ERASMUS MUNDUS JOINT MASTER DEGREE
MASTER IN ASTROPHYSICS AND SPACE SCIENCE

Tutorial 4: Black holes and accretion disk parameters

Introduction to Active Galactic Nuclei

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Why do we estimate black hole mass in AGN?

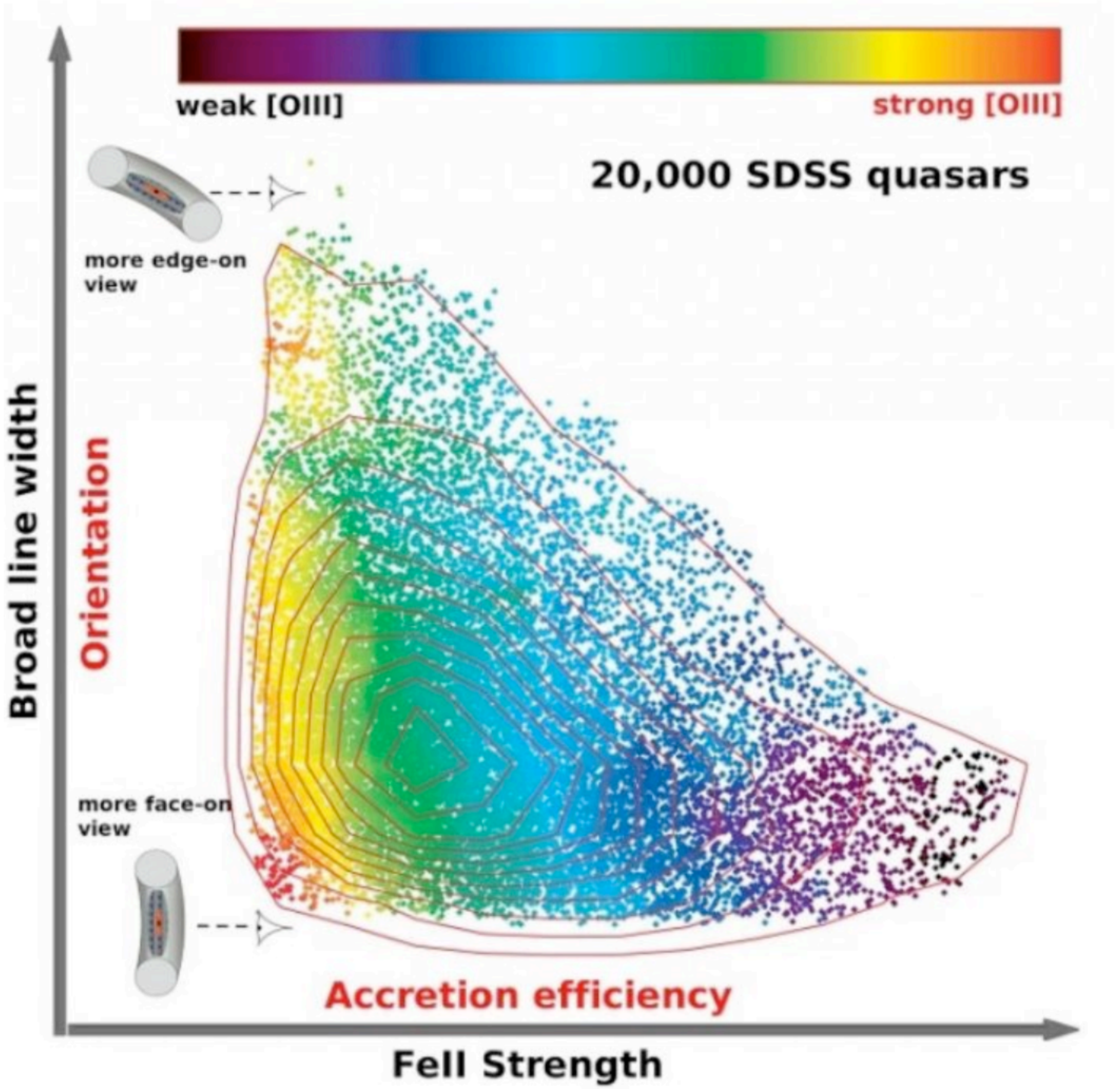
- Constrain the properties of their central engines and understand the physics of energy generation.

