Andy Howell: RM AGN campaigns ➔

AGN/QSO observations with AST3?

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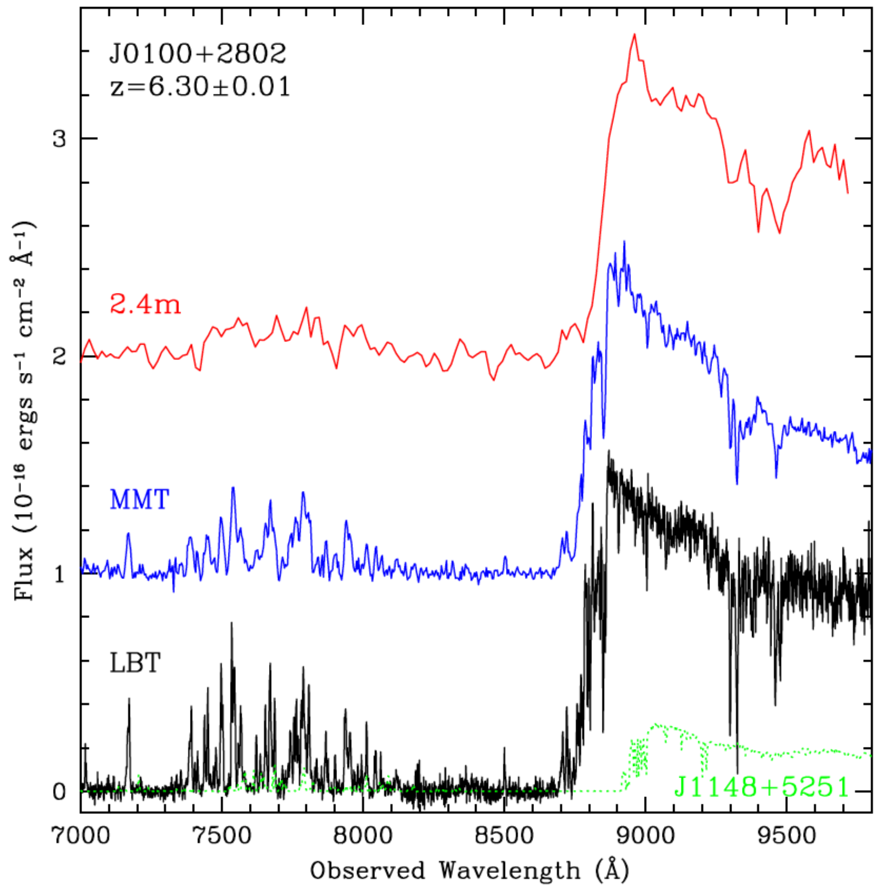
- Detection: background in SN search!
- Science with AGN/quasars?

Latest high redshift quasar observed by Chinese astronomers: Wu XB et al....

Feb 28, 2015 arxiv: 1502.07418



Luminosity distances with AGN and quasars

A NEW COSMOLOGICAL DISTANCE MEASURE USING AGN

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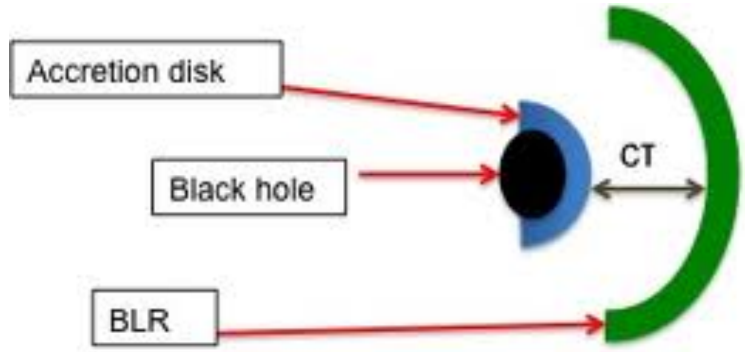
ABSTRACT

Accurate distances to celestial objects are key to establishing the age and energy density of the Universe and the nature of dark energy. A distance measure using active galactic nuclei (AGN) has been sought for more than forty years, as they are extremely luminous and can be observed at very large distances. We report here the discovery of an accurate luminosity distance measure using AGN. We use the tight relationship between the luminosity of an AGN and the radius of its broad line region established via reverberation mapping to determine the luminosity distances to a sample of 38 AGN. All reliable distance measures up to now have been limited to moderate redshift—AGN will, for the first time, allow distances to be estimated to $z \sim 4$, where variations of dark energy and alternate gravity theories can be probed.

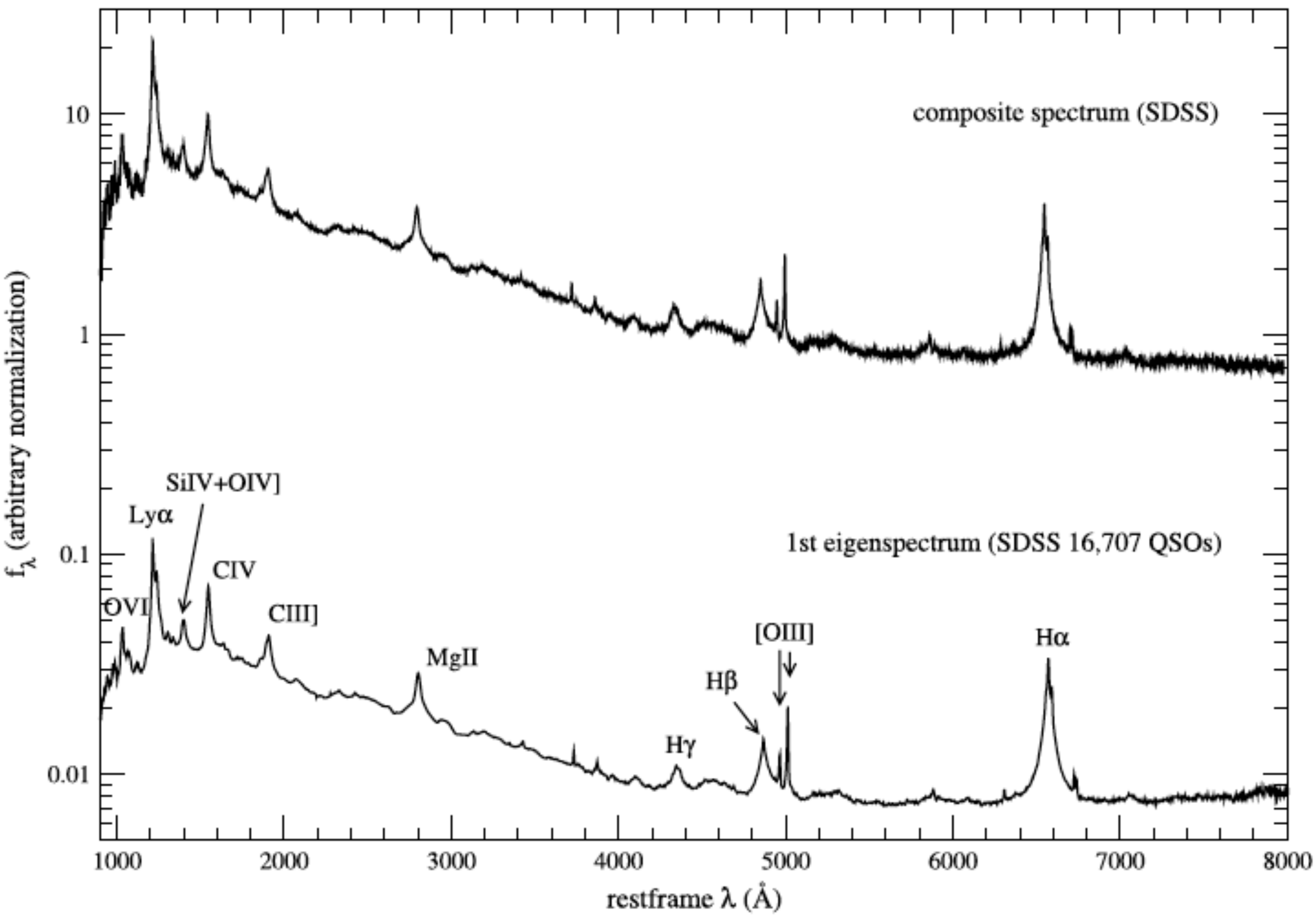
Tight relationship between AGN luminosity and radius of broad line region from reverberation mapping time delays.



