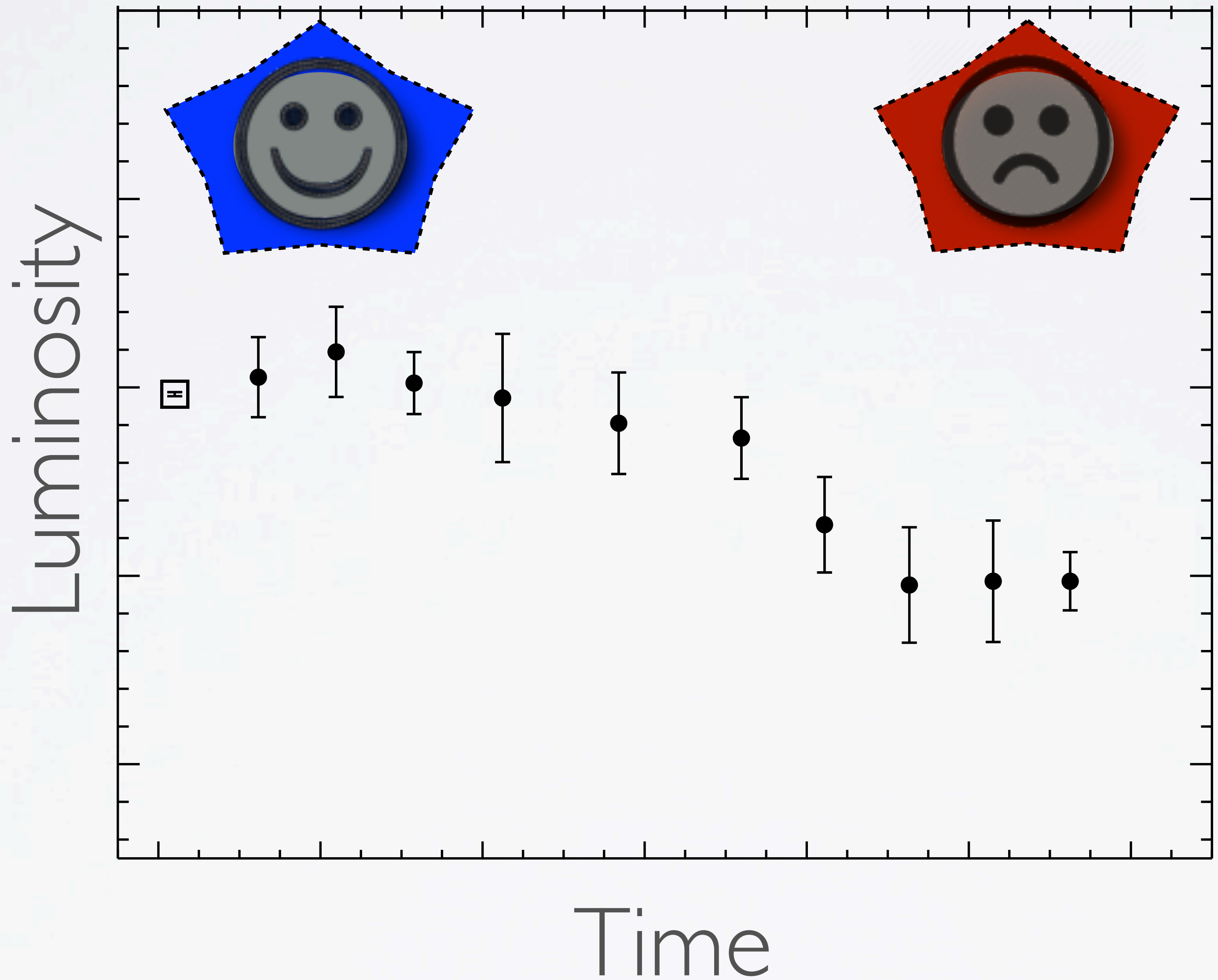
A Systematic Search for Changing-Look Quasars



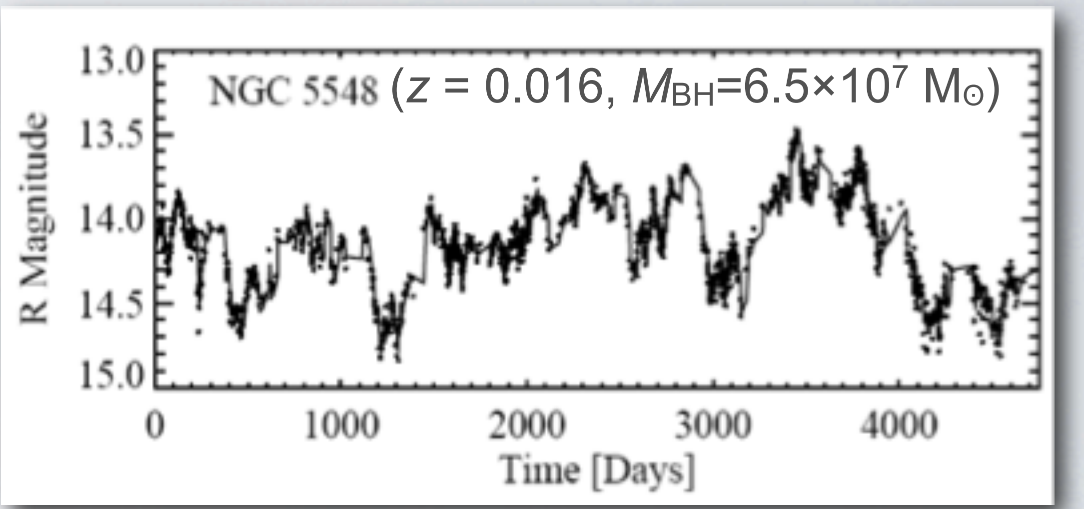
Chelsea MacLeod (CfA / SAO)

Disks, Dynamos, and Data: Confronting MHD Accretion Theory with Observations
KITP, Santa Barbara, 9 Feb 2017

Collaborators: Paul Green (SAO), Nic Ross (ROE), Andy Lawrence (ROE), Jessie Runnoe (UMich), Mike Eracleous (PSU), John Ruan (UW), Scott Anderson (UW), Matthew Graham (Caltech)

Optical Quasar Variability

Continuum:

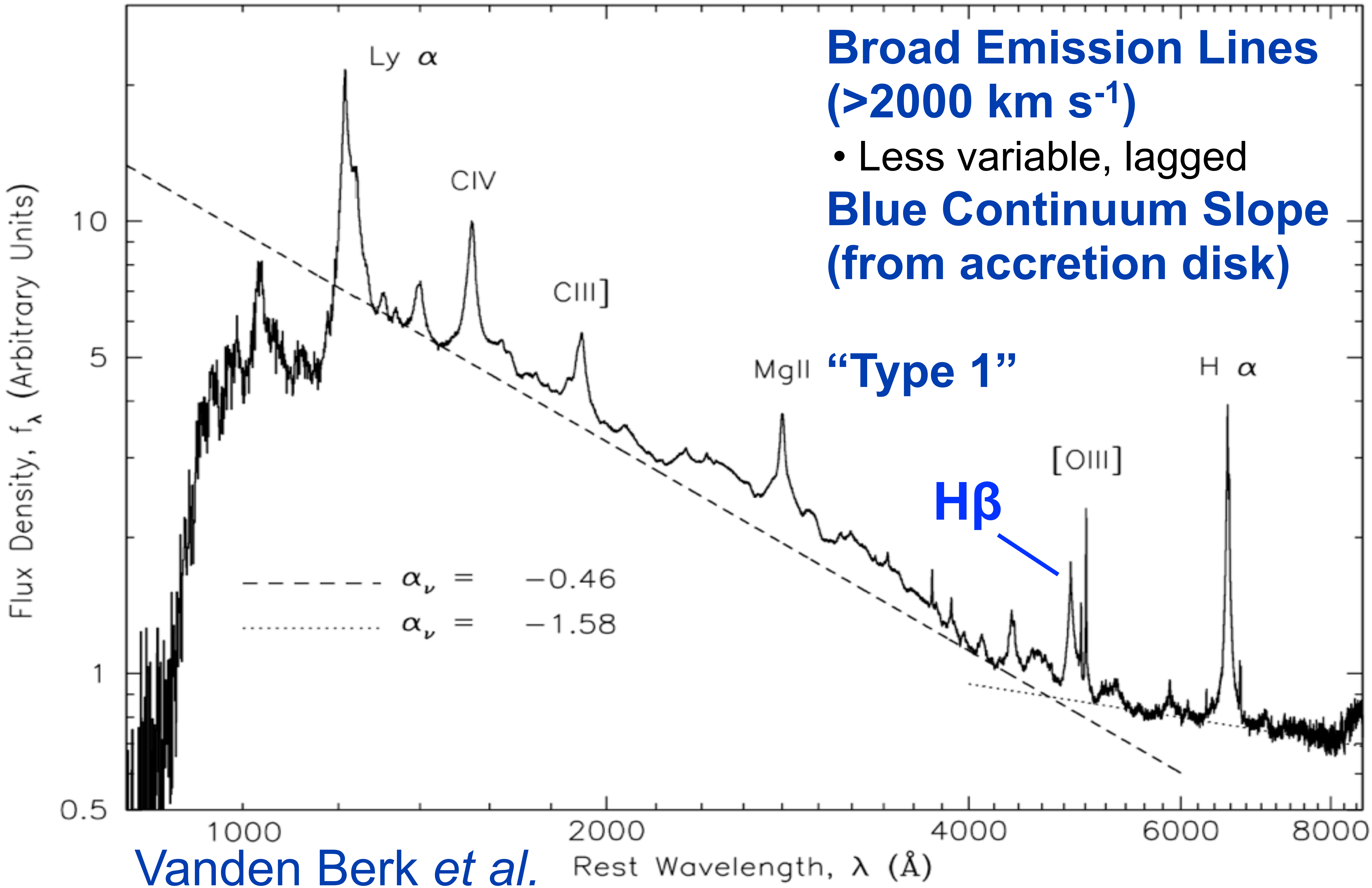


Kelly+ 2009

- rms ~ 0.2 mag over ~1 year
- Aperiodic, stochastic red noise
- Contains reprocessed UV (X-ray) emission:

NGC 5548 (Edelson+ 2015; Fausnaugh 2016);
NGC 2617 (Shappee+ 2014);
Fairall 9 (Pal+ 2017)

Quasar Spectra



Broad Emission Lines ($>$2000 km s^{-1})

- Less variable, lagged

Blue Continuum Slope (from accretion disk)

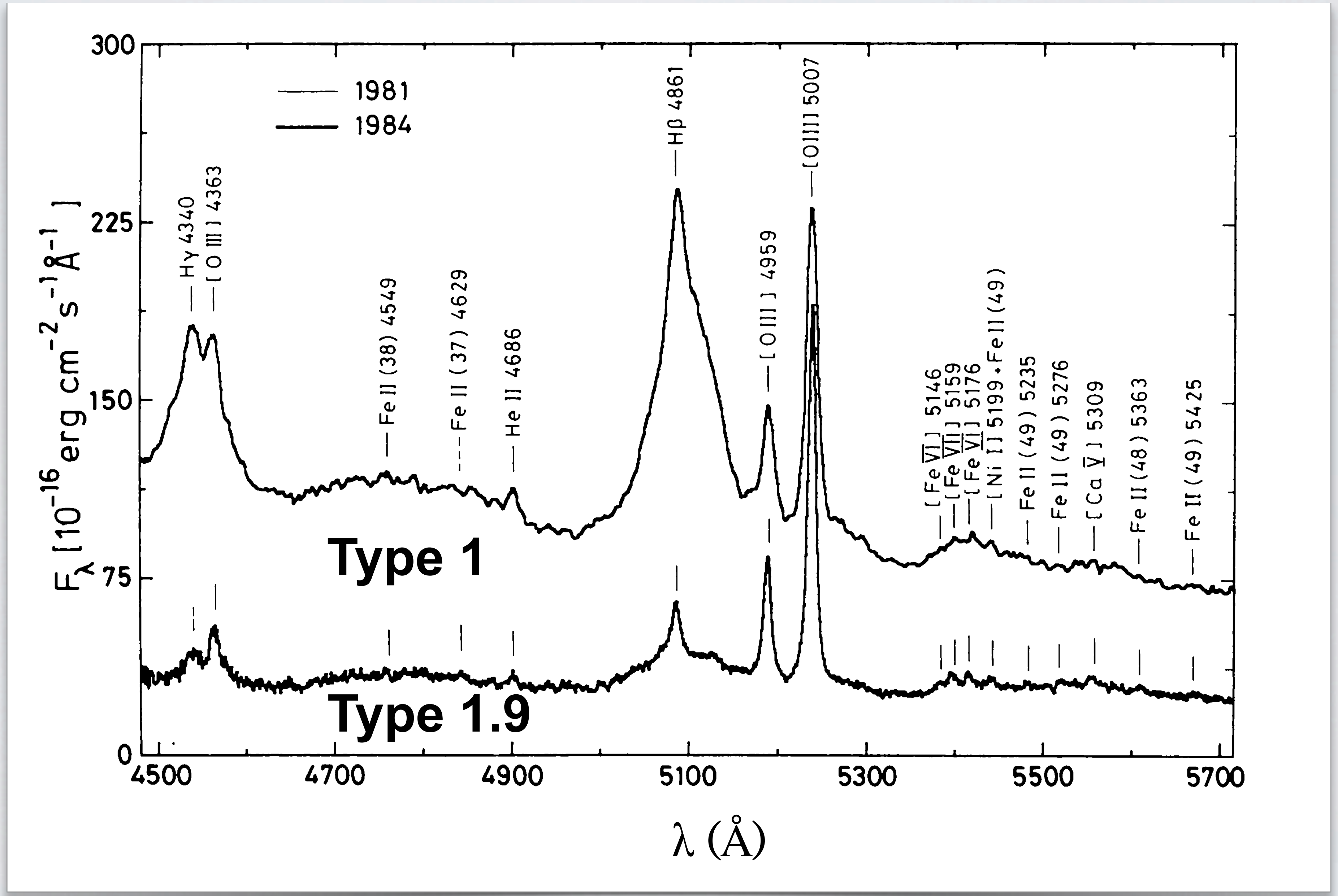
"Type 1"

Vanden Berk *et al.* 2001, AJ, 122, 549

Changing-Look AGN ("CLAGN")

