Real-time bright transient identification with ML for ZTF

The Transient and Variable Universe

21st June 2023

Nabeel Rehemtulla, Adam Miller on behalf of ZTF

Northwestern University, CIERA

Northwestern

Zwicky Transient Facility

Zwicky Transient Facility (ZTF)

- Wide-field time-domain survey in g- and r-band
- 10^6 alert packets / night

https://www.ztf.caltech.edu/

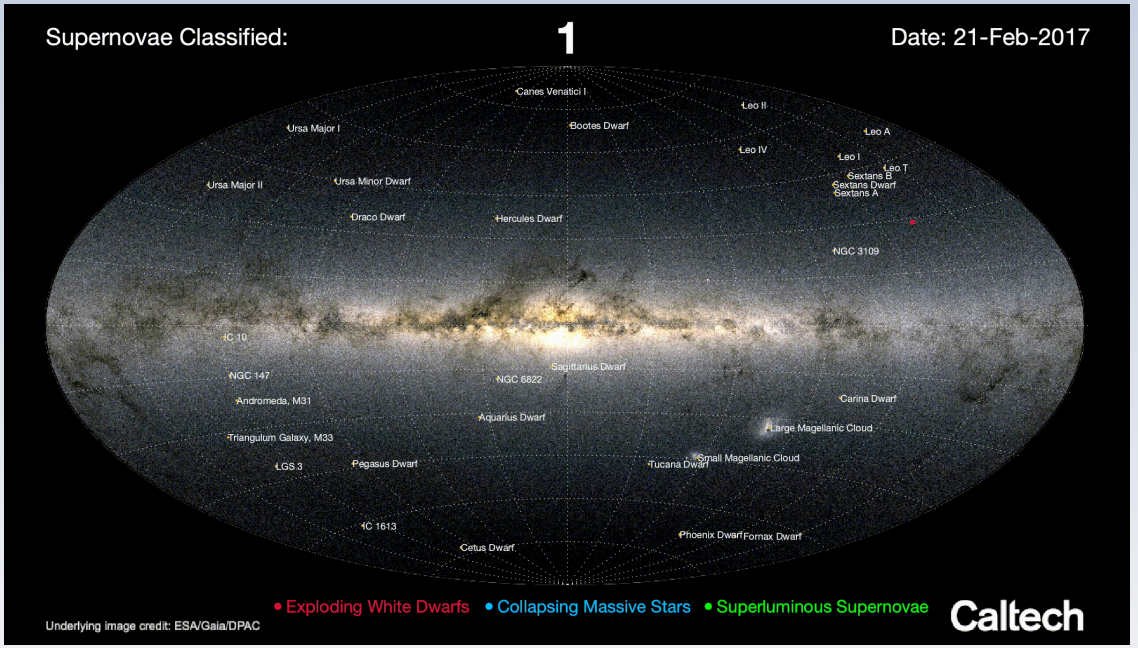
Bellm+16

The Bright Transient Survey (BTS)

Spectroscopically classify **all** extragalactic transients from ZTF with $m_{\rm peak} < 18.5$ mag

2018 → Present

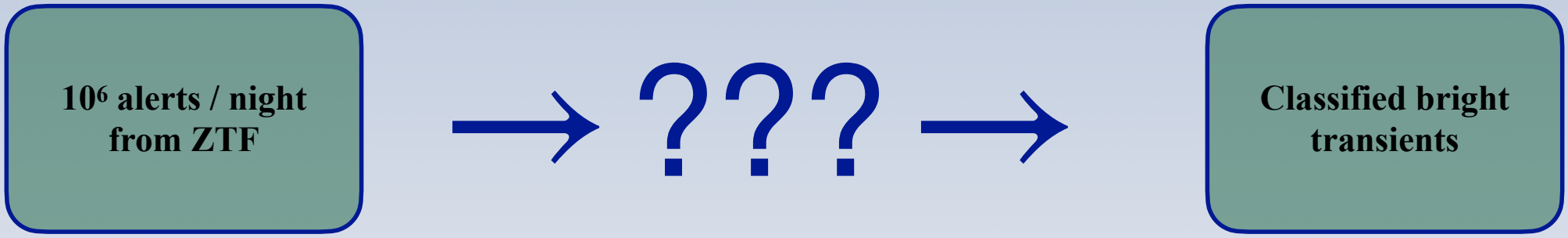
- >7,000 SNe publicly classified
- Near-perfect completeness
- Best SN population estimations



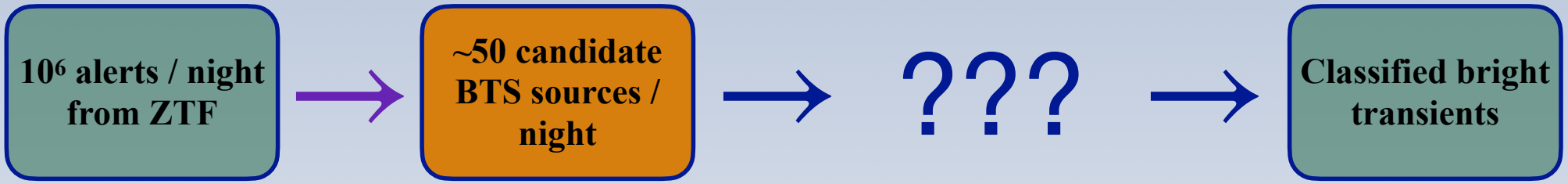
Animation credit: Christoffer Fremling

Fremling+20, Perley+20

How does BTS work?



How does BTS work?

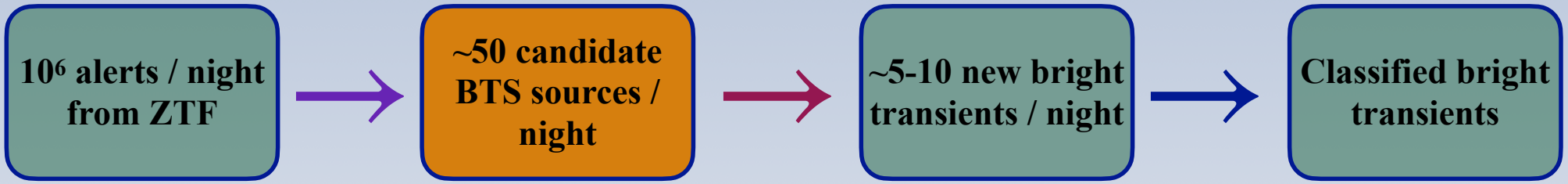


Static filters remove:

- **Bogus alerts**
- **Asteroids**
- **Some variables**
- **Alerts >19 mag**

Candidate BTS sources include **bright and dim transients, AGN, CVs, variable stars**

How does BTS work?



Static filters remove:

- **Bogus alerts**
- **Asteroids**
- **Some variables**
- **Alerts >19 mag**

Candidate BTS sources include **bright and dim transients, AGN, CVs, variable stars**

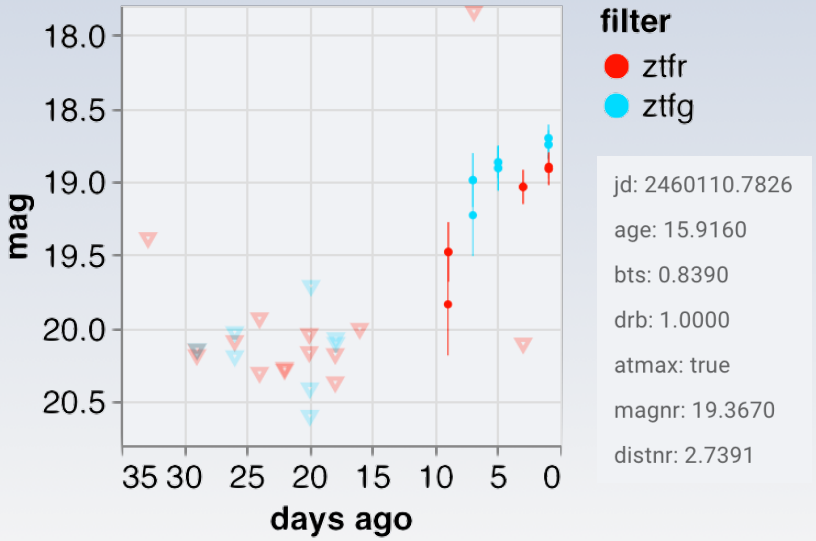
"Scanning": Humans manually inspect BTS candidates and bookmark ("save") bright transients

Data available to scanners

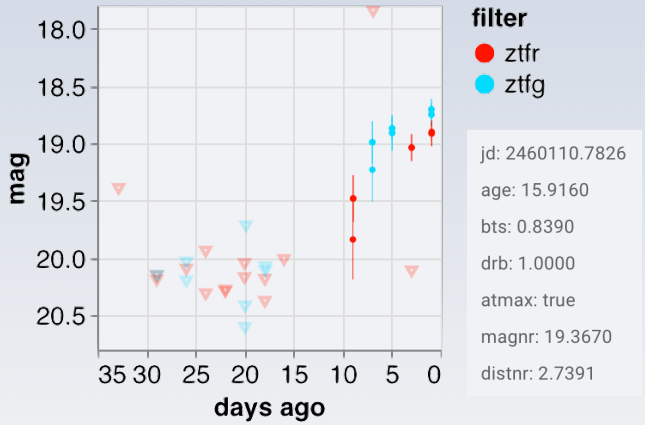
Cutouts
(science, reference, difference)

