Accretion Flow and Emission Mechanism in Narrow-line Seyfert 1 Galaxies

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Abstract

We present the results of a systematic study of Narrow-line Seyfert 1 galaxies (NLS1s). NLS1s are Sefyert 1 galaxies with relatively narrow (< 2000 km s^{-1}) optical Balmer lines, and they are thought to possess relatively smaller ($10^{6-7} M_{\odot}$) black holes compared with those of the Seyfert 1 galaxies with broad (> 2000 km s^{-1}) optical Balmer lines (broad-line Seyfert 1 galaxies; BLS1s). From *ROSAT* and *ASCA* observations, it has been known that this class of objects show significantly larger amplitude and rapid X-ray variations than BLS1s, and their X-ray spectra are characterized by a steeper power law plus a stronger soft X-ray emission than those of BLS1s. However, it has been unknown what is a key causing such differences between these classes. Here, we focus on the most prominent spectral feature characterizing NLS1s, namely, the strong soft X-ray emission. Since this spectral component is though to be a hard X-ray tail of thermal emission coming from an innermost part of an accretion disk, studies of its spectral shape and timing properties provide us direct information about the environment of the vicinity of a central supermassive black hole.

In order to well constrain spectral and timing properties of NLS1s, we analyzed a sample of NLS1s observed with *XMM-Newton*, which has an unprecedented effective area over the 0.3–12 keV energy range. The 2–12 keV X-ray spectra of NLS1s are well represented by a single power law with a photon index $\Gamma \sim 2$. When this hard power law continuum is extrapolated into the low energy band, we found that all objects in our sample show prominent soft excess emission below 2 keV on top of the power law continuum. This excess emission is well reproduced by the thermal emission expected from an optically thick accretion disk, and we found following three peculiar features of the soft excess component: 1) The derived temperatures kT of the disk are significantly higher than that expected from the central mass of a black hole, if we assume the standard Shakura-Sunyaev accretion disk model. 2) The temperatures are distributed within an extreme narrow range ($\Delta kT \sim 0.07$ keV) with an average temperature of 0.18 keV in spite of the range of 4 orders of magnitude in luminosity (10^{41}–10^{45} erg s^{-1}). 3) We found an anti-correlation between kT and the luminosity of the soft excess component $L_{\rm soft}$, during the observations of the most luminous NLS1 PKS 0558-504. These results strongly suggest that the standard accretion disk picture is no longer appropriate in the nuclei of NLS1s. In order to further characterize the properties of the soft excess emission, we investigate the ratio of the bolometric luminosity $L_{\rm bol}$ inferred from $L_{\rm soft}$ to the Eddington luminosity $L_{\rm E}$, i.e., Eddington ratio. We found that most objects shine at a near- or super-Eddington luminosity. The high Eddington ratio implies that the mass-accretion rate $\dot{M}$ in the accretion flow exceeds the critical mass-accretion rate $\dot{M}_{\rm crit}$ defined as $\dot{M}_{\rm crit} \equiv L_{\rm E}/c^2$, where c is the light velocity. This result suggests that a high mass-accretion is common in NLS1s and the accretion flow in NLS1s may be in an extreme mode. From a view point of the high mass-accretion rate, we discuss a possible origin for the soft excess component, and suggest that a slim disk, which is expected in high $\dot{M}$ regime, may be able to explain the observational results 1)–3).

We also found that the luminosity of the soft excess component $L_{\rm soft}$ has a strong positive correlation with that of the 2–10 keV power law continuum. Moreover, this relation is also held in a typical BLS1 NGC 5548. According to the inverse Compton model, soft photons of the excess component are up-scattered into the power law component by hot electron clouds. The strong correlation between intensities of the two components support that such a model works commonly for both BLS1s and NLS1s. It is favorable for the unified scheme of all Seyfert galaxies.

Contents

1 Introduction **1**

2 Review **3**

2.1 Overview of Active Galactic Nuclei (AGN) 3

2.1.1 Discovery of AGNs 3

2.1.2 Classification of AGN 4

2.2 Supermassive Black Hole Hypothesis 5

2.2.1 Mass estimation 5

2.2.2 Physical parameters around a black hole 5

2.2.3 Accretion disks 6

2.3 Narrow-line Seyfert 1 galaxies (NLS1s) 8

2.3.1 Optical properties 8

2.3.2 X-ray properties 9

3 Instrumentation **13**

3.1 *XMM-Newton* 13

3.2 X-ray Telescopes (XRTs) 13

3.2.1 Design Structure 13

3.2.2 Point-spread function (PSF) of XRTs 16

3.2.3 Effective Area (EA) of XRTs 17

3.2.4 Straylight Rejection 17

3.3 European Photon Imaging Camera (EPIC) 19

3.3.1 Two Types of EPIC Cameras: MOS and PN 20

3.3.2 Science Modes of the EPIC Cameras 20

3.3.3 Characteristics of EPIC Cameras 21

3.3.4 EPIC Background 25

3.4 Reflection Grating Spectrometer (RGS) 25

4 Observation and Data Reduction **31**
4.1 Analyzing *XMM-Newton* Data . . . 31
4.1.1 Data reduction . . . 31
4.1.2 Image Analysis . . . 31
4.1.3 Spectral Analysis . . . 32
4.1.4 Timing Analysis . . . 34
4.2 Observation . . . 35

5 Results **39**
5.1 NGC 5548 . . . 39
5.1.1 Introduction . . . 39
5.1.2 Light curves . . . 39
5.1.3 Energy spectra . . . 41
5.1.4 Discussion . . . 45
5.1.5 Summary . . . 48
5.2 NGC 4051 . . . 49
5.2.1 Introduction . . . 49
5.2.2 Timing analyses . . . 49
5.2.3 Spectral analyses . . . 50
5.2.4 Discussion . . . 56
5.3 PKS 0558-504 . . . 57
5.3.1 Timing analyses . . . 57
5.3.2 Spectral analyses . . . 60
5.4 Mrk 335 . . . 61
5.4.1 Time variability . . . 62
5.4.2 X-ray spectrum . . . 63
5.5 I Zw 1 . . . 64
5.5.1 Time variability . . . 64
5.5.2 Overall spectrum . . . 65
5.6 Ton S180 . . . 67
5.6.1 Time variability . . . 68
5.6.2 Spectral analyses . . . 68
5.7 Mrk 359 . . . 71
5.7.1 Timing analysis . . . 72
5.7.2 Overall spectral analysis . . . 72
5.8 NAB 0205+024 . . . 73
5.8.1 Timing analyses . . . 75
5.8.2 X-ray spectral analyses . . . 75
5.9 1H 0707-495 . . . 77

5.9.1 Timing analyses . . . 77
5.9.2 Spectral analyses . . . 77
5.10 RE 1034+396 . . . 80
5.10.1 Timing analyses . . . 80
5.10.2 Spectral analyses . . . 80
5.11 PG 1211+143 . . . 82
5.11.1 Timing analyses . . . 82
5.11.2 Spectral analyses . . . 82
5.12 PG 1244+026 . . . 84
5.12.1 Timing analyses . . . 84
5.12.2 Spectral analyses . . . 87
5.13 IRAS 13224-3809 . . . 87
5.13.1 Timing analyses . . . 88
5.13.2 Spectral analyses . . . 88
5.14 Mrk 478 . . . 90
5.14.1 Timing Analyses . . . 92
5.14.2 Spectral analyses . . . 92

6 Discussion **95**
6.1 Summary of Results . . . 95
6.1.1 Time variability . . . 95
6.1.2 Spectrum . . . 95
6.2 Timing properties . . . 97
6.2.1 X-ray variability amplitude . . . 97
6.2.2 Spectral variability . . . 100
6.3 X-ray spectral properties . . . 102
6.3.1 Soft excess component . . . 102
6.3.2 Hard power law . . . 103
6.3.3 Iron lines . . . 106
6.4 Origin of soft component . . . 106
6.4.1 Selection effects . . . 107
6.4.2 kT-$L_{\rm soft}$ relation . . . 108
6.4.3 Possible models for the soft component . . . 110

7 Conclusion **115**

A X-ray Images of Narrow-Line Seyfert 1 Galaxies in our sample **117**

List of Figures

2.1 Narrow-line Seyfert 1 composite spectrum 9
2.2 Excess variance from *ASCA* observations of NLS1s 10

3.1 Sketch of the highly elliptical *XMM-Newton* orbit 14
3.2 Sketch of the *XMM-Newton* payload 14
3.3 The light path in *XMM-Newton*'s XRT with the PN camera in focus 15
3.4 The light path in *XMM-Newton*'s XRT with the MOS and RGA 15
3.5 On-axis images of the MOS1, MOS2 and PN XRTs (left to right). 16
3.6 Radial counts distribution for the on-axis PSF of the MOS1 XRT in the 0.75–2.25 keV energy range. 17
3.7 The encircled energy function as a function of angular radius (on-axis) at different energies. 17
3.8 The net effective area of all *XMM-Newton* XRT, combined with the response characteristics of the focal detectors. 18
3.9 Vignetting function as a function of off-axis angle at several different energies. . . 18
3.10 The effect of straylight appeared in PN image of GRS 1758-258. 18
3.11 A rough sketch of the field of view of the two types of EPIC cameras (MOS, left; PN, right). 19
3.12 The rayout of the EPIC MOS1 camera. The readout node of each CCD is located with a small box. 20
3.13 The rayout of the EPIC MOS2 camera. 20
3.14 The rayout of the EPIC PN camera. 21
3.15 Operating modes for the MOS camera. 22
3.16 Operating modes for the PN camera. 22
3.17 The EPIC MOS energy resolution (FWHM) as a function of energy. 23
3.18 The EPIC PN energy resolution (FWHM) as a function of energy. 23
3.19 Quantum efficiency of the EPIC MOS camera as a function of photon energy. . . 24
3.20 Quantum efficiency of the EPIC PN camera as a function of photon energy. . . . 24
3.21 Light curve badly affected by soft proton flares. 25

3.22 Background spectrum for the MOS1 camera during an observation with the filter wheel in the closed position. 26

3.23 Background spectrum for the PN camera during an observation with the filter wheel in the closed position. 26

3.24 Background images for the PN camera with spatially inhomogeneous fluorescent lines. 27

3.25 Optical design of the RGS. 29

3.26 Photograph of the RGS unit onboard *XMM-Newton*. 29

3.27 Schematic drawing of a grating, including some of the key dimensions and angles. 29

3.28 Effective area for the two RGSs. 30

4.1 left: 0.3 10 keV image of PKS 0558-504 obtained from EPIC MOS cameras, right: azimuthally averaged profile of surface brightness of PKS 0558-504 as a function of radial distance. 32

4.2 Spectral discrepancy between MOS and PN. 33

4.3 Energy spectrum of $F_{\rm var}$ (left) and spectral ratio between high and low state (right). High state is defined as periods with count rates above an average value, and low state implies periods with count rates below an average. 35

4.4 2 10 keV $F_{\rm X}$–$L_{\rm X}$ relationship 36

5.1 Light curves of *EUVE* DS (open circles) and *ASCA* SIS (filled circles) binned to 5700 sec and 20 ksec, respectively. The origin epoch of the abscissa corresponds to MJD 50260. The ordinate unit shown at the right hand side indicates the DS counting rate and at the left for SIS. 41

5.2 Correlation between *EUVE* DS and *ASCA* SIS counting rate on long time scales. The numbers in the figure indicate the order of each observation day. The solid line is the best-fit linear function to five data points, on the other hand, the dashed line is for four data points (#2 – #5). 41

5.3 The photon spectrum obtained by *EUVE* SW (filled circles) and DS (open circle). The dashed line indicates the best-fit blackbody spectrum ($kT = 15.8$ eV). . . . 43

5.4 *ASCA* SIS X-ray spectrum. The model consists of a power law absorbed by the Galactic neutral matter and a warm absorber, and an Fe-K emission line. The upper panel shows the count spectrum (crosses) and the model folded through the detector response (histogram). The lower panel shows the residuals. 43

5.5 Correlation between the 2 - 10 keV flux and the photon index Γ. 45

5.6 Combined spectra of *EUVE* DS, SW and *ASCA* SIS corrected for the Galactic absorption. SW (filled circles) and SIS (crosses) spectra are derived from averages over the entire observation, while an open square and an open triangle indicate the DS maximum flux (1st day) and minimum one (4th day), respectively. The dashed line represents the best-fit power law component and the dot-dashed line indicates the disk blackbody component with $kT = 17$ eV. The dotted line shows the 60 eV blackbody radiation previously reported by Nandra et al. (1993). This plot is used for visualization purposes only. 47
5.7 Correlation between the 2 - 10 keV X-ray luminosity and the DS counting rate corrected for the contribution of the X-ray power law component. The dashed line and dot-dashed line indicate the model relationships calculated as a function of the mass accretion rate of a disk blackbody and a simple blackbody with a central mass of $6 \times 10^7\ M_\odot$, respectively. The horizontal dotted lines show the ratio of the disk luminosity to the Eddington luminosity. 48
5.8 NGC 4051: 0.3–12.0 keV light curves of EPIC PN camera. 50
5.9 NGC 4051:Plot of $F_{\rm var}$ against various energy bins. 50
5.10 3–12 keV spectra of NGC 4051 fitted with partial covering model. 52
5.11 RGS spectra of NGC 4051. 53
5.12 Photon spectra of NGC 4051. 53
5.13 Velocity shift of individual lines. 55
5.14 NGC 4051: Overall spectra. *left*, high state; *right*, low state. 55
5.15 PKS 0558-504:0.3–12.0 keV EPIC light curves of each observation. 58
5.16 PKS 0558-504:Plot of fractional variability amplitude against observed energies. . 59
5.17 PKS 0558-504:0.3–12 keV overall spectra fitted with a power law and MCD models. 60
5.18 Relationship between temperature and 0.3–10 keV luminosities of soft excess component. 61
5.19 0.3–12.0 keV Light curves of Mrk 335. 62
5.20 Plot of Fractional variability amplitude versus energy for the EPIC light curves. 62
5.21 The 2–10 keV EPIC spectra fitted by the absorbed power law plus Gaussian. . . 63
5.22 Overall spectra of Mrk 335. 64
5.23 0.3–12.0 keV Light curves of I Zw 1. 65
5.24 Plot of hardness ratio against the total count rate in the 0.3–12.0 keV band for the EPIC PN data. 66
5.25 Plot of Fractional variability amplitude versus energy for the EPIC light curves. 66
5.26 Spectral ratio between the flare phase and stable phase. 66
5.27 Overall spectra of I Zw 1. 67
5.28 0.3–12.0 keV Light curves of Ton S180 obtained from the 2000 observation. . . . 69
5.29 0.3–12.0 keV Light curves of Ton S180 obtained from the 2002 observation. . . . 69

5.30 Energy dependence of fractional variability amplitude $F_{\rm var}$. 69
5.31 Ton S180: 2–12 keV data to model ratio 70
5.32 Ton S180: Overall spectral fit 71
5.33 0.3–12.0 keV Light curves of Mrk 359. 72
5.34 Plot of Fractional variability amplitude versus energy for the EPIC light curves. 73
5.35 RGS spectra of Mrk 359 74
5.36 0.3–12.0 keV overall spectra of Mrk 335. 74
5.37 0.3–12.0 keV Light curves of NAB 0205+024. 75
5.38 Plot of Fractional variability amplitude versus energy for the EPIC light curves. 75
5.39 Overall spectra of NAB 0205+024 76
5.40 0.3–12.0 keV Light curves of 1H 0707-495. 77
5.41 Plot of Fractional variability amplitude versus energy for the EPIC light curves. 78
5.42 2–12 keV EPIC spectra. The data have been fitted by a partial covering model. . 78
5.43 Overall spectra of 1H 0707-495 79
5.44 0.3–12.0 keV Light curves of RE 1034+396. 80
5.45 Plot of Fractional variability amplitude versus energy for the EPIC light curves. 81
5.46 Overall spectra of RE 1034+396. 81
5.47 0.3–12.0 keV Light curves of PG 1211+143. 83
5.48 Plot of Fractional variability amplitude versus energy for the EPIC light curves. 83
5.49 Ratio of RGS spectra to MCD plus power law model. 85
5.50 0.3-12 keV spectra of PG 1211+143. 85
5.51 0.3–12.0 keV Light curves of PG 1244+026. 86
5.52 Plot of Fractional variability amplitude versus energy for the EPIC light curves. 86
5.53 0.3–12.0 keV overall spectra of PG 1244+026. 87
5.54 0.3–12.0 keV Light curves of IRAS 13224-3809. 88
5.55 Plot of Fractional variability amplitude versus energy for the EPIC light curves. 89
5.56 Strong residuals appeared around 1.2 keV when the continuum models are fitted to the data. 90
5.57 Overall spectra of IRAS 13224-3809. 90
5.58 Photon spectrum of IRAS 13224-3809. Sharp structures appeared around 1.2 keV are due to iron L-shell absorption lines. Green; MCD model, Blue; power law. . . 91
5.59 0.3–12.0 keV Light curves of Mrk 478. 92
5.60 Plot of Fractional variability amplitude versus energy for the EPIC light curves. 93
5.61 Plot of hardness ratio against PN 2–12 keV count rate using 1000 s time bins. . . 93
5.62 Overall spectra of Mrk 478. 94

6.1 Correlation between $F_{\rm var}$ and 2–10 keV luminosity. 100
6.2 Plot of the PSD normalization calculated from $F_{\rm var}$ and length of observation as a function of the 2–10 keV luminosity. 101

6.3 Plot of the PSD normalization calculated from $F_{\rm var}$ and length of observation as a function of inferred central mass of black hole. 101
6.4 Comparison between the soft band (0.3–0.5 keV) $F_{\rm var}$ and hard (2–4 keV) $F_{\rm var}$. . 102
6.5 Relationship between the disk temperature kT and disk luminosity $L_{\rm disk}$. 104
6.6 Plot of the photon index Γ as a function of 2–10 keV luminosity. Filled circles: our sample of NLS1s. Open squares: Reynolds (1997) sample of BLS1s. 105
6.7 Correlation between the soft component luminosity $L_{\rm soft}$ and 2–10 keV luminosity L_{2-10}. The ordinate unit shown at the righthand side indicates the bolometric luminosity $L_{\rm bol}$ estimated using a bolometric correction factor of 20. 105
6.8 Plot of the observed line energies against the 2–10 keV luminosities. 106
6.9 Correlation between temperature and Eddington ratio for PKS 0558-504. 109
6.10 Correlation between the temperature and Eddington ratio for our sample. 110
6.11 Relation of Temperature and Eddington ratio. Filled circles indicate a model predictions based on the photon trapping effect. Filled squares show the observed values of PKS 0558-504. 112
6.12 Relation of temperature and Eddington ratio in our sample. Filled circles indicate a model predictions based on the photon trapping effect. 113

A.1 X-ray images in our sample. 118

List of Tables

3.1 The on-axis in orbit and on ground 1.5 keV HEW of the different XRT. 16
3.2 Basic numbers for the science modes of EPIC. 21
3.3 Key performance parameters of the RGSs. 28

4.1 Compiled NLS1s and their optical emission line properties. 36
4.2 *XMM-Newton* observation log 37

5.1 X-ray spectral fits to the *ASCA* SIS + GIS data. 44
5.2 NGC 4051:Fit results of partial covering model. 51
5.3 Absorption and emission line properties. 54
5.4 NGC 4051:Best-fit parameters. 56
5.5 PKS 0550-584:Results of the overall spectral fitting. 61
5.6 The results of the overall spectral fitting. 64
5.7 The results of the overall spectral fitting. 67
5.8 Ton S180: Results of the power law plus Gaussian line in the 2–12 keV band. . . 70
5.9 Ton S180: Fitting results of continuum parameters. 72
5.10 The results of the overall spectral fitting. 74
5.11 Overall spectral fitting results. 76
5.12 Overall spectral fitting results. 79
5.13 Overall spectral fitting results. 82
5.14 PG 1211+143: Overall spectral fitting results. 85
5.15 The results of the overall spectral fitting. 87
5.16 IRAS 13224-3809: Overall spectral fitting results. 91
5.17 Mrk478: Overall spectral fitting results. 94

6.1 Summary of timing properties. 96
6.2 Summary of the spectral parameters. 98
6.3 Properties of supermassive black hole. 99

Chapter 1

Introduction

Active Galactic Nuclei (hereafter AGNs) are one of the most spectacular objects in the universe. They produce huge energy, which is apparently as much as 10^4 times that of a typical galaxy in some case, in tiny volume ($\ll 1$ pc^3). This radiation emerges over an extraordinarily broad range of energies, i.e. from radio to γ-ray and it is thought to be the liberated gravitational energy by the accretion of matter onto a central supermassive black hole (SMBH) (Rees 1984).

Recent observations revealed that most galaxies possess a SMBH in their center (e.g. Kormendy & Richstone 1995; Ferrarese & Merritt 2000; Gebhardt et al. 2000a; Gebhardt et al. 2000b; Ho 1999) and that there are many varieties of activity which may be connected with a mass of SMBH and a mass accretion rate. In such galaxies, it is suggested that the objects displaying the highest mass accretion rate (i.e. active growthing phase of SMBH) is Narrow-line Seyfert 1 galaxies (NLS1s), which are Seyfert 1 galaxies with relatively narrow ($<$ 2000 km s^{-1}) Balmer lines in their optical spectra (Osterbrock & Pogge 1985). Therefore, a study of NLS1s offers unique opportunities to investigate the emission mechanism and the circumnuclear environments during the evolving phase of SMBH.

X-ray observations are one of the most powerful tools to study the AGN phenomena, since X-rays are emitted from just in the vicinity of the central SMBH. Furthermore, X-ray observations show distinct signatures between NLS1s and Seyfert 1 galaxies with broad ($>$ 2000 km s^{-1}) Balmer lines (Broad-line Seyfert 1 galaxies; BLS1s). For example, NLS1s are known to show larger amplitude variability on shorter timescales than BLS1s (Leighly 1999a), and their X-ray power law continua are systematically steeper than that of BLS1s (Leighly 1999b). Some Seyfert 1 galaxies show evidence for an excess of X-rays below $\sim$ 1 keV, when the hard X-ray power law is extrapolated to lower energies. This soft excess component is more prominent and more frequent in NLS1s than in BLS1s (Vaughan et al. 1999a, Leighly 1999b, Reeves & Turner 2000). However, the origin of the time variability, steep power law continuum, and soft excess component have not been known.

In this thesis, we show X-ray properties of NLS1s using the highest sensitivity and high energy

resolution data obtained with *XMM-Newton*, and we investigate the emission mechanism and circumnuclear environment in an extreme condition, i.e. high mass accretion rate. In chapter 2, we present a review of current understanding of AGNs and NLS1s. The *XMM-Newton* and its onboard instruments are described in chapter 3. The data reduction and observation logs are summarized in chapter 4. Chapter 5 describes the results on individual objects. In chapter 6, we discuss the X-ray properties of NLS1s. Conclusions are given in Chapter 7.

Chapter 2

Review

2.1 Overview of Active Galactic Nuclei (AGN)

2.1.1 Discovery of AGNs

Historically, an observation of AGNs was begun when Fath discovered some emission lines in the spectrum of NGC 1068 in 1908. Seyfert is the first scientist to study AGNs systematically (Seyfert 1943), and he found that 1)some galaxies possess a bright nucleus, 2)emission lines from highly ionized atoms are appeared in their spectrum, and 3)these emission lines are significantly broadened. The galaxies showing such features are currently called Seyfert galaxy. The importance of AGNs was recognized again in the 1950s, when radio telescopes with large enough apertures were built by groups at both Cambridge University and Sydney University. The first useful large catalog, the 3C (for 3rd Cambridge) catalog, collected almost 500 sources brighter than 9 Jy at 178 MHz. The Sydney group identified a few "radio stars" with optical counterparts and found that both M 87 and NGC 5128 were the homes of powerful radio sources Virgo A and Centaurus A, respectively (Bolton, Stanley, & Slee 1954). Baade & Minkowski (1954) also identified Cygnus A with a cD galaxy 3C 405 and measured the redshift of $z = 0.057$. Their emission line spectra were very similar to that of Seyfert Galaxies. Other 3C radio sources (e.g. 3C 48 and 3C 273), however, proved to be more difficult to identify, because they appeared to be star-like with no image of host galaxy and moreover their spectra were dominated by "unidentified" broad emission lines without absorption lines. This mystery was solved by Schmidt in 1963. He found that the emission lines in the 3C 273 were able to be identified with the well-known nebular emission lines if the source has an unusually large redshift of $z = 0.158$ (Schmidt 1963). Immediately after, Greenstein & Matthews (1963) identified 3C 48 to be also a galaxy with $z = 0.368$. According to the Hubble law, such large redshift implies that the sources are very distant and then the absolute magnitude of the source are three orders magnitude larger than that of normal galaxies. These objects were named "quasi-stellar radio sources" and currently called "quasars".

As a result of systematic surveys of AGNs and progress of observations, numerous AGNs have been catalogued. At present we identify various types of AGNs from nearby to very distant galaxies. Hence, we review classification of AGNs in the next section.

2.1.2 Classification of AGN

AGNs are classified into some subclasses based on their optical spectra, radio properties, luminosities, and so on. Based on the radio loudness, two subclasses are defined as radio quiet AGNs and radio loud AGNs. The former are further classified into Seyfert galaxies and radio quiet quasars, while the latter into radio galaxies and radio loud quasars with increasing luminosity.

Seyfert galaxies are divided into two categories; Seyfert 1 (type 1) and Seyfert 2 (type 2) based on widths of optical permitted lines. Seyfert 1s show both broad (FWHM > 1000 km s^{-1}) and narrow (~ 500 km s^{-1}) permitted lines, which are emitted from a Broad-line region (BLR) and Narrow-line region (NLR), respectively. On the other hand, Seyfert 2s show only narrow lines. The same classifications are also applicable to quasars and radio galaxies. In general, it is thought that the difference between Seyfert 1s and Seyfert 2s are only attributed to the difference of the observer's viewing angle and both types of Seyfert galaxies are intrinsically same (Antonucci et al. 1993; Lawrence et al. 1987). In fact, Antonucci & Miller (1985) detected polarized broad emission lines by spectropolarimetry from the prototypical Seyfert 2 galaxy NGC 1068 and revealed that the BLR is also present in Seyfert 2s. Miller & Goodrich (1990) observed several Seyfert 2s and detected polarized broad lines. These polarized broad lines are interpreted as scattered flux by electrons located above an "obscuring torus". The [O III]λ5007 line image shows biconical structure (ionizing cone) which suggests emission from the central source is collimated by a torus (e.g. Tadhunter & Tsvetanov 1989). The detection of hard X-ray emission obscured by column densities of $N_{\rm H} = 10^{22-24}$ cm^{-2} with the *GINGA* satellite provides further evidence for Seyfert 2s contain hidden Seyfert 1 nuclei (Awaki et al. 1990; Awaki et al. 1991). On the other hand, there are increasing pieces of evidence against this simple unification scheme. For example, Seyfert 2s indicate more molecular gas, far infrared emission, dust, and circumnuclear starburst than Seyfert 1s. These properties are not caused by obscuration of molecular torus (Heckman et al. 1989; Dahari & De Robertis 1988).

As mentioned above, AGNs are mainly divided into two classes, i.e. type 1 and type 2. Osterbrock & Pogge (1985), however, have identified a class of AGNs having all properties of the Seyfert 1s but with relatively narrow (< 2000 km s^{-1}) Balmer lines and strong optical Fe II lines. They are called Narrow-line Seyfert 1 galaxies (NLS1s). In section 2.3, we describe properties of NLS1s in detail.

