ZTFbh: AGN and TDE SWG

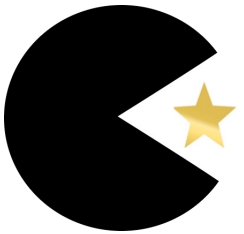
Who are we?

Suvi Gezari, UMd (coordinator), Matthew Graham, Caltech (deputy coordinator)

ZTFbh SWG Dinner @ Daisy Mint
March 19, 2018

Nadia Blagorodnova, Caltech
Tiara Hung, UMd
Sara Frederick, UMd
Scott Anderson UW
Charlotte Ward, UMd
Shri Kulkarni, Caltech
Peter Nugent, LBNL
Tom Barlow, Caltech
Brad Cenko, GSFC
Sjoert van Velzen, UMd
Lin Yan, Caltech
Po-Chieh Yu, NCU
Zeljko Ivezic, UW
Robert Stein, DESY
David Shupe, Caltech/IPAC
Nathaniel Roth, UMd and GSFC
Daniel Stern, Caltech/JPL
Alexander Dittman, UMd

ZTFbh: AGN and TDE SWG



What are we interested in?

Nuclear Transients (< 0.5 arcsec from host galaxy center):

- variable active galactic nuclei
- changing-look quasars
- tidal disruption events
- supermassive black holes (binary, recoiling, intermediate-mass)

What tools do we use?

GROWTH Marshal (commenting, aggregating follow-up, triggering SEDm)

AMPEL channels (filtering, cross-matching with catalogs, pushing into Marshal)

Light-curve classification, host galaxy characterization, spectroscopic classification

How can you find us?

weekly telecon: Wednesday at 2:30pm Eastern

ztfbh.slack.com

ztfbh@lists.astro.caltech.edu

ZTFbh SWG Presentation

- TDE overview & reflections: Suvi
- 1st ZTF TDE Ned Stark; TDE selection; rates: Sjoert (presented by Suvi)
- ZTF transient alert offset distribution (nuclear vs. off-nuclear); search for offset AGN: Charlotte
- Changing Look AGN & Other AGN science: Sara

ZTFbh: AGN and TDE SWG

Panchromatic follow-up programs:

SEDm (PI: Tiara Hung):

- spectroscopic follow-up of **blue** (g-r < 0) *nuclear* (distnr < 0.5" of galaxy host) **bright** (r < 19 mag) transients
- expect 2 SEDm triggers per week, expect 6 bonafide TDEs per year

HST (PI: Brad Cenko)

70 orbits of STIS UV spectroscopy of 5 UV-bright TDEs
Includes 2 nights of Gemini optical spectroscopy

XMM (PI: Suvi Gezari)

108 ks of XMM X-ray imaging for 2-6 TDEs discovered p

VLA (PI: Sjoert van Velzen)

32 hours of VLA radio follow-up of 7 TDEs

Spitzer(PI: Lin Yan)

24 hours of Spitzer MIR follow-up

ZTF Confirmed TDEs!

- ZTF18aabtxvd (NedStark)

First alert on March 6, 2018

(during commissioning, caught in MSIP reference image)

- ZTF18aahqkbt (JonSnow)

First alert on April 9, 2018

(MSIP, r-band only)

ZTF Confirmed TDEs!

- ZTF18aajpunt (TyrionLannister)

First alert on May 31, 2018

(Partnership)

- ZTF18abgxjie (DaenerysTargaryen)

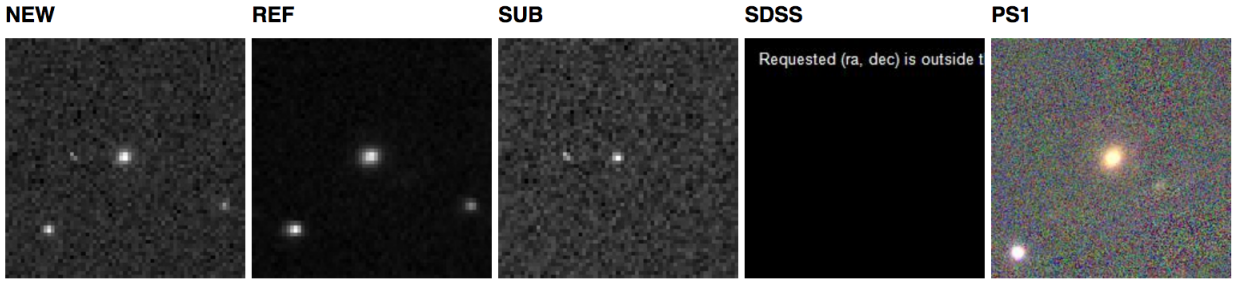
First alert on July 14, 2018

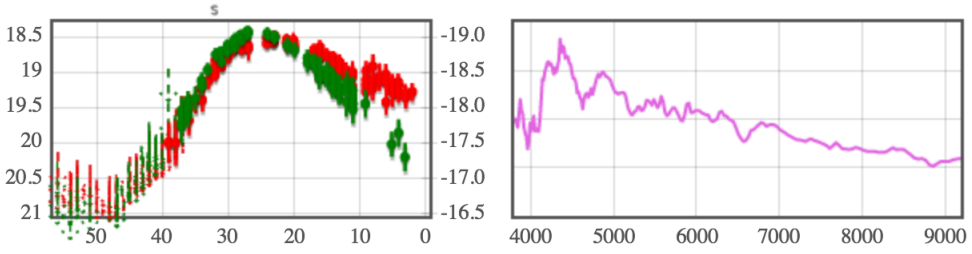
(Partnership)

Beware of Joffries (SNe Ia)

ZTF18abdfwur SN Ia 16:20:43.18 +65:38:2
245.179920 +65.639154

OVERVIEW | PHOTOMETRY | SPECTROSCOPY | OBSERVABILITY





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z = 0.07 | Upload New Spectroscopy
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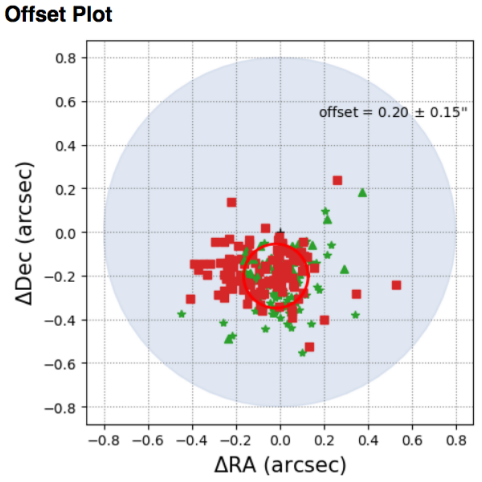

Beware of AGN (Whitewalkers)

ZTF18aavtklk AGN

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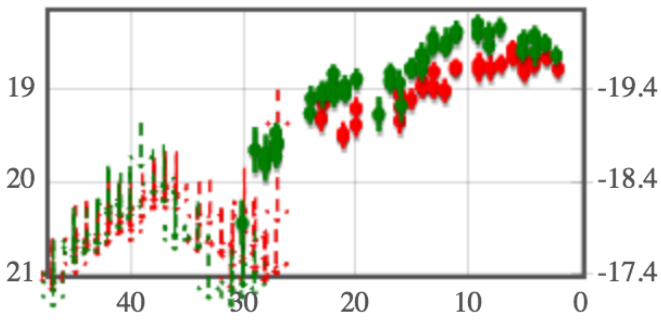
247.033790 +63.823751

OVERVIEW | PHOTOMETRY | SPECTROSCOPY | OBSERVABILITY



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Upload New Spectroscopy

DM (approximate) = 38.40

ZTF18aabtxvd TDE

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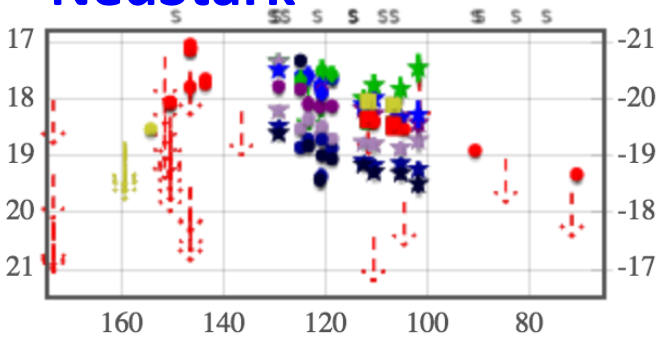
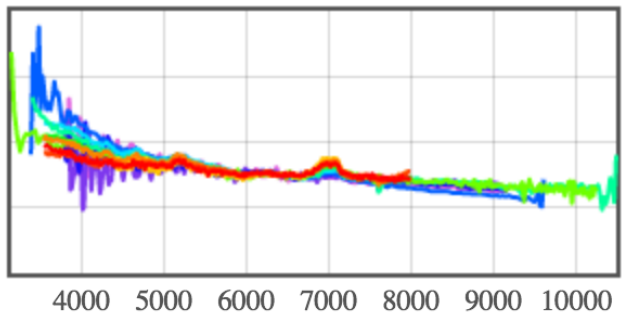
OVERVIEW PHOTOMETRY SPECTROSCOPY OBSERVABILITY

NEW REF SUB SDSS PS1

NedStark





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z = 0.075 | Upload New Spectroscopy
DM (approximate) = 37.63

ZTF18aahqkbt TDE

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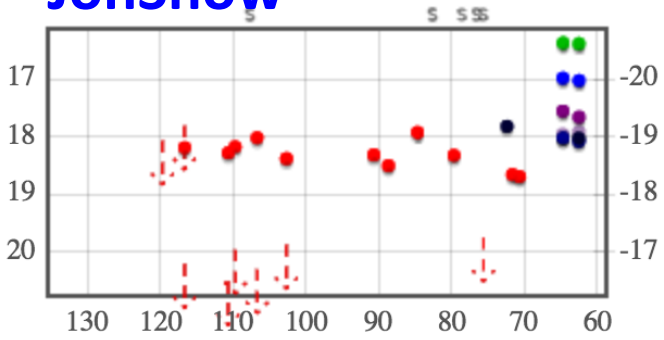
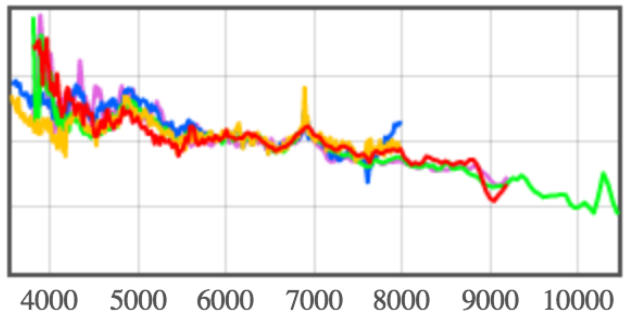
OVERVIEW | PHOTOMETRY | SPECTROSCOPY | OBSERVABILITY

NEW | REF | SUB | SDSS | PS1

JonSnow





r = 18.7 (70.7 d) | Upload New Photometry

z = 0.051 | Upload New Spectroscopy
DM (approximate) = 36.73

ZTF18aajupnt TDE

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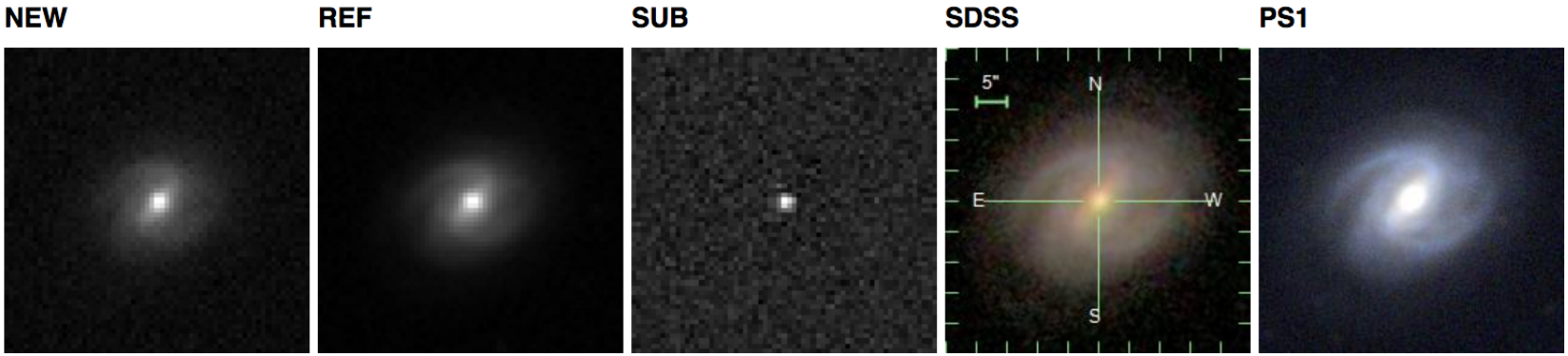
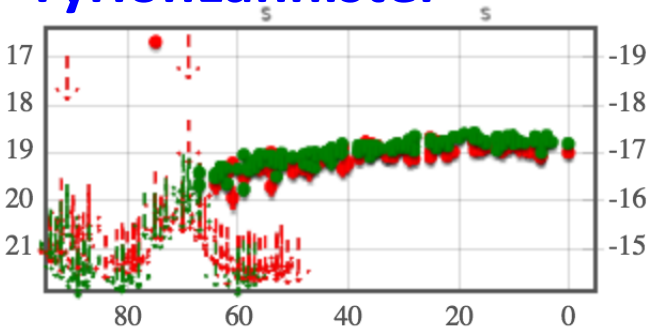
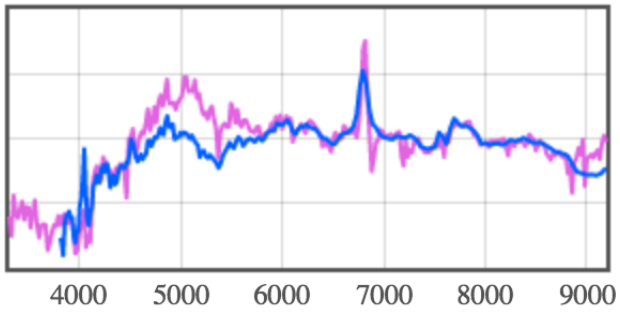
OVERVIEW PHOTOMETRY SPECTROSCOPY OBSERVABILITY



TyrionLannister





Nuclear UV brightening detected by Swift

r = 19.0 (0.1 d) | Upload New Photometry

z = 0.0367 | Upload New Spectroscopy
DM (approximate) = 35.99

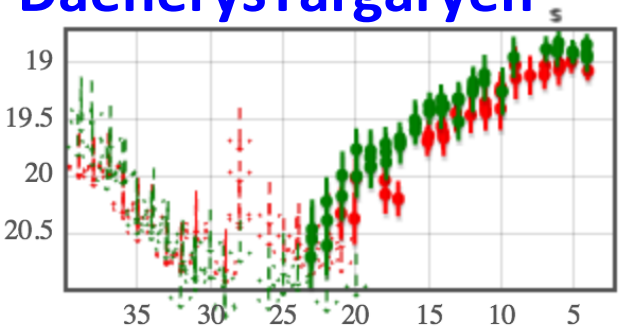
ZTF18abgxjie TDE

19:00:02.05 +51:55:23.1
285.008544 +51.923096

OVERVIEW PHOTOMETRY SPECTROSCOPY OBSERVABILITY

NEW REF SUB SDSS PS1

DaenerysTargaryen



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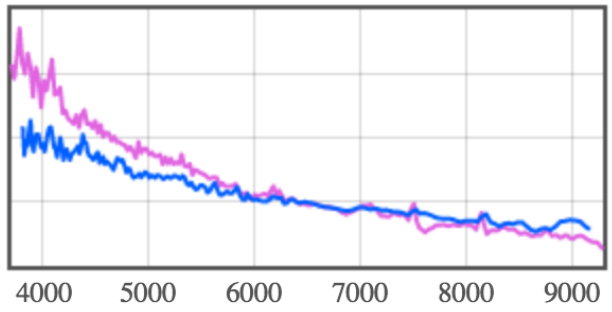


Upload New Spectroscopy

Swift measures UV transient source!

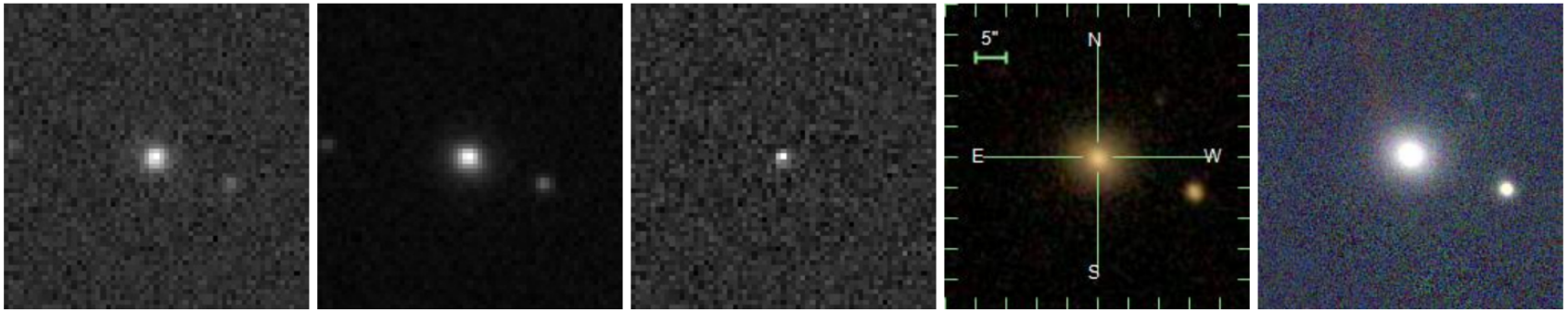
ZTF18abdrclf

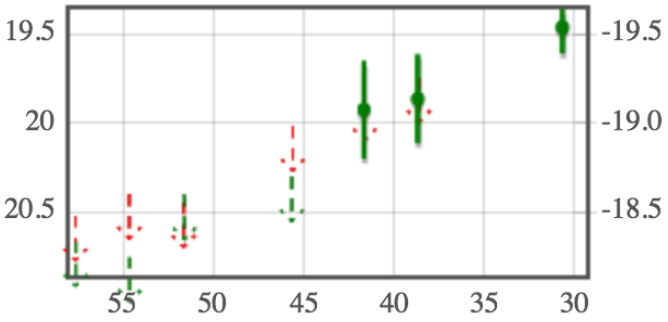
12:04:35.67 +36:30:12.4
181.148643 +36.503448

View anoth

OVERVIEW | PHOTOMETRY | SPECTROSCOPY | OBSERVABILITY

NEW | REF | SUB | SDSS | PS1





r > 19.3 (35.6 d) | Upload New Photometry

Upload New Spectroscopy
DM (approximate) = 39.00

Red galaxy spectrum from SDSS. Not visible right now.

