Spectral states of AGN: clues from Galactic X-ray binaries

Małgosia Sobolewska
and
Aneta Siemiginowska

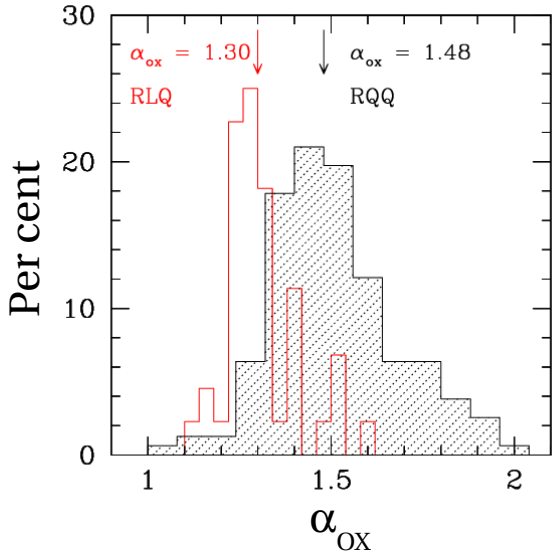
Smithsonian Astrophysical Observatory

Accretion Workshop, 13 – 15 July, 2010, Boston, MA

Plan of the talk

- Motivation
- Parametrization of the GBH SEDs with a disk-to-Comptonization index, α_{GBH}, similar to the α_{OX} defined for AGN
- Origins of the correlation between the AGN α_{OX} and the luminosity at 2500A
- AGN α_{OX} as a function of the Eddington luminosity ratio
- Comparison of the simulations and real AGN data
- Summary

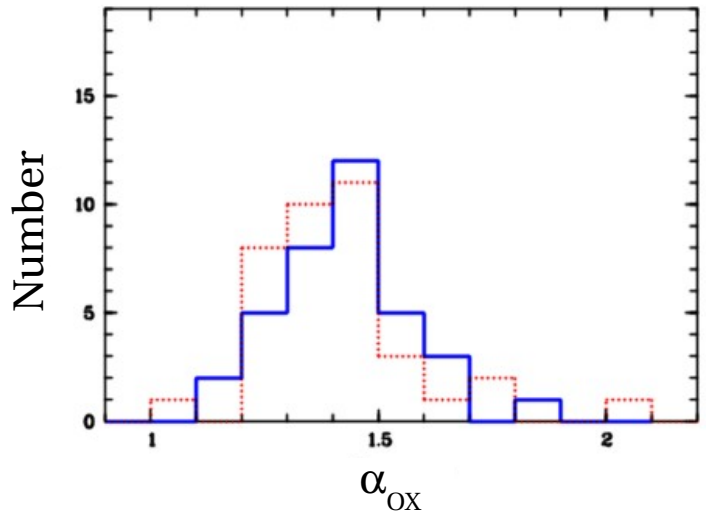
Motivation – distribution of α_{OX} in AGN



Distribution of α_{OX} (the index of a power law between O = 2500A and X = 2 keV) for quasars.

The filled histogram shows a sample of 157 optically selected **radio-quiet** AGN from Kelly et al. (2007), while the open one shows the subsample of 44 radio-loud quasars from Green et al. (1995). The medians of the two samples are indicated with arrows.

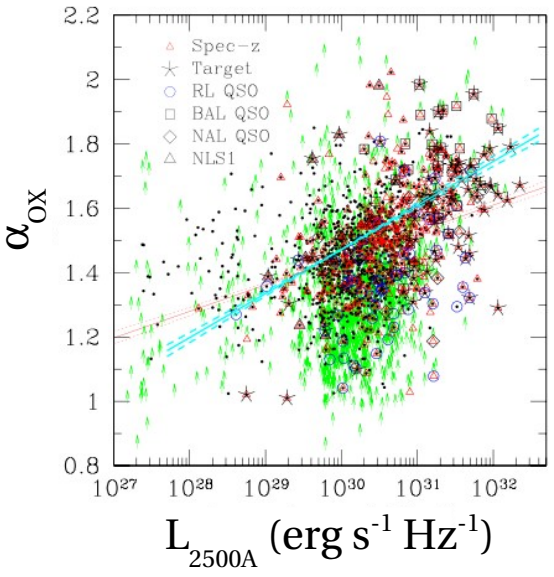
$$\alpha_{OX} = -\frac{\log(\nu L_\nu)_O - \log(\nu L_\nu)_X}{\log \nu_O - \log \nu_X} + 1$$



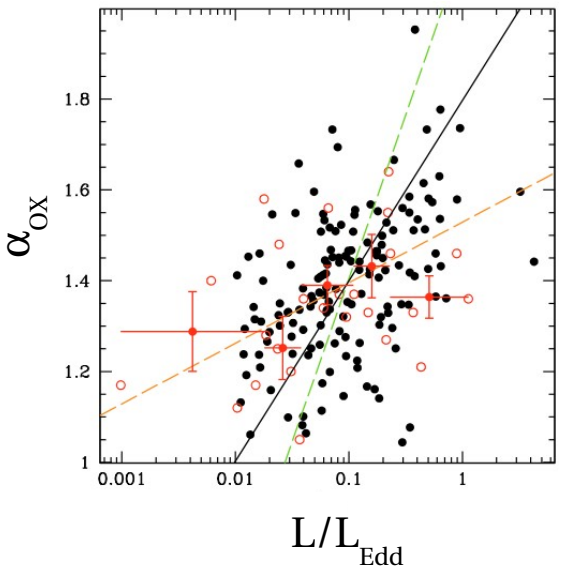
Distribution of α_{OX} for in a Swift sample of bright soft X-ray selected AGN. Broad Line Sefert 1s – red, Narrow Line Seyfert 1s – blue, Grupe et al. (2010).