2.2 Supermassive Black Hole Hypothesis

2.2.1 Mass estimation

It is now widely accepted that the power source of AGNs is mass accreting onto a central supermassive black hole. There are several observational pieces of evidence to support the supermassive black hole hypothesis. The most reliable mass estimation may be a "reverberation mapping technique" (e.g. Kaspi et al. 2000; Nelson et al. 2000). Monitoring the variability of the continuum and emission line fluxes in broad line AGNs shows that both intensities are highly correlated but that the emission lines lag behind the continuum by times ranging from days to months. The lag is best explained as a light travel time effect and can be used to estimate the size of the broad line region (BLR). If one further assumes that the BLR kinematics are nearly Keplerian, one can use the line widths as a characteristic velocity and in turn determine the total mass contained within the BLR. The reverberation studies have now yielded the mass of numerous Seyfert 1 galaxies and quasars (e.g. Wandel, Peterson, & Malkan 1999).

The empirical relationship between the size of BLR and monochromatic continuum luminosity at 5100 Å also has been used to estimate a black hole masses $M_{\rm BH}$. Kaspi et al. (2000) found the following relation,

$$R_{\rm BLR} = 32.9 \left(\frac{\lambda L_\lambda (5100\ \text{Å})}{10^{44}\ \text{ergs}^{-1}} \right)^{0.7} \quad \text{lt day}, \tag{2.1}$$

where λL_λ is estimated from the B-magnitude by adopting an average optical spectral index of -0.5. Assuming that the BLR is virialized, the black hole mass can be estimated by $M_{\rm BH} = R_{\rm BLR} V^2 G^{-1}$, where G is the gravitational constant, V can be estimated from the emission line width, $V = \sqrt{3}/2\ FWHM$, by assuming BLR clouds in random orbit motion. On the other hand, for nearby galaxies (ellipticals and spiral bulges), recent works by Gebhardt et al. (2000a) and Ferrarese & Merritt (2000) have demonstrated that the central mass is tightly correlated with the stellar velocity dispersion. Gebhardt et al. (200b) included 7 AGNs, in which the central masses are obtained by the reverberation mapping method, and they found that these objects follow the same correlation with small scatter. Nelson & Whittle (1996) also found a good correlation between the [O III] width and the stellar velocity dispersion. This may suggest that the [O III] line width also can be an indicator for the central black hole mass.

By connecting the black hole mass estimated from the size of the broad line region and [O III] line width, Wang & Lu (2001) suggests that NLS1s show the similar relation between the black hole mass and [O III] line width.

2.2.2 Physical parameters around a black hole

Here, we briefly describe some physical parameters around a black hole. A black hole has no physical surface, but a characteristic radius can be defined. This radius is called Schwarzschild

radius and given as

$$R_{\rm S} = \frac{2GM_{\rm BH}}{c^2} \tag{2.2}$$

where c is the speed of light. It is useful to represent scales around a blck hole with $R_{\rm S}$. For example, the smallest stable orbital radius for an accreting matter around a non-rotating black hole is $3R_{\rm S}$.

AGNs are shining by converting the gravitational energy of accreting matter to the radiation. In other words, the gravitational force needs to overcomes the radiation-pressure force to accrete the matter. This implies the existence of critical luminosity. This is called Eddington luminosity, which is defined as the luminosity at which the radiation pressure force on ionized gas is exactly balanced by the gravitational force. The Eddington luminosity is given by

$$L_{\rm E} = \frac{4\pi c G M_{\rm BH} m_{\rm p}}{\sigma_{\rm T}} = 1.25 \times 10^{38} \left(\frac{M_{\rm BH}}{M_\odot}\right) \ \ {\rm erg\ s^{-1}} \tag{2.3}$$

where $m_{\rm p}$ is the proton mass, $\sigma_{\rm T}$ is the Thompson scattering cross-section, $M_\odot$ is the solar mass. Note that $L_{\rm E}$ only depends on the central mass. In the case of AGNs with typical luminosity $L \sim 10^{46}$ erg s^{-1}, the mass of the central supermassive black hole should be $M_{\rm BH} \sim 10^8 M_\odot$, if it shines at the Eddington luminosity.

The critical mass accretion rate $\dot{M}_{\rm crit}$ associated with the Eddington luminosity is defined as

$$\dot{M}_{\rm crit} \equiv \frac{L_{\rm E}}{c^2} = 1.4 \times 10^{17} \frac{M_{\rm BH}}{M_\odot} \ \ {\rm g\ s^{-1}} \tag{2.4}$$

If the energy conversion rate by accretion is η, then the luminosity due to the mass accretion rate $\dot{M}$ is $L = \eta \dot{M} c^2$.

2.2.3 Accretion disks

It has been thought that an accretion disk plays a crucial role in conversion of gravitational energy into radiation around compact objects (Lynden-Bell et al. 1969). Shakura & Sunyaev (1973) provides a prototypical formalism called a standard accretion disk model and Mitsuda et al. (1984) proposed its simple mathematical approximation called 'multicolor disk (MCD)' blackbody model, which is a superposition of many blackbody emission up to a certain maximum color temperature $T_{\rm in}$ that is expected to occur near the innermost disk boundary. This model is known to give a successful physical description of X-ray spectra of soft state black hole binaries (BHBs) (Makishima et al. 1986; Ebisawa et al. 1993; Kubota et al. 1998). Makishima et al. (2000) also analyzed *ASCA* spectra of ultraluminous compact X-ray sources (ULXs) in nearby spiral galaxies, and found that most sources were well described with MCD model, although measured temperatures of accretion disk were too high to be compatible with the inferred black hole masses. In the case for AGNs, its spectral energy distribution (SED) exhibits a big bump in their optical/UV to soft X-ray band (Koratkar & Blaes 1999). Since most of the energies

emitted from AGNs are emerged in that energy band, this spectral component is thought to be a primary emission originated from an accretion disk (e.g. Turner et al. 2002).

Here, we briefly describe physical parameters associated with the MCD model. More detailed descriptions are seen in Mitsuda et al. 1984, Makishima et al. 1986, and Kubota et al. 2001.

When the disk is optically thick in the vertical direction, the energy generated in the disk is radiated from the surface of the disk as blackbody radiation. Shakura & Sunyaev (1973) showed that the surface temperature $T_{\rm eff}(r)$ is given as

$$T_{\rm eff}(r) = \left\{ \frac{3GM_{\rm BH}\dot{M}}{8\pi\sigma r^3} \left(1 - \sqrt{\frac{R_{\rm in}}{r}} \right) \right\}^{1/4}, \tag{2.5}$$

where σ is the Stefan-Boltzmann constant and $R_{\rm in}$ is the inner boundary radius. Since we assume that the surface of the disk radiates locally the blackbody radiation,

$$B_\nu(r) = \frac{2h}{c^2} \frac{\nu^3}{\exp\left\{\frac{h\nu}{k_B T(r)}\right\} - 1}, \tag{2.6}$$

which has a different temperature at different radii (i.e. multicolor), the observed flux S_ν of the disk is calculated by integrating the B_ν over the surface of the disk. In the MCD model, however, the $T_{\rm eff}(r)$ is approximated as

$$T_{\rm eff}(r) = T_{\rm in} \left(\frac{r}{r_{\rm in}} \right)^{-3/4} \tag{2.7}$$

with apparent inner radius $r_{\rm in}$ and the maximum temperature $T_{\rm in} \equiv T_{\rm eff}(r_{\rm in})$. Then the observed flux is expressed as

$$\begin{aligned} S_\nu &= \frac{\cos i}{D^2} \int_{r_{\rm in}}^{r_{\rm out}} B_\nu(r) 2\pi r dr \\ &= \frac{8\pi r_{\rm in}^2 \cos i}{3D^2} T_{\rm in}^{8/3} \int_{T_{\rm out}}^{T_{\rm in}} B_\nu(T) T^{-11/3} dT, \end{aligned} \tag{2.8}$$

where i is the inclination angle of the disk and D is the distance to the disk. Since $T_{\rm out}$ usually falls much below the observable X-ray band, the MCD model has only two adjustable parameters, $T_{\rm in}$ and the normalization factor $r_{\rm in}^2 \cos i \; D^{-2}$. The bolometric luminosity of the disk $L_{\rm disk}$ is given by

$$L_{\rm disk} = 4\pi \left(\frac{R_{\rm in}}{\xi} \right)^2 \sigma \left(\frac{T_{\rm in}}{\kappa} \right)^4 \tag{2.9}$$

where κ is the ratio of the color temperature to the effective temperature, or "spectral hardening factor", which is introduced to explain the effect of the electron scattering in the disk ($\kappa \sim 1.7$ for BHBs, Simura & Takahara 1995), and ξ is a correction factor reflecting the fact

that $r_{\rm in}$ determined from the MCD approximation is somewhat larger than $R_{\rm in}$, which provides as same $T_{\rm in}$ as $r_{\rm in}$, in the Shakura & Sunyaev formalism. Kubota et al. (1998) give $\xi = 0.412$.

Although the standard accretion disk model successfully explained the spectra of many BHBs, it cannot represent all spectra of the compact objects, including AGNs. The geometrical structure and physical condition of accretion disks are thought to be varied by depending on black hole mass and/or a mass accretion rate. As mentioned in the following section, Narrow-line Seyfert 1 galaxies are thought to have smaller black hole mass and to show a high mass accretion rate, hence, we are able to obtain an unique opportunity to study an extreme condition of an accretion disks.

2.3 Narrow-line Seyfert 1 galaxies (NLS1s)

Narrow-line Seyfert 1 galaxies (NLS1s) are a subclass of AGNs that manifest a distinctive ensemble of properties. They are remarkable for their extreme continuum and emission line properties which are not well understood. Here, we introduce basic properties of NLS1s with focusing on the Optical and X-rays.

2.3.1 Optical properties

NLS1s are identified by their optical line properties: Hβ FWHM is less than 2000 km s^{-1}, the [O III]λ5007 to Hβ ratio is less than 3, and there are high-ionization lines and frequently strong Fe II emission present in the spectrum (Osterbrock & Pogge 1985, Goodrich et al. 1989). Although their permitted lines are only slightly broader than their forbidden lines, they can be clearly distinguished from Seyfert 2s. For example, the permitted lines are polarized differently than the forbidden lines, indicating two emission regions (Goodrich et al. 1989). Recently, Véron-Cetty, Véron, & Gonçalves (2001) have compiled a list of 83 object classified as NLS1s and tried to characterize their narrow and broad-line regions. They found that the broad Balmer components are well fitted by a single Lorentzian profile rather than a Gaussian profile in most cases. In general, the [O III] lines have a relatively narrow ($\sim$ 200–500 km s^{-1}) profile, but they found an additional broad ($\sim$ 500–1800 km s^{-1}) and blueshifted component. They also suggested that the strength of Fe II relative to Hβ could be the best parameter to recognize NLS1s as a Seyfert 1s with high accretion rate. Other emission line studies were reported by Constantin & Shields (2003). They employed *Hubble Space Telescope* (*HST*) observations of 22 NLS1s in order to construct a high signal-to-noise composite spectrum of NLS1s. Figure 2.1 shows the composite spectrum they obtained. In order to determine the correlation between the observed emission line properties, Boroson & Green (1992) performed a principal component analysis (PCA) against a sample of 87 QSOs, and showed that much of the variance in line properties can be traced to a single eigenvector, despite the fact that different emission lines are thought to originate in widely separated parts of the AGNs. Furthermore, NLS1s are located at

the extreme end of this eigenvector, therefore, they exemplify an extreme value of this physical parameter.

Figure 2.1: Narrow-line Seyfert 1 composite spectrum (top panel). See Constantin & Shields (2003).

2.3.2 X-ray properties

In X-ray regime, NLS1s exhibit peculiar timing properties and/or spectra, hence provide an unique opportunity to investigate a physical state in the strong radiation and gravitational field. In this section, we describe their X-ray properties with focusing on the difference between the NLS1s and Seyfert 1 galaxies with broad Balmer lines (Broad-line Seyfert 1 galaxies; hereafter BLS1s).

Time variability

NLS1s show systematically larger amplitude variations on shorter timescales than BLS1s. In the case of the narrow-line Seyfert 1 galaxy IRAS 13224-3809, its intensity changes by a factor of 10 or more have occured within a few hours (Boller et al. 1993; Boller et al. 1997). Leighly (1999a) demonstrated that the "normalized excess variance", which implies a magnitude of a variability amplitude (Nandra et al. 1997a), are significantly larger in NLS1s than in BLS1s (see

Figure 2.2). From such a short time variation, it has been believed that NLS1s have a smaller black hole compared with that of BLS1s (Boller, Brandt, & Fink 1996). The small back hole mass may naturally explain why Balmer lines of NLS1s are narrow, because lower Keplerian velocities will be produced as gravitational field becomes weaker.

Figure 2.2: Excess variance from *ASCA* observations of NLS1s. See Leighly (1999a) and Nandra et al. (1997a) for detail.

Spectra

In general, Seyfert galaxies show a power law continuum in their X-ray spectra. Moreover, an exponential cut-off at several hundreds keV has been found in spectra of BLS1s (De Rosa et al. 2002; Perola et al. 2002; De Rosa, Fabian, & Piro 2002; Malizia et al. 2003; Pounds et al. 2003). Such an X-ray continuum can be explained adequately by thermal Comptonization process, where hot electrons scatter off some soft seed photons and boost them into hard X-rays (Sunyaev & Titarchuk 1980). The power law photon indices Γ of BLS1s are distributed around ~ 1.8, while that of NLS1s are significantly larger (~ 2.2) (Boller, Brandt, & Fink 1996; Forster & Halpen 1996; Laor et al. 1997; Vaughan et al. 1999; Leighly 1999b). Interestingly, this power law slope was found to be anti-correlated with the Hβ FWHM (Boller, Brandt, & Fink 1996; Forster & Halpern 1996; Laor et al. 1997). This may suggest the direct link between the central emission and broad-line region clouds.

The most prominent spectral difference between NLS1s and BLS1s appears in their soft ($<$ 1 keV) X-ray band. The extrapolation of the hard power law toward low energy band revealed the existence of excess emission above the power law continuum. This component is called "soft excess" and is stronger and more frequent in NLS1s than in BLS1s. In fact, NLS1s comprise less

than 10 % of the hard X-ray selected AGNs (Laor et al. 1997; Piccinotti et al. 1982), while they apparently comprise about a half of the AGNs in a soft X-ray selected sample compiled with the *ROSAT* All Sky Survey (Grupe et al. 1998; Grupe et al. 1999). The origin of the soft excess component, however, has been unknown, although several interpretations have been proposed. One of such models is that the observed soft excess emission would be represented by a hard tail of thermal emission originated from an accretion disk (e.g. Ross, Fabian, & Mineshige 1992; Mineshige et al. 2000; Watarai & Mineshige 2001; Wang & Netzer 2003; Kawaguchi et al. 2003).

Unfortunately, since *ROSAT* sensitivity is limited to energies less than 2 keV and *ASCA* has no sensitivity below 0.5 keV, it was difficult to determine the soft and hard spectral components simultaneously. *XMM-Newton* has an unprecedented sensitivity from 0.3 keV to 12.0 keV, hence, it is suitable for studying the spectra of NLS1s in detail.

Chapter 3

Instrumentation

3.1 *XMM-Newton*

XMM-Newton (Jansen et al. 2001) was launched on the 10th December 1999 by an Ariane 5 launcher into a highly elliptical orbit, with an apogee of about 115,000 km and a perigee of about 6,000 km (Figure 3.1). The orbital inclination is 33°, the right ascension of the ascending node is 195° and the argument of perigee 89o. Such an orbit provides the best visibility in the southern celestial sky. Objects are continuously observable during the entire visibility period in an orbit, as *XMM-Newton* is operated with three ground stations which are located at Perth, Kourou and Santiago. Thus, the complete visibility period (145 ksec) is available for continuous observations.

XMM-Newton carries two distinct types of telescopes: three X-ray telescopes with different X-ray detectors in their foci, and a 30-cm optical/UV telescope with a microchannel-plate pre-amplified CCD detector in its focal plane. Thus, *XMM-Newton* can cover the wide energy band simultaneously.

There are three types of scientific instruments onboard *XMM-Newton*: three X-ray CCD cameras called the European Photon Imaging Camera (EPIC), two high-resolution X-ray spectroscopy instruments called the Reflection Grating Spectrometer (RGS), and the Optical Monitor (OM). The three EPICs and the two detectors of the RGSs reside in the focal planes of the X-ray telescopes, while the OM has its own telescope. Figure 3.2 displays a sketch of the *XMM-Newton* payload. In the following section, we explain the characteristics of these instruments in detail.

3.2 X-ray Telescopes (XRTs)

3.2.1 Design Structure

XMM-Newton's three XRTs are co-aligned with an accuracy of better than about 1 arcmin. Each

Figure 3.1: Sketch of the highly elliptical *XMM-Newton* orbit.

Figure 3.2: Sketch of the *XMM-Newton* payload. The mirror modules, two of which are equipped with Reflection Grating Arrays (RGAs), are visible at the lower left. At the right end of the assembly, the focal X-ray instruments are shown.

of the three telescopes consists of 58 Wolter type-I mirrors, and the mirror grazing incidence angles range between 17 and 42 arcmin. The focal length is 7.5 m and the diameter of the largest mirrors is 70 cm. One telescope with the PN camera at the focal point has a light path as shown in Figure 3.3. The two others have grating assemblies in their light paths, diffracting part of the incoming radiation onto their secondary focus (see Figure 3.4). About 44 % of the incoming light focused by the XRT is directed onto the MOS camera at the prime focus, while 40 % of the radiation is dispersed by a grating array onto a linear strip of CCDs. The remaining light is absorbed by the support structures of the RGAs.

Figure 3.3: The light path in *XMM-Newton*'s XRT with the PN camera in focus.

Figure 3.4: The light path in *XMM-Newton*'s XRT with the MOS camera and RGA.

3.2.2 Point-spread function (PSF) of XRTs

A point-spread function (PSF) determines the imaging quality of an XRT. Figure 3.5 shows the in orbit on-axis images obtained by each detector. The radial substructures are caused by the spiders holding the mirror shells. Figure 3.6 displays the azimuthally averaged profile of the PSF of one XRT together with the best-fit King profile, which has the form $A(1/[\{1+(r/r_c)^2\}^\alpha])$, where r is the radial distance from the center of the PSF, r_c is the core radius and α is the slope of the King model. Figure 3.7 shows the encircled energy function (EEF) as a function of radius from the center of the PSF for several different energies. For on-axis source, high energy photons are reflected and focused predominantly by the inner shells of the XRTs. The inner shells apparently give better focus than the average of all shells, hence the EEF increase with increasing photon energy. A half energy width (HEW), which means the width including half of all the reflected photons, of the PSF can be derived from EEF. Table 3.1 lists the on-axis HEW of the different XRTs measured in orbit and on ground.

The PSFs of the XRTs depend on the source off-axis angle. As the off-axis angle increases, the HEW of PSF becomes larger. Our samples presented in this thesis, however, are all point-like source and were observed at almost on-axis position. Therefore, effect of off-axis dependency is negligible.

Figure 3.5: On-axis images of the MOS1, MOS2 and PN XRTs (left to right). The images are 110 arcsec wide and a logarithmic scale has been used to visualize the wings of the point spread function.

Table 3.1: The on-axis in orbit and on ground 1.5 keV HEW of the different XRT.

Instr.	PN	MOS1	MOS2
	orbit/ground	orbit/ground	orbit/ground
HEW [arcsec]	15.2/15.1	13.8/13.6	13.0/12.8

Figure 3.6: Radial counts distribution for the on-axis PSF of the MOS1 XRT in the 0.75–2.25 keV energy range. The solid line indicates the best-fit King profile.

Figure 3.7: The encircled energy function as a function of angular radius (on-axis) at different energies. The curves are calculated assuming a fractional encircled energy of 100 % at a radial distance of 5 arcmin.

3.2.3 Effective Area (EA) of XRTs

An effective area is an indicator of ability of collecting photons. *XMM-Newton* carries the XRT with the largest effective area of focusing telescope ever. The total mirror geometric effective area (EA) at 1.5 keV energy is about 1,550 cm^2 for each telescope, i.e., 4,650 cm^2 in total. Figure ?? shows the on-axis effective area of all *XMM-Newton* XRTs. The EAs of the two MOS cameras are lower than that of the pn, because only part of the incoming radiation falls onto these detectors, which are partially obscured by the RGAs (see Figure 3.4). Not only the shape of the X-ray PSF, but also the effective area of the XRT is a function of off-axis angle within the field of view. Decreasing of photons reflected effectively in the XRT arises from an increasing off-axis angle. This effect is called vignetting. Figure 3.9 displays the vignetting function as a function of off-axis angle for several different energies. The vertical axis is normalized by the on-axis effective area.

3.2.4 Straylight Rejection

X-ray straylight is produced by rays which are singly reflected by the mirror hyperbolas and which reach the sensitive area of the focal plain detectors. Thus, an X-ray baffle was implemented to shadow those singly reflected rays. It consists of two sieve plates made of concentric annular aperture stops located in front of the mirrors at 85 mm and 145 mm, respectively. The design is such that the entrance annular aperture of each mirror remains unobstructed for on-axis rays. The collecting area of straylight in the EPIC detector as a function of off-axis angle for a point source is about 3 cm^2 for stray sources located between 20 arcmin and 1.4° from the optical

Figure 3.8: The net effective area of all *XMM-Newton* XRT, combined with the response characteristics of the focal detectors.

Figure 3.9: Vignetting function as a function of off-axis angle at several different energies (based on simulations).

axis. The ratio of the X-ray straylight collecting area to the on-axis effective area is smaller than 0.2 % at 1.5 keV for a point source located at off-axis angles of 0.4–1.4° and negligible at higher off-axis angles. Figure 3.10 displays the effect of straylight, which is obtained from the observation of GRS 1758-258 (a black hole candidate near the Galactic center). Some sharp arcs are caused by single mirror reflections of photons possibly from GX 5-1 which is located at off-axis angle of 40 arcmin to the north and outside the field of view.

Figure 3.10: The effect of straylight appeared in PN image of GRS 1758-258.

3.3 European Photon Imaging Camera (EPIC)

Two of *XMM-Newton*'s X-ray telescopes are equipped with EPIC MOS (Metal Oxide Semiconductor, Turner et al. 2001) CCD arrays, the third carries a different CCD camera called EPIC PN (Strüder et al. 2001). The EPIC cameras offer the possibility to perform extremely sensitive imaging observations over a field of view of 30 arcmin and the energy range from 0.15 to 15 keV, with moderate spectral ($E/\Delta E \sim 20$–50) and angular resolution (15 arcsec HEW). The detector layout and the baffled X-ray telescope FOV of both types of EPIC cameras are shown in Figure 3.11. The PN chip array is slightly offset with respect to the optical axis of its X-ray telescope so that the nominal, on-axis observing position does not fall on the central chip boundary. This ensures that more than 90 % of the energy of an on-axis point source are collected on one PN CCD chip. Two EPIC MOS cameras are rotated by 90° with respect to each other. The dead spaces between the MOS chips are not gaps, but unusable areas due to detector edges (the MOS chip physically overlap each other, the central one being located slightly behind the ones in the outer ring). All EPIC cameras are operated in photon counting mode with a fixed, mode dependent frame read-out frequency.

Figure 3.11: A rough sketch of the field of view of the two types of EPIC cameras (MOS, left; PN, right). The shaded circle depicts a 30 arcmin diameter area which is equivalent with the XRT field of view.

3.3.1 Two Types of EPIC Cameras: MOS and PN

The two types of EPIC cameras are fundamentally different. This does not only hold for the geometry of the MOS chip array and the PN chip array, but other properties as well, for example, their readout times. The readout of the PN chips is much faster than that of the MOS cameras, because each pixel column has its own readout node. Another important difference is that the MOS chips are front-illuminated, while the PN CCDs are back-illuminated, which affects the detector quantum efficiencies decisively.

The MOS chip arrays consist of 7 individual identical, front-illuminated chips. The individual CCDs are not co-planar, but offset with respect to each other, following closely the slight curvature of the focal surface of the Wolter telescopes. Technically, this leaves space for the connections to the central CCD. The numbering scheme for the EPIC MOS chip array, the individual chip coordinate frames and the directions of the detector coordinates are displayed in Figure 3.12 and 3.13.

The heart of the PN camera is a single Silicon wafer with 12 CCD chips integrated. The PN chip array numbering scheme, the individual chip coordinate frames and the directions of the detector coordinates are displayed in Figure 3.14.

Figure 3.12: The rayout of the EPIC MOS1 camera. The readout node of each CCD is located with a small box.

Figure 3.13: The rayout of the EPIC MOS2 camera.

3.3.2 Science Modes of the EPIC Cameras

The EPIC cameras allow several modes of data acquisition, which are called *Full frame mode*, *Large window mode*, *Small window mode* and *Timing mode*. Table 3.2 summarizes the basic

Figure 3.14: The rayout of the EPIC PN camera. The readout is located at the top (for CCDs 1–6) or bottom (for CCDs 7–12) of the displayed array.

numbers for the science modes of EPIC cameras, and Figure 3.15 and 3.16 display the images obtained in each operating mode.

Table 3.2: Basic numbers for the science modes of EPIC.

	Time resolution MOS [s]/PN [ms]	Max count rate [c s^{-1}] MOS/PN
Full frame	2.6/73.4	13.8/13.6
Large window	0.9/48	1.8/12
Small window	0.3/6	5/130
Timing	0.0015/0.03	100/1500

3.3.3 Characteristics of EPIC Cameras

Angular resolution

The EPIC MOS and PN cameras have pixels with sizes of 40 and 150 μm, respectively. For the focal length of the X-ray telescopes (7.5 m), these pexel size corresponds to 1.1 arcsec and 4.1 arcsec on the sky. Since they are smaller than the HEW of XRT (15 arcsec), EPIC's angular resolution is basically determined by the PSF of the mirror modules.

Figure 3.15: Operating modes for the MOS camera. top left, Full frame mode: top right, Large window mode: bottom left, Small window mode: bottom right, Timing mode.

Figure 3.16: Operating modes for the PN camera. top left, Full frame mode: top right, Large window mode: bottom left, Small window mode: bottom right, Timing mode.

Energy resolution

The resolving power of EPIC cameras is determined by the intrinsic energy resolution of the individual pixels. Figure 3.17 and 3.18 show the energy resolution (FWHM) of MOS and PN, respectively. The measured in-flight FWHM of the Al Kα (1.5 keV) and Mn Kα (5.9 keV), which are the on-board calibration lines, are also plotted in Figure 3.17. It is well known that the energy resolution of MOS cameras has been gradually decrease due to the CTI (charge transfer inefficiency) effect, which means the imperfect transfer of charge as it is transported through the CCD to the output amplifiers. The latest calibration status is found at *XMM-Newton* Science Operation Centre.[1] The accuracy of the energy determination is about 10 eV over the full energy range and for all modes except for MOS timing mode.

Quantum efficiencies

The quantum efficiency of both types of EPIC CCD chips as a function of photon energy is displayed in Figure 3.19 and 3.20. These chips were calibrated using laboratory X-ray beams, synchrotron generated monochromatic X-ray beams, before launch, and celestial X-ray source measurements. We can see the typical X-ray absorption fine structure (XAFS) behavior around

[1] *http://xmm.vilspa.esa.es/external/xmm_sw_cal/calib/documentation.shtml#EPIC*

Figure 3.17: The EPIC MOS energy resolution (FWHM) as a function of energy. The solid curve is a best-fit $E^{0.5}$ function to ground calibration data between 0.1–12.0 keV. Below around 0.6 keV (shown by the dotted region), surface charge loss effects distort the main photopeak significantly from a Gaussian form and, hence the effective energy resolution. The measured in-flight FWHM of the Al Kα (1.487 keV) and Mn Kα (5.893 keV) lines are also plotted.

