Prospects for using AGN from the LSST data to cosmology

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Basic statement of current astrophysics

We are in a period of data-driven science:

- Most of the topics during this conference reflect recent observation of some unexpected phenomenon
- Hotly discussed topics in cosmology are tensions with the standard model, and the alternative are hundreds (or more) of parametric models which are not deeply satisfactory

Why is that?

- Current physics does not offer any new break-through theory
- We have very rich known physics phenomena, but we have a very hard time to bridge micro-physics (elementary processes) to macro-physics (viscosity, magnetic field reconnection etc.) despite the considerable development of the computer power

What to do? **Get more data !**

New observational facilities

All telescopes (ground-based or in space) can be broadly divided into two categories:

- Observatories dedicated to point-like observations (now for example JWST). Usually there is a call for proposals, and best proposals for interesting sources are selected. These telescopes have usually small field of view (e.g. JWST has 3' x 3'), take long exposures (measured in ksec) and never cover whole available sky
- Survey telescopes (e.g. e-ROSITA). They have large field of view (e-ROSITA with 1 deg circular), they do not concentrate on any specific source but cover large portions of the sky and measure whatever is there. Usually do not accept any specific proposals.
- Sometimes a combination of different telescopes, particularly in case of space missions.

I will talk about Vera Rubin Observatory

- And this is a ground-based survey telescope.

VRO/LSST – name issue

When the idea of large ground-based optical telescope – analogous to the succesfull LSST but devoted to variability studies – was born, the name was LSST – Large Synoptic Space Telescope. Recently the telescope has got a new name – Vera C. Rubin Observatory.

But the name LSST was so popular, that currently it is still used but in slightly different context:

Vera C. Rubin Observatory will perform the Legacy Survey of Space and Time.

Vera C. Rubin

Vera Cooper Rubin (1928 – 2016) was born in Filadelfia, but her father Philip Cooper was born in Winius as Pesach Kobczewski. Her mather was from Bessarabia (in present-day Moldova). Her parents met in US.

Vera constructed her first telescope at the age of 14. Her father, a talented electrical engineer, supported her passion by helping her build a telescope. She became professional astronomer but she got recognition quite late, after a series of papers about the rotational curves of galaxies showing the presence of the dark matter.
1970 – Rubin & Ford (Andromeda)
1978 – Rubin et al. (bright spirals)
1980 – Rubin et al. (broad range of galaxies), and more...

Vera Rubin - from Urania 2020

The telescope

Location: Cerro Pachón, Northern Chile

30°14′40.7″S   70°44′57.9″W

Altitude: 2 663 m

Main mirror: 8.417 m

Field of view: 3.5 degrees in diameter (7 times Moon size)

Camera (prime focus) : 3.2-gigapixel

Exposure: 2 x 15 sec or 30 sec (not set)

Repointing in 5 sec, reading in 5 sec

Filters: ugrizy

5sigma limit: r = 24.5 mag (r = 27.8 tot)

Vera Rubin - from official web page, arrival of the mirror

First light expected: January 2025

Sky coverage

Total sky covered: 20 000 deg (15 visits per year per color, 150 in 10 yr)

Two types of sky coverage:

- Main Survey – in one day the whole sky can be covered in all six filters
- Deep Drilling Fields: 10 – 20 % of time will be devoted to four selected special fields

	ELAIS S1	XMM-LSS	Extended Chandra Deep Field-South	COSMOS
RA 2000	00 37 48	02 22 50	03 32 30	10 00 24
DEC 2000	-44 00 00	-04 45 00	-28 06 00	+02 10 55
Galactic l	311.30	171.20	224.07	236.83
Galactic b	-72.90	-58.77	-54.47	42.09
Ecliptic l	345.97	31.04	40.29	150.70
Ecliptic b	-43.18	-17.90	-45.47	-9.39

DDFs will have 10 times better time coverage than the rest of the sky

The goals of the Survey

Automatic coverage of the whole sky means that broad scientific topics will bo covered:

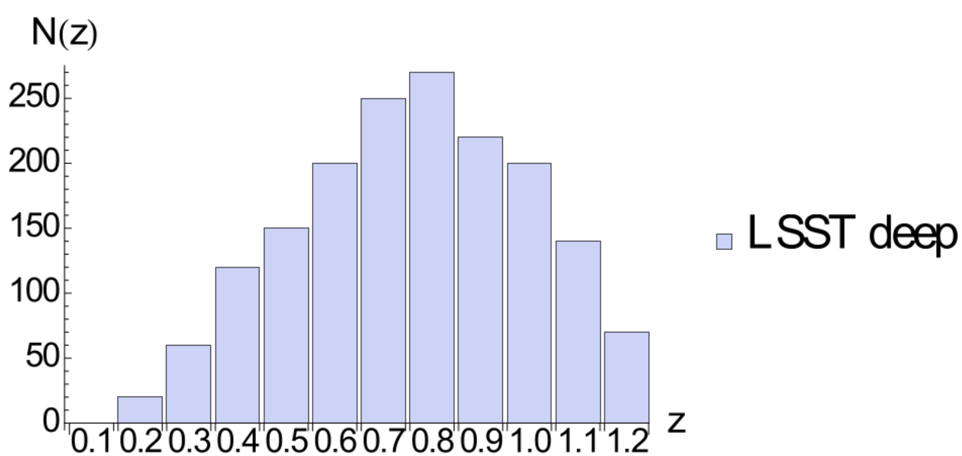
- Exporing the Solar System, including Hazardous Asteroids
- Following transient phenomena in our Galaxy
- Mapping the Milky Way
- Detecting optical counterparts of gravitational waves
- Studying dark matter and dark energy by:

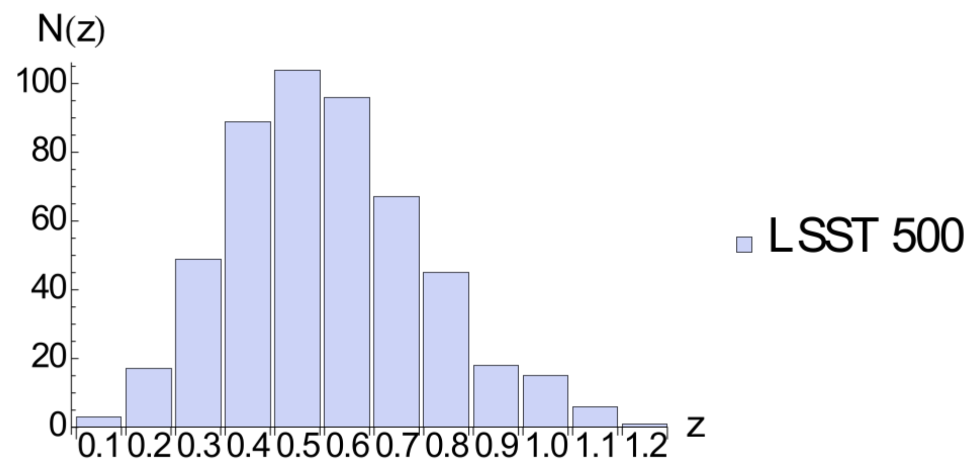
  - Weak gravitational lensing
  - Barion Acoustic Oscillations
  - SN I a

AGN are not on their primary goal list which creates a cadence problem. Still, we hope to do well for some sub-classes of AGN.

Expected new SN Ia

Since our method based on is relatively similar to SN Ia method (determination of the luminosity distance for each source) we mention the expectations for those objects from 10 yr of data (Heneka et al. 2019):



