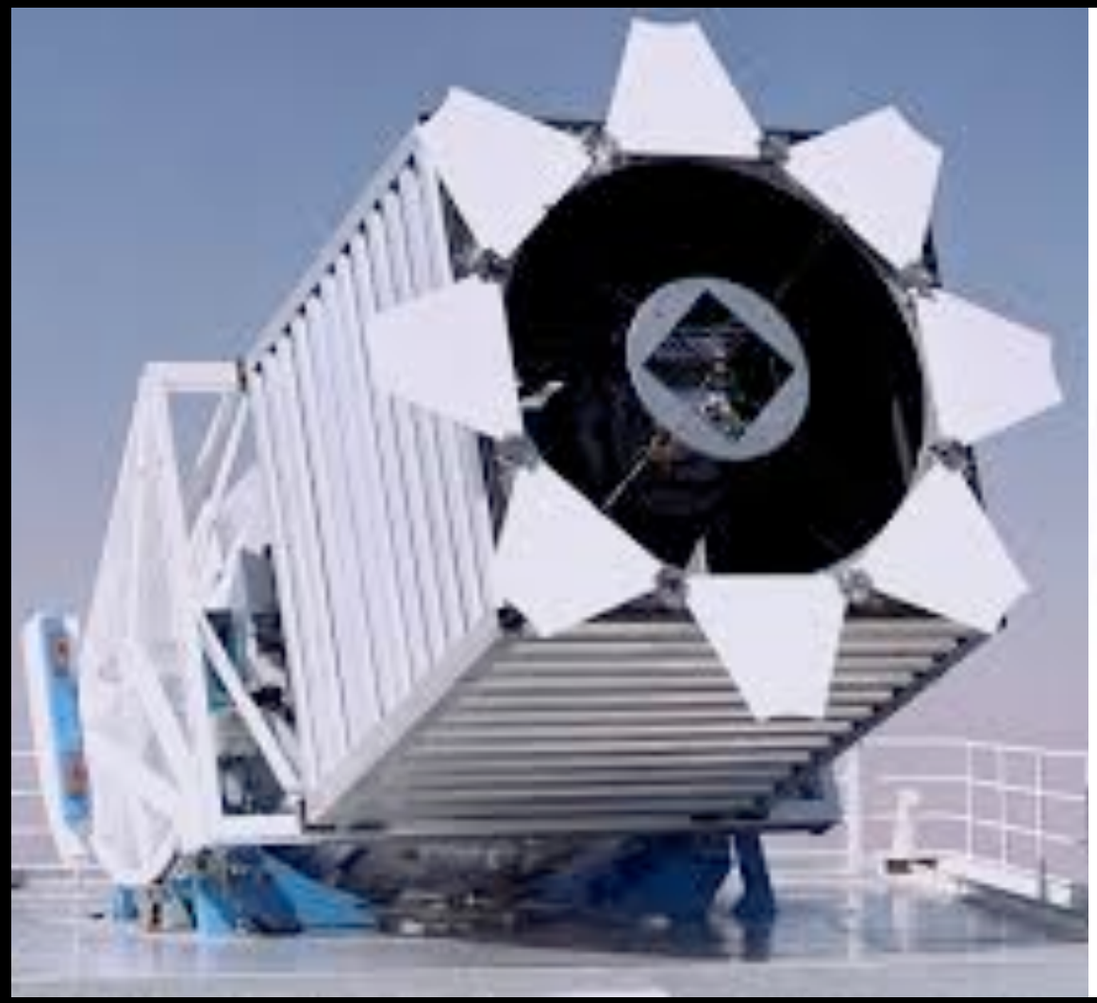
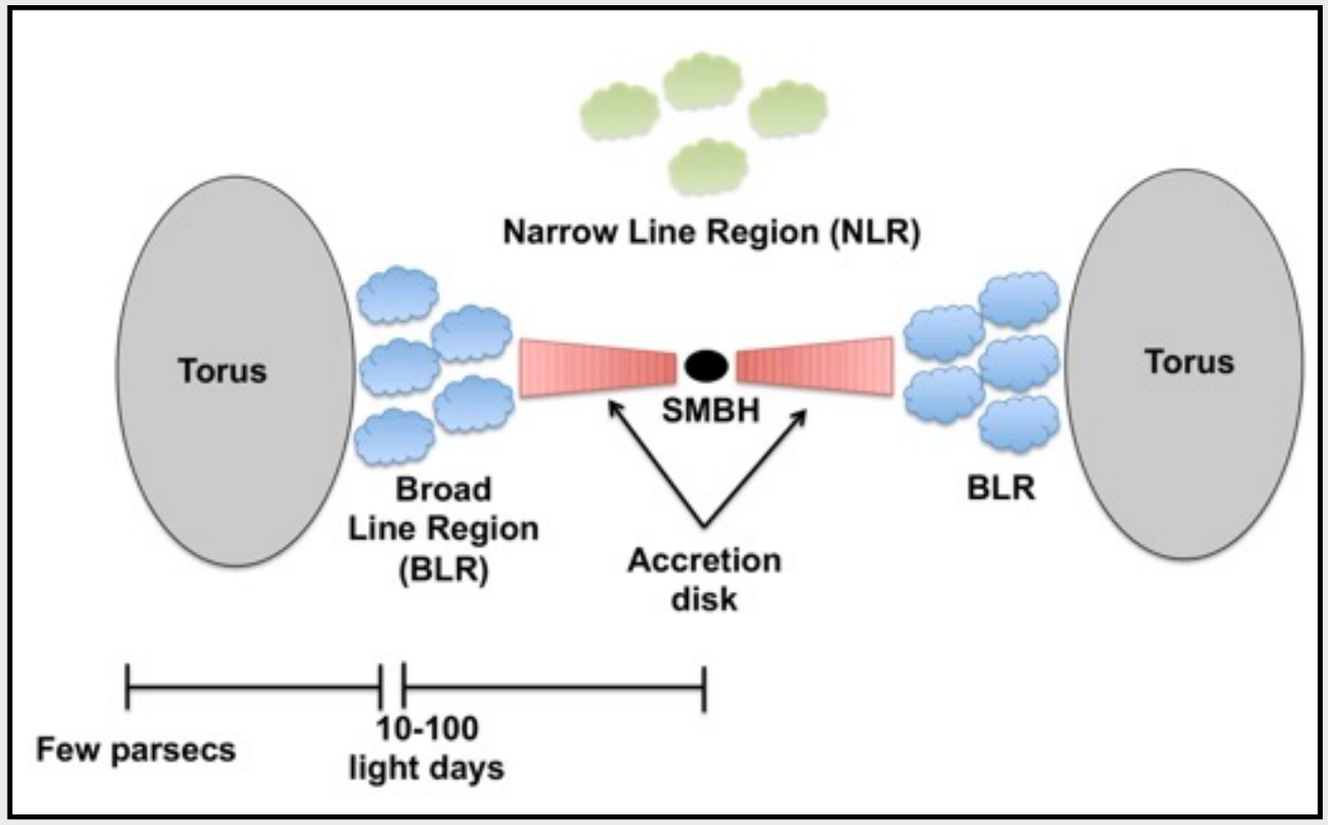
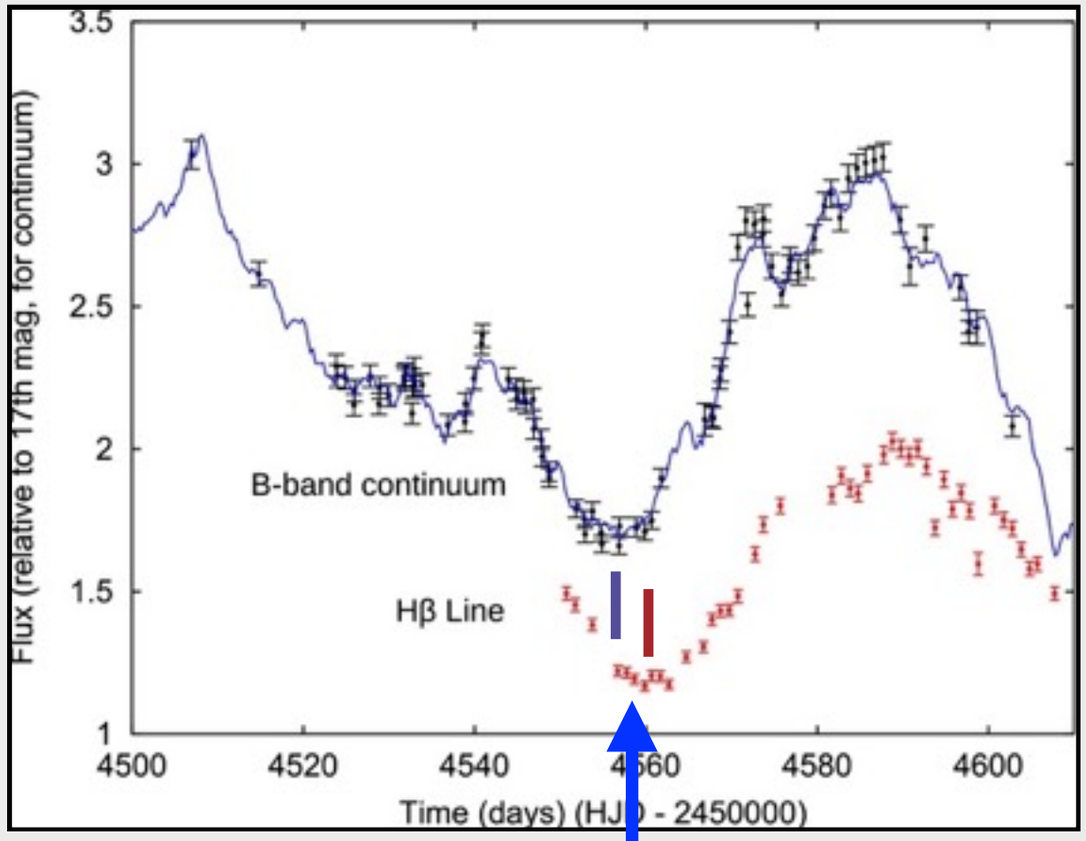
The Sloan Digital Sky Survey Reverberation Mapping Project (SDSS-RM)



AGN Reverberation Mapping (one slide)