Figure 3.18: The EPIC MOS energy resolution (FWHM) as a function of energy. Curves are given for single and double events (full frame mode) at the focus position as well as at a position 10 pixels away from the readout node.

the silicon K edge at 1.838 keV. Ground calibration measurements have shown that the quantum efficiency of MOS CCDs is uniform above 400 eV. Below this energy, spatial variations are seen as patches in the outer parts of the CCDs where the response is degraded. This inhomogeneity is currently not taken into account by the *XMM-Newton* science analysis system (SAS).

Figure 3.19: Quantum efficiency of the EPIC MOS camera as a function of photon energy.

Figure 3.20: Quantum efficiency of the EPIC PN camera as a function of photon energy.

EPIC photon pile-up

Photon pile-up, which means the arrival of more than one X-ray photon in one camera pixel or in adjacent pixels before it is read out, can affect both the PSF and the spectral response of EPIC. Molendi & Sembay (2003) reported the pile-up effect in detail by using the data from the observations of 3C 273 and they found no significant spectral distortion in PN spectra. On the other hand, in MOS spectra, pile-up effect is appeared in the PSF core at the observed counting rate of $\sim$ 17 counts s^{-1}.

EPIC filters

The EPIC CCDs are not only sensitive to X-ray photons, but also to IR, visible and UV light. Therefore, if an astronomical target has a high optical to X-ray flux ratio, there is a possibility that the X-ray signal becomes contaminated by those photons. To prevent such a contribution, each EPIC camera is equipped with a set of 3 separate aluminised optical blocking filters, named *thick*, *medium* and *thin*. The thick filter should be used for all point source targets up to m_V of 1–4 (MOS) or 0–3 (PN). The medium filter is about 10^3 less efficient than the thick filter, therefore, it is useful for preventing optical contamination from point sources as bright as m_V = 8–10. The thin filter is about 10^5 less efficient than the thick filter, so the use of this filter

will be limited to point sources with optical magnitudes about 14 magnitudes fainter than the corresponding thick filter limitations.

3.3.4 EPIC Background

The EPIC background can be divided into 3 different types of background. First one is a cosmic X-ray background (CXB) dominated by thermal emission at lower energies ($E < 1$ keV) and a power law at higher energies (primarily from unresolved cosmological sources). Second one is EPIC external flaring background due to soft protons ($E \sim$ a few 100 keV) which are most likely organized in clouds populating the Earth's magnetosphere. Figure 3.21 shows the lightcurve badly affected by soft proton flares. The spectra of soft proton flares are variable and no clear correlation is found between intensity and spectral shape. The last one is the EPIC internal quiescent background which is associated with high energy ($E > 100$ MeV) particles interacting with the structure surrounding the detectors and the detectors themselves. Figure 3.22 and 3.23 display this type of background spectra. The component shows only small intensity variations in time, however shows the spatially inhomogeneous intensity variations (see Figure 3.24).

Figure 3.21: Light curve badly affected by soft proton flares.

3.4 Reflection Grating Spectrometer (RGS)

Two of the three *XMM-Newton*'s XRTs are equipped with RGS units (den Herder et al. 2001). These consist of Reflection Grating Assemblies (RGAs) and RGS Focal Cameras (RFCs). The RGS optical design is illustrated in Figure 3.25. Figure 3.26 displays the photograph of the RGS units onboard *XMM-Newton*. Each incorporates an array of reflection gratings placed in

Figure 3.22: Background spectrum for the MOS1 camera during an observation with the filter wheel in the closed position. The prominent features around 1.5 and 1.7 keV are Al K and Si K fluorescence lines, respectively.

Figure 3.23: Background spectrum for the PN camera during an observation with the filter wheel in the closed position. The prominent features are identified as Al-K (1.5 keV), Cr-K (5.5 keV), Ni-K, Cu-K, Zn-K (8.0 keV) and Mo-K (17.5 keV), respectively.

Figure 3.24: Background images for the PN camera with spatially inhomogeneous fluorescent lines. top left, Ti-K + Cr-K: top right, Ni-K: bottom left, Cu-K: bottom right, Mo-K. The inhomogeneity is mainly caused by the electronics board mounted below the CCDs.

the converging beam of the XRT. The grating stack consists of 182 precisely aligned reflection gratings and intercepts about 58 % of the light emanating from the telescope. The gratings are actually located on a toroidal Rowland surface, formed by rotating the Rowland circle about an axis passing through the telescope and spectroscopic foci. The gratings are slightly trapezoidal, since their edges lie along rays converging on the telescope focus. The field of view in the cross-dispersion direction is determined by the width of the CCDs (± 2.2 arcmin), and the spatial resolution in this direction is largely determined by the imaging properties of the mirror. In the dispersion direction the aperture of RGS covers the entire FOV of the mirrors, only the effective area reduces significantly for off-axis sources.

Nine back-illuminated CCDs are located on the Rowland circle to detect the dispersed spectra in single photon counting mode. However there are problems with failing drive electronics of two CCDs (CCD 4 in RGS-2, covering the wavelength range from 20.1 to 23.9 Åand CCD 7 in RGS-1, 10.5 to 14.0 Å). The position of the X-ray on the detector gives the wavelength through the dispersion equation

$$m\lambda = d(\cos\beta - \cos\alpha) \tag{3.1}$$

where m is the spectral order (-1, -2, ...), d is the groove spacing and α and β are the angles of the incident and dispersed rays measured from the grating plane, respectively (see Figure 3.27). Key parameters are summarized in Table 3.3 and Figure 3.28 indicates the effective areas of both RGS units.

Table 3.3: Key performance parameters of the RGSs.

Parameter	Value	Comments
A_{eff}	140 cm^2	peak effective area (at 15 Å)
λ	5–38 Å	1st order wavelength range
E	0.35–2.5 keV	1st order energy range
$\lambda/\Delta\lambda$ (FWHM)	100–500	resolving power (line separation)
$\lambda/\Delta\lambda$ (HEW)	100–800	resolving power (weak line detection)
$1/d$	645.6 lines/mm	central groove density
σ_λ	7 mÅ	1σ wavelength accuracy
bin size (3×3 on chip binned)	2.5 arcsec	cross dispersion
	7–14 mÅ	dispersion, 1st order

Figure 3.25: Optical design of the RGS (not to scale). X-rays enter from the top. Numerical values for a few key dimensions and angles are indicated (linear dimensions in mm, angles in degrees).

Figure 3.26: Photograph of the RGS unit onboard *XMM-Newton*.

Figure 3.27: Schematic drawing of a grating, including some of the key dimensions and angles.

Figure 3.28: Effective area for the two RGSs. The large drops appeared in 10 14 and in 21 24 Åare due to the failing read-out of CCD 4 in RGS-2 and CCD 7 in RGS-1, respectively. Narrow deep drops implies the gaps between the CCDs and narrow small dips are due to corrections for cosmetic blemishes.

Chapter 4

Observation and Data Reduction

4.1 Analyzing *XMM-Newton* Data

4.1.1 Data reduction

XMM-Newton reformatted telemetry is organized in the Observation Data Files (ODFs). The ODFs were processed to produce calibrated event lists by using the *XMM-Newton* Science Analysis System (SAS) version 5.4.1.

The event lists of EPIC cameras were generated from the tasks called "*emchain*" and "*epchain*". The event lists were further cleaned by removing hot, dead, and flickering pixels. We used X-ray events corresponding to pattern 0–12 (single, double, triple, and quadruple pixel events) for the MOS cameras and pattern 0–4 (single and double) for the PN camera. As mentioned in section 3.3.4, some of our sample were affected by significant background flares. Such periods were excluded throughout the analyses. Source spectra and light curves were extracted from a circular region with a radius of 45 arcsec and background were taken from an offset position close to the source with a same radius.

For the RGSs, event lists were generated by the process called "*rgsproc*". Source spectra were extracted using a spatial filter in dispersion/cross-dispersion coordinates. Subsequently, the first order events were selected by applying a dispersion/pulse-height filter. Background spectra were generated using the events that lie outside the source spatial region.

4.1.2 Image Analysis

X-ray image is made and examined whether X-ray emission is point-like or not. We also checked contributions from other X-ray sources.

In our sample, PKS 0558-504, which is classified as a radio-loud quasar, has been known to be a bright point-like source and it was one of the calibration target for the *XMM-Newton* telescopes (Aschenbach et al. 2000). Therefore, we first made an azimuthally averaged profile of surface brightness of this source (see Figure 4.1) in order to estimate an in-orbit point spread

function (PSF) of the XRTs. With thus estimated PSF, we compared radial profiles of other objects. As is mentioned in the later sections, X-ray continua of our sample are well reproduced by a combination of a power law, which dominates above ~ 2 keV, and a soft excess component, which dominates below 2 keV. Therefore, we made radial profiles in 0.3–2 keV band, and in 2–10 keV band. We found no evidence for a significant diffuse emission around a central object. We found many discrete sources in a EPIC field of view, but they are fully separated from a central object and their intensities are one or more orders of magnitude less than that of central object. Therefore, all X-ray emissions are coming from the nuclei of our sample galaxies. In Appendix, we show the X-ray images and radial profiles in our sample.

Figure 4.1: left: 0.3–10 keV image of PKS 0558-504 obtained from EPIC MOS cameras, right: azimuthally averaged profile of surface brightness of PKS 0558-504 as a function of radial distance.

4.1.3 Spectral Analysis

All spectral fits were performed with an X-ray spectral fitting package "XSPEC" version 11.2 (Arnaud 1996). All of the source spectra (EPICs and RGSs) were grouped such that each bin contains at least 20 counts in order to perform the χ^2 minimization technique. Since the RGS spectra, however, have much smaller counts than that of EPIC cameras, this grouping method makes spectral bin width wider than the energy resolution of RGSs. Therefore, we also grouped the RGS spectra into ~ 0.04 Å bin width, which is about half of the RGS resolution (~ 0.07 Å), in order to see complex absorption/emission features. All fit parameters are given in the source rest-frame and errors are quoted at the 90 % confidence level for one interesting parameter (i.e.

$\Delta\chi^2 = 2.7$), unless otherwise stated. Throughout this thesis, $H_0 = 70$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$ are assumed.

In the following spectral analyses, spectra of EPICs and RGSs are fitted simultaneously in order to maximize a signal to noise ratio, although relative normalization factors are left free to consider a calibration uncertainty. The spectral calibration of the EPICs is still evolving. We found significant spectral discrepancies between MOS and PN camera below 1 keV. Figure 4.1.3 shows an example of such discrepancy appeared in the spectra of NGC 4051. This has been known to be due to an increase in the surface charge loss property of MOS CCDs which degrades the low energy resolution. In order to mitigate this effect, we ignored MOS data below 0.7 keV throughout the spectral analyses.

Figure 4.2: Spectral discrepancy between MOS and PN. Red, MOS spectrum; Black, PN spectrum. Spectra are derive from a observation of NGC 4051.

Hard X-ray continua of AGNs are generally represented well by a power law modified by Galactic absorption;

$$I(E)dE = AE^{-\Gamma}\exp(-\sigma(E)N_{\rm H}^{\rm Gal}), \tag{4.1}$$

where Γ is a photon index, A is a normalization factor, $\sigma(E)$ is the photo-electric absorption cross section for interstellar medium taken from Balucinska-Church & McCammon (1992), and $N_{\rm H}^{\rm Gal}$ is an equivalent hydrogen column density of Galactic absorber. In some objects, There appears an edge-like feature around 7 keV, which may be attributed to an Fe-K absorption edge. Moreover, some of such objects (e.g. 1H 0707-495, NGC 4051) show much flatter ($\Gamma \sim 1$) continuum than the average value of Seyfert 1 galaxies ($\Gamma \sim 1.9$). These may be signatures of a partial covering model, which is seen in Seyfert 2 galaxies, and is represented by a combination of a heavily ($N_{\rm H} > 10^{22}$ cm^{-2}) absorbed power law and a leaked one. A following is the formula;

$$I(E)dE = A\exp(-\sigma(E)N_{\rm H}^{\rm Gal})\{f\exp(-\sigma(E)N_{\rm H} + (1-f)\}E^{-\Gamma}, \tag{4.2}$$

where f is the covering fraction.

As shown in the next chapter, all galaxies in our sample show a soft excess emission with a convex shape when the hard X-ray power law is extrapolated toward a lower energy band. This excess component cannot be well reproduced by an additional power law model, even if we allow a column density of Galactic absorber $N_{\rm H}^{\rm Gal}$ to be varied. Therefore, we introduced a multicolor disk blackbody (MCD) model in order to parameterize the soft component. As is explained in section 2.2.3, MCD model has two adjustable parameters, the maximum disk temperature kT and the normalization factor $K = r_{\rm in}^2 \cos i\ D^{-2}$, where $r_{\rm in}$ is the inner radius, i is the inclination angle of the disk and D is the distance to the disk. The formula of a power law plus MCD model is expressed as follow;

$$I(E)dE = \exp(-\sigma(E)N_{\rm H}^{\rm Gal})(AE^{-\Gamma} + MCD(kT, K)). \tag{4.3}$$

In the case of a partial covering model, we used the following formula;

$$I(E)dE = \exp(-\sigma(E)N_{\rm H}^{\rm Gal})\{f\exp(-\sigma(E)N_{\rm H} + (1-f)\}(AE^{-\Gamma} + MCD(kT, K)), \tag{4.4}$$

where we assume that the size of the power law emission region is the same as that of the disk emission region. Therefore, care must be taken in estimating an intrinsic luminosity of the soft component.

Some objects in our sample exhibit complex absorption features imprinted by photoionized gas in the line of sight. In order to quantify the ionized absorber, we used a model calculated from the "XSTAR" photoionization code (Kallman & Krolik 2003). This model has three independent parameters: a column density of the absorber $N_{\rm ph}$, an ionization parameter ξ ($\equiv Lion/nR^2$; $L_{\rm ion}$, luminosity of the ionizing source; n, density of the gas; R, distance from the ionizing source to the gas), and an iron abundance $A_{\rm Fe}$. We assume that the irradiating source has a power law shape with a photon index $\Gamma = 2$. Throughout the model calculation, the density n and the temperature T of the ionized gas are assumed to be 1×10^9 cm^{-3} and 1×10^5 K, respectively. These values are estimated from the OVII triplet appeared in the RGS spectra of NGC 4051. To save processing time, we fixed a turbulent velocity $v_{\rm turb}$ of the gas to be 1×10^3 km s^{-1}.

4.1.4 Timing Analysis

As mentioned in section 2.3, Narrow-line Seyfert 1 galaxies generally exhibit large amplitude intensity change on short (10^3–10^4 sec) timescales. Hence, it is important to quantify the magnitude of variability. Here, we introduce the Fractional variability amplitude ($F_{\rm var}$) following Edelson et al. (2002). $F_{\rm var}$ is defined as follow,

$$F_{\rm var} = \frac{1}{\langle X \rangle}\sqrt{S^2 - \langle \sigma_{\rm err}^2 \rangle}, \tag{4.5}$$

where S^2 is the total variance of the light curve, $\langle \sigma_{\rm err}^2 \rangle$ is the mean error squared, and $\langle X \rangle$ is the mean count rate. Therefore, $F_{\rm var}$ implies the intrinsic variability amplitude that corrects for the

effects of measurement noise. The error on $F_{\rm var}$ is estimated using the following equation given by Edelson et al. (2002).

$$\sigma_{F_{\rm var}} = \frac{1}{F_{\rm var}}\sqrt{\frac{1}{2N}\frac{S^2}{\langle X\rangle^2}}. \tag{4.6}$$

We calculated $F_{\rm var}$ in various energy bands, and made an energy spectrum of $F_{\rm var}$. As is noticed by the definition of $F_{\rm var}$, the shape of this energy spectrum of $F_{\rm var}$ is consistent with a ratio of a spectrum during a high count rate (above average) period to a spectrum during a low count rate (below average) period. Figure 4.3 shows the energy spectrum of $F_{\rm var}$ (left) and spectral ratio (right) calculated using the data of IRAS 13224-3809. Indeed, both plots show a similar energy dependence. Therefore, the spectrum of $F_{\rm var}$ is very useful to estimate a spectral variability during an observation.

Figure 4.3: Energy spectrum of $F_{\rm var}$ (left) and spectral ratio between high and low state (right). High state is defined as periods with count rates above an average value, and low state implies periods with count rates below an average.

4.2 Observation

We compiled *XMM-Newton* data of NLS1s from the public archives. NLS1s analyzed here are based on some literatures (Constantin & Shields 2003; Véron-Cetty, Véron & Gonçalves 2001; Leighly 1999a). Our sample of NLS1s are tabulated in Table 4.1 with their optical properties. Table 4.2 also shows the *XMM-Newton* observation log of these targets. The observed fluxes and luminosities of our targets are plotted in Figure 4.4. With these targets, we can cover a wide range of luminosities as much as four orders of magnitude.

Table 4.1: Compiled NLS1s and their optical emission line properties.

Target name	z	N_H[a] 10^{20} cm^{-2}	Hβ FWHM km s^{-1}	Hβ EW Å	FeII/Hβ	[OIII]/Hβ
Mrk 335	0.02575	3.77(M)	1640	86	0.38	0.25
I Zw 1	0.06114	5.07(E)	1240	48	1.14	0.44
Ton S180	0.06198	1.56(D)	1085	46	1.03	0.18
Mrk 359	0.01739	4.79(M)	900	18	<0.5	1.32
NAB 0205+024	0.15530	2.99(E)	1050	58	0.62	0.36
PKS 0558-504	0.137	4.39(D)	1250	45	1.56	0.04
1H 0707-495	0.0411	5.79(D)	1050	32	1.36	0.19
RE 1034+396	0.04244	1.43(M)	935	17	<1.5	0.93
NGC 4051	0.00234	1.31(E)	1120	50	0.25	0.55
PG 1211+143	0.0809	2.83(E)	1975	95	0.44	0.12
PG 1244+026	0.048	1.93(E)	740	36	1.09	0.47
IRAS 13224-3809	0.0667	4.79(D)	650	23	2.42	0.60
Mrk 478	0.07905	0.97(M)	1270	72	0.55	0.17

[a] Reference for Galactic N_H: (M) Murphy et al. 1996; (E) Elvis et al. 1989; (D) Dickey & Lockman 1990.
Reference for Optical properties: Véron-Cetty, Véron & Gonçalves 2001.

Figure 4.4: 2–10 keV F_X–L_X relationship.

Table 4.2: *XMM-Newton* observation log

Target name	Date	Observation Mode[a] (Filter[b])			Duration
	Y/M/D	PN	MOS1	MOS2	ksec
Mrk 335	2000/12/25	FF(Med)	LW(Med)	LW(Med)	31.6
I Zw 1	2002/06/22	LW(Med)	SW(Med)	SW(Med)	21.0
Ton S180(1)	2000/12/14	SW(Med)	TM(Med)	SW(Med)	29.4
Ton S180(2)	2002/06/30	SW(Med)	TM(Med)	SW(Med)	18.0
Mrk 359	2000/07/09	LW(Med)	SW(Med)	SW(Med)	7.40
NAB 0205+024	2002/07/23	FF(Thin)	TM(Thin)	FF(Thin)	43.5
PKS 0558-504(1)	2000/05/24	FF(Med)	LW(Med)	LW(Med)	13.5
		SW(Med)	LW(Med)	LW(Med)	13.6
PKS 0558-504(2)	2000/10/10	SW(Thin)	LW(Thin)	LW(Thin)	10.7
		FF(Thin)	FF(Thin)	FF(Thin)	8.60
PKS 0558-504(3)	2001/06/26	FF(Med)	FF(Med)	FF(Med)	11.7
1H 0707-495	2000/10/21	FF(Med)	LW(Med)	LW(Med)	40.7
RE 1034+396	2002/05/01	LW(Thin)	LW(Thin)	LW(Thin)	12.8
NGC 4051(1)	2001/05/16	SW(Med)	TM(Med)	SW(Med)	106
NGC 4051(2)	2002/11/22	LW(Med)	LW(Med)	LW(Med)	49.9
PG 1211+143	2001/06/15	LW(Med)	SW(Med)	SW(Med)	53.1
PG 1244+026	2001/06/17	FF(Thin)	FF(Thin)	FF(Thin)	8.16
IRAS 13224-3809	2002/01/19	FF(Med)	LW(Med)	LW(Med)	60.8
Mrk 478	2001/12/23	LW(Thin)	LW(Thin)	LW(Thin)	25.8

[a] (FF) Full Frame mode; (LW) Large Window mode; (SW) Small Window mode; (TM) Timing mode.

[b] (Thin) Thin filter; (Med) Medium filter.

Chapter 5

Results

In this chapter, we present results of timing and spectral analyses. First of all, we introduce the results from the *ASCA* observations of NGC 5548, which is not classified into narrow-line Seyfert 1s but is a typical broad-line Seyfert 1 galaxy. Since the results of NGC 5548 can be a good indicator for the physical conditions in BLS1s, it is very useful to clarify the specificities of NLS1s compared with BLS1s.

5.1 NGC 5548

5.1.1 Introduction

NGC 5548 (z=0.0174), a typical Seyfert 1 galaxy with broad Balmer lines, is one of the brightest objects from optical/UV to X-ray band. Therefore, it has been intensively observed in broad wave bands from ground and space observatories. Its light curves have been monitored from days to years in many world wide campaigns.

Here we present successful simultaneous observations of NGC 5548 with *Extreme Ultlaviolet Explorer* (*EUVE*) and *ASCA* in 1996.

5.1.2 Light curves

EUVE observation

In order to measure EUV fluxes and spectra, we performed observations with *EUVE* (Bowyer & Malina 1991) for about two weeks from the end of June 1996. The EUV flux is monitored by the deep survey (DS) instrument in the wavelength band from 65 through 200 Å. The peak effective area is 25 cm^2 at 93 Å(0.13 keV) with the band width of about 50 Å(0.07 keV) FWHM. The EUV short wave length spectrometer (SW) is used to observe the dispersed spectrum from 65 through 100 Å, or from 0.12 keV to 0.18 keV. Since the effective area of the SW detector is small, we have to accumulate all SW counts over the full 12-day observations to provide clear

spectra with enough statistics especially for the line feature suggested from previous *EUVE* observations (Kaastra, et al. 1995). Therefore, DS counts are used to examine light curves, while the SW system is only used to obtain a detailed spectrum averaged over the entire observation. *EUVE* started to observe NGC 5548 from June 26 (MJD = 50260.9015) through July 7 (MJD = 50271.9543) in 1996. The light curve with open circles shown in Figure 5.1 is the DS counting rates which are corrected for the effects of deadtime, Primbsching, which is variable loss of photons when the count rate is high because of designed telemetry sharing between the instruments on *EUVE*, vignetting, and encircled energy fraction. The origin epoch of the abscissa is MJD of 50260. Each DS data point corresponds to the data accumulated over one orbit of the *EUVE* satellite (for about 95 min). The ordinate unit is shown at the right hand side for DS. The observed DS counting rate shows a high state ($\sim$ 0.12 counts s^{-1}) on the first two days with a sharp dip in the middle. After another sharp drop at MJD $\sim$ 50262.5, it becomes rather stable around 0.05 counts s^{-1} throughout our observation. The flux level higher than 0.1 counts s^{-1} with DS on the first two days is the highest among four *EUVE* observations of this source in 1993 and 1996.

X-ray observation

For the *ASCA* observations, we have planned five observations of about 20 ksec exposure on every other day. The first observation was on June 27 and the last one was on July 5, so that the longest time scale we cover becomes 9 days. The *ASCA* satellite (Tanaka et al. 1994) is equipped with four grazing incidence X-ray telescopes (XRT; Serlemitsos et al. 1995) capable to focus X-rays up to 10 keV. On the focal plane of two XRTs, imaging gas scintillation proportional counters (GIS 2 and 3; Ohashi et al. 1996) are mounted. The GIS detectors have an energy resolution of 500 eV at 6 keV and an energy coverage from 0.7 through 10 keV. For the other two XRTs, CCD cameras (SIS 0 and 1; Burke et al. 1994) are attached. The SIS detectors have a better spectral resolution of 120 eV at 6 keV and an energy coverage from 0.5 through 10 keV. The GISs were operated in the PH normal mode and the SISs were operated in 1 CCD FAINT mode. Data were cleaned by the following selection criteria; for both GIS and SIS, satellite should not be in the South Atlantic Anomaly (SAA), the object should be at least 5° above the Earth's limb and the local geomagnetic cut-off rigidity (COR) should be greater than 6 GeV/c. In addition, the object should be at least 25° above the day-time Earth's limb and the time after day/night transition should be greater than 50 sec for SIS only. The X-ray spectra and light curves were extracted from circular regions centered on the nucleus with a radius of 4' for SIS and 6' for GIS. The background data were accumulated from a source-free region in the same field of view. The spectra were rebinned so that each bin contained at least 20 counts. In the following spectral analysis, both GIS and SIS spectra are fitted simultaneously.

The solid circles in Figure 5.1 indicate the average SIS flux between 0.5 and 10 keV for each 20 ksec observation. On the first day, NGC 5548 was brightest also in X-rays, and it gradually

decreased, following the similar trend of the *EUVE* DS light curve.

In Figure 5.2, the SIS counts are plotted against the DS counts averaged over the same time period from the beginning to the end of each 20 ksec X-ray observation. The numbers in the figure indicate the order of the *ASCA* observations. The best fit linear function is $F_X = 19.0 \times F_{EUV} + 0.84$ for 5 data points (the solid line). It shows a clear linearity of the X-ray flux against the DS counts but with a substantial offset. The error bars are shown for the DS counts, while those of the SIS counts are smaller than the circle of each data point. Since the scatter of the data points is larger than the error bars, the reduced chi square ($\chi^2_\nu = 2.53$) is much larger than unity. On the other hand, the data are better fitted to the linear function if the first day is excluded. The best fit function for the points #2 to #5 is $F_X = 24.4 \times F_{EUV} + 0.59$ (the dashed line) with a reduced chi-square of 0.89. The data point on the first day is much above the dashed line that represents the X-EUV relation of the latter four data points.

Figure 5.1: Light curves of *EUVE* DS (open circles) and *ASCA* SIS (filled circles) binned to 5700 sec and 20 ksec, respectively. The origin epoch of the abscissa corresponds to MJD 50260. The ordinate unit shown at the right hand side indicates the DS counting rate and at the left for SIS.

Figure 5.2: Correlation between *EUVE* DS and *ASCA* SIS counting rate on long time scales. The numbers in the figure indicate the order of each observation day. The solid line is the best-fit linear function to five data points, on the other hand, the dashed line is for four data points (#2 – #5).

5.1.3 Energy spectra

EUVE SW spectrum and DS flux

The energy spectrum observed by the *EUVE* SW detector is shown in Figure 5.3. Since the SW flux is as low as 0.001 counts s^{-1} in total, all data during the 12-day observation is accumulated.

Since we are interested in the continuum spectrum in the present work, the SW spectral data are binned in wider wavelength steps (see Figure 5.3). This spectrum can be fitted with a blackbody of $kT = 15.8^{+20.8}_{-5.8}$ eV (not corrected for the contribution of an extrapolation of a hard X-ray continuum model. In the following sections, we will apply a blackbody model with power law continuum model extrapolated from the X-ray band). In these analyses, the detected DS and SW counts are converted to the incident photon spectrum corrected for the Galactic column density of 1.6×10^{20} cm^{-2} (Murphy et al. 1996). In order to examine a SW spectral change during the dip, we compare the spectrum before the dip with that after the dip. However, the low SW counting rate and short duration of the dip prevent us to detect a significant change. The DS flux in the energy band from 0.095 to 0.165 keV is also shown in Figure 5.3 with open circles, which is averaged over the whole observation. The SW spectrum exactly matches the DS data point thus obtained.