- Shed light on formation, growth and co-evolution with their host galaxies.

- Creating unified framework for AGN to understand different AGN classes: study large populations in multidimensional parameter space which includes black hole mass, accretion rate, inclination angle, gas properties, etc.

Quasar main sequence

Shen & Ho (2014)



Direct methods

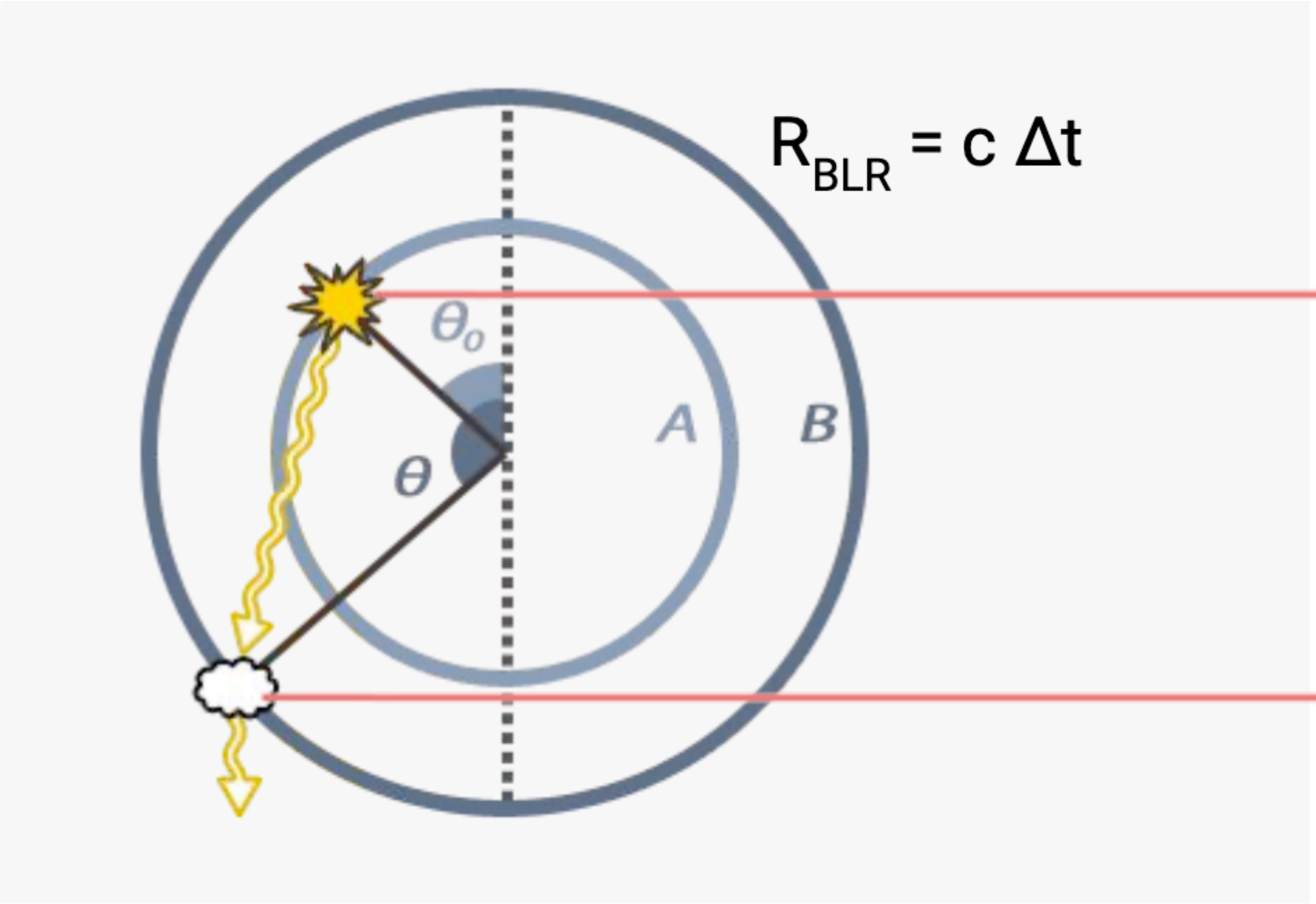
Reverberation mapping

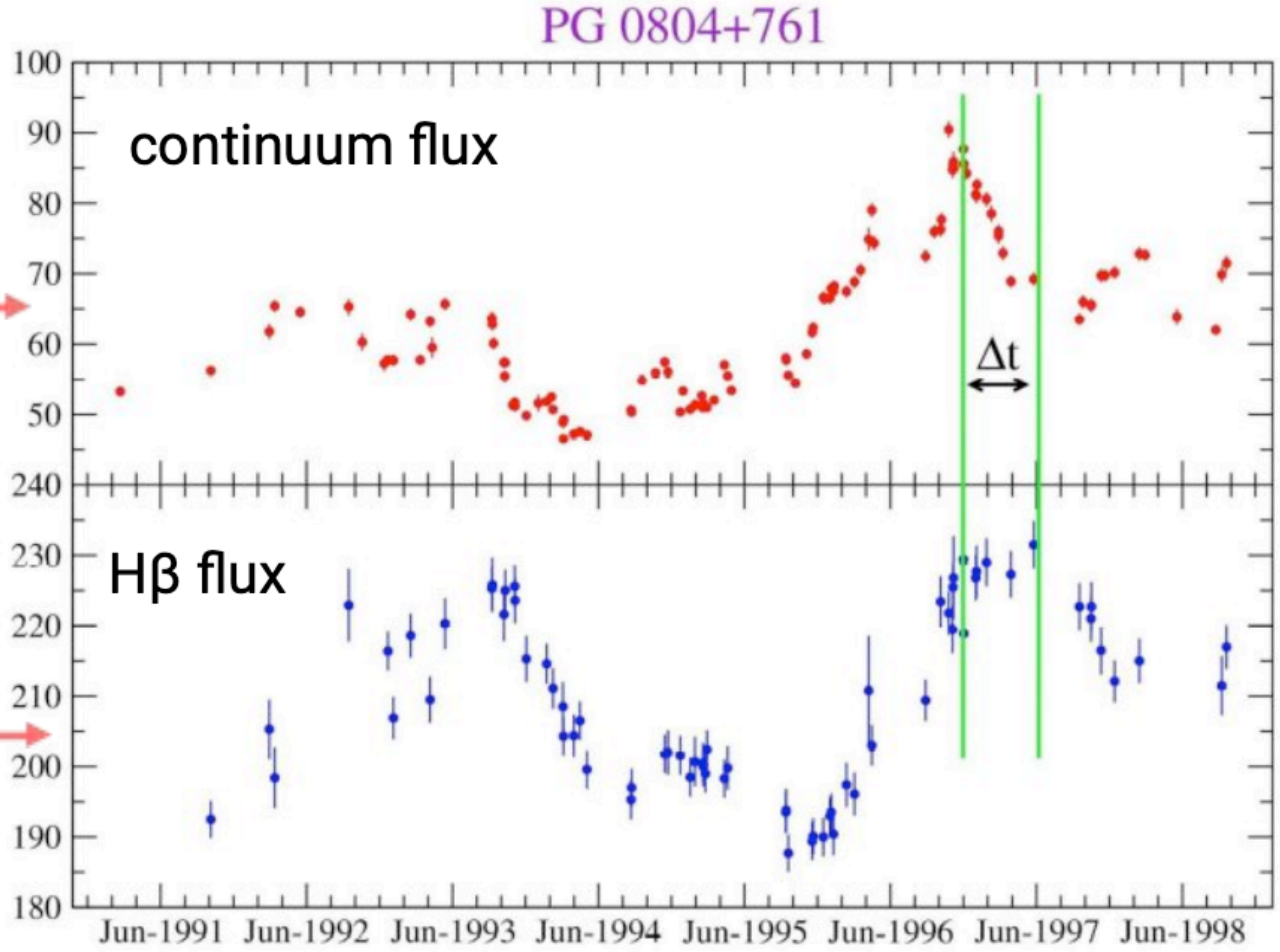
- Delayed response (i.e., time-lag) of different line emitting regions to the continuum variability occurring in the accretion disk is used to determine the radial distance of this emitting region from the central source (R_{BLR}).

Stellar and gas dynamics

- Measure gravitational potential and BH mass by observing the motions of stars or gas in the vicinity of the BH

Reverberation mapping





Kaspi et al. (2000)

Assumption: BLR gas is photoionized by the continuum from the accretion disk.

