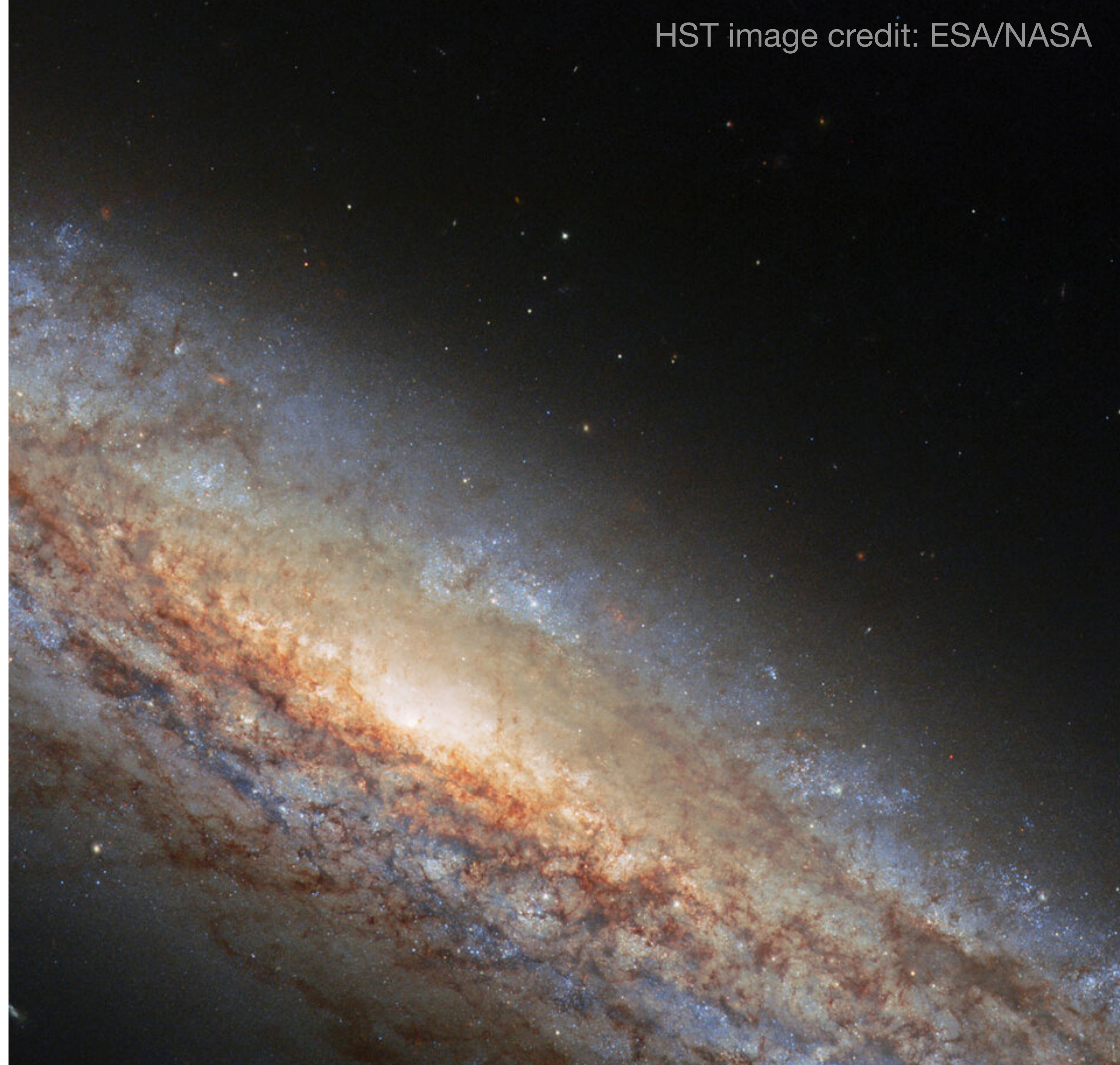


Nuclear Transients in ZTF and GW follow up

MMS Meeting
June 5, 2023

Simeon Reusch



I) ZTF

**It has been an exciting
few years for the study
of nuclear transients!**

First ZTF TDE

van Velzen+ 2019

THE ASTROPHYSICAL JOURNAL, 872:198 (11pp), 2019 February 20

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<https://doi.org/10.3847/1538-4357/aafe0c>


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The First Tidal Disruption Flare in ZTF: From Photometric Selection to Multi-wavelength Characterization

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Seventeen Tidal Disruption Events from the First Half of ZTF Survey Observations: Entering a New Era of Population Studies

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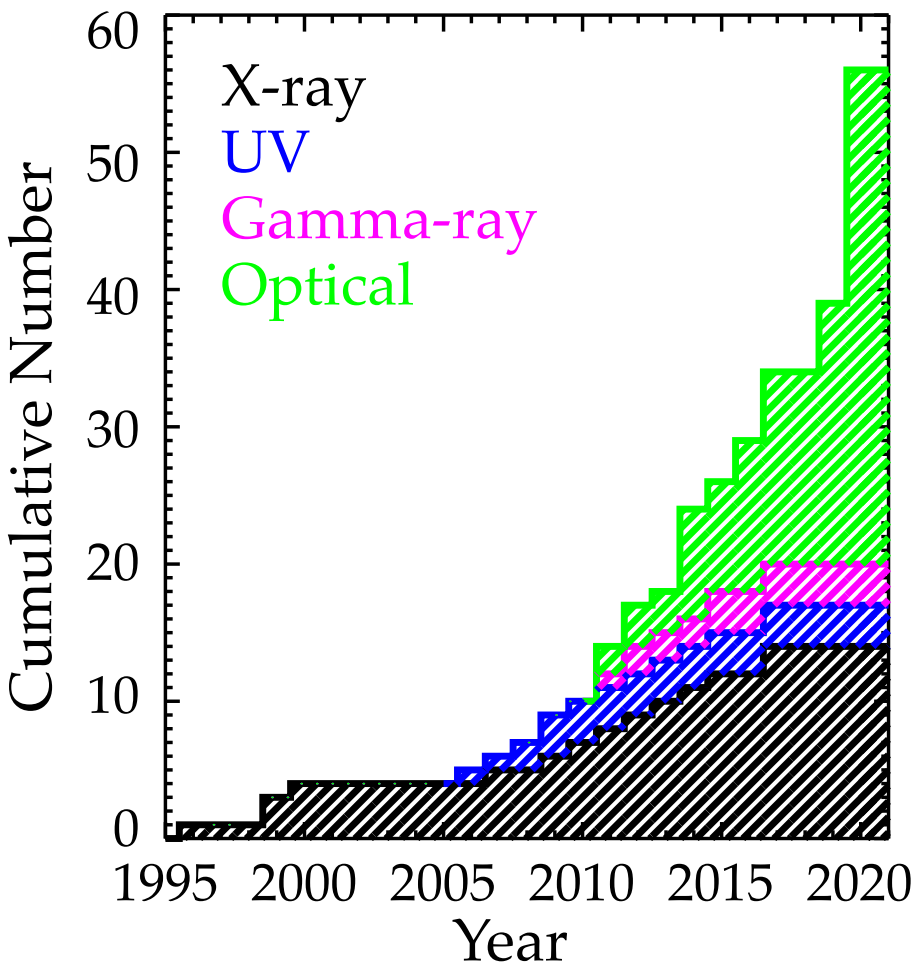
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Nadejda Blagorodnova⁹, Igor Andreoni¹⁰, Eric C. Bellm¹¹, Valery Brinnel¹², Kishalay De¹⁰, Richard Dekany¹³,
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Seventeen Tidal Disruption Events Entering a New Era

Sjoert van Velzen^{1,2}, Suvi Gezari^{1,3}, Erica Hammerstein^{1,2,3}, Tiara Hung⁴, S. Bradley Cenko^{3,5}, Robert Stein⁶, Da Nadejda Blagorodnova⁹, Igor Andreoni¹⁰, Eric C. Bellm¹¹, Michael Feeney¹³, Christoffer Fremling¹⁰, Matt Anna. Y. Q. Ho¹⁰, Mansi M. Kasliwal¹⁰, Charles Russ R. Laher¹⁶, Ashish Mahabal^{10,17}, Frank J. Masci¹⁴, Ben Rusholme¹⁶, Jakob van Santen⁶, Yashvi Sharma¹⁶

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The Final Season Reimagined: 30 Tidal Disruption Events from the ZTF-I Survey

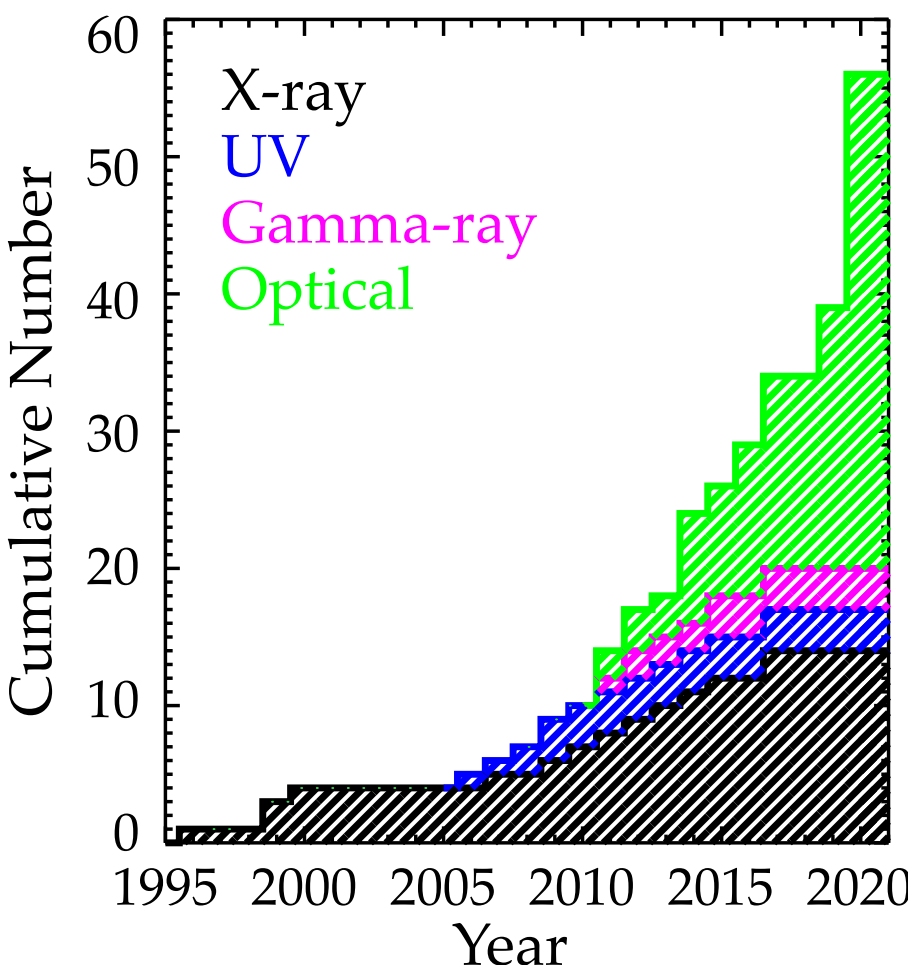
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Abstract

Tidal disruption events (TDEs) offer a unique way to study dormant black holes. While the number of observed TDEs has grown thanks to the emergence of wide-field surveys in the past few decades, questions regarding the nature of the observed optical, UV, and X-ray emission remain. We present a uniformly selected sample of 30 spectroscopically classified TDEs from the Zwicky Transient Facility Phase I survey operations with follow-up observations in the X-ray, UV, and optical bands.



A jetted TDE

Article

A very luminous jet from the disruption of a star by a massive black hole

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Tidal disruption events (TDEs) are bursts of electromagnetic energy that are released when supermassive black holes at the centres of galaxies violently disrupt a star that passes too close¹. TDEs provide a window through which to study accretion onto supermassive black holes; in some rare cases, this accretion leads to launching of a relativistic jet^{2–9}, but the necessary conditions are not fully understood. The best-studied jetted TDE so far is Swift J1644+57, which was discovered in γ-rays, but was too obscured by dust to be seen at optical wavelengths. Here we report the optical detection of AT2022cmc, a rapidly fading source at cosmological distance (redshift

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Reimagined: 30 Tidal Disruption Events from the ZTF-I Survey

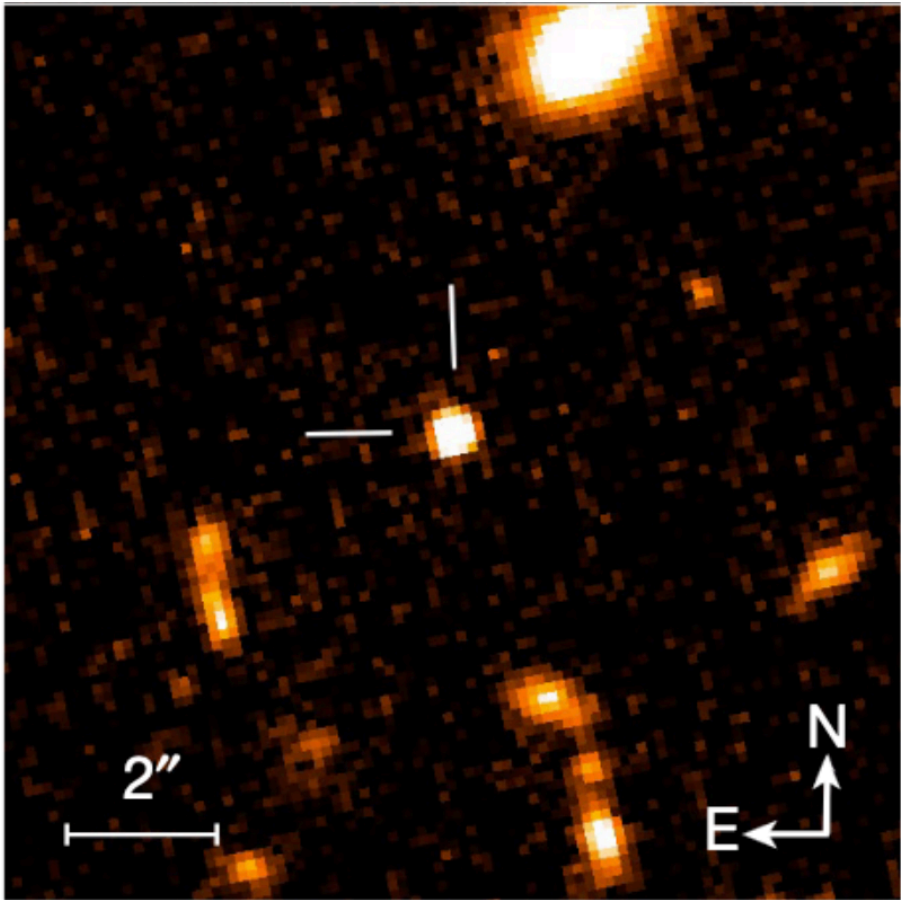
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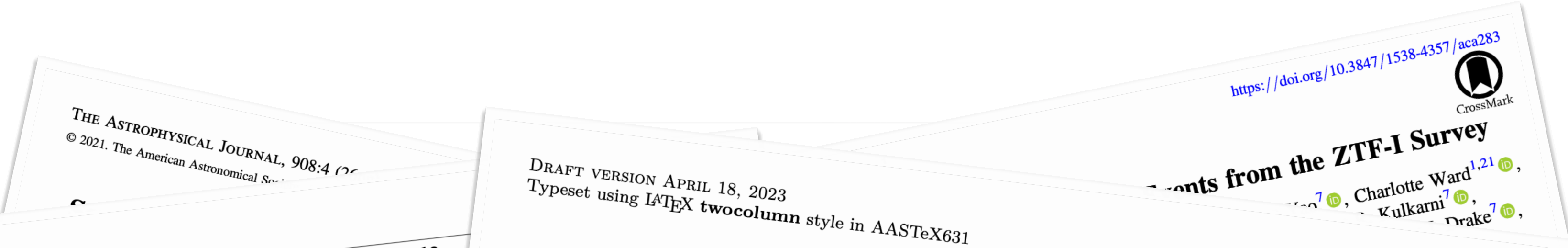
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An extremely energetic TDE



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Article

A very luminous jet from the distant star by a massive black hole

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Tidal disruption events (TDEs) occur when a star passes too close to a supermassive black hole. TDEs provide a natural laboratory for studying supermassive black holes; they are thought to produce relativistic jets^{2–9}, but the number of observed jetted TDEs is small. The most studied jetted TDE so far is AT2019axf, which was too obscured by dust to be seen at optical wavelengths. The detection of AT2022cmc, a rapidly fading source at optical wavelengths, provides a natural laboratory for studying supermassive black holes.

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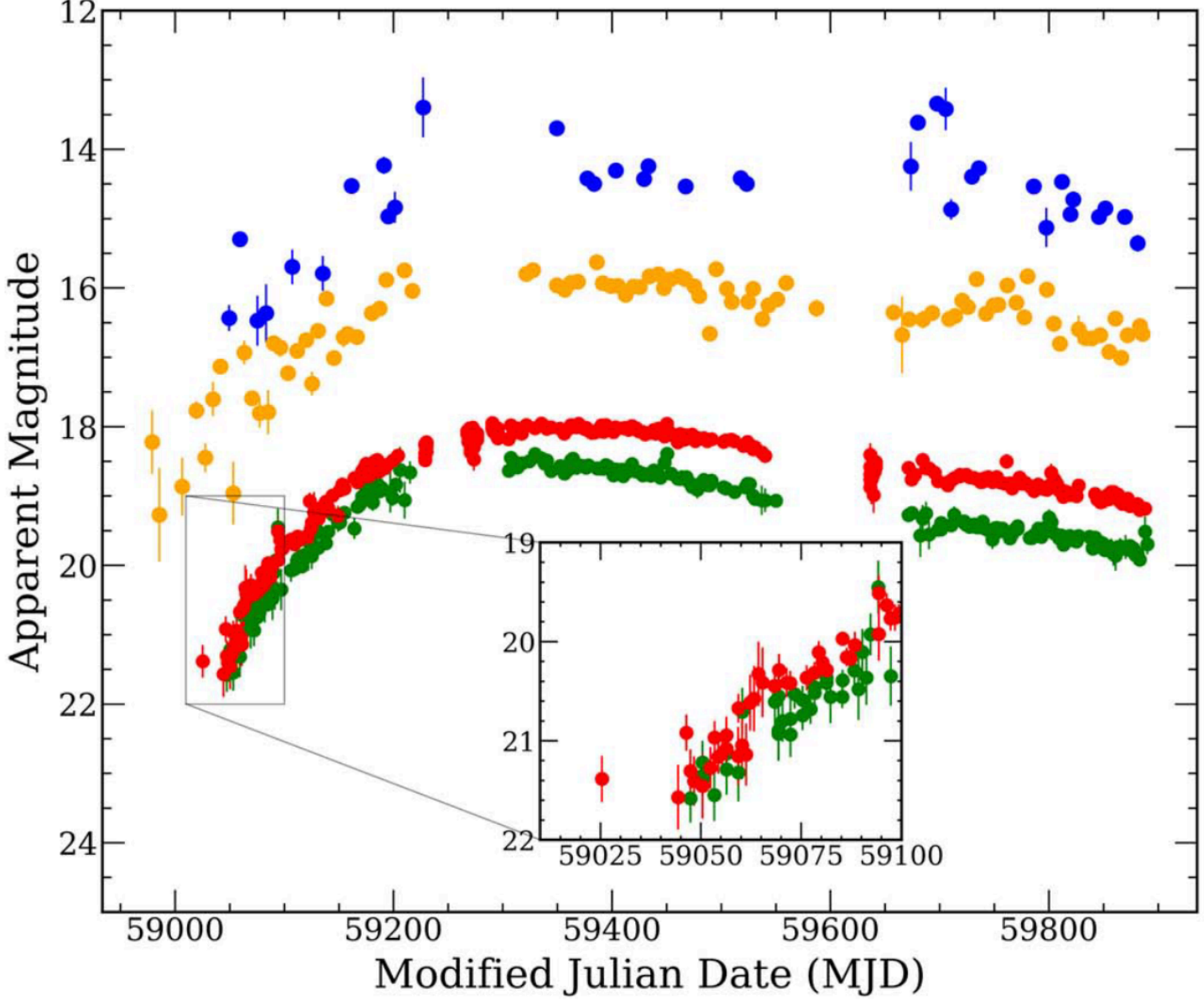
Scary Barbie: An Extremely Energetic, Long-Duration Tidal Disruption Event Candidate Without a Detected Host Galaxy at $z = 0.995$

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ABSTRACT

We report multi-wavelength observations and characterization of the ultraluminous transient AT2021lwx (ZTF20abrbeie; aka “Barbie”) identified in the alert stream of the Zwicky Transient Facility (ZTF) using a Recommender Engine For Intelligent Transient Tracking (REFITT) filter on the ANTARES alert broker. From a spectroscopically measured redshift of 0.995, we estimate a peak observed pseudo-bolometric luminosity of $\log(L_{\text{max}}/\text{erg/s}) = 45.7$ from slowly fading ztf-g and ztf-r light curves spanning over 1000 observer-frame days. The host galaxy is not detected in archival Pan-STARRS3 images. This event is the most energetic TDE candidate discovered to date.



Possible EM counterparts to BH-BH mergers

Article

A very luminous jet from a star by a massive black hole

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A Light in the Dark: Searching for Electromagnetic Counterparts to Black Hole–Black Hole Mergers in LIGO/Virgo O3 with the Zwicky Transient Facility

Matthew J. Graham¹, Barry McKernan^{2,3,4,5}, K. E. Saavik Ford^{2,3,4,5}, Daniel Stern⁶, S. G. Djorgovski¹, Michael Coughlin⁷, Kevin B. Burdge^{8,9}, Eric C. Bellm¹⁰, George Helou¹¹, Ashish A. Mahabal^{12,13}, Frank J. Masci¹¹, Josiah Purdum¹⁴, Philippe Rosnet¹⁵, and Ben Rusholme¹¹

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Abstract

The accretion disks of active galactic nuclei (AGNs) are promising locations for the merger of compact objects detected by gravitational wave (GW) observatories. Embedded within a baryon-rich, high-density environment, mergers within AGNs are the only GW channel where an electromagnetic (EM) counterpart must occur (whether detectable or not). Considering AGNs with unusual flaring activity observed by the Zwicky Transient Facility (ZTF), we describe a search for candidate EM counterparts to binary black hole (BBH) mergers detected by LIGO/Virgo O3.

- van Velzen+ 2019
- van Velzen+ 2021
- Hammerstein+ 2021
- Andreoni+ 2022
- Subrayan+ 2023
- Graham+ 2023

Three neutrino-associated TDE candidates

Article

A very luminous jet from a star by a massive black hole

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A Light in the Hole

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ARTICLES

<https://doi.org/10.1038/s41550-020-01295-8>

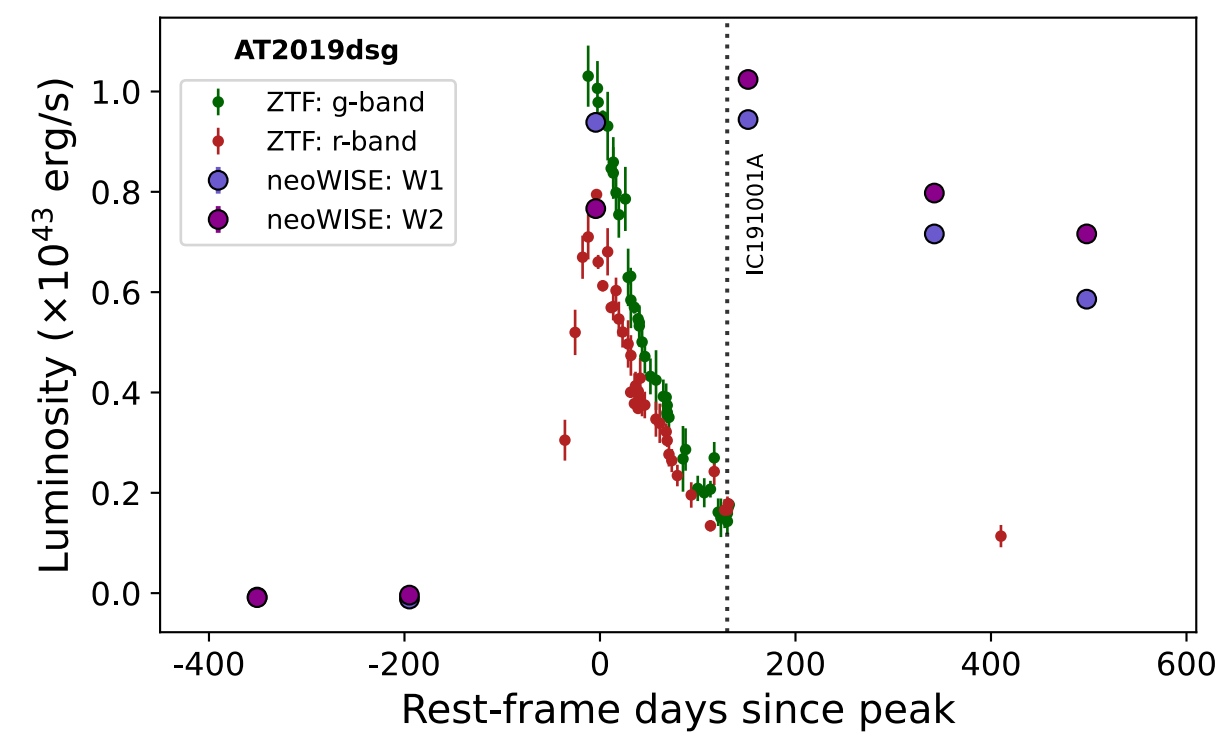
A tidal disruption event coincident with a high-energy neutrino

Robert Stein, Sjoert van Velzen, Marek Kowalski, Anna Franckowiak, Suvi Gezari, James C. A. Miller-Jones, Sara Frederick, Itai Sfaradi, Michael F. Bietenholz, Assaf Horesh, Rob Fender, Simone Garrappa, Tomás Ahumada, Igor Andreoni, Justin Belicki, Eric C. Bellm, Markus Böttcher, Valery Brinnel, Rick Burruss, S. Bradley Cenko, Michael W. Coughlin, Virginia Cunningham, Andrew Drake, Glennys R. Farrar, Michael Feeney, Ryan J. Foley, Avishay Gal-Yam, V. Zach Golkhou, Ariel Goobar, Matthew J. Graham, Erica Hammerstein, George Helou, Tiara Hung, Mansi M. Kasliwal, Charles D. Kilpatrick, Albert K. H. Kong, Thomas Kupfer, Russ R. Laher, Ashish A. Mahabal, Frank J. Masci, Jannis Necker, César Rojas-Bravo, Ben Rusholme, Mickael Rigault, Simeon Reusch, Hector Rodriguez, Daniel A. Perley, David L. Shupe, Leo P. Singer, Jesper Sollerman, Maayane T. Soumagnac, Daniel Stern, Kirsty Taggart, Jakob van Santen, Charlotte Ward, Patrick Woudt and Yuhang Yao

Cosmic neutrinos provide a unique window into the otherwise hidden mechanism of particle acceleration in astrophysical objects. The IceCube Collaboration recently reported the likely association of one high-energy neutrino with a flare from the relativistic jet of an active galaxy pointed towards the Earth. However a combined analysis of many similar active galaxies revealed no excess

The accretion disks of active galaxies are the only GW channel where an electromagnetic (EM) counterpart is detectable or not). Considering AGNs with unusual flaring activity observed by the Zwicky Transient Facility (ZTF), we describe a search for candidate EM counterparts to binary black hole (BBH) mergers detected by LIGO/Virgo.

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A very luminous star by a massive black hole

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PHYSICAL REVIEW LETTERS **128**, 221101 (2022)

Editors' Suggestion Featured in Physics

Candidate Tidal Disruption Event AT2019fdr Coincident with a High-Energy Neutrino

Simeon Reusch^{1,2,*}, Robert Stein^{1,2,3}, Marek Kowalski^{1,2,†}, Sjoert van Velzen⁴, Anna Franckowiak^{1,5}, Cecilia Lunardini⁶, Kohta Murase^{7,8}, Walter Winter¹, James C. A. Miller-Jones⁹, Mansi M. Kasliwal³, Marat Gilfanov^{10,11}, Simone Garrappa^{1,2}, Vaidehi S. Paliya¹², Tomás Ahumada¹³, Shreya Anand³, Cristina Barbarino¹⁴, Eric C. Bellm¹⁵, Valéry Brinnel², Sara Buson¹⁶, S. Bradley Cenko^{17,18}, Michael W. Coughlin¹⁹, Kishalay De³, Richard Dekany²⁰, Sara Frederick¹³, Avishay Gal-Yam²¹, Suvi Gezari^{22,13}, Marcello Giroletti²³, Matthew J. Graham³, Viraj Karambelkar³, Shigeo S. Kimura²⁴, Albert K. H. Kong²⁵, Erik C. Kool¹⁴, Russ R. Laher²⁶, Pavel Medvedev¹⁰, Jannis Necker^{1,2}, Jakob Nordin², Daniel A. Perley²⁷, Mickael Rigault²⁸, Ben Rusholme²⁶, Steve Schulze²⁹, Tassilo Schweyer¹⁴, Leo P. Singer³⁰, Jesper Sollerman¹⁴, Nora Linn Strotjohann²¹, Rashid Sunyaev^{10,11}, Jakob van Santen¹, Richard Walters²⁰, B. Theodore Zhang⁸, and Erez Zimmerman²¹

¹Deutsches Elektronen Synchrotron DESY, Platanenallee 6, D-15738 Zeuthen, Germany
²Institut für Physik, Humboldt-Universität zu Berlin, D-12489 Berlin, Germany
³Division of Physics, Mathematics, and Astronomy, California Institute of Technology, 1200 East California Boulevard, MC 249-17, Pasadena, California 91125, USA
⁴Leiden Observatory, Leiden University, Postbus 9513, 2300 RA, Leiden, Netherlands
⁵Fakultät für Physik und Astronomie, Ruhr-Universität Bochum, D-44780 Bochum, Germany
⁶Department of Physics, Arizona State University, Tempe, Arizona 85287-1504, USA
⁷Department of Physics; Department of Astronomy and Astrophysics; Center for Multimessenger Astrophysics, Institute for Gravitation and the Cosmos, The Pennsylvania State University, University Park, Pennsylvania 16802, USA
⁸Center for Gravitational Physics, Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Kyoto 606-8502, Japan
⁹International Centre for Radio Astronomy Research - Curtin University, GPO Box U1987, Perth, Washington 6845, Australia
¹⁰Space Research Institute (IKI), Russian Academy of Sciences, Profsoyuznaya ul. 84/32, Moscow 117997, Russia
¹¹Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, D-85741 Garching, Germany
¹²Aryabhata Research Institute of Observational Sciences (ARIES), Manora Peak, Nainital-263001 Uttarakhand, India
¹³Department of Astronomy, University of Maryland, College Park, Maryland 20742, USA

(ZTF), we describe a search for candidate EM counterparts to binary black hole (BBH) mergers detected by LIGO/

nature astronomy

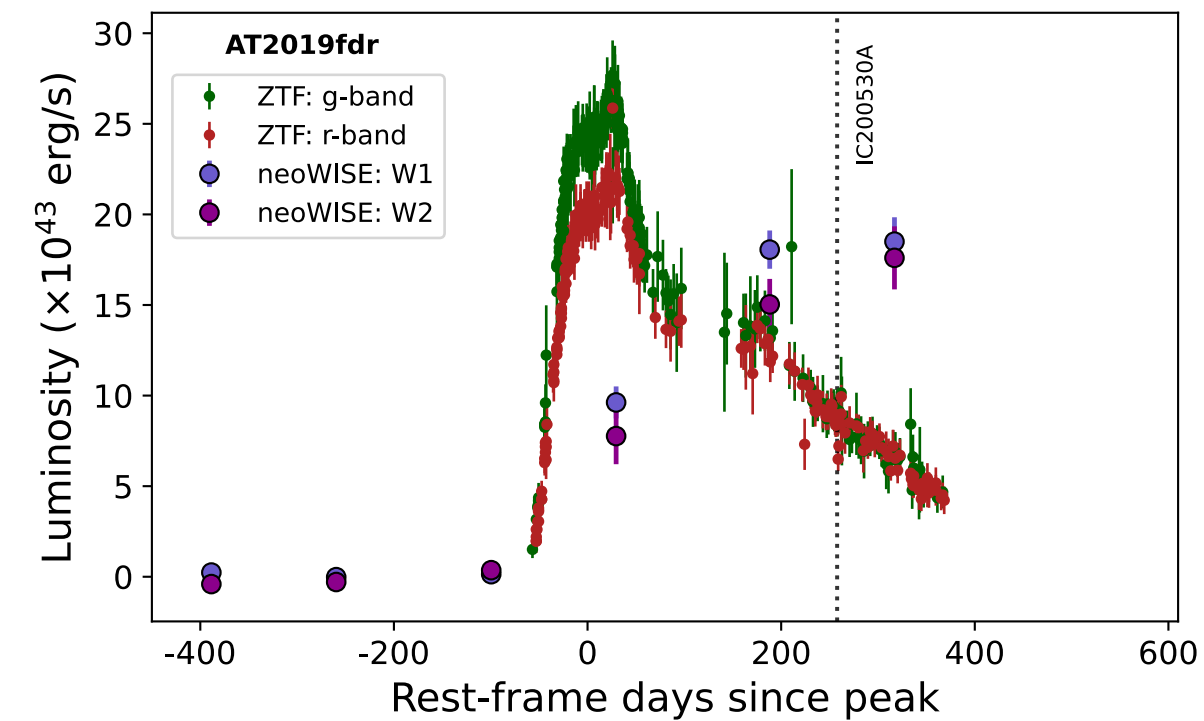
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chael F. Bietenholz^{10,11},
r Andreoni¹⁴,
S. Bradley Cenko^{17,18},
arrar³,
Goobar¹⁴,
Mansi M. Kasliwal¹⁴,
14,
aniel A. Perley²⁸,
Ben Rusholme²⁴,
21,31, Daniel Stern³²,
14

astrophysical objects.
from the relativistic jet
is revealed no excess

- van Velzen+ 2019
- van Velzen+ 2021
- Hammerstein+ 2021
- Andreoni+ 2022
- Subrayan+ 2023
- Graham+ 2023
- Stein+ 2021
- Reusch+ 2022



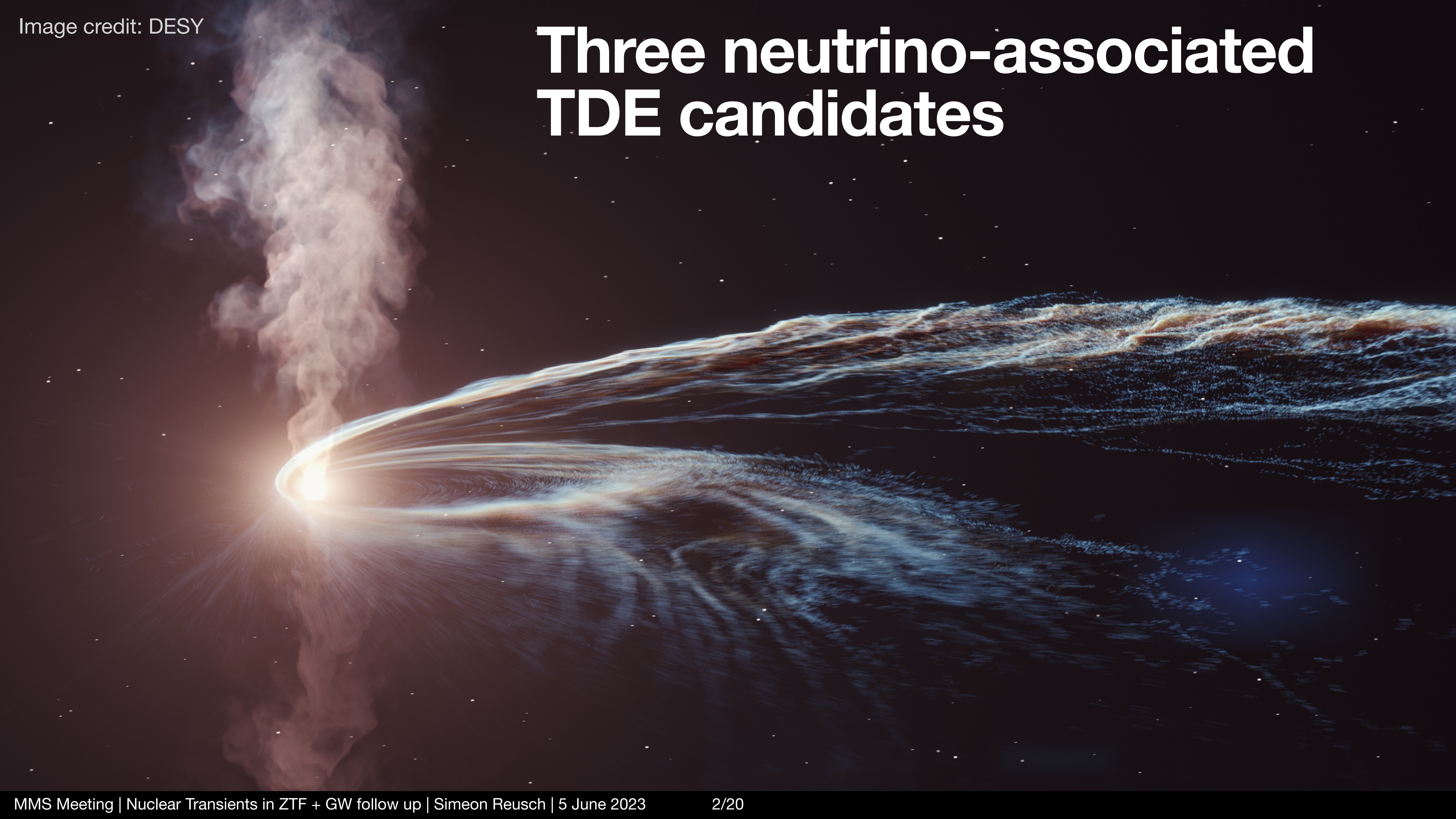


Image credit: DESY

Three neutrino-associated TDE candidates

Three neutrino-associated TDE candidates

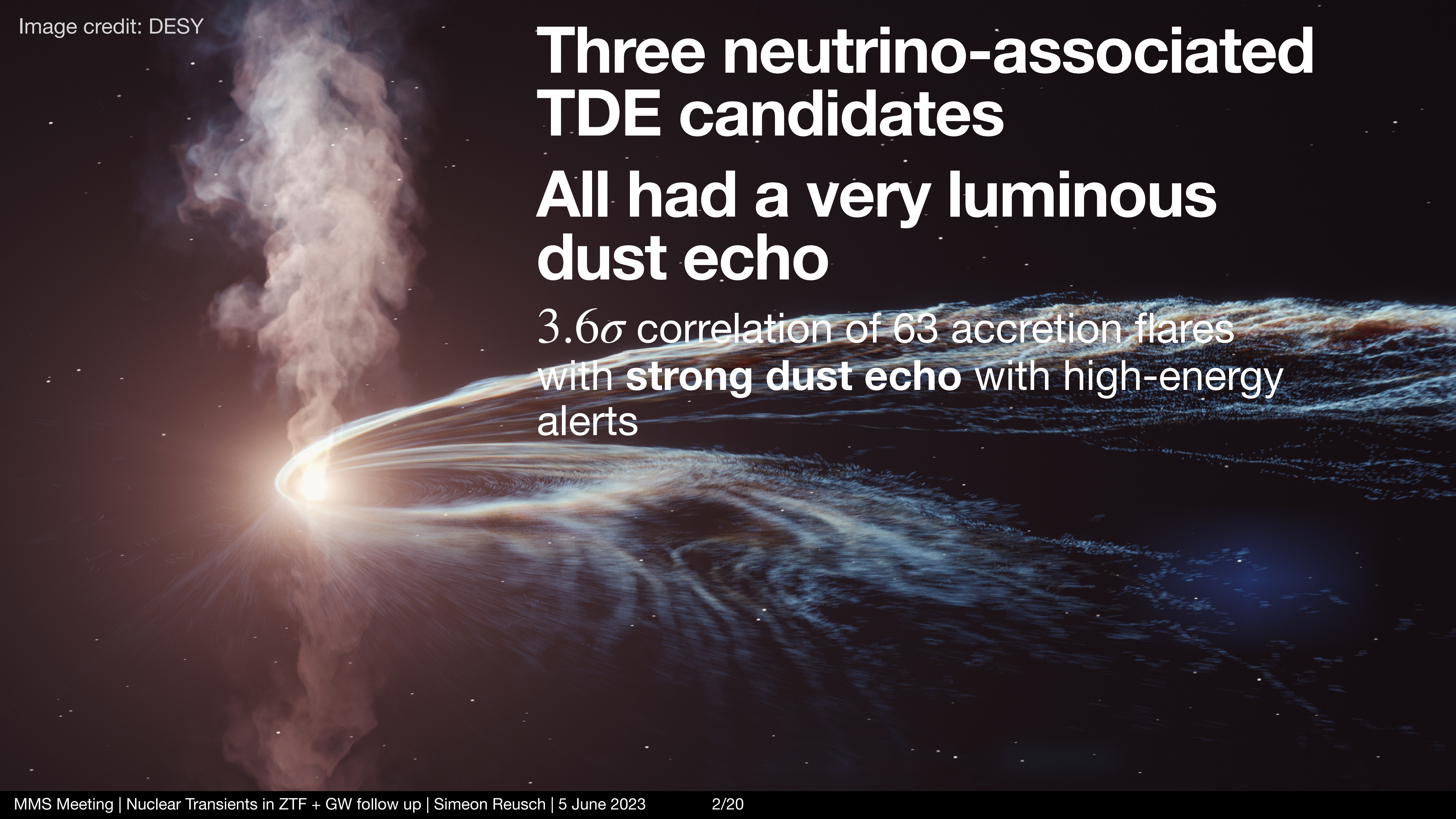
All had a very luminous
dust echo



Three neutrino-associated TDE candidates

All had a very luminous dust echo

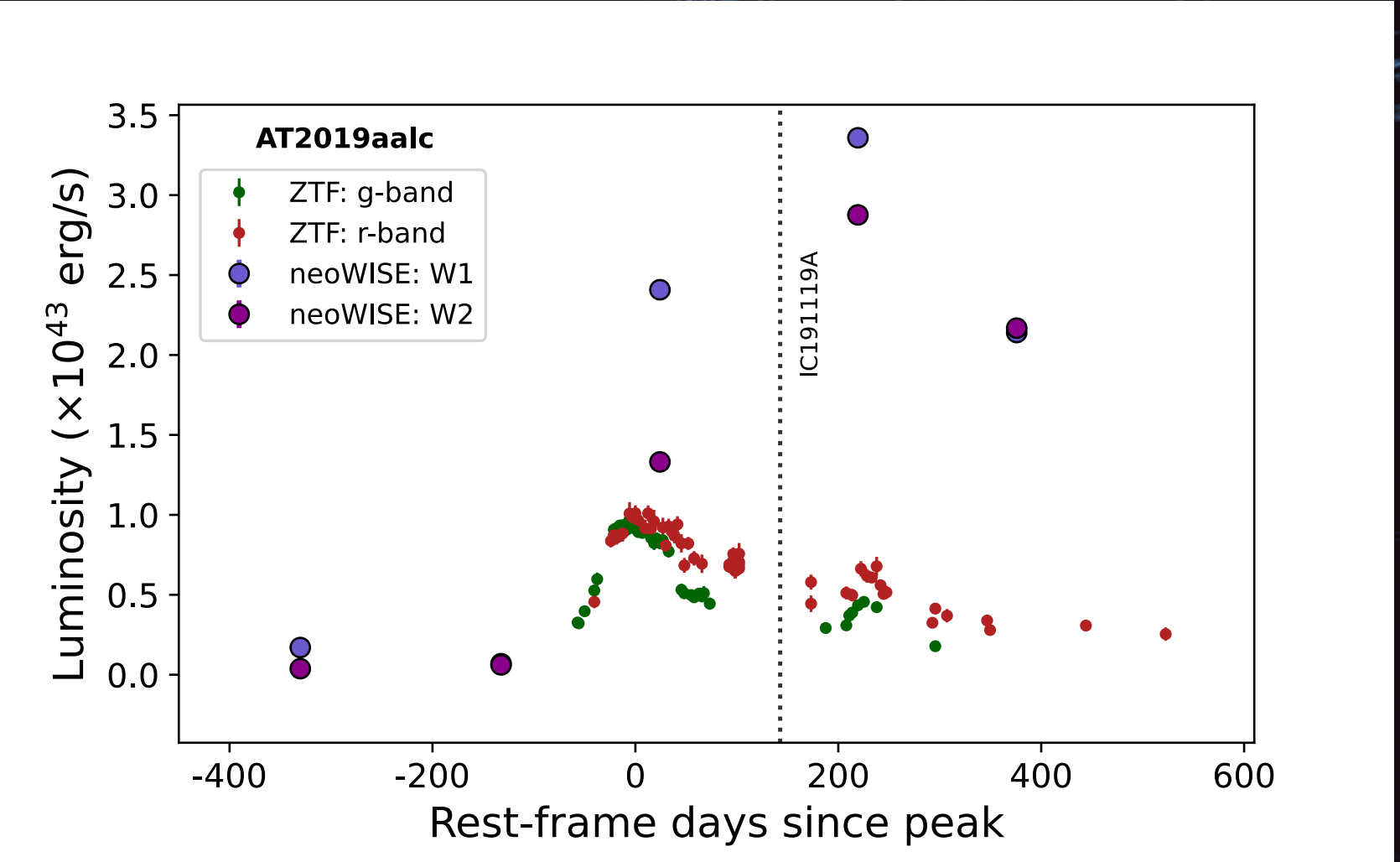
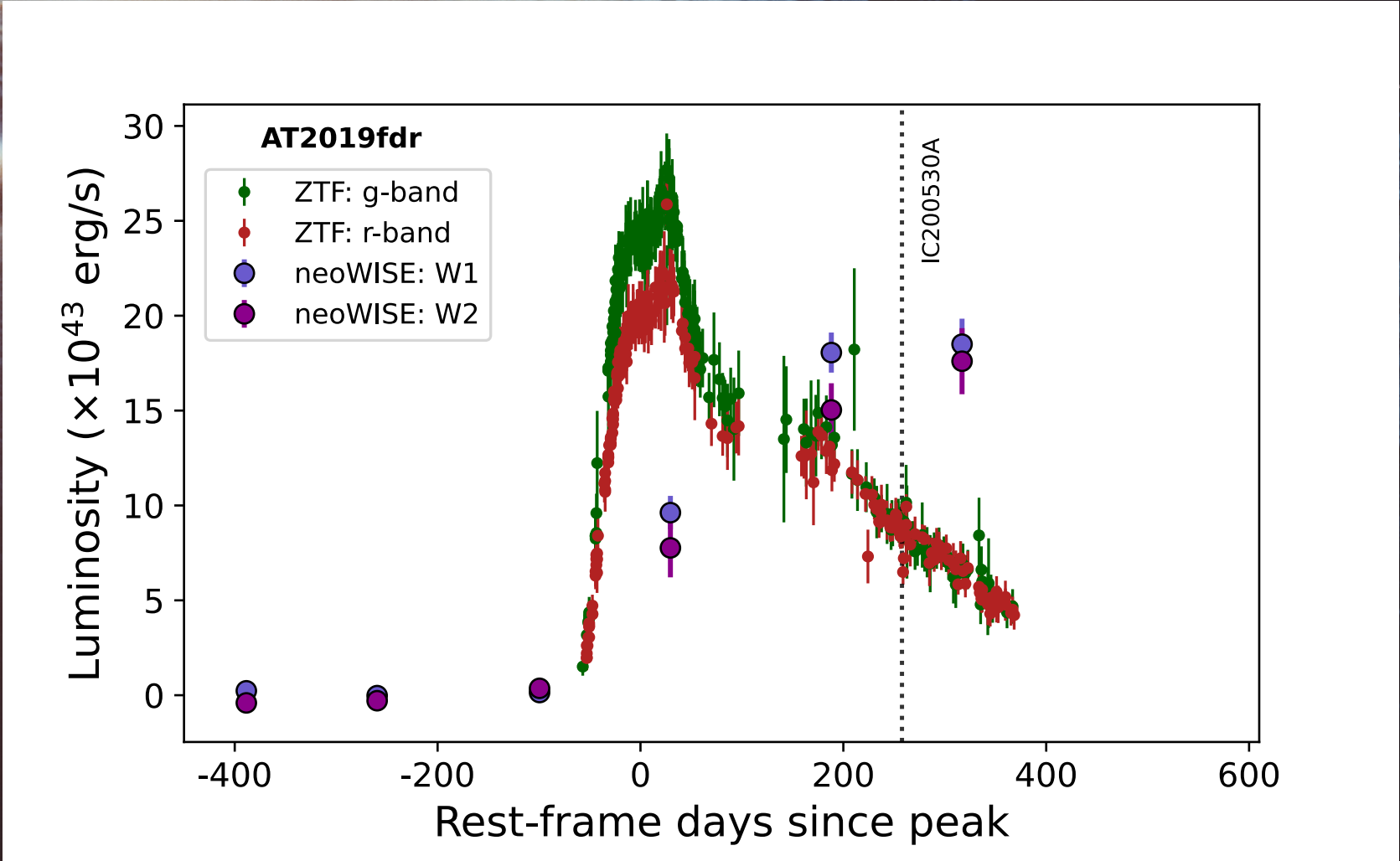
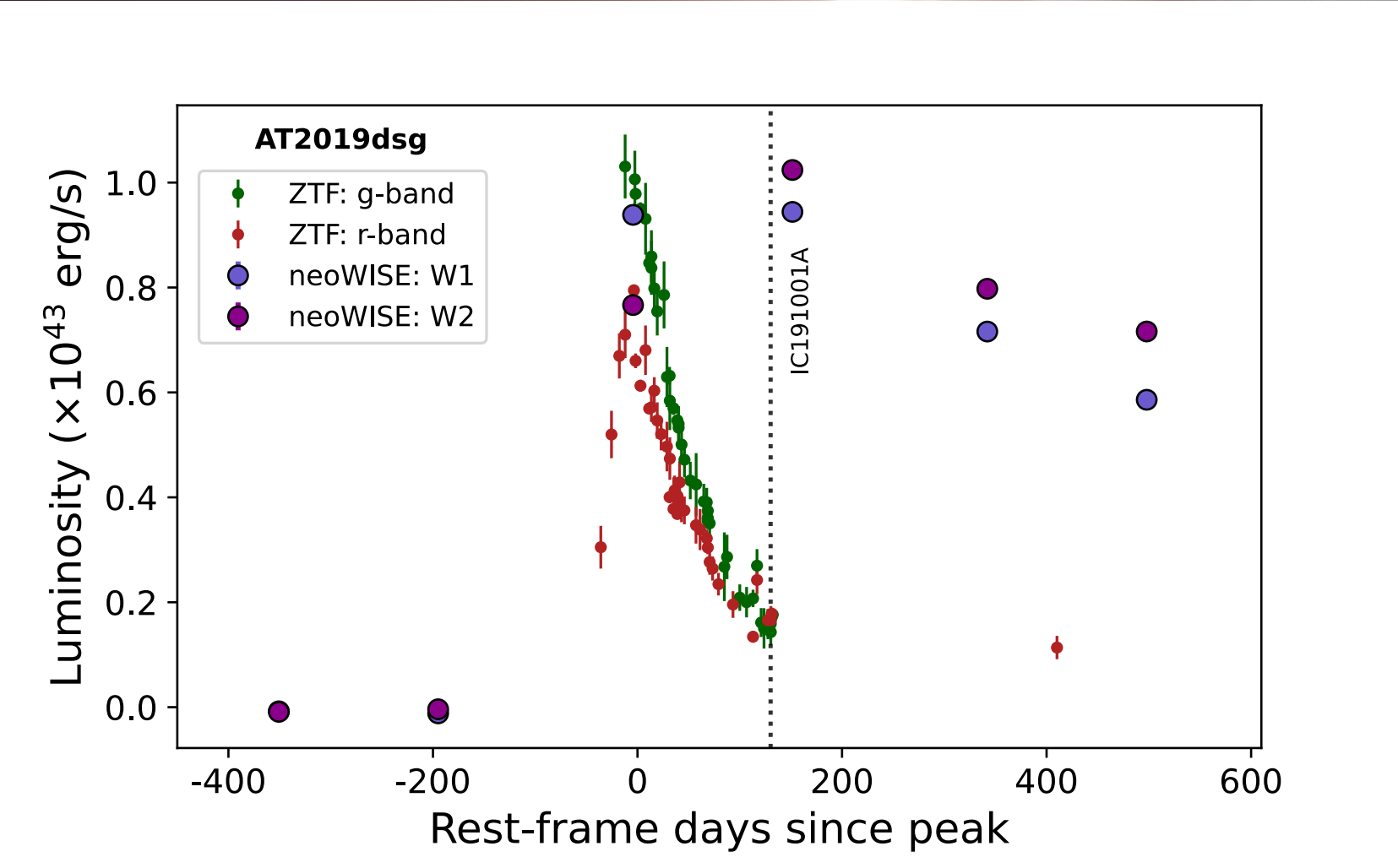
3.6 σ correlation of 63 accretion flares
with **strong dust echo** with high-energy
alerts



