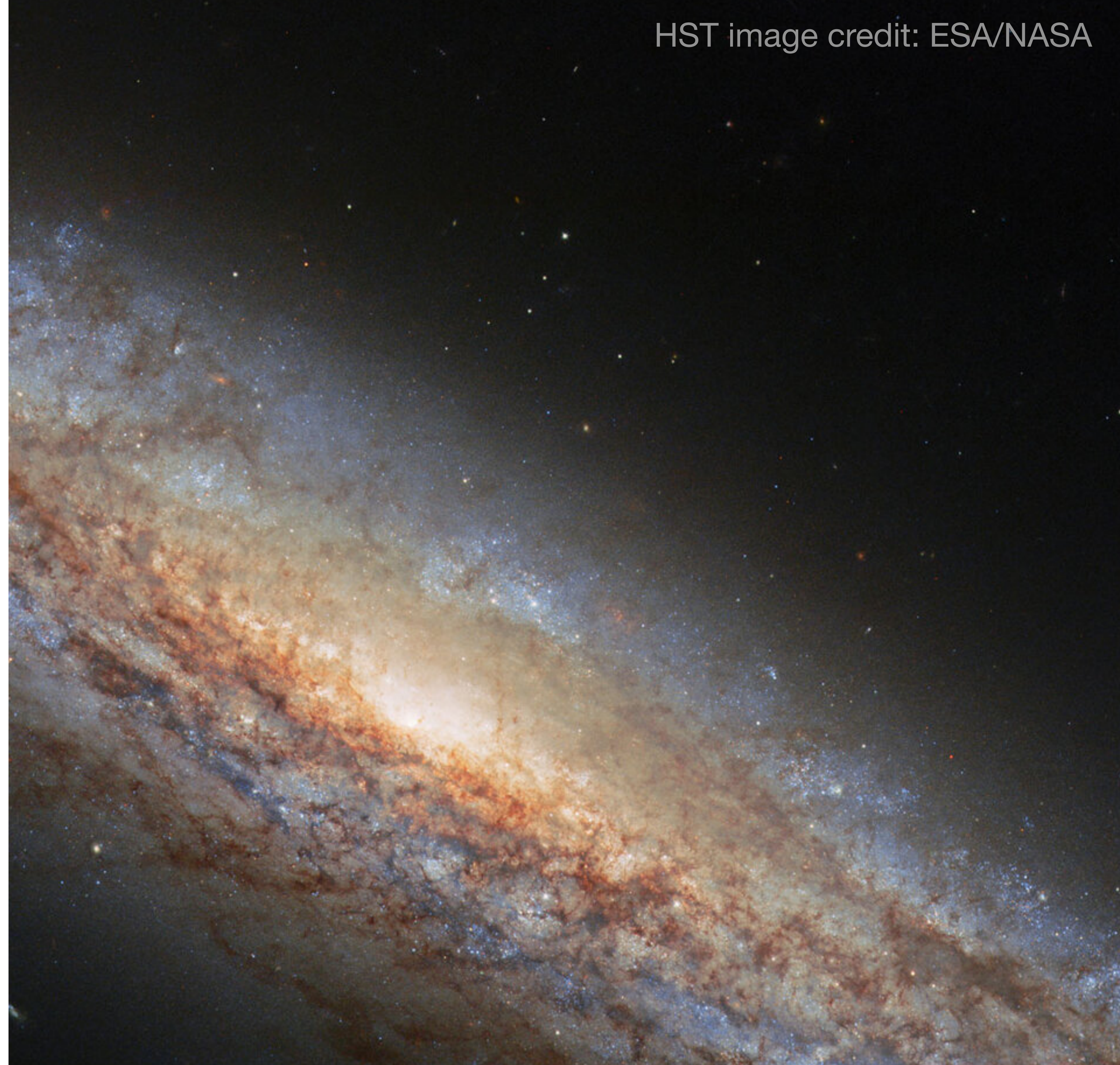


Nuclear Transients in ZTF

O4 Workshop
May 9, 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>



CrossMark

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

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29 more

van Velzen+ 2019

van Velzen+ 2021

THE ASTROPHYSICAL JOURNAL, 908:4 (26pp), 2021 February 10
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February 20

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

 CrossMark

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

<https://doi.org/10.3847/1538-4357/abc258>

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Nadejda Blagorodnova⁹, Igor Andreoni¹⁰, Eric C. Bellm¹¹, Valery Brinnel¹², Kishalay De¹⁰, Richard Dekany¹³,
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Anna. Y. Q. Ho¹⁰, Mansi M. Kasliwal¹⁰, Charles D. Kilpatrick⁴, Shrinivas R. Kulkarni¹⁰, Jakob Nordin¹², Reed Riddle¹³,
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91125, USA

29 more

van Velzen+ 2019
van Velzen+ 2021
Hammerstein+ 2021



A jetted TDE

Article

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

https://doi.org/10.1038/s41586-022-05465-8

Received: 5 April 2022

Accepted: 19 October 2022

Published online: 30 November 2022

Check for updates

THE ASTROPHYSICAL JOURNAL, 908:4 (2022)

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Igor Andreoni^{1,2,3,57,58}, Michael W. Coughlin^{4,57,58}, Daniel A. Perley⁵, Yuhan Yao⁶, Wenbin Lu⁷, S. Bradley Cenko^{1,3}, Harsh Kumar⁸, Shreya Anand⁶, Anna Y. Q. Ho^{9,10,11}, Mansi M. Kasliwal⁶, Antonio de Ugarte Postigo¹², Ana Sagués-Carracedo¹³, Steve Schulze¹³, D. Alexander Kann¹⁴, S. R. Kulkarni⁶, Jesper Sollerman¹⁵, Nial Tanvir¹⁶, Armin Rest^{17,18}, Luca Izzo¹⁹, Jean J. Somalwar⁶, David L. Kaplan²⁰, Tomás Ahumada², G. C. Anupama²¹, Katie Auchett^{22,23,24}, Sudhanshu Barway²¹, Eric C. Bellm²⁵, Varun Bhalerao⁸, Joshua S. Bloom^{9,10}, Michael Bremer²⁶, Mattia Bulla¹⁵, Eric Burns²⁷, Sergio Campana²⁸, Poonam Chandra²⁹, Panos Charalampopoulos³⁰, Jeff Cooke^{31,32}, Valerio D'Elia³³, Poonam Chandra²⁹, Panos Charalampopoulos³⁰, Jeff Cooke^{31,32}, Valerio D'Elia³³, Kaustav Kashyap Das⁶, Dougal Dobie^{31,32}, José Feliciano Agüi Fernández¹⁴, James Freeburn^{31,32}, Cristoffer Fremling⁶, Suvi Gezari¹⁷, Simon Goode^{31,32}, Matthew J. Graham⁶, Erica Hammerstein², Viraj R. Karambelkar⁶, Charles D. Kilpatrick³⁴, Erik C. Kool¹⁶, Melanie Krips²⁶, Russ R. Laher³⁵, Giorgos Leloudas³⁰, Andrew Levan³⁶, Michael J. Lundquist³⁷, Ashish A. Mahabal^{6,38}, Michael S. Medford^{9,10}, M. Coleman Miller^{1,2}, Anais Möller^{31,32}, Kunal P. Mooley⁶, A. J. Nayana³⁹, Guy Nir⁹, Peter T. H. Pang^{40,41}, Emmy Paraskeva^{42,43,44,45}, Richard A. Perley⁴⁶, Glen Petitpas⁴⁷, Miika Pursiainen³⁰, Vikram Ravi⁶, Ryan Ridden-Harper⁴⁸, Reed Riddle⁴⁹, Mickael Rigault⁵⁰, Antonio C. Rodriguez⁶, Ben Rusholme³⁵, Yashvi Sharma⁶, I. A. Smith⁵¹, Robert D. Stein⁶, Christina Thöne⁵², Aaron Tohuvavohu⁵³, Frank Valdes⁵⁴, Jan van Roestel⁶, Susanna D. Vergani^{55,56}, Qinan Wang¹⁷ & Jielai Zhang^{31,32}

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

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

https://doi.org/10.3847/1538-4357/aca283

CrossMark

art van Velzen⁴, Suvi Gezari⁵, S. Bradley Cenko^{2,6}, Yuhan Yao⁷, Charlotte Ward^{1,21}, Lia Villanueva⁹, Jean J. Somalwar⁷, Matthew J. Graham⁷, Shrinivas R. Kulkarni⁷, Pradipt Gatkine⁷, Eric C. Bellm¹¹, Richard Dekany¹², Suhail Dhawan¹³, Andrew J. Drake⁷, Kool¹⁶, Frank J. Masci¹⁴, Michael S. Medford^{17,18}, Daniel A. Perley¹⁹, Mansi M. Kasliwal⁷, Yashvi Sharma⁷, Jesper Sollerman¹⁶, Kirsty Taggart²⁰, and Lin Yan¹²

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2022 February 25; revised 2022 October 13; accepted 2022 October 14; published 2022 December 28

Abstract

Tidal disruption events (TDEs) offer a unique way to study dormant black holes. While the number of observed events 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

van Velzen+ 2019
van Velzen+ 2021
Hammerstein+ 2021
Andreoni+ 2022

O4 Workshop | Nuclear Transients in ZTF | Simeon Reusch | 9 May 2023 1/13

An extremely energetic TDE



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

Possible EM counterparts to BH-BH mergers

Article

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

Received: 5 April 2022
Accepted: 19 October 2022
Published online: 30 November 2022

Check for updates

THE ASTROPHYSICAL JOURNAL, 942:99 (19pp), 2023 January 10
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OPEN ACCESS

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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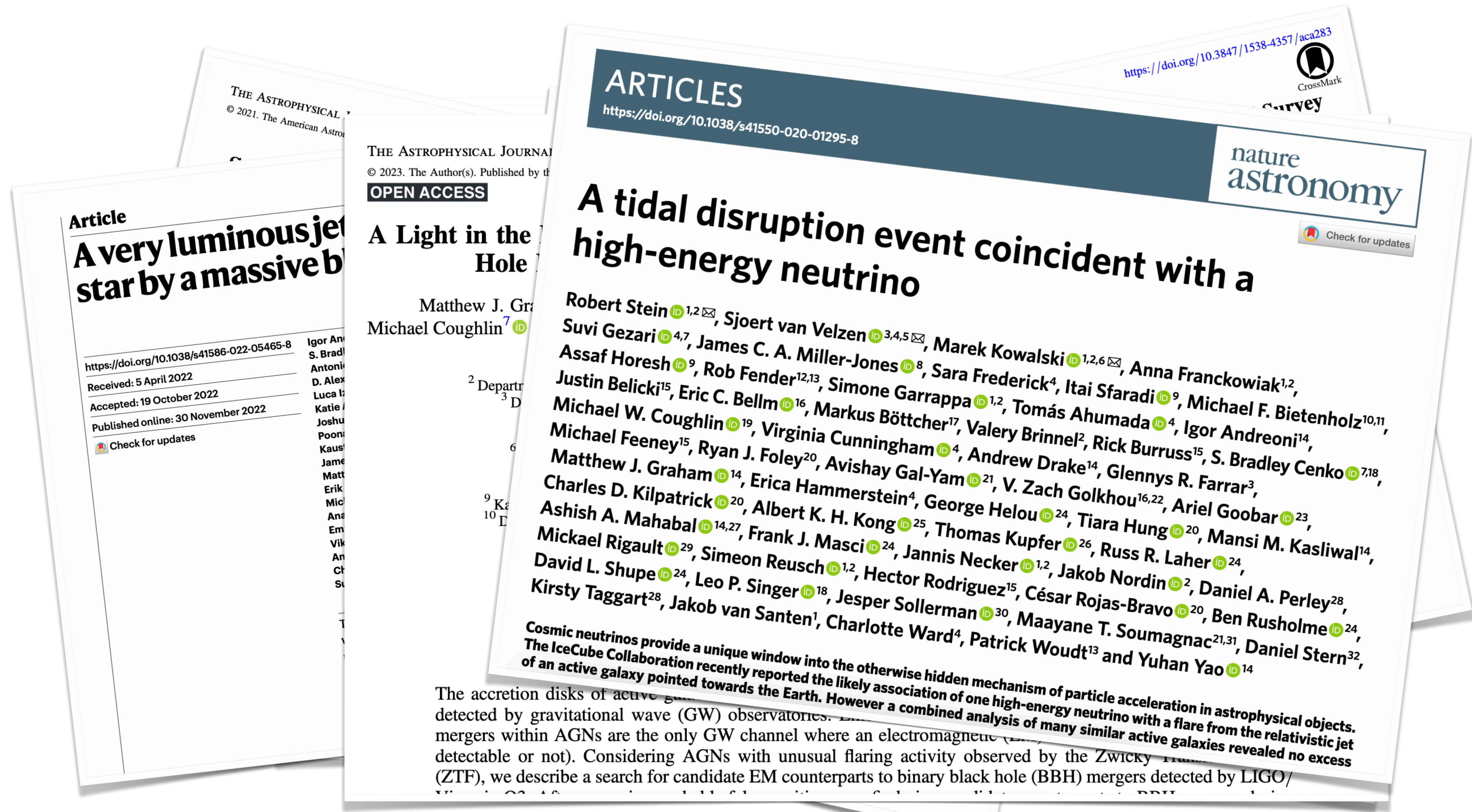
Received 2022 September 23; revised 2022 November 15; accepted 2022 November 19; published 2023 January 17

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



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

Three neutrino-associated TDE candidates

Article

A very luminous star by a massive black hole

<https://doi.org/10.1038/s41586-022-022-0>

Received: 5 April 2022

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THE ASTROPHYSICAL JOURNAL

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ARTICLES

<https://doi.org/10.3847/1538-4357/aca283>

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Survey

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. Kasliwal¹⁰, 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

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

nature astronomy

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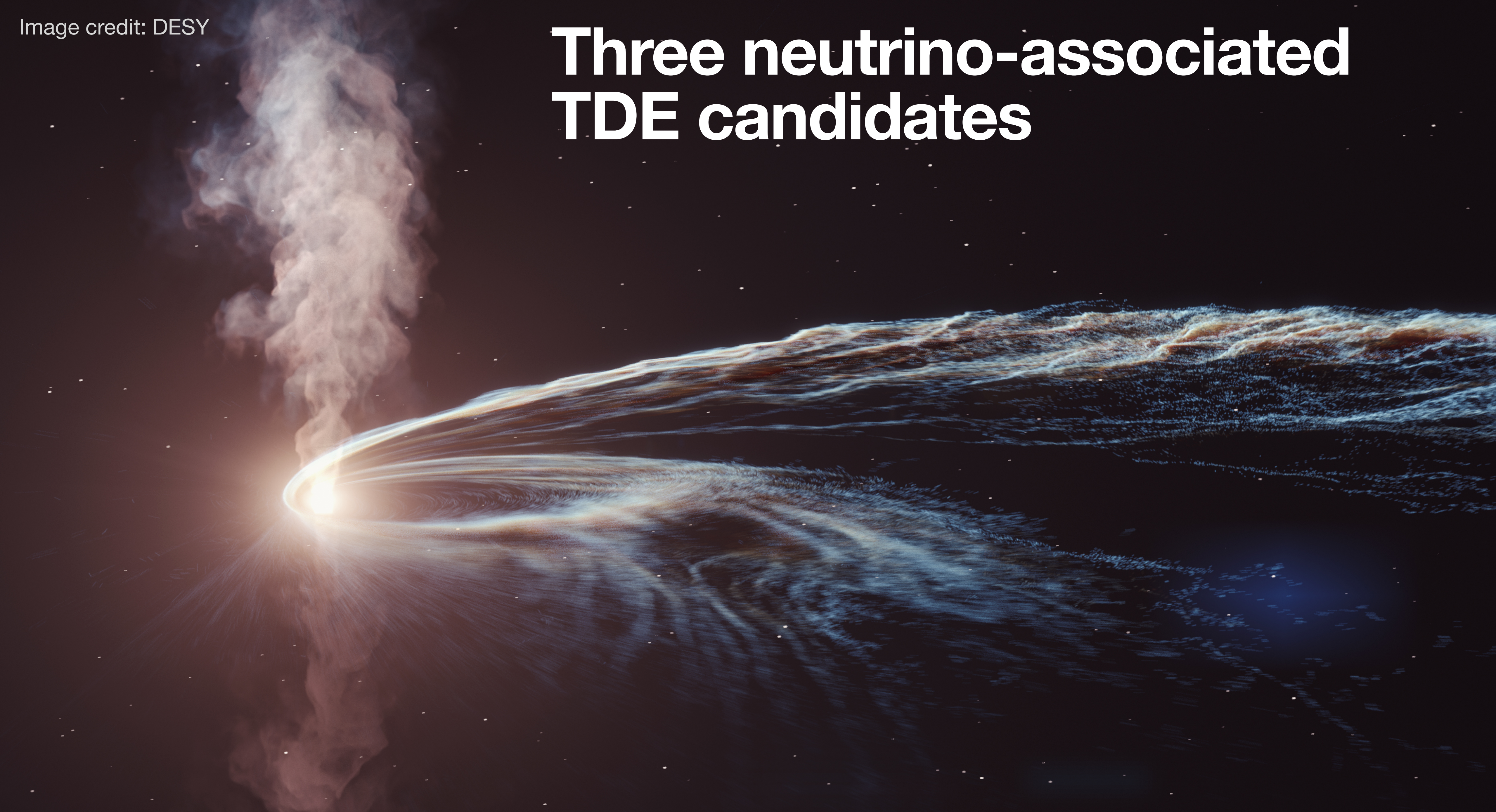
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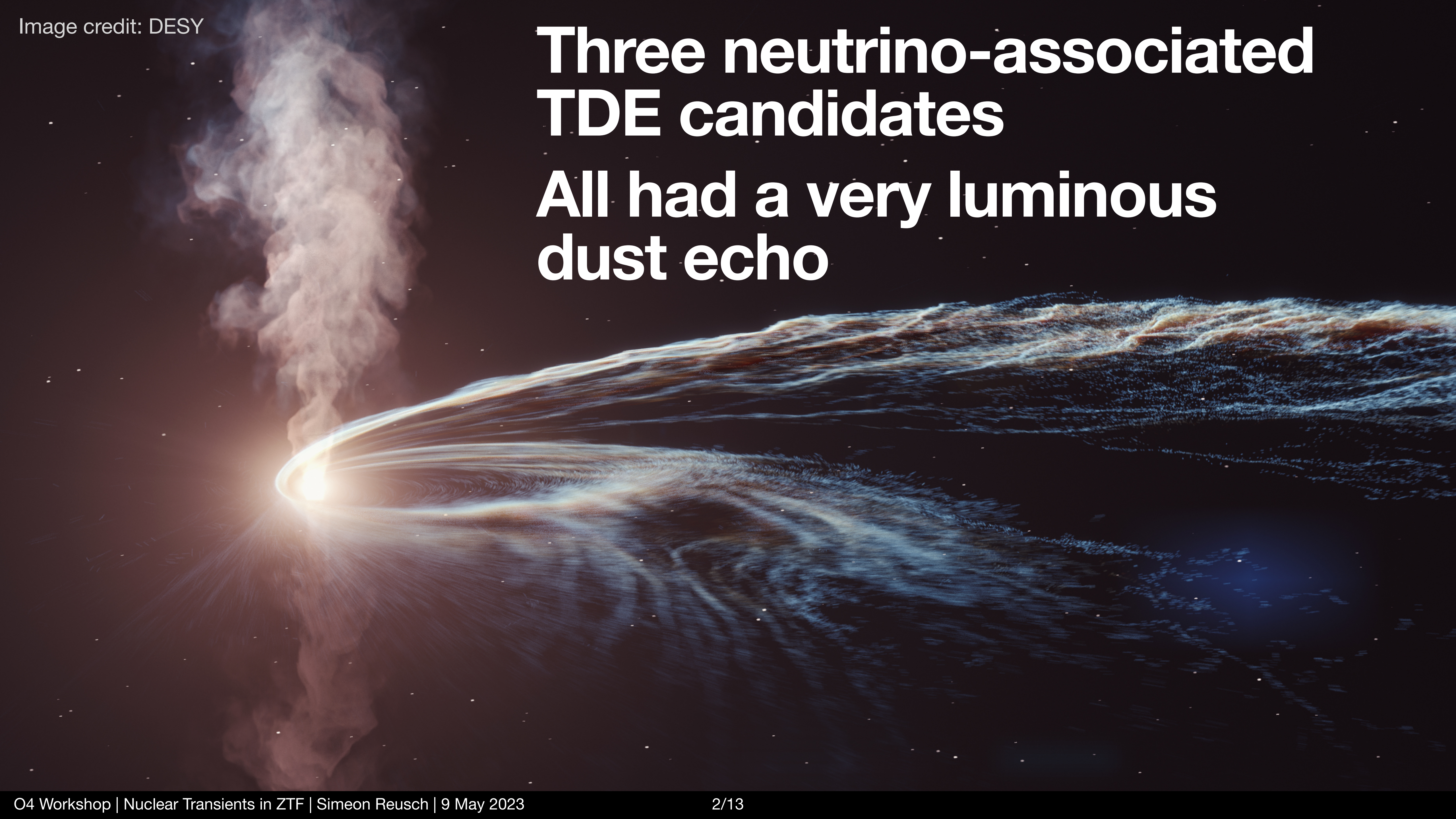
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- Andreoni+ 2022
- Subrayan+ 2023
- Graham+ 2023
- Stein+ 2021
- Reusch+ 2022

Three neutrino-associated TDE candidates



Three neutrino-associated TDE candidates

All had a very luminous
dust echo



Three neutrino-associated TDE candidates

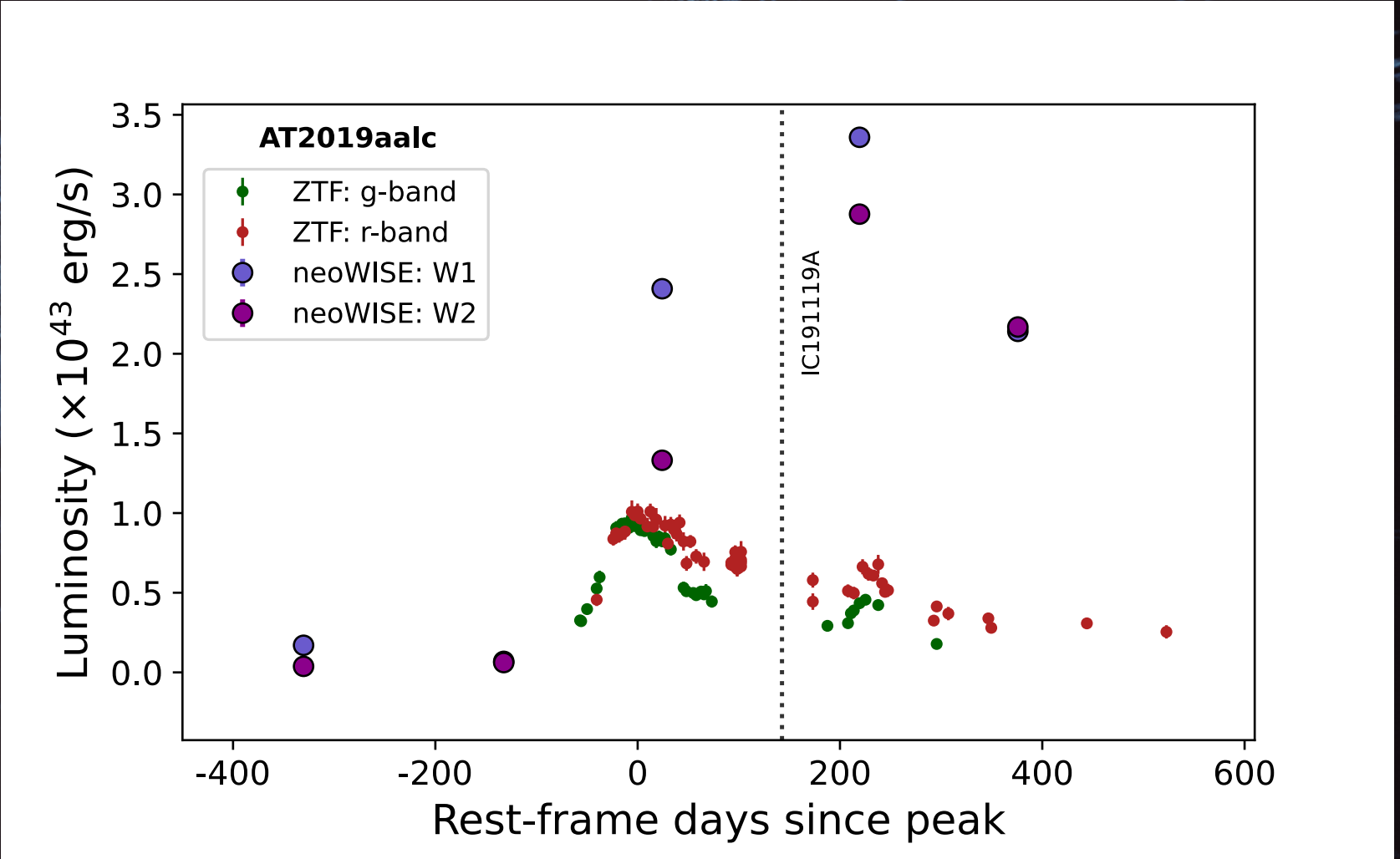
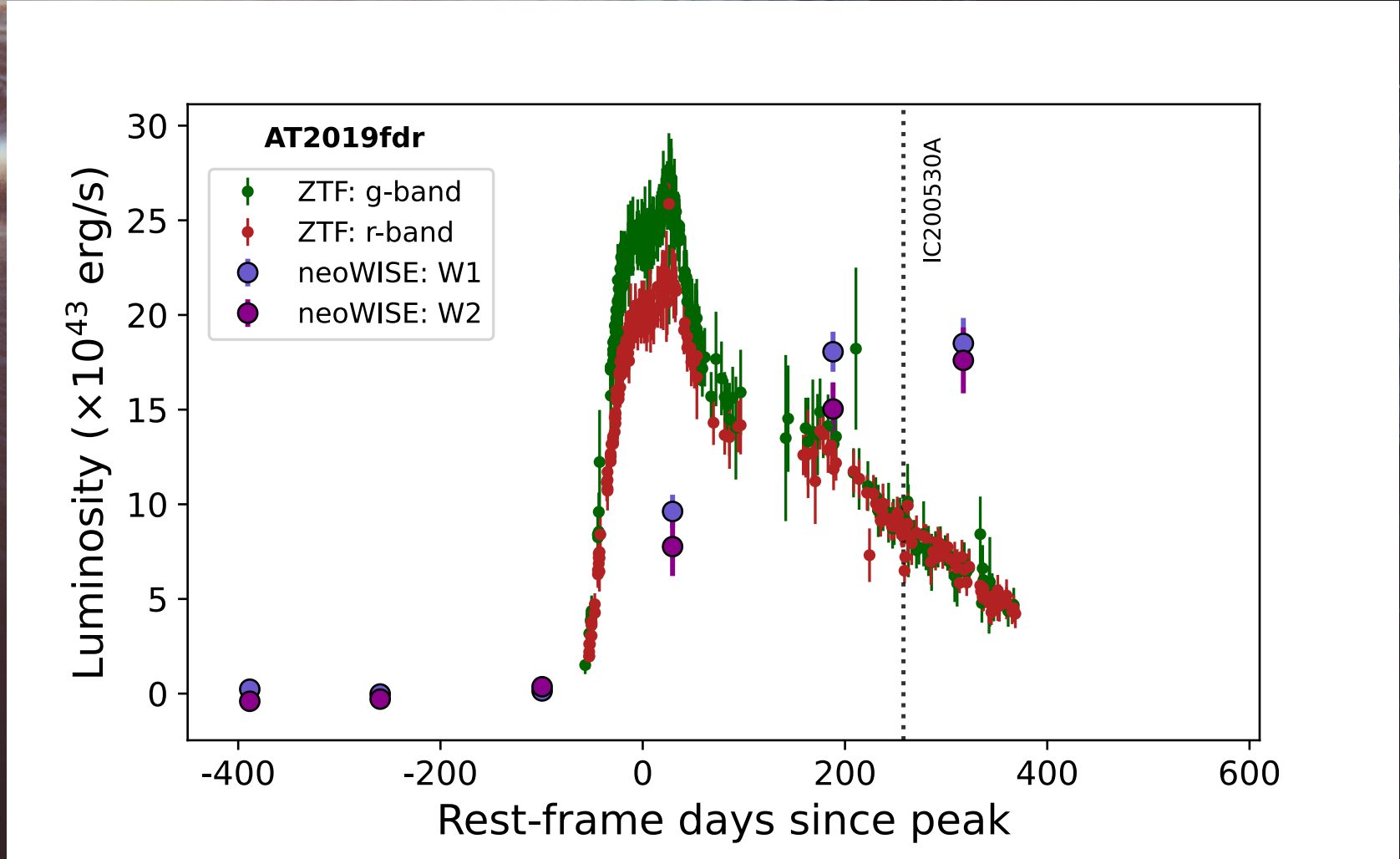
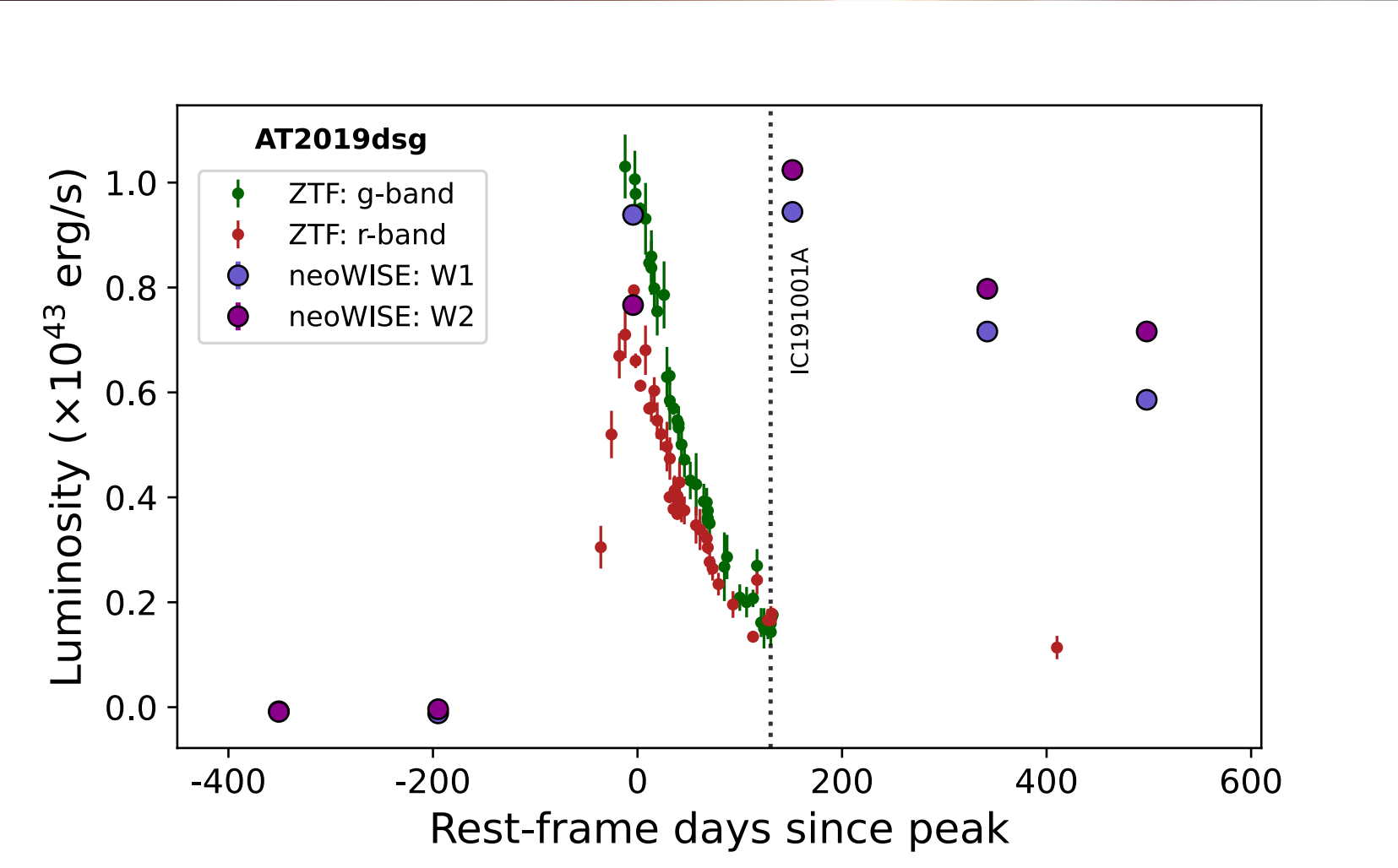
All had a very luminous
dust echo

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)

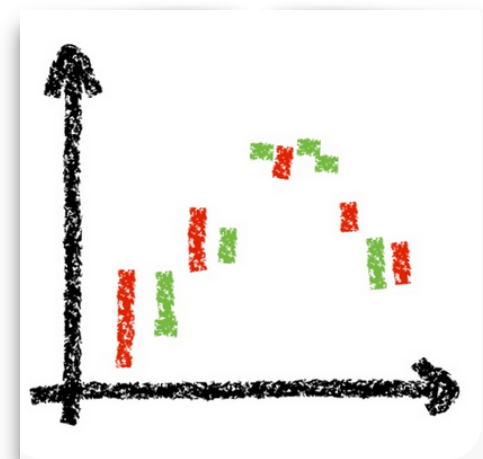
Filtered by **host distance**, **PS1 star-galaxy score**, max. **brightness** and number of **detections**

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

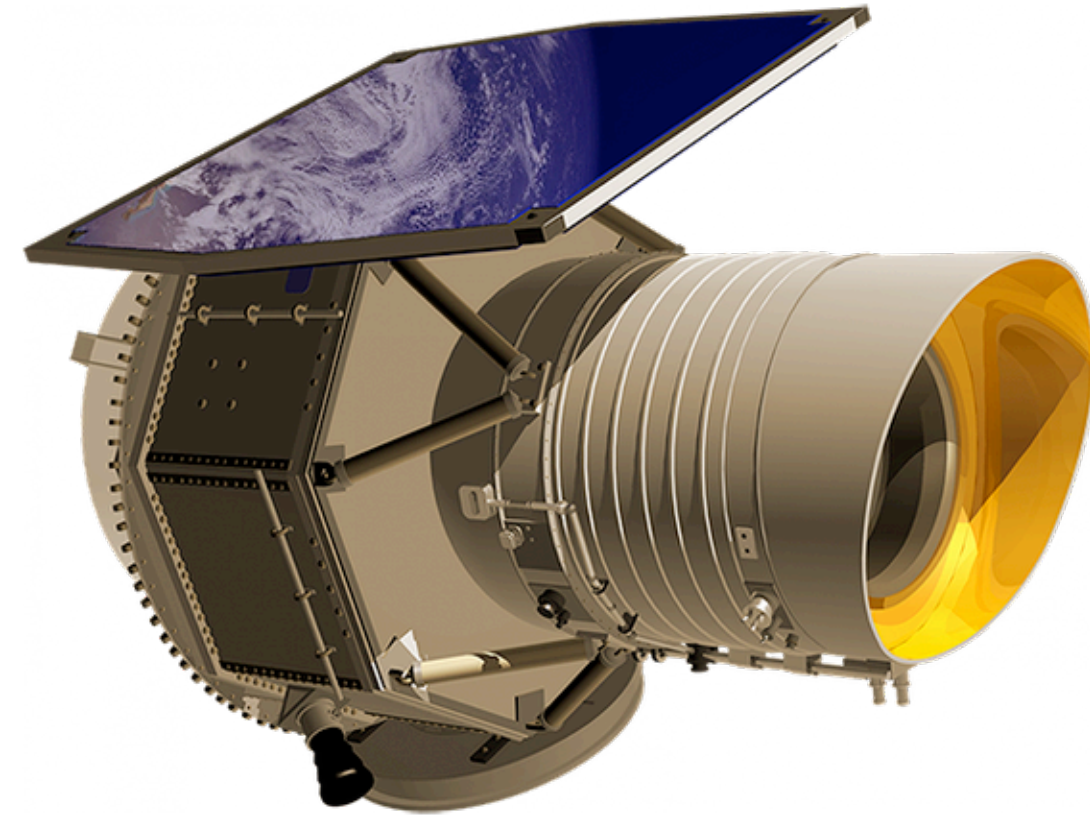


Image credit: NASA

Crossmatch with WISE IR

Vast majority
has a WISE
counterpart

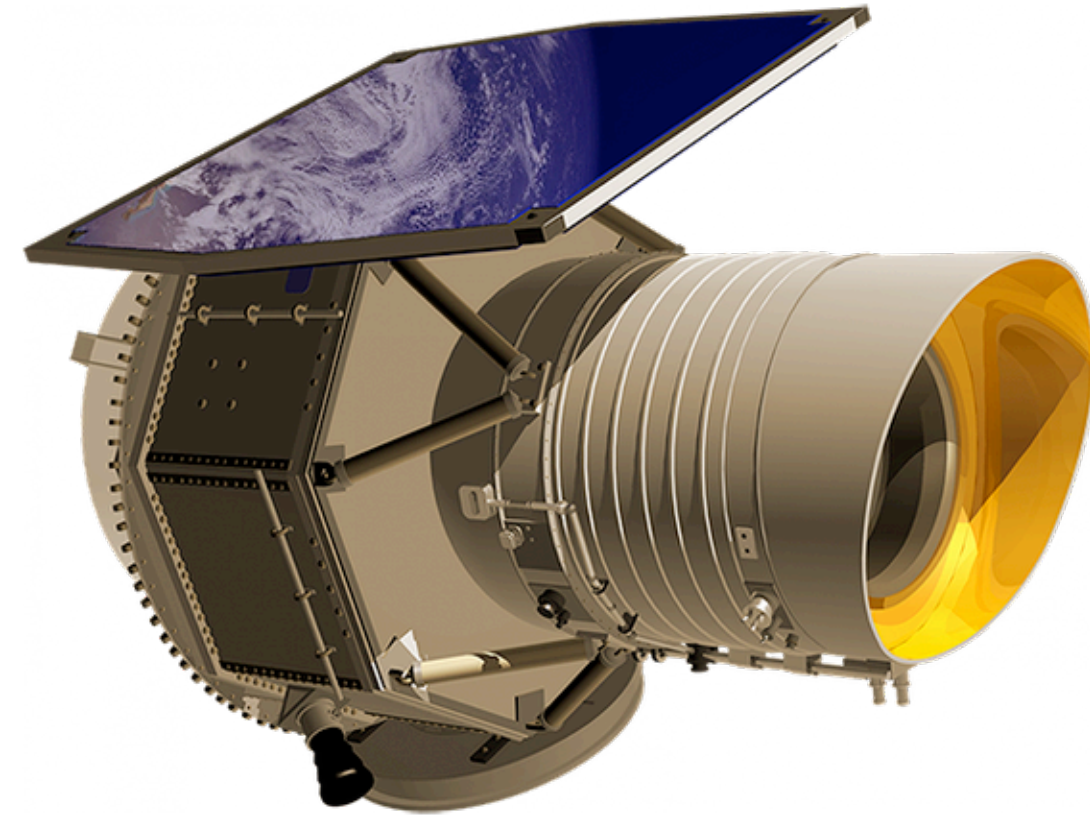
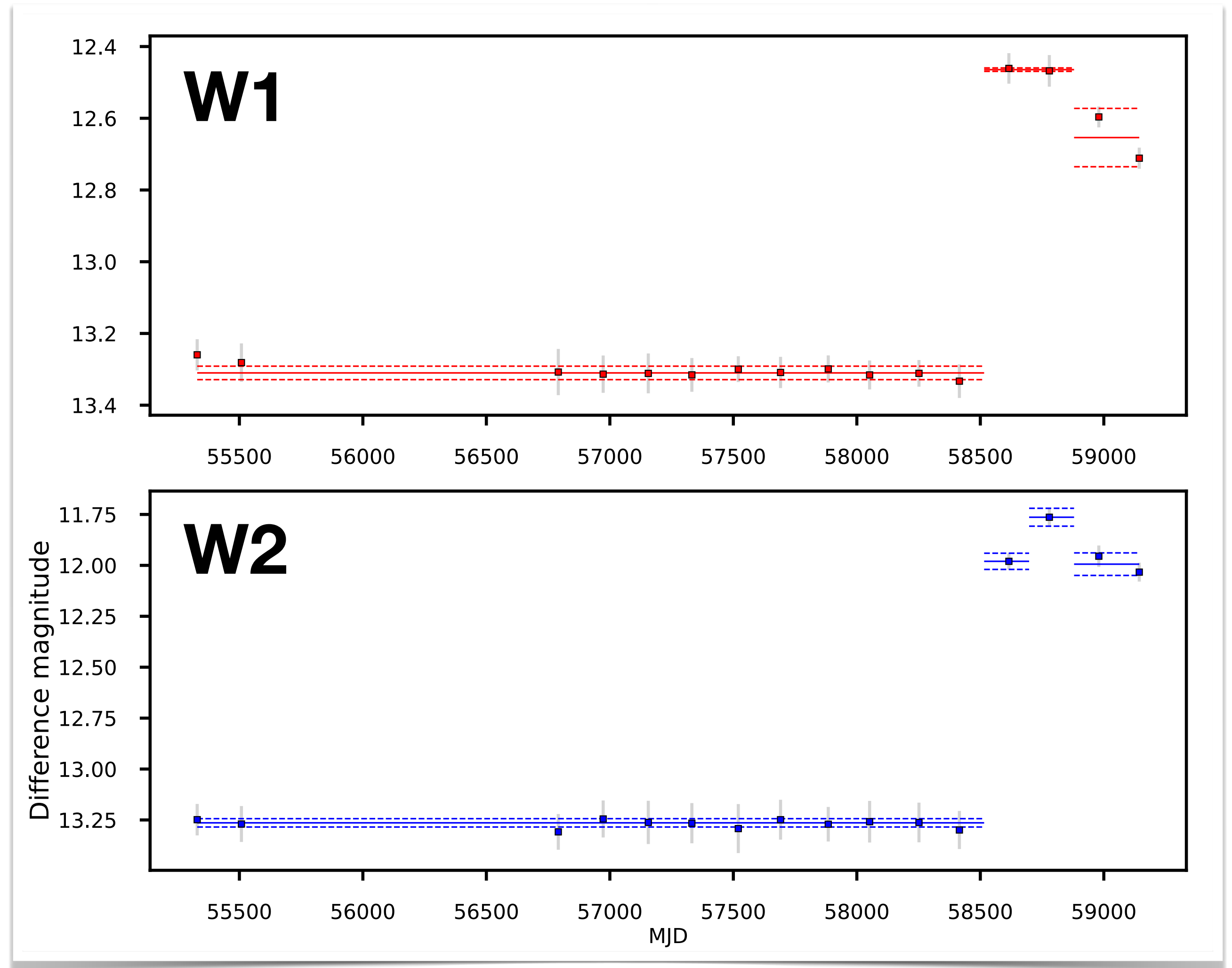