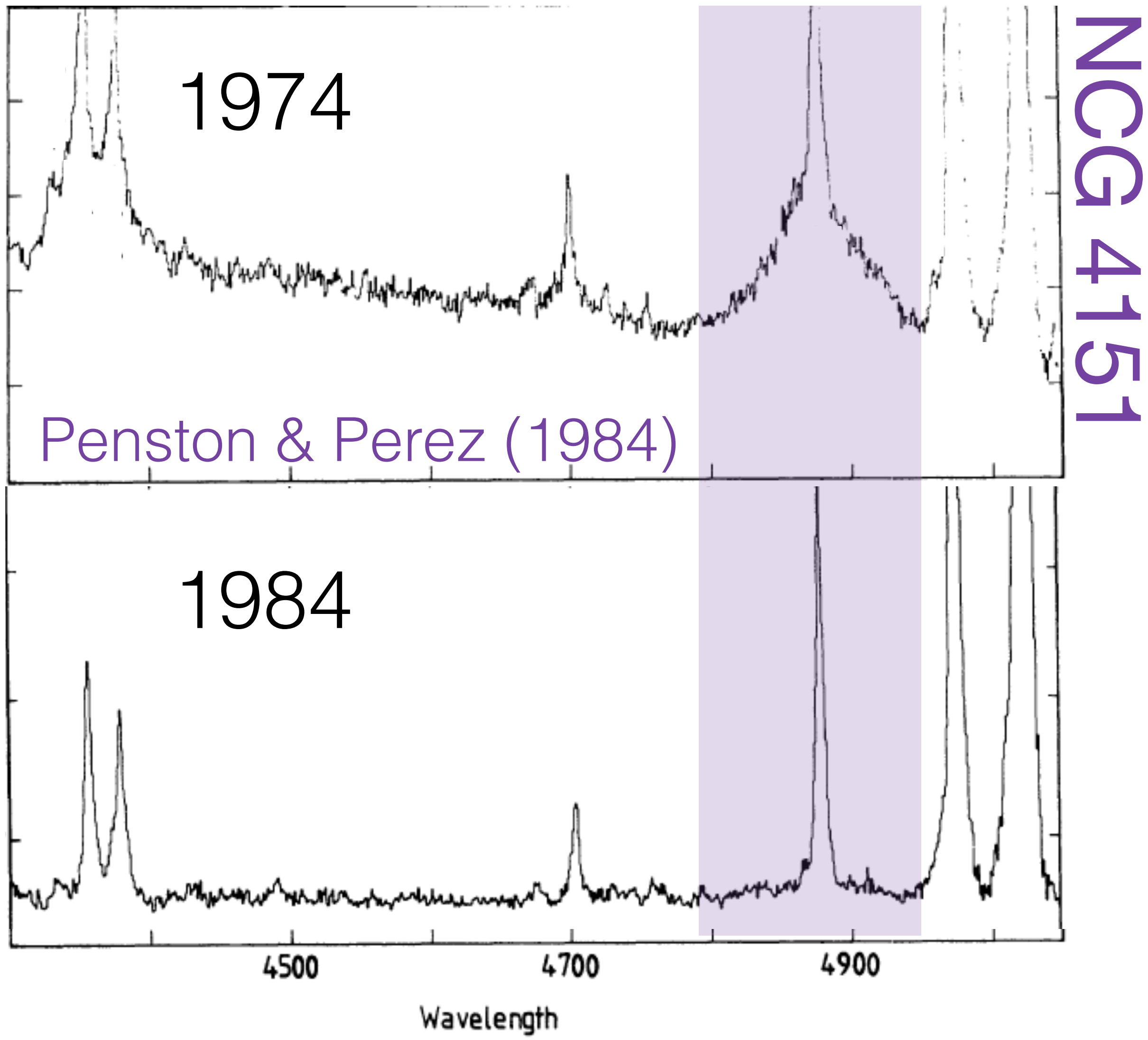
- Broad Balmer BEL (dis)appearance associated with ***continuum change*** in Seyfert galaxies

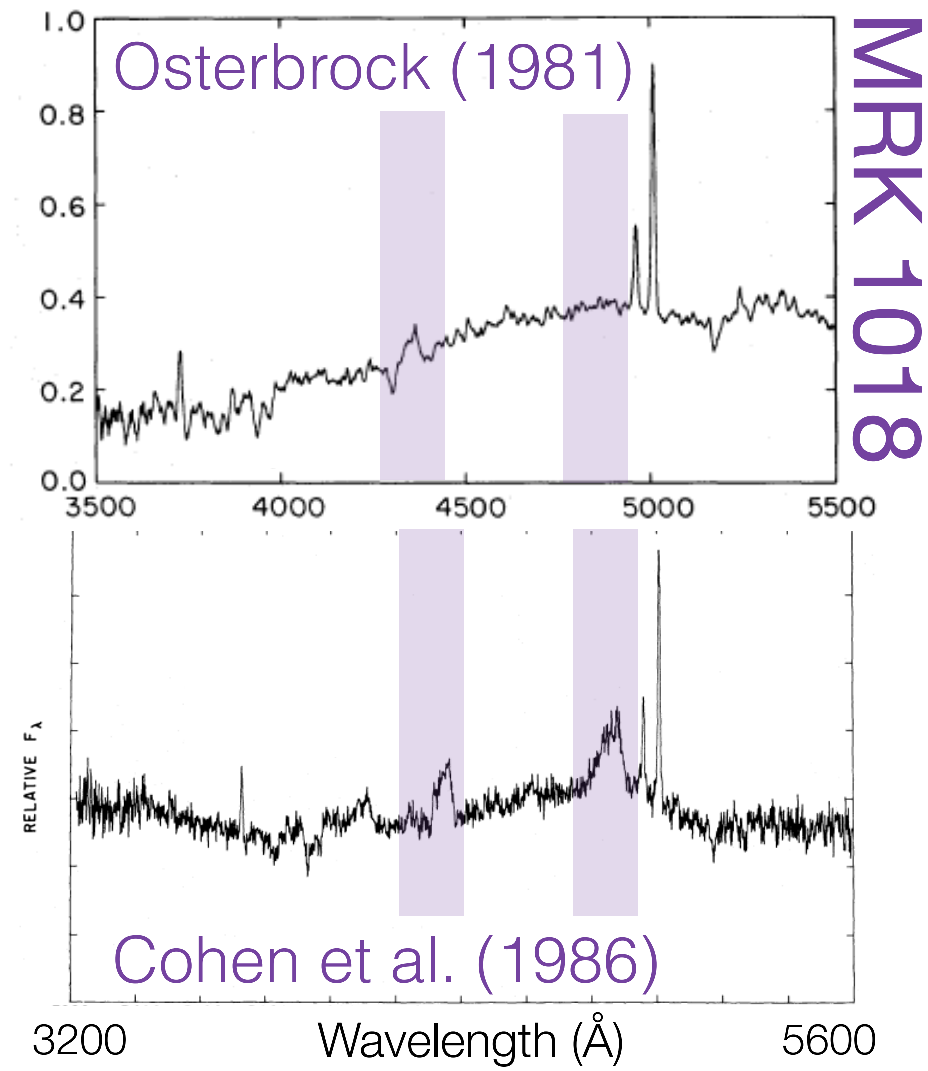
Fairall 9, 1981-4



Kollatschny & Fricke 1985

The transitions go both ways



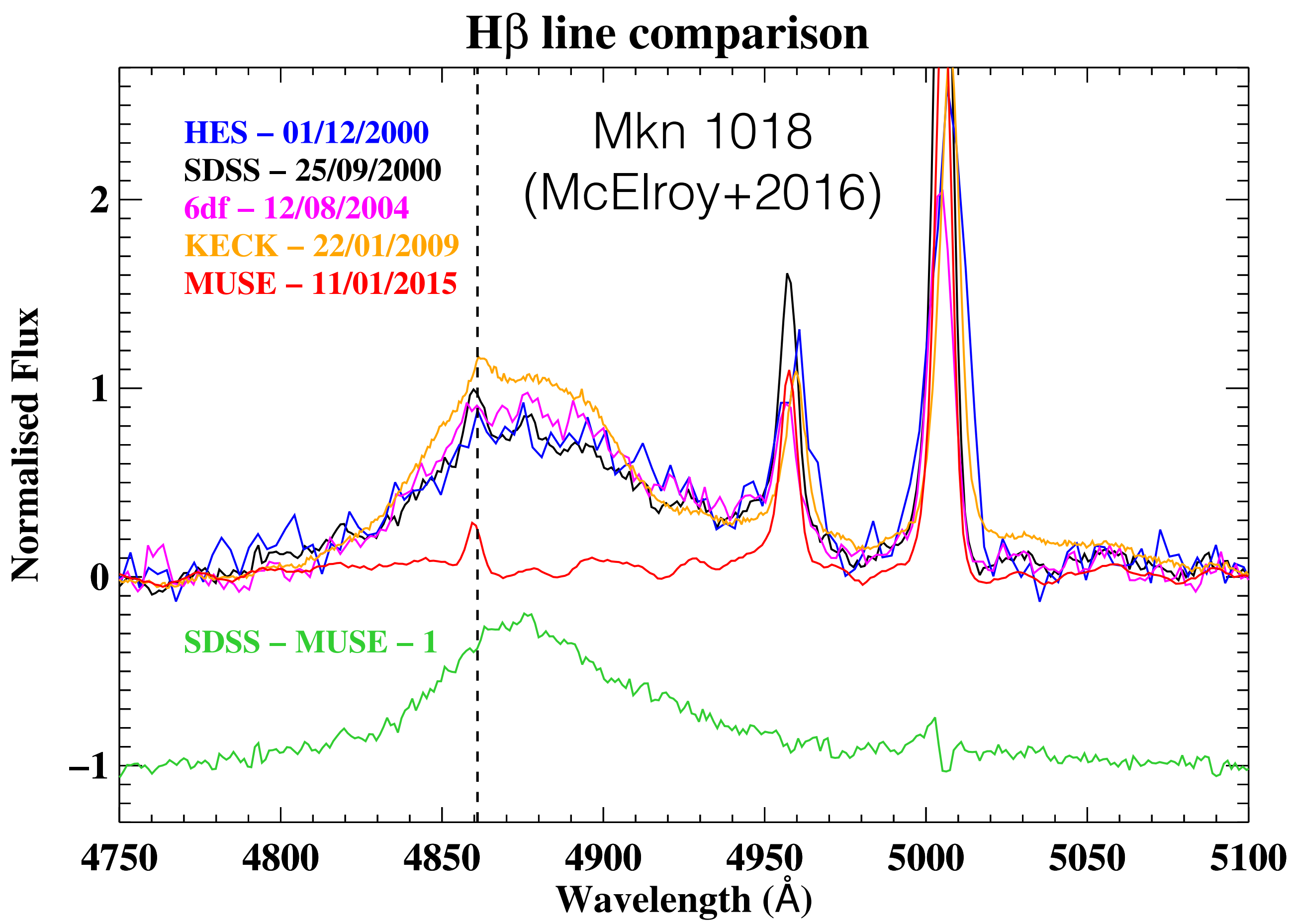


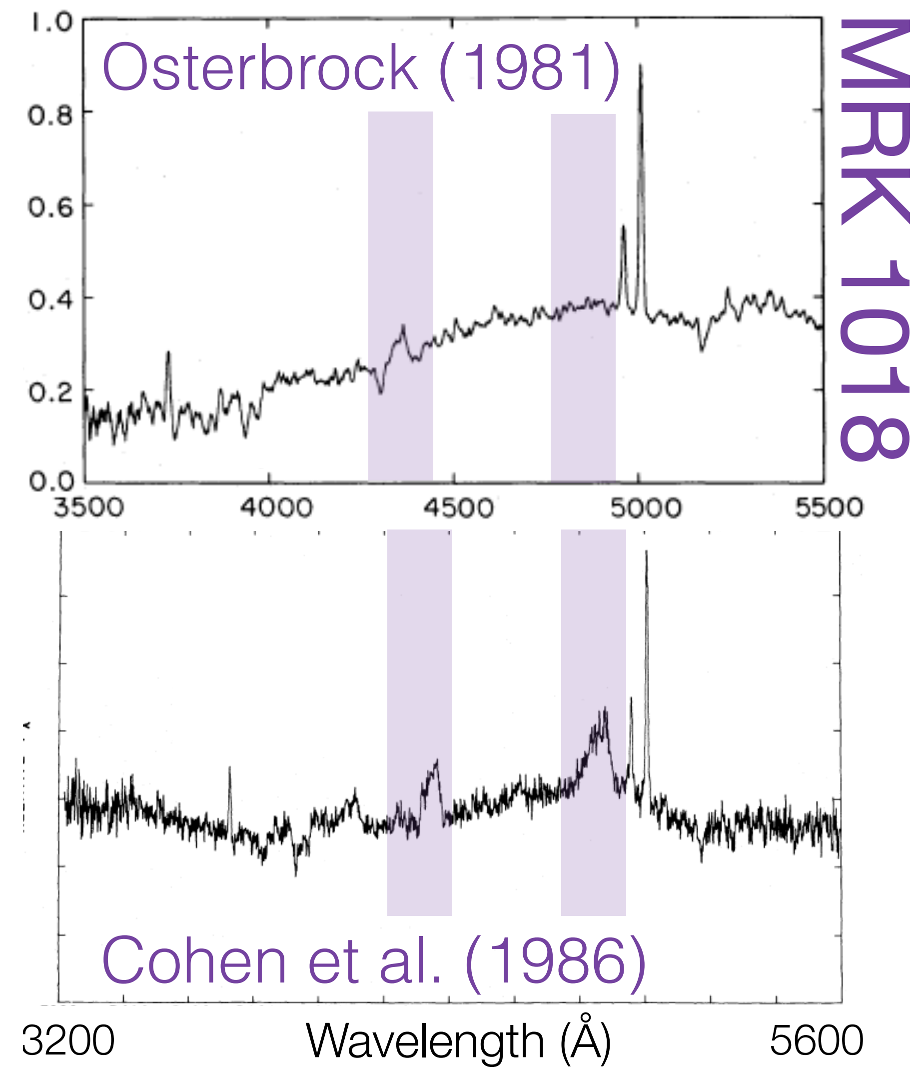
Tohline & Osterbrock (1976)
Goodrich et al. (1995)
Sanmartim et al. (2014)
Denney et al. (2014)
Barth et al. (2015)

Tran et al. (1992)
Storchi-Bergmann et al. (1993)
Aretxaga et al. (1999)
Eracleous & Halpern (2001)
Shappee et al. (2014)
Parker et al. (2016)

Courtesy: J. Runnoe

The transitions go both ways and back again





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Courtesy: J. Runnoe

What causes the changing look?

Dust extinction

- MRK 993
- NGC 7603
- NGC 1087
- NGC 7582 (?)

