REMAP: **RE**verberation **M**apping of **A**ctive Galactic Nuclei **P**rogram at the 2-m Himalayan Chandra Telescope

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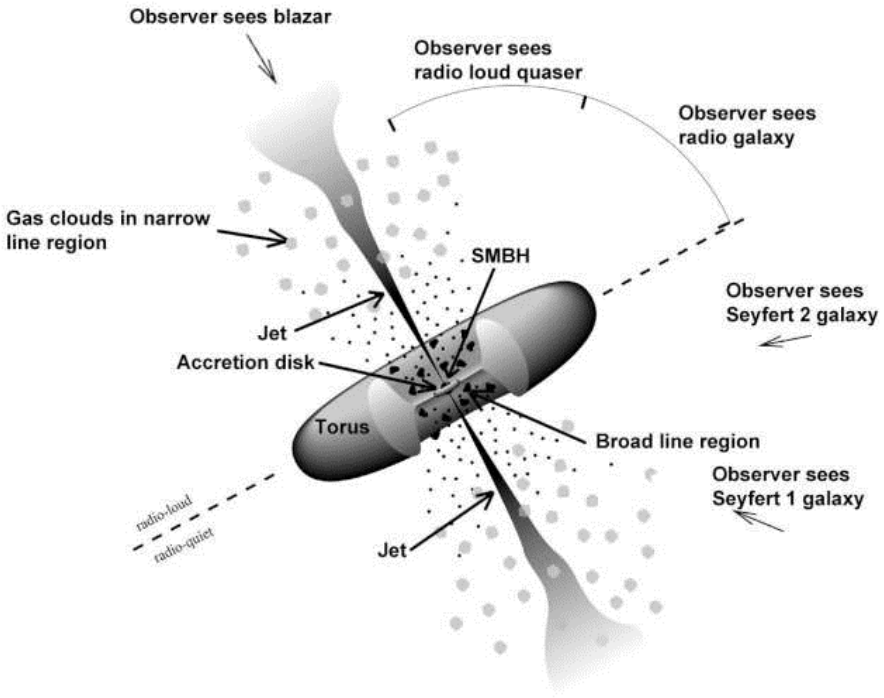
Introduction

- Active Galactic Nuclei (AGN): one of the most luminous objects confined within a very small concentrated volume(~ 1 cubic parsec)

- Luminosity L ~ 10^{44} erg s^{-1}

- Powered by accretion of matter onto super-massive blackhole (SMBH) located at the centers of galaxies

- Unification scheme of AGN



The technique of Reverberation mapping

Echo / Reverberation mapping (Blandford and McKee 1982; Peterson 1993, 2014) is a standard tool for probing the structure and kinematics of the BLR and dust torus region in AGN.

- In its simplest form, the mean time delay between continuum and emission line / NIR variations is measured typically by cross-correlation of the respective light curves.
- Transfer equation:

$$b(t) = \int \psi(\tau)\, a(t - \tau)\, d\tau$$

a(t) => optical / UV continuum light curve, b(t) => line / NIR light curve, $\psi(\tau)$ => transfer function, τ => lag between the two light curves .

Application of Reverberation Mapping

- Reverberation mapping / Echo mapping can be used as a tool to probe the inner regions of AGN not resolvable using any imaging techniques available today.
- Applications are:

    1. Spectroscopic reverberation to find the mass of the black hole
    2. Photometric reverberation to find the mass of the black hole
    3. Dust reverberation to find the extent of the dust torus

Objectives

- Estimation of the size of the dust torus using dust reverberation mapping (DRM).
- Estimation of the mass of the black hole using spectroscopic reverberation.

Dust Reverberation Mapping (DRM)

- Dust Reverberation mapping is based on the response of the near infrared (NIR) flux to the optical flux (V-band).
- NIR flux reverberates / echoes with the optical/UV flux. Therefore, a lag is expected between the NIR flux and the optical V-band flux.
- Reverberation mapping observation provides a unique and important tool for investigating the structures of the innermost dust torus.

