

We present an opportunity to pursue a PhD in the context of multi-wavelength (MWL) and multi-messenger (MM) astronomy. Full funding for this 3-year PhD at Laboratoire Leprince-Ringuet (LLR; part of École Polytechnique in France) is available through the “MOTS (Multi-messenger Observations of the Transient Sky)” programme [0], funded by the French Agence Nationale de Recherche (ANR). The successful candidate will undertake their PhD research at LLR, working closely with three researchers : Deirdre HORAN, Mathieu de NAUROIS and Stephen FEGAN. The PhD student will exploit observations made by the state-of-the-art gamma-ray observatories, *Fermi*-LAT, H.E.S.S, and CTA, as described below.

These are exciting times for multi-messenger (MM) transient astronomy. The first joint detection of gravitational waves (GW) from the binary neutron star merger GW 170817 [1], of its electromagnetic counterpart in form of the short gamma-ray burst GRB 170817A, and of the subsequent kilonova signified the dawn of a new MM era. Recently, very-high-energy (TeV) gamma-ray emission has also been discovered from GRBs [2] and, in October 2022, an extremely luminous GRB, GRB 221009A was detected. Dubbed the “BOAT” (brightest of all time) by the press¹, this GRB has already garnered many preprints due to the claimed detection of 18 TeV photons [3]. The IceCube Collaboration recently announced the association of high-energy neutrinos with the nearby active galaxy NGC 1068, further strengthening the link between active galactic nuclei (AGN) and high-energy neutrino emission [4].

It is within this context that this PhD will be undertaken. The successful candidate will work with scientists at LLR on the exploitation of gamma-ray data from *Fermi*-LAT and H.E.S.S. on transient MM sources whilst also preparing for such observations with the Medium-Sized telescope of the Cherenkov Telescope Array (CTA), a wide-field camera, particularly well-suited to the search for transient gamma-ray emission. According to the research interests of the candidate, this PhD can focus more strongly on the active AGN-neutrino side or on the gravitational-wave/GRB side of MM astrophysics. In parallel, the PhD candidate will help the development of an API so that data from TeVCat [5] (an online catalogue for gamma-ray astronomy) can be read by the Astro-COLIBRI platform [<https://astro-colibri.com>, 6].

This PhD will start by focusing on the *Fermi*-LAT side of the project. The successful candidate will begin by undertaking “shifts” within the LAT Collaboration - these will comprise Flare Advocate (FA) and Burst Advocate (BA) shifts. Since the LAT (Large Area Telescope) is a wide-field-of-view instrument, it is able to monitor a large part of the sky at any given time. This means that it is particularly well-suited to the study of gamma-ray emission from transient sources. During the FA shift, the gamma-ray data from the LAT instrument are monitored in near real-time to search for new sources of transient emission and to search for flaring activity from known gamma-ray sources, eventually reporting on them in an Astronomer’s Telegram (e.g. [7]). Our team will then participate in the follow-up analysis of the data if the transient is of interest. Typically, the origin of these transient signals is AGNs and, therefore, there is a strong connection with the search for the source of the high-energy astrophysical neutrinos from with detectors such as IceCube and the search for corresponding TeV emission with Cherenkov telescopes such as H.E.S.S. and, eventually

¹ [See for example Ars Technica 2022-10-17](#)

CTA. For the BA shifts, the sky is monitored in real time for gamma-ray emission from gamma-ray bursts. The resulting data are then analysed and assembled for publication in a circular on the Gamma-ray Burst Coordinates Network (GCN) and in an Astronomer's Telegram if the event proves to be of exceptional interest. With the upcoming commencement of O4 at the LIGO-Virgo-KAGRA array, there will be particular interest in searching for emission from GRBs, which is the electromagnetic counterpart of gravitational wave events. With our MOTS collaborators at CEA and at IJCLab, we will participate in this search. The transient gamma-ray sky is, by definition, unpredictable so the eventual direction of the PhD will depend upon which transients occur and on the observational follow-up campaigns in which we participate.

We strongly encourage any interested candidates to get in touch with Deirdre HORAN (deirdre@llr.in2p3.fr), Stephen FEGAN (sfegan@llr.in2p3.fr) or Mathieu DE NAUROS (denauroi@in2p3.fr) for an informal chat or, indeed, for an in-depth discussion of the possibilities related to this PhD.

- [0] MOTS: <https://www.multimessenger-astronomy.com/mots.html>
- [1] VIRGO/Ligo et al., "Multi-messenger Observations of a Binary Neutron Star Merger", *ApJL* 848 (2017) 2, L12. [arXiv: 1710.05833](https://arxiv.org/abs/1710.05833)
- [2] H.E.S.S. collaboration, "A very-high-energy component deep in the Gamma-ray Burst afterglow", *Nature* 575 (2019) 7783, 464-467. [arXiv: 1911.08961](https://arxiv.org/abs/1911.08961)
- MAGIC collaboration, "Teraelectronvolt emission from the γ -ray burst GRB 190114C", *Nature* 575 (2019) 7783, 455-458. [arXiv: 2006.07249](https://arxiv.org/abs/2006.07249)
- H.E.S.S. collaboration, "Revealing x-ray and gamma ray temporal and spectral similarities in the GRB 190829A afterglow", *Science* 372 (2021) 6546, 1081-1085. [arXiv: 2106.02510](https://arxiv.org/abs/2106.02510)
- [3] See references here: <http://tevcat2.uchicago.edu/sources/S2jO4c>
- [4] IceCube Collaboration, "Evidence for neutrino emission from the nearby active galaxy NGC 1068", *Science* 378, 6619, 538-543 (2022), [arXiv: 2211.09972](https://arxiv.org/abs/2211.09972)
- [5] <https://tevcat2.in2p3.fr>; Wakely & Horan, "TeVCat: An online catalog for Very High Energy Gamma-Ray Astronomy", *Proc. 30th ICRC* (2007) Volume 3, p.1341-1344 [30th ICRC](https://arxiv.org/abs/0708.0691), [Merida, Mexico](https://arxiv.org/abs/0708.0691)
- [6] <https://astro-colibri.com>; P. Reichherzer et al., "Astro-COLIBRI -- The COincidence LIBrary for Real-time Inquiry for multimessenger astrophysics", 2021 *ApJS* 256 5. [arXiv: 2109.01672](https://arxiv.org/abs/2109.01672)
- [7] Valverde, J. et al. "Fermi-LAT detection of a new gamma-ray source associated with the FSRQ PMN J1032-1400", *ATel* 15642, Oct. 2022, <https://ui.adsabs.harvard.edu/abs/2022ATel15642....1V/abstract>
- [8] Bissaldi, E. et al., "GRB 221009A or Swift J1913.1+1946: Fermi-LAT detection", *GCN* 32637, Oct. 2022, "" <https://gcn.gsfc.nasa.gov/gcn3/32637.gcn3>