



ERASMUS MUNDUS JOINT MASTER DEGREE
MASTER IN ASTROPHYSICS AND SPACE SCIENCE

Introduction to Active Galactic Nuclei

Tutorial 3

Black holes and accretion disk parameters

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But first..

Homework 1 feedback + Q&A

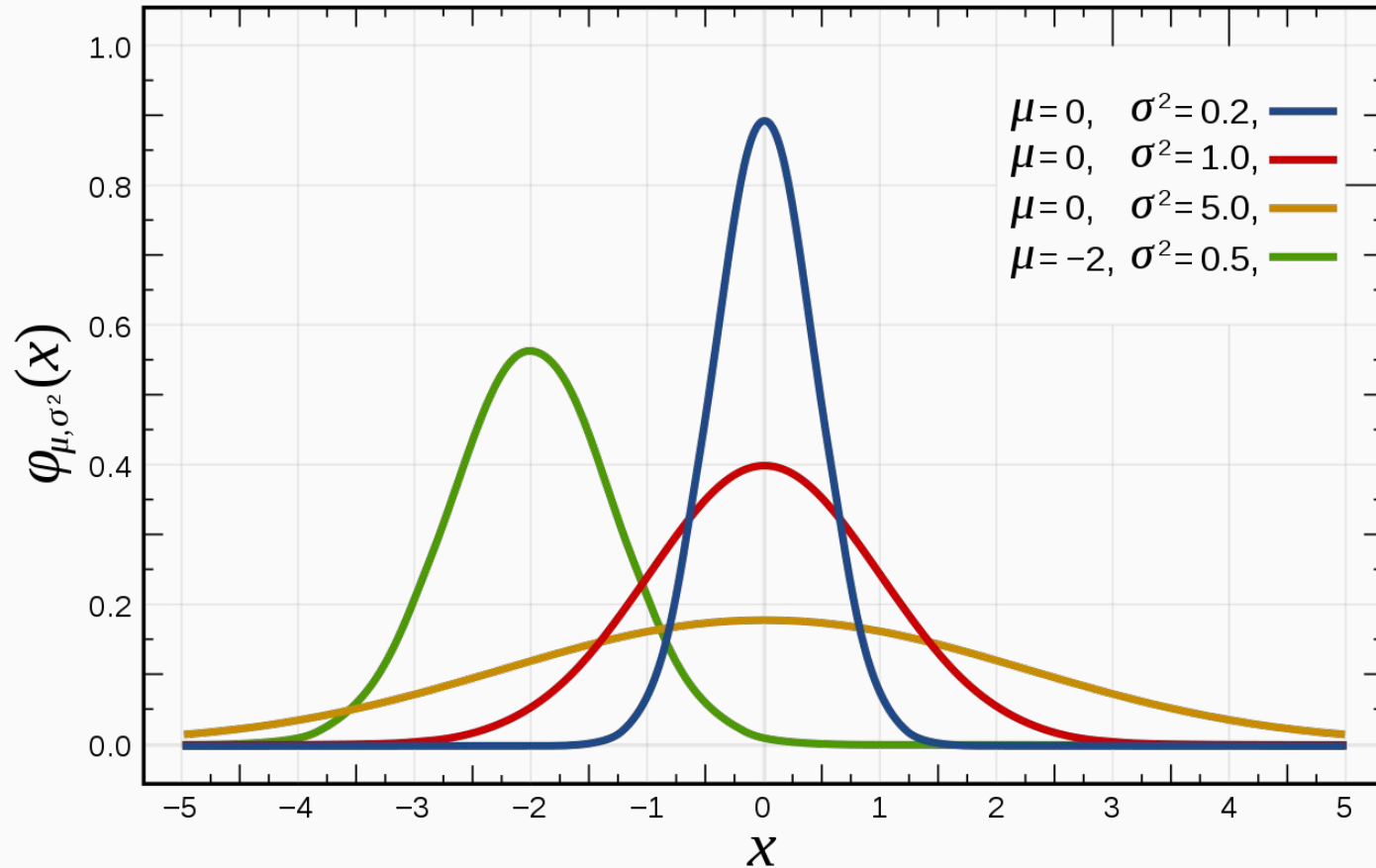
How do we obtain FWHM from sigma (velocity dispersion)?

