The Sloan Digital Sky Survey Reverberation Mapping Project

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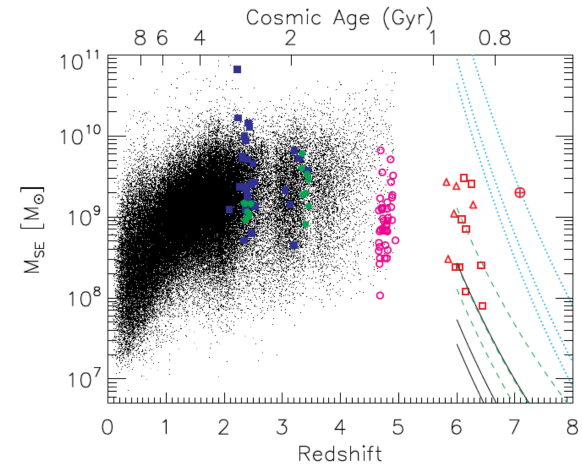
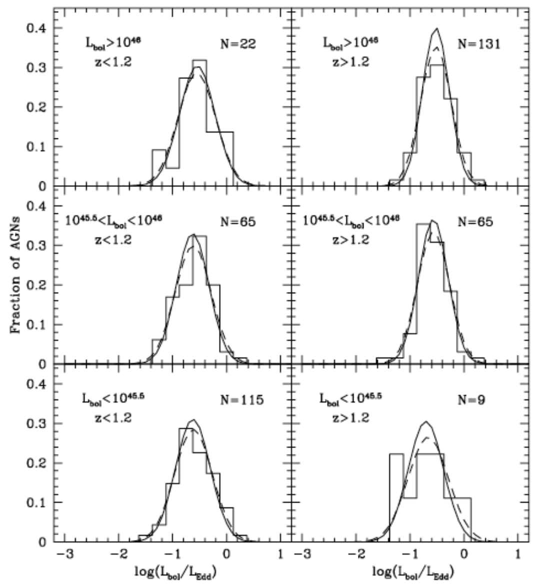
On behalf of the SDSS-RM team

Lijiang RM Workshop (Oct, 2016)

Wide/wild applications of SE BH masses

BH demography: Vestergaard et al. (2008), Kelly et al. (2010), Shen & Kelly (2012)

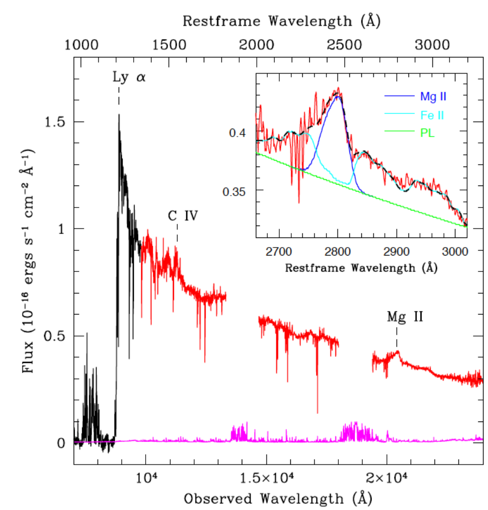




Eddington ratios: e.g., Kollmeier et al. (2006)

Searches for low-mass BHs: Greene, Ho, Barth et al.

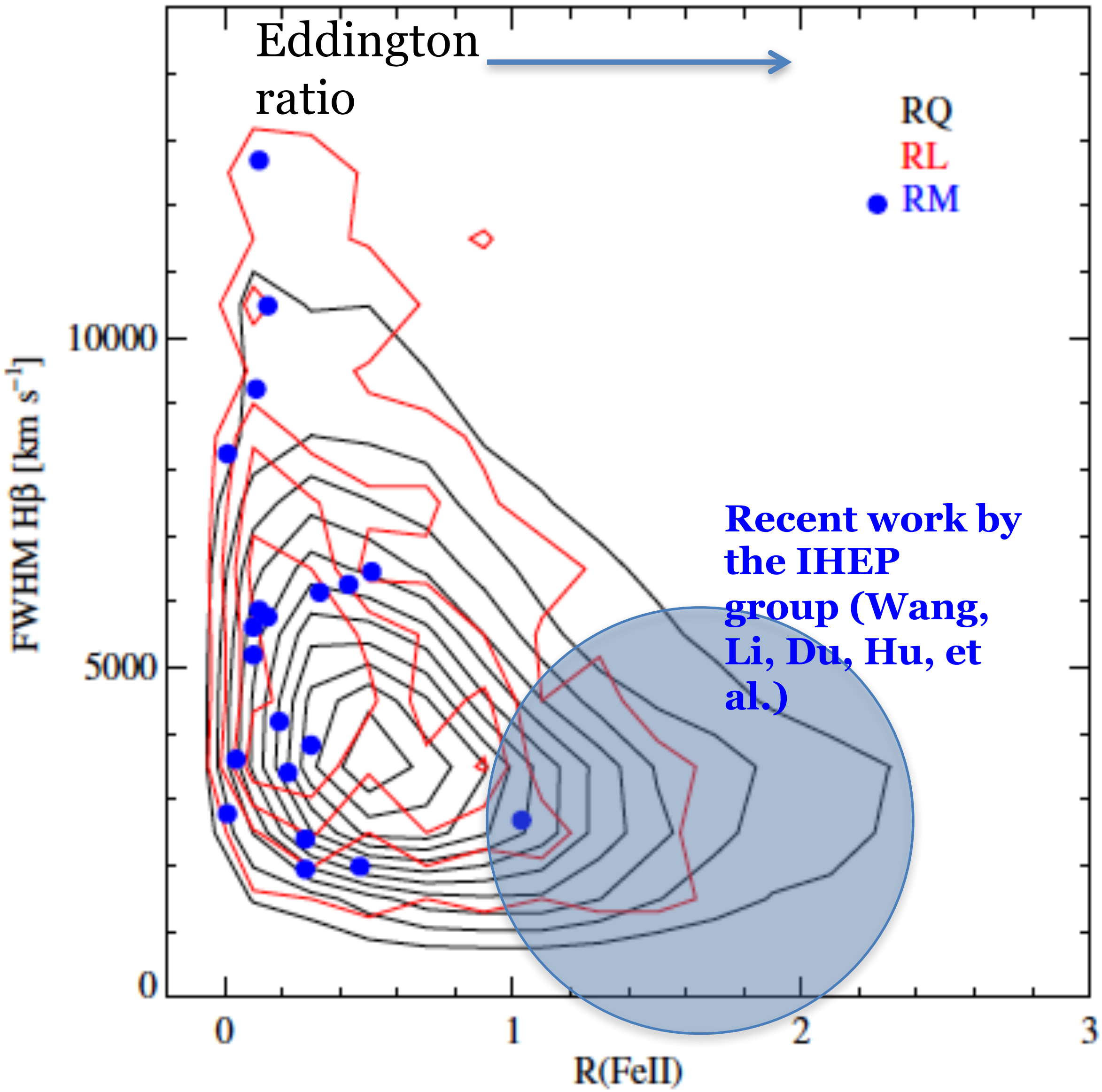
A 12-billion Msun BH at z=6.3, e.g., Wu et al. (2015, Nature)



