

Deep learning for the Zwicky Transient Facility (ZTF): real/bogus classification and identification of fast-moving objects

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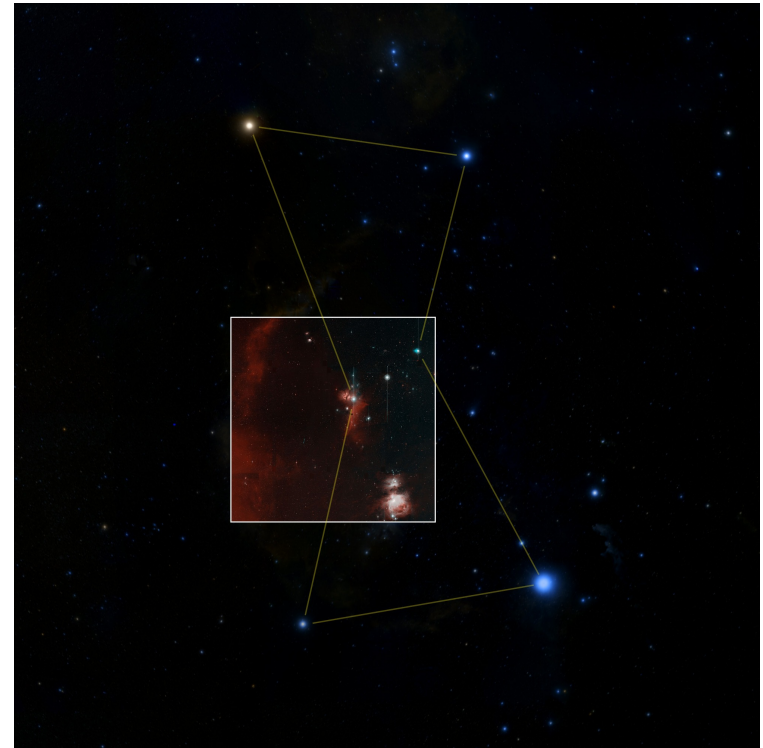
On behalf of the Caltech/IPAC ZTF team



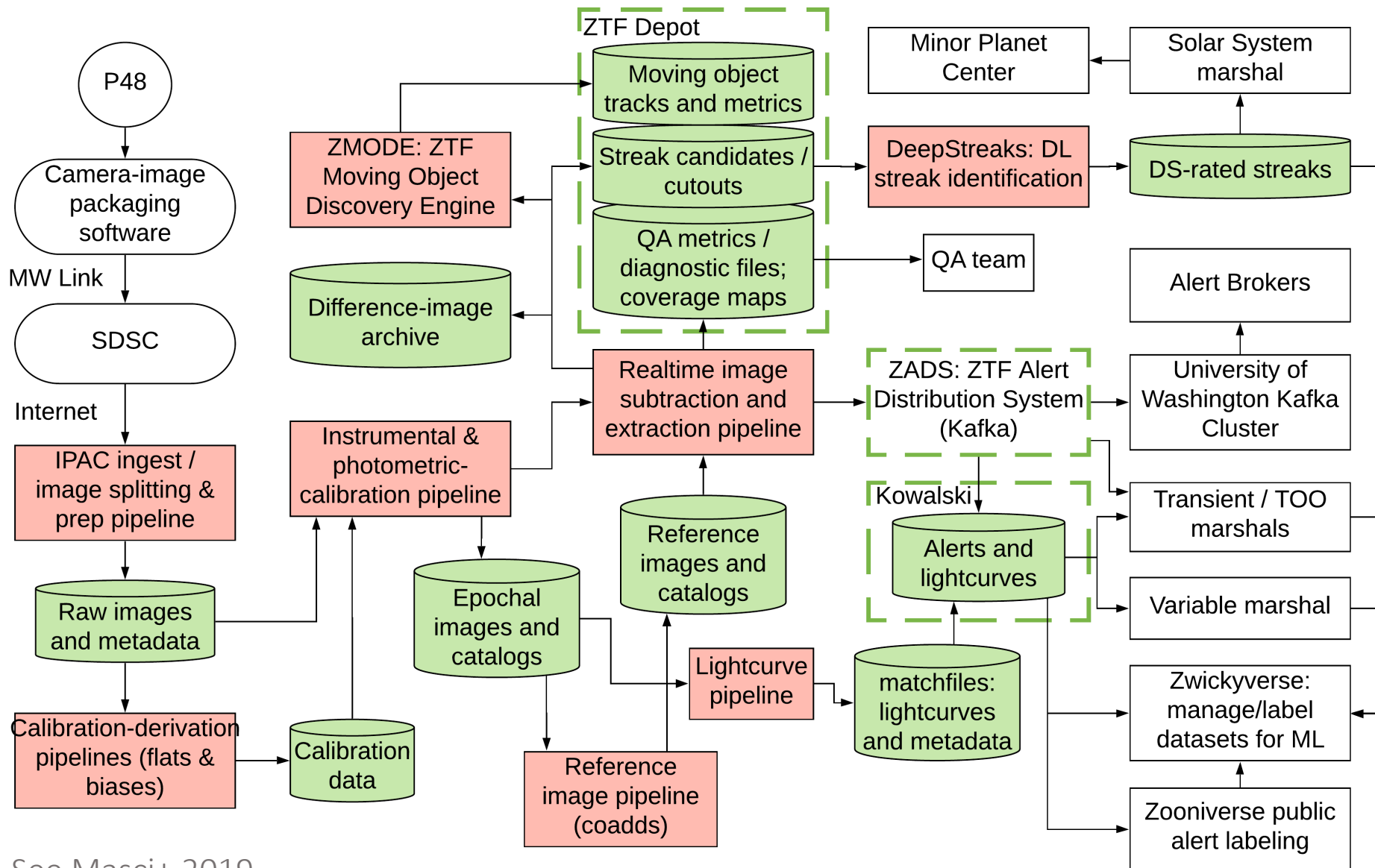
ZTF at a glance

- Telescope: Samuel Oschin 48-inch Schmidt, Palomar Observatory
- Active detector area: $\sim 47 \text{ deg}^2$
- Areal survey rate: $4300 \text{ deg}^2 / \text{hour}$
- Nominal survey duration: 3 years
- Filters: $g / r / i$
- Nominal exposure time: 30 sec
- Single exposure depth (5σ): $20.8 / 20.6 / 19.9$
- Image quality (FWHM): $2.1'' / 2.0'' / 2.1''$
- CCDs: $16 \times 6k \times 6k, 1.0'' / \text{pix}$
- Survey entire Northern visible sky to $\delta \sim -30^\circ$
- A fast, wide-area time-domain survey:
 - fast, young, and rare flux transients
 - counterparts to gravitational wave sources
 - low- z Type Ia SNe for cosmology
 - variable stars & eclipsing binaries
 - Solar System objects

