dr hab. Krzysztof Gęsicki prof. UMK
Centrum Astronomii UMK

Recenzja rozprawy doktorskiej mgra Diogo Teixeira Belloni ,,On Cataclysmic Variable Properties in Evolving Star Clusters based on MOCCA Dynamical Simulations"

Overview of the dissertation

The thesis presented for the degree of Doctor of Philosophy by Diogo Belloni is written under a supervision of dr hab. Mirosław Giersz. It is composed of an introductory 33 pages followed by published versions of five scientific articles. In Poland such a structure is rather typical for "habilitacja" thesis, it is not so common for PhD. In my review I will refer to the five articles contributing to the thesis as Paper 1, Paper 2, etc. I also will use some abbreviations as CV (cataclysmic variable), GC (globular cluster).

The title is not very precisely formulated, we can deduce from it that the dissertation is about some properties of some selected variable stars and this work uses a particular numerical code. The *Abstract* is not much more helpful in defining the objective and in specifying the main results, it says rather about "some aspects", "better understanding" and about several "improvements". A particular conclusions of the thesis that can be found in the *Abstract* concern the lack of dwarf novae outbursts in globular clusters and the formation of bright and faint populations of cataclysmic variables.

The Chapter 1 *Introduction* is divided into seven sections of different lengths and importance.

Sect.1.1 *Why should one investigate CVs in GCs?* contains two pages of text mostly copied from introductory sections of Paper 1 and Paper 2. It presents a very brief classification of CVs, a general introduction of CVs in GCs, and points to the importance of CVs to initial conditions in modelling GCs.

Sect.1.2 *What do we know from observations and what are the main issues to address?* contains three pages with a brief history of observations and problems related with them. This time it is not a copy-and-paste but author's description, with reference to Paper 1. Within the text there are hidden two goals of the dissertation, exactly the same as in *Abstract*. This sections contains a long discussion of GC 47 Tuc and at the end a list of the issues to be addressed/explained in the thesis: the two mentioned previously and a couple of others actually related with faint and bright CVs.

Sect.1.3 *Objectives of this thesis, Methodology and Main Results* contains 4.5 pages. It begins with a list of five main goals of the thesis however only the first one and the third come from the goals introduced in the previous section, other goals are discussed in the next pages. The followed brief description of the MOCCA code is a copy from Paper 1. Next there is a summary of the main results with references to Papers 1-5. At the end there are formulated some problems which will be considered in the future simulations, what actually means in Sects. 1.4 and 1.5.

Sect.1.4 *Upgrades to the MOCCA code* takes half of a page and very briefly describes improvements made to the two components of the code: the initial binary population (Paper 4) and binary evolution module.

Sect.1.5 *Preliminary results based on 96 MOCCA GC models* is the longest section written in 14 pages. In contains new results not published yet. In comparison with Papers 1, 2, and 3 it is based on significantly increased number of GC models taking into account several values of numerous parameters. Already at the beginning of the discussion (page 14/15) there is presented a result concerning the white dwarf mass distribution that disagrees with previously obtained in Papers 1-3. In page 16 the new result concerning the CV dominant formation channel is in

disagreement with Paper 3. The explanation for both cases is provided in terms of a much better parametrization of CV evolution adopted now. The following discussions end with a warning that any future spectroscopic verification of GC CV candidates can change the observed statistics and in consequence the fitted models parameters. This section closes with a list of 8 detailed conclusions.

Sect.1.6 *Properties of the Milky Way CV population originated from dissolution of embedded clusters* is written on 7.5 pages. This work is continuation of Paper 5 and applies the approach explored in that paper to the discussion of Milky Way CV population. Derived are some parameters needed to explain selected observed properties of CVs. At the end there are listed six detailed conclusions and we can find a rather modest statement that this work "offers an additional evidence supporting the idea" which was already explored in Paper 5. This work is rather loosely related with the general subject of the thesis.

In Sect.1.7 *General Conclusions of this Thesis* on 1.5 pages there are listed 23 detailed conclusions.

Following the Introduction chapter there are five chapters containing the printed copies of five scientific articles, all of them in the refereed journal *Monthly Notices of the Royal Astronomical Society* in years 2016-2018, all with several authors but with D. Belloni as the first author.

Paper 1 introduces the CATUABA code which was developed by D. Belloni. This code analyses snapshots obtained from another well tested code, MOCCA designed for modelling the stellar cluster evolution. The CATUABA code identifies CVs in the stellar population computed by MOCCA and conducts for them a complete study. The applied methods are described in details, the authors honestly admit that "the procedure described above is somewhat forged, although reasonable". The first applications of this code was presented for six models of globular clusters. The paper ends with a list of 10 detailed conclusions.

