

Looking for objects with unusually bright UV emission in modern sky surveys

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FZU

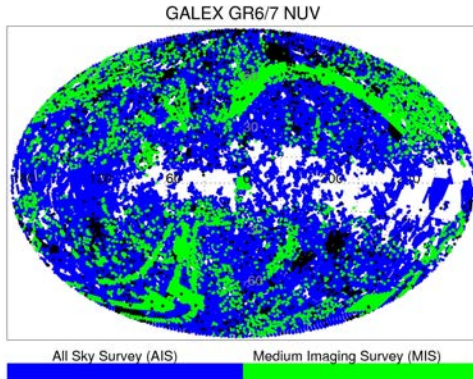
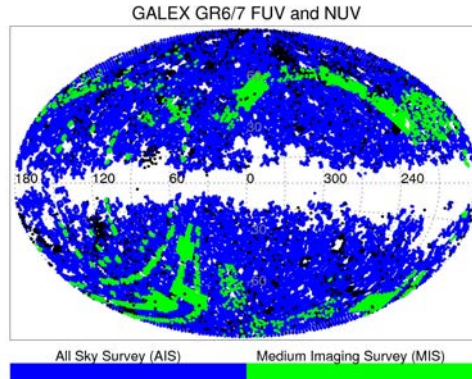
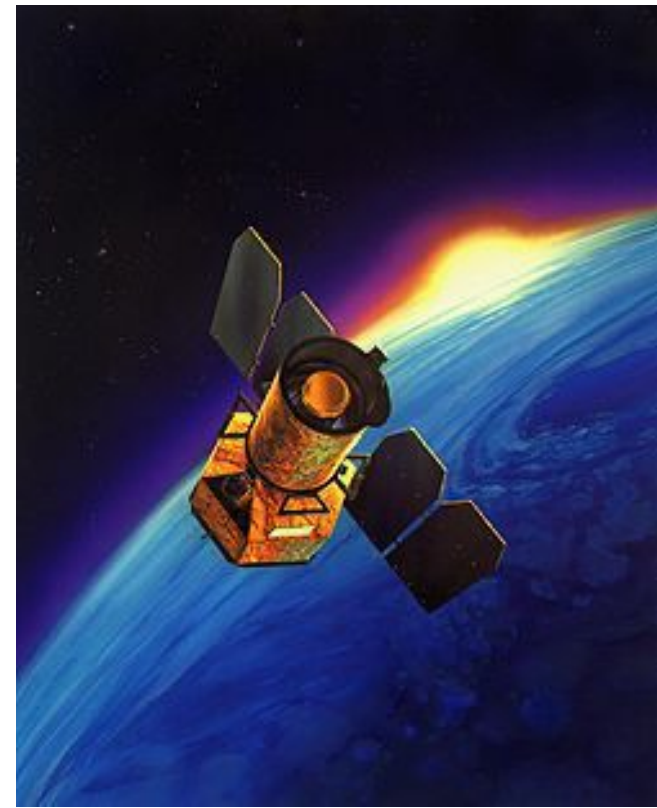
Institute of Physics
of the Czech
Academy of Sciences

GALEX satellite and its legacy

Nearby Galaxy Survey (NGS), Deep (DIS), Medium (MIS), and **All Sky Imaging Survey (AIS)**
(nearly all sky, multiple visits, ~100-1000 s exposures)

Final catalogue of GALEX-detected objects - GUVcat_AIS, **82,992,086** objects
Bianchi et al. (2017), re-processing of all AIS data of the mission

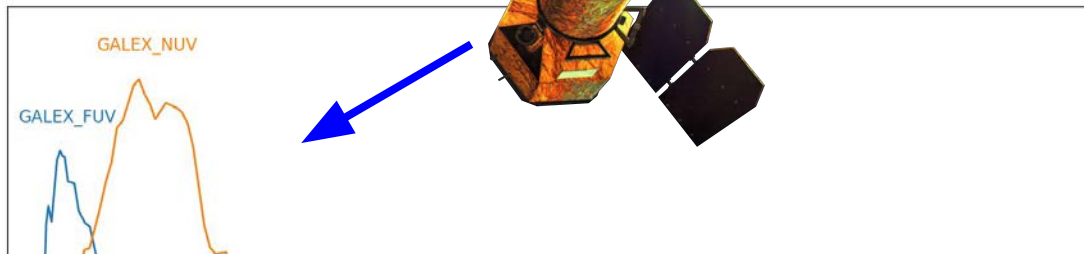
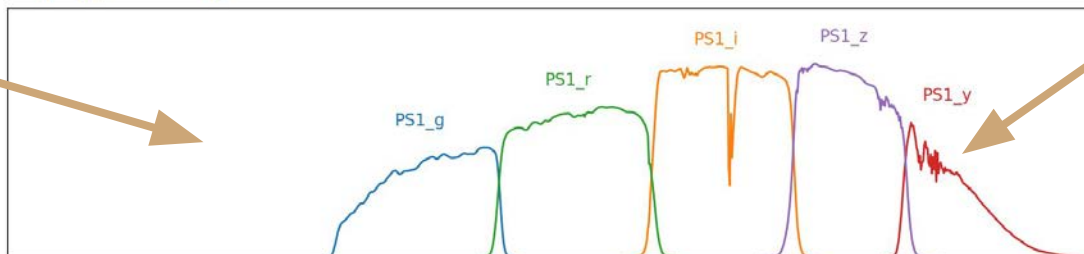
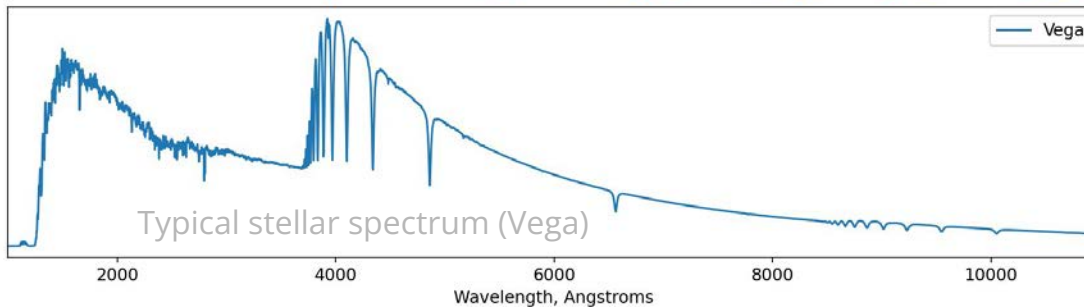
GPhoton - (slow) API for accessing all photons acquired by GALEX (time, position, ...)
Allows reconstruction of both images and light curves (including intra-visit ones)



Launch: April 28, 2003
Observing: July 7, 2003 - February 7, 2012
FUV inactive since 2009

Image scale: 1.5" per pixel
Image FWHM: ~4.2" (FUV)
~5.3" (NUV)

4 m Victor M. Blanco Telescope
CTIO, Chile
since 2012 with DECam
~12% of the sky in DES DR2



