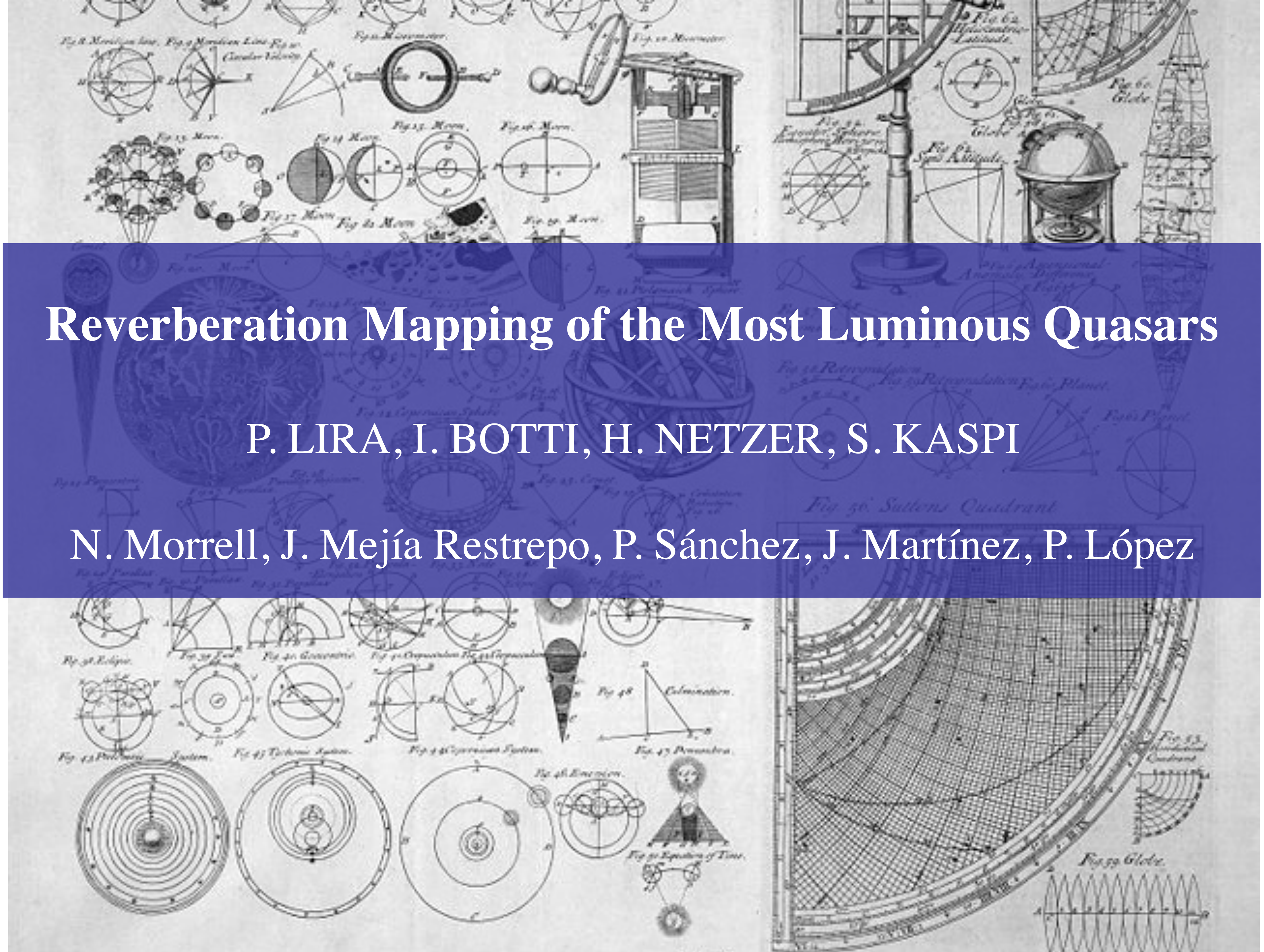

Reverberation Mapping of the Most Luminous Quasars

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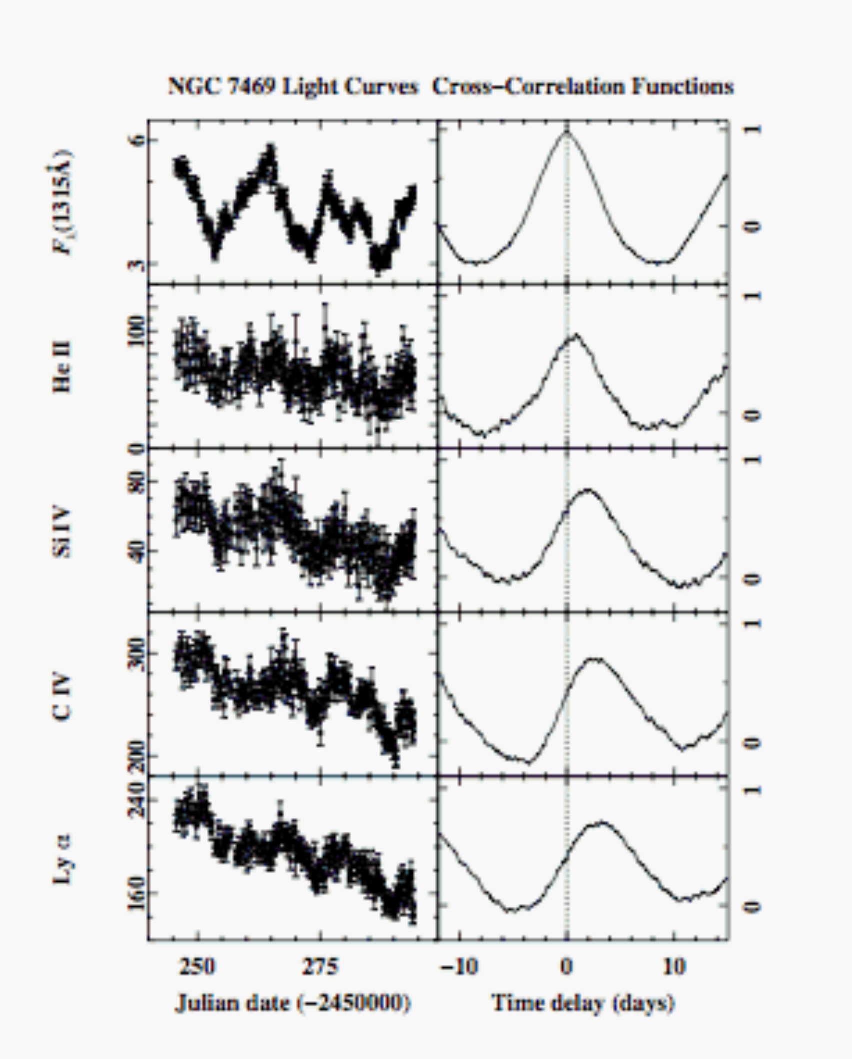
N. Morrell, J. Mejía Restrepo, P. Sánchez, J. Martínez, P. López

Reverberation Mapping



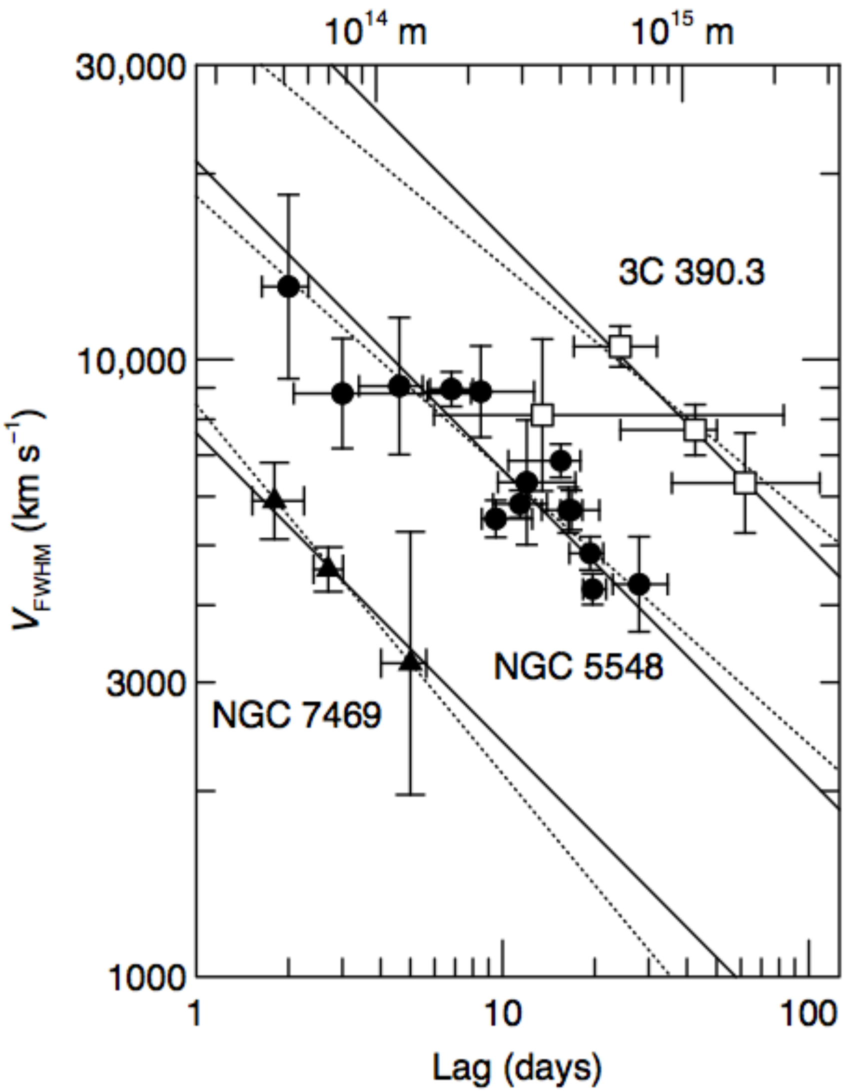
Wanders et al., 1997

Lines from highly ionized gas (HeII, CIV) respond faster than those from lower ionization ions (e.g., Balmer lines).

Line/Band	τ^{rest}_{cent}	τ^{rest}_{peak}
F(λ1460)	...	...
F(λ1835)	0.1^{+3}_{-3}	0^{+2}_{-2}
F(λ5150)	1.6^{+2}_{-2}	1^{+2}_{-2}
He II λ1640 + O III] λ1663	0.5^{+4}_{-4}	1^{+2}_{-2}
Si IV λ1400 + O IV] λ1402	3.9^{+4}_{-4}	5^{+2}_{-2}
Lyα	3.8^{+3}_{-3}	4^{+2}_{-2}
C IV λ1549	5.4^{+3}_{-3}	5^{+2}_{-2}
Si III] λ1892 + C III] λ1909[c]	15.6^{+4}_{-4}	9^{+2}_{-2}
Hβ	7.1^{+2}_{-2}	8^{+2}_{-2}

Ionization structure in the BLR with more highly ionized lines closer in to the central source: the BLR is *stratified*.