Image credit: NASA

Analyzed with a
Bayesian block framework to
find flares



Crossmatch with WISE IR

Vast majority
has a WISE
counterpart

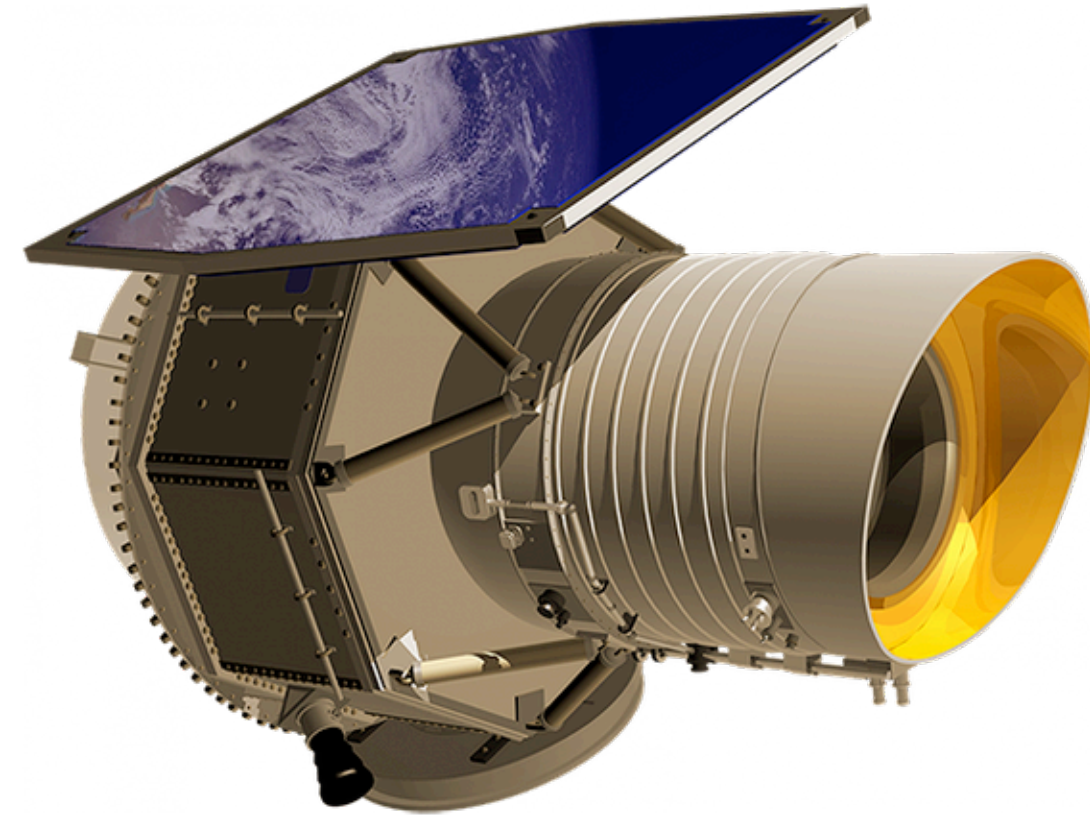
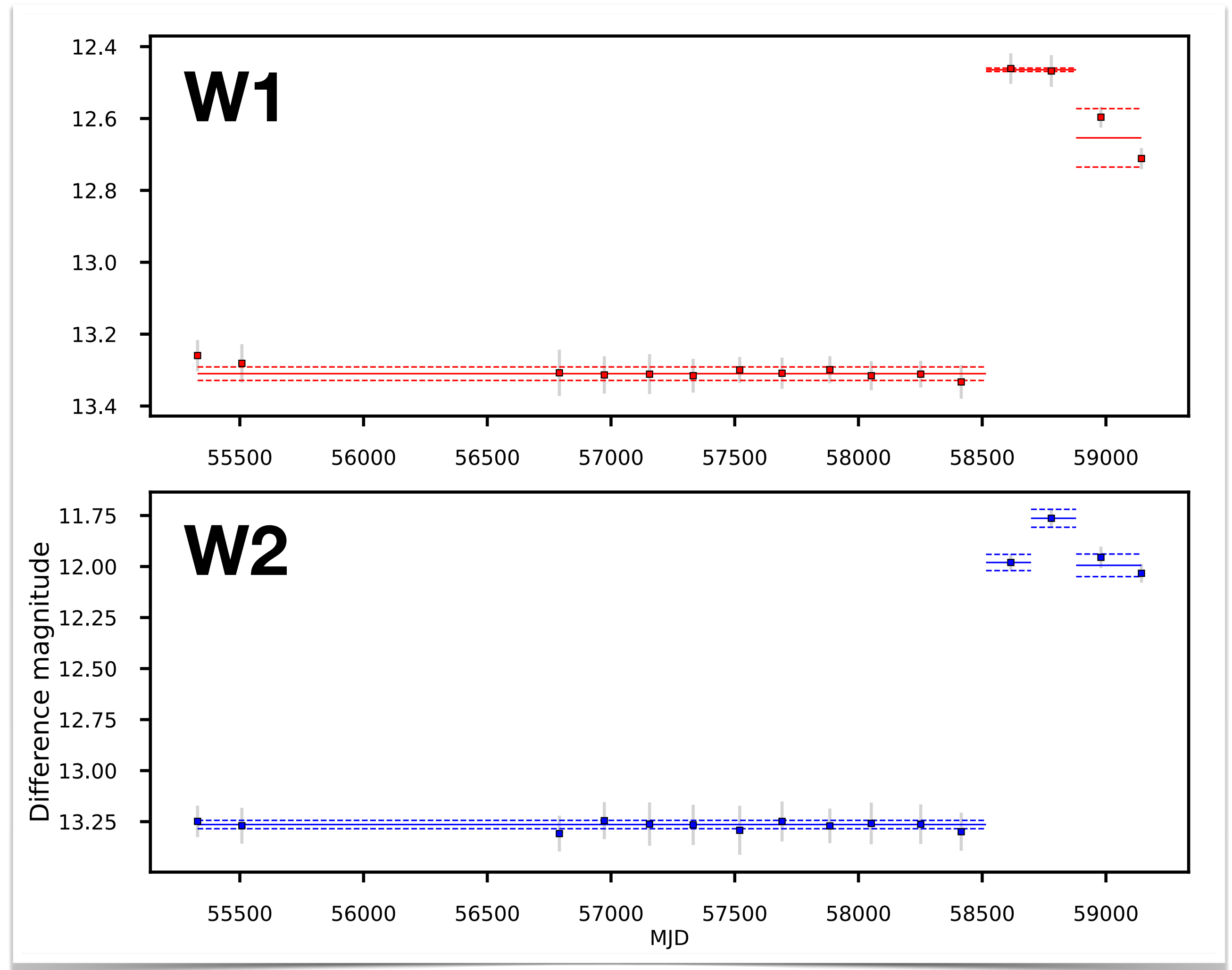


Image credit: NASA

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 Bright Transient Survey

see Dan
Perley's talk

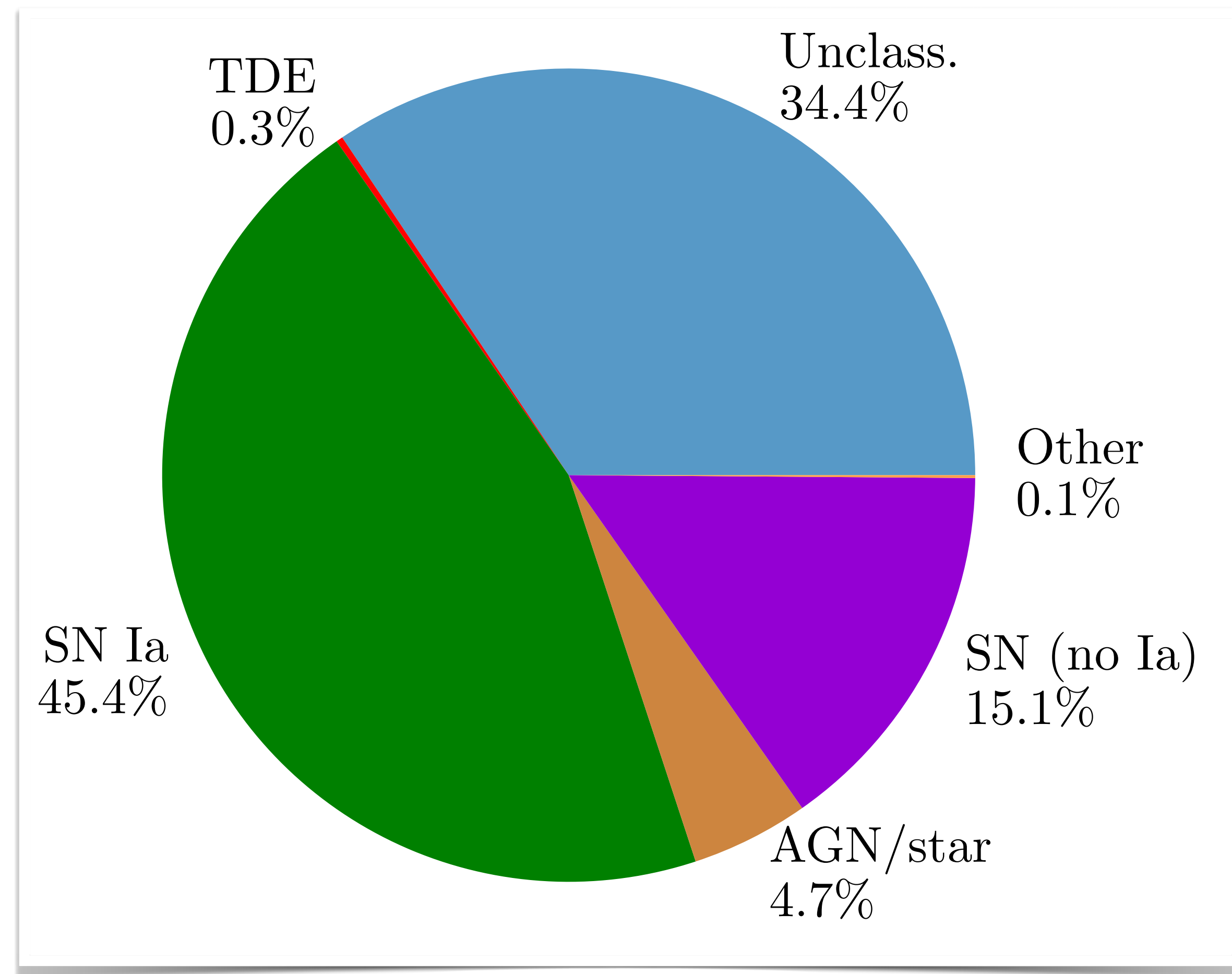
7284 ZTF transients

Trained BDT classifier with noisified lightcurves from Bright Transient Survey

see Dan
Perley's talk

7284 ZTF transients

5315 of them classified
(brighter than 18.5 mag)



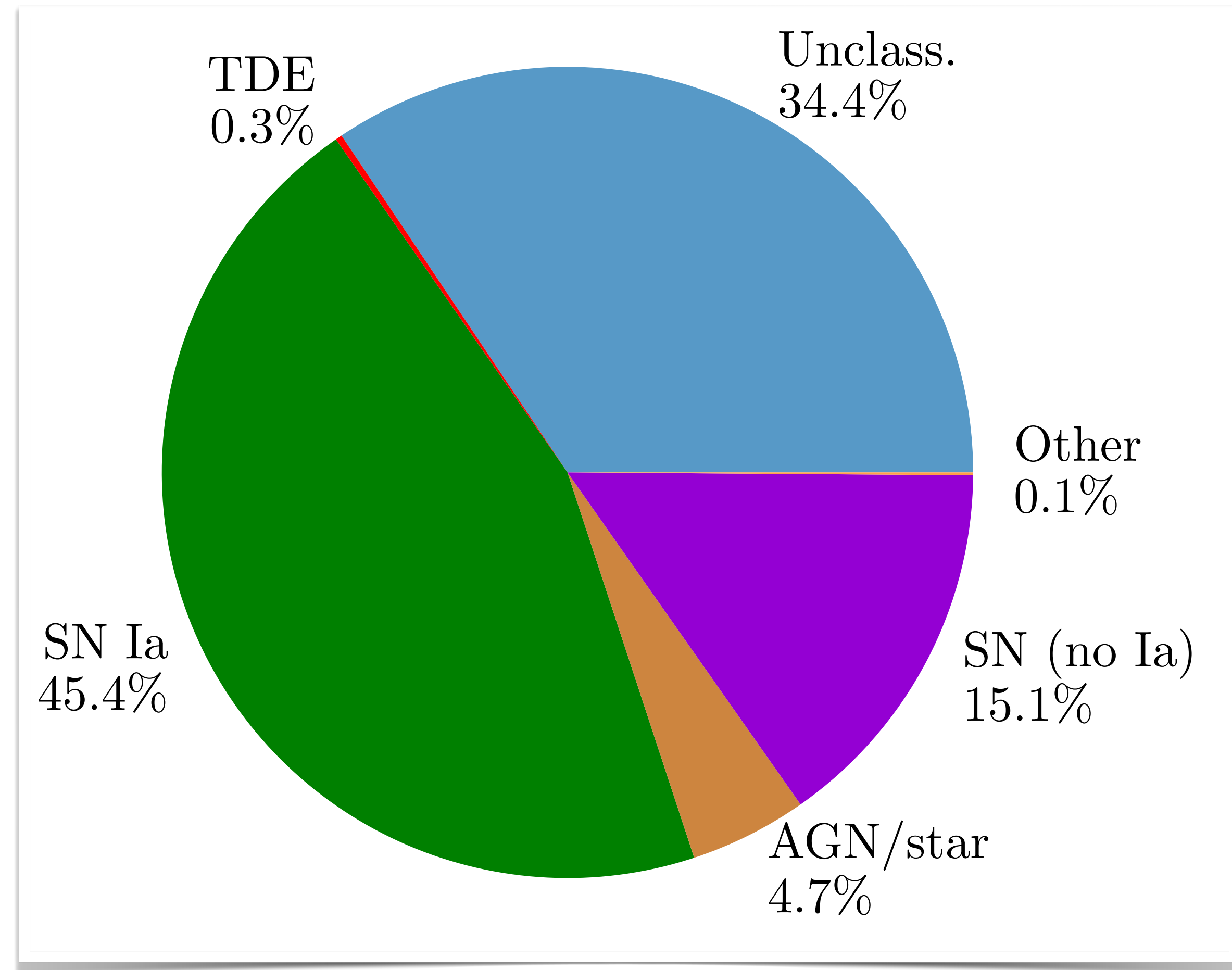
Trained BDT classifier with noisified lightcurves from Bright Transient Survey

see Dan
Perley's talk

7284 ZTF transients

5315 of them classified
(brighter than 18.5 mag)

Problem: Brighter than
nuclear selection, high
class imbalance



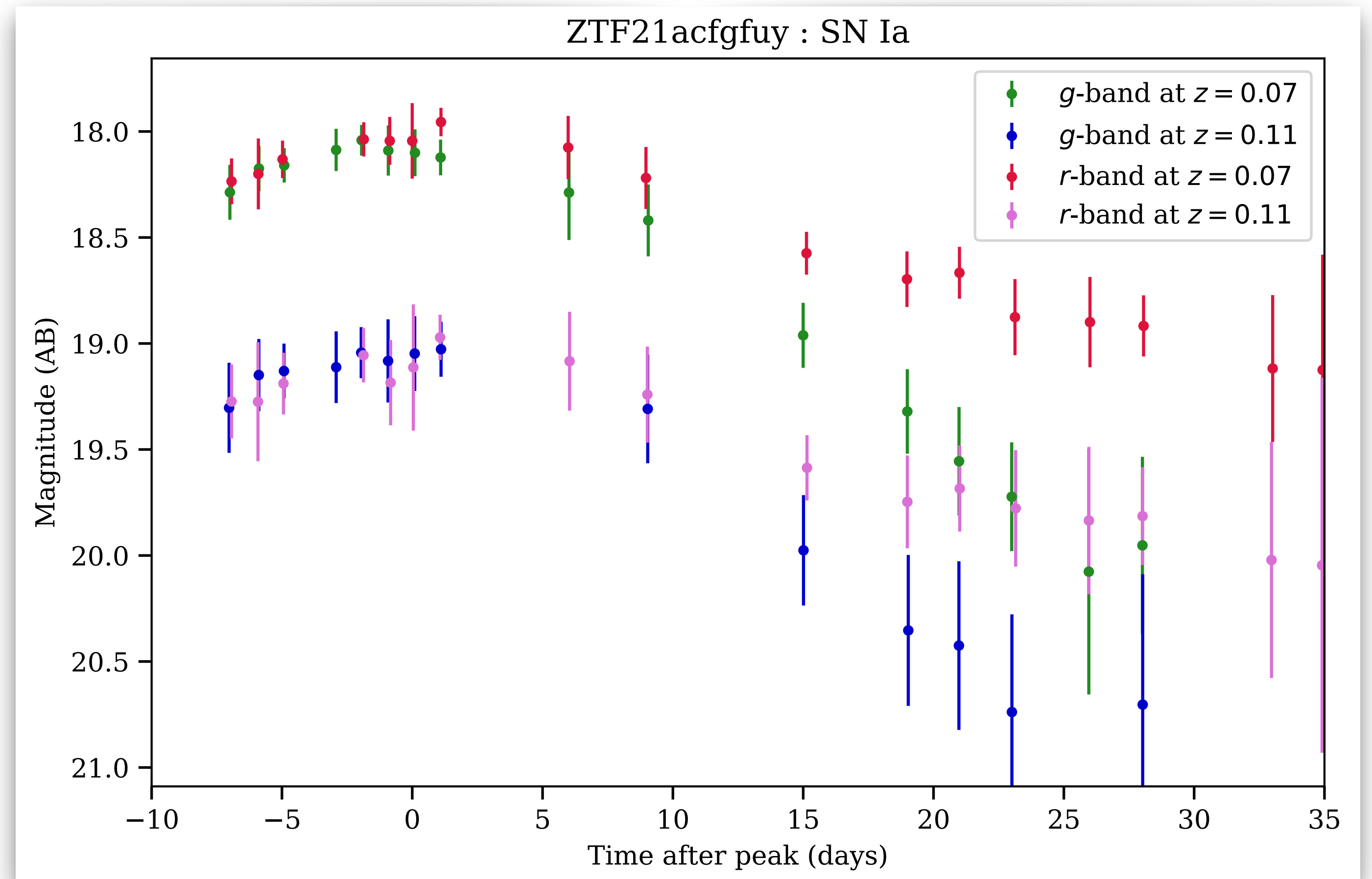
Trained BDT classifier with noisified lightcurves from the Bright Transient Survey

Noisification: Physically motivated remedy

Trained BDT classifier with noisified lightcurves from the Bright Transient Survey

Noisification: Physically motivated remedy

- redshift
- noisify
- K-correct

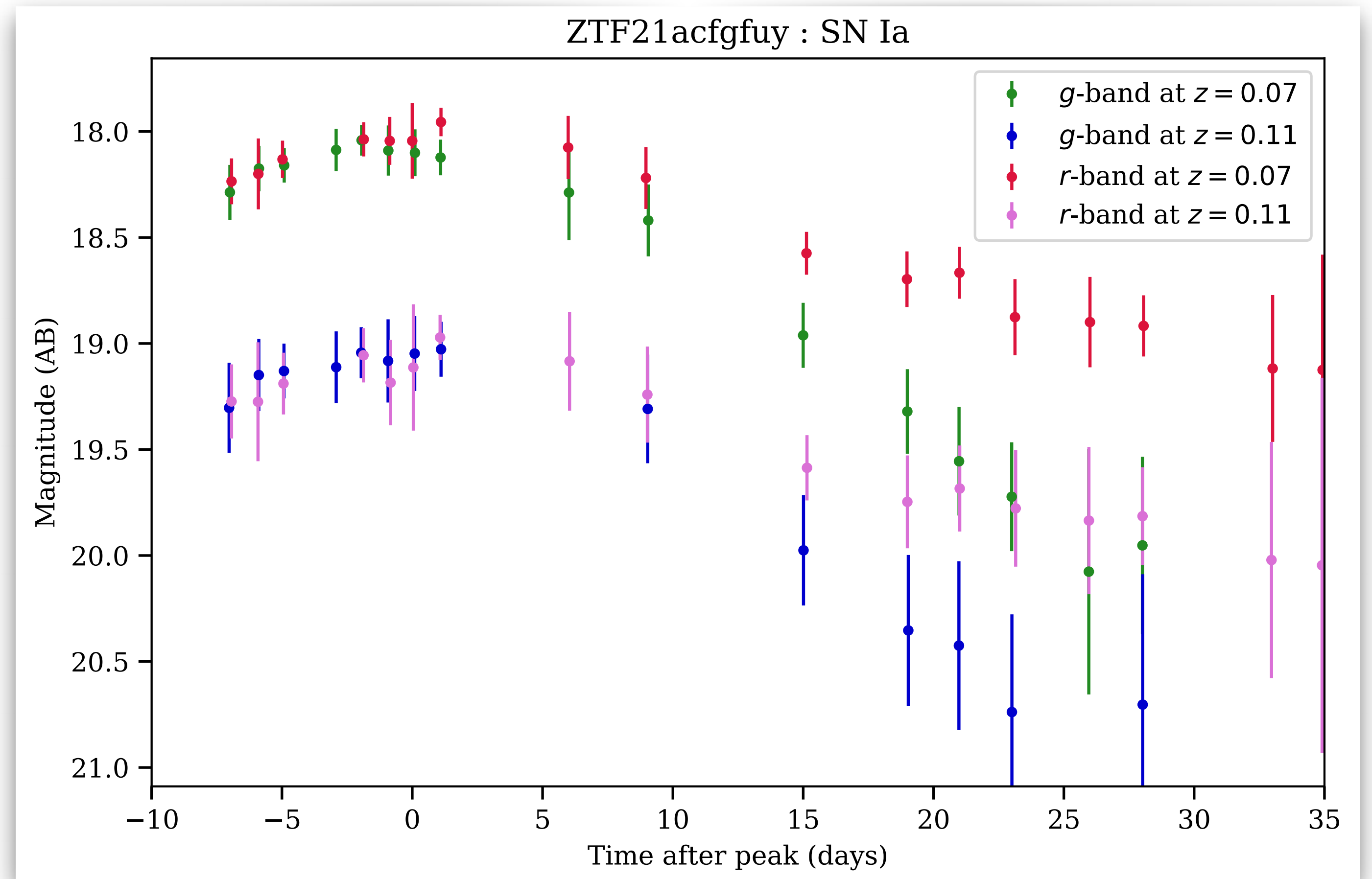


Trained BDT classifier with noisified lightcurves from the Bright Transient Survey

Noisification: Physically motivated remedy

- redshift
- noisify
- K-correct

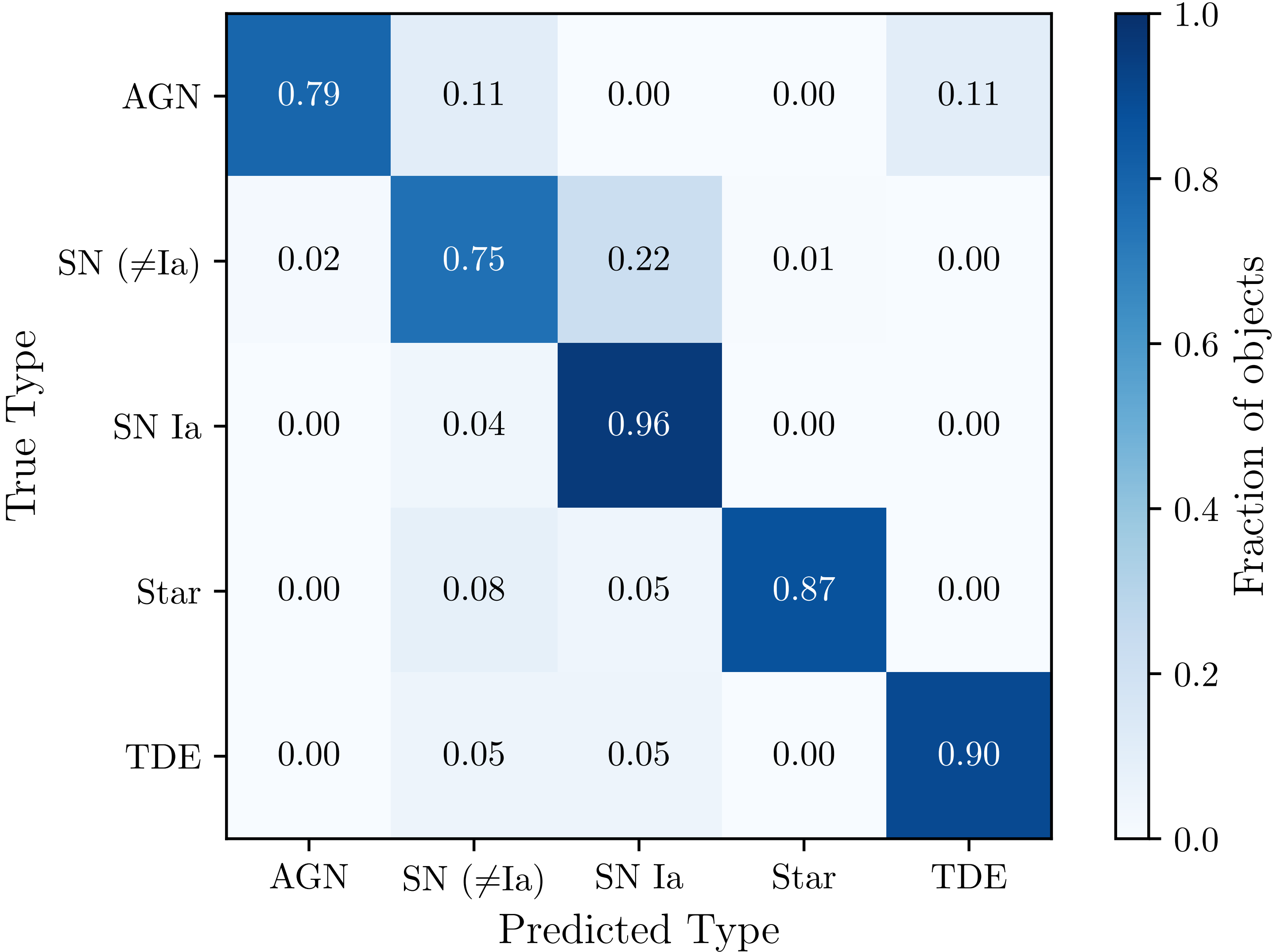
Feature extraction,
currently only based
on optical data



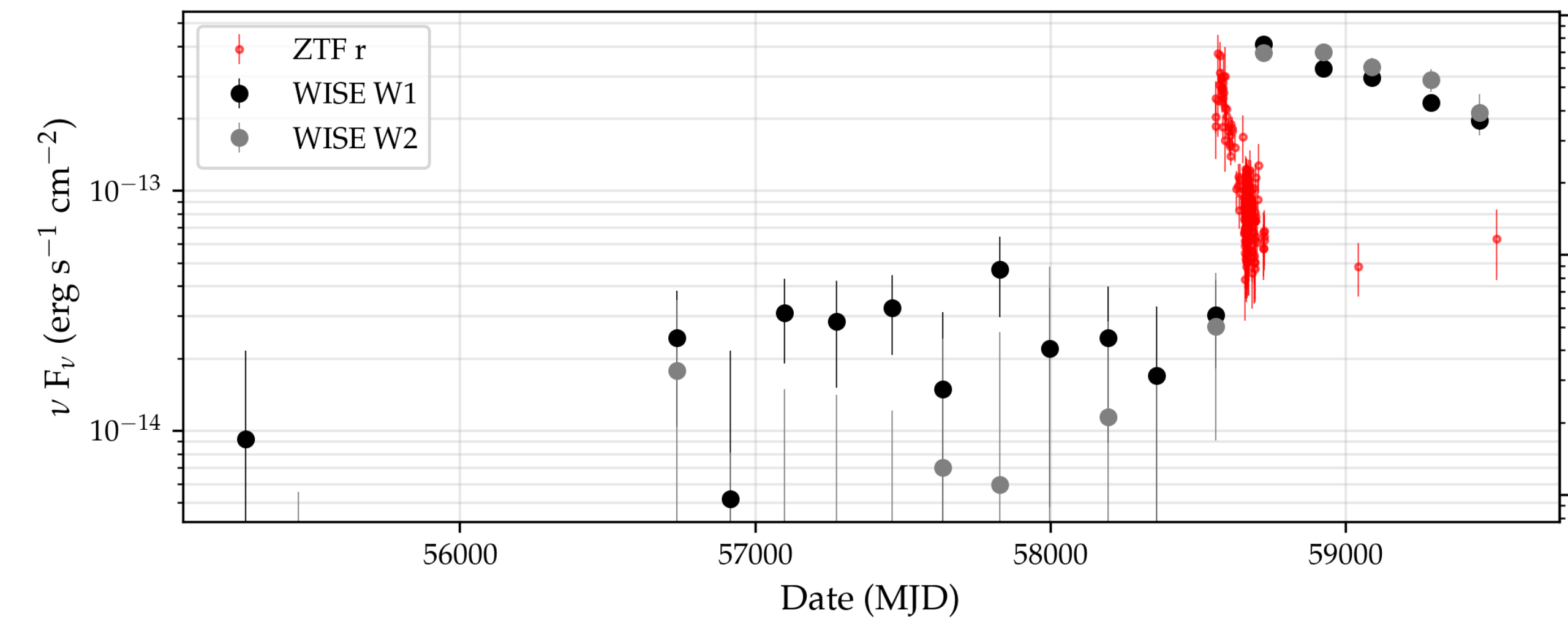
Evaluation with test sample

preliminary

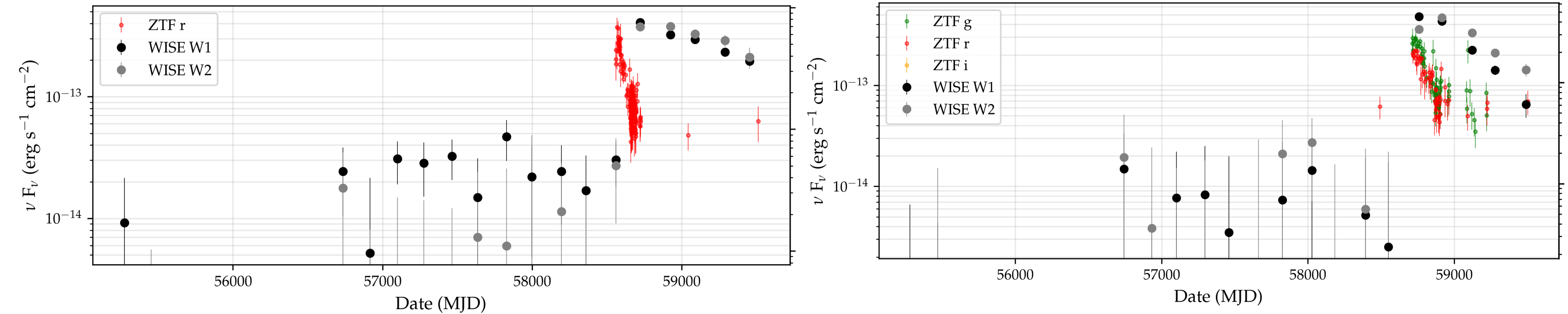
Not including noisified
lightcurves in the test
sample



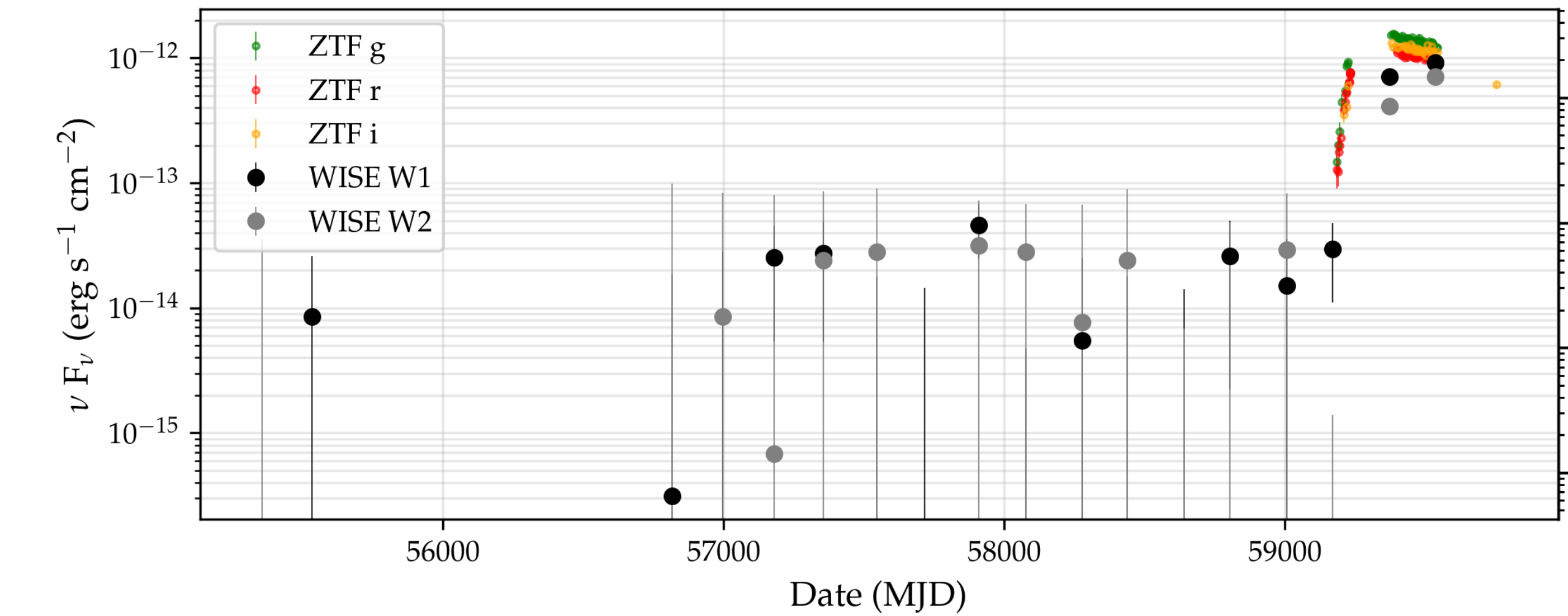
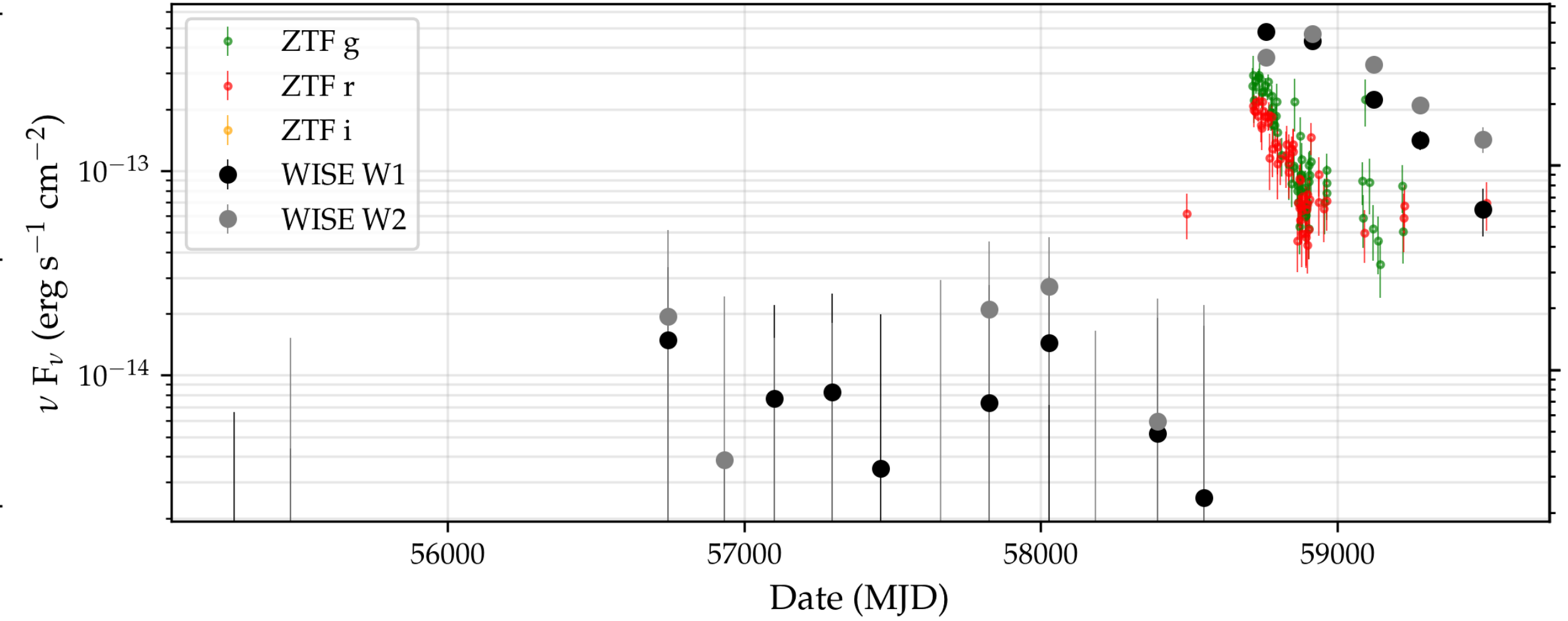
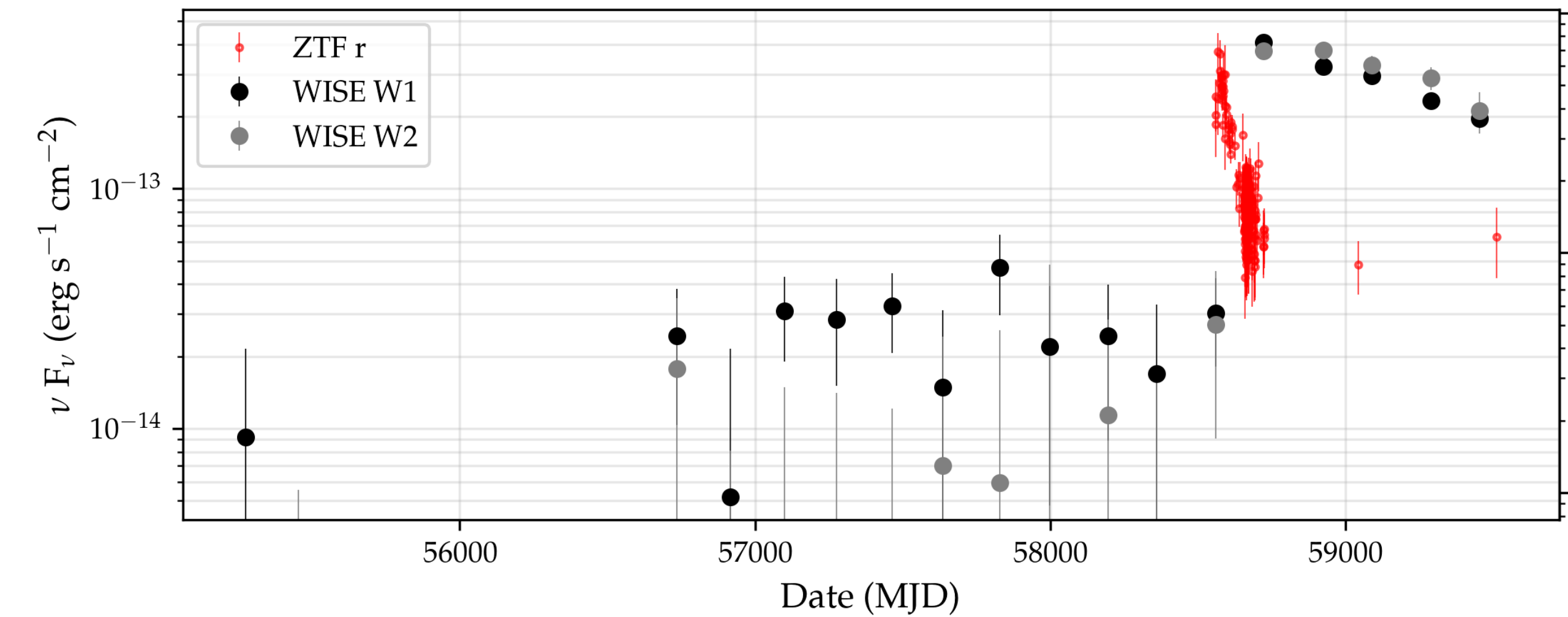
Identified some strong TDE candidates previously missed



