# SPM - Reververation Mapping Project

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# Work Team

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- Alan Watson
- Margarita Pereira
- William Lee

## UC - Irvine:

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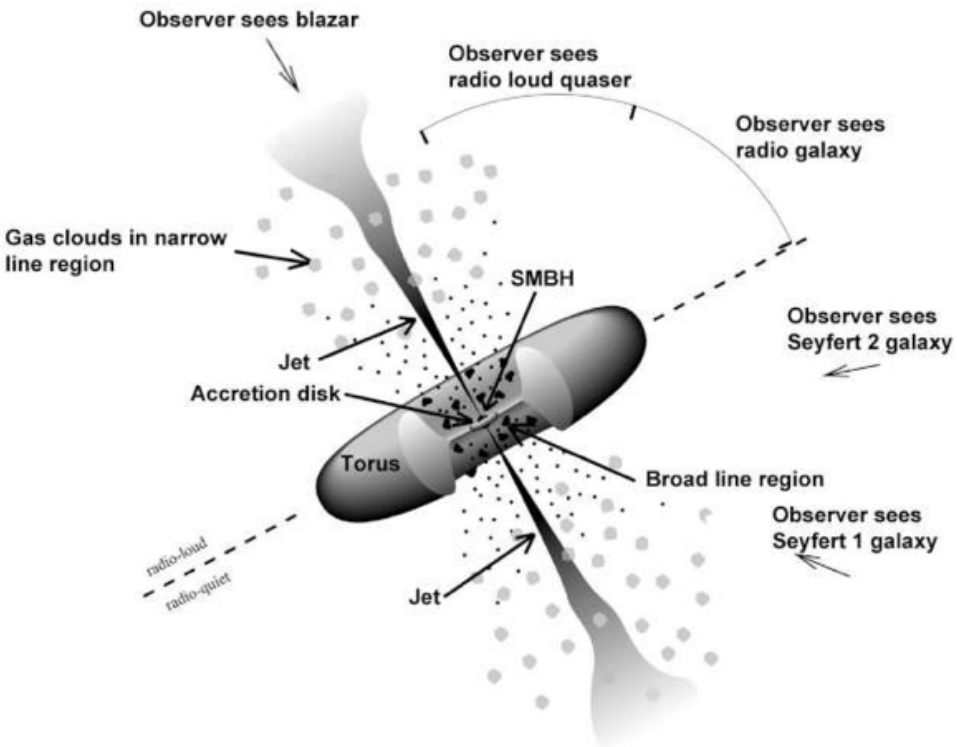
- Dale Muud
- Vivian U.

## Other collaborators

Erin Kara (University of Maryland), Ian McHardy (University of Southampton), Jong-Hak (Seoul National University)...

# Overview

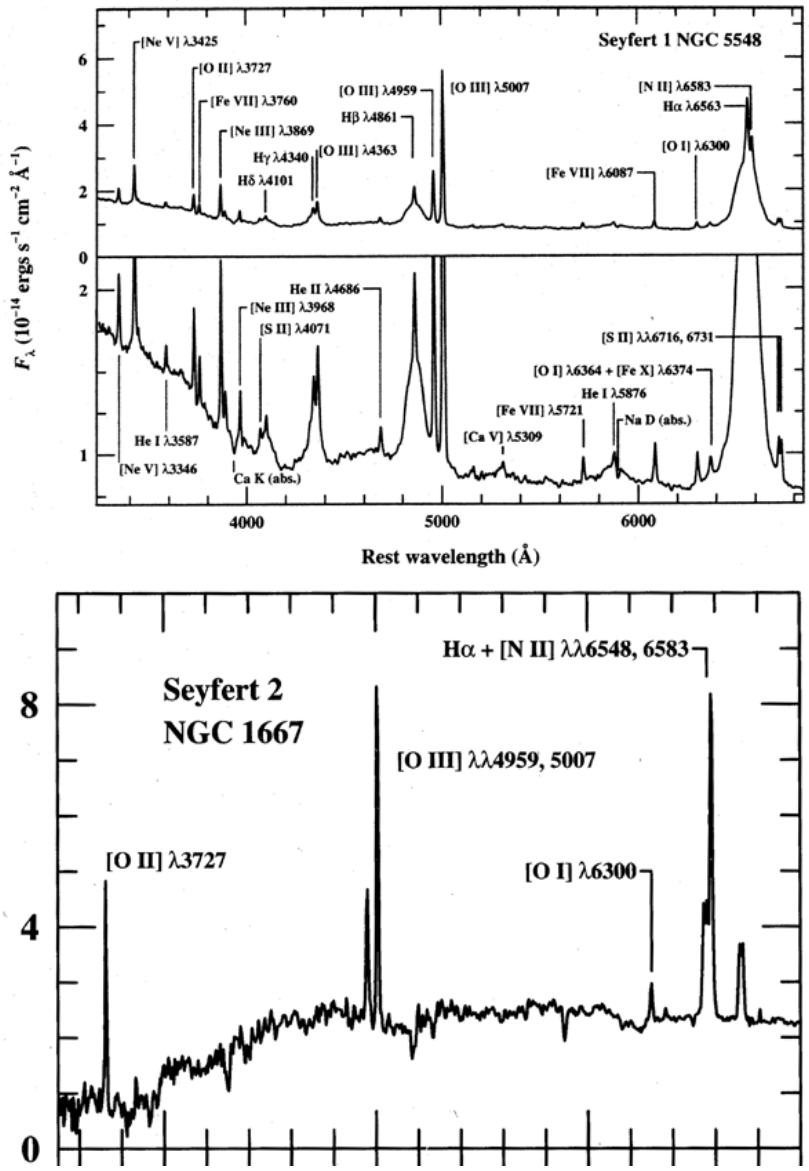
# Introduction




Characteristics of the AGNs:

- SM Black Hole ($> 10^5 M_\odot$)
- Accretion disk
- Obscuring Torus
- Jets
- Narrow-line region
- Broad-line Region

The unified model suggest that the observed differences between the different types of AGN is simply and orientation effect (Urruy & Padovani 1995).