Motivation – correlation between α_{OX}, Γ and luminosities

Green et al. (2009)



Lusso et al. (2010)

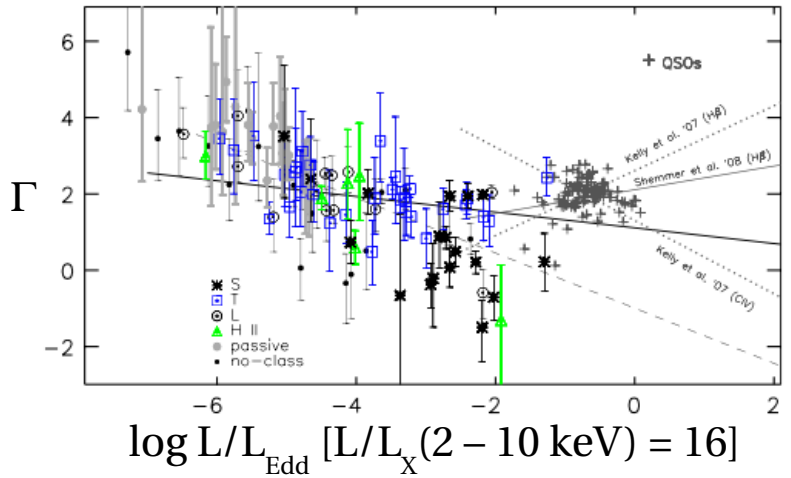


Are the correlations observed in the AGN spectra between the spectral indeces (α_{OX}, Γ) and luminosities real?

What are the **physical origins** of these correlations?

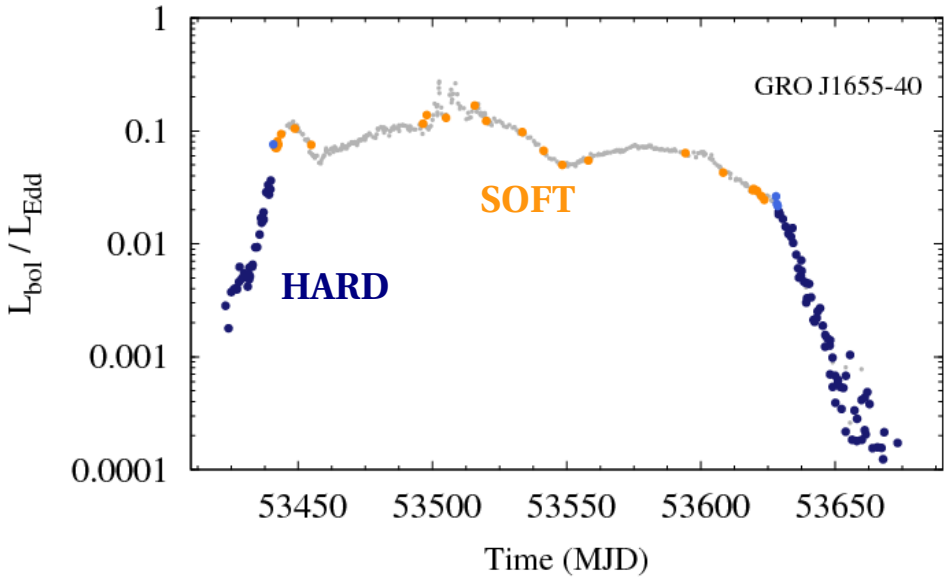
In particular we focus on the dependance on the luminosity at 2500A and Eddington luminosity ratio.

Constantin et al. (2009)



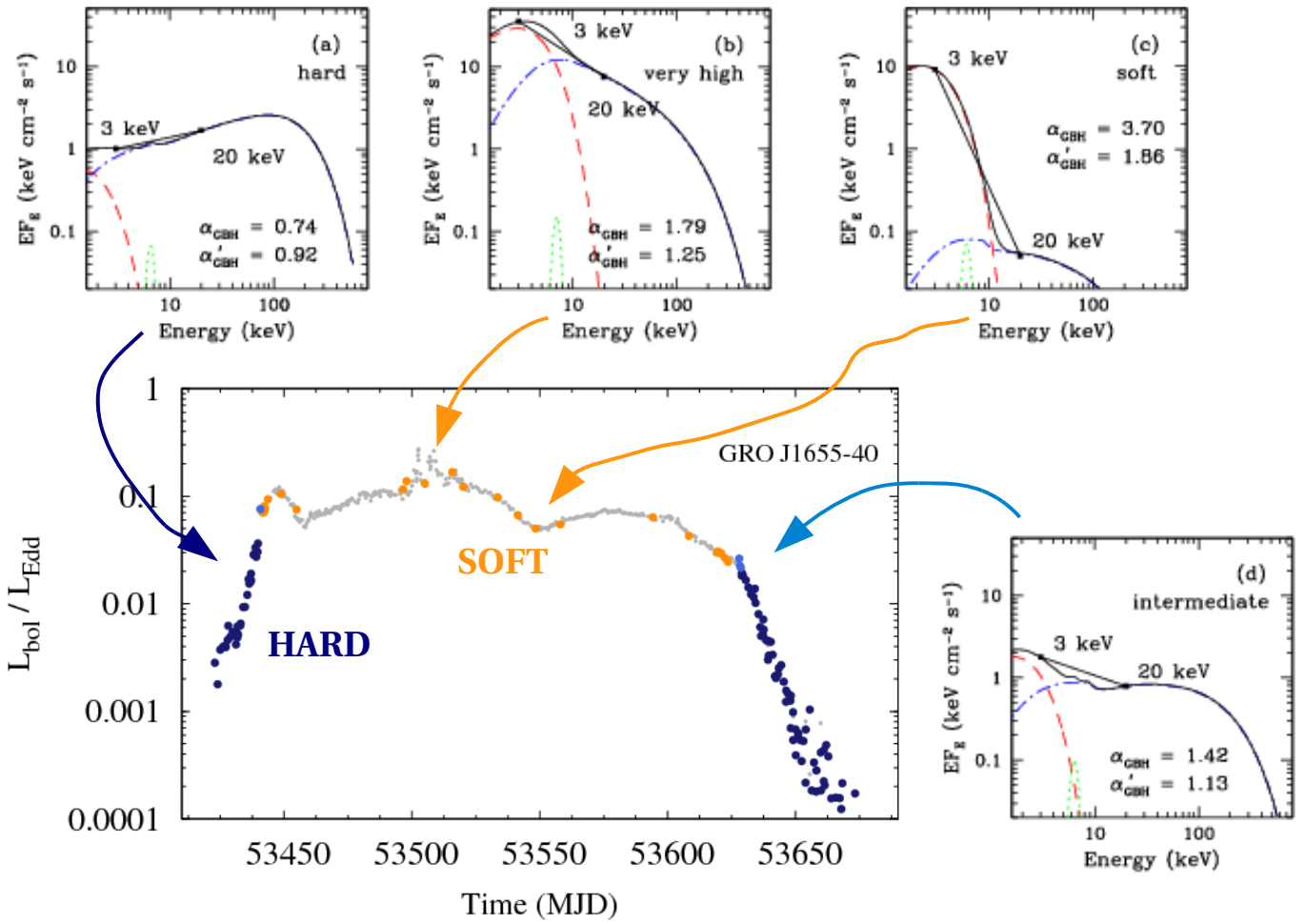
See also talks by Monica Young (Tuesday) and Anca Constantin (Thursday)

