SNAD: anomaly detection for large scale time-domain astronomy

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on the behalf of the SNAD team
+ all our side collaborators

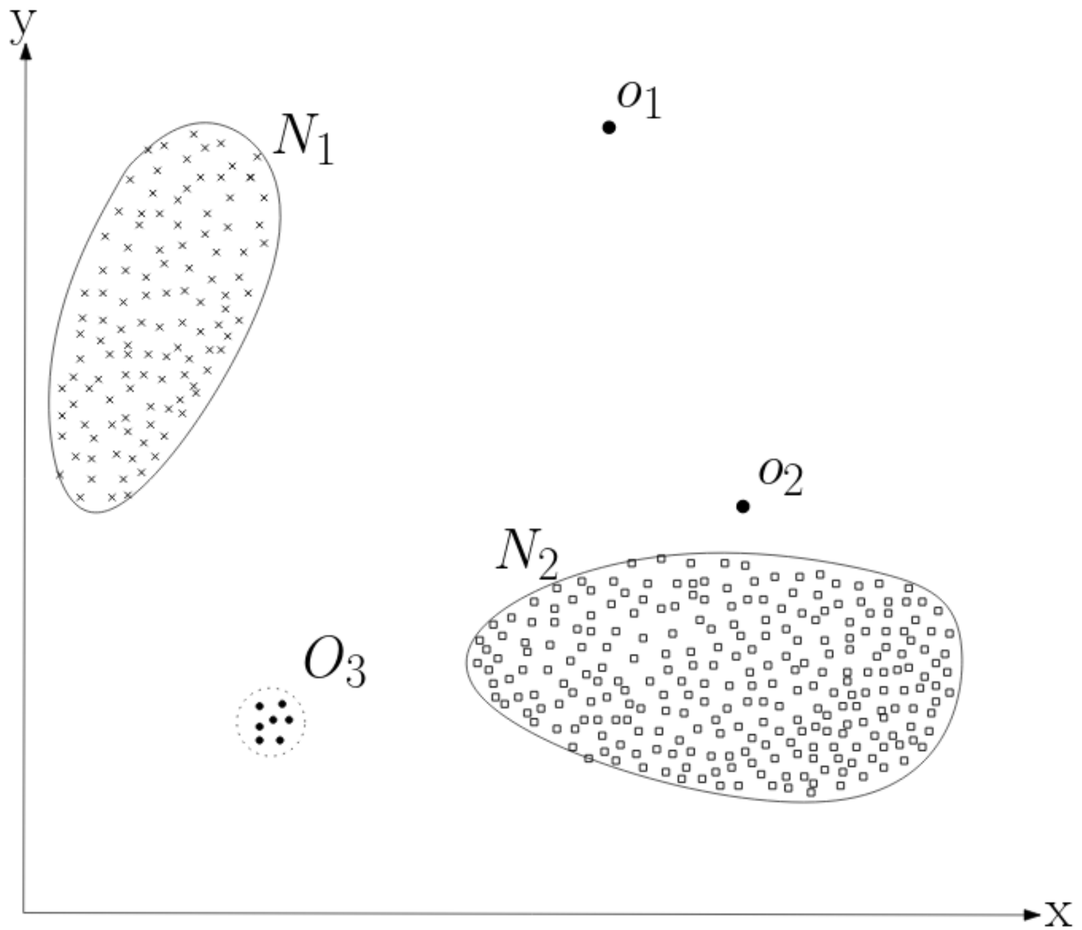
Paris, 2022.06.21

Anomaly detection

We look for anomalies

- Def. *Outlier* is an object located in a sparse region of the feature space

- Def. *Anomaly* is an astrophysical source having unusual properties for its class or a representative of some rare class



Chandola+ 2009

Discovery

ML only produces recommendations

Light curves

↓

Preprocessing

→

Machine learning
Outlier detector

→

Potentially interesting anomalies:

- Candidate 1
- Candidate 2
- Candidate 3
- …
- …
- ...
- ...

↓

Not interesting

Interesting

Very interesting!

←

Get more data and Publication

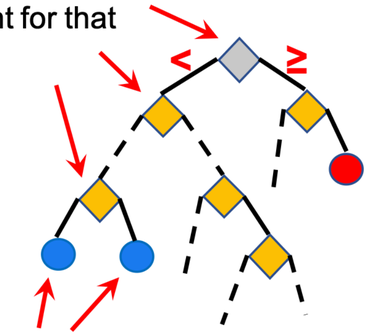
←

metadata
images
simulations
catalogs

Outlier detection: Isolation Forest

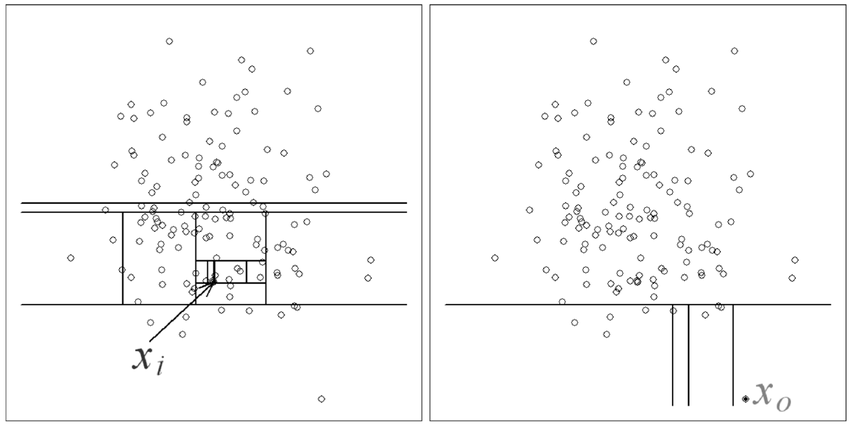
iTree

Select a random feature at each node, and a random split point for that feature



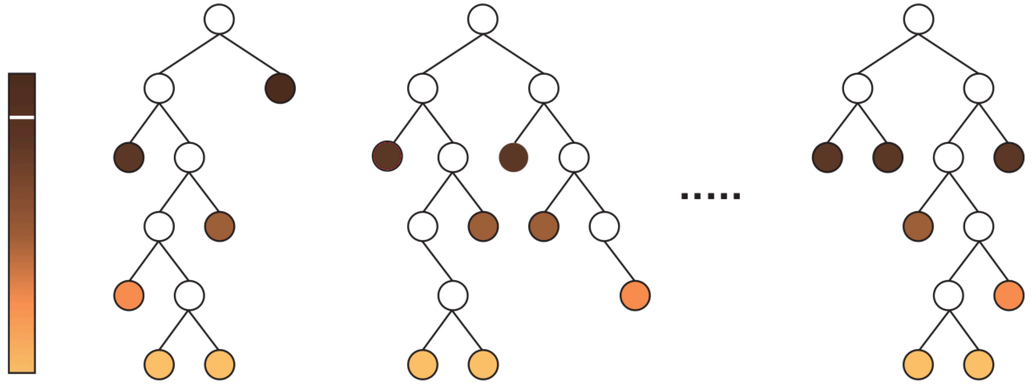
Shallower leaf nodes have higher anomaly scores, whereas, deeper leaf nodes have lower anomaly scores.

