Summary of Professional Accomplishments

Przemysław Bartczak

Astronomical Observatory Institute
Adam Mickiewicz University
in Poznań

Poznań, 2019

1 Academic Curriculum Vitae

1.1 Contact information

- name: Przemyslaw Bartczak
- place of work: Astronomical Observatory Institute,
  Adam Mickiewicz University,
  ul. Słoneczna 36, 60-286 Poznań,
  tel. +48 61 829 2775,
  e-mail: przebar@amu.edu.pl

1.2 Education

- 1994-1999 — studying Physics at Adam Mickiewicz University's Physics Department, specialisation: Astronomy
- 1999 — earning the title of Magister (Master of Science), thesis: *Astrolabe: vertical axis motion*,
  Astronomical Observatory, Adam Mickiewicz University, advisor: Associate Professor Krystyna Kurzyńska PhD, DSc
- 2005 — earning the title of PhD in Physics, dissertation: *Gravitational potential of the ensemble of material segments and its application to the study of binary asteroids*,
  Astronomical Observatory, Adam Mickiewicz University, advisor: Sławomir Breiter PhD, DSc

1.3 Employment history

- 17.07.1998 — 30.09.1999 — Technical Employee, Astronomical Observatory, Adam Mickiewicz University, Poland
- 01.10.1999 — 30.09.2004 — Doctoral Student, Astronomical Observatory, Adam Mickiewicz University, Poland
- 01.10.2004 — 30.11.2005 — Technical Employee, Astronomical Observatory, Adam Mickiewicz University, Poland
- 01.12.2005 — 30.03.2006 — Scientific/Technical Employee, Astronomical Observatory, Adam Mickiewicz University, Poland
- 01.04.2006 — 31.03.2009 — Post-doc internship, Institut d'Astrophysique et de Géophysique Université de Liège , Belgium
- since 1.04.2009 — Assistant Professor, Astronomical Observatory, Adam Mickiewicz University, Poland

2 Scientific achievements which are the basis for habilitation proceedings

The scientific achievement is the series of publications titled: **Modelling asteroid shape and rotation parameters based on photometric data.**

2.1 List of scientific publications which are the basis for habilitation proceedings

H1 Santana-Ros, T., **Bartczak, P.**, Michałowski, T., Tanga, P. and Cellino, A. 2015.
Testing the inversion of Gaia photometry of asteroids combined with ground-based observations
Monthly Notices of the Royal Astronomical Society 450, 333-341, IF(2015)=4.952,
In the publication I tested the inversion method developed for Gaia mission, using photometric observation simulations I produced. Input: 40%.

H2 **Bartczak, P.**, Michałowski, T., Santana-Ros, T. and Dudziński, G., 2014.
A new non-convex model of the binary asteroid 90 Antiope obtained with the SAGE modelling technique
Monthly Notices of the Royal Astronomical Society 443, 1802-1809, IF(2014)=5.107,
The publication contains the results of the (90) Anitope binary system modelling. Input: 60%

H3 **Bartczak, P.**, Kryszczyńska, A., Dudziński, G., Polińska, M., Colas, F., Vachier, F., Marciniak, A., Pollock, J., Apostolovska, G., Santana-Ros, T., Hirsch, R., Dimitrow, W., Murawiecka, M., Wietrzycka, P. and Nadolny, J., 2017.
A new non-convex model of the binary asteroid (809) Lundia obtained with the SAGE modelling technique
Monthly Notices of the Royal Astronomical Society 471, 941-947, IF(2017)=5.194,
The publication contains the results of (809) Lundia binary system modelling. Input: 60%.

H4 **Bartczak, P.** and Dudziński, G. 2018.
Shaping asteroid models using genetic evolution (SAGE)
Monthly Notices of the Royal Astronomical Society 473, 5050-5065, IF(2017)=5.194
The publication describes the non-convex inversion method I developed. Input: 60%.

H5 **Bartczak, P.** and Dudziński, G. 2019.
Volume uncertainty assessment method of asteroid models from disk-integrated visual photometry
Monthly Notices of the Royal Astronomical Society doi:10.1093/mnras/stz300, IF(2017)=5.194
The publication describes my method of assessing the uncertainty of asteroid model's physical parameters. Input: 60%.

