Quasars In Crisis
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Changing-state quasars in CRTS (and beyond)

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CENTER FOR DATA-DRIVEN DISCOVERY

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Collaborators

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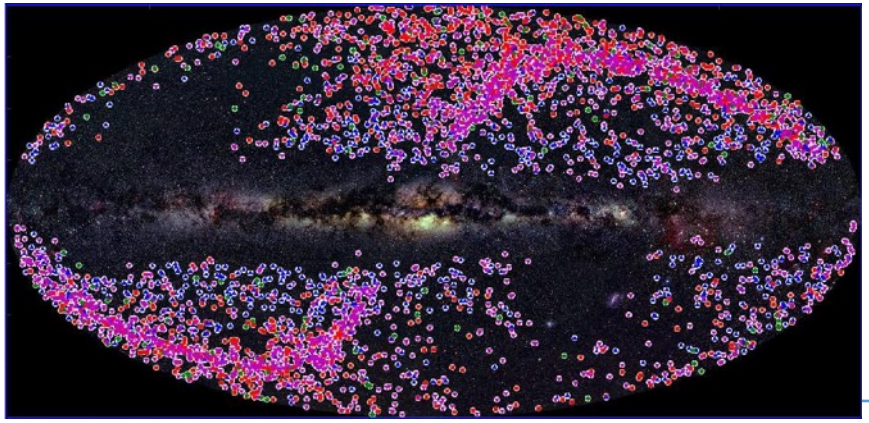
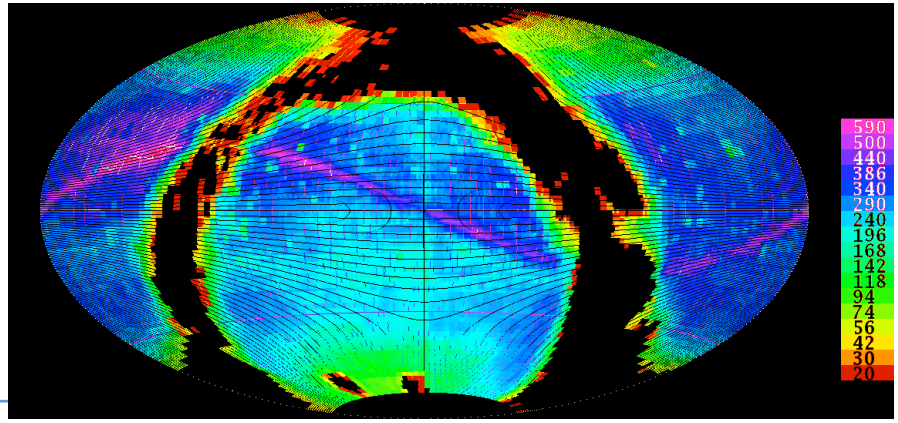
- Saavik Ford (AMNH/CUNY)
- Nic Ross (ROE)
- Yutaro Tachibana (Tokyo Tech)
- Suvi Gezari and the ZTF BH/TDE Working Group

Looking for more…

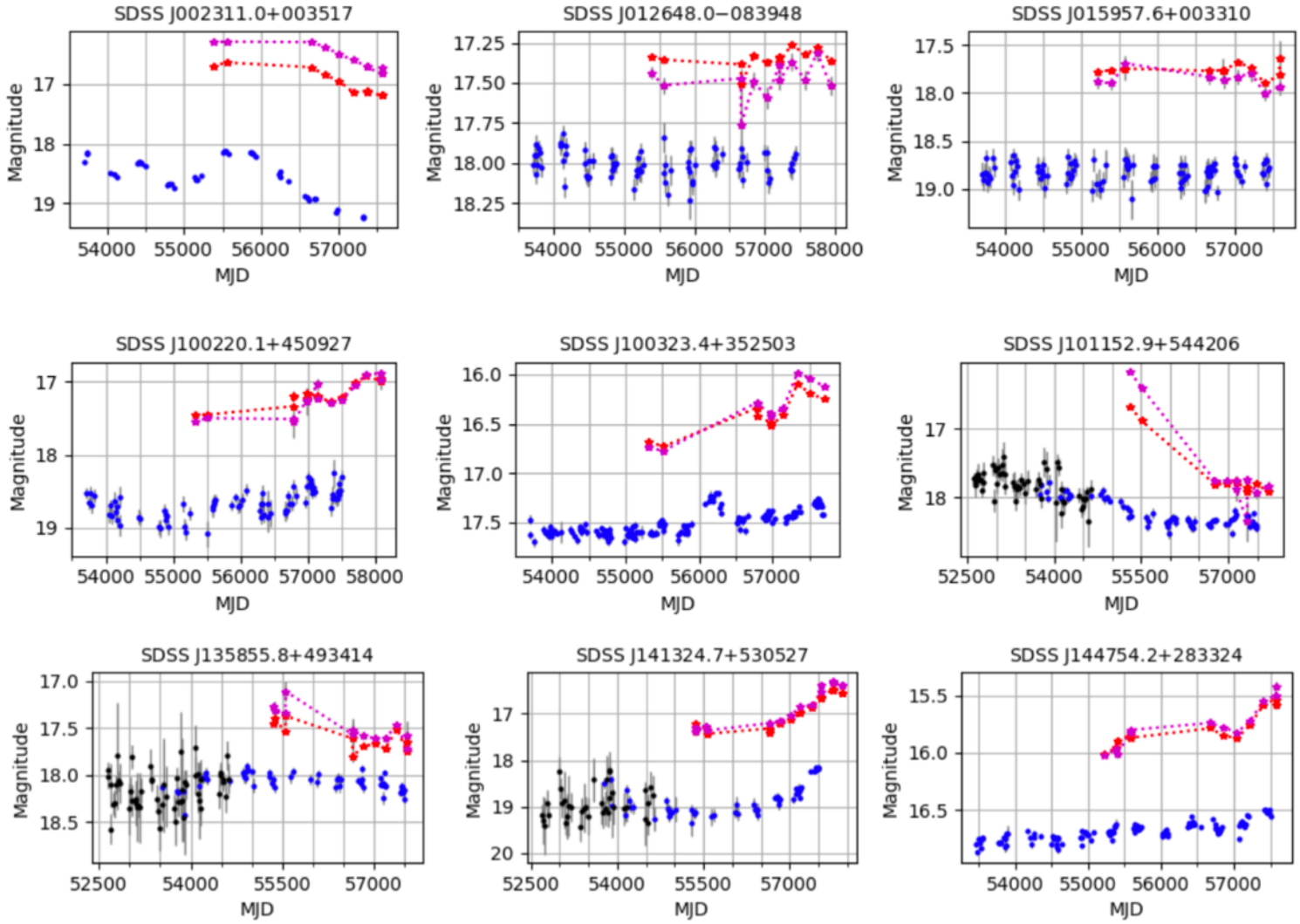
The Catalina Real-time Transient Survey (CRTS)

- Collaborative survey with Catalina Sky Survey (LPL, UA)
- Unfiltered observations 21 nights/lunation covering up to 2000 deg^2/night
- Covers 33000 sq. deg. (0 < RA < 360, -75 < Dec < 70).
- Calibrated photometry for 500 million objects (> 100 billion data points)
- Depth V = 19 to 21.5
- 100 – 600 observations in most regions (median ~ 320)
- Temporal baselines of 10 min to ~12 years
- Basis for quasar variability studies: characteristic timescales (Graham et al. 2014); close binaries (Graham et al. 2015a,b); major flaring (Graham et al. 2017)

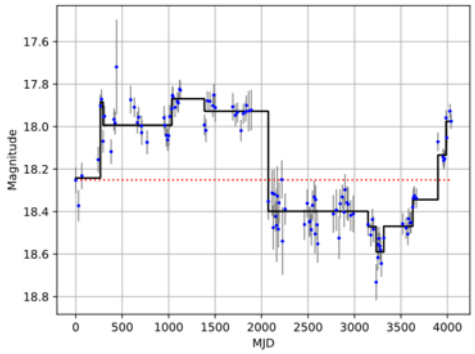


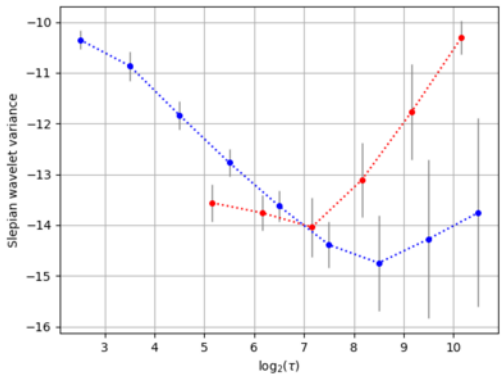


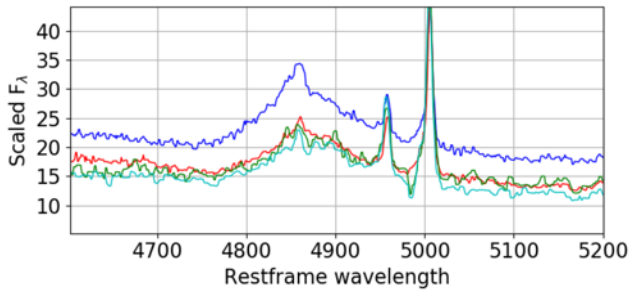
What does a CLQ look like?

