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Reverberation Study of AGN with LSST: starlight contamination

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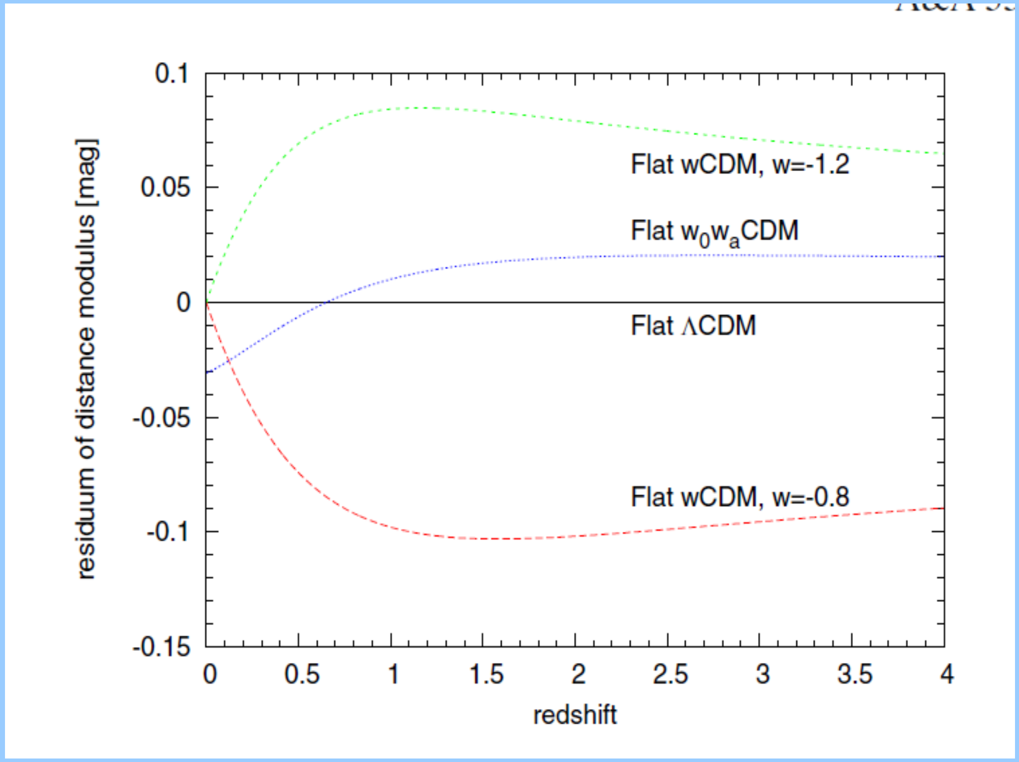
LSST in Europe 2, 21 June 2016, Belgrade

Quasars as probes of the dark energy

Quasars can be used as probes since:

• They are numerous (over 100 000 in SDSS, expected up to 10^7 from LSST)

• They cover large range of redshifts (up to 7) while SNIa are problematic beyond 1.5