Motivation – spectral states of Galactic black hole binaries



RXTE (PCA/HEXTE) 3-200 keV lightcurve covering ~250 days of the 2005 outburst of GRO J1655-40, a 6.3 M⊙ Galactic black hole binary located at the distance of 3.2 kpc (Sobolewska et al. 2009).

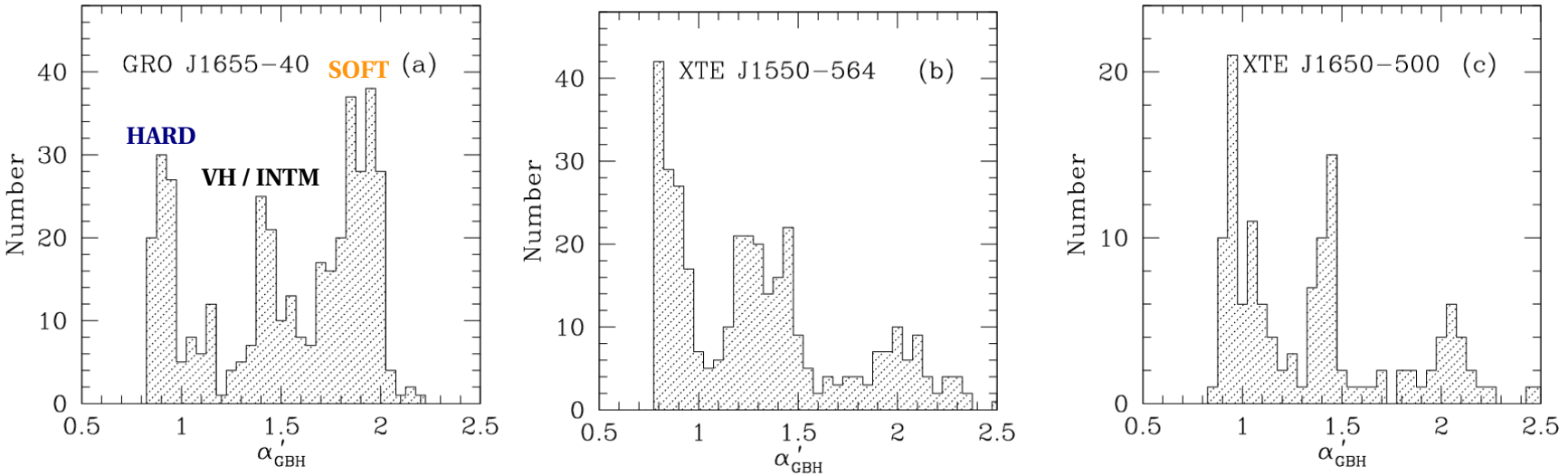
Motivation – spectral states of Galactic black hole binaries



RXTE (PCA/HEXTE) 3-200 keV lightcurve covering ~250 days of the 2005 outburst of GRO J1655-40, a 6.3 M⊙ Galactic black hole binary located at the distance of 3.2 kpc (Sobolewska et al. 2009).

Motivation – distribution of α'_{GBH}

(Sobolewska et al. 2009)



Distribution of $\alpha'_{GBH}=C\times(\alpha_{GBH}-1)+1$, where $C=(\log 3-\log 20)/(\log 0.005-\log 2)\simeq 0.32$, and

$$\alpha_{GBH} = -\frac{\log(\nu F_\nu)_D - \log(\nu F_\nu)_C}{\log(\nu_D) - \log(\nu_C)} + 1$$

Three main peaks can be distinguished, close to $\boldsymbol{\alpha'_{GBH}}$ values of **1, 1.5 and 2**, contrary to the case of AGN. These peaks correspond to a hard, very high/intermediate, and soft/ultrasoft spectral states, respectively (Sobolewska et al. 2009).

What are the origins of the correlation between the α_{OX} and luminosities in AGN?

Scaling the SED of a GBH to the case of an AGN

<u>Assumptions:</u>

The physics of accretion is similar in AGN and GBHs.