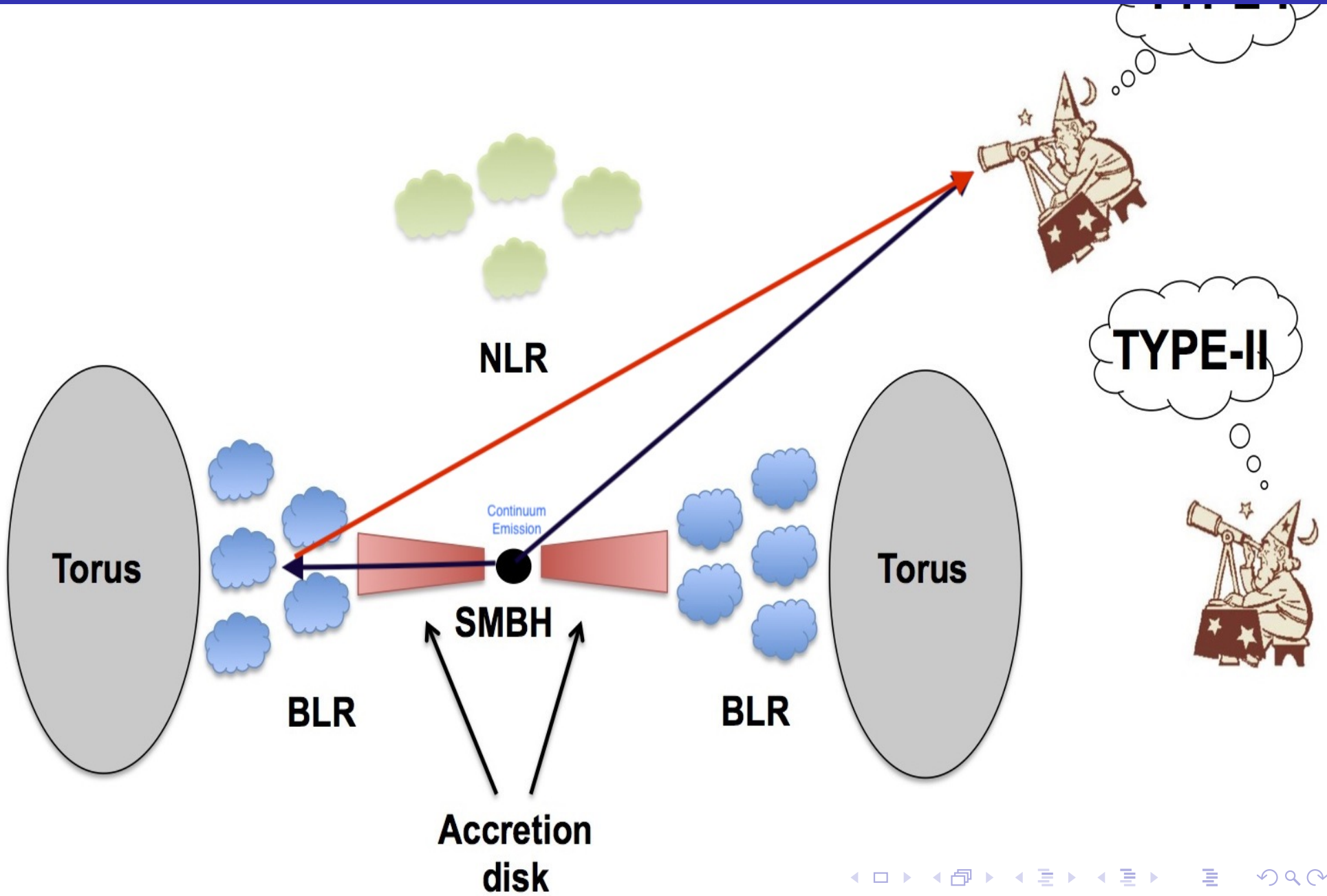

B.M. Peterson An Introduction to Active Galactic Nuclei, Cambridge University Press, (1997)

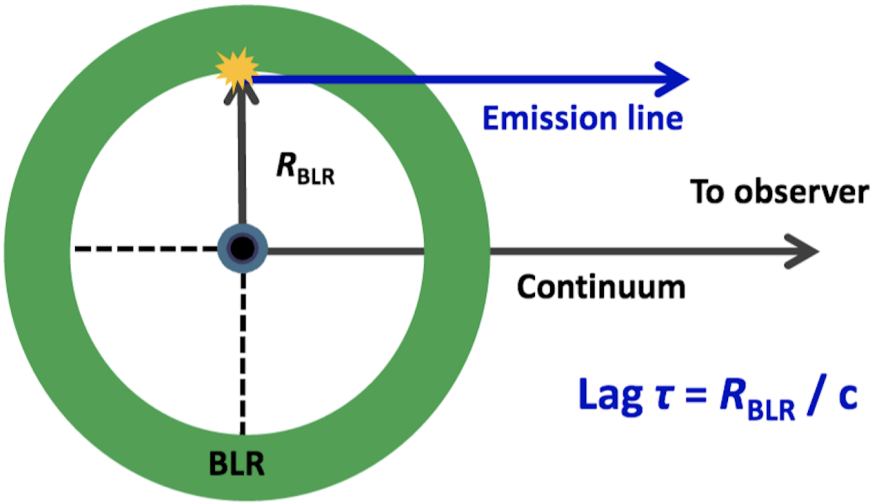
Understanding the interior structure of AGNs has been a major goal of extragalactic astrophysics since their identification as cosmological objects (Schmidt 1963), but the details of the AGN interior structure remain poorly understood.