Reverberation Mapping



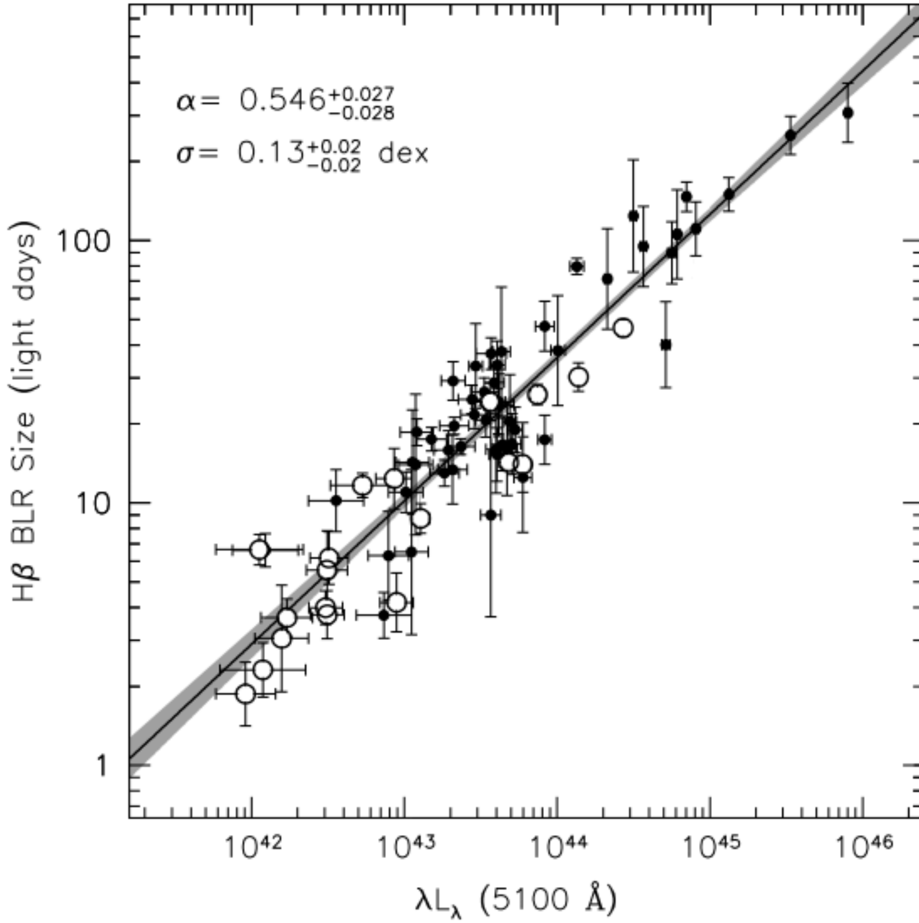
Peterson & Wandel (2000)

In 3 AGN the FWHM of lines with different ionization levels are consistent with Keplerian rotation.

The BLR is gravitationally bound:

$$V_{\rm BLR} \propto \tau^{-1/2} \propto R_{\rm BLR}^{-1/2}$$

$$M_{\rm BH} = f\, R_{\rm BLR} V_{\rm BLR}^2 / G$$



Bentz et al. (2013)

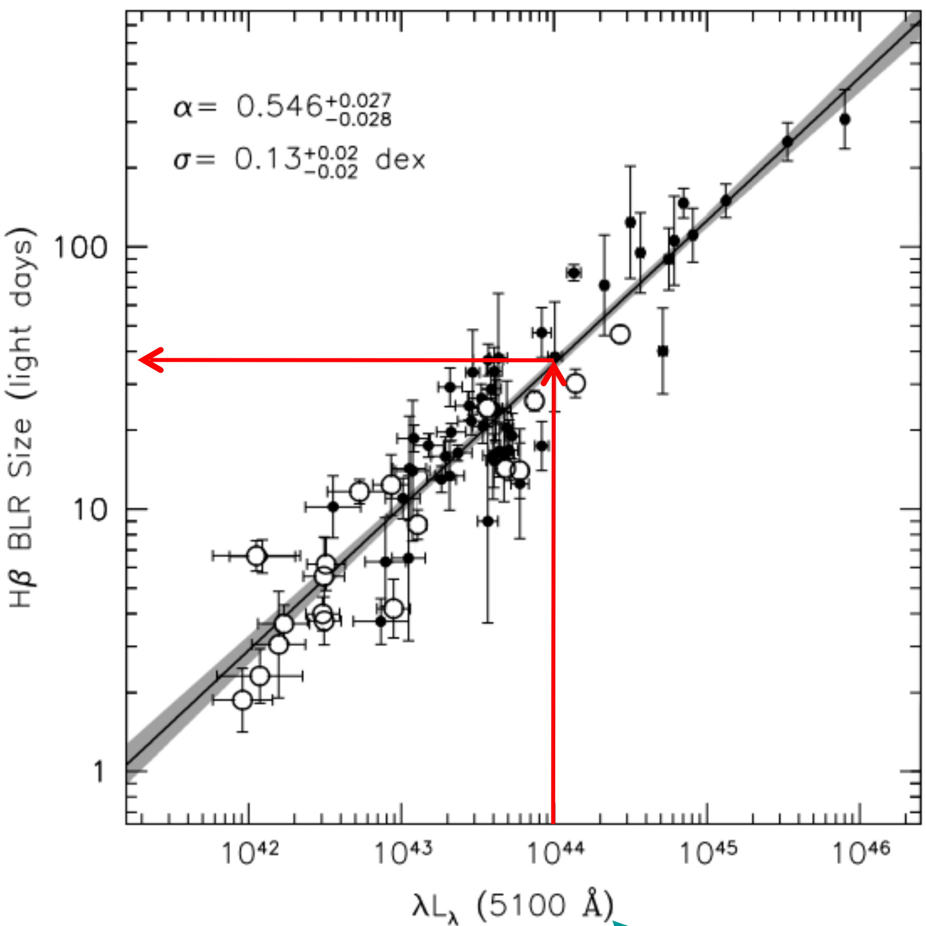
$$M_{\rm BH} = f\, R_{\rm BLR} V_{\rm BLR}^2 / G$$

$$M_{\rm BH} = \hat{f}\, R_{\rm BLR}\, {\rm FWHM}^2 / G$$

$$M_{\rm BH} = K (\lambda L_\lambda)^\alpha {\rm FWHM}^2 / G$$

Mejía-Restrepo et al. (2016)

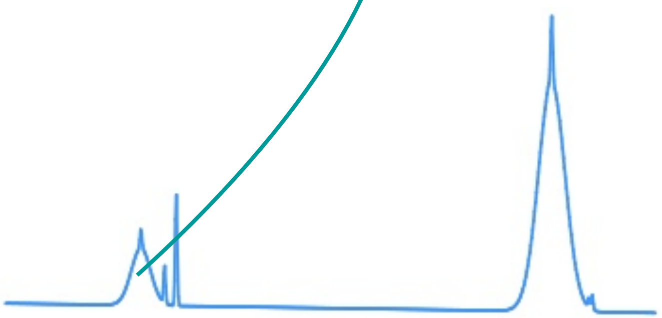
Hβ Radius-Luminosity Relation



Bentz et al. (2013)

$$R_{\rm BLR} = 0.18 \left[\frac{\lambda L_\lambda(5100\text{Å})}{10^{44}\text{ergs/s}}\right]^{(0.55\pm0.02)} \text{lt-days}$$

$$M_{BH} \approx v^2\ R\ /\ G$$



This scaling relationship allows to determine M_{BH} using *single-epoch* spectroscopy

Simplistic picture:

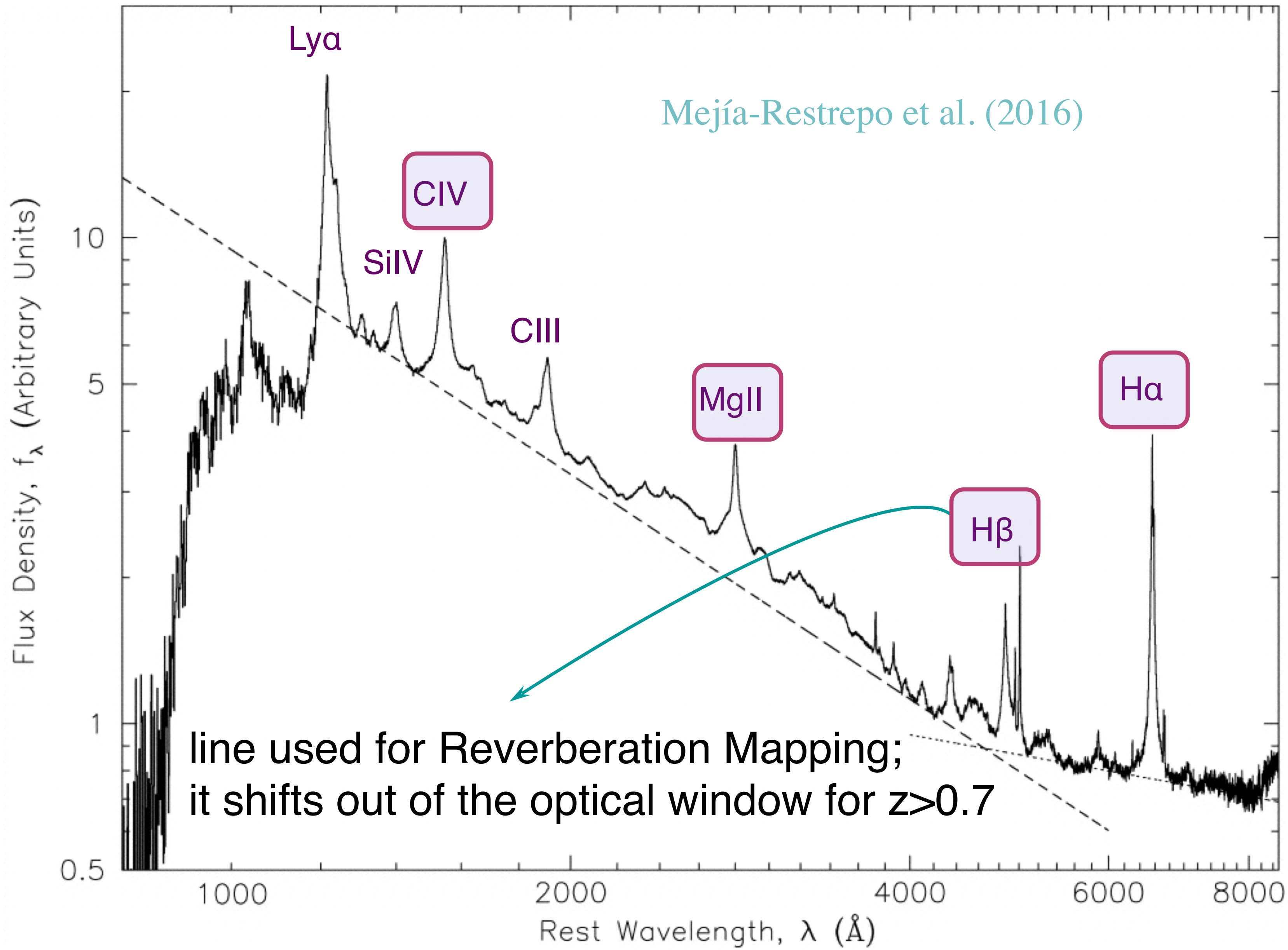
$$U = \frac{L_{\rm ion}}{h\nu \times 4\pi R^2 c} \times \frac{1}{n} \qquad R_{\rm BLR} \propto \sqrt{L_{\rm ion}}$$

A particular line requires a particular value of U (and n) to be emitted

It is found: $$R_{BLR} \simeq 0.4 \left[\frac{\lambda L_\lambda(5100)}{10^{46}\ \mathrm{erg/sec}}\right]^{0.6\pm0.1} \mathrm{pc}$$

$$M_{\rm BH} = 1.05 \times 10^8 \left(\frac{L_{5100}}{10^{46}\ \mathrm{ergs\ s^{-1}}}\right)^{0.65} \left[\frac{\mathrm{FWHM(H\beta)}}{10^3\ \mathrm{km\ s^{-1}}}\right]^2 M_\odot$$

