Multi-component Analysis of a sample of bright X-ray selected Active Galactic Nuclei

Dirk Grupe (Pennsylvania State University)

Abstract: I report on the statistical analysis of a sample of about 100 Active Galactic Nuclei (AGN) with simultaneous UV and X-ray observations from Swift. I found clear correlations between the X-ray spectral slope alpha_x, the UV slope alpha_UV, and the optical-to-x-ray spectral slope alpha_ox with the Eddington ratio L/Ledd. A major aspect of the statistical analysis will be multi-variant analysis statistical tools such as the Principal Component Analysis (PCA) and cluster analysis. This analysis shows that the main driver of the AGN properties in this sample is the Eddington ratio L/Ledd. Although separating Seyfert 1s into Narrow Line Seyfert 1s and Broad Line Seyfert 1s is still a good classification, with the 2000 km/s cutoff line it is arbitrary. The cluster analysis of this AGN sample suggests that we can separate AGN into those with high and low Eddington ratios and that they form physically distinct groups.

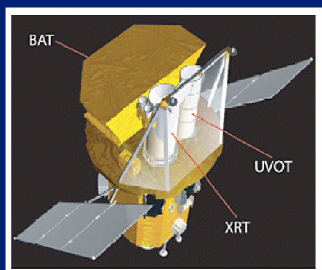

Figure 1: The NASA Gamma-Ray Burst Explorer Mission Swift. It is equipped with anUV/Optical and an X-ray telescope which allow simultaneous Optical/UV to X-ray observations. (Credit: NASA/GSFC)

I. Introduction

Introduction: It is a fact that almost all galaxies harbor a supermassive black hole in their center. While most galaxies appear to be inactive, about 10% show activity in their center. Powered by accretion of surrounding matter onto the central black hole these Active Galactic Nuclei (AGN) are one of the must luminous persistent sources in the Universe.

There are several question that we want to answer in AGN research: How do black holes in Active Galactic Nuclei evolve? Are there different phases in the evolution of an AGN? How long does the AGN activity last? How do measurements of the low-redshift Universe relate to high-redshift quasars at the early phases of the Universe?

In order to answer these questions, the key tools are multi-variate statistical methods that can explore the parameter space that is spanned by the AGN emission line and continuum properties. The observed properties of AGN are mainly driven by two parameters: the mass of the central black hole and the accretion rate (e.g. Sulentic et al. 2000, Boroson 2002, Grupe 2004, 2011). Both are tied together by the Eddington ratio L/L_{Edd}. .

II. Narrow Line Seyfert 1 Galaxies:

Although Narrow-Line Seyfert 1 Galaxies (NLS1s) are Seyfert 1 galaxies, which means that we do see broad emission lines from the broad line region (BLR), their BLR lines are significantly narrower than what is seen typically from Seyfert 1s (Osterbrock & Pogge 1985). NLS1s exhibit extreme properties and the occupy one extreme end in the AGN parameter space. These are AGN with steep X-ray spectra, blue Optical/UV continua, very strong optical FeII emission, and weak emission from the narrow line region. Our interpretation is that NLS1s are AGN with relatively small black hole masses and high Eddington ratios L/Ledd. Possibly they are AGN in an early stage of their development. Supporting this hypothesis are our findings that NLS1s fall below the well-known M-σ relation (Grupe & Mathur 2004) which connects the mass of the central black hole with the (stellar velocity dispersion of the) host galaxy bulge. The interpretation is that the black holes in NLS1s are still rapidly growing towards the M-σ relation.

III. Sample Selection and Swift

The original AGN sample was selected from the ROSAT All-Sky Survey and contains all 110 bright soft X-ray selected AGN (Grupe et al. 2001). The advantages of this sample is that all sources are bright in X-rays as well as in the Optical/UV. The AGN in this sample are not (strongly) intrinsically absorbed or reddened. Many of these AGN appear to be highly variable at Optical/UV and X-ray energies, which makes studies of the spectral energy distributions of these objects challenging if they are not performed simultaneously. However, with Swift (Figure 1) we are able to observe objects simultaneously in the optical to X-ray regime. By January 2010 Swift has observed 92 of these with simultaneous X-ray and UV observations (Grupe et al. 2010).

IV. Simple Correlation Analysis

One of the aspects of studying the spectral energy distributions of this sample of AGN is to find correlations that would allow us to estimate the Eddington ratio L/Ledd from other parameters. For our sample we calculated bolometric corrections for the luminosities at 5100Å and 0.2-2.0 keV. We also found strong correlations between the X-ray, UV/Optical, and Optical to X-ray spectral slopes with the Eddington ratio. High L/Ledd AGN have the steepest X-ray spectra, bluest Optical/UV continua and appear to be X-ray weaker than low L/Led AGN (Grupe et al. 2010). While simple Correlation analysis gives you some information about the data set, only multi-variate analysis methods access the full parameter space. For our AGN sample we applied a Principal Component Analysis (PCA) a well as hierarchical Cluster Analysis. All multi-variate analysis has been performed in **R.**

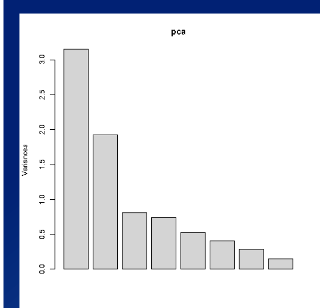

Figure 2: Strengths of the eigenvectors of the PCA of the AGN sample . The columns represent each eigenvector, starting with eigenvector 1 at the left.