Indirect methods

BLR scaling relationships

- Empirical relationships established between the size of the BLR, the luminosity of the AGN, and the mass of the black hole.

Host galaxy scaling relationships

- M_{BH} empirical correlations with host galaxy properties.

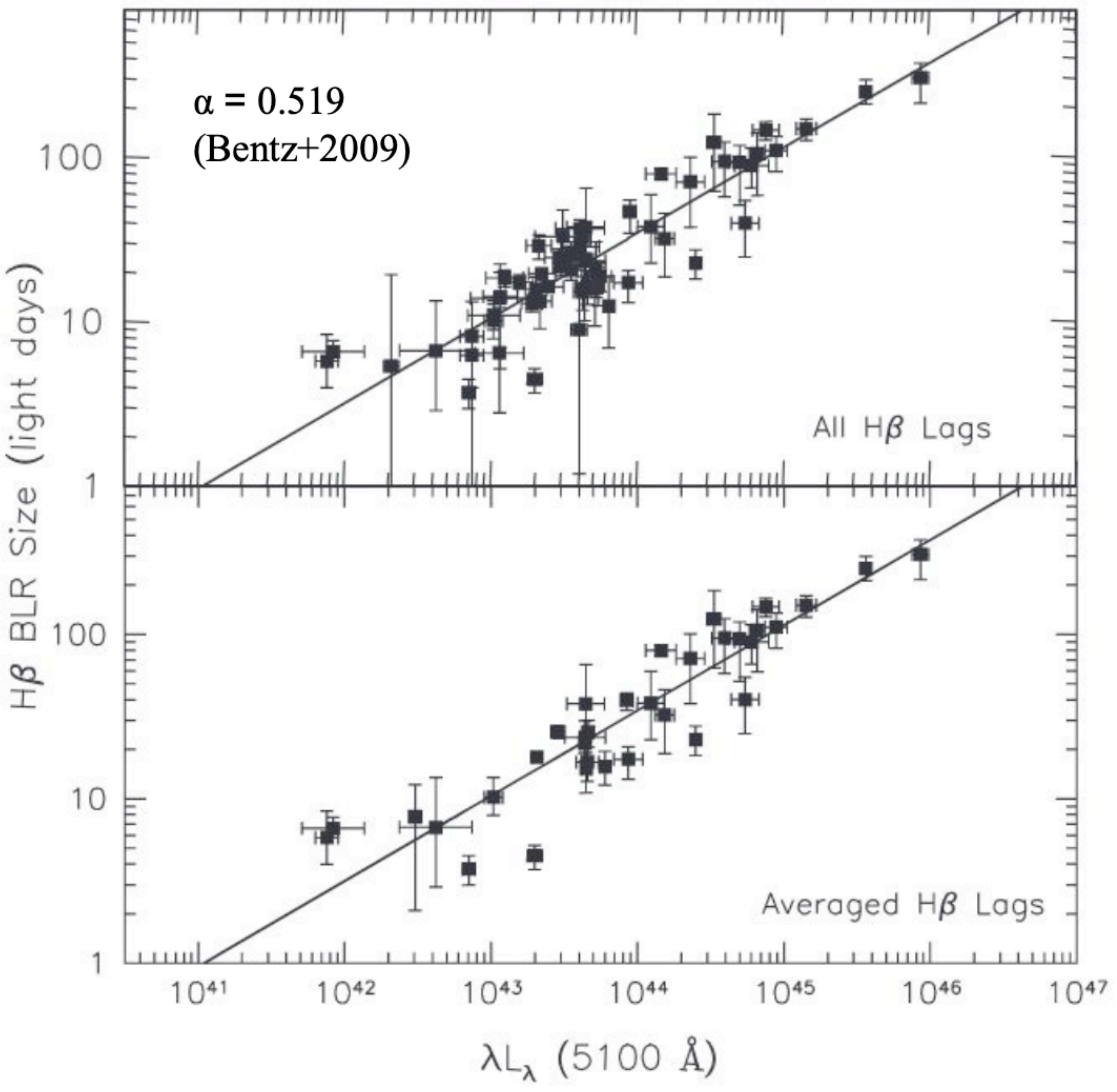
X-ray scaling relationships

- M_{BH} empirical correlations with X-ray luminosity.