Limitations of the current RM AGN sample

~60 AGN with RM lag mea

- almost exclusively at z<
- Most are Hbeta lags with lags and few MgII lags
- Sample heterogeneous, not uniformly sample th parameter space (lumin Eddington ratios, emissi properties)

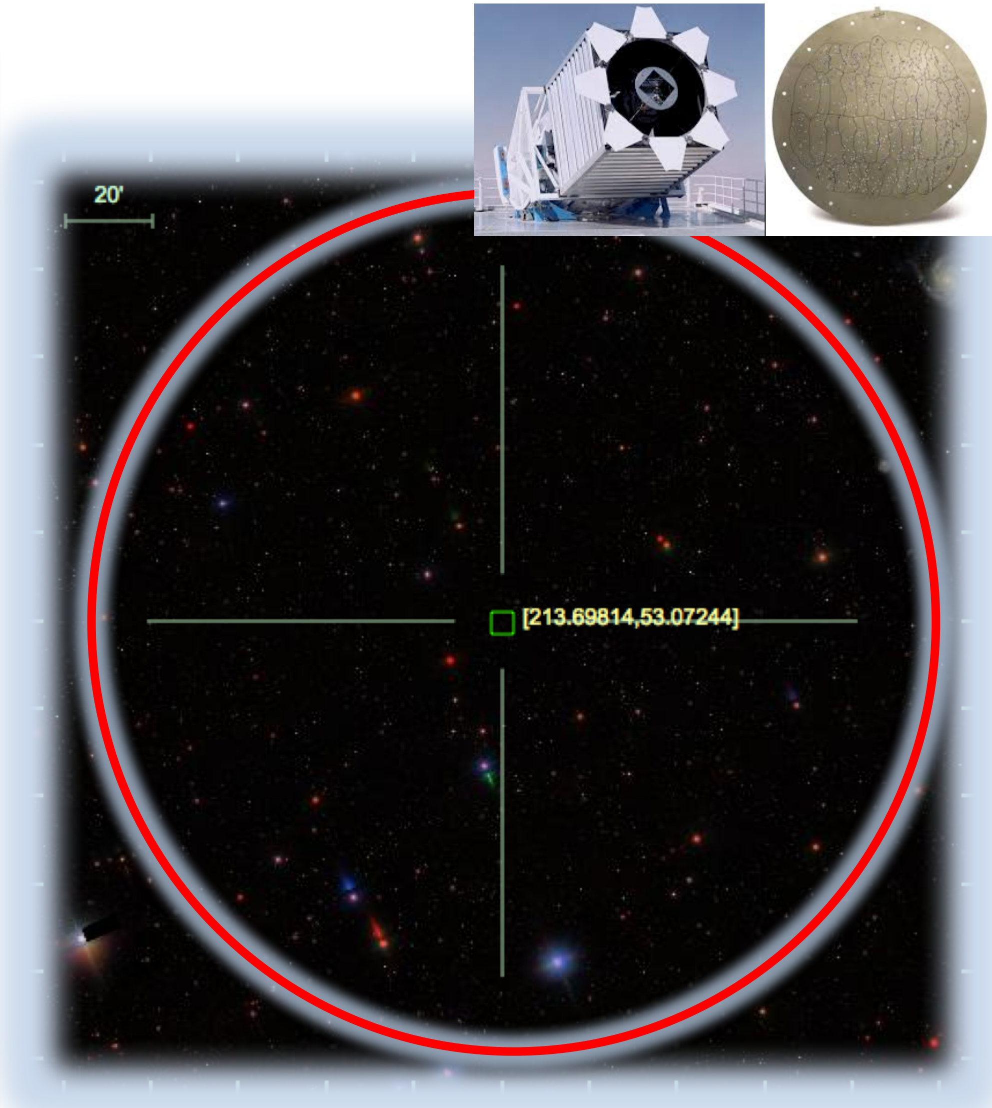


The limitations of the c reliability of the single-

Need to substantially improve the RM sample, in a more efficient way.

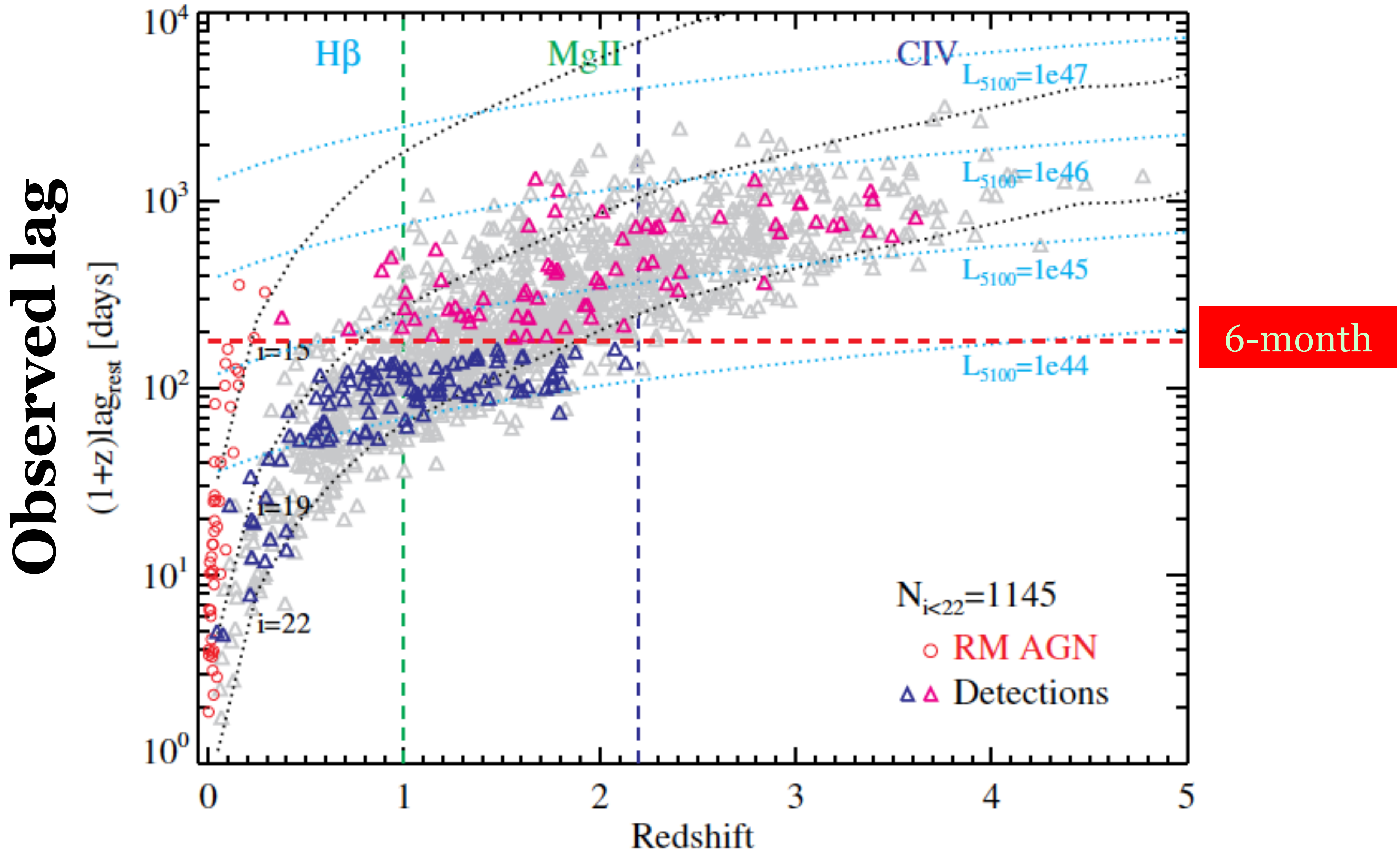
SDSS-RM in a nutshell

- Motivation: expanding the RM AGN sample in both size 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 spectrograph; 32 epochs completed in 2014A; continue through 2017 with reduced cadence
- Dense photometric light curves (~2-4 day cadence) since 2010 (PanSTARRS 1 + SDSS-RM imaging)
- Multiwavelength follow-up (XMM, Spitzer, HST)



