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The ALeRCE Broker

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Abstract. The Automatic Learning for the Rapid Classification of Events (ALeRCE) broker is processing the alert stream from the Zwicky Transient Facility (ZTF), and is an official Community Broker for the Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST). ALeRCE uses cloud infrastructure and machine learning to bring real-time processed products and services to the astronomical community. Here we summarize the available services and tools (e.g., web explorer, data releases, watchlist, client, and jupyter notebooks) that can be used by the scientific community and show some examples of Active Galactic Nuclei (AGN) science that have been developed using these services.

Keywords. Surveys, Catalogs, Galaxies: active

1. Introduction

In the era of large-scale survey telescopes, such as the Zwicky Transient Facility (ZTF, Bellm *et al.* 2018) and the Vera C. Rubin Observatory, which will carry out the Legacy Survey of Space and Time (LSST; Ivezic *et al.* 2021), alerts are generated every time a change greater than 5σ with respect to a reference image is detected. As a result, systems capable of ingesting and processing the resulting volume of data have become essential. This is where the concept of a broker comes into play.

Brokers are specialized systems designed to process the vast alert streams generated by modern survey telescopes. They ingest raw alerts, enrich them through cross-matching with catalogs, apply machine learning classification or filtering, and discover the most promising events for scientific follow-up. For the Vera C. Rubin Observatory, there are seven official full-stream community brokers selected to receive the complete alert stream: ALeRCE, AMPEL, ANTARES, Babamul, Fink, Lasair, and Pitt-Google. In addition, two downstream brokers – SNAPS (Solar System Notification Alert Processing System, Trilling *et al.* 2023) and POI (Point of Interest) – operate on subsets of alerts tailored to specific scientific interests. Each broker provides a distinct set of services intended for use by the scientific community.

2. The ALeRCE broker

Among the full-stream brokers, ALeRCE (Automatic Learning for the Rapid Classification of Events, Förster *et al.* 2021) is a Chilean-led initiative combining real-time ingestion, cross-matching, and machine learning-based classifiers using the stamps and the light-curves. It is developed by a multidisciplinary team of astronomers, software engineers, data scientists, and machine learning experts, and aims to provide rapid and reliable classification of transient and variable astronomical sources.

2.1. *Services*

In what follows, we provide an overview of the ALeRCE services and tools currently available, developed in the context of ZTF:

• **Classifiers:** ALeRCE uses machine learning classifiers to categorize astronomical alerts. A stamp-based classifier applies a convolutional neural network to image cutouts for early classification of transients (Carrasco-Davis *et al.* 2021). In parallel, several light curve-based classifiers refine these predictions over time. The main one is based on a Balanced Hierarchical Random Forest (BHRF, Sánchez-Sáez *et al.* 2021), and is used to classify sources into 15 classes, as shown in Figure 1. There are two recent additions: a version adapted for forced photometry of the BHRF, and the Astronomical Transformer

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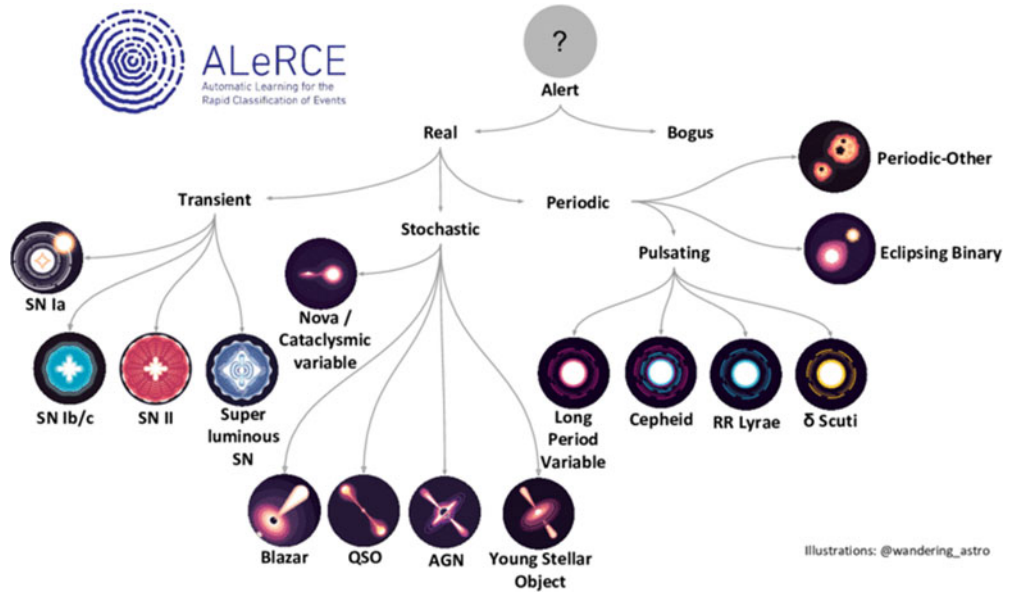


Figure 1. The classical ALeRCE taxonomy (from Förster *et al.* 2021 and Sánchez-Sáez *et al.* 2021).

for time series and Tabular data (ATAT, Cabrera-Vives *et al.* 2024), a transformer-based model combining time-series and tabular data, which include two new classes: tidal disruption events (TDE, Pávez-Herrera *et al.* 2025) and microlensing. These updates will be reported in a forthcoming publication (Cabrera-Vives et al., in prep.).

