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Report on the PhD thesis entitled "Perturbed Stellar Motion in Stellar Clusters" by Vaclav Pavlik.

Pavlik's thesis consists of six chapters containing a review of the general material together with five research papers, all of which have been accepted, and published in international, refereed journals. I find the thesis to be clear and well written. The papers address some of the important questions in current astrophysics. I will begin with a discussion of the first chapters, then review each paper in the order in which they appear.

Pvalik's PhD thesis concerns in broad terms dynamical encounters within stellar clusters. The introductory six chapters of his thesis concerns therefore the dynamical evolution of stellar clusters and the objects within them (i.e. stars and stellar evolution, including black holes and neutron stars – the end states of the most-massive stars). Stellar clusters do not exist as isolated objects: they sit within the galactic potential with galactic tides stripping away stars. Chapter six provides a short summary of currently-active areas of research. In my view, these six chapters provide a very good review of the subjects covered by the research papers of the thesis.

The first research paper is entitled "The black hole retention fraction in star clusters". The fraction of black holes retained is an important quantity as globular clusters are factories for producing exotic objects via dynamical encounters, for example producing black hole-black hole binaries which may spiral together and merge as they emit gravitational radiation. Stellar-mass black holes and neutron stars are produced in the core-collapse (type II) supernova explosions from the most-massive stars. Observing the motions of young neutron stars (seen as radio pulsars) has shown that neutron stars receive substantial kicks when they are formed. It may well be that black holes receive similar kicks, or perhaps kicks of slightly lower magnitude. These kicks could well be sufficient to remove black holes from globular clusters. This first paper produced an interesting (and important) result by using N-body simulations: namely that some 20 per cent of black holes are retained in massive stellar clusters. This result will have important implications for those who study gravitational wave sources such as merging stellar-mass black holes.

The second research paper is entitled "Neutron stars and millisecond pulsars in star clusters: implications for the diffuse gamma-radiation from the Galactic Centre". A large fraction of neutron stars retained in globular clusters encounter other stars or binaries leaving them within a binary. They are then spun-up when their stellar companion evolves and transfers mass onto the neutron star. These spun-up (millisecond) pulsars radiate in gamma rays. Both globular clusters and the Galactic Centre are observed

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to be emitting gamma rays. In this paper, they show using N-body simulations how the gamma-ray luminosity scales with cluster mass for globular clusters producing an impressive match. The nuclear stellar cluster may have formed via the merger of inspiralling globular clusters. The authors make the interesting suggestion that the gamma rays observed in the Galactic Centre come from millisecond pulsars provided by infalling globular clusters. This result will be important for those who study galactic nuclei.

The third research paper is entitled "The hunt for self-similar core collapse". Core collapse within stellar clusters comes about because self-gravitating systems have a negative heat capacity: meaning that as stars in the middle of a cluster give energy to other stars via two-body scattering they sink further into the centre of the cluster leading to a runaway increase in central density. Here the authors use N-body simulations to study core collapse within stellar clusters. In particular, they look at the production of very tight binaries as an allias to flag the onset of core collapse.

The fourth research paper is different from the others. Entitled "A MODEST review", it is a review written by several PhD students/young postdocs following the Modest-17 conference held in Prague in September, 2017. Modest – short for Modelling and Observing Dense Stellar Systems – is an international informal association having the goal to help people work together and take stellar cluster research forward. There is a Modest conference once a year. It is a measure of Vaclav Pavlik's engagement in the astronomical community that he volunteered to contribute to the writing of this review. It contains a very nice and detailed review of the state of the research field together with some discussion of possible directions for future research. Being a co-author, demonstrates Pavlik's understanding of the field of stellar clusters.

The fifth research paper is entitled "Do star clusters form in a completely mass-segregated way?". Over time, the most-massive stars will sink towards to centre of a stellar cluster replacing less-massive stars. This paper concerns the interesting question of whether stellar clusters form with the massive stars already segregated, i.e. already in the centre. Mass segregation, if present, has important effects on the evolution of a stellar cluster and the stars it contains. The paper clearly sets out the N-body simulations carried out, where they determine the degree of mass segregation as a function of time for various initial conditions. In this paper they make an important conclusion: that observations of the Orion Nebula Cluster are best matched by clusters which have mass segregation from the beginning. This is an important result for those who study star formation.

I summary, I find the whole thesis to be well-written. The thesis begins with a good summary of the general area. The research papers represent topics drawn from some of the most important questions in contemporary stellar cluster research and provide several new, important results as described above. The thesis proves the authors ability for creative scientific work. I can recommend that the defence of the thesis should go ahead in front of the jury. In my view, provided the defence is satisfactory, Vaclav Pavlik should be recommended for the degree of PhD.

Yours sincerely

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