arXiv:1708.0944

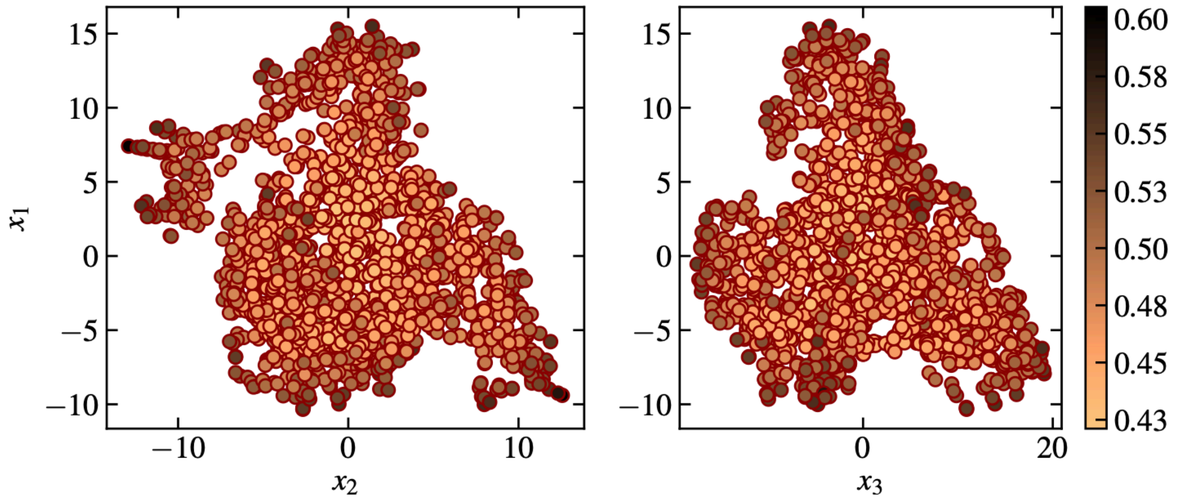


(a) Isolating x_i (b) Isolating x_o

Liu+ 2008, Liu+ 2012



Darker is more anomalous

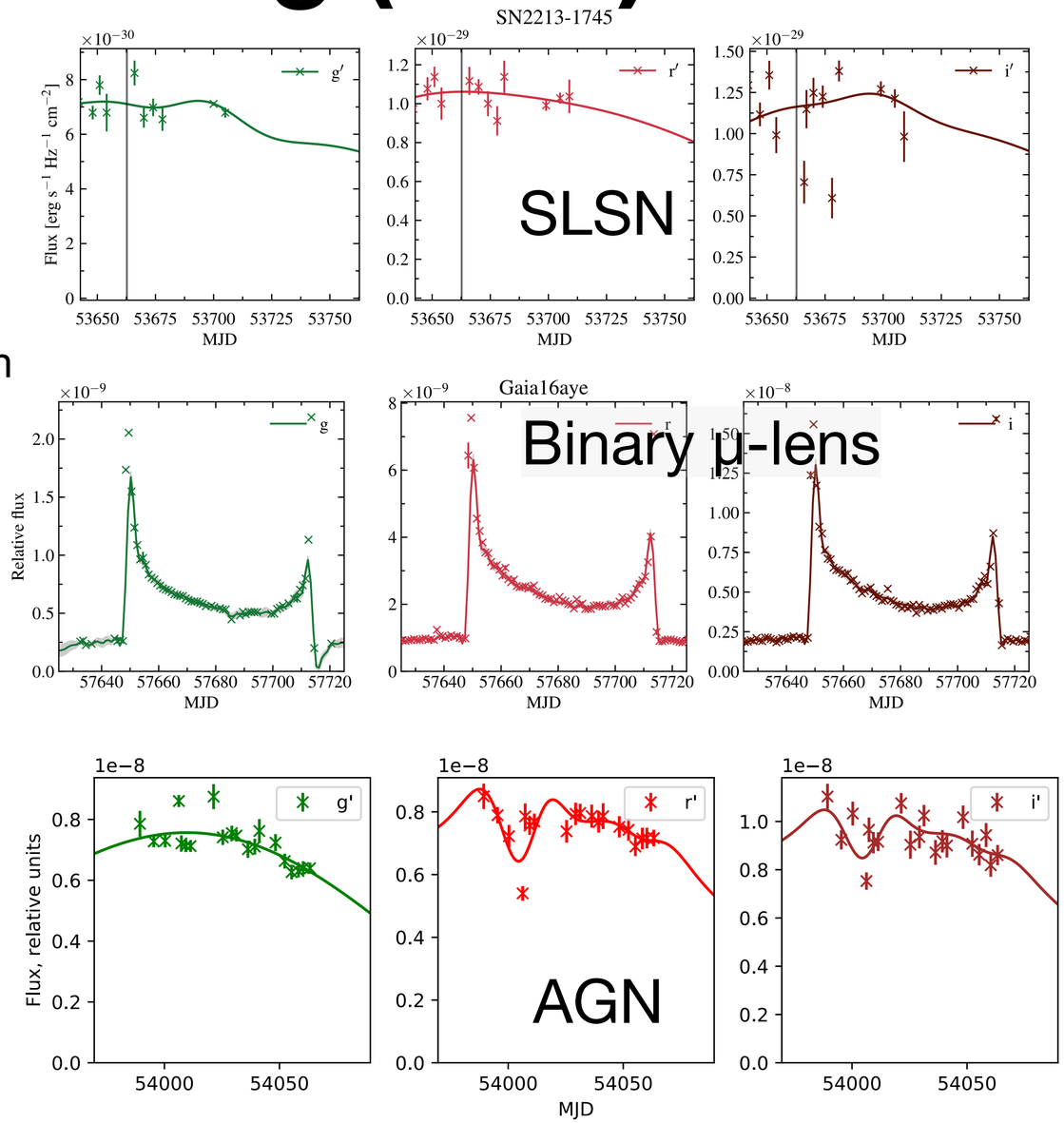


arXiv:1905.11516

Case: Open Supernova Catalog (OSC)