**Panoramic Survey Telescope and
Rapid Response System**

1.5 m telescope
Haleakala observatory
Hawaii
since 2008

~75% of the sky in DR1



THE DARK
ENERGY SURVEY

Let's look for the objects visible in UV but not in optical

Parameter space

Idea is to look for GALEX objects with
no significant optical counterparts

- **Depth of catalogues**

GALEX: NUV < 21

Pan-STARRS: $g < 23.3$

DES: $g < 24.7$

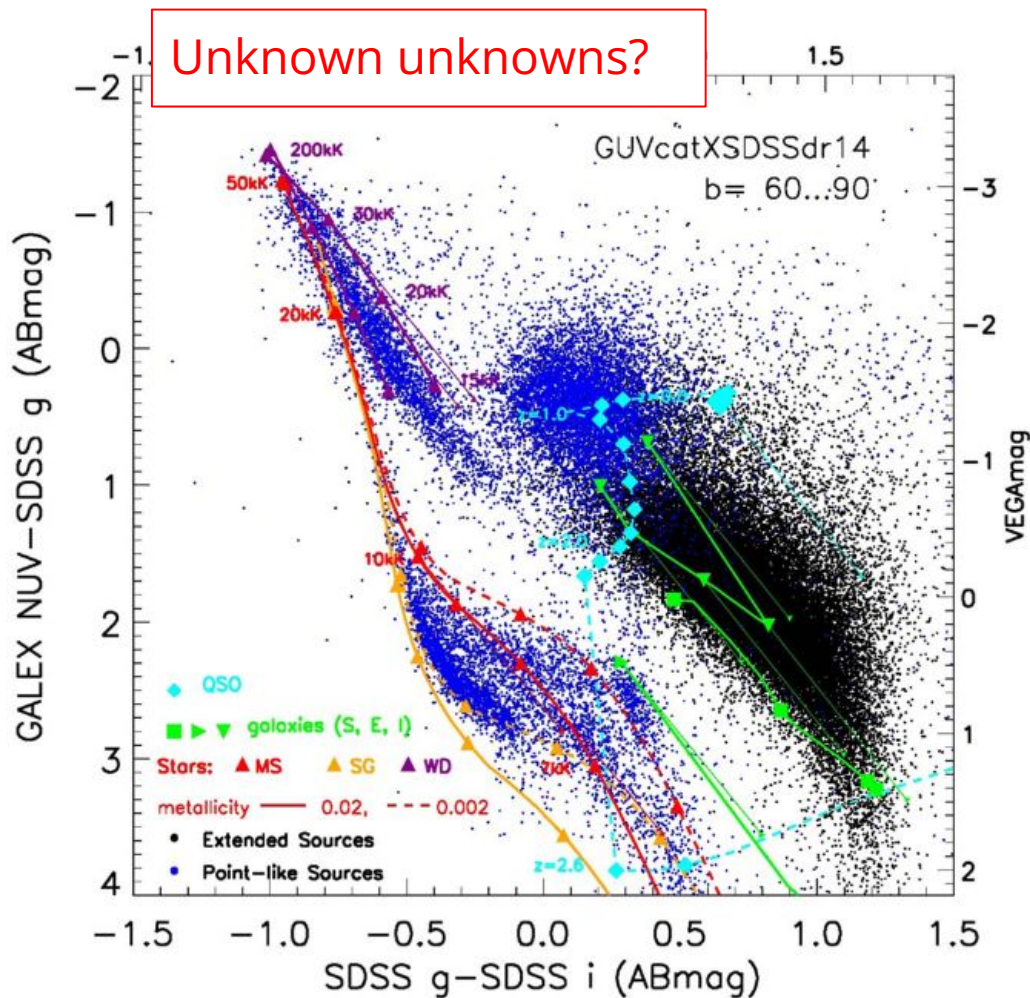
- **Where to look for extreme objects?**

Non-matched objects will have

$\text{NUV} - g < -2 \dots -4$

Physical processes?

- (self-absorbed) synchrotron
- (redshifted) emission lines
- strong g-band absorption
- extreme UV upturn?



Cross-matching large catalogues

GALEX GR6/7 + Pan-STARRS DR1 + DES DR2

- **Local Databases**

- Spherical indexing
 - HEALPix, HTM, Q3C, ...
- Arbitrarily complex SQL queries
- Huge tables to download

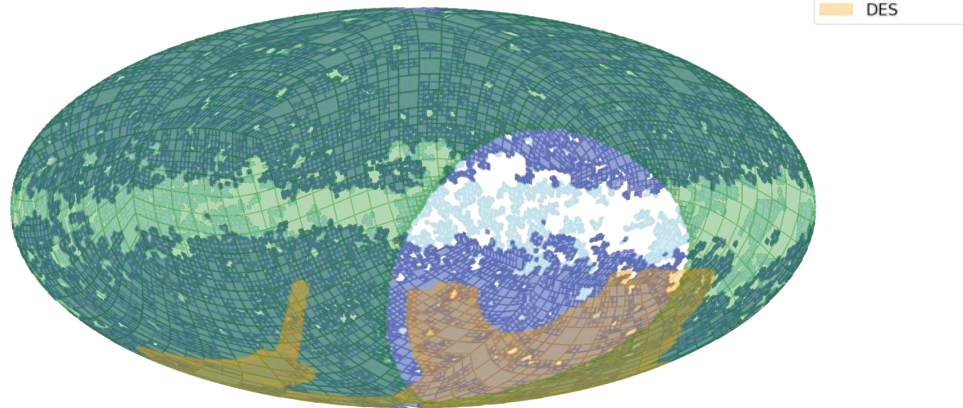
- **Online services**

- MAST CasJobs (no DES)
- SDSS SkyServer (no Pan-STARRS or DES)
- NOIRlab Astro Data Lab (no GALEX)

- **CDS XMatch**

- all catalogues, no SQL interface

Non-uniform sky coverage!



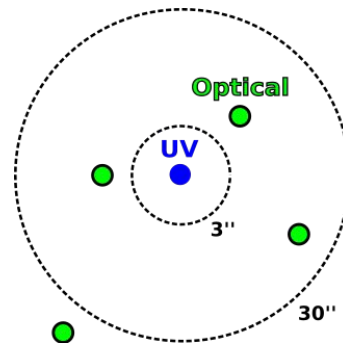
- Split into sky segments using HEALPix
- Match with **30''** to ensure sky coverage

-

- Match with **3''** to get matched objects

=

- Keep only non-matched objects
(matches within 30'' but not within 3'')



Additional GALEX quality cuts

No extraction flags

$$N_{\text{exf}} = 0$$

No dichroic or window reflection artifact flags

$$(N_{\text{exf}} \ \& \ 6) = 0$$

Signal/Noise > 5

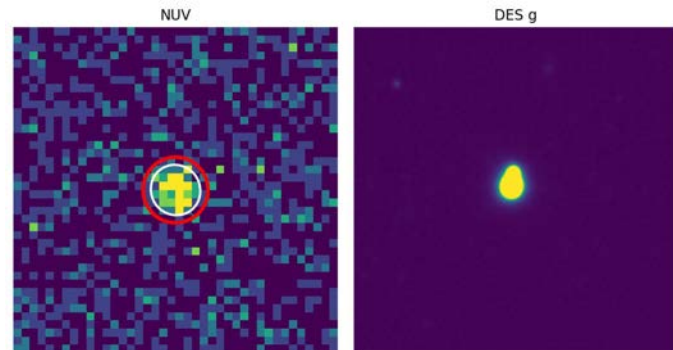
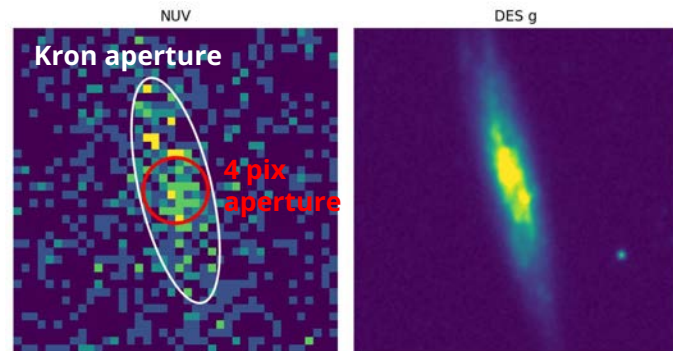
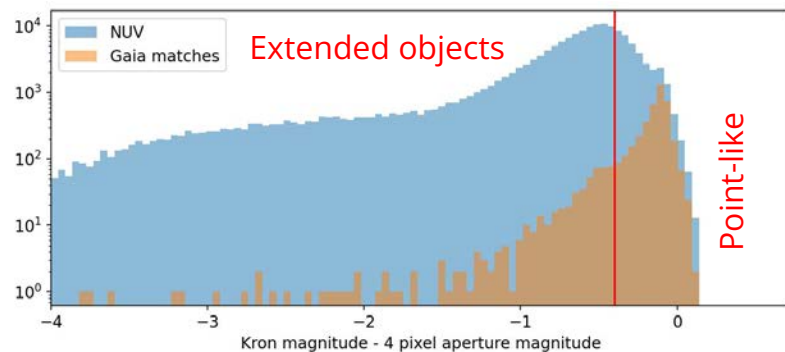
$$e_{\text{NUV}} < 0.2$$

No extendedness

$$\text{NUV.a} - \text{NUV.4} > -0.4$$

(difference between Kron and 4 pixel wide apertures)

We (try to) keep only well-defined point sources
not associated with artefacts



Filtering in optical images

Get Galex + Pan-STARRS / DES cutouts from [CDS hips2fits](#) service, 60" x 60"

