Vita Summary

1. Name: **Dariusz Graczyk**

2. Academic degrees:
   Master of Science in Astronomy, Nicolaus Copernicus University, Toruń, 1996
   Methods of averaging in celestial mechanics.

   Doctor of Philosophy in Astronomy, Nicolaus Copernicus University, Toruń, 2003
   Long period eclipsing binary stars.

3. Work with academic institutions.
   Institute of Astronomy, University of Zielona Góra, 2003
   University of Concepción, Departamento de Astronomía, Chile, 2009-2016
   Nicolaus Copernicus Astronomical Center (CAMK), PAS, Poland 2016-

4. Scientific achievements:

a. title of scientific work
   Eclipsing binary stars as unique astrophysical tool and labolatory

b. (author, title of paper, year, publisher)

H1. **Graczyk, D.**, Pietrzyński, G., Thompson, I. B., Gieren, W., Pilecki, B., Konorski, P., Udalski, A., Soszyński, I., Villanova, S., Górski, M., Suchomska, K., Karczmarek, P., Kudritzki, R.-P., Bresolin, F., Gallenne, A., 2014, ApJ, 780, 59
The Araucaria Project. The Distance to the Small Magellanic Cloud from late-type eclipsing binaries citations=80, impact factor=6.063

H2. Hełminiak, K. G., **Graczyk, D.**, Konacki, M., Pilecki, B., Ratajczak, M., Pietrzyński, G., Sybilski, P., Villanova, S., Gieren, W., Pojmański, G., Konorski, P., Suchomska, K., Reichart, D. E., Ivarsen, K. M., Haislip, J. B., LaCluyze, A. P., 2015, MNRAS, 448, 1945, *Orbital and physical parameters of eclipsing binaries from the ASAS catalogue - VIII. The totally eclipsing double-giant system HD 187669*, citations=17, impact factor=4,729

H3. **Graczyk, D.**, Smolec, R., Pavlovski, K., Southworth, J., Pietrzyński, G., Maxted, P. F. L., Konorski, P., Gieren, W., Pilecki, B., Taormina, M., Suchomska, K., Karczmarek, P., Górski, M., Wielgórski, P., Anderson, R. I., 2016, A&A, 594, A92
A solar twin in the eclipsing binary LL Aquarii
citations=4, impact factor=5.185

H4. **Graczyk, D.**, Konorski, P., Pietrzyński, G., Gieren, W., Storm, J., Nardetto, N., Gallenne, A., Maxted, P. F. L., Kervella, P., Kołaczkowski, Z., 2017, ApJ, 837, 7
The Surface Brightness-color Relations Based on Eclipsing Binary Stars: Toward Precision Better than 1% in Angular Diameter Predictions
citations=6, impact factor=5.533

c. **Description of scientific aims of the above papers, achieved results and applications.**

All mentioned the above papers, which make my habilitation thesis, are connected by a subject of different applications of eclipsing binary stars in astrophysics. Every mentioned work presents unique scientific discovery or analysis of some issue, which for the first time was formulated and fully depicted in scientific work. I will describe individual papers in more details later, here I will briefly summarize their content. Paper **H1** presents in details, the first determination of a distance to the Small Magellanic Cloud (SMC) using late type detached eclipsing binary stars and discuss different aspects of the method. Paper **H2** reports first detailed analysis of Milky Way eclipsing binary consisting of two giant stars. Work **H3** reports on the discovery of the first known a solar twin in detached eclipsing binary and the first full characterization of physical parameters of such a star in a way completely independent of stellar evolution models. And last paper **H4** presents first precise calibration of the surface brightness-color calibration for stars using only eclipsing binaries, and describes the whole needed methodology in details. All those papers are team works and they resulted from international research undertaken within the Araucaria Project. The main aim of this project is to calibrate precisely local extragalactic distance scale and precise characterization of different standard candles used while building this scale. My participation in the mentioned papers was essential (**H2**) or decisive (**H1**, **H3** and **H4**).

