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Report on the PhD Thesis "Detection techniques for the H.E.S.S. II telescope, data modeling of gravitational lensing and emission of blazars in HE-VHE astronomy" by Anna Barnacka:

In her dissertation " *Detection techniques for the H.E.S.S. II telescope, data modeling of gravitational lensing and emission of blazars in HE-VHE astronomy* " Anna Barnacka investigates a series of interesting aspects of high energy astrophysics. The first part of the thesis concentrates on an instrumental aspect which becomes highly relevant exactly as this thesis is submitted. In the past, telescope arrays for Cerenkov astronomy consisted of a small number (two to four) of identical telescopes which are typically triggered in a homogeneous fashion such that the trigger signals of the analogous cameras operating at the different telescopes are treated identically. The most sensitive of the current arrays, H.E.S.S., has now been extended to include a fifth telescope, which is significantly larger than the previously existing four telescopes. As a result, the camera at this fifth telescope is sensitive to a wider range of gamma-ray energies and the trigger system becomes considerably more complex. Triggers to the large telescopes ought to be dealt with both independently as well as in coordination with the other cameras in the array. This requires a novel logic in the trigger system. A new algorithm for this trigger system has been developed by Anna Barnacka. The thesis describes the the motivation and the logic of the new system, simulations and hardware implementation. The overall project is still in the phase of commissioning such that the characteristics of the performance are based on expectations.

The chapter starts with a brief introduction to the principle of the atmospheric Cherenkov technique, including a very clear description of the distribution of the light yield of different showers on the ground. This provides an excellent motivation for the nested trigger scheme. The description of the trigger scheme is written in a concise and very informative way. While some of the specifics are described in a rather brief style, all relevant aspects are mentioned and reference to more detailed treatments are made. The new algorithms are described and their specifics are detailed in chapter 1.7. Ch. 1.8 gives an overview of the simulations and illustrate the high potential of the new trigger algorithm. Following the description of the hardware, ch. 1.10. provides brief conclusions.

The new trigger algorithm is an essential element in the improvements expected from observations of the mixed-array which will be used with HESS-II. This part of Anna Barnacka's thesis provides a very concise description of the trigger system, which will be a very valuable addition to the new H.E.S.S. system. While it is never easy to precisely delineate the contribution of an individual in a cooperative experimental development, it becomes clear, that Anna Barnacka provided an essential contribution to this important advancement.

One of the advantages of the new system will be a much improved performance at lower energies, which - among many other aims - will allow for a detailed study of the high-energy emission of AGN with different characteristics. One of the very few AGN with strong emission lines that have already been detected with the existing system is the quasar PKS 1510-089. A detailed analysis of this source and a quantitative model of the radiative characteristics is described in the second chapter of the thesis. Such studies are particularly interesting, since quasars are a much more numerous class of AGN than the BL Lac objects which had previously been searched for with higher priorities. Understanding the high-energy characteristics of the more numerous source class is of high importance also, because the process of internal gamma-ray absorption needs to be dealt with in a more elaborate way. This thesis provides a very valuable contribution to this goal.

The chapter starts out with an introduction to AGN taxonomy and then describes the different physical building blocks in AGN (chapters 2.1 to 2.7). The radiation and absorption processes are introduced in chapters 2.8 to 2.13. Ch. 2.14 introduces the particular source, quasar PKS 1510-089, which is one of the closest quasars to the sun. These introductory chapters necessarily contain mostly reviews of the literature, and Anna Barnacka again provides a comprehensive and concise description. It is impossible to be complete in any of these introductory descriptions, but all elements essential for an understanding of her own work in the subsequent chapters are provided. Chapter 2.15 gives a full description of her analysis of H.E.S.S. and Fermi observations of the source. Despite being relatively bright, the analysis of the behavior of this object is not trivial due to the observational constraints and the rather short time-scales involved in the variability. The most important part of the thesis is the theoretical modeling, which involves the computation of external IC spectra with seed photons from the dusty torus as well as the Broad Line Region. Photon-photon absorption on the radiation fields providing the seeds for external Compton scattering and the diffuse backgrounds are also considered in detail. It is shown that the observed VHE emission provides constraints on the location of the gamma-ray emitting region while IC scattering of BLR photons is suppressed by Klein-Nishina effects. The results are summarized in chapter 2.18.