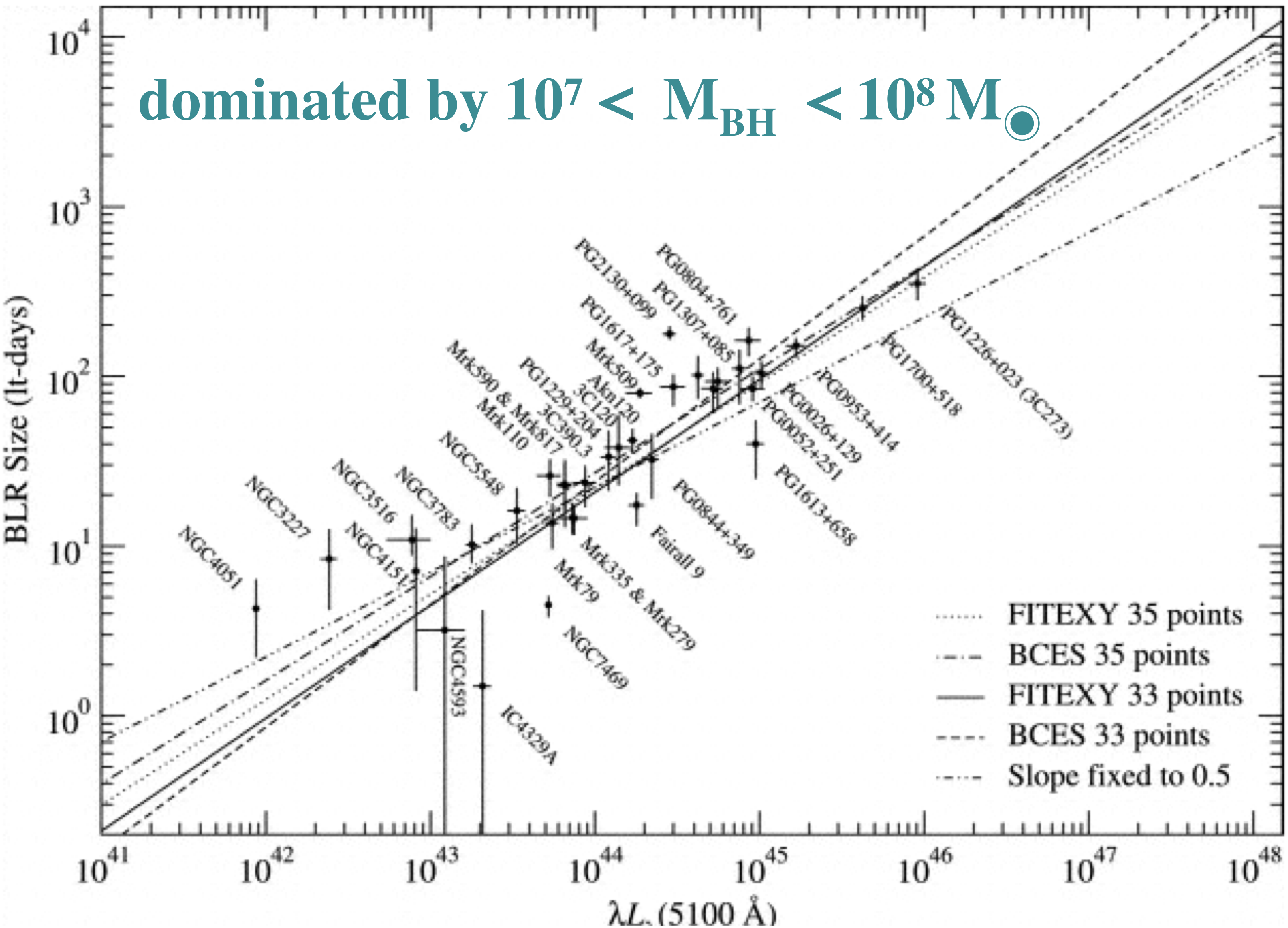
Single-epoch BH mass determinations only need L and V



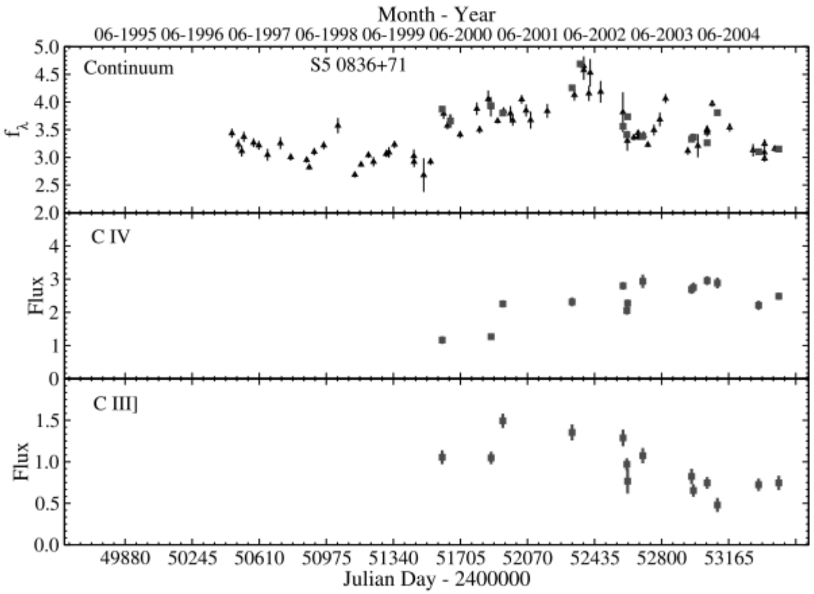
Composite SDSS spectrum: vanden Berk et al. (2001)

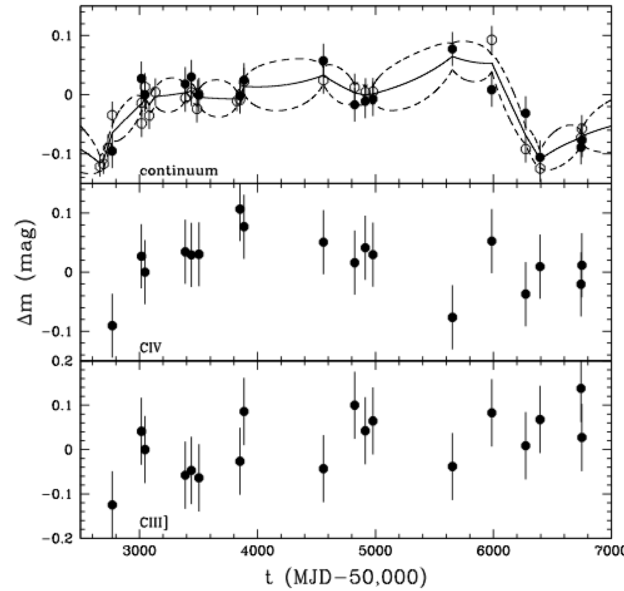
Reverberation Mapping

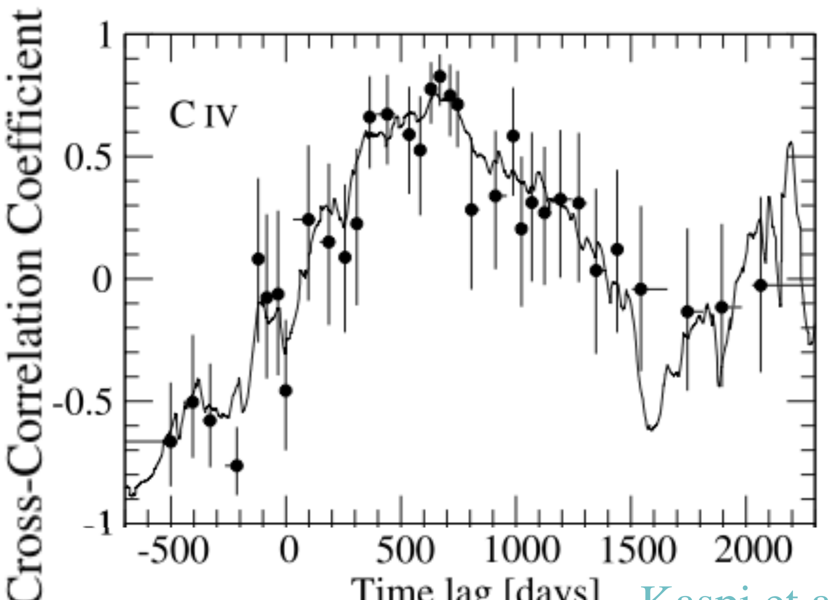
dominated by $10^7 < M_{BH} < 10^8 M_\odot$



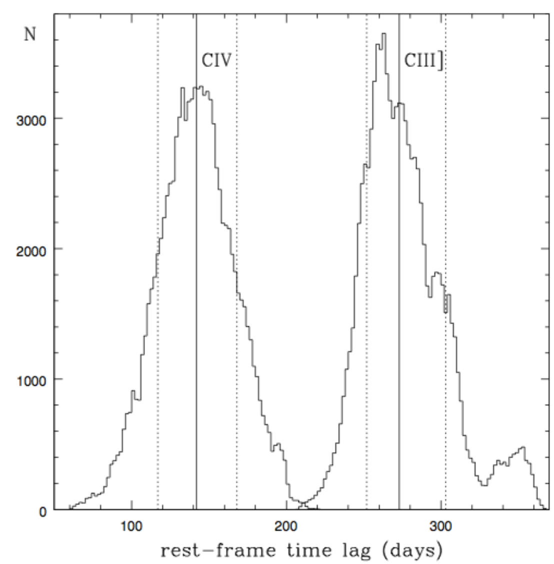
Previous RM results for high-L, high-M, high-z Quasars







Kaspi et al., 2007



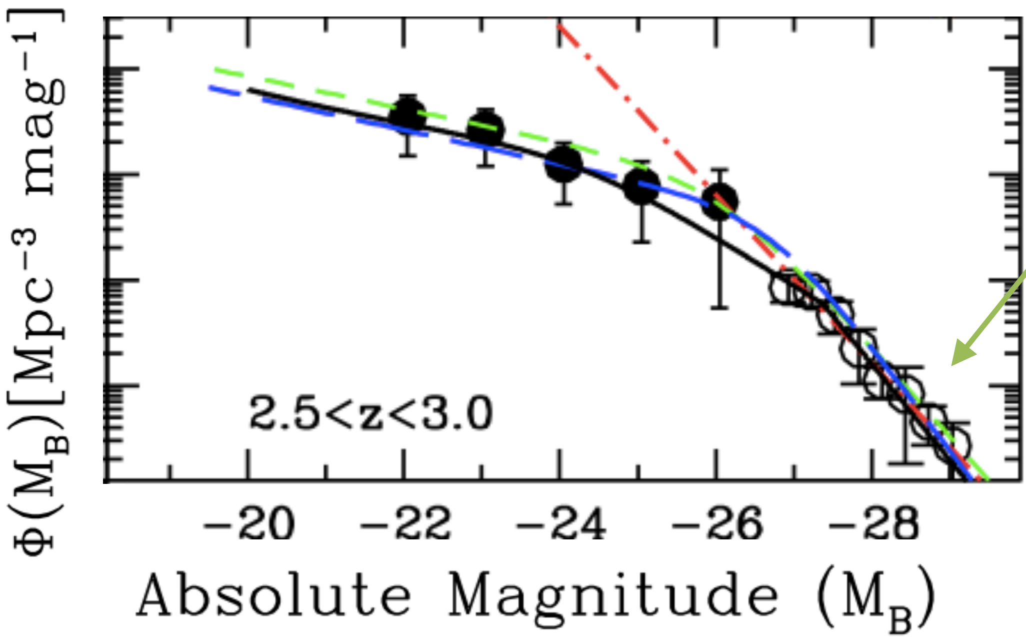
Trevese et al., 2014

Extending RM techniques to the most massive quasars has some issues:

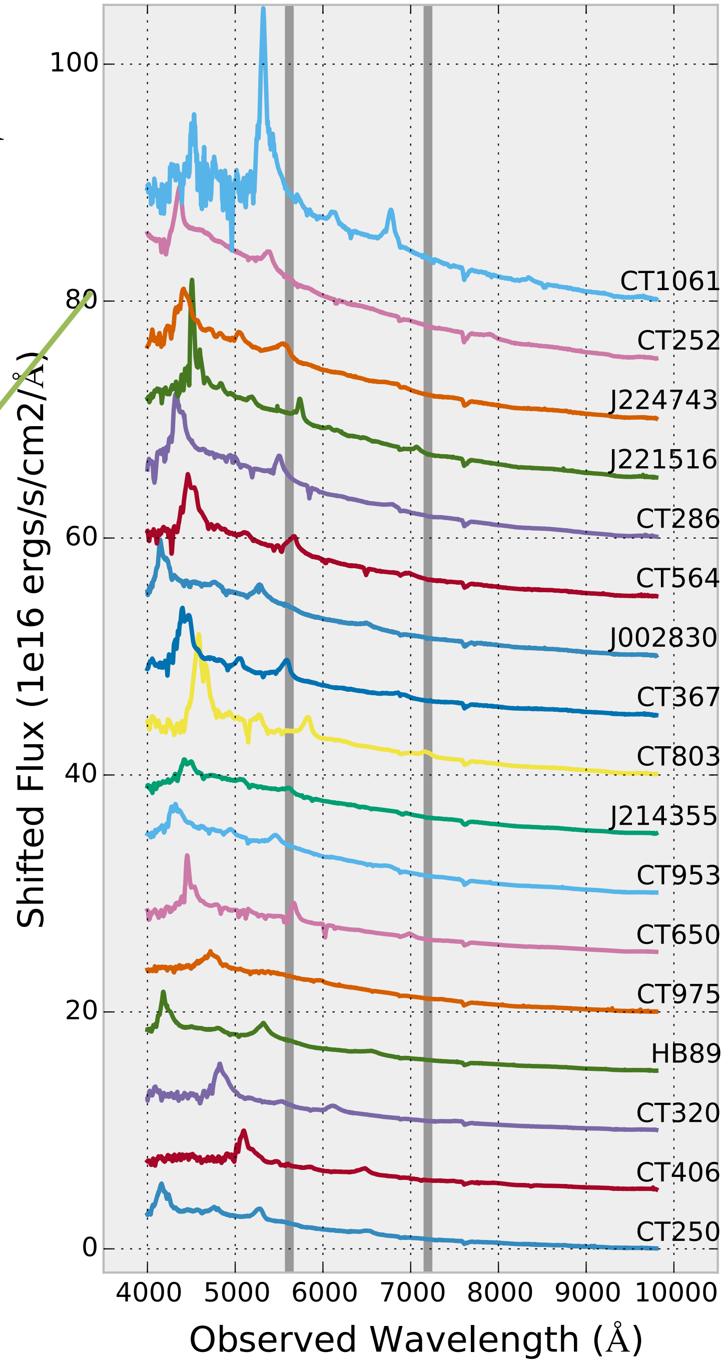
- The most massive BHs were active in the high-z Universe (z~2-3)
- These are intrinsically slowly varying sources
- A factor (1+z) makes matters worse
- Line variations are expected to be of the order of ~ few %

Our approach: R-band monitoring of ~50 high-z with SMARTS telescopes (soon to be replaced by LCOGTN) quasars followed by spectroscopic follow up with the 100 inch du Pont telescope.

B-band Quasar Luminosity Function

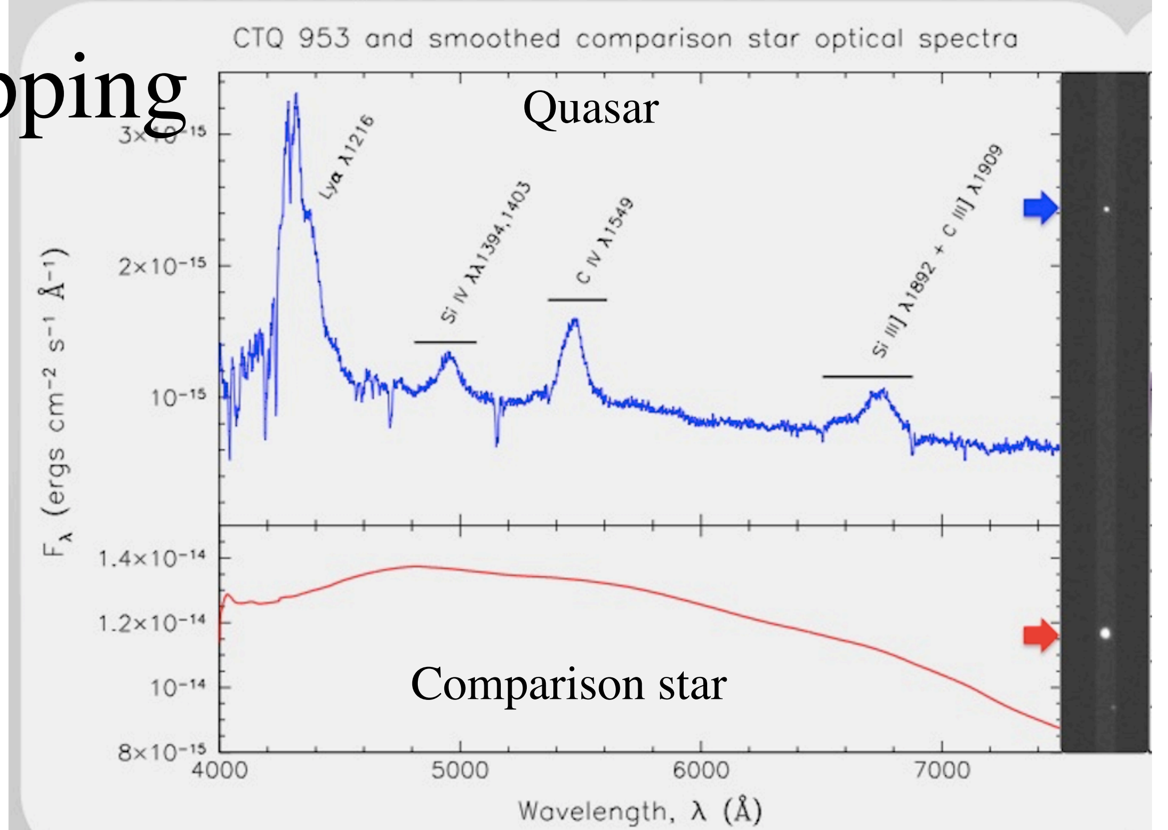


Bongiorno et al. (2007)