Reflections

- We are almost ready to move away from scanning to automated saving to Marshal from AMPEL filters.
- We have significantly improved star/galaxy separation using Gaia.
- Of the last 20 TDE candidates, only 1/3 are from MSIP. This means our rates will be increasing dramatically when MSIP references are complete.
- There is potential synergy with Gaia which could provide very accurate astrometry (< mas) for transients relative to their host galaxies to cut down contamination from SNe.
- Do we want to coordinate more ground-based follow-up u-band resources?

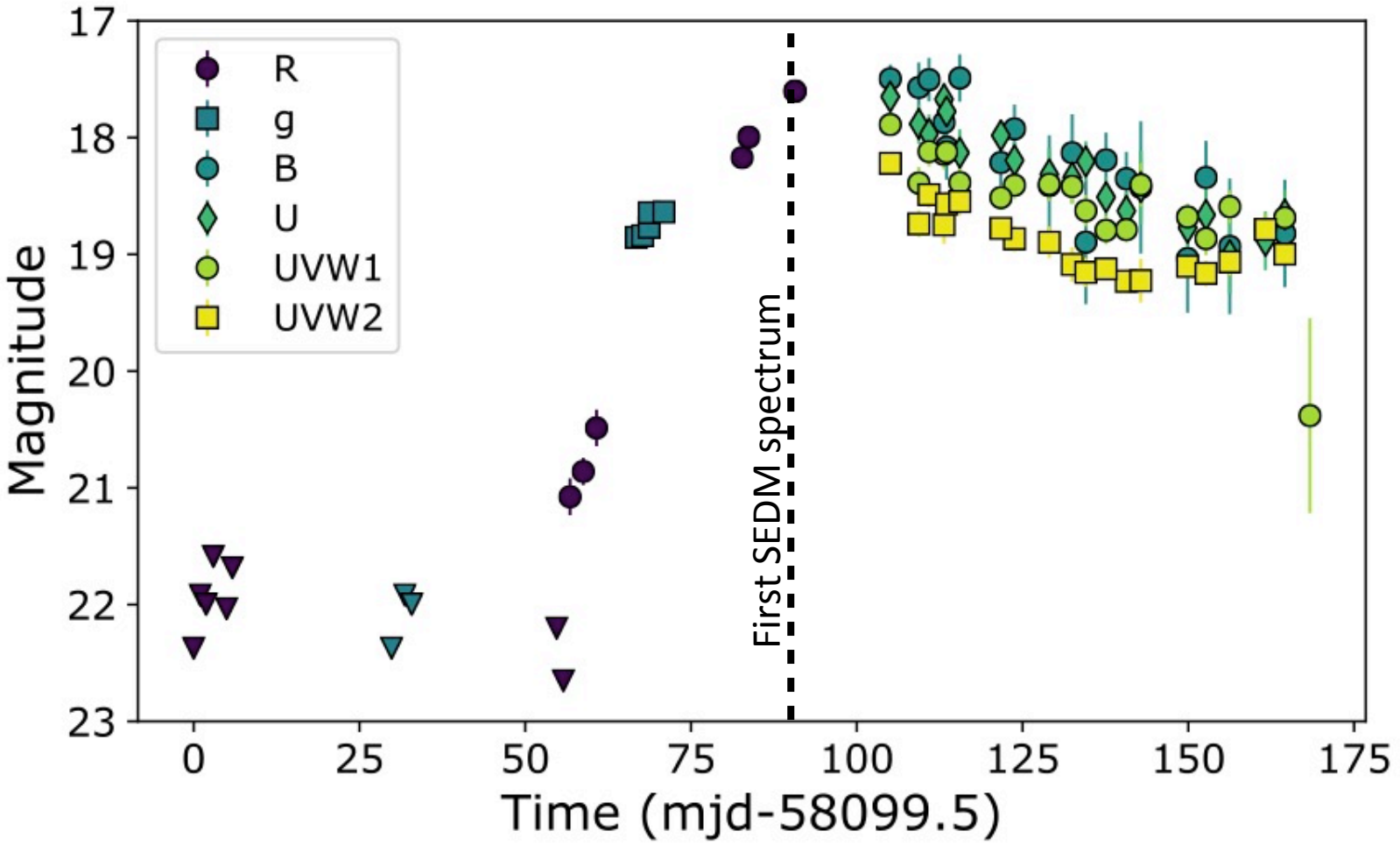
ZTF TDF Search

The first Zwicky TDF: ZTF18aabtxvd

Brief history

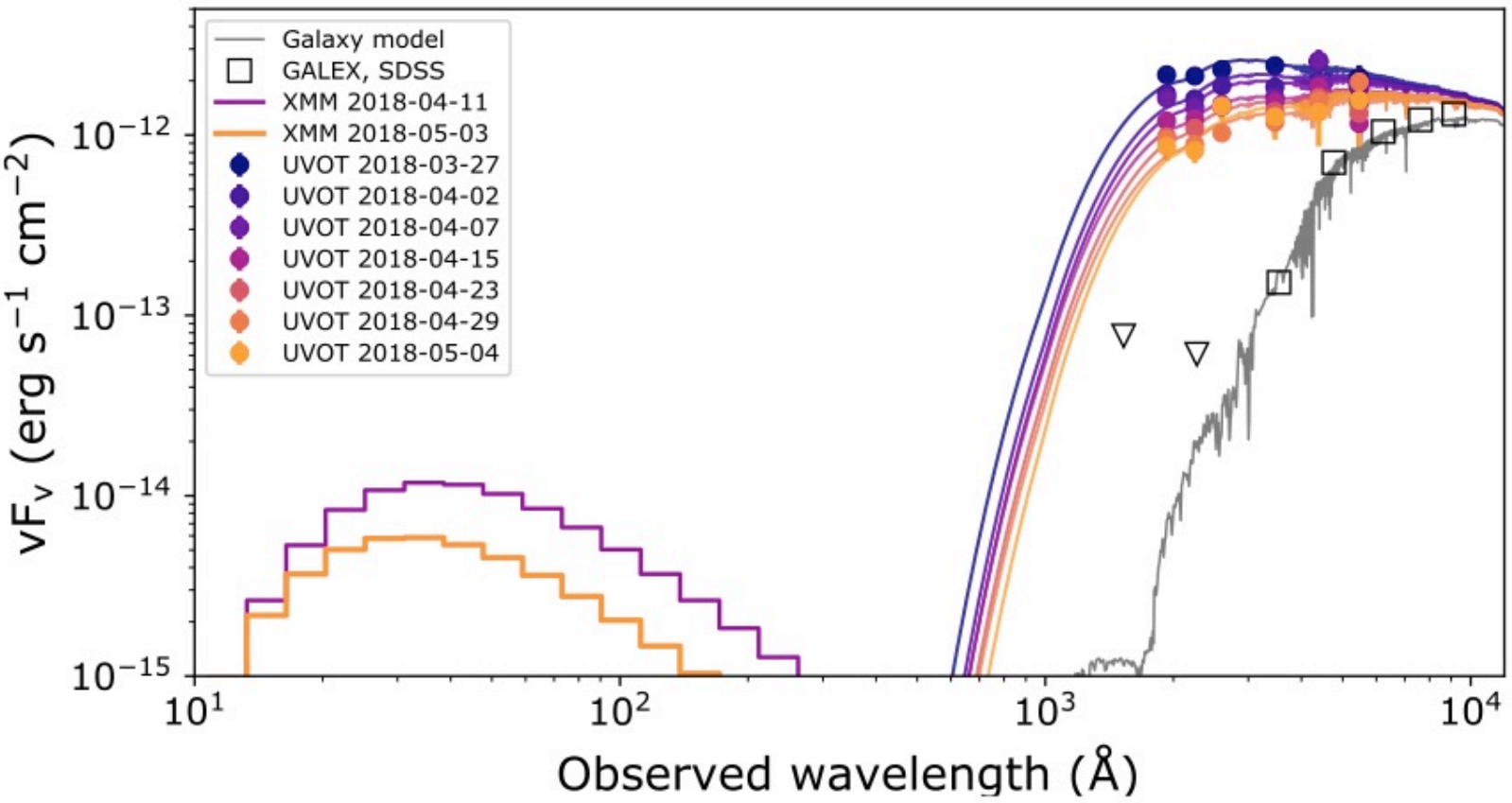
- 03-06: Saved in Marshal, bright nuclear transient, limited light curve info (no g-band)
- 03-09: SEDM spectrum with evidence for broad He emission
- 03-24: Announced on ATEL by PS1-group
- 03-28 Triggered HST, XMM, VLA
- Start MSIP: transient caught in the *new* reference image, no useful data
- Rise detected by re-analyzing commission data (by Brad)

Light curve



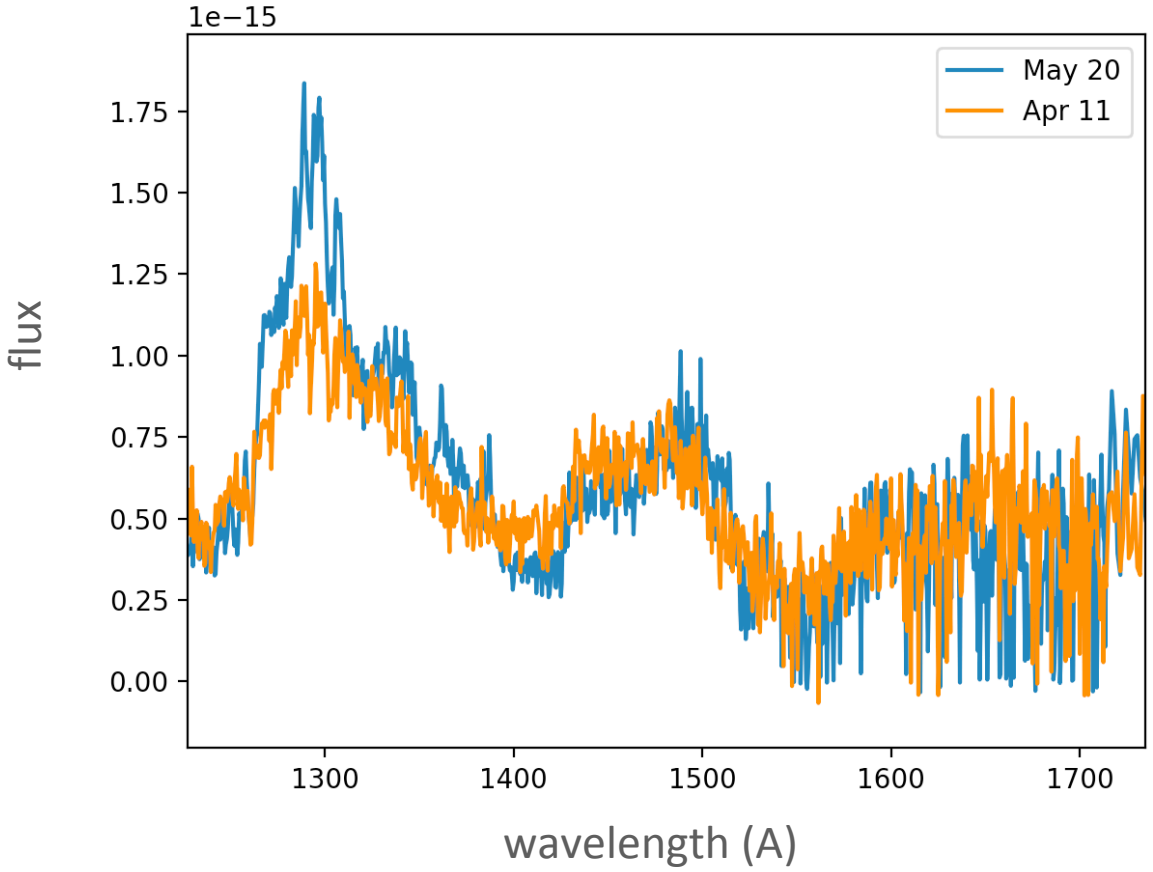
van Velzen et al. (2018 in prep)

SED



van Velzen et al. (2018 in rep)

HST FUV spectra



Hung et al. (2018 in prep)

Each new TDF is valuable

Some dozen TDFs are known, but few have good data

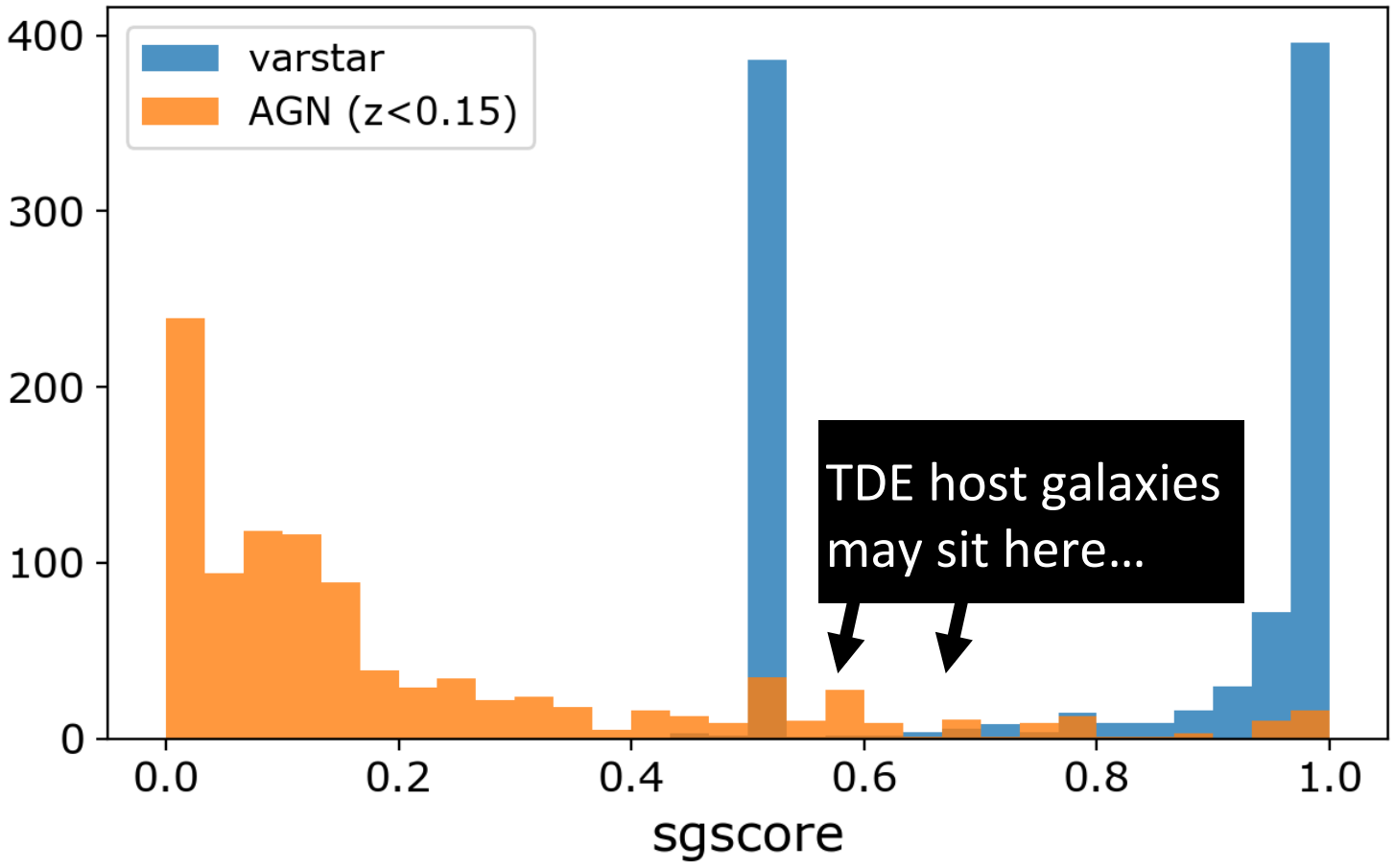
- This is only the fourth TDF with a detected rise to peak
- Fourth TDF with HST UV spectroscopy
- The second TDF with *early* and *sensitive* X-ray imaging
- The deepest radio upper limits to date

Let’s find some more

Overview of TDE selection

- 1: Select nuclear transients (0.5” from ZTF/PS1 ref)
- 2: Minimal selection at scanning (only star removal)
- 3: Remove AGN (using catalogs)
- 4: Monitor saved source (sync Marshal photometry)
- 5: Select transients that are either: **slow rising**, **blue**, or **not-cooling**

