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

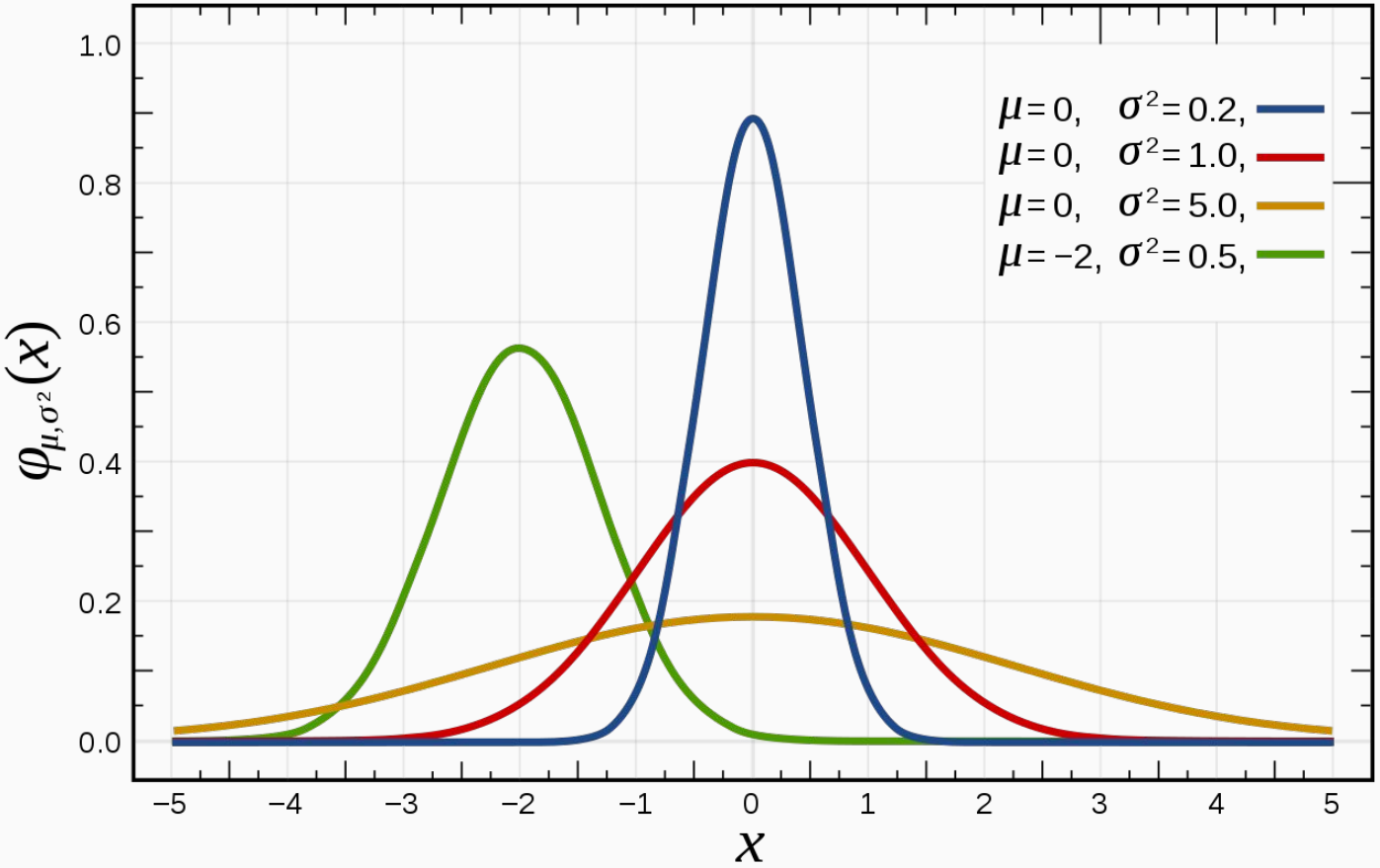
How do we obtain FWHM from sigma (velocity dispersion)?