SDSS-RM Project: http://www.sdssrm.org

SDSS-RM: Promises and Challenges



Expected lag detections from SDSS-RM

Shen et al. (2015a)

Science from SDSS-RM

Primary Science

- BLR RM lags and BH masses at $z>0.3$
- Structure and kinematics of the BLR
- The R-L relations for different lines
- Better SE BH mass estimators

Ancillary Science

- Photometric and spectral quasar variability
- Quasar/host decomposition of coadded spectra and imaging
- BALQSO trough variability
- Quasar narrow metal absorption lines

Pathfinder RM program for the big-data era!

Project Status

Current and upcoming data

- **Imaging:**
  - PanSTARRS1 Medium-Deep field imaging light curves: 2010-2013 (~300 epochs each in *grizy*)
  - Dedicated SDSS-RM imaging light curves (CFHT/Bok/Mayall): 2014-2016 (~100 epochs each in *gi*)
  - PanSTARRS2 light curves: 2016- (same cadence as in PS1)
- **Spectroscopy:**
  - BOSS spectroscopy in SDSS-III: 2014 (32 epochs in Jan-July)
  - eBOSS spectroscopy in SDSS-IV: 2015-2017 (12 epochs/year)
- **Multi-wavelength follow-up:**
  - HST, Spitzer, XMM, UKIRT

The goal is to extend SDSS-RM to ~2019, to build an unprecedented baseline of 10-year photometric monitoring and 6-year spectroscopic monitoring for a large sample

Science analysis

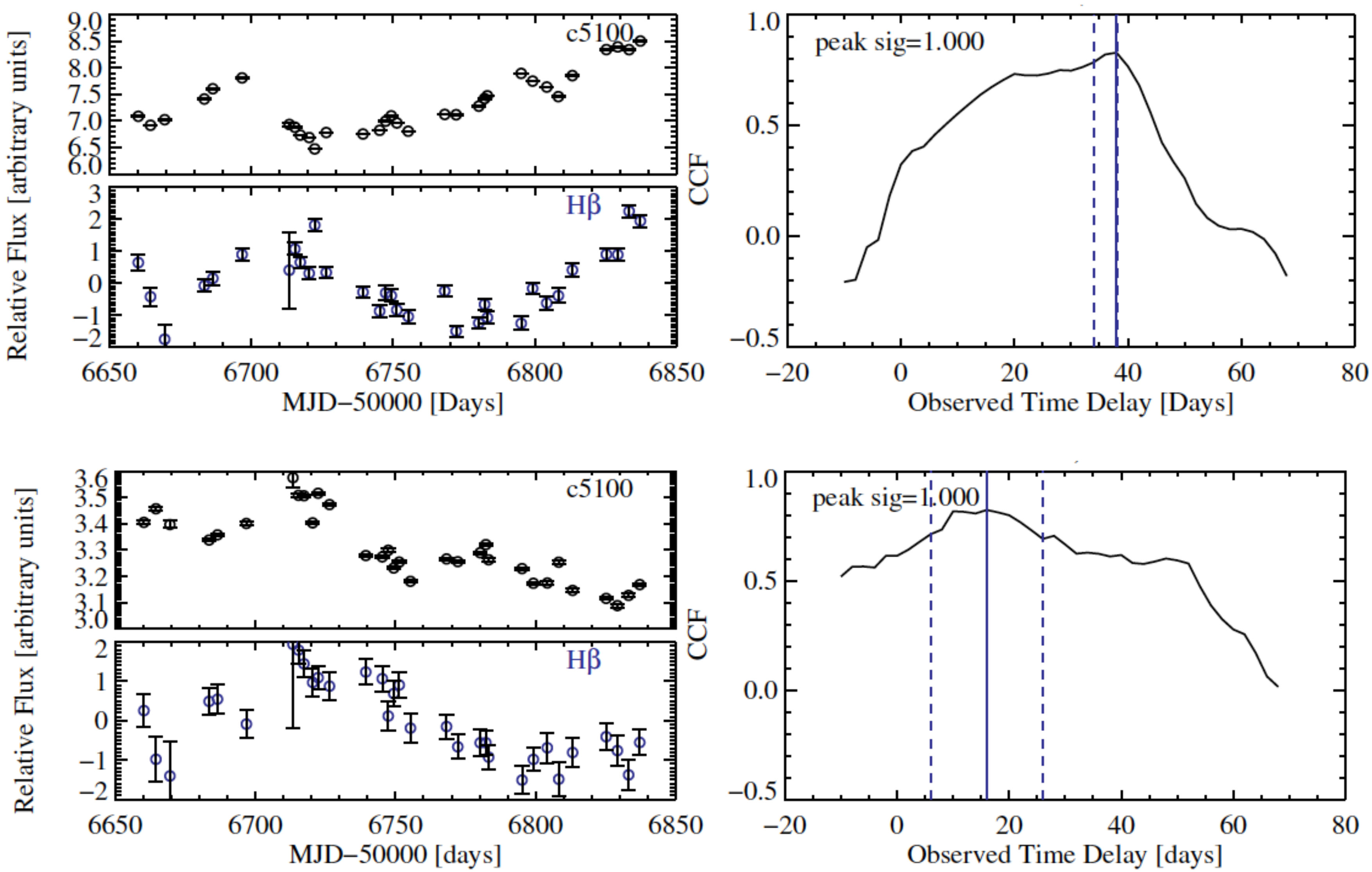
- Currently analyzing 2014 BOSS spectroscopy+CFHT/Bok imaging: 1 technical paper and 9 science papers produced already, with a few more coming soon
- Will soon start analyzing eBOSS spectroscopy in combination of all earlier data

Some early science results (based on 2014 spectroscopy alone):

- **First RM broad-line lag detections at z>0.3**: Shen et al. 2016a
- **Discovery of a M-sigma relation at z~0.6**: Shen et al. 2015b
- **Stellar populations of quasar hosts from coadded SDSS-RM spectra**: Matsuoka et al. 2015
- **Rapid trough variability in a broad absorption line quasar:** Grier et al. 2015
- Structure functions of broad-line variability: Sun et al. 2015
- Velocity shifts in quasar emission lines: Shen et al. 2016b
- CIV emission line profiles: Denney et al. (2016a,b)
- Composite broad-line lags: Li et al. 2016