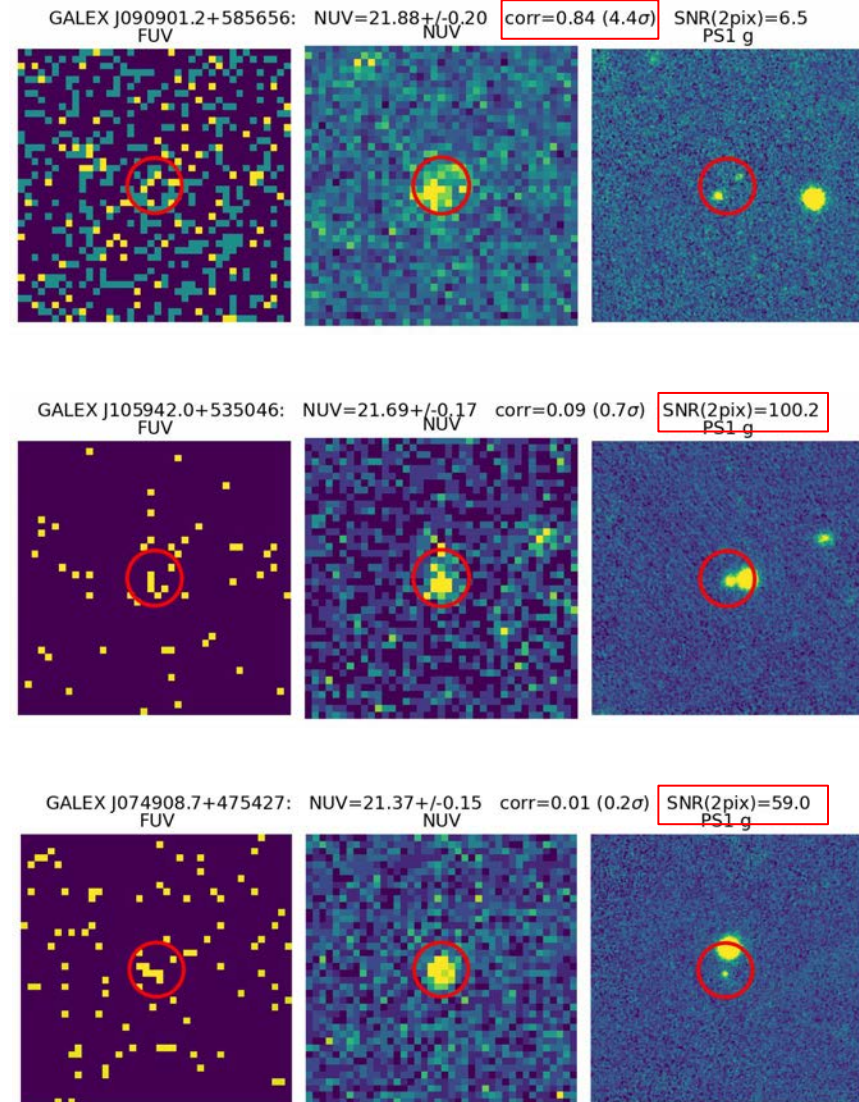
Degrade optical resolution to match NUV

Check optical / NUV correlation inside 6"
rejects blended objects

Check optical SNR inside 3"
rejects undetected optical objects

Visual vetting of candidates
rejects artifacts and residual blends

We also reject close optical pairs
that are blended in GALEX images



Distractors: proper motions of stars

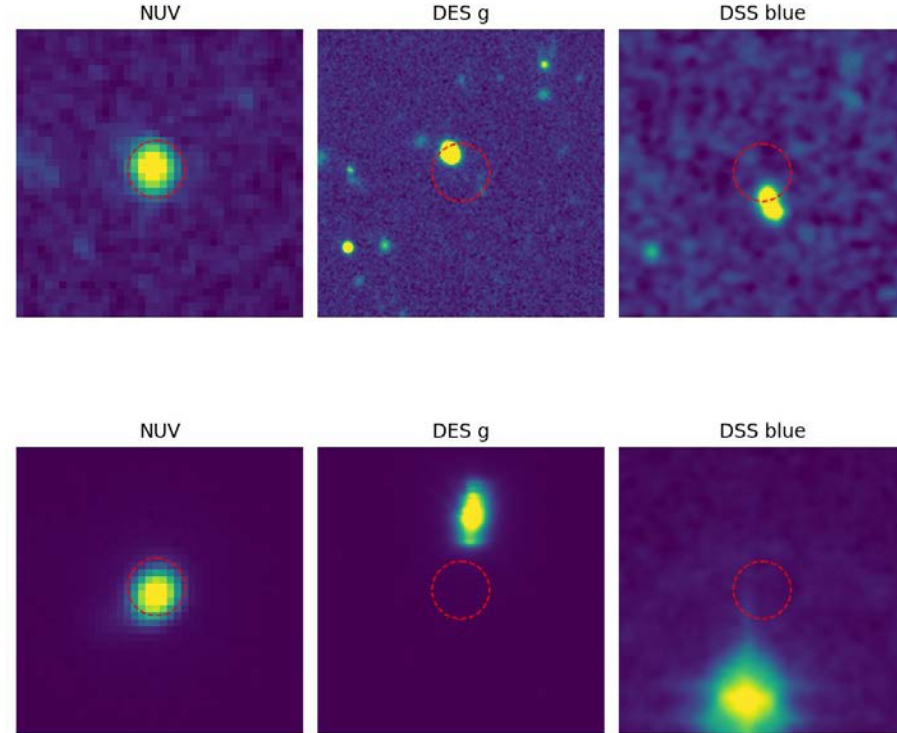
Different epochs of catalogues

- GALEX: 2003-2012
- Pan-STARRS: 2009-2014
- DES: 2013-2019
- DSS2: 1978-1998

Filtering based on Gaia DR3

Closer than 30"

$PM > 0.1''/\text{year}$



We reject fast moving objects
that displace optical detections w.r.t. GALEX objects

Visit-level analysis: flux stability between visits

gPhoton database (Million et al 2016)

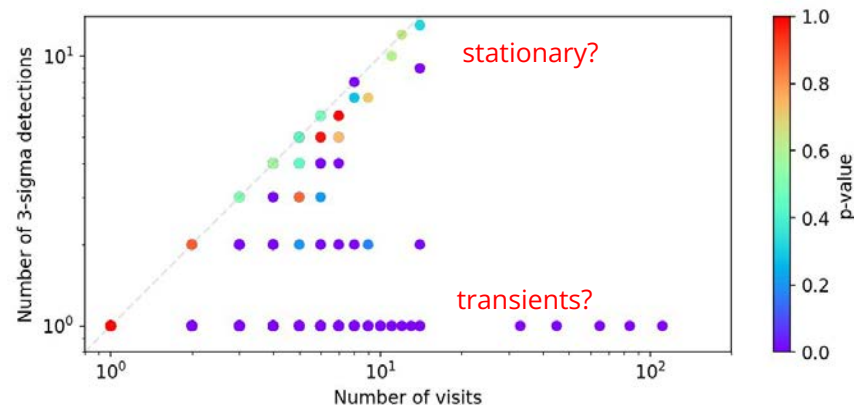
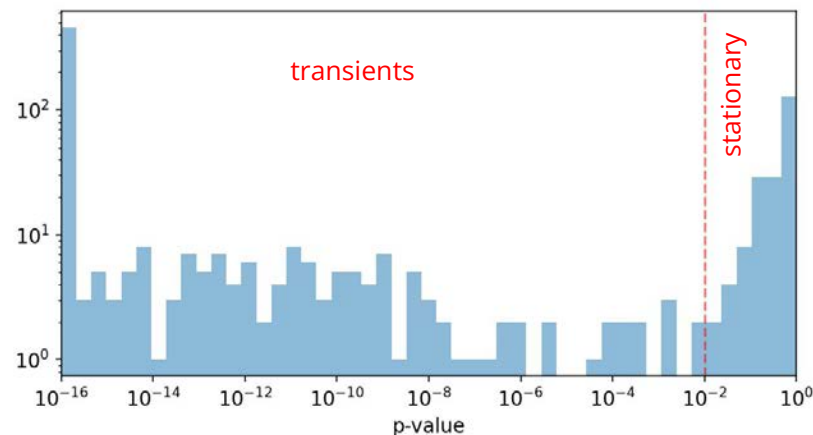
- Visits metadata
- Photon lists
 - per-visit cutouts
 - **per-visit aperture photometry**

$$\bar{f} = \frac{\sum_{i=1}^N f_i / \sigma_i^2}{\sum_{i=1}^N 1 / \sigma_i^2}, \quad \chi^2 = \sum_{i=1}^N \frac{(f_i - \bar{f})^2}{\sigma_i^2}$$

Chi-square test of flux stability

p-value < 0.01 – **transient** event

p-value > 0.01 – **stationary** source?



