# Selection and Characterization of AGN with Gaia

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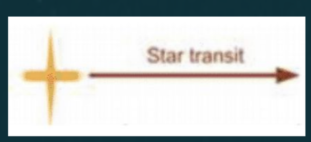
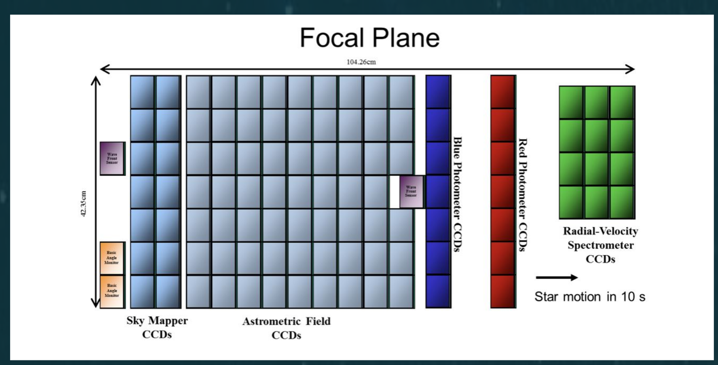
## The Gaia Mission

Launched by the European Space Agency (ESA) in 2013, the Gaia mission is revolutionizing our understanding of the Milky Way by creating the most precise 3D map of the galaxy ever made. Gaia measures the positions, distances, and velocities of over a billion stars with unprecedented accuracy, thanks to its sophisticated onboard instruments.

Gaia is equipped with two telescopes that provide a wide-angle view of the sky, and a billion-pixel camera—the largest ever sent into space. This camera is supported by a Radial Velocity Spectrometer (RVS), which measures the speed at which stars move toward or away from us, and a Photometric Instrument that captures the brightness and color of celestial objects across three bands: G (broadband visible light, 330-1050 nm), GBP (blue photometric band, 330-680 nm), and GRP (red photometric band, 630-1050 nm). These bands allow Gaia to analyze the physical properties of stars, such as temperature, chemical composition, and luminosity.

One of Gaia's unique capabilities is its ability to observe the same regions of the sky multiple times over its mission. This repeated coverage has enabled Gaia to detect and catalog nearly 10 million variable objects, including their light curves, as part of Data Release 3 (DR3). Among these variable objects are Active Galactic Nuclei (AGNs), which are some of the most energetic and distant objects in the universe. Gaia's data on variability is invaluable for studying the dynamic processes occurring in stars and galaxies, deepening our understanding of stellar evolution and cosmic phenomena.