Three neutrino-associated TDE candidates

All had a very luminous
dust echo

3.6 σ correlation of 63 accretion flares
with **strong dust echo** with high-energy
alerts



**Lots of interesting transients,
but rather unstructured**

**Lots of interesting transients,
but rather unstructured**

**What if we had a systematic
sample of optical and IR
lightcurves of the ZTF nuclear
transients? 🤔**

II) A nuclear sample

Full Sample of all nuclear transients

Full Sample of all nuclear transients



[2018.5, 2021] → 3.5 years worth of data
(400 million alerts)

Full Sample of all nuclear transients



AMPEL nuclear
filter

[2018.5, 2021] → 3.5 years worth of data

(400 million alerts)

Filtered by **host distance**, **PS1 star-galaxy score**, max. **brightness** and number of **detections**

11687 transients in final selection

Full Sample of all nuclear transients



AMPEL nuclear
filter



fpbot

[2018.5, 2021] → 3.5 years worth of data

(400 million alerts)

Filtered by **host distance**, **PS1 star-galaxy score**, max. **brightness** and number of **detections**

11687 transients in final selection

Obtained forced photometry with **fpbot**, applied baseline correction

Crossmatch with WISE IR

Crossmatch with WISE IR

Vast majority
has a WISE
counterpart

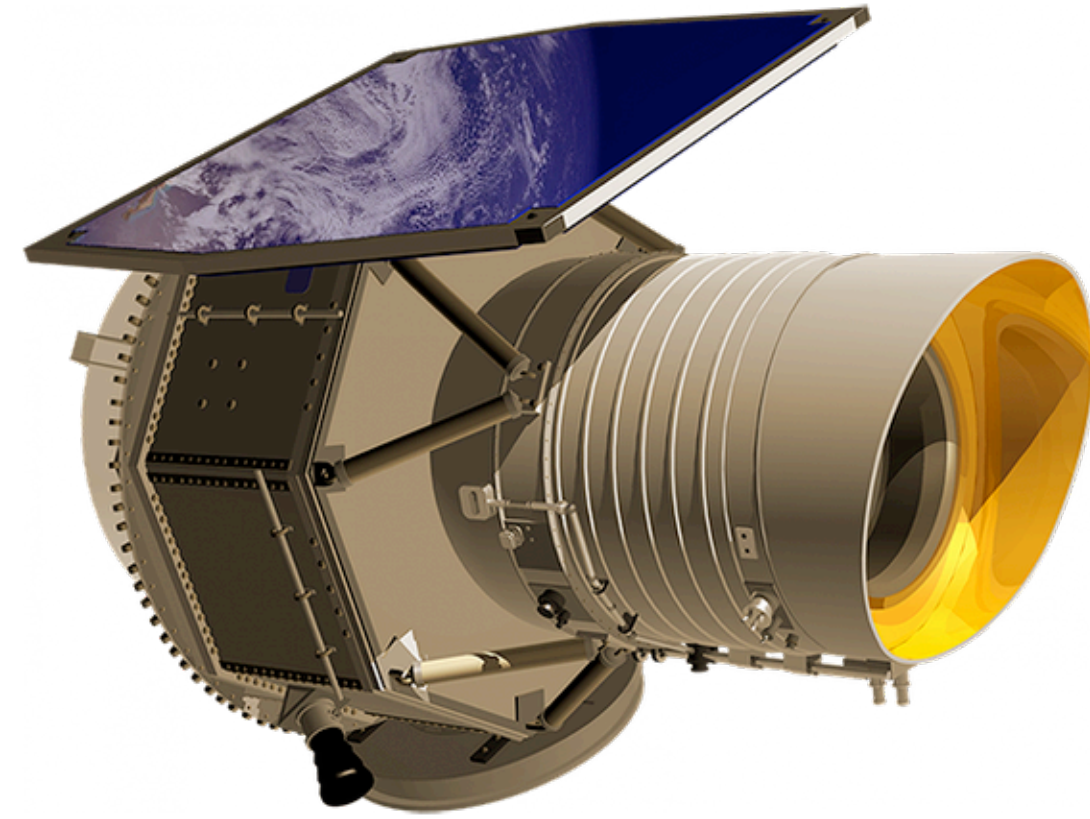


Image credit: NASA

Crossmatch with WISE IR

Vast majority
has a WISE
counterpart

Analyzed with a
Bayesian block framework to
find flares

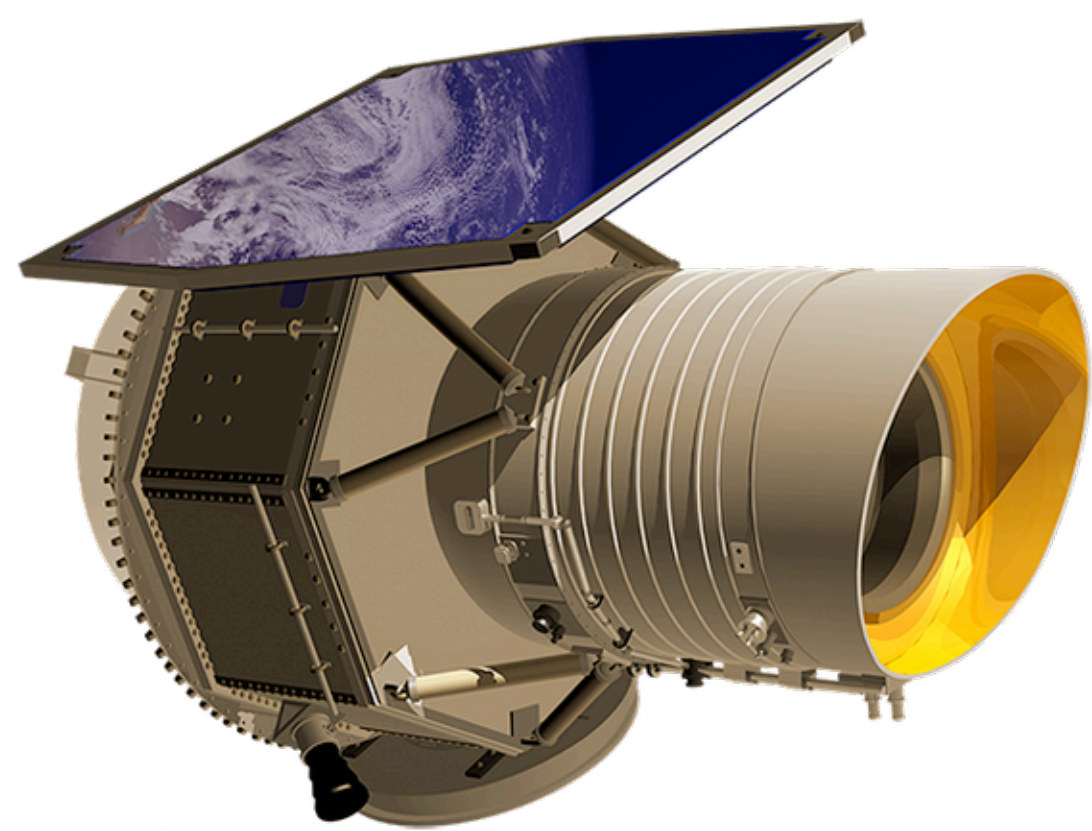
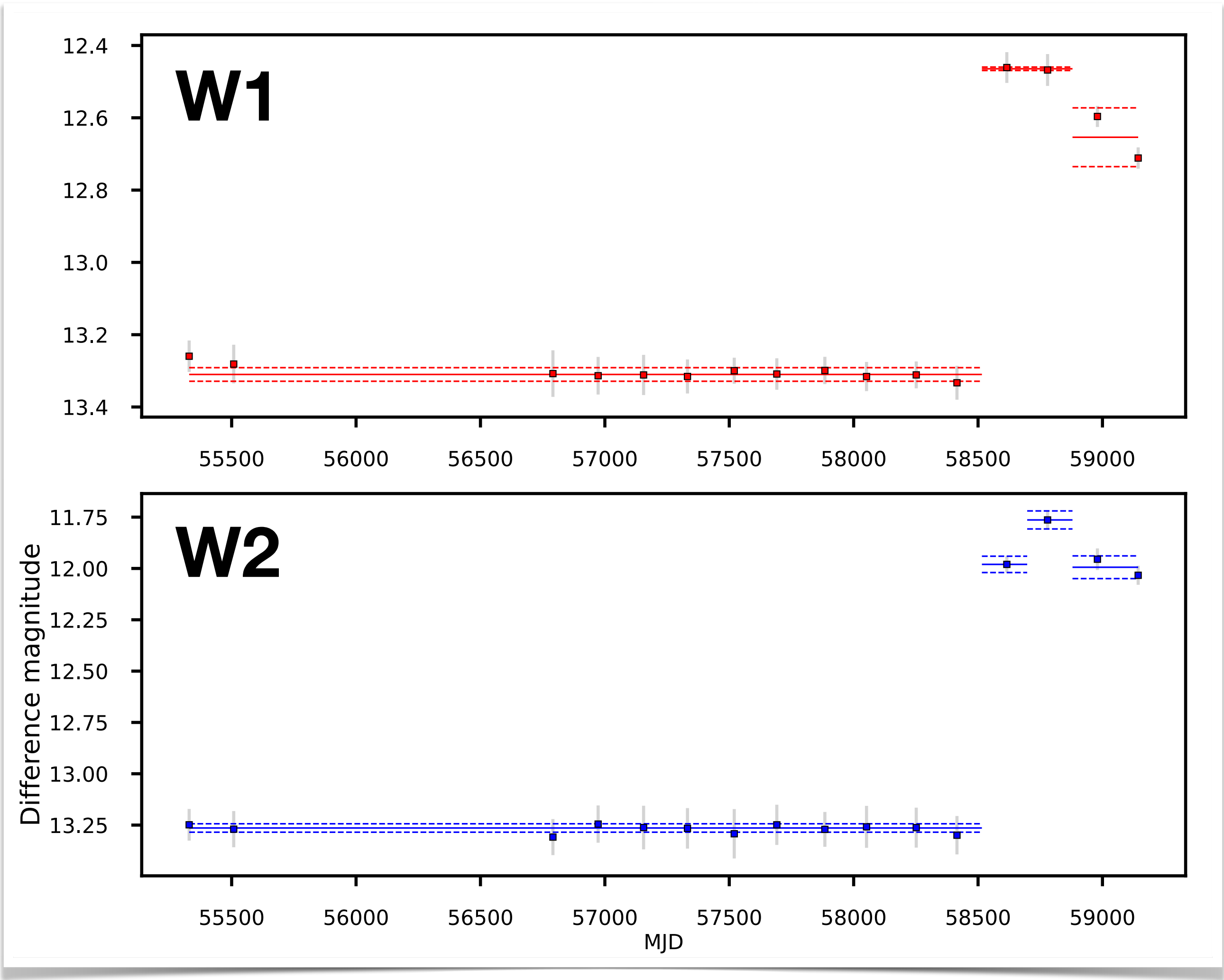


Image credit: NASA



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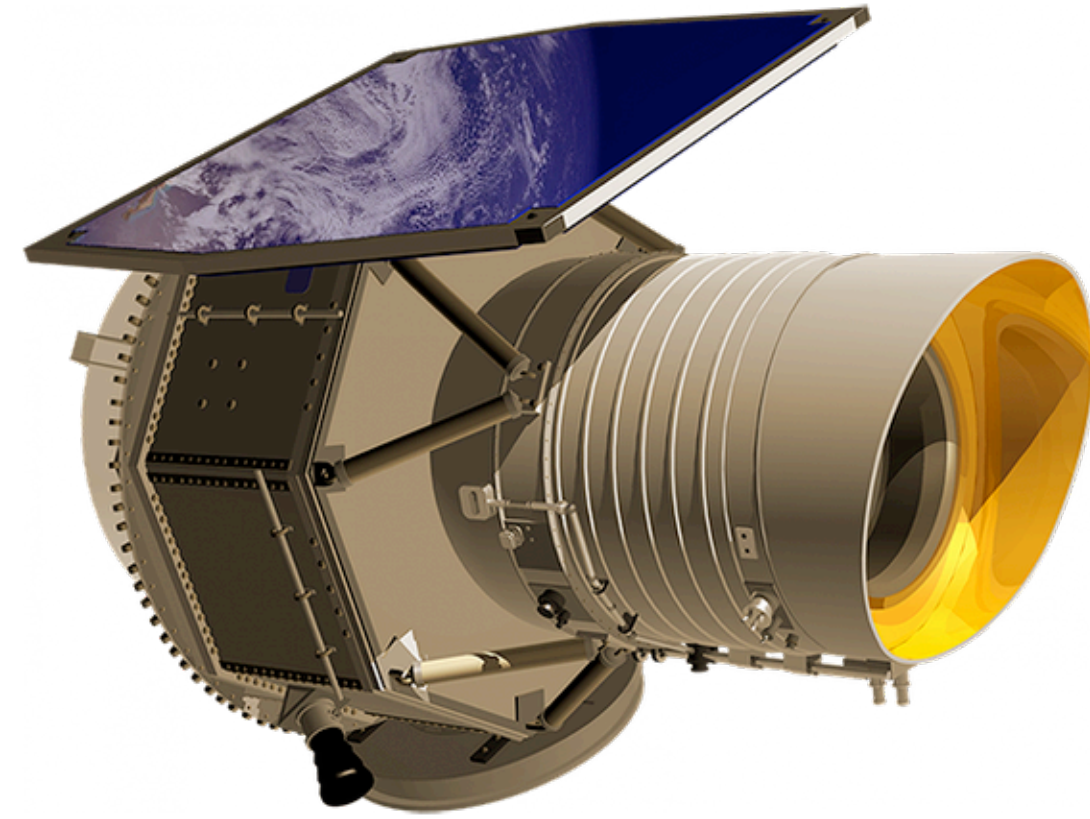
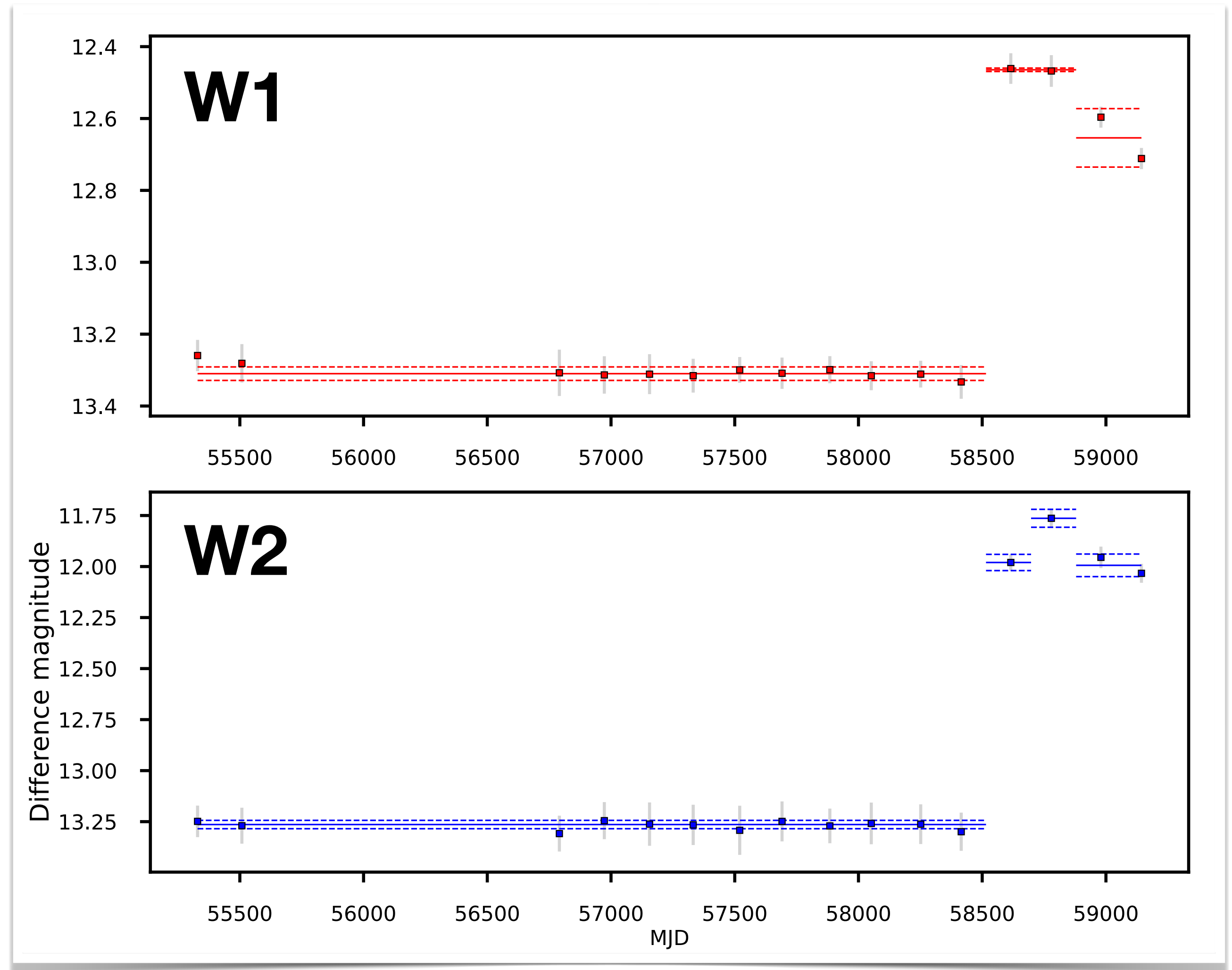


Image credit: NASA

Analyzed with a
Bayesian block framework to
find flares

15% have a prominent IR flare

2% flare **after** the optical peak



Trained BDT classifier with noisified lightcurves from the Bright Transient Survey

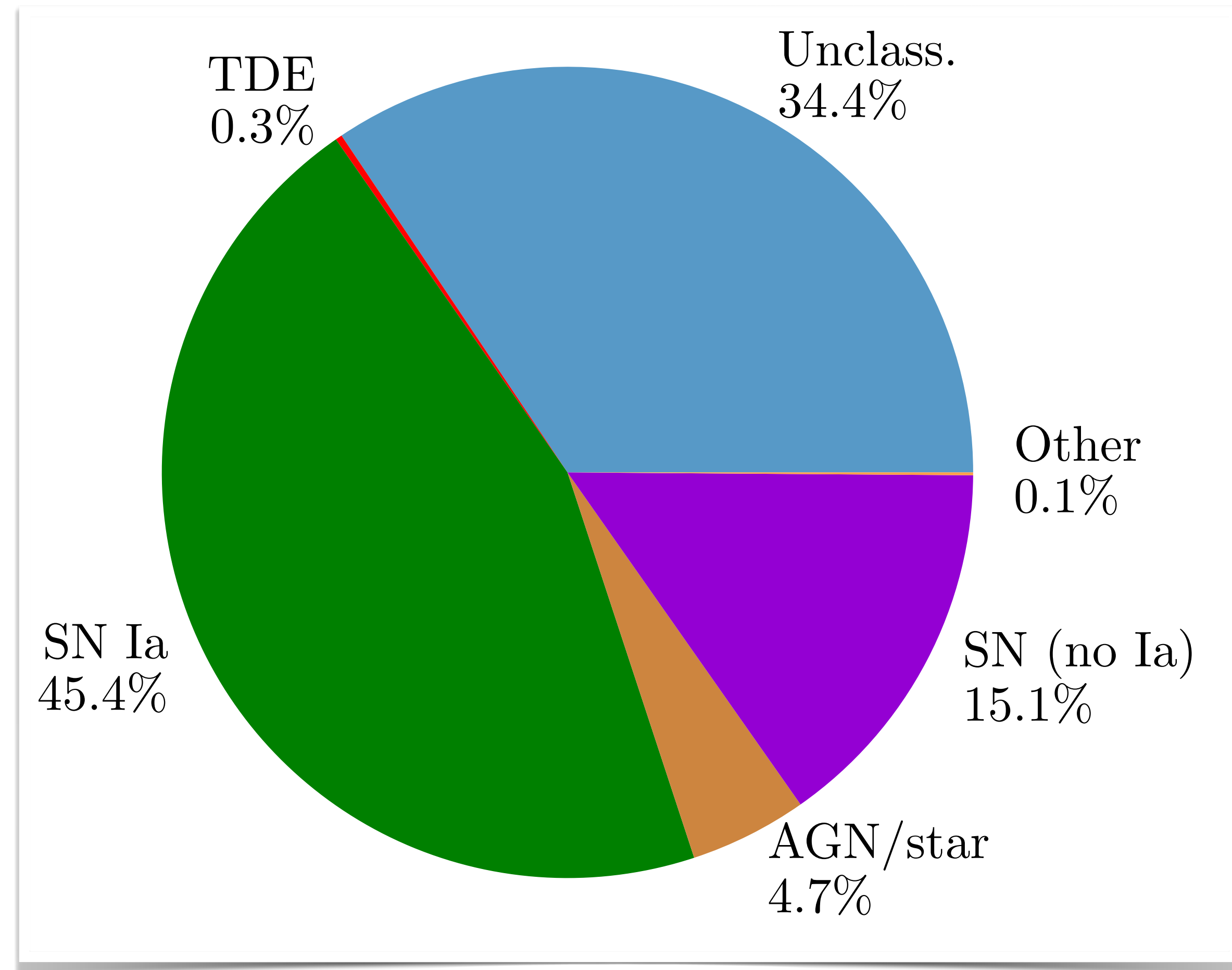
Trained BDT classifier with noisified lightcurves from the Bright Transient Survey

7284 ZTF transients

Trained BDT classifier with noisified lightcurves from the Bright Transient Survey

7284 ZTF transients

5315 of them classified
(brighter than 18.5 mag)

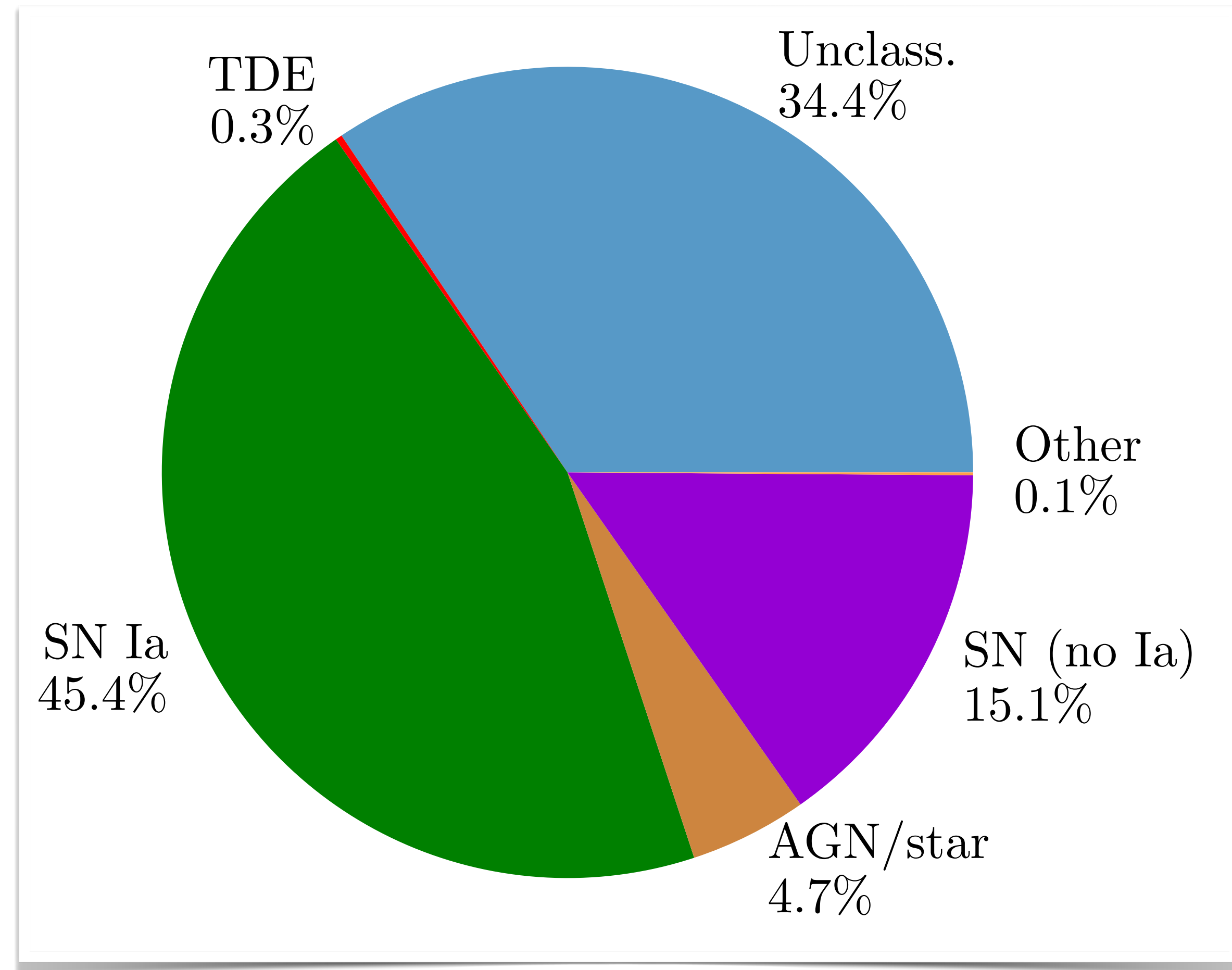


Trained BDT classifier with noisified lightcurves from the Bright Transient Survey

7284 ZTF transients

5315 of them classified
(brighter than 18.5 mag)

Problem: Brighter than
nuclear selection, high
class imbalance



Trained BDT classifier with noisified lightcurves from the Bright Transient Survey

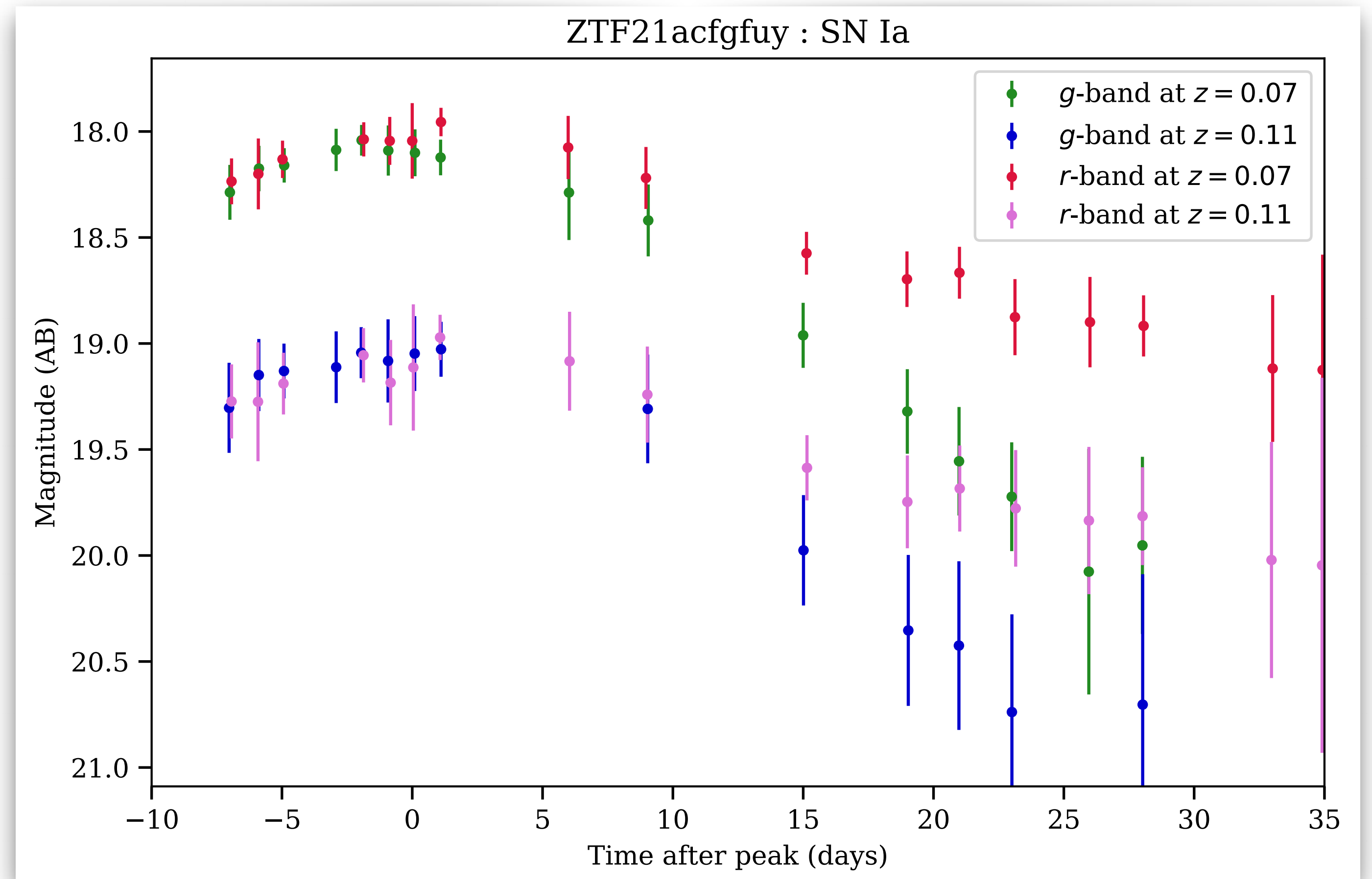
Trained BDT classifier with noisified lightcurves from the Bright Transient Survey

Noisification: Physically motivated remedy

Trained BDT classifier with noisified lightcurves from the Bright Transient Survey

Noisification: Physically motivated remedy

- redshift
- noisify
- K-correct



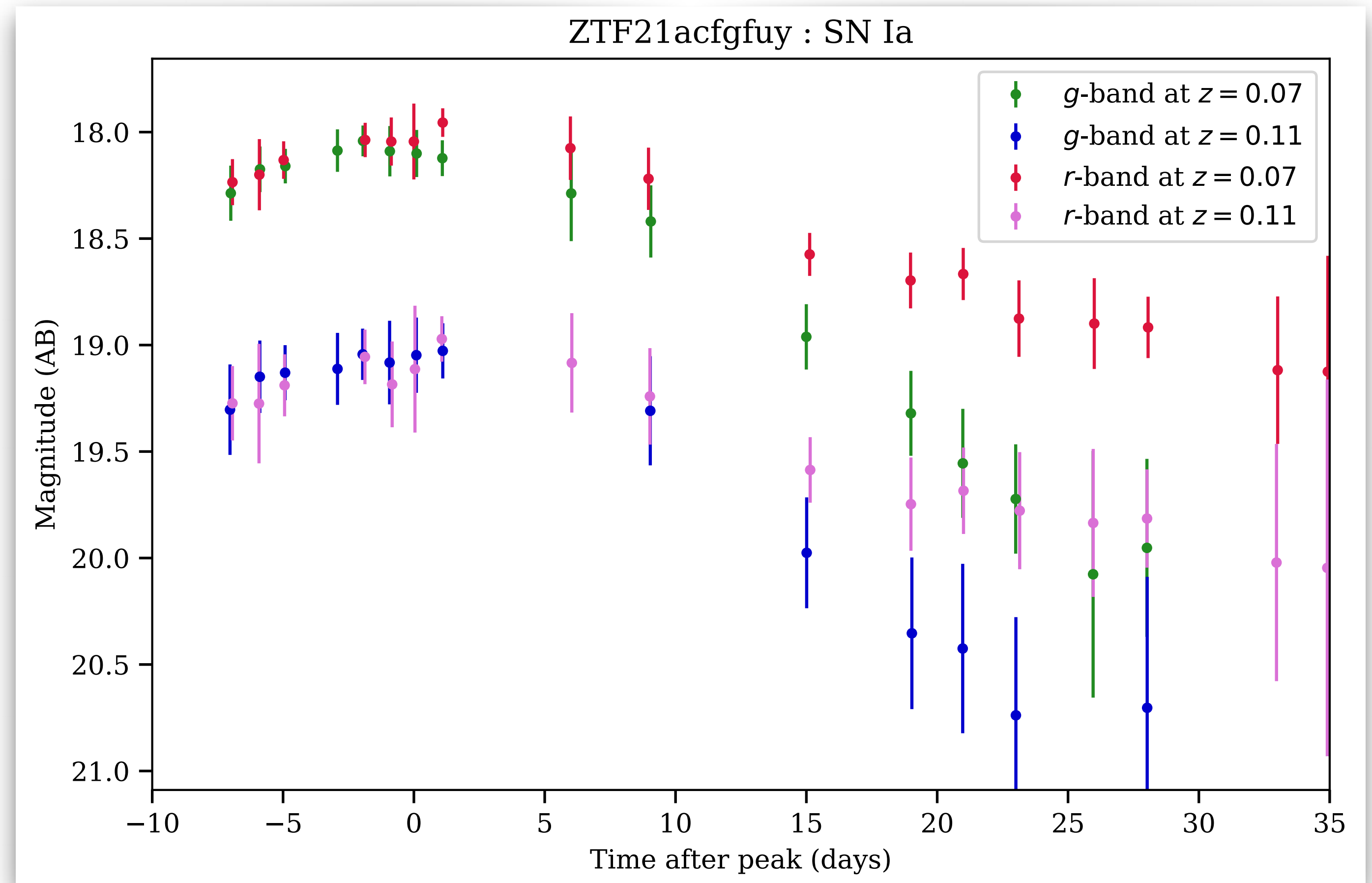
Trained BDT classifier with noisified lightcurves from the Bright Transient Survey

Noisification: Physically motivated remedy

- redshift
- noisify
- K-correct

See Alice's talk!

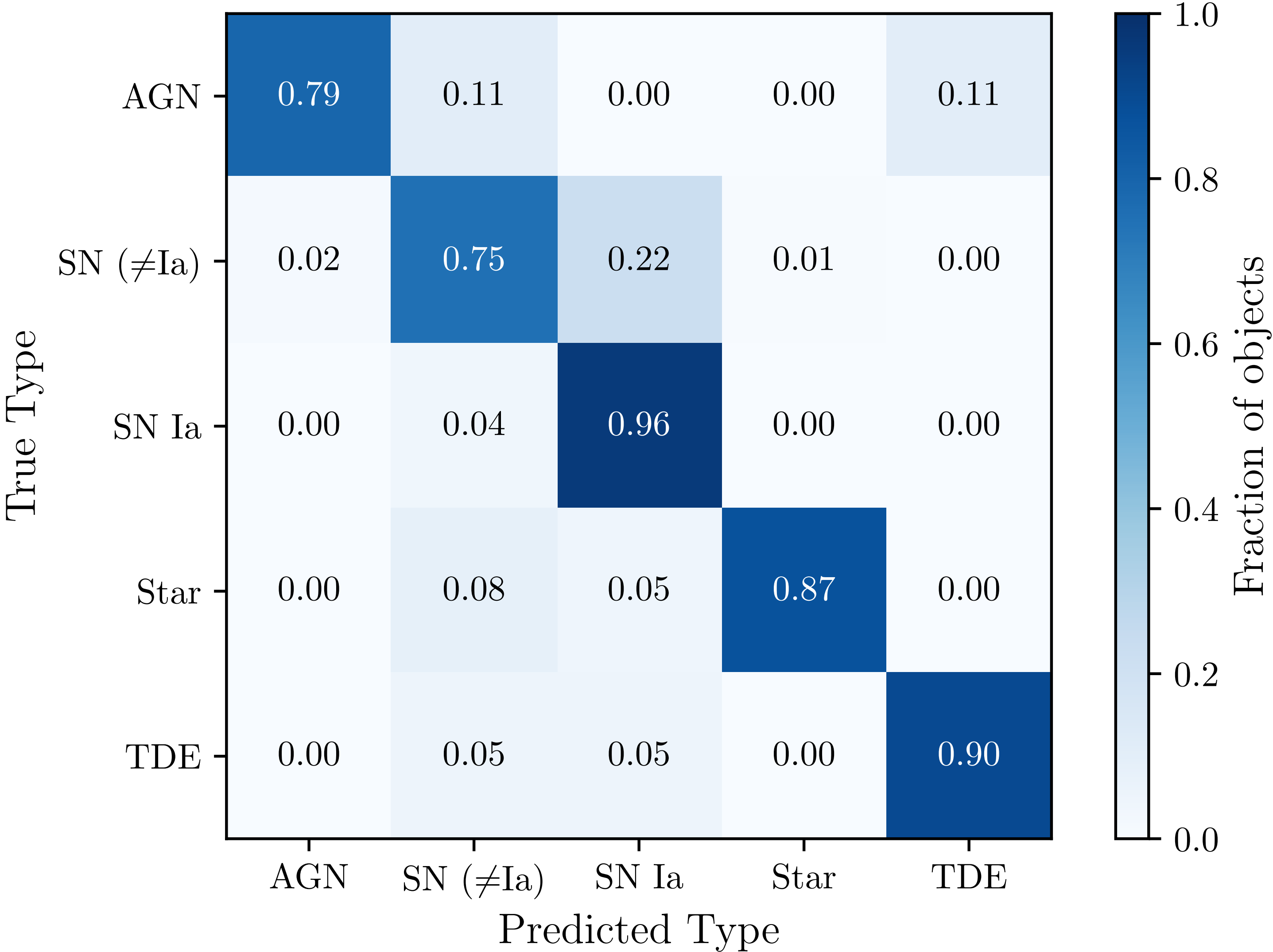
Feature extraction, currently only based on optical data



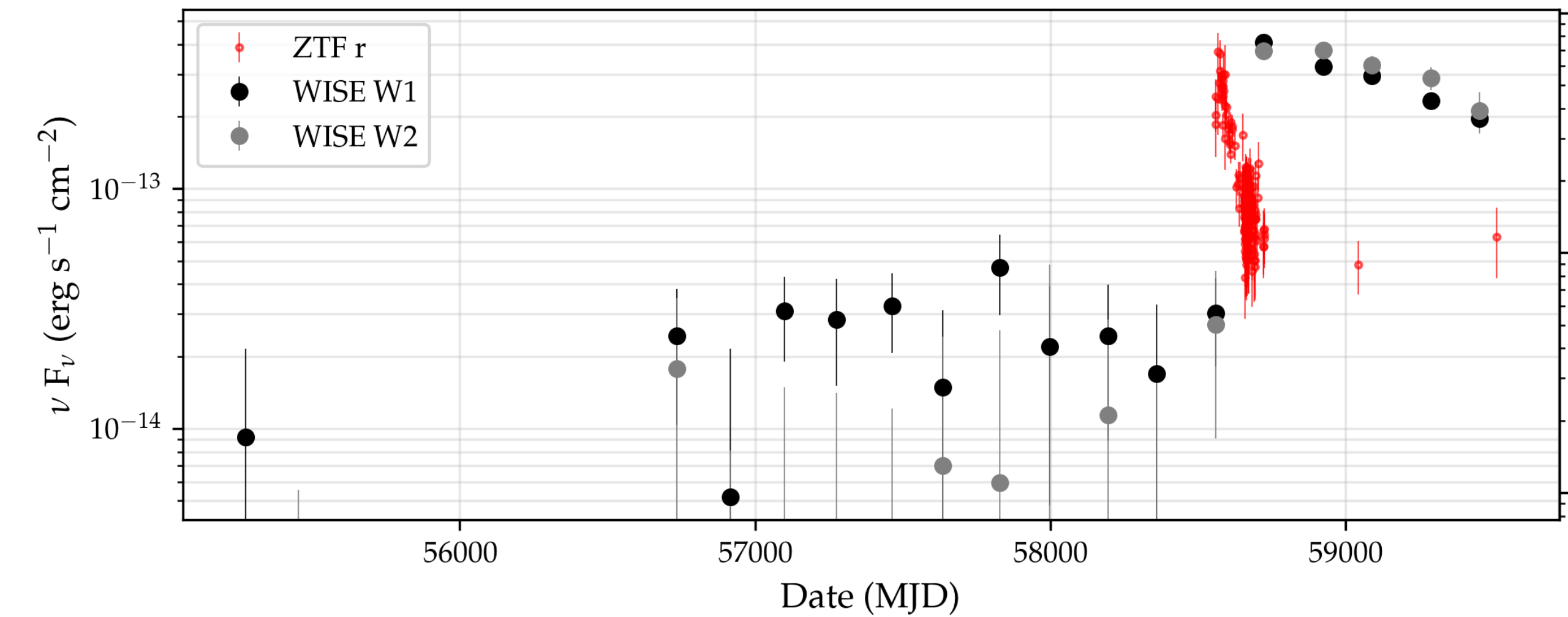
Evaluation with test sample

preliminary

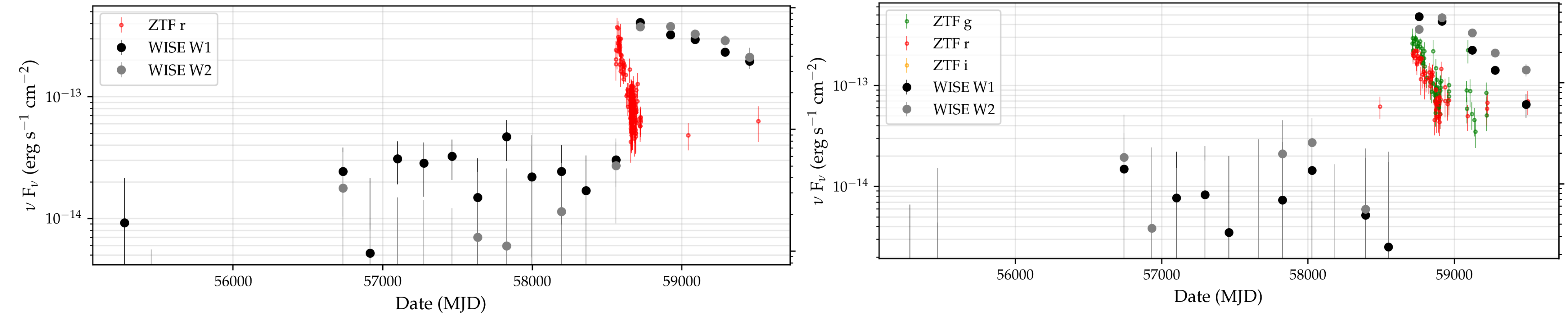
Not including noisified
lightcurves in the test
sample