Visit-level analysis: flux stability between visits

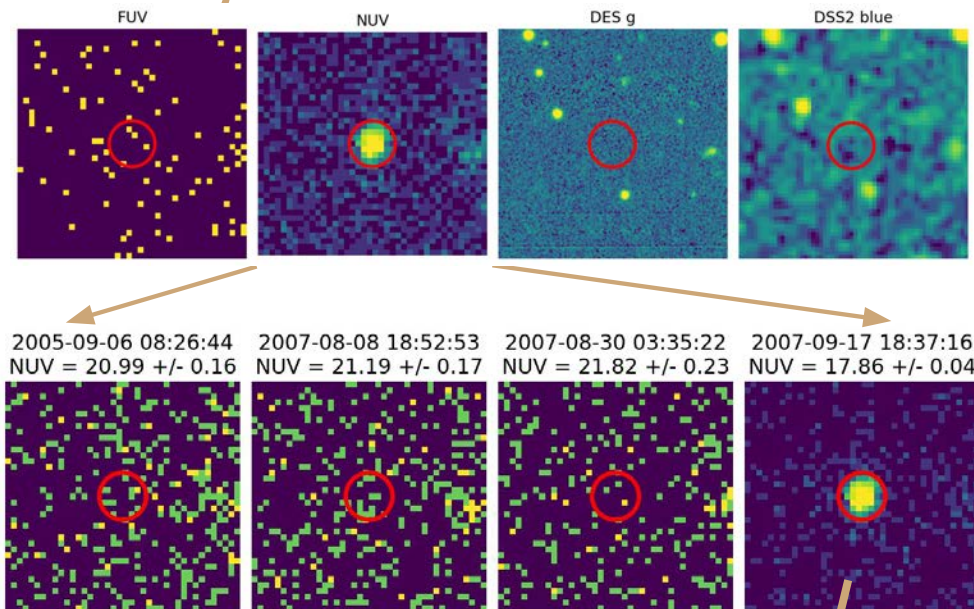
gPhoton database (Million et al 2016)

- Visits metadata
- Photon lists
 - per-visit cutouts
 - per-visit aperture photometry

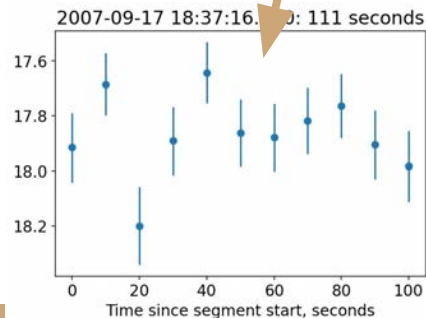
$$\bar{f} = \frac{\sum_{i=1}^N f_i / \sigma_i^2}{\sum_{i=1}^N 1 / \sigma_i^2}, \quad \chi^2 = \sum_{i=1}^N \frac{(f_i - \bar{f})^2}{\sigma_i^2}$$

Chi-square test of flux stability

p-value < 0.01 – transient event
p-value > 0.01 – stationary source?



SkyBoT check:
Asteroid 776
Berbericia
at 4.3 arcsec



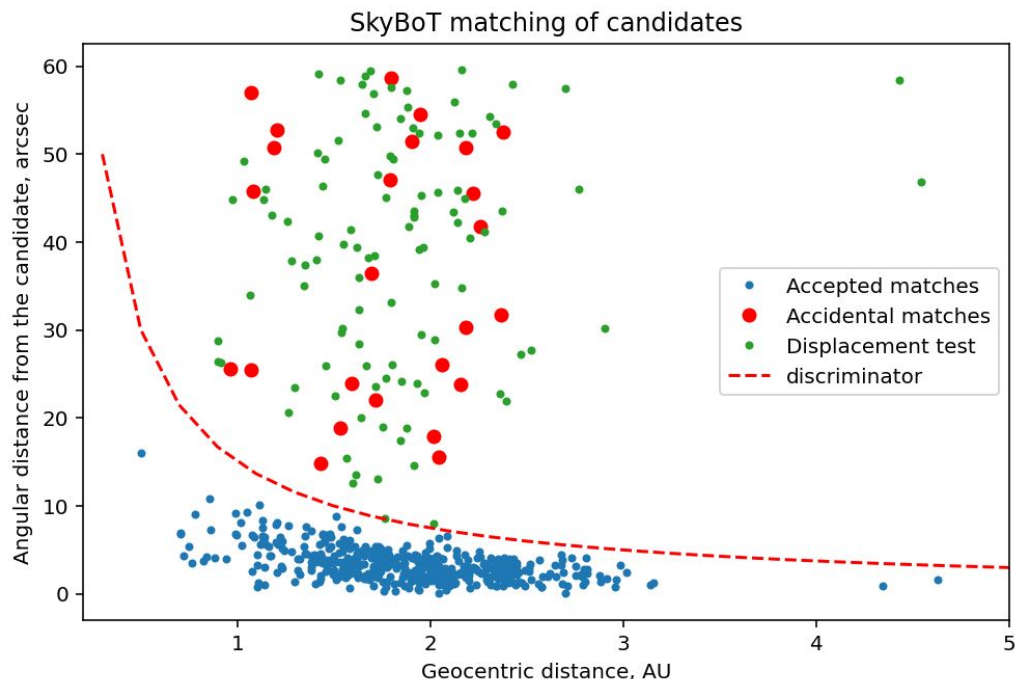
Distractors: Solar system objects

Sources with single / close epochs of significant detections

Per-visit matching with SkyBoT

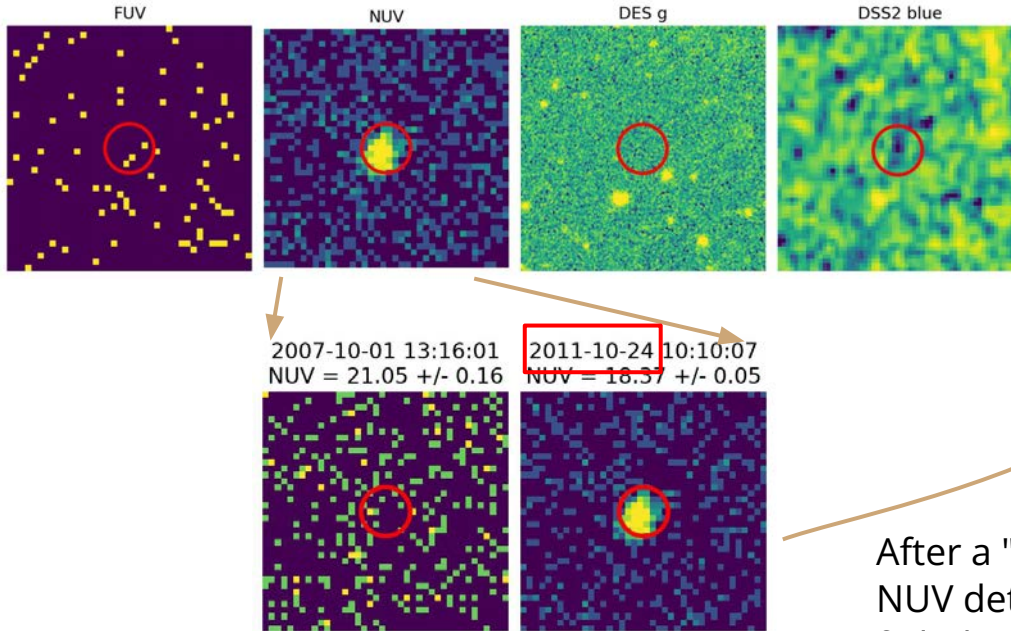
Check for accidental associations by displaced positions matching

$$\text{ang.dist.} < 15'' / D \text{ (AU)}$$



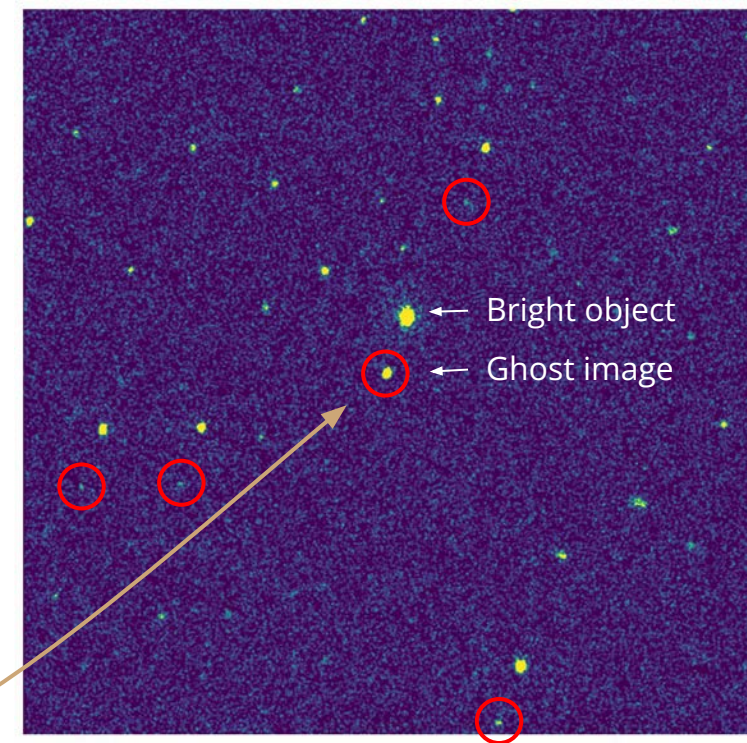
25 asteroids in DES, 448 in PanSTARRS

Distractors: image ghosting



Auto-correlation check on 800x800 pix cutouts

13 ghost sources in DES, 146 in PanSTARRS



After a "Coarse Sun Point" (CSP) anomaly on 2010 May 4, NUV detector started showing severe streaking due to failed capacitor. While the effect is mostly corrected by post-processing, some residual ghosting still may happen around brighter objects at 30-60 arcseconds distance.

