# THE HISTORY OF RADIO ASTRONOMY IN POLAND: FROM SOLAR PATROLS TO PULSARS AND VLBI

**K.T. Chyży**
*Astronomical Observatory of Jagiellonian University,*
*ul. Orla 171, 30-244 Kraków, Poland.*
E-mail: chris@oa.uj.edu.pl

**J. Kijak**
*Janusz Gil Insitute of Astronomy, University of Zielona Góra,*
*ul. Prof Z. Szafrana, 65-516 Zielona Góra, Poland.*
E-mail: jkijak@ia.uz.zgora.pl

**A. Kus**
*Institute of Astronomy, Nicolaus Copernicus University,*
*ul.Gagarina 11, 87-100 Toruń, Poland.*
E-mail: ajk@astro.uni.torun.pl

**M. Soida**
*Astronomical Observatory of Jagiellonian University,*
*ul. Orla 171, 30-244 Kraków, Poland.*
E-mail: soida@oa.uj.edu.pl

**and**

**R. Wielebinski**
*Max-Planck-Institut für Radioastronomie, Auf dem Huegel 69,*
*53121 Bonn, Germany.*
E-mail: rwielebinski@mpifr.de

**Abstract:** The development of radio astronomy in Poland took some time to occur, in view of the destruction of the country during World War II. Also, the shift of the country's borders in favor of the Soviet Union led to the loss of two important astronomy observatories: the historic centers of astronomy in Wilno and Lwów. The relocation of these important astronomical centers to Toruń and Wrocław in the West needed considerable effort. Hence radio astronomy was a second priority as the optical astronomers had to become operational first. Nevertheless, in the 1950s groups in Kraków and Toruń started to erect radio telescopes. In Kraków solar radio astronomy became established. In Toruń, there were experiments with low frequency parabolic antennas. First, a 15-m dish was built, and later a 32-m dish became operational. In Kraków the solar patrol continued and a LOFAR station was added. Contacts with radio observatories in other parts of the world were established. In 1988 a new regional university was established in Zielona Góra, and a group involved in pulsar research was built up there.

Astrophysics departments existed at Warszawa (Warsaw) University and at the Nicolaus Copernicus Astronomical Center (CAMK) of the Polish Academy of Sciences, and the universities in Poznań, Gdańsk and Lublin had astronomical departments, but none of these was involved in radio astronomy.

**Keywords:** Poland, radio astronomy, Kraków, Toruń, Zielona Góra University, LOFAR, solar research, pulsars, VLBI

## 1 INTRODUCTION

Astronomy in Poland has a long history. The foremost historical astronomer is Nicolaus Copernicus (Mikołaj Kopernik) (1473–1543) who initiated the heliocentric theory that placed the Sun in the centre of the Solar System. Copernicus was born in Toruń, studied at Jagiellonian University in Kraków, and later lived in Italy until his death in the lands of the Teutonic Order (in Frombork). Another important Polish astronomer was Johannes Hevelius (1611–1687), who lived in Danzig (Gdańsk).

The age of observatories began with the creation of the first observatory in Wilno (now Lithuania) in 1753. This observatory was moved to Toruń in 1945. Kraków Observatory was established in 1792 by the astronomer and mathematician Jan Śniadecki (1756–1830). Lwów Observatory, which was founded in 1771, had to move to Wrocław, since Lwów became a part of the USSR (now Ukraine). Other observatories existed in Poznań and Lublin, just to name the larger cities. The important observatories in the Polish capital Warszawa (Warsaw), founded in 1825, were destroyed during the Second World War. However, with the creation of the Polish Academy of Sciences and the support of the Warsaw University this city has remained an important centre for astronomy through to the present day.

Polish astronomy was in a bad shape in 1945. Two main pre-war observatories (Wilno and Lwów) were lost due to border changes in the East. Some of the staff from these observatories moved to the cities of Toruń and Wrocław in the West. A new university named after Nicolaus Copernicus was established in Toruń. The development of the Astronomy Faculty in Toruń was led by Professors W. Dziewulski (1878–1962) and Wilhelmina Iwanowska (1905–1999). The observatory in Poznań was not destroyed, and teaching there already began in 1945. The head of the Poznań Observatory was Professor J. Witkowski, and he started to push for a national astronomical centre that in due course became a part of the Polish Academy of Sciences (PAN) in Warsaw. The Kraków Observatory became active with Professor Tadeusz Banachiewicz (1882–1954) as the Director. The astronomers from Lwów settled in Wrocław, reconstructing the ruins of the former German university observatory there.

The major problem plaguing all astronomical observatories in Poland in these early years after 1945 was the political insistence of the Polish Government to 'learn from the USSR'. Thus, there was political pressure not to have contact with Western institutes. For a long time this made it difficult to obtain permission to travel to observatories or university astronomy departments in Western countries.

## 2 JAGIELLONIAN UNIVERSITY AND THE RADIO ASTRONOMICAL OBSERVATORY IN KRAKÓW

During World War II Jagiellonian University was closed down by the Nazis. The war caused the loss of almost 28% of the professors, but several hundred students risked their lives to participate in clandestine education. Fortunately, the University buildings survived the war. Krakow Observatory was the only one in Poland to operate during the occupation. Meteorological measurements were made, and with the quiet consent of Kurt Walter (the Director of the Observatory appointed by the German occupation authorities in Poland) astronomical observations also were carried out. Until 1944 there was an observing station on the Mt. Lubomir near Kraków, but the Germans burned it down in retaliation for the activities of Polish partisans.

In the decades following the war Poland remained under the political influence of the Soviet Union, and it was only after the political changes in 1989 that the University regained full autonomy.

Already in 1948 an attempt was made to restart full-scale astronomical research. Dr Stefan Piotrowski visited Harvard Observatory, and returned with a photomultiplier. Sometime in the early 1950's Professor Tadeusz Banachiewicz gave Adam Strzałkowski a copy of a paper by Grote Reber. Although the paper was a Spanish translation, a lively discussion about radio astronomy took place in meetings at the university. This led to a decision to start radio astronomy. After this discussion Adam Strzałkowski teamed up with Oleg Czyżewski and Jerzy de Mezer and started a project to construct a radio telescope. With the limited resources available, only a small (5-m diameter) antenna was envisaged, but this would allow the observation of solar radio emission at 1-m wavelength.

### 2.1 Fort Skała: the New Radio Observatory

The search for a new radio observatory site outside the city of Kraków finally led to a decision to concentrate on Fort Skała (Figure 1). It was a decision that was not unanimous because nearby the Polish Air Force was expanding its airport in Balice (now the Kraków International Airport), which could be a potential source of electrical interference.

Fort Skała was a relic from the days of the Austrian Empire. There was a whole chain of such forts around Kraków intended for defence from all directions. The fort was used during the War by the German Wehrmacht, first for imprisonment of Red Army soldiers and later for storage of military equipment. In 1945 the Germans blew up the bridge to the fort and the entrance to the buildings, which created postwar access difficulties, but in 1953 Professor Tadeusz Banachiewicz used his skill as an alpinist and was able to inspect the Fort. He found that damage to the building was minor, and once the bridge was rebuilt a radio astronomy laboratory was installed. Local villages provided the first employees, notably the general caretaker, Stanisław Moroz.

The first contacts with the military authorities trying to obtain some old German military antennas led to interrogation by the security police. Thus, in-house construction of a radio telescope had to be considered and this was done by the engineer Leon Kowalski. The plan was to have a 5-m dish, with an equatorial mounting and manual declination change. From the beginning, a motor-assisted right ascension movement was available. The radio telescope structure was made from welded

Figure 1: Fort Skała, an old Austrian fort, was the first radio astronomical observatory of Jagiellonian University. On the roof is the 7-m antenna that later was used for solar monitoring (courtesy: Jagiellonian University Archive; henceforth JUA).

steel pipes with a wire mesh surface. Long discussions took place about the shape of the antenna—radar handbooks from the USA were obtained that defined the need to meet a 1 cm surface accuracy. Kowalski decided to put in a safety factor of three, and insisted on a 3 mm surface accuracy. Because of this decision the manufacture of the pipe segments caused problems in the accuracy, and many spares were made, enough to build a second antenna with a lower surface accuracy. Discussions about making an interferometer took place. However, Kowalski insisted on the rejection of the sub-standard sections so as 'not to demoralise the manufacturer'.

There was a partial eclipse of the Sun on 30 June 1954 and all efforts were made to observe this event. The antenna was ready only at the beginning of June and extensive adjustments and calibrations were needed. The observing frequency was 332 MHz ($\lambda$ = 90 cm). Since initially there was no electrical power at the site, batteries were used. The radio telescope could be driven in right ascension but needed manual setting in declination. They started just 30 minutes before the eclipse maximum, and continued for two hours. These were the first scientific radio astronomical observations made in Poland (Masłowski, 1957) and they marked the beginning of radio astronomy at Jagiellonian University.

In 1955, after the death of Professor Banachiewicz, renewed efforts were made to obtain more advanced instrumentation for the Radio Observatory. The International Geophysical Year 1957–1958 led to a decision to make regular solar radio observations at Fort Skała. Professor Karol Kozieł assembled a team comprising Oleg Czyżewski, Józef Masłowski (Figure 2) and Czesław Jarosz. Professor Adam Strzałkowski continued as a consultant to this young team. This led to the extension of the 5-m dish to 7-m in 1959, and it was equipped with a receiving system for 810 MHz ($\lambda$ = 37 cm). Observations of solar activity remained the main task of this radio telescope (see Zięba et al. 1976). The inner section of the dish got a new solid copper sheet surface. The Fort Skała Radio Observatory eventually was connected to electrical power, and a telephone line was installed. A more advanced receiver system was constructed for 460 MHz ($\lambda$ = 65 cm) that was used for observing the solar eclipse of 15 February 1961.

Figure 2: Professor Józef Masłowski (1931–2020), Director of the Radio Observatory during 1979–1984 and 1989–1999 (courtesy: JUA).

At this stage a proposal to construct a larger (15-m) dish was made by Oleg Czyżewski. This proposal was coupled with the 600-year Jubilee Celebrations of Jagiellonian University. The person who pushed this proposal was Professor Eugeniusz Rybka, the new Director of the Radio Observatory. The Observatory was officially opened on 5 May 1964 but there was no money for a new radio telescope. The 7-m dish was then moved to a new site and became a solar patrol instrument. The observing zeal of staff members (see Zięba and Michalec, 1969) led to a series of long-term observations of the Sun at 430 and 810 MHz.

Based on these humble beginnings, Professor Kozieł, the new Director of Theoretical Astronomy and Geophysics, began negotiations to construct a 15-m radio telescope (see Machalski and Masłowski, 1972). This project was put in the hands of industry, and the firm Mostostal was awarded the contracts for both the steel structure and the drives. The construction of the deep dish (f/D = 0.23) by the company lead to various problems needing redesign in order to reach the required specifications. In parallel Józef Masłowski negotiateed with the Institute for Telecommunications in Warsaw and ordered a parametric amplifier for 1300 MHz ($\lambda$ = 23 cm). This receiver was delivered in 1969 and the first observations of radio sources were made with the new 15-m dish. Jerzy Machalski then made plans for a Cassegrain focus, and this project was only completed after enormous effort. The construction of the secondary mirror of 1.5 m led to negotiations with the Akademia Górniczo-Hutnicza, where the aluminium blank was poured. The final shaping was done in the Radio Observatory's workshop since no engineering company in Kraków was able to do this job. At the same time the receiving equipment had to be fitted to the telescope structure. Since the parametric amplifiers weighed some 50 kg innovative methods of joining the feed to the amplifier had to be developed. The finished 15-m antenna is shown below in Figure 3.