Ionizing continuum

- MRK 590
- NGC 2617
- MRK 883
- NGC 3065
- HE 1136-2304
- MRK 1018

Supernovae

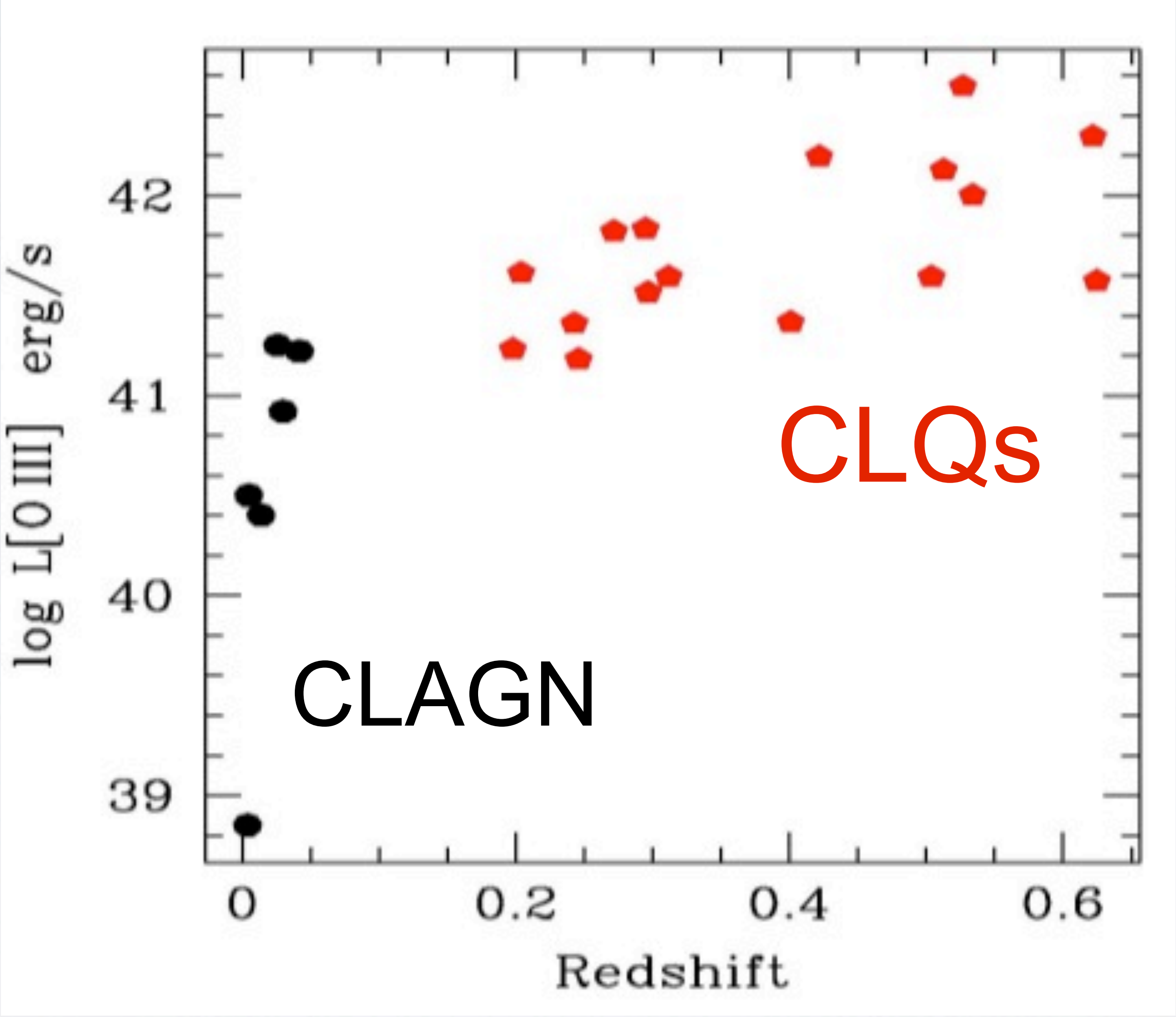
- NGC 7582(?)

TDEs

- NGC 3065 (?)
- NGC 7582 (?)

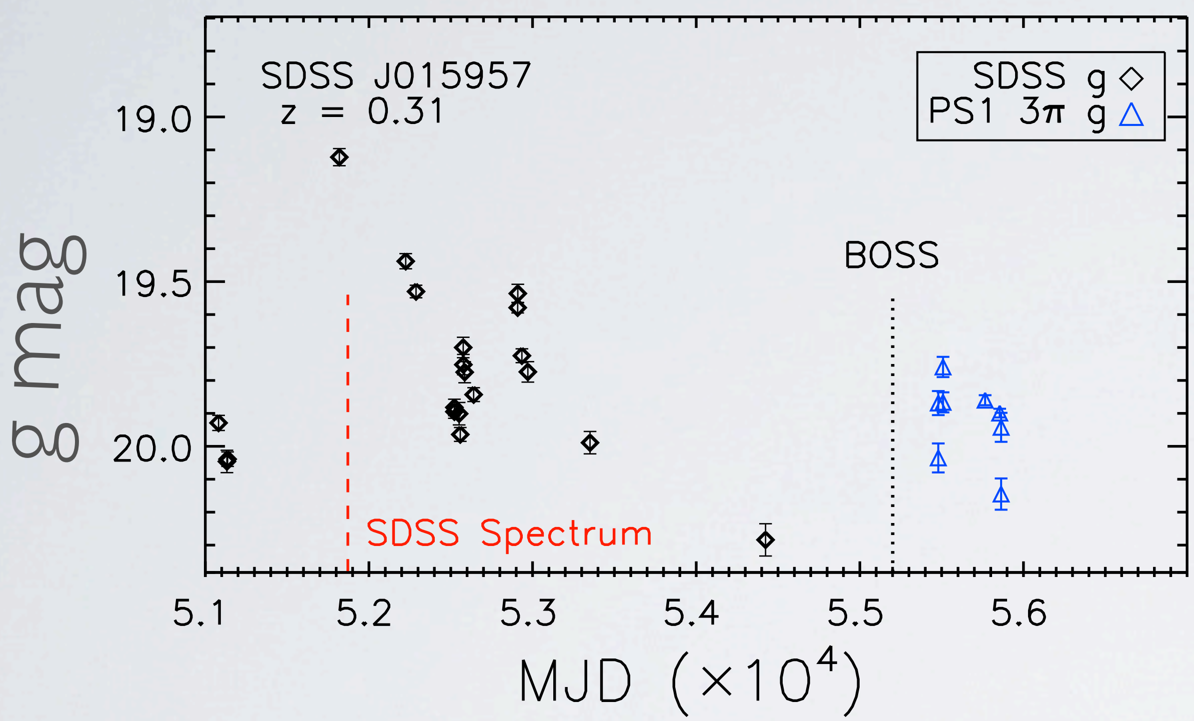
Courtesy: J. Runnoe

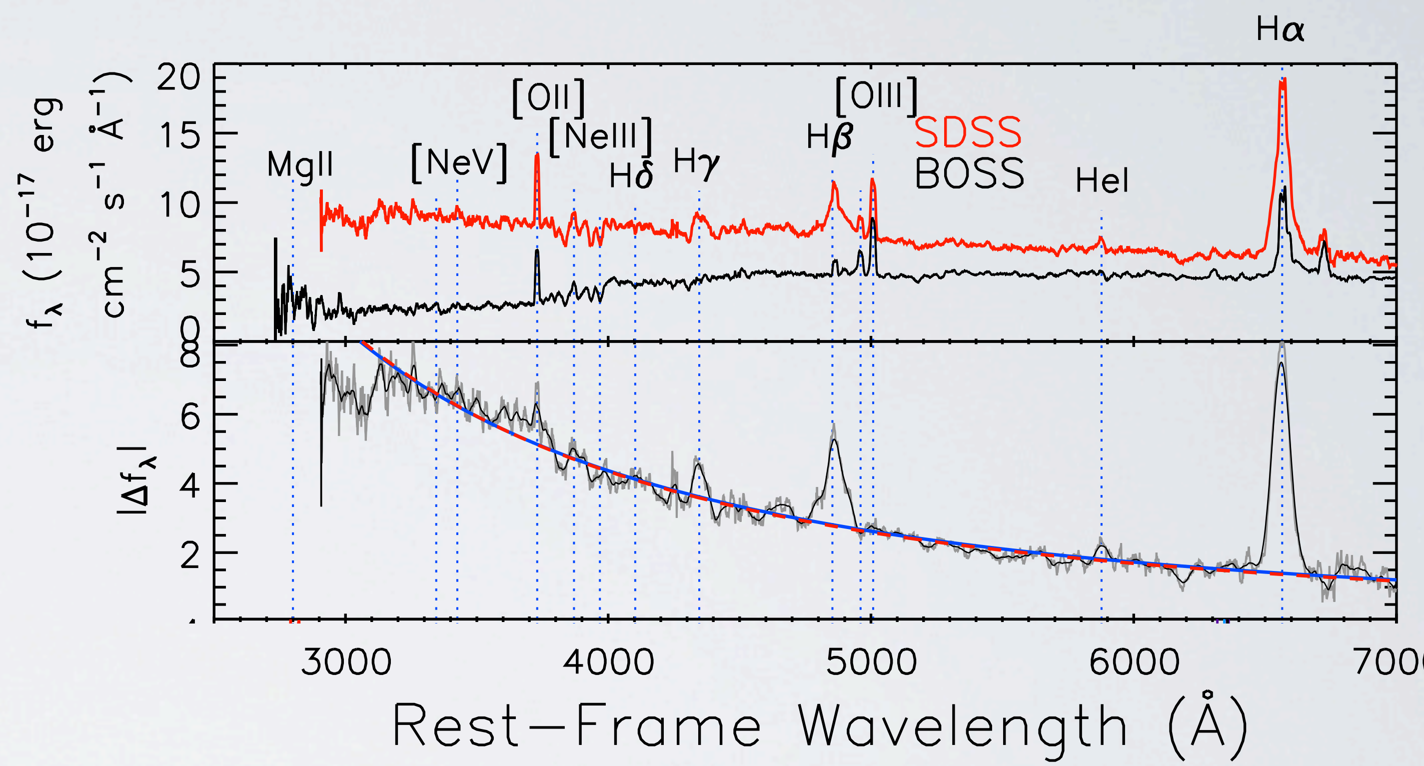
Surveys Extending CLAGN To Higher *z*, *L*



- SDSS, BOSS, Pan-STARRS, PTF, CRTS, ASAS-SN
- Large sky coverage, long time baseline

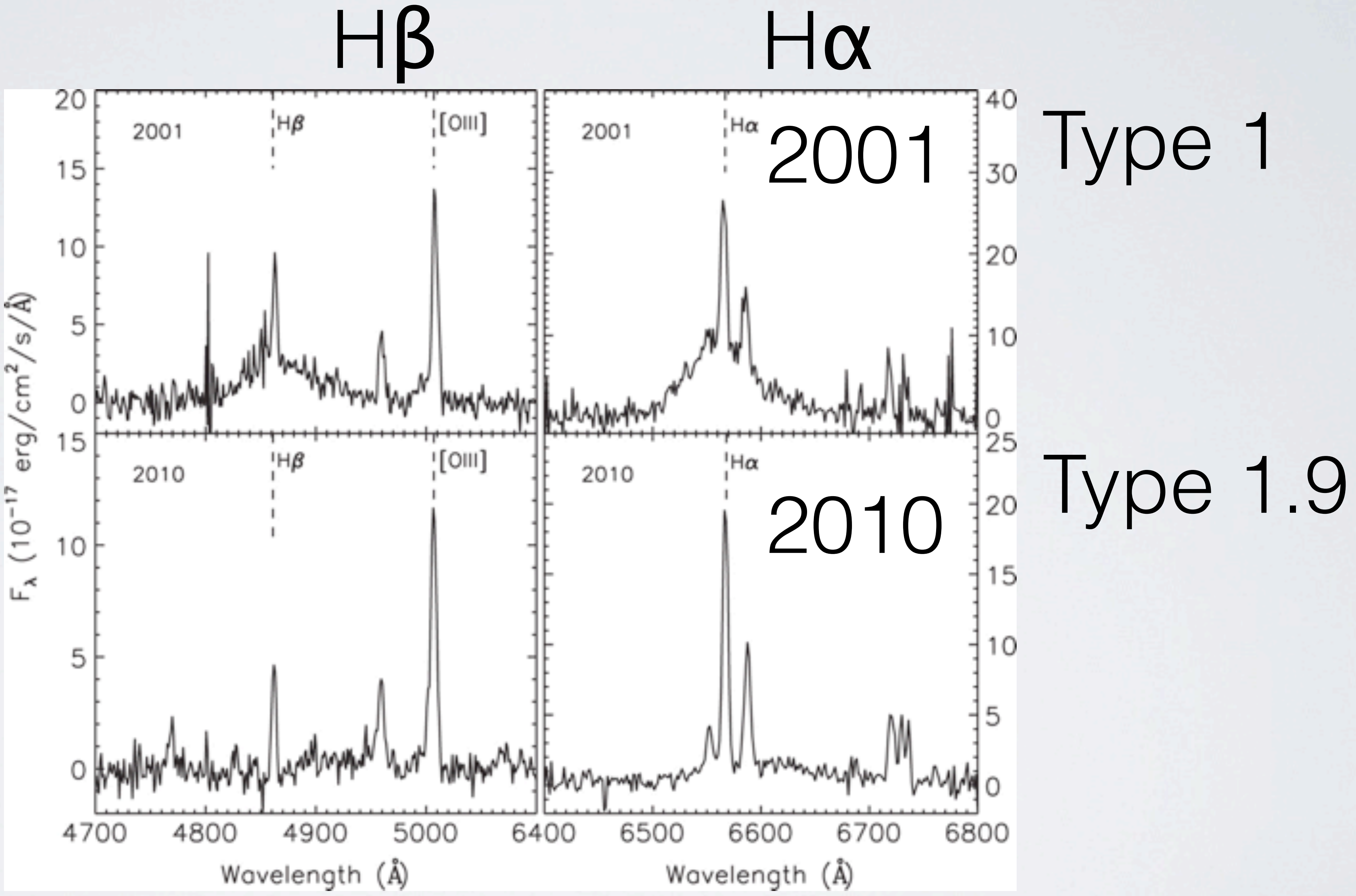
Changing-Look Quasars at $L_{bol} > 10^{44}$ erg s^{-1} ("CLQs")



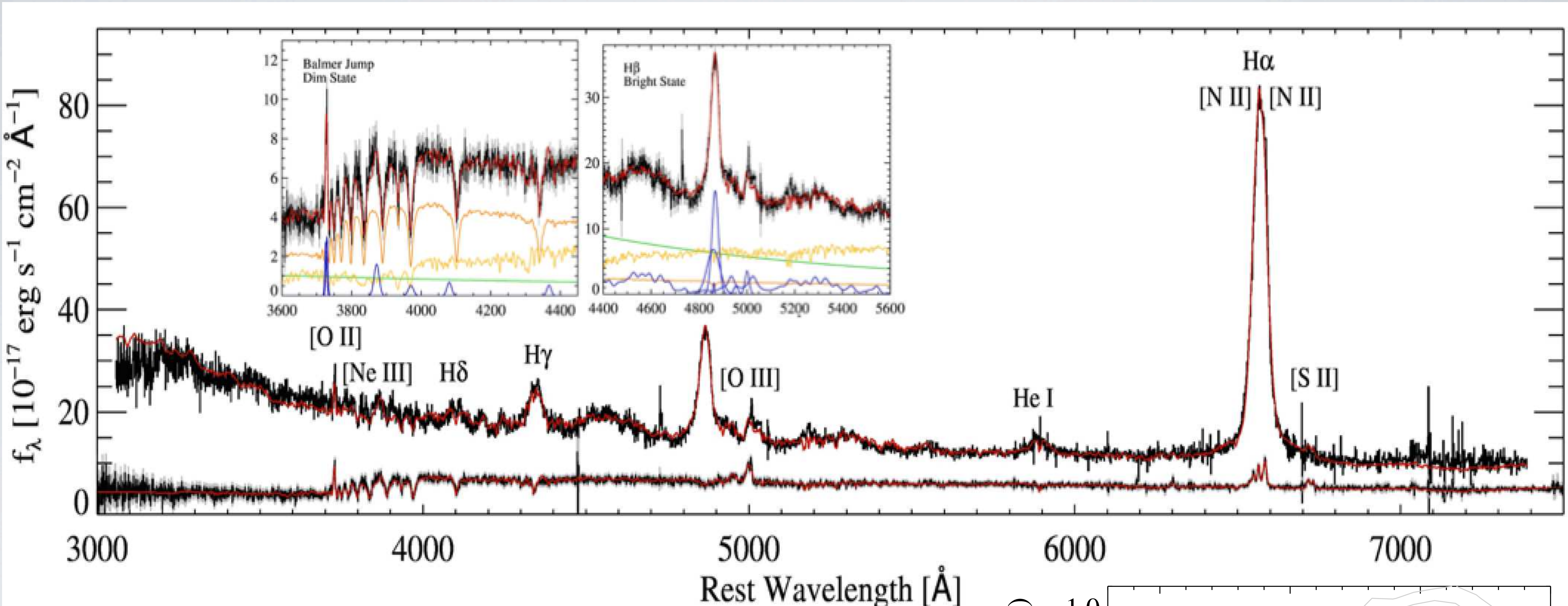


- Broad Balmer BEL (dis)appearance associated with ***continuum change*** in radio-quiet quasars
- Serendipitous discovery for $z = 0.31$ quasar (LaMassa+2015)
- Archival X-ray observations rule out variable obscuration.