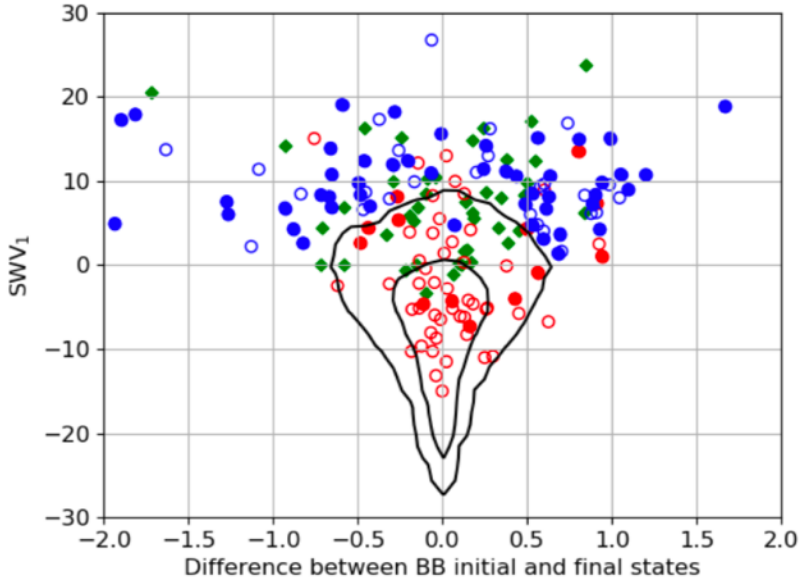


Can we be more systematic?





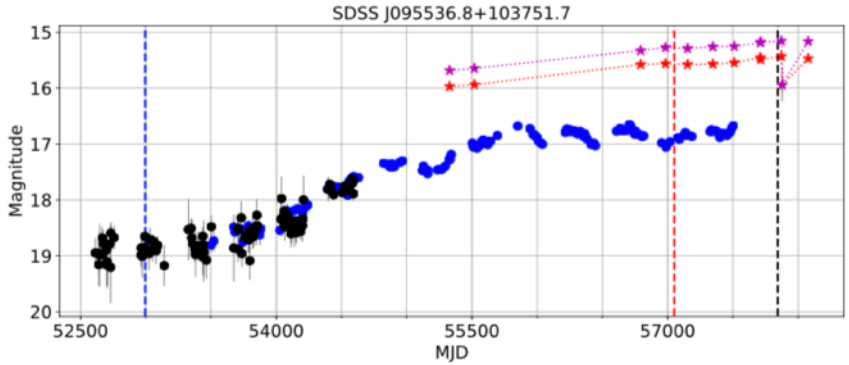


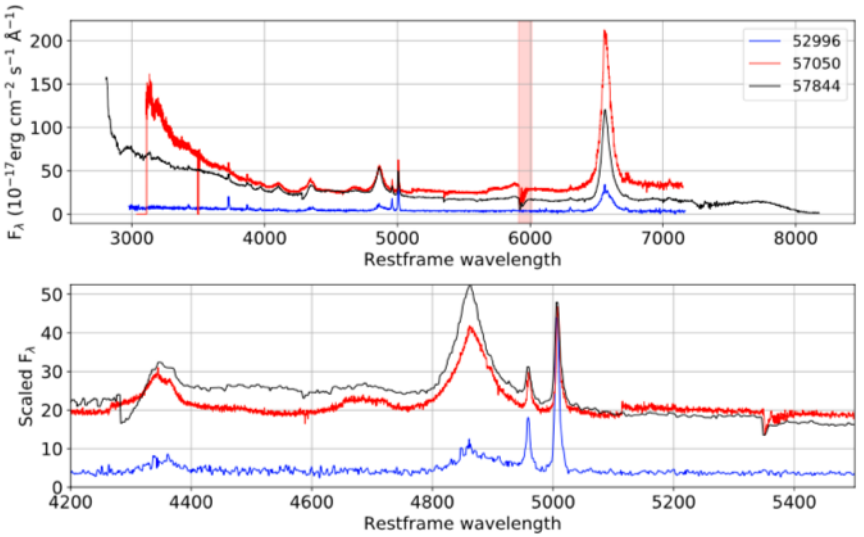


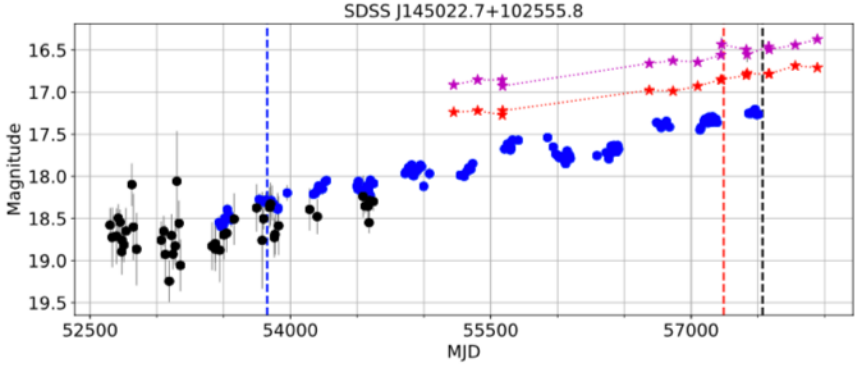
Selection	Total #
Number of MQ sources with CRTS light curve	1,411,364
with more than 10 observations	1,143,162
and not a known blazar	1,139,438
and outside 95% contour in BB/SWV$_1$ space	65,816
and $\Delta\|W1\|$ or $\Delta\|W2\| > 0.2$	47,451
and $z < 0.95$	14,412
and has SDSS spectrum	7,576
and has second epoch spectrum after ≥ 500 days	617
and Hβ / [O III] ratio changes by $> 30\%$	94

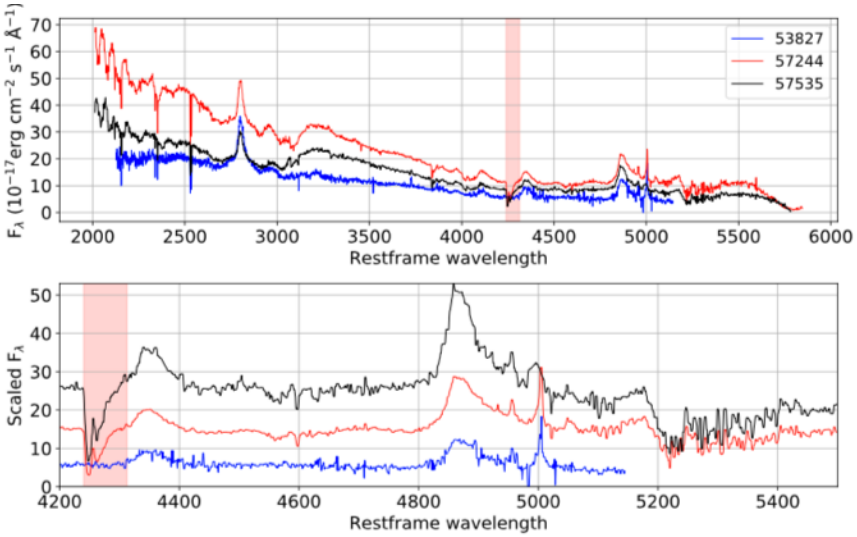
(Graham et al. 2019)