One more image doubling event is found on Aug 14, 2004, caused by intra-visit pointing drift (or astrometry failure?)

Final candidates

GALEX + DES DR2 = 4786 sq.deg

449,534,091 matches within 30"

13,447,176 matches within 3"

3,299,100 initial "un-matches"

149,803 after catalogue quality cuts

12,938 point-like with S/N>5

6,832 after Gaia filtering

47 after image-level checking

38 after visual vetting

25 after ghost rejection

25 asteroids

0 other transients

0 stationary objects

GALEX + PanSTARRS DR1 = 25497 sq.deg

519,789,167 matches within 30"

48,740,086 matches within 3"

22,679,667 initial "un-matches"

585,423 after catalogue quality cuts

34,567 point-like with S/N>5

27,206 after Gaia filtering

1,086 after image-level checking

789 after visual vetting

643 after ghost rejection

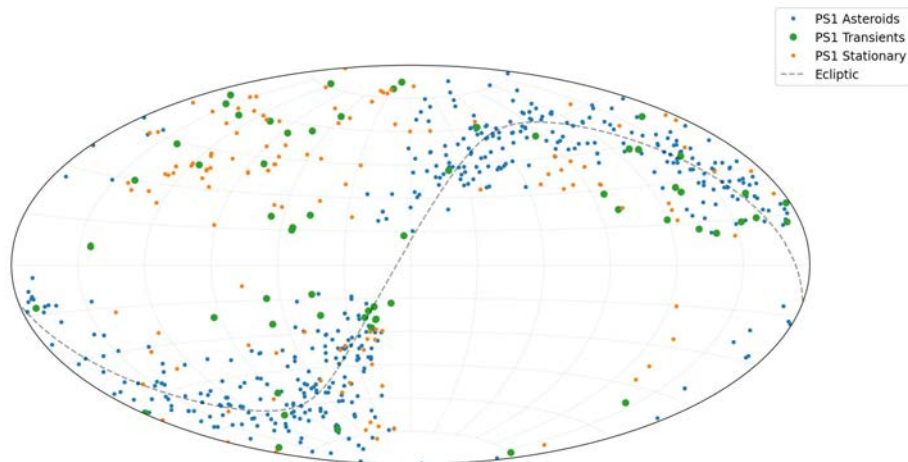
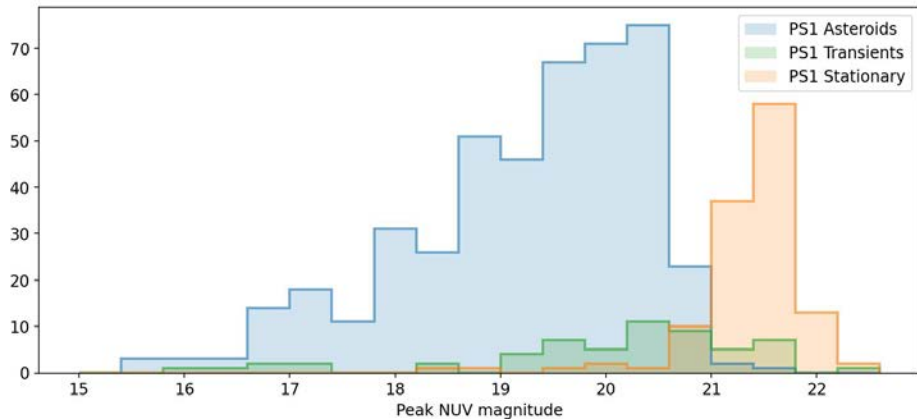
448 asteroids

59 other transients

128 stationary objects

8 single-epoch observations

Final candidates



GALEX + PanSTARRS DR1 = **25497** sq.deg

519,789,167 matches within 30"

48,740,086 matches within 3"

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643 after ghost rejection

448 asteroids

59 other transients

128 stationary objects

8 single-epoch observations

Final candidates: Legacy Survey DR11

DECaLS + BASS + MzLS + further DECam imaging

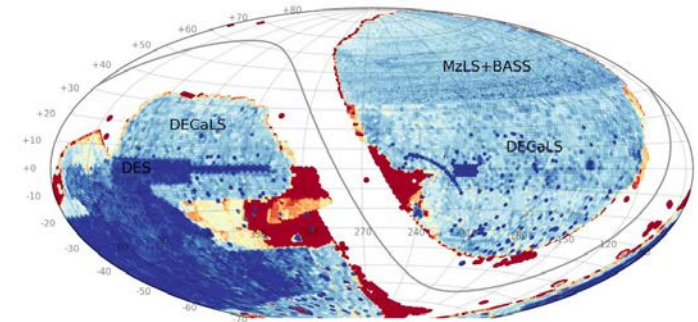
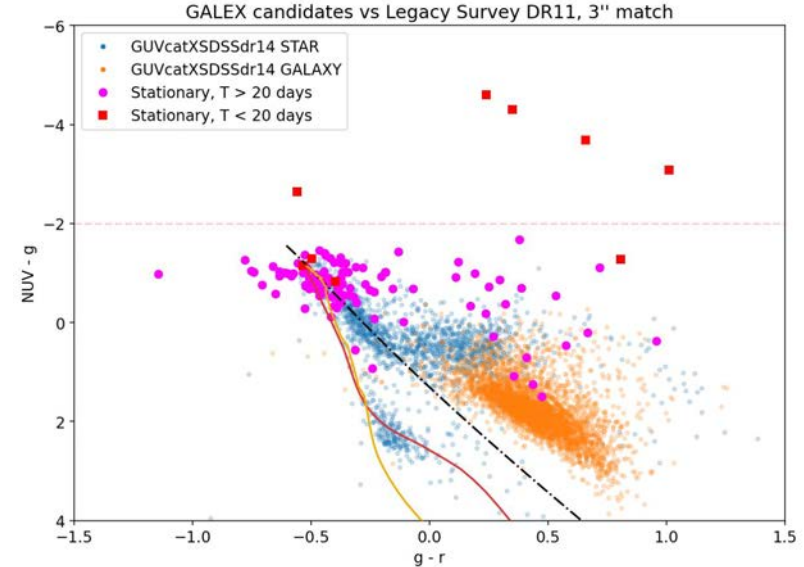
~30000 sq.deg in g band

Available in NOIRLab Astro DataLab

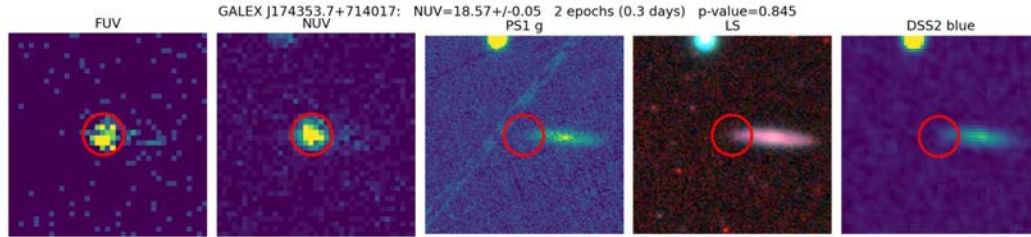
Positional 3" cross-match with `ls_dr11.tractor` table

Group	Total	Covered	Matched	Unmatched
Stationary	128	122	119	3
Transient	59	54	40	14
Single-epoch	8	7	7	0
Total	195	183	166	17