Figure 3: The 15-m dish with its Cassegrain focus, which marked the beginning of serious radio astronomy in Kraków (courtesy: Astronomical Observatory Library).

The effort to bring the 15-m radio telescope into operation strained the resources of the Observatory. For example, the parametric amplifier needed a klystron as a pump, and the life of such devices was very short, hence they were expensive. Also, the change of a klystron needed extensive retuning of the whole system. As a result of all these problems, the 15-m radio telescope was used for some time without the drives in the scan mode. The connection of the feed to the receiver in the laboratory was implemented by the use of wave guides. This needed rotation wave guide joints, that could not be purchased with Polish money. During all the phases of implementation of the 15-m telescope solar monitoring with the 7-m dish continued.

## 2.2 International Contacts

In the late 1960s, the political opening up of Poland allowed the staff of the Radio Observatory to travel to other observatories, and to institutes in Western countries. This allowed staff to gain additional experience, and support in construction of technical instruments.

The first person to travel to the National Radio Astronomy Observatory (NRAO) in the USA was Józef Masłowski, and his experience formed the basis for the success of observational radio astronomy in Poland over the coming years. In 1971 Masłowski returned from his sabbatical year in the USA with state-of-art receiving elements for the solar radio telescope. This required the support of the NRAO Director since many of the items were restricted and on the 'Embargo' list. Arguing that the electronic items would be used for science only, permission was granted.

On the astronomy side, Masłowski became involved in the detailed studies of a sample of radio sources (known as the GB survey) detected by the NRAO 300-foot radio telescope in Green Bank at 1400 MHz (Masłowski, 1971). To study the spectral properties of the sources, 2695 MHz observations also were made with the same antenna (Masłowski, 1974). The survey allowed the counting of radio sources to show a certain anisotropy of their position in the sky. This important result was confirmed much later, that galaxies are not uniformly distributed in space, but form structures now called the 'cosmic web'. A collaboration with Jerzy Machalski continued the detailed investigation of the radio sources in the GB/GB2 area. New and high-resolution studies of the GB/GB2 sources with the VLA were made (Machalski and Condon, 1983). Spectral investigations of the Green Bank sources continued, and finally the samples GB/GB2/GB3 were used by Ryś and Machalski (1990) to investigate radio variability in complete samples of extragalactic radio sources at 1.4 GHz.

Contact with the Max-Planck-Institut für Radioastronomie (MPIfR) was first made at the URSI General Assembly in Warsaw in 1972. However, it took some time to organise permission to travel to the MPIfR in Bonn. It was only in 1976 that the first visit by Józef Masłowski could take place. The study of GB/GB2 radio sources was followed in collaborative observations of the sources at a frequency of 4850 MHz using the Effelsberg 100-m radio telescope (Masłowski et al., 1981).

The excellent opportunities for combining local preparations using the small solar telescopes, leading later to the use of state-of-art instruments in the world, involved an extensive travel program. Dr Marek Urbanik went to the MPIfR in Bonn in 1980 and joined the magnetic fields group. The Effelsberg 100-m radio telescope had excellent polarization properties and sufficient angular resolution for the study of nearby galaxies. The earliest observations were made of large galaxies, such as M31 and M33. One of the early observed sources involving Marek Urbanik was the southern galaxy NGC253 (Klein et al., 1983). A survey of interacting galaxies and Virgo cluster galaxies was performed with the 100-m radio telescope at 2.8 cm (Urbanik et al., 1985). Signatures of helical galactic magnetic fields were studied in nearby galaxies, such as M31 (Urbanik et al., 1994) and the Magellanic Clouds (Urbanik et al., 1997).

Soon, two younger staff members from Kraków, Krzysztof Chyży and Marian Soida, were invited to continue the collaboration initiated by Marek Urbanik, and they became frequent guests of the MPIfR. Having extensive access to the Effelsberg radio telescope, the collaboration used either the Effelsberg dish alone or to enhance high-resolution VLA data on galaxies with missing extended emission.

A very lively collaboration also developed with the group at Bochum University led by Professor Dr Ralf-Jürgen Dettmar, where experience in optical data of galaxies, especially calibrated H$\alpha$ maps of galaxies, were invaluable in correlating magnetic fields with properties of the interstellar medium. This collaboration of the Kraków-Bonn-Bochum groups led to a series of papers with excellent results. The magnetic fields and strong density wave effects could be studied (Soida et al., 1999) by combining continuum and CO observations. The discovery of strong, ordered, magnetic fields in the irregular, weakly rotating galaxy NGC4449 (Chyży et al. 2000) was published. Also in cooperation with Bochum University Tüllmann et al. (2000) investigated the thermal and non-thermal gaseous halo of NGC 5775.

Magnetic fields in interacting galaxies in groups were studied (Soida et al., 2001), showing strong radial magnetic fields in the absence of density wave flows (Chyży et al,, 2003; Knapik et al., 2000; Soida et al., 2002; and many more). Magnetic fields were detected in galactic tidal tails (Chyży and Beck, 2004) revealing the relation between galactic magnetic fields and star formation activity.

At the same time, Michał Ostrowski spent a two-year Scientific Visitor's Scholarship at the Max-Planck-Institut für Extraterrestrische Physik in Garching, and undertook theoretical

Figure 4: Katarzyna Otmianowska-Mazur, was Director of the Observatory from 2005 to 2012, and was an inspiring researcher of magnetic fields (courtesy: M. Mazur).

work on the acceleration of cosmic rays in shock waves (e.g. Ostrowski, 1988). This subject, considerably extended to particle propagation of high-energy particles in highly turbulent plasma regions, in radio jets of extragalactic sources and in quasars, continued in the following years in a broad international and national collaboration (e.g. see Ostrowski, 1991; Ostrowski and Bednarz, 2002; Ostrowski and Schlickeiser, 1993).

Meanwhile, theoretical and modelling studies devoted to star-forming galaxies were undertaken by Professor Katarzyna Otmianowska-Mazur (1957–2020; Figure 4), who made 3D-numerical magneto-hydrodynamic simulations of the magnetic field evolution in a turbulent interstellar gas (Otmianowska-Mazur and Chiba, 1995). The modelling was developed and refined over many years and successfully applied to explain particular types of observed magnetic field patterns in spiral, barred, irregular and Virgo Cluster galaxies (e.g. Elstner et al.; 2000; Kowal et al., 2009; Otmianowska-Mazur et al., 2000, 2003). Many joint conferences date to this cooperation of theorists and observers.

In October 1995, a new 8-m solar radio telescope with full automation and a new system for observation and data collection, without the participation and presence of an observer in the cabin, was launched at the Observatory, replacing the old 7-m dish. New, daily observations, conducted simultaneously in several radio bands from 10 cm to over 1 meter, became the foundation of detailed analyses of the solar activity cycles over the following years (e.g. see Zięba et al., 2001).

Research on active objects has also progressed over the years. Multi-frequency studies of giant radio sources were undertaken by Jerzy Machalski, who discovered the largest radio galaxy in the Universe, J1420−0545 (Machalski et al., 2008). In order to explain such objects, spectral ageing analysis and dynamical analysis were used in analytical modelling of the evolution of such sources (e.g. Machalski et al., 2007).

Ageing analysis of the giant radio galaxies was also of interest to Marek Jamrozy, who spent a postdoc year at Bonn University (e.g. Jamrozy et al., 2005). He soon became a specialist on double-double radio sources (Jamrozy et al., 2008), often using the Giant Metrewave Radio Telescope (GMRT) at the National Centre for Radio Astrophysics in Pune (India).

At a history colloquium in 2005 Masłowski and Strzałkowski (2006) presented an overview of earlier developments in radio astronomy at Jagiellonian University.

## 2.3 Contribution to the LOFAR Project and Recent Astronomical Highlights

The involvement of the Kraków radio astronomy group in many international projects has opened up opportunities to gain access to the newest generation instrument: the LOw Frequency ARray (LOFAR). The development of the LOFAR system in Europe was organised by the Netherlands Institute for Radio Astronomy with international partners as the International LOFAR Telescope (ILT). The first stage was completed in 2012 by ASTRON, giving access to high resolution, low frequency observations. Logically, in view of their interests in magnetic fields and radio sources, the Jagiellonian University radio astronomy group wanted to join this European project.

Preparations took several years. In March

2007 five Polish institutes initiated the Polish LOFAR consortium, POLFAR, headed by Jagiellonian University and Katarzyna Otmianowska-Mazur. It was agreed that three stations should be set up in Poland so that, if necessary, the simplest interferometer using Polish stations could be established, and the stations could conduct independent studies of various objects and phenomena. Opportunities were sought to finance this idea. In the meantime, scientific cooperation with LOFAR international research groups began. In 2008 Krzysztof Chyży became the Polish representative in the Surveys Key Science Project and a member of the Core Team, then he also became a member of the LOFAR Magnetism Key Science Project, a member of the Management Team, and the vice-coordinator of the Nearby Galaxies Working Group. In June 2010, the project of building Polish stations was prioritised and entered into the prestigious Polish Roadmap for Research Infrastructures. Active efforts were then made to obtain funds, and finally this happened in 2013 when the Ministry of Science and Higher Education awarded a grant of 26 million PLN.

Three stations were actually built, one for the Jagiellonian University at Łazy, 50 km from Kraków. The work of setting up this station, completed in October 2015 (see Figures 5 and 6), was supervised by Marian Soida and technical staff from ASTRON, supported by the University radio astronomers, technical staff, and students. Polish stations significantly increased the longest baselines of the LOFAR interferometer and raised its sensitivity, especially at the highest spatial resolution. The POLFAR project then obtained funding for the annual contributions to the ILT and operational costs for running the Polish stations from the Ministry of Science and Higher Education.

Kraków radio astronomers began contributing to numerous LOFAR science projects e.g. the LOFAR two-meter Sky Survey, or LoTSS (Shimwell et al., 2017, 2019); the studies of intergalactic magnetic fields (O'Sullivan et al., 2019); and studies of giant radio galaxies (Dabhabe et al., 2020). The analysis of a large sample of galaxies and their radio spectra was conducted by Chyży et al. (2018), and new LOFAR data made it possible to refute the earlier hypothesis that the low-frequency galaxy spectra are flattened due to thermal absorption. Modeling of galaxies has shown that spectral curvatures are caused by cosmic ray energy losses and propagation effects. Błażej Nikiel-Wroczyński studied galaxies in compact galaxy groups based on the LoTSS survey. He proved the common character of the magnetic field inside galaxy groups and its detectability (Nikiel-Wroczynski et al., 2019).

Research of the Kraków's radio astronomers was not limited to a single instrument. Using X-ray and radio data Marek Weżgowiec et al. (2016) proposed the magnetic reconnection in the magnetic arm regions of NGC 6946 galaxy as the possible cause of the additional heating of the gas and ordering of strong magnetic fields. A young staff member Urszula Pajdosz-Śmierciak, using the GMRT, revealed episodic jet activity with a precessing jet axis in the blazar SBS B1646+499, which showed the properties of merger (Pajdosz-Śmierciak et al., 2018). Recent magneto-hydro-dynamical modelling by Siejkowski et al. (2018) showed that the cosmic-ray-driven dynamo works efficiently enough to amplify the magnetic field even in low-mass dwarf and irregular-type galaxies.