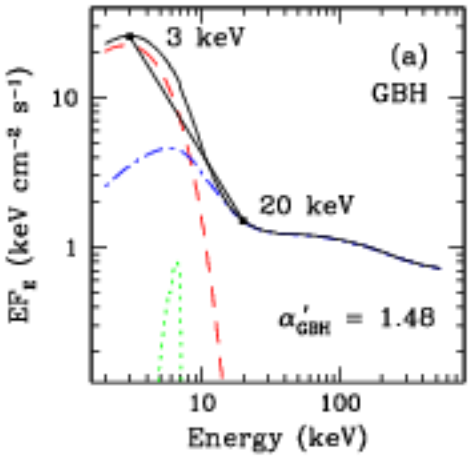
The heating-to-cooling compactness ratio l_h/l_s evolves in a similar way as a function of the mass accretion rate in AGN and GBHs.

The fundamental difference in the SEDs of AGN and GBHs is caused by the black hole mass dependance:

$$T_{disc} \propto M^{-1/4} \qquad\qquad L_{bol} \propto M$$

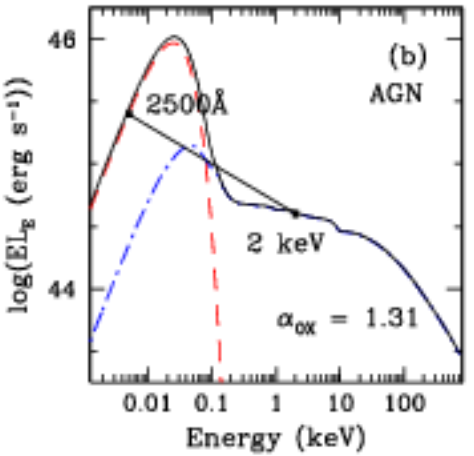
Scaling the SED of a GBH to the case of an AGN

GBH – GRO J1655-40
real spectrum



$M = 10^8\ M\odot$

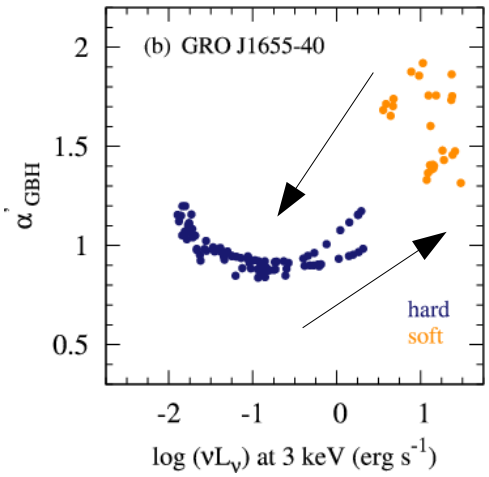
AGN
simulated spectrum



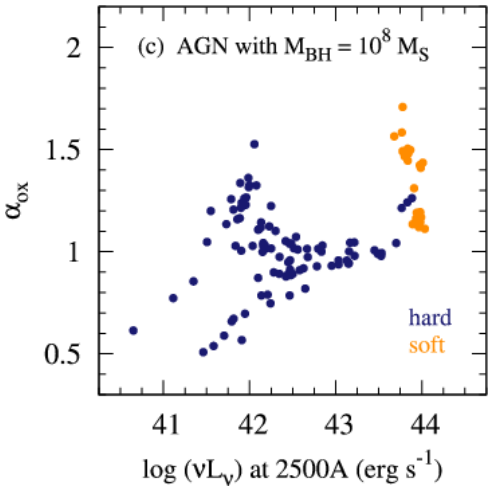
We apply black hole mass scaling to both the temperature of the accretion disc and the bolometric luminosity infered from the GBH spectra:

$$T_{disc} \propto M^{-1/4}$$

$$L_{bol} \propto M.$$

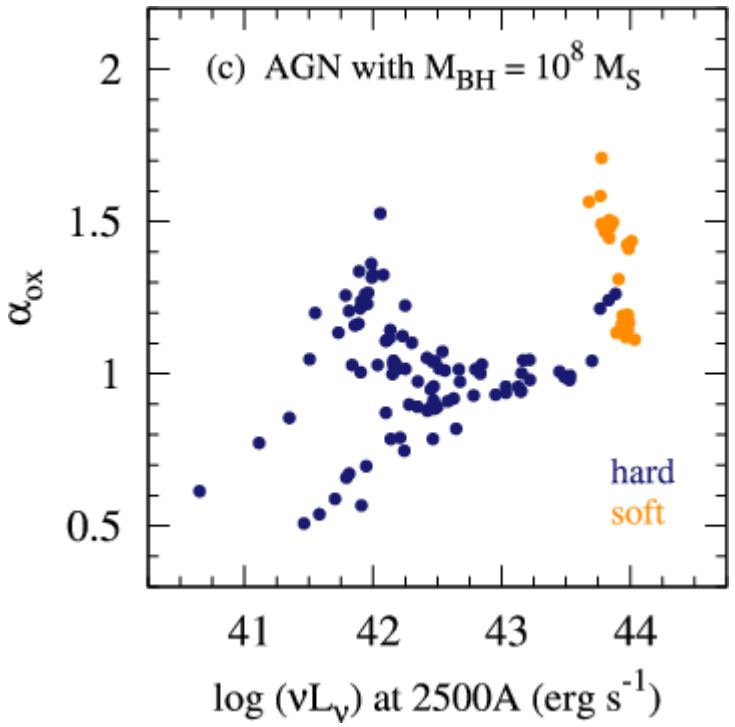


As a result we obtain a set of simulated AGN spectra based on which we calculate simulated X-ray loudness, α_{OX}, and monochromatic luminosity at 2500A.



$M = 10^8\ M\odot$

Scaling the SED of a GBH to the case of an AGN



Results:

The α_{OX} in the simulated AGN spectra is in the 0.5 – 2.0 range, consistent with observations.