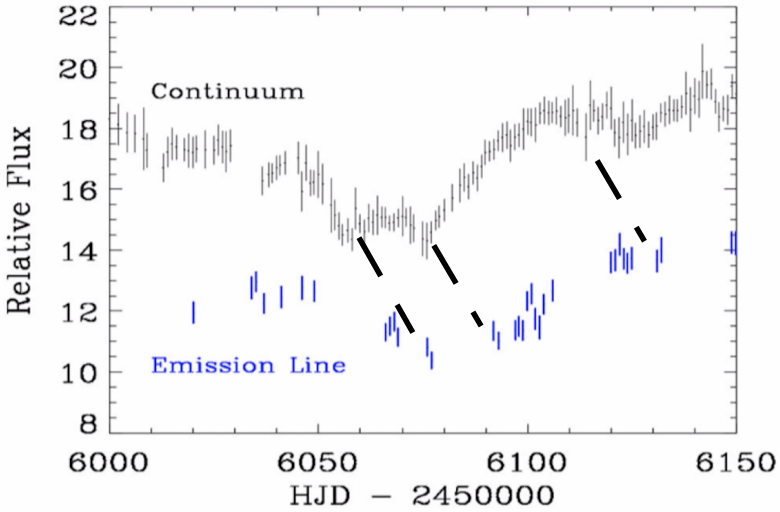
Reverberation mapping (RM, Peterson 2014) is an effective way of investigating the AGN scenarios. RM exploits the intrinsic variability of AGNs to investigate the matter distribution around the SMBH. The inner parts of the accretion disk emit in the far-UV providing ionizing photons that dive line emission from BLR gas. As the accretion disk are reprocessed as line emission by the BL gas after a time delay that correponds to the light-travel time across the BLR.

- Spectroscopy reverberation to find the mass black hole.
- Photometric reverberation study of the accretion disk.

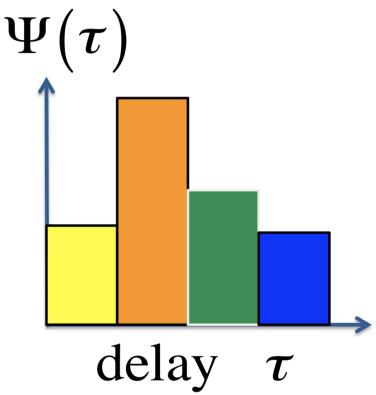
# Reverberation Mapping

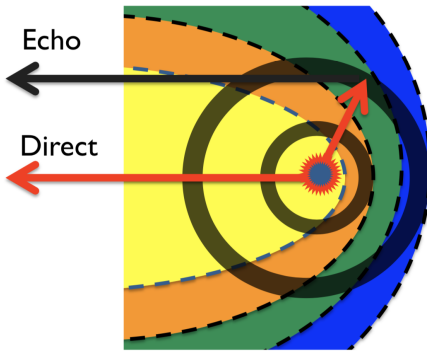





L. Pei et al. 2017



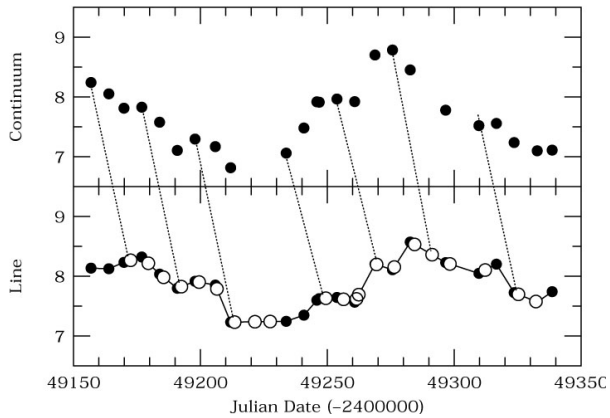

By combining the measured time delay $\tau$ with the emission- line width $\Delta V$ a virial mass can be obtained,

$$M_{BH} = \frac{f c \tau \Delta V^2}{G} \qquad (1)$$

# lag Time measurement

There are two standard method to calculate the lag time:

1. **Cross-Correlation Function (CCF)**: CCF measures the delay time between two light curves through an interpolation between the data points using a Monte Carlo Method.




2. **JAVELIN** models the behavior of the light curve of the continuum through an autoregressive process using a damped random walk model (DRW), and assumes that all light curves of the other bands (or wavelengths) are scaled and shifted versions of the light curve of the continuum (Zu et al. 2011, 2013).