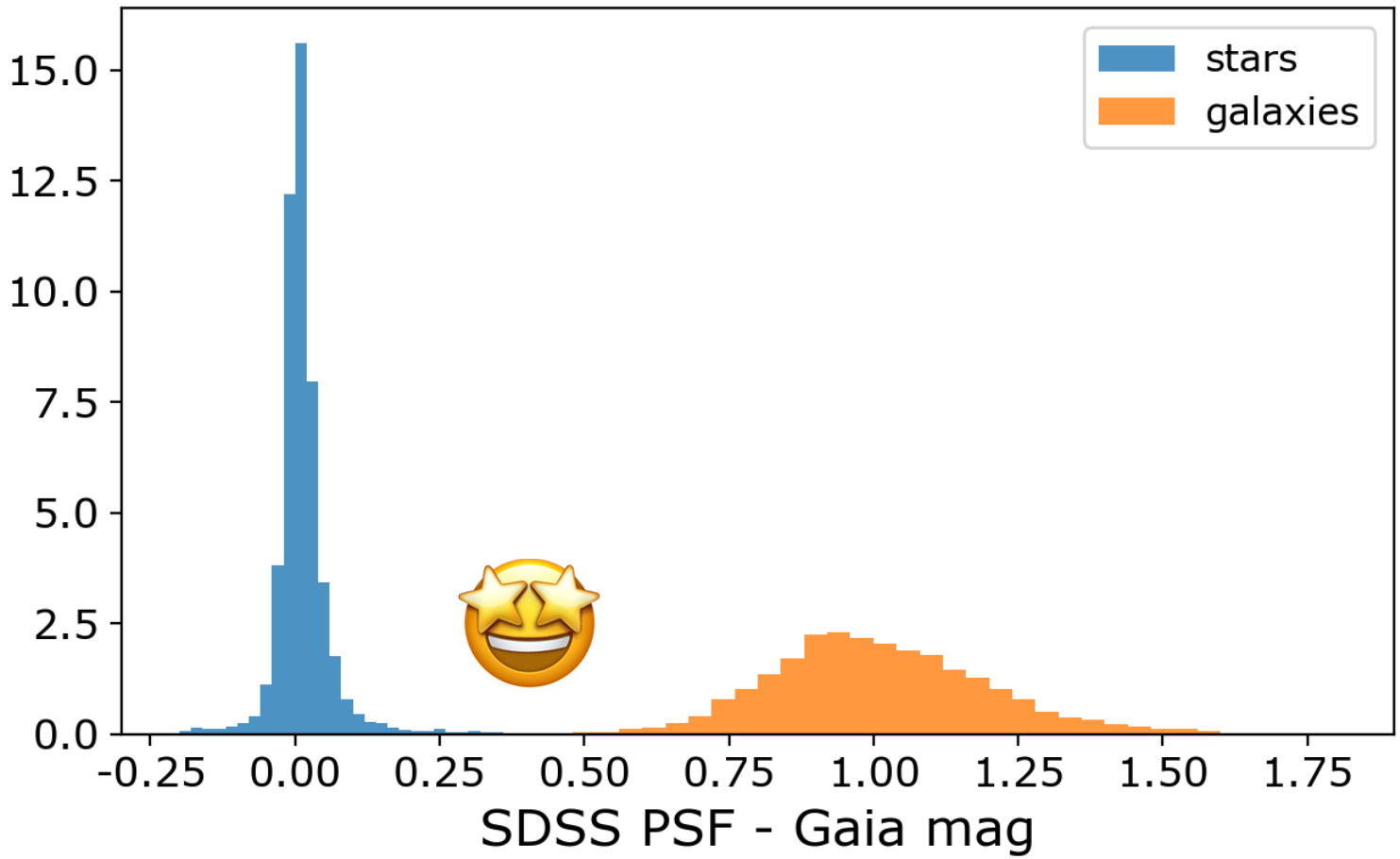
Variable stars often have sgscore=0.5



AMPEL filter with Gaia veto

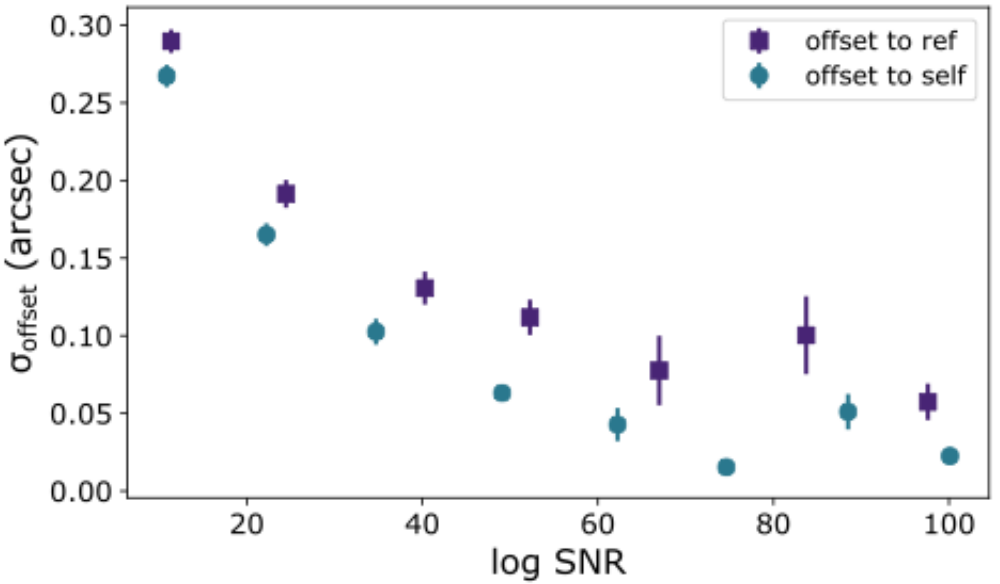
- At 0.3<sgscore<0.8, up to 50% of our sources are stars (double stars or variables)
- Currently removed by visual inspection.
- Automated using AMPEL:
  - Remove if parallax detected by Gaia
  - Remove if two Gaia matches within 2”
  - Remove if Gaia/PS1 flux ~ 1

Gaia yields the ultimate sgscore

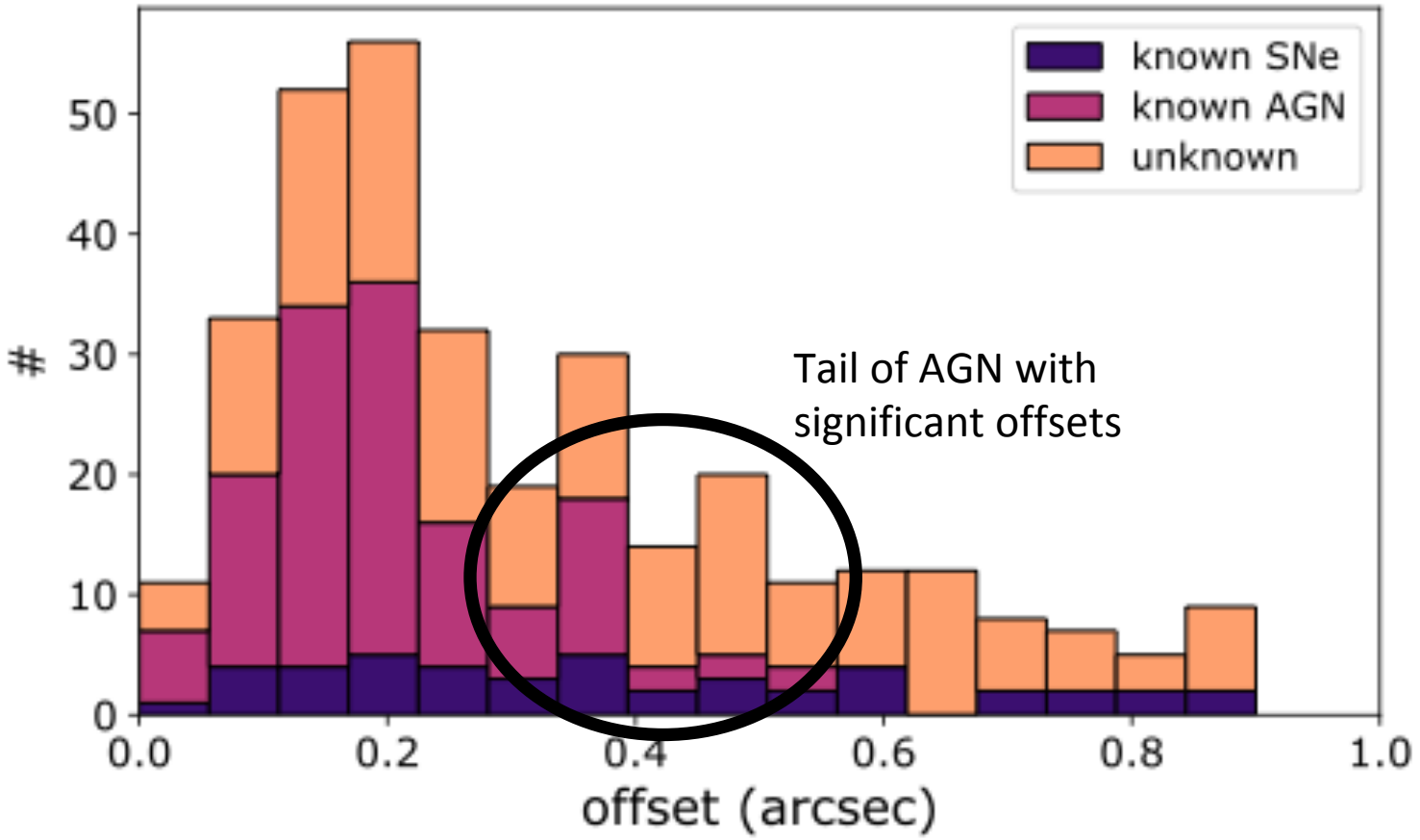


Selection of nuclear flares

- Compute the inverse-variance weighted offset
- See also Charlotte's talk



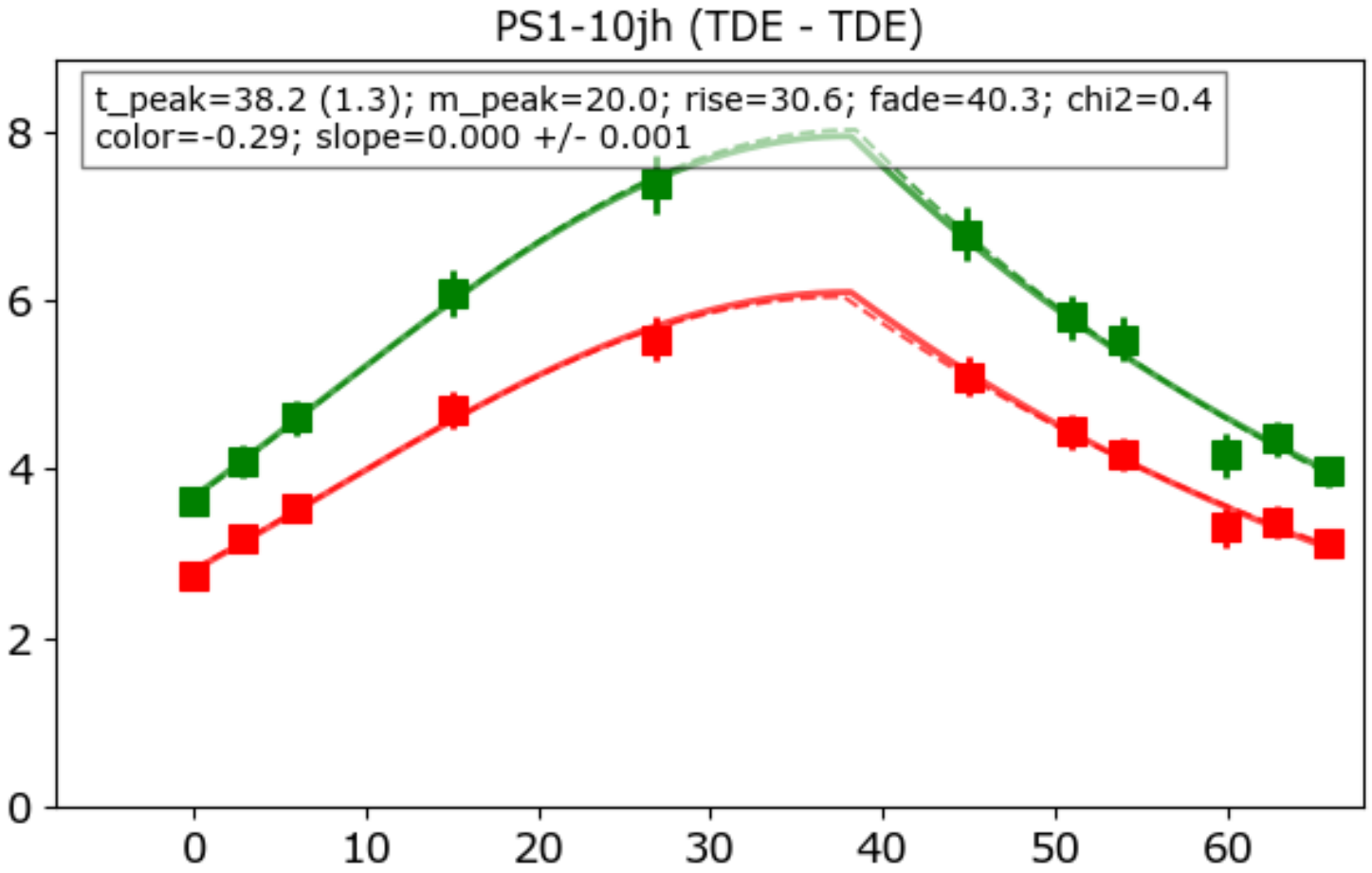
Mean offset of SNe and AGN



Last step: photometric typing

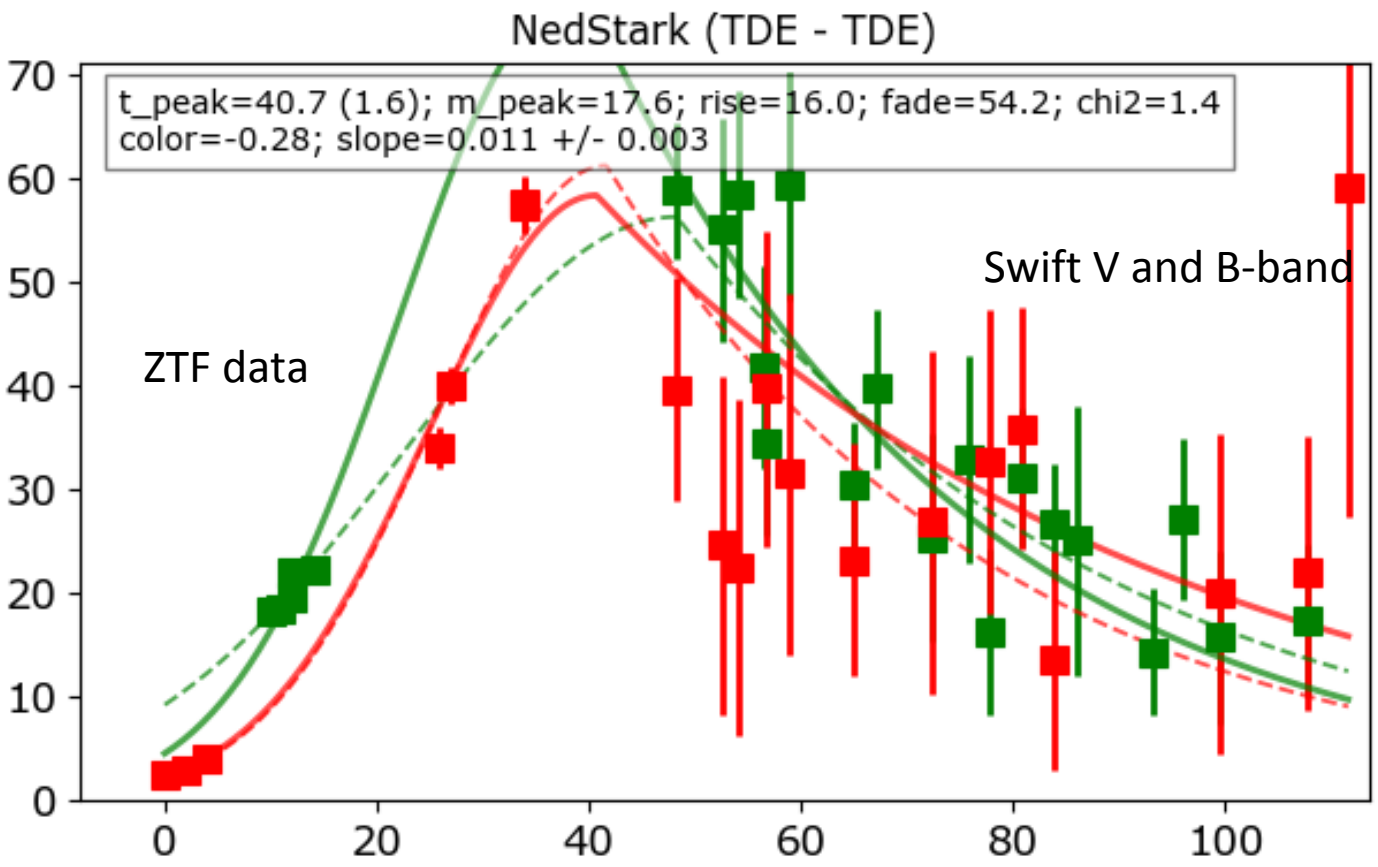
- Fit both g and r-band simultaneously
- Find peak of light curve
- Fit Gaussian rise pre peak
- Fit exponential decay post peak
- Measure mean g-r color and its first derivative
- Photometric classification:
  “TDE”, “SN”, “not SN”, “AGN”.

Example: a famous TDE

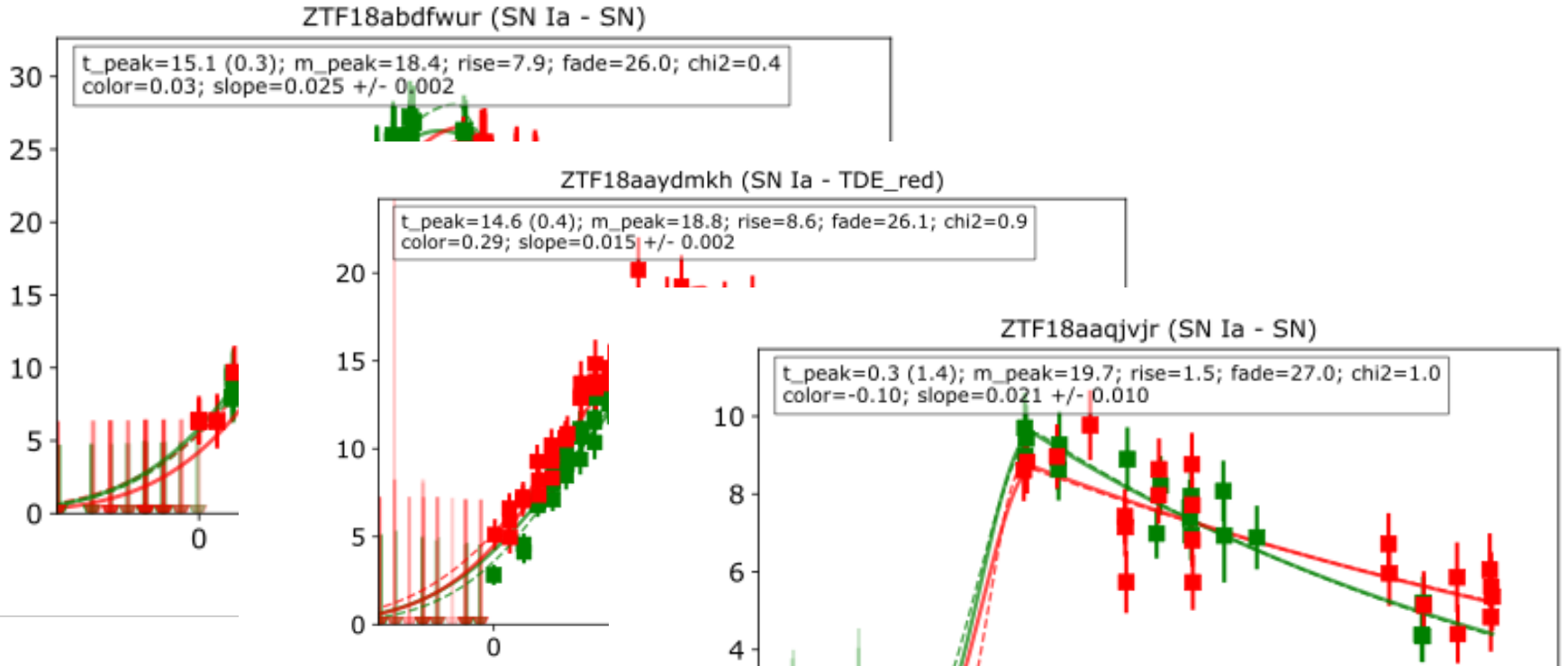


PS1-10jh: Gezari et al. (2012)