There is no simple correlation between the simulated α_{OX} and luminosity at 2500A. Instead a characteristic U-shape can be observed.

In an AGN sample with narrow range of black hole masses we would expect a deviation from a correlation between α_{OX} and luminosity at 2500A.

What about a sample of AGN with a wide range of black hole masses?

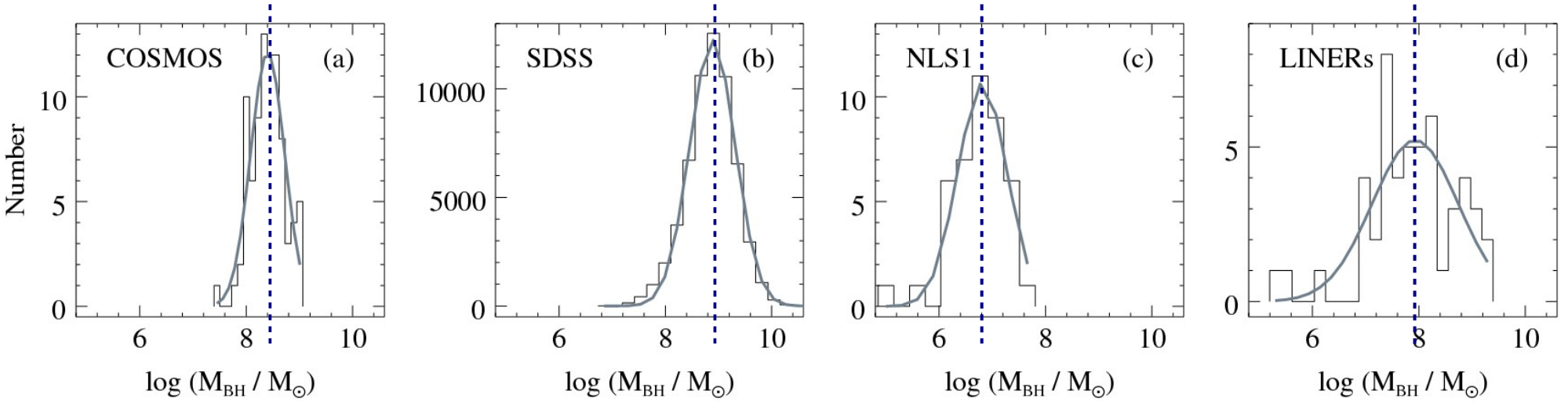
Distribution of black hole masses in AGN

Merloni et al. 2010

Shen et al. 2008

Grupe et al. 2010

Maoz 2007
Gu & Cao 2009
Eraclaous et al. 2010



# of AGN: 86 ~60.000 42 50

The solid lines are the best-fit Gauss functions.

The AGN black hole masses have a log-normal distribution.

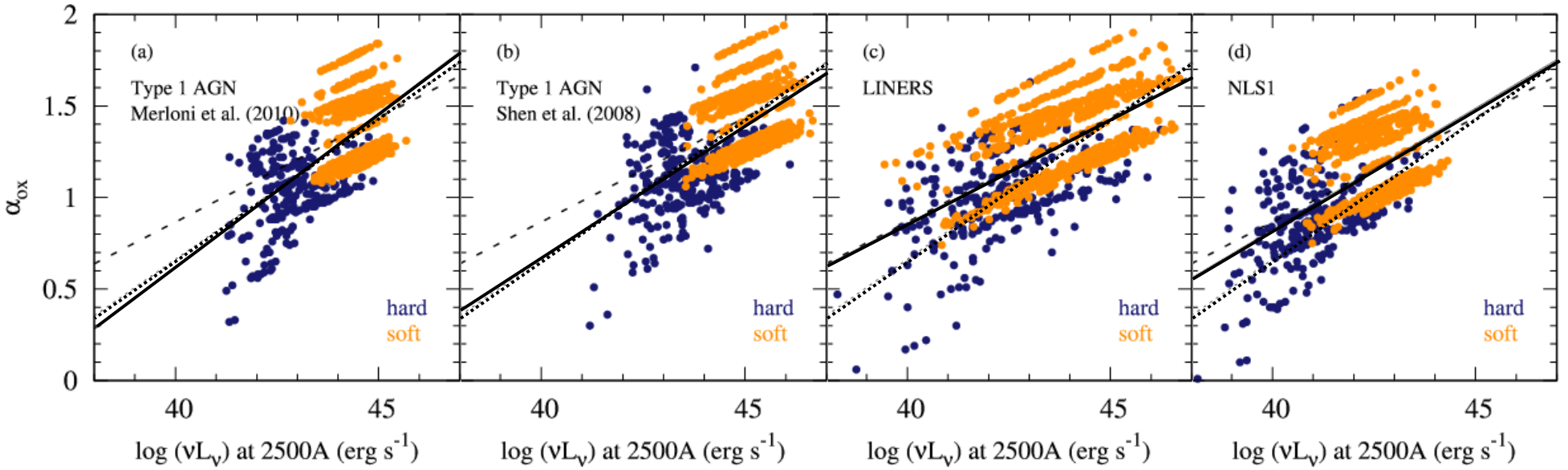
Correlation between the α_{OX} and luminosities in the simulated AGN spectra

The observed AGN are a mixture of systems in various spectral states with black holes that differ in mass by several orders of magnitude.

