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Referee's report on Habilitation Thesis presented by Dr. Jan Schee

Dear Habilitation Committee,

Dr. Jan Schee submits the Habilitation Thesis, titled "Optical phenomena probing the gravitational field of compact objects governed by alternative theories of gravity" in the subject branch of Theoretical Physics and Astrophysics at the Faculty of Philosophy and Science in Opava (Silesian University in Opava). Dr. Schee presents his Thesis, written in English language, in the form of a collection of twelve original research papers that are supplemented by 56 pages of an explanatory summary and an overview of the main aspects of the adopted research line.

The Habilitation Thesis deals with theories of gravitation. This is a very fundamental and timely area of research in theoretical physics. We are aware of the fact that Einstein's General Theory of Relativity must cease its validity at certain level, where quantum effects become important, however, a valid alternative theory is not identified despite numerous proposals. Optical phenomena are the centrepiece of the current astrophysical research and observational effort aimed to study collapsed cosmic objects with strong gravity –black holes and their more exotic siblings. Defined by the occurrence and unusual properties of event horizons and singularities, the objects of this Thesis connect General Relativity to various viable alternative theories. For decades, till the discovery of gravitational waves, these mathematical ideas could be explored and tested only by studying their impact on

electromagnetic radiation produced by nearby sources. This is also the main content of the highly interesting research carried out by Dr. Schee and described in his Thesis.

While the commentary has been arranged conveniently in six chapters of Part I – “Comments on research”, the subsequent Part II includes papers published in respected professional journals. This collection represents an impressive achievement and a result of systematic effort over the past decade. It demonstrates very convincingly the enthusiasm and significant impact of the author. Given the breadth of intricate features of potentially observable images and the complex topology, the commentary part is very useful for the reader to understand the papers.

I read the commentary with great interest. Following a very brief *Introduction* in Section 1, alternative approaches to General Relativity are introduced in Section 2 – *Theories of Gravity*. Despite (or thanks to) brevity of this chapter, an uninitiated physics reader or an advanced student will find it to be a very useful starting overview. Section 3 – *Photons as Spacetime Probes* describes the author's contribution to an open problem of constraining the gravity theories and discriminating among them by studying the properties of electromagnetic propagation and observing photons, as they travel through the curved spacetime. Section 4 – *Raytracing and Transfer Function Methods* addresses the problem from the side of semi-analytical and numerical modelling of the tentative images. In particular, the properties of light escape cones (figures 1–3) and synthetic images of extended sources (fig. 7 and subsequent ones) are very informative. Also, the graphics of the plots is of very high standard. Section 5 – *Astrophysical Applications* gives some further thought about the ways of observational confirmation of the predicted effects via astronomical techniques, such as spectroscopy (skewed and shifted profiles of spectral lines) and timing (light-curve oscillation frequencies). This section suggests the methodology to test theories of gravity, however, this goal is in my opinion rather far ahead of us and the author still has to demonstrate that a quantitative and statistically significant result can be obtained from real astrophysical sources. However, I suspect this will be very difficult to achieve with the current and forthcoming instruments and the convincing constraints are still far ahead of us in distant future. In fact, despite its title, the section 5 and the entire Thesis do not provide any attempt to analyze and quantify the mentioned effects by assessing real astronomical data. Nonetheless, Section 6 – *New Directions of Research* presents very briefly a promising new approach to the problem by synergy with gravitational wave experiments. The latter topic is left as a possible future direction of research, and indeed it seems that some kind of combination between electromagnetic and gravitational signatures can provide a way to proceed.

Next, Part II presents the full text of papers selected for the Habilitation. The published papers have already attracted interest in the professional community, as can be demonstrated by formal bibliometrical measures. The papers have resulted in a number of conference presentations and proceedings contributions. These are mentioned in passing and quoted in References.

The context of testing the alternative theories of gravity has gained a lot of interest in the community and it has far-reaching impact on different scales, especially in cosmology. As a suggestion for the discussion I would appreciate if the applicant could place his own research within this broad topic in comparison, e.g., with the paper by Baker et al. (*The Astrophysical Journal*, 802, Issue 1, article id. 63, 2015) and similar.

The scientific language and the graphical representation are of very high standard, both in the Commentary and in the individual papers selected for the Habilitation. I just

noticed a few colloquial expressions and typos that could be made more precise (e.g. subsect. 4.1.2 "Toroidal images" probably means "Images of Toroidal Structures").

I very much value the courage and competence of the author who embarks on difficult problems where the progress is not guaranteed and the competition is severe. At the same time, Jan Schee helps students to take part in the original research and gradually develop right scientific attitude.

I conclude that the candidate has clearly demonstrated his competence and readiness to accept duties of the Associate Professor (docent) affiliation. I strongly recommend accepting the submitted Habilitation Thesis and awarding Dr. Jan Schee the title of Docent at the Silesian University in Opava.

Yours sincerely,



Prof. RNDr. Vladimír Karas, DrSc.



Prague, 27th April 2018