Early identification of optical tidal disruption events with the Fink broker.

S.Karpov (FZU)

M. Llamas Lanza, E. Russeil, E. Quintin,
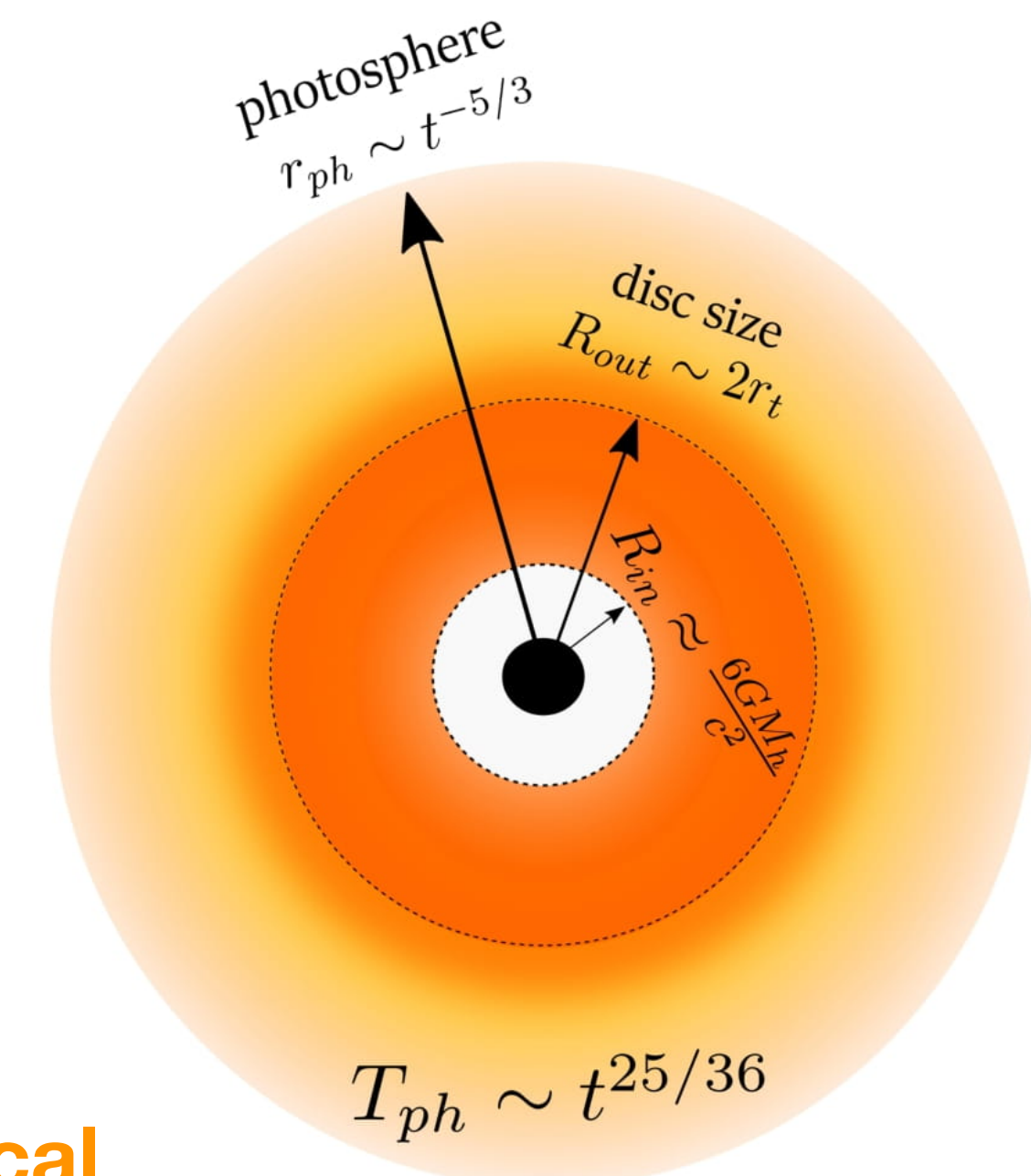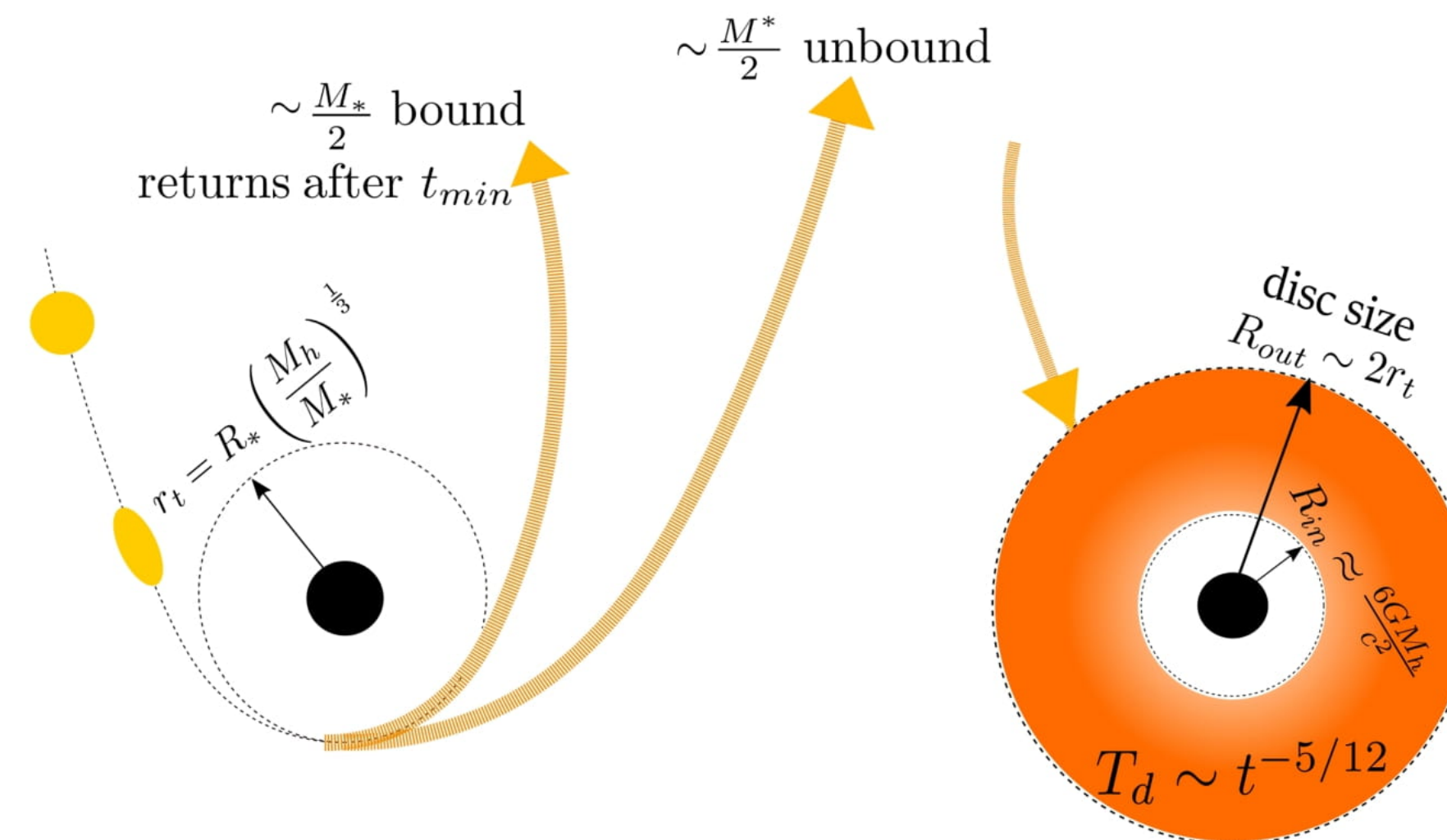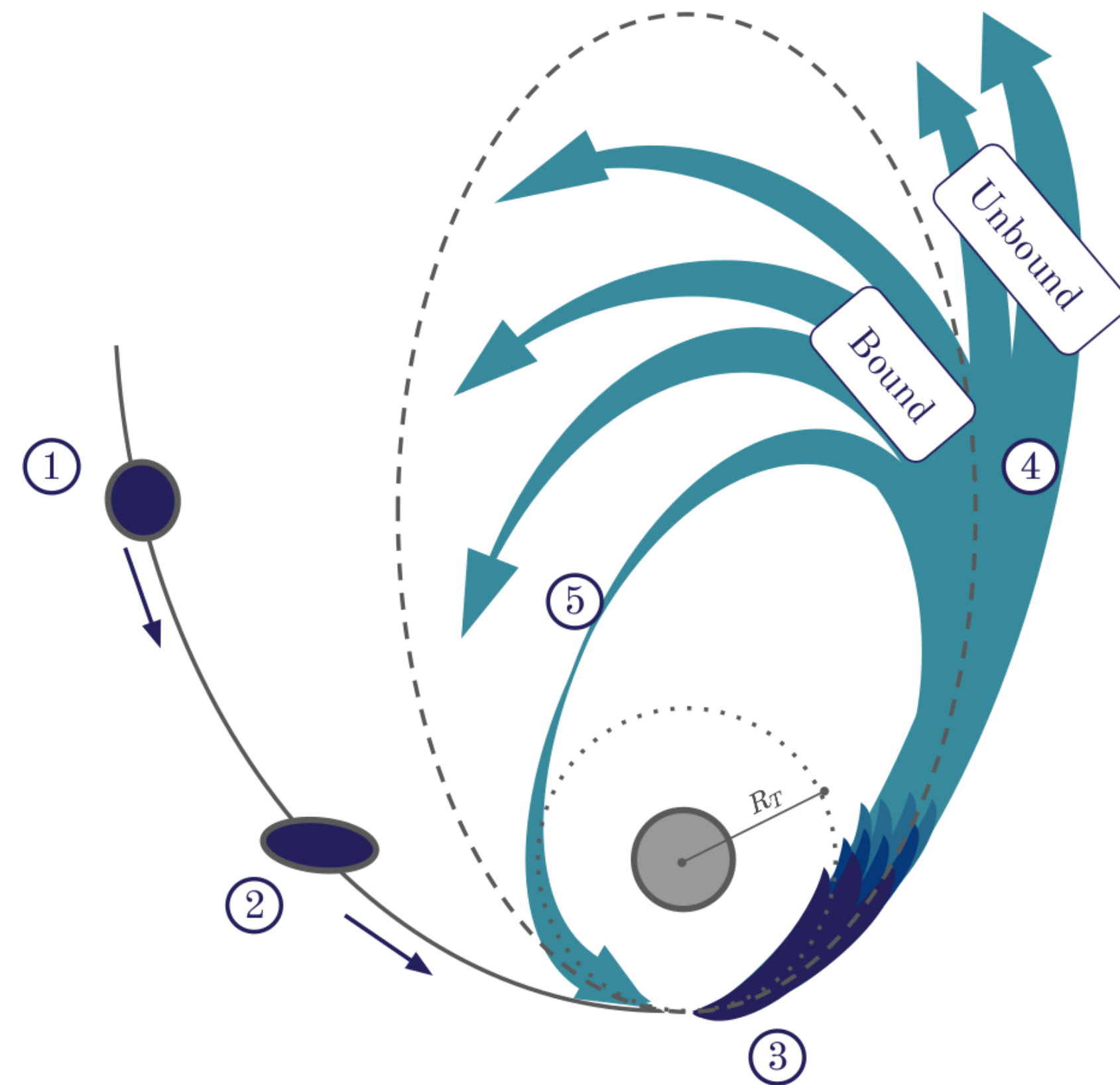E. Ishida, M. Pruzhinskaya, A. Möller, J. Peloton

Tidal Disruption Events

Disruption of a star on its passage near SMBH

- bound material returns in a ~month
- fallback rate ~ $t^{5/3}$
- circularization after ~year

Unbound

Bound

R_T

$\sim \frac{M^*}{2}$ unbound

$\sim \frac{M_*}{2}$ bound returns after t_{min}

$r_t = R_* \left(\frac{M_h}{M_*}\right)^{-1/3}$

disc size $R_{out} \sim 2r_t$

$R_{in} \approx \frac{6GM_h}{c^2}$

$T_d \sim t^{-5/12}$

photosphere $r_{ph} \sim t^{-5/3}$

disc size $R_{out} \sim 2r_t$

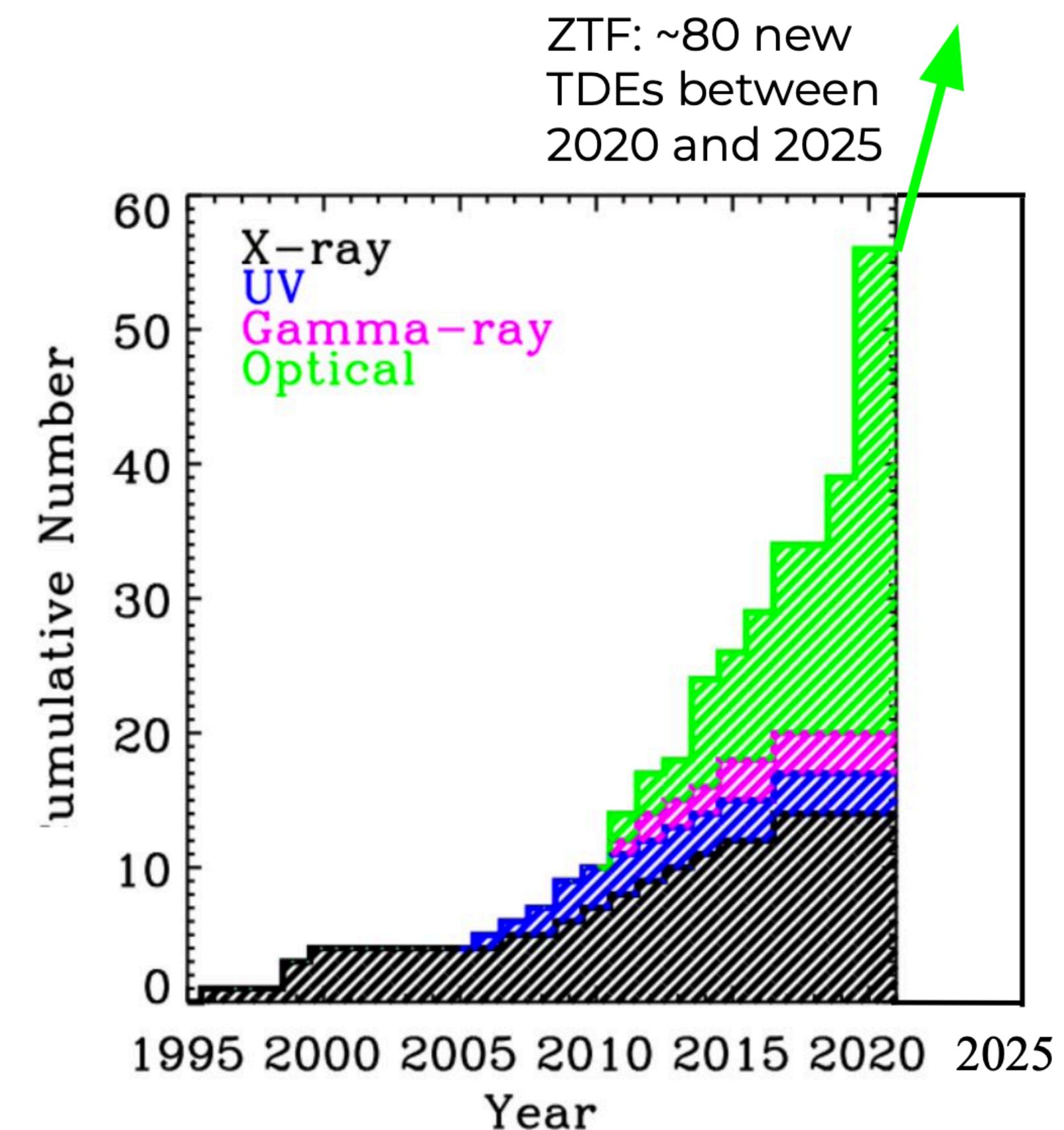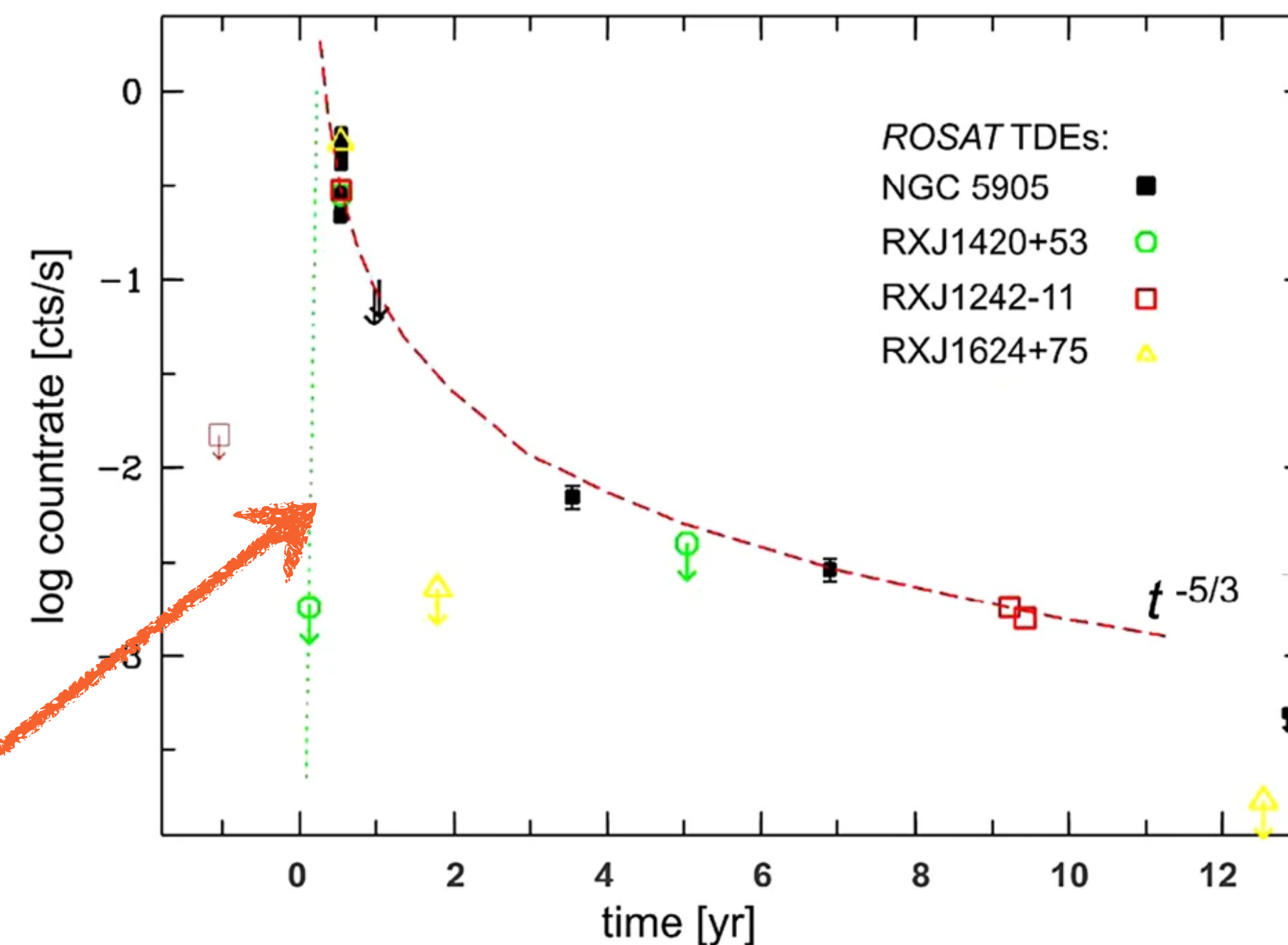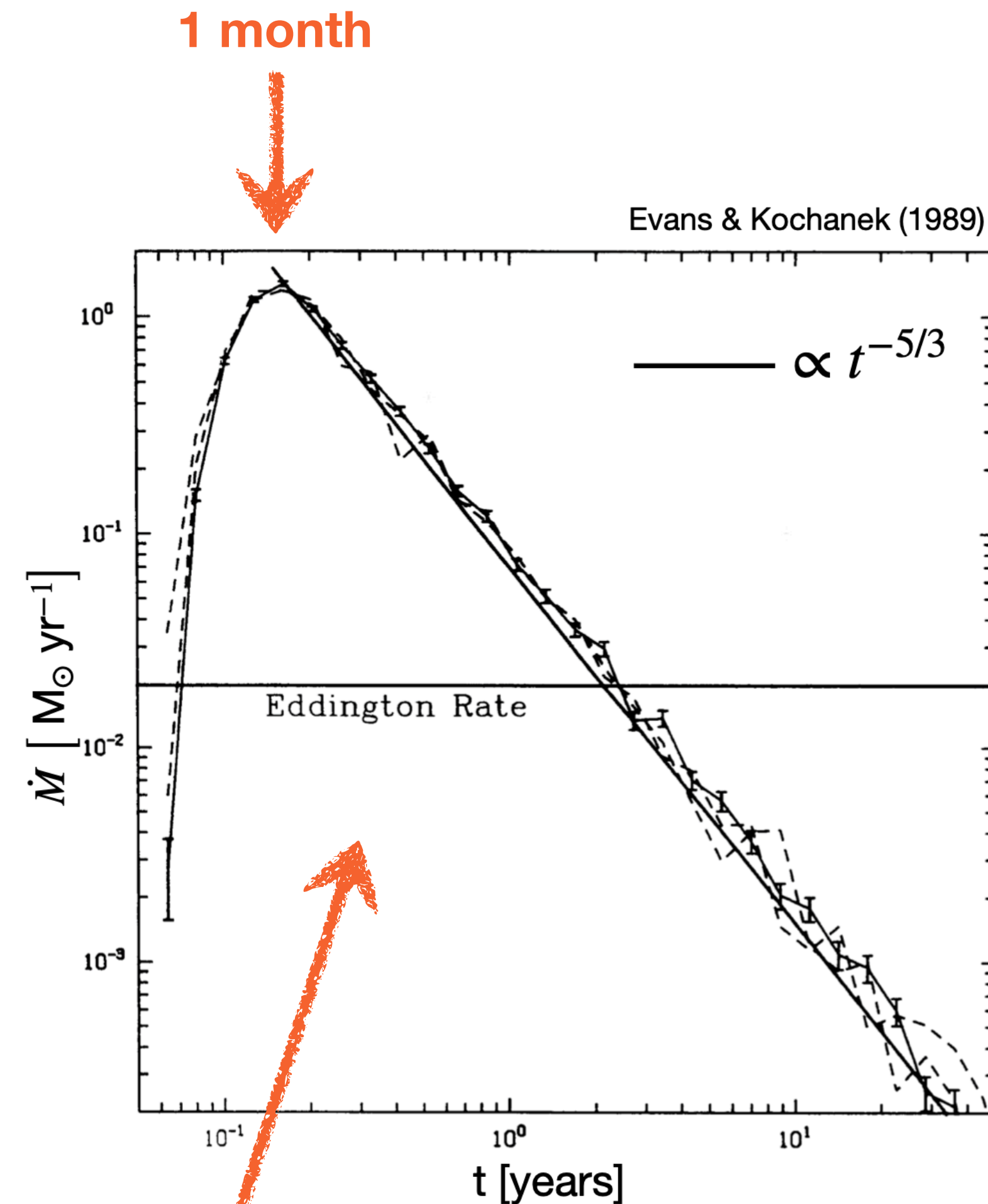$R_{in} \approx \frac{6GM_h}{c^2}$

$T_{ph} \sim t^{25/36}$

accretion -> X-rays -> reprocessing -> UV/optical

Tidal Disruption Events
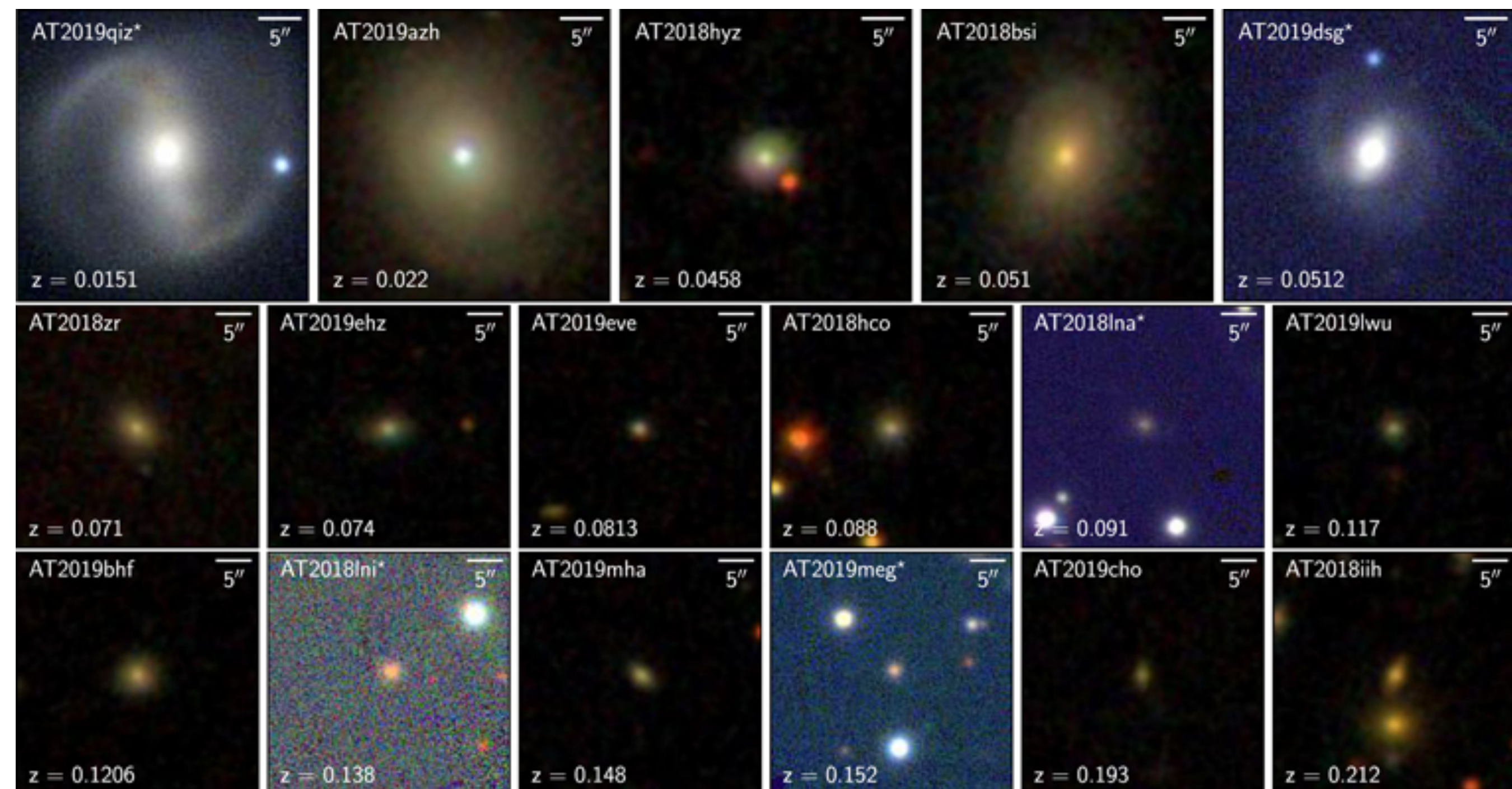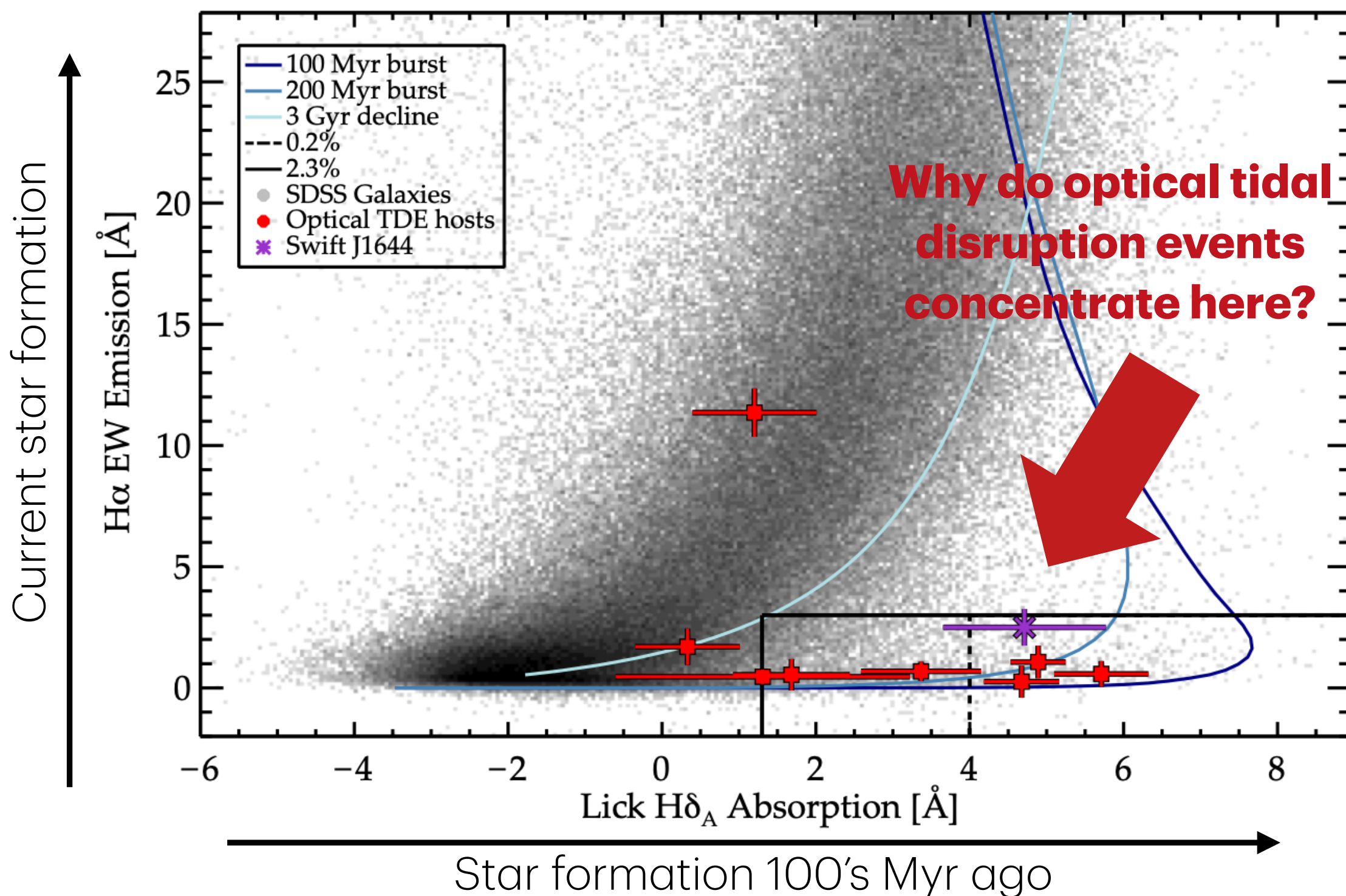
Disruption of a star on its passage near SMBH

- peak in ~weeks
- post-peak brightness ~ $t^{5/3}$
- M ~ -17..-20

1 month

Evans & Kochanek (1989)

$\propto t^{-5/3}$

Eddington Rate

$\dot{M}$ [M$_\odot$ yr^{-1}]

t [years]

theoretical accretion rate

X-rays

ROSAT TDEs:
NGC 5905
RXJ1420+53
RXJ1242-11
RXJ1624+75

$t^{-5/3}$

log countrate [cts/s]

time [yr]

ZTF: ~80 new TDEs between 2020 and 2025

X-ray
UV
Gamma-ray
Optical

Cumulative Number

Year

Tidal Disruption Events

Disruption of a star on its passage near SMBH

- mostly in quiescent post-starburst galaxies
- rate ~ 10^{-4} / galaxy / year

Why do optical tidal disruption events concentrate here?