The development of the Radio Astronomy and Space Physics Department of the Astronomical Observatory moved to be the responsibility of the younger University Professors Krzysztof Chyży and Marian Soida. The general direction remains the same: magnetic fields in the Universe and active galaxies studied now with the largest telescope systems, including LOFAR, which is currently the group's largest instrumental project. Preparations for the upgrade of LOFAR to version 2.0 are already underway, which will significantly improve the quality of the data acquired, their calibration and images. This development will allow us to maintain LOFAR as the best low-frequency instrument also for the next decade. This project will one day culminate in the Square Kilometer Array, and some of the Jagiellonian University staff are already actively involved in the preparation of research for this instrument.

## 3 THE NEW ASTRONOMICAL OBSERVATORY IN TORUŃ

The Nicolaus Copernicus University (Uniwersytet Mikołaja Kopernika; UMK) in Toruń was founded in August 1945. Astronomers from the Stefan Batory University in Wilno were expelled by the Soviets and eventually settled in Toruń, attracted by the fact that this was the birth city of Copernicus. The teaching of astronomy began in December 1945. Władysław Dziewulski became the Founding Professor of the Astronomy Department, and Professor Wilhelmina Iwanowska (Figure 7) was responsible for the astrophysics section of the Department. Both were actively involved in the foundation of the Astronomical Faculty at Nicolaus Copernicus University.

Figure 5: Installation of the high band antennas at the LOFAR station in Łazy near Kraków during September 2015 (courtesy: B. Śmieriak).

Figure 6: Operational low band antennas at the LOFAR station in Łazy near Kraków in October 2015 (courtesy: M. Soida).

In addition to having working space within the city of Toruń they searched for land that would be suitable for an observatory. This was found in Piwnice, 12 km from the city. The first building at Piwnice, which was constructed in 1948, was a 5-m dome for an 8-inch Draper astrograph that was a present from the Harvard College Observatory. Further optical instruments were installed at Piwnice through the support of Professor Bertil

Lindblad (1895–1965) from Sweden. Professor Iwanowska had good contacts with overseas astronomical institutes, and managed to visit the USA on an IAU scholarship. Professor W. Dziewulski also was able to attend the 1948 IAU General Assembly in Zurich. Meanwhile, to accommodate the political climate, in 1954 Professor Iwanowska led an expedition to observe a solar eclipse from the Caucasus, in the USSR.

The first radio astronomy contacts were made by H. Iwaniszewski, who visited the Crimean Radio Astronomy Observatory in 1956. At that time, radio astronomy was considered a military secret in the USSR, but an earlier proposed visit by Stanisław Gorgolewski (who had come to Toruń from Poznań University) to the Crimean Radio Observatory had been refused, because he wished to become familiar with electronics, which was top secret in the USSR.

The Polish Academy of Sciences (PAN) was formed in 1953, and in January 1957 it established astronomical institutes with branches in Warsaw, Borowiec and in Toruń. A large institute for astronomy, the Centrum Astronomiczne im Mikołaja Kopernika (CAMK), was constructed in Warsaw. This institution supported the radio astronomy institutes by offering courses in astrophysics, and several staff members from the radio astronomy institutes were educated at the CAMK. The top people in astrophysics in Poland were attracted to CAMK: Bohdan Paczyński (1940–2007), J. Smak, W. Dziembowski, A. Zdziarski, M.J. Sarna, B. Czerny, and others. A smaller branch became the PAN Laboratory of Astrophysics in Toruń. Close cooperation between the staff members of the UMK Observatory and the PAN Laboratory was established.

The International Geophysical Year (IGY), which started in August 1957, led to many efforts to improve the observational possibilities of the UMK Observatory. The launching of Sputnik in 1957 clearly pointed to the need to become involved in radio astronomy. Professor Iwanowska organized a visit by Professor K. Grzesiak to the Nançay Radio Observatory in France. Dr Stanisław Gorgolewski (1926–2011; Figure 8) was transferred from the Physics Department to an Astrophysics Chair. The first solar radio receiver (containing more than 100 valves) was completed in June 1957, and in that same year the first radio telescope, the 12m × 26m RT-1 cylindrical reflector, was completed (see Figure 9). This instrument was used to make successful observations of the Sun. Good contacts with the Warsaw University of Technology and Telecommunication

Figure 7: Professor Wilhelmina Iwanowska (1905–1999) came from Wilno and was active in the development of radio astronomy in Toruń. She was also a Vice-President of the International Astronomical Union and strongly supported contacts with overseas institutes (courtesy: S. Krawczyk).

Institutes were established. It was a momentous task to build up the technical laboratories needed to support radio astronomy in such a new regional university.

In spite of political difficulties, with strong support from Professor W. Iwanowska, international contacts were established with radio astronomical institutes in Western countries. In 1957 Professor A. Woszczyk went to Liege on a Belgian Scholarship, and in 1958 Professor Gorgolewski won a British Council Scholarship and went to the Cavendish Laboratory, Cambridge, to work under the supervision of Professors Martin Ryle and Antony Hewish.

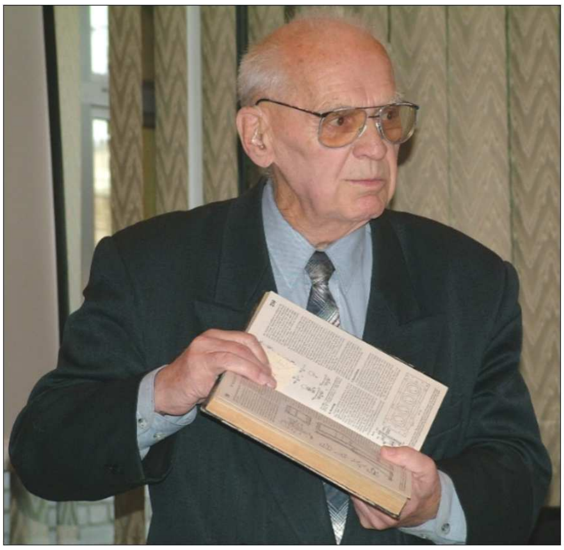


Figure 8: Professor Stanisław Gorgolewski, the long-time Director of the Toruń radio astronomy group was responsible for building up the technical observing facilities and construction of the 32-m dish (courtesy: S. Krawczyk).

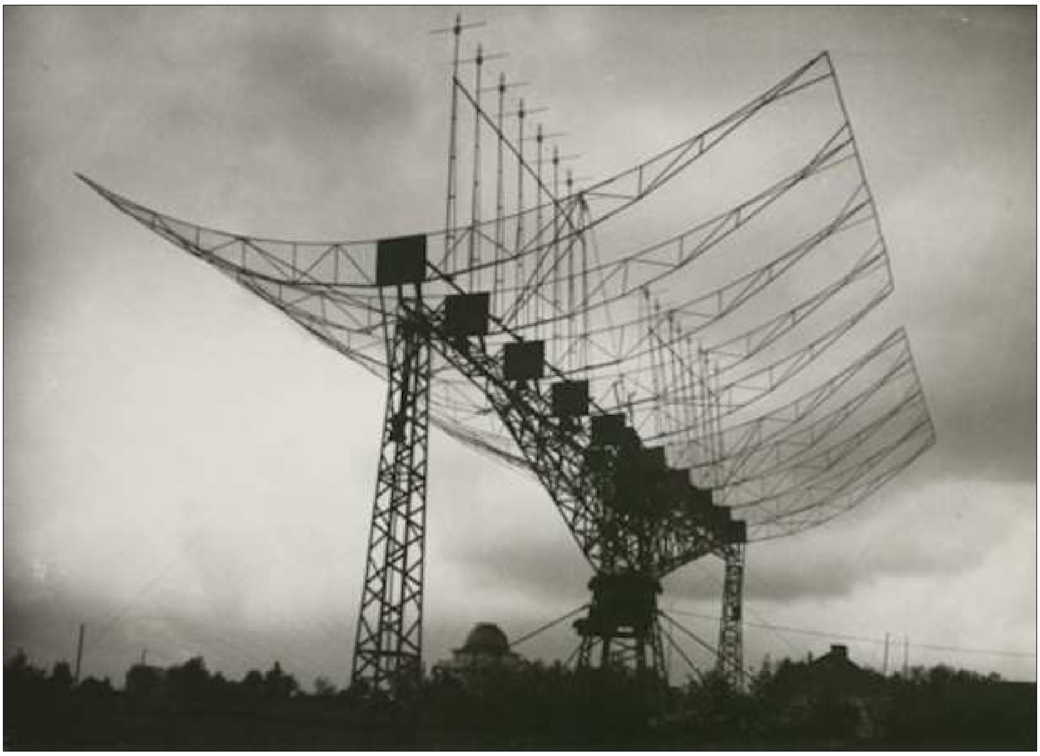


Figure 9: The RT-1 radio telescope (photograph: H. Iwaniszewski).

Upon returning from Cambridge in 1960 Stan (as he was called) brought back electronic equipment, and he started to construct the first low frequency receivers. He was impressed by the 'string, sealing wax and plastic tape' methods that he learnt at Cambridge. There, he had worked with Antony Hewish, and he was fascinated by the possibility of doing state-of-the-art research with simple instrumentation. Thus, antennas were constructed for the observation of Jovian bursts at low radio frequencies (i.e. 21 MHz), and 32 MHz interferometric studies of the solar corona were published (Gorgolewski and Hewish, 1960; Gorgolewski et al., 1962; Gorgolewski, 1965). At one stage three antennas were connected as an interferometer for solar research. Cooperation with Dr Jan Hanasz from the Polish Academy Toruń Unit was established, which later was extended to a space radio astronomy project. In addition, a 12-m dish was constructed and used for solar patrol observations, first at 127 MHz and later at 327 MHz.

## 3.1 Instrumental Developments in Toruń

New young people were joining the radio astronomy group bringing in new ideas. One person who deserves special mention is Dr Zygmunt Turło, a physicist, with a good knowledge of electronics. Since the political situation did not give much financial support for science projects Dr Turło decided to construct a 15-m dish antenna that could be included in European VLBI observations. First a 12-m dish named RT-2 was constructed in 1959 (Figure 10). This was a fundamental change in thinking: away from the low frequency antennas, and towards the future of European radio astronomy. The RT-2 was followed by the RT-3 dish. This was a major step for the Toruń radio astronomers to move to higher radio frequencies.