X-ray spectra

The *ASCA* SIS energy spectrum is shown in Figure 5.4, being averaged over all observations. The best-fit spectral parameters are summarized in Table 5.1 for a model consisting of a power law, neutral gas absorption, three edges below 2 keV, and a Gaussian line between 6 and 7 keV (fit 1). In this fitting procedure, the Gaussian line width is fixed at 0.43 keV which is an average value obtained from a statistical analysis of Seyfert 1s (Nandra et al. 1997). The photon index 1.6 – 1.9 is comparable to those of typical Seyfert 1s, although some weak excess can be seen above 7 keV.

In recent grating observations of *Chandra* and *XMM-Newton*, many absorption lines are seen below 1 keV in NGC 5548 (Kaastra et al. 2002, Steenbrugge et al. 2003). Especially, in the first *Chandra* LETGS observation when this source was 40 % fainter, only absorption lines were detected and no edge feature was necessary to reproduce the grating spectra (Kaastra et al. 2002). However, in the present *ASCA* analysis, we applied simpler absorption edge models to the warm absorber. The derived parameters are listed in Table 5.1. The obtained edge energies ($E_{th1} = 0.69$ keV, $E_{th2} = 0.81$ keV; source rest frame) are lower than OVII (0.74 keV) and OVIII (0.87 keV) K-edge energies. These may suggest the contributions of K-shell absorption lines of OVII, OVIII, L-shell absorption lines of FeXVII, and $2p$ - $3d$ UTA (unresolved transition array) of cool iron (Sako et al. 2001).

An Fe-K line is seen with an equivalent width (EW) of a few hundred eV, depending on the continuum models. If a reflection component ("PEXRAV" in XSPEC, Magdziarz & Zdziarski 1995) is introduced to explain the excess above 7 keV, a smaller EW of the iron line is obtained (see Table 5.1, fit 2), though the reflection factor $R = \frac{\Omega}{2\pi}$ are relatively large (in this model, the cut-off energy of power law continuum is fixed at 240 keV, which is derived by Pounds et al. (2003)). If we allowed the line width to vary, the line is not narrow but requires a broadening of about 0.1 keV. We also applied the disk line model to the data. We fixed the line energy at 6.4

keV in the source rest frame, emissivity index at -2, and the inner and outer radius at $6r_g$ and $1000r_g$, respectively. This model provides a good fit to the data ($\chi^2_\nu = 0.894$ for 466 dof), and then the derived upper limit on the inclination angle is 34 degree and the *EW* becomes 68^{+38}_{-32} eV.

If we apply the continuum models above to the data, the power law X-ray spectral component extends down to the *EUVE* DS energy band, so that about 40 % of the DS flux comes from the power law component. The last row of Table 5.1 shows the photon flux ratio of the power law component to the DS counting rate in the 0.1 - 0.17 keV energy band.

Figure 5.3: The photon spectrum obtained by *EUVE* SW (filled circles) and DS (open circle). The dashed line indicates the best-fit blackbody spectrum ($kT = 15.8$ eV).

Figure 5.4: *ASCA* SIS X-ray spectrum. The model consists of a power law absorbed by the Galactic neutral matter and a warm absorber, and an Fe-K emission line. The upper panel shows the count spectrum (crosses) and the model folded through the detector response (histogram). The lower panel shows the residuals.

In order to examine the long term spectral variability, the data are grouped in the 5 individual days. The best-fit spectral parameters are summarized in the right half of Table 5.1. One of the most clear changes of the X-ray spectral features is the slope change corresponding to the flux change. The spectrum becomes steeper when the X-ray flux is higher, as has been known for typical Seyfert 1s (e.g. Chiang et al. 2000 for NGC 5548; Iwasawa et al. 1996 and Lee et al. 2000 for MCG–6-30-15; Done et al. 2000 for IC 4329A; Lamer et al. 2000 for NGC 5506; Lamer et al. 2003 for NGC 4051). Figure 5.5 shows the change of the photon index Γ against the 2 - 10 keV flux variation. The photon index Γ changed from 1.8 to 1.6 as the X-ray flux in the 2 - 10 keV band decreased from 6.7 to 4.6 $\times$ 10^{-11} ergs cm^{-2} s^{-1}. Since we found a positive correlation between the EUV and X-ray count rate in the previous section, the X-ray spectrum becomes softer when the EUV flux is higher. This relation is consistent with the idea that the

Table 5.1: X-ray spectral fits to the *ASCA* SIS + GIS data.

Parameters	Total Spectrum		Each Day Spectra				
	Fit1[a]	Fit2[b]	1st	2nd	3rd	4th	5th
F_X^c	$5.62^{+0.17}_{-0.15}$	$5.69^{+0.17}_{-0.17}$	$6.74^{+0.22}_{-0.10}$	$6.17^{+0.24}_{-0.20}$	$5.09^{+0.21}_{-0.18}$	$4.57^{+0.20}_{-0.17}$	$5.52^{+0.18}_{-0.17}$
Γ	$1.78^{+0.03}_{-0.02}$	$1.90^{+0.04}_{-0.03}$	$1.84^{+0.03}_{-0.03}$	$1.80^{+0.04}_{-0.04}$	$1.76^{+0.02}_{-0.04}$	$1.69^{+0.04}_{-0.04}$	$1.70^{+0.04}_{-0.03}$
R^d	—	$2.77^{+0.55}_{-0.53}$			—		
$E_{K\alpha}{}^e$ [keV]	$6.27^{+0.13}_{-0.13}$	$6.18^{+0.11}_{-0.10}$	$6.34^{+0.27}_{-0.27}$	$6.35^{+0.46}_{-0.41}$	$6.29^{+0.31}_{-0.29}$	$6.11^{+0.31}_{-0.29}$	$6.29^{+0.36}_{-0.30}$
$\sigma_{K\alpha}$ [keV]	0.43(fix)	$0.13^{+0.15}_{-0.13}$			0.43(fix)		
$F_{K\alpha}{}^f$	$2.09^{+0.40}_{-0.39}$	$0.37^{+0.21}_{-0.17}$	$2.42^{+0.91}_{-0.88}$	$1.61^{+0.98}_{-0.95}$	$2.15^{+0.84}_{-0.85}$	$2.06^{+0.79}_{-0.79}$	$1.77^{+0.86}_{-0.82}$
EW [eV]	363^{+82}_{-77}	55^{+34}_{-26}	364^{+145}_{-140}	259^{+173}_{-156}	413^{+183}_{-174}	415^{+183}_{-170}	306^{+164}_{-146}
E_{th1} [keV]	$0.68^{+0.02}_{-0.02}$	$0.67^{+0.02}_{-0.02}$			0.68(fix)		
τ_{th1}	$0.39^{+0.08}_{-0.08}$	$0.47^{+0.08}_{-0.08}$	$0.23^{+0.09}_{-0.09}$	$0.39^{+0.11}_{-0.11}$	$0.63^{+0.10}_{-0.15}$	$0.40^{+0.12}_{-0.19}$	$0.43^{+0.12}_{-0.14}$
E_{th2} [keV]	$0.80^{+0.03}_{-0.02}$	$0.81^{+0.02}_{-0.02}$			0.80(fix)		
τ_{th2}	$0.26^{+0.07}_{-0.09}$	$0.28^{+0.05}_{-0.08}$	$0.20^{+0.06}_{-0.06}$	$0.17^{+0.08}_{-0.07}$	$0.33^{+0.08}_{-0.07}$	$0.30^{+0.09}_{-0.09}$	$0.25^{+0.08}_{-0.07}$
E_{th3} [keV]	1.23(fix)	$1.24^{+0.07}_{-0.08}$					
τ_{th3}	< 0.04	$0.024^{+0.020}_{-0.020}$					
χ^2_ν/dof	0.966/469	0.893/465	0.897/377	0.824/328	0.884/310	0.696/277	0.723/344
fraction[g] [%]	39.2	51.8	35.6	40.5	40.0	36.9	36.9

Notes.—Line and edge energies are in the observed frame. Columns 2 – 3 show the parameters obtained from fitting the averaged spectrum of the entire observation. Columns 4 – 8 show the parameters obtained from fitting the spectrum of each observation day.

[a]Power law continuum fit

[b]Cut-off power law plus cold reflection model ("PEXRAV" in XSPEC). The cut-off energy is fixed at 240 keV.

[c]2-10 keV flux in unit of 10^{-11} ergs s^{-1} cm^{-2}

[d]Reflection factor of cold matter; $R = \frac{\Omega}{2\pi}$

[e]Line energy in the observed frame

[f]Line flux in unit of 10^{-4} photons s^{-1} cm^{-2}

[g]Fraction of the extrapolated X-ray continuum flux to DS flux in the 0.1-0.17 keV band

X-ray emission is produced by the inverse Compton scattering of soft (EUV) photons in hot electron clouds which become cooler as the soft photons increase (Chiang et al. 2000, Nandra et al. 1998).

Figure 5.5: Correlation between the 2 - 10 keV flux and the photon index Γ.

5.1.4 Discussion

Combined energy spectra

Figure 5.6 shows the photon spectra of *EUVE* SW, DS and *ASCA* SIS data averaged over the entire observation. In this plot, the intrinsic photon spectra are derived from the observed spectra, taking account of the absorption due to the Galactic neutral column density of 1.6×10^{20} cm^{-2}. The X-ray data points with error bars are derived via the "UFSPEC" plot option in XSPEC. In this plot, we exclude the absorption edge models in order to avoid the ambiguity of the model for the warm absorber. It is not an exact de-convolution of the observed data to the intrinsic spectra, but just to show how the data follow the model. The extrapolation of the X-ray power law component ($\Gamma = 1.78$) of the total spectrum is indicated by a dashed line. The high energy end of the SW spectrum (solid circles) coincides with the X-ray power law at 0.2 keV, and starts to rise up towards the DS data point (open square). The open-square and open-triangle correspond to the highest (1st day) DS flux and the lowest (4th day) DS flux, respectively. The excess of the EUV spectrum over the X-ray power law component suggests the existence of an EUV excess component on top of the X-ray power law component. The 0.1 - 10 keV continuum can be well reproduced by a power law ($\Gamma = 1.78$) plus a blackbody spectrum of $kT = 11^{+20}_{-5}$ eV, though it cannot be definitive because the spectral curvature towards the blackbody peak is not clearly seen in the SW spectral window yet. Though it is interesting to examine the time variability of the EUV spectrum, the statistics of the grating spectrometer SW data is too poor to obtain SW energy spectra for each day.

In the monitoring observations of NGC 5548 with *ROSAT* in 1992 and 1993, a soft flare was

found in a series of 2000 sec observations every other day. The flare spectrum was explained by a combination of a constant power law and a flaring soft excess component, whose spectrum can be presented by blackbody radiation with a temperature of $\sim$ 80 eV (Done et al. 1995). Nandra et al. (1993) also found a soft excess component which is represented by blackbody with a temperature of 60 eV in 1990 *ROSAT* observation when the 2-10 keV flux was factor $\sim$ 3 fainter than that in our observation. Unfortunately, since *ASCA* and *EUVE* have no sensitivity in the 0.2 - 0.5 keV energy band, where the 60 eV blackbody emission is most prominent, it is difficult to discuss the existence of this component. In Figure 5.6, the dotted curve represents the blackbody radiation reported by Nandra et al. (1993), where the normalization is multiplied by 3 in order to adjust it to the present flux state. The flux of this component is an order of magnitude less than the observed flux in 0.1-0.2 keV band, so the EUV spectrum that we observed is not of the *ROSAT* type of excess component but is much softer and becomes dominant below 0.2 keV.

As we mentioned above, the EUV spectrum is well represented by 11 eV blackbody emission, which leads us to the idea that this thermal emission originates from the surface of the inner part of the accretion disk. In this case, however, the bolometric luminosity of the blackbody becomes $\sim 3 \times 10^{45}$ ergs s^{-1}, which corresponds to 35 % of the Eddington luminosity for a central black hole mass of 6.8×10^7 $M_\odot$ (Wandel, Peterson & Malkan 1999). This value is too large compared with previous results of optical/UV observations (e.g., Koratkar & Blaes 1999). If we assume a disk luminosity $L_{\rm disk}$ 20 times larger than the 2 - 10 keV luminosity L_{2-10} (e.g., Padovani & Rafanelli 1988, Woo & Urry 2002), then $L_{\rm disk}$ is 7×10^{44} ergs s^{-1}. We repeated a spectral fit by fixing $L_{\rm disk}$ at this value and we obtained the best-fit value of kT is 12.7 eV. On the other hand, we also calculated a multicolor disk blackbody (MCD) spectrum according to the standard disk model (Shakura & Sunyaev 1973) with $L_{\rm disk} = 7 \times 10^{44}$ ergs s^{-1} and a radius of innermost accretion disk $R_{\rm in} = 3R_{\rm S}$ ($R_{\rm S} = \frac{2GM_{BH}}{c^2}$). This yields a temperature $kT_{\rm in}$ of 17 eV for a central mass of 6×10^7 $M_\odot$. Such a disk spectrum is shown in Figure 5.6 (dot-dashed curve), and it represents well the observed EUV spectrum. The EUV emission would come from the innermost and hottest part of the accretion disk .

Correlation of the EUV and X-ray variation on timescales of days

On timescales of days, the flux levels in EUV and X-rays show a linear correlation with an offset (see Figure 5.2). The first simple explanation of the offset is that the X-ray flux consists of a persistent component and another variable one, which is proportional to the EUV flux. However, as far as the X-ray continuum is concerned, it is reproduced by a simple power law, suggesting that two components are not necessary.

Before moving to the further discussion of this correlation with an offset, we introduce a correction of the contribution from the X-ray power law component to the *EUVE* DS data, which is dependent on the spectral X-ray slope (seen in Table 5.1 bottom row). A new plot of the 2 - 10 keV luminosity against the *EUVE* DS counting rate is given in Figure 5.7, in which

Figure 5.6: Combined spectra of *EUVE* DS, SW and *ASCA* SIS corrected for the Galactic absorption. SW (filled circles) and SIS (crosses) spectra are derived from averages over the entire observation, while an open square and an open triangle indicate the DS maximum flux (1st day) and minimum one (4th day), respectively. The dashed line represents the best-fit power law component and the dot-dashed line indicates the disk blackbody component with $kT = 17$ eV. The dotted line shows the 60 eV blackbody radiation previously reported by Nandra et al. (1993). This plot is used for visualization purposes only.

we subtracted the flux due to the power law component from the DS data. The slope becomes steeper, but still a clear offset is seen.

If we inspect the plot in Figure 5.2 carefully, the EUV flux at the maximum flux level on the first day (#1) is higher than we expect from the linear relation fit to the following four days (dashed line). It suggests that the correlation may not be a straight line but a convex curve, which goes through the data point #1 and may approach to the origin of the coordinate. If we assume that X-rays are produced by inverse Compton scattering, the X-ray intensity has to follow the change of the EUV photon flux. If the EUV radiation is explained by a blackbody spectrum, the *EUVE* DS band corresponds to the Wien side of the spectrum. As the accretion rate decreases, the accretion disk becomes cooler and the EUV flux dims. Such a change leads to not only a decreasing of normalization but also a shift of the spectrum towards the low energy side. In the low state, the flux included in the *EUVE* DS band is much smaller than the total soft photon flux and then the DS count rate decreases faster than the X-rays, which means a flatter slope with an X-ray offset in the correlation plot between *EUVE* DS versus X-rays.

To model the relationship between the EUV count rate and L_{2-10}, we assume that L_{2-10} is proportional to $L_{\rm disk}$ which is proportional to $T_{\rm in}^4$. By calculating the blackbody (or MCD) spectra at various temperature, we predict the flux (photons cm^{-2} s^{-1}) in the 0.1 - 0.17 keV DS energy band. In Figure 5.7, the dashed (applying a DBB) and the dot-dashed (applying a simple blackbody) curves indicate the calculated correlation based on the above considerations. The horizontal dotted lines show the ratio of the disk luminosity to the Eddington luminosity

for a central mass of $6 \times 10^7\ M_\odot$. Both curves reproduce well the variation trend of the data points. An important feature of this relation is that the last data point (#5) appears just on the model line after the flux minimum (#4) one day before. It means that there is no time lag of X-rays from EUV flux on time scales longer than a day. It does not conflict with the previous report (Chiang et al. 2000) of the time lag of X-rays from EUV flux on a time scale of 10 - 30 ksec, that is just one fourth of a day.

Figure 5.7: Correlation between the 2 - 10 keV X-ray luminosity and the DS counting rate corrected for the contribution of the X-ray power law component. The dashed line and dot-dashed line indicate the model relationships calculated as a function of the mass accretion rate of a disk blackbody (DBB) and a simple blackbody with a central mass of $6 \times 10^7\ M_\odot$, respectively. The horizontal dotted lines show the ratio of the disk luminosity to the Eddington luminosity.

5.1.5 Summary

Broadband spectra of NGC 5548 are obtained simultaneously from 0.1 through 10 keV. The X-ray spectrum is well reproduced by several components, a single power law with photon index $\Gamma \sim 1.8$, absorption due to warm gas, and an Fe-K emission line. The extrapolation of the X-ray power law continuum into the 0.1–0.17 keV EUV band reveals the existence of soft excess component. The MCD model with kT of 17 eV is well fitted to the soft excess component. This suggests that the EUV excess emission would come from an innermost hottest part of the accretion disk. On timescales of days, EUV and X-ray photons are well correlated, furthermore, X-ray spectra tend to be softer as the EUV photons increase. Such a trend is consistent with the scenario that the harder X-rays are produced via the thermal Comptonization of the EUV photons originating from the accretion disk.

5.2 NGC 4051

5.2.1 Introduction

NGC 4051 lies in a low luminosity end of the narrow-line Seyfert 1 galaxies. Its typical luminosity is about a few 10^{41} erg s^{-1}. It has also been well known that the source exhibits extreme X-ray variability and associated strong spectral variability on both long ($\sim$ year) and short ($\sim$ 1000 s) timescales (e.g. Papadakis et al. 2002; Lamer et al. 2003). In order to explain such an rapid intensity and spectral change, Kunieda et al. (1992) proposed the "blob" model, where the optically thick ($\sim 10^{24}$ cm^{-2}) blobs are moving around the central emission region and the flux and spectral variations result from a change of the blob number in the line of sight. This blob model successfully explained various flux and spectral state observed by *Ginga*, furthermore, this model predicted that the observed spectral change may not be an intrinsic behavior but may arise from the modification of the intrinsically constant spectrum by the change of a covering fraction of the blobs. Another interesting flux variation is that the source sometimes enters an extremely low activity state. The X-ray spectrum during this low state was measured simultaneously by *BeppoSAX* and *RXTE* in May 1998 (Guainazzi et al. 1998; Uttley et al. 1999) and found to have extremely flat ($\Gamma \sim 0.8$) shape. The recent *Chandra* observation was also catching the source in the low activity state ($\sim 8 \times 10^{40}$ erg s^{-1}), and revealed that the source showed the very hard ($\Gamma \sim 1$) power law continuum (Uttley et al. 2003).

Here, we present the results from *XMM-Newton* observations of NGC 4051 performed in 2001 and 2002. In the 2001 observation, source showed a rapid and large amplitude flux variability with a historical mean intensity, on the other hand, source entered a low flux state in 2002. Accompanied by such a state change, we found a drastic spectral change, especially in the hard X-ray continuum and low energy absorption/emission spectra.

5.2.2 Timing analyses

Figure 5.8 shows the 0.3–12 keV EPIC PN light curves in 200 s bins. Filled circles and open squares indicate the light curves obtained from a 2001 and 2002 observation, respectively. Different timing behavior between these observations is clearly seen. In the 2001 observation, source is in a high flux state and exhibits the rapid and large amplitude variability, on the other hand, in 2002 observation, source counts drop off and show relatively stable variation around $\sim$ 4 counts s^{-1}. Hereafter, we define 2001 and 2002 data as the high and low state, respectively. To quantify the feature of the variation, we calculate a fractional variability amplitude ($F_{\rm var}$) following Edelson et al. (2002). The results are shown in Figure 5.9 using 200 s binning of the light curves (left, high state; right, low state). Source shows a clear energy dependency of $F_{\rm var}$, but the dependency is quite different between high and low state. The $F_{\rm var}$ gradually decrease as energy increase in high state, while the prominent decrease of $F_{\rm var}$ is seen around 0.9 keV in the low state. Such a sharp drop of $F_{\rm var}$ was first found at $\sim$ 6 keV, where a prominent iron

line is appeared, in the Seyfert 1 galaxy MCG–6-30-15 (Fabian et al. 2002; Matsumoto et al. 2003; Inoue & Matsumoto 2003), and the NLS1 Mrk 766 (Pounds et al. 2003). As is described in the following section, $\sim$ 0.9 keV is coincide with the energy of Ne IX forbidden line, which is clearly seen in the low state RGS spectrum and has a large equivalent width ($\sim$ 14 eV, see Table 5.3). Although, the physical origin of this $F_{\rm var}$ drop has been under discussion and several models are proposed (e.g., a light bending effect, Miniutti et al. 2003; an absorption effect, Inoue & Matsumoto 2003), the reduced variability amplitude could be strongly connected with the existence of emission lines.

Figure 5.8: NGC 4051: 0.3–12.0 keV light curves of EPIC PN camera. Filled circles and open squares indicate the light curves in 2001 (high state) and 2002 (low state), respectively.

Figure 5.9: Plot of $F_{\rm var}$ against various energy bins. *top panel*, high state; *bottom panel*, low state.

5.2.3 Spectral analyses

3–12 keV spectra

Since we are interested in the spectral change accompanied with the flux variation, we first fitted the 3-5.5 keV spectra with a single power law modified by a Galactic absorption (1.31 $\times$ 10^{20} cm^{-2}, Elvis et al. 1989) in order to determine the shape of a primary continuum emission. The derived best-fit photon index Γ was 1.8 for the high state and 1.0 for the low state. Such an extreme flat slope was also found in 1998 (Uttley et al. 1999) and 2001 (Uttley et al. 2003), where NGC 4051 appeared to enter a low-flux state. Extrapolating these power law component to higher energy band, both data show a prominent line emission at $\sim$ 6.4 keV and edge-like feature above $\sim$ 7 keV, which are possibly attributed to an iron Kα fluorescent line and an absorption edge, respectively. These spectral features and the spectral variation trend

between the high and low state lead us to the idea that the observed spectra would consist of heavily absorbed ($N_{\rm H} \sim 10^{23}$ cm^{-2}) continuum emission and leaky direct one, namely, partial covering scenario, which is used to explain the sharp spectral drop found at 7-8 keV during the observation of typical narrow-line Seyfert 1 galaxy 1H 0707-495 (Boller et al. 2002) and IRAS 13224-3809 (Boller et al. 2003). The 3–12 keV spectra of NGC 4051 are well presented by this partial covering model. The resultant parameters are summarized in Table 5.2, and the observed spectra are shown in Figure 5.10. Interestingly, even in the low state, the intrinsic spectral slope is kept ~ 2, which is close to the average value (2.19± 0.10) of narrow-line Seyfert 1s (Leighly 1999).

Table 5.2: NGC 4051:Fit results of partial covering model.

Parameter	High state	Low state
$N_{\rm H}{}^a$	$1.46^{+0.13}_{-0.10}$	$1.84^{+0.13}_{-0.12}$
$C_{\rm f}{}^b$	$0.32^{+0.03}_{-0.04}$	$0.61^{+0.03}_{-0.04}$
Γ^c	2.19±0.04	1.99±0.07
$F_{2-10}{}^d$	$2.40^{+0.20}_{-0.19}$	$0.65^{+0.10}_{-0.09}$
$L_{2-10}{}^e$	$2.78^{+0.23}_{-0.22}$	$0.75^{+0.12}_{-0.10}$
$E_{\rm K}{}^f$	6.38±0.01	6.41±0.01
σ^g	$58.2^{+23.3}_{-25.3}$	$63.6^{+17.2}_{-17.4}$
$F_{\rm line}{}^h$	$2.46^{+0.34}_{-0.32}$	$1.94^{+0.30}_{-0.25}$
EW^i	94^{+22}_{-19}	198^{+68}_{-50}

[a]Column density of partial covering absorber in unit of 10^{23} cm^{-2}

[b]Covering fraction

[c]Photon index

[d]Absorption corrected 2-10 keV flux in unit of 10^{-11} ergs s^{-1} cm^{-2}

[e]Absorption corrected 2-10 keV luminosity in unit of 10^{41} ergs s^{-1}

[f]Line energy in unit of keV

[g]Line width in unit of eV

[h]Line flux in unit of 10^{-5} photons s^{-1} cm^{-2}

[i]Line equivalent width in unit of eV

RGS spectra

The extrapolation of this continuum model into low energy band reveals the existence of an excess component, which is dominant below ~ 2 keV. It was difficult to reproduce this component by simple continuum models such as a power law, a blackbody, and a multi-color disk blackbody. This may suggest contributions from emission and/or absorption features. There-

Figure 5.10: 3–12 keV spectra of NGC 4051 fitted with partial covering model. *left*, high state; *right*, low state

fore, we analyzed the RGS data focusing on discrete emission/absorption lines. The individual absorption and emission lines are modeled as negative and positive Gaussians. In the high state spectrum, we found broad absorption features around 0.7–1.0 keV. This may be attributed to the absorption edges. Hence, we added the absorption edge models in the fitting procedure. Figure 5.11 show the RGS spectra of the high (left) and low state (right), respectively. Also Figure 5.12 left panel shows a photon spectra of both state and right panel displays the enlarged spectra in the 18–23 Åband. It is obvious that a drastic spectral change has been occured from high to low flux state. In the high state, the spectrum is dominated by the absorption lines from He- and H-like C, N, O, and Ne ions, while in the low state, many emission lines from same ions are prominent and absorption lines are week or absent. In Table 5.3, the properties of strong absorption/emission lines are summarized. Figure 5.13 also shows the velocity shift of the individual ions. Filled circles indicate the absorption lines observed in the high state, while open squares and triangles show the emission lines seen in the high and low state, respectively. We found that all of the absorption lines are blueshifted with an average outflow velocity of -445±47 km s^{-1} relative to the systemic velocity, while emission lines tend to have a smaller or no outflow velocity (-100±125 for the high state and -32±121 for the low state). A similar trend has been found in several Seyfert 1 galaxies (e.g. Kaspi et al. 2002 for NGC 3783, Kaastra et al. 2002 for NGC 5548). Interestingly, although the overall spectrum is quite different between the high state and the low state, the OVII and NeIX forbidden lines, which are the most prominent emission lines in the spectra, have a constant flux over a period of 1.5 years (OVII, $1.90\pm0.27\times10^{-4}$ and $1.44\pm0.21\times10^{-4}$ photons s^{-1} cm^{-2} in the high and low state; NeIX, $6.52\pm1.98\times10^{-5}$ and $3.69\pm0.94\times10^{-5}$ photons s^{-1} cm^{-2} in the high and low state). These values are also consistent with the flux obtained from the *Chandra* observation performed in 2000 April 24-25 (Collinge et al. 2001). Therefore, the physical condition of the ionized gas surrounding the nucleus would have been kept constant on timescales of years, despite large variations in the

ionizing continuum.

Figure 5.11: RGS spectra of NGC 4051. *left*, high state; *right*, low state.

Figure 5.12: Photon spectra of NGC 4051. Black, high state; Red, low state. Right panel shows the enlarged spectra in the 18–23 Ärange.

Overall spectra

We re-analyzed the 0.3–12 keV overall spectra using informations from RGS analyses. The MCD model was introduced in order to parameterize the soft excess component, on the other hand, we applied a partial covering power law continuum with an Fe-K emission line for a hard band spectrum. This is a base continuum model. The low state spectrum is well represented by a base continuum model and three additional emission lines, which are consistent with OVII(f), OVIII Lyα, and NeIX(f). The derived line equivalent widths (17.5 eV for OVII(f); 5.3 eV for OVIII Lyα; 14.6 eV for NeIX(f)) are in good agreement with the RGS results (see Table 5.3). On the other hand, the EPICs spectra in the high state were approximately reproduced by a base continuum with two absorption edge models. The derived edge energies and optical

Table 5.3: Absorption and emission line properties.