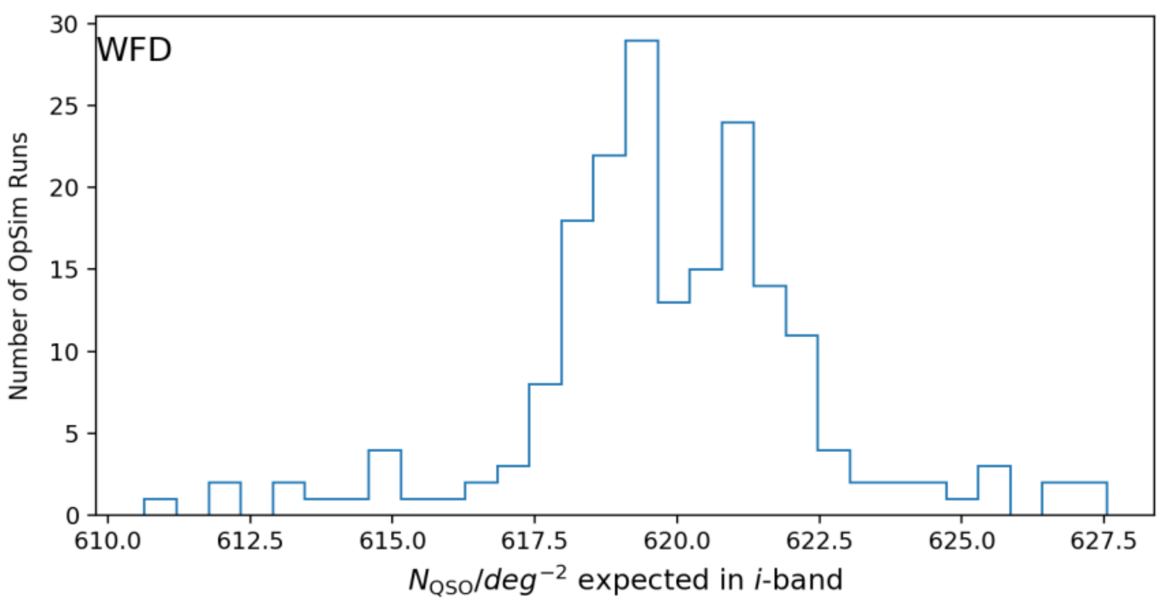


Expected noumber of SNIa from DDF will be comparable to what is know by now, right panel shows expectations from one random Main Field (we have roughly 500 such fields). This will give an increase of the total number roughly by a factor of 100, i.e. up tp 200 000 objects.

Expected SN Ia detection are always at redshift smaller than 1.2 for technical reasons.

Expected Active Galactic Nuclei

AGN are bright objects, visible even at high redshifts (above 7). The current number of known AGN is or oder of 1 million. The expected quasar detection rate in LSST:

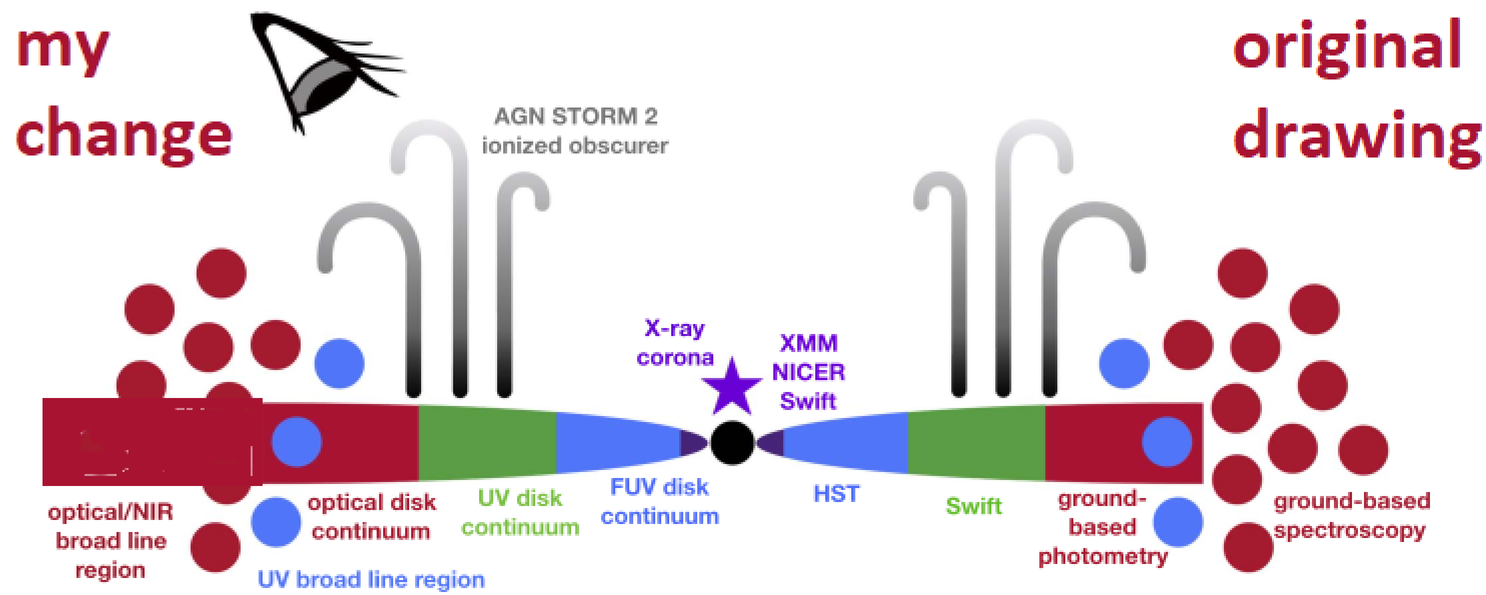


Detection rate of 620 quasars (bright AGN) per square degree implies the total number of quasars 620*20000 = 12 milions of objects (Assef et al.)

Only a fraction of these sources will be suitable for application to cosmology.

