QUASAR X-RAY SPECTRAL VARIABILITY FROM THE XMM-NEWTON SERENDIPITOUS SOURCE CATALOGUE

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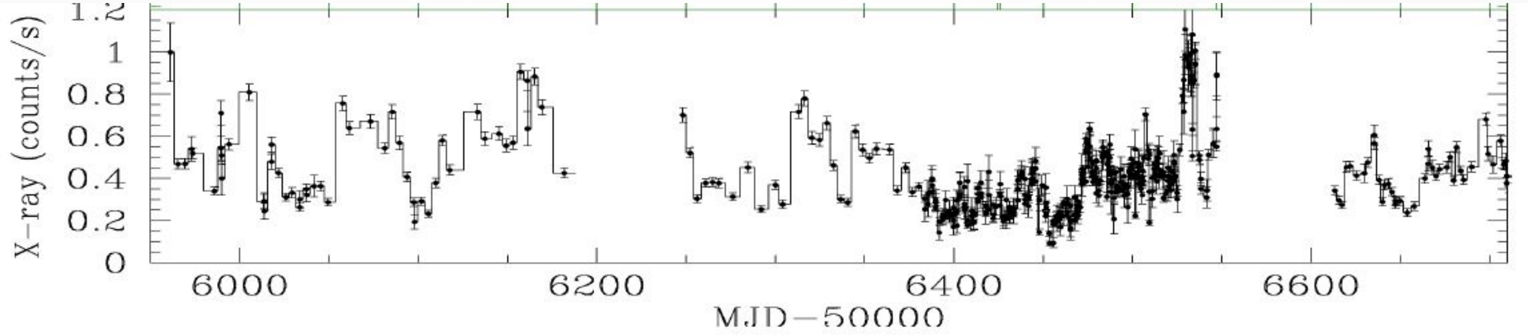
VARIABILITY



All classes of Active Galactic Nuclei show some kind of amplitude variability in nearly all bands, including X-rays.

X-ray variability happens at a very wide range of timescales: hours up to few years (e.g. Vagnetti et al, 2011)

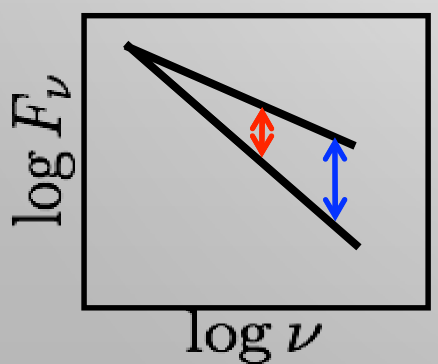
In addition to amplitude variability it is also important to study the **spectral variability**, i.e. the variability of the photon index of the spectrum Γ, defined as $N(E) \propto E^{-\Gamma}$.

SPECTRAL VARIABILITY

We quantify the spectral variability with the **spectral variability parameter β** (Trevese and Vagnetti, 2002), which is defined as:

$$\beta = \frac{d\alpha}{d \log F} \qquad F \propto \nu^{\alpha} \qquad \alpha = \frac{d \log F}{d \log \nu}$$

Optical/UV → $\beta > 0$ → The spectrum typically gets 'flatter' in the brighter phases (harder when brighter behaviour), Trevese and Vagnetti, (2002)

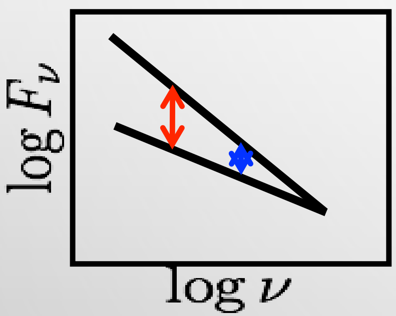


SPECTRAL VARIABILITY

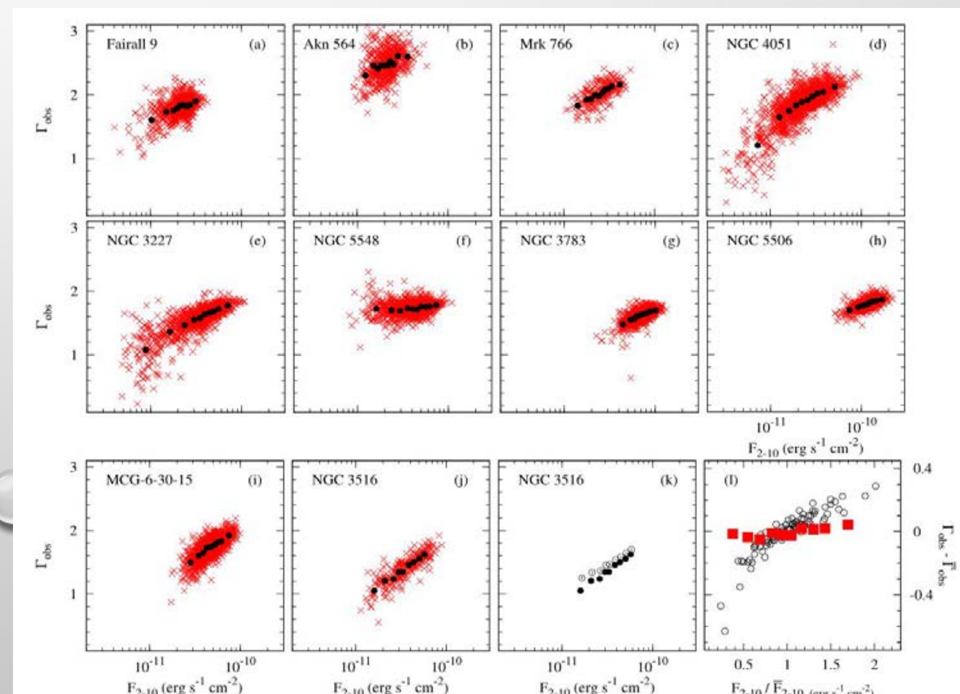
In the X-ray band, the spectral variability parameter is defined in terms of the photon index Γ.