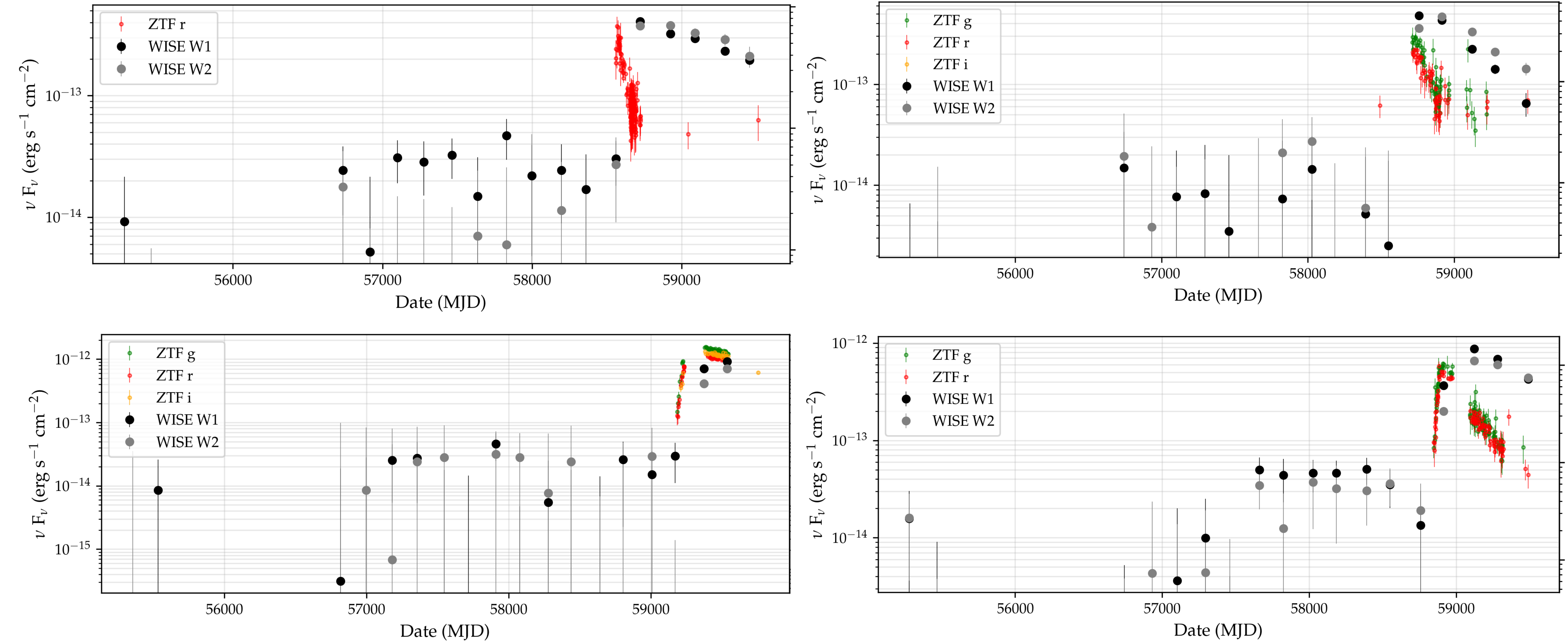
Identified some strong TDE candidates previously missed



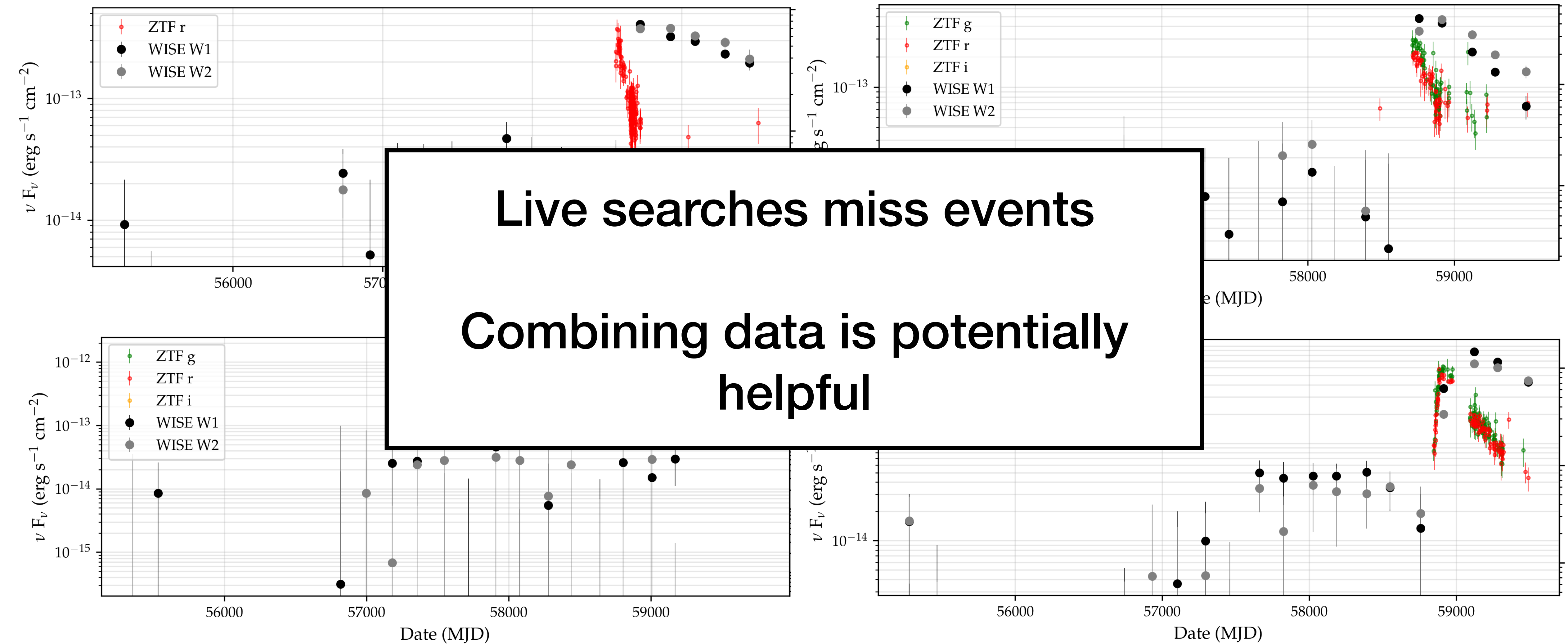
Identified some strong TDE candidates previously missed



Identified some strong TDE candidates previously missed



Identified some strong TDE candidates previously missed



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

What can we learn from such a sample?

Photometric identification is still a challenge!

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

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!)

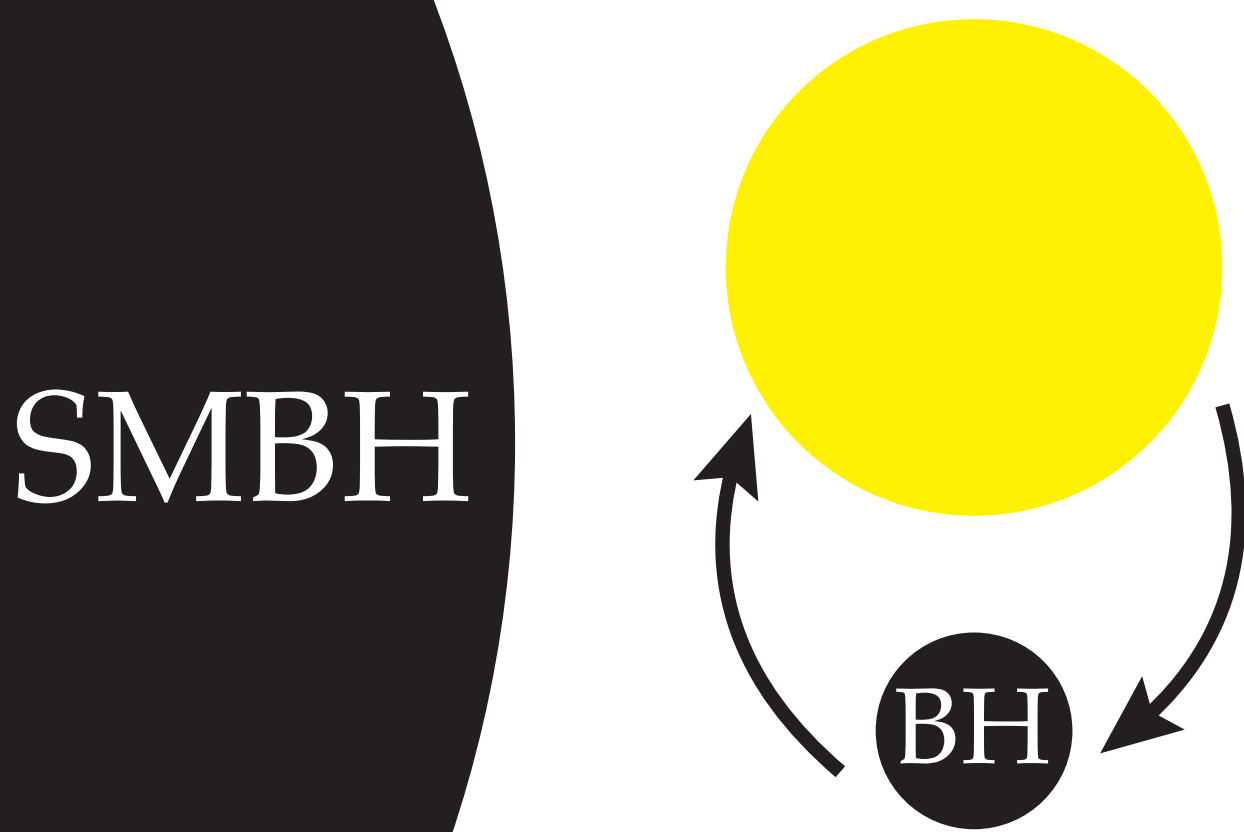
[See Matthew Graham's talk](#)

Example: What about micro-TDEs?

Y. Yang+ 2022

Example: What about micro-TDEs?

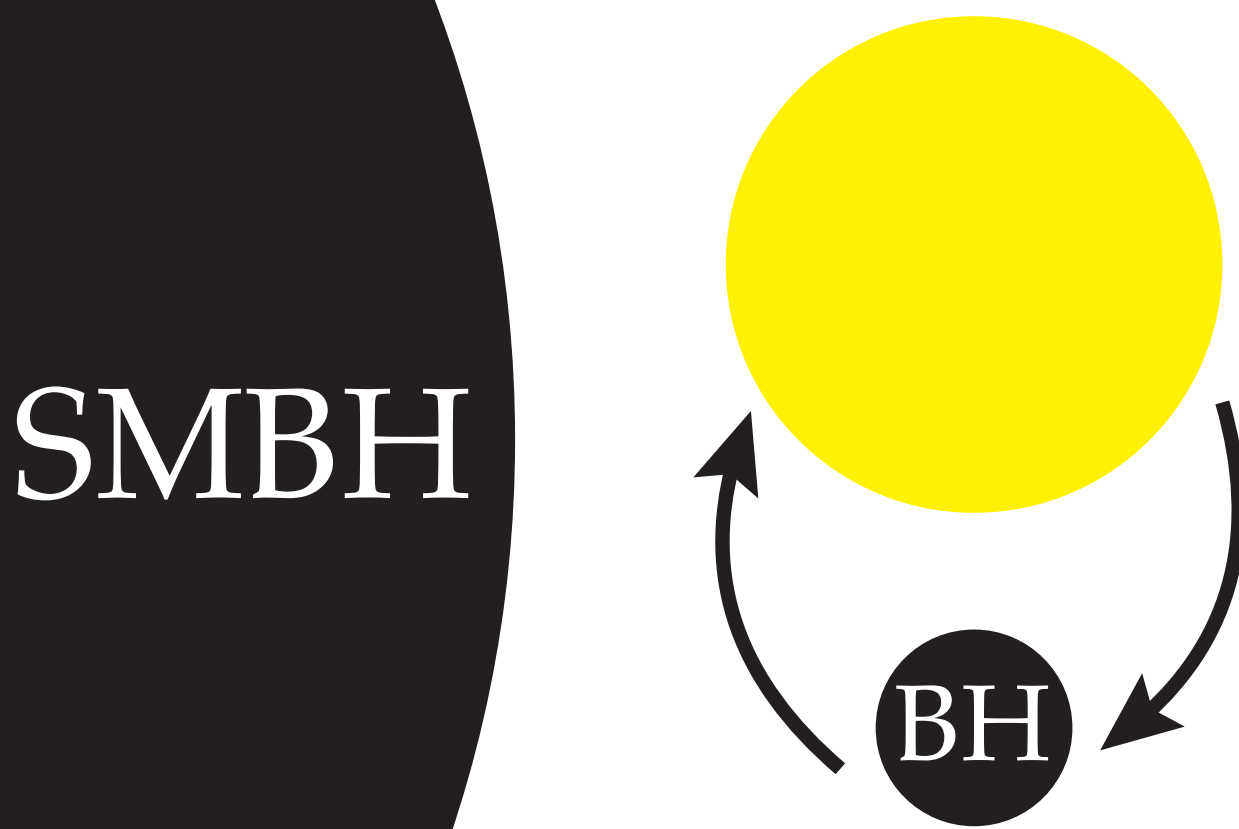
stellar mass BH tidally disrupting a star



Y. Yang+ 2022

Example: What about micro-TDEs?

stellar mass BH tidally disrupting a star

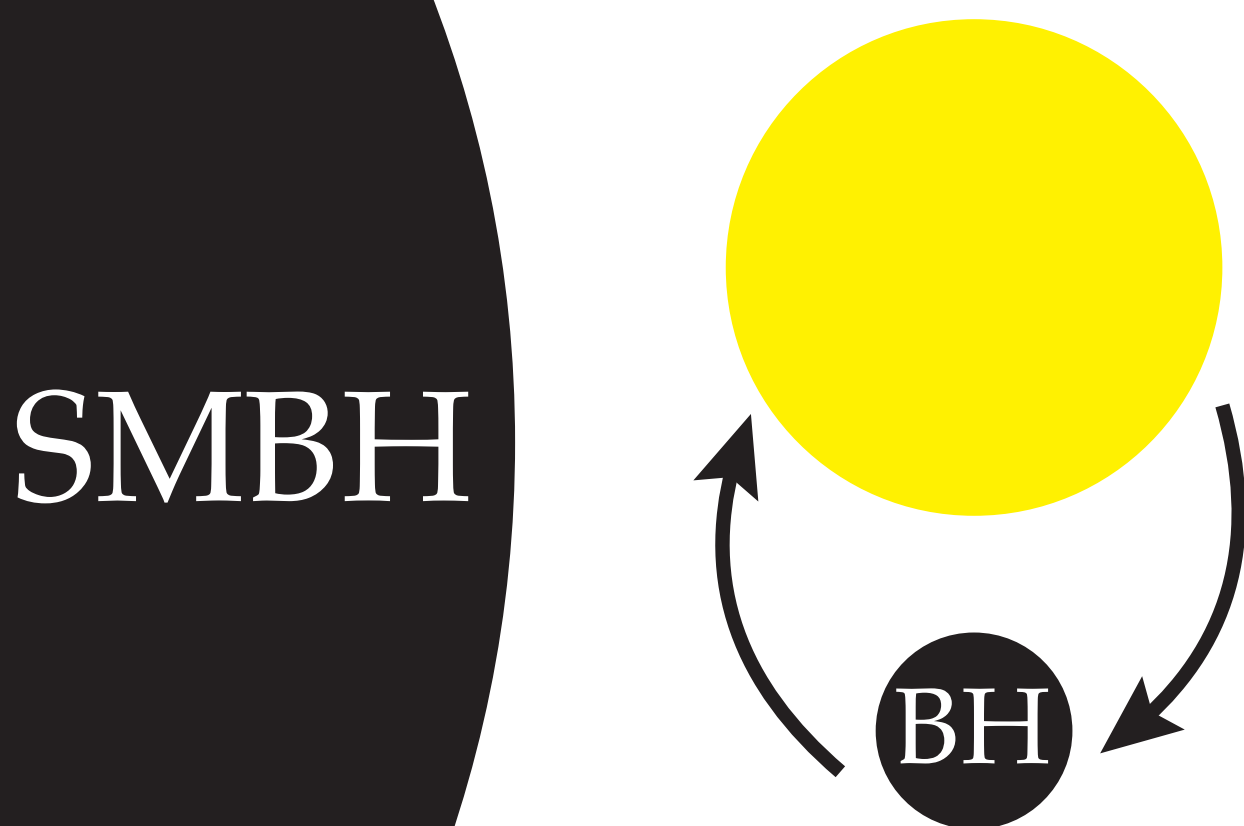


Maybe enhanced rate close to the SMBH due to pre-existing accretion disk

Y. Yang+ 2022

Example: What about micro-TDEs?

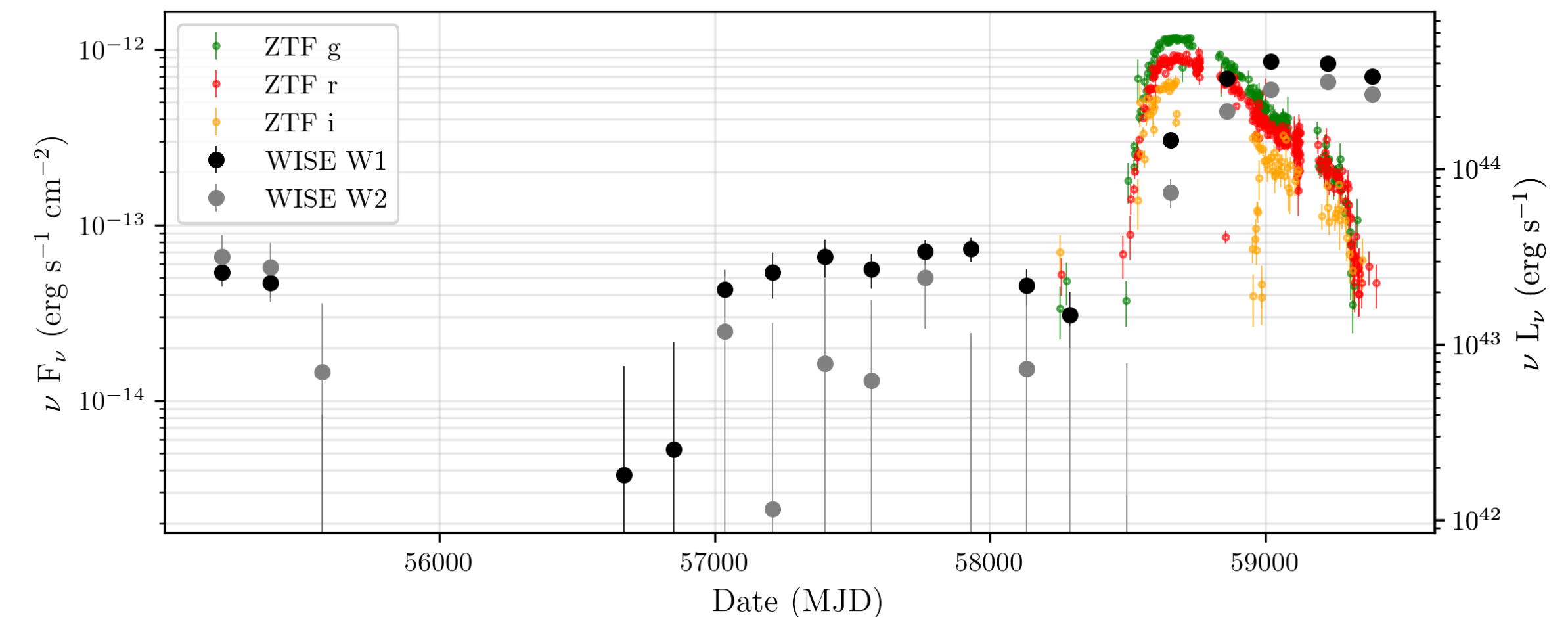
stellar mass BH tidally disrupting a star



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



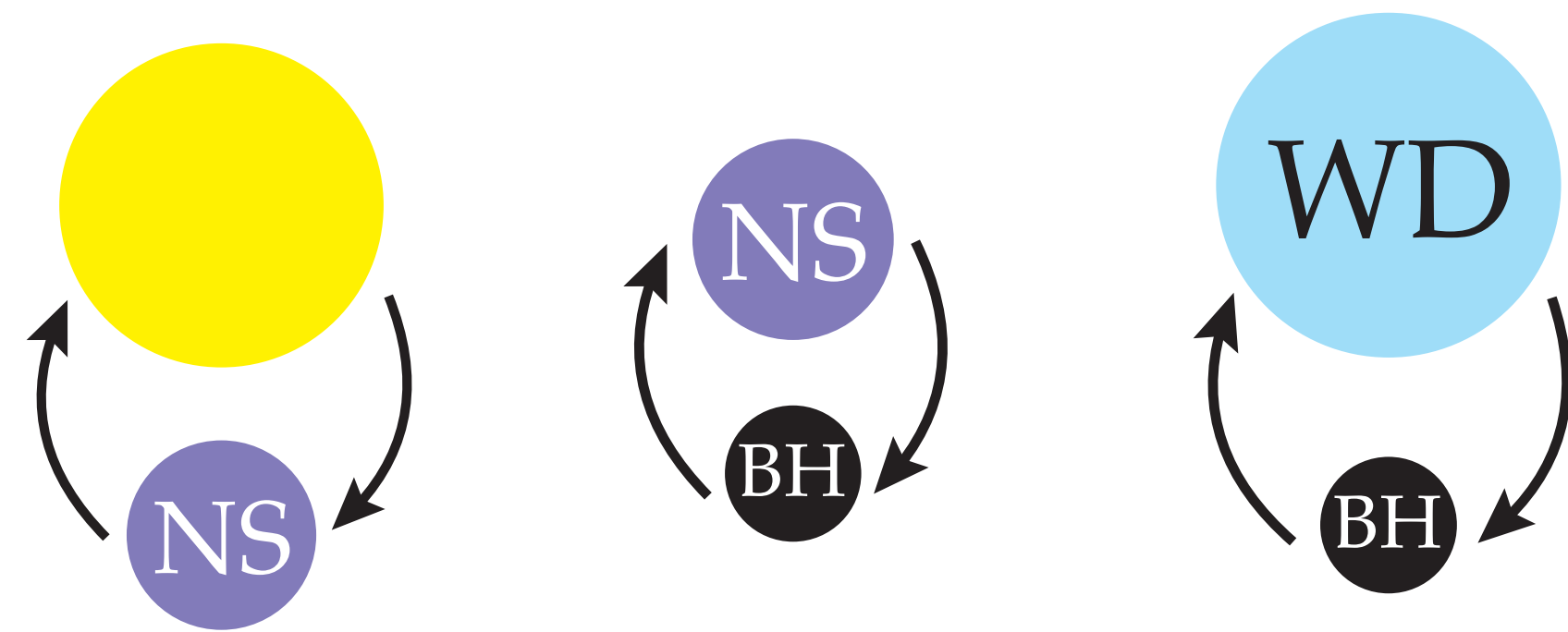
Literature candidate μ TDE
ZTF19aailpwl (part of the sample)

Y. Yang+ 2022

Event type possibly observable as EM transients

SMBH

Event type possibly observable as EM transients

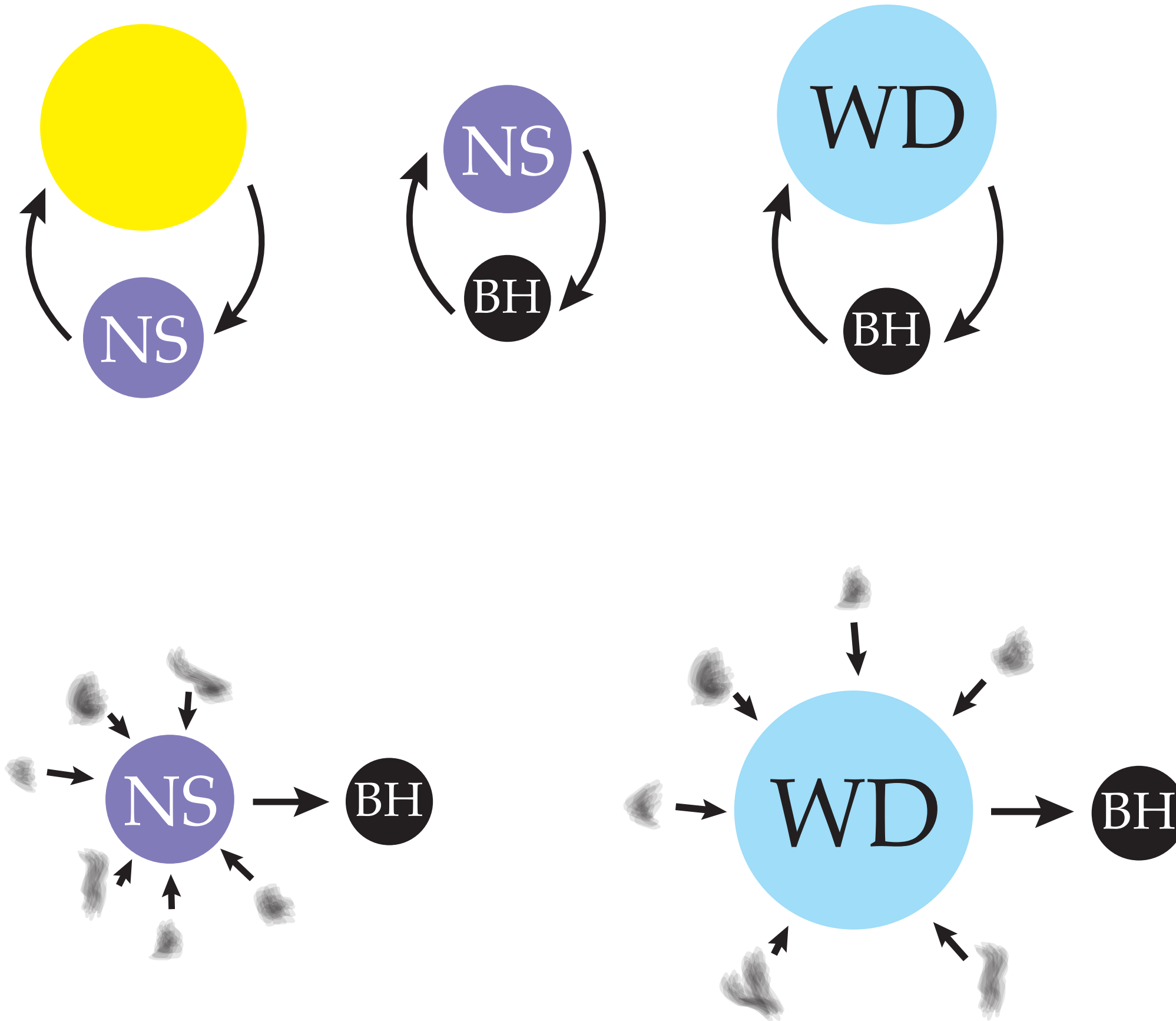


Other μ TDE channels

SMBH

Event type possibly observable as EM transients

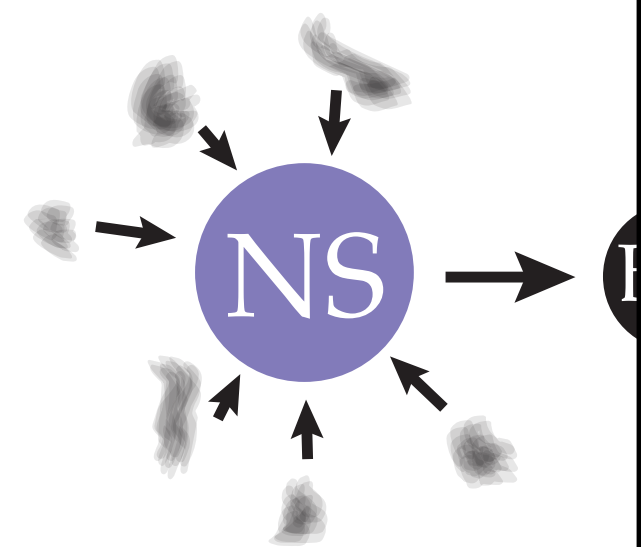
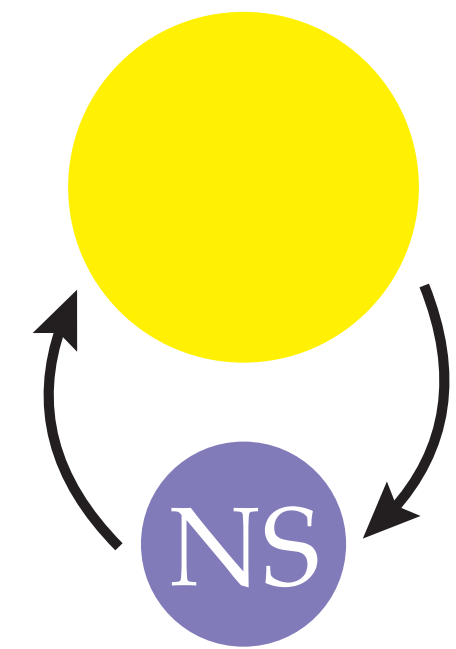
SMBH



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

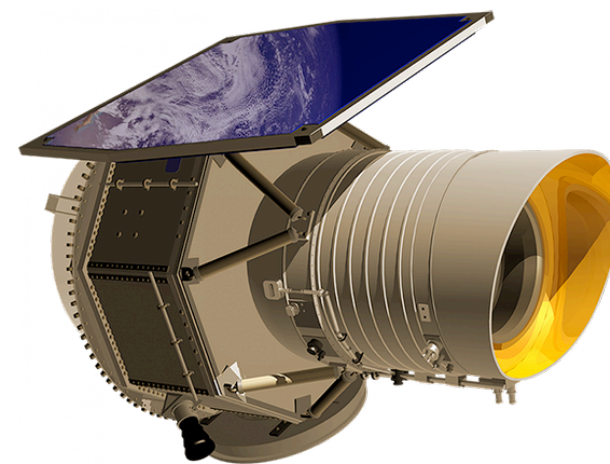
GW signals unlikely to be accessible to LVK

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

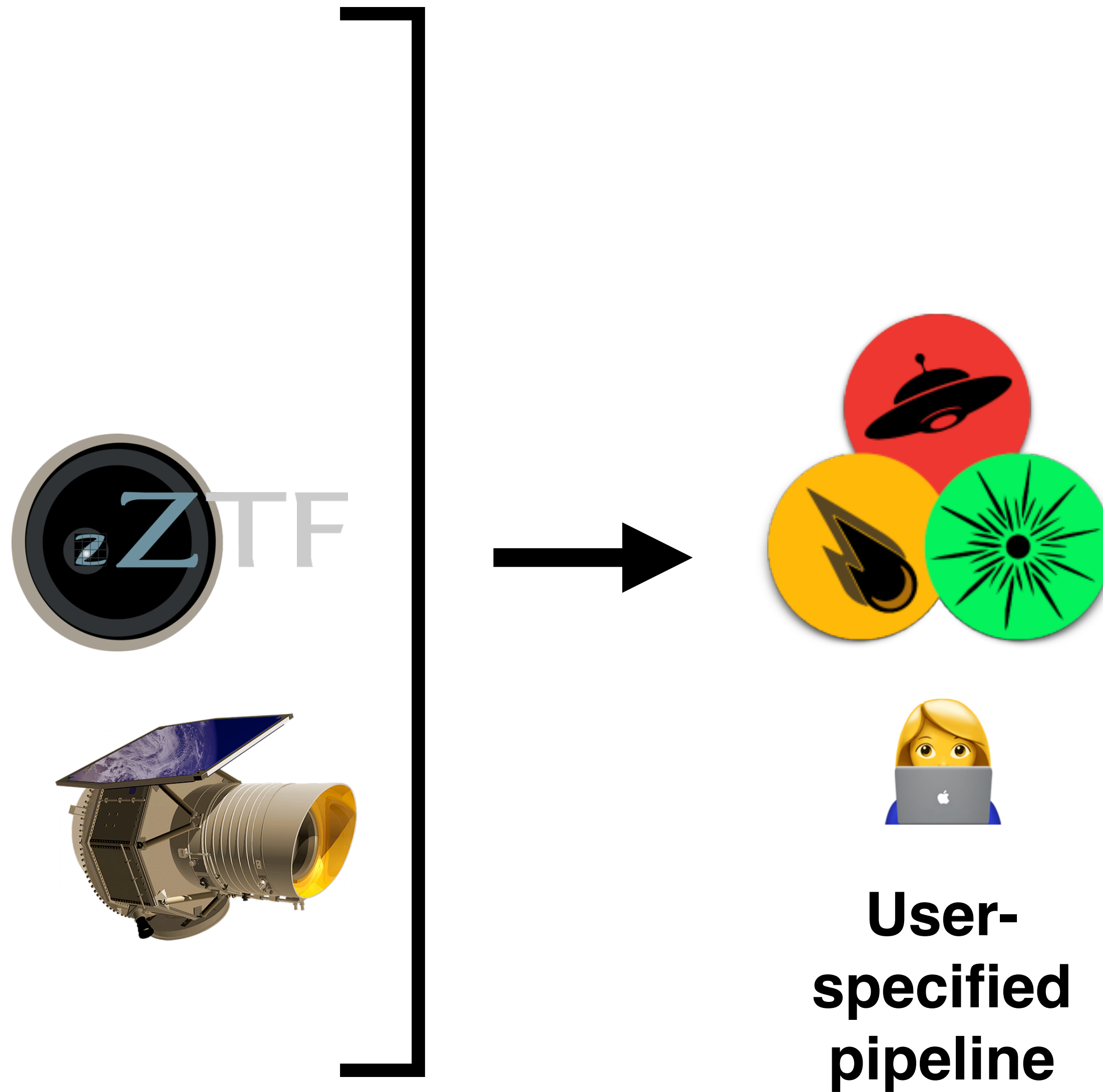
ls

duced

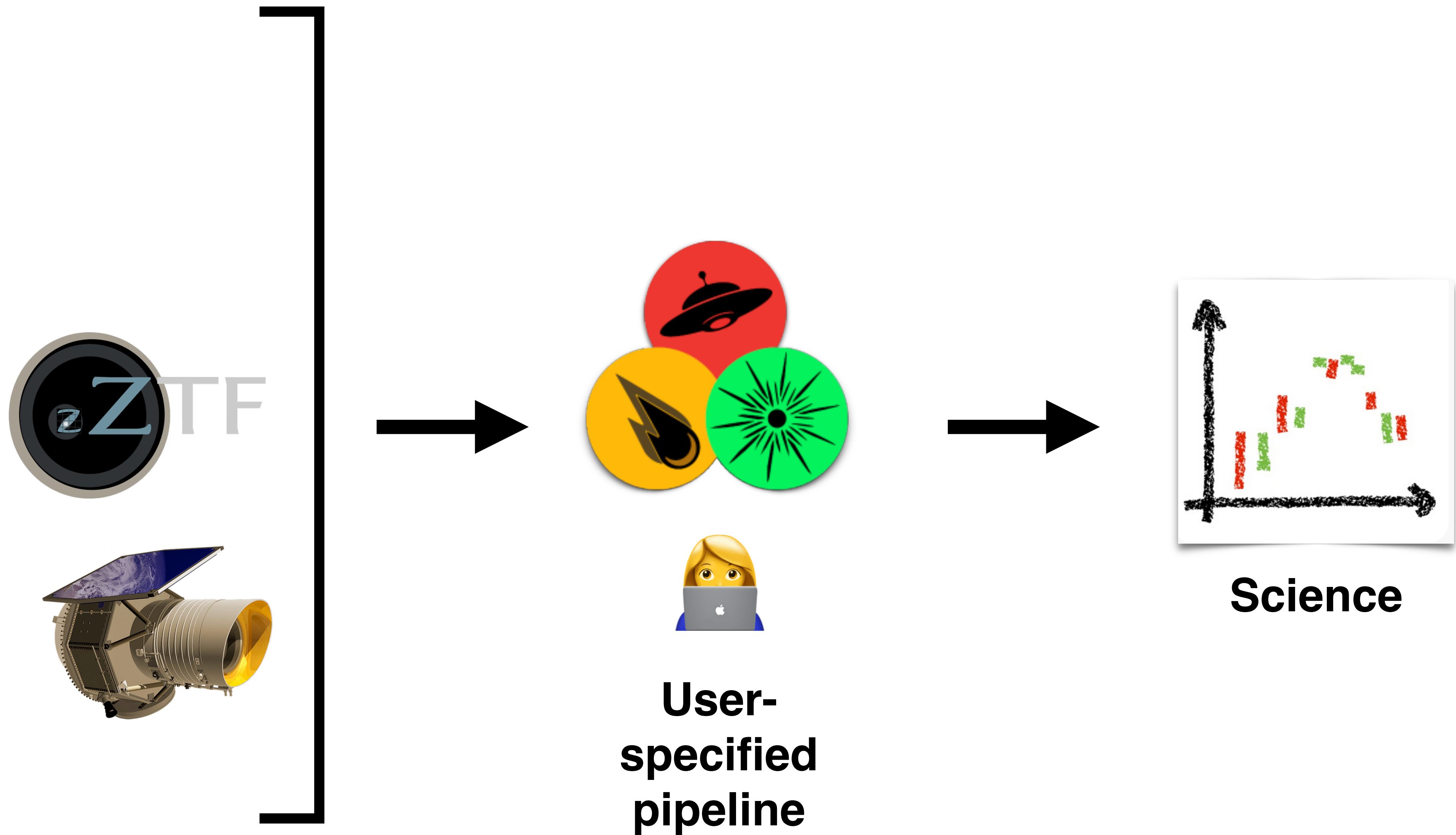
Nuclear sample: Created with AMPEL



Nuclear sample: Created with AMPEL

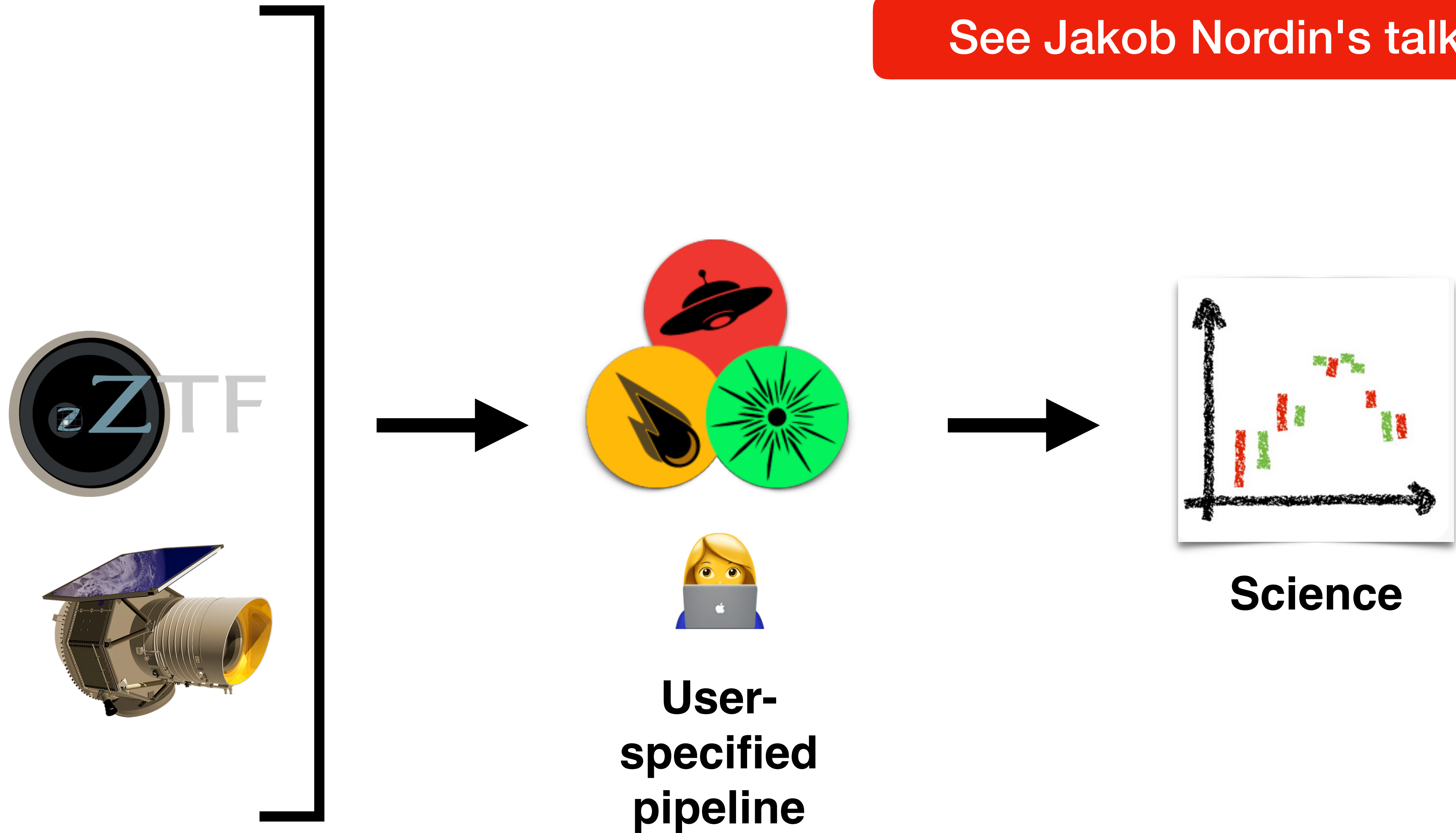


Nuclear sample: Created with AMPEL



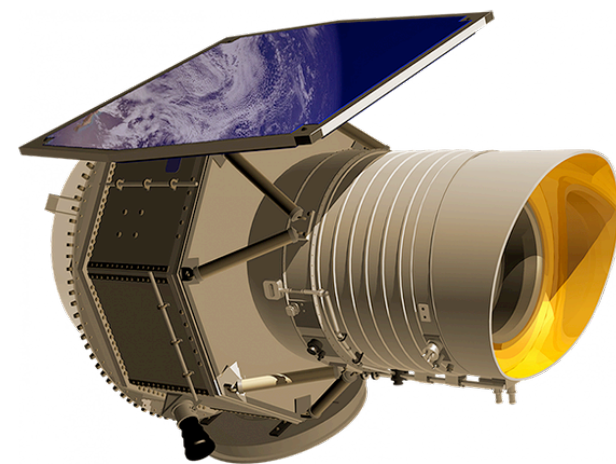
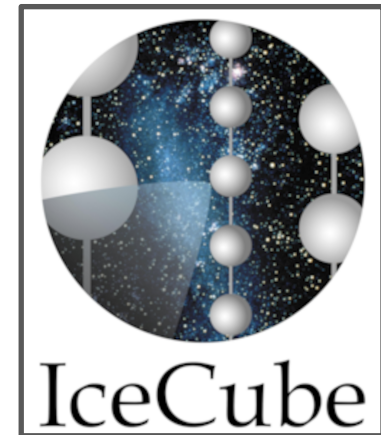
Nuclear sample: Created with AMPEL