In order to extend their knowledge, all Toruń radio astronomers were encouraged, especially by Professor Iwanowska, to make visits to radio astronomy institutes throughout the world. Also, small technical improvements took place, such as the move to semiconductors *in lieu* of valve electronics. New young people, such as Drs A. Kus and A. Wolszczan, joined the radio astronomy effort in Toruń. The visits to other radio astronomy institutes led to regular visits by A. Wolszczan to the Max-Planck-Institute for Radio Astronomy (MPIfR) in Bonn, starting in 1972. In the early papers that were published (e.g. Hewish et al., 1985; Nowakowski et al., 1982; Wolszczan, 1980; Wolszczan et al., 1974, 1981) there was an emphasis on pulsar scintillations. In 1973 Dr Kus went to Cambridge and worked on the 5C6 and 5C7 surveys of radio sources (Pearson and Kus, 1978). Also, contacts were made by Dr Kus with the Jodrell Bank Observatory (JBO) at this time, which became the basis for further developments, i.e. Dr Kus got a postdoc position at JBO in 1979, where he

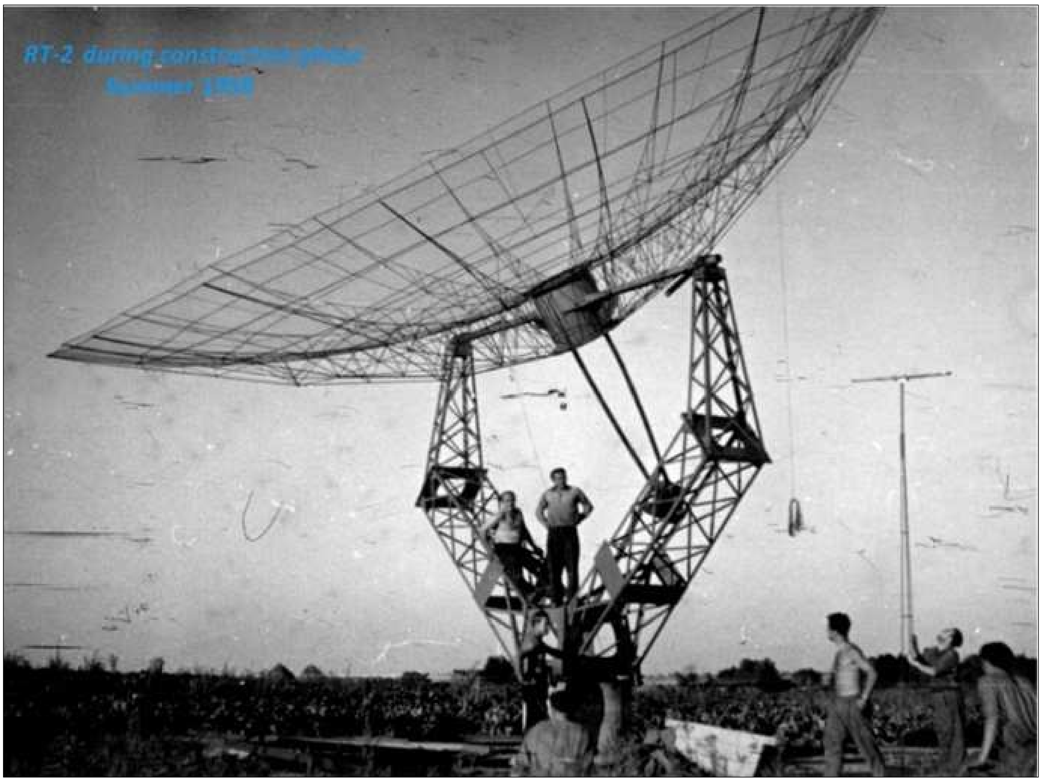



Figure 10. The 12-m RT-2 radio telescope (photograph: H. Iwaniszewski).

made the first ever map of a OH maser shell around an IR star using the MERLIN array (Booth et al., 1981).

Next, a 15-m antenna, named RT-3, became operational in 1977 (see Figure 11). The antenna was equipped with the following double frequency receivers: the 50 cm and 6 cm (parametric amplifier) Westerbork unit, and a locally made 75 cm receiver, combined with a 2.8 cm parametric receiver from the MPIfR. Later an L band 21 cm/18 cm receiver combined with a 90 cm receiver were also added. Several papers were published describing the characteristics of the RT-3 radio telescope (e.g. see Kus et al., 1983; Szymczak et al., 1983).

The first VLBI tests, with a locally built terminal MkIIc, between Toruń and the Effelsberg 100-m radio telescope took place in June 1981. Then the first radio spectroscopy pulsar observations in Poland were made with the RT-3 telescope in 1984. The following year, on 5 November 1985, Poland became an Associate Member of the European VLBI Network (EVN).

The need for modern observational facilities became urgent, and a group of planners started by urging the university authorities to build laboratories and working space in Piwnice. At first the Polish Academy of Sciences (PAN) was involved in the planning, however the PAN withdrew from financial participation. The coming of an important historical event in 1973, the 500th Anniversary of the birth of Copernicus, helped to get some financial support. A few days before the September 1973 IAU Symposium 065 took place in Toruń, the new office and laboratory buildings for the radio astronomers were completed. However, the hoped-for financial support for new instruments was not realized.

In conjunction with the Copernicus Anniversary the Soviet Academy and the Polish Academy suggested the joint construction of a space experiment. The solar 'Intercosmos-Kopernik 500' spectrograph was constructed under the management of the Toruń radio astronomers. Both Professor Gorgolewski and Dr Hanasz were involved. The strict scheduled completion date led to considerable problems for both the Radio Astronomy group and the Toruń Academy astronomy unit, but the satellite was launched on time in April 1973. The Anniversary IAU Symposium in 1973 led to the awarding of three Honorary Doctorates by the Copernicus University in Toruń to Professor Martin Ryle (Cambridge), Professor Jan Oort (Leiden) and Professor Wilhelmina Iwanowska (Toruń).

Professor Gorgolewski was the Director of the Institute of Astronomy from 1977 to 1979, then the Toruń Radio Astronomy Observatory (TRAO) became an independent unit within the

Figure 11: Completion of the 15-m RT-3 dish resulted in Toruń joining the European VLBI network (photograph: A. Kus).

the Faculty of Physics in 1979, and Professor Gorgolewski was Director of the TRAO until 1991. The development of radio astronomy at Toruń in these early years is described in detail by Krygier (1985). Professor Kus was the Director of the TRAO from 1992 until May 2006, then the Director was Professor Szymczak from 2006 to 2011. Professor K. Katarzynski was the Head of the Department of Radio Astronomy during 2012–2014 and Professor A. Marecki from 2015 to 2019.

In late 1980s efforts were undertaken to obtain funds for a larger radio telescope in order to get full participation in European and global VLBI networks. Professor Gorgolewski was instrumental in the political discussion that finally led to the agreement to fund a 32-m radio telescope. Contacts were signed with various firms capable of designing various sections of a large radio telescope. To ensure that the whole system would be manageable, tests of VLBI functionality were made in 1994 between the 15-m RT-3 Telescope in Piwnice and the 100-m radio telescope in Effelsberg, Germany. It became clear that a bigger dish antenna in Poland was needed to become a full participating member of the EVN. The political situation was ripe to bring in a bigger project through the Ministry of Science. In addition, a steel construction designer, the engineer Z. Bujakowski, was found who had great enthusiasm for radio astronomy. Mr Bujakowski travelled to several institutes with advanced radio telescopes and used his findings when design-

Figure 12: The 32-m RT-4 radio telescope at Piwnice, near Toruń, which was inaugurated 1996. In the foreground is Professor Stanisław Gorgolewski, who was the driving force behind the design and in political negotiations (courtesy: Astronomical Observatory UMK).

ning the Polish 32-m antenna. This radio telescope, designated RT-4 (Figure 12), was built between 1986 and 1994 by nearly 60 Polish companies led by 'Mostostal'. The local instrumental infrastructure including a time service with an H-maser clock was completed thanks to additional substantial funds received from the Ministry of Science.

The cryogenic receivers were built by Toruń radio astronomers and the Observatory technical staff, with important help from ASTRON, the MPIfR and the NRAO. The key

Figure 13: The Radio Astronomy Department and the RT-3 and RT-4 radio telescopes in October 2011 (courtesy: Astronomical Observatory UMK).

instrumentation, the VLBI MKIII P&G terminal, was purchased with European funds. Great help and support in this matter was received from Professor Richard Schilizzi. The RT4 radio telescope became operational in 1996, and full membership of the EVN was achieved in 1998. This allowed Toruń to truly become a European radio astronomy centre (see Figure 13). For the role they played in this, Copernicus University awarded honorary doctorates to Professor Richard Wielebinski and Professor Roy Booth in 1993. The University also awarded honorary doctorates to Professor Bohdan Paczyński and Professor Peter Wilkinson in 2006 and 2010 respectively.

The RT-4 radio telescope and supporting infrastructure was the largest and the most expensive and technologically advanced investment in astronomy that Poland has ever made. It had great impact on future research in radio astronomy in Poland and contributed significantly to international co-operation, participating on many EVN key programs. It also fostered the technological capabilities of many of the Polish companies that spent years designing or building the RT-4. This 32-m radio telescope was a flagship achievement for Poland.

A modern computing centre, equipped with a Convex-C120 (replaced later by Sun work stations), was commissioned at Piwnice in 1990. This was needed for the throughput of considerable data in various observational projects.

In 1996 the two independent astronomy units, the TRAO and Institute of Astronomy, were united under a new name, the Toruń Centre for Astronomy (TCfA); this combined what were two different Departments (optical astronomy and radio astronomy) into a single entity. The TCfA was directly protected by the University Rector. The position of TCfA Director was held by Professor Alex Wolszczan from January 1997 until December 2000, then by Professor Andrzej Kus from January 2001 to December 2010), followed by Professor Jan Hanasz (January 2011 to May 2019) and Professor K. Katarzynski (since June 2019). Professor Wolszczan organized the new Center and defined the important strategic directions for research. These decisions helped to integrate the dispersed astronomical community and allowed it to concentrate on advanced modern research targets.

## 3.2 The New Horizons in Toruń

Starting in 1996 the development of active research groups, able to compete in research on the world stage, became possible. Also, a competent electronics group was installed to match the antenna with other similar instruments found in Europe. Here special mention must be made to E. Pazderski, an astronomer, exceptionally talented in electronics, who designed and built cryogenic receivers and the digital backends. He also developed software for the RT-4 radio telescope control, and very competently led the Electronics Laboratory for many years. Support also was received from other European institutes, such as the JBO, MPIfR, ASTRON and NRAO. The first VLBI fringes were received with the RT-4 radio telescope and a Mark III P&G terminal in May 1996.

A long-term collaboration in pulsar research was organized by Professor Wolszczan, first with Arecibo and later with Penn State University. Numerous important publications resulted (e.g. Cordes and Wolszczan, 1986; Wolszczan and Cordes, 1987; Wolszczan and Frail, 1992; Wolszczan et al., 1980, 1981, 2000, 2002). Professor Wolszczan organized at Toruń a research group studying neutron stars. Building on his experiences in Effelsberg, Arecibo and Penn State University he concentrated on studies of neutron star timing, in cooperation with doctoral students. The timing program at 1.7 GHz on the RT-4 radio telescope started in June 1996, using the Penn State Pulsar Machine II. The main goal of this program was the search for planetary companions around neutron stars, however the database was also used for interstellar scintillation analysis, the study of average pulse stability and the timing noise properties for more than a hundred pulsars (Jacoby et al., 1997; Konacki et al., 1999; Lewandowski et al., 2000, 2004; Redmerska et al., 2000). In particular, a detailed study of the pulsar B1257+12 (with planets) led to a very exciting development. The cooperation with Arecibo and Effelsberg continues, more recently with optical studies (exoplanets search) on the SALT telescope in South Africa and on the HET of McDonald Observatory. Large scale exoplanets search continues within the Pen State–Toruń University program (e.g. Niedzielski et al., 2007).

Professor Kus led a group that concentrated on studies of active galactic nuclei (AGNs) using VLBI data. The variable structures of CSO (Compact Symmetrical Object) and CSS (Compact Steep Spectrum) AGNs were observed regularly. This aspect of research is important since the activity of AGNs is repeatable and their evolution tracks are non-standard. Super Luminal Motion was detected in 3C309.1, and the youngest ($\ll 10^4$ years) classical double lobe CSOs were found (Gawronski et al., 2006; Kunert-Bajraszewska et al., 2005; 2006; Kus et al., 1981; Marecki et al., 2003a, 2003b; Owsianik and Conway, 1998; Owsianik et al., 1998). The CSO and CSS sources studied at Toruń are at early stages of their development or at a reborn phase. The results led to a new, modified model of AGN evolution. According to this, objects with low radio brightness will expire at an early stage of evolution, and are short lived. Such short episodes of radio activity can happen many times before radio structure finally escapes the host galaxy and evolves to the size of large-scale FRI or FRII. The work also suggests that the population of such short-lived objects is large, and radio-strong CSS and GPS (Gigahertz Peak Sources) sources are only a small percentage of them. Studies using SALT, Chandra X-ray and most recently LOFAR as complementary to VLBI were also carried out.