arXiv:1905.11516

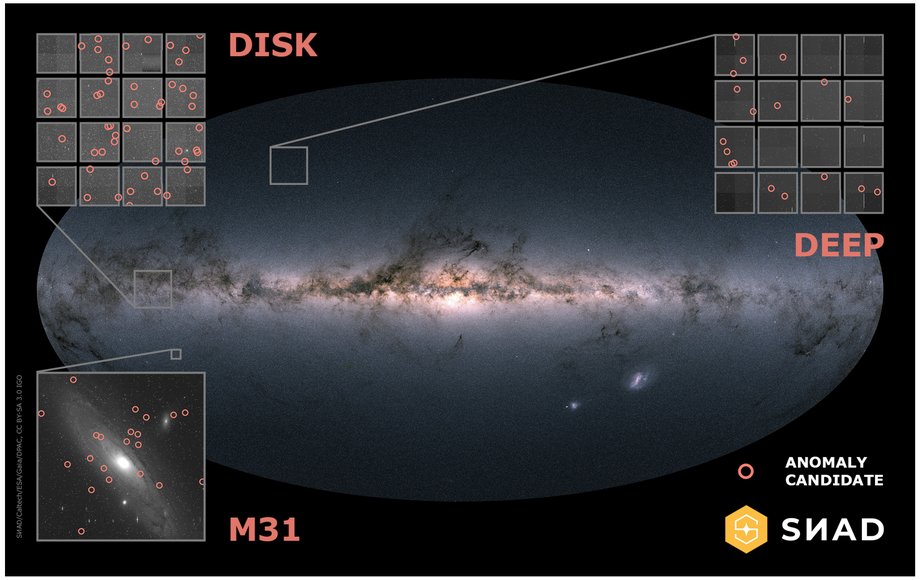
- 1999 SNe in *gri*, *g'r'i'* & *BRI* taken from the OSC (Guillochon+ 2017)
- Multivariate Gaussian process approximation (Semenikhin+ in prep.) & t-SNE
- 30/100 anomaly candidates
  - Two known SLSNe
  - Several known peculiar SNe
  - Several known cases of misclassification, including binary μ-lens
  - **16 previously unknown cases of misclassification** (10 stars and 6 AGNs), including SN 2006kg suggested as a "template" SN II (Okumara+ 2014)

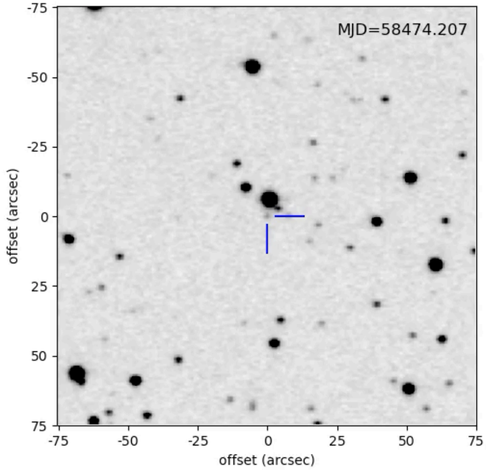


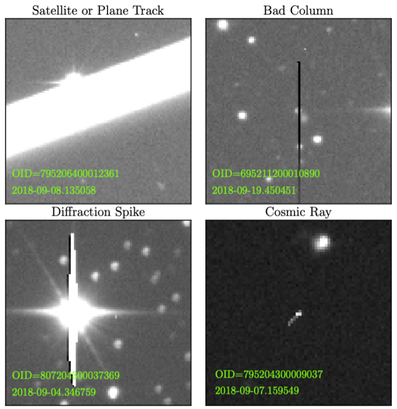
Case: Zwicky Transient Facility DR3

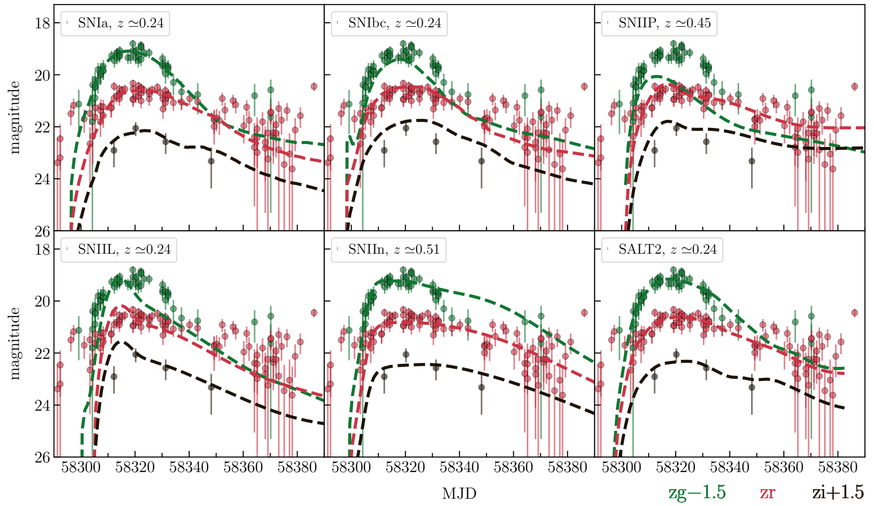
arXiv:2012.01419

- Three fields of ZTF DR3
- **~2×10^6 objects total**
- Four outlier detection algorithms
- 89/227 anomaly candidates
  - **Six (5/6 are new!) SN Ia candidates**
  - RS CVn (confirmed by our spectra)
  - Mira binary candidate
- 188/277 bogus light curves
  - Double star defocusing
  - Bright Mira "echos"
  - Asteroid overlap
  - Bad columns, satellites, spikes, ghosts, etc