See Jakob Nordin's talk



There is so much more data to be combined

See Jakob Nordin's talk



**User-
specified
pipeline**



Science

To ponder

To ponder

Wealth of data should increase the likelihood of serendipitous discovery

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

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

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

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")

Summary

Image credit: Palomar Observatory



Summary

Image credit: Palomar Observatory

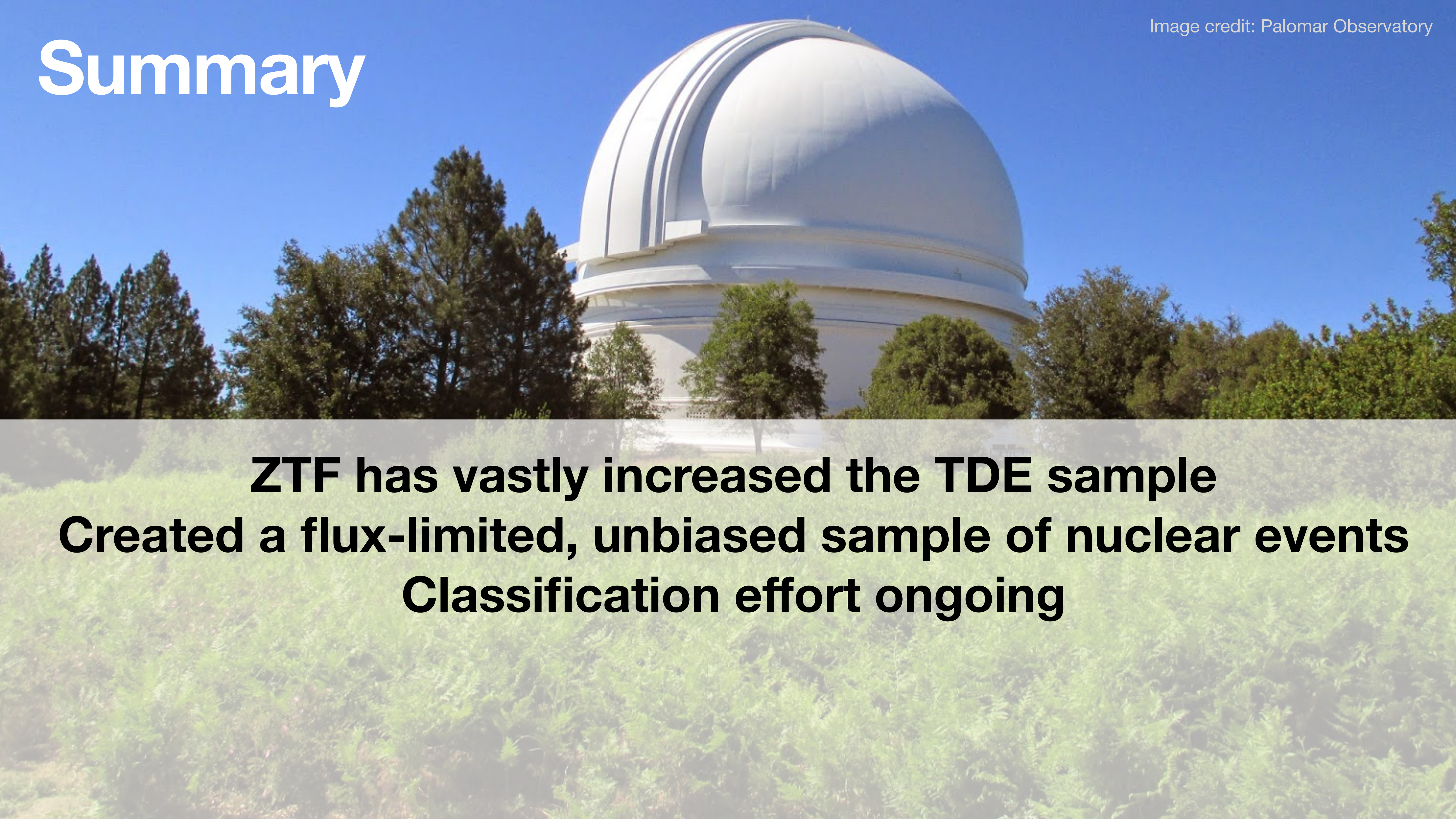
ZTF has vastly increased the TDE sample

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


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ZTF has vastly increased the TDE sample
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Explore the wealth of transients contained in the sample

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

Summary

Image credit: Palomar Observatory



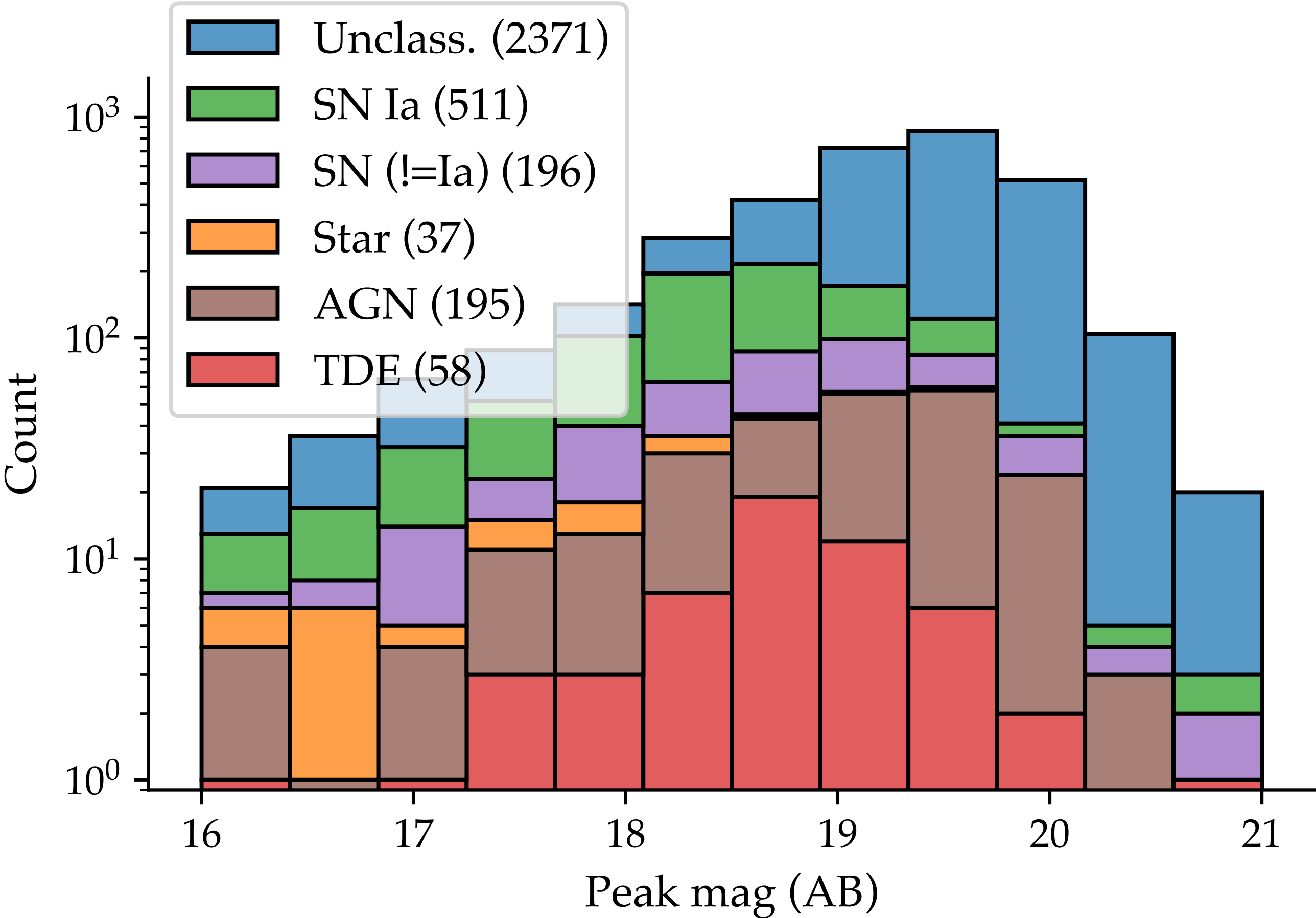
ZTF has vastly increased the TDE sample
Created a flux-limited, unbiased sample of nuclear events
Classification effort ongoing
Explore the wealth of transients contained in the sample
🚦 AMPEL enables all this
Archival analyses have their own merits

Bonus

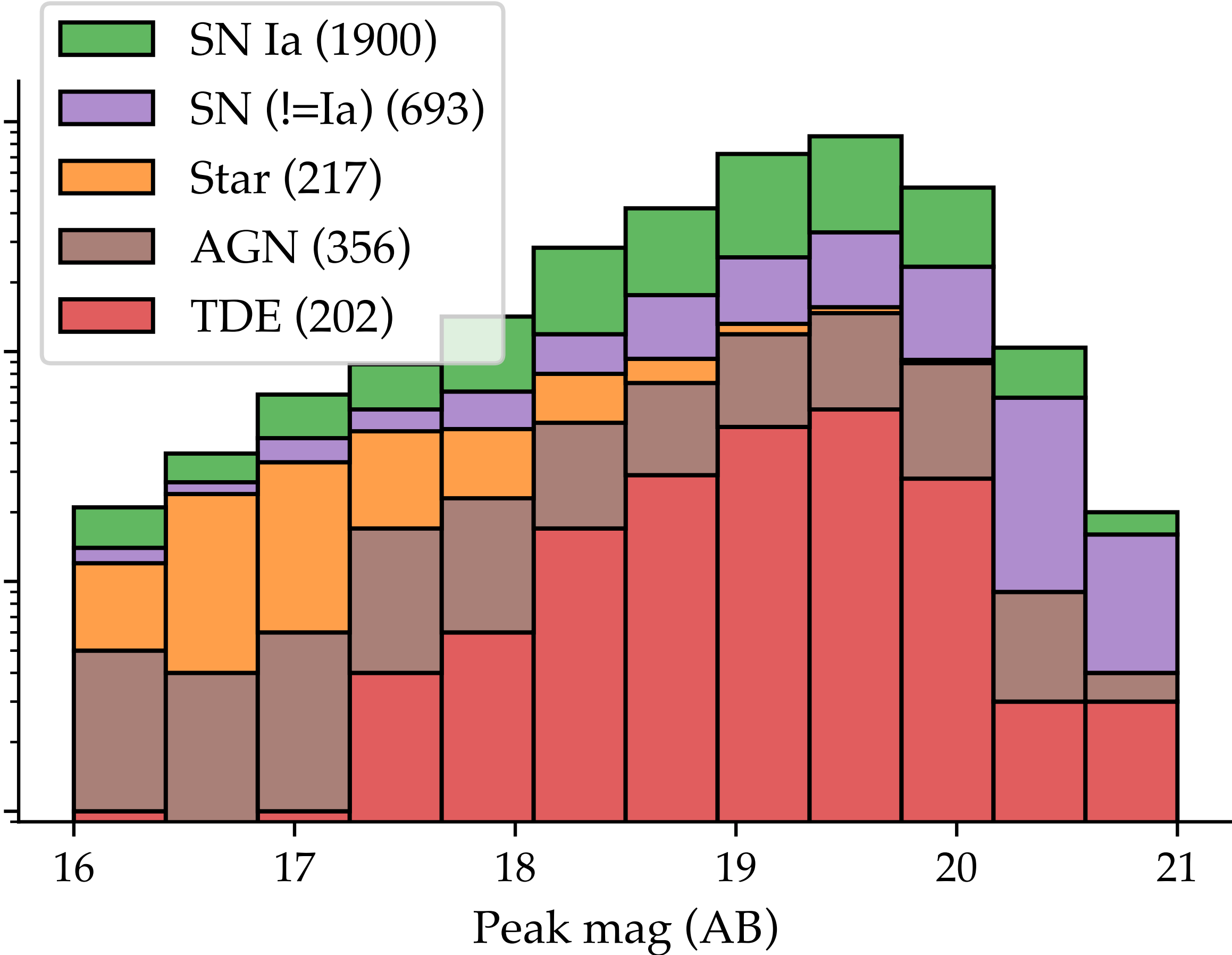
Classification results

preliminary

Community Classification

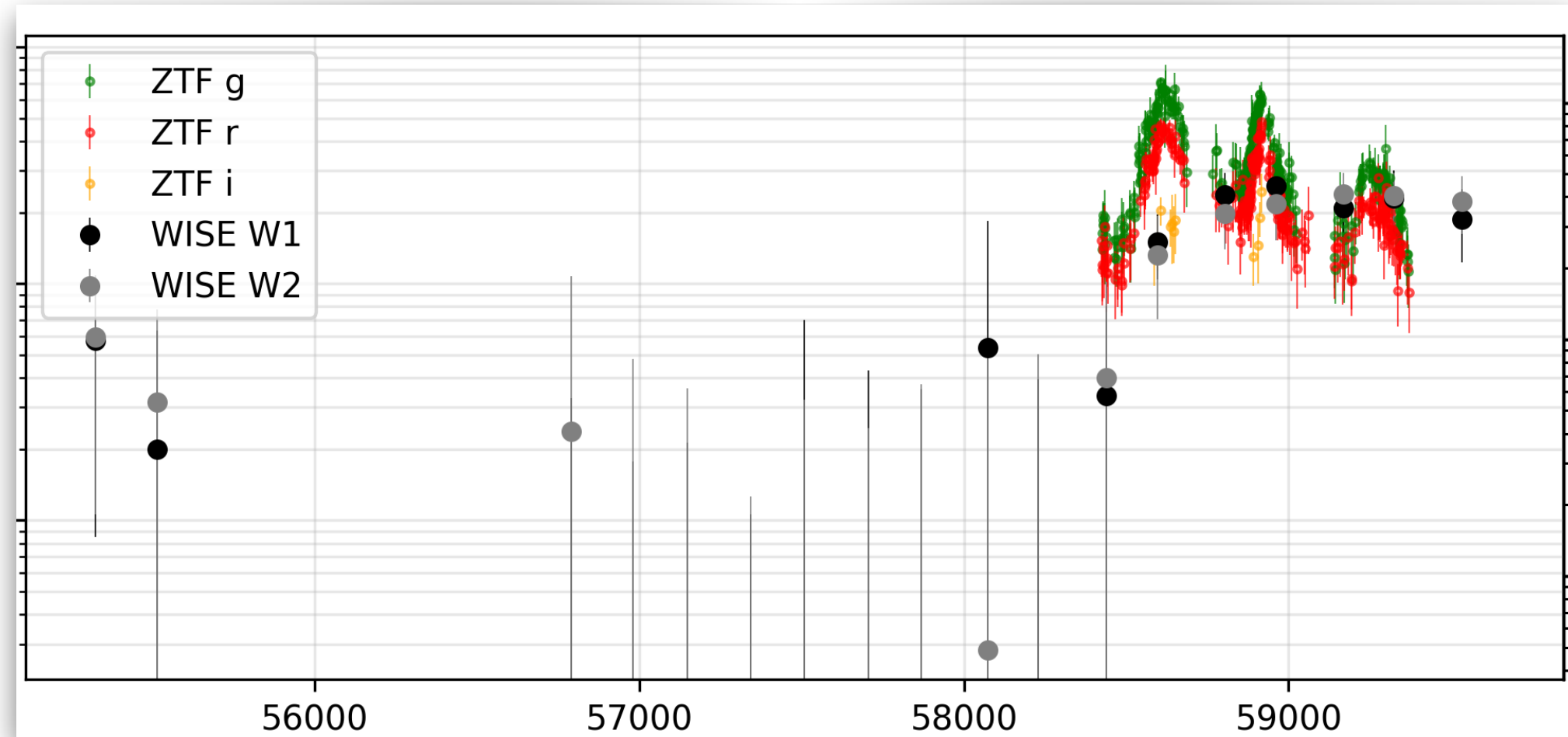


ML Classification

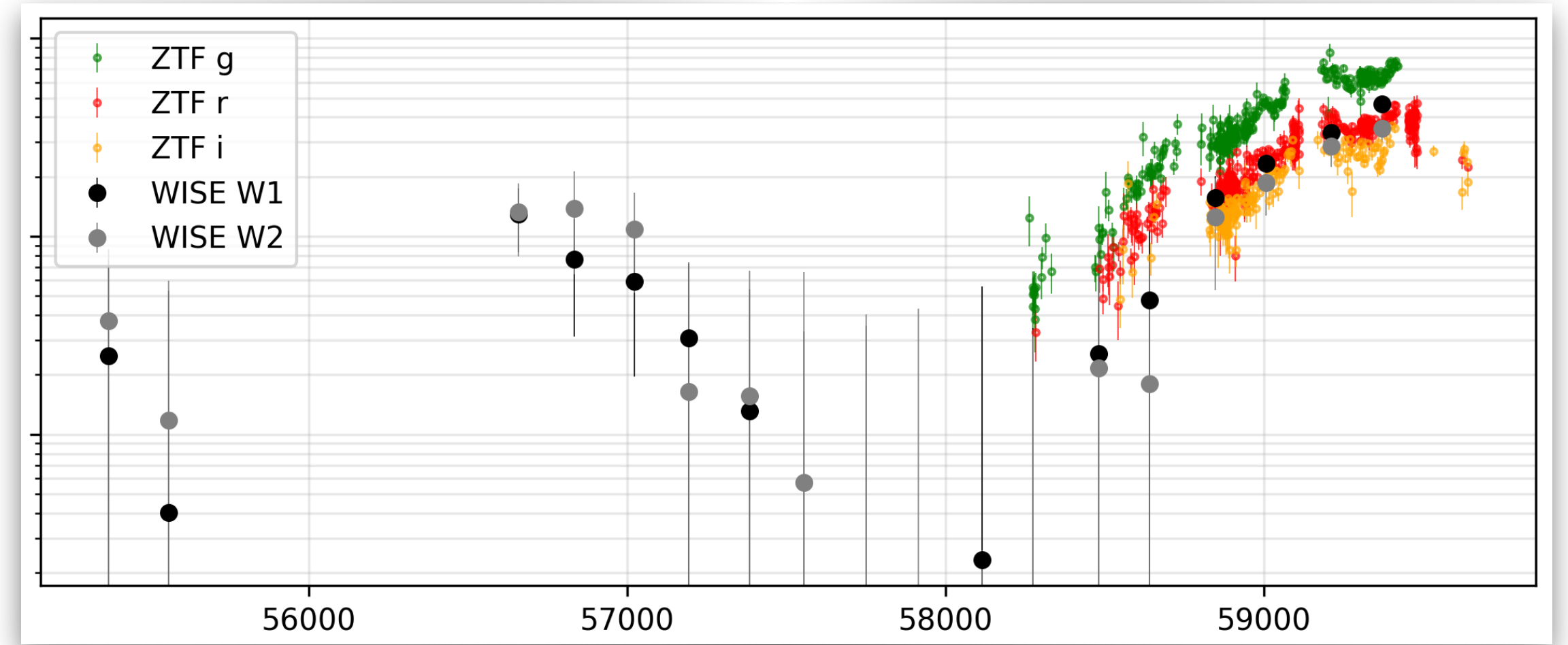


IR transients: Filtered by IR

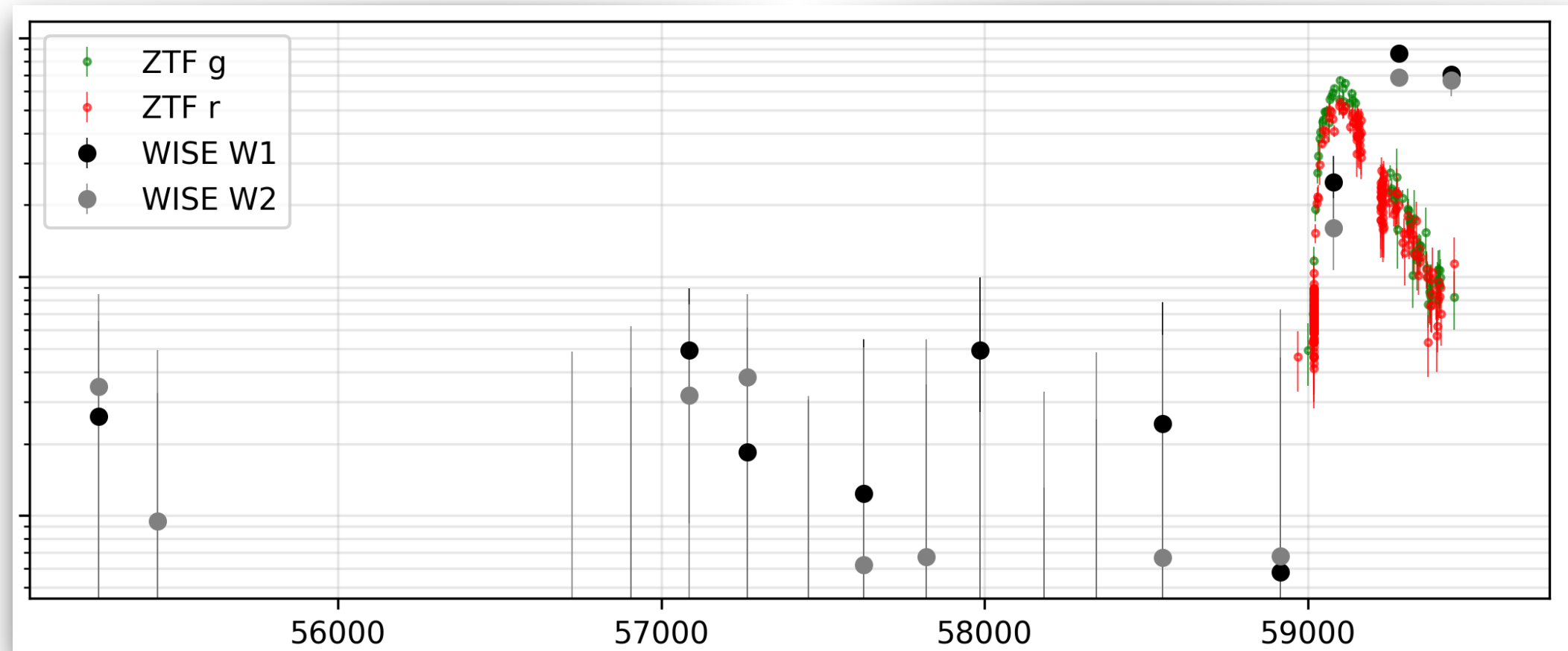
Blazar candidates



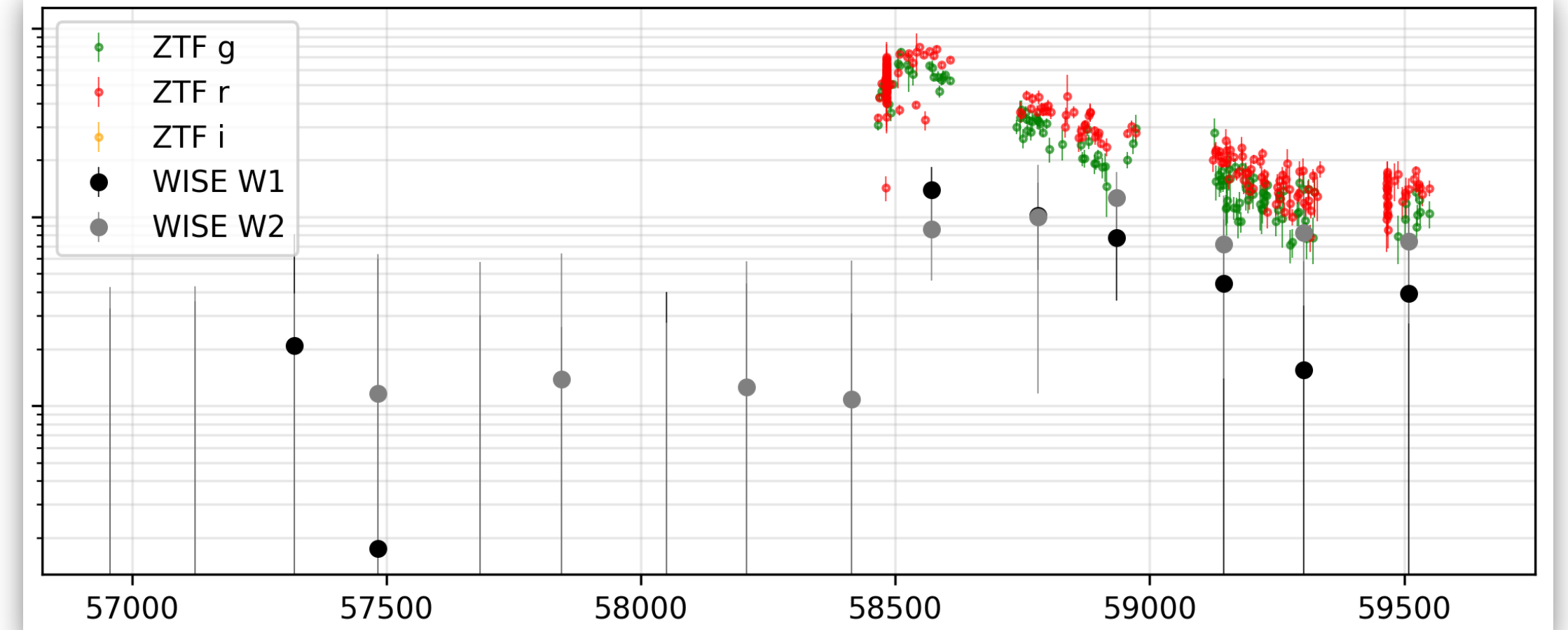
slow rise, simultaneous IR rise



TDE candidate

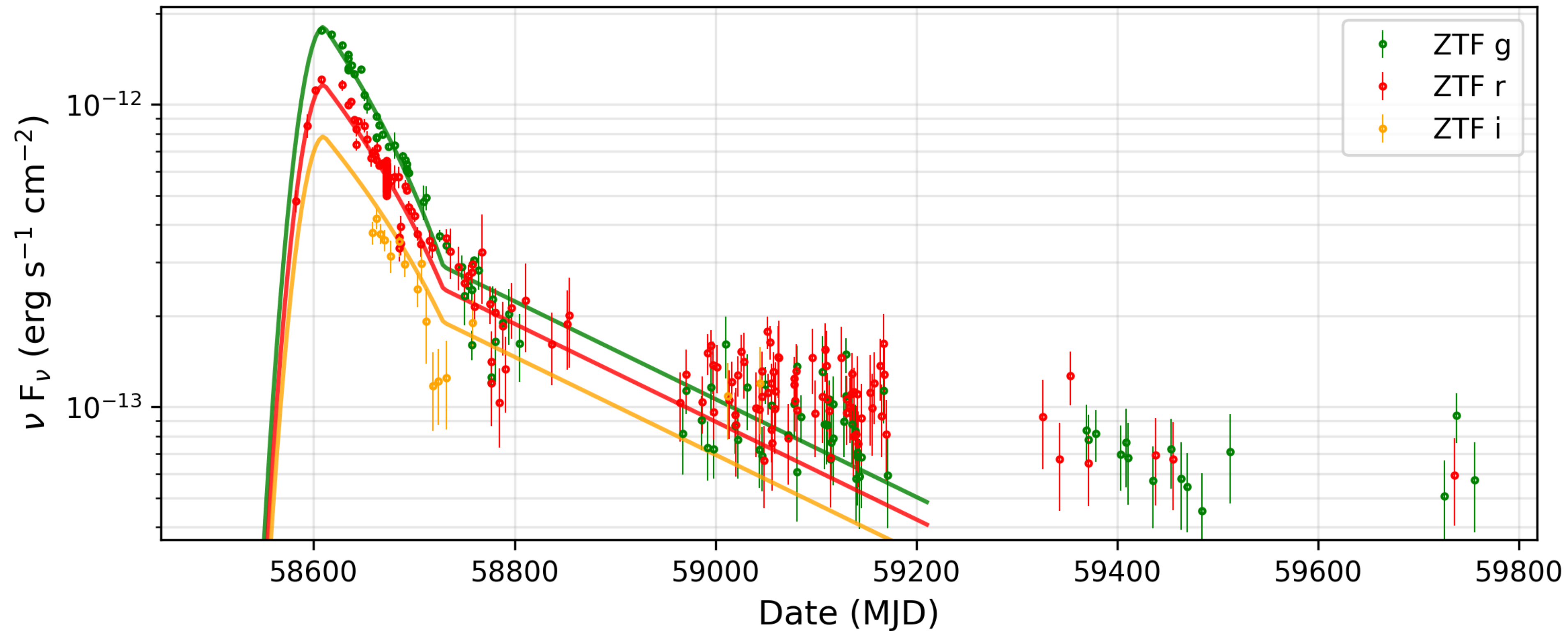


Tywin-like

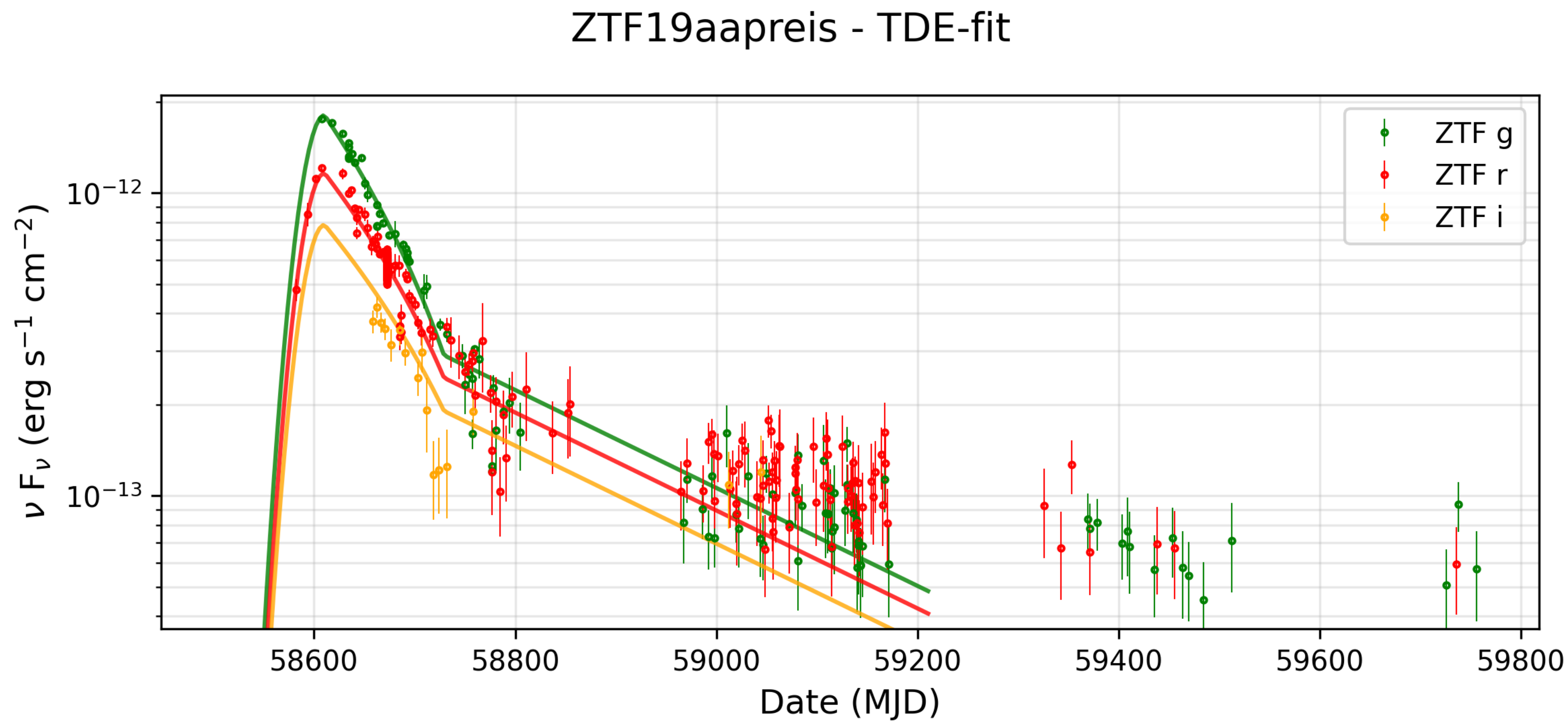


Feature extraction: TDE Fit

ZTF19aapreis - TDE-fit



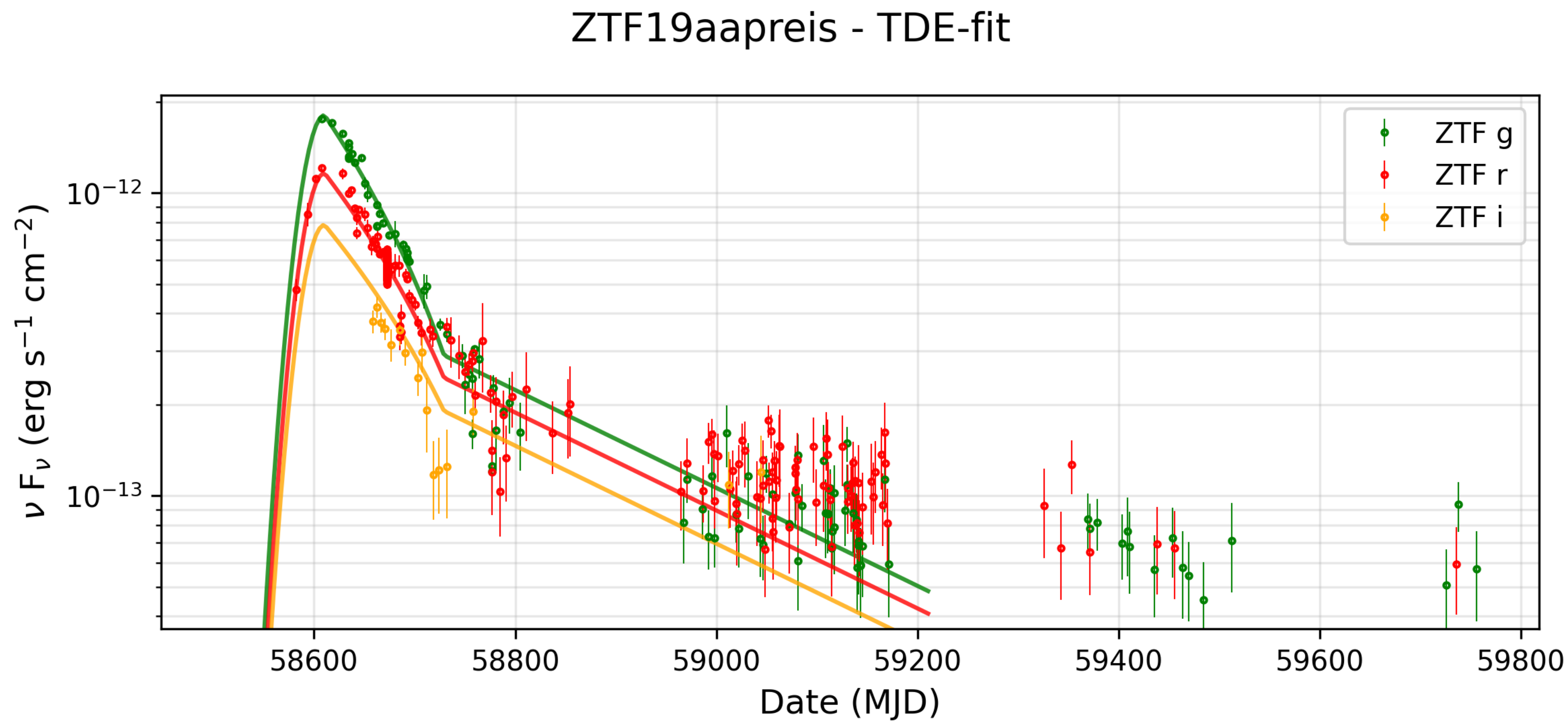
Feature extraction: TDE Fit



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

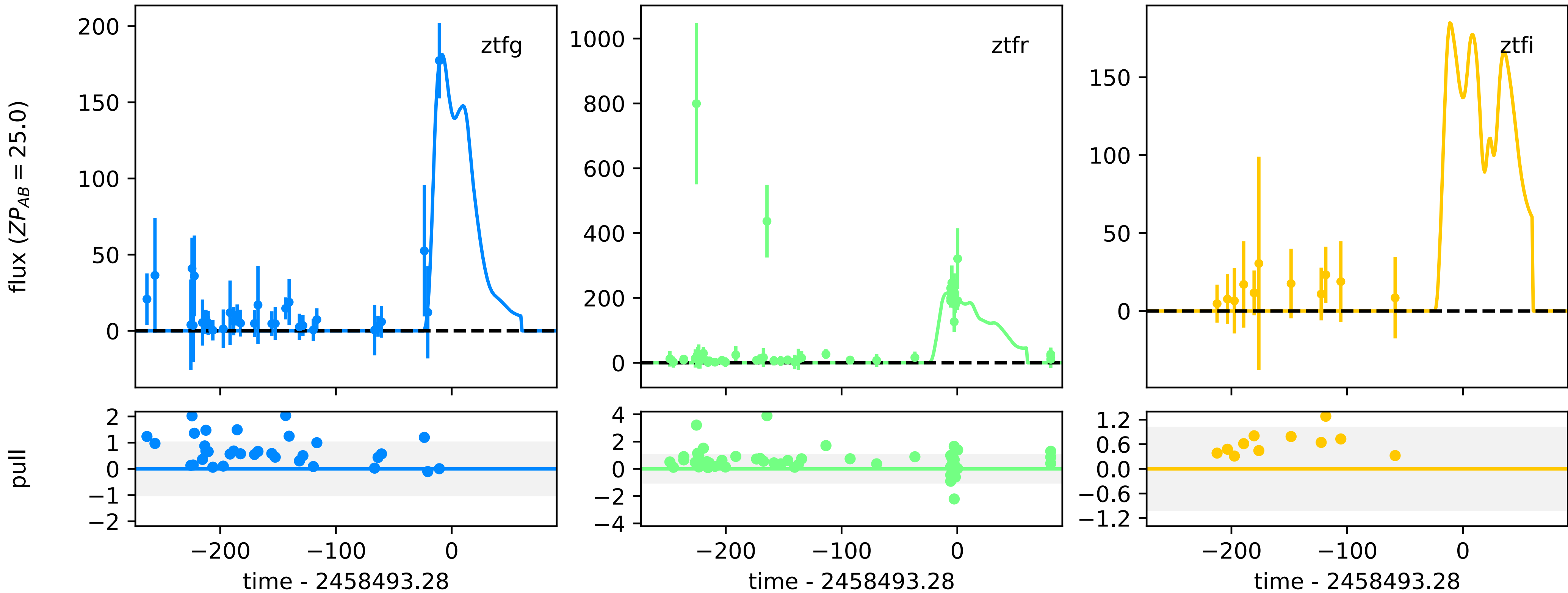
Fitted twice
(stability)
Problem: T
runaway (no UV)

