The search for variable AGN with GAIA

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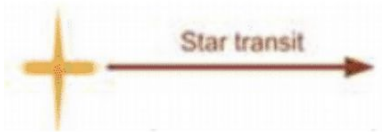
gaia

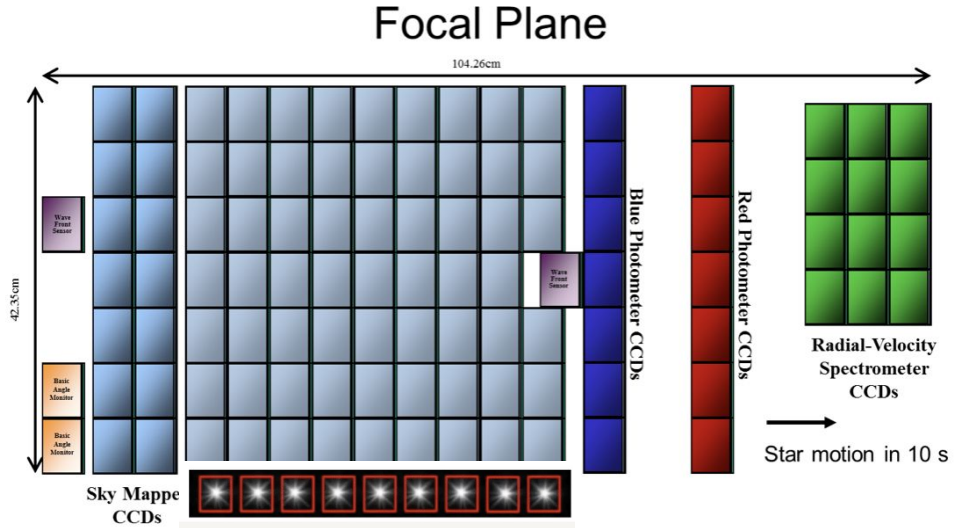
Gaia DPAC

Data Processing & Analysis Consortium

GAIA: INSTRUMENTS

- ASTROMETRY
- (SPECTRO) PHOTOMETRY (G, G_{BP}, G_{RP})
  330-1050 nm 330-680 nm 640-1050 nm
- SPECTROSCOPY (BP, RP, RVS)
  R~ 20-90 847-874 nm R=11,500





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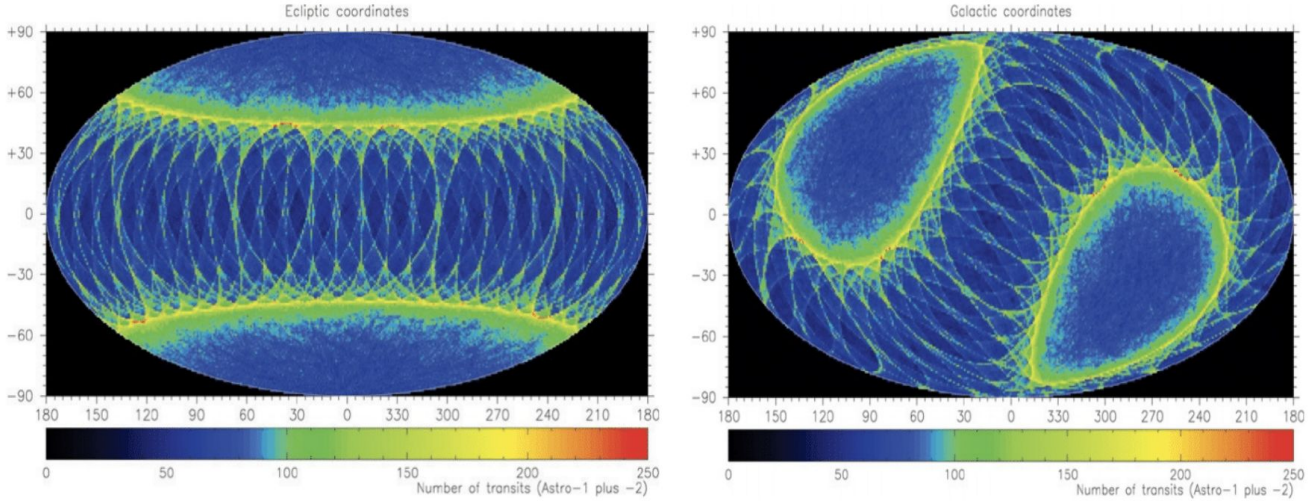
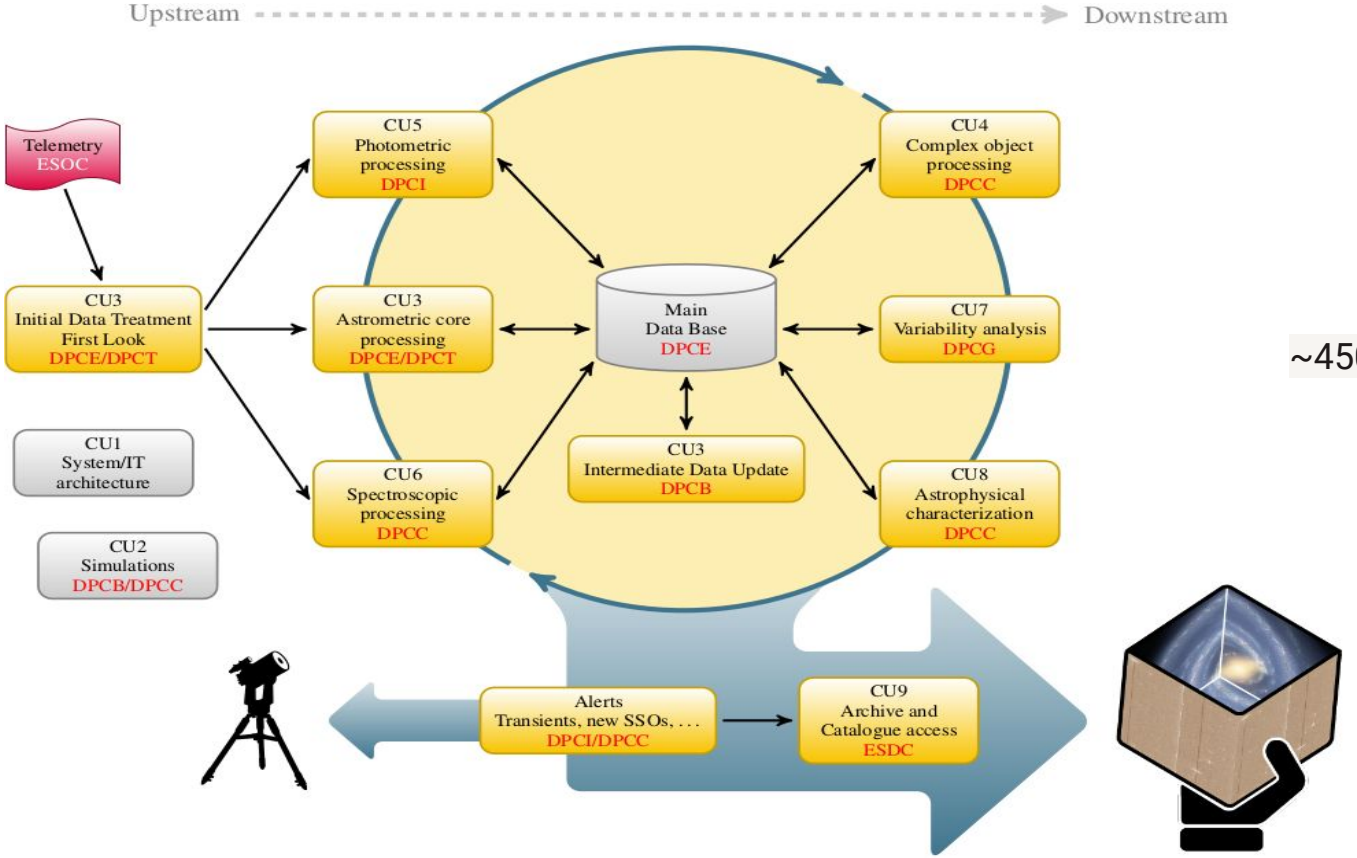


