevation</td>
<td>5 – 90 deg</td>
<td></td>
</tr>
<tr>
<td>Range of movement in azimuth</td>
<td>+/- 270 deg</td>
<td></td>
</tr>
<tr>
<td>Tracking / pointing precision</td>
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<td>Pointing and tracking</td>
</tr>
<tr>
<td>Slew rate max</td>
<td>30 deg/min</td>
<td></td>
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<tr>
<td>Drive mechanism /mechanical mount</td>
<td>hydraulic</td>
<td>Alt-Az with hydraulic motors</td>
</tr>
<tr>
<td>Total weight</td>
<td>~3000 ton</td>
<td>All construction</td>
</tr>
<tr>
<td>Field of view (amplitude losses &lt; 5%)</td>
<td>5 deg</td>
<td>Depends on frequency</td>
</tr>
<tr>
<td>Frequency coverage</td>
<td>0.5-22 GHz</td>
<td>In secondary focus</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>2.7 -0.5 arcmin</td>
<td>In a range of 5 – 22 GHz</td>
</tr>
<tr>
<td>Tsys</td>
<td>25-35 K</td>
<td>In a range of 5 -22 GHz</td>
</tr>
<tr>
<td>Sensitivity for 1 sec integration (full bandwidth)</td>
<td>1.2 mJy</td>
<td>Continuum, 5 x RMS</td>
</tr>
<tr>
<td>Sensitivity for 1 hour integration (full bandwidth)</td>
<td>20 microJy</td>
<td>As above</td>
</tr>
<tr>
<td>Confusion limit</td>
<td>0.3 – 0.1 mJy</td>
<td>For 5 - 22 GHz</td>
</tr>
<tr>
<td>Number of independent receivers</td>
<td>49 (~100)</td>
<td>initial (final) like in FP7 APRICOT</td>
</tr>
<tr>
<td>Number of independent 2 GHz channels</td>
<td>784 (1600)</td>
<td></td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>1 kHz</td>
<td></td>
</tr>
<tr>
<td>Time resolution</td>
<td>0.1 msec</td>
<td></td>
</tr>
<tr>
<td>Backends type - Pulsar machine, Polarimeter and Spectrometer units</td>
<td>digital FPGA</td>
<td>FP7 UNIBOARD As prototypes</td>
</tr>
<tr>
<td>Antenna location</td>
<td>Dębowiec</td>
<td>53°39'31.4&quot;N 18°21'43.8&quot;E</td>
</tr>
<tr>
<td>Data transfer and communication</td>
<td>&gt;10 Gb/s x 4</td>
<td>Dedicated broad band fibre</td>
</tr>
<tr>
<td>Full remote control from</td>
<td>Piwnice</td>
<td>TCIA NCU</td>
</tr>
</tbody>
</table>

In summary:
• RT90+’s principal role is to produce unique sky surveys rather than being a general-purpose pointed instrument like the Effelsberg 100m; GBT 100m or SRT 64m telescopes. It can, however, be used for VLBI and pointed observations when required.
• RT90+ employs standard material technology, with wide-field optics evolved from the TCfA 32-m; the novel feature of the design for a radio telescope is in the reflector positioning system using hydraulics. This is, however, industry standard outside the telescope arena.
• We have explicitly restricted aspects of the design to save costs in particular limiting the upper frequency to 22 GHz and the lower elevation limit to 25° – the latter follows the example of the Parkes 64m which is limited to elevations above 30° and yet is still a leading instrument well into its 5th decade of operation.
• The proposed multi-pixel receiver systems are also an evolution of existing FPA experience and has been studied to produce a costed design within the FP7 APRICOT programme. Appropriate back-ends for spectroscopic and pulsar surveys are already operational for the current generation of receivers – and for the next generation of more cost-effective systems they are being developed within the FP7 programme UNIBOARD.

The feasibility to design and to build in Poland the RT90+ successfully is fully realistic. We have managed to design and to build the RT32m with great success. This was done in a very difficult economically and politically times in the years of 1986-1994. Over 60 Polish companies were involved in the process of RT32m construction. In effect it proved that we can construct advanced instrumentation, this high class medium size instrument has already served Polish and European astronomers for nearly 20 years, leading to discoveries and large number of refereed publications.

The potential of experienced Polish scientists, engineers and technicians gathered around RT90+ project, together with international support via an experts group, is sufficient to undertake the ambitious task. Recent discussions, seminars, contacts among project participants and experts from the US and Europe made us even more confident that this type of instrument can be built and successfully used in Poland. (We refer here to two International Seminars on RT90 held at Gdansk Technical University in 2011 and 2012 and two International Seminars on RT90 held at Torun Centre for Astronomy in 2009 and 2010, also to other conferences where the RT90 concept was presented – 2 in USA, 1 in UK, 1 in Germany).

The technical challenges of RT90+ create conditions to develop and use in Poland advanced technologies in the following areas:

a) large scale constructions based on composite materials
b) production of light and precise panels for main dish surface
c) building the 9m subreflector with the use of composite materials
d) anti corrosion protection, ecology friendly materials
e) effective hydraulic drive systems (motors and pull-push arms)
f) high precision control of telescope drives, state of the art algorithms
g) active surface for gravity deformation control (homology and actuators)
h) advanced ultra broad band, extremely low noise cryogenic microwave receivers
i) new passive and active microwave components
j) building of radio camera with 50-100 independent pixels
k) digital ultra wide bandwidth real time processing
l) ultra wide band fibre optical lines connecting the RT90+ with users and data archive
m) direct fibre optical links to the European VLBI Correlator in the Netherlands

The RT90+ will be built at initially chosen site of Debowiec gm. Osie, woj. Kuj-pom. The antenna and basic infrastructure (service labs, service workshop, basic offices and accommodation facility) shall be located there.

In Torun an extension to the existing buildings of the Department of Radio Astronomy TCfA NCU
will consist of new electronics laboratory, telescope control room, offices for ~ 10 new staff, local basic communication and computing lab. New scientific instrumentation to serve the laboratories needs will be purchased. These should contain general purpose network analyzers, spectrum analyzers, RF generators, noise measuring equipment, digital oscilloscopes, cryogenic systems.