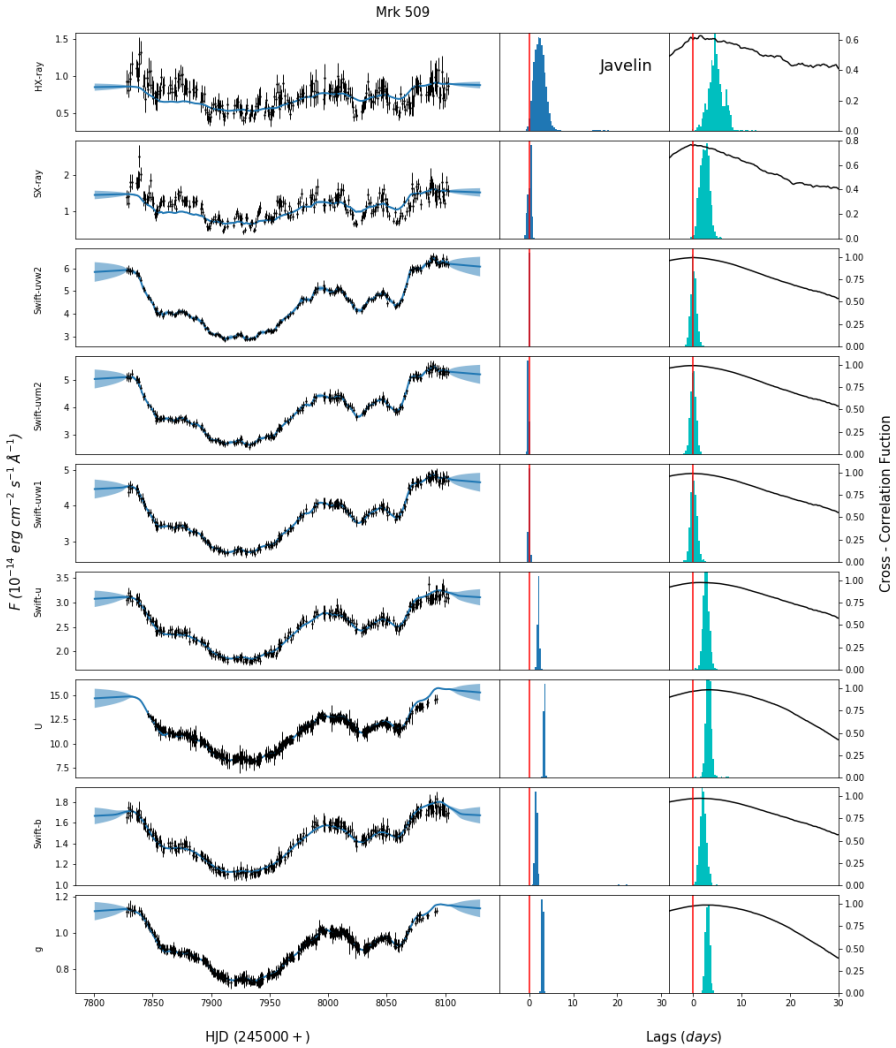
# Example - Continuum Reverberation Lag Measurements for Mrk 509

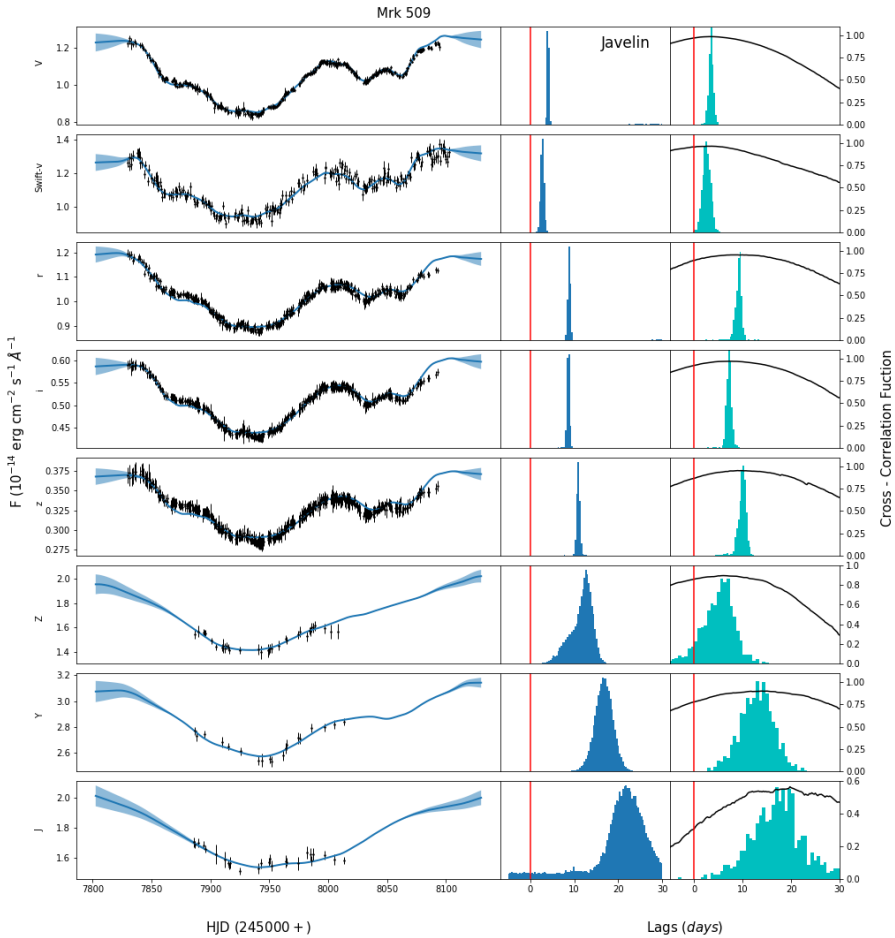
## Mrk 509

- Seyfert-1 Mrk509 is considered one of the brightest galaxies known so far
- with a luminosity of $L_{bol} = 3.5 \times 10^{45} erg\, s^{-1}$,
- with a redshift of 0.034 and a BH mass of $\sim 1.43 \times 10^{8} M_{\odot}$ (Peterson et al. 2004).