CSQs getting brighter…

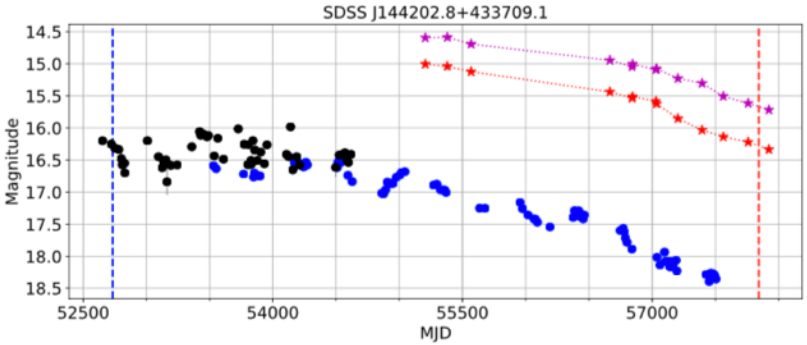


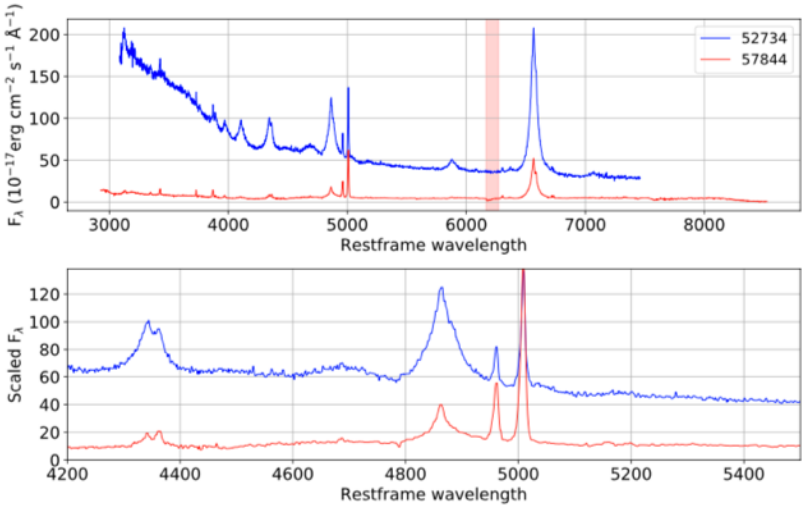


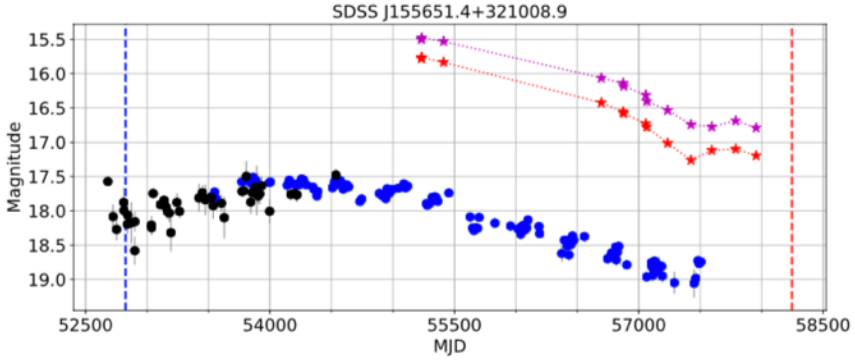


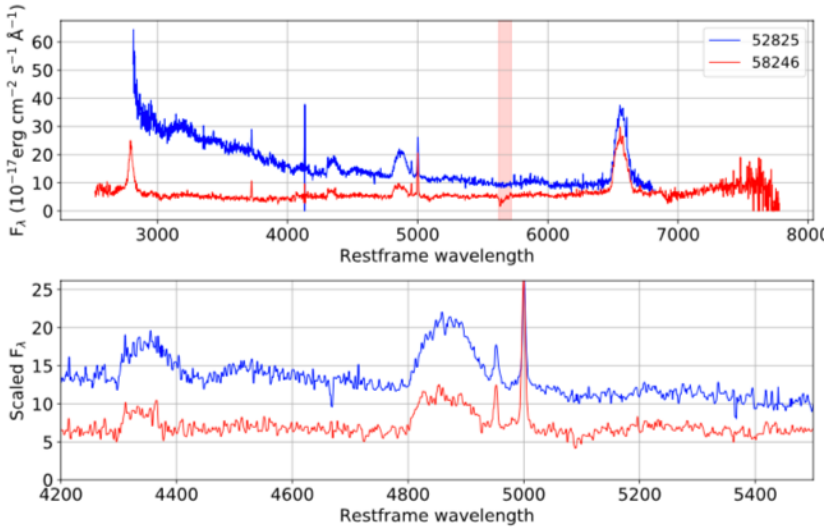


… and dimmer

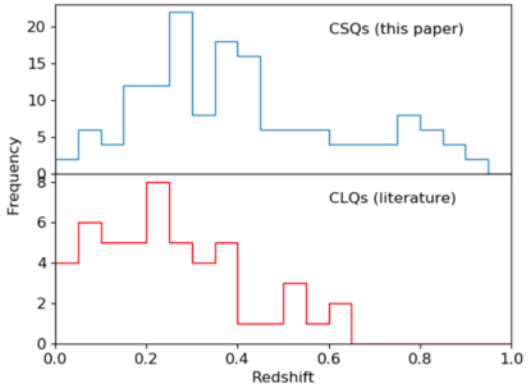

SDSS J144202.8+433709.1
Magnitude
MJD

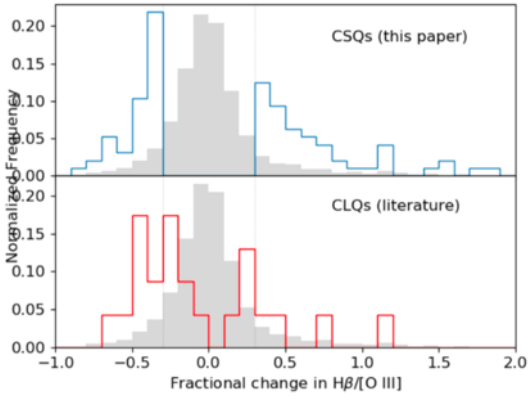

52734
57844
F_λ (10^{-17}erg cm^{-2} s^{-1} Å^{-1})
Restframe wavelength
Scaled F_λ
Restframe wavelength

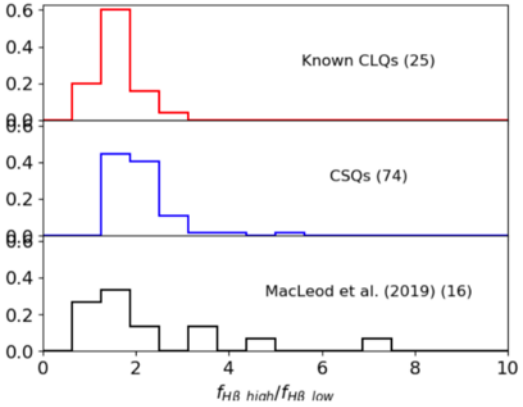

SDSS J155651.4+321008.9
Magnitude
MJD

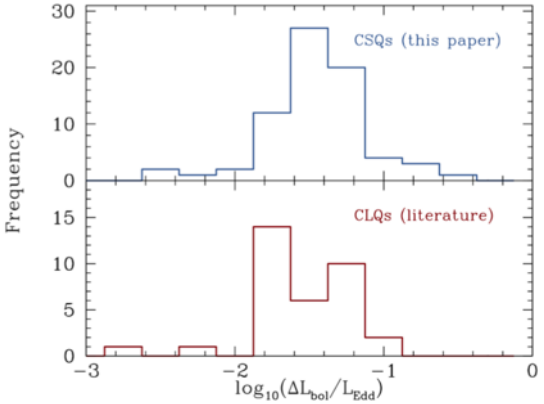

52825
58246
F_λ (10^{-17}erg cm^{-2} s^{-1} Å^{-1})
Restframe wavelength
Scaled F_λ
Restframe wavelength