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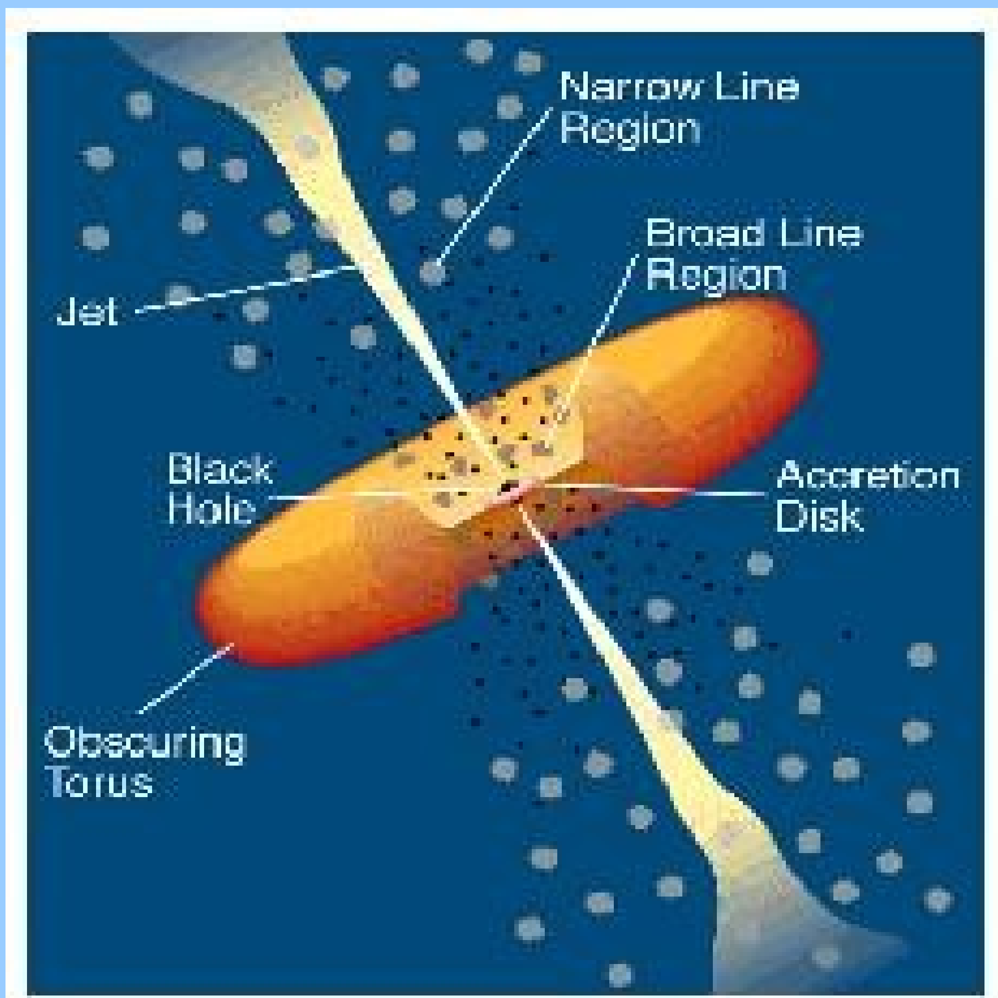