2.2 Scientific goals and results

It is estimated that there are a few million asteroids in our Solar System. There have been discovered over 200 of them with a diameter of over 100 kilometres. Based on infrared measurements it has been ascertained that about 1.7 million asteroids have a diameter of over 1 kilometre (Tedesco and Desert, 2002). The vast majority of asteroids are located in the belt between the orbit of Mars and the orbit of Jupiter. Even though the mas of all asteroids is estimated at about 4% of the mas of the Moon (Krasinsky et al., 2002), they are an important source of information on how the Solar System came to be and how its evolution will proceed. Rotation axis orientation, rotation period, and shape of an asteroid are significant parameters in the process of modelling Yarkovsky and YORP effects (Yarkovsky-O'Keefe-Radzievskii-Paddack) (Vokrouhlický et al., 2015). Yarkovsky effect is responsible for asteroid orbit parameter change. In case of Near Earth Objects (NEO), the change in orbit parameters can lead to a collision with our planet and threaten the safety of our civilisation. YORP effect affects the change in asteroid rotation axis orientation and rotation period, upon which Yarkovsky effect depends. Moreover, the increase in rotation speed can lead to asteroid breaking apart. The evolution of these parameters under YORP influence is strongly related to body's shape.

Currently, ground-based asteroid observations are conducted using a variety of measuring techniques, such as: recording time of star occultation by an asteroid, adaptive optics observations, radar observations using the Doppler effect, as well as infrared, spectroscopic and polarimetric observations. Nonetheless, the oldest technique, which provides the biggest number of observations, is photometry. It covers the biggest number of objects in the known asteroid population. The development of telescopes and light sensitive photographic plates enabled the mensuration of relative and absolute asteroid brightness for larger number of objects, and for larger range of observable phase angle. The rapid evolution of CCD cameras lead to an increase in photometric and time resolution of lightcurves.

The development of radar observations, adaptive optics and stellar occultations allowed the collection of additional data about shapes of observable asteroids, yet it was Galileo space probe which delivered the first direct photographs of asteroids in 1991-1993 when it travelled past 951 Gaspra and 243 Ida asteroids (Belton et al., 1992, 1996). Space missions in later years provided direct observations of asteroids, based on which their models have been created. Unfortunately it was possible only for a dozen of objects out of over 700000 known asteroids. The photographs taken during the mission showed irregular, non-convex shapes of asteroids with cratered surface. Further development of observation techniques providing new, more precise information about asteroids required creation of new modelling methods which can utilise them. First deliberations about asteroid shape reconstruction using photometric lightcurves started in 1906 (Russell, 1906). The analysis was done with the assumption of geometric scattering law and photometric data obtained at 0 phase angle. It has been concluded that based on photometric observations the orientation of spin axis of an object can be determined. Whereas to determine an unambiguous shape of asteroids is outside of this observational technique's reach, because the change in brightness during rotation is caused not only by object's irregularities, but also by uneven albedo of its surface. Therefore, it is currently assumed in methods of shape reconstruction from photometric data that albedo is constant unless there is an indication of its variability.

The advent of new observational techniques (CCD), and resulting data amount growth for an increasing number of known asteroids, inspired in late 1980s/early 1990s a search for new methods of shape determination.

An analytical method was developed, which combines absolute brightness and lightcurve amplitude with the epoch method (Magnusson et al., 1989; Michalowski, 1993), which facilitates determination of triaxial ellipsoid semi-axes from photometric data. At the same time a concept was created to replace triaxial ellipsoid with a model which was a combination of 8 octants of different ellipsoids. (Cellino et al., 1989). According to the aforementioned papers the determination of spin axis orientation and asteroid's shape are inseparably linked. Therefore, in the remaining sections of this summary of professional accomplishments I will use the term **shape-rotation parameters (SRP)** as a collective name for rotation period, spin axis orientation and shape model.

The evolution of computers and the growing computational power of processors led to the emergence of numerical methods (Uchida and Goguen, 1987; Karttunen and Bowell, 1989), based on representing asteroid shape using small surface elements (facets), which allowed for the use of more sophisticated light scattering laws on individual facets. It improved the compatibility of observations with lightcurve modelling for triaxial ellipsoid. The use of simplified shape models based on triaxial ellipsoids made it impossible to explain precisely the brightness changes for observed asteroids.

The breakthrough came with convex inversion method (Kaasalainen and Torppa, 2001; Carry et al., 2010b), which provides SRP. The condition for getting the correct result is using photometric observations gathered over years, for various Sun-asteroid-Earth geometries. Unfortunately the aforementioned methods, based on photometric observations, are limited to convex shapes, regardless of the actual shape of an object in question.

