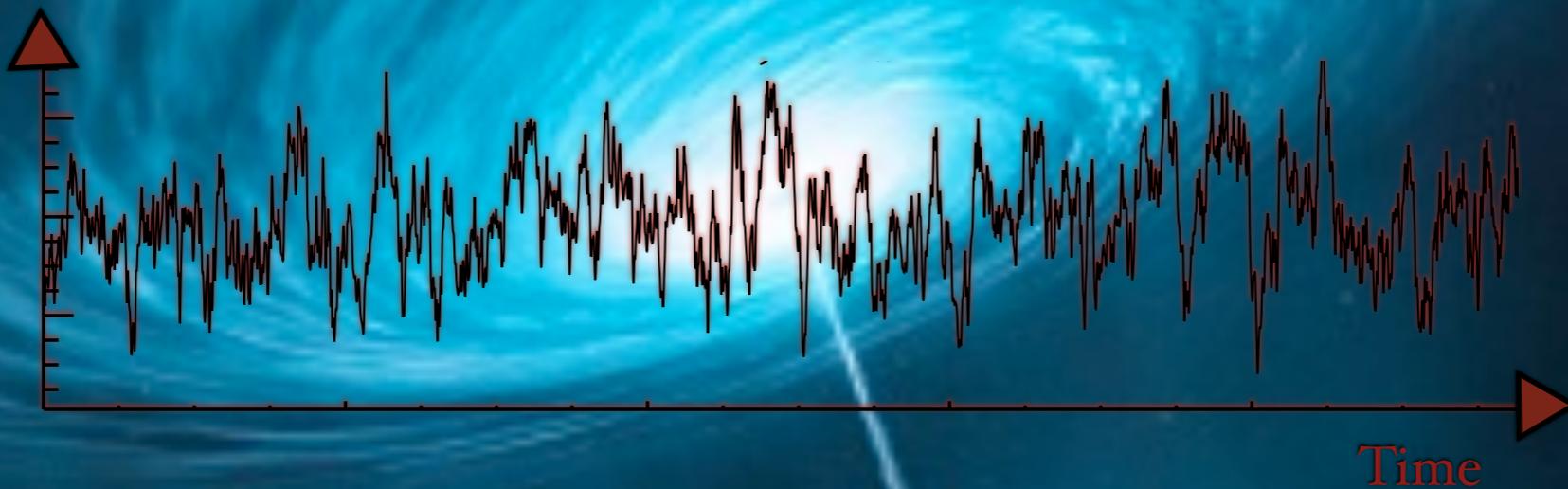


Spectroscopic Followup of Changing-Look Quasar Candidates



Chelsea MacLeod

Unveiling the Physics Behind Extreme AGN Variability – 11 July 2017

In collaboration with:

Paul Green (CfA), Nic Ross (ROE) , David Homan (ROE),
Alastair Bruce (ROE), Andy Lawrence (ROE), John Ruan
(UW), Jessie Runnoe(UMich), Michael Eracleous (PSU), Scott
Anderson (UW), Matthew Graham (Caltech)



SDSS

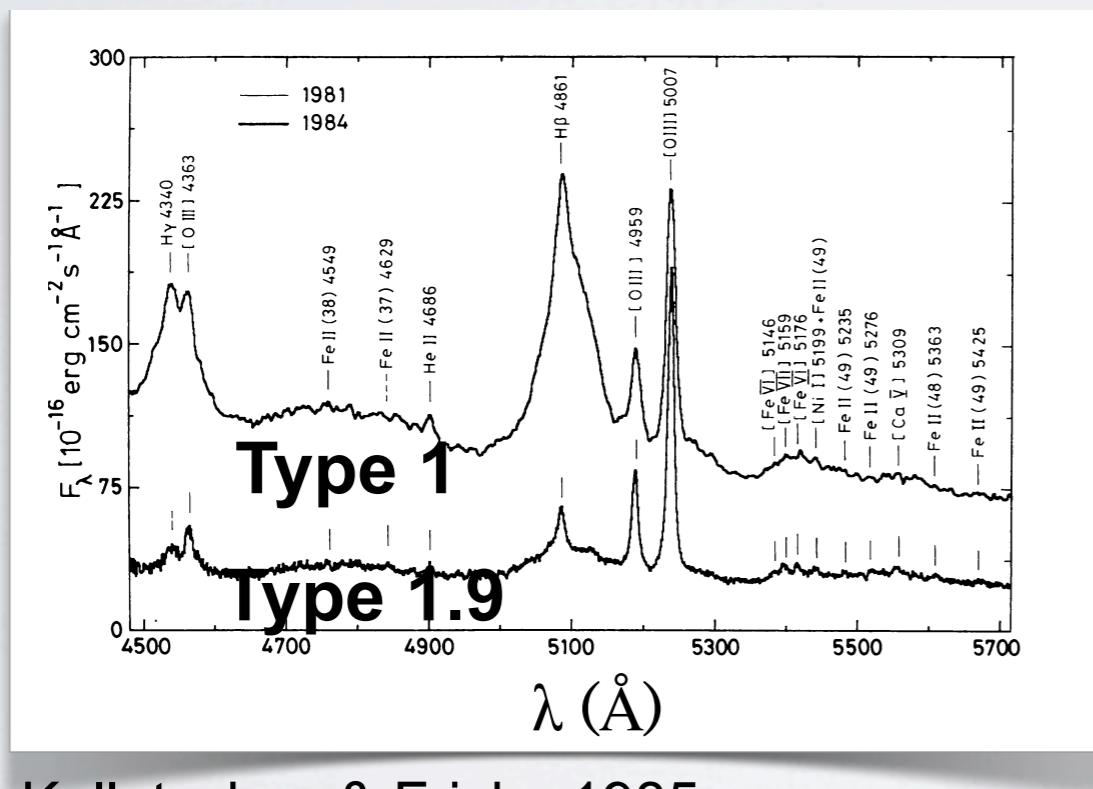


Pan-STARRS

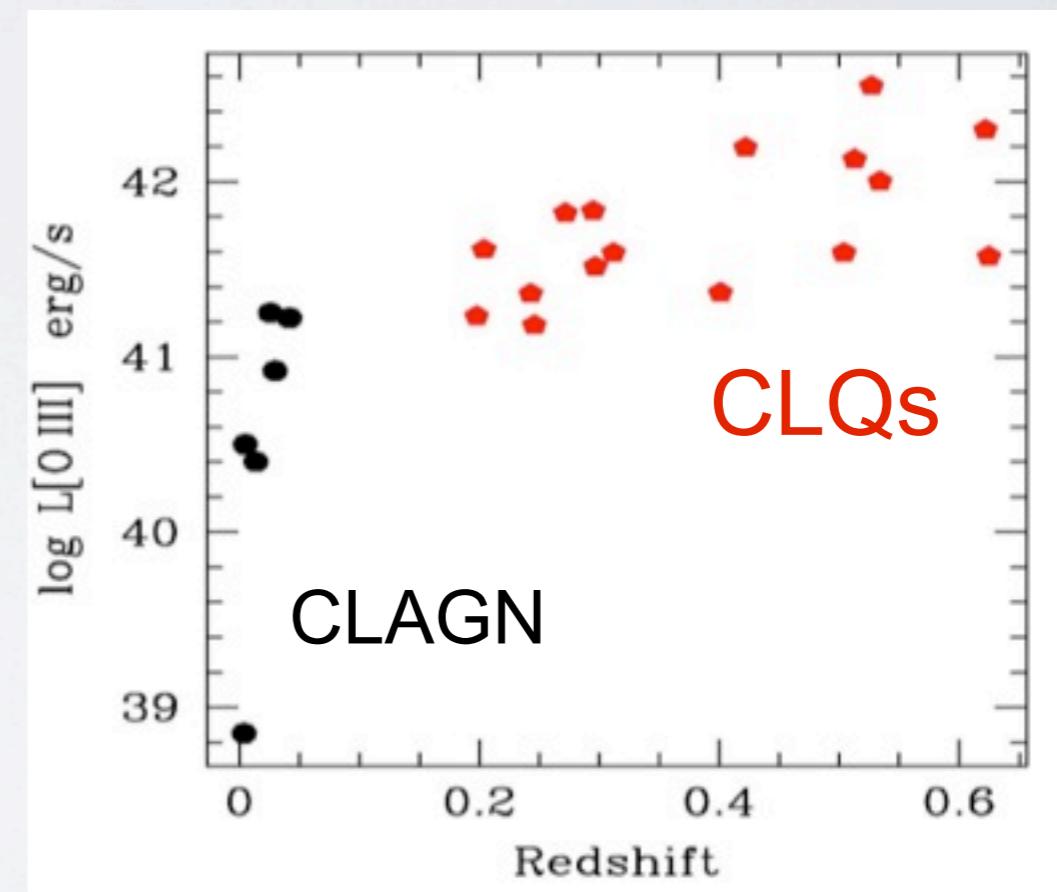
Changing-Look AGN (“CLAGN”)

- Broad Balmer BEL (dis)appearance associated with **large continuum change** in Seyfert galaxies
- Changing-Look Quasars at $L_{\text{bol}} > 10^{44}$ erg s⁻¹ (“CLQs”)