In collaboration with JIVE (Garrett et al., 2001) studies of AGNs in the Hubble Deep Field were made. The Toruń team was also involved in space VLBI programs: VSOP and Radio Astron (Fomalont et al., 2000; Kovalev et al., 2020). Some VLBI research was expanded to the mm wave range and detailed studies were made at 3 mm and 7 mm using a dedicated global array of ultra high frequency telescopes (Baath et al., 1992, Krichbaum et al., 1990). The observations revealed earlier unknown sub-parsec scale substructure close to the central Black Hole.

In cooperation with Professor Roy Booth from the Onsala Space Observatory), Professor Kus initiated a spectral program to study methanol maser sources, and later Professor M. Szymczak took the lead and organized a group that carried out studies of new star-forming regions and stars in the late stages of evolution. A survey of galactic plane methanol clouds was important. The first result of this research was the publication of a survey of the 6.7 GHz methanol line for a large sample of star-forming regions selected from their infrared color indicators (Szymczak et al., 2000). Subsequently, a blind survey of a narrow strip of the Galactic Plane revealed more methanol maser sources associated with massive stars in the early stages of evolution (Szymczak et al., 2002; 2005).

Detailed study of the physical properties of these objects was undertaken using VLBI (Blartkiewicz et al., 2009). The discovery of ring-like morphological structures with a well-defined velocity gradient demonstrated that the 6.7 GHz maser radiation of methanol is produced in molecular disks, where the kinematics of individual clouds is determined by accretion processes or outflows. Studies of magnetic fields in clouds surrounding the masers were also successful.

In the years 2009–2013, a key spectral EVN program for monitoring the variability of methanol masers led to discovery of periodic objects and the reconstruction of the 3D disk structure. One of the more significant results was the finding of periodic alternating variability of emission in the methanol and water vapor lines (Szymczak et al., 2016). The second known transition line of methanol (at 12.2 GHz) had also been surveyed with the RT-4 radio telescope and spectra were analysed in comparison with the main 6.7 GHz lines (Błaszkiewicz and Kus, 2004). With all this concentrated research, Toruń became the leading centre for cosmic methanol maser studies in Europe.

In cooperation with Professor Peter Wilkinson and Professor Ian Browne from JBO, Professor Kus originated the One Centimetre Receiver Array (OCRA) project (Browne et al, 2000). The initial aim was to operate a 16 channel multi-beam receiver on the RT-4 radio telescope at ~9 mm wavelength. The prototype two horn OCRA-p receiver was installed on the RT-4 antenna in December 2002. OCRA-f was an eight-beam receiver and the first half of the full planned OCRA, which was installed three years later. With co-workers (E. Pazderski and R. Feiler) and students, several steps in the development of this technically difficult project were made. Improved radio telescope properties, via holographic measurements of antenna surface panel adjustments, as well as the antenna pointing correction table, were achieved.

The scientific plan aimed at a deep survey of small selected areas of the sky, to search for the S-Z effect, the absorption of 2.7 K CMB radiation in galaxy clusters, and also to study AGN variability, and planetary nebula physics. Results from the OCRA program were published by Gawronski et al. (2010), Lancaster et al. (2007; 2011), Lowe et al. (2007) and Pazderska et al. (2009). The OCRA project also had a tremendous impact on RT-4 radio telescope performance in sensitivity, stability and precision tracking.

In parallel to OCRA cosmology results Professors B. Roukema and A. Marecki built up studies of the large-scale Universe. Detailed analysis of the WMAP observations were the basis of these theoretical studies (Roukema et al., 2004).

Participation in the SALT optical telescope project coupled with interest in radio polarization measurements with the RT-4 antenna led to the Toruń group's active involvement in the RoboPol optical polarimetry program (e.g. Blinov et al., 2016; Pavlidou et al., 2014; Ramaprakach et al., 2019). The aim of the project (Blinov et al., 2015) was to collect observational data on a selected sample of Fermi sources (AGNs), which would allow a statistical study of the connections between observational properties of the sources observed over an extremely large range of wavelengths. Critical results on the fast rotation of the ***E*** vector were obtained for regions close to the Black Hole, that improved our understanding of emission processes and jet physics, and allowed tracking of the complex evolution of active regions in blazars. This research by the Toruń radio astronomy group is being done in close cooperation with teams from Caltech and the University of California (in the USA), the MPIfR, and the [IUCfAA] Inter-University Centre for Astronomy and Astrophysics in India. The Toruń group, which was led by Professor Kus, included E. Pazderski, B. Pazderska and R. Feiler.

The Toruń Department of Radio Astronomy had been the initiator of several European Union FP projects. Some examples are:

- 'Infrastructure Cooperation Network in Radio Astronomy'
- 'FARADAY' – Focal-plane Arrays for Radio Astronomy.
- 'RADIONET" – A large project involving cooperation in EVN VLBI and the development of modern technologies, and observation methods of radio astronomy.
- 'PHAROS' – the development and construction of a prototype multi-beam antenna system for use on single parabolic antennas.

These programs cemented scientific and technological cooperation among European radio observatories.

The period 1996–2020 was a scientifically fruitful time for the Toruń radio astronomy group. The team developed advanced international collaborations and gained recognition as a high-standard European research and education centre in Eastern Europe. Recently some of research activities of the radio astronomy group have expanded to include high energy astronomy (HESS and CTA) and theoretical astrophysics and cosmology. However, long-term research on the radio spectroscopy of cosmic masers and VLBI by the EVN on AGNs remain the central focus of the group.

## 4 RADIO ASTRONOMY AT THE UNIVERSITY OF ZIELONA GÓRA

The University of Zielona Góra is the most recent addition in Poland, which supports a radio astronomy research program. Originally, radio astronomy in Zielona Góra had its beginning at the Pedagogical University, which after merging with the Technical University in 2001 became the University of Zielona Góra.

The development of the Zielona Góra Centre of Astronomy was started by Professor Janusz Gil (1951–2014; Figure 14) in 1989. Gil first studied at the Higher Pedagogical School in Rzeszów, Poland. He then completed doctoral studies at Warsaw University, and continued with post-doctoral studies in the USA, first at the NRAO and later at the University of Kentucky. Initially, Professor Gil began working at the Zielona Góra Pedagogical High School in 1988, and became the foundation Professor in the Institute of Astronomy (Figure 15) after the High School became a University. Eventually, the Institute became an internationally respected center of radio astronomy research.

Professor Gil's research area was pulsar theories, and he built up a research group comprising graduate students and visiting astronomers (Gil, 1981; 1984; 1985; Gil and Snakowski, 1990; Gil and Sendyk, 2000). One of the long-term visitors, who eventually became a Professor at the University of Zielona Góra, was the Georgian theoretician George Melikidze, who worked on the emission theories of pulsars. On the observational side, several students became associates, notably Associate Professor Jaroslaw Kijak. Professor Gil and his students and staff members developed long-term associations with the MPIfR astronomers in Bonn, and many pulsar publications came from this. In 2001, Professor Gil became an Alexander von Humboldt scholar. His students and staff also developed a lively collaboration with the National Centre for Radio Astrophysics in Pune (India), where they used the Giant Metrewave Radio Telescope. Numerous publications resulted from this association, and these are summarised in the following sections.

## 4.1 The Beginning

The first international pulsar conference in Poland was held in 1990 not far from Zielona Góra, in the castle village of Łagów. The conference was about "The Magnetospheric Structure and Emission Mechanisms of Pulsars", and it was IAU Colloqium Number 128. At the time of that conference, Janusz Gil established the Astronomical Centre of Zielona Góra (which was the former name of the Institute of Astronomy). Among the distinguished astronomers who came to Zielona Góra were Antony Hewish and Francis Graham-Smith (see Figure 16).

Figure 14: Professor Janusz Gil was the very active founder of this new astrophysics group (photograph: W. Wielebinski).

A second pulsars conference, this time on "Electromagnetic Radiation from Pulsars and Magnetars", was organized in honor of Professor Gil on the occasion of his 60th Birthday. It was held at the University of Zielona Góra on 24–27 April 2012, and the Proceedings were published by the Astronomical Society of the Pacific in their Conference Series (Volume 466). The international audience that assembled for this conference is shown in Figure 17.

Figure 15: The Institute of Astronomy, University of Zielona Góra. In the tower amateur observers are introduced to astronomy (photograph: R. Wielebinski).

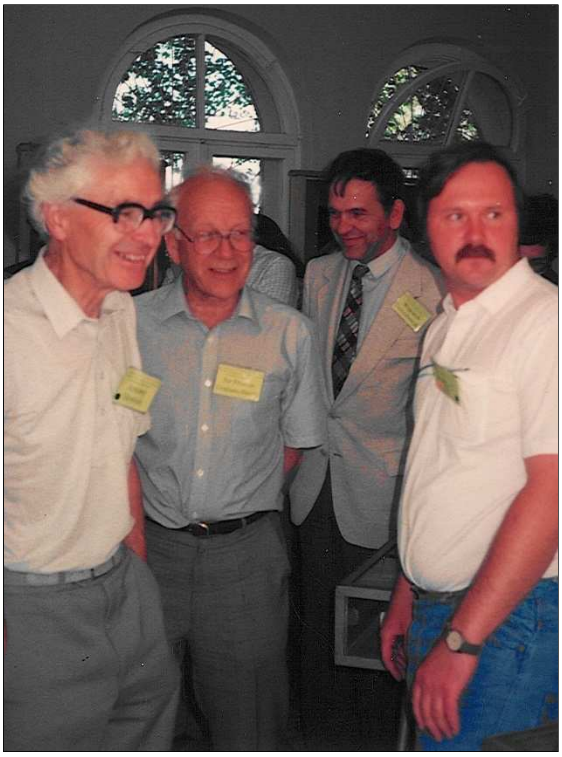


Figure 16: The opening ceremony of the Institute of astronomy in Zielona Góra in 1990. Shown from left to right are A. Hewish, F. Graham-Smith, J. Kijak and J. Gil (courtesy: family of J. Gil).

Janusz Gil died suddenly 19 October 2014 in Wilkanowo near Zielona Góra. He leaves an active major astrophysics institute in Poland. On the Professor's birthday on 24 October 2015 a ceremony was held at the Institute of Astronomy which was renamed the 'Professor Janusz Gil Institute of Astronomy'.

In the following sections summaries are presented of the different research topics that were worked on.

## 4.2 Radio Pulsar Spectra

One of the main research interests at the Institute is the analysis of the radio spectra of pulsars. Pulsar radio emission is non-thermal in nature and is usually characterized by a steep power-law spectrum. Generally, the observed spectra can be modelled with a negative spectral index (Maron et al., 2000). Several research projects involving Effelsberg and GMRT observations, however, have revealed some very interesting results in this field (Kijak et al., 2011). The discovery of the gigahertz-peaked spectra (GPS) pulsars, i.e. objects that show a maximum flux in the spectrum close to 1 GHz was a surprise (Kijak et al., 2017). It is believed that the most likely cause for such spectral behavior is absorption of the pulsar signal in its immediate surroundings. Most of these objects find themselves in very peculiar environments, such as pulsar wind nebulae, supernova remnant nebulae or dense H II regions (Lewandowski et al., 2015).