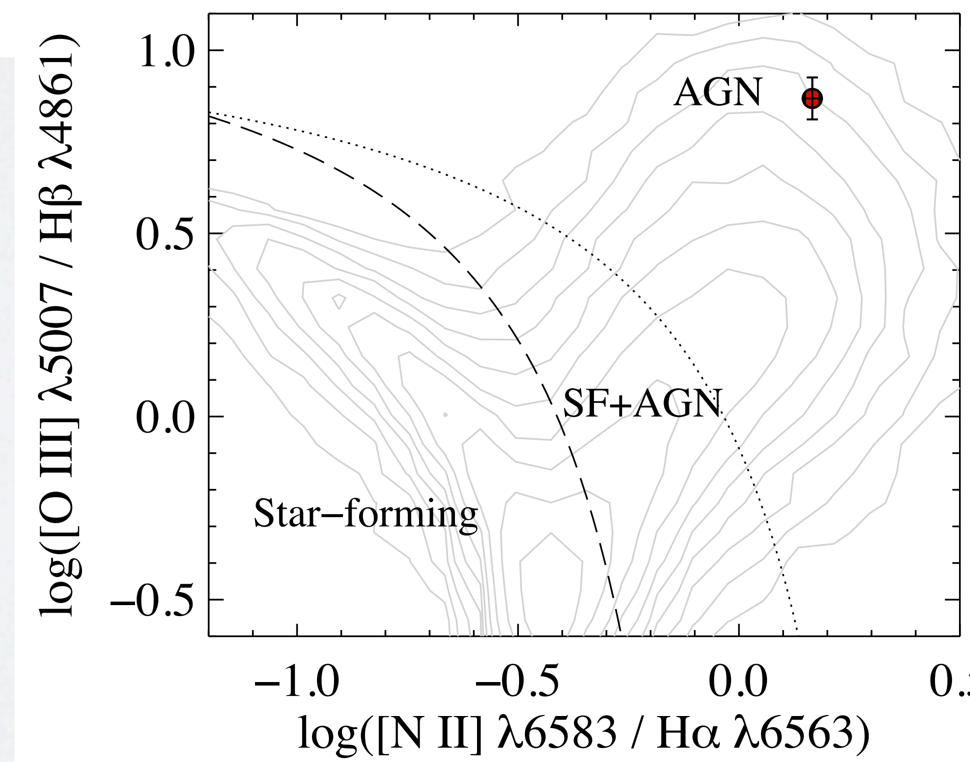
Changing-Look Quasars at $L_{bol} \gtrsim 10^{44}$ erg s^{-1} ("CLQs")



Revealing A Post-Starburst Galaxy In CLQ SDSSJ1011



The narrow lines require an AGN:



Runnoe+ 2016, MNRAS, 455, 1691

A systematic search of the SDSS

- **Systematic search for objects which have dramatic changes between quasar and galaxy spectral states.**

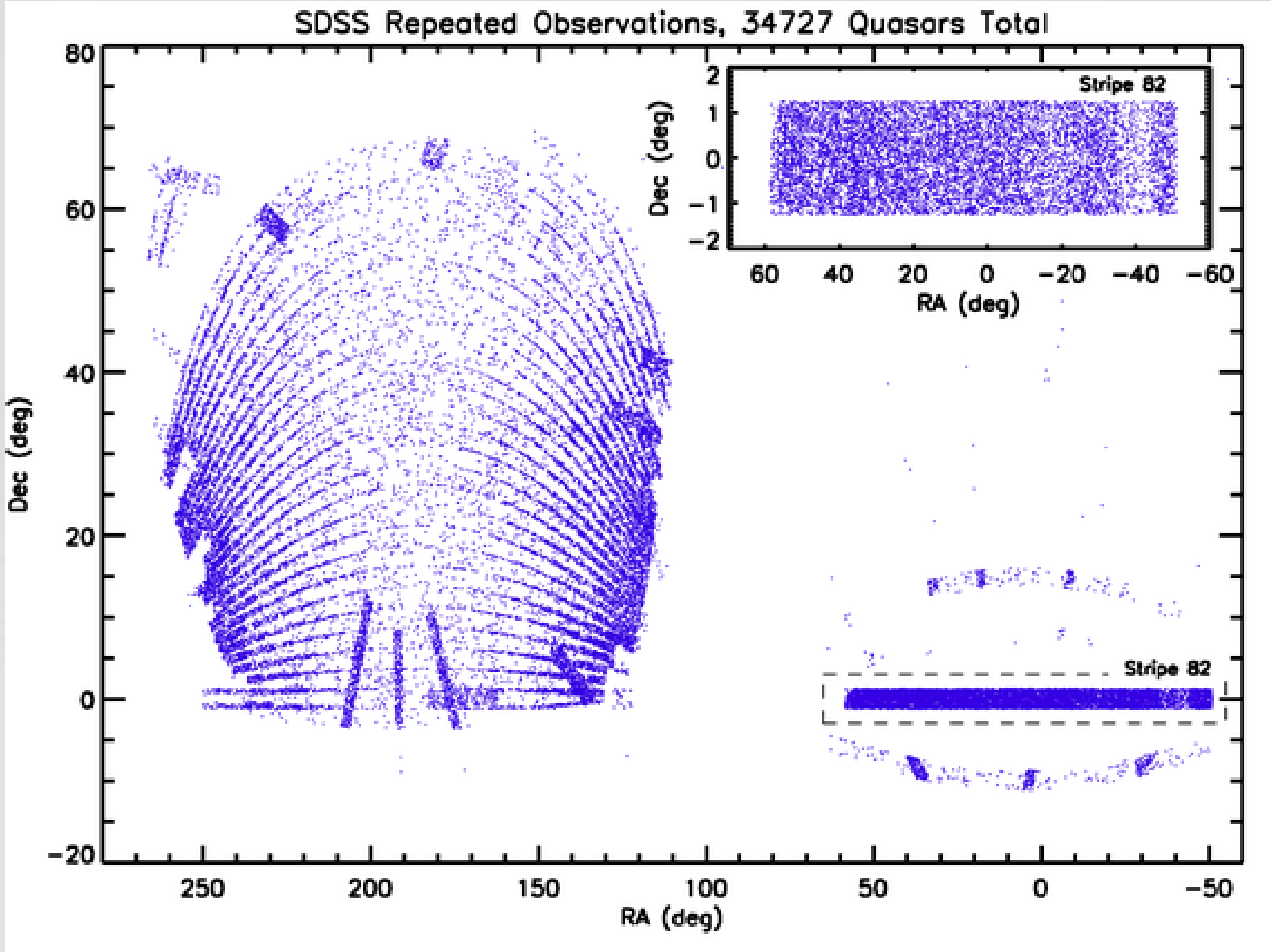
  Ruan et al. 2016, ApJ, 826 188

- **Selection:**
  - 2,510,060 objects with CLASS = ‘GALAXY’
  - 587,306 objects with CLASS = ‘QSO’
  - 117 candidates
  - 3 changing-look quasars (2 new)

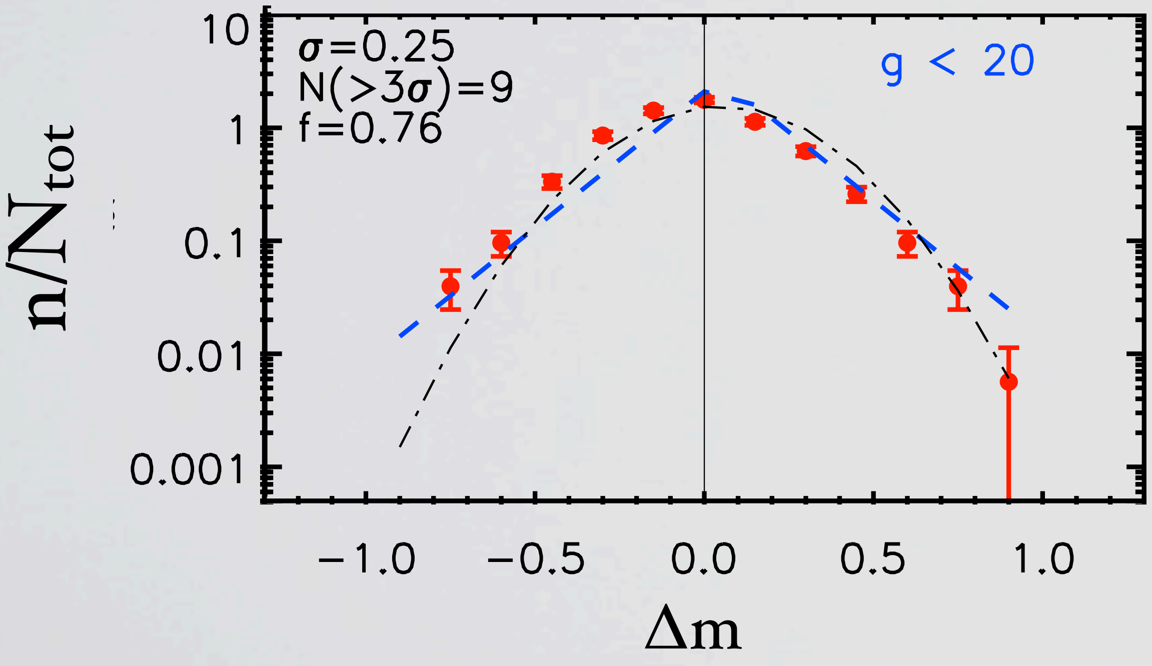
Systematic Search Based On Photometric Variability

SDSS Repeated Imaging

- Stripe 82: ~60 epochs over 10 yr (N=9,275)
- NGC: 2-3 epochs (N=25,000)
- Repeat spectroscopy from BOSS for 15%



SDSS qsos: Δt = 1400-1600 days



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

(slide from Nigel Metcalfe talk, NAM 2015)

Sample Selection of CLQ Candidates

- **SDSS DR7Q**: $M_i < -22$, both point sources and resolved objects (Schneider et al. 2010)

- $|\Delta g| > 1.0$ mag among any observations in SDSS and PS-1

Selection	Total #	In S82
SDSS Quasars in DR7Q	105 783	9474
with BOSS spectra	25 484	2304
and $\|\Delta g\| > 1$ mag and $\sigma_g < 0.15$ mag	1011	287
and that show variable BELs	10	7

- 6348 DR7Q objects have $|\Delta g| > 1.0$ mag

- We do not consider 3 blazars, radio sources with ~2-3 mag changes over months; see e.g. Ruan et al. 2012.

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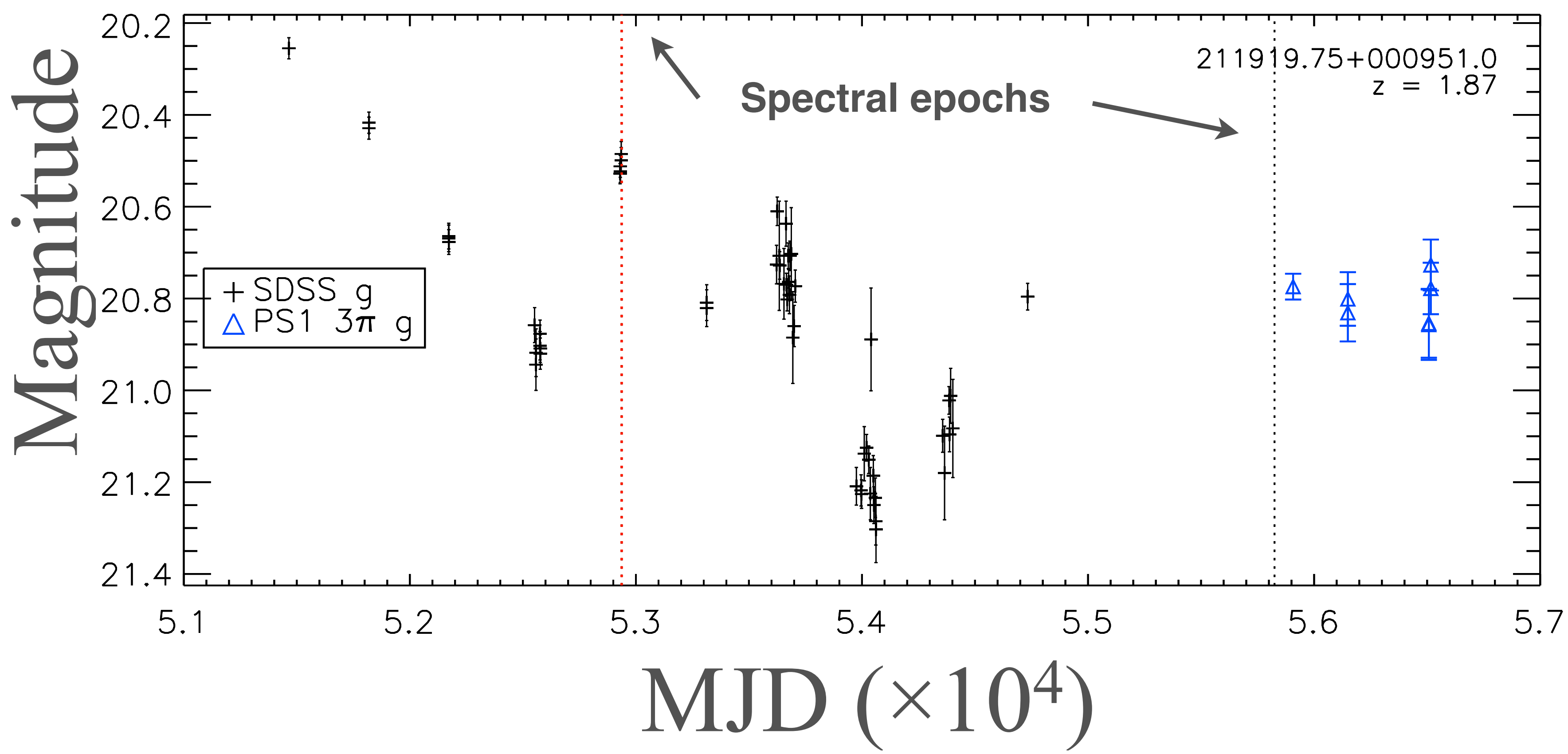

