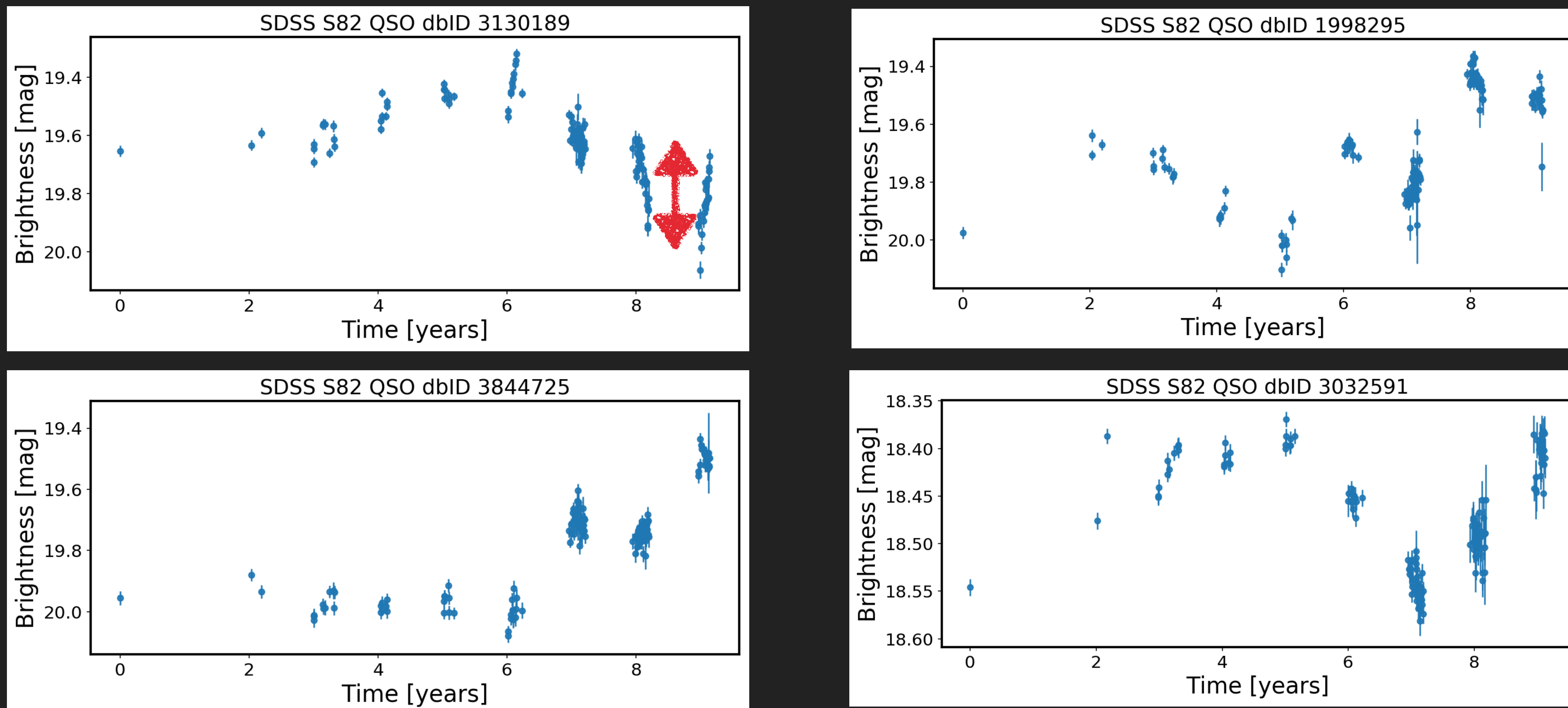
CHANGING LOOK QUASARS

Chris Suberlak, Jun 27, AD 2023
suberlak.github.io

QUASARS – VARIABLE SOURCES

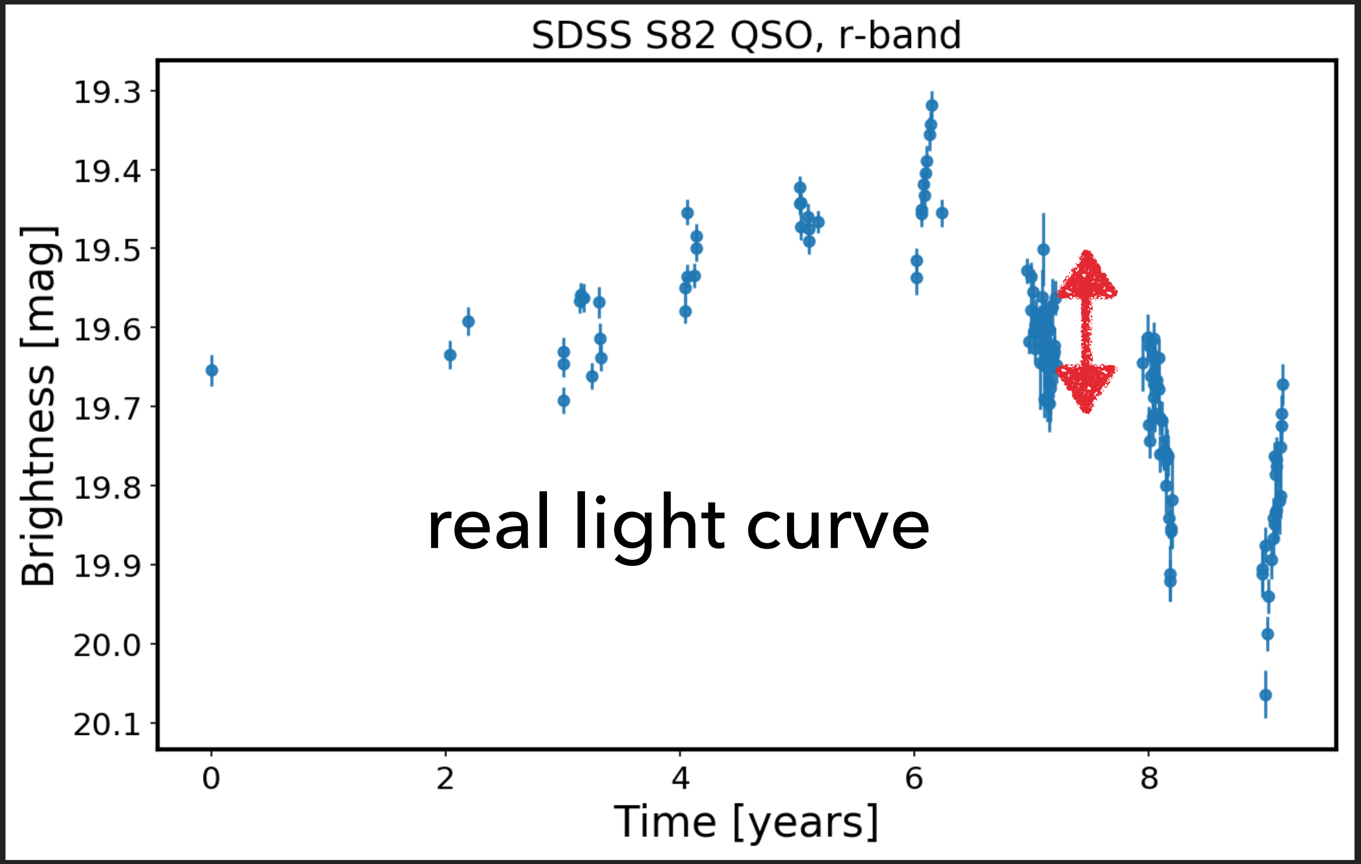


- root-mean-squared 0.2 mag optical variability over ~1 yr
- stochastic variability : non-repeating pattern in time series (light curve)

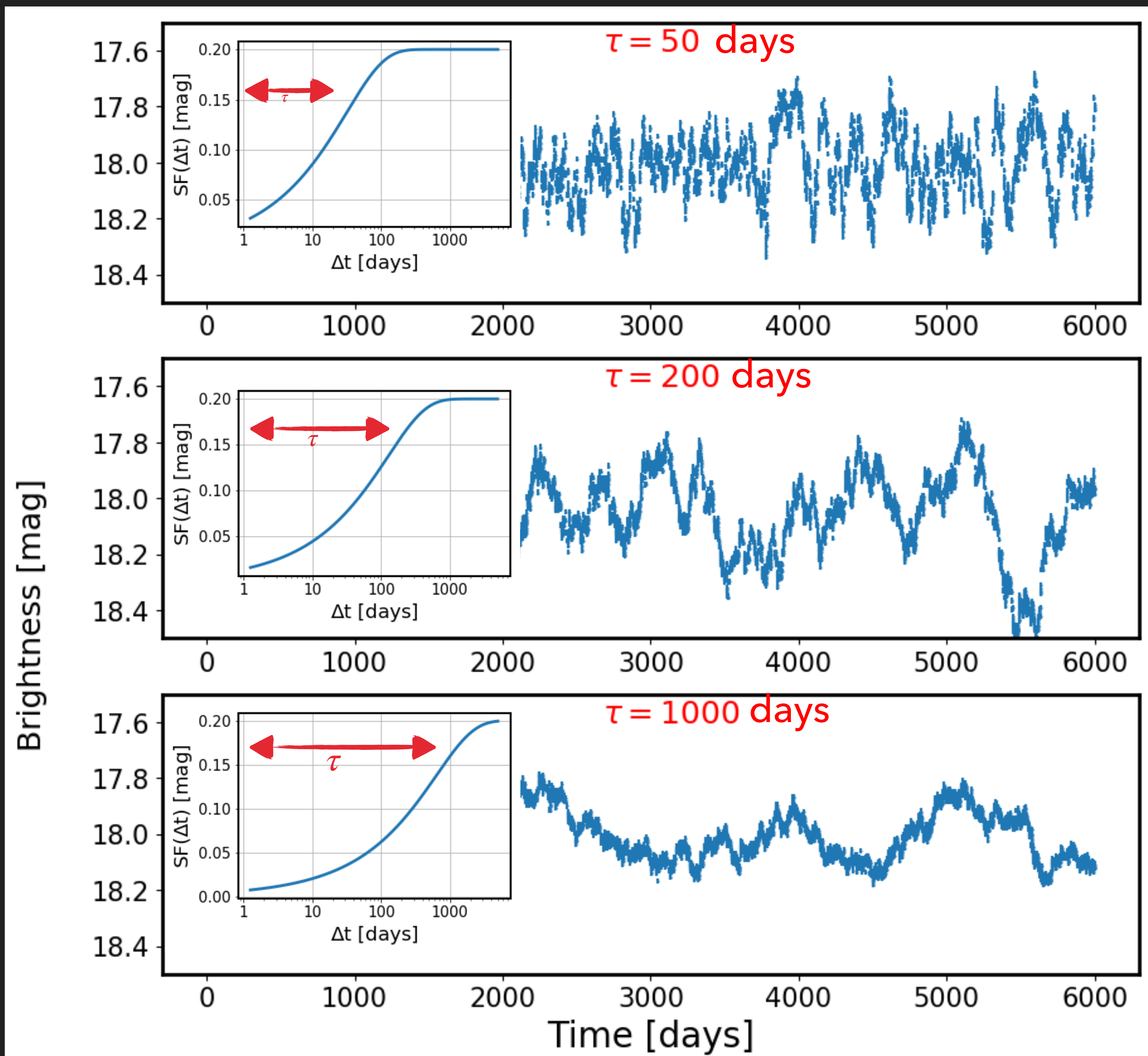
STATISTICAL DESCRIPTION OF QUASAR VARIABILITY

- Damped Random Walk model - a Gaussian process with an exponential covariance matrix

- SF_{∞} : asymptotic amplitude, τ : characteristic time scale



DRW PARAMETERS : TIMESCALE τ

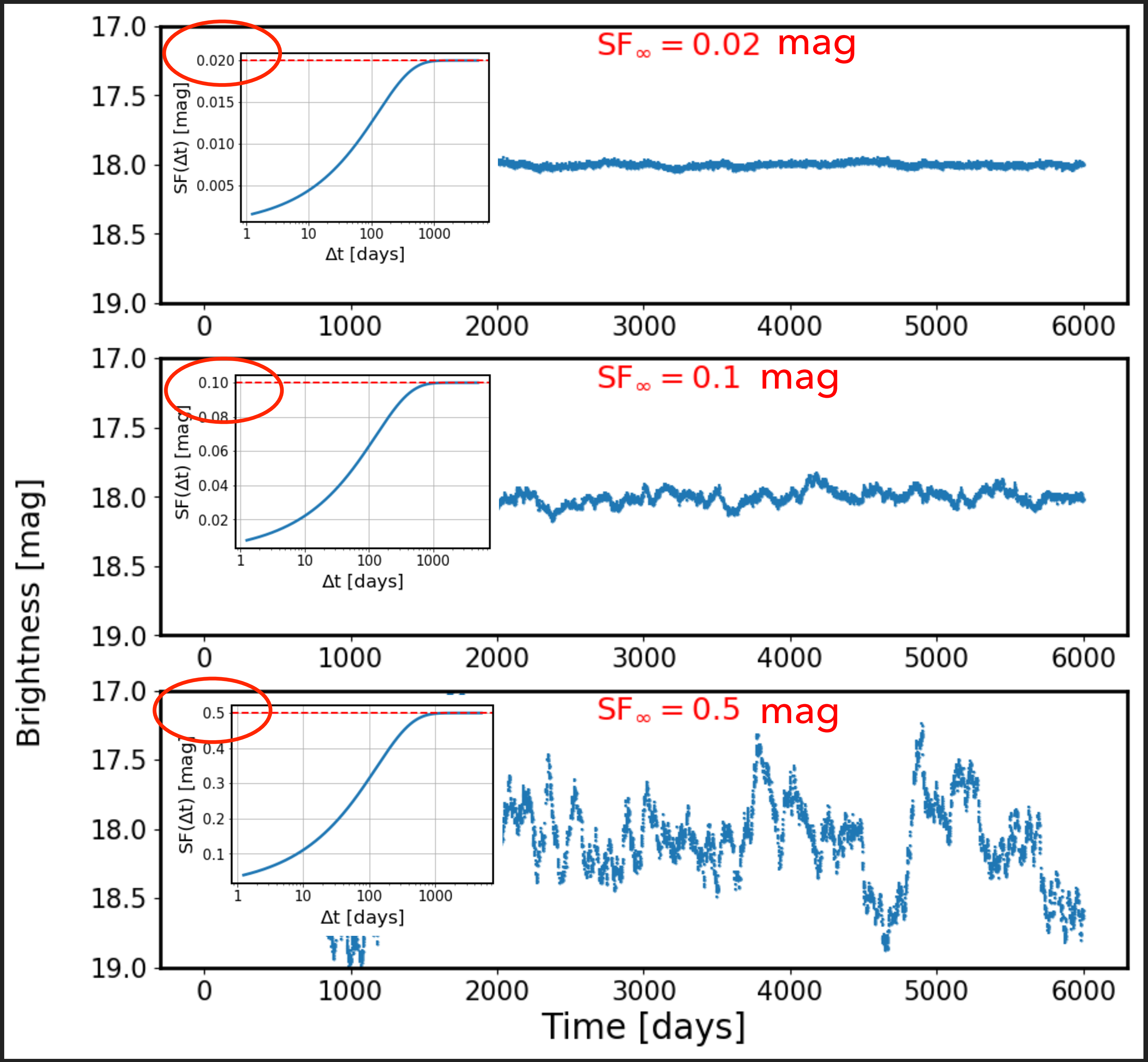


SF_∞ = 0.2 mag

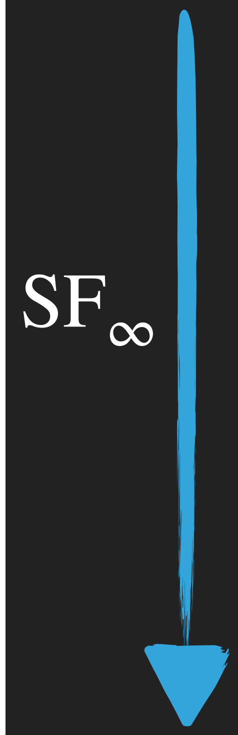
τ

as τ increases, keeping SF_∞ fixed, the light curve appears smoother - there is much less short timescale variability

DRW PARAMETERS : ASYMPTOTIC AMPLITUDE SF_∞



τ = 200 days

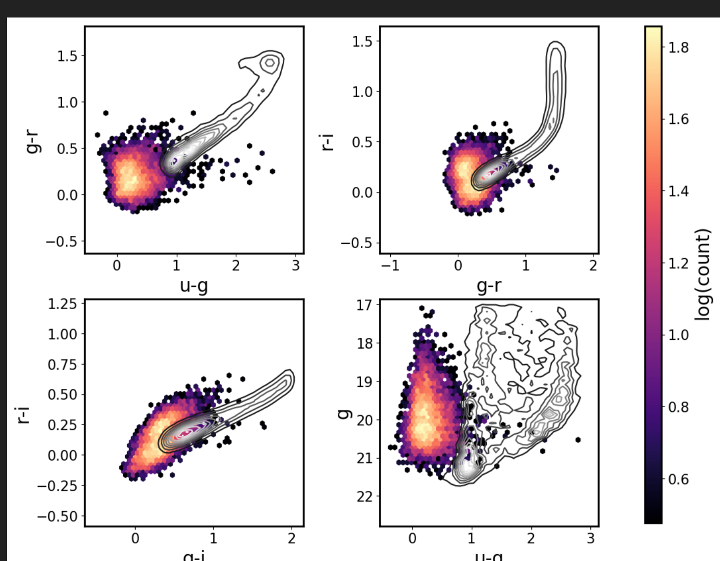


as SF_∞ increases, the amplitude of variability increases

UTILITY OF DRW PARAMETRIZATION?

Any parametric description of quasar variability (eg. DRW)

CLASSIFICATION



ESTIMATION OF PHYSICAL PROPERTIES

DRW TIMESCALE, AMPLITUDE

BLACK HOLE MASS, QSO LUMINOSITY,

FIRST, WHY IMPROVE THE DRW PARAMETERS?

Any parametric description of quasar variability (eg. DRW)

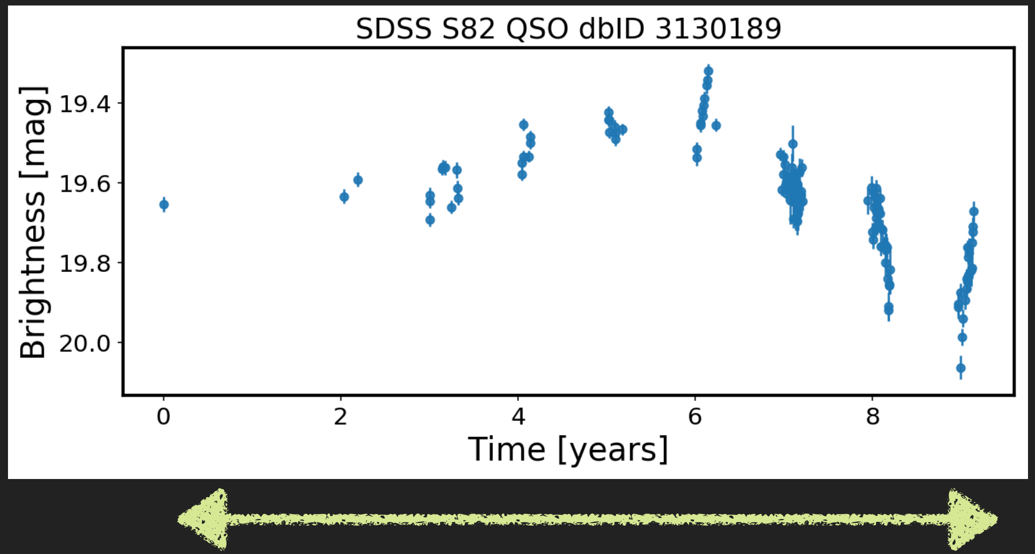
CLASSIFICATION

- QSO have different DRW parameters than eg. stars or galaxies
- biases are not very relevant, as long as parameters are constrained (Sesar+2008)

ESTIMATION OF PHYSICAL PROPERTIES

- Utilizing multi-dimensional correlations between measured parameters (eg. τ, SF_∞), and physical quantities (black hole mass, quasar luminosity)
- biases are **important** as they affect inferred physical properties (MacLeod+2010)

HOW TO IMPROVE RETRIEVAL OF DRW PARAMETERS?



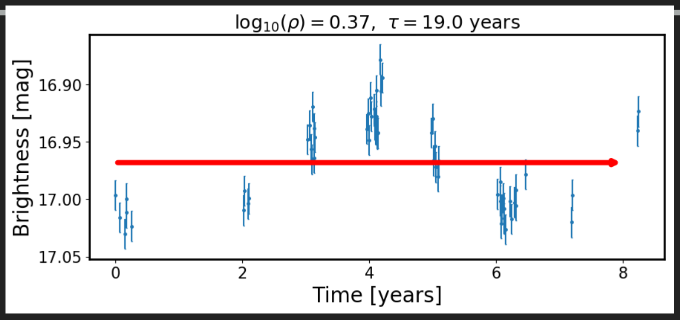
baseline = longest Δt

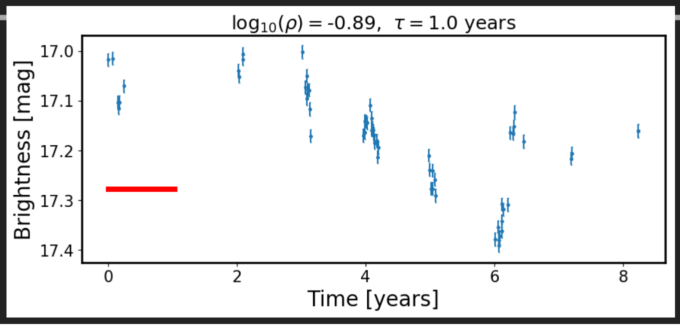
- Studies showed that extending the light curve baseline affects DRW parameter recovery (Kozłowski+2016)
- We parametrize the ratio of DRW characteristic timescale to baseline:

  ρ = timescale / baseline

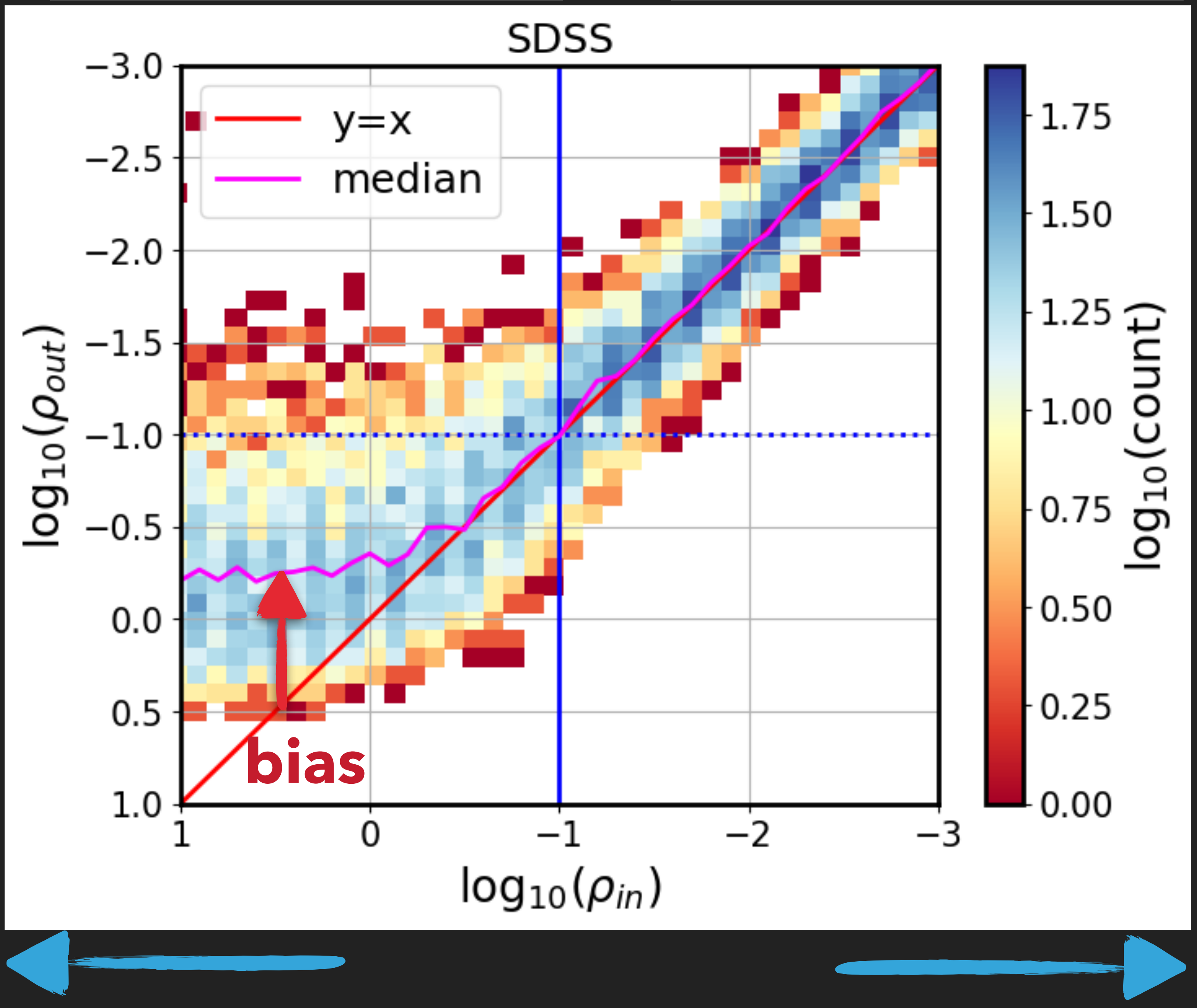
- We simulate light curves with different ρ , and compare input to fit results : ρ_{in} to ρ_{out}

WHAT AFFECTS PARAMETER RECOVERY?





- $\rho = \tau$ / baseline
- vary input τ to probe a range of ρ
- cadence is less relevant than the **span of light curve**



large τ / short baseline

small τ / long baseline

Suberlak+2021

WHAT AFFECTS PARAMETER RECOVERY?