Light curve

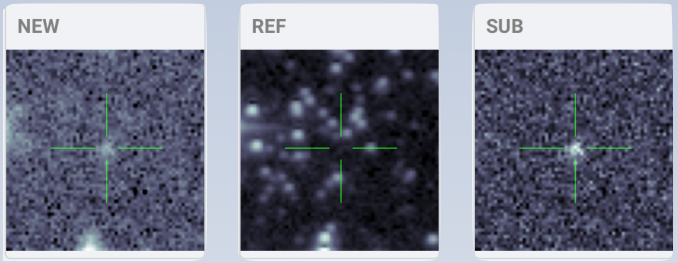
Miscellaneous features
(RA, Dec., other survey images)

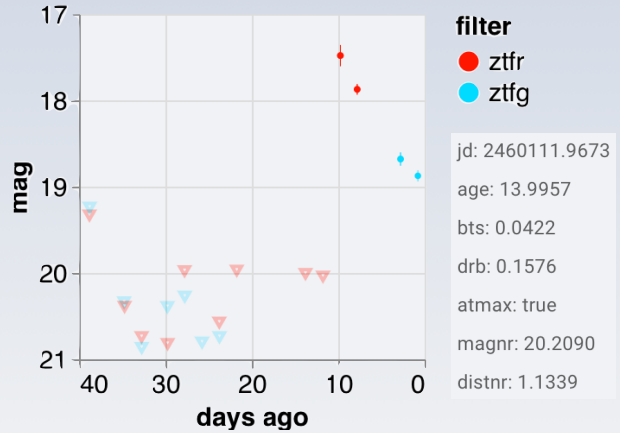


Data available to scanners



1/50





2/50

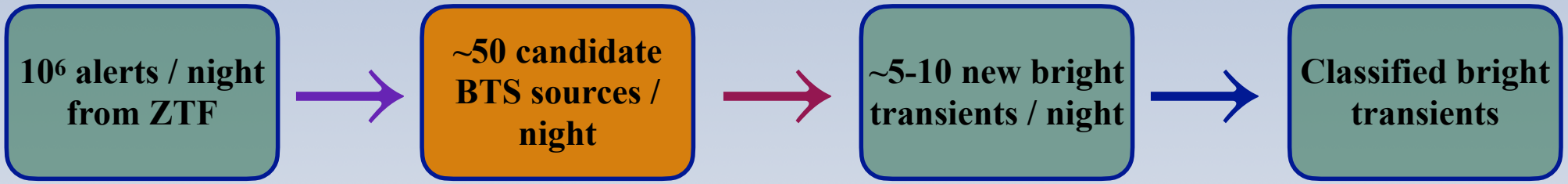
50x / night!

Problems with scanning

Time

- Tedious & requires expertise
- Human delay
- Not scaleable to deeper surveys (e.g., Rubin)

How does BTS work?



Static filters remove:

- **Bogus alerts**
- **Asteroids**
- **Some variables**
- **Alerts >19 mag**

Candidate BTS sources include **bright and dim transients, AGN, CVs**

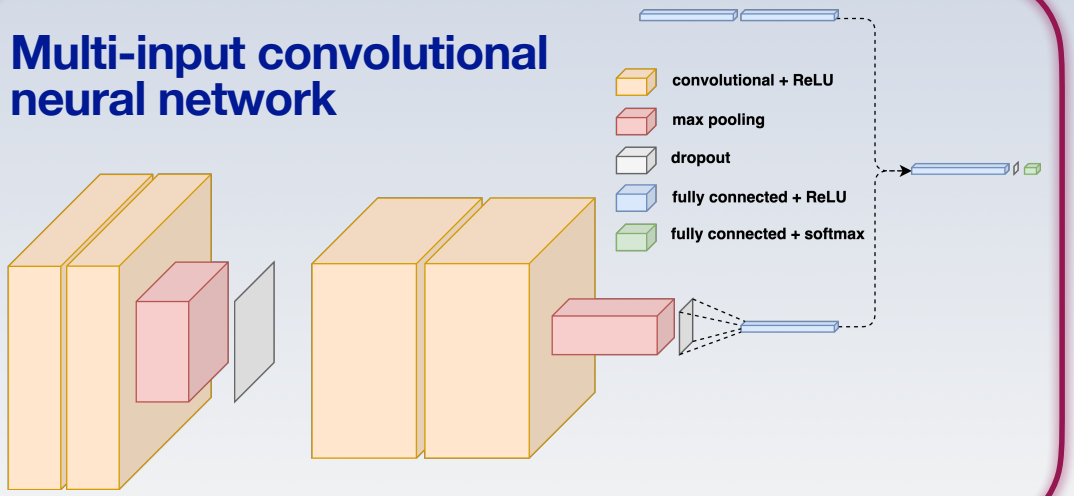
"Scanning": Humans manually inspect BTS candidates and bookmark bright transients

How does BTS work?

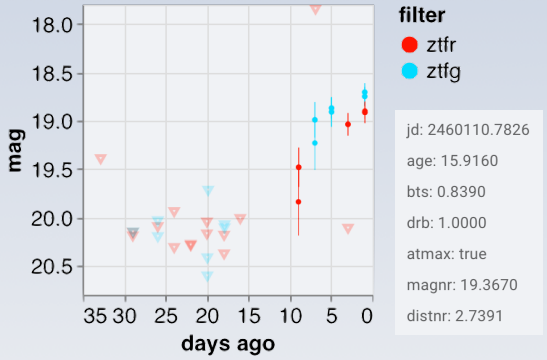
10^6 alerts / night from ZTF → ~50 candidate BTS sources / night → ~5-10 new bright transients / night → Classified bright transients

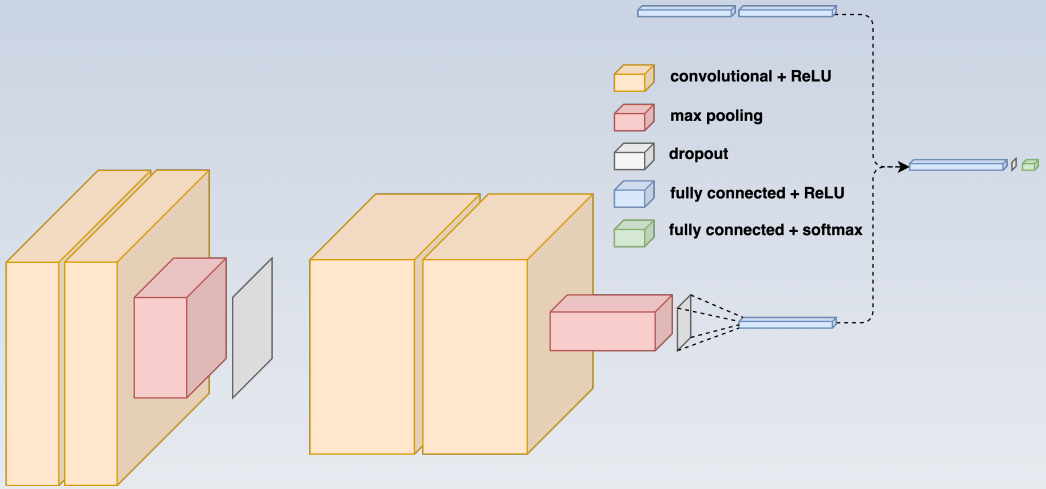
~~"Scanning": Humans manually inspect BTS candidates and bookmark bright transients~~

Multi-input convolutional neural network

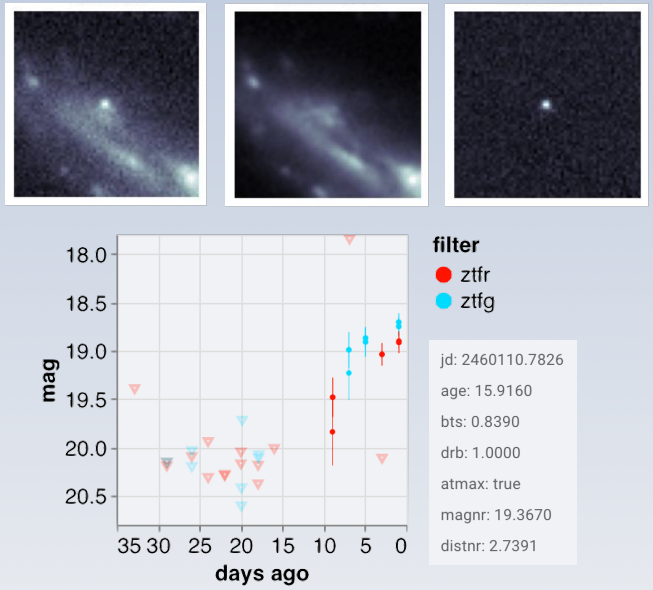


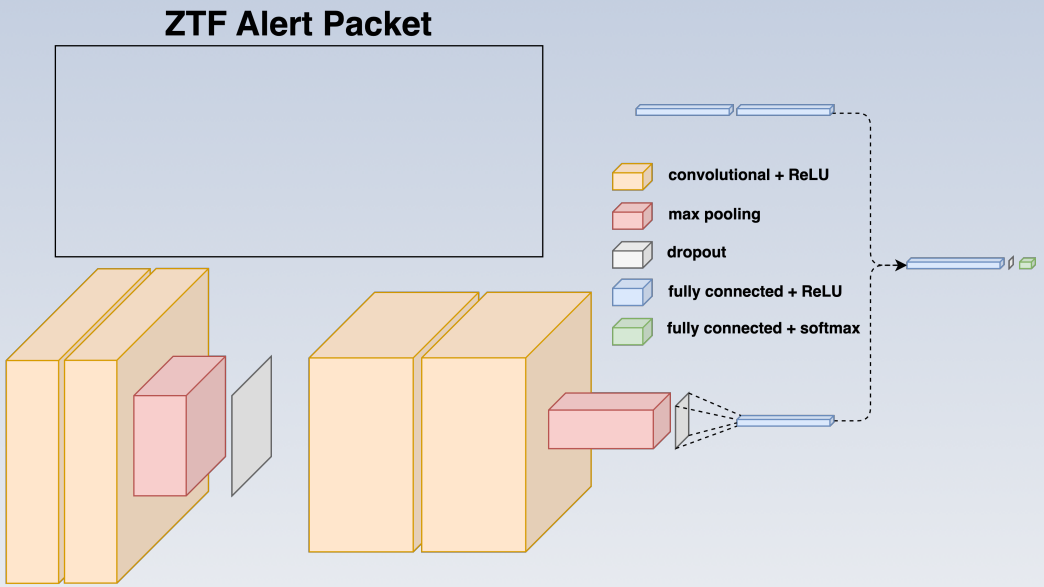
BTSbot, a multi-input convolutional neural network