Feature extraction: SALT Fit (SN Ia)

ZTF19aaafvzy salt2 None
chisq 87.77
ndof 90

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

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

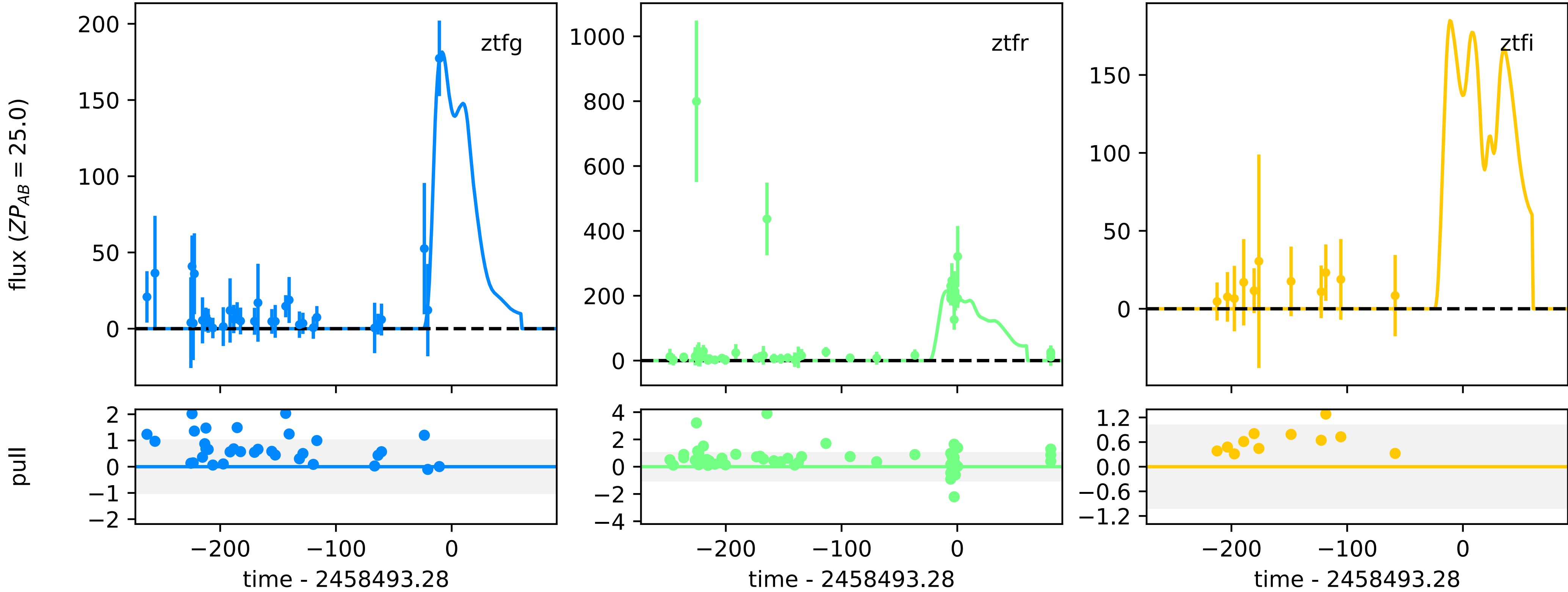


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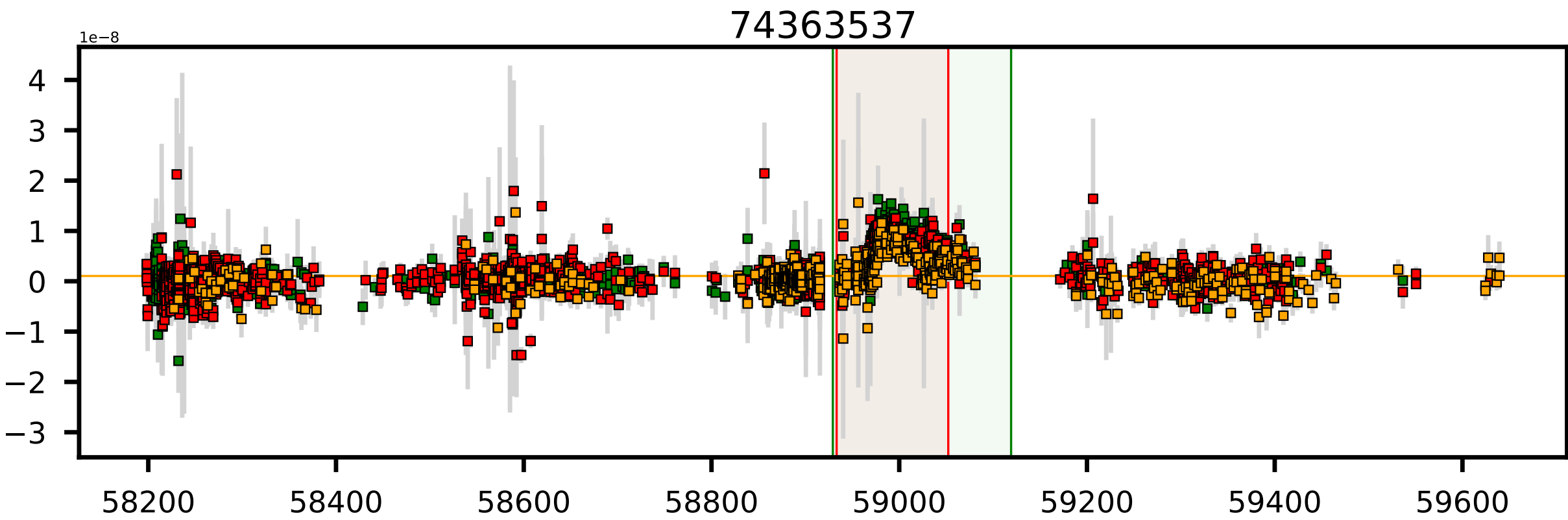
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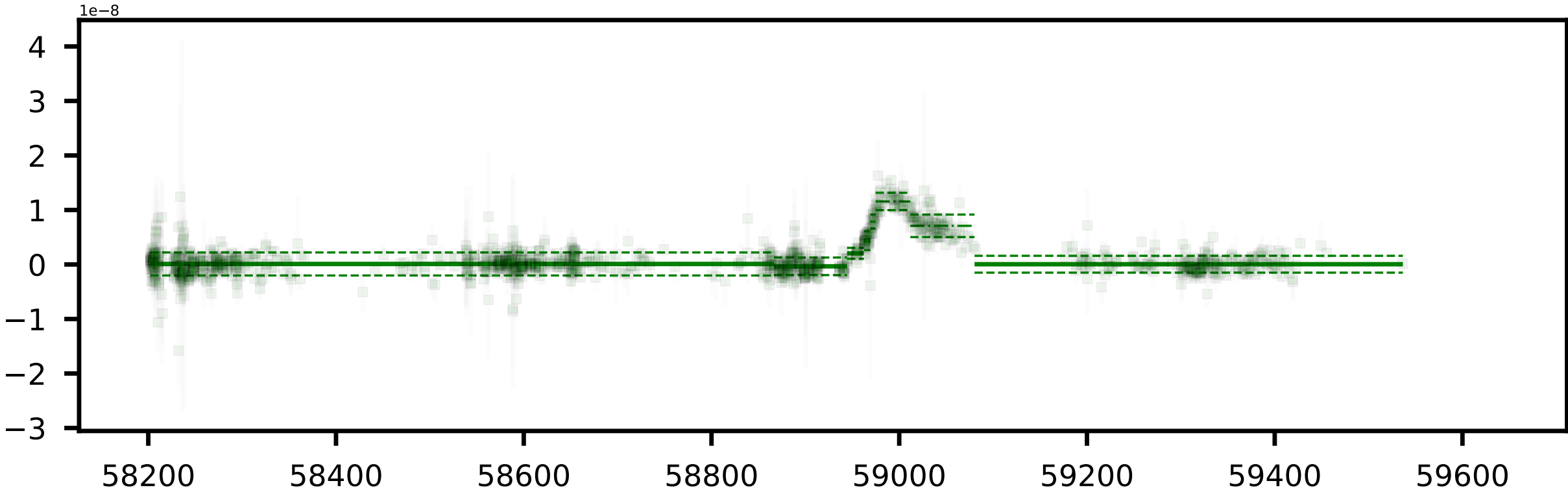


Feature extraction

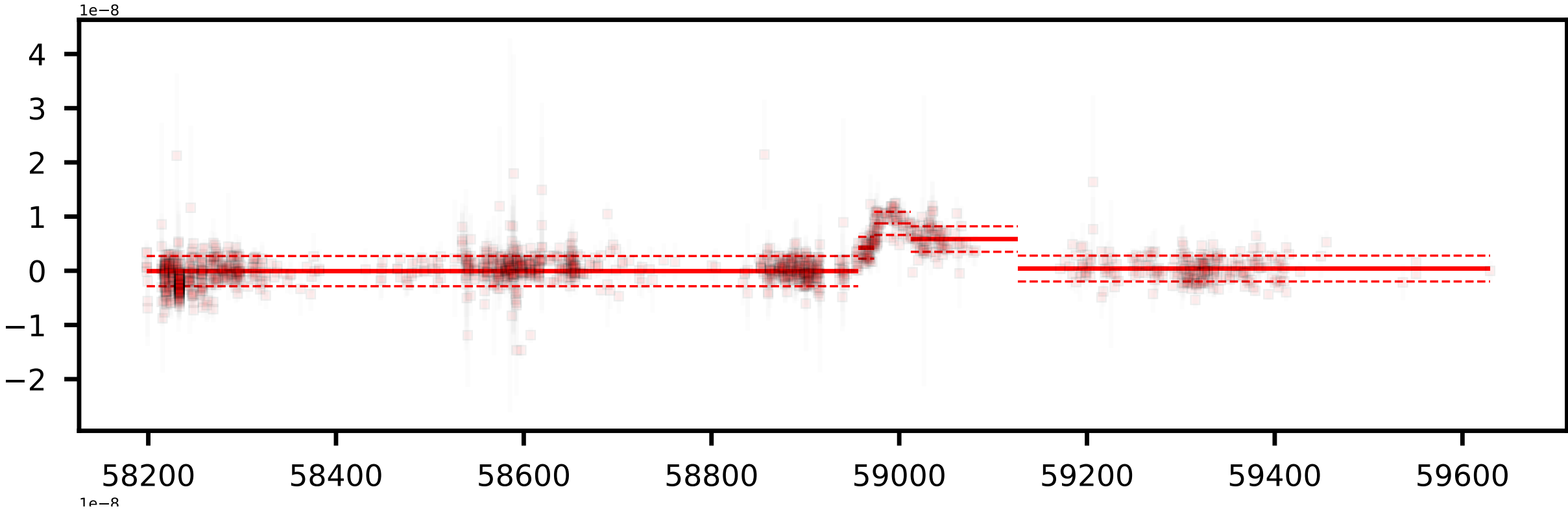
all bands



g-band



r-band

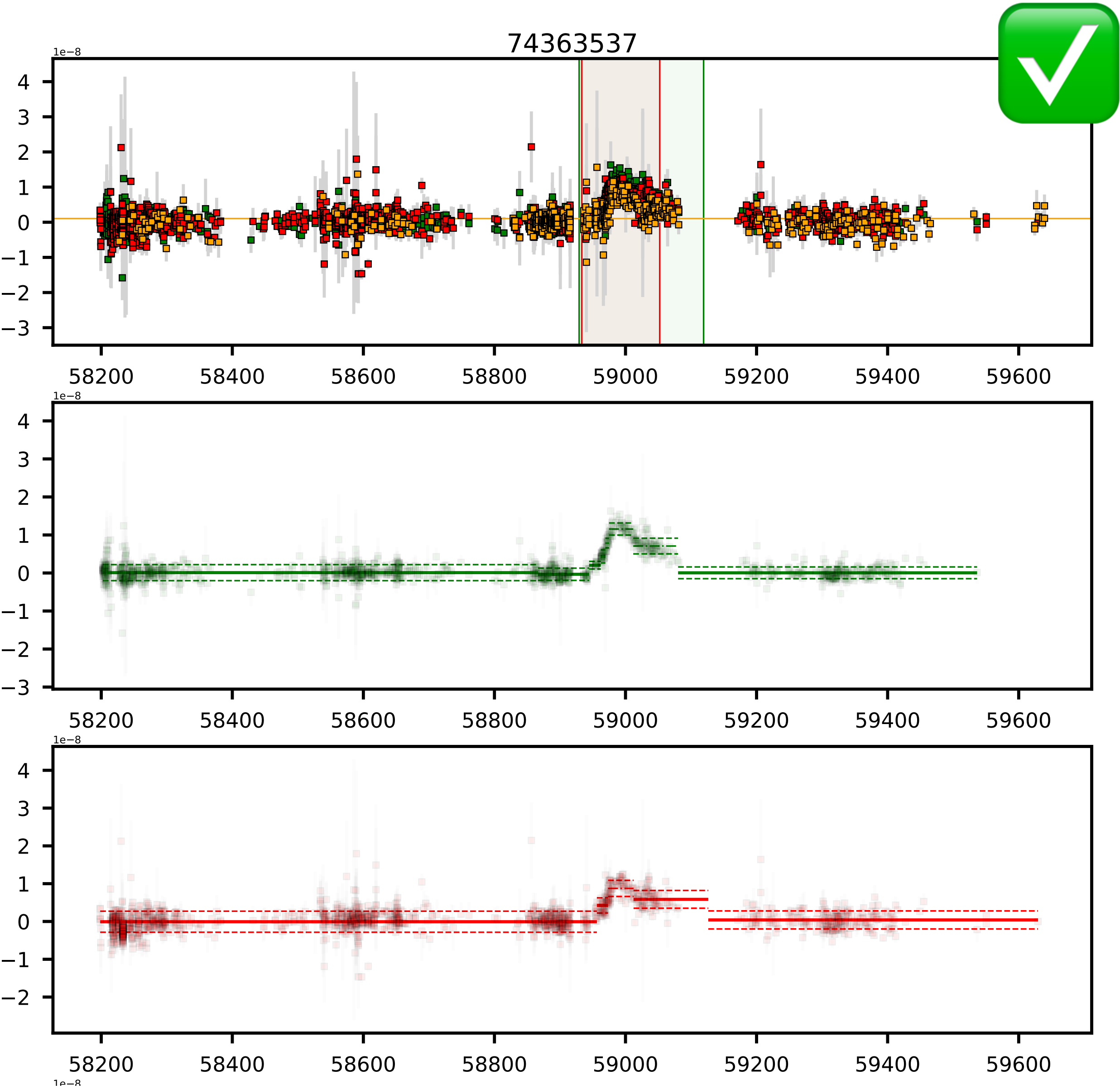


Feature extraction

all bands

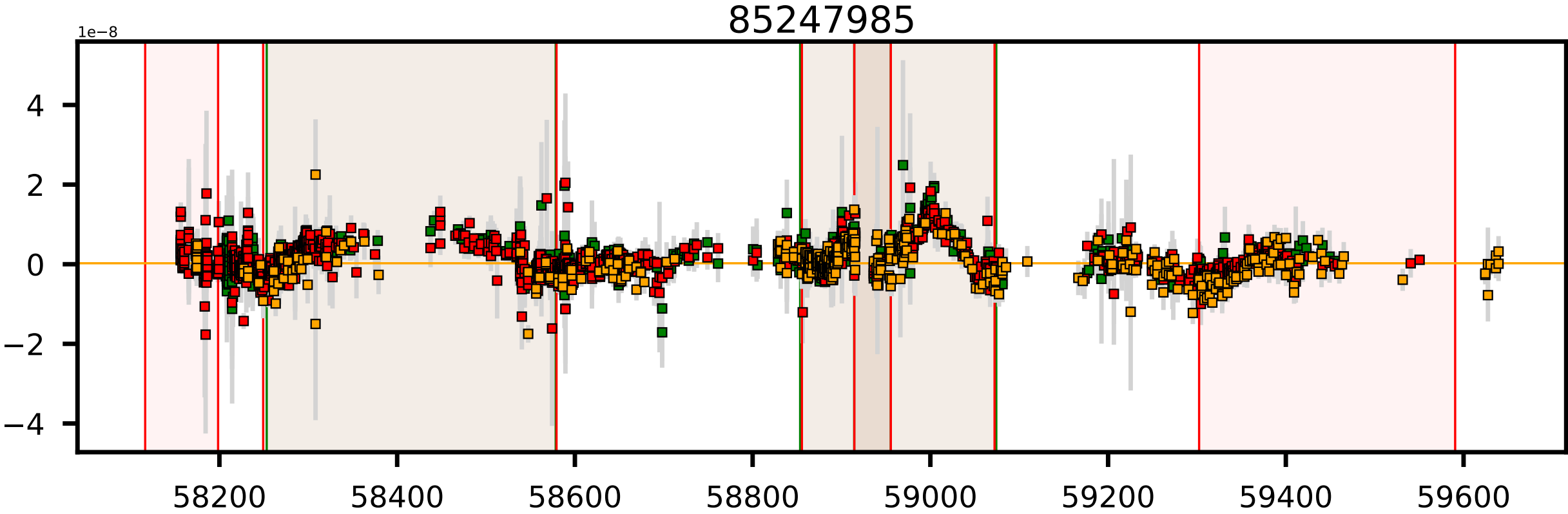
g-band

r-band

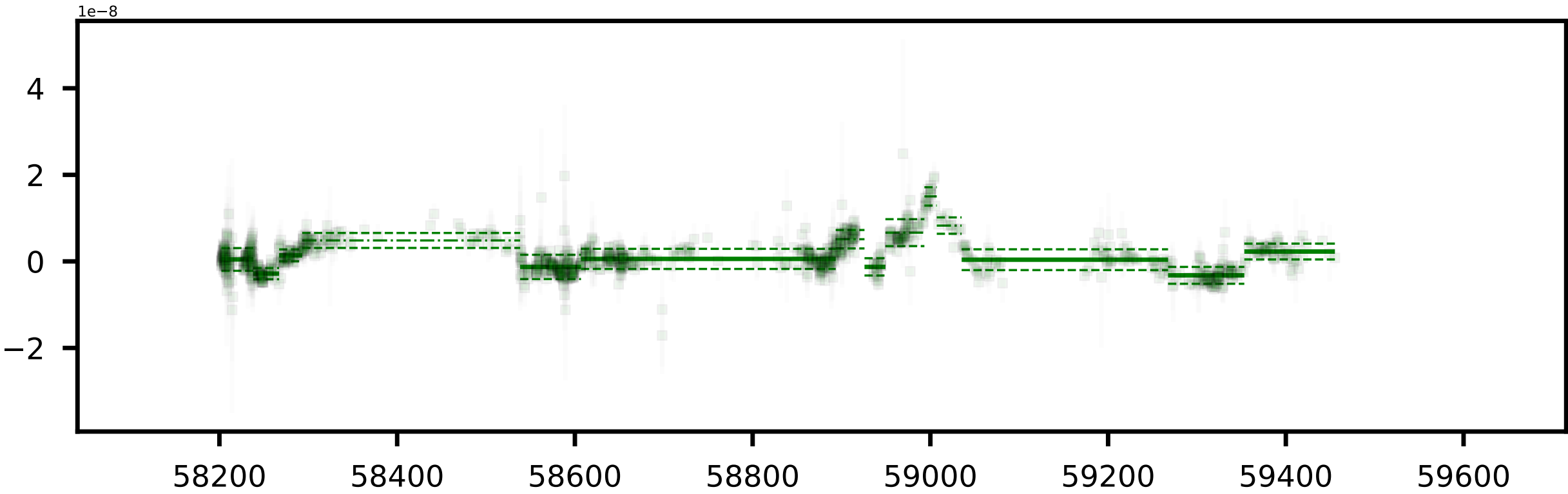


Feature extraction

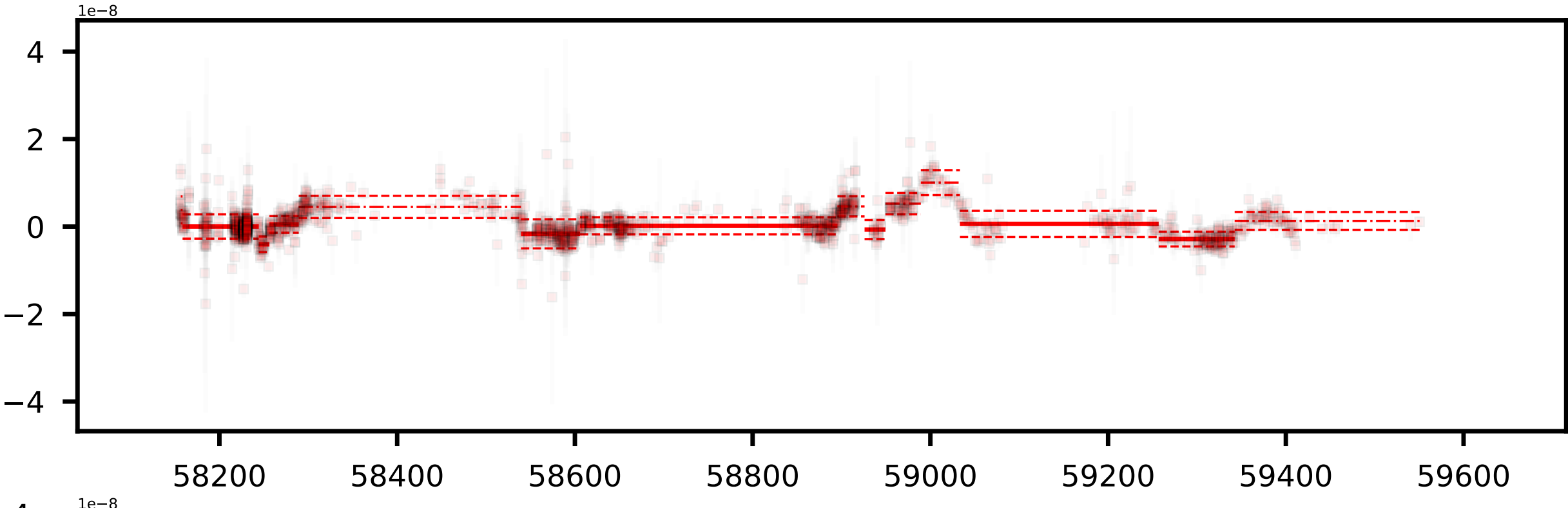
all bands



g-band



r-band

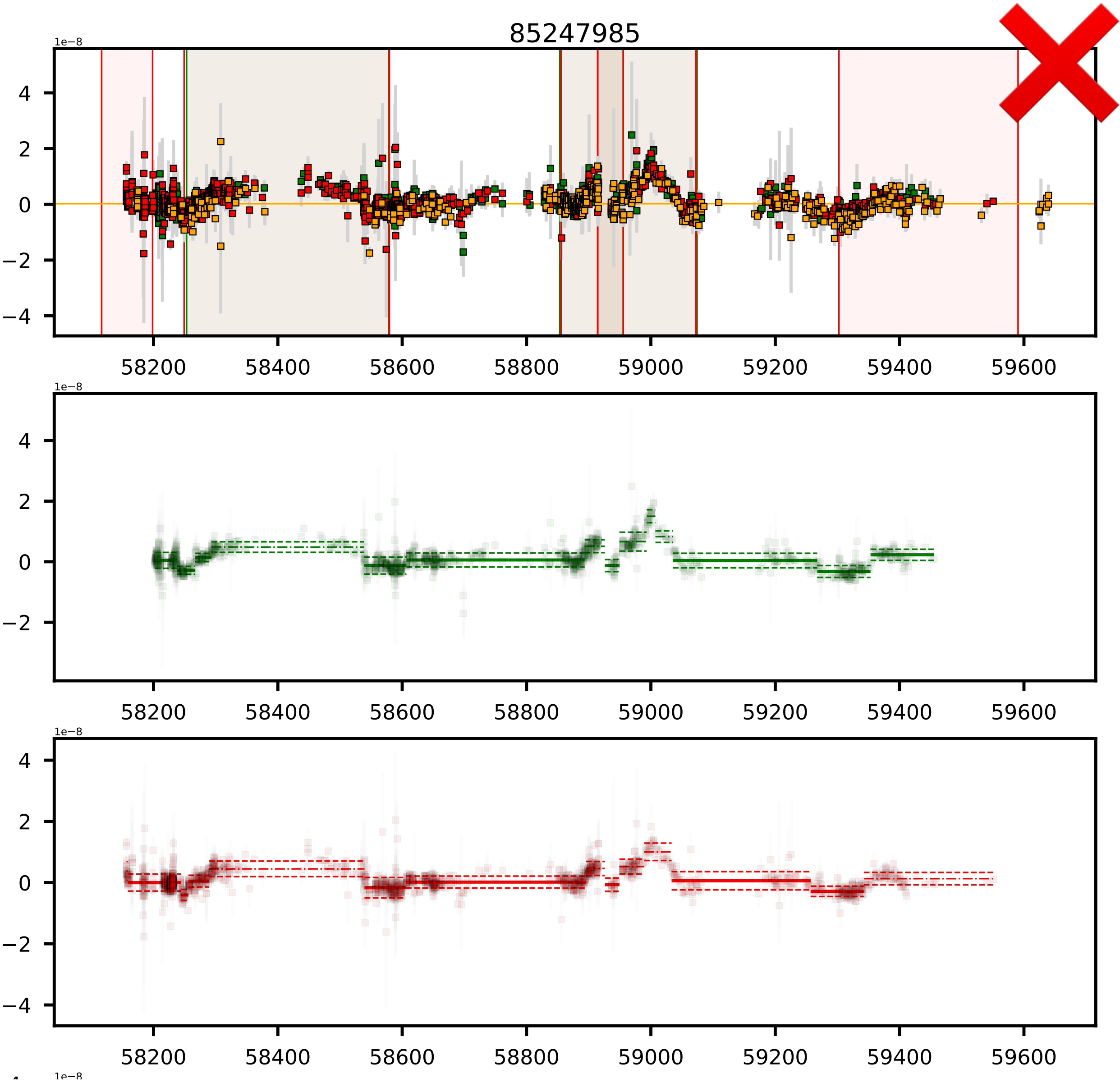


Feature extraction

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

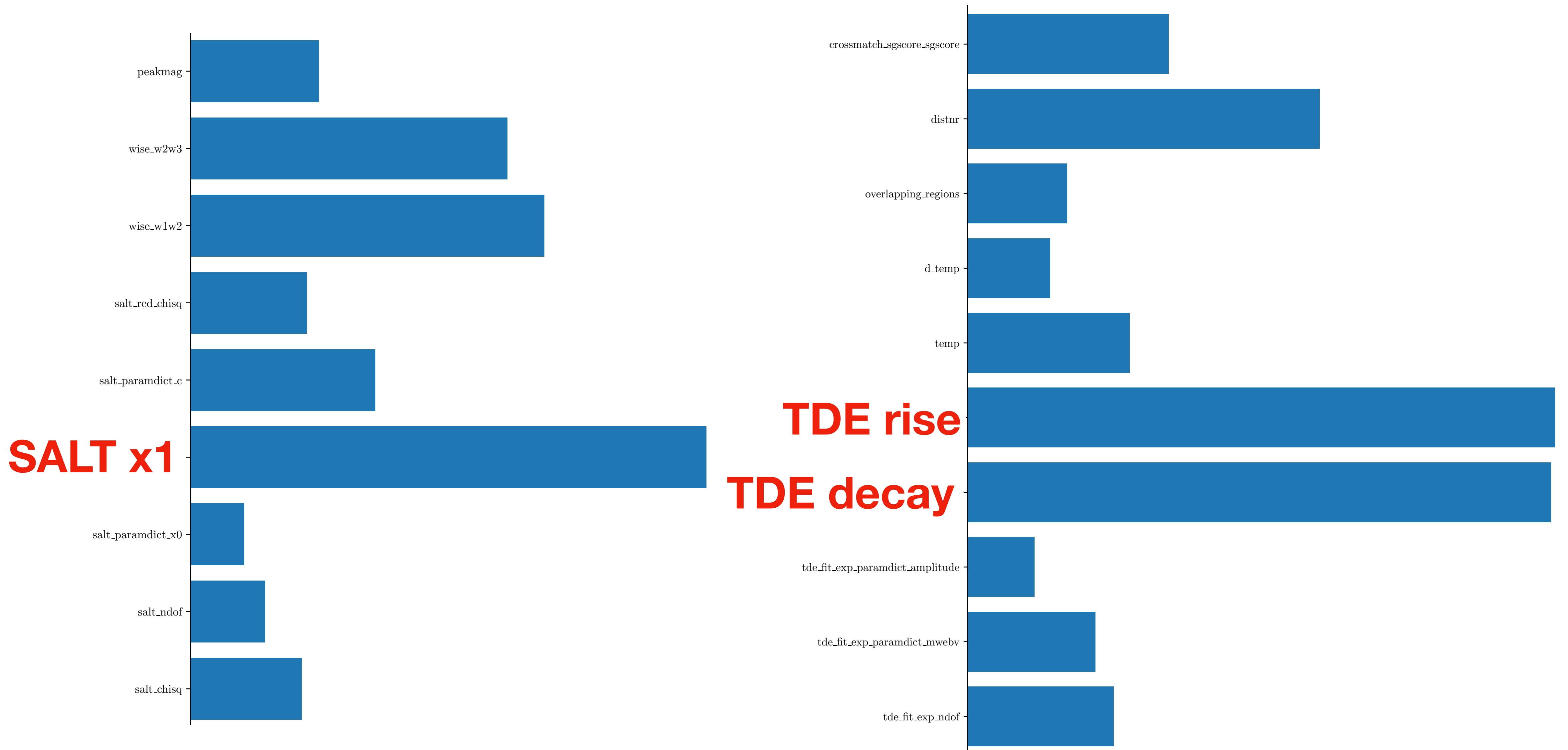
Train XGBoost

train-validation fraction = 0.7

test fraction = 0.3

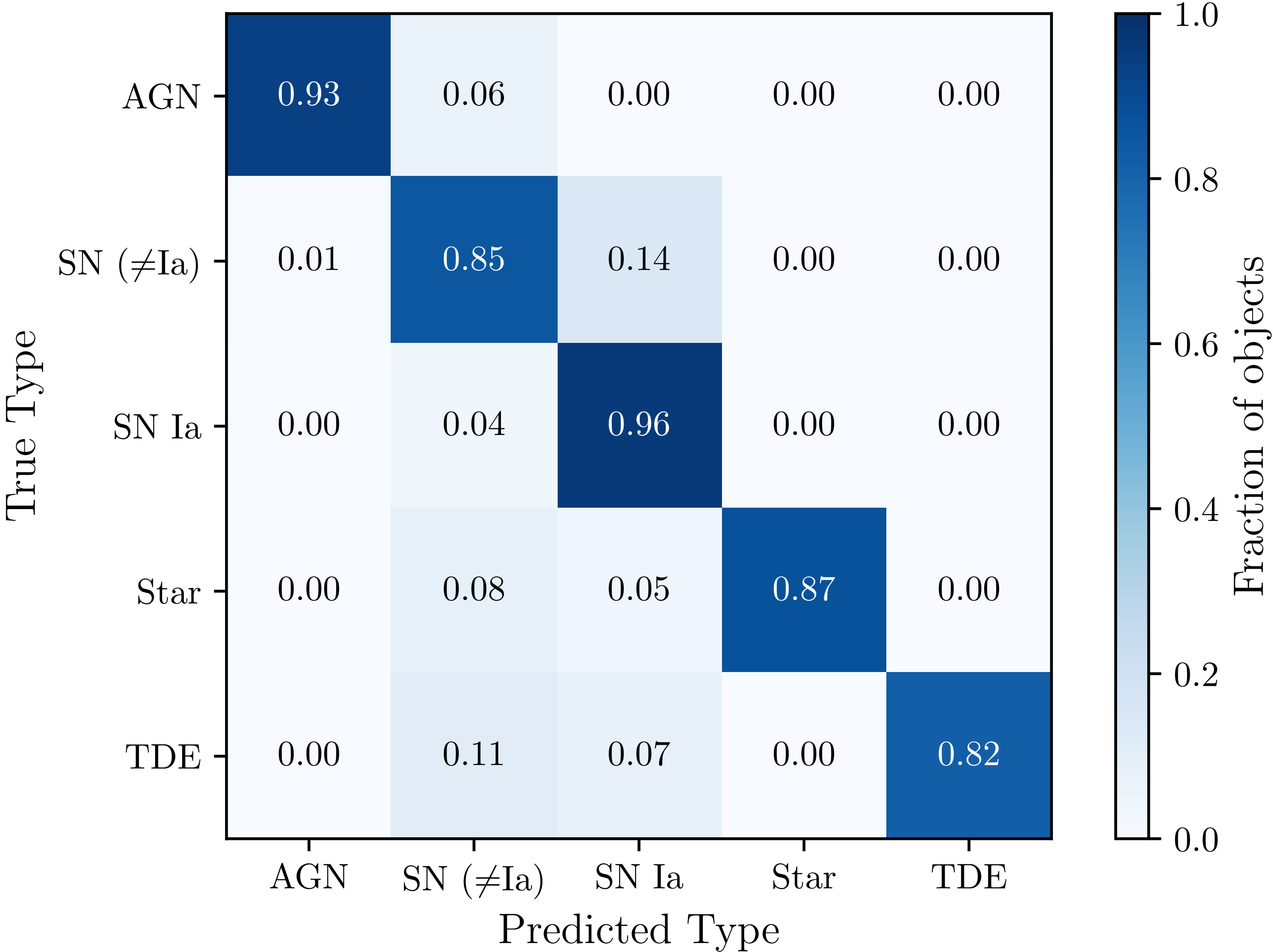
hyper parameter search (9 parameters) with 50 iterations

