Echo Mapping of Active Galactic Nuclei

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Physical scales of components of AGN

- Accretion disk (R ~ 0.001 pc)
- Broad Emission line Region (BLR) (R ~ 0.01 - 0.1 pc)
- Dust torus (R ~ 0.1 - 1 pc)
- Narrow Line Region (NLR) (R ~ 1 - few 10 pc)
- Relativistic Jets (Can extend upto Mpc scales)

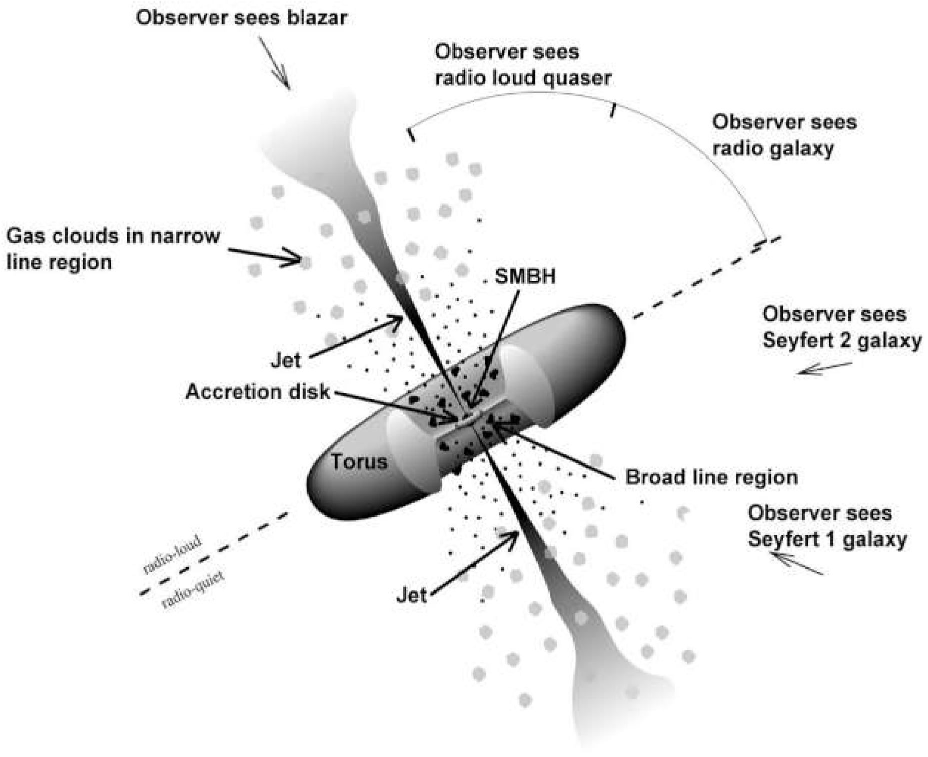


image courtesy: Fermi Gamma-ray Space Telescope

Probing central engine of AGN

➢Difficult using any direct imaging techniques.

➢NIR Interferometry was applied for only few nearby ($z < 0.1$) bright AGN to measure torus size (Kishimoto et al. 2011, Gonzagon et al. 2016).

➢GRAVITY Collaboration (2018) observed 3C 273 using GRAVITY and found BLR size of 145 +/- 35 days using Pa α.

➢Carilli et al. (2019) found an elongated structure in Cygnus A perpendicular to the radio jets and centered on the core with a full length of 0.48" (528 pc), and a full width of 0.26" (286 pc) using Jansky Very Large Array.

- Indirect method: Reverberation mapping / Echo mapping technique (Blandford and Mackee 1982, Peterson 1993, 2014).

- Though NIR and radio interferometric observations are able to find the extent of the BLR/torus in 3C273 and Cygnus A, interferometric observations can be extended to only few nearby AGN, limited to brightness as well as the redshift of the sources. This limitation is not with Reverberation Mapping.