Identification	Rest frame Wavelength [Å]	Velocity [km sec^{-1}]	Equivalent Width [eV]
	Absorption Lines in High State		
CVI(Lyα)	33.7360	-551^{+68}_{-67}	0.65±0.12
CVI(Lyβ)	28.4656	-297^{+89}_{-98}	0.64±0.12
CVI(Lyγ)	26.9898	-417^{+335}_{-307}	0.37±0.13
CV(1s^2-1s3p)	34.9728	-482^{+105}_{-106}	0.54±0.12
CV(1s^2-1s4p)	33.4262	-358^{+98}_{-122}	0.24±0.16
CV(1s^2-1s5p)	32.7542	-386^{+193}_{-190}	0.42±0.12
CV(1s^2-1s6p)	32.3998	-12^{+341}_{-420}	0.27±0.12
NVII(Lyα)	24.7810	-501^{+92}_{-95}	0.88±0.15
NVI(r)	28.7870	-381^{+80}_{-79}	0.81±0.11
NVI(1s^2-1s3p)	24.8980	-286^{+242}_{-341}	0.13±0.16
OVIII(Lyα)	18.9689	-703^{+117}_{-123}	1.19±0.27
OVIII(Lyβ)	16.0059	-433^{+195}_{-305}	1.11±0.35
OVII(r)	21.6020	-482^{+97}_{-95}	1.17±0.23
OVII(1s^2-1s3p)	18.6270	-397^{+133}_{-118}	1.28±0.27
OVII(1s^2-1s4p)	17.7680	-249^{+185}_{-163}	0.89±0.27
OVII(1s^2-1s5p)	17.3960	-546^{+228}_{-189}	0.30±0.30
OVI(1s^{2}2s-1s2p(^{1}P)2s)	22.05	-733^{+94}_{-94}	0.93±0.25
NeIX(r)	13.4471	-423^{+517}_{-511}	1.43±0.78
SXII(2p-3d)	36.398	-710^{+118}_{-109}	0.24±0.13
	Emission Lines in High State		
NeIX(i)	13.5517	-92^{+837}_{-1564}	1.24±0.86
NeIX(f)	13.6984	1^{+293}_{-241}	2.67±0.81
OVII(i)	21.8027	563^{+364}_{-431}	0.79±0.30
OVII(f)	22.1012	-143^{+119}_{-106}	2.77±0.39
NVI(i)	29.0829	-36^{+254}_{-381}	0.14±0.14
NVI(f)	29.5343	-164^{+124}_{-134}	0.25±0.17
	Emission Lines in Low State		
NeIX(i)	13.5517	1201^{+628}_{-628}	2.92±1.12
NeIX(f)	13.6984	115^{+371}_{-321}	14.1±3.6
OVII(i)	21.8027	-343^{+279}_{-308}	6.34±1.32
OVII(f)	22.1012	-210^{+129}_{-129}	14.0±2.0
NVI(f)	29.5343	-154^{+294}_{-255}	1.44±0.60
CVI(Lyα)	33.7360	101^{+187}_{-186}	1.24±0.53
NVII(Lyα)	24.7810	119^{+198}_{-176}	2.27±0.72
OVIII(Lyα)	18.9689	72^{+170}_{-205}	11.7±2.8

Negative signs in column 3 implies blueshit relative to the systemic velocity

Figure 5.13: Velocity shift of individual lines. Negative velocity implies blueshift relative to the systemic velocity

depths are $E_1 = 0.730^{+0.001}_{-0.003}$ keV, $E_2 = 0.899^{+0.005}_{-0.006}$ keV and $\tau_1 = 0.256^{+0.004}_{-0.005}$, $\tau_2 = 0.126^{+0.006}_{-0.004}$, respectively. Within a current status of EPIC calibrations for an energy determination ($\pm$ 10 eV), threshold energies correspond to those expected from OVII (0.739 keV) and OVIII (0.871 keV) ions. Uing a photoionization cross section for an ionized oxygen ($\sigma_{\rm OVII} = 2.4 \times 10^{-19}$ cm^2, $\sigma_{\rm OVIII} = 9.9 \times 10^{-20}$ cm^2) calculated by Verner et al. 1996 and assuming a solar abundance ($A_{\rm oxygen} = 4.9 \times 10^{-4}$), we can estimate equivalent hydrogen column densities of OVII and OVIII ions to be 2.2×10^{21}, and 2.6×10^{21} cm^{-2}, respectively. These values are consistent with the estimations from equivalent width of oxygen absorption lines. Figure 5.14 shows the spectra of each states, and derived best-fit parameters are summarized in Table 5.4.

Figure 5.14: NGC 4051: Overall spectra. *left*, high state; *right*, low state.

Table 5.4: NGC 4051:Best-fit parameters.

Parameter [unit]	High state	Low state
$N_{\rm H}^{\rm Gal}$ [10^{20} cm^{-2}]	$1.41^{+0.03}_{-0.02}$	$1.67^{+0.08}_{-0.28}$
$N_{\rm H}$ [10^{23} cm^{-2}]	$1.72^{+0.08}_{-0.05}$	$1.75^{+0.05}_{-0.05}$
$C_{\rm f}$	$0.306^{+0.004}_{-0.007}$	$0.652^{+0.003}_{-0.019}$
kT [keV]	$0.1652^{+0.0003}_{-0.0009}$	$0.1525^{+0.0005}_{-0.0013}$
Γ	$2.159^{+0.005}_{-0.002}$	$2.038^{+0.005}_{-0.024}$
$E_{\rm K}$ [keV]	6.392±0.015	6.414±0.012
σ [eV]	$66.2^{+21.1}_{-19.2}$	$61.3^{+15.8}_{-18.9}$
$F_{\rm line}$ [10^{-5} ph s^{-1} cm^{-2}]	$2.19^{+0.21}_{-0.25}$	$2.03^{+0.18}_{-0.20}$
EW [eV]	82^{+29}_{-22}	202^{+57}_{-54}
$L_{0.3-10}$ [10^{41} erg s^{-1}]	$8.01^{+0.05}_{-0.22}$	$1.76^{+0.01}_{-0.05}$
L_{2-10} [10^{41} erg s^{-1}]	$2.86^{+0.01}_{-0.03}$	$0.78^{+0.02}_{-0.03}$
χ^2_ν/dof	1.15/2069	1.22/1343

5.2.4 Discussion

We found a drastic spectral change accompanied by a flux change. In the high state, the X-ray spectrum is found to be characteristic of a Seyfert 1 galaxy, with a canonical photon index $\Gamma \sim 2$, a narrow Fe-K emission line, and an absorption feature by a photoionized "warm" gas. On the other hand, the spectrum in the low state exhibits more characteristics of a Seyfert 2 galaxy, where the absorption-dominate spectrum is replaced with an emission-dominate spectrum and the apparent spectral slope in a 2–10 keV band becomes very flat ($\Gamma \sim 1$). However, these spectral variation may be not an intrinsic change of the nucleus but may be explained by only a geometry change of an absorbing material in our line of sight. In the RGS analyses, we showed that emission line fluxies of OVII(f) and NeIX(f) are almost constant on timescales of $\sim$ year. We also found a constancy of flux in an Fe-K emission line (see Table 5.4). Since these lines are thought to be arise from matters irradiated by a central continuum emission, the constancy of the flux may indicate that a continuum emission and surrounding materials are not so different in both states. Moreover, we demonstrated that the 2–10 keV spectral variation can be well explained by a partial covering scenario, where an intrinsic power law slope is kept constant, but a covering fraction of an absorbing matter to a power law emission region is changed (see Table 5.4). From these results, we consider that a possible origin of the absorption might be due to an accretion tori. In fact, since NGC 4051 is classified as Seyfert 1.5, the nucleus might be viewed so that our line of sight penetrates the rim of the torus. If a scale height of the tori becomes large, a covering fraction in the line of sight will increase. Consequently, a continuum emission is attenuated and its spectral shape is changed by a partial covering effect. Moreover,

the increase of a covering fraction by cold tori may relatively reduce an absorbed fraction by a photoionized gas in our line of sight, while emission of the gas comes from an entire region out of the line of sight. Therefore, the emission lines are relatively enhanced in the low state spectrum.

In this present analyses, the column density of a partial covering absorber is estimated to be $\sim 10^{23}$ cm^{-2}. However, a presence of much heavily ($\geq 10^{24}$ cm^{-2}) absorved power law component cannot be ruled out, because it is hard to detect such component in the 0.3–12 keV *XMM-Newton* band pass. Therefore, the intrinsic luminosity of NGC 4051 might be much larger than that estimated here. We will be able to obtain much clearer view for the circumnuclear environment of NGC 4051 by an observation with *Astro-E2*.

5.3 PKS 0558-504

PKS 0558-504 is one of the rare radio-loud NLS1. In the *ASCA* observation of this source, Wang et al (2001) found a very short timescale flare, where the X-ray counts increased and decreased by a factor of 2 within 33 minutes. They also found that the spectrum during this flare is significantly harder than an average spectrum. Since PKS 0558-504 is one of the calibration target for the instruments onboard *XMM-Newton*, several observations are performed (see Table 4.2). O'Brien et al (2001) has already reported the spectral analyses results obtained from 1 March 2000 and 24 May 2000 observations. The spectrum was well reproduced by a power law and three blackbody components, which dominates mainly below ~ 2 keV. The timing analyses results has also been reported by Gliozzi et al. (2001). They found a clear tendency for the X-ray continuum to harden when the count rate increases, as was seen in the flare event during the *ASCA* observation. Such a spectral behavior is quite different from that of BLS1s, where the spectrum tends to softer when the source becomes brighter. Therefore, the detailed investigation of the broadband spectral change can be a important key factor to understand the physical conditions of NLS1s distinguished from BLS1s.

5.3.1 Timing analyses

Figure 5.15 shows the 0.3–12 keV light curves obtained from the EPIC cameras. Source shows relatively small amplitude variation on timescales of $\sim$ day. We could not find a clear flare event, which was found in *ASCA* observation. Throughout the whole observations, source varies by a factor of 2, although it should be paid a caution that each observations were performed by different observation modes and filters, hence comparing absolute values of count rate do not reflect the intrinsic flux correctly. Figure 5.16 displays the energy dependency of the fractional variability amplitude $F_{\rm var}$. The variability amplitude is less than 10 % in each observation, and no significant energy dependency is found.

Figure 5.15: 0.3–12.0 keV EPIC light curves of each observation.

Figure 5.16: Plot of fractional variability amplitude against observed energies.

5.3.2 Spectral analyses

First, we fitted the 2–12 keV spectra with a power law absorbed by a Galactic materials (4.39 $\times$ 10^{20} cm^{-2}, Dickey & Lockman 1990), and found that the hard X-ray continuum is well represented by a single power law with photon index $\Gamma \sim 2$. When the hard continuum is extrapolated into the low energy band, a large and broad excess component was found in all of the observations. In order to characterize this excess component, we applied a MCD model to the data. The MCD plus power law model gave a good description of the observed spectra. Figure 5.17 shows the observed spectra and the best-fit MCD plus power law models. The derived parameters are summarized in Table 5.5. The 0.3–10 keV luminosity of $\sim 10^{45}$ erg s^{-1} is the largest one in our sample objects.

Figure 5.17: 0.3–12 keV overall spectra fitted with a power law and MCD models.

By comparing the spectral properties of each observation, we found that the observed kT tends to be higher when the source becomes fainter. In order to investigate the spectral variability in detail, we further divided the whole observation into 9 segments, which are determined so that each segment has a similar duration. The vertical dotted lines in Figure 5.15 indicates the intervals of each segment. All spectra is well fitted by a power law and a MCD model.

Table 5.5: Result of the overall spectral fitting.

Obs. date	$N_{\rm H}$ [10^{20} cm^{-2}]	kT [keV]	Γ	$L_{0.3-10}$ [10^{45} erg s^{-1}]	L_{2-10} [10^{44} erg s^{-1}]	χ^2_ν/dof
2000 May 24	$3.3^{+0.4}_{-0.2}$	$0.173^{+0.002}_{-0.001}$	$2.293^{+0.014}_{-0.008}$	$1.46^{+0.49}_{-0.36}$	$4.37^{+0.26}_{-0.17}$	1.06/2515
Oct 10	$3.6^{+0.3}_{-0.3}$	$0.188^{+0.002}_{-0.001}$	$2.200^{+0.011}_{-0.010}$	$1.50^{+0.34}_{-0.45}$	$5.16^{+0.05}_{-0.06}$	1.06/2132
2001 Jun 26	$3.2^{+0.6}_{-0.3}$	$0.195^{+0.003}_{-0.002}$	$2.100^{+0.015}_{-0.012}$	$1.16^{+0.19}_{-0.39}$	$4.61^{+0.12}_{-0.13}$	1.04/1597

Figure 5.18: Relationship between temperature and 0.3–10 keV luminosities of soft excess component.

Figure 5.18 shows the relationship between kT and 0.3–10 keV luminosity of soft excess component. We can see a clear anti-correlation between them. This relation is quite opposite, if we consider that the soft excess component is a emission coming from a standard accretion disk. In the standard accretion disk model, a disk luminosity is proportional to kT^4 with a fixed inner radius. In fact, this standard picture is satisfied in some blackhole binaries and ultraluminous compact X-ray sources (Makishima et al. 2000; Kubota 2001). Therefore, the accretion mechanism in PKS 0558-504 might be intrinsically different from the standard accretion picture. We will discuss the kT-$L_{\rm X}$ relation of NLS1s in section 6.4.2 in detailed.

5.4 Mrk 335

Mrk 335 was first detected in X-rays by *UHURU* (Tananbaum et al. 1978). The spectrum of Mrk 335 exhibits a prominent big blue bump. Based on observations in the UV, optical and infrared bands, Edelson & Malkan (1986) and Sun & Malkan (1989) construct a spectrum, which can be fitted with a blackbody with a temperature of 25,600 K. Pounds et al. (1987) also suggest that the strong soft excess could be the high energy tail of the thermal emission coming from

an accretion disk.

5.4.1 Time variability

X-ray light curves obtained with the MOS and PN cameras are shown in Figure 5.19. The source exhibits a variability of up to a factor of 1.5 during the observation. Figure 5.20 indicates the fractional variability amplitude of each energy bins. All data points lie within a 10–20 % amplitude. The most variable energy segment is 1.5–2 keV one, and from this segment, the $F_{\rm var}$ gradually decrease toward low and high energy band.

Figure 5.19: 0.3–12.0 keV Light curves of Mrk 335. *left*; PN, *right*; MOS1 and MOS2.

Figure 5.20: Plot of Fractional variability amplitude versus energy for the EPIC light curves.

5.4.2 X-ray spectrum

2–10 keV spectra

First, we fitted the EPIC spectra above 2 keV with a power law absorbed by the Galactic $N_{\rm H}$ of 3.77×10^{20} cm^{-2}. We found clear positive residuals around 6 keV, which may be attributed to the fluorescent iron line. Therefore, we added a Gaussian profile to the data. This model provides a good description (χ^2_ν/d.o.f = 1.17/1063) of the observed spectra. The best-fit line center energy $E_{\rm line} = 6.59^{+0.14}_{-0.11}$ is slightly higher than the line energy expected from the cold or low ionized iron (< Fe XVII). Such an ionized Fe emission line has been also found in the spectra of typical NLS1 Ton S180 (Comastri et al. 1998), Ark 564 (Comastri et al. 2001) and Mrk 766 (Pounds et al. 2003). The line is not narrow but requires a broadening of $0.53^{+0.37}_{-0.15}$ keV. The derived photon index $\Gamma = 2.254^{+0.033}_{-0.022}$ is significantly steeper than the average value of the Seyfert 1 galaxies with broad Balmer lines ($\langle\Gamma\rangle = 1.81$ by Reynolds et al. 1997; $\langle\Gamma\rangle = 1.91$ by Nandra et al. 1997b), but is consistent with the NLS1's average value of $\langle\Gamma\rangle = 2.19 \pm 0.10$ obtained by Leighly et al. (1999). The 2–10 keV spectra and the best-fit models are shown in Figure 5.21.

Figure 5.21: The 2–10 keV EPIC spectra fitted by the absorbed power law plus Gaussian.

Overall spectra

The extrapolation of the power law continuum determined in the 2–10 keV band into the low energy band reveals the existence of a excess component. In order to characterize this excess component, we adopted a multicolor disk blackbody (MCD) model to the data. The overall continuum is well represented by the MCD plus power law model, though, we find a weak emission line like feature around 0.5 keV. The addition of a narrow (i.e. line width is fixed at 0) Gaussian line significantly improves the fit ($\Delta\chi^2 = 130$) for two additional parameters (line center energy and intensity). The derived line center energy is $0.565^{+0.011}_{-0.010}$ keV, which is in

good agreement with that of O VII resonance line (0.574 keV). RGS spectra also confirmed the existence of this emission line, whose center energy is determined at 0.574±0.001 keV. Figure 5.22 shows the overall spectra of Mrk 335 and we summarize the best-fit parameters in Table 5.6.

Figure 5.22: Overall spectra of Mrk 335. The data are fitted with multicolor disk blackbody, power law, and two Gaussian lines. (Black;PN, Red;MOS1, Green;MOS2, Blue;RGS1, Light-blue;RGS2)

Table 5.6: The results of the overall spectral fitting.

$N_{\rm H}$ [10^{20} cm^{-2}]	$3.37^{+0.18}_{-0.43}$
kT [keV]	$0.170^{+0.004}_{-0.007}$
Γ	$2.244^{+0.012}_{-0.027}$
$E_{\rm line}$ [keV]	$6.57^{+0.12}_{-0.26}$
$\sigma_{\rm line}$ [keV]	$0.46^{+0.19}_{-0.32}$
$F_{\rm line}$ [10^{-5} ph s^{-1} cm^{-2}]	$3.43^{+0.61}_{-1.53}$
EW [eV]	265^{+144}_{-85}
$L_{0.3-10}$ [10^{43} erg s^{-1}]	$6.60^{+0.02}_{-0.03}$
L_{2-10} [10^{43} erg s^{-1}]	$2.21^{+0.01}_{-0.02}$
χ^2_ν/dof	1.13/3257

5.5 I Zw 1

5.5.1 Time variability

Figure 5.23 shows the 0.3–12.0 keV light curves of EPIC cameras. A flare event is clearly present around 1×10^4 sec. The count rate increased from 6.66±0.04 counts s^{-1} (average over 0–9000 sec in PN data) to the peak count rate 9.89±0.22 counts s^{-1} on timescales of $\sim$ 1,000 sec.

In order to investigate the spectral change accompanied by the flux change, we compare the soft (0.3–2.0 keV) band light curve with the hard (2.0–12.0 keV) light curve. Figure 5.24 exhibits the correlation between the hardness ratio and total (0.3–12.0 keV) count rate. Filled squares indicate the hardness ratios for the flare phase, while filled circles are for the stable phase. We can see the clear positive correlation, which implies that spectrum becomes harder as source is brighter, during the flare. We confirmed this result by the examination of the $F_{\rm var}$-energy relation (see Figure 5.25). In general, spectra of BLS1s tend to be softer when X-ray flux is higher (e.g. Chiang et al. 2000 for NGC 5548; Iwasawa et al. 1996 and Lee et al. 2000 for MCG–6-30-15; Done et al. 2000 for IC 4329A; Lamer et al. 2000 for NGC 5506). The quite opposite behavior found in I Zw 1 may be associate with the flare event, which are more frequent in NLS1s. In fact, typical NLS1 Ark 564 and PKS 0558-504 exhibit the tendency that spectra become harder during the flare phase (Negoro et al. 2001; Wang et al. 2001).

Figure 5.23: 0.3–12.0 keV Light curves of I Zw 1. *left*; PN, *right*; MOS1 and MOS2.

5.5.2 Overall spectrum

The 2–12 keV spectrum is well reproduced by single power law absorbed by the Galactic $N_{\rm H}$ of 5.07×10^{20} cm^{-2}. The derived photon index Γ of 2.262 ± 0.024 is consistent with the average value of NLS1s. Some positive residuals can be seen at around 6.8 keV, which are consistent with emission from H- and He-like iron. The addition of narrow Gaussian slightly improves the fit with $\Delta\chi^2 = 18$ for two additional parameters. The extrapolation of the power law continuum into low energy band reveals the deficit of counts from the power law. Therefore, we introduce an additional absorption model. This model, however, does not provide a acceptable fit ($\chi^2_\nu = 1.40$). As mentioned previous section, we found the different time behavior between soft (< 2 keV) and hard (> 2 keV) energy band. Figure 5.26 shows the spectral ratio of the flare phase to the stable phase. We also plot various absorption models (dashed, dotted, and dash-dotted lines are corresponding to $N_{\rm H}$ of 1×10^{20}, 3×10^{20}, and 5×10^{20} cm^{-2}, respectively) in order to examine whether the change of absorption fraction can produce the spectral variation. The spectral

Figure 5.24: Plot of hardness ratio against the total count rate in the 0.3–12.0 keV band for the EPIC PN data. Filled squares are indicating the hardness ratio during the flare, while filled circles are that in the stable phase.

Figure 5.25: Plot of Fractional variability amplitude versus energy for the EPIC light curves.

Figure 5.26: Spectral ratio between the flare phase and stable phase. The spectrum during the flare is divided by that in the stable periods.

change cannot be well explained by the change of the column density of the cloud in the line of sight. This might imply that the spectrum consists of at least two different components, which are the hard power law and an additional soft component. A multicolor disk blackbody plus power law fit provides an adequate description for the observed spectrum. Table 5.7 summarizes the resultant fitting parameters, and Figure 5.27 shows the spectrum of I Zw 1.

Figure 5.27: Overall spectra of I Zw 1. (Black;PN, Red;MOS1, Green;MOS2, Blue;RGS1, Light-blue;RGS2)

Table 5.7: The results of the overall spectral fitting.

$N_{\rm H}$ [10^{20} cm^{-2}]	$9.48^{+0.46}_{-0.36}$
kT [keV]	$0.217^{+0.015}_{-0.010}$
Γ	$2.324^{+0.025}_{-0.025}$
$E_{\rm line}$ [keV]	$6.84^{+0.04}_{-0.05}$
$\sigma_{\rm line}$ [keV]	0 (fix)
$F_{\rm line}$ [10^{-5} ph s^{-1} cm^{-2}]	$0.67^{+0.22}_{-0.25}$
EW [eV]	90^{+51}_{-68}
$L_{0.3-10}$ [10^{43} erg s^{-1}]	$16.0^{+0.1}_{-0.1}$
L_{2-10} [10^{43} erg s^{-1}]	$7.23^{+0.06}_{-0.06}$
χ^2_ν/dof	1.24/954

5.6 Ton S180

XMM-Newton observations of Ton S180 were performed twice in 2000 and 2002 to study the timing and spectral properties in detail. Ton S180 is known to be one of the EUV/X-ray brightest and ultrasoft narrow-line Seyfert 1 galaxy. Intensive monitoring observation was performed with *ASCA*, *RXTE*, and *EUVE* during 1999 December 3–15 (Edelson et al. 2002). Source showed

the persistent, rapid variation on timescales of thousands second to days. Turner et al. (2002) discuss the spectral energy distribution (SED) using simultaneous *Chandra*, *ASCA*, and *EUVE* data with contemporaneous *FUSE*, *HST*, and ground-based optical and infrared data. The resulting SED shows that the most of the energy is emitted in the 10–100 eV regime, which may be the primary energy source, and soft X-ray emission of Ton S180 might be interpreted as the hard tail of the primary emission. Therefore, it is the most suitable target for studying the origin of the soft X-ray emission.

5.6.1 Time variability

Figure 5.28 and Figure 5.29 show the 0.3–12.0 keV light curves of EPIC cameras derived from the 2000 and 2002 observations, respectively. In the first observation, source exhibits a factor of ~ 2 variation on timescales of 5,000 s, while a factor of 1.5 variation is occurring in the second observation. The average count rate in the first observation is about 1.5 times larger than that in the second observation. In order to investigate an energy dependence of a variability amplitude, we calculate the $F_{\rm var}$ in various energy band. Figure 5.30 indicates the energy dependence of the $F_{\rm var}$ (left, 2000 observation; right, 2002 observation). In the first observation, all energy bins are varied about 13 % and we cannot find any trends between the energies and $F_{\rm var}$. On the other hand, $F_{\rm var}$ in the second observation tend to decrease toward the higher energy band. A value of $F_{\rm var}$ generally depends on a length of an observation because it can be related to the integrated power spectral density of a light curve. Therefore, we re-calculate the $F_{\rm var}$ in the 2000 observation by adjusting the time span to the length of the 2002 observation. However, the different energy-trend of $F_{\rm var}$ between the first and the second observations is still appeared. As mentioned in section ??, the shape of the $F_{\rm var}$-energy relation corresponds to the spectral ratio between high (above average flux) and low (below average flux) state. Therefore, the different energy dependence of $F_{\rm var}$ may also suggest the different spectral behavior against the flux change between two observations. Such a different spectral behavior related to the flux level was found in the *XMM-Newton* observations of typical narrow-line Seyfert 1 galaxy PKS 0558-504 (Gliozzi et al. 2001). In this observations, the spectrum becomes harder as the count rate increases, when the mean flux is above a certain threshold. On the other hand, when the flux is below a certain level, the spectral behavior is in the opposite sense. At intermediate count, no significant spectral variability is observed. Ton S180 might exhibit as same behavior as PKS 0558-504, and such behavior could be common as the class.

5.6.2 Spectral analyses

When we fitted the 2–12 keV spectra with a power law absorbed Galactic column density of 1.56 $\times$ 10^{20} cm^{-2}, we found the positive residuals around 6 keV in both observations. Figure 5.31 shows the ratio of observed data to the power law model. the vertical dotted line indicates the

Figure 5.28: 0.3–12.0 keV Light curves of Ton S180 obtained from the 2000 observation. *left*; PN, *right*; MOS2.

Figure 5.29: 0.3–12.0 keV Light curves of Ton S180 obtained from the 2002 observation. *left*; PN, *right*; MOS2.

Figure 5.30: Energy dependence of fractional variability amplitude $F_{\rm var}$. *left*; 2000 observation, *right*; 2002 observation.

expected energy for the fluorescent emission line from a cold iron (6.4 keV) in the observer's rest-frame. The observed emission line energy is clearly higher than that expected from the neutral Fe-K line and the line is significantly broadened. We summarize the resultant parameters of power law plus single Gaussian fit in Table 5.8. The derived parameters are almost same between 2000 and 2002 observations, except for the continuum flux (F_{2-10}). The source becomes 20 % fainter in 2002 compared with that in 2000.

Figure 5.31: Ton S180: 2–12 keV data to model ratio. The continuum spectra have been fitted by a power law absorbed by a Galactic material. *left*, 2000 observation; *right*, 2002 observation

Table 5.8: Ton S180: Results of the power law plus Gaussian line in the 2–12 keV band.