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:

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

It is not hard to derive from the Gaussian distribution, see here:
https://mathworld.wolfram.com/GaussianFunction.html

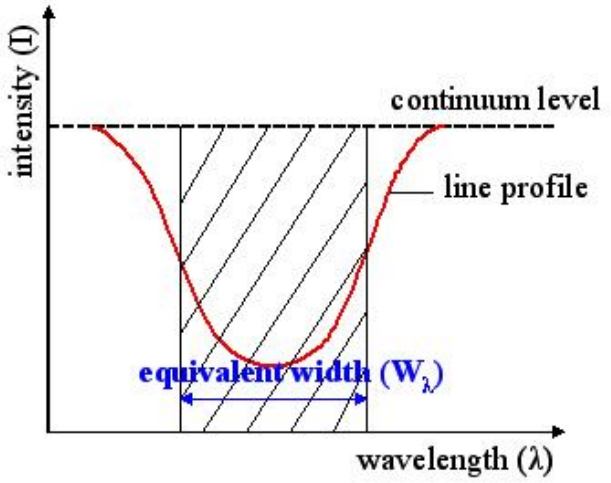
Using equivalent width sign to select emission or absorption lines

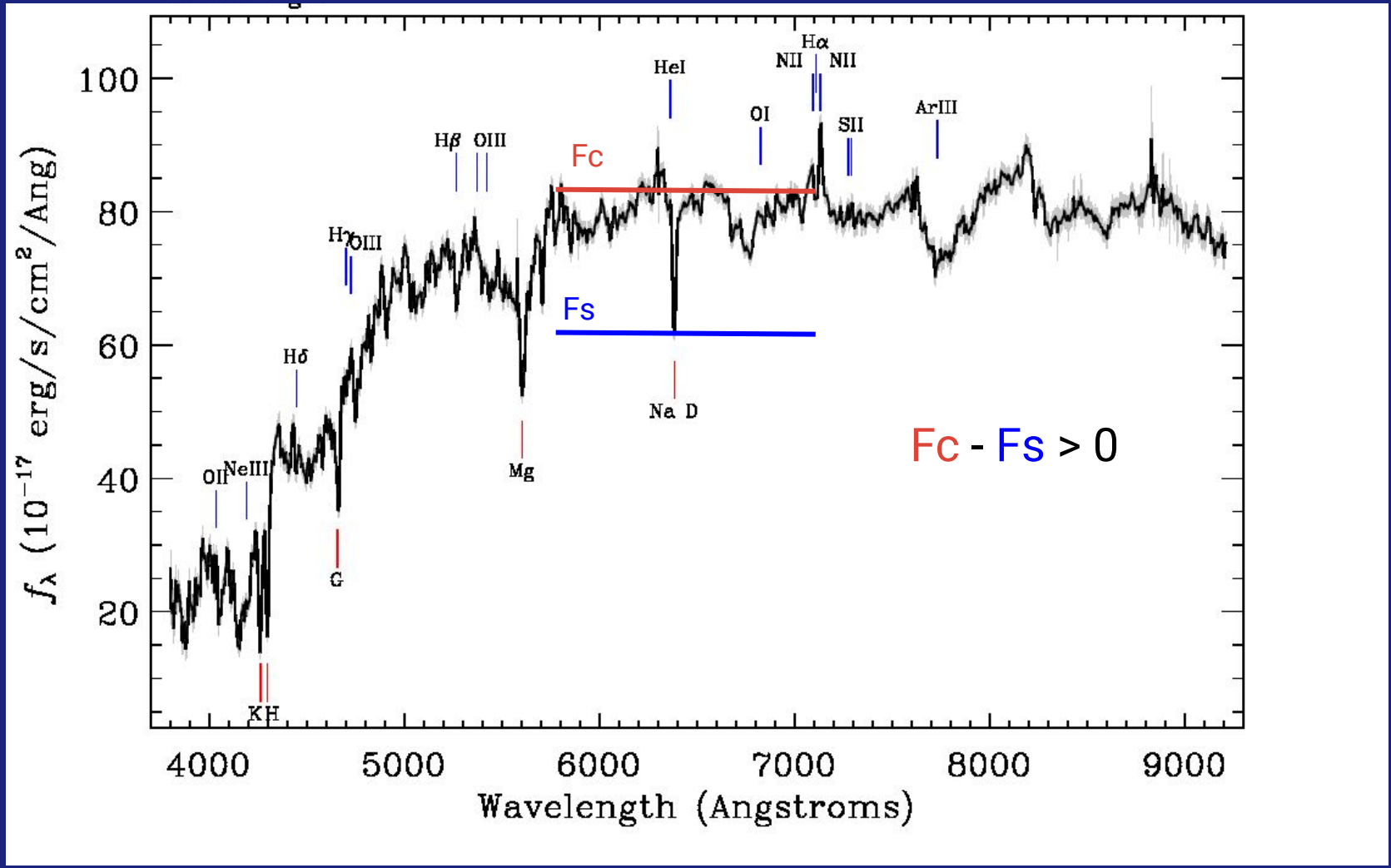
Consider the formula for calculating equivalent widths:

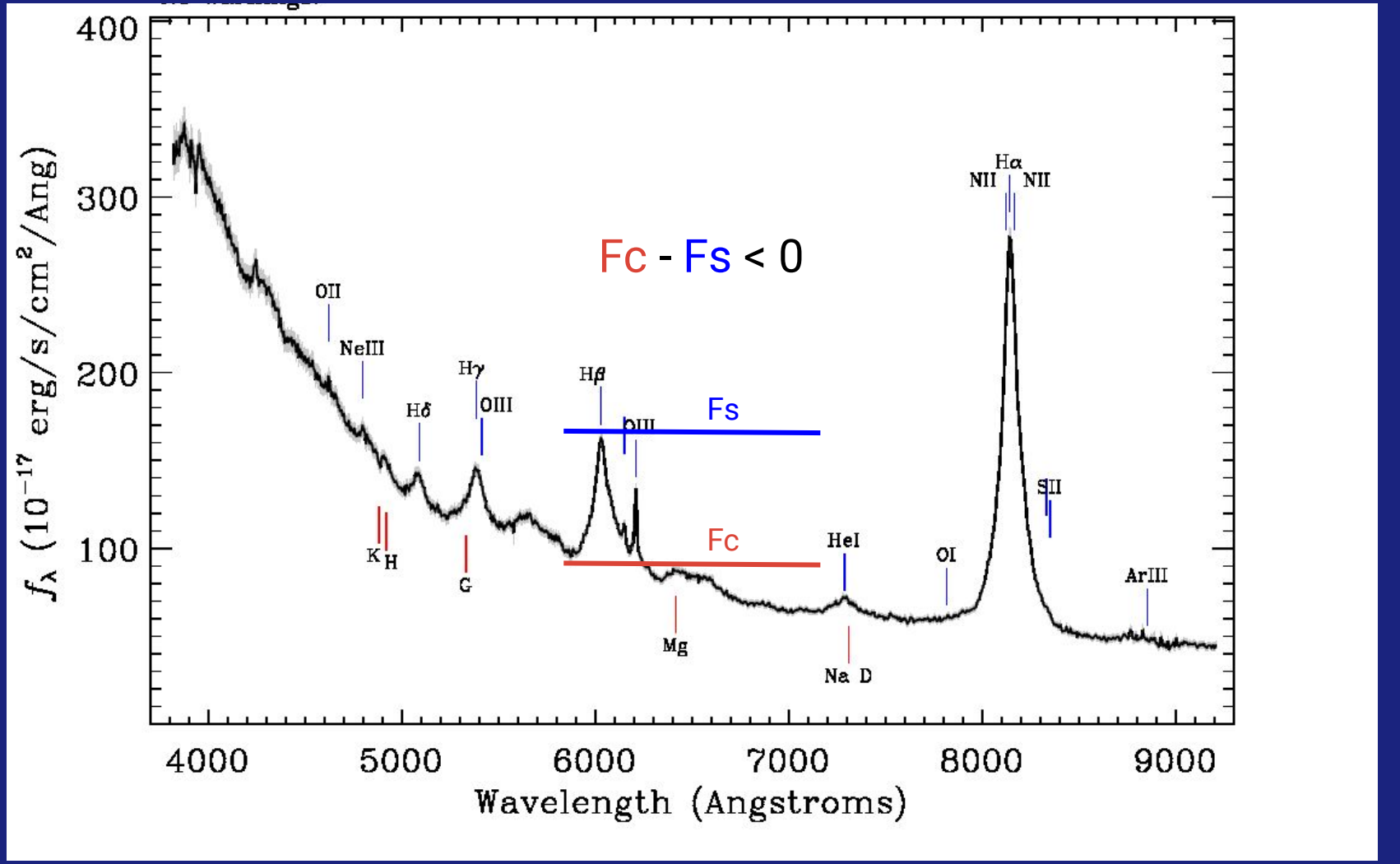
$$W_\lambda = \int \frac{F_c - F_s}{F_c} d\lambda$$