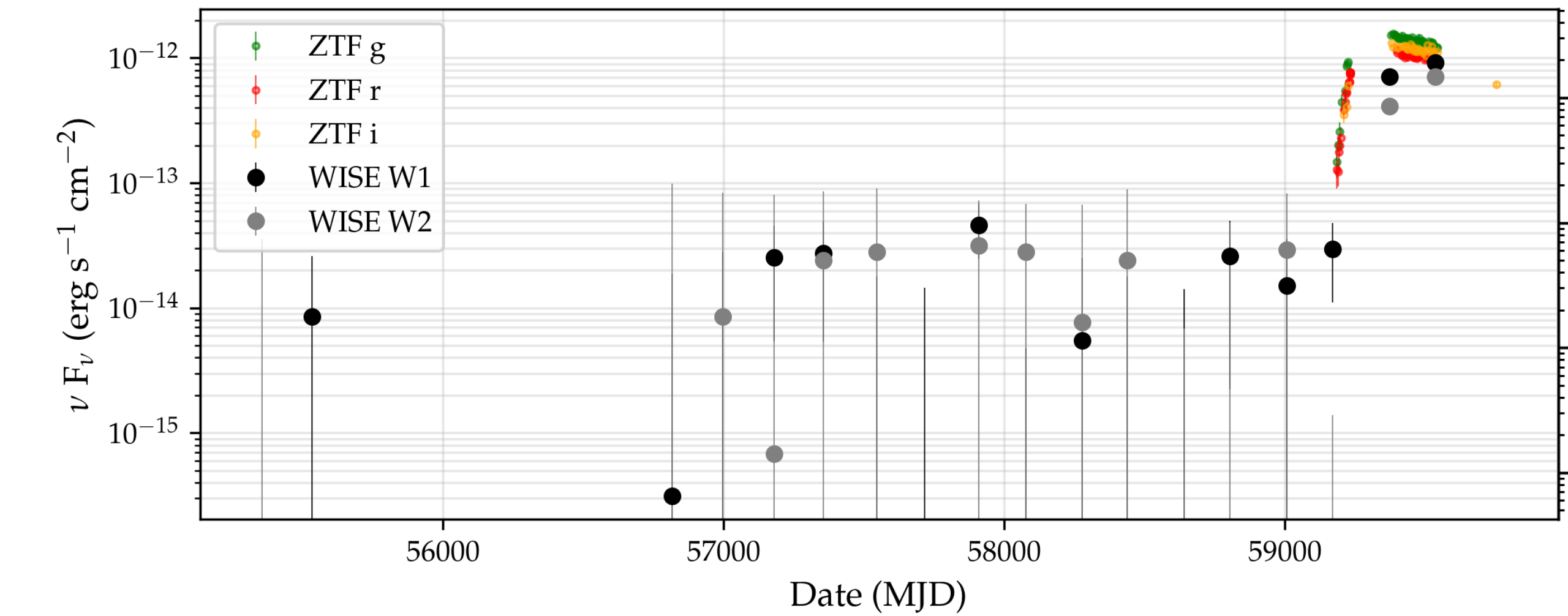
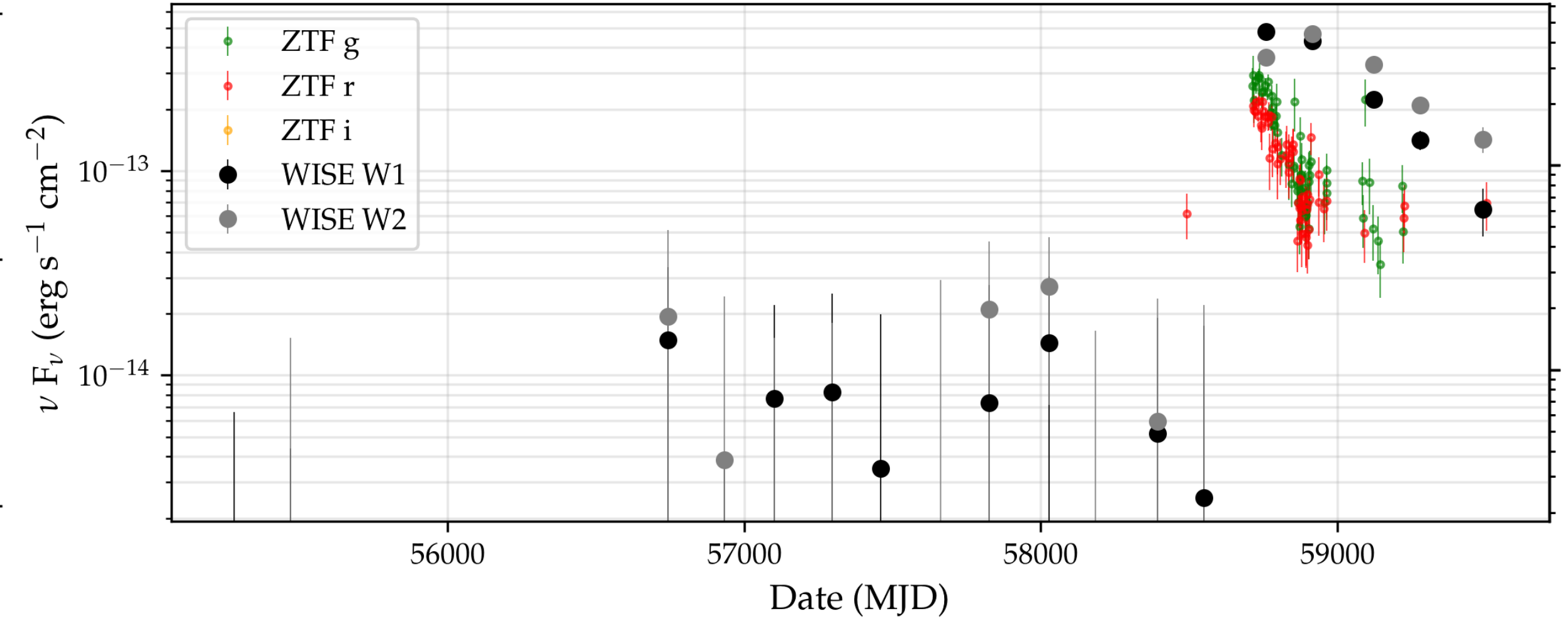
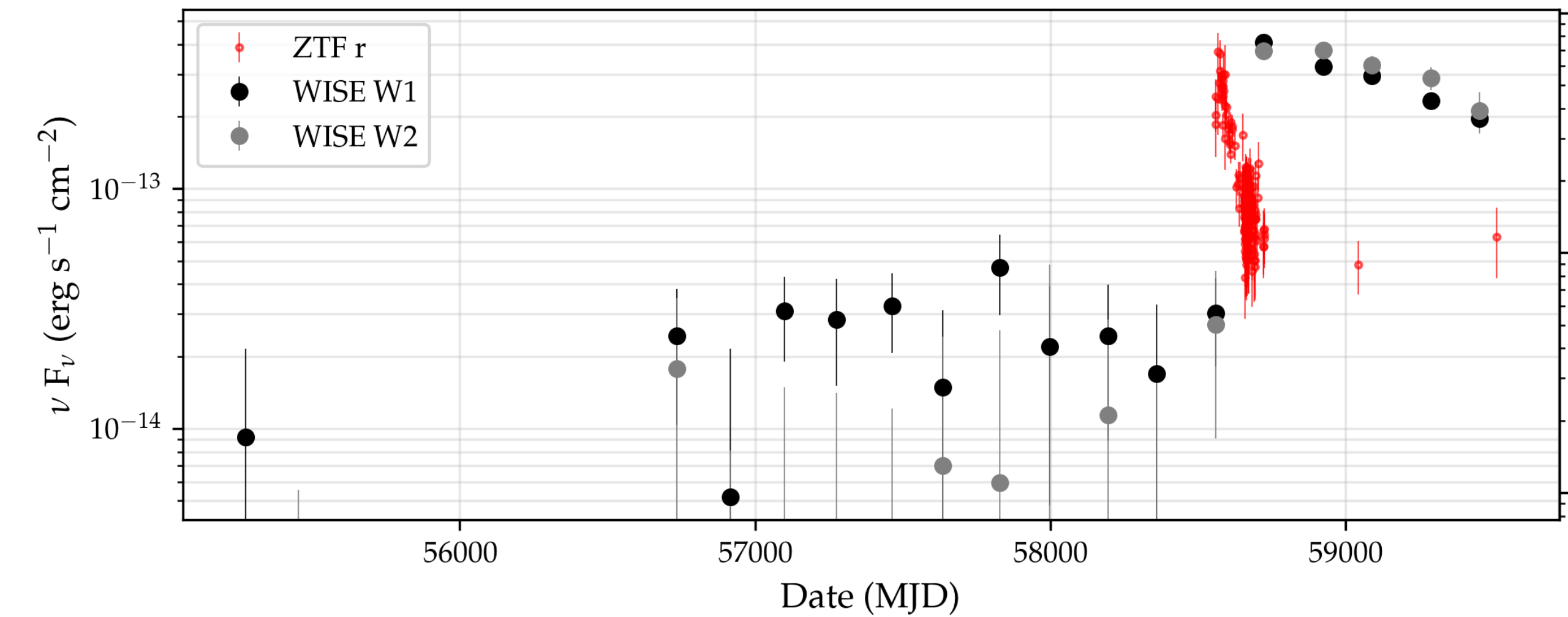
Identified some strong TDE candidates previously missed



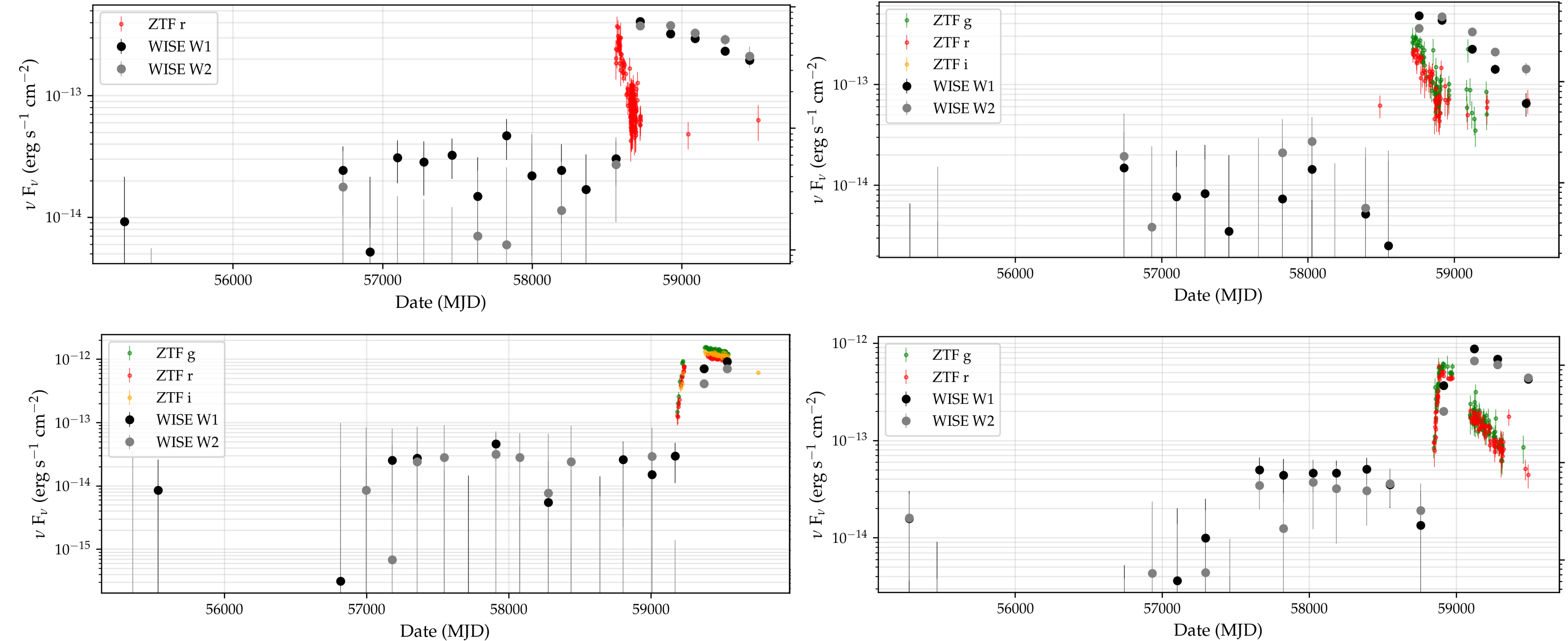
Identified some strong TDE candidates previously missed



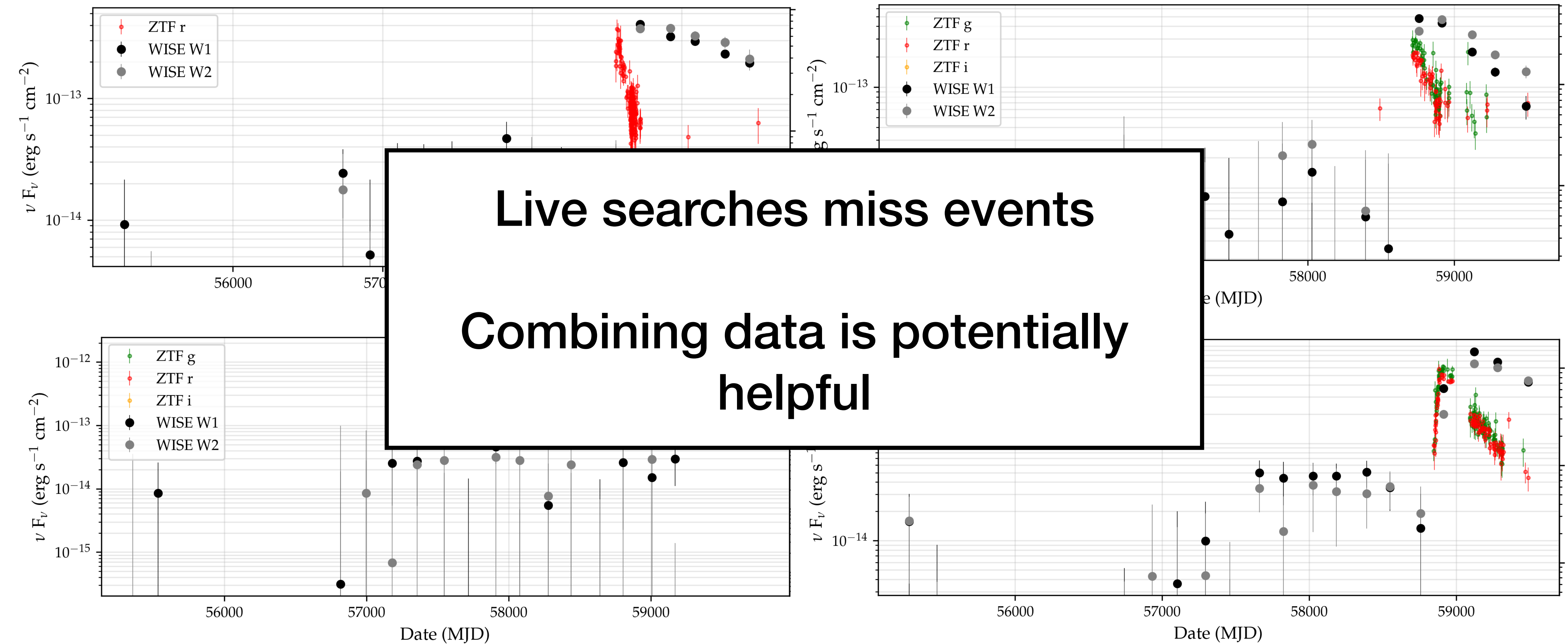
Identified some strong TDE candidates previously missed



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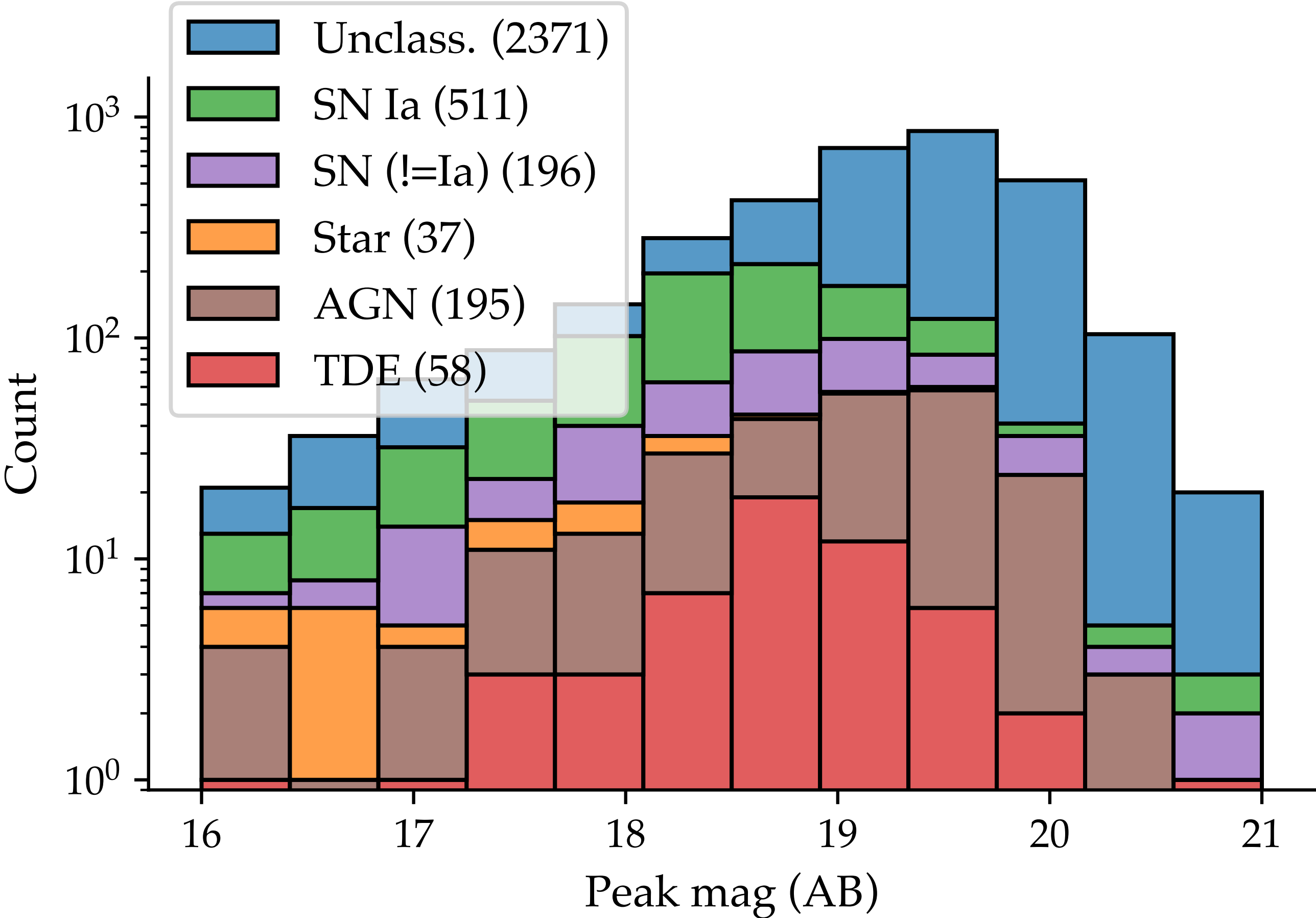
Identified some strong TDE candidates previously missed



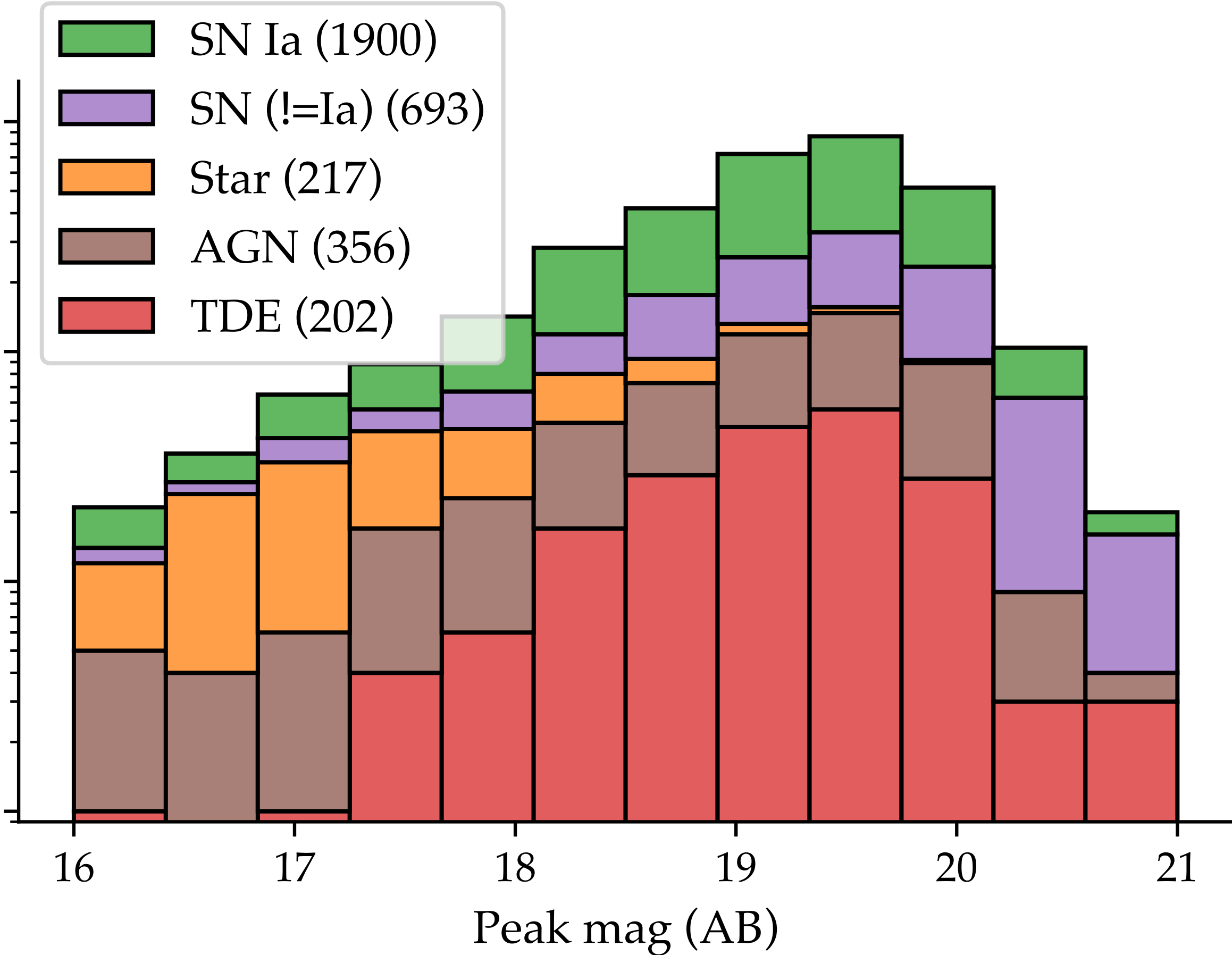
Classification results

preliminary

Community Classification



ML Classification



**III) What does this
tell us about GW
follow up?**

What can we learn from such a sample?

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Photometric identification is still a challenge!

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There might be types of events in the sample we missed so far

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Photometric identification is still a challenge!

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We know about SNe, stochastic AGN variability, AGN flares, CVs and TDEs. But what else?

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Photometric identification is still a challenge!

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We know about SNe, stochastic AGN variability, AGN flares, CVs and TDEs. But what else?

Exclusively looking for KN signatures poses the danger of missing something

What can we learn from such a sample?

Photometric identification is still a challenge!

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We know about SNe, stochastic AGN variability, AGN flares, CVs and TDEs. But what else?

Exclusively looking for KN signatures poses the danger of missing something

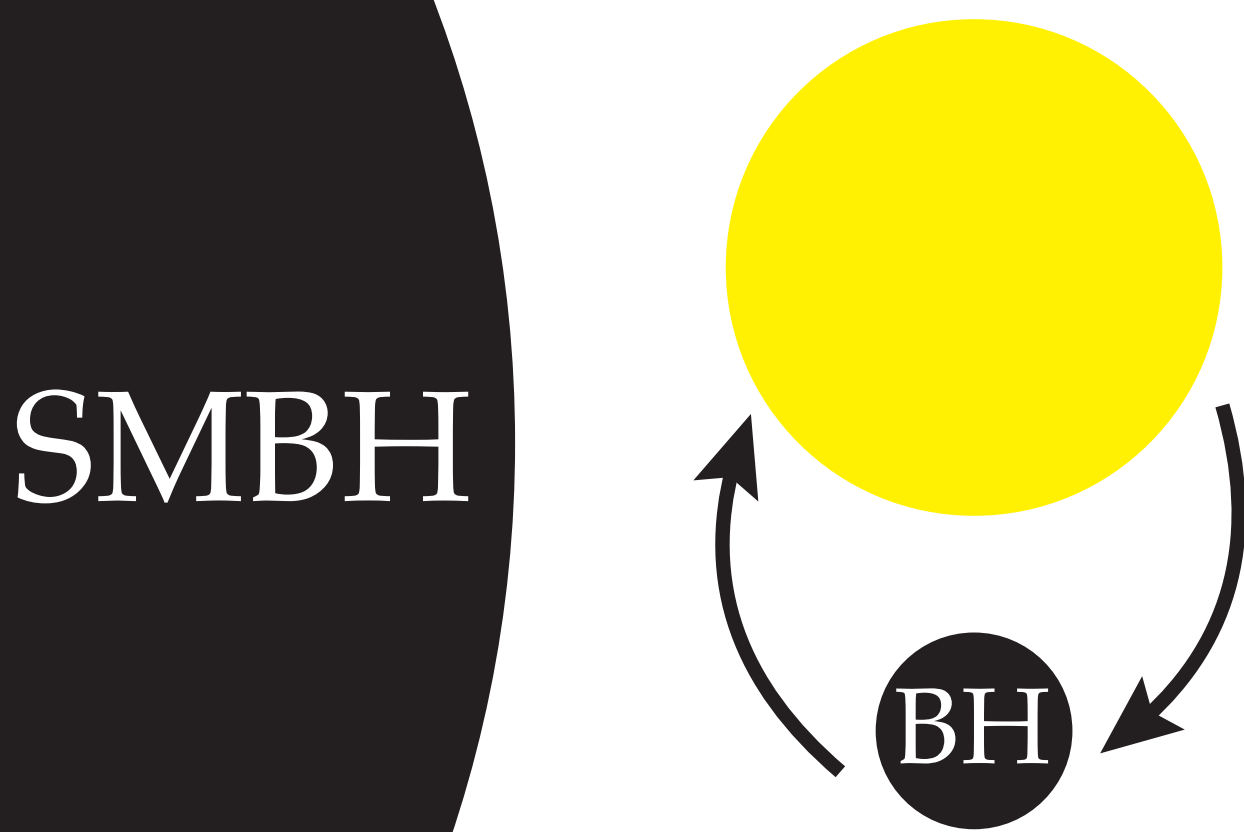
BBH counterparts (slowly evolving!)

Example: What about micro-TDEs?

Y. Yang+ 2022

Example: What about micro-TDEs?

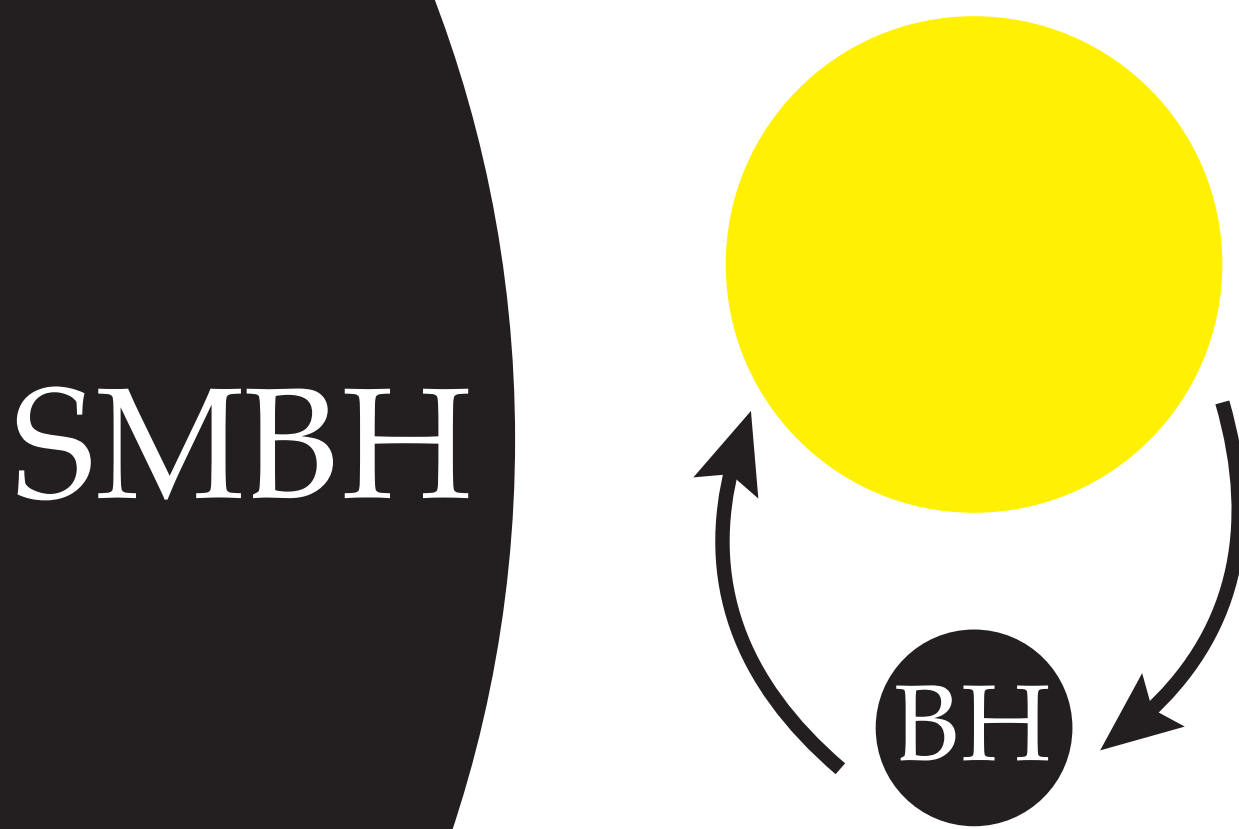
stellar mass BH tidally disrupting a star



Y. Yang+ 2022

Example: What about micro-TDEs?

stellar mass BH tidally disrupting a star

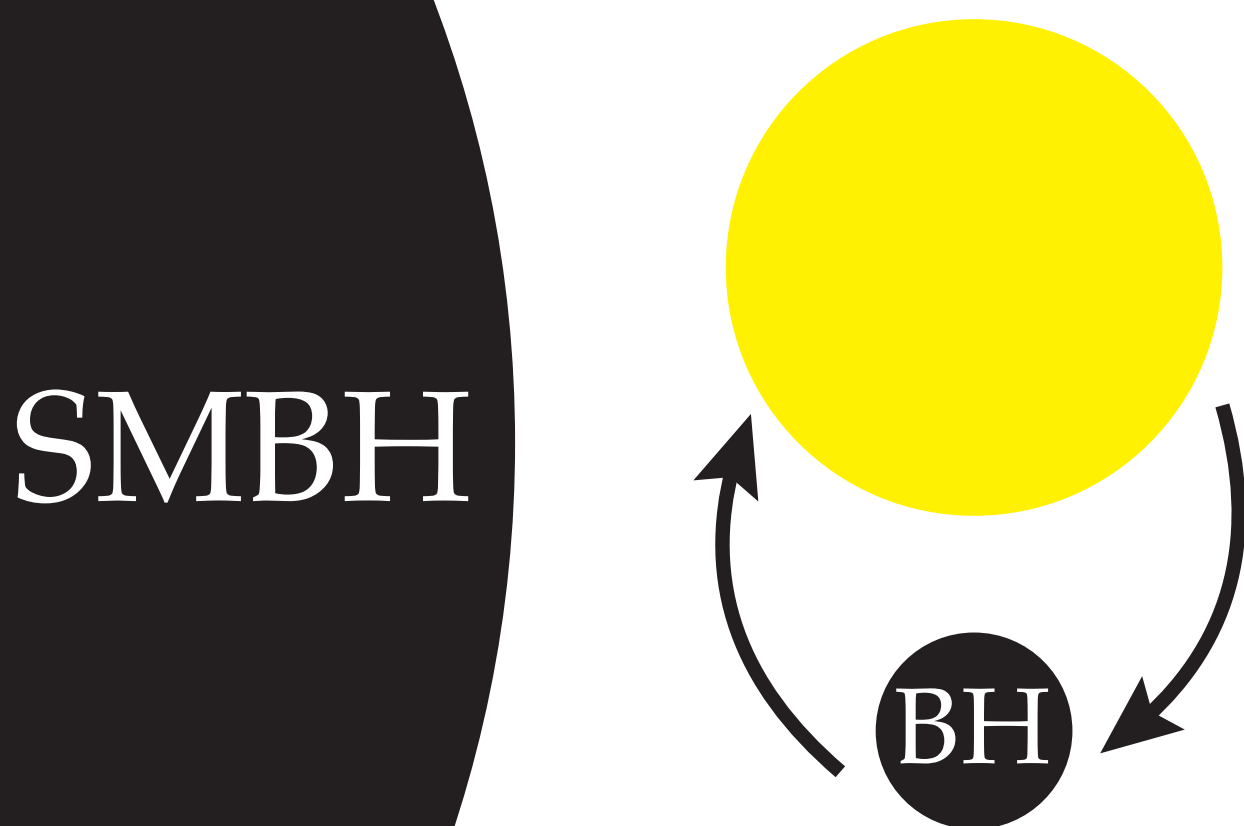


Maybe enhanced rate close to the SMBH due to pre-existing accretion disk

Y. Yang+ 2022

Example: What about micro-TDEs?

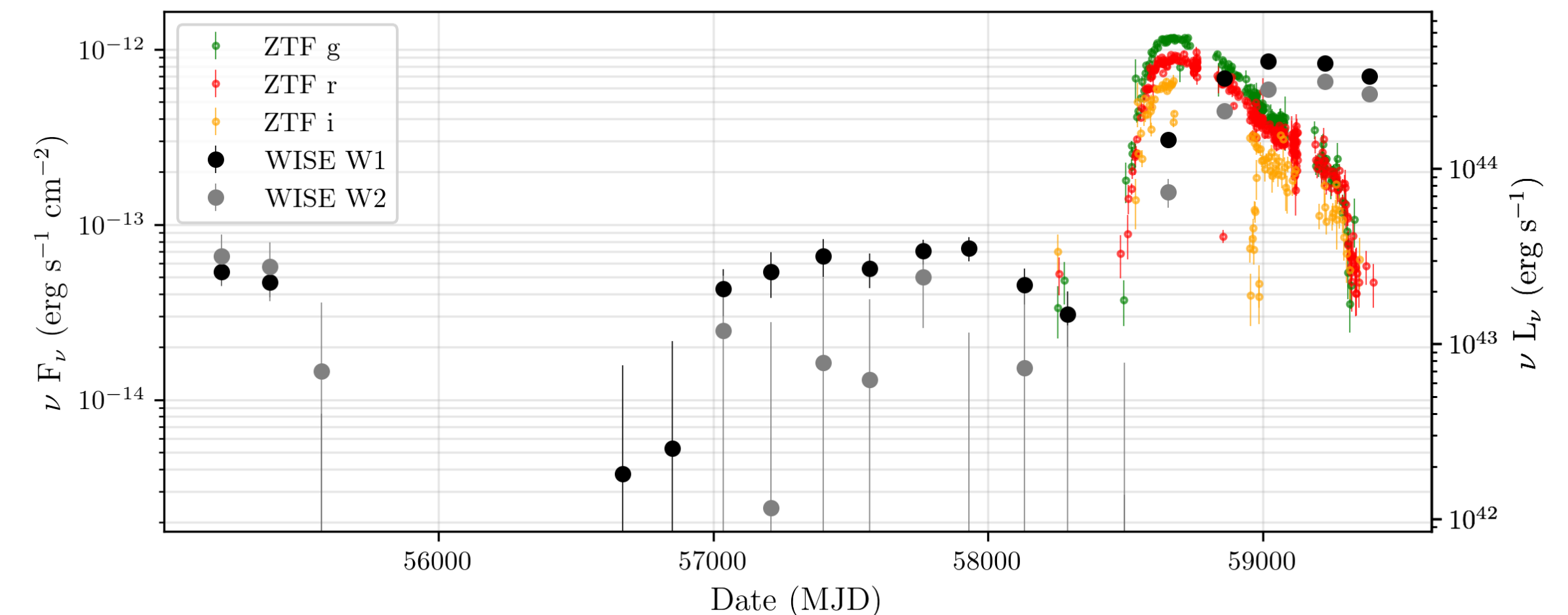
stellar mass BH tidally disrupting a star



Maybe enhanced rate close to the SMBH due to pre-existing accretion disk

EM signature: Similar to TDEs, but SMBH mass above Hills mass for **bright** μ TDEs

Faint μ TDEs: unusual flaring in the AGN light curve



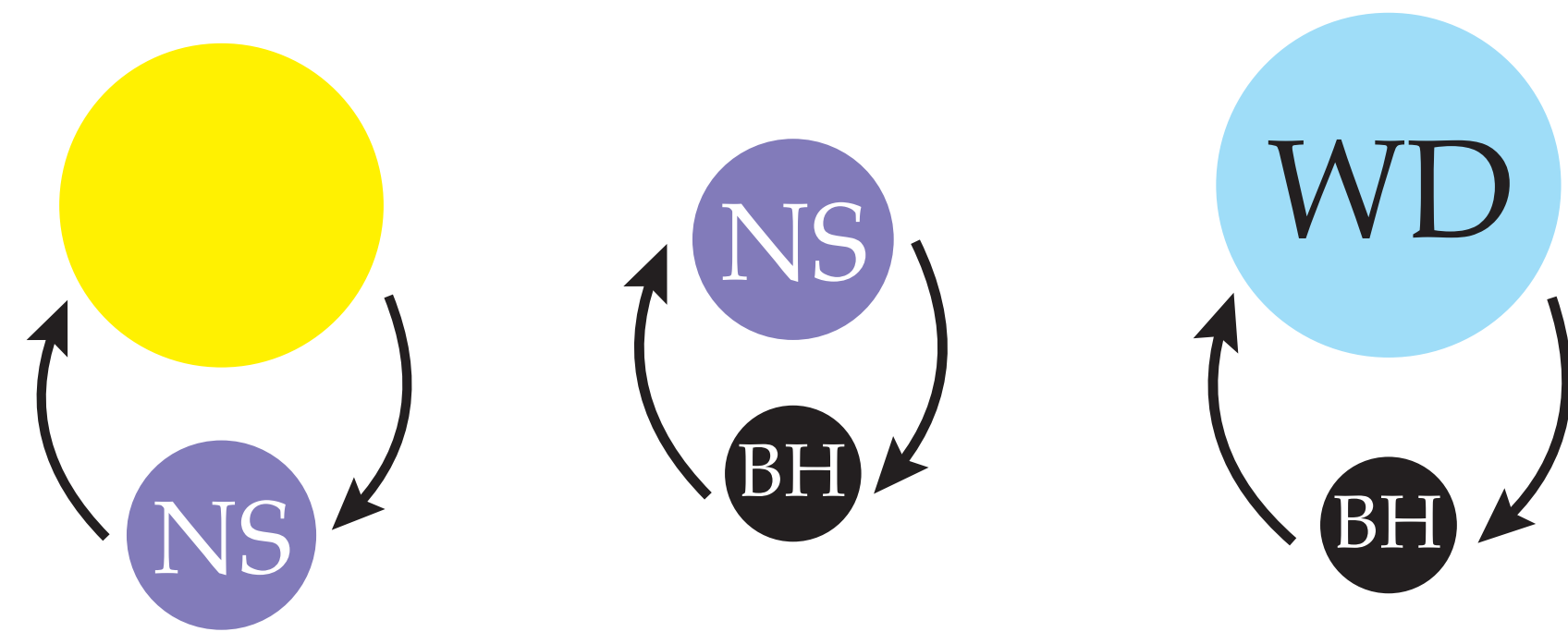
Literature candidate μ TDE
ZTF19aailpwl (part of the sample)

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Event type possibly observable as EM transients

SMBH

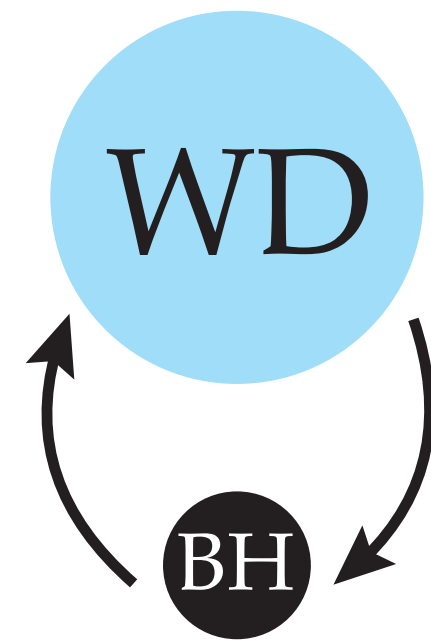
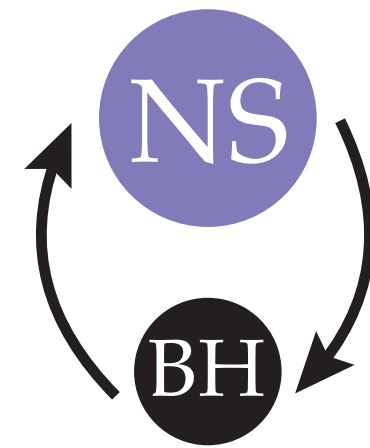
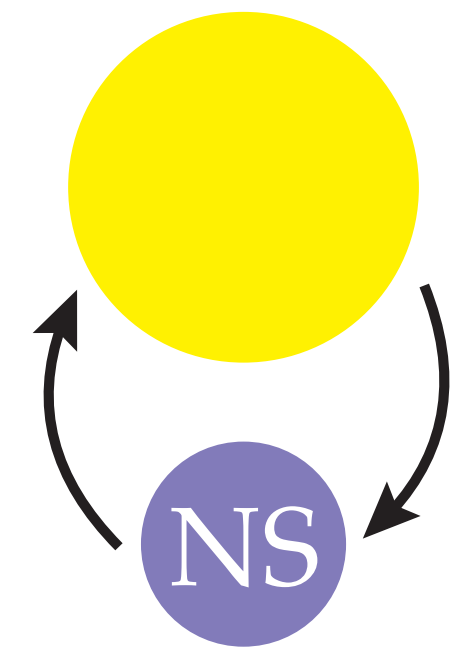
Event type possibly observable as EM transients



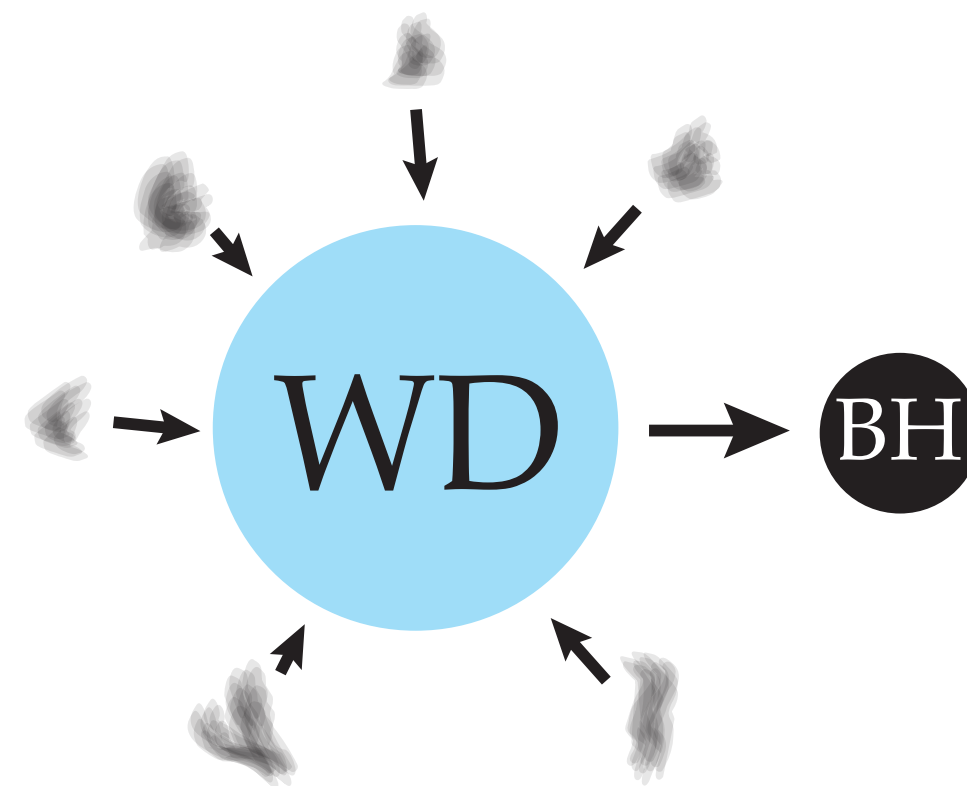
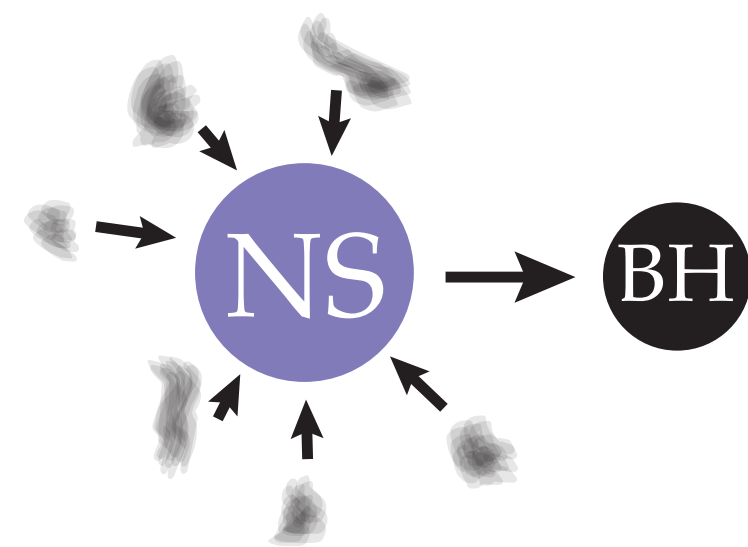
Other μ TDE channels

SMBH

Event type possibly observable as EM transients

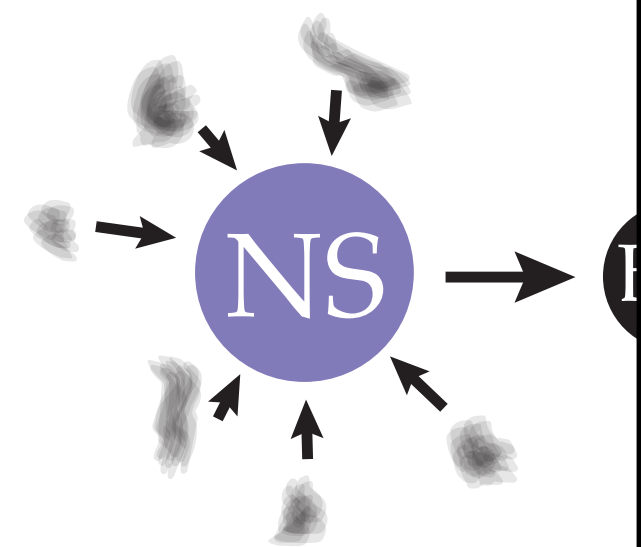
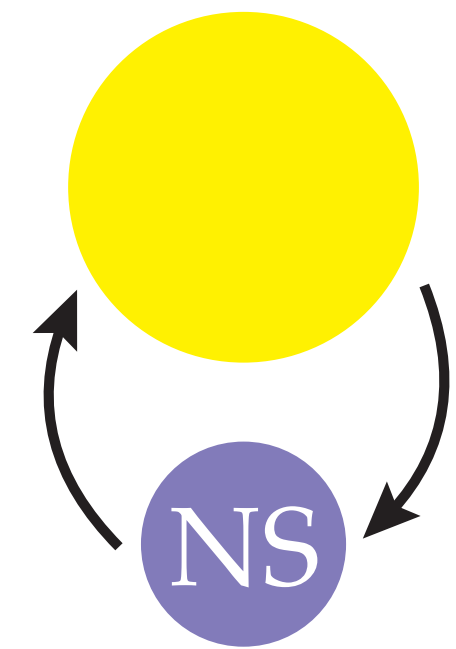


Other μ TDE channels



**Accretion induced
collapse**

Event type possibly observable as EM transients



There should be some of these contained in the nuclear sample

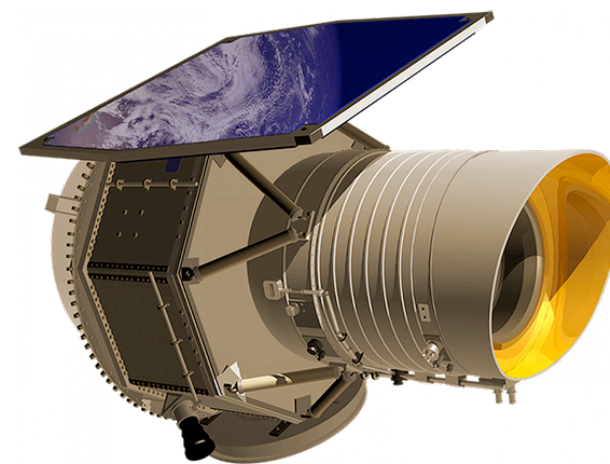
GW signals unlikely to be accessible to LVK

But one can potentially learn about BH evolution and binary formation in AGN disks