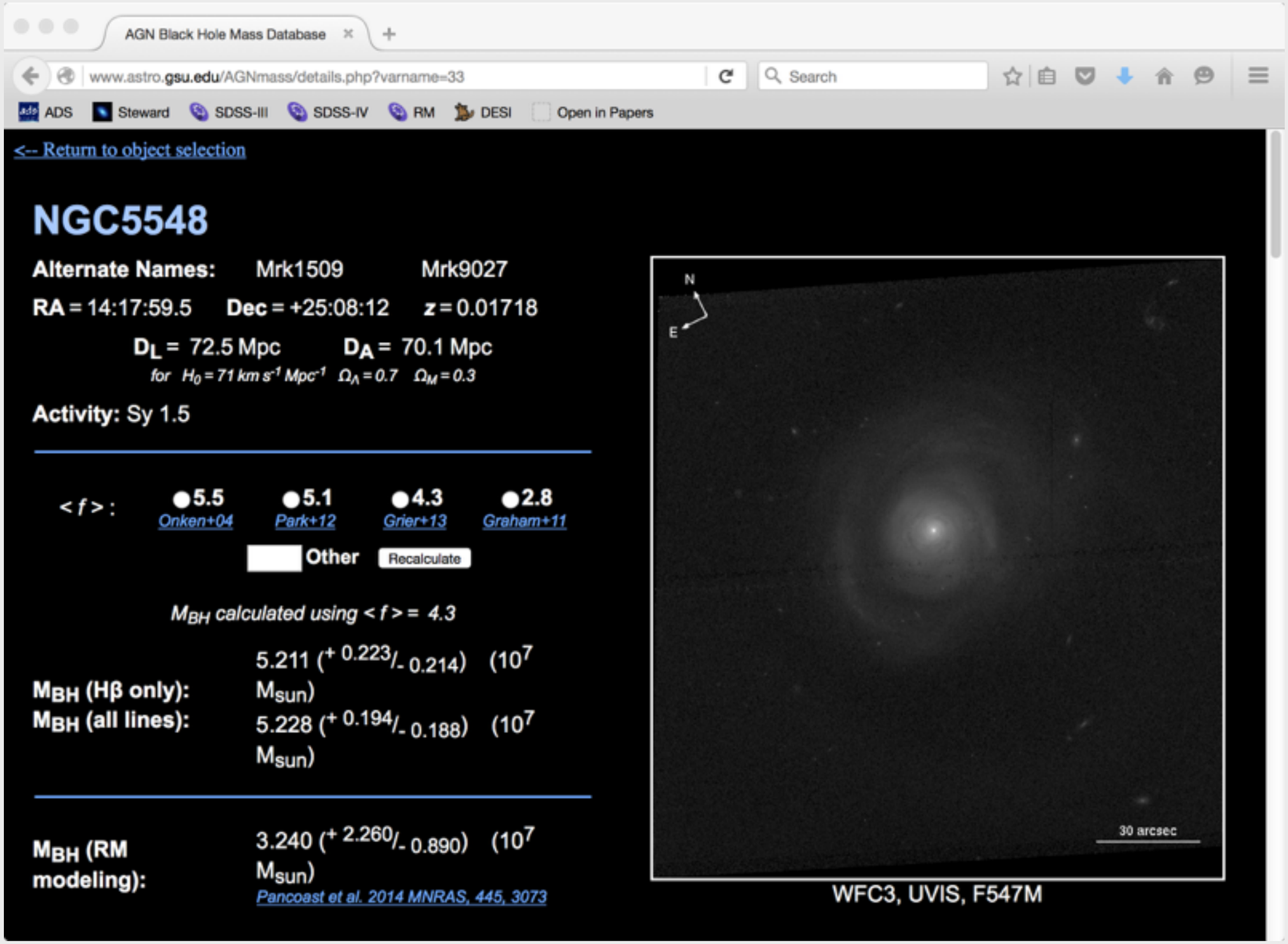
www.isdc.unige.ch/~ricci



Barth et al. 2011

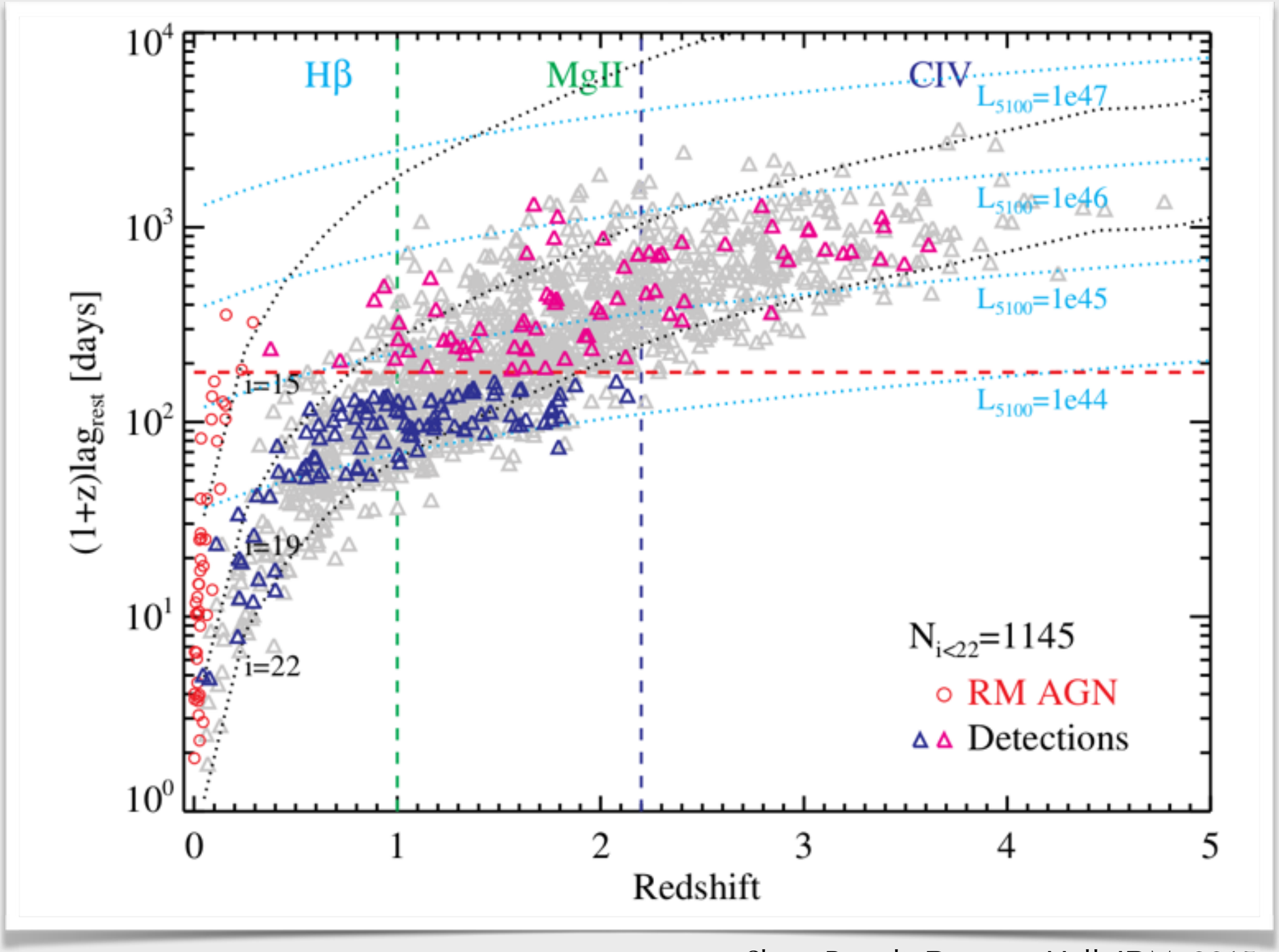
time lag between continuum & emission lines

What current RM AGN look like:



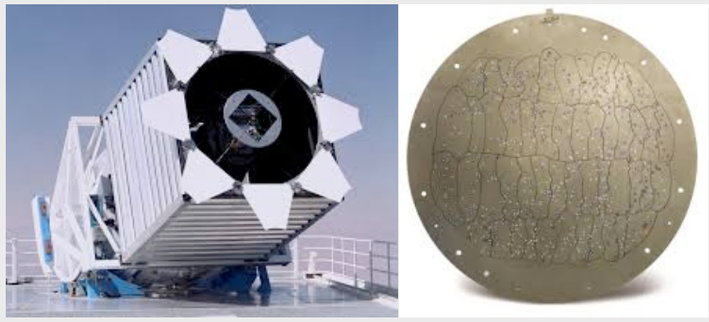
Misty Bentz / GSU

SDSS-RM: multi-object RM for *quasars*

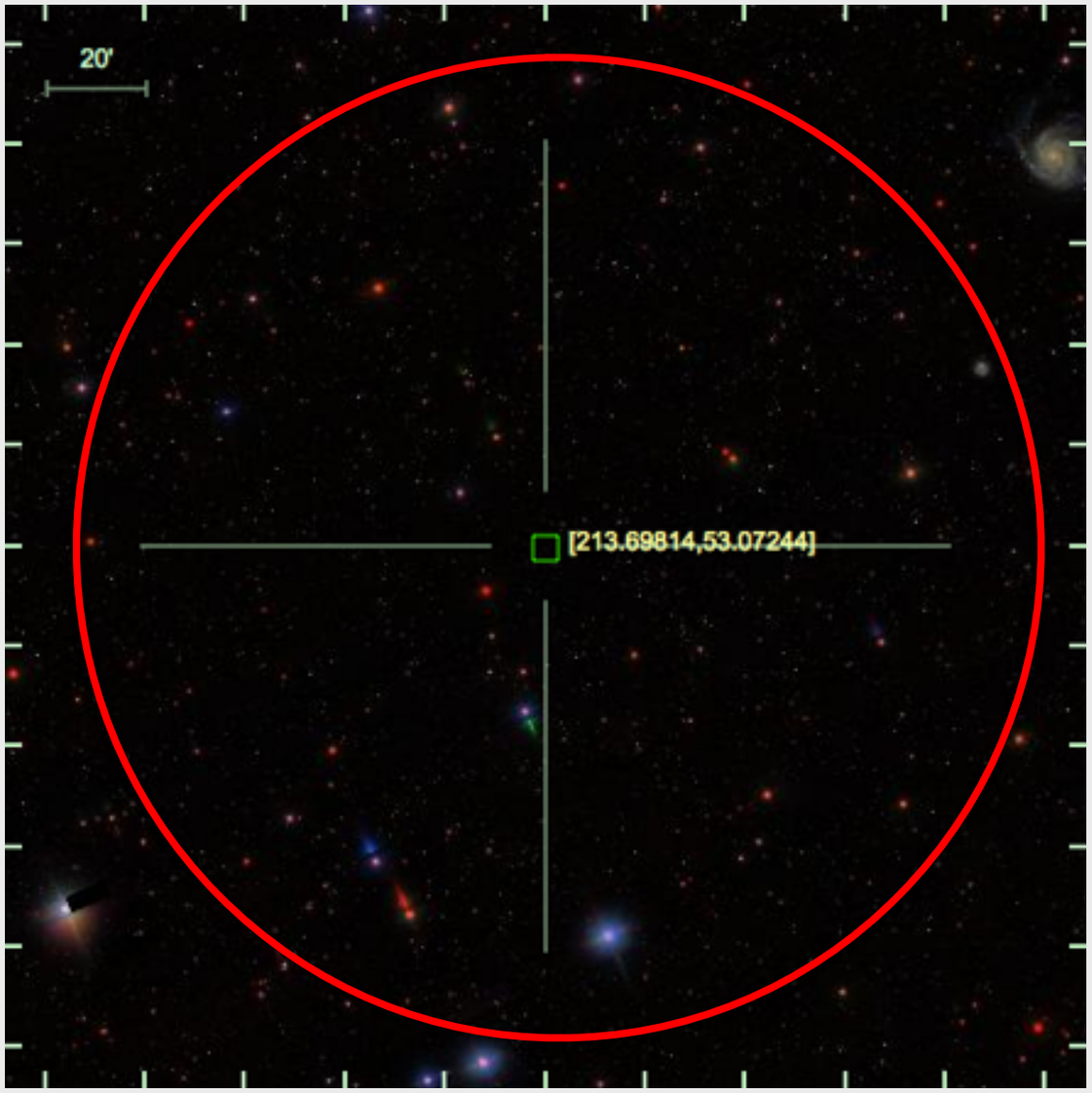


Shen, Brandt, Dawson, Hall, IDM+2015

SDSS-RM in a nutshell



- Motivation: **expanding** current RM AGN samples in scale and luminosity range
- Simultaneous monitoring a uniform sample of **849 quasars** at 0.1<z<4.5 in a single **7 deg²** field with the SDSS-BOSS **multi-object, fiber-fed** spectrograph
- **Dense photometric light curves** (~2-4 day cadence) since 2010 (PanSTARRS 1 + SDSS-RM imaging)
- Multiwavelength follow-up (**XMM, Spitzer, HST, UKIRT**)

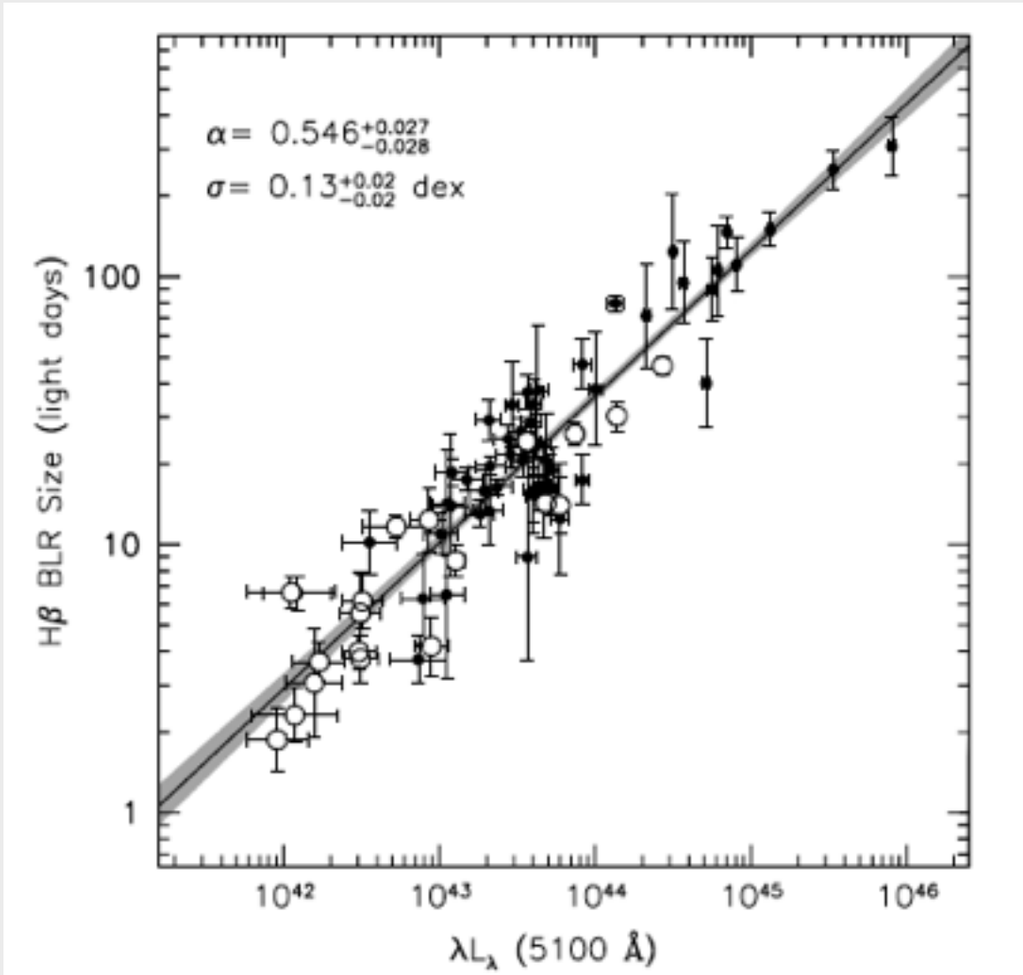


http://www.sdssrm.org

Major Goals/Aims of SDSS-RM

- Measure $\mathbf{M_{BH}}$ with reverberation mapping for **~200 quasars**
- Fill out the AGN **parameter space** covered by the current RM sample
- Obtain R-L relations for **Mg II** and **CIV**, which are currently not well-calibrated
- And lots more! Lots of Ancillary science!
  - **Quasar variability studies**
  - Absorption line studies
  - Host galaxy properties
  - Single-epoch M_{BH} measurements
  - Multiwavelength studies