Supermassive black holes (at the heart of every AGN) are surrounded at a distance by high velocity gas clouds

➔ **broad and narrow emission lines**

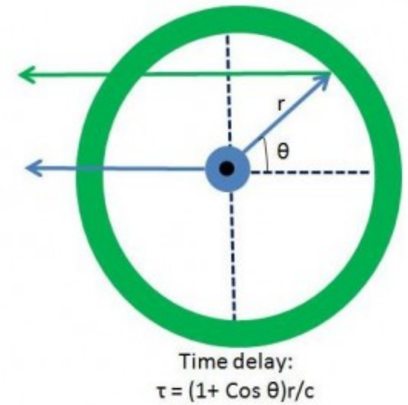
➔ characteristic of the spectra of **near–face-on AGN, i.e. quasars and Seyfert 1 galaxies**.



Yip et al., 2004

FIG. 2.—First eigenspectrum of 16,707 SDSS quasars in the rest wavelengths 900–8000 Å. For comparison, the SDSS composite quasar spectrum (Vanden Berk et al. 2001) using over 2200 QSOs is also shown. Prominent emission lines are indicated.

Reverberation Mapping



(Blandford & McKee 1982; Peterson 1993).

Photons emitted by BLR gas.

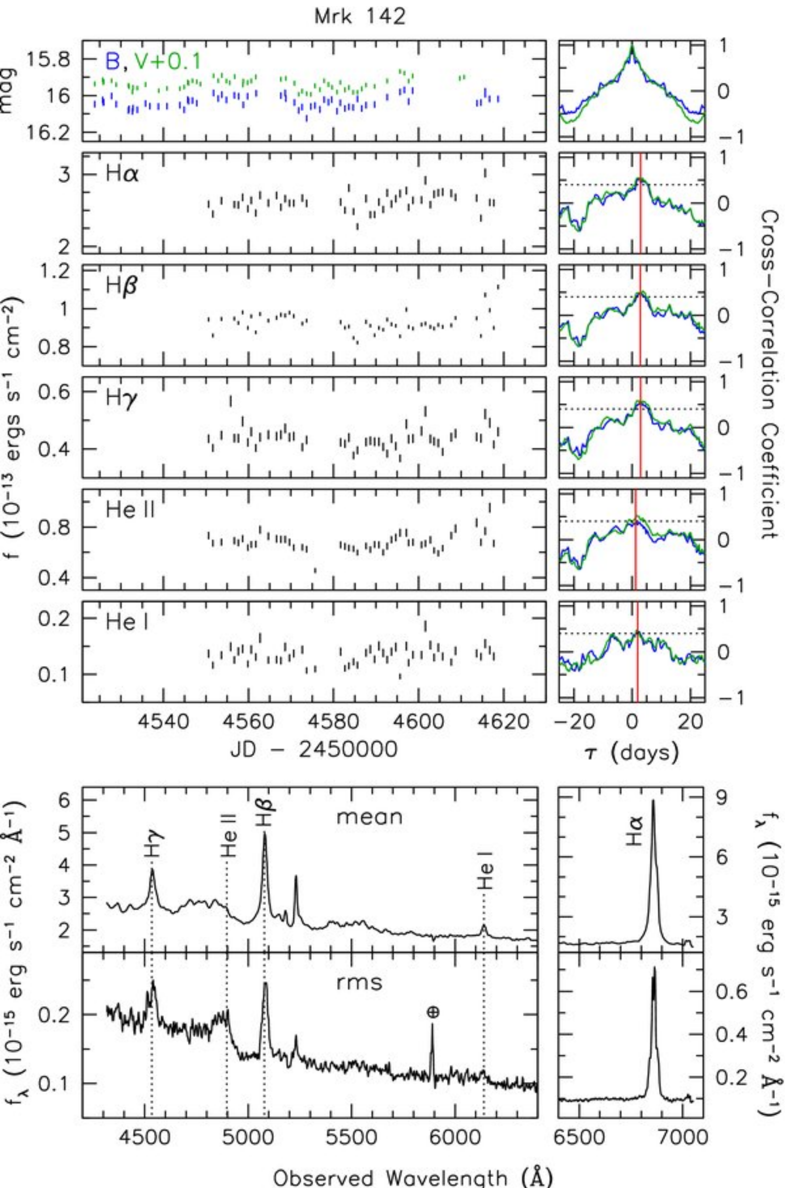
Radius measured by time lag between
- changes in the continuum luminosity of the AGN
- and changes in the luminosity of a bright emission line (typically Hβ or C IV).

The time lag should therefore be proportional to the square root of the luminosity of the central source:

$$\tau \propto \sqrt{L}.$$

Observable quantity: $\boldsymbol{\tau/\sqrt{F}}$, (F = measured AGN continuum flux)
= luminosity distance to the source.

Light curves of AGN: Continuum and Emission Lines



+ AGN continuum (typically measured at 5100 Å)
+ broad emission lines (most Hβ) monitored over an extended time period.

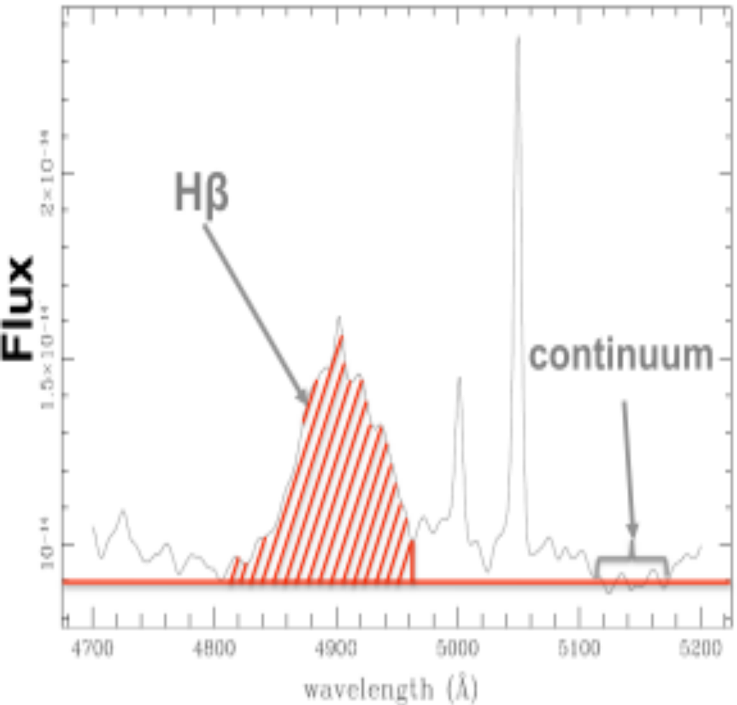
Emission-line regions are photo-ionized by the central source:
changes in the AGN continuum strength
➔ changes in the emission-line fluxes