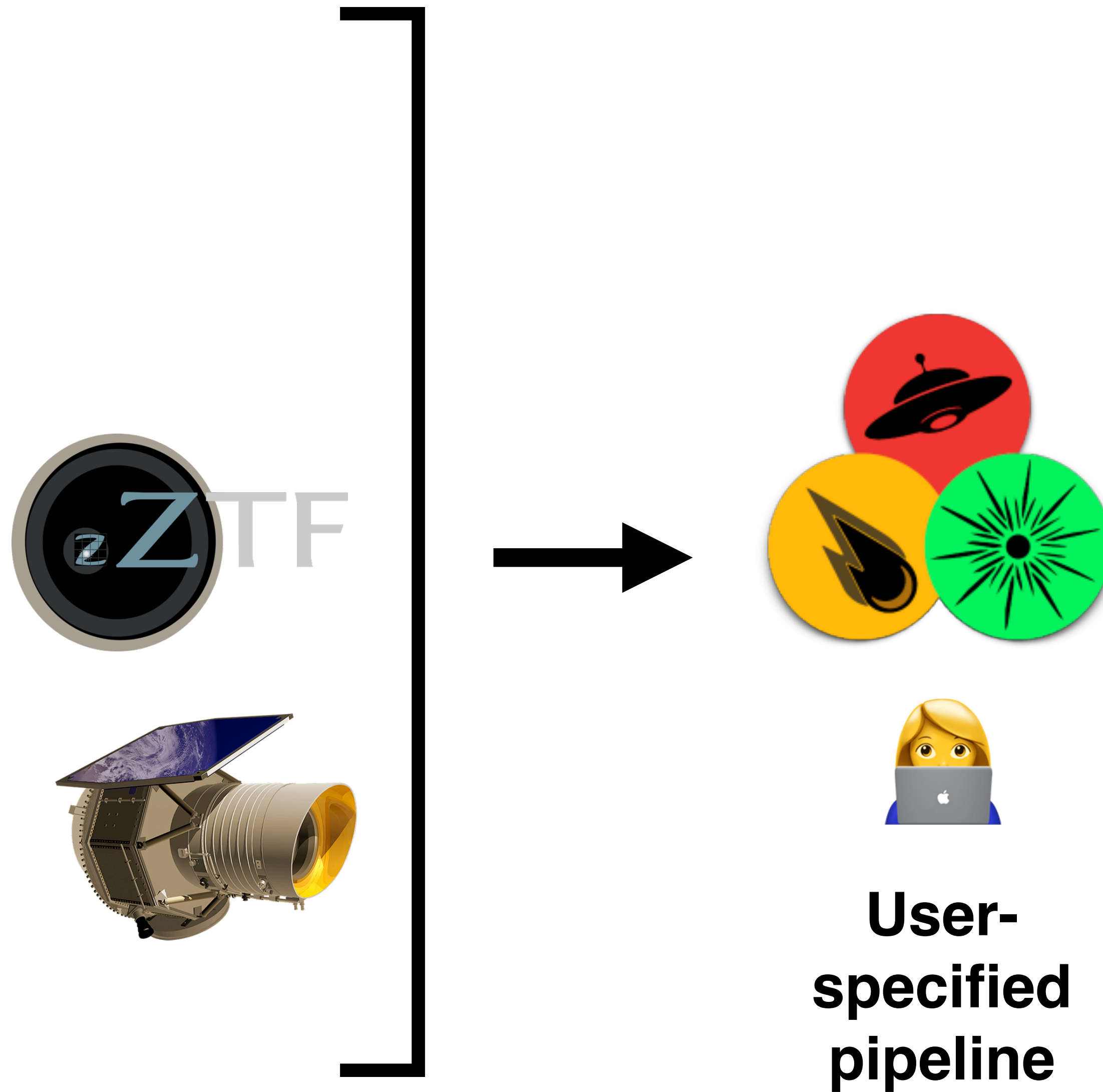
ls

duced

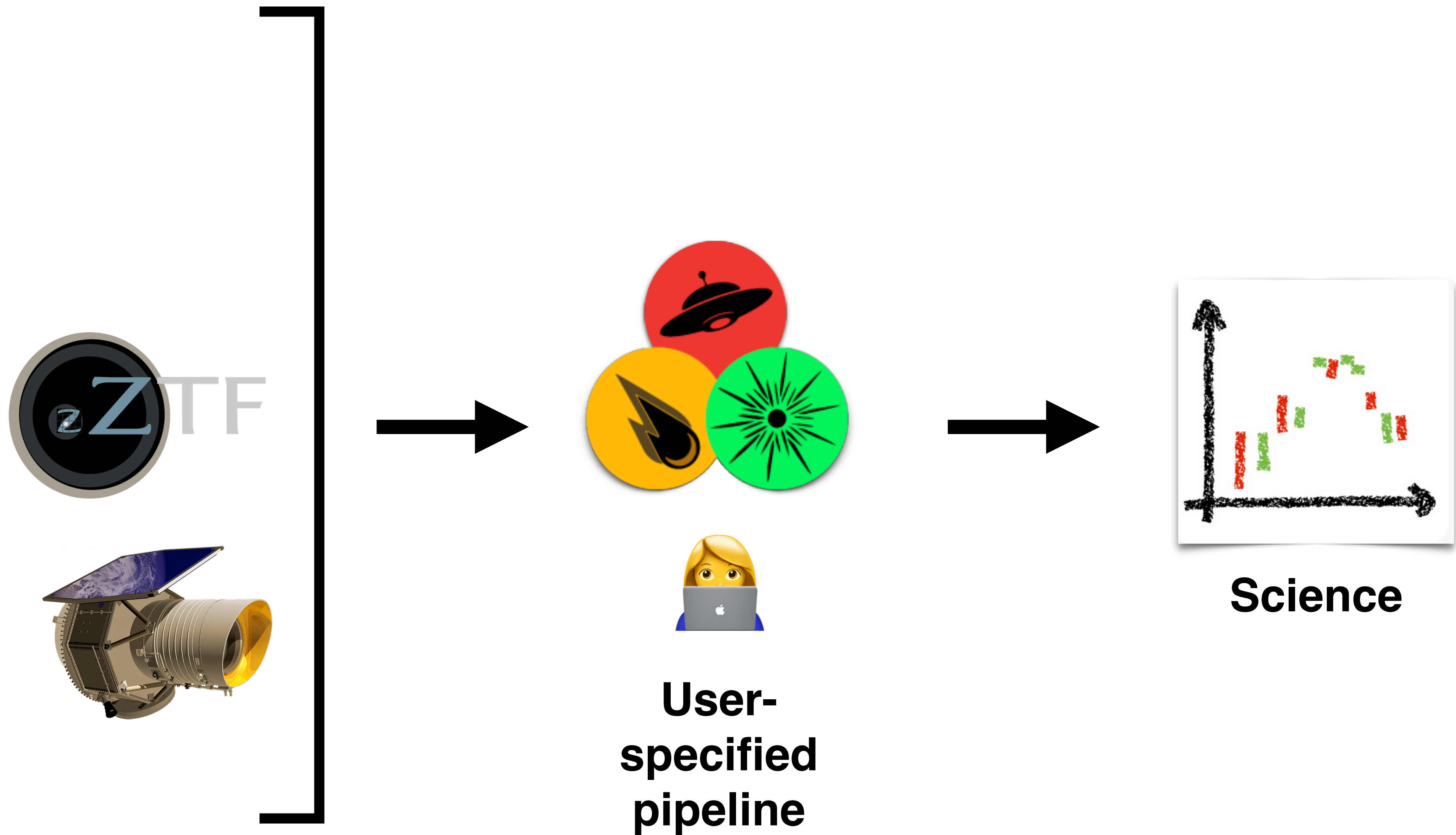
Nuclear sample: Created with AMPEL



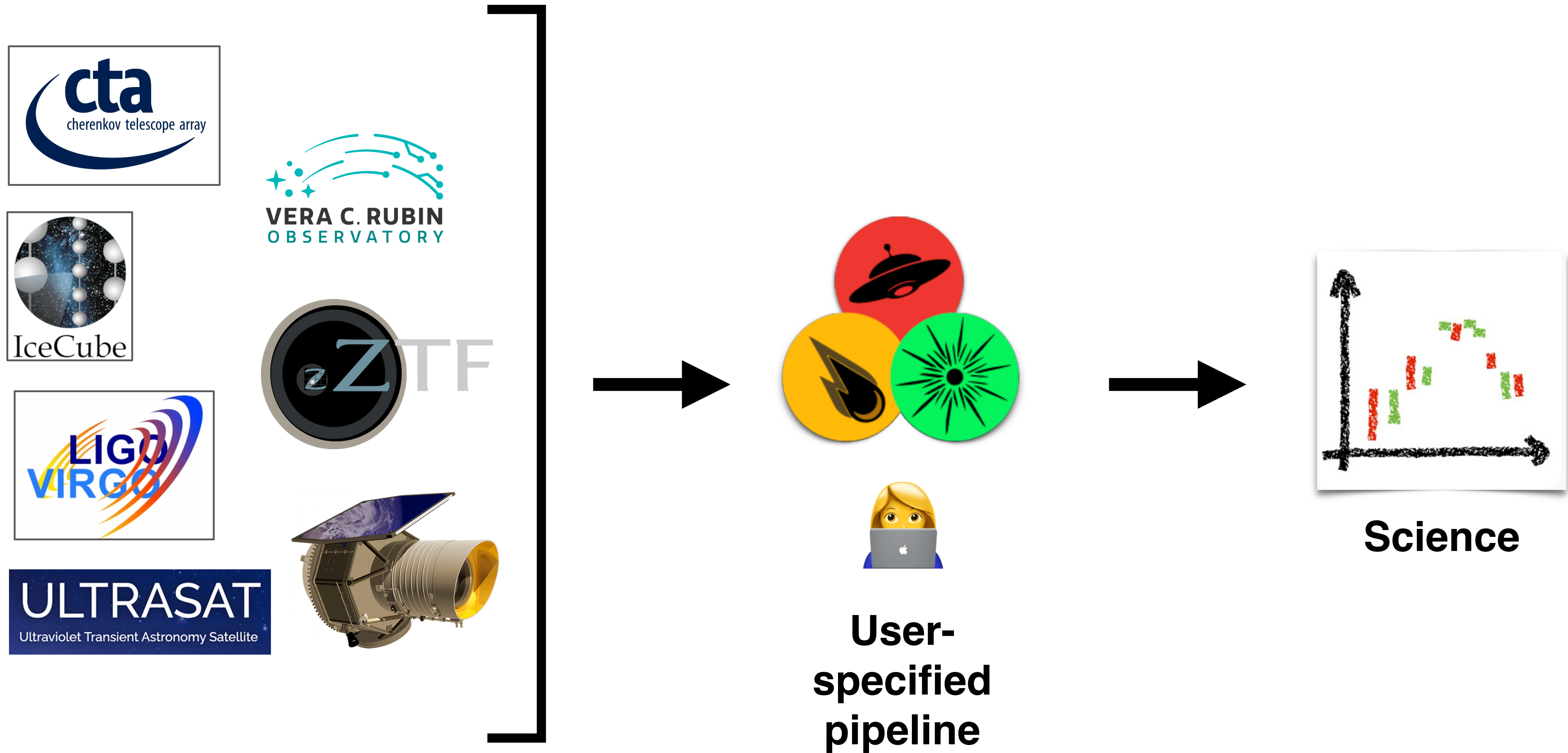
Nuclear sample: Created with AMPEL



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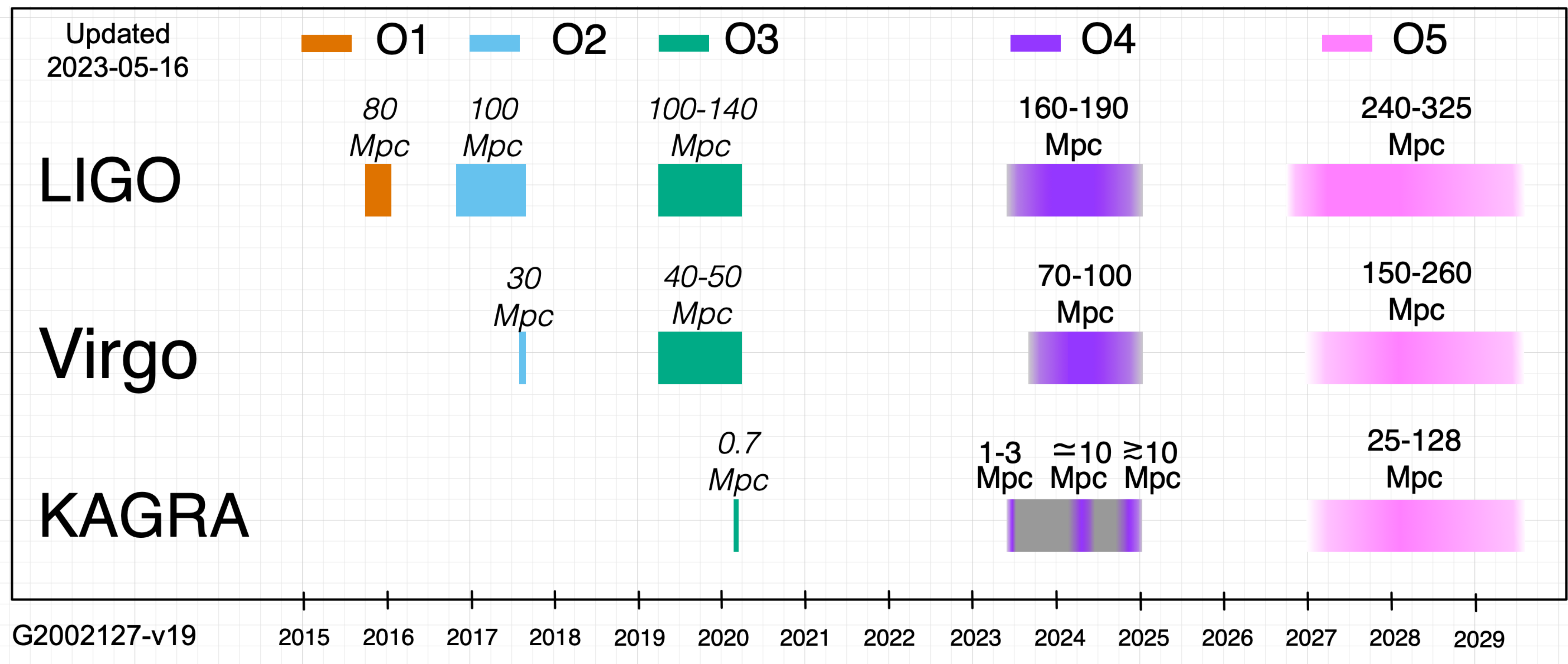


There is so much more data to be combined



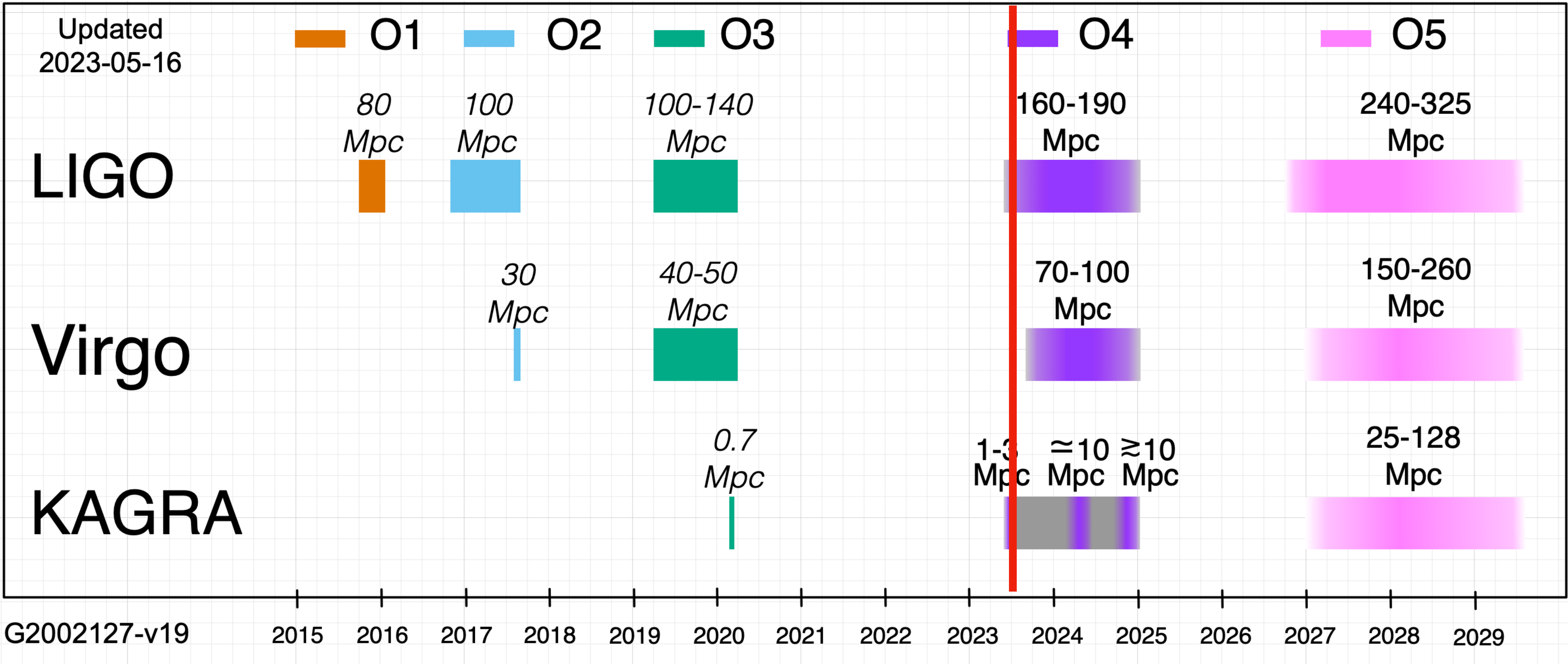
IV) Current ZTF O4 status

O4 Status



O4 Status

We are here!



O4 Status

O4 Status

Expected range: 140 – 170 Mpc

O4 Status

Expected range: 140 – 170 Mpc

40% higher distance than O4, 2.6 the volume

O4 Status

Expected range: 140 – 170 Mpc

40% higher distance than O4, 2.6 the volume

Expected event rates: 10 (+52/-10) BNS detections

O4 Status

Expected range: 140 – 170 Mpc

40% higher distance than O4, 2.6 the volume

Expected event rates: 10 (+52/-10) BNS detections

FAR rate:

low significance: $\text{FAR} > 1/\text{month (CBC) or } > 1/\text{year (burst)}$

significant: $\text{FAR} < 1/\text{month (CBC) or } < 1/\text{year (burst)}$

O4 Status

Expected range: 140 – 170 Mpc

40% higher distance than O4, 2.6 the volume

Expected event rates: 10 (+52/-10) BNS detections

FAR rate:

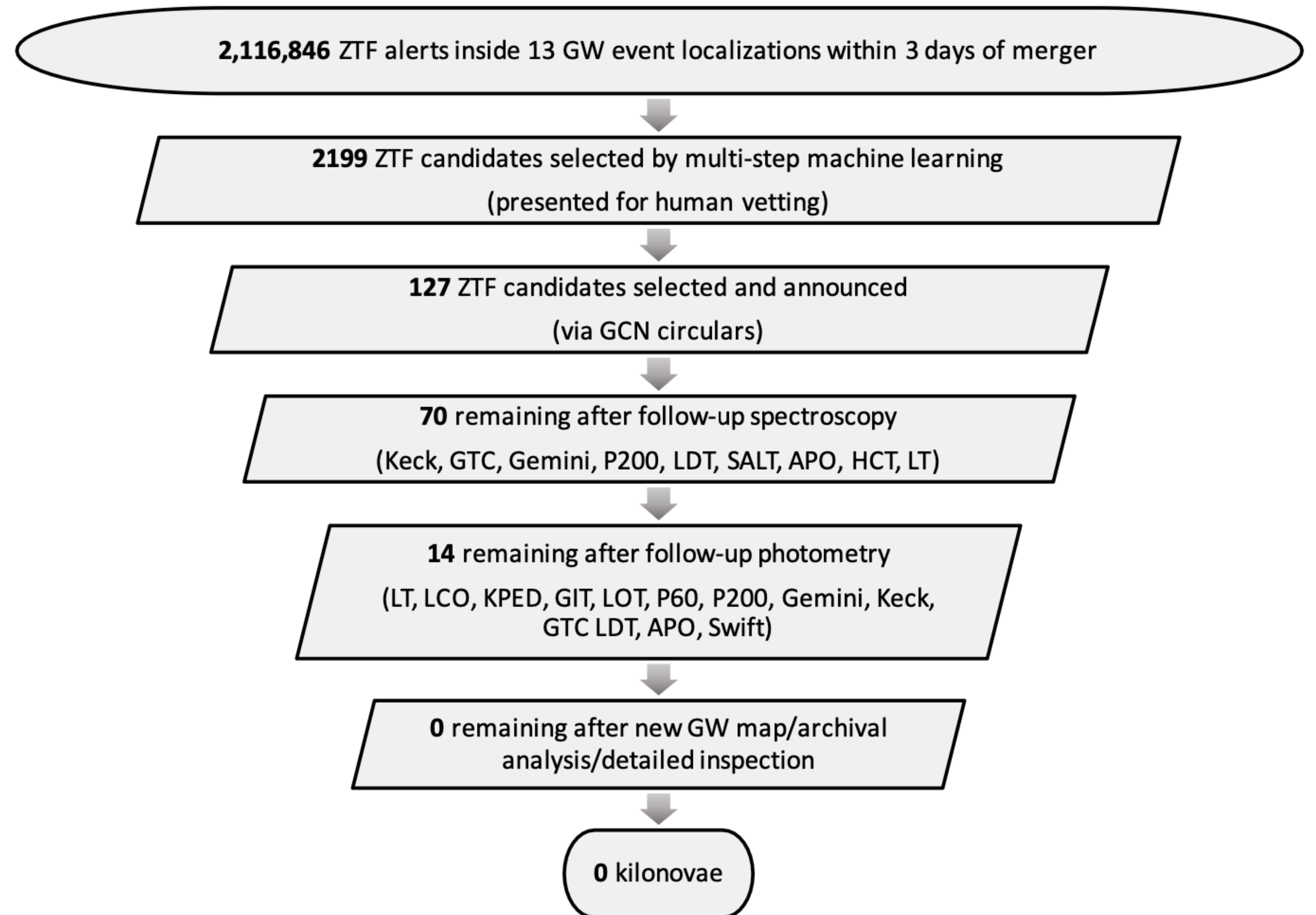
low significance: $\text{FAR} > 1/\text{month (CBC) or } > 1/\text{year (burst)}$

significant: $\text{FAR} < 1/\text{month (CBC) or } < 1/\text{year (burst)}$

Localization: **Comparable to O3**

Recap: O3 with ZTF

Or: How to go
from 2.1 Million
to zero 🤔



O4 Trigger Strategy

Parameter	Go-deep	Go-wide	Deliberate	No Go
Strategy	300 sec Push distance	30 sec Push localization	Action Item: human interaction	
Frequency of triggers	1 per month 3 night	2 per month 5 nights		
FAR min(FAR) - 'Best'	< 1 per century Any pipeline	< 1 per decade Any pipeline	1 per year - century	> 1 per year All pipelines
max(p-astro)	> 0.9	> 0.9	0.1-0.9	<0.1
HasNS	>0.9	>0.9	0.1-0.9	<0.1

Redundant machinery for ZTF scanning



fritz.science
(Fritz database)



nuztf + AMPEL
(AMPEL DB)

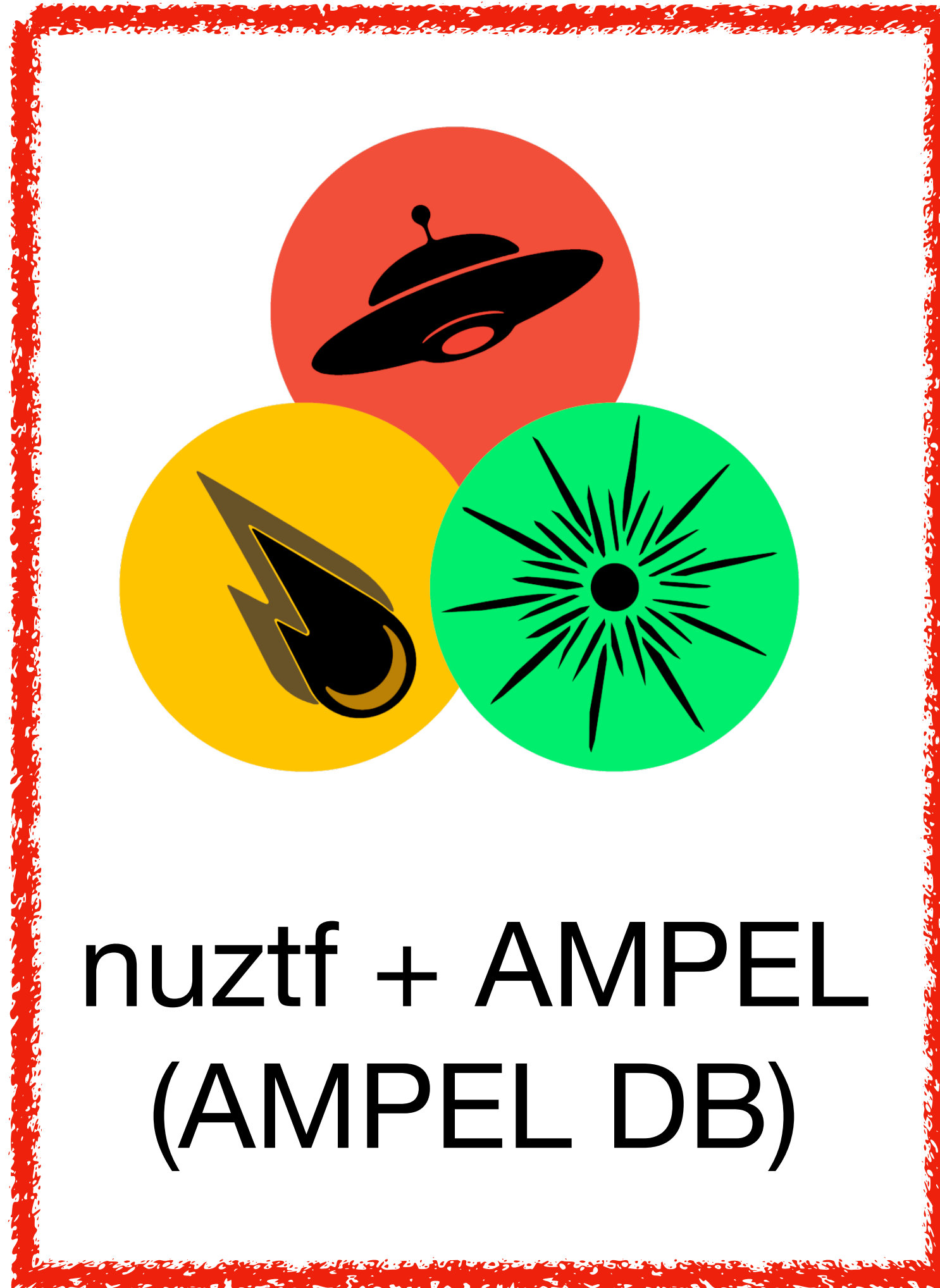


emgwcave
(Kowalski DB)

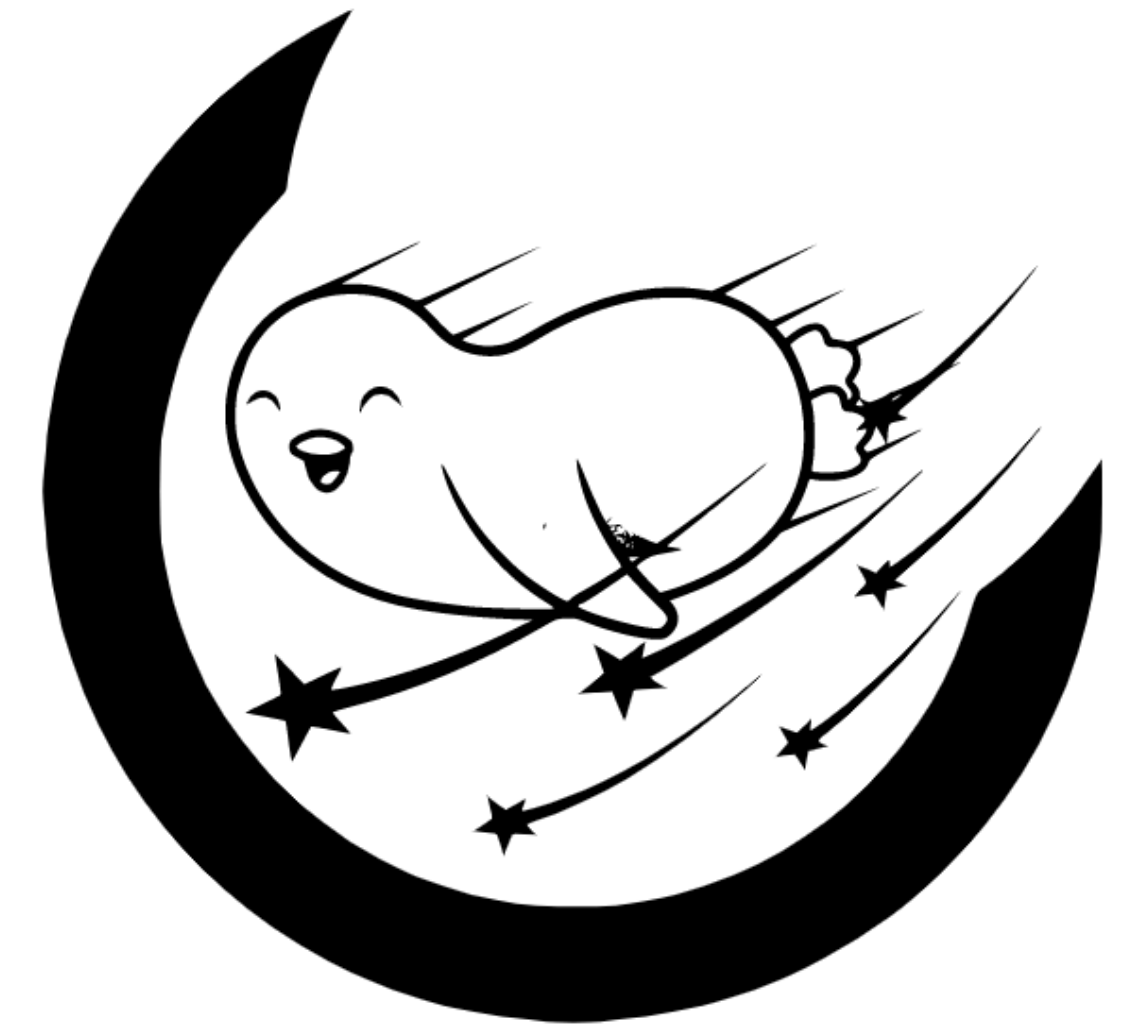
Redundant machinery for ZTF scanning



fritz.science
(Fritz database)



nuztf + AMPEL
(AMPEL DB)

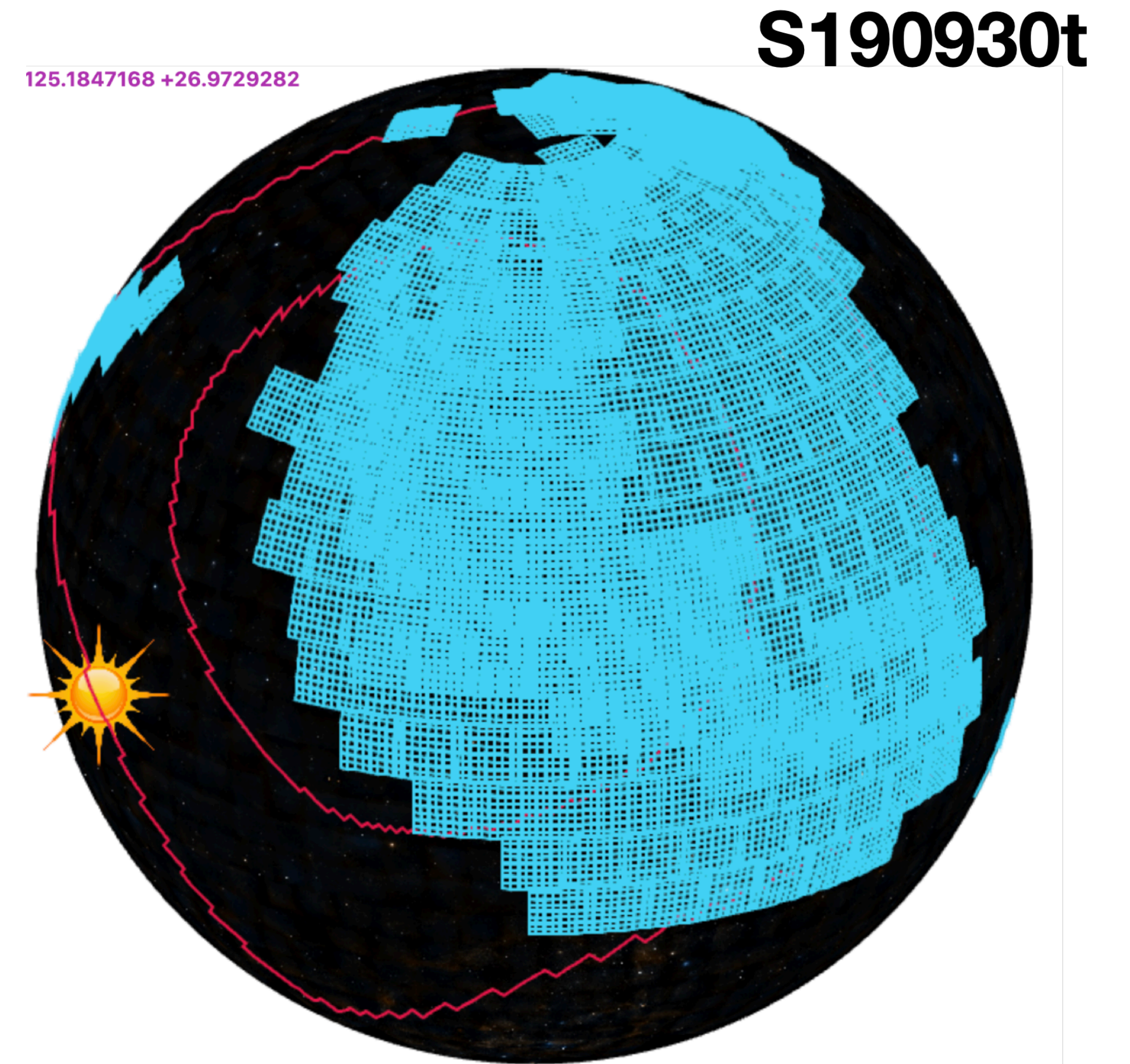


emgwccave
(Kowalski DB)

Example: nuztf + AMPEL

Example: nuztf + AMPEL

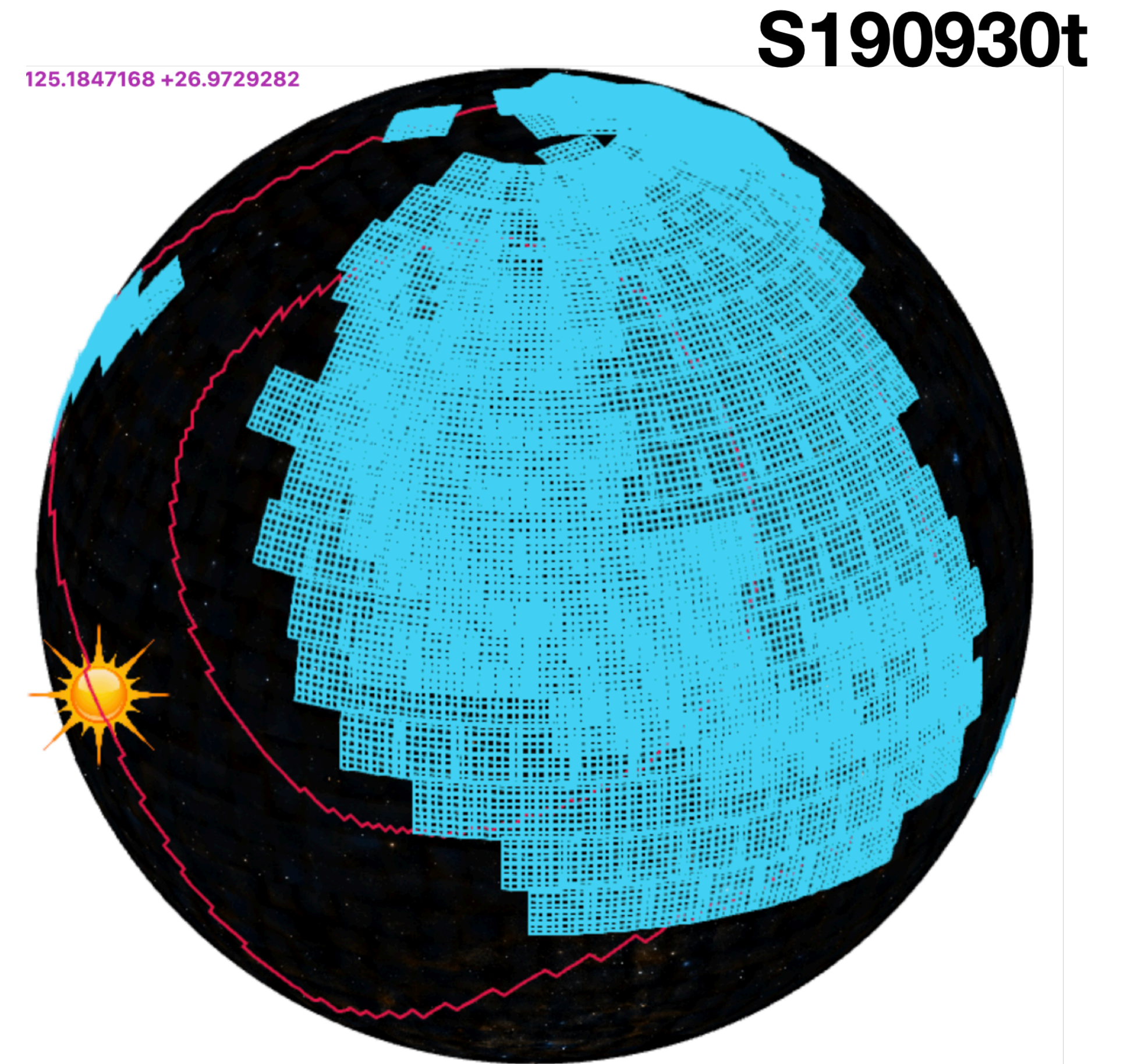
Scan **S190930t** comprising **24,000 sq. deg.** (3 day window)



Example: nuztf + AMPEL

Scan **S190930t** comprising **24,000 sq. deg.** (3 day window)

Retrieve 180,000 alerts in **7 min**
Filter them in **5 min**



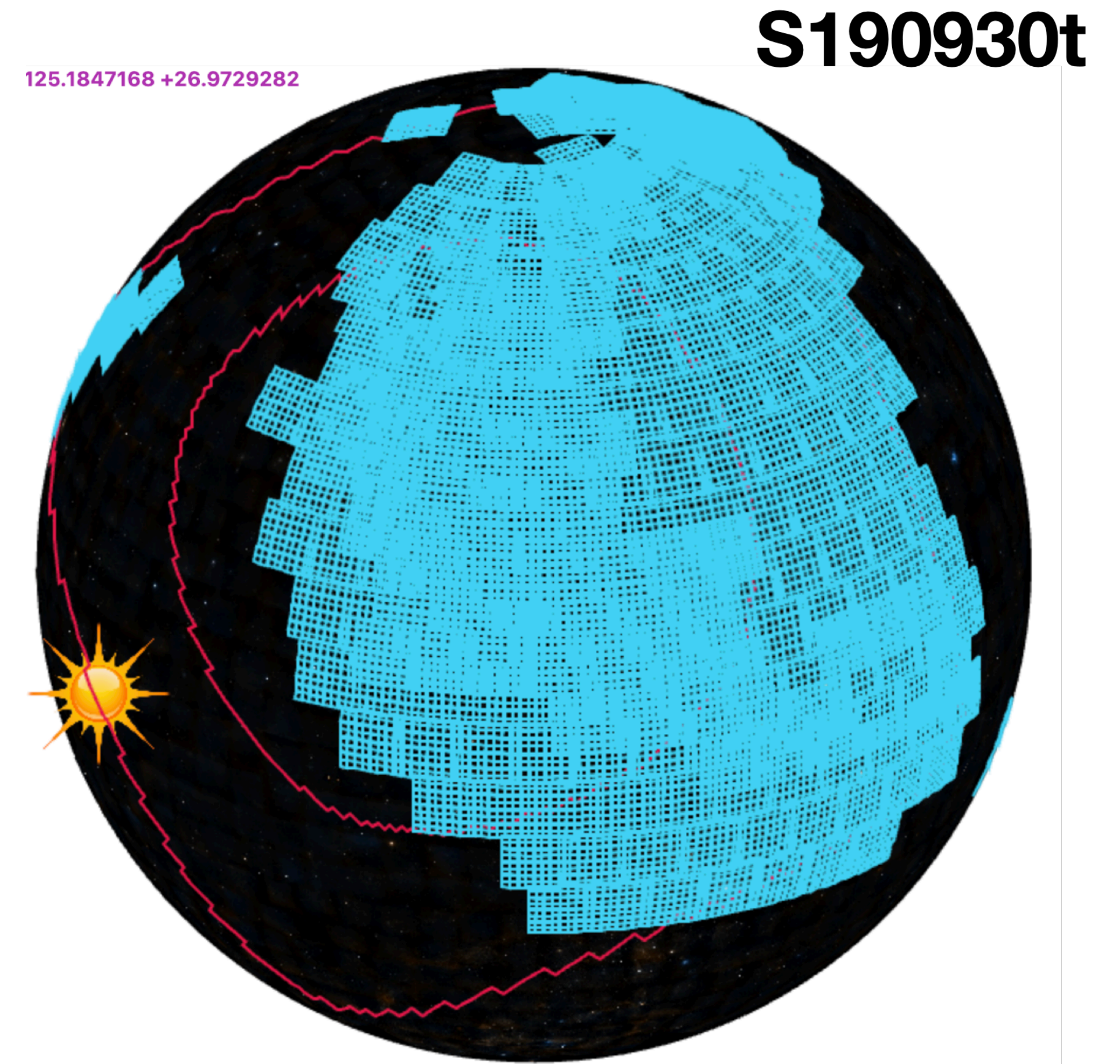
Example: nuztf + AMPEL

Scan **S190930t** comprising **24,000 sq. deg.** (3 day window)

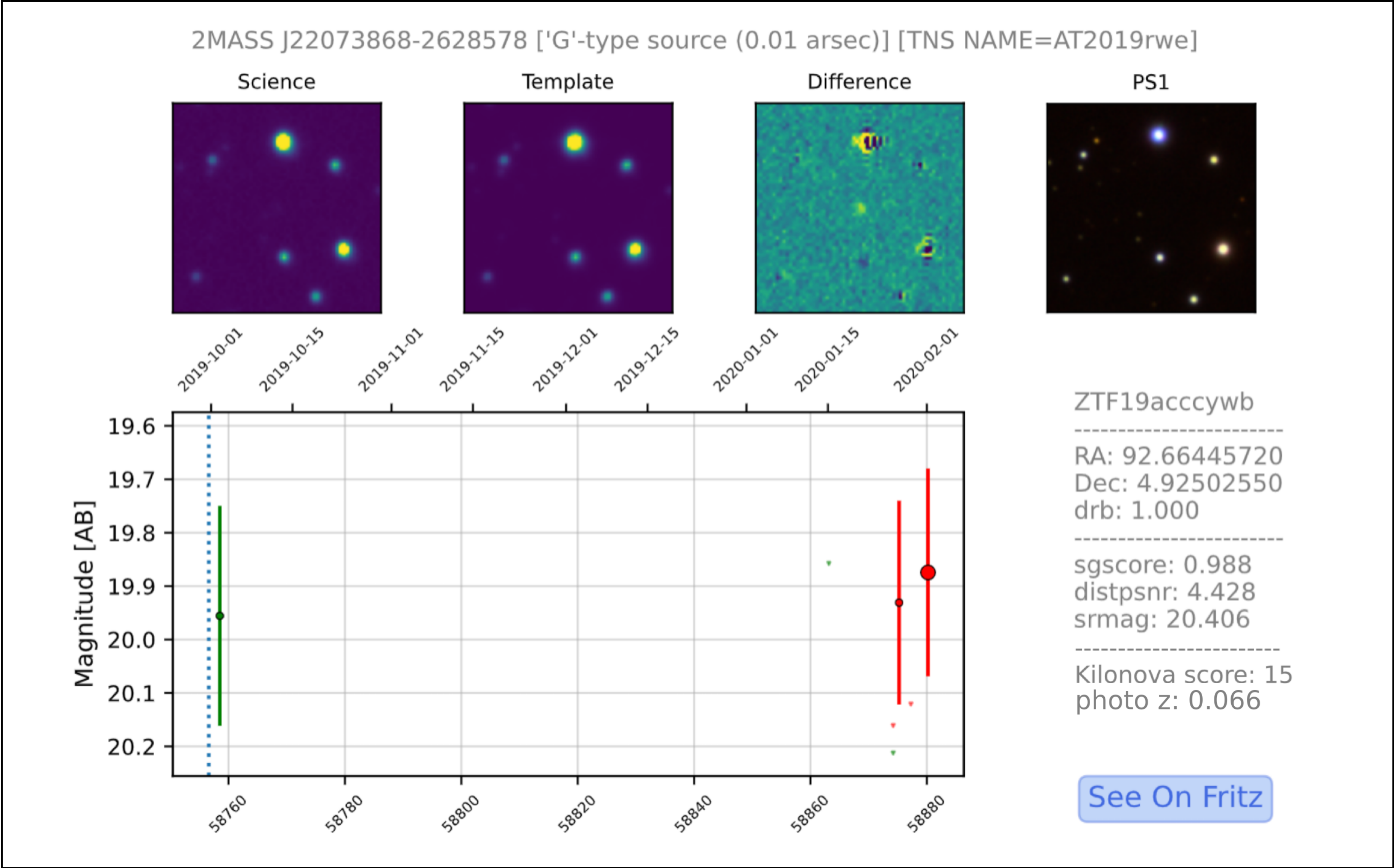
Retrieve 180,000 alerts in **7 min**

Filter them in **5 min**

Photometry SQL database (although it is HEALPix indexed in several resolutions) - can output **~500 alerts/second**