The knowledge of realistic shape model and accurate information about object's density are the necessary conditions to conduct research on the dynamics of the discovered binary asteroids and gravitational stability of rings discovered around certain objects (Braga-Ribas et al., 2014; Ortiz et al., 2017). The correct determination of body's density requires the knowledge of its volume, which is connected to its shape. Determination of Yarkovsky and YORP effects, and planning of future manoeuvres in gravitational field during space missions to asteroids require more accurate asteroid shape models as well.

In order to overcome the limitations of the convex inversion method, the KOALA method was developed (Carry et al., 2010a), in which modelling is based on photometric observations supplemented by observations done by telescopes using adaptive optics. ADAM method (Viikinkoski et al., 2015) on the other hand includes more information from other observation techniques. SHAPE method uses photometric and radar data for shape reconstruction. (Hudson, 1993).

The aforementioned methods provide non convex models of asteroids. Unfortunately the number of asteroids for which such observations can be obtained using methods other than photometry is low and restricted to objects that are big and/or near Earth.

There had not been any inversion method which would allow for non convex shape modelling of asteroids which have numerous photometric observations, but no additional information from other observation techniques. This fact became an inspiration to begin my scientific research for a new non convex inversion method and a method of determining uncertainties for physical parameters of generated models. Additionally, I used the models provided by space missions to verify the results obtained using my methods.

2.2.1 Research goals

The objective of my scientific research was to find answers to the following questions about Solar System's small bodies modelling based on photometric data:

1. What limitations occur in asteroid SRP determination?
2. Is it possible to determine SRP of asteroids using non convex inversion method?
3. What are the uncertainties of the determined SRPs?

2.2.2 Testing limitations in SRP determination using photometric observations

The first aspect of my research connected with asteroid modelling pertains to the influence of the amount of the information in photometric observations on the modelling results. The most common observations are ground-based photometric observations, which determine asteroid brightness by compering it to the brightness of nearby stars. As a result of these observations we acquire not the information about absolute brightness, but about the changes in brightness over time. Whereas photometric ground-based sky surveys contain information about temporary absolute brightness of asteroids, but they do not provide lightcurves. The accuracy of lightcurves is at 0.01 mag, and that of photometric sky surveys is at 0.1 mag. Since 2013 Gaia space mission has been conducting a photometric sky survey with very high accuracy of about 0.001mag (Spoto et al., 2018). I examined the influence of quantity and quality of observations on the SRP determination process during modelling. (**H1**). In order to do so I used the technical data about Gaia mission to simulate photometric observations for over 10000 random shape models with random orientations of their spin axes. I used the simulated photometric data to determine SRP parameters utilising genetic inversion method prepared for mission's data reduction (Cellino et al., 2006). I compared the obtained SRP values with the parameter values of the shape models used for simulations.

It has been demonstrated in **H1** that SRP reconstruction from photometric data is always influenced by Sun-asteroid-Earth geometry, the modelled body's spin axis orientation and shape, as well as the quality of measurements. The limitations of Sun-asteroid-Earth geometry can be minimised by taking it into account in observation campaigns. I proposed to support satellite observations with ground-based photometric observations. Thanks to European Space Agency financing, GaiaGOSA internet service was created, which facilitates the synchronisation of ground-based observations with satellite observations (http://gaiagosa.eu).

The improvement of photometric measurement accuracy is another important factor reducing the uncertainties of determined SRP values. The development of observation techniques allows us to improve the accuracy of measurement points. Unfortunately the last two factors: spin axis orientation and body's shape, upon which our modelling success depends the most, are beyond our control.

The tests conducted in **H1** have shown, that the inversion method based on photometric data introduces systematic errors in SRP. Being unaware of these errors may lead to incorrect scientific conclusions. An example of that would be the interpretation of asteroid spin axes distribution as an indication of non-gravitational effects' influence on the evolution of the asteroid population (Vokrouhlický et al., 2015). Incorrect shape parameters influence the determined body's volume, which is then used to determine its density.