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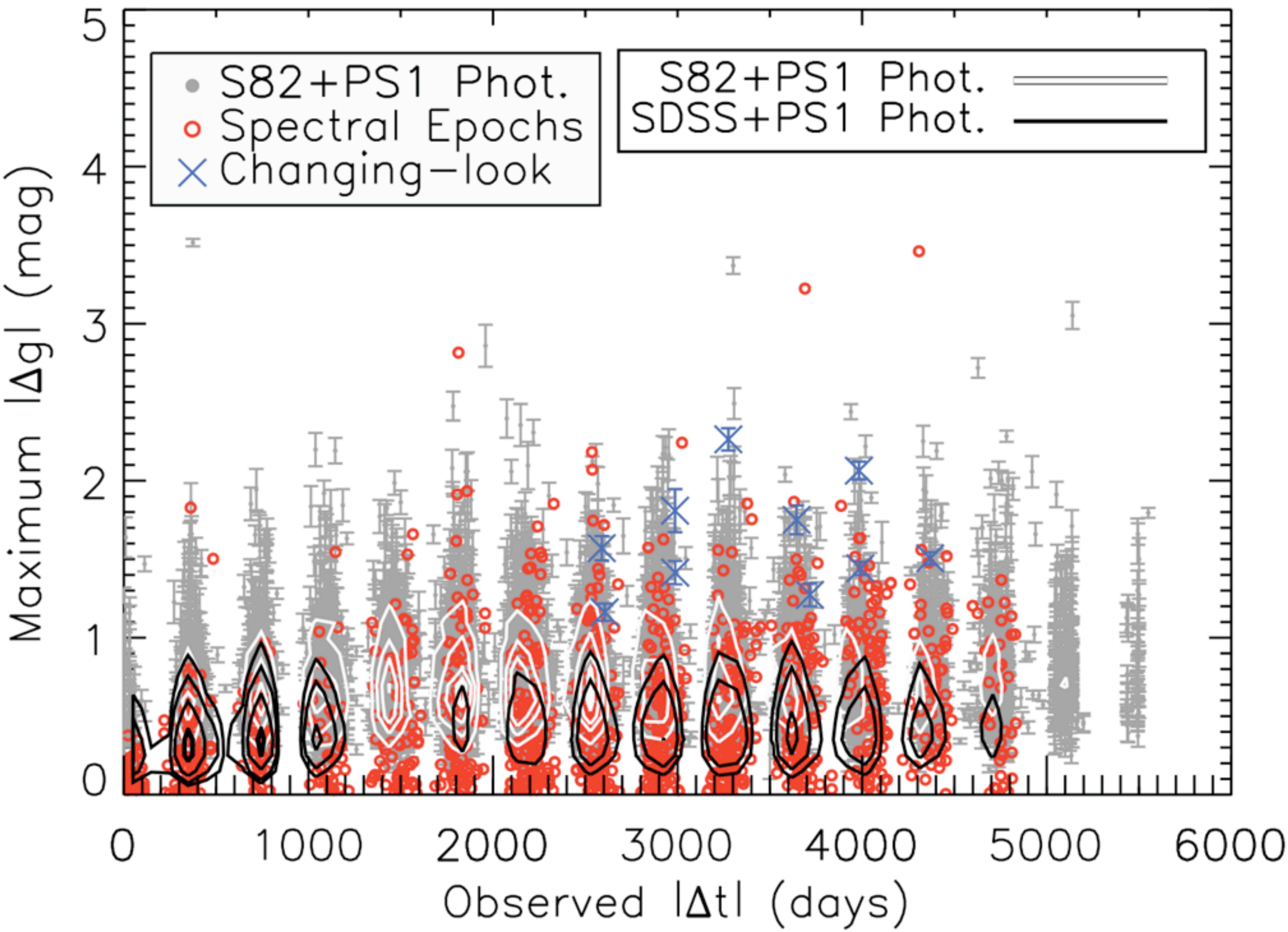
Discovery of 10 CLQs

Name (SDSS J)	z	Max(Δg)	Δt_{RF} (d)	BEL behaviour	(MJD|plate|fibre)$_1$	(MJD|plate|fibre)$_2$	$\lvert\Delta f_\nu\rvert \propto \nu^\beta$
002311.06+003517.5	0.422	-1.50 ± 0.04	3072	Appear	51816|0390|0564	55480|4219|0852	0.04 ± 0.02
015957.64+003310.4	0.312	1.16 ± 0.06	1985	Disappear	51871|0403|0549	55201|3609|0524	0.27 ± 0.02
022556.07+003026.7	0.504	1.81 ± 0.14	1985	Both	52944|1508|0556	55445|3615|0617	0.16 ± 0.03
022652.24−003916.5	0.625	1.75 ± 0.09	2242	Disappear	52641|1071|0281	56577|6780|0339	0.2 ± 0.1
100220.17+450927.3	0.400	1.41 ± 0.07	2134	Disappear	52376|0943|0310	56683|7284|0122	-0.20 ± 0.02
102152.34+464515.6	0.204	1.44 ± 0.04	3313	Disappear	52614|0944|0603	56769|7386|0410	0.175 ± 0.007
132457.29+480241.2	0.272	1.27 ± 0.07	2923	Disappear	52759|1282|0045	56805|7406|0527	0.86 ± 0.02
214613.31+000930.8	0.621	-1.57 ± 0.08	1597	Appear	52968|1107|0358	55478|4196|0774	0.1 ± 0.1
225240.37+010958.7	0.534	-2.06 ± 0.06	2596	Appear	52174|0676|0442	55500|4294|0045	-0.45 ± 0.08
233317.38−002303.4	0.513	-2.26 ± 0.07	2164	Appear	52199|0681|0114	55447|4212|0312	0.75 ± 0.07

Sample Selection of CLQ Candidates



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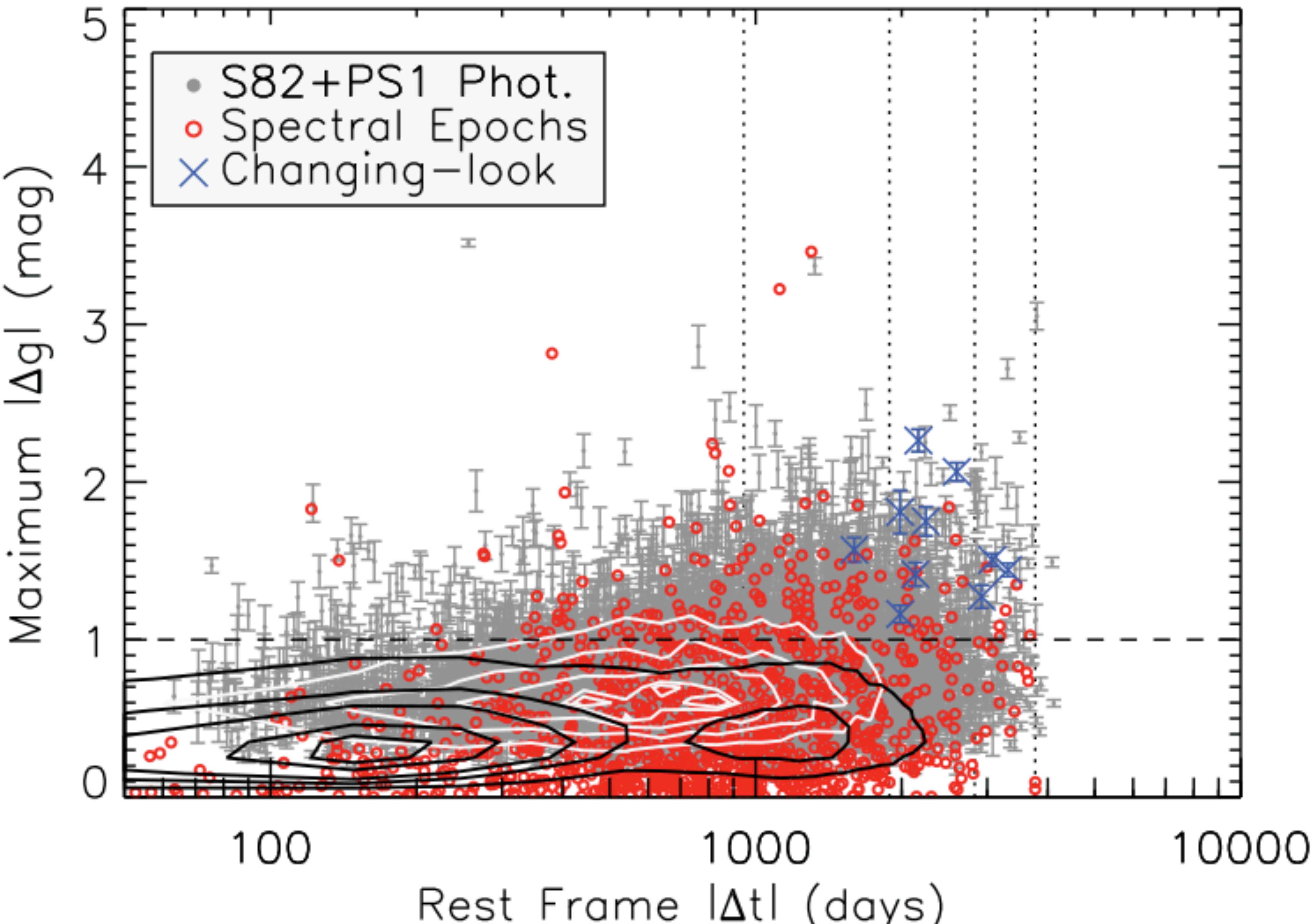
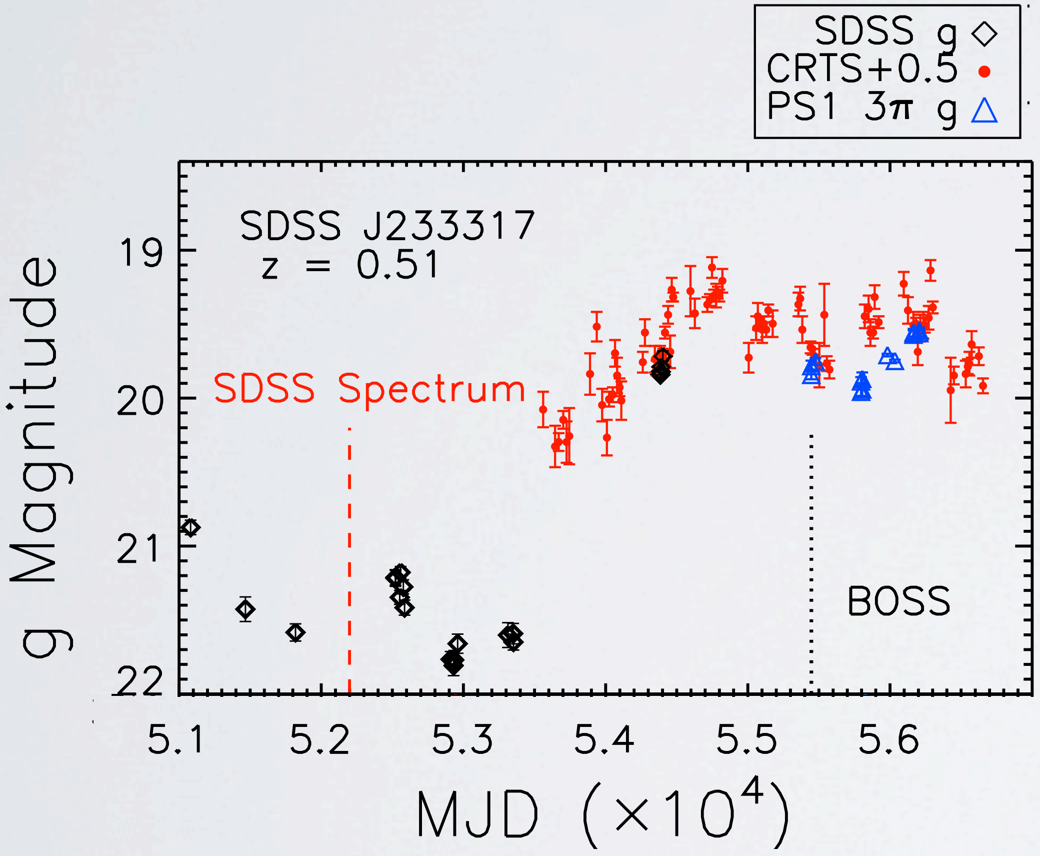
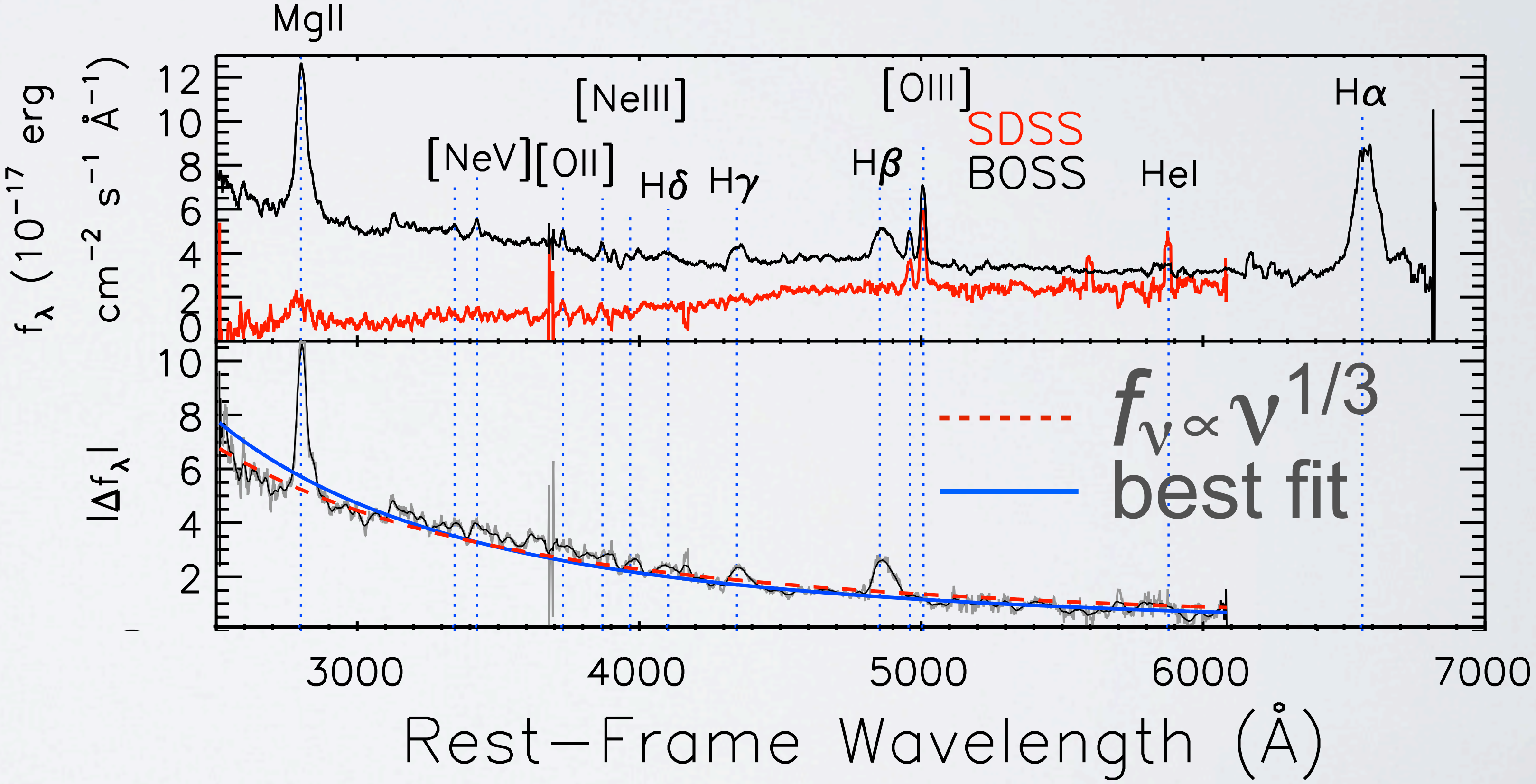