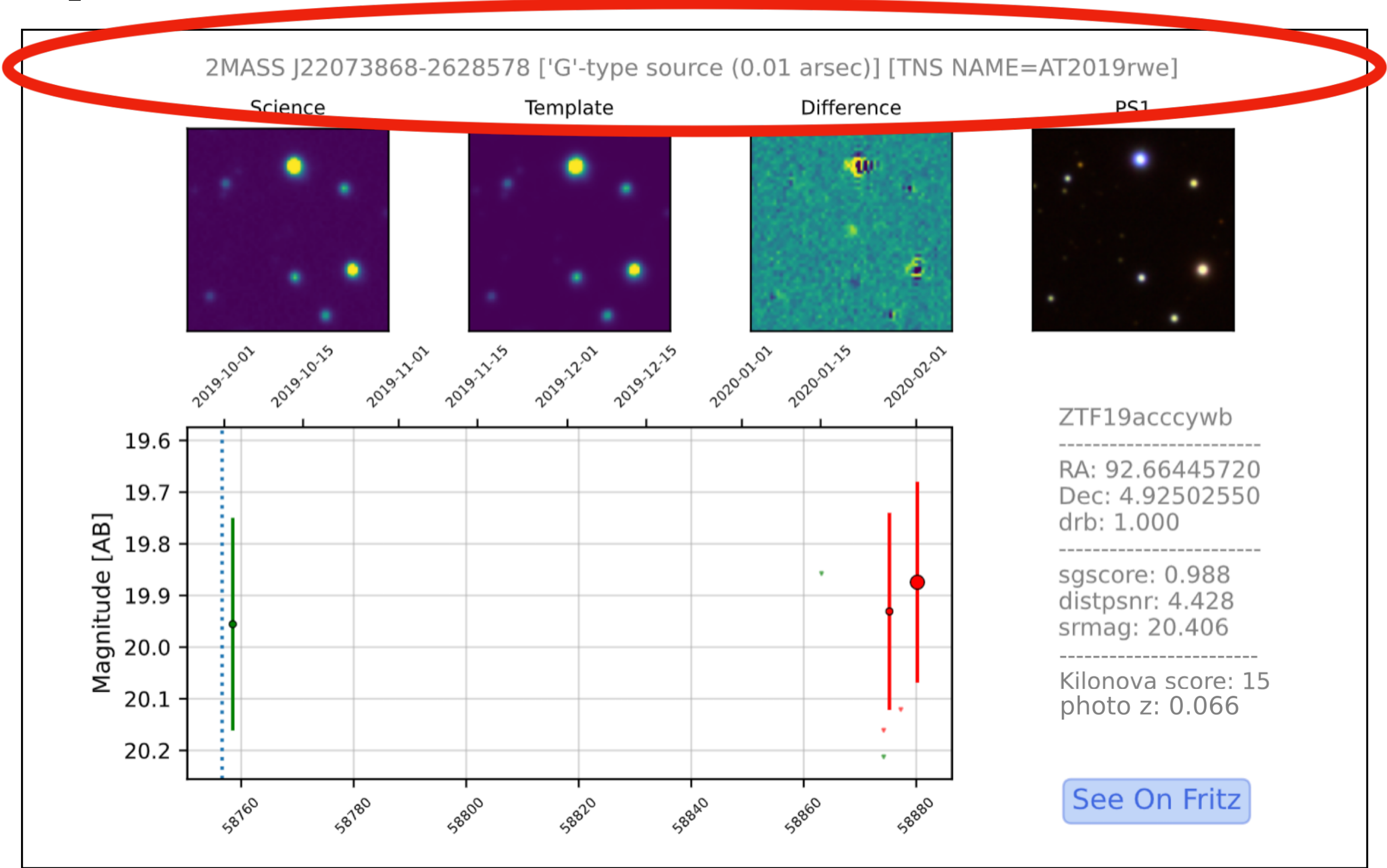


Example: nuztf + AMPEL

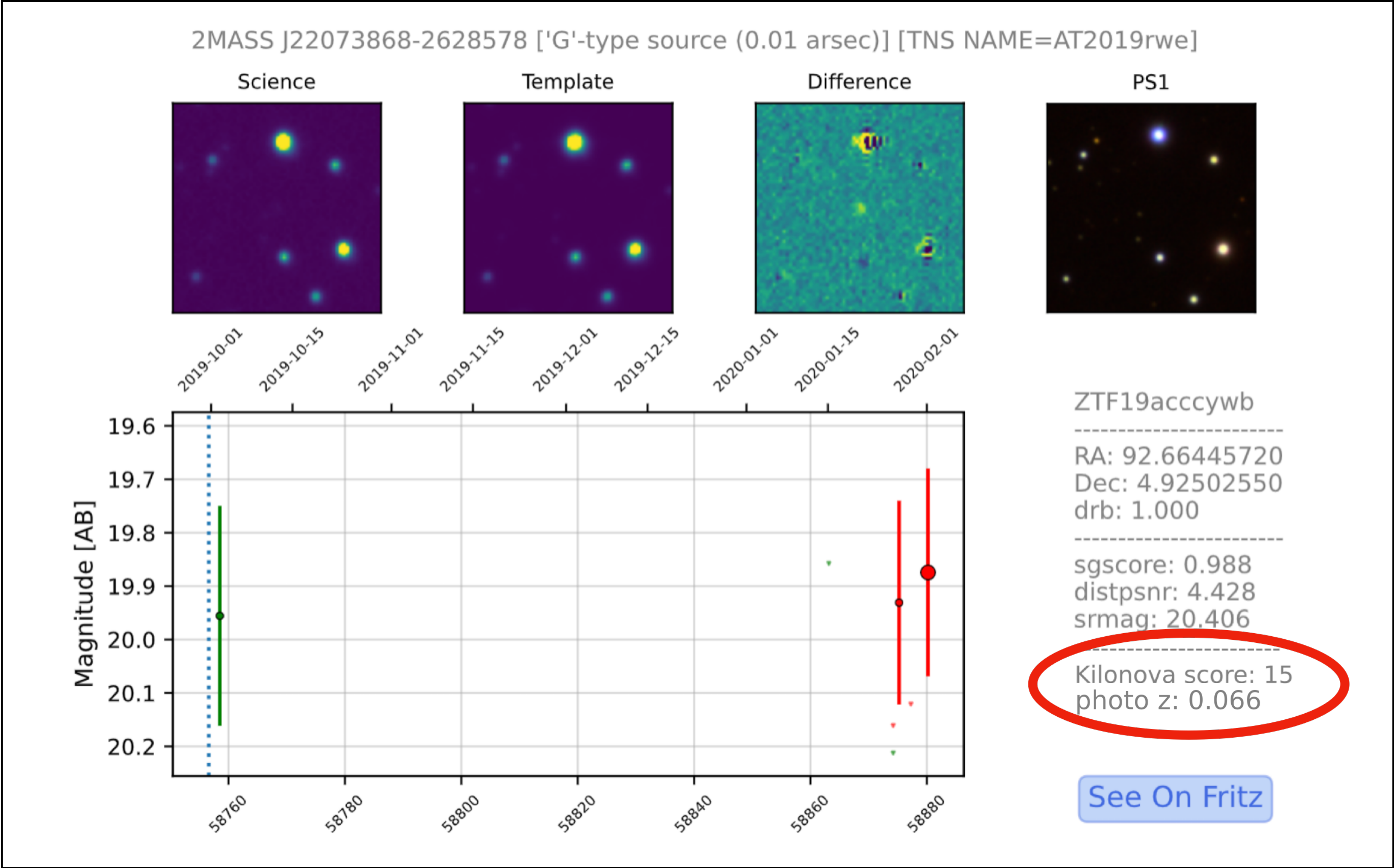


Example: nuztf + AMPEL

Crossmatch

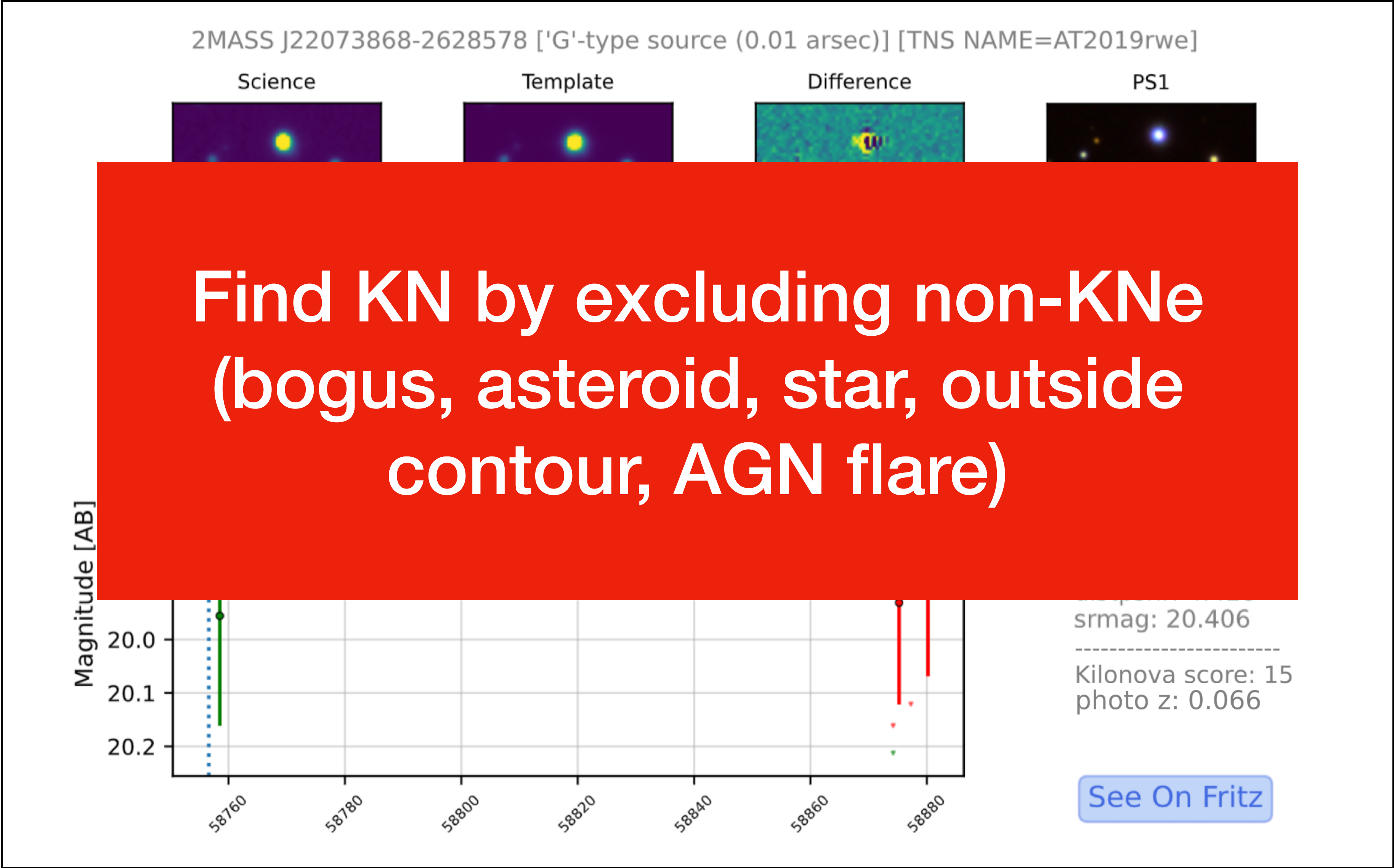


Example: nuztf + AMPEL



Metrics

Example: nuztf + AMPEL



Redundant machinery for scanning

Weekly shifts

Always 5 people (US, Europe, India)

Already had a few GW alerts

Stay tuned! 🧐

Summary

Image credit: Palomar Observatory



Summary

Image credit: Palomar Observatory

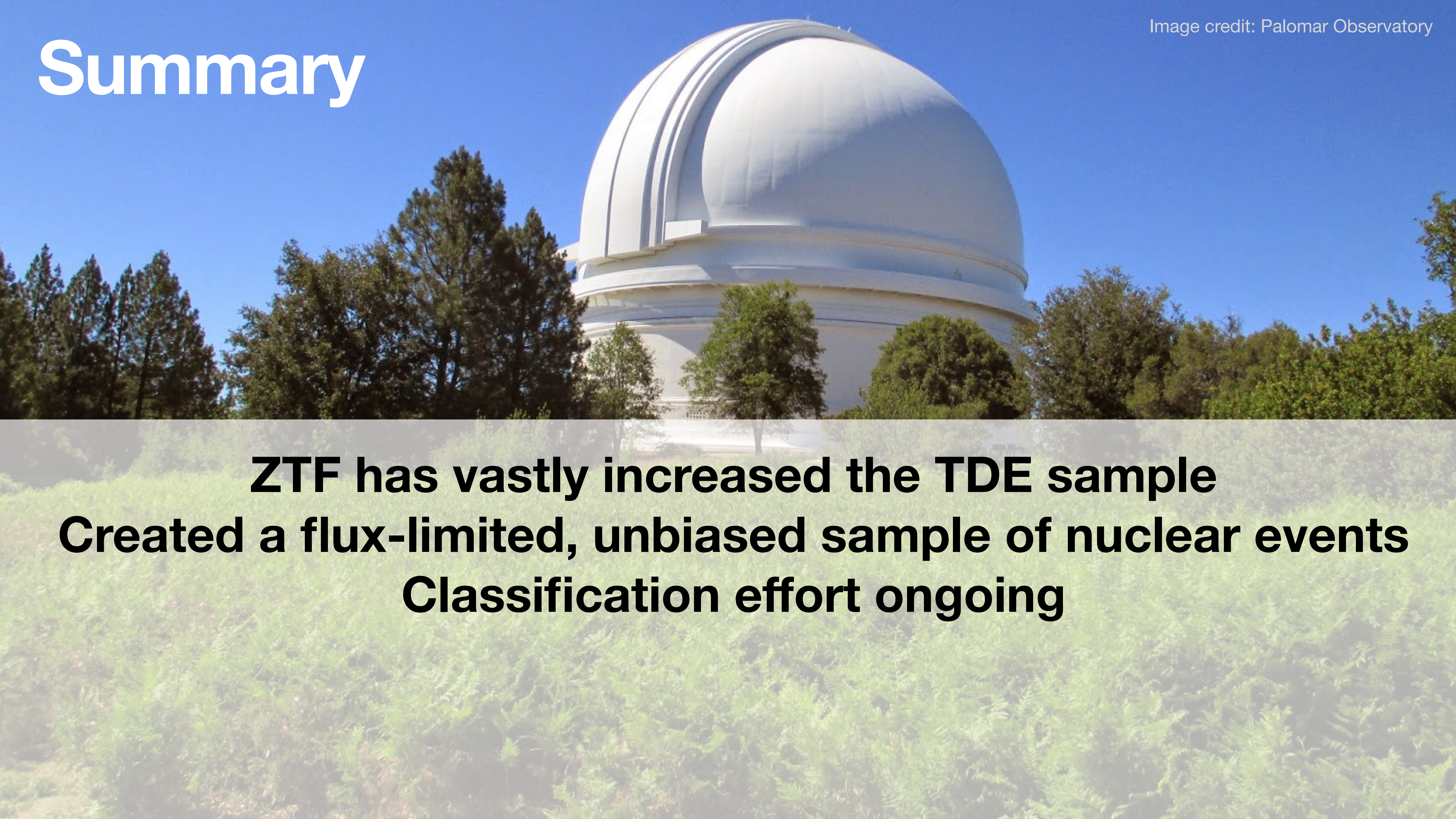
ZTF has vastly increased the TDE sample

Summary

**ZTF has vastly increased the TDE sample
Created a flux-limited, unbiased sample of nuclear events**

Summary

Image credit: Palomar Observatory



ZTF has vastly increased the TDE sample
Created a flux-limited, unbiased sample of nuclear events
Classification effort ongoing

Summary

Image credit: Palomar Observatory



ZTF has vastly increased the TDE sample
Created a flux-limited, unbiased sample of nuclear events
Classification effort ongoing
Explore the wealth of transients contained in the sample

Summary

Image credit: Palomar Observatory



ZTF has vastly increased the TDE sample
Created a flux-limited, unbiased sample of nuclear events
Classification effort ongoing
Explore the wealth of transients contained in the sample
🚦 AMPEL enables all this

Summary

Image credit: Palomar Observatory



ZTF has vastly increased the TDE sample
Created a flux-limited, unbiased sample of nuclear events
Classification effort ongoing
Explore the wealth of transients contained in the sample
🚦 AMPEL enables all this
O4 underway!

Bonus

To ponder

Wealth of data should increase the likelihood of serendipitous discovery

➡ But only if we have the right tools for it!

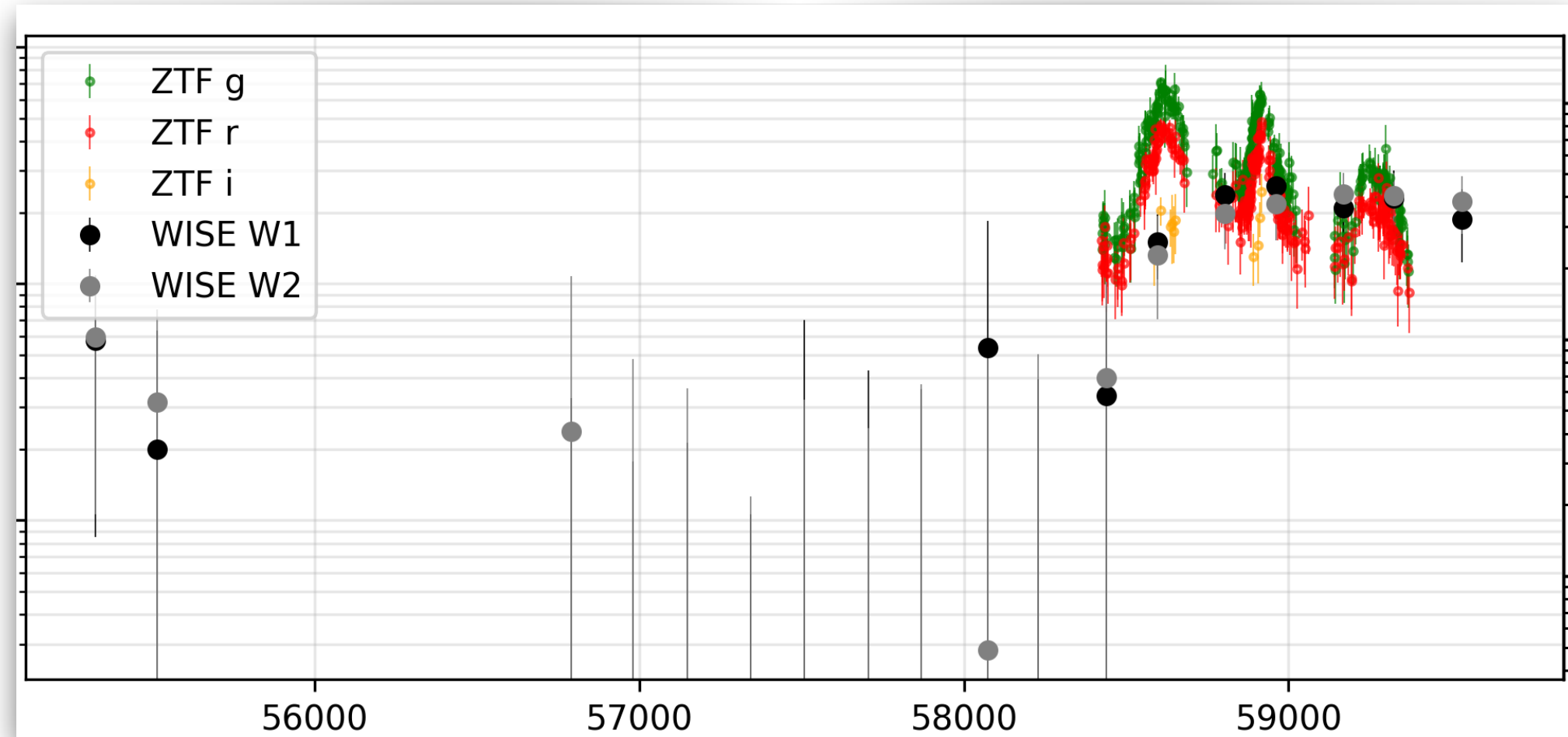
Rapid follow up is great! But maybe there is something to be gained from archival studies

How about automatic coincidence searches for **all** O4 alerts?

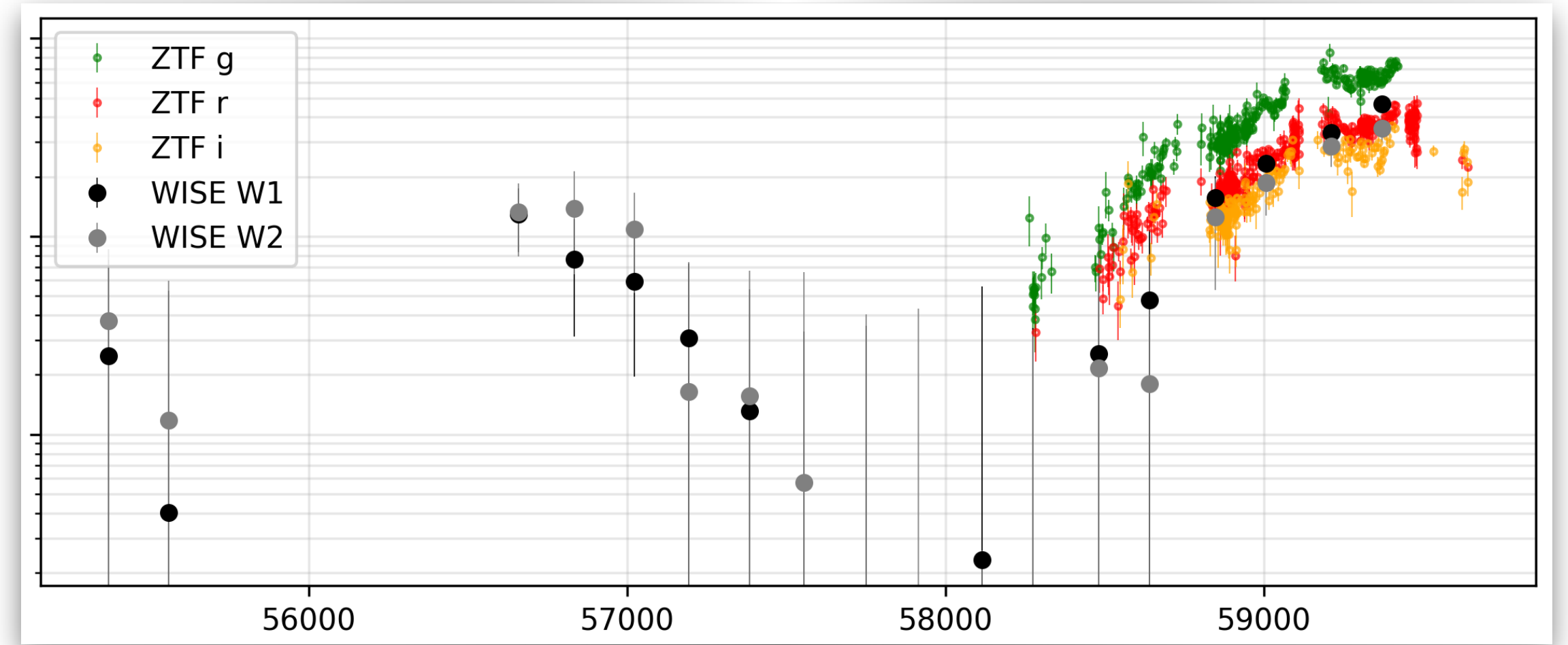
 Background studies using the normal survey ("blind")

IR transients: Filtered by IR

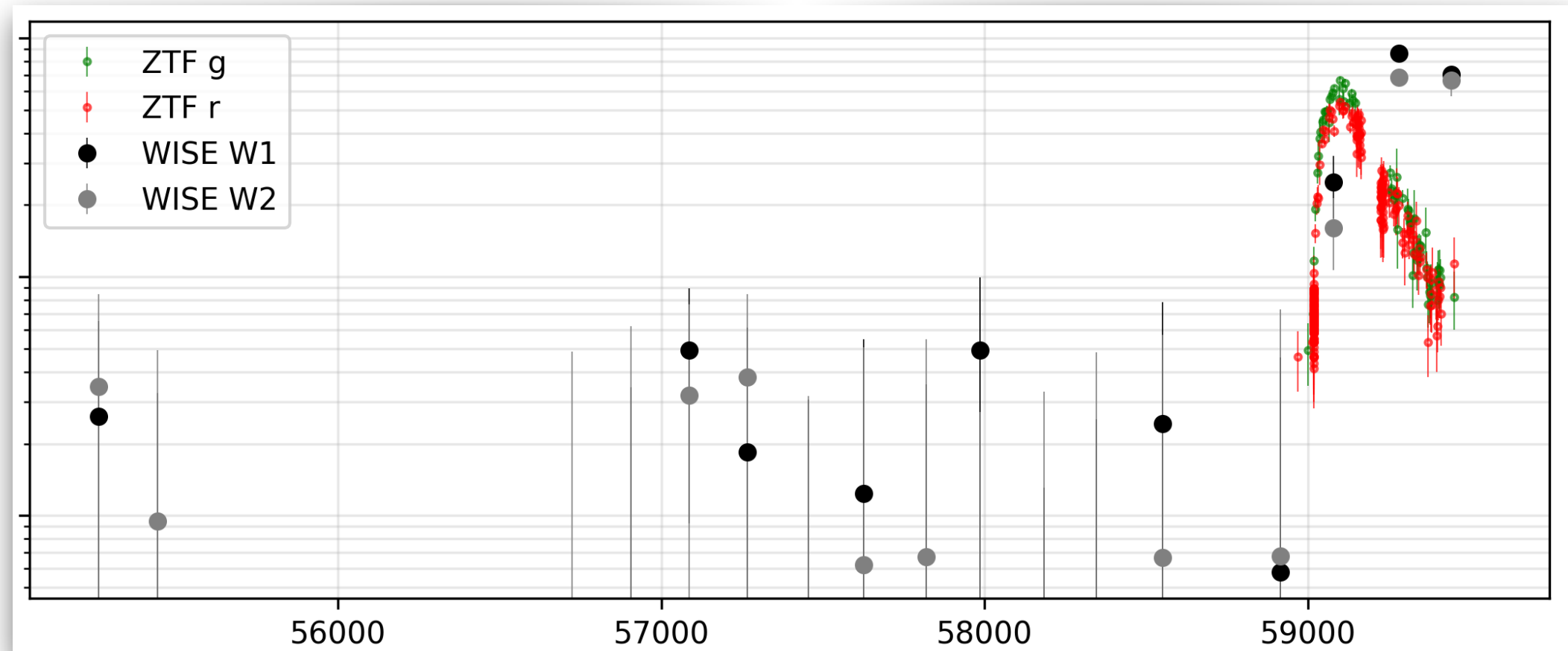
Blazar candidates



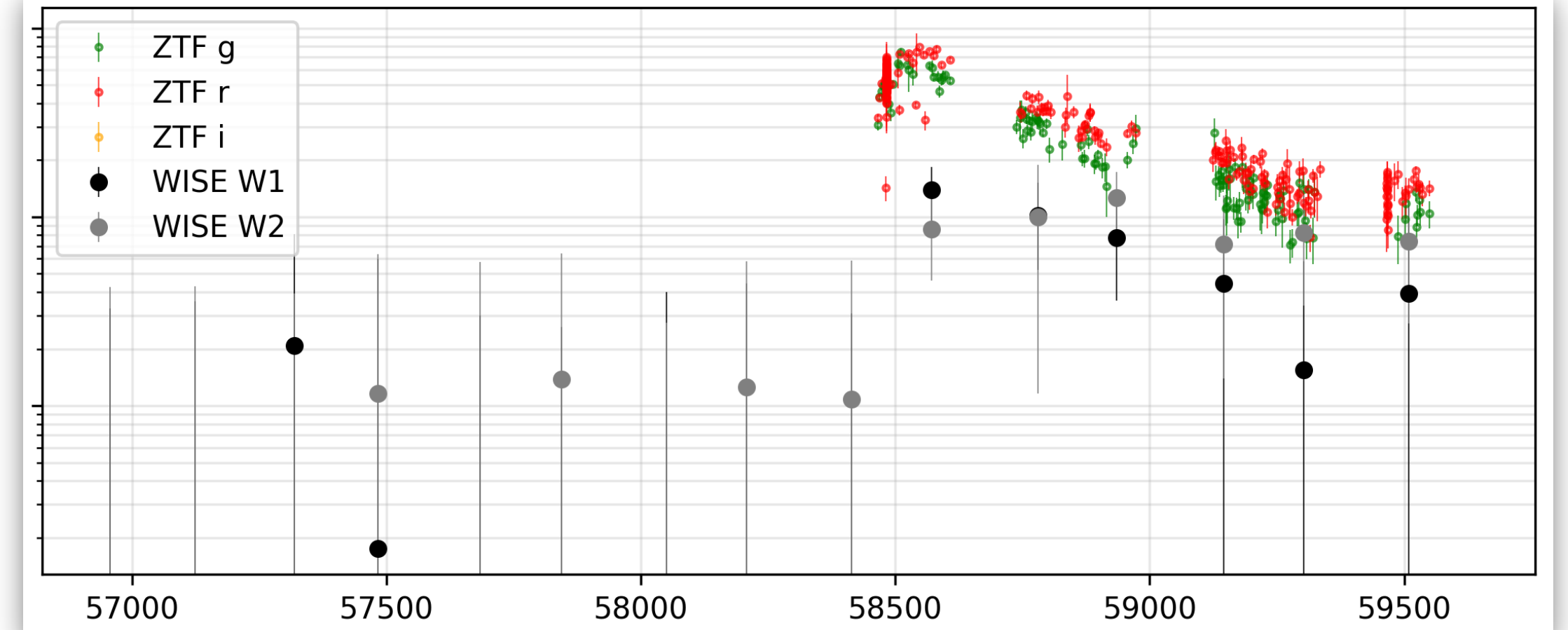
slow rise, simultaneous IR rise



TDE candidate

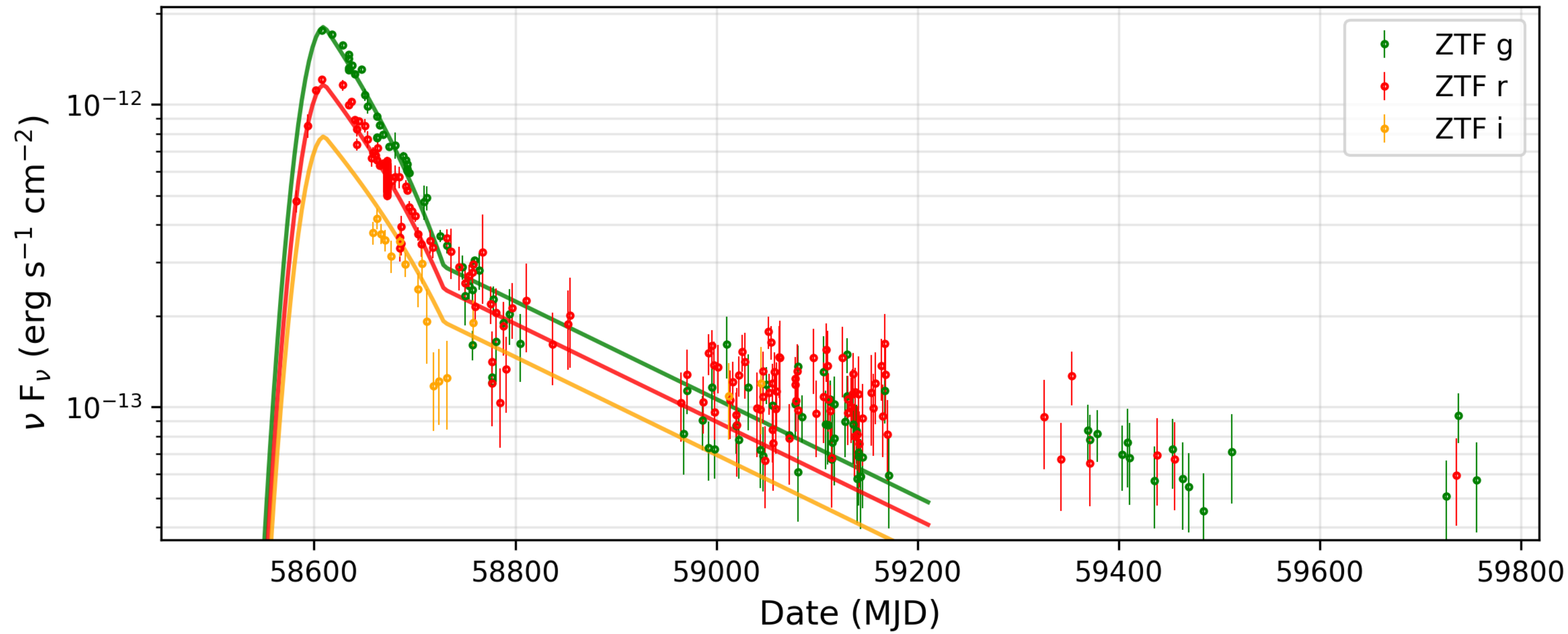


Tywin-like

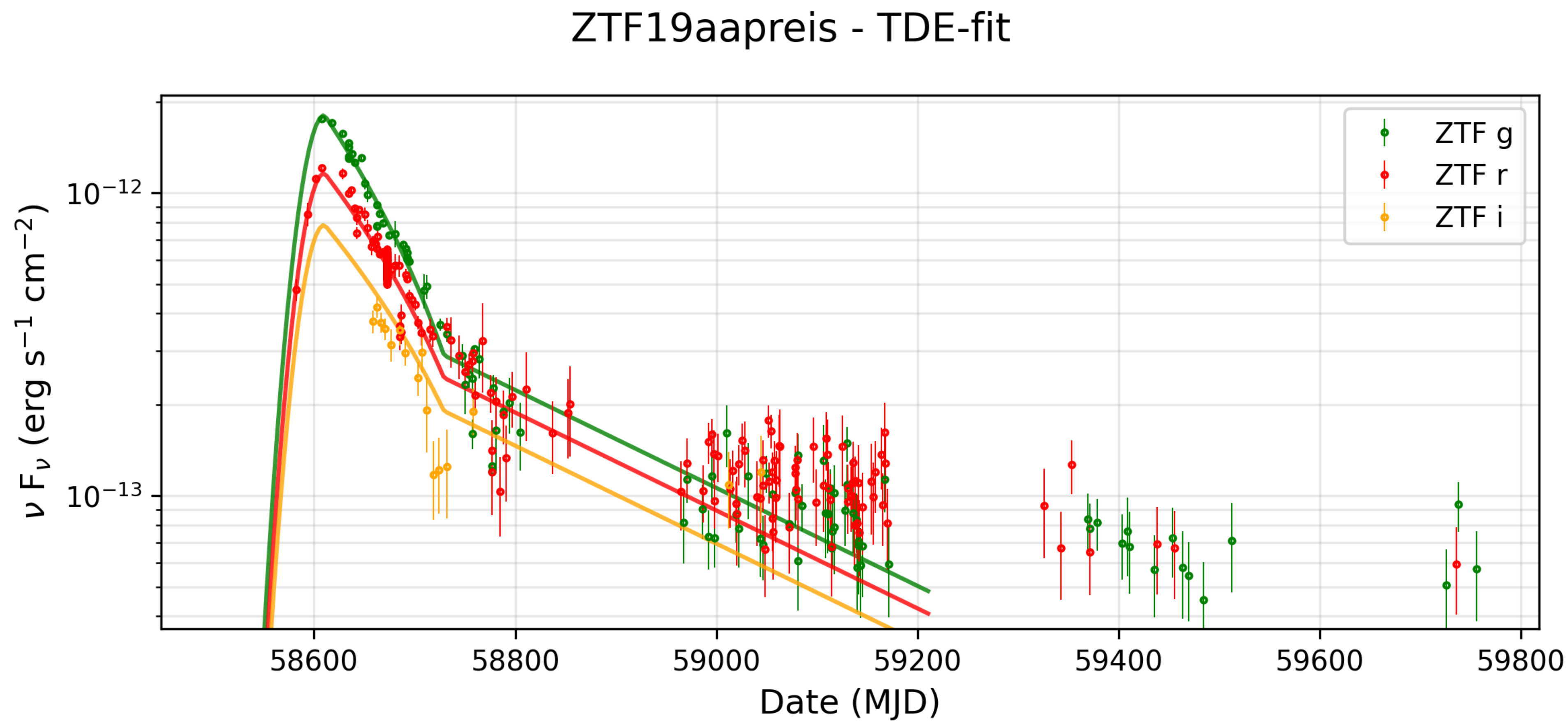


Feature extraction: TDE Fit

ZTF19aapreis - TDE-fit



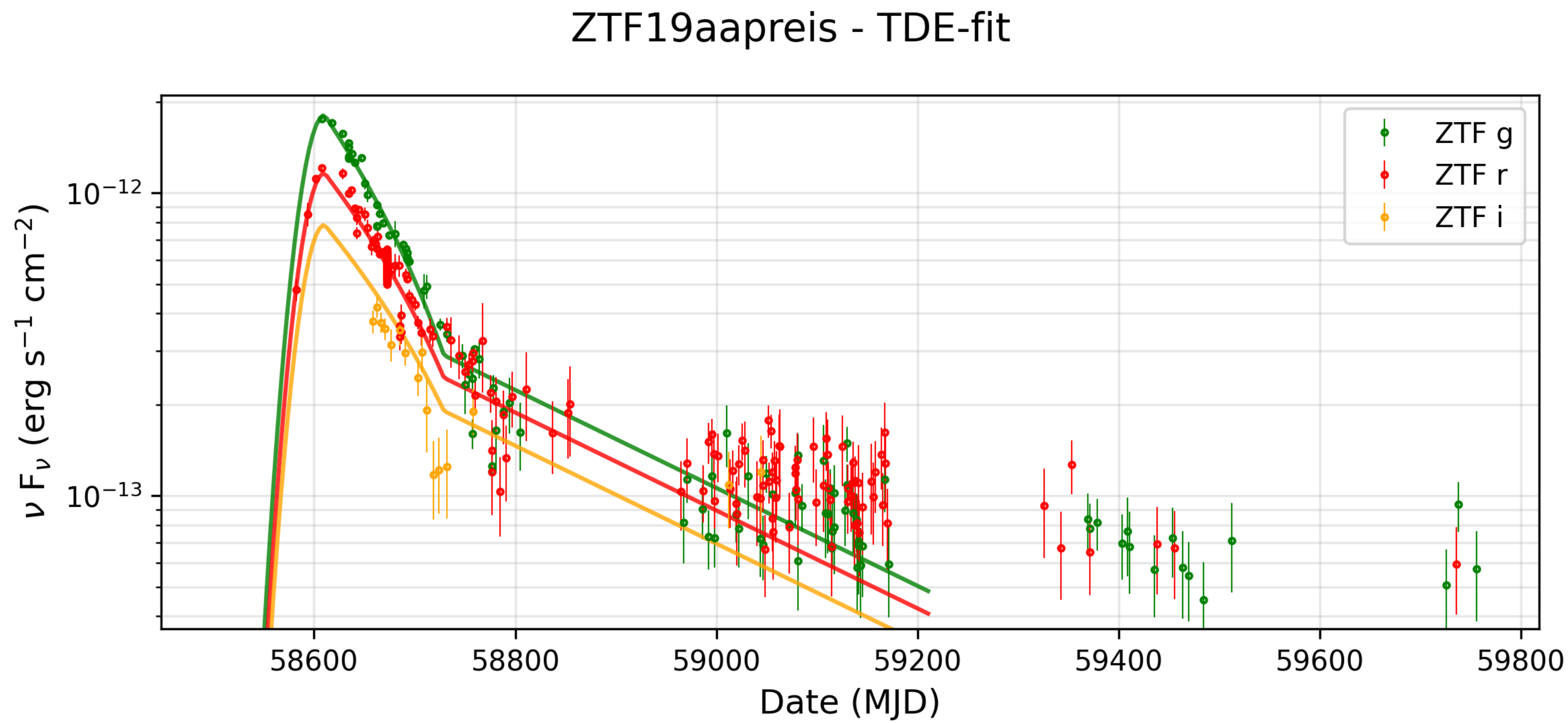
Feature extraction: TDE Fit



Fit parameters:

- risetime**
- decaytime**
- BB temp**
- BB d_temp**
- t_evo time**

Feature extraction: TDE Fit



Fit parameters:

risetime
decaytime
BB temp
BB d_temp
t_evo time

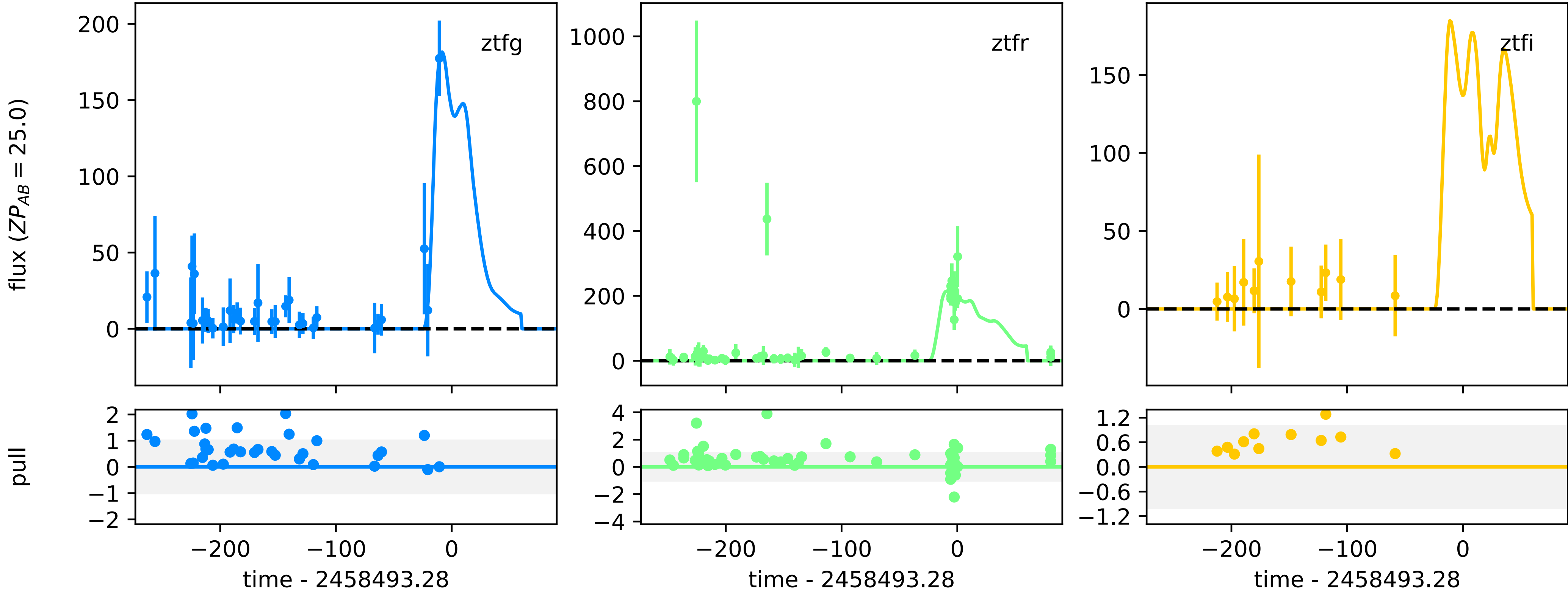
Fitted twice
(stability)
Problem: T
runaway (no UV)

Feature extraction: SALT Fit (SN Ia)

ZTF19aaafvzy salt2 None
chisq 87.77
ndof 90

$z = 0.21352750$
 $t_0 = 2458493.3$
 $x_0 = 2.6827823 \times 10^{-4}$
 $x_1 = 8.3501711$

$c = 0.17711280$
 $mwebv = 0.068765168$
 $mwr_v = 3.1000000$

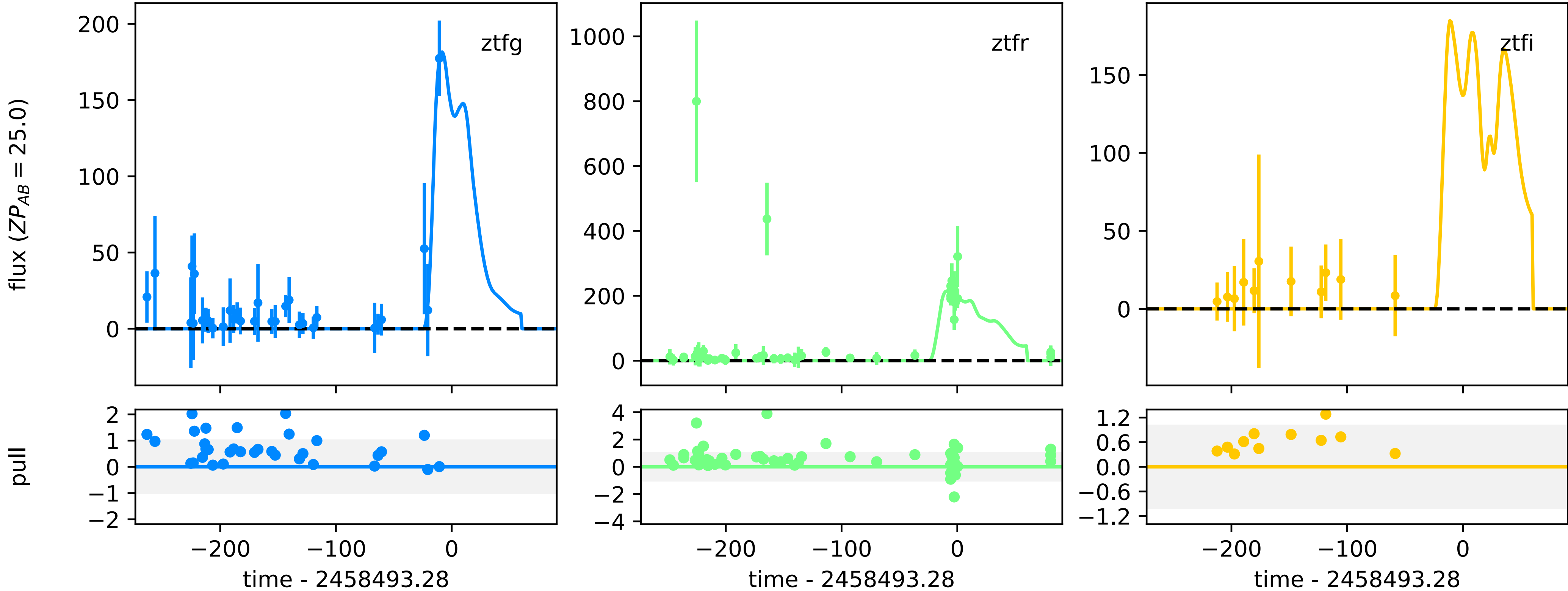


Feature extraction: SALT Fit (SN Ia)

ZTF19aaafvzy Salt2 None
chisq 87.77
ndof 90

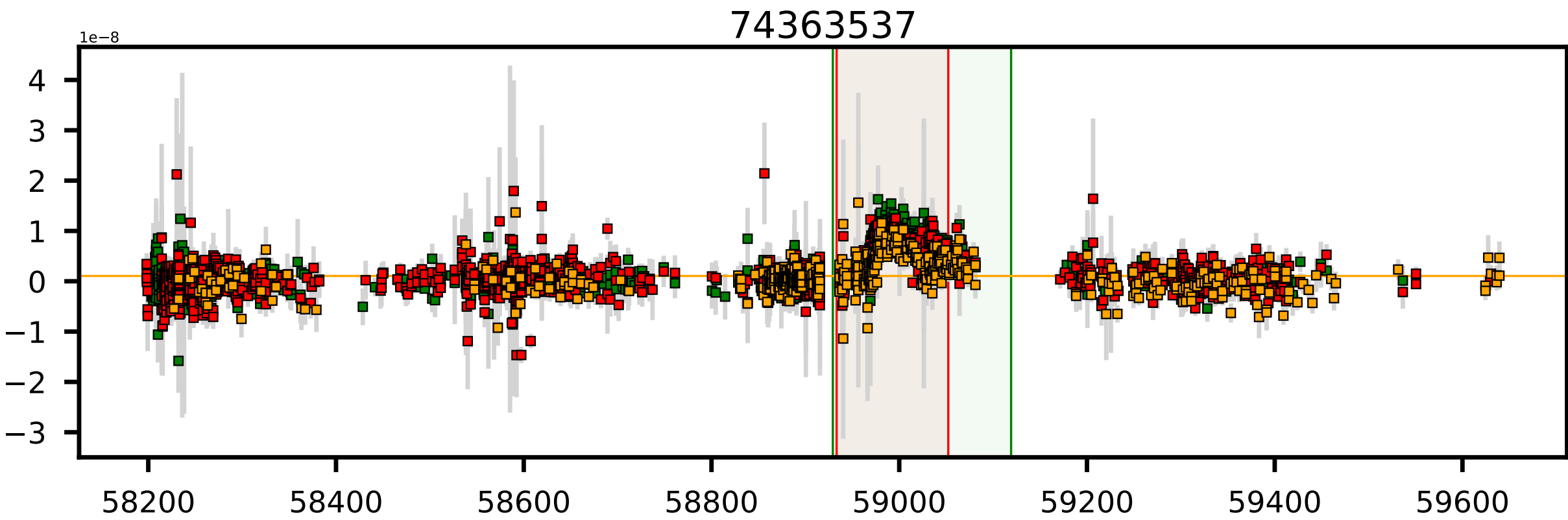
$z = 0.21352750$
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$c = 0.17711280$
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 $mwr_v = 3.1000000$