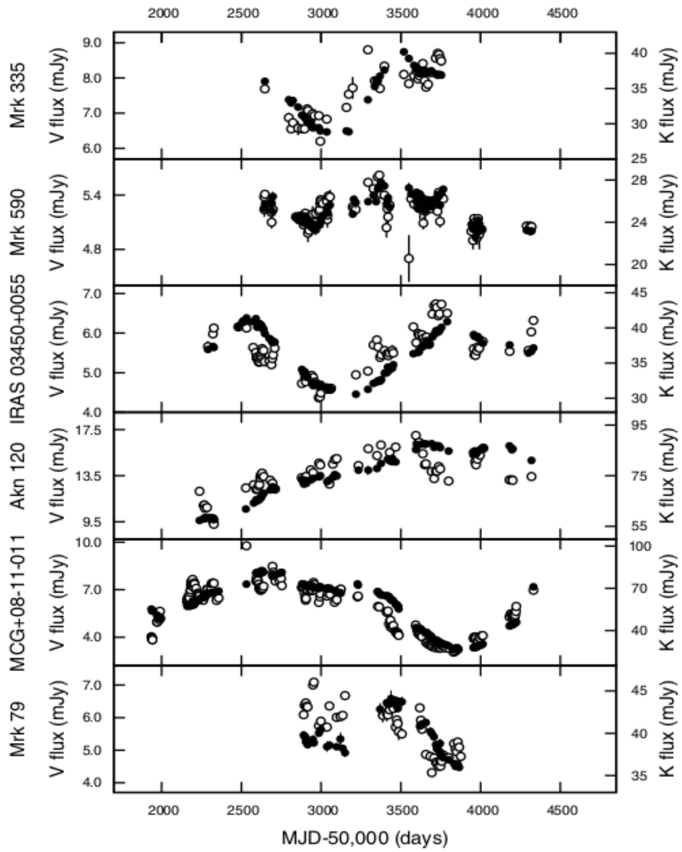
The current scenario

‣Spectroscopic reverberation has now been done for about 100 AGN, has enabled to find the BH masses (major uncertainty here is the scale factor).

‣Dust reverberation has been applied to about a dozen AGN (needs to increase this)

‣The light curves used in DRM so far are not well sampled and have large errors in lags

‣Example of light curves from Koshida et al. (2014).



V-band (open circles) and K-band (filled circles) light curves of Mrk 33 Mrk 590, IRAS 03450+0055, Akn 120, MCG +08-11-011 and Mrk 79.

REMAP : REverberation Mapping of AGN Program

- **REMAP** was initiated in 2016.
- **REMAP** includes : i) Dust Reverberation Mapping (DRM)

  ii) BLR Reverberation

AIM

- 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.
- 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.
- BLR Reverberation: Photometric BLR reverberation mapping using two narrow band filters.

Methodology

➢**Observation**

Observations are carried out using 2m Himalayan Chandra Telescope (HCT), Hanle operated by Indian Institute of Astrophysics.

Telescope is located at Hanle, at an altitude of 4500 m, operated remotely from Bangalore, through dedicated Satellite link provided by the Indian Space Organization (ISRO).

Detector	CCD	gain(e^- / ADU)	Readout Noise (e^-)
HFOSC	2KX2K	1.22	4.8
TIRSPEC	1KX1K	6	25

Our Sample

Selection criteria: a) Objects having dec > -10 deg, b) BLR lags must be less than 10days, c) Objects must be brighter than 16.7 magnitude in V-band

S. No.	Object Name	RA	DEC	V (mag)
1	H0507+164	05:10:45.5	+16:29:56	15.77
2	Z 229-15	19:05:25.9	+42:27:40	15.62
3	Mrk 142	10:25:31.3	+51:40:35	16.12
4	SBS116+583A	11:18:57.7	+58:03:24	16.69
5	Arp 151	11:25:36.2	+54:22:57	16.47
6	Mrk 1310	12:01:14.3	-03:40:41	15.89
7	Mrk 202	12:17:55.0	+58:39:35	16.39
8	NGC 5273	13:42:08.3	+35:39:15	13.12

Analysis

Subtraction of the Accretion disk component from the NIR (J, H, K_s -band) flux:

- The observed NIR-flux contains continuum 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, is done as follows (Koshida et al. 2014):

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

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 are determined using cross-correlation function (CCF) analysis.

- We used both Discrete Cross-correlation analysis (DCF: Edelson & Krolik 1988) and Interpolated Cross-correlation analysis (ICCF: Gaskell & Sparke 1986; Gaskell & Peterson 1987) method.

- The errors in the lag are determined by Monte Carlo methods .

Results

- From our sample of 8 sources, we completed observation and analysis of one source namely H0507+164.

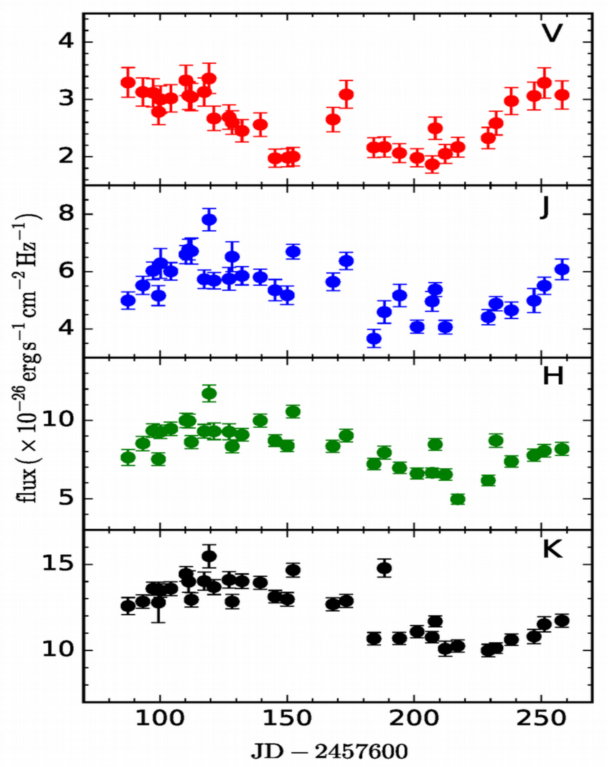
- Observations of two more sources are over.

