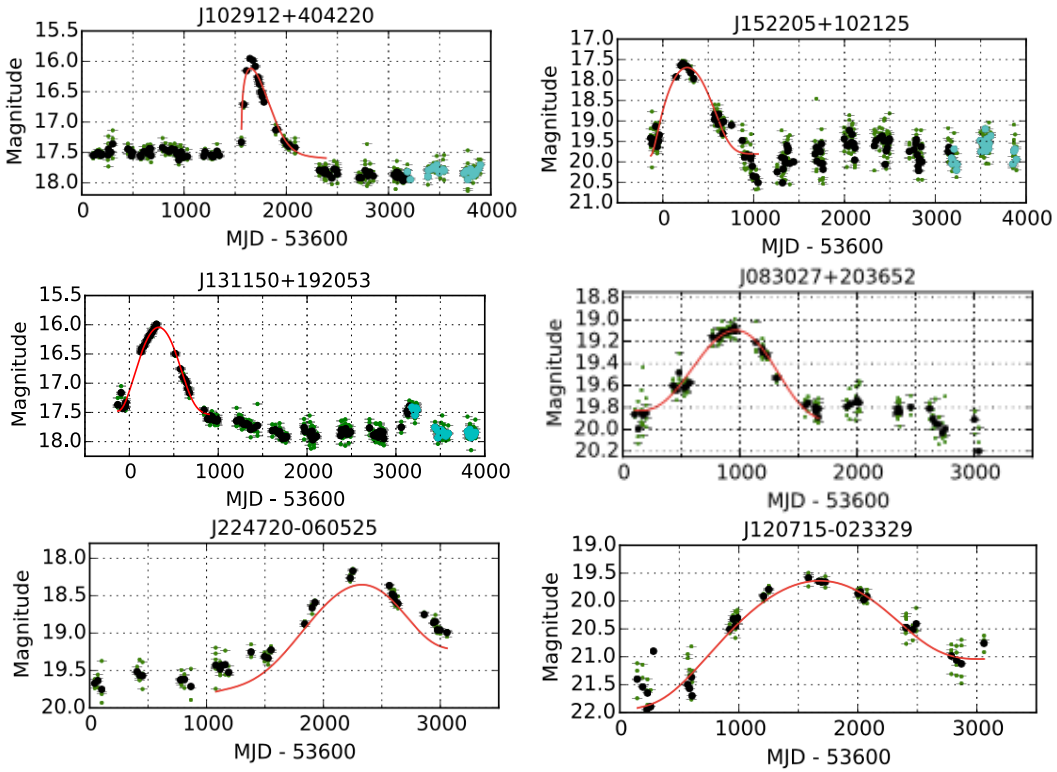
ZTF Team Meeting, “Pasadena”
20 October 2020

AGNs: bridging EMGW, transients, and variables

Matthew J. Graham
ZTF Project Scientist
mjg@caltech.edu

With Charlotte Ward, Sara Frederick

AGN optical flares



A sample of 51 AGN with a significant flaring event inconsistent with DRW behavior