<https://ztf.caltech.edu>



ZTF data/processing flow



Data volumes and source stats

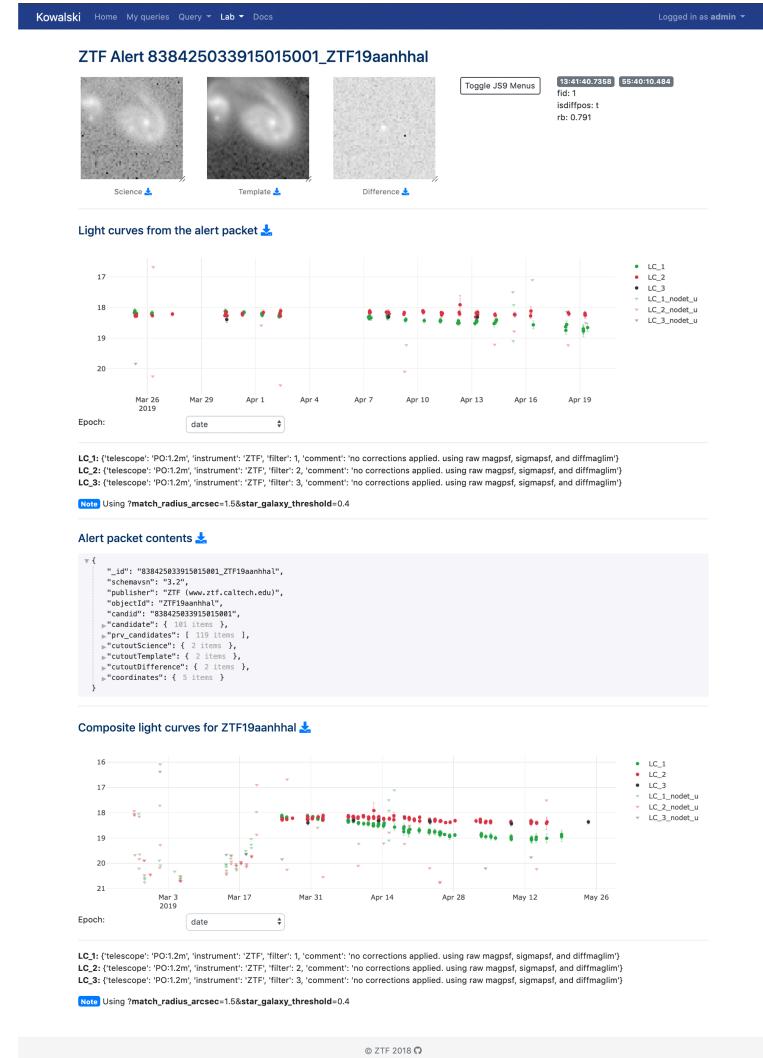
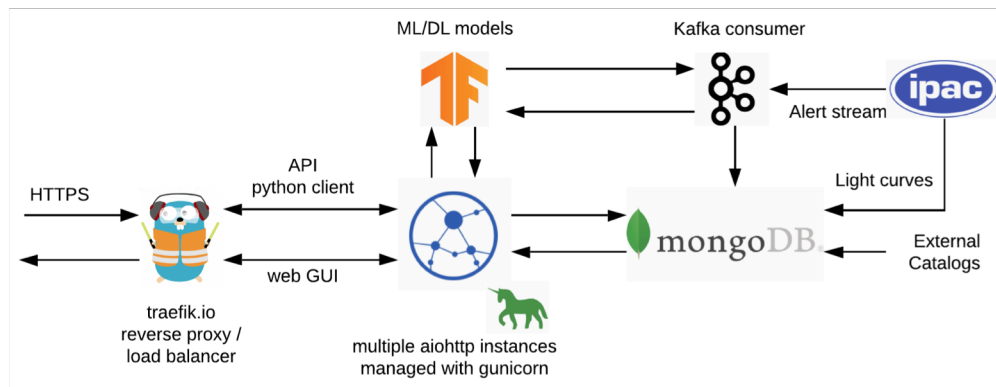
Single night	8h40m
# on-sky exposures	~700
Raw image data	~1 TB
Real-time data products	~4 TB
# unvetted 5σ alerts	$\sim 10^5 - 10^6$
# ML-vetted alerts	$\sim 10^3 - 10^5$
# unvetted streaks	$\sim 10^4 - 10^6$
# ML-vetted streaks	$\sim 10^2 - 10^3$

Nominal survey	3 x 260 n
Volume of data products	~3.2 PB
Volume of ref images	~60 TB
# CCD quad ref images	$\sim 2.8 \times 10^5$
Volume of matchfiles	~50 TB
# matchfiles	$\sim 2.8 \times 10^5$
# single-epoch PSF-fit source measurements	~800 B
# single-epoch aperture source measurements	~230 B