Reverberation Mapping Assumptions

- The continuum originates in a single central source.
- Light-travel time is the most important time scale. We assume that the dust torus responds instantaneously to changes in the continuum flux.
- There is a simple, though not necessarily linear relationship between the observed continuum and the ionizing continuum.

Dust lag vs. Optical/UV Luminosity

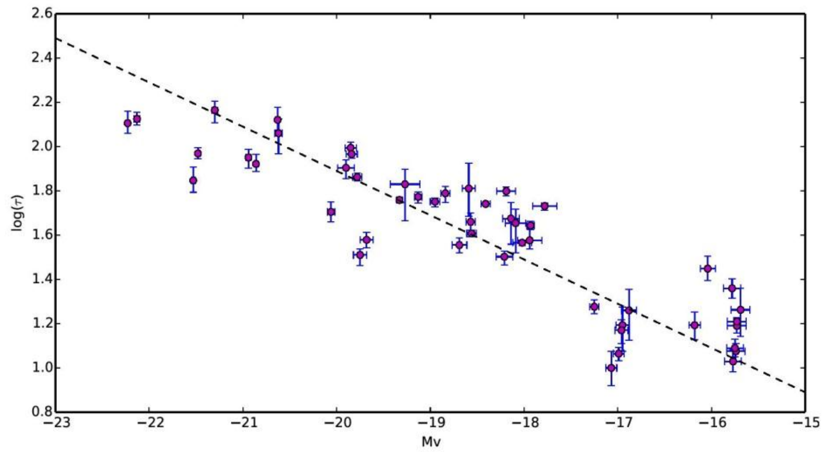
- The inner radius of the dust torus is given by Tomita et al. (2006) and Koshida et al. (2014):

$$R_{sub} = 1.3\,(L_{UV} / 10^{44}\ \mathrm{erg\ s\ -1})^{0.5}\,(T_{sub} / 1500\mathrm{K})^{-2.8}\,(a / 0.05\mu\mathrm{m})^{-0.5}$$

L_{UV} ⇒ UV luminosity of the accretion disk, T_{sub} ⇒ sublimation temperature of dust, a ⇒ dust grain size

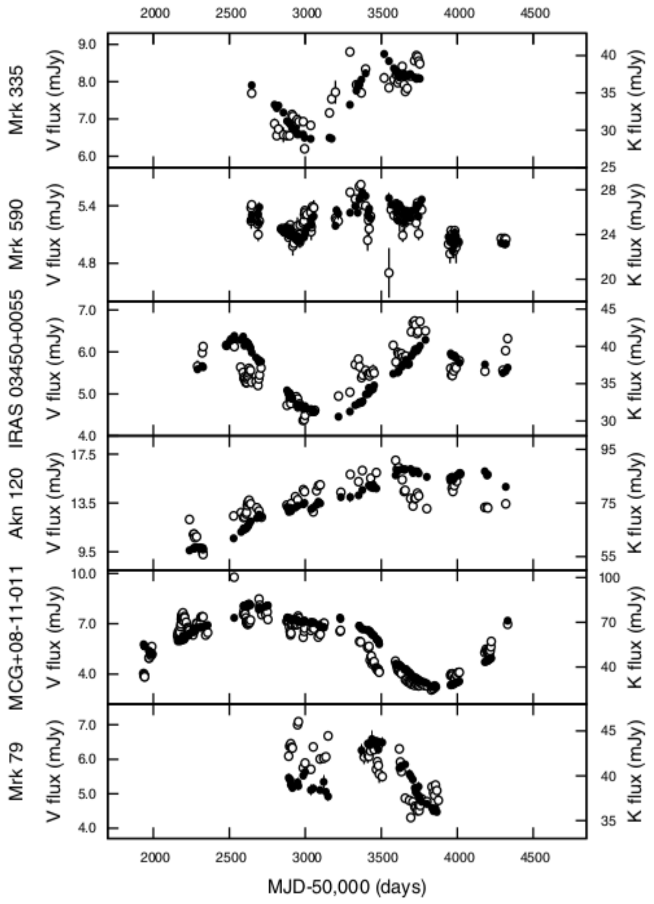
- Lag-luminosity Relationship based

on data of Koshida et al. (2014)