- Draw a **black hole mass** from an observationally motivated log-normal distribution.
- Draw a GBHs spectrum (hard vs. soft state)
- Scale the GBH spectrum to the case of an AGN – **mass dependance** of the disk temperature and bolometric luminosity
- Calculate the α_{OX} and luminosity at 2500A of the simulated AGN spectrum
- Study the **correlations** of the simulated α_{OX} with the luminosity at 2500A and Eddington luminosity ratio.
- **Comparison with the observational samples of AGN**

Correlation between the α_{OX} and 2500A luminosity in the simulated AGN spectra

Solid – best fits to the simulated data, **dotted** – Lusso et al. (2010), **dashed** – Grupe et al. (2010)

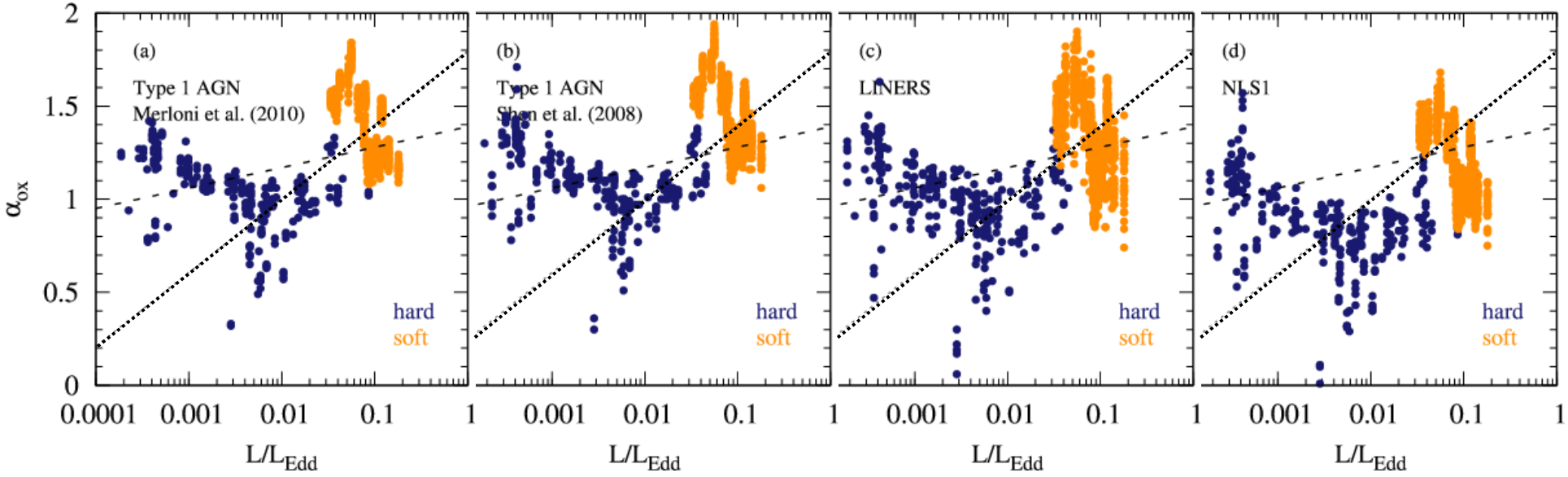


The **spread in AGN's black hole masses** leads to a **correlation** between the α_{OX} and luminosity at 2500A.

The wider the FWHM of the mass distribution, the more significant the overlap between the soft and hard state regions occupied by the simulated (α_{OX}, 2500A luminosity) pairs.

Correlation between the α_{OX} and Eddington luminosity ratio in the simulated AGN spectra

Dotted – Lusso et al. (2010), **dashed** – Grupe et al. (2010)

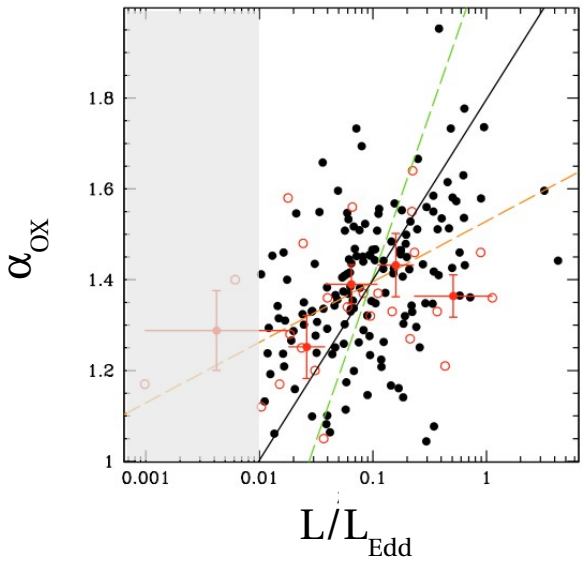


The α_{OX} correlates positively with the Eddington luminosity ratio down to $\mathbf{L/L_{Edd} \sim 0.007}$. Below this value the correlation changes its sign.

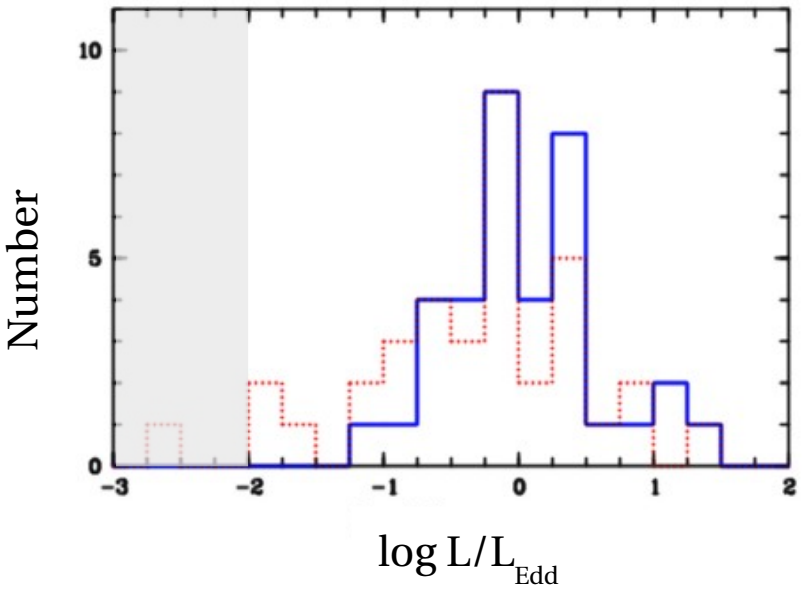
Our simulations roughly reproduce the slope of the Lusso et al. (2010) correlation for $L/L_{Edd} > 0.007$.