Reverberation mapping of AGN in application to cosmology

Kara et al. (2021)



Inner part of an AGN is unresolved, the disk emission comes from inner 0.01 pc and broad emission lines come from an inner 0.1 pc. The host galaxy size: 10 kpc

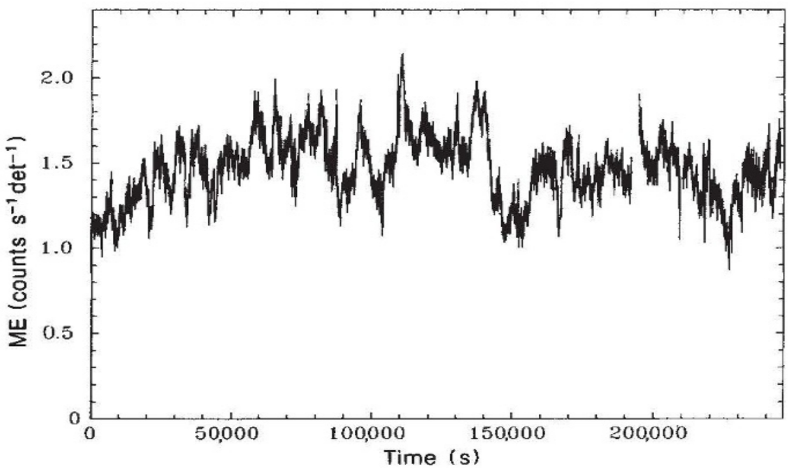
Reverberation mapping of AGN in application to cosmology

Two methods can be applied to determine the absolute luminosity of a give source independently from its redshift:

AGN emission is strongly variable in the central part where most of the energy is dissipated. Variable emission affects the other parts of the nucleus with some time delay.

- Continuum time delay
- Delay of the broad emission lines

The expected delays depend on the region size, and the size depends on the absolute luminosity. This opens a way to convert the delay to an absolute luminosity.



McHardy & Czerny (1987), NGC 5506

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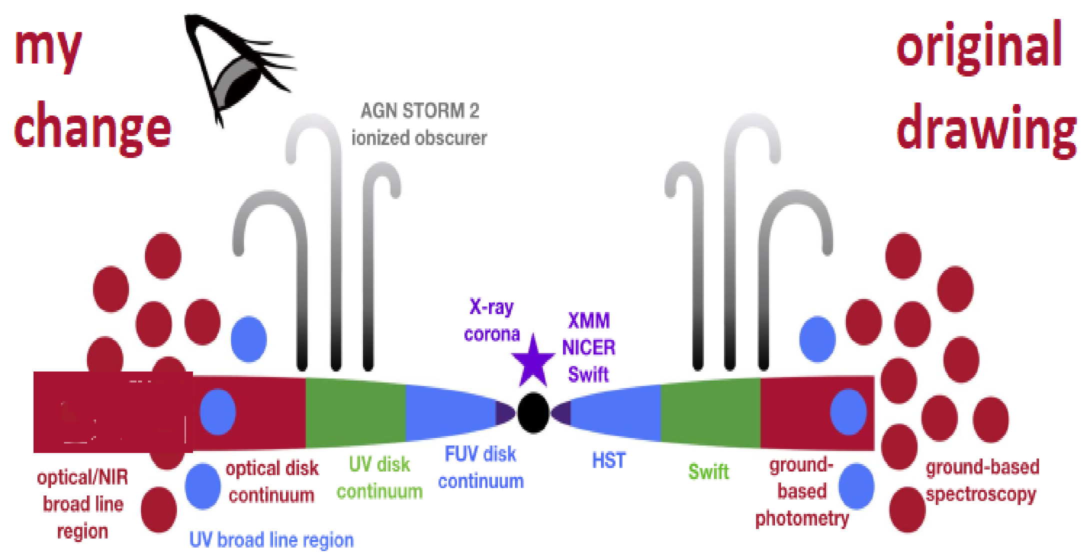


Continuum time delay

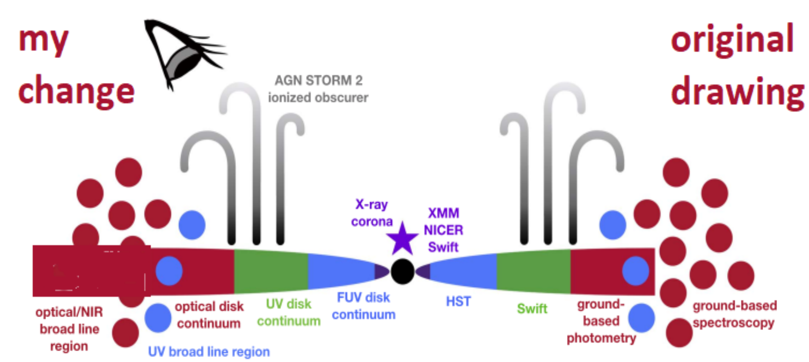
It was proposed already by Collier et al. (1999). The idea is based on a simple Shakura-Sunyeav accretion disk model.

