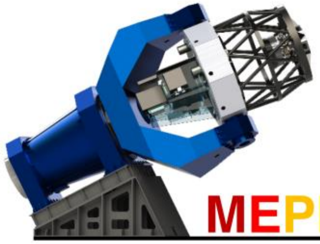


The Zwicky Transient Facility Bright Transient Survey. III. BTSbot: Automated Identification and Follow-up of Bright Transients with Deep Learning

Nabeel Rehemtulla[1,2] Adam A. Miller[1,2] Theophile Jegou Du Laz[3] Michael W. Coughlin[4] Christoffer Fremling[3,5] Daniel A. Perley[6] Yu-Jing Qin[3] Jesper Sollerman[7] Ashish A. Mahabal[3,8] Russ R. Laher[9] Reed Riddle[5] Ben Rusholme[9] and Shrinivas R. Kulkarni[3]

[1] Department of Physics and Astronomy, Northwestern University, 2145 Sheridan Road, Evanston, IL 60208, USA
[2] Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA), 1800 Sherman Ave., Evanston, IL 60201, USA
[3] Division of Physics, Mathematics, and Astronomy 249-17, California Institute of Technology, Pasadena, CA 91125, USA
[4] School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455, USA
[5] Caltech Optical Observatories, California Institute of Technology, Pasadena, CA 91125, USA
[6] Astrophysics Research Institute, Liverpool John Moores University, IC2, Liverpool Science Park, 146 Brownlow Hill, Liverpool L3 5RF, UK
[7] Department of Astronomy, The Oskar Klein Center, Stockholm University, AlbaNova, SE-10691 Stockholm, Sweden
[8] Center for Data Driven Discovery, California Institute of Technology, Pasadena, CA 91125, USA
[9] IPAC, California Institute of Technology, 1200 E. California Blvd, Pasadena, CA 91125, USA

Lunwei Zhang
2024-05-17

https://www.frontiersin.org/articles/10.3389/fspas.2021.718139/full

Outline

Part I Introduction

Part II Data and Method

Part III Results and Disscusion

Part IV Summary

Part I Introduction

1.1 Introduction

- The goal of the Bright Transient Survey (BTS) is to spectroscopically classify all extragalactic transients brighter than 18.5 mag (<18.5 mag)in either the g-ZTF or r-ZTF-filters at peak brightness and immediately announce those classifications to the public.

- Some of the largest **SN population studies** conducted to date (e.g., Perley et al. 2020; Irani et al. 2022; Sharon & Kushnir 2022; Sollerman et al. 2022; Rodr´ıguez et al.2023; Cold & Hjorth 2023; Sharma et al. 2023)

- The survey also provides **unique discoveries**(e.g., Goobar et al. 2023; Yang et al. 2021)

- Paving the way for using SNe to **study large scale structure** (Tsaprazi et al. 2022)

……

1.2 Introduction-previous work

BTS

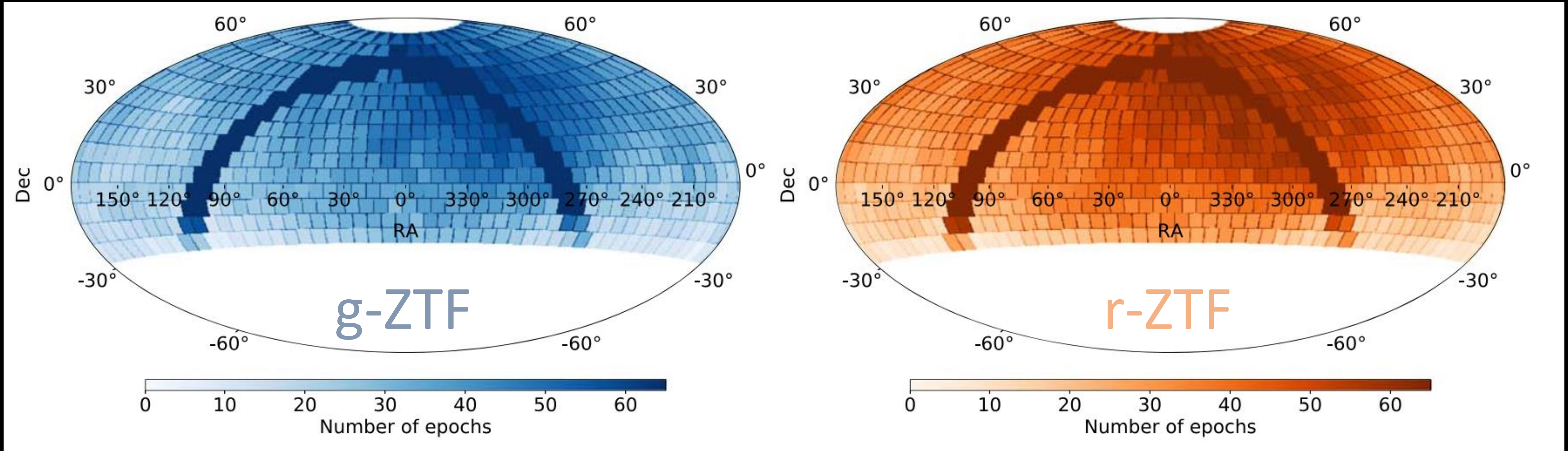


Figure 1. Coverage maps for the ZTF MSIP surveys, in the g_{ZTF} (left panel) and r_{ZTF} bands (right panel) between 2018 April 1 and 2018 December 31. The colored rectangles represent the fixed ZTF main field grid. The color intensity indicates the number of observations during this time period, truncated to a maximum of 65.

2018 Apr. 1 to 2018 Dec. 31

1.1 Introduction-previous work

The Astrophysical Journal, 895:32 (19pp), 2020 May 20 https://doi.org/10.3847/1538-4357/ab8943

CrossMark

The Zwicky Transient Facility Bright Transient Survey. I. Spectroscopic Classification and the Redshift Completeness of Local Galaxy Catalogs

C. Fremling[1], A. A. Miller[2,3], Y. Sharma[1], A. Dugas[1,4], D. A. Perley[5], K. Taggart[5], J. Sollerman[6], A. Goobar[7], M. L. Graham[8], J. D. Neill[1], J. Nordin[9], M. Rigault[10], R. Walters[1,11], I. Andreoni[1], A. Bagdasaryan[1], J. Belicki[11], C. Cannella[12], E. C. Bellm[8], S. B. Cenko[13], K. De[1], R. Dekany[11], S. Frederick[14], V. Z. Golkhou[8,15,21], M. J. Graham[1], G. Helou[16], A. Y. Q. Ho[1], M. M. Kasliwal[1], T. Kupfer[17], R. R. Laher[16], A. Mahabal[1,18], F. J. Masci[16], R. Riddle[11], B. Rusholme[16], S. Schulze[19], D. L. Shupe[16], R. M. Smith[11], S. van Velzen[14,20], Lin Yan[11], Y. Yao[1], Z. Zhuang[1], and S. R. Kulkarni[1]

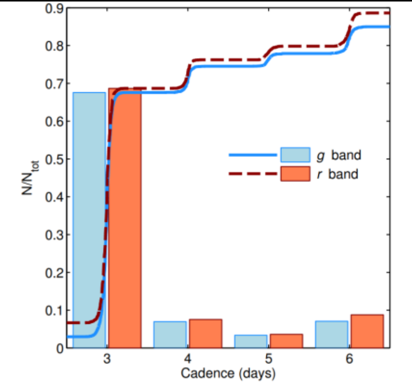


Figure 2. Cadence distribution for the ZTF NSS, in the $g_{\rm ZTF}$- (blue bars) and $r_{\rm ZTF}$-band (red bars), truncated at six days. Cumulative distributions are shown as a blue solid line for the g band and a red dashed line for the r band. $N/N_{\rm tot}$ is the fraction of observations at a specific cadence compared to the total number of observations between 2018 Apr. 1 and 2018 Dec. 31.