DL -> genuine astrophysical events/objects

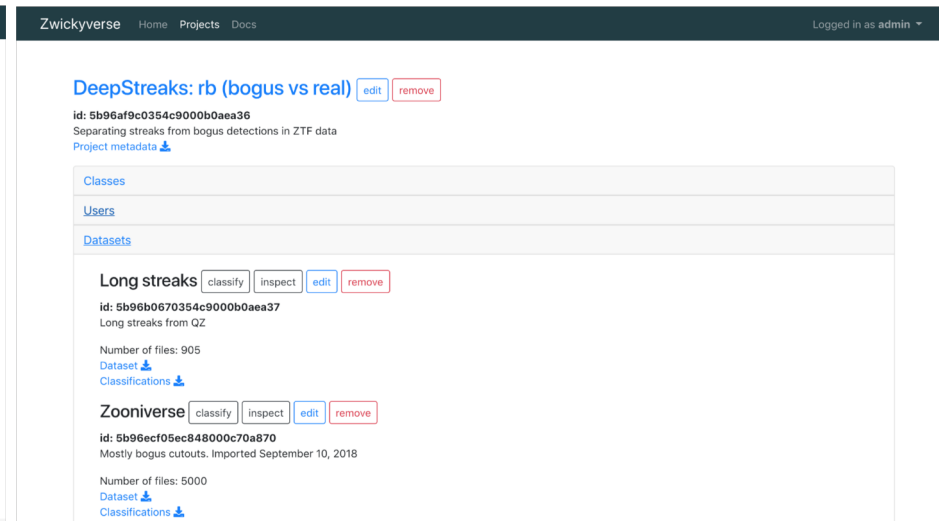
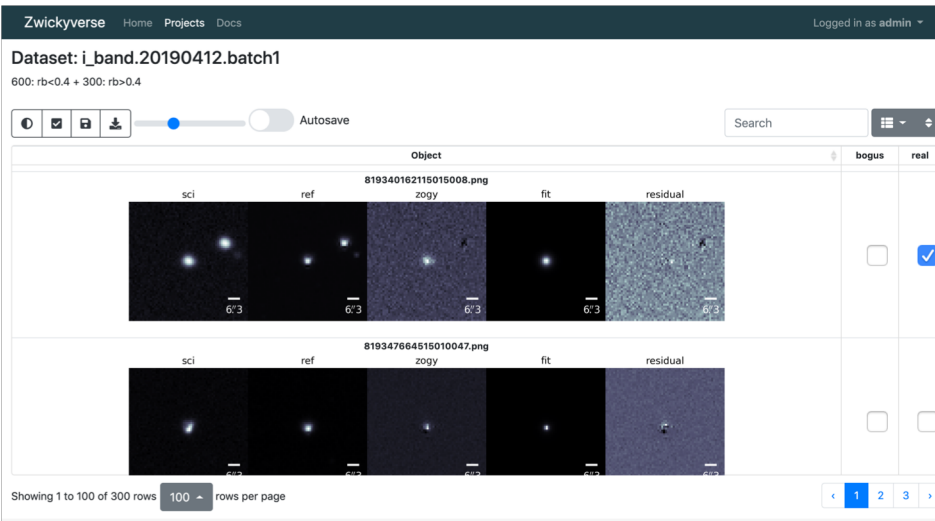
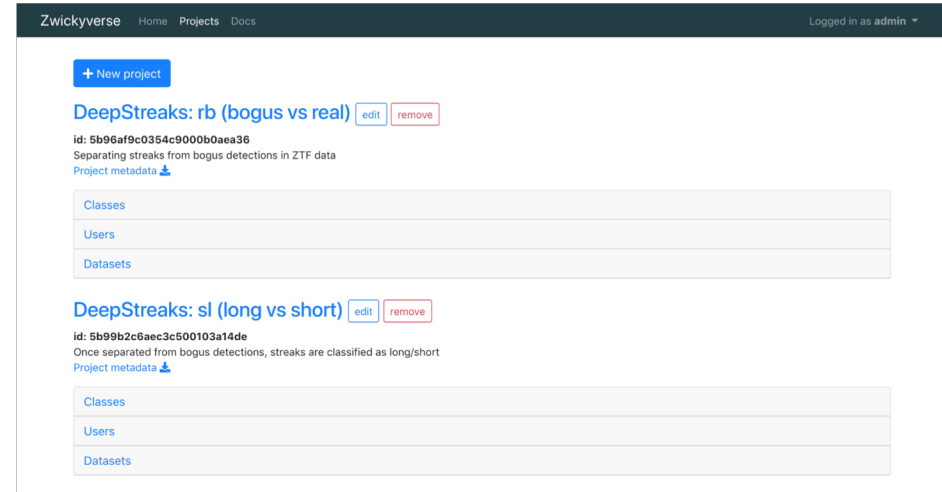
Kowalski: store+access ZTF alerts/LC

- “Swiss knife” system for time domain astronomy (with ZTF)
 - ...
 - API, python client
 - 115M+ ZTF alerts, 2.5B+ ZTF light curves
- ZTF Alert Lab
 - Filter and display/access alerts
 - Packet and compound LC, corrected for reference flux if necessary



Zwickyverse: manage/label datasets for ML

- Efficiently label large amounts of image data
- Collaborative
- API, python client to get data in/out