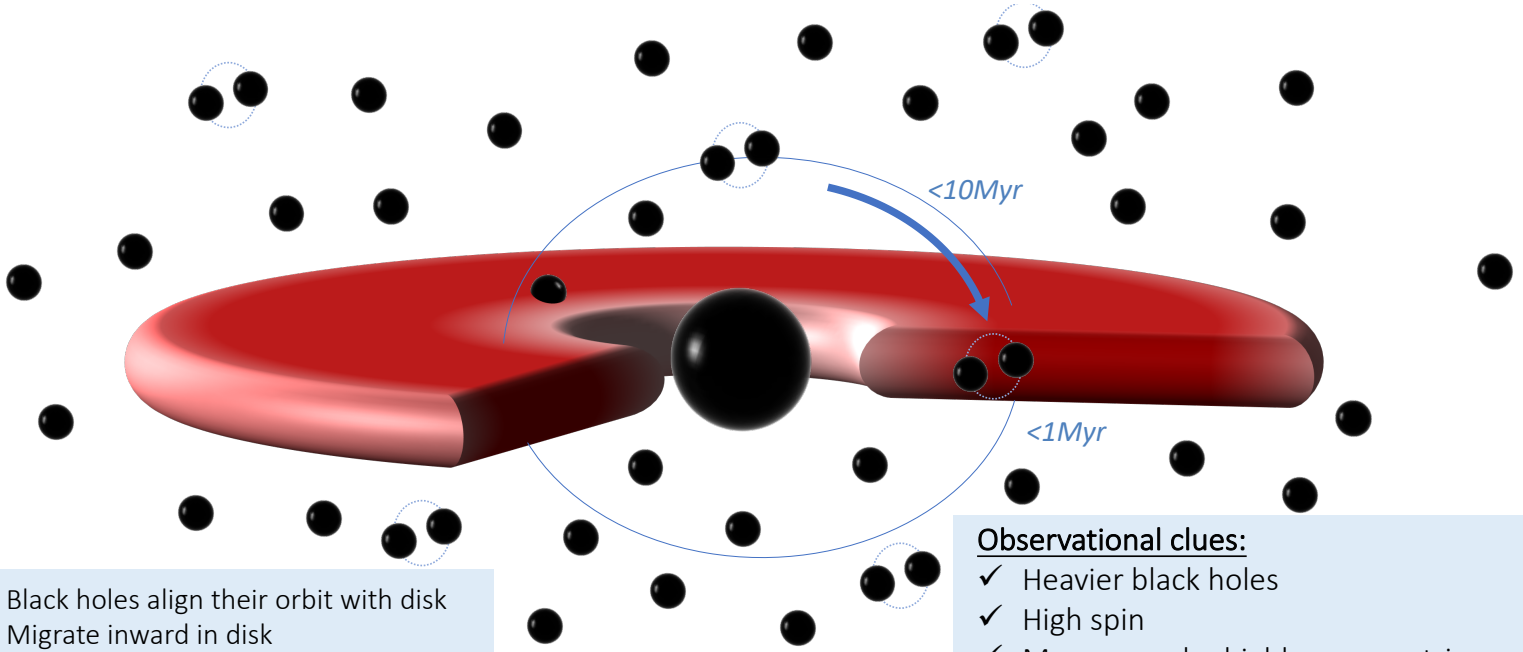
- Superluminous supernova (SLSN-II)
  - J102912+404220 (Drake et al. 2011) wi
    150pc of the nucleus of NLS1
- Slow TDE (spinning SMBH)
  - Relativistic precession from black hole spin prevents the TDE debris stream from self-interacting until after many windings
  - Not for M > 10^8 solar masses
- Stellar mass black hole merger
  - Potentially important dynamic sub-channel

=> Explosive stellar activity in the accretion disk

- Accretion disk wind – BLR interaction?

Graham+, 2017

How do we know if a binary merger happened in an AGN disk?



1. Black holes align their orbit with disk
2. Migrate inward in disk
3. Gas capture → form binaries
4. Rapidly merge due to dynamical friction + binary-single interactions
5. Repeat (hierarchical mergers)

McKernan+ ApJ 2012
Bartos+ ApJ 2017
Stone+ MNRAS 2017
Yang+ PRL 2019

Observational clues:

- ✓ Heavier black holes
- ✓ High spin
- ✓ Masses can be highly asymmetric
- ✓ Eccentricity
- ✓ Multi-messenger counterpart
- ✓ Correlation with AGN locations