$T^4 \sim 1/R^3$; emission at a given radius is dominted by the Wien peak $T \sim \lambda^{-1}$, and R is measured by the time delay τ:

$\tau \sim \lambda^{4/3}$ and the proportionality constant actually depend on the monochromatic luminosity, so measuring the time delay and the monochromatic observed flux we can measure the luminosity distance.

$$\frac{D}{6.3\mathrm{Mpc}} = \left(\frac{\tau}{\mathrm{d}}\right)\left(\frac{\lambda}{10^4\,\mathrm{\mathring{A}}}\right)^{-3/2}\left(\frac{f_\nu^{\mathrm{B}}/\cos i}{\mathrm{Jy}}\right)^{-1/2} \times \left(\frac{1-\varepsilon}{1-\varepsilon^{3/2}}\right)^{2}.$$

Cackett et al. (2007)

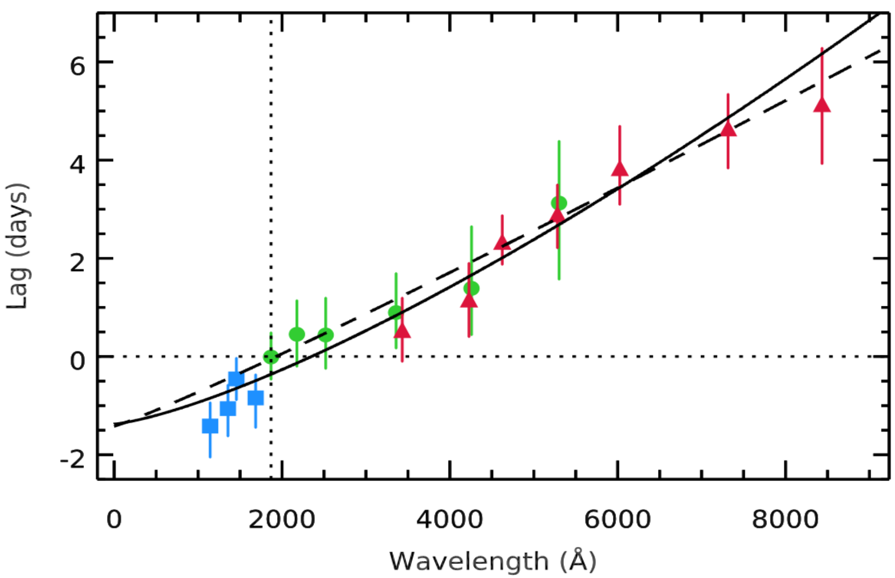


As you may guess, the issue is actually not that simple, Cackett et al. (2007) obtained a Hubble constant of 44 km/s/Mpc....

