Edna L. Ruiz Velasco
edna.ruizvelasco@lapp.in2p3.fr

Summary of scientific activities

My research focuses on the study of Gamma-Ray Bursts (GRBs) and their detection at very high energies (VHE), combining observations with Cherenkov telescopes, synthetic population modelling, and the development of analysis and calibration tools. I have contributed significantly to experiments such as H.E.S.S., HAWC, and currently LST/CTAO, as well as to the development of the future SWGO observatory.

During my PhD at Heidelberg and MPIK, I developed an instrumental efficiency model for HAWC that introduced a systematic correction based on the temporal degradation of detector units. This model, calibrated using atmospheric muons as Cherenkov light sources, was integrated into HAWC's official simulation chain and reduced systematic errors in reconstructed spectra. It has since been adopted in key HAWC publications on sources like the Crab Nebula (Abeysekara et al., 2019).

I also led a new GRB search strategy in HAWC based on time-dependent flux models, optimising integration windows for different burst durations and delays. This approach allowed reinterpretation of archival data in the context of the first VHE GRB detections such as GRB 180720B and GRB 190114C. While no significant detections were found, upper limits were established and validated against $Swift$-XRT and $Fermi$-GBM data, identifying promising events for future low-energy sensitive instruments (Ruiz Velasco, 2021).

At H.E.S.S., I focused on the two first GRBs detected at VHE: GRB 180720B and GRB 190829A. In the former, detected 10 hours post-trigger, I led the spectral and temporal analysis, revealing a transient emission with similar decay in optical, X-ray, and VHE bands. Published in Nature (Abdalla et al., 2019), this result challenged standard synchrotron models, requiring either very high Lorentz factors or small-scale magnetic turbulence. For GRB 190829A, a nearby GRB minimally affected by EBL absorption, multi-night detections enabled detailed spectral evolution modelling. The VHE spectrum appeared compatible with extended synchrotron emission beyond the burn-off limit, with no clear SSC component. The results, published in Science (Abdalla et al., 2021), provide key insight into particle acceleration mechanisms in GRBs.

As a postdoctoral researcher at MPIK, I contributed to the design of software for SWGO and to GRB detectability studies (La Mura et al., 2021; Ashkar et al., 2024). I co-initiated the development of pyswgo, a Python package enabling atmospheric shower reconstruction, gamma/hadron separation using machine learning, and the generation of standardised instrument response functions (IRFs) compatible with gammapy. This package is now used as the SWGO baseline for sensitivity studies (SWGO Collaboration et al., 2025).

Since November 2023, I have been based at LAPP as a postdoc in the gamma-ray astrophysics group, where I lead the GRB observation programme with the LST-1 telescope of CTAO. I am PI of the highest-rated proposal in the current observing cycle. I coordinated the integration of alerts from the Einstein Probe satellite into the LST transient system, expanding the science scope to TDEs and stellar flares. I have started building a catalogue of GRBs observed by LST since 2019, defining prioritisation criteria to mitigate trial factors. I also oversee the large-scale production of calibrated and reconstructed data with associated IRFs for the LST-CTAO collaboration.

In parallel, I am implementing two new statistical methods for transient detection. One is a temporal extension of the Li & Ma test that includes power-law flux decay ($t^{-\alpha}$), offering improved sensitivity in delayed GRB follow-ups. This method is now integrated into a gammapy-compatible analysis chain and will be proposed for LST real-time analysis. A dedicated paper is in preparation, and preliminary results have been presented in internal meetings and conferences (Le Moigne et al., 2023).

To support this work, I am a lead developer of lappana, a modular Python package for reproducible LST data analysis, including run selection, quality validation, and data reduction. This tool has been presented at collaboration meetings and is proposed as the basis for automatic high-level LST data production.

Additionally, I have worked on GRB population studies using generative techniques. With CTGAN neural networks, I produced synthetic GRB populations consistent with satellite observables (*Swift*, *Fermi*) to estimate expected detection rates with SWGO. This approach reproduces distributions in fluence, redshift, and duration. Comparing SWGO sensitivity curves to these populations suggests that SWGO could detect up to one GRB per year above 125 GeV, including events like GRB 190114C at lower redshifts (SWGO Collaboration et al., 2025). This framework is promising for broader astrophysical applications and I am eager to exploit.

Lastly, I resumed and coordinated the long-delayed publication of the H.E.S.S. GRB catalogue (2004–2019), which is now under review at Astronomy& Astrophysics. I extracted X-ray spectra for selected GRBs and wrote the methodology and scientific sections. The paper systematically documents GRB follow-up strategies in H.E.S.S., localisation-dependent methods, and the resulting differential flux limits, establishing a reference for future VHE GRB searches (Ruiz-Velasco et al., 2025).

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