Filter-Based Reverberation Mapping for Measuring the Mass of Supermassive Black Holes

מדידת המסה של חורים שחורים סופר מסיביים באמצעות מיפוי ההדהוד על בסיס פילטרים

משרד החינוך
המינהל הפדגוגי
האגף למחוננים ולמצטיינים

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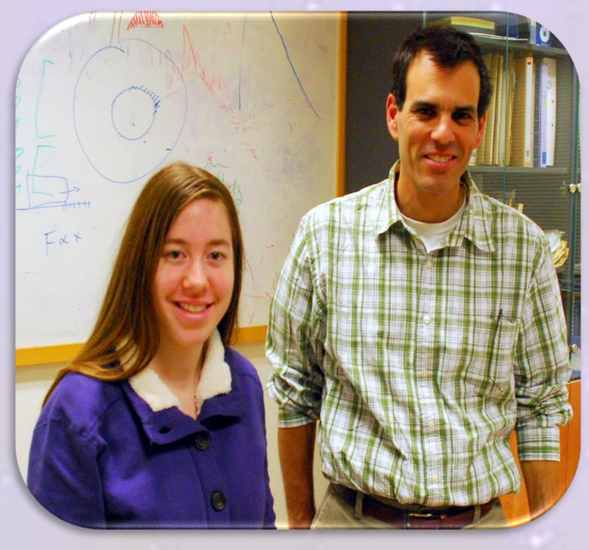
מכון הנרייטה סאלד
המכון הארצי למחקר במדעי ההתנהגות



Background

Active Galactic Nucleus (AGN) is a small region at the center of a galaxy that has extremely high luminosity. The AGN radiation is believed to be an effect of an accumulation of mass caused by a supermassive black hole in the center of a galaxy. A galaxy containing an AGN is called an **Active Galaxy**.

Broad optical emission lines are formed by gas near the central supermassive black hole. The lines are broad because of the Doppler shifts triggered on the photons, caused by the emitted material spinning around the black hole at high velocities.

Narrow optical emission lines are formed further from the center of the black hole, but are slower than the high velocity broad-line material.

NGC 4395 is a nearby spiral active galaxy.

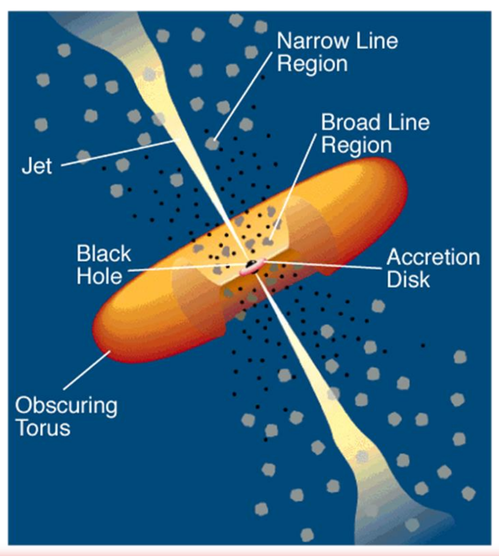
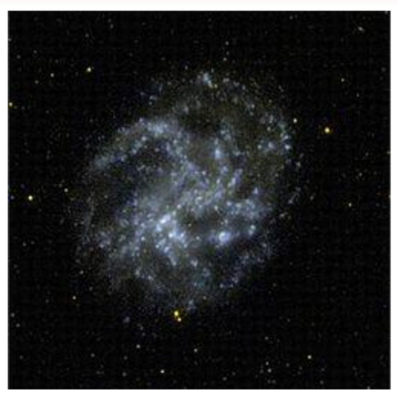
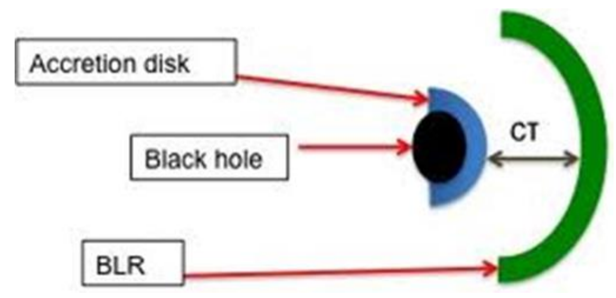


Fig. 1: Cartoon showing the AGN structure.
Fig 2: NGC 4395 Galaxy



The Reverberation Mapping Method

Reverberation mapping is an astrophysical technique for estimating the mass of a black hole at the center of an active galaxy. The technique is based on measurements of the distance of the broad emission line region (BLR) from the black hole, which is define as cτ .