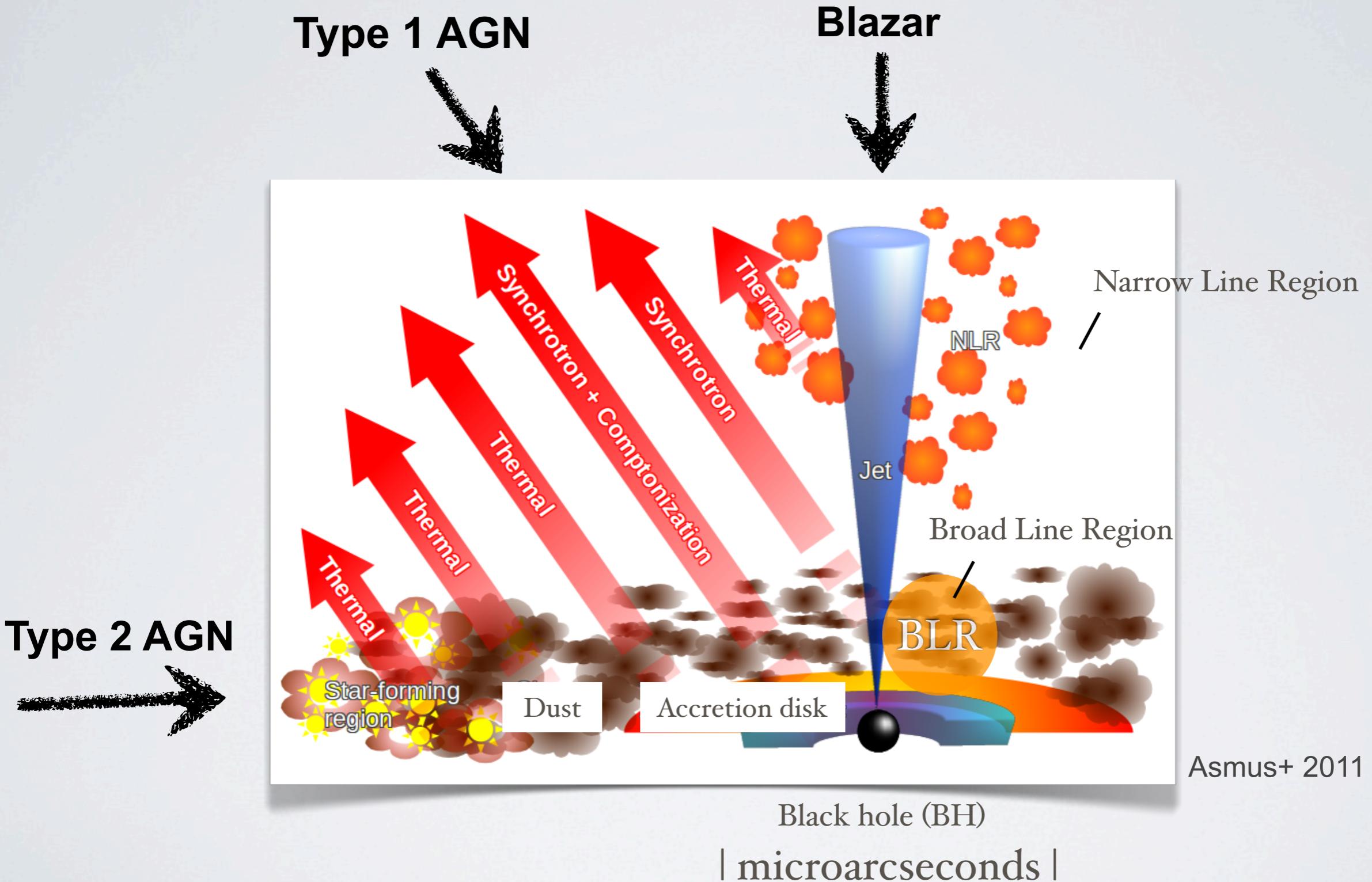
Fairall 9, 1981-4



Kollatschny & Fricke 1985



A Challenge To The AGN Unification Model



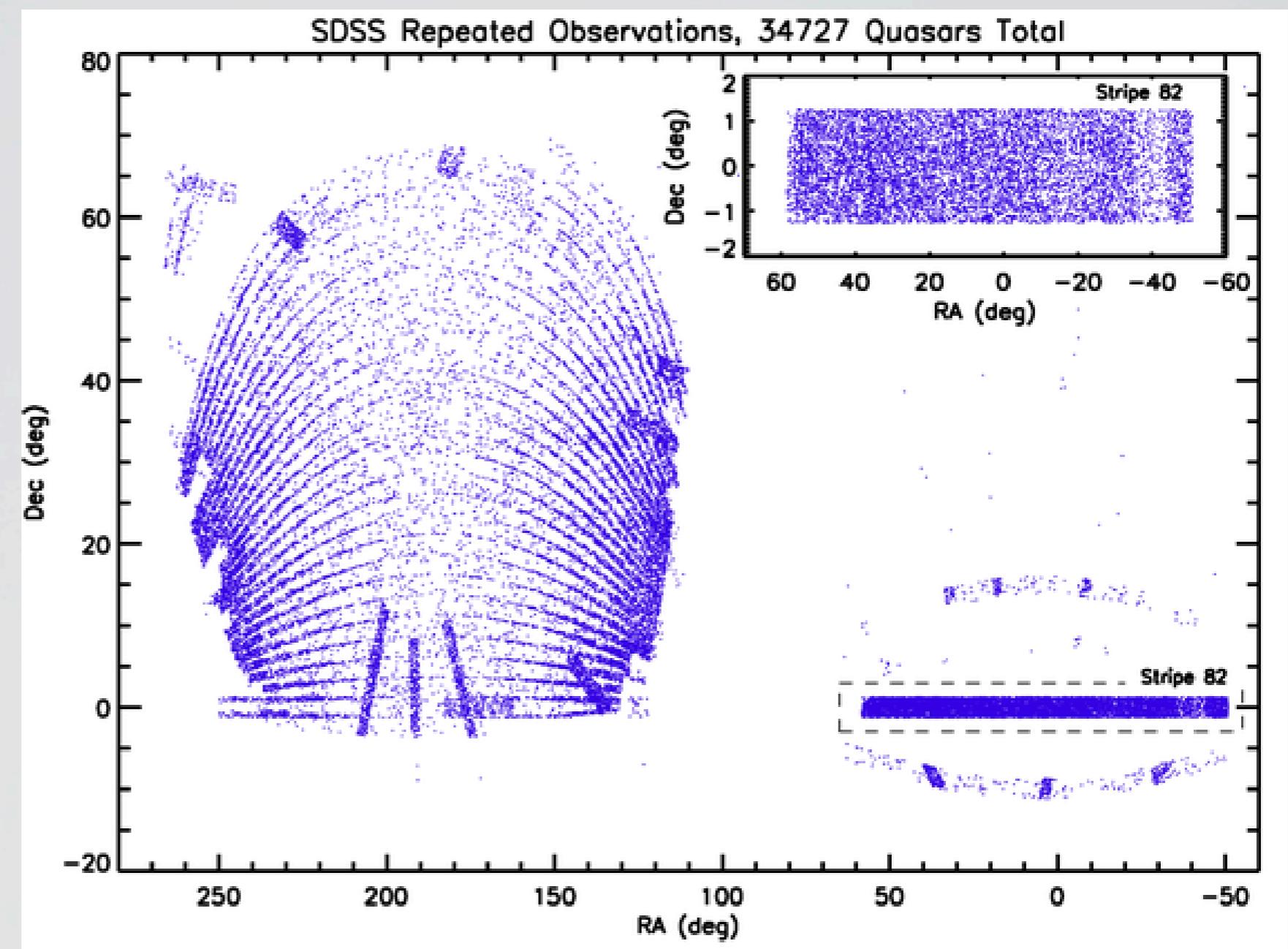


SDSS Repeated Imaging

- Stripe 82 (S82):
~60 epochs
over 10 yr
(N=9,275)
(Recalibrated data:
Ivezic+ 2004)

- NGC: 2-3
epochs
(N=25,000)

Repeat
spectroscopy from
BOSS for 15%



MacLeod+ 2012



Pan-STARRS 3π Survey

- Whole sky north of Dec -30.
- Target was 4 exposures per filter per year, composed of two 15 min pairs (in the same lunation for gri, several months later for zy).
- Ideally, at the end of the survey there should 12 visits per band, with a 6-dither pattern.

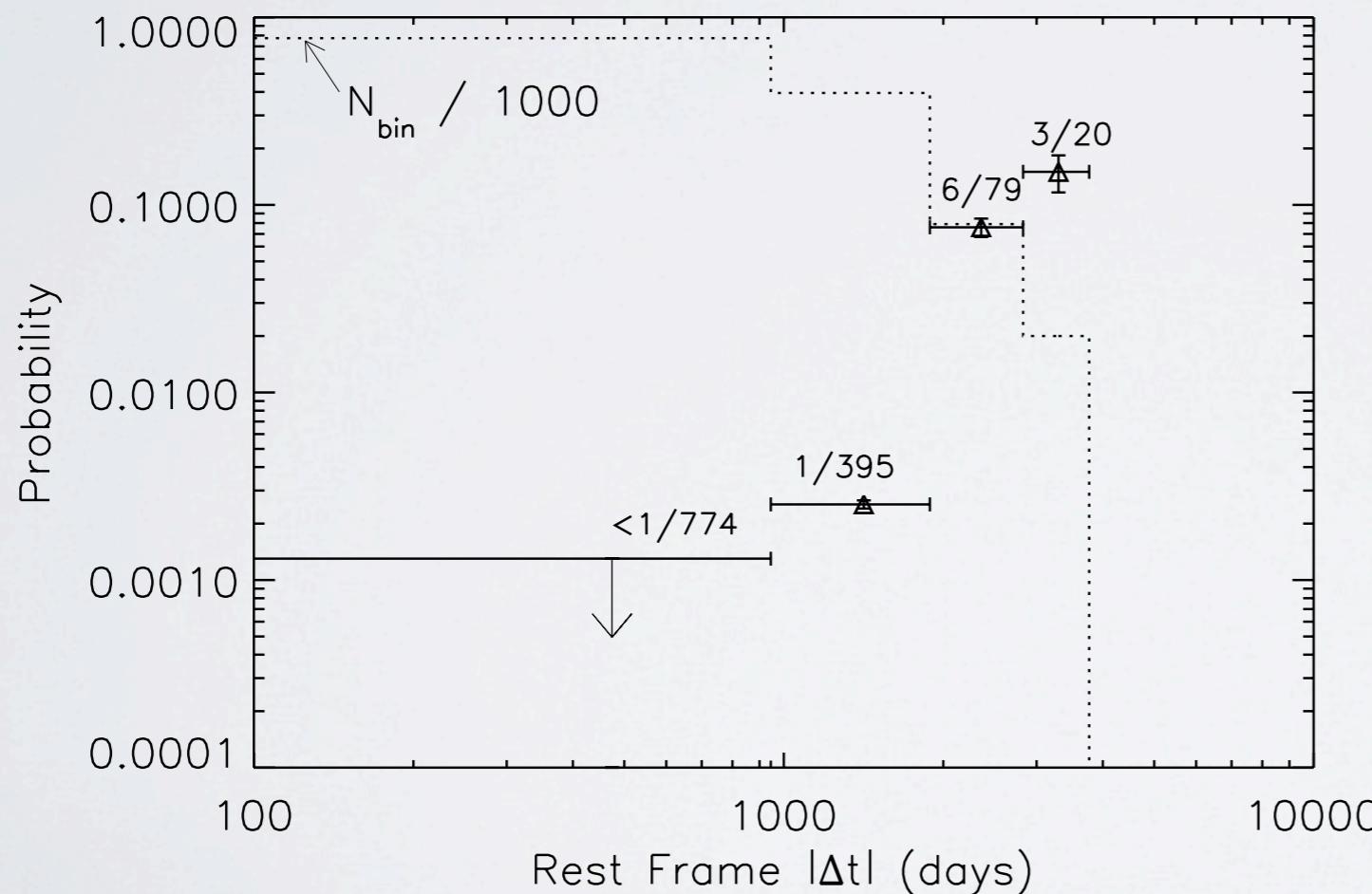
Single pointing point source modal depths (AB mags):

| Band | 5σ | Bright |
|------|-----------|--------|
| g | 22.0 | 14.5 |
| r | 21.8 | 15.0 |
| i | 21.5 | 15.0 |
| z | 20.9 | 14.0 |
| y | 19.7 | 13.0 |

Systematic Search for CLQs

| Selection | Total # | In S82 |
|--|---------|--------|
| SDSS Quasars in DR7Q | 105783 | 9474 |
| with BOSS spectra | 25484 | 2304 |
| and $ \Delta g > 1$ mag and $\sigma_g < 0.15$ mag | 1011 | 287 |
| and that show variable BELs | 10 | 7 |

MacLeod, Ross et al. (2016)



Other discoveries:

LaMassa+ 2015

Ruan+ 2016

Runnoe+ 2016

Gezari+ 2016

>15% of strongly variable quasars are CLQs on rest-frame timescales of 8-10 yr.

Spectroscopic Followup Of CLQ Candidates

Goal: Test the CLQ fraction among highly variable QSOs.

Selection criteria:

1. In SDSS DR7Q (N=105,783), *not BOSS*
2. $|\Delta g| > 1$, $|\Delta r| > 0.05$, $\sigma < 0.15$ mag in SDSS / PS1 3 π (“EVQ”)
3. $z < 0.83$, Radio-quiet
4. $|\Delta g| > 1$ from earlier spectrum

William Herschel
(4.2m)



MMT
(6.5m)

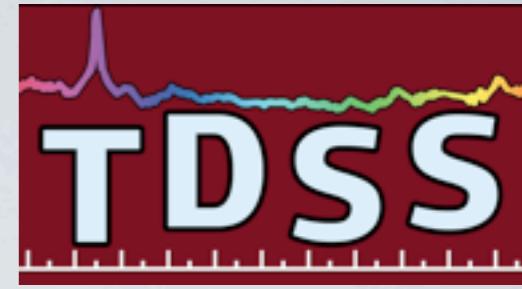


Magellan
(6.5m)





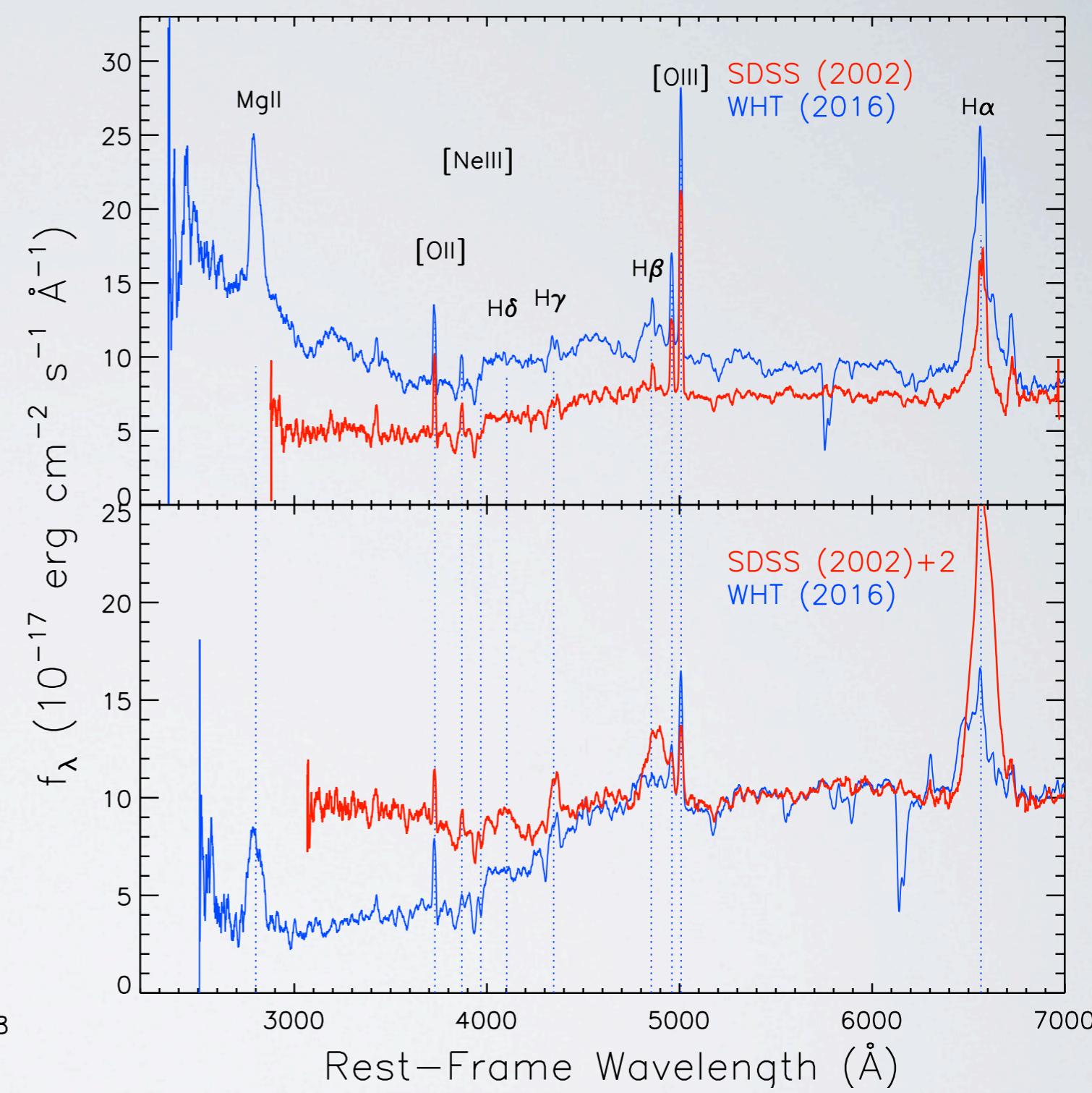
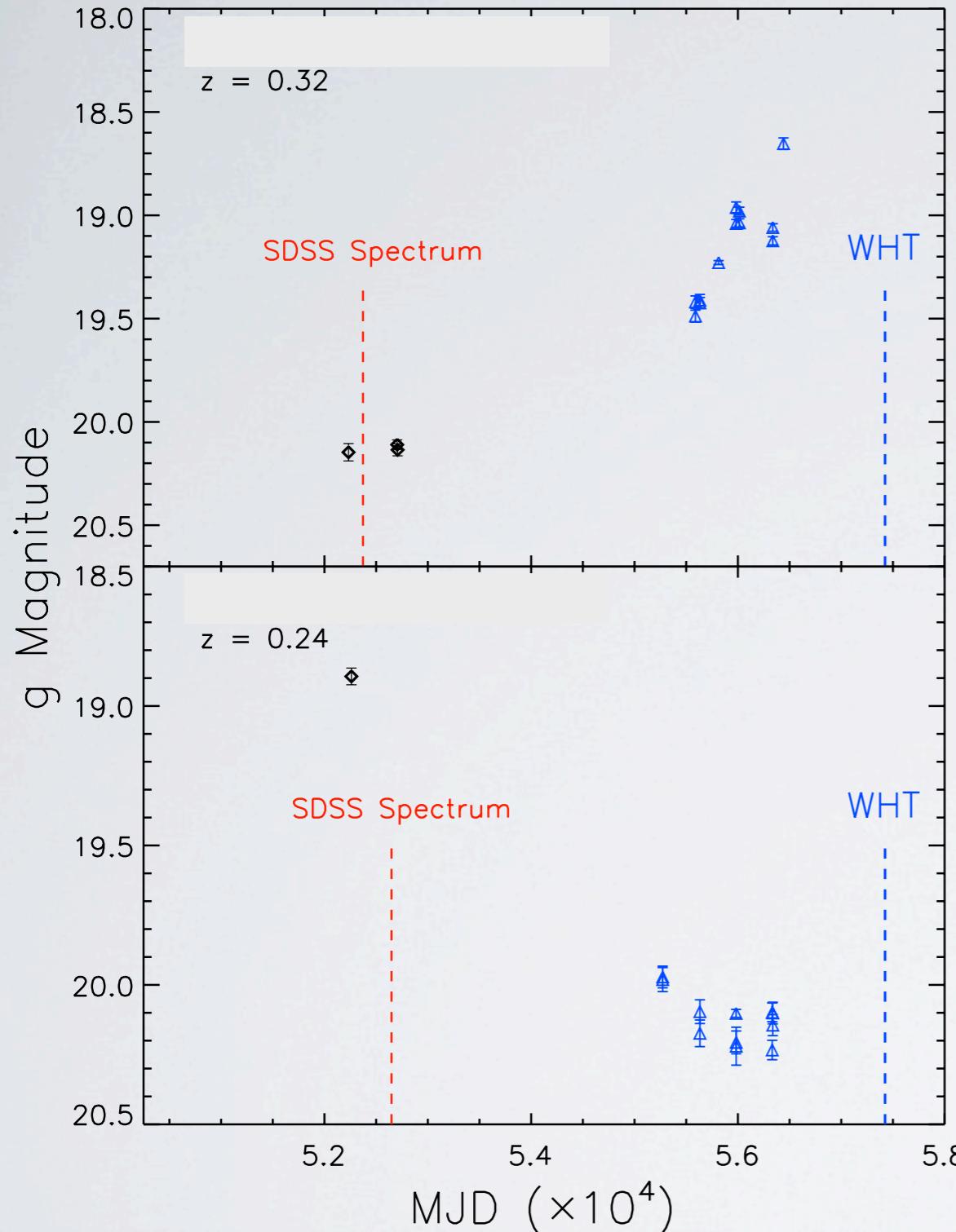
SDSS-IV Time Domain Spectroscopic Survey