He-dominated

N III / O III

H-dominated

N III   He II

O III   N III   Hγ   Hβ   [N II]   He I   Hα   He I

ASASSN-15oi

PS1-10jh

iPTF15af

AT 2018dyb

ASASSN-14li

iPTF16axa

PTF09djl

ASASSN-14ae

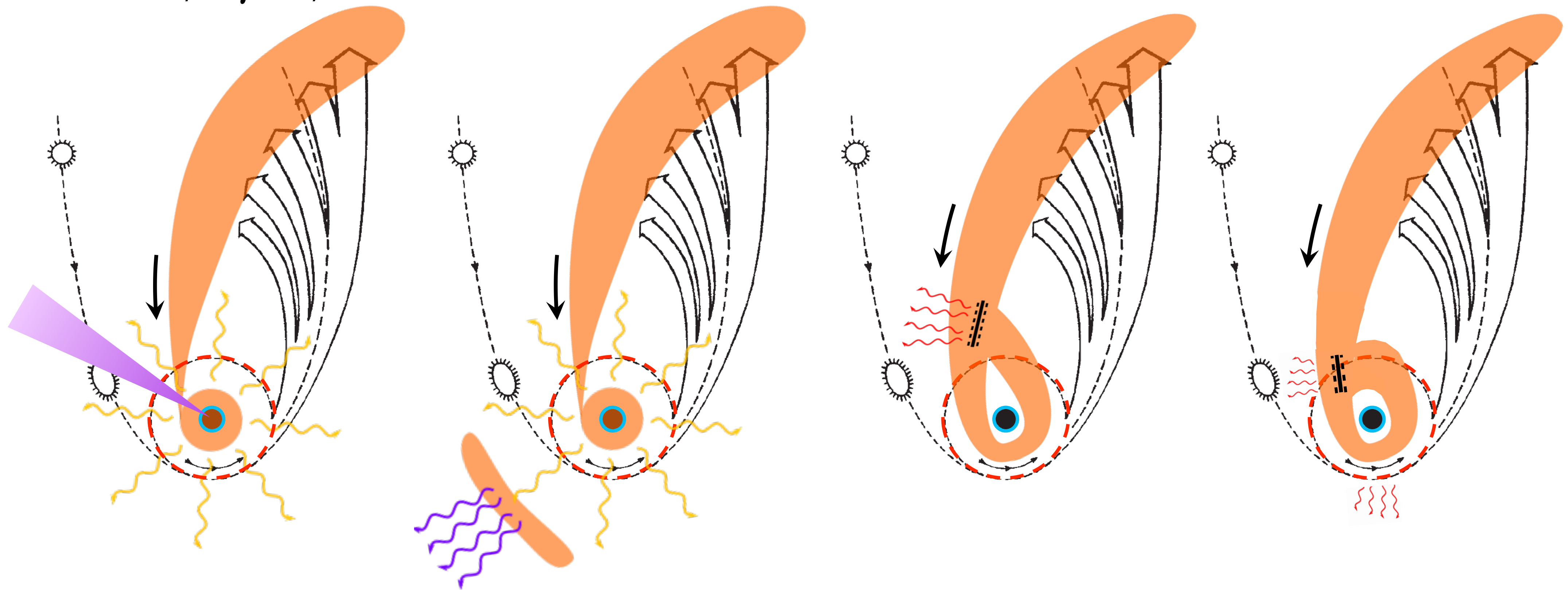normalised F$_\lambda$ + offset

Rest-frame Wavelength (Å)
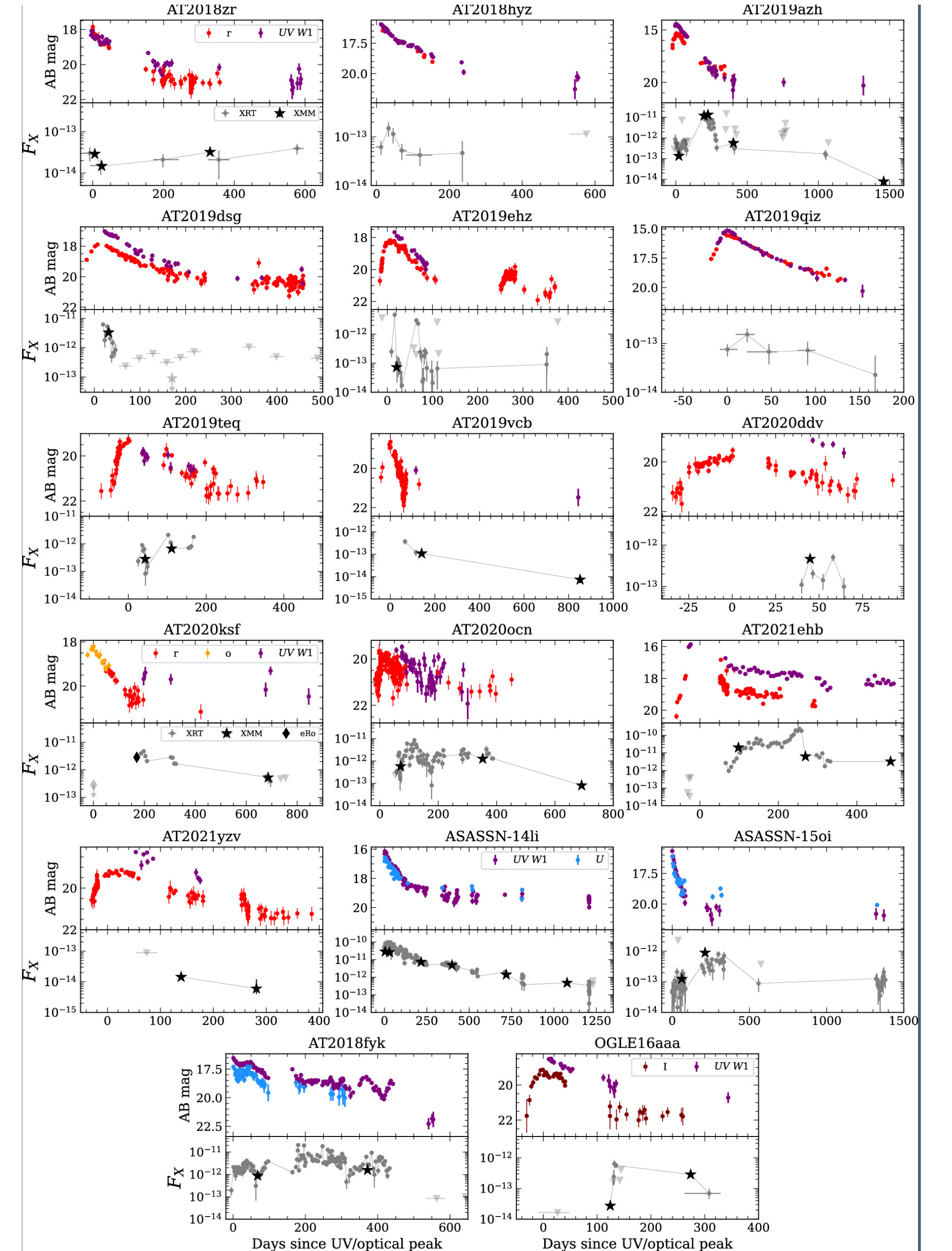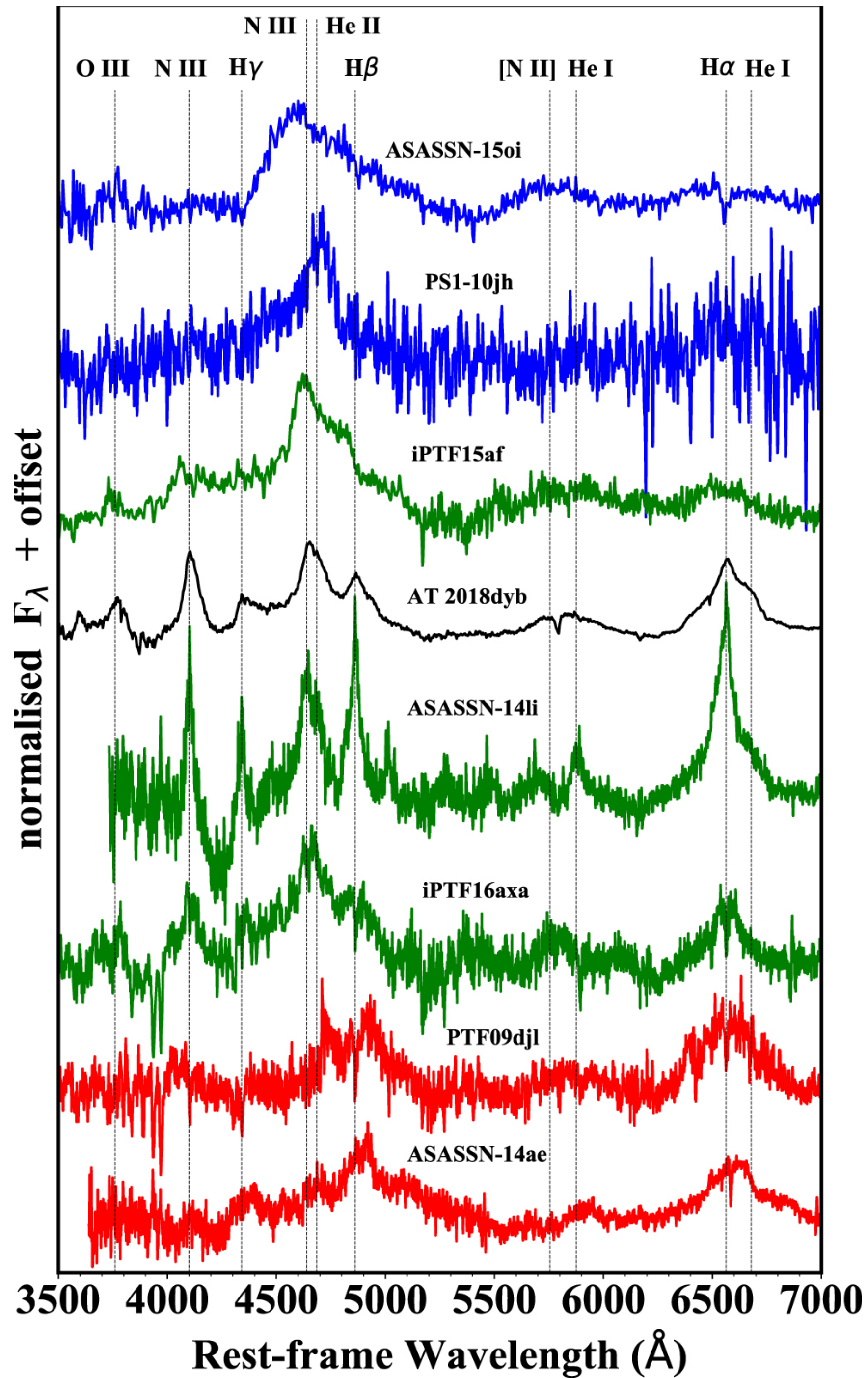
Tidal Disruption Events

Disruption of a star on its passage near SMBH

X-ray + γ-rays

UV/optical
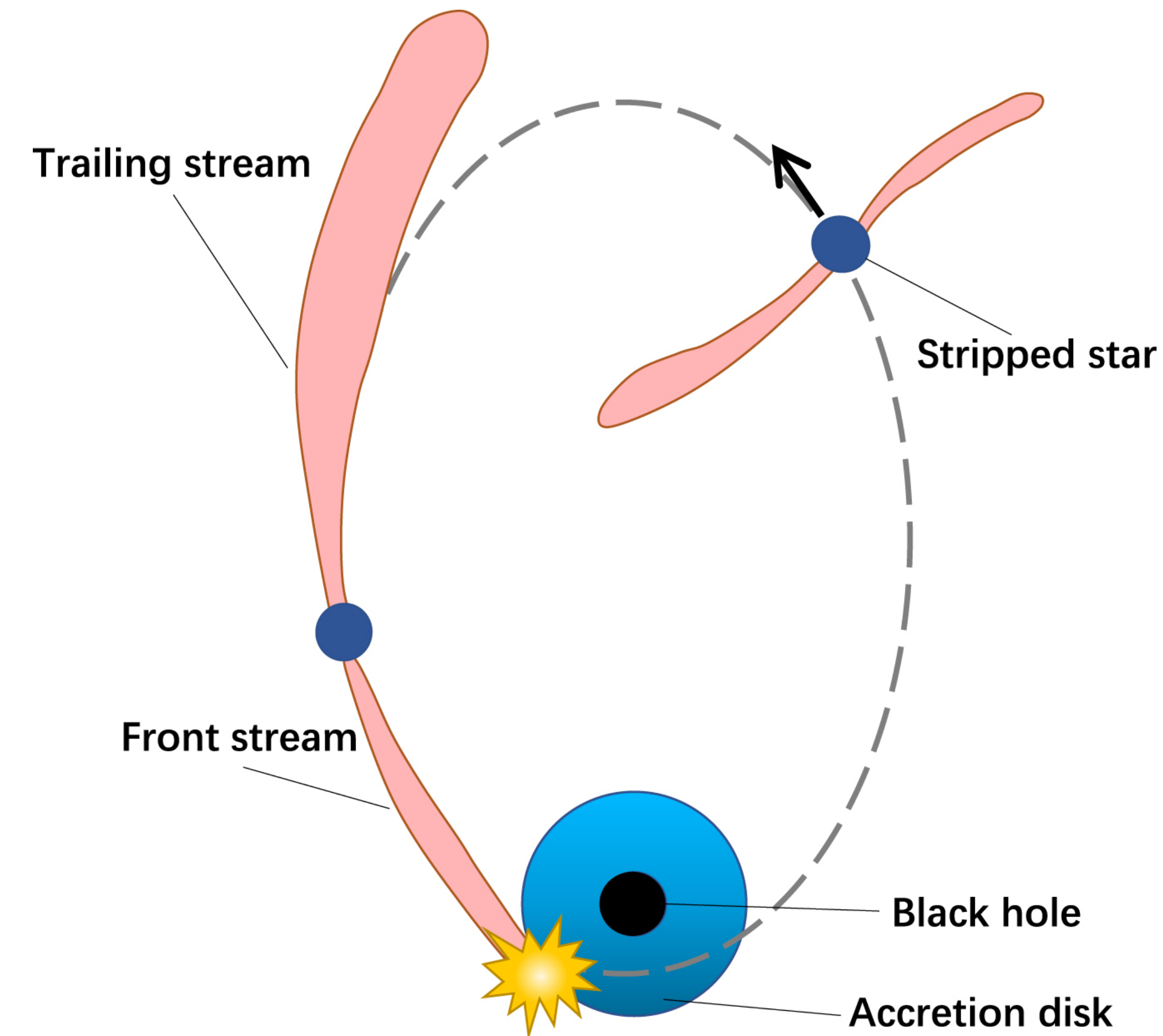
C. Bonnerot

Disk + Jet   **Reprocessing**   **Outer shocks**   **Stream-Disk collisions**
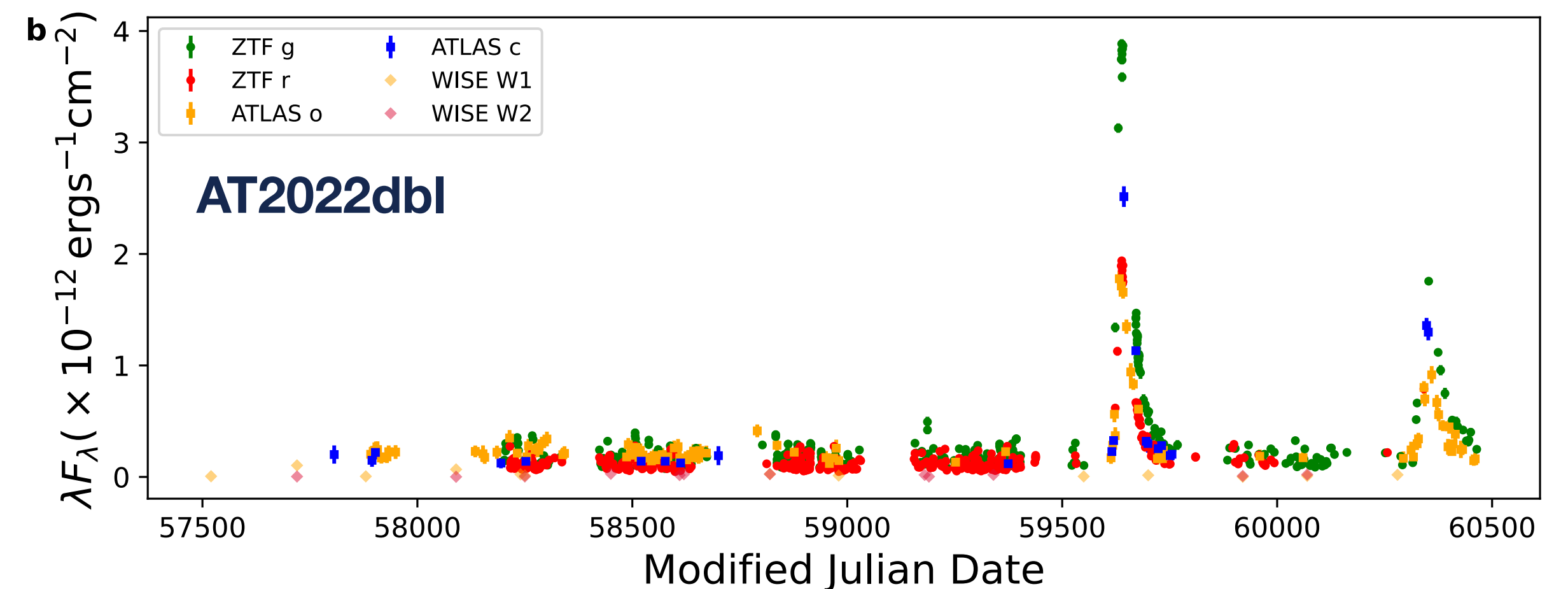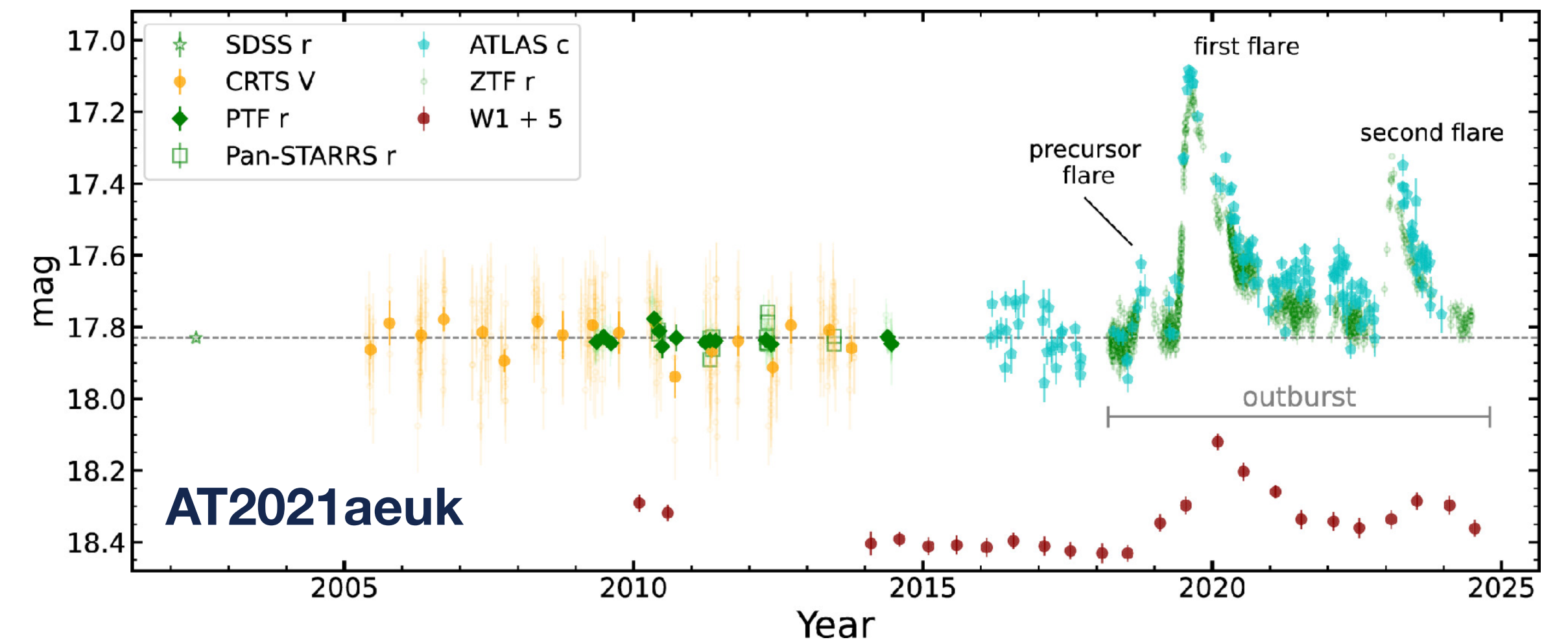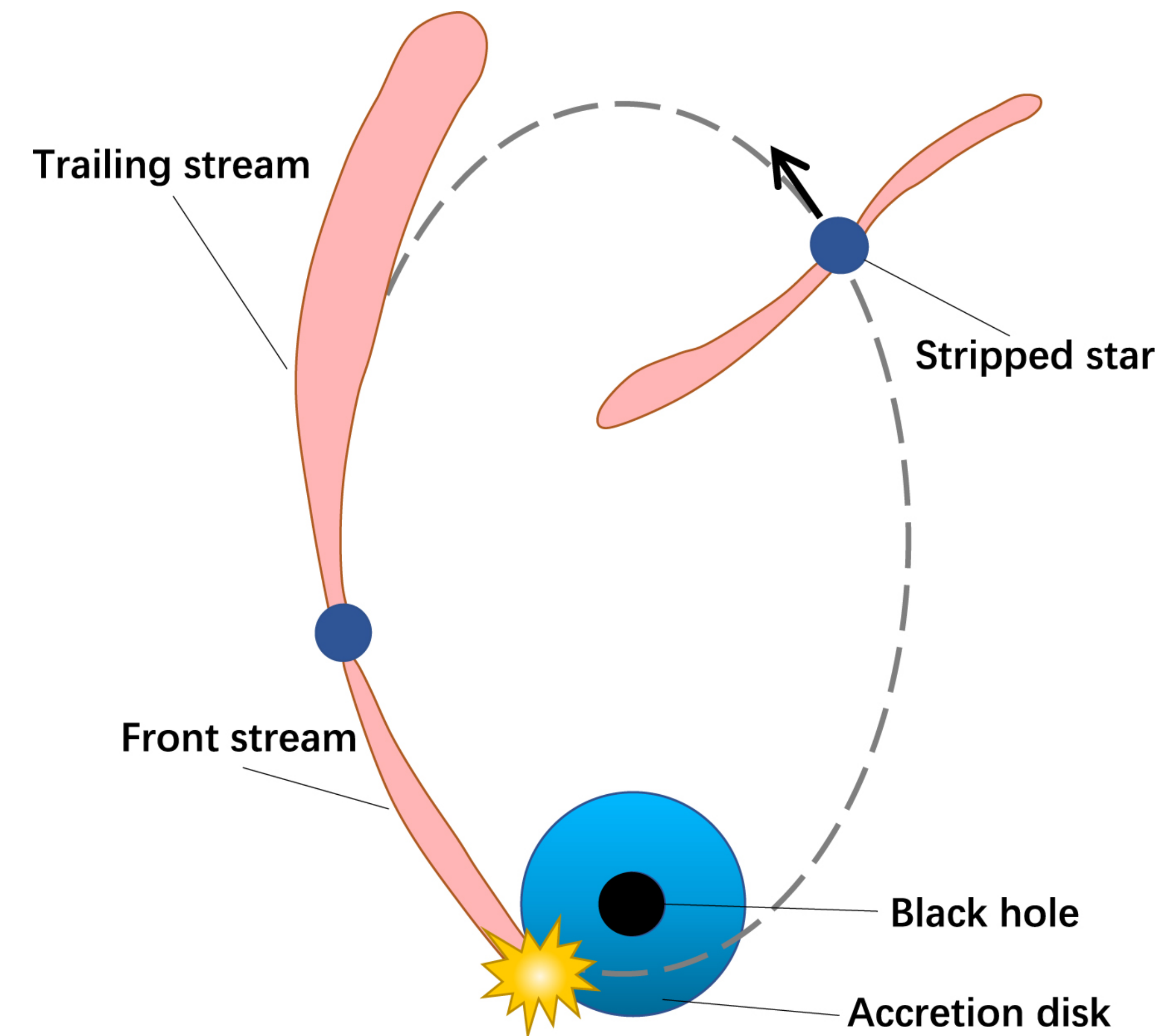
Tidal Disruption Events

(partial) Disruption of a star on its passage near SMBH
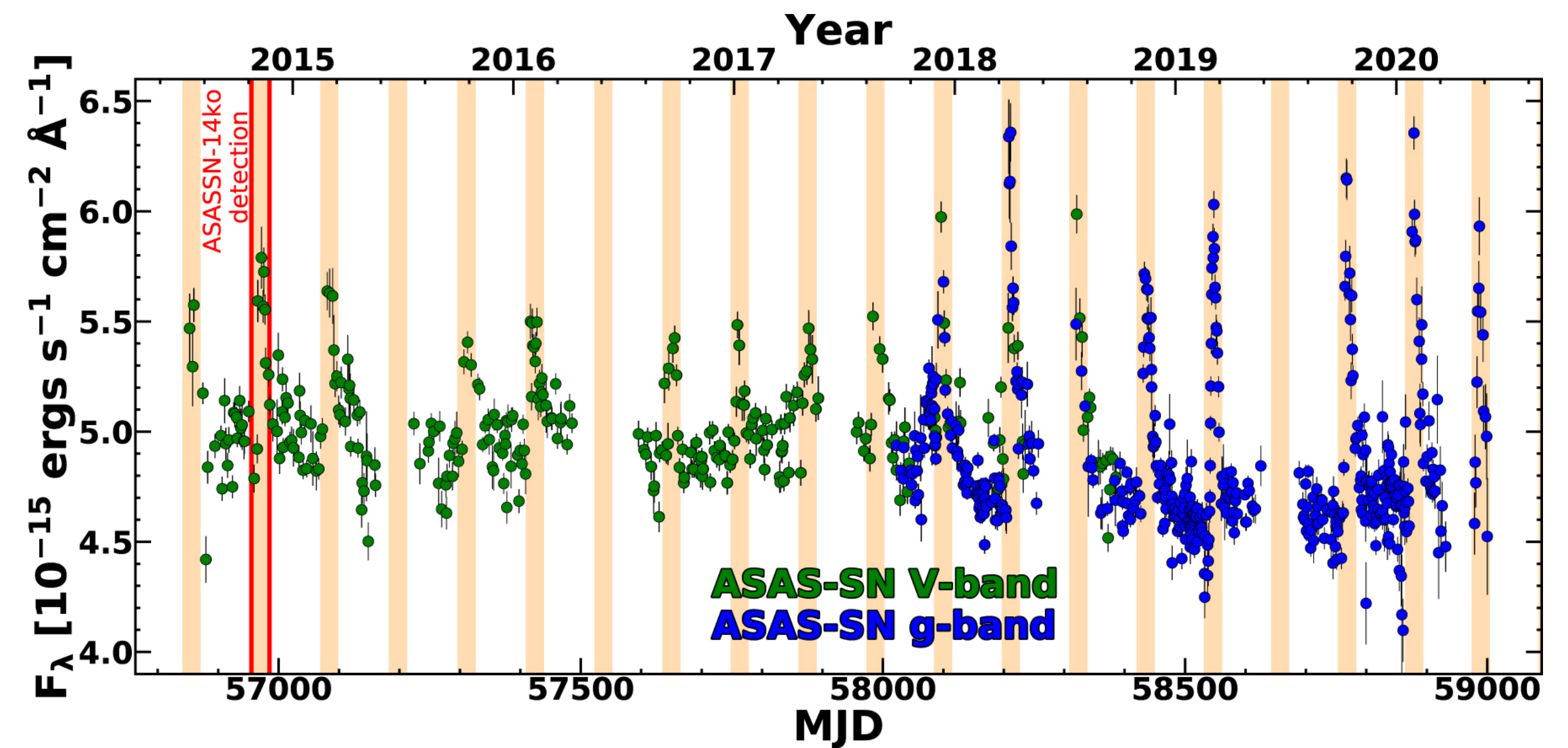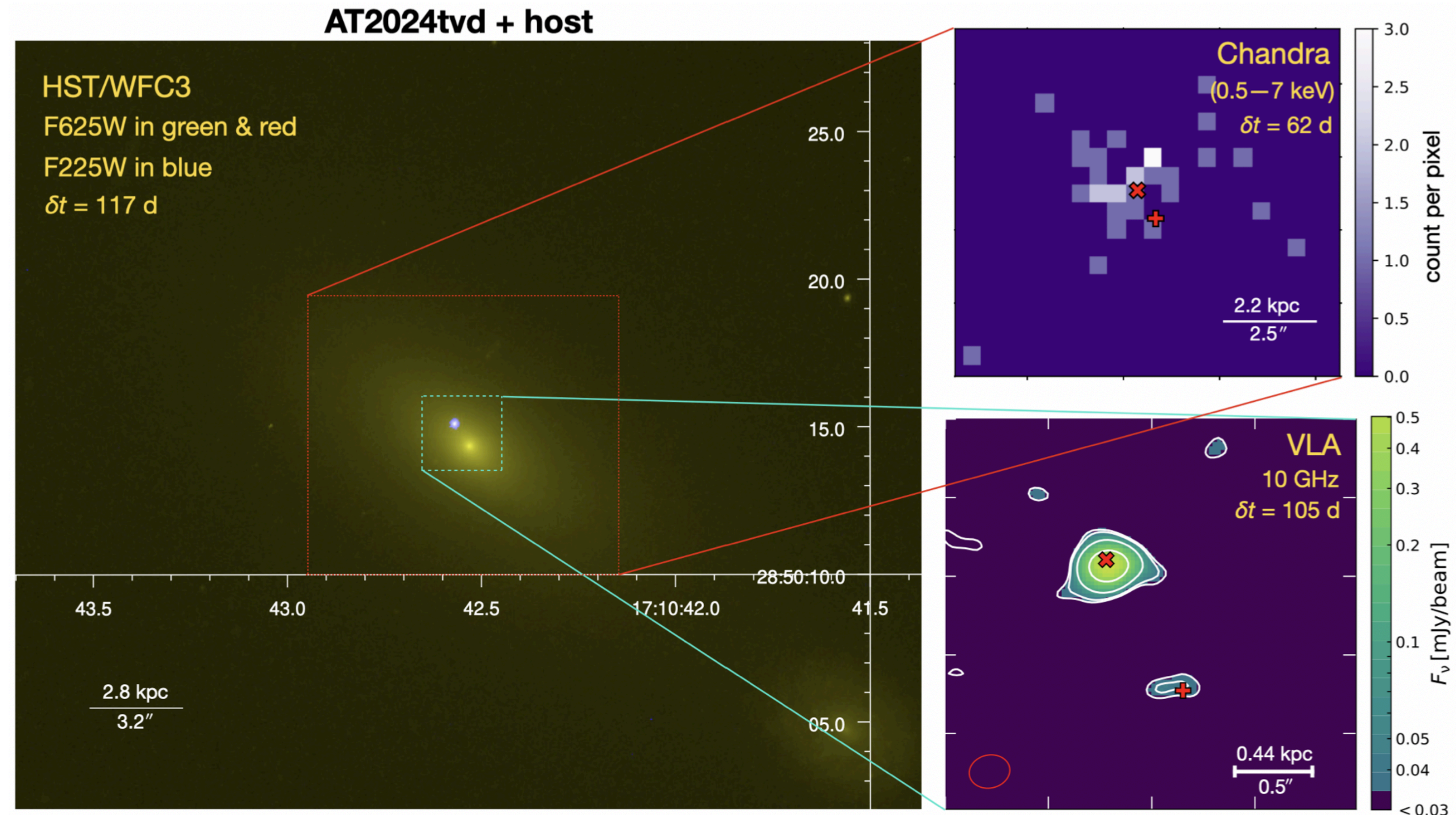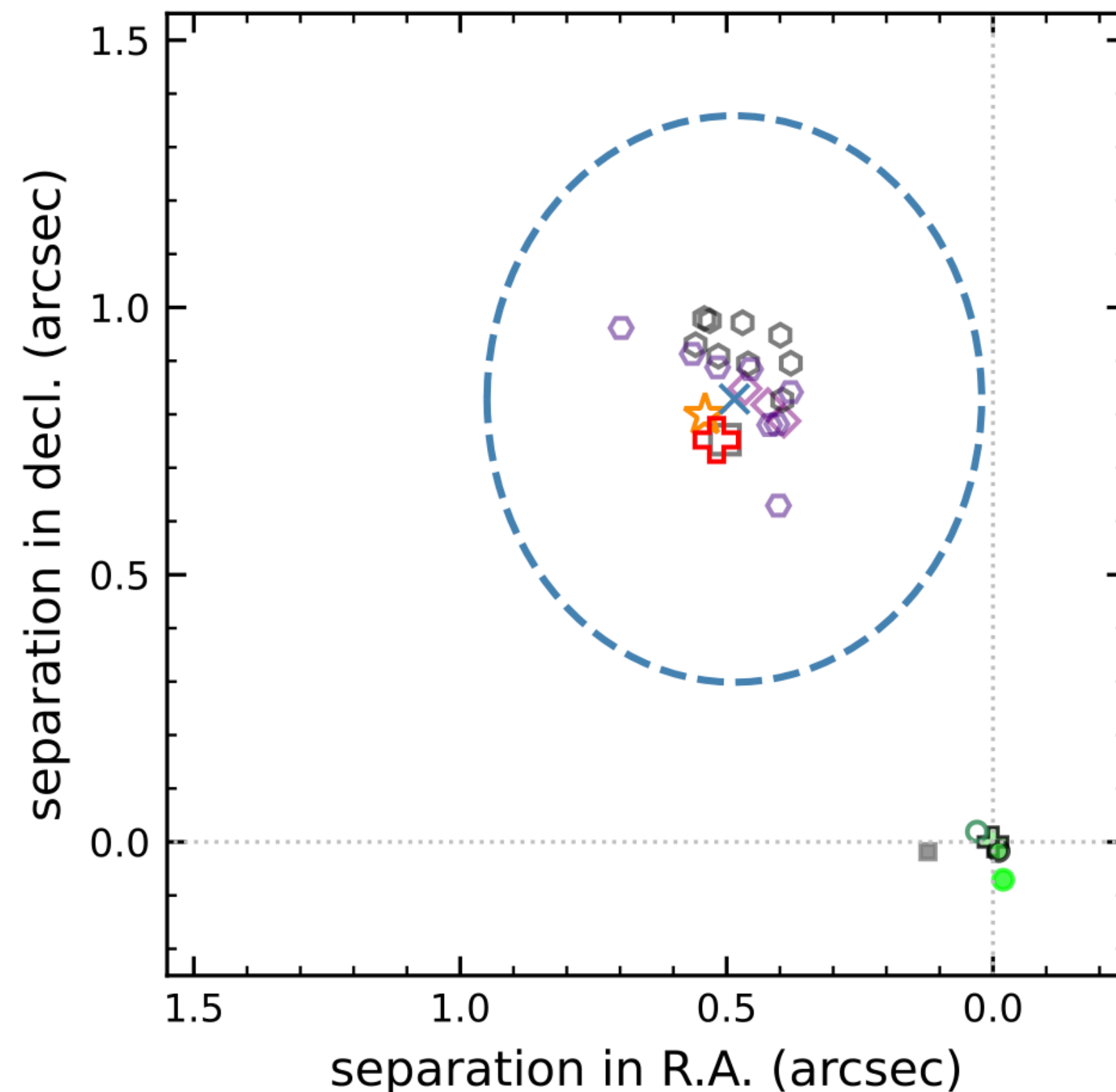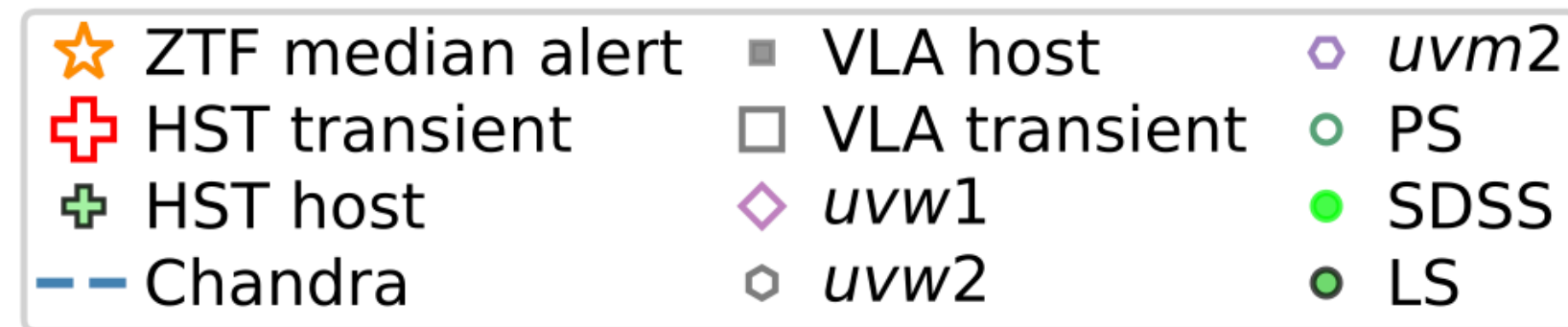