XGBoost feature importance



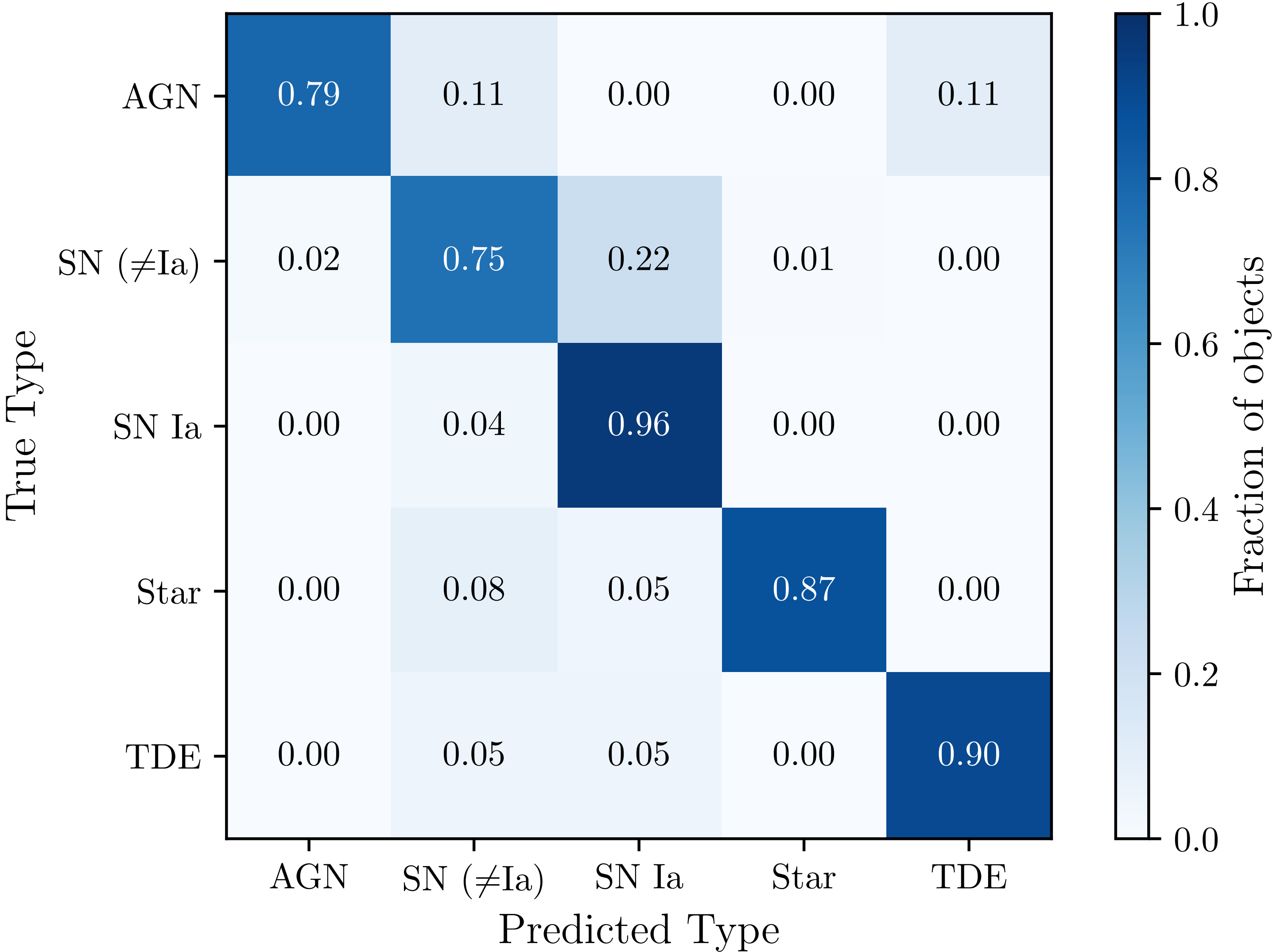
Evaluation with test sample

Including noisified
lightcurves in the test
sample



Evaluation with test sample

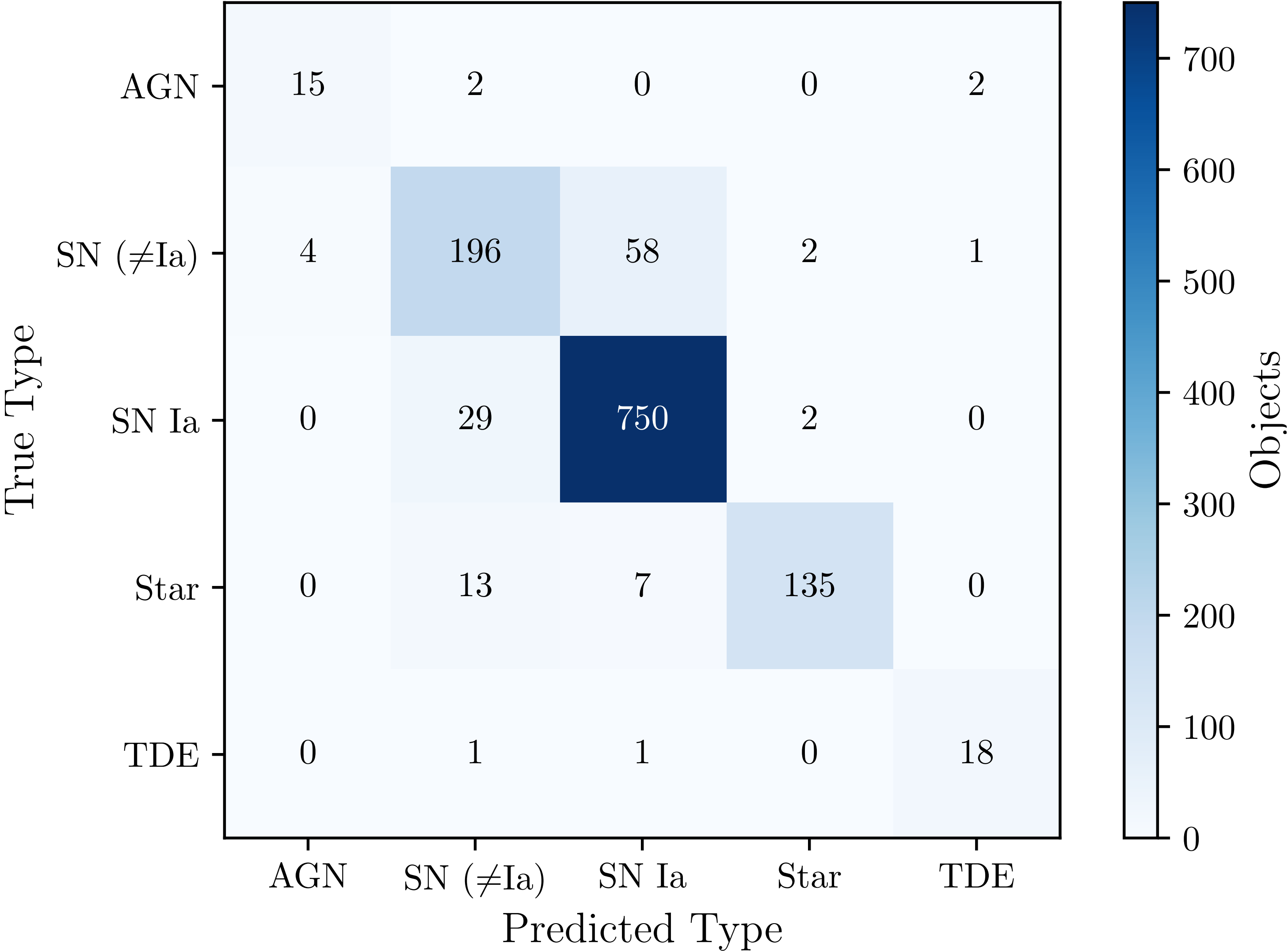
Not including noisified lightcurves in the test sample



Evaluation with test sample

Not including noisified
lightcurves in the test
sample

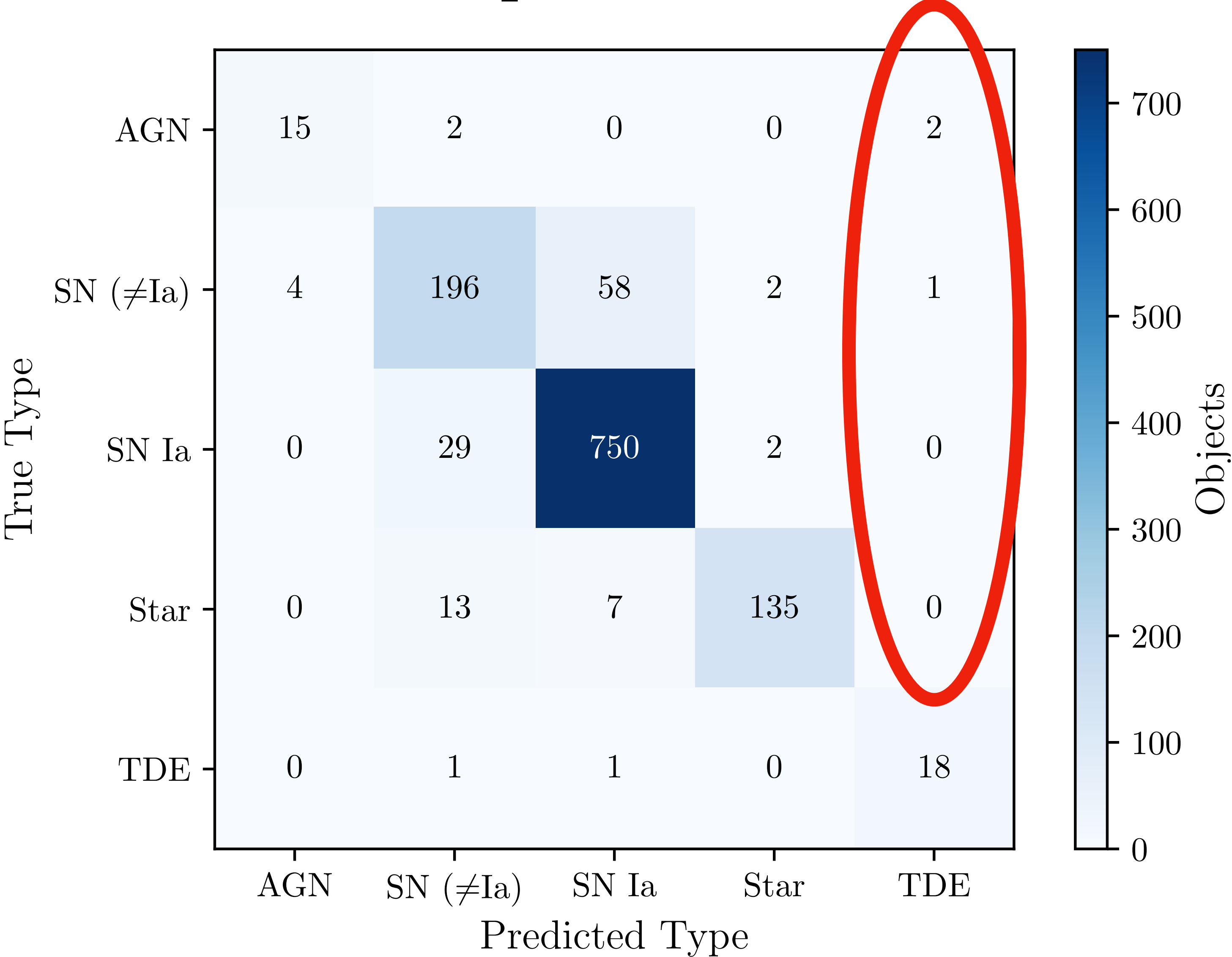
absolute numbers



Evaluation with test sample

Not including noisified
lightcurves in the test
sample

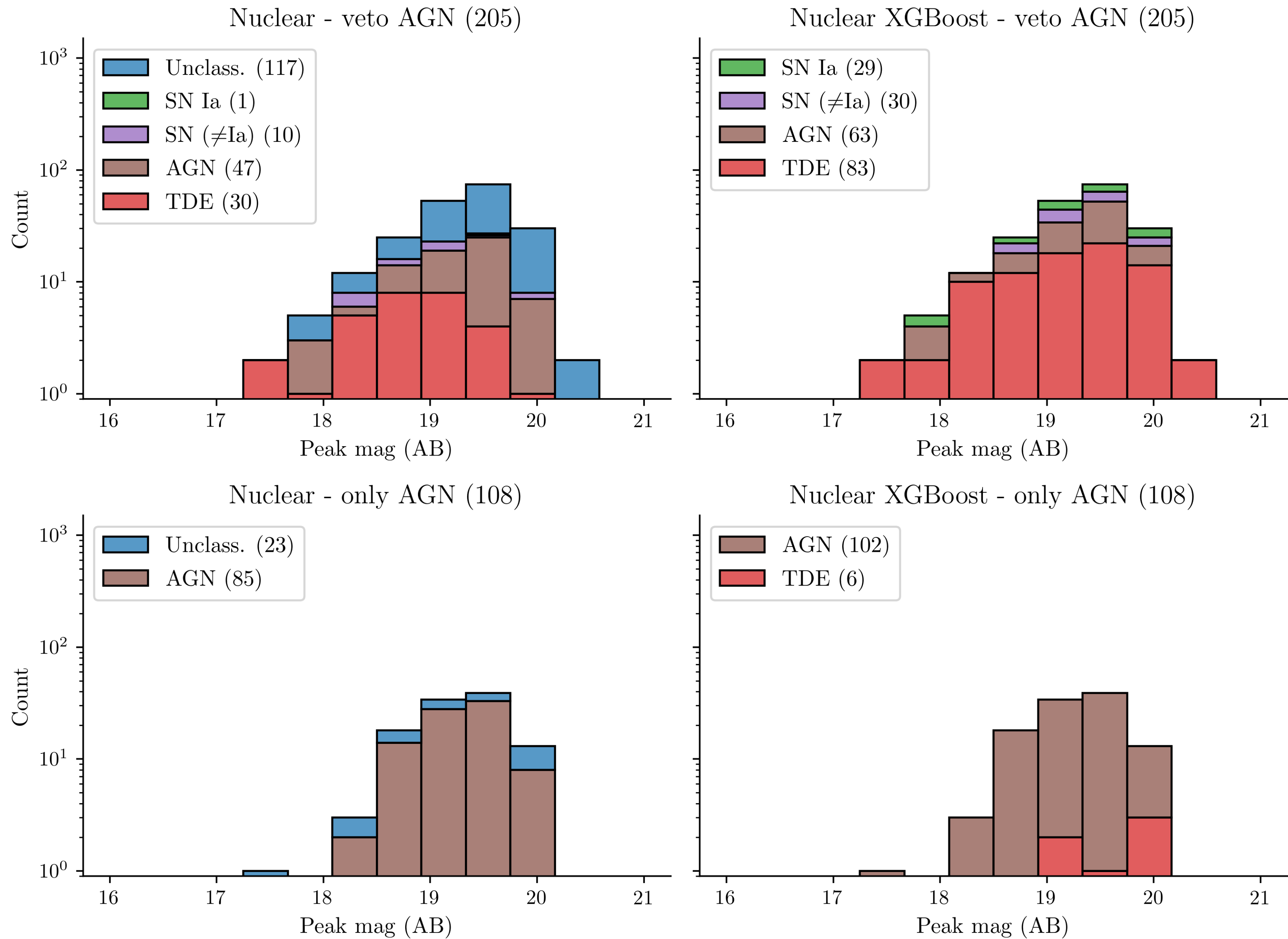
absolute numbers



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

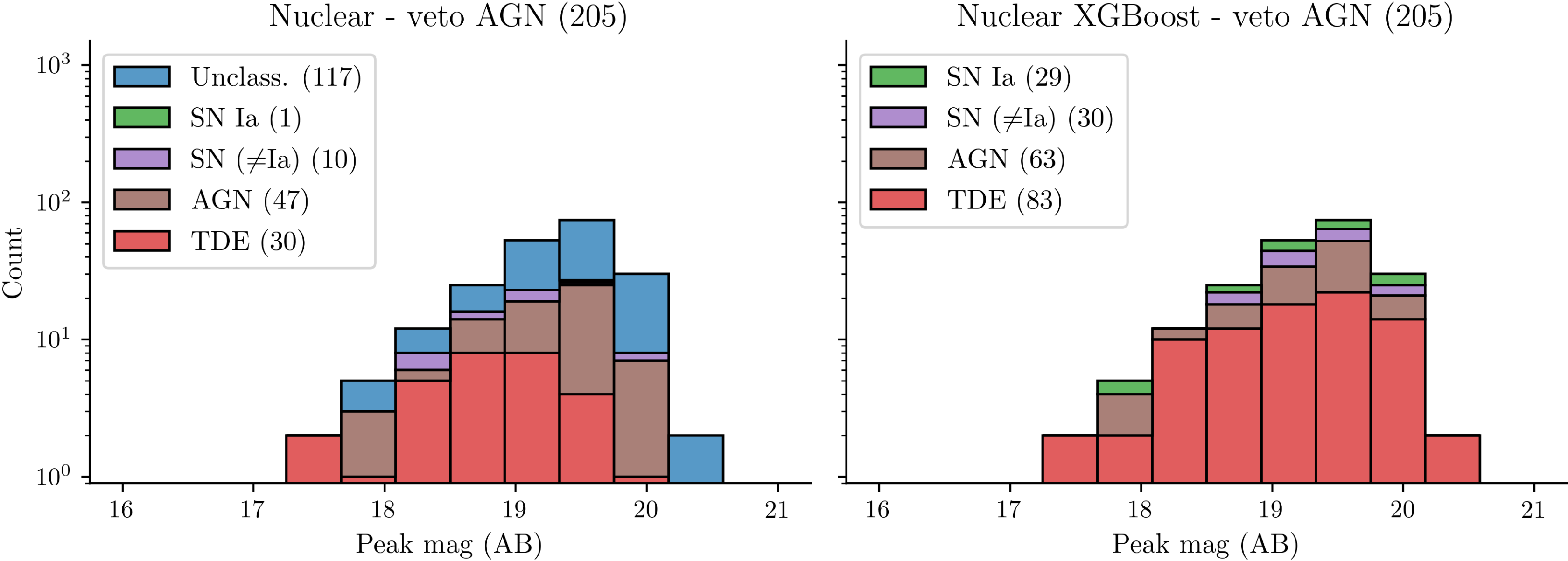
after all cuts

cut stage: exactly 1 flare

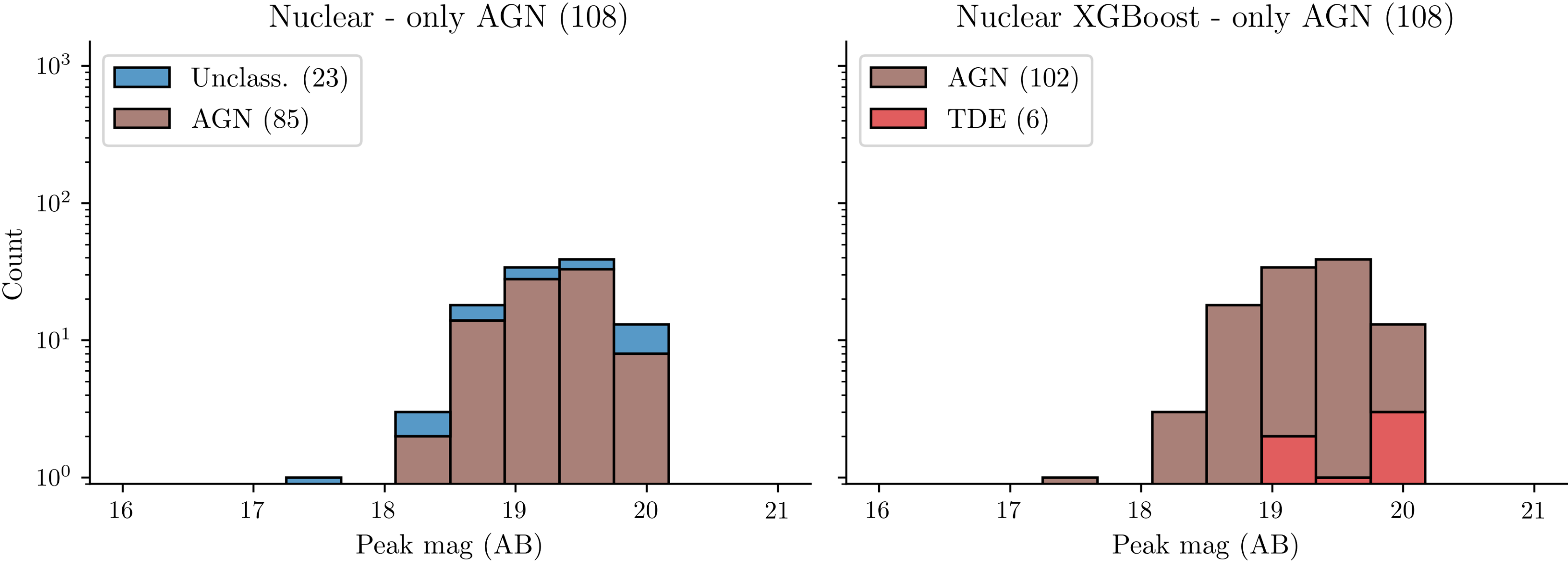


cut stage: exactly 1 flare

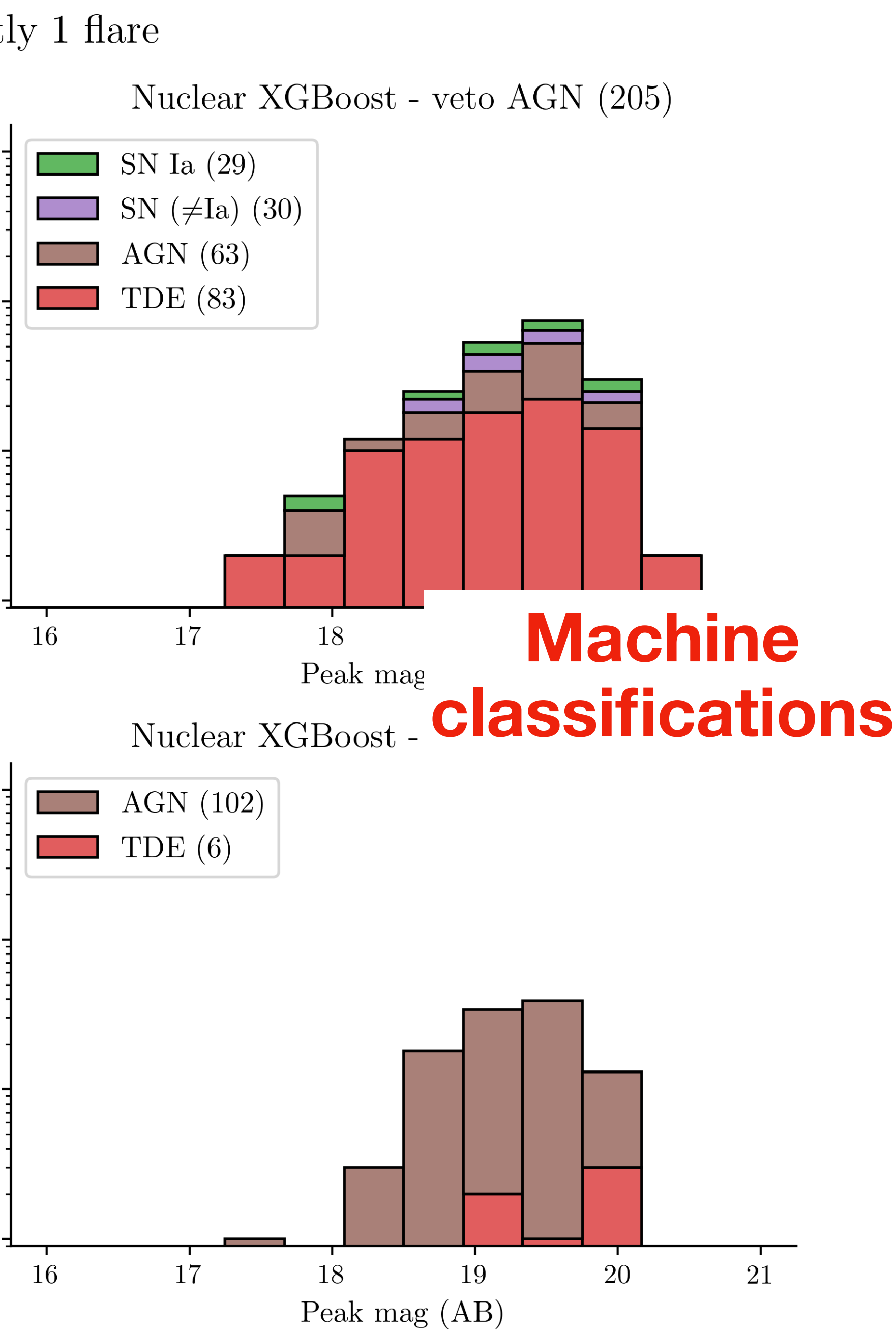
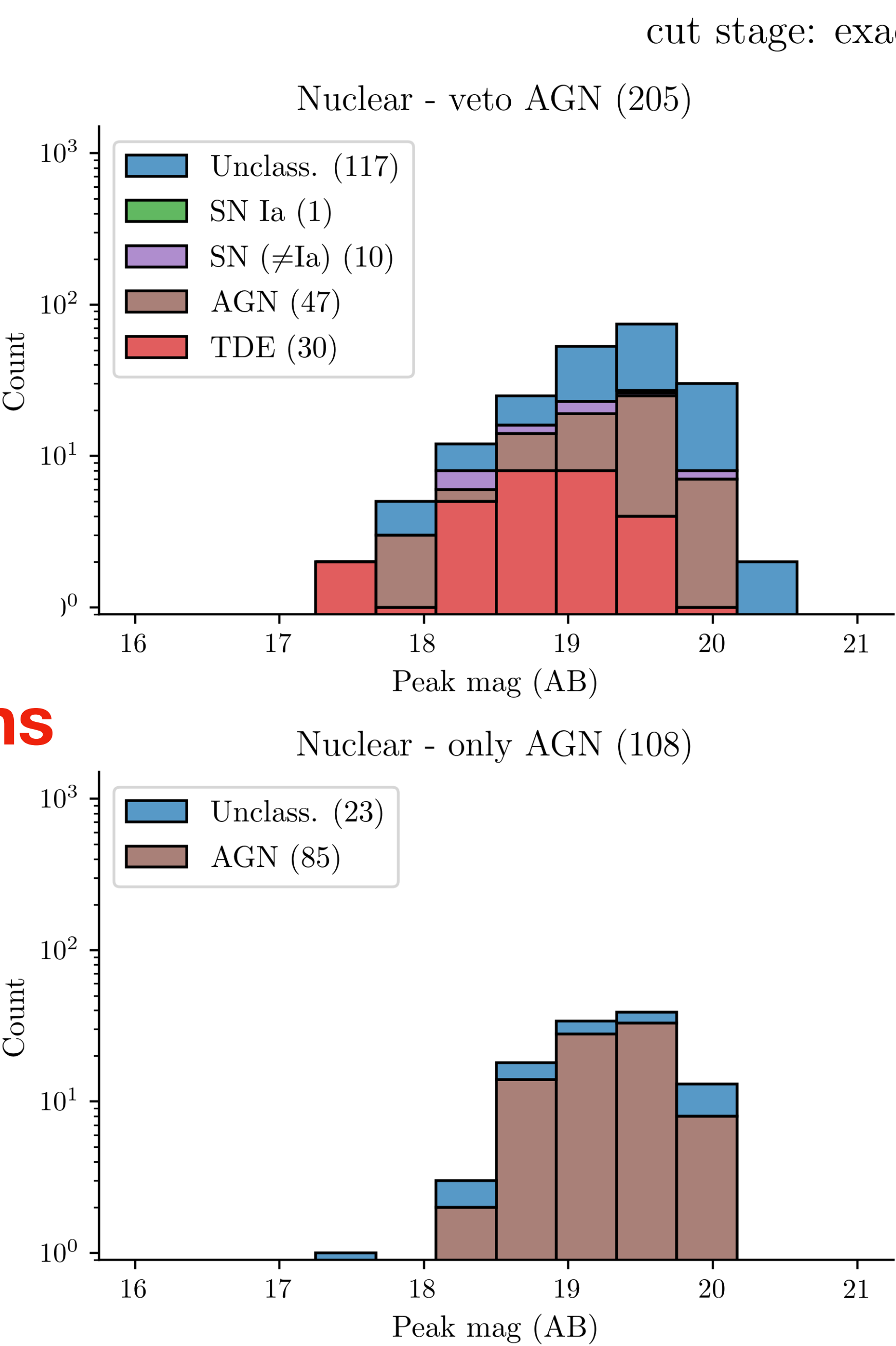
no Milliquas match
(not AGN)



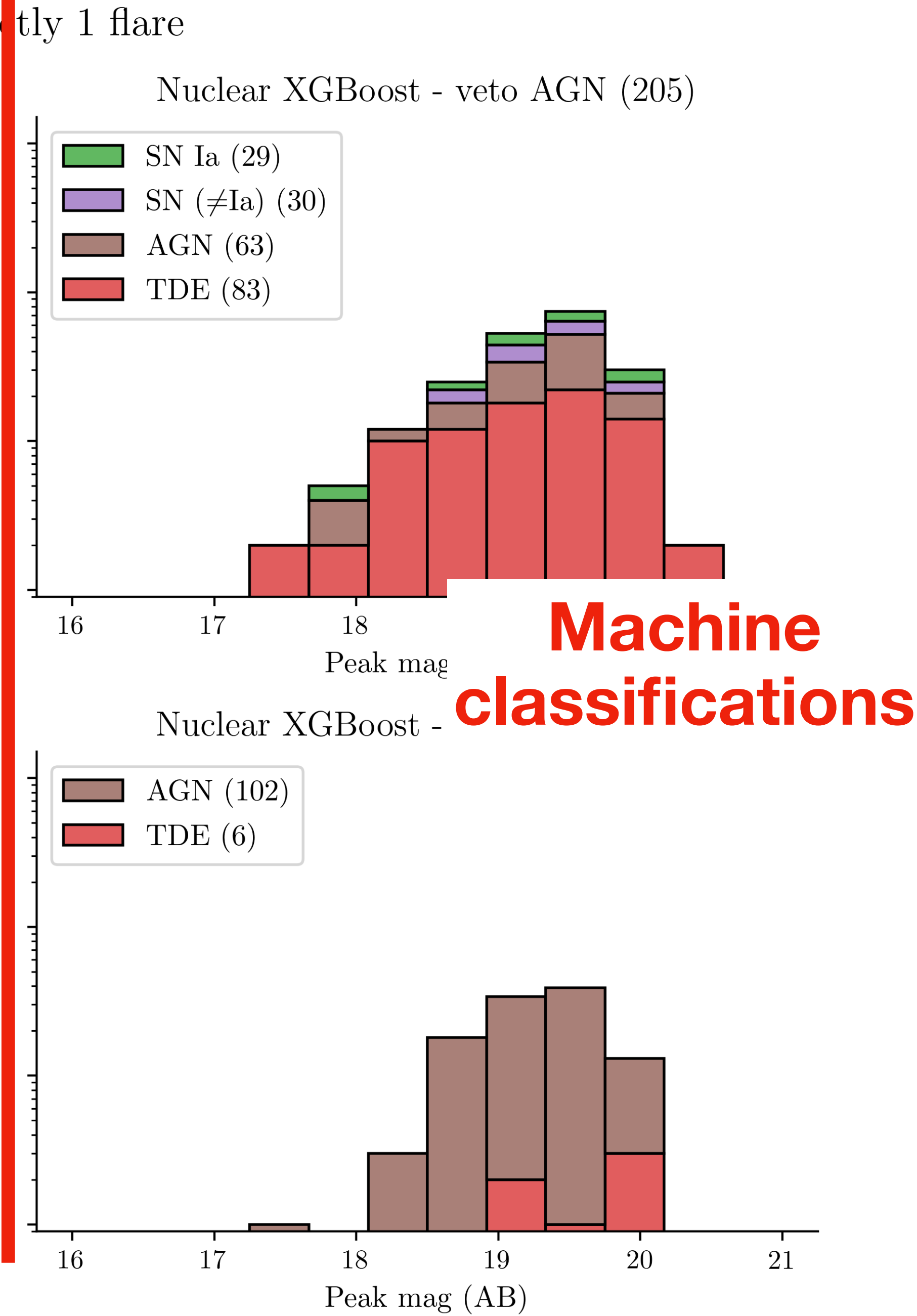
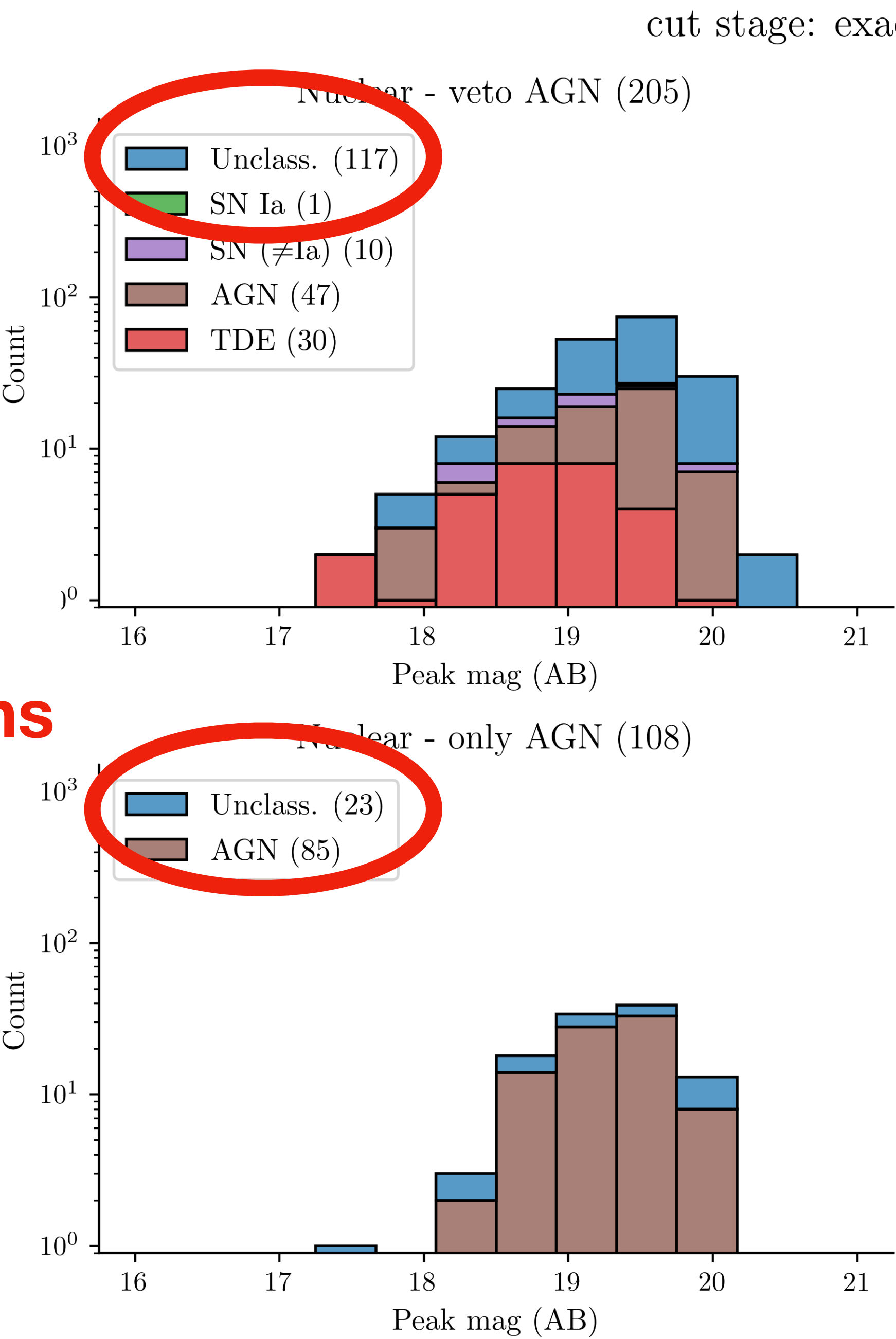
has Milliquas match
(AGN)