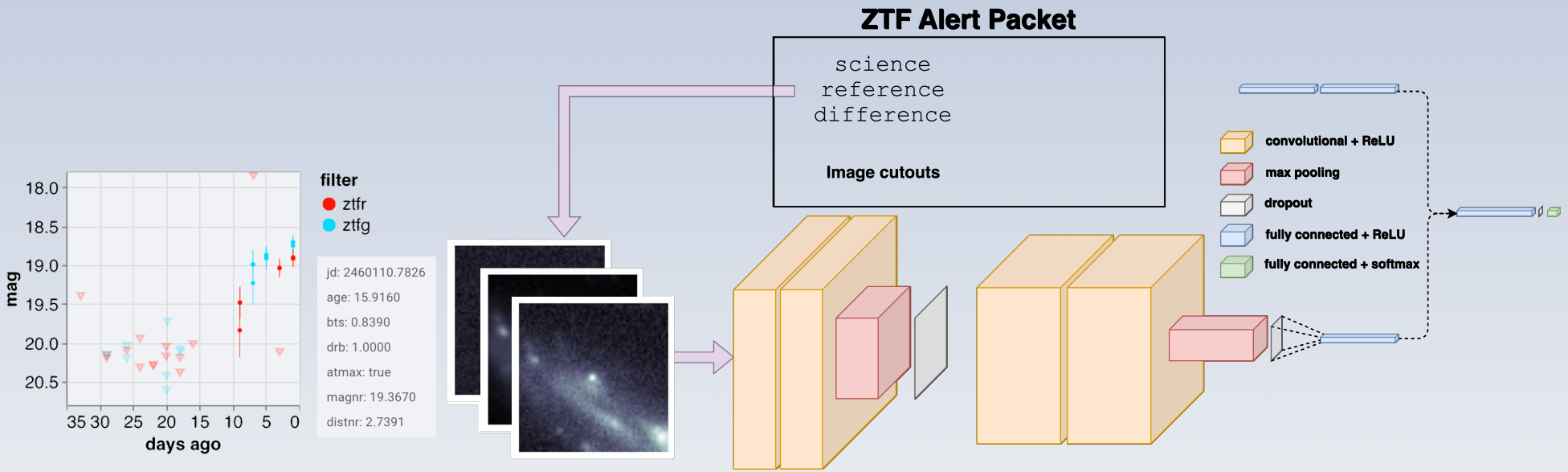


BTSbot, a multi-input convolutional neural network

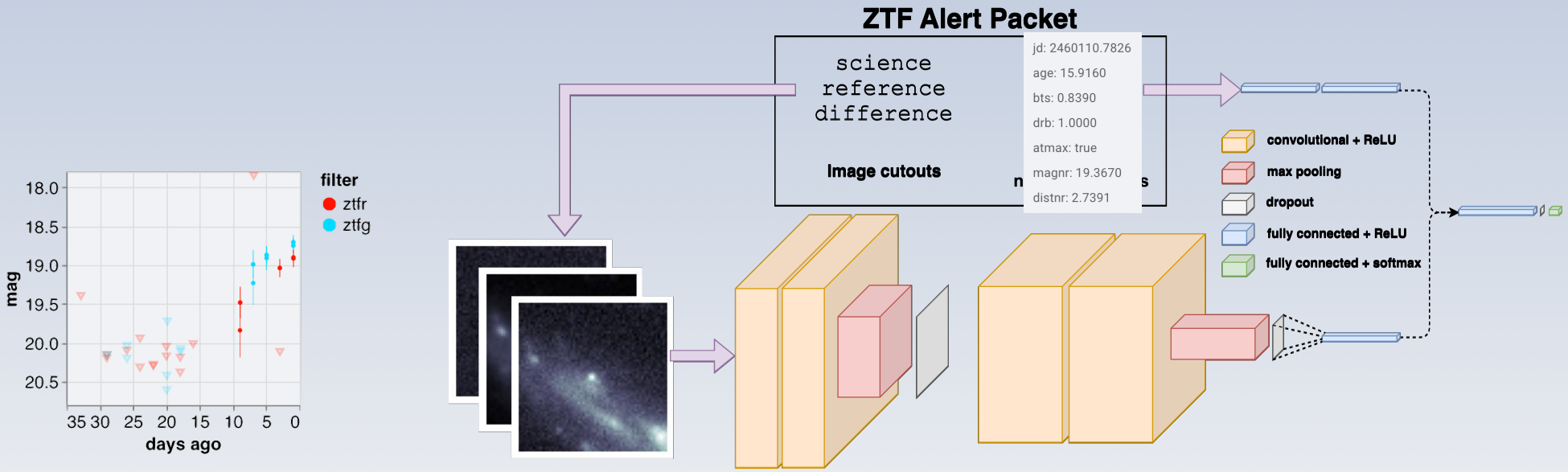




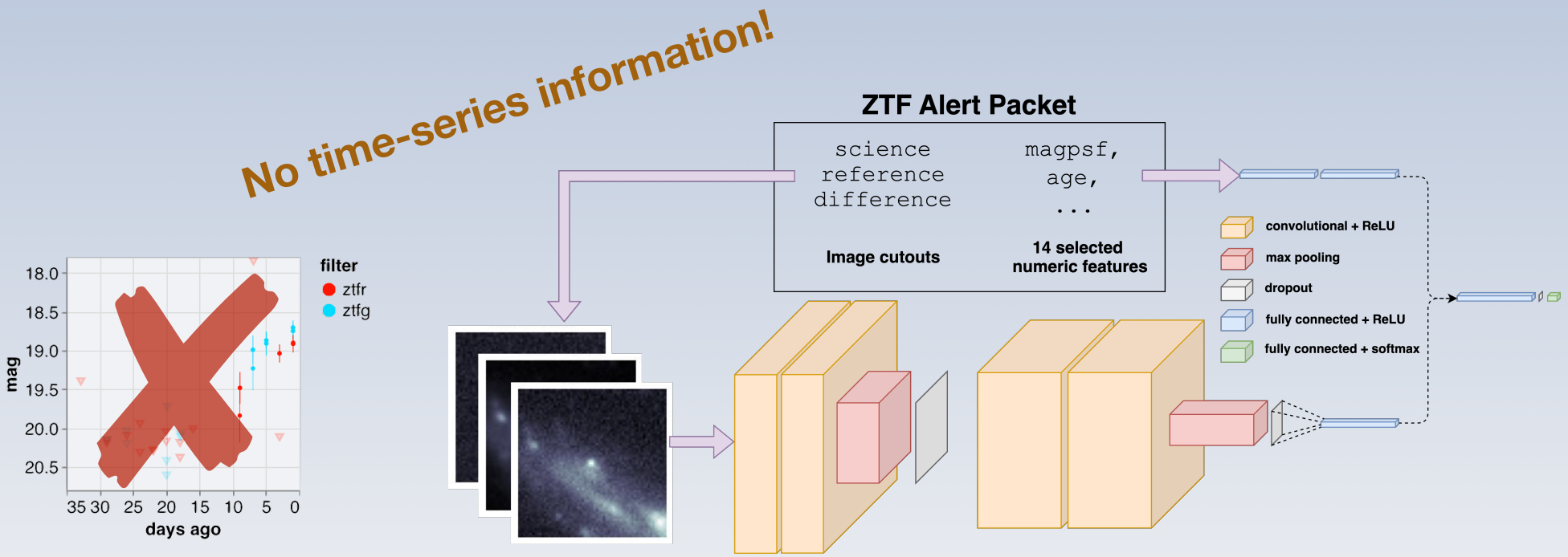
BTSbot, a multi-input convolutional neural network