ASAS-SN 14ko: 114-day period, decreasing with time

Tidal Disruption Events

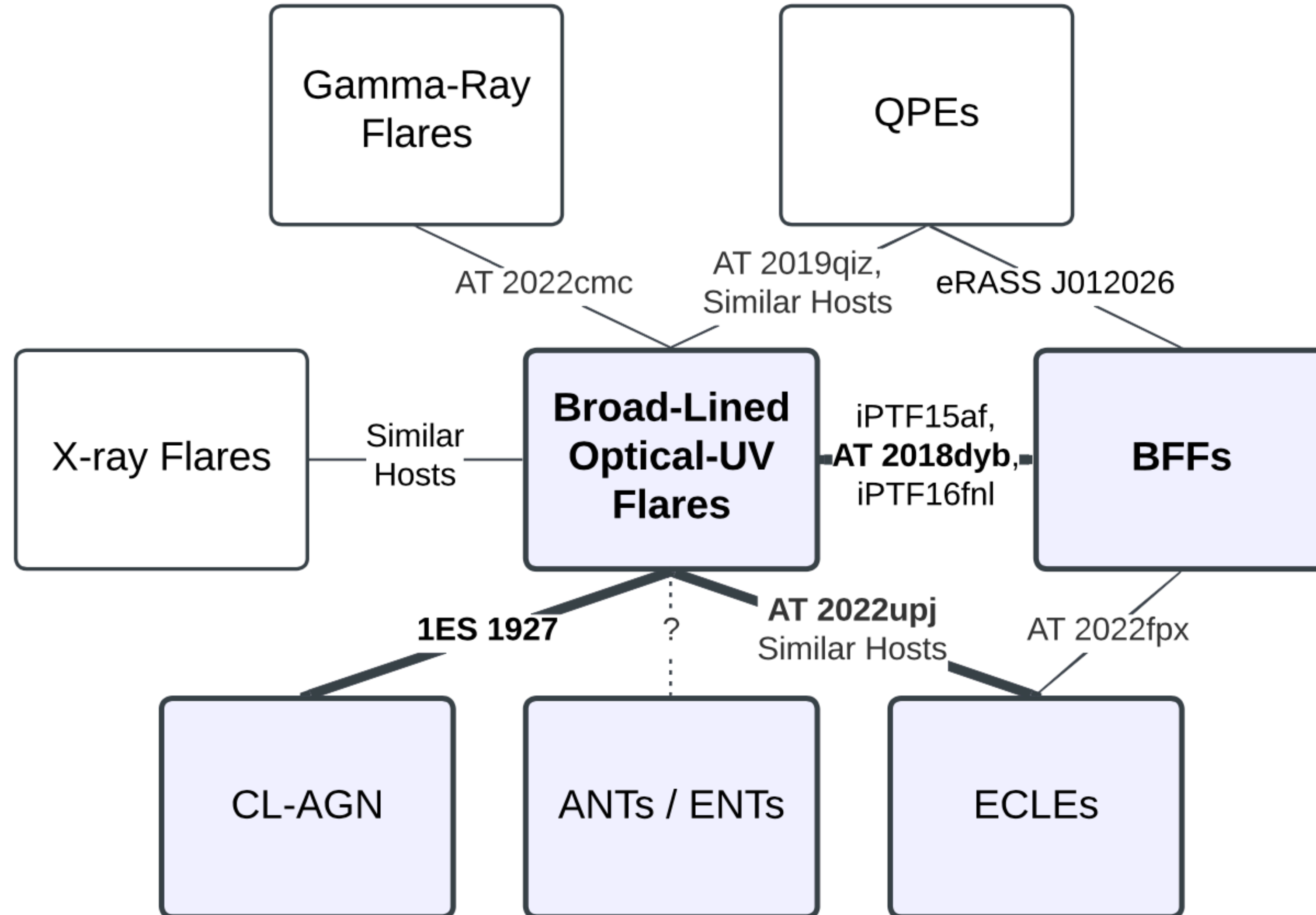## (partial) Disruption of a star on its passage near SMBH

Tidal Disruption Events

(partial) Disruption of a star on its passage near massive BH

Yao et al. 2025

Also - 3XMM J2150 and EP240222a, all three less massive BHs around nuclear SMBH

…also in active galaxies

…also in active galaxies

How to find TDEs?

1. Photometric properties

- Color
- Shape
- Amplitude

2. Spectroscopic properties

- Broad lines
- H/He/H+He/Featureless
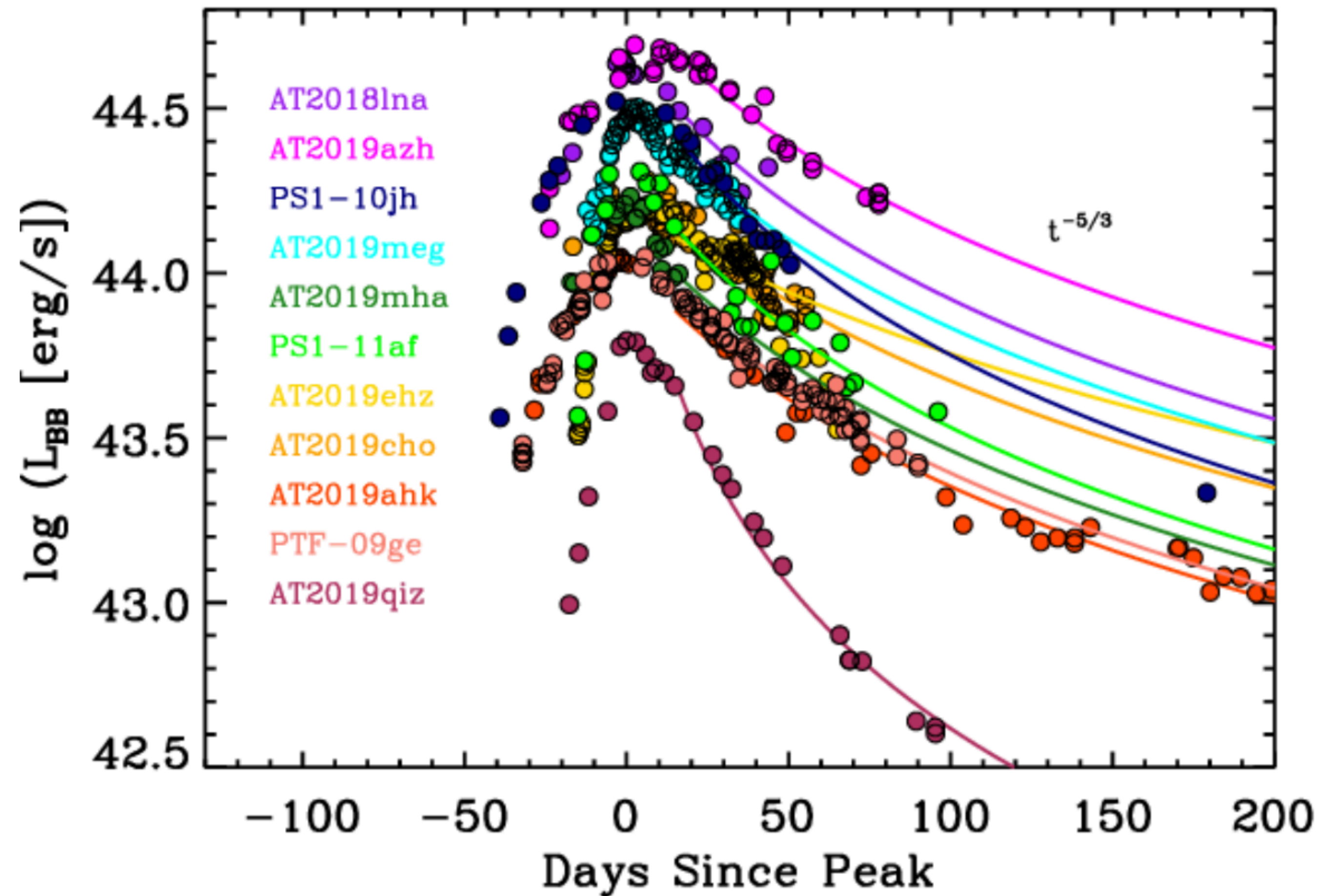- Possible: ECLE / Bowen

3. Context information

- Nuclear
- Green valley
- Low-mass passive host
- Multi-wavelength information
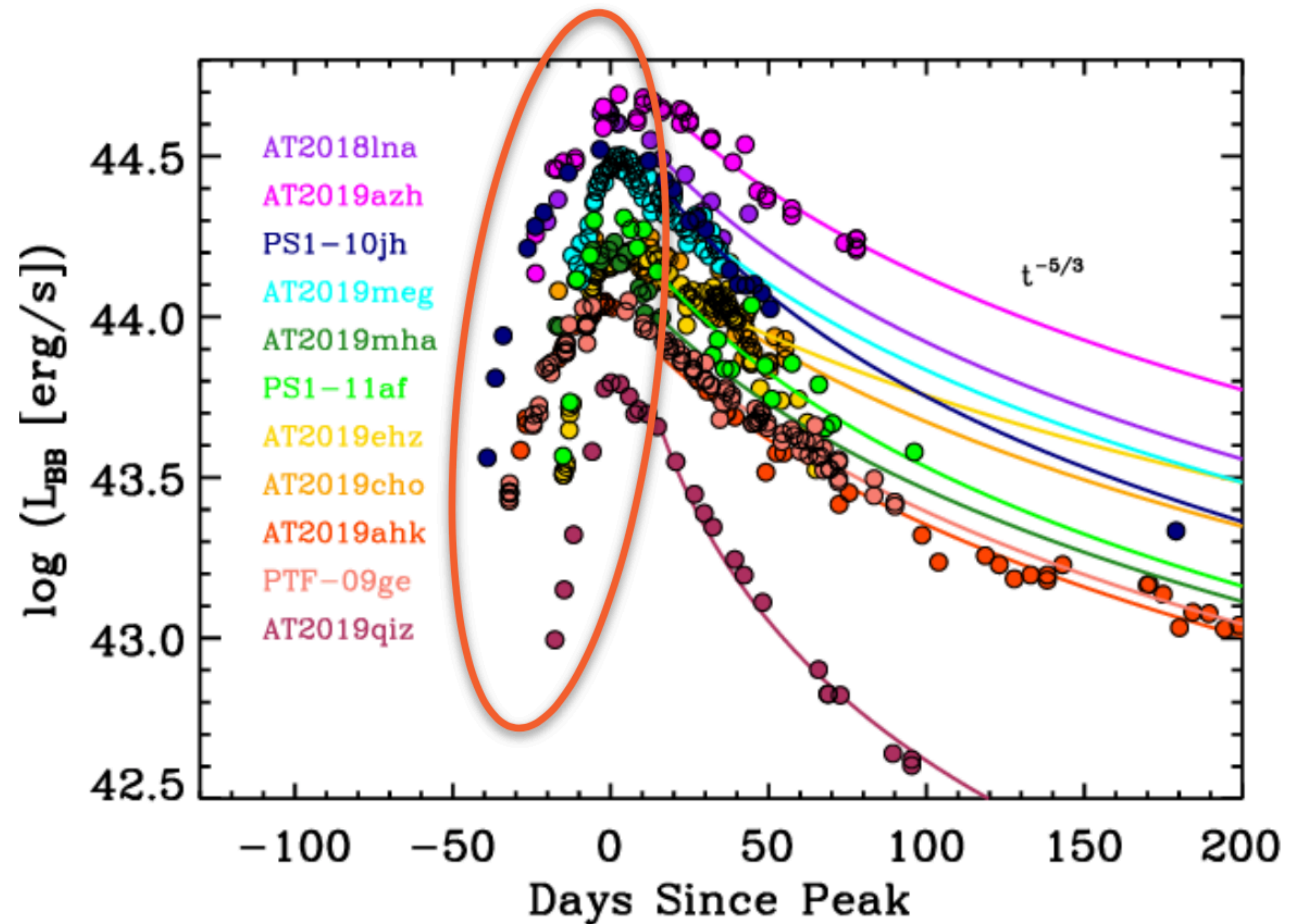
Photometric properties

~100 known TDEs

- Nuclear transients

- ~30 day rise

- $t^{-5/3}$ decay

- High temperature

- Constant temperature

- M ~ -17 to -20

- Possibly repeating

Legend:
AT2018lna
AT2019azh
PS1−10jh
AT2019meg
AT2019mha
PS1−11af
AT2019ehz
AT2019cho
AT2019ahk
PTF−09ge
AT2019qiz

$t^{-5/3}$

y-axis: $\log(L_{BB}\ [\mathrm{erg/s}])$

x-axis: Days Since Peak

Gezari, Suvi. (2021)

Photometric properties

~100 known TDEs

- Nuclear transients

- ~30 day rise

- $t^{-5/3}$ decay

- High temperature

- Constant temperature

- M ~ -17 to -20

- Possibly repeating

Gezari, Suvi. (2021)

Palomar 48-inch Samuel Oschin Telescope

HSC, 1.7 deg²

DES, 2.5 deg²

PS1, 7 deg²

PTF/iPTF, 7.3 deg²

ZTF, 47 deg²

LSST, 9.6 deg²

1 deg

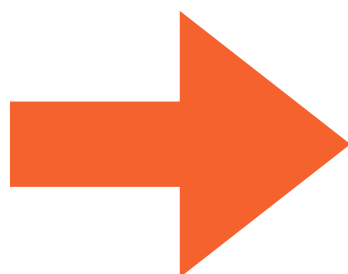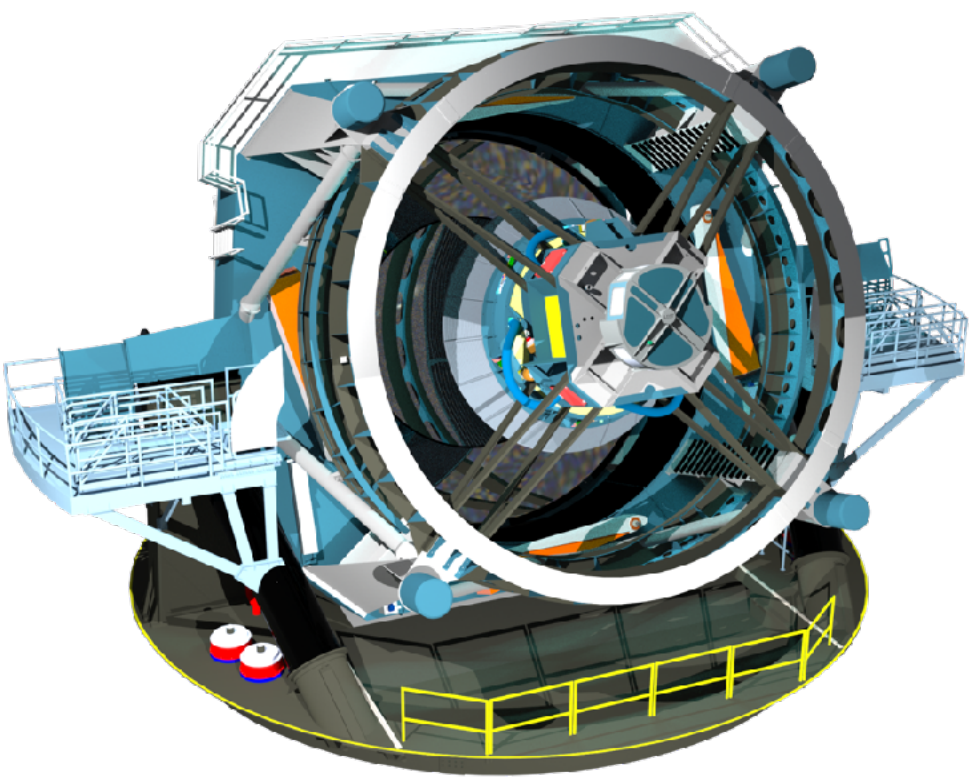**8.4-m Simonyi Survey Telescope**

ZTF (2018 - 2027?..)

• Sky coverage once per 1-2 nights
  • *g* and *r* filters (*i* very rarely)
  • northern sky mostly
  • limit ~20.5 mag
• Public alerts for transients
  • differential photometry
• Periodic data releases
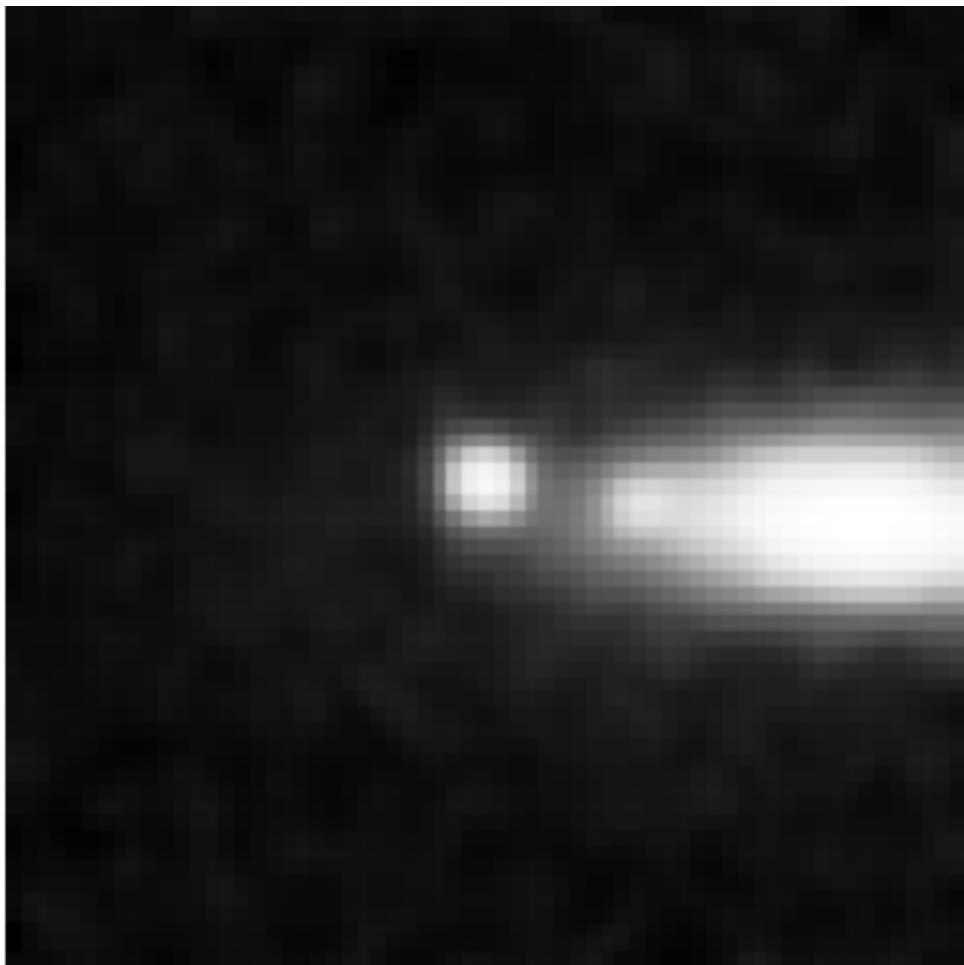 • direct photometry

Rubin / LSST (2026 - 2036???)

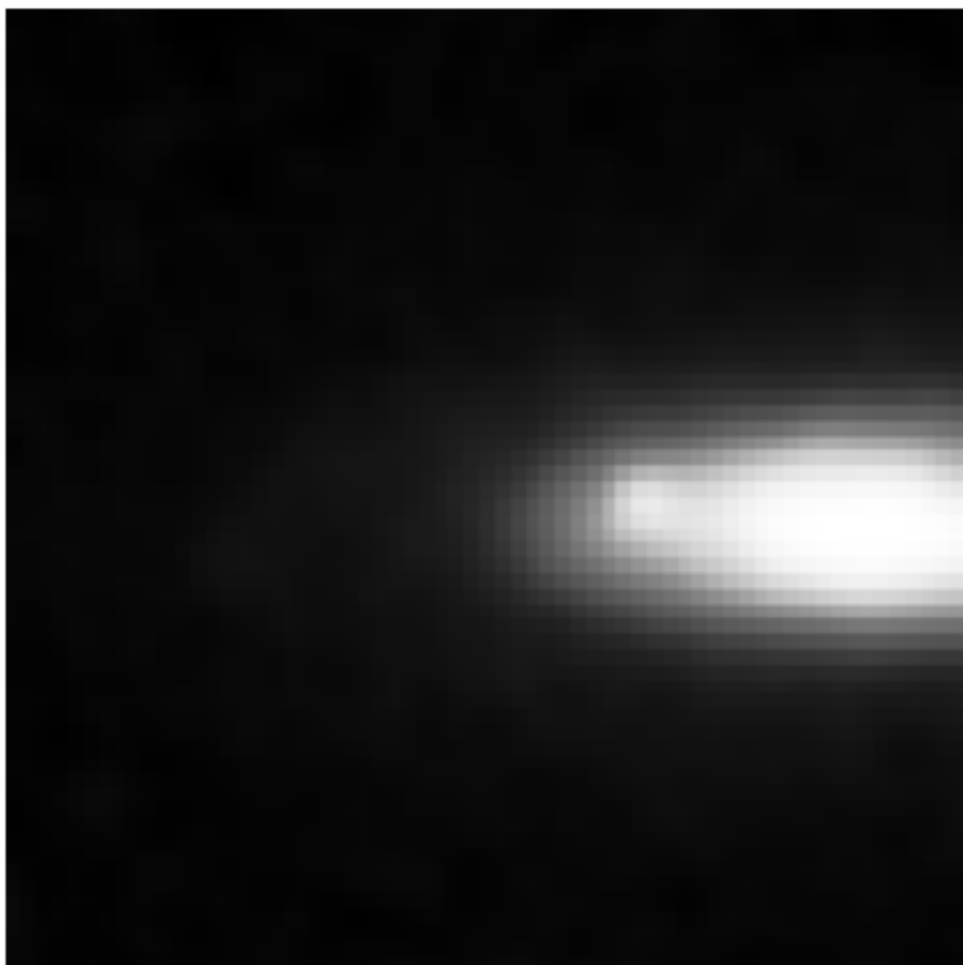• *ugrizy* filters, southern sky
• limit ~24.5 mag ???

