Bachelor / Master Thesis

Gamma-ray astronomy searches for evidence of astrophysical particle accelerators - sources of energetic Cosmic Rays. Examples include supernova remnants, pulsar wind nebulae and stellar clusters, whilst target material such as molecular clouds can be illuminated by Cosmic Ray interactions to then shine in gamma-rays.

Gamma-ray Data Analysis and Astrophysical Modelling

Projects available analysing archival data from the H.E.S.S. experiment, both on characterising known sources and searching for new gamma-ray sources. These projects will use open source software such as *gammapy* for data analysis and modelling packages to reconcile the data with astrophysical phenomena. Depending on the project, there may be scope to incorporate data from the all-sky scanning satellites Fermi-LAT (gamma-ray) and eROSITA (X-ray). Predictions can be made for the forthcoming Cherenkov Telescope Array observatory.

You will develop programming and data analysis skills, whilst gaining a deeper knowledge of the physics of astrophysical particle accelerators.

Physics topics related to this work:

- High Energy Astrophysics
- Gamma-ray Astronomy
- Pulsar environments
- Imaging Atmospheric Cherenkov Telescopes

Skills acquired during this work:

- Python programming
- Gamma-ray data analysis
- Astrophysical source modelling

Composite multi-wavelength image of the Crab pulsar wind nebula.

Interested? Please get in touch:

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Erlangen Centre for Astroparticle Physics

Bachelor / Master's thesis

Gamma-ray astronomy is concerned with some of the highest energy signals from the universe. Ground-based instruments detect gamma-ray photons via the Extensive Air Showers that they generate in the Earth's atmosphere. A cascade of highly energetic particles produces Cherenkov emission as they pass through water tanks located at high altitudes. This Cherenkov emission is detected by photomultiplier tubes (PMTs) situated within the water tanks.

The Southern Wide-field Gamma-ray Observatory (SWGO), is a Water Cherenkov Detector facility being planned to observe the Southern sky. Some of the PMTs for SWGO are being recycled from a former neutrino detector, ANTARES - and are now located at ECAP.

Characterisation of recycled PMTs for SWGO

This project will characterise key parameters of recycled PMTs, establishing which ones perform satisfactorily for SWGO and determining the initial settings required for their eventual deployment in Chile. Dark rooms and a water tank for testing are available at ECAP. Key parameters include gain, dark count, afterpulsing, transit time spread, resolution, quantum efficiency and angular acceptance.

You will be working in a laboratory environment and will develop programming and data analysis skills, as well as learning detector physics.

Physics topics related to this work:

- Extensive Air Showers
- Water Cherenkov Detectors

Skills acquired during this work:

- Laboratory measurements
- Python and/or C++ programming
- Data analysis

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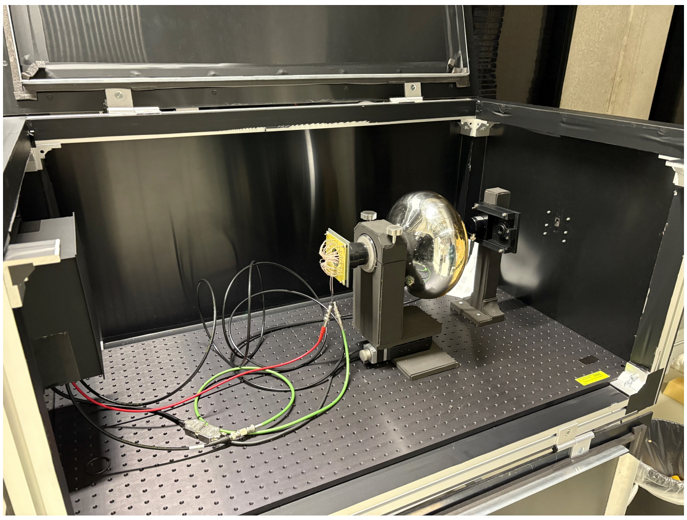

One of our lab setups to characterise PMTs.