$F_c\ (\lambda)$ - underlying continuum flux

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




100
80
60
40
20
f_λ (10^{-17} erg/s/cm^2/Ang)
4000
5000
6000
7000
8000
9000
Wavelength (Angstroms)
OII
NeIII
KH
Hδ
G
Hγ
OIII
Hβ
OIII
Mg
HeI
Na D
OI
NII
Hα
NII
SII
ArIII
Fc
Fs
Fc - Fs > 0


Fc - Fs < 0
Fs
Fc
OII
NeIII
Hδ
Hγ
OIII
Hβ
OIII
K
H
G
Mg
HeI
Na D
OI
NII
Hα
NII
SII
ArIII
400
300
200
100
4000
5000
6000
7000
8000
9000
Wavelength (Angstroms)
f_λ (10^{-17} erg/s/cm^2/Ang)

Some additional info

- Good practice —> **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 Hβ is weaker than in AGN. In case of ellipticals where we don't have much hot gas and star formation, the Hβ is hardly detectable.
- Spectroscopic **subclasses** explanation (under *Object Information* section): https://www.sdss4.org/dr17/spectro/catalogs/

Questions?

Tutorial 3

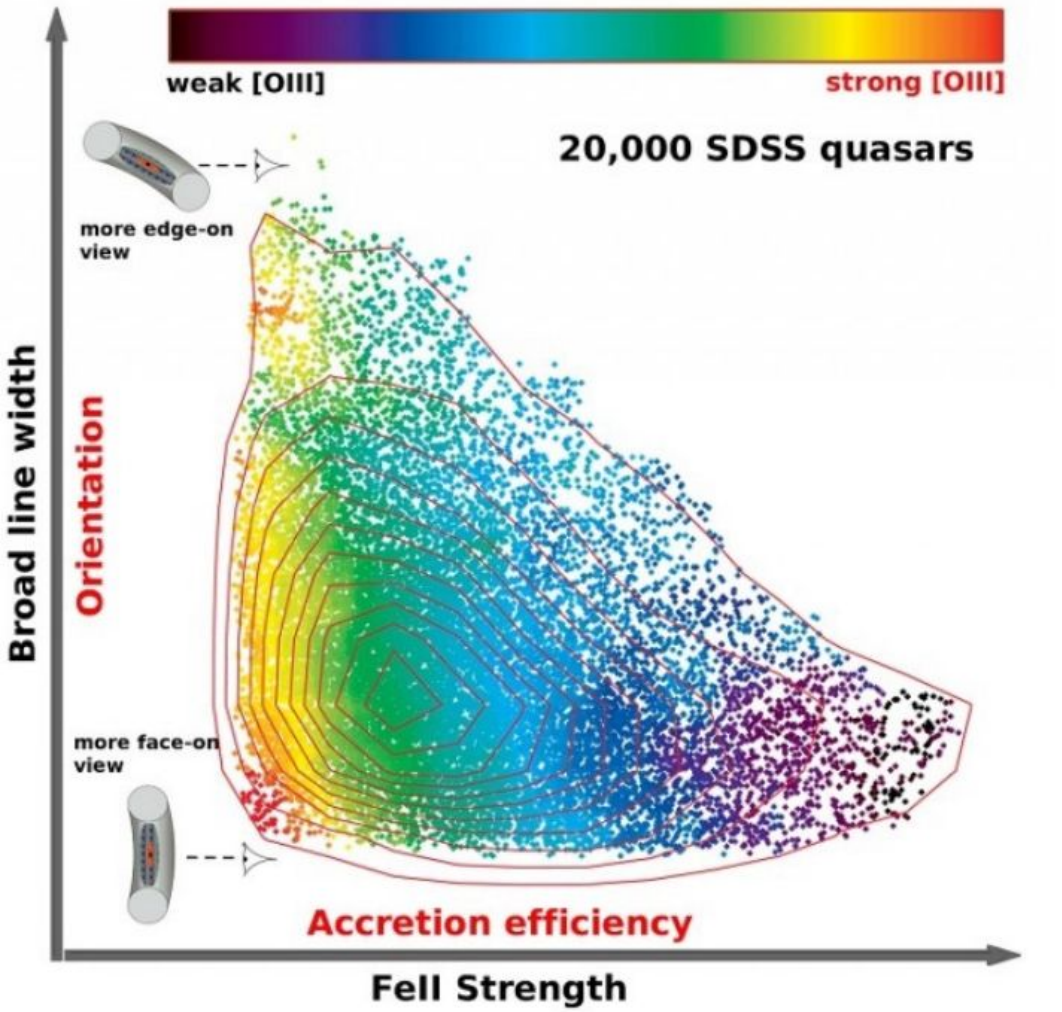
Black holes and accretion disk parameters