Obs.	Γ	F_{2-10} [10^{-12} ergs s^{-1} cm^{-2}]	$E_{\rm line}$ [keV]	σ [keV]	line flux [10^{-5} ph s^{-1} cm^{-2}]	EW [eV]	χ^2_ν/dof
2000	$2.36^{+0.08}_{-0.05}$	$4.95^{+0.09}_{-0.12}$	$6.83^{+0.29}_{-0.36}$	$0.71^{+0.92}_{-0.35}$	$1.5^{+2.4}_{-0.8}$	359^{+393}_{-297}	1.17/158
2002	$2.28^{+0.07}_{-0.06}$	$4.14^{+0.12}_{-0.13}$	$6.77^{+0.20}_{-0.21}$	$0.51^{+0.40}_{-0.20}$	$1.7^{+1.4}_{-0.7}$	474^{+350}_{-304}	1.07/180

The extrapolation of the hard continuum into low energy band reveals the existence of a strong excess component. First, we introduced the MCD model in order to parameterize the soft component. However, this model was unable to reproduce well the observed spectra. The observed soft excess component seems to be much broader and flatter than the prediction of the MCD model. Therefore, we introduce an additional blackbody emission to the data. This model gave a good fit to the data (χ^2_ν/dof = 1.08/1384 for the 2000 observation and 1.04/1136 for the 2002 observation). The derived temperature of MCD and blackbody are 119±2 eV and 202±7 eV for the 2000 observation, and 104±4 eV and 184±10 eV for the 2002 observation. Although the soft excess component is well reproduced by the MCD plus blackbody model, it has no physical basis. The MCD model is a superposition of many blackbody emission, whose temperature

T is considered to scale as $T(r) \propto r^{-0.75}$, where r is radial distance from the blackhole. The observed soft excess component requires not only $\sim$ 100 eV MCD emission but also higher $\sim$ 200 eV blackbody emission. This indicates that the spectrum of soft excess component is harder than 100 eV MCD but softer than 200 eV blackbody spectrum. Such situation may be explained if the radial dependency of the disk temperature is slightly different from the MCD picture. Therefore, we applied a p-free disk model instead of the MCD plus blackbody model. Figure 5.32 shows the observed spectra and the fitted models, which consist of p-free disk model, power law, and broad Gaussian (left, 2000 observation; right, 2002 observation). The derived parameters are summarized in Table 5.9. The p-free disk model provides a good description for the soft excess component. The obtained p value of $\sim$ 0.5 is significantly smaller than that expected from the standard MCD model (0.75). This indicates that a radiation from inner part of the accretion disk is decreased compared with the case for the standard accretion disk. The accretion disk structure of Ton S180 might be intrinsically different from the standard accretion disk system.

Figure 5.32: Ton S180: Overall spectral fit. The continuum spectra have been fitted by a power law absorbed by a Galactic material and p-free disk model. *left*, 2000 observation; *right*, 2002 observation

5.7 Mrk 359

Mrk 359 is known to be the first discovered narrow-line Seyfert 1 galaxy (Osterbrock & Dahari 1983). Veilleux et al. (1991) found that the line width (FWHM) of some forbidden lines and permitted lines are about 135 km s^{-1} and 800 km s^{-1}, respectively. Mrk 359 has little previous X-ray data. The first detection was made during the *Einstein* slew survey (Elvis et al. 1992). Boller et al. (1996) found that its spectral index Γ is 2.4 in the *ROSAT* bandpass. Therefore, the *XMM-Newton* observation of Mrk 359 can be the first case to study the broad band spectra and timing properties.

Table 5.9: Ton S180: Fitting results of continuum parameters.

Parameters [unit]	2000	2002
$N_{\rm H}$ [10^{20} cm^{-2}]	1.56 (fix)	1.56 (fix)
kT [keV]	$0.189^{+0.009}_{-0.007}$	$0.183^{+0.013}_{-0.009}$
p	0.44 ± 0.02	$0.46^{+0.01}_{-0.02}$
Γ	$2.452^{+0.025}_{-0.028}$	2.369 ± 0.038
$L_{0.3-10}$ [10^{44} erg s^{-1}]	$2.15^{+0.01}_{-0.02}$	$1.60^{+0.01}_{-0.02}$
L_{2-10} [10^{44} erg s^{-1}]	$0.425^{+0.004}_{-0.005}$	$0.359^{+0.004}_{-0.005}$
χ^2_ν/dof	1.08/1390	1.09/1144

5.7.1 Timing analysis

Figure 5.33 shows the 0.3–12.0 keV light curves of EPIC detectors. No large amplitude variability is detected during the 7 ksec observation, although the source intensity is not constant. Due to the relatively stable variation, we cannot obtain the meaningful $F_{\rm var}$ in some energy ranges (see Figure 5.34). In the 1992 *ROSAT* observation, however, Mrk 359 varied by a factor of 1.5 within $\sim$ 40,000 sec. This would implies that the power spectral density (PSD) of Mrk 359 has more power in the longer timescales (i.e. lower frequencies) than in the shorter ones.

Figure 5.33: 0.3–12.0 keV Light curves of Mrk 359. *left*; PN, *right*; MOS1 and MOS2.

5.7.2 Overall spectral analysis

The EPIC spectra above 2 keV are well reproduced ($\chi^2_\nu = 0.94$) by a power law absorbed by the Galactic $N_{\rm H}$ of 4.79×10^{20} cm^{-2}. However, prominent emission line feature is appeared around 6.4 keV. When we added a Gaussian model, the derived line center energy 6.43±0.04 is in good agreement with that of cold or low ionization FeK fluorescence line. The line is not resolved (σ

Figure 5.34: Plot of Fractional variability amplitude versus energy for the EPIC light curves.

< 120 eV) and has an equivalent width *EW* of 190 eV. The slope of the underling continuum is 1.79±0.06, which is slightly flatter than the standard value of NLS1s.

Extrapolating the best-fit power law continuum into the 0.3–2.0 keV band clearly reveals a broad soft excess component. We introduce the MCD model to parameterize the 0.3–12.0 keV broad band spectrum. The overall spectra is well represented by the power law, MCD, and Gaussian model ($\chi^2_\nu = 0.99$ for 636 degrees of freedom). This model also well reproduces the RGS spectra, although we found some emission line features in the data-model residuals. The most prominent features are seen in the 18.0–24.0 wavelength band (observed frame). Figure 5.35 shows the data residuals from best-fit continuum model. These features are consistent with O VIII Lyα and O VII triplet. We introduce the additional narrow Gaussian component into the data. The derived line center energy of 0.57±0.02 keV (source rest frame) is in good agreement with that of the O VII resonance (0.574 keV) or intercombination (0.569 keV; e.g. Porquet & Dubau 2000) line and its equivalent width is estimated to be 7±4 eV. The best-fit parameters are summarized in Table 5.10 and the overall spectra with best-fit model are shown in Figure 5.36.

5.8 NAB 0205+024

In 1996, NAB 0205+024 was observed by *ASCA* with a total elapsed time of 119 ksec. The source showed the persistent variability and a factor of 2 variation was present on a timescale of 15 ksec (Fiore et al. 1998). Its X-ray spectrum tends to be more soft in lower energy band as other NLS1s. The slope of the 0.1–2 keV spectrum derived from the *ROSAT* position sensitive proportional counter exceed ~ 3 (Fiore et al. 1994).

Figure 5.35: RGS spectra of Mrk 359.

Figure 5.36: 0.3–12.0 keV overall spectra of Mrk 359. (Black;PN, Red;MOS1, Green;MOS2, Blue;RGS1, Light-blue;RGS2)

Table 5.10: The results of the overall spectral fitting.

$N_{\rm H}$ [10^{20} cm^{-2}]	$4.88^{+0.41}_{-0.13}$
kT [keV]	$0.181^{+0.004}_{-0.002}$
Γ	$1.871^{+0.012}_{-0.019}$
$E_{\rm line}$ [keV]	$6.44^{+0.03}_{-0.06}$
$\sigma_{\rm line}$ [keV]	< 0.12
$F_{\rm line}$ [10^{-5} ph s^{-1} cm^{-2}]	$1.08^{+0.61}_{-0.28}$
EW [eV]	181^{+103}_{-48}
$L_{0.3-10}$ [10^{42} erg s^{-1}]	$8.14^{+0.83}_{-2.50}$
L_{2-10} [10^{42} erg s^{-1}]	$3.91^{+0.22}_{-0.43}$
χ^2_ν/dof	1.04/753

5.8.1 Timing analyses

Figure 5.37 shows the light curves of EPIC cameras. Since *XMM-Newton* observation of NAB 0205+024 was heavily affected by background flares (see section 3.3.4), several large gaps are appeared in the light curves. Figure 5.38 also displays the relationship between the $F_{\rm var}$ and energies. We found that the variability amplitude tend to be larger in higher energy band. This result suggests that the spectrum becomes harder as source brighter. Similar trend is seen in the observation of I Zw 1.

Figure 5.37: 0.3–12.0 keV Light curves of NAB 0205+024. *left*; PN, *right*; MOS2.

Figure 5.38: Plot of Fractional variability amplitude versus energy for the EPIC light curves.

5.8.2 X-ray spectral analyses

The 2.0–12.0 keV X-ray spectra of EPIC cameras are well reproduced by a power law absorbed by a Galactic column density of 2.99×10^{20} cm^{-2}. No significant emission features are seen in the spectra. The photon index Γ of 2.20±0.06 is standard value of NLS1s and is consistent with

the previous *ASCA* observation (Fiore et al. 1998). The extrapolation of power law continuum into low energy band reveals an existence of soft excess component. To characterize the low energy spectra, MCD model is examined. This model gave an acceptable fit to the data (χ^2_ν = 1.14 for 659 degrees of freedom), but we found some positive residuals around 0.5 keV, which is close to the O VII triplet in the observer's rest frame. Therefore, we checked the RGS spectra in order to investigate the presence of emission and/or absorption features. The RGS spectra were well fitted with MCD plus power law model ($\chi^2_\nu = 1.07$ for 259 d.o.f). We found very weak positive residuals at 0.492 keV which corresponds to O VII intercombination lines (observed frame). Due to the low statistics, we cannot determine a line profile in detail. if we added a narrow Gaussian with fixing the line energy at 0.492 keV, we only derived an upper limit of the line equivalent width 3 eV. The RGS-EPIC combined spectral fit also suggests that the upper limit of line equivalent width is 7 eV. Finally, we summarize the best-fit parameters derived from the MCD plus power law fit in Table 5.11. Figure 5.39 indicates the observed spectra and best-fit model.

Figure 5.39: Overall spectra of NAB 0205+024.

Table 5.11: Overall spectral fitting results.

$N_{\rm H}$ [10^{20} cm^{-2}]	$4.38^{+0.56}_{-0.51}$
kT [keV]	$0.157^{+0.004}_{-0.004}$
Γ	$2.326^{+0.019}_{-0.036}$
$L_{0.3-10}$ [10^{44} erg s^{-1}]	$3.87^{+0.08}_{-0.07}$
L_{2-10} [10^{44} erg s^{-1}]	$0.95^{+0.02}_{-0.02}$
χ^2_ν/dof	1.07/919

5.9 1H 0707-495

1H 0707-495 is known to be one of the most variable NLS1 (Turner et al. 1999; Leighly et al. 1999a). The spectrum is very steep and shows a strong soft excess component (Vaughan et al. 1999; Leighly et al. 1999a). 1H 0707-495 is the first object that the sharp spectral drop at $\sim$ 7 keV is detected with *XMM-Newton* (Boller et al. 2002). Boller et al. (2002) applied various models to explain the 7 keV feature, and they demonstrated that the observed spectrum can be well fitted by a partial-covering model or an ionized reflection model (Ross, Fabian, & Young 1999), although these models require an iron overabundance ($\sim$ 35). Here, we try to reproduce the broad band spectrum, especially with focusing on soft excess component.

5.9.1 Timing analyses

Figure 5.40 shows the 0.3-12.0 keV light curves of EPIC detectors. The source exhibits a large amplitude (factor of $\sim$ 6) and rapid ($\sim$ 1000 s) variability. In order to search for spectral variabilities, we calculate the $F_{\rm var}$ in various energy bands with a time bin size of 2,000 s to have enough counts. In spite of the large flux change, $F_{\rm var}$ in Figure 5.41 seems to be constant over the *XMM-Newton* bandpass. As pointed out in the results of Ton S180, the spectral behavior could depend on the observed flux level. In fact, in the recent *XMM-Newton* observation, 1H 0707-495 exhibits a strong spectral variability (L. Gallo 2003, private communication).

Figure 5.40: 0.3–12.0 keV Light curves of 1H 0707-495. *left*; PN, *right*; MOS1 and MOS2.

5.9.2 Spectral analyses

2–12 keV spectrum

As is suggested by Boller et al. (2002), the large amount of count deficits are clearly seen above 7 keV. When we fitted the 2–12 keV EPIC spectra with a power law absorbed by Galactic column and an edge model, we obtained the edge energy of $7.07^{+0.10}_{-0.08}$ keV, the optical depth

Figure 5.41: Plot of Fractional variability amplitude versus energy for the EPIC light curves. $F_{\rm var}$ is calculated with the time bin size of 2000 s

of $2.33^{+0.77}_{-0.52}$ and the photon index of 1.13±0.09. This extreme flat power law continuum and the edge-like feature around 7 keV lead us to the idea that the hard X-ray continuum may be represented by the partial covering model. Figure 5.42 shows the 2–12 keV spectra fitted by the partial covering model. The 90 % of the primary continuum emission would be covered by the gas with a column density of 6×10^{22} cm^{-2}. The data requires the iron abundance of 11 times larger than the solar value.

Figure 5.42: 2–12 keV EPIC spectra. The data have been fitted by a partial covering model. Blue and light blue line indicate the absorbed power law component.

Overall spectrum

The extrapolation of the hard continuum into low energy band reveals the large amount of excess emission below 2 keV. In order to parameterize this excess component, we introduced the MCD model. This model, however, unable to reproduce the overall spectrum well due to the presence of

the absorption feature around 1 keV. Such feature was also found in the *ASCA* spectra. Leighly et al. (1997) interpreted this feature as the absorption edge of the relativistically outflowing O VII/O VII ions, on the other hand, Nicastro, Fiore, & Matt (1999) discussed the possibility of the resonance absorption by L-shell iron. Hence, we added the absorption model calculated by the XSTAR photoionization code. This model has four independent parameters, which are a column density, an ionization parameter, a redshift, and an iron abundance. Figure 5.43 shows the overall spectra and the best-fit model and Table 5.12 indicates the derived continuum parameters. The 1 keV absorption feature is well represented by the gas with the outflow velocity of $0.09^{+0.04}_{-0.01}c$, the column density of 1×10^{21} cm^{-2}, the ionization parameter $\log \xi$ of -0.09 and the iron abundance of 19.

Figure 5.43: Overall spectra of 1H 0707-495

Table 5.12: Overall spectral fitting results.

$N_{\rm H}$ [10^{20} cm^{-2}]	$4.65^{+0.85}_{-0.83}$
kT [keV]	$0.143^{+0.001}_{-0.002}$
Γ	$2.763^{+0.088}_{-0.233}$
$N_{\rm pcf}$ [a] [10^{22} cm^{-2}]	$5.9^{+1.8}_{-1.6}$
$A_{\rm Fe}$ [b]	$11.2^{+2.7}_{-1.0}$
$L_{0.3-10}$ [10^{42} erg s^{-1}]	$8.48^{+1.97}_{-6.28}$
L_{2-10} [10^{42} erg s^{-1}]	$1.61^{+0.10}_{-0.81}$
χ^2_ν/dof	1.23/664

[a] The column density of partial covering absorber.

[b] Iron abundance relative to solar.

5.10 RE 1034+396

RE 1034+396 is know to be one of the ultrasoft narrow-line Seyfert 1 galaxy. Furthermore, The *ASCA* observation of this target was a breakthrough in the understanding of NLS1s (Pounds, Done, & Osborne 1996). The *ASCA* spectrum revealed a very strong soft excess component dominating the spectrum below 1–2 keV, and a very steep hard X-ray power law with photon index ~ 2.6. This spectrum is very different from that of typical Seyfert 1 galaxies with broad Balmer lines, which tend to have a flatter power law with photon index 1.7–1.9, and the soft excess is generally weak or absent in the *ASCA* bandpass. Pounds et al. (1996) suggests that NLS1s and BLS1s are the supermassive black hole analogs of Galactic black hole candidates (GBHC) in the soft and hard state, respectively. Soft state GBHC are thought to be accreting at a larger fraction of the Eddington limit than in the hard state. The accretion rate can be one of the key parameter to understand the properties of NLS1s.

5.10.1 Timing analyses

The light curves of EPIC cameras are shown in Figure 5.44. The source intensity varied by a factor of 1.4 on a timescales of $\sim$ 2,000 sec. We investigate the spectral change by calculating the $F_{\rm var}$ in various energy bands. As is seen in I Zw 1 and NAB 0205+024, $F_{\rm var}$ tends to be larger in higer energy band (see Figure 5.45).

Figure 5.44: 0.3–12.0 keV Light curves of RE 1034+396. *left*; PN, *right*; MOS1 and MOS2.

5.10.2 Spectral analyses

The 2–10 keV X-ray spectrum is well reproduced by a single power law with photon index Γ of 2.41±0.14, which is consistent with a previous value obtained from the *ASCA* observation. Extrapolating the hard power law continuum into 0.3–2 keV band reveals a large amount of excess component, which has about an order of magnitude higher counts than that of the hard

Figure 5.45: Plot of Fractional variability amplitude versus energy for the EPIC light curves.

power law component in the 0.3–0.4 keV range. In order to parameterize the soft excess, we added multicolor disk blackbody. In this fitting procedure, we fixed the column density of neutral absorption at the Galactic value ($N_{\rm H} = 1.43\times10^{20}$ cm^{-2}). Although the MCD plus power law model adequately represents the observed spectrum ($\chi^2_\nu = 1.16$ for 747 d.o.f), the derived photon index becomes slightly larger (~ 2.9) and there are some positive residuals above ~ 4 keV. If we introduced a p-free disk blackbody model instead of the MCD model, then the photon index of hard power law becomes 2.51 and the residuals above 4 keV is less than that appeared in the MCD plus power law fit. In Table 5.13, we summarize the fitting results of both MCD plus power law and p-free disk and power law models. The observed spectra of each detectors and the applied models are shown in Figure ??.

Figure 5.46: Overall spectra of RE 1034+396. *left*; MCD + power law model, *right*; p-free disk + power law model. (Black;PN, Red;MOS1, Green;MOS2, Blue;RGS1, Light-blue;RGS2)

Table 5.13: Overall spectral fitting results.

Parameters [unit]	MCD + power law	p-free disk + power law
$N_{\rm H}$ [10^{20} cm^{-2}]	1.43 (fix)	1.43 (fix)
kT [keV]	$0.120^{+0.001}_{-0.001}$	$0.168^{+0.004}_{-0.004}$
p	–	0.39±0.01
Γ	$2.926^{+0.088}_{-0.033}$	$2.511^{+0.079}_{-0.090}$
$L_{0.3-10}$ [10^{43} erg s^{-1}]	$3.83^{+0.07}_{-0.08}$	$3.98^{+0.03}_{-0.02}$
L_{2-10} [10^{43} erg s^{-1}]	$0.27^{+0.01}_{-0.01}$	$0.32^{+0.01}_{-0.02}$
χ^2_ν/dof	1.16/747	1.03/746

5.11 PG 1211+143

The quasar PG 1211+143 is a classic example of an AGN with a particularly prominent UV/soft X-ray excess (Bechtold et al. 1987; Elvis et al. 1991; Comastri et al. 1992; Saxton et al. 1993). The observation of PG 1211+143 was performed with *ASCA* in 1993. Yaqoob et al. (1994) characterized the spectrum by sum of a power law with a photon index Γ of 2 and blackbody with a temperature of 125 eV. They also found a short term flux variability of up to a factor of 2 on a timescales of 2×10^4 s in both the soft and hard energy bands.

5.11.1 Timing analyses

The 0.3-12.0 keV EPIC light curves are shown in Figure 5.47. The source shows a relatively stable variability except for the period from 2×10^4 s to 3.5×10^4. During this variable period, source intensity rises up by a factor of ~ 1.5. When we searched for the spectral variability by calculating the hardness ratio between 0.3–2.0 keV and 2.0–12.0 keV band, we found that the spectrum get slightly harder during the variable period. A same result was obtained from the analysis of $F_{\rm var}$, where the larger amplitude variation is occurring in higher energy band (see Figure 5.48).

5.11.2 Spectral analyses

First, we fitted the 2-12 keV EPIC spectra with a single power law absorbed by a Galactic column of 2.83×10^{20} cm^{-2}. This model was poorly fitted to the data due to the significant counts deficits above 7 keV. The addition of the absorption edge model significantly improved the fit ($\Delta\chi^2 = 232$ for two additional parameters). The derived edge energy of 7.27±0.08 keV is slightly higher than that expected from the absorption by the neutral iron. The optical depth of the edge is 0.68±0.08, which implies a equivalent hydrogen column density of $\sim 10^{23}$ cm^{-2}. If such a absorber subtends a large fraction of the continuum emission region, one can expect that

Figure 5.47: 0.3–12.0 keV Light curves of PG 1211+143. *left*; PN, *right*; MOS1 and MOS2.

Figure 5.48: Plot of Fractional variability amplitude versus energy for the EPIC light curves.

an observed spectrum should be heavily affected by this absorber at low energy band. However, there is no evidence for such a absorption signatures in our spectra. Therefore, we applied the partial covering model to the data. The observed spectrum is well reproduced by an about half of total power law continuum absorbed by a material with column density of $\sim 2 \times 10^{22}$ cm^{-2} ($\chi^2_\nu = 1.02$ for 804 degrees of freedom), although 30 $\times$ larger iron abundance is required in the model.

When this hard component was extrapolated into the low energy band, there appeared a large amount of excess emission on top of the power law continuum. Hence, we added the MCD model in order to parameterize the soft excess component. This model, however, cannot reproduce well the observed spectra due to the broad absorption-like features around 1.0 keV and emission-like features around 0.5–0.6 keV. Figure 5.49 shows the ratio of the RGS data to the MCD plus power law model. Expected energies from the OVII/OVIII emission lines and absorption edges are also labeled in the Figure 5.49. The observed energies of emission features are in good agreement with that of OVII triplet and OVIII Lyα, while the absorption features are significantly higher than the absorption edge energy of OVII and OVIII. To characterize these features, We added the two Gaussian and two edge models, and obtained an acceptable fit. In this fitting procedure, we fixed the line energies at 0.538 keV and 0.605 keV, which are obtained from the RGS data, for EPIC cameras and the line width at zero for all instruments. Figure 5.50 displays the 0.3–12 keV observed spectra and best-fit model. The obtained parameters are summarized in Table 5.14. The derived edge energies are about 10 % higher than that of OVII/OVIII photoelectric absorption edges (0.741 keV, OVII; 0.871 keV, OVIII). If we assume that the absorption features are imprinted by the ionized oxygen in an approaching matter, then its outflow velocity becomes $\sim 0.1c$. Alternatively, the 1 keV features may be interpreted as a resonance absorption of L-shell iron. In fact, Nicastro, Fiore, & Matt (1999) presented the photoionization models accounting for both photoelectric and resonant absorption, and they found that the strong and complex Fe L absorption lines are appeared around 1 keV when the ionizing continuum has a steep spectrum. Therefore, the absorption features appeared in low energy band can also be one of the key factor to distinguish NLS1s from BLS1s.

5.12 PG 1244+026

5.12.1 Timing analyses

PG 1244+026 exhibits a factor of ~ 2 variation during the *XMM-Newton* observation. Figure 5.51 shows the 0.3–12.0 keV light curves of EPIC cameras. The $F_{\rm var}$ is gradually increase toward the high energy band (see Figure 5.52). We only derived upper limit on the 4–12 keV $F_{\rm var}$ of 38 %.

Figure 5.49: Ratio of RGS spectra to MCD plus power law model. Expected energies of OVII/OVIII emission lines and absorption edges are labeled.

Figure 5.50: 0.3-12 keV spectra of PG 1211+143. (Black;PN, Red;MOS1, Green;MOS2, Blue;RGS1, Light-blue;RGS2)

Table 5.14: PG 1211+143: Overall spectral fitting results.

$N_{\rm H}$ [10^{20} cm^{-2}]	$4.21^{+0.12}_{-0.18}$
kT [keV]	$0.162^{+0.002}_{-0.001}$
Γ	$2.136^{+0.032}_{-0.020}$
$N_{\rm pcf}{}^{a}$ [10^{22} cm^{-2}]	$2.13^{+0.24}_{-0.32}$
$f_{\rm pcf}{}^{b}$	0.46 ± 0.03
$A_{\rm Fe}{}^{c}$	$34.0^{+6.9}_{-4.5}$
$E_{\rm edge1}$ [keV]	$0.983^{+0.005}_{-0.006}$
τ_1	$0.524^{+0.030}_{-0.020}$
$E_{\rm edge2}$ [keV]	$0.806^{+0.002}_{-0.007}$
τ_2	$0.386^{+0.028}_{-0.014}$
$EW1^{d}$ [eV]	$7.9^{+3.0}_{-5.5}$
$EW2^{e}$ [eV]	18^{+6}_{-8}
$L_{0.3-10}$ [10^{44} erg s^{-1}]	$1.19^{+0.50}_{-0.47}$
L_{2-10} [10^{44} erg s^{-1}]	$0.44^{+0.13}_{-0.14}$
χ^2_ν/dof	1.16/1807

[a]Column density of the partial covering absorber.

[b]Covering fraction.

[c]Iron abundance.

[d]Equivalent width of OVIII Lyα.

[e]Equivalent width of OVII triplet.

Figure 5.51: 0.3–12.0 keV Light curves of PG 1244+026. *left*; PN, *right*; MOS1 and MOS2.

Figure 5.52: Plot of Fractional variability amplitude versus energy for the EPIC light curves.

5.12.2 Spectral analyses

First, we fitted the 2.0–12.0 keV spectra with a single power law absorbed by the Galactic materials ($N_{\rm H}$ = 1.93×10^{20} cm^{-2}). We obtained acceptable fit (χ^2_ν = 1.31 for 177 degrees of freedom) with power law photon index Γ of $2.49^{+0.08}_{-0.09}$. When the hard power law continuum is extrapolated into the soft energy band, a large amount of excess counts are appeared. To characterize the soft excess component, the observed spectra were fitted by the MCD plus power law model without fixing the neutral absorption column density. The data were well reproduced by this model. The derived best-fit parameters are summarized in Table 5.15 and the observed spectra are shown in Figure 5.53 together with the best-fit model.

Figure 5.53: 0.3–12.0 keV overall spectra of PG 1244+026. (Black;PN, Red;MOS1, Green;MOS2, Blue;RGS1, Light-blue;RGS2)

Table 5.15: The results of the overall spectral fitting.

$N_{\rm H}$ [10^{20} cm^{-2}]	$2.47^{+0.30}_{-0.66}$
kT [keV]	$0.205^{+0.009}_{-0.007}$
Γ	$2.410^{+0.030}_{-0.061}$
$L_{0.3-10}$ [10^{43} erg s^{-1}]	$5.62^{+0.11}_{-0.16}$
L_{2-10} [10^{43} erg s^{-1}]	$1.11^{+0.04}_{-0.05}$
χ^2_ν/dof	1.04/846

5.13 IRAS 13224-3809

IRAS 13224-3809 is one of the most extreme NLS1. The source showed a factor of about 60 flux variation within just 2 d during the 30 day ROSAT monitoring observation (Boller et al. 1997). A giant soft excess and unusual absorption feature around ∼ 1 keV have been found in

the spectrum (Otani, Kii, & Miya 1996; Leighly et al. 1997; Dewangan et al. 2002; Boller et al. 2003). Furthermore, a sharp spectral cut-off at ~ 8 keV was discovered, similar to the spectral drop at ~ 7 keV observed in 1H 0707-495 (Boller et al. 2003). The author of this thesis has contributed to the publication as a co-author.