BTSbot, a multi-input convolutional neural network



BTSbot, a multi-input convolutional neural network



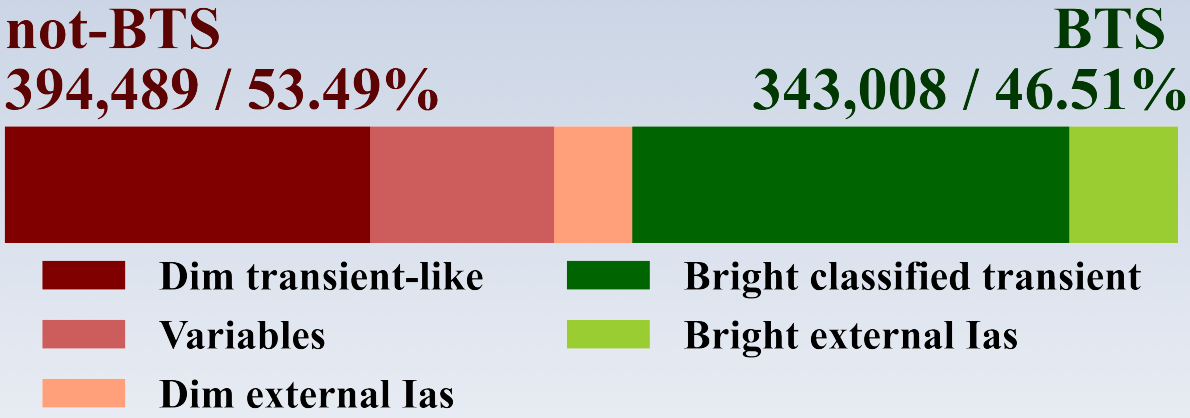
Training the model

Training set

Enabled by ZTF archive

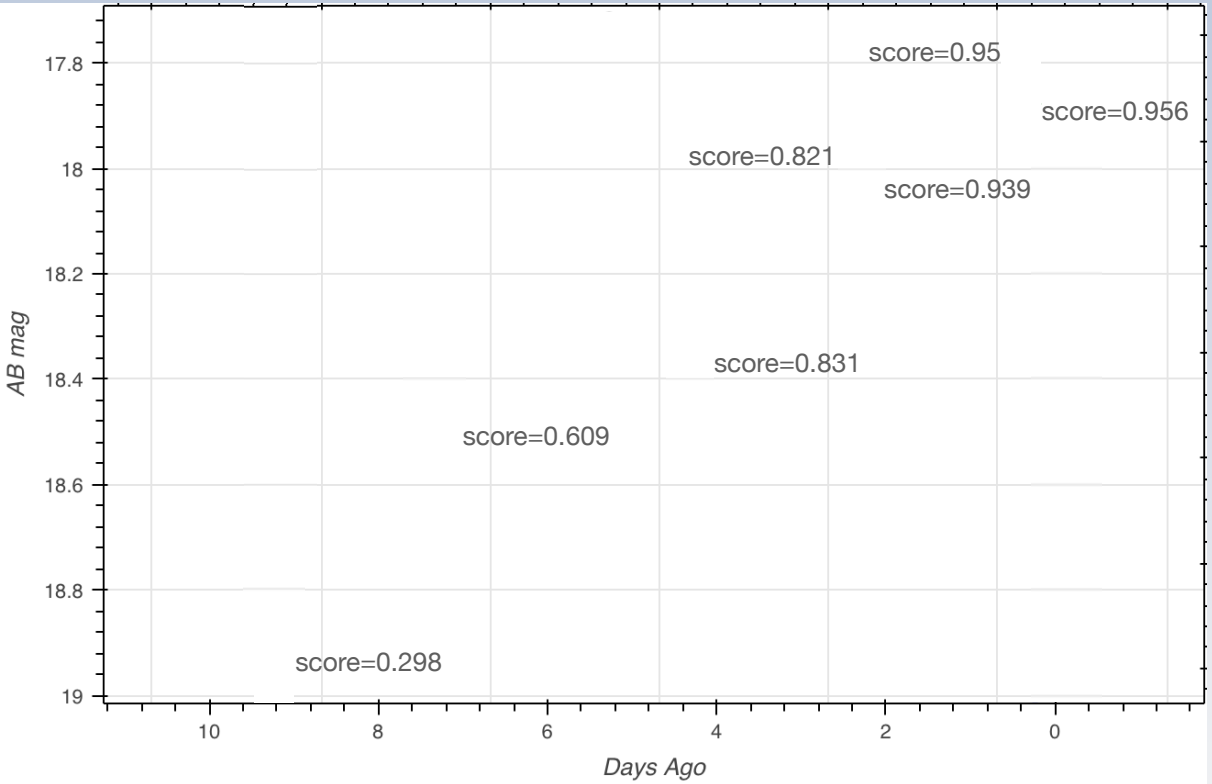
Prevent overfitting

- Class weights
- Thinning alerts
- Data augmentation



Alert-to-source classification policy

- Many scores per source
- When to call a **source** a bright transient?
- Define *policy*

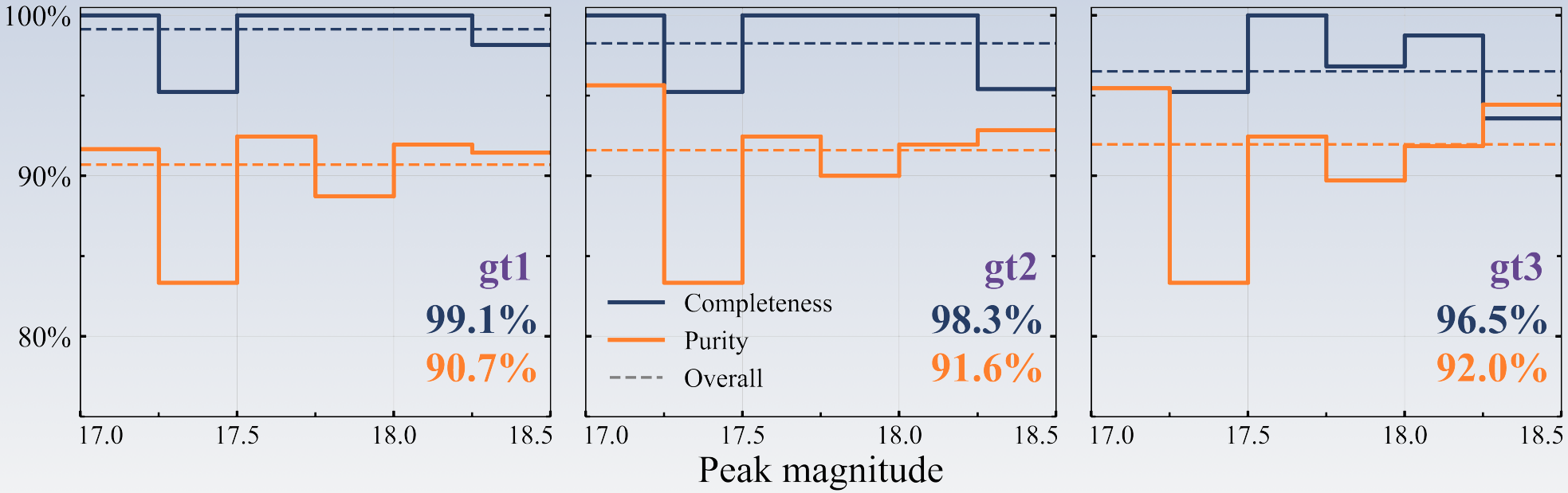


Completeness and purity

$$\text{Completeness} = \frac{\text{TP}}{\text{TP} + \text{FN}}$$

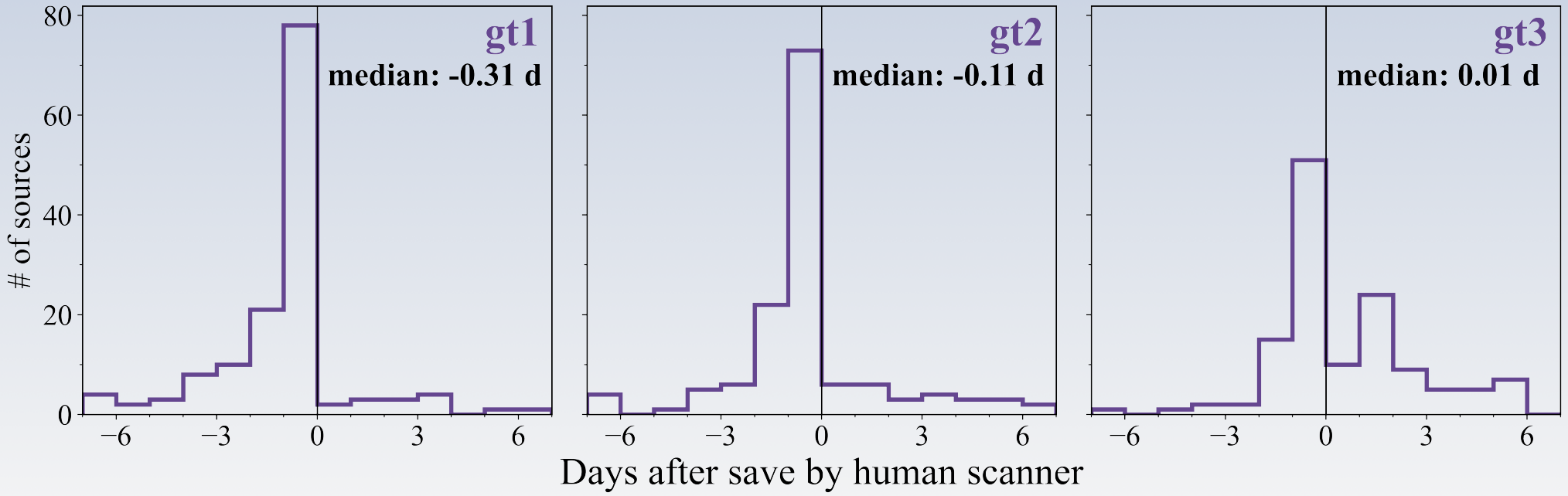
$$\text{Purity} = \frac{\text{TP}}{\text{TP} + \text{FP}}$$