## 4.3 A Model of Radio Emission from Pulsars

A group of scientists from the Institute has pioneered the study of the coherent radio emission mechanism problem. Based on high quality radio observations, they established that the pulsar radio emission originated from regions below 10% of the light cylinder radius (Kijak and Gil, 2003). This important constraint


Figure 17: Participants of the conference "Electromagnetic Radiation from Pulsars and Magnetars" in 2012 (photograph: Kazimierz Adamczewski).

requires a mechanism where coherent emission is excited in relativistic pair plasma where stable charge bunches (charged solitons) moving relativistically along the curved open dipolar magnetic field lines capable of exciting coherent curvature radio emission (Melikidze et al., 2000). In this model, the essential feature is the presence of an inner accelerating gap region, where a nonstationary relativistic plasma flow can be established. It was demonstrated that in order to explain the observed highly non-dipolar surface magnetic field (Gil et al., 2002) a thermostatically regulated partial screened gap (Gil et al., 2003) must exist above the polar cap. However, the radio emission arises higher up in regions where the magnetic field is dipolar (Melikidze et al., 2014).

The PSG model in conjunction with the soliton model currently serves as the basis for explaining a large number of observational phenomena in pulsars, particularly the X-ray hotspot, certain aspects of sub-pulse drifting, and some mean features of the pulsar emission.

### 4.4 LOFAR/POLFAR and the Scattering of Pulsar Radio Waves

While pulsars are interesting objects to study on their own, they can also be used as tools for other astrophysical applications. One of those is the study of the ionized interstellar medium through the effects of interstellar scattering and scintillation of pulsar signals. A group of researchers from the Institute, led by Professor Wojciech Lewandowski, has analysed the largest sample of interstellar scattering measurements made with a variety of radio telescopes, such as the GMRT, GBT, Effelsberg and Parkes. The aim was to study the frequency dependence of scattering, which gives us an insight into the turbulent nature of the interstellar medium (Lewandowski et al., 2015). It occurs that the frequency scaling of scattering is weaker than the simple scattering theories predict, and the most likely causes are the anisotropy of the scattering or multiple scattering events. The group is continuing the research with nearby pulsars, utilizing the Polish stations of the LOFAR radio telescope, at frequencies between 44 and 190 MHz. The long-term monitoring of scattering for a selected group of pulsars should provide us with more information about the inhomogeneity and anisotropy of the ionized interstellar medium.

## 5 COOPERATION BETWEEN THE INSTITUTES

In view of the small community of radio astronomers in Poland, numerous contacts and exchanges of staff between the groups have taken place. Within the frame of the Polskie Towarzystwo Astronomiczne (Polish Astronomical Society), radio astronomy sessions were always on the program at the annual meetings. Smaller conferences were held in Kraków, Toruń and Zielona Góra, with international participation. A semi-regular conference series were the Bochum-Bonn-Kraków meetings on magnetic fields. The participation in the European VLBI network (EVN) supported exchanges. Students and staff were moving between the individual groups.

## 6 ACKNOWLEDGEMENTS

The development of radio astronomy in Poland was supported by many colleagues in the radio astronomy community around the world. Special mention should be made of Sir Martin Ryle, Professor A. Hewish, Professor R. Booth, Dr J.J. Condon, Professor P. Wilkinson, Professor A. Readhead, Professor I. Browne, Professor R. Schilizzi, Professor A. van Ardenne, the author Professor R. Wielebinski, and many other colleagues not mentioned here by name.

## 7 REFERENCES

Bååth, L.B., Rogers, A.E.E., Inoue, M., Padin, S., Wright, M.C.H. (and 15 more authors), 1992. VLBI observations of active galactic nuclei at 3 mm. *Astronomy & Astrophysics*, 237, 31–46.

Błaszkiewicz, L., and Kus, A.J., 2004. 12.2 GHz survey towards 6.7 GHz methanol masers. A comparison of 12.2 GHz and 6.7 GHz spectra. *Astronomy & Astrophysics*, 413, 233–240.

Blinov, D., Pavlidou, V., Papadakis, I., Kiehlmann, S., Panopoulou, G. (and 24 more authors), 2015. RoboPol: first season rotations of optical polarization plane in blazars. *Monthly Notices of the Royal Astronomical Society*, 453, 1669–1683.

Blinov, D., Pavlidou, V., Papadakis, I.E., Hovatta, T., Pearson, T.J. (and 24 more authors), 2016. RoboPol: optical polarization-plane rotations and flaring activity in blazars. *Monthly Notices of the Royal Astronomical Society*, 457, 2252–2262.

Booth, R.S., Kus, A.J., Norris, R.P., and Porter, N., 1981. Observations of a circumstellar shell around the OH/IR star OH127.8-0.0. *Nature*, 290, 5805, 382–384.

Browne, I.W., Mao, S., Wilkinson, P.N., Kus, A.J., Marecki, A., and Birkinshaw, M., 2000. OCRA: a one-centimeter receiver array. In Butcher, H.R. (ed.), *Radio Telescopes*. Proc. SPIE, Volume 4015. Pp. 299–307.

Chyży, K., Beck, R., Klein, U., and Urbanik, M., 2000. Regular magnetic fields in the dwarf irregular galaxy

NGC4449. *Astronomy & Astrophysics*, 355, 128–137.
Chyży, K., Knapik, J., Bomans, D.J., Klein, U., Beck, R. (and 2 more authors), 2003. Magnetic fields and ionized gas in the local group of irregular galaxies IC10 and NGC 6822. *Astronomy & Astrophysics*, 405, 513–524.
Chyży, K., and Beck, R., 2004. Magnetic fields in merging spirals – the antennae. *Astronomy & Astrophysics*, 417, 541–555.
Chyży, K.T., Jurusik, W., Piotrowska, J., Nikiel-Wroczyński, B., Heesen, V. (and 35 more authors), 2018. LOFAR MSSS: flattening low-frequency radio continuum spectra of nearby galaxies. *Astronomy & Astrophysics*, 619, id. A36 (22 pp.).
Cordes, J.M., and Wolszczan, A., 1986. Multiple imaging of pulsars by refraction in the interstellar medium. *Astrophysical Journal*, 307, L27–L31.
Dabhabe, P., Röttgering, H.J.A., Bagchi, J., Shimwell, T.W., Hardcaste, M.J. (and 5 more authors), 2020. Giant radio galaxies in the LOFAR Two-metre Sky Survey. *Astronomy & Astrophysics*, 635, id. A5 (27 pp.).
Elstner, D., Otmianowska-Mazur, K., von Linden, S., and Urbanik, M., 2000. Galactic magnetic fields and spiral arms. *Astronomy & Astrophysics*, 357, 129–138.
Fomalont, E.B., Frey, S., Paragi, Z., Gurvits, L.I., Scott, W.K. (and 3 more authors), 2000. The VSOP 5 GHz continuum survey: the prelaunch VLBA observations. *Astrophysical Journal Supplement Series*, 131, 95–183.
Garrett, M.A., Muxlow, T.W.B., Garrington, S.T., Alef, W., Alberdi, A. (and 8 more authors), 2001. AGN and starbursts at high redshift: high resolution EVN observations of the Hubble Deep Field. *Astronomy & Astrophysics*, 366, L5–L8.
Gawroński, M.P., Marecki, A., Kunert-Bajraszewska, M., and Kus, A.J., 2006. Hybrid morphology of radio sources from the FIRST survey. *Astronomy & Astrophysics*, 447, 63–70.
Gawroński, M.P., Peel, M.W., Lancaster, K., Battye, R.A., Birkinshaw, M. (and 14 more authors), 2010. 30 GHz observation of sources in the Very Small Array field. *Monthly Notices of the Royal Astronomical Society*, 406, 1853–1864.
Gil, J., 1981. The frequency dependence of micropulse separation. *Astronomy & Astrophysics*, 194, 69–71.
Gil, J., Gronkowski, P., and Rudnicki, W., 1984. Geometry of the emission region of PSR 0950+08. *Astronomy & Astrophysics*, 132, 312–316.
Gil, J., 1985. Interpulse beams and profile components. *Astrophysical Journal*, 299, 154–60.
Gil, J., and Snakowski, J.K., 1990. Curvature radiation and core emission of pulsars. *Astronomy & Astrophysics*, 234, 237–242.
Gil, J., and Sendyk, M., 2000. Spark model for pulsar radiation modulation patterns. *Astrophysical Journal*, 541, 351–366.
Gil, J., Melikidze, G.I., and Mitra, D., 2002. Modelling of surface magnetic fields in neutron stars: application to radio pulsars. *Astronomy & Astrophysics*, 388, 235–245.
Gil, J., Melikidze, G.I., and Geppert, U., 2003. Drifting sub-pulses and inner acceleration regions in radio pulsars. *Astronomy & Astrophysics Supplement*, 107, 315–324.
Gorgolewski, S., and Hewish, A., 1960. The irregular structure of solar corona during 1959 June. *The Observatory*, 80, 99–103.
Gorgolewski, S., Hanasz, J., Iwaniszewski, H., and Turło, Z., 1962. Interferometric investigations of the outer corona at the 32.1 MHz band. *Acta Astronomica*, 12, 75–83.
Gorgolewski, S., 1965. Recent radio observations of the outer solar corona. *Acta Astronomica*, 15, 261–271.
Hewish, A., Wolszczan, A., and Graham, D.A., 1985. Quasi-periodic scintillation patterns of pulsars 1133+16 and 1642-03. *Monthly Notices of the Royal Astronomical Society*, 213, 167–179.
Jacoby, B., Lewandowski, W., and Redmerska, M., 1997. Timing and scintillation observations of pulsars with the TCfA 32-meter radiotelescope. *Acta Cosmologica*, 23, 155–158.
Jamrozy, M., Machalski, J., Mack, K.-H., and Klein, U., 2005. Ageing analysis of the giant radio galaxy J1343+3758. *Astronomy & Astrophysics*, 433, 467–477.
Jamrozy, M., Konar, C., Machalski, J., and Saikia, D.J., 2008. A multifrequency study of giant radio sources – II. Spectral ageing analysis of selected sources. *Monthly Notices of the Royal Astronomical Society*, 395, 1286–1296.
Kijak, J., and Gil, J., 2003. Radio emission attitudes of pulsars. *Astronomy & Astrophysics*, 397, 969–972.
Kijak, J., Lewandowski, W., Maron, O., Gupta, Y., and Jessner, A., 2011. Pulsars with Gigahertz-peaked spectra. *Astronomy & Astrophysics*, 531, id. A16 (9 pp.).
Kijak, J., Basu, R., Lewandowski, W., Rożko, K., and Dembska, M., 2017. Gigahertz-peaked spectra pulsars and thermal absorption model. *Astrophysical Journal*, 840, 108–121.
Klein, U., Urbanik, M., Beck, R., and Wielebinski, R., 1983. Survey of the distribution of λ2.7 cm radio continuum in NGC253. *Astronomy & Astrophysics*, 127, 177–185.
Knapik, J., Soida, M., Beck, R., Dettmar, R.J., and Urbanik, M., 2000. Detection of regular magnetic fields in two flocculent galaxies. *Astronomy & Astrophysics*, 362, 910–920.
Konacki, M., Lewandowski, W., Wolszczan, A., Doroshenko, O., and Kramer, M., 1999. Are there planets around the pulsar PSR B0329+54? *Astrophysical Journal*, 519, L81–L84.
Kovalev, Y.Y., Kardashev, N.S., Sokolovsky, K.V., Voitsik, P.A., An, T. (and 55 more authors), 2020. Detection statistics of the RadioAstron AGN survey. *Advances in Space Research*, 65, 705–711.
Kowal, G., Lazarin, A., Vishaniac, E.T., and Otmianowska-Mazur, K., 2009. Numerical tests of fast reconnection in weakly stochastic magnetic fields. *Astrophysical Journal*, 700, 63–85.
Krichbaum, T.P., Witzel, A., Booth, R.S., Kus, A.J., Ronnang, B.O. (and 20 more authors), 1990. 43 GHz VLBI observations of 3C273 after a flux outburst in 1988. *Astronomy & Astrophysics*, 237, 3–11.