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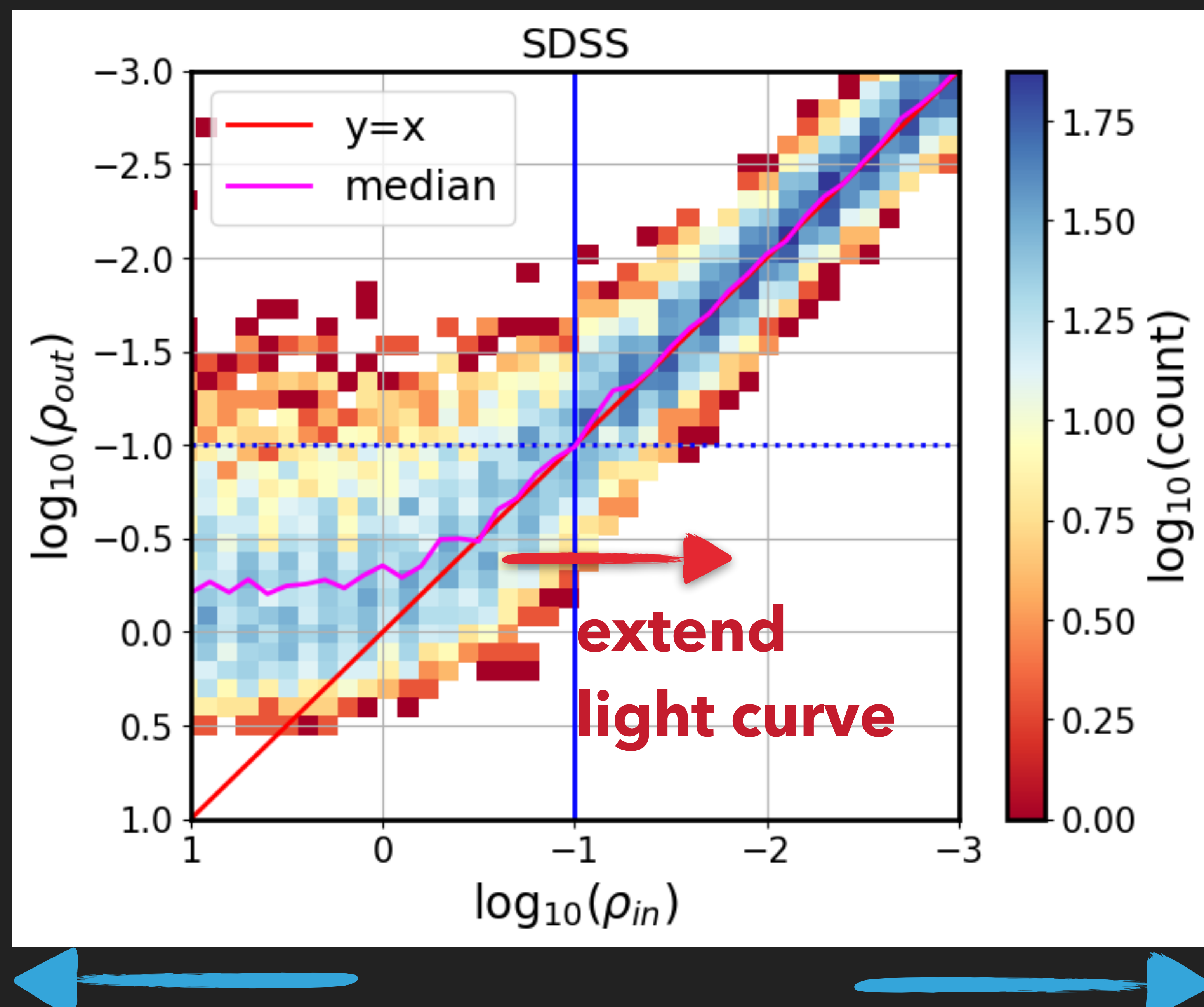


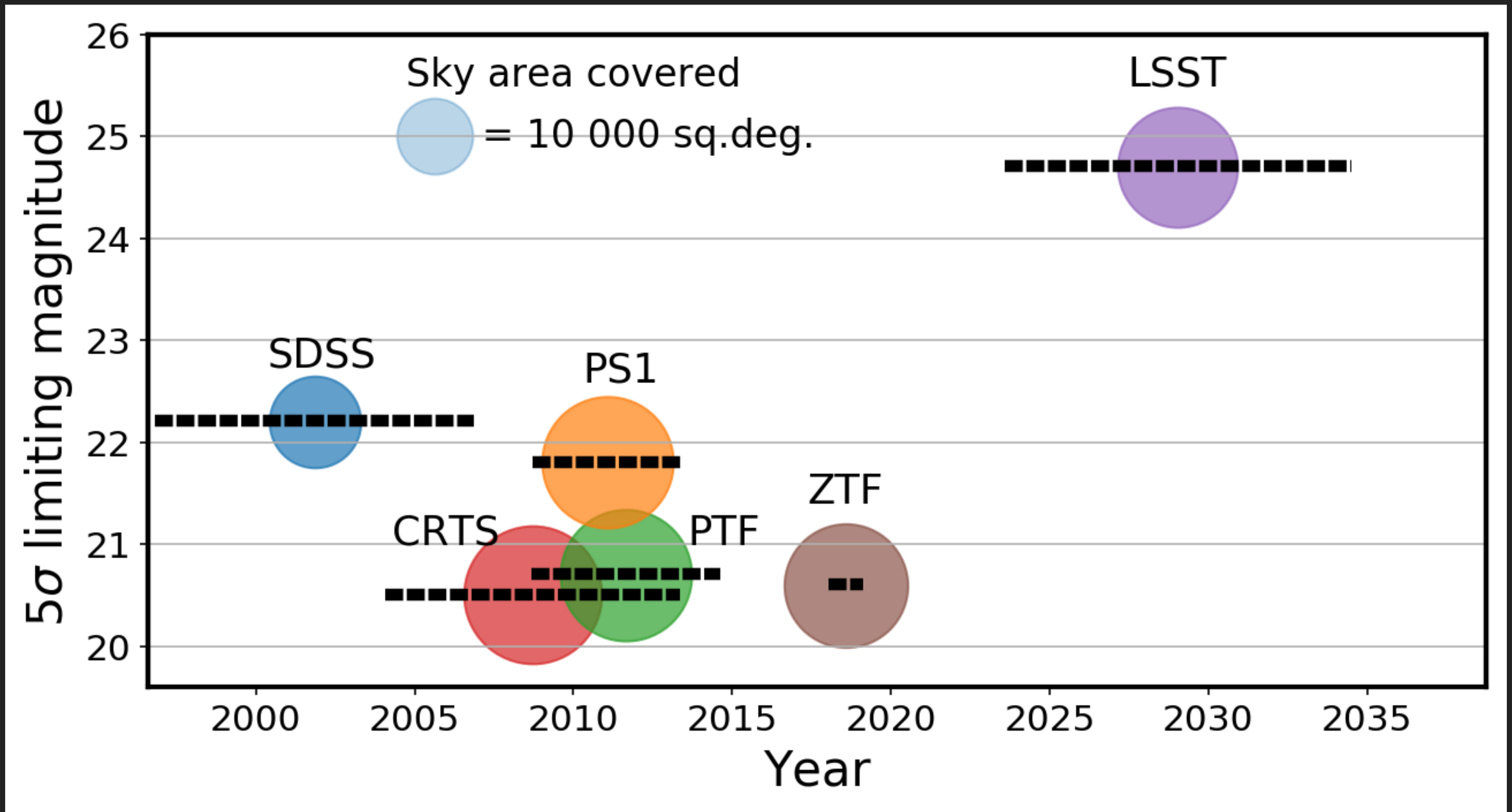
large τ / short baseline

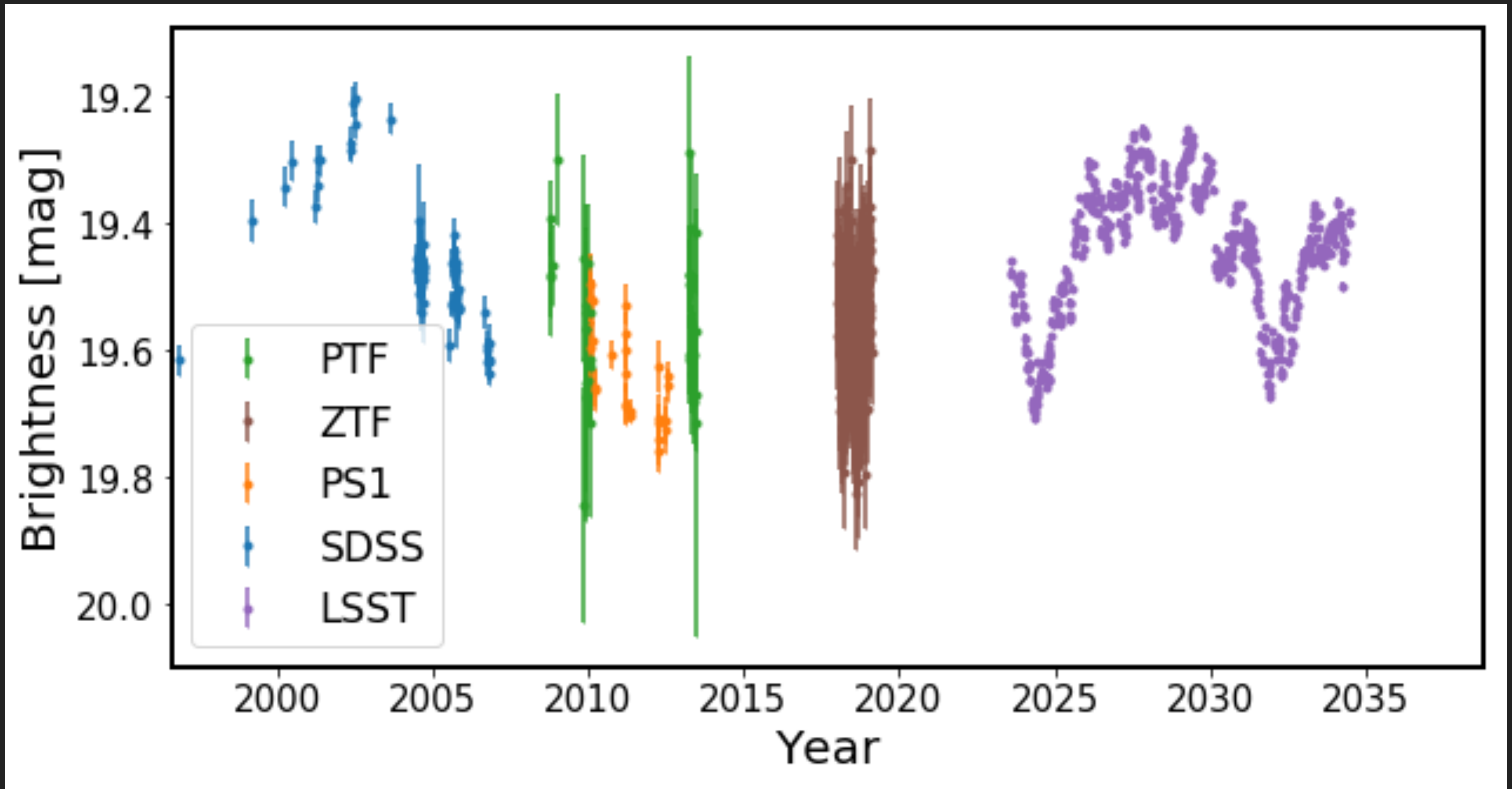
small τ / long baseline

Suberlak+2021

EXTENDING LIGHT CURVE BASELINE

- Use data from a variety of sky surveys - currently available SDSS, PS1, CRTS, ZTF and in the future - **LSST**





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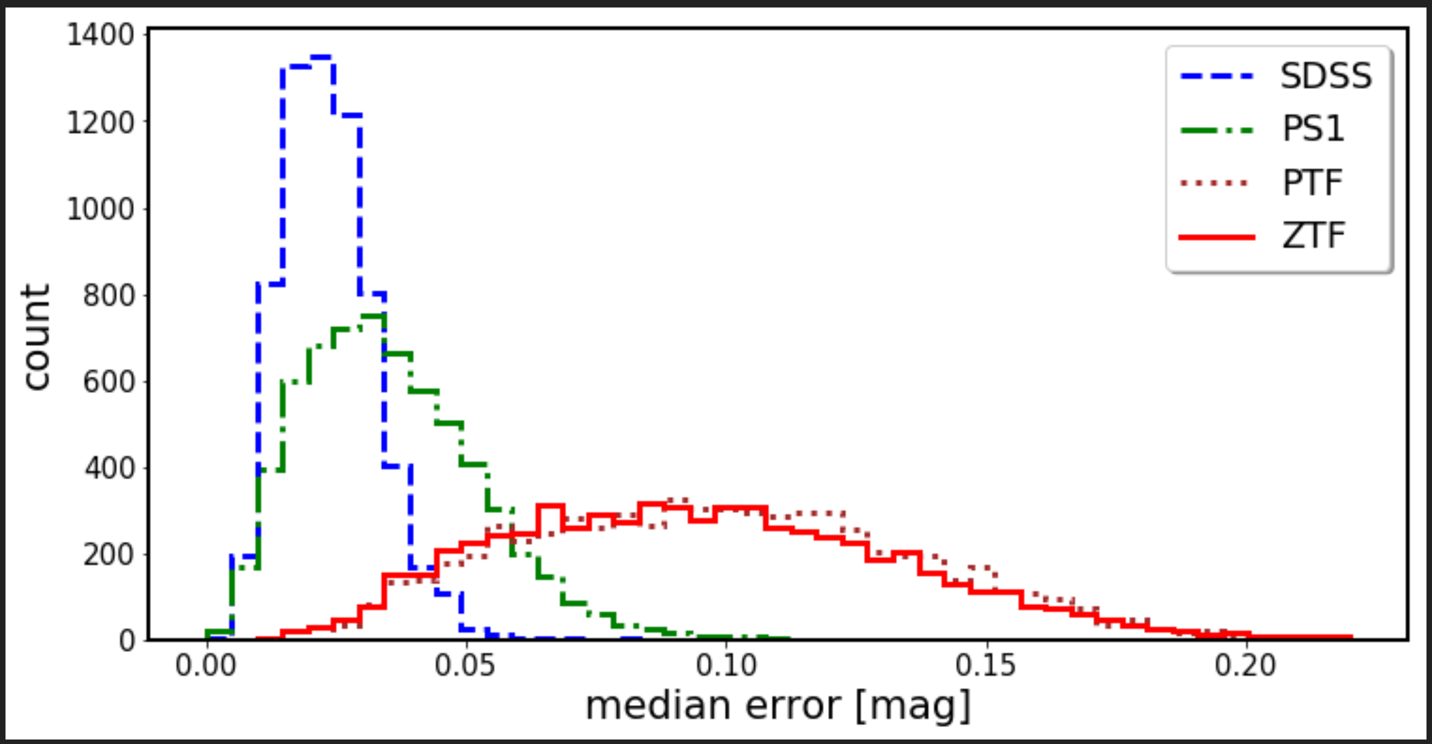
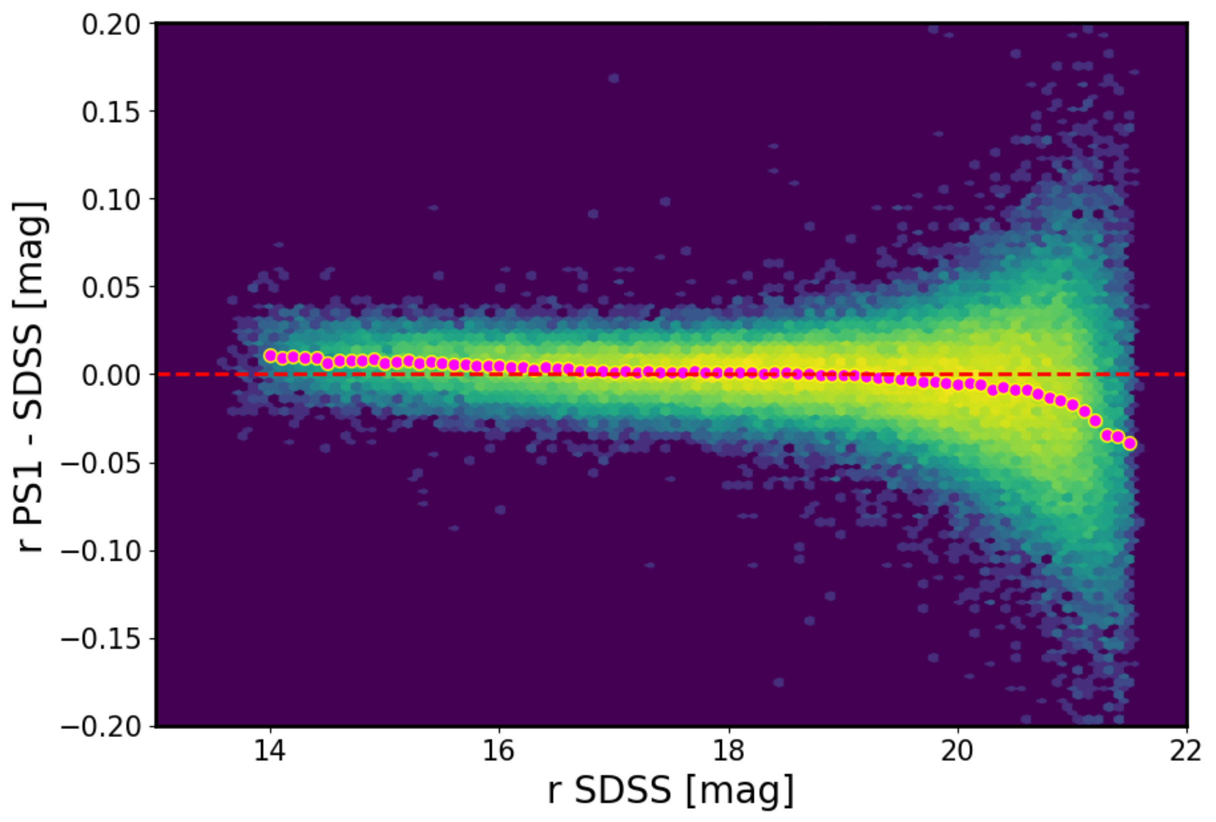
CHOOSING DATA: PHOTOMETRIC UNCERTAINTIES





- Uncertainties are much smaller for SDSS, PS1, because for generally faint sources like quasars, for ZTF and PTF we are reaching all the way to 5σ limit

- we limit our study to SDSSr- PS1r , without any color offset

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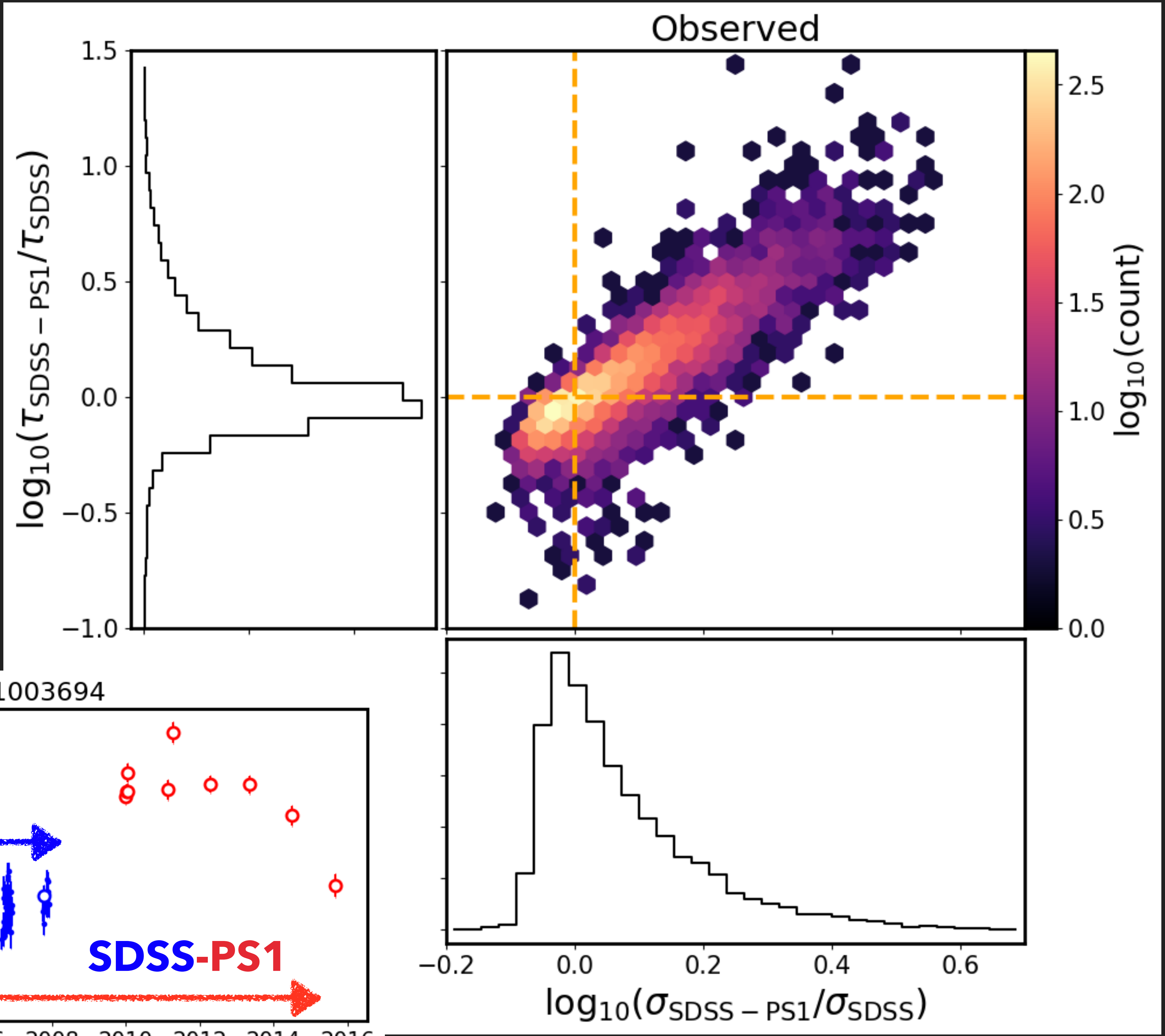
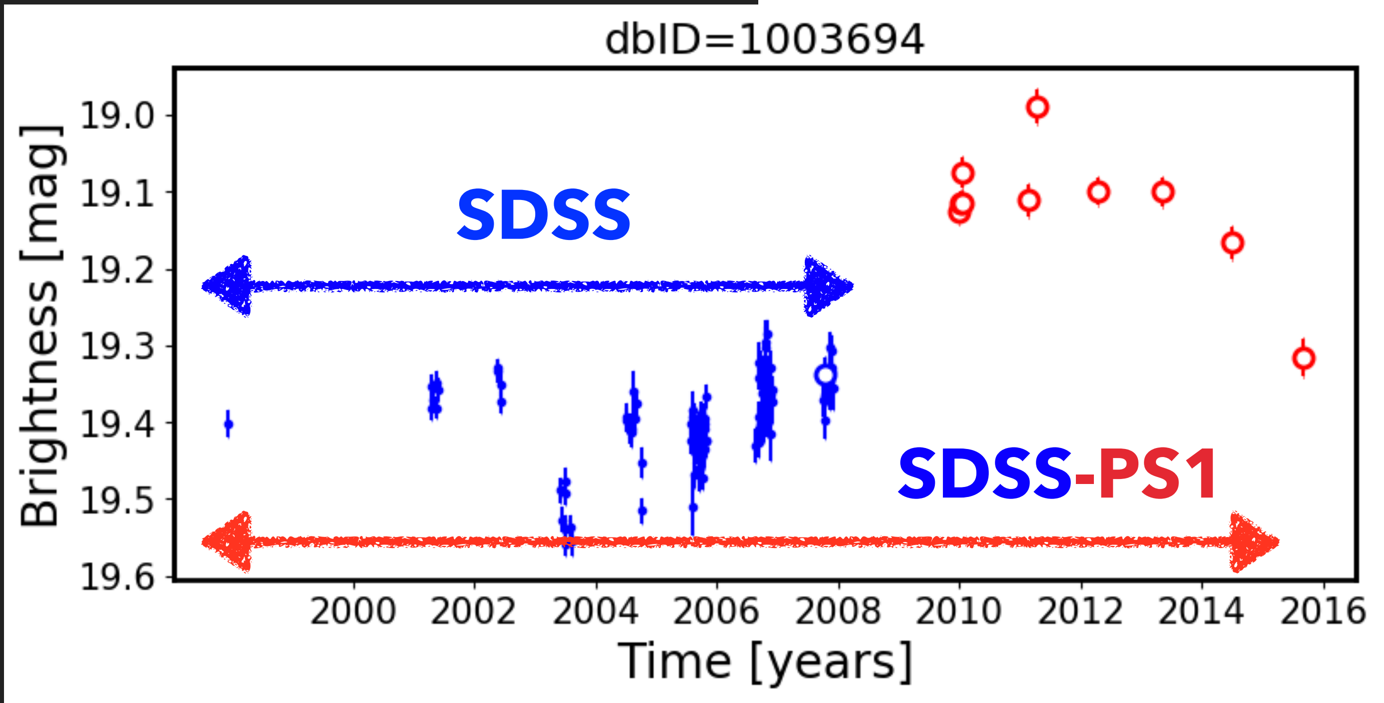
SDSS VS SDSS-PS1 DRW PARAMETERS





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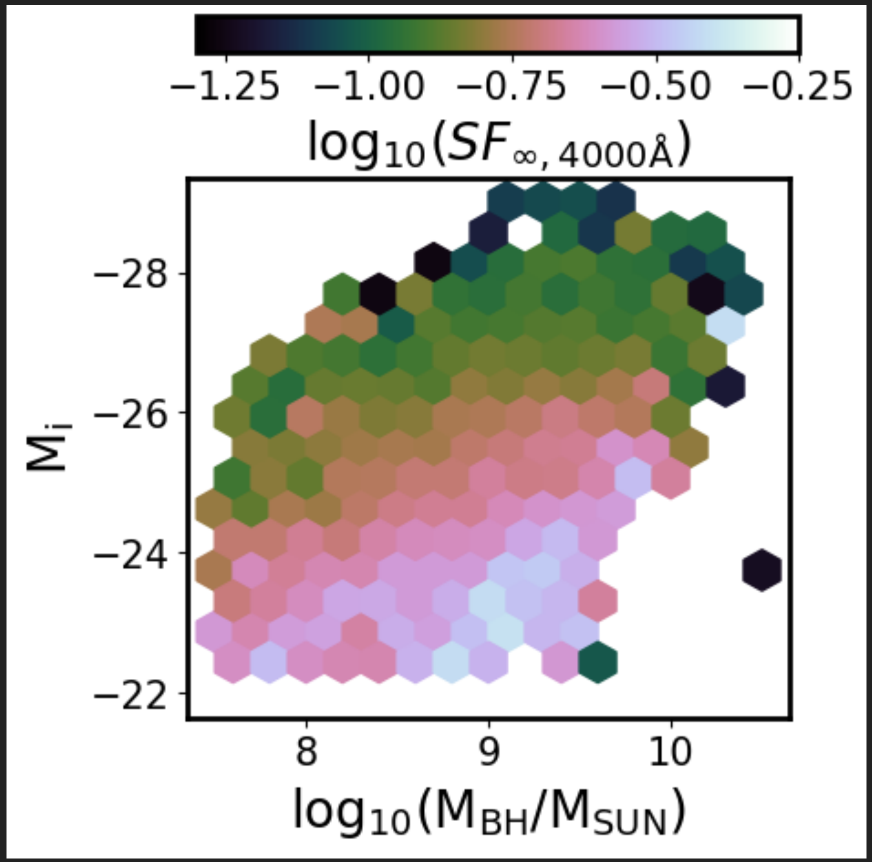
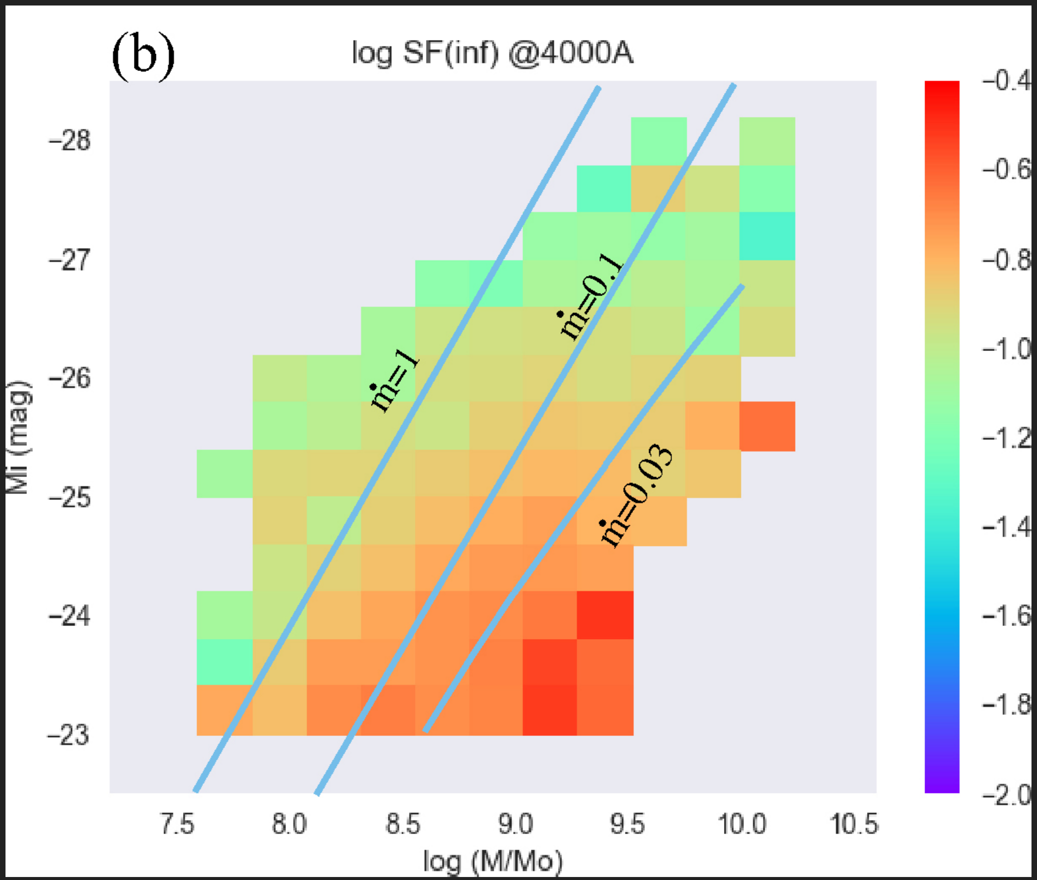
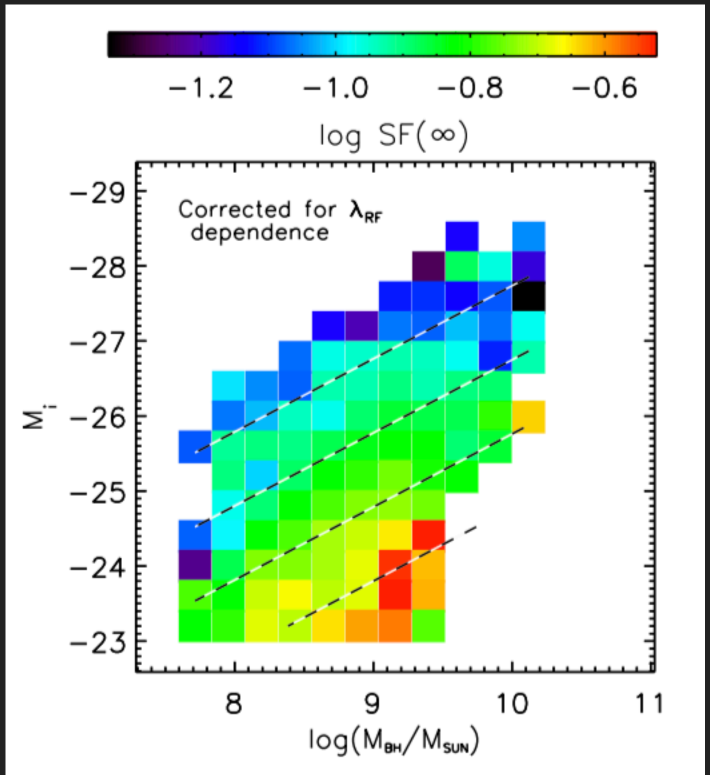
VARIABILITY VS BLACK HOLE MASS, LUMINOSITY