761 BTS SNe

2018 Apr. 1 to 2018 Dec. 31

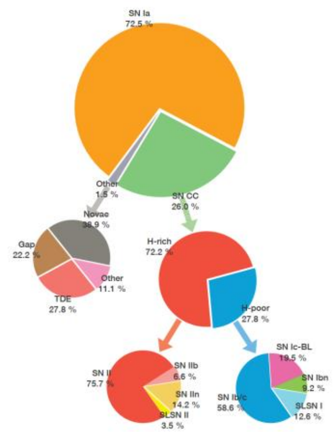
The Astrophysical Journal, 904:35 (24pp), 2020 November 20 https://doi.org/10.3847/1538-4357/abbd98

CrossMark

The Zwicky Transient Facility Bright Transient Survey. II. A Public Statistical Sample for Exploring Supernova Demographics*

Daniel A. Perley[1], Christoffer Fremling[2], Jesper Sollerman[3], Adam A. Miller[4,5], Aishwarya S. Dahiwale[2], Yashvi Sharma[2], Eric C. Bellm[6], Rahul Biswas[7], Thomas G. Brink[8], Rachel J. Bruch[9], Kishalay De[2], Richard Dekany[10], Andrew J. Drake[2], Dmitry A. Duev[2], Alexei V. Filippenko[8,11], Avishay Gal-Yam[12], Ariel Goobar[7], Matthew J. Graham[2], Melissa L. Graham[6], Anna Y. Q. Ho[2,8,13], Ido Irani[12], Mansi M. Kasliwal[2], Young-Lo Kim[14], S. R. Kulkarni[2], Ashish Mahabal[2,15], Frank J. Masci[16], Shaunak Modak[8], James D. Neill[2], Jakob Nordin[17], Reed L. Riddle[10], Maayane T. Soumagnac[9,18], Nora L. Strotjohann[12], Steve Schulze[12], Kirsty Taggart[1], Anastasios Tzanidakis[2], Richard S. Walters[2], and Lin Yan[10]

1206 BTS



1.2 Introduction-Motivations

- **BTS critically relies on visual inspection ("scanning") to select targets for spectroscopic follow-up, which, while effective, has required a significant time investment over the past ~5 yr of ZTF operations;**

- **Under the large, wide-field time-domain surveys, alert filters are needed to identify candidate sources of interest;**

- **Adopting ML will be near-compulsory to efficiently extract knowledge from the next generation of surveys;**

- While appropriate in some cases with traditional ML or CNN, limiting these models to extracted features alone ignores potentially valuable information present in the images from which the features are extracted.

Part II Data and Method

2.1 Data

BTS only from ZTF

1/3 query

"trues"

"vars"

"dims"

"rejects"

~~"junk"~~

Name of Query	Number of Sources	Number of Alerts
Initial queries		
trues[a]	5,212	308,934
vars[b]	1,127	150,017
dims[c]	8,979	249,087
rejects[d]	4,417	407,357
Total	19,735	1,115,395

2/3 humman

“Humman Scanner"

63×63×3,reference,science,difference

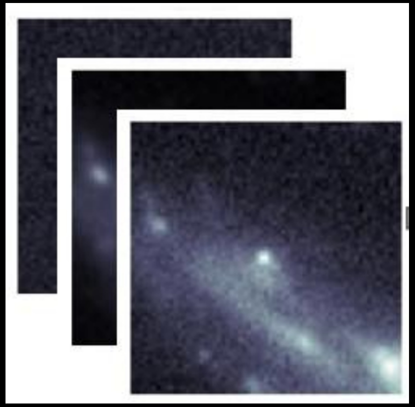


Table 4. BTSbot metadata features

Feature name	Definition [unit]
Alert packet metadata	
sgscore{1,2}	Star/Galaxy score of nearest two PS1 sources
distpsnr{1,2}	Distance to nearest two PS1 sources [arcsec]
fwhm	Full Width Half Max [pixels]
magpsf	magnitude of PSF-fit photometry [mag]
sigmapsf	1-σ uncertainty in magpsf [mag]
chipsf	Reduced χ^2 of PSF-fit
ra	Right ascension of source [deg]
dec	Declination of source [deg]
diffmaglim	5-σ magnitude detection threshold [mag]
ndethist	Number of previous detections of source
nmtchps	# of PS1 cross-matches within 30 arcsec
drb	Deep learning-based real/bogus score
ncovhist	# of times source on a field and read channel
chinr	χ parameter of nearest source in reference
sharpnr	sharp parameter of nearest source in reference
scorr	Peak-pixel S/N in detection image
sky	Local sky background estimate [DN]
Custom metadata	
days_since_peak	Time since brightest alert [days]
days_to_peak	Time from first to brightest alert [days]
age	days_since_peak + days_to_peak
peakmag_so_far	Source's minimum magpsf thusfar [mag]
maxmag_so_far	Source's maximum magpsf thusfar [mag]
nnondet[a]	ncovhist - ndethist

25 metadata features

3/3 clean

Clean

Cleaned training set		
trues[a]	5,206	264,317
vars[b]	1,126	109,934
dims[c]	8,824	223,934
rejects[d]	4,402	241,478
Total	19,558	839,663

2.1 Data

Table 1. Training set size before/after cleaning cuts

Name of Query	Number of Sources	Number of Alerts
Initial queries		
trues[a]	5,212	308,934
vars[b]	1,127	150,017
dims[c]	8,979	249,087
rejects[d]	4,417	407,357
Total	19,735	1,115,395
Cleaned training set		
trues[a]	5,206	264,317
vars[b]	1,126	109,934
dims[c]	8,824	223,934
rejects[d]	4,402	241,478
Total	19,558	839,663

[a] Spectroscopically confirmed bright ($m_{\mathrm{peak}} \leq 18.5$ mag) extragalactic transients.