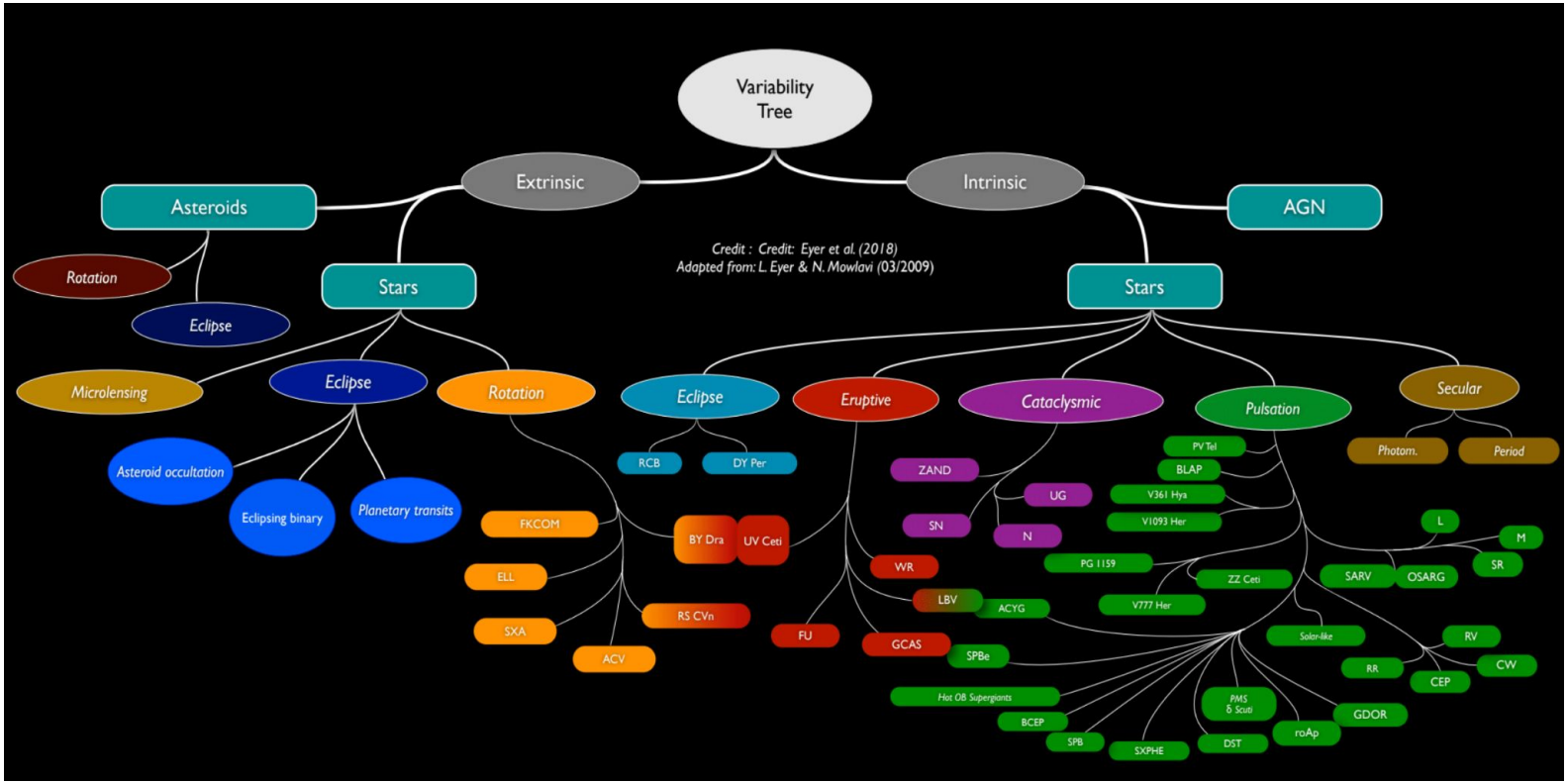
First 5 years of mission
N ~ 70 (G, G_{BP}, G_{RP})
N ~ 40 (RVS)

Gaia Data Processing and Analysis Consortium (DPAC)