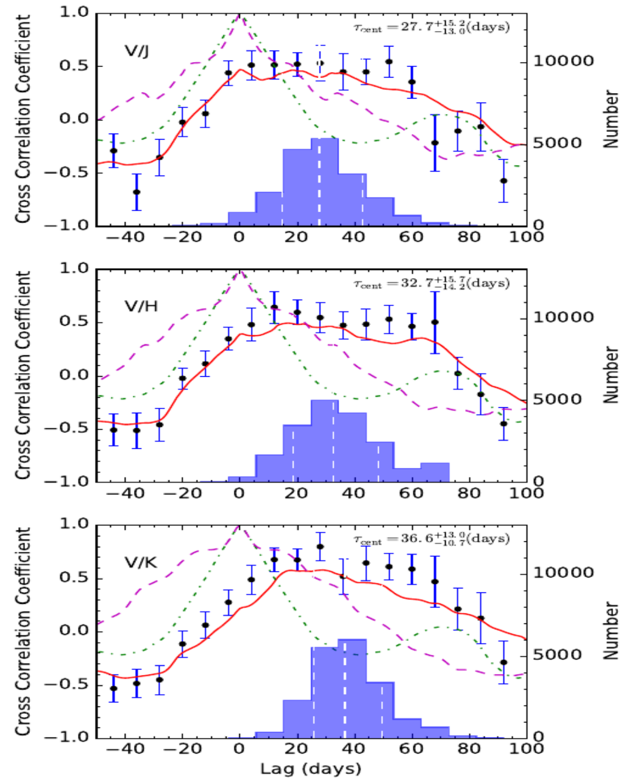
- Observations of the fourth source in our sample is going on.

H0507+164

- Observing period: October 2016 to April 2017
- Epochs: 35

Bands	Rest frame time lag (days)
V-J	27.1 (+13.5/-12.0)
V-H	30.4 (+13.9/-12.0)
V-K_s	34.6 (+12.1/-9.6)





Mandal et al. (2018), MNRAS, 5330-5337

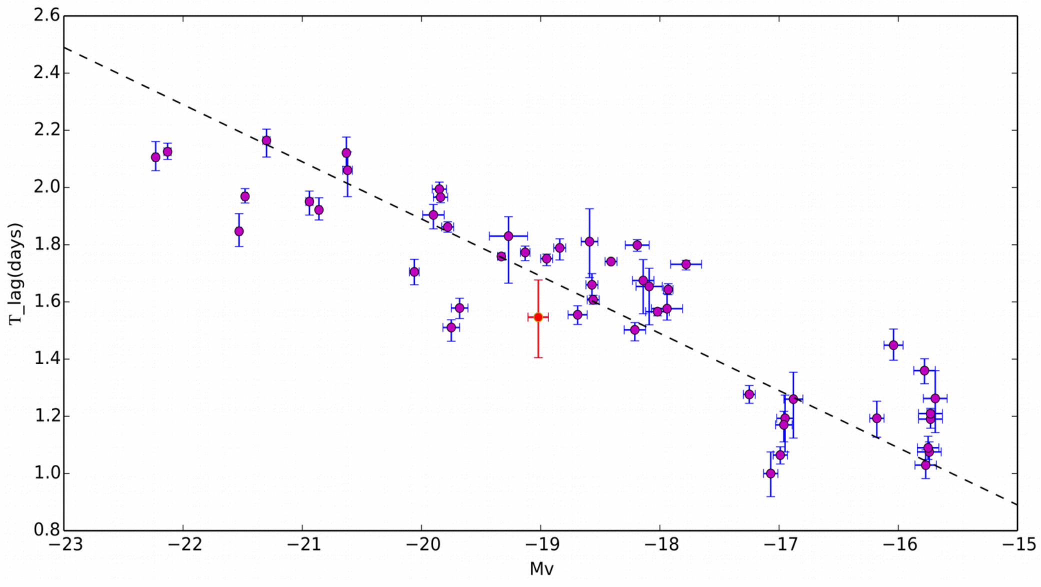
Lag – luminosity relationship

The inner radius of the dust torus (dust sublimation radius)