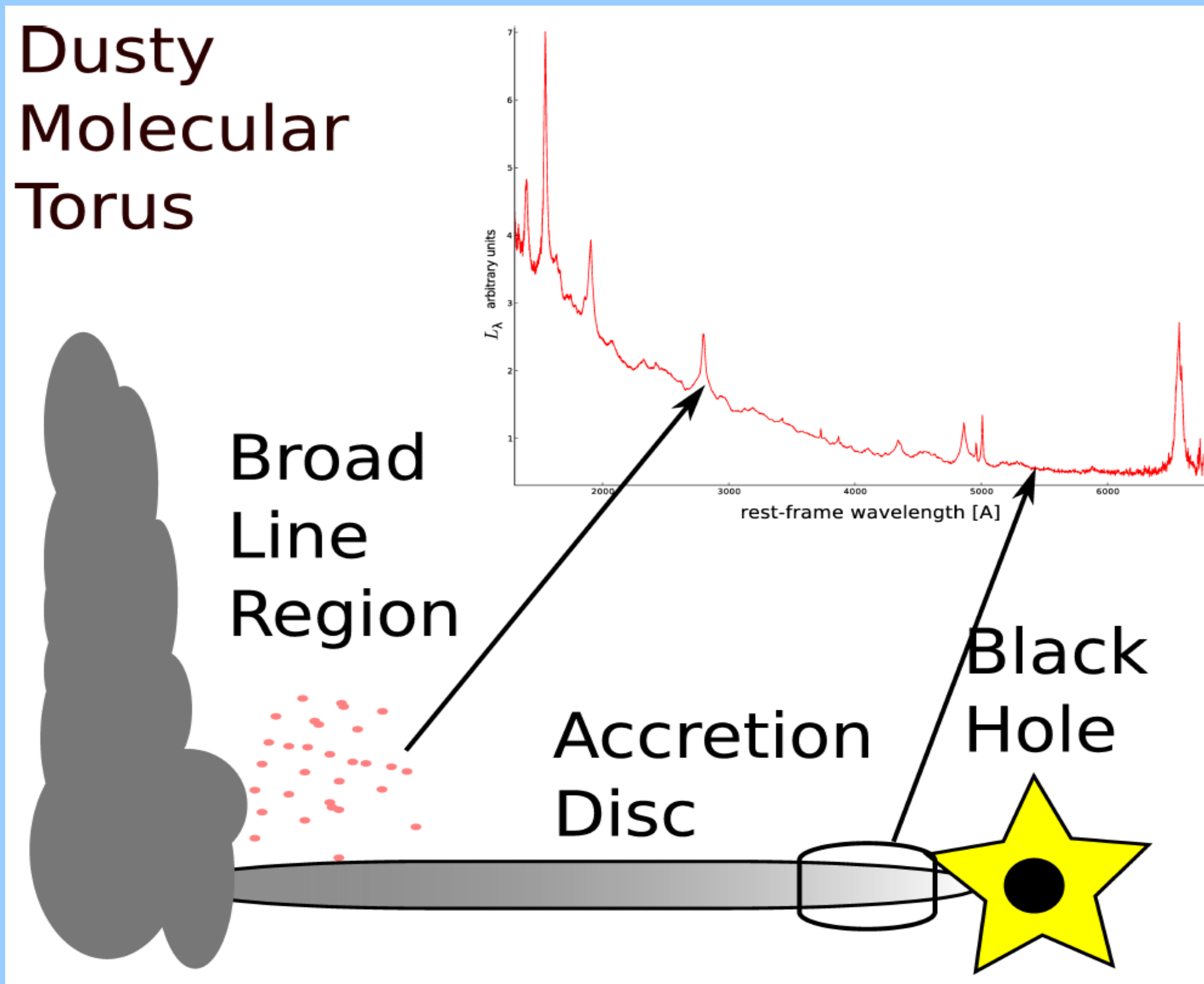
Quasars as probes of the dark energy