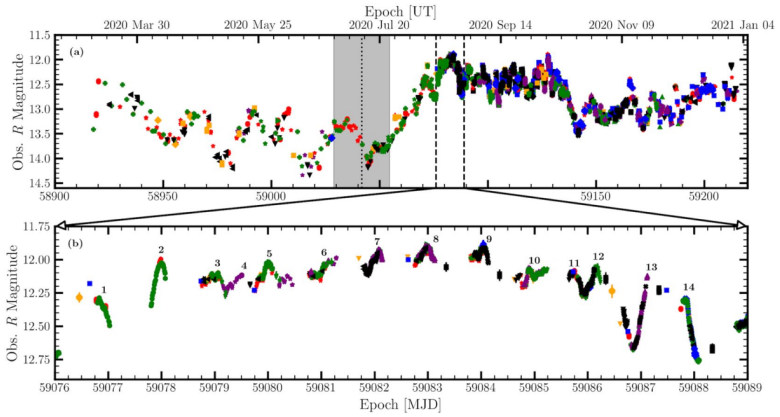
~450 Persons

Variable Sources

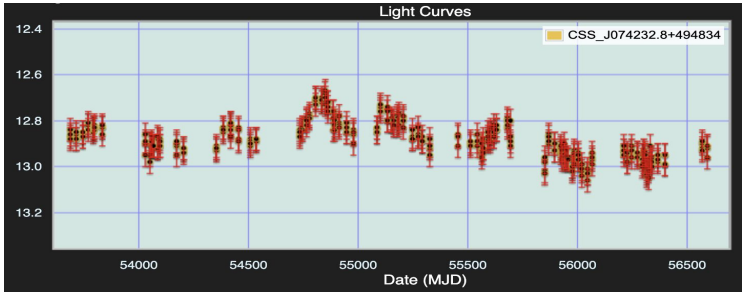


Variability

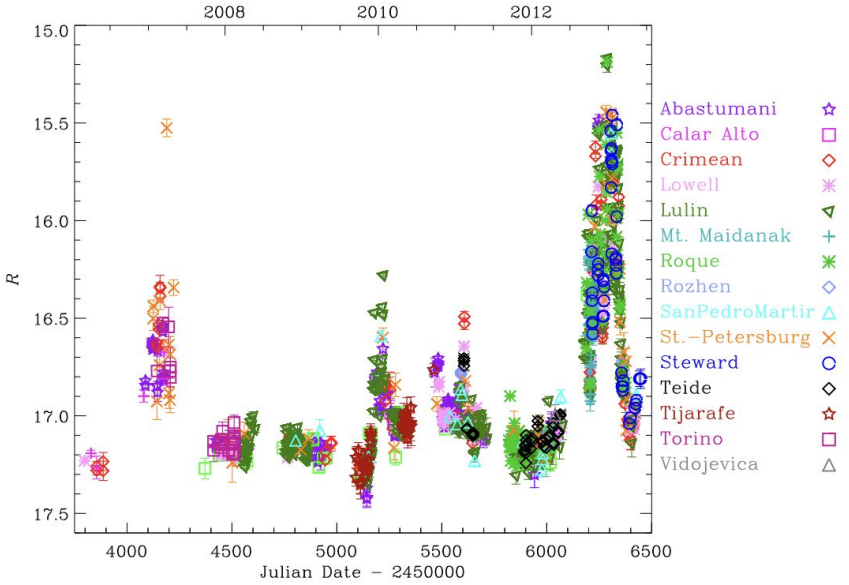
Temporal variability at several scales (month-years but sometimes days, hours…).



BL Lacertae, Jorstad S. G. et al 2022, Nature, 609, 265



Mrk 79, Catalina Sky Server



OJ 248, Carnerero, M. I. et al, 2015, MNRAS.450.2677C

Gaia Data Release 3:

The first *Gaia* catalogue of variable AGN

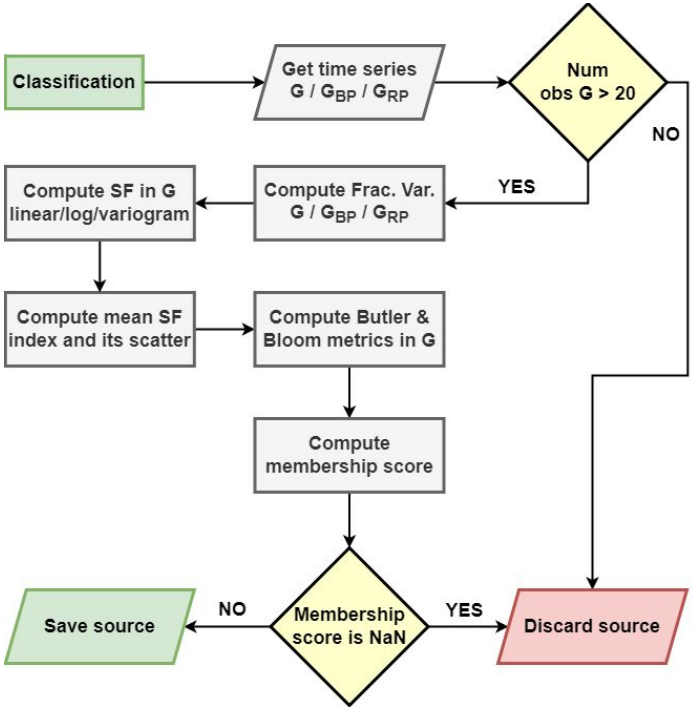
Maria I. Carnerero[1], Claudia M. Raiteri[1], Lorenzo Rimoldini[2], Deborah Busonero[1], Enrico Licata[1], Nami Mowlavi[2,3], Isabelle Lecoeur-Taïbi[2], Marc Audard[2,3], Berry Holl[2,3], Panagiotis Gavras[4], Krzysztof Nienartowicz[5], Grégory Jevardat de Fombelle[2], Ruth Carballo[6], Gisella Clementini[7], Ludovic Delchambre[9], Sergei Klioner[8], Mario G. Lattanzi[1], and Laurent Eyer[3]

The goal of this work was the creation of a catalogue of variable AGN, whose selection was based on Gaia data only, and as pure as possible.

Variability parameters

We defined some mandatory metrics, values are listed in the Gaia-DR3 vari_AGN table.

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



Variability parameters- Fractional variability

A common parameter to characterize variability is the mean fractional variation

$$\texttt{fractional\_variability\_g} = \frac{\sqrt{\mathrm{MAD}^2(F) - <\sigma_F^2>}}{\mathrm{median}(F)}$$

MAD median absolute deviation

$<\sigma_F^2>$ mean of the squared flux uncertainties

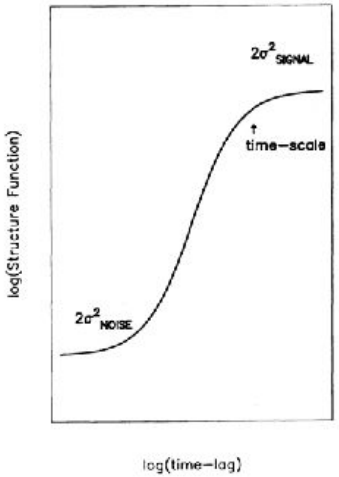
$\mathrm{median}(F)$ median flux for all *N* observations

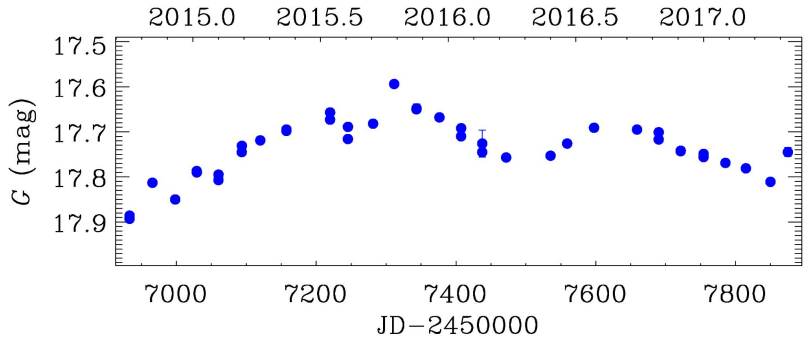
To mitigate the effect of outliers, we modified the standard fractional variability definition, adopting for the flux statistics the median instead of the mean, and the median absolute deviation instead of the standard deviation

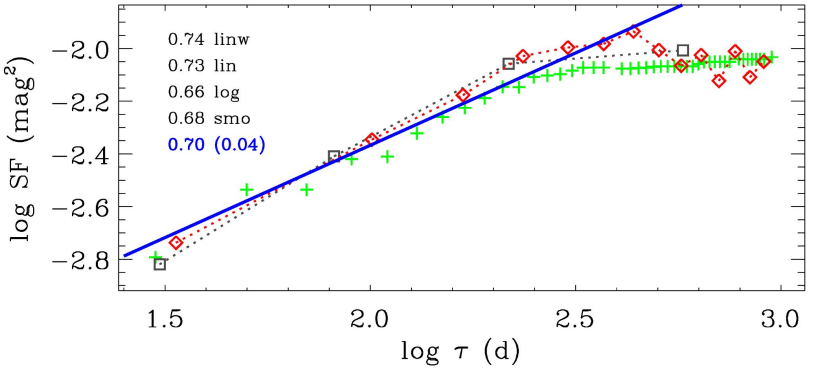
Variability parameters - Structure Function index

