Centrum Fizyki Teoretycznej
Polskiej Akademii Nauk
02-668 Warszawa, Al. Lotników 32/46
REGON 000844815
tel: (+48 22) 847 09 20, tel/fax: (+48 22) 843 13 69
email: cft@cft.edu.pl
www.cft.edu.pl

Warsaw, 2 August, 2024

Report on the Doctoral Thesis of Mr Marcel Stolc,
entitled
"Stars Moving in Gaseous Medium Near a Galactic Center"

prepared at the Faculty of Mathematics and Physics of the Charles University

Marcel Stolc's dissertation investigates the dynamics of stars in the vicinity of a galactic center, particularly focusing on their interactions with the surrounding gaseous medium. This study aims to enhance our understanding of the complex processes governing star movements and their implications on the spectral energy distribution of active galaxies. The topic of thesis is timely and important from the point of view of novel observations that are planned with current and future experiments.

The Thesis is composed of 5 Chapters. They give a general introduction to the topic of active galaxies powered by supermassive black holes, and to the accretion theory (Chapters 1 and 2), present results of original research conducted by the Candidate (Chapter 3), provide discussion of these results in some broader context (Chapter 4), and finally give conclusions and prospects for future work (Chapter 5). The original results have been published in 3 articles that appeared in refereed journals, out of which 2 are regarded as higher rank (IF>4), and in one of them the Candidate is first/corresponding Author. This fulfills the common requirements for the PhD Thesis and proves the ability of the Candidate to conduct research projects with a valuable contribution to the field.

Below I would like to outline several potential weaknesses that I found in the Thesis. This is not meant to lessen the value of the whole work, which I consider as satisfactory, but is mainly addressed to provide a critical evaluation and facilitate discussion on some important points or open questions.

In the Introductory part, several aspects are described quite vaguely, and in particular the ADAF solution is just sketched, without the derivation or presentation of governing equations. Does the Author consider here a two-temperature flow here where the ADAF can give contribution to the observed radiation through the synchrotron radiation, or give rise to the synchrotron – self Compton (SSC) process in high energies. From the rest of the Thesis, however, one may have an impression, that the only emissions of ADAF are in the UV part of the spectrum, given by a fitting formula (2.7). It is not explained where does this formula come from.

Another aspect is the assumed model of the thin accretion disk. The Author considers large Eddington ratios (for some reason he calls them relative accretion rates), on the order 0.1-1. For such rates, the standard accretion disk can be dominant by radiation pressure and hence it is unstable in its innermost parts. Can this effect impact the assumed model, specifically in the context of the inspiral timescale of 10^4 yrs?

For the SED modeling, presented in Chapter 3, Author uses color correction of 1.6. It is not explained how this quantity is defined, and what is the range of values allowed by accretion theory. How would different values affect the results?

Distinguishing the various scenarios presented in Chapter 3 is also a bit of a challenge for the reader, and I find the motivation here somewhat unclear. First of all, the Author states on page 50, that they assume “no entanglement” between the accretion rate and size of ADAF. This is in clear contradiction with the introduction in Chapter 2 (equation 2.6 and plot 2.2). Possibly, if such “entanglement” was considered, then no dust component would be necessary to fit the spectra? Also, about the dust component, I am not sure how can it “replace” the ADAF, as being located much further away from the central black hole, it must be emitting radiation in Infrared. Furthermore, the summary presented in Chapter 4, mentions the dust component only for alternative version of scenario I, while in Figure 3.1 this dust was shown also in the third (bottom) panel. Finally, as the fitting results to mock data are sensitive to the redshift parameter (Fig. 3.9), one may have impression that there is degeneracy in these scenarios, and the dust component might not be needed at all.

A sufficiently long list of references is provided in the Thesis, documenting all sources and studies cited throughout the dissertation. This includes foundational papers in astrophysics, recent studies on accretion dynamics, and key observational data sources. What I find a bit missing in the introduction part, is some more discussion about the multi-scale hydrodynamic and MHD simulations of accretion flows in galaxy centers, such as those devoted to transonic accretion in weakly active galaxies. Also, some simulations address the problem of viscous torque imposed by the gas environment, which may cause a phase shift in the gravitational wave signal. The electromagnetic emissions and the GW signal together may provide us with a useful probe of the gas in galaxy cores and a diagnostic of the physics of black hole accretion. In recent years, multiple analytical and numerical studies have been carried out to investigate this EM emission, mostly in binary systems with equal masses in general relativistic hydrodynamics.

The dissertation concludes with a summary of the key findings and their significance. Marcel Stolc also outlines potential directions for future research, emphasizing the need for more detailed observations and improved models. The latter should focus on (i) investigating the impact of varying gas densities and temperatures, (ii) exploring the role of magnetic fields in the interactions between stars and the gaseous medium, and (iii) extending the models to include general relativistic effects near supermassive black holes.

What I think should be emphasized clearly for these future plans, is the need to develop a much more realistic model for the scenario II, namely the passage of secondary black hole through the disk. At the present stage, the effect is only through the gap made in the thin disk, which ‘eats out’ a part of the spectrum. This model neglects even any type of inviscid, Bondi-like accretion onto the secondary, which in fact is a source of strong gravitational potential. However, in a realistic scenario, we do not have a 1D laminar gas flow. Instead, we have to deal with nonlinear turbulent fluid that continuously interacts with the secondary orbiting BH. These nonlinear hydrodynamic interactions will lead to rapid changes in density, velocity and magnetic fields, which enhance or suppress the torque value over time. The deviation from the linear torque can in turn affect the orbital evolution of the binary, change merger timescale and size of the gap. The perturber-driven fluctuations of accretion disk torque , on the other hand, can be studied even in Newtonian approach, used for the protoplanetary disks.

Despite the above concerns, the presented dissertation meets the requirements for Ph.D. theses and the Candidate has clearly demonstrated his qualifications and original ideas in astrophysics. Therefore, I recommend admission of the Candidate to the subsequent stages of the procedure, including the public defense.

Prof. dr hab. Agnieszka Janiuk
Center for Theoretical Physics
Polish Academy of Sciences
Warsaw