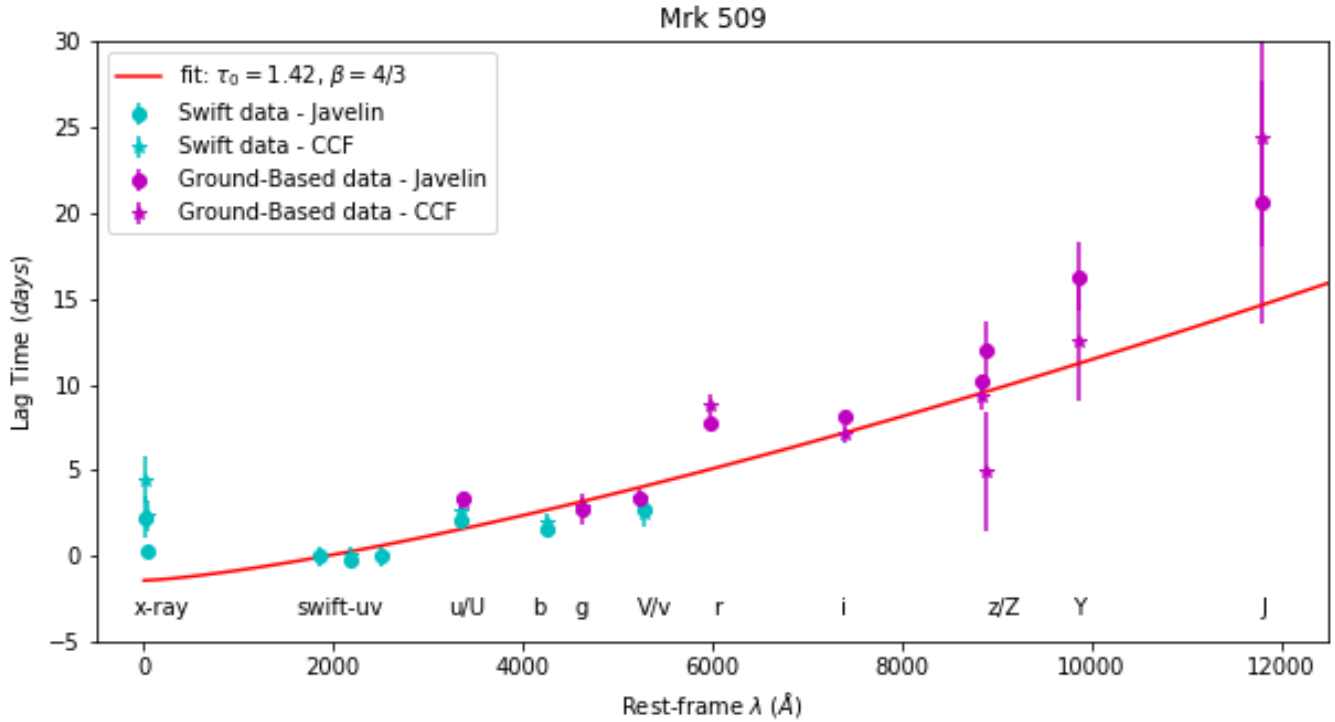
# Observations

# The light curves - Mrk 509



# Lag-wavelength fits




The model of an optically thick, geometrically thin accretion disk proposed by Shakura & Sunyaev (1973)

The T follow the relation $T(R) \propto R^{-3/4}$ for the disk, a lag time $\tau = R/c$ and relation $\lambda \propto T^{-1}$. This leads us to predict follows relationship.

$$\tau = \tau_0[(\lambda/\lambda_0)^{4/3} - 1]$$

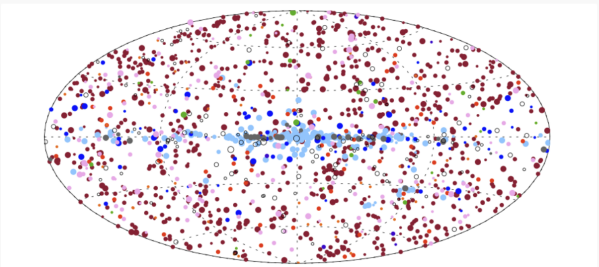
$$r = ct = 0.09(X\frac{\lambda}{1928\mathring{A}})^{4/3} M_8^{2/3} (\frac{m_{Edd}}{0.10})^{1/3} lt - days$$

Edelson et al. (2017)

# SPM - Reverberation Mapping Project

Most of the RM projects are focused on Seyfert I type, bright and widely variable.
one limitation is obtaining continuous, well-sampled (of order 1 day or less) light curves on time scales of weeks to months

## Swift BAT 105-Month Hard X-ray Survey




All-sky map showing the classification of the BAT 105 month survey sources. The figure uses a Hammer-Aitoff projection in Galactic coordinates. The size of the filled dots indicate the measured hard X-ray flux in three different scales ($\log f_{14\text{-}195} < 1.0 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$, $1.0 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ $\leq \log f_{14\text{-}195} < 1.5 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$, and $\log f_{14\text{-}195} \geq 1.5 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$). The colors correspond to each type of the source as shown in the legend.