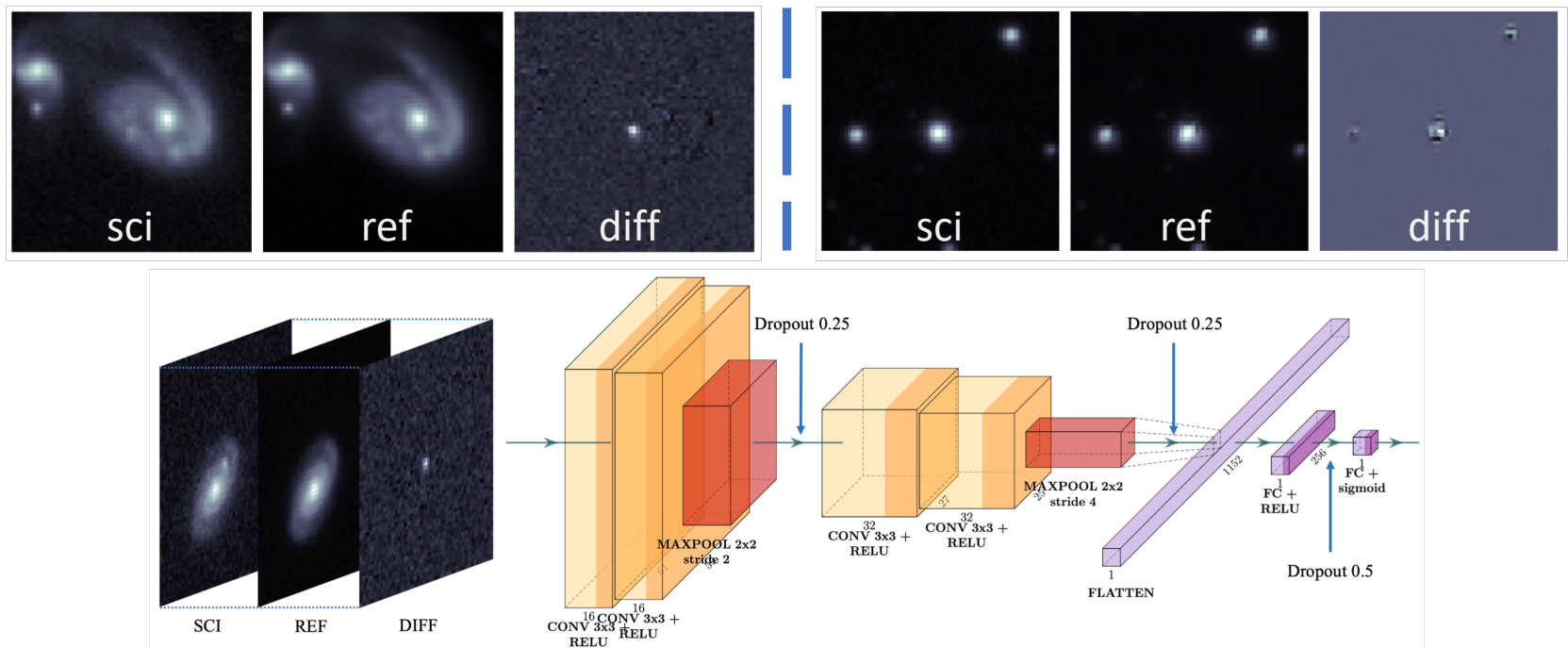


<https://github.com/dmitryduev/zwickyverse>

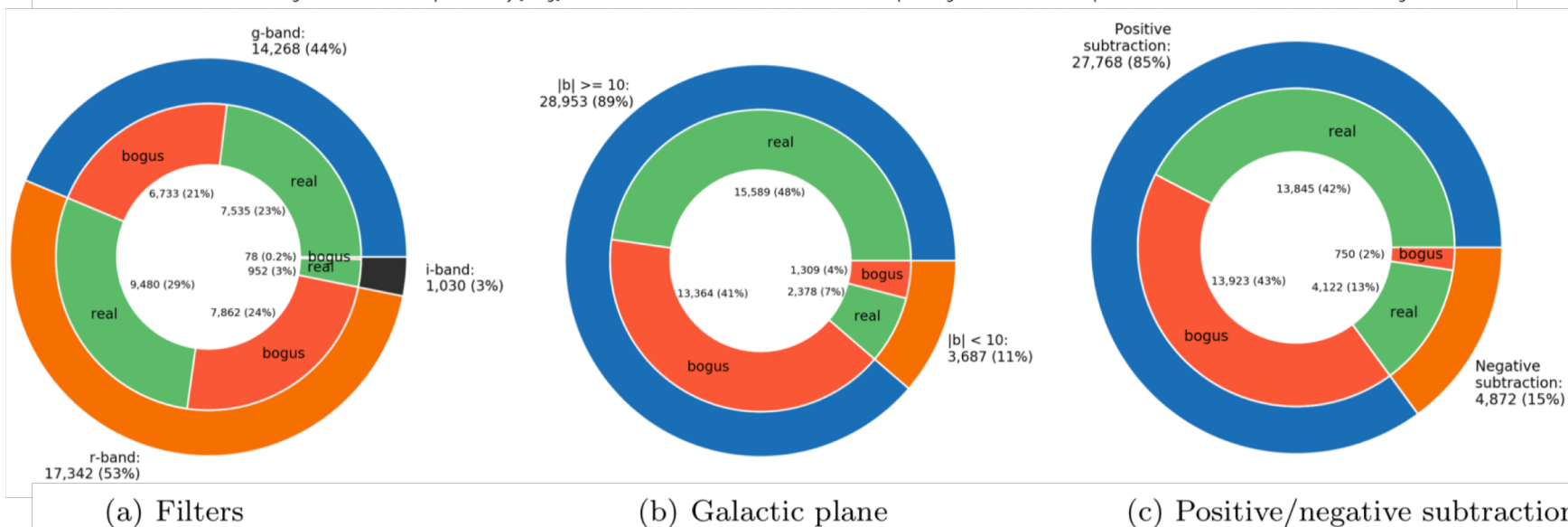
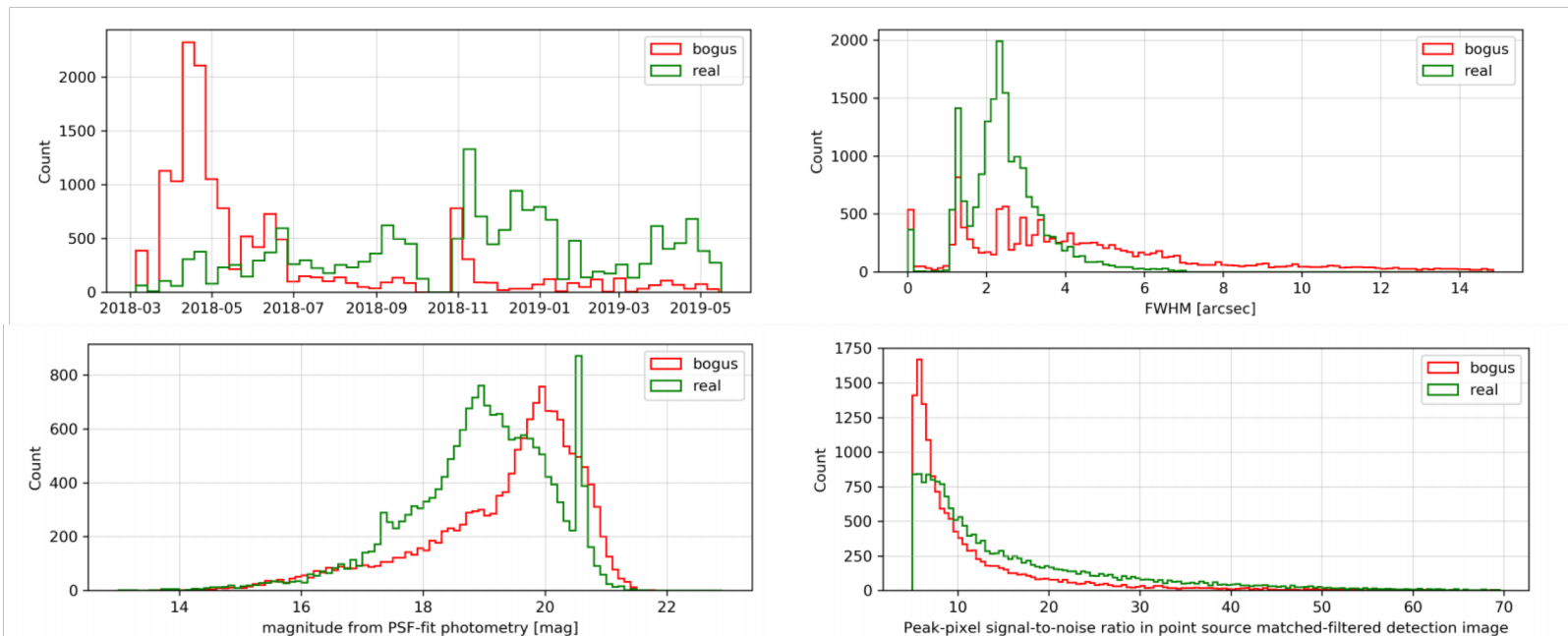
Duev+ in prep.