Current Scenario of DRM: Limitations

- DRM is applied for only about about 20 AGN to measure the dust radius (KoDRM is applied for
- The light curves used in DRM so far are not well sampled in time having large error bars in lag measurement.



Aim of DRM

- The main aim is to find the inner radius of the dust torus.
- Multi-wavelength studies were used to reveal the structure of the dust torus.
- The method of dust reverberation mapping as of now has been applied to about twenty AGN to measure the inner rim of the torus.
- The possible reasons for the lack of such data could be due to

    a) Difficulties in scheduling observations in the optical and NIR.

    b) Due to limited attempts made in this direction.

- These observations will be used to increase the sample size for the measurement of dust torus and also decrease the error bars due to gaps in the time series data.

Our Sample

Selection criteria: a) The original sample from Bentz (2015) data base containing 60 objects, b) BLR lags must be less than 10days, c) Objects must be brighter than 16 magnitude in V-band

S. No.	Object Name	RA	DEC	g (mag)
1	H0507+164	05:10:45.5	+ 16:29:56	15.88
2	Z 229-15	19:05:25.9	+ 42:27:40	15.40 (B)
3	Mrk 142	10:25:31.3	+ 51:40:35	15.82
4	SBS116+58A	11:18:57.7	+ 58:03:24	15.68
5	Arp 151	11:25:36.2	+ 54:22:57	15.90
6	Mrk 1310	12:01:14.3	– 03:40:41	14.83
7	Mrk 202	12:17:55.0	+ 58:39:35	15.40
8	NGC 5273	13:42:08.3	+ 35:39:15	11.98

Observation

- Observations are carried out using 2m HCT, Hanle operated by Indian Institute of Astrophysics.

Himalayan Chandra Telescope

(Aperture : 2m)

Detector	CCD	Gain (e^- / ADU)	Readout Noise (e^-)
HFOSC	2K X 2K	1.22	4.8
TIRSPEC	1K X 1K	6	25

Optical and NIR data Reduction

- The optical data reduction are carried out using IRAF (Image Reduction and Analysis Facility) and MIDAS (Munich Data Analysis System).
- The NIR data in J, H, K_s bands are reduced using TIRSPEC Data Reduction pipeline and IRAF.

Subtraction of the accretion disk component from the NIR (J, H, K_s band) Flux

- The NIR-flux also contains emission component coming from accretion disk.
- This accretion disk component would make the time lag shorter than the actual lag of the dust-torus emission.
- Contribution of accretion disk needs to be removed, will be done as follows:

$$f_{NIR,disk}(t) = f_V(t)\ (\nu_{NIR} / \nu_{NIR})^{\alpha}$$

$f_V(t) \Rightarrow$ V-band flux, ν_V & ν_{NIR} are effective frequencies of V, NIR (J, H, K_s)-bands respectively, $\alpha \Rightarrow$ power-law index