2.2.3 Determination of asteroid physical parameters using non-convex inversion method

The second aspect of my research was the creation, programming and testing of non-convex inversion method SAGE (Shaping Asteroids with Genetic Evolution). It is based on genetic algorithm supporting the search for the global minimum of SRP function, enabling modelling of both binary and single asteroids. First, I created SAGE method for binary asteroids described in **H2**. I limited it to synchronous binary systems, as they are dynamically stable. The process begins with a model of a binary system consisting of two bodies located in some distance from each other. The spin axis orientation, distance and the size ratio of system's components along with their shape are subjected to the modelling process. The modelling starts with spherical bodies, then their shapes are randomly distorted by the mutation function. Additionally, the mutation function alters the orientation of body's spin axis, components' size ratio and the distance between them. For each such model the centre of mass and axes of inertia are calculated to preserve dynamical properties (i.e. the rotation about the centre of mass and axis of the greatest inertia). Next, synthetic lightcurves are calculated using programming libraries, which enable quick calculations on graphics cards. Comparing synthetic lightcurves with observations allows us to determine rotation period and RMSD (Root Mean Square Deviation) value, which then becomes the criterion for the selection of the best shape model. The selected model becomes the base model for next mutations of physical parameters. This way I get a looped evolution process. Modelling ends when RMSD value stabilises, which means the solution has been found. Additionally I created a dynamic function for weighing individual pieces of data during modelling process, which supports the process of finding a global solution. Using this method I determined SRP for 90 Antiope binary system (**H2**). I compared the model with 2011 stellar occultation chords, which confirmed model's accuracy and allowed the determination of system's size and density. I also used this method to determine SRP for 809 Lundia asteroid (**H3**). In this case I used the information from Spitzer space telescope to determine the binary system's size, which allowed me to determine its density as well. Next I created a single asteroid version of SAGE method, described in **H4**. Modelling also begins with a spherical body, which is then randomly mutated by the mutation function. Additionally, the mutation function alters body's spin axis orientation. For each such model the centre of mass and axis of inertia are calculated, as well as synthetic lightcurves and RMSD - similarly as in the binary system version. Modelling is concluded after RMSD stabilises. Using SAGE I conducted SRP modelling for 9 Metis and 433 Eros (**H4**). I compared the results for 9 Metis with adaptive optics observations, confirming the result. Stellar occultations also indicate that the result is correct, and they additionally provide information about the size of the body. **H4** shows a comparison of the final 433 Eros model with the one provided by NEAR Shoemaker mission (Zuber et al. (2000)). The model is similar to the one based on space probe's laser ranger data. SAGE method was utilised in 'Efekty selekcji obserwacyjnej w fizyce planetoid' (The effects of observational bias in physics of asteroids) project, led by Anna Marciniak, PhD, in which I was the primary researcher. I determined SRP values for the following asteroids: 159 Aemilia, 227 Philosophia, 329 Svea, 478 Tergeste and 487 Venetia (Marciniak et al., 2018).

Moreover I used SAGE in 'Small Bodies Near and Far' project, financed by H2020-COMPET-2015 European programme by determining SRP values for the following asteroids: 68 Leto, 114 Kassandra, 654 Zelinda, 402 Chloe, 441 Bathilde, 145 Adeona, 297 Caecilia, 308 Polyxo, 3 Juno, 381 Myrrha, 89 Julia, 13 Egeria, 14 Irene,721 Tabora, 704 Interamia, 64 Angelina and 21 Lutetia. The results are being published and will constitute a part of the final summary of the project.

I created ISAM (Interactive Service of Asteroid Models) web service, which can be used to generate and view lightcurves of available asteroid models for any moment in time. It is publicly available and used by research teams to determine asteroid sizes from stellar occultations (http://isam.astro.amu.edu.pl).

Calculations based on genetic algorithms and graphics libraries require significant computing power. Thanks to being awarded the „Modele kształtów niesymetrycznych planetoid wykorzystywanych do badań efektów YORP i Jarkowskiego" (Assymetric asteroid shape models used for YORP and Yarkovsky effects research) grant [N 203 404139] by the Department of Science and Higher Education I was able to develop my method and finance the purchase of 18 computers with graphics cards. I built and programmed a computation cluster so to get the most out of the computing power during SAGE modelling.

Thanks to the 'Small Bodies Near and Far' project being financing by H2020-COMPET-2015 programme I expanded the computer cluster by 65 computers. The resulting computing power allows me to conduct further research connected with SAGE method.

The experience gained during research described in **H4** unambiguously indicated that in order to correctly interpret physical properties of models obtained with inversion methods it is imperative to know uncertainties of the determined SRP.

