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Referee report on Habilitation Thesis presented by RNDr. Dalibor Nosek, Dr.

Dear professor Trlifaj,

RNDr. Dalibor Nosek, Dr. submits his Habilitation Thesis, titled "Mass Composition and Arrival Directions of the Highest Energy Cosmic Rays" in the subject branch of Physics – Subnuclear Physics at the Faculty of Mathematics and Physics (Charles University in Prague). Dr. Nosek works in the Institute of Particle and Nuclear Physics and now he presents this Thesis, written in English language, in the form of a collection of four original research papers that are supplemented by fifty pages of an explanatory summary, list of scientific references, and an overview of the main aspects of the adopted research line. In this work Dr. Nosek describes his own original contributions as well as the status of the experimental exploration of the Ultra-High Energy Cosmic Rays (UHECRs) as of 2018. While UHECRs can range from the energy about 1 GeV up to ~100 EeV, the detected flux is typically very small at the Earth: typically, only about one particle per square meter per year can be recorded at the PeV range.

Six sections form the Thesis. They cover: 1. Preface; 2. Challenges in comic ray physics; 3. The Pierre Auger Observatory; 4. Mass composition; 5. Arrival directions; and 6. Summary and Outlook. The four papers are published in respected professional journals and they represent a collaborative effort, as is usual (and necessary) in this extremely broad field encompassing diverse aspects of modern science and technology.

In the papers, Dr. Nosek and his collaborators deal with the mass composition and arrival directions of primary cosmic particles, which is the area where they are experts. Their research has been carried out with the help of unique data mainly originating from the Pierre Auger Observatory (PAO), revealing the properties of secondary shower particles and detecting the light that is emitted during passages of secondary particles through the Earth atmosphere. The PAO experiment covers a huge area of about 3000 km^2 and the group is an active and very visible member of this multi-national endeavor. I have very much enjoyed reading the introductory Section 2 of the Thesis, which provides a brief but non-trivial and well-balanced exposition (suitable also to students and non-experts) of the present state of the field and the major questions that need to be addressed, difficulties encountered when attempting to tackle the questions, as well as potentially promising approaches to find answers.

Within the Pierre Auger experiment, Dr. Nosek with collaborators demonstrated [A01] that the dispersion of mass in primary cosmic ray beams can be explored by employing variety of constraints that are present in the signal induced by extensive air showers. The Habilitation includes also another paper [A02], where the candidate and the collaborators have introduced a novel method to constrain numerically the primary mass composition by subjecting the fluorescence data to the maximum entropy analysis. Furthermore, I find very interesting and useful the other two contributions [B01, B02] by Nosek et al., where the authors deal with the lasting debate about the effects of directionality of UHECRs and their sensitivity to the intervening cosmic magnetic fields in the context of PAO observations.

Despite a continued observational effort, it is still a mystery where the most energetic particles originate from. This open question of primary composition of cosmic rays at ultra-high energies stands out very prominently. The presented papers address some of the unsolved problems of utmost importance for the contemporary astrophysics and cosmology. The papers are supplemented by citations to numerous additional published works, where the author contributed as a member of the. Indeed, the research area is extremely active and it offers great prospects of upcoming discoveries. This can be highlighted by the very recent progress in analyzing the significance of anisotropy of the incoming cosmic rays' distribution on the sky, which exceeds the magnitude of the dipole resulting from the peculiar motion of the Earth and speaks in favor of an extragalactic origin of a certain fraction of UHECRs. This has been also described in the commentary part of the Habilitation together with a detailed discussion of the current state of (so far inconclusive) effort to identify UHECRs sources with nearby active galaxies.

The investigation of cosmic rays, and in particular the aspects and the detection of UHECRs require a long-term coordinated international effort on both side of technology and science. These topics are on the border-line of particle physics, astronomy and astrophysics, and the present-day cosmology. UHECRs data can be employed to explored interactions at the energies much larger than currently available in ground-based accelerators. In this context it is encouraging that the Czech contribution to this effort is active and well visible, including the work done by Dr. Nosek. I consider the description of the Pierre Auger Observatory in Sec. 3 to be the central part of the commentary; it presents the essential background information of the geometrical set-up and the installed technology necessary for the operation of the adopted hybrid instrumentation. It also stands behind much of the author's original contributions and is needed to understand further technical details. The individual subsections introduced both the on-site surface detectors, fluorescence detectors, the telescopes and the additional instrumentation and its upgrades

that allow the observatory to enhance the unique operation in complementary (hybrid) modes.

In order to suggest some interesting topics for the Thesis discussion, couple of comments/questions follow. Personally, I find extremely promising the ongoing engineering effort towards the PAO augmentation to include the Auger Engineering Radio Array. It would be highly informative to listen to the latest developments in this direction. I would very much like to learn if the expected improvements from the radio domain will be directly relevant also for Dr. Nosek's and the group further work.

A commentary related to Fig. 4 (p. 20) seems to be based on the preliminary (2017) data; can the plot be confirmed or updated to the present status? Further, unless I overlooked information in the text regarding Fig. 7 (p. 23), it would be interesting to explain how the systematic (thin) error bars are estimated in the PAO measurements; my expectation from other areas is that this must be a very laborious task.

Finally, Dr. Nosek has demonstrated how fruitful the synergy between PAO and Fermi measurements has been for the discussion of directionality. In this context it would be interesting to comment on a comparison and differences between the ground based PAO and the space-born DAMPE experiments to detect cosmic ray particles and gamma rays, and whether these could be employed in future studies.

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 very much value the competence of the author who embarks on challenging collaboration projects on the largest scales, where the time frame of the progress is not guaranteed and the competition is severe.

I conclude that the candidate has clearly demonstrated his competence and readiness to accept duties of the Associate Professor (docent) affiliation. I have no hesitation to recommend accepting the submitted Habilitation Thesis and awarding Dr. Dalibor Nosek the title of Docent at the Faculty of Mathematics and Physics of the Charles University in Prague.

Yours sincerely,

Prof. RNDr. Vladimír Karas, DrSc.

Prague, 18th July 2018

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