Hundreds of images per night
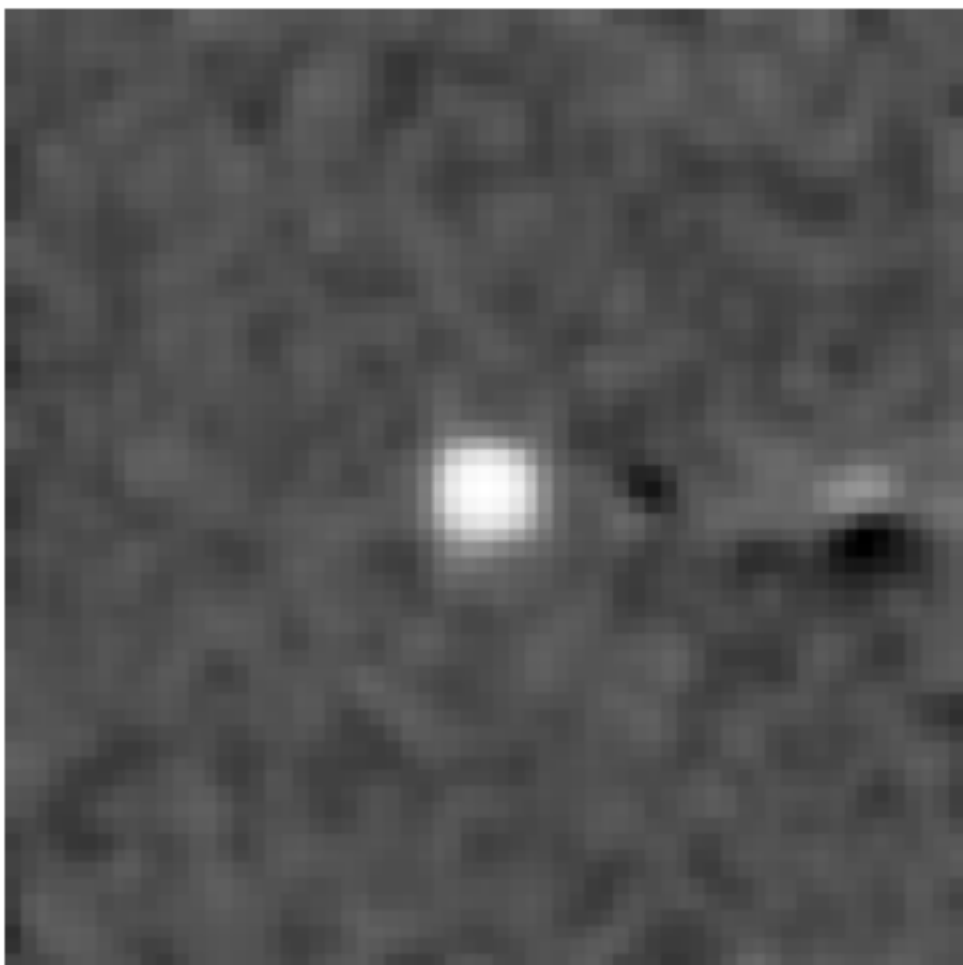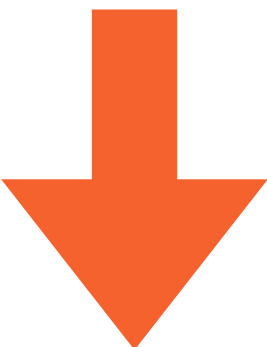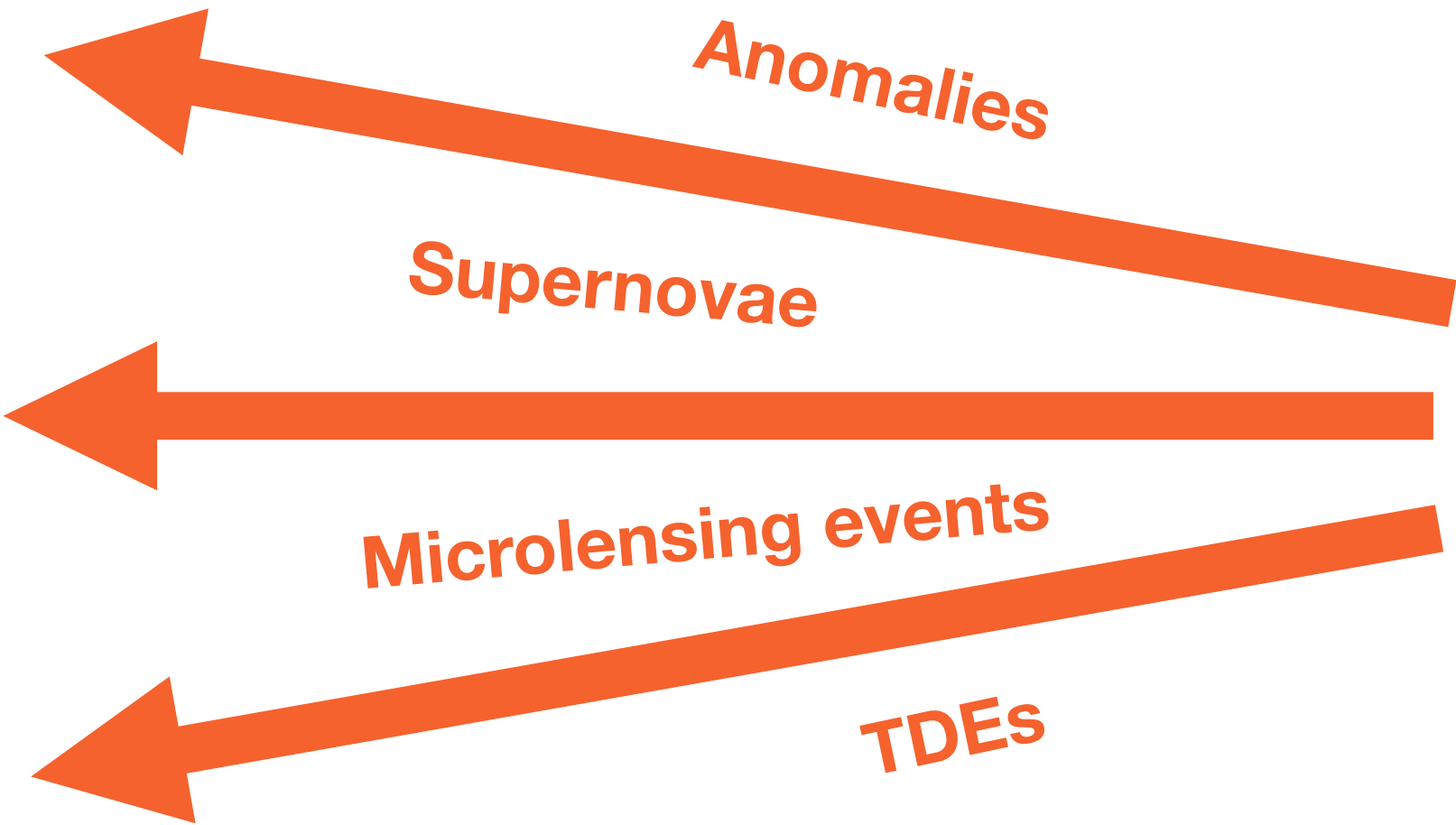
Science − Reference = Difference

Triggers an alert

Tons of alerts per night
~200k for ZTF
~10M for LSST

Alert brokers

Anomalies

Supernovae

Microlensing events

TDEs

Scientific community

ALeRCE
Automatic Learning for the
Rapid Classification of Events

F/INK

ANTARES

Lasair

Filters ML Aggregation XMatch

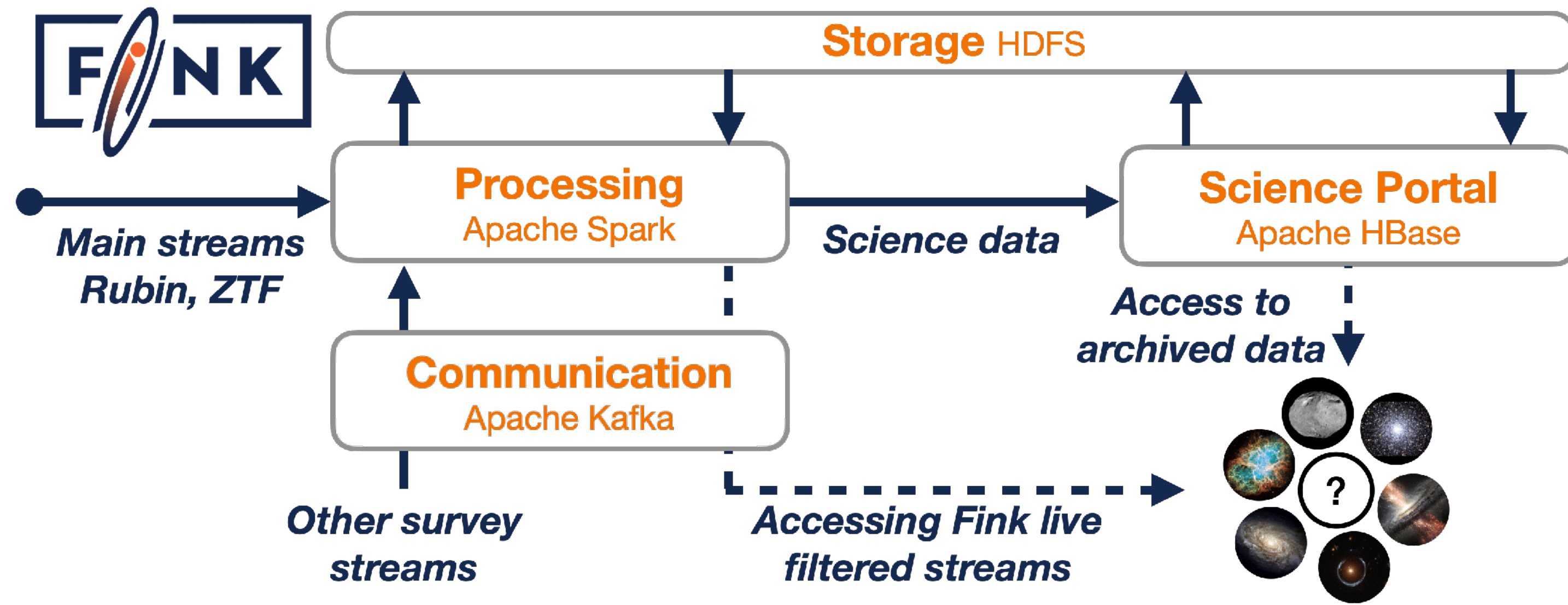# Fink broker
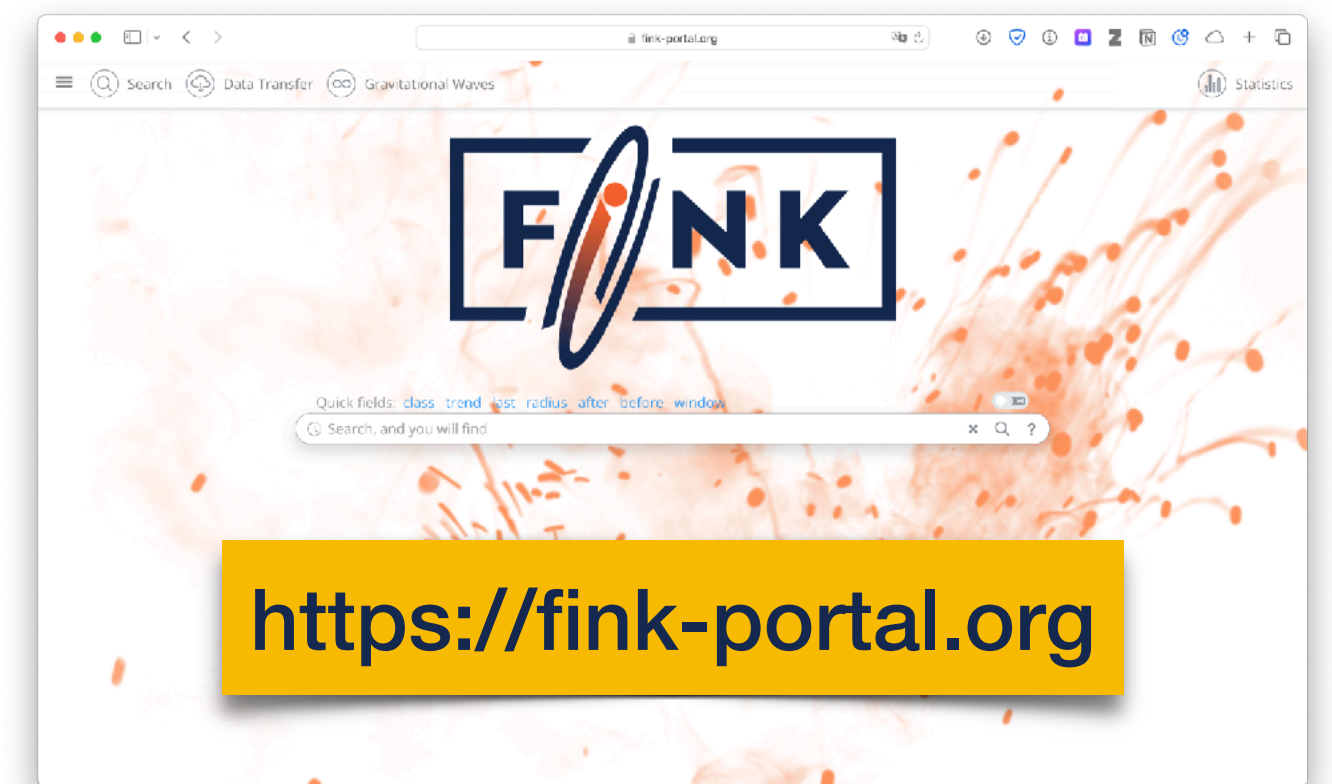
https://fink-broker.org
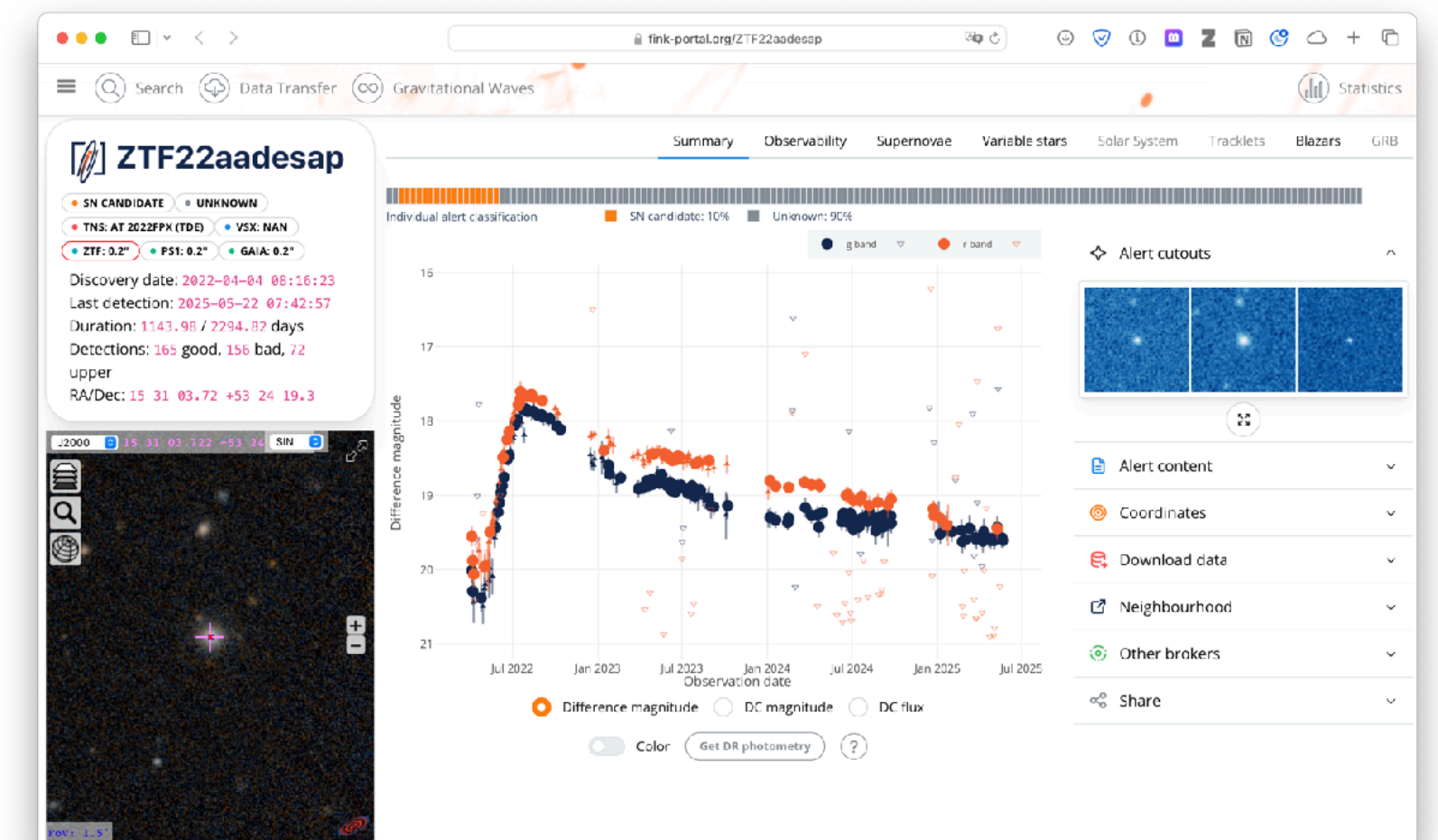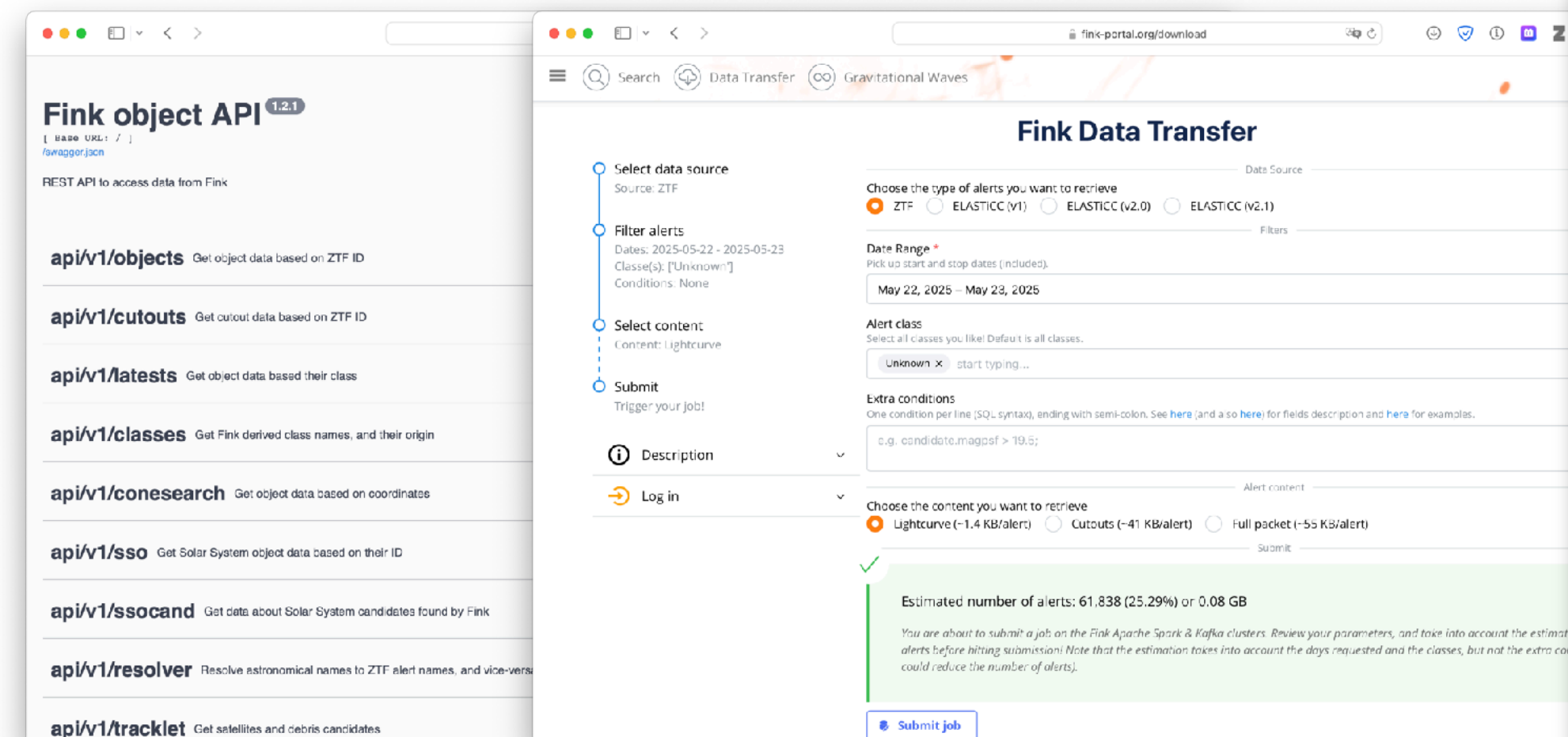https://github.com/astrolabsoftware/fink-broker

Operating since Nov 2019
**~200 million alerts**

Nightly rates (~200k alerts):
- ~75,000 known variable stars
- ~25,000 known SSO
- ~100 new SSO candidates
- ~100 new supernovae & core-collapse candidates
- ~10 satellite glints
- ~5 new SN Ia candidates
- ~1 fast transient candidate (KN, GRB, CV ...)
- ~1 new microlensing candidate

Historical ZTF dataset

- Aggregated light curves for all objects, Nov 2019 - Feb 2025

- SSO and non-extragalactic SIMBAD associations excluded

- Galactic |b| > 20

- at least 5 detections

~600k light curves
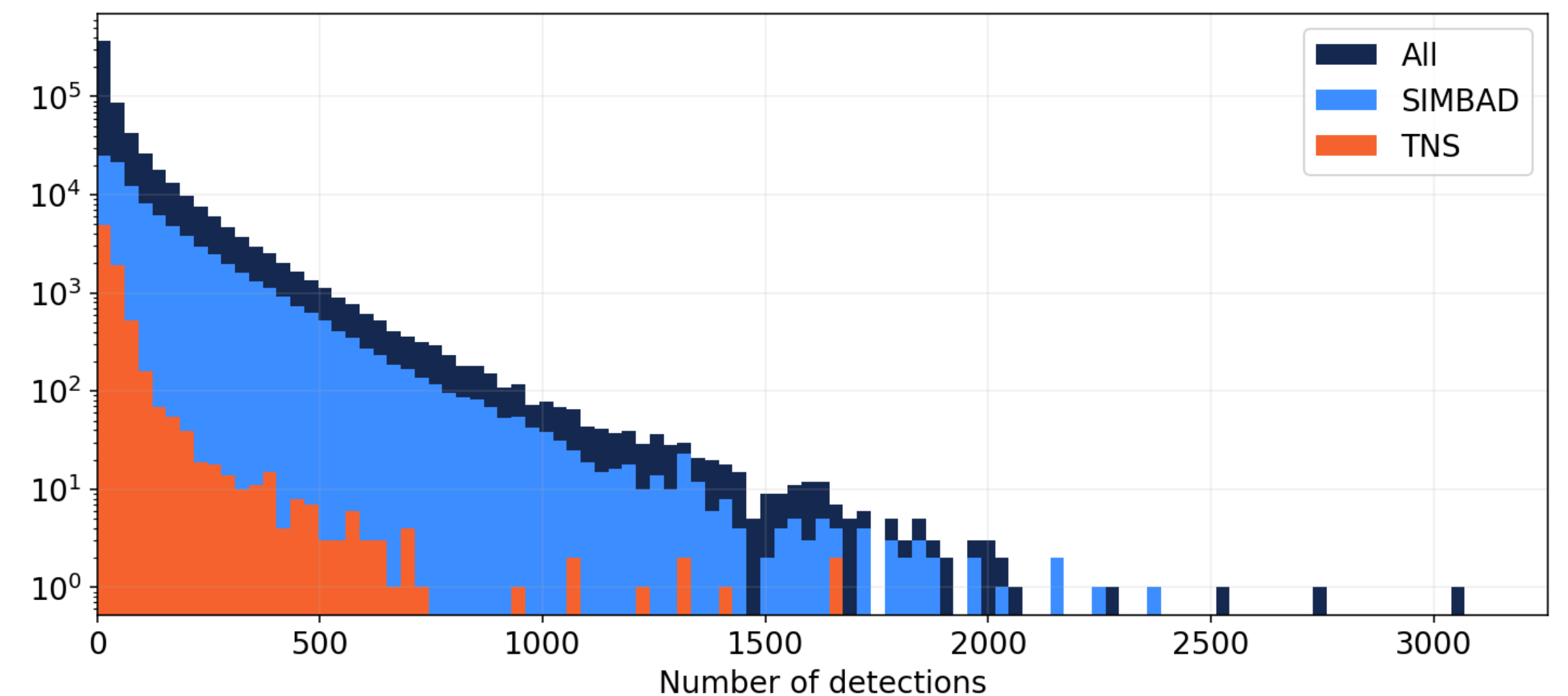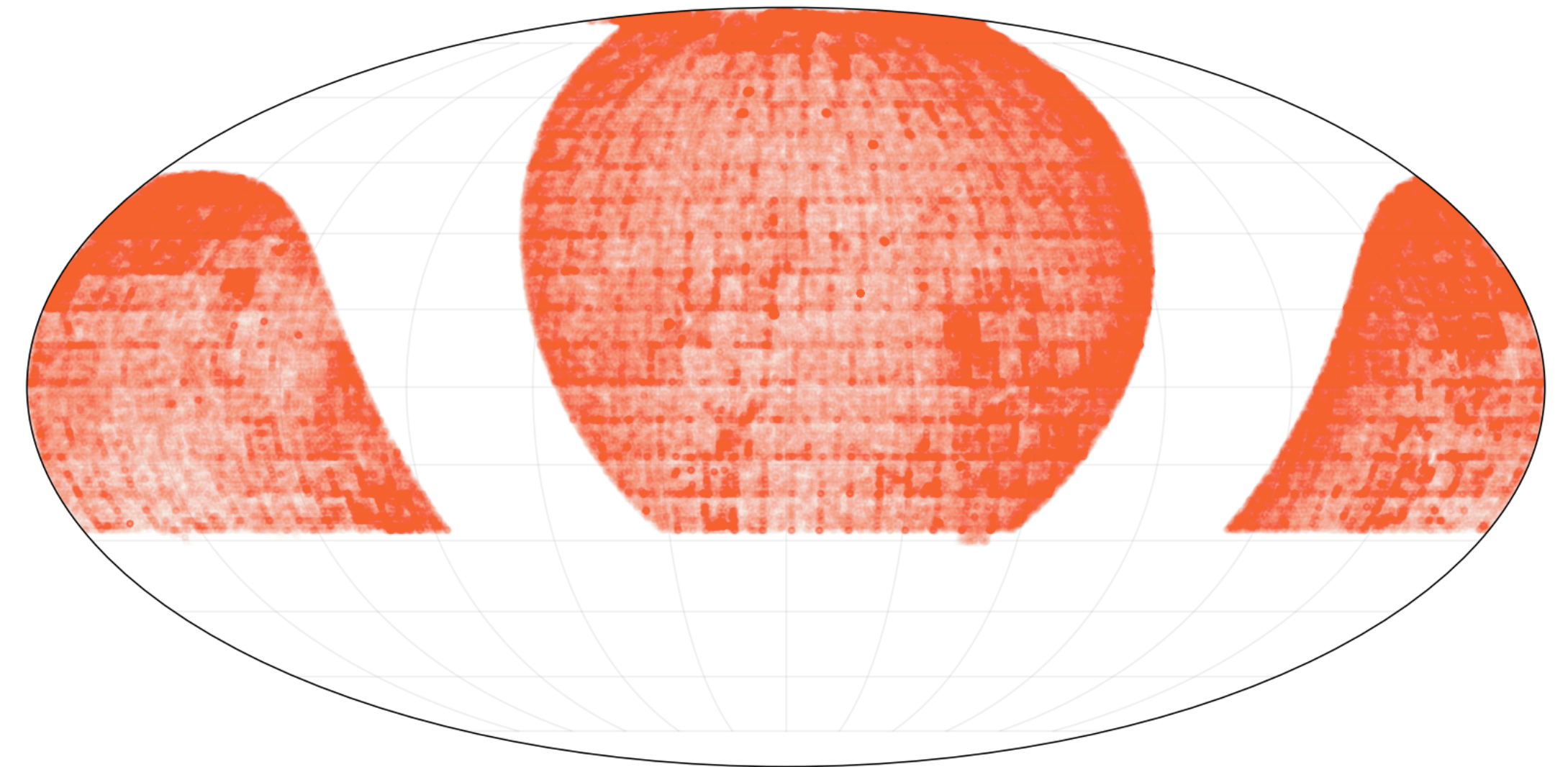
Rising parts of light curves

- 100 days long window for analysis

- at least 5 points, in both filters

- no detections in 100 days before

- no negative detections prior to that

- rising in both bands

  - last point is above minimum, or

  - significantly positive slope

- not fading in both bands

  - last point is not below maximum

  - every point is not below preceding one
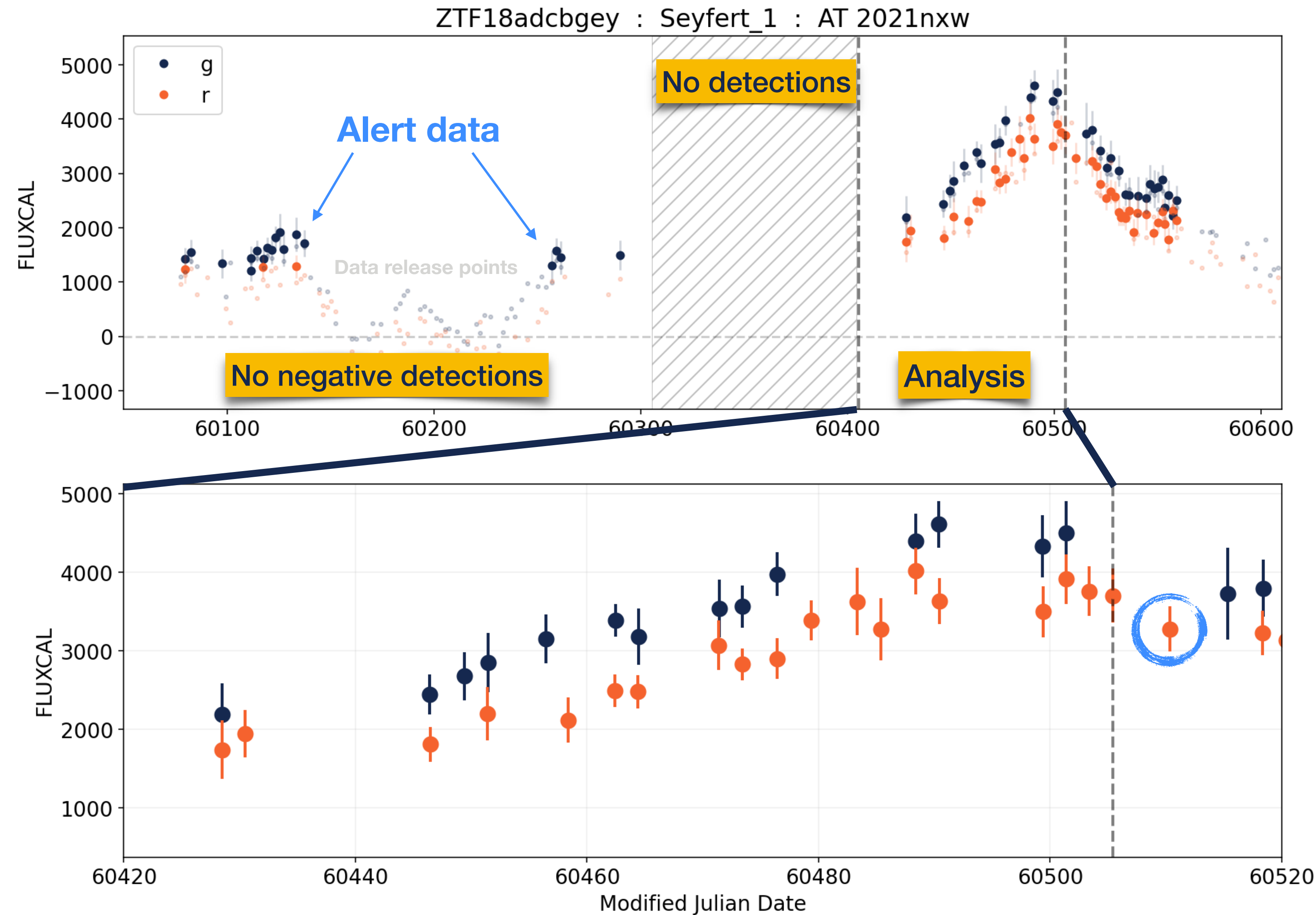
ZTF18adcbgey : Seyfert_1 : AT 2021nxw
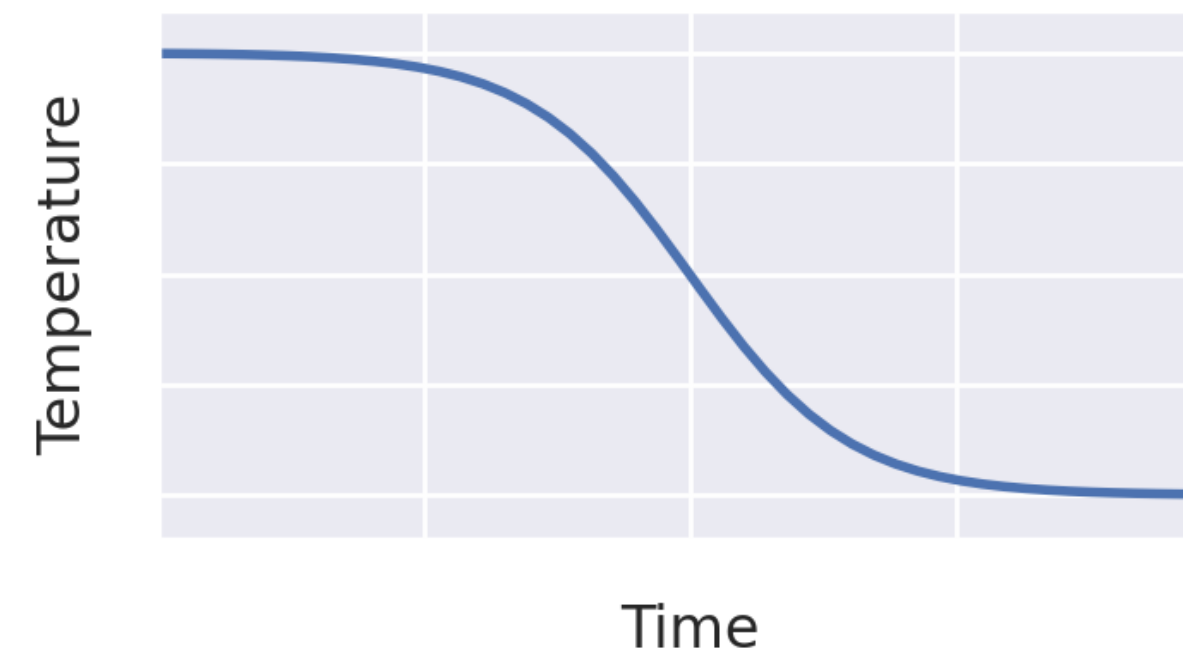
Rainbow fitting

Russeil et al. (2024)