HW1, question a) asked to constrain the search to include only objects with FWHM H_beta > 1000 km/s.

Assumption: Balmer emission lines are fitted using Gaussian line profile (see Tremonti et al. 2004 where galSpecLine table is described)

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

Gaussian profile with different variance and mean values.



How do we obtain FWHM from sigma (velocity dispersion)?

We can utilize `sigma_balmer` parameter **given in km/s** from `galSpecLine` table to find FWHM:

$$\text{FWHM} = 2\sqrt{2\ln 2} \times \sigma \approx 2.355 \times \sigma$$

It is not hard to derive from the Gaussian distribution, see here:

<https://mathworld.wolfram.com/GaussianFunction.html>

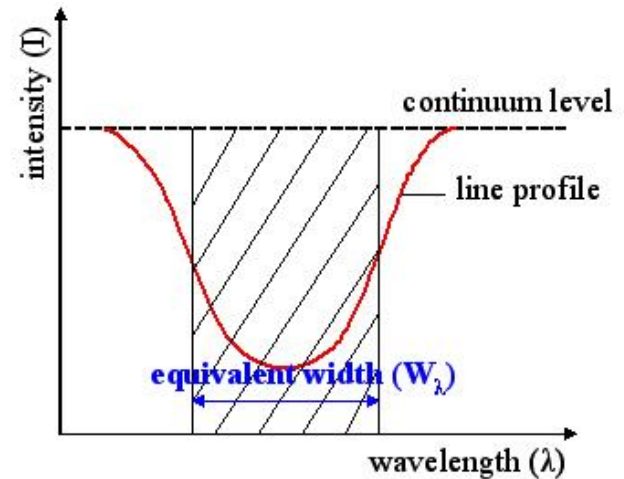
Using equivalent width sign to select emission or absorption lines

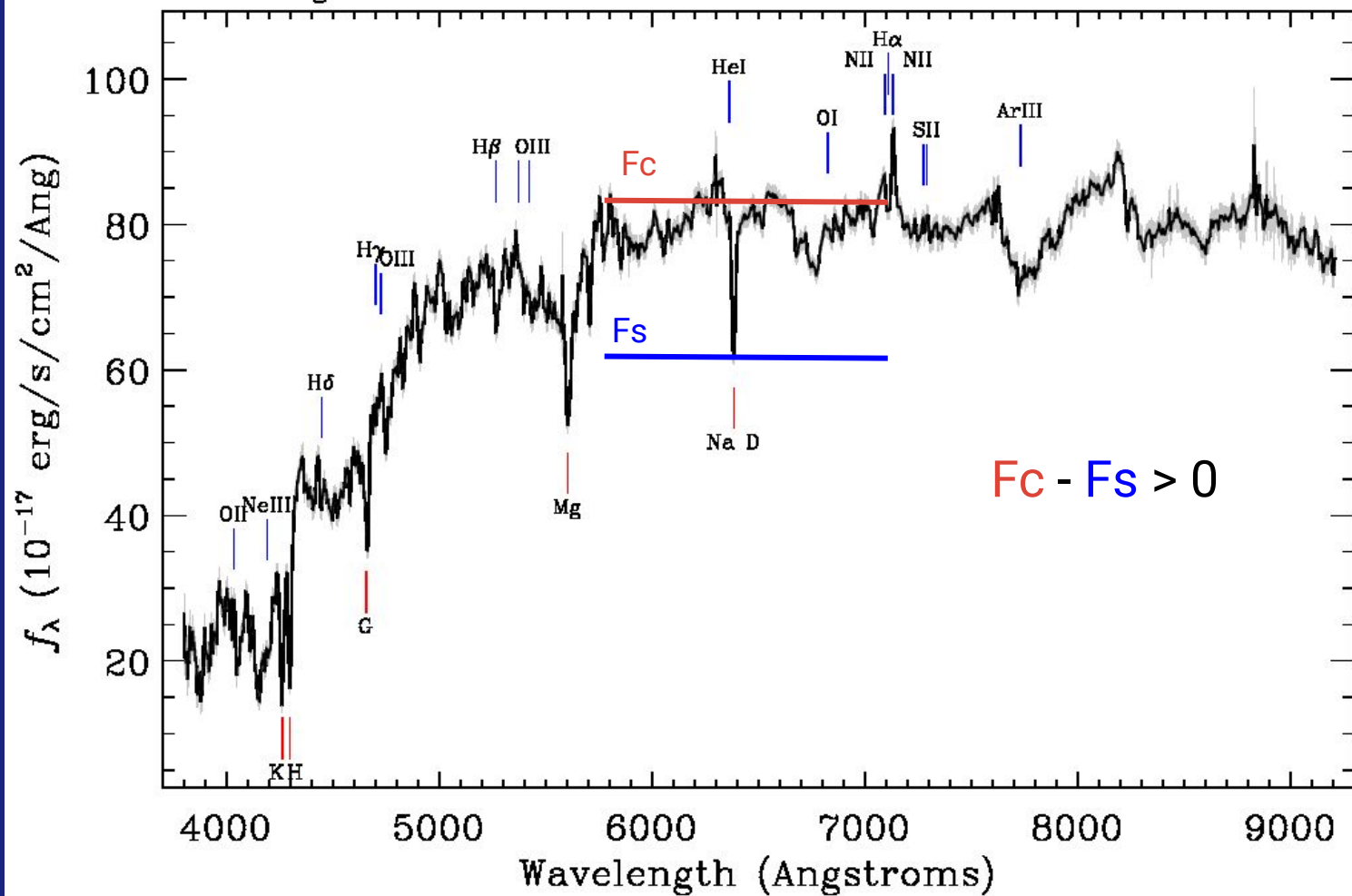
Consider the formula for calculating equivalent widths:

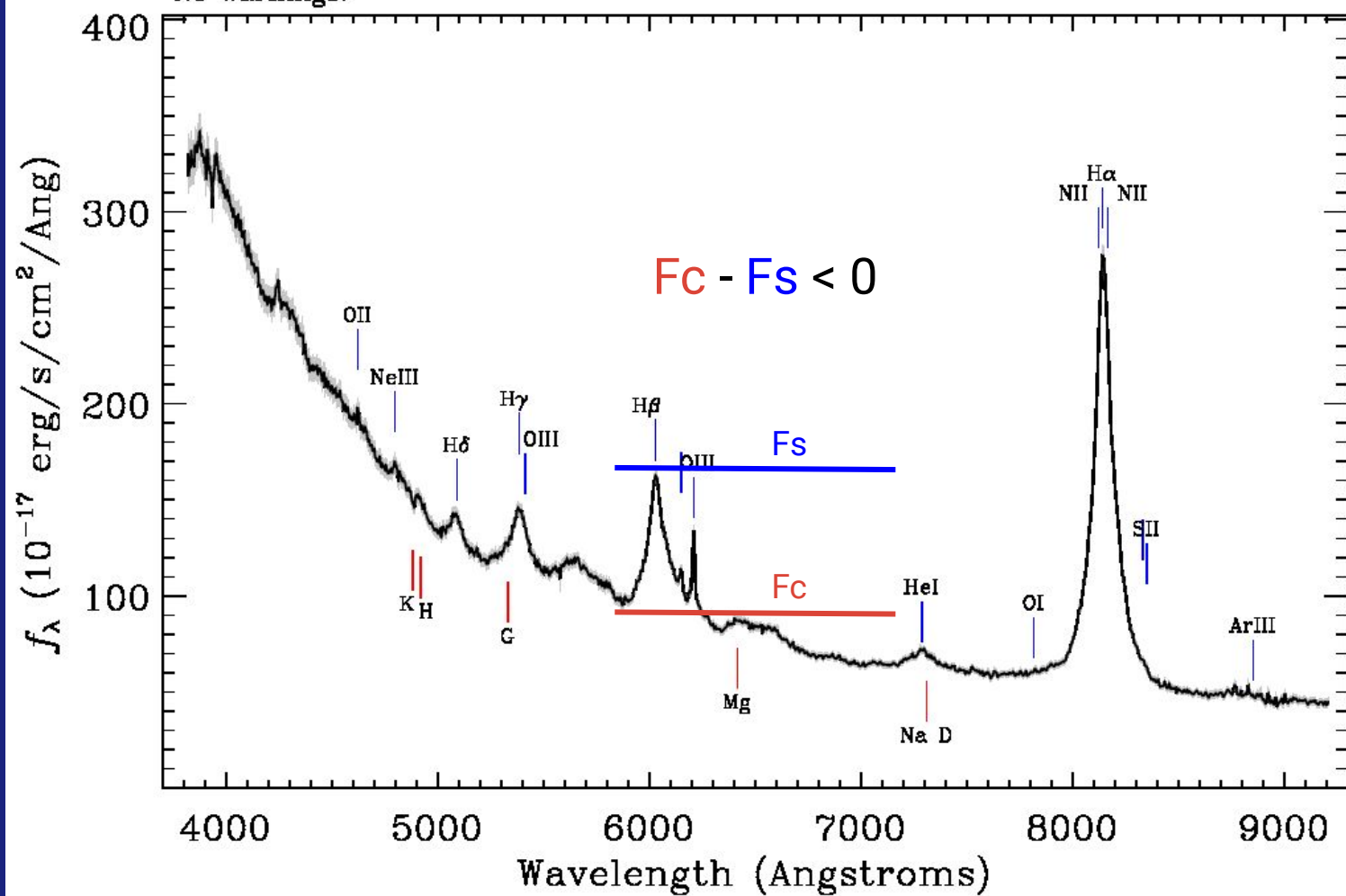
$$W_{\lambda} = \int \frac{F_c - F_s}{F_c} d\lambda$$