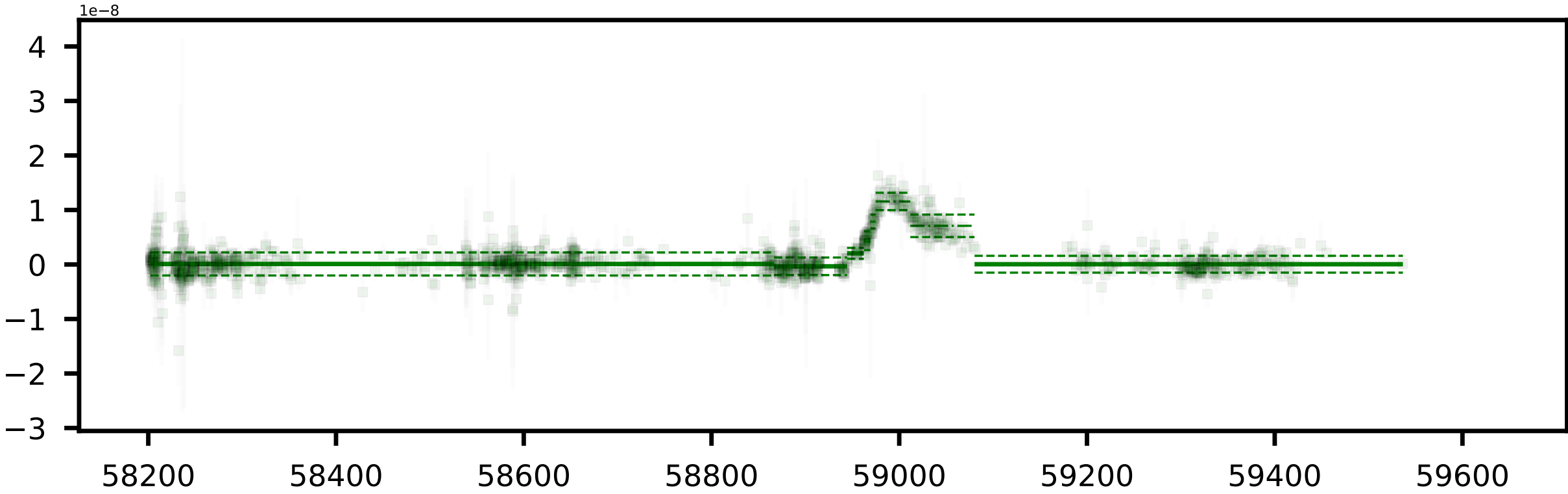


Feature extraction

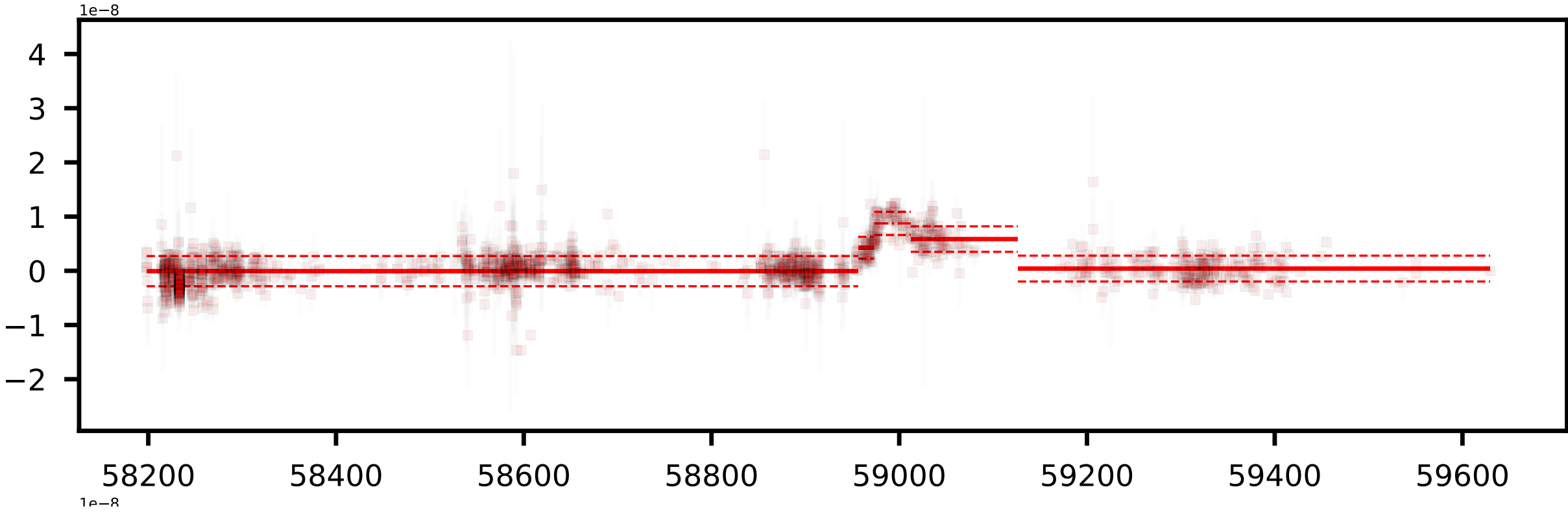
all bands



g-band



r-band

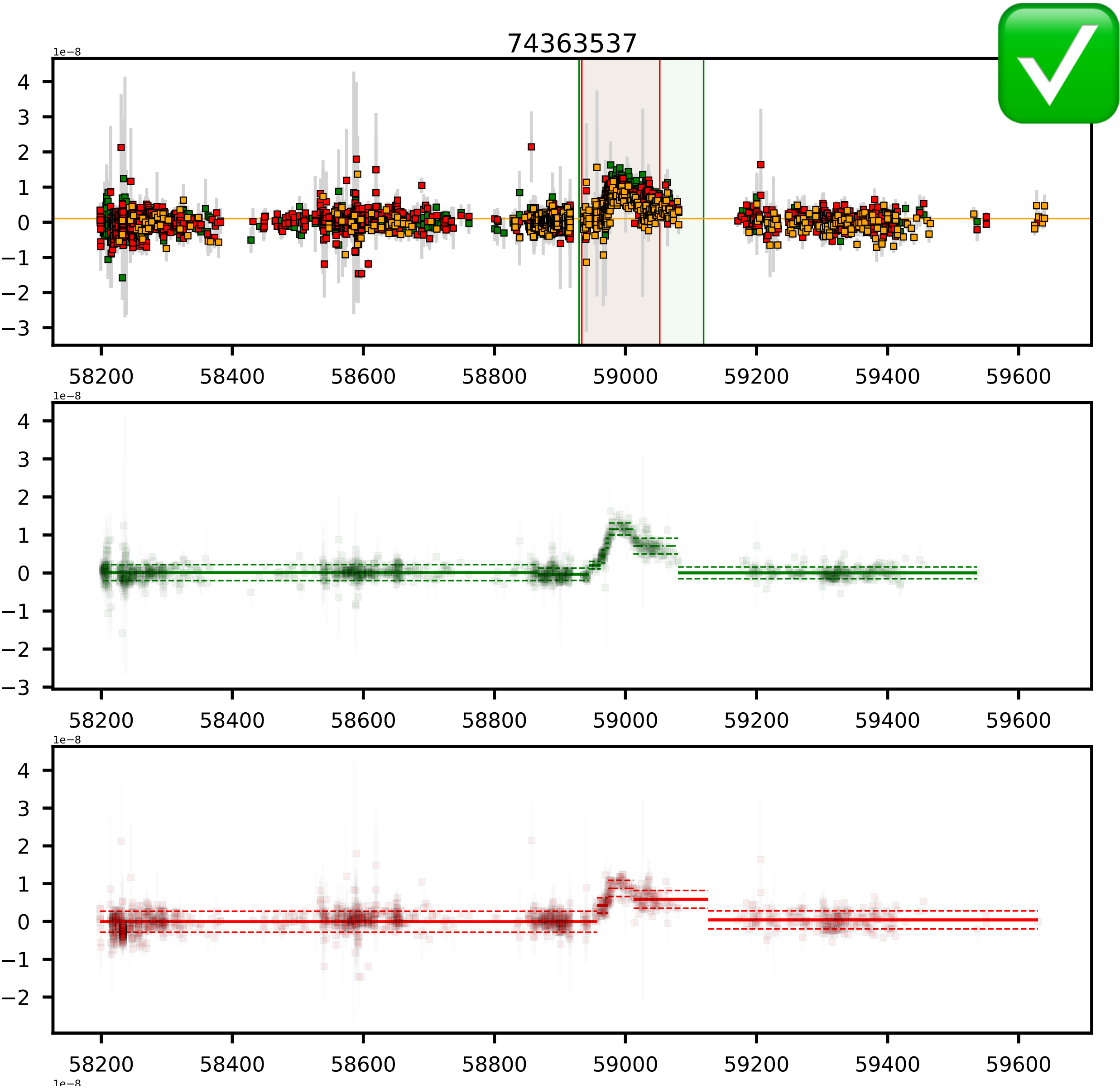


Feature extraction

all bands

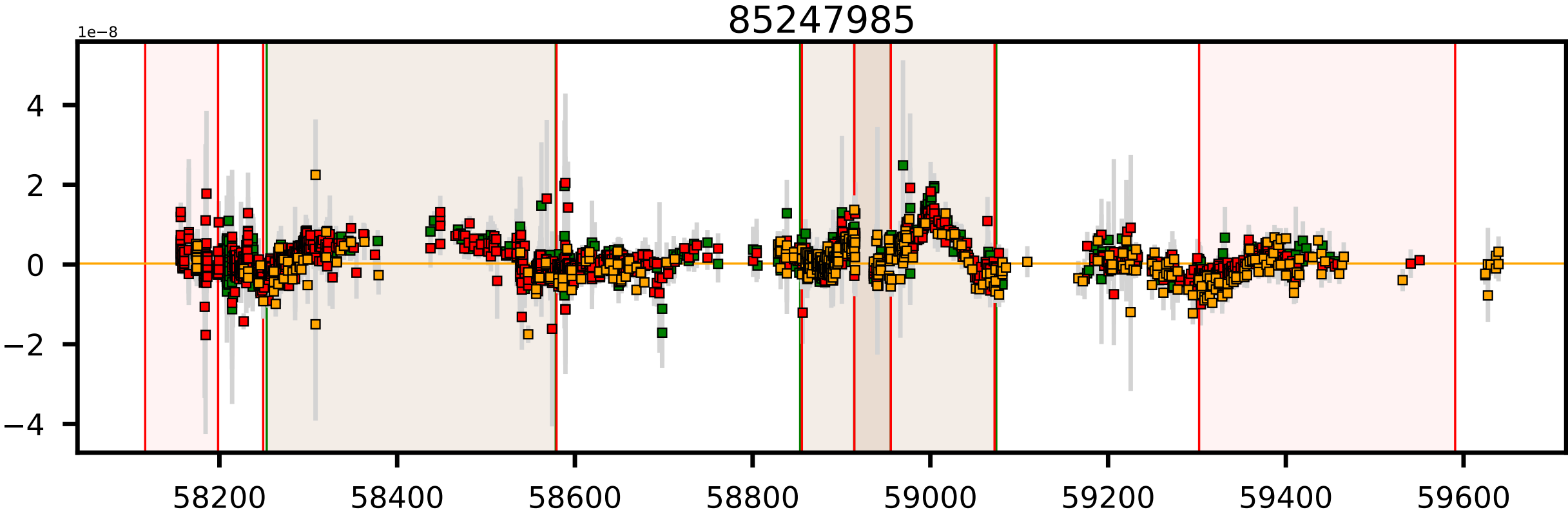
g-band

r-band

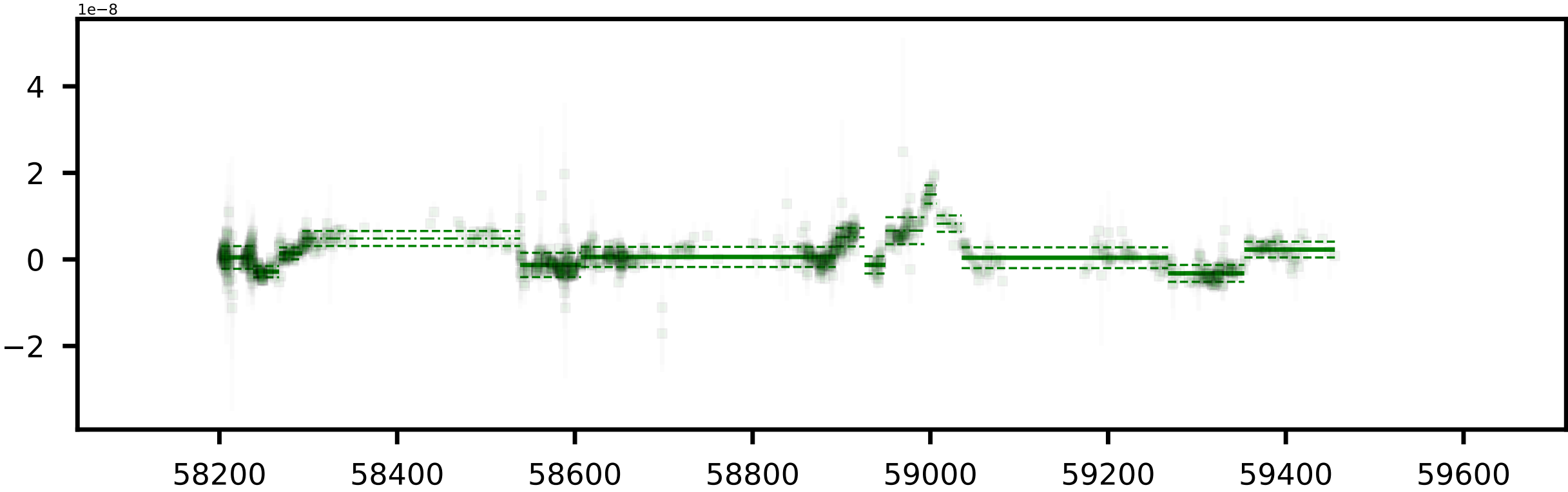


Feature extraction

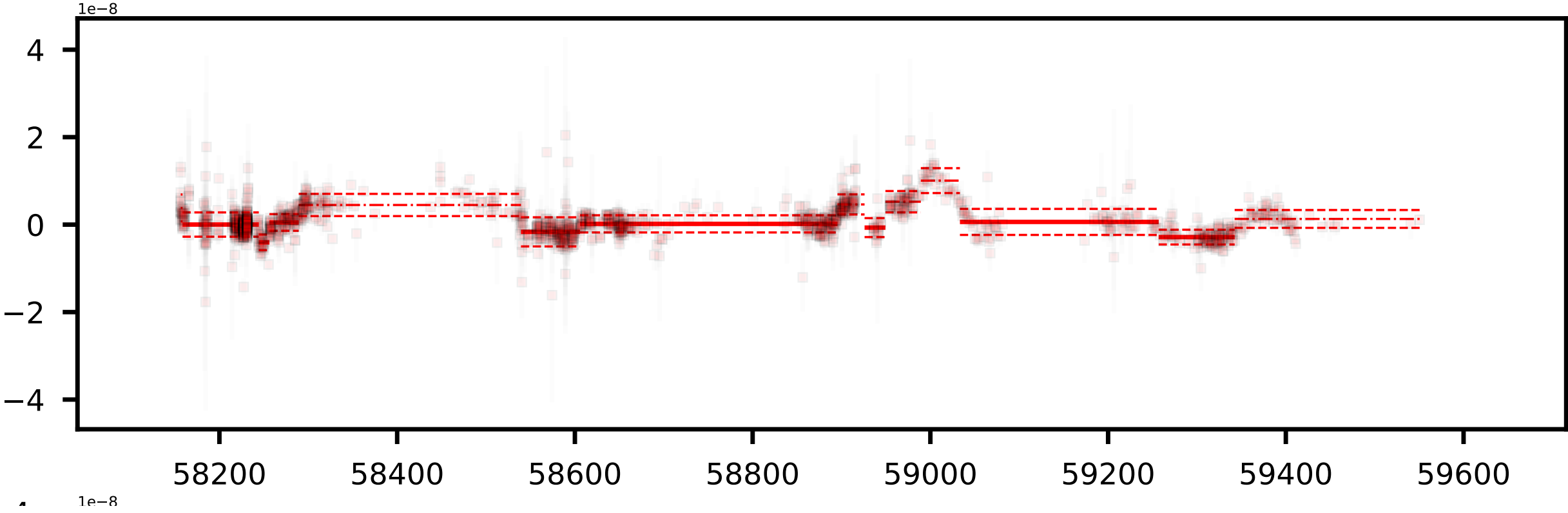
all bands



g-band



r-band

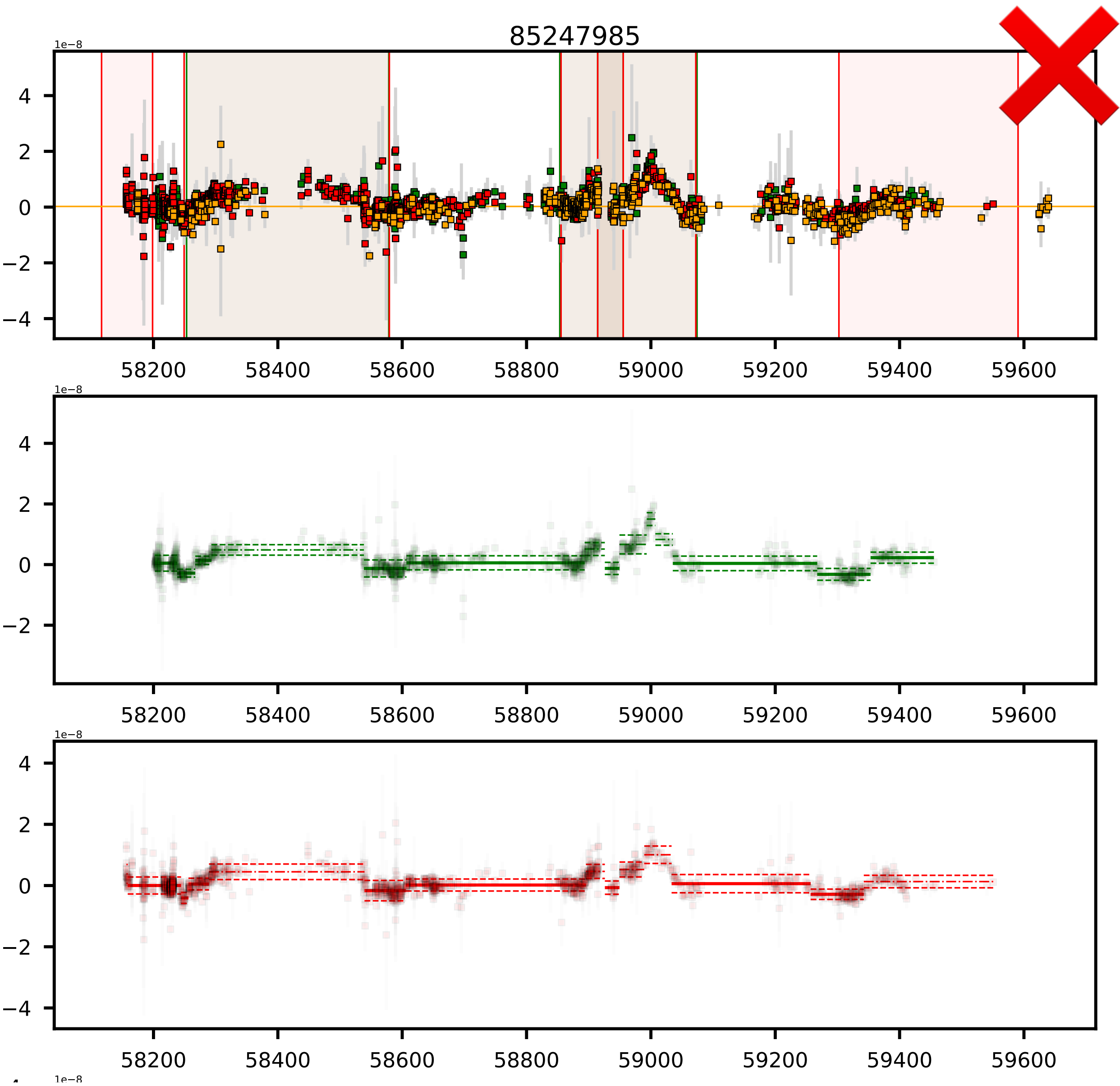


Feature extraction

all bands

g-band

r-band



Features used (20 in total)

peak apparent mag

sgscore

WISE colors (with scatter for noisified child lightcurves)

SALT fit results (c , x_0 , x_1)

TDE fit results (rise, decay, temp, d_temp)

distnr (core distance, scaled for noisified child lightcurves)

Bayesian block analysis: overlapping regions

no z (only indirectly for some of the SALT fits)

Noisification

K-correct (bandpasses see different flux depending on object redshift)

Redshift

Random dropout

Wiggle time a bit

Generate child lightcurves:

SN Ia: 12683 TDE: 10231 SN $\neq$ Ia: 10852 AGN: 8220 star: 505

Children per object

SN Ia: 4 TDE: 155 SN $\neq$ Ia: 10 AGN: 94 star: 0

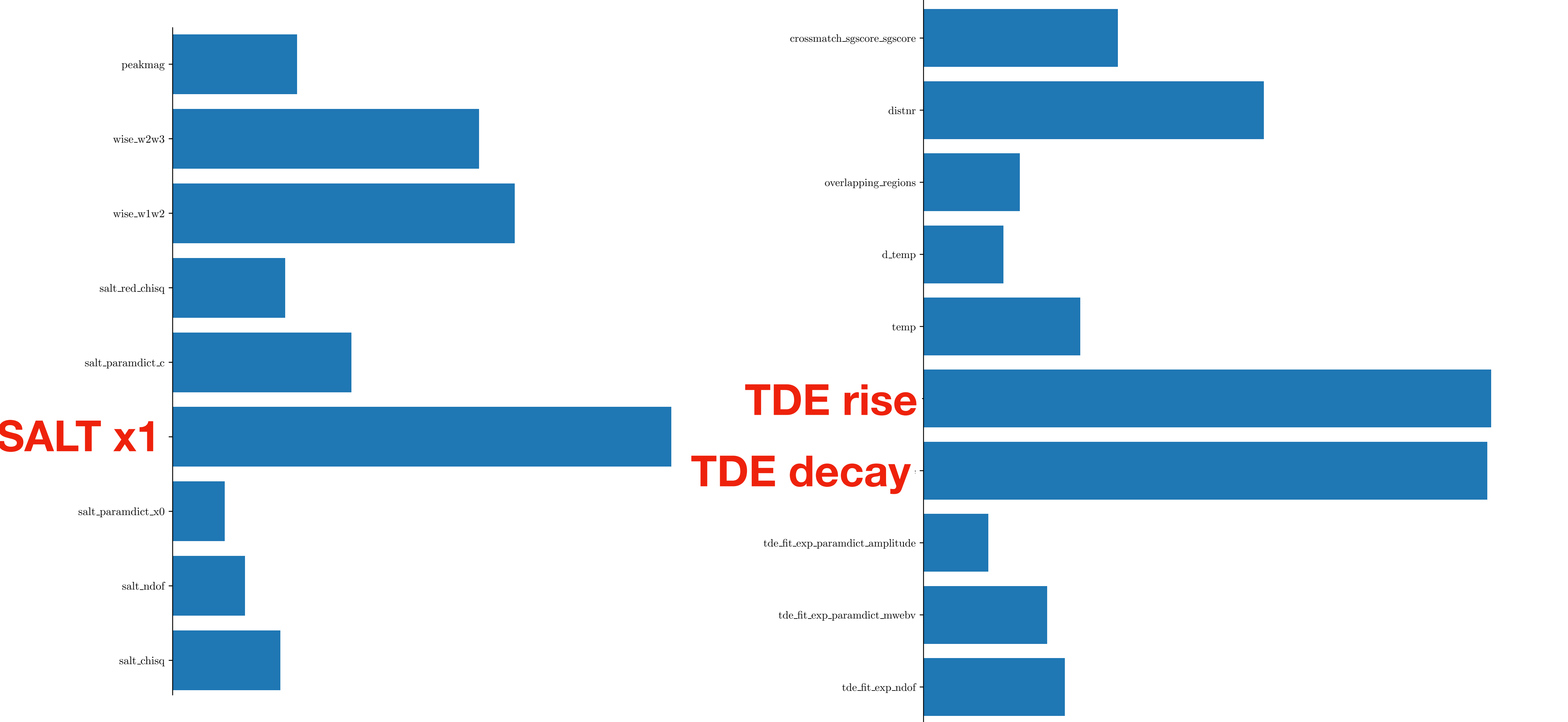
Train XGBoost

train-validation fraction = 0.7

test fraction = 0.3

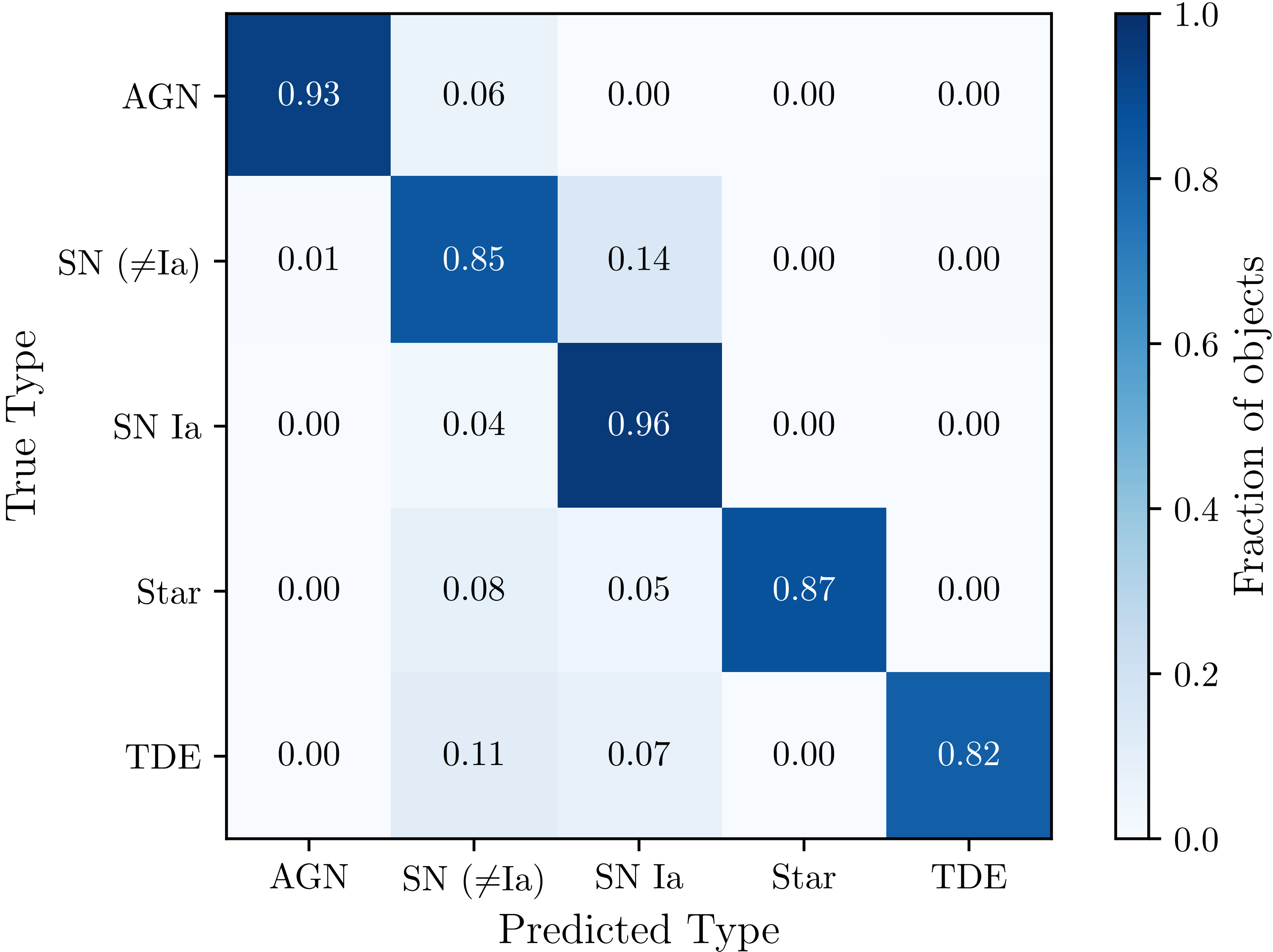
hyper parameter search (9 parameters) with 50 iterations

XGBoost feature importance



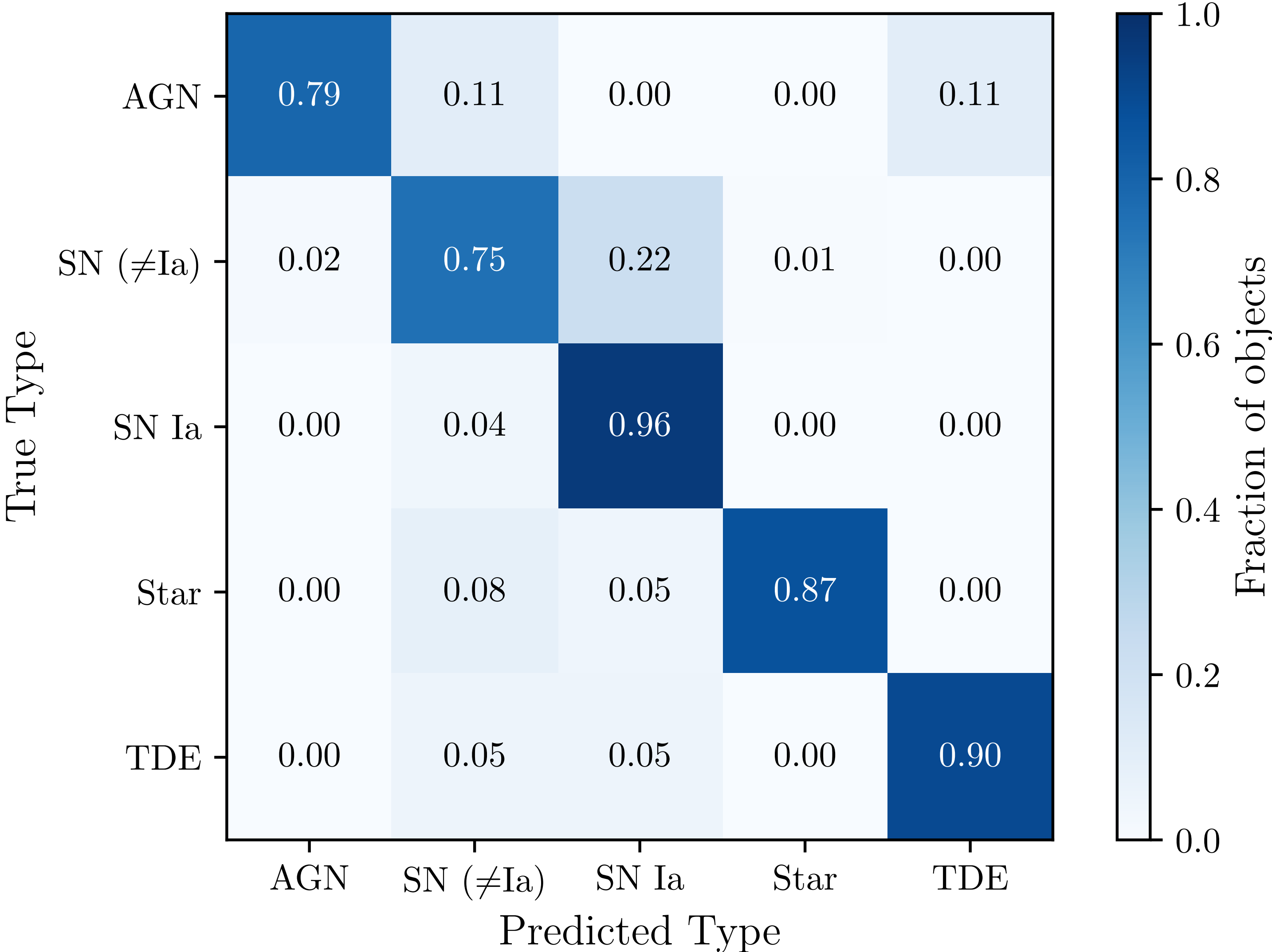
Evaluation with test sample

Including noisified lightcurves in the test sample



Evaluation with test sample

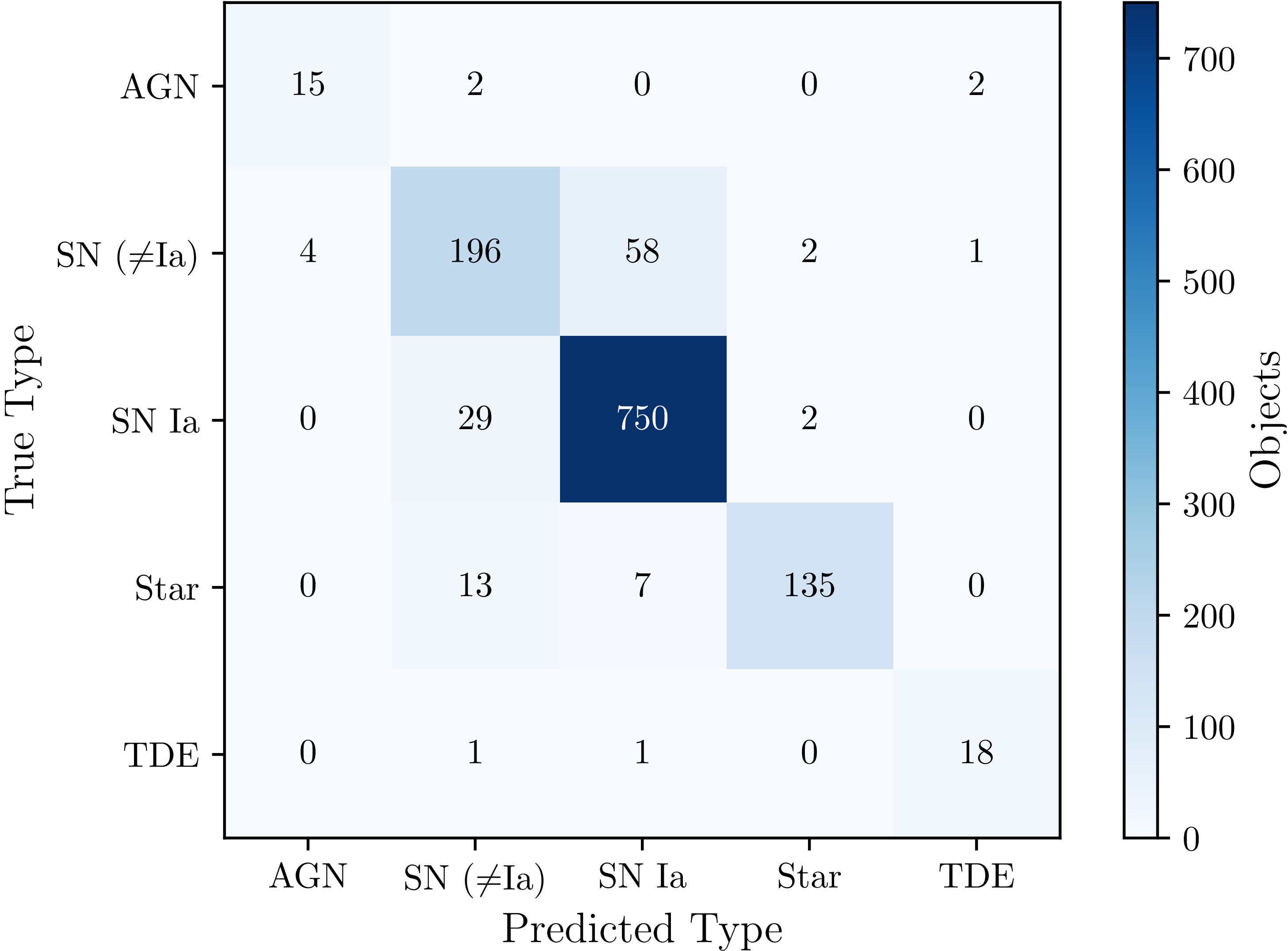
Not including noisified lightcurves in the test sample



Evaluation with test sample

Not including noisified
lightcurves in the test
sample

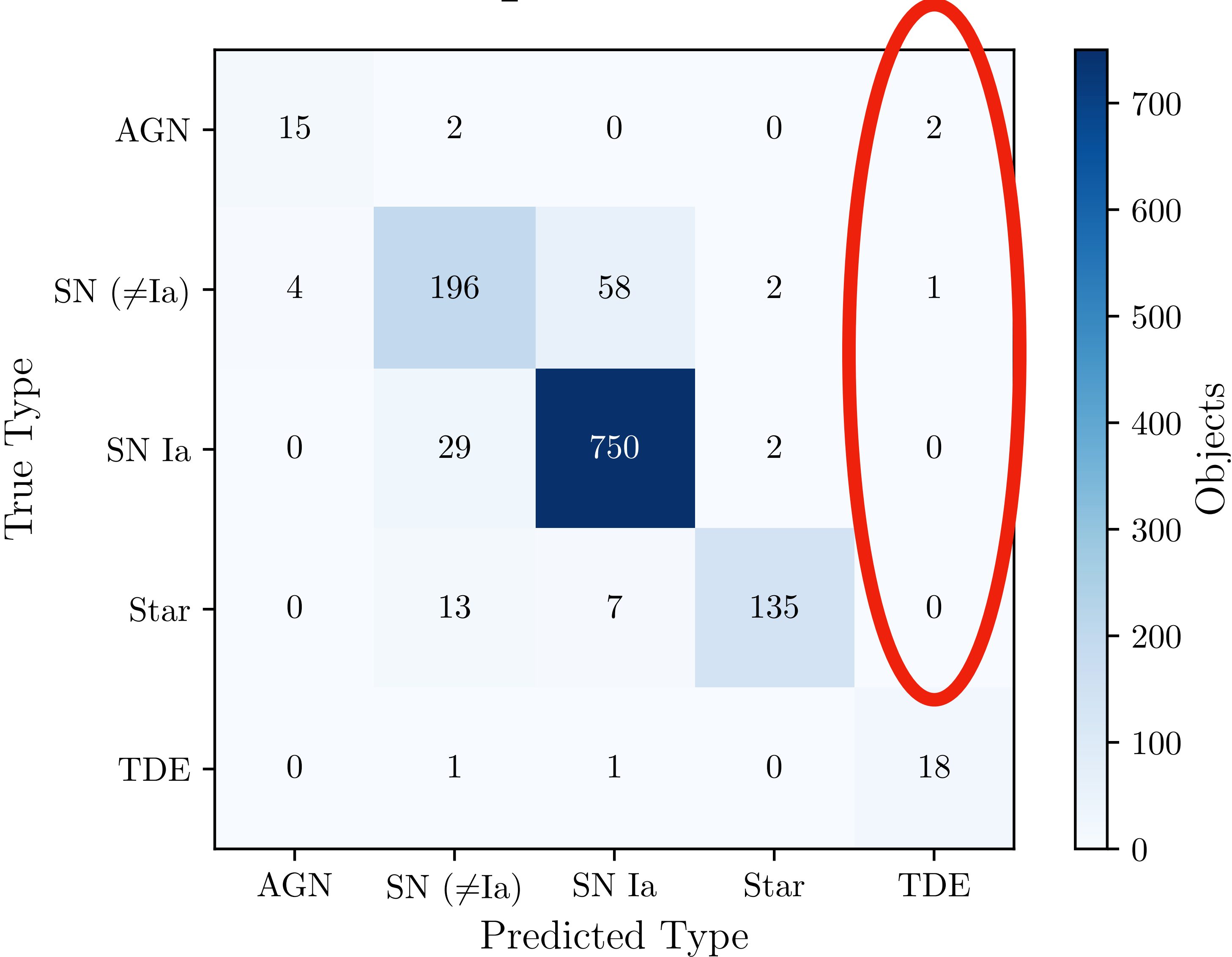
absolute numbers



Evaluation with test sample

Not including noisified
lightcurves in the test
sample

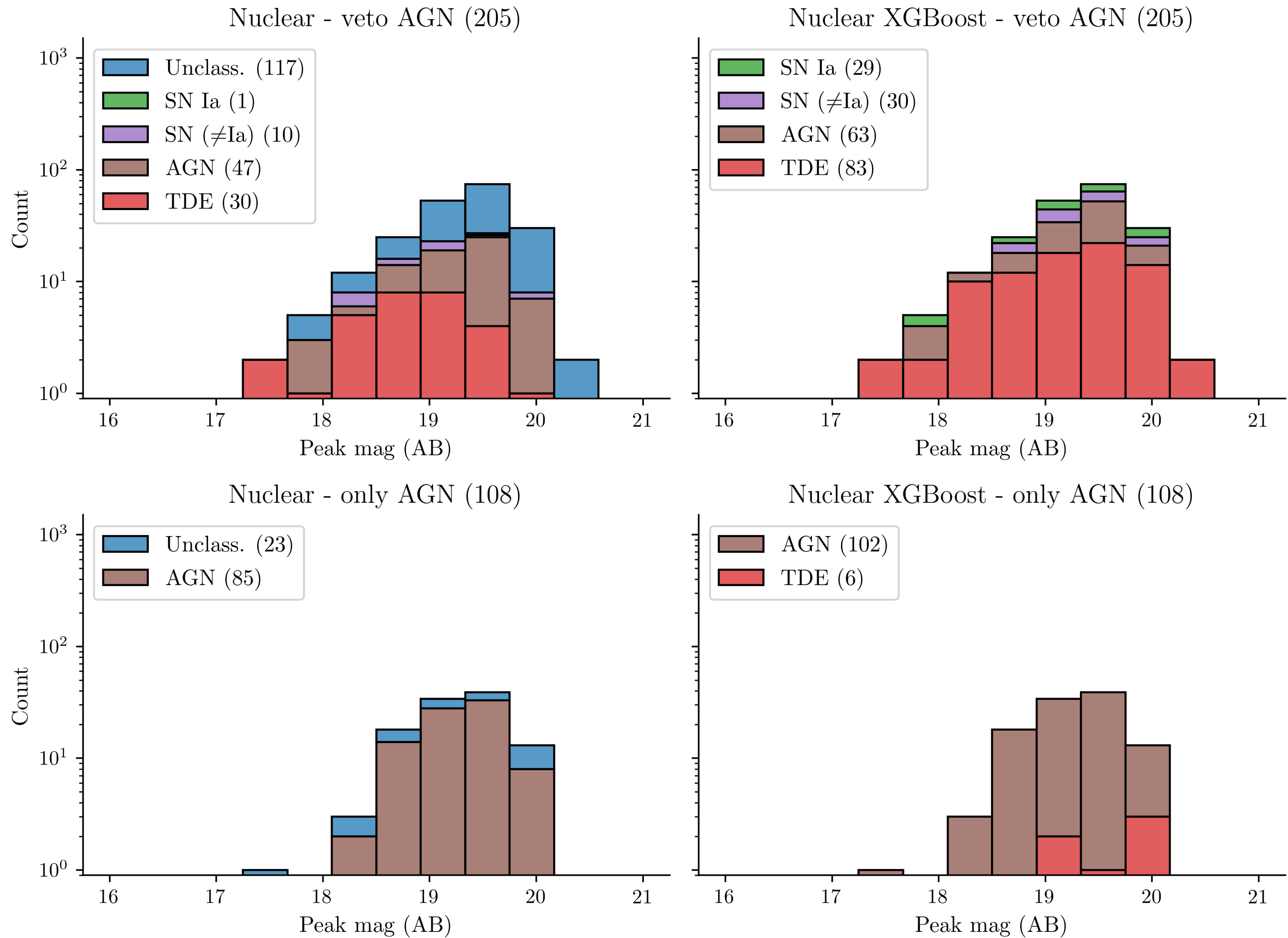
absolute numbers



**No we apply the classifier
to the nuclear sample**

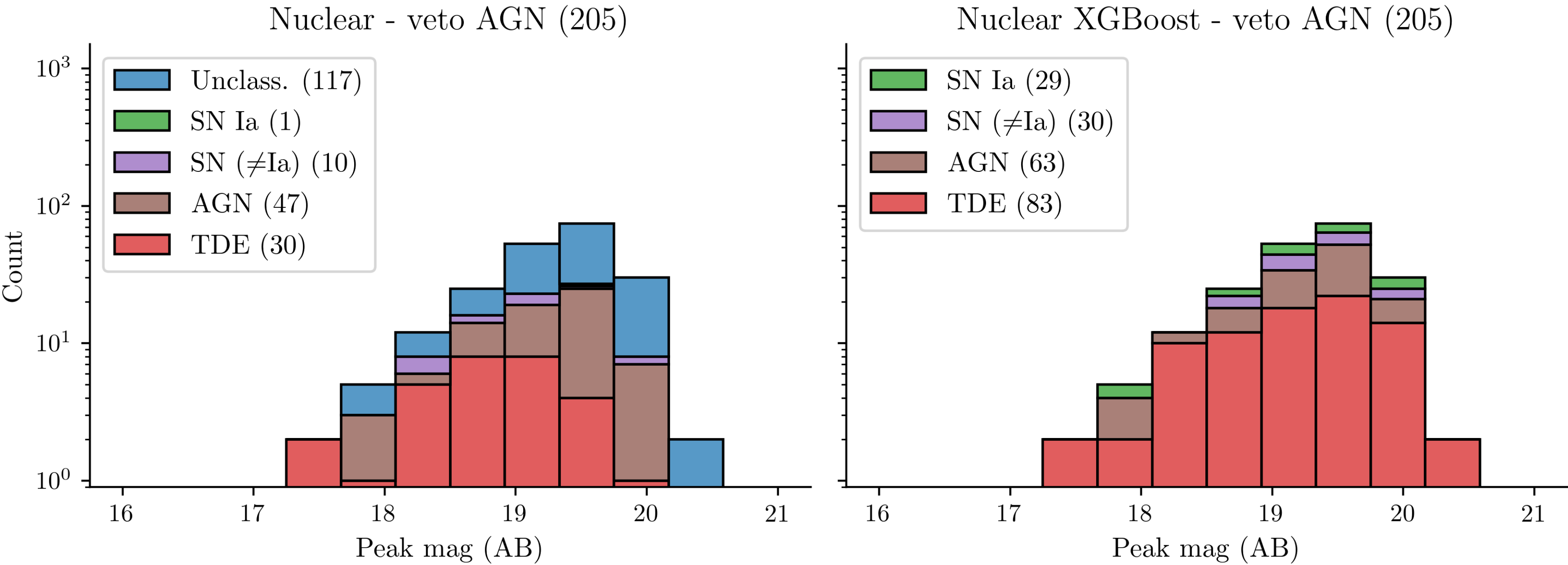
after all cuts

cut stage: exactly 1 flare

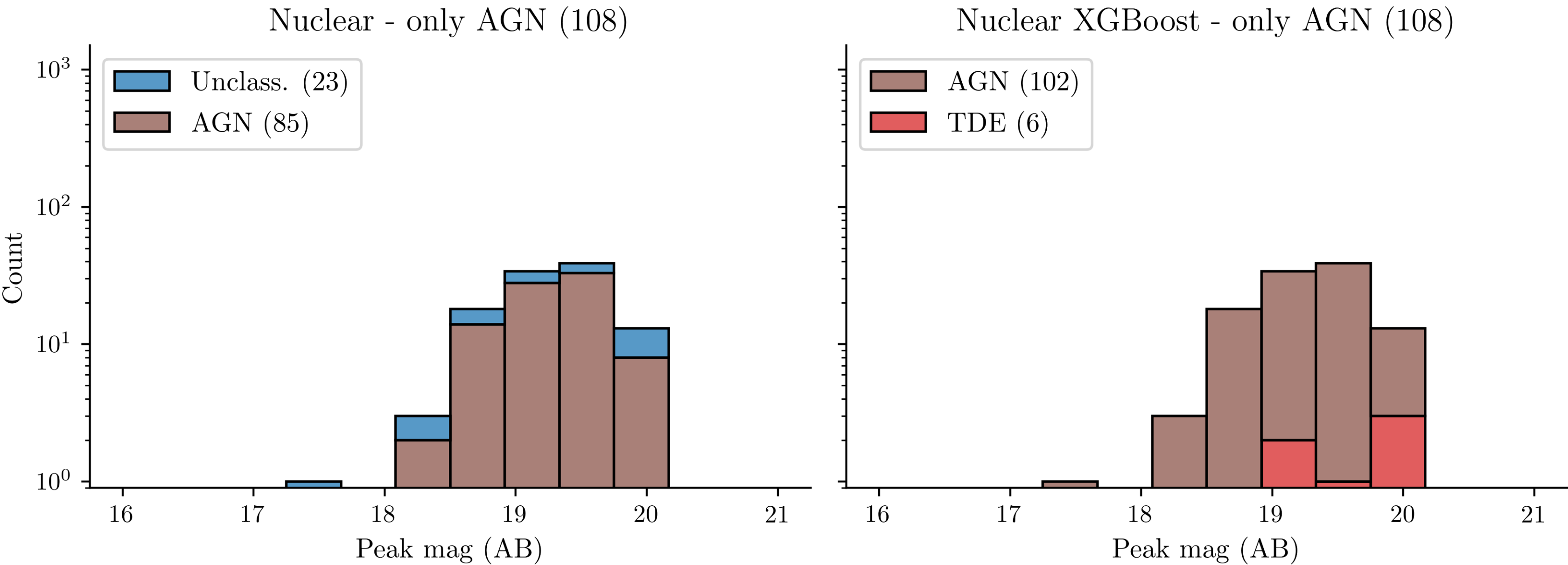


no Milliquas match
(not AGN)

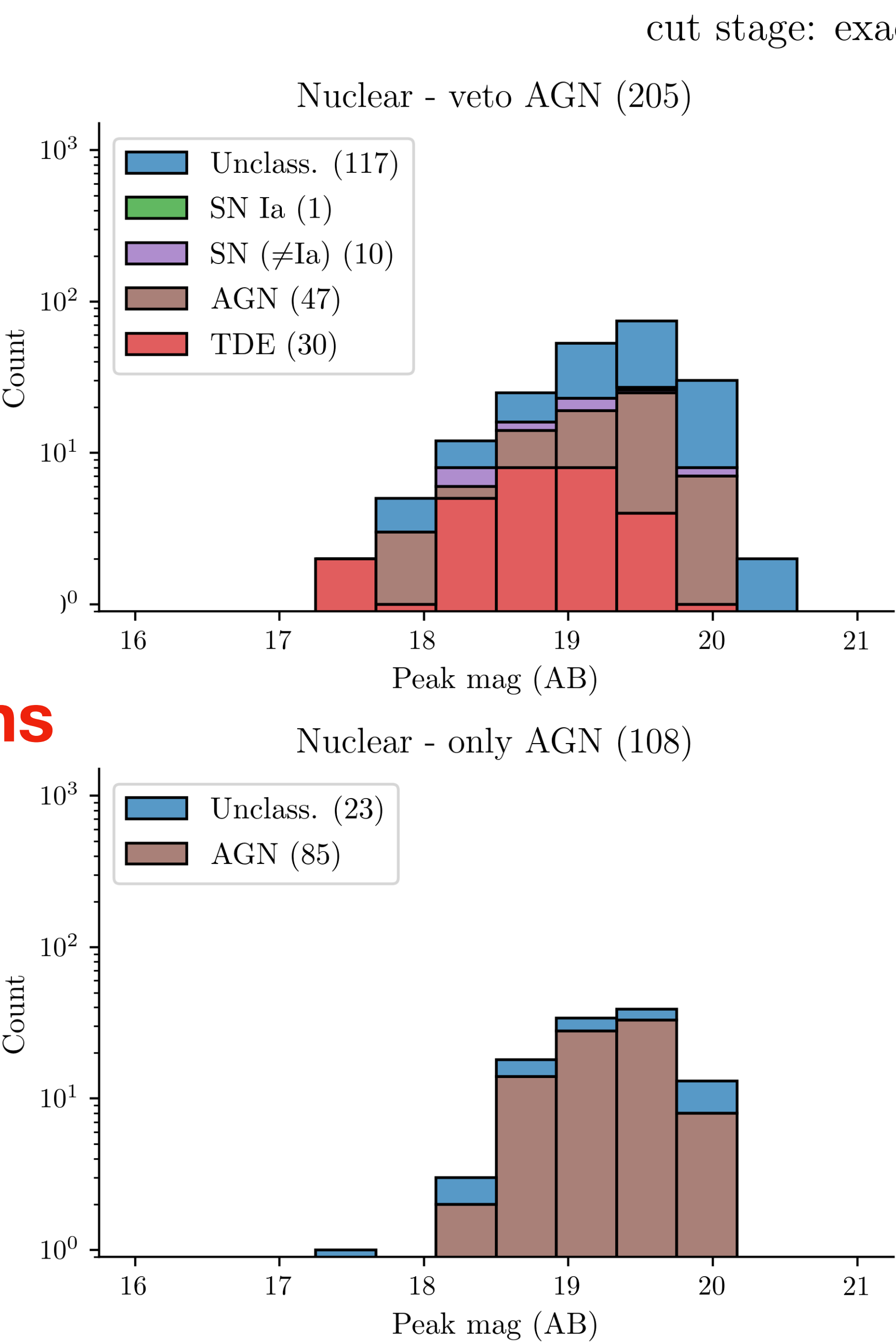
cut stage: exactly 1 flare



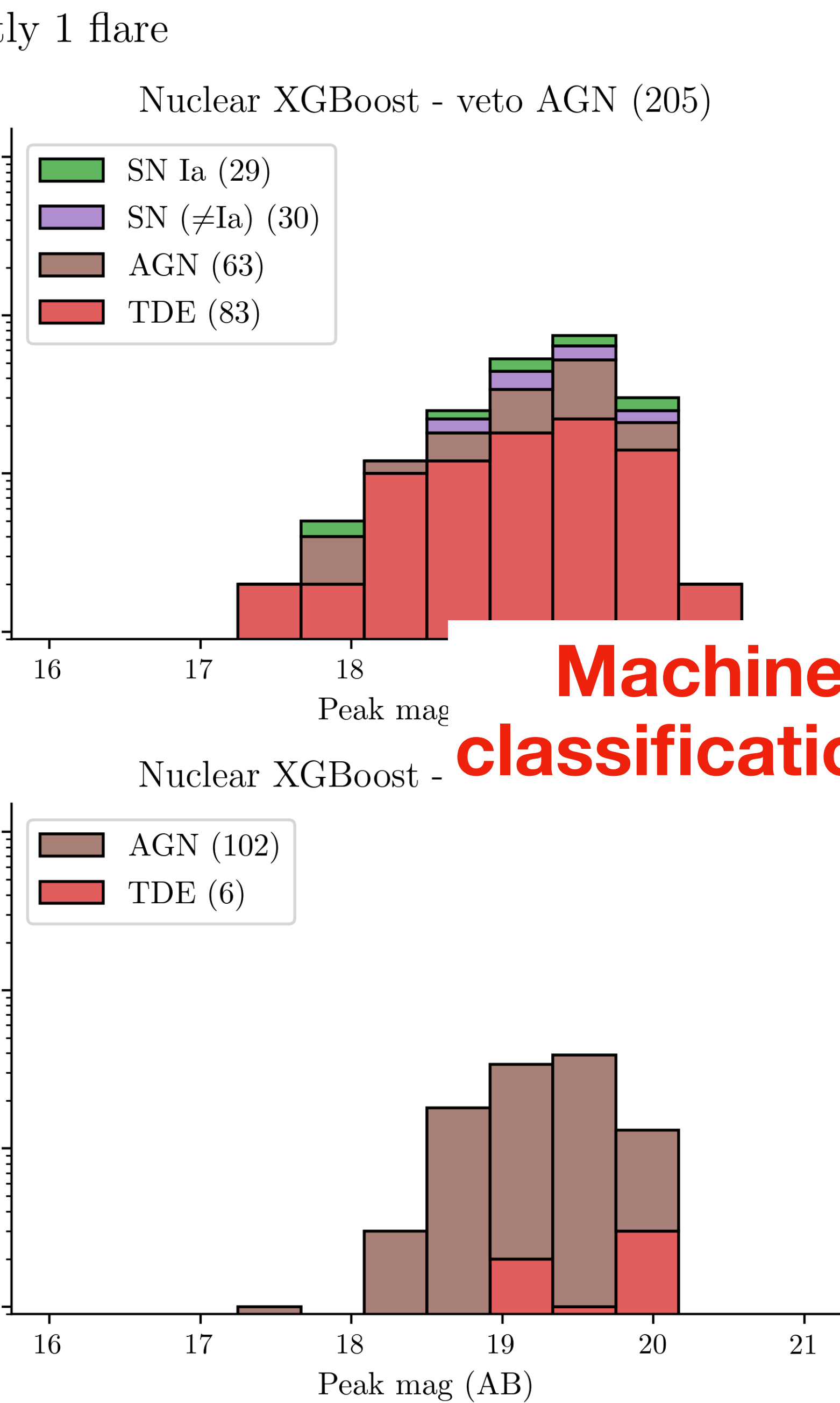
has Milliquas match
(AGN)