Example: the first ZTF TDE

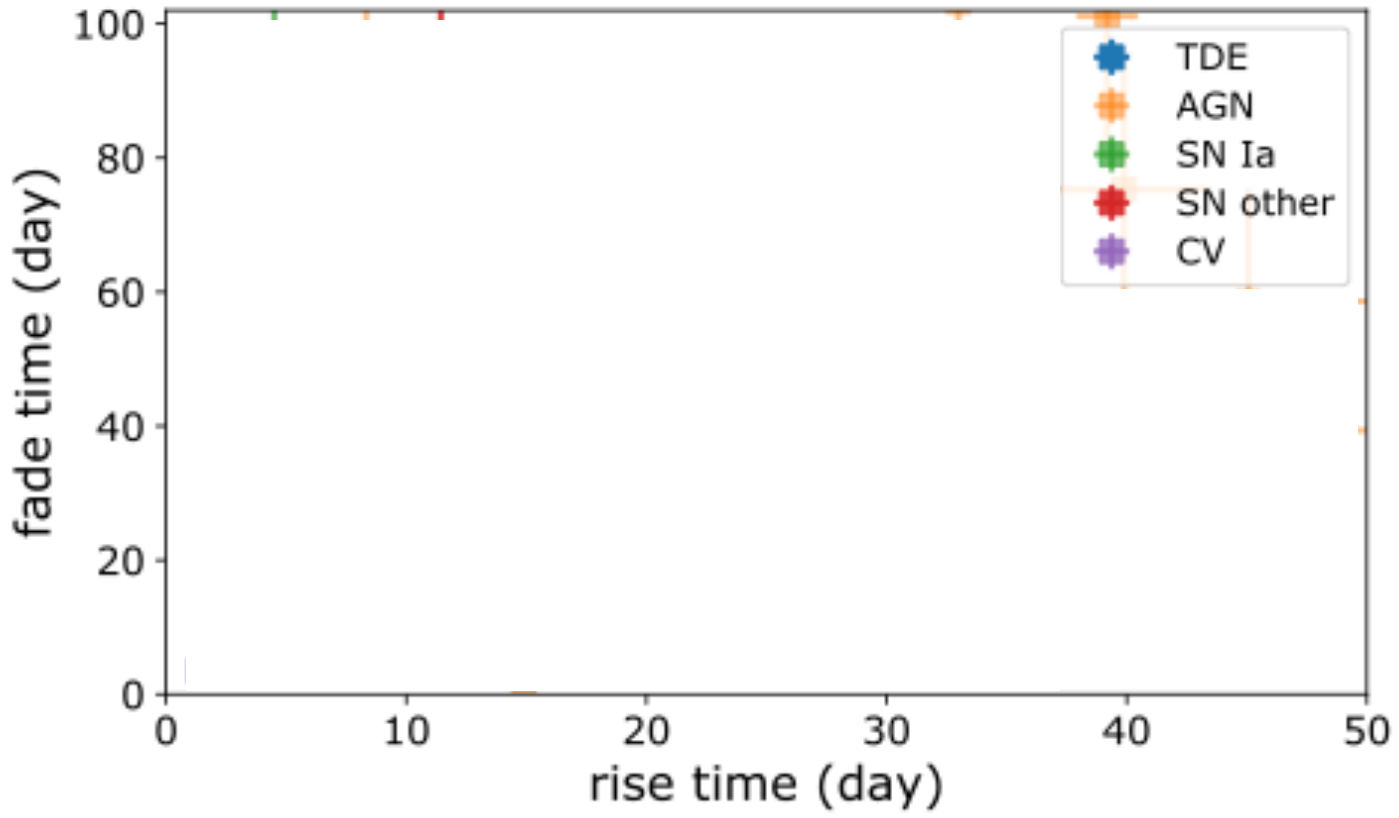


Example: SNe

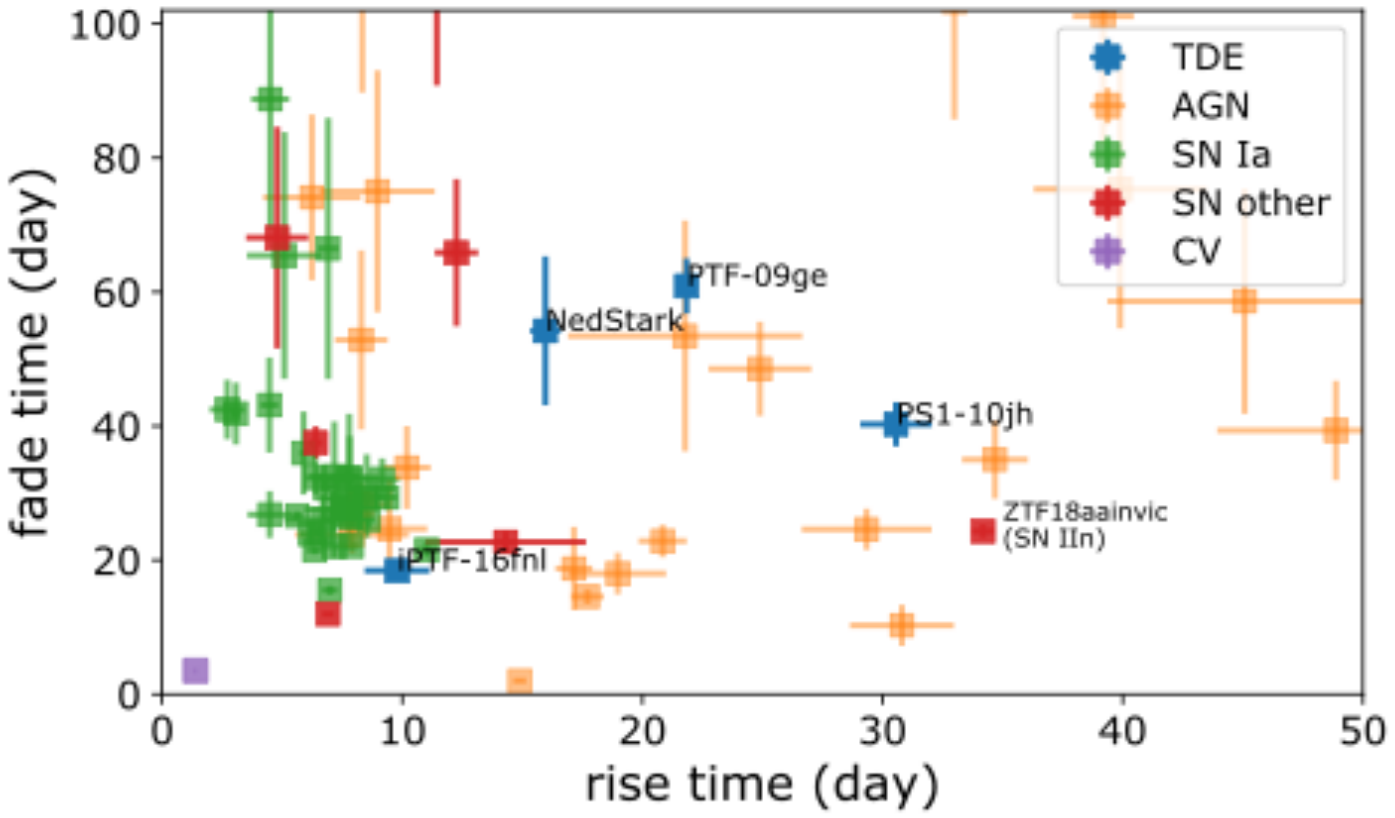


Fitting also works when only the rising or fading part of the light curve is observed

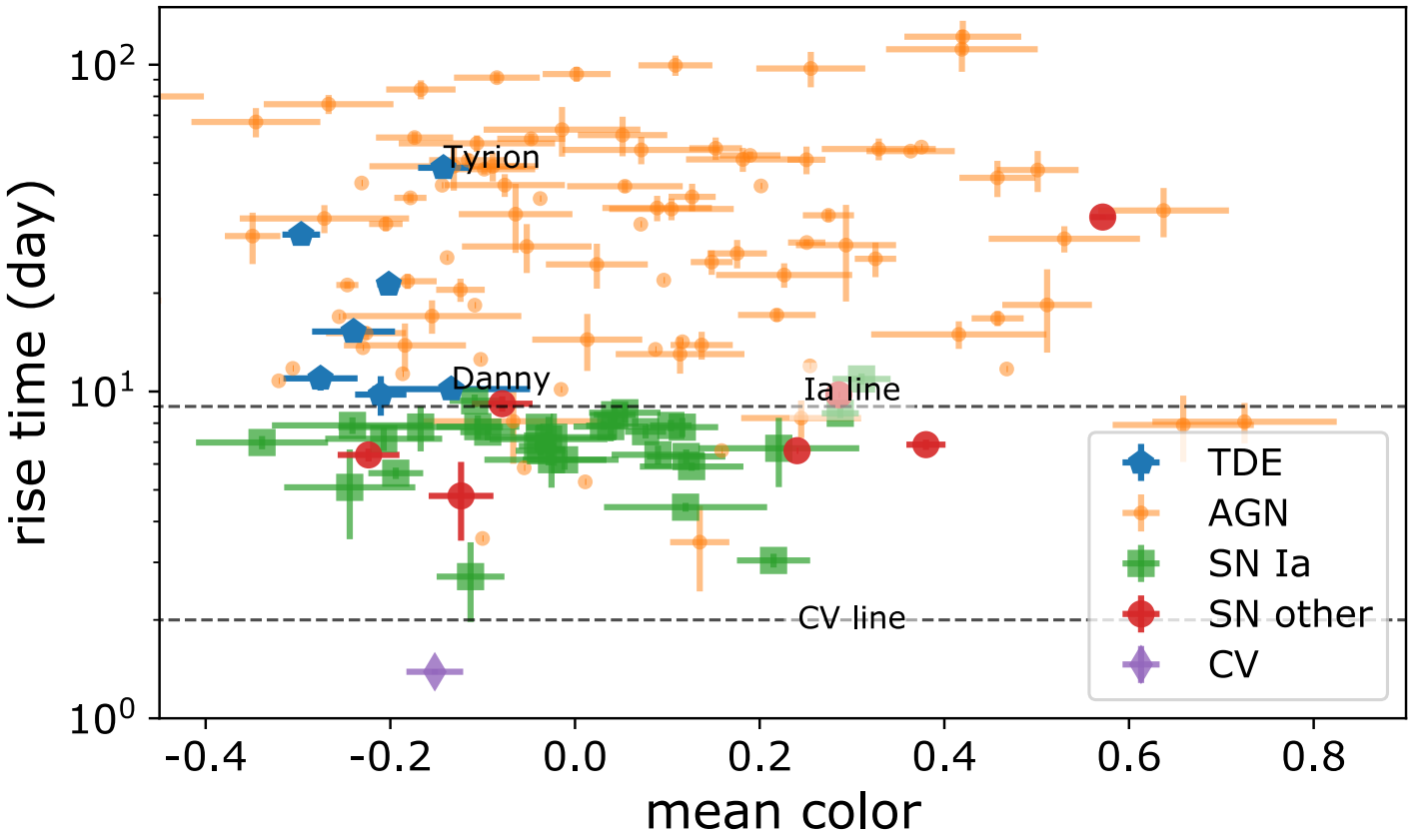
Light curve properties (using ZTF data of nuclear transients)



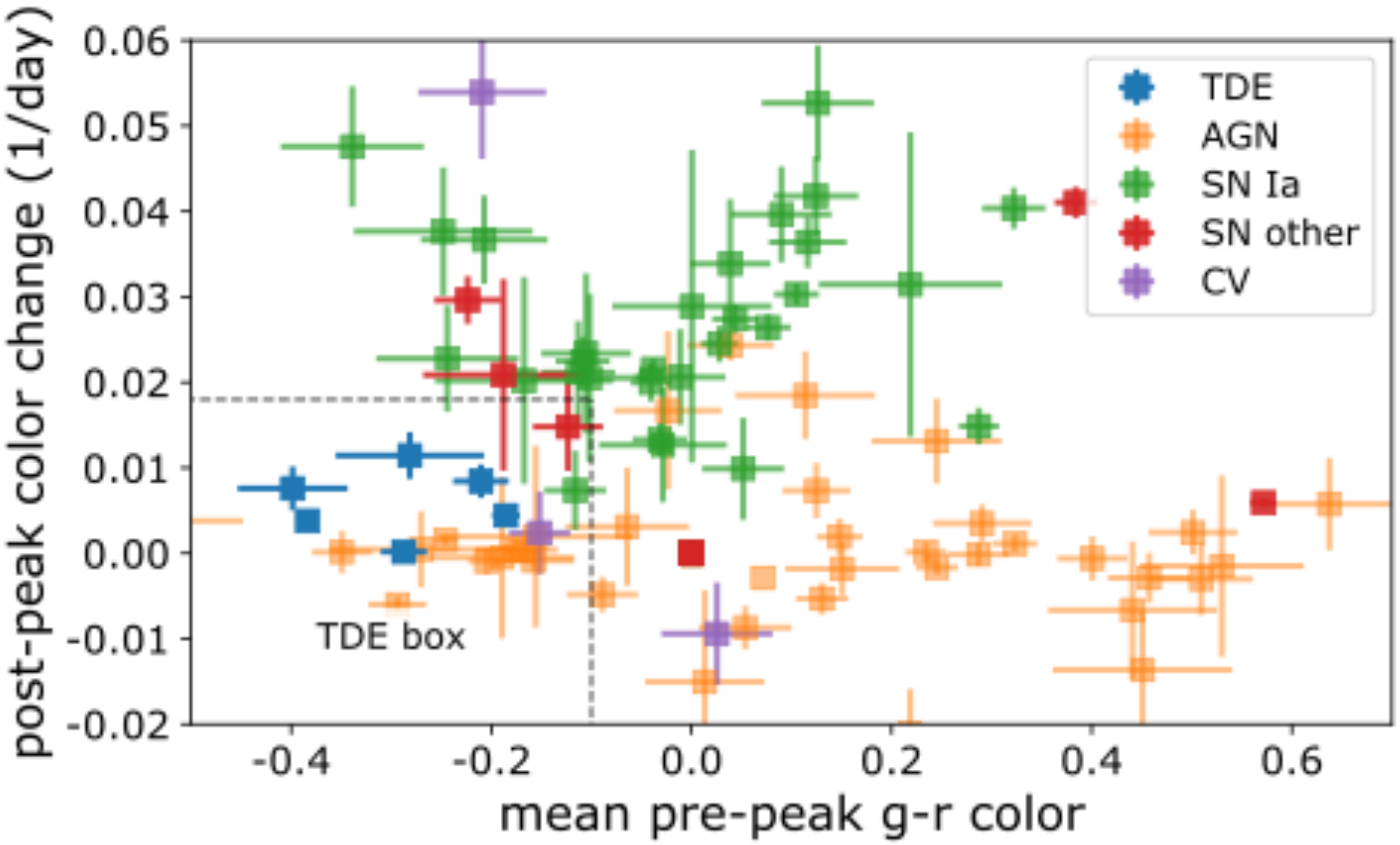
TDFs have slower rise/fade timescales than SNe



color vs rise time



TDFs are blue and have constant g-r color



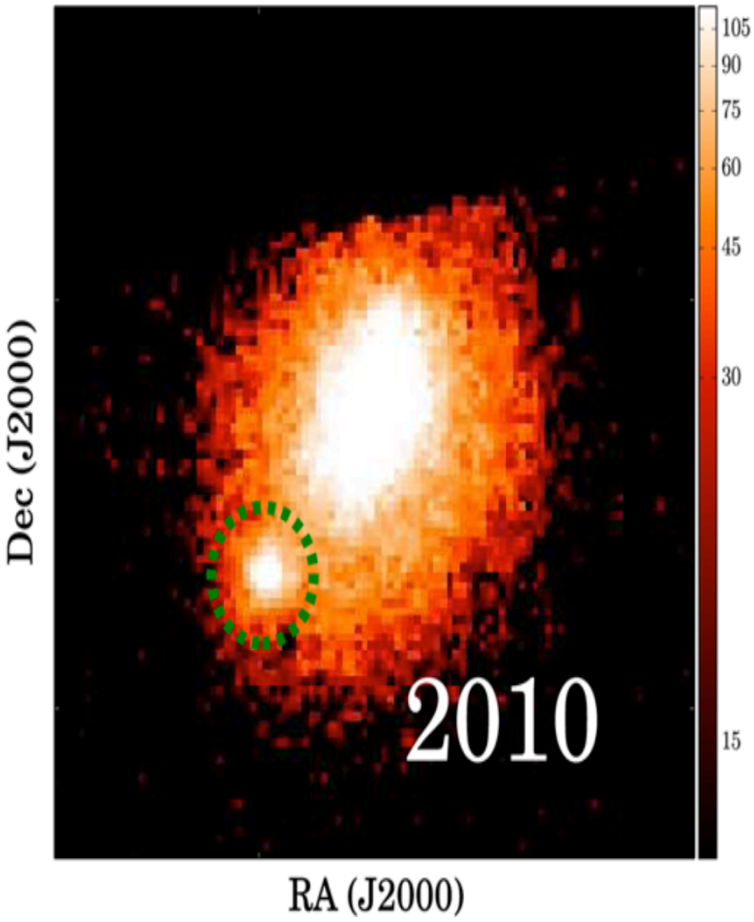
Conclusions

- Photometric typing possible
- Multiple modes of TDF selection: slow, blue, or constant color
- Expected detection rate of TDE candidates:

m>20.0: 8.4/
week
m>19.5: 4.5/
week
m>19.0: 1.8/
week
m>18.5: 0.6/
week

Recoiling black holes

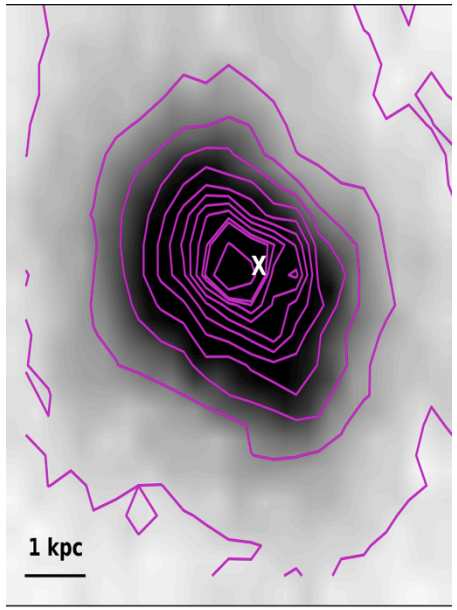
- Asymmetry in masses or spins of two coalescing SMBHs → up to 5000 km/s recoil kick for merged BH.
- Can use to study efficiency of black hole spin alignment.
- Can study unique BH/ galaxy co-evolution.
- No confirmed candidates e.g. Koss et al (2014)