2.2.4 Determining asteroid SRP uncertainties

The third aspect of my research was to determine asteroid SRP uncertainties from convex and non-convex inversion processes using photometric data. In order to do so I programmed a SRP uncertainty assessment method based on lightcurves and data provided by photometric sky surveys (**H5**).

The method checks the admissible changes in SRP values accepted within match error margin for modelled and observed photometric data. For this purpose the examined model of an asteroid (base) is multiplied (clones) and nominal SRP values are altered in accordance with random distortion function. The necessary condition to create a proper statistical sample was to deliver a significant number of clones (about 1.2 million) and provide even statistical distribution for individual SRPs. The acceptance limit for individual clones is determined based on RMSD produced by comparing modelled photometric data for the base model with observations, taking into consideration the number of observations and the number of free parameters. All clones with RMSD value (determined by comparing modelled and observed photometric data) under the acceptance limit are included in the clone set, which represents variations from base model's SRP.

Statistical analysis of the resulting clone set provides information about SRP and volume uncertainties. The analysis of the issue presented in **H5** demonstrated that relative photometric observations do not contain sufficient information to determine flattening of a body along the spin axis, which is the main factor influencing determined volume uncertainty.

I proposed to use the data from photometric sky surveys to determine SRP uncertainty because changes in asteroid model flattening along spin axis influence its absolute brightness for various Sun-asteroid-Earth geometries.

A potential use of available photometric data to determine model's SRP uncertainty taking into consideration the limitations connected with observation quality, number of measurement points and observation geometry has been meticulously analysed in **H5**.

It turns out that asteroid SRP uncertainty determination mostly depends on observation conditions and SRP value, which prevents the creation of simple, universal system describing model's 'quality'. The method of determining asteroid SRP uncertainty described in **H5** for the first time allows the approach to be changed from deterministic to stochastic.

I used my method to determine SRP uncertainties for the following asteroids: 21 Lutetia, 433 Eros, 89 Julia, 243 Ida and 162173 Ryugu (**H5**). Subsequently, I compared the calculated SRPs and their uncertainties with physical parameter values from space missions. The tests have shown that the method correctly determines uncertainty values for individual asteroid SRPs confirming the results.

The correct asteroid SRP uncertainty values are vital to propagate them onto physical values based on SRP. They also need to be taken into account when asteroid model is used to determine additional physical parameters using other observational techniques. As the method from **H5** provides a set of clones for individual asteroid model, it is possible to use them in this process. It allows to e.g. determine body's size based on stellar occultations taking into account observation uncertainty along with model's uncertainties.

2.3 Summary

The publications mentioned above are about SRP modelling of Solar System asteroids. The research includes testing of existing inversion methods, the development of a new asteroid SRP modelling method and determination of their uncertainties based on photometric data. I tested the convex inversion method created for the Gaia mission data reduction (**H1**).

I created two methods concerning:

- non-convex asteroid shape modelling using photometric data SAGE (Shaping Asteroids with Genetic Evolution)
(**H2**, **H4**),
- asteroid SRP uncertainty determining (**H5**),

which are the first and unique solutions in this research area. Both methods require a significant number of high-performance graphic cards, therefore to conduct my research I built a computer cluster financed by MNISW (N N203 404139) grant, which I lead, and H2020-COMPET-2015 european grant, lead by Thomas Müller (Max-Planck-Institut fur Extraterrestrische Physik (MPE)).

I determined SRP for the following asteroids:

- binary: 90 Antiope (**H2**) and 809 Lundia (**H3**)
- single: 9 Metis (**H4**), 433 Eros (**H4**) and 89 Julia (**H5**)
(models 159 Aemilia, 227 Philosophia, 329 Svea, 478 Tergeste, 487

Venetia, 68 Leto, 114 Kassandra, 654 Zelinda, 402 Chloe, 441 Bathilde, 145 Adeona, 297 Caecilia, 308 Polyxo, 3 Juno, 381 Myrrha, 89 Julia, 13 Egeria, 14 Irene, 721 Tabora, 704 Interamia, 64 Angelina and 21 Lutetia were published in peer-reviewed journals or are not part of the habilitation achievement)

Additionally, two internet services have been created:

- Interactive Service for Asteroid Models (ISAM),
- Gaia-Groundbased Observational Service for Asteroids (GaiaGOSA),

supporting the process of observational data collection and presenting asteroid models.

In near future I plan to develop SAGE method to include other observational techniques in the modelling process, such as: radar observations, adaptive optics, stellar occultations and absolute photometry.