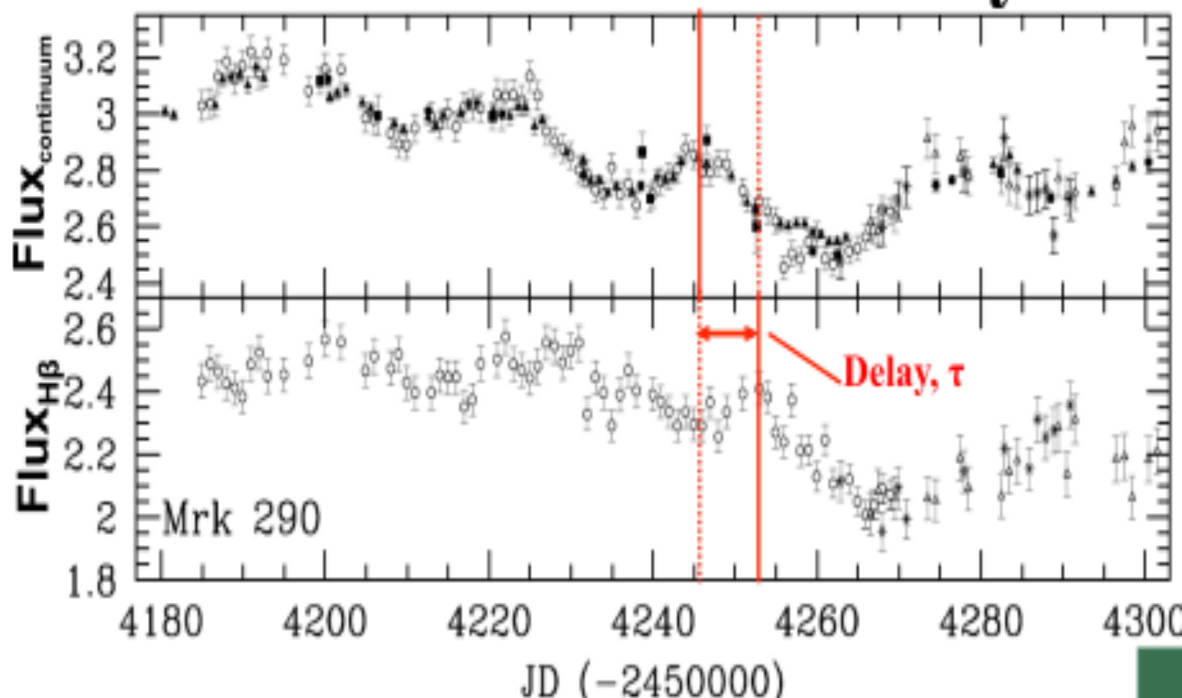
Time lag

- depends on light-travel time across the broad-line region (BLR).
- measured by cross-correlation of the continuum and emission-line light curves,
- gives the radius of the BLR

Denney AAS 2012

1. Reverberation Mapping Measures Broad-Line Region Radius via Line Emission Time Delay

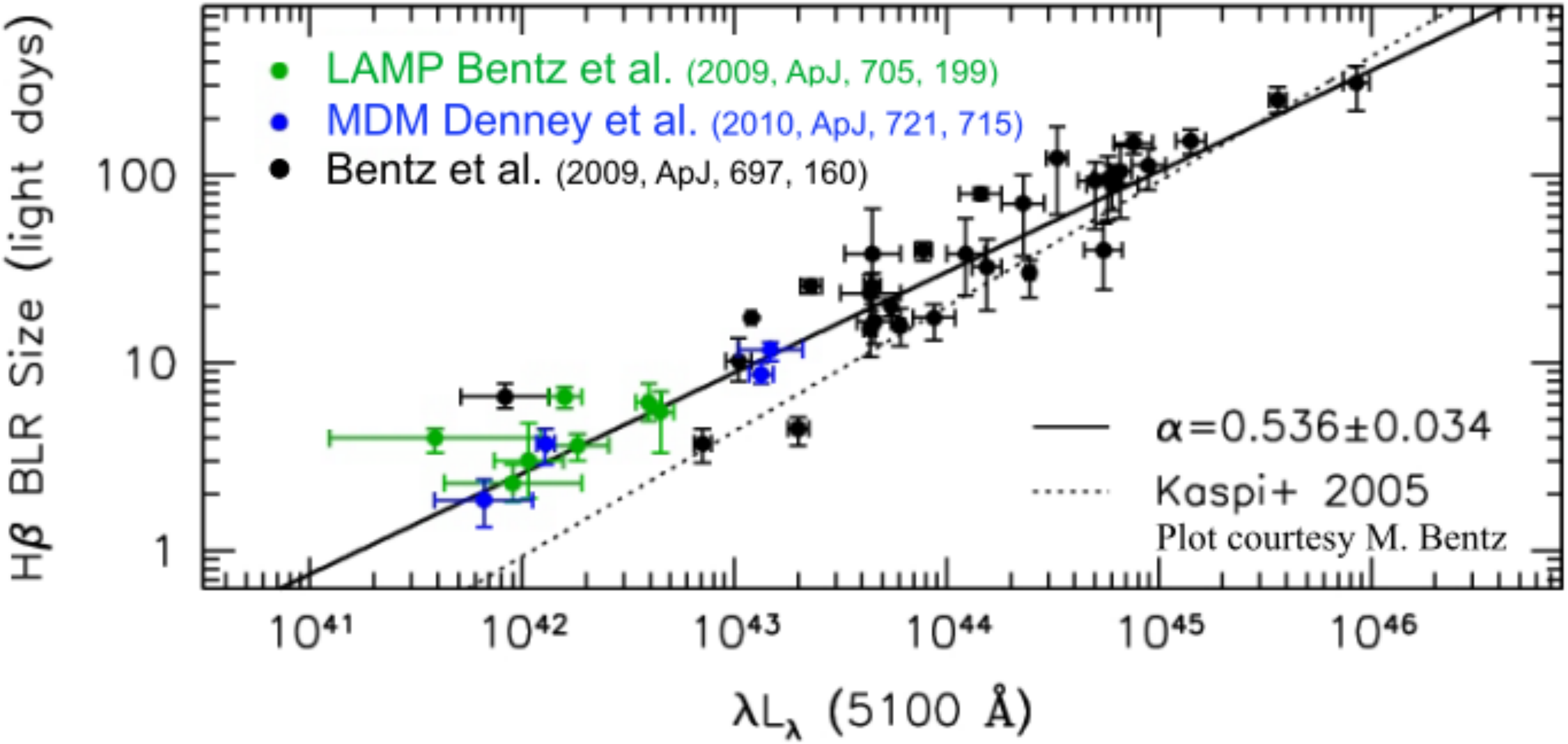




<u>**Reverberation Mapping Basics**</u> – The distance, *R*, to the broad emission-line emitting region (BLR) is determined from a measure of the delayed response of the line emission flux to a burst of continuum emission, presumably originating from the AGN accretion disk, because of the finite light travel time of the continuum photons, $R = c\tau$, and the fact that the BLR gas is photoionized by the continuum photons.