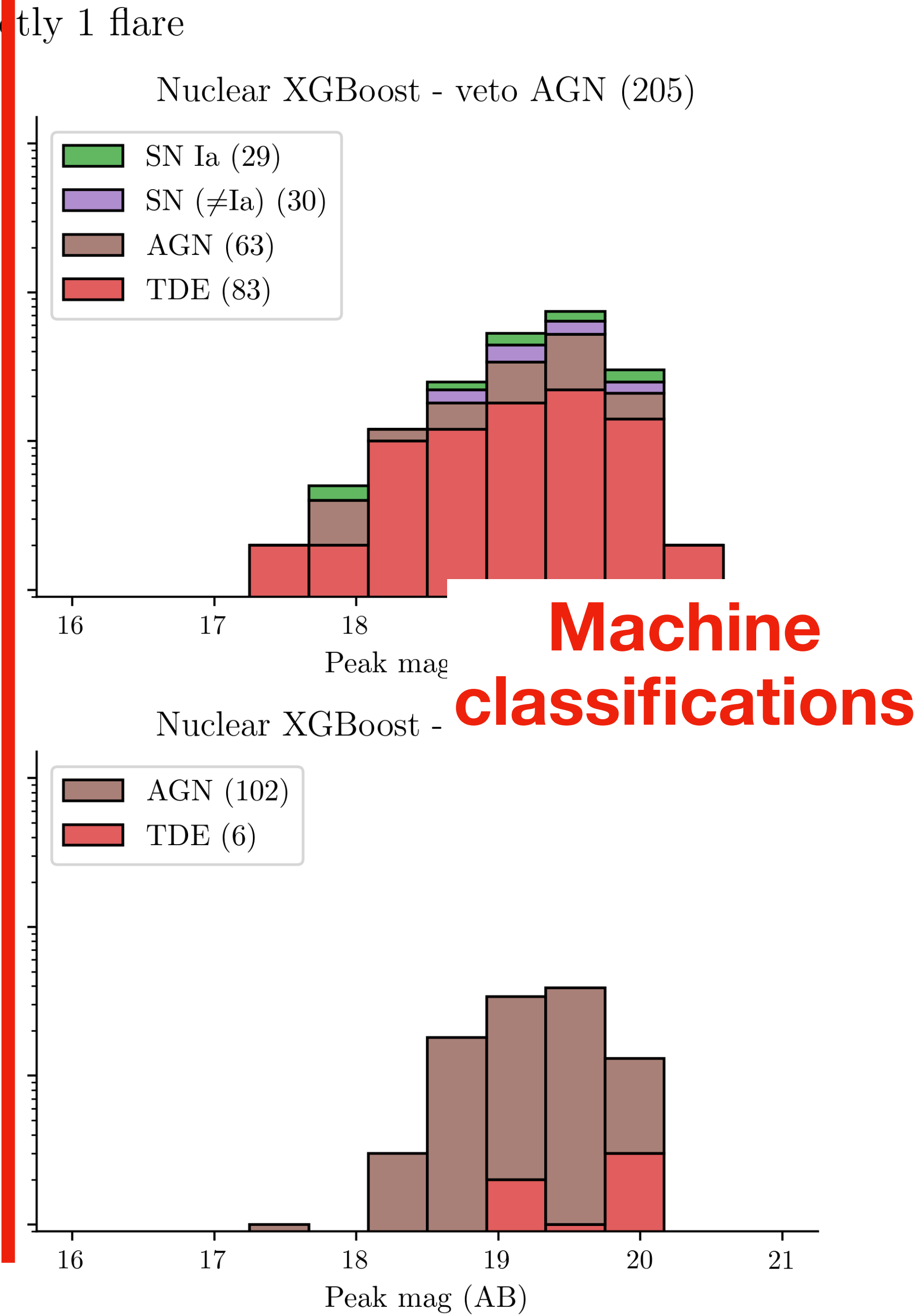
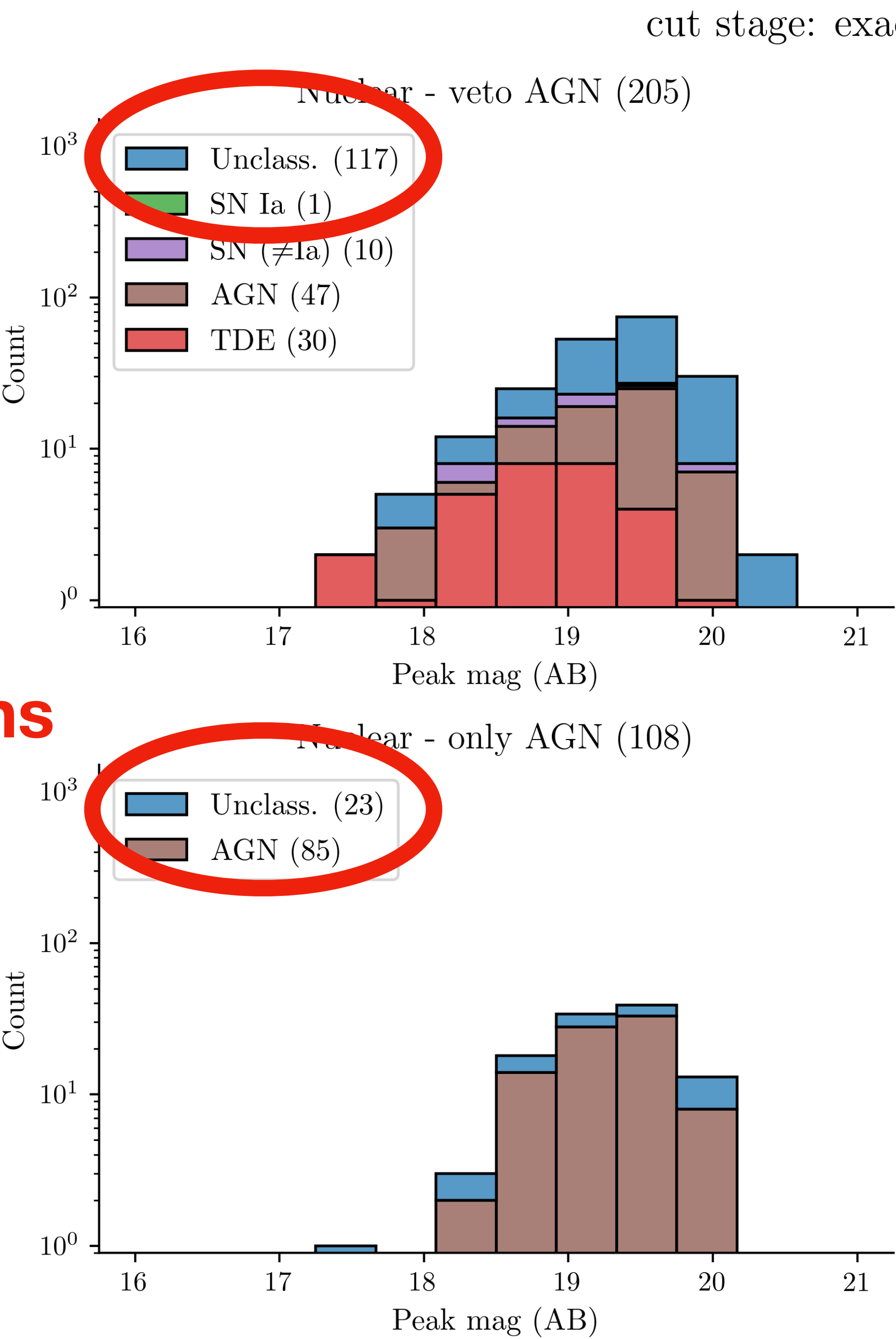
**Human
classifications**



**Machine
classifications**

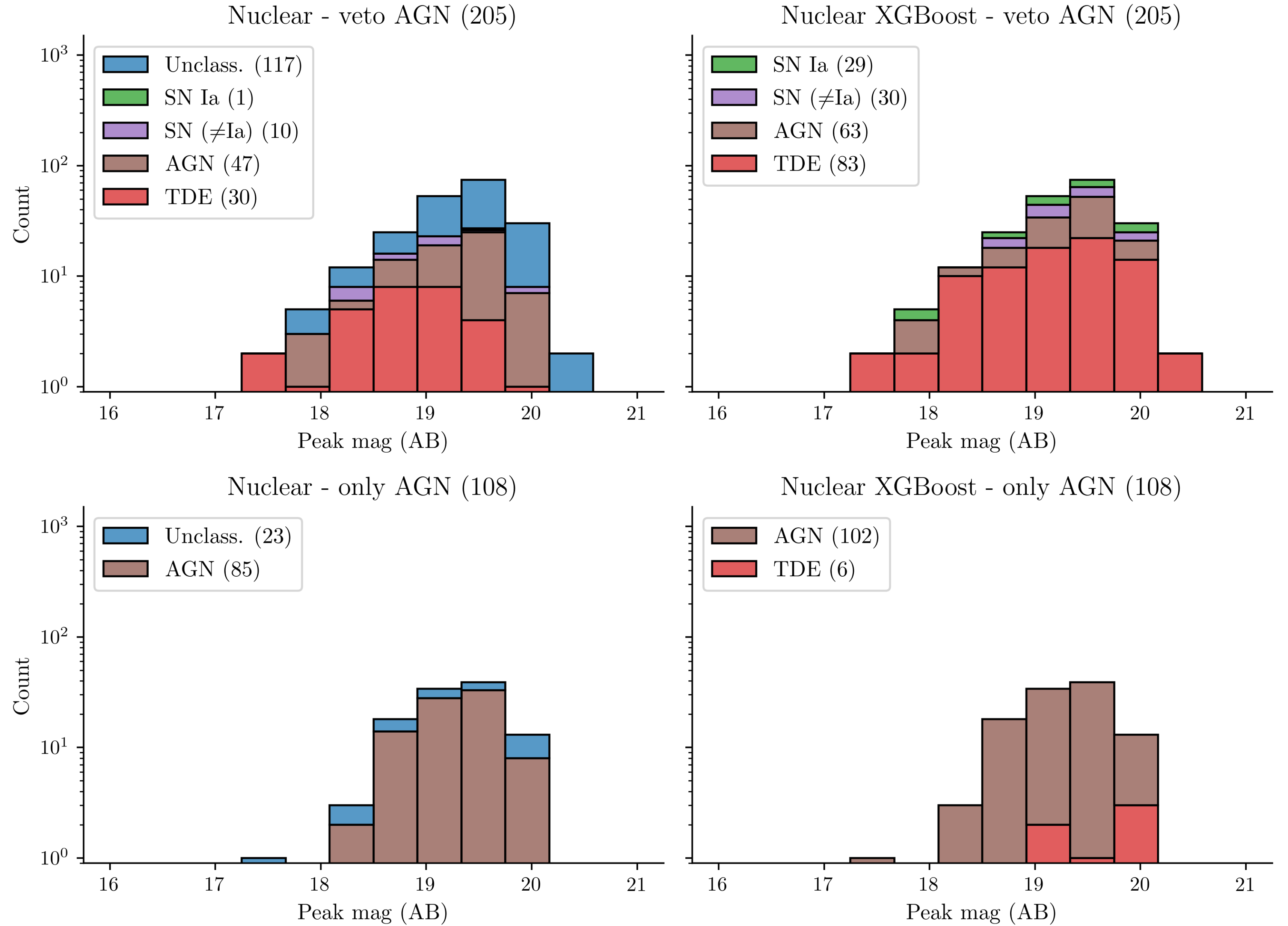


**Human
classifications**

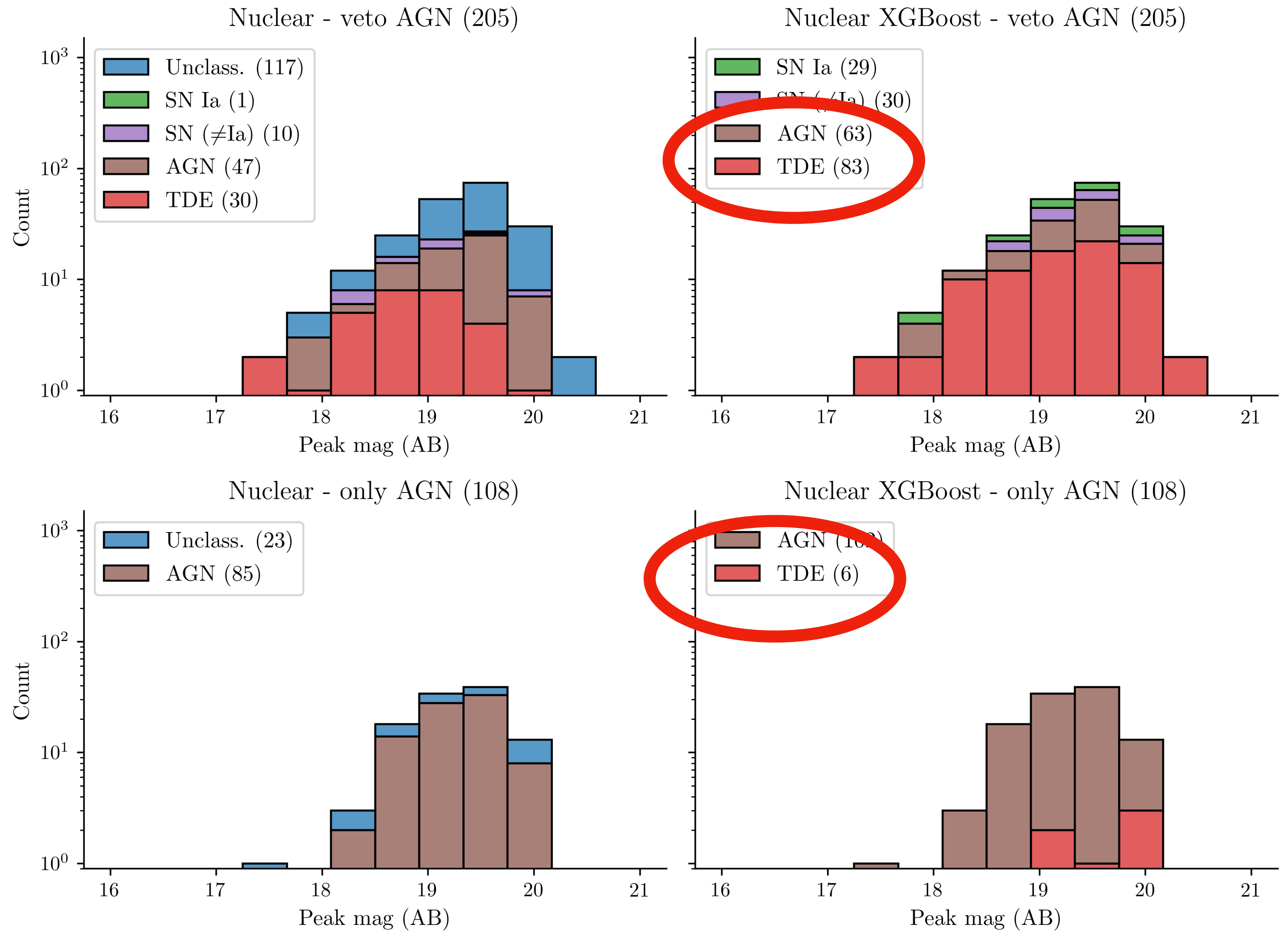


**Machine
classifications**

cut stage: exactly 1 flare



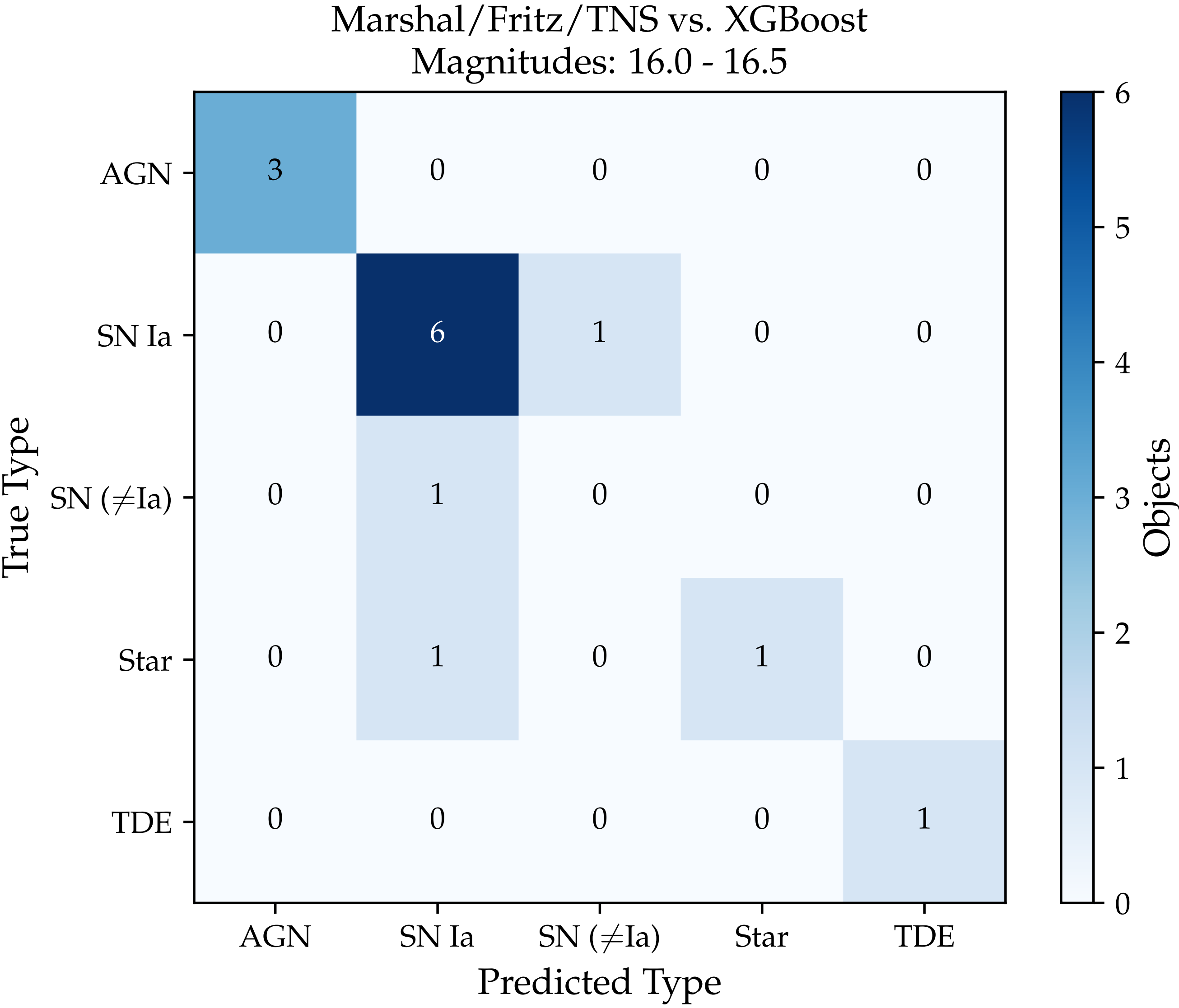
cut stage: exactly 1 flare



**Compare to unsecure
classifications pulled from
the internet**

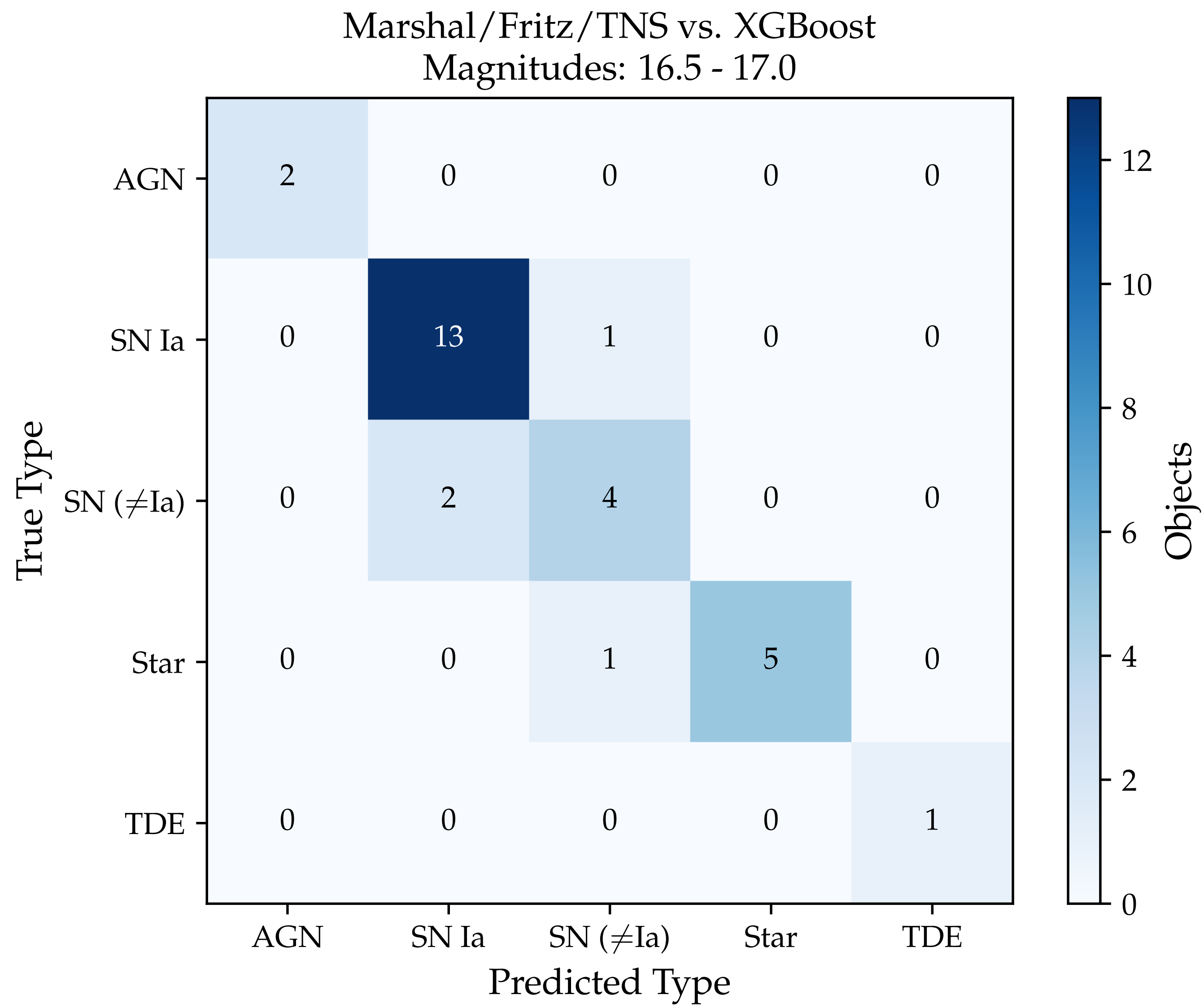
Evaluation with unsecure truth

Mag:
16.0-16.5



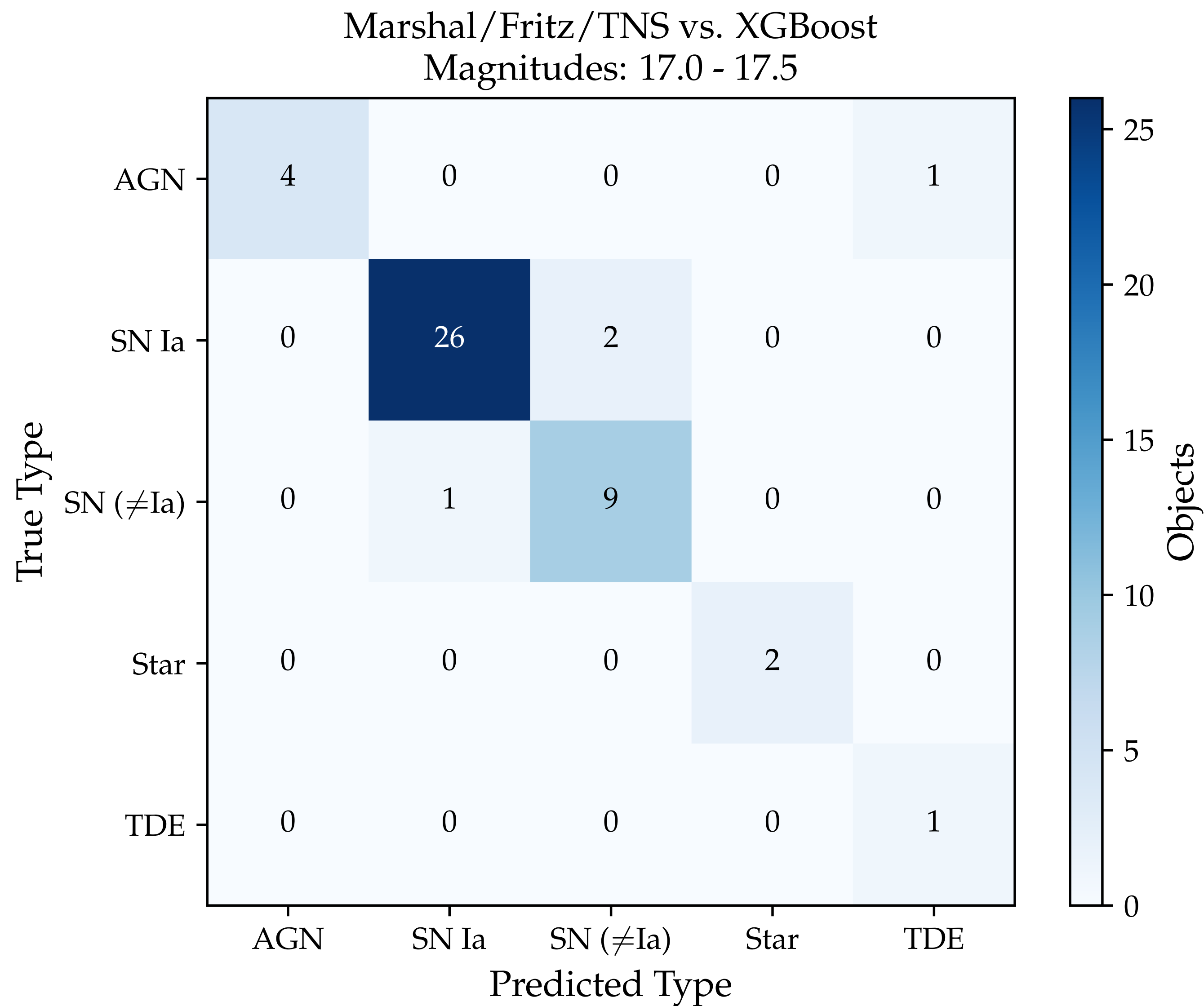
Evaluation with unsecure truth

Mag:
16.5-17.0



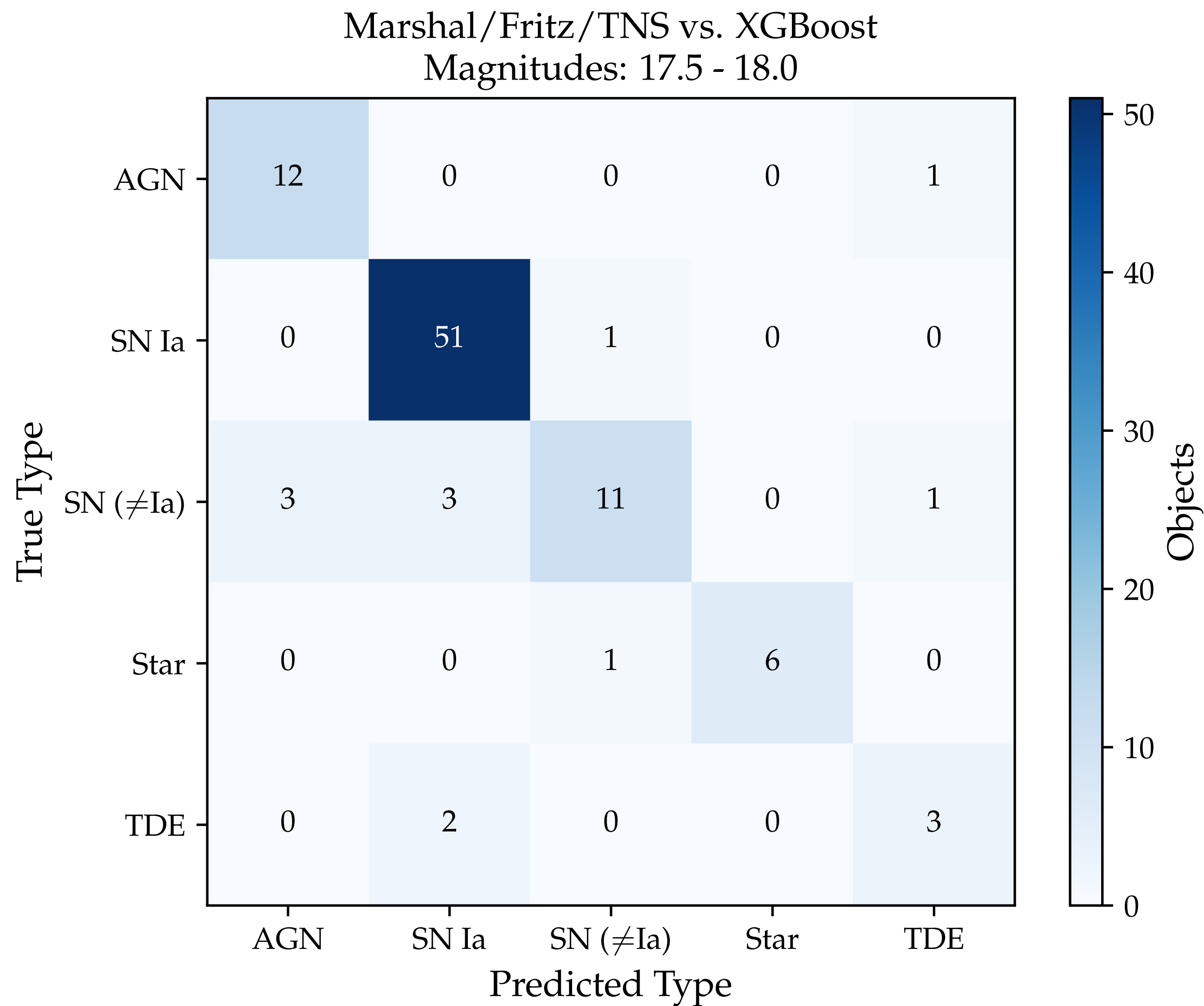
Evaluation with unsecure truth

Mag:
17.0-17.5



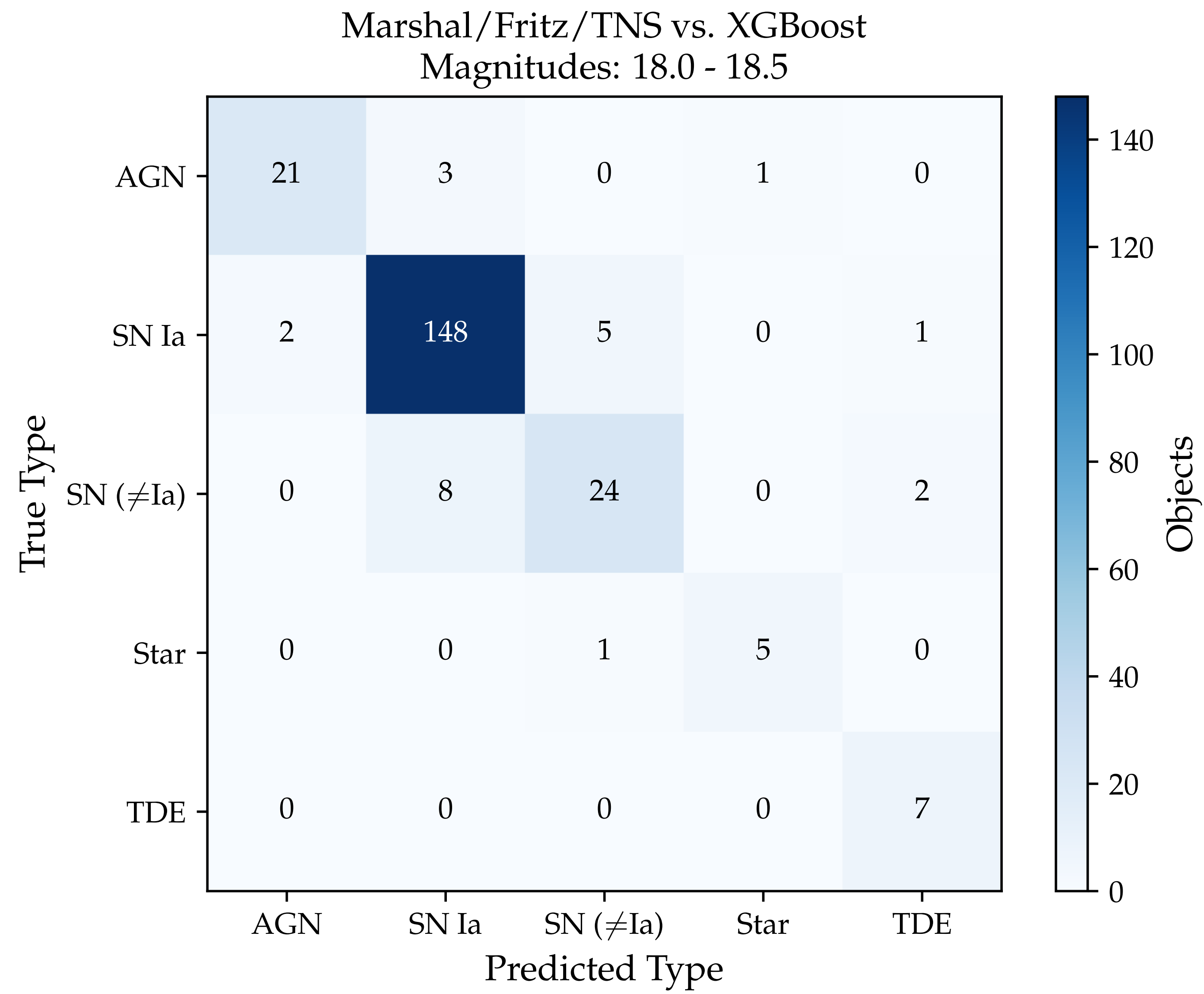
Evaluation with unsecure truth

Mag:
17.5-18.0



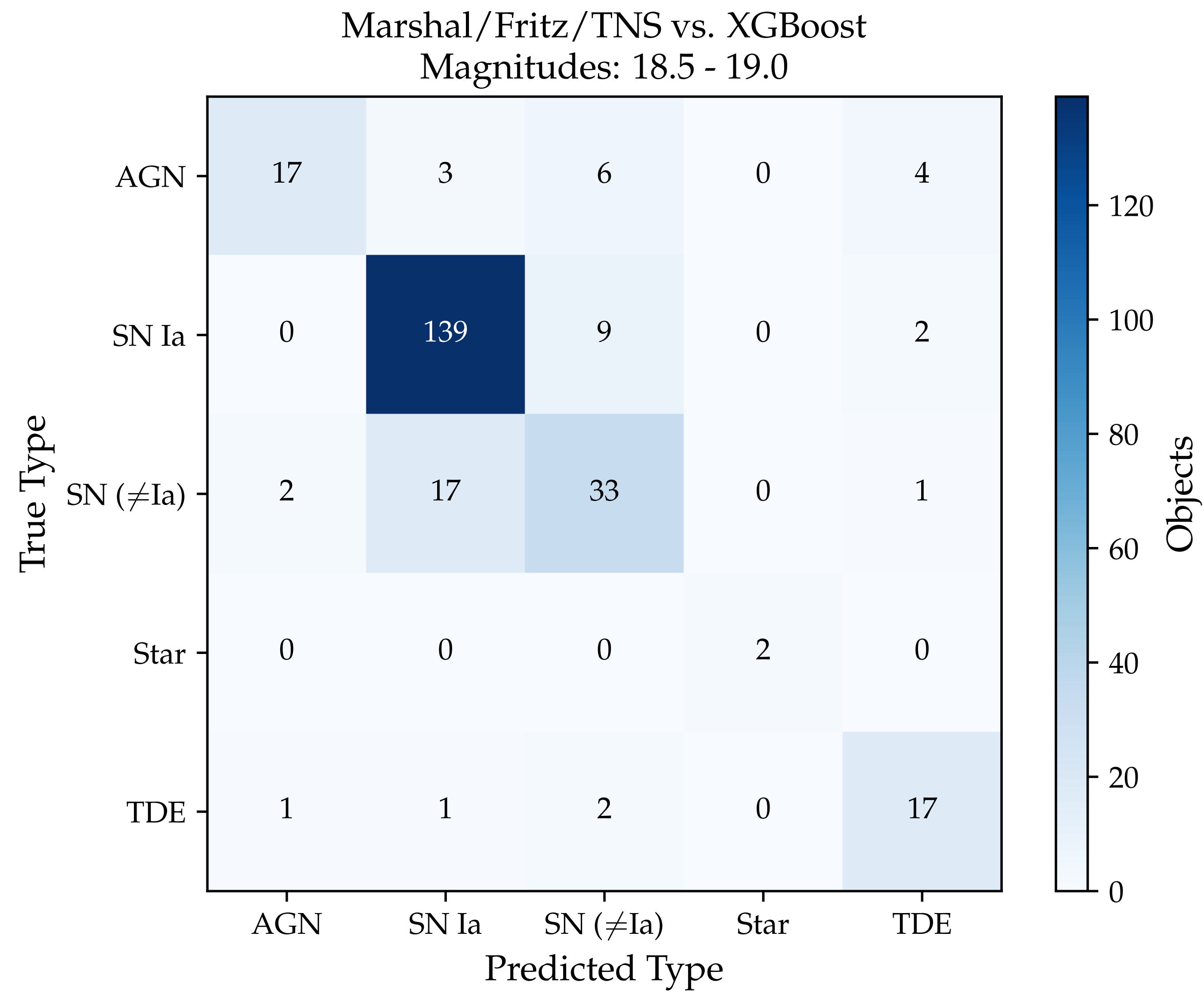
Evaluation with unsecure truth

Mag:
18.0-18.5



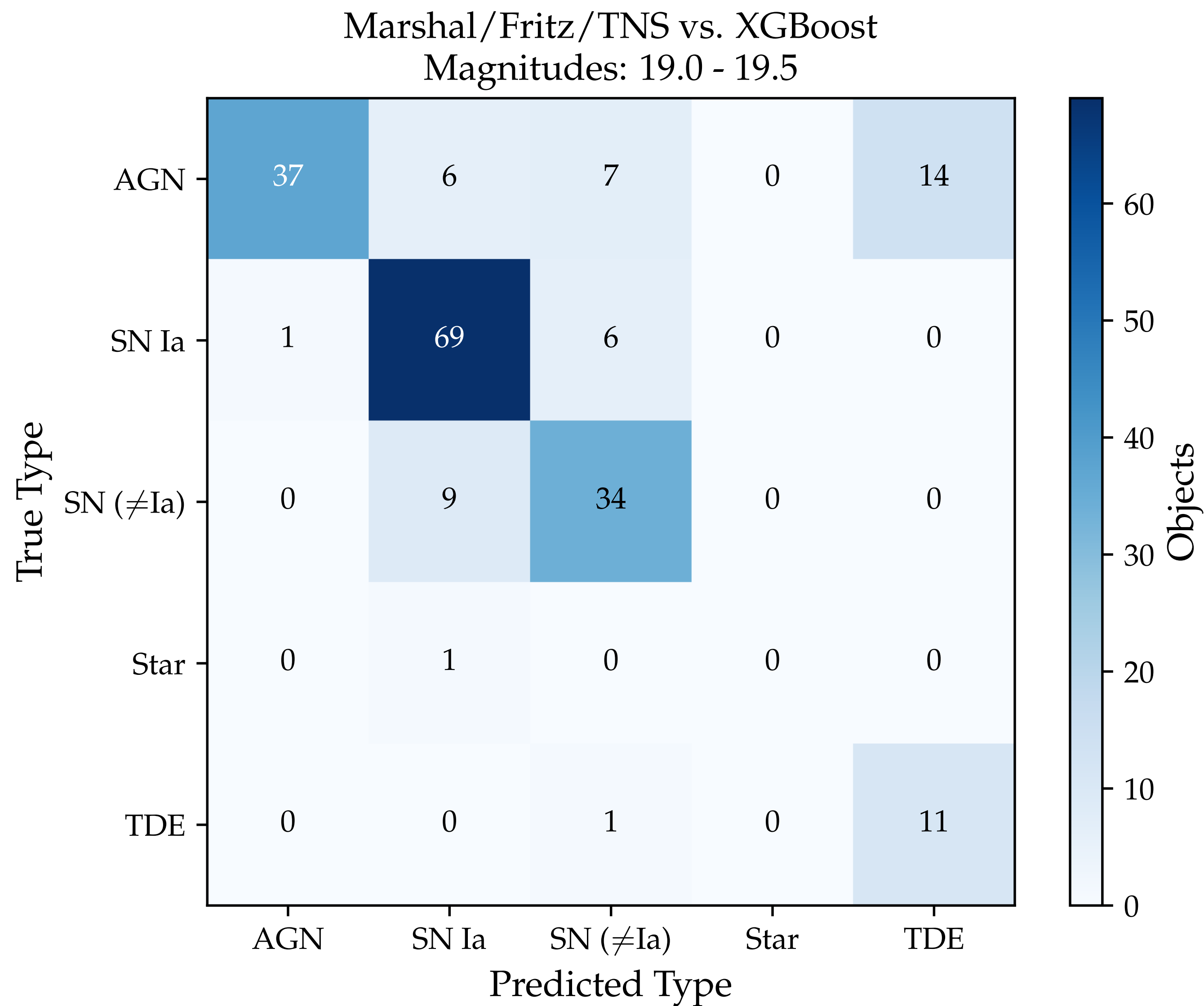
Evaluation with unsecure truth

Mag:
18.5-19.0



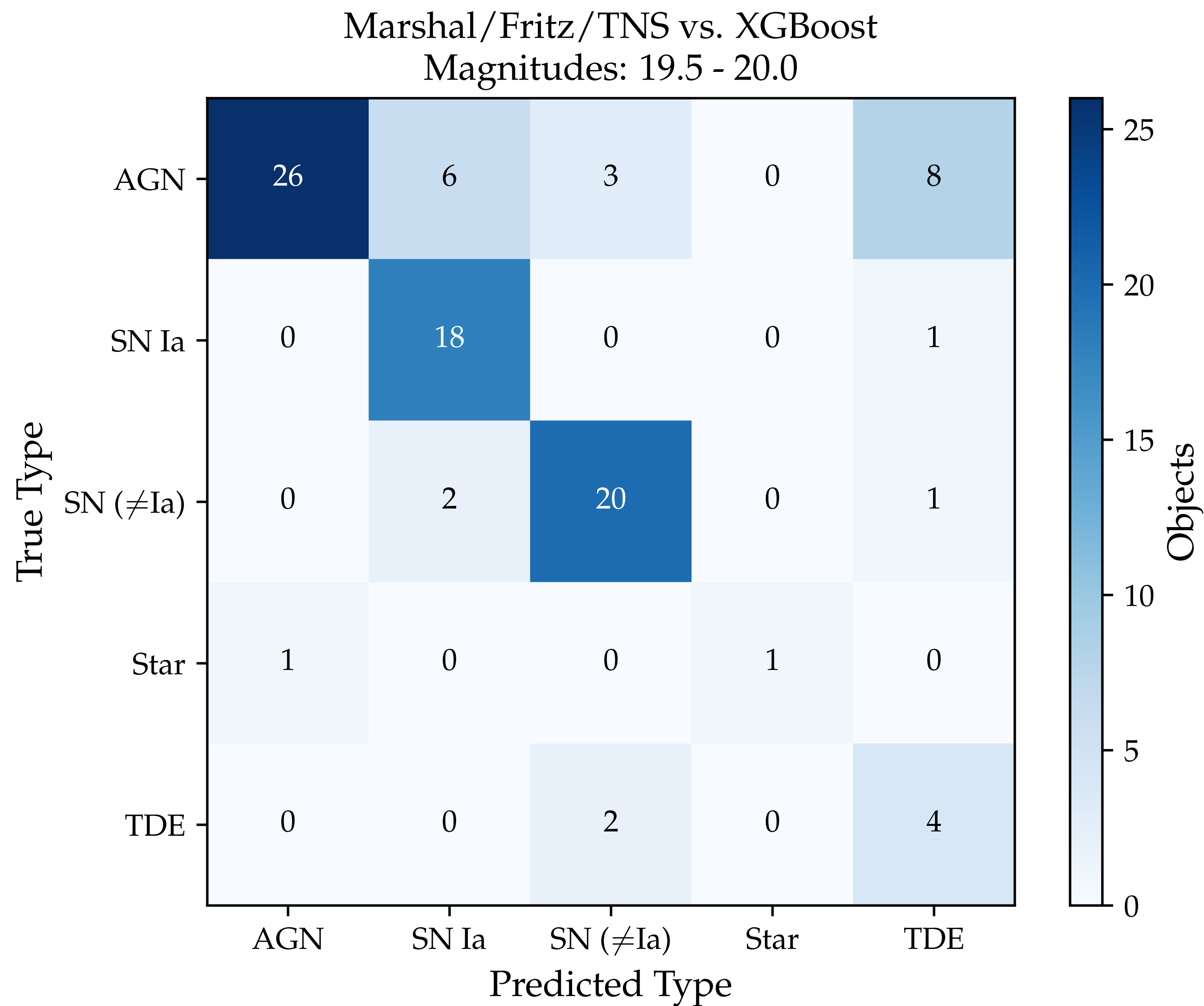
Evaluation with unsecure truth

Mag:
19.0-19.5



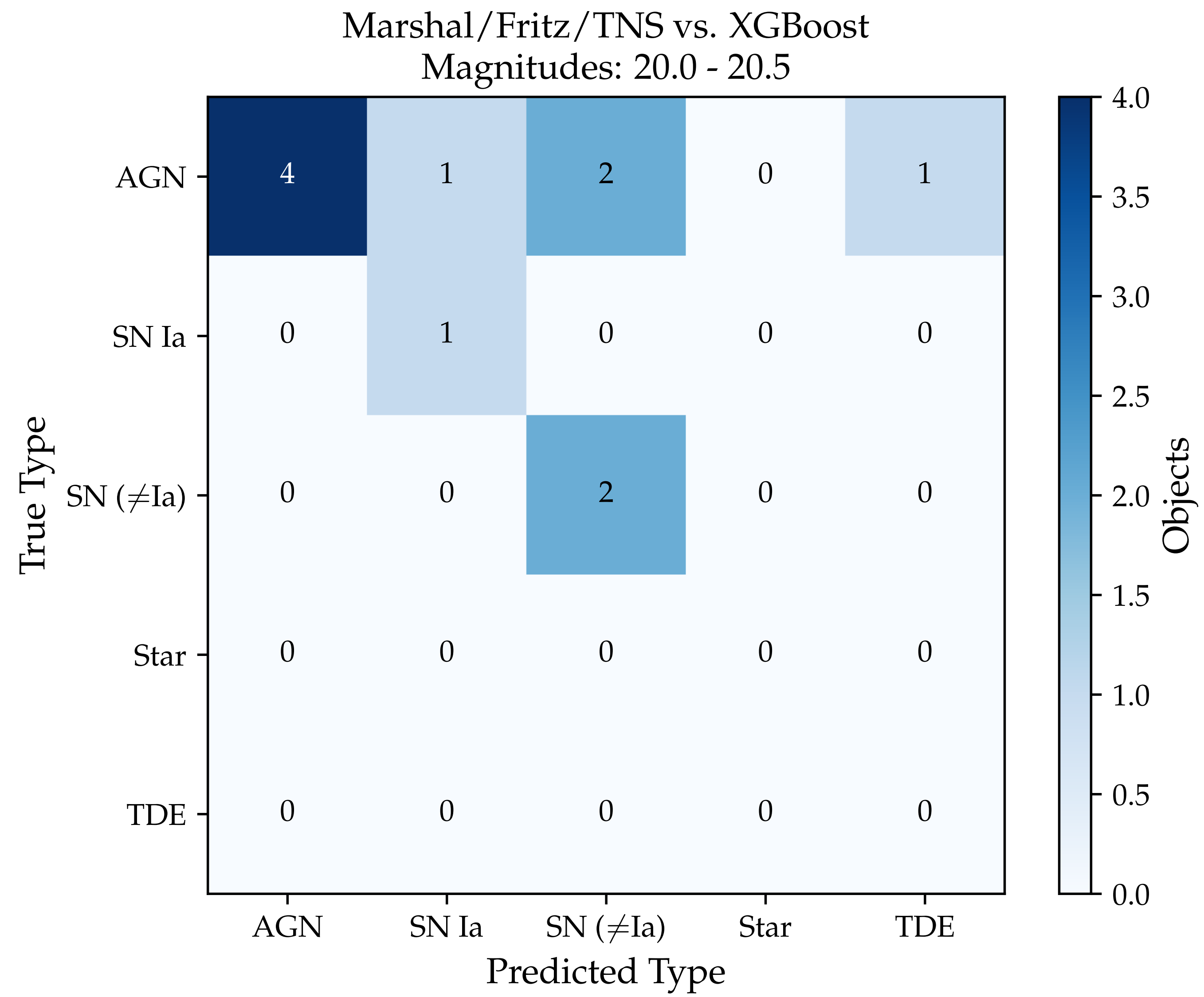
Evaluation with unsecure truth

Mag:
19.5-20.0



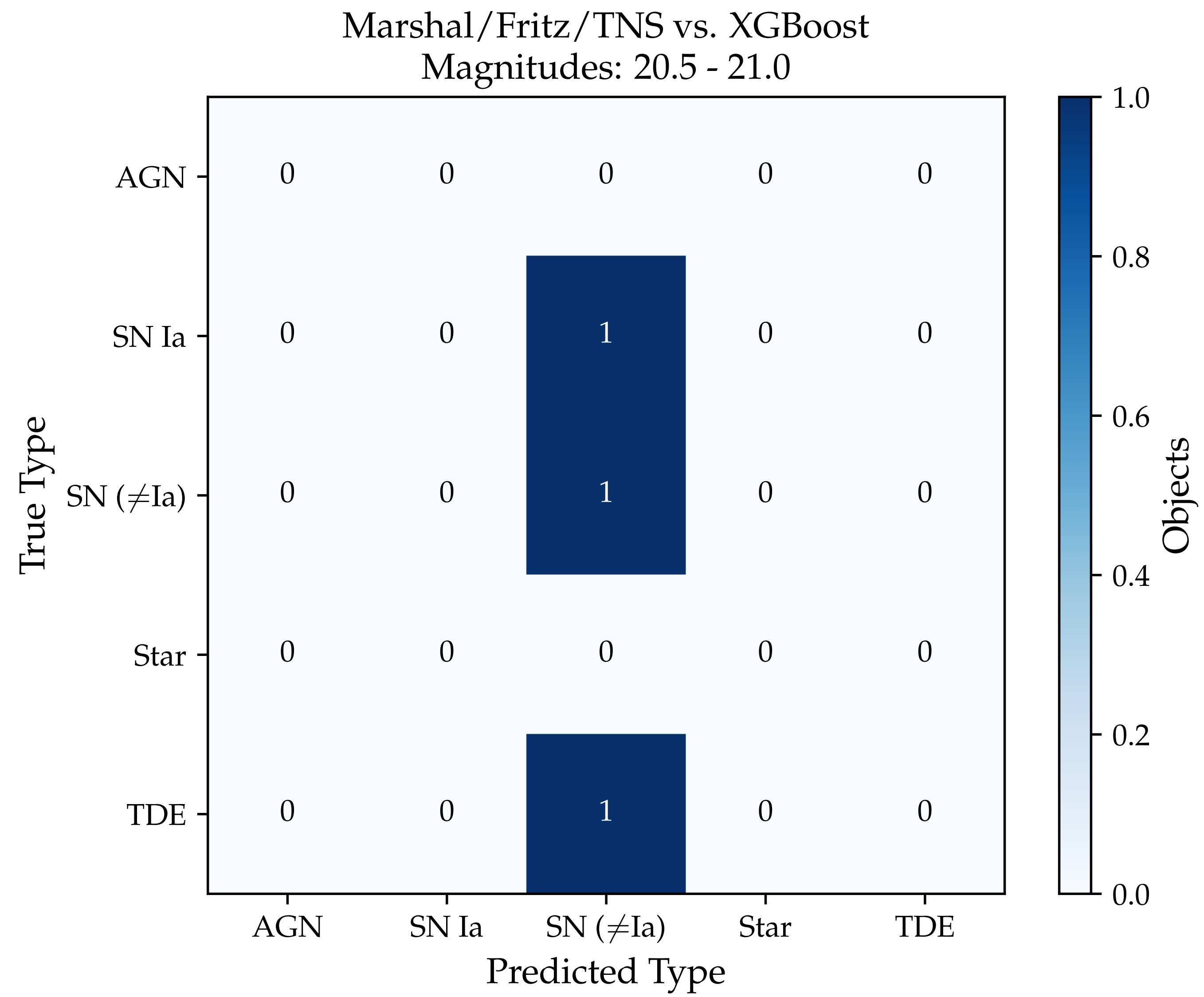
Evaluation with unsecure truth

Mag:
20.0-20.5



Evaluation with unsecure truth

Mag:
20.5-21.0



Questions

How to address uncertain classifications?