Mean difference in flux densities versus time separation (e. g. Simonetti et al. 1985)

$$SF_{Sim}(\tau) =< [mag(t) - mag(t+\tau)]^2 >$$

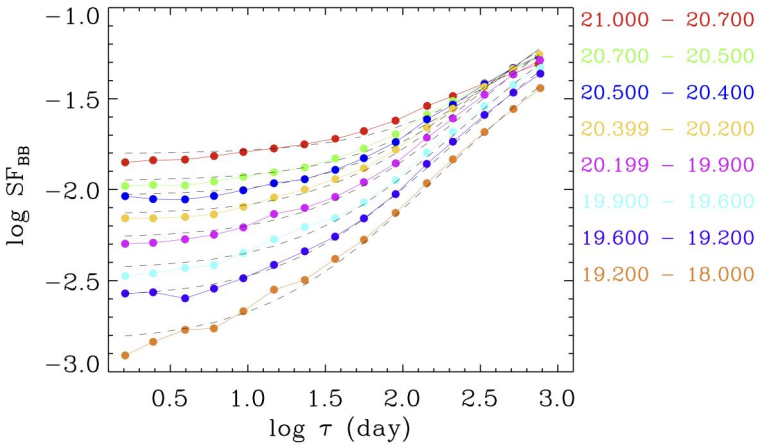


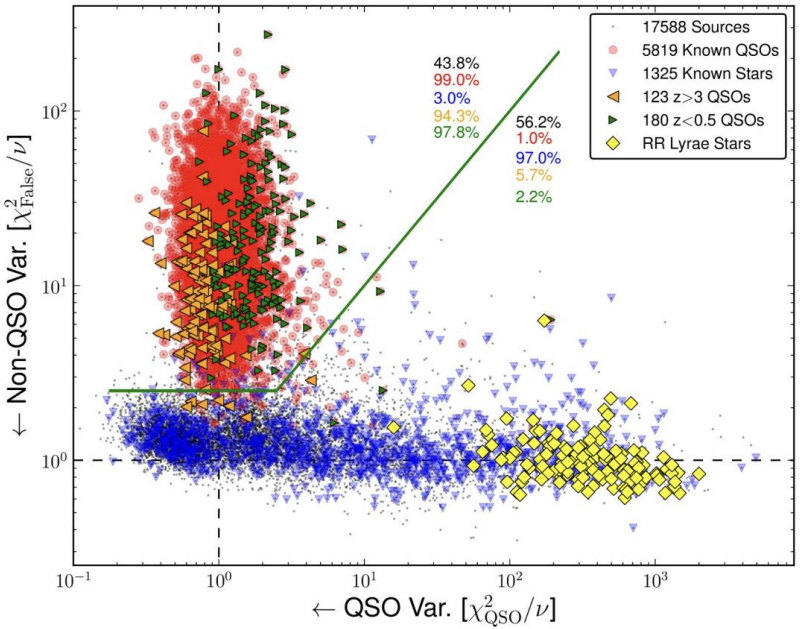




Variability parameters - Butler & Bloom parameters

qso_variability and non_qso_variability

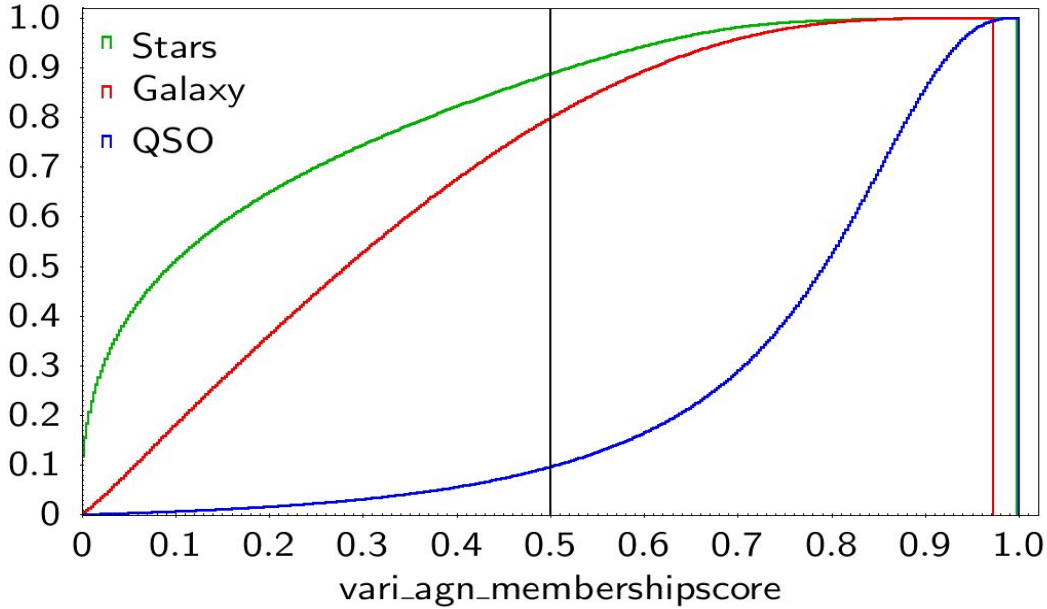




Butler & Bloom 2011,AJ,141,93B

Variability parameters - membershipscore

we calculated the membership score with the inverse of the Mahalanobis distance D based on five parameters (fractional_variability_g, structure_function_index, qso_variability, non_qso_variability, and abbe_mag_g_fov)



More than *90%* of *AGN* have values greater than 0.5

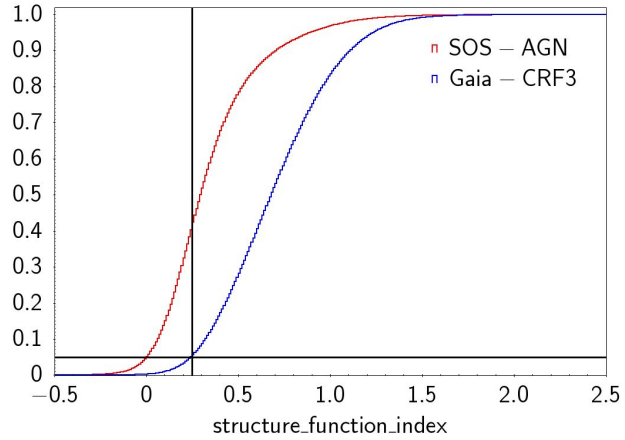
Only *10%* of *variable stars* have values greater than 0.5

Only 20% of *galaxies* have values greater than 0.5

Selection procedure

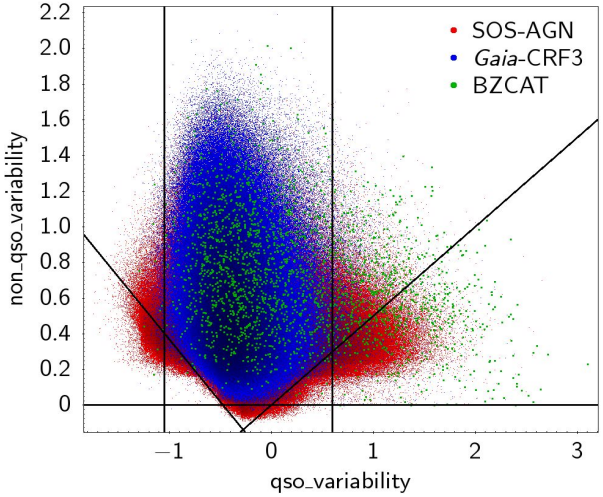
Application of a sequence of filters tailored on the *Gaia-CRF3* sample. The goal was to obtain a variable AGN sample as pure as possible, with the minimum loss of *Gaia-CRF3* sources.