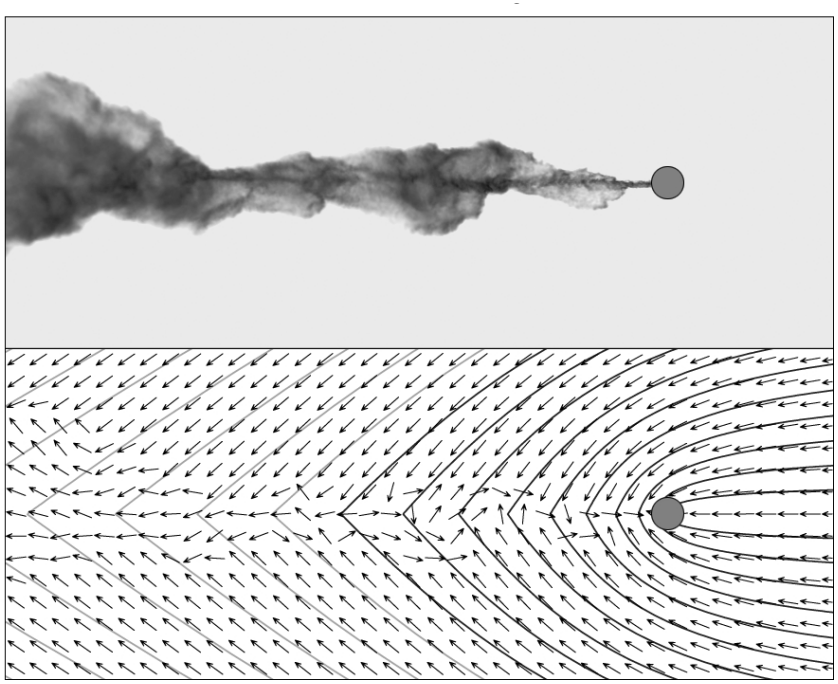
I. Bartos

Predicted light curve

short lag (~10 days) from GW event to onset of UV/optical emission, due to photon diffusion within accretion disk

rising ram pressure shock emission as gas is stripped off, lasting ~20 days; then this emission drops

after ram pressure strips gas, Bondi-Hoyle-Lyttleton accr
and lasting until BH leaves disk (~70 days)



In particular, note that:

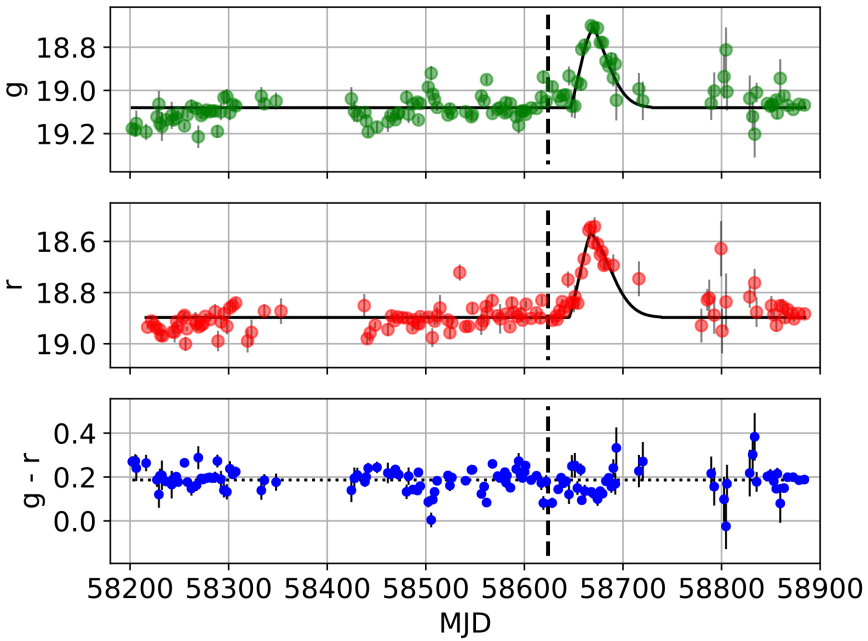
ram pressure shock emission luminosity scales as M_{BH}^3

BHL emission luminosity scales as M_{BH}^2

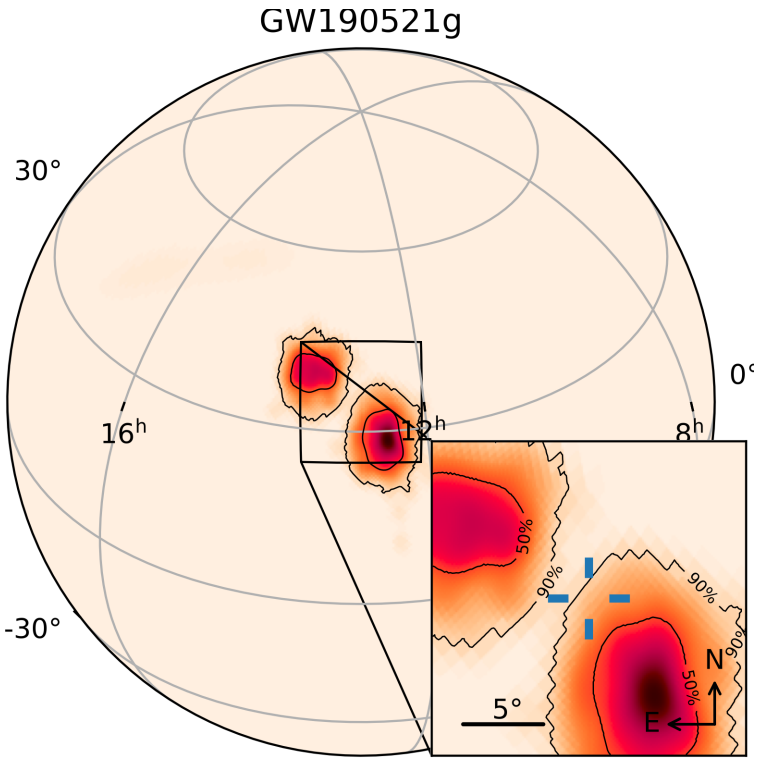
Is there anything there?