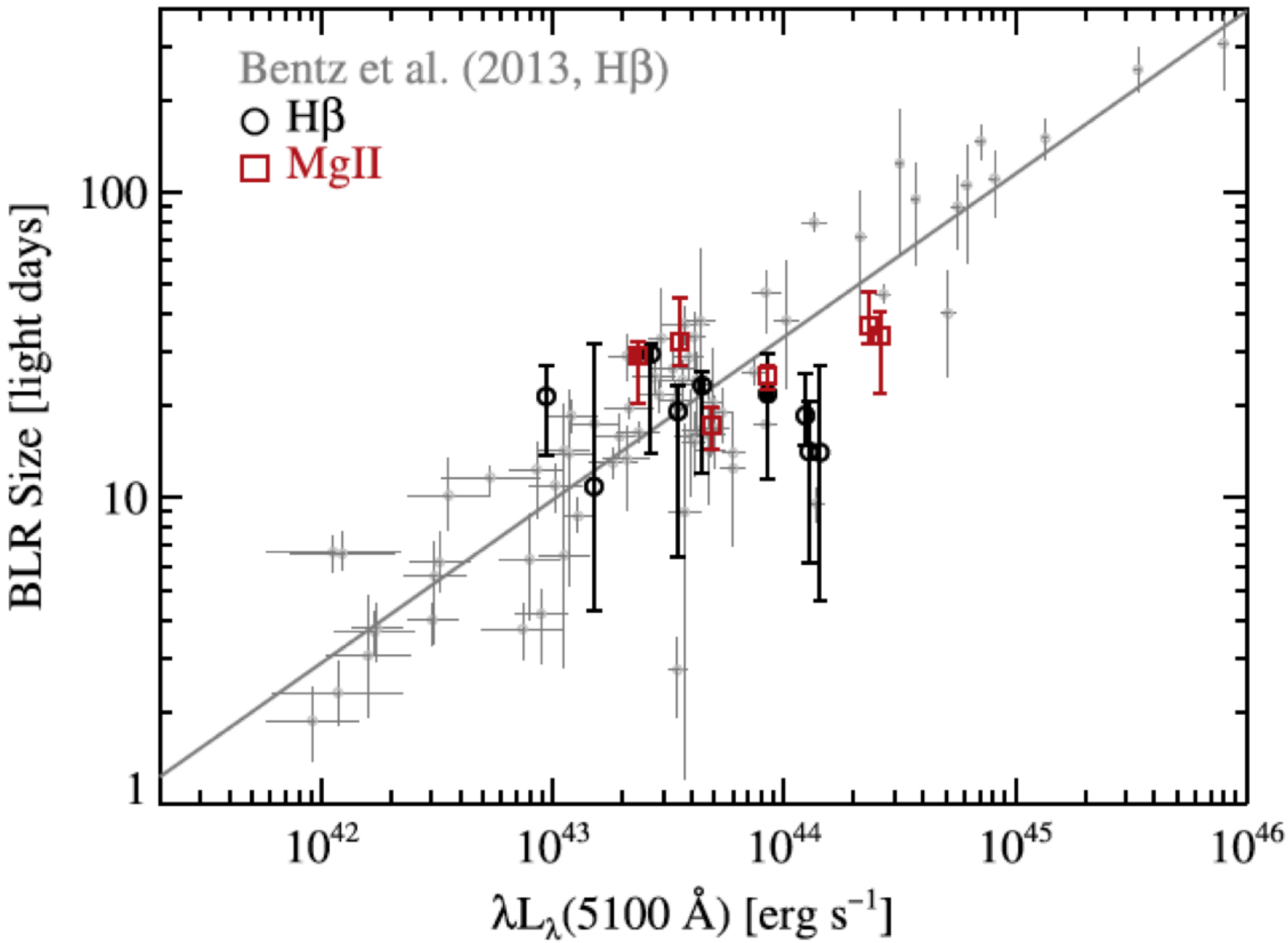
First lag detections at z>~0.3

Based on 6-month spectroscopy only



Shen et al. (2016a)

First lag detections at z>~0.3



Shen et al. (2016a)