In Gdansk a completely new facility to serve the technical development needs of RT90+ will be constructed. The planned new building located on GUoT campus, temporally named as National Centre for Space Engineering (NCfSE) will provide facilities to develop scientific instrumentation for RT90+ and will serve requests for Space programs of ESA coordinated by Space Research Centre PAS in Warsaw. NCfSE will also serve educational needs in fields of Space Research Technologies and applications to other areas of relevant civil engineering. GUoT will create synergies in cooperation with other members of the Consortium and intends to offer leading exclusive study as part of activities within planned National Centre of Aerospace Engineering. This could become the country’s leading aerospace engineering development center as an important partner in the European space programs, operating on the basis of their own graduates. The NCfSE will administrate and coordinate large data base of RT90+ containing continuously flowing results and will coordinate all relevant informatics work performed on the GALERA super computer.

In Zielona Gora (UZ) we plan to build new laboratory the Regional Centre for Radio Astronomy and Space Technology to allow access to the main data base and local data processing. This unit will also have educational character to teach radio astronomy techniques and space technology applications. It should contain investment into main building, with laboratories equipped with specialized instrumentation, and seminar rooms.

In Bydgoszcz (UTLS) we plan to build new and to expand existing laboratories, which are highly specialized and are unique among the partners institutes. The areas covered at UTLS cover high speed communication and data transfer systems, control systems, automatics and wide range of civil engineering relevant to the construction and maintenance of large scale structures (RT90+).

Proposed time-line and estimated cost

<table>
<thead>
<tr>
<th>Milestones</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Initial preparatory work, applications for the funds, concept study of the RT90, site selection for RT90 and building permission documentation</td>
<td>05.2013</td>
<td>12.2013</td>
</tr>
<tr>
<td>2 Documentation of the RT90 design and other directly relevant investment, blueprints (20)</td>
<td>01.2014</td>
<td>12.2014</td>
</tr>
<tr>
<td>3 Design project of the associate, accompanying facilities CRASR (5)</td>
<td>01.2014</td>
<td>12.2014</td>
</tr>
<tr>
<td>4 Project and realization of prototype receiving systems (10)</td>
<td>07.2013</td>
<td>03.2014</td>
</tr>
<tr>
<td>5 Project and accomplishment of fibre optical connection lines from the telescope to the control centre (3)</td>
<td>04.2014</td>
<td>06.2015</td>
</tr>
<tr>
<td>7 Building of the accompanying cubature KCIK, NCR (70)</td>
<td>09.2014</td>
<td>08.2016</td>
</tr>
</tbody>
</table>
Fulfillment of administrative procedures

The proposed research infrastructure named “The National Centre for Radio Astronomy” with the major investment of the 90m radio telescope in Bory Tucholskie – Debowiec has been written to the following documents

- Torun Centre for Astronomy Board resolution in 2010
- Faculty of Physics, Astronomy and Computer Sciences NCU – strategy document 2014-2020
- Nicolaus Copernicus University strategy document 2014-2020
- Development Strategy of Kujawko-Pomorskie Region 2010
- The central government document prepared by the Ministry of Regional Development - Framing of the Country Development till year 2030 (Konsepcja Przestrzennego Zagospodarowania Kraju - KPZK 2030)
- Decision of local administration at gmina Osie – region where the building of telescope is planned. The local council accepted by voting the proposed localization at Debowiec. The decision has been communicated to the Consortium via letter signed by local governor gminy Osie – wojt Michal Grabski. This document informs also on positive decision made by Environment Regional Office in Bydgoszcz and that the formal building permission can be granted.
- Investments at Torun, Gdansk and Zielona Gora are planned on their own University’s grounds, thus the building permission procedures should be relatively easy.

4: The overall research objectives and the research programme:

A. The scientific rationale for the RT90+ as a stand-alone telescope

1) Molecular studies of star-forming regions, circumstellar envelopes (CSEs): The main targets are the molecular clouds in which stars are formed. Unbiased spectroscopic imaging will locate the likely star forming regions diagnosed by regions of high density/column density/temperature. Once found, the aim is to map column density and then from model calculations to infer the temperature/density. A large format camera will enable surveys of complete clouds to be carried out at high resolution in one day.

2) Search for new molecules in the Interstellar Medium and solar system objects. Recent observations have identified increasing numbers of complex organic species in interstellar clouds including glycolaldehyde (CH₂OHCHO), formic acid (HCOOH) and acetic acid (CH₃COOH). These species may be precursors to biologically important molecules which may seed protoplanetary disks around the young stars, and indeed the planets which form within these disks. The chemical composition of the dense core in which a star forms might therefore have a direct impact on the evolution of biological systems on planets.

3) Redshifted CO(1-0) emission of sources with redshift z between 3.8 and 10.5. The CO(1-0) rotational transition has a rest frequency of 115 GHz, which is shifted into the 10-20 GHz band for these values of z.
CO is the most abundant molecule after H₂, and has therefore the highest chance to be detected of all molecules, as H₂ itself has no permanent dipole moment and cannot be observed at radio frequencies. Detection of CO in a galaxy in this band allows one to determine its distance, and to get a basic estimate of its mass. A large format camera will enable effective blind surveys for redshifted CO to be carried out.

4) Blind surveys for discrete sources: A deep large-area sky survey at a wavelength of ~2cm may reveal a new source population of faint sources not found in decimeter wave surveys (see the “2CMS” survey below). Deep surveys at this frequency will also complement the results from the Planck space mission, providing the high-angular-resolution information to the Planck large-sky surveys. For astrophysics of active galactic nuclei (AGN) such surveys are particularly sensitive to flat-spectrum radio sources or “High-Frequency Peakers”. The latter are of particular interest since they are likely to mark the earliest phase (10 and 1000 years) of radio AGN evolution.

5) Continuum surveys of the Galaxy: the diffuse polarized continuum from The Galaxy is a combination of synchrotron and free-free emission (dominant below ~60 GHz), anomalous dust emission (“spinning dust” dominant between ~15 and ~40 GHz) and thermal dust (dominant above ~60 GHz). Multi-pixel radio cameras mounted cameras on the RT90+ will allow detailed dissections of the contributions of the different emission mechanisms in selected regions of astrophysical importance. For example in circumstellar stellar disks, the frequency regime for which RT90 is optimised will allow detailed studies of the contributions of the different emission mechanisms in selected regions of astrophysical importance. For example in circumstellar stellar disks, the frequency regime for which RT90 is optimised will allow detailed studies of the contributions of the different emission mechanisms in selected regions of astrophysical importance.