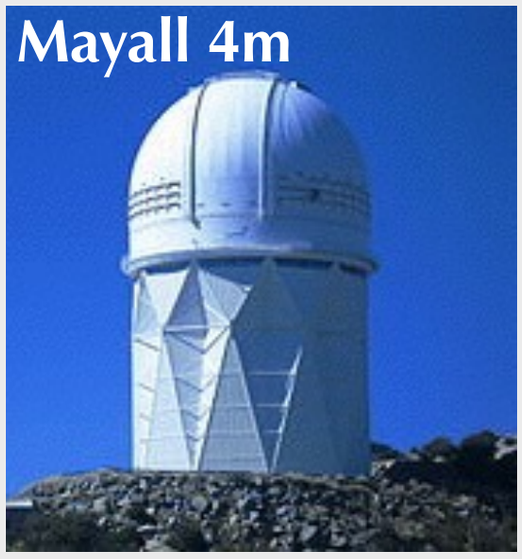
R-L relation

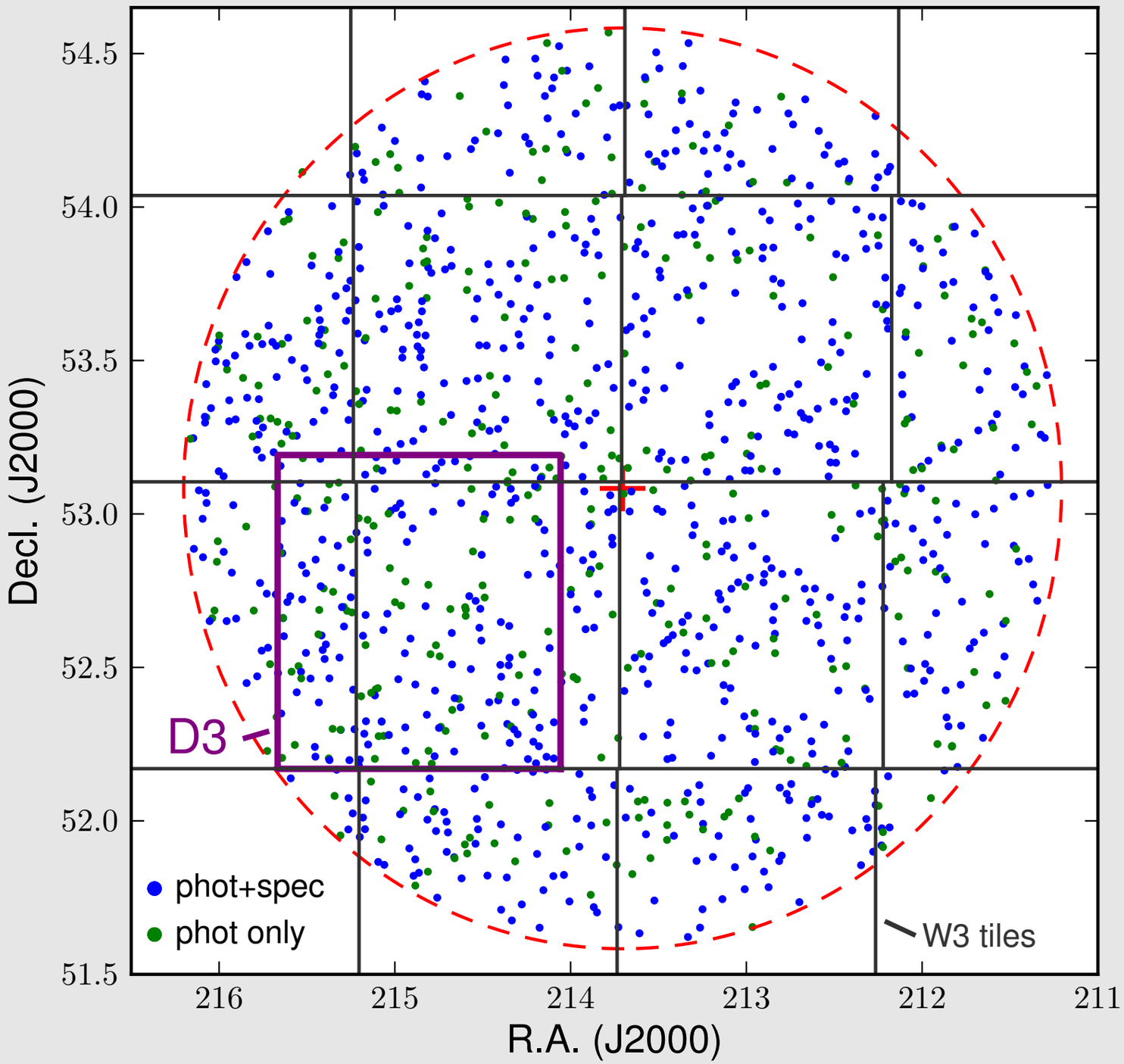


Bentz et al. (2013)

$$M_{\rm BH} = \frac{fR\Delta V^2}{G}$$

SDSS-RM observations





SDSS-RM Fact Sheet

7 deg^2 (one SDSS plate)

N_{QSO} = 1200 (photo, $i < 22$)
= 849 (spec, $i < 21.7$)

2014A monitoring:
- 30 epochs spectroscopy
- 60 epochs Bok imaging
- 30 epochs CFHT imaging

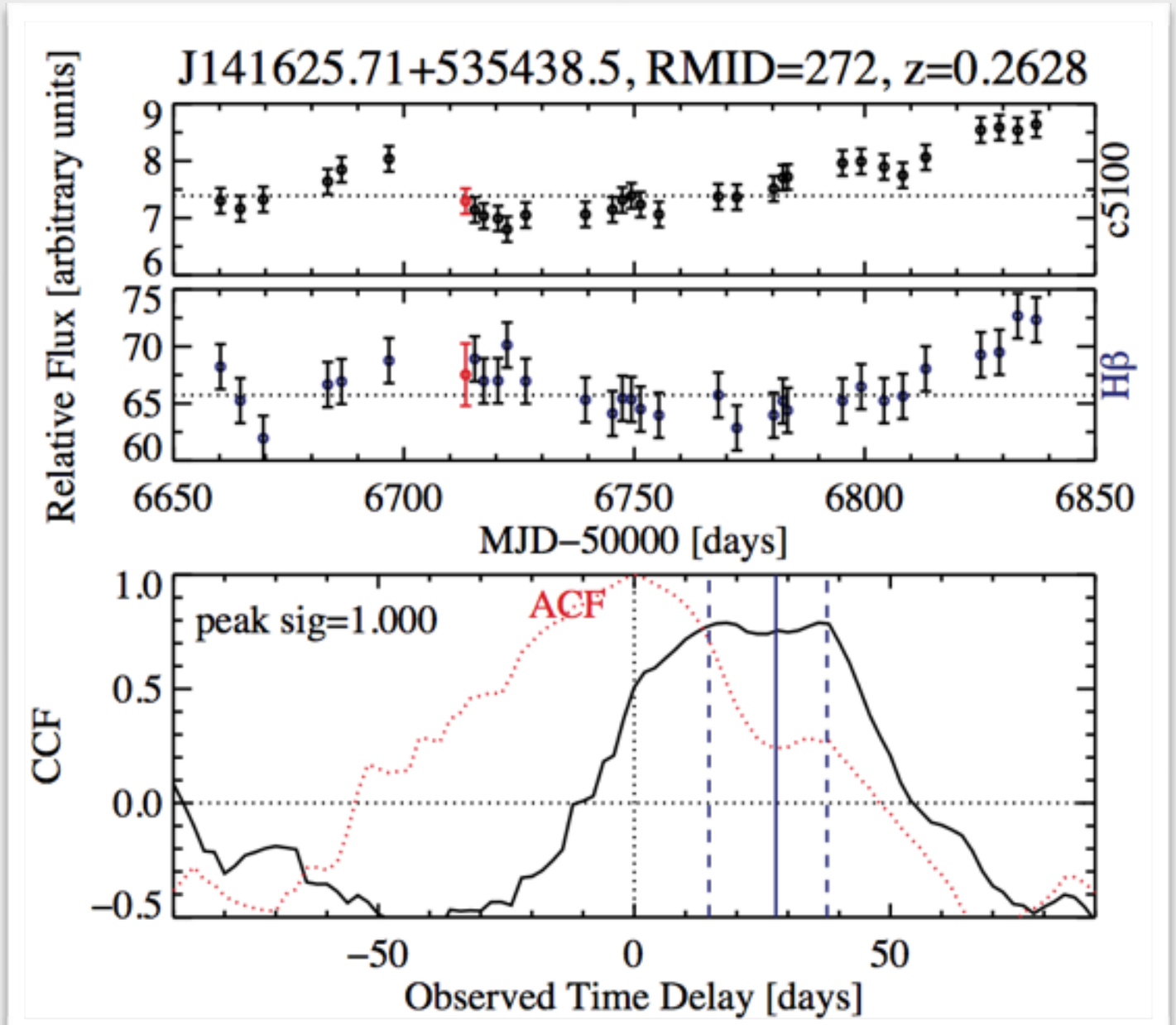
Previous data:
- SDSS-I (2003)
- CFHTLS-Wide (W3, 2003-5)
- CFHTLS-Deep (D3, 2003 -9)
- Pan-STARRS1 (MD07, 2010-13)

SDSS-IV extension (2015-16):
- 12 epochs spectroscopy
- 24 epochs Bok
- 24 epochs CFHT