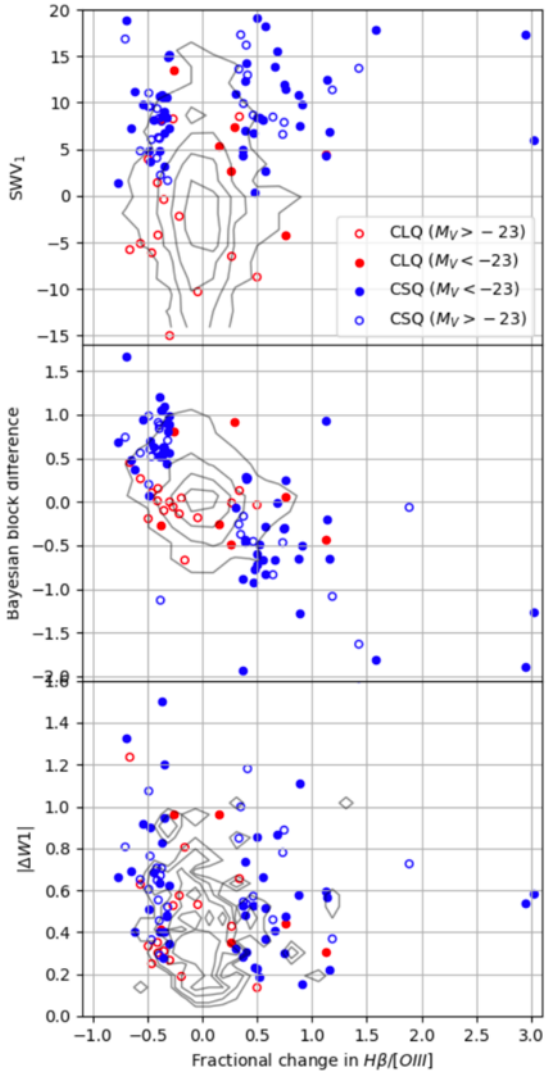
Comparing samples





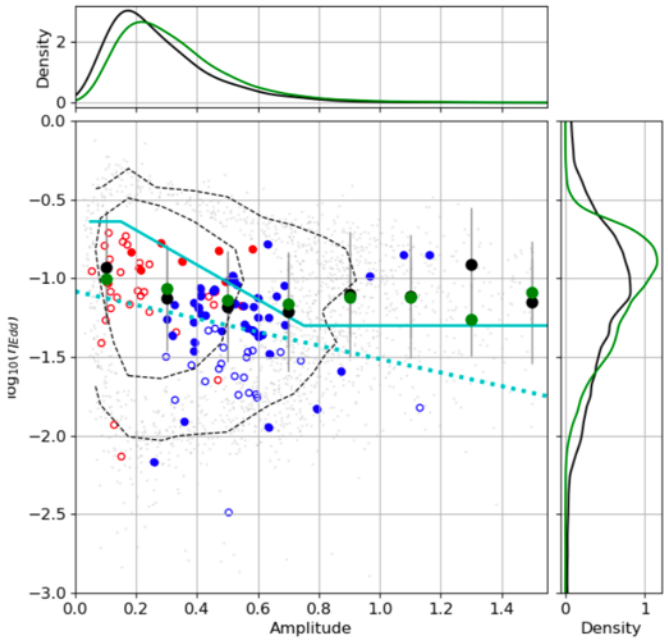


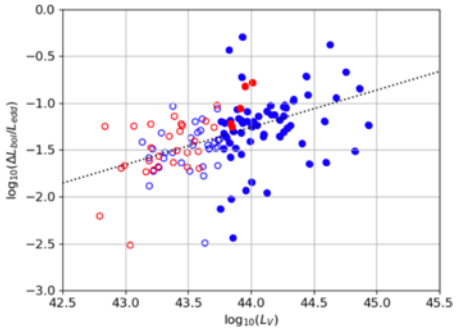


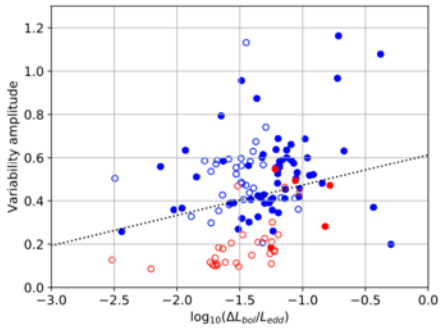


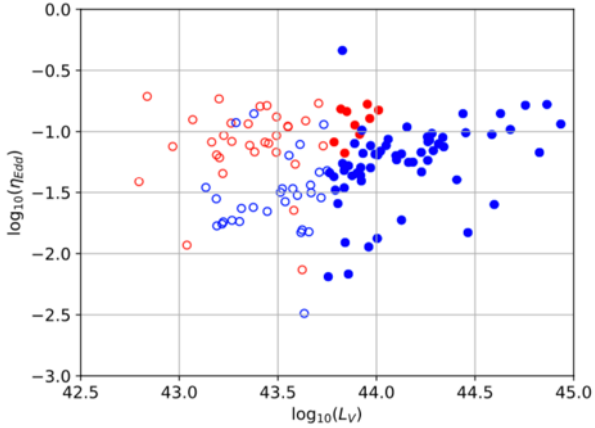
The demographics of CQs

Sample	$amp \propto \Delta\eta_{\rm Edd}$ (Fig. 19R)	$\log(\Delta\eta_{\rm Edd}) \propto L$ (Fig. 19L)	$\log(\eta_{\rm Edd}) \propto 1/amp$ (Fig. 14)	$L \propto 1/\eta_{\rm Edd}$ (Fig. 20)
Low luminosity	No	Yes	Yes	No
High luminosity	Yes	Yes	No	$L \propto \eta_{\rm Edd}$