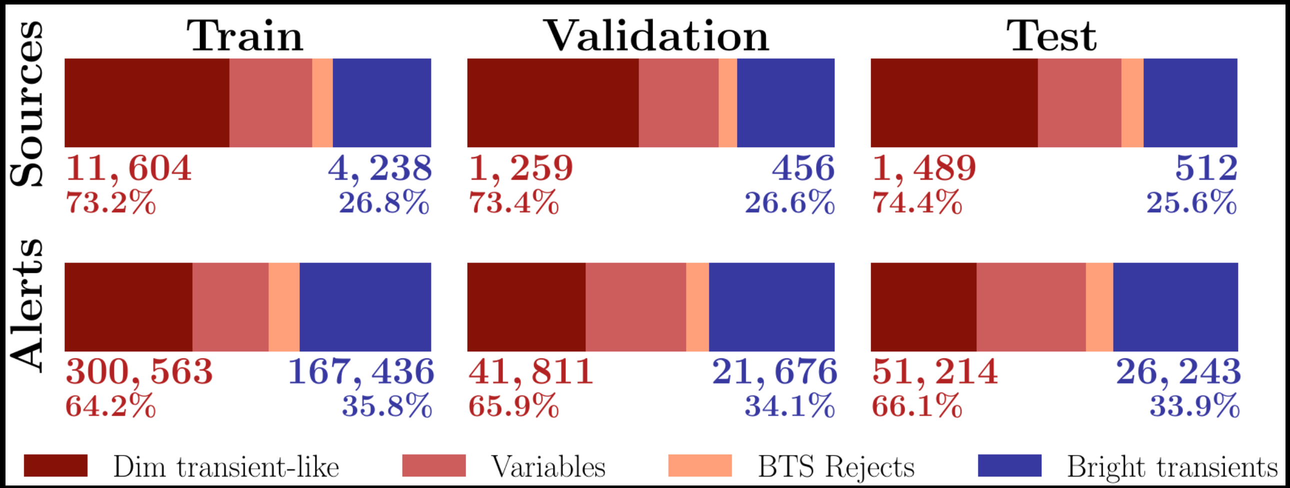
[b] Sources classified as AGN, CVs, VarStars, or QSOs.

[c] Dim ($m_{\mathrm{peak}} > 18.5$ mag) sources with transient-like light curves.

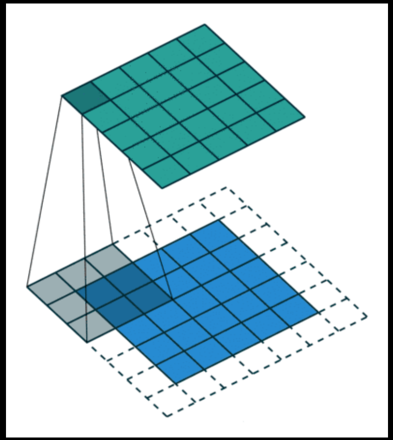
[d] Sources not marked as bright extragalactic transients by BTS scanners.