Simple analytic decomposition of observed multi-color light curves into temperature and bolometric luminosity terms, assuming blackbody spectrum
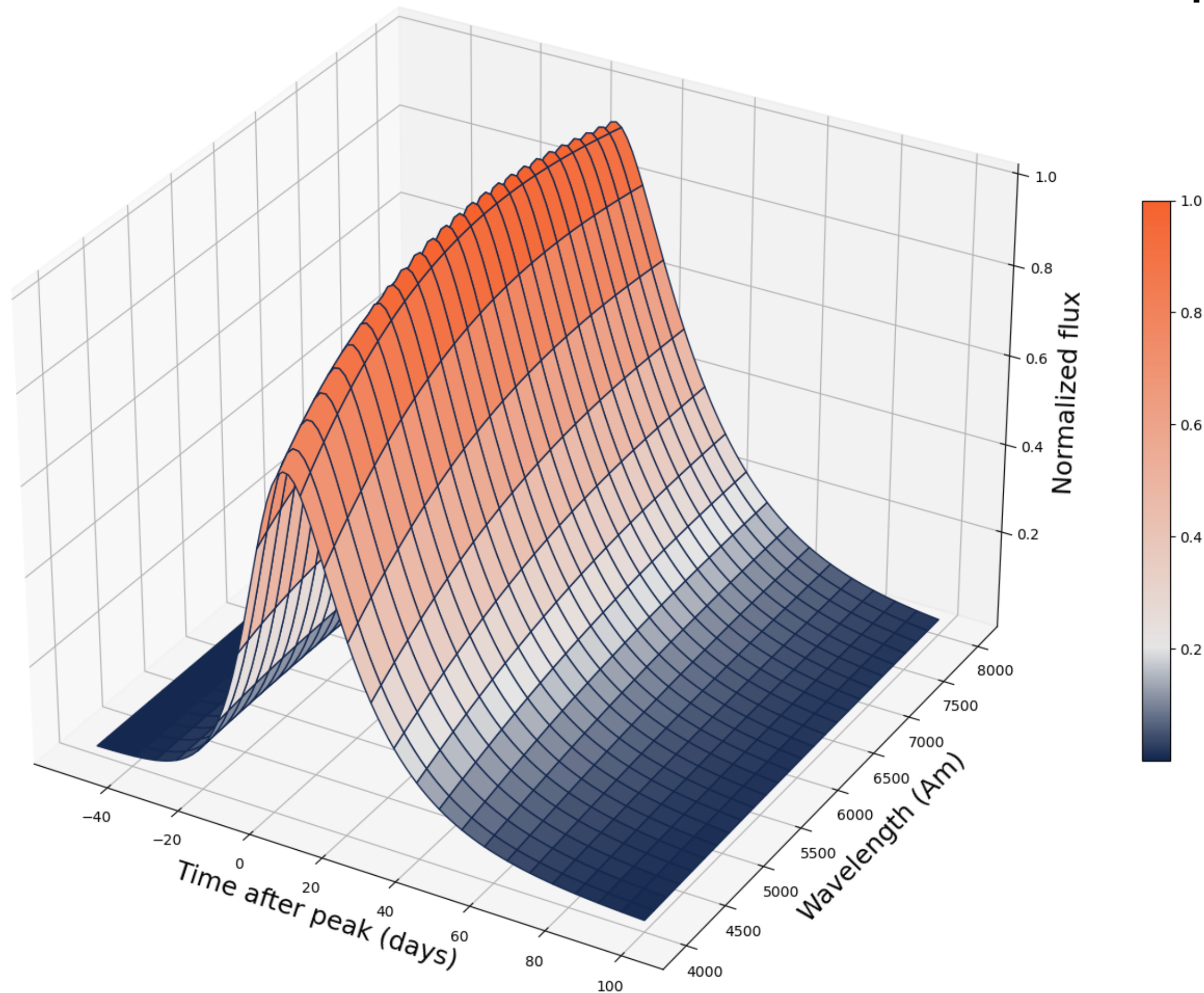
$$F_\nu(t, \nu) = \frac{\pi}{\sigma_{SB}} \times \frac{B_\nu(T, \nu)}{T(t)^4} \times F_{bol}(t)$$

$$T(t) = T_{min} + \frac{T_{max} - T_{min}}{1 + e^{\frac{t - t_0}{\tau}}}$$

sigmoid

$$F_{bol}(t) = \frac{A}{e^{-\frac{t - t_0}{\tau_{rise}}} + e^{\frac{t - t_0}{\tau_{fall}}}}$$

Bazin

https://github.com/light-curve/light-curve-python

Supernova-like light curves

Rainbow fitting

Russeil et al. (2024)

Simple analytic decomposition of observed multi-color light curves into temperature and bolometric luminosity terms, assuming blackbody spectrum

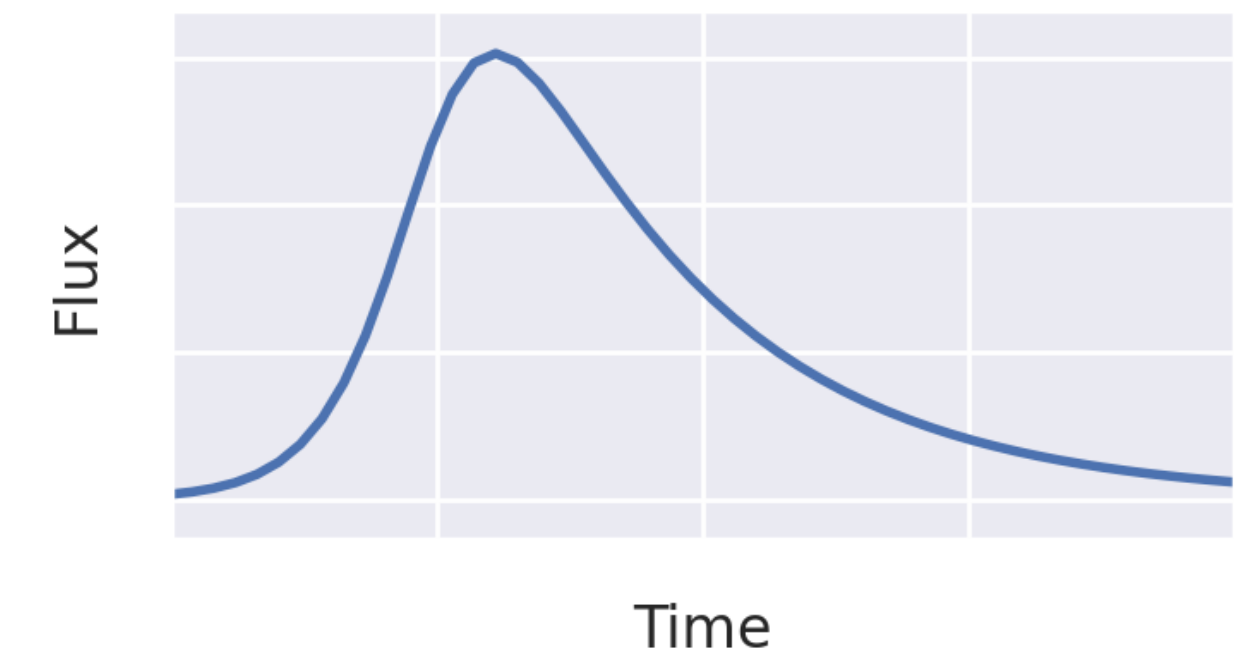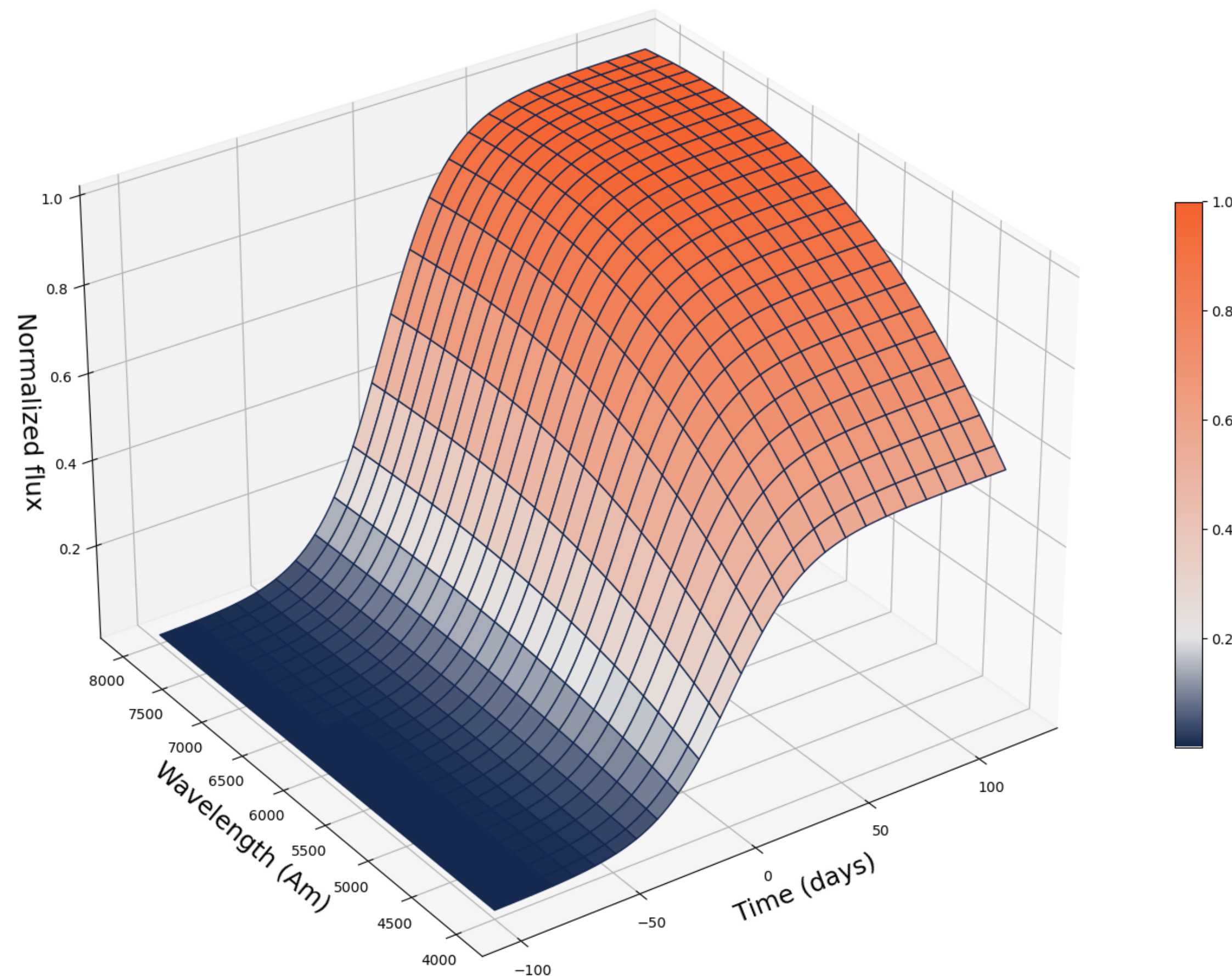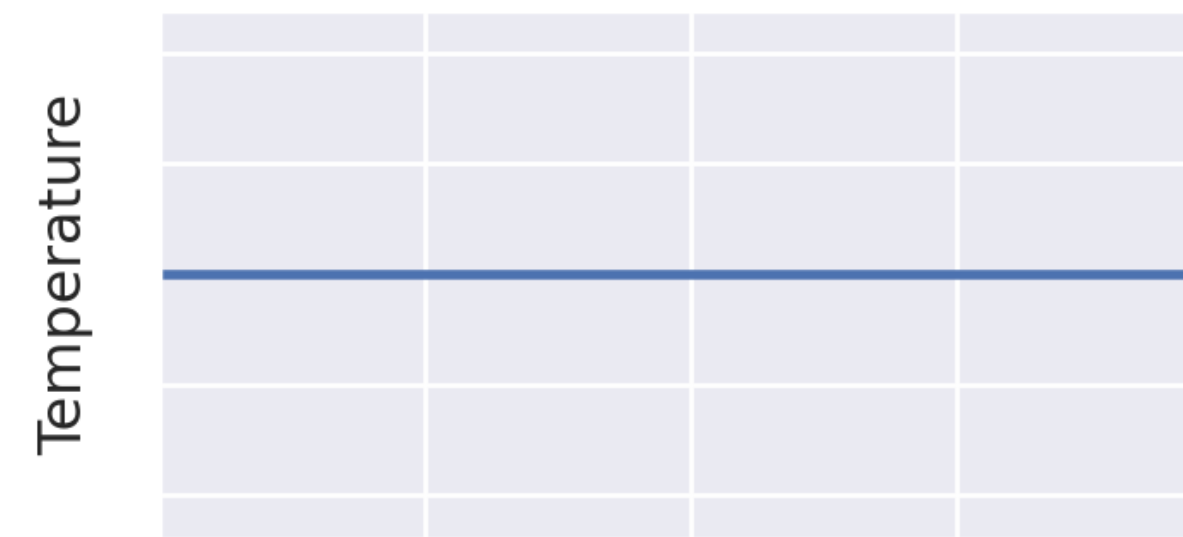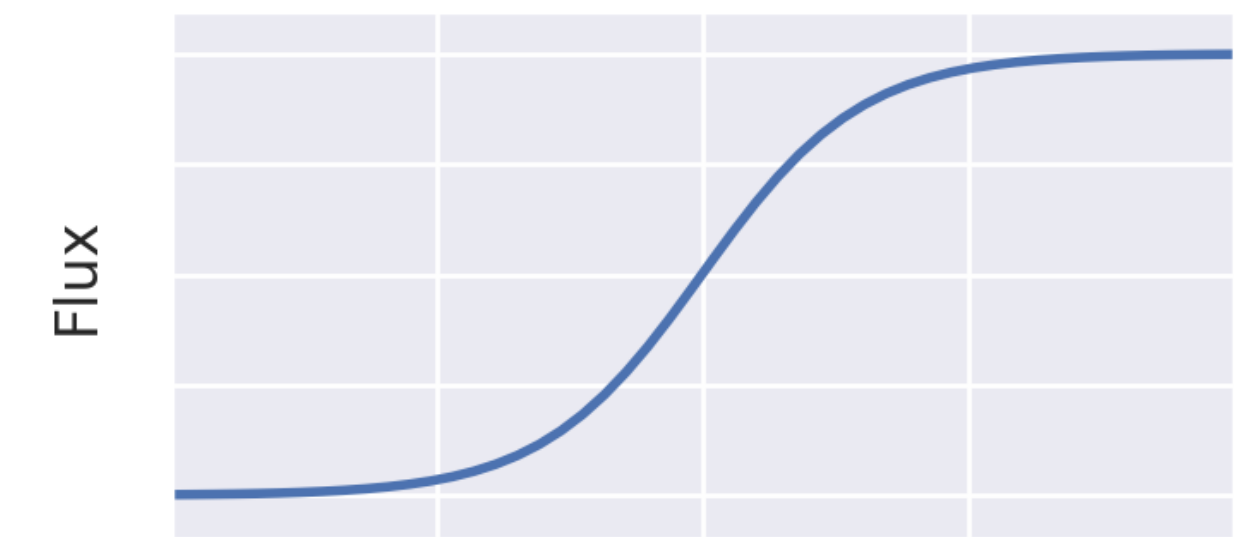$$F_\nu(t, \nu) = \frac{\pi}{\sigma_{SB}} \times \frac{B_\nu(T, \nu)}{T(t)^4} \times F_{bol}(t)$$

$$T(t) = const$$

constant

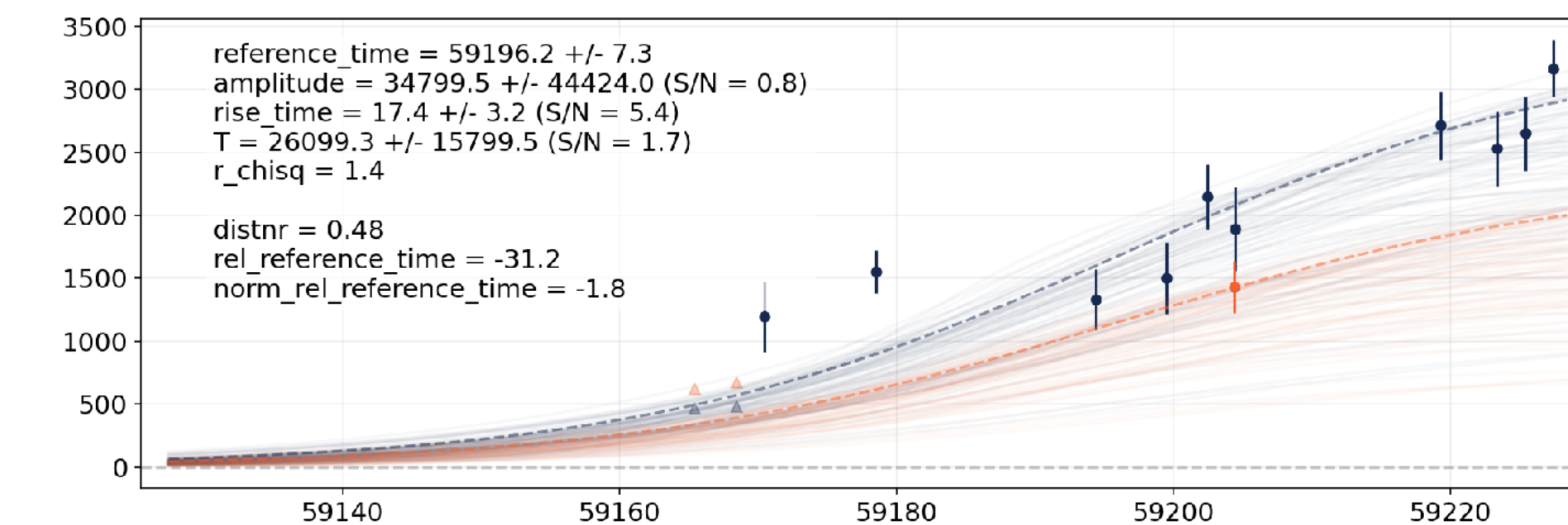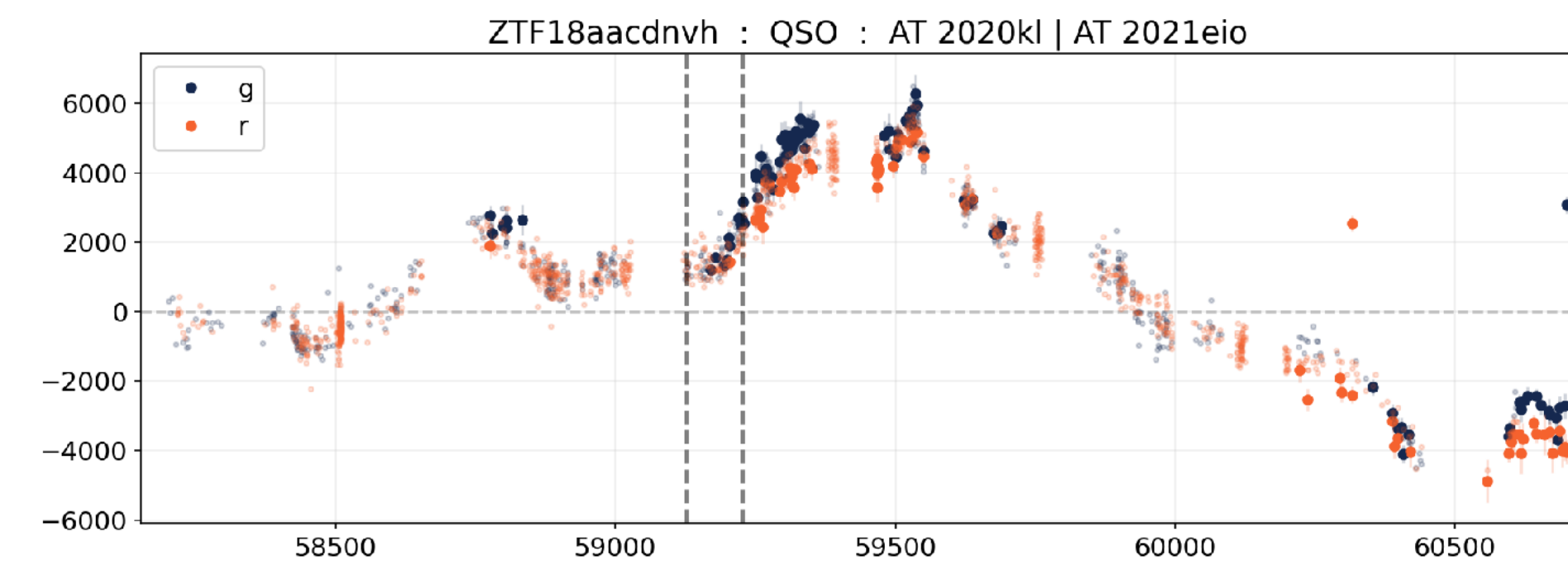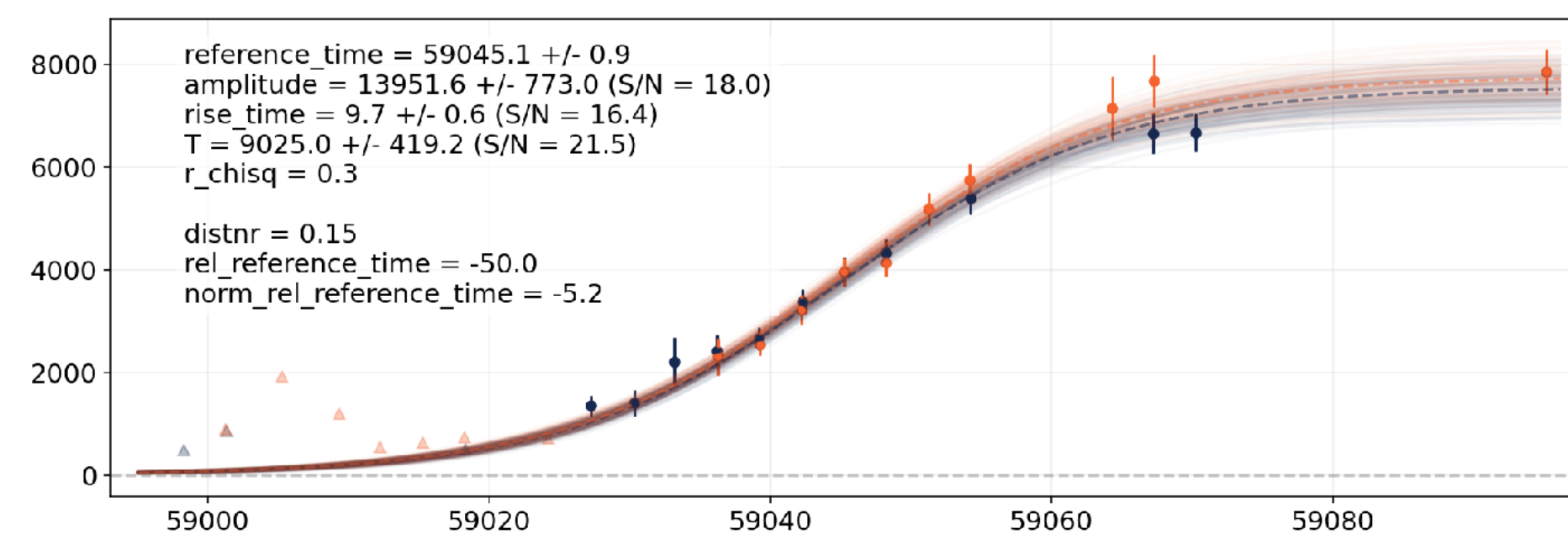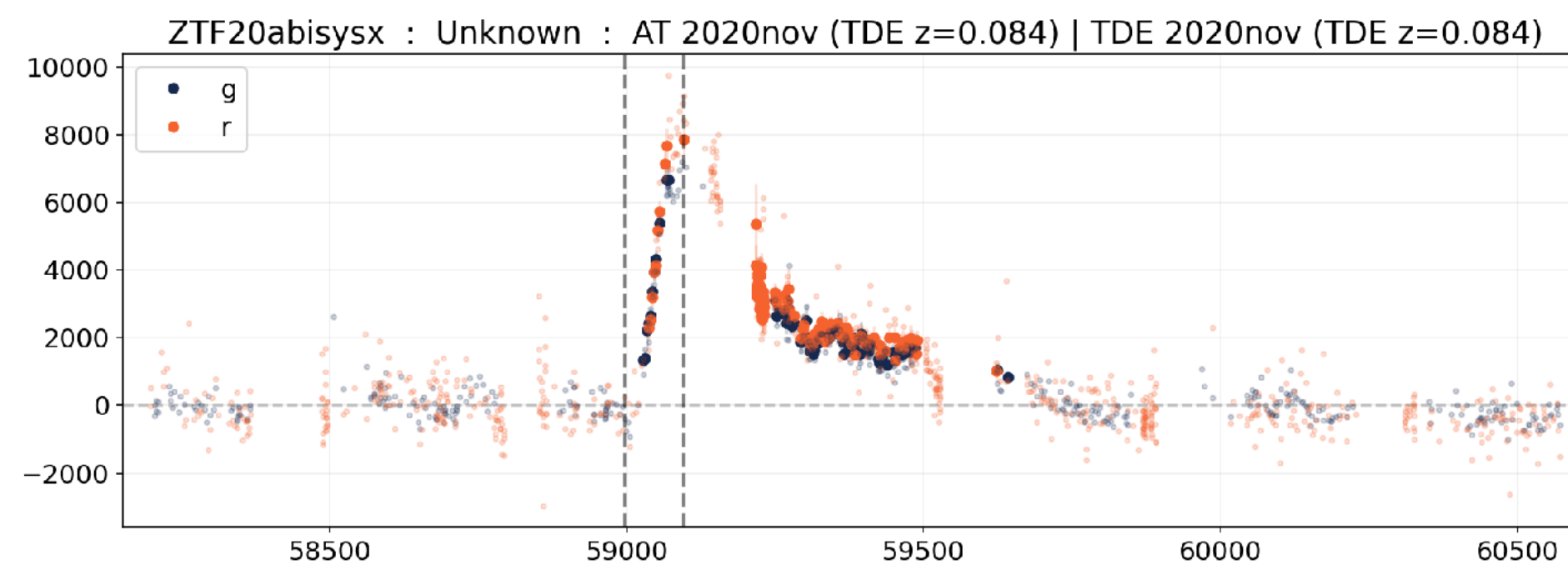$$F_{bol}(t) = \frac{A}{1 + e^{-\frac{t - t_0}{\tau}}}$$

sigmoid

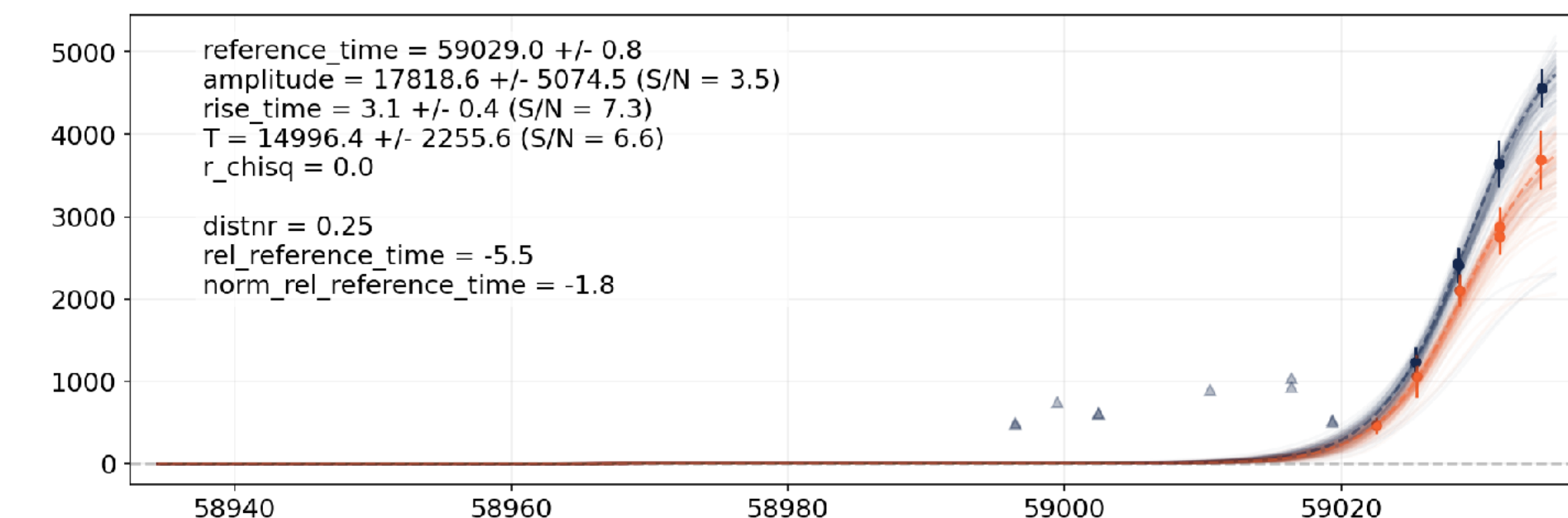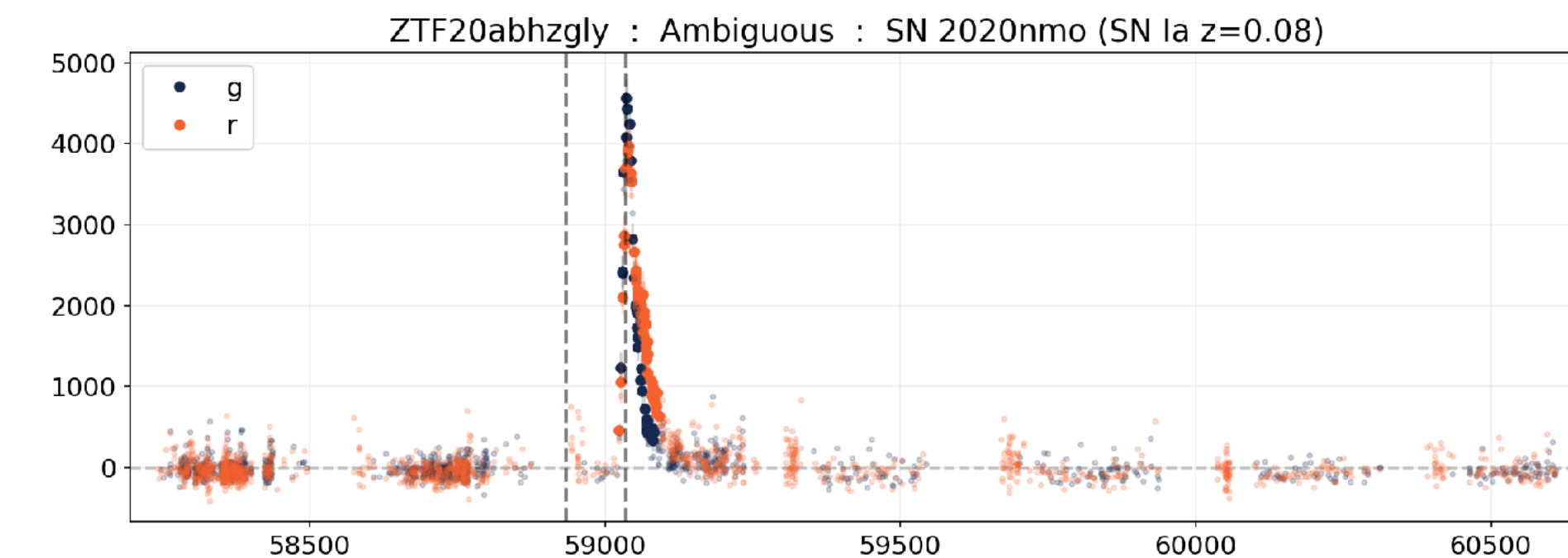**Early TDE-like light curves**

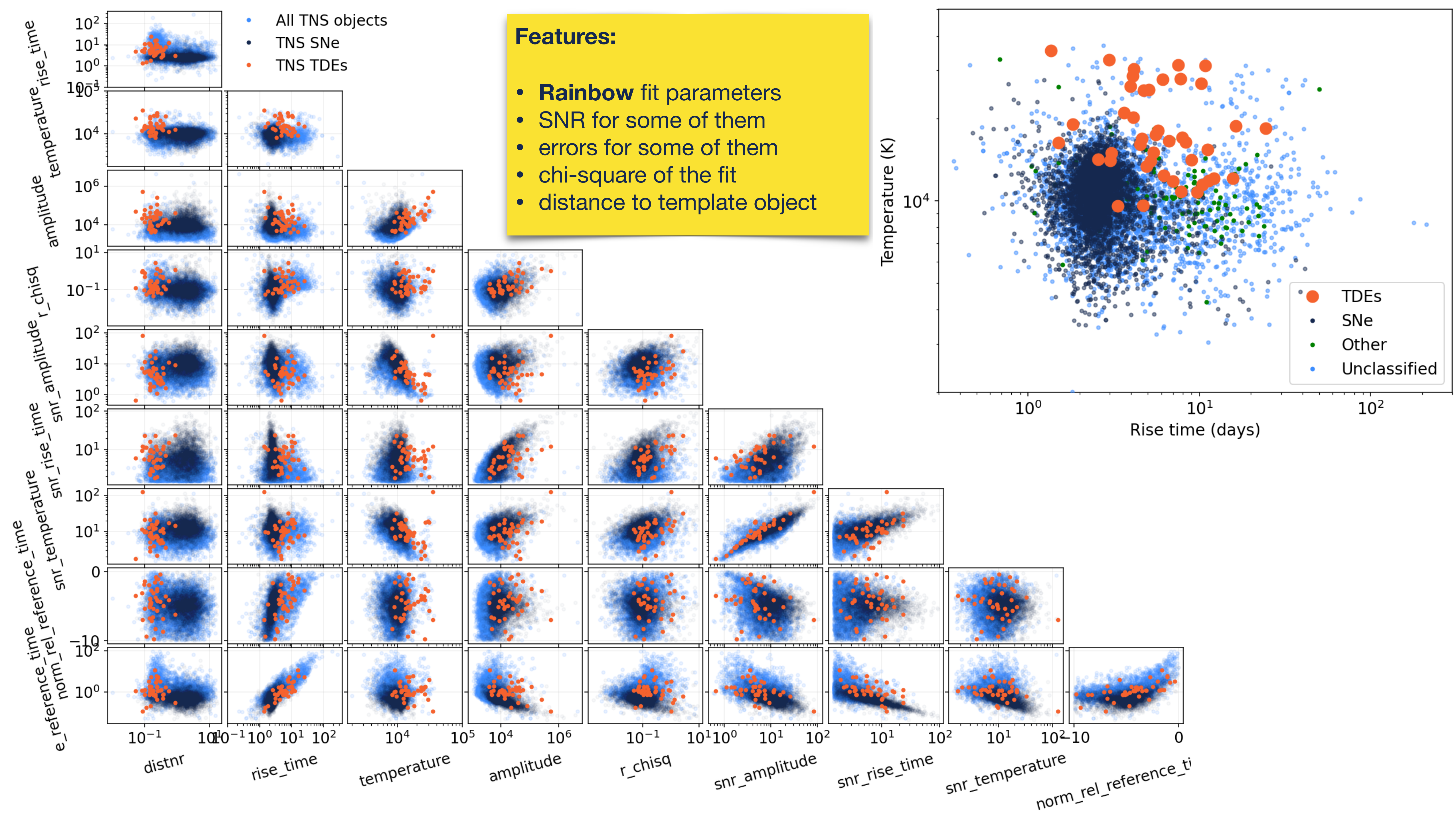https://github.com/light-curve/light-curve-python

Training sample

- **~600k** light curves → **40k** peaks in total
  - **12600** good fits (χ^2, S/N, ..)