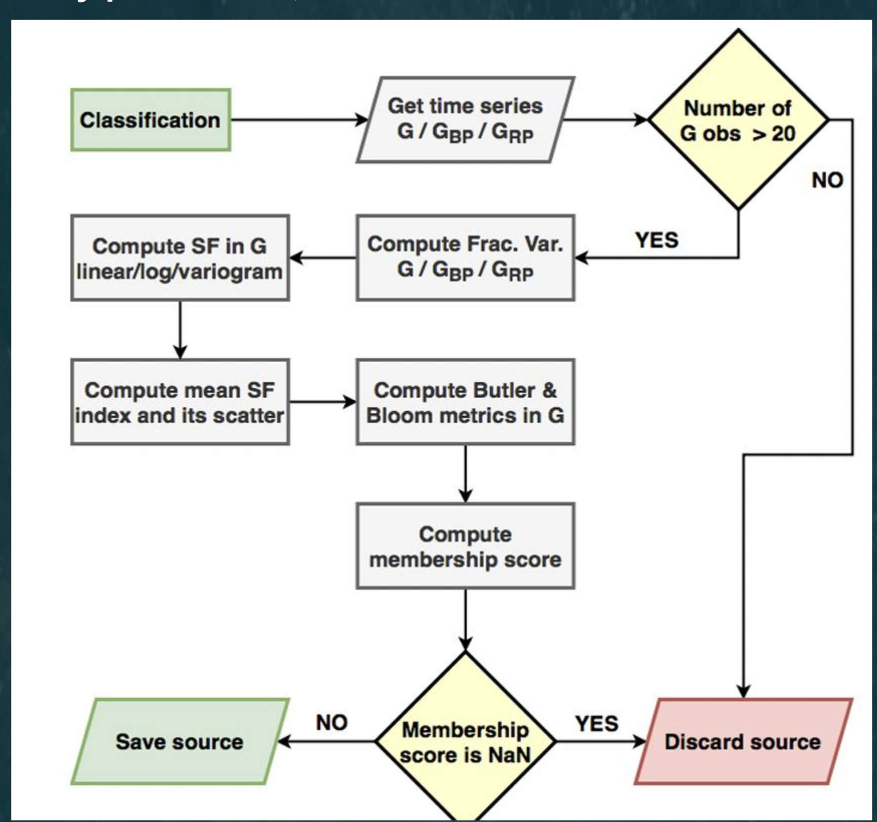

## The First Gaia Catalogue of Variable Active Galactic Nuclei

**Objective:** The goal of this study is to create a catalogue of variable AGN, selected exclusively using Gaia data.

**Methods**

1. **Sample selection:**
   - The selection started with millions of sources identified as AGN candidates by 11 different classifiers.
   - The focus was on variability properties based on light curves in Gaia's G band. We adopted several mandatory variability parameters, listed below:

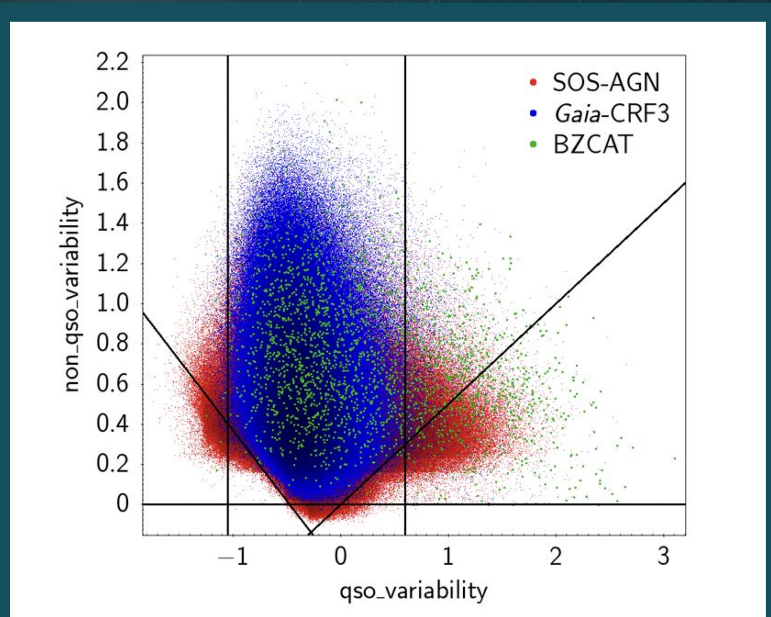
- fractional_variability_g
- structure_function_index
- structure_function_index_scatter
- qso_variability
- non_qso_variability
- vari_agn_membershipscore



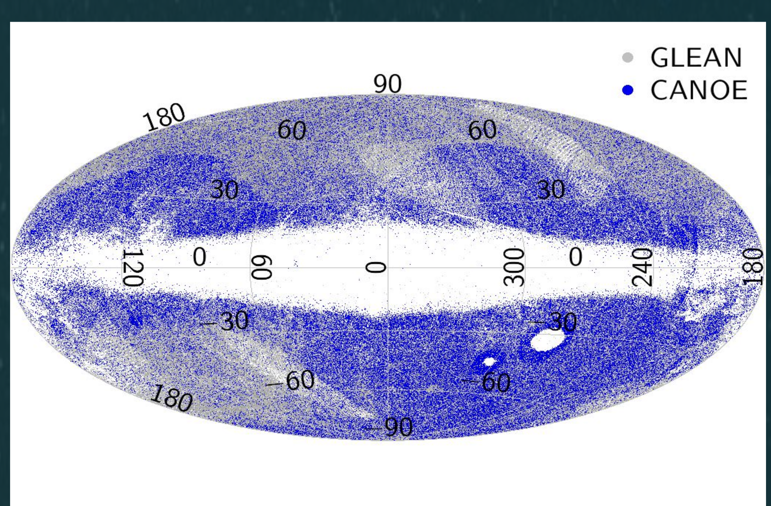

Flow chart of the SOS-AGN package.

2. **Filtering Process:**
   - A series of filters was applied to refine the sample, using only Gaia data and the Gaia Celestial Reference Frame 3 (Gaia-CRF3) as a reference.
   - This led to a final sample with high purity.