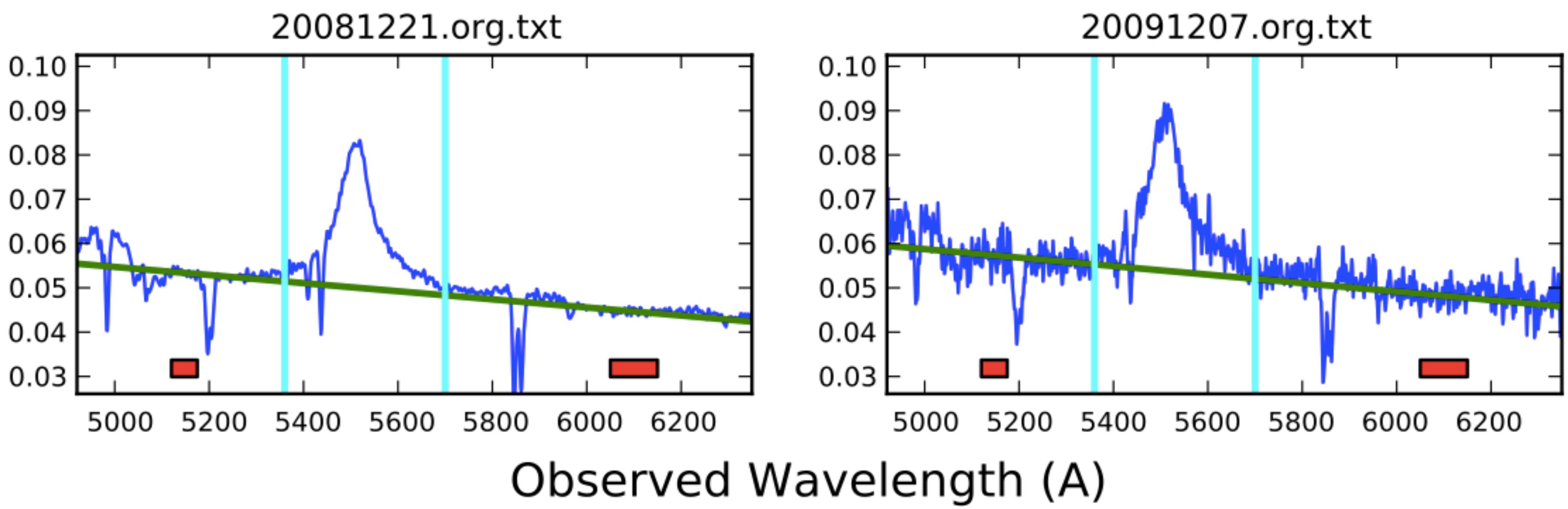


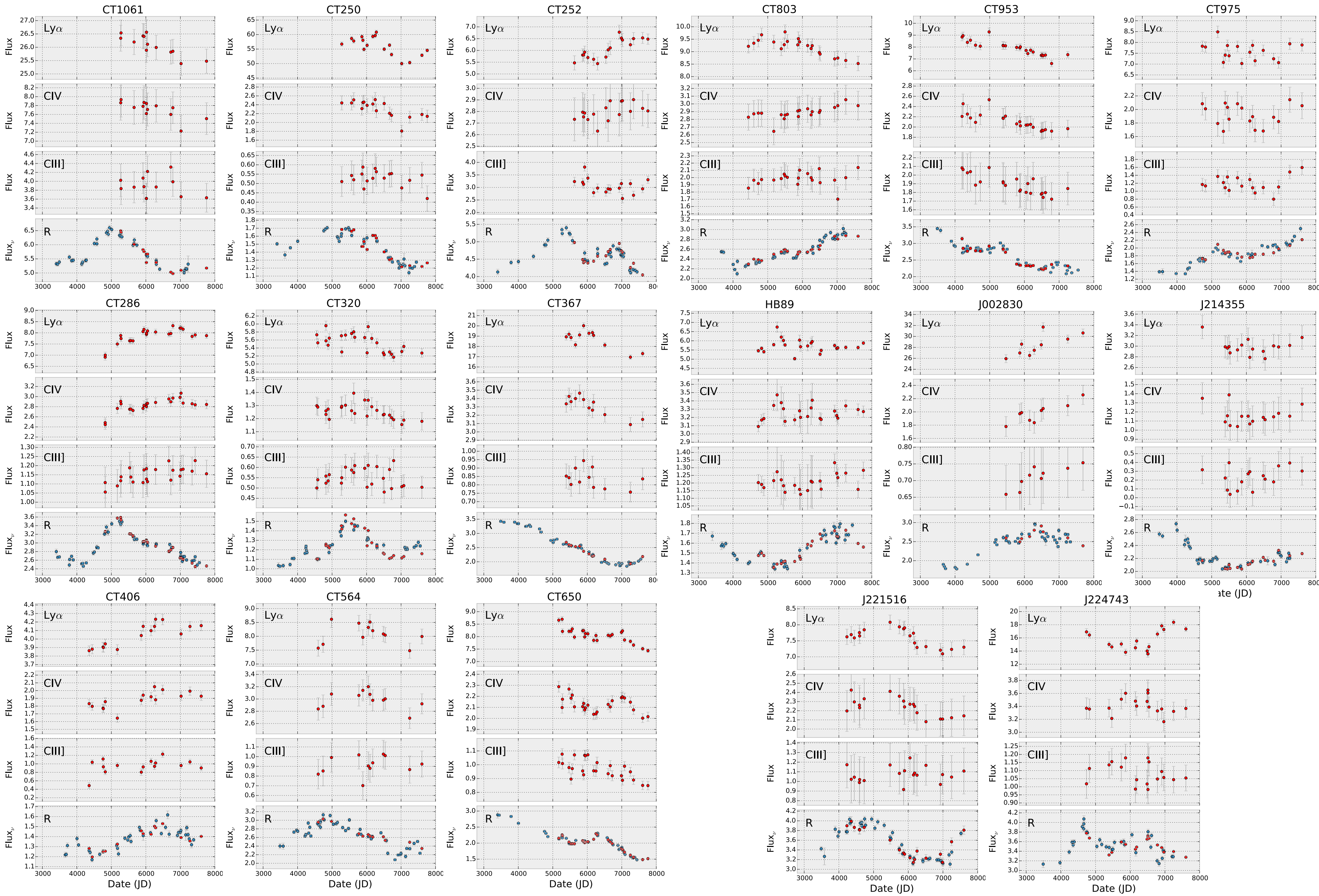
Reverberation Mapping

Our technique: differential spectrophotometry



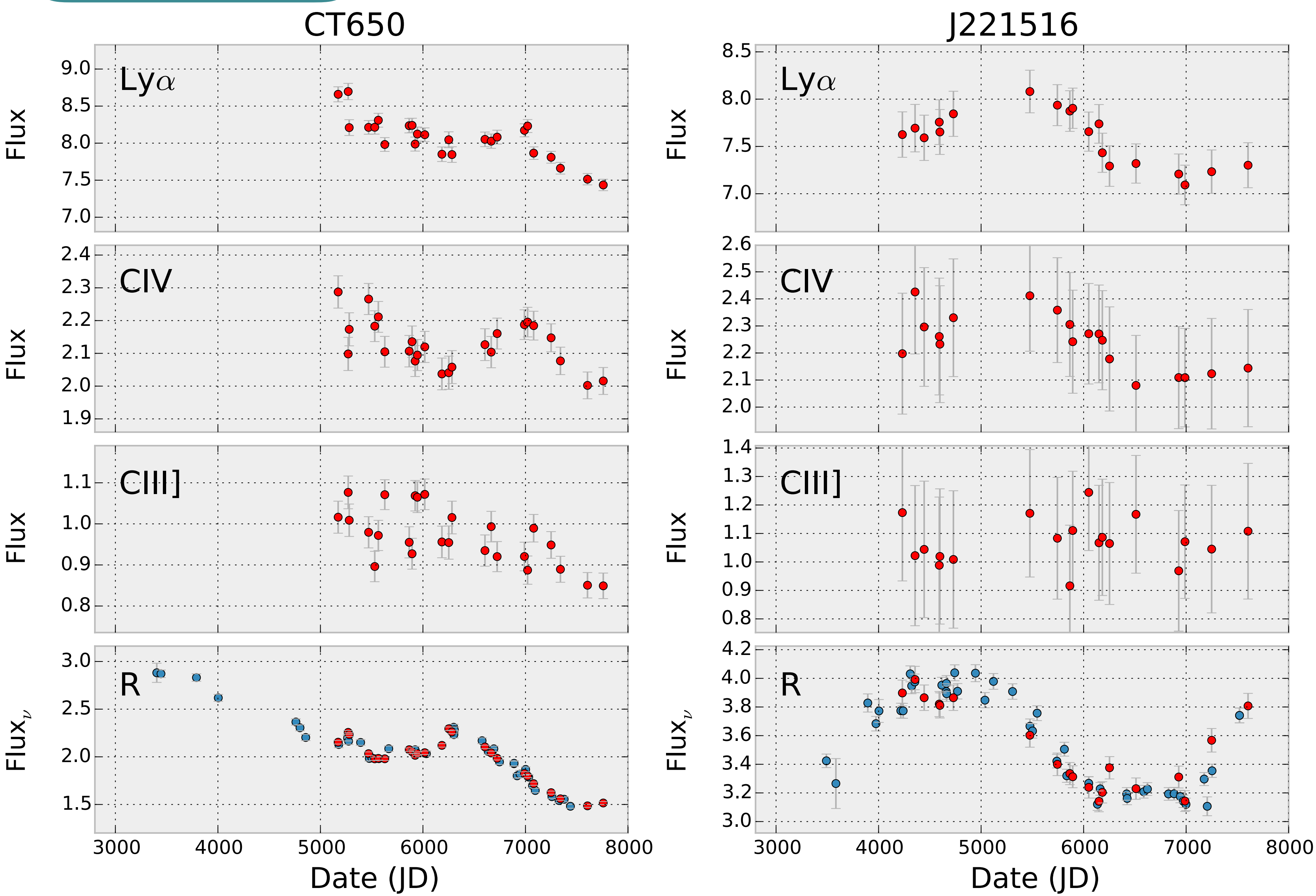
CT286:



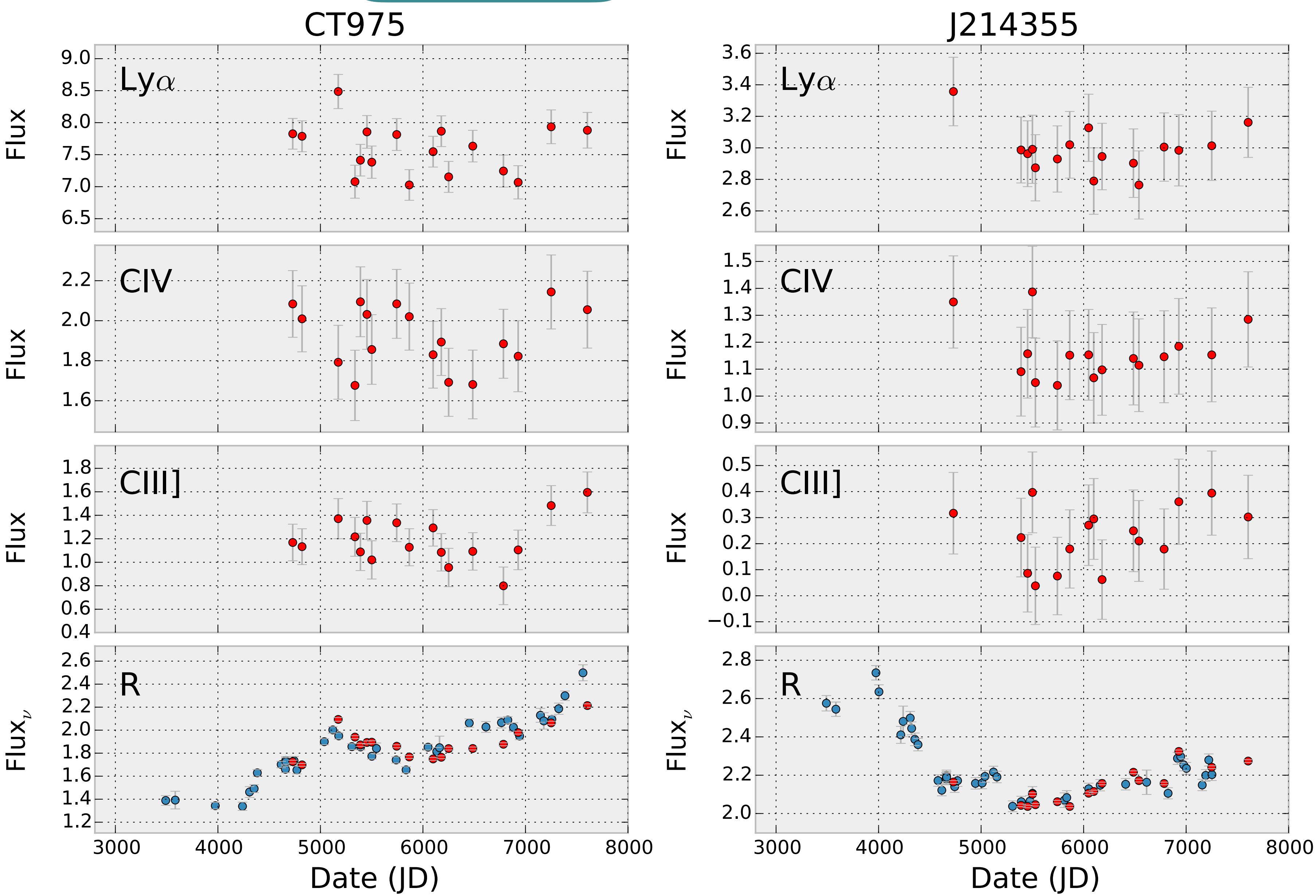


CT1061
CT250
CT252
CT803
CT953
CT975
CT286
CT320
CT367
HB89
J002830
J214355
CT406
CT564
CT650
J221516
J224743
Lyα
CIV
CIII]
R
Flux
Flux$_\nu$
Date (JD)