$F_c(\lambda)$ - underlying continuum flux

$F_s(\lambda)$ - spectrum flux (continuum and line)







Some additional info

- Good practice \rightarrow **flux** > **a** * **flux err**; a - constant
- Also, you can set **EW** < -1 to be sure to select emission lines
- Not setting this conditions gives you larger number of galaxies, because H β is weaker than in AGN. In case of ellipticals where we don't have much hot gas and star formation, the H β is hardly detectable.
- Spectroscopic **subclasses** explanation (under *Object Information* section):
<https://www.sdss4.org/dr17/spectro/catalogs/>

Questions?

Tutorial 3

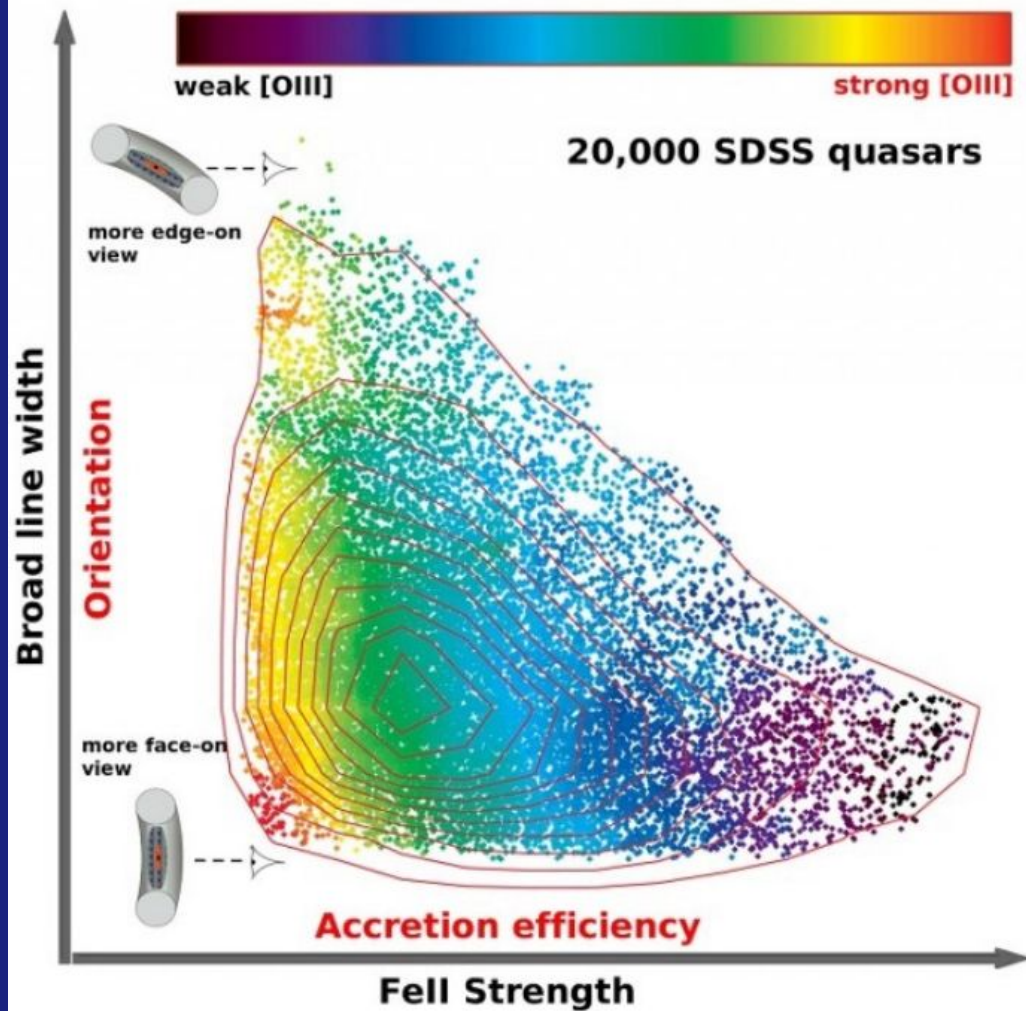
Black holes and accretion disk parameters

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

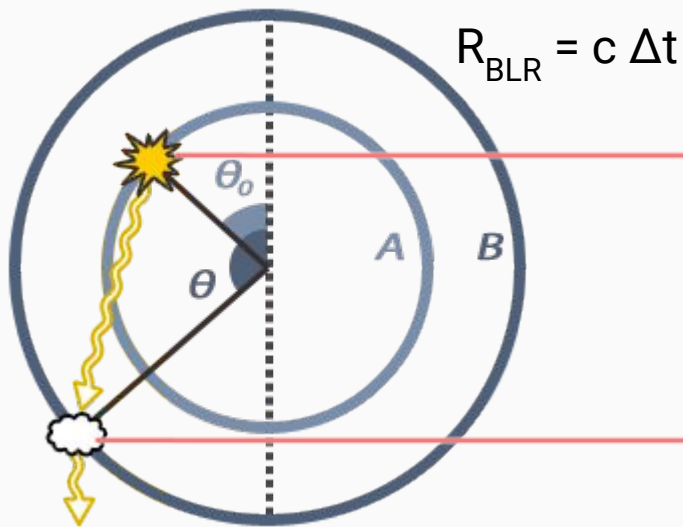
Reverberation mapping

- 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}).