Paul Green (P-I, SAO), Scott Anderson (P-I, UWa), Chelsea MacLeod (SAO), Michael Eracleous (PSU), Niel Brandt (PSU), Sean McGraw (PSU), Kate Grier (PSU), Jessie Runnoe (UMich), Eric Morganson (UIUC), John Ruan (UWa), Don Schneider (PSU), Yue Shen (UIUC), the TDSS Team, the SDSS-IV Collaboration, and the Pan-STARRS1 Science Consortium

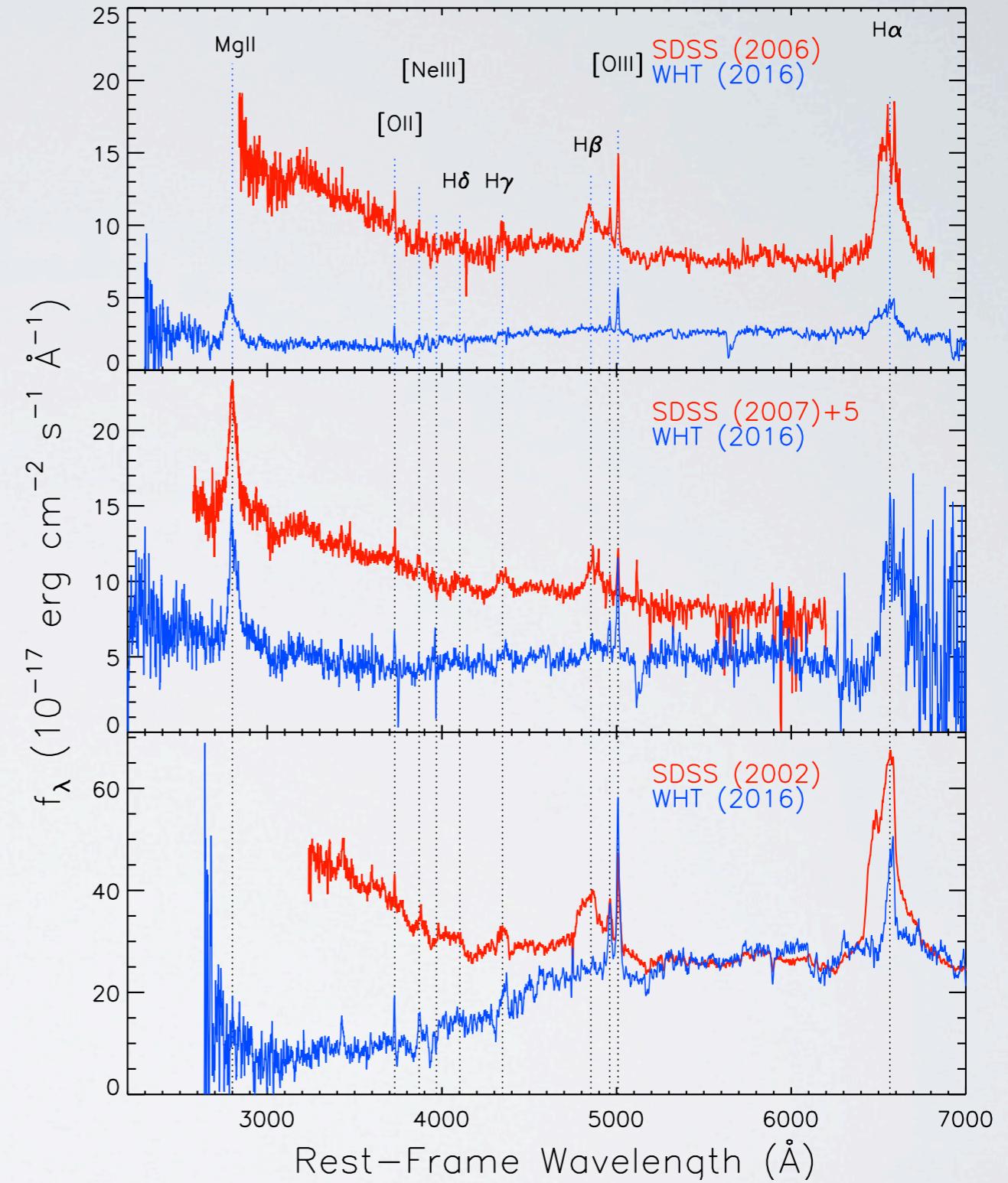
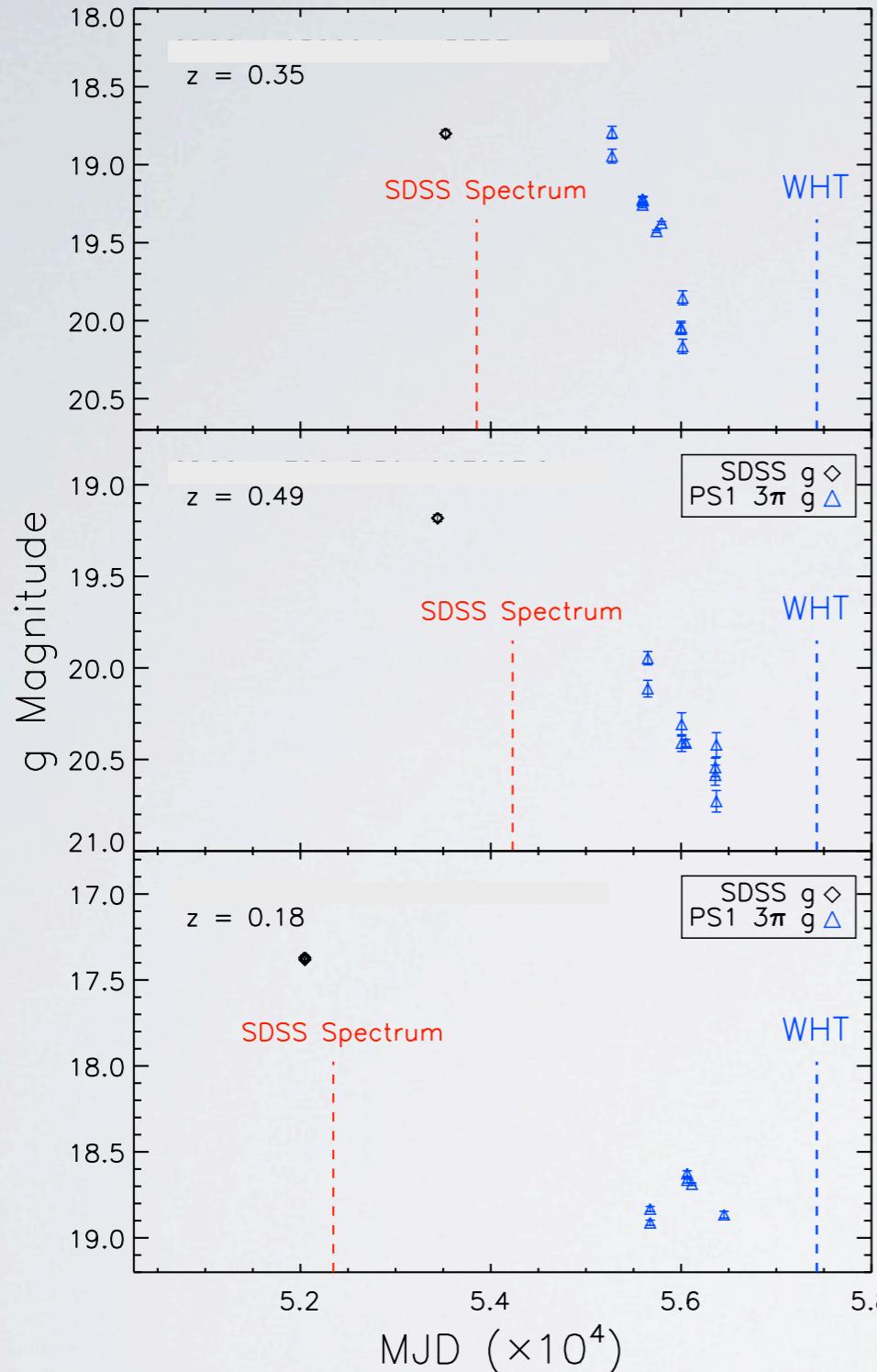
- ★ Unbiased spectral survey for ~200,000 celestial variables (*SES*; Morganson+ 2015; Ruan+ 2016)
- ★ Repeat spectra for **13K Quasars** (*RQS*; MacLeod+ 2017)
- ★ Repeat spectra for ~1K Hypervariable Quasars ($|\Delta m| > 0.7$ mag) using *SES* selection method
- ★ Repeat spectra for ~**200 CLAGN Candidates** on S82X ($|\Delta g| > 1$ mag)
using MacLeod+16 selection method

Results From WHT Follow-up ($g < 20.5$)



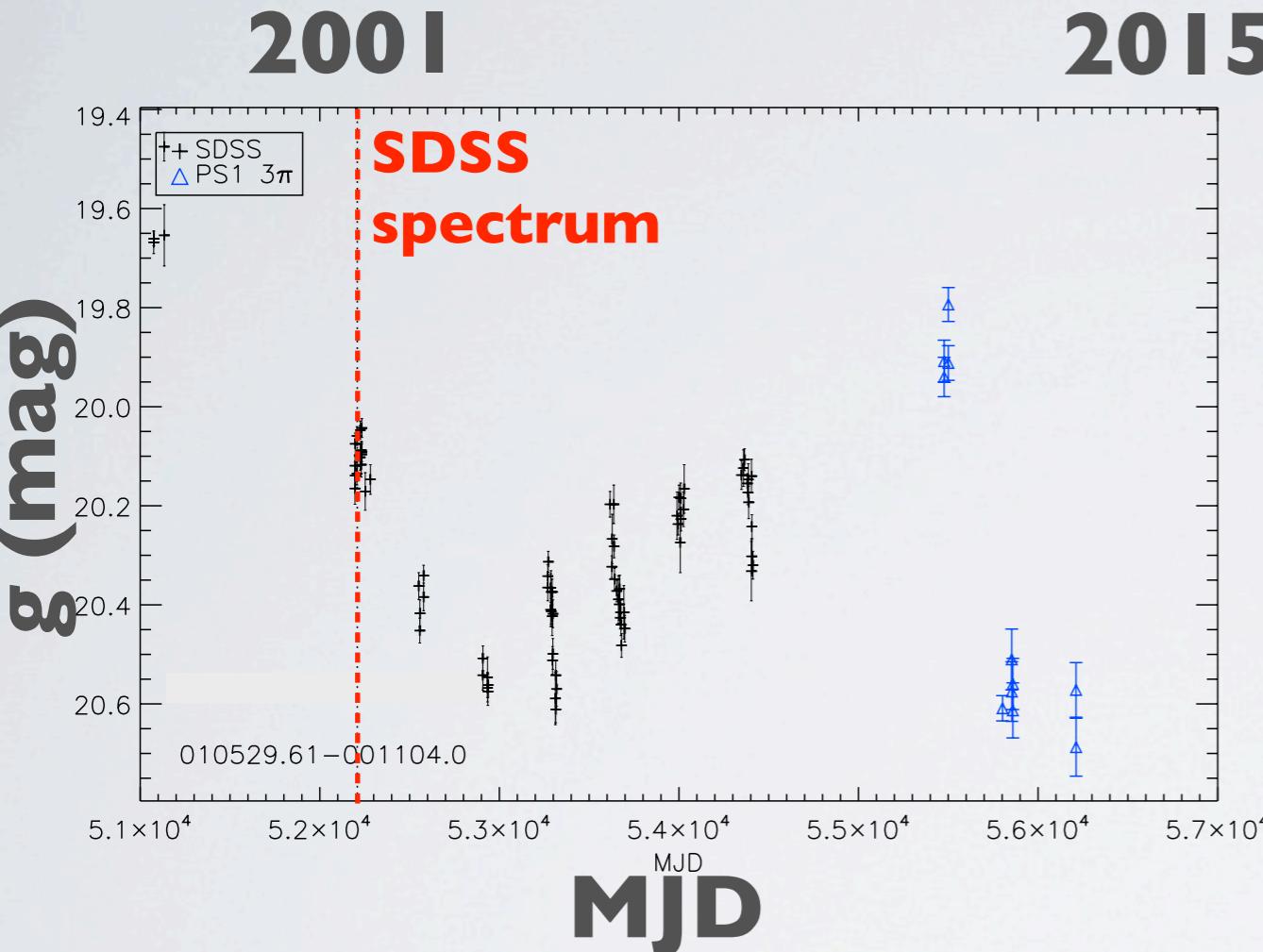
- CLQ fraction is 30% of $|\Delta g| > 1.3$ mag, $g < 20.5$ targets