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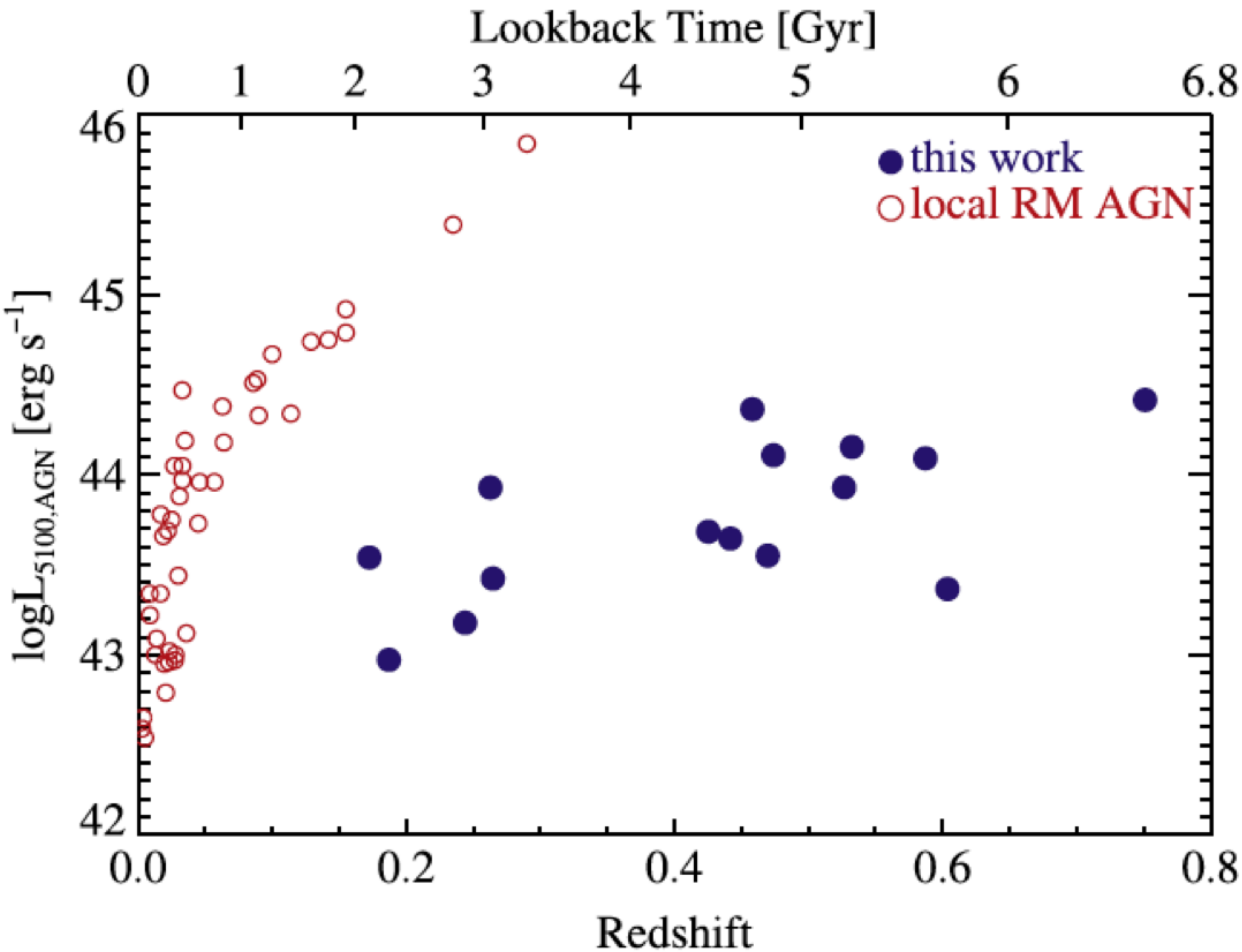
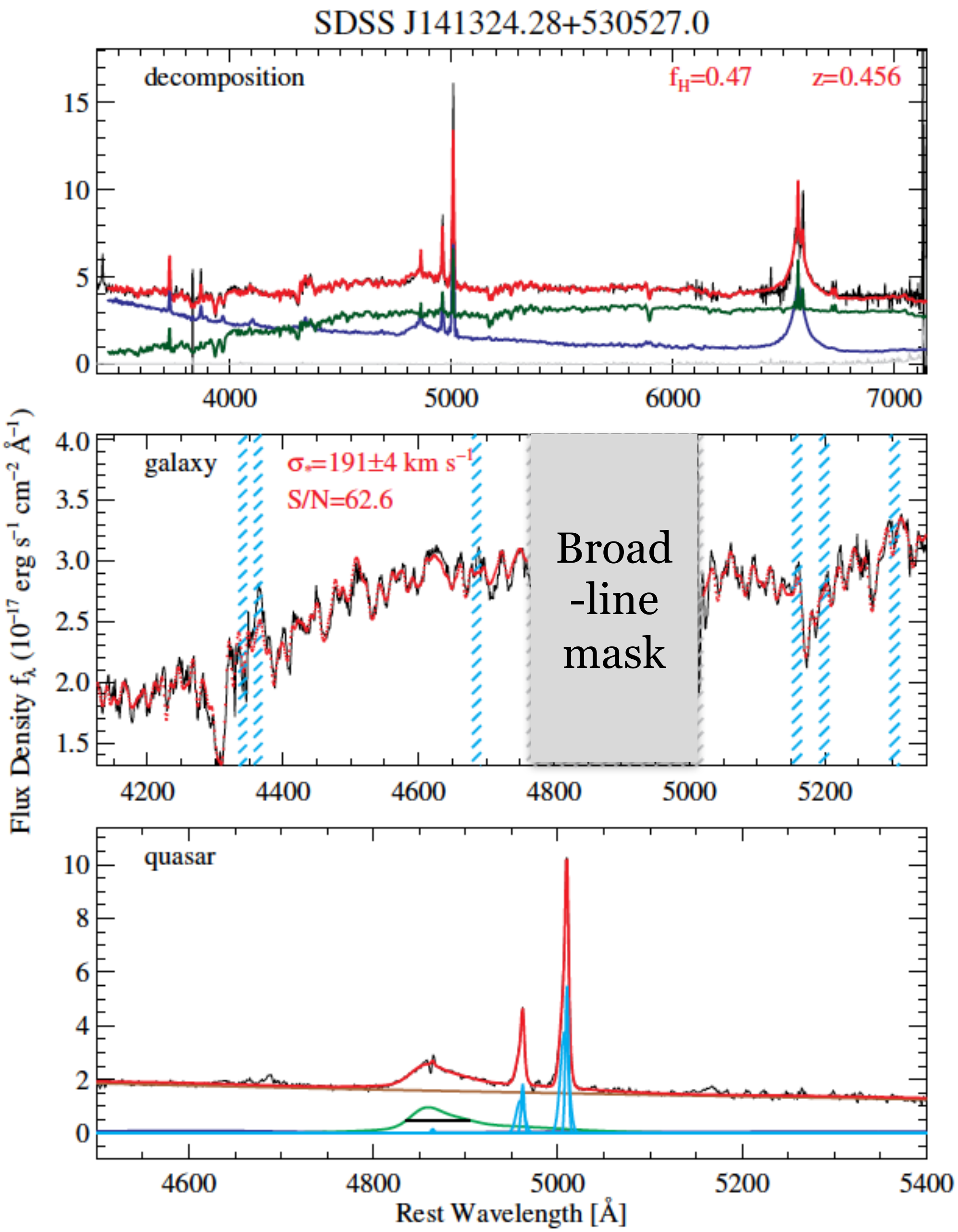


Shen et al. (2016a)

Stellar velocity dispersion (sigma) in high-z quasar hosts



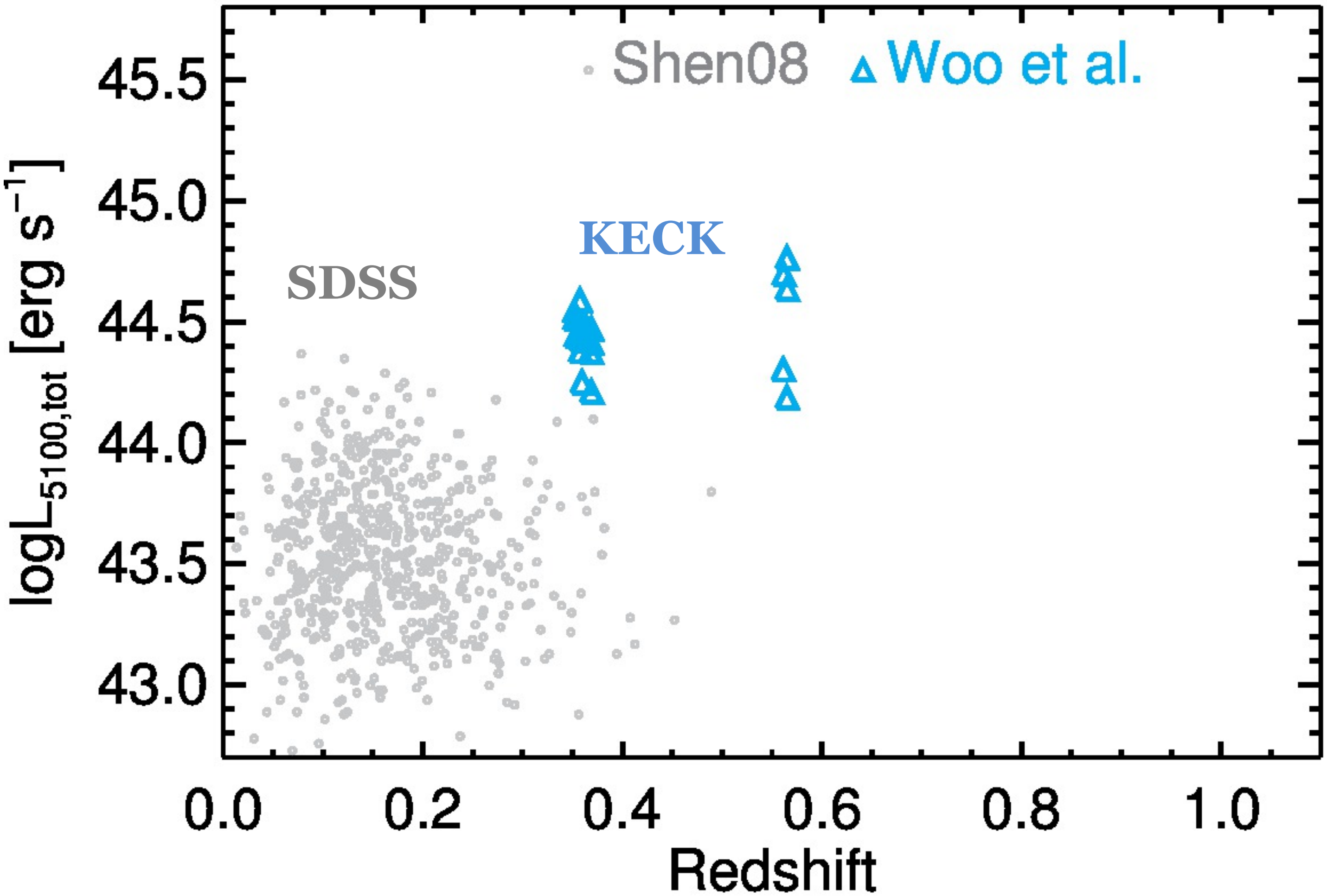
Coadded spectra from SDSS-RM: ~ 6-8 hrs on 6-8m telescopes – hundreds of them!