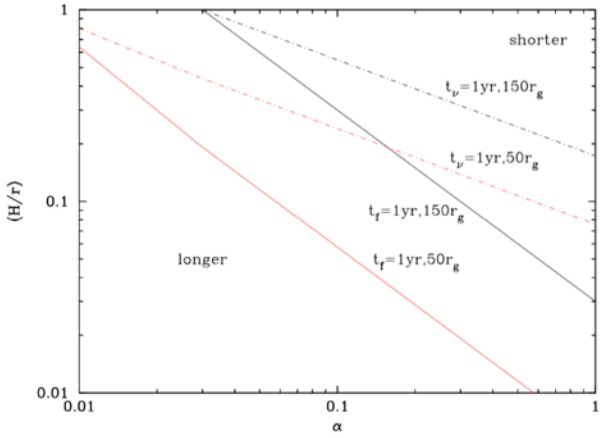


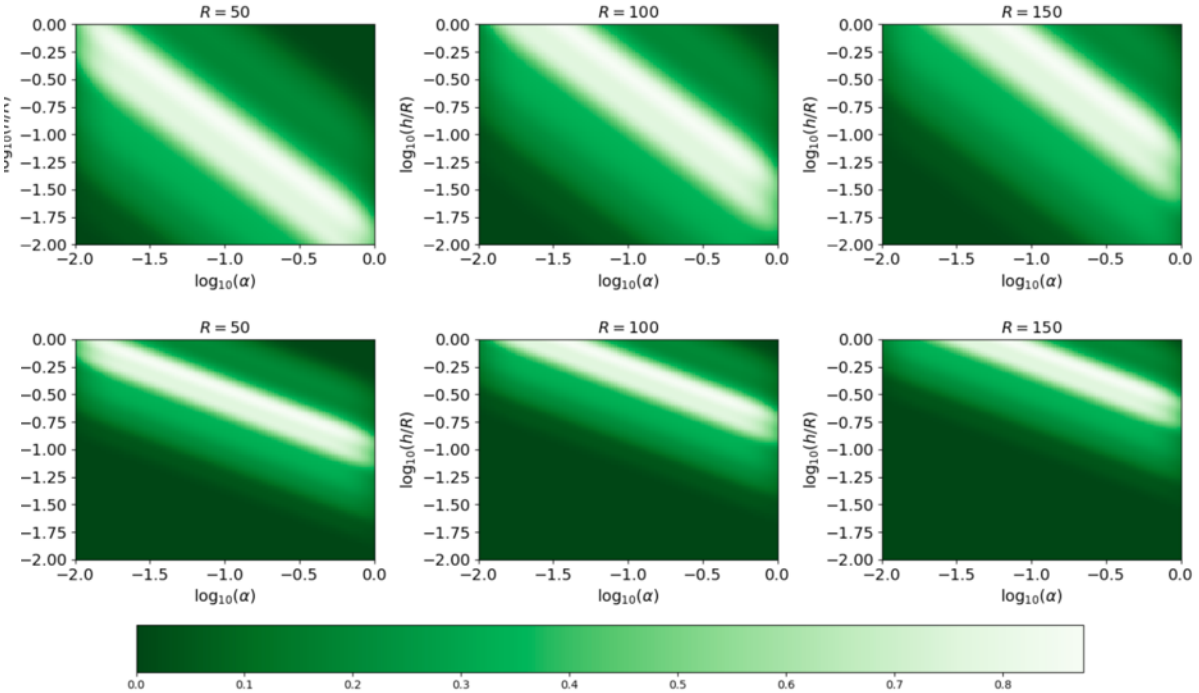


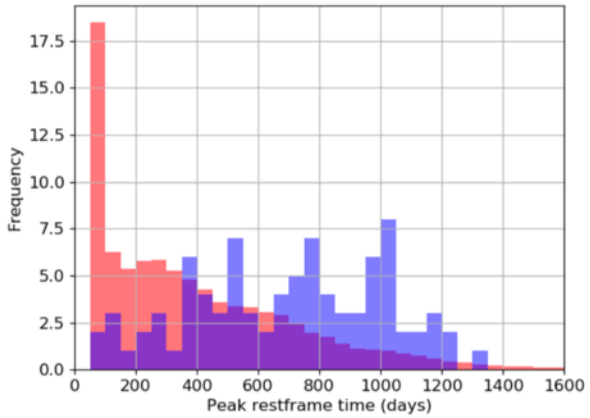




Timescales

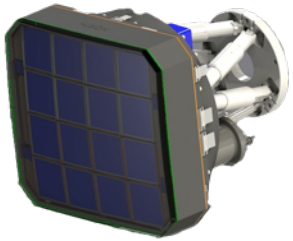

shorter
t_ν=1yr,150r_g
t_ν=1yr,50r_g
t_f=1yr,150r_g
longer
t_f=1yr,50r_g
(H/r)
α

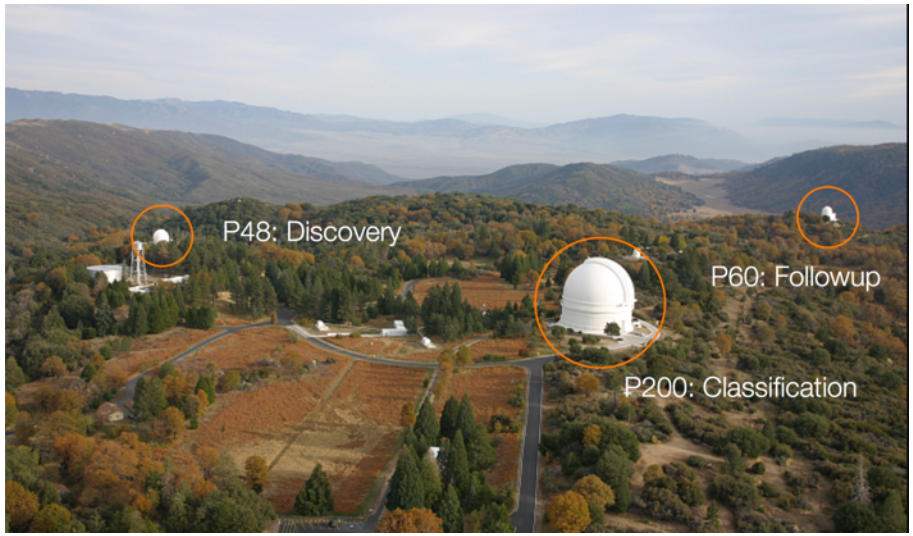

R = 50
R = 100
R = 150
log10(h/R)
log10(α)


Frequency
Peak restframe time (days)

The Zwicky Transient Facility (ZTF)

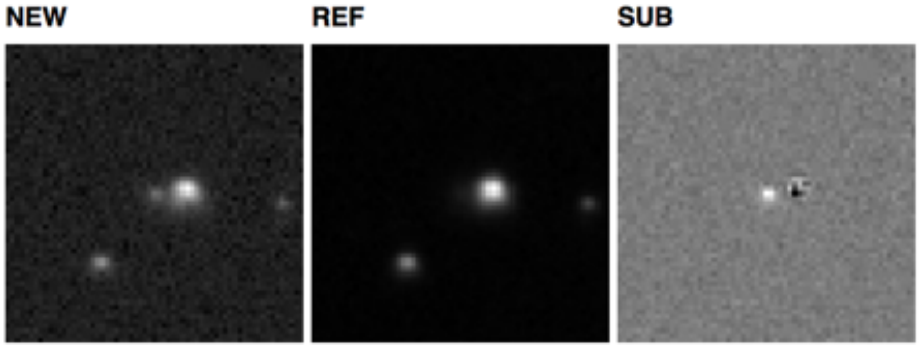
- 47 deg^2 field of view camera on Palomar Oschin 48”
- 3750 deg^2 / hr to 20.5-21 mag (1.4 TB / night)
- Full northern sky every three nights in g and r
- Galactic Plane every night in g and r
- NEW: TESS Sector every night in g and r (July 18, 2019)
- Over 3 years: 3 PB, 750 billion detections, ~1000 detections / source
- First megaevent survey: 10^6 alerts per night (~50M public since June 2018)

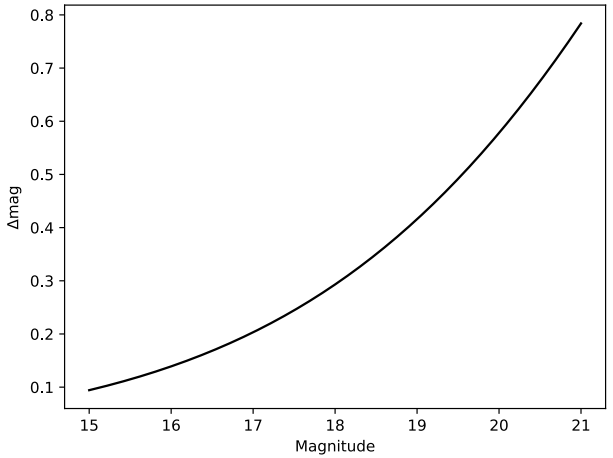


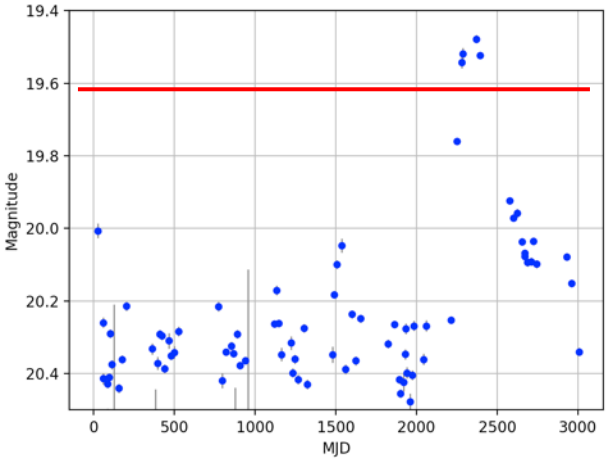


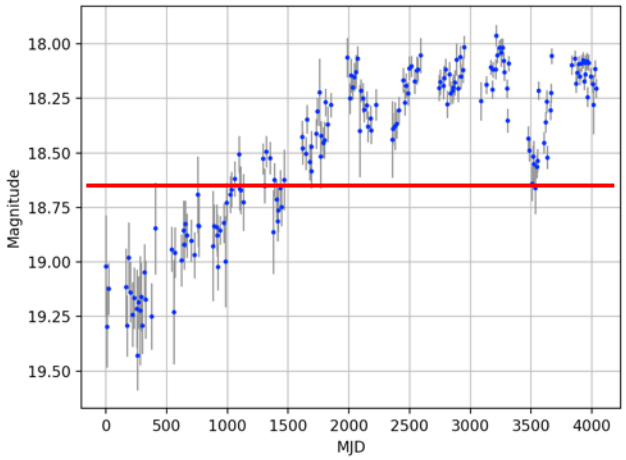
	ZTF	LSST
No. of sources	1 billion	37 billion
No. of detections	1 trillion	37 trillion
Annual visits per source	1000 (2+1 filters)	100 (6 filters)
No. of pixels	600 million (1320 cm^2 CCDs)	3.2 billion (3200 cm^2 CCDs)
Field of view	47 deg^2	9 deg^2
Hourly survey rate	3750 deg^2	1000 deg^2
Nightly alert rate	1 million	10 million
Nightly data rate	1.4 TB	15 TB

