Postprint: Distribution Differences of Power-Law Indices in the Hard X-ray Light Curve Power Spectra of AGN Subclasses

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Abstract

Based on the hard X-ray band light curve data of Active Galactic Nuclei (AGN) observed by Swift/BAT, we analyzed the distribution characteristics of the power-law index ( ) of the power spectra for Seyfert 1, Seyfert 2, flat-spectrum radio quasars (FSRQ), and BL Lac objects using the discrete Fourier transform method. It was found that the distribution of Seyfert 2 exhibits significant differences from that of Type I AGN, while the differences in distribution among various subclasses of Type I AGN are not significant. The hard X-ray emission of Seyfert 2 may originate from the inner region of the accretion disk and the hot corona, whereas the hard X-ray emission of Seyfert 1 primarily comes from an outflowing corona. We find that hard X-ray emission from relativistic jets or outflowing coronae statistically shows a larger power-law index, while hard X-ray emission from the accretion disk hot corona has a smaller power-law index.

Full Text

Differences in the Distribution of Power Law Indices of Hard X-ray Light Curve Power Spectra Among AGN Subclasses

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Abstract

Based on hard X-ray light curve data of Active Galactic Nuclei (AGN) observed by Swift/BAT, we analyzed the distribution characteristics of power law indices ( ) of power spectral densities for Seyfert 1 galaxies, Seyfert 2 galaxies, flat-spectrum radio quasars (FSRQs), and BL Lac objects using the Fast Fourier Transform method. Our results reveal that the distribution of Seyfert 2 galaxies differs significantly from that of type I AGNs, while the distributions among type I AGN subclasses show no significant differences. The hard X-ray emission in Seyfert 2 galaxies likely originates from the inner region of the accretion disk and its hot corona, whereas Seyfert 1 galaxies receive primary contributions from outflowing coronae. We find that hard X-rays from relativistic jets or outflowing coronae exhibit statistically larger power law indices, while those from the thermal corona of the accretion disk display smaller indices.

Keywords: Hard X-ray; Active Galactic Nuclei; Light Curve; Power Law Index

0 Introduction

Active Galactic Nuclei (AGN) harbor supermassive black holes at their centers, surrounded by accretion disks that, in conjunction with the black hole, generate highly collimated jets perpendicular to the disk plane and produce radiation across the electromagnetic spectrum from radio to gamma rays. The prevailing unified model posits that type I and type II AGN represent the same physical objects viewed from different angles, with the central black hole encircled by a thick dusty torus. Type II AGN are observed edge-on through the torus, while type I AGN are viewed face-on. This orientation-based unification scheme exhibits pronounced anisotropy.

Consequently, observational perspective gives rise to differences in emission lines, luminosity, and continuum spectra. AGN can be broadly classified into categories including Seyfert galaxies, quasars, radio galaxies, and BL Lac objects. Advances in observational techniques have enabled finer subdivisions; for instance, Seyfert galaxies are divided into type I (Seyfert 1) and type II (Seyfert 2) based on whether the line-of-sight radiation is absorbed by the dusty torus.

A distinctive property of AGN is variability across all wavelengths, with hard X-ray variability providing crucial information about the innermost regions of these systems. Hard X-ray emission in AGN can be produced through thermal Comptonization of soft photons from the accretion disk by hot plasma in a corona above the disk, or through synchrotron radiation and inverse Compton scattering from relativistic electrons in jets. These different physical origins imprint distinct variability characteristics on the hard X-ray light curves.

Shimizu and Mushotzky previously calculated hard X-ray (15–150 keV) power spectral densities (PSDs) for 30 AGN using Swift/BAT data, finding that all but one could be well-fitted by a simple power law. In this work, we perform a statistical analysis of PSDs for Seyfert 1, Seyfert 2, FSRQ, and BL Lac objects using Swift/BAT hard X-ray data. By fitting the PSDs to obtain power law indices and analyzing their distribution differences among AGN subclasses, we investigate how PSD characteristics correlate with AGN classification.

1 Data Sample

Our primary sample was drawn from the Swift/BAT Hard X-ray Transient Monitor, which provides continuous hard X-ray light curves spanning approximately 14 years for 1019 sources. We selected AGN from this catalog, specifically identifying BL Lac objects, FSRQs, Seyfert 1, and Seyfert 2 galaxies. Notably, all quasar entries in this database are FSRQs. While both FSRQs and BL Lac objects belong to the blazar subclass of AGN, they differ in accretion rates and broad-line region properties, suggesting potentially different X-ray production mechanisms that warrant separate investigation. presents the sample counts for these four subclasses.

