Emission Lines in Active Galaxies: New Methods and Techniques
ASP Conference Series, Vol. 113, 1997
B.M. Peterson, F.-Z. Cheng, and A.S. Wilson (eds.)

A Link Between Seyfert Emission-Line Widths and X-Ray Continuum Slopes

Th. Boller[1] and W.N. Brandt[2]

[1]*Max-Planck-Institut für Extraterrestrische Physik, Postfach 1603, D-85748 Garching, Germany*

[2]*Institute of Astronomy, Madingley Road, Cambridge CB3 0HA, UK*

Abstract. This paper reports on AGN with extremely soft X-ray spectra observed with *ROSAT*. From their optical emission lines, these objects are classified as narrow-line Seyfert 1 galaxies (NLS1), almost all with extremely large Fe II/Hβ flux ratios and relatively narrow optical lines of hydrogen. NLS1 have generally steeper soft X-ray continuum slopes than normal Seyfert 1s, and there may exist an anticorrelation between 0.1–2.4 keV continuum slope and the FWHM of the Hβ line. Objects with steep 0.1–2.4 keV continuum slopes and Hβ FWHM $> 3000\,\mathrm{km\,s^{-1}}$ are clearly discriminated against by nature. When simple power-law models are fit to the data, photon indices reach values up to about 5, much higher than is usually seen in Seyfert 1s. Models with smaller-mass black holes and/or higher accretion rates show some promise to explain the relation between the FWHM of the Hβ line and the X-ray continuum slope. We further report evidence for persistent giant and rapid variability in the ultrasoft narrow-line Seyfert 1 galaxy *IRAS* 13224−3809.

1. Introduction

Narrow-line Seyfert 1 galaxies (hereafter NLS1) are a peculiar group of AGN where (1) the Balmer lines of hydrogen are only slightly broader than the forbidden lines such as [O III], [N II] and [S II]; (2) there are often present emission lines from Fe II (i.e., the optical multiplets centered at 4570 Å, 5190 Å and 5300 Å) or higher-ionization iron lines such as [Fe VII] λ6087 and [Fe X] λ6375 (these lines are often seen in Seyfert 1 galaxies, but generally not in Seyfert 2 galaxies); and (3) the ratio of [O III] λ5007 to Hβ is < 3, a level which Shuder & Osterbrock (1981) found to discriminate well Seyfert 1s from Seyfert 2s. The full width at half maximum (FWHM) of NLS1 hydrogen Balmer lines is usually in the range $\sim$ 500–1500 $\mathrm{km\,s^{-1}}$.

2. Results on NLS1 as a Class

With *ROSAT*, NLS1 were discovered to have remarkable X-ray properties (see Boller, Brandt & Fink 1996, hereafter BBF96). Their X-ray spectra are often

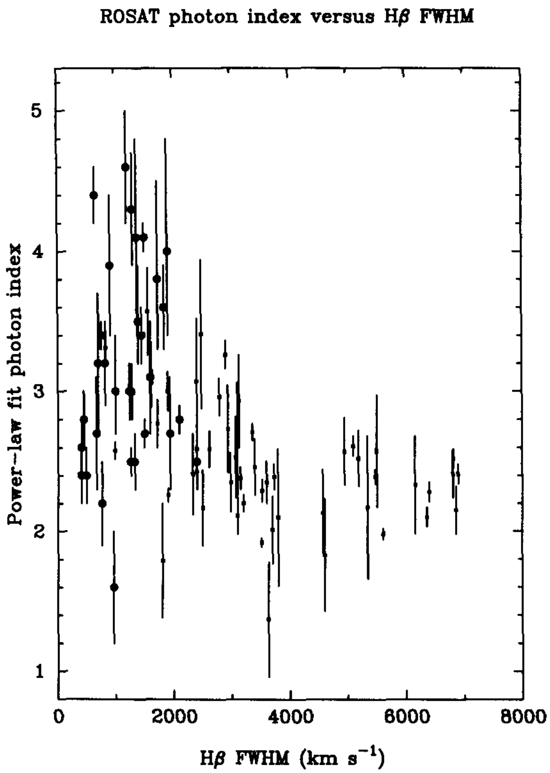

Figure 1. X-ray continuum slope, obtained from a power-law fit, versus FWHM of Hβ for Seyfert 1 galaxies (vertical bars) and NLS1 (filled dots).

much softer than those of Seyfert 1 galaxies with broader lines, and they can exhibit remarkably rapid and giant-amplitude variability.

2.1. Steep Soft X-Ray Spectrum AGN

As a class NLS1 generally appear to have steeper soft X-ray spectra than normal Seyfert 1s. In Fig. 1, we illustrate this by showing a plot of the *ROSAT* 0.1–2.4 keV photon index versus the FWHM of the Hβ line. NLS1 and normal Seyfert 1 groups appear to merge continuously with each other. This is in harmony with the work of Goodrich (1989), who argued that the 'differences' between NLS1 and normal Seyfert 1s really represent a continuum of properties.

2.2. The Soft X-ray Variability of NLS1

Many NLS1 show rapid soft X-ray variability (cf. Table 1 and Fig. 9 of BBF96). Rapid large-amplitude variations indicate that substantial fractions of the soft X-rays from NLS1 come from compact regions less than a light day in size. Variability on short time scales argues that most of the soft X-ray emission from

https://doi.org/10.1017/S0252921100040203 Published online by Cambridge University Press

NLS1 must be seen directly from the emitting regions, indicating that NLS1 almost certainly do not have obscured cores.