Host galaxy subtraction and error calculation

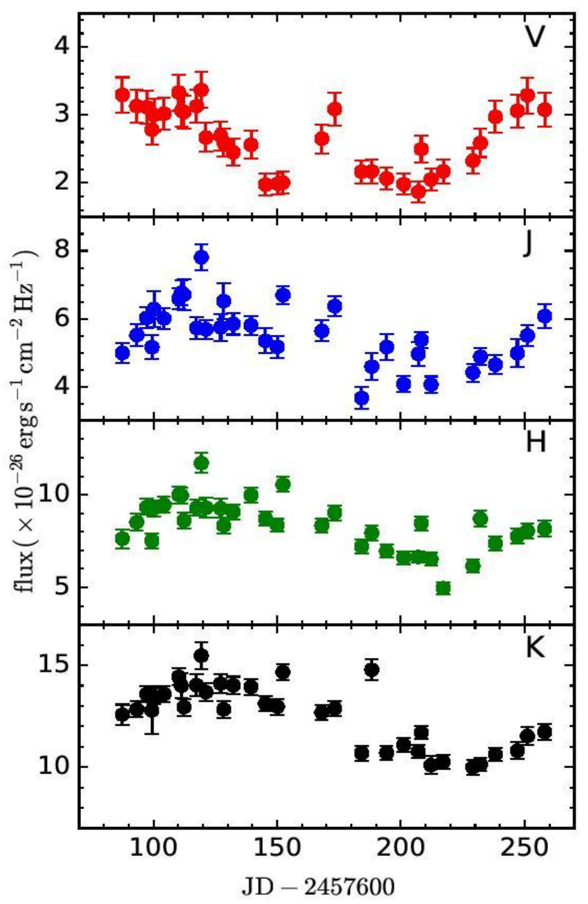
- Some sources can have prominent host galaxy that can affect the photometry. In such cases GALFIT will be used to remove the host galaxy.
- Once the final light curves are generated, lags will be determined using cross-correlation function (CCF) analysis. The errors in the lag will be determined by Monte Carlo methods.

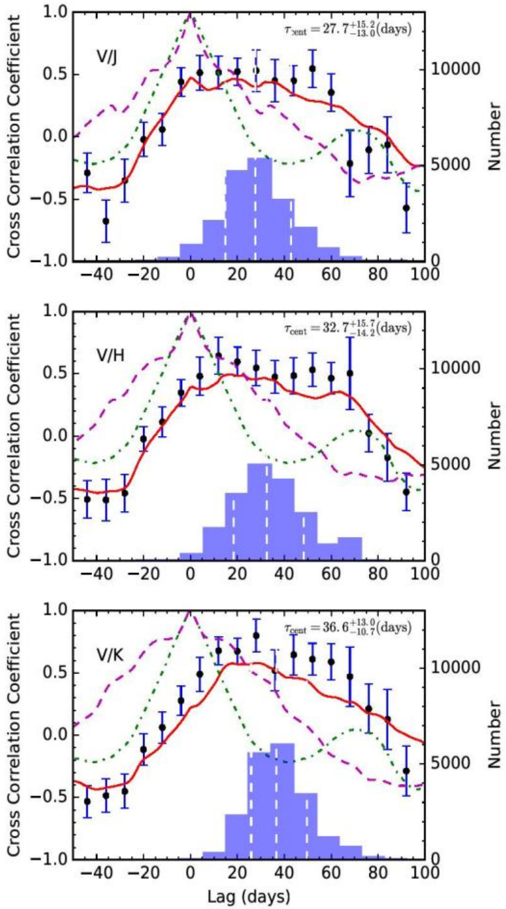
Status so far

- From our sample of 8 sources, we have completed observation and analysis of one source namely H0507+164.
- The observation of the second source is ongoing (one data point every 5 days weather permitting).
- This is expected to be completed by the end of October 2018.
- After October 2018, 6 more sources in our sample needs to be observed.

Results for H0507+164

- The lag between V and K_s band was taken as the measurement of the inner radius of the dust torus.
- The lag of $35.2^{+12.3}_{-9.8}$ days between V-band and K_s -band for the bin-size $\Delta\tau = 5$ days obtained from DCF analysis was taken to calculate the inner radius of the dust torus.
- So based on light travel time argument we found $\approx 0.03^{+0.01}_{-0.008}$ pc as the inner dust torus radius for H0507+164.

