H.E.S.S. multi-messenger studies searching for the origin of cosmic rays

OVERVIEW

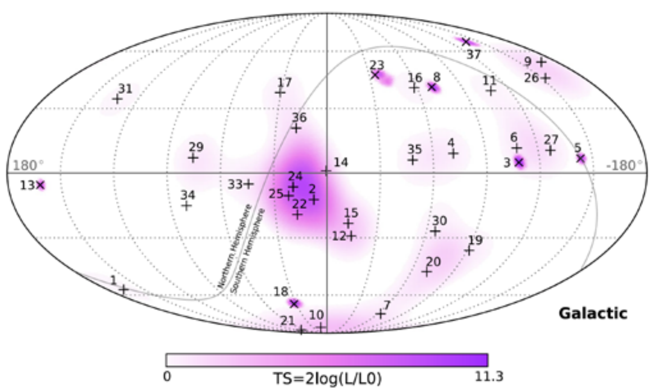
Cosmic rays are one of the most mysterious phenomena in the high-energy universe. These fundamental particles arrive at Earth with energies orders of magnitude above those produced in man-made accelerators but their origin remains illusive. The key question to resolve this century old mystery is to locate their astrophysical sources and study the acceleration mechanisms able to produce the fantastic energies observed. Over the last years it has become increasingly obvious that multiple messengers and novel techniques will be needed to achieve this task. Fortunately, several of these new messengers have allowed opening new windows to the high-energy universe recently: high-energy gamma rays and neutrinos are now providing unprecedented insights into the most violent phenomena ever observed.

New and significant conclusions can be obtained by combining these new messengers. These combinations are currently being performed on archival data, 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 become clear that another important step would 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., the world's most sensitive high-energy gamma-ray observatory, and IceCube, the world's largest neutrino telescope. The detection of a transient high-energy gamma-ray source in coincidence with high-energy neutrinos will provide the long sought evidence for their common origin and resolve the century old quest for the origin of high-energy cosmic rays.

In addition, the proposed system will allow combining information from a large variety of messengers like gravitational waves, gamma-ray bursts and transient radio emissions. By scanning the data acquired with high-energy gamma-ray observatories in real-time, it will be 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 an astrophysical neutrino**. If found, the **combined observations will (for the first time ever) unequivocally prove the existence of a hadronic cosmic ray accelerator** as only high-energy hadrons are able to create a time and spatially correlated signal in both neutrinos and gamma rays.



Left: The H.E.S.S. array of Cherenkov telescopes in Namibia. Right: Skymap of high-energy neutrinos detected by the IceCube observatory at the South Pole used as input for gamma-ray follow-up searches.

POTENTIAL WORK ITEMS

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

- Searches for gamma-ray counterparts of **High-Energy Neutrinos**
  - Analysis of existing archival gamma-ray data (H.E.S.S, Fermi-LAT, etc.)
  - Implementation and optimization of a fast response of the H.E.S.S. system to external alerts
  - Analysis of data taking in response to real-time alerts from neutrino telescopes
- Searches for gamma-ray counterparts of **Fast Radio Bursts** (FRBs)
- Searches for gamma-ray counterparts of **Gravitational Waves** (GW)
  - Implementation and optimization of the H.E.S.S. response to GW alerts
- Preparation and implementation of multi-messenger analyses using **CTA** data

ENVIRONMENT (COLLABORATIONS, INSTITUTE, THESIS DIRECTOR)

The PhD student will become a member of the H.E.S.S. 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 analysis. Participation in the onsite operation of the experiment in Namibia 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 will be 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 the CTA consortium in collaboration with several groups within the H.E.S.S./CTA collaborations (Desy-Zeuthen/Berlin, MPIK/Heidelberg, LLR/Palaiseau, etc.). Interaction with external partners and members of other collaborations (e.g. Univ. Alberta/Canada, PennState/US, Univ. Stockholm/Sweden, etc.) will allow the student to enlarge his horizon and become a key member of the growing multi-messenger community.

The thesis director (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-gamma ray correlations and participates in the definition of the science case and the real-time analysis framework for 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

Fabian Schüssler: fabian.schussler@cea.fr, Tel.: 01 69 08 30 20
Homepage: http://irfu.cea.fr/Pisp/fabian.schussler/index.html