SDSS-RM: first lag detections

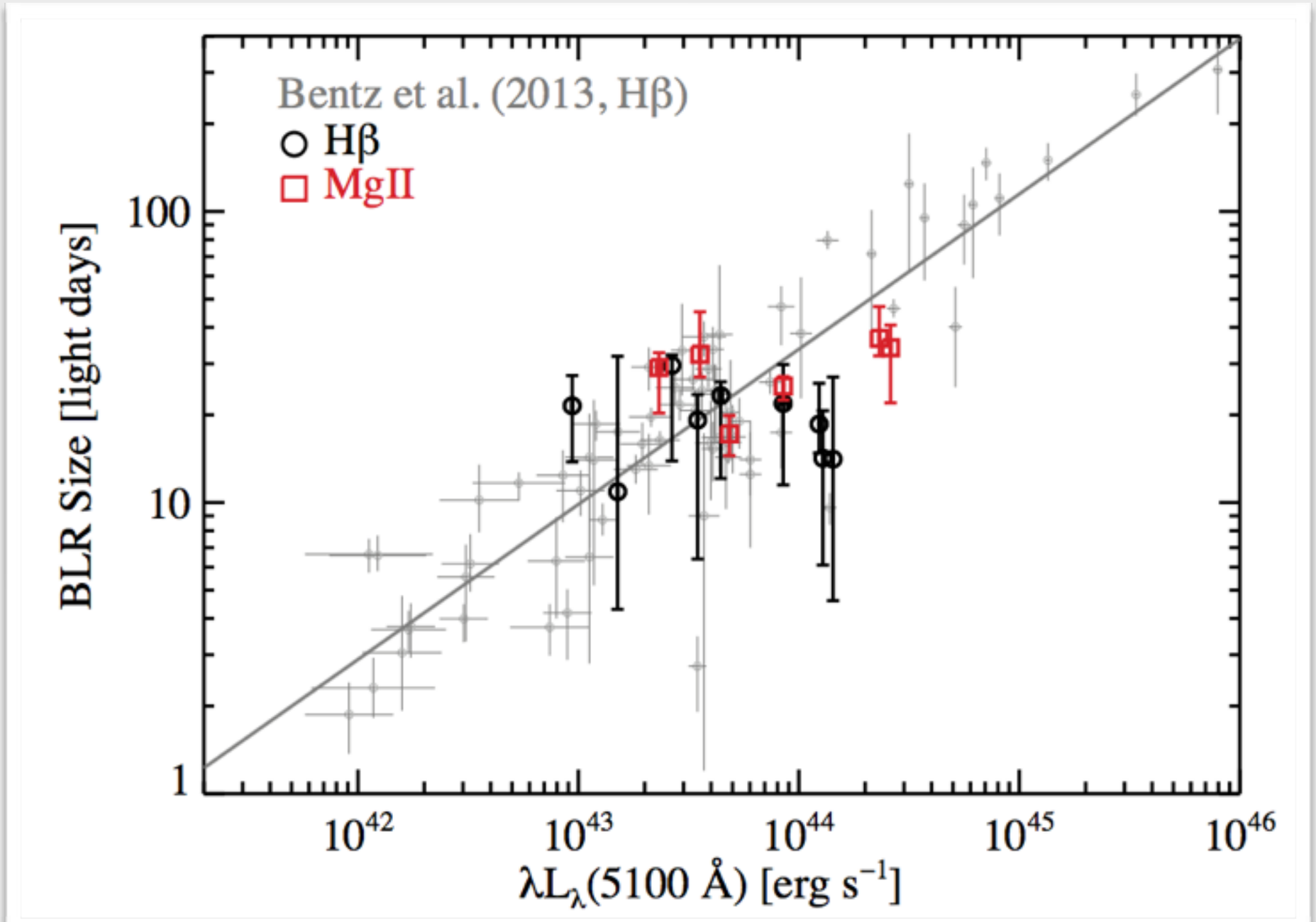
first lags from spectroscopy (Shen+2016)

- 2014 SDSS spectroscopy (32 epochs)
- Hβ/MgII lags at **z<0.8** (~100 quasars)
- **15 lags reported (9 Hβ, 6 MgII)**



Shen+2016

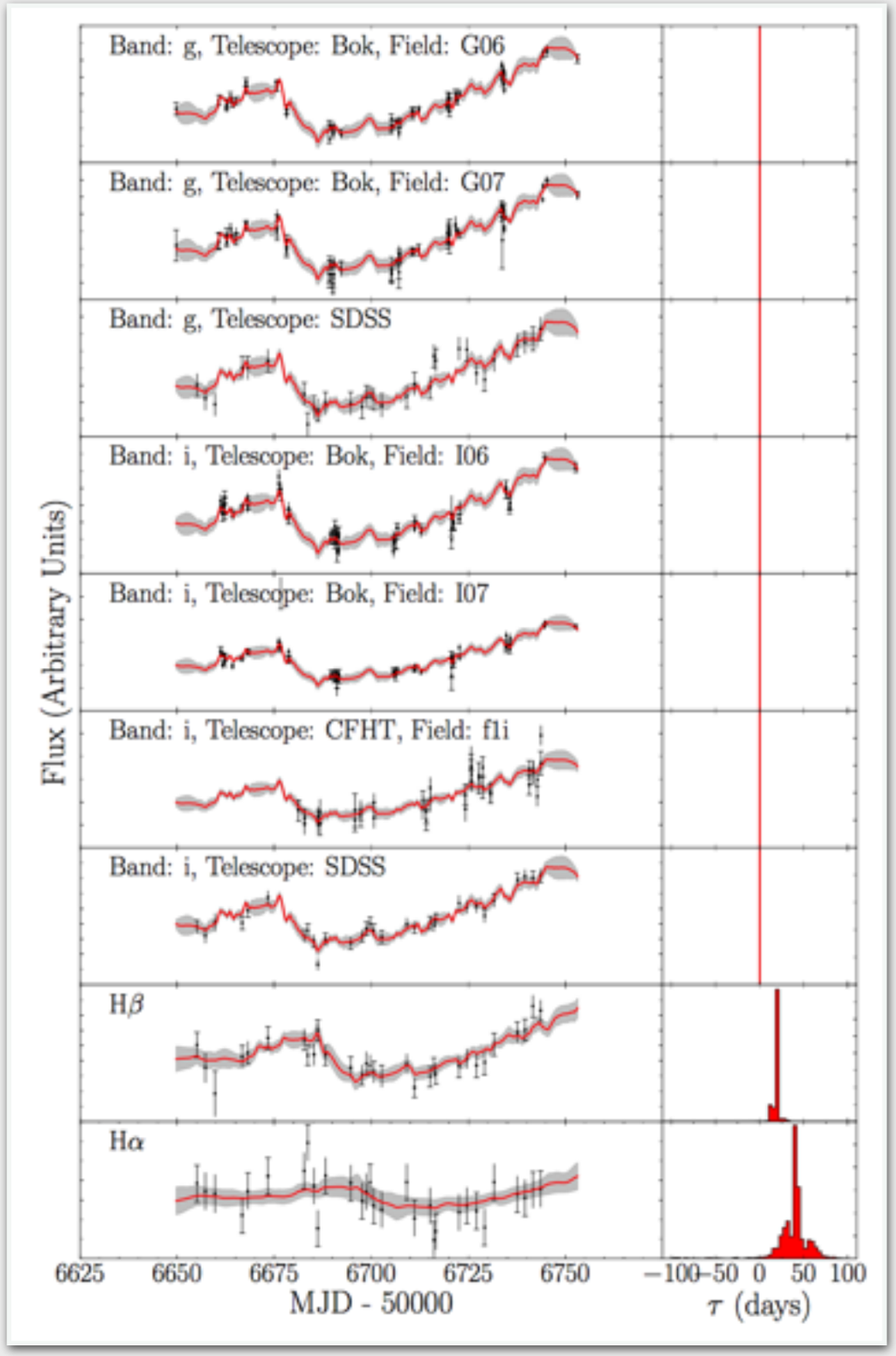
R-L relation



Shen+2016

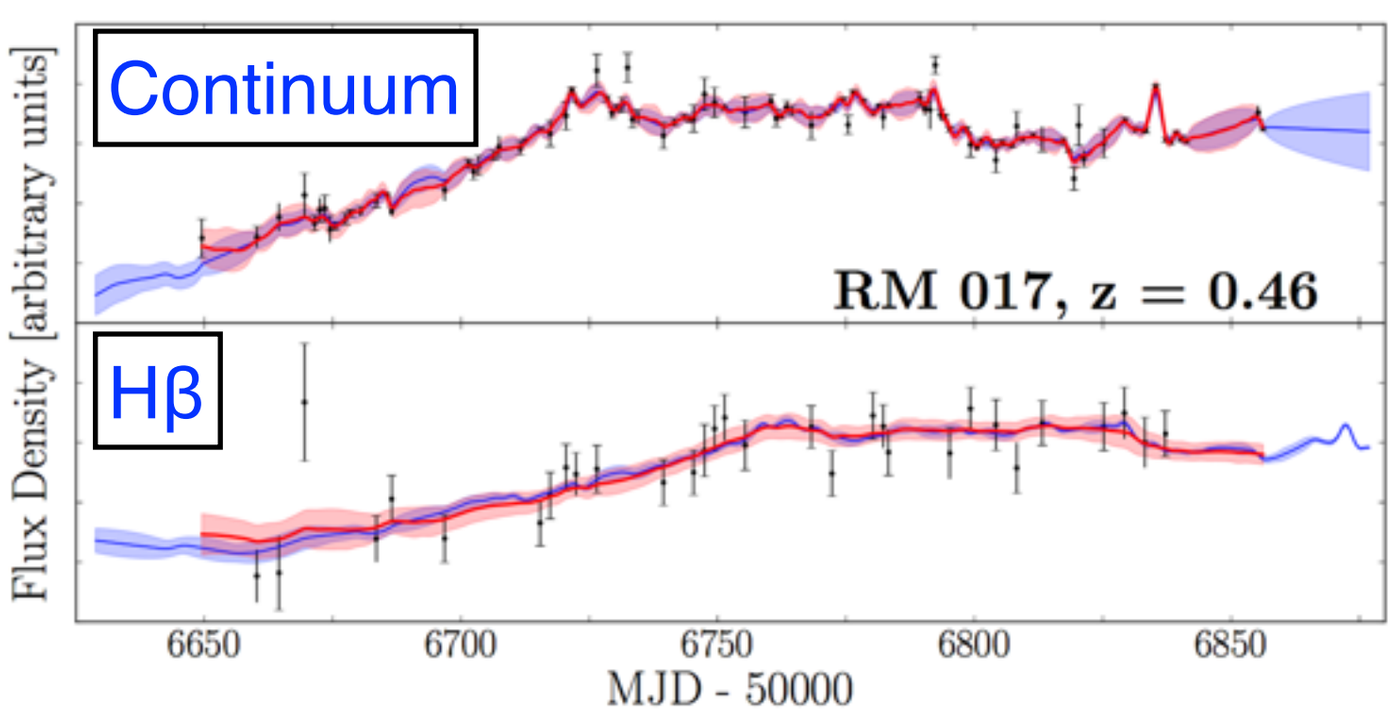
first lags with photometry (Grier+, submitted)

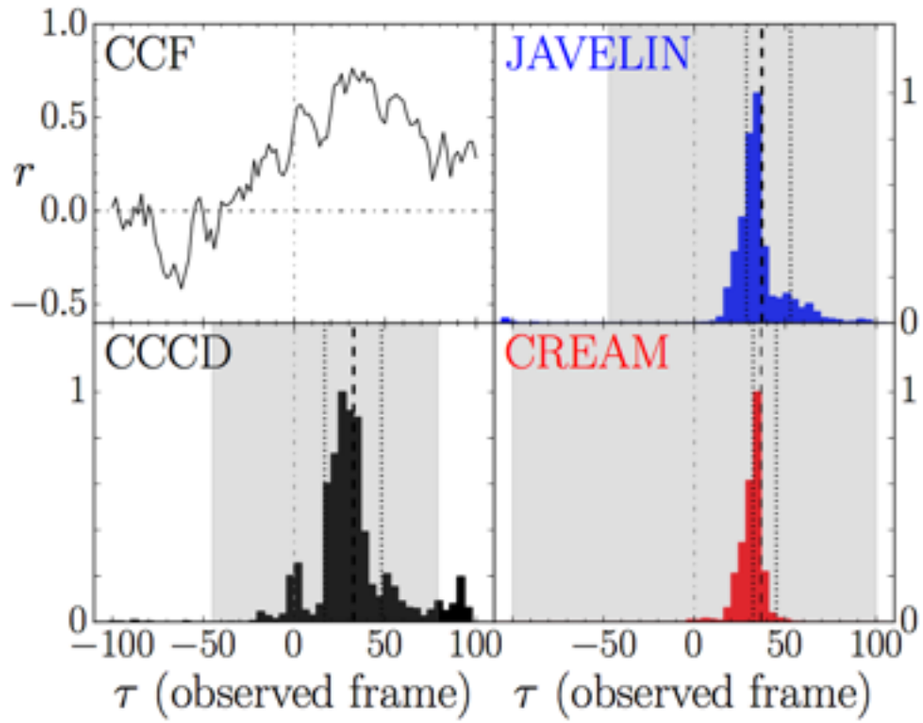
- 2014 SDSS spectroscopy and photometry (Bok+CFHT)
- Hβ/Hα lags at **z<1.13** (222 quasars)
- **48 lags reported**
  - 44 Hβ, 18 Hα
  - ~10% false positives
  - 8/9 Shen et al. lags confirmed
  - ~20% overall success rate



Grier et al.