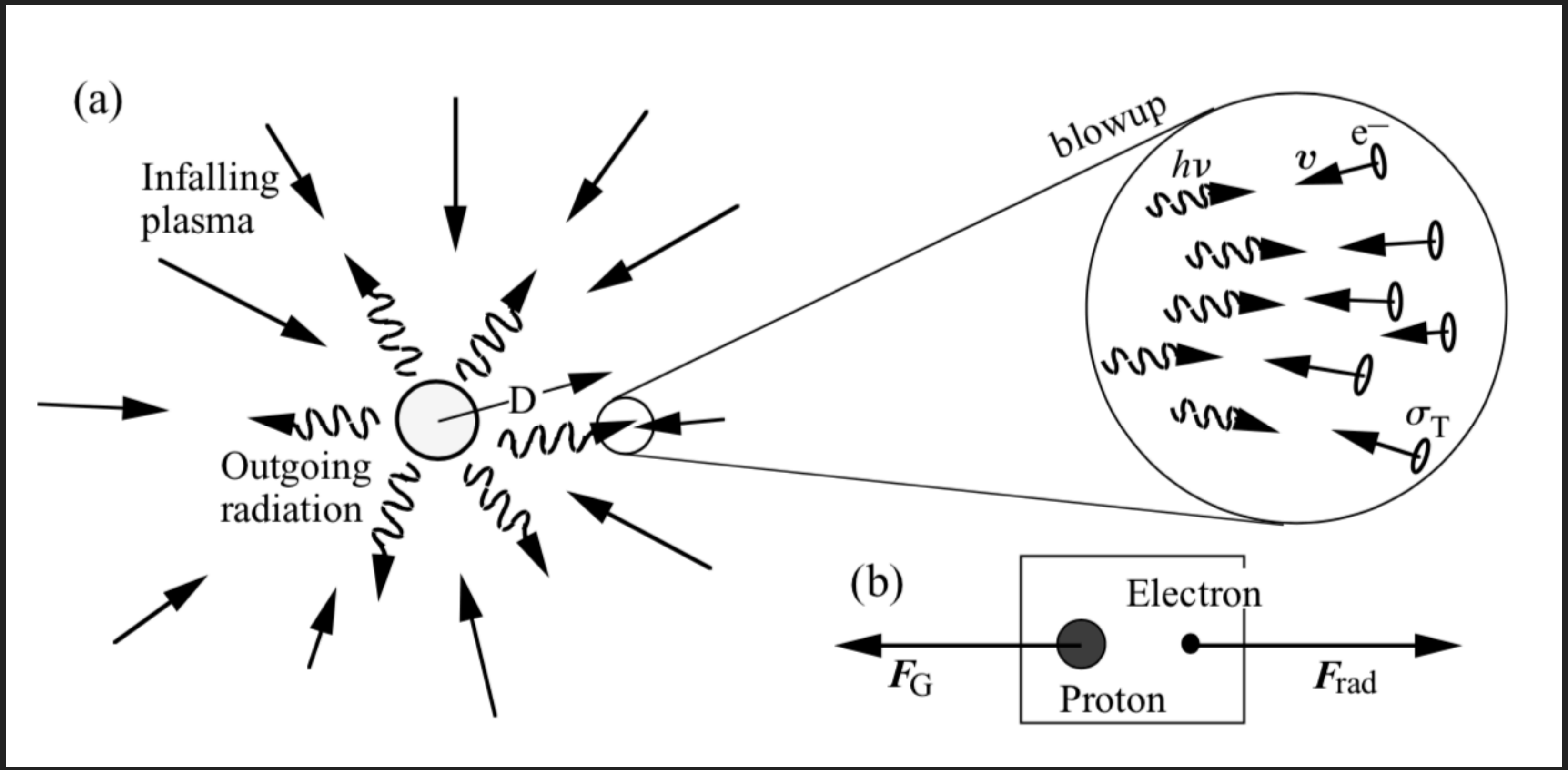




- the amplitude of variability is anti-correlated with bolometric luminosity, can be linked to eg. accretion rate

MacLeod+2010, Kubota+2018, Suberlak+2021

EDDINGTON RATIO: LUMINOSITY & BLACK HOLE MASS

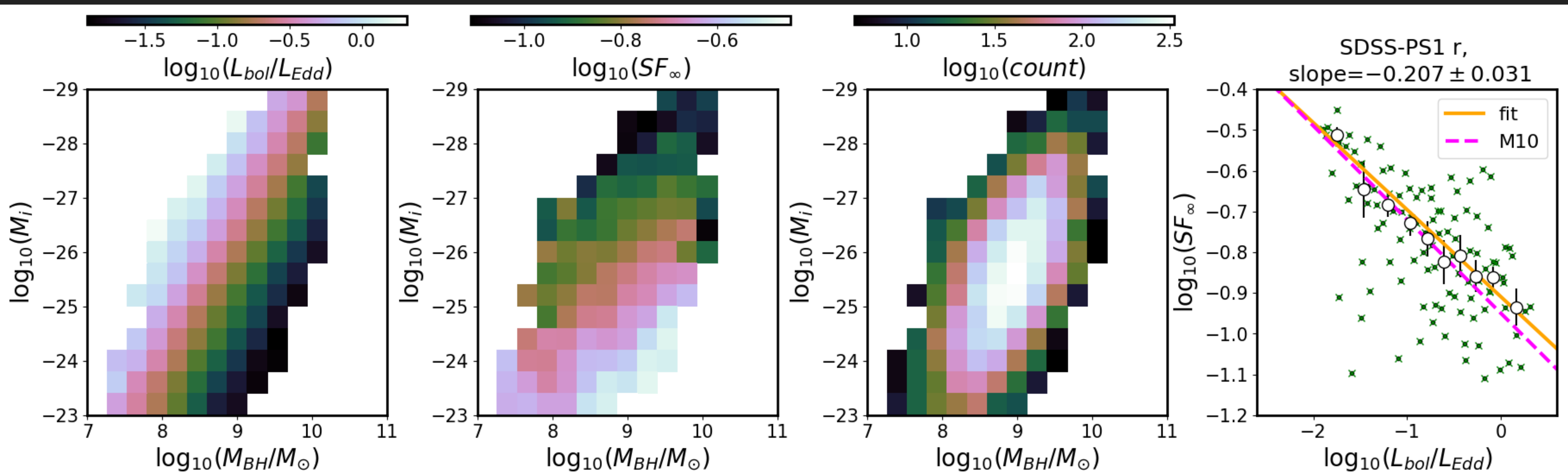


$$f_{Edd} = \frac{L_{Bol}}{L_{Edd}} \sim \frac{L_{Bol}}{M_{\rm BH}}$$

$$L_{Edd} = 1.26 \cdot 10^{38} M_{\rm BH} \; \mathrm{erg\,s^{-1}}$$

Bradt,2008

VARIABILITY VS THE EDDINGTON RATIO

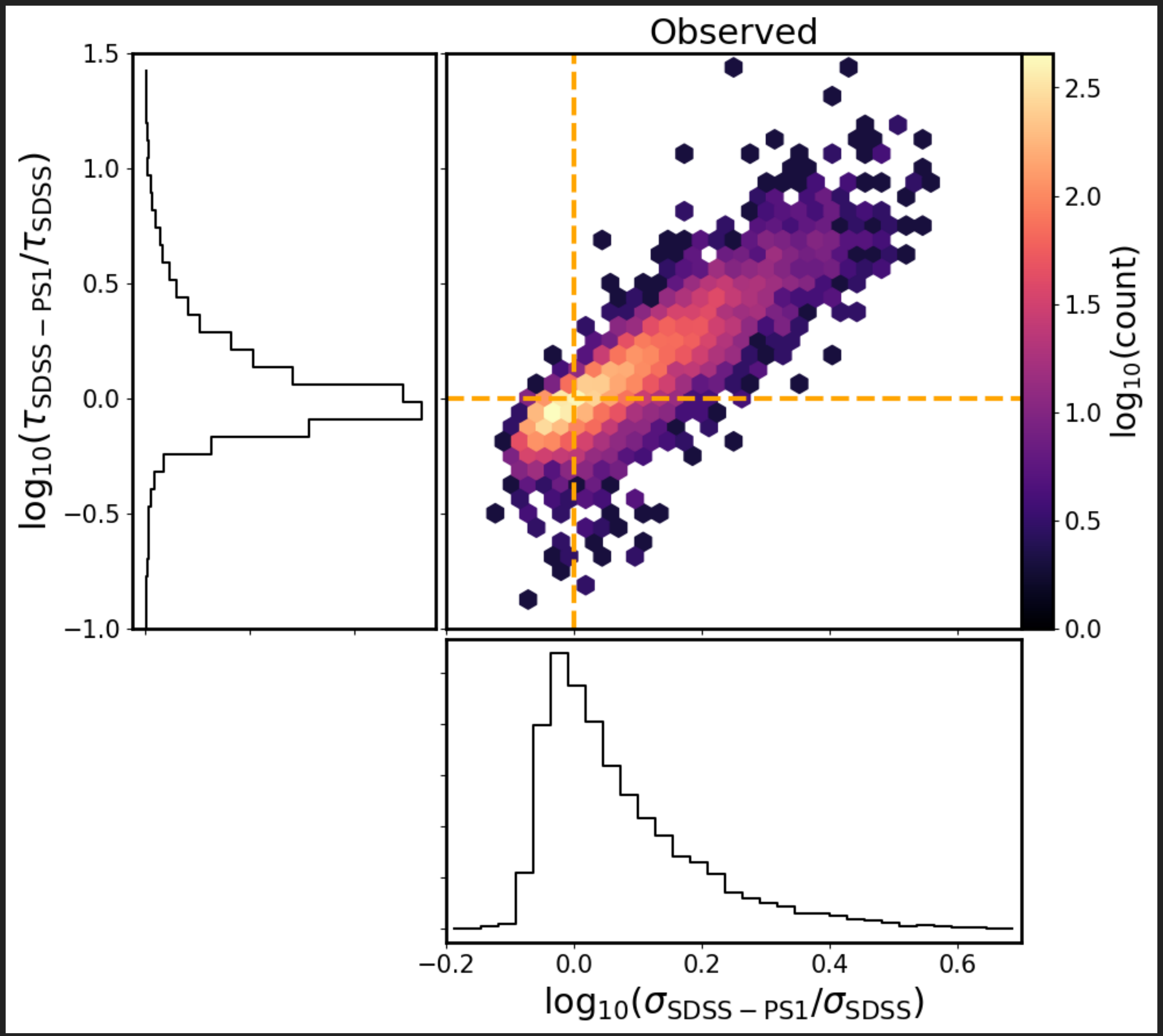


- lower Eddington ratio - dwindling fuel supply & larger variability

$$f_{Edd} = \frac{L_{Bol}}{L_{Edd}} \sim \frac{L_{Bol}}{M_{\rm BH}}$$

Suberlak+2021

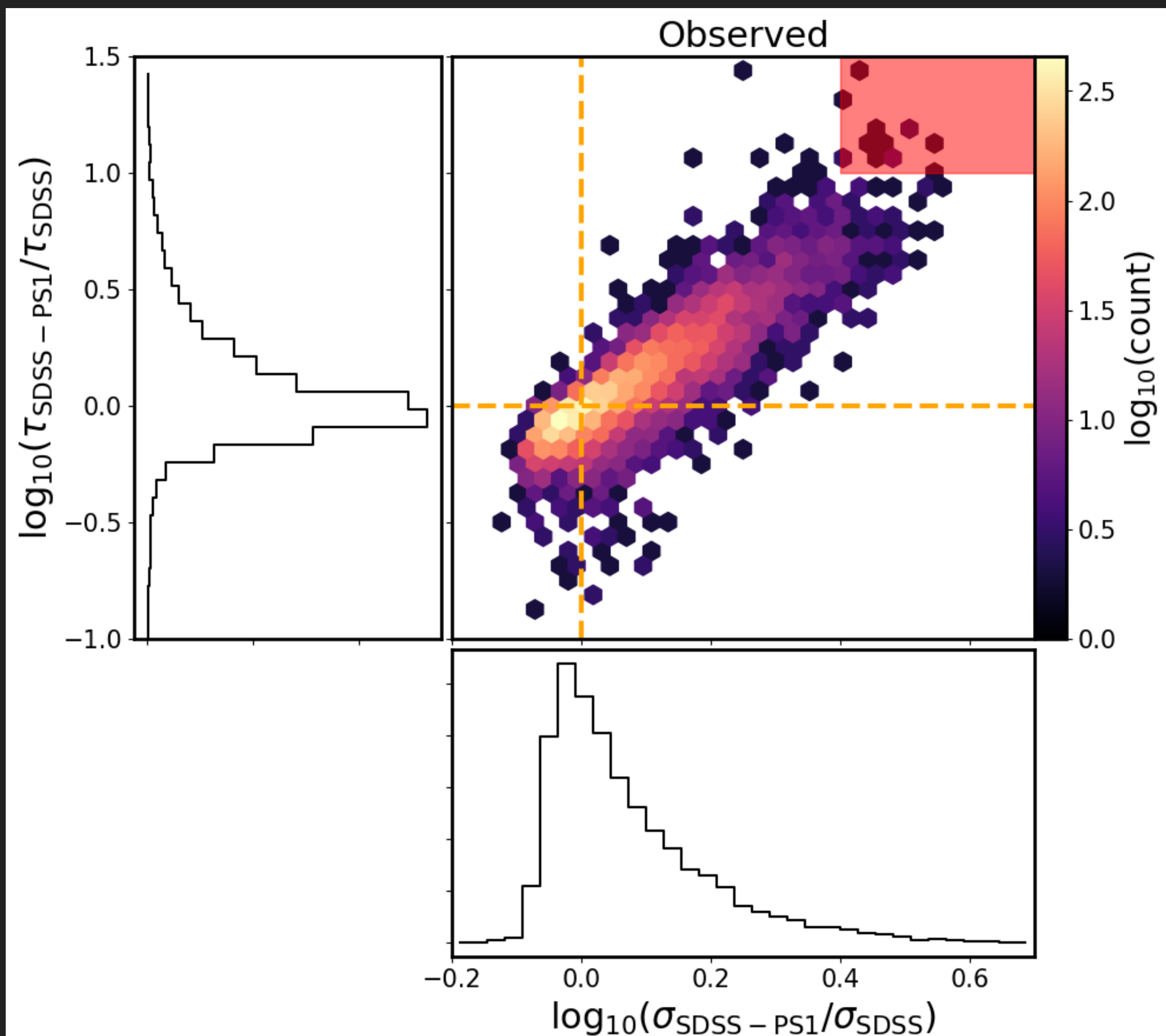
OUTLIERS IN DRW



- compare DRW parameters retrieved using SDSS vs SDSS+PS1 data

Suberlak+2021

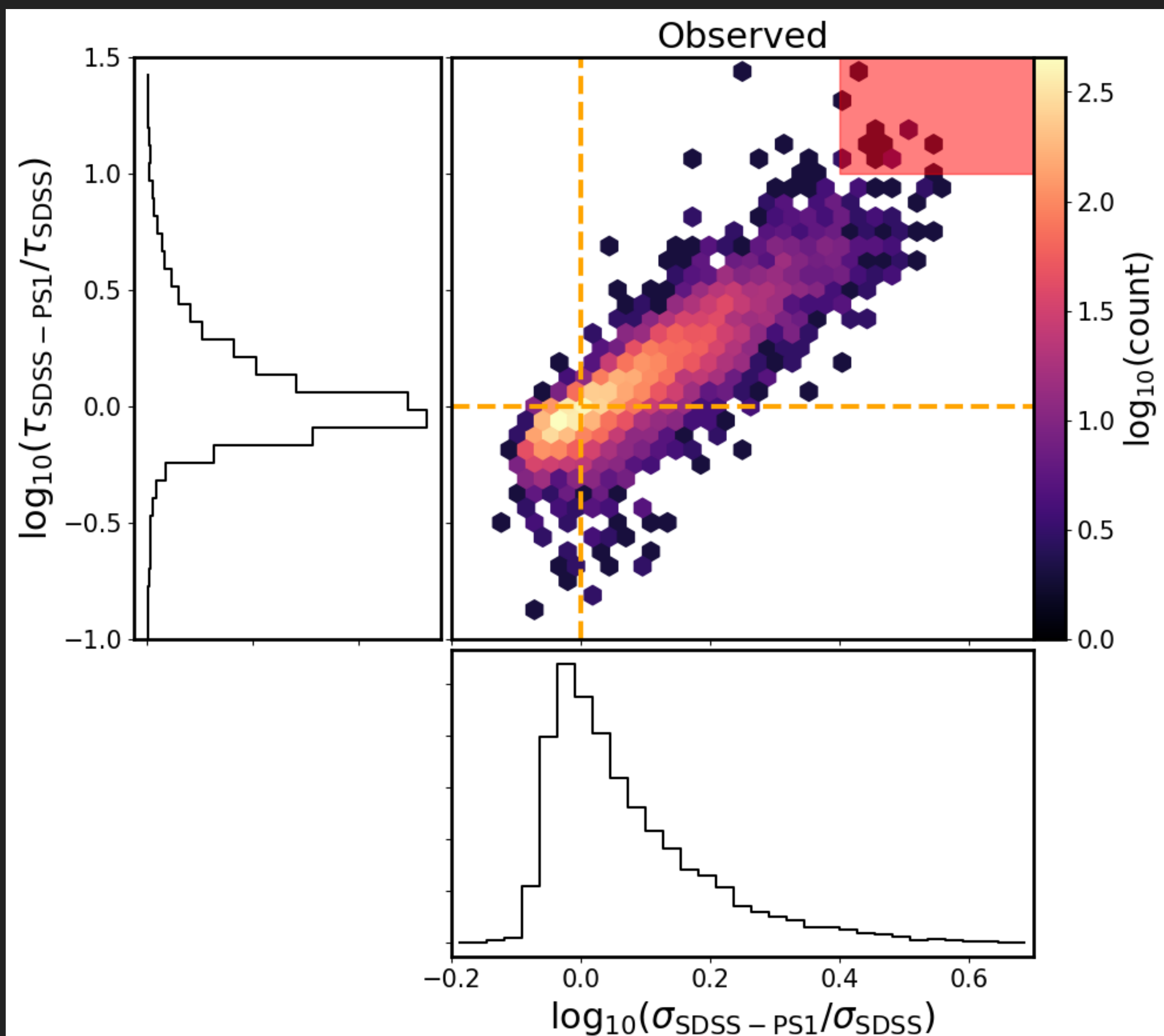
OUTLIERS IN DRW

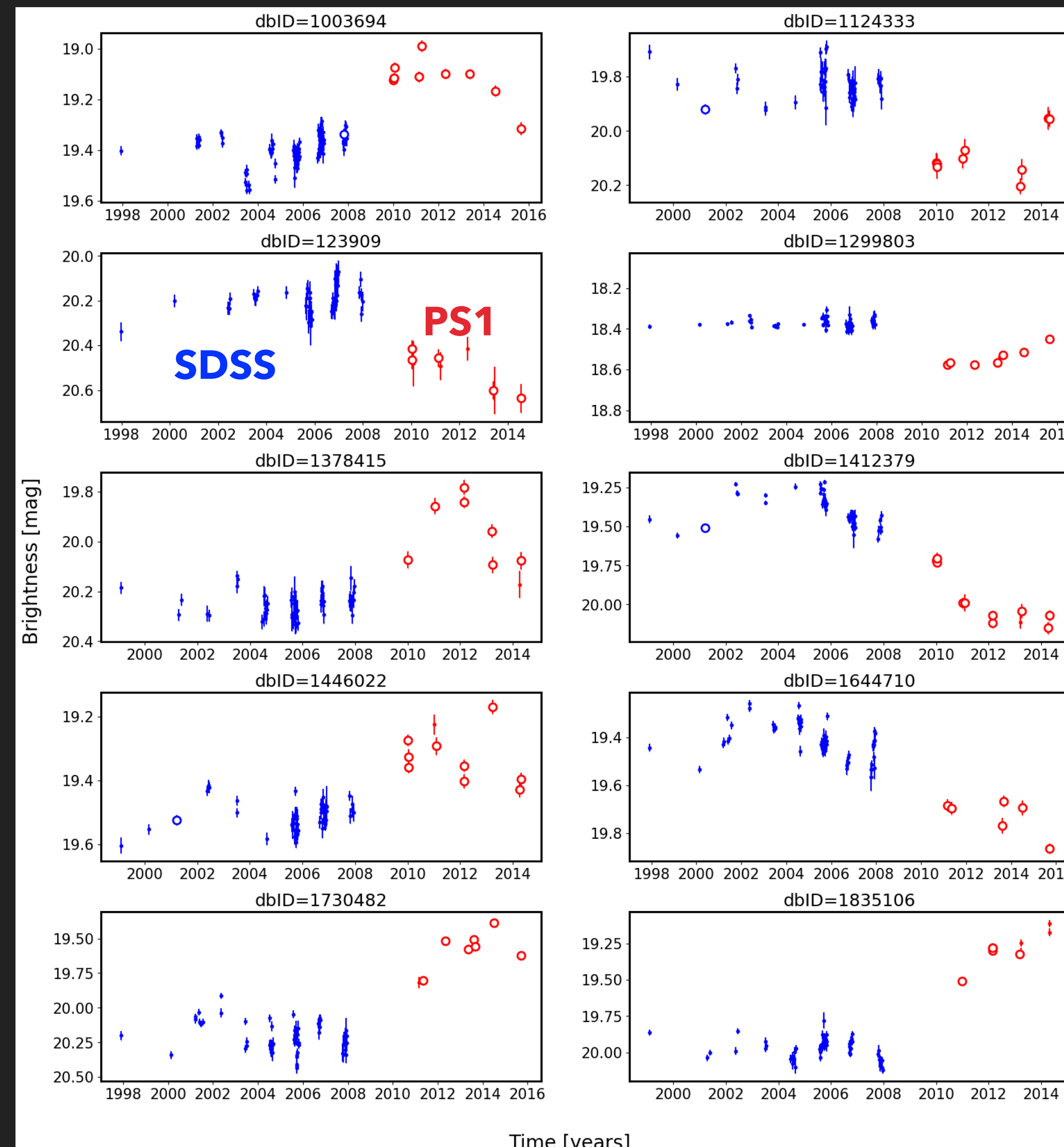


- compare DRW parameters retrieved using SDSS vs SDSS+PS1 data

Suberlak+2021

RESULTS: OUTLIERS ARE INTERESTING





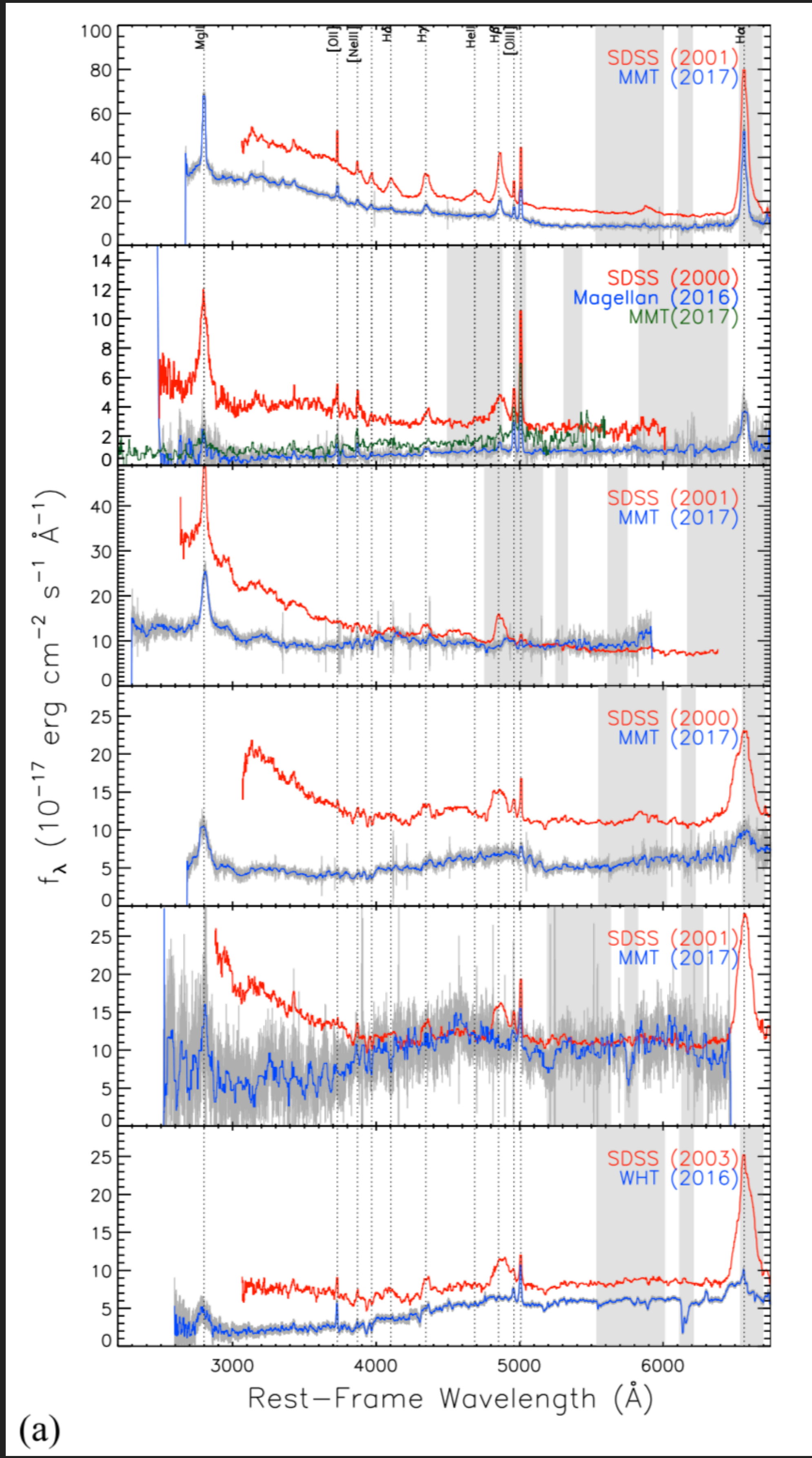
- compare DRW parameters retrieved using SDSS vs SDSS+PS1 data

Suberlak+2021

CHANGING LOOK QUASARS : CONTEXT

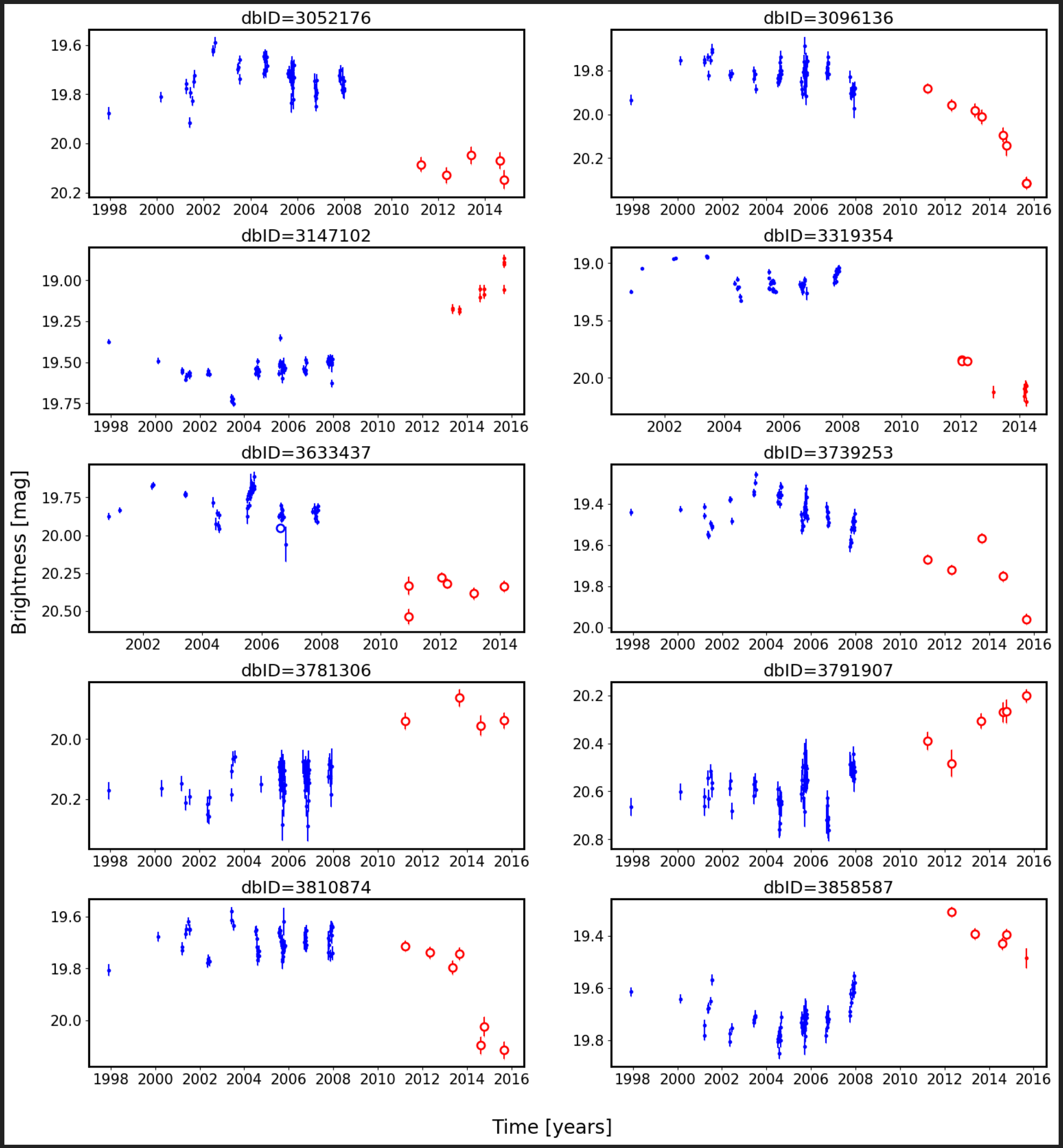
Changing-Look phenomenon corresponds to the (dis)-appearance of broad emission lines and a non-stellar continuum, changing eg. between type 1.8-2 (narrow-line) to type 1 (broad-line) AGN (or vice versa) on a timescale of years.

This may mean that in a dim state we may be able to see more clearly the host galaxy contribution, without the contamination of AGN continuum.