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IACTs as Optical Telescopes

Bachelor thesis topics

Imaging Atmospheric Cherenkov Telescopes (IACTs) are designed to detect Cherenkov radiation from energetic charged particles in the Earth's atmosphere. As Cherenkov radiation is emitted at optical wavelengths, IACTs are also sensitive to a 'night sky background' - optical light from stars, meteors, satellites - inadvertently, they can be use for optical astronomy.

Optical Transients in IACT Data

IACTs occasionally capture fast optical transients such as meteors, satellites, or novae. Your task will be to build a detection pipeline that automatically identifies and classifies these events. This project is well-suited for those interested in exploratory data analysis. There is potential for unexpected discoveries, and the project offers room for machine learning methods if desired.

Satellite-based calibration of IACTs

Satellites regularly cross the field of view in IACTs, offering independent calibration sources. Some of these emit regular laser pulses, potentially visible in HESS (an IACT in Namibia). You would model the expected signal, compare it to measurements, and constrain telescope throughput and atmospheric conditions. An interdisciplinary project combining satellite tracking databases with IACT data, this project pursues a novel approach to telescope calibration.

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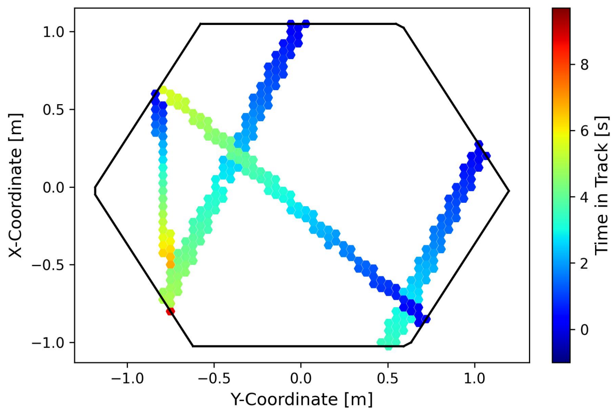

Four satellite trails detected by H.E.S.S. within half an hour of observations.

Calibration using Muons

Bachelor or Master thesis topic

Imaging Atmospheric Cherenkov Telescopes (IACTs) are designed to detect Cherenkov radiation from energetic charged particles in the Earth's atmosphere. Amongst these charged particles are muons - the amount of Cherenkov radiation produced by muons is well-defined and analytically predictable, such that muons are used as a natural calibration source for IACTs.

Muon-Rings for Mirror Calibration in IACTs

When muons pass close to the imaging atmospheric Cherenkov telescopes, they produce characteristic ring-shaped images with well-understood geometry – ideal for calibrating mirror alignment and reflectivity. You will analyse muon ring data, improve existing methods or develop new approaches, and benchmark against other calibration techniques. A solid entry point into IACT analysis with tangible results and direct impact on data quality.

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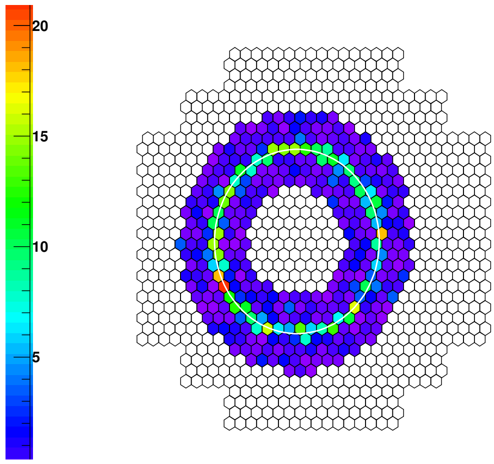


Example muon event detected by one of the H.E.S.S. telescopes.

Erlangen Centre for Astroparticle Physics

Bachelor / Master’s thesis

Gamma-ray astronomy is concerned with some of the highest energy signals from the universe. Ground-based instruments detect gamma-ray photons via the Extensive Air Showers that they generate in the Earth’s atmosphere. A cascade of highly energetic particles produces Cherenkov emission as they pass through water tanks located at high altitudes. By reconstructing these Cherenkov light signals, the energy and direction of the original gamma-ray photon can be determined.