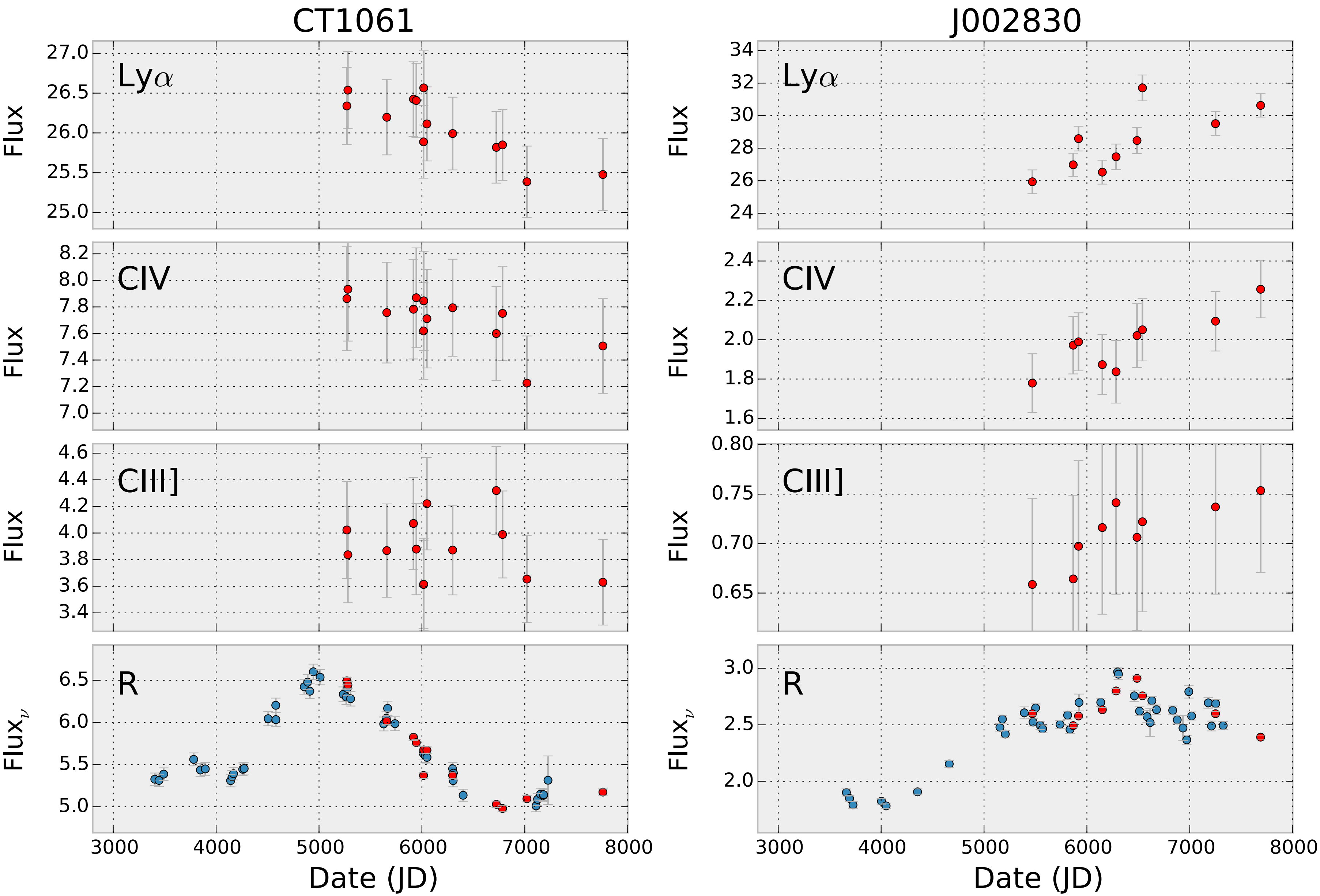
The Good, The Bad, The Ugly and The Odd



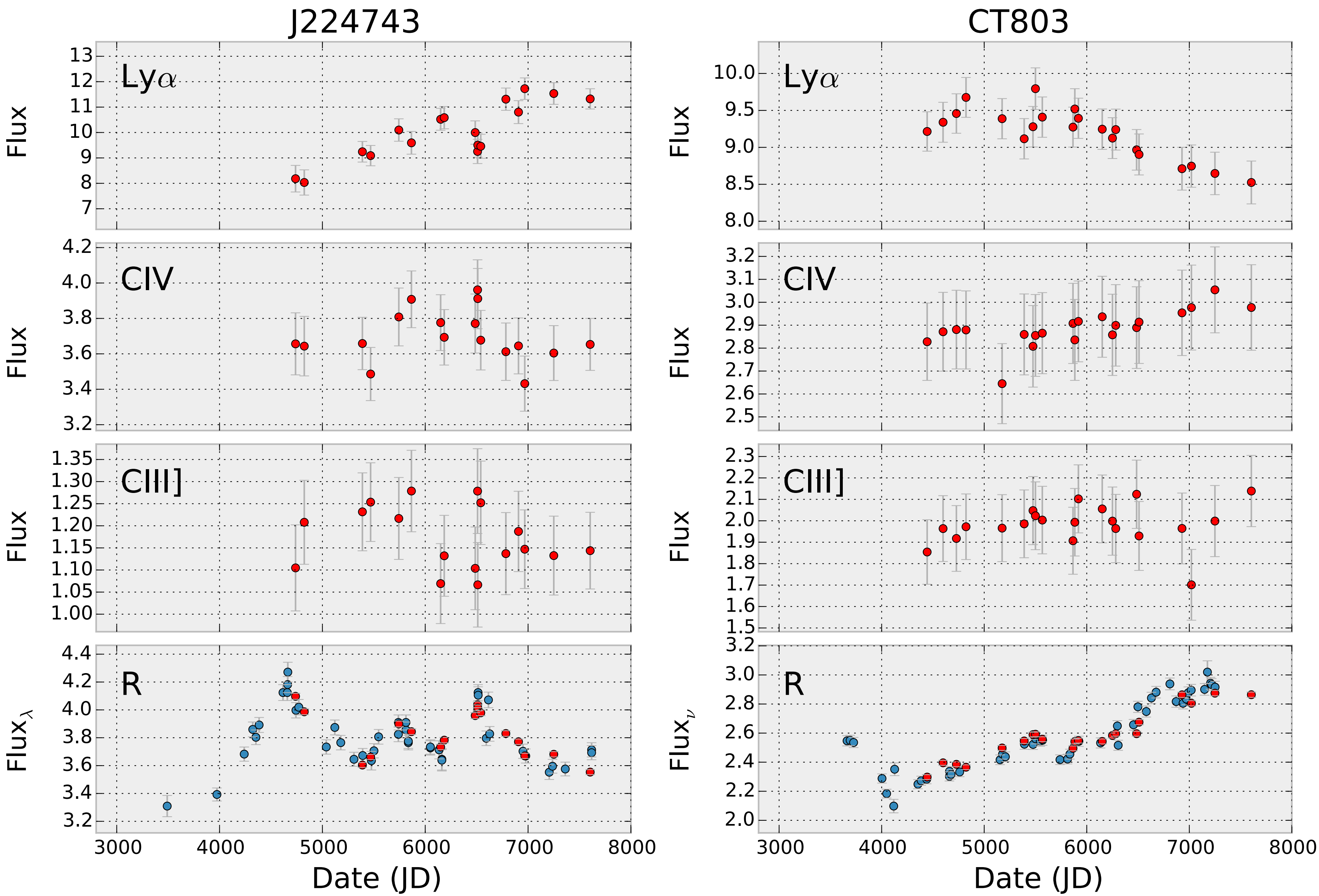
The Good, The Bad, The Ugly and The Odd

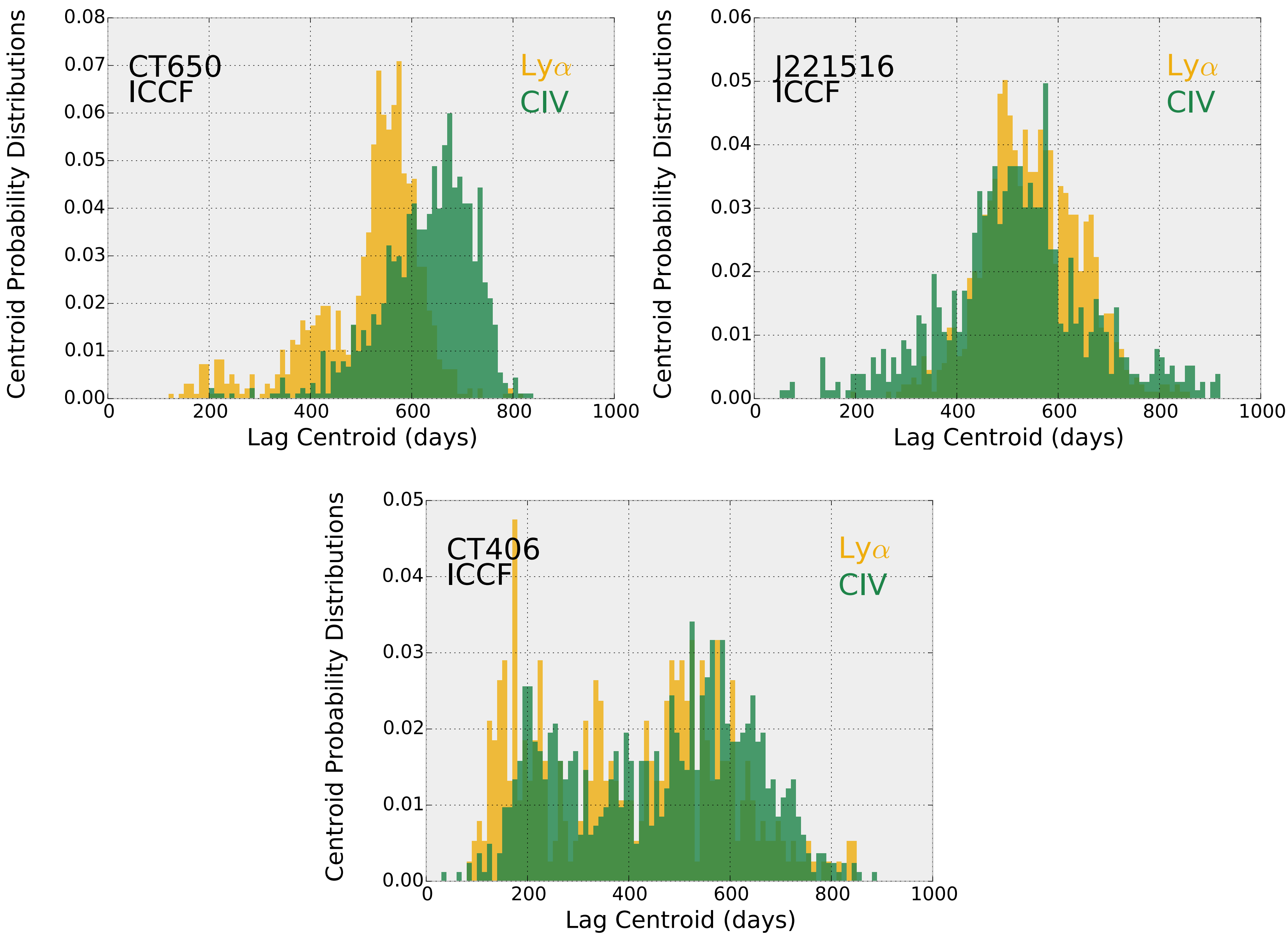


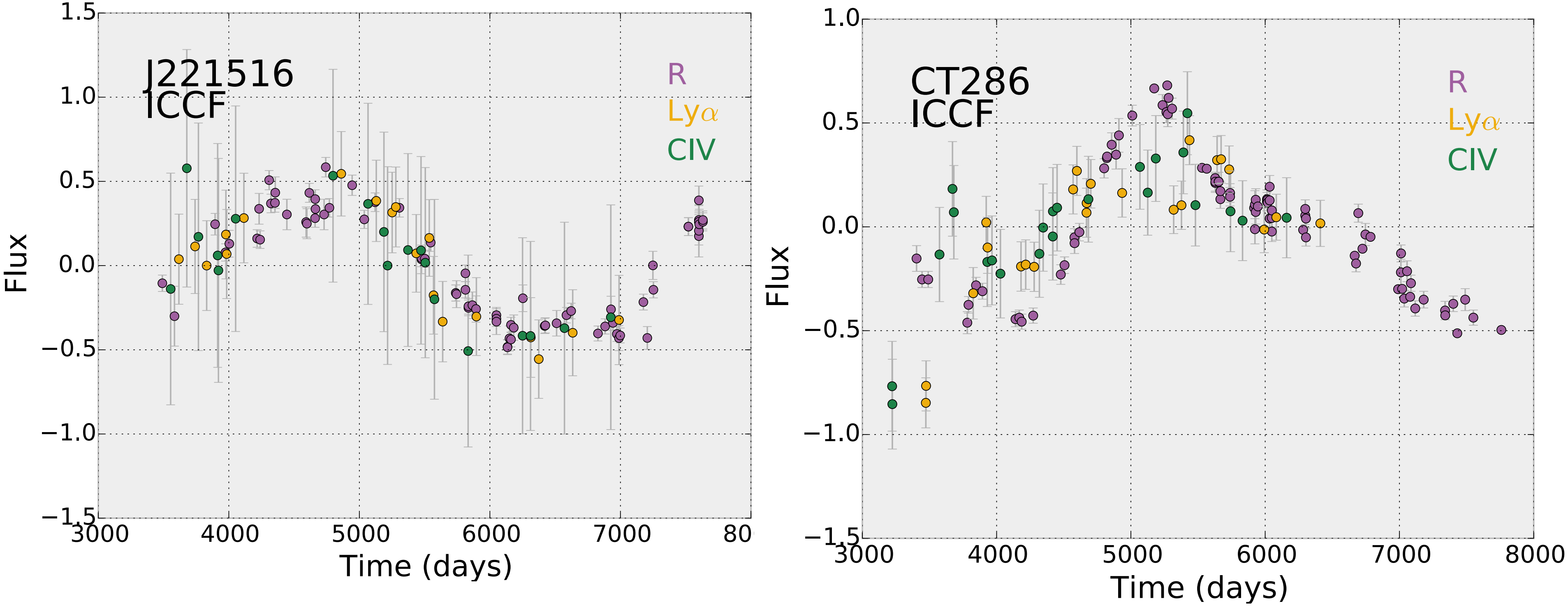
The Good, The Bad, The Ugly and The Odd



The Good, The Bad, The Ugly and The Odd

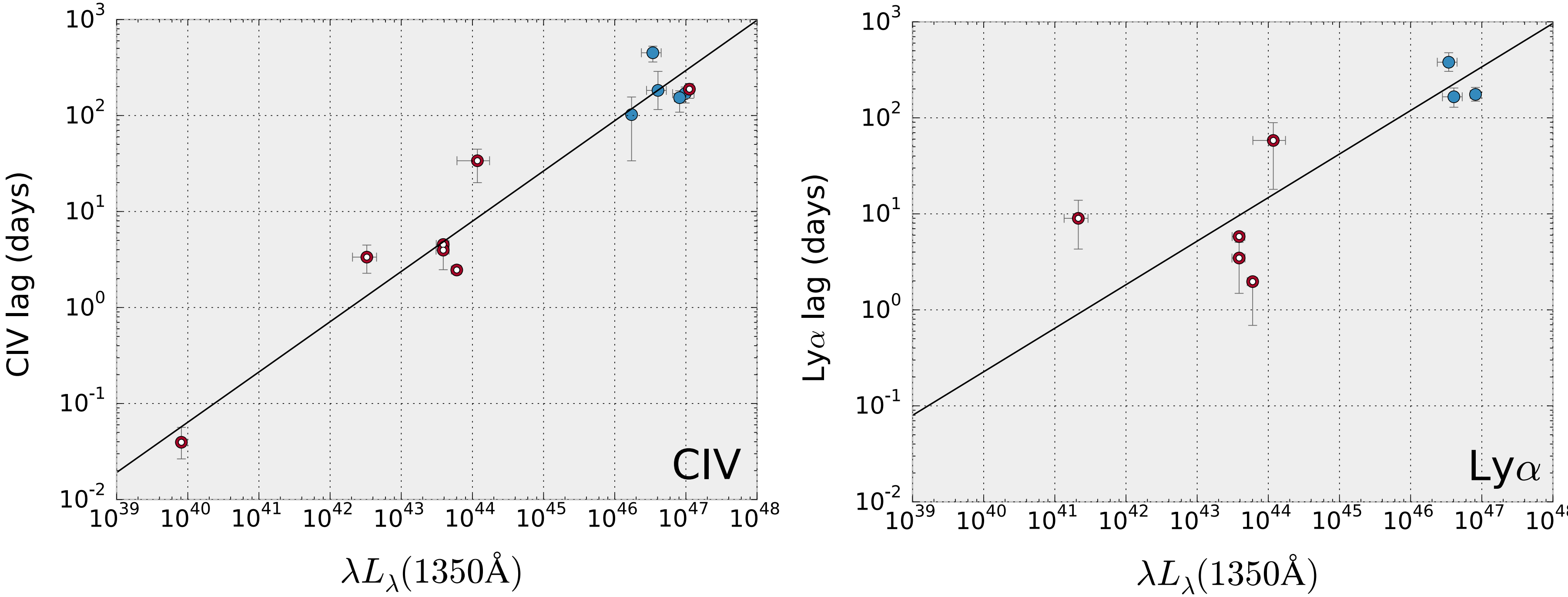



CT650
ICCF
Lyα
CIV
J221516
ICCF
Lyα
CIV
CT406
ICCF
Lyα
CIV
Centroid Probability Distributions
Lag Centroid (days)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0
200
400
600
800
1000

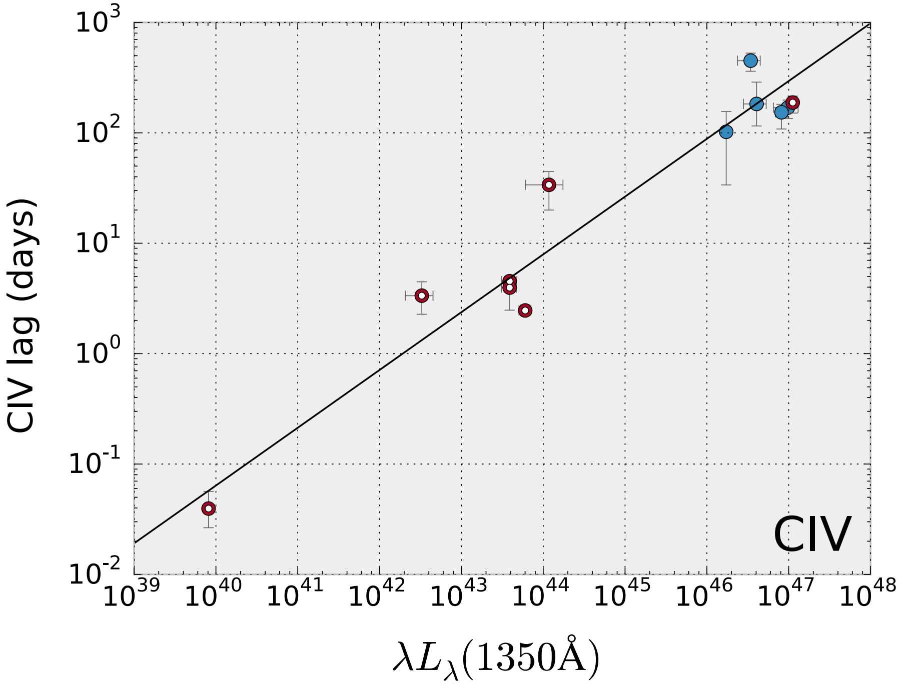