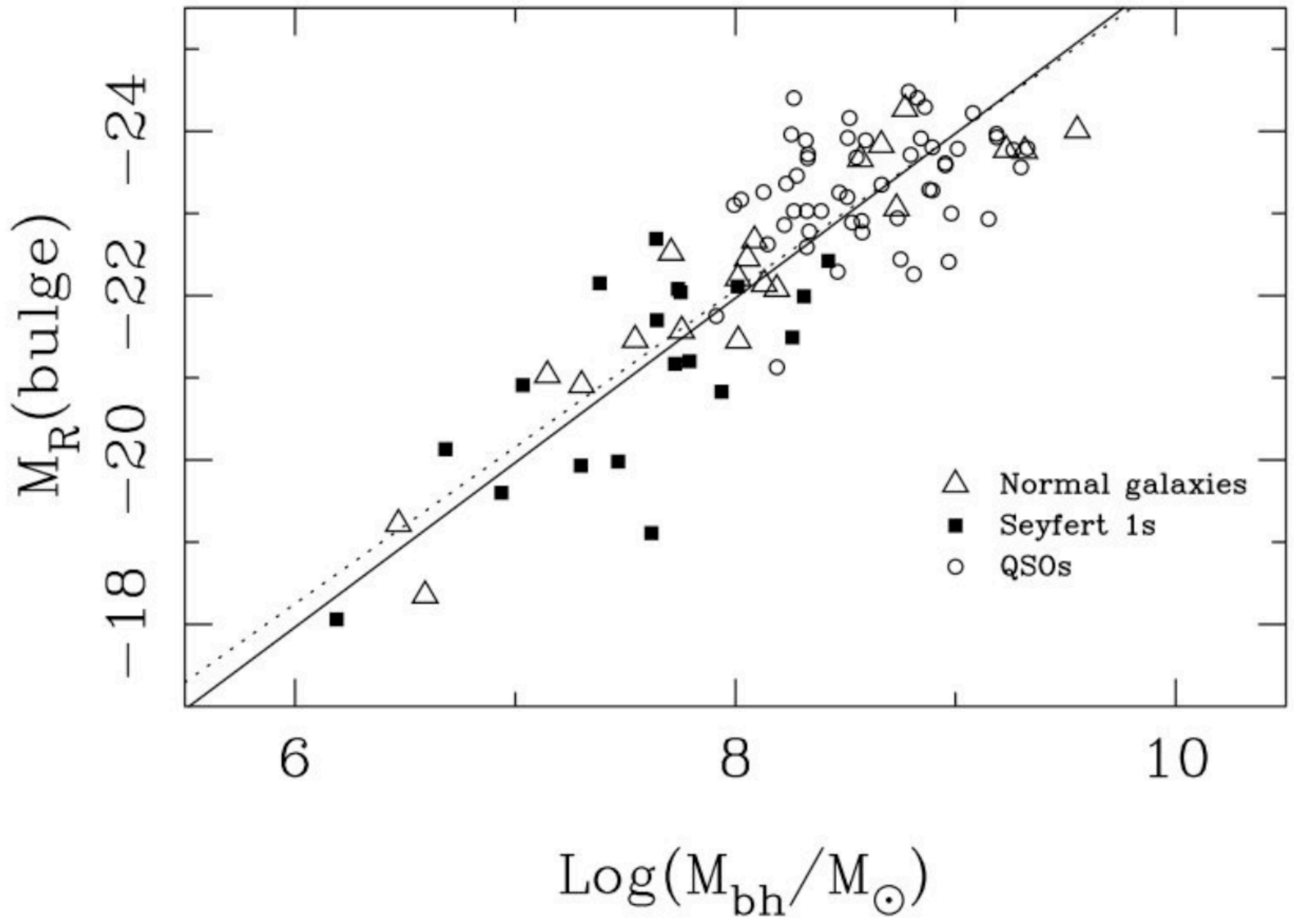
R_{BLR} - L relation

Kaspi et al. (2000)
Greene & Ho (2005)
Bentz et al. (2009)
etc.

$$R \propto L^{\alpha}$$



M_{BH} - L_{bulge}



McLure & Dunlop (2002)

Hands-on session (begin now, finish at home)

Data: 500 SDSS quasars with spectral parameters measured by Shen et al. (2011).