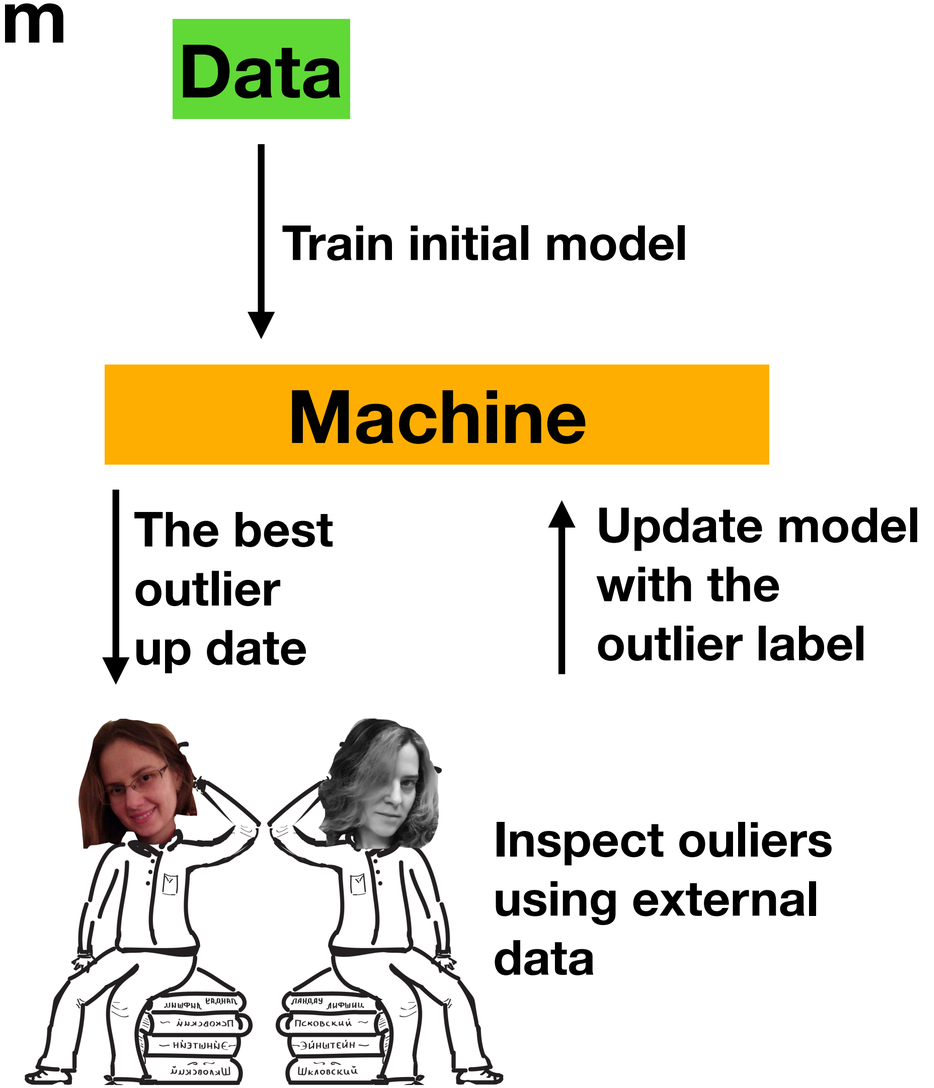




Applying expert bias to anomaly detection

From outlier to anomaly detection algorithm

- How to discriminate annoying non-anomalies sources and bogus light curves?
  - We can ask an expert interactively about each new outlier
  - If it is not an anomaly, set lower probability to objects like this
  - Retrain, ask the expert again
- We can do the opposite: highlight interesting class of objects for classification of rare objects. Listen Emille Ishida's talk about this

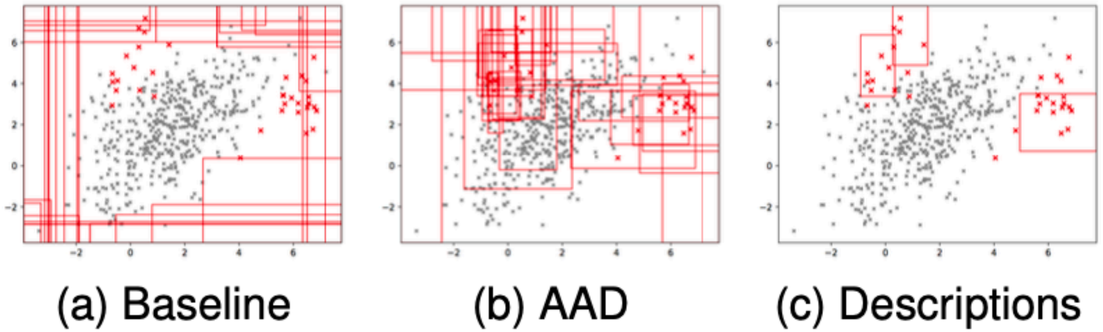


Active anomaly detection (AAD)

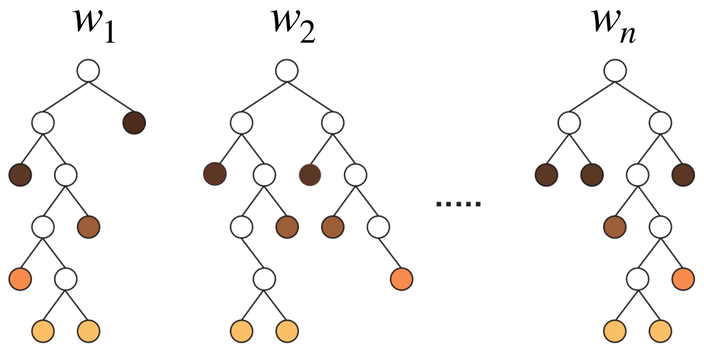
Implementation of the machine—expert loop, Das+2018

Algorithm:

1. Initialize isolation forest, set equal w_i to each iTree
2. Ask the forest for the outlier with the largest score
3. Ask an expert to classify the object as normal or anomaly
4. If anomaly, go to step 2 and ask next outlier
5. If normal, update $\{w_i\}$ to give lower influence to wrong detectors, go to step 2



arXiv:1809.06477

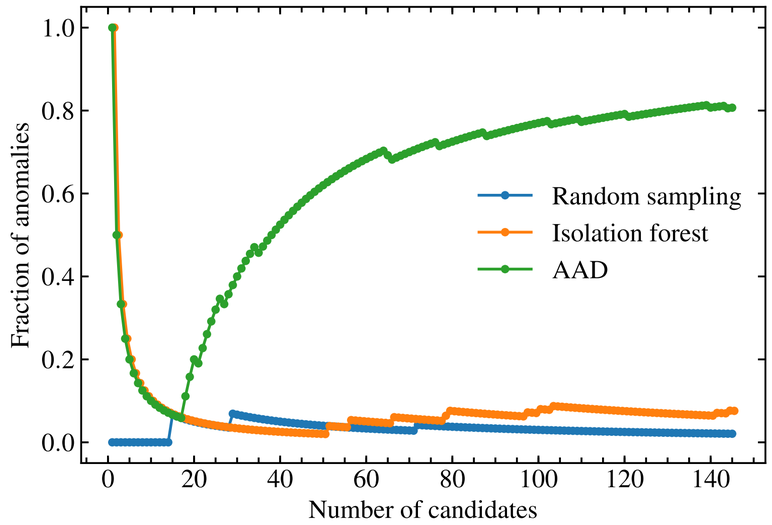


There are other algorithms to solve this problem, we are developing a (better) alternative (Korolev+, in prep)