braai: real/bogus classifier for ZTF

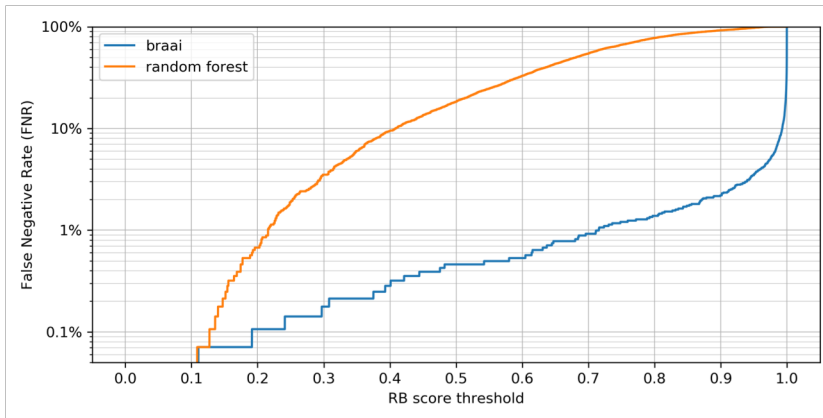
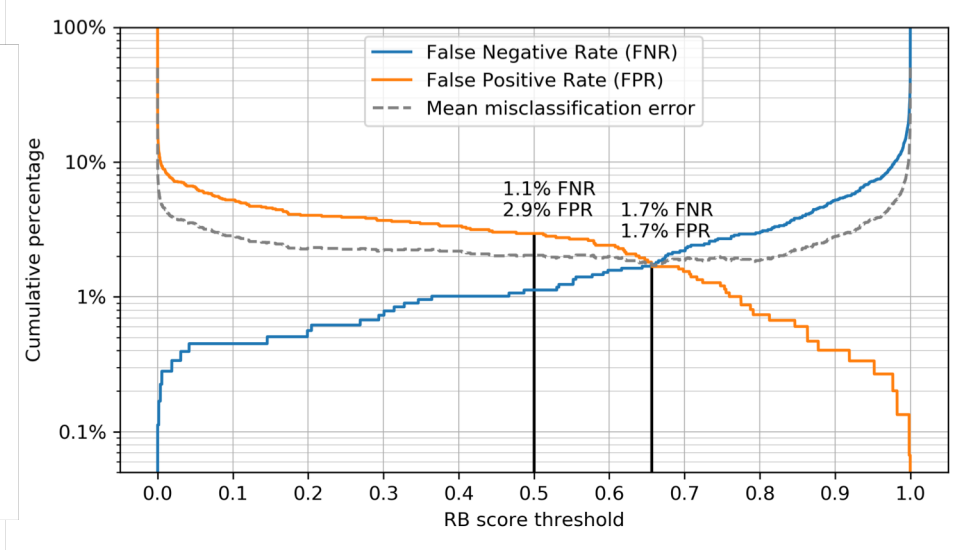
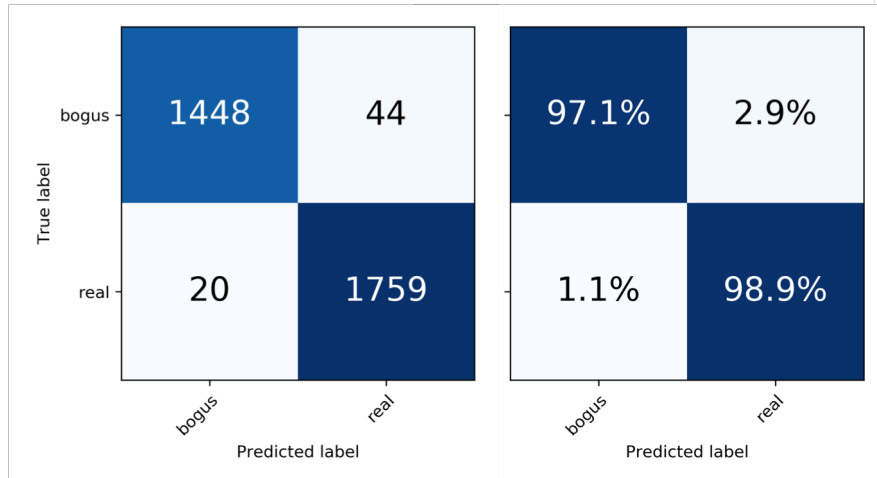
- braai: bogus/real adversarial artificial intelligence
- CNN-based architecture (“VGG6”), TensorFlow/Keras
- Input: stacked triplets [science, reference, ZOGY]
- 30K+ training examples; Zwickyverse for labeling; trained on GPU; active learning
- Data sources: Kowalski; ZTF transient and variable marshals, Zooniverse