Slow to detect as transient phenomena



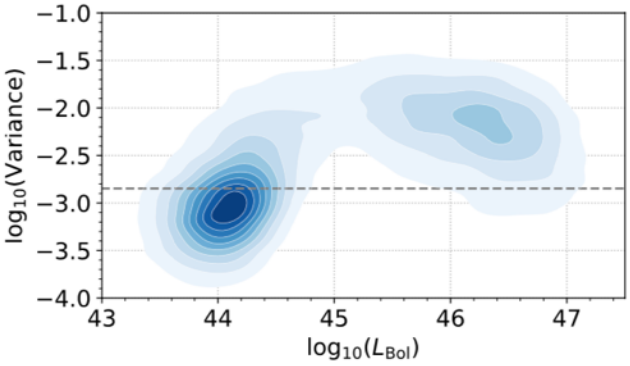




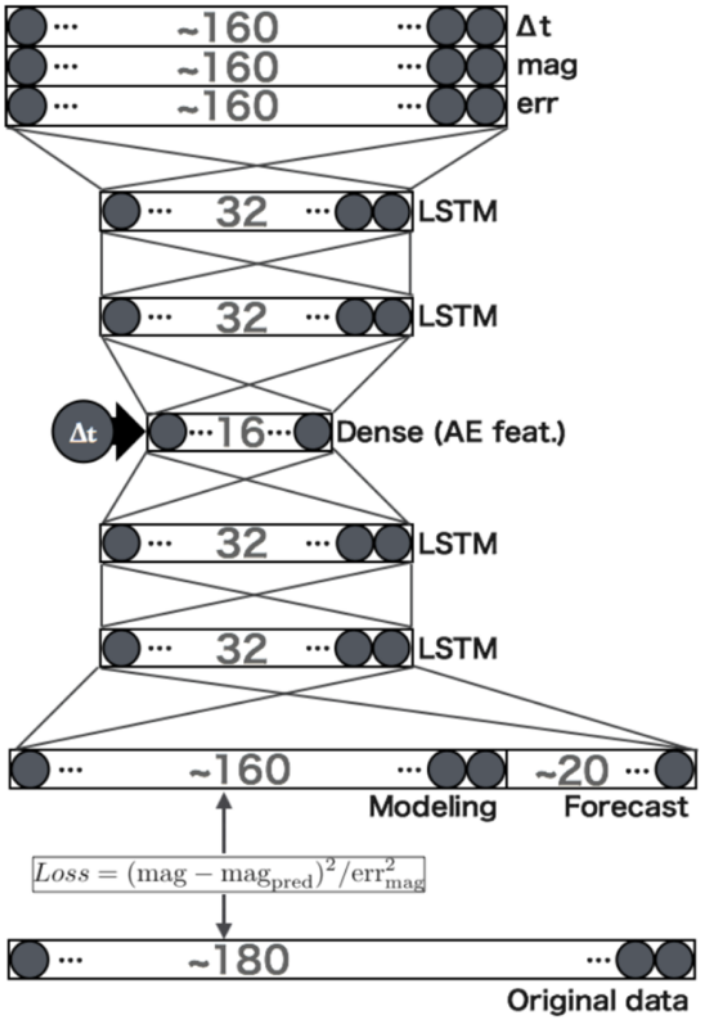


Deep modelling of time series

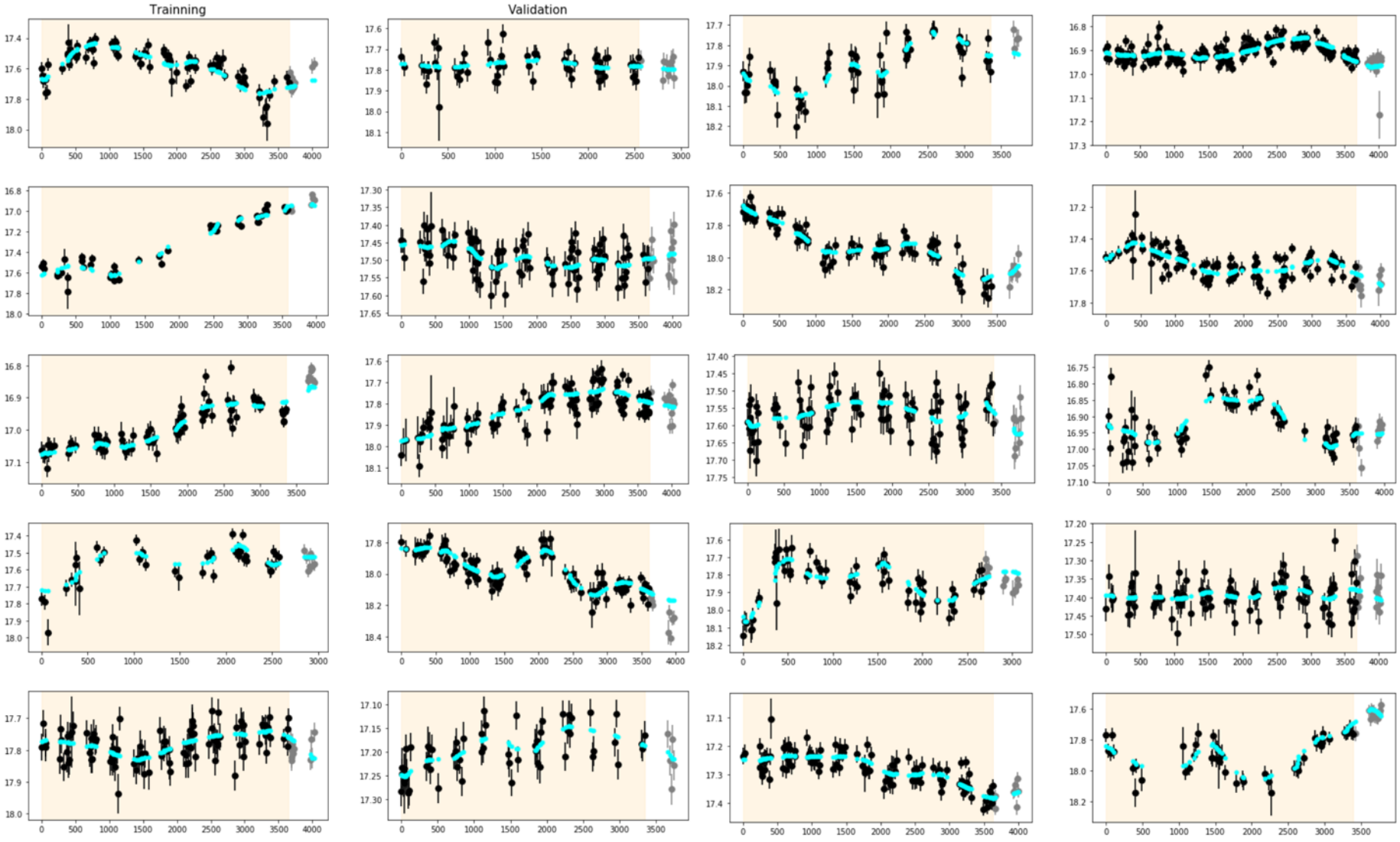
- Autoencoder model with RNN autoencoder:
  - Consider: $(y_0, \Delta t_0) \oplus (\Delta t_0) \rightarrow y_1$
  - Consider: $(y_0, \Delta t_1, \dot{y}_0, \ddot{y}_0) \rightarrow y_1$