6) The Sunyaev-Zel’dovich effect in galaxy clusters: large filled aperture telescopes with multi-pixel receivers are the fastest way to detect and study the SZ effect from hot-gas in clusters of galaxies. The establishment of the red-shift dependent statistics for such mass agglomerations in the range 10¹⁵ to 10¹⁶ M☉ provides a direct handle on the growth of the first structures and hence on cosmological parameters and the Ω-parameter for the equation of state of dark energy. For this work resolutions of <1 arcmin and as many pixels are possible are required for locating many SZ clusters. Higher resolution studies of specific clusters, combined with X-ray imaging from Chandra, probes the combination of dark and baryonic matter in the cluster.

7) Transient Sources: the capabilities of the RT90+ make it ideally suited for searches for “transient” radio sources. These will certainly cover a wide range of time scales and be rare, in terms of finding one in any particular reception beam at any given time. The Parkes radio telescope, equipped with a previous generation 13-beam camera at 1.4 GHz, has discovered a new class of rapid transients whose origin is unknown. There have been no systematic searches for transients at centimetre wavelengths. The high survey speed of the RT90+ when equipped with large multi-pixel radio cameras will allow it to carry out such searches for new transient radio sources which may well include phenomena we have not yet thought of – which leads us on to the general concept of making discoveries with large radio telescopes.

8) Radio Pulsars – neutron stars: Generally, the observed radio spectra of most pulsars can be modeled as a power law with negative spectral indices of about –1.8 (Maron et al. 2000). Some sources, moreover, show a low-frequency turnover, normally observed at frequencies below a few hundred megahertz (Sieber 1973). On the other hand there have been observed few pulsars whose spectra are observed to peak above 1 GHz followed by an otherwise typical high-frequency spectrum (Kijak et al. 2011a). This phenomenon in radio magnetars and pulsars was discovered recently (Kijak et al. 2011b, 2013) and called the Gigahertz Peaked Spectra (GPS). Its nature is not known despite many attempts to resolve it. Finding the physical phenomena responsible for its appearance will have significant impact on our knowledge (and possibly the future studies) about the neutron star environment physics. Both the radio magnetars and the isolated pulsars that show this effect have very interesting - and sometimes peculiar - environments, like the pulsar wind nebulae or dense HII regions. The explanation of the GPS phenomenon as the effect of the interaction of the pulsar radiation with these objects will give us additional information about those object as well, and expand our knowledge about their physics. Additionally, a thorough study of the GPS phenomenon (including a search for more of such objects) will have an impact on the strategies of future pulsar/magnetar search surveys, which was already noted in at least one of the recent publications on that topic. Based on statistical simulations the authors of the mentioned paper estimated that the GPS pulsars constitute up to about 10% of the population which given that we currently know about 2000 pulsars, should amount to about 200 sources. And yet there is only a few documented cases, which is probably due to the fact, that the spectra of most of the radio pulsars are not thoroughly studied over a wide range of frequencies. Therefore, a search for GPS in the entire pulsar/magnetar population is necessary. The big aperture telescope with sensitive high frequency
receivers would be an ideal instrument for this important research.

Another big task for large radio telescope like RT90+ is monitoring of known and search for new “part-time pulsars”, which are detectable for only short time intervals. The extreme example of such sources are RRATs, which seem to emit just one, two pulses in a series, with the episodes of activity separated by intervals being multiples of pulsar period. Yet another group called “intermittent pulsars” are also very attractive sources for RT90 type of instrument. The objects are radio-loud for several tens of periods and radio quiet for long periods of times. Those pulsars are easy to be missed even in careful searches, so most likely there many of them out there to be discovered. Sensitive observations are needed to resolve the important question, whether in silent periods these pulsars do not emit any radio waves or there are just too weak to be detected.

Large aperture radio telescope is an ideal tool for precise pulsar timing. This is especially important for attempts of direct detection of gravitational waves by looking for specific signals in timing residuals of a group of millisecond pulsars (Pulsar Timing Arrays). Also, searching for new pulsars using a multibeam high frequency detection system planed for RT90, can be quite successful programme.

An RT90+ Legacy Project: “2CMS” the 2-Centimetre Million Source survey

The RT90+ equipped with large focal plane receivers can be the pivotal element in a multi-wavelength census of the sky at arcminute resolution. The paradigm survey is the NRAO NVSS at 1.4 GHz made with the Very Large Array (VLA). It covers the sky north of Declination -40° (82% of the celestial sphere) with 45 arcsec angular resolution and the catalog contains almost 2 million sources above a flux density of ~2.5 mJy. We propose a 15 GHz survey with the RT90+ with a comparable angular resolution to NVSS but somewhat higher surface density of sources. We anticipate that complementary 1.4 and 5 GHz surveys will be carried out in the next decade with NRAO's upgraded Jansky Very large Array (JVLA). Areas of research which could make use of the data from 2CMS are:

- Interpretation of surveys of the Cosmic Microwave Background: at high multipoles poisson fluctuations of discrete sources can dominate CMBR fluctuations on scales <30 arcmin (multipoles >400).
- Radio source Luminosity Functions and their evolution: epoch dependent luminosity functions for galaxies and radio quiet quasars now well determined to high z – there are attempts to provide physical explanations for evidence for earlier formation of more massive objects. Direct evidence for substantial decline at z>2 remains controversial.
- Polarisation statistics: DZ adduce evidence that there is a trend of increasing flux polarisation with decreasing flux density – which is at variance with current models of population mix and evolution. If the degree of polarisation is 5% the polarised flux in a 5 mJy source is 0.25 mJy i.e. above the survey noise level. – hence 2CMS will be able to measure position angles for most ~5 mJy sources – this will provide a catalog of 150,000 polarised sources.
- Wide area surveys and large scale structure: Extragalactic surveys are well suited to probing large-scale structure of universe since they are unaffected by dust extinction. 2-D clustering statistics are currently available from NVSS and other surveys – although at small angular scales one can encounter problems from intrinsically multiple sources – this will be less of a problem at 15 GHz. NVSS sees a correlation from 0.1-10 degrees with the implication that radio galaxies are more strongly clustered than optically-selected galaxies. Correlations on angular scales greater than 1-2 degrees are in conflict with CDM paradigm and it is not clear how to reconcile the two. Ideally one requires a 3-D distribution requiring optically-derived distance data to establish the 3-D distribution. Higher frequency radio surveys like 2CMS have much higher optical identification rates – so 2CMS catalogs will provide good target for complementary redshift surveys.
Particular Classes of Sources: In addition to statistical studies of the entire population of radio sources 2CMS will study particular classes of radio source. Here we briefly sketch in some areas where 2CMS data will be valuable

- **ADAF & ADIOS sources**: With luminosities below a few per cent of the Eddington limit may be advection-dominated accretion flows (ADAF which may include the Galactic Centre); or adiabatic inflow–outflow scenarios (ADIOS). They are typically very weak inverted spectrum sources in the centres of otherwise quiet ellipticals and may correspond to late stages of AGN evolution – but observational data on this population is currently very limited.