5.13.1 Timing analyses

The 0.3–12.0 keV light curves derived from the EPIC cameras are shown in Figure 5.54. Since we ignore the period affected by the high background flaring events, the data gap is appeared around 2×10^4 s in the light curves. The source shows the rapid and persistent variation during the observation. We detect variations by a factor of about 10 on a timescale of $\sim 1 \times 10^4$ s and we can see the significant flux change even within the 200 s. As a next step, we investigate a spectral variability by calculating the $F_{\rm var}$ with 2000 s time bin in the different energy bands. The derived relationship between $F_{\rm var}$ and energy is shown in Figure 5.55. It is clearly seen that all energy bands have more than 30 % amplitude. The most variable energy band is the 1.5-2.0 keV band, in which the $F_{\rm var}$ reaches about 70 % variability amplitude. As discussed following section, the 1.5-2.0 keV spectrum is quite complex as it includes the Fe-L absorption features and the point where the soft excess component and hard power law component intersect. Therefore, it is difficult to conclude that any spectral components affect such a large amplitude variation.

Figure 5.54: 0.3–12.0 keV Light curves of IRAS 13224-3809. *left*; PN, *right*; MOS1 and MOS2.

5.13.2 Spectral analyses

As is found in the spectrum of 1H 0707-495, the sharp spectral drop is also seen in the IRAS 13224-3809 spectrum. Unfortunately, the edge structure cannot be constrain by the MOS data due to the low signal to noise ratio above ~ 7 keV. The edge energy is significantly higher than that expected from a cold iron absorption edge (7.1 keV). When we fitted the spectrum

Figure 5.55: Plot of Fractional variability amplitude versus energy for the EPIC light curves. $F_{\rm var}$ is calculated with the time bin size of 2000 s

with a absorbed power law plus absorption edge, the derived edge energy is $8.2^{+0.2}_{-0.1}$ and the optical depth is $1.73^{+1.02}_{-0.58}$. If this is due to an absorption edge of a cold iron, then the outflow velocity of the absorber is $\sim 0.15c$. More detailed discussions for this 8 keV feature are seen in Boller et al. (2003). First, we attempted the partial covering model to the data. This model adequately reproduced the observed continuum shape and edge-like feature, but required a much steep slope ($\Gamma \sim 3$) and an amomalous Fe abundance of ~ 200. As pointed out by Boller et al. (2003), an powr law with an exponetial cut-off gave a more reasonable spectral slope (~ 2) and an iron abundance (~ 10) to the data. Unfortunately, the low signal to noise ratio above 6 keV and lack of the high energy (> 10 keV) part of the spectrum prevent us from fruther constraining on the underlying continuum shape. Here, we used a simple phenomenological model which consists of a MCD model, a power law partially absorbed by materials with solar abundance, a leaky power law, and an absorption edge to explain the 8 keV feature. In addition, this model required a further absorption feature around 1.2 keV. Such a feature also found in the spectra of 1H 0707-495 and PG 1211+143. The profile of this absorption feature is seems to be symmetrical rather than edge-like (see Figure 5.56). Therefore, we included a negative Gaussian. The derived line center energy is 1.20±0.01, and the equivalent width is 136 eV. Figure 5.57 shows observed spectra and residuals from the best-fit model. The resultant spectral parameters are summarized in Table 5.16.

This deep absorption feature was first reported by Leighly et al. (1997) from the *ASCA* observation. They interpreted it as a resonant absorption by highly ionized oxygen ions with relativistic outflow velocity (0.2–0.3c). On the other hand, Nicastro, Fiore & Matt (1999) interpreted it as resonant absorption by L-shell iron ions. Therefore, we calculated a spectrum emerged from a photoionized plasma using an "XSTAR" photoionization code (Kallman & Krolik 2003). We assumed a plasma with a temperature of 10^5 K, a density of 10^9 cm^{-3}, and

a turbulent velocity of 1000 km s^{-1}. An ionizing source was assumed to be a power law with a photon index Γ of 2 and a 0.1–20 keV luminosity of 10^{44} erg s^{-1}. Thus obtained model spectrum is shown in an upper panel of Figure 5.58 together with an observed photon spectrum. A lower panel of the figure shows data residuals from the model. The observed absorption feature is well reproduced by iron L-shell absorption lines. The ionization parameter ξ, which is defined as $\xi = L/nR^2$ (L, luminosity of an ionizing source; n, electron number density of the absorber; R, distance between the ionizing source and absorber), and column density of the absorber is estimated to be 1000 and 2×10^{22} cm^{-2}, respectively. We also found that the absorber had an outflow velocity of $\sim 0.2c$ compared with a systemic velocity. This is comparable to the velocity estimated from the absorption edge feature around 8 keV, but the ionization parameter is quite different. This may suggest the radial ionization stratification of the absorber. Unfortunately, due to the low statistics and medium energy resolution of the EPIC cameras, we cannot further constrain on the geometry of the absorber. A future X-ray mission, such as *NeXT*, will get much clear view in terms of an outflowing absorber in NLS1s.

Figure 5.56: Strong residuals appeared around 1.2 keV when the continuum models are fitted to the data.

Figure 5.57: Overall spectra of IRAS 13224-3809.

5.14 Mrk 478

Mrk 478 is a classic example of the NLS1 class with a strong, steep X-ray spectrum (Gondhalekar et al. 1994) and low interstellar column density (9.7×10^{20} cm^{-2}, Murphy et al. 1996). Also it is known to be one of the brightest NLS1 in the extreme ultraviolet (Gondhalekar et al. 1992; Marshall, Fruscione, & Carone 1995). The recent *Chandra* observation reveled that the spectrum obtained from Low Energy Transmission Grating Spectrometer (LETG) is remarkably featureless, i.e., no significant emission or absorption features are detected, and the 0.15–10 keV

Figure 5.58: Photon spectrum of IRAS 13224-3809. Sharp structures appeared around 1.2 keV are due to iron L-shell absorption lines. Green; MCD model, Blue; power law.

Table 5.16: IRAS 13224-3809: Overall spectral fitting results.

Parameters [unit]	Value
$N_{\rm H}$ [10^{20} cm^{-2}]	$6.37^{+0.62}_{-0.47}$
kT [keV]	$0.178^{+0.001}_{-0.002}$
Γ	$2.159^{+0.049}_{-0.086}$
$N_{\rm pcf}$ [a] [10^{22} cm^{-2}]	$34.3^{+19.3}_{-14.1}$
$C_{\rm f}$ [b]	$0.41^{+0.16}_{-0.08}$
$E_{\rm edge}$ [c] [keV]	$8.14^{+0.15}_{-0.10}$
τ [d]	$1.84^{+1.01}_{-0.59}$
$E_{\rm abs}$ [e] [keV]	$1.20^{+0.01}_{-0.01}$
$\sigma_{\rm abs}$ [f] [eV]	152^{+9}_{-10}
$F_{\rm abs}$ [g] [10^{-4} ph s^{-1} cm^{-2}]	$-1.41^{+0.14}_{-0.11}$
EW [h] [eV]	-136^{+56}_{-26}
$L_{0.3-10}$ [10^{43} erg s^{-1}]	$3.24^{+1.68}_{-2.09}$
L_{2-10} [10^{42} erg s^{-1}]	$4.57^{+0.46}_{-0.81}$
χ^2_ν/dof	1.15/664

[a]The column density of partial covering absorber, [b]Covering fraction, [c]Absorption edge energy, [d]Optical depth, [e]Center energy of the absorption line, [f]Absorption line width, [g]Flux of the absorption line, [h]Equivalent width of the absorption line.

spectrum is well fitted by the sum of two power laws with $\Gamma_1 \sim 3$, which dominates below 2 keV and $\Gamma_2 \sim 1.4$, which dominates above 2 keV (Marshall et al. 2003).

5.14.1 Timing Analyses

Figure 5.59 shows the light curves obtained from *XMM-Newton* EPIC detectors. The data gaps appeared in the light curves implies the periods of the high background flares. The source exhibits a factor of about 1.5 variation during the observation. Figure 5.60 displays the relationship between $F_{\rm var}$ and energies. The $F_{\rm var}$ are seems to be gradually increase toward the higher energy band, although the possibility of constant is not rejected. To investigate the spectral variability, we calculate the hardness ratio between the 0.3–2.0 keV and 2.0–12.0 keV bands using 1000 s time bins. In Figure 5.61, we plot the hardness ratio against the 2–12 keV count rate. There is a clear positive correlation between them. This results indicate that the spectrum of Mrk 478 becomes harder when the hard photon (> 2 keV) flux is increase. This tendency is quite opposite to that of typical BLS1s, whose spectra become softer when the sources are brighter (e.g. Haba et al. 2003). The spectral behavior against the flux may be one of the important key parameter to understand the emission mechanism of NLS1s and the difference between NLS1s and BLS1s.

Figure 5.59: 0.3–12.0 keV Light curves of Mrk 478. *left*; PN, *right*; MOS1 and MOS2.

5.14.2 Spectral analyses

The 2–12 keV spectrum is well reproduced by a single power law absorbed by a Galactic column density of 9.7×10^{19} cm^{-2} (Murphy et al. 1996). When we extrapolate this power law continuum into the low energy band, there are a significant fraction of excess counts below ~ 1.5 keV. First, we fitted this excess component using the second additional power law, which was successfully reproduced the *Chandra* LETG spectrum. This model gave a reasonable fitting result ($\chi^2_\nu =$ 1.08 for 807 degrees of freedom) and the derived photon indices of both power law components

Figure 5.60: Plot of Fractional variability amplitude versus energy for the EPIC light curves.

Figure 5.61: Plot of hardness ratio against PN 2–12 keV count rate using 1000 s time bins.

are, respectively, 3.11±0.03 and 1.36±0.07, which are in good agreement with the results of *Chandra* LETG. However, we found systematic clear difference in the 0.3–0.7 keV range, where the model overestimates the 0.3–0.4 keV counts, on the other hand, it underestimates the 0.5-0.7 keV counts. These residuals are still appeared, even if we added the further absorption model. These results may imply that the soft component does not have a simple power law shape but requires a convex curve such as a thermal emission. Therefore, we fitted the spectrum with a power law plus MCD model. This model gave a excellent fit to the data ($\chi^2_\nu = 1.00$ for 1343 degrees of freedom). However, in this time, we found systematic positive residuals above 5 keV (see Figure 5.62 left panel). Similar residuals are seen when we fitted the Ton S180 spectrum with a power law plus a MCD model. As is discussed in the spectral analyses of Ton S180, the spectrum is well reproduced by a p-free disk model rather than a simple MCD model, hence we introduce the p-free disk model instead of a MCD model. The resultant fitting parameters are shown in Table 5.17 and the right panel of Figure 5.62 displays the observed spectra and best-fit model.

Figure 5.62: Overall spectra of Mrk 478. *left*; MCD + power law model, *right*; *p*-free disk + power law model. (Black;PN, Red;MOS1, Green;MOS2, Blue;RGS1, Light-blue;RGS2)

Table 5.17: Mrk478: Overall spectral fitting results.

Parameters [unit]	MCD + power law	*p*-free disk + power law
$N_{\rm H}$ [10^{20} cm^{-2}]	< 0.56	0.97 (fix)
kT [keV]	$0.154^{+0.002}_{-0.007}$	$0.193^{+0.009}_{-0.006}$
p	—	$0.44^{+0.03}_{-0.02}$
Γ	$2.440^{+0.036}_{-0.027}$	$2.376^{+0.039}_{-0.041}$
$L_{0.3-10}$ [10^{44} erg s^{-1}]	$1.91^{+0.02}_{-0.06}$	$1.91^{+0.01}_{-0.04}$
L_{2-10} [10^{44} erg s^{-1}]	$0.374^{+0.005}_{-0.006}$	$0.378^{+0.009}_{-0.007}$
χ^2_ν/dof	1.00/1343	0.98/1343

Chapter 6

Discussion

6.1 Summary of Results

We analyzed 13 narrow-line Seyfert 1 galaxies observed by *XMM-Newton*. In this section, we briefly summarize the results.

6.1.1 Time variability

From the beginning of studies of X-ray time variability in AGN, it has been suggested that the more luminous sources show slower time variation. Barr & Mushotzky (1986) were the first to show that the "two-folding" timescale, which is defined as the timescale for the observed flux to change by a factor of two, was shorter in lower luminosity objects. Nandra et al. (1997a) also found an anti-correlation between the variability amplitude and source luminosity. These may suggest the strong link between the X-ray variability and central supermassive black hole, if we naively assume that more luminous source harbors a larger black hole.

We investigate variability of X-ray fluxes using light curves binned to 200 s. Table 6.1 shows the basic properties of light curves. Column 2 indicates the mean count rate, and column 3 shows the chi-square values derived from a constant fit to the PN light curves. We found that all of the objects show significant variabilities ($\chi^2/\mathrm{dof} \gg 1$) within the observation.

6.1.2 Spectrum

The 2–12 keV X-ray continua of all objects are well represented by a single power law with photon index $\Gamma \sim 2$, although a partial covering model provides a better description for some objects (1H 0707-495, IRAS 13224-3809, PG 1211+143, and NGC 4051). We found that all objects show a large amount of excess below 2 keV on top of the hard X-ray power law component. This component is well described by a thermal emission from an optically thick accretion disk.

Some objects (1H 0707-495, IRAS 13224-3809, PG 1211+143) exhibit a peculiar absorption feature around 7 keV, which may be attributed to the Fe-K absorption. Interestingly, these

Table 6.1: Summary of timing properties.

Target name	PN/MOS1/MOS2 mean count rate [counts s^{-1}]	χ^2/dof[a]	F_{var}[b] [%]
Mrk 335	15.88/4.96/5.03	5679/159	10.4±0.6
I Zw 1	6.95/2.15/2.21	2306/100	13.9±1.0
Ton S180(1)	7.43/—/2.68	3931/147	12.9±0.8
Ton S180(2)	5.49/—/1.91	1134/91	9.8±0.8
Mrk 359	4.19/1.17/1.19	75.8/36	3.7±0.8
NAB 0205+024	2.85/—/0.78	706.7/140	8.6±0.7
PKS 0558-504(1)	11.10/3.88/3.95	1140/127	5.8±0.8
PKS 0558-504(2)	16.28/4.26/4.30	460.1/98	4.8±0.6
PKS 0558-504(3)	9.63/2.74/2.80	374.0/59	5.4±0.6
1H 0707-495	0.92/0.23/0.24	6099/204	44.2±2.0
RE 1034+396	4.24/1.08/1.11	243.7/65	5.8±0.7
NGC 4051(1)	13.21/—/4.83	531070/531	50.2±1.6
NGC 4051(2)	4.31/1.13/1.15	26424/251	49.4±2.2
PG 1211+143	2.98/0.76/0.78	926.9/267	6.8±0.4
PG 1244+026	4.82/1.37/1.42	570.6/42	10.6±1.3
IRAS 13224-3809	1.43/0.34/0.35	19792/286	44.5±1.9
Mrk 478	5.58/1.46/1.51	1198/107	9.8±0.8

[a] Chi-square values of constant fit to the light curves with 200 s bin obtained with PN.

[b] Fractional variability amplitude calcurated over the 0.3–12 keV band.

sources also show the large counts deficits around $\sim$ 1 keV. An Fe-K emission line is detected from Mrk 335, I Zw 1, Ton S180, Mrk 359, and NGC 4051. In the case of Mrk 335, I Zw 1, and Ton S180, the line energies are slightly higher than that expected from neutral iron. Furthermore, the lines of Mrk 335 and Ton S180 are significantly broadened.

The best-fit parameters of the X-ray continua are summarized in Table 6.2. Column 2 shows equivalent neutral hydrogen column density in unit of 10^{20} cm^{-2}, while column 3 and 4 indicate power law photon index Γ and temperature of soft component, respectively. Column 5 and 6 show the observed 2 10 keV flux (10^{-11} erg s^{-1} cm^{-2}) and luminosity (10^{43} erg s^{-1}), while Column 7 and 8 implies the absorption corrected intrinsic luminosity of soft component (0.3–10 keV) and power law (2 10 keV), respectively. We also summarize properties associated to a central supermassive black hole in Table 6.3. In our sample, black hole masses of only 3 objects (Mrk 335, NGC 4051, and PG 1211+143) are derived from a reverberation mapping technique, which is one of the most reliable mass estimation method. Except for these objects, masses are estimated from an empirical relationship between the size of BLR and monochromatic continuum luminosity at 5100 Å (see equation 2.1). Column 2 of Table 6.3 indicates black hole masses thus estimated. Using these black hole masses, we estimated Eddington luminosities in our sample (column 3). Since we adopted an MCD model to a soft excess component, we can estimate an innermost radius of an accretion disk. Column 4 indicates innermost radii normalized by a Schwarzschild radius.

6.2 Timing properties

6.2.1 X-ray variability amplitude

In order to quantify the magnitude of variation, we calculate the fractional variability amplitude $F_{\rm var}$ using the 0.3 12 keV light curves. The values are tabulated in column 4 of Table 6.1 and are plotted in Figure 6.1 as a function of observed 2-10 keV luminosities. A similar plot is shown in Figure 2.2, which is derived from *ASCA* observations of NLS1s (Leighly 1999a) and BLS1s (Nandra et al. 1997a). As suggested by Leighly (1999a), care must be taken in interpreting the relationship between $F_{\rm var}$ and luminosity. $F_{\rm var}$ can be related to the power spectral density (PSD) by the following equation,

$$F_{\rm var} \propto \int_{1/T_{\rm obs}}^{1/T_{\rm min}} P(f)W(f)df, \tag{6.1}$$

where f is the frequency, $P(f)$ is the PSD function, $W(f)$ is the window function, $T_{\rm obs}$ is the length of the observation, and $T_{\rm min}$ is the minimum bin size of the light curve. Therefore, the comparison of the $F_{\rm var}$ is valid when the length of the observation is taken into account and the shape of the PSD is assumed to be same in all objects. We assume the power law index of PSD to be 1.5, which is reasonable value for this class of object (Leighly 1999a, Edelson et al. 2002).

Table 6.2: Summary of the spectral parameters.

Target name	$N_{\rm H}$	Γ	kT	F_{2-10}	L_{2-10}	$L_{\rm soft}$	L_{2-10}
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mrk 335	$3.37^{+0.18}_{-0.43}$	$2.244^{+0.012}_{-0.027}$	$0.170^{+0.004}_{-0.007}$	1.49	$2.21^{+0.01}_{-0.02}$	$1.80^{+0.17}_{-0.23}$	2.21
I Zw 1	$9.48^{+0.46}_{-0.36}$	$2.324^{+0.025}_{-0.025}$	$0.217^{+0.015}_{-0.010}$	0.85	$7.23^{+0.06}_{-0.06}$	$6.56^{+3.00}_{-2.54}$	7.44
Ton S180(1)	1.56	$2.452^{+0.025}_{-0.028}$	$0.189^{+0.009}_{-0.007}$	0.48	$4.25^{+0.04}_{-0.05}$	$9.79^{+2.66}_{-1.27}$	4.26
Ton S180(2)	1.56	$2.369^{+0.038}_{-0.038}$	$0.183^{+0.013}_{-0.009}$	0.41	$3.59^{+0.04}_{-0.05}$	$6.80^{+2.61}_{-3.10}$	3.60
Mrk 359	$4.88^{+0.41}_{-0.13}$	$1.871^{+0.012}_{-0.019}$	$0.181^{+0.004}_{-0.002}$	0.59	$0.39^{+0.02}_{-0.04}$	$0.225^{+0.005}_{-0.010}$	0.39
NAB 0205+024	$4.38^{+0.56}_{-0.51}$	$2.326^{+0.019}_{-0.036}$	$0.157^{+0.004}_{-0.004}$	0.16	$9.50^{+0.20}_{-0.20}$	$27.8^{+3.1}_{-2.4}$	9.60
PKS 0558-504(1)	$3.3^{+0.4}_{-0.2}$	$2.293^{+0.014}_{-0.008}$	$0.173^{+0.002}_{-0.001}$	0.96	$43.7^{+2.6}_{-1.7}$	$56.5^{+2.7}_{-1.6}$	43.9
PKS 0558-504(2)	$3.6^{+0.3}_{-0.3}$	$2.200^{+0.011}_{-0.010}$	$0.188^{+0.002}_{-0.001}$	1.15	$51.6^{+0.5}_{-0.6}$	$51.3^{+3.3}_{-1.2}$	51.8
PKS 0558-504(3)	$3.2^{+0.6}_{-0.3}$	$2.100^{+0.015}_{-0.012}$	$0.195^{+0.003}_{-0.002}$	1.04	$46.1^{+1.2}_{-1.3}$	$29.1^{+3.1}_{-3.0}$	46.3
1H 0707-495	$4.65^{+0.85}_{-0.83}$	$2.763^{+0.088}_{-0.233}$	$0.143^{+0.001}_{-0.002}$	0.043	$0.16^{+0.01}_{-0.08}$	$1.98^{+0.07}_{-0.09}$	0.56
RE 1034+396	1.43	$2.511^{+0.079}_{-0.090}$	$0.168^{+0.004}_{-0.004}$	0.077	$0.32^{+0.01}_{-0.02}$	$3.50^{+0.36}_{-0.26}$	0.32
NGC 4051(1)	$1.41^{+0.03}_{-0.02}$	$2.159^{+0.005}_{-0.002}$	$0.165^{+0.001}_{-0.001}$	2.39	$0.0286^{+0.0001}_{-0.0003}$	$0.033^{+0.001}_{-0.001}$	0.035
NGC 4051(2)	$1.67^{+0.08}_{-0.28}$	$2.038^{+0.005}_{-0.024}$	$0.153^{+0.001}_{-0.001}$	0.65	$0.0078^{+0.0002}_{-0.0003}$	$0.016^{+0.001}_{-0.001}$	0.013
PG 1211+143	$4.21^{+0.12}_{-0.18}$	$2.136^{+0.032}_{-0.020}$	$0.162^{+0.002}_{-0.001}$	0.30	$4.40^{+1.30}_{-1.40}$	$6.90^{+0.30}_{-0.12}$	6.37
PG 1244+026	$2.47^{+0.30}_{-0.66}$	$2.410^{+0.030}_{-0.061}$	$0.205^{+0.009}_{-0.007}$	0.21	$1.11^{+0.04}_{-0.05}$	$2.92^{+0.61}_{-0.52}$	1.12
IRAS 13224-3809	$6.37^{+0.62}_{-0.47}$	$2.159^{+0.049}_{-0.086}$	$0.178^{+0.001}_{-0.002}$	0.044	$0.46^{+0.05}_{-0.08}$	$7.94^{+1.07}_{-1.20}$	0.75
Mrk 478	0.97	$2.376^{+0.039}_{-0.041}$	$0.193^{+0.009}_{-0.006}$	0.26	$3.78^{+0.09}_{-0.07}$	$8.46^{+4.39}_{-1.56}$	3.79

Col.(1)—Target name; Col.(2)—Column density of neutral absorption in unit of 10^{20} cm^{-2}; Col.(3)—Photon index Γ; Col.(4)—Disk temperature kT in unit of keV; Col.(5)—2–10 keV flux in unit of 10^{-11} erg s^{-1} cm^{-2}; Col.(6)—2–10 keV observed luminosity in unit of 10^{43} erg s^{-1}; Col.(7)—Soft component luminosity integrated over the 0.3–10 keV band in unit of 10^{43} erg s^{-1}; Col.(8)—2–10 keV intrinsic luminosity in unit of 10^{43} erg s^{-1}.

Table 6.3: Properties of supermassive black hole.

Target name	$M_{\rm BH}$	$L_{\rm E}$	$R_{\rm in}$
	$10^7 M_\odot$	10^{44} erg s^{-1}	$R_{\rm S}$
Mrk 335	0.63	7.88	1.22
I Zw 1	none	none	none
Ton S180(1)	1.16	14.5	0.26
Ton S180(2)			0.25
Mrk 359	0.17	2.1	2.06
NAB 0205+024	2.00	25.0	0.38
PKS 0558-504(1)	3.20	40.0	0.29
PKS 0558-504(2)			0.23
PKS 0558-504(3)			0.16
1H 0707-495	0.30	3.75	2.71
RE 1034+396	0.23	2.88	1.20
NGC 4051(1)	0.13	1.63	9.12
NGC 4051(2)			7.76
PG 1211+143	4.05	50.6	0.15
PG 1244+026	0.13	1.63	2.70
IRAS 13224-3809	0.30	3.75	2.00
Mrk 478	1.87	23.4	0.34

Col.(1)—Target name; Col.(2)—Black hole mass; Col.(3)—Eddington luminosity; Col.(4)—Innermost radius of an accretion disk.

Reference for black hole mass: Wang & Lu (2001), Kawaguchi (2003)

From the observed $F_{\rm var}$ and span of an observation, we can estimate the normalization of PSD at 1/32 ksec^{-1}, which corresponds to the mean length for all observations. In this estimation, the span of an observation is also corrected for the redshift of the object by multiplying by $(1+z)^{-1}$. The PSD normalization thus obtained are plotted against 2-10 keV luminosities in Figure 6.2. We found weak anti-correlation between them. We also plotted the PSD normalization as a function of inferred black hole masses in Figure 6.3. Filled circles indicate the masses estimated from the empirical relationship described in equation 2.1, while the open squares are ones derived from the reverberation mapping technique, which may be most reliable method for the mass estimation. For only three objects ($1.3\times10^6 M_\odot$, NGC 4051; $6.3\times10^6 M_\odot$, Mrk 335; $4.0\times10^7 M_\odot$, PG 1211+143), central masses are estimated from the reverberation mapping technique. There is a clear anti-correlation between the black hole mass and variability amplitude, if we only consider the three data points derived from the reverberation mapping. Recently, Papadakis (2004) demonstrate that the variability amplitude of 2–10 keV long term (from $\sim$ days to $\sim$ years) light curves derived from *RXTE* observations decreases with increasing central black hole mass. This suggests that the X-ray variability amplitude may strongly connected to the black hole mass, i.e. the size of the system.

Figure 6.1: Correlation between $F_{\rm var}$ and 2–10 keV luminosity.

6.2.2 Spectral variability

The presence of spectral variability can also be investigated by comparing the soft band $F_{\rm var}$ with that in the hard band. Figure 6.4 shows the relationship between 0.3–0.5 keV $F_{\rm var}$ and 2–4 keV $F_{\rm var}$. As discussed in the following sections, the spectra of NLS1s are well reproduced by the combination of a soft thermal emission and a hard power law. The 0.3–0.5 keV energy band is dominated by the soft thermal component, while the power law component dominates above 2 keV. Therefore, Figure 6.4 implies the difference of the variability amplitude between the soft and the hard components. A dashed-line indicate the $F_{\rm var}$(soft) = $F_{\rm var}$(hard). We

Figure 6.2: Plot of the PSD normalization calculated from the $F_{\rm var}$ and the length of the observation as a function of the 2–10 keV luminosity. Redshift is also taken into account for the calculation of the PSD normalization (see text for details).

Figure 6.3: Plot of the PSD normalization calculated from the $F_{\rm var}$ and the length of the observation as a function of inferred central mass of black hole.

found a clear positive correlation between the soft and hard band variability amplitude. This may suggest that the variation of the soft and hard component are synchronized each other. On the other hand, some of the objects show much larger amplitude in the higher energy band. This result is likely to suggest that the X-ray spectrum becomes harder as the source brighter, because a shape of an energy spectrum of $F_{\rm var}$ is similar to a spectral ratio between the high and the low flux state (see §4.1.1). Such a trend is quite opposite compared with broad-line Seyfert 1 galaxies (BLS1s), such as NGC 5548, which tend to be softer when its intensity increases (see Figure 5.5). Similar results are also reported by Cheng, Wei & Zhao (2002) using the *ROSAT* pointing data, where they found that NLS1s show a positive correlation between the hardness ratio and count rate, while BLS1s show a negative correlation between them.