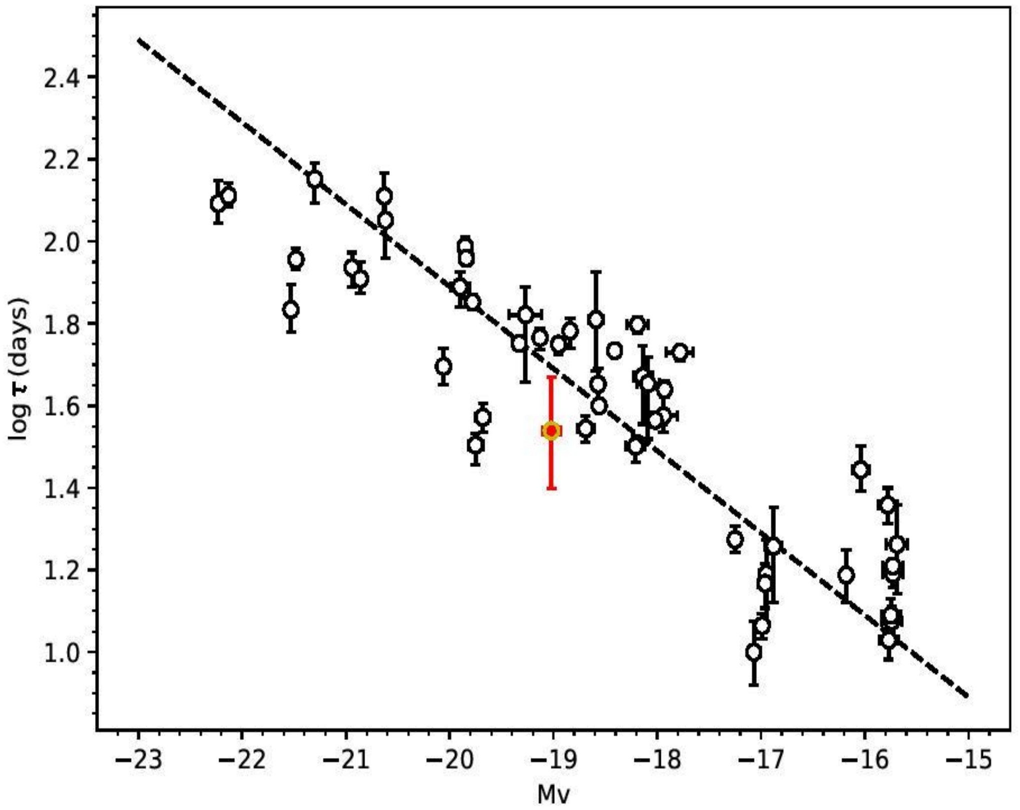




Lag – luminosity relationship

- Dust lag–luminosity relationship using the data of Koshida et al. (2014). The filled circle corresponds to the lag between the V and K s bands determined for H0507+164, which lies close to the regression line (dashed line), obtained by Koshida et al. (2014). The lag times were corrected for the time dilation effect using the object redshift.

The obtained results are published in Mandal et al. 2018 (MNRAS, Volume 475, Issue 4, p.5330-5337)



Summary

a. Reverberation mapping is an excellent tool to find the inner edge of the dust torus.

b. We have started a program called REMAP (REverberation Mapping of AGN Program) using the 2m HCT which also involves reverberation observations (spectroscopic / photometric) to find the mass of the central black hole.

c. Our sample for dust reverberation consists of 8 sources.

d. Observations completed for one source, second one is expected to be over by the end of October 2018. Observations on the remaining 6 sources is expected to be completed by the year 2020.

REMAP @ BINA

Reverberation is a method to find the inner extent of the dusty torus using moderate sized telescopes

It is now possible to resolve the inner regions of AGN via direct imaging using large telescopes

We want to do this. Our targets could be low redshift AGN. The telescope is VLTI and the instrument is GRAVITY (Jean Surdej, Denis Defrere)

Sample selection is over, proposal will be submitted in March 2019

Would also explore the possibility of dust reverberation mapping on small telescopes available within BINA


Thank you