$R_{sub} \propto L_{UV}^{\ 0.5}$

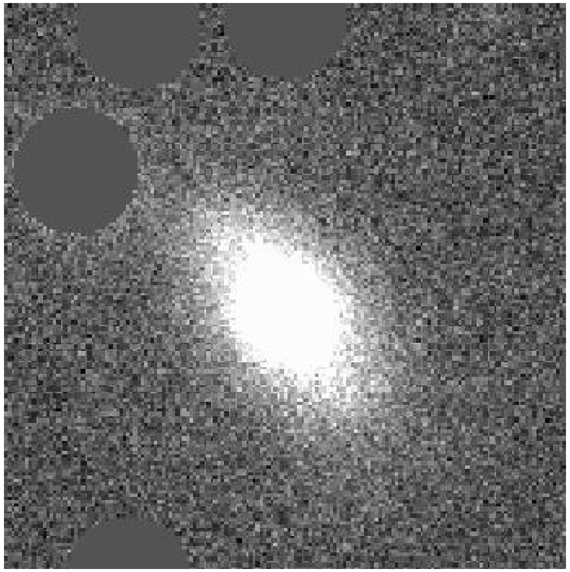
Inner radius of dust torus for H050+164 ~ 0.03 pc (lag between V and K_s bands) (Mandal et al. 2018)

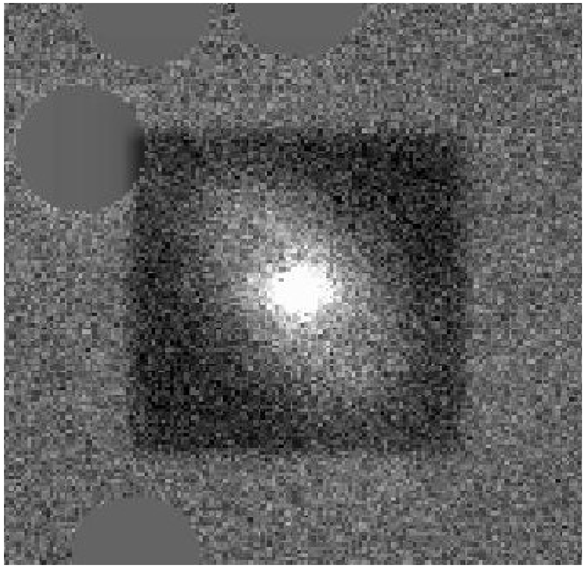
Dust lag–luminosity relationship using the data of Koshida et al.(2014). The filled circle corresponds to the lag between the V and K_s bands determined for H0507+164, which lies close to the regression line (dashed line), obtained by Koshida et al. (2014). The lag times were corrected for the time dilation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

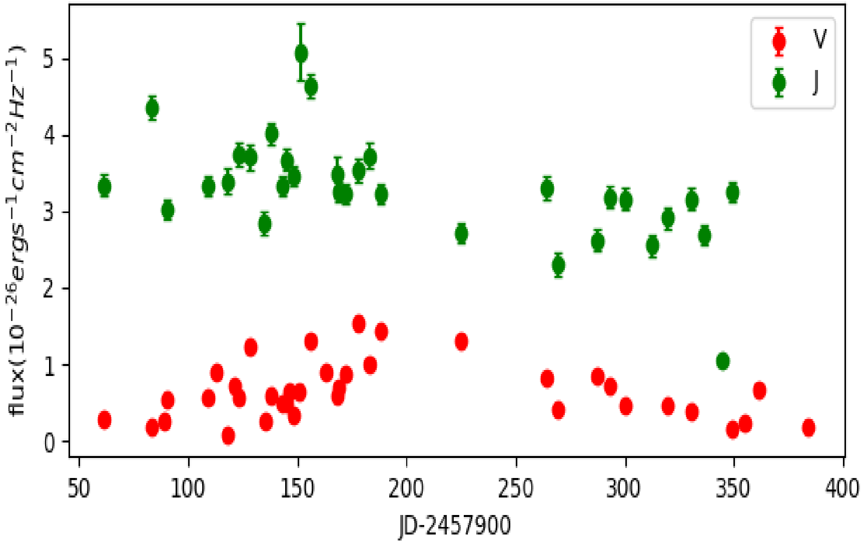


Z229-15

- Observations are completed; have accumulated 48 epochs of data over the period of 26-07-2017 to 14-06-2018 .
- Has a conspicuous host galaxy
- GALFIT was performed on the observed optical images
- Optical observations done in V and B-bands; with an aim to get the spectral index and subsequently use that to remove the continuum contribution in the IR.







Status

DRM: Sample = 8, completed =1, partially completed =2 (observations are over, analysis is ongoing), 5 more sources will be observed.

BLR Reverberation: Two sources selected for photometric BLR reverberation mapping using two narrow band filters (4861A and 6563A).


Thank you