**Note:**

Unknown class indicates that we do not know source type of the optical counterpart. In particular, 'Unknown class I' is used when there is no soft X-ray (3-10 keV) detection despite its archival soft X-ray observation.

'Unknown class II indicates sources for which there is a soft X- ray detection with SNR threshold greater than 3 from archival soft X-ray observation. When available, we list their 2MASS counterpart source matched within 5 arcsec of angular distance in Table 2.

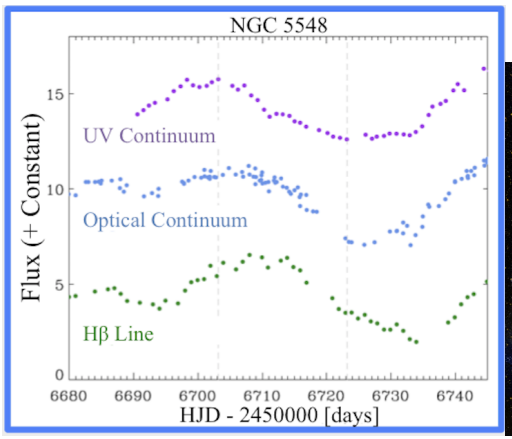
'Unknown class III' includes sources without archival soft X-ray observations.

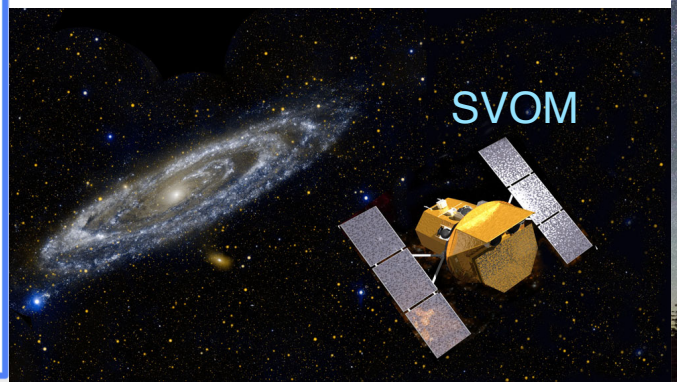
**Update (2018-07-12):**

The counterpart positions have been updated based on the WISE positions based on additional measurements from Ricci et al. 2018, to be consistent with the positions listed in the public version of Oh et al. (2018). There are 57 counterpart position updates (50 of them with less than 1 arcsec offset, and 7 of them with less than 1 arcsec offset, comparing to the old positions). The sources with counterpart position updates can be found in this list.

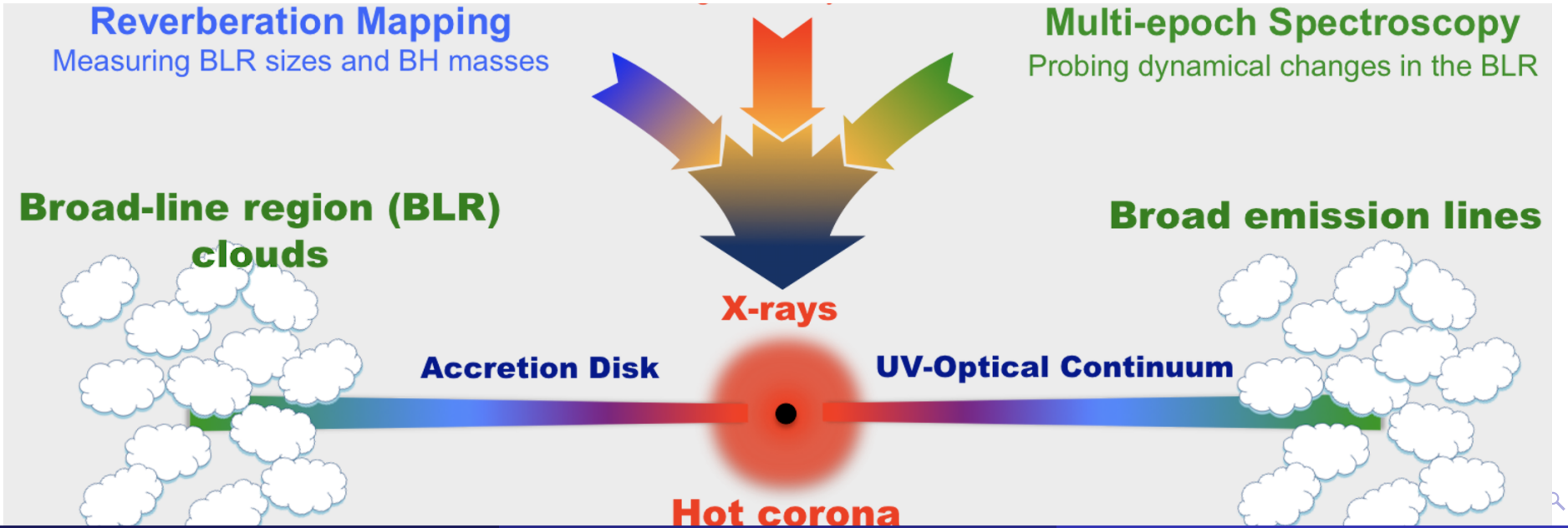
| Class | Source Type | # in Catalog |
|---|---|---|
| 10 | Unknown class I | 36 |
| 11 | Unknown class II | 55 |
| 12 | Unknown class III | 38 |
| 15 | Multiple | 10 |
| 20 | Galactic Center | 1 |
| 30 | Galaxy Cluster | 26 |
| 40 | Seyfert I (Sy 1.0-1.8) | 379 |
| 50 | Seyfert II (Sy 1.9-2.0) | 448 |
| 60 | LINER | 6 |
| 70 | Unknown AGN | 114 |
| 80 | Beamed AGN (Blazar/FSRQ) | 158 |
| 90 | Cataclysmic Variable Star (CV) | 75 |
| 100 | Symbiotic Star | 4 |
| 110 | Other Star | 12 |
| 120 | Open Star Cluster | 1 |
| 130 | Starburst Galaxy | 1 |
| 140 | Compact Group of Galaxies | 1 |
| 150 | Pulsar | 25 |
| 160 | Supernova Remnant (SNR) | 7 |
| 170 | Nova | 6 |
| 180 | High Mass X-ray Binary (HMXB) | 108 |
| 190 | Low Mass X-ray Binary (LMXB) | 109 |
| 200 | Other X-ray Binary (XRB) | 8 |
| 210 | Globular Cluster (GC) | 1 |
| 220 | Molecular Cloud | 2 |
| 230 | Gamma-ray Source | 1 |
| | **Total** | 1632 |