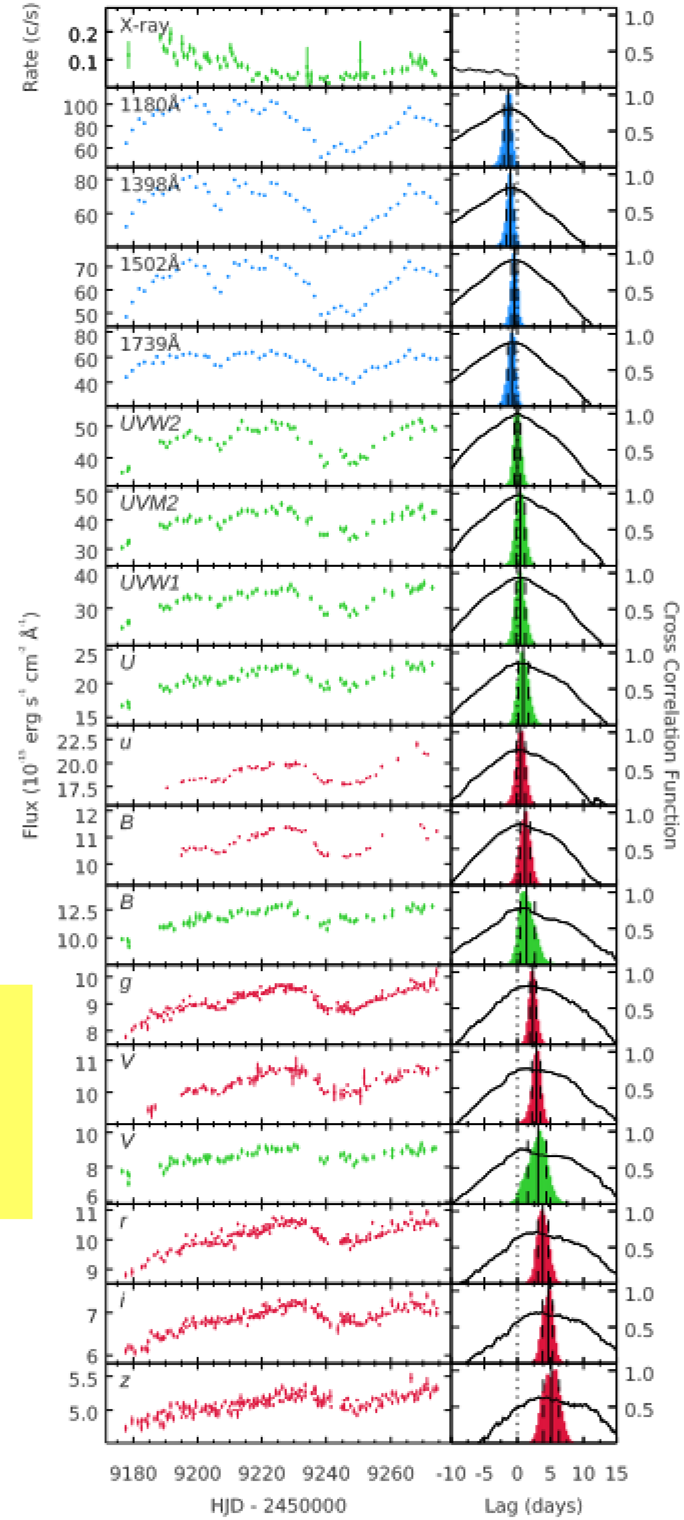
Continuum time delay – current campains

This is a very time consuming process, but the recent data shed some light on the problems behind the failure in the Hubble constant aspect.

This is the exemplary fotometric data for the object Mrk 817 (project STORM, Kara et al. 2021). It includes Swift and ground-based data.



The normalization is still a problem...



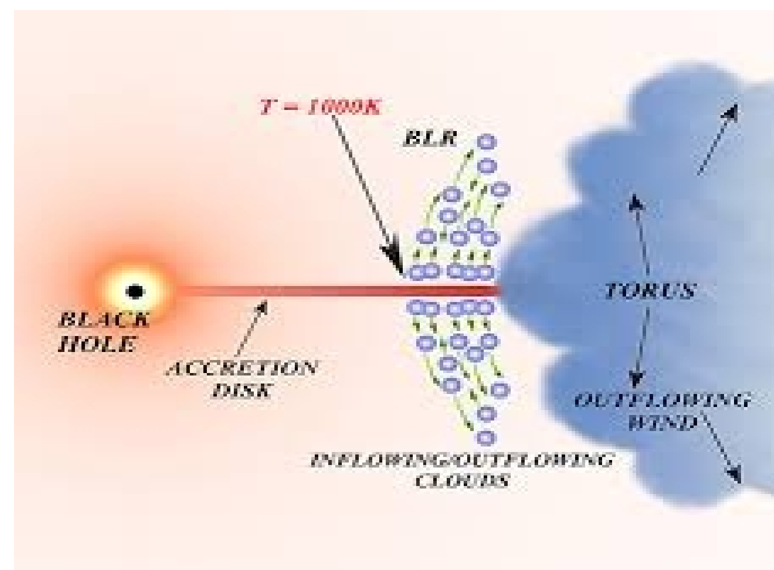
Emission line time delay

It was proposed by Watson et al. (2011) and Haas et al. (2011) The idea is based on a a radius-luminosity relation connecting the onset of the BLR with the monochromatic luminosity

$R_{BLR} \sim L_{5100}^{1/2}$

In our model (Czerny & Hryniewicz 2011) this results from the dust-driven model of the BLR, and the proportionality constant depends on the dust sublimation temperature.

Attempts to use the currently available time delay measurements (about 200) without a specific model assumption does not allow to determine the Hubble constant but allows in principle to constrain other cosmological parameters.



Czerny et al. (2017)