Results From WHT Follow-up ($g < 20.5$)

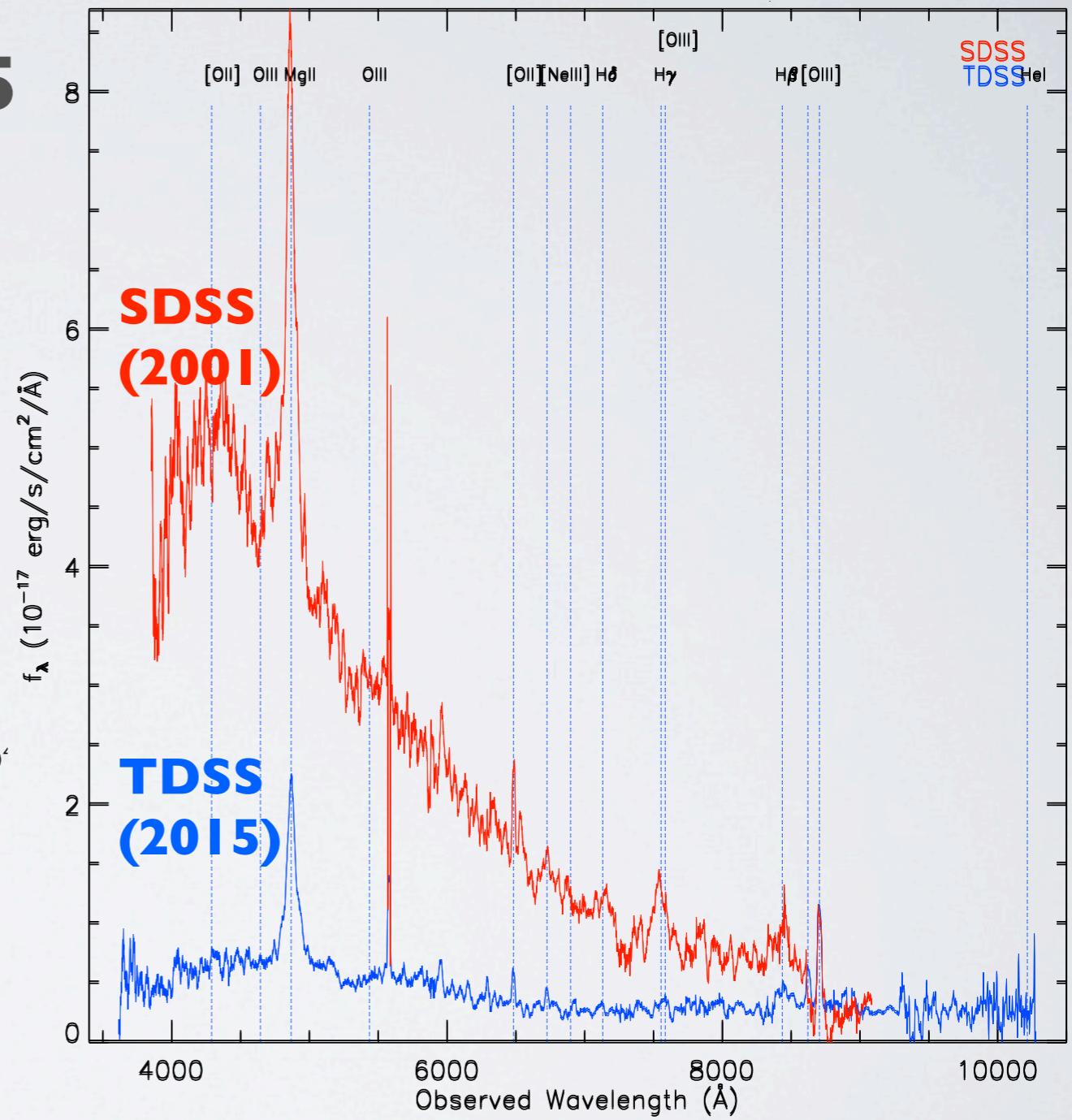


- CLQ fraction is 30% of $|\Delta g| > 1.3$ mag, $g < 20.5$ targets

TDSS S82X CLAGN Target

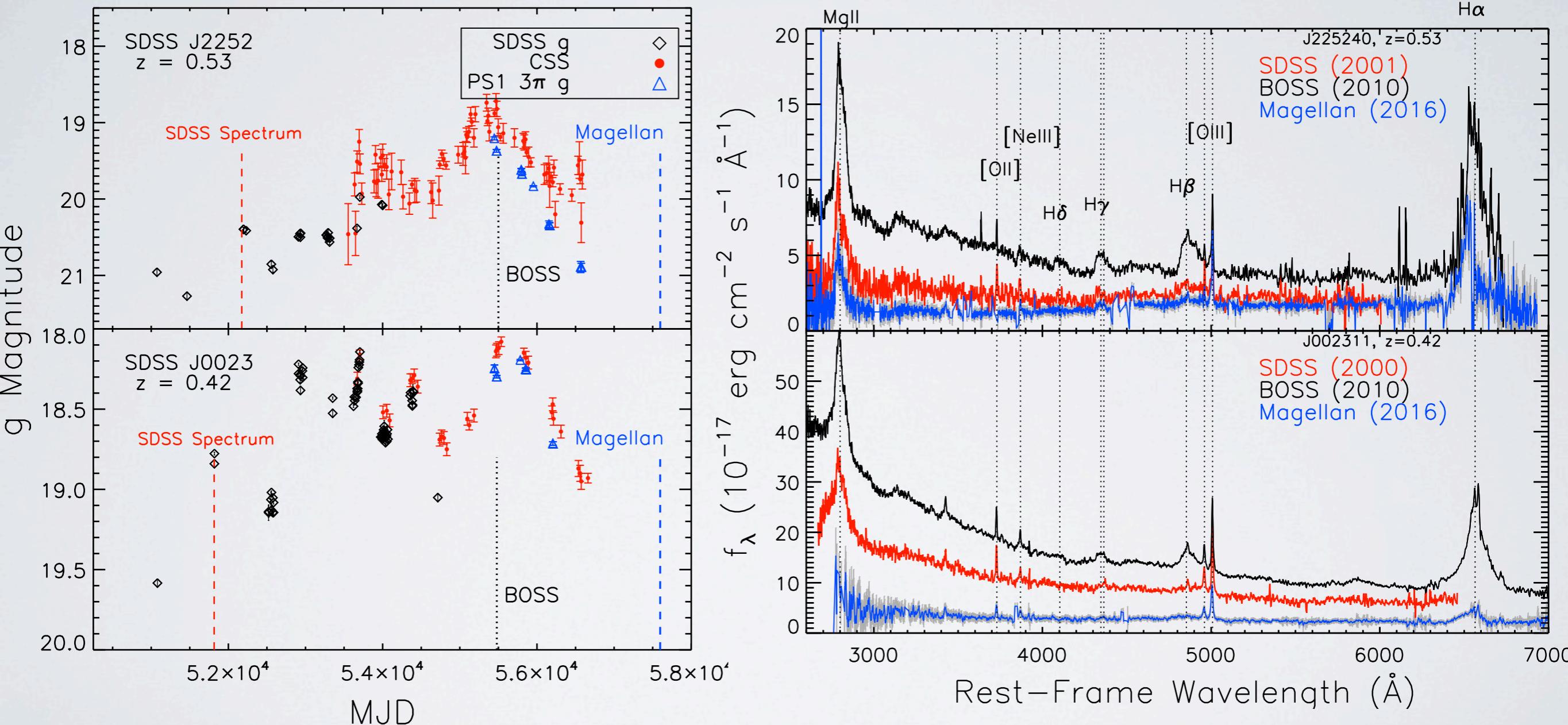


- 189 CLAGN targets on S82X special plates



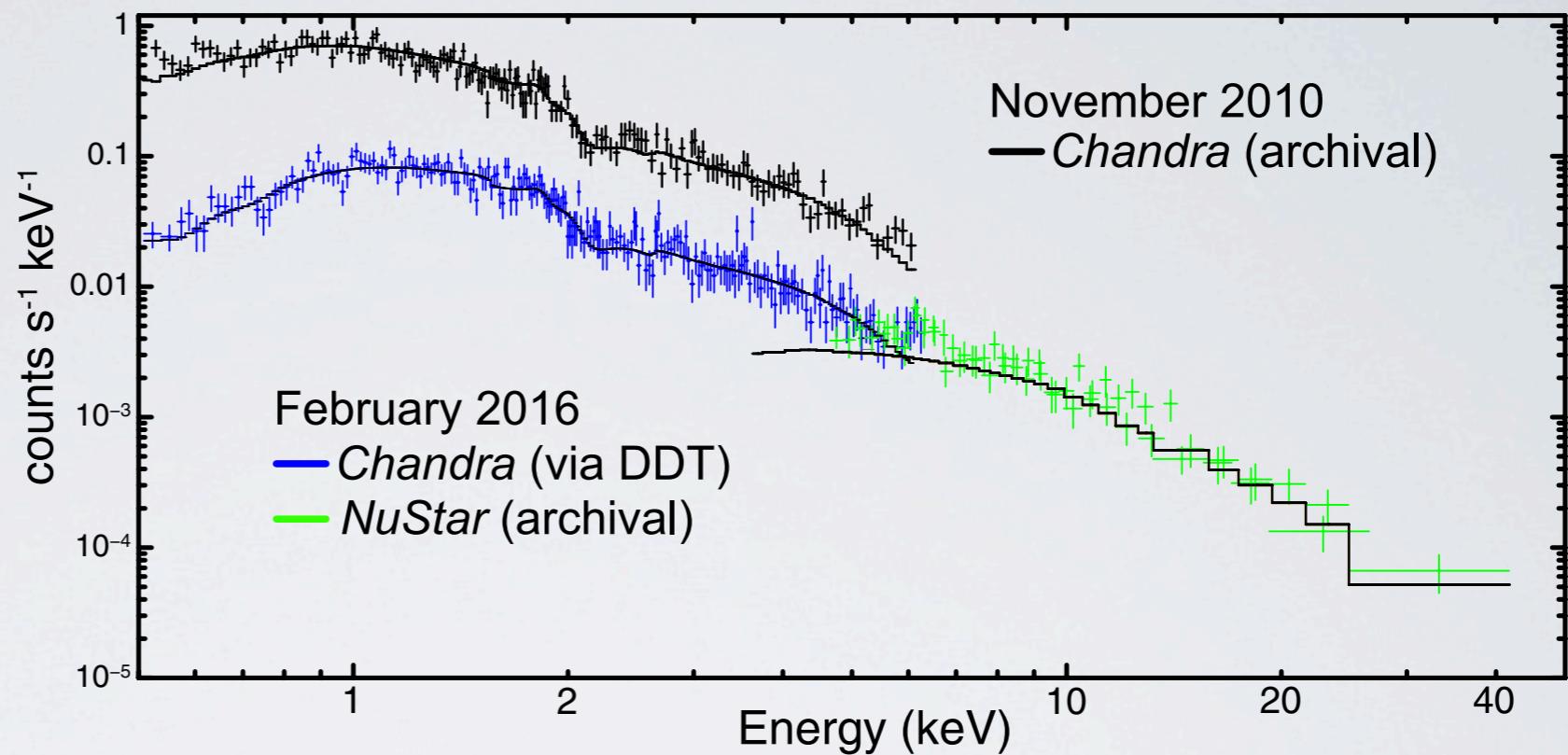
Obs. Wavelength (Å)

Two CLQs from SDSS/BOSS search “turn back off”



