Review of the PhD thesis of Mgr. Stanislav Štefánik
"Study of high energy cosmic gamma rays"

The topic of the submitted PhD thesis is high-energy gamma rays of astrophysical origin. Two independent studies are presented:

1/ The first study falls into the realm of the Cherenkov Telescope Array (CTA) – the next-generation gamma-ray observatory, currently in the prototyping and testing phase. In particular, the author presents a calibration method for determining the atmospheric transparency coefficient for imaging atmospheric Cherenkov telescopes.

2/ The second study comprises an analysis of more than 7 years of data from the satellite-based Fermi Large Area Telescope (Fermi-LAT). In the process of characterizing the astrophysical source of interest – the active galactic nucleus ES 0229+200 – the author identified five other high-energy gamma sources in the region of interest, and documented their spectral and temporal behavior.

The thesis is divided into three, thematically well balanced chapters, and is complemented by a reprint of a paper published in a peer-reviewed scientific journal ("Atmospheric monitoring and inter-calibration of the telescope optical throughput efficiencies using the trigger rates of the Cherenkov Telescope Array", S. Stefanik et al., Astropart. Phys. 109 (2019) 12–24), of which Mgr. Štefánik is the leading author. The thesis counts 66 pages without the bibliography and appendices, and 94 pages total (without the reprint of the author's publication). The text is written in the English language with a high level of command.

Chapter 1 – Astroparticle physics at high energies:
In this chapter, the author concisely introduces the reader to the field of high-energy astroparticle physics. The non-thermal origin of high-energy cosmic gamma rays is explained, as are two available detection methods: satellite-based experiments, such as Fermi, and terrestrial imaging atmospheric Cherenkov telescopes, such as CTA. Both points are critical for the understanding of the two subsequent chapters. Details concerning the development of electromagnetic and hadronic showers in the Earth's atmosphere and a brief description of the phenomenon of Cherenkov radiation are deferred to appendices A and B, respectively.

Chapter 2 – Calibration in the Cherenkov Telescope Array:
The second chapter focuses on the calibration of the Cherenkov Telescope Array using the Cherenkov transparency coefficient (CTC). This method uses the stereo trigger rates of telescopes in regular data taking mode to either determine the atmospheric transparency to Cherenkov photons or the relative optical efficiencies of two telescopes. While the method itself is known and has already been used by existing gamma-ray experiments (e.g. H.E.S.S.), the extension to a large and complex array of telescopes such as CTA is non-trivial. The author uses a simulated air shower data set (no experimental data are available yet) to study the dependency of pairwise trigger rates on different parameters such as the zenith angle of the incoming shower, the inter-telescope distance and the alignment with respect to the shower direction. The effect of the Earth's magnetic field is also discussed. The author presents studies for both planned observation sites of CTA (located on the Canary Islands and in Chile), and quotes a resolution of 4–7% for the CTC calibration method.

Chapter 3 – High energy γ-ray sources observed by Fermi-LAT:
In this chapter, the author presents an analysis of several years of experimental data collected by the Fermi-LAT instrument (3FGL catalog). The focus lies on the active galactic nucleus (AGN) 1ES 0229+200, a highly relevant and interesting object, as AGNs are prime candidates for the acceleration of ultra-high-energy cosmic rays. After explaining the basics of the analysis and the choice of parameters for the source and background models, the author proceeds to present the spectral energy distributions and light curves not only for 1ES 0229+200, but also for five other sources S1–S5 that he identified in the analyzed region of interest. The potential classification of those objects is discussed in the context of multi-wavelength observations. The chapter closes with a brief report on the high-energy gamma-ray emission from Centaurus A, the closest AGN to Earth, that has been implicated by the Pierre Auger Observatory as a potential accelerating site of ultra-high-energy cosmic rays.

Comments and remarks:

- The pairwise trigger rate in figure 2.5 is given in arbitrary units, whereas in figures 2.6 and 2.7 it is given in units of Hertz. Consistently using the same unit would aid understanding and comparison.

- Table 1.2.2 that is referenced on page 60 does not (seem to) exist in the presented manuscript.

- The text is grammatically and stylistically well written. There are occasional mistakes in the usage of the definite and indefinite article; in this regard the manuscript would benefit from proofreading by a native speaker. However, these small mistakes in no way affect the scientific value of the thesis.

- The commentary under table 3.1 contains superfluous parentheses.

- The general writing style is concise and brief, additional information and sources are well referenced. For a reader from the field of gamma astronomy, this form is certainly preferred, however readers from related or even more distant fields may find the text, especially the frequent references to the reprint of the author's paper at the end of the manuscript, cumbersome.

Questions and input for discussion:

- CTA will observe not only during complete dark time, but also during periods of moonlight, of course limited to acceptable moon fractions and separations between the moon and the observed target. How will the CTC method be affected by the presence of moonlight? Can the method still be successfully applied to observations during moonlight and with a partial cloud cover, i.e. in the presence of scattered moonlight?

- The CTC method can be used to cross-check the optical efficiencies of two telescopes. In the presented thesis, this study is done for pairs of identical telescopes, i.e. two large-, mid- or small-sized telescopes. It would indeed be very useful to be able to cross-calibrate different telescope classes. Can the method be extended to cover this application? In addition, could the performance of the method be improved by using the stereo trigger rates of more than two telescopes?

- In chapter 3, the identified high-energy gamma sources S1 to S5 are characterized in terms of their spectral and temporal behavior. Which of these sources would the author recommend as the most suitable for observations by the gamma-ray observatories H.E.S.S. and MAGIC?

- Currently, multi-messenger analyses suggest that there is no significant correlation between high-energy gamma-ray and neutrino emission from blazars. It would be interesting to learn about the availability of multi-messenger data on the sources S1–S5; in particular, does the position of the sources S1–S3 fall within the localization region of an astrophysical neutrino detection by the IceCube Observatory?

- How robust is the Fermi-LAT data analysis with respect to the choice of the parameters of the source and background models, and the freeing/freezing of the source model parameters in the region of interest?

The presented PhD thesis by Mgr. Stanislav Štefánik deals with highly relevant topics in the field of high-energy gamma astronomy. Both presented studies, i.e. the extension and application of the CTC calibration method to the Cherenkov Telescope Array and the analysis of data from the Fermi-LAT telescope which resulted in the description of two unknown sources, are important contributions to the field. The methodology and results are laid out clearly and concisely, and have been presented to the scientific community in a peer-reviewed journal as well as at international conferences. In my opinion, the author has convincingly demonstrated the ability to conduct independent scientific research and thus I recommend the presented thesis for oral defense.

Erlangen, 29 May 2019 Lenka Tomankova