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RESUME

1. About the habilitant

[redacted] I started my education in 1984 in the Primary School no. 1 in Choszczno. In the 7th and 8th grade I participated and scored high in the mathematical and physical school competitions at the regional level. In 1992 I started the Secondary School in Choszczno in the class of mathematical-physical profile. I participated in the geographical and astronomical olympiad competition at a central level and in the Polish Astronomical-Astronautical Seminar in Grudziądz, where I received the first place award in 1994 for presenting the radio-interferometer for solar observations. In years 1992-1996 I was a member of the Polish Astronomical Club "Almukantarat". In the third and fourth grade I was a scholar of the Polish Childrens Fund and I received an award from the Ministry of Education. In 1995 I received an award at the ESA's International Forum on Applications for Satellites in Nordwijk, The Nederlands. In 1996 I participated in the London International Young Scientists Forum as the only Polish participant.

In 1996 I passed my Matura exam (equivalent of A-levels) and began my astronomical studies at the Department of Physics at the University of Warsaw. In the third year I became involved in the scientific research under supervision of Grzegorz Pietrzyński. I conducted photometric observations of the open clusters using the Ostrowik Observatory of the Warsaw University. This work was then turned into my first scientific publications (Pietrzynski, Wyrzykowski et al. 2001, Wyrzykowski et al. 2002). In the fourth year I was invited to join the *Optical Gravitational Lensing Experiment* (OGLE) project, which was operated at the Warsaw University Astronomical Observatory. Within this project I was conducting the observations using the dedicated OGLE's telescope located in the Las Campanas Observatory in Chile. I finished my studies in 2001 with a Master's dissertation, supervised by Professor Andrzej Udalski, entitled "Distances to the galaxies of the Local Group". I analysed the observations of galaxy IC1613, finding numerous Cepheids variables and showing lack of dependence on metallicity in the period-luminosity relation for Cepheids (Udalski, Wyrzykowski, et al. 2001).

In 2001 I started my PhD studies at the Warsaw University Astronomical Observatory. In the first two years I worked mainly on detection and classification of variable stars. Using OGLE-II data I produced two, largest at the time, catalogues of eclipsing variable stars in the Large and Small Magellanic Clouds (Wyrzykowski et al. 2003a, Wyrzykowski et al. 2004). For the preparation of those catalogues I developed and applied a novel method for variable stars classification based on artificial neural networks. That work was supported by the grant I received from the Komitet Badań Naukowych (KBN). I also measured the time-delay in the gravitationally lensed quasar HE1104-1805 using OGLE data (Wyrzykowski et al. 2003b). During my PhD studies I regularly travelled to Chile to conduct observations for the OGLE project in the Las Campanas Observatory (on average twice a year, each run of 2-3 weeks). As a member of the OGLE team I actively participated in research carried out by the group and I co-authored numerous publications.

In 2003/2004 I spend 9 months on a research visit at the University of Tel-Aviv in Israel. I collaborated with researchers working on eclipsing variable stars and gravitational microlensing. In 2004 I received a stipend within the European Marie Curie Training Site programme for a research visit at the University of Manchester in the UK. I worked mainly with Professor Shude Mao and in my research there I concentrated on detection and classification of gravitational microlensing events towards the Galactic Centre. In February 2005 I spend a month at Princeton University, USA, working with Professor Bohdan Paczyński, the founder of the microlensing field.

I finished my PhD studies in 2005 and after a successful viva in November 2005 I received a PhD with distinction for my thesis entitled "Microlensing towards the Galactic Centre". In my thesis I analysed the first 5 years of the OGLE-III data on the Galactic Bulge. I searched for microlensing events and detected and catalogued several thousands of them. Among them I discovered and distinguished new class of events with variability in their baselines, which can be used for obtaining additional information about the event (Wyrzykowski et al. 2006). Using the catalogued standard events I created the first ever map of the microlensing optical depth towards the Bulge, which can be used for studies of the inner structure of the Galaxy.