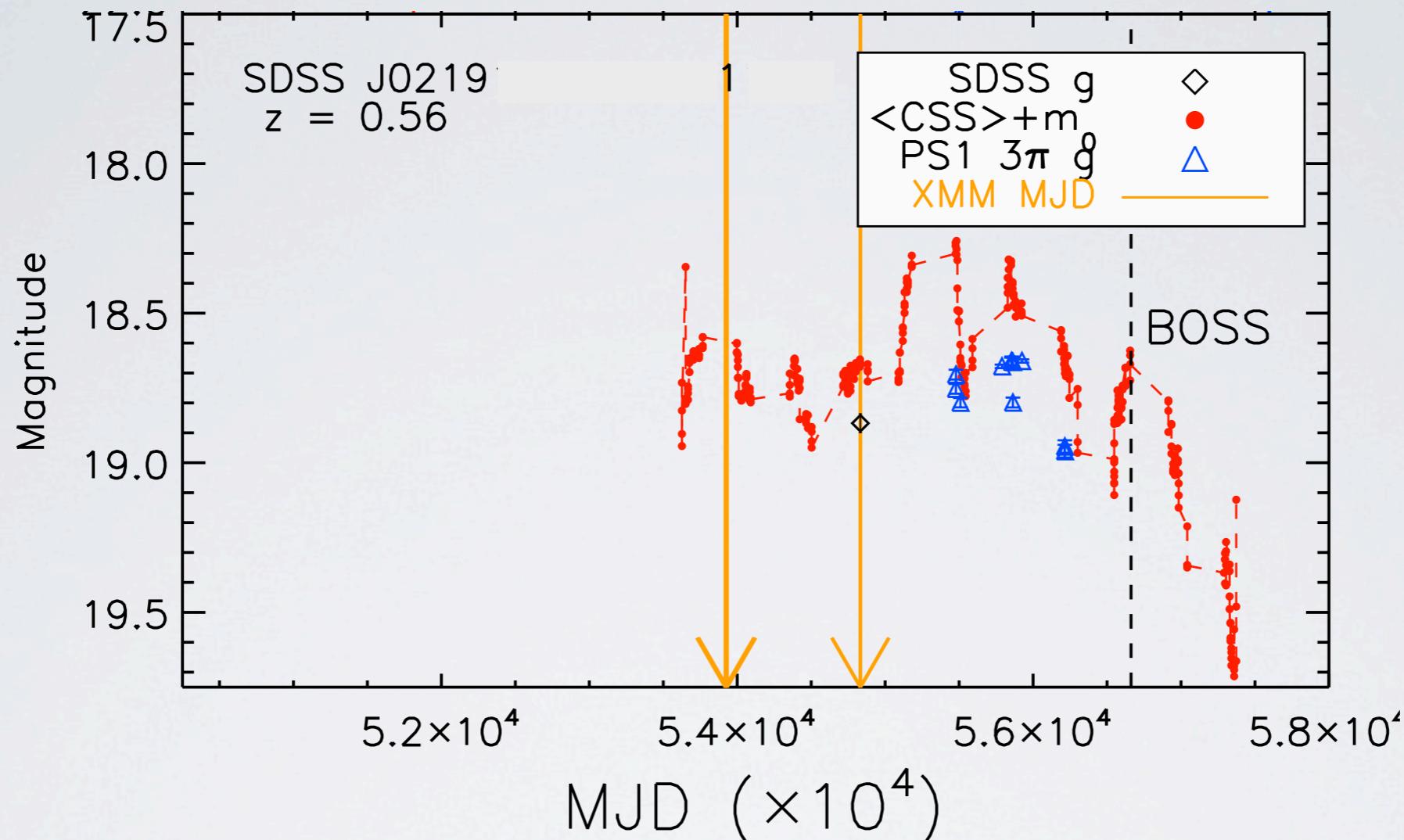
Variable Absorption Ruled Out By X-rays

Mkn 1018:



- X-ray flux changes by factor:
 - **10** in Mkn 1018 (Husemann+2016)
 - **>10** in NGC 2617 (Shappee+2014)
 - **30** in HE 1136-2304 (Parker+2016)
 - **12** in SDSSJ0159 (LaMassa+2015)
 - **>3** in iPTF 16bco (Gezari+ 2016)
- No evidence for obscuration

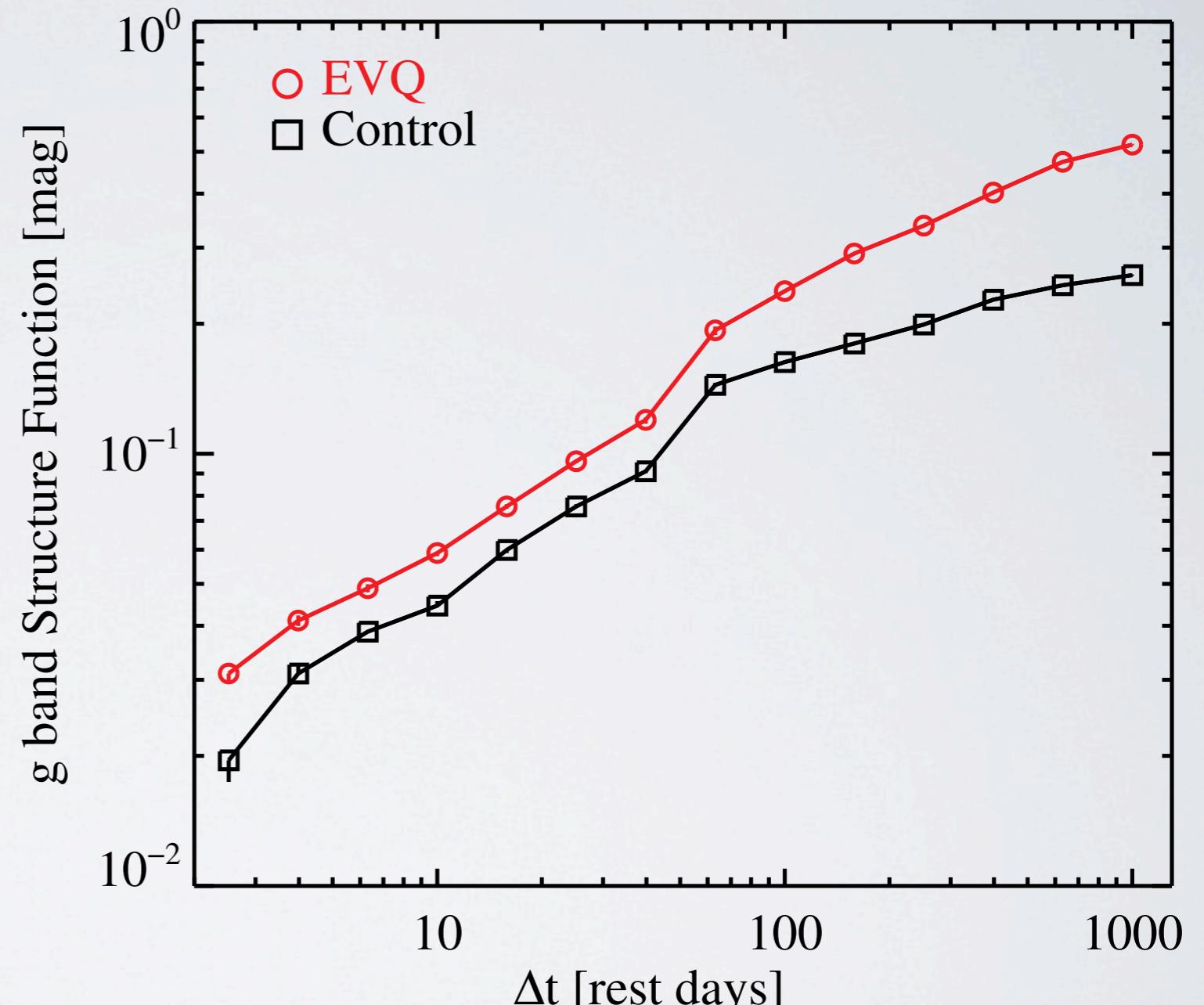
X-ray Followup Of CLQ Candidates



- Chandra ToO program (P-I: Green)
- Test obscuration hypothesis via N_h
- $\Gamma \rightarrow L/L_{\text{Edd}}$ (à la XRBs, e.g., Dong et al. 2014)

Structure Function Analysis

- ~10K SDSS S82 DR7 Quasars in DES
- 10% are extremely variable quasars (**EVQ**) with $|\Delta g| > 1$
- EVQs more variable on all timescales
- Enhanced excess variability on *long* timescales



Rumbaugh et al. (2017)

Are CLQs Just The Tails?

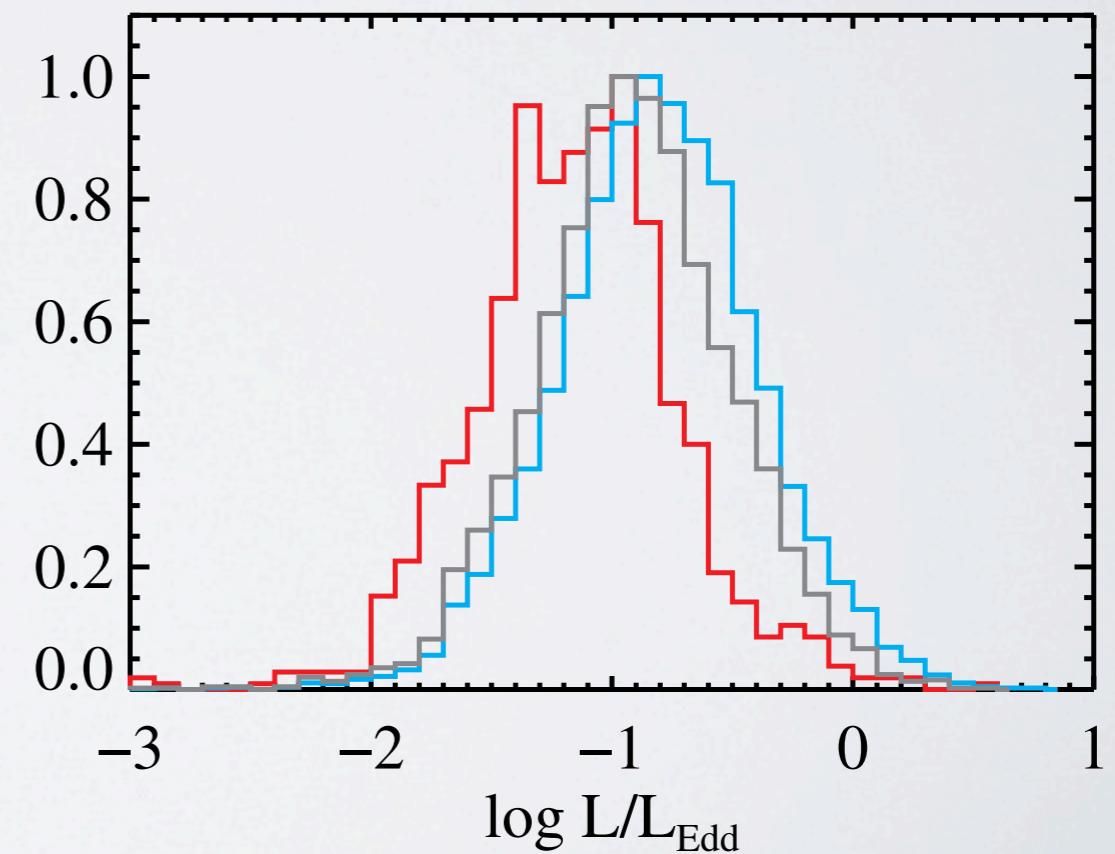
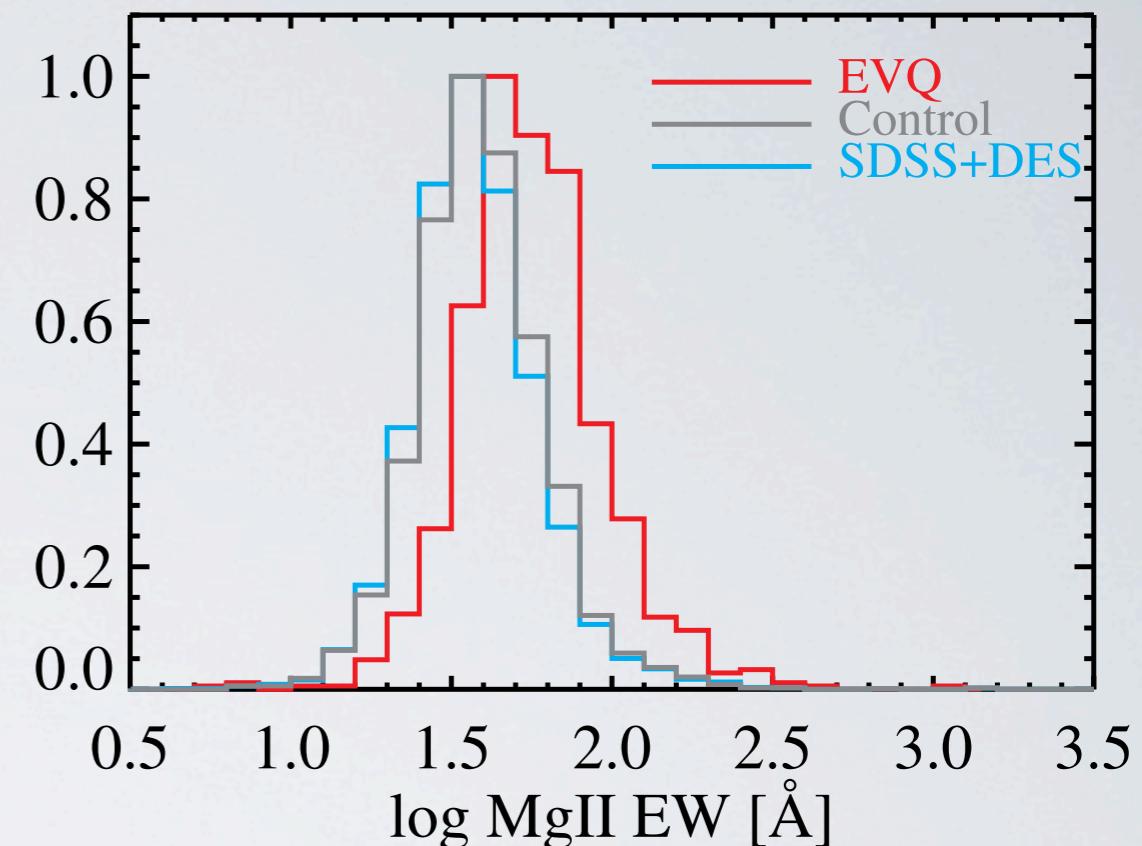
(Which EVQs are CLQs?)

Which QSOs are EVQs?