Krygier, B., 1985. 25 lat radioastronomii w Toruniu. *Kwartalnik HNIT*, 3–4, 761–776 (in Polish).
Kunert-Bajraszewska, M., Marecki, A., Thomasson, P., and Spencer, R.E., 2005. FIRST-based survey of compact steep spectrum sources. II. MERLIN and VLA observations of medium-sized symmetric objects. *Astronomy & Astrophysics*, 440, 93–105.
Kunert-Bajraszewska, M., Marecki, A., and Thomasson, P., 2006. FIRST-based survey of compact steep spectrum sources. IV. Multifrequency VLBA observations of very compact objects. *Astronomy & Astrophysics*, 450, 945–958.
Kus, A.J., Wilkinson, P.N., and Booth, R.S., 1981. The radio structure of 3C309.1 determined by multi-baseline interferometry. *Monthly Notices of the Royal Astronomical Society*, 194, 527–535.
Kus, A.J., Gorgolewski, S., Kempa, A., Krygier, B., Mazurek, J., and Pazderski, E., 1983. Receivers for RT-3 radio telescope. *Postępy Astronomii*, 31, 303–314.
Lancaster, K., Birkinshaw, M., Gawroński, M.P., Browne, I.W.A., Feiler, R. (and 4 more authors), 2007. Preliminary Sunyaev-Zel'dovich observations of galaxy clusters with OCRA-p. *Monthly Notices of the Royal Astronomical Society*, 378, 673–680.
Lancaster, K., Birkinshaw, M., Gawroński, M.P., Battye, R.A., Browne, I.W.A. (and 13 more authors), 2011. Sunyayev-Zel'dovich observations of a statistically complete sample of galaxy clusters with OCRA-p. *Monthly Notices of the Royal Astronomical Society*, 418, 1365–2966.
Lewandowski, W., Konacki, M., Redmarska, M., Feiler, G., and Wolszczan, A., 2000. Pulsar timing measurements with the 32-m TCfA radiotelescope. In Kramer, M., Wez, N., and Wielebinski, R. (eds.). *Pulsar Astronomy – 20000 and Beyond*. San Francisco, Astronomical Society of the Pacific (Conference Series, Volume 202). Pp. 63–64.
Lewandowski, W., Wolszczan, A., Feiler, G., Konacki, M., and Sołtysiński, T., 2004. Arecibo timing and single-pulse observations of 18 pulsars. *Astrophysical Journal*, 600, 905–913.
Lewandowski, W., Kowalińska, M., and Kijak, J., 2015. The analysis of the largest sample of multifrequency pulsar scatter time estimates. *Monthly Notices of the Royal Astronomical Society*, 449, 1570–1583.
Lewandowski, W., Rożko, K., Kijak, J., and Melikidze, G.I., 2015. Thermal absorption as the cause of Gigahertz-peaked spectra in pulsars and magnetars. *Astrophysical Journal*, 808, id. 18 (9pp.).
Lowe, S.R., Gawronski, M., Wilkinson, P.N., Kus, A.J., Browne, I.W.A. (and 3 more authors), 2007. 30 GHz flux density measurements of the Caltech-Jodrell flat-spectrum sources with OCRA-p. *Astronomy & Astrophysics*, 474, 1093–1100.
Machalski, J., and Masłowski, J., 1972. The 15m Krakow Radiotelescope. *Acta Astronomica*, 22, 419–430.
Machalski, J., and Condon, J.J., 1983. A complete sample of sources from the GB/GB2 Surveys. IV. VLA observations and optical identifications. *Astronomical Journal*, 88, 1591–1616.
Machalski, J., Chyży, K.T., Stawarz, Ł., and Kozieł, D., 2007. A method for estimating the dynamical age of FR II-type radio sources from multi-frequency data. *Astronomy & Astrophysics*, 462, 43–55.
Machalski, J., Kozieł-Wierzbowska, D., Jamrozy, M., and Saikia, D.J., 2008. The radio galaxy larger than 3C236. *Astrophysical Journal*, 679, 149–155.
Marecki, A., Barthel, P.D., Polatidis, A., and Owsianik, I., 2003a. 1245+676 – a CSO/GPS source being an extreme case of a double-double structure. *Publications of the Astronomical Society of Australia*, 20, 16–18.
Marecki, A., Spencer, R.E., and Kunert, M., 2003b. Location of weak CSS sources on the evolutionary path of radio-loud AGN. *Publications of the Astronomical Society of Australia*, 20, 46–49.
Maron, O., Kijak, J., Kramer, M., and Wielebinski, R., 2000. Pulsar spectra of radio emission. *Astronomy & Astrophysics Supplement*, 147, 195–203.
Masłowski, J., 1957. Radio frequency observations of the solar eclipse of June 1954. *Acta Astronomica*, 7, 199–207.
Masłowski, J., 1971. A Green Bank sky survey in search of radio sources at 1400 MHz. *Astronomy & Astrophysics*, 14, 215–222.
Masłowski, J., 1974. The 2695 MHz observations of GB sources in the 5C region. *Astronomy & Astrophysics*, 36, 395–400.
Masłowski, J., Pauliny-Toth, I.I.K., Witzel, A., and Kühr, H., 1981. A 4850 MHz survey of the 5C6 area. *Astronomy & Astrophysics*, 95, 285–294.
Masłowski, J., and Strzałkowski, A., 2006. 50 lat krakowskiej radioastronomii. *Akademia Umiejętności*, Kraków, 7, 133–181 (in Polish).
Melikidze, G.I., Gil, J., and Pataraya, A.D., 2000. The spark-associated soliton model for pulsar radio emission. *Astrophysical Journal*, 544, 1081–1096.
Melikidze, G.I., Mitra, D., and Gil, J., 2014. On the adiabatic walking of plasma waves in a pulsar magnetosphere. *Astrophysical Journal*, 794, id. 105 (10 pp.).
Niedzielski, A., Konacki, M., Wolszczan, A., Nowak, G., Maciejewski, G. (and 4 more authors), 2007. A planetary-mass companion to the K0 giant HD 17092. *Astrophysical Journal*, 669, 1354–1358.
Nikiel-Wroczyński, B., Berger, A., Herrera Riuz, N., Bowmans, D.J., Blex, S. (and 12 more authors), 2019. Exploring the properties of low frequency radio emission in compact galaxy groups. *Astronomy & Astrophysics*, 622, id. A23 (14 pp.).
Nowakowski, L., Usowicz, J., Wolszczan, A., and Kępa, A., 1982. A multi-frequency fluctuation analysis in nine pulsars. *Astronomy & Astrophysics*, 116, 158–163.
O'Sullivan, S.P., Machalski, J., van Eck, C.L., Heald, G., Brüggen, M. (and 25 more authors). 2019. The intergalactic magnetic field probed by a giant radio galaxy. *Astronomy & Astrophysics*, 622, id. A16 (12 pp.).
Ostrowski, M., 1988. Acceleration of relativistic particles in shocks with oblique magnetic field. *Monthly Notices of*

*the Royal Astronomical Society*, 233, 257–264.

Ostrowski, M., 1991. Monte Carlo simulations of energetic particle transport in weakly inhomogeneous magnetic fields – I. Particle acceleration in relativistic shock waves with oblique magnetic fields. *Monthly Notices of the Royal Astronomical Society*, 249, 551–559.

Ostrowski, M., and Schlickeiser, R., 1993. Diffuse first and second order Fermi acceleration at parallel shock waves. *Monthly Notices of the Royal Astronomical Society*, 268, 812–822.

Ostrowski, M., and Bednarz, J., 2002. Comment on the first-order Fermi acceleration at ultra-relativistic shocks. *Astronomy & Astrophysics*, 394,1141–1144.

Otmianowska-Mazur, K., and Chiba, M., 1995. Numerical solutions of large-scale magnetic field evolution in spiral galaxies. *Astronomy & Astrophysics*, 301, 41–54.

Otmianowska-Mazur, K., Chyży, K., Soida, M., and von Linden, S., 2000. Modelling magnetic structure in irregular galaxies of Magellanic type. *Astronomy & Astrophysics*, 359, 29–40.

Otmianowska-Mazur, K., and Vollmer, B., 2003. Magnetic field evolution in galaxies interacting with the intra-cluster medium. *Astronomy & Astrophysics*, 402, 879–889.

Owsianik, I., and Conway, J.E., 1998. First detection of hotspot advance in a compact symmetric object. Evidence for a class of very young extragalactic radio sources. *Astronomy and Astrophysics*, 337, 69–79.

Owsianik, I., Conway, J.E., and Polatidis, A.G., 1998. Renewed radio activity of age 370 years in the extragalactic source 0108+388. *Astronomy and Astrophysics*, 336, L37–L40.

Pajdosz-Śmierciak, U., Jamrozy, M., Soida, M., and Stwarz, Ł., 2018. Megaparsec-scale radio structure of the hybrid blaser SBS B1646+499: epjsodic jet activity with precessing axis. *Astrophysical Journal*, 868, id. 64 (10 pp.).

Pavlidou, V., Angelakis, E., Myserlis, I., Blinov, D., King, O.G. (and 21 more authors), 2014. The RoboPol optical polarization survey of gamma-ray-loud blazars. *Monthly Notices of the Royal Astronomical Society*, 442, 1693–1705.

Pazderska, B.M., Gawroński, M.P, Feiler, R., Birkinshaw, M., Browne, I.W.A. (and 7 more authors), 2009. Survey of planetary nebulae at 30 GHz with OCRA-p. *Astronomy & Astrophysics*, 498, 463–470.

Pearson, T.J., and Kus, A.J., 1978. The 5C6 and 5C7 surveys of radio sources. *Monthly Notices of the Royal Astronomical Society*, 182, 273–274.

Ramaprakash, A.N., Rajarshi, C.V., Das, H.K., Khodade, P., Modi, D. (and 28 more authors), 2019. RoboPol: A four-channel optical imaging polarimeter. *Monthly Notices of the Royal Astronomical Society*, 485, 2355–2366.

Redmerska, M., Konacki, M., Lewandowski, W., and Wolszczan, A., 2000. Observations of the interstellar scintillation of nearby pulsars at 1.7 GHz with the 32-m Torun radiotelescope. In Kramer, M., Wez, N., and Wielebinski, R. (eds.). *Pulsar Astronomy – 20000 and Beyond*. San Francisco, Astronomical Society of the Pacific (Conference Series, Volume 202). Pp. 555–556.

Roukema, B.F., Lew, B., Cechowska, M., Marecki, A., and Bajtlik, S., 2004. A hint of Poincaré dodecahedral topology in the WMAP first year sky map. *Astronomy & Astrophysics*, 423, 821–831.

Ryś, S., and Machalski, J., 1990. Radio variability in complete sample of extragalactic sources at 1.4 GHz. *Astronomy & Astrophysics*, 236, 15–24.