This difference would result from the different nature of a soft excess component and a hard power law in NLS1s. If we assume simply that the $F_{\rm var}$ represents the size of the emission region, i.e, the larger $F_{\rm var}$ implies the smaller emission region, then the soft excess component could be radiated from a larger volumes compared with a power law emission region. However, it seems difficult to consider that the size of the emission region is so different between the soft and hard components, if we assume that the soft component is the hard tail of the thermal emission from an inner part of the accretion disk. On the other hand, the variability amplitude of the soft component would be intrinsically smaller than that of hard power law. It has been thought that the power law continuum is produced by a thermal Comptonization, wherein hot electrons scatter off some soft seed photons, which originate from the accretion disk, and boost them into

hard X-rays (e.g., Sunyaev & Titarchuk 1980). In this case, the variability of the X-ray power law is related not only to soft seed photons but also hot electrons. The origin of hot electrons are still unknown, but one of the possible production mechanisms may be a magnetic flare on the accretion disk (Galeev et al. 1979; Kawaguchi et al. 2000). Indeed, we found that the spectrum of I Zw 1 becomes harder during the rapid flare event (see Figure 5.24). Also, typical narrow-line Seyfert 1 galaxy Ark 564 and PKS 0558-504 exhibited the spectral hardening during the X-ray flare in the *ASCA* observations (Negoro 2001; Wang et al. 2001). Hence the studying the flare mechanism may be a key to understanding the nature of the X-ray variability in NLS1s.

Figure 6.4: Comparison between the soft band (0.3–0.5 keV) $F_{\rm var}$ and hard (2–4 keV) $F_{\rm var}$. The dashed line indicate the $F_{\rm var}$(soft) = $F_{\rm var}$(hard).

6.3 X-ray spectral properties

6.3.1 Soft excess component

The soft excess is the most prominent spectral feature in NLS1s. We demonstrated that all of the objects exhibit a soft excess emission when a hard power law is extrapolated into the low energy band. This excess component has been conventionally thought to be the high energy tail of the accretion disk spectrum. The spectral shape of the soft excess component is not a power law but requires a convex shape. Therefore, we tried to parameterize the spectra with a relatively simple model, i.e., multicolor disk blackbody (MCD) model, which has successfully reproduced the soft state spectra of black hole binaries.

We found that this simple model also provides a good description for the soft excess component in NLS1s. Figure 6.5 shows the relationship between the disk maximum temperature kT

and the disk luminosity $L_{\rm disk}$, i.e., Hertzsprung-Russell (H-R) diagram for an accretion disk. In this H-R diagram, the most surprising feature is the constancy of the estimated temperatures over the four orders of magnitude in luminosity. The disk temperatures are distributed from 0.14 to 0.22 keV with an average of 0.18 keV. To explain the kT constancy, we investigate the kT-$L_{\rm disk}$ relation within the frame work of the standard accretion disk model.

According to the standard accretion disk model, we can predict the relationship between the disk temperature and disk luminosity. The dotted lines and dashed lines in the figure indicate the predicted kT-$L_{\rm disk}$ relation with different black hole mass and Eddington ratio, respectively. If we assume that the all of the objects has same Eddington ratio, then the observed range of the temperature corresponds to the mass range of one order of magnitude. In this case, however, the corresponding luminosity range also becomes one order of magnitude, which is much narrower than the observed luminosity span. If the distribution of the Eddington ratio is taken into account in order to spread the luminosity range, then the range of two orders magnitude in Eddington ratio is needed. In this case, however, the predicted range of the temperature becomes much wider than the observed range. These results strongly suggest that the soft excess component in NLS1s cannot be explained by the simple accretion disk model, such as a standard accretion disk, and that it is necessary to consider the some special mechanisms so as to concentrate the temperatures into an extremely narrow range.

Another indication for a breakdown of the standard accretion picture is that the observed temperature is significantly higher than the model prediction. Since the maximum disk temperature is proportional to $M_{\rm BH}^{-0.25}$ within a frame work of the standard accretion disk picture, the higher temperature implies a smaller black hole mass. In Figure 6.5, it is obvious that the predicted black hole mass is significantly smaller than $1 \times 10^6 M_\odot$. The masses estimated from the standard accretion disk model are typically two order of magnitude smaller than that derived from the optical observations.

We further discuss possible models for the soft excess component in section 6.4.

6.3.2 Hard power law

The 2–12 keV continua of our sample were well fitted by a single power law absorbed by a Galactic material, except for 1H 0707-495, NGC 4051, PG 1211+143, and IRAS 13224-3809. These objects show the absorption signature around 7 keV, which may be attributed to the iron K shell absorption, hence we applied a partial covering model to the data. It has been already suggested that the photon index from NLS1s appears to be on average steeper than that from BLS1s (e.g., Brandt, Mathur & Elvis 1997, Leighly 1999b). In Figure 6.6, the photon indices Γ for the NLS1s (filled circles) and for BLS1s (open squares) taken from Reynolds (1997) are plotted as a function of the 2–10 keV intrinsic luminosity L_{2-10}. It is clear that the power law continua of the NLS1s are a systematically steeper than that of BLS1s. We found no significant correlation between Γ and L_{2-10}. On the other hand, we found a strong correlation between

Figure 6.5: Relationship between the disk temperature kT and disk luminosity $L_{\rm disk}$. The dotted lines and dashed lines indicate the kT-$L_{\rm disk}$ relation predicted from a standard accretion disk model with different black hole mass and Eddington ratio, respectively.

L_{2-10} and the luminosity of the soft excess component $L_{\rm soft}$. The $L_{\rm soft}$ are plotted against L_{2-10} in Figure 6.7. Most objects are distributed around the $L_{2-10} = L_{\rm soft}$ line (dotted line in the figure). In order to investigate whether such a linear relation can be held or not even in the BLS1s, we roughly estimate the bolometric luminosity $L_{\rm bol}$. We assume that the $L_{\rm bol}$ is 20 times larger than $L_{\rm soft}$. The ordinate unit shown at the righthand side indicates the bolometric luminosity $L_{\rm bol}$. The filled circle indicate the data points obtained from the analyses of typical BLS1 NGC 5548. Interestingly, both types of objects show a similar $L_{\rm bol}$-L_{2-10} relation in spite of one order of magnitude difference between the soft excess temperature of NLS1s and BLS1s.

As discussed in section 5.1.4, the observational relationship between the disk luminosity and 2–10 keV X-ray continuum of NGC 5548 is consistent with the scenario that the hard power law continuum is produced via the inverse Compton scattering of soft photons coming from the accretion disk in hot electron clouds. Since the X-ray power law intensity are determined by the multiplication of the energy density of seed photons, number density of hot electron and Lorentz factor, if these parameters are assumed to be same in both types of objects, then the observed $L_{\rm bol}$-L_{2-10} relation could be explained. Moreover, if the temperature of the hot electron, which determines the shape of the emergent X-ray power law, is systematically cooler in NLS1s than in BLS1s, the difference of the power law slope could be explained. However, as we suggested in the results of the timing analysis, the temporal behavior of X-ray spectrum may be different between NLS1s and BLS1s, and the physical reason why the electron clouds in NLS1s are cooler than that in BLS1s is unclear. In order to investigate a physical origin of

hard power law component in detail, it is important to observe the much higher (> 10 keV) energy part of the spectrum, because it is expected that the cut-off energy, which reflects the temperature of the hot electron clouds, is appeared in such a high energy band. Unfortunately, there has been very little information above 10 keV from NLS1s. As Astro-E2 has a sensitivity up to 700 keV, it will enable us to quantitatively constrain on the emission mechanism of hard power law continuum.

Figure 6.6: Plot of the photon index Γ as a function of 2–10 keV luminosity. Filled circles: our sample of NLS1s. Open squares: Reynolds (1997) sample of BLS1s.

Figure 6.7: Correlation between the soft component luminosity $L_{\rm soft}$ and 2–10 keV luminosity L_{2-10}. The ordinate unit shown at the righthand side indicates the bolometric luminosity $L_{\rm bol}$ estimated using a bolometric correction factor of 20.

6.3.3 Iron lines

We detected iron K emission from only a few objects; Mrk 335, I Zw 1, Ton S180, Mrk 359, and NGC 4051. In the case of BLS1s, the observed line energy is consistent with emission from neutral or low ionized iron, i.e., 6.4 keV. Recent *Chandra* HETGs observations have resolved the narrow line width and suggested that the narrow iron line is originated from the distant matter, such as a putative accretion torus, warm absorber and so on (e.g. Yaqoob et al. 2001). On the other hand, in the case of NLS1s, some of the objects exhibits an emission line expected from mildly or highly ionized iron ions (e.g., Turner et al. 2001 for Ton S180; Pounds et al. 2003 for Mrk 766). In our sample, Mrk 335, I Zw 1 and Ton S180 showed a higher energy (> 6.4 keV) emission line in their spectra. Interestingly, the observed line energies are seems to be correlated with the 2–10 keV power law luminosities. We plotted the line energy against the 2–10 keV luminosity in Figure 6.8. The line energy tends to be higher when the source luminosity increases. This could be attributed to an increase of the ionization parameter of materials irradiated by the power law continuum. In fact, such an X-ray "Baldwin effect" was suggested by Iwasawa & Taniguchi (1993), and confirmed by Nandra et al. (1997c).

Figure 6.8: Plot of the observed line energies against the 2–10 keV luminosities.

6.4 Origin of soft component

In the previous section, we found that the temperatures of soft excess emission in NLS1s are distributed within an extreme narrow range across four orders of magnitude in luminosity. Furthermore, the observed temperatures are much higher than the prediction from the standard accretion disk model. These may suggest that the simple accretion picture can no longer be

achieved in NLS1s.

In this section, we discuss implications of the soft excess component and a possible model for its origin.

6.4.1 Selection effects

First of all, we consider whether some biases in the sample selection could influence the observed kT-$L_{\rm disk}$ relation.

As mentioned in the previous section, the narrow distribution of kT cannot be explained by the difference of the black hole masses. Furthermore, the 0.3–12 keV band pass of *XMM-Newton* is capable of determining the temperature down to $\sim$ 80 eV. Therefore, the lack of a object having a temperature above 0.2 keV may not be suffering from the observable window effect.

Next, we consider the possibility of objects existing outside the observed luminosity range. In our sample, PKS 0558-504 is the most luminous object with a 0.3–12 keV luminosity of 1.5 $\times$ 10^{45} erg s^{-1}. Recently, Ueda et al. (2003) report the hard X-ray luminosity function of AGNs obtained from *HEAO1*, *ASCA* and *Chandra* observations. The number density of AGNs rapidly decreases with increasing luminosity. This indicates that the objects having a higher luminosity ($>$ 10^{45} erg s^{-1}) are intrinsically rare and it is difficult to be observed with a limitted survey area. Therefore, we cannot reject the possibility that high luminosity objects are missed in our sample. Alternatively, the lack of higher luminosity objects might be connected to the Eddington ratio, because under an accretion system, an object cannot be shining infinitely. If this is the case, the mass accretion rate would play an important role in the determination of an upper limit on the luminosity.

On the other hand, we tried to search for less luminous ($<$ 10^{41} erg s^{-1}) AGNs with narrow optical lines. Ho et al. (1997) presented nearby galaxies with a broad Hα emission line. 16 out of 46 objects show a narrow ($\leq$ 2000 km s^{-1} FWHM) Hα emission line (see their Table 1). The intensive X-ray studies of these galaxies were carried out by Terashima et al. (2002) and Terashima & Wilson (2003). They found that the X-ray spectra of most objects are well described by a combination of a soft component from a thermal plasma and a hard power law. There was no evidence for the blackbody type of soft component in their sample. This would indicate that the none of less luminous object have prominent disk emission such as objects in our sample.

Finally, we confirmed that the selection effects, if it exists, little affect the observed kT-$L_{\rm disk}$ relation.

6.4.2 kT-$L_{\rm soft}$ relation

As the zeroth order approximation, we applied an MCD model in order to parameterize the soft excess component. However, in the previous section, we suggest that the observed kT-$L_{\rm disk}$ relation cannot be explained by the simple standard accretion disk model. Therefore, we use a 0.3–10 keV luminosity subtracted a power law component as a soft component luminosity $L_{\rm soft}$, instead of $L_{\rm disk}$, which is estimated from MCD model. We also keep in mind that the observed temperature no longer reflects the prediction from the MCD model.

Our scientific goal of the present thesis is to derive physical parameters of accretion disks around supermassive black hole and reveal the origin of the X-ray emission from AGNs. The variety of AGN environmental parameters, however, makes it somewhat difficult to have a clear view of central region of active galaxies. Therefore, in order to disentangle this complexity, we focus on one particular object and try to investigate a time variability of soft component. This has an advantage that some free parameters characterizing an AGN environment (e.g., central mass, disk inclination) must be constant in different observations of the same target.

As is mentioned in section 5.3.2, we found a peculiar $kT - L_{\rm soft}$ relation during the observations of PKS 0558-504, where the disk temperature tends to be higher when the luminosity of the soft component decreases (see Figure 5.18). Since no absorption features in low energy band and/or signature of partial covered power law is found in the spectra of PKS 0558-504, the derived temperature and luminosity does not suffer from these effects at all.

As well as a temperature and a luminosity, an Eddington ratio is also a fundamental and important parameter to characterize the accretion system. Hence, we roughly estimate the bolometric luminosity of PKS 0558-504. If we assume that the bolometric luminosity $L_{\rm bol}$ is 20 times larger than the observed 0.3–10 keV luminosity of soft component (e.g., Padovani & Rafanelli 1988; Woo & Urry 2002; Turner et al. 2002), then the $L_{\rm bol}$ of PKS 0558-504 is about 1×10^{46} erg s^{-1}. Similar value was also obtained from *ROSAT* high resolution imager observations (Gliozzi et al. 2000), and an optical/UV to X-ray broad band SED (O'Brien et al. 2001). The mass of PKS 0558-504 was estimated as $3 \times 10^7 M_\odot$ from the empirical relation described in section 2.2.1. This yields the Eddington luminosity of 4×10^{45} erg s^{-1}. Figure 6.9 shows the relationship between the temperature and Eddington ratio inferred. In general, the mass estimation used here has a typical uncertainty of 0.5 dex. Even if we assume a 5 times larger black hole mass, still data points distribute around nearly unity. Indeed, PKS 0558-504 may be shining at a near- or super-Eddington luminosity.

Here, we define the critical mass-accretion rate $\dot{M}_{\rm crit}$ associated with the Eddington luminosity as

$$\dot{M}_{\rm crit} \equiv \frac{L_{\rm E}}{c^2}. \tag{6.2}$$

If the energy conversion rate by accretion is η, the luminosity due to the mass-accretion rate $\dot{M}$

is $\eta \dot{M} c^2$. When the luminosity becomes Eddington luminosity, $\dot{M}$ is represented by

$$\dot{M} = \frac{1}{\eta} \frac{L_{\rm E}}{c^2} = \frac{\dot{M}_{\rm crit}}{\eta}. \tag{6.3}$$

Since η is always less than 1 (for a disk accretion onto a black hole), the $\dot{M}$ must exceed the $\dot{M}_{\rm crit}$ in order to shine at or more luminous than the Eddington luminosity. Therefore, the negative correlation of kT-$L_{\rm soft}$ observed here may be due to this extreme condition of accretion flow. In fact, in such a high mass-accretion regime, it has been expected that the advective energy transport in the accretion flow dominates over radiative cooling (Abramowicz et al. 1988; Kato, Fukue & Mineshige 1998). Such a disk is called slim disk, since it is moderately thick geometrically.

In order to investigate the Eddington ratio for other object, we performed a same procedure as PKS 0558-504. Figure 6.10 shows the relationship between kT and Eddington ratio for all objects. Indeed, most objects are distributed 0.2 $8L_{\rm Edd}$ (except for NGC 4051). Therefore, a near- or super-critical mass-accretion flow may be commonly occured in NLS1s. Incidentally, broad-line Seyfert 1 galaxy NGC 5548 lies much far away from the location of the sample of NLS1s in the kT-$L_{\rm bol}/L_{\rm E}$ plane, because its bolometric luminosity is estimated as $\sim$ 10 % of Eddington luminosity and the disk temperature is 17 eV (see section 5.1.4). The differences of the X-ray properties between BLS1s and NLS1s may reflect the different modes of an accretion flow around the central supermassive black hole.

Figure 6.9: Correlation between temperature and Eddington ratio for PKS 0558-504.

Figure 6.10: Correlation between the temperature and Eddington ratio for our sample.

6.4.3 Possible models for the soft component

In the previous section, we suggest that the peculiarities of the soft excess component in NLS1s may result from the extreme high Eddington ratio, i.e., high mass-accretion rate. Since the standard accretion disk model is constructed under number of approximations and its treatment is only valid when the mass-accretion rate $\dot{M}$ is less than the critical mass-accretion rate $\dot{M}_{\rm crit}$, it is likely that the accretion flow in NLS1s is quite different from the standard picture.

One of the most important processes that are not considered in the standard disk model is "advective cooling". In the standard model, it is assumed that a viscous heating rate in the accretion flow balances with a radiative cooling rate. There exist, however, distinct branches of stable disk solution under a high mass-accretion rate and optically thick regimes. In this condition, the efficiency of the radiation is so low that the energy generated by viscosity is swallowed by a central supermassive black hole before it is radiated away, i.e., the viscous heating $Q_{\rm vis}$ balances with an advective cooling $Q_{\rm adv}$ and a radiative cooling $Q_{\rm rad}$. Such an accretion disk is called slim disk, since it has a moderately thick geometrically.

A slim disk model can naturally explain why the observed temperature of soft excess component is significantly higer than the prediction from the standard disk model. Abramowicz et al. (1988) demonstrated that a substantial amount of radiation is expected from even inside the marginal last stable orbit, when the innermost part of the accretion disk become advection dominated. Consequently, the inner disk temperature becomes systematically higher than the values expected by the standard relation. Such a disk model was applied to ultraluminous X-ray sources (ULXs) by Watarai, Mizuno & Mineshige (2001), and to NLS1s by Mineshige et al. (2000). These works, however, did not consider relativistic effects (e.g., a gravitational redshift,

doppler effect) near the black hole. Recently, Kawaguchi (2003) examined effects of the electron scattering (opacity and Comptonization) and relativistic corrections on the emergent spectra from a super-Eddington accretion flow. The resultant spectra are also harder compared with the predictions of the standard accretion disk model.

The unique feature is also expected in an extremely high mass-accretion system. In an optically thick accretion flow such as a slim disk, frequent interactions between matters and photons delay liberation of the radiation energy arising deeper inside the disk. Thus, the radiation energy is trapped in the flow and advected inward. Such an effect is called a "photon-trapping effect" and this may play an important role when the radiative diffusion timescale is longer than the accretion timescale. Ohsuga et al. (2002), Kawaguchi (2003) and Ohsuga, Mineshige, & Watarai (2003) investigated the photon-trapping effects by paying attention to energy transimission inside an optically thick accretion flow around a black hole, and found that this effect becomes more effective with increasing mass accretion rate. Therefore, kT-$L_{\rm disk}$ relation is also changed depending on a mass accretion rate.

When a flow luminosity is below about twice the Eddington luminosity ($2L_{\rm Edd}$), photon trapping is ineffective and the disk temperature shifts to the higher energy side as luminosity increases. The disk temperature becomes at maximum three times higher than that given by the standard disk model. When the flow luminosity exceeds $2L_{\rm Edd}$, in contrast, the disk temperature tends to decrease with increase of mass-accretion rate. This can be recognized as follows: Since high energy photons are generated near the equatorial plane, i.e., deeper inside the accretion flow, they can be more effectively trapped within the accretion flow than low energy photons, thus, the high energy part of radiation is suppressed. As the photon trapping can be more effectively with a mass-accretion rate increases, the emergent spectrum becomes softer (i.e., an apparent disk temperature becomes lower) in spite of luminosity increasing. The filled circles in Figure 6.11 show the relationship between kT and the Eddington ratio under a significant influence of the photon trapping effect (This calculation result is provided by Ohsuga, in private communication). The central mass of $5 \times 10^7 M_\odot$ is assumed throughout the calculation. The numbers in the figure indicate mass-accretion rates normalized by the critical mass-accretion rate, i.e., $\dot{m} \equiv \dot{M}/\dot{M}_{\rm crit}$. The disk temperature and luminosity gradually increases as $\dot{m}$ increases until $\dot{m}$ becomes 50.0, at which the disk temperature becomes a maximum value. On the other hand, when the $\dot{m}$ exceeds 50.0, the disk temperature significantly decreases with slight increase of luminosity. This is due to enhanced photon trapping effect. In Figure 6.11, we plotted the temperature-Eddington ratio relation found in the observations of PKS 0558-504. Although we applied a bolometric correction factor of 29 in order to adjust the data point to the model predictions, the observed behavior of the disk temperature and luminosity is well explained by the photon trapping effect.

In Figure 6.12, we also plotted other objects on the $kT - L_{\rm bol}/L_{\rm Edd}$ plane, and find that the distribution of $kT - L_{\rm bol}/L_{\rm Edd}$ in our sample may be explained by the slim disk scenario,

if the photon trapping effect is properly taken into acount. In this case, the narrow range of the observed temperatures is recognized as the fact that the objects in our sample just lie in the stage where the disk temperature is saturated by the photon trapping effect. The inferred mass-accretion rates in our sample are 10–100$\dot{M}_{\rm crit}$, these imply that the central mass of the black hole can become $10^8 M_\odot$ only within 10^8 yr. Thus NLS1s could be suggested to be in an extreme growth stage with a very high mass-accretion rate.

Figure 6.11: Relation of Temperature and Eddington ratio. Filled circles indicate a model predictions based on the photon trapping effect. Filled squares show the observed values of PKS 0558-504. In order to adjust the data points to the model, we applied the bolometric correction factor of 29 to the data points.

Figure 6.12: Relation of temperature and Eddington ratio in our sampel. Filled circles indicate a model predictions based on the photon trapping effect.

Chapter 7

Conclusion

We have studied narrow-line Seyfert 1 galaxies (NLS1s) observed by *XMM-Newton*. We also analyzed a typical broad-line Seyfert 1 galaxy (BLS1) NGC 5548 in order to reveal the similarity and difference between both types of objects. The followings are our main results and conclusions.

1. BLS1 NGC 5548

The 0.1–10 keV continuum spectrum is well reproduced by a combination of a single power law and a thermal emission from an accretion disk. The derived photon index of 1.8 is the typical value for BLS1s, and the disk temperature measured of 17 eV is in good agreement with the prediction from the standard Shakura-Sunyaev accretion disk picture. We found a clear positive correlation between the disk luminosity and 2–10 keV power law luminosity. Furthermore, we found that the power law continuum tend to be steeper when the luminosity increases. This behavior is consistent with the scenario that the X-ray power law continuum is produced by inverse Compton scattering of soft seed photons coming from an accretion disk in hot electron clouds.

2. Soft component of NLS1s

The 2–12 keV continuum is well described by a single power law with a photon index $\Gamma \sim 2$, which is systematically steeper than that of BLS1s. We detected a prominent soft excess emission from all objects, when the hard power law was extrapolated into the low energy band. The spectrum of this excess emission is well parameterized by a thermal emission from an accretion disk. The disk temperature measured, however, is significantly higher than the prediction from the standard accretion disk picture. Furthermore, the disk temperature is nearly constant around 0.18 keV, despite of four orders of magnitude differences in their luminosity. Moreover, we found an anti-correlation between the disk temperature and the luminosity of the soft excess component during the observations of PKS 0558-504, which is thought to have the highest Ed-

dington ratio, i.e., highest mass-accretion rate among our sample. According to the standard disk model, a disk luminosity is proportional to kT^4 with a fixed inner radius. Therefore, these results suggest that the standard accretion disk picture is no longer appropriate in the nucleus of NLS1s. We discussed a possible origin for the soft excess component from a view point of the high mass-accretion rate, and suggest that a slim disk, which is predicted when mass-accretion rate becomes higher, may be able to explain the observed properties of the soft excess component.

3. $L_{\rm soft}$ v.s. L_{2-10}

We also found that the luminosity of the soft excess component $L_{\rm soft}$ has a strong positive correlation with that of the 2–10 keV power law continuum. Moreover, this relation is also held in a typical BLS1 NGC 5548. According to the inverse Compton model, which well explained the observed behavior of the power law continuum of NGC 5548, soft photons of the excess component are up-scattered into the hard power law component by hot electron clouds. The strong correlation between intensities of the two components support that such a model works commonly for both BLS1s and NLS1s. It is favorable for the unified scheme of all Seyfert galaxies.

Appendix A

X-ray Images of Narrow-Line Seyfert 1 Galaxies in our sample

In this section, we show X-ray images in our sample. Since X-ray continua of our sample are well represented by a combination of a power law, which dominates above 2 keV, and a soft excess component, which dominates below 2 keV, we made two band (0.3–2 and 2–12 keV) images. Left and right panels in Figure A.1 exhibit the soft (0.3–2 keV) and the hard (2–12 keV) X-ray images of 30' × 30' region, which is consistent with the field of view of *XMM-Newton*. The soft band images are ranging from a peak counts to three order magnitude less counts than the peak, on the other hand, the hard band ones are from a peak to two order of magnitude less counts than the peak intensity. We also plotted radial profiles in each energy band. The shapes are almost the same in our sample.

Figure A.1: X-ray images and radial profiles in our sample. Left, 0.3–2 keV band; right, 2–12 keV band

Tos S180, (RA, DEC)=(00 57 19.94, -22 22 59.1)
arcmin

Tos S180, (RA, DEC)=(00 57 19.94, -22 22 59.1)
arcmin

PSF
[arcsec]

PSF
[arcsec]

Mrk 359, (RA, DEC)=(01 27 32.60, +19 10 44.0)
arcmin

Mrk 359, (RA, DEC)=(01 27 32.60, +19 10 44.0)
arcmin

PSF
[arcsec]

PSF
[arcsec]

NAB 0205+024, (RA, DEC)=(02 07 49.80, +02 42 56.0)
arcmin

NAB 0205+024, (RA, DEC)=(02 07 49.80, +02 42 56.0)
arcmin

PSF
[arcsec]

PSF
[arcsec]

PKS 0558-504, (RA, DEC)=(05 59 47.40, -50 26 51.0)
arcmin

PKS 0558-504, (RA, DEC)=(05 59 47.40, -50 26 51.0)
arcmin

PSF
[arcsec]

PSF
[arcsec]

1H 0707-495, (RA, DEC)=(07 08 41.10, -49 32 36.2)
arcmin

1H 0707-495, (RA, DEC)=(07 08 41.10, -49 32 36.2)
arcmin

PSF
[arcsec]

PSF
[arcsec]

RE 1034+396, (RA, DEC)=(10 34 38.90, +39 38 32.0)
arcmin

RE 1034+396, (RA, DEC)=(10 34 38.90, +39 38 32.0)
arcmin

PSF
[arcsec]

PSF
[arcsec]

NGC 4051, (RA, DEC)=(12 03 09.63, +44 31 53.2)
arcmin

NGC 4051, (RA, DEC)=(12 03 09.63, +44 31 53.2)
arcmin

PSF
[arcsec]

PSF
[arcsec]

PG 1211+143, (RA, DEC)=(12 14 17.60, +14 03 12.5)
arcmin

PG 1211+143, (RA, DEC)=(12 14 17.60, +14 03 12.5)
arcmin

PSF
[arcsec]

PSF
[arcsec]

PG 1244+026, (RA, DEC)=(12 46 35.29, +02 22 08.3)
arcmin

PG 1244+026, (RA, DEC)=(12 46 35.29, +02 22 08.3)
arcmin

PSF
[arcsec]

PSF
[arcsec]

IRAS 13224-3809, (RA, DEC)=(13 25 19.28, -38 24 53.5)
arcmin

IRAS 13224-3809, (RA, DEC)=(13 25 19.28, -38 24 53.5)
arcmin

PSF
[arcsec]

PSF
[arcsec]

Mrk 478, (RA, DEC)=(14 42 07.46, +35 26 22.9)
arcmin

Mrk 478, (RA, DEC)=(14 42 07.46, +35 26 22.9)
arcmin

PSF
[arcsec]

PSF
[arcsec]

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