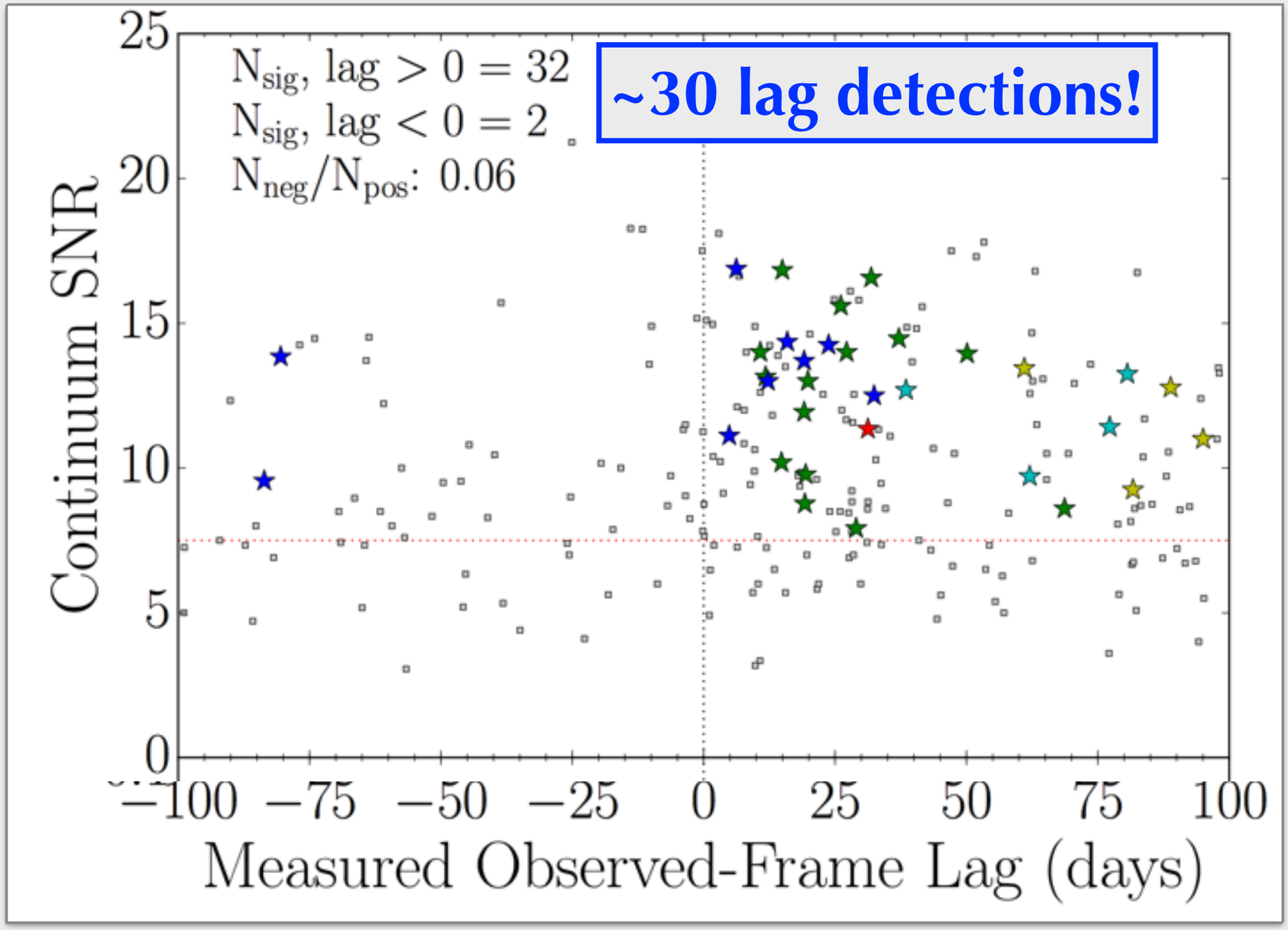
multiple cross-correlation methods



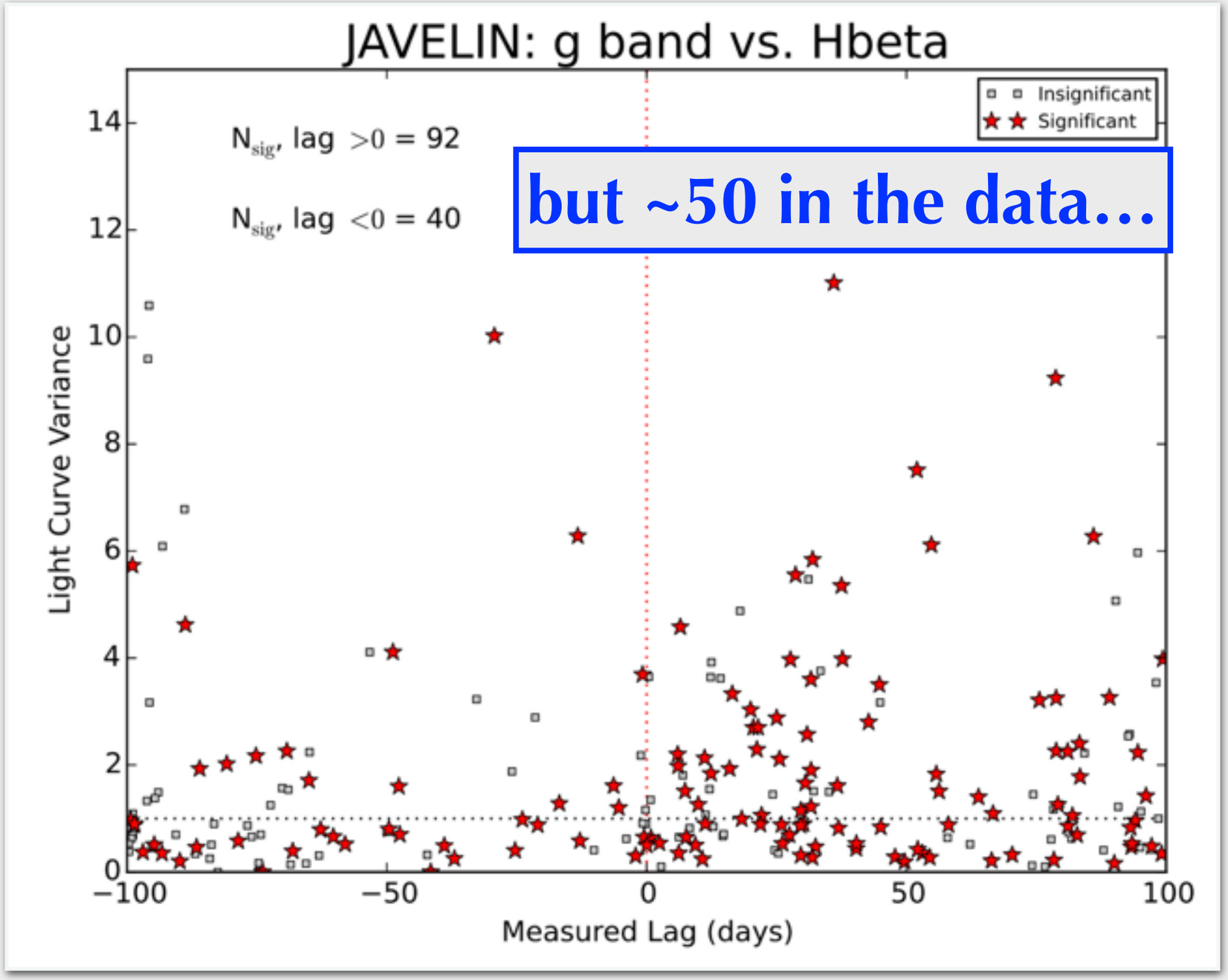


Grier et al.

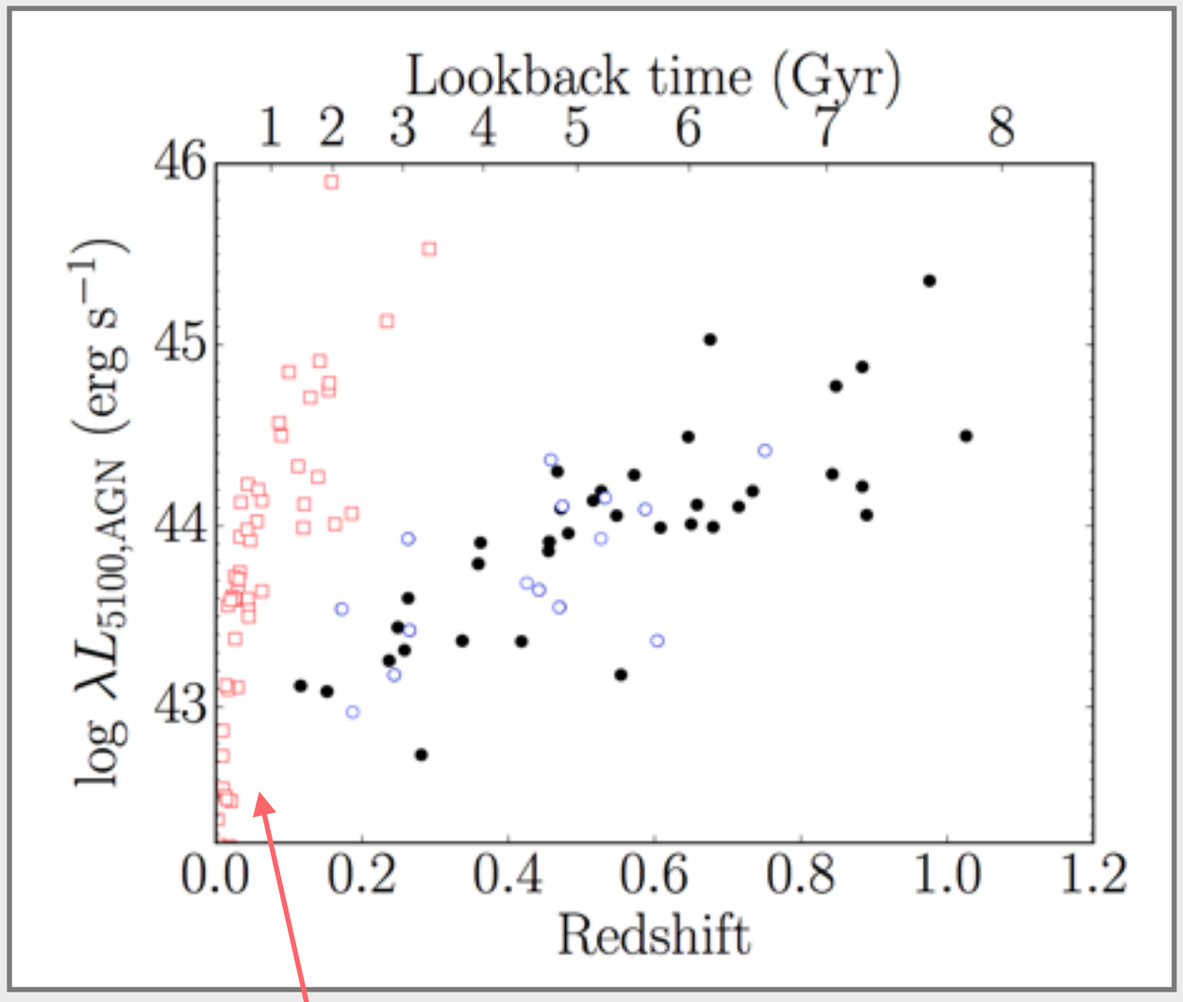
lag significance tests (Javelin-only)



Grier et al.