on source

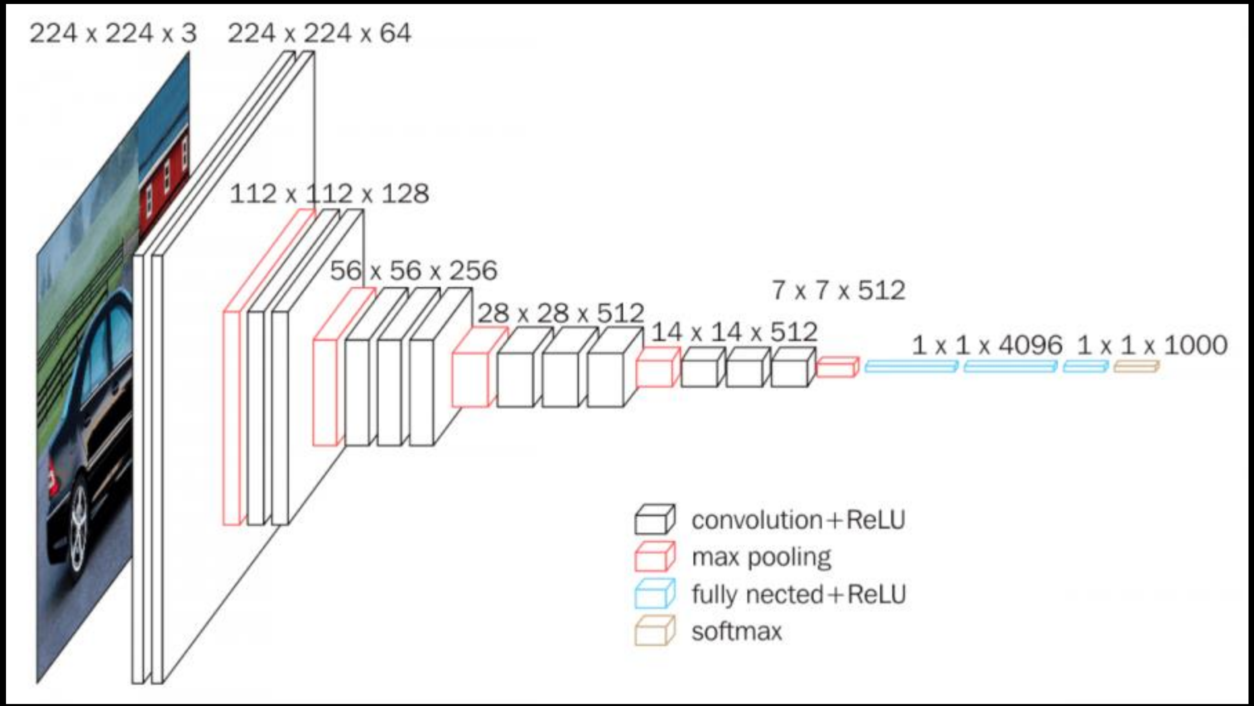
Train: 81%
Validation: 9%
test : 10%



2.2 Method



Convolution



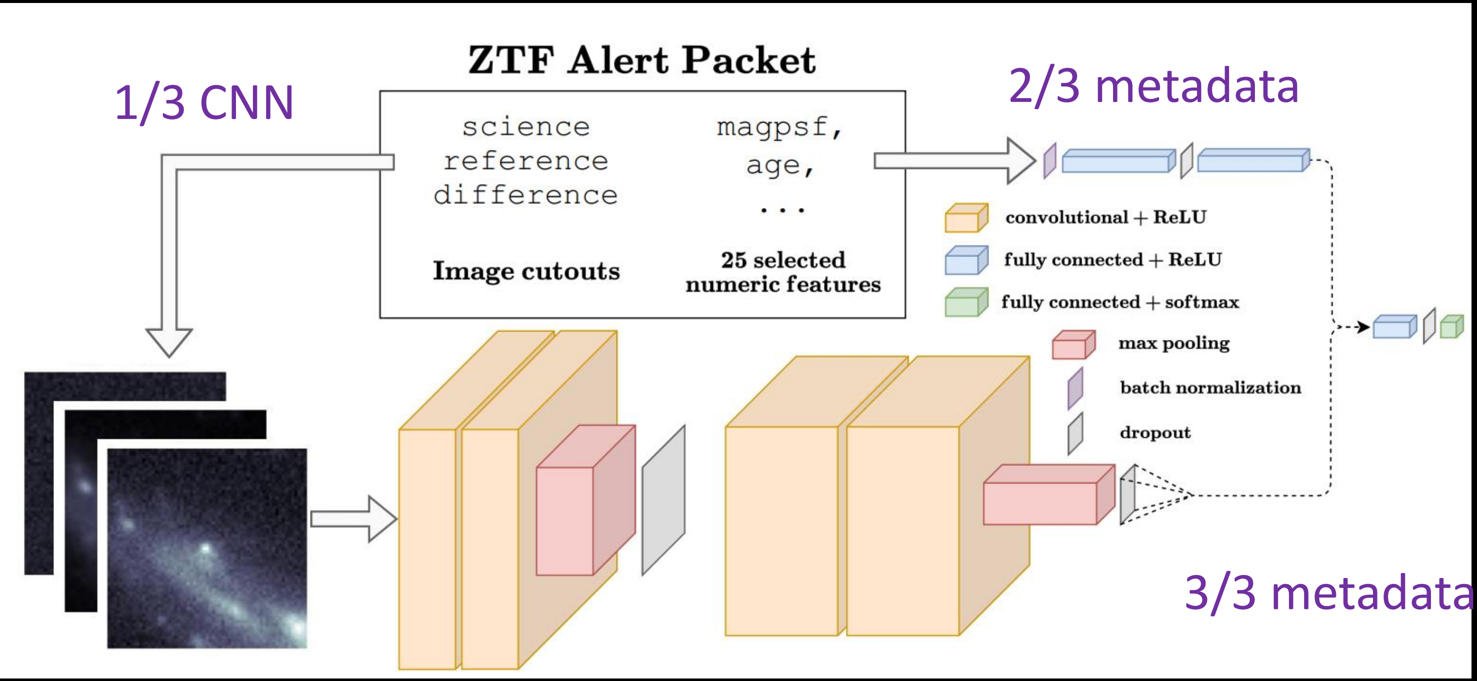
VGG network

CNN

Credit from the Internet

2.2 Method-BTSbot

Motivation: the images and the extracted features provide complementary information for performing our task



The architecture of BTSbot

Table 2. BTSbot layer configurations

Layer type	Layer parameters	Hyperparameter search range
Convolutional branch		
2D Conv.	32 filters, 5 × 5 kernel	8 – 128 filters[a]
2D Conv.	32 filters, 5 × 5 kernel	[3, 5, 7] kernel size[a]
Max pool	2 × 2 kernel	-
Dropout	0.50	0.1 – 0.8
2D Conv.	64 filters, 5 × 5 kernel	8 – 128 filters[a]
2D Conv.	64 filters, 5 × 5 kernel	[3, 5, 7] kernel size[a]
Max pool	4 × 4 kernel	-
Dropout	0.55	0.1 – 0.8
Metadata branch		
Batch norm.	-	-
Dense	128 units	32 – 256 units
Dropout	0.25	0.1 – 0.8
Dense	128 units	32 – 256 units
Combined section		
Dense	8 units	8 – 128 units
Dropout	0.20	0.1 – 0.8
Dense	1 unit	-

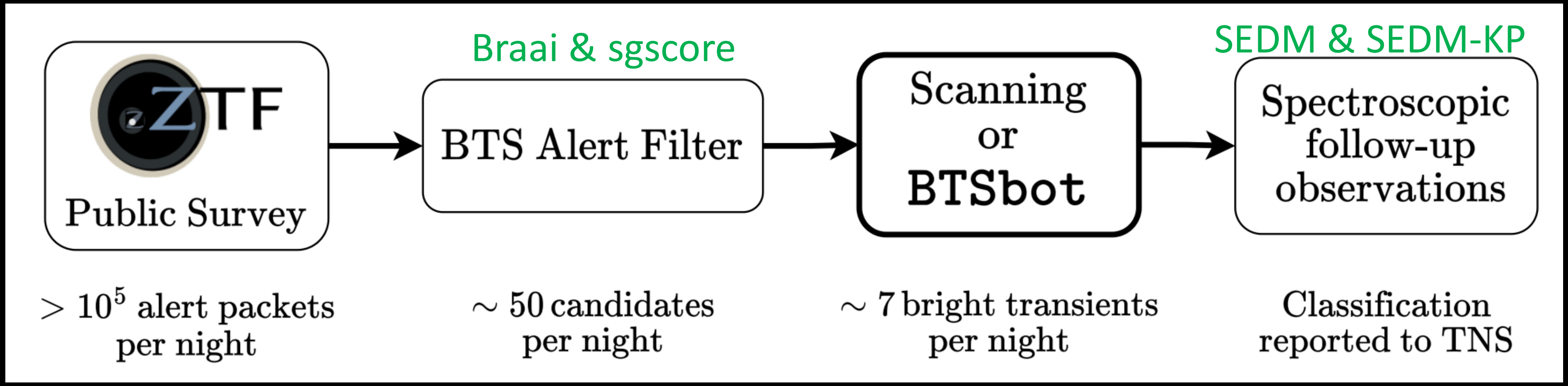
[a] All 2D Convolutional (Conv.) layers have the same search range for filter counts and kernel size.

Table 3. BTSbot hyperparameters

Parameter name	Optimized value	Hyperparameter search range
batch size	64	8 – 64
Adam β_1	0.99	0.81 – 0.999
Adam β_2	0.99	0.9 – 0.9999
learning rate (α)	10^{-4}	$10^{-2} - 5 \times 10^{-6}$
α decrease factor	0.4	0.25 – 0.75
$\alpha_{\min}$	5×10^{-10}	$10^{-10} - 10^{-5}$
$N_{\max}$	100	$1 - \infty$

BTSbot: https://github.com/nabeelre/BTSbot

2.2 Method-BTSbot



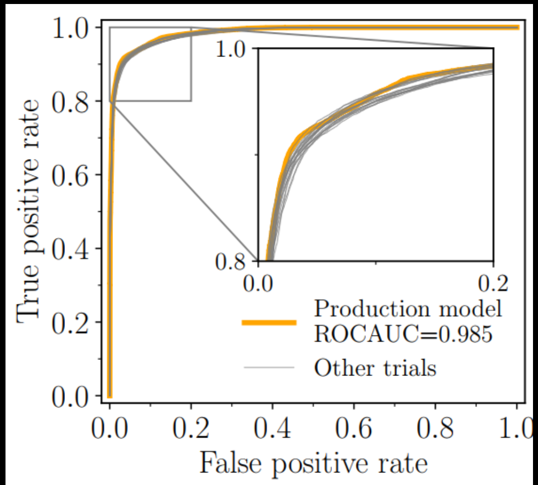
BTSbot has been integrated in Fritz and Kowalski to enable running in real-time on incoming alert packets from IPAC's alert-producing and brokering system.