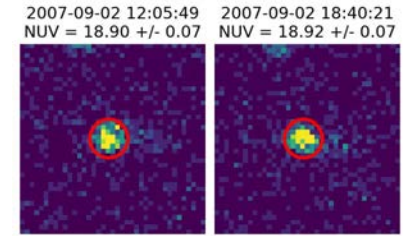
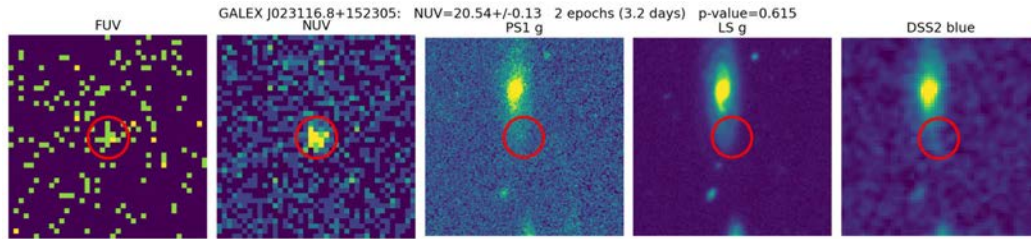
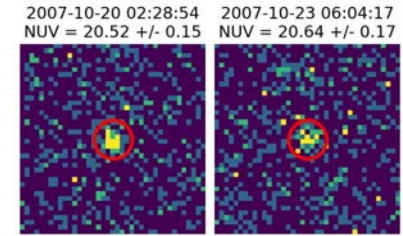
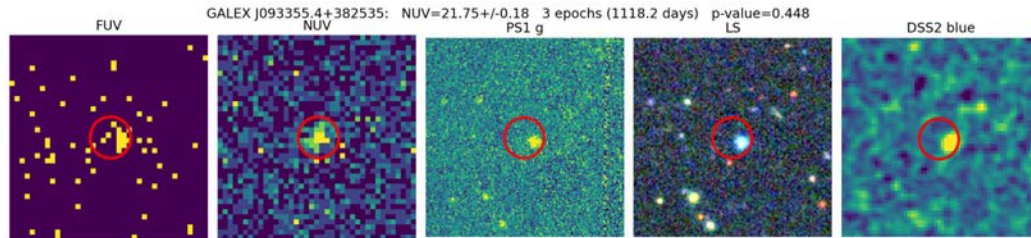
Stationary candidates matched with Legacy Survey DR11 and having $\text{NUV} - g < -2$ all have short ($T < 20$ days) baselines, consistent with actually being **transients**.



Final candidates: unmatched stationary objects

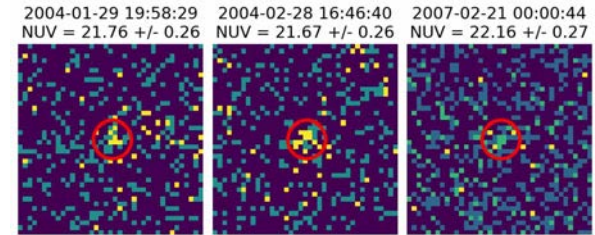


Short baselines
Nearby galaxies
Supernovae?..

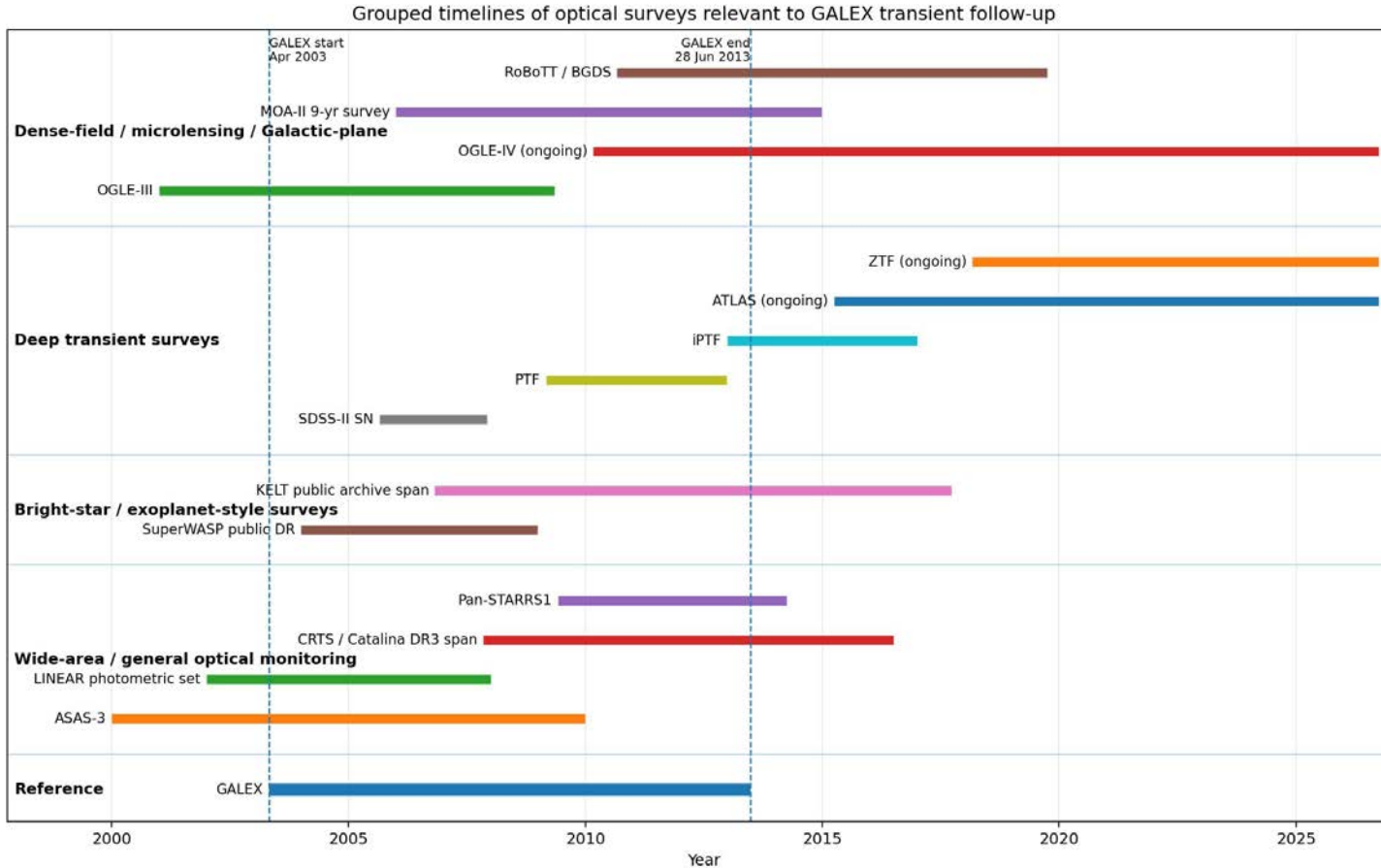


Low S/N
Galaxy?

Needs
additional
analysis



Final candidates: transients



What may we dig for GALEX transients in other experiments' archives?..