This is an example of the filters applied: the Butler & Bloom (2011) metrics (specifically, their logarithm) non-QSO variability versus QSO variability plot, showing the position of the variable AGN candidates (red dots), distinguishing those in the Gaia-CRF3 sample (blue dots) and the blazars in the BZCAT5 catalogue (green dots). The lines highlight the cuts performed to remove contaminants.




**RESULT:**
**GLEAN** (*Gaia* variabLE AgN) final sample: 872228 sources
**CANOE** (CANdidates tO Explore) sample: 150017 sources not in *Gaia*-CRF3,
**21735 new identifications**

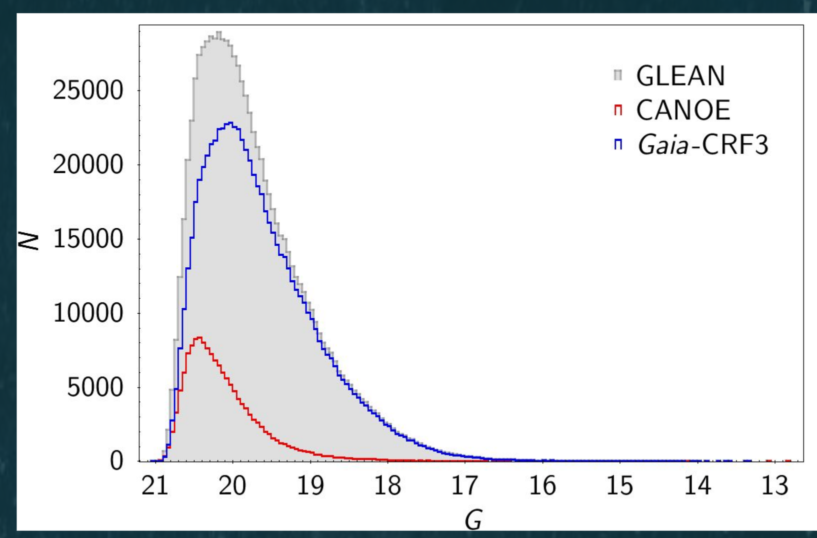


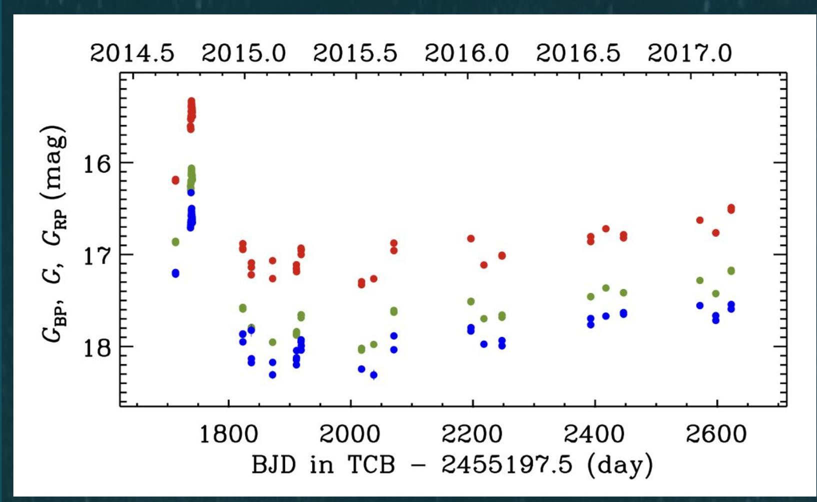

Sky distribution of the sources in the GLEAN (grey) and CANOE(blue) samples in Galactic coordinates. Mostly because of the environment filter, the Galactic Plane and Magellanic Clouds are almost empty. Some scanning law footprints are still visible

We conservatively estimate the sample purity to be around 95%.