MacLeod+2019

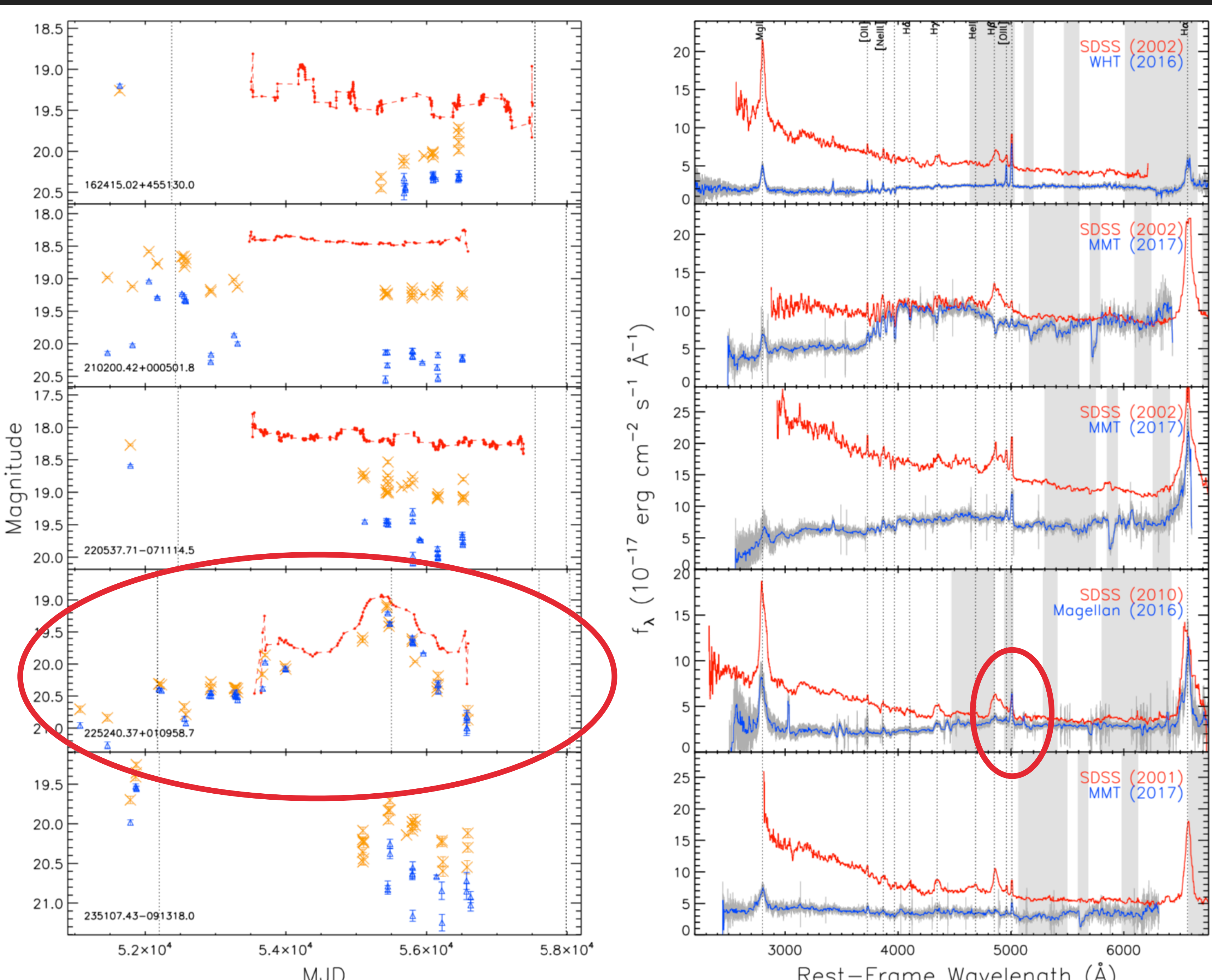
CLQSO CANDIDATES



Suberlak+2021

- CLQs are found near the critical luminosity below which the BLR disappears
- CLQs have lower Eddington ratios than a control sample matched in redshift and luminosity
- CLQs are probably the tail end of a continuous distribution of QSO variability (MacLeod+2019)

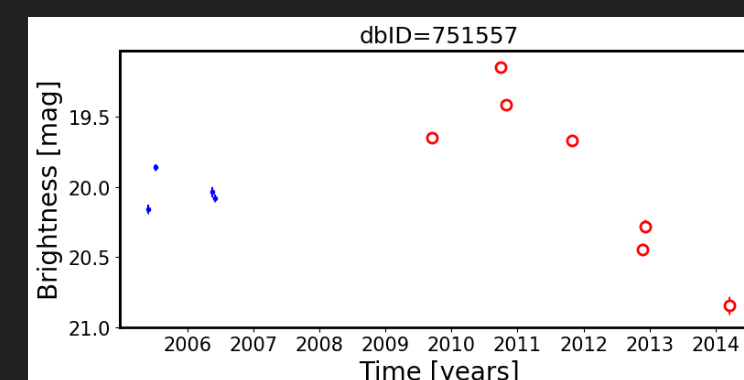
CONFIRMED CLQSO CANDIDATE



(c)

Figure 2. (Continued.)

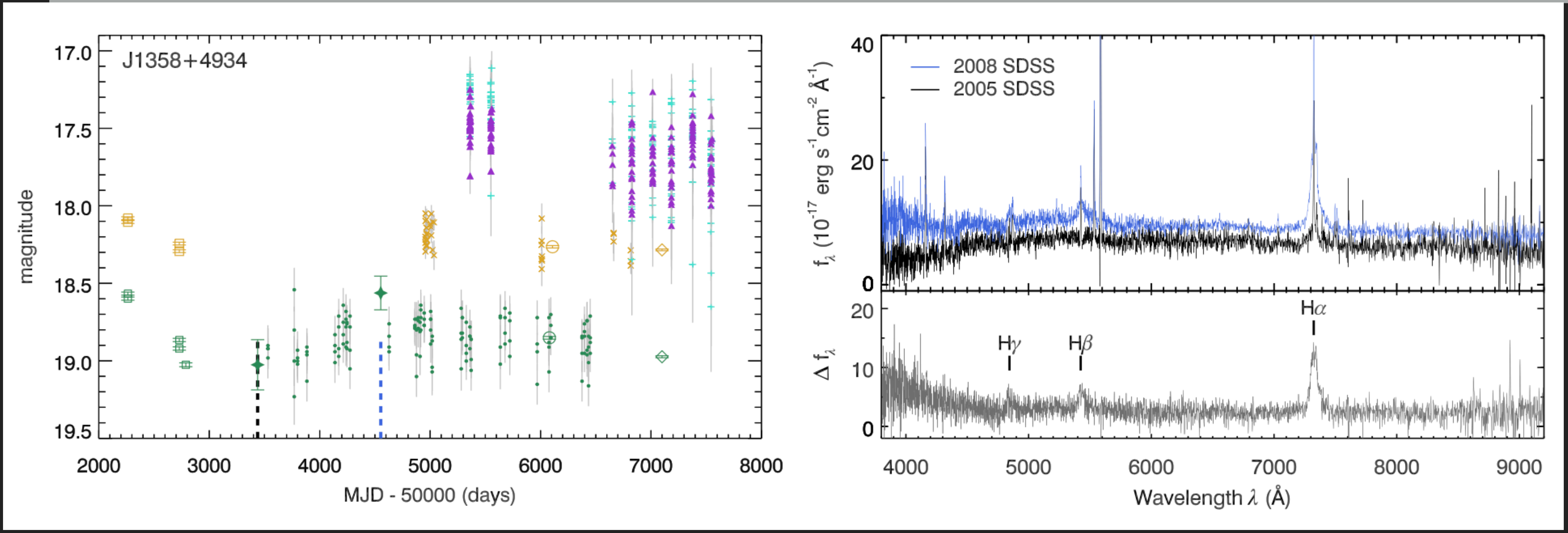
one of our candidates:
SDSSJID
225240.37+010958.7



MacLeod+2019

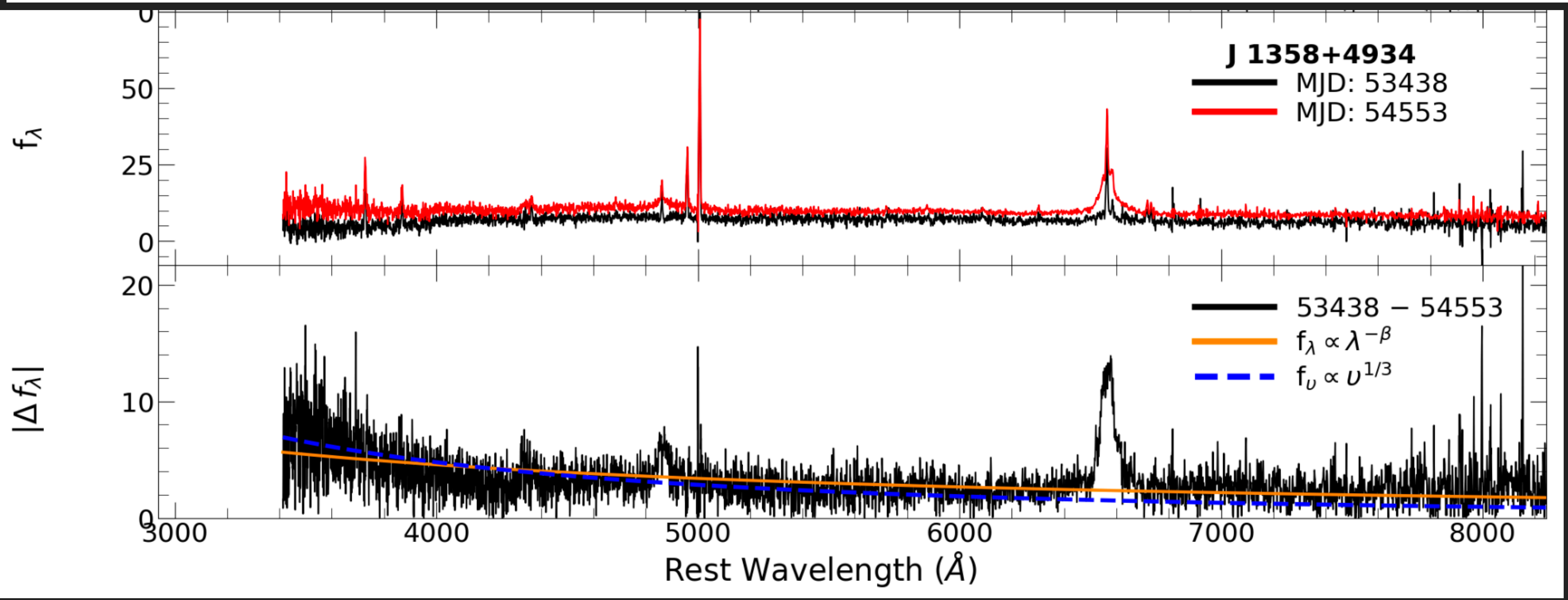
FOLLOW-UP : CLQSO SPECTROSCOPY

SPECTROSCOPY: J135855, TURN-ON



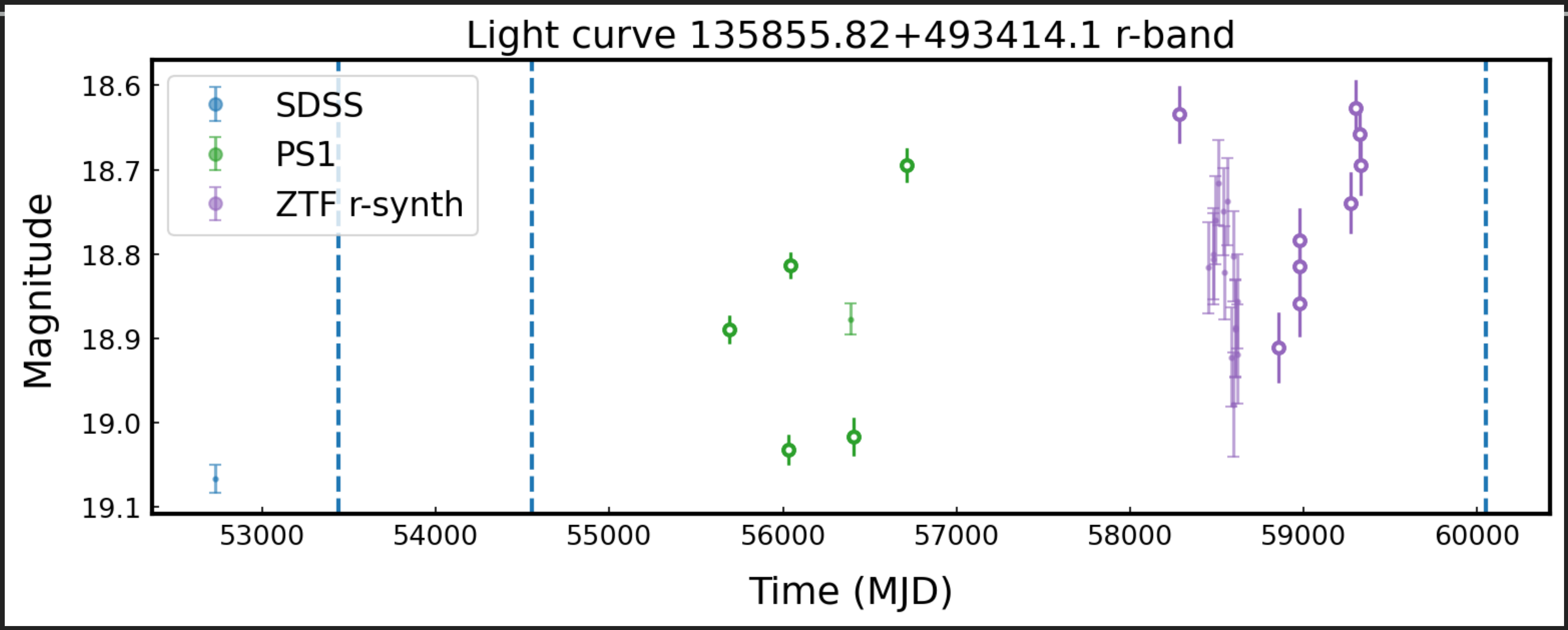
Yang+2018, Fig.5

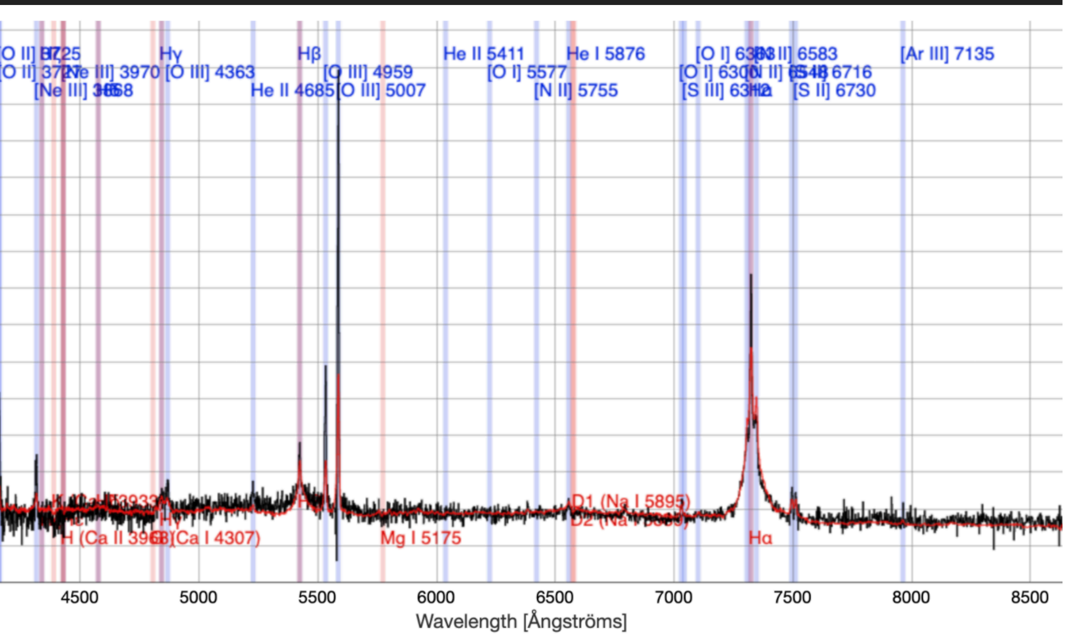
z=0.11592

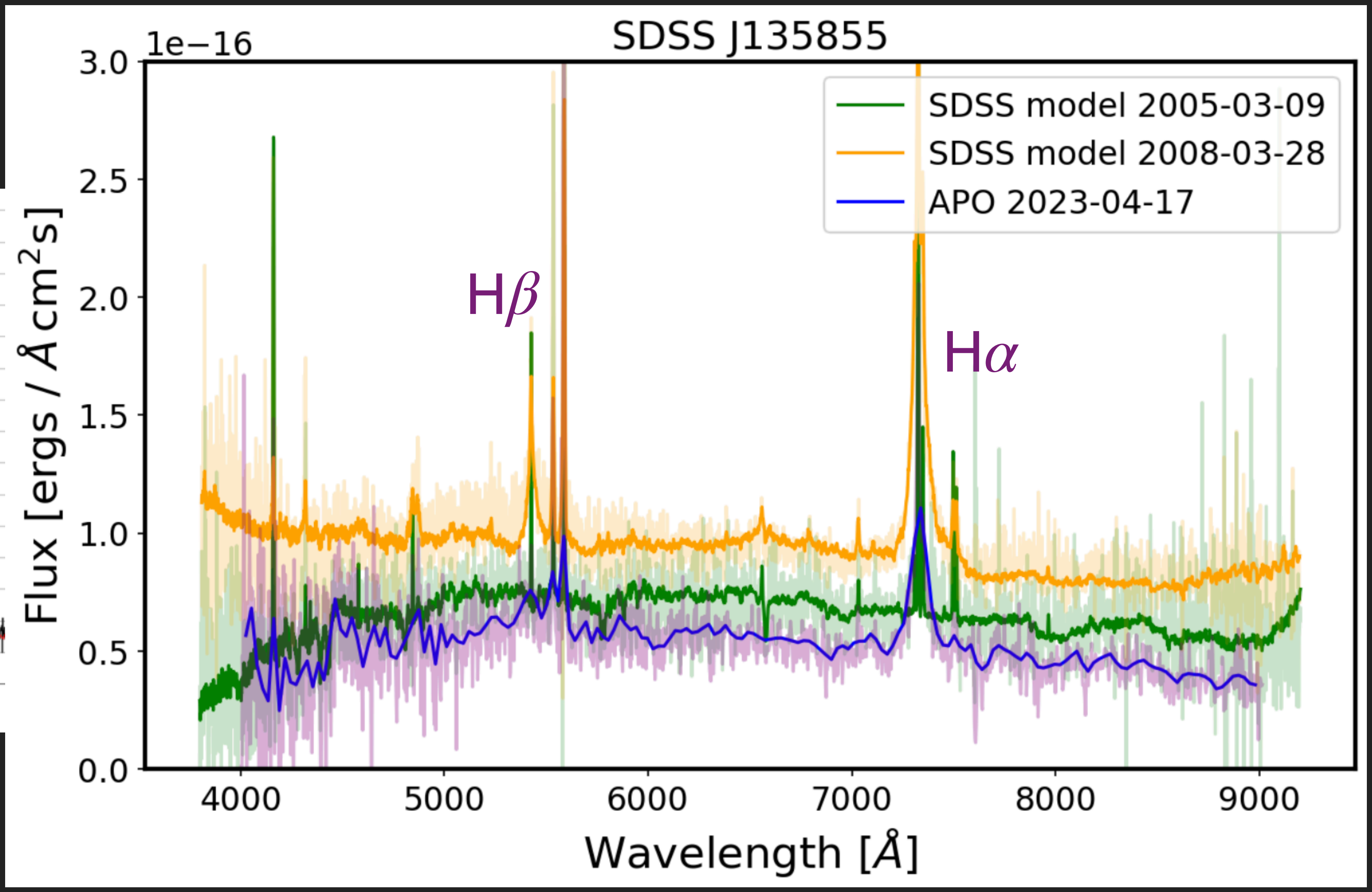


Potts-Villforth+2021, Fig.2

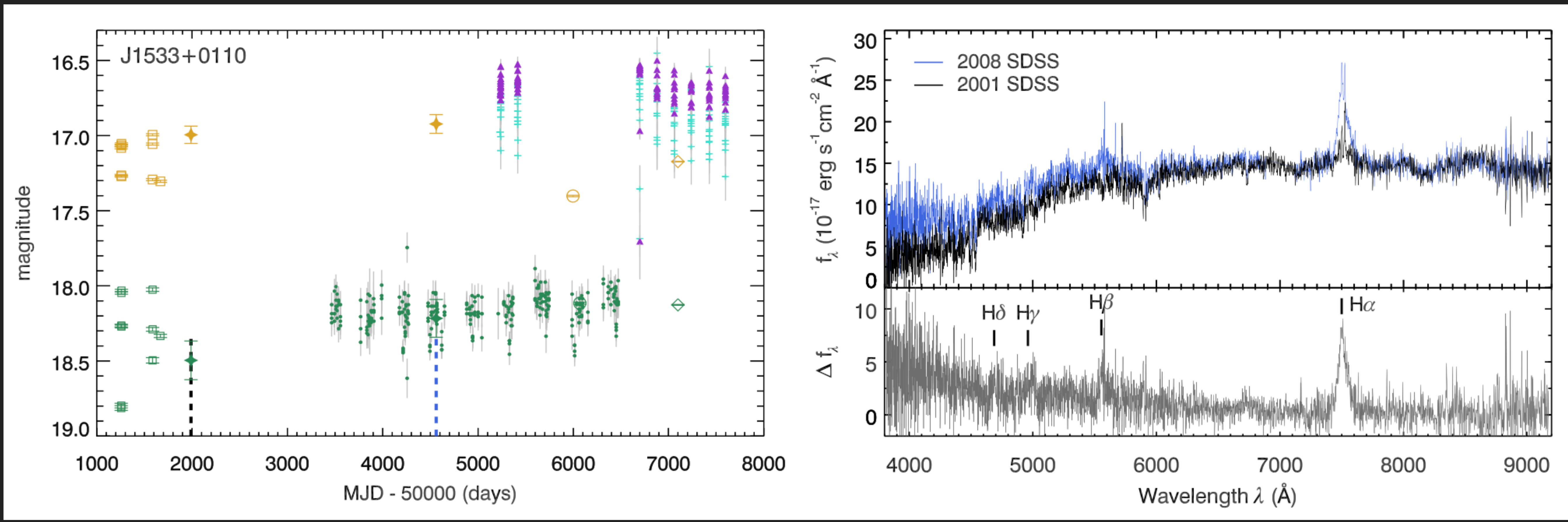
SPECTROSCOPY: J135855 TURN-ON







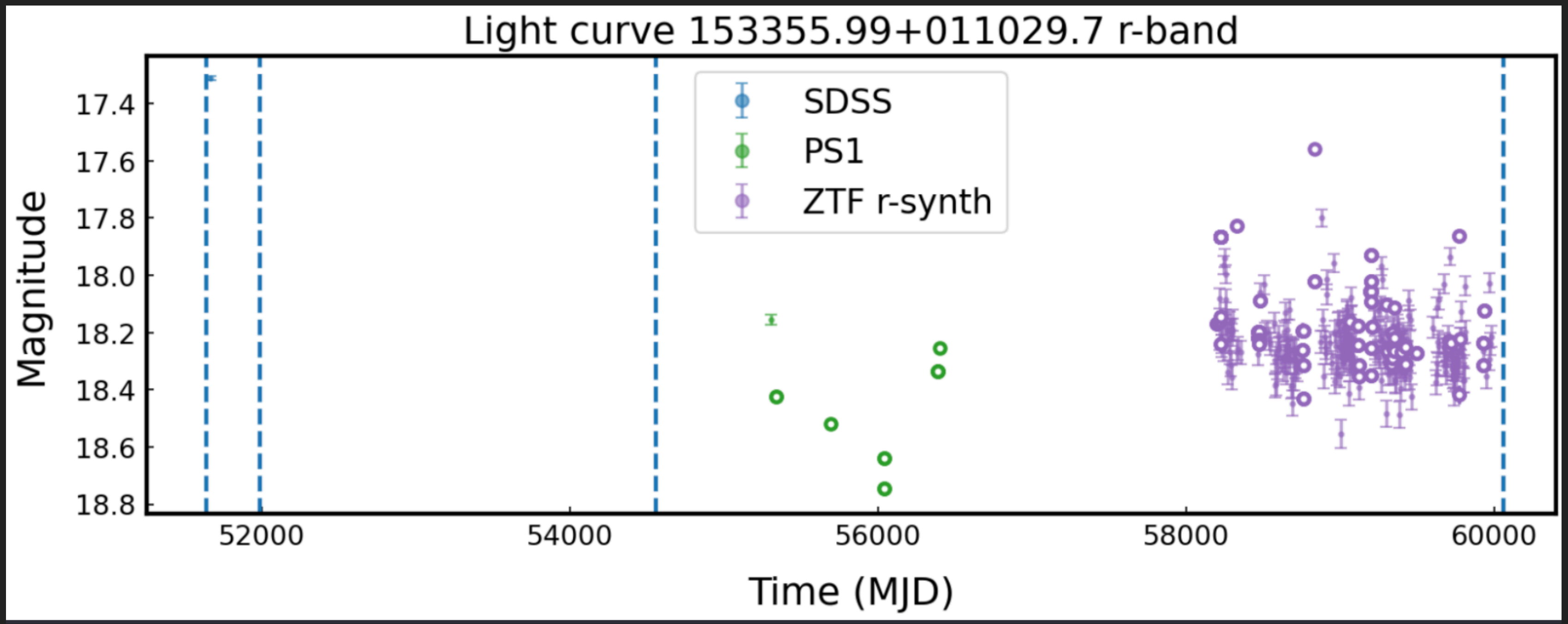
FOLLOW-UP SPECTROSCOPY 153355 (TURN-ON)

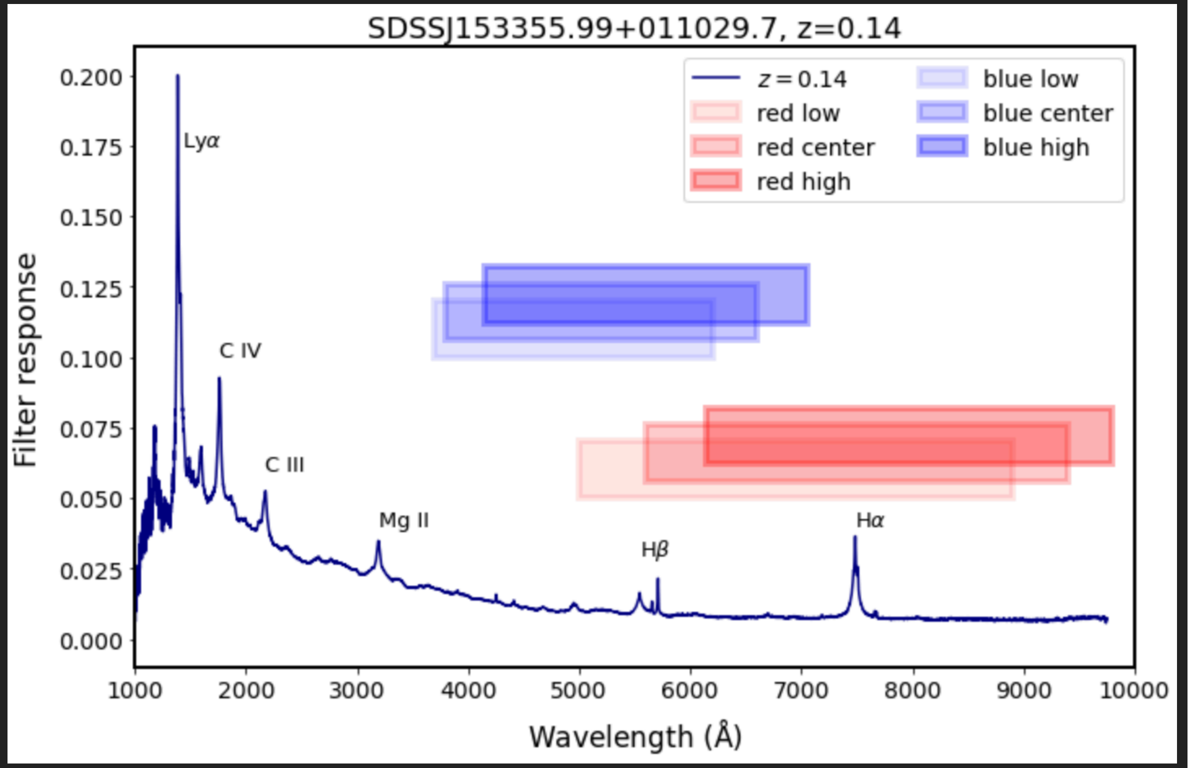


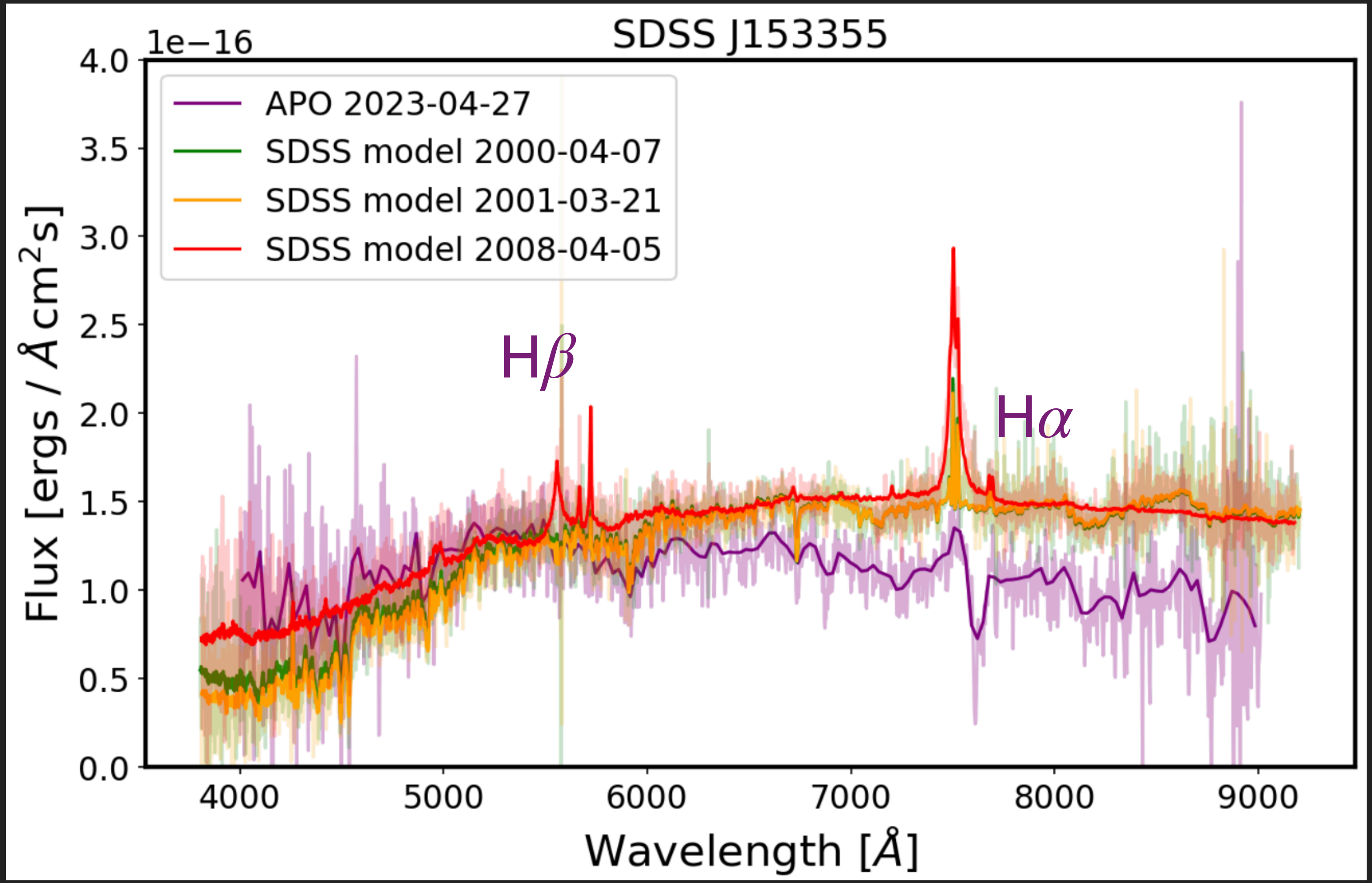
Yang+2018, Fig.5

z=0.1426

FOLLOW-UP SPECTROSCOPY 153355 TURN-ON (?)