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

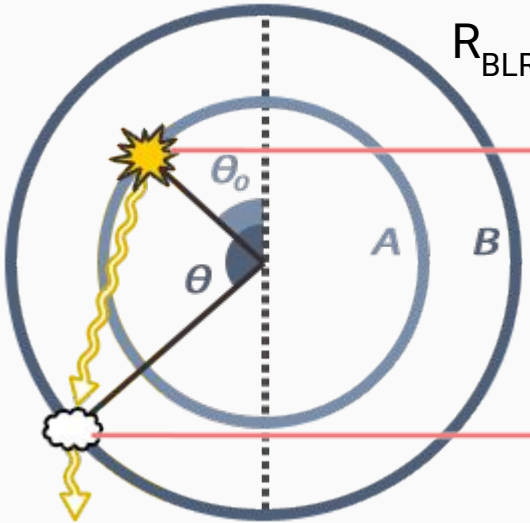
Reverberation mapping

- 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}).

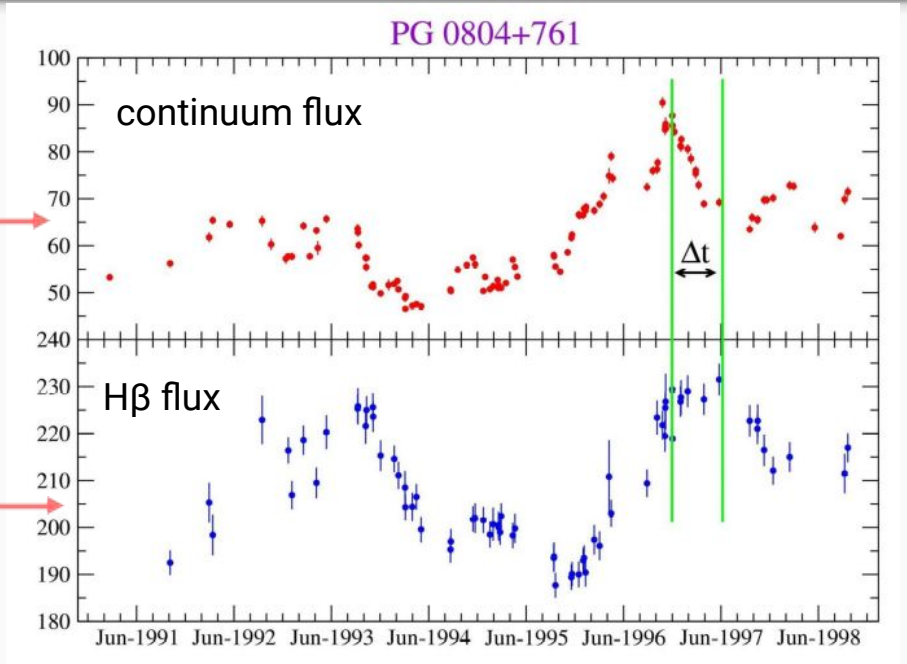
Stellar and gas dynamics