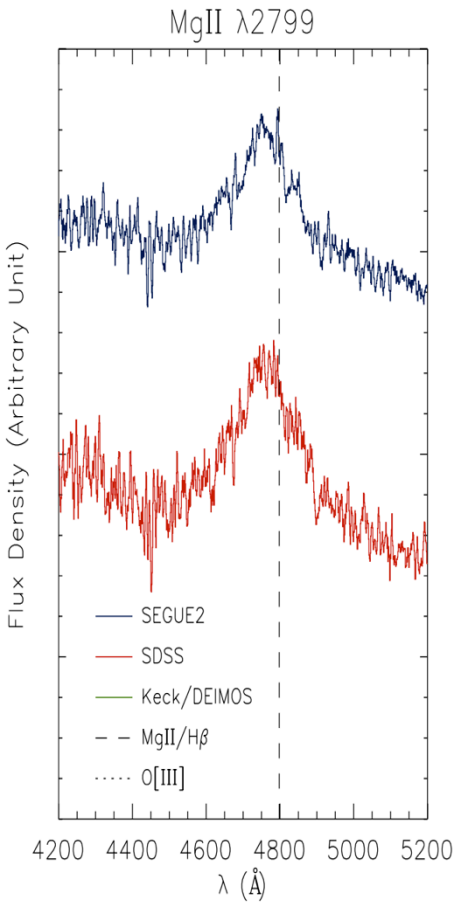


Koss et al 2014

Finding BH recoil candidates with ZTF

- **Spatial offset:** Relative to photometric centre of galaxy.
- **Velocity offset:** Quasar broadline region offset relative to narrow line region and host galaxy. <200km/s for non-spinning to

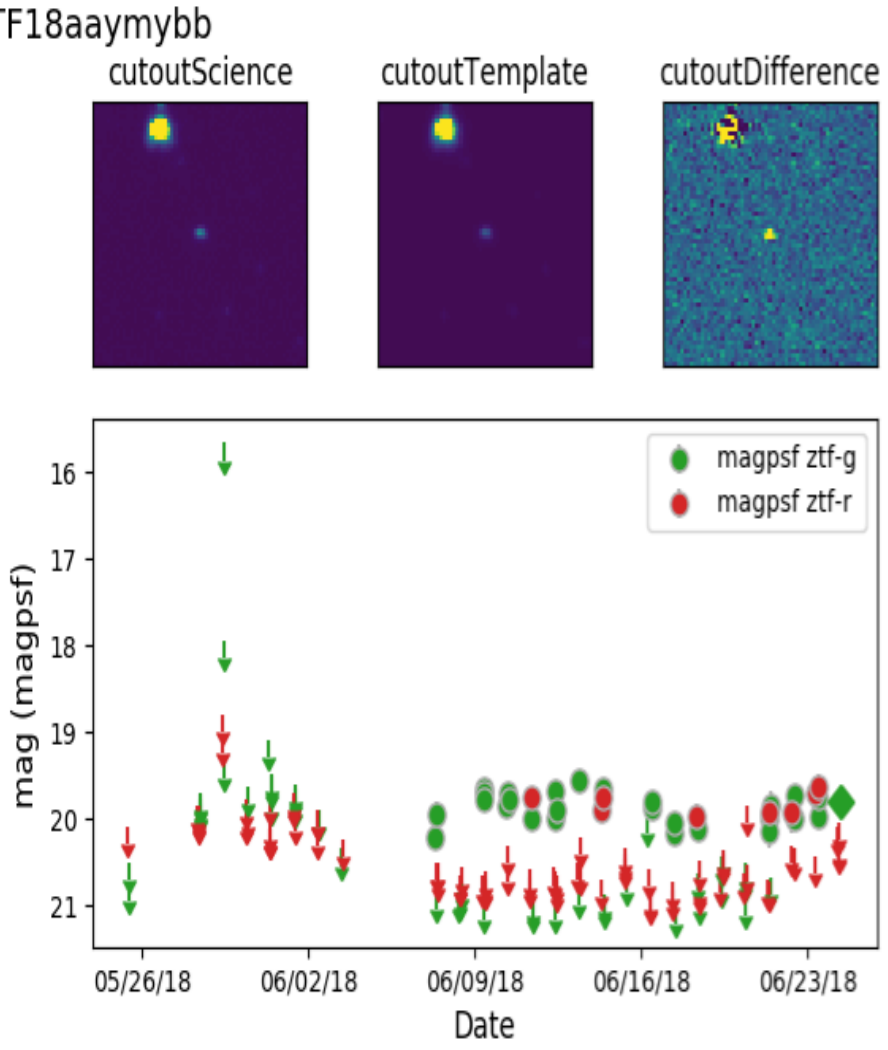




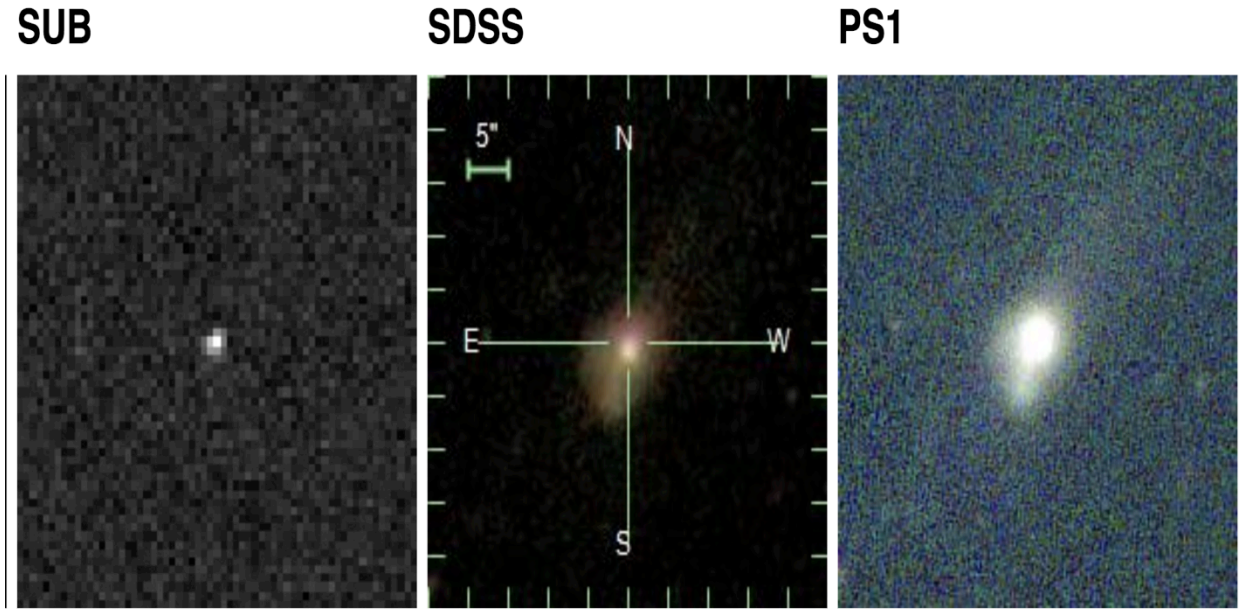
Steinhardt et al 2012

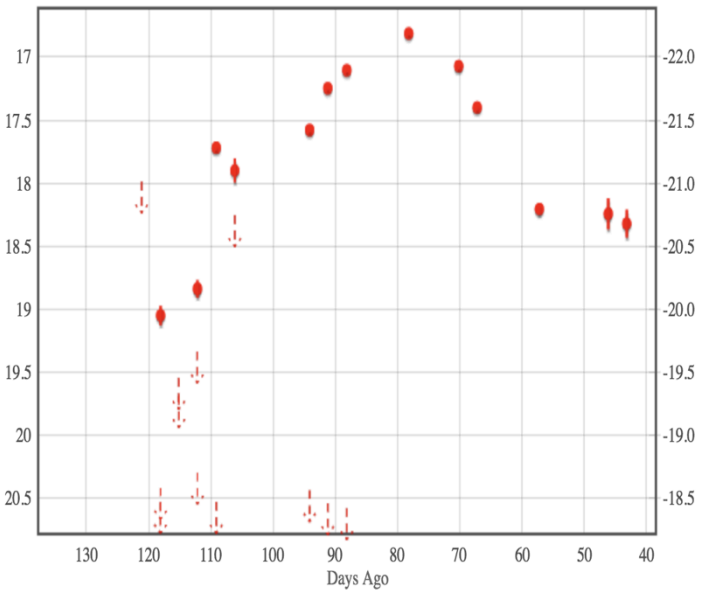
Ampel

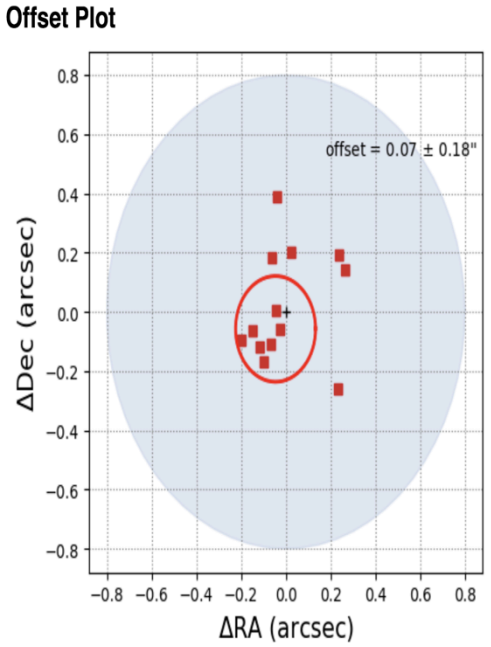
- Similar to nuclear transients filter.
- Search for offsets between galaxy centre and transient of 0.5 to 8 arcseconds.
- Search for differences between g and r band galaxy positions in external



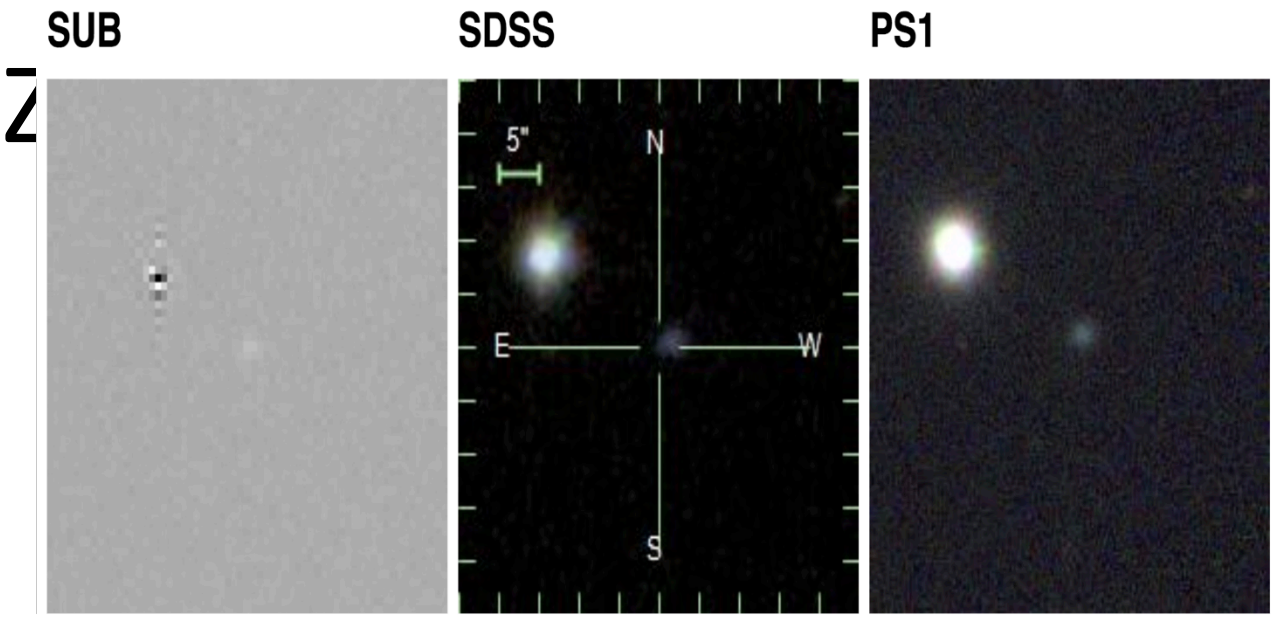
- Confirmed AGN
- Next steps:
- Galaxy shape modelling
- Spectral line analysis

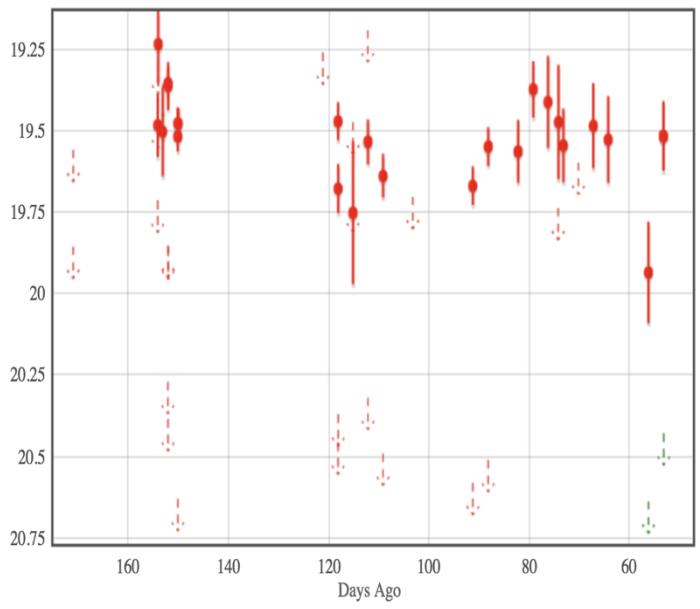


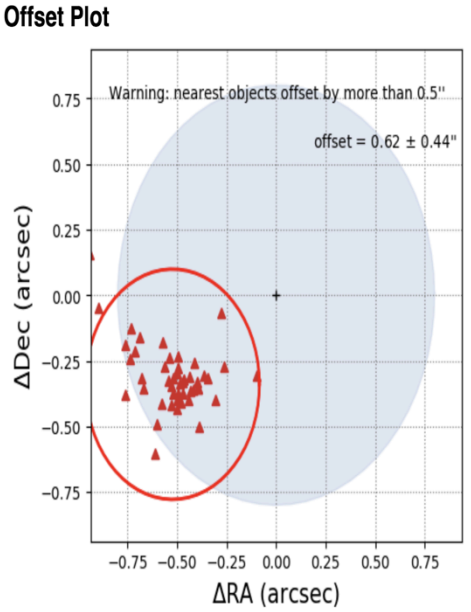




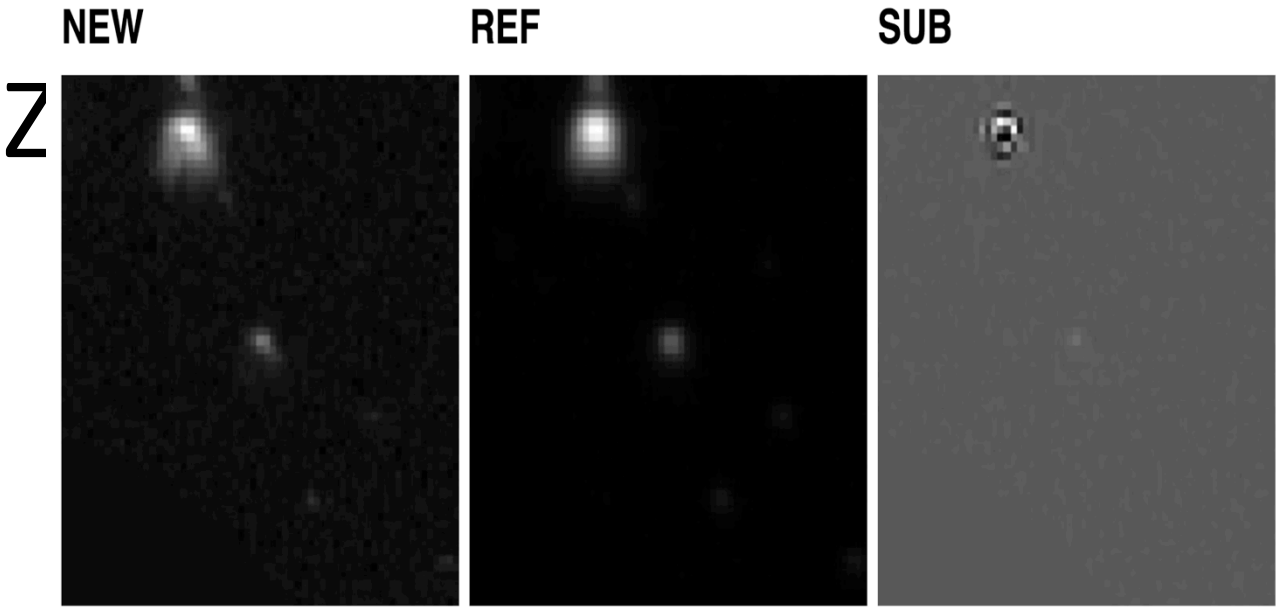
- Transient and galaxy visible in highest depth science images
- Need confirmation that AGN is real.