Luminosity Relationship

Denney AAS 2012



Behind the Radius-Luminosity Relationship – The BLR size, *R*, scales tightly with the nuclear luminosity, $R \sim L^{\alpha}$ --- a consequence of the photoionization physics responsible for regulating the production of line emission from the BLR. This physics dictates that $U = L_{ion}/(4\pi R^2 nc)$, where *U* is the BLR ionization parameter, L_{ion} is the ionizing luminosity, and *n* is the BLR gas density. The empirically-calibrated relation based on reverberation measurements shows a tight correlation with a slope consistent with the phyical expectation of $R \sim L^{0.5}$.

Hubble Diagram for 38 AGN with time lag (H_β vs continuum)

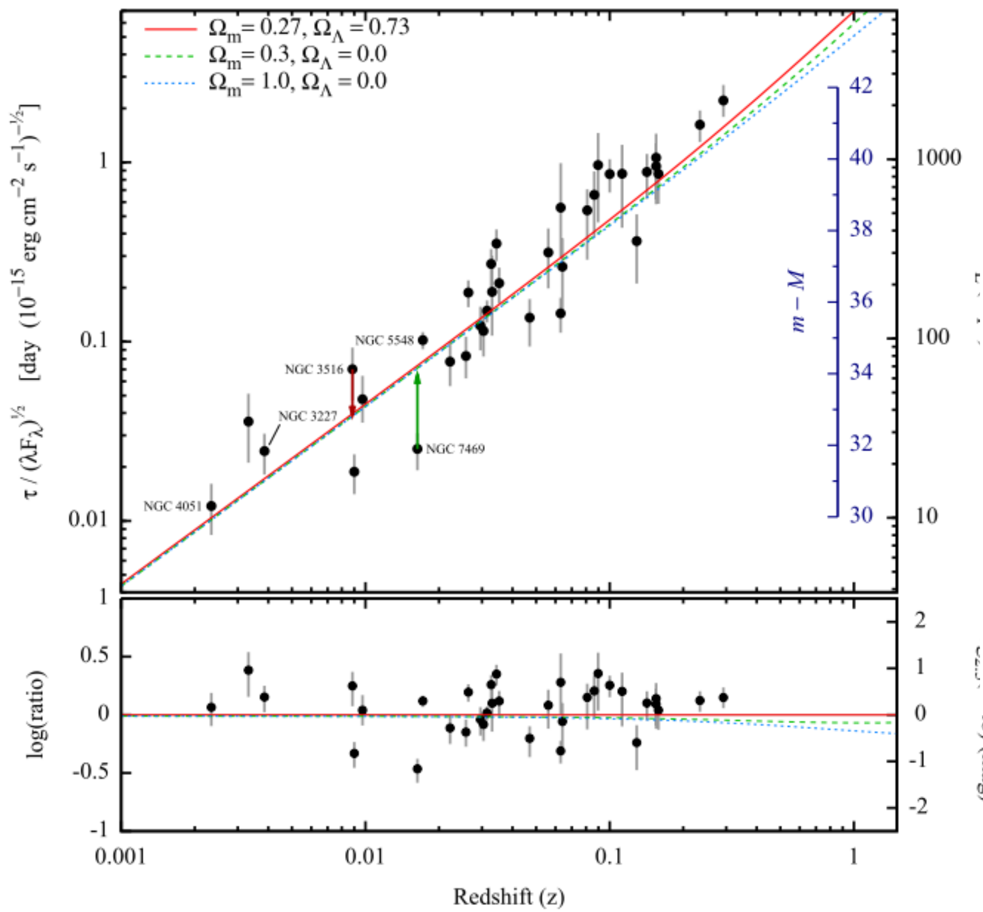


FIG. 2.— The AGN Hubble diagram. The luminosity distance indicator $\tau/\sqrt{F}$ is plotted as a function of redshift for 38 AGN with Hβ lag measurements. On the right axis the luminosity distance and distance modulus $(m-M)$ are shown using the surface brightness fluctuations distance to NGC 3227 as a calibrator. The current best cosmology (Komatsu et al. 2011) is plotted as a solid line. The line is not fit to the data but clearly follows the data well. Cosmologies with no dark energy components are plotted as dashed and dotted lines. The lower panel shows the logarithm of the ratio of the data compared to the current cosmology on the left axis, with the same values but in magnitudes on the right. The red arrow indicates the correction for internal extinction for NGC 3516. The green arrow shows where NGC 7469 would lie using the revised lag estimate from Zu et al. (2011). NGC 7469 is our largest outlier and is believed to be an example of an object with a misidentified lag (Peterson 2010).

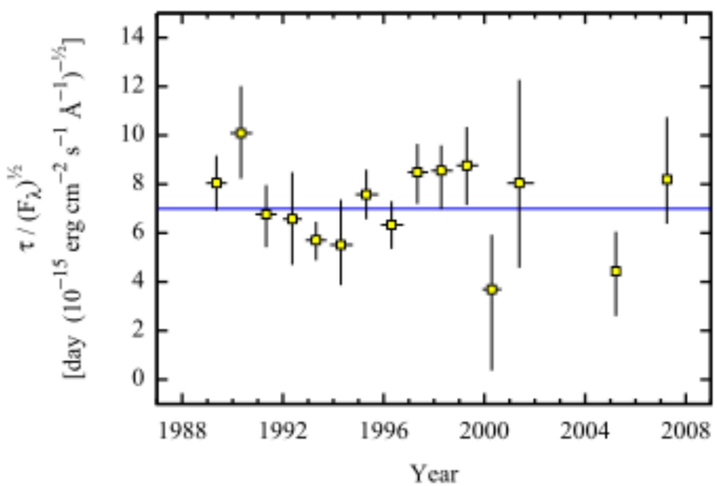
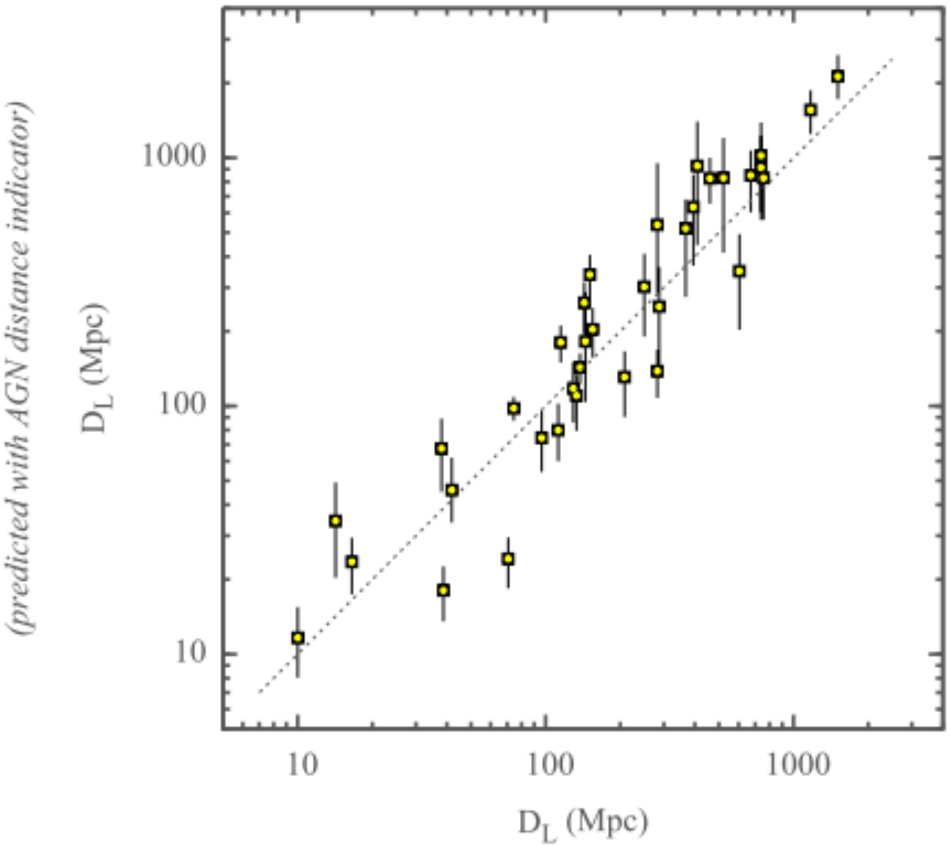