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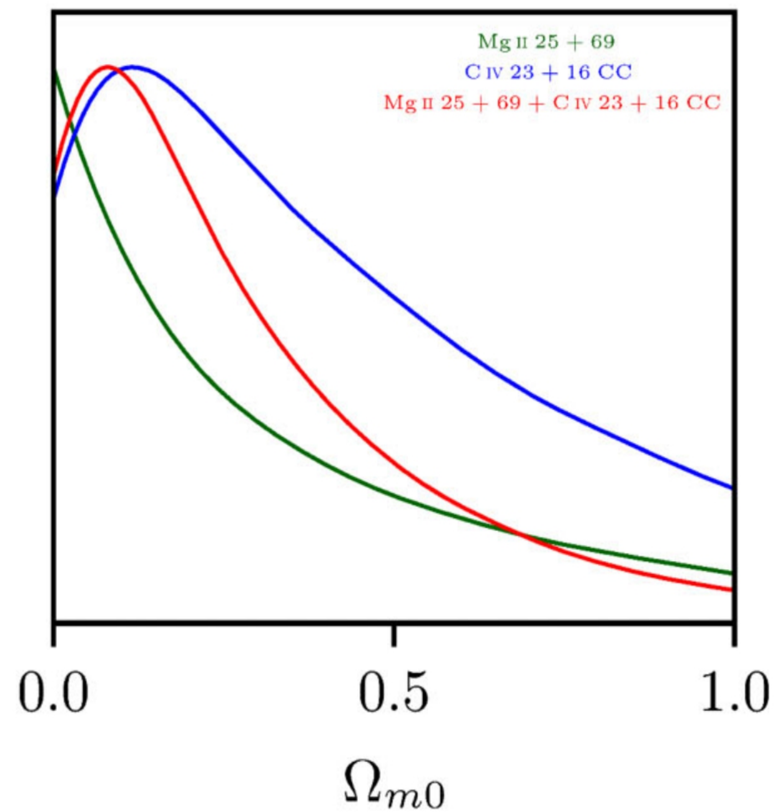
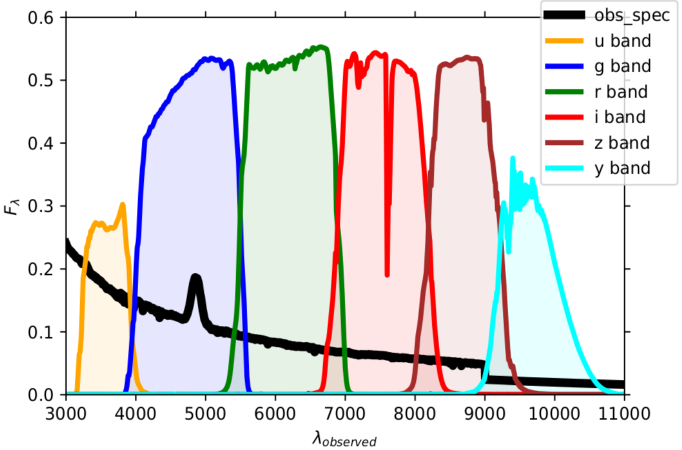


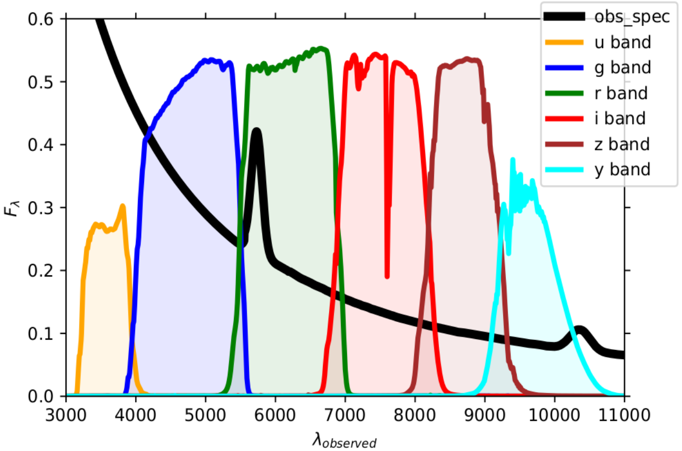
In Cao et al. (2024)* we combined the Mg II and CIV line delay from the literature, plus three Mg II delays measured with the SALT telescope. However, the constraints from quasars alone are very weak. The dispersion of the inhomogeneus measurements is too large.

*co-authors: Michal Zajacek ,Bozena Czerny, Swayamtrupta Panda, and Bharat Ratra

Emission line time in LSST context

The data are not yet available, but we did some simulations for the possibility of measuring line delay despite having just a photometry. In Czerny et al. (2023)* we estimated the contamination of the various bands by the line flux, created simulated lightcurves and considered exemplary cadence as planned for the Main Survey and for the DDFs.