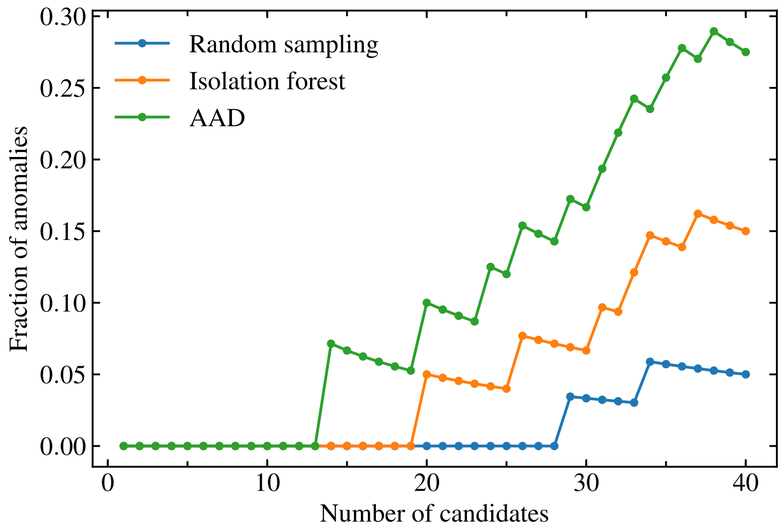
Case: PLAsTiCC & OSC

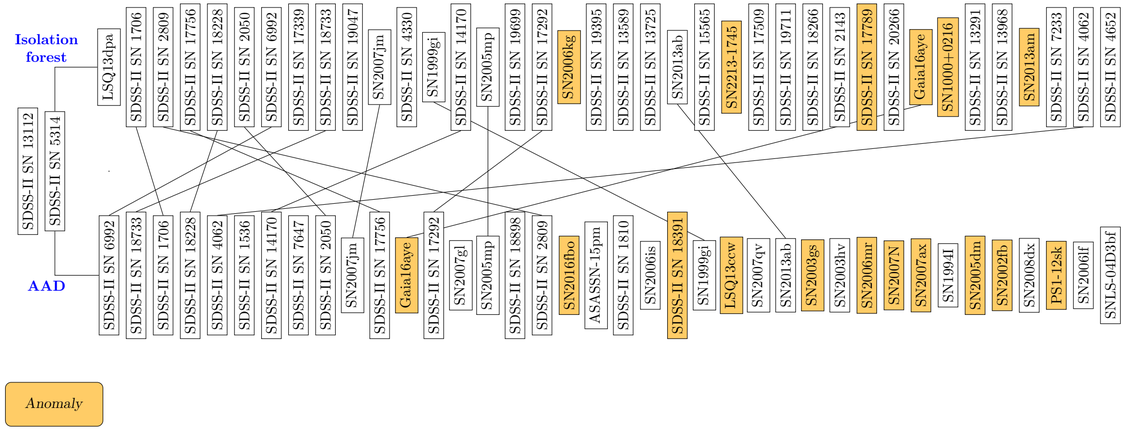
arXiv:1909.13260

PLAsTiCC (LSST sims)



OSC



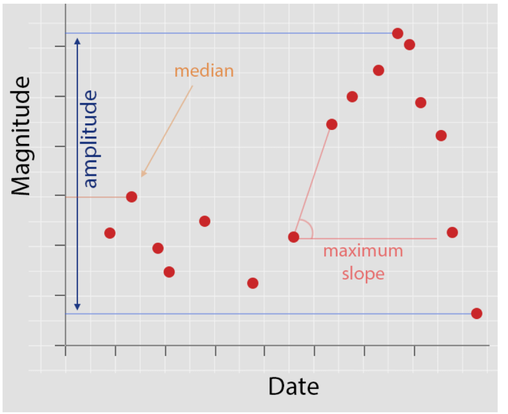


Lessons learnt:

- AAD works
- Anomaly definition (expert bias) matters
- Real data is much harder!

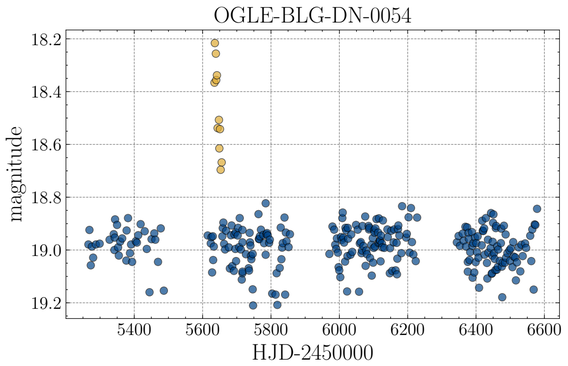
By-product: `light-curve` feature extractor

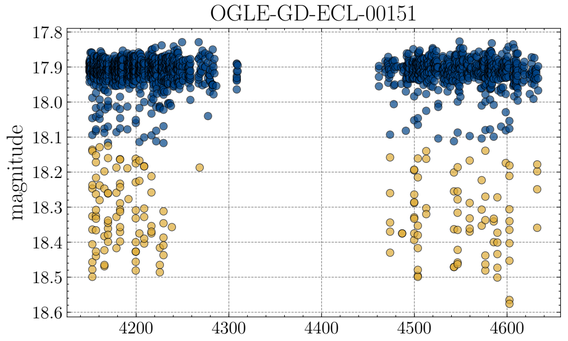
https://github.com/light-curve



Anastasia Lavrukhina

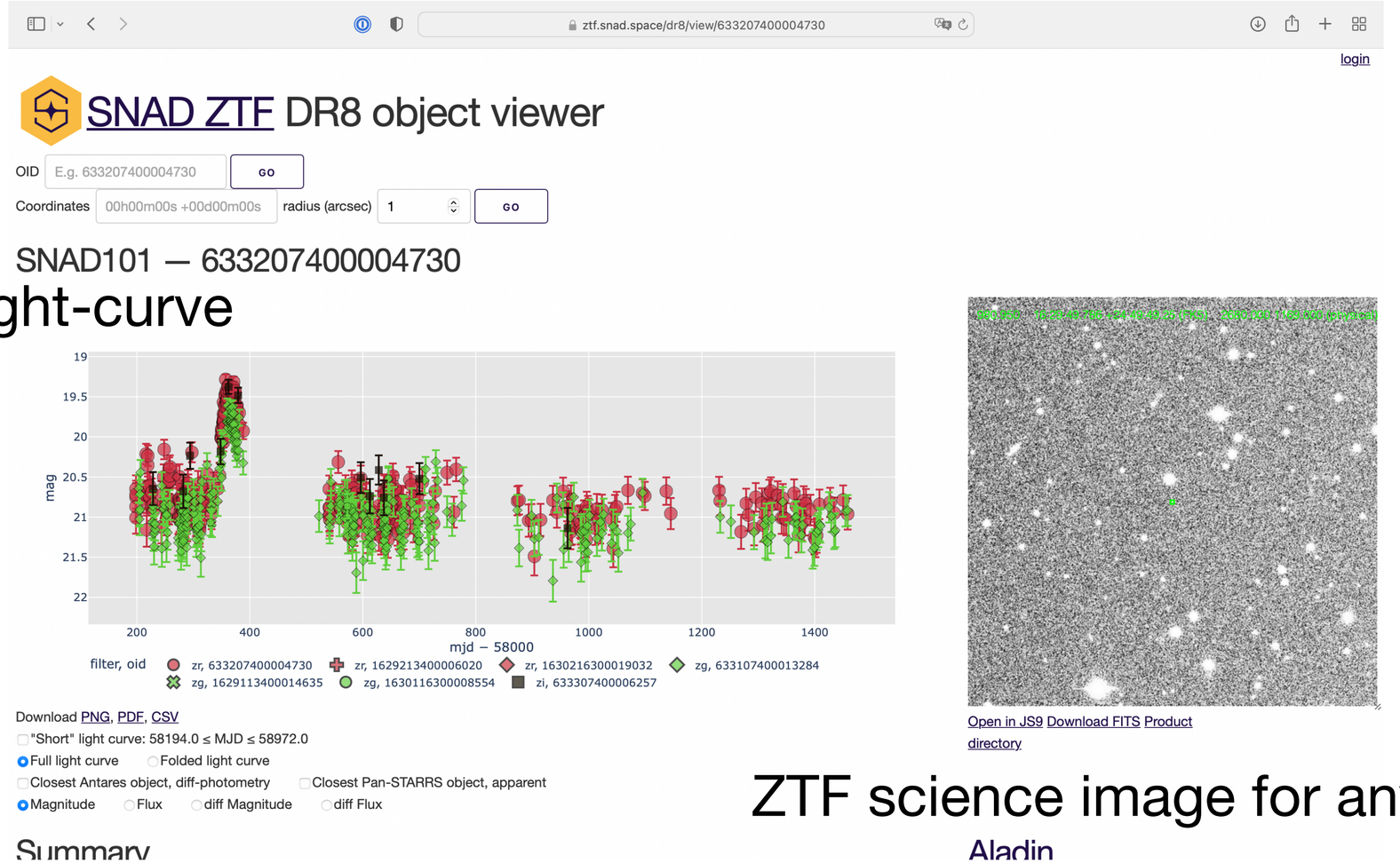
- **Performant** Rust/Python code: processing of ~10^6 light-curves, Nobs ≳ 100, takes few CPU hours
- Rich feature set
  - Magnitude statistics: mean-, median-, momentum- quartile-based
  - Shape-based: Stetson (1996) K, η^e (Kim+ 2014)
  - "Fast" Lomb–Scargle periodogram peaks and other derivatives
  - Parametric fits: linear, SN-like functions (Bazin+ 2009, Villar+ 2019)
  - **New Otsu-split extractor**: powerful features to classify recurrent outbursts, eclipsing binaries, etc (Lavrukhina & Malanchev in prep.)
- Hundreds of unit tests, packages for Linux and Intel Macs
- Serves **three ZTF/LSST brokers**: Ampel, Antares, Fink
- `python3 -m pip install light-curve`