Structure Function Index > 0.25



SOS-AGN — 10 536 184 / 6 286 047
***Gaia-CRF3* — 1 112 764 / 1 055 586**

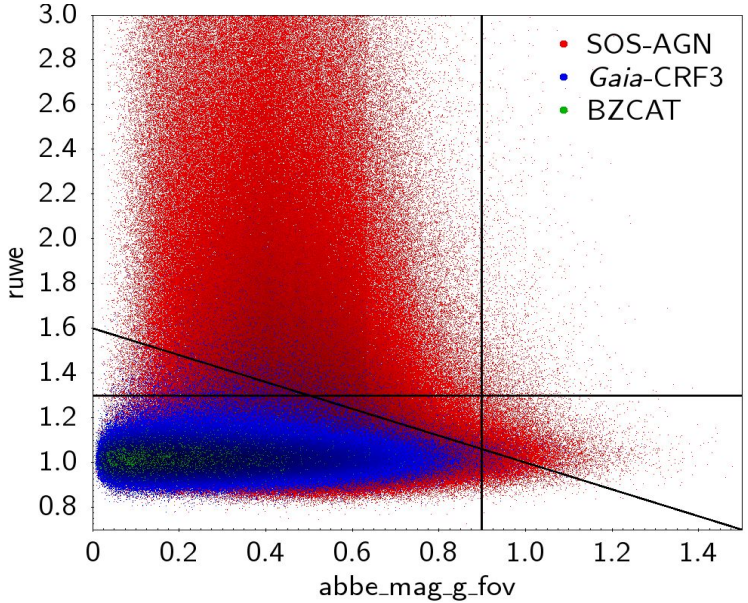
Butler & Bloom metrics (qso_variability vs non_qso_variability)

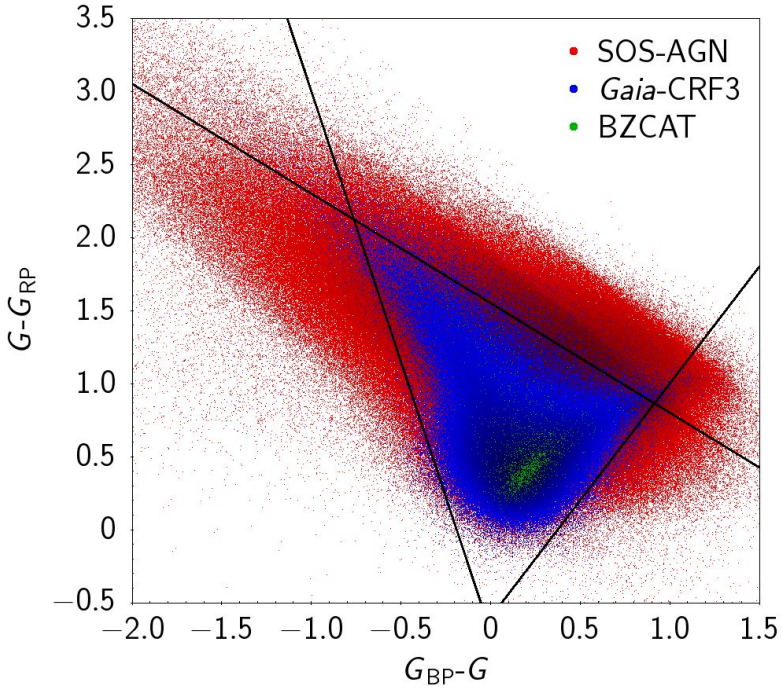


SOS-AGN — 6 286 047 / 5 992 038
***Gaia-CRF3* — 1 055 586 / 1 047 334**

Selection procedure

Additional filters





ruwe (renormalised unit weight error): gives an estimate of the suitability of the single-star astrometric model for a given source

abbe: half of the ratio of the mean square difference between consecutive data points in the light curve to its variance.

SOS-AGN — 5 992 038 / 3 881 285

***Gaia-CRF3* — 1 047 334 / 1 030 304**

Selection procedure

Cut on the astrometric parameters

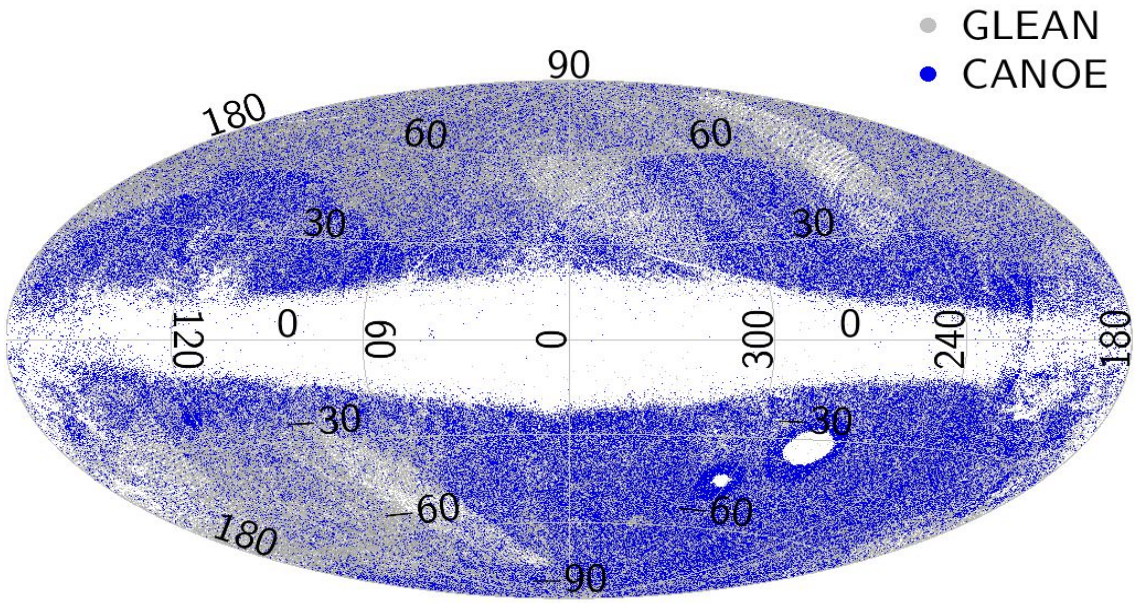
- PARALLAX/ERR < 5
- PROPER MOTION/ERR < 5