Negative photon flux values occasionally appear in these AGN light curves, likely arising from CCD quantum efficiency effects, thermal noise, and sky background. Since the power law index of the X-ray variability power spectrum primarily reflects the characteristics of the variability itself, the impact of background noise removal on our analysis is negligible.

[Figure 1: see original paper] illustrates the linear fitting of the power spectrum for NGC 1365 in logarithmic coordinates, where the fitted slope corresponds to the power law index .

2 Analysis Methods

We performed Fast Fourier Transform (FFT) on the light curves of these sources to obtain their power spectra. [Figure 1: see original paper] shows an example for NGC 1365. Linear fitting was then applied to derive the power law index ( ) for each source, and statistical analysis of these indices across different source types was conducted, with results presented in [Figure 2: see original paper].

Comparisons were made between the power law index distributions of all four AGN subclasses: Seyfert 2 versus Seyfert 1, Seyfert 2 versus BL Lac, Seyfert 2 versus FSRQ, Seyfert 1 versus BL Lac, Seyfert 1 versus FSRQ, and BL Lac versus FSRQ. Cumulative normalized distributions were also compared, as shown in [Figure 2: see original paper], with power law index distribution histograms in the first and third columns and cumulative probability distributions in the second and fourth columns.

We employed the Kolmogorov-Smirnov (K-S) test to quantify the significance of distribution differences, with results summarized in . The analysis reveals highly significant differences between Seyfert 1 and Seyfert 2, between FSRQ and Seyfert 2, and between BL Lac and Seyfert 2. Moderately significant differences are found between BL Lac and FSRQ, while differences between BL Lac and Seyfert 1 and between FSRQ and Seyfert 1 are less pronounced.

3 Conclusions and Discussion

We collected hard X-ray observations of 381 AGN and analyzed their light curves using FFT to examine the distribution of power law indices ( ) across AGN subclasses. The K-S test was applied to assess the significance of these differences, with results presented in . Seyfert 2 galaxies, as type II AGN obscured by dusty tori, show significantly different distributions compared to type I AGN (BL Lac objects, FSRQs, and Seyfert 1 galaxies).

The hard X-ray spectral components in AGN are complex, with two primary origins: emission from relativistic jets (as in blazars, where beaming effects dominate due to small viewing angles) and emission from the inner accretion disk and hot corona (as in Seyfert galaxies). Whether X-ray radiation is jet-dominated or corona-dominated leads to distinct observational signatures, with observed hard X-ray fluxes typically representing a mixture of both components in varying proportions across AGN types.

Seyfert galaxies, as low-luminosity AGN, are well-described by the disk-corona model where soft photons from the accretion disk are Compton-scattered in the corona to produce X-rays, explaining the characteristic power-law spectra. Recent studies indicate that X-ray emission from AGN coronae is moderately anisotropic, suggesting a bipolar, elongated coronal geometry with outflows at velocities of 0.3–0.5 times the speed of light. The X-ray differences between Seyfert 1 and Seyfert 2 galaxies may primarily stem from coronal anisotropy rather than dust absorption, with Seyfert 1 hard X-rays predominantly originating from outflowing coronae. For low-luminosity AGN with accretion rates below a critical threshold (~10 times the Eddington rate), X-ray emission is more likely jet-dominated rather than from an advection-dominated accretion flow (ADAF). According to the AGN unification model, type I AGN hard X-rays generally originate from relativistic jets or outflowing coronae with anisotropic emission, while type II AGN hard X-rays arise from the thermal corona of the accretion disk with absorption.

These physical distinctions explain our observed distribution differences: hard X-rays from relativistic jets or outflowing coronae exhibit statistically larger power law indices ( ) due to Doppler boosting effects, while those from accretion disk thermal coronae show smaller indices. Consequently, the distribution characteristics of hard X-ray variability power law indices can serve as a new statistical criterion for distinguishing between type I and type II AGN classifications.