Systematic Search for CLQs

Results:

- BEL (dis)appearance associated with large changes in continuum flux.
- 5 with ***emerging*** BELs

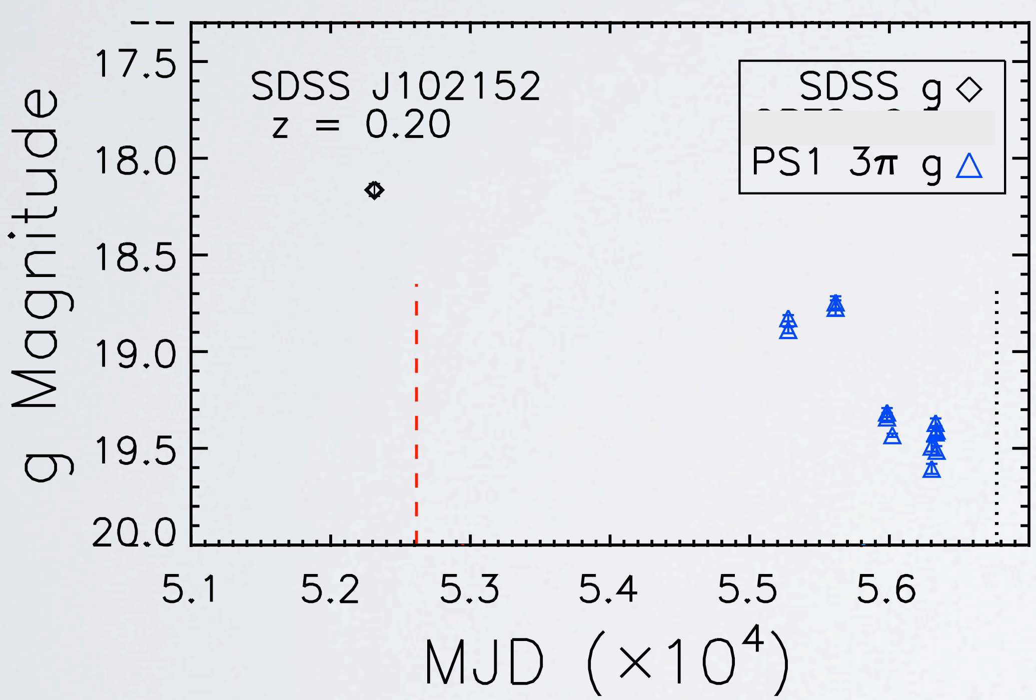


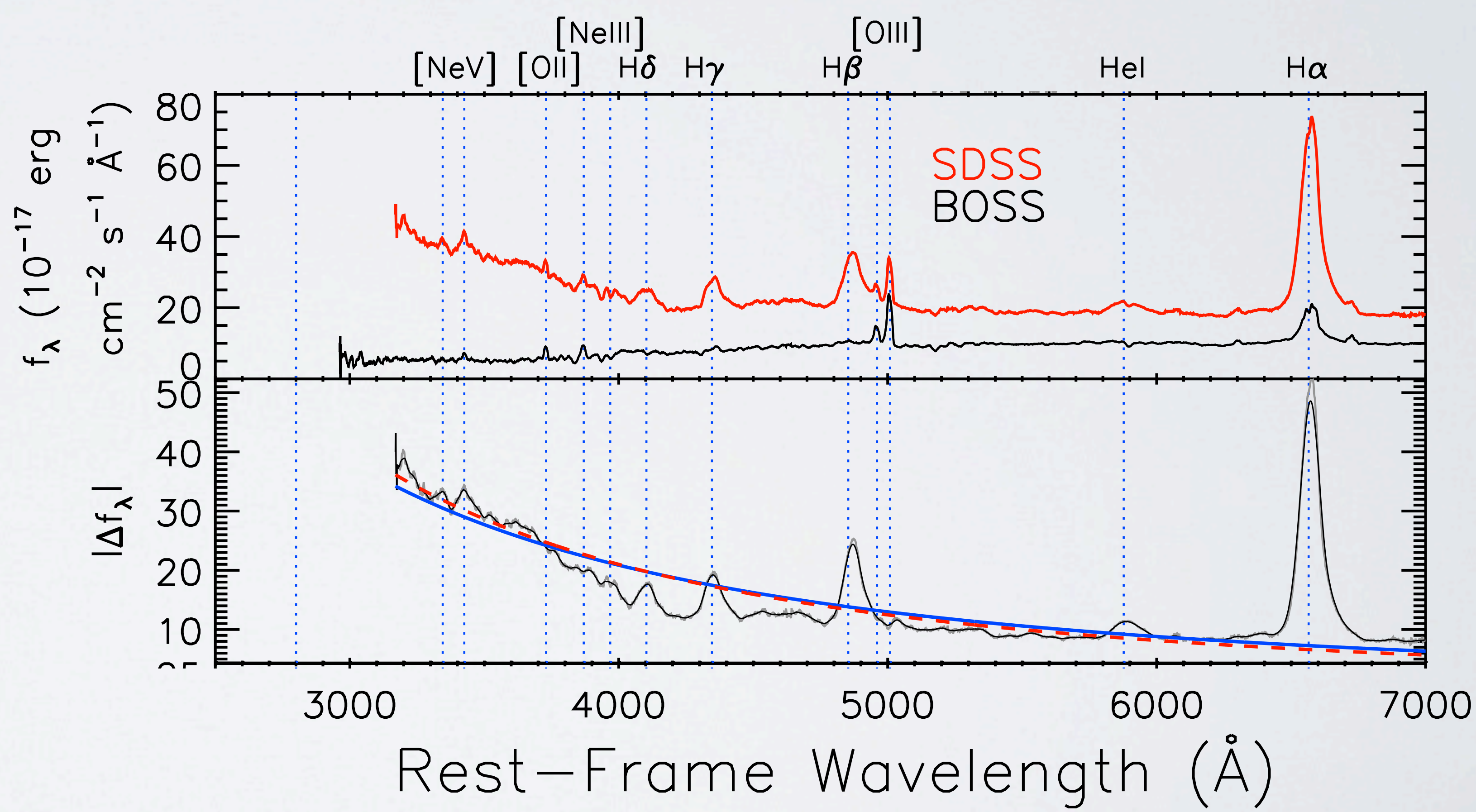


Systematic Search for CLQs

Results:

- BEL (dis)appearance associated with large changes in continuum flux.
- 5 with ***emerging*** BELs
- 5 with ***disappearing*** BELs