Cut on the environment

- numdensity100asec < 0.01

Cut on spurious effects

- lhm_corr_g < 0.8 (scan angle)
- variability_probability



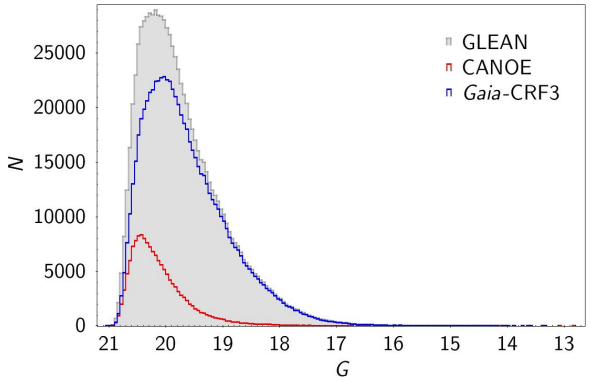
RESULT:

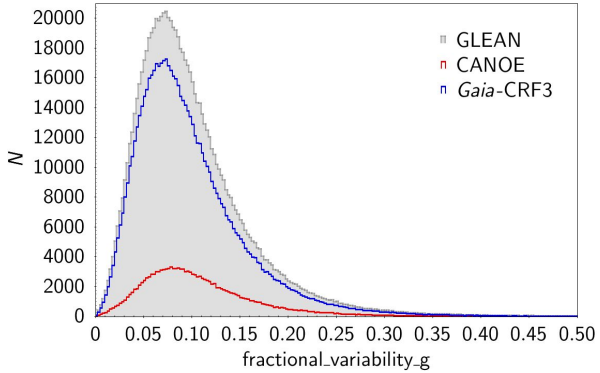
GLEAN (*Gaia* variabLE AgN) final sample: 872228 sources

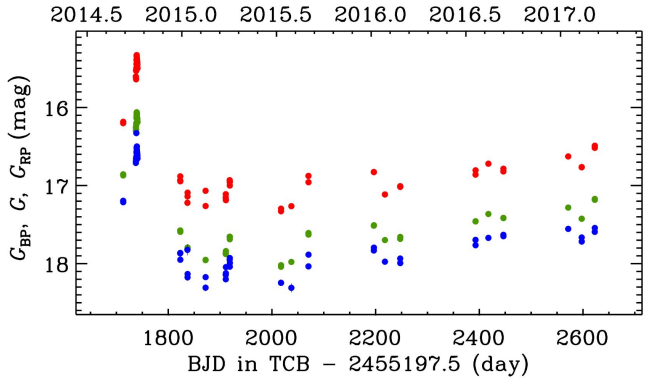
CANOE (CANdidates tO Explore) sample: 150017 sources not in *Gaia*-CRF3, **21735 new identifications**

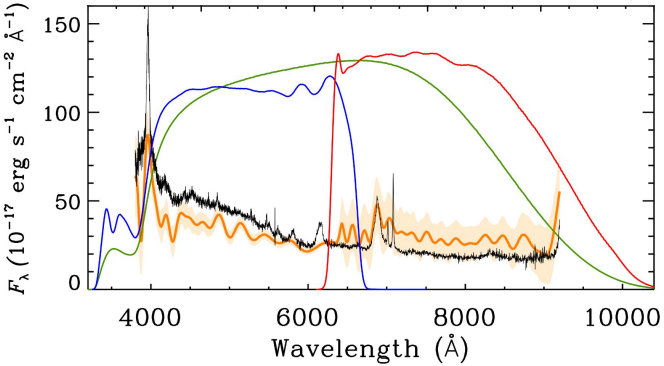
The Gaia variable AGN sample.

GLEAN: 872228 sources
CANOE: 150017 sources









RP

G

BP

SDSS spectrum

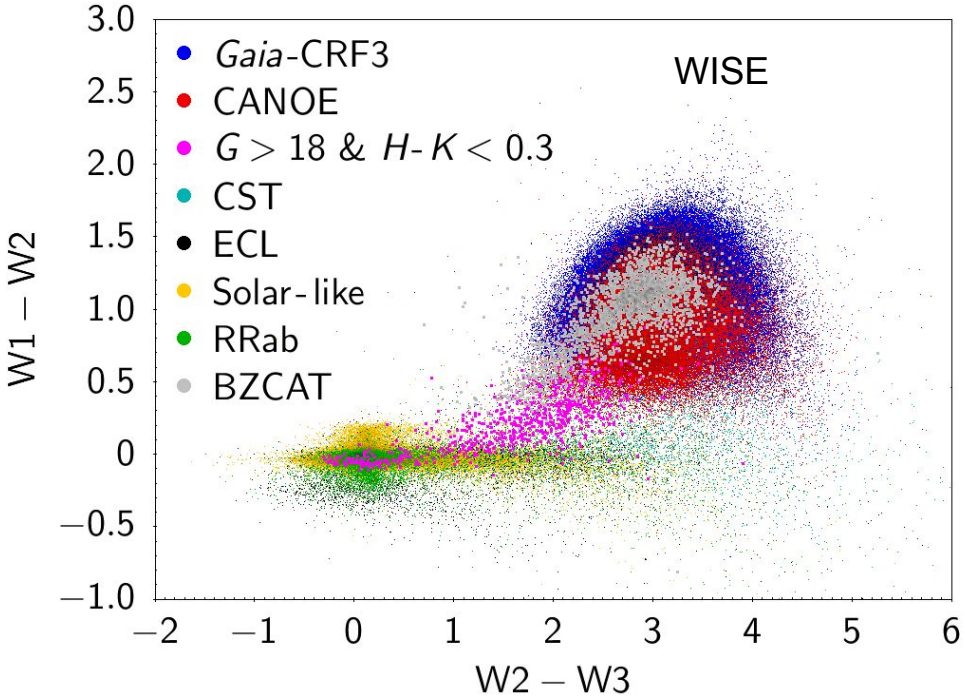
Gaia low resolution spectrum with its uncertainty

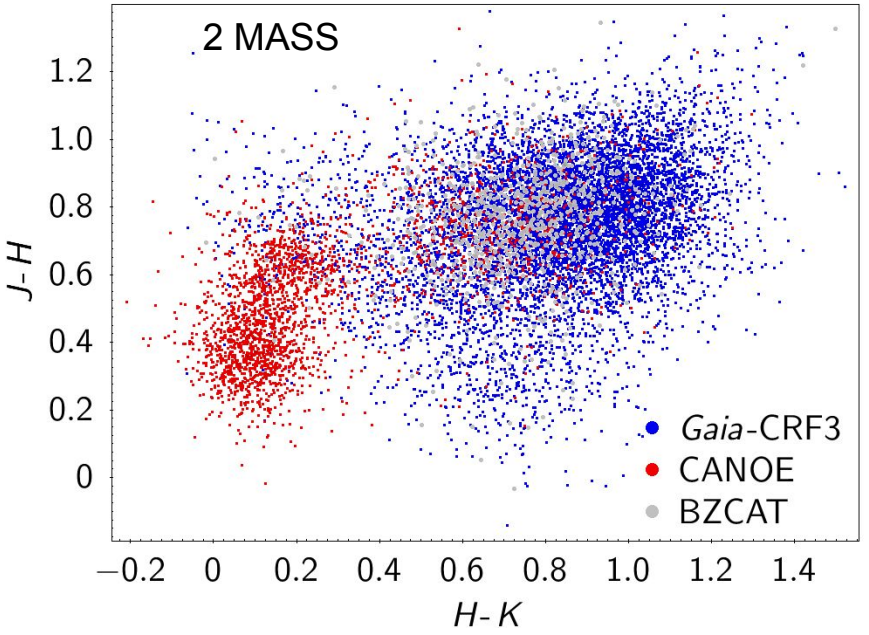
Gaia passbands (**BP**, **G**, **RP**)

The *Gaia* variable AGN sample.