$$\beta = -\frac{d\Gamma}{d\log F} \qquad \Gamma = 1 - \alpha$$

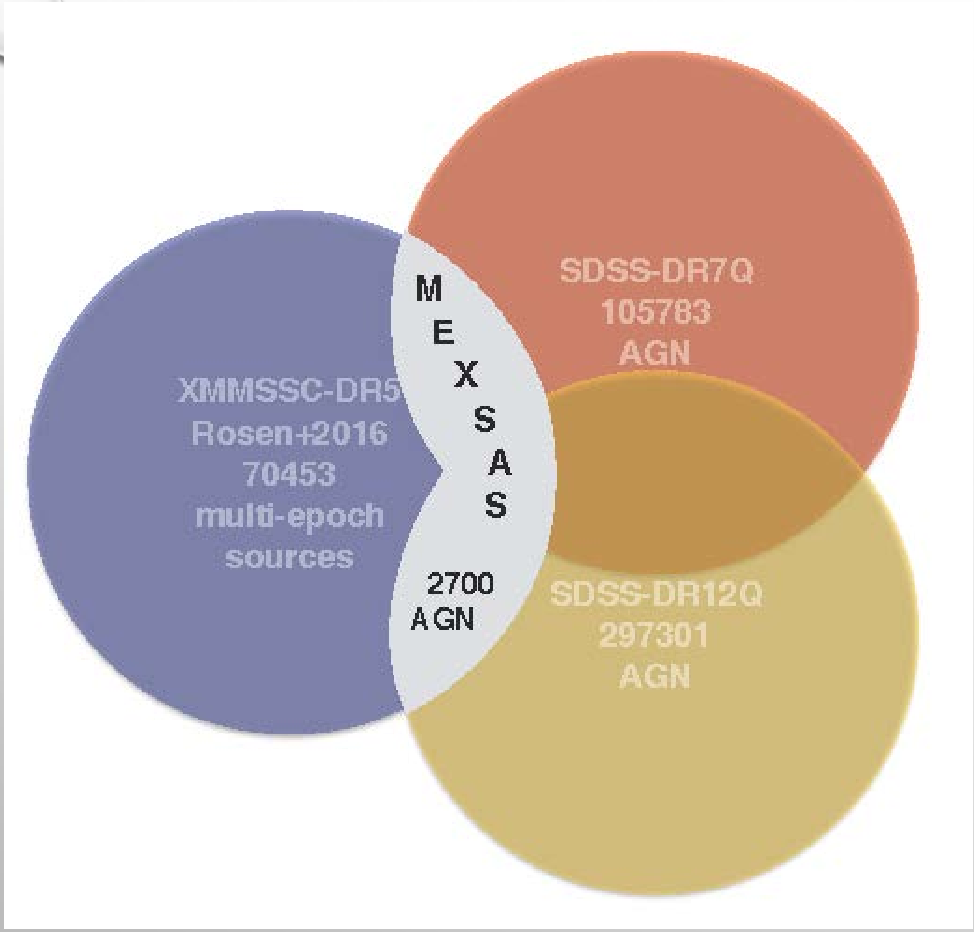
X-rays ⟶ $\beta < 0$ ⟶ Results from nearby sources (Sobolewska and Papadakis, 2009) show a 'softer when brighter' trend.



Ten nearby Seyfert galaxies sources show this trend. The authors also provided an ensemble figure, showing that they have similar trends among each other, although we estimate that the spectral variability parameter varies approximately between 0 and -1.



MEXSAS CATALOGUE



Multi-Epoch XMM Serendipitous AGN Sample catalogue (Vagnetti et al, 2016):

- 2,700 sources
- 7,837 observations (only multi-epoch sources were selected)
- Does **NOT** include Seyfert galaxies, BL Lac and Type-2 AGNs.
- Lists integral fluxes in five bands: F_1 $(0.2 - 0.5$ keV), F_2 $(0.5 - 1$ keV), F_3 $(1 - 2$ keV), F_4 $(2 - 4.5$ keV) and F_5 $(4.5 - 12$ keV).

PHOTON INDEX COMPUTING

Mexsas catalogue does not include the photon index Γ

If we take the five integral fluxes, we can estimate the monochromatic fluxes at the lowest energy of the band using the following procedure:

$$F_X = \int_{\nu_i}^{\nu_s} F_i \left(\frac{\nu}{\nu_i}\right)^{1-\Gamma} d\nu = \frac{F_i \nu_i}{2-\Gamma}\left[\left(\frac{\nu_s}{\nu_i}\right)^{2-\Gamma} - 1\right]$$

Therefore

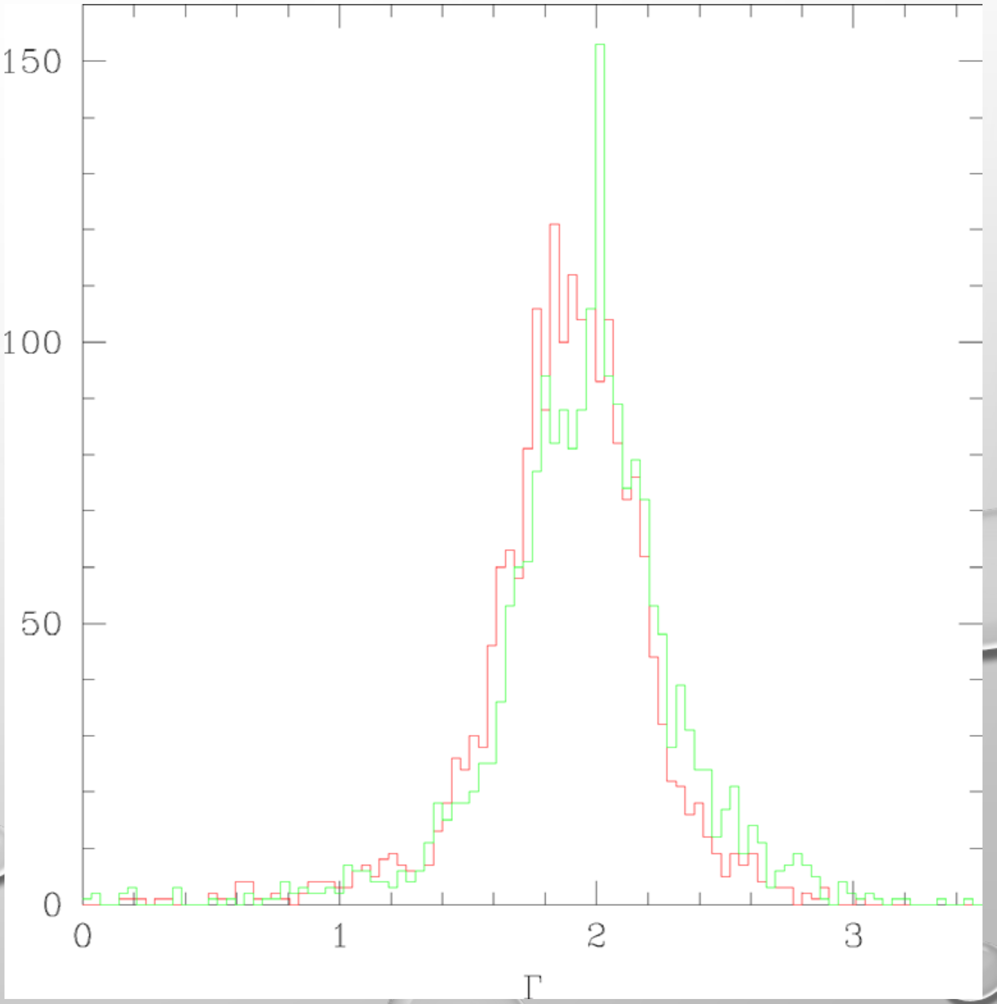
$$F_i = \frac{h F_X (2-\Gamma)}{E_i\left[\left(\frac{E_s}{E_i}\right)^{2-\Gamma} - 1\right]}$$

→

It is possible, assuming a PL spectrum, to perform spectral fits of five monochromatic fluxes, although some absorption is present at low energies and therefore we ecluded the first point from all spectra and performed 4-point spectral fits.