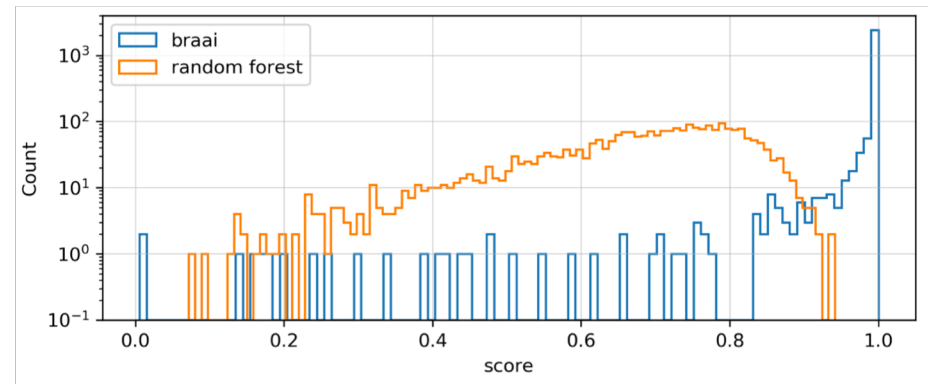
braai: data diversity



braai: performance

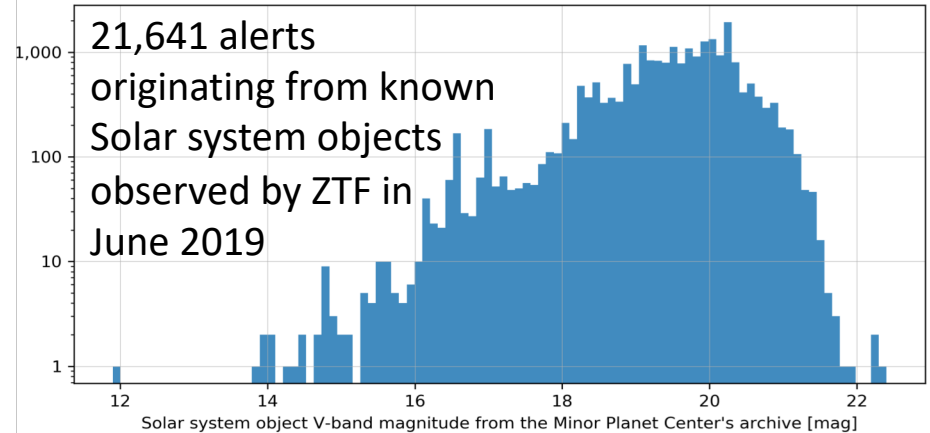
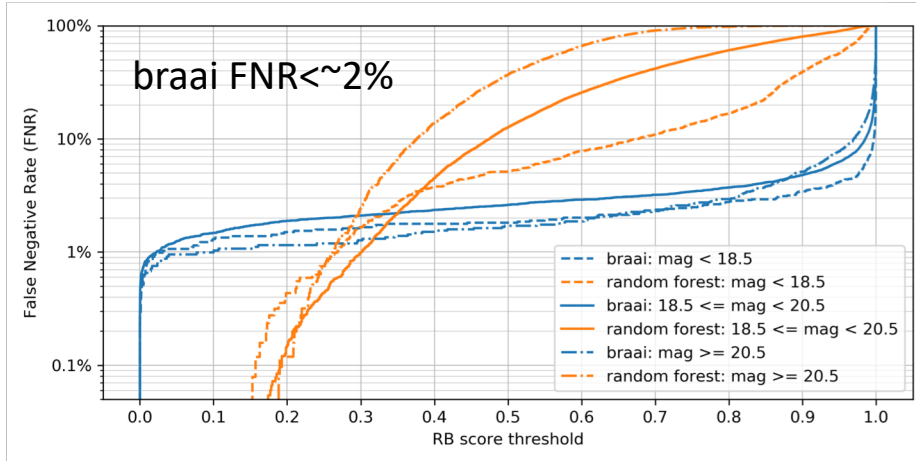


2,820 alerts from a set of 140 SN detected in 2019.
0.5% braai FNR vs 20% RF RB FNR



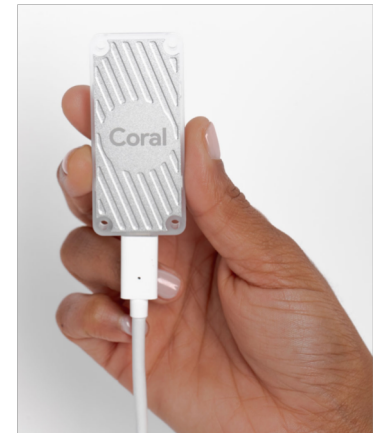
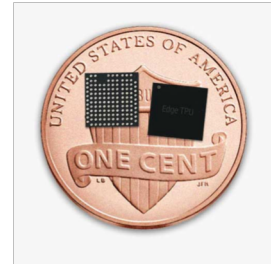
2,633 ZTF alerts from the night of May 14, 2019 from 921 (vetted) real objects on GROWTH marshal. 0.7% braai FNR vs 11% RF RB FNR