# Future observations



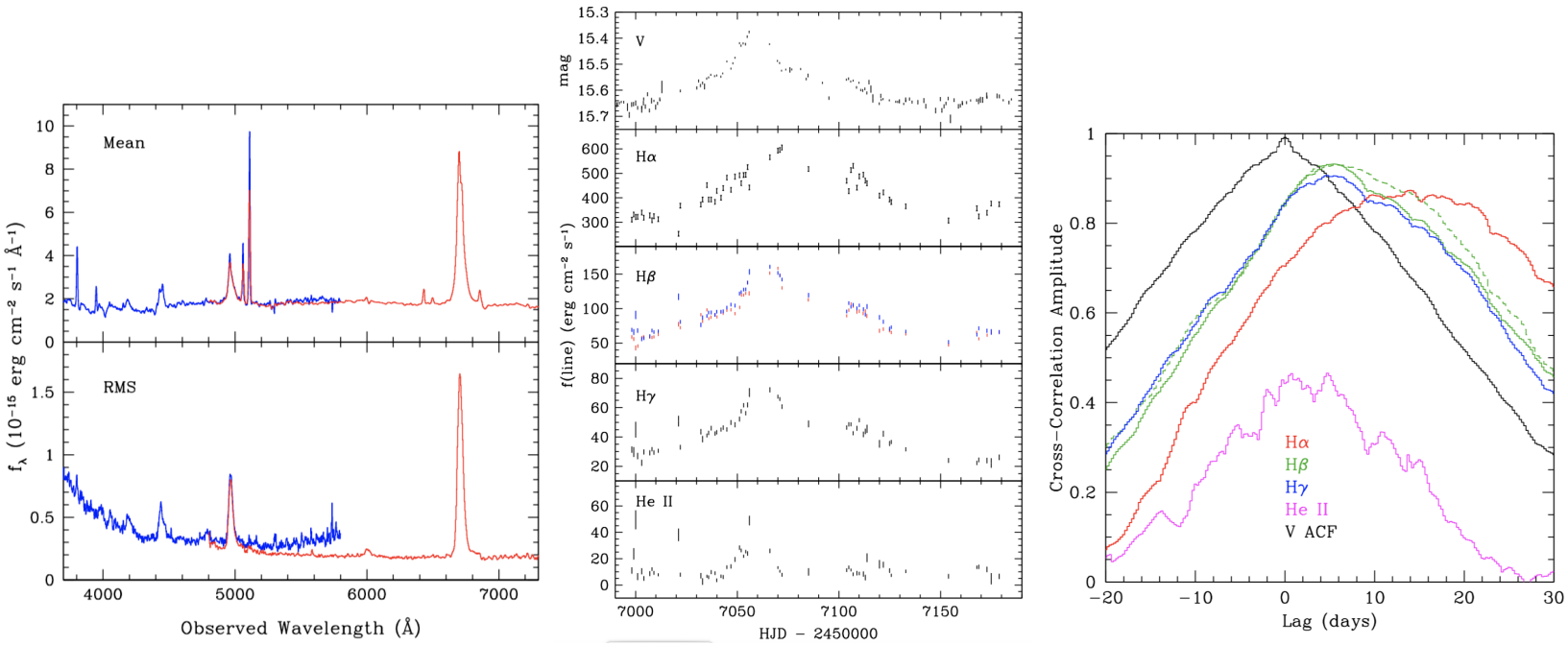







# Example: ROBOTIC REVERBERATION MAPPING OF ARP 151

1. 1-m telescope at McDonald Observatory.
   FLOYDS are a pair of near-identical low-resolution slit spectrographs for the Las Cumbres Observatory 2-meter Faulkes Telescope.
   Resolution $\lambda/\Delta\lambda = 400 - 700$, $\delta\lambda \sim 3200 - 10000$Å.