Paper 2 is a continuation of the previous paper. It was intended to expand the older results and to follow the pioneering ideas of Ivanova et al. (2006) and Shara & Hurley (2006) about the possible channels of CV formation, this time using MOCCA and CATUABA codes. The paper ends with a list of 9 detailed conclusions.

Paper 3 continues the discussions of CVs in GCs with "more realistic" model parameters. The new models contradict one of the conclusions of Paper 2 which despite previous statistical tests appears now as an artefact of small-number statistics and now we know that CV formation is different for different clusters. The final conclusions here are not numerous and are clear: very short CV duty cycles explain the apparent lack of CVs in GCs, and bright CVs in GCs are young. There was suggested an upgrade of the binary evolution module of the MOCCA code.

Paper 4 also discusses initial parameters for GC evolution but this time there is applied a different numerical tool (written by A. Askar) which simulates colour-magnitude diagrams. Comparing theoretical and observed diagrams the modifications were derived providing "a first step towards a better description" of population synthesis. However this paper is not related at all with CVs while the modifications should not change the previous results.

Paper 5 explores a concept of populating the Galactic stellar field via dissolution of stellar clusters and applying for this the numerical MOCCA cluster simulations with introduced in Paper 4 modifications. This concept appears useful and in good agreement with older analytical results of Marks & Kroupa (2011). Again this paper is not related with CVs.

Attached to the thesis are statements from the co-authors about their contribution to the collective papers, these letters are very helpful in evaluating the work of D. Belloni.

Evaluation of the dissertation

According to the polish "Act on academic degrees and academic title" a doctoral dissertation should constitute an original solution to the scientific problem, and demonstrate the general theoretical knowledge of the candidate in a given discipline and the ability to independently conduct scientific work. This means that evaluated are not only the scientific investigations but also their description in a form of a booklet - dissertation. Both aspects will be refereed below.

Scientific aspect

Globular clusters are characterized by very high star density what makes their observations and modelling quite challenging. Intriguing objects as blue stragglers and cataclysmic variables can originate from close encounters in dense populations and/or can be affected by them. These objects within GCs are a well known subject of studies.

The MOCCA code which is an upgraded (around year 2013) version of an older code for globular cluster Monte Carlo simulations, has been already applied to the formation of blue stragglers and black holes. Its application to the analysis of CVs in GCs is an obvious next step, and also natural because CVs are successfully analysed in Warsaw since many years.

The dissertation shows how the PhD project evolved, how the gradually improved theoretical methods increased our knowledge on CVs in evolving GCs. Paper 1 set the stage, Paper 2 derived some conclusions which were later improved in Paper 3 based on a better statistics. Then Sect.1.5 based on the improved modelling parameters (Paper 4) further improved the conclusions. Paper 5 applied MOCCA to populating Galactic stellar field, what is not related with the main PhD objective, however Sect.1.6 (next in this sequence) came back to CVs and extended the work of Paper 5 onto the Milky Way CVs (although not globular cluster).

From the list of papers that used MOCCA code (ADS bibliographic service) we see that D.Belloni is involved in all 4 papers dealing with CVs in evolving GCs, playing a leading role in this research. This appears as a proper PhD project given to a PhD student who in turn performed very well. All publications of the candidate (according to ADS: refereed 6, citations 31, H-index 4, in five of them as the first author), constitute a convincing evidence that D. Belloni is able to conduct independently the scientific research.

The first main problem of the thesis - the deficit of the observed CVs in GCs - has been successfully explained in terms of a very short duty cycle of the majority of GC CVs what makes the probability of their detections very small. This solution has been presented already in Paper 1 and confirmed in Paper 3 with more realistic models. The second main problem of the thesis concerned the origin of the bright and faint populations of CVs in GCs. This has been mentioned in Paper 1 and extensively discussed in Paper 3 and in Sect.1.5 in terms of the age of CVs and their interactions within a dense GC environment. Although I regard the first result as more important it is the second one which has been already noticed by the astronomical community (see Rivera Sandoval et al., 2018, MNRAS 475, 4841).