GLEAN: 872228 sources
CANOE: 150017 sources

XM with WISE and 2MASS catalogues





Completeness and Purity

Completeness with respect to *Gaia*-CRF3: 51%

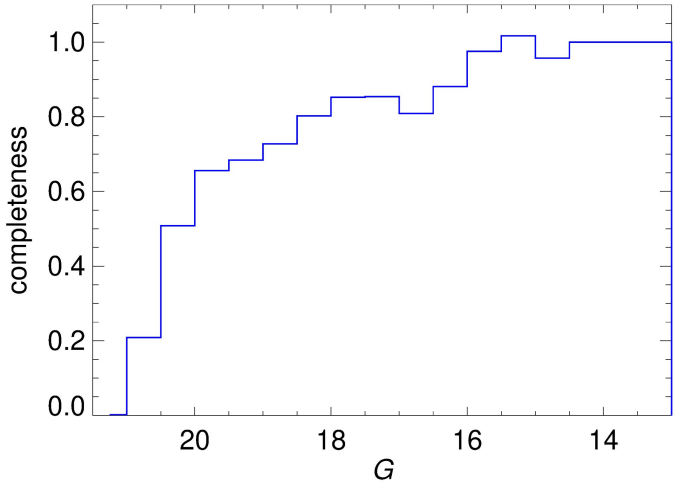
Results of the XM of the GLEAN and CANOE samples with large AGN catalogues

Catalogue	N_{cat}	$N_{match,ini}$	$N_{match,fin}$	Ratio	$N_{match,new}$	Reference
WISE C75	20 907 127	925 988	602 782	0.65	28 574	1
WISE R90	4 543 530	788 714	526 388	0.67	4 569	1
Gaia–unWISE	2 734 464	1 363 764	819 677	0.60	108 345	2
Gaia-DR2	2 690 021	1 025 599	652 900	0.64	85 662	3
***Gaia*-CRF3**	**1 614 173**	**1 141 892**	**722 211**	**0.63**	**0**	**4**
SDSS DR16Q Superset v3	1 440 615	295 426	196 907	0.67	1 360	5
AllWISE AGN	1 354 775	494 067	323 225	0.65	2 316	6
MILLIQUAS	1 115 619	411 742	273 422	0.66	5 545	7
SDSS DR16Q v4	750 414	291 484	195 946	0.67	1 201	5
LQAC5	592 809	259 127	174 076	0.67	89	8
LQRF	100 165	81 560	61 159	0.75	40	9
BROS	88 211	6 304	4 510	0.72	304	10
APOP (QSO)	86 821	72 107	54 407	0.63	33	11
LAMOST5	52 453	38 341	29 188	0.76	92	12
2QZ	49 425	19 254	13 794	0.72	184	13
e-ROSITA	21 952	5 122	3 319	0.65	289	14
OCARS	13 589	6 541	5 099	0.78	147	15
Seyfert	11 101	7 802	5 578	0.71	26	16

Note: (1) Assef et al. (2018); (2) Shu et al. (2019); (3) Bailer-Jones et al. (2019); (4) Gaia Collaboration et al. (2022b); (5) Lyke et al. (2020); (6) Secrest et al. (2015); (7) Flesch (2021); (8) Souchay et al. (2019); (9) Andrei et al. (2009); (10) Itoh et al. (2020); (11) Qi et al. (2015); (12)Yao et al. (2019); (13) Croom et al. (2004); (14) Liu et al. (2021); (15) Malkin (2018); (16) Rakshit et al. (2017)

completeness

The GLEAN completeness versus G magnitudes



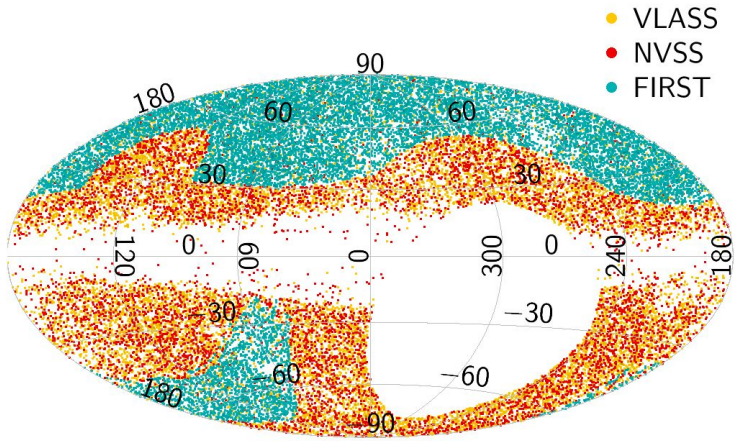
Purity: 21735/872228= 0.025 -> less than 3% possible contamination ?

We reasonably estimate the sample purity around 95%

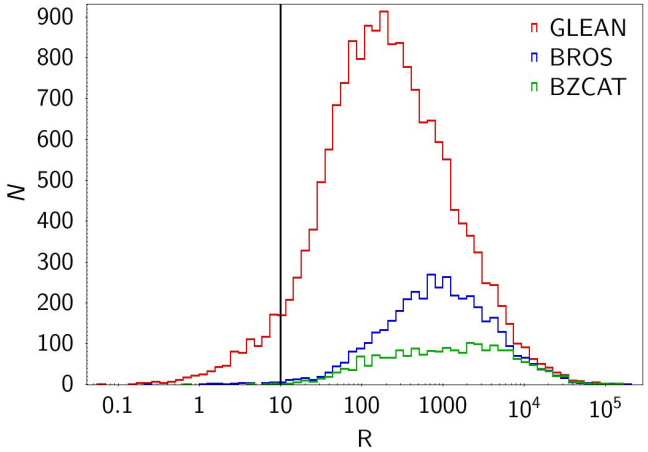
XM with radio catalogues

A fraction of AGN is radio-loud. This fraction is generally assumed to be around 10%, but depends on both redshift and luminosity

Name	Band (GHz)	Sky (%)	N_{cat}	N_{cross}
FIRST	1.4	25.6	946 432	13 133
VLASS	3.0	82	3 381 277	31 378
NVSS	1.4	82	1 773 484	11 041



$$R = \frac{F_{5GHz}}{F_B} > 10$$



Distribution of the radio-loudness parameter R for the 17399 GLEAN sources with radio counterparts in 2 radio bands (blazars: 2058 in BZCAT5 and 4209 in BROS)