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3 Other achievements

After earning my PhD I also worked on problems connected with celestial mechanics, scientific instruments, online services, and various observation techniques for asteroids and Earth's artificial satellites.

Celestial mechanics

I began my research career by working on gravitation fields of models consisting of points and material segments. I programmed a model of two perpendicular segments of imaginary length, which serves as a perfect representation of triaxial ellipsoid's gravitation field, and makes its mathematical representation simpler (Bartczak and Breiter, 2003). In the subsequent paper I presented gravitation field models based on points and material segments, which allow for quicker determination of value for triaxial ellipsoids (Bartczak et al., 2006).

Next, I used the potential model I programmed to examine torque-free and torque-induced precession of single and binary asteroids. I created a model of 90 Antiope asteroid in which the elements of the system were in shapes of a triaxial ellipsoid and of a sphere (Michałowski et al., 2004). Moreover, I participated in research on the dynamics of synchronous binary asteroid systems. I analysed the stability of 90 Antiope system using MEGNO method to determine stability areas of the binary system (Breiter et al., 2005). I took part in the meteoroid swarms simulation, which led to the creation of orbital probability function using the differences between orbital energies, vectors of angular momentum and Laplace's vectors (Jopek et al., 2008). The function made it easier to correctly classify the observed meteoroid swarms. I contributed to YORP effect research for 25143 Itokawa asteroid and to the creation of a method to determine its value using unidimentional thermal model. I developed and applied the YORP effect calculation method to a model with high resolution triangle mesh using dispersed network of work stations (Breiter et al., 2009). In 10 years since then, no other publication contains results with such high resolution (3 million triangles).

Building scientific instruments

Between 2004 and 2006 I took part in the construction of a telescope (PST1) consisting of two 40 centimetre mirrors, which was put together at Astronomical Observatory Institute of Adam Mickiewicz University. I created software for the telescope's drivers and interface for the observers. I participated in engineering and construction of the telescope's mount. The telescope has the capacity to perform both photometric and spectroscopic observations. Studies based on observations performed with this telescope were published in high esteem scientific journals found on JCR list (Baranowski et al. i, 2009; Sekalska et al., 2010; Polińska et al., 2014; Dimitrov et al., 2014; Bensch et al., 2014; Dimitrov et al., 2015).

In 2008 and 2009 I participated in laser ranger modernisation at Space Research Centre of Polish Academy of Sciences' Astrogeodynamical Observatory in Borowiec. My task was to adapt DOS programme to UNIX operating system. Moreover, I developed a communication protocol between computers to parallelise managing processes. The biggest instrumental project I am a part of since 2006 is the construction of a 4-metre International Liquid Mirror Telescope, ILMT (Surdej et al., 2006). For 3 years I worked at Liege University as a post-doc and developed a reduction pipeline for ILMT data. After I finished my post-doc internship, Astronomical Observatory Institute of Adam Mickiewicz University became a member of the consortium building ILMT and I became the local coordinator in Poland. Other members of the consortium include: Universite de Liege, FNRS Belgium, Aryabhata Research Institute of Observational Sciences (ARIES, Indie), Royal Observatory of Belgium. For this project I built and programmed a computer cluster consisting of 10 work stations, which will be used for data reduction and storage (Pradhan et al., 2018). As part of my work in the consortium, I travelled to Liege for a month every year while the telescope was being designed and set up. In 2016 the telescope was transported to Devasthal (Uttarakhand, India) and in 2019 it will start systematic observations. Homepage of the project can be found at: http://www.ilmt.ulg.ac.be .

Online Services

I designed and developed ISAM service (Interactive Service for Asteroid Models, http://isam.astro.amu.edu.pl), which makes the existing asteroid shape models available to the public (Bartczak and Marciniak, 2011; Marciniak et al., 2012). For a selected model the service's functions make it possible to:

- generate exact sky projections necessary for size determination from stellar occultation observations,
- create synthetic lightcurves,
- animate model's rotation while simultaneously simulating its lightcurve,
- create 3D images in various stereoscopic techniques.

Aside from its scientific utility, ISAM service is a great tool for popularising science.