Shimwell, T.W., Röttgering, H.J.A., Best, P.N., Williams, W.L., Dijkema, T.J. (and 67 more authors), 2017. The LOFAR Two-metre Survey. I. Survey description and preliminary data release. *Astronomy & Astrophysics*, 598, id. A104 (22 pp.).

Shimwell, T.W., Tasse, C., Hardcastle, M.J., Mechev, A.P., Williams, W.L. (and 102 more authors), 2019. The LOFAR Two-metre Survey. II. first data release. *Astronomy & Astrophysics*, 622, id. A1 (21 pp.).

Siejkowski, H., Soida, M., and Chyży, K.T., 2018. Magnetic field evolution in dwarf and Magellanic-type galaxies. *Astronomy & Astrophysics*, 611, id. A7 (7 pp.).

Soida, M., Urbanik, M., Beck, R., and Wielebinski, R., 1999. Magnetic fields and strong density waves in the interacting galaxy NGC3627. *Astronomy & Astrophysics*, 345, 461–470.

Soida, M., Urbanik, M., Beck, R., Wielebinski, R., and Balkowski, C., 2001. Unusual magnetic fields in the interacting spiral NGC3627. *Astronomy & Astrophysics*, 378, 40–50.

Soida, M., Beck, R., Urbanik, M., and Braine, J., 2002. Magnetic fields in absence of spiral density waves. *Astronomy & Astrophysics*, 394, 47–57.

Szymczak, M., Kus, A.J., and Gawronska, G., 1983. Parameters of the RT-3 radio telescope. *Postępy Astronomii*, 30, 307–314.

Szymczak, M., Hrynek, G., and Kus, A.J., 2000. A survey of the 6.7 GHz methanol maser emission from IRAS sources. *Astronomy & Astrophysics* Supplement, 143, 269–301.

Szymczak, M., Kus, A.J., Hrynek, G., Kępa, A., and Pazderski, E., 2002. 6.7 GHz methanol masers at sites of star formation. *Astronomy & Astrophysics*, 392, 277–286.

Szymczak, M., Pillai, T., and Menten, K.M., 2005. Masers as signposts of high-mass protostars. *Astronomy & Astrophysics*, 434, 613–621.

Szymczak, M., Olech, M., Wolak, P., Bartkiewicz, A., and Gawroński, M., 2016. Discovery of periodic and alternating flares of the methanol and water masers in G107.298+5.639. Monthly Notices of the Royal Astronomical Society, 459, L56–L60.

Tüllmann, R., Dettmar, R-J., Soida, M., Urbanik, M., and Rossa, J., 2000. The thermal and non-thermal gaseous halo of NGC5775. *Astronomy & Astrophysics*, 364, L36–L41.

Urbanik, M., Gräve, R., and Klein, U., 1985. A survey of the distribution of λ2.8 cm radio continuum in nearby galaxies. Four bright Virgo galaxies. *Astronomy & Astrophysics*,166, 107–114.

Urbanik, M., Otmianowska-Mazur, K., and Beck, R., 1994. Helical magnetic field structure in M31? *Astronomy &*

*Astrophysics*, 287, 410–418.
Urbanik, M., Elstner, D., and Beck, R., 1997. Observational signatures of helical galactic magnetic fields. *Astronomy & Astrophysics*, 326, 465–476.
Weżgowiec, M., Ehle, M., and Beck, R., 2016. Hot gas and magnetic arms of NGC6946 indicating reconnection heating. *Astronomy & Astrophysics*, 585, id. A3 (20 pp.).
Wolszczan, A., Hesse, K.H., and Sieber, W., 1974. Observations of pulsar spectra at 1420 MHz. *Astronomy & Astrophysics*, 37, 285–290.
Wolszczan, A., 1980. A correlation of the $P_3$ periods of pulsars with their magnetic field age. *Astronomy & Astrophysics*, 86, 7–10.
Wolszczan, A., Bartel, N., and Sieber, W., 1981. Spectrum of the interstellar turbulence of the pulsar PSR0329+54. *Monthly Notices of the Royal Astronomical Society*, 196, 473–480.
Wolszczan, A., and Cordes, J.M., 1987. Interstellar interferometry of pulsar PSR1237+25. *Astrophysical Journal*, 320, L35–L39.
Wolszczan, A., and Frail, D.A., 1992. A planetary system around the millisecond pulsar PSR1257+12. *Nature*, 355, 145–147.
Wolszczan, A., Doroshenko, O., Konacki, M., Kramer, M., Jessner, et al. (and 4 more authors), 2000. Timing observations of four millisecond pulsars with the Arecibo and Effelsberg radio telescopes. *Astrophysical Journal*, 528, 907–912.
Zięba, S., and Michalec, M., 1969. The Quiet Sun at 810 MHz during the minimum of solar activity 1964. *Acta Univeristatis Wratislavientis*, 77, 45–49.
Zięba, S., Guła, R., and Michalec, A., 1976. The 810 MHz solar radio bursts in the years 1957–1967. *Acta Astronomica*, 26, 351–369.
Zięba, S., Masłowski, J., Michalec, A., and Kułak, A., 2001. Periodicities in data observed during the minimum and the rising phase of solar cycle 23; years 1996–1999. *Astronomy & Astrophysics*, 377, 297–311.

**Professor Krzysztof Chyży** studied astronomy at Jagiellonian University, and obtained his PhD from Nicolaus Copernicus University in Toruń in 1997, with a thesis titled *Asymmetries and Linear Sizes of Radio Sources and their Cosmological Evolution*. His main research interests, presented in a number of published papers are: generation and evolution of regular and turbulent magnetic fields within galaxies, connection of magnetic fields with star-forming activity of galaxies, observations and investigations of properties of dwarf and interacting galaxies as well as galaxies within clusters, modelling of galactic radio spectra at low frequencies, and transport processes of cosmic ray particles.

Since 2009 he is a Head of the Department of the Radioastronomy and Space Physics at the Astronomical Observatory at Jagiellonian University. He leads a research team in Krakow that uses LOFAR observations and participates in leading international groups related to LOFAR Key Science Projects.

**Jaroslaw Kijak** is an Associate Professor at the Janusz Gil Institute of Astronomy at the University of Zielona Góra, in Poland. He received a PhD in astrophysics from University of Warsaw in 1994.

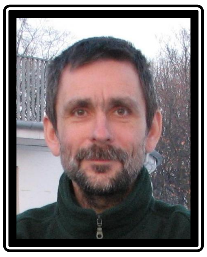
He worked as a Postdoctoral Fellow at the Max Planck Institute for Radio Astronomy (Bonn) between 1995 and 1996, and was a Visiting Scientist at the National Centre for Radio Astrophysics (Pune, India) in 2004–2005. Since 2016 he has been a member of The Committee on Astronomy of the Polish Academy of Sciences. His research interests focus on the study of observational and theoretical aspects of the radio pulsar astrophysics.

**Professor Andrzej Kus** was born in Krakow, Poland on 21 June 1944. After the war the family migrated to a new settlement in the city of Slupsk (Pomerania). This is the place where he got the basic education up to 'matura' exams. His interest in astronomy triggered a decision to study at Nicolaus Copernicus University in Toruń. He graduated in astronomy with a Masters degree in 1967. That same year he was employed as a young Assistant in the Institute of Astronomy to work under supervision of Professor S. Gorgolewski in the radio astronomy group.

In 1973, thanks to the support of Professor W. Iwanowska he received a one year British Council scholarship to study at Cambridge University. There he worked in the Mullard Radio Astronomy Observatory under supervision of Prof. Sir Martin Ryle. This had been a fantastic opportunity to learn and practice radio interferometry and aperture synthesis techniques. After returning to Toruń he defended his doctorate in 1975. The habilitation degree was obtained in 1991 and an Associate Professorship at Nicolaus Copernicus University in 1993. He received his full academic Professor's title in 2003.

Andrzej Kus spent over six years working in leading research centers in Europe (JBO, MPIfR, OSO, Astron, Jive, ESO) and in the USA (Caltech, MIT, NRAO). He was elected an Associate Member of the Royal Astronomical Society in 1995 and in 2005 he was awarded the highest prize in astronomy by the Polska Academia Umiejetności in Krakow for leading a team of radio astronomers from Nicolaus Copernicus University that prepared instrumentation and carried out a survey of methanol maser sources in the Milky Way.

After retirement Andrzej Kus received an Honorary Professorship from Nicolaus Copernicus University (2015). Currently he is engaged in an ongoing polarization program (RoboPol), and he also shares his time with amateur astronomers and promoting research in astronomy and public outreach.



**Dr hab. Marian Soida** studied astronomy at Jagiellonian University, and obtained his PhD there in 2004. In 2012 he was appointed Deputy Director of the Astronomical Observatory in Kraków, and has been the Director since 2020. He was the main coordinator of building three Polish LOFAR stations.

His main interest is the role of magnetic fields in the interstellar medium of spiral galaxies and their surroundings. He is involved in radio observations of nearby galaxies complemented by numerical simulations of magnetized plasma.

**Professor Richard Wielebinski** was born in Pleszew, Poland in 1936. In December 1939 the Wielebinski family was evicted from their house as part of the ethnic cleansing and spent ten years being moved to various camps in Poland and Germany. Finally, the Wielebinski family emigrated to Australia, arriving in Hobart, Tasmania, in 1949. At the age of 14 Richard could attend a school for the first time in his life, but first he had to learn English.

After Hobart High School Richard studied Electrical Engineering at the University of Tasmania. During his university studies he worked for the American radio astronomy pioneer Grote Reber, who came to Tasmania and was installing low frequency antennas. After completing Bachelor and Master of Engineering Science degrees Richard worked for the Postmaster-General Department, constructing a TV transmitter on Mt. Wellington above Hobart.

Having won a Shell Postgraduate Scholarship, in 1960 Richard was accepted as a PhD student by Martin Ryle in Cambridge. In 1963 Richard moved to a lectureship in the Department of Electrical Engineering at the University of Sydney. There, in addition to lecturing he conducted sky surveys with the 64-m Parkes Radio Telescope and pulsar observations with the Molonglo Cross, as well as doing antenna studies for the Arecibo Radio Telescope.

In 1966 Richard was invited by Professor Hachenberg as a Guest Professor at Bonn University. The contacts were active after this visit and in 1969 an invitation came from the Max-Planck-Gesellschaft to become a Director of the Max-Planck-Institut für Radioastronomie (MPIfR) in Bonn. The 100m Effelsberg radio telescope was under construction and Richard took charge of the Electronics Division. In the following 35 years, in addition to the Electronics Division Richard built up an active research group studying cosmic magnetic fields and pulsars. For his studies of magnetic fields in 2017 he was awarded the Karl-Schwarzschild Medal of the Astronomische Gesellschaft. The MPIfR moved to mm research in collaboration with France (and later Spain), leading to the establishment of the IRAM institute in Grenoble. A sub-mm project with the Steward Observatory led to the construction of the HHT telescope on Mt. Graham in Arizona.

Richard Wielebinski holds honorary Professorships at Bonn University, the Chinese Academy of Sciences University (Beijing) and the University of Southern Queensland (Toowoomba, Australia). He is a member of several academies and holds Honorary Doctorate degrees from Nicolaus Copernicus University (Toruń), Jagiellonian University (Kraków), the University of Tasmania (Hobart, Australia), and the University of Zielona Góra. After retiring in 2004 Richard became involved in the history of Radio Astronomy. He is still active in this field, and for three years was the Chairman of the IAU Historical Radio Astronomy Working Group.