88 quasars at 0.1<z<1 (<z>=0.6) with sigma measurements.

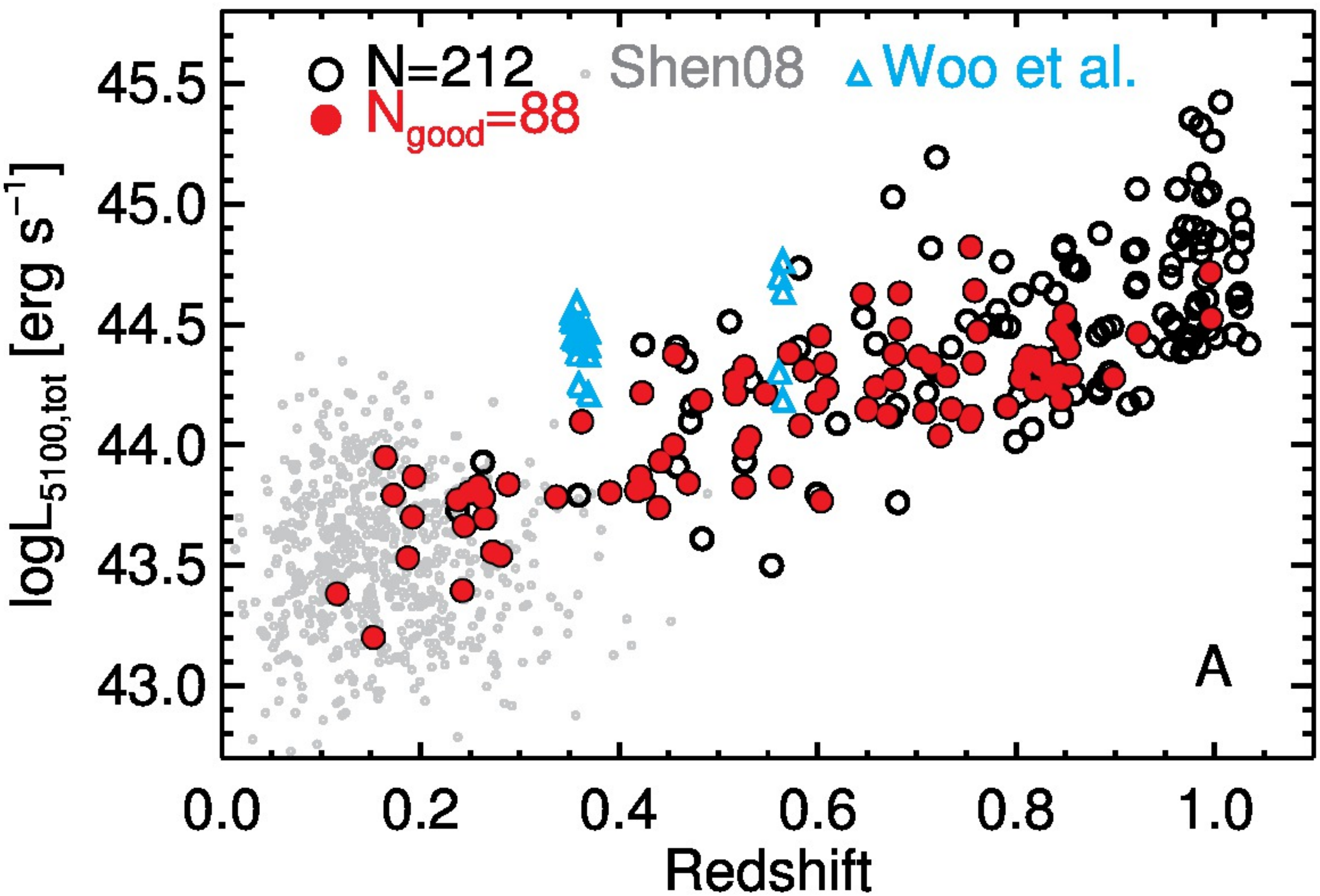
46 are at z>0.6, where no sigma has been measured in quasars before

Shen et al. (2015b)