Both results without any doubts constitute an original solution to the scientific problem. However in the *Introduction* there are listed many more conclusions. I consider them as of secondary importance, related rather with the methods, not being the main results, they usually refer to initial conditions, interactions, modifications, assumptions, dependencies, predictions that can be verified, etc. What I miss is a discussion of astrophysical consequences of the obtained results. Their interpretation in terms of parameters and empirical formulae applied in codes might be sufficient for a publication directed to specialists however in the PhD dissertation expected is a qualitative discussion of phenomena underlying these results. For example: what teaches us about close binary evolution the brief duty cycle of outbursts?

Editorial aspect

The introductory part of the dissertation is definitely too compact. The candidate has to prove his/her general knowledge within the given discipline. Therefore expected is a book (booklet) that describes the current state-of-art in the field of research and of the methods applied and which justifies the undertaken investigation. Certainly something like that is present in the dissertation, the corresponding titles of sections sound properly but, as I mentioned reviewing the content, 2-4 pages is too little. Some details are too much simplified, as for example the definition (page 2) of a period bouncer in terms of the donor type instead of the period evolution. What is also important significant fragments of those sections are direct copies from the published articles. What is appropriate for a scientific article not necessarily fits to the PhD dissertation. References to the review articles do not fill the gap in this case.

According to PhD supervisor (in the co-author statement) the project was defined as

applying the MOCCA code to solve the problem of paucity of observed CVs in GCs. Certainly such work needs literature study, the modifications of the old code and a development of any needed new specialized numerical codes. But the original project grew to more dimensions and the primary problem seems to be dissolved among numerous side-problems and questions. Is this a matter of unclear description or too much dispersed work? My answer is: both.

As I already pointed the dissertation lacks of a thesis which clearly formulated at the beginning would be verified at the end, something that is expected at PhD. Instead we can deduce from the dissertation and from supervisor statement two main goals which were eventually achieved. The first problem of lack of dwarf novae outbursts was already solved in Paper 1 (conclusion vi) and repeated in Paper 3. The second problem of the origin of bright and faint CV populations was solved in Paper 3 and repeated in Sect.1.5 (conclusion vii). In my opinion this material would be sufficient to be brought together, described and presented as PhD dissertation. That would be homogeneous and easy to read, and to review.

The remaining material, i.e. Paper 5 and Sect.1.6 certainly proves that D. Belloni mastered the code MOCCA and can successfully analyse the Milky Way CV population. But this work is only loosely, if at all, related with the thesis subject and the reader is directed away from the two main goals. However I should point that much worse critics would be if it was necessary to add a couple of sections instead of remove.

A serious editorial fault is the final long list of detailed conclusions. It appears as assembled from shorter lists scattered in the subsections of the *Introduction* and in Papers 1-5. One trouble is that the conclusions are typed in succession within the same paragraph. Were they listed in separate paragraphs, as in the published papers, would be much better readable. What is worse they are typed in a chaotic order. The two apparently most important goals of this PhD are listed in Sect.1.7 as (iv) and (xx) among 23 conclusions while the conclusion (xvii) concerns both goals. Listed as first is the conclusion concerning orbital period gap, which problem was not mentioned in the *Abstract* nor in the lists of goals. Were the conclusions separated into groups of different importance and with different subjects then they would be easier to discuss and to review. The presented summary looks rather oddly.

In the *Introduction* there is no single mention about CATUABA code. This is a shortage because this is the numerical tool developed by the candidate, why not to show off?

The English language used in the dissertation looks correct, nevertheless a few typos can be found, why spell-check was not applied? As an example can serve the title of Sect.1.7. Also the Roman numbering of items in this section was not verified - two items are missing.

The scientific language overuses the abbreviations what makes the text difficult to read for a non-specialist. Certainly there is a dictionary with 17 entries intended to help but there are often too many abbreviations in a single sentence, for example in p.6: “Are GC CVs similar to MW CVs?”.

Despite the critics I am convinced that the candidate knows his field of research while the indicated shortages, chaos and usage of copy-and-paste originated from a hurry to finish the thesis.

Summary

The PhD candidate Diogo Belloni presented a dissertation which despite editorial shortages solves a couple of contemporary astrophysical problems and proves that the candidate can conduct a scientific research. In concluding the above review I declare that the dissertation meets the requirements of Art. 13 of the polish “Act on academic degrees and academic title”. It also meets the usual requirements of the astronomical community. I propose the dissertation to be publicly defended.

Konkludując powyższą recenzję stwierdzam, że rozprawa spełnia wymagania Art.13 „Ustawy o stopniach naukowych”. Spełnia także zwyczajowe wymagania środowiska astronomicznego. Wnoszę o dopuszczenie jej do publicznej obrony.

Piwnice, 26 kwietnia 2018 Krzysztof Gęsicki