The Magellanic Clouds are very important rung in extragalactic distance ladder. Because of numerous population of classical cepheids and of smaller than Milky Way metallicity, both Clouds are used for calibration of an inclination and a zero point of cepheids P-L relations. More important of the two is the LMC and the distance to this galaxy (e.g. Macri et al. 2015, Riess et al. 2016) because of a relatively small complexity of its structure and small geometrical depth in a direction of a view. The SMC, on the other hand, is a galaxy significantly more distorted through tidal interaction with the LMC and Milky Way. The distance to the SMC plays role in evaluation of universality of P-L relations of cepheids and dependency of them on metallicity (e.g. Ngeow et al. 2015, Wielgórski et al. 2017) thanks to its smaller metal content than the metallicity of the LMC (e.g. Westerlund 1997). Also, a relative distance between both Magellanic Clouds is important because it allows for verification of different population effects of standard candles (e.g. Górski et al. 2016, Wielgórski et al. 2017). The distance to the LMC for many years was a subject of a debate and its determinations were significantly discrepant (e.g. Gibson 2000) and eventually they were subjected to clustering of results (so called band-wagon effect, Schaefer 2008). A paper by Pietrzyński et al. (2013), in which I participated essentially, resolved the problem of distance to the LMC and precisely constrained its uncertainty to only 2% by means of eclipsing binary late type-giant stars. The same method, with small modifications, was applied to derive a distance to central parts of the SMC with a large precision of 3%, what was my main aim to achieve in paper **H1**.

What is a basis of this method? Using light and radial velocity curves of two components they are derived absolute dimension of the system such like: separation of components, their masses and radii utilizing the Wilson-Devinney code (1971, Wilson 1979, 1990). Then dereddened V-K colors of both components are determined using infrared photometry and interstellar extinction maps. These colors combined with the surface brightness calibrations of stars (e.g. Kervella et al. 2004, di Benedetto 2005) give angular diameters of components. Knowing linear and angular dimensions of two stars we can calculate directly a distance to them from simple geometric considerations. The distance to the SMC derived in paper **H1** has smallest systematic uncertainty from all the SMC distance determinations methods used (e.g. de Grijs & Bono 2015). From the moment of publication of this distance measurement, it becomes some kind of a standard in literature being cited often in pair with our distance determination to the LMC (Pietrzyński et al. 2013).

Another important result of paper **H1** is that I determined physical parameters of four unique eclipsing binaries containing late-type giant stars. In addition to another such system in the SMC analyzed before (Graczyk et al. 2012), it results in precise physical parameters such like masses, radii, temperatures and metallicities for 10 giant stars in this galaxy. These are the only such precise parameters of giant stars in the SMC in the literature. Results of the paper were used for calibration and testing stellar evolution models after leaving the main sequence, especially in a range of low metallicity (e.g. Claret & Torres 2016, Eggleton & Yakut 2017).

In subsequent paper **H2** included in my habilitation thesis together with dr K. Hełminiak we precisely determined a contribution of different systematic uncertainties presented in the analysis of eclipsing binary stars with late-type giant components. To this end, we used binary system HD 187669 lying in the direction of the galactic bulge and discovered by project ASAS (Pojmański 2002). One of the important goals of paper **H2** was a determination of high precision parameters of red giant stars (Red Gian Branch and Red Clump stars) in a model independent way or without specific assumptions. Such stars are burning hydrogen in a shell around helium core (RGB) or they ignited helium in a core (RC). Both stars comprising system HD 187669 are at the beginning of their evolution on RGB and we determined that age of the systems is 2.2 billion years. In our work for the first time were presented precise parameters, like mass and radius, of red giant stars in Milky Way eclipsing binary. Especially for purposes of the work, I obtained a unique high-resolution HARPS spectrum of the system during a primary total eclipse, thus the spectrum contains pure light of the secondary component. To establish the contribution of systematic effects photometric and spectroscopic data were analyzed by two independent groups: one led by me (Group G) and a second one led by K. Helminiak (Group H). For more, on every stage of the analysis, we used different data analysis tools and different models. Of course, during long half-year work we were consulting some partial results to avoid possible gross errors. From our point of view, this work has special meaning to the Araucaria project, because it evaluated possible systematic effects in the method we used for the LMC (Pietrzyński et al. 2013, Elgueta et al. 2016) and the SMC (Graczyk et al. 2012, **H1**).