`gtN`: Classify as bright transient when $\geq N$ alerts with score ≥ 0.5



Save-time analysis

`gtN`: Classify as bright transient
when $\geq N$ alerts with score ≥ 0.5

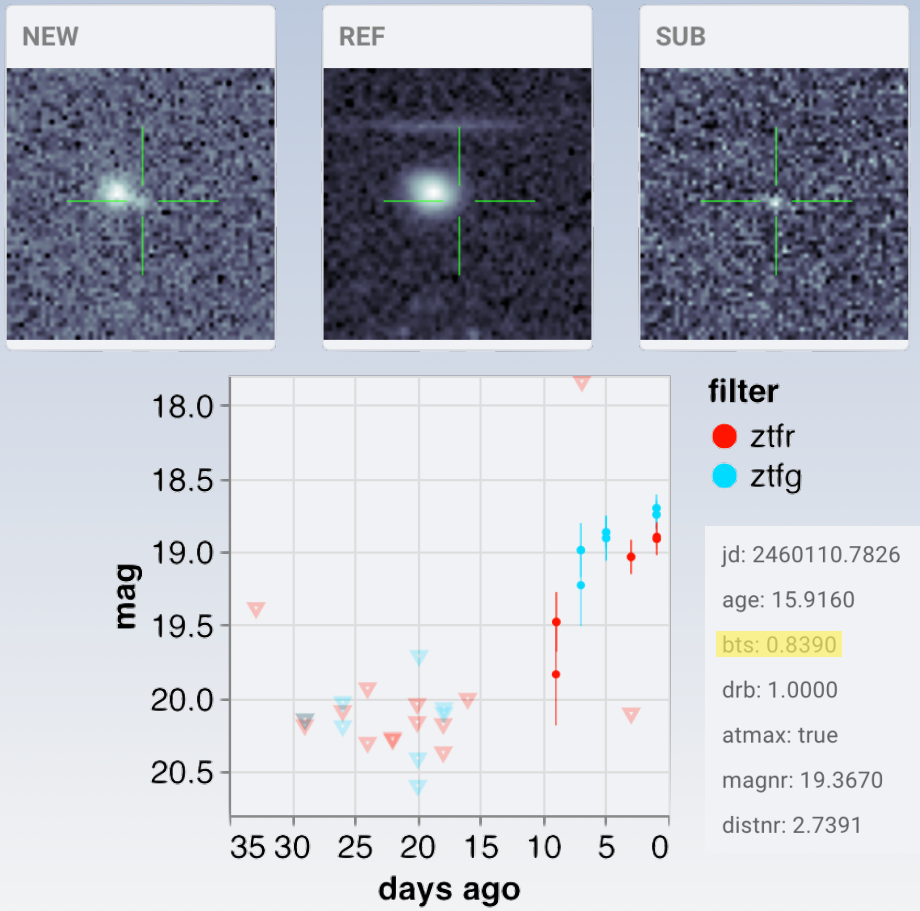


Operating in real-time

- Running in real-time on all new ZTF alerts

`autoscan`

- Check for new bright transients during the night
- Save sources that pass chosen policy
- *Next*: Automatically request a spectrum during the night

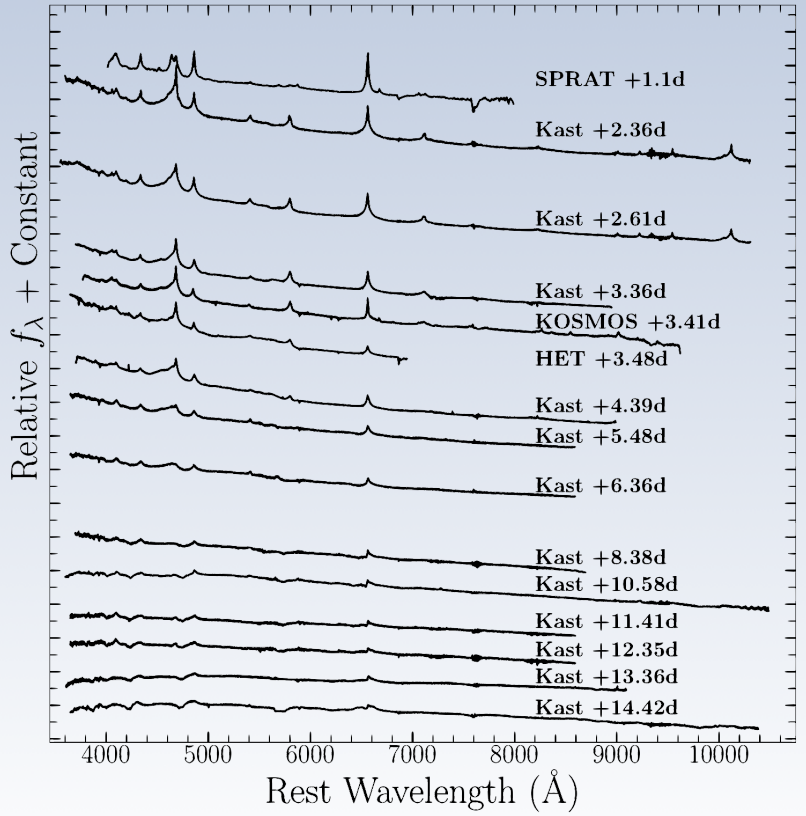


Same-night follow-up

Case study: SN2023ixf, a SN in M101

- Discovered by Koichi Itagaki - 05/19 14:42 PDT
- First spectrum (Perley+2023) - 05/19 15:23 PDT
- Detection by ZTF - 05/19 00:45 PDT
  - Score=0.840 from **`BTSbot`**

- **`autoscan`** sees new alert by - 05/19 01:00 PDT
  - Identify source and request spectrum
- End of observing - 5/20 05:00 PDT



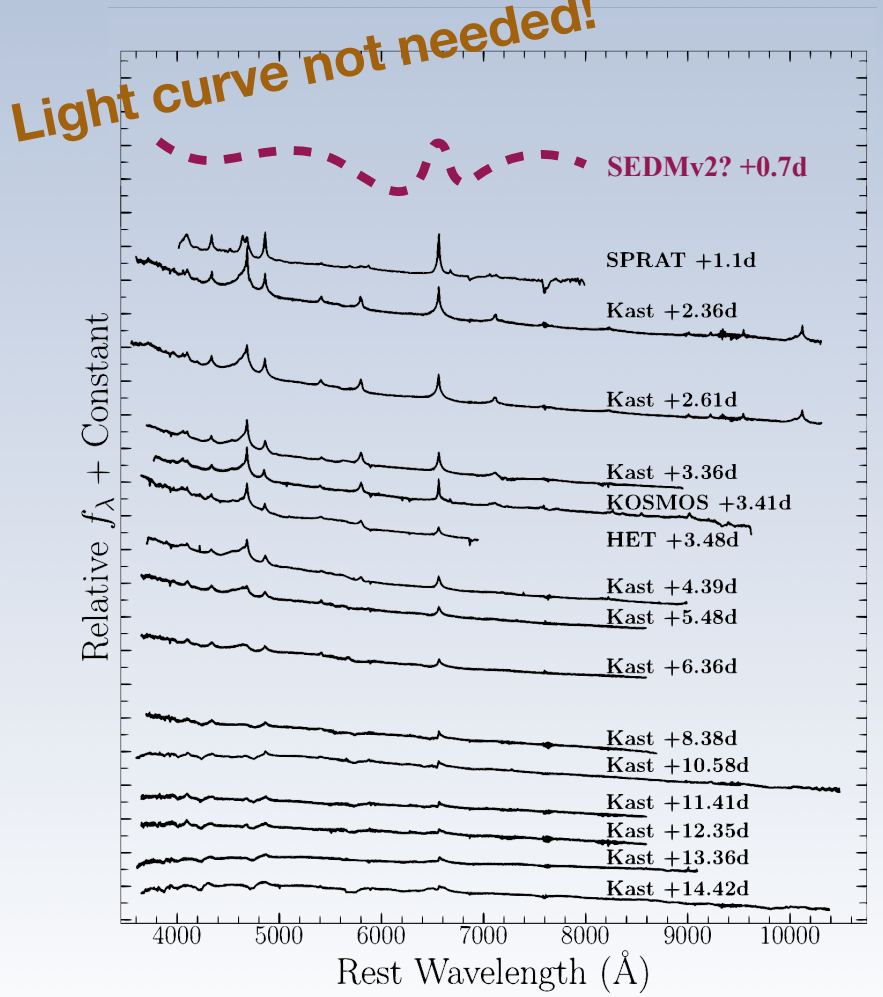
www.wis-tns.org/object/2023ixf, Figure modified from Jacobson-Galán+2023

Same-night follow-up

Case study: SN2023ixf, a SN in M101

- Discovered by Koichi Itagaki - 05/19 14:42 PDT
- First spectrum (Perley+2023) - 05/19 15:23 PDT
- Detection by ZTF - 05/19 00:45 PDT
  - Score=0.840 from **`BTSbot`**

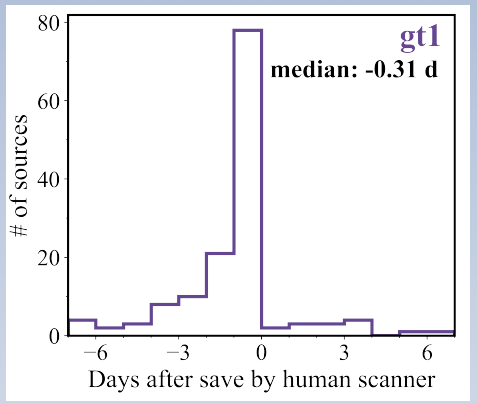
- **`autoscan`** sees new alert by - 05/19 01:00 PDT
  - Identify source and request spectrum
- End of observing - 5/20 05:00 PDT

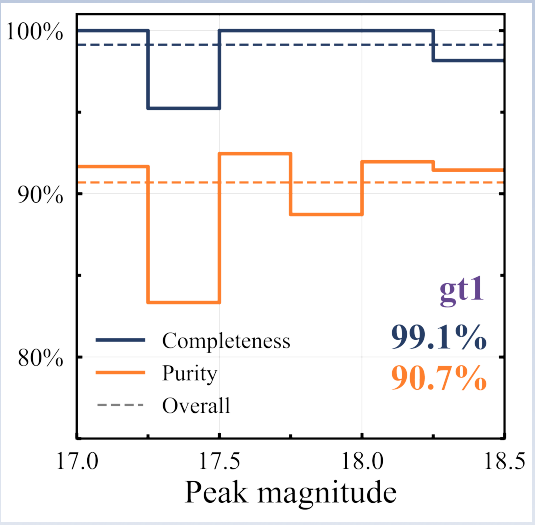


www.wis-tns.org/object/2023ixf, Figure modified from Jacobson-Galán+2023

Conclusions

- Automating scanning for BTS
- **`BTSbot`**: MI-CNN, no light-curves
- Outperforms expert scanners
  - 99% complete, 0.3 d quicker
- Integrated into ZTF
- **`autoscan`**: accelerating follow-up





Ask me about:

- Techniques to mitigate overfitting
- Model performance without metadata
- Application to LSST, LS4, etc.