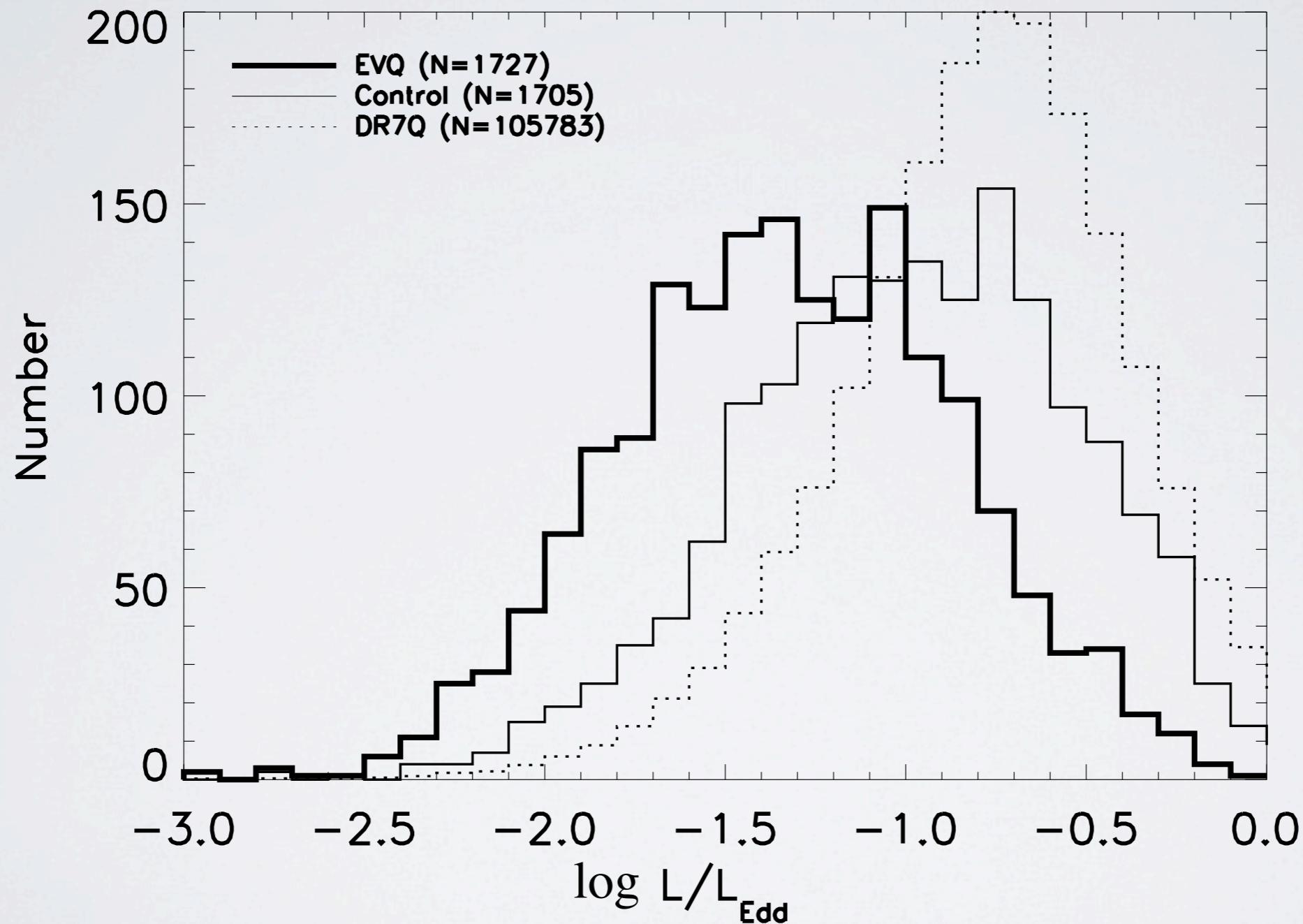
Compared to normal quasars at similar redshifts, luminosities:

- EVQs have stronger BELs
 - Not due to orientation effect
- EVQs have lower L/L_{Edd}

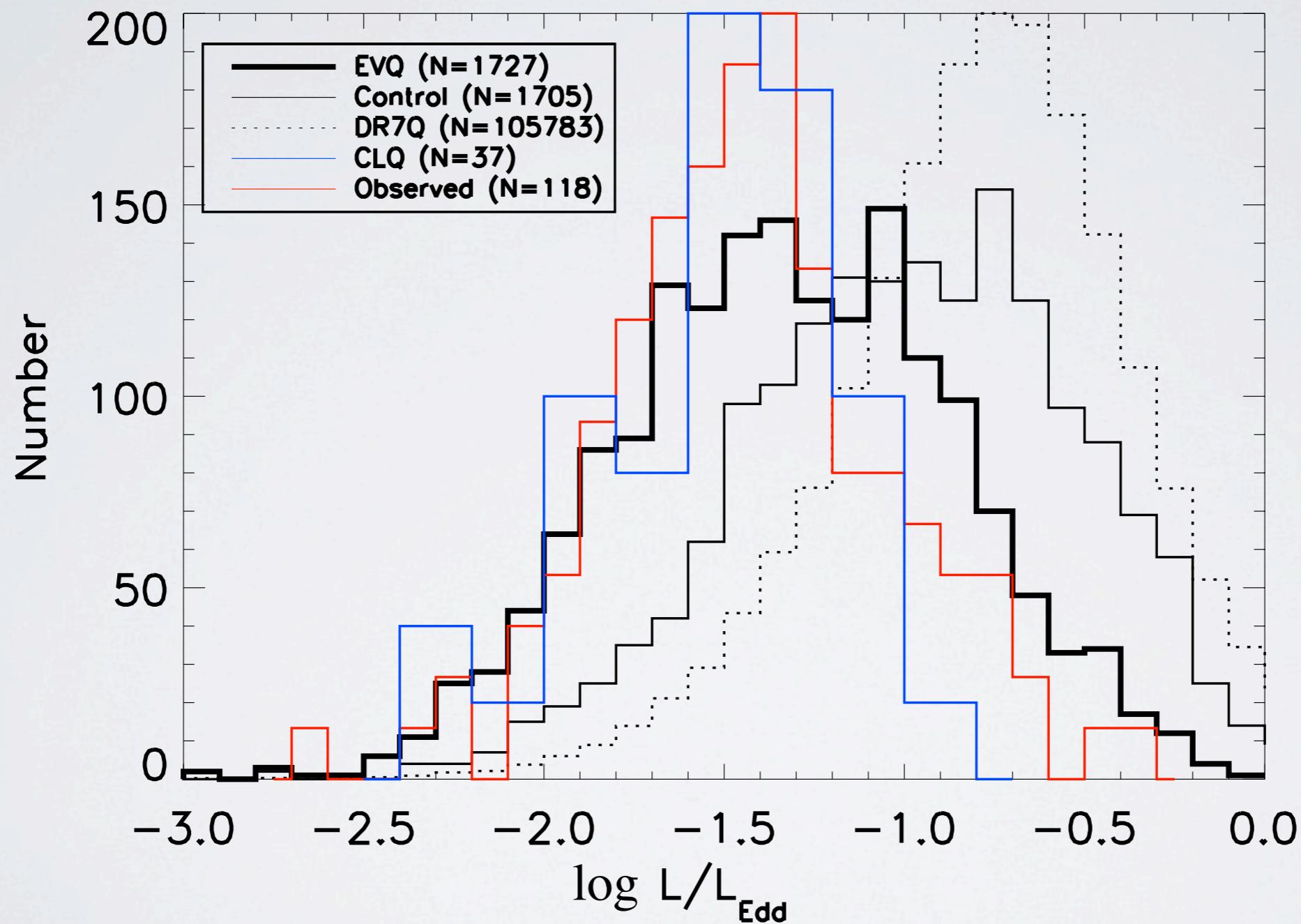
Rumbaugh et al. (2017)



EVQs in SDSS/PS1: Low L/L_{Edd}

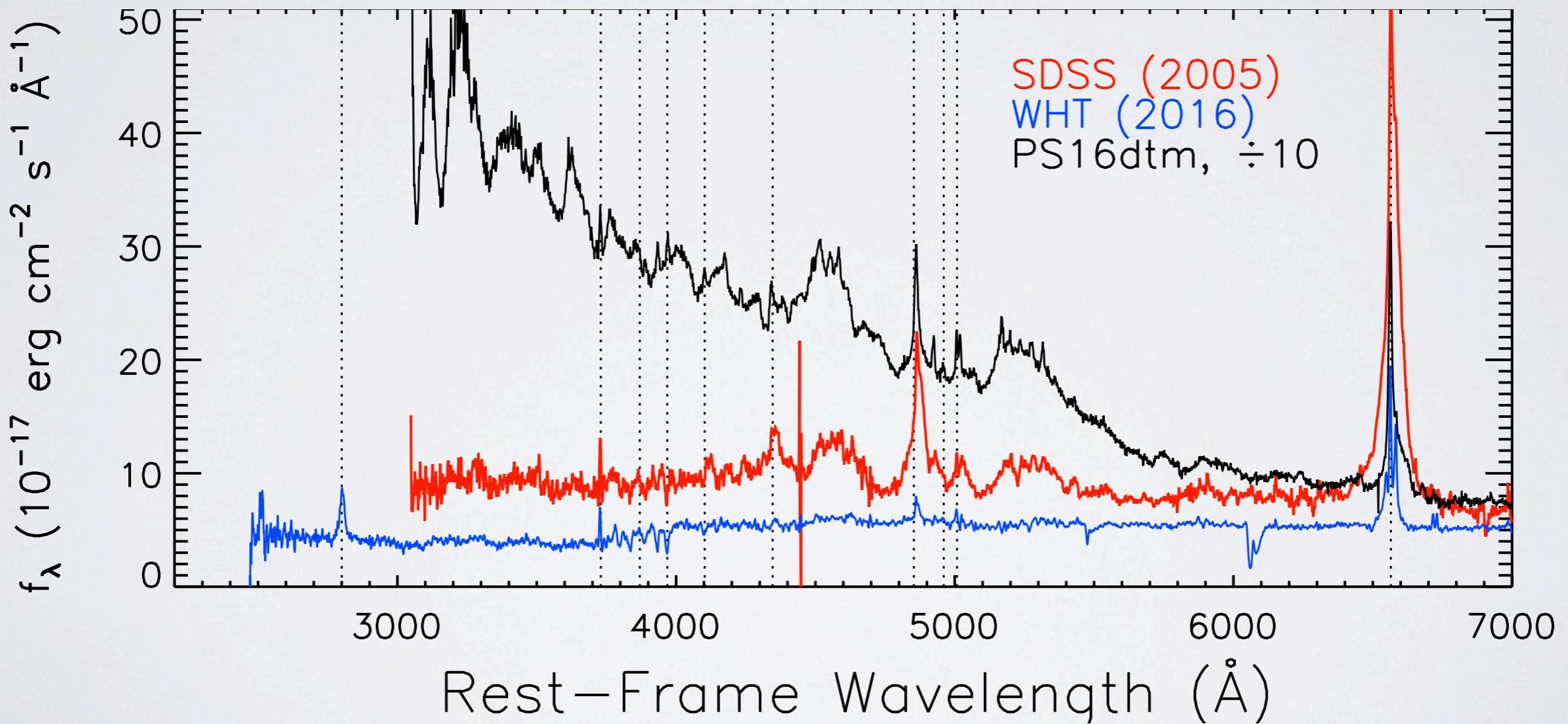
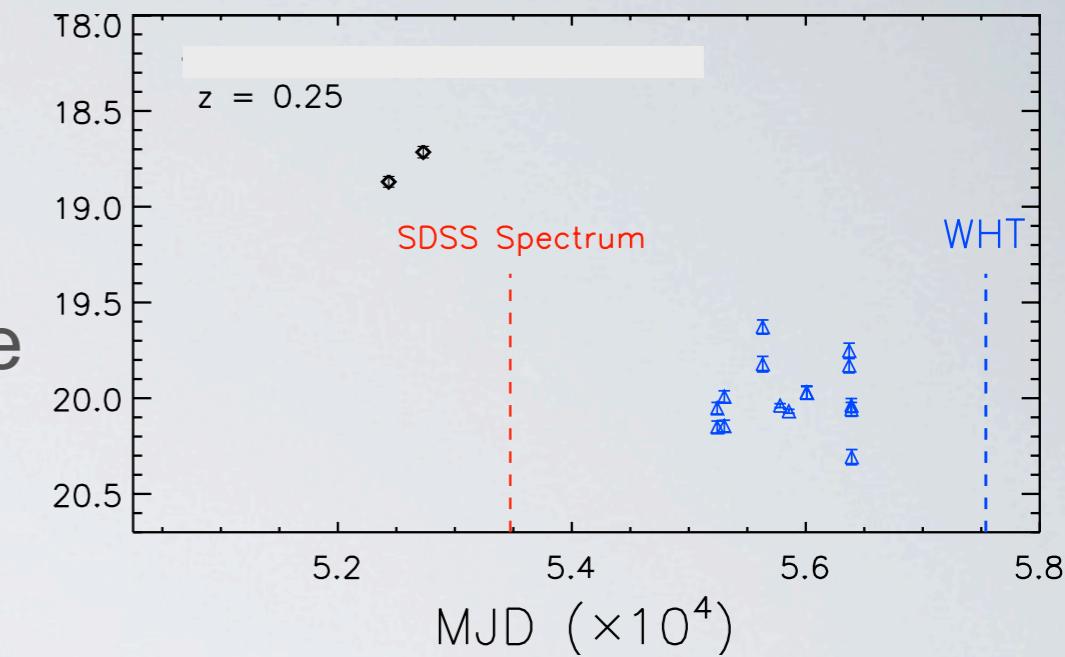


EVQs in SDSS/PS1: Low L/L_{Edd}



NLS1 CLQ

- $\log(L/L_{\text{Edd}}) = -1.057$, Strong Fell line change
- Similar to TDE candidate (Blanchard+17)