In 2005 I started my postdoctoral fellowship in the Institute of Astronomy at the University of Cambridge to work within the European FP6 Marie Curie network *ANGLES.* I researched on gravitational microlensing and strong lensing and attended many international conferences in this field (e.g. in Nagoya, Japan, and Santa Barbara, USA). Collaboration with the scientists from the University of Cambridge resulted in my co-authorship in publications regarding, e.g., searching and modeling new gravitational lenses with large image separations (Belokurov et al. 2007). I also participated in the preparation and publication of the photometric-astrometric catalogue based on the SDSS data (Bramich et al. 2008), which contains about 4 million objects and allows for studies of various aspects of variability. Based on that catalogue we also found one of the largest samples of about a 1000 of white dwarfs in the Galactic Halo (Vidrih et al. 2007). I also co-authored one of the first discoveries of the substructures in the Galactic Halo based on clumps of the RR Lyrae-type stars (Watkins et al. 2009).

In January 2008 in Cambridge I became a member of the team preparing the operation of the Gaia satellite (launch planned for June 2013), European Space Agency's major space mission of this decade. I am responsible for designing and preparing an early warning system for detecting astrophysical anomalies and transient objects, e.g. microlensing events or supernovae. The system will operate in near-real-time and will analyse data from the satellite in order to detect and classify the alerts and publish them to the worldwide astronomical community. Preparation of such a system has required not only understanding the operation of the Gaia satellite and advanced methods of the data analysis, but also expanding my knowledge on various types of transient events like supernovae, novae, Be stars, R CrB and others and conducting extensive simulations of these events. I developed an automated classification system utilising novel methods like Self-Organizing Maps (Wyrzykowski & Belokurov, 2008). In 2010 and 2011 in Cambridge I organized international meetings on Gaia alerts, during which the wider astronomical community was informed about the mission and its potential. During the workshops I also initiated creation of a dedicated ground-based telescope network for Gaia alerts follow-up.

As a member of the OGLE project, I remained active as an observer and researcher within the team. I participated in the studies in the field of gravitational microlensing which resulted in discoveries of the extrasolar planets (e.g. Bond ed al. 2004, Udalski et al. 2005, Beaulieu et al. 2006, Gaudi et al. 2008) and in detections of planets with the transit method (e.g. Udalski et al. 2002). I also contributed to numerous works on the catalogues of variable stars from the OGLE data (e.g. Soszyński et al. 2008, 2009, 2010, Poleski et al. 2010).

In the last three years my research work has been focused on the issue of the dark matter studies with the gravitational microlensing. This resulted in the habilitation material, described in detail in the next section.

Summarising, within my research career I authored or co-authored 112 works published in refereed astronomical journals, cited in total 2909 times (2513 without auto-citations) and 15 circulars and conference proceedings. My Hirsch index is currently 30 and total impact factor is 593.102 (as of 24 October 2011, data according to the Web of Science).

2. Summary of the habilitation work

Cycle of publications entitled "Studies of the Dark Matter in the Galaxy with the gravitational microlensing" is composed of the following works:

1. "The OGLE view of microlensing towards the Magellanic Clouds - I. A trickle of events in the OGLE-II LMC data", Wyrzykowski et al., 2009, MNRAS 397, 1242,

2. "The OGLE view of microlensing towards the Magellanic Clouds - II. OGLE-II Small Magellanic Cloud data", Wyrzykowski et al., 2010, MNRAS 407, 200,

3. "The OGLE view of microlensing towards the Magellanic Clouds - III. Ruling out subsolar MACHOs with the OGLE-III LMC data", Wyrzykowski et al., 2011, MNRAS 413, 508,

4. "The OGLE View of Microlensing towards the Magellanic Clouds. IV. OGLE-III SMC Data and Final Conclusions on MACHOs", Wyrzykowski et al., 2011, MNRAS, 416, 2961,

and was based on the data from the OGLE project from years 1996-2009. The main aim of this research was to verify whether microlensing events towards the Magellanic Clouds were caused by the hypothetical dark matter compact objects, called MACHOs.

Dark matter exhibits its presence in the halos of the galaxies mainly through the flatness of the radial velocity curves and strong gravitational lenses. However, so far it has been impossible to find out what the dark matter really is. One of the hypotheses was raised by Bohdan Paczyński (Paczyński, 1986) in which he suggested that the dark matter could be present in large numbers as invisible stellar-like objects, for example brown dwarfs or black holes. Paczyński suggested also a method for verification of this hypothesis based on gravitational microlensing, which is sensitive to the mass, not the light of the object.