The second service – GaiaGOSA – was financed by ESA grant. It was created in collaboration with Poznań-based ITTI commercial enterprise. The service is designed to aid professional and amateur astronomers in ground-based observations supplementing Gaia space mission observations (Santana-Ros et al., 2016a,b, 2014). The service's observations planner automatically schedules observations of the targets currently in Gaia's field of view. Users can upload their data to the service for reduction which is done at our Institute. Afterwards, the results are made available through the GaiaGOSA service. Additionally, the service offers educational materials, which help amateurs learn and develop their observation technique. The best observers are awarded with special certificates endorsed by ESA. The service is a great tool for communication between amateurs and professionals offering tangible scientific benefits.

Near Earth Objects

Thanks to the cooperation with European Space Agency I was able to support the astronomers studying asteroids, Near Earth Objects (NEO) in particular. The first project I took part in pertained to a feasibility study for NEO tracking and detection software based on photometric observations from Space Situational Awareness (SSA) telescopes with the potential use of Graphics Processing Units (GPU) and cloud infrastructure to store data („ESA PANOPTES" [4000110300/14/NL/CHI]). I helped to create software which uses graphic libraries to visualise shapes of asteroid models. The project was run by Wrocław-based Vratis and Toruń-based Sybilla Technologies.

The next project („NEO User Support Tools" [4000114527/15/D/MRP]) dealt with the creation of programming of tools for planning and conducting NEO observations. An increase in the number of discovered NEO is necessary to prevent potential collisions with our planet. In this project I designed and calculated the positions of asteroids using tools and data provided by NeoDys and AstDys services. All of these tools are going to be integrated with the official ESA site (http://neo.ssa.esa.int/). The project was carried out by Astronomical Observatory Institute of Adam Mickiewicz University and Poznań-based ITTI.

„NEO Data Exchange and Collaboration Service (NEODECS)" project [4000119392/17/D/MRP] is set to deliver the communication mechanisms known from social media (Facebook, Twitter) to the astronomer community in order to help plan and conduct NEO observations. It will improve telescope time management and facilitate coordination of observational campaigns. The service will also contain metadata of physical parameters and NEO observations. For the project I developed and tested a communication protocol between various available data sources online. I also took part in the design of the user interface. The project is carried out by Poznań-based ITTI and Astronomical Observatory Institute of Adam Mickiewicz University.

Another project, „NEO&SST Observation Assistant Service (NOAS)" [4000120682/17/D/MRP] aims to create an application capable of coordinating night-long sky observations for a particular telescope using TSM universal language. TSM protocole is to be used as a universal communication method between robotic telescopes networks. Our system will be tested on OGS telescope in ESA observatory on Tenerife and RBT telescope located in Arizona (USA), owned by Astronomical Observatory Institute of Adam Mickiewicz University. For this project I created a service on a computer server, which filters potential objects for observation considering their geocentric and topocentric positions. Then, I mapped out and produced modules for communication between TSM editor and computer server service. The project is carried out by Astronomical Observatory Institute of Adam Mickiewicz University and Poznań-based ITTI.

„Service for Archival NEO Orbital and Rotational Data Analysis (SANORDA)" [4000121390/17/D/AH] project is going to enable gathering of observational data and its analysis. To do so a database was created, containing observational data gathered so far, capable of storing new data from other sources. Additionally, the database is going to store the analysis of long computation processes. The service is going to provide astronomers studying NEO with comfortable tools to search, filter and visualise data. My role in the project was supporting time-consuming computations with my parallel computation software. The project is carried out by Astronomical Observatory Institute of Adam Mickiewicz University and Poznań-based ITTI.

Stellar ocultations

Stellar occultation is an observation technique which makes it possible to determine the size of an asteroid. The observations rely on a precise recording of star's light being occulted by an asteroid travelling in the observed star field. The data obtained by a greater number of observers from different locations on Earth can help in the analysis of asteroid's shapes. I created software for data reduction and for determining asteroids' sizes based on observational data from The Planetary Data System (NASA). I was able to determine the size of 9 Metis [H2], 159 Aemilia, 329 Svea (Marciniak et al., 2018) and 90 Antiope [H5] binary system. I am a co-author of a publication in Nature, which contains the discovery of a ring around Haumea asteroid using stellar occultation observations.

Adaptive Optics

I work in a research team lead by Pierre Varnazza from Laboratorie d'Astrophysique de Marseille (LAM). The team works on a large observational programme on VLT ESO (Very Large Telescope European Southern Observatory) in Chile. The members of the consortium include: Observatorie de la Cote d'Azur Nice, SETI Institute, Charles University in Prague, Institut de Mecanique Celeste et de Calcul des Ephemerides (Paris), Jet Polusion Laboratory (California Institute of Technology), European Space Agency, European Southern Observatory and Astronomical Observatory Institute of Adam Mickiewicz University in Poznań.