Outstanding Questions

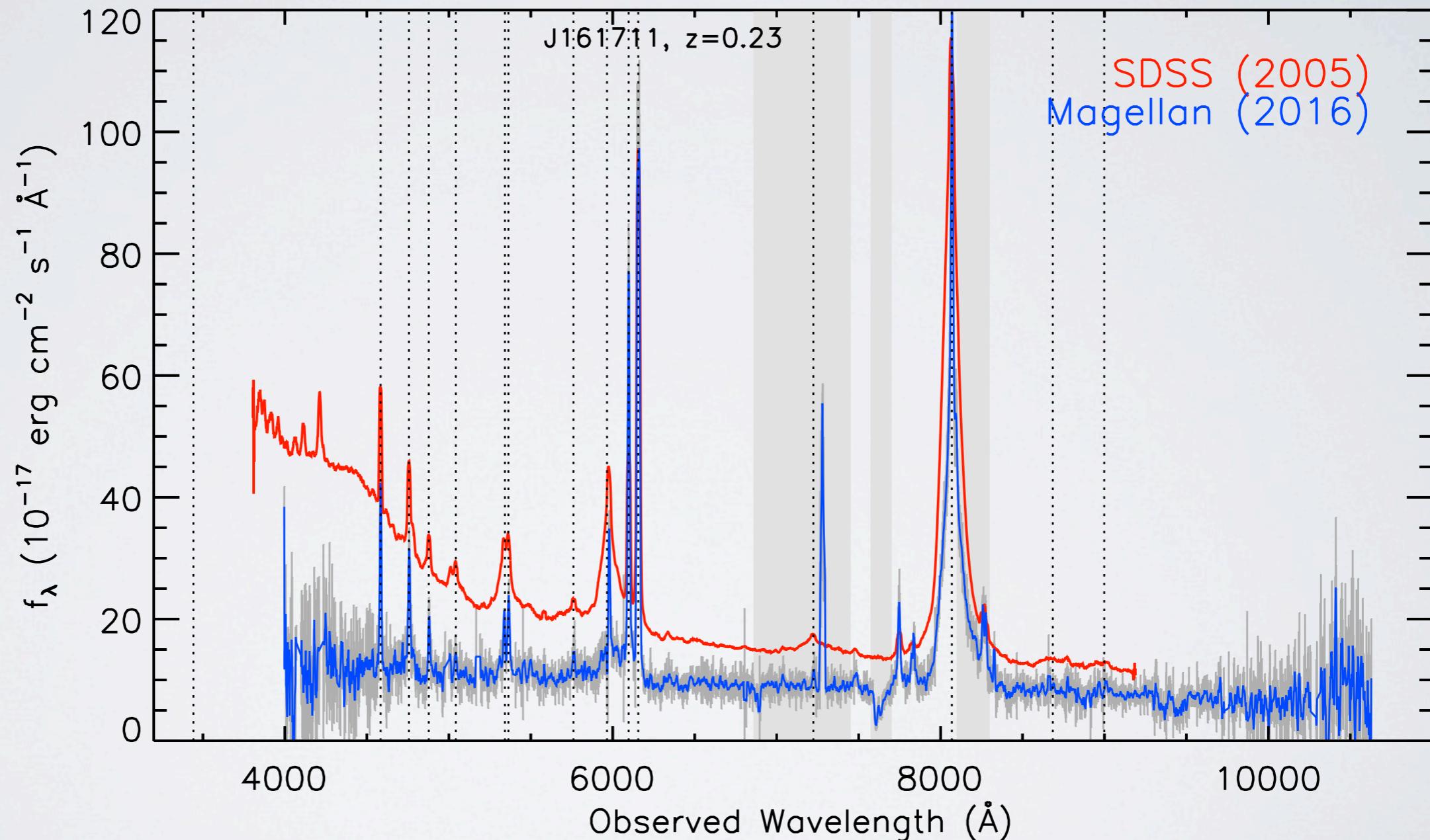
- Are all CLQs part of the low Eddington tail, or are some one-off events with different physics, e.g., TDEs?
- Different physics operating in EVQs over longer timescales compared to normal quasars?

Summary, Conclusions, & Future

- Quasar variability can be extreme; Eddington ratio is a driving factor.
- CLQ fraction is roughly 30% among EVQs; but may be largely uncertain if recent short-term variability is unaccounted for.
- Importance of continued monitoring; ZTF, LSST!

Extra Slides

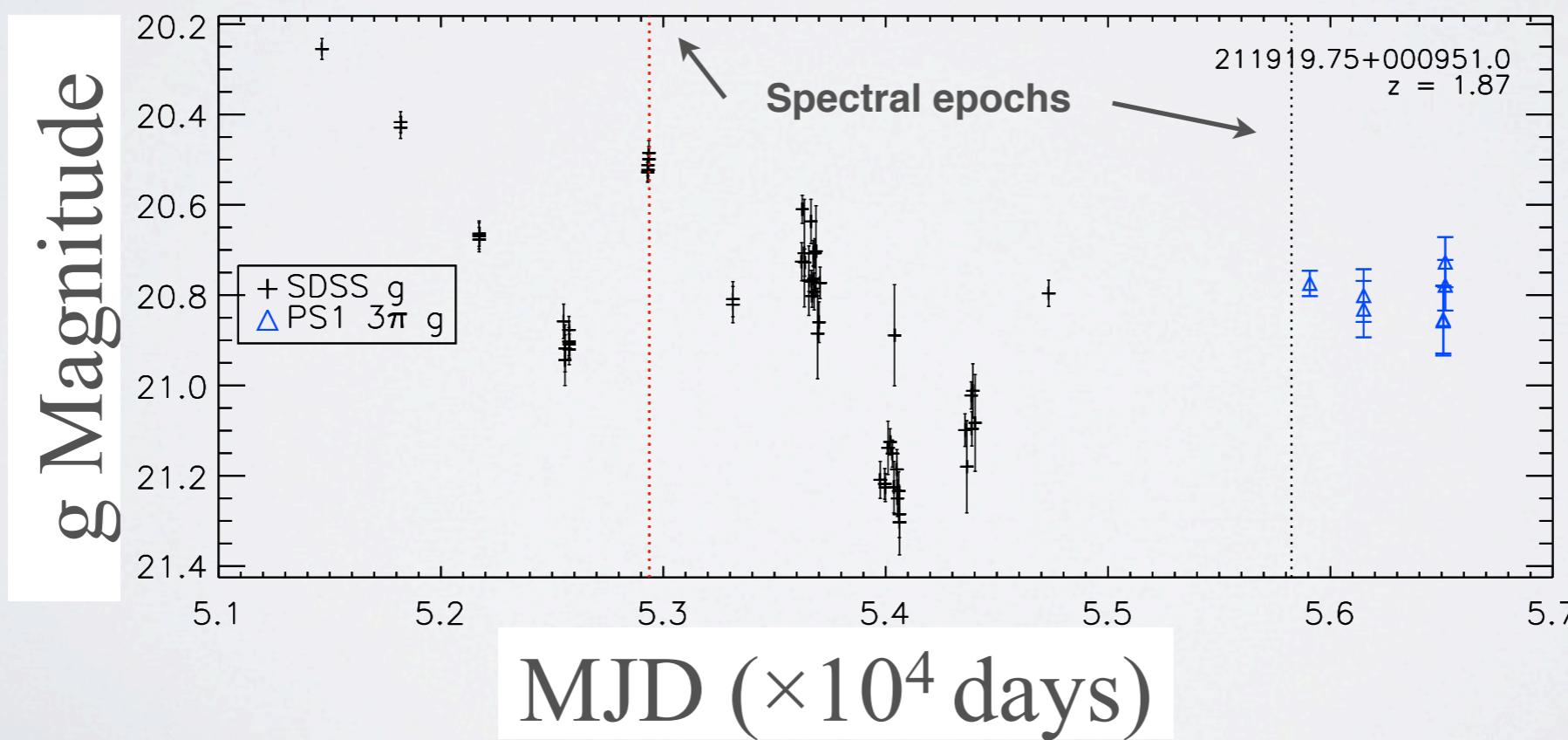
Followup Spectra of CLQ Candidates



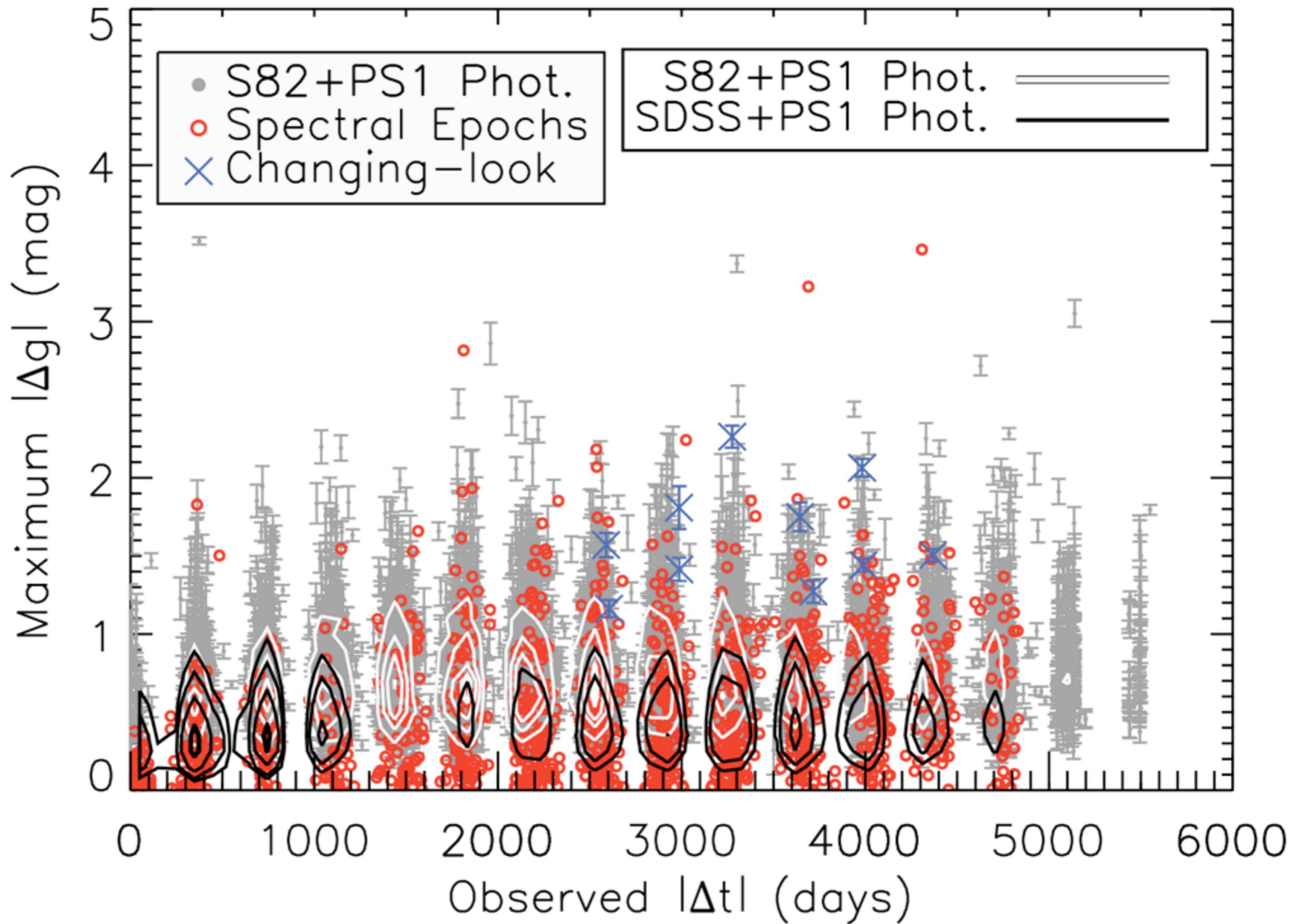
Systematic Search for CLQs

- $|\Delta g| > 1$ mag among any observations in SDSS and PS1
- In the SDSS DR7 quasar catalog (Schneider et al. 2010)
- Must have repeat spectra (have z , L , BH mass)

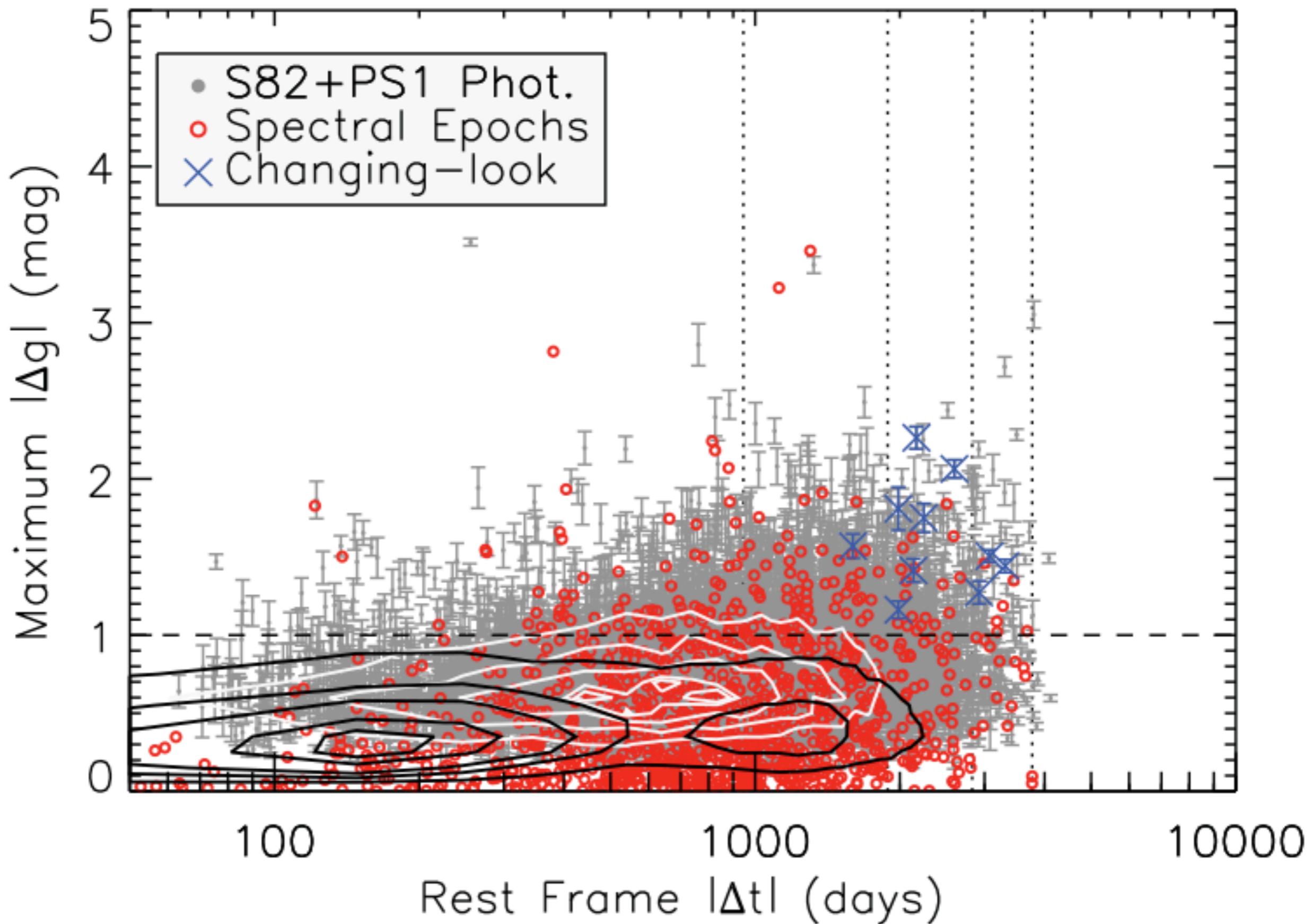
| Selection | Total # | In S82 |
|---|---------|--------|
| SDSS Quasars in DR7Q | 105783 | 9528 |
| with $ \Delta g > 1$ mag and $\sigma_g < 0.15$ mag | 6348 | 1692 |
| and that have BOSS spectra | 1010 | 287 |
| and that show variable BELs | 11 | 8 |