Recently, there is augmented interest in red giant stars thanks to new ways of their study by asteroseismology (space missions *CoRoT* and *Kepler*) and high-resolution infrared spectroscopy (Apache Point Observatory Galactic Evolution Experiment - *APOGEE*). Red giant stars are used for investigating dynamical and chemical evolution of our galaxy through analysis of mono-aged and mono-abundance population of stars (e.g.: Mackereth et al. 2017, Anders et al. 2017) - also on skirts of our galaxy (e.g.: Mathur et al. 2016), for determination of galactic rotation (e.g.: Lopez-Corredoira 2014, Huang et al. 2016), for determination of distances to massive stars in galactic arms (e.g. Suchomska et al. 2015), just to mention few most important research areas. However, in almost all these studies some statistical properties of red giant stars are assumed, but individual properties of the stars like a mass or a radius are seldom known with precision reaching 4-5%. Still, only eclipsing binary systems containing red giants are a source of accurate physical parameters for them with precision reaching 1%. Here, an interesting application of eclipsing binaries is calibration of asteroseismological relations combining fundamental parameters of stars with the separation frequency $\Delta\nu$ and frequency of oscillation maximum power ν_{max}, called the scaling relations (e.g.: Kjeldsen & Bedding 1995). A paper by Gaulme et al. (2016) reported on an analysis of 10 eclipsing binary systems found by *Kepler* mission consisting of a red giant and a main sequence star what resulted in a conclusion that there is a discrepancy between dynamical and asteroseismic masses of up to 15%.

The most important conclusions from paper **H2** can be summarized as follow:

1) standard methods of analysis of eclipsing binary stars indeed allows for deriving accurate parameter (1%) for systems containing red giants, taking into account systematic effects;
2) the spectrum taken during a total eclipse perfectly corresponds to the spectrum obtained with the disentangling of components spectra; it probated a method of disentangling of spectra which we used for Magellanic Cloud's eclipsing binaries;
3) stellar evolution models (PARSEC - Bressan et al, 2012) well fit observational characteristic of the system, however, precision of derived parameters is high (1%) is insufficient for precise calibration the convective overshooting which affects the stellar evolution of stars more massive than the sun.

Paper **H3** emerged as a result of a long-term project of observing nearby eclipsing binaries, which I lead (Graczyk et al. 2015). In this paper, I intended a few aims, namely: a very precise determination of parameters of eclipsing binary LL Aqr, a confirmation if a cooler component of this system is a solar twin and testing evolutionary models of solar-type stars. A solar twin is a star having physical parameters such like radius, temperature and chemical composition very close or identical to the sun. Those stars have fundamental applications for indirect determination of solar colors (e.g. Casagrande et al. 2012), for identification of eventual the sun's peculiarities (e.g. Melendez et al. 2009) and searching for extrasolar planetary systems similar to our own system (e.g. Ramirez et al. 2014). Although we know few dozens of such stars (e.g. Porto de Mello et al. 2014) and some of them have the spectra, which are almost undistinguished from the solar spectrum, like HIP 56948 (Melendez et al. 2012), up to now any of them have had their masses and radii derived precisely. Usually, these physical parameters of a solar twin are determined indirectly by using stellar evolution models and thus they have potentially large systematic uncertainties, which are, however, difficult to properly estimate. In the case of LL Aqr, I could use very high-quality spectra from HARPS and CORALIE spectrographs combined with a very good quality light curve from SWASP (Polacco et al. 2006) to obtain the radii and the masses of both components with a precision of 0.5% and 0.07%, respectively. I put a special attention to a determination of temperatures of the two stars. They were derived using a few independent methods giving consistent results. The candidate component for a solar twin turned out to be a bit more massive and a bit cooler than the sun. The disentangled spectrum of the cooler component is very similar to the solar spectrum and metallicity of the two components is solar. Also, colors of the candidate star derived from multiband photometry are in perfect agreement with solar colors. All tests carried out confirmed that the cooler component is indeed a solar twin star.