FIG. 3.— The distance indicator for NGC 5548, the best observed AGN in our sample, showing that the indicator is constant over time. The scatter in the data is consistent with the statistical uncertainty, showing that the scatter in excess of the observational uncertainty in the AGN Hubble diagram is largely due to object-to-object variations

Luminosity distances
AGN vs WMAP7



(from current best cosmology)

FIG. 1.— Comparison of AGN-derived distances to Hubble distances based on the best current cosmology (Komatsu et al. 2011). The dotted line is the equality of both distances. The AGN distance estimates follow the best current cosmology Hubble distances to good accuracy

TABLE 1
SCATTER IN THE AGN HUBBLE DIAGRAM

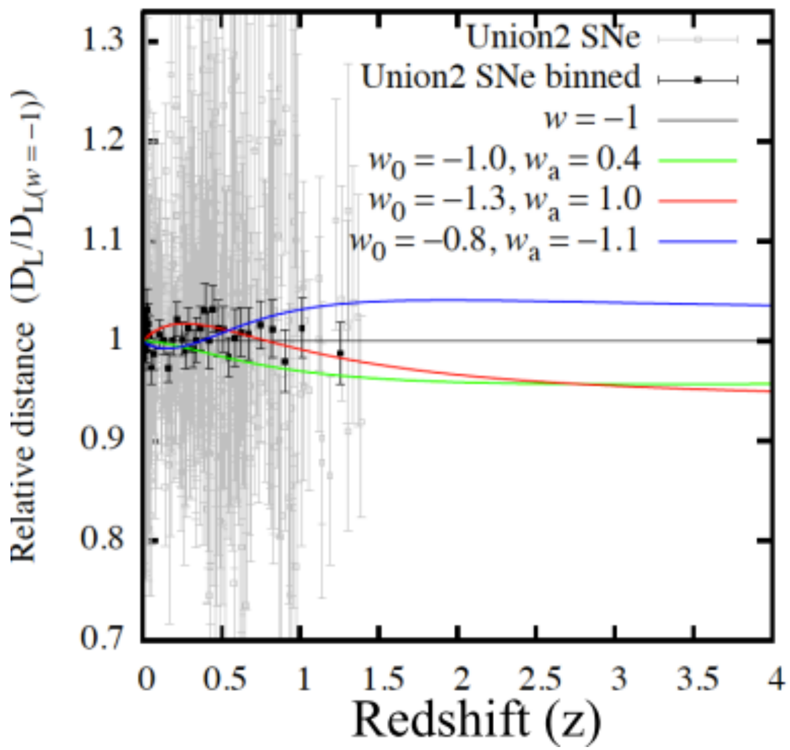
Source of scatter[a]	Current	Can be reduced to
Observational	0.14 (0.36)	0.05 (0.13)
Extinction	0.08 (0.20)	0.04 (0.10)
Bad lags	0.11 (0.28)	0.00 (0.00)
Other	0.05 (0.13)	0.05 (0.13)
Total	0.20 (0.50)	0.08 (0.20)

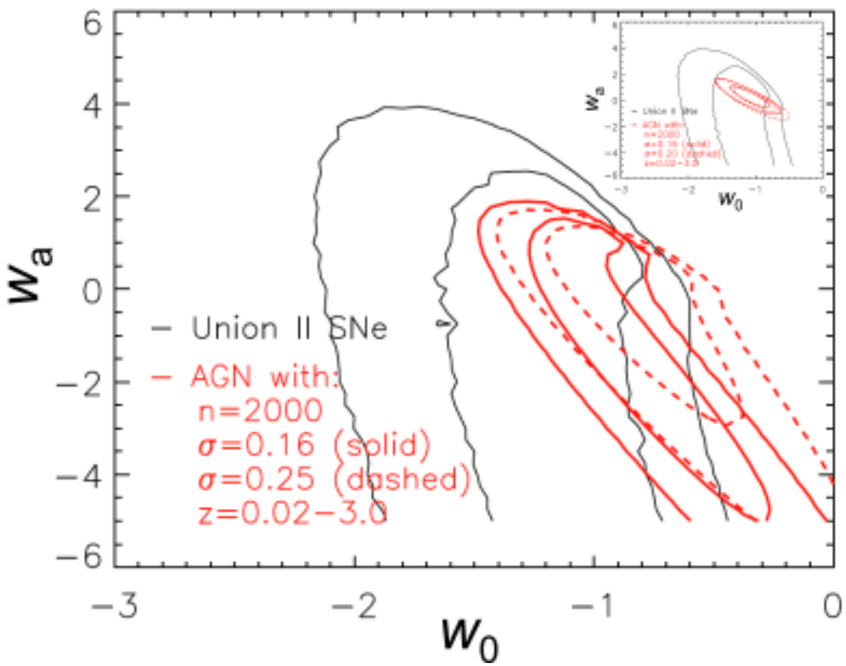
[a]Root mean square scatter in dex (mag)

Compares with SNIa !

Need more statistics and higher redshifts >2 to replace SNIa as geometric probes?!

Comparison with SNIa (simulation)





MAPPING THE BROAD-LINE REGION

B.M. Peterson [1] and K. Horne [2]
http://ned.ipac.caltech.edu/level5/March10/Peterson/Peterson_contents.html

- ***High time resolution,* (less than 0.2 - 1 day, depending on the emission line).** The interval between observations translates directly into the resolution in the time-delay axis.
- ***Long duration (several months).*** A rule of thumb in time series analysis is that the duration of the experiment should exceed the maximum timescale to be probed by at least a factor of three.

  Take a lag for Hβ in NGC 5548 is typically around 20 days, so the longest timescale to be probed is $2r/c$. The duration should thus be at least ~ 120 days to map the Hβ emitting region.

~ 200 days of observations are required *to be certain* that such an event occurs, and to observe its consequences in the emission lines.

- ***Moderate spectral resolution* (600 km s^{-1}).**
- ***High homogeneity and signal-to-noise ratios* (*S/N* 100).** Both continuum and emission-line flux variations are small on short time scales, typically no more than a few percent on diurnal timescales. Excellent *relative* flux calibration and signal-to-noise ratios are necessary to make use of the high time resolution.

What about AST3?

AGN/QSO can be detected by AST3

- Similar to SNIa for precision photometry
- RM needs many spectra!
- For AGN osmology cf Andy Howell comment on SNII cosmology?