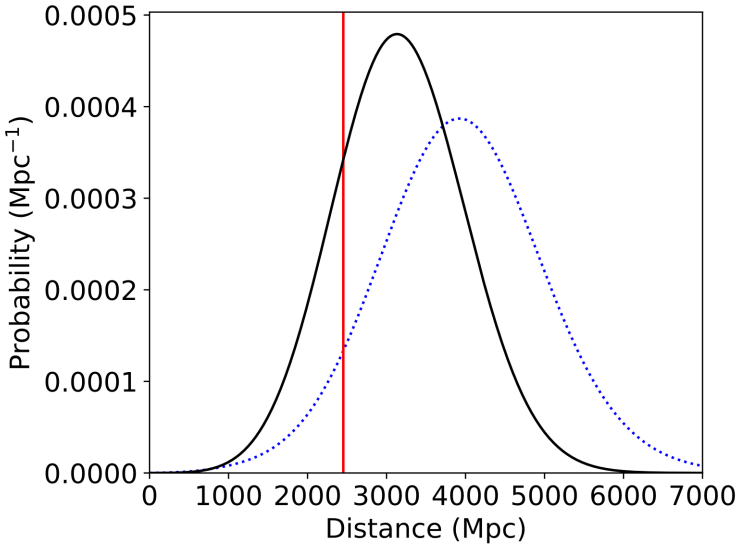
For 21 LIGO BBH triggers in O3a, looked at ZTF alerts for all AGN flares. Specifically:

- within 90% GW confidence regions
- within 3-sigma distance distribution
- flare onset within 60 days of GW event
- well detected flare (Bayesian information criterion ΔBIC > 10)
- >25% increase in flux in both *g*- and *r*-bands
- lasting >20 days
- no blazars



Localization





Updated localization from LIGO (9/3/20) places Notorious BIG at ~67% confidence limit

What else could it be?

AGN variability: Analyzed light curves of 2.5 million WISE-selected AGN from Assef et al. (2018) with ZTF coverage, looking for flares. Find 393 events. Comparison with damped random walk (DRW) model to ZTF light curves and identifying sources where flare is strong preferred over regular quasar variability drops this number to 13. So probability of a linear light curve with a well-detected >20 day flare is ~5e-6.

Look elsewhere effect: Looked at longer term CRTS light curves for all 3255 AGN within GW 190521g area, and Monte Carlo'd their light curves (1000x per AGN), assuming DRW model, with ZTF sampling. Find just 5 comparable flares, without visual inspection. So O(0.5%) likelihood of chance event.

Supernova: Rejected given the timescale (too short for a SN) and uniform color over time (SNe vary in color as they evolve) and no spectral features

Microlensing: Rejected given the level of magnification, expected years-long event, not weeks.

Tidal disruption event (TDE): Rejected; doesn't match luminosities, GW signal and SMBH mass.