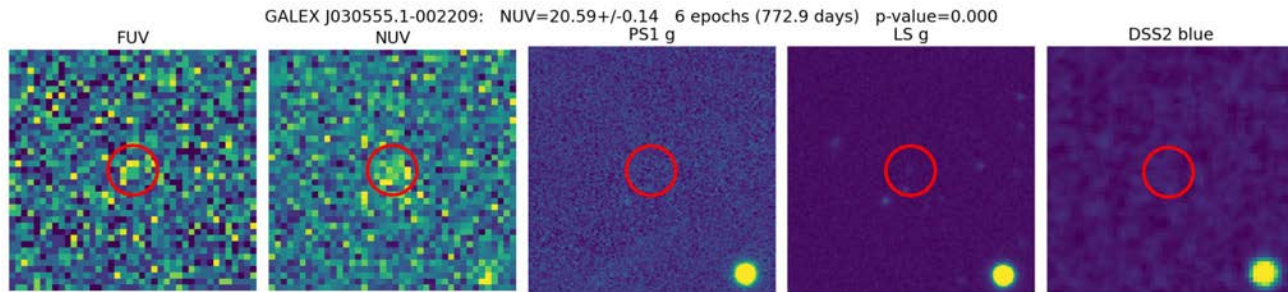
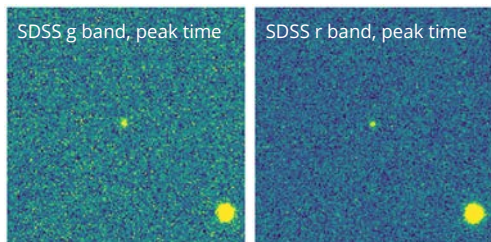
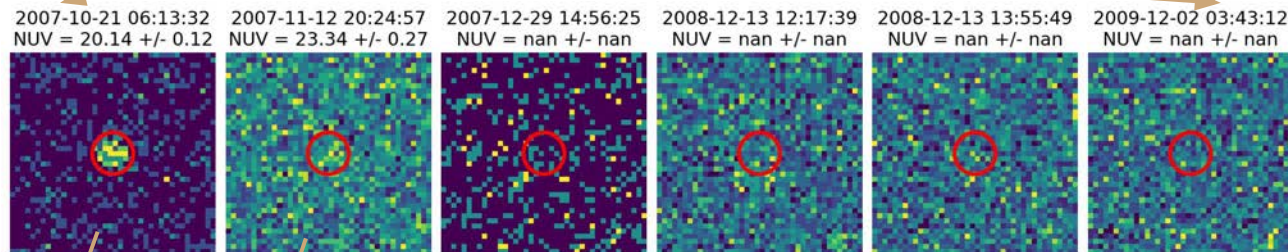
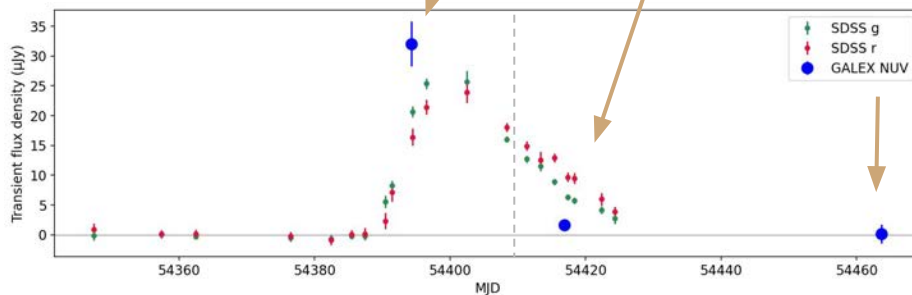
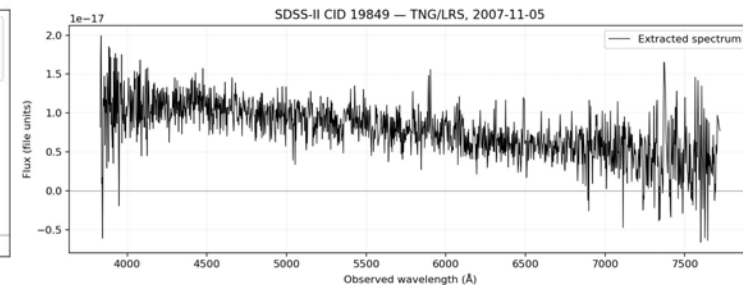
ZTF alerts:
15 matches

TNS transients:
11 matches

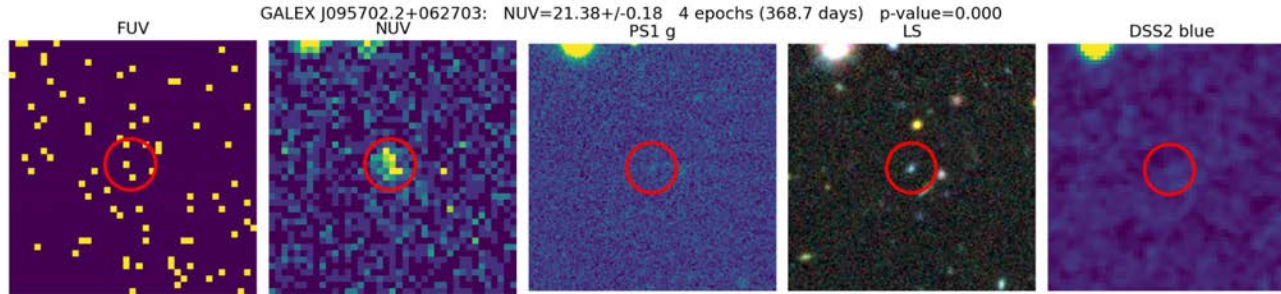
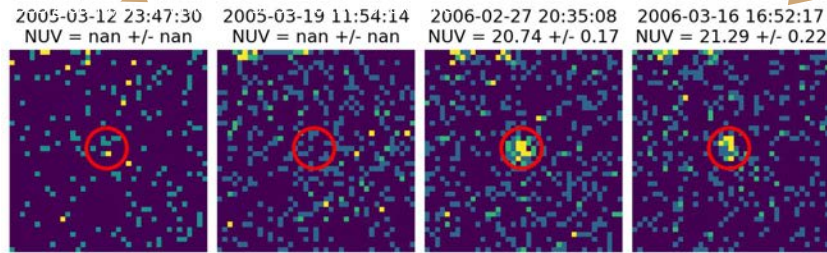
SDSS-II SNe:
1 unclassified

Final candidates: transients

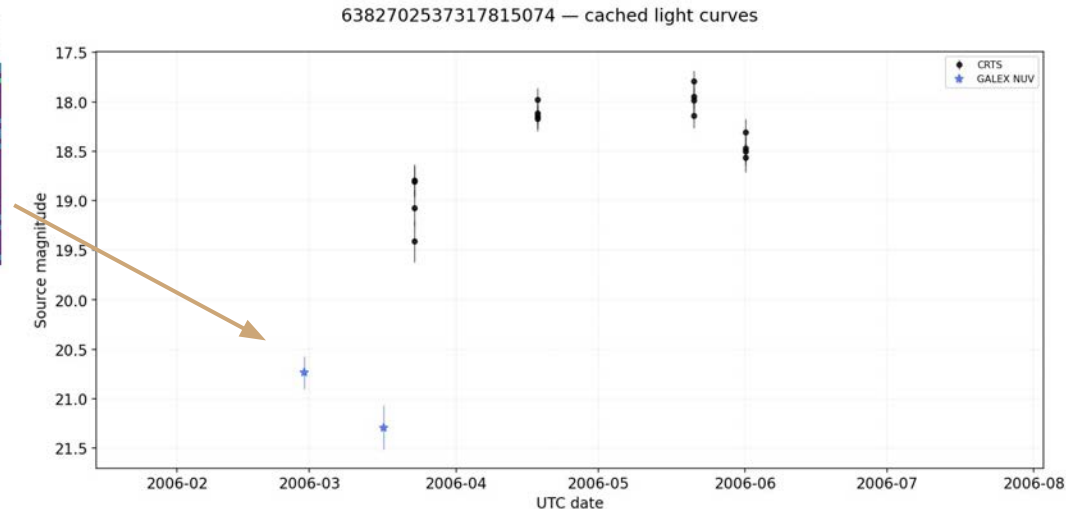
SDSS Stripe 82
SDSS-II CID 19849
TNG spectrum
no type classification



Final candidates: transients

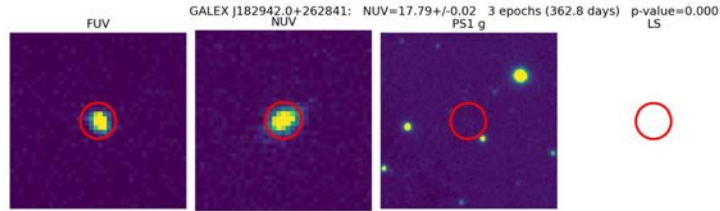
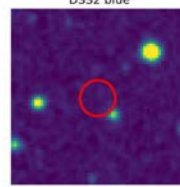
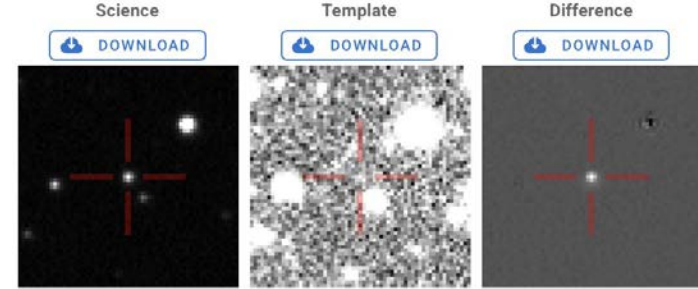
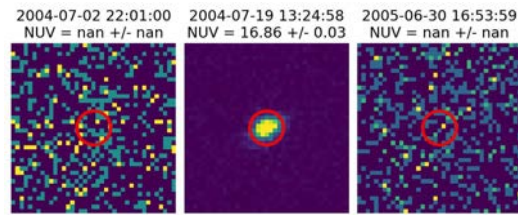
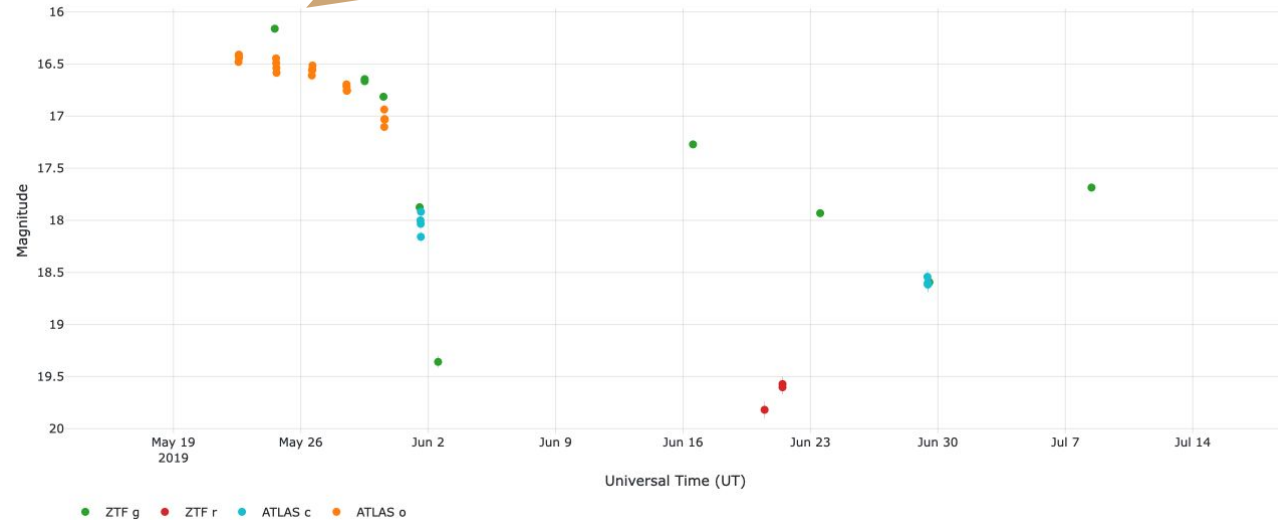