Previous quasar samples with sigma measurements

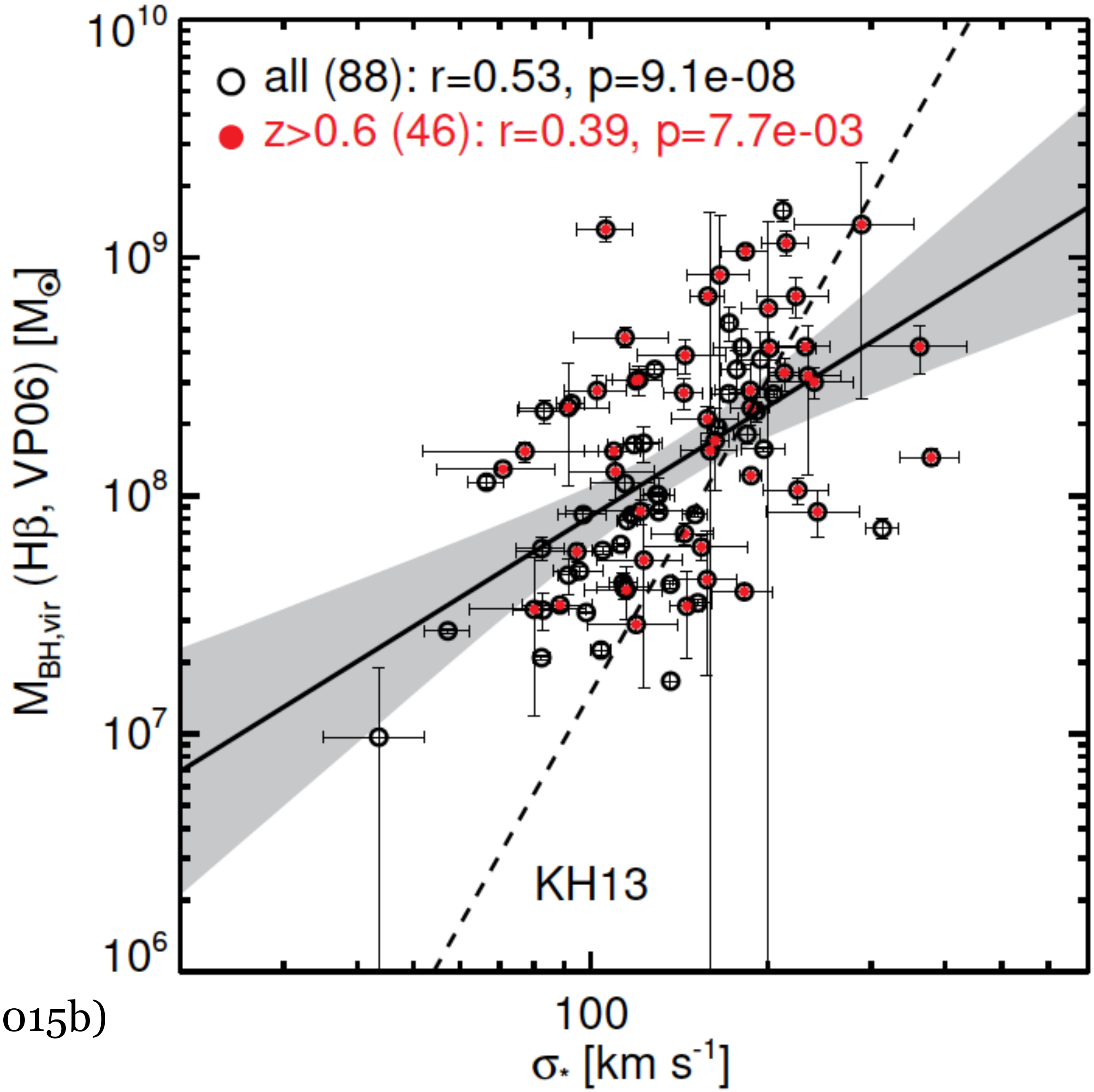


Improvement over previous samples



Shen et al. (2015b)

A M-sigma relation at z~0.6



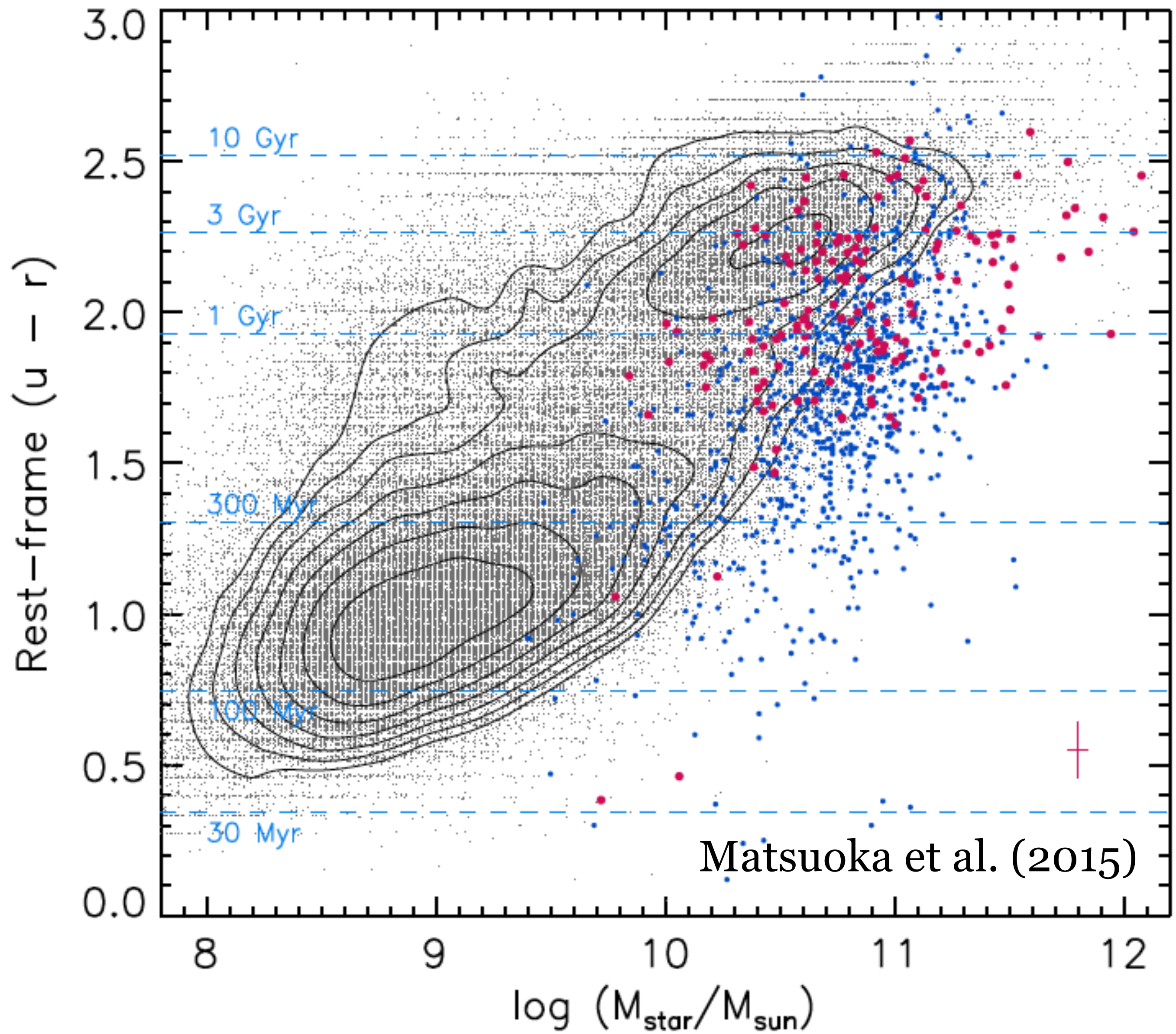
Shen et al. (2015b)

Contours: inactive galaxies at 0.6<z<1 (Muzzin et al. 2013)

Blue dots: SDSS quasar hosts (z<0.6) based on deep imaging (Matsuoka et al. 2014)

Red dots: SDSS-RM quasar hosts (median z~0.7) measured from deep spectroscopy (Matsuoka et al. 2015)