In our work, we do not use a spectrometer as in standard RM studies, but filters. Since the filters can be broad and include the two signals combined, we need to use statistical methods to separate the continuum from the lines. The method computes the Cross Correlation Function (CCF) and subtracts from it the Auto Correlation Function (ACF) in order to calculate the time lag (τ) between the signals.

Observations and Data

We observed the galaxy NGC 4395 with the 1m telescope in Mizpe Ramon. In September we used the broad filters i’, r’, g’. We switched between the filters every 5 minutes to create an image of the object. We observed the target for 8 full nights. The H_{α} signal appears in the r’ filter, as shown in fig. 3.

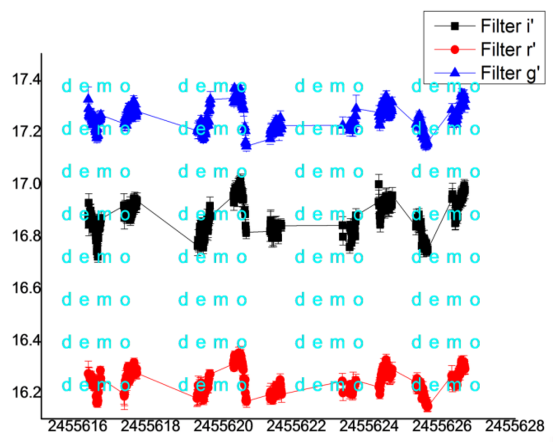


Fig. 5: Astronomical Magnitude as a function of time (days).

Analysis

I wrote a code that computes the CCF and the ACF, based on the data observed. I created graphs of the CCF and ACF for all of the filters from September, and subtracted the ACF of i’ from the CCF to receive only the line contribution to the correlation. Fig. 7 shows the ACF of the three filters.

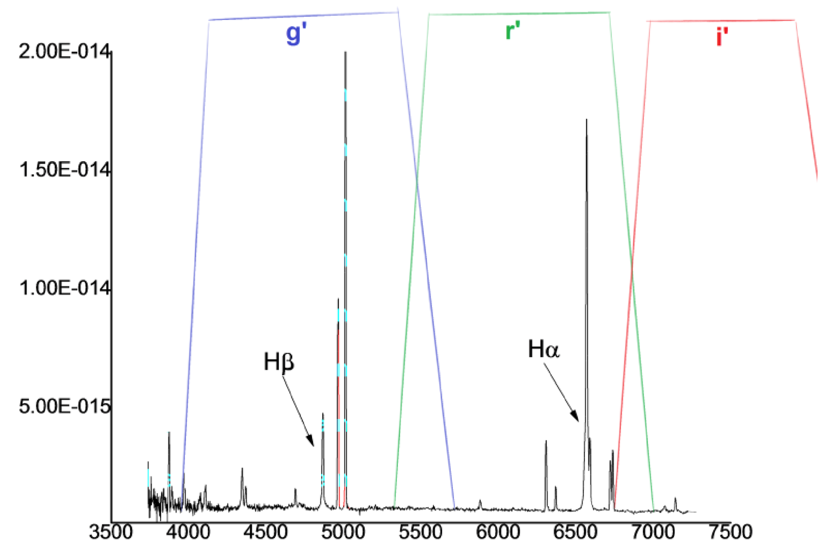


Fig. 3: Spectrum of NGC4395, shows the wavelength range of each filter.