Statistics of the current RM AGN sample

~50 AGN with RM lag measurements

- almost exclusively at z<0.3
- Most are Hbeta lags with some CIV lags and little/no MgII lags
- Sample heterogeneous, and does not uniformly sample the AGN parameter space (luminosity, emission line properties)

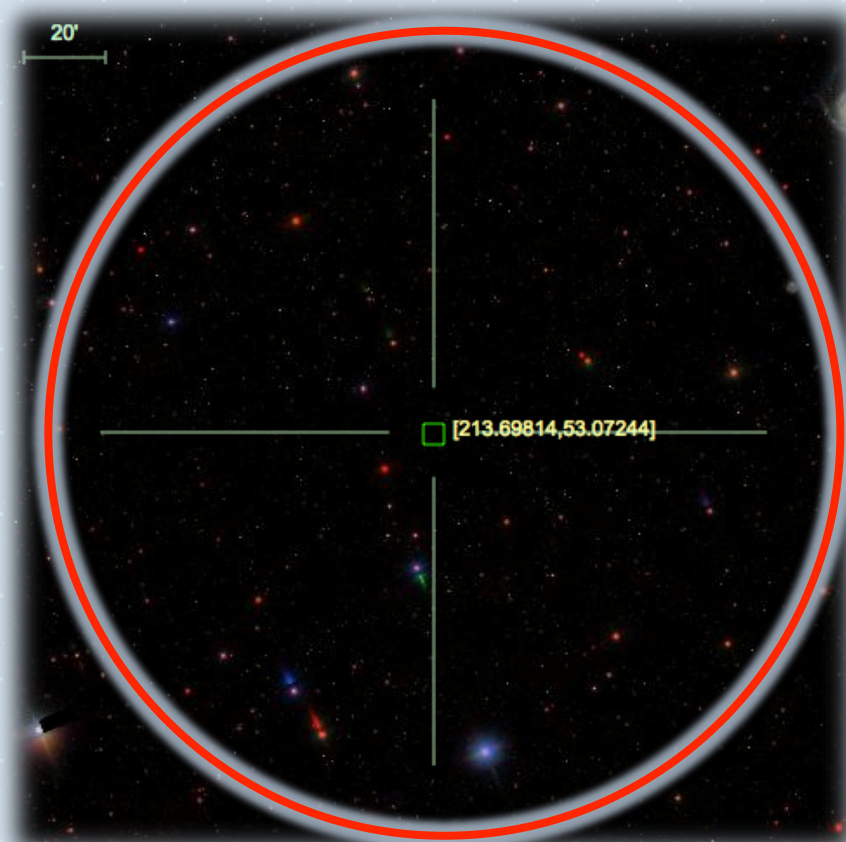
Two decades of effort !!

The limitations of the current RM sample severely impact the reliability of the single-epoch BH mass estimators at high-redshift.

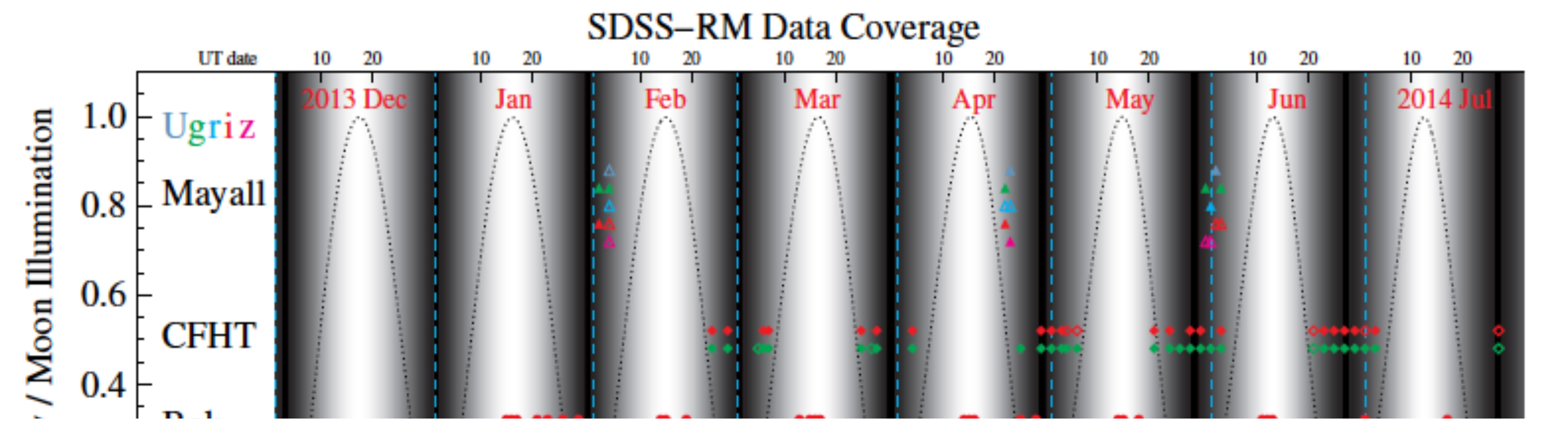
Desperately need to improve the RM sample, in a more efficient way.

SDSS-RM in a nutshell

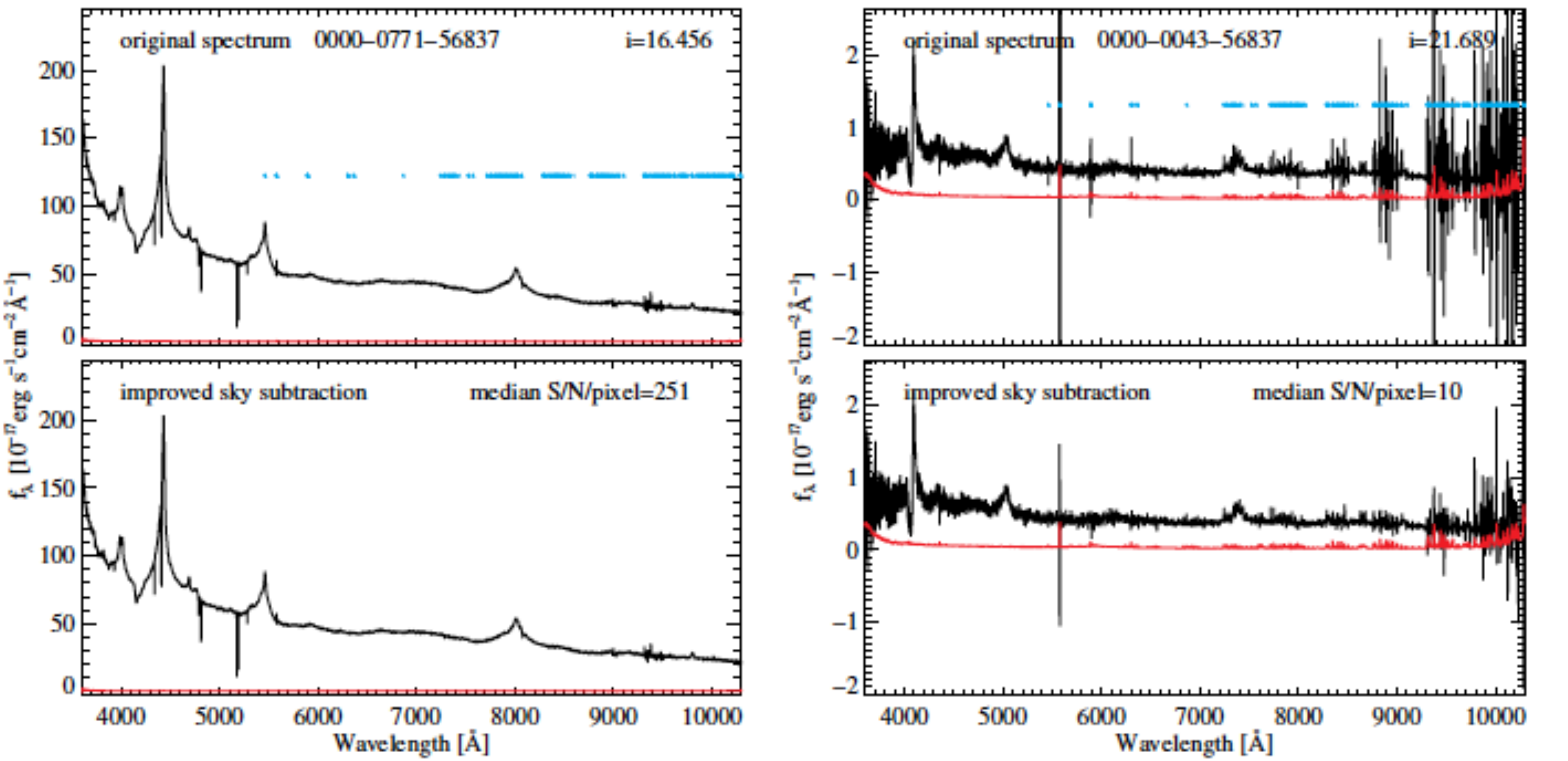
- Motivation: expanding the RM AGN sample in both size and luminosity range
- Simultaneous monitoring 849 quasars at $0.1<z<4.5$ in a single 7 deg^2 field with the SDSS-BOSS spectrograph
- Dense photometric light curves since 2010-