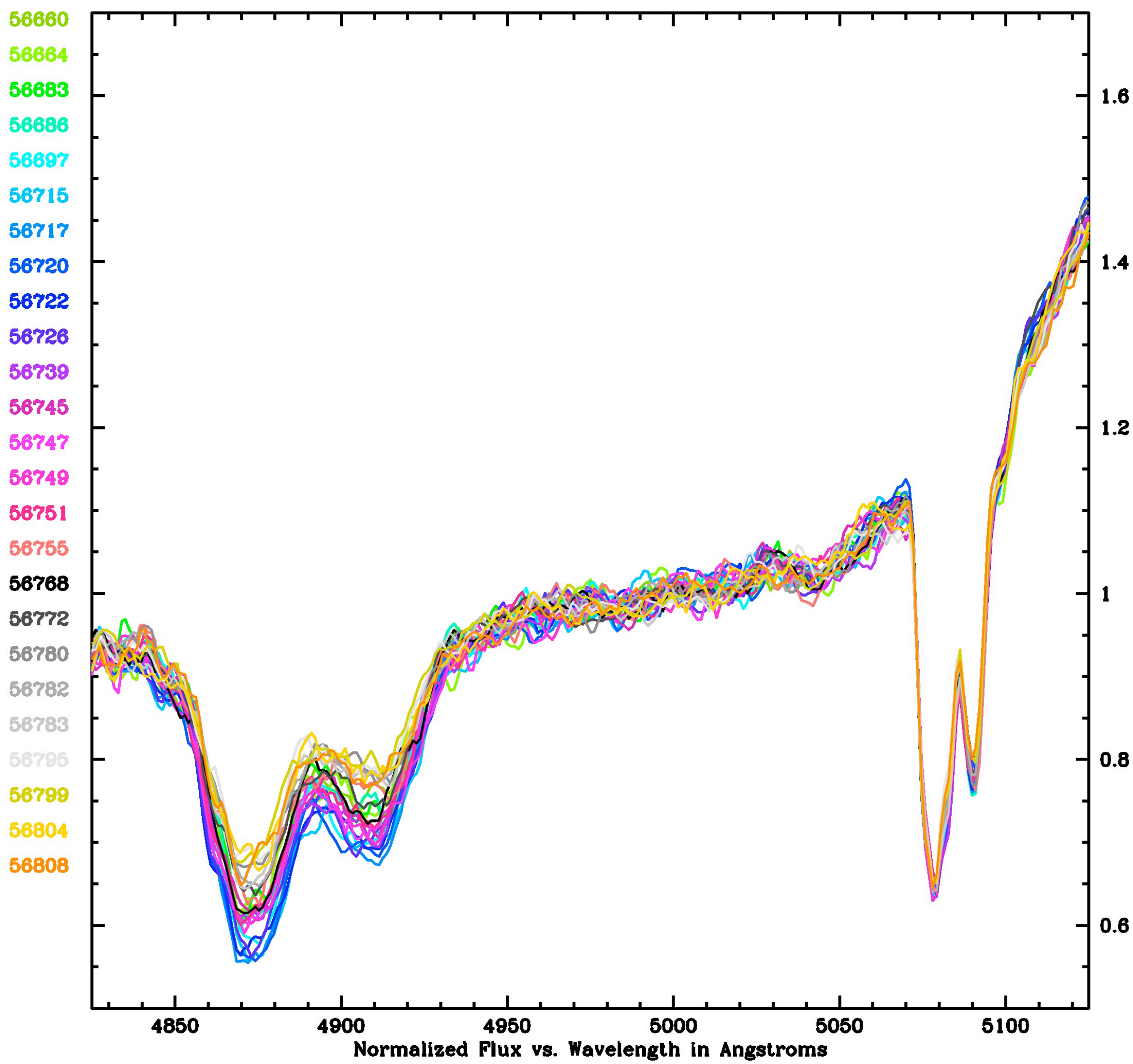
Galaxy color-stellar mass diagram – Quasars in massive hosts with stellar ages around 1 Gyr



Major episode of SF in past ~ Gyr which was subsequently quenched/suppressed.

Early science results: Rapid BAL variability

Grier et al. 2015



Fastest broad absorption trough variability ever detected (1.2 days in rest-frame of the quasar)

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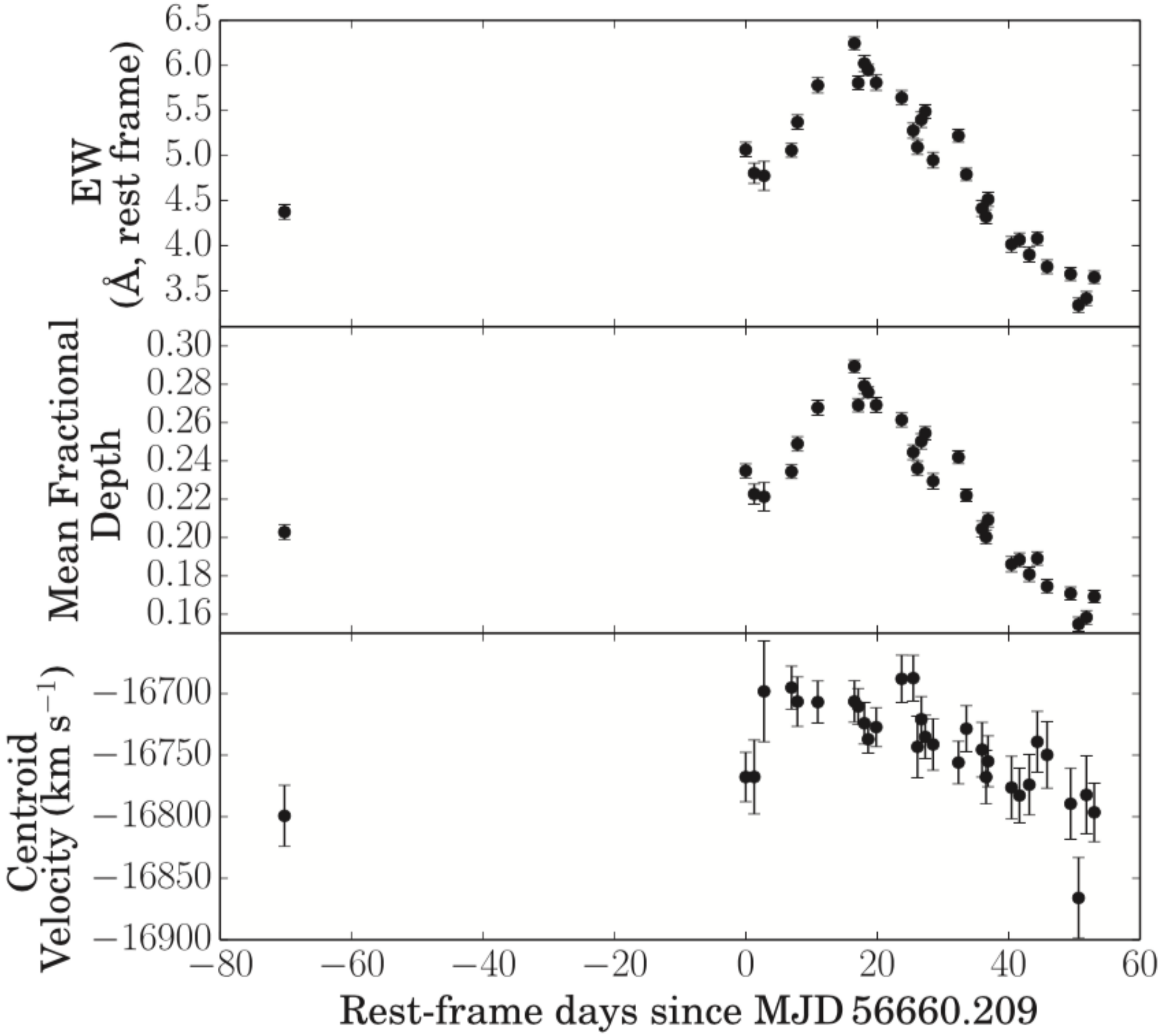

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The future of MOS-RM

- More MOS RM programs in the era of wide-field spectroscopic surveys:

OZDES (2013-2017)

4m AAT

4MOST (2019-)

4m VISTA

- DESI ?
- Subaru PFS (1.3 deg, 2400 fiber, 380-1260 nm, 2017-)
- MSE: Maunakea Spectroscopic Explorer (ngCFHT, 10m, 1.8 deg^2, 360-1800 nm, 2025-)
- LSST synergy

Summary

- Reverberation mapping is a powerful technique to probe the inner structures of quasars
- SDSS-RM is the first step to explore multi-object RM for uniform quasar samples at z>0.3
- MOS and time-domain large surveys are starting to change the landscape of performing RM to understand the BLR structure and measure quasar BH masses