braai: performance

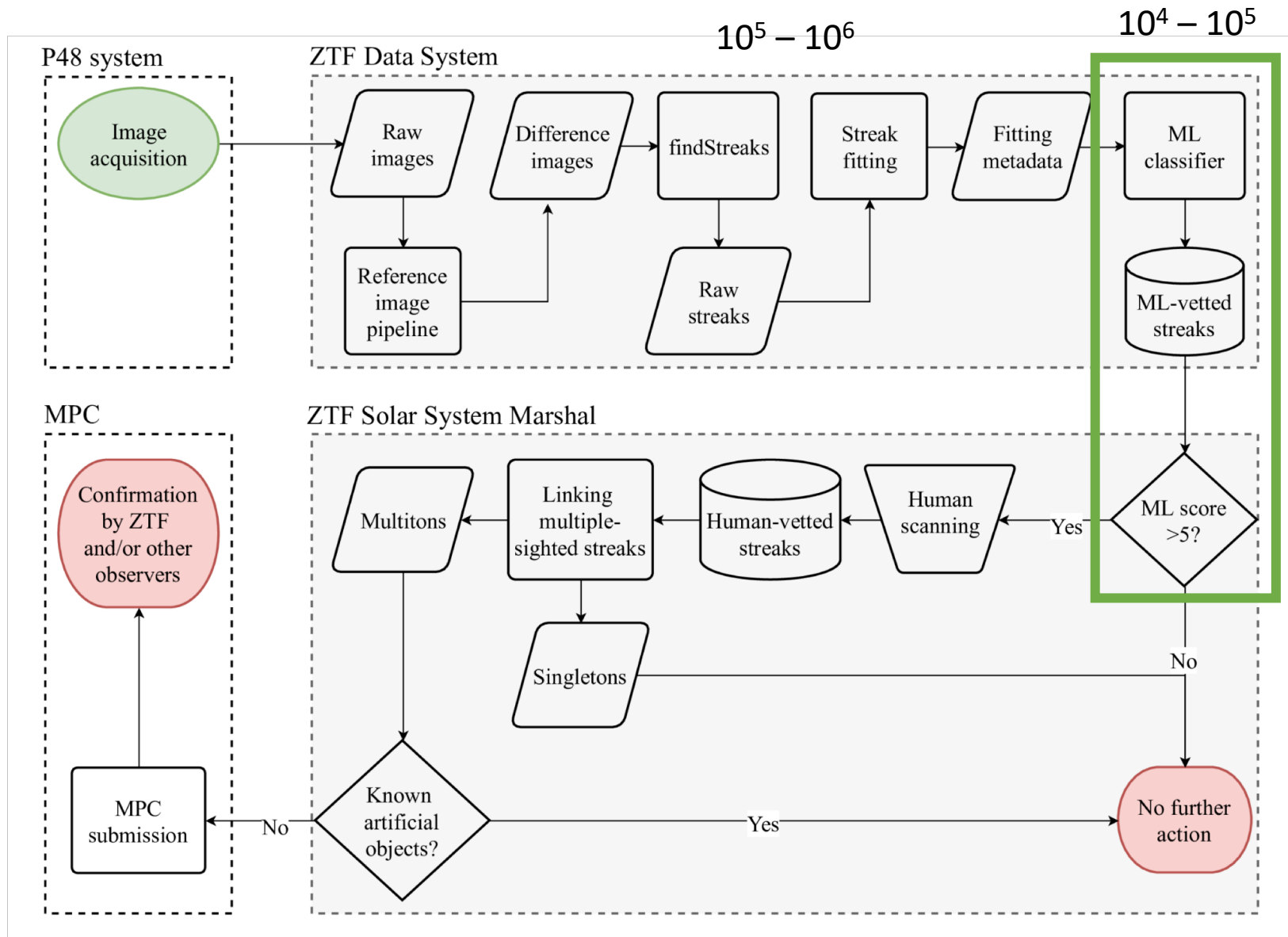


Google's Coral Edge TPUs:

- Compiled (uint8) model -> same performance
- 3-5 minutes (including I/O) to process 200k alerts, ~50x beefy multi-core desktop
- ~\$100-150



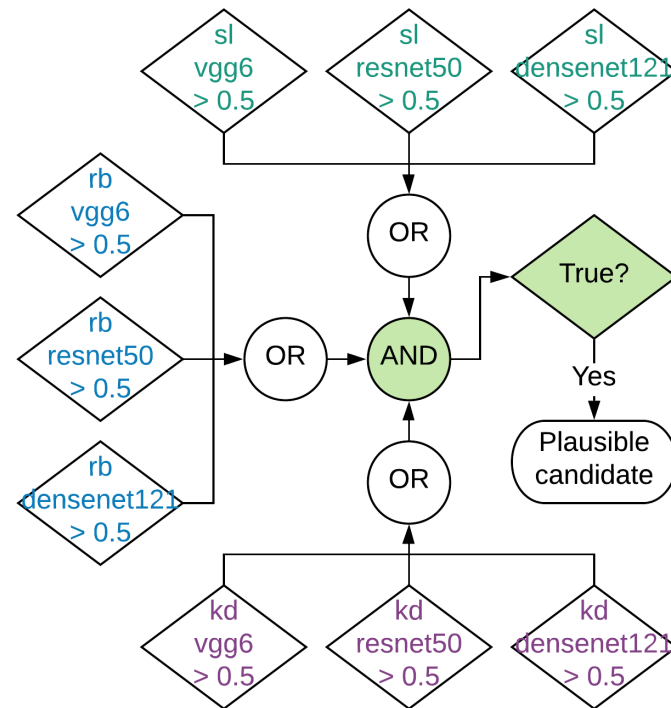
ZTF Solar System framework



DeepStreaks: architecture

Convolutional-neural-network, deep-learning system designed to efficiently identify streaking FMOs/NEOs

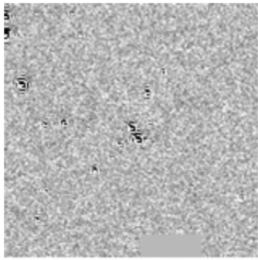
- "rb": bogus or real streak?
Identify all streak-like objects, including actual streaks from FMOs, long streaks from satellites, and cosmic rays
- "sl": long or short streak?
- "kd": ditch or keep? Is this a real streak, or a cosmic ray/some other artifacts?



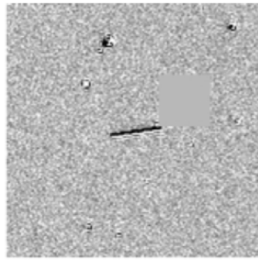
- Three different CNN architectures within each family: VGG6, ResNet50, and DenseNet121

DeepStreaks: dataset

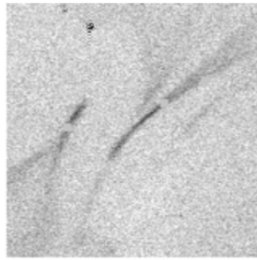
30k training examples; used Zwickyverse for labeling; trained on GPU



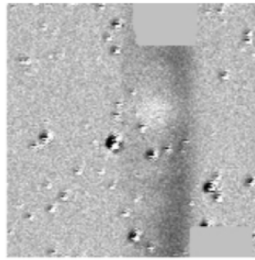
(a) Bad subtraction



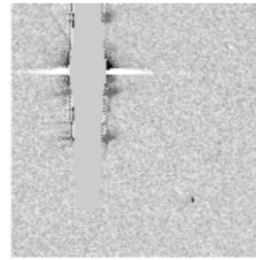
(b) Cosmic ray



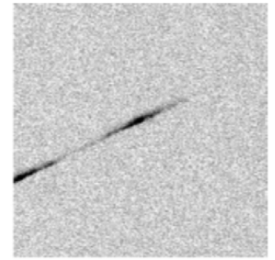
(c) "Dementor"