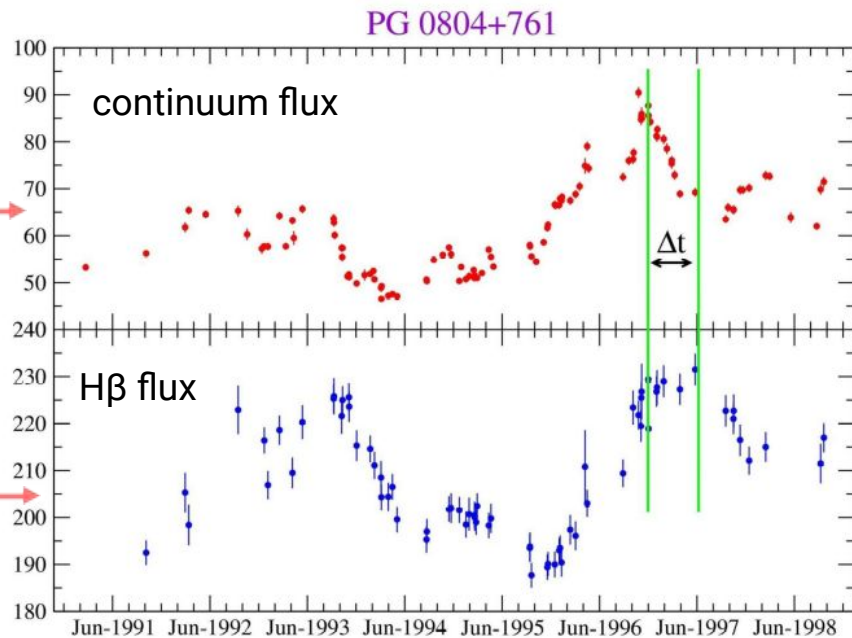
Stellar and gas dynamics

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

Reverberation mapping



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



Kaspi et al. (2000)

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

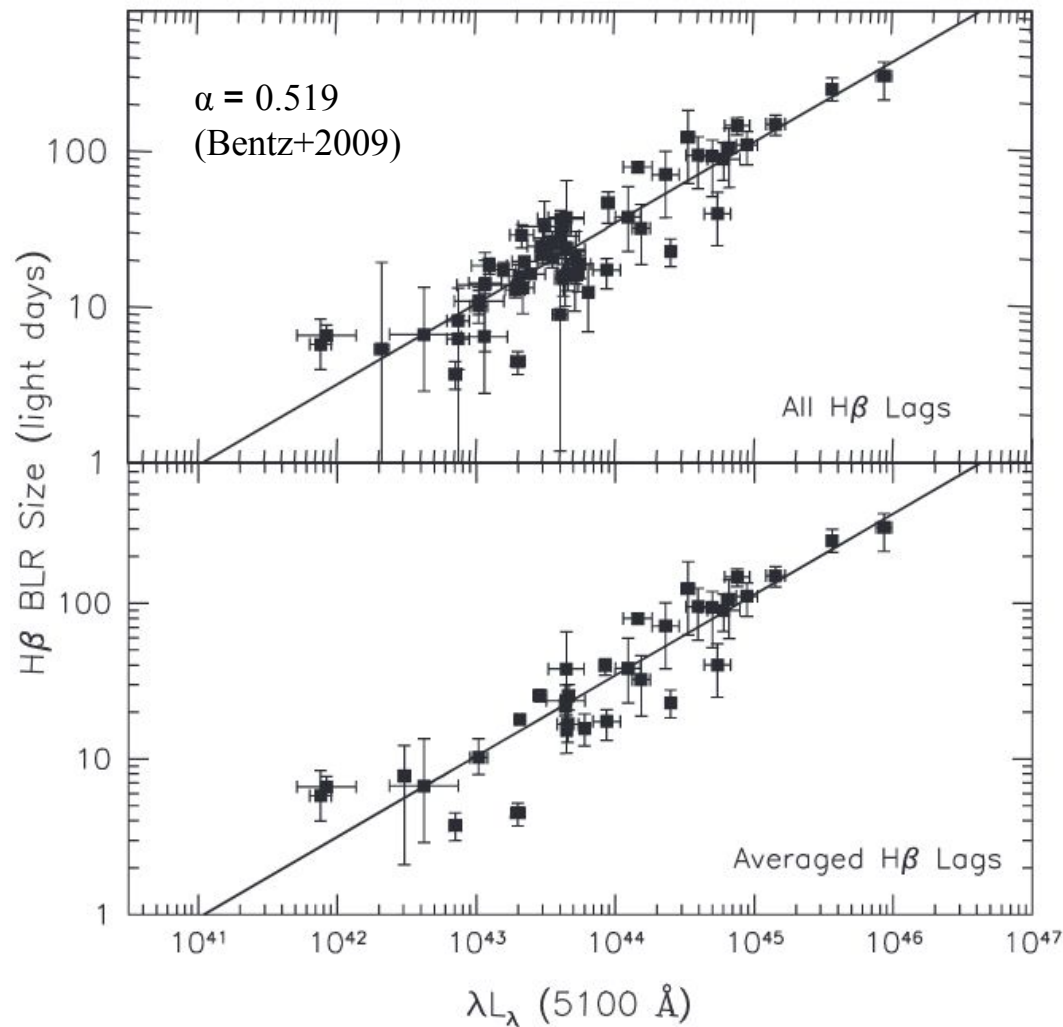
Kaspi et al. (2000)