S. Valenti et al. (2015) - Arp 151

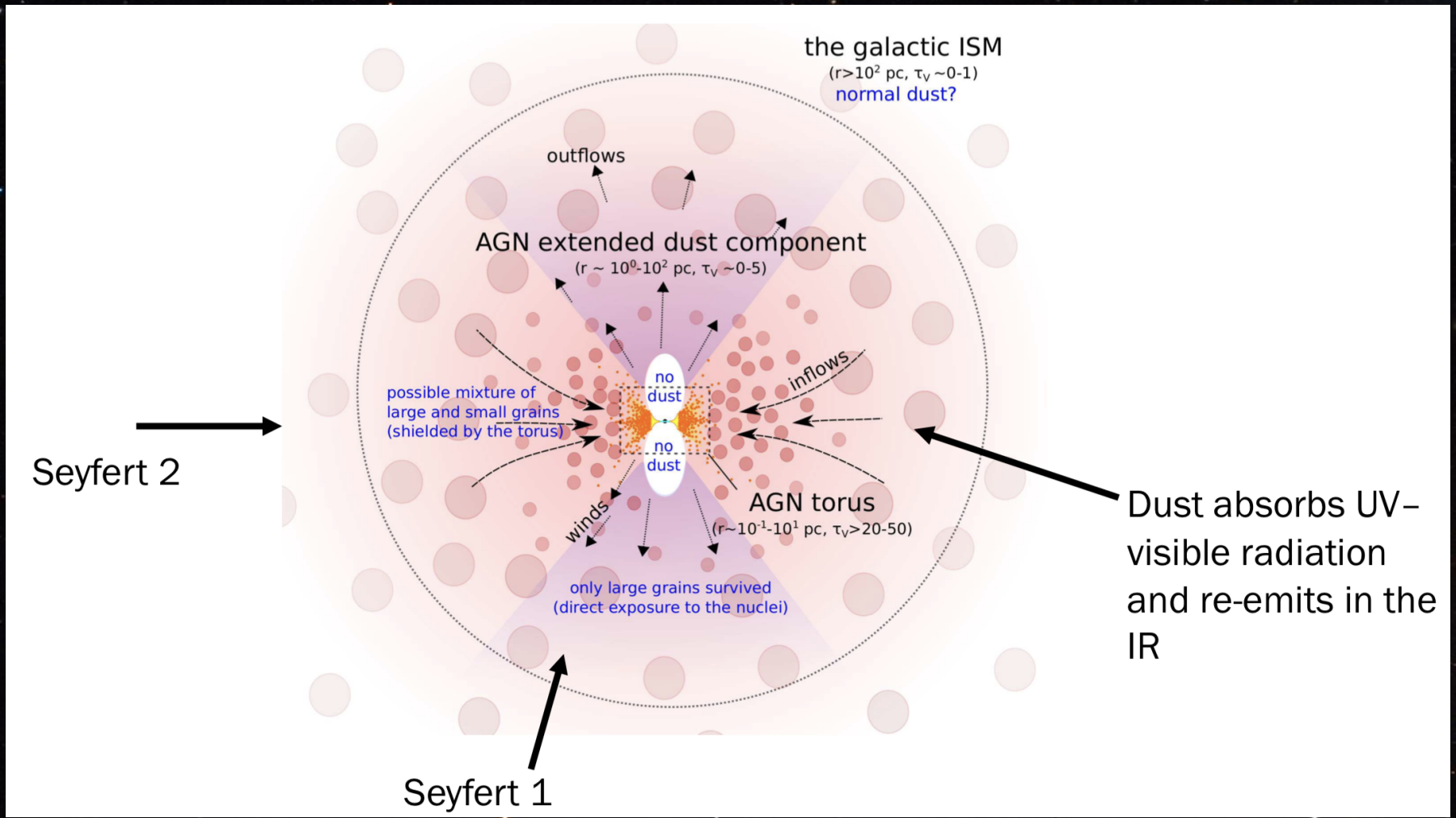
2. they measure time lags between the V-band and the H$\alpha$, H$\beta$ and H$\gamma$ emission lines, with $\tau = 13.89^{1.39}_{-1.41}$, $7.52^{1.42}_{-1.06}$, $7.40^{1.50}_{-2.32}$
3. $B_{BH} = 6.2^{1.4}_{-1.2} \times 10^6\, M_\odot$

# conclusions

Our main goals for the SPM-RM project are:

1. expand the number of reverberation-mapped AGN.
2. To compare the X-ray, UV, optical/IR LCs of the new-AGNs over a concurrent monitoring period, and search for time delays between the continuum and different wavelength.
3. To measure the lags for the emission lines $H\beta$, $H\alpha$, $H\gamma$ and HeII$\lambda$4686. Through the spectroscopic data determine the size of the BLR, and together with the LCs, calculate the time delay and estimate the mass of the BH by means of the RM method.
4. To calculate black hole virial masses, and with the obtained data we will analyze the BLR radius-luminosity correlation and the new-AGN $M_{BH} - \sigma_*$ relationship.


Thank you


the galactic ISM
(r>10² pc, τV ~0-1)
normal dust?
outflows
AGN extended dust component
(r ~ 10⁰-10² pc, τV ~0-5)
possible mixture of
large and small grains
(shielded by the torus)
no
dust
no
dust
inflows
winds
AGN torus
(r~10⁻¹-10¹ pc, τV>20-50)
only large grains survived
(direct exposure to the nuclei)
Seyfert 2
Seyfert 1
Dust absorbs UV–visible radiation and re-emits in the IR