Single ~100 days activity episode
(not reported anywhere)
 $g=23$ / $g-r=0.45$ mag source in LS11



Final candidates: transients

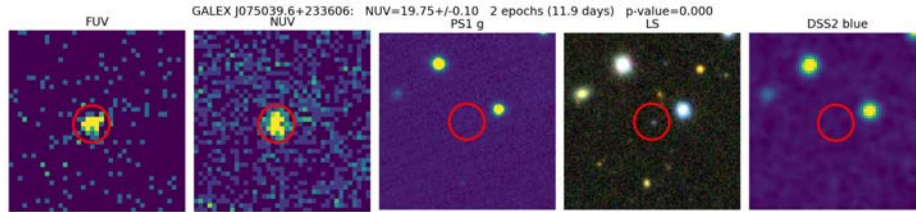
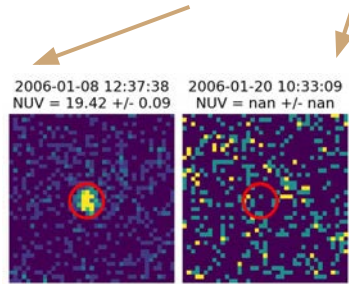
AT 2019fun / ZTF19aaviqnb / ATLAS19lgv



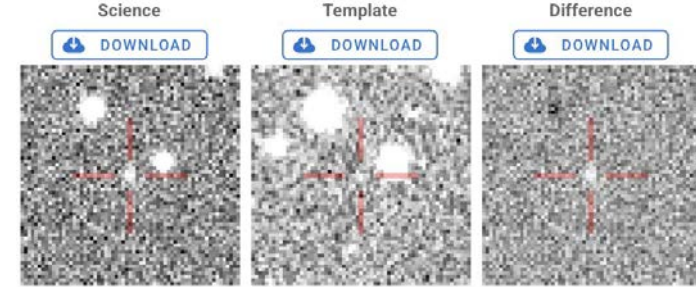
Repeated activity
2004 (UV) + 2019 (O)
dwarf nova?

Final candidates: transients

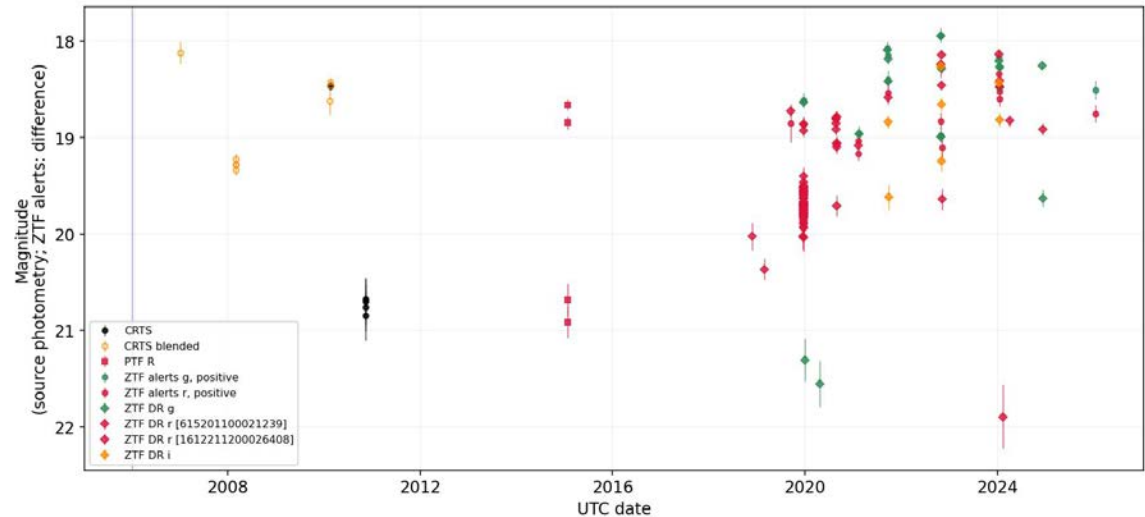
AT 2020zrb / ZTF17aacpcac / Gaia20fgg



Recurrent outbursts
dwarf nova?



6377882322367153744 — cached optical detections



Final candidates: interesting objects

Objid	GALEX name	Peak NUV	$N_{3\sigma}/N_{\text{visit}}$	$\Delta t_{3\sigma}$ (d)	p	Associated names	UV group	Interpretation
6377882322367153744	J075039.6+233606	19.42	1/2	0.00130	4.3×10^{-30}	AT 2020zrb ZTF17aacpcac	Transient	Recurrent outbursts; accreting binary?
6374363919518008477	J145011.1+655942	20.91	1/1	0.00212	—	RX J1450.1+6559 AT 2021yzx ZTF21acbqaqa	Single	Known CV; candidate polar
6379747050064445723	J195847.0–193811	16.04	1/9	0.00125	$< 10^{-300}$	AT 2025pgi ZTF25aayfzaz	Transient	Episodic variable; type unknown
6375173070955483987	J182942.0+262841	16.86	1/3	0.00139	$< 10^{-300}$	AT 2019fun ZTF19aaviqnb	Transient	Episodic variable; accreting binary?
6377284140797004579	J030555.1–002209	20.14	2/6	22.61	1.2×10^{-15}	SDSS-II CID 19849	Transient	Possible SN; subtype uncertain
6382702537317815074	J095702.2+062703	20.74	2/4	16.85	5.9×10^{-7}	—	Transient	SN favoured; nuclear flare possible
6380274800613393301	J011916.7+060939	19.79	2/2	1.58	0.819	—	Stationary	Possible extended transient; short UV baseline
6376580461945162439	J210937.3+022102	19.90	2/2	0.069	0.647	AT 2024nrt ZTF24aauifykp	Stationary	Variable candidate; UV persistence unresolved
6382209963624762443	J113347.9–130547	21.37	2/2	419.23	0.921	1eRASS J113347.4–130551	Stationary	AGN candidate; photometric redshift
6374399050200913682	J120906.0+581304	21.42	1/8	0.00127	9.9×10^{-5}	SDSS J120906.02+581303.7	Transient	Known quasar; $z = 1.118$
6371338033451502848	J180338.7+394720	21.05	3/3	1821.98	0.650	—	Stationary	Long-lived UV source; blue optical counterpart
6375560189242771390	J172939.2+015702	19.90	1/1	0.00145	—	AT 2025wud ZTF25abihbtg	Single	Optical variable/transient; type unknown

Conclusions

We investigated an approach for detection of unique or transient objects by cross-matching multi-wavelength catalogues and looking for non-matched entries, using GALEX and largest uniform optical sky surveys – Pan-STARRS DR1 and DES DR2

We were able to implement it using publicly available online tools and services.

We detected a number of (known) asteroids and interesting transients. We did not (yet) detect any reliable stationary candidate that is consistent with absence of optical counterpart or unusual UV-optical color

Thank you!