PHOTON INDEX COMPUTING

Surprisingly, this method is robust. For a subset of particularly bright observations ($F_S \gtrsim 10^{-14} erg\ cm^{-2} s^{-1}$) there are photon indices available in the XMMFITCAT catalogues (Corral et al, 2015), computed directly from their full spectrum.



The histogram of the photon indices of this subset (in green) is very similar to the one of our Γs (red): the difference between the two mean values is about 0.07.

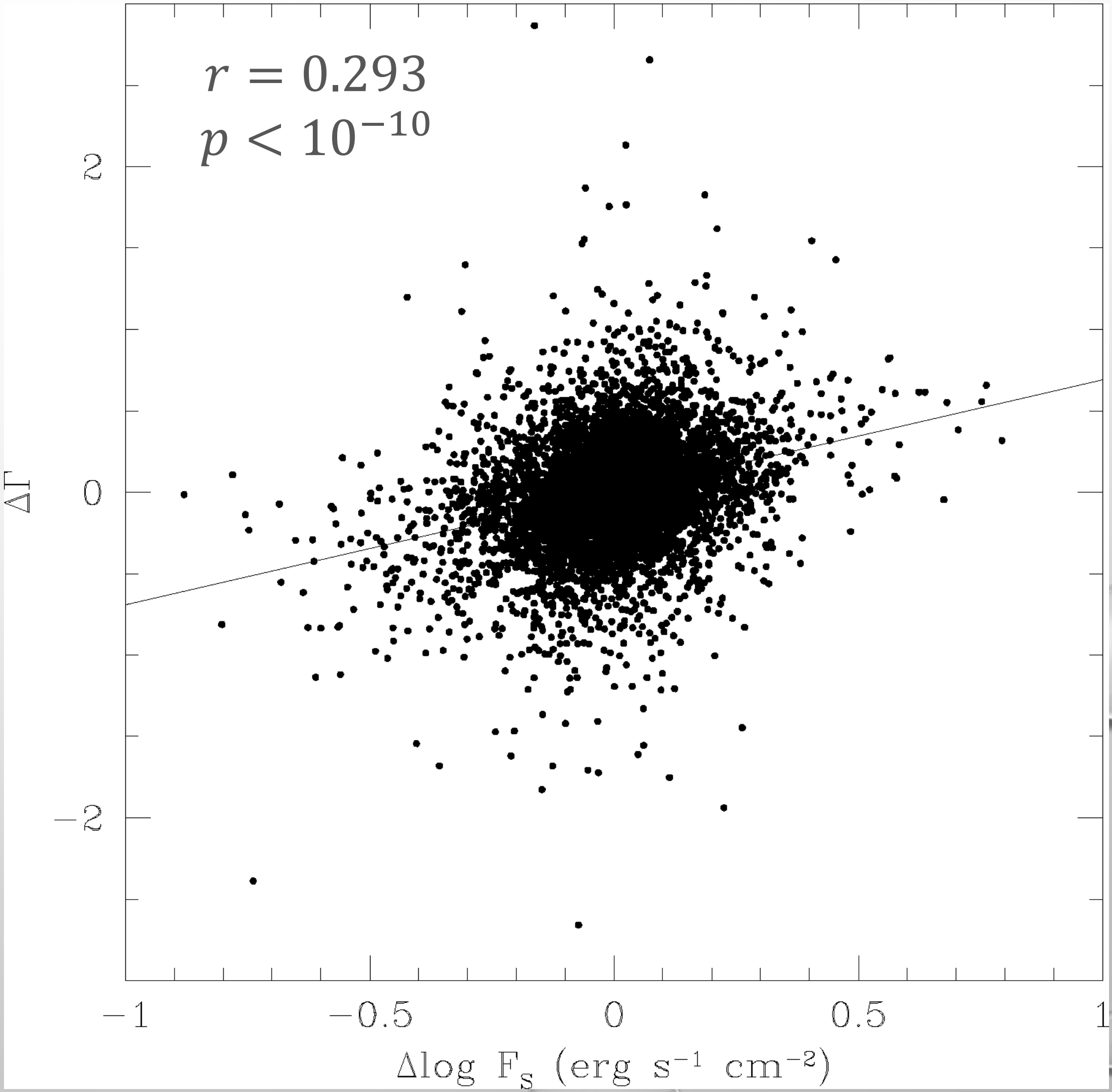
ENSEMBLE RESULT

$$\beta = -\frac{d\Gamma}{d\log F}$$

$$\Delta\Gamma = \Gamma - \bar{\Gamma}$$
$$\Delta\log F = \log F - \overline{\log F}$$

$$\beta = -0.69 \pm 0.03$$

The negative value of β means that the ensemble X-ray spectral variability of quasar has an average softer when brighter trend, confirming the Seyfert galaxies result.