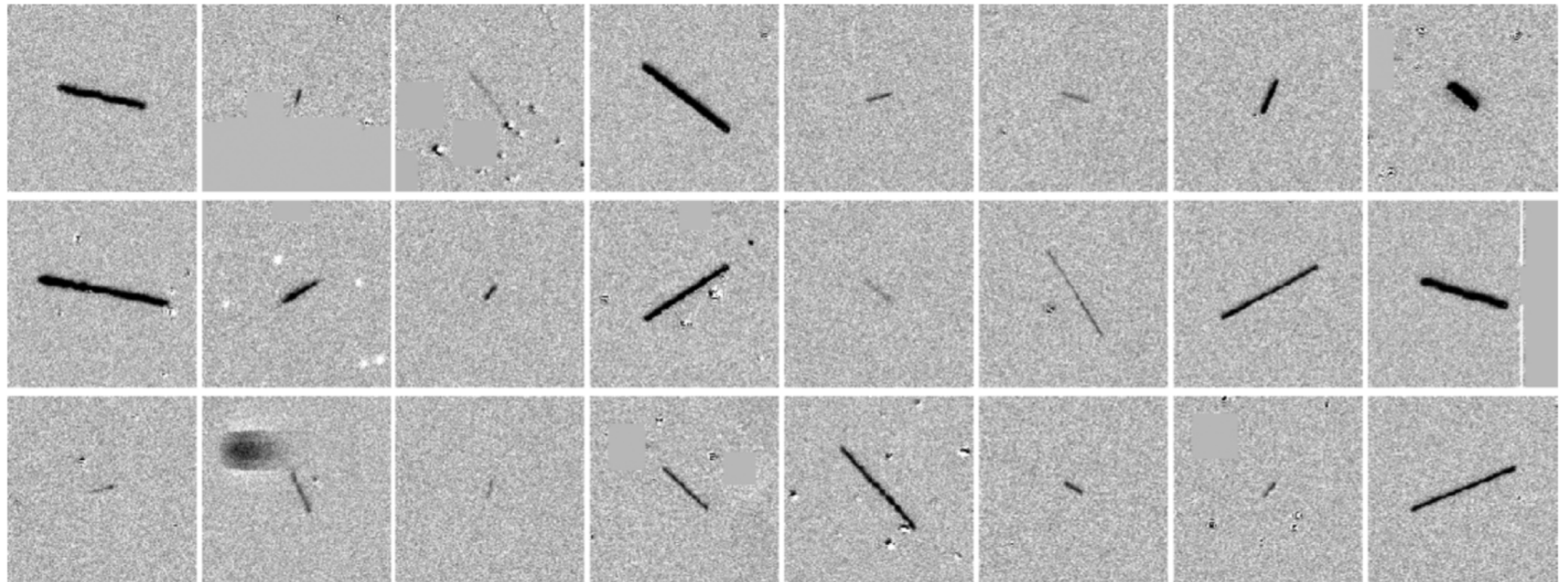
(d) "Ghost"



(e) Masked star

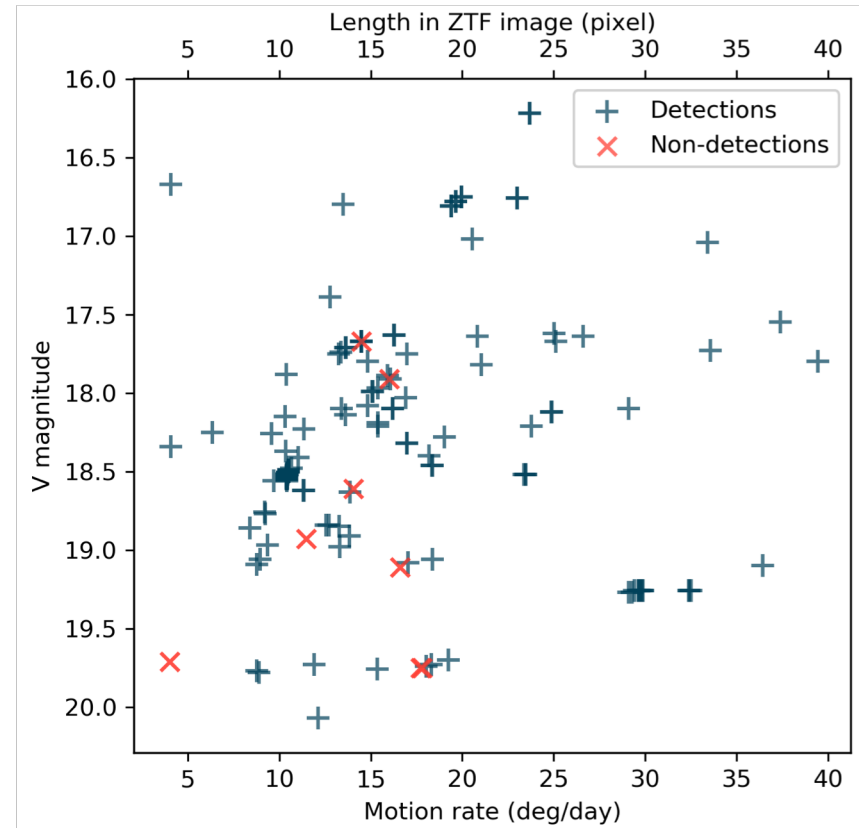


(f) Satellite trail



DeepStreaks: performance/results

- 96-98% true positive rate, depending on the night
 - Quantified by performance on test data sets and using known NEOs observed by ZTF
- Below 1% false positive rate, 50x-100x improvement over original RF classifier
 - Sanity check: 0% FPR on 8,000 random ImageNet images
- Near-real-time operations; below 10 min per day spent by human scanners vs ~hours with original RF classifier
- 60+ confirmed new NEAs
- Another 50+ “lost” due to insufficient follow-up



Completeness identifications using known NEOs observed by ZTF in October 2018 – January 2019. Out of 210 streaks from real NEOs detected by the ZTF Streak pipeline at IPAC, 202 (96%) are correctly classified.