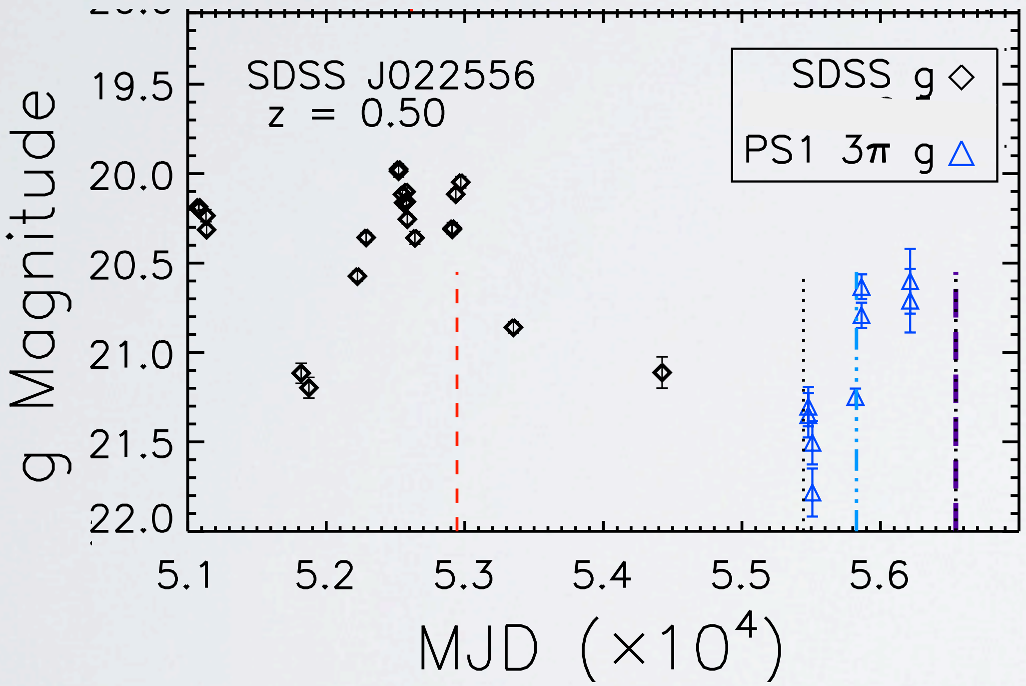


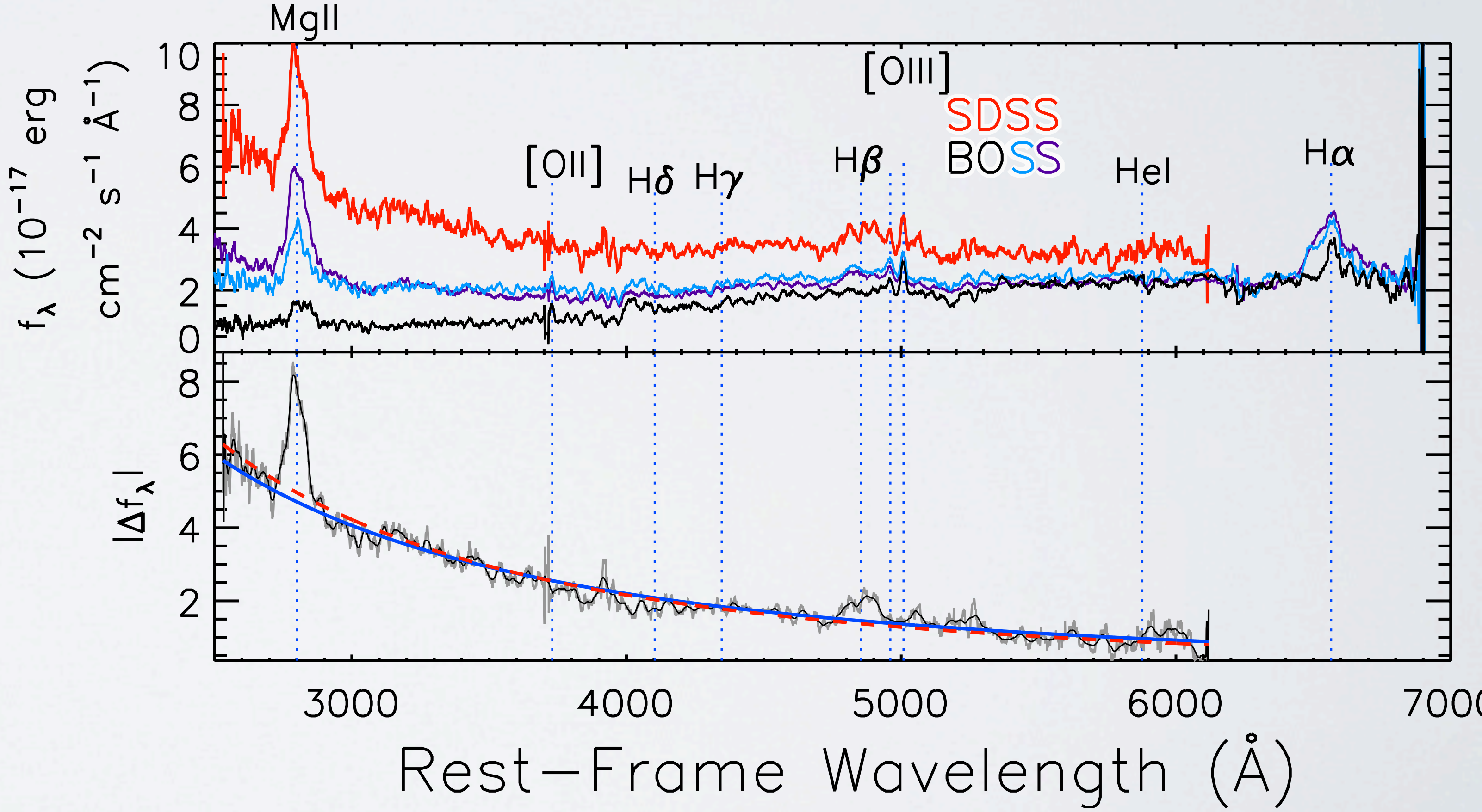


Systematic Search for CLQs

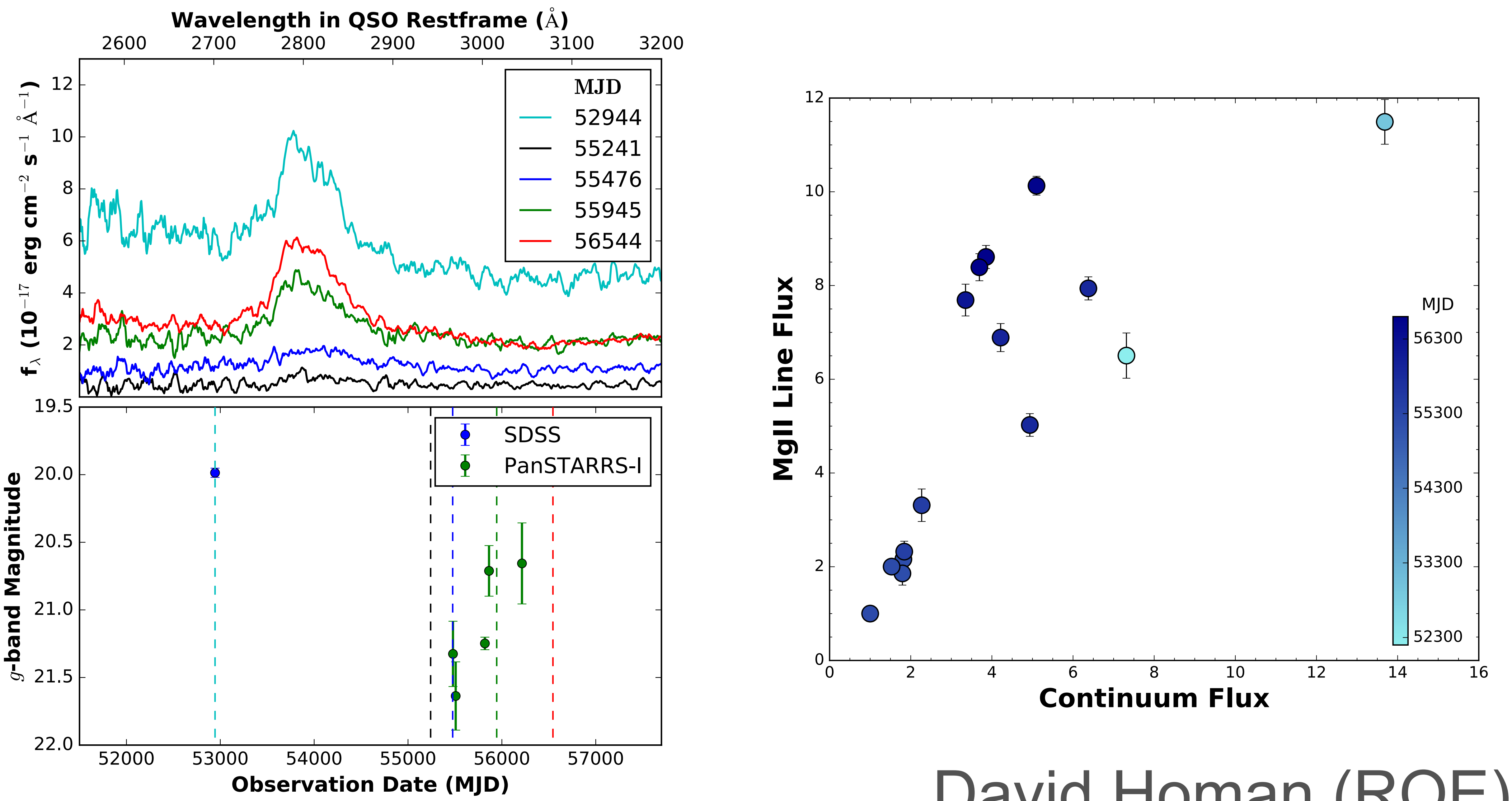
Results:

- BEL (dis)appearance associated with large changes in continuum flux.
- 5 with ***emerging*** BELs
- 5 with ***disappearing*** BELs
- One with ***both*** emerging and vanishing BELs





MgII BEL Response



David Homan (ROE)

- Unresponsive in reverberation mapping (e.g. Cackett et al. 2015)

Systematic Search for CLQs

Results:

- BEL (dis)appearance associated with large changes in continuum flux.
- 5 with ***emerging*** BELs
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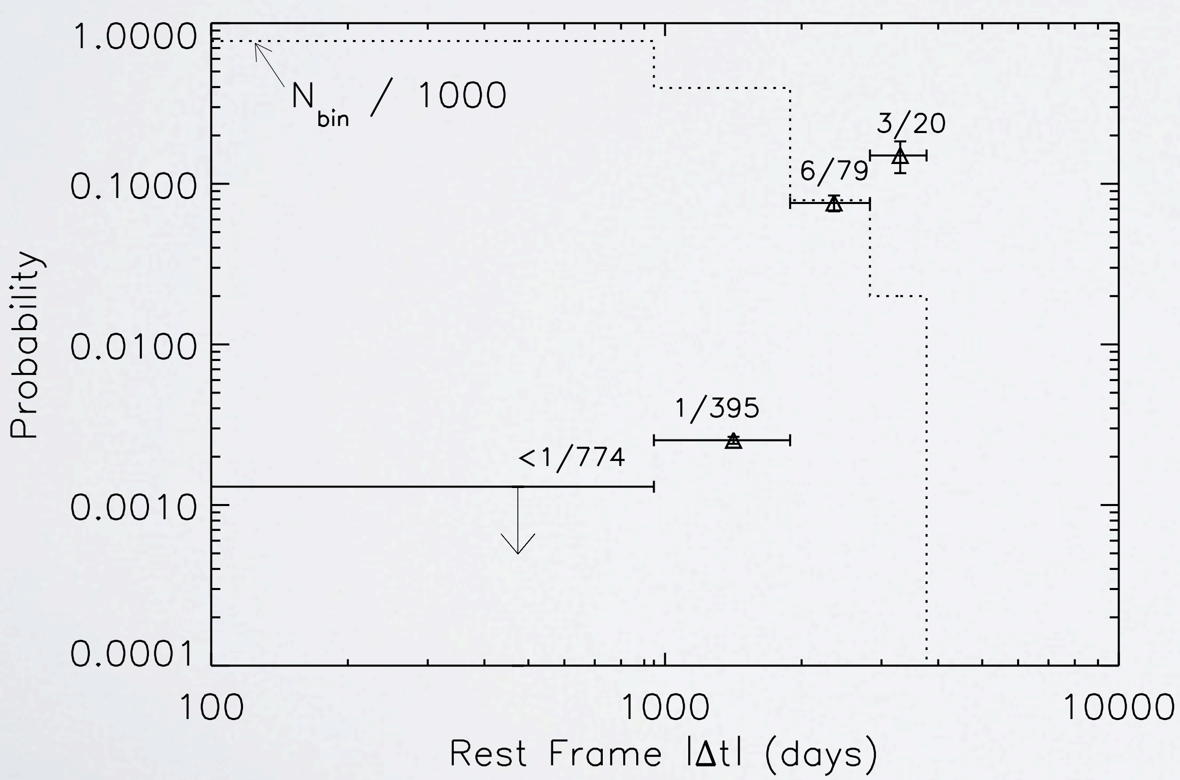
- One with ***both*** emerging and vanishing BELs
- Timescales shorter than expected for accretion rate changes in the optical emitting region

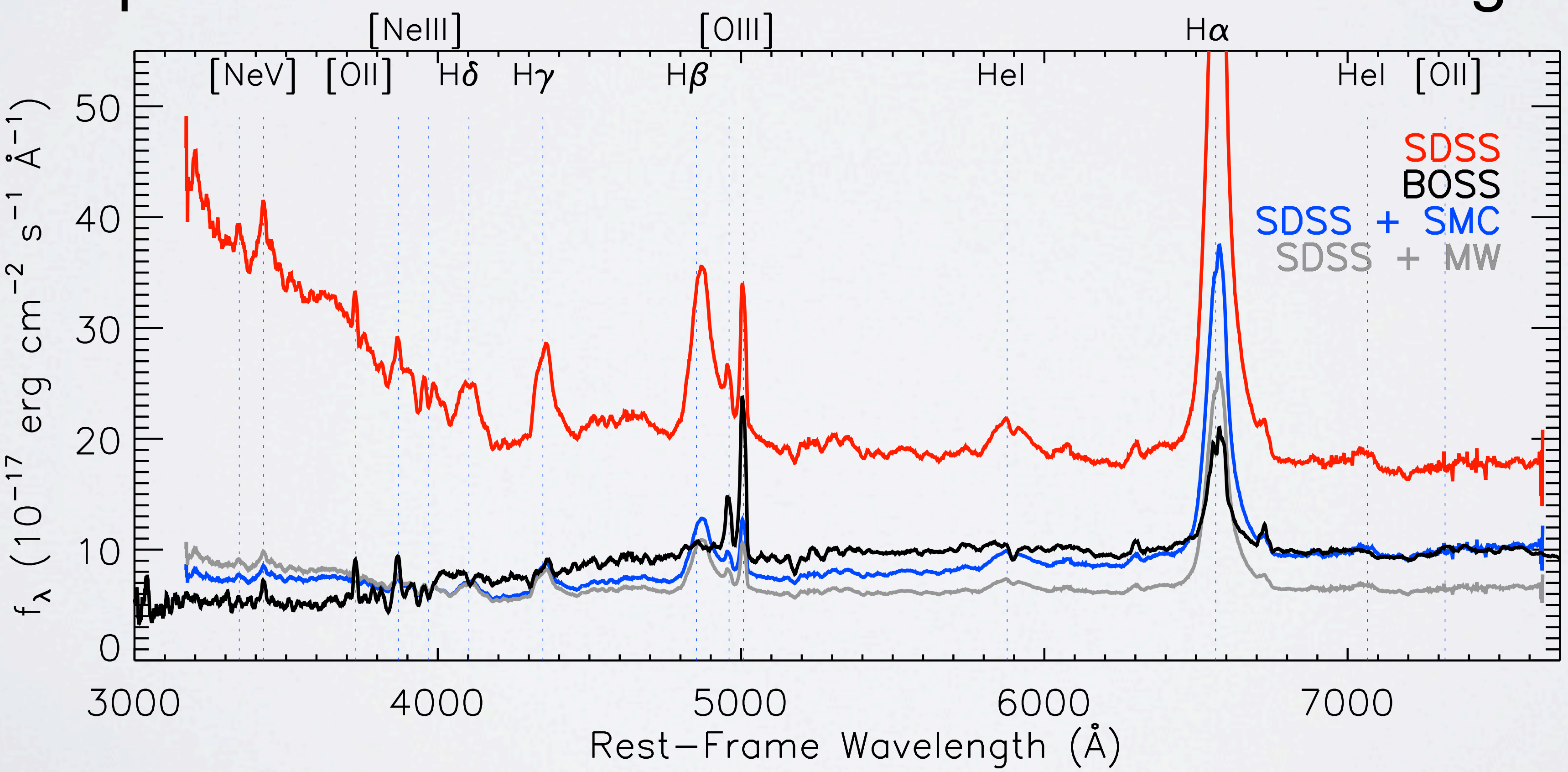


“ >15% of strongly variable luminous quasars display changing-look BEL features on rest-frame time-scales of 8-10 years. ”

Systematic Search for CLQs

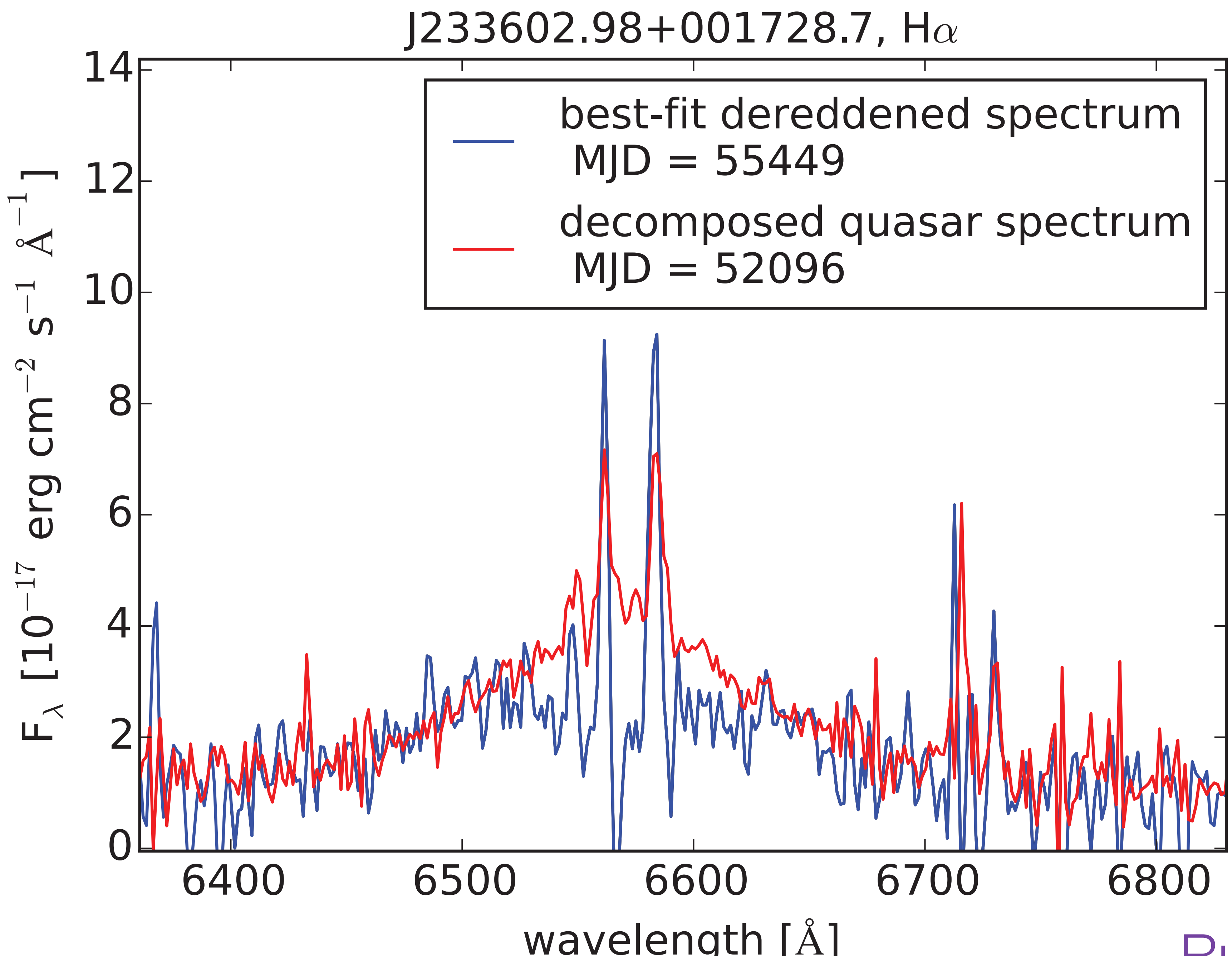
Results:

- BEL (dis)appearance associated with large changes in continuum flux.
- 5 with ***emerging*** BELs
- 5 with ***disappearing*** BELs
- One with ***both*** emerging and vanishing BELs
- Timescales shorter than expected for accretion rate changes in the optical emitting region
- Simple obscuration cannot account for BEL changes



Spectral reddening test

- The dim-state spectrum is **not** a reddened version of the bright state.