The number of radio-loud sources in our GLEAN sample is of the order of 4%

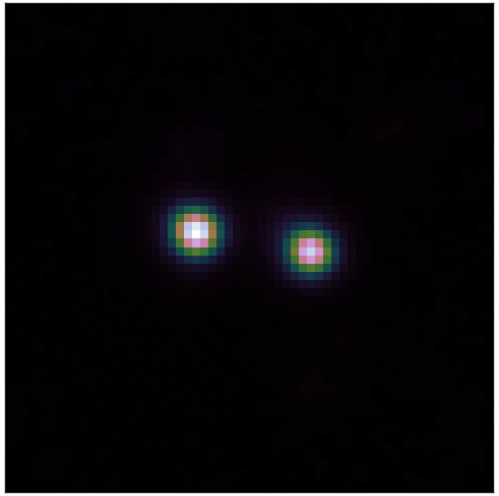
Lensed Quasars

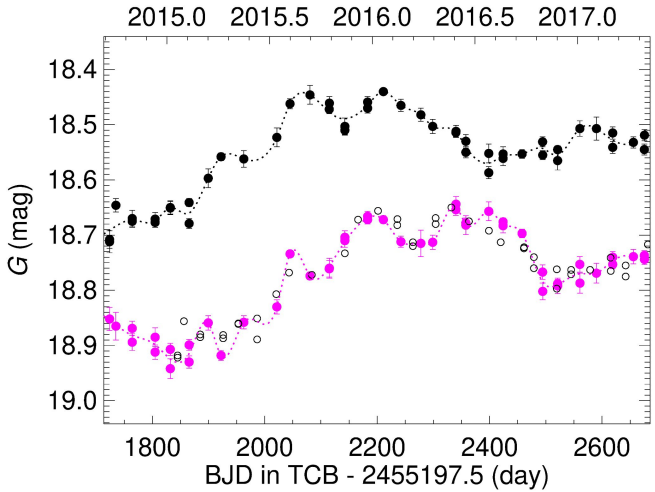
The GLEAN sample includes more than a hundred known gravitationally lensed quasars.

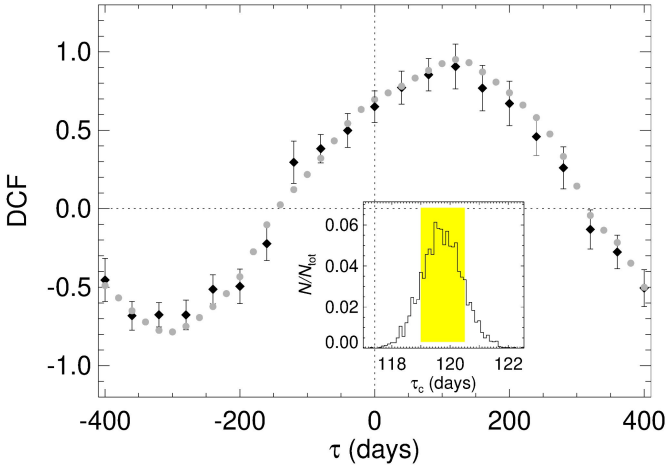
We investigated the possibility to derive robust measurements of the time lag between the observed flux variations corresponding to the various images of a lensed quasar. Difficult task!

One example: DESJ0501-4118

τ = 120±1 d

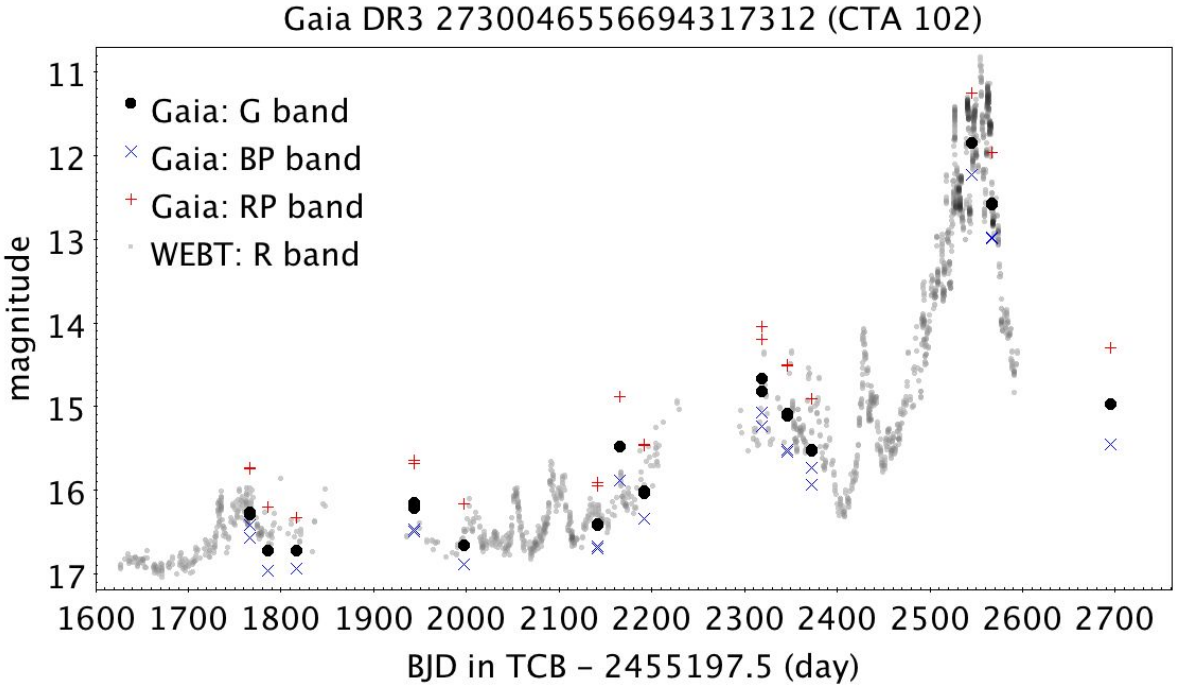






Whole Earth Blazar Telescope
(WEBT; https://www.oato.inaf.it/blazars/webt))

Long-term and short-term study on a few sources



GAIA

Long-term study on the AGN population

FOR DR4 (66 months of data)

New variability parameters:

beyond1st: Percentage of points beyond one st. dev. from the weighted mean.

flux_percentile_ratio_mid20: Ratio of flux percentiles (60th-40th) over (95th-5th)

linear_tren: Slope of a linear fit to the light-curve fluxes

max_slope: Maximum absolute flux slope between two consecutive observations

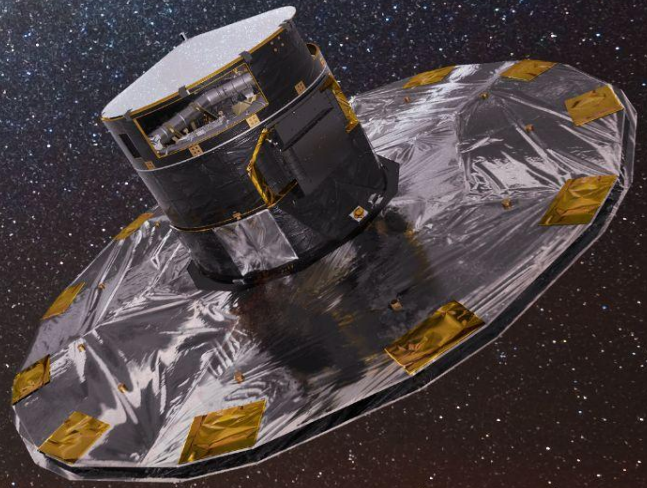
median_absolute_deviation: Median discrepancy of the fluxes from the median flux

median_buffer_range_percentage: Percentage of fluxes within 20% of the amplitude from the median.

small_kurtosis: Kurtosis of the fluxes, reliable down to a small number of epochs

…..

Thank you for your attention!!!



Suggestions are welcome.