By-product: SNAD ZTF viewer

https://ztf.snad.space

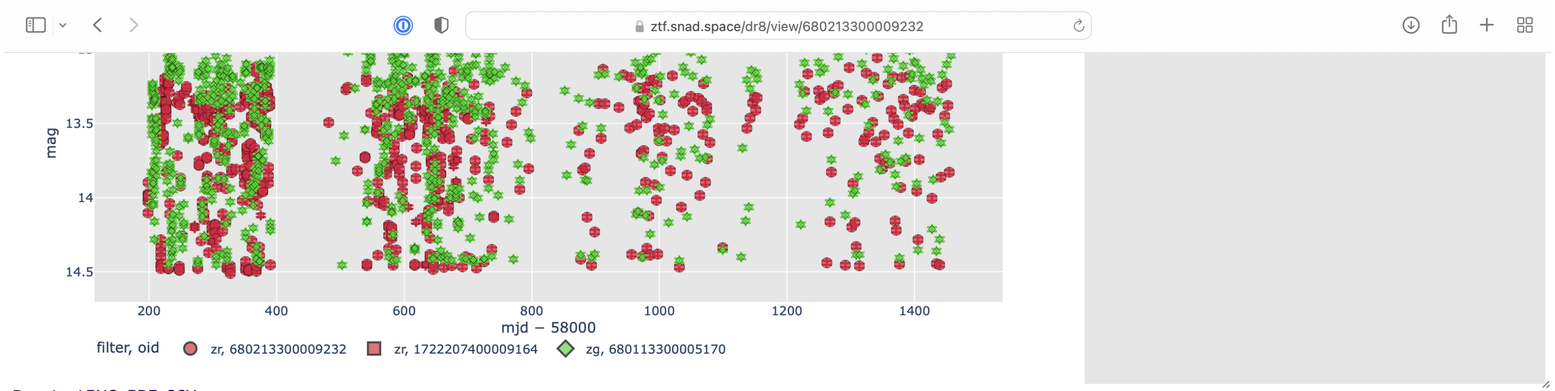


Self-matched ZTF light-curve

ZTF science image for any detection

By-product: SNAD ZTF viewer

https://ztf.snad.space



Download PNG, PDF, CSV

"Short" light curve: 58194.0 ≤ MJD ≤ 58972.0

Full light curve Folded light curve

Closest Antares object, diff-photometry Closest Pan-STARRS object, apparent

Magnitude Flux diff Magnitude diff Flux

Summary

Name: ZTF18aabpzic (0.266″ Alerce), ZTF18aabpzic (0.353″ Fink), J254.4575+35.3423 (0.124″ ATLAS), 1338822021487330304 (0.115″ Gaia EDR3 Distances), HZ Her (0.711″ GCVS), PSO J254.4575+35.3423 (0.109″ Pan-STARRS DR2 Stacked), V* HZ Her (0.081″ Simbad), 15037 (0.720″ VSX), ZTFJ165749.81+352032.4 (0.124″ ZTF Periodic)

Type: LMXB (0.353″ Fink), IRR (0.124″ ATLAS), XPR+E (0.711″ GCVS), LowMassXBin (0.081″ Simbad), LMXB:/XPR+E (0.720″ VSX), EW (0.124″ ZTF Periodic)

Period, days: 1.700 (periodogram S/N=78.620), 1.700 (0.124″ ATLAS), 1.700 (0.711″ GCVS), 1.700 (0.081″ Simbad), 34.875 (0.720″ VSX), 3.400 (0.124″ ZTF Periodic)

Distance: 7.00 kpc (0.115″ Gaia EDR3 Distances), 6.60 kpc (0.081″ Simbad)

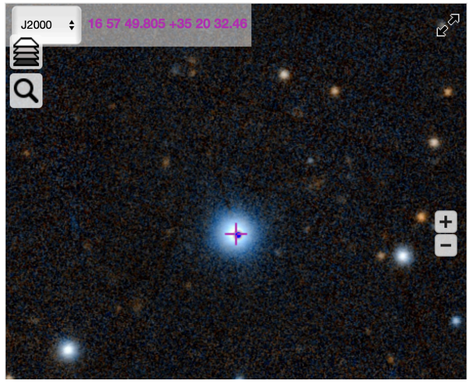
Average mag (including neighbourhood): zg 13.55, zr 13.68, (zg–zr) -0.13

Extinction: SFD E(B-V) = 0.01, Bayestar & Gaia EDR distance Ag = 0.07 Ar = 0.05 Ai = 0.03