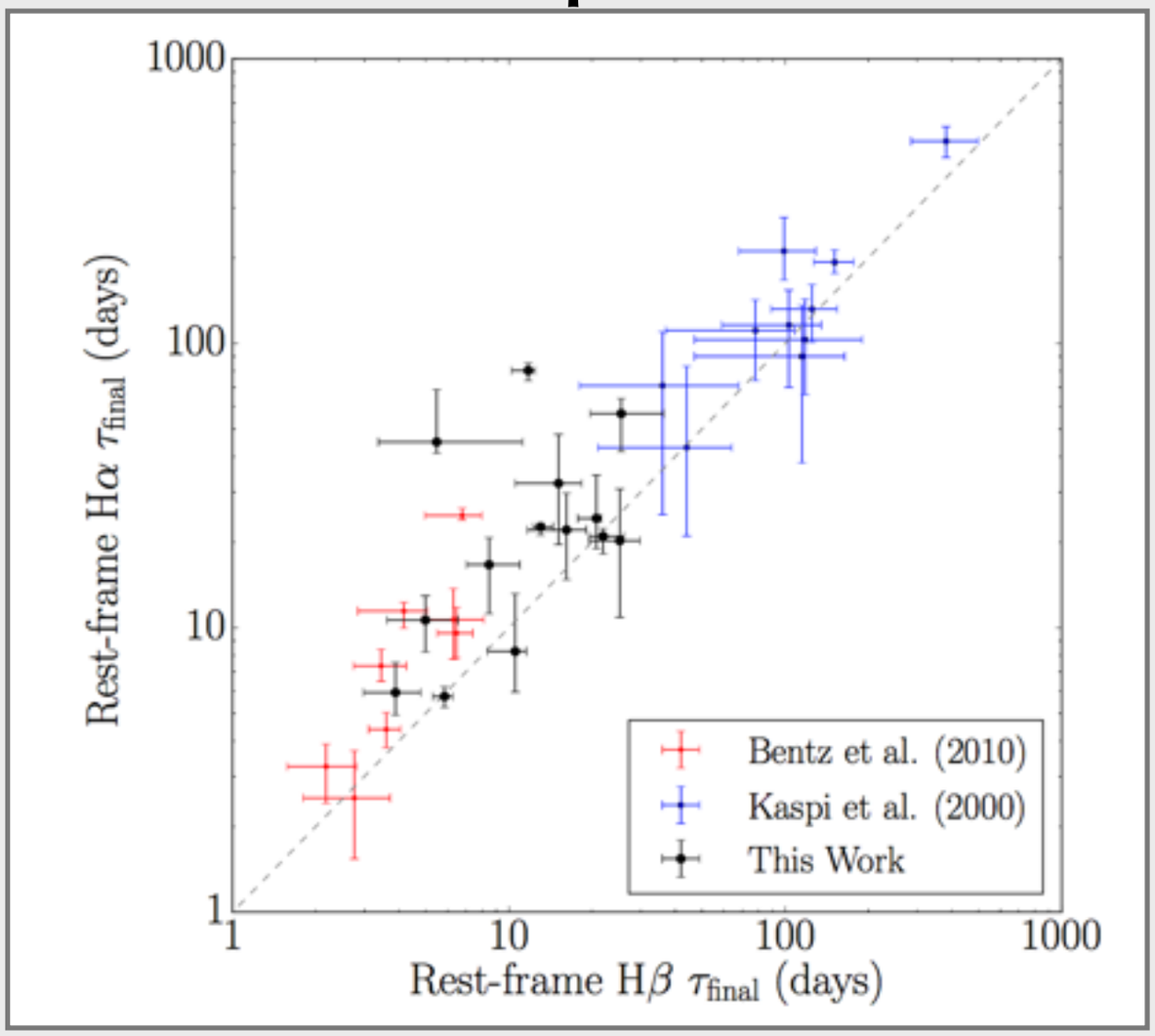

JAVELIN: g band vs. Hbeta
Insignificant
Significant
N_{sig}, lag >0 = 92
N_{sig}, lag <0 = 40
but ~50 in the data…
Light Curve Variance
Measured Lag (days)
0
2
4
6
8
10
12
14
−100
−50
0
50
100

✔ higher redshifts



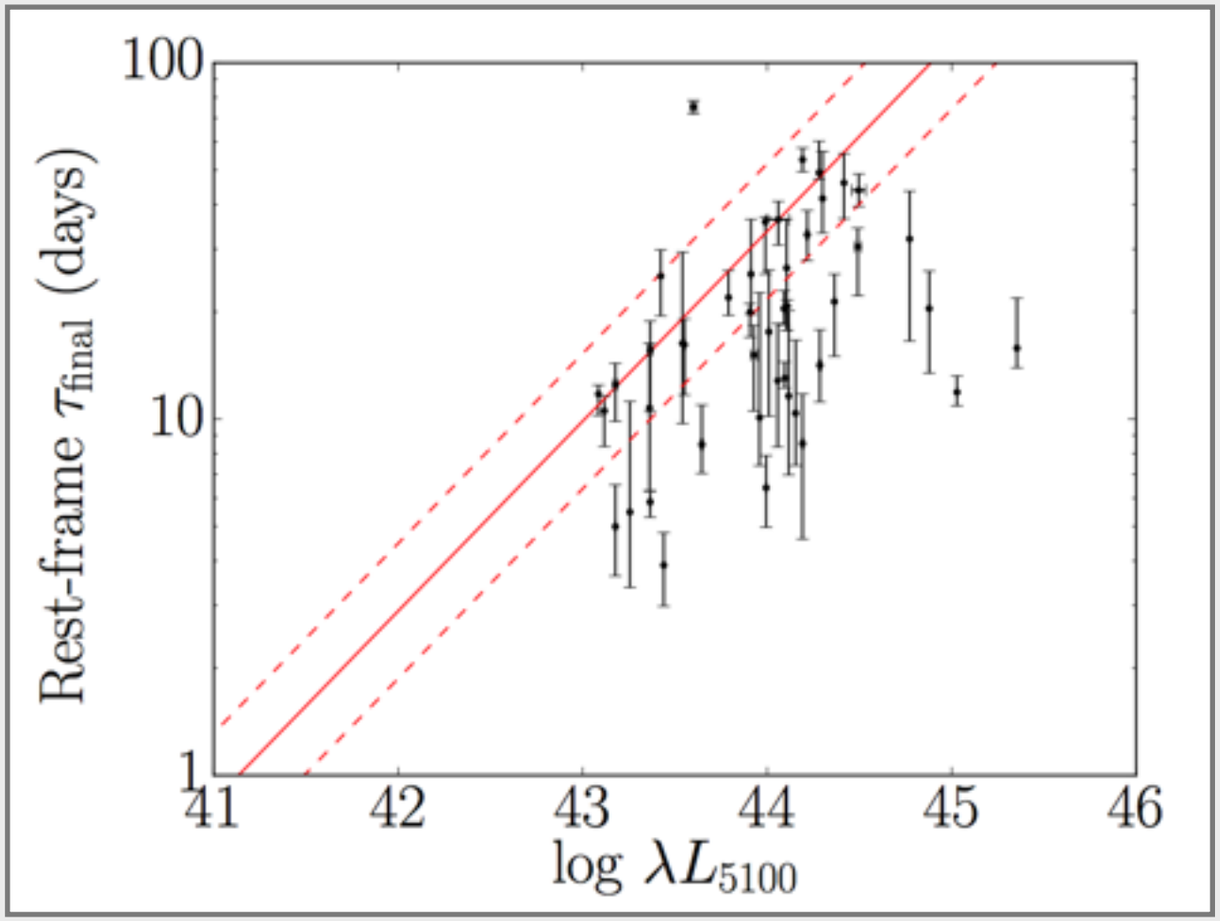
current RM AGN

✔ multiple lines

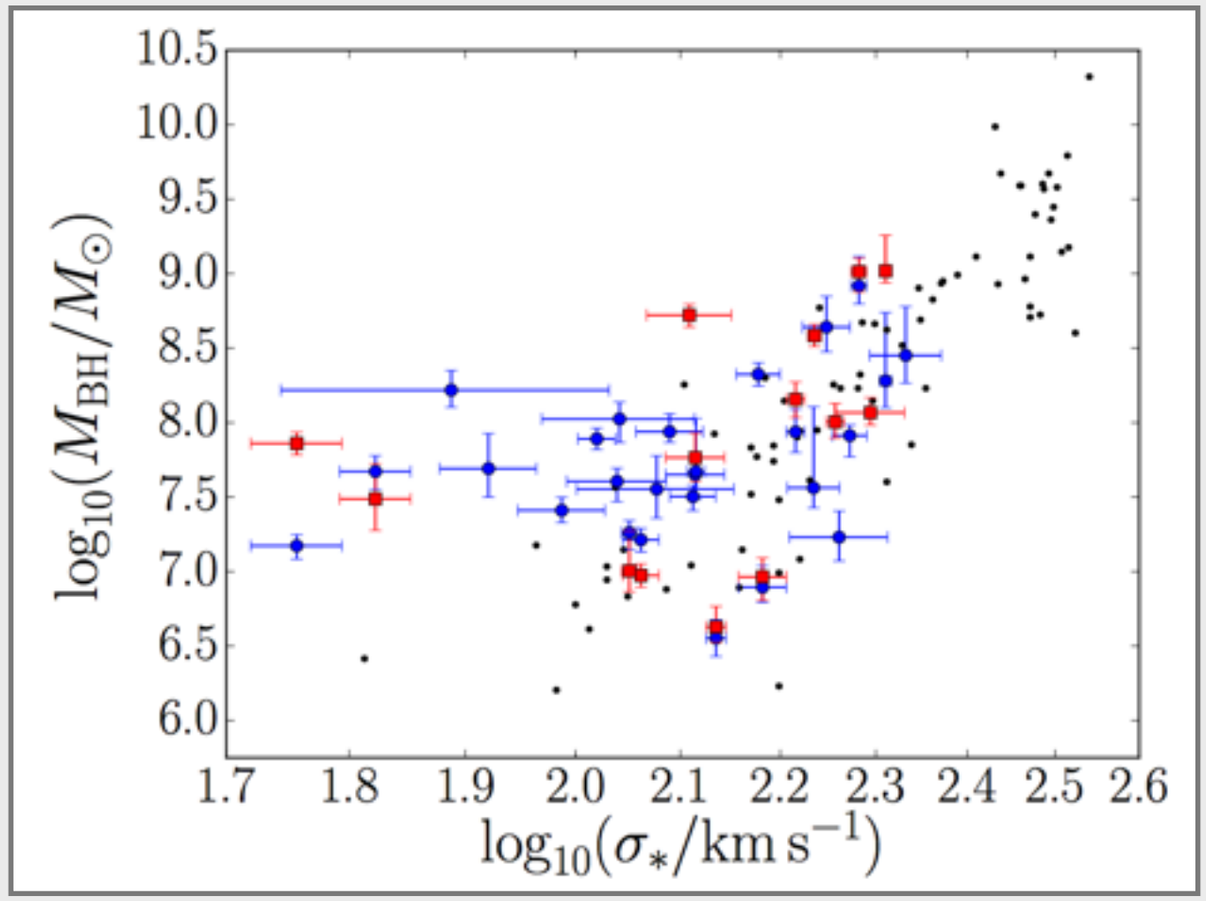


Grier et al.

