ASTRO-COLIBRI: A SMARTPHONE APP FOR MULTIMESSENGER ASTROPHYSICS

In astronomy and astrophysics observations of transients, i.e., short-lived astrophysical phenomena like as supernova explosions, fast radio bursts (FRBs), and gamma-ray bursts (GRBs) are of increasing relevance. At the same time, an increasing number of fundamentally new cosmic messengers provide crucial information about these sources. Today, the detection of high-energy neutrinos and gravitational waves (GWs) routinely supplement traditional astronomical observations in the electromagnetic spectrum. These trends will continue in the coming years, which will see the advent of a large variety of next-generation observatories dedicated to time-domain astronomy and astrophysics. These observatories cover the full electromagnetic spectrum from the radio domain (e.g., SKA), optical observations (e.g., Vera Rubin Observatory/LSST), X-rays (e.g. SVOM, ATHENA), to the highest energy gamma-rays (e.g., CTA, LHAASO, SWGO). These are complemented by significant improvements and commissioning of new observatories of novel messengers from the violent universe: high-energy neutrinos (IceCube-Gen2, KM3NeT, GVD) and GWs (Advanced Virgo/LIGO/KAGRA, LISA).

The wealth of information provided by the worldwide network of observatories, combined with the need for reactions in real-time to catch the most violent explosions in the universe requires novel approaches and new tools. In this context we have developed "Astro-COLIBRI", a platform that evaluates alerts of transient observations in real time, filters them by user-specified criteria, and puts them into their multiwavelength and multimessenger context. Through fast generation of an overview of persistent sources as well as transient events in the relevant phase space, Astro-COLIBRI contributes to an enhanced discovery potential of both serendipitous and follow-up observations of the transient sky. The software's architecture comprises an Application Programming Interface (API), both a static and a real-time database, a cloud-based alert system, as well as a website (https://astro-colibri.com) and apps for iOS and Android as clients for users. The latter provide a graphical representation with a summary of the relevant data to allow for the fast identification of interesting phenomena along with an assessment of observing conditions at a large selection of observatories around the world. Providing direct access to a large number of additional and external services, Astro-COLIBRI is a central point of accessing information about astrophysical sources and transient events (cf. Fig. 1).

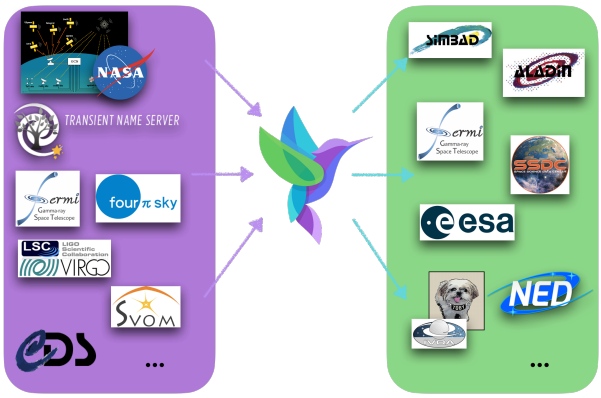

Figure 1: Astro-COLIBRI is a central point for information about astrophysical sources and transient events

A screenshot of the website is shown in Figure 2. The clients are connected to our real-time database via streams linked to a real-time database hosted at the Firebase/Firestore provided by Google. Transient events which are interesting for the user are displayed via these streams in real time and announced via push notifications on mobile devices. While the central API is based on Python and is running on a cloud computing platform called Heroku, the frontends have been developed in the open source framework *Flutter* proposed by Google.

Figure 2: Website of Astro-COLIBRI (https://astro-colibri.com)

In multiwavelength and multimessenger astronomy, there is an increasing demand for rapid and multi-mission coordination for follow-up observations of transient events. At the moment, Astro-COLIBRI provides the near-term and long-term visibility and observability of transient events of all major observatories or custom locations. The visibility plots contain the monitoring of source altitude, Sun and

Moon altitude, Moon phase, Moon-to-source separation if available, etc.

Figure 3: Illustration of the Astro-COLIBRI smartphone application

Astro-COLIBRI is free to use for both professional and amateur astronomers. It is already regularly being employed by burst advocates in several observatories (e.g. H.E.S.S., CTA/LST-1, SVOM, etc.). The website is available at https://astro-colibri.science and the smartphone apps can be found in the relevant app stores (Android / iOS). Further information, tutorials, etc. are available on our dedicated YouTube channel. You can also find us on Twitter: @AstroColibri
A paper describing the functionalities has just been published in the Astrophysical Journal [1] and concrete examples of use-cases are described in [2].

Master thesis internship: Facilitate global campaigns searching for the counterparts of gravitational waves with the help of Astro-COLIBRI

The aim of the internship to expand the functionalities of Astro-COLIBRI for multi-observatory follow-up campaigns. Especially the search for electromagnetic counterparts of gravitational wave events is challenging due to the large localization uncertainty areas provided by the GW observatories Ligo/VIRGO/KAGRA. Dedicated scheduling algorithms have been developed within the group at IRFU / CEA Paris-Saclay. These algorithms take into account the 3-dimensional localization of the GW events, combine them with catalogs of galaxies, and use the individual parameters of the follow-up instruments (e.g. field-of-view, visibility constrains, sensitivity, etc.) to derive an optimal observing pattern. These tools have been used extremely efficiently over the last years with the H.E.S.S. and CTA high-energy gamma-ray observatories [3].
During this internship we will adapt and include these algorithms within the Astro-COLIBRI API. The resulting observing patterns will then be visualized in the web and smartphone apps to allow for an efficient organization of follow-up observations by a large range of instruments around the world. Extensive testing with real GW events detected over the last years, as well as simulated real-time alerts will precede the deployment of the new functionalities within Astro-COLIBRI (incl. submission to the Google and Apple apps stores). This will facilitate a novel and collaborative way of conducting these crucial observations during the next data taking run (O4, starting March 2023).
Given the perfect timing, we'll be able to immediately employ the developed tools in follow-up observations of GW events. For this we have access to a large range of observatories in the high-energy domain: H.E.S.S., CTA/LST-1, and our partners (MeerKAT, ATCA, ATOM, Swift, etc.).
The internship will thus be a perfect introduction and preparation of the PhD thesis project proposed in the group at IRFU that will further improve the scheduling algorithms before actively using them in searches for VHE gamma-ray counterparts to GW events with H.E.S.S. and CTA. See HERE for details.

References

[1] P. Reichherzer *et al.* 2021 *ApJS* **256** 5, link
[2] F. Schüssler *et al.* PoS (ICRC2021) 935 (2021), link
[3] H. Ashkar *et al.* JCAP03 (2021) 045, link

Further information about the supervisor and the astroparticle physics group at IRFU:
https://www.multimessenger-astronomy.com

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