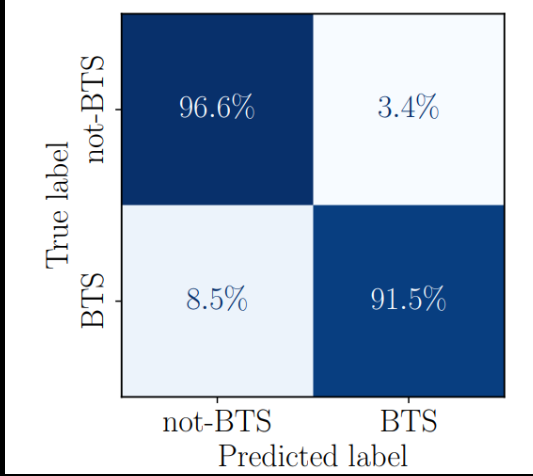
Example: About 14 hours before the first TNS report, SN 2023ixf was detected by ZTF, and, just minutes later, this alert packet was assigned a bright transient score of 0.840 by an early version of BTSbot.

Part III Results and Discussion

3.1 Results

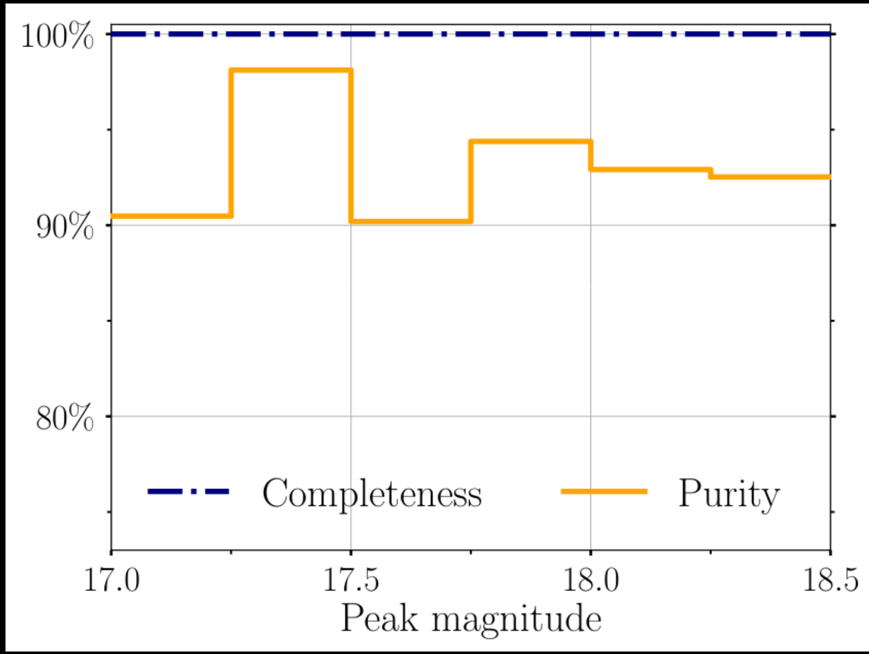
1) ROC





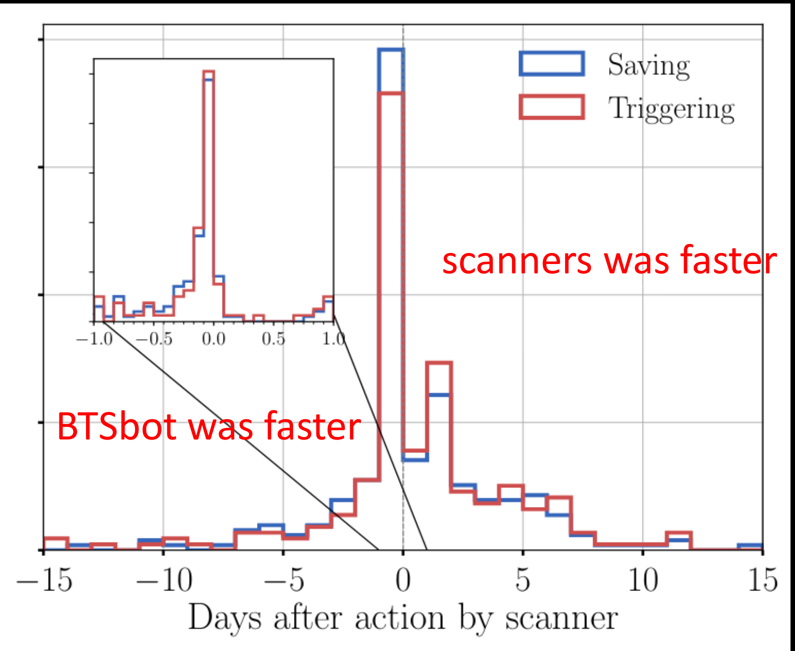
2) Confusion Matrix

3) Completeness and Purity



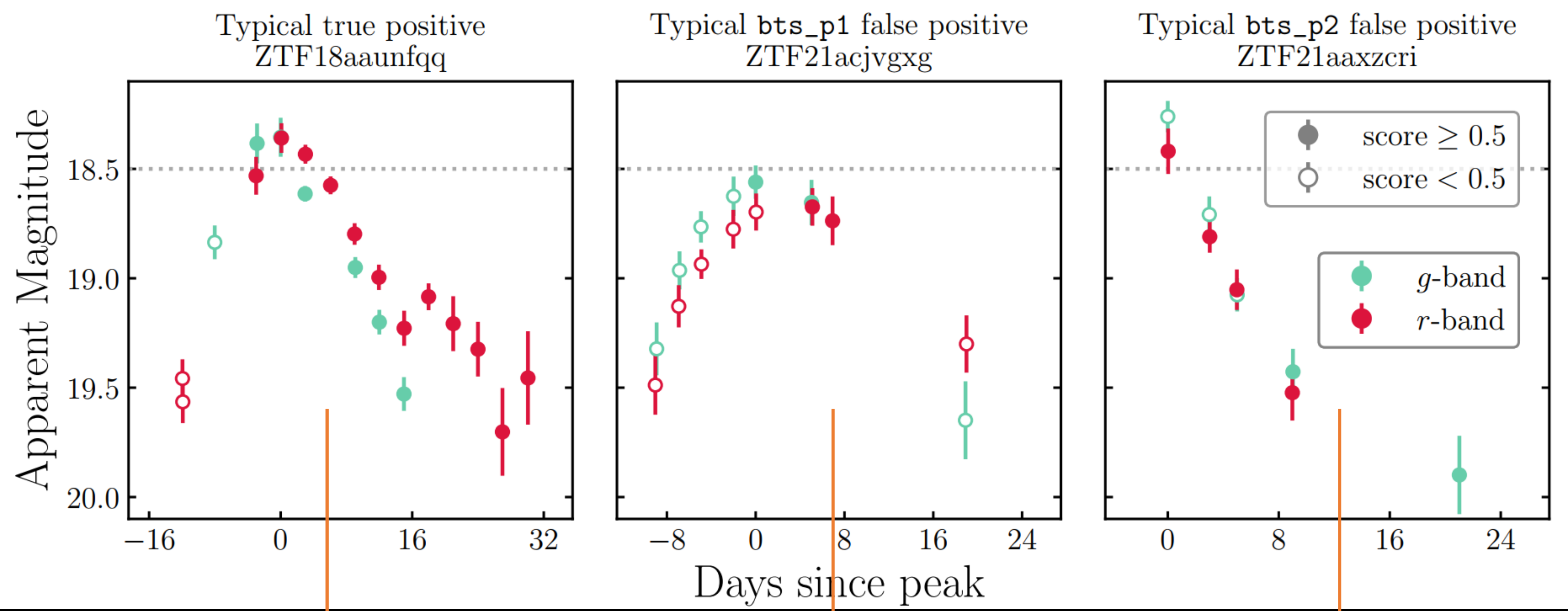
The completeness curve is exactly 100% in all peak magnitude bins, giving perfect overall completeness.