Way to discard "bad" predictions?

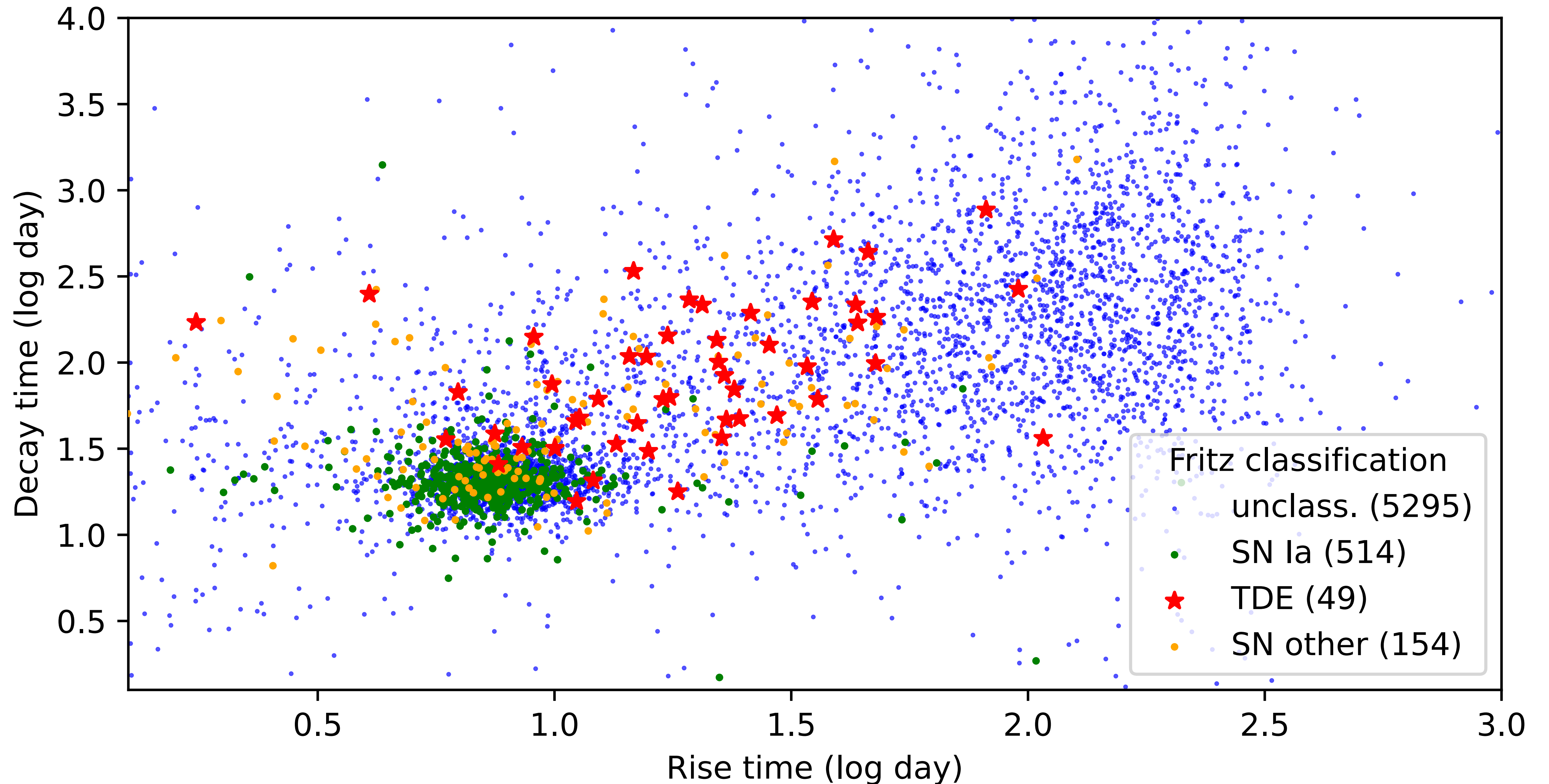
Waterfall plots?

Suggestions to improve on the training? E.g:
normalization of features (numerical values)?

Anomaly detection?

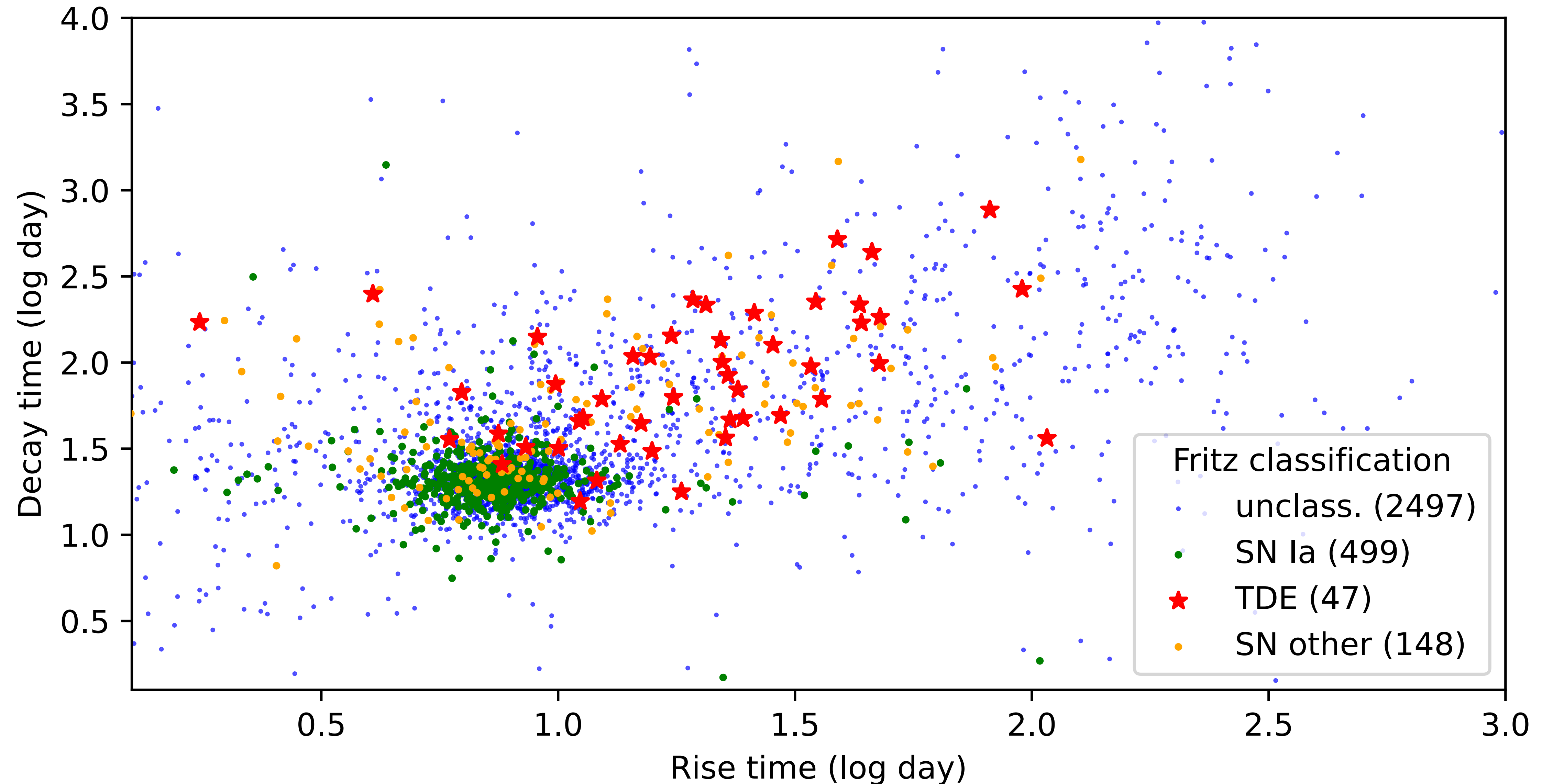
No cut (6012 transients)

Purity: 0.8% / Efficiency: 100.0 %



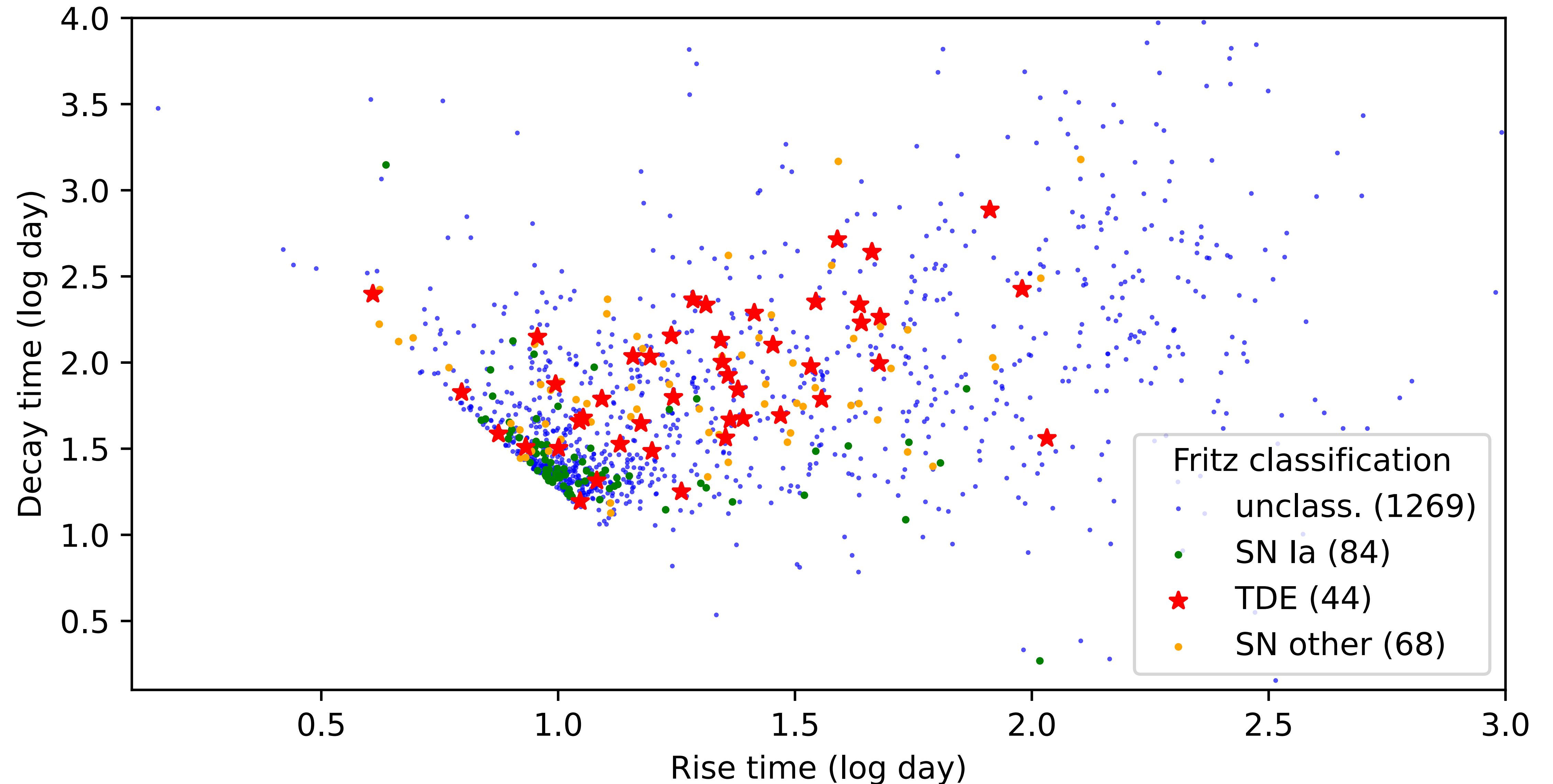
WISE colors (3191 transients)

Purity: 1.5% / Efficiency: 95.9 %



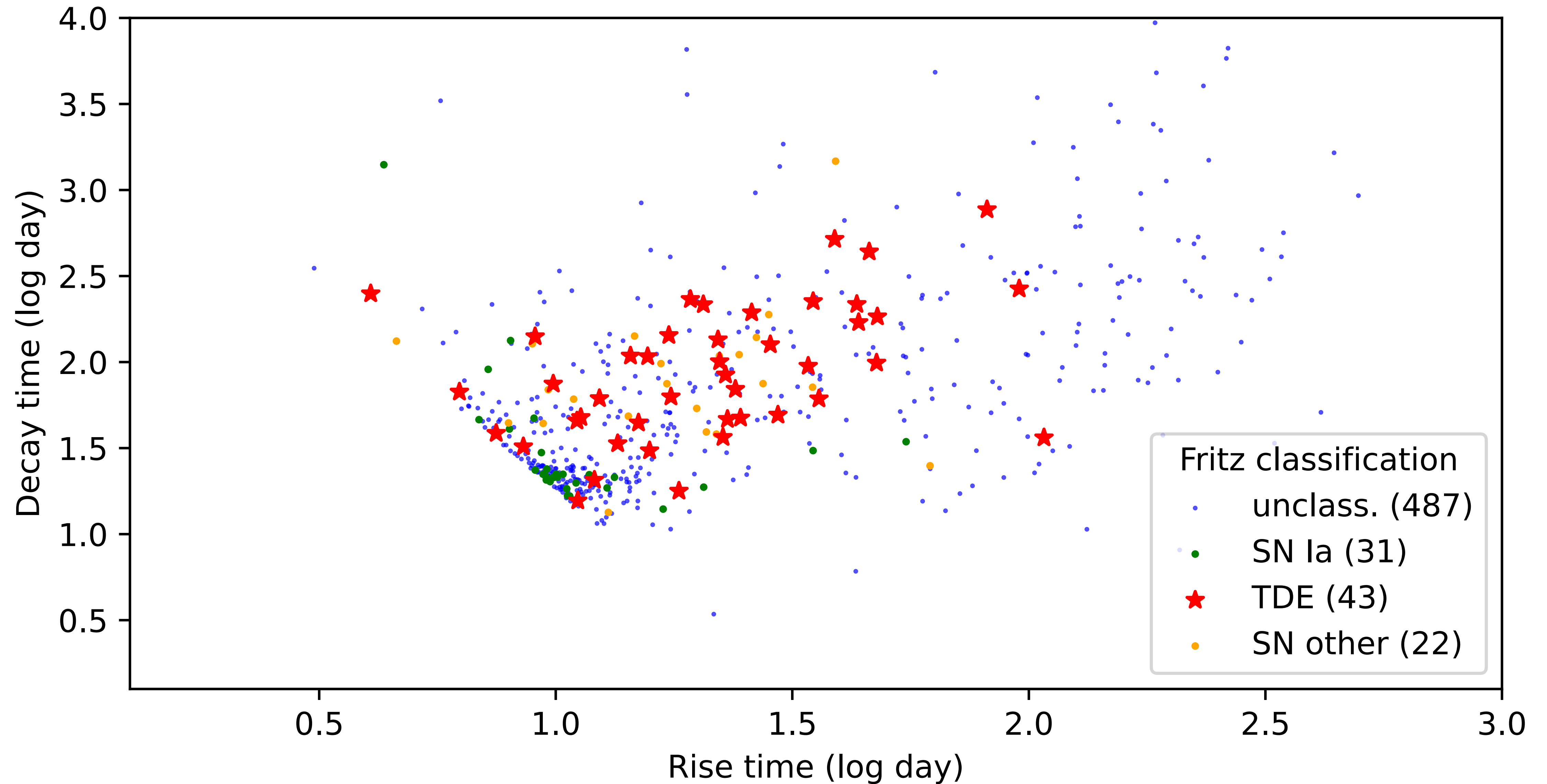
Diagonal cut (1465 transients)

Purity: 3.0% / Efficiency: 89.8 %



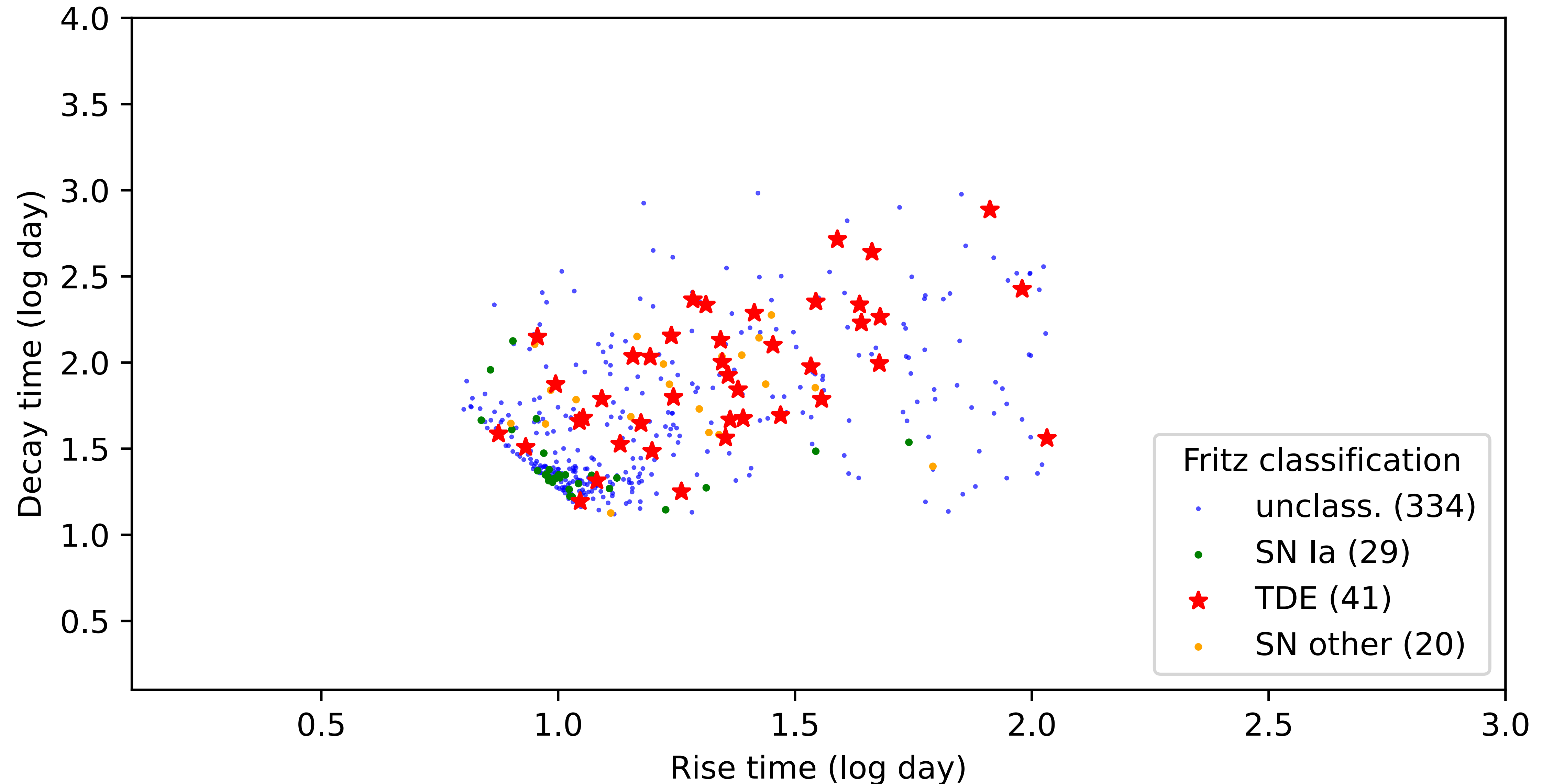
Temperature cut (583 transients)

Purity: 7.4% / Efficiency: 87.8 %



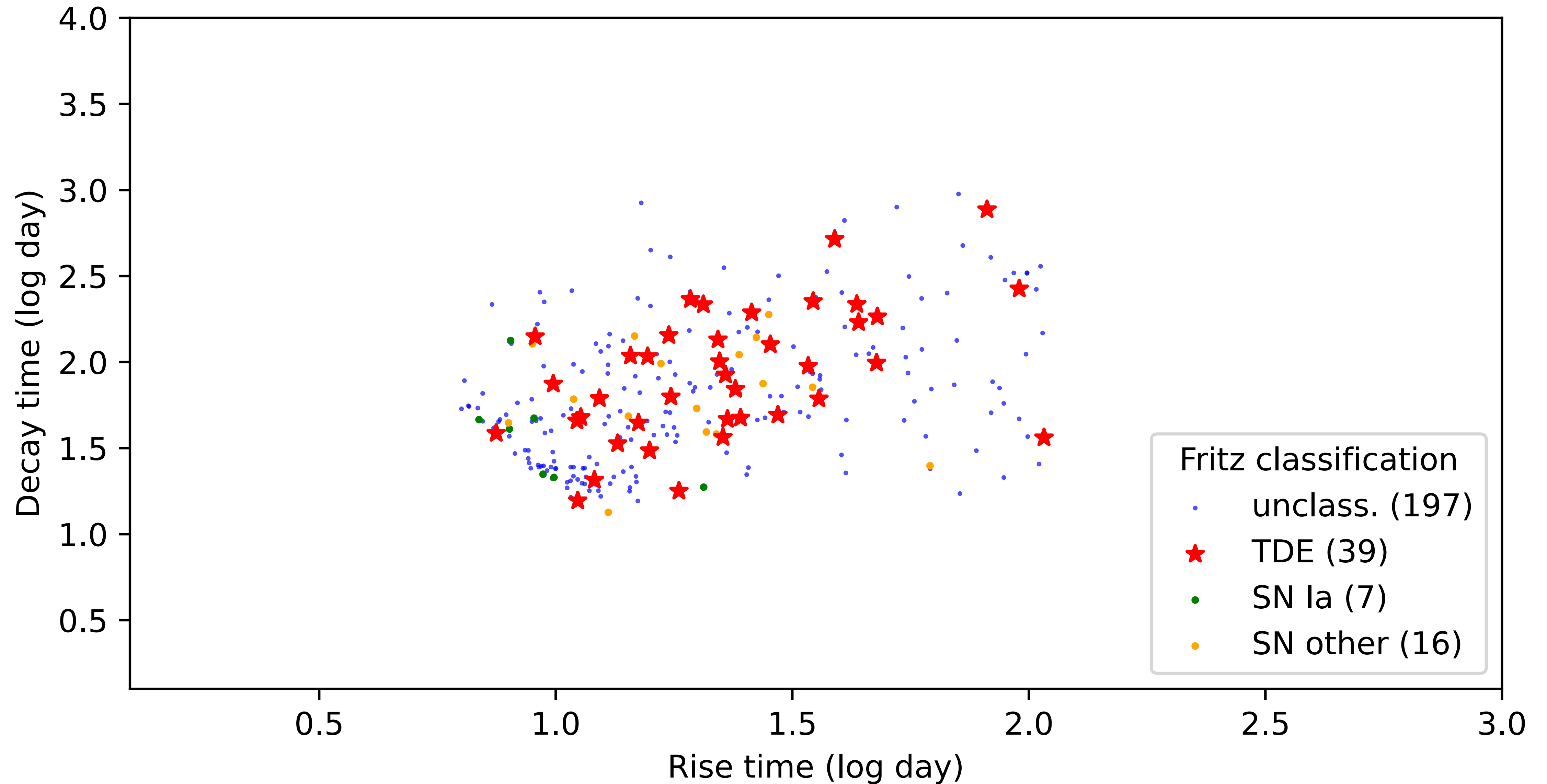
Rise-decay cut (424 transients)

Purity: 9.7% / Efficiency: 83.7 %



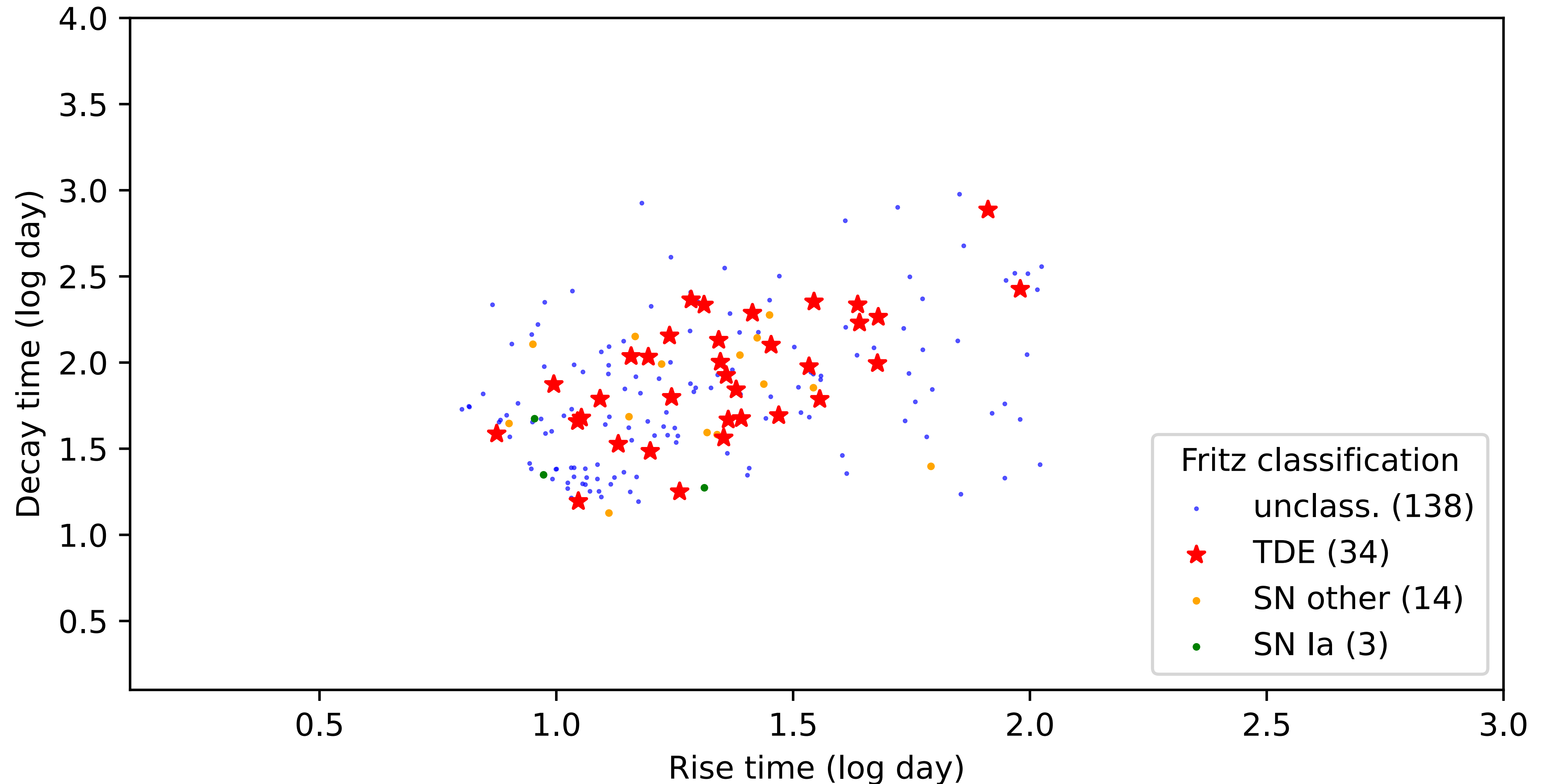
Chisquare cut (259 transients)

Purity: 15.1% / Efficiency: 79.6 %

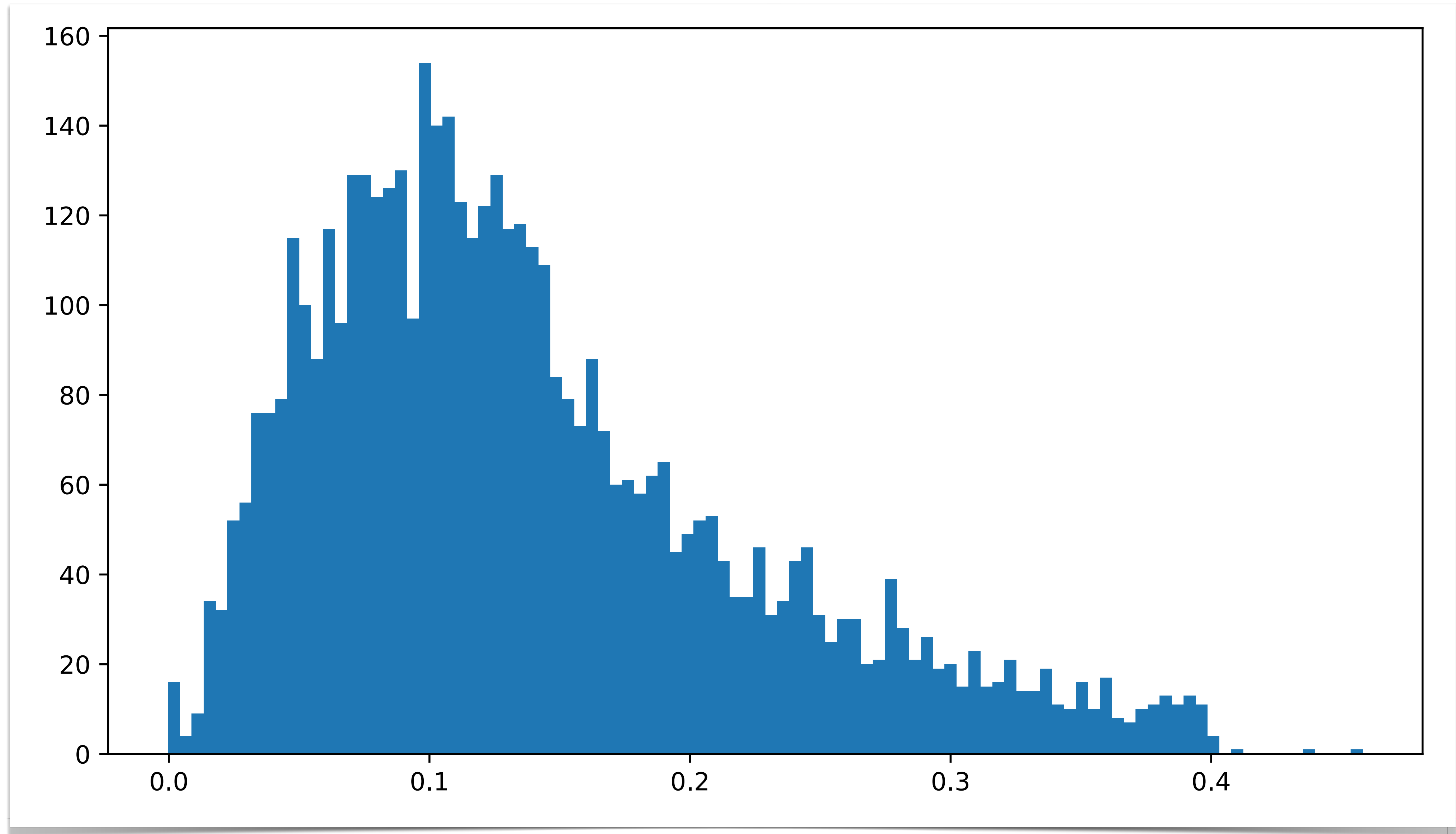


Bayesian block cut (189 transients)

Purity: 18.0% / Efficiency: 69.4 %

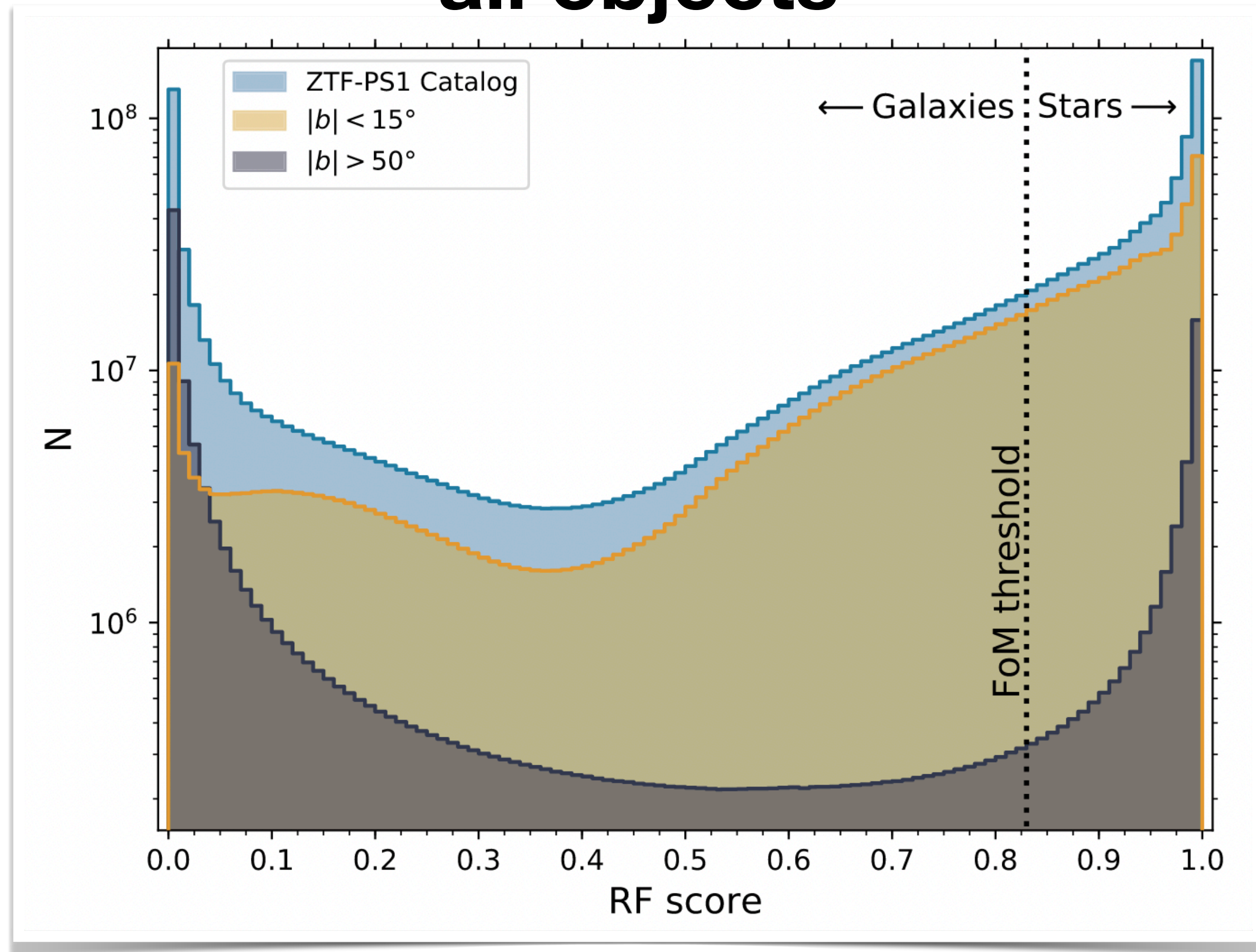


Redshift distribution (including photoz, n=4883)

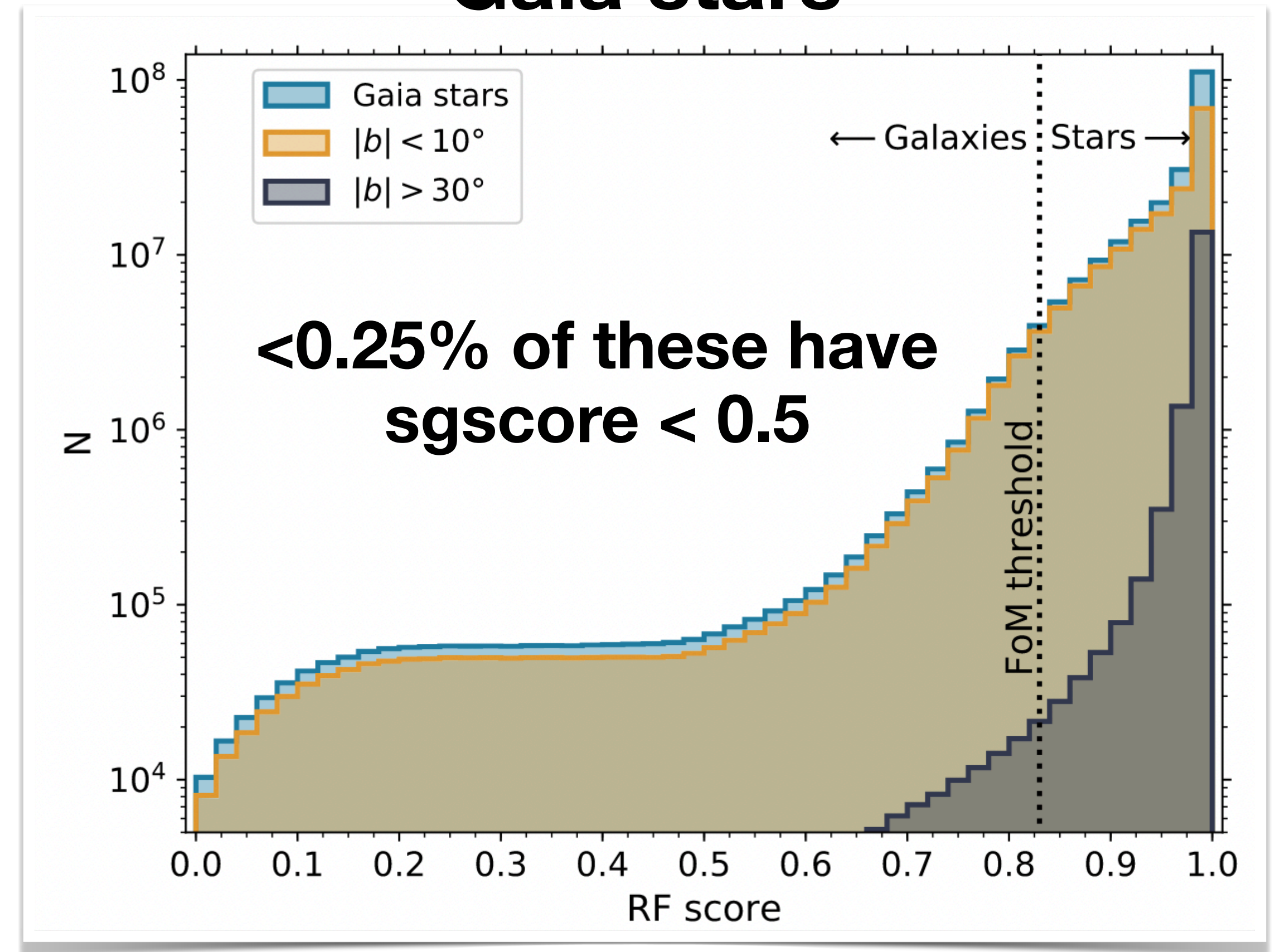


sgscore distribution

all objects

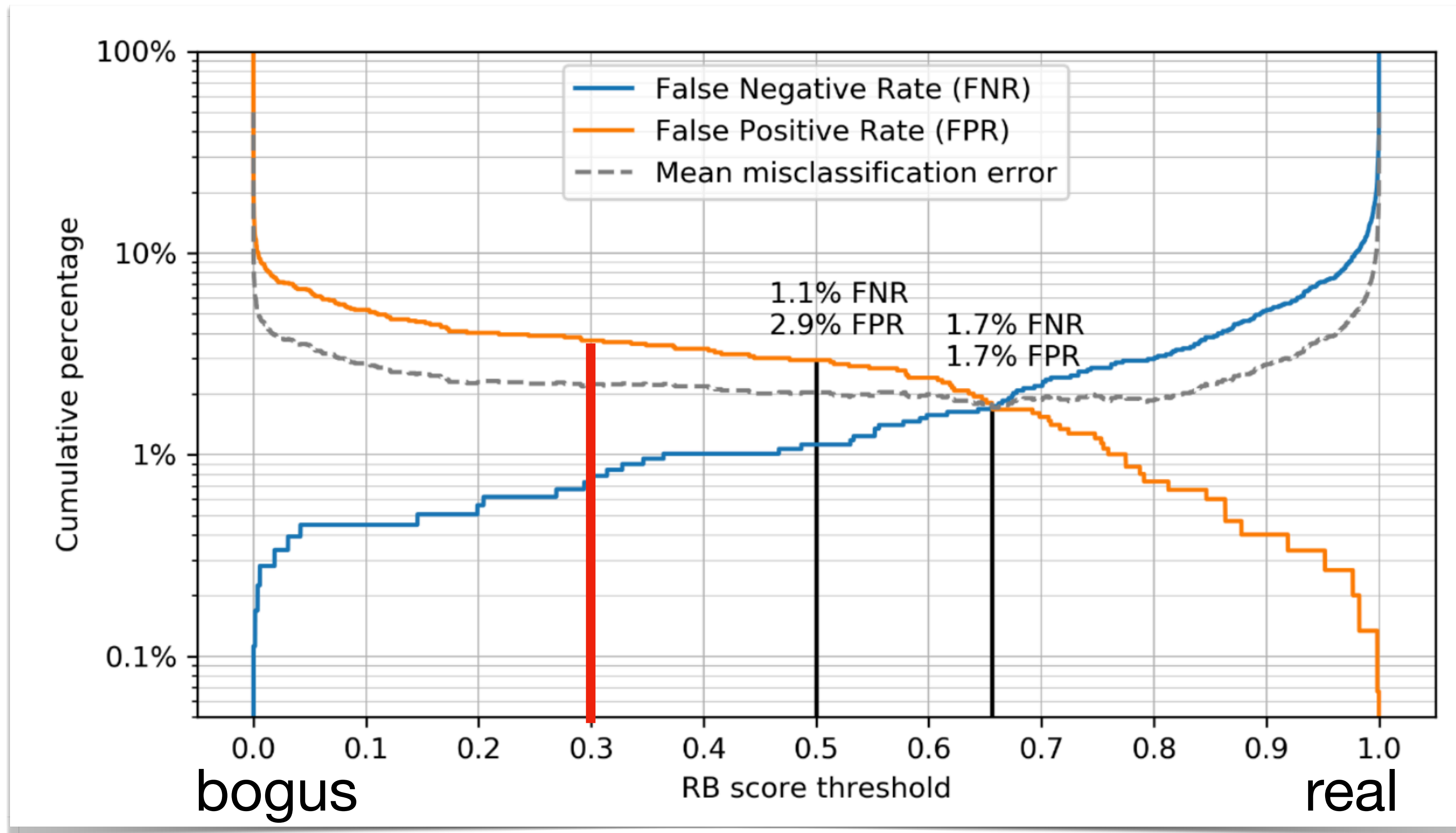


Gaia stars



Tachibana & Miller,
2018 (PASP)

rb distribution



0.7% FNR
4 % FPR

Duev et al., 2019
(MNRAS)