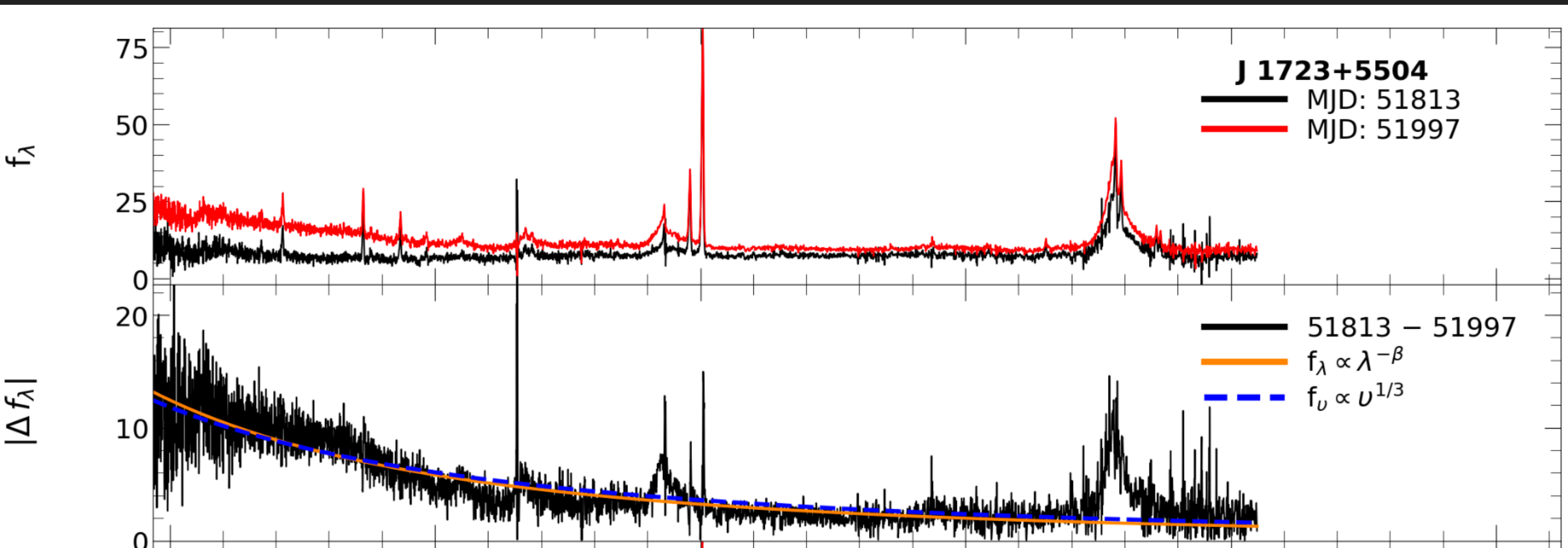


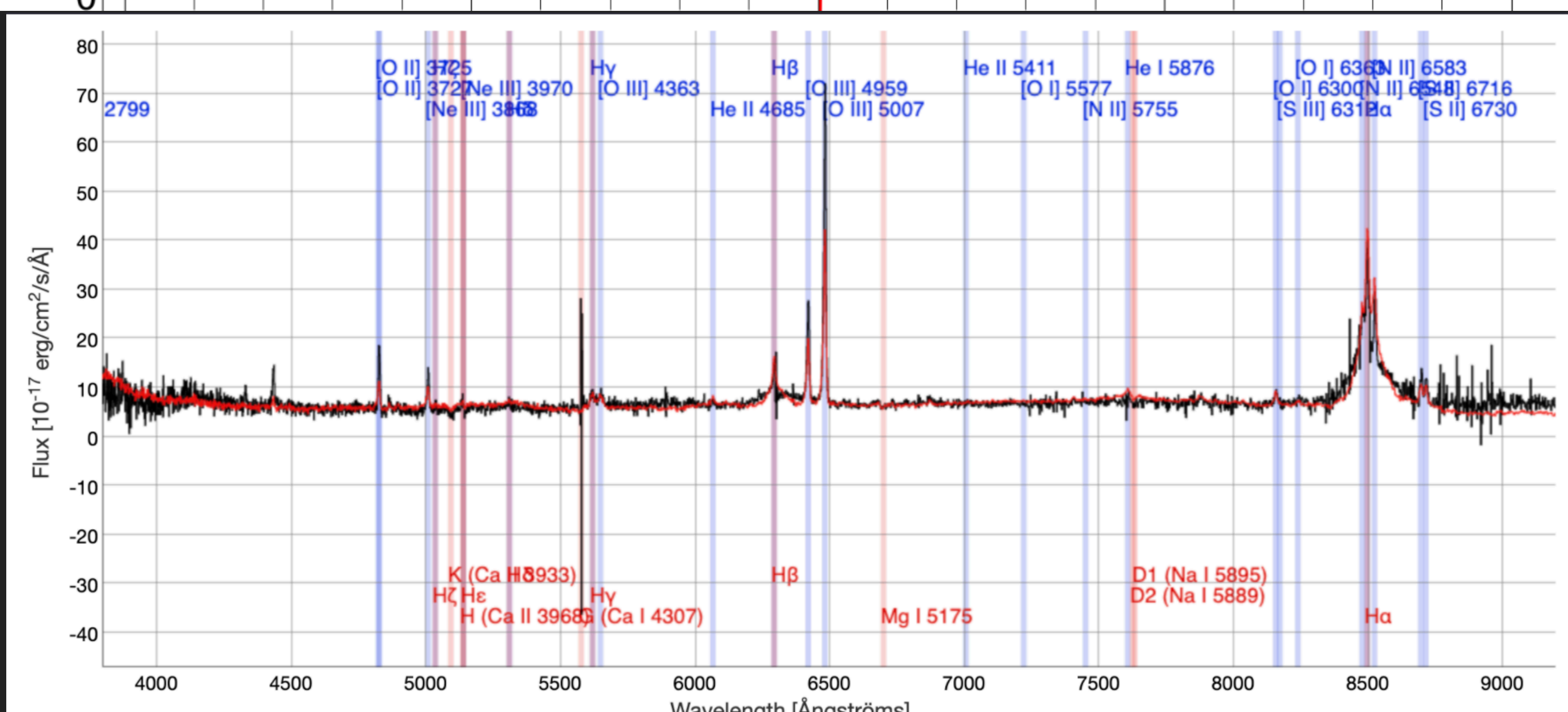




z=0.1426

FOLLOW-UP SPECTROSCOPY 172322 (TURN-ON)



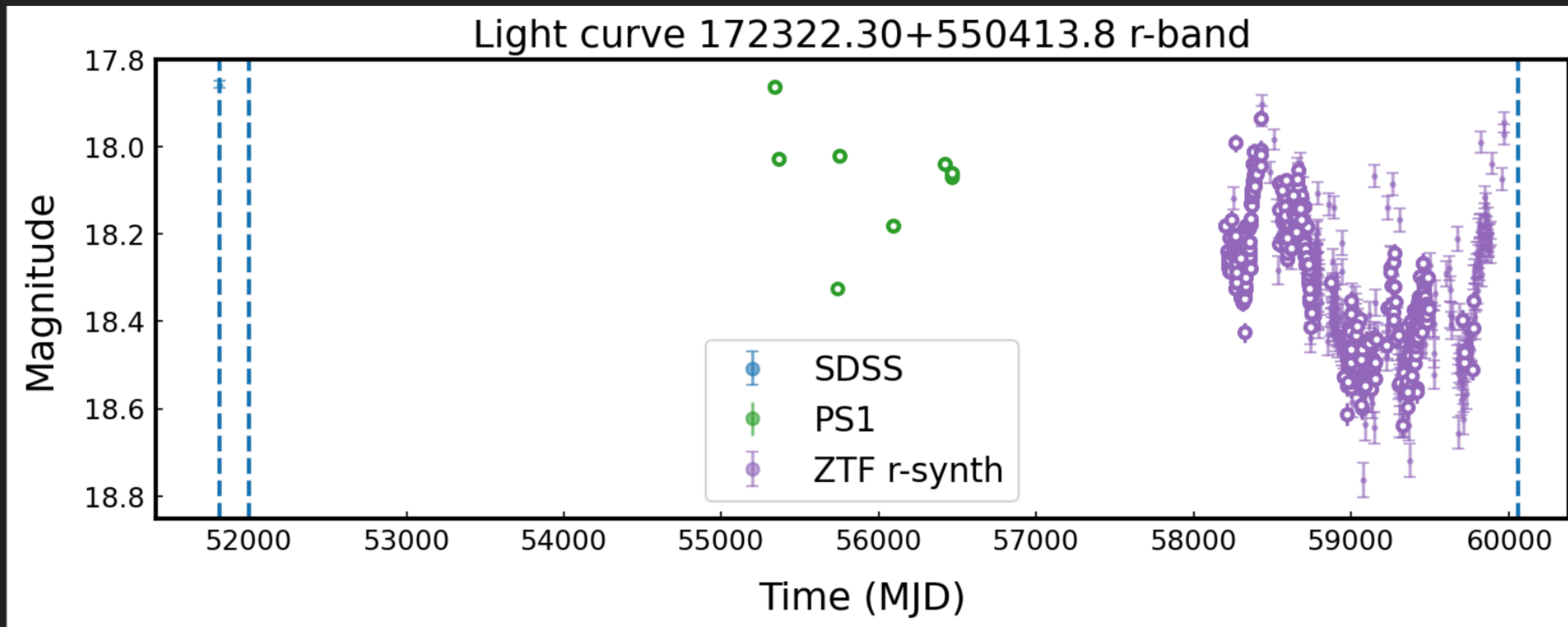


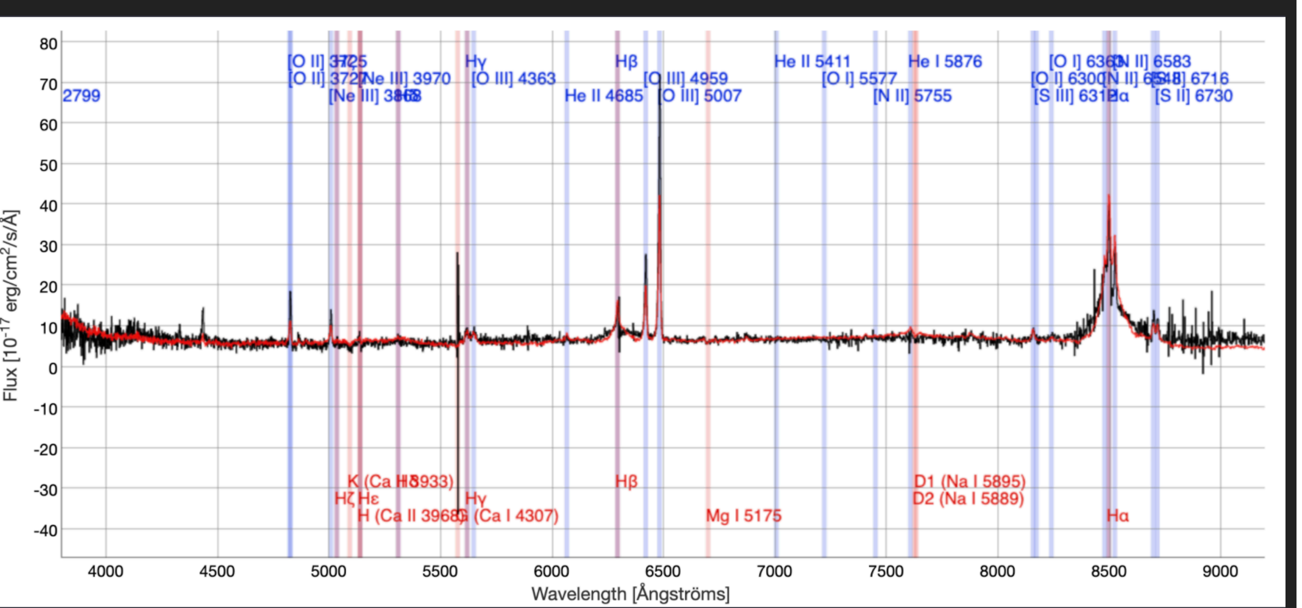
Potts-Villforth+2021, Fig.2

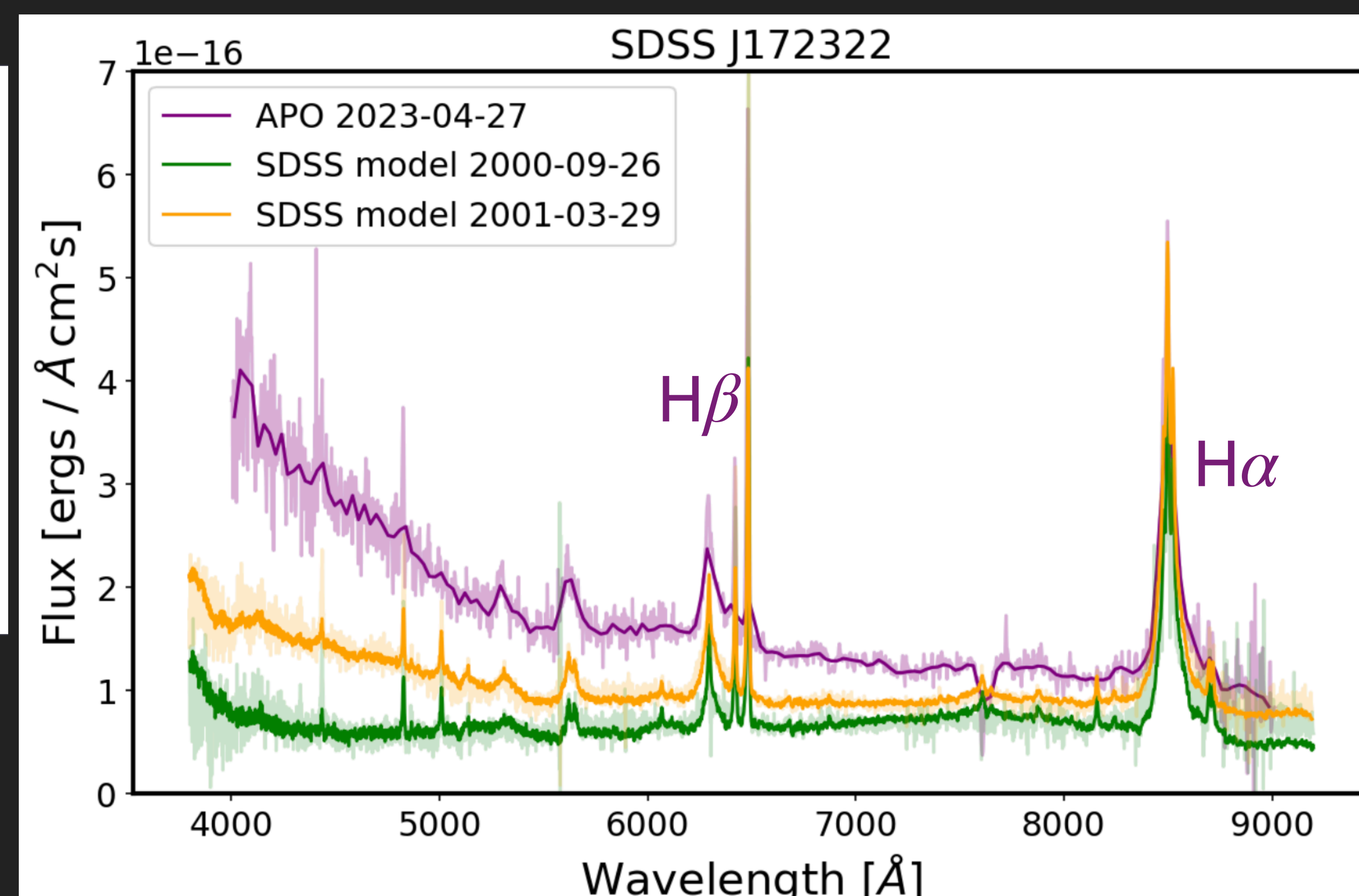
172322 transitioned from AGN type 1.83 to type 1 in just 184 days (142 in rest frame).

MJD51813: weak Hβ
MJD51997: stronger Hβ and Hα.

FOLLOW-UP SPECTROSCOPY 172322 (TURN-ON)

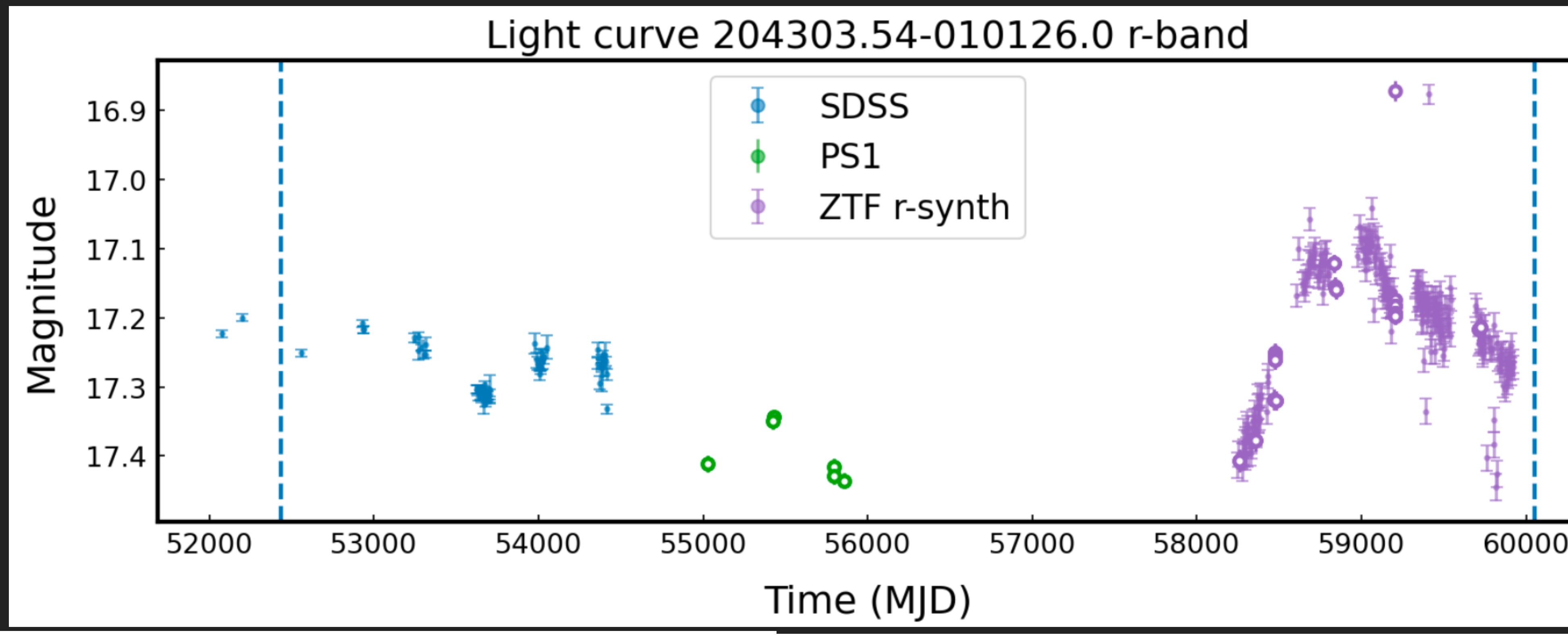




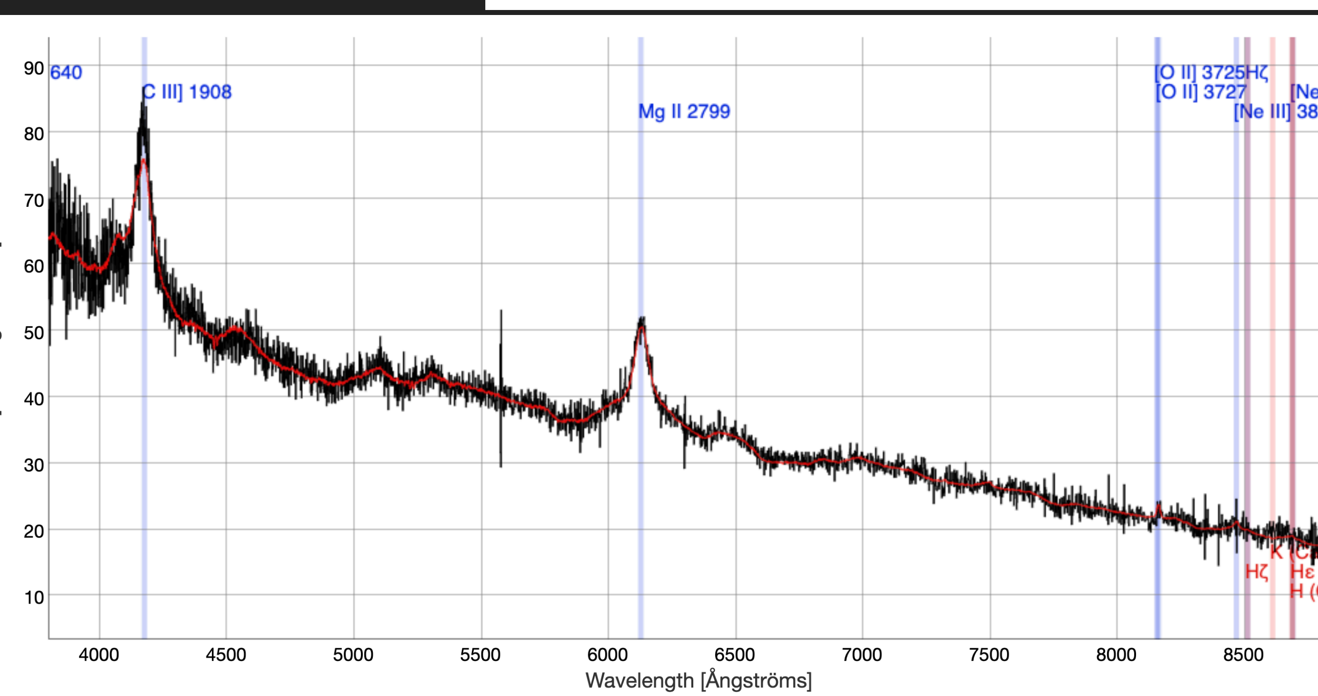


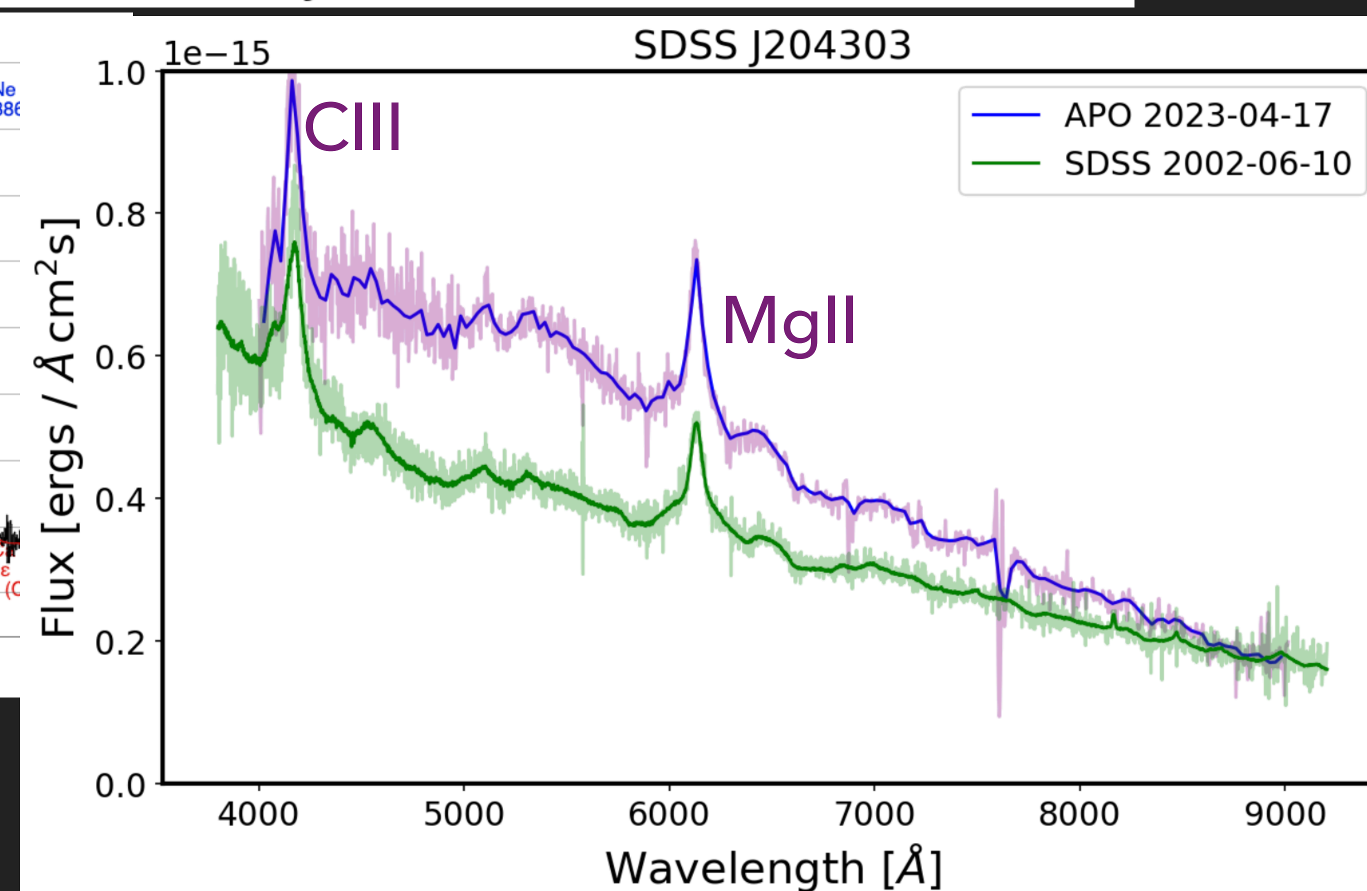
APO shows continued "turn on" trend

SPECTROSCOPY: J204303 (S82)