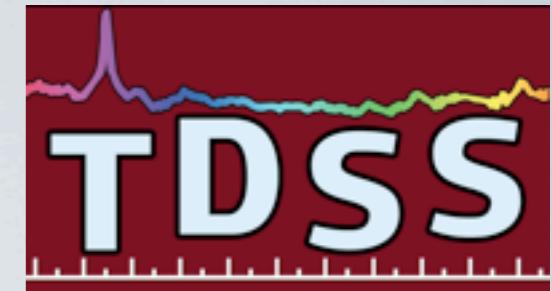
Sample Selection of CLQ Candidates



Sample Selection of CLQ Candidates

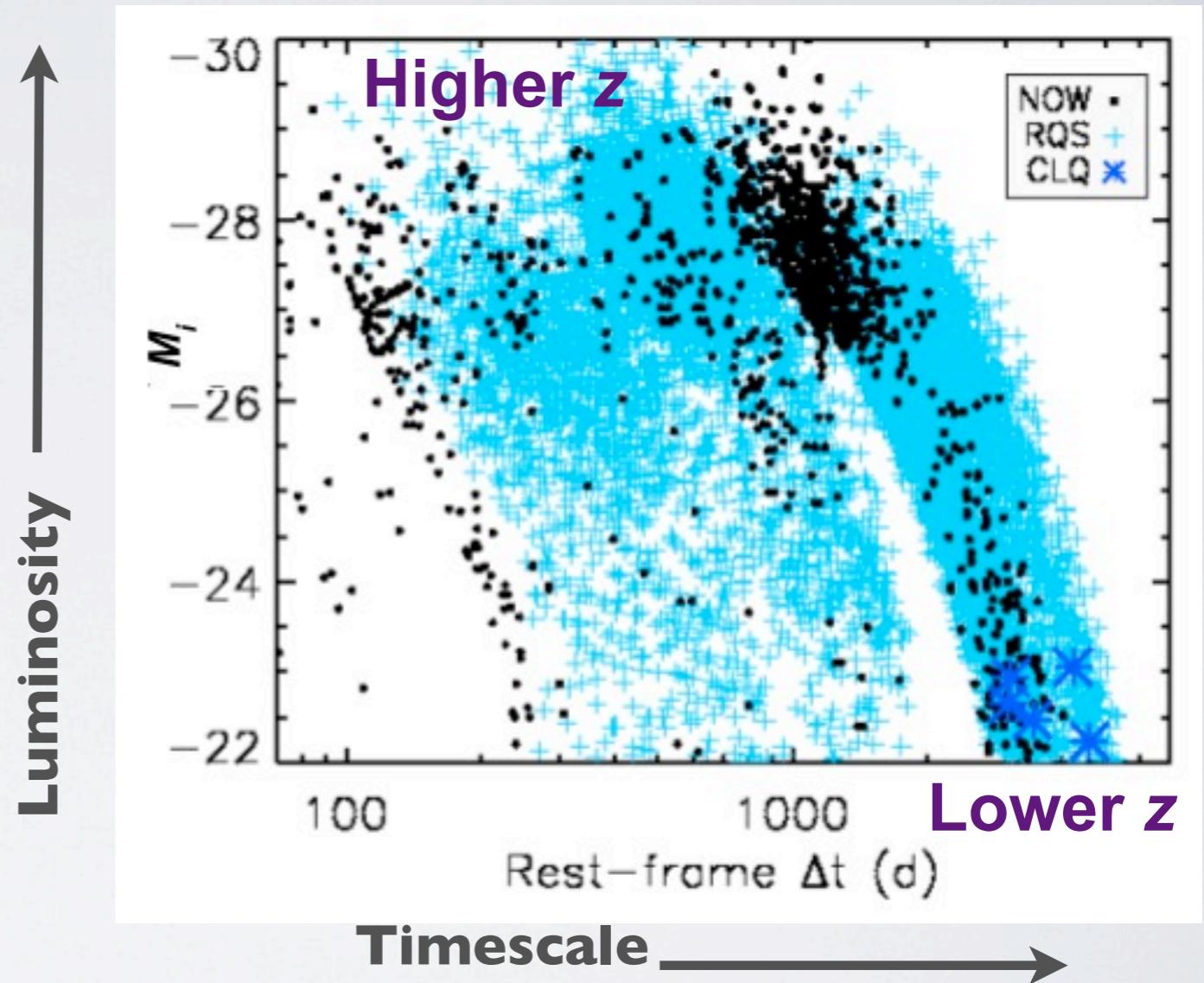


SDSS-IV Time Domain Spectroscopic Survey



Repeat spectra for:

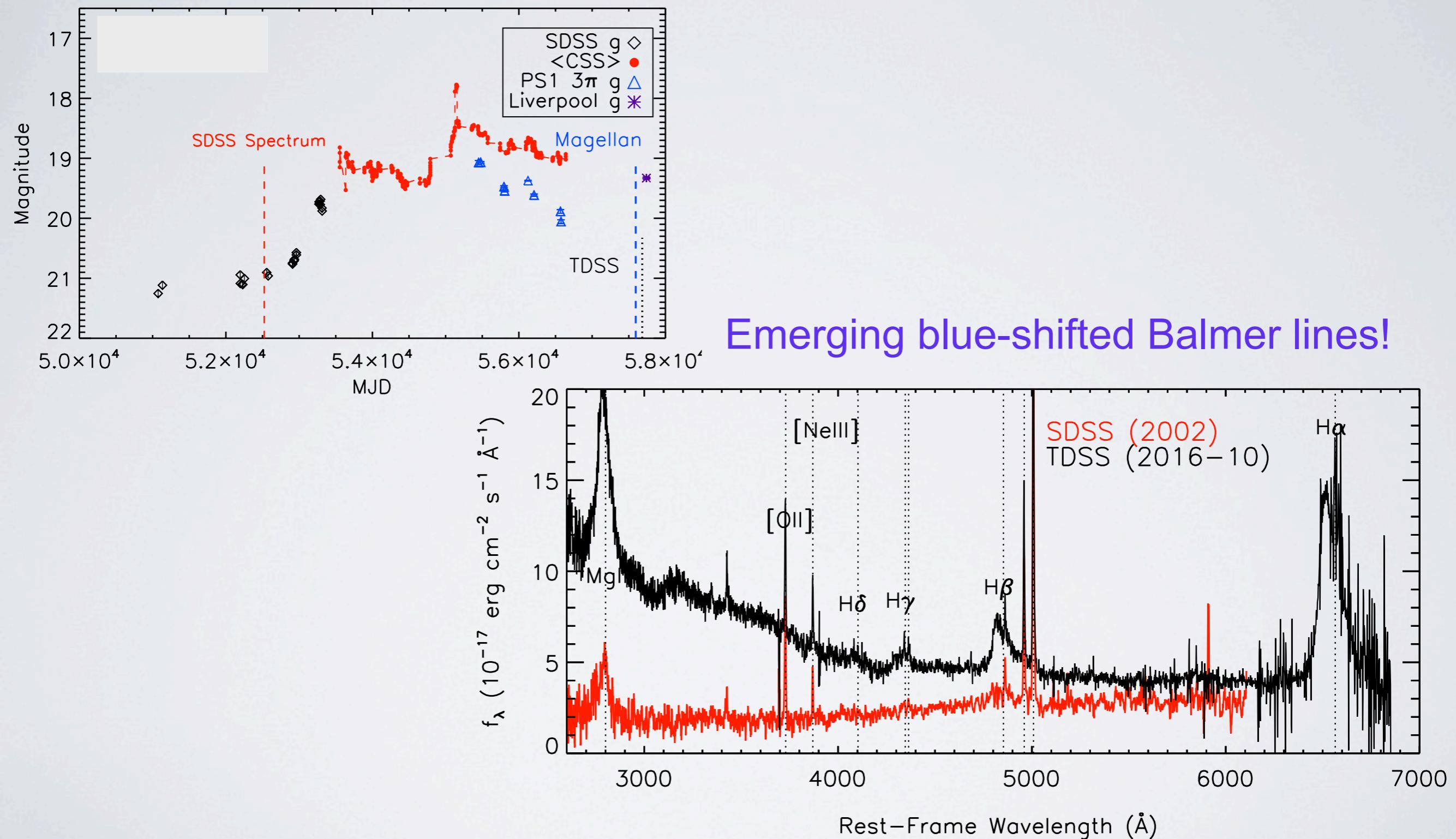
- 13K quasars
- 1K hypervariable quasars ($|\Delta m| > 0.7$ mag)
- 3500+ quasars at $z < 0.83$



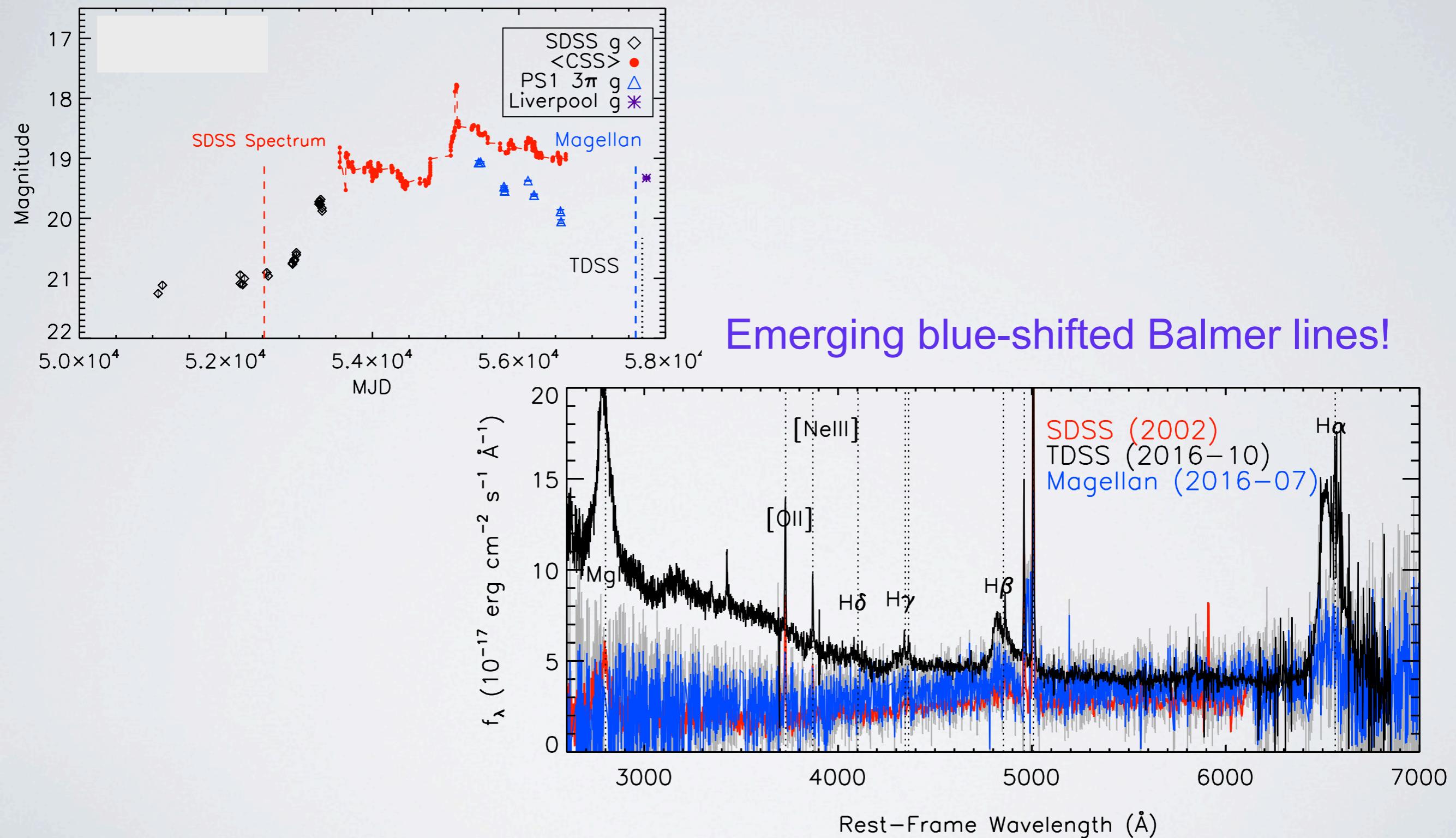
With large sample of quasars with repeat spectra:

- Spectroscopic variability as function of quasar properties

TDSS Repeat Quasar Spectroscopy: Early Results



TDSS Repeat Quasar Spectroscopy: Early Results



Multiepoch Sky Surveys And The Lifetime Of Quasars

- 3814 quasars in the SDSS Early Data Release and Digitized Sky Survey (Martini & Schneider 2003): quasar lifetime must be $> 20,000$ yr
- I.e., none seem to disappear or appear between epochs