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



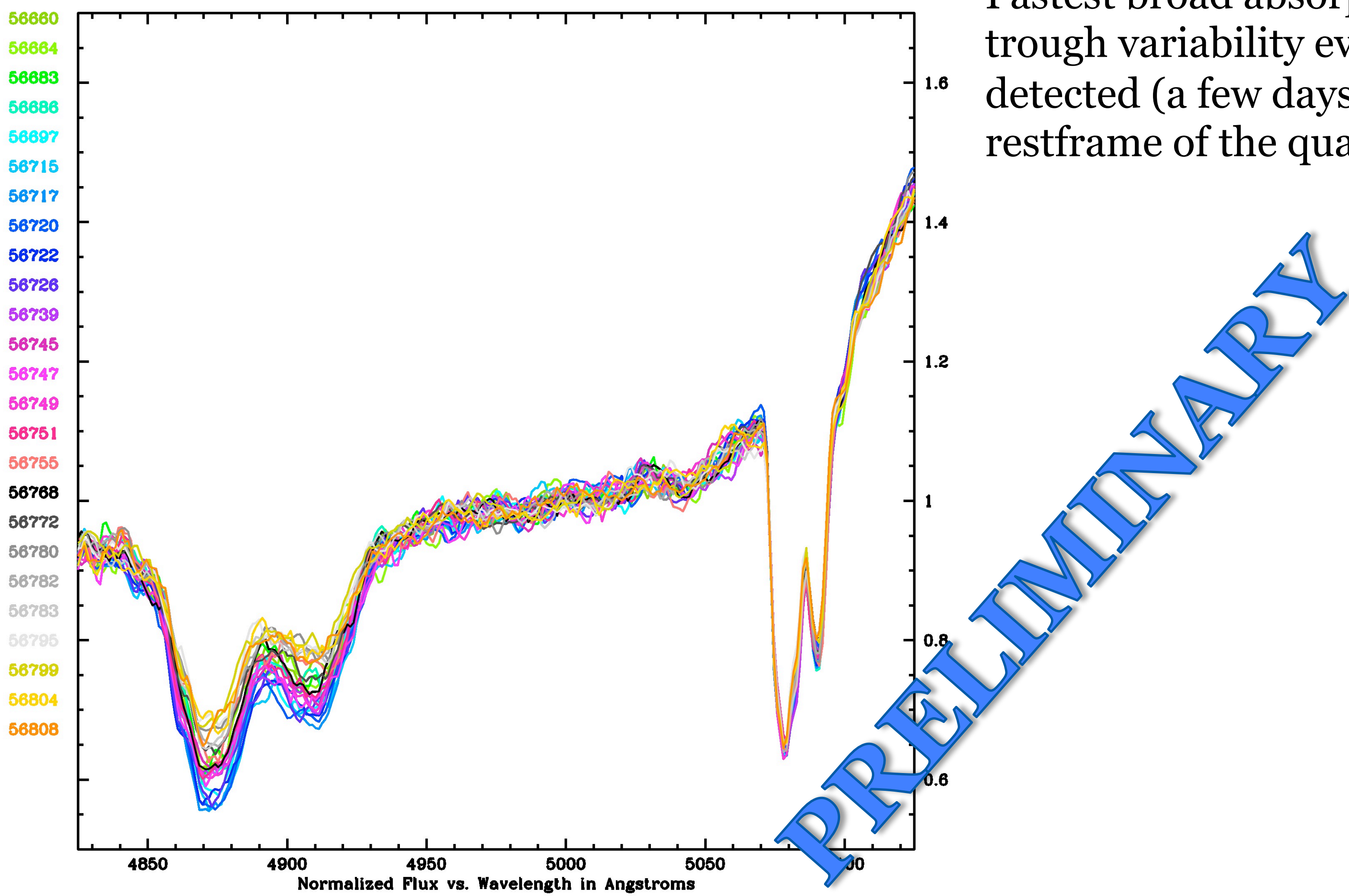
SDSS–RM Data Coverage
UT date
10
20
2013 Dec
Jan
Feb
Mar
Apr
May
Jun
2014 Jul
Ugriz
Mayall
CFHT
/ Moon Illumination
1.0
0.8
0.6
0.4



original spectrum 0000–0771–56837
i=16.456
improved sky subtraction
median S/N/pixel=251
original spectrum 0000–0043–56837
i=21.689
improved sky subtraction
median S/N/pixel=10
f_λ [10^{-17}erg s^{-1}cm^{-2}Å^{-1}]
Wavelength [Å]
4000
5000
6000
7000
8000
9000
10000

Early science results. I. Rapid BAL variability

Grier et al., in prep



Fastest broad absorption trough variability ever detected (a few days in restframe of the quasar)

Co-evolution of galaxies and SMBHs

Kormendy & Ho (2013, ARAA)