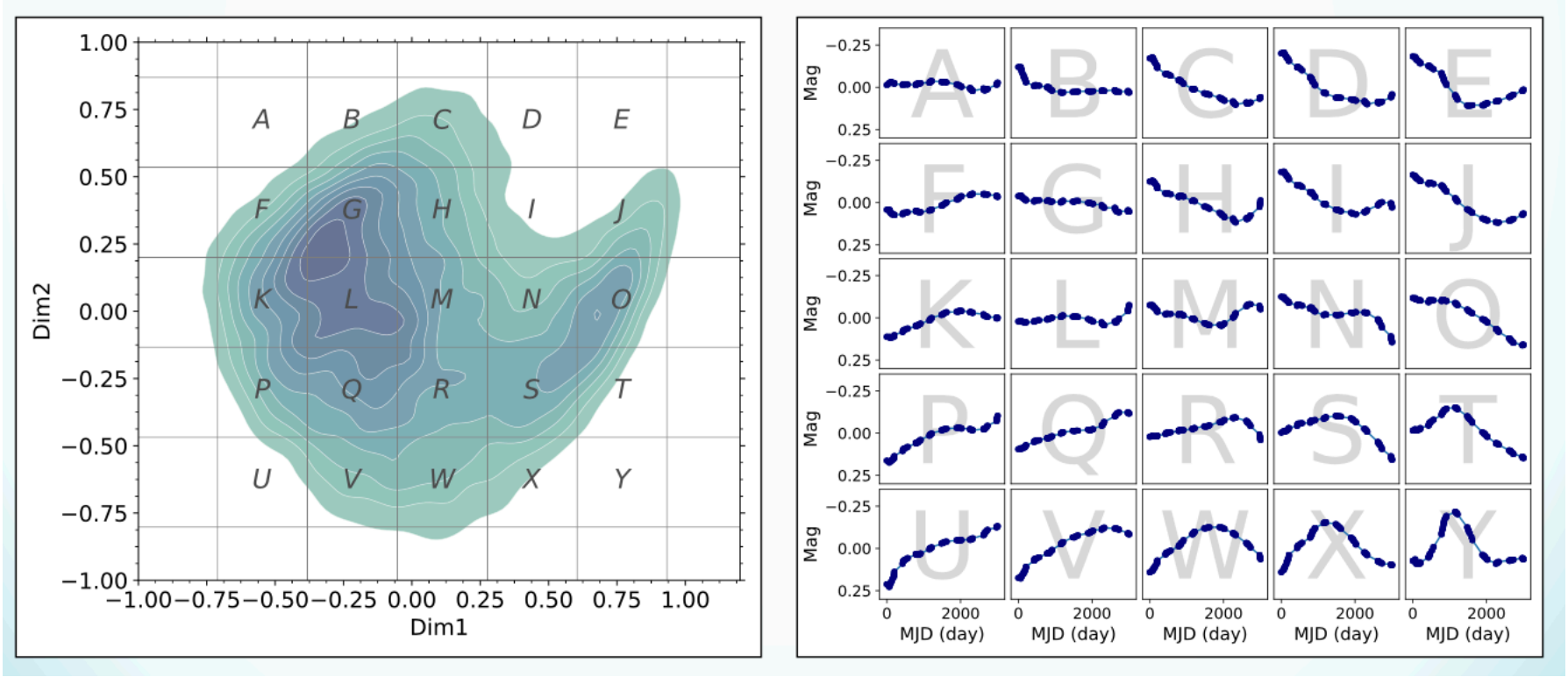
- 12,000 quasars with $\Delta t = 500$ days



QSOs with RNNs

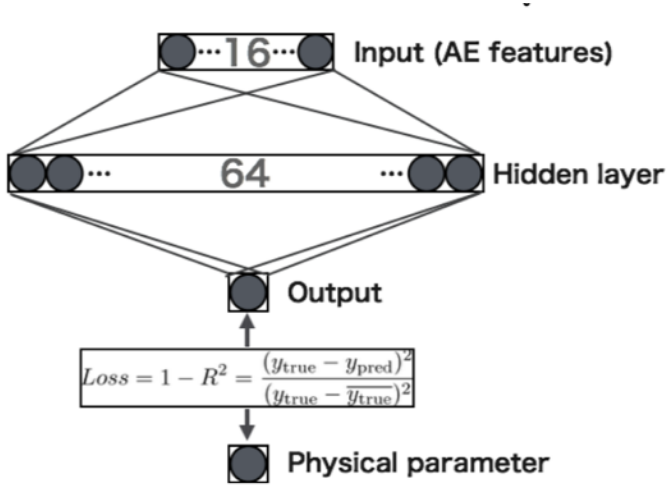


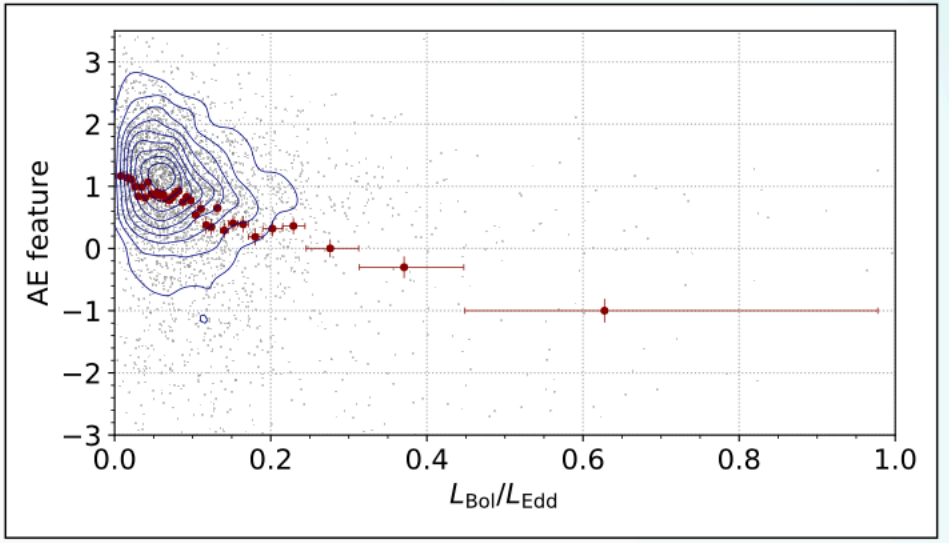
Deep time series features

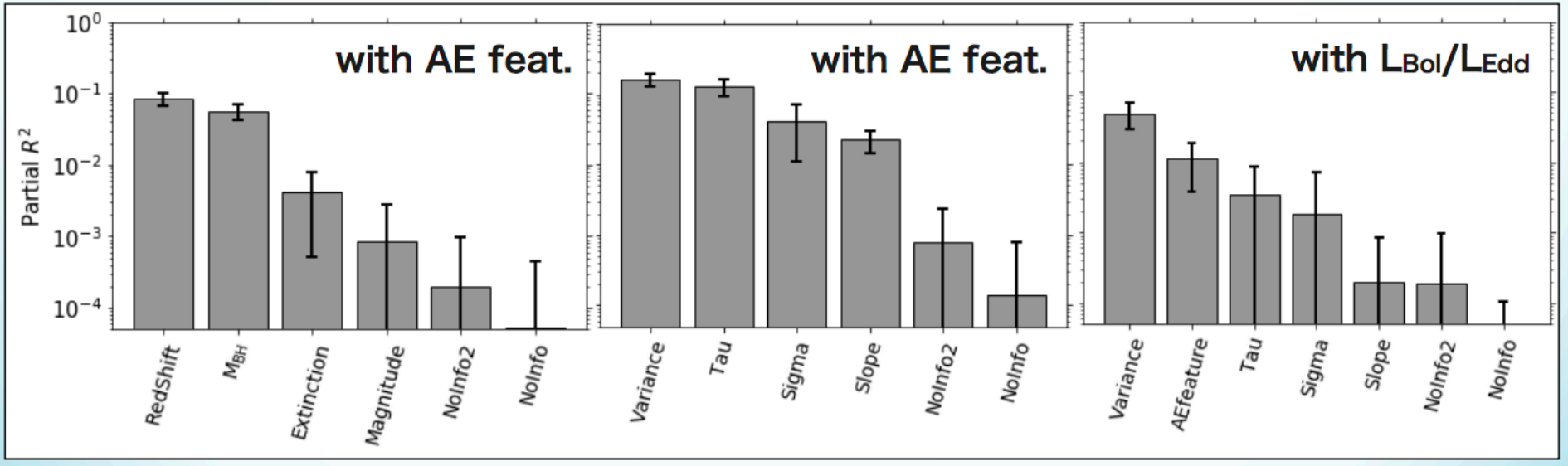


(Tachibana et al. 2019)