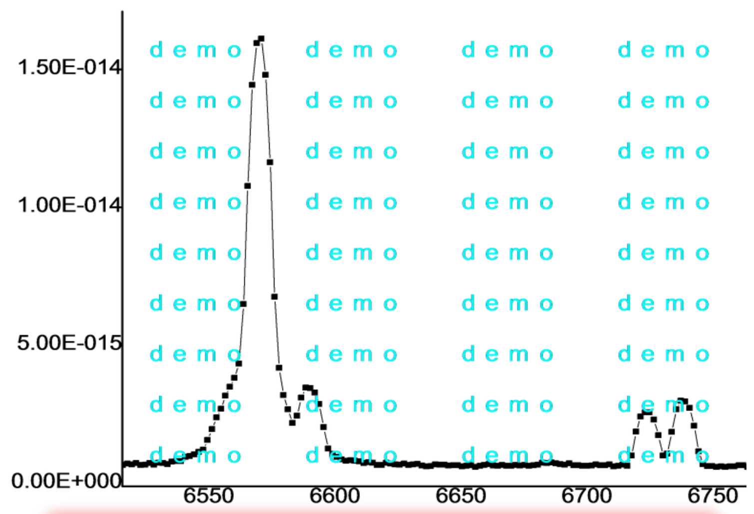


Fig. 4: Spectrum of NGC4395, Amplitude as a function of the wavelength. The Hα line is the bright line on the left.

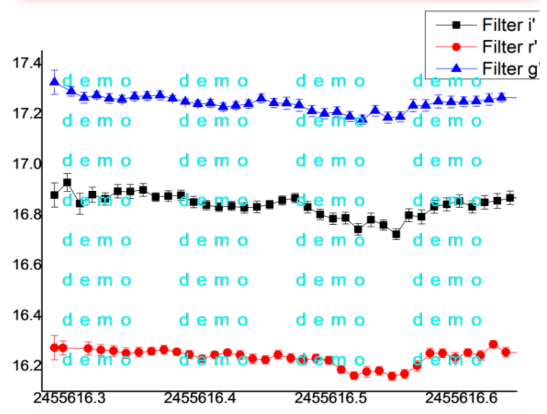


Fig. 6: The first night of the data observed with the broad filters (Fig. 5)

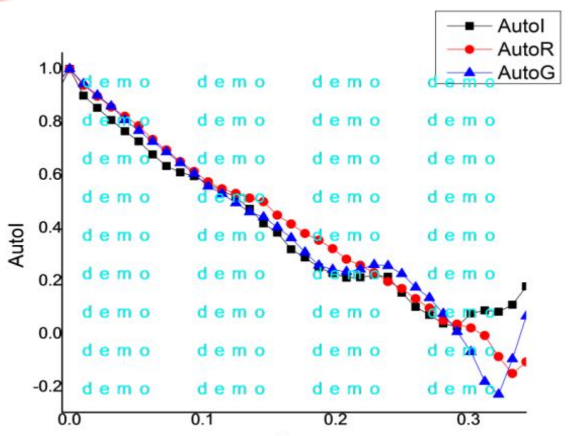


Fig. 7: The ACF of i’, g’, and r’ filters as a function of the time lag τ

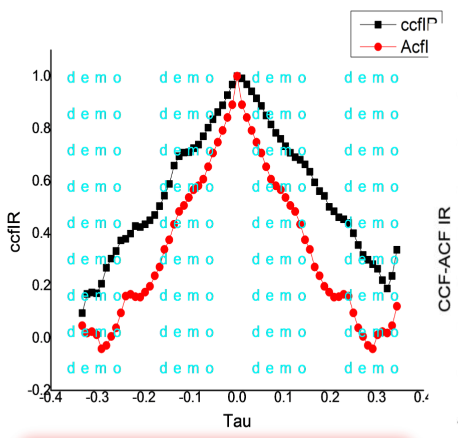


Fig. 8: CCF of the i’& r’ filters and the ACF of the I’ filter as a function of the time lag τ