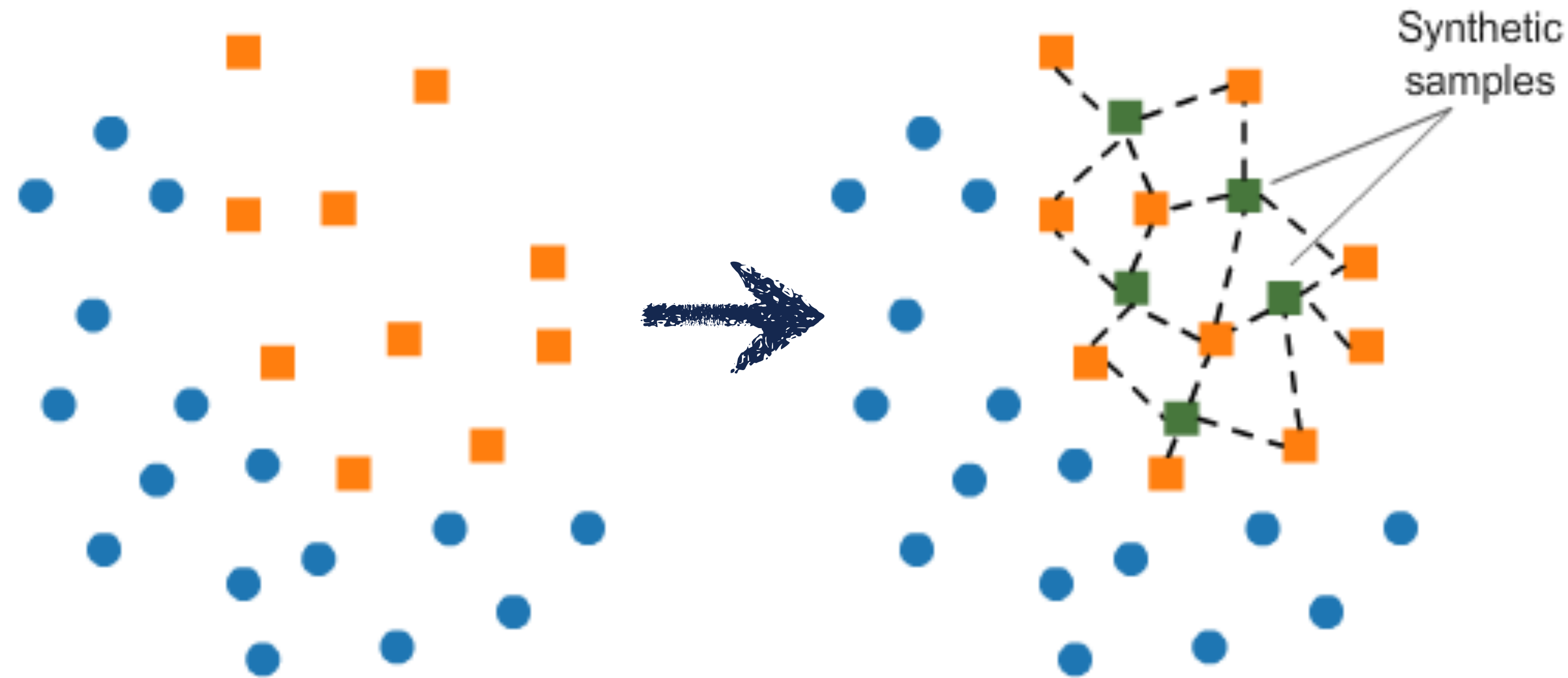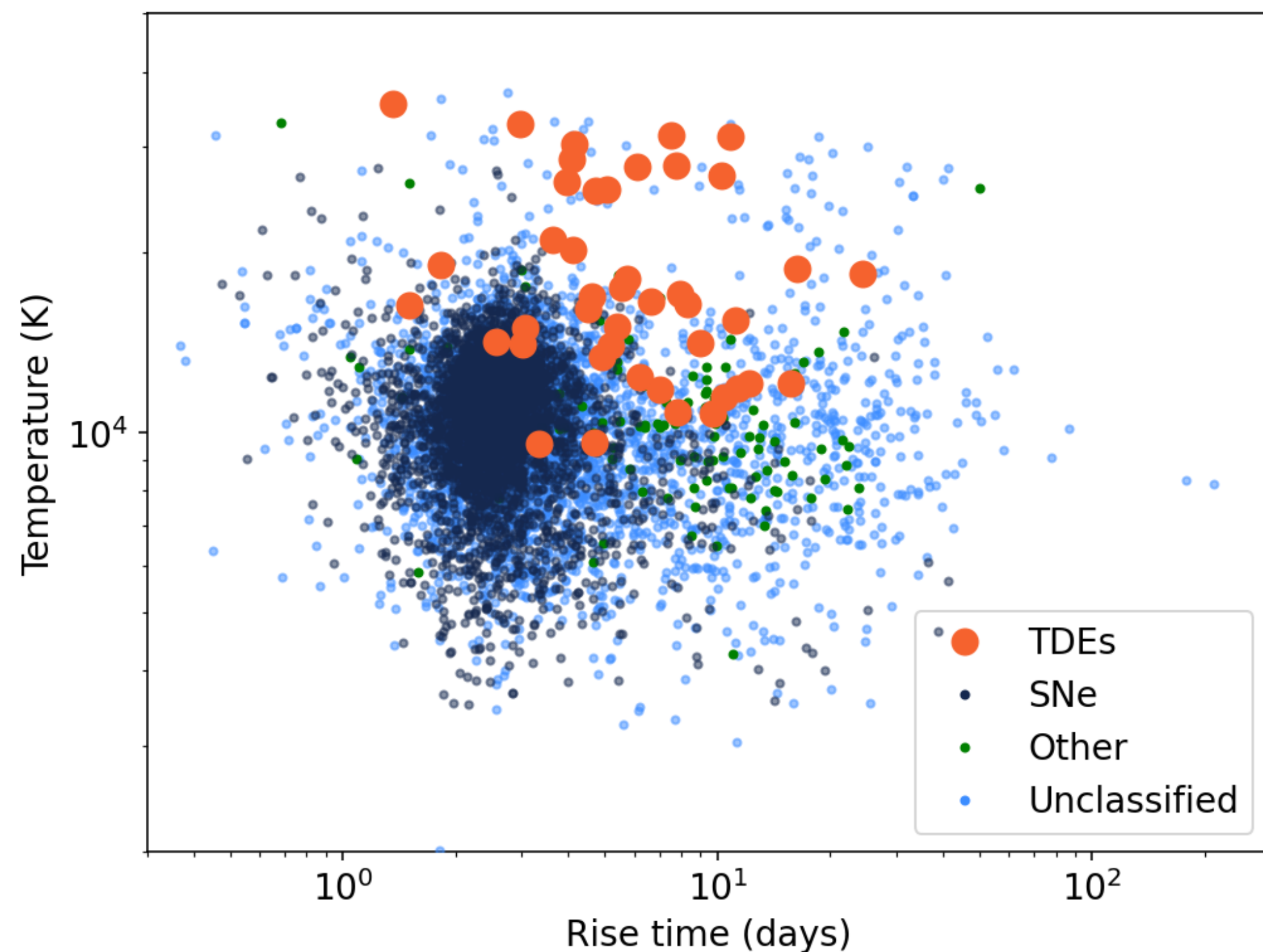- **8863** TNS entries
- **3956** SNe
- **42** TDEs

TRANSIENT NAME SERVER

42 positives
8821 negatives

ZTF20abhzgly : Ambiguous : SN 2020nmo (SN Ia z=0.08)

reference_time = 59029.0 +/- 0.8
amplitude = 17818.6 +/- 5074.5 (S/N = 3.5)
rise_time = 3.1 +/- 0.4 (S/N = 7.3)
T = 14996.4 +/- 2255.6 (S/N = 6.6)
r_chisq = 0.0

distnr = 0.25
rel_reference_time = -5.5
norm_rel_reference_time = -1.8

ZTF20abisysx : Unknown : AT 2020nov (TDE z=0.084) | TDE 2020nov (TDE z=0.084)

reference_time = 59045.1 +/- 0.9
amplitude = 13951.6 +/- 773.0 (S/N = 18.0)
rise_time = 9.7 +/- 0.6 (S/N = 16.4)
T = 9025.0 +/- 419.2 (S/N = 21.5)
r_chisq = 0.3

distnr = 0.15
rel_reference_time = -50.0
norm_rel_reference_time = -5.2

ZTF18aacdnvh : QSO : AT 2020kl | AT 2021eio

reference_time = 59196.2 +/- 7.3
amplitude = 34799.5 +/- 44424.0 (S/N = 0.8)
rise_time = 17.4 +/- 3.2 (S/N = 5.4)
T = 26099.3 +/- 15799.5 (S/N = 1.7)
r_chisq = 1.4

distnr = 0.48
rel_reference_time = -31.2
norm_rel_reference_time = -1.8

Features:

- **Rainbow** fit parameters
- SNR for some of them
- errors for some of them
- chi-square of the fit
- distance to template object

Features:

- **Rainbow** fit parameters (+/-)
- ~~SNR for some of them~~
- errors for some of them (-/+)
- ~~chi-square of the fit~~
- distance to template object (**!!!**)

Highly imbalanced dataset

Non-discriminating features?

TDEs
SNe
Other
Unclassified

All TNS objects
TNS SNe
TNS TDEs

Temperature (K)

Rise time (days)

Class balancing with oversampling

SMOTE - Synthetic Minority Over-sampling Technique
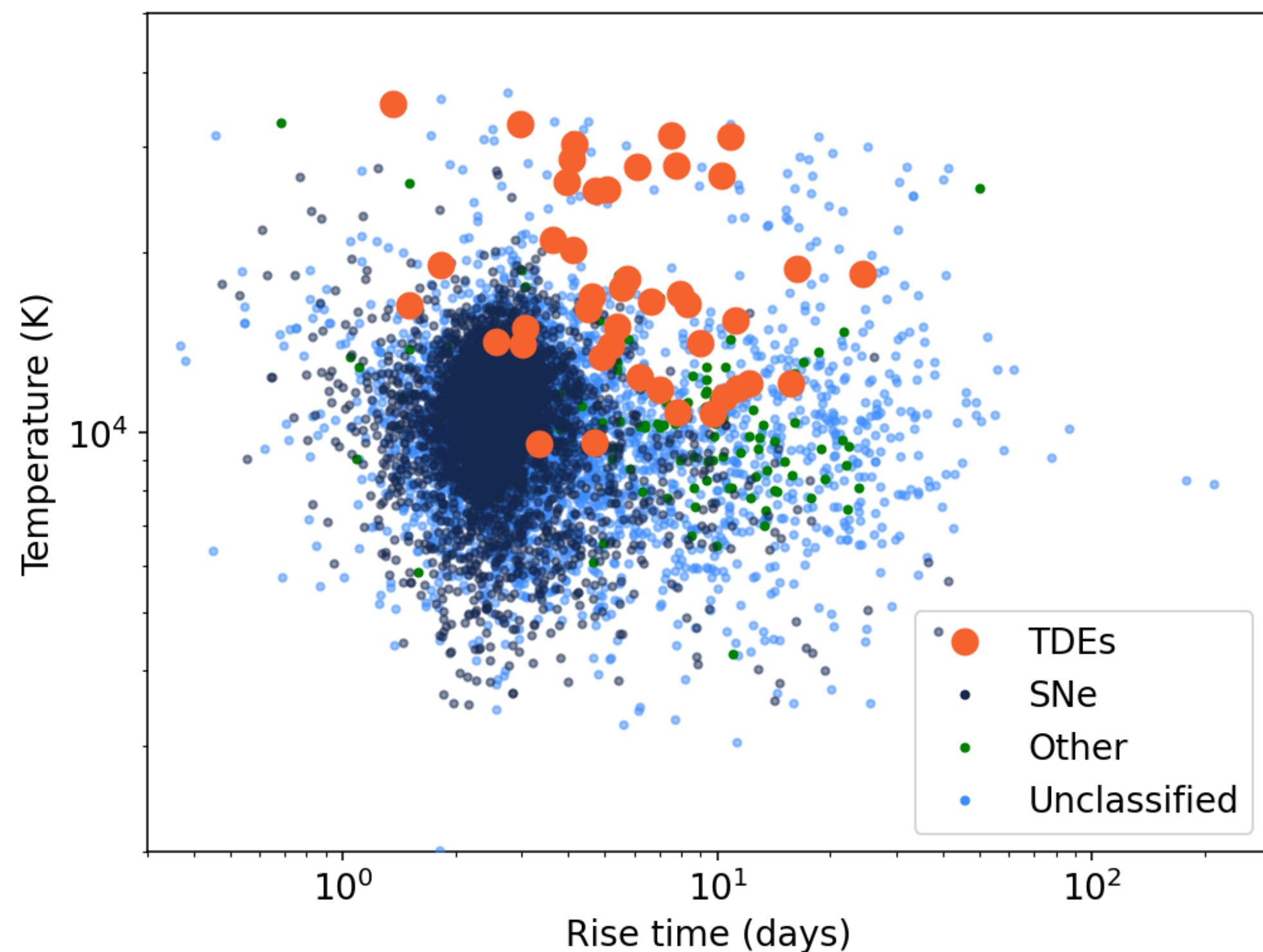
find groups of nearby points
add new ones by linear interpolation in pairs
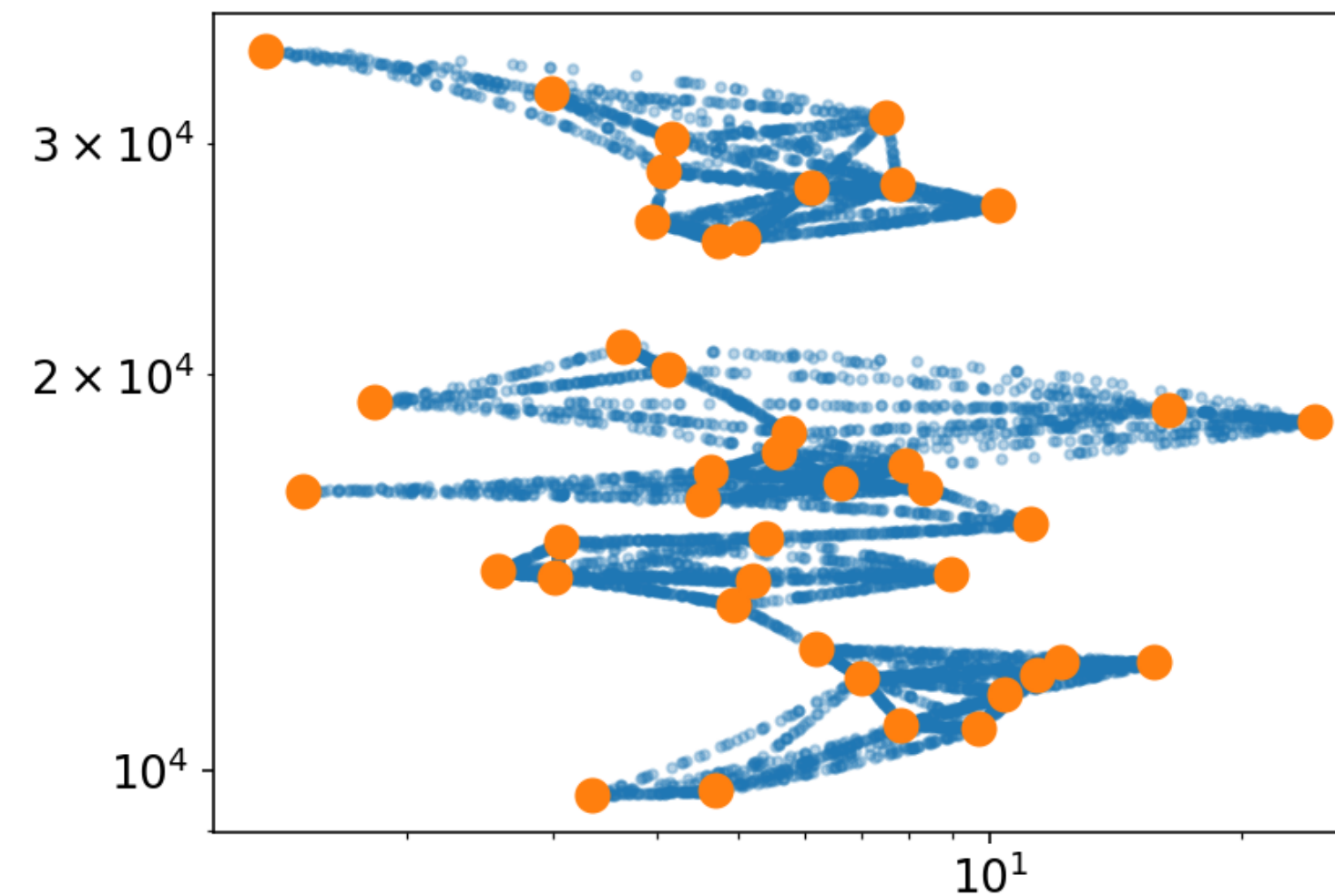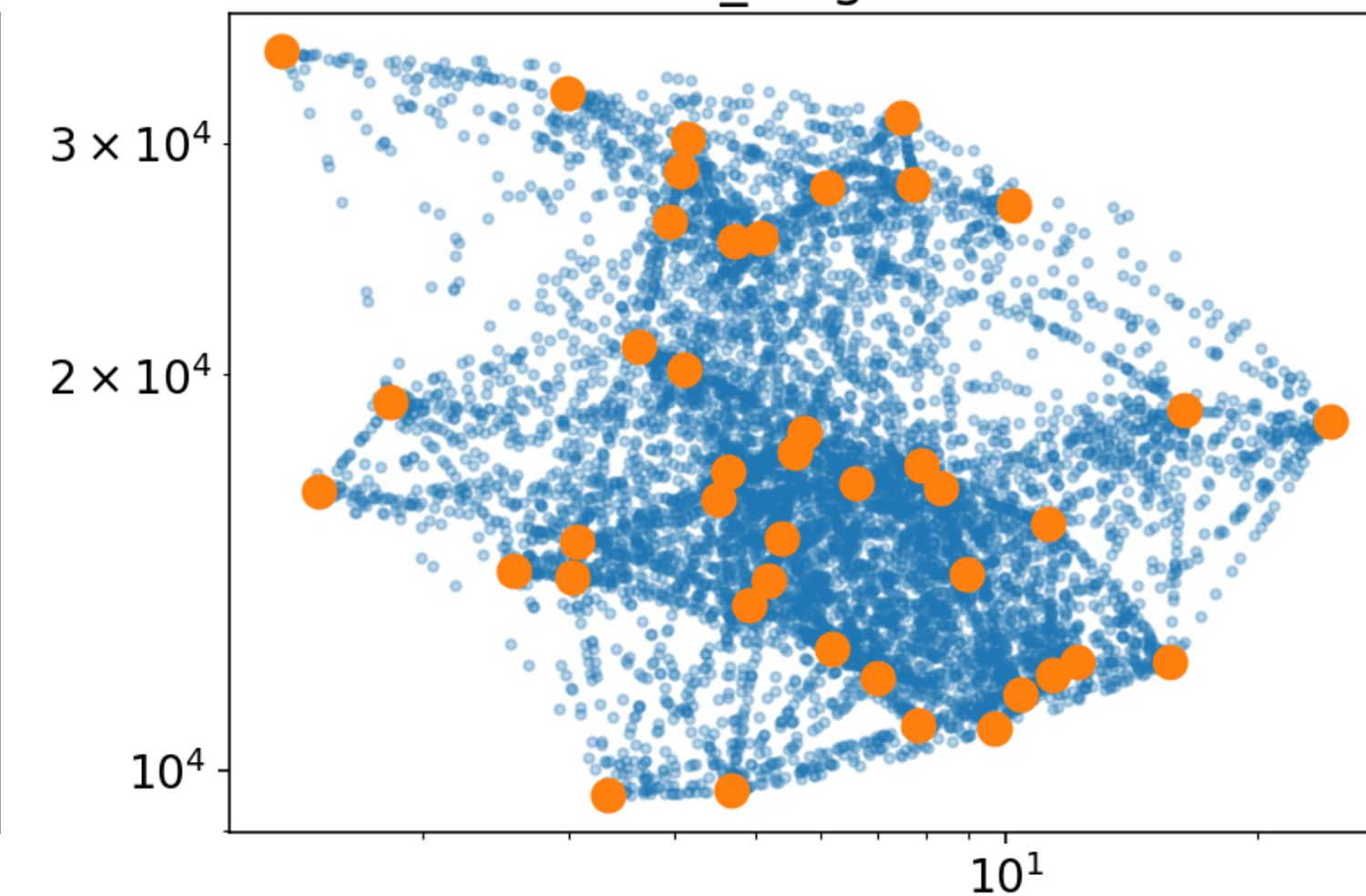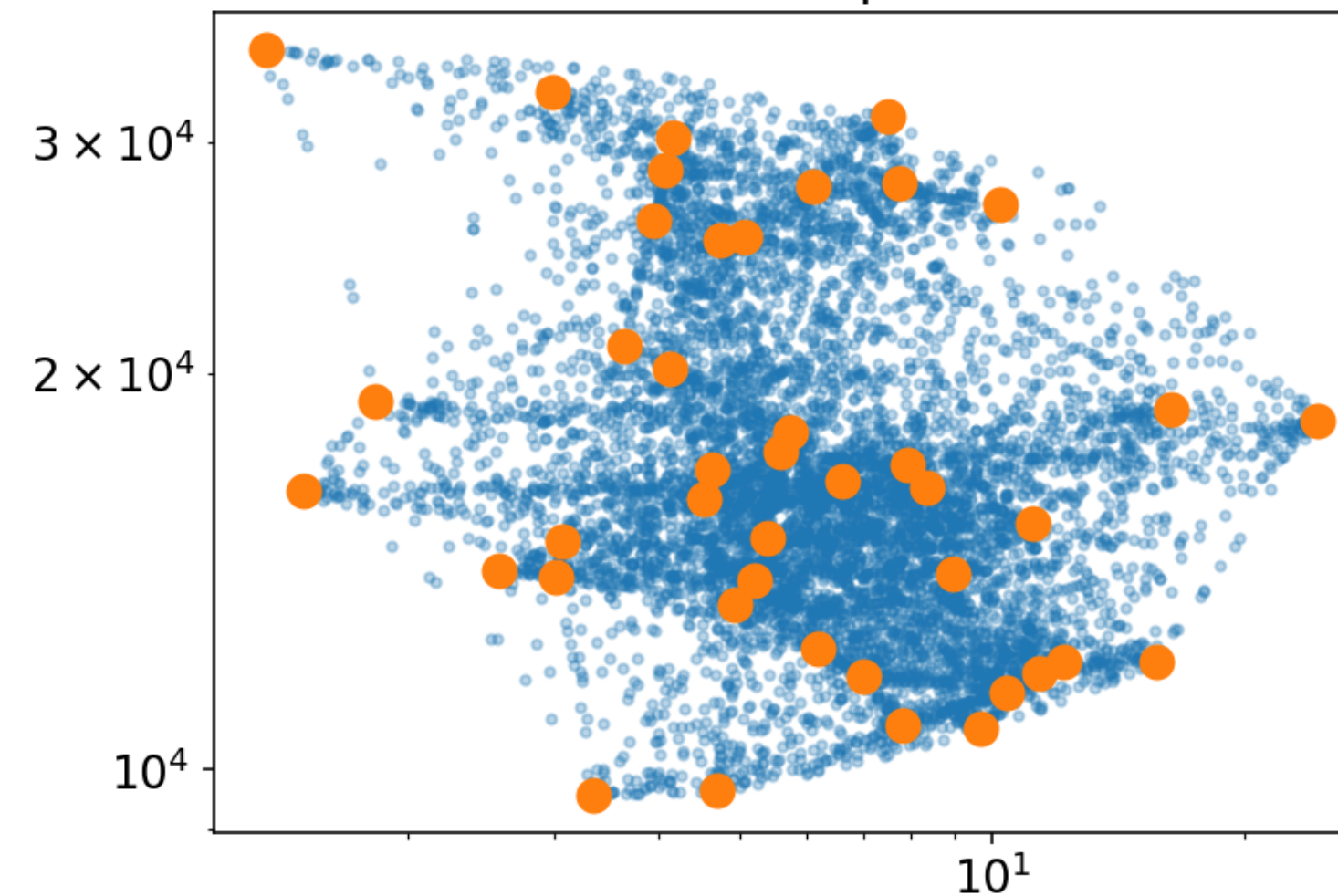use for training only, validate on original dataset

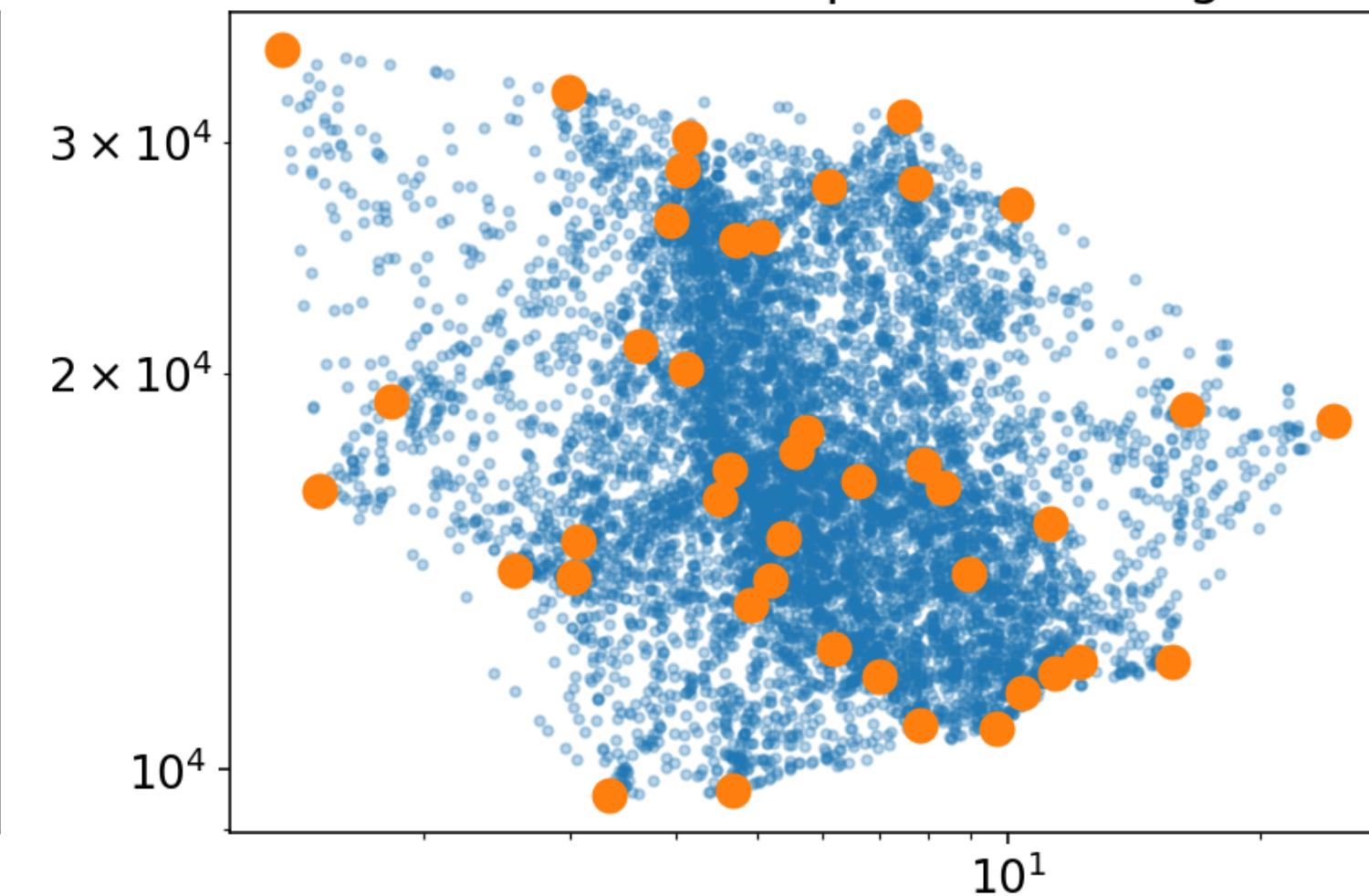https://imbalanced-learn.org/

Class balancing with oversampling

SMOTE - Synthetic Minority Over-sampling Technique

find groups of nearby points
add new ones by linear interpolation in pairs
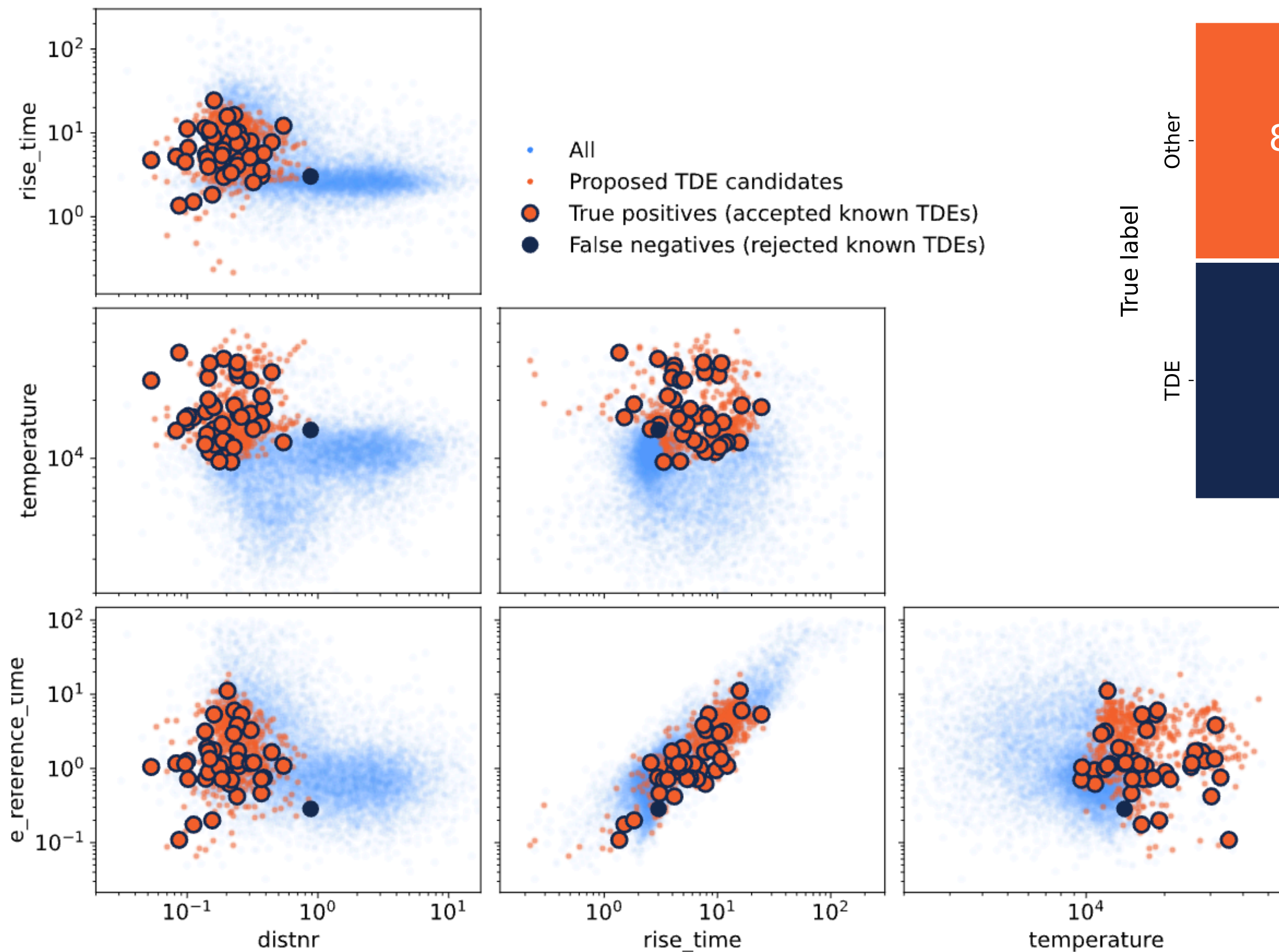use for training only, validate on original dataset

https://imbalanced-learn.org/

"Generalizing" classifier

Nuclear (confusion matrix)