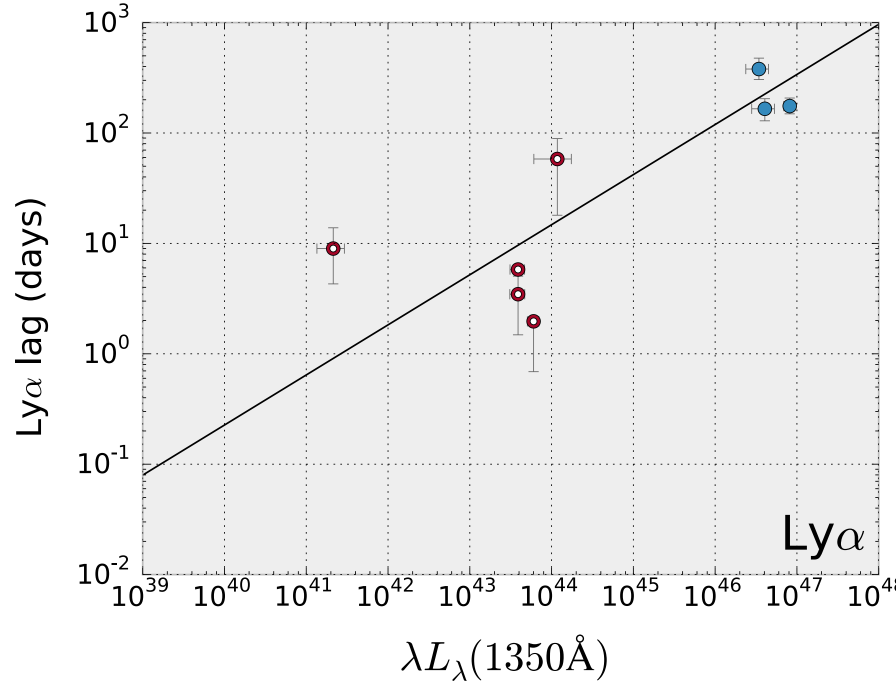
J221516
ICCF
R
Lyα
CIV
Flux
Time (days)
CT286
ICCF
R
Lyα
CIV
Flux
Time (days)

~~Radius~~ - Luminosity Relations
Lag



~~Radius~~ Lag - Luminosity Relations

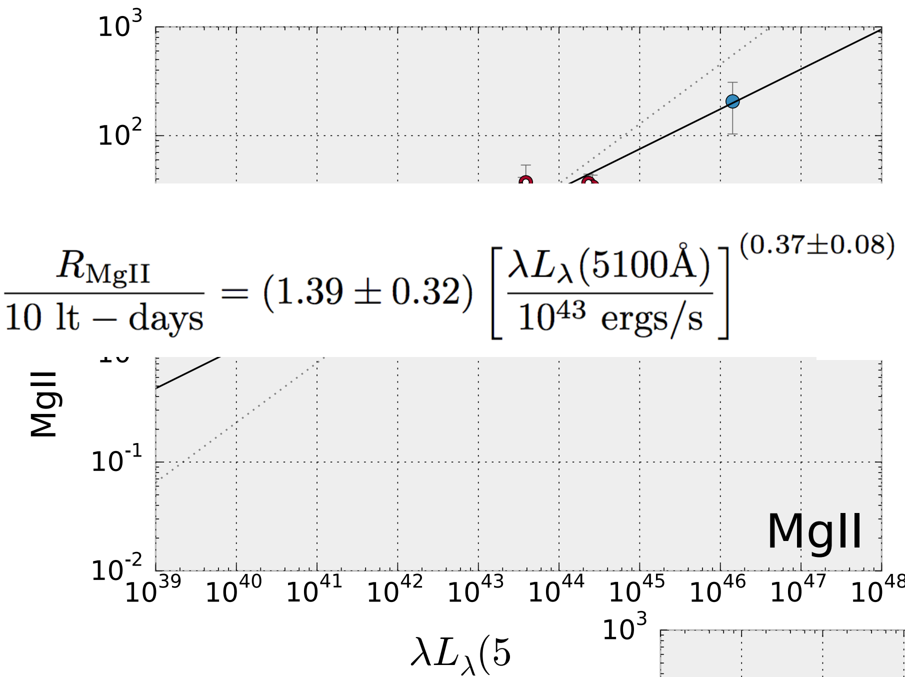




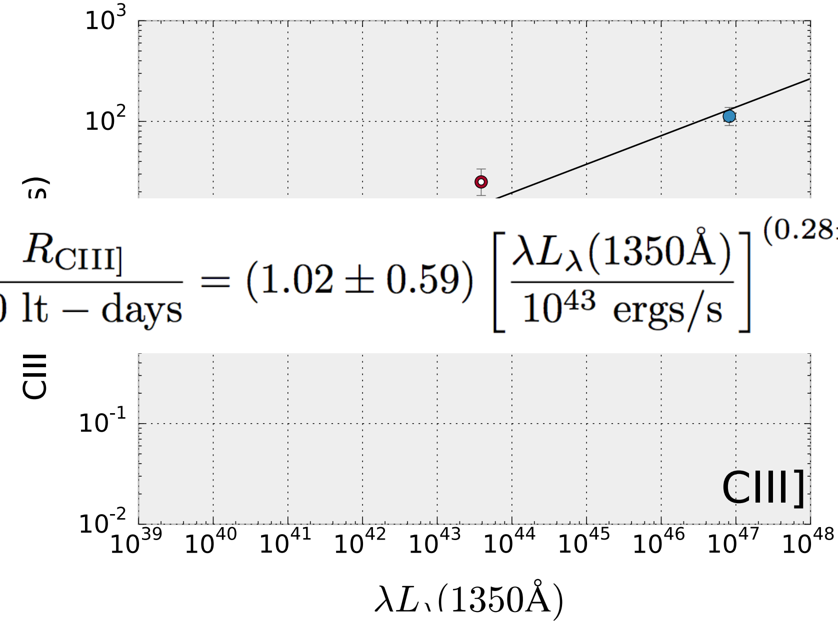
$$\frac{R_{\rm CIV}}{10\ \rm lt-days} = (0.24 \pm 0.08) \left[\frac{\lambda L_\lambda(1345\text{Å})}{10^{43}\ \rm ergs/s}\right]^{(0.52\pm0.06)}$$

$$\frac{R_{\rm Ly\alpha}}{10\ \rm lt-days} = (0.52 \pm 0.59) \left[\frac{\lambda L_\lambda(1345\text{Å})}{10^{43}\ \rm ergs/s}\right]^{(0.45\pm0.22)}$$