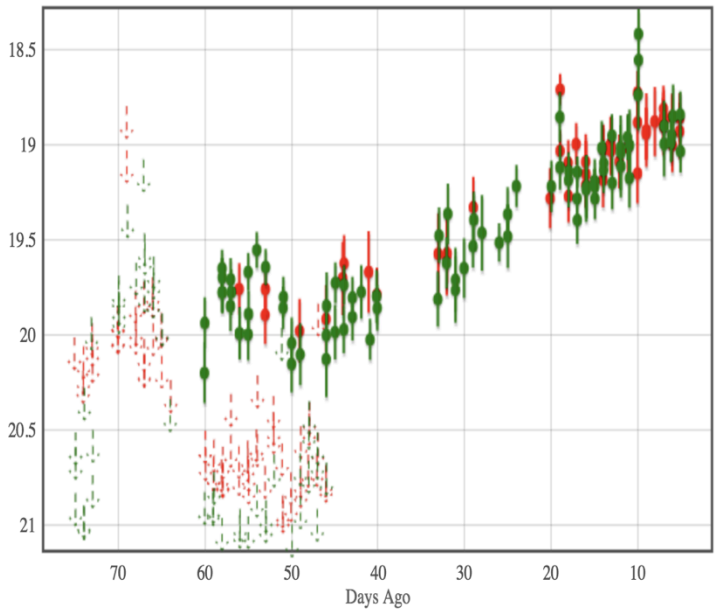


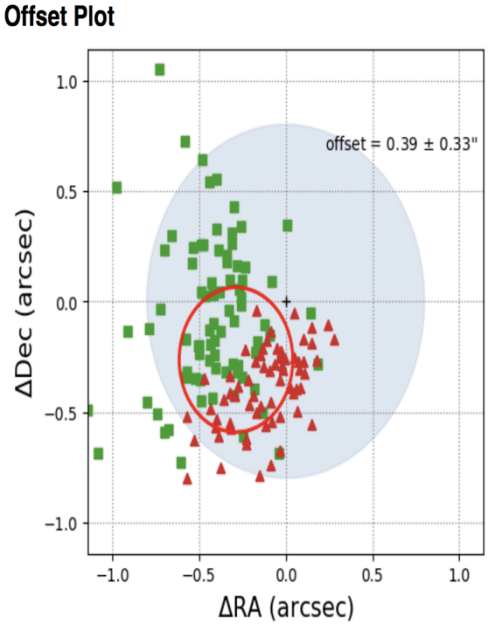




- XMMSL source
- Next steps: Modelling to determine location of AGN

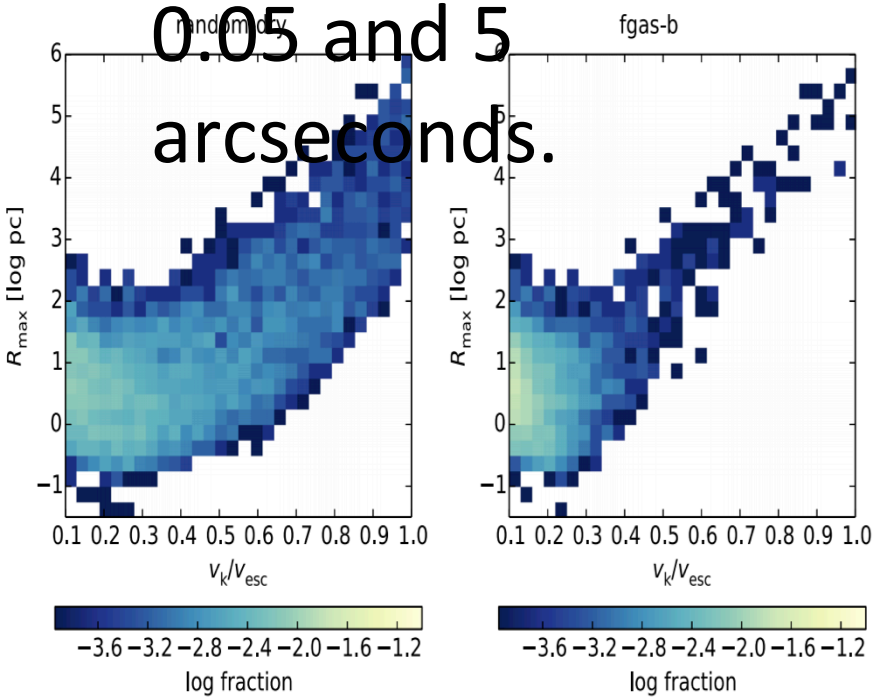


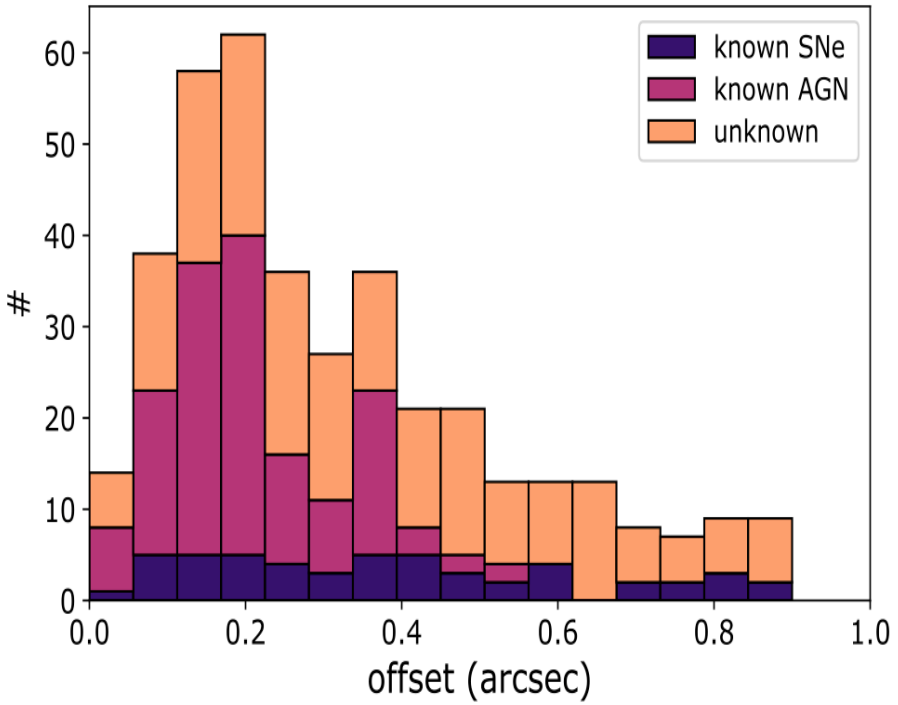


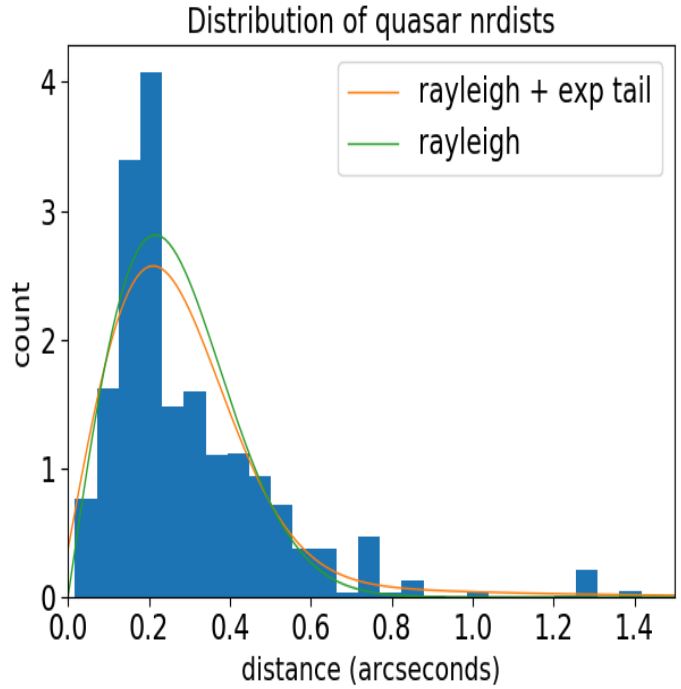


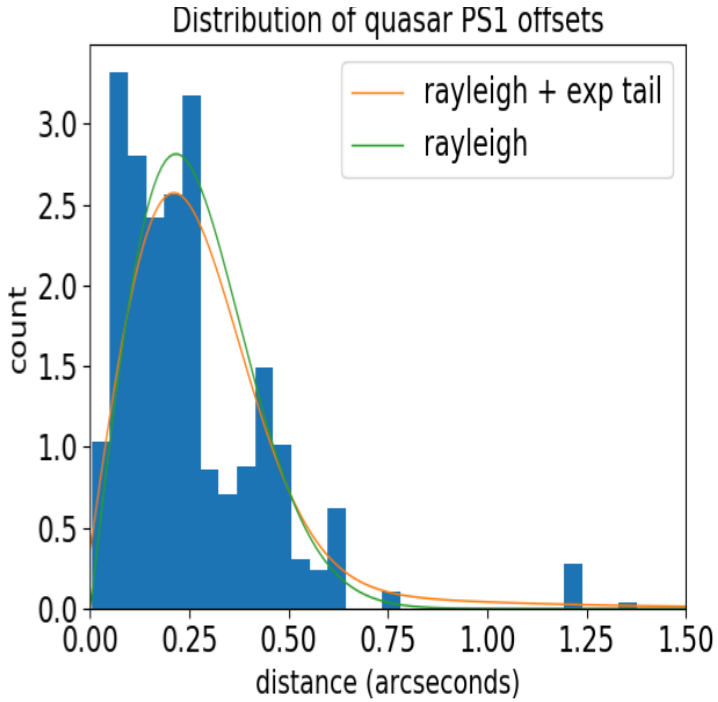
Astrometry

- Existing recoil candidates have offsets between 0.05 and 5 arcseconds.

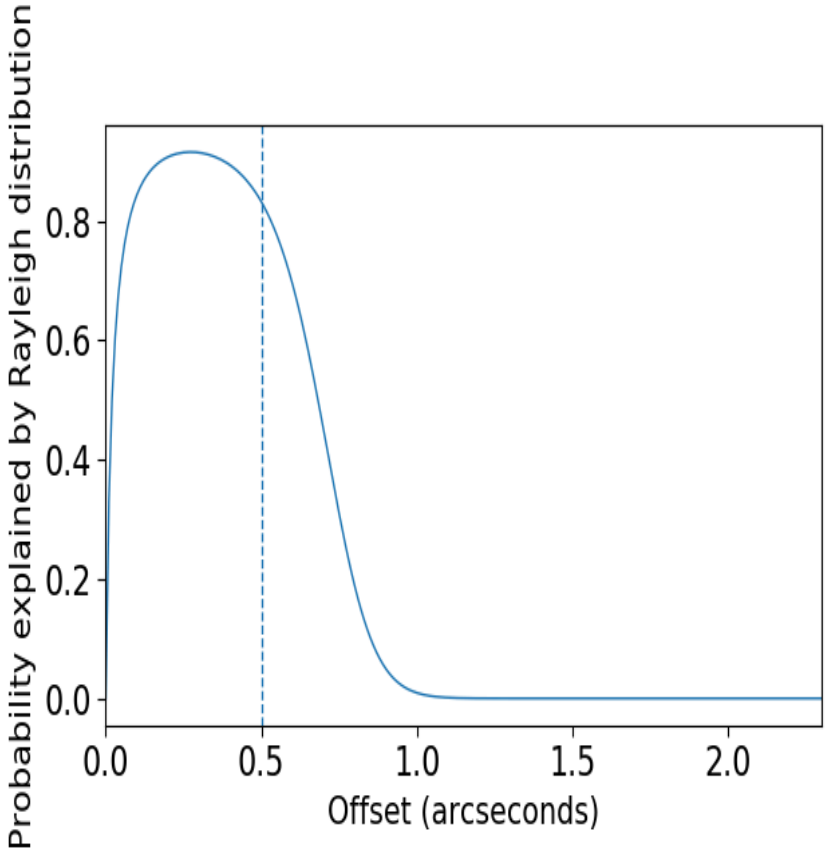








- Need to determine reasons for structure in offset distribution



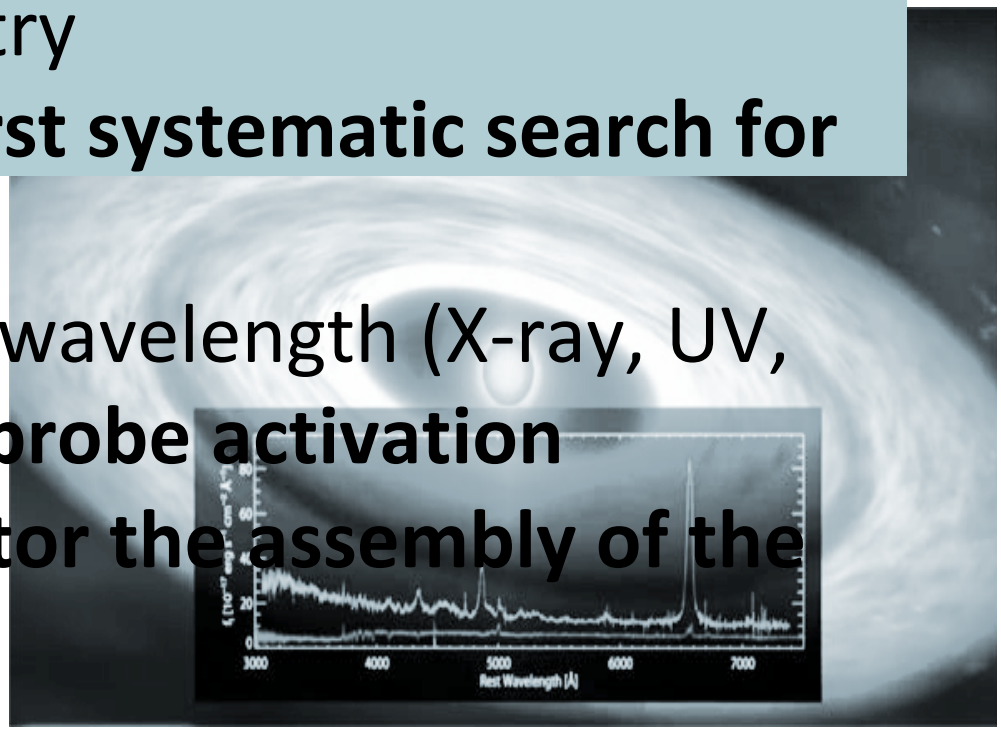
ZTF CLAGN Summary

Sara Frederick

ZTF August Meeting

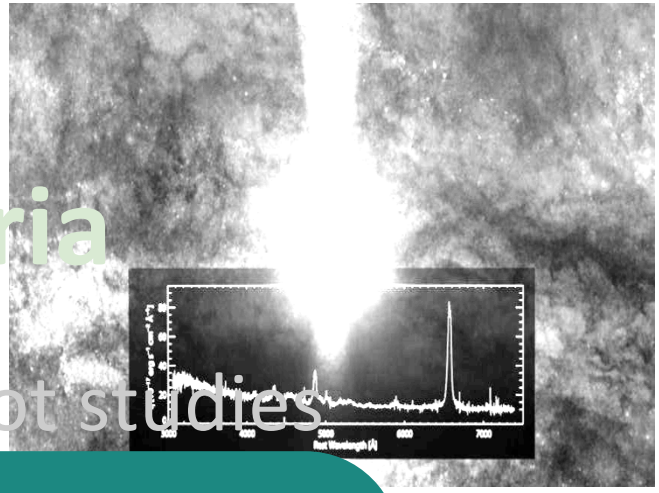
Tuesday, Aug 7, 2018

- Only dozens of Changing-look quasars (variable AGN turning on) have been identified to-date, many inadvertently
- We are using a time domain survey to identify obscured AGN that should ***not*** be variable but are discovered to suddenly light up in differential photometry
- ZTF will enable the **first systematic search for CLAGN in real-time**
- Ultimate goal is multiwavelength (X-ray, UV, optical) follow-up to **probe activation timescales and monitor the assembly of the BLR**



Background

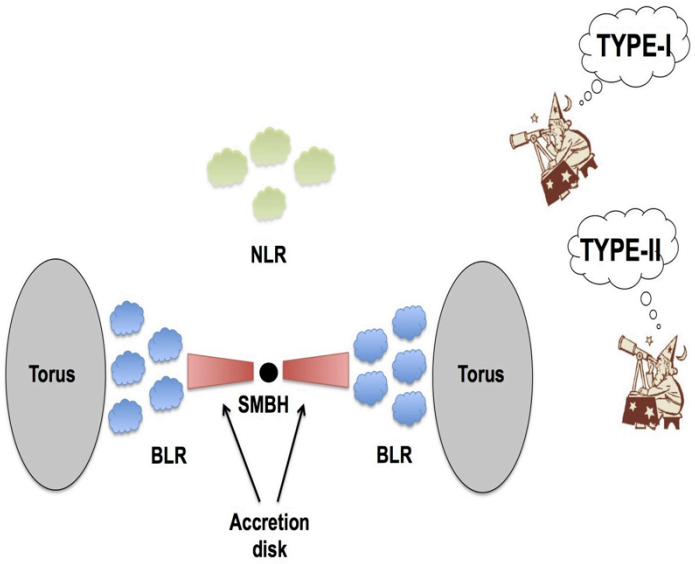
Selection Criteria

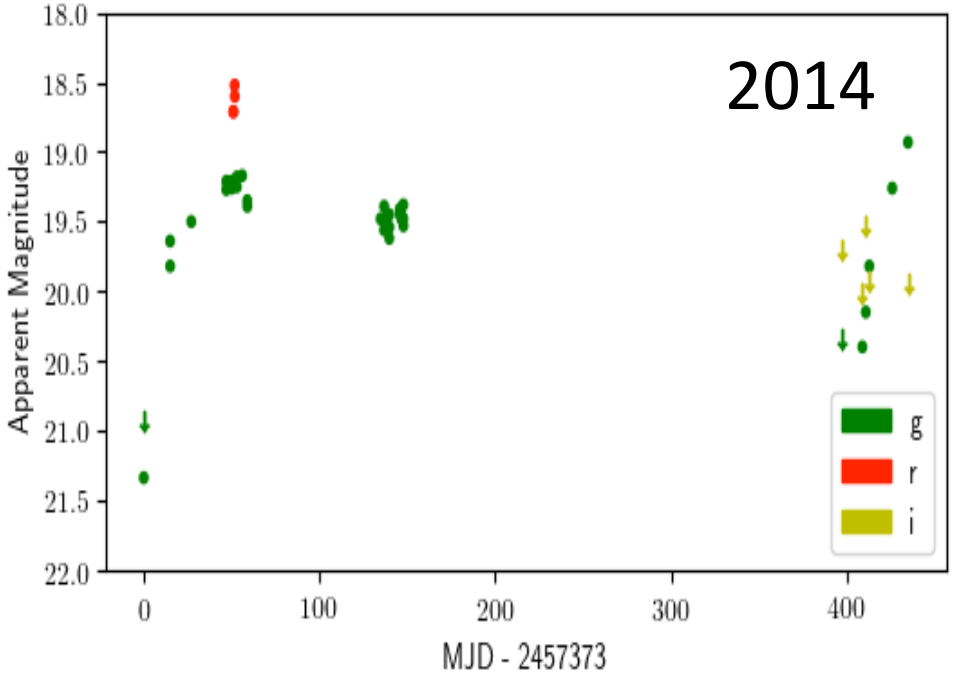


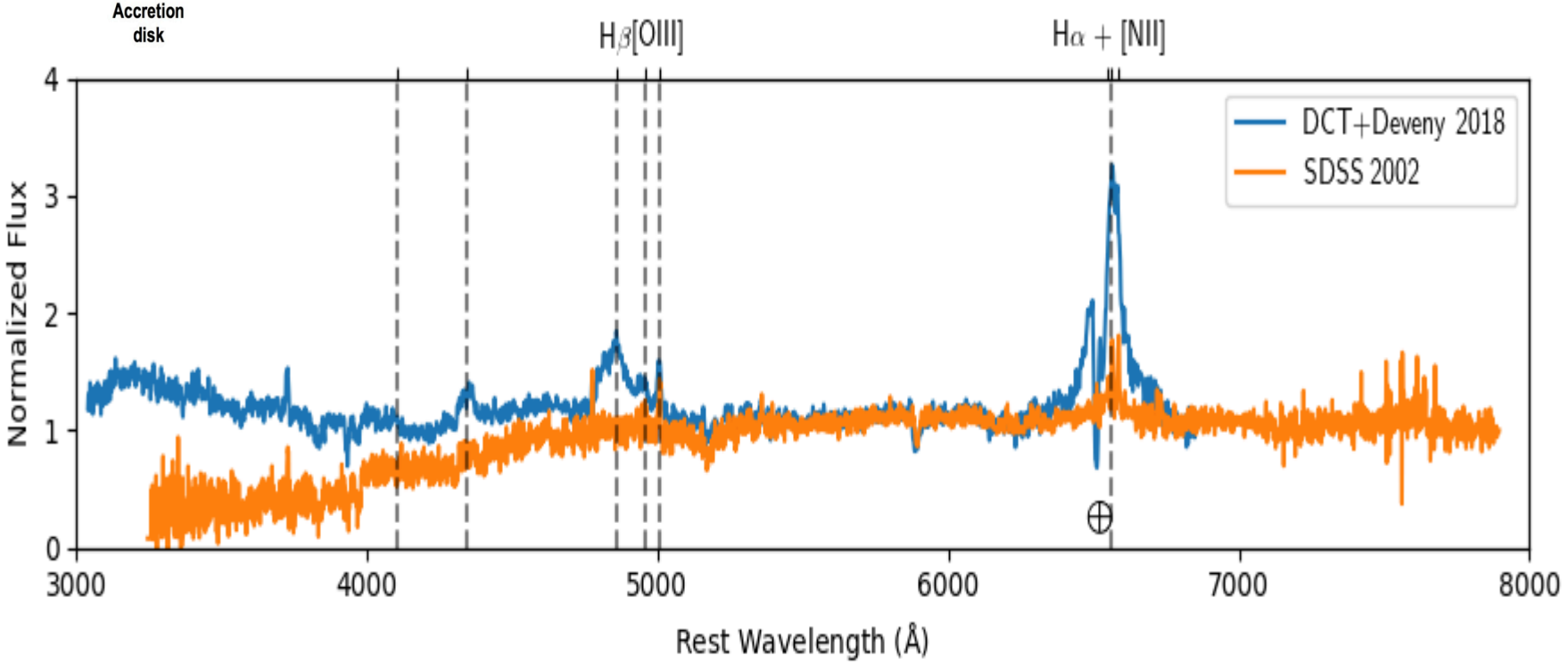
- *Percentages based on iPTF pilot studies