- **Ultra-steep spectrum sources (α steeper than 1.3)**: This is a well-known empirical route to detect high-redshift radio galaxies. By comparing flux densities with existing surveys – in particular LOFAR, NVSS and FIRST at 1.4 GHz, 2CMS will pick out very faint steep-spectrum sources – these are likely to lie at high redshifts.

- **CSS/CSO/GPS sources**: Are accepted as early stages of evolution of radio source hence identification and investigation of these sources is a key element in AGN studies. Compact Symmetric Sources (CSOs) are invariably identified with galaxies and are clearly young double sources. Current samples of GigaHertz Peaked Spectrum (GPS) quasars are too small to allow their evolution to be studied. 2CMS will help to locate very many more of these objects – especially since the receiver will have a broad band and hence provide yield instantaneous spectra in the 12-18 GHz range.

- **Star-forming galaxies**: There is a well-known tight correlation between radio and far-IR emission. There have been many attempts to include star-forming population into source counts below 1 mJy at 1.4 GHz. The combination of LOFAR/NVSS etc and 2CMS-Deep data will help to constrain the evolutionary properties of this population.

- **Radio afterglows of gamma-ray bursts**: The radio flux above the self-absorption break (at or below 5 GHz) is proportional to $v^{1/3}$ and the peak frequency decreases with time as the blast wave expands.

- **S-Z measurements**: Measurements of thermal Sunyaev-Zeldovich (SZ) effect would test the models of the evolution of the bayron-DM ratio

**Physics of neutron stars – radio pulsars**

Comparing to other non-thermal radio sources radio pulsars usually are steep spectrum sources with a characteristic spectral index of -2. For many of them one can observe a turn-over in the spectrum at low observing frequencies around 100 MHz. Recently another group of pulsars was found, and this subgroup is characterized by a high frequency turn-overs in their spectra that happen near the frequency of 1 GHz (hence the name GigaHertz-Peaked spectra - GPS). Such kind of spectra was observed earlier in other extragalactic point-source objects, but in case of radio pulsars this is a really new result. Hence arose the need to extend our knowledge about the pulsar spectra in general, since for about 2000 known radio pulsars we can reliably claim that we know the spectra of only 400 of them, and the reminder was usually very sparsely sampled.

The 90-meter radio telescope with a range of observing frequencies from 600 MHz up to 10 GHz seems to be a perfect tool for the job of ascertaining the pulsar spectra. The spectral studies, and especially for the GPS-type spectra can help us understand, whether the (high frequency) turn-overs are caused by magnetospheric absorption, or emission mechanism efficiency loss, or possibly is only an interstellar propagation effect. The latter seems very likely, as most of the GPS pulsars seem to adjoin very peculiar environments, such as Pulsar Wind Nebulae (PWNs), supernova remnants or dense HII regions (all of which are also good targets for high-energy, i.e. X-ray and gamma observations). Extended documentation of the GPS phenomenon, and estimation of the percentage of sources showing it may be also useful for future pulsar surveys, especially if they are to be performed at low frequencies (i.e. such as LOFAR and SKA). The existence of non-standard spectra pulsars will affect the success rate estimates for such surveys.

Another interesting area of study would be the “part-time pulsars” i.e. objects that share majority of pulsar properties, but for various reasons do not radiate constantly like the regular radio pulsars. Amongst this kind of objects one can find classic “transient” sources such as RRATs (Rotating Radio Transients), which we know to be rotating neutron stars, but for some reason radiating for periods much shorter than one rotation, and then remain quiet for periods ranging from a few minutes to several hours. Another subgroup consists of “intermittent” pulsars, such as B1931+24, for which both the “loud” and “quiet” periods are much longer, and my last from a week to several weeks. Another interesting subgroup of “part-time” pulsars is flare pulsars, with its prototype PSR J1752+2359. These are usually radiating for few tens of rotations and then become quiet for few minutes (few hundreds to a thousand rotations).
All the above mentioned classes objects would be excellent targets for the 90-meter telescope observations. We know very little about the reasons for their unusual behavior, but what we know indicates that understanding the emission mechanism of these special neutron stars may help us to understand the radio-pulsar radiation in general. Large collecting area of the 90-meter radio telescope will be extremely useful, especially that a vital part of the study would be devoted to finding some residual (and very weak) emission in the quiescent state of these objects, just to eliminate the possibility, that the apparent quiescence is caused only by an instrumental lack of sensitivity. A wide range of frequencies available for observation will help us to understand the physics behind the emission mechanism and the causes of turn-offs.

Amongst other possible applications of the 90-meter radio telescope is of course also a whole lot of standard pulsar observing methods, such as pulsar timing (especially for the part-time pulsars), single pulse characteristics studies (nulling, drifting subpulses phenomenon etc.) and the study of the Interstellar Medium by the means of scintillation and scattering observations of pulsars. For all of these the large collecting area of the telescope, and wide frequency coverage will be extremely helpful and may yield significant scientific results.

Pulsar and transient search surveys, as it was shown by the Parkes Multibeam Pulsar Survey amy be especially fruitful type of study if conducted systematically by the means of using a multibeam receiver which is developed for RT-90. Not only for the reason of finding new radio pulsars, but also for the possibility of finding the solution to a problem that appeared recently - the Lorimer-type bursts and Fast Radio Bursts (FRBs). These are highly dispersed, extremely narrow and very strong isolated pulses, that apparently are of extra-galactic origin, but we have absolutely no idea on their cause - and that is probably caused by the fact that we found only nine of those. A vast improvement of the statistics is needed if we are to understand the physics behind them.

Summarizing, the above mentioned science projects are probably not the only pulsar- and transient-related projects that may be realized with the use of 90-meter radiotelescope, given the enormous collecting area of such antenna and the range of observing frequencies available; however these are probably the most promising ones, the ones that guarantee large publication outcome and possibly will be of interest to the general public and the media.