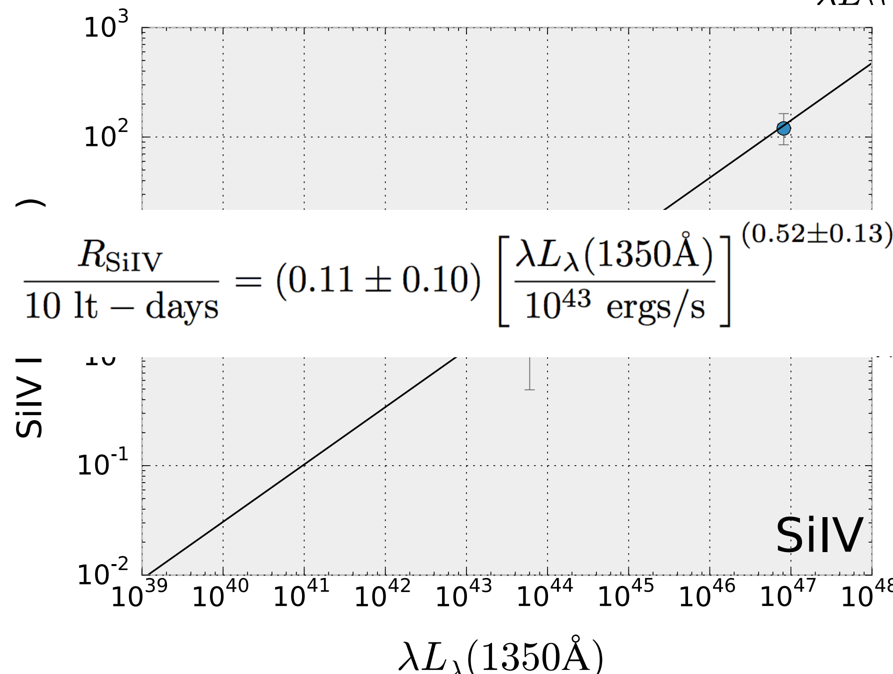
Radius - Luminosity Relations



$$\frac{R_{\rm MgII}}{10\ \rm lt-days} = (1.39 \pm 0.32)\left[\frac{\lambda L_\lambda(5100\text{Å})}{10^{43}\ \rm ergs/s}\right]^{(0.37\pm0.08)}$$

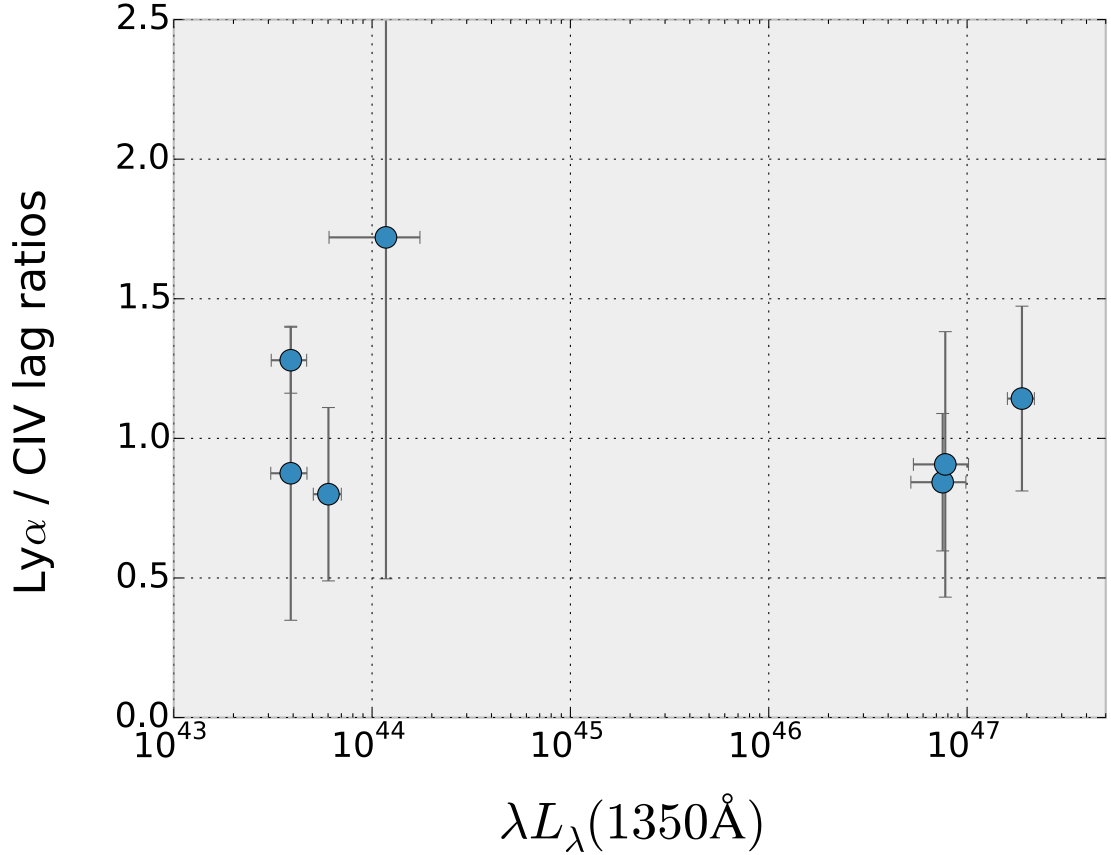


$$\frac{R_{\rm CIII]}}{10\ \rm lt-days} = (1.02 \pm 0.59)\left[\frac{\lambda L_\lambda(1350\text{Å})}{10^{43}\ \rm ergs/s}\right]^{(0.28\pm0.14)}$$



$$\frac{R_{\rm SiIV}}{10\ \rm lt-days} = (0.11 \pm 0.10)\left[\frac{\lambda L_\lambda(1350\text{Å})}{10^{43}\ \rm ergs/s}\right]^{(0.52\pm0.13)}$$

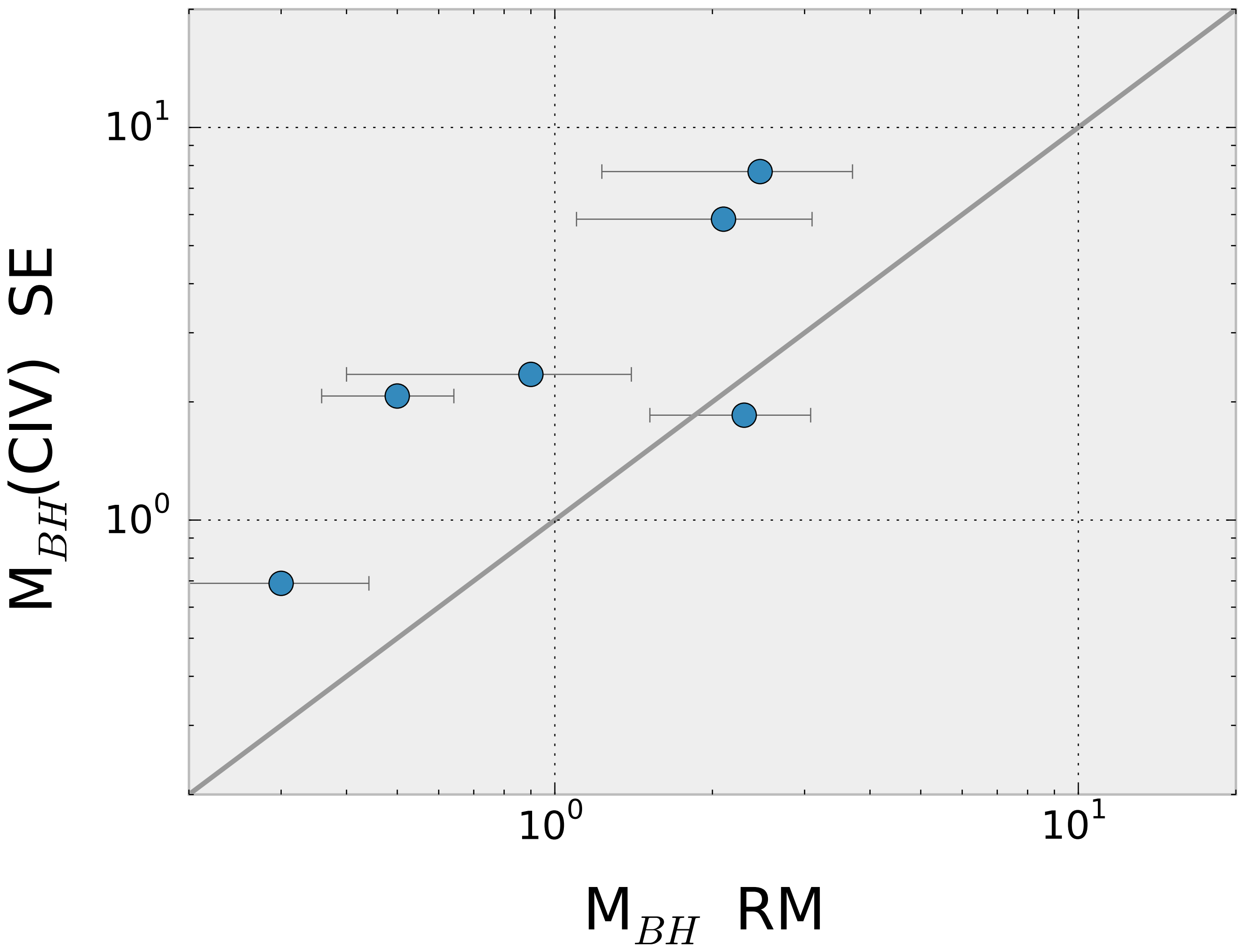
Lyα / CIV Lag Ratios



$$R_{\mathrm{Ly}\alpha}/R_{\mathrm{CIV}} \sim 1 \qquad R_{\mathrm{H}\beta}/R_{\mathrm{CIV}} \approx 4.4 \pm 1.8$$

$$R_{\mathrm{MgII}}/R_{\mathrm{CIV}} \sim 1.54 \pm 0.72$$

RM vs SE Masses



Summary

- 17 high-z high-L quasars: all show strong continuum variation; for several line cross-correlation measurements were feasible
- In 2/17 the lines are **not** responding to the observed 1500A continuum
- Determined R-L relations for CIV, Lyα, SiIV, CIII], MgII
- CIV and Lyα are produced at the same R from the central BH
- CIV-SE-based masses are systematically overestimated