Correlation between the α_{OX} and Eddington luminosity ratio in the simulated AGN spectra

Lusso et al. (2010)

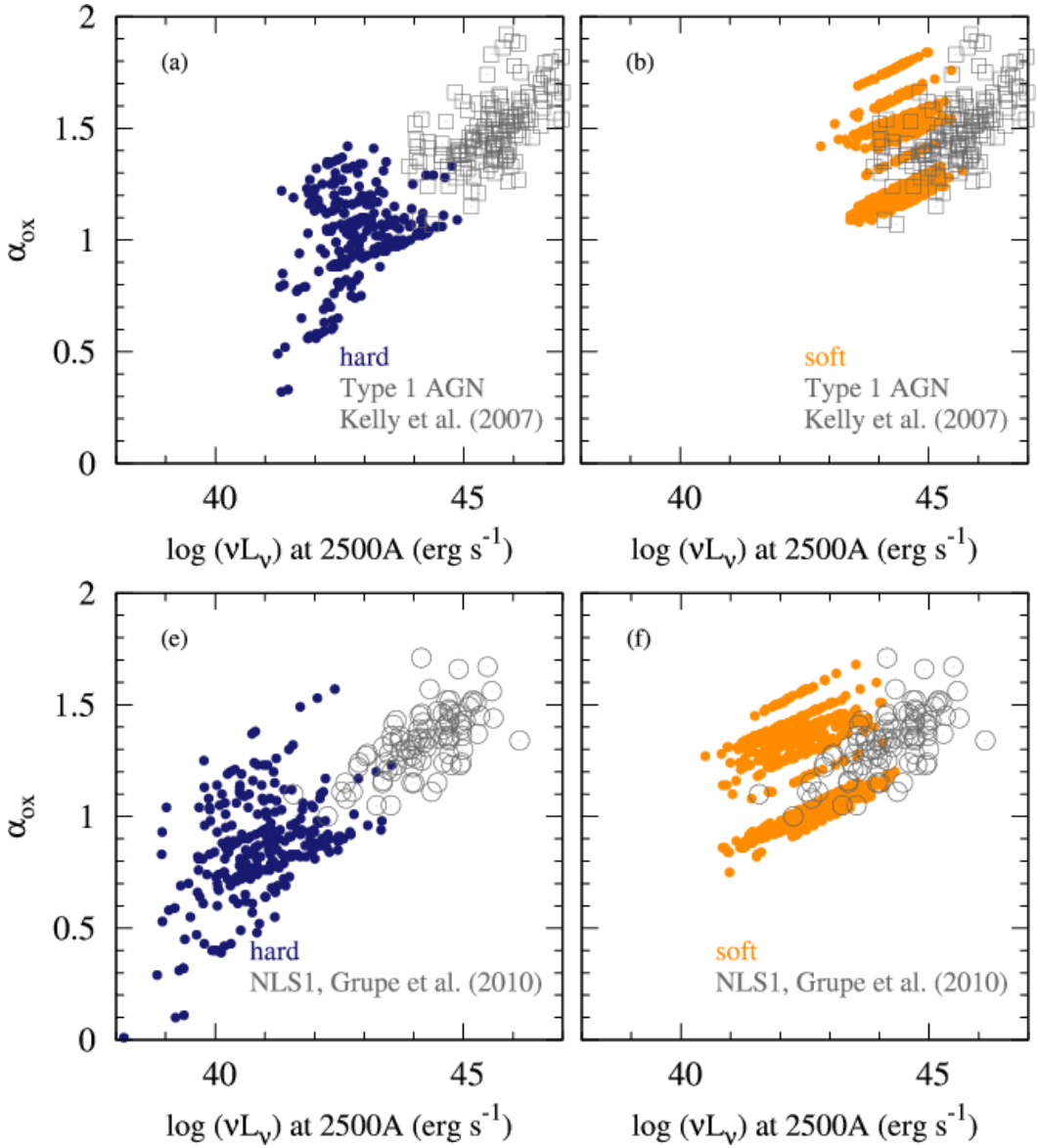


Grupe et al. (2010)



There are no observational constraints on the α_{OX} vs. Eddington luminosity ratio correlation for $L/L_{Edd} < 0.01$

Determining spectral states of AGN (Type 1 AGN and NLS1)