The Big Search for O3 EM Counterparts

- $BIC_{flare} < BIC_{lens}, BIC_{tde}, BIC_{lin} - 10$
- $5 < t_g < 100$, $10 < t_e < 200$, $0 < t_{peak} - MJD_{ligo} < 100$
- At least 10% increase in flux
- Detected in at least two filter
- Fit flares after MJD = 58574
- Bayesian changepoint detection
- Search alerts + regular photometry

<u>Expected numbers:</u>

LIGO events in O3: 50

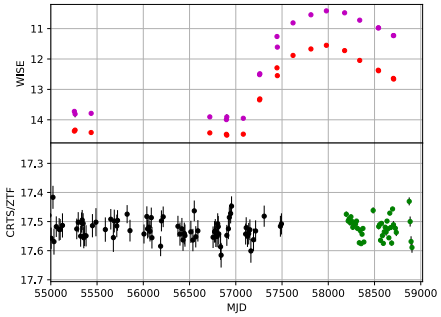
Fraction from AGN: 25

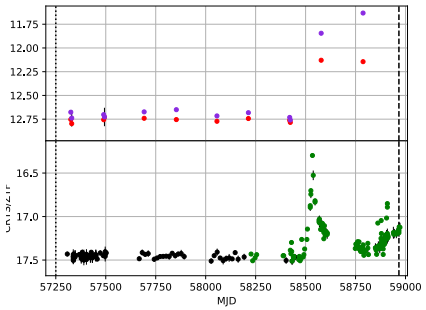
Covered by ZTF: 12

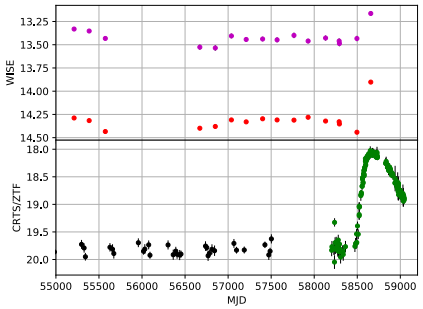
Associated with Type 1 AGN: 6

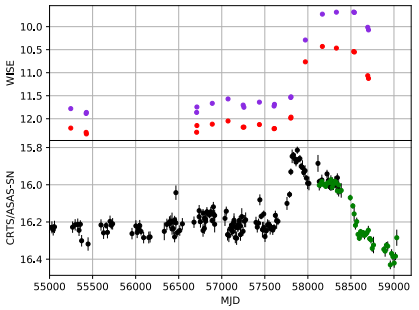
Pointing in our direction: 3 * 2 (symmetry) = 6

The Demographics of AGN Flaring









Photometrically can categorize in terms of amplitude, characteristic timescale (rise and fall), flare morphology, energy budget, and rates

Spectroscopic observations to characterize flare and host, e.g., Bowen fluorescence -> microturbulence from differential rotation or disk instabilities

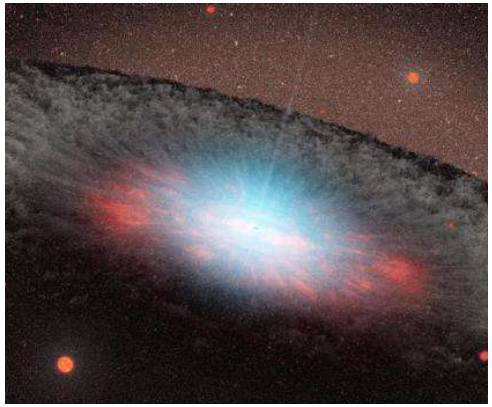
Multiwavelength observations for SED change and probe different regions

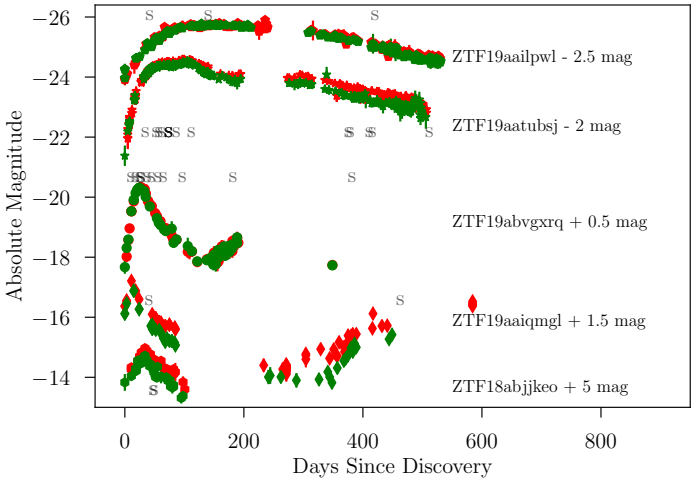
Distinguish supernovae, TDEs, microlensing, etc.