You have two tasks:

1. Estimate M_{BH} using scaling relations derived from *reverberation mapping studies* + estimation of accretion rate.
2. Estimate M_{BH} from galactic *host bulge luminosity* + estimation of accretion rate.

Hands-on session (begin now, finish at home)

1. This part of the assignment is designed as a guide for estimating black hole mass using scaling relations derived from reverberation mapping studies.

   You are given a sample of 500 quasars with a selection of measured spectral parameters from Shen et al. (2011), including SDSS spectral identification numbers (mjd, plate, fiber) and full width at half maximum of Hβ line[1]. Other parameters, like Hβ line luminosity, bolometric luminosity, black hole masses, and Eddington ratio are provided as a reference for comparison to the values you calculate yourself. See Shen et al. (2011) catalog for detailed description of these and other parameters. For the purpose of this exercise, you are allowed to use only FWHM Hβ for your calculations.

[1]Optionally, you are invited to test for a selected object from the given sample, what would you get for the Hβ FWHM with your own spectral analysis with FANTASY.

Hands-on session (begin now, finish at home)

a) To begin, cross-match provided catalog with SDSS to obtain Hβ flux and redshift. Do some exploratory data analysis of the sample: plot redshift and FWHM distribution of the sample, plot i-band magnitude vs. redshift, and describe sample limitations in terms of these plots and parameters (hint: pandas is useful for this).

b) Next, using the provided FWHM and SDSS data, find:

- The luminosity of the Hβ emission line. For this, you will need to calculate the luminosity distance for each object using formulas given by Hogg (2000). For cosmological constants, use ones from Planck (H0=67.8 km/s MPc, Ωm=0.31, Ωλ=0.69). Using luminosity distance, Hβ flux and redshift, find the luminosity of the Hβ emission line.

Hands-on session (begin now, finish at home)

- Using the empirical relation from Section 3 in Wu (2009), calculate black hole mass using the luminosity of the Hβ line and FWHM Hβ. You should elaborate on the assumption you have to make to use this relation.

- Estimate the Eddington luminosity and Eddington ratio after having derived the bolometric luminosity (e.g., use empirical relations from Wu 2009).

c) How would you describe these AGNs based on the properties you found? Provide histograms of obtained black hole masses and Eddington ratios. Present your results as in Figure 2 from Wu (2009), and Figure 7 from McLure & Dunlop (2002), or on any plots that you find appropriate to illustrate your conclusions. Optionally, you can compare your values to values from Shen et al. (2011).

Hands-on session (begin now, finish at home)

2. In this part of the assignment you will learn how to estimate black hole mass from galactic host bulge luminosity. It is useful in cases when you don't have spectroscopic data for broad emission lines.

   Calculate black hole mass for at least 10 objects from Wu (2009) using the relation between black hole mass and host galaxy absolute magnitude in the R band given in Wu (2009) and proposed by McLure & Dunlop (2002). Elaborate on the assumptions you have to make in order to use this relation. You will need to obtain magnitudes in Johnson- Cousins photometric system (e.g., you can try searching the NED database). Additionally, find the Eddington ratio and plot it against obtained black hole masses. Optionally, you can plot your black hole mass and Eddington ratio estimates against ones from Wu et al. (2009) and discuss what you find.

Hands-on session (begin now, finish at home)

References:

Hogg 2000; https://arxiv.org/abs/astro-ph/9905116
McLure & Dunlop 2002; http://adsabs.harvard.edu/abs/2002MNRAS.331..795M
Shen et al. 2011 paper; https://ui.adsabs.harvard.edu/abs/2011ApJS..194...45S/abstract
Shen et al. 2011 catalog; https://vizier.cds.unistra.fr/viz-bin/VizieR-3
Wu 2009; http://adsabs.harvard.edu/abs/2009MNRAS.398.1905W

NED database: https://ned.ipac.caltech.edu/

SDSS DR18: https://skyserver.sdss.org/dr18/

Homework

Due date: 23rd May 2024, 11:59 PM

It is preferred to create a report in the form of a Jupyter notebook (with text describing the steps you take, code and plots), but other formats are also accepted.

Next tutorial: Friday, 24th or 31st May @ 1PM

Photometric Reverberation Mapping