4) Comparison with human scanner



BTSbot acts as quickly as human scanners on new bright transients

3.2 Discussion-misclassifications



TPs may have low scoring alerts while still dim

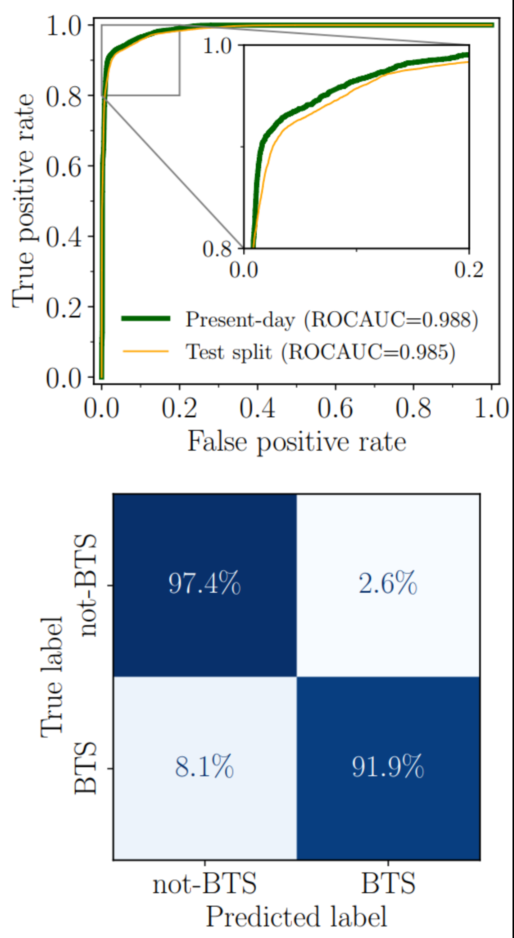
Almost all bts_p1 FPs are dim (m_peak > 18.5 mag) transients

Many bts_p2 FPs are CVs

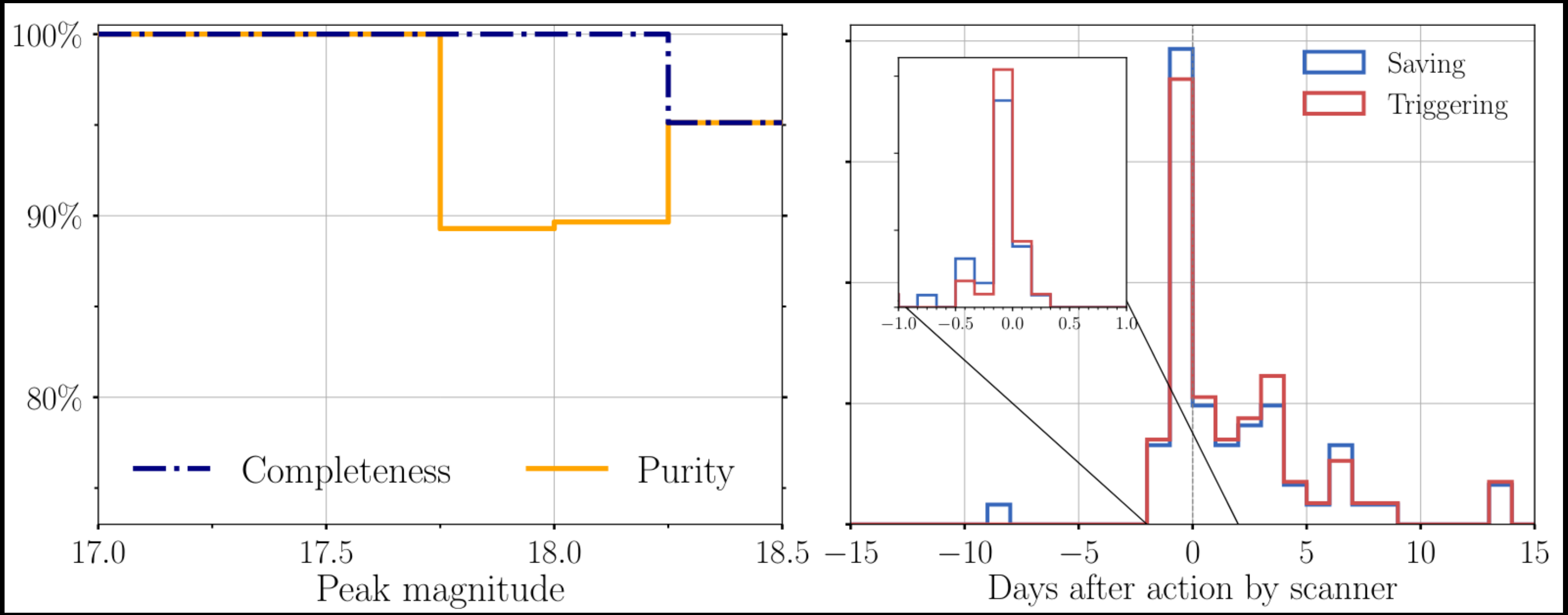
bts_p1: A source have at least two alerts with high (≥ 0.5) bright transient score and magpsf ≤ 19 mag before being saved and having an SEDM trigger sent at priority 1; bts_p2: A source meet bts_p1 as well as having at least one alert with magpsf ≤ 18.5 mag before a trigger being sent with priority 2

3.2 Discussion-performance-present-day

Test split robust and representative, but includes many alerts that are years old and a subtle data shift can have associated biases



2460175.5(19 August 2023) < JD < 2460216.5 (29 September 2023)



Performance is very similar to the metrics computed from test split data

3.3 Discussion-comparion with similar models

ALeRCE
(SN, AGN, VarStar, asteroid, bogus)

ACAI
(hosted, orphan, nuclear, VarStar, bogus)

Neither the stamp classifier nor ACAI learn class definitions that are sensitive to the source's brightness.