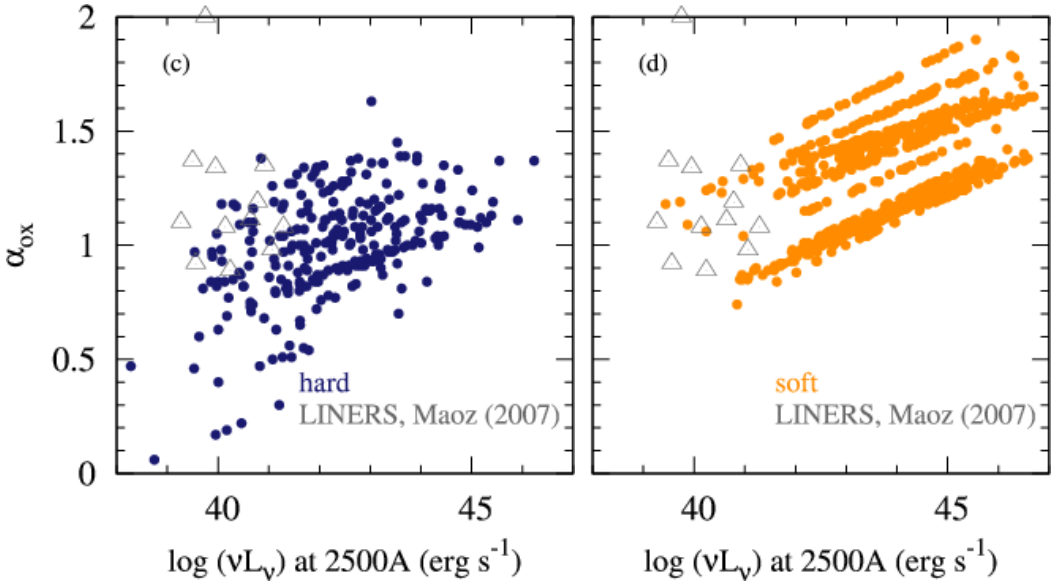
Orange – soft state simulated AGN SED.

Blue – hard state simulated AGN SED.

Squares and circles – real AGN data.

Both type 1 AGN from Kelly et al. (2007) and NLS1s from Grupe et al. (2010) overlap with the regions occupied by the soft state simulated SEDs.

Determining spectral states of AGN (LINERs)

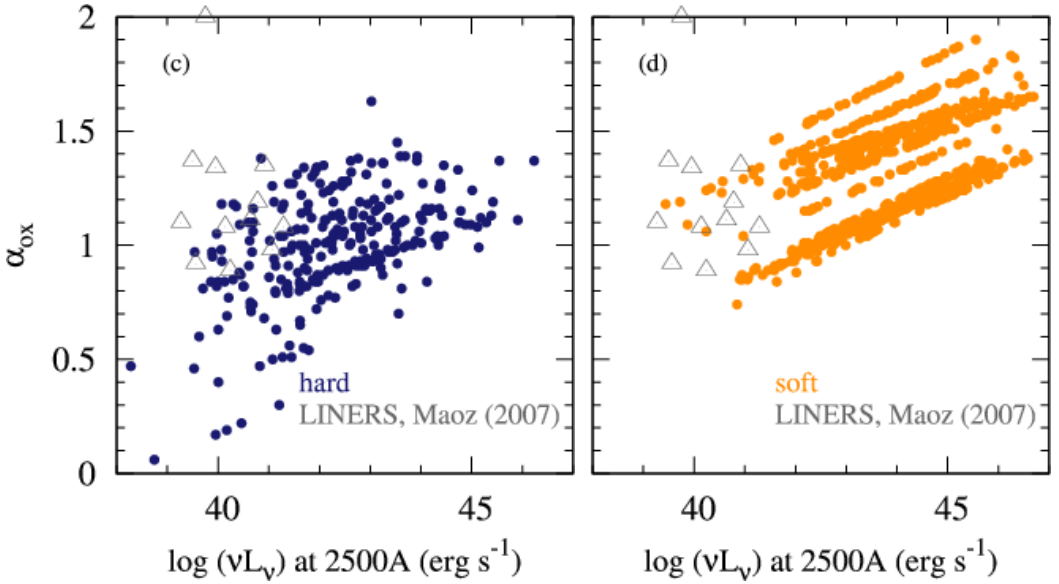


Orange – soft state simulated AGN SED.

Blue – hard state simulated AGN SED.

Triangles – real AGN data.

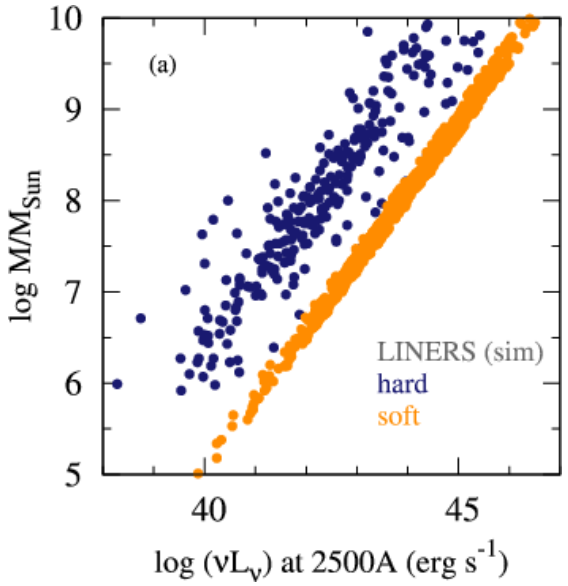
Determining spectral states of AGN (LINERs)



Orange – soft state simulated AGN SED.

Blue – hard state simulated AGN SED.

Triangles – real AGN data.



LINERs in the sample of Maoz (2007) host heavy black holes, with $10^{7-9.5}$ Solar masses.

The soft state simulated SEDs result in required log of luminosity at 2500A for black hole masses smaller than 10^6 Solar mass.

We conclude that LINERs in Maoz (2007) are most probably in the hard spectral state.

Summary

- **The spread in AGN black hole masses leads to a correlation between the α_{OX} and luminosity at 2500A**

The slope of our simulated correlation is roughly consistent with those reported from observations.

- **We reproduce a correlation between the α_{OX} and Eddington luminosity ratio in the simulated AGN SEDs down to $L/L_{Edd} \sim 0.007$**

For $L/L_{Edd} < 0.007$ the α_{OX} vs. L/L_{Edd} correlation changes its sign. This prediction remains to be tested observationally. Interestingly, the observations already shown that the Γ vs. L/L_{Edd} correlation changes sign for $L/L_{Edd} \sim 0.007$.

- **Bright Type 1 quasars and NLS1s might be in the soft spectral state while LINERs might be similar to GBHs in a hard spectral state**