more intriguing results… but systematics to explore…



R-L relation



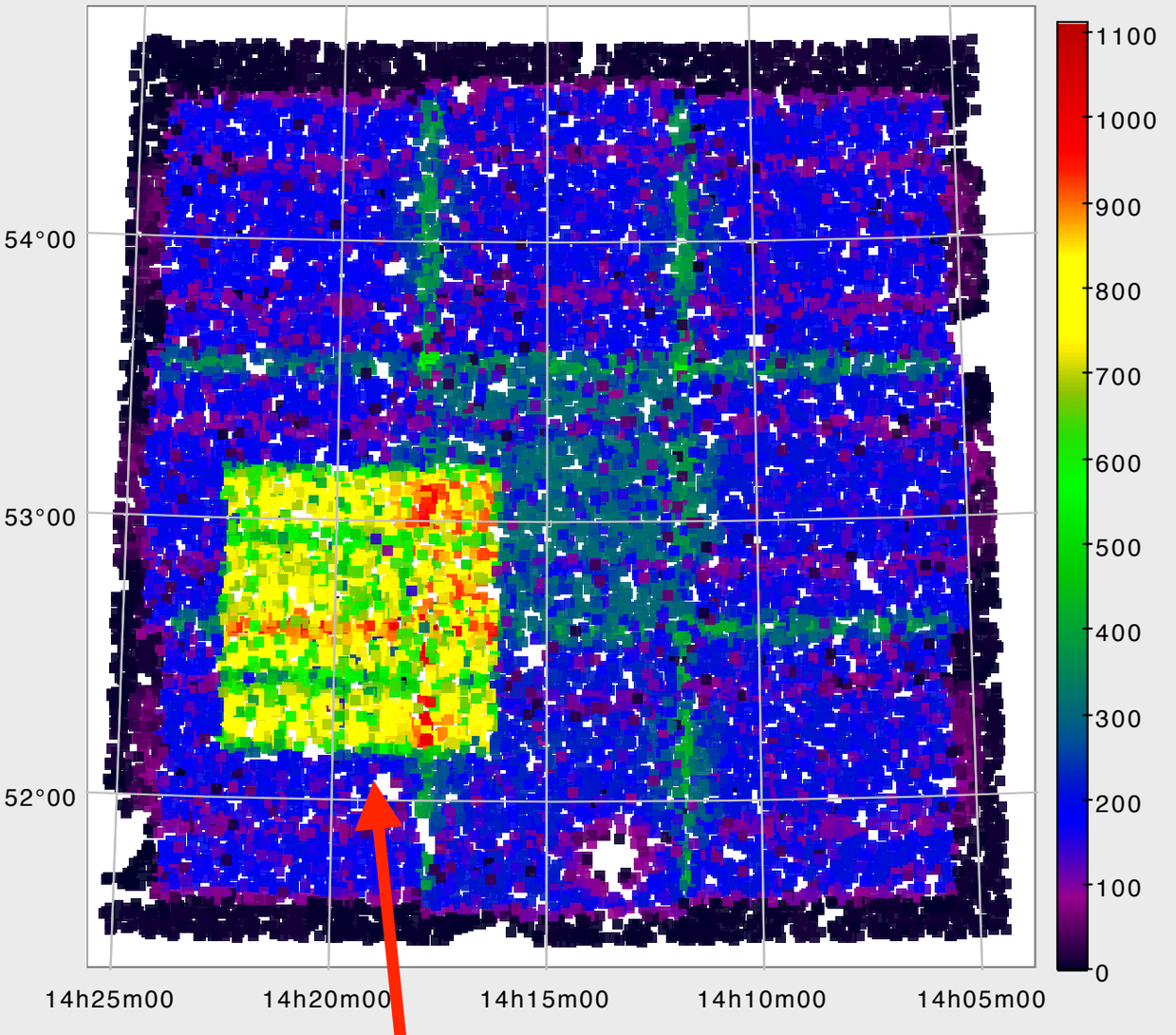
M-σ relation

Quasar Variability from SDSS-RM

g-band coverage maps

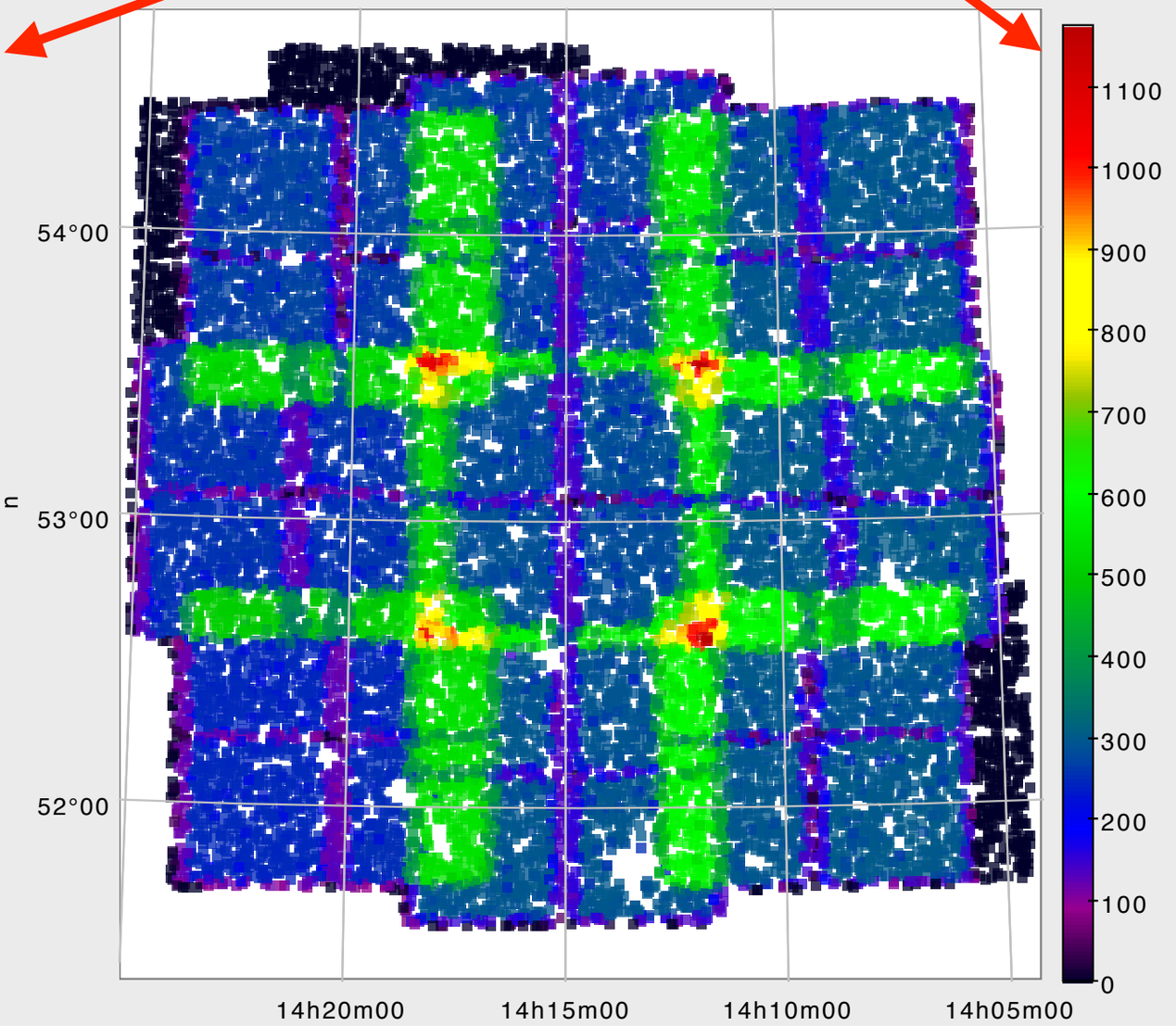
100s - 1000s of observations!

CFHT

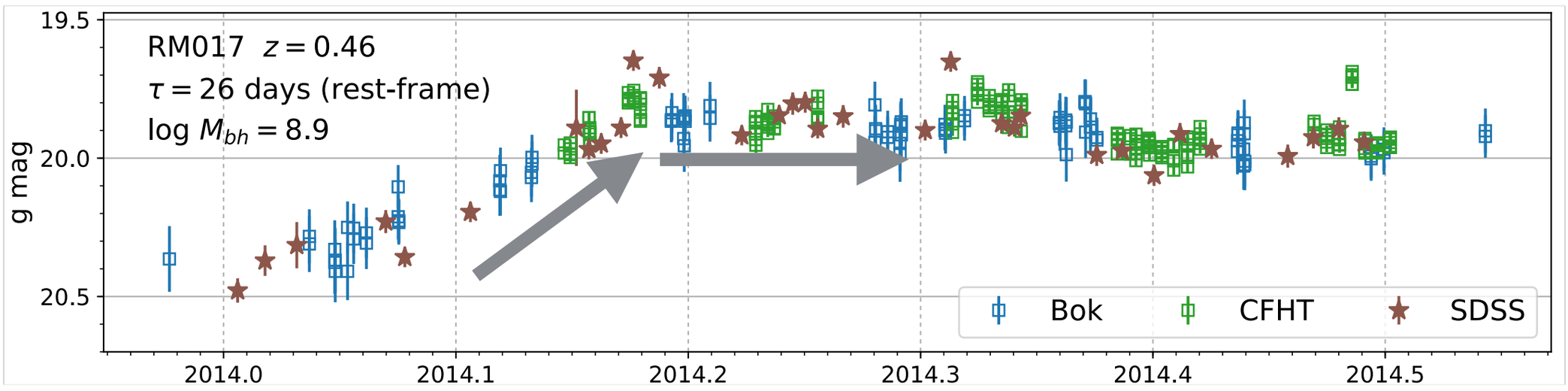


D3

Bok



example quasar with lag detection



2014 (first lags)

RM017 $z = 0.46$

$\tau = 26$ days (rest-frame)