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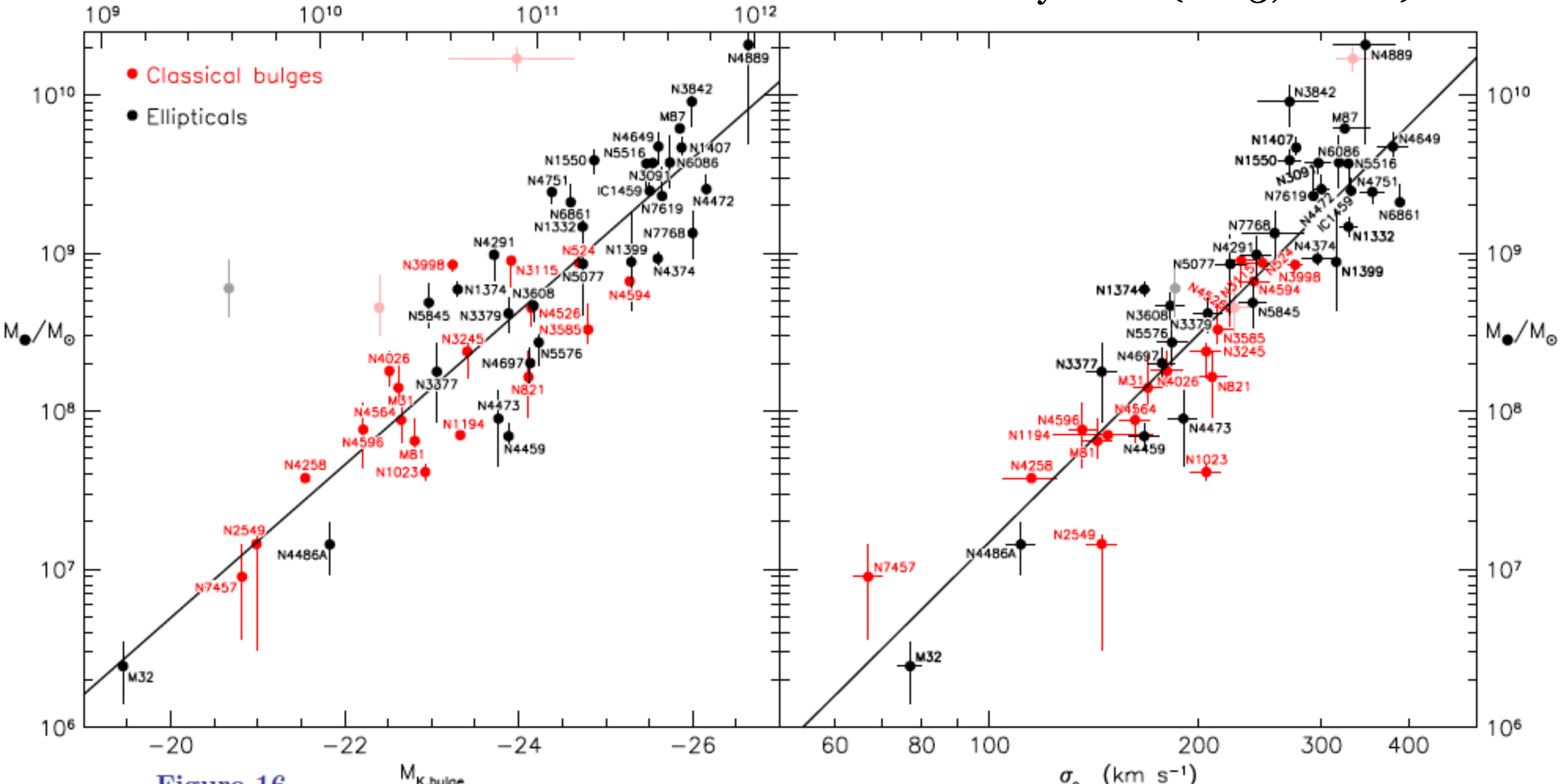


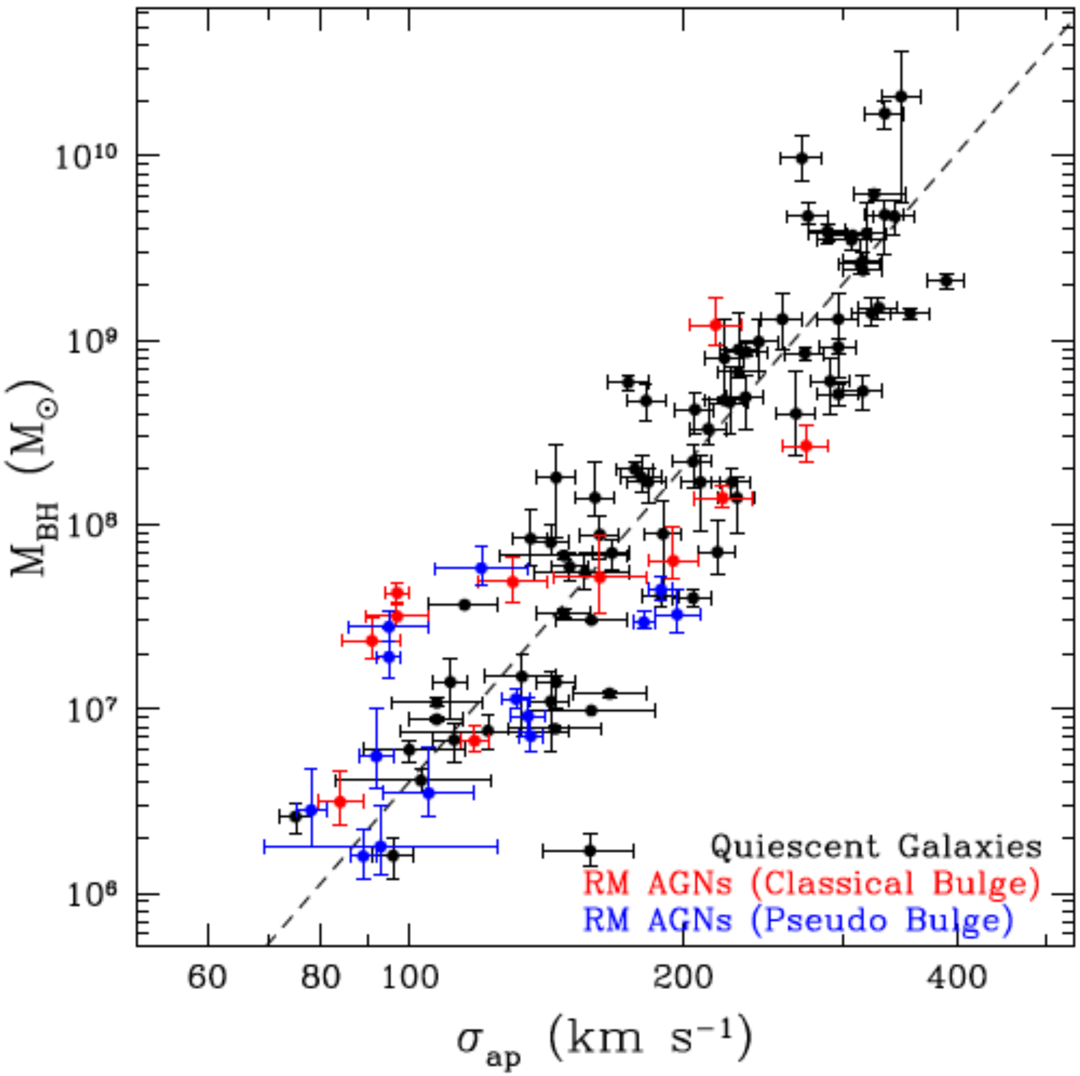
Figure 16

Correlation of dynamically measured BH mass $M_\bullet$ with (*left*) K-band absolute magnitude $M_{\mathrm{K,bulge}}$ and luminosity $L_{K,\mathrm{bulge}}$ and (*right*) velocity dispersion σ_e for (*red*) classical bulges and (*black*) elliptical galaxies. The lines are symmetric least-squares fits to all the points except the monsters (*points in light colors*), NGC 3842, and NGC 4889. **Figure 17** shows this fit with 1-σ error bars.

Co-evolution of galaxies and SMBHs

- Challenges beyond the local universe ($z>0.3$):
  - No dynamical BH masses
  - Exclusively relying on broad-line AGN
  - Host properties difficult to measure in the presence of AGN – need high S/N data

Co-evolution of galaxies and SMBHs



Bennert et al. (2014)

Thank you for your attention!