## The Gaia variable AGN sample

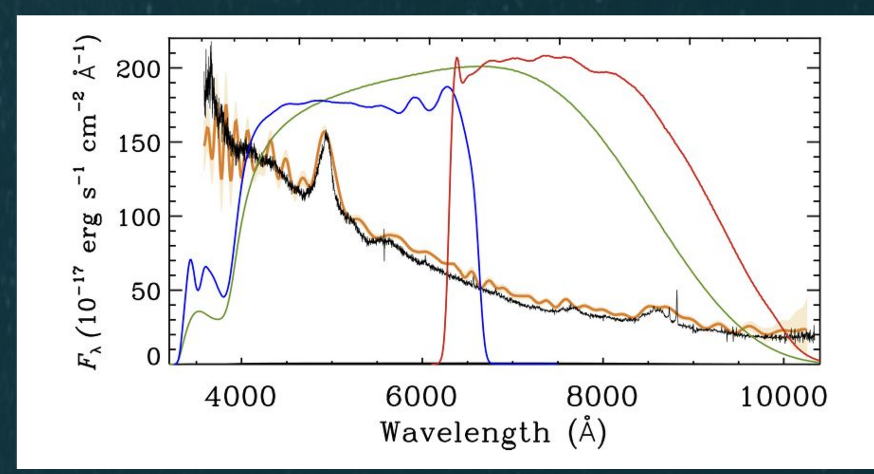
The G magnitude distribution (median_mag_g_fov) is plotted in the figure on the right for the complete GLEAN sample as well as for the sources in the CANOE and Gaia-CRF3 sub-samples. The distribution of the CANOE sources peaks at a fainter magnitude than that of the CRF3 objects.



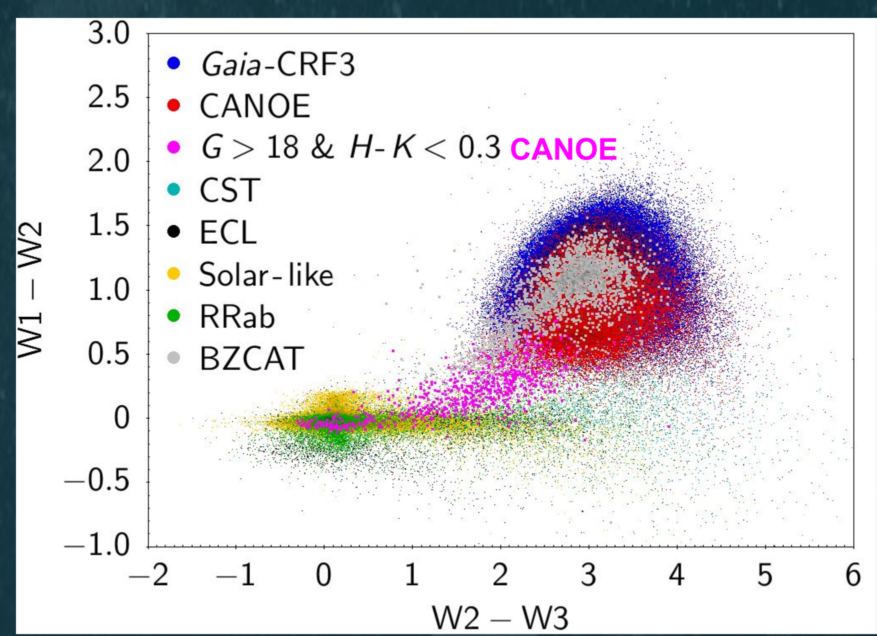




One of the main novelties of Gaia DR3 is the publication of the light curves for the AGN selected in this paper and in the paper by Rimoldini et al. (2023). In the figure on the left, we display the Gaia multiband light curves (G (green), GRP (red), and GBP (blue)) of the FSRQ-type source 5BZQJ1549+0237 (Gaia DR3 source_id: 4423448219003043968).

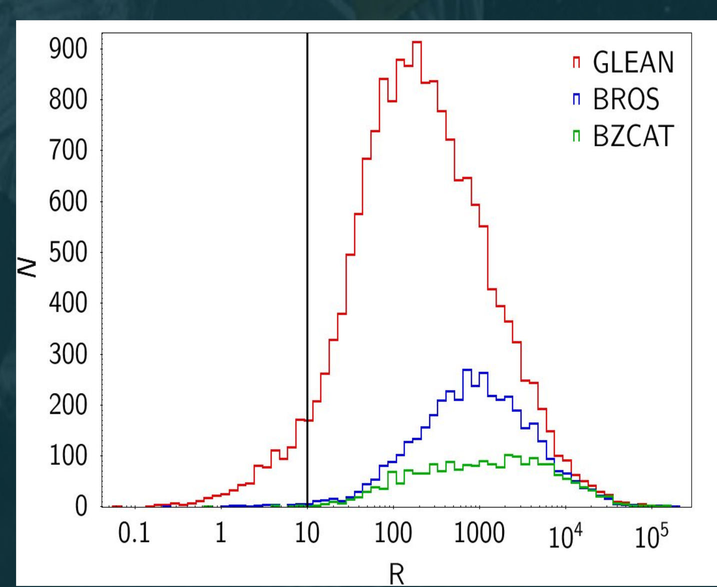
The figure on the right shows the low-resolution Gaia spectrum (orange) with uncertainties (shaded orange region), together with the SDSS spectrum (Abolfathi et al. 2018, black), and the Gaia passbands (blue, green, and red) to highlight the spectral coverage of the Gaia filters. The source is a FBQS J163709.3+414030 (Gaia DR3 source_id: 1356927713819217664).