50 %	Nuclear Transient	• Offset < 0.8” in iPTF • Will use Offset < 0.5”
2%	Has AGN Spectrum	• SDSS/BOSS • Veron Cetty
200	~~Clear broad lines~~	• SDSS/BOSS • MQC?
100	Sy > 1.8 or LINER	• BPT Heidelberg • Veron Cetty
2	Spectral Change	• LINER → Sy 1 in 2016 • Sy > 1.8 → Sy 1 in 2014

iPTF Changing

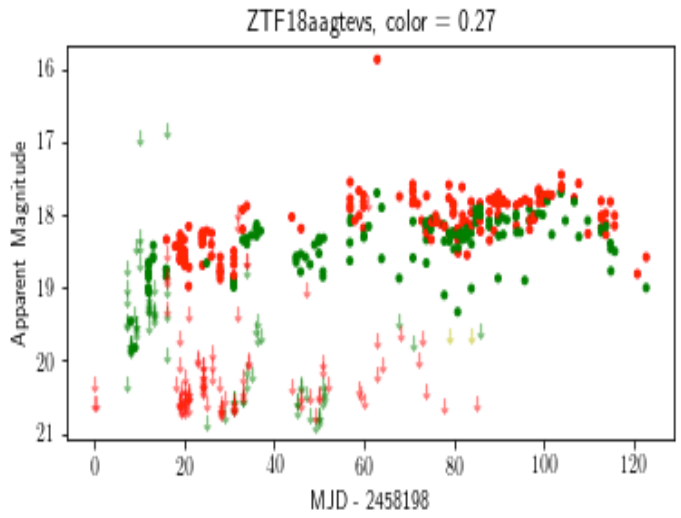


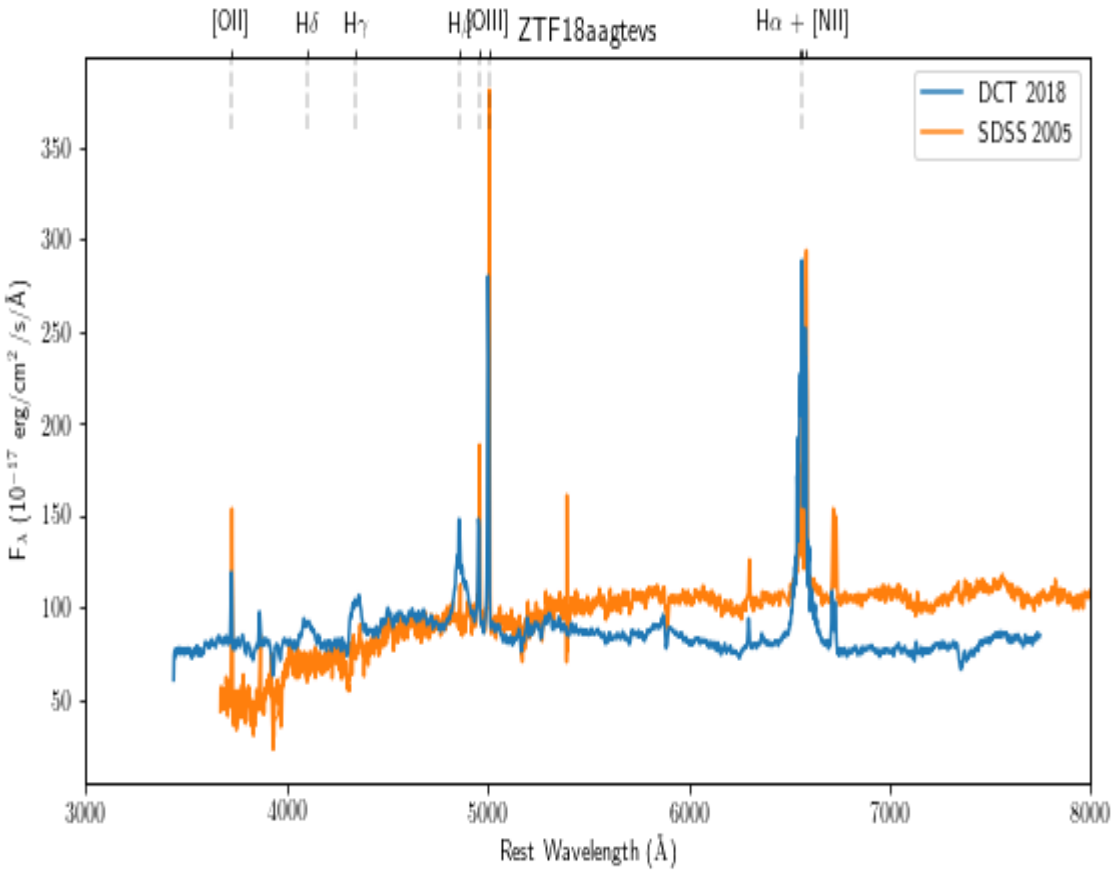




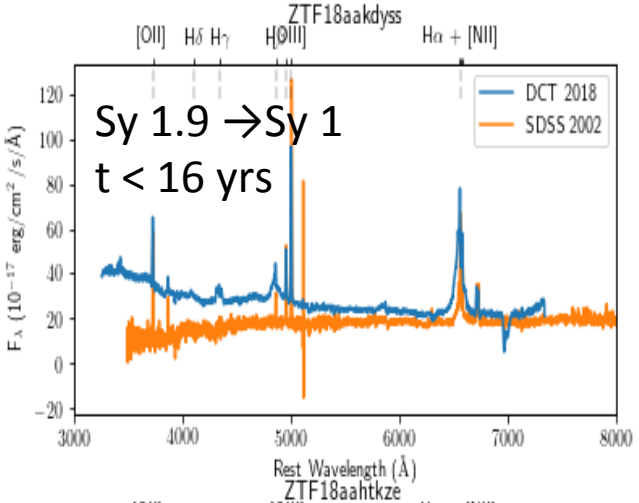
Results

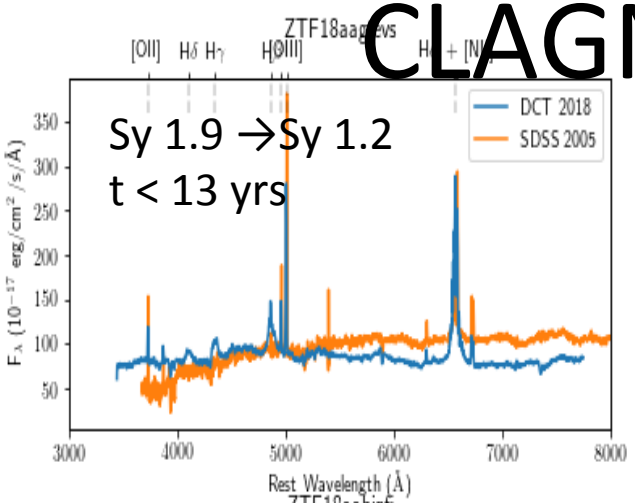
- Story of the first CLAGN found in ZTF: **ZTF18aagtevs**
- Have since discovered 6 more via DCT & P200 follow-up

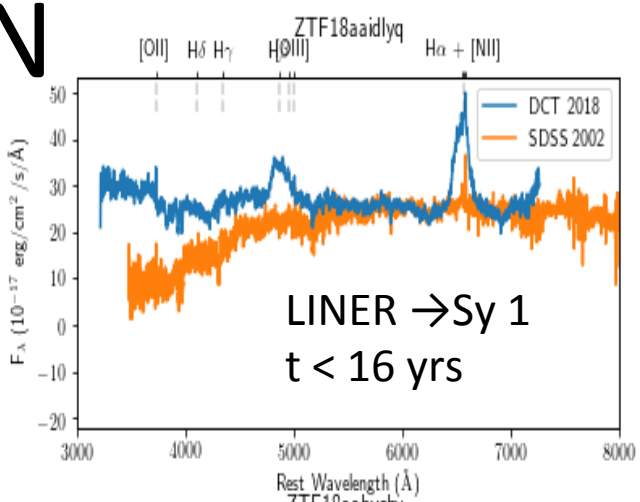


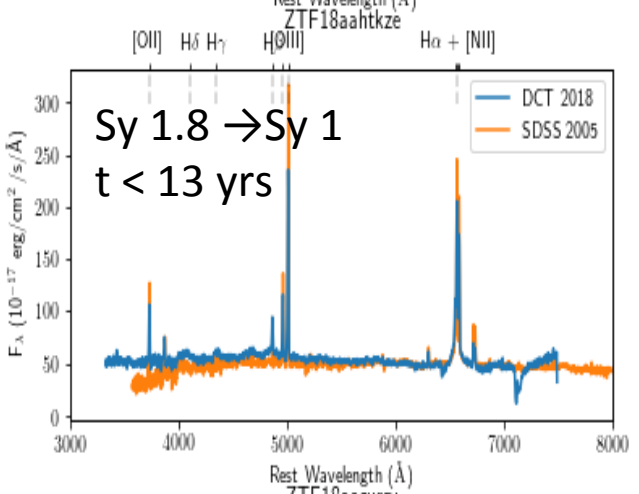


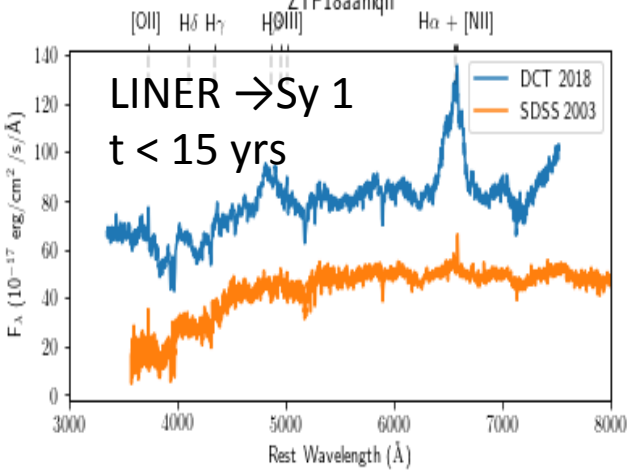
Comparison spectra of all ZTF CLAGN

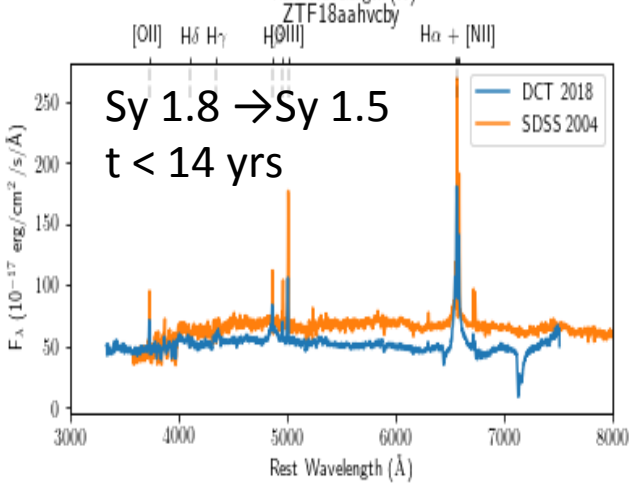


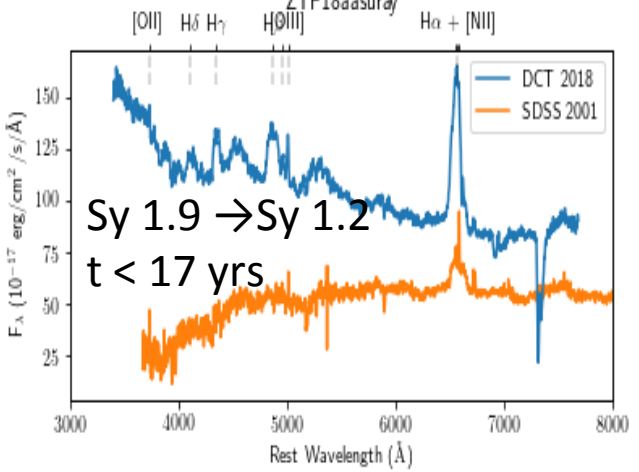






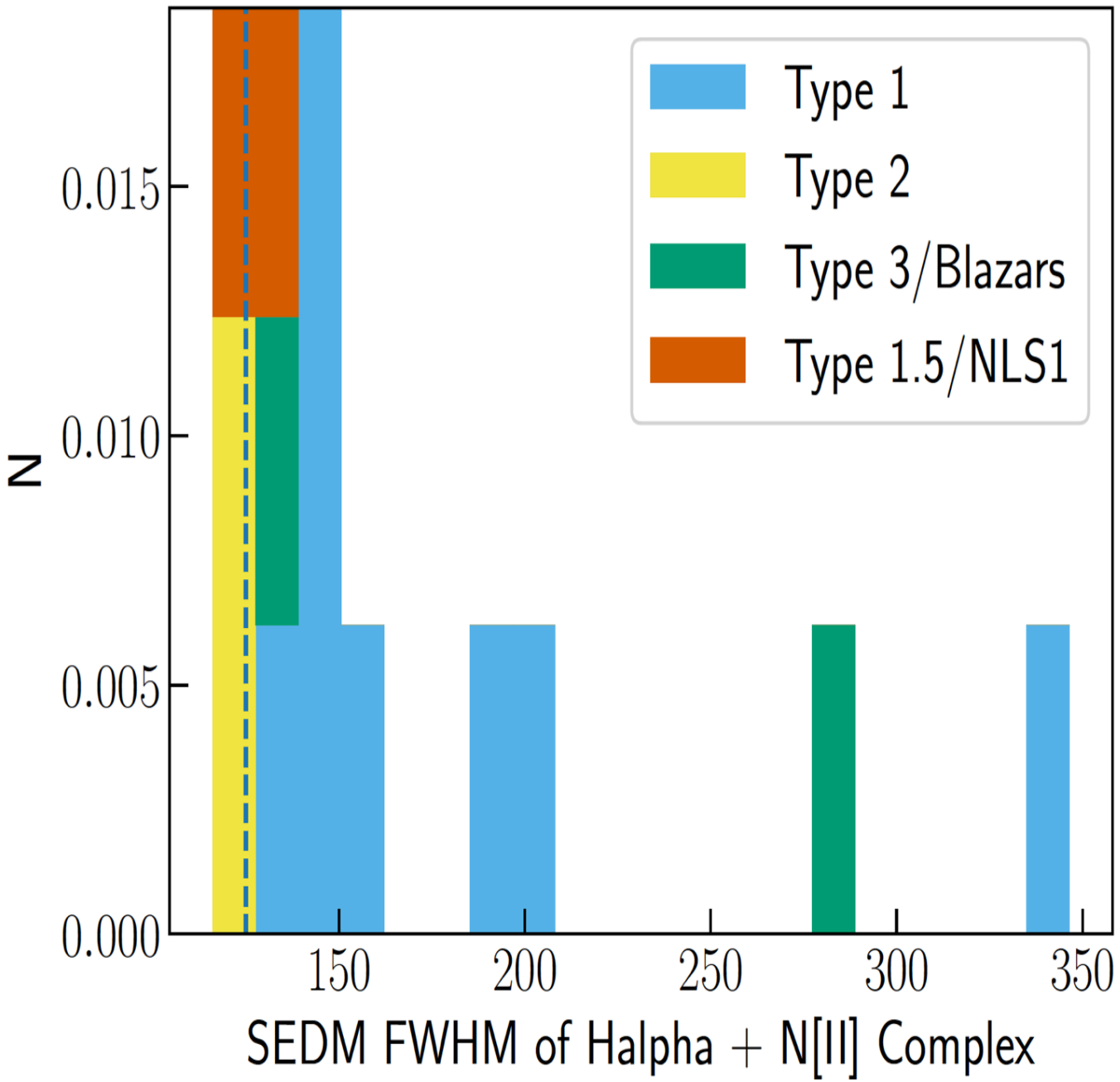






SEDM Follow-up

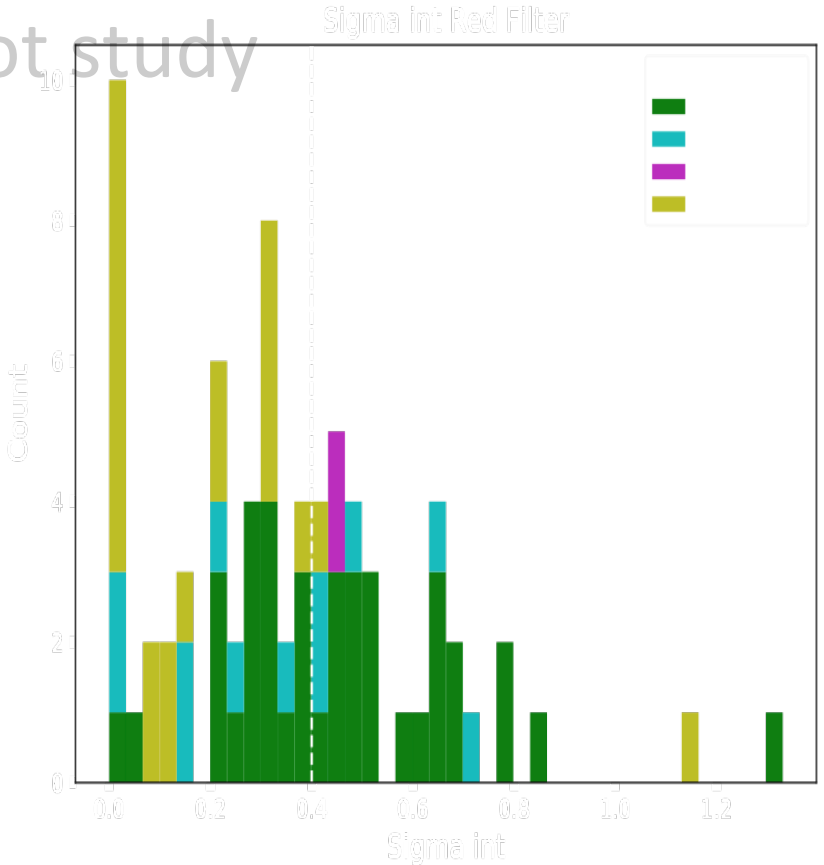
Capability to distinguish true broad-line AGN from narrow-line AGN at low-resolution using cutoff