FLUX DEPENDENCE

All fluxes in erg $\cdot s^{-1} \cdot cm^{-2}$

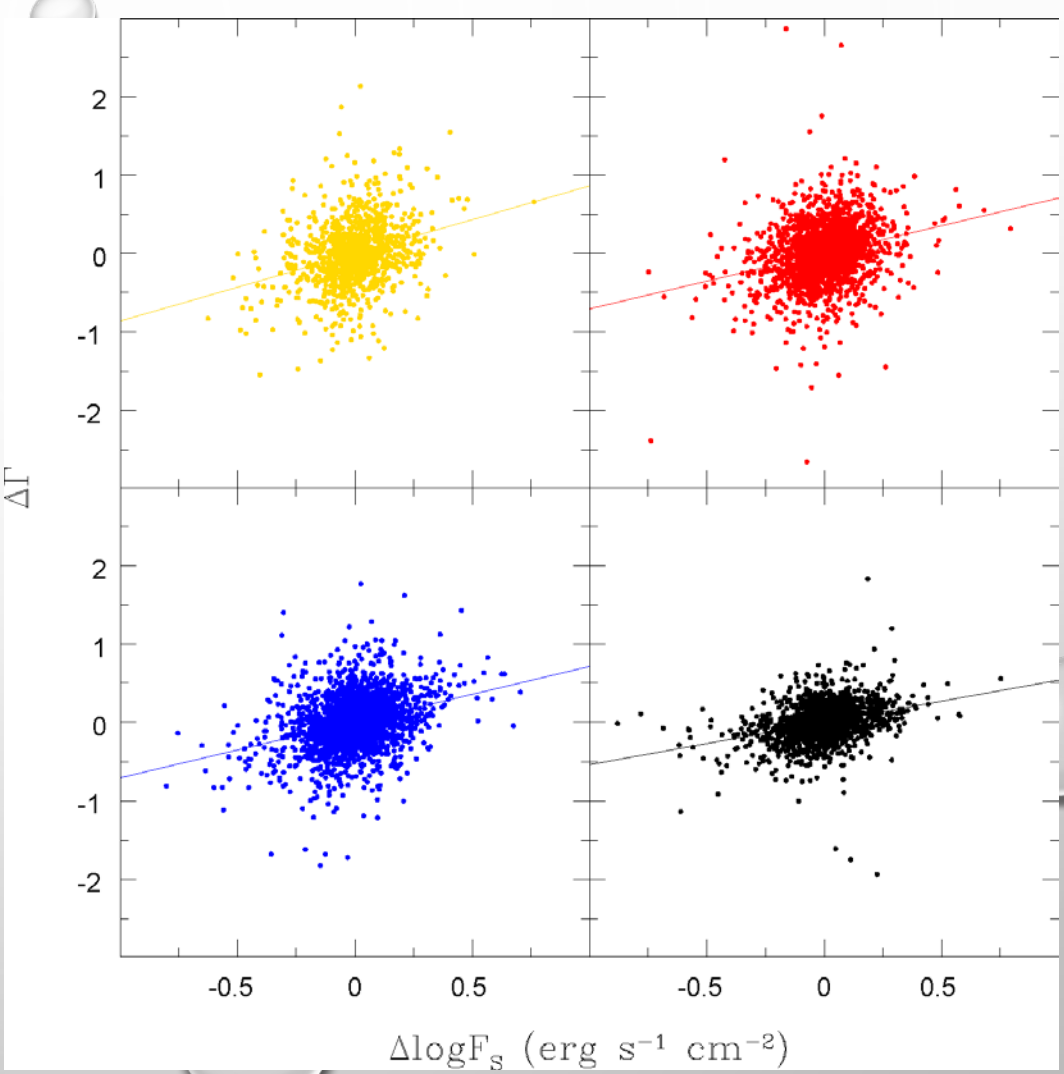
Yellow bin
$\bar{F_S} < 5 \cdot 10^{-15}$
$\beta = -0.86 \pm 0.08$

Red bin
$5 \cdot 10^{-15} \leq \bar{F_S} < 10^{-14}$
$\beta = -0.71 \pm 0.06$

Blue bin
$10^{-14} \leq \bar{F_S} < 2.5 \cdot 10^{-14}$
$\beta = -0.71 \pm 0.04$

Black bin
$\bar{F_S} \geq 2.5 \cdot 10^{-14}$
$\beta = -0.54 \pm 0.03$

Brighter sources, that have lower errors on Γ, have a better correlation. Even though the exact values are slightly different they all show a softer when brighter trend.



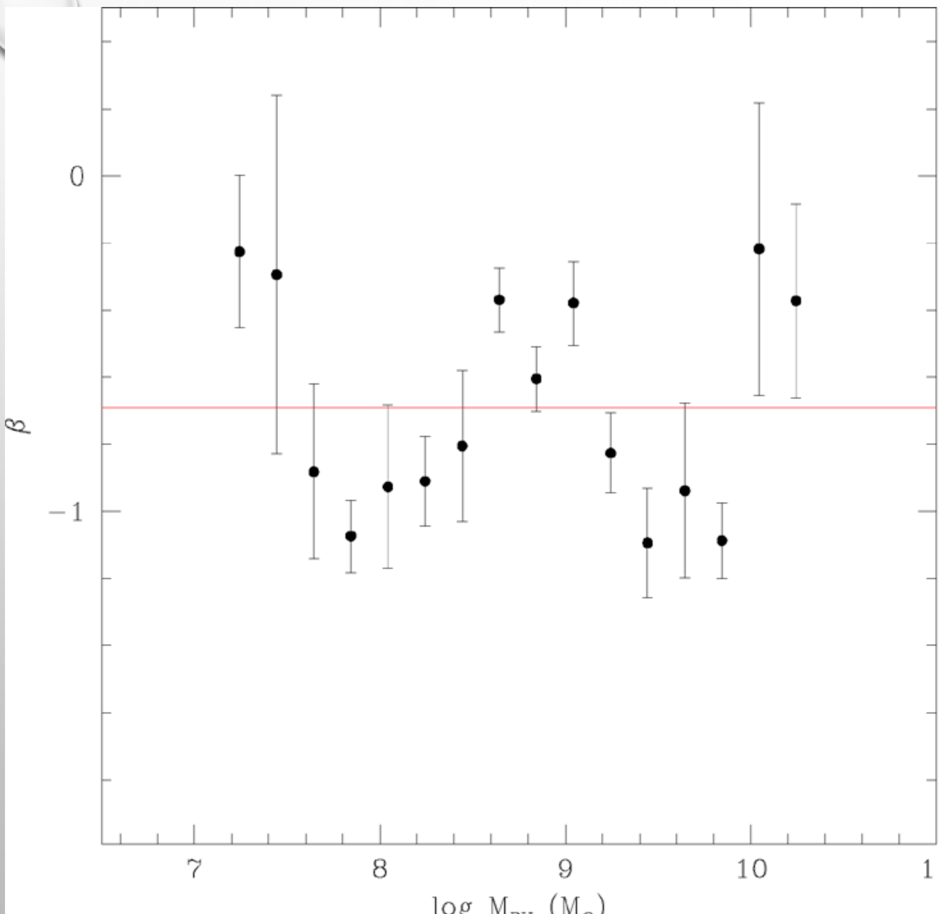
Correlations for fainter sources are affected by higher errors on Γ.

DEPENDENCE ON AGN PARAMETERS

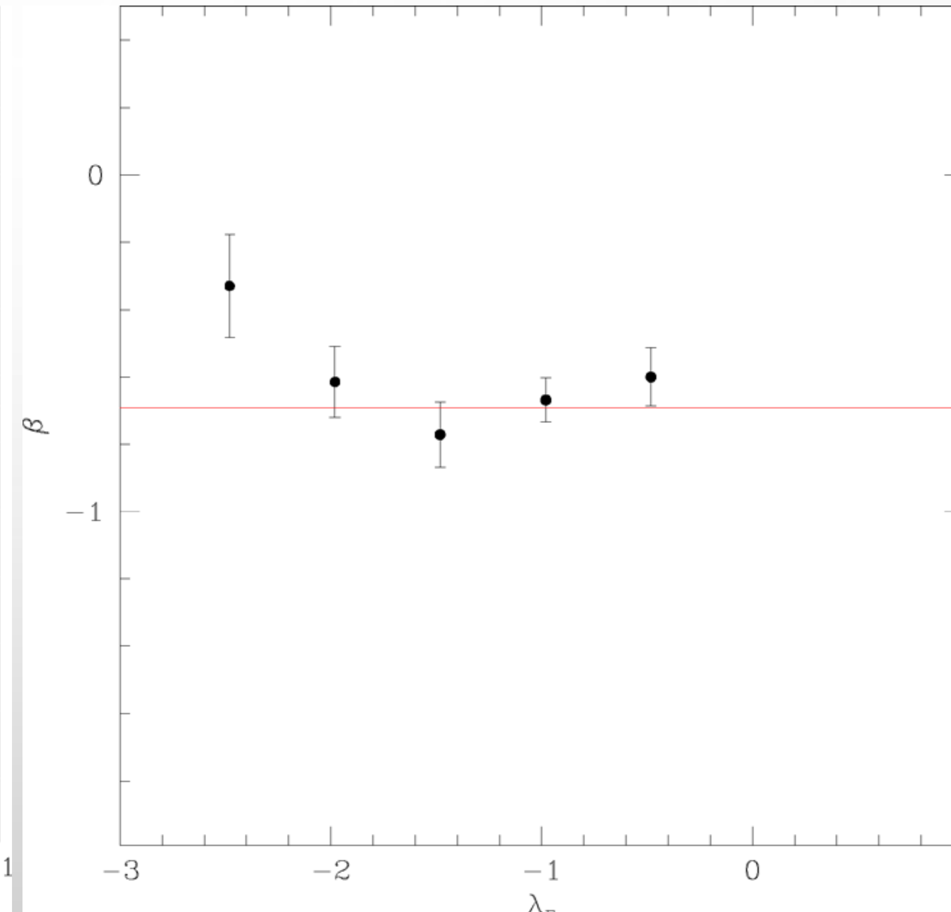
We computed β on many bins of four different AGN parameters:

- Black hole mass (Shen et al, 2011)
- Eddington ratio (Shen et al, 2011)
- Redshift (Available from SDSS, DR7Q and DR12Q)
- X-ray luminosity (Computed from redshift)

DEPENDENCE ON AGN PARAMETERS

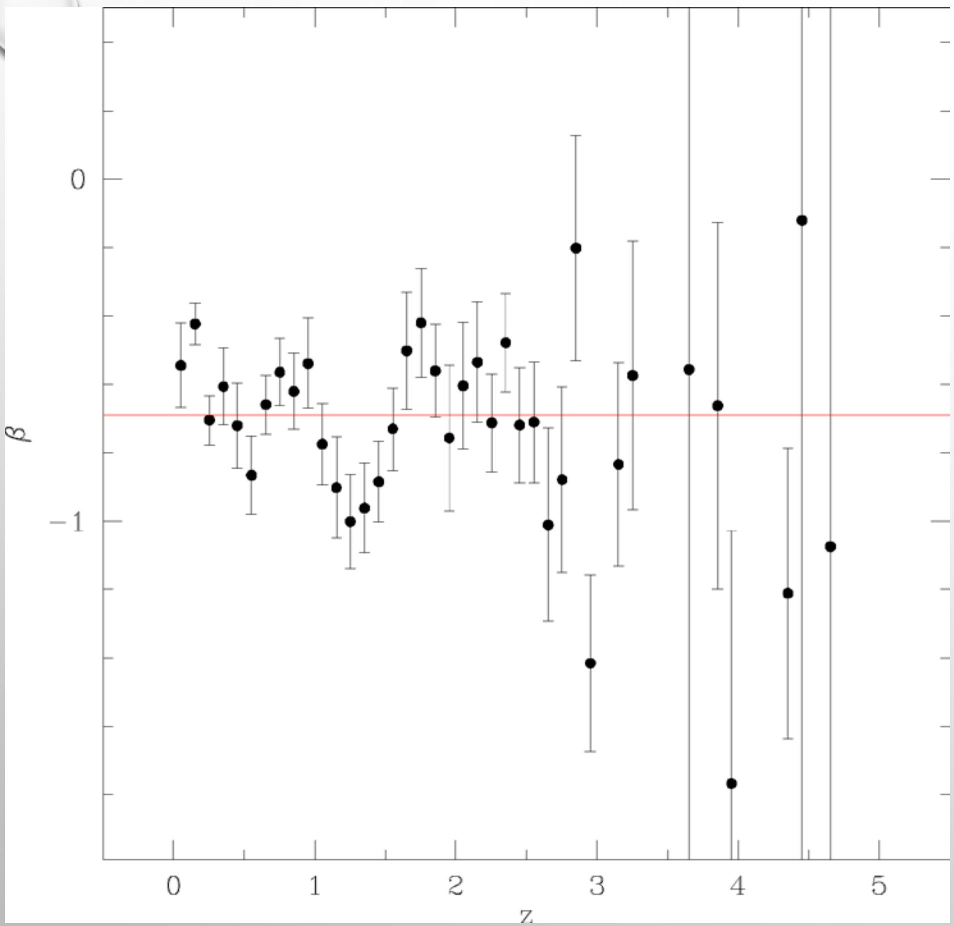


Central black hole mass

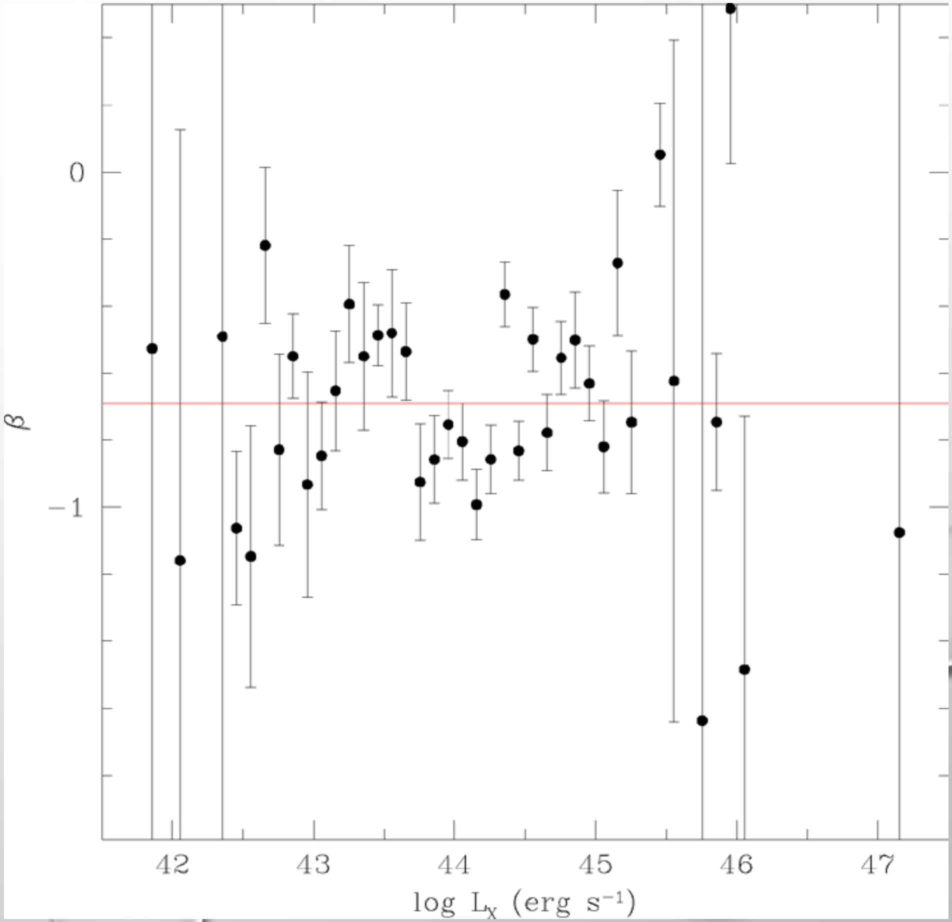


Eddington ratio

DEPENDENCE ON AGN PARAMETERS



Redshift



X-ray luminosity

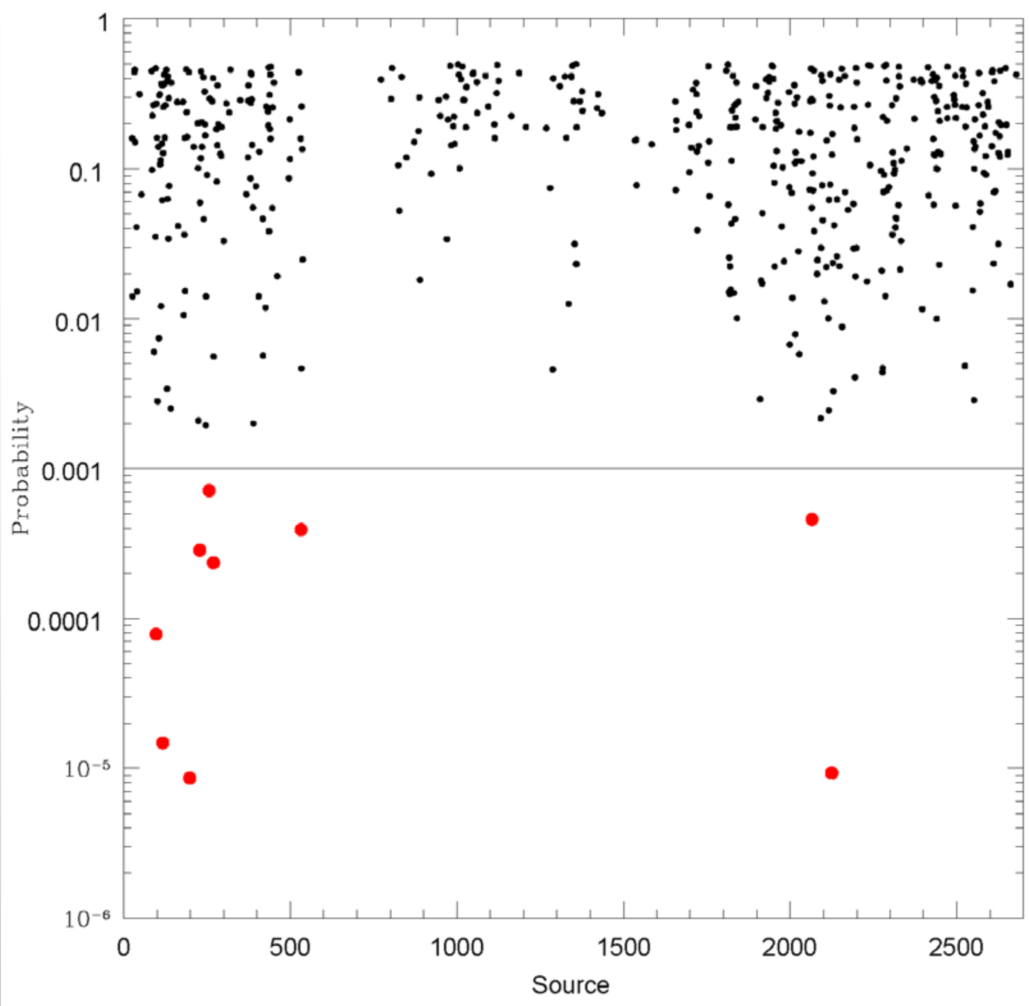
SINGLE SOURCES