Search in brokers: ALeRCE, Antares, Fink, MARS

Coordinates: Eq 254.45752 35.34235, Gal 58.149 37.5231

Aladin

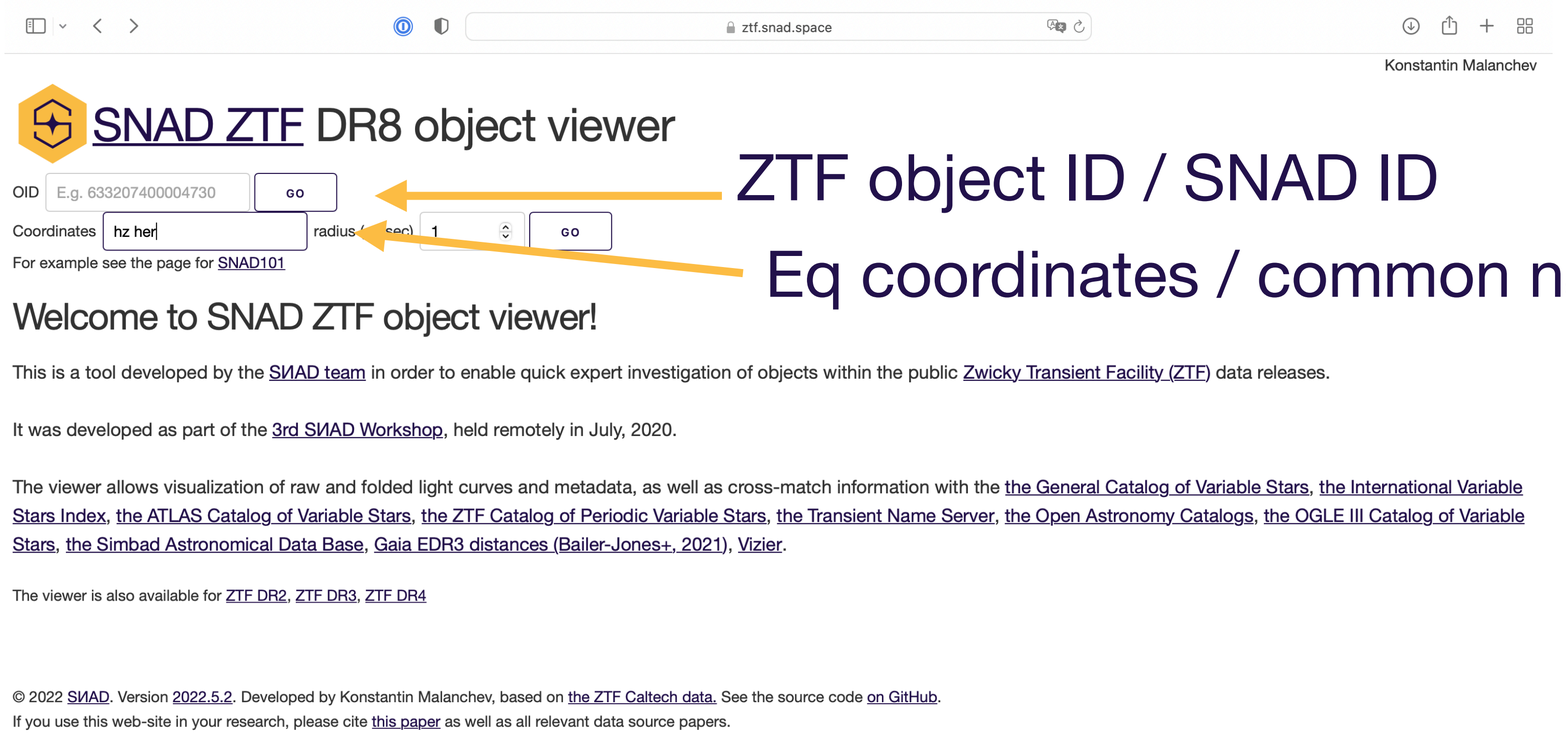


Name, type, period, distance & extension from other catalogs and our periodogram

By-product: SNAD ZTF viewer

https://ztf.snad.space

Home page



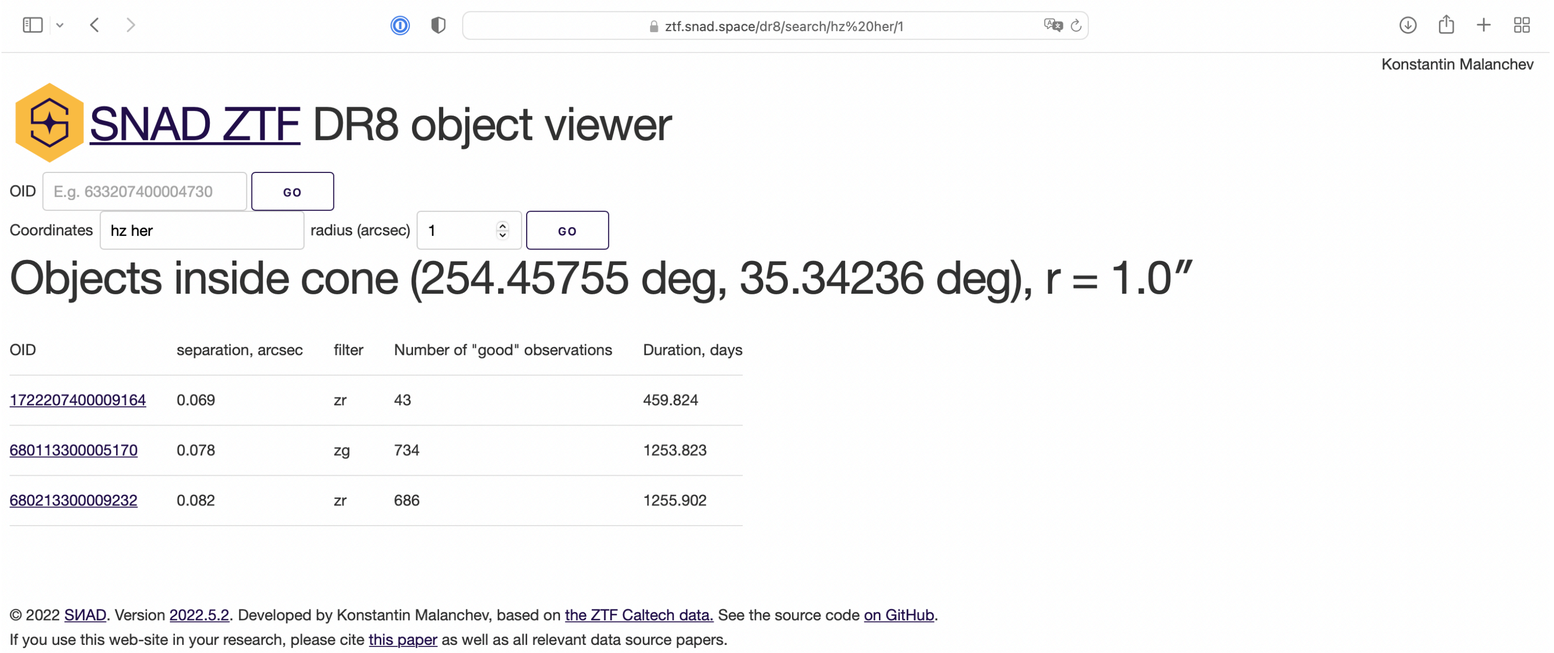
ZTF object ID / SNAD ID

Eq coordinates / common name

By-product: SNAD ZTF viewer

https://ztf.snad.space

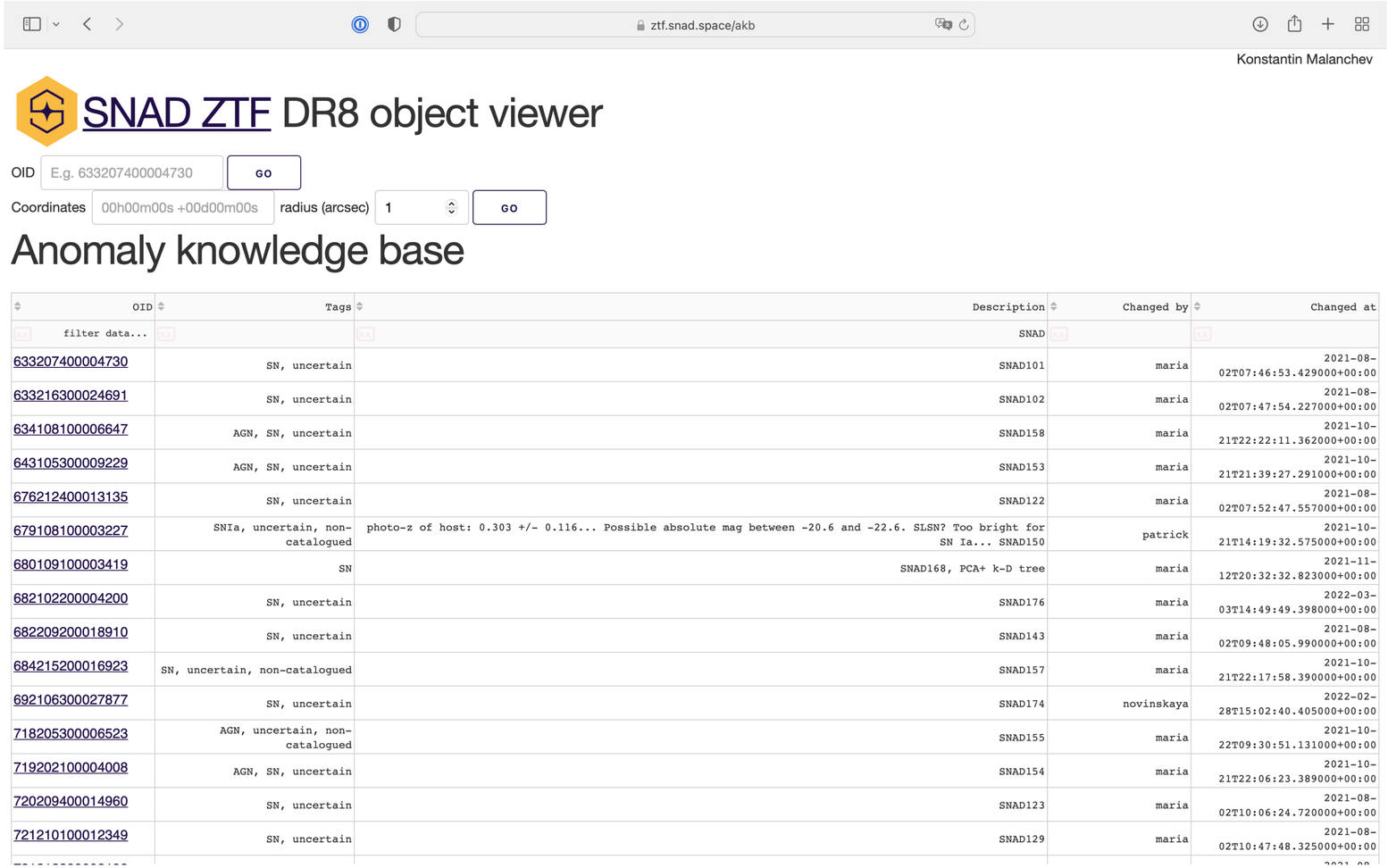
Same source, different OIDs



By-product: SNAD ZTF viewer

https://ztf.snad.space

SNAD experts tagged >2000 objects, >70 are submitted to the TNS!



OID	Tags	Description	Changed by	Changed at
filter data...		SNAD		
633207400004730	SN, uncertain	SNAD101	maria	2021-08-02T07:46:53.429000+00:00
633216300024691	SN, uncertain	SNAD102	maria	2021-08-02T07:47:54.227000+00:00
634108100006647	AGN, SN, uncertain	SNAD158	maria	2021-10-21T22:22:11.362000+00:00
643105300009229	AGN, SN, uncertain	SNAD153	maria	2021-10-21T21:39:27.291000+00:00
676212400013135	SN, uncertain	SNAD122	maria	2021-08-02T07:52:47.557000+00:00
679108100003227	SNIa, uncertain, non-catalogued	photo-z of host: 0.303 +/- 0.116... Possible absolute mag between -20.6 and -22.6. SLSN? Too bright for SN Ia... SNAD150	patrick	2021-10-21T14:19:32.575000+00:00