Part IV Conclusion and future work

4.1 Summay

- Presented a new multi-modal binary classifier, BTSbot, to automated classify bright transient / not bright transient; ~95% accuracy on input alerts and identified 100% in our test split with 93% purity;

- BTSbot focus on relatively narrow domain(m_peak ≤ 18.5 mag, reject other extragalactic transients and all other sources), but significantly more alerts (608,943) than other models with similar architectures,such as the ALeRCE stamp classifier (~52,000; the ACAI models (~200,000);

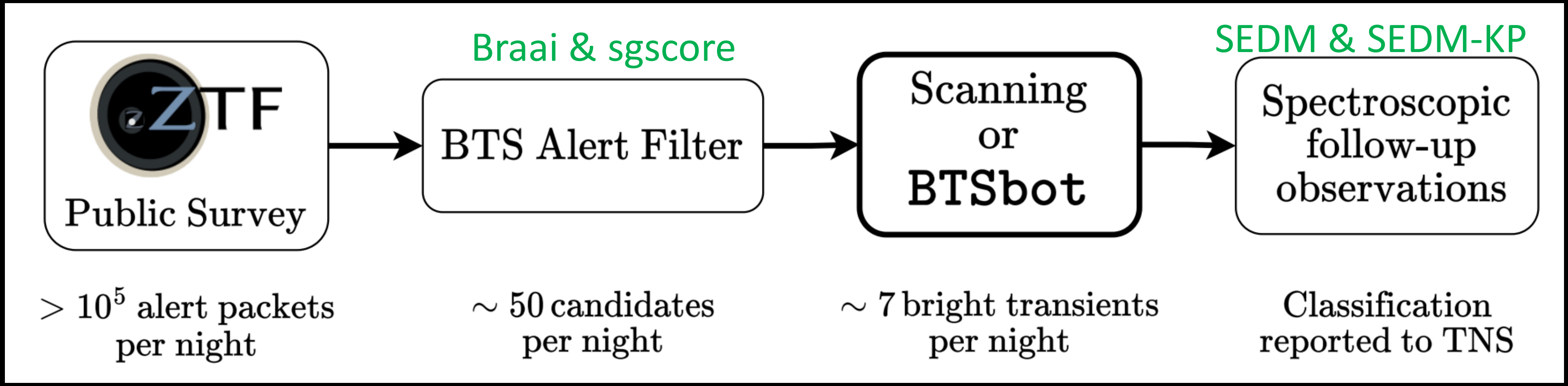
- BTSbot acts as quickly as human scanners on new bright transients(fig 7) and particularly well suited for the automated identification of very young transients;

- BTSbot joins a rich collection of ML models and automation tools central to daily BTS operations, has been integrated into Fritz and Kowalski and now sends automatic spectroscopic follow-up requests for the new transients it identifies

Fritz and Kowalski

BTS workflow

BTSbot has been integrated in Fritz and Kowalski to enable running in real-time on incoming alert packets from IPAC's alert-producing and brokering system.

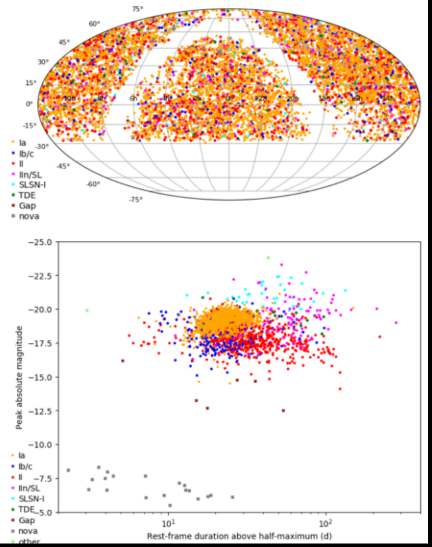


SN-like events passing sample cuts:

mag ≤	19.0	18.5	18.0	17.5	17.0
All typed	5378	3573	1827	987	489
All SNe	5319	3524	1795	965	474
Ia	4009	2657	1341	724	358
Ia-CSM	8	7	4	3	3
Iax	11	7	4	4	2
Ib/c	305	203	105	51	25
Ibn	24	18	13	5	1
Ic-BL	50	39	19	10	6
SLSN-I	43	22	11	8	1
II	962	642	338	182	90
IIb	75	47	25	14	7
IIn	139	98	51	26	14
SLSN-II	21	11	6	2	1
TDE	20	14	7	4	4
Gap	9	8	5	4	2
Ca-rich	1	0	0	0	0
LRN	3	3	1	1	0
ILRT	2	2	2	2	1
LBV	3	3	2	1	1
Novae	28	25	19	13	8
Other	2	2	1	1	1

All events:

mag ≤	19.0	18.5	18.0	17.5	17.0
All typed	8851	6082	3238	1771	904
All SNe	8733	5987	3176	1732	882
Ia	6404	4412	2328	1275	663
Ia-CSM	19	14	8	5	5
Iax	19	15	10	8	5
Ib/c	461	327	184	90	43
Ibn	31	25	17	8	3
Ic-BL	66	53	28	14	8
SLSN-I	70	37	19	12	2
II	1798	1211	645	355	174
IIb	116	75	46	26	14
IIn	242	169	89	47	21
SLSN-II	39	22	8	2	1
TDE	50	36	19	9	5
Gap	19	16	9	5	3
Ca-rich	5	3	0	0	0
LRN	4	4	2	1	0
ILRT	4	3	3	2	1
LBV	6	6	4	2	2
Novae	47	41	33	24	13
Other	2	2	1	1	1



BTS weblink: https://sites.astro.caltech.edu/ztf/bts/bts.php

Thank you for your attention!
Q&A

ZTF-limiting magnitude

Table 4. BTSbot metadata features

Feature name	Definition [unit]
Alert packet metadata	
`sgscore{1,2}`	Star/Galaxy score of nearest two PS1 sources
`distpsnr{1,2}`	Distance to nearest two PS1 sources [arcsec]
`fwhm`	Full Width Half Max [pixels]
`magpsf`	magnitude of PSF-fit photometry [mag]
`sigmapsf`	1-σ uncertainty in `magpsf` [mag]
`chipsf`	Reduced χ^2 of PSF-fit
`ra`	Right ascension of source [deg]
`dec`	Declination of source [deg]
`diffmaglim`	5-σ magnitude detection threshold [mag]
`ndethist`	Number of previous detections of source
`nmtchps`	# of PS1 cross-matches within 30 arcsec
`drb`	Deep learning-based real/bogus score
`ncovhist`	# of times source on a field and read channel
`chinr`	χ parameter of nearest source in reference
`sharpnr`	sharp parameter of nearest source in reference
`scorr`	Peak-pixel S/N in detection image
`sky`	Local sky background estimate [DN]
Custom metadata	
`days_since_peak`	Time since brightest alert [days]
`days_to_peak`	Time from first to brightest alert [days]
`age`	`days_since_peak` + `days_to_peak`
`peakmag_so_far`	Source's minimum `magpsf` thusfar [mag]
`maxmag_so_far`	Source's maximum `magpsf` thusfar [mag]
`nondet`[a]	`ncovhist` - `ndethist`