B. The scientific rationale for the RT90+, VLBI

The birth of stars and planets: The single dish surveys of maser species give a thorough picture of star-formation in the Galactic plane at a resolution of 5 arcmin (e.g. Szymczak+ 2012). VLBI follow-up of subsamples will be vital to disentangle the properties of young stars and to test of how the IMF and the star-formation rate depends of metallicity, large scale matter and magnetic fields. High sensitivity and multi-frequency VLBI observations would constrain the structure of collapsing clouds on the scale of tens of AU and local physical conditions (e.g. Bartkiewicz+ 2009, Bartkiewicz+ 2012 ). Measurements of Zeeman splitting with high-resolution would be crucial to confirm the role of magnetic field as a main agent controlling the collapse rate and then becoming wound into protostellar discs. Proper motion measurements would facilitate establishing the nature of periodic maser sources (Szymczak+ 2011) and the maser transitions in Keplarian discs.

Emission of molecules and dust in the environments of cool stars observed with the VLBI would be crucial to test whether the mass loss is determined by macroscopic stellar processes such as clumps of star spots, magnetic phenomena, or convection cells. VLBI observations of rapidly evolving post-AGB objects would be vital to track disappearance of symmetric AGB envelope and formation of bi-conical outflow and testing directly the colliding winds model. The case study of object OH17.7-2.0, which is undergoing dramatic variations in the structure of circumstellar envelope.

Space research: A large areas of possible research activities are envisaged. Research on development of space technologies, application of space techniques, development of advanced space qualified radio communication and active participation in designs and applications of satellite telecommunications systems, space and ground networks and services ( wireless technology ), microwave engineering. Special interest among project partners receives the solar activity and the interaction of solar wind the Earth magnetosphere and with atmospheric molecules like the CO and N2. The use of clean solar energy can be more effective by increased efficiency of solar panels, which are currently being developed at Consortium Universities. The work in this field already has started in general item of renewable energy sources.
Important and promising is the research on future space navigation systems based on natural signals from cosmic sources in particular from the pulsars. The high stability of millisecond pulsars can be used to build extremely precise clocks and to build precise independent time measurements systems.

Large antenna can be used for communication with space probes allowing data reception and remote control of the probes instrumentation. The RT90+ can be very competitive to other existing space communication and navigation sites and can be effectively applied for ESA and NASA space programs.

5: The uniqueness of the proposed RI and its potential contribution to the advancement of scientific research (e.g. at national or European level); envisaged contribution to the consolidation of the relevant research capacity in Poland (e.g. including list of leading centres involved in the R&D field of the proposed RI in Poland); envisaged contribution to the increased competitiveness of the Polish research sector (e.g. enhanced capability to compete for HORIZON 2020 projects, prospect for future enlargement into a pan-European RI) and to the attractiveness of conducting research in Poland (the potential for “brain gain” or preventing “brain drain”):

It has been shown in sections 1-4 how and in which areas the RT90+ project can influence the science development and technology advancement on regional and European scales.

i) This will be the first time anywhere in world that a radio telescope has been constructed with the same Richey-Chretien wide field optics as used in optical telescopes - ideally suited for mounting cameras – these are now becoming possible to construct cost-effectively. Poland can be the first to take advantage of this with a special new facility.

ii) Parts of the cameras can be constructed in Poland and/or with international partners – the major point is that the unique characteristics of the RT90+ will inevitably attract non-Polish partners to work on/ contribute to advanced instrumentation – thus bringing in knowledge of the world-wide state-of-the art in high tech areas (especially digital electronics and big-data software techniques) to Poland. People will want to work with Poland since it has a unique capability to offer as its contribution to the partnership.

iii) The Horizon 2020 projects need involvement and development of industry partnerships. The proposed investment and technology research particularly in areas of advanced innovative digital electronics and processing as well as the huge data handling, are very general purpose universal requirements throughout technical industry.

iv) The European VLBI Network (EVN) of radio telescopes enhanced by the RT90+ will double the sensitivity so important to many astronomical and space advances. It will dramatically increase Polish and regional (Eastern Europe) capabilities to conduct “first league” research and created the RT90+ NCRST can act as the attractor for further development of science and technology.

v) RT90+ will be not only part of e-EVN (path finder for the ESFRI SKA project) but will allow direct extension of SKE to Europe.

vi) The Consortium of Universities and Research Centers - the NCRST will reorganize itself in future to the International Institute of the same name. The consolidation of relevant capacity of Poland has already taken place, and when the RT90+ project is completed, the new Institute will retain the same attraction power of bringing new partners to important space research and high tech development areas. At the moment three more institutes have put forward applications to join the NCRST Consortium.

v) The future enlargement of NCRST to pan-European Research Infrastructure is envisioned and the present international cooperation under the EC umbrella (many Frame Programs, Technology Innovation Centers, access to Large Scale European Infrastructure) paves the way towards Regional European Centre specialized in smart technologies innovation and space research applications. The potential of such RI will be built both on the international cooperation with research and educational Institutes and pan-regional cooperation with industry.

6: The research potential of the consortium (e.g. number and quality of publications relevant to the future RI’s activities); human resources in the R&D field of the proposed RI and expected future requirements (e.g. number of relevant personnel, concept to reach the target); research
The Consortium institutes’ capability is best in this field in Poland. At Torun we have 32 staff working in Radio Astronomy at TCfA. To maintain RT90 operation we need at minimum 10 more people on site (8 technicians 2 scientific positions)

All expected technical and research including R&D is challenging to us, we already possess wide knowledge and experience in the field and are involved in many European R&D programs for last 20 years

<table>
<thead>
<tr>
<th>Partner Institution</th>
<th>Fields of experience and expertise relevant to the RT90+ project</th>
<th>Dedicated own staff to the RI project (*)</th>
<th>Requested RI new positions</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCfA</td>
<td>Radio astronomy, instrumentation, R&amp;D on antennas, receivers, control systems, data processing</td>
<td>8 academics, 13 technicians, 4 doctorants</td>
<td>10</td>
</tr>
<tr>
<td>GUoT</td>
<td>Civil engineering, space technologies, application of space techniques, radio communication, applied informatics, digital data processing, control systems, computer networks, electromagnetic compatibility, radio communication system and devices, mechanics, industrial automation, planetology, precise measurement of time (clocks pulsars, nuclear, mechanical), modeling of large engineering structure, reliability, safety and risk reduction, the use of microwave in geoengineering methods.</td>
<td>10 academics, 13 technicians, 6-8 doctorants</td>
<td>10</td>
</tr>
<tr>
<td>SRC</td>
<td>Space qualified instrumentation, control systems, automated processes, satellite tracking and space communication, Solar wind – Earth interaction, physics of interplanetary space, magnetospheres of planets</td>
<td>5 scientists, 5 engineers, 3 doctorants</td>
<td>2</td>
</tr>
<tr>
<td>MUoT</td>
<td>Wide range of technical specializations. Large scale structure design and computer models, structure stress, microwave technologies, remote sensing, defense techniques, ground and space navigation, monitoring of the atmosphere</td>
<td>10 scientists 4 engineers 4 doctorants</td>
<td>5</td>
</tr>
<tr>
<td>NCAC</td>
<td>Computer modelling, advanced astrophysics</td>
<td>4 scientists</td>
<td>1</td>
</tr>
<tr>
<td>AO UJ</td>
<td>Radio polarimetry, radiometry, Low and Extremely Low Frequencies,</td>
<td>4 academics, 2 engineers</td>
<td>1</td>
</tr>
</tbody>
</table>
 (*) some of our staff will work on RT90 and NCR project 25-30% of their time. There are other natural commitments to education and research some of which are of common interest.