Extending the modeling of Blazars by including the treatment of unavoidable IC scattering of external photons is important for any study beyond the traditional - but by astronomical standards rather rare - subclass of BL Lac objects. Anna Barnacka's thesis provides a clear example of the constraints that can be obtained for the much more numerous class of Quasars.

In the remainder of the thesis Anna Barnacka discusses effects of gravitational lensing at high photon energies. While gravitational deflection of electromagnetic radiation is independent of the photon energy, the observational constraints in gamma-ray astronomy require different approaches and enable new insights compared to studies at lower energies. Anna Barnacka first describes the theory of gravitational lensing (chapter 3). While this introduction is largely based on published works, she provides an excellent background for the approach of chapters 4 and 5 where she studies two phenomena related to temporal variability.

In chapter 4 she develops a novel technique to extract time delays in unresolved images and applies this techniques to the radio-loud quasar PKS 1830-211, which was previously identified as a system exhibiting strong gravitational lensing with two bright lensed images - well resolved at radio wavelengths - superposed on an elliptic ring-like structure. The individual lensed images show a delay in their variability patterns which allows the reconstruction of the lensing geometry. Gamma-ray observations (in this case obtained using the satellite-borne Fermi LAT instrument) suffer from low angular resolution (such that the different lensed images cannot be spatially resolved), but benefit from exceedingly regular observing patterns (such that the timing properties of the blended images can be examined with unprecedented sampling frequency).

Following an assessment of the probability of strong lensing in Fermi AGN (Ch. 4.2), Anna Barnacka studies the Fermi data of PKS 1830-211, whose radio-image had long been used as a textbook example of a gravitational lens. She describes the source and her data analysis in chapters 4.3 and 4.4. The key part is the development of the double power spectrum method. She introduces the idea, tests the algorithms with Monte Carlo simulations and applies the method to demonstrate that gamma-ray data can be used to determine the gravitational-lens induced delay even in a regime with very low photon statistics. Despite the low signal-to-noise, the delay was constrained to a precision comparable to those of the earlier radio-data.

In the final chapter of her thesis, Anna Barnacka turns to lower energy gamma-rays still and uses observations obtained with the Gamma-Ray Burst monitor (GBM) aboard the Fermi spacecraft to search for signals of femtolensing. A number of cosmological scenarios speculate that the Big Bang also generates primordial Black Holes. The number density of such Black Holes is completely speculative. Experimentally, the low-mass end if particularly challenging, and one of the very few ways of constraining the mass density in small-mass Black Holes is given by the phenomenon of strong gravitational lensing, which - in this regime - became known as femtolensing. In such cases interferometric effects have to be considered, since the Schwarzschild radius of the lens becomes comparable to the photon wavelength. Anna Barnacka used the data archive of the GBM experiment to set upper limits on the frequency of femtolensing in gamma-ray burst spectra and thus on the mass-density of low-mass primordial black holes.

After introducing primary black holes and the effect of fermtolensing, Anna Barnacka describes the data used in her study, the data analysis and simulations (chapters 5.3, 5.4, and 5.5, respectively). Fitting GRB spectra with standard models does not provide evidence for the fringing patterns expected in the case of femtolensing, and the 20 events selected are then used to derive an upper limit on the cosmic density of primordial Black Holes in this mass range, which in turn, is compared to the results of other estimates in the concluding chapter 5.7.

A final chapter provides a concluding summary of the four different projects that comprise this thesis. The thesis consists of a number of individual projects to which Anna Barnacka contributed in an important way. All of the four individual projects described above mark a scientific advancement in the field of high energy gamma-rays by offering a new instrumental approach, a new interpretation of a new source class, a novel method to explore lensing in unresolved images and a new approach to constrain the number density of primordial Black Holes. The presentation of the works in the written thesis is very clear and comprehensive.

The strongest point of the thesis is the very broad range of aspects in high-energy astrophysics covered therein. Anna Barnacka has demonstrated her skills in the instrumental, observational, and interpretational disciplines of astrophysics and dealt with a wide set of astrophysical phenomena. While this very impressive breadth necessarily comes with the cost of not being able to examine all aspects in full detail, Anna Barnacka has successfully demonstrated her abilities in detailed work in many examples throughout the thesis. The thesis has a very high quality by international standards and is certainly worth of being granted with a doctorate degree. The thesis complies with all statutory and customary requirements of doctoral dissertations and I move for allowing the public defense of the thesis.

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