680109100003419	SN	SNAD168, PCA+ k-D tree	maria	2021-11-12T20:32:32.823000+00:00
682102200004200	SN, uncertain	SNAD176	maria	2022-03-03T14:49:49.398000+00:00
682209200018910	SN, uncertain	SNAD143	maria	2021-08-02T09:48:05.990000+00:00
684215200016923	SN, uncertain, non-catalogued	SNAD157	maria	2021-10-21T22:17:58.390000+00:00
692106300027877	SN, uncertain	SNAD174	novinskaya	2022-02-28T15:02:40.405000+00:00
718205300006523	AGN, uncertain, non-catalogued	SNAD155	maria	2021-10-22T09:30:51.131000+00:00
719202100004008	AGN, SN, uncertain	SNAD154	maria	2021-10-21T22:06:23.389000+00:00
720209400014960	SN, uncertain	SNAD123	maria	2021-08-02T10:06:24.720000+00:00
721210100012349	SN, uncertain	SNAD129	maria	2021-08-02T10:47:48.325000+00:00

Conclusion

- Using real data from the very beginning
- Astronomical experts are queens: their opinion matters from the start of the algorithm construction to the last stage
- Developing new tools — and sharing them with the community
- Recent and ongoing projects:
  - Developing new active anomaly detection algorithm for new features, better computation and detection performance (Korolev+ in prep., ask me about it!)
  - Using AAD for classification, listen **talk by Emille Ishida** about SNe
  - Mining transients with k-D tree, see **poster by Patrick Aleo** (presented by me)