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

Reverberation mapping



$R_{BLR} = c\,\Delta t$



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

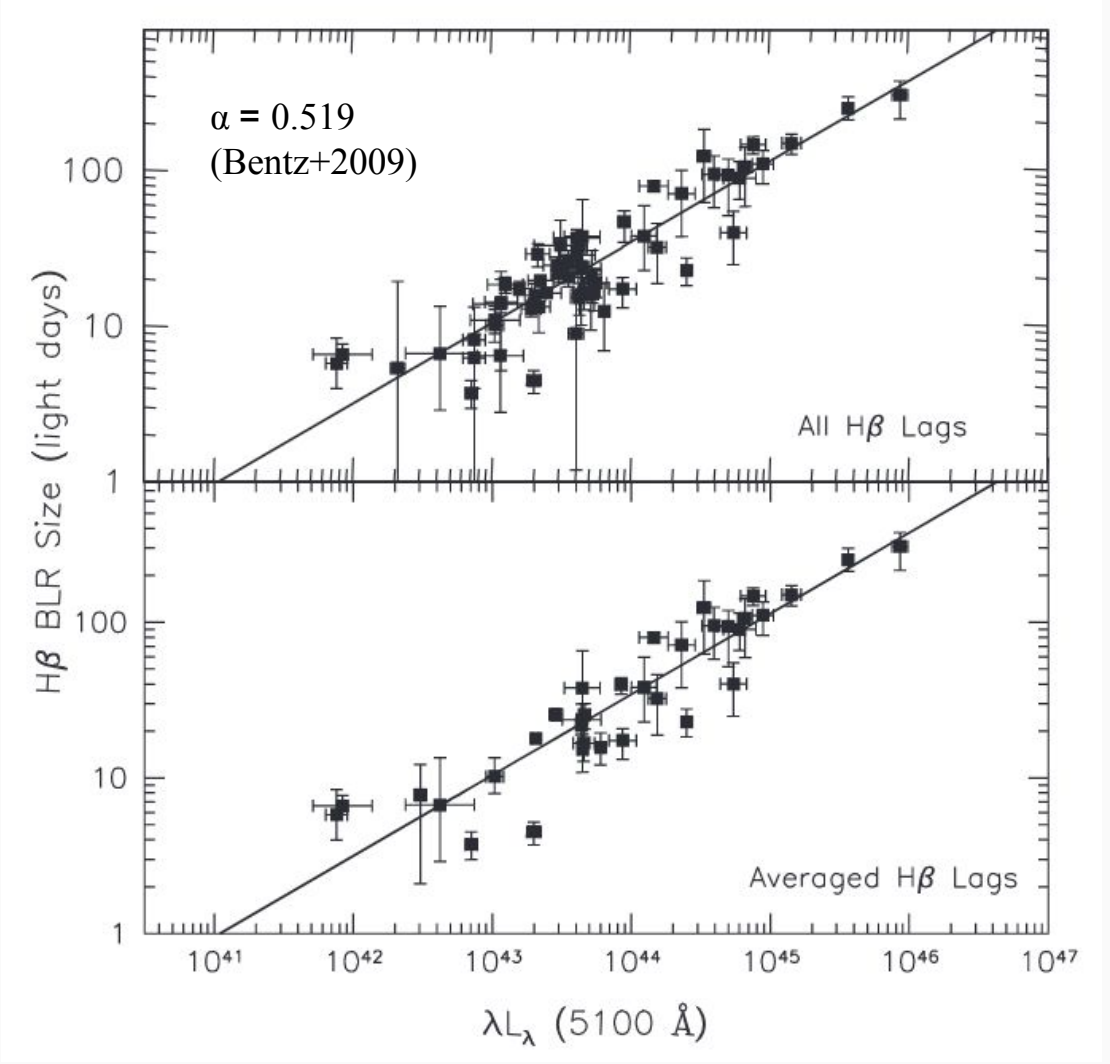
Kaspi et al. (2000)