2.3. Soft X-ray Absorption by Cold Matter

X-ray spectral fits to our sample of NLS1 generally do not show evidence for large amounts of cold absorption over the Galactic column. The weighted mean difference between the value of the neutral hydrogen column density derived from our spectral fits and the foreground Galactic value derived from radio maps (Stark et al. 1992) is $1.13 \times 10^{20}\,\mathrm{cm}^{-2}$ and the uncertainty in this mean is less than $0.10 \times 10^{20}\,\mathrm{cm}^{-2}$.

3. Models for NLS1 and Relevant Physical Processes

Relevant physical models for NLS1 are presented in §6 of BBF96. We examined NLS1 models where NLS1 are Seyfert 1s with extreme values of orientation, black-hole mass and/or accretion rate, warm absorption, and BLR thickness. All simple models appear to have drawbacks. Models with smaller-mass black holes and/or high accretion rates show some promise. If NLS1 have stronger soft components or soft components that extend to higher energies than usual, this would make them appear to have steeper *ROSAT* spectra since there would be more flux in the low-energy part of the *ROSAT* band. Smaller-mass black holes and/or AGN with a higher accretion rate are predicted to have hotter soft X-ray components that extend to higher energies (compare, for example, Figs. 3 and 4 of Ross, Fabian, & Mineshige 1992) and narrower Seyfert 1 optical emission lines may result from larger accretion rate to black-hole mass ratios.

4. ROSAT Discovery of Persistent Giant and Rapid Variability

Here we (Boller et al. 1996) report the discovery of persistent giant and rapid variability in the narrow-line Seyfert 1 galaxy *IRAS* 13224−3809. Within a 30-day *ROSAT* HRI monitoring observation, at least five giant-amplitude variations are clearly visible, with the maximum observed amplitude of variability being about a factor of 60. *IRAS* 13224−3809 appears to be the most variable radio-quiet AGN known. In Fig. 2, we illustrate the observed variability by showing a plot of the *ROSAT* HRI count rate versus time. The data are binned into bins with widths of 2000 seconds or less. The amount of integration time per bin is always larger than 400 seconds, to avoid apparent flux variations due to the *ROSAT* wobble. We have computed the lowest and highest count rates observed to determine the maximum amplitude of variability. The lowest count rate is observed during day 5. We have fitted a constant model to these data and obtain a source count rate of $(4.7 \pm 2.5) \times 10^{-3}$ counts s^{-1}. The maximum observed count rate was 0.287 ± 0.019 counts s^{-1}, during a 791-second exposure interval starting on Julian Date 17.9861. The most probable maximum variability amplitude is a factor of 61. The most extreme amplitude variation in a short time occurs between days 16.0160 and 17.9861. We observe an increase of the count rate from $(5.0 \pm 1.9) \times 10^{-3}$ counts s^{-1} (summed over an exposure interval of 4656 seconds) to 0.287 ± 0.019 counts s^{-1} (exposure interval of 791 seconds). This

https://doi.org/10.1017/S0252921100040203 Published online by Cambridge University Press

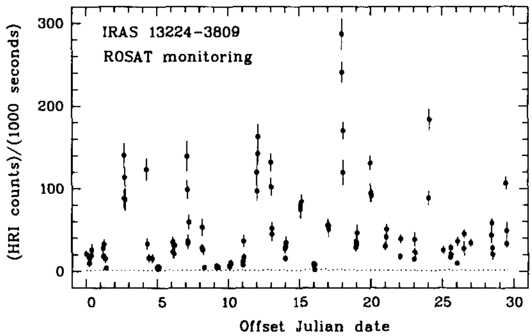

Figure 2. *ROSAT* HRI light curve obtained in an 30-day monitoring observation between 1996 January 11 (0:33:42) and 1996 February 9 (13:23:28) of the narrow-line Seyfert 1 galaxy *IRAS* 13224−3809. The abscissa label gives the Julian Date minus 2450093.523 days. The dashed curve indicates the background counting rate within the source extraction circle as a function of time. At least five giant-amplitude variations are visible.

corresponds to an amplitude for giant variability of about 57 within about two days. The *ROSAT*-band isotropic luminosity rises from about 1.5×10^{43} ergs s^{-1} to about 8.3×10^{44} ergs s^{-1} within about two days, giving strong constraints on starburst models for AGN. We carefully examined the identification of the highly variable X-ray source with the distant galaxy, and it appears to be secure. The persistent giant-amplitude X-ray variability we see from *IRAS* 13224−3809 suggests that interesting physical processes are operating in the core of this galaxy. Possible explanations for the variability will be presented in Boller et al. (1996).

References

Boller, Th., Brandt, W. N., & Fink, H. 1996, A&A 305, 53 (BBF96).

Boller, Th., Brandt, W. N., Fabian, A. C., & Fink, H. 1996, in preparation.

Goodrich, R. W. 1989, ApJ 342, 224.

Ross, R. R., Fabian, A. C., and Mineshige, S. 1992, MNRAS 258, 189.

Shuder, J. M., & Osterbrock, D. E. 1981, ApJ 250, 55.

Stark, A. A., Gammie, C. F., Wilson, R. W., Bally, J., Linke, R., Heiles, C., & Hurwitz, M. 1992, ApJS 79, 77.