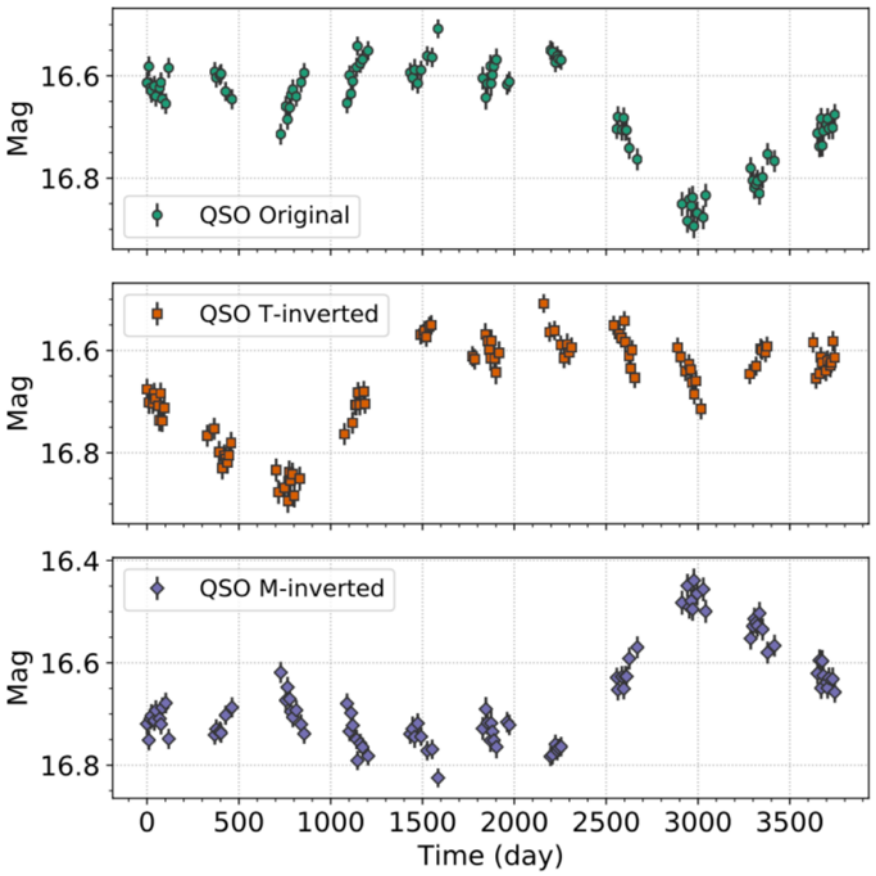
Physical correlations

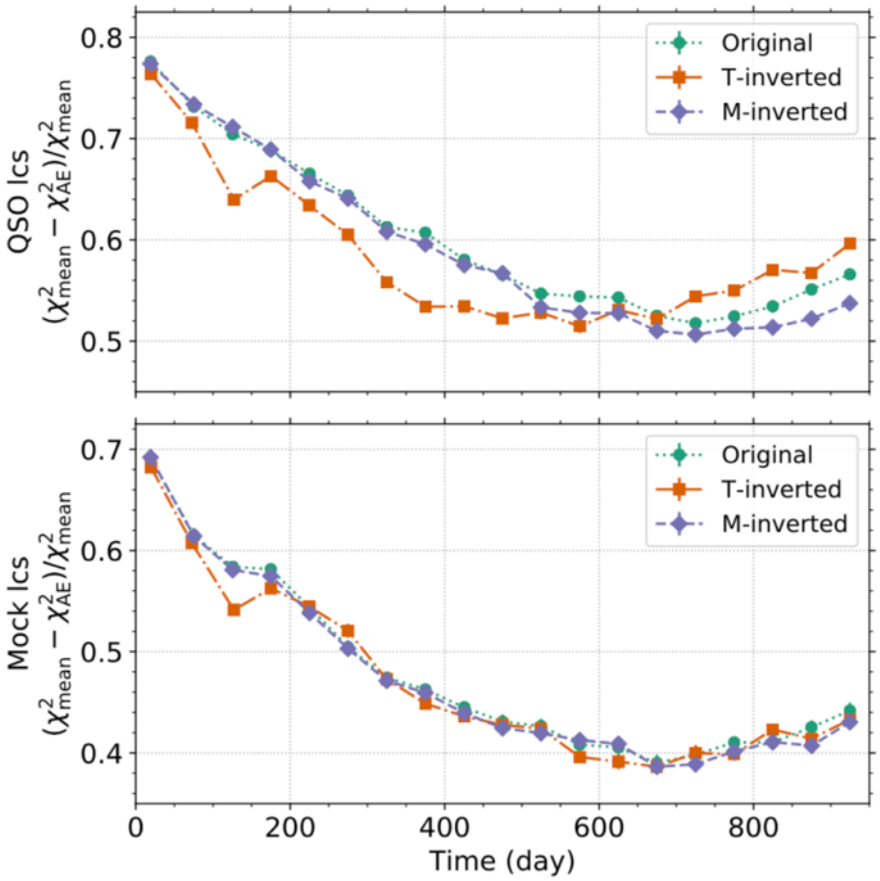






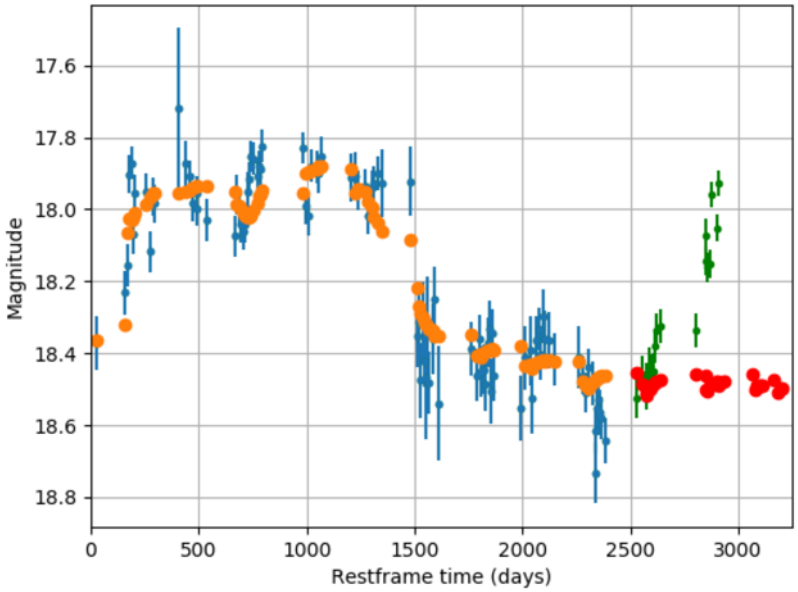
Evidence for asymmetry

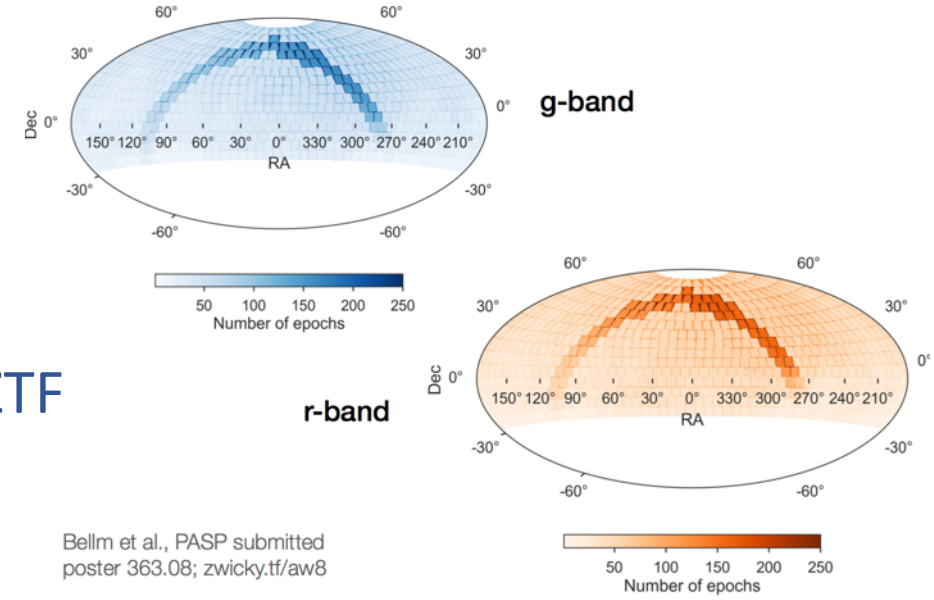




- Magnitude of asymmetry decreases as luminosity or black hole mass increases
- Consistent with self-organized disk instability model

Can we forecast behavior?





- Ongoing program of looking for aberrant behavior with ZTF relative to CRTS

Bellm et al., PASP submitted
poster 363.08; zwicky.tf/aw8

Summary

- Systematic searches for photometrically/spectroscopically variable quasars are now producing statistical samples
- Evidence in favor of heating/cooling fronts propagating through the disk to explain changing look/state quasars
- The search is on for:
  - higher redshift equivalents
  - multiwavelength equivalents
  - Different AGN types
- What is the trigger? Same mechanism in all?
- Can we detect these early with nightly monitoring?
- Deep learning is a viable descriptor of quasar variability
  - Latent features correlate with physical parameters
  - The arrow of time is detectable
- Forecasting seems tractable