Thank you!

Zwicky Transient Facility

Bonus slides

Performance metric definitions

Completeness, purity, and save-time analysis

$$\text{Completeness} = \frac{\text{TP}}{\text{TP} + \text{FN}}$$

$$\text{Purity} = \frac{\text{TP}}{\text{TP} + \text{FP}}$$

$\text{jd}_{\text{BTSbot}}$ jd of first alert to pass policy

$\text{jd}_{\text{scanner}}$ jd of save to BTS group on Fritz (alert broker)

$$\Delta\text{jd} = \text{jd}_{\text{scanner}} - \text{jd}_{\text{BTSbot}}$$

Selected metadata features

- `sgscore{1,2}` - Star-galaxy score of nearest two sources PS1-catalog
- `distpsnr{1,2}` - angular distance to nearest two sources PS1-catalog
- `fwhm` - Full Width Half Max
- `magpsf` - PSF magnitude
- `sigmapsf` - 1-sigma uncertainty in PSF magnitude
- `ra, dec` - Right Ascension and Declination

zwickytransientfacility.github.io, Miller+2017

Selected metadata features

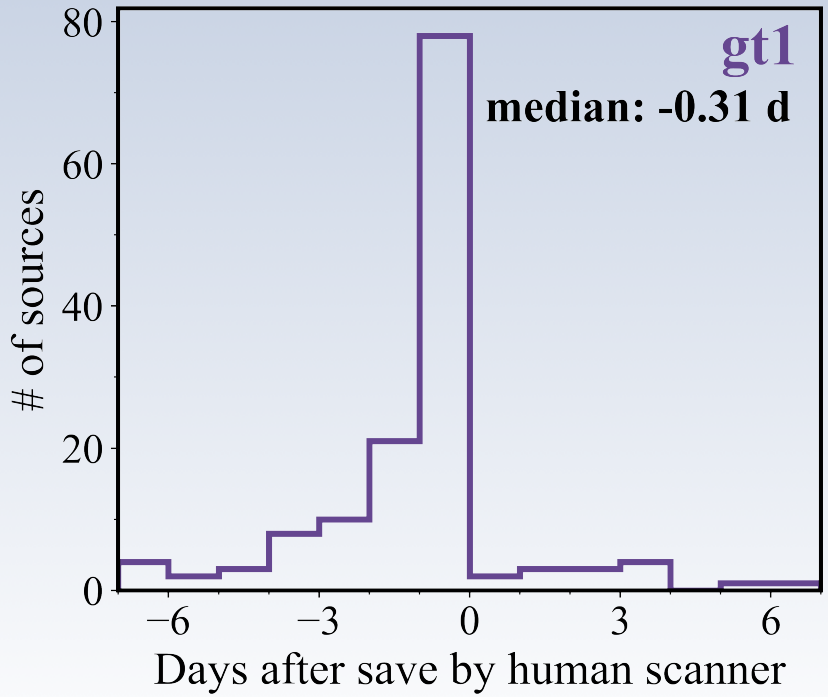
- `diffmaglim` - Limiting magnitude for detection in difference image
- `ndethist` - Number of ZTF detections at this location
- `nmtchps` - Number of PS1 source matches within 30”

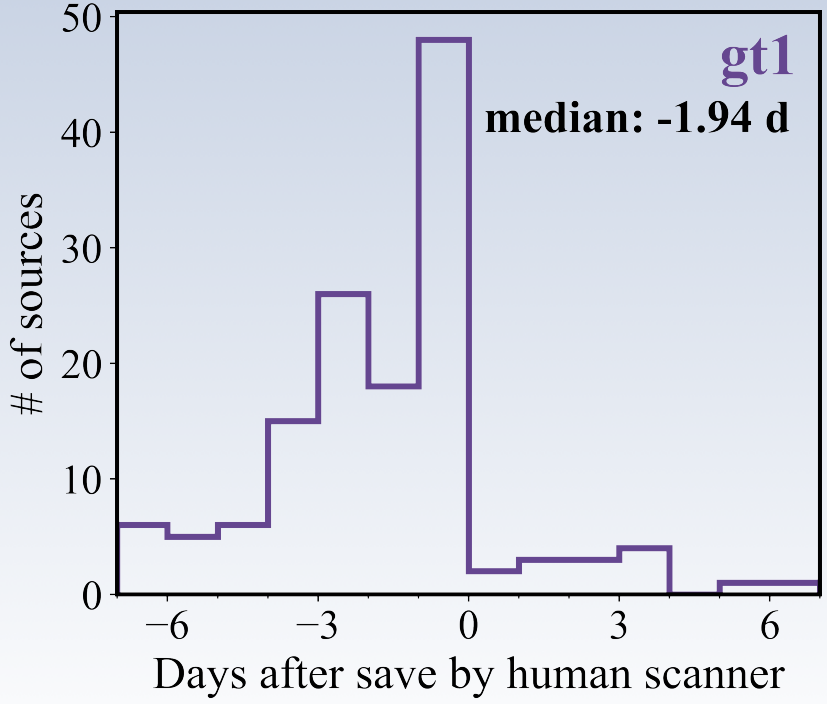
Custom features:

- `age` - Days since first detection
- `peakmag` - Brightest PSF magnitude so far