The consortium members are and will continue to be involved in design process of 90m telescope control systems, receivers, back-end electronics, software tools and research programs. The roles are initially allocated with TCfA and SRC being natural leading Institutes for instrumental development.

The proposed NCRST will be created by leading Polish radio astronomical and space research institutions. The project will be coordinated mostly by a team of scientists from Toruń Centre for Astronomy (TCfA) that already have extensive international experience.

Since 70's TCfA is the active member of European VLBI Network (EVN) that provides the most sensitive and accurate radio astronomical observations in the world. Note that there are many Polish research institutions (not only astronomical) being involved into big international projects similar to EVN but most of them are providing only a manpower for those projects. TCfA is engaging not only the manpower for the EVN but also very important research facility of 32 m radio telescope. This medium size radio telescope as well as previously used small one (15 m) were designed, build and equipped by Polish engineers and companies. TCfA has become a leading radio astronomical observatory not only in Poland but also on European scale. The observatory was one of the first European institutions that tested and introduced a new technique of the interferometric observations that is using data-transfer through the internet. This technique is now well know as e-VLBI. All this makes the experience of the TCfA team unique in Central/Eastern Europe. Director of TCfA has been elected to chair the Board of EVN Directors jn 2009-2011.

List of important international projects  (TCfA, PSSC, SRC, OA UJ, IA UZ, NCAC)

Cooperation in Science and Technology with Central and Eastern European Countries – CIPD3510PL928495, 1992-1995
The European VLBI Network of Radio Telescopes, ERBCHGECT920011 1995-1998
EXPReS – A production Astronomy e-VLBI Infrastructure, Contract No. 026642, 2006-2008
SKADS – Square Kilometre Array Design Studies, Contract No 011938, 2006-2008
RadioNet FP7, Advanced Radio Astronomy in Europe, grant agreement 227290, 2009-2012
RadioAstron – the Russian space VLBI program
GN3 - Multi-Gigabit European Research and Education Network and Associated Services, 2009-2013
DORII - Deployment of Remote Instrumentation Infrastructure – 2008-2010
Examples of most recent publication activity of some Consortium Institutes


Stefański, J., Low cost method for location service in the WCDMA system, Nonlinear Analysis: Real World Applications 14 (2013) 626-634


Lancaster, Katy; Birkinshaw, Mark; Gawroński, Marcin P.; Battye, Richard; Browne, Ian; Davis, Richard; Giles, Paul; Feiler, Roman; Kus, Andrzej; Lew, Bartosz; and 8 coauthors, Sunyaev-Zel'dovich observations of a statistically complete sample of galaxy clusters with OCRA-p, 2011, MNRAS, 418, 1441


Also look at:
Articles on RT90 in „Urania-Postępy Astronomii” 1-4/2010 (in Polish)
Space Research Centre, Annual Reports, 2010-12.

7: The concept for execution of the research programme; proposed access rules for external users; expected national or international dimension of the RI (e.g. envisaged proportion between domestic and external users after the first 5 years of operations):

The instrument will be open to all professional researchers in Poland based on a system of
submission of observing proposals. Observing time will be allocated by the Program Committee (PC) based on the scientific merits of the proposals and the technical capabilities of the 90m RT. At least 50% of the telescope time will be dedicated to the international community to increase competitiveness. The 32m RT presently provides observing services to the VLBI network for about 25% of the available observing time. A similar practice will applied for the 90m RT. The time allocation for VLBI observations is based on the recommendations of the Program Committee of the EVN (European VLBI Network), which judges the scientific merit of the observing proposals.

All scientific data obtained with the 90m RT will be made public after a maximum 1 year proprietary period. Polish and international scientists making observations on the telescope will be requested to post preprints of their publications based on their observations with the open access preprint server ArXiv, which is widely used in astronomy. Archiving of the observational data will be developed using principles similar to those used by, e.g. the Very Large Array (VLA) telescope in the United States, with the intention of developing interfaces for integration with the European Virtual Observatory project. Several members of the Toruń Centre for Astronomy participated in the European Virtual Observatory - Astronomical Infrastructure for Data Access School in Strasbourg in January 2010.

8: The overall cost estimates of the construction (e.g. main components, indication of the level of already available funding, expected sources of funding), the yearly cost estimates of future operations (including expected sources of funding):

RT90 occupies a new position in world astronomical instruments, we save its cost by limiting upper frequency to 22 GHz (the atmospheric conditions in Poland make this limit), by limiting sky coverage (operation above 25 deg in elevation) and by innovative hydraulic support and control. Making the instrument to work in automatic modem with remote control from any site of Consortium members should significantly lower the overall operation cost as compared to existing telescopes.

<table>
<thead>
<tr>
<th>Components</th>
<th>Estimated range (in millions of PLN)</th>
<th>Requested max (in millions of PLN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Construction cost of RT90+ radio telescope, our evaluation is based on costs of existing world instruments, depends on the diameter (90-110m)</td>
<td>120-180</td>
</tr>
<tr>
<td>2</td>
<td>Cost of needed additional instrumentation (also to build radio camera, receivers and digital backends, laboratories)</td>
<td>40-50</td>
</tr>
<tr>
<td>3</td>
<td>Cost of additional buildings, roads, fences etc., overall infrastructure</td>
<td>60-70</td>
</tr>
<tr>
<td>4</td>
<td>Total investment cost (1+2+3) Source: 85% the European infrastructure funds and 15% the state budget</td>
<td>220 – 300</td>
</tr>
<tr>
<td></td>
<td>Maintenance and running costs, which are based on present experience with 32 m and 15 m radio telescopes of TCfA and the operation cost of similar European EVN facilities</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Positions for additional 10 people of personnel (engineers, technicians, including three scientists positions)</td>
<td>1.0</td>
</tr>
<tr>
<td>6</td>
<td>Materials, media, transportation, the telescope site other costs</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Cost of EVN cooperation and correlator operation at JIVE, international cooperation, visiting scientists.