As part of the project we are conducting observations using SPHERE detector, which makes it possible to image Main Belt asteroids bigger than 100 kilometres in diameter. Thanks to the measurements it is possible to determine shape, albedo, size and density, if the mass is known. I use my own method – SAGE – to independently determine asteroid's physical parameters in order to verify the results from methods using photometric data and adaptive optics. The results of team's efforts are models of the following asteroids: 16 Psyche (Viikinkoski et al., 2018), 89 Julia (Vernazza et al., 2018), 4 Vesta, 7 Iris and 41 Daphne (in preparation).

Radio observations

By using Doppler effect in radar observations we are able to obtain valuable information about asteroid shapes. Observation campaigns are conducted using 300 meter radio telescope in Arecibo (Puerto Rico) and 70 meter radio telescope at Goldstone observatory (JPL, NASA). Together with Grzegorz Dudziński, we developed two processes of using radar observations to create asteroid models. The first one compares synthetic radar images (based on a model) with observations. The other one analyses radar data and creates a 3D model of a body based on the probability density distribution of surface position. My contribution consisted of designing the method, writing the software and modelling of asteroid 1996HW1 (Dudzinski and Bartczak, 2016).

Photometric Observations - GAIA mission

I have started working on a new project financed by ESA. It is called "GAVIP-GridComputing" [4000120180/17/NL/CBi] and I am the project's leader. GAVIP-GC platform will facilitate effective utilisation of the data gathered by Gaia mission for scientific purposes. The access to Gaia mission data will be granted through GAVIP service, which is publicly available (http://docs.gavip.science/) and allows scientists to exchange algorithms for the mission's data analysis. GAVIP-GC project will strengthen the potential of GAVIP service and solve the problems with service's limitations, connected with the lack of sufficient computational power for the processes requiring massive amounts of computation. For this purpose a network of volunteers will be created within BOINC project (https://boinc.berkeley.edu/) to provide the necessary computational power.

Satellites and space debris

During the works on 4 meter liquid mirror telescope (ILMT) i suggested to use astrometric and photometric observations from this telescope to determine the physical parameters of satellites and space debris. Using the specific activity of CCD camera in TDI (Time Delayed Integration) mode it is possible to gather information about speed and direction of a particular satellite. I developed a method, which has been tested on observations from 1.3 meter telescope in Devasthal. Until now, the parameters of 9 pieces of space debris have been determined (Pradhan et al., 2018).

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4 Summary of academic achievements

I am a co-author of a total of 29 publications in Journal Citation Reports (JCR) database, 27 of which have been published after I obtained my PhD. I am also the author or a co-author of 42 other publications. A total number of all citations is, according to Web of Sciencie - 253, and according to ADS - 313. The number of citations excluding self-citations is 221 and 278 respectively. The total impact factor of all the publications, according to Journal Citation Reports (JCR) as per publication year, is 138.137.
My Hirsch index is, according to Web of Science h=10, and according to ADS h=11.

I took part in 13 research projects:

- 7 research projects financed by KBN, NCN, ESA, 7PR UE, H2020 UE, PAN-FNRS,
- 6 projects with commercial enterprises, which were financed by ESA.

I was the leader of three projects.

I belong to 4 research consortiums:

- 4m International Liquid Mirror Telescope,
- Gaia Research for Europen Astronomy Training -ITN (finished in 2015),
- ESO/VLT/SPHERE,
- Small Bodies Near and Far.

I participated in 18 conferences for which I authored or co-authored 19 oral presentations and 16 posters. I did 9 scientific internships in the following research facilities: ULG Liege (Belgium), SETI Institute (USA), ESTEC ESA (The Netherlands) i PARP (Poland). I am a member of Polish Astronomical Association and International Astronomical Union. I delivered 8 course lectures, 2 laboratory classes and 2 classes for students of astronomy, physics and geography. I am an advisor to two students writing their bachelor's theses, three students writing their master's theses, and an assistant advisor to two students writing their PhD dissertations. I delivered 7 popular science lectures.

I received 4 team awards from Adam Mickiewicz University Rector for scientific and organisational achievements. In July 2017 asteroid 10470 was named "Bartczak" by International Astronomical Union's Name commission as a recognition for contribution in asteroid research, inversion methods in particular.