The superb precision of determined parameters of LL Aqr system allowed for testing stellar evolution models and determination its evolutionary status. This part of work was done with a collaboration with dr R. Smolec and dr P. Maxted. MESA and GARSTES models were used. In a case of MESA models, it was very difficult to obtain agreement between observed physical parameters of the components and model predictions. Only after adjusting the differential mixing-length scale and the metal diffusion parameters it was possible to obtain 1σ agreement. The age of the system was estimated to be about 2.5 Gyr, i.e. both stars are just in the beginning of their evolution on the main sequence. It is an interesting thing that by fitting standard evolutionary tracks to observed parameters of components of LL Aqr (i.e. the effective temperature, the surface gravity, the metallicity) we obtained masses and radii different from directly determined ones by about 5 percent. It shows that reported in literature very precise masses and radii of solar twins derived from isochronal fitting (e.g. Yana Galarza et al. 2016) may have additional large systematic uncertainties not accounted for by authors of these reports. However, until now results of paper **H3** were not discussed in the field. Some results of the paper **H3**, in particular, precise stellar parameters, were used for calibration of the surface brightness - color relations (paper **H4**) and for testing systematics of trigonometric parallaxes from DR1 Gaia cosmic mission (Stassun & Torres 2016a,b).

The existence of tight relation between the stellar surface brightness and stellar colors was empirically verified at the turn of 60' and 70' (e.g. Wesselink 1969, Barnes & Evans 1976). The surface brightness of a star is a photometric parameter determined from its angular diameter and an observed magnitude in a standard photometric band (e.g. Hindslay & Bell 1989). The angular diameters are nowadays derived mostly by means of long-base interferometry working in the optical and the near-infrared. The most important application of the surface brightness- color relations in astrophysics is an estimation of angular diameters of stars basing on their colors. In conjunction with estimation of an absolute dimension of a star, it allows for direct determination of its distance by the Baade-Wesselink method (e.g. Fouque & Gieren) or by the eclipsing binary method (e.g. Graczyk et al. 2012, **H2**). Most precise calibrations are derived for colors joining V or B optical bands with near-infrared K band (e.g. Kervella et al. 2004). In case of late-type stars precision of such calibrations in predicting angular diameters is reaching 2% (e.g. di Benedetto 2005), however, for early-type stars precision of the best calibrations reach merely about 7% (e.g. Challouf et al. 2014). In paper **H4** I shoot at a few aims. First of all derivation of precise calibrations for late-type stars basing only on angular diameters determined from analysis of a carefully selected sample of detached eclipsing binary stars (35 systems). Secondly, evaluation if such the calibrations are consistent with calibrations derived from interferometric measurements of stellar angular diameters and thirdly evaluation and discussion of all needed steps in order to achieve a precision of calibrations better than 1% by using eclipsing binary stars.

All mentioned the above aims were achieved in the paper **H4**. The angular diameters of eclipsing binary components were determined from their physical radii resulting from standard light and radial velocity solutions and combined with geometrical distances to eclipsing binary systems. Geometrical distances were derived from the trigonometric parallaxes included in the first data release of the *Gaia* mission (2016, DRS1) or in re-reduction of the *Hipparcos* mission (van Leeuwen 2007). In the paper, I described in details the method, which I used and I presented a catalog of suitable eclipsing binaries. The derived calibrations turned out to have precision comparable with the best calibrations published in the literature (about 3%). I proved also, that the methods of calibrations, by using interferometry and eclipsing binaries, are fully complementary and equivalent each other, and, most importantly, the calibrations derived by these two methods are consistent. This is the most important result of the paper **H4**. The interesting additional result is confirmation of findings by Stassun & Torres (2016b), that trigonometric parallaxes from the *Gaia* DR1 are systematically too small by about 3%. This error, even if appears to be large as for expected precision of the Gaia mission, is in fact within predicted limits of systematics for the DR1 of Gaia (2016). The paper **H4** also fruited in a homogenization of published in literature physical parameters of tens of eclipsing binaries. I put a special attention to prepare a signpost route to reach in near future a much better precision in predicting angular diameters of stars. The most important points of this route are enlarging the sample to about 100 systems, obtaining high quality, homogenous near-infrared photometry and, of course, utilization of high precision trigonometric parallaxes from final data realize of the Gaia mission.