Requested additional contribution to run the telescope and to maintain its operation (5+6+7) 
Source: Ministry for Science and Higher Education, and EC FP programs.

The TCfA of Copernicus University will dedicate in addition to p.8 its technical staff (10 engineers, 5 technicians, with 80% commitments to RT90+, RT32 and NCR), the scientific staff (6 with 50% commitments) and also the current funds(SPUB) obtained from the Ministry, and from the EC FP7 and future programs (Trans National Access).

Consortium members will contribute in form of research grants.

Summarizing the yearly operation for the RT90+ telescope (8+9+10)

Consortium Institutes partners (internal)

To operate RT90 and to support activities within the Consortium we shall apply for additional SPUB and research grants (National sources – Ministry of Science)

Main expenses
- Antenna D=90m ok. 120 mln. PLN; D=110m ok. 180mln PLN.
- Buildings ~ 70 mln PLN
- Scientific equipment ~ 50 mln. PLN
- Total c.a. 240-300 mln zł, +10% reserv 330 mln (depends on the diameter of antenna)

Proposed investment into the laboratories at the Consortium Institutes is described in section 3.

The table reflects needs for the investment and (up to 5 years) scale running cost. Future, above 5 years and later after the completion of RT90, there will be need to reorganize the proposed National Centre for Radio Astromy and Space Technology and gather all available funds to the central administration. On the longer scale 10-30 years the NCRST should become fully independent from the parent, partner’s institutions and research organizations. Such reorganization will give more flexibility and would better suit us for serving the community with access to RT90+ and naturally to VLBI, ALMA and SKA. The NCRST might play the leading role of the coordinator in Radio Astronomy and Space research in Poland and in whole region of Eastern Europe.

Previous experiences, current involvement and plans with regard to collaboration with other sectors on regional and national level (e.g. industry, services, NGOs, scientific, social or cultural societies, SMEs, etc.):

Well documented cooperation with industry, with regional education and business centers takes place around Technical Universities of this Consortium. The Gdansk University of Technology – is known as the leader in the region in a number and quality of innovations and technology advancement as well effective partner of industry. Similarly the Space Research Centre and Military University of Technology are best examples of Polish Institutions who have and further expand broad cooperation with industry, other research institutes in Warsaw region.
The RT90+, so spectacular project, will attract experts from various sectors of industry (optics, automation, mechanics, mechatronics, IT technologies, construction). The openness of the project based on the study of RT90+, and laboratories with advanced technique and technology will drive technological and scientific progress. The real is the creation of spin-offs, which were acquired experience and skills will use in their business operations.

The Toruń Centre for Astronomy has experience to coordinate 60 companies, who were involved in the process of designing and building of high precision 32m antenna. Until now very profitable cooperation remains with Lenze, Aniro and Apator companies. The new challenges of RT90+ project will open up chances for small businesses and spin offs in the Pomerania and Kujawy regions.

10: Future possibilities for education and training of students and scientists (e.g. involvement in dissemination and/or exploitation, and management of intellectual property):

The National Radio Astronomy Centre will employ experts in many fields of science and engineering, providing an excellent environment for the education of students and post-graduate students. The maintenance of a modern radio telescope requires a wide knowledge in astronomy and astrophysics as well as mechanics, electronics, cryogenics and many others technologies used in industrial applications. Examples of technology that are crucial for radio astronomy and also very important for industry, especially for telecommunication, are low noise microwave amplifiers, and high speed digital signal processing and the handling of large data sets including data mining techniques.

This project will provide the opportunity of training students from many disciplines from universities and institutes of technology, i.e., PhD and MSc students, as well as through Summer Training Schools. This will concern not only Polish students but will also provide an attractive opportunity for international students, especially graduates (so called post-doc’s).

A superb precedent for using a national flagship project to encourage and develop and retain a nation’s “human capital” is the South African bursary programmes associated with the SKA. In the period 2008-2013 401 young people benefited SKA South Africa bursaries and scholarships, including a significant number of students from other African countries. The total comprises: Post-Doctoral Fellowships (39); Bursaries for Post-graduate (207), Undergraduate (103), Technical Diploma (28) students together with Internships (10) and Artisan programmes (14). This total is currently growing at over 90 per year. In addition five new research chairs dedicated to science and instrumentation of astronomy and attracting scientists from all over the world have been established in leading universities. These help to create a sustainable programme of technical and scientific education in the host nation.

One of the main goals of the NCRST Consortium and RT90+ project is to establish a leading research and education facility where young people will be trained and will carry out world-class, original scientific research. Exclusive education of young engineers and scientists that create the conditions to be competitive in field of modern technology is in line with the recommendations of the Commission for the Evaluation of Higher Education Report. These could include studies in broad range of attractive subjects, namely:

- space engineering – the interdisciplinary subjects,
- space qualified materials and components,
- ground and space navigation,
- high stability frequency standards,
- remote sensing and radiometry,
- cosmic magnetic fields and their role in the evolution of the Universe,
- high energy plasma physics and astrophysics,
- theory and modeling of radio emission and its propagation,
- advanced signal processing and coding,
- modeling of astrophysical signals of gravitational waves,
• chemical evolution of matter in the Universe,
• cosmology,
• mathematical physics,
• construction of large scale structures,
• dynamic models of deformable bodies, theories and applications,
• disasters and theories of self-organization and others.

The RT90+ proposal has already tiggered activites at some of the Consortium Institutions (GuoT, UZ, MUoT) to start the new subjects of studies, which combine engineering, physics and space technologies.

11: Interconnections of the proposed RI with the landscape of research infrastructures in Europe (e.g. list of similar RI in Europe, anticipated international collaboration, prospect for upgrading to regional RI level); vision for future collaboration with other national or pan-European RIs (eg. from the ESFRI roadmap); vision for collaboration with other European initiatives (e.g with European Technology Platforms, EIT or Joint Technology Initiatives):

The RT90+ will automatically be incorporated to the European VLBI Network (EVN) of largest radio telescopes in the world with great enthusiasm. As it has been mentioned earlier the EVN has not only European but in fact global character. It is so far the most advanced, most expensive, best ever sensitivity and highest ever achieved angular resolution astronomical instrument. Adding the new large antenna (30-40% of observing time) will make this array twice more sensitive and it total collecting area can come closer to ~ 0.25 of the SKA, the future ESFRI project (2025). The Polish telescope will join the large egsiting antennas at Effelsberg (100m MPIfR) and Sardinia (64m INAF). The EVN involvement guarantees further innovations in technologies to be implemented for joint future R&D projects.