Quasars are not standard candles but we have a way to determine the absolute monochromatic luminosity of a single quasar. Thus quasars can be located on the luminosity distance vs. redshift diagram.

From Urry & Padovani 1995

Continuum and the emission lines



Optical/UV continuum comes from an inner part of accretion disk surrounding the central black hole

Optical and UV Broad Emission Lines come from an outer disk region, from clouds above an accretion disk

$$R_{BLR} = const \quad L_\nu^{1/2}$$

Determination of the absolute monochromatic luminosity of a quasar

Basic idea:

· Size of the Broad Line Region depends on the absolute monochromatic luminosity (theory)

• Size of the Broad Line Region can be measured as a time delay between the emission lines and continuum (observations: reverberation method)

• Thus measured size allows to determine the monochromatic luminosity of a quasar, comparison of observed monochromatic luminosity and absolute luminosity gives the luminosity distance and locates the source on distance – redshift diagram.

Formation of the Broad Line Region

Idea presented by Czerny & Hryniewicz (2011): BLR as failed wind – **FRADO**

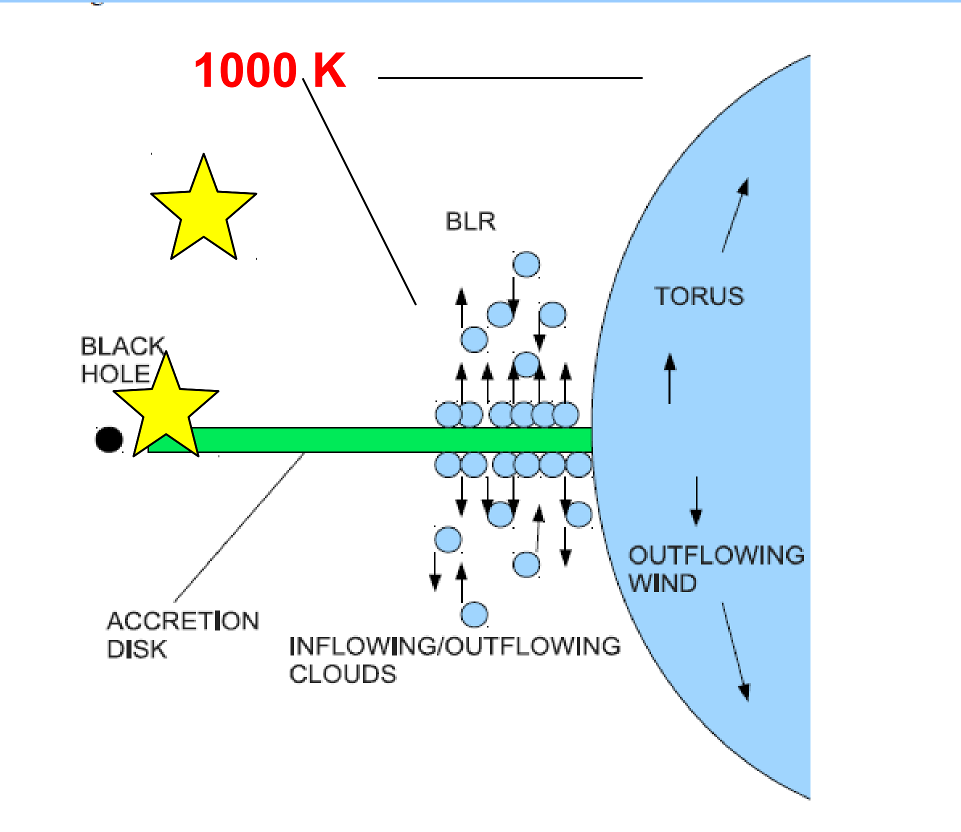


Fig. 1. The BLR region covers the range of the disk with an effective temperature lower than 1000 K: the dusty wind rises and then breaks down when exposed to the radiation from the central source. The dusty torus is the disk range where the irradiation does not destroy the dust and the wind flows out.

Dust leads to outflow and forces the material to rise high above the disk but dust cannot survive in the temperature much higher than 1000 K!

Strong radiation field kills the dust (evaporation process) and the material falls back.

Wind, which is not a wind, is what we need for BLR!

More accurately, this is proposed for the Low Ionization Line part of BLR, like Hbeta and Mg II which do not show a systematic shift in velocity with respect to NLR.

Extension towards high redshifts

$$R_{BLR} = const \quad L_\nu^{1/2}$$

All we need is to do the measurement of the time delay between the line and continuum. This is being done spectroscopically since a long time for nearby AGN (e.g. Kaspi et al. 2000, Bentz et al. 2012) but with its theoretical support is can be safely extended towards high redshift quasars. We do not expect systematic problems since the metallicity of quasars, and quasar dust properties do not seem to depend on redshift.

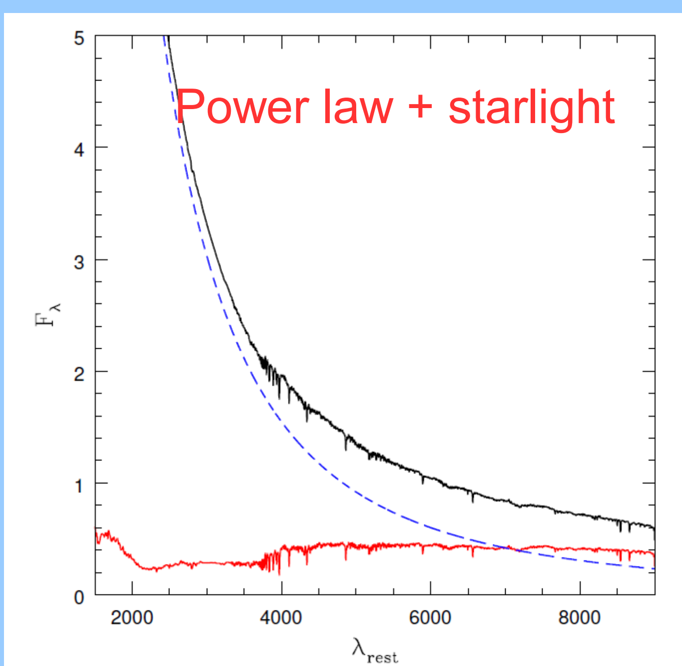
Lines good for reverberation:

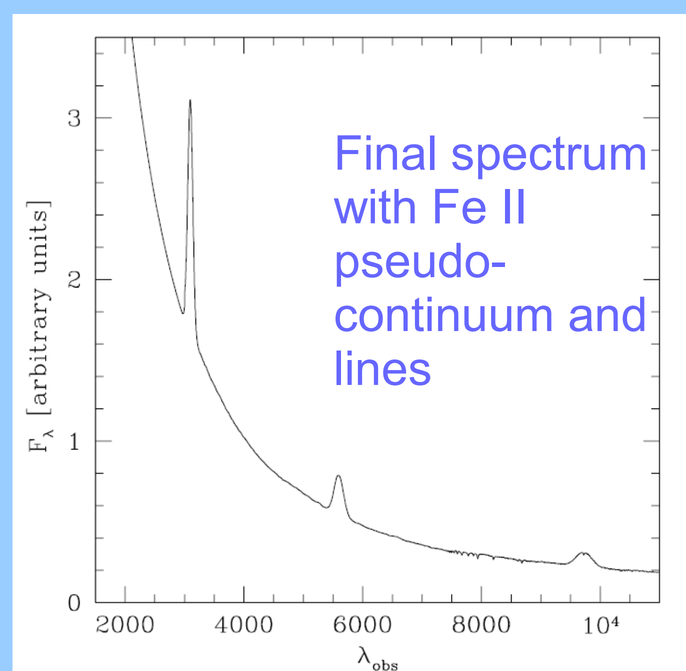
Hbeta – nearby object
Mg II – intermediate quasars
CIV – high redshift quasars

Reverbation measurements with LSST require the use of photometry instead of spectroscopy which is a challenge. Pioneering work with photometric reverberation was done by Chelouche & Daniel (2012), using two-color photometry: one with, and one without line contamination.

Simulations of photometric reverberation with LSST

We assume representative (average values) for EW from the Shen et al. (2011) quasar catalog:
EW(Hbeta) = 87 A   EW(MgII) = 47 A
EW(CIV) = 45 A   FWHM = 4000 km/s for all three lines.
We include FeII pseudo-continuum in all wavelength range, and starlight shape taken from our modelling of REJ 1034+396 (Czerny et al. 2016).