**Human
classifications**

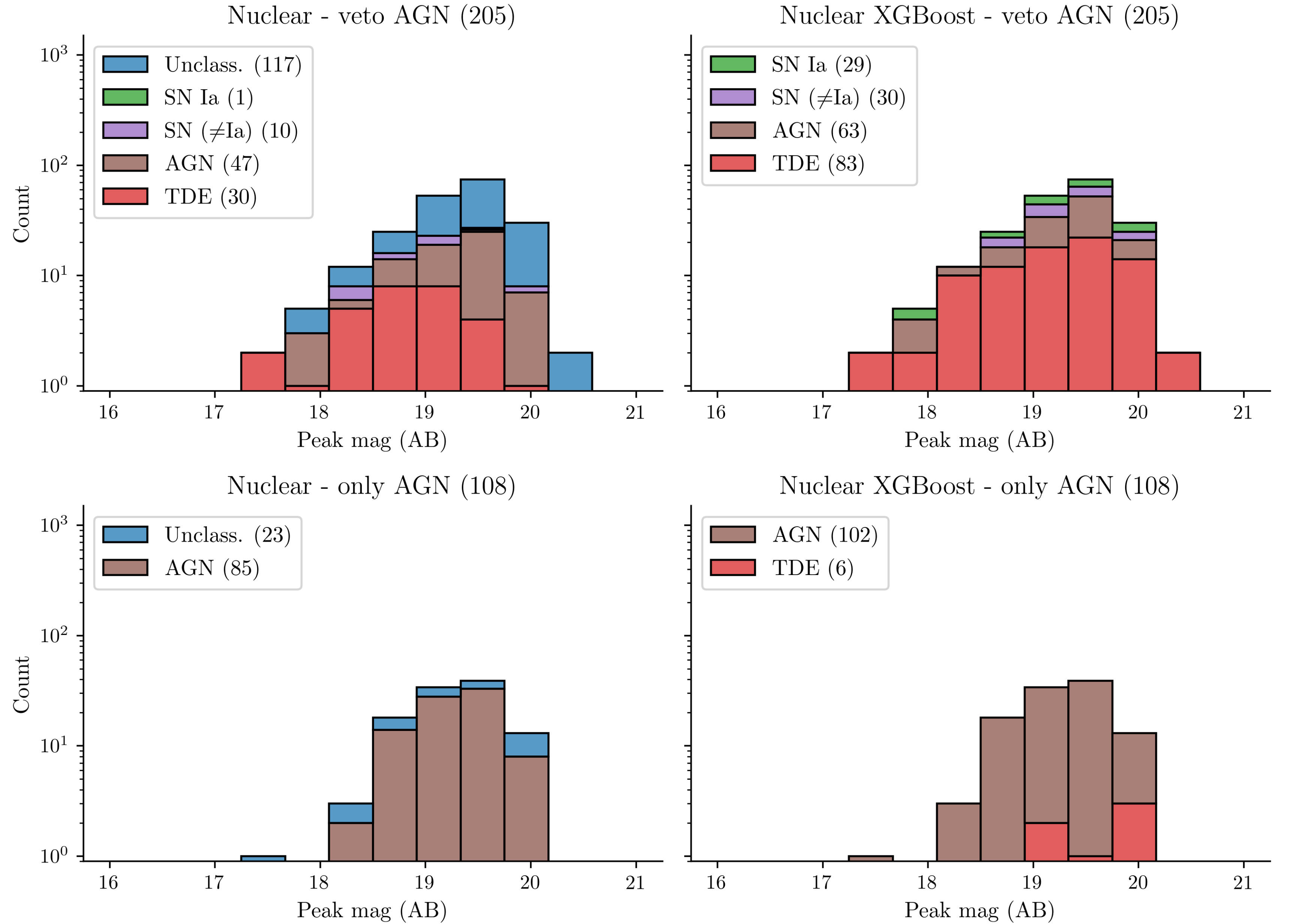


**Human
classifications**

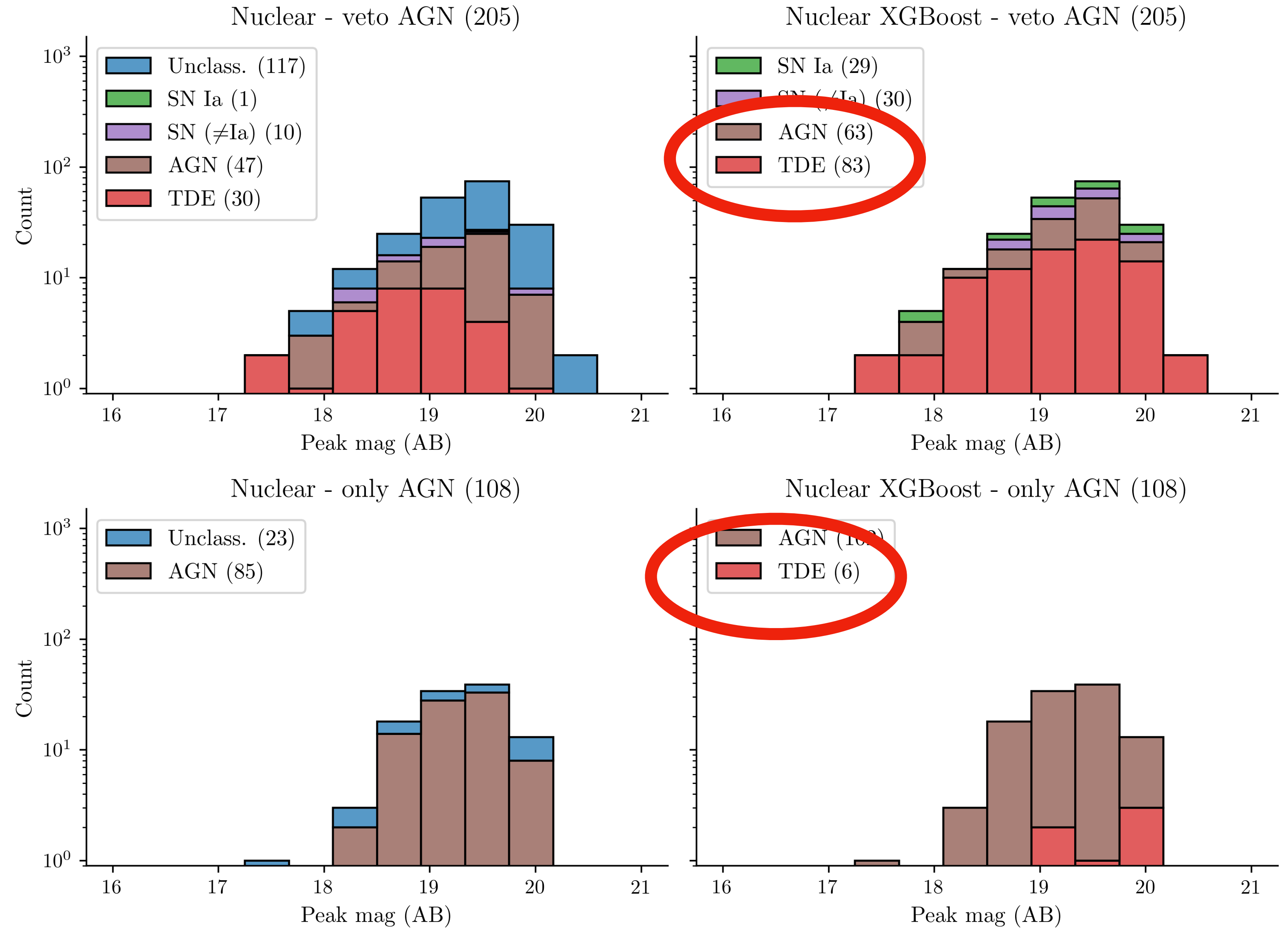


**Machine
classifications**

cut stage: exactly 1 flare



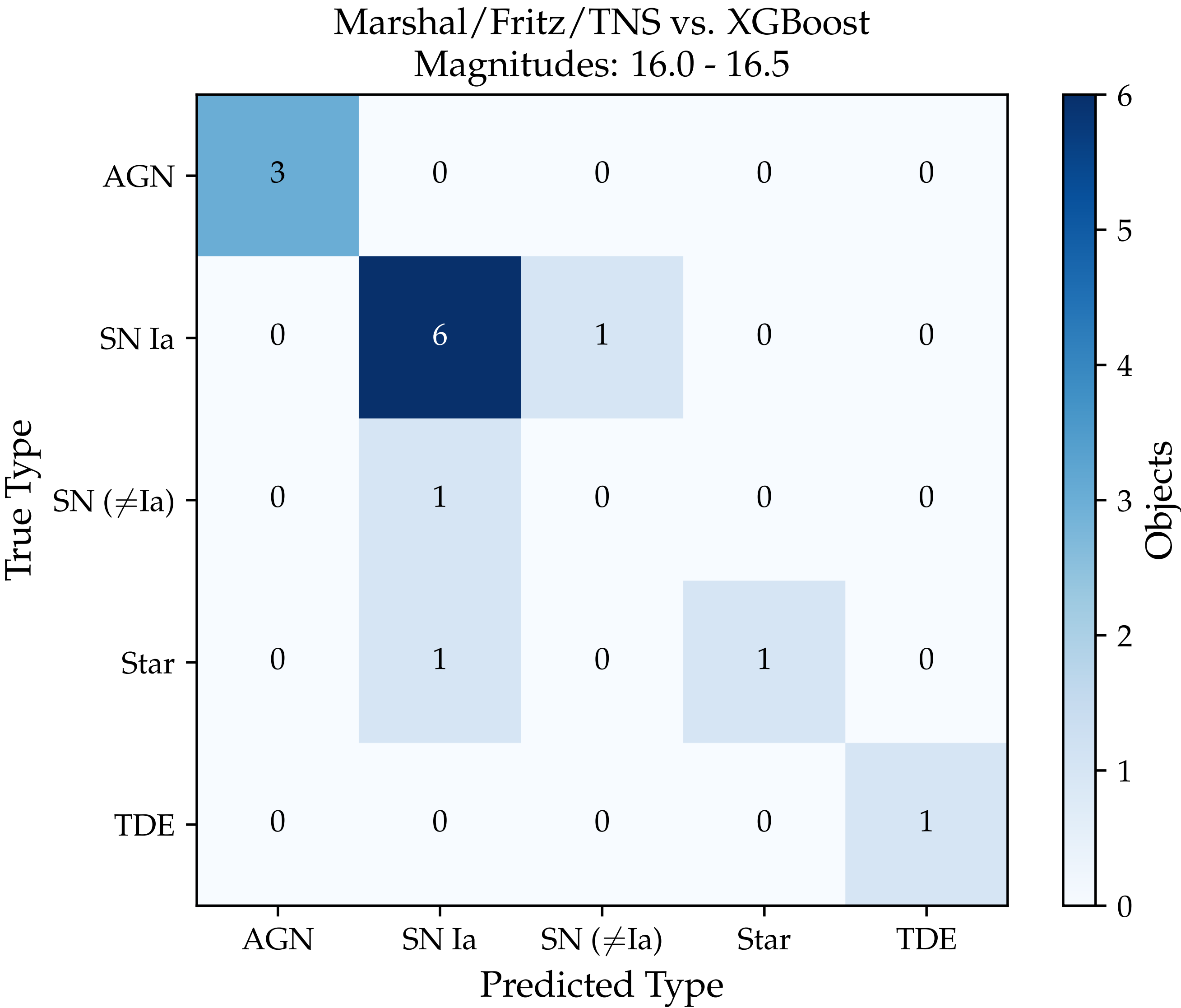
cut stage: exactly 1 flare



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

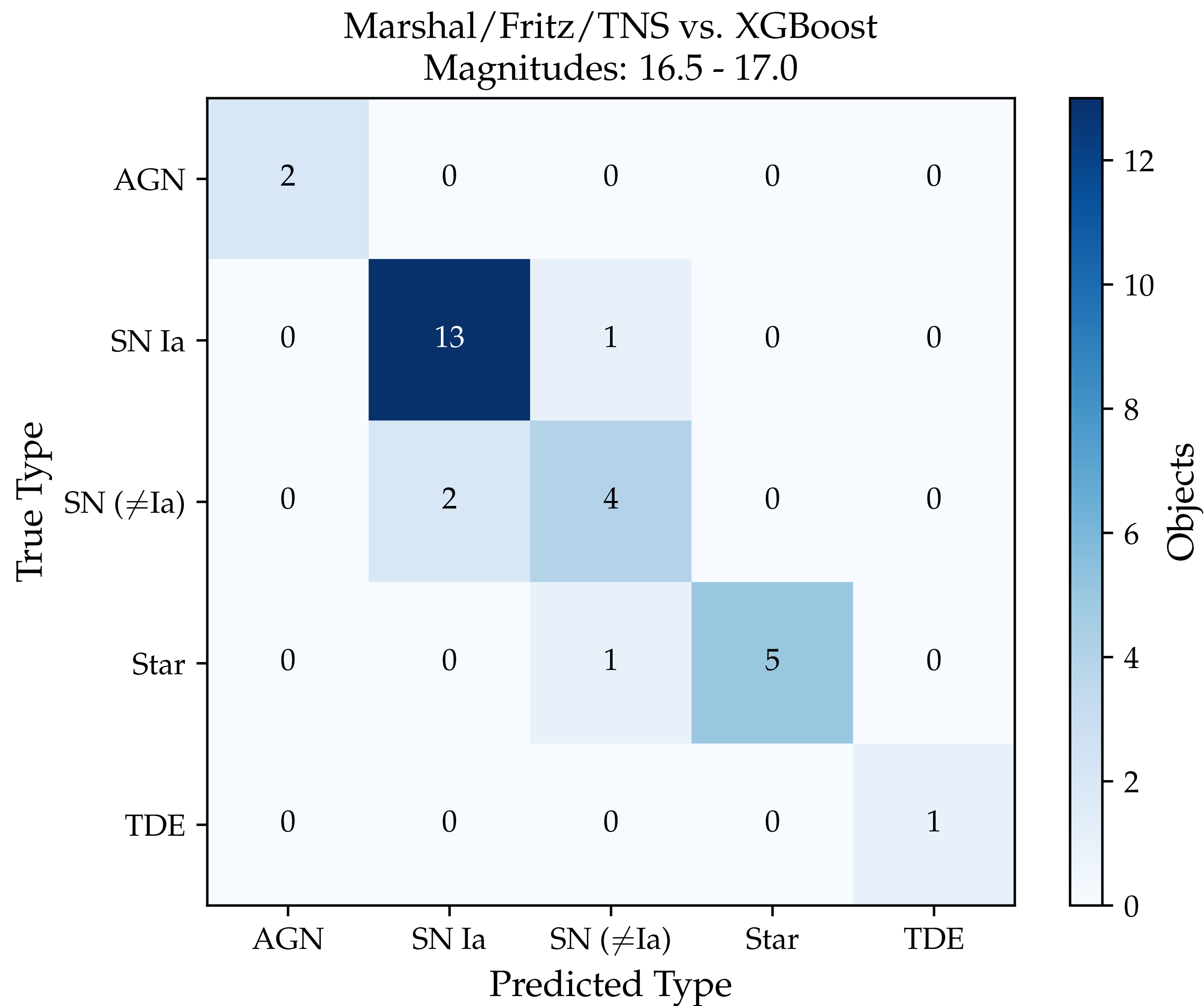
Evaluation with unsecure truth

Mag:
16.0-16.5



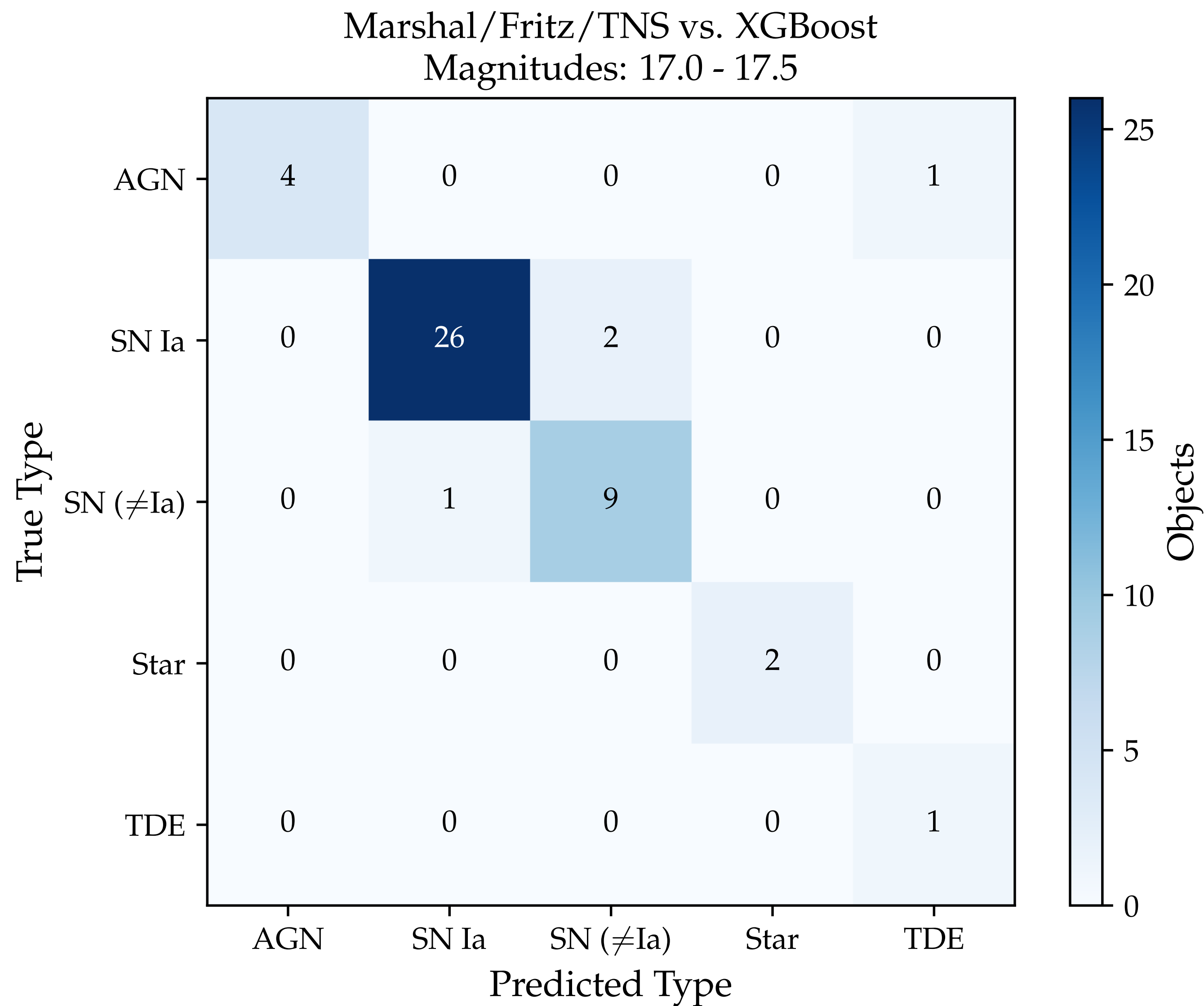
Evaluation with unsecure truth

Mag:
16.5-17.0



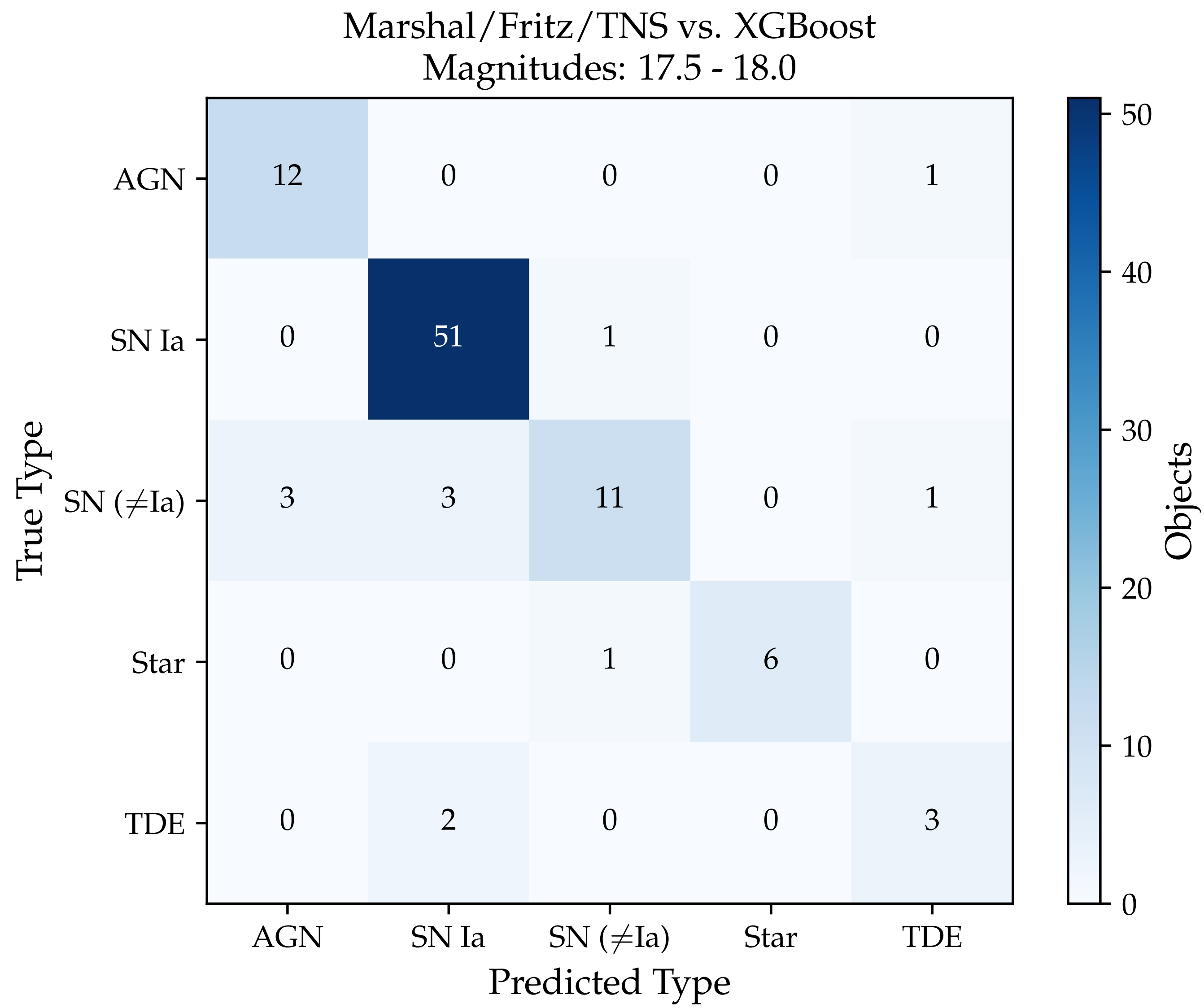
Evaluation with unsecure truth

Mag:
17.0-17.5



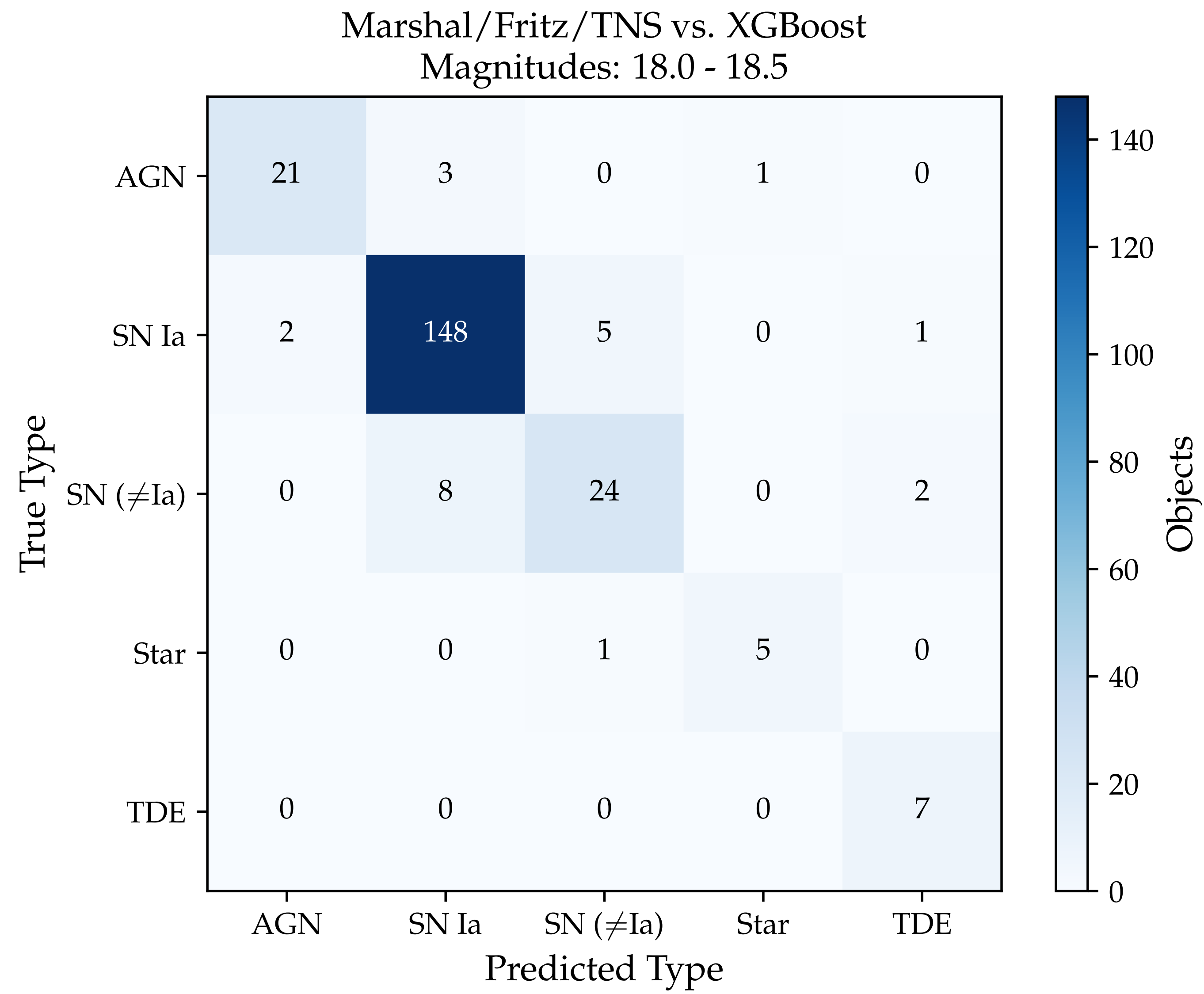
Evaluation with unsecure truth

Mag:
17.5-18.0



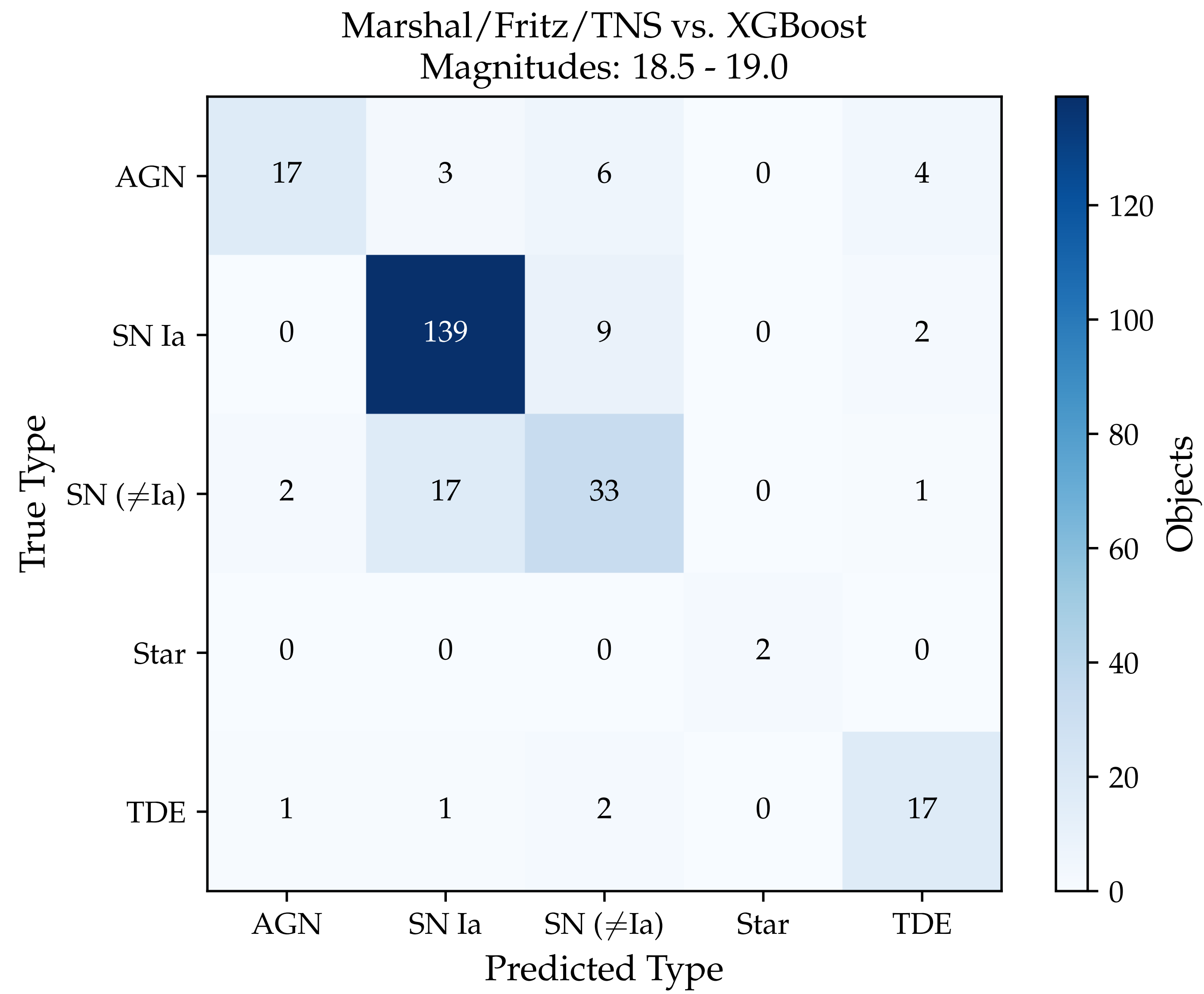
Evaluation with unsecure truth

Mag:
18.0-18.5



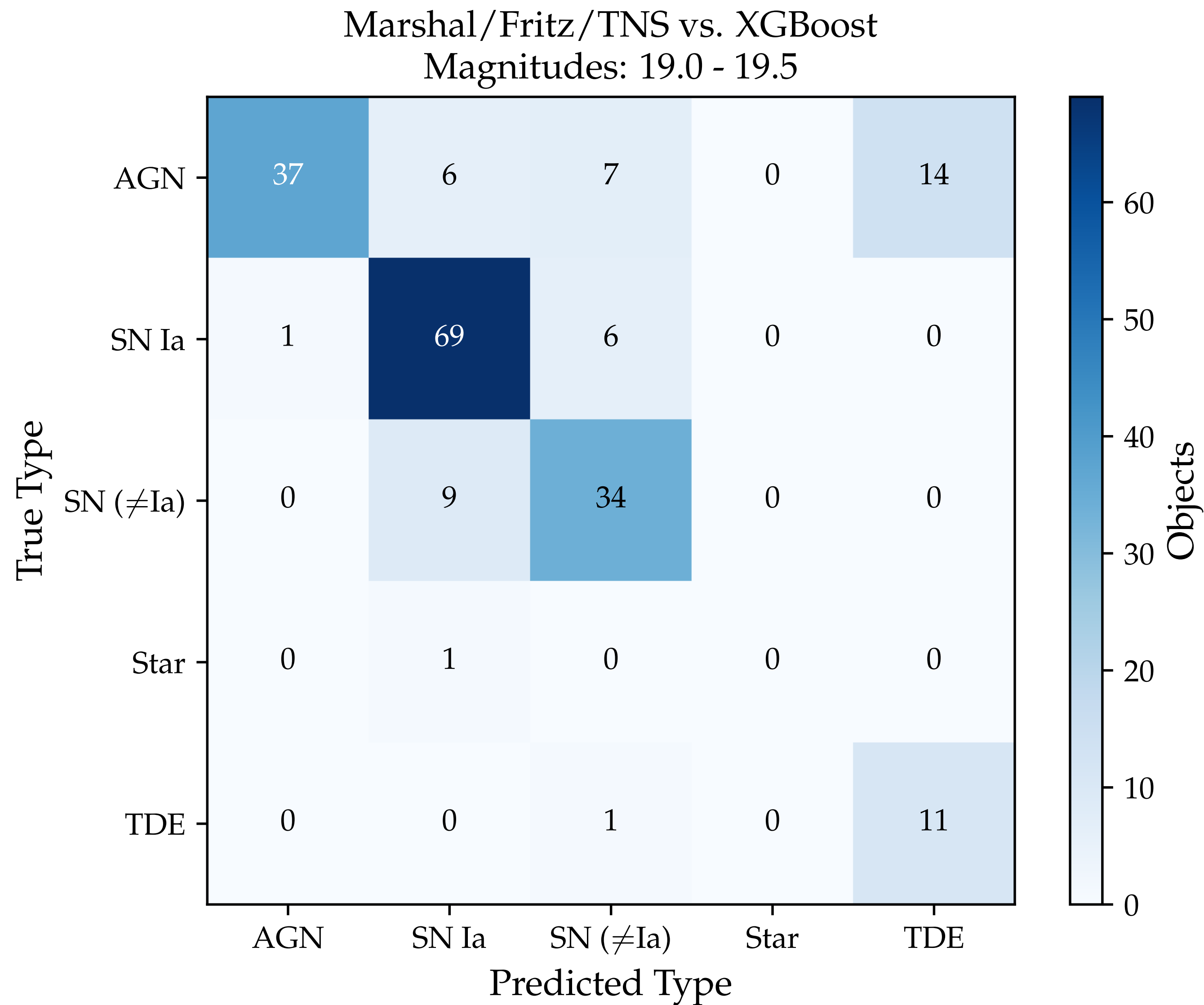
Evaluation with unsecure truth

Mag:
18.5-19.0



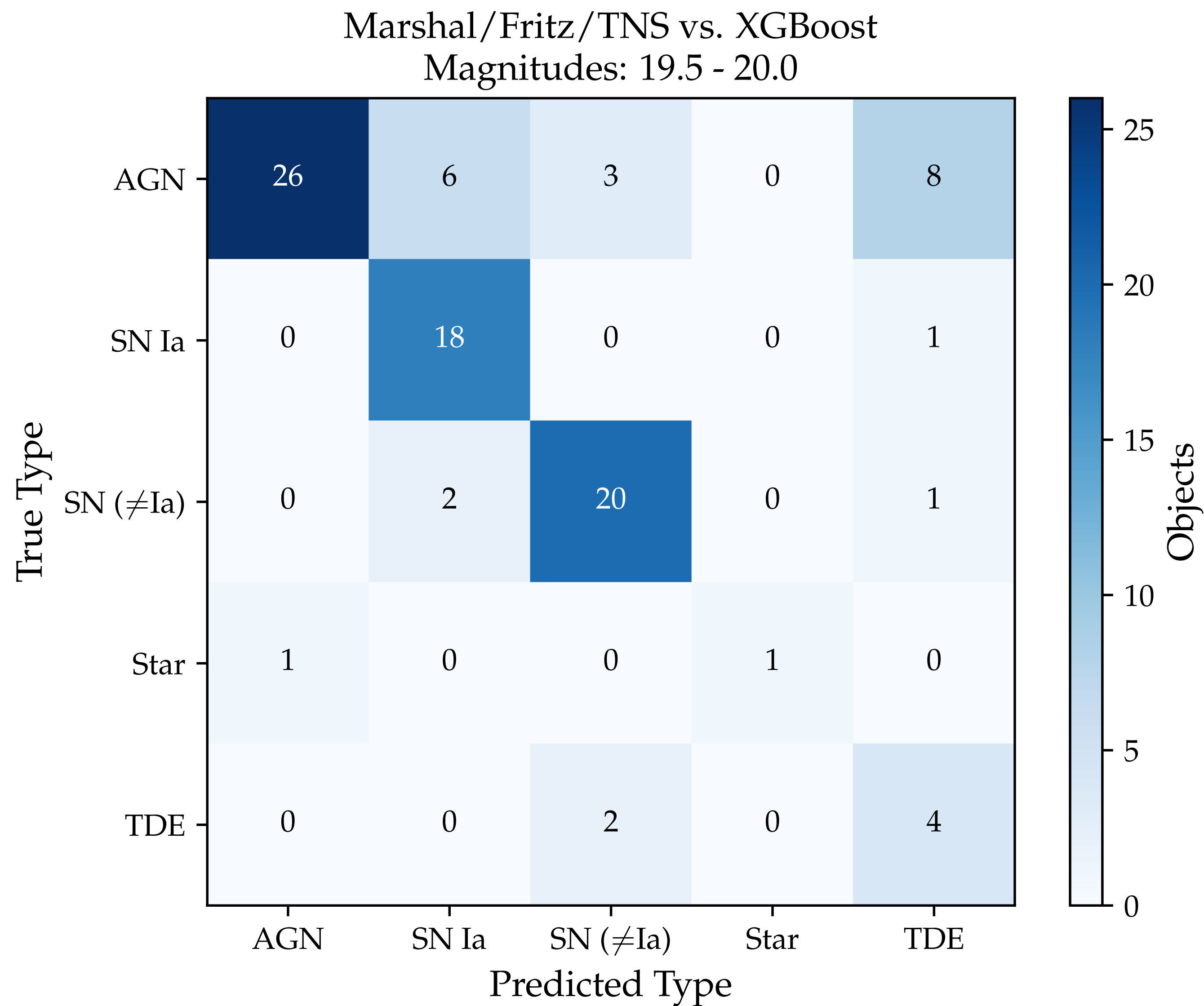
Evaluation with unsecure truth

Mag:
19.0-19.5



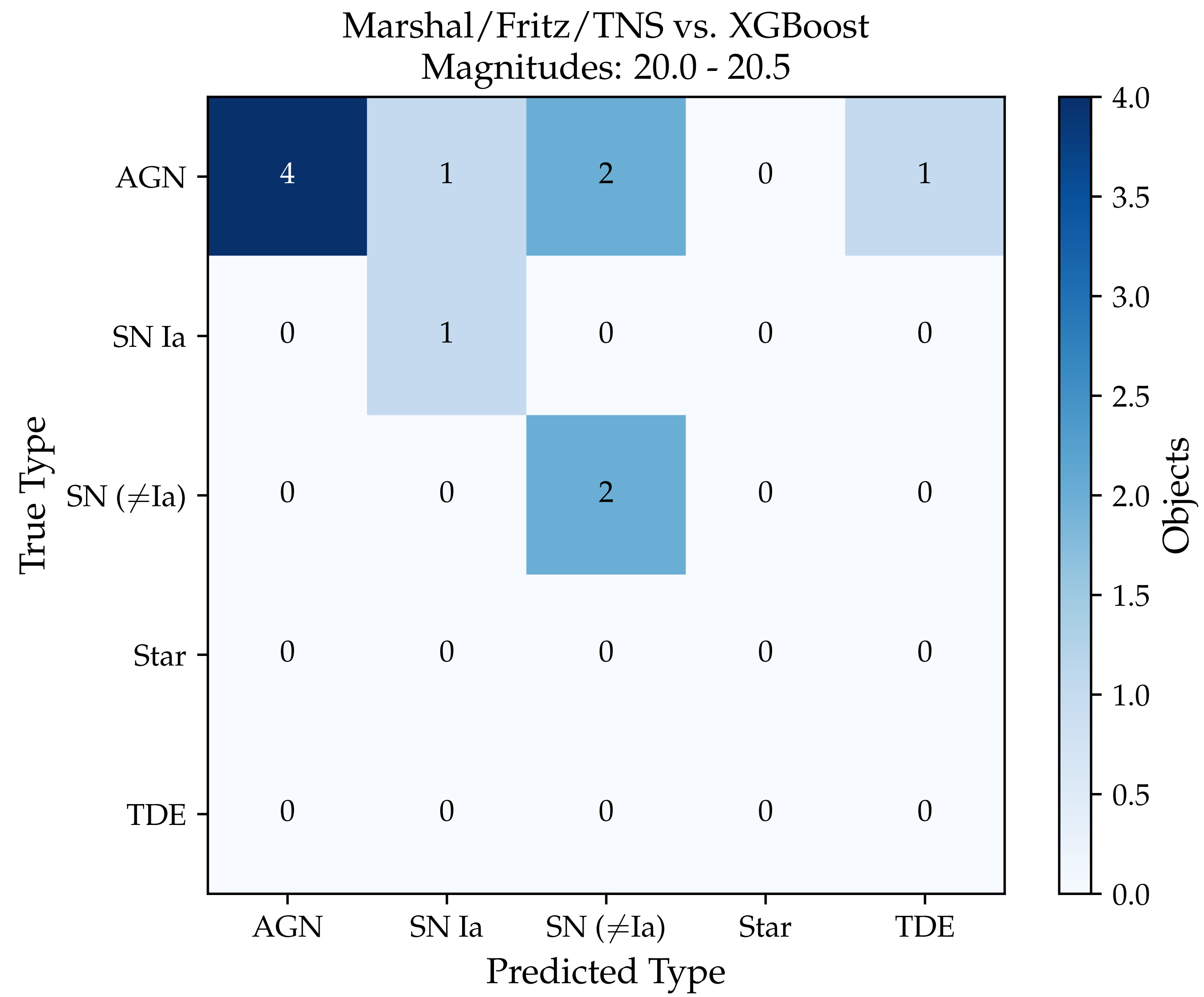
Evaluation with unsecure truth

Mag:
19.5-20.0



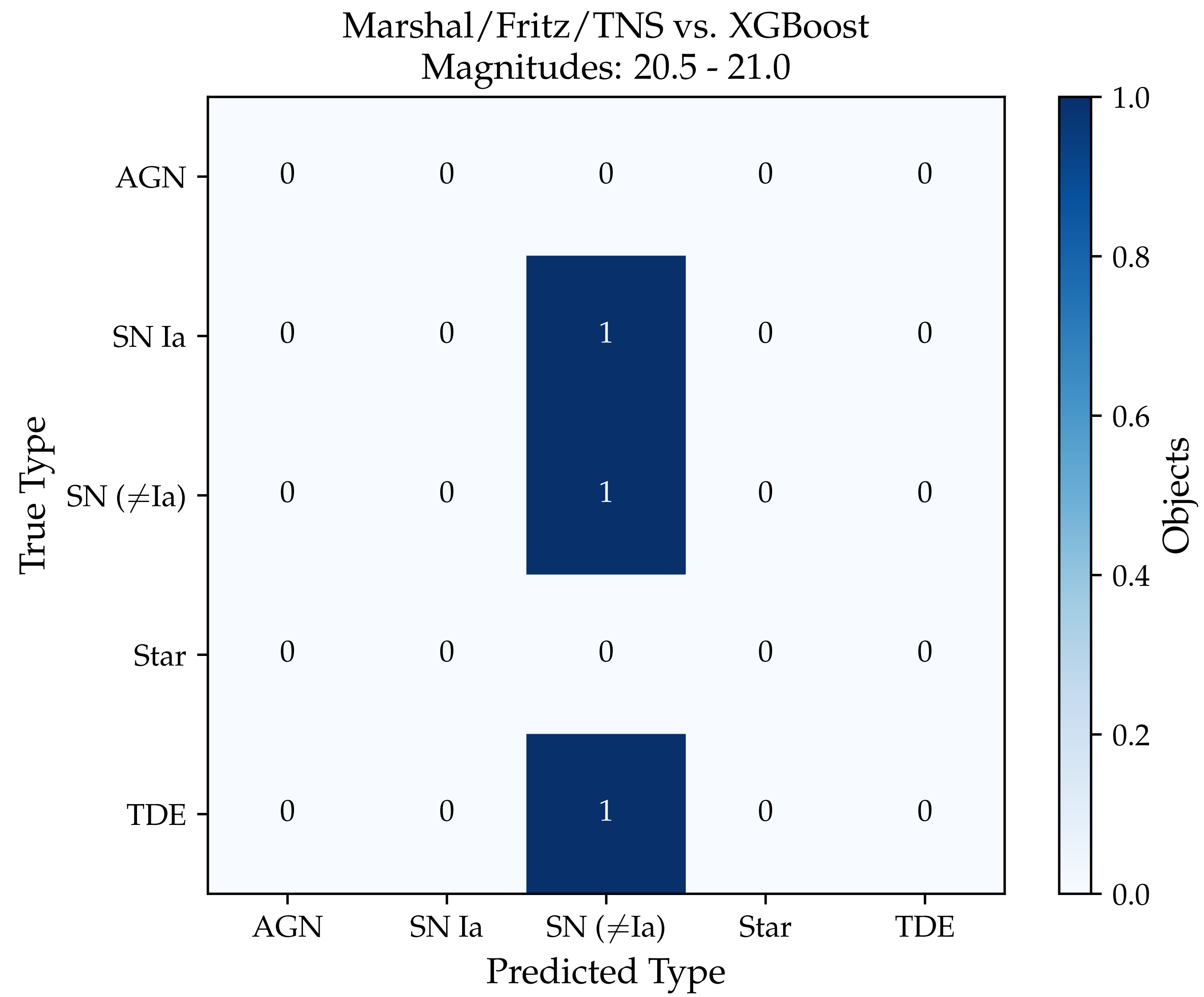
Evaluation with unsecure truth

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?

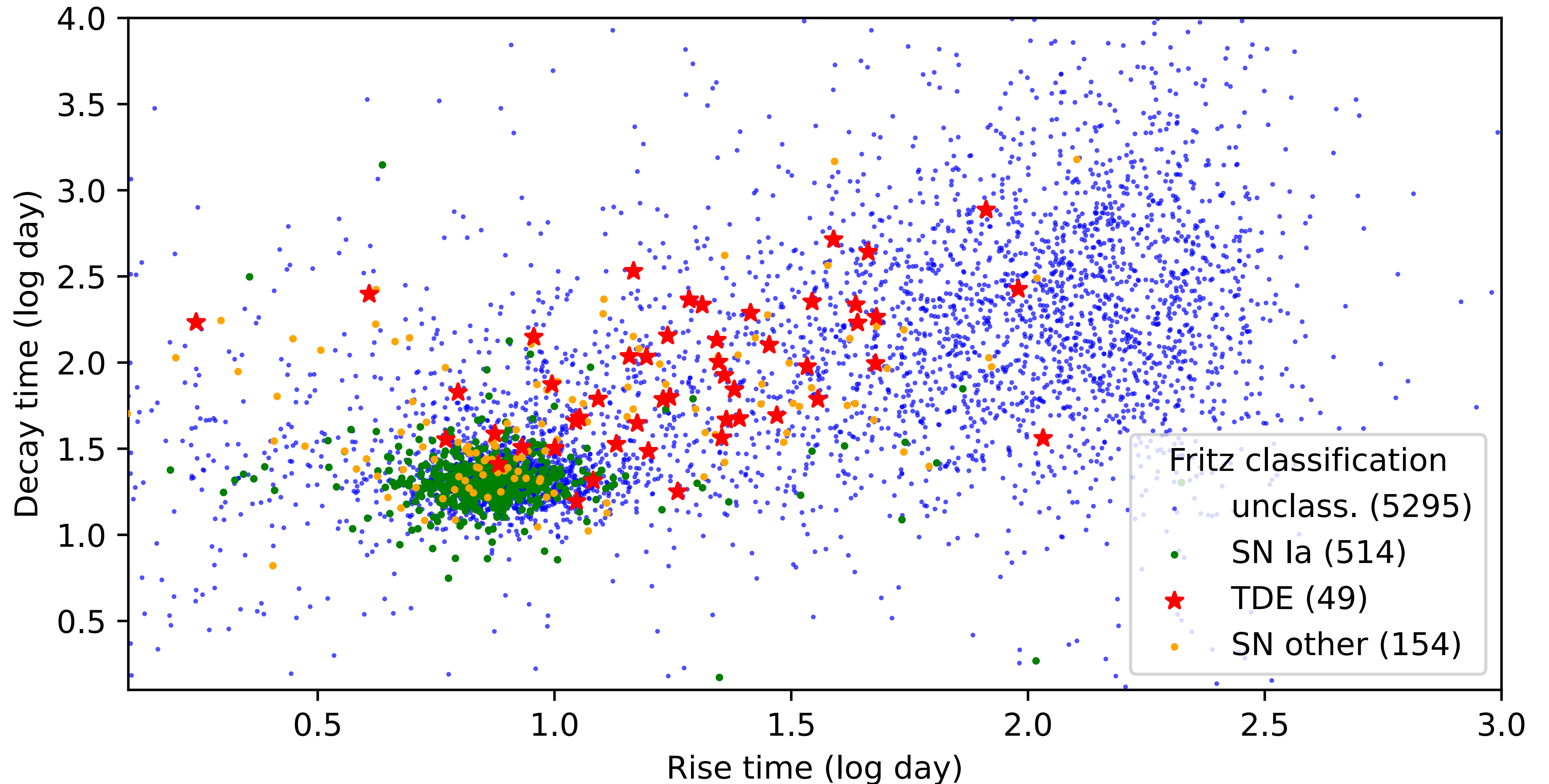
Waterfall plots?

