Thesis abstract Roman Le Montagner

"High-Energy Transient Universe in the Era of Large Optical Surveys"

Multi-messenger astronomy involves combining data from various sources like photons, gravitational waves (GW), neutrinos, and cosmic rays. It made significant progress in 1987 with the detection of neutrinos from a nearby supernova and, more recently, in 2017 with the joint detection of gravitational waves, a short gamma-ray burst, and a kilonova from a neutron star merger. This field is expected to grow in importance over the next decade, especially with the launch of new observatories such as SVOM, Einstein Telescope, Icecube, KM3Net, and the Vera C. Rubin Observatory, expanding observational capabilities.

The Legacy Survey of Space and Time (LSST) is set to begin observing the sky in 2025, continuing for a decade. This survey will delve into various scientific areas, including solar system science, dark matter, and dark energy. LSST will detect and alert the scientific community about significant changes in luminosity in the sky, resulting in up to 10 million notifications each night. In order to handle the vast amounts of data and associated scientific challenges, astronomical alert brokers like Fink have been established on large computing systems. These brokers automatically process, categorize, and store multiple alert streams in real time, offering various services to the scientific community. In this context, Fink has been using the Zwicky Transient Facility (ZTF) for many years in order to establish robust scientific exploitation of alert streams and scale out to LSST.

This research work has been conducted within Fink, aiming to advance multi-messenger astronomy. I developed an automatic system, Fink-MM, to correlate LSST optical alerts with high-energy alerts from GW observatories, neutrinos, or gamma-ray bursts (GRBs) in real time. To minimize the number of false associations resulting from the poor localization of individual high-energy events, I devised a method to select a limited number of promising candidate counterparts. First, I rely on Fink's scientific results generated by machine learning algorithms and cross-referenced with external catalogues to significantly reduce the number of candidates. However, given Fink's limited classification capabilities, too many possible associations remain. By focusing on the optical counterparts of gamma-ray bursts, I further refine the analysis by providing an occurrence probability. This method was tested on known GRBs in the Fink database to establish the optimal threshold for obtaining a minimal number of alert candidates suitable for follow-up observations. During the testing phase, I successfully identified an optical counterpart, which was independently detected and confirmed by another team.

Despite the efforts made, the search for fast extragalactic transients remains heavily influenced by the presence of unidentified objects, most of which have only a few detections on the same night, indicating the possible presence of moving objects such as solar system asteroids. Although a substantial number are already catalogued, LSST will detect millions of new ones. In this context, I extended Fink's capabilities by developing the Fink Asteroid Tracker, which identifies the trajectories of uncatalogued solar system objects and provides preliminary estimates of orbits and ephemerides for follow-up observations. I also contributed to a new model explaining more precisely the evolution of asteroid luminosity, allowing for the extraction of their spin and shape. Finally, to compensate for the sparse cadence of optical surveys, I describe GVOM, a network of telescopes under construction, specifically designed to quickly provide additional scientific data to preliminary candidates identified by Fink.