True label	Predicted: Other	Predicted: TDE
Other	8585	238
TDE	10	32

12% purity
76% completeness

- XGBoost
- Balance by **two-step SMOTE**
- Force **shallow trees**
- Optimize hyperparameters for **recall**
  - use F2 score
- **Leave-One-Out** cross-validation

| Name	Value	
	Nuclear	Broad
Manually set		
`max_depth`	3	3
Optimized for F2 score		
`n_estimators`	200	200
`subsample`	0.8	0.8
`reg_lambda`	1	1
`reg_alpha`	1	1
`learning_rate`	0.06	0.06
`colsample_bytree`	1.0	1.0
`min_child_weight`	5	5
Final scores		
F2 score	0.37	0.25
F1 score	0.20	0.13
Precision	0.12	0.07
Recall	0.76	0.74
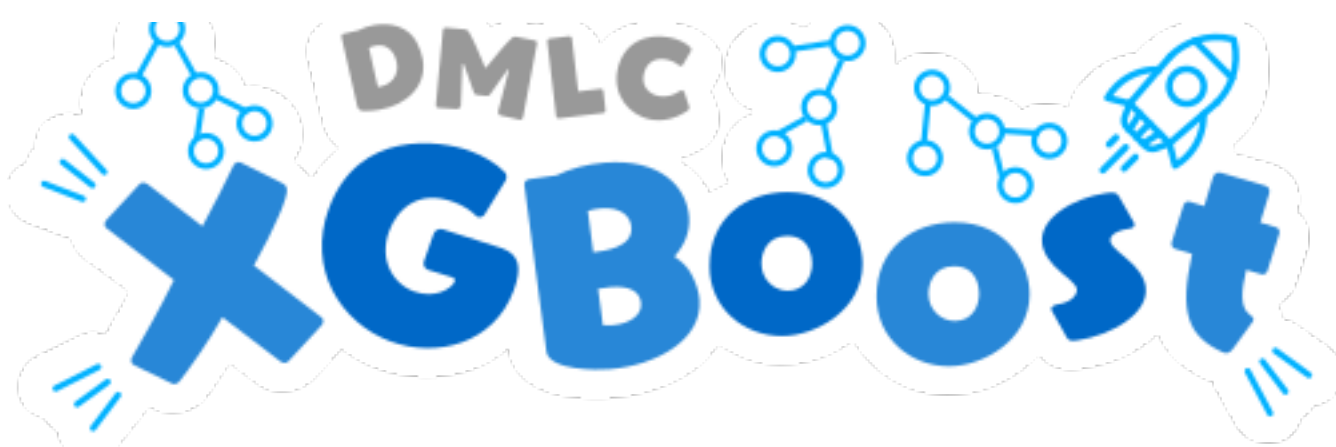
eXtreme Gradient Boosting library for classification and regression tasks, with good performance and many parameters

https://xgboost.ai
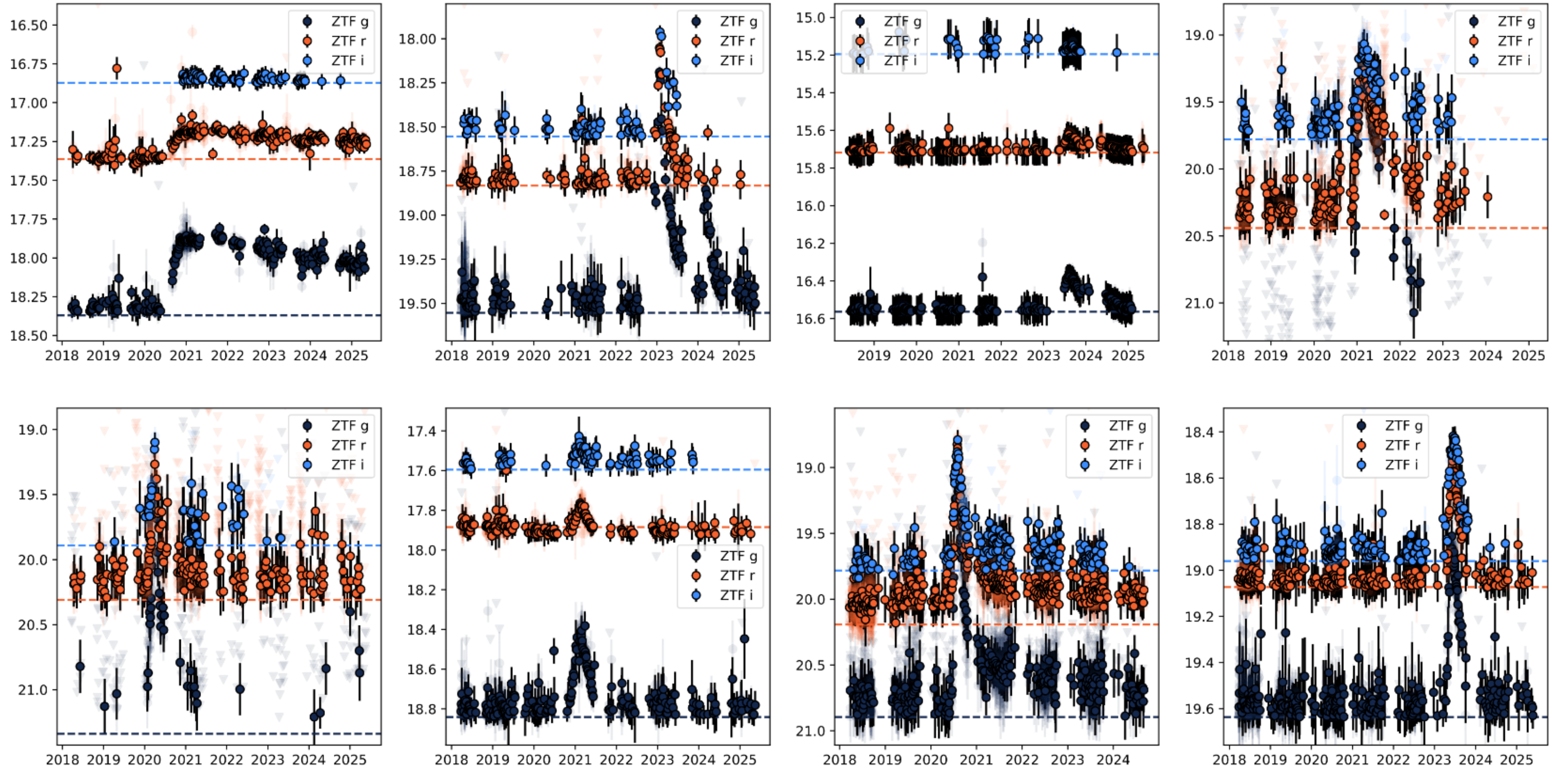
Candidates from historical dataset
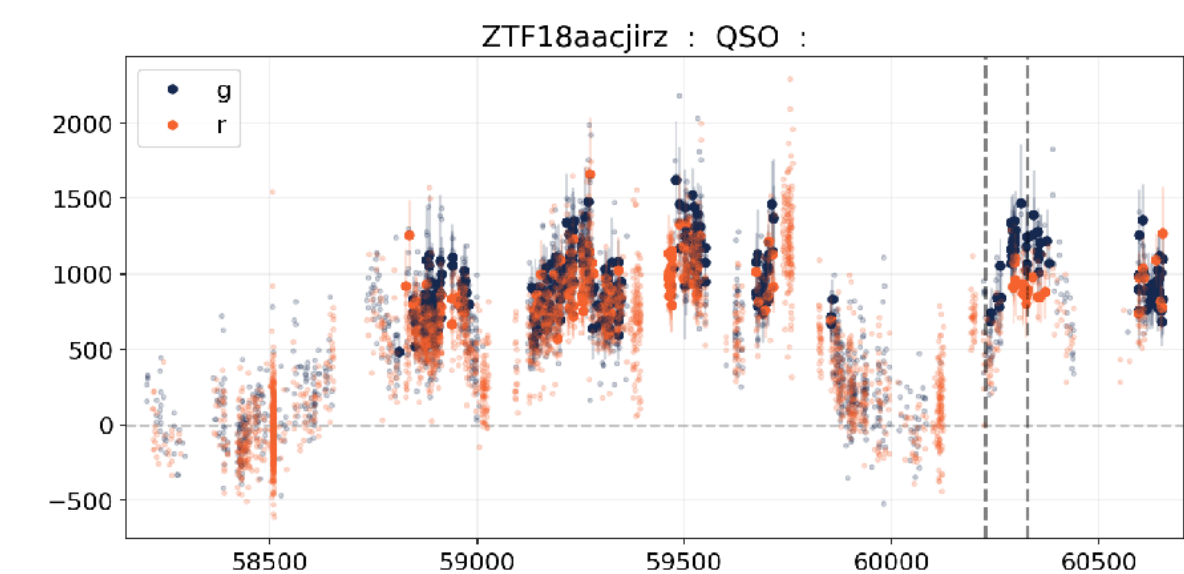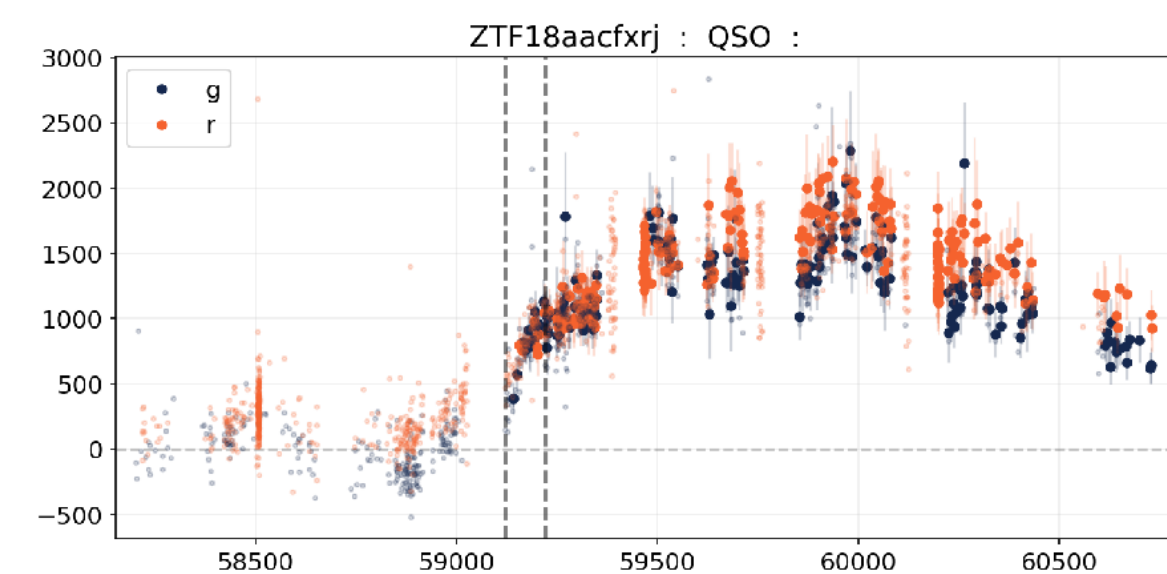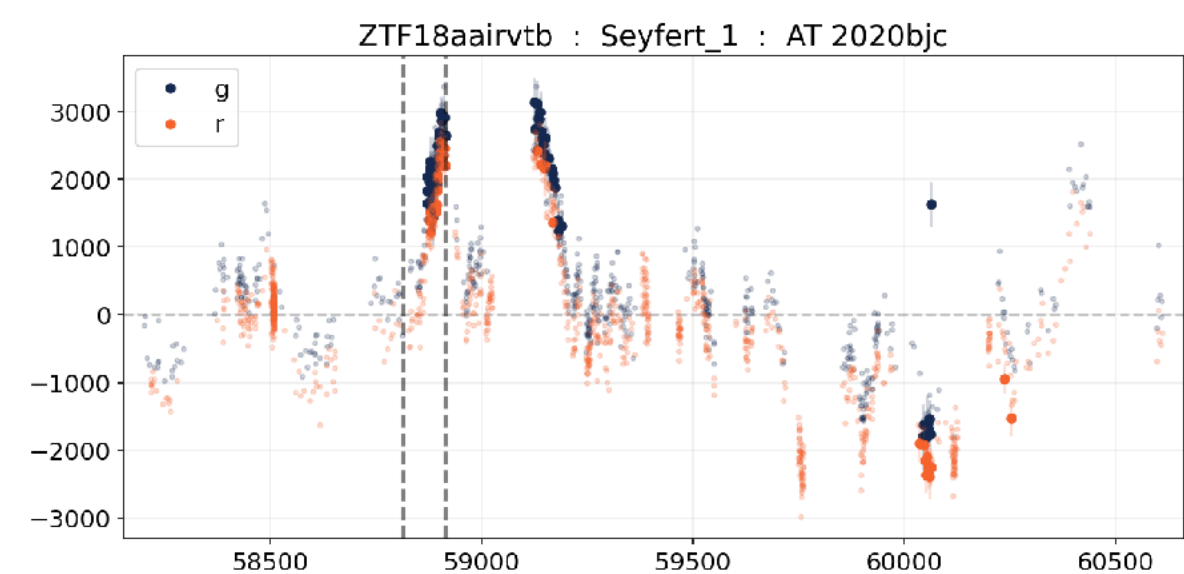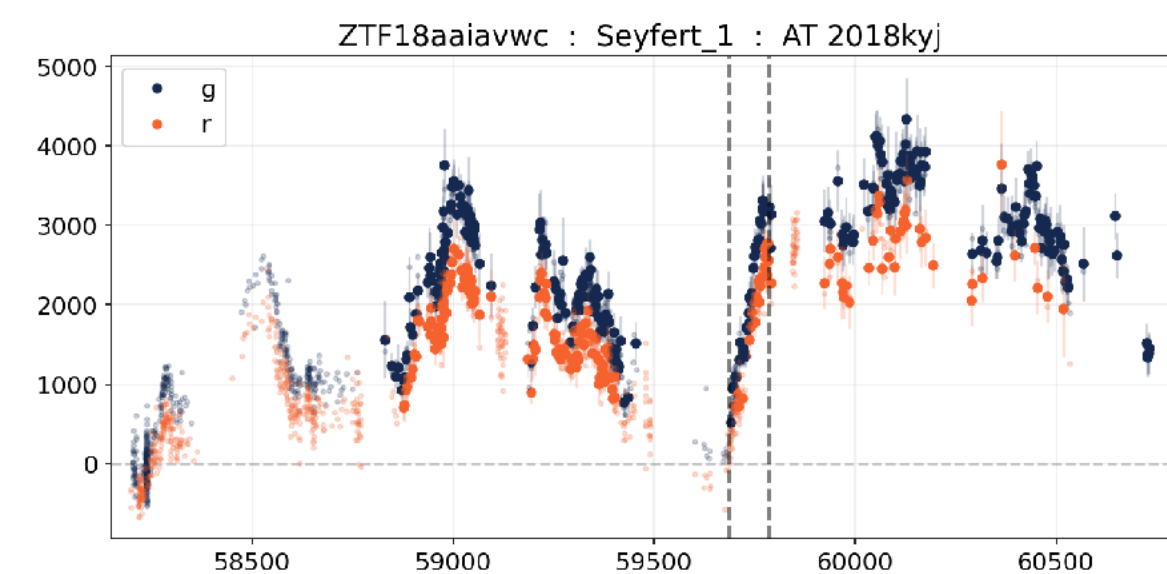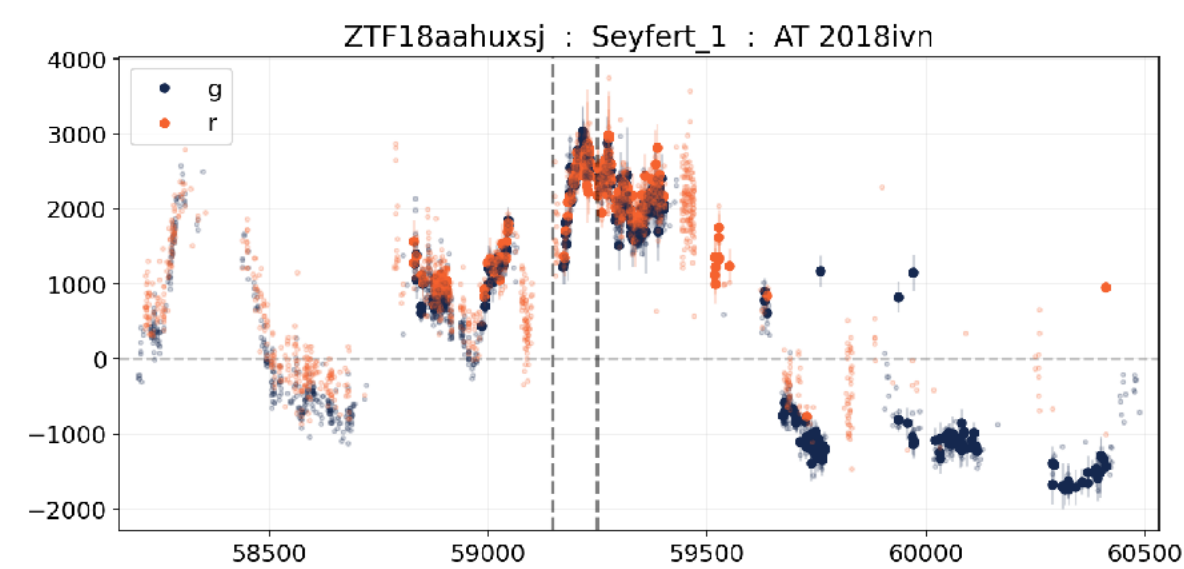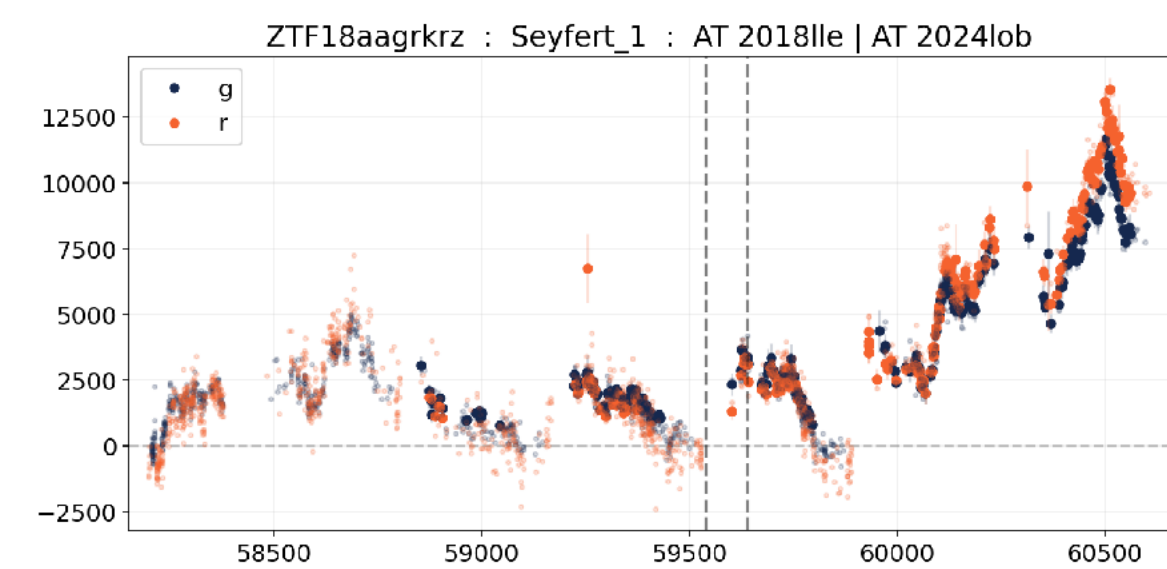
~30 candidates visually consistent with TDE light curves
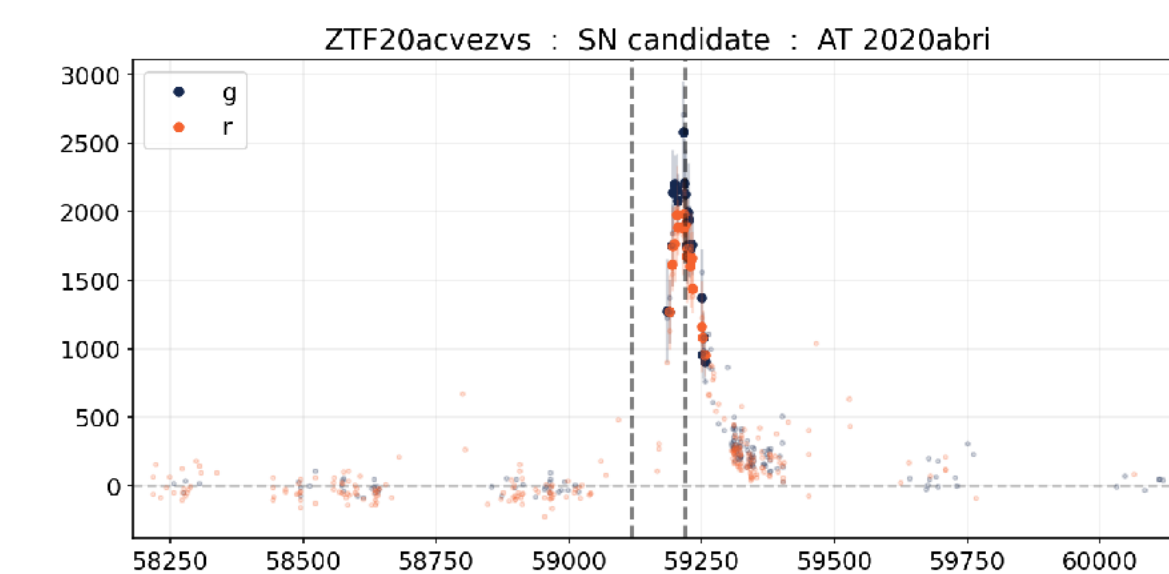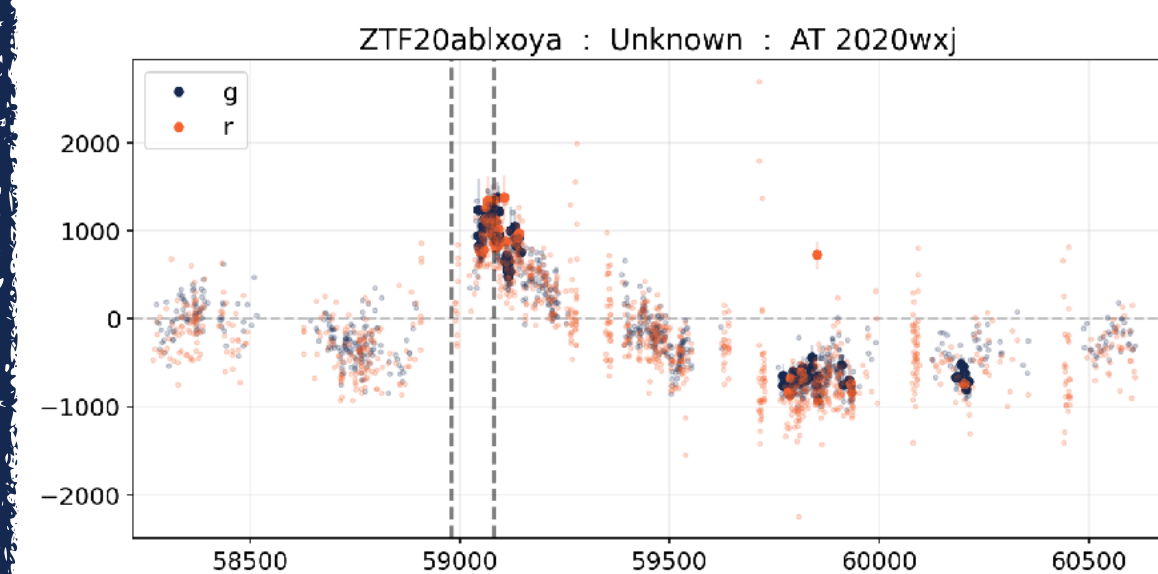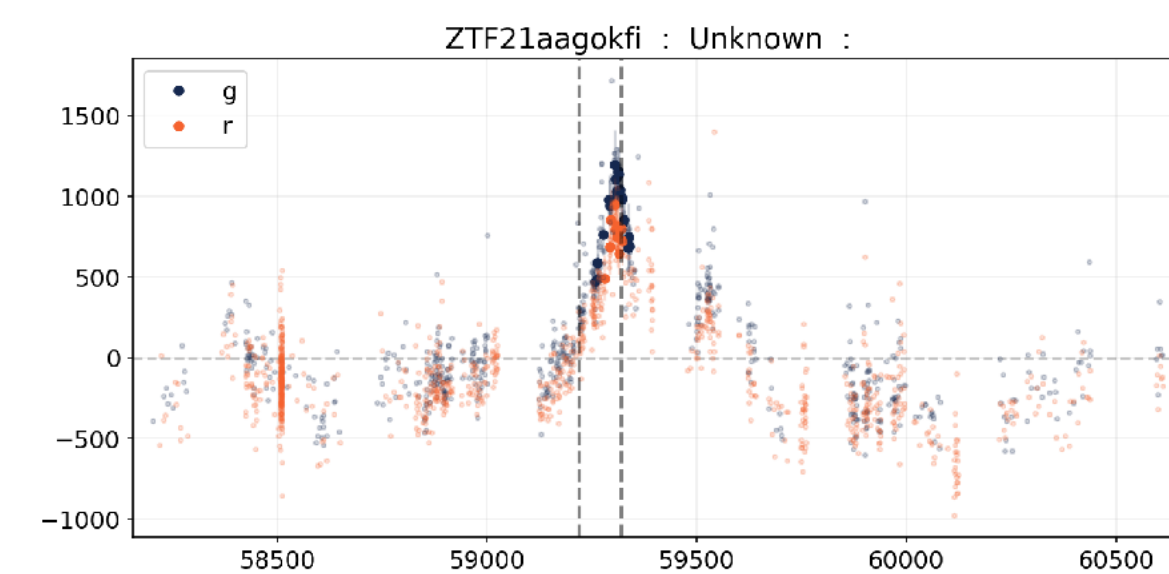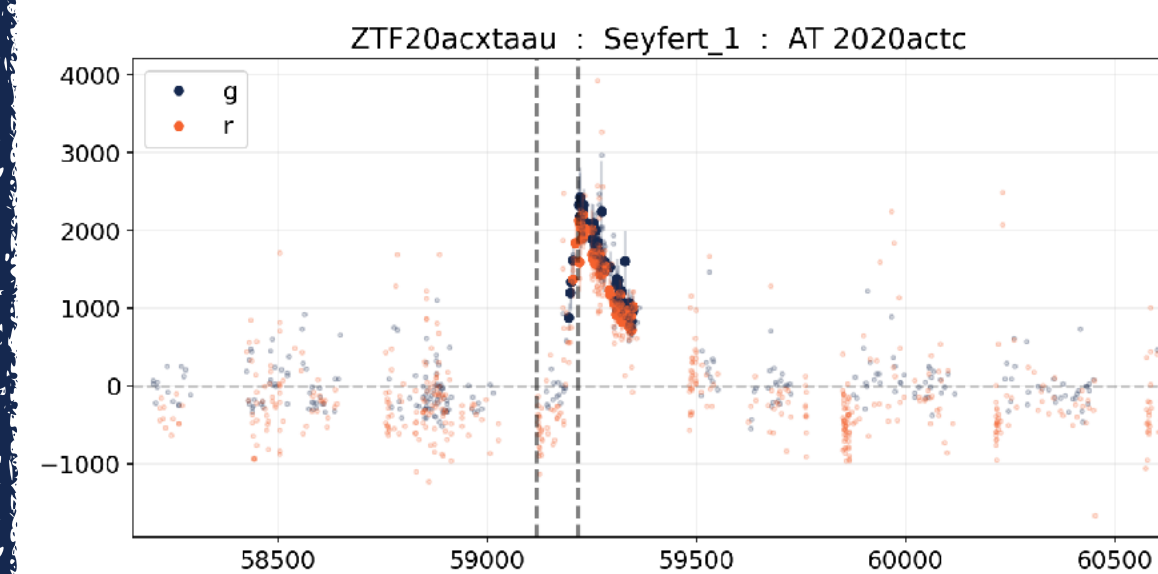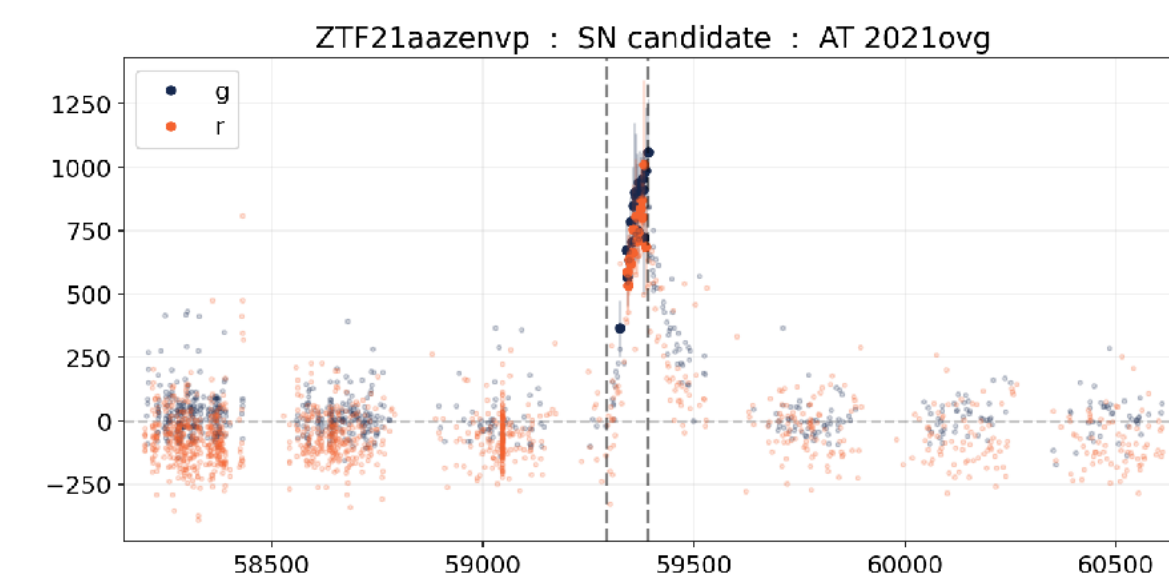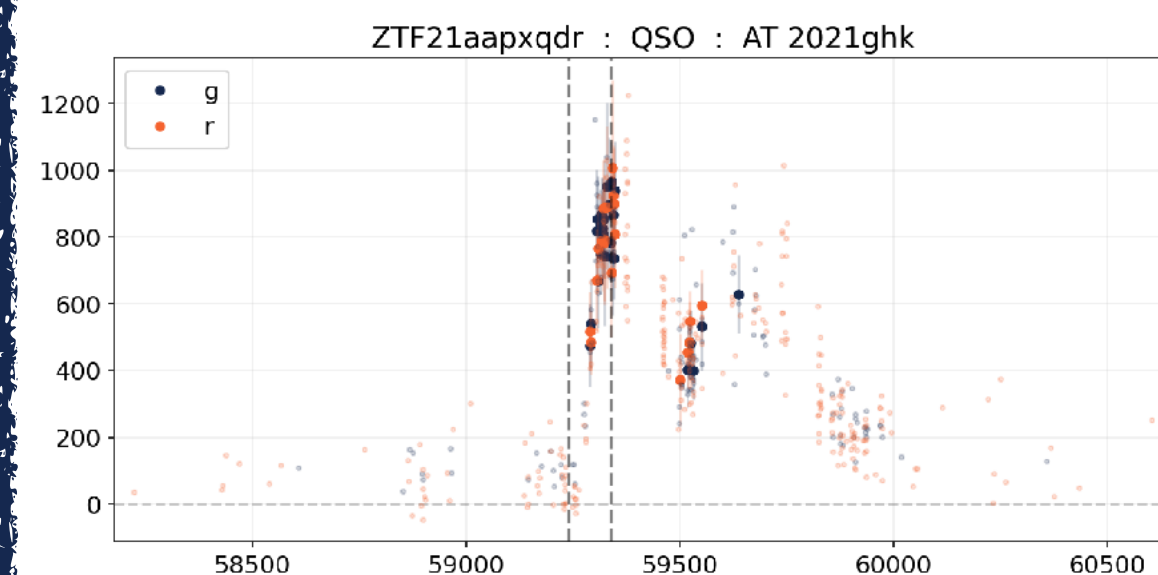
About ~1800 candidates for the whole historical dataset

TDE candidates in passive galaxies

Quintin et al. in prep.