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

Anomaly detection?

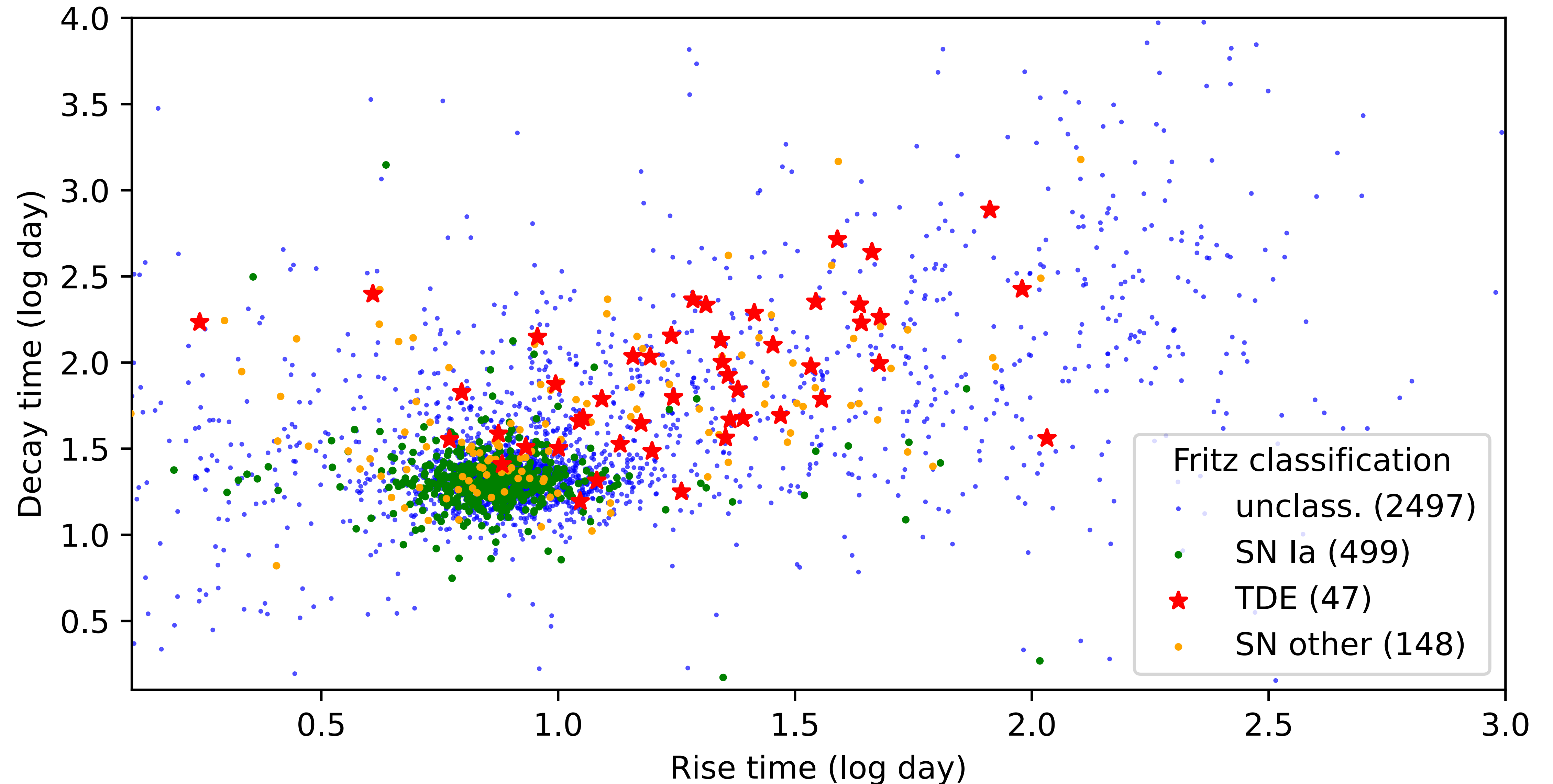
No cut (6012 transients)

Purity: 0.8% / Efficiency: 100.0 %



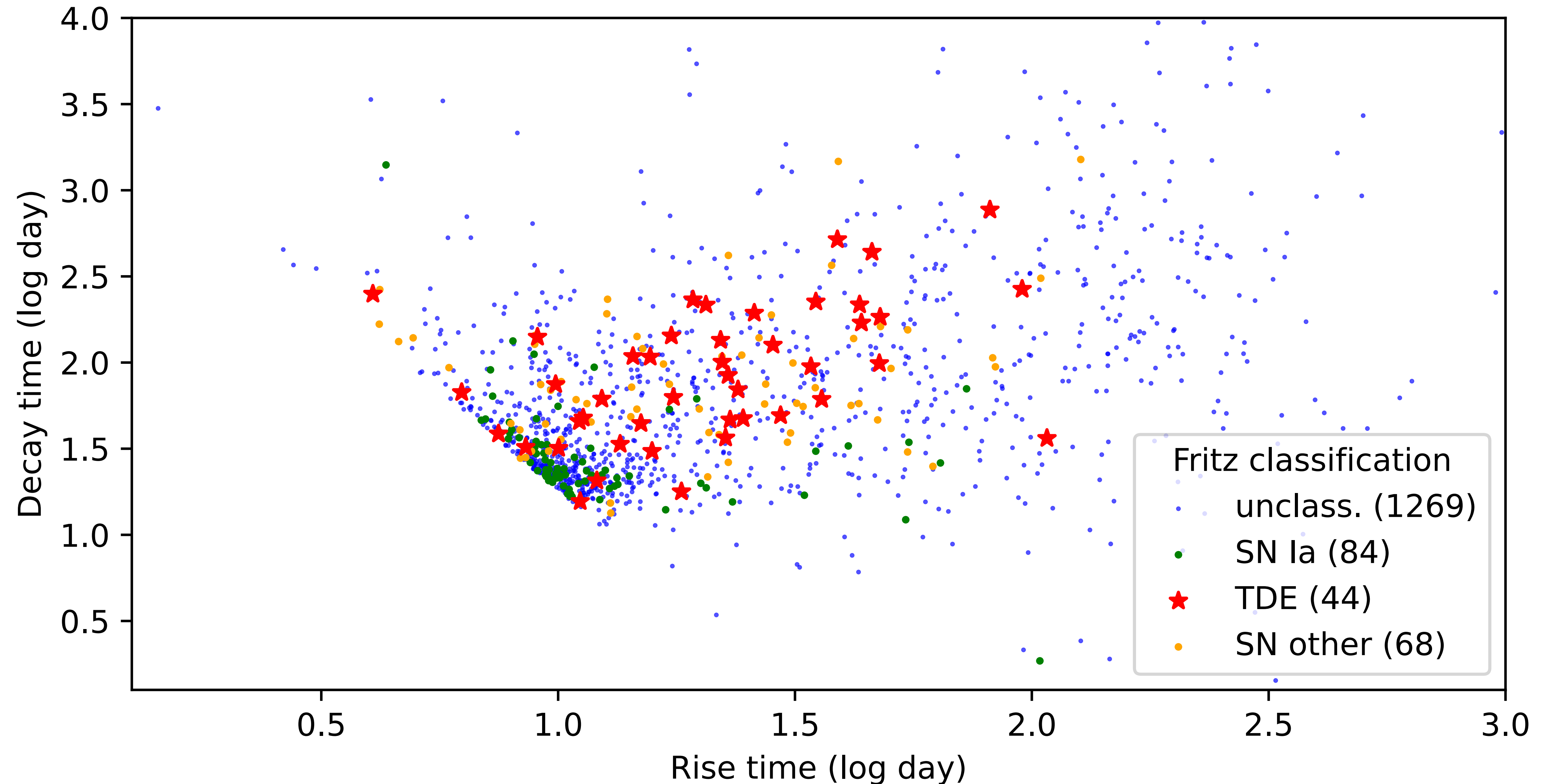
WISE colors (3191 transients)

Purity: 1.5% / Efficiency: 95.9 %



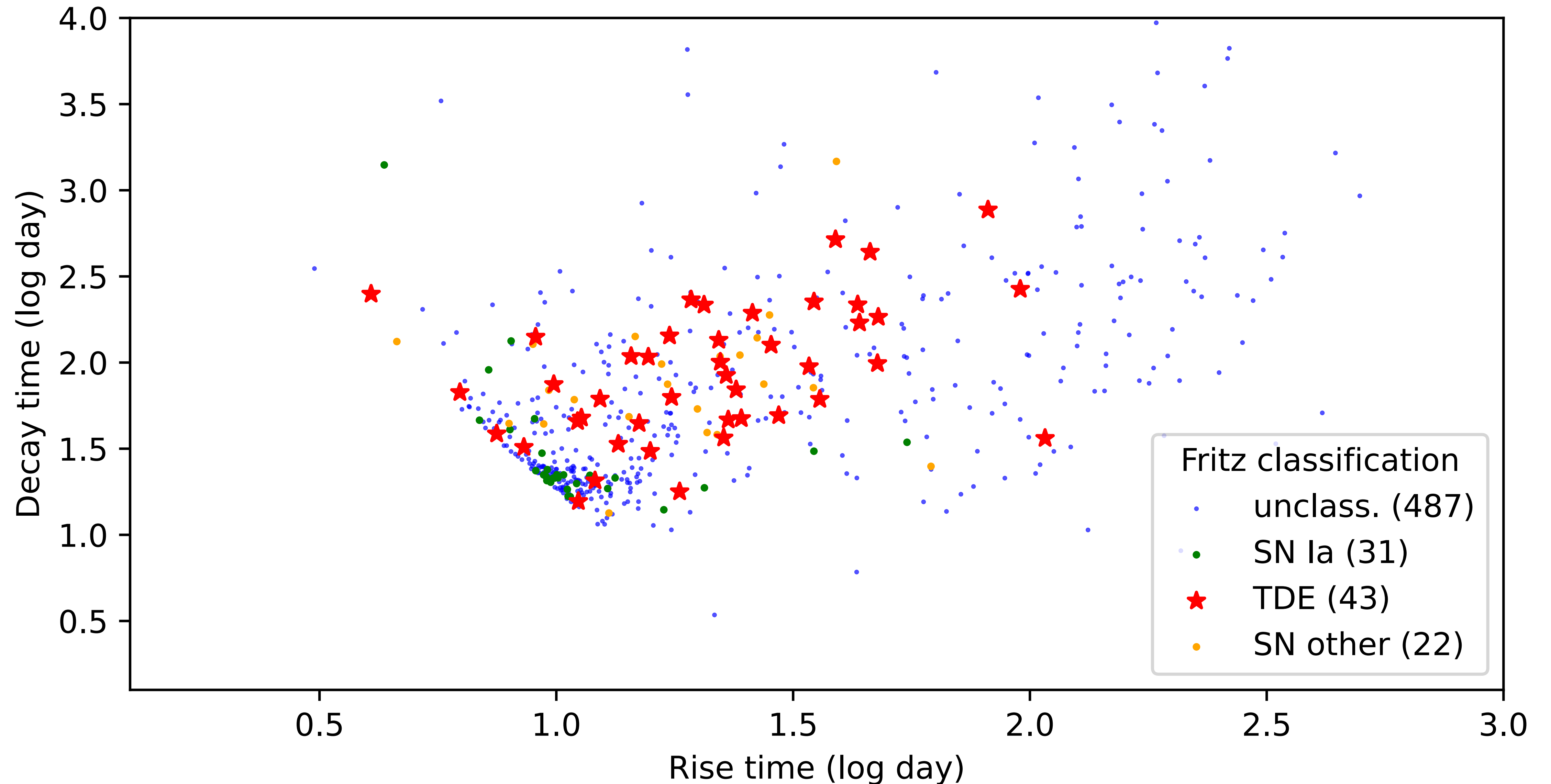
Diagonal cut (1465 transients)

Purity: 3.0% / Efficiency: 89.8 %



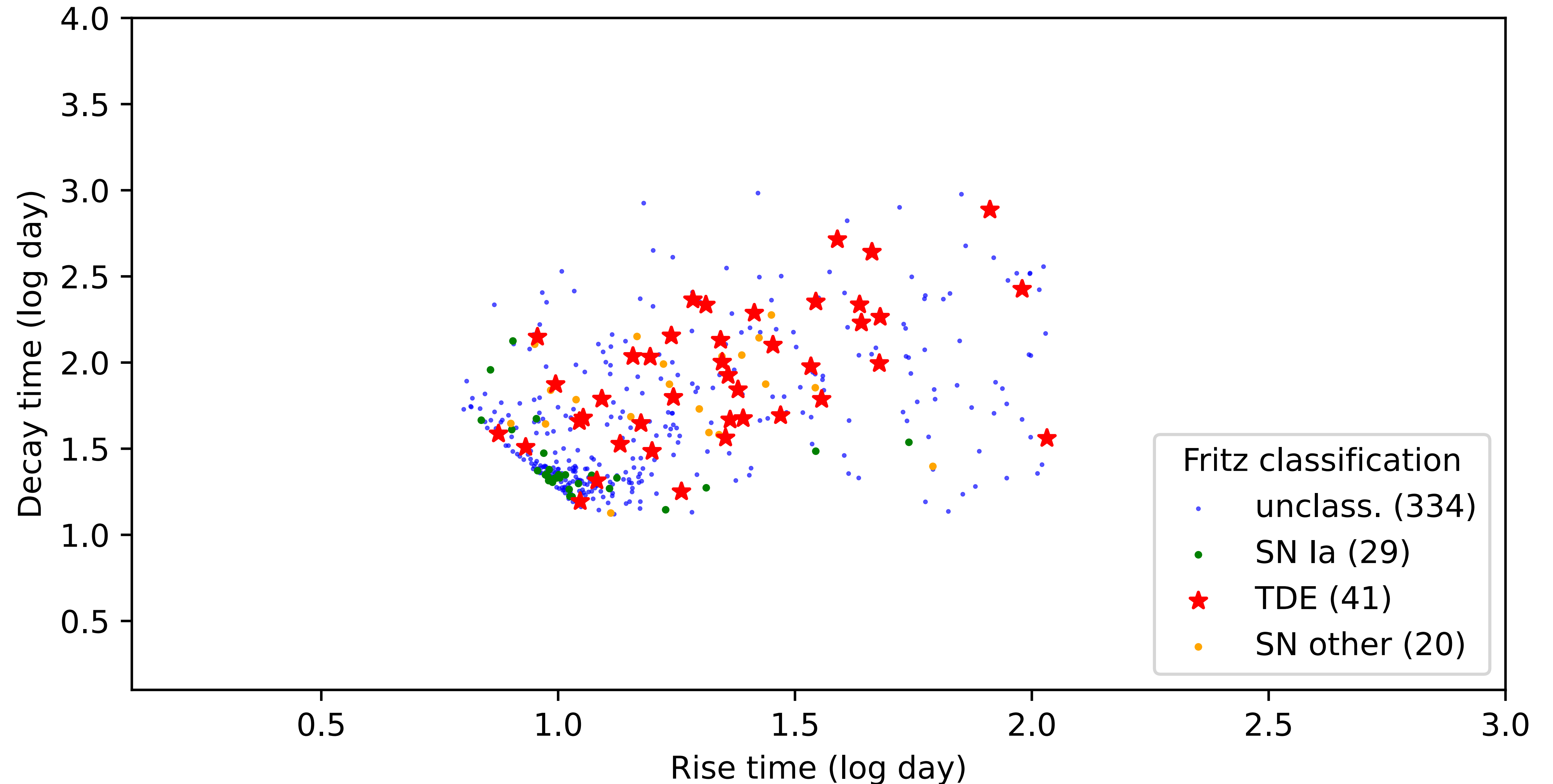
Temperature cut (583 transients)

Purity: 7.4% / Efficiency: 87.8 %



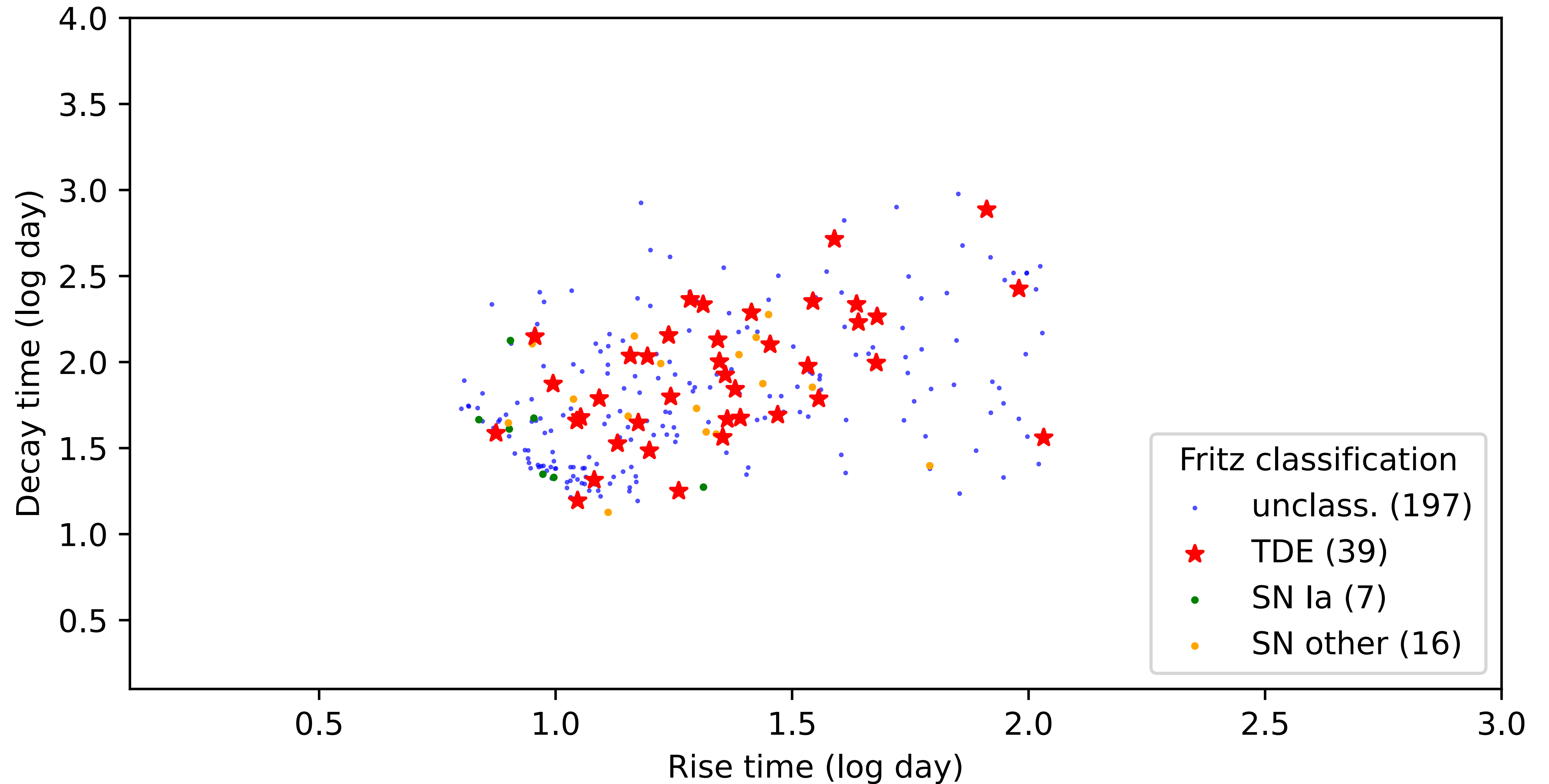
Rise-decay cut (424 transients)

Purity: 9.7% / Efficiency: 83.7 %



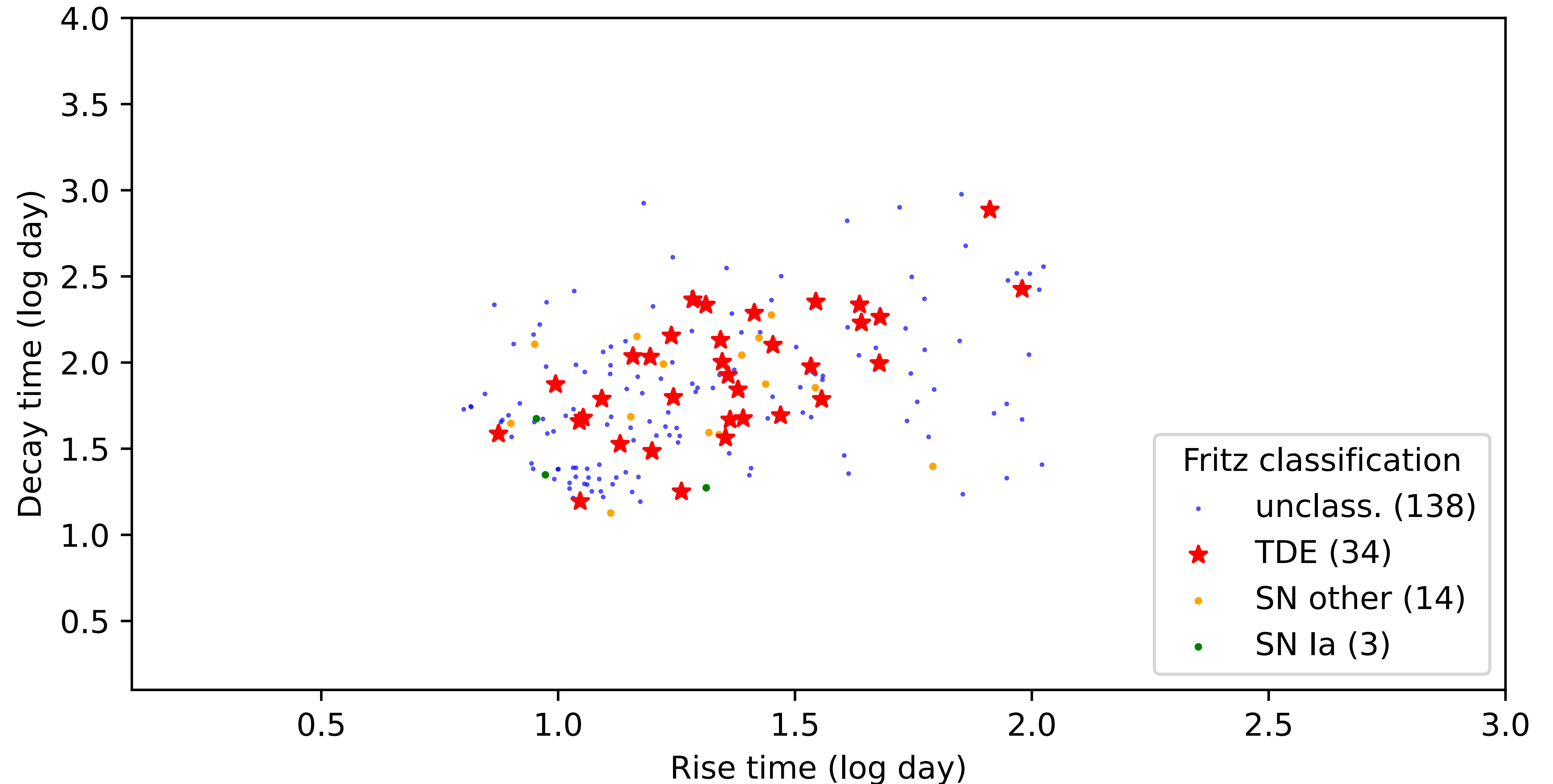
Chisquare cut (259 transients)

Purity: 15.1% / Efficiency: 79.6 %

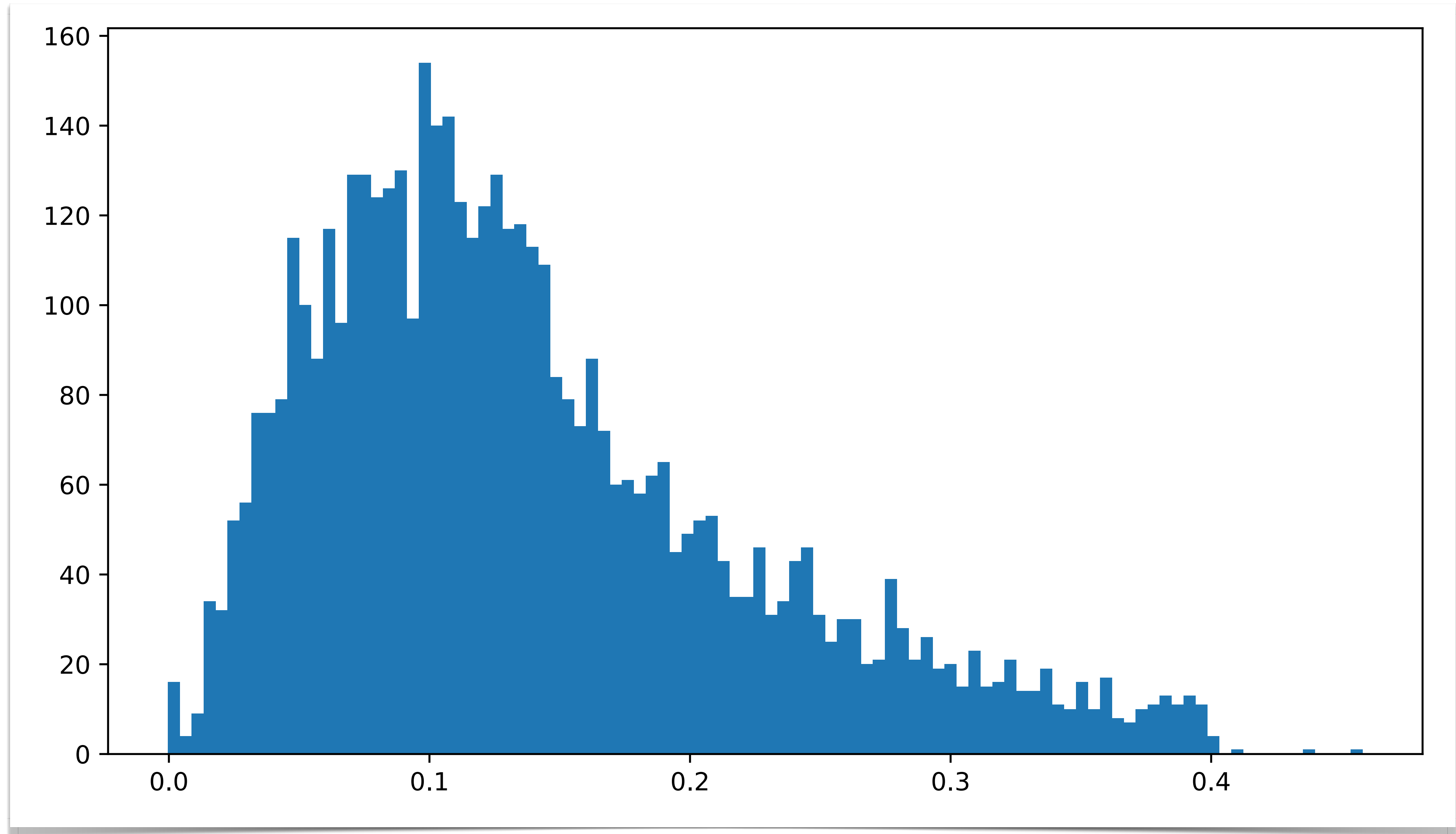


Bayesian block cut (189 transients)

Purity: 18.0% / Efficiency: 69.4 %

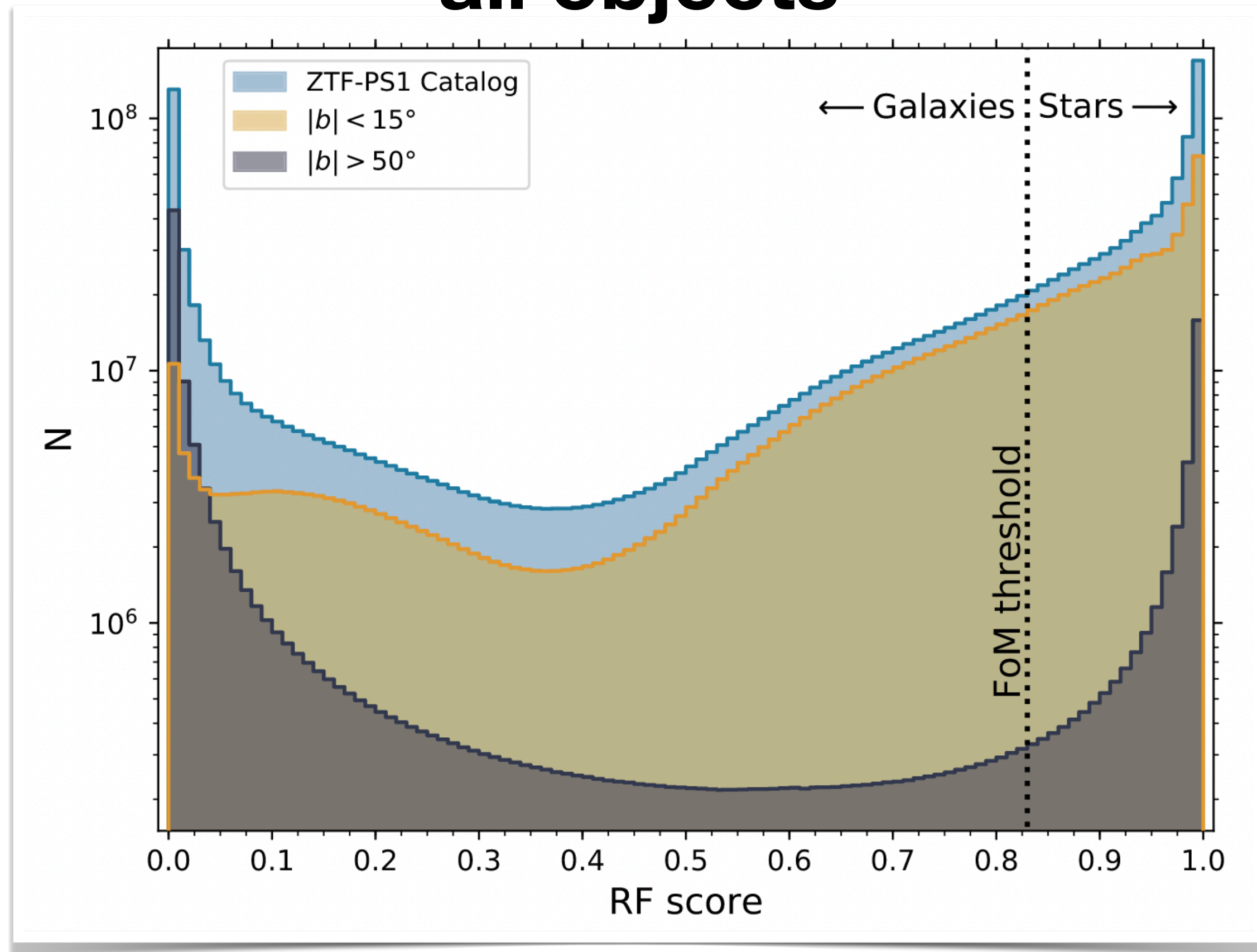


Redshift distribution (including photoz, n=4883)

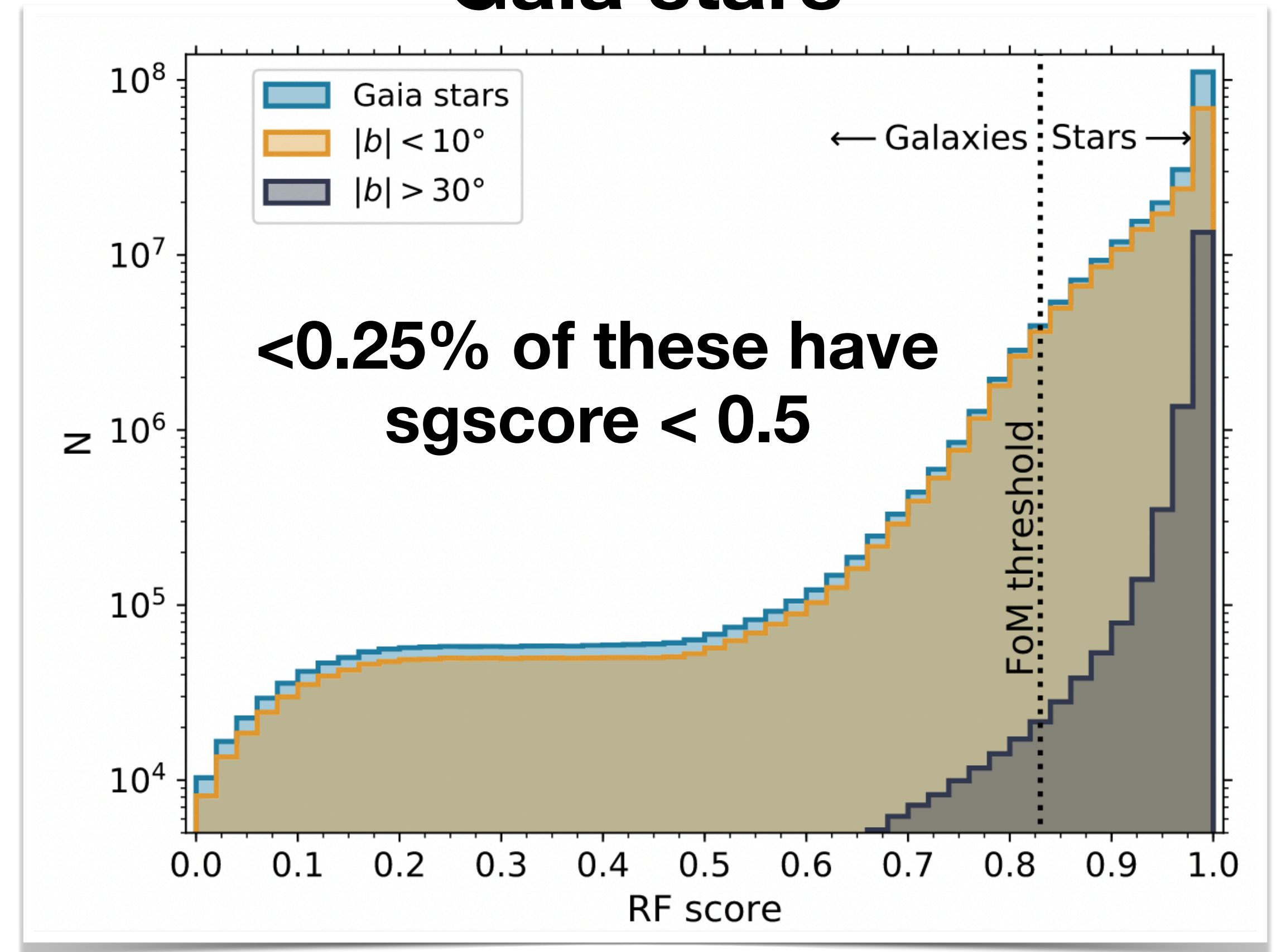


sgscore distribution

all objects

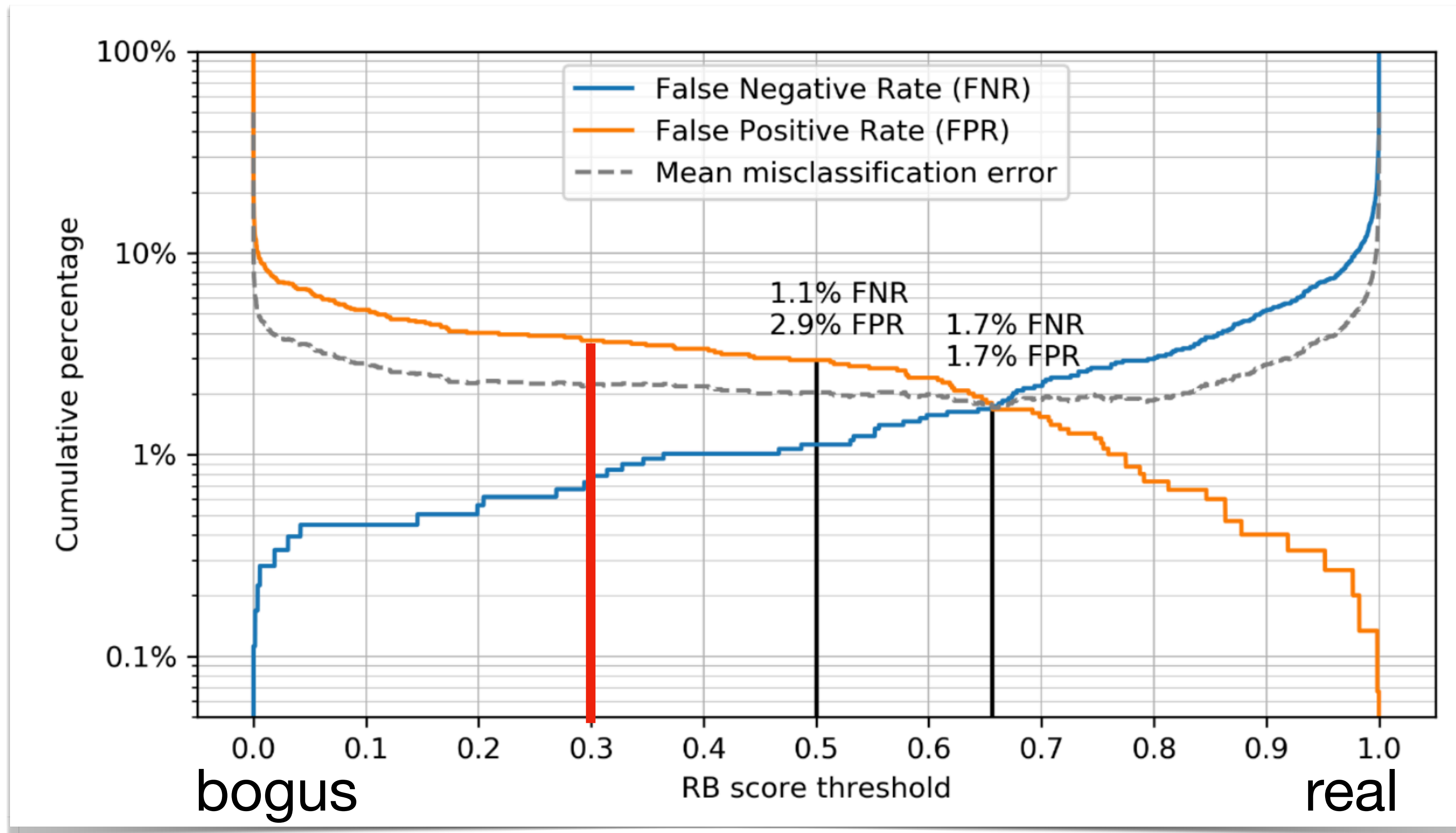


Gaia stars



Tachibana & Miller,
2018 (PASP)

rb distribution



0.7% FNR
4 % FPR

Duev et al., 2019
(MNRAS)