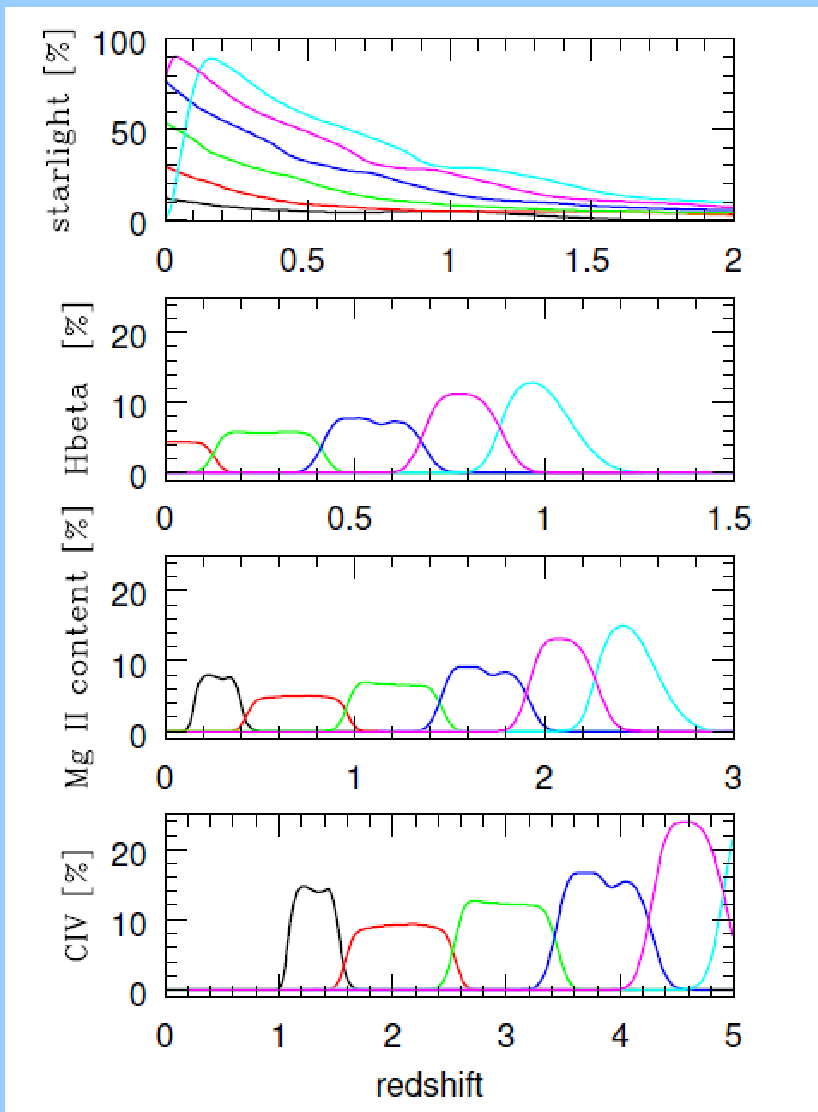




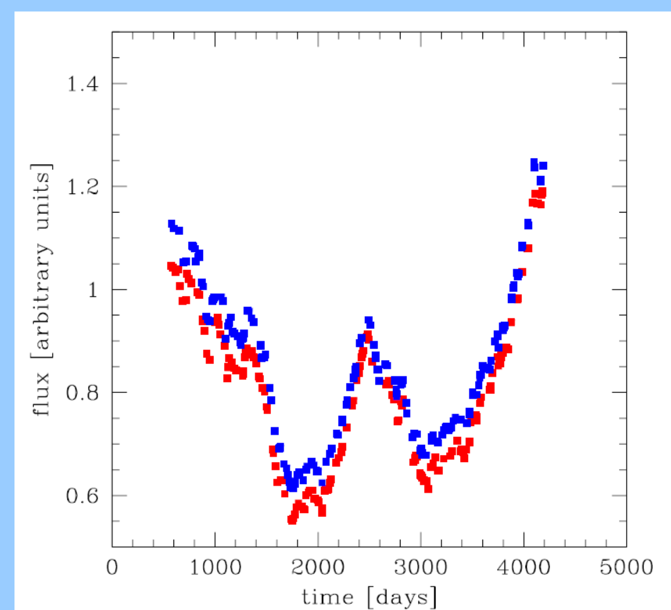
Continuum is modeled as a power law with slope flat on nuFnu.

Our current study is done just for one representative quasar, located at redshift z = 1.

Photometric reverberation



The basic lightcurve is created using the Timmer-Koenig algorithm. It represents a red-noise continuum variability. Lines are modeled with the same lightcurve, but shifted in time and with Gaussian smearing (width of 0.1 of the delay). The measurement in a given channel is cretated using the LSST responces.