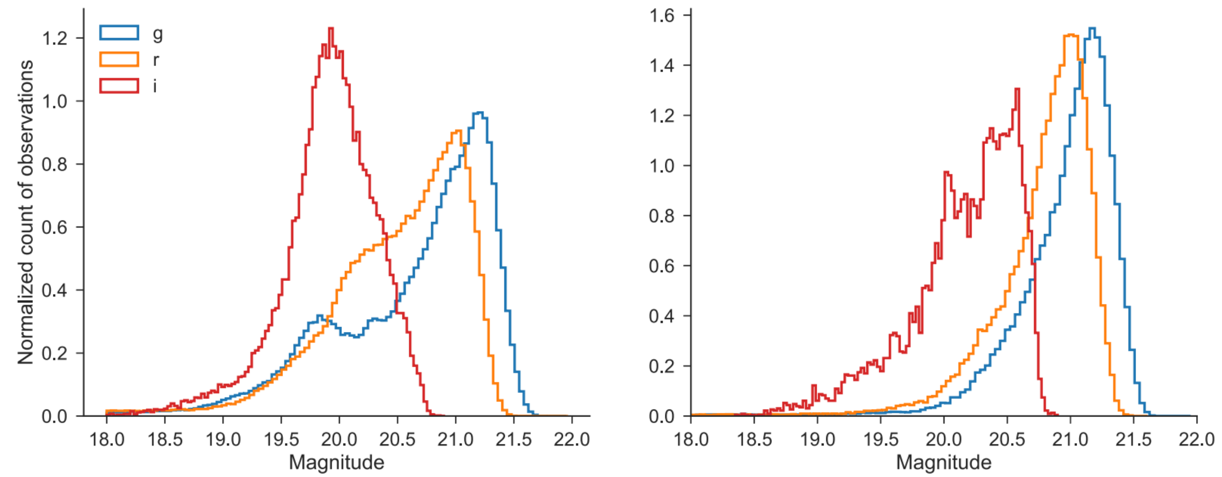
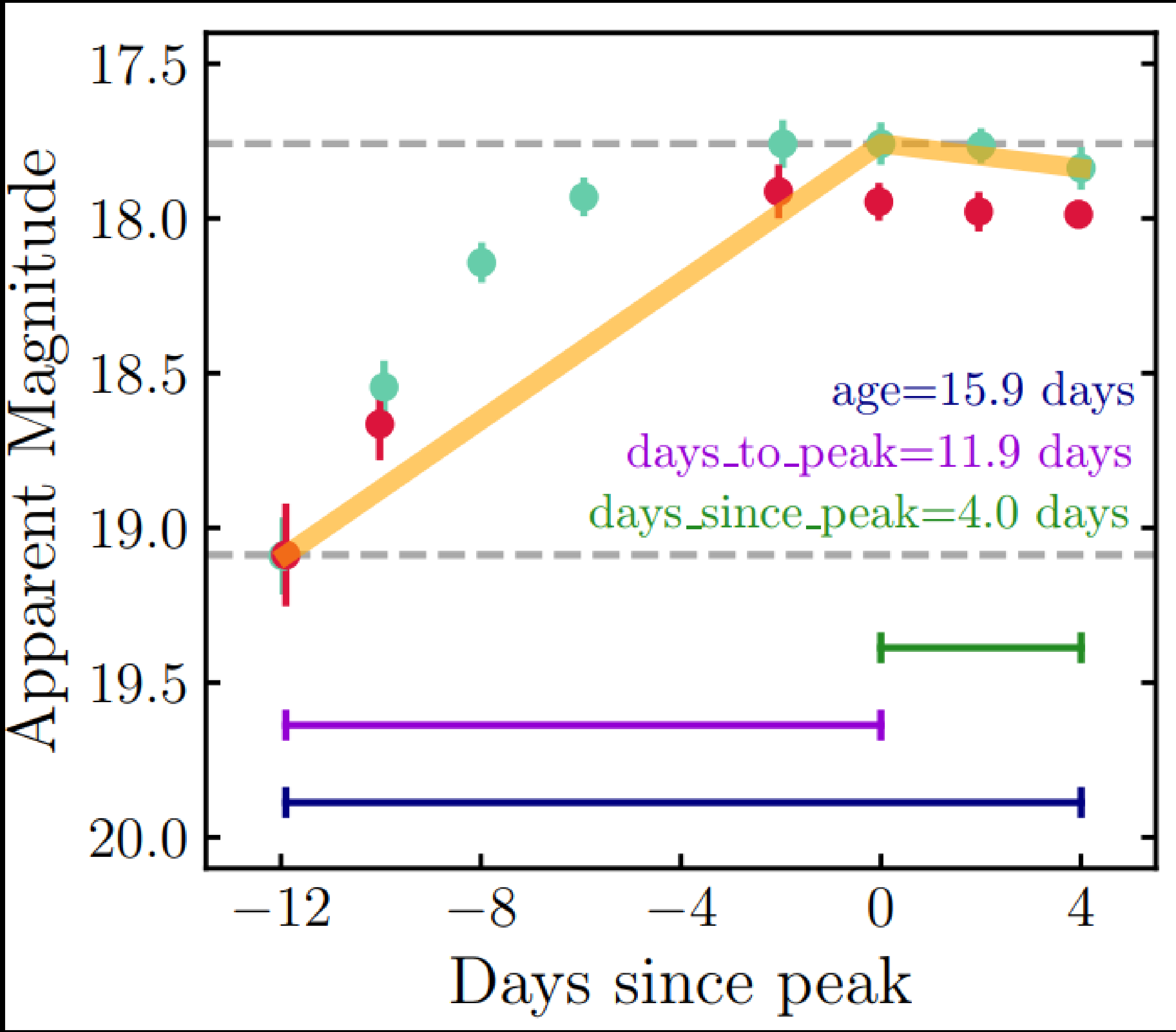


Figure 6. Left: histogram of five-sigma limiting magnitudes in 30 s exposures for g (blue), r (orange), and i (red) bands over one lunation. Right: limiting magnitudes for observations obtained within ±3 days of new moon.
(A color version of this figure is available in the online journal.)

Median Sensitivity (30 s, 5σ)	$m_g = 20.8,\ m_r = 20.6,\ m_i = 19.9$
	$m_g = 21.1,\ m_r = 20.9,\ m_i = 20.2$ (new moon)

Metadata features



Days_to_peak (purple),days_ since _peak (green), age (navy), peakmag so far (upper dashed gray), and maxmag so far (lower dashed gray)