There is **no clear correlation** between β and any of the quantities studied above

In some bins the value could deviate sensibly from ensemble value

This suggest that there might be single sources that also have β that differs from the ensemble value.

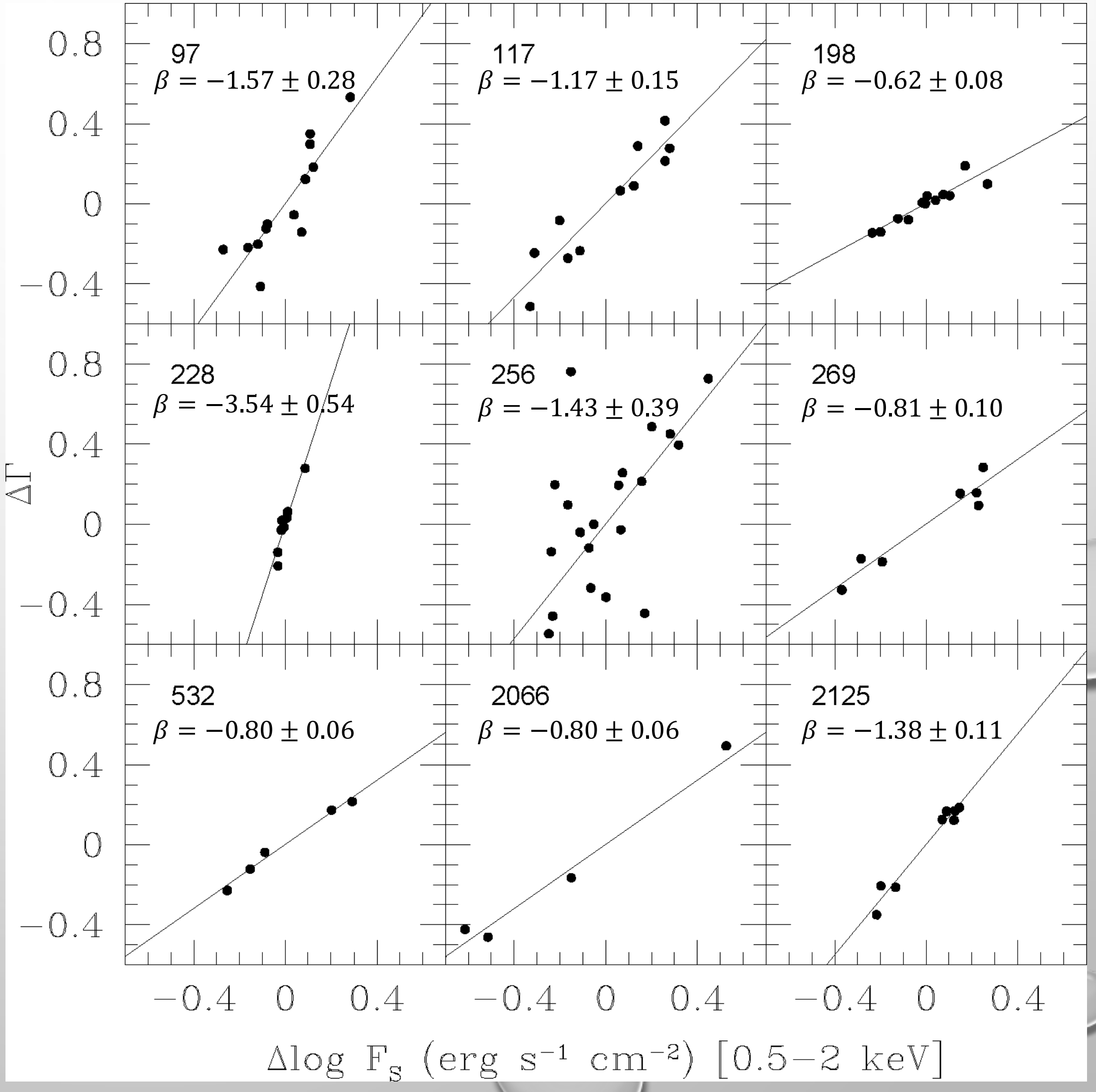
We selected nine sources, the ones with the most significant $\Gamma - \log F$ correlation, the ones which probability of finding the correlation by chance is $p \leq 10^{-3}$.



