High-energy multi-messenger astrophysics with H.E.S.S. and CTA

Very recently a fundamentally new domain of astronomy and astrophysics has shown its first results: multi-messenger and real-time astrophysics. The simultaneous detection of various new astrophysical messengers (gravitational waves, high-energy gamma rays and high-energy neutrinos) and the exchange and combination of data from very different observatories allows to open new windows and provides unprecedented insights into the most violent phenomena ever observed.

New and significant conclusions can be obtained by combining these new messengers. Joint analyses of archival observations in different wavelengths have brought enormous insights in the past and, as this technique provides an assured and certain scientific return, it will also be used in the proposed thesis project. At the same time it has becomes clear that another important step does greatly enhance the sensitivity of multi-messenger searches: the need to gain full access to the wealth of information provided by analyzing and combining the data in real-time. The proposed thesis project will allow opening this new window to the high-energy universe: real-time multi-messenger astronomy at very high energies. The combination of the various particles and radiations in a truly multi-messenger online alert system will resolve several challenges faced in high-energy astrophysics and especially allow detecting and studying violent transient phenomena that are supposed to be at the origin of high-energy cosmic rays. The project will introduce the time domain to high-energy astrophysics and has the potential to cause a paradigm shift in how observations and data analyses are performed.

The core of the proposed system will be H.E.S.S., currently the world’s most sensitive gamma-ray observatory, and CTA, the next generation, global high-energy gamma-ray observatory. We’ll combine their data with events recorded by IceCube, the world’s largest neutrino telescope and the advanced Virgo and Ligo gravitational wave interferometers. The detection of a transient high-energy gamma-ray source in coincidence with gravitational waves or high-energy neutrinos will provide the long sought evidence for their common origin and may resolve the century old quest for the origin of high-energy cosmic rays. We’ll also collaborate with the world’s most sensitive radio observatories (e.g. the SKA precursors MeerKAT and ASKAP) to search for counterparts to Fast Radio Bursts and in general study a large variety of messengers like gamma ray bursts or flares from active galactic nuclei. By scanning the data acquired with high-energy gamma-ray observatories in real-time, it will also possible to send alerts to the wider astronomical community to ensure simultaneous observations at other wavelengths.

The core of the proposed thesis project will be the real-time search for transient high-energy gamma-ray sources directly after the detection of a gravitational wave, an astrophysical neutrino, a Gamma-Ray Burst or a Fast Radio Burst. If found, the combined observations will (in most cases for the first time ever) unequivocally prove the existence of a high-energy cosmic ray accelerator related these violent multi-messenger phenomena.

Left: The H.E.S.S. array of Cherenkov telescopes in Namibia. Right: The first CTA telescope on La Palma.
**POTENTIAL WORK ITEMS**

During the proposed thesis project several out of these items can be explored:

- Searches for gamma-ray counterparts of **Gravitational Waves** (GW)
  - Optimization of the H.E.S.S. + CTA response to GW alerts
  - Analyses of obtained data (incl. their multi-wavelength and multi-messenger context)
- Searches for gamma-ray counterparts of **High-Energy Neutrinos**
  - Analysis of H.E.S.S. data obtained in coincidence with neutrino telescopes
- Searches for gamma-ray counterparts of **Fast Radio Bursts** (FRBs)
  - Preparation and analysis of H.E.S.S. observations in cooperation with major radio facilities
- Preparation and implementation of multi-messenger analyses using **CTA**
  - Optimization of the CTA response to multi-messenger alerts
  - Analysis of the first CTA data

**ENVIRONMENT (COLLABORATIONS, INSTITUTE, THESIS DIRECTOR)**

The PhD student will become a member of the H.E.S.S., HAWC and CTA collaborations. He/she will participate and later lead the preparation of observation proposals in close collaboration with external partners and will be in charge of the subsequent data analyses. Participation in the onsite operation of the experiments in Namibia and La Palma as well as the data calibration is foreseen. The student will have an extensive set of data analysis tools at his disposal but will also have the opportunity to develop novel methods and techniques taking full advantage of the information provided by multiple messengers. These novel techniques are being applied and tested to H.E.S.S. data before being transferred to CTA. Analysis of the first CTA physics data will conclude the thesis project opening multiple possibilities for further studies and employments.

The PhD student will evolve within the astroparticle physics group at Irfu/CEA-Saclay, which is one of the major groups within H.E.S.S. and CTA. Interaction with external partners and members of other collaborations (Desy-Zeuthen/Berlin, MPIK/Heidelberg, Univ. Alabama/US, etc.) as well as within the active astrophysics community of Paris-Saclay will allow the student to enlarge his horizon and become a key member of the new and rapidly growing multi-messenger community.

The thesis director ([fabian.schussler@cea.fr](mailto:fabian.schussler@cea.fr)) is member of the H.E.S.S., CTA and ANTARES collaborations. He is the official H.E.S.S. contact for multi-messenger studies, leads several working groups on neutrino/GW-gamma ray correlations involving various observatories and the preparation of the science data taking of CTA.

**REQUIREMENTS**

- Basic knowledge of astro/astroparticle physics
- Basic knowledge of programming (C/C++, Python, etc.)

**OBTAINED KNOWLEDGE AND EXPERIENCES**

- Data analysis (“Big Data”: large volumes of complex data)
- Software development (novel algorithms, machine learning, etc.)
- Work in a competitive, international environment
- Synthesis of results and presentation at international conferences
- Scientific publications in international journals

**CONTACT**

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