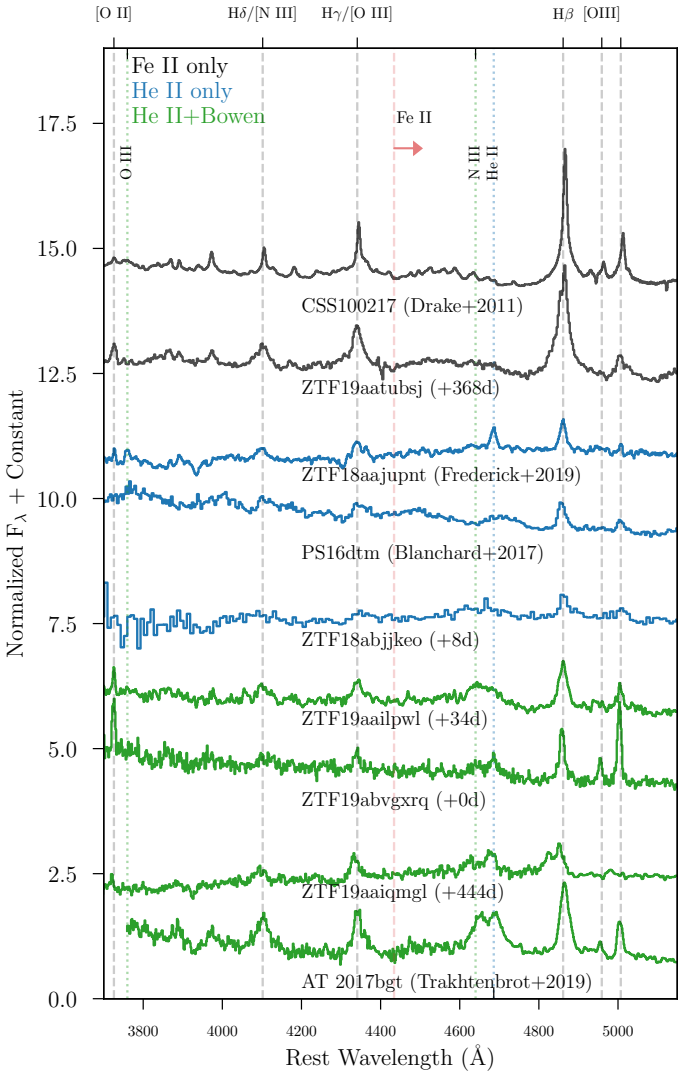
A Family Tree of Optical Transients in Narrow Line Seyfert 1 Galaxies

Frederick, Gezari, Graham, et al. 2020, submitted to ApJ

- **Smooth flares observed serendipitously in NLSy1s**
  - *Preferential occurrence? Frequency may be due to BH mass, timescales, accretion mode, or selection*
- UV-bright, 2 out of 5 are X-ray-bright (1 eROSITA)
- Framework for classifying AGN-like (3 out of 5) or TDE-like (2 out of 5) & spectroscopic classes based on presence of Fe II, He II, and Bowen features
  - *Trakhtenbrot+2019: NLSy1s w/ enhanced accretion*
  - *Comparison to transients in NLS1s (PS16dtm, AT2017bgt, CSS100217)*





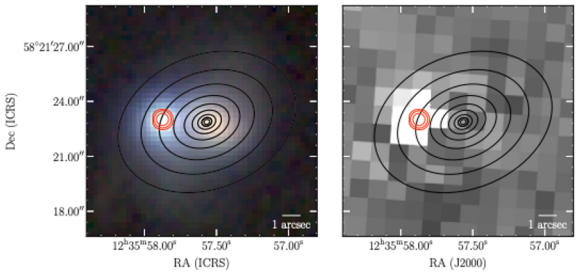


Off-nuclear AGN in ZTF

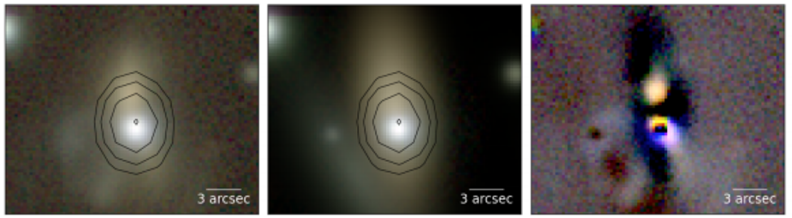
Charlotte Ward

The paper describing our search for off-nuclear AGN in ZTF is ready for pub board submission. The paper includes:

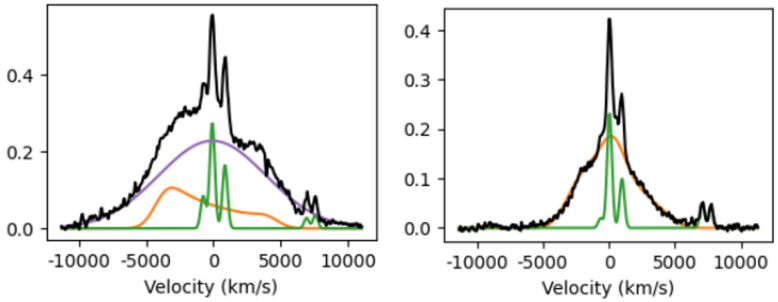
- Description of novel search strategy to find variable off-nuclear AGN in ZTF with *Tractor* forward modeling.
- Nine recoiling SMBH candidates. Five show double-peaked emission from an exposed accretion disk (compared to 15% double-peaked fraction of ZTF AGN overall). 4 show radio jet emission and 7 are X-ray bright.
- 57 variable AGN in merging galaxies, including a new spectroscopically confirmed dual AGN.
- ZTF rebrightening of a previously discovered recoiling SMBH candidate SDSS 1133 (Koss 2014). Return of P-Cygni features suggests this is an outbursting luminous blue variable star which has been variable since 1950.



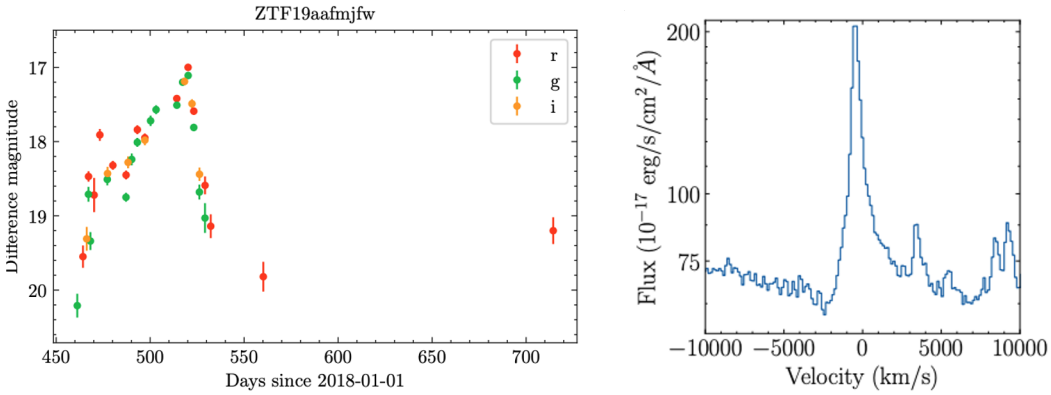
Off-nuclear AGN discovery example: DECam coadd (left), ZTF subtraction (right) and Tractor model from ZTF science images (contours).



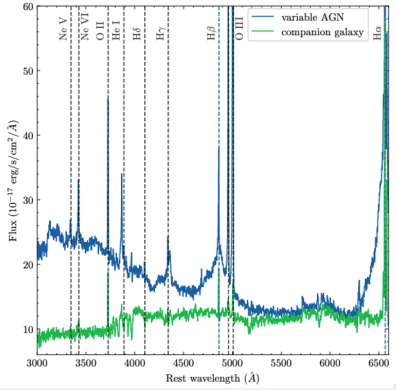
GW recoil candidate ZTF18absvcae: DECam image (left), *Tractor* model (center), residuals showing tidal structures (right) and FIRST 20cm radio image (contours).



Double peaked Hα accretion disk emission of 2 recoiling SMBH candidates with theoretical disk model overlaid (orange).



ZTF rebrightening of recoiling SMBH candidate SDSS1133 (left) and Hβ profile observed in spectroscopic follow-up (right). P-Cygni features suggest this is an outbursting LBV.



Spectroscopically confirmed dual AGN ZTF18aaxvmpg. Spectrum shows ZTF broad line AGN (blue) and LINER/AGN companion (green).