SINGLE SOURCES

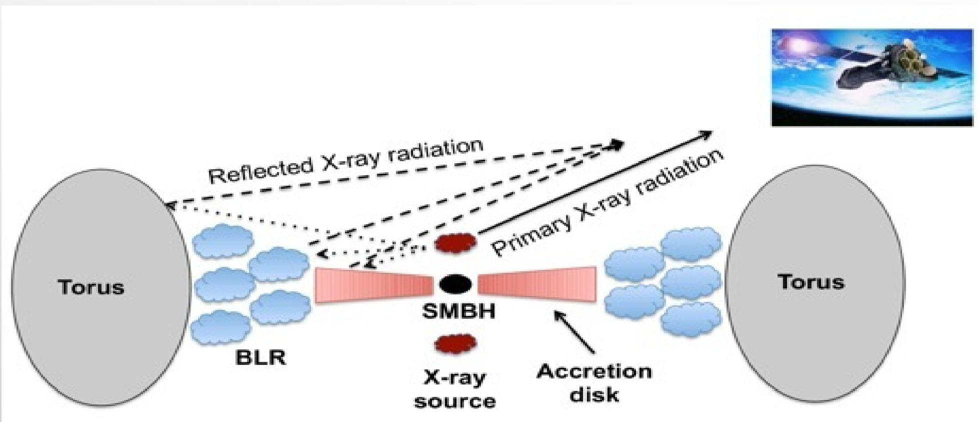
All the sources have a softer when brighter trend, which means that the mechanism behind the spectral variability is likely the same.

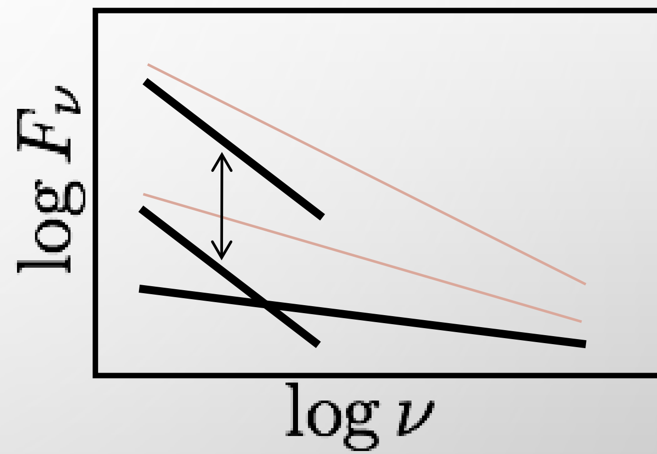
The 9 sources show a wide spread of values of β, from $\beta = -3.54 \pm 0.54$ to $\beta = -0.62 \pm 0.08$, varying of a factor of about 6.



IMPLICATIONS

Softer when brighter behaviour might be due to two main reasons:



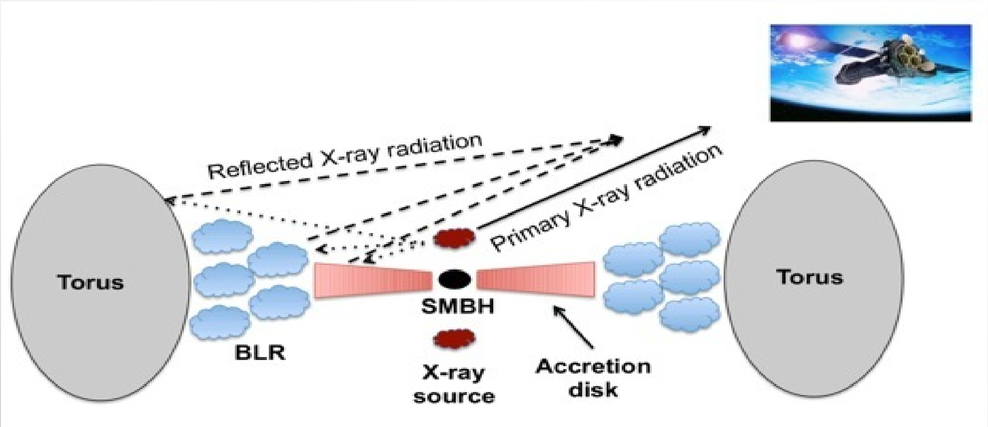


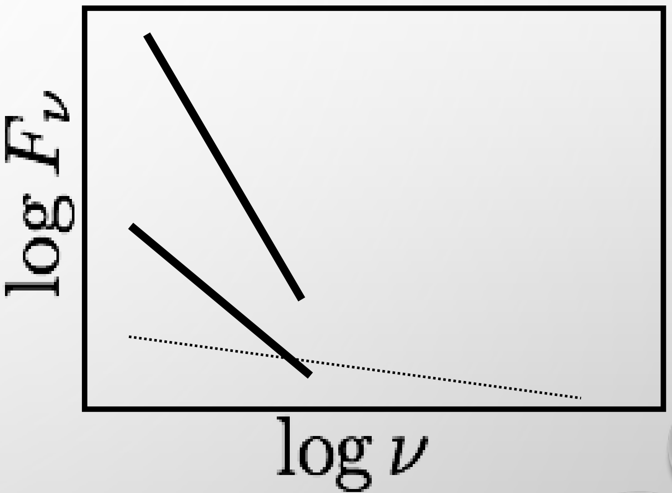
PRIMARY RADIATION ONLY VARIABLE IN FLUX

According to this model, we have an X-ray primary radiation that is variable in amplitude but not in spectrum, while some of this radiation is reflected by the other components of the AGN. This reflected components would not be variable, steepening the spectrum as observed.