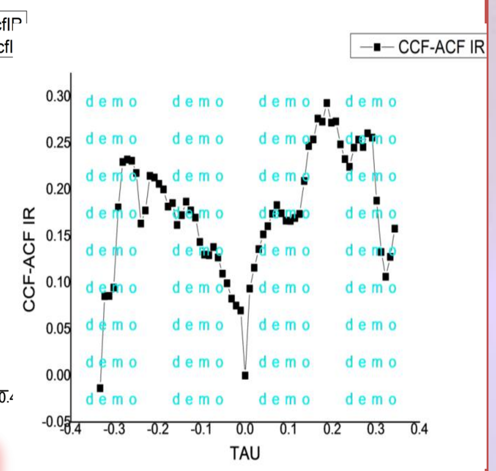


Fig. 9: Difference between the CCF and the ACF in Fig. 8

Velocity Calculations

For the velocity estimate, we use a line resolved spectrum obtained from an observatory in China. The measurement of the line width is demonstrated on the spectrum in Fig. 10. Table 1 lists the widths measured for other lines as well.

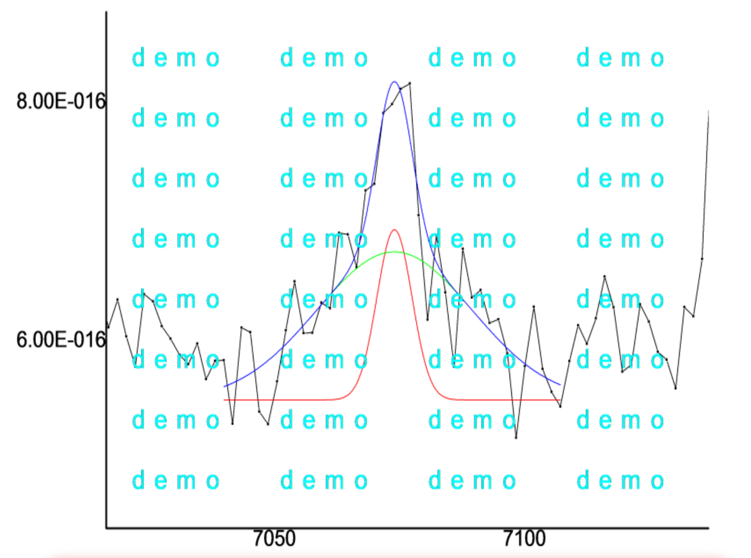


Fig. 10: Gaussian functions fit. The blue is the narrow line, the red is medium line and the green is broad line

Filter I	Filter II	ACF substracted?	Tau
i'	g'	Yes	4.80
i'	r'	Yes	4.56
r'	g'	Yes	3.36
ipr	Hα31	No	4.08
ipr	v	No	3.60
v	Hα31	No	3.36
average			3.96

Table 2: The time lag between every two filters, obtained by the 80% method (Fig. 11)

Results

From the graphs we can obtain the time lag between the line and the continuum. The lag τ is the X co-ordinate of the peak. we find it by drawing a line at 80% of the peak and by calculating the mean of the graph above the line, as shown in Fig. 11. The best-constrained lag of about 4 hours is obtained from the CCF of r’ and g’ filters, which is close to the mean lag (Table 2). Using the measured lags from the CCF, and the velocity from the spectral lines, we are ready to calculate the M_{BH} . We obtain a mass of $M_{BH} = 30{,}000 \pm 15{,}000\ M_{\odot}$.

Line ID (λ0)	λ mesured	Standard Error λ	v [km/s]	Standard Error v [km/s]	Δv	Standard Error Δv	Width
Hδ λ4101	4106.88	0.38	429.5	27.7	765.5	49.5	8.9
Hβ λ4861	4866	0.1	308	6	704	14	9.7
$[O\ I]\lambda 6300$	6307	0.08	333.333	3.8	470	5.4	8.4
Hα λ6563	6569.8	0.18	319.6	8	569.9	14.6	10.6
$[S\ II]\lambda 6716$	6723.7	0.16	342.79	7	462.3	9.6	8.8

Table 1: Spectral lines widths and velocities, measured from the spectrum by the Gaussian method

Bibliography: H. Edri, S. E. Rafter, S. Kaspi, D. Chelouche, E. Behar 2012 Photometric Reverberation Mapping of NGC4395 ApJ, 756, 73 - 80 , D. Chelouche & E. Daniel 2012, ApJ, 747, 62