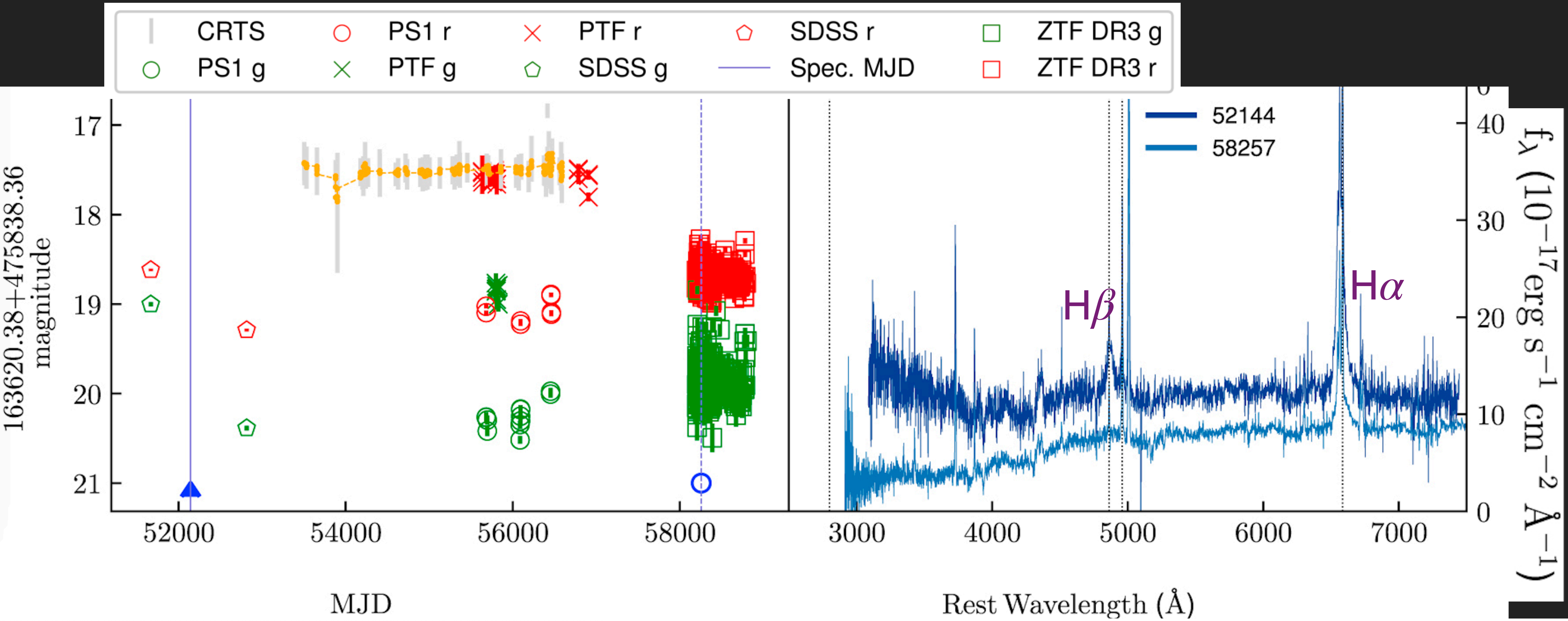
z=1.19

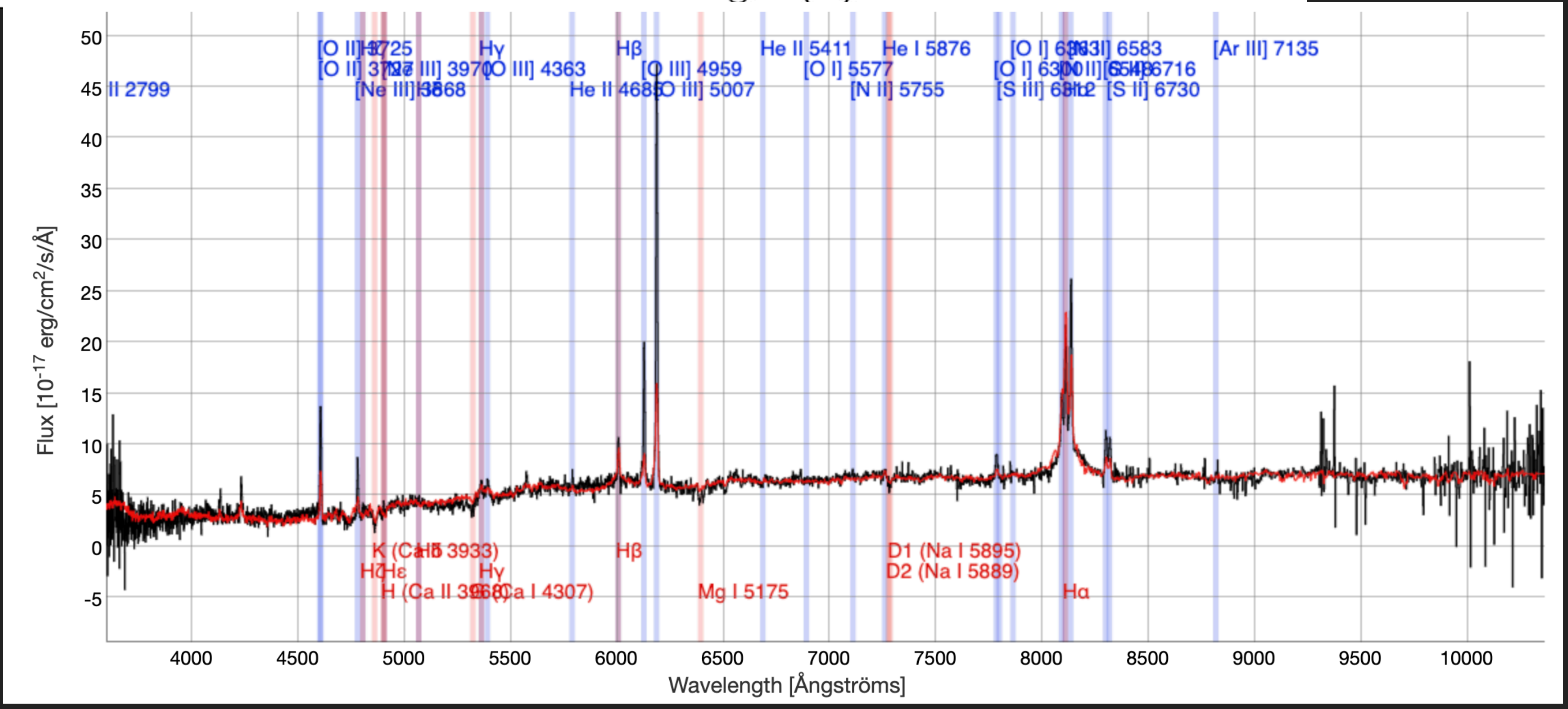




APO shows stronger blue continuum

FOLLOW-UP SPECTROSCOPY 163620 (TURN-OFF)





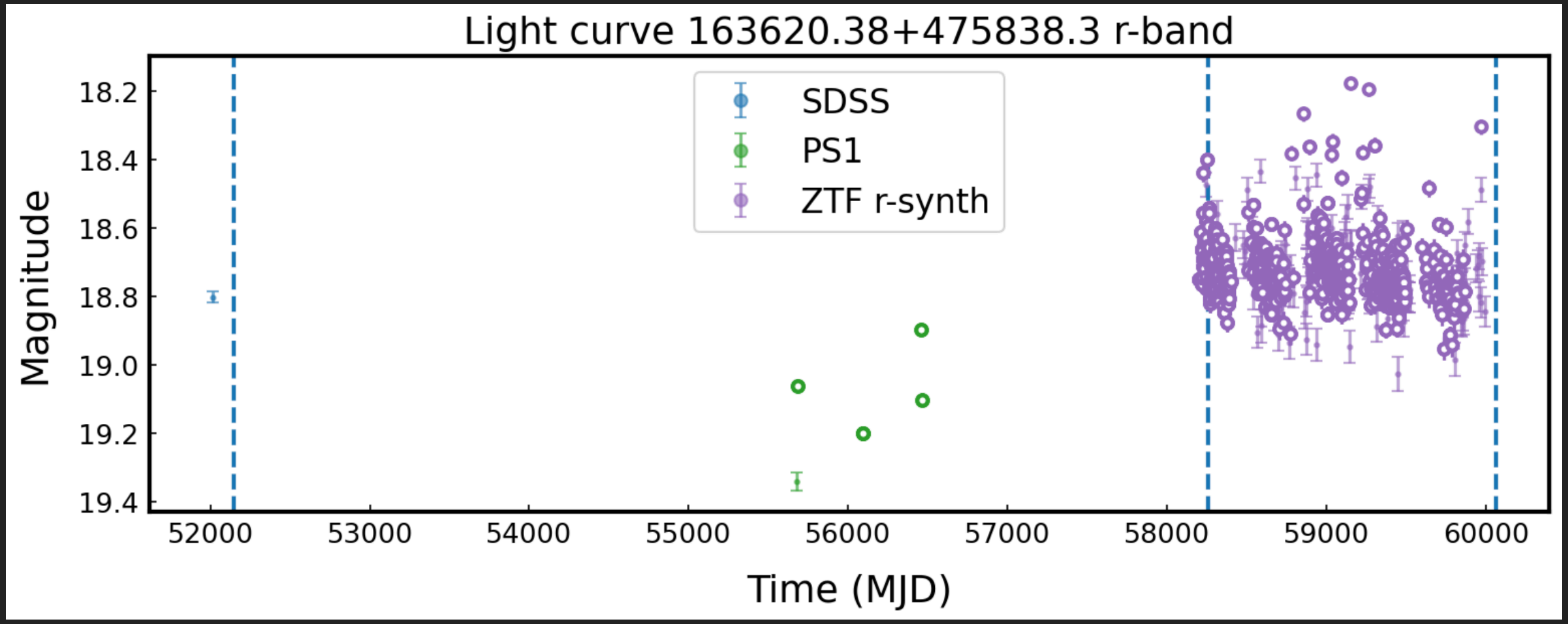
z=0.236

SDSS BOSS vs eBOSS:

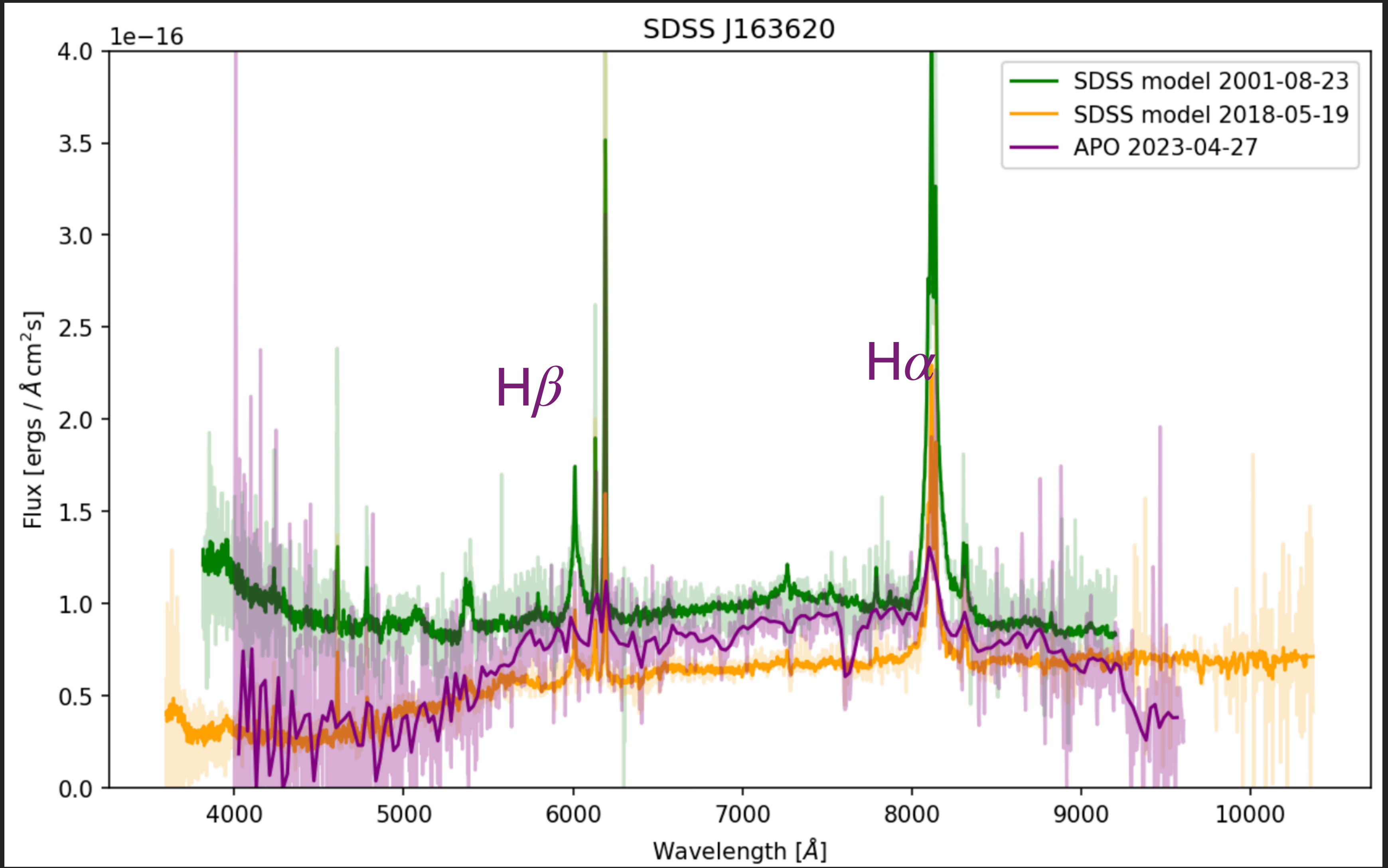
disappearance of Hβ

Green+2022, Fig.1.4

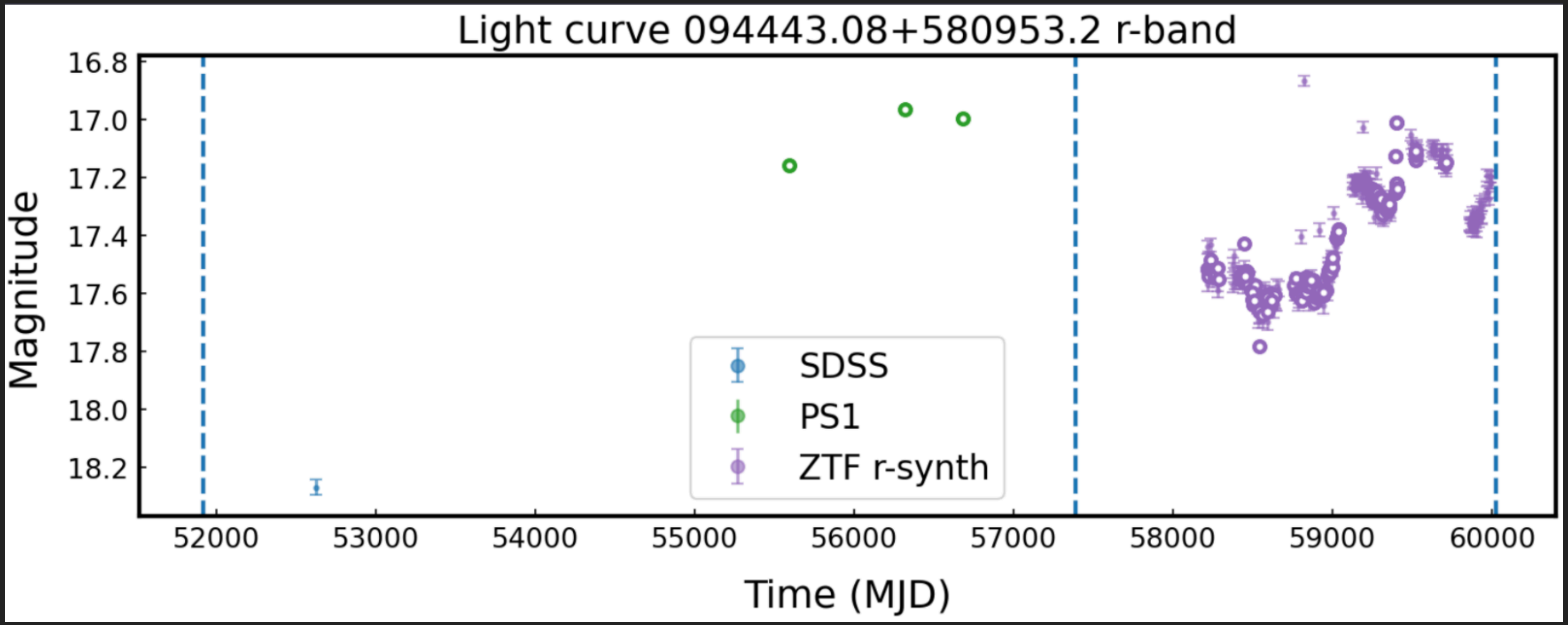
FOLLOW-UP SPECTROSCOPY 163620

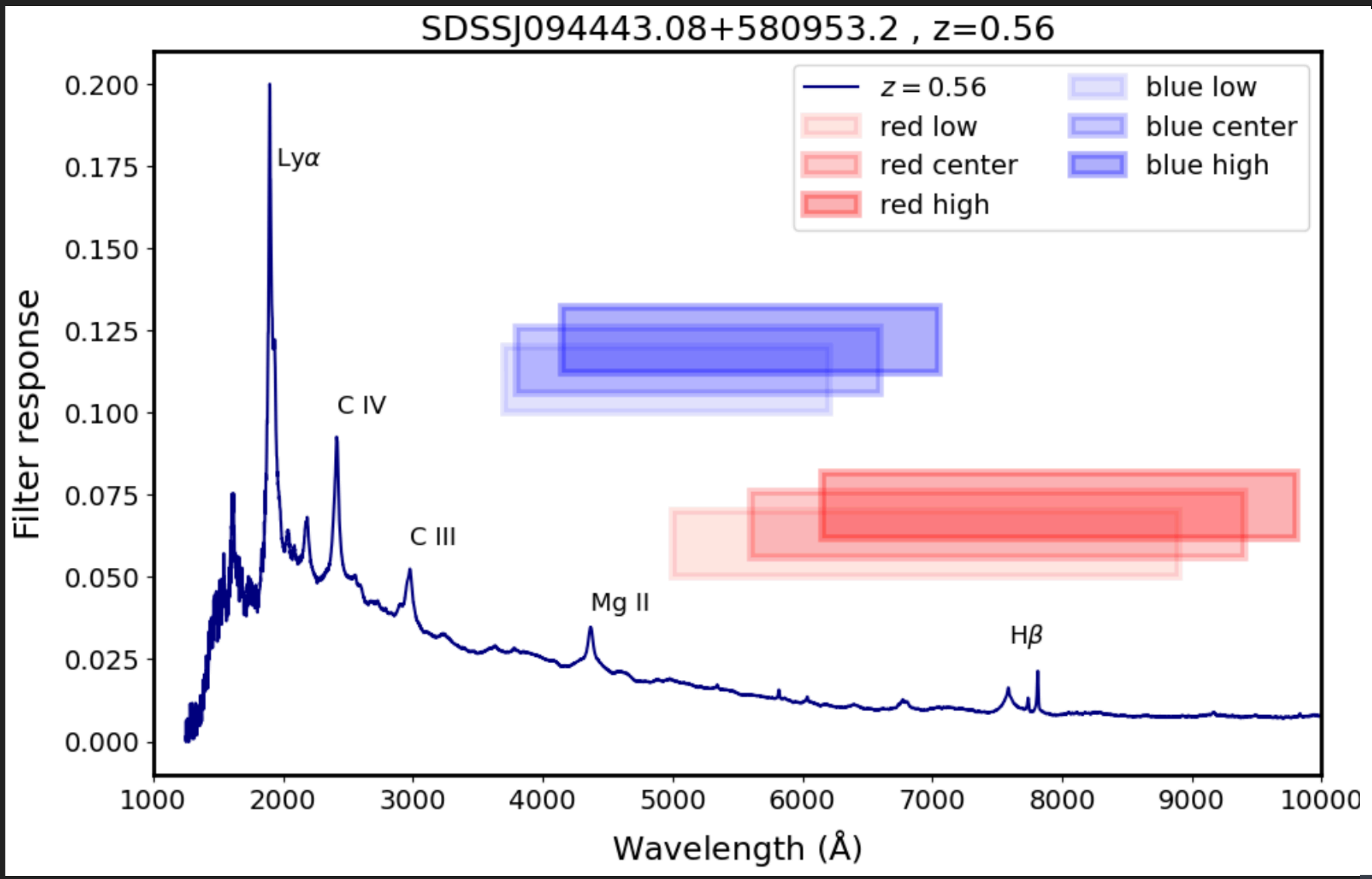


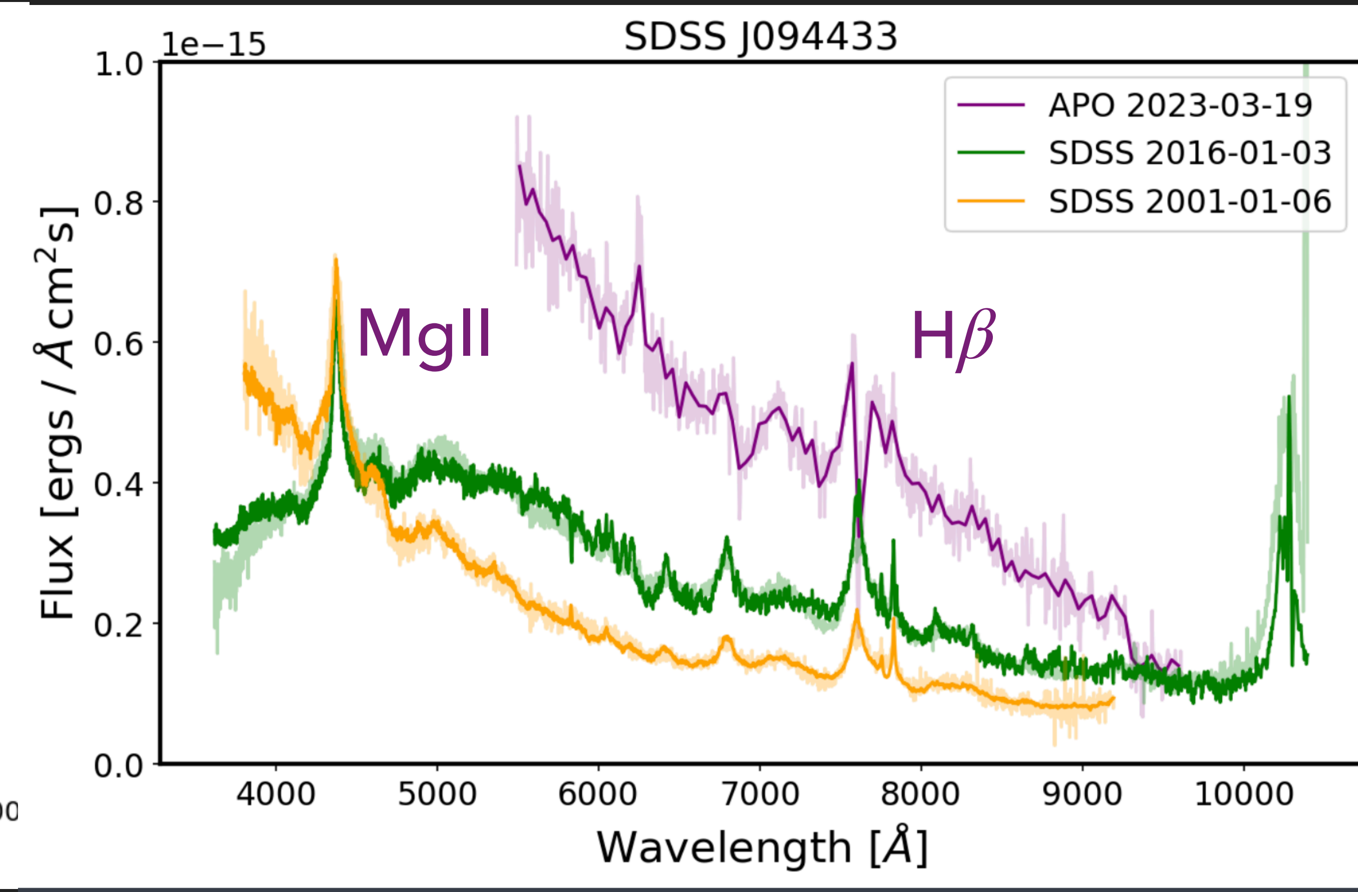
APO data:
Weak Hα,
continuum
returning
to earlier level