Greene & Ho (2005)

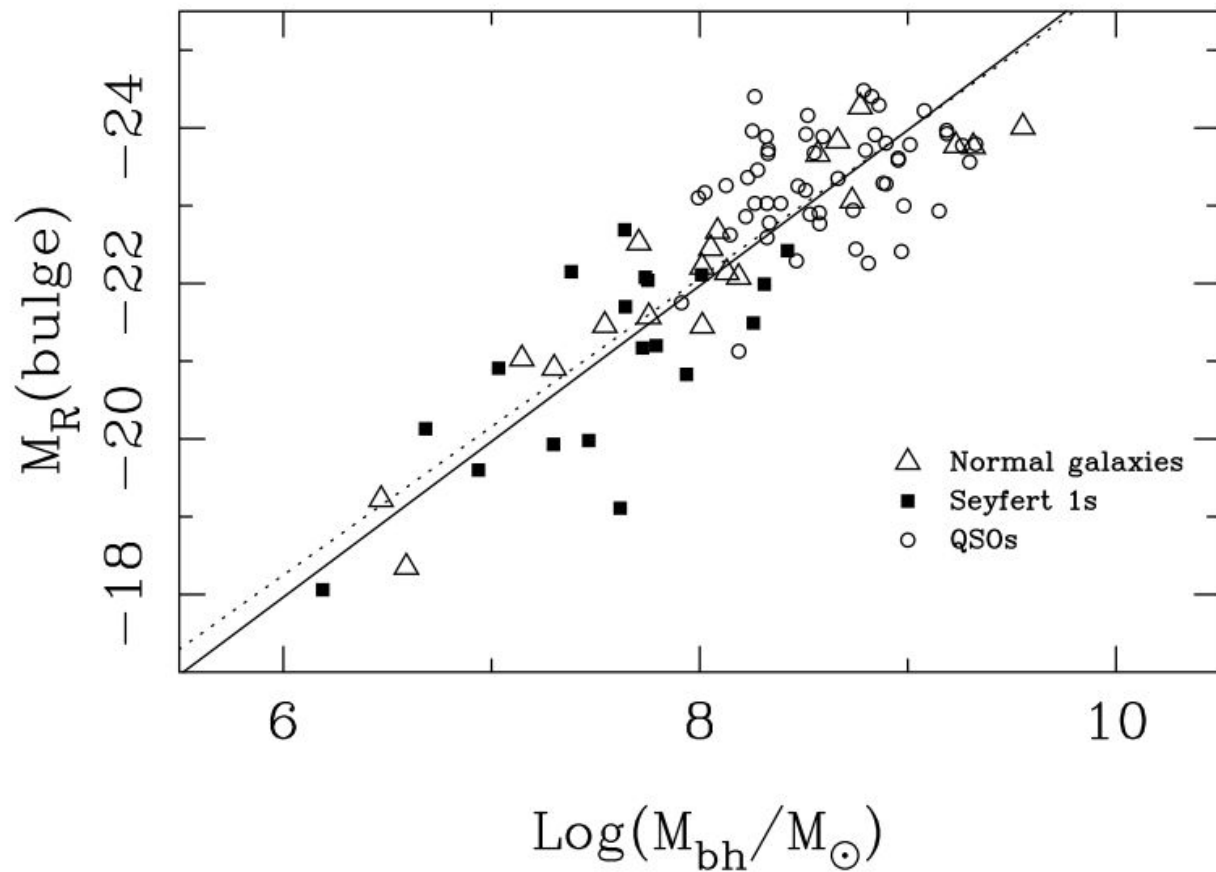
Bentz et al. (2009)

etc.

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



$M_{\text{BH}} - L_{\text{bulge}}$ relation



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.

Homework 3 deadline: **Friday 07.04, 23:59h**

Send your reports to

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