Even quicker, deeper saves

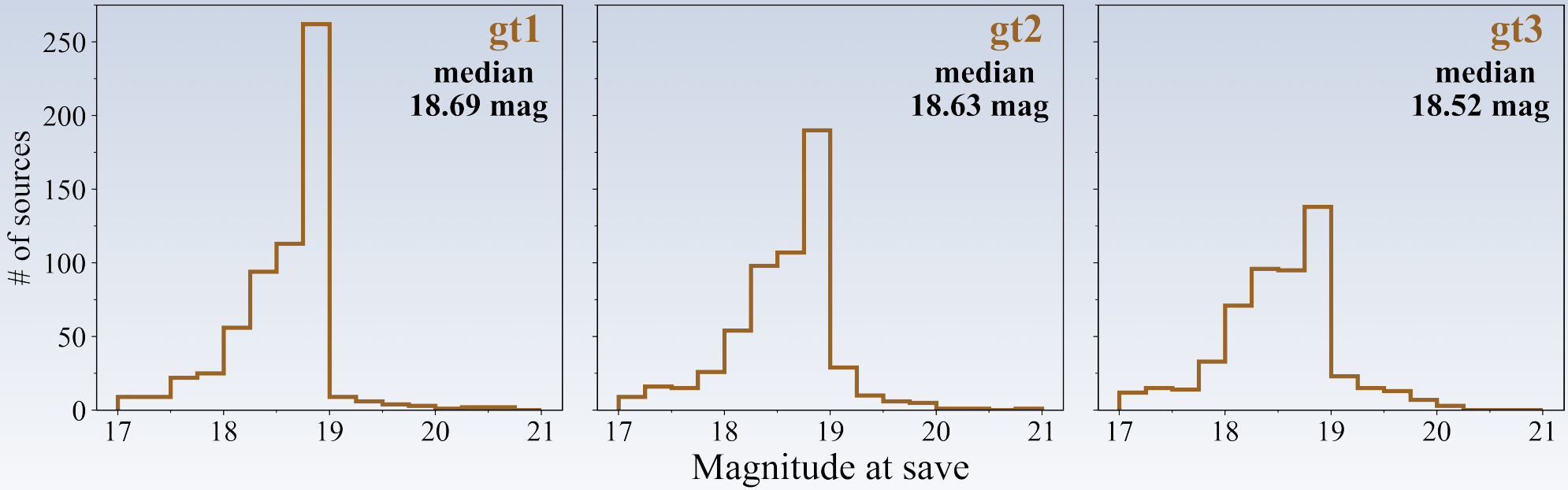
Trigger on sources with m<19 mag



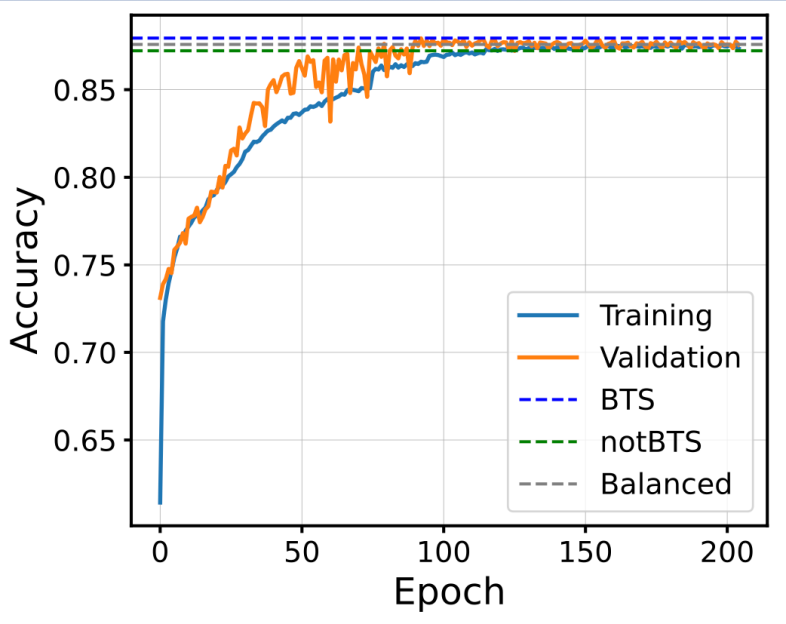


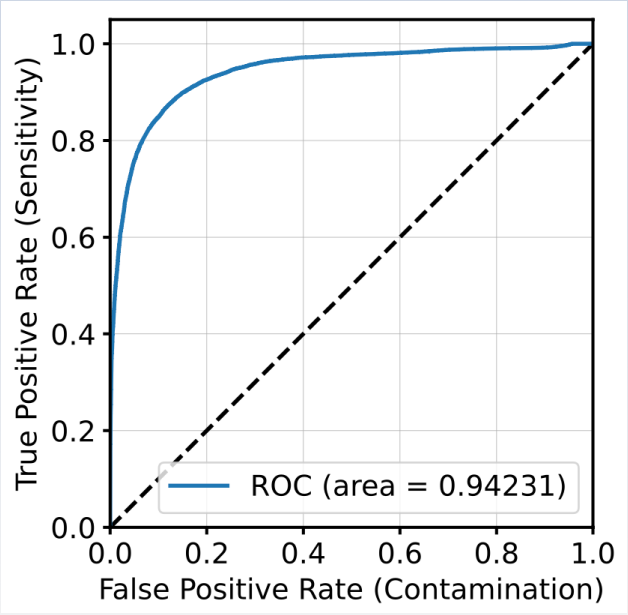
Even quicker, deeper saves

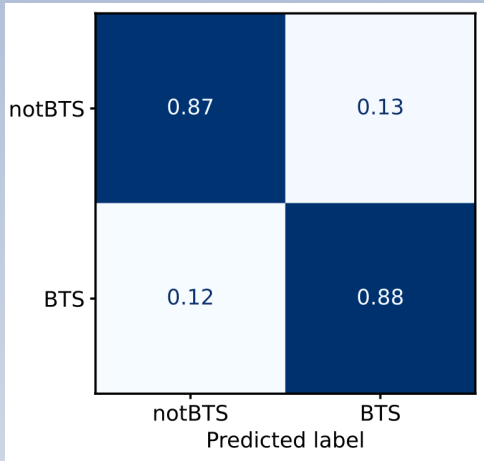
gt1 is as fast as possible for many sources