Another interesting result of the paper **H4** was noticing that for early-type stars calibrations based on the color B-K have smaller dispersion than standard V-K color and smaller sensitivity to interstellar extinction uncertainties. Calibrations based on B-K color could be used in the future for determination direct precise distances to eclipsing binary systems in nearby large galaxies like M31 and M33 in the Local Group of galaxies.

5. Report on other scientific achievements after the PhD.
   - detailed analysis of eclipsing binary stars in the Small Magellanic Cloud, calculaion of their physical parameters and a selection of best systems for distance determination (Graczyk 2003);
   - first determination of the distance to the Large Magellanic Cloud by means of the late-type eclipsing binary (Pietrzyński et al. 2009);
   - elaboration of the method for identification of eclipsing binary stars in a large groud-based photometric survey based on statistical moments analysis (Graczyk & Eyer 2010);
   - preparation of a large catalog of eclipsing binary stars in the LMC from the third phase of the OGLE project, it was the largest catalog of eclipsing binaries while published, and it has a large fraction of detached systems and a large degree of completeness (Graczyk et al. 2011);
   - the building of full models of first confirmed eclipsing binary systems containing a radially pulsating star: a classical cepheid (Pietrzyński et al. 2010, 2012) and unique system with a star which mimics RR Lyr type variability but it has completely different evolutionary status (Pietrzyński et al. 2012);
   - essential contribution to determination of very precise distance to the LMC with a precision of 2% (Pietrzyński et al. 2013), this work is now a standard reference for a distance to this important galaxy, the result was confirmed by my later work devoted to another eclipsing binary OGLE-LMC-ECL-25658 (Elgueta et al. 2016);
   - collaboration on preparation a catalog of eclipsing binary stars in the SMC based on the third phase of the OGLE project (Pawlak et al. 2013);
   - essential contribution to preparation of novel method for analysis eclipsing binary systems containing radially pulsating star (Pilecki et al. 2013); the method was tested on cepheid OGLE-LMC-CEP-0227 and we derived for the first time so called the projection factor (*p-factor*) independently of the distance; this work is a large extension to Pietrzyński et al. (2010);
   - collaboration on determination a new calibration of the surface brightness - color relation for early-type stars based on new interferometric angular diameters (Challouf et al. 2014);
   - determination of spectroscopic orbits and analysis of the light contribution of individual components of eclipsing binaries containing a classical cepheid (Pilecki et al. 2015, Gieren et al. 2015);
   - determination of precise parameters of massive eclipsing binary in the Saggitarius Arm in Milky Way (Suchomska et al. 2015), I was a research head on the behalf of the Araucaria project;
   - collaboration on very precise determination of masses and a distance to evolved eclipsing binary TZ For (Gallenne et al. 2016), in this work I worked out the first preliminary test of existing the surface brightness-color relations, this work is a part of a larger project devoted to determination of orbital parallaxes to a number of nearby eclipsing binaries and testing *Gaia* mission results.
   - determination of fundamental parameters of 40 late type giants in the Large Magellanic Cloud comprising eclipsing binary stars (Graczyk et al. 2018); this work is a base for more precise determination of a distance to this galaxy with a pecision of 1%, which is a milestone in astronomy (Pietrzyński et al. 2018, sent to Nature)

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