V: Principal Component Analysis

Figure 2 displays the strengths of the eigenvectors in the PCA of the AGN sample. Input parameters were the X-ray, UV, and optical-to-X-ray spectral slopes, widths of the Hβ and [OIII] lines, FeII/Hβ and [OIII]/Hβ line ratios, and the 0.2-2.0 keV luminosity. We found the tha first two eigenvectors already account for 64% of the variance in the sample. A strong eigenvector 1 results in steeper X-ray spectra, bluer UV continua, steeper optical to X-ray slopes, and stronger FeII and weaker [OIII] emission.

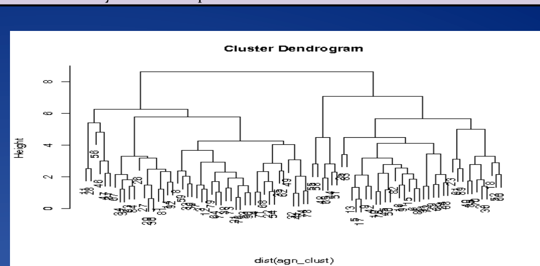

Figure 4: Dendrogram of the cluster analysis of the AGN sample. The input parameters are the same as for the PCA. The sample can clearly be divided into two groups.

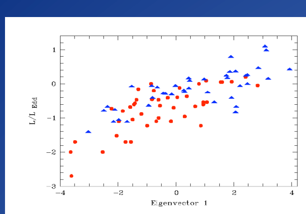

Figure 3: Eigenvector 1 vs. L/Ledd in our AGN sample. Clearly, eigenvector 1 is strongly correlated with L/Ledd.

VI. Interpretation of the PCA.

What do the eigenvectors mean? Because the PCA is a purely mathematical tools the results may not be physically meaningful. However, the results from the PCA and the simple correlation analysis suggest that eigenvector 1 can be interpreted as the Eddington ratio L/Ledd. Figure 3 displays the strong correlation between eigenvector 1 and L/Ledd. We therefore conclude that for the PCA of our AGN sample, eigenvector 1 is the Eddington ratio. The interpretation for eigenvector 2 is that this is the mass of the central black hole. As mentioned earlier, we can also interpret a high L/Ledd as an indicator of the AGN being in an early stage of their development (e.g. Grupe et al., 1999, Mathur 2000).

VI. Cluster Analysis

The next step is to run a cluster analysis on the AGN sample. The dendrogram of this hierarchical cluster analysis is displayed in Figure 4. Clearly, the sample can be divided into two main groups. These two groups show significantly different properties. Group 1 is characterized by steeper X-ray spectra, bluer optical/UV continua, steeper optical to X-ray spectral slopes, narrower Hβ lines, stronger Fe/Hβ, which all together suggests that the AGN in this group all have high L/Ledd.

VII. Interpretation of the Cluster Analysis

In order to verify that group 1 really are the AGN with high L/Ledd, the two groups were displayed I the eigenvector diagram that was found from the PCA. This plot is shown in Figure 5. Indeed, group 1 are the AGN with large eigenvector 1s which we interpreted in the PCA as objects with high L/Ledd. The clear separation of the two AGN groups from the cluster analysis suggest that we can divide AGN in general into high and low L/Ledd AGN. Consequently this goes together with the usual separation into NLS1s and BLS1s. However, the classical cut-off line at 2000 km/s turns out to be not always the best way to separate between the two classes. Often we find NLS1s with relatively flat X-ray spectra, etc. and BLS1s that show typical properties of NLS1s but their FWHM(Hβ) is just above the 2000 km/s cut-off line. Therefore it may be better to use L/Ledd to characterize AGN (Grupe 2011)

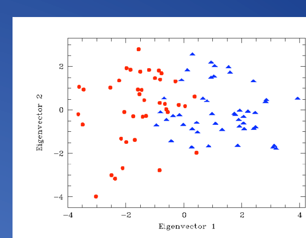

Figure 5: The two groups found by the cluster analysis displayed in the eigenvector 1 – eigenvector 2 diagram of the PCA. Group 1 is displayed as blue triangles and group 2 as red squares. Group 1 is dominated by AGN with high eigenvector 1 values which we interpreted before as high L/Ledd objects.

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