Greene & Ho (2005)

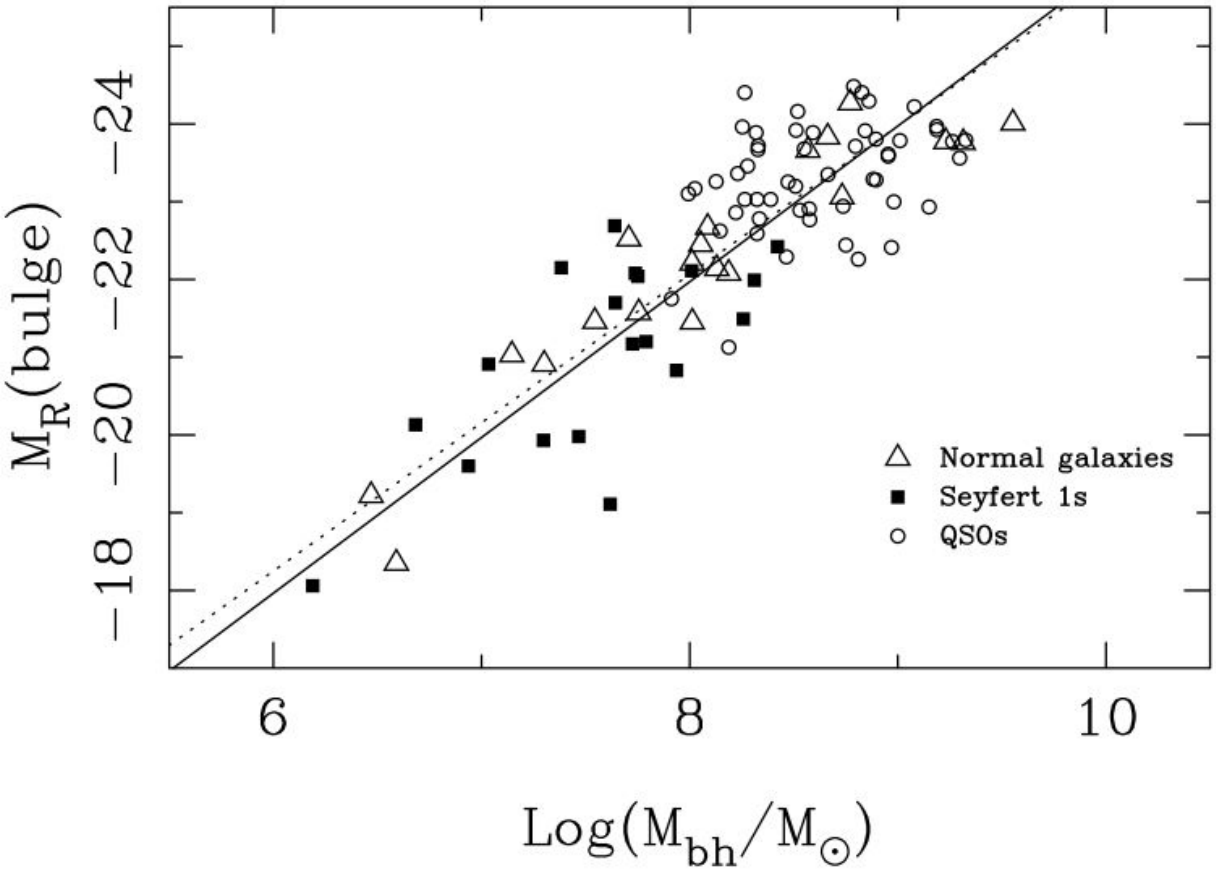
Bentz et al. (2009)

etc.

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



M_{BH} – L_{bulge} 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: **Thursday 13.04, 13h**

Send your reports to

ijankov@proton.me