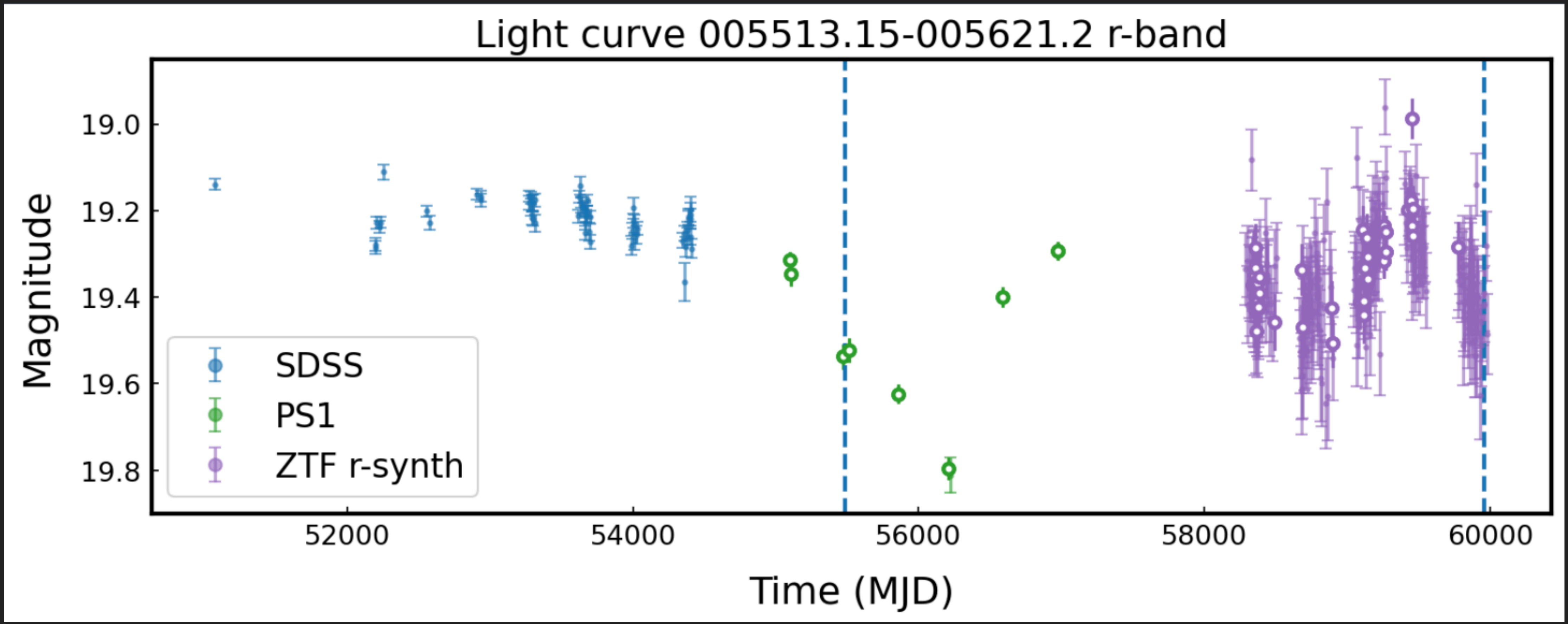
FOLLOW-UP SPECTROSCOPY 094433

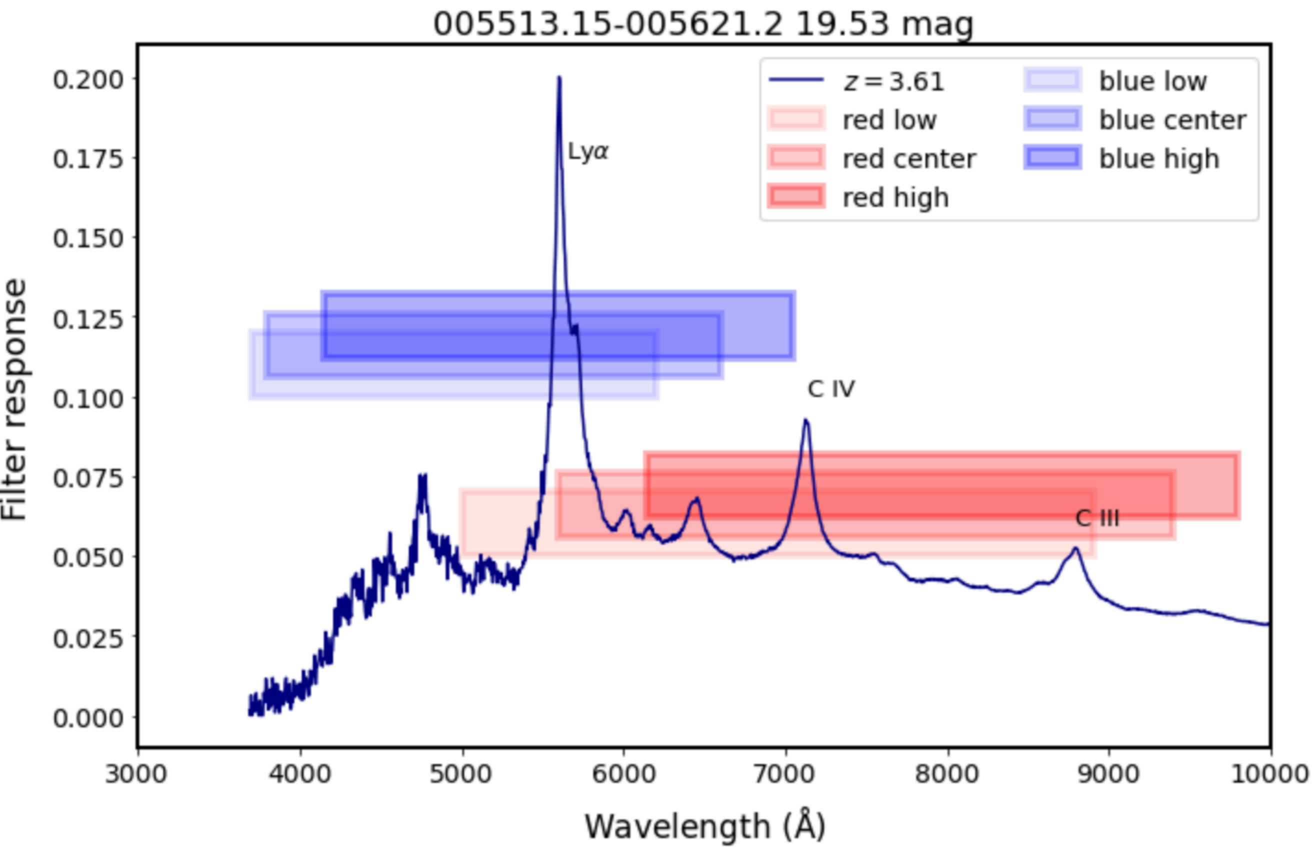


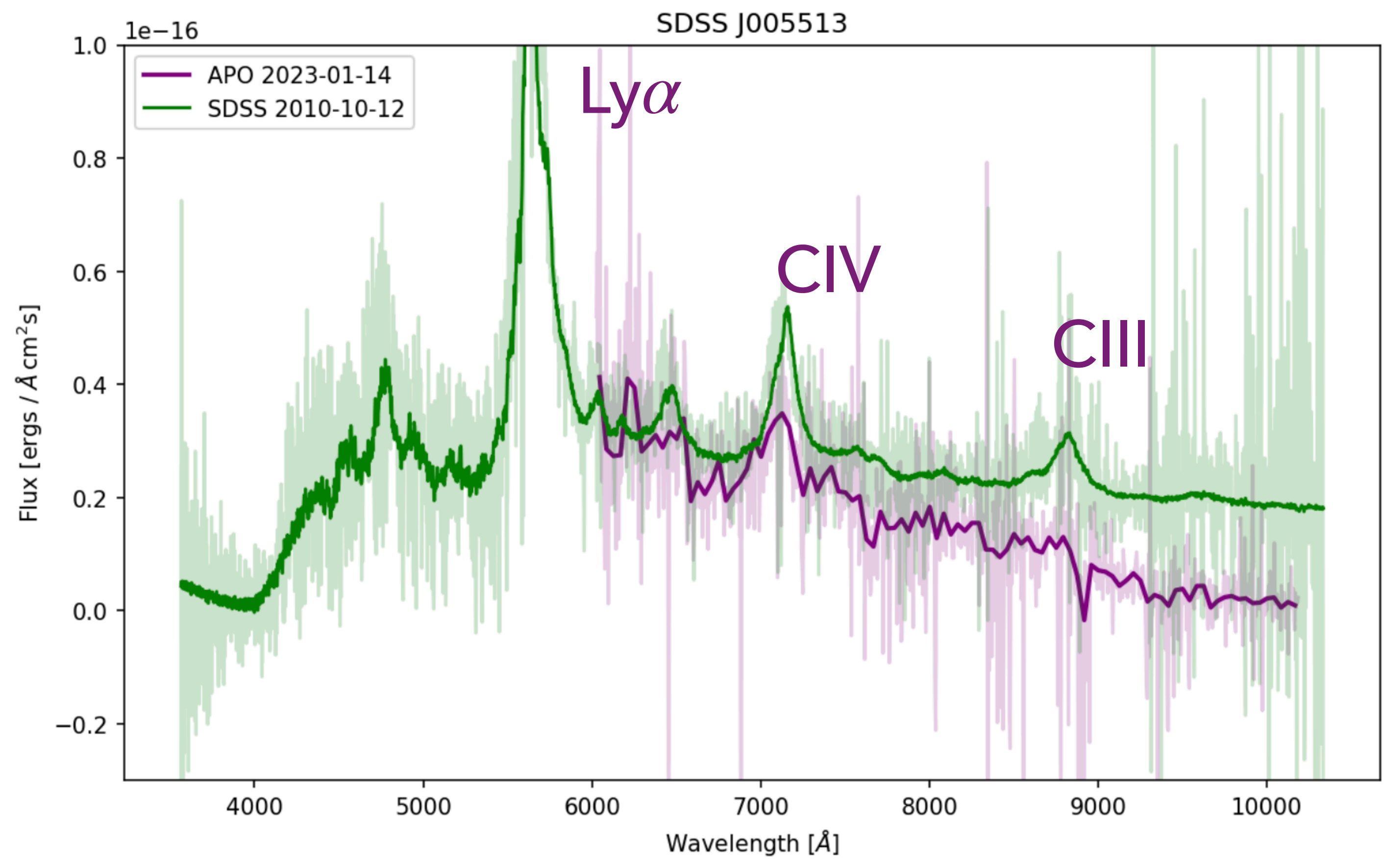




FOLLOW-UP SPECTROSCOPY: 005513 (S82)







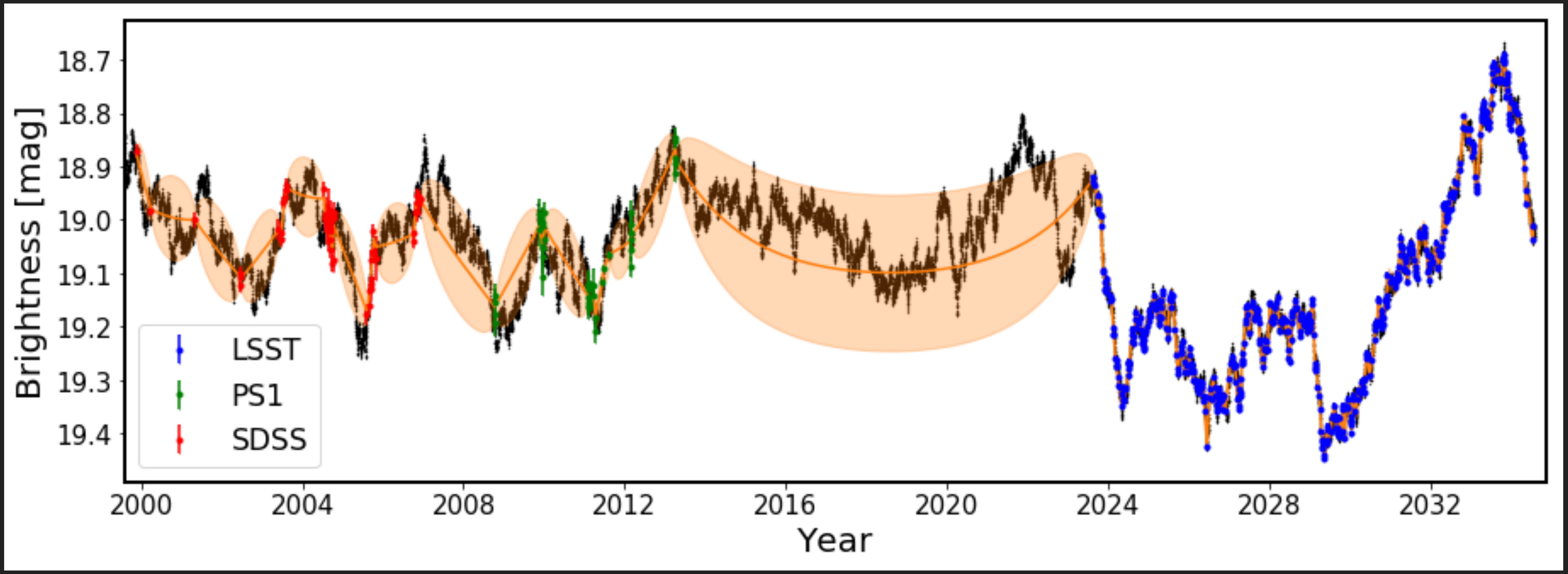
QSO SCIENCE: CONCLUSIONS

- Quasars are stochastically variable at the level of 0.2 mag
- Distinct variability pattern can be used to distinguish quasars from other variable objects
- Variability parameters can be linked to physical quantities such as the black hole mass, bolometric luminosity
- Combining SDSS, PS1, and (soon) LSST, we can recover quasar DRW parameters with much higher accuracy than before (and find interesting outliers in the process)

THANK YOU!

BACKUP SLIDES

BASELINE EXTENSION

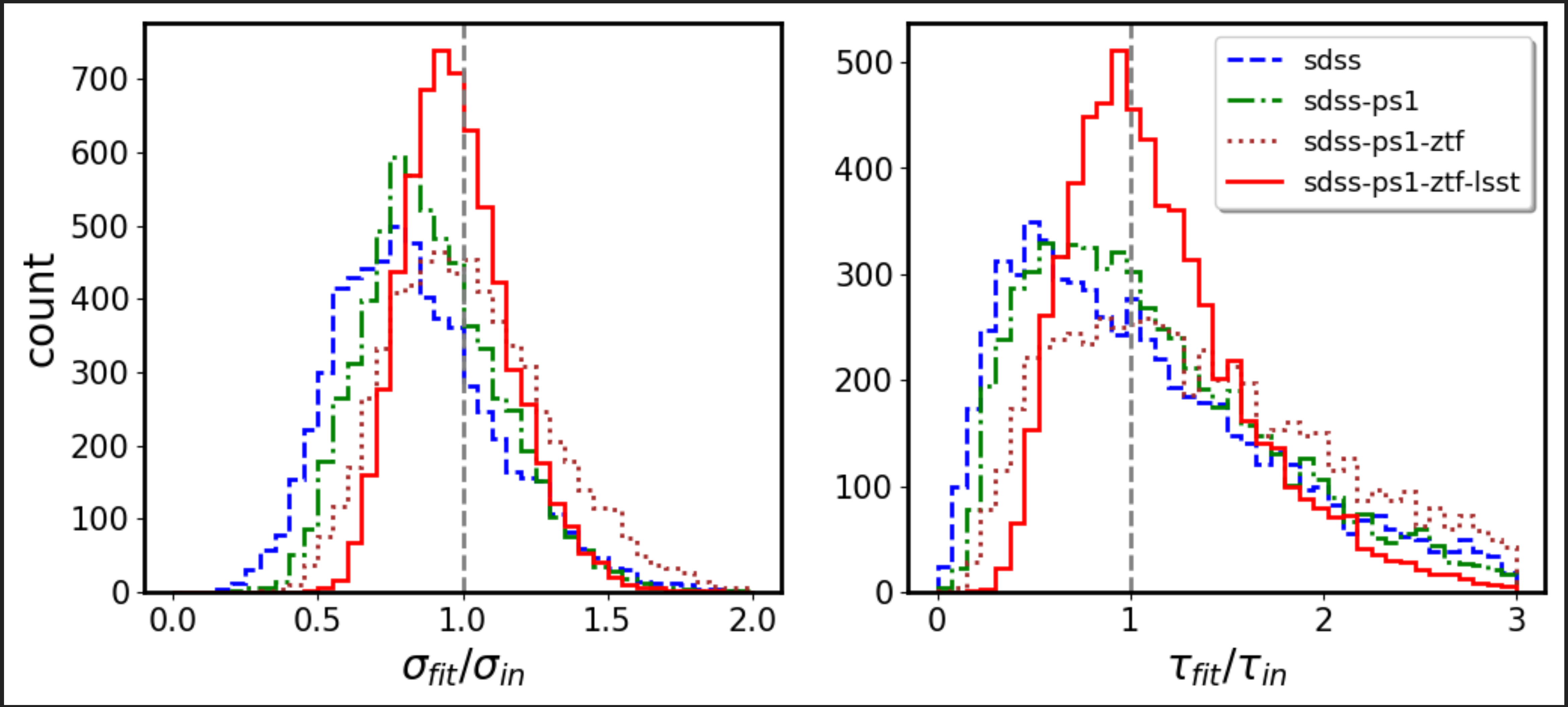


- simulated quasar light curves, single input timescale and variability amplitude, sampled at realistic cadence

Suberlak+2019

EXTENDING THE BASELINE : SIMULATION

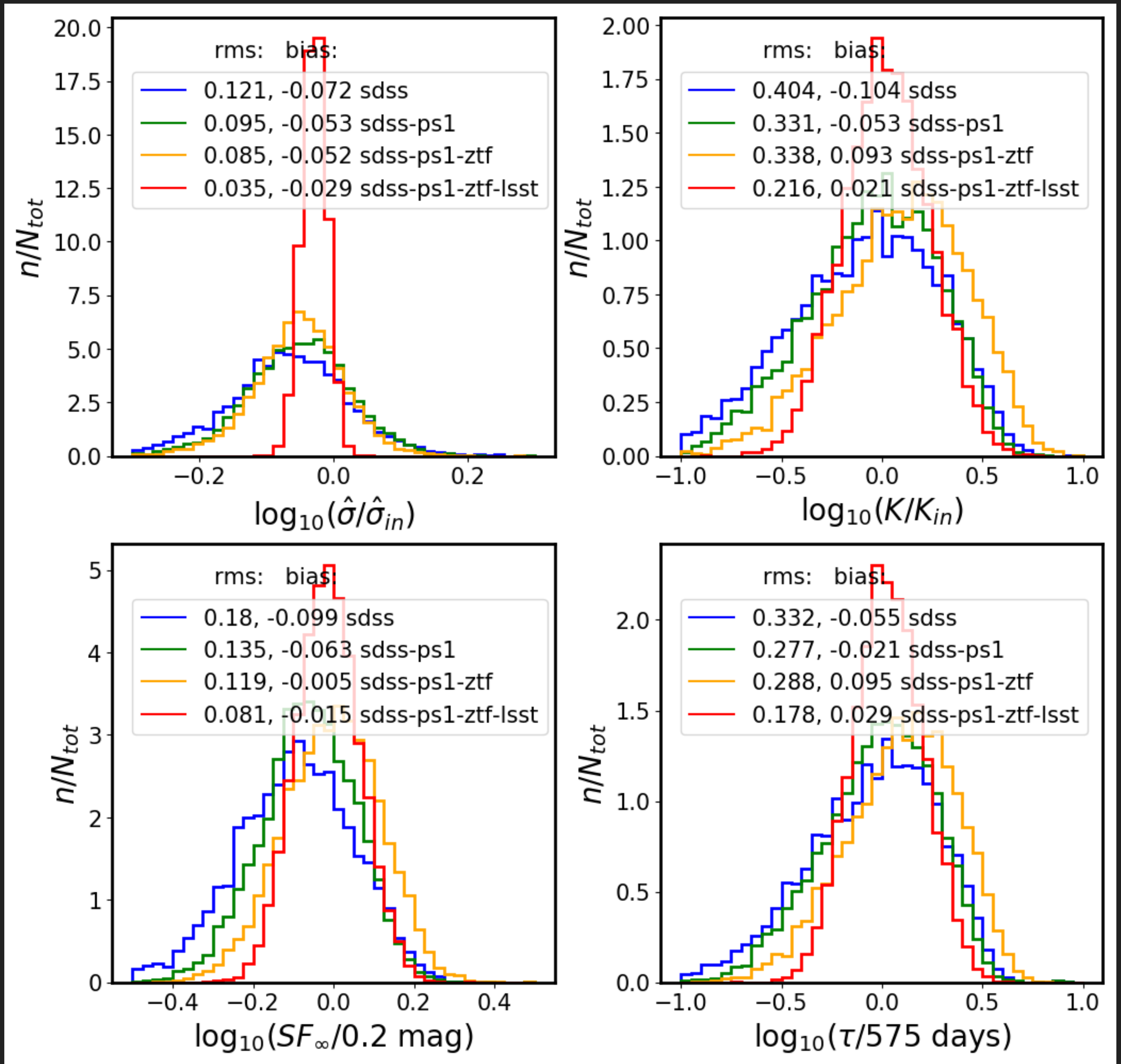
- DRW parameter recovery improves with baseline extension



- ZTF will make things better, but LSST will be awesome

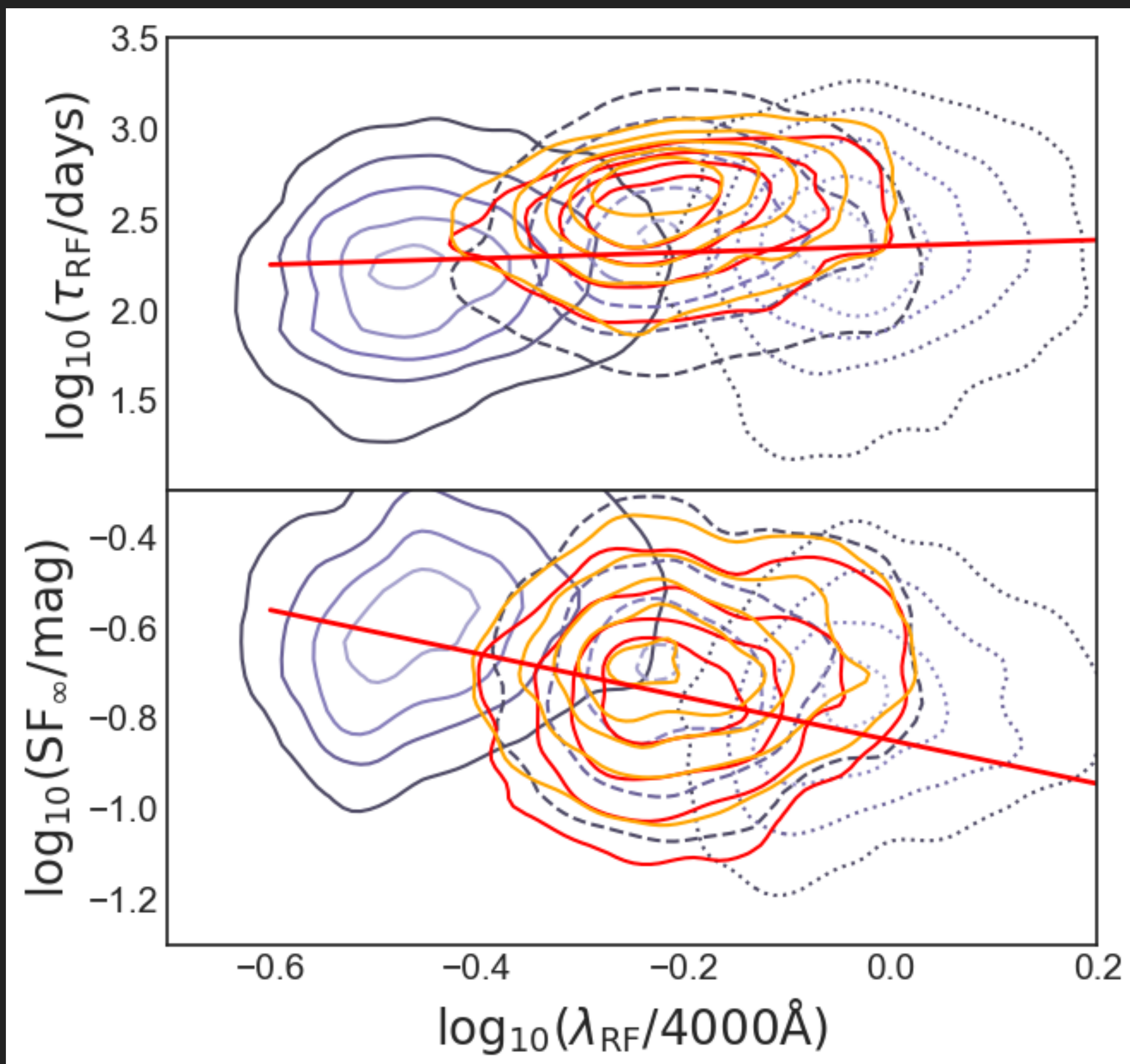
Suberlak+2019

EXTENDING THE BASELINE : SIMULATION



- ZTF will make things better, but LSST will be awesome
- we decided to not include ZTF due to color offset

FIRST, CORRECT FOR WAVELENGTH DEPENDENCE



- correct for wavelength-dependence: because SDSS ugriz bandwidths is fixed, the higher the redshift, the shorter the rest-frame wavelength probed

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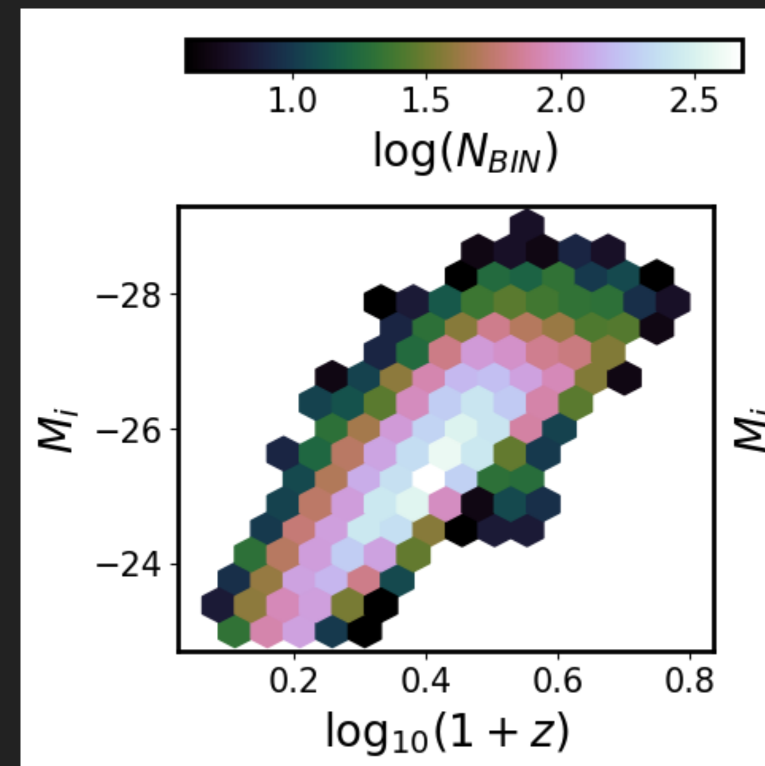
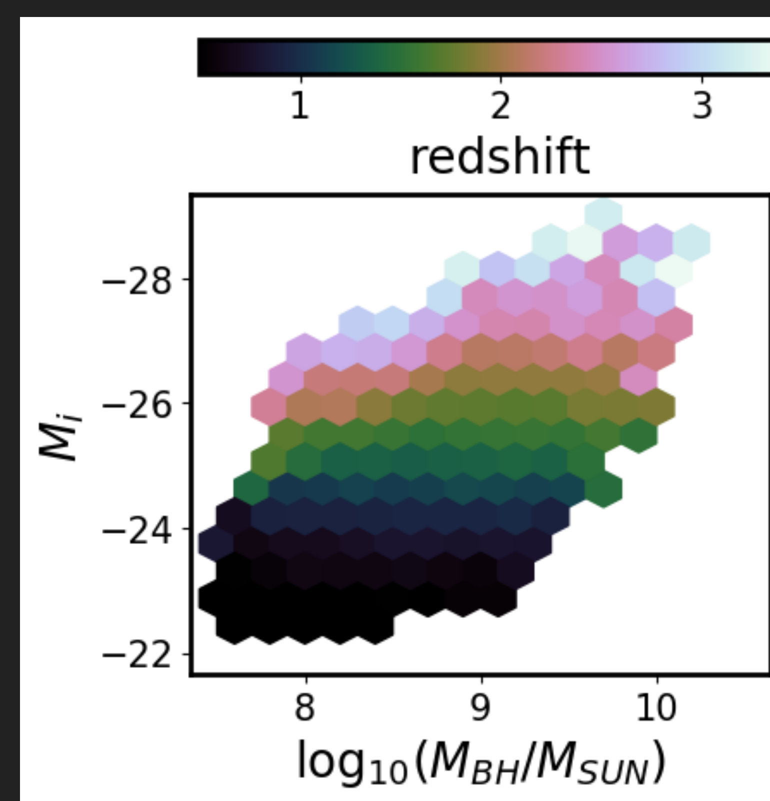
FIRST: UNDERSTAND INTRINSIC CORRELATIONS

- magnitude limit illusion, aka luminosity-redshift degeneracy - we see only the most luminous QSO (magnitude limit)



- L-z degeneracy is independent of black hole mass



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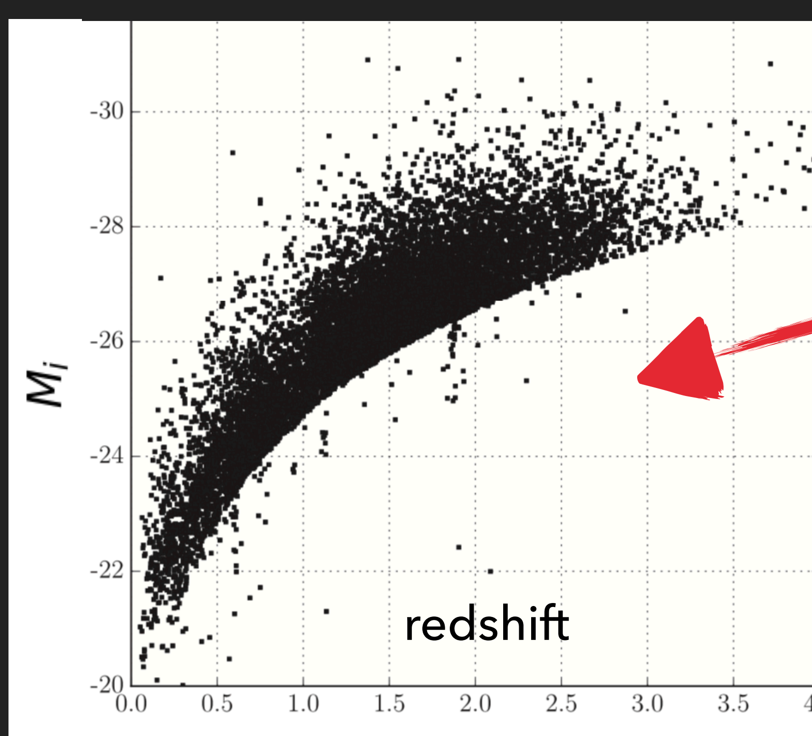
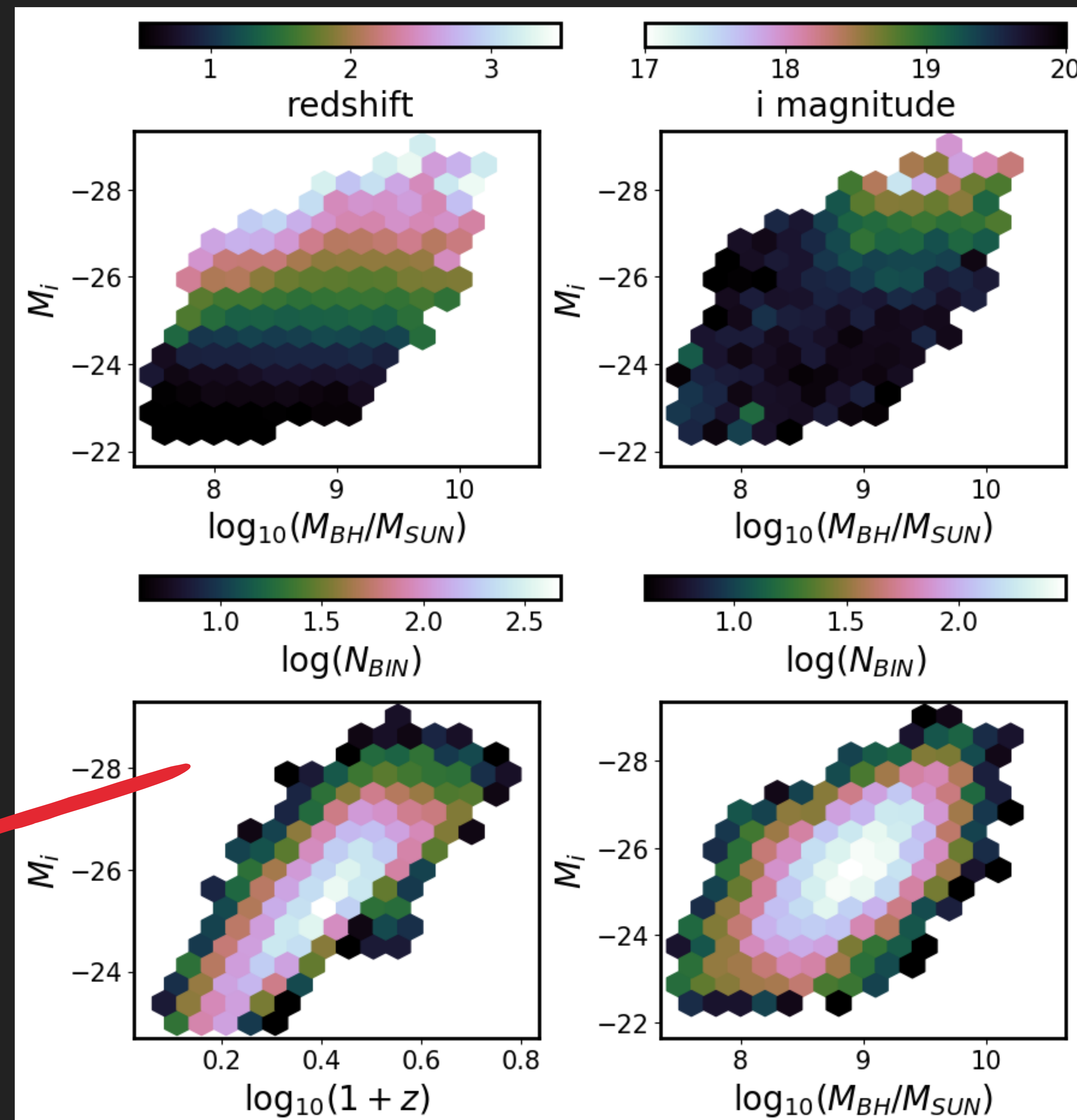
QUASAR PROPERTIES

- luminosity-redshift degeneracy - we see only the most luminous QSO (magnitude limit) - independent of black hole mass
- shorter rest-frame wavelength probed at higher redshifts