log $M_{bh} = 8.9$

~0.5 mag

Bok CFHT SDSS

g mag

RM campaign

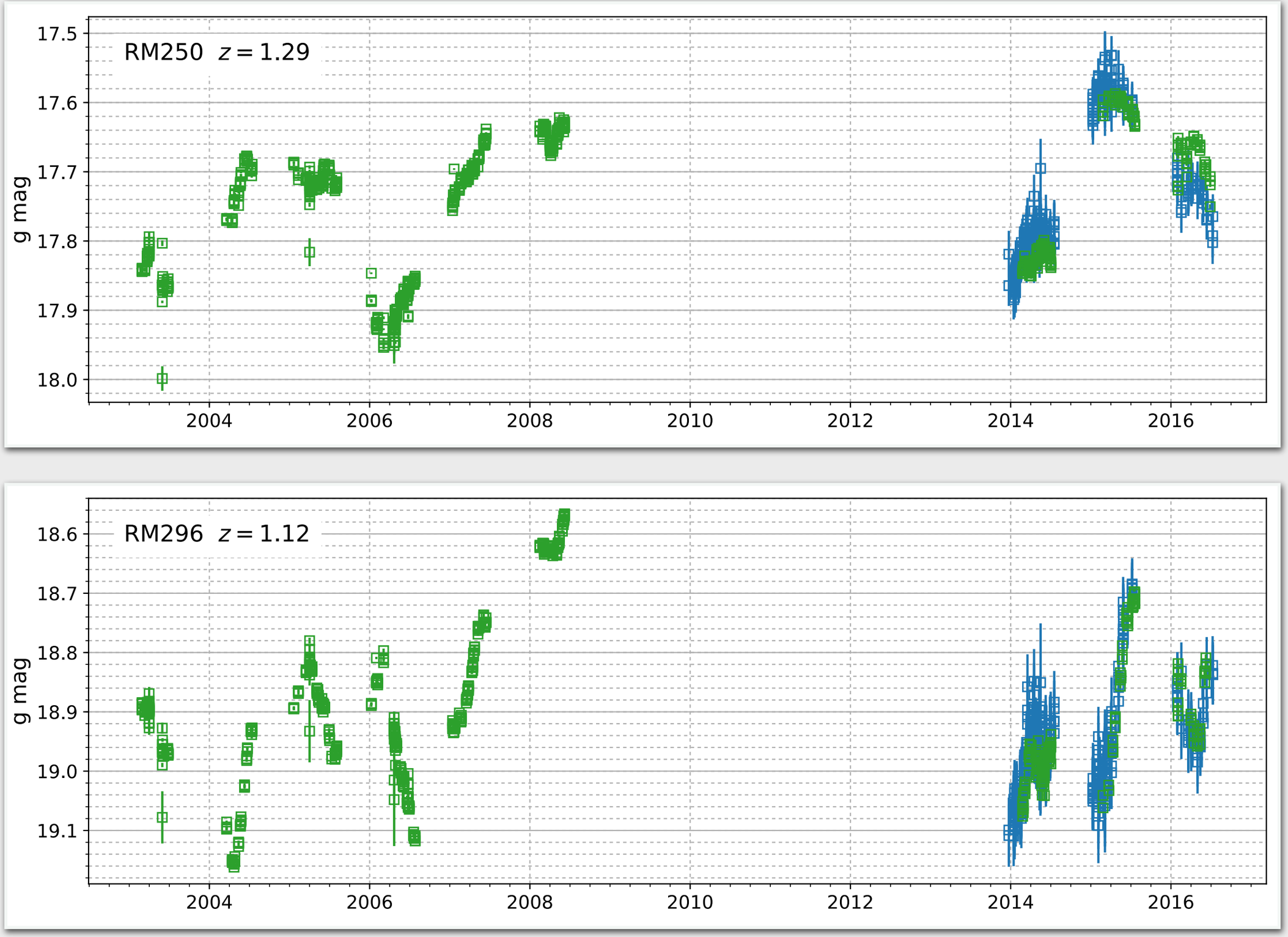
~2 mag

+ CFHT archive

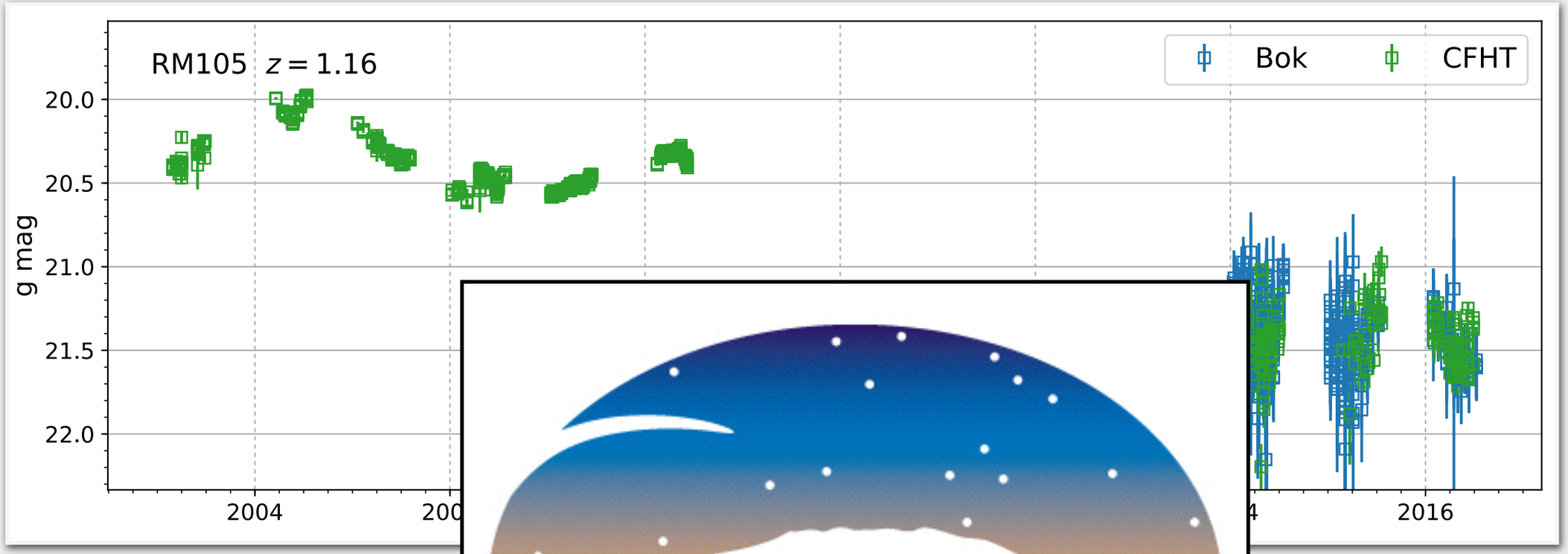
λ_{edd} -> ~0.9% to ~8%

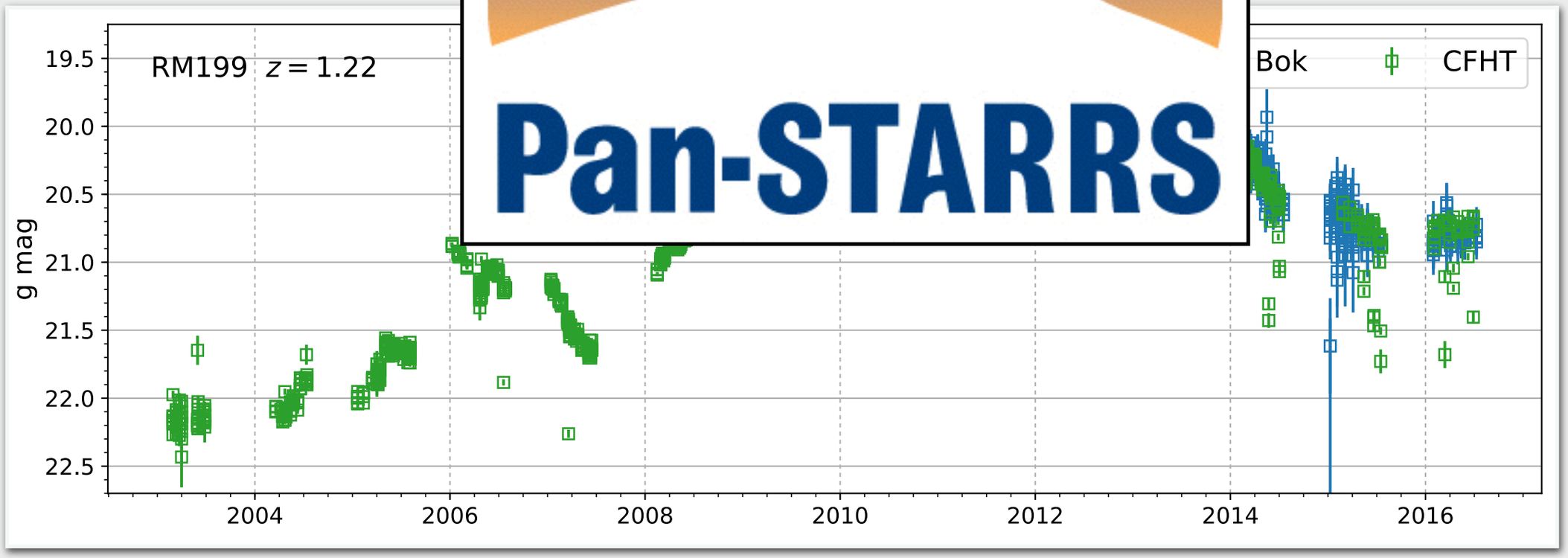
SDSS spec

bright quasars with Deep coverage

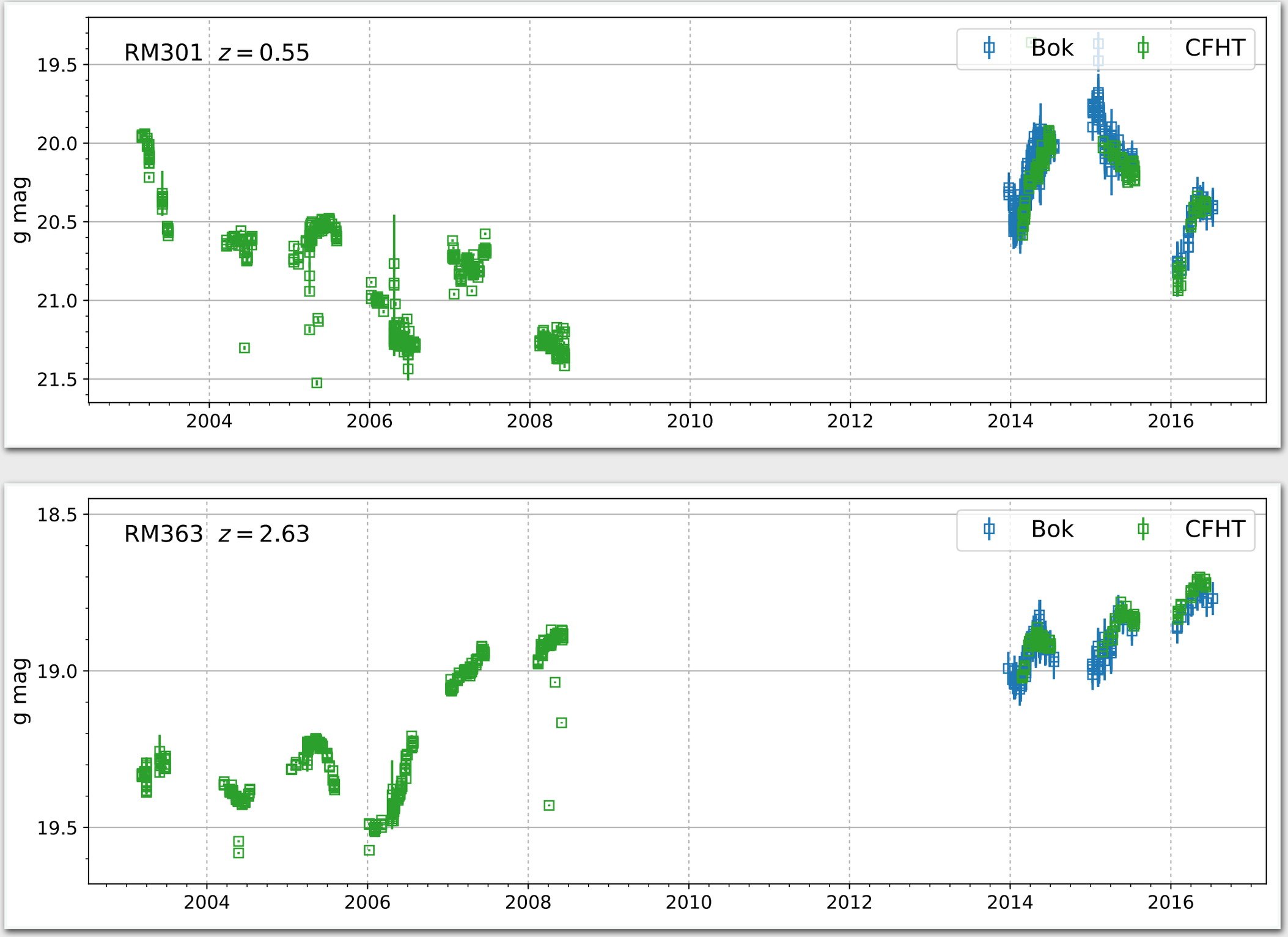


quasars with ΔIQR(g) > 1.0 mag

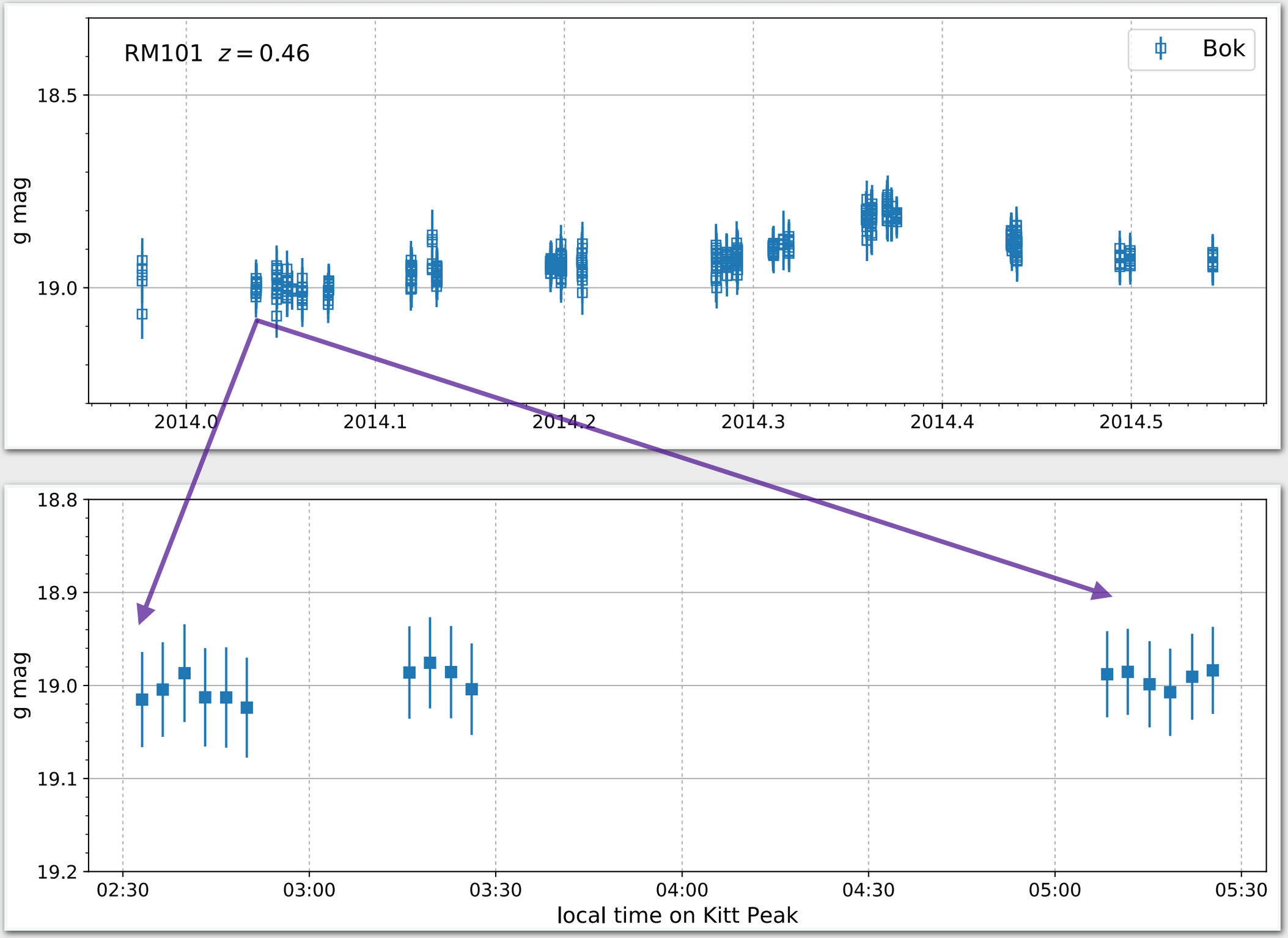




more highly variable quasars



short timescale variability from dense lightcurves



summary

- nearly 50 lag detections so far
- 1200 quasars with thousands of observations over a 15-year baseline

future

- long lags (high-L/z)
- color variability / continuum lags
- DRW model fits
- short-term variability (~minutes)
- SF_∞ (turnover at long timescales)
- host galaxies

http://sdssrm.org/

PI: Yue Shen (UIUC)
Spectroscopy PIs: Niel Brandt (PSU),
Yue Shen (UIUC)
Photometry PIs: Pat Hall (York),
Ian McGreer (U of Arizona),
Yue Shen (UIUC)
Photometry Scientist: Karen Kinemuchi (APO)

- ***Biases in z>1.46 Redshifts Due to Quasar Diversity*** Denney et al. 2016, ApJ, 833, 33
- ***Velocity Shifts of Quasar Emission Lines*** Shen et al. 2016, ApJ, 831, 7
- ***An Investigation of Biases in C IV Emission Line Properties*** Denney et al. 2016, ApJS, 224, 14
- ***First Broad-line Hβ and MgII Lags at z > 0.3 from Six-month Spectroscopy*** Shen et al. 2016, ApJ, 818, 30
- ***Post-Starburst Signatures in Quasar Host Galaxies at z>1*** Matsuoka et al. 2015, ApJ, 811, 91
- ***Ensemble Spectroscopic Variability of Quasar Broad Emission Lines*** Sun et al. 2015, ApJ, 811, 42
- ***Rapid CIV Broad Absorption Line Variability*** Grier et al. 2015, ApJ, 806, 111
- ***No Evidence for Evolution in the M-σ Relation to z~1*** Shen et al. 2015, ApJ, 805, 96
- ***Technical Overview*** Shen et al. 2015, ApJS, 216, 4