Ruan et al. 2016

Physical properties

Max. Timescales

4.2 - 9.7

years

Black Hole Masses

0.3 - 140

10^8 $M_\odot$

L_{bol}

***0.9 - 30.2**

0.3 - 1.5

10^{44} erg s^{-1}

Eddington Fractions

***0.1 - 53**

0.2 - 4

10^{-2} L/L_{edd}

Courtesy: J. Runnoe

Interpretation

(Very low level) Interpretation

- "Difference spectra" consistent with $f_\nu \propto \nu^{1/3}$ suggesting **variable** component has an *SED similar to an accretion disk*

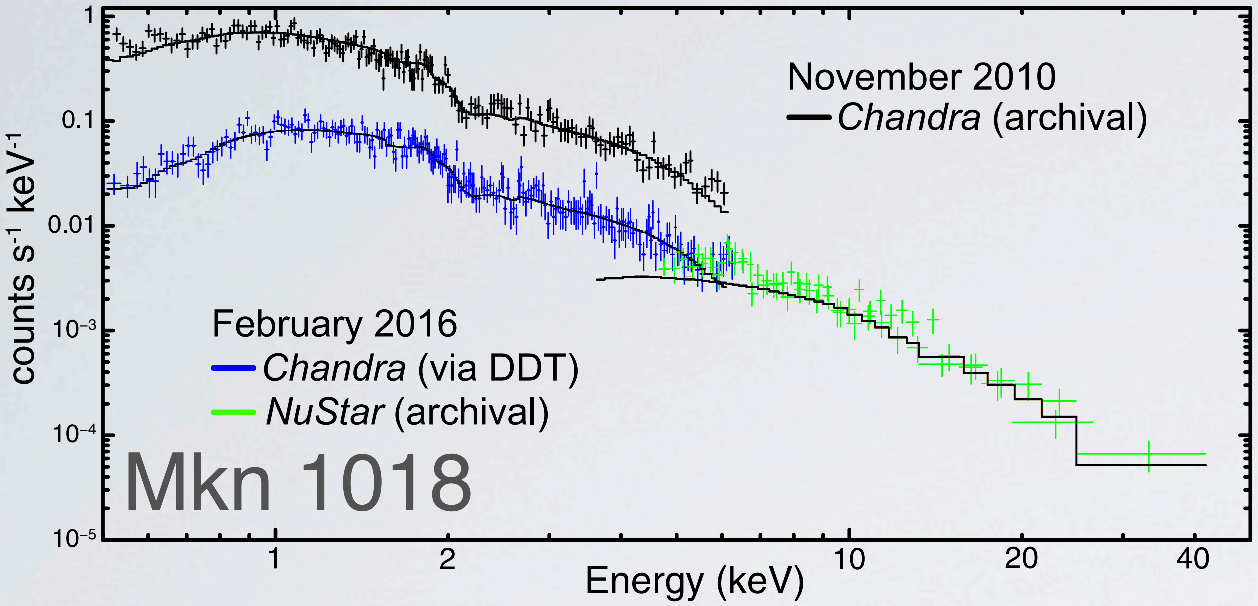
- Simple *dust obscuration models* (e.g. MW, SMC) **ruled out**

- Light Curves and narrow emission ***not*** consistent with Tidal Disruption Events (TDE short, sharp event)

- Light Curves ***not*** consistent with e.g. (clumps of) dust crossing timescales ($t_{\text{cross, dust}}$ OoM too long)

- ***Potentially*** due to change in ***accretion rates***; but needs some thought into e.g. "disc reprocessing" mechanisms

Clues From X-rays



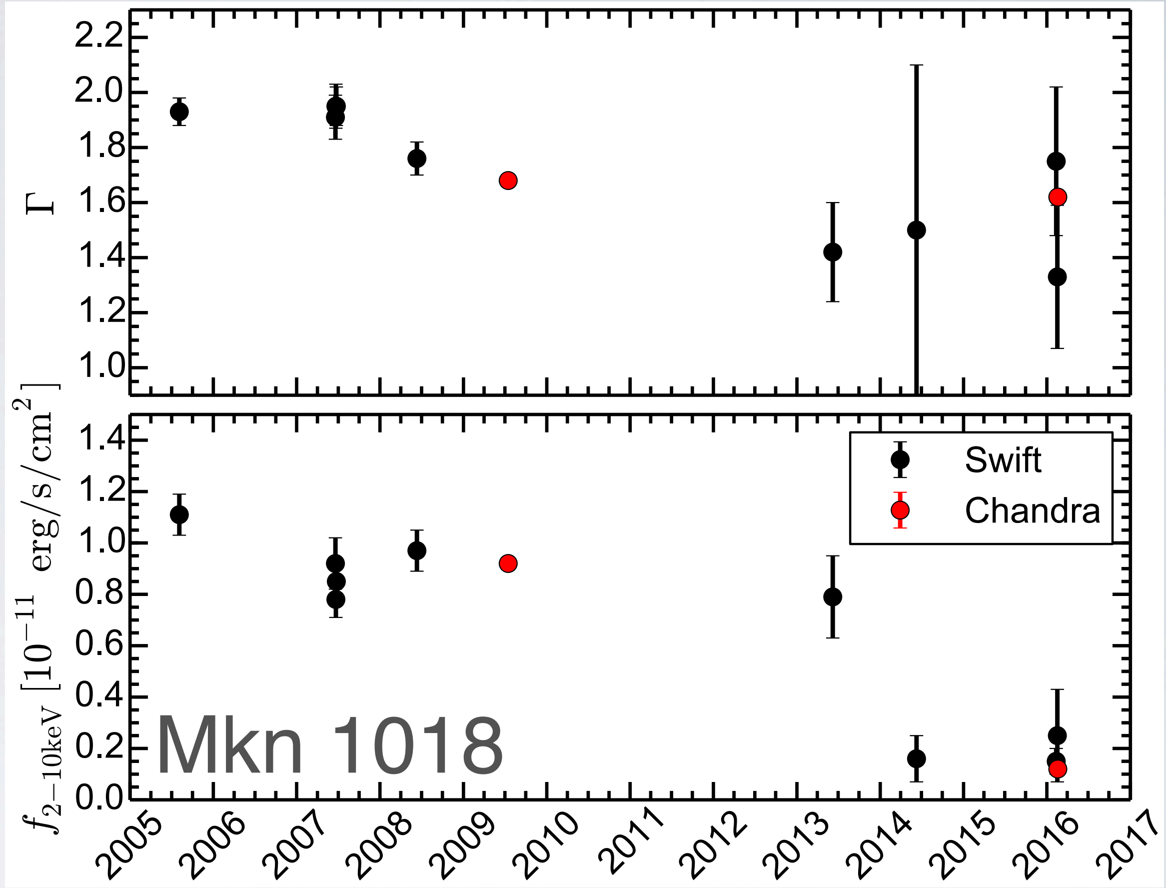


Fig. 2. Time evolution of the X-ray photon index Γ and the 2–10 keV flux from 2005 until 2016 based on the *Swift* and *Chandra* data.

- X-ray flux changes by factor:
  - **10** in Mkn1018 (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

-Are all CLQs/CLAGN associated with large changes in X-ray flux?

-Does X-ray irradiation drive the UV/IR variability?

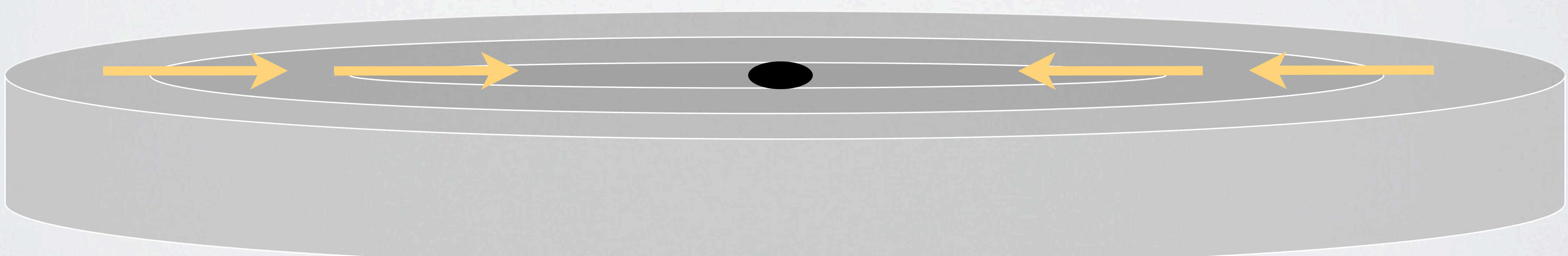
Physical Timescales

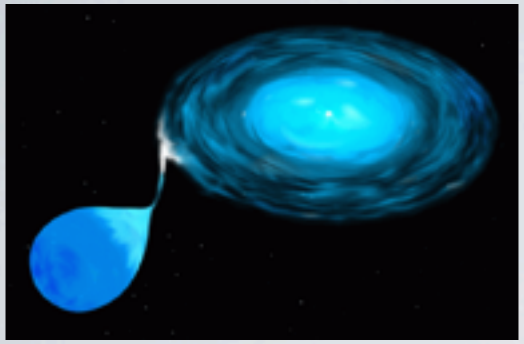
- **viscous** ("radial drift") timescale

  Optical: ~10,000 yr

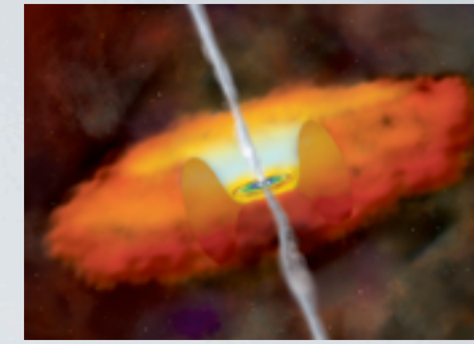
  UV: ~days

$$t_{\rm infl} = 5\times10^{4} \left[\frac{\alpha}{0.1}\right]^{-1} \left[\frac{\lambda_{\rm Edd}}{0.05}\right]^{-2} \left[\frac{\eta}{0.1}\right]^{2} \left[\frac{r}{50 R_{\rm S}}\right]^{7/2} \left[\frac{M_{8}}{2.1}\right] {\rm yr}.$$

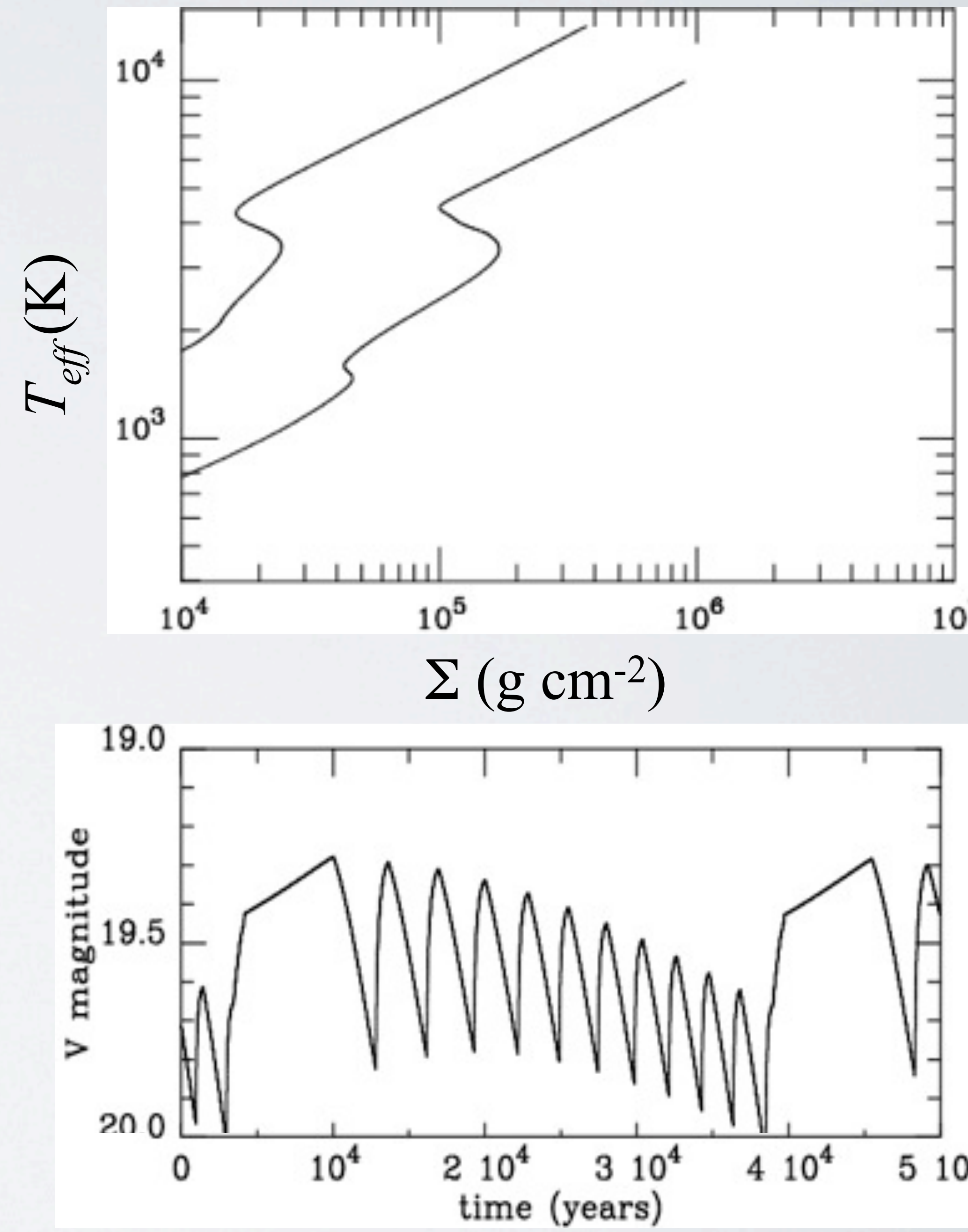




Scaled Up X-ray Novae



- Limit cycle in CVs over weeks-months → ~10^5 yr in AGN (Siemiginowska+1996)
- But: Outbursts on timescales of minutes detected in XRB GRS1915+105 (Fender & Belloni 2004) → ~10 yr in AGN!



Hameury et al. (2009)

Connecting To Physical Models

Thermal Instability:

$$t_{th} = 1.6\,(\alpha/0.01)^{-1}\;(M/10^{8}M_{\odot})\;(r/50R_{S})^{3/2}\;\text{yr}$$

- Thermal timescale for *temperature change*, $L \propto T^4$ (Mkn 1018, Husemann et al 2016)
- *Cold chaotic accretion* models (Gaspari+2015)
- *Opacity bump* effects at low metallicity (Jiang+2016)

Ongoing/ Future Work

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 >100,000 celestial variables (Morganson+ 2015; Ruan+ 2016)

★ Repeat spectra for:

- 13K Quasars
- ~1K Hypervariable Quasars with $|\Delta m| > 0.7$ mag
- 3500+ quasars at $z < 0.83$