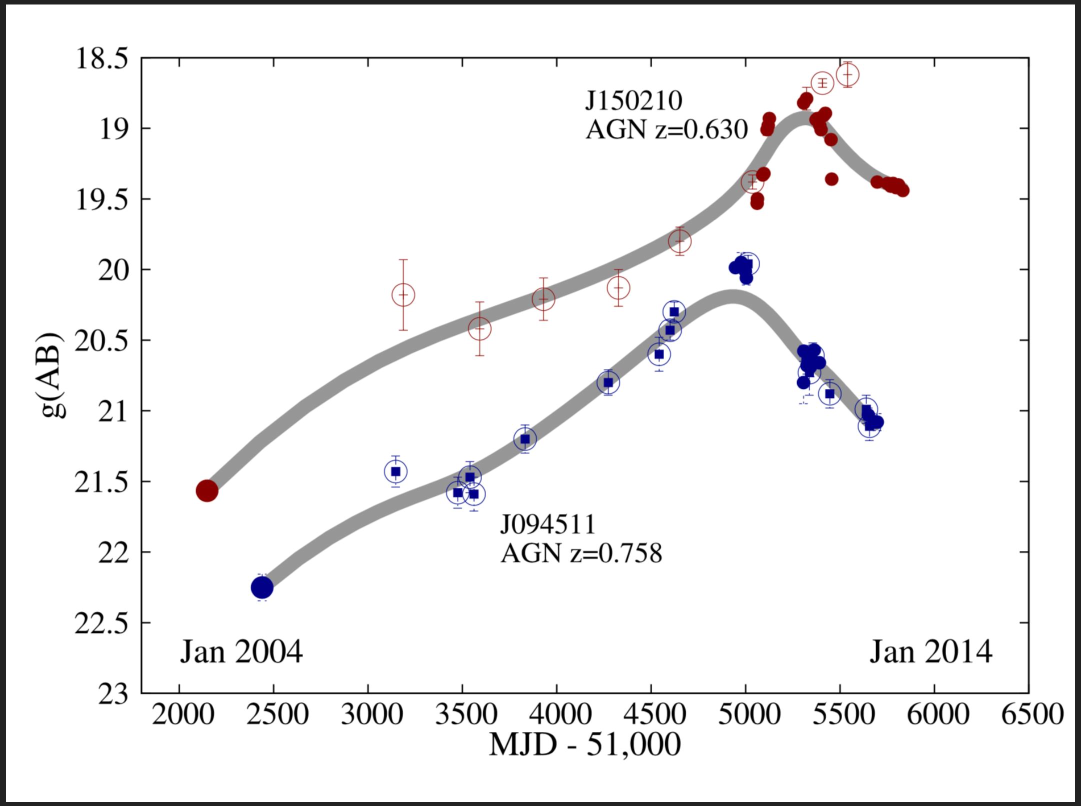




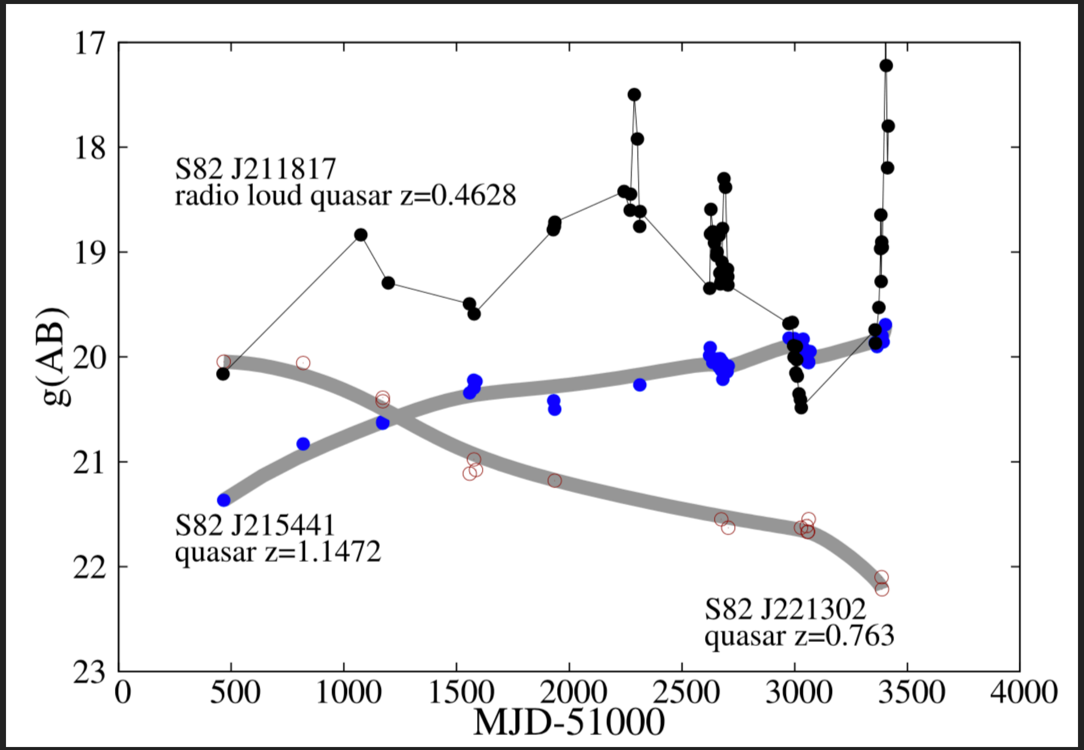
Dong+2018

CLQSO EXAMPLES

CLQSO: LAWRENCE+2016

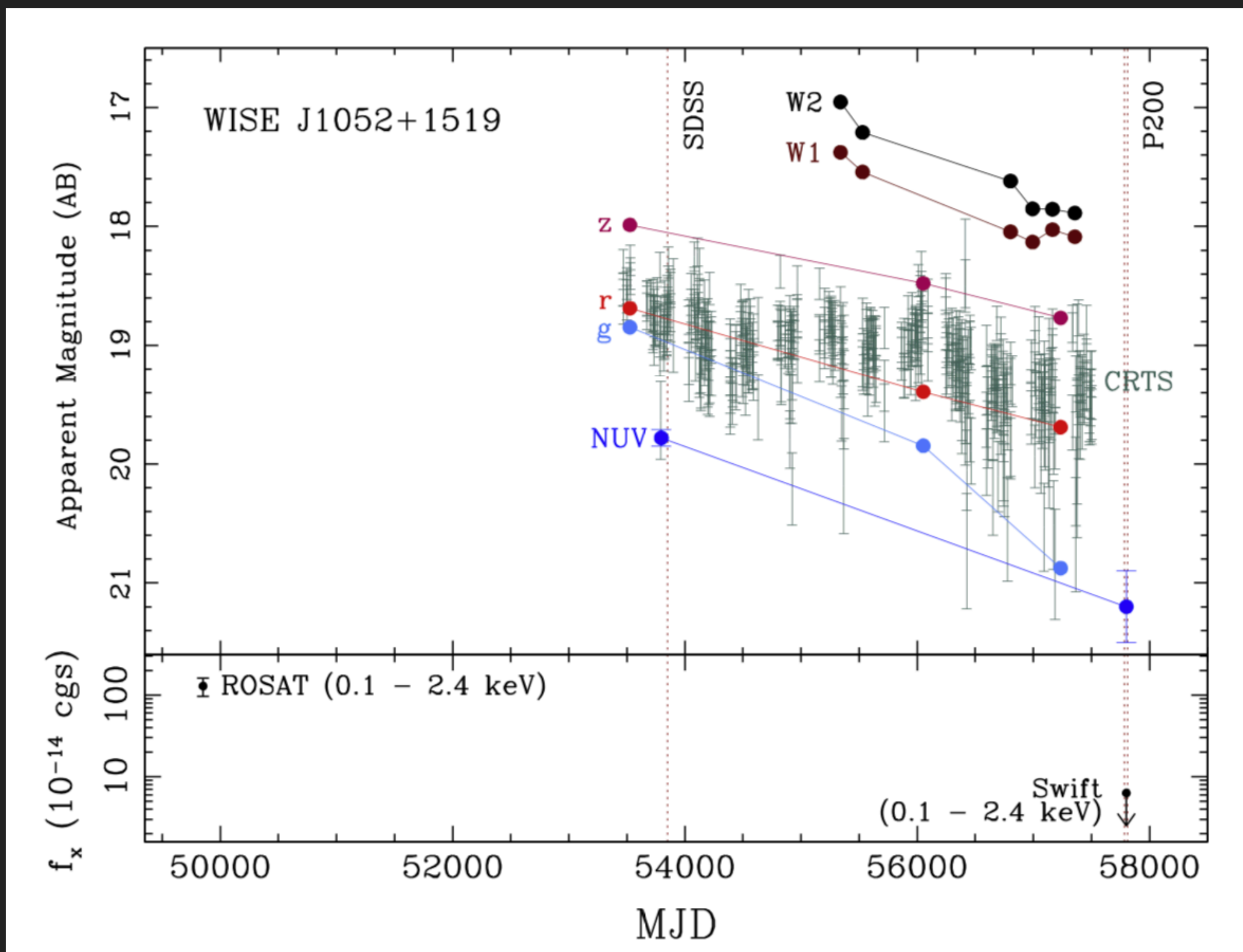


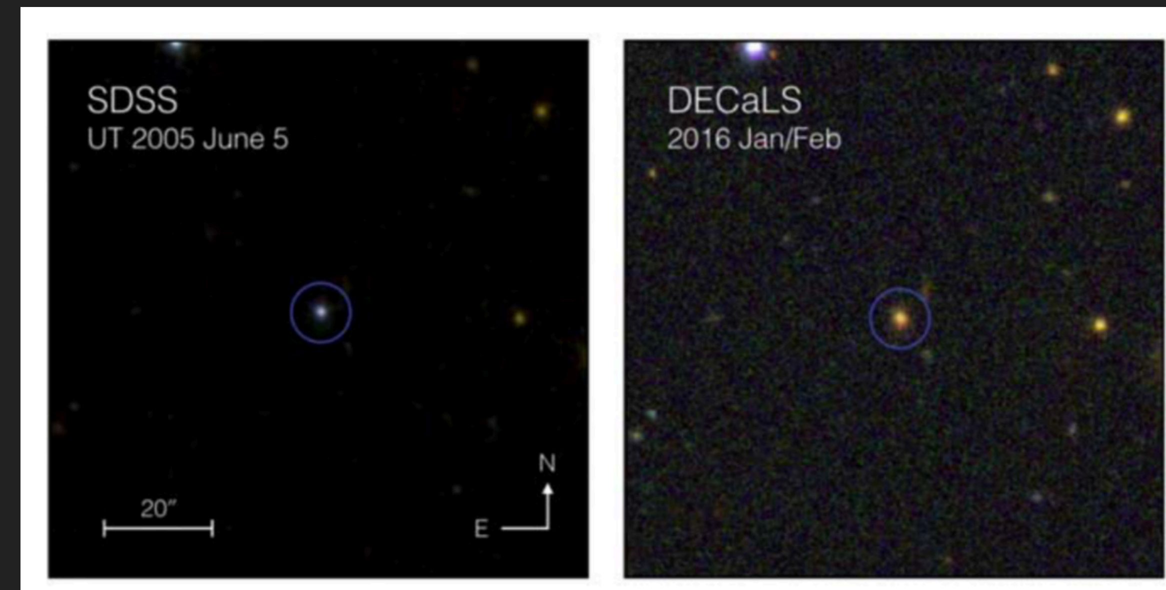
Lawrence+2016, Fig.7

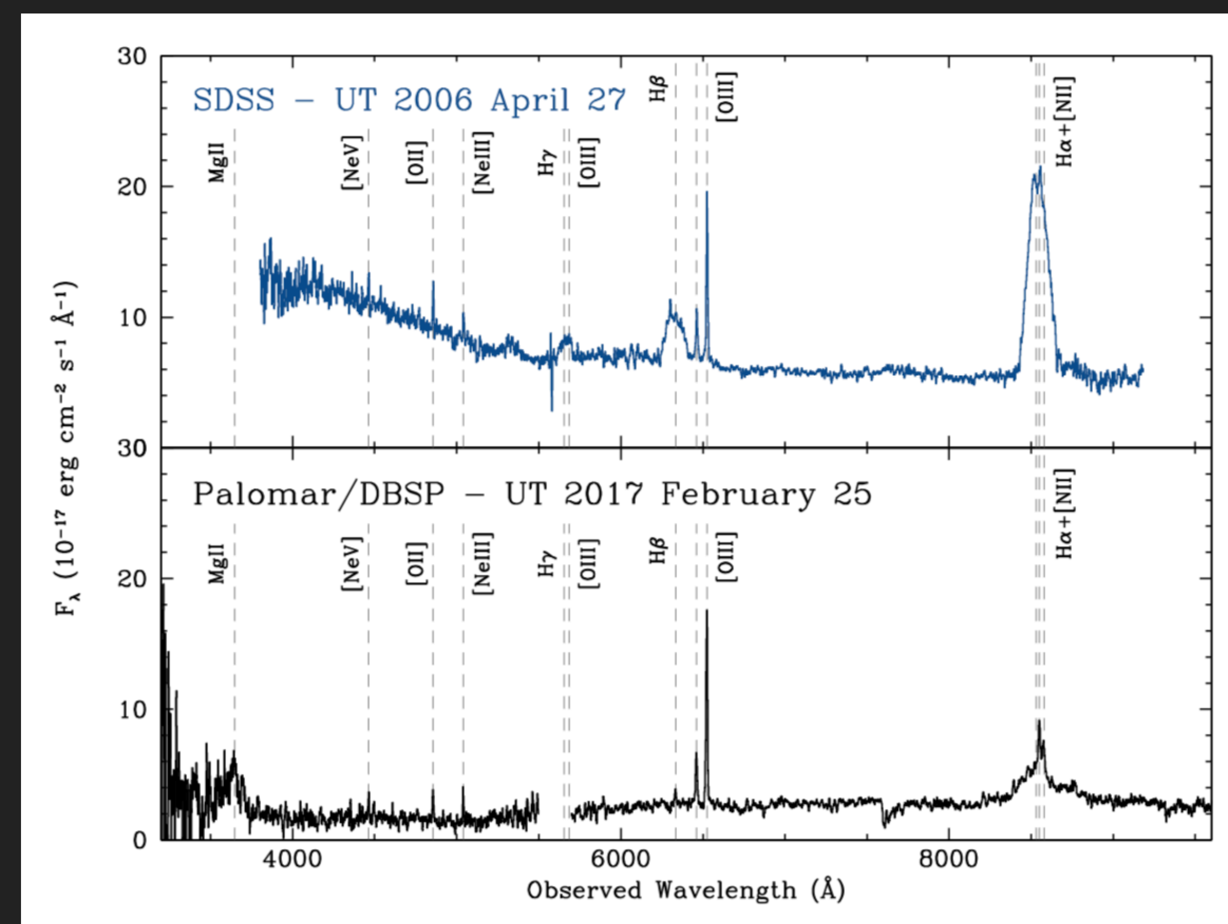


Lawrence+2016, Fig.14

CLQSO EXAMPLES: STERN+2018





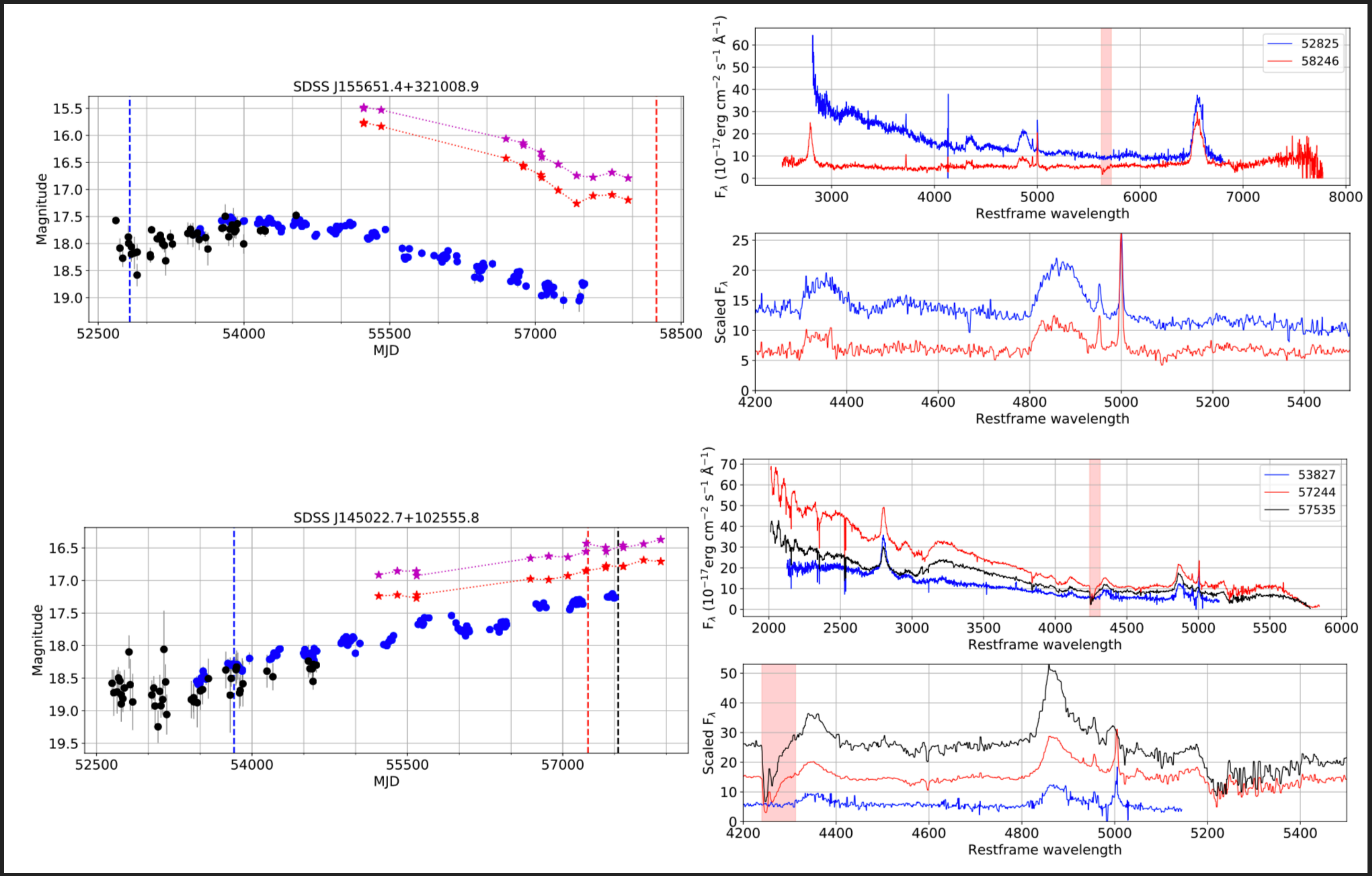


~~TDE~~ ~~lensing~~

~~dust~~ ~~flares~~

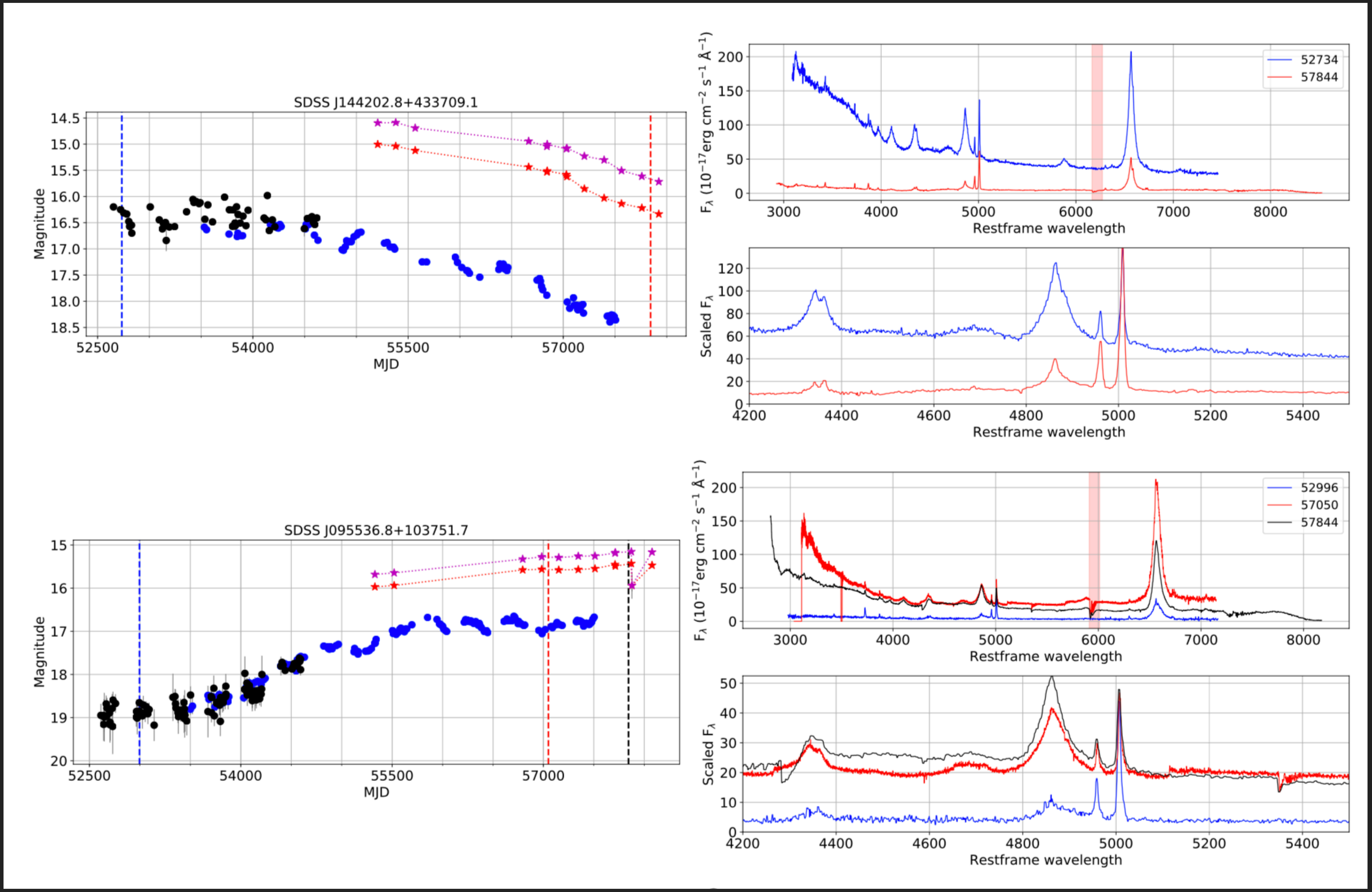
Stern+2018,Figs. 2,3,4

CLQSO: GRAHAM+2019



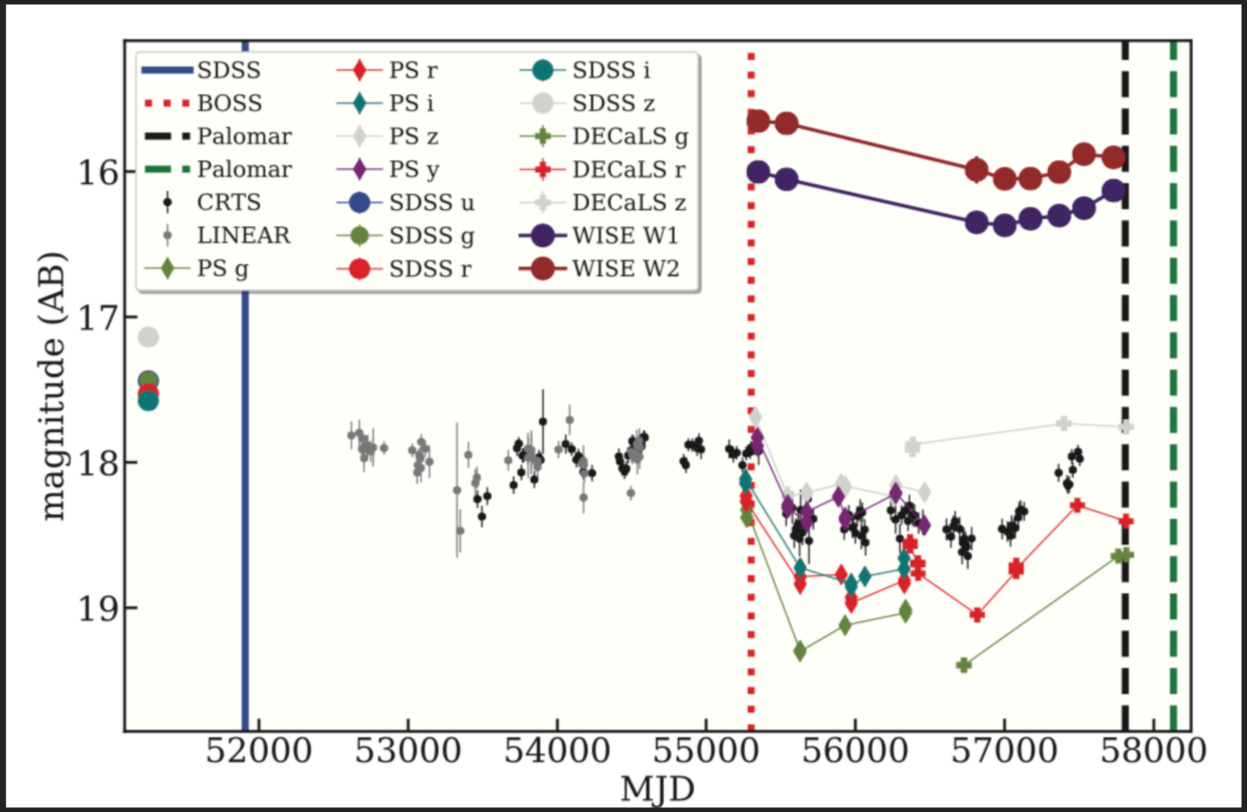
Graham+2019, Fig.5

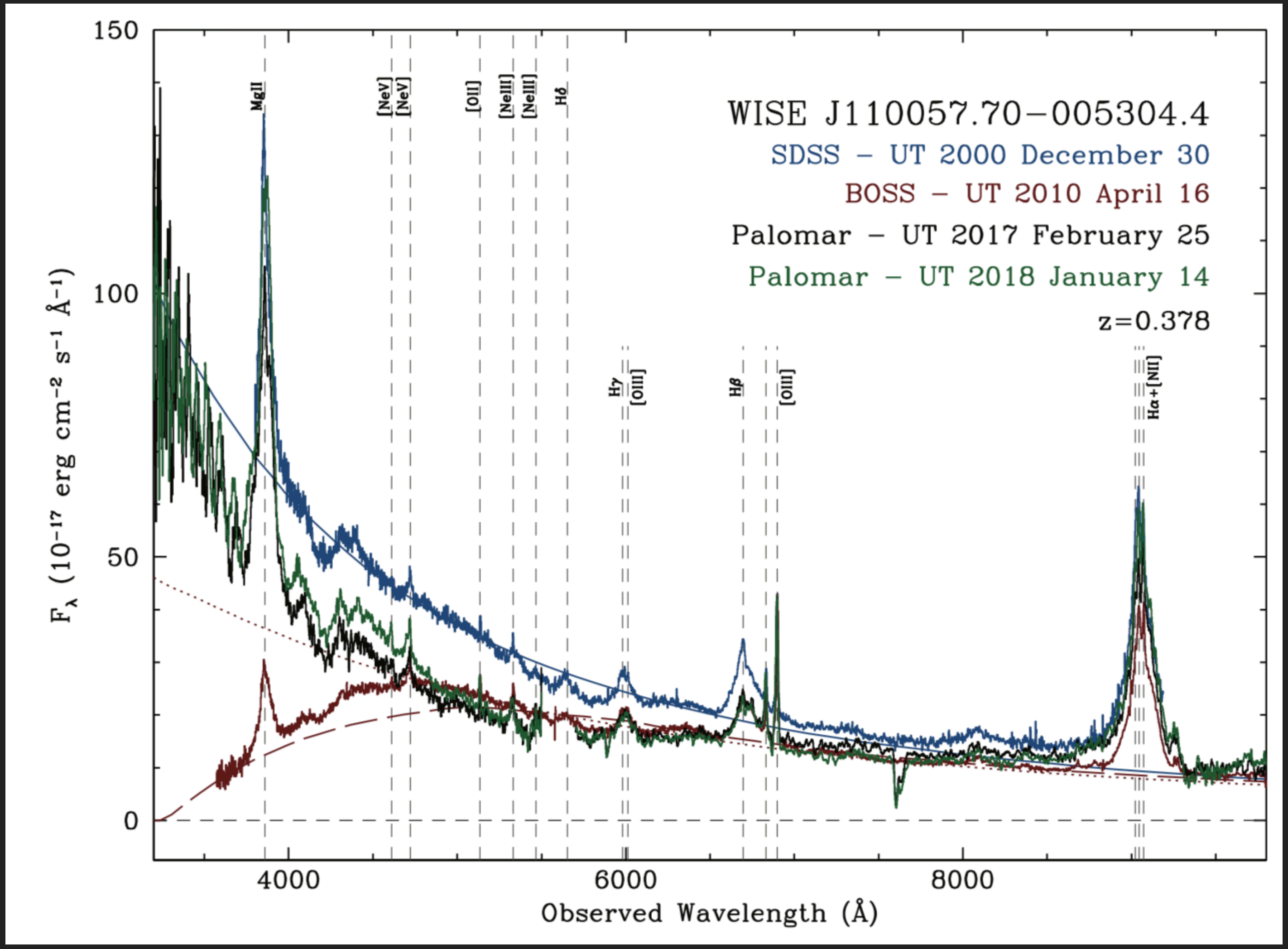
APPLICATION: OUTLIERS ARE INTERESTING



Graham+2019, Fig.5

CLQSO: ROSS+2018





Ross+2018, Fig.1,2