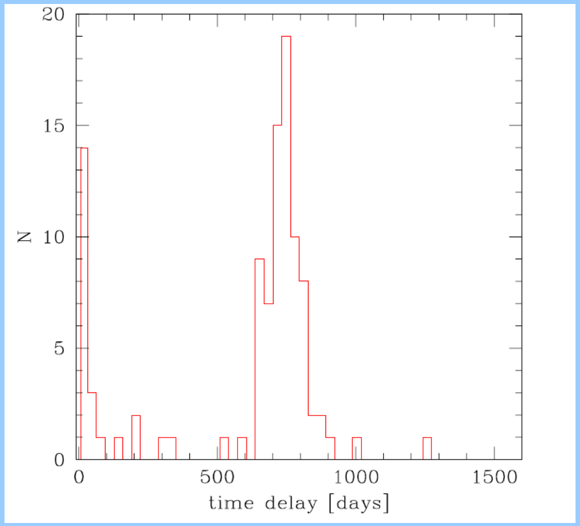


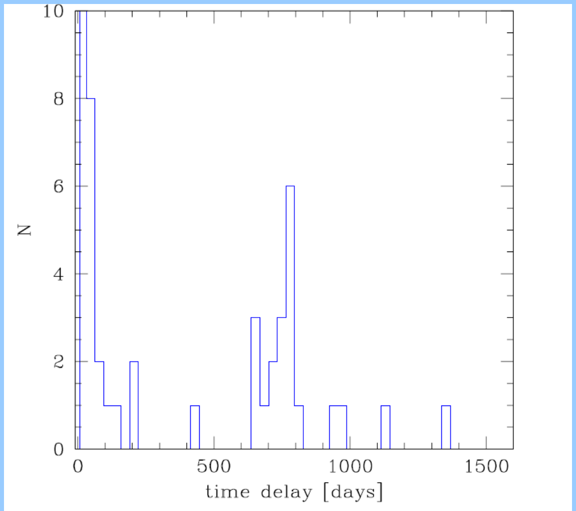
Exemplary lightcurve (quasar z = 1) with little line contamination (red; color i) and with Mg II contamination (blue, color y). The delayed Mg II contribution is small!

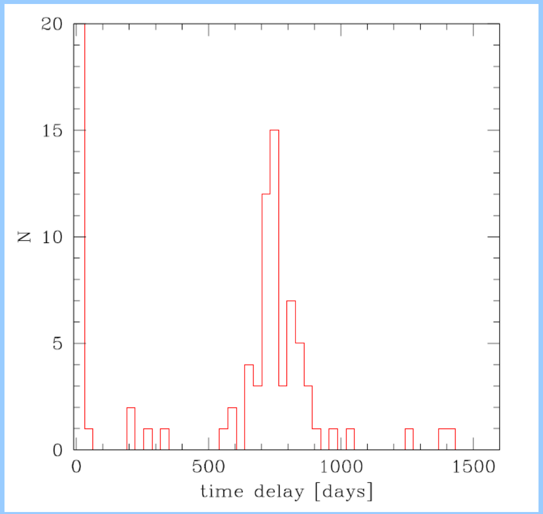
Average contribution of the line to the 6 LSST photometric chanels in our representative spectrum, as a function of quasar redshift

Reverberation results from 100 artificial lightcurves for a quasar z=1

We created 100 random lightcurves for a quasar at redshift z = 1, assumed delay 780 days, and we try to recover the delay from photometric lightcurves. Number of points in each band taken from Ivezic et al. 2014, Table 1. Assumed photometric accuracy 0.1 %.







Hbeta, contribution 16 %, no starlight
Recovered delay: 595 +/- 304
Succesful measurement in about 80 per cent of cases

Mg II, contribution 6 %
Recovered delay: 182 +/- 320
Reasonably succesful measurement in about 20 % of cases

Hbeta, contribution 12 %, starlight
Recovered delay: 495 +/- 392
Succesful measurement in about 68 per cent cases

PROBLEM OF FREQUENT ZERO DELAYS
WHICH INCREASES DISPERSION UNREASONABLY

Summary and future plans

- Our current modelling implies that we can derive the photometris delay with LSST setup for quasars when the line contribution is comparable or larger than the variability amplitude of the continuum (red noise issue)
- The photometric accuracy is not critical but must be better by a factor 5 than the level of the line contribution

- We used so far linear interpolation combined with chi2 method to recover assumed delay; chi2 works better than ICCF but 'interpolation' with DRW may give improvement
- We used purely random distribution of measurements in all colors; very specific pattern may change the results (not very likely)
- We neglected the change of the continuum slope; this is a serious problem and may increase the difficulties

- We could repeat the analysis on all Shen et al. quasars (taking their appropriate parameters) to see which fraction is likely to have precise measurement of the delay (Mg II should be nice for z=2 quasars).