TDE candidates in active galaxies (ANTs)

M<-24
ENTs

Quintin et al. in prep.
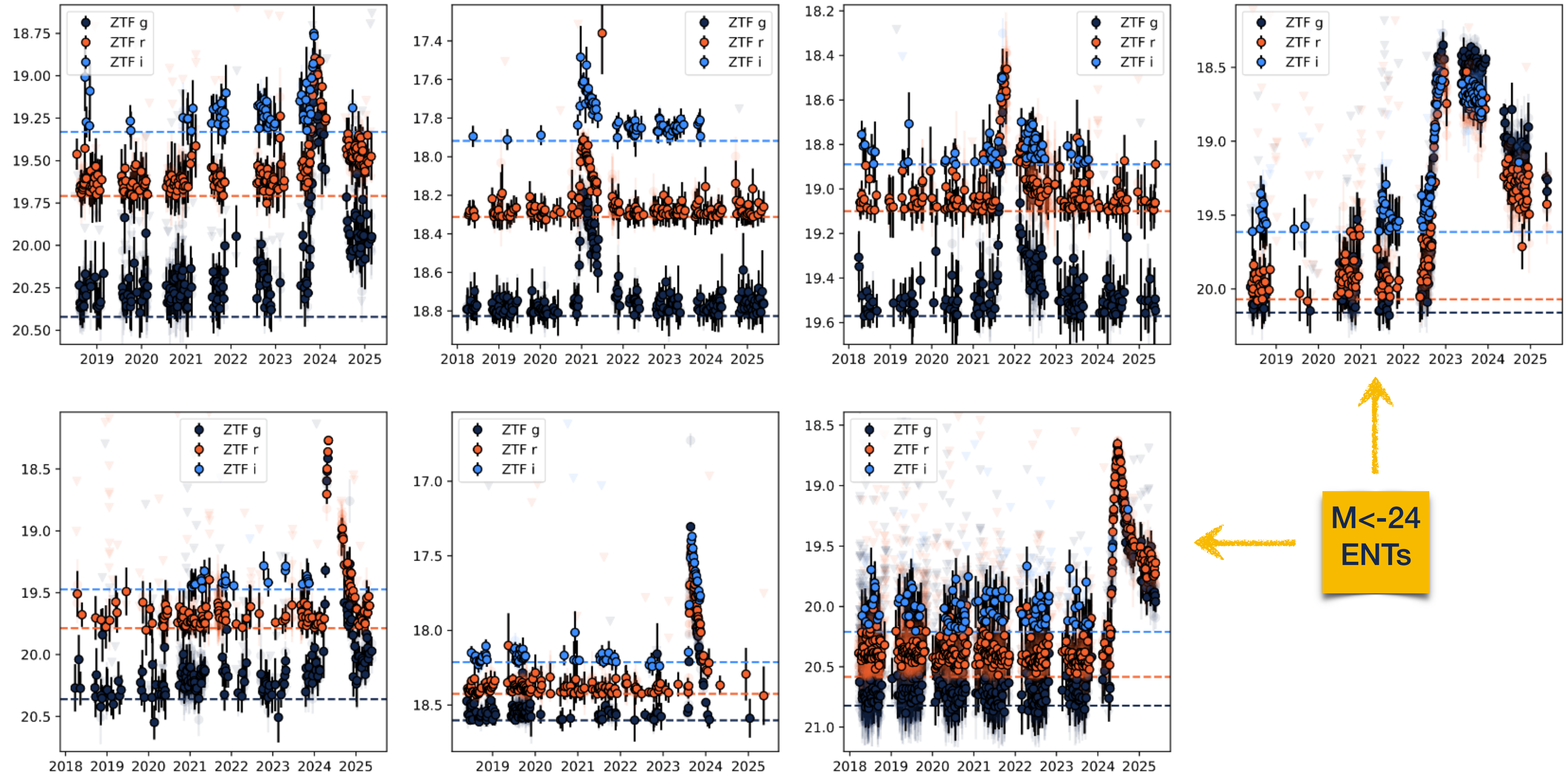
Repeated TDE candidates

Quintin et al. in prep.
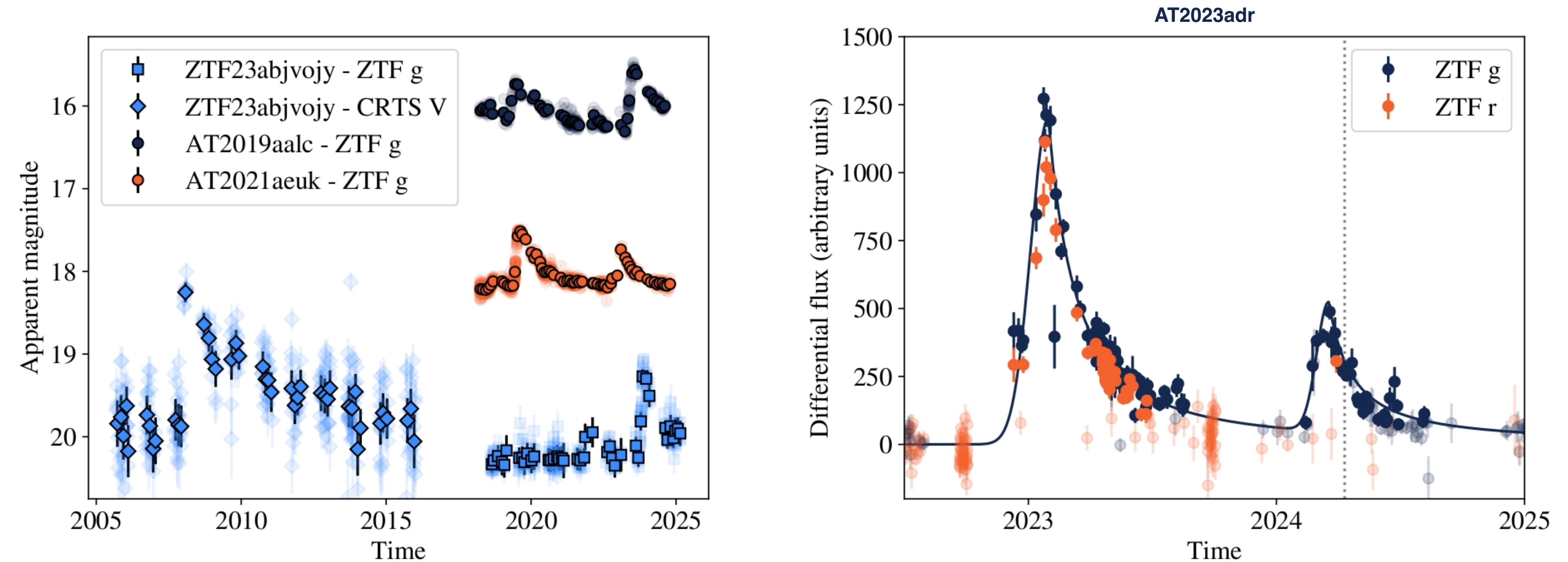
Early detection performance

First detection time

ZTF25aagtjfn : AT 2020ddv

Peak time

First positive score time
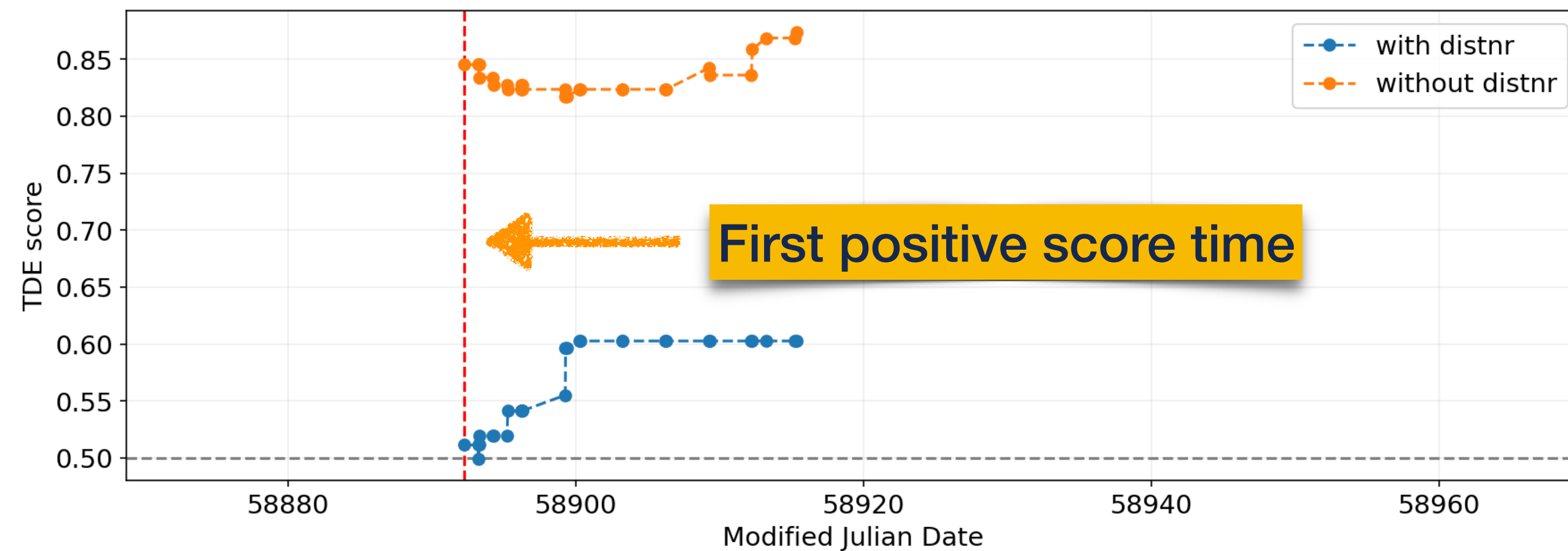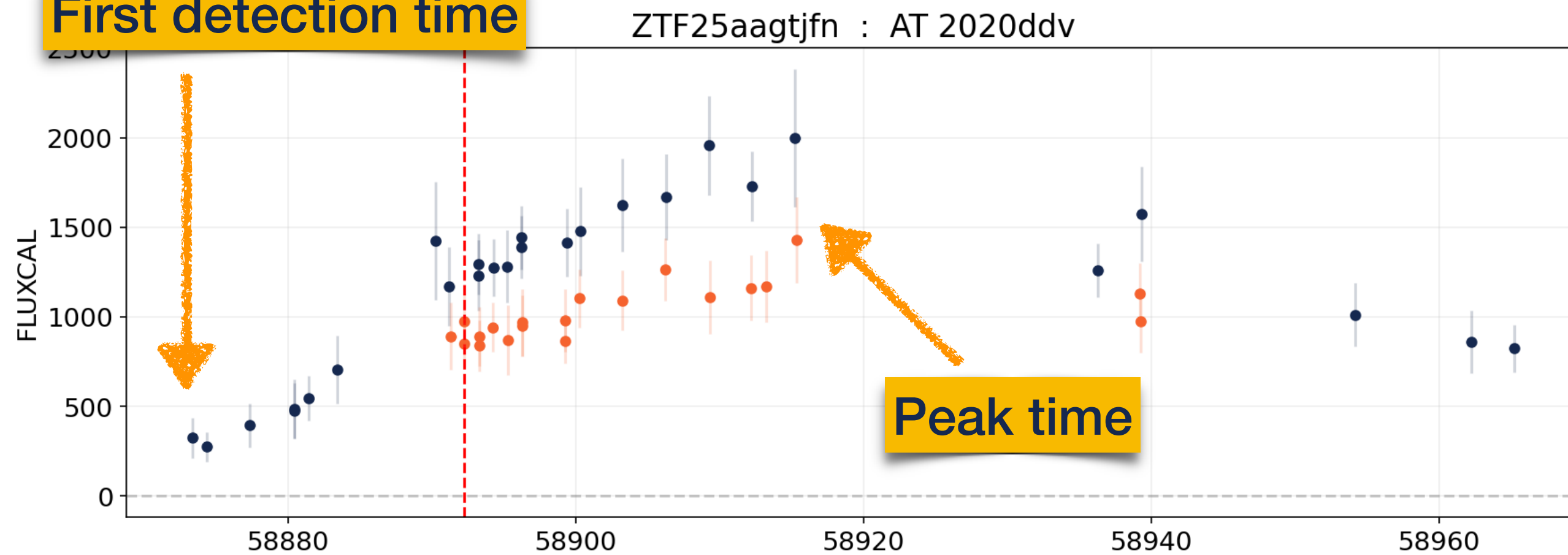
Estimated by Leave-One-Out approach
to exclude test points from the training set

Most of real TDEs are detectable early

Alert stream processing

Table 2. Number of alerts on various steps of the processing of ZTF data stream in 84 nights of Jan − Apr 2025.

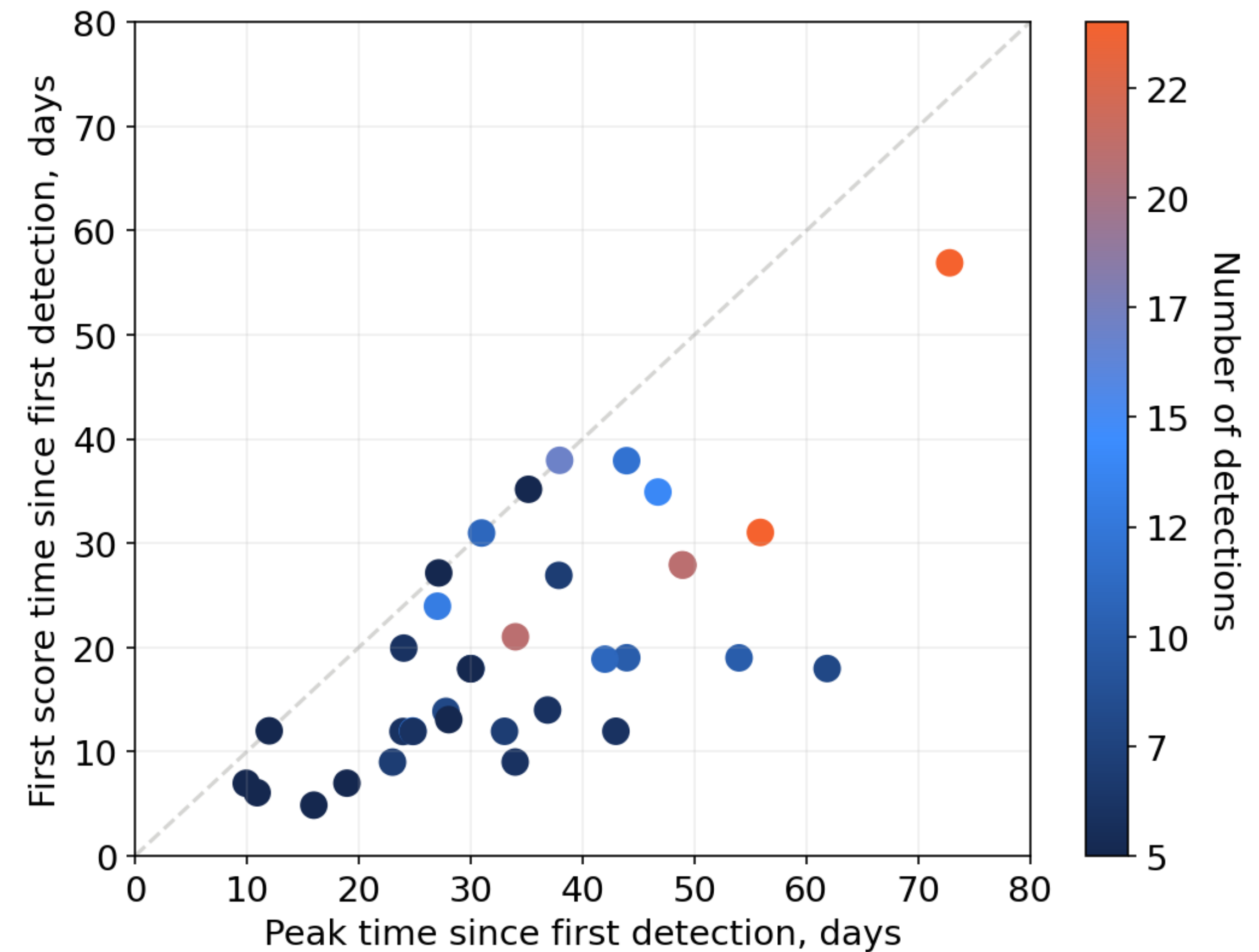| Step	Number of alerts
Individual alerts level	
Received by FINK	14,833,282
Passed internal quality cuts	9,813,510
After MPC filter	8,572,610
After SIMBAD type filter	3,981,797
At least 5 good points	1,545,771
No more than 1 negative point	694,212
Both bands have data	614,572
Galactic $|b| > 20$	322,362
Rising and not decaying	9,538
Full lightcurves level	
Detections prior to 100 days	3,735
Good quality RAINBOW fit	3,632
Quality cuts on features	1,452
$\geq$ 10% of probable fits identified ($p > 0.5$)	248
unique objects	111
Best fit identified ($p > 0.5$)	130
unique objects	45

Data rate on different steps of processing

- Processing of alerts after ZTF night ends
- Basic cuts on alert contents (up to 30 days)
- Cuts and Rainbow fits on complete light curves (~100 per night)
- Scores on best fits and random samples within fit covariances

~1 candidate per night

Alert stream processing

- Processing of alerts after ZTF night ends

- Basic cuts on alert contents (up to 30 days)

- Cuts and Rainbow fits on complete light curves (~100 per night)

- Scores on best fits and random samples within fit covariances

  ~1 candidate per night

- Fink Slack + public Telegram

- Light curve, Pan-STARRS cutout

- Classifier scores

- TNS / Fink classifications

- Links to Fink / TNS /SIMBAD / SNAD / VSX
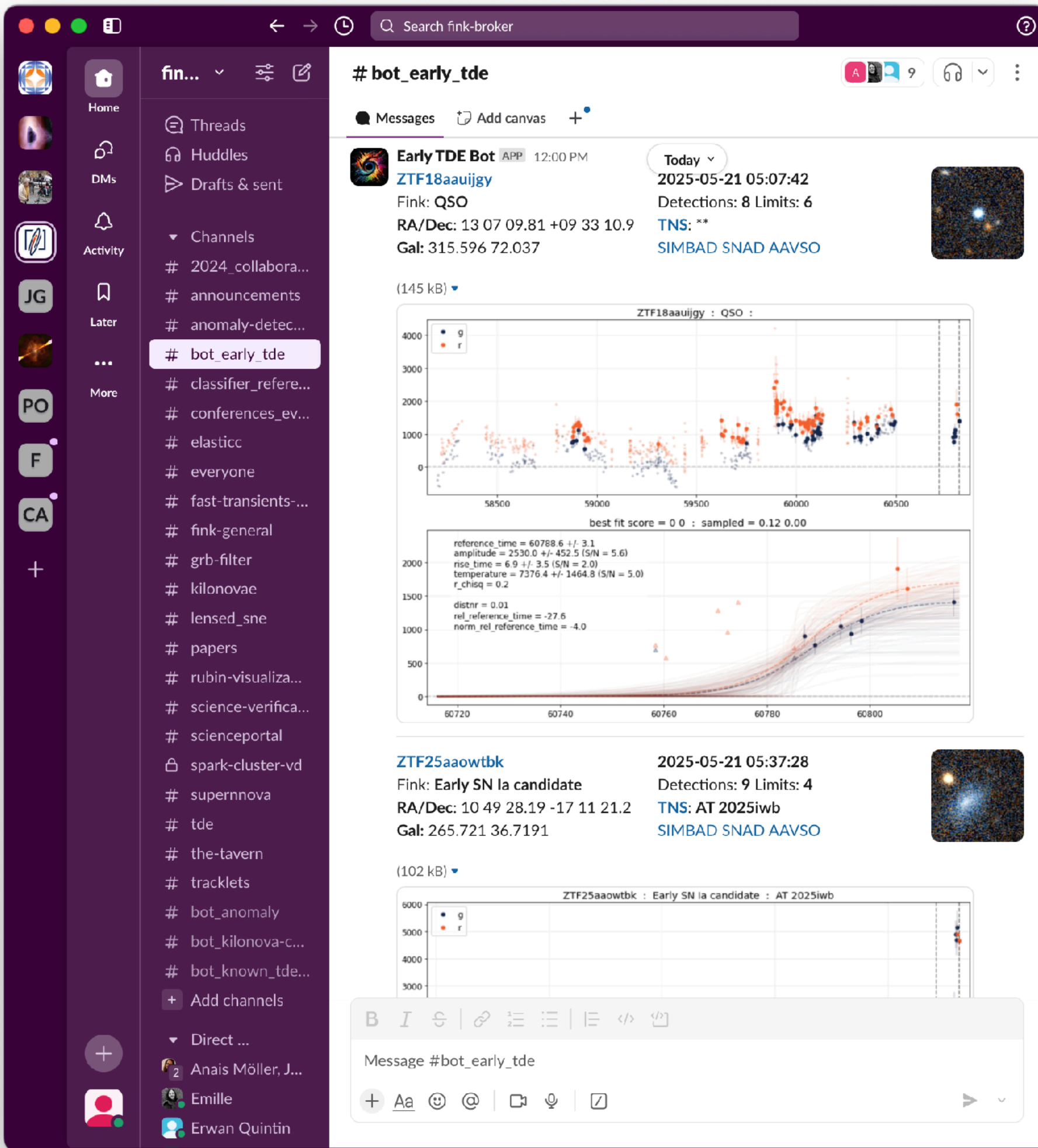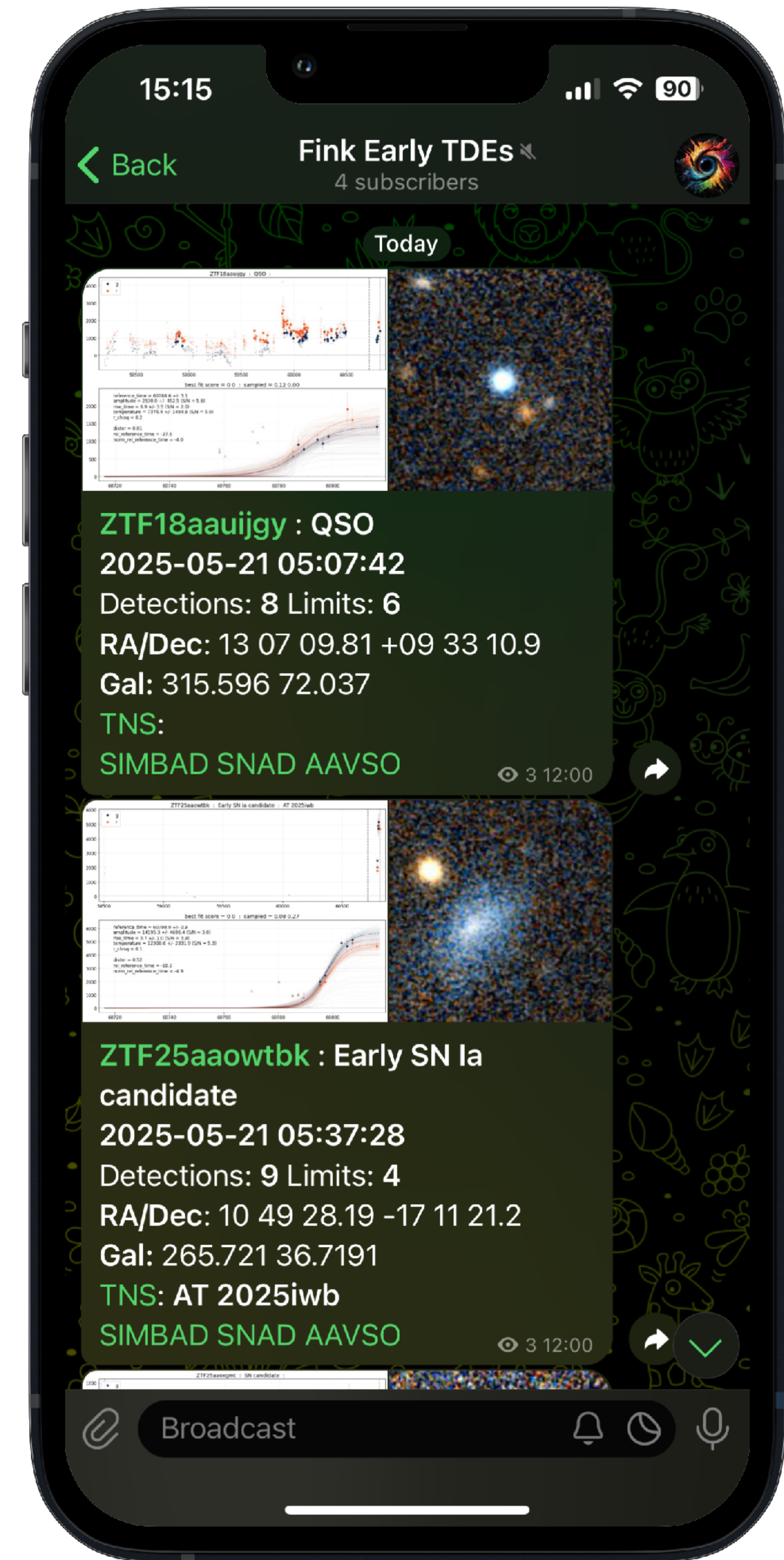
Adapting for LSST

- From ~100 to 1000/year with LSST (Bricman & Gomboc 2020)

- Deeper limits, no galaxy catalogue, …

- greater distances <-> physically different objects?

- Smaller FOV = slower cadence

- Six bands instead of two

- RAINBOW fitting is perfect for it!

  - 4 parameters for sigmoid / rising

  - 5 parameters for Bazin / full

  - one point per filter is enough?..
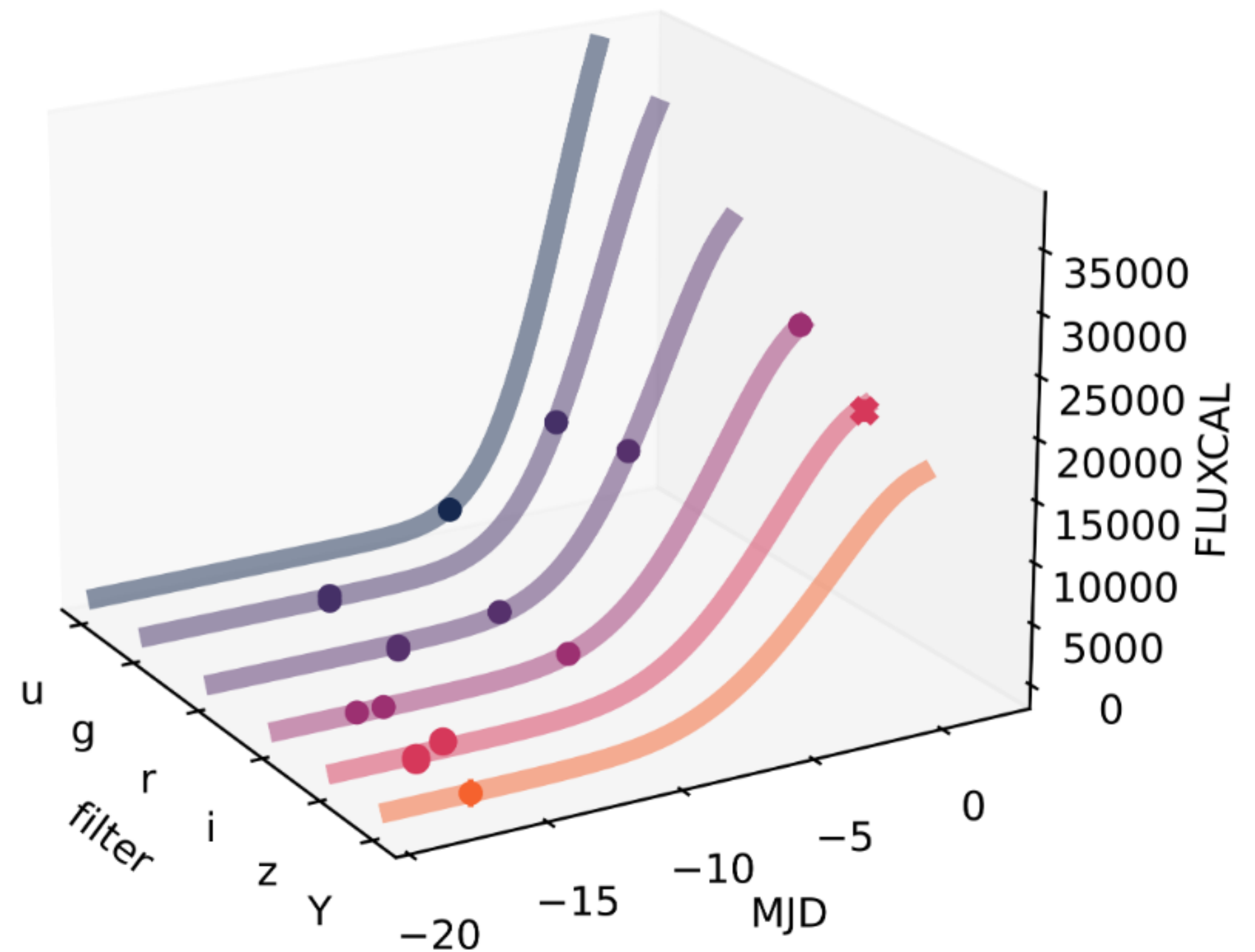
What to do with all the candidates???