IMPLICATIONS

Softer when brighter behaviour might be due to two main reasons:





INTRINSIC VARIATIONS OF THE PRIMARY X-RAY RADIATION

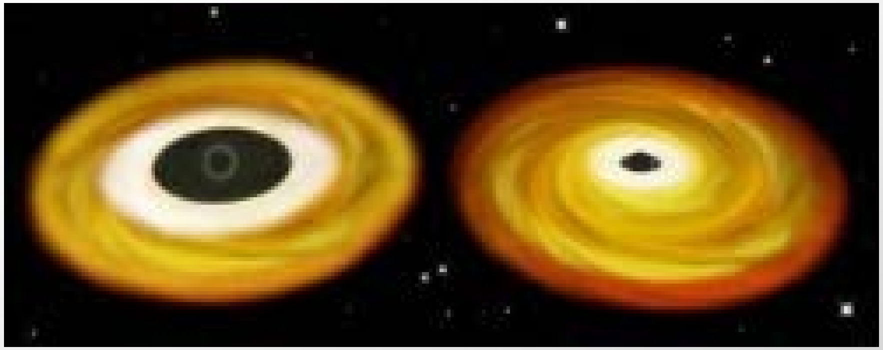
According to this more complex model, the primary X-ray radiation is variable in both amplitude and spectrum, while the reflected component is still not variable, resulting in the observed steepening of the spectrum.

IMPLICATIONS

The reason why the spectral variability parameter β varies so much from source to source is not entirely clear. Might be due to:

- Black hole spin

A higher black hole spin diminishes the minum stable orbit, and therefore the size of the disk. This could be crucial in altering the variability properties of the source.

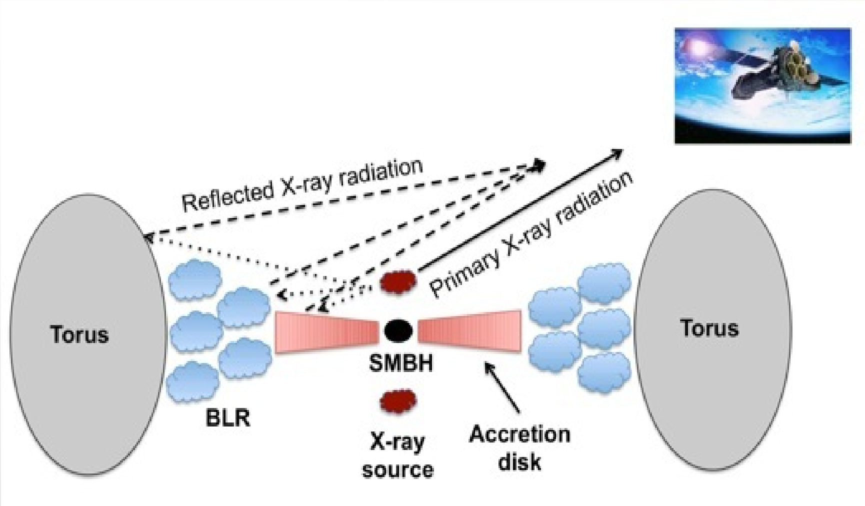


IMPLICATIONS

The reason why the spectral variability parameter β varies so much from source to source is not entirely clear. Might be due to:

- Black hole spin
- Angle of view

The inclination of the quasar with respect to the line of sight might be a factor in determining its variability properties. The reflected component, for instance, might be not isothropic.

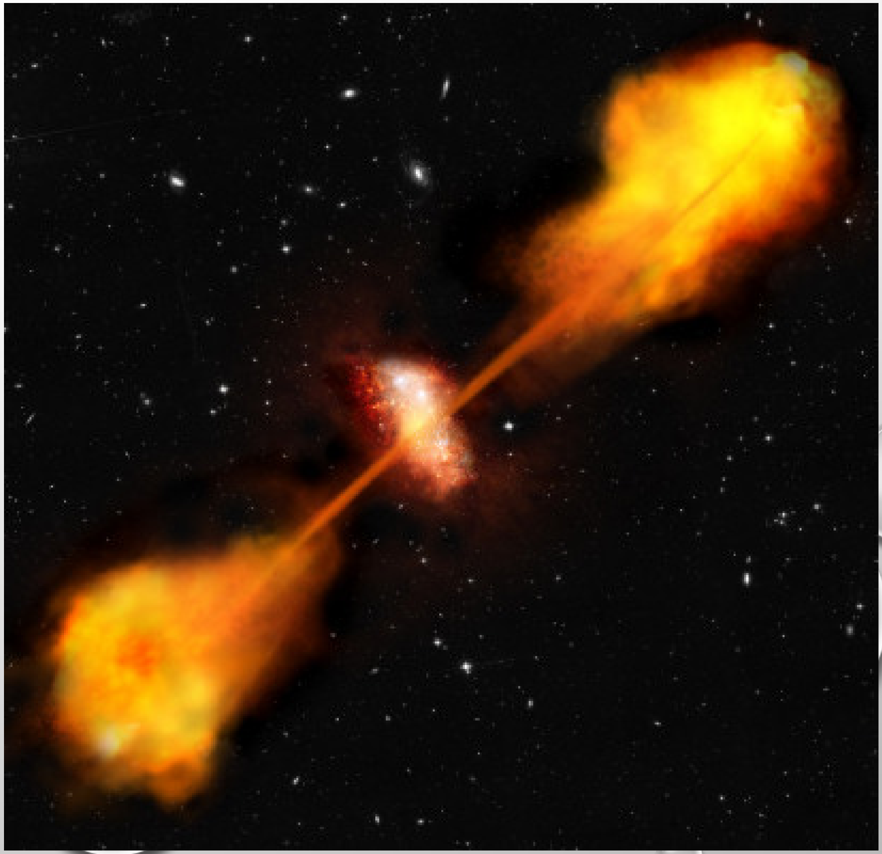


IMPLICATIONS

The reason why the spectral variability parameter β varies so much from source to source is not entirely clear. Might be due to:

- Black hole spin
- Angle of view
- Radio-loudness

Radio-loudness implies an enhanced X-ray emission associated with a jet component, and might be a factor that influences the spectral variability.



IMPLICATIONS

The reason why the spectral variability parameter β varies so much from source to source is not entirely clear. Might be due to:

- Black hole spin
- Angle of view
- Radio-loudness
- Entirely stochastic processes

The mechanism behind spectral variability might be influenced by stochastic events.

SUMMARY

- We have found a negative spectral variability parameter β for an ensemble sample of 7,837 observations from 2,700 quasars.
- This means that the X-ray spectral variability has an average 'softer when brighter' trend, that might be due the combination of a primary X-ray radiation only variable in flux with a reflected not variable component, or to a primary X-ray radiation variable in both flux and spectrum.
- No clear correlation between β and M_{BH}, λ_E, z or L_X was found.
- Study of nine individual sources shows quite a different spectral behaviour among different sources.
- This might be due to some unconsidered factors such as black hole spin, angle of view, radio-loudness or it might be influenced by entirely stochastic phenomena.