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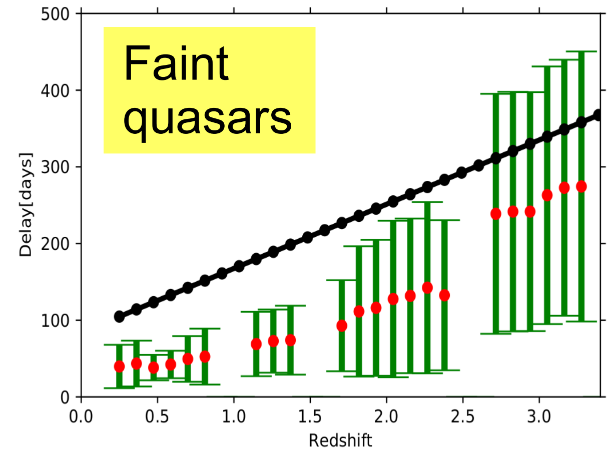
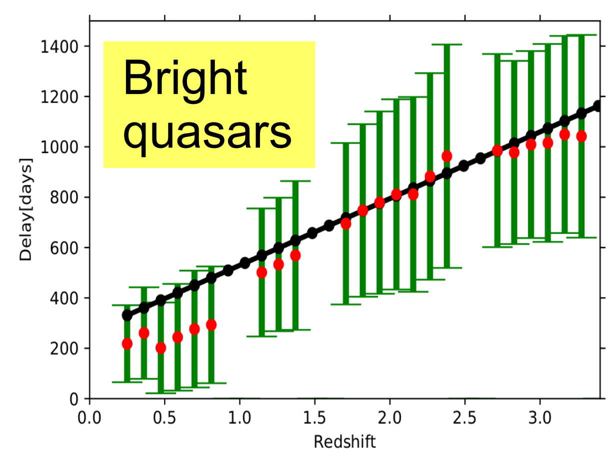


Main Survey is suitable for time delay measurements in case of bright quasars (log L3000 = 45.7) at higher redshifts since the expected delays are longer.

DDFs are suitable also for fainter sources, although not quite without a cadence problem.



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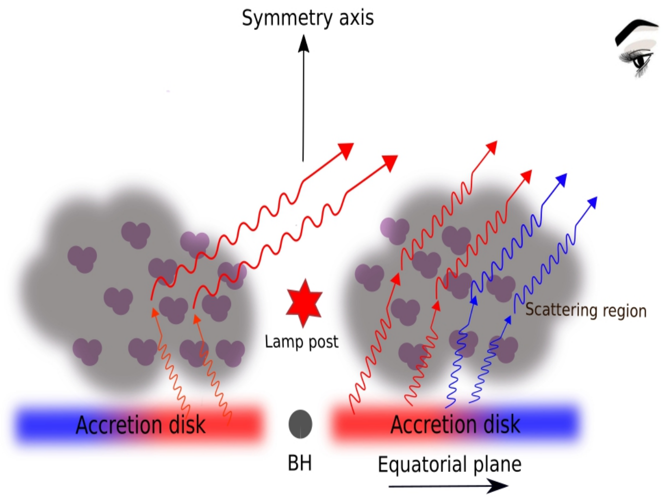
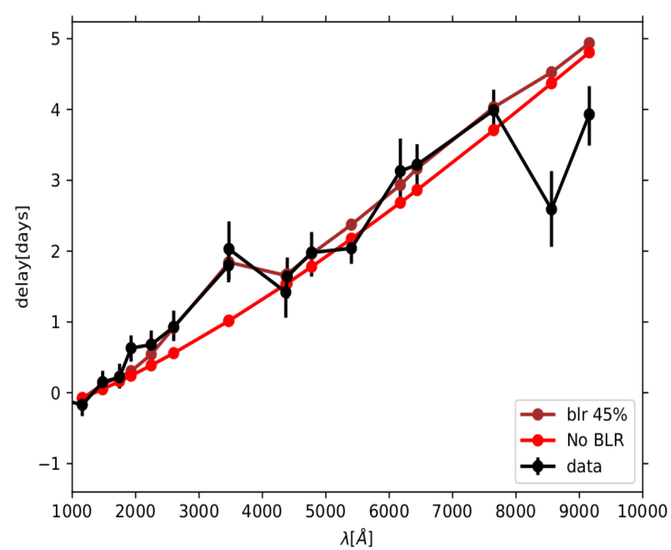
Continuum time delay

The problem with the determination of the Hubble constant from continuum time delay lies in the fact that the continuum time delay...

… is actually a combination of a delay due to the disk reprocessing and some contiribution to continuum from the region emitting broad lines.



*Jaiswal et al. 2023**



Jaiswal et al., in preparation

An attempt to model the time delay for NGC 5548 with two media delay (not yet satisfactory)... Work in progress

*includes Raj Prince, Swayamtrupta Panda and myself

Continuum time delay in LSST context

You will hear about that during the talk by Francisco Pozo Nunez after the cofee break!

Summary

- **We will have roughly similar number of line-delay measurements from the Main Survey as the number of SN Ia detections (about 100 000) but they will cover broader range of redshifts (up to 4)**
- **20 % error on individual measurements combined with 100 000 measurements gives roughly 0.06 % net error on the luminosity distance; Hubble tension is at the level of ~ 5 %**
- **The systematic errors may be still a problem – more tests are needed, we work on that**
- **We will have a few thousand of continuum time delays from DDF (see the talk of Francisco)**