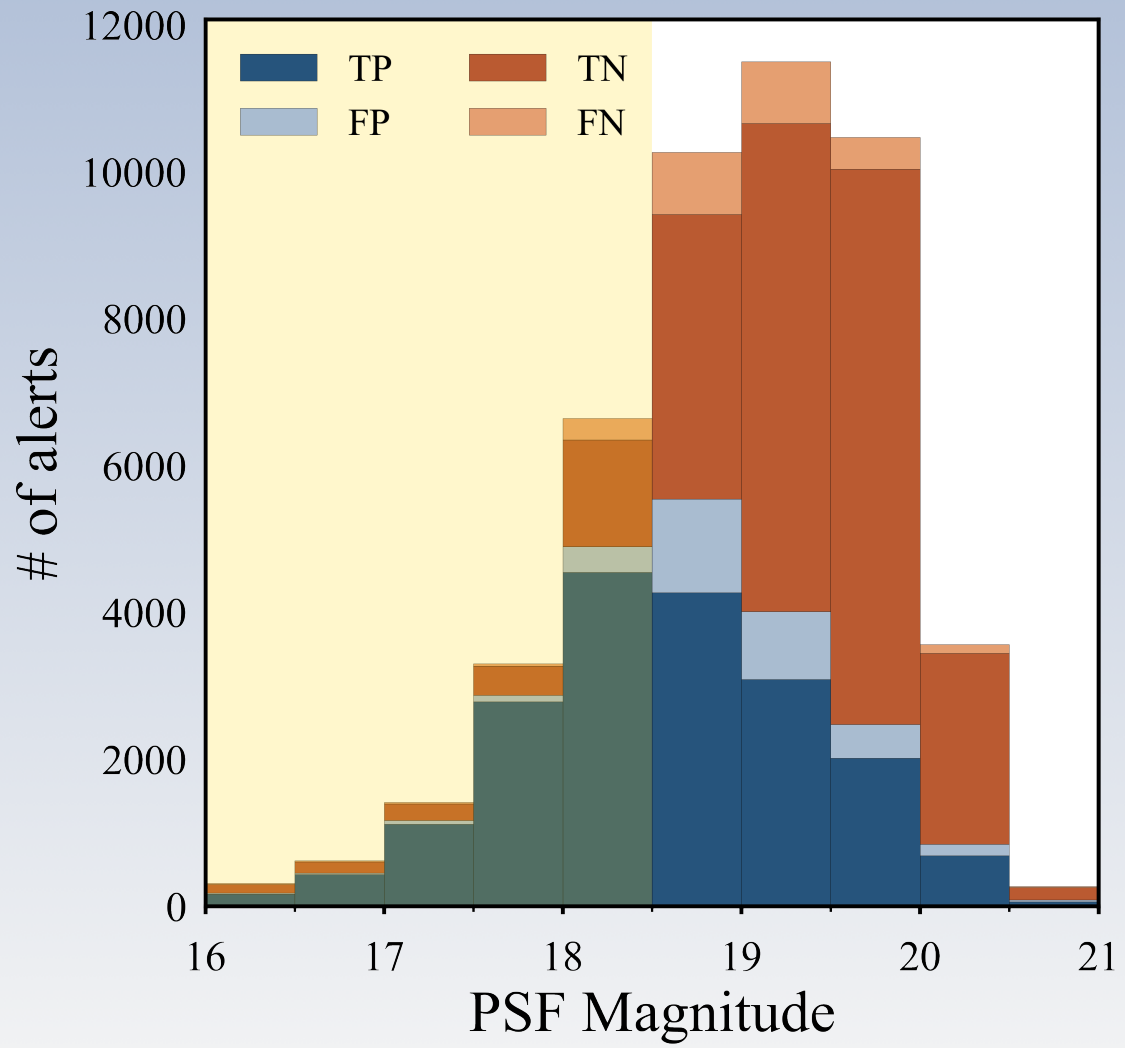


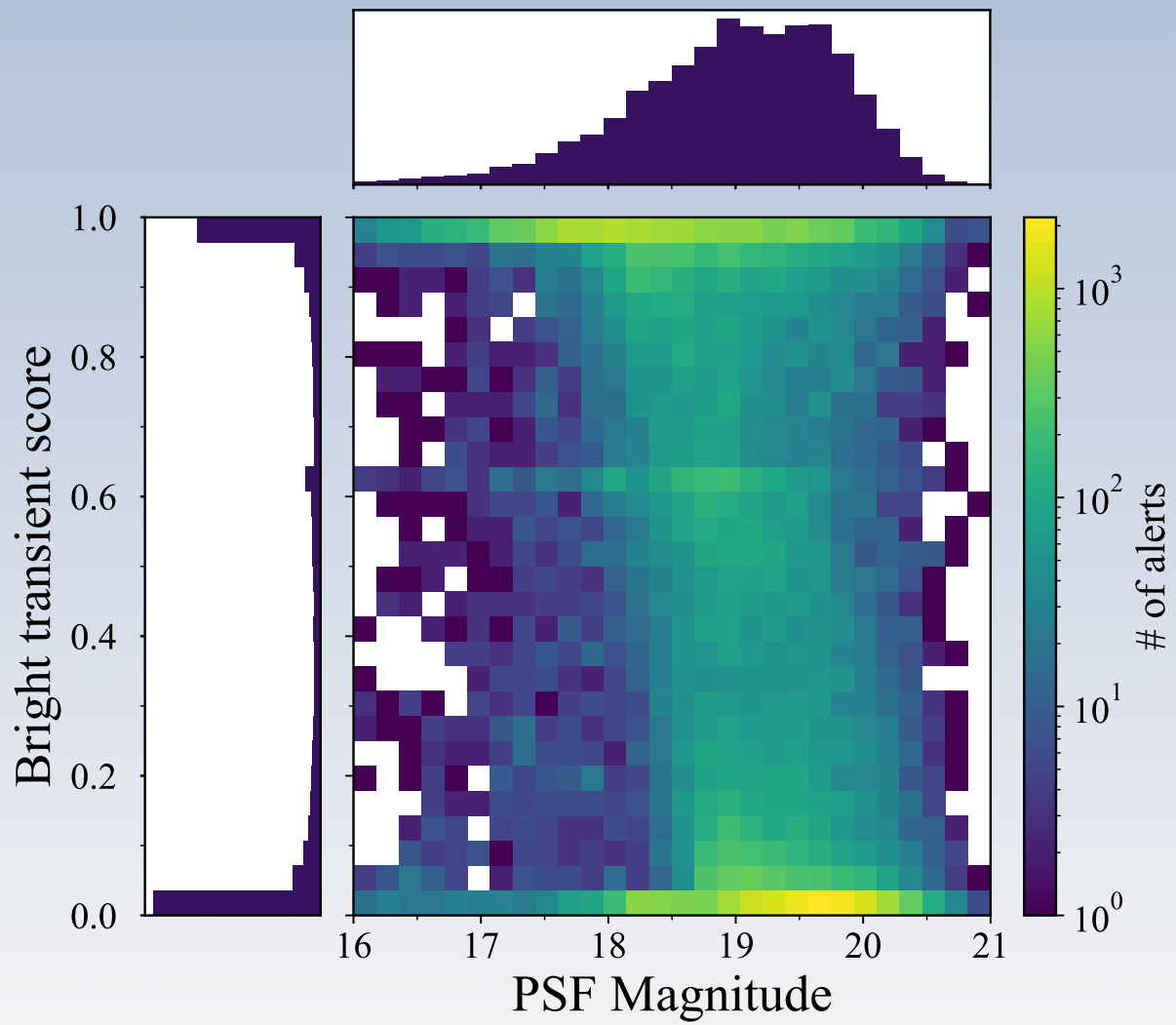
Other performance metrics



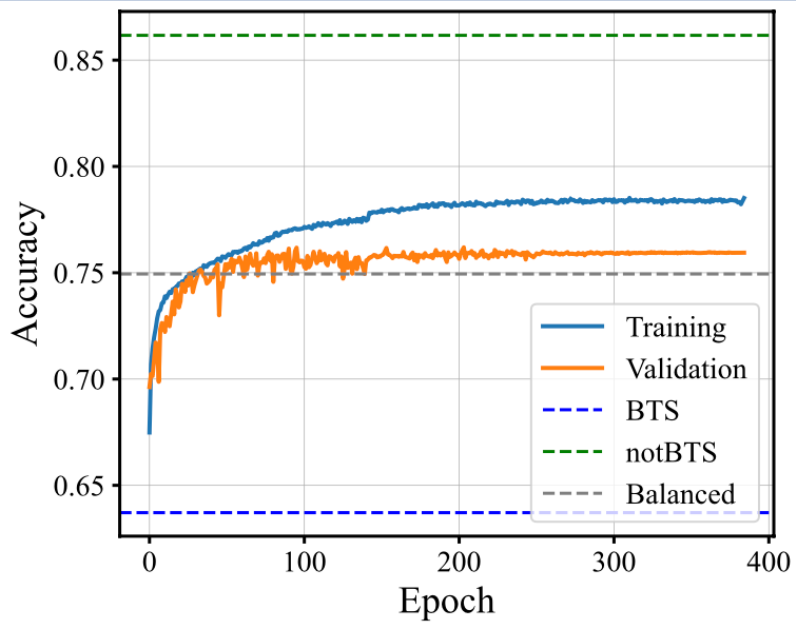


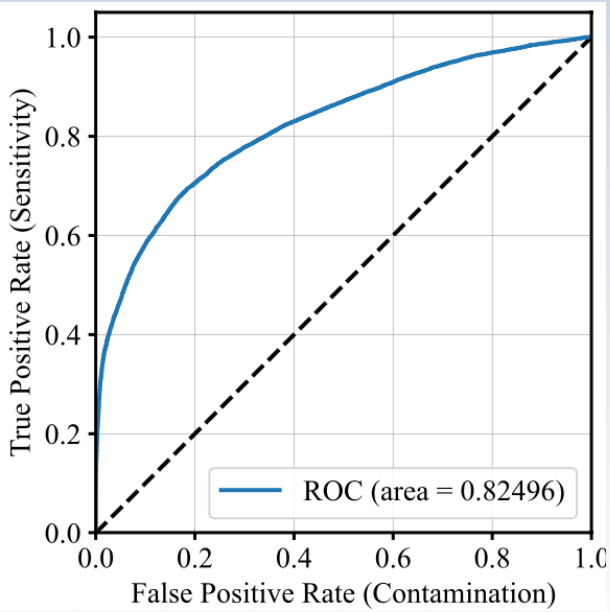


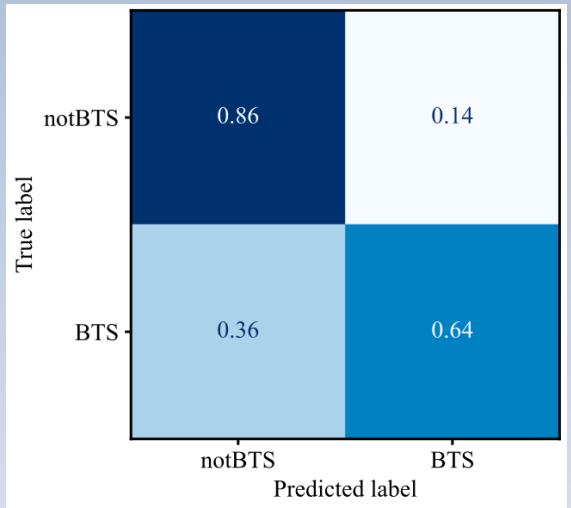

TP
TN
FP
FN
12000
10000
8000
6000
4000
2000
0
# of alerts
16
17
18
19
20
21
PSF Magnitude


Bright transient score
1.0
0.8
0.6
0.4
0.2
0.0
16
17
18
19
20
21
PSF Magnitude
10^3
10^2
10^1
10^0
# of alerts

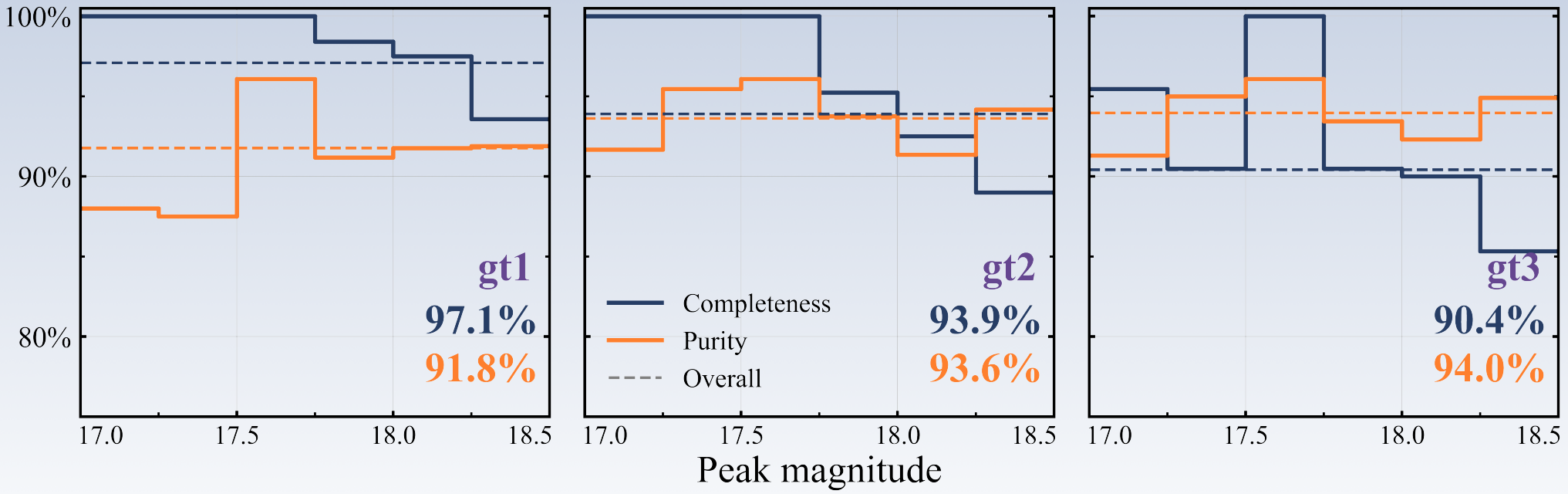
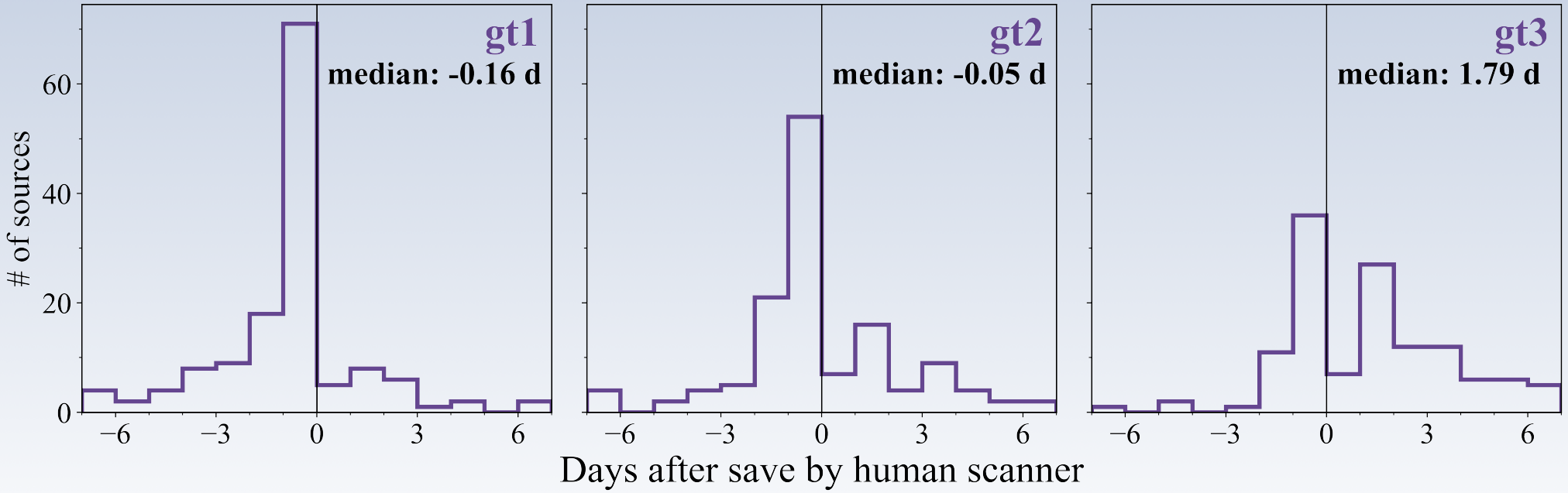
Traditional CNN performance







Traditional CNN performance



Traditional CNN performance