• The **Supernova Hunter** (Figure 2, upper-left) is a web-based tool designed to support the visual inspection and validation of supernova candidates. It displays stamp images and metadata for alerts classified as likely supernovae by the ALeRCE stamp classifier.

• The **ALeRCE Explorer** (Figure 2, upper-right) is an interactive web interface that allows users to explore individual astronomical sources in detail. It provides access to light curves, stamp images, classifications, and cross-matched catalog information. The tool is designed for rapid inspection and is useful for both scientific analysis and educational purposes.

• The **ALeRCE Watchlist** (Figure 2, bottom-left) allows users to perform real-time crossmatching between incoming alerts and a custom list of coordinates. When a match is found, a notification can be received by email, enabling timely inspection and follow-up.

• **Client, Data Base, and Jupyter Notebooks:** ALeRCE provides a Python client and public API that offer programmatic access to its database, including light curves, classifications, and cross-matched metadata. Additionally, a collection of Jupyter Notebooks is available to demonstrate typical use cases and facilitate reproducible analysis. Figure 2 (bottom-right) shows an example jupyter notebook for a particular science case.

3. AGN Science with ALeRCE

We highlight two representative cases of Active Galactic Nuclei (AGN) selected by ALeRCE and followed up through multi-wavelength campaigns:

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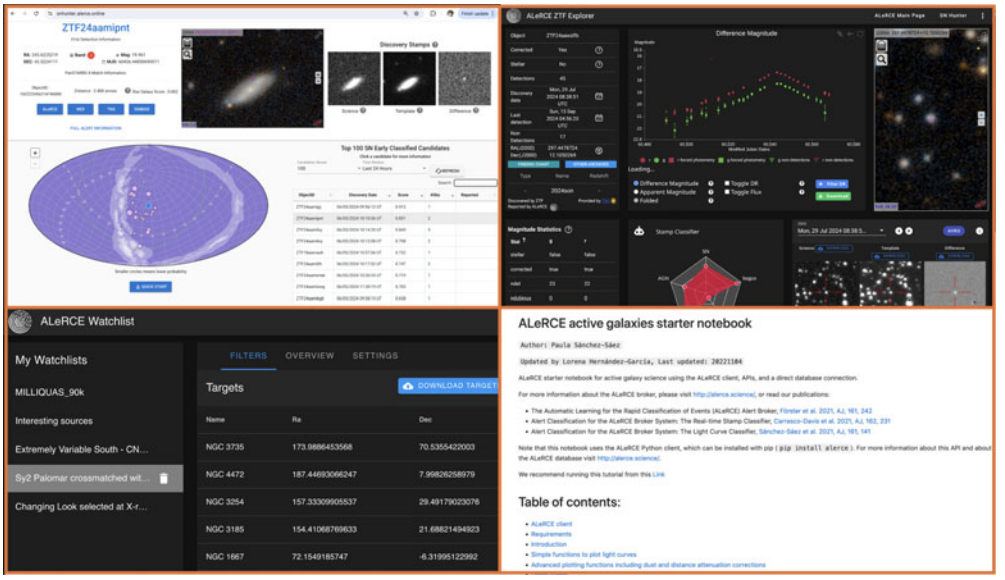


Figure 2. ALeRCE Services: SN Hunter (upper-left), ALeRCE explorer (upper-right), ALeRCE Watchlist (bottom-left), and an example Jupyter Notebook (bottom-right).

• **AT 2021hdr (ZTF21aaqqwsa)**: Selected by ALeRCE from ZTF alerts in 2021. Classified as a Seyfert 1 galaxy, it began exhibiting periodic optical brightenings every 60–90 days, also seen in UV and X-ray with *Swift* (Muñoz-Arancibia *et al.* 2024; Hernández-García *et al.* 2024). Its variability could be consistent with the partial disruption of a gas cloud by a supermassive black hole binary (Goicovic *et al.* 2016), with orbital separation ∼0.83 mpc and merger timescale of ∼70,000 years.

• **Ansky (ZTF19acnskyy)**: Discovered in 2019 and classified by ALeRCE, this source is interpreted as a rare nuclear transient or an AGN awakening (Sánchez-Sáez *et al.* 2024). It was later monitored by *NICER*, *XMM-Newton*, *Swift*, and *Chandra*, and exhibited powerful quasi-periodic eruptions (QPEs) in X-rays, recurring on ∼4.5 days timescales, each lasting over a day and releasing up to 10^{48} erg per event (Hernandez-García *et al.* 2025).

These cases exemplify ALeRCE's ability to identify rare AGN transients in real time and trigger coordinated, multi-wavelength follow-up campaigns.

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