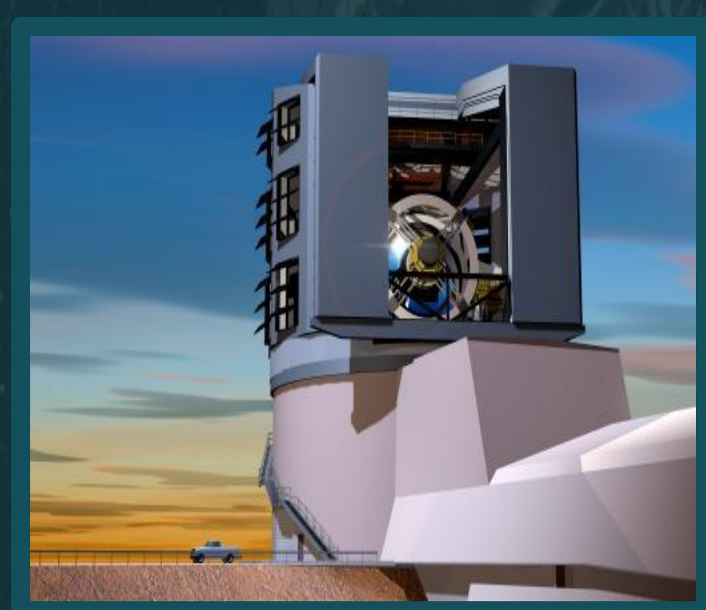

We searched for infrared counterparts of our candidates in the AllWISE archive. We used a 3 arcsecond search radius and required a signal-to-noise ratio (SNR) greater than 3 in the W1, W2, and W3 bands. The figure on the left shows the location of the GLEAN sources in the WISE color-color diagram, W1−W2 versus W2−W3, which is known to be a powerful tool for classifying sources. The variable AGN candidates mostly lie in the region where quasars and other types of AGN (e.g., blazars) are expected to be, confirming our selection. The 'blazar strip' (Massaro et al. 2012; Raiteri et al. 2014), connecting the locus of quasars with that of early-type galaxies and mostly populated by BL Lac objects, is clearly traced by sources belonging to the BZCAT5 catalogue. The plot also includes stellar objects of different types, which are largely separated from the AGN candidates.




A fraction of AGNs are radio-loud. We cross-matched the GLEAN sample with the catalogs of the radio sky surveys FIRST, NVSS, and VLASS using a 1.5 arcsecond radius. We investigated the percentage of radio-loud sources in our sample. The classical definition of a radio-loud source is that $R = F_{5GHz}/F_B > 10$. The distribution of the radio-loudness parameter R is shown in the figure on the right. The number of radio-loud sources is 16,459, which represents 95% of the 17,399 sources for which we were able to estimated the parameter R. If we simply generalize this result to all sources with a radio counterpart, taking into account the different sky coverage of Gaia with respect to the radio surveys, we would infer that the number of radio-loud sources in our GLEAN sample is approximately 4%.




## LSST



In the next future (2025-2035) the Vera C. Rubin Legacy Survey of Space and Time Telescope (LSST; at 8.4 meter telescope located in Chile) will carry out a survey of the southern hemisphere sky (at least 18,000 square degrees). Each ~9 square degree observing field will be revisited every few days with a different filter (ugrizy). This is known as the Wide-Fast-Deep survey (WFD, or "Main Survey"). In addition, a fraction of time between 10 and 20% will be devoted to special surveys on selected sky areas: Mini-Surveys and Deep Drilling Fields (DDFs).

The work done on the classification and characterization of AGNs using Gaia data has provided us with valuable methodologies and insights. These will be instrumental as we explore new AGNs with the LSST, which will observe at greater depths. LSST will enable us to probe farther into the universe, increasing the number of AGNs detected and opening up new opportunities for their study. By applying these techniques, we expect to identify and characterize previously unknown AGNs.

**For more details: Carnerero et al. 2023A&A...674A..24C**

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