The Southern Wide-field Gamma-ray Observatory (SWGO), is a Water Cherenkov Detector facility being planned to observe the Southern sky. This project will develop new techniques for calibrating the efficiency with which water Cherenkov facilities - such as SWGO - measure Cherenkov radiation.

Light Efficiency Calibration of SWGO using Muons

This project will use simulations of muons within SWGO to develop a method of calibrating the light collection efficiency. The aim is to recover how well the expected light signal from muons can be characterised, and how sensitive this measurement is to degradations in efficiency. (For example via degradation of the photomultiplier tube or of the water quality.) Furthermore, inter-calibration of individual water tanks within the array may be explored.

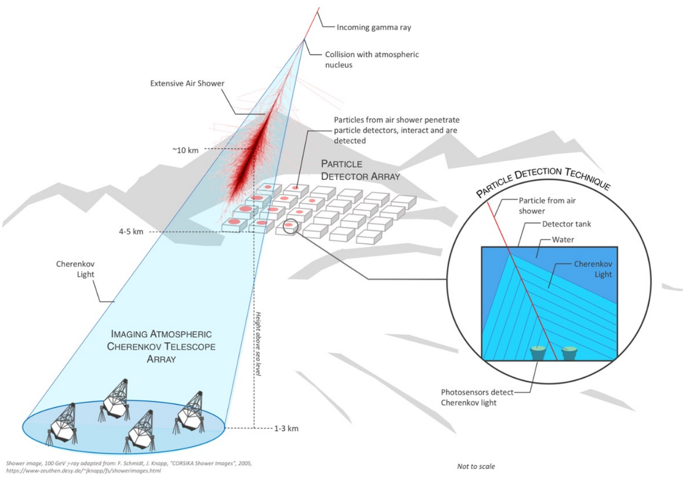
You will develop programming and data analysis skills, whilst gaining a deeper knowledge of the physics of extensive air showers and the detector.

Physics topics related to this work:

- Extensive Air Showers
- Water Cherenkov Detectors

Skills acquired during this work:

- Python and/or C++ programming
- Data analysis
- Calibration



Schematic showing the detection of Cherenkov radiation from an Extensive Air Shower.

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Master Thesis Project

Gamma-ray astronomy searches for evidence of astrophysical particle accelerators - sources of energetic Cosmic Rays. Gamma-rays are detected via Extensive Air Showers (EAS) that develop in the Earth's atmosphere, cascades of particles producing Cherenkov light. The size of the EAS relates to the energy of the gamma-ray, such that atmosphere acts as a calorimeter for gamma-ray detection. The light from these Extensive Air Showers is detected by Imaging Atmospheric Cherenkov Telescopes (IACTs) such as the H.E.S.S. telescope array located in Namibia.

Variation of atmospheric conditions, e.g. by the presence of aerosols of cirrus clouds, can affect the amount of Cherenkov light detected. To correctly account for these effects, Lidar measurements are used, where a laser beam is fired into the atmosphere and the amount of light reflected from different altitudes is measured.

Correcting for Atmospheric Effects using a Lidar

This project will use Lidar measurements from the H.E.S.S. site to construct an altitude dependent transmission profile for the atmosphere under varying conditions. The level of natural variations and optimum correction methods will be investigated. Different approaches will be compared, in particular their result on the final gamma-ray performance metrics. Evaluation of the methods may use both on data from the H.E.S.S. telescopes and preliminary data for the forthcoming Cherenkov Telescope Array.

You will develop programming and data analysis skills, whilst studying the physics of particle interactions and the Earth's atmosphere.

Physics topics related to this work:

- Atmospheric Physics
- Gamma-ray Astronomy
- Imaging Atmospheric Cherenkov Telescopes

Skills acquired during this work:

- Python / C++ programming
- Gamma-ray data analysis
- Lidar instrument data analysis

Photo of a Lidar at the VLT ESO site, Paranal. Image credit: ESO/Y. Beletsky

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