The scientific programs of SKA and RT90+ will overlap in source surveys at declination zero, what will have large impact on both survey programs.

The RT90+ will become the important part of European extension of SKA and space communication (via ESA and NASA) network.

There is a great chance that taking to account the value added to the European RI, our project can be written to European ESFRI list as the Polish contribution and could be then financed totally from the EC funds.

Another large and significant investment into astronomical research is associated with Extremely Large Telescope (ELT) a 42m diameter optical telescope, also on ESFRI list, to be built in Chile. The RT90+ will directly link with ELT via program of transformational sky surveys in optical and radio – areas of sky overlap. A simultaneous observations on both telescopes may become possible and this would price the value of RT90+ additinally.

The RT90+ and the International Centre for Radio Astronomy and Space Technology may be invited to join the European Technology Platform. At the moment it is in the Polish Technology Platform for Defence. Similar action is highly probable with other European initiatives. This class of unique RI will be invited to join various European organizations and certainly will be engaged into European R&D activities through the ESA and possibly soon ESO connections.

12: Previous experience in serving the scientific community, the industry or the society (e.g. technology or knowledge transfer projects or initiatives); expected socio-economic impact (e.g. collaboration with local industry, with local schools or NGOs, SMEs); expected service activities:

The Astronomical Observatory of the NCU in Piwnice has fantastic record of visitors – about 50 thousands per year. The outreach and education of the general public, dominated by the young generation of future student has always been important to us. The major attractions are direct visual observations via optical telescope and the large 32m radio telescope. From many years experience it is obvious that theRT90+ will have outstanding visibility and will be extremely attractive. Thus together with the construction of the telescope the local governor of the region plans to invest into touristic facilities and to visitors centre. Overall investment in the telescope location will create...
fantastic conditions to promote since, education and technologies. The unique place in Poland and in eastern Europe. The touristic offers will be done professionally with help from the observatory staff. There is chance to build large complex of facilities with optical telescopes to accommodate interested visitors for few days and nights. The area of Bory Tucholskie and Wdecki Park Krajobrazowy have been already known for their unspoiled nature and recreation environment. The RT90 telescope can only bring more attractions as it will be by definition an ecological design.

Huge potential for public understanding of science and “outreach” from school children of all ages to undergraduates at Polish universities. All part of the “Human Capital Development” agenda which South Africa has done so well – just look at the SKA South Africa web site for many examples of involvement - over and above what I quoted earlier for Bursaries.

Another area of service for the society is to apply radio astronomy technique mainly radio interferometry VLBI to measure tectonic motion of the land and monitor rapid changes in such motion. Among more practical and very useful applications is the passive radiometry of Vistula flood (dikes) embracement along river bank. The radio method can help to localize weak parts of the dike and reinforce such parts on time preventing floods.

Many research staff members moved to the industry from the Institutes of this Consortium. It is not so common for the Universities doing research in astronomy but very common for the Technical Universities. Thus this service to the society is taking place and will continue on a larger scale in the future, when the RT90+ is completed.

RT90+ as a large-scale project can involve many more industry links – from large companies making the innovative telescope to small/medium enterprises (SMEs) supplying innovative hardware and/or software solutions for specific tasks to those simply supplying manpower materials and components for construction.

The aim would be to achieve the European standards in an economy “benefit-cost ratio” of around a factor two for the local economy – i.e. for every Euro spent specifically on project another euro of activity (often on related services) is generated.

13: Coherence of the proposed RI with goals and priorities of the Operational Programme Smart Growth – the version of September 2013\(^1\) or/and regional strategic documents (e.g. regional development strategies, regional innovation strategies):

The project to build RT90+ and to establish advanced centre for research in radio astronomy and space sciences – the NCRAST has been seen by the governors of regions of consortium member institutes ians best example of fulfilling the Smart Growth Operation Programme.

The RT90+ project is written into startegy documents of the regions Kujawsko-pomorskie and Pomorskie and also to the polish government document KPZK 2030 mentioned in section 3 – the fulfillment of administration procedures.

The project, especially its technology and space research, is considered as the best example of regional and Polish specialization, which so perfectly matches the expectations of the Operation Programme Smart Growth. It should become a national pride.

Obviously the growth encompass regional investments including industry and business as well as quality education on all levels.

In this respect the project of RT90+ has highest priority among others considered in regions of Pomorze and Kujawi. We have very good support and understanding of the projectuniversal values by the governors on regional and the central government administration.

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In this section we explain why the update is necessary and what has been changed since the original proposal submitted successively at the end of 2010. The project has been positively evaluated and positioned on the Polish Road Map of Research Infrastructure.

Since 2010 several changes were accounted.

Firstly due to rising cost of materials and labor in Poland the initial cost of the telescope with equipment estimated to be around 120 MPLN has risen to 120 – 180 MPLN for antenna only in 2013 cost evaluation. The second reason for RT90 price increase has been related to change in the concept to steering mechanisms. From the original proposal to use hydraulic pull-push arms of the Stuart platform concept we changed to the classical rail azimuth – elevation mechanical drive. It is more expensive and may add 25% of the antenna cost yet it was a good decision since our review of existing telescopes and proposed new ones clearly showed variety of problems to get sufficient positional accuracy and required robustness from the Stuart platform design.

The Consortium made another decision to expand the project towards high tech innovative solutions, which could also be used two fold to boost the local industry and to make use of developed technologies for other project especially needed for Space research. Poland has joined ESA and we need to build up groups of experienced engineers and technicians capable to undertake ambitious requests from ESA and NASA Space programs.

State of the art ultra wide band, ultra low noise receivers designed and build for RT90+, high speed digital data processing in real time, ultra wide band fibre optical networks to super computers and finally data archive system with nearly instant access, all designed and build in this country will open up new chances for expansion these technologies to space research. The groups of experienced engineers and technicians, also scientific staff, built around RT90 and NCRST, will definitely be capable to undertake any technical challenges covering area of their unique skills.

Thus an extra cost of investment is planned to spent on a new Centre for Space engineering in Gdansk University of Technology, the laboratories at Technical University in Bydgoszcz and laboratories both at the TCF and Astronomical Institute at University of Zielona Góra.

Coat of the equipment needed to design and to build receivers is significantly higher than that estimated in 2009.

In a summary the cost given in this update is realistic and if we make successful proposal to receive European funds this will be sufficient and safe to complete the investment.