References

[1] Urry C M, Padovani P. Unified Schemes for Radio-Loud Active Galactic Nuclei[J]. Publications of the Astronomical Society of the Pacific, 1995, 107(715):803-845.
[2] 黄克谅. 类星体与活动星系核 [M]. 中国科学技术出版社, 2005.
[3] Soldi S, Beckmann V, Baumgartner W H, et al. Long-term variability of

AGN at hard X-rays[J]. Astronomy & Astrophysics, 2014, 563: 57(16 pp).
[4] Haardt F, Maraschi L. X-ray spectra from two-phase accretion disks[J]. Astrophysical Journal, 1993, 413: 507(11 pp).
[5] McHardy I, Lawson A, Newsam A, et al. Simultaneous X-ray and infrared variability in the Quasar 3C273 - II. Confirmation of the correlation and X-ray lag[J]. Monthly Notices of the Royal Astronomical Society, 2007, 375: 1521(7 pp).
[6] Arevalo P, McHard I M, Summons D P. X-ray variability of the Seyfert 1 Markarian 335: power spectrum and time lags[J]. Monthly Notices of the Royal Astronomical Society, 2008, 388: 211(8 pp).
[7] Czerny B, Nikolajuk M, Piasecki M, et al. Black hole masses from power density spectra: determinations and consequences[J]. Monthly Notices of the Royal Astronomical Society, 2001, 325: 865(10 pp).
[8] McHardy I M, Koerding E, Knigge C, et al. Active galactic nuclei as scaled-up Galactic black holes[J]. Nature, 2006, 444: 730(3 pp).
[9] Uttley P, McHardy I M. X-ray variability of NGC 3227 and 5506 and the nature of active galactic nucleus 'states' [J]. Monthly Notices of the Royal Astronomical Society, 2005, 363: 586(11 PP).
[10] Soldi S, Türler M, Paltani S, et al.The multiwavelength variability of 3C 273[J]. Astronomy and Astrophysics, 2008, 486: 411(16 pp).
[11] Bell M E, Tzioumis T, Uttley P, et al. X-ray and radio variability in the low-luminosity active galactic nucleus NGC 7213[J]. Monthly Notices of the Royal Astronomical Society, 2011, 411: 402(9 pp).
[12] Zoghbi A, Fabian A C, Uttley P, et al. Broad iron L line and X-ray reverberation in 1H0707-495[J]. Monthly Notices of the Royal Astronomical Society, 2010, 401: 2419(14 pp).
[13] Caballero-Garcia M, Papadakis I, Ajello M, et al. Hard X-ray spectral variability of the brightest Seyfert AGN with SWIFT/BAT[C]. The X-ray Universe 2011, Presentations of the Conference held in Berlin, Germany, 27-30 June 2011.
[14] Uttley P, McHardy I M, Papadakis I E. Measuring the broad-band power spectra of active galactic nuclei with RXTE[J]. Monthly Notices of the Royal Astronomical Society, 2002, 332: 231(20 pp).
[15] Papadakis I E. The scaling of the X-ray variability with black hole mass in active galactic nuclei[J]. Monthly Notices of the Royal Astronomical Society, 2004, 348: 207(7 pp).
[16] Shimizu T T, Mushotzky R F. The First Hard X-Ray Power Spectral Density Functions of Active Galactic Nucleus[J]. The Astrophysical Journal, 2013, 770: 60(21 pp).
[17] Ghisellini G, Maraschi L, Tavecchio,F. The Blazar' s Divide and the Properties of Fermi Blazars[J]. Monthly Notices of the Royal Astronomical Society, 2009, 396: L105(5 pp).
[18] Kamraj N, Fabian A, Lohfink A, et al. Probing the Physical Properties of the Corona in Accreting Black Holes[J]. arXiv:1903.05241,
[19] Antonucci R. Unified Models for Active Galactic Nuclei and Quasar[J]. Annual Review of Astronomy and Astrophysics, 1993, 31 (1):
[20] Liu T, Wang J X, Yang H, et al. Are X-Ray Emitting Coronae around

Supermassive Black Holes Outflowing[J]? The Astrophysical Journal, 2014, 783: 106(14 PP).
[21] Yuan F, Yu Z, Ho, L C. Revisiting the "Fundamental Plane" of Black Hole Activity at Extremely Low Luminosities[J]. The Astrophysical Journal, 2009, 703: 1034(10 PP).