In the last decade of the 20th century numerous observing surveys started their operation: OGLE (Udalski et al. 1993), MACHO (Alcock et al. 1993), EROS (Aubourg et al. 1993) and MOA (Yock, 1998). For many years the projects were regularly observing dense regions of the sky and detected thousands of events. Most of the events were found in the direction of the Galactic Bulge and only a small fraction towards the Magellanic Clouds. In 2000 MACHO group analysed their data (Alcock et al. 2000) and announced the detection of an excess of microlensing events towards the LMC which suggested that about 20% of the mass of the Galactic Halo is present as a dark matter compact objects (MACHOs) with an average mass of about 0.5 Solar masses. The optical depth derived by the MACHO group was $\tau_{LMC\text{-}MACHO}=1.0\times10^{-7}$ (revised value after removing a few false candidates in Bennet, 2005). This result was later questioned because of possible contamination of the sample of events (Belokurov et al. 2004). On the other hand, the results obtained by the EROS group were contrary to the MACHO's result, as they suggested that MACHOs were not needed to explain the observed microlensing rates (the derived upper limit for MACHOs of about 0.4 Solar masses was at 7% of total Halo mass).

Therefore, data collected by the OGLE project were providing an independent test and opportunity to solve this puzzle. Spanning over years 1996-2009, this dataset was the longest available and the best in terms of the precision of the measurements. The algorithm for finding the microlensing events relied on a series of cuts applied to the parameters of all light curves with detected brightening. For example, I removed all candidates which location on the colour (V-I) - magnitude (I) diagram coincided with the region of "Blue Bumpers" (stars belonging to a family of active Be stars exhibiting singular brightenings resembling those of microlensing). One of the most important cuts was related with the goodness of fit of the microlensing model to the candidate's data over the entire light curve and at the peak of the event. Parameters of each cut were adjusted for each dataset considered, e.g. events' magnitude cut was at 20.4 mag for the LMC and at 21.0 mag for the SMC, what was related with different observing strategy of these galaxies linked with different stellar densities.

As a result of the search in the OGLE-II data two candidates for microlensing events were found towards the LMC and one towards the SMC. In the OGLE-III data for the LMC two candidates were found along with another two potential events. In the SMC data I found three robust events. Some of these events were known before as they were detected in real-time by the EWS system (Udalski, 2003). Light curves of all events were carefully studied in order to determine the origin of each event. In most cases the most likely scenario was self-lensing, i.e. lensing of a background star from the Cloud by another star from the Cloud. The only exception was the event OGLE-SMC-02 for which additional data were available from the Spitzer satellite. This allowed for a complete solution of the microlensing event and conclusion that most probably it was caused by a binary black-hole with components with masses of 3 and 7 Solar masses, located in the Galactic Halo (Dong et al. 2007).

In order to calculate the optical depth towards the LMC and SMC, it was necessary for each of the datasets to first derive the efficiency of events' detection. In this procedure I carefully considered the issue of blending, taking into account the realistic blending distributions obtained with archival Hubble Space Telescope's (HST) data. After combining the luminosity functions of OGLE and the HST for areas with different stellar densities it was possible to derive real blending distributions. These were, in turn, used in simulations of event simulation and efficiency calculation.

The optical depth measured for each dataset was: $\tau_{LMC\text{-}O2}=0.43\pm0.33\times10^{-7}$, $\tau_{LMC\text{-}O3}=0.16\pm0.12\times10^{-7}$, $\tau_{SMC\text{-}O2}=1.55\pm1.55\times10^{-7}$, $\tau_{SMC\text{-}O3}=1.30\pm1.01\times10^{-7}$. Because of small number of events found, the values of the optical depths have relatively large error bars. However, their values are still consistent with the expectations for the self-lensing alone (e.g. Calchi-Novati et al. 2009). After combining all four optical depth measurements I derived an upper limit on the MACHOs abundance in the Halo of less than 4% for masses smaller than 0.1 Solar masses, 6% for 0.1-0.4 Solar masses and 20% for objects of about 20 Solar masses. These are the strongest limits on MACHOs obtained so far.

In conclusion, the results obtained from 13 years of monitoring of the Magellanic Clouds in the OGLE project allowed for the most accurate test for the MACHOs hypothesis. The OGLE data practically rule out barionic dark matter in the form of compact objects as a significant contributors to the Galactic Halo dark matter mass. The detection of a potential black-hole object is in agreement with the expected amount of stellar black-holes in the Galaxy.

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