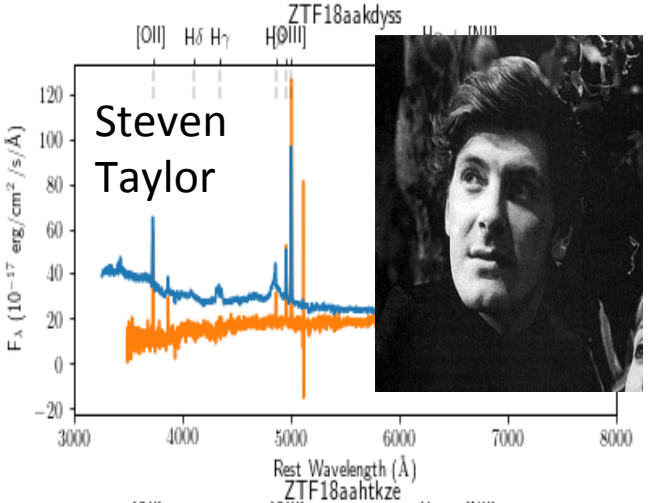
http://noir.caltech.edu/twiki_ptf/bin/view/ZTF/Analyses

Next Step

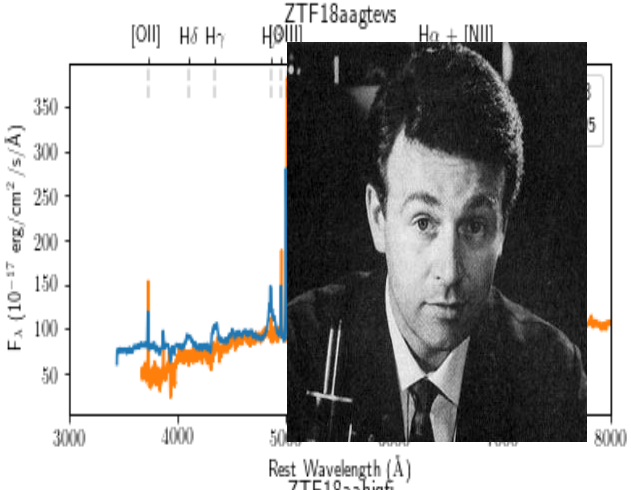
- Automated follow-up prioritization based on light curve variability statistics utilizing outcomes from iPTF pilot study

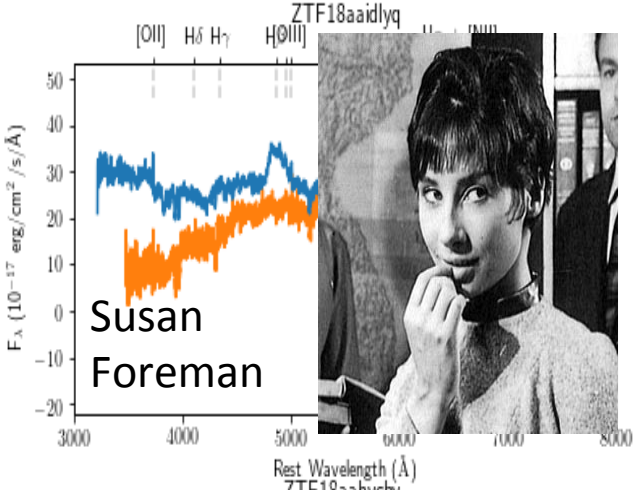


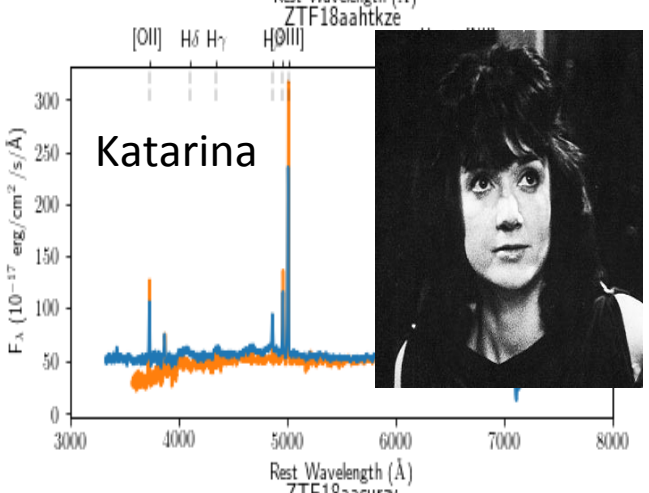
Dr. Who Mnemonic

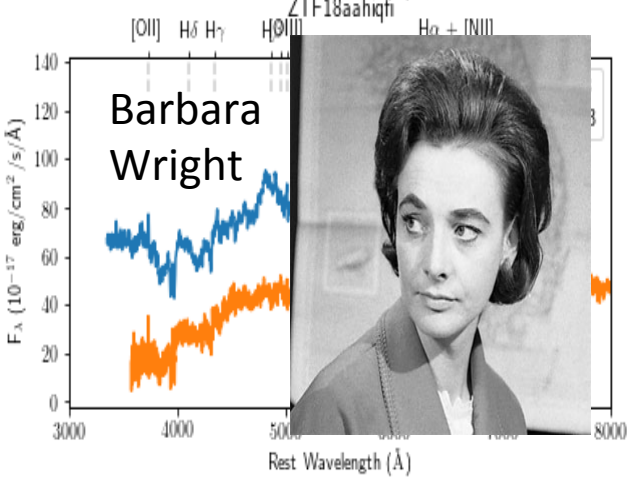


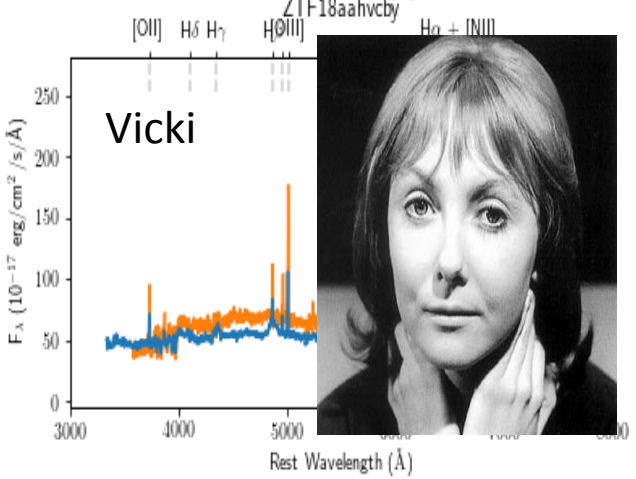
Ian Chesterton

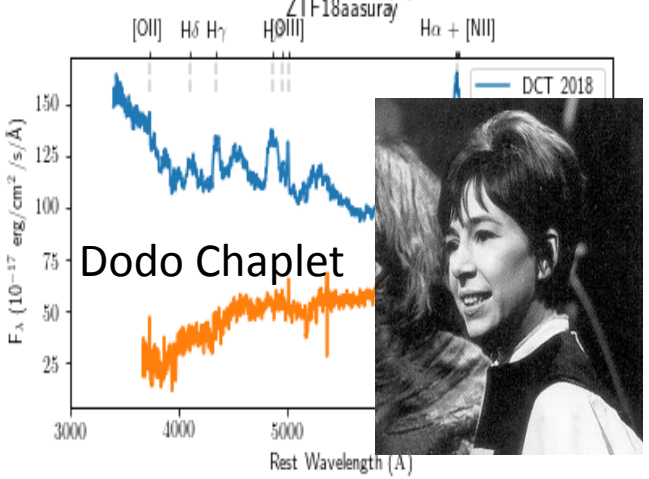




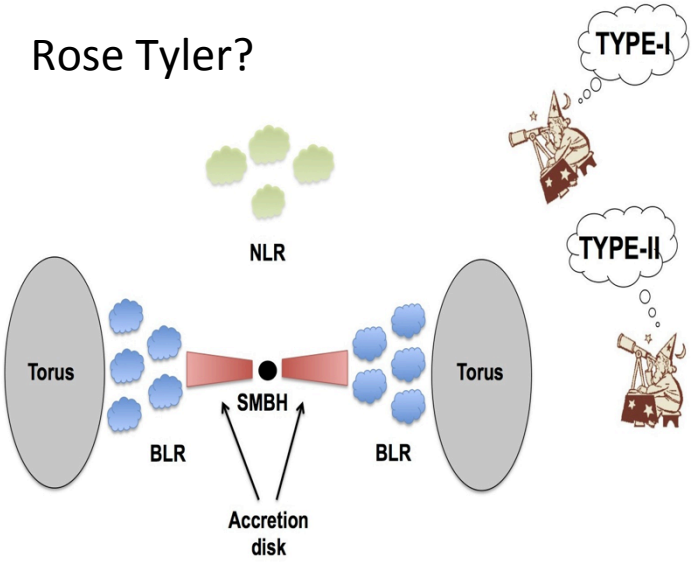






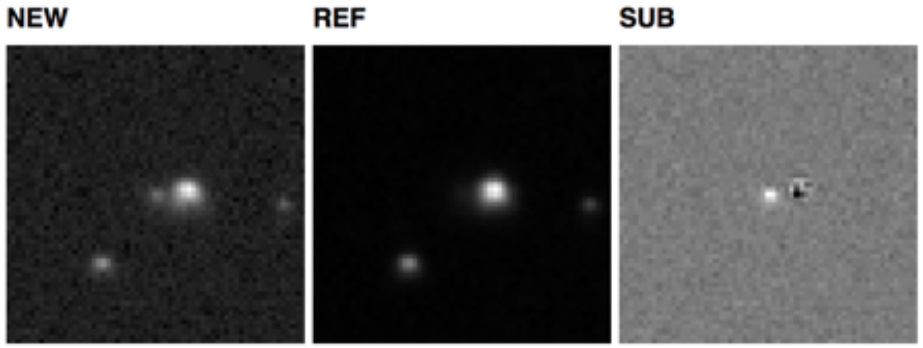


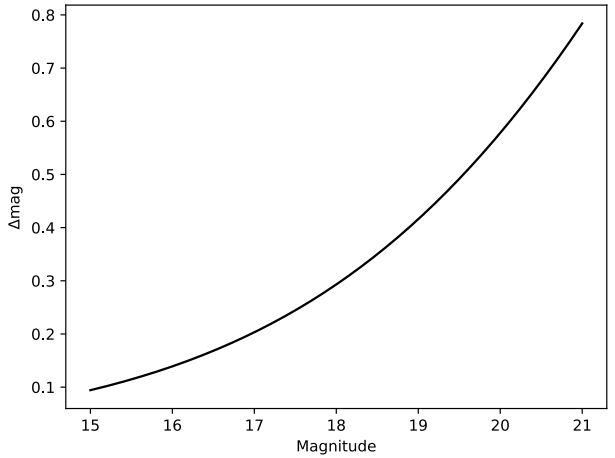
Rose Tyler?


TYPE-I
TYPE-II
NLR
Torus
Torus
SMBH
BLR
BLR
Accretion
disk

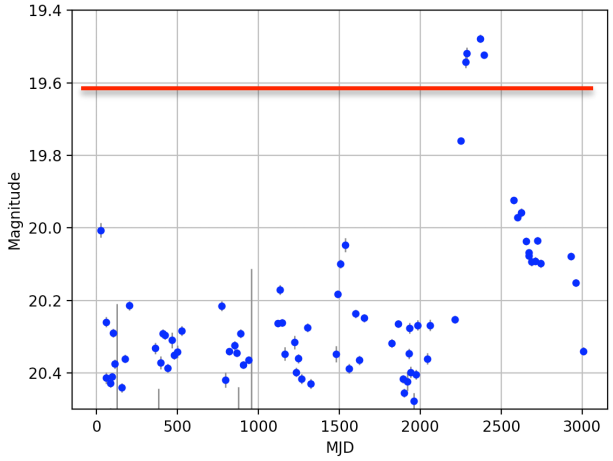

POLICE PUBLIC CALL BOX
POLICE PUBLIC CALL BOX

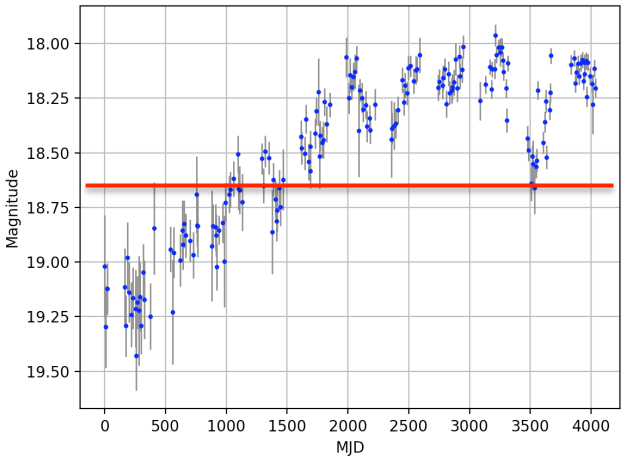
The issue with differential photometry





(F. Masci)



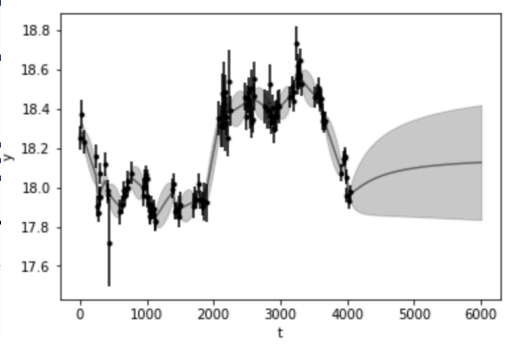


Better Gaussian processes

DRW = CAR(1) = CARMA(1,0) = CARIMA(1,0,0) = CARFIMA(1,0,0)

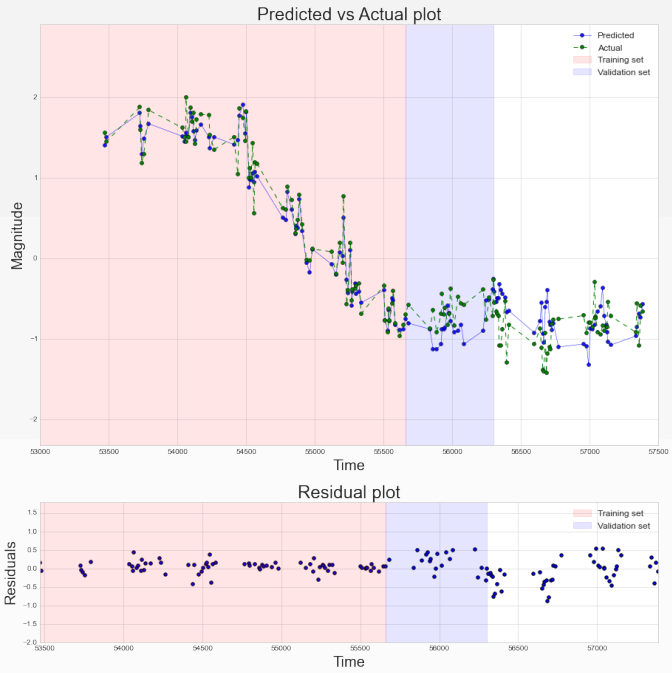
- (Zero mean) Gaussian processes are completely defined by their covariance function
- Ornstein-Uhlenbeck (DRW) but no closed form for (super)parent models
- Fractional Brownian motion is equivalent to CARFIMA and a Cauchy class separates characterization of the fractal dimer (roughness) and long range depende

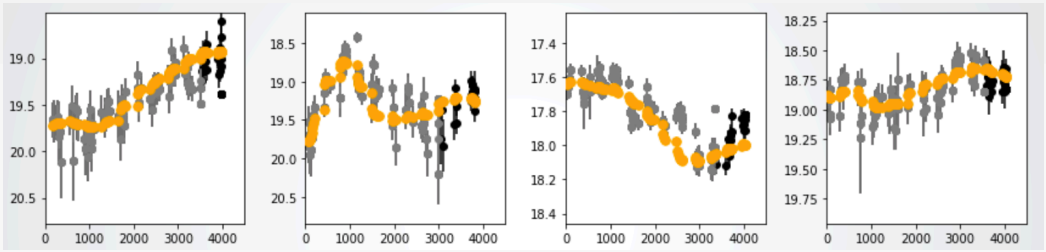
$$K(x,x') = \sigma^2 (1+(\theta|x-x'|)^\gamma)$$



Going deeper

- Some neural networks architectures have “memory” - connections between links forming directed cycles, e.g., RNNs, LSTMs, good for time series





Y. Tachibana

Summary

- Need to understand extreme photometric/spectroscopic variability but how to get initial (fast) rise coverage?
- Traditional time series analyses in astronomy involve:
  - (simple) discriminative features as (possible) inputs to machine learning algorithms
  - little predictive power
- Data volumes now mean that we can *model individual* sources:
  - capturing full time series behavior
  - with generative approaches
- Next generation surveys enable real-time validation of predicted behaviors and swift identification of deviance
- Watch this space…