Publ. Astron. Soc. Japan **43**, L37–L42 (1991)

Discovery of Strong Absorption in the X-Ray Spectrum of Seyfert 2 Galaxy NGC 4507

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(Received 1991 April 26; accepted 1991 May 22)

Abstract

We discovered an obscured nucleus in Seyfert 2 galaxy NGC 4507 with the Ginga satellite. The 2–10 keV X-ray luminosity is 3.2×10^{43} erg s^{-1}, and the continuum radiation is well described by a power law model with a photon index of $1.34^{+0.28}_{-0.25}$. The column density of the obscuring matter is $(4.9 \pm 0.7) \times 10^{23}$ cm^{-2}, which is sufficiently thick to hide the broad-line region and the nucleus. An iron line with equivalent width of 420^{+100}_{-110} eV has also been detected in the X-ray spectrum. In order to explain the large equivalent width, a large covering factor for the matter around the nucleus is needed. The obscuration can be naturally explained in terms of a torus in the unified Seyfert model.

Key words: Active galactic nuclei; NGC 4507; Seyfert 2 galaxies.

1. Introduction

Seyfert galaxies are a class of active galactic nuclei which have a compact nucleus with powerful non-stellar radiation extending from the radio to γ-ray range. Seyfert galaxies are divided into two subclasses, Seyfert 1 galaxies and Seyfert 2 galaxies, based upon the presence or absence of a broad (FWHM $>$ 2000 km s^{-1}) emission line of hydrogen and other elements of optical wavelength.

Recent studies using optical spectropolarimetry and X-ray spectra obtained by Ginga have revealed obscured nuclei and hidden broad line regions in several Seyfert 2 galaxies (Antonucci and Miller 1985; Koyama et al. 1989; Warwick et al. 1989; Miller and Goodrich 1990; Awaki et al. 1990). These results support the "unified Seyfert model," in which the broad line region and a central powerful source are present in both types of Seyfert galaxies, but are surrounded by a geometrically, optically thick disk. The differences between Seyfert 1 and Seyfert 2 galaxies can be described by one parameter, e.g., the viewing angle (e.g., Antonucci and Miller 1985).

In the soft X-ray band (0.5–4.5 keV) Seyfert 1 galaxies are luminous objects emitting typically 10^{44} erg s^{-1}, while Seyfert 2 galaxies have typical luminosities of only 5×10^{41} erg s^{-1} (Kriss et al. 1980; Kruper et al. 1990). This may be explained by the unified model: the X-ray emission from the central engine of Seyfert 2 galaxies is heavily absorbed. Therefore, broad-band X-ray observations are powerful tools which can be used to discover a hidden nucleus in Seyfert 2 galaxies. In this paper, we report clear evidence of such an obscured nucleus in the Seyfert 2 galaxy NGC 4507.

2. Observations and Results

Observations were made on 1990 July 7–8 with the Large Area Counters (LAC) onboard the Ginga satellite. The LAC comprises eight identical proportional counters, sensitive in the 1.5–38 keV band, with a total effective area of 4×10^3 cm^{-2} (Turner et al. 1989). The LAC field of view is about 1° by 2° (FWHM). The observations were sampled in 49 energy channels (MPC-1 data processing mode, with low bit rate). The source was observed for one day; after that a nearby blank field was observed.

In order to obtain a reliable spectrum, we selected data with a high cut-off rigidity ($>$ 9 GeV/c) from the low-background orbits (Hayashida et al. 1989; Awaki et al. 1991a). Unusually large count rates caused by sudden increases in the number of charged particles were carefully analyzed and excluded. The effective observation time of the source was 7×10^3 s.

The raw data includes the intrinsic background of the detectors (IBG) and the cosmic diffuse X-ray background (CXB). The IBG and CXB were estimated separately. IBG was estimated using the LAC house-keeping count rate (SUD described in Hayashida et al. 1989) as well as the counting rate in the 2–7 energy channels located in the middle layers of the detector. A local CXB spectrum for NGC 4507 was produced from the average CXB spectrum by normalizing the total flux to that of the nearby sky. The normalizing factor was 1.035, indicating that fine tuning of the local CXB was negligibly small.

We used only the data from the top layers of the detectors, since the S/N ratio of the top layer, alone, is better than that for the combined data (top plus middle layer) in the 2–10 keV energy band. Figure 1 shows the pulse-height spectrum in the top layer after background subtraction. The observed count rate was about 3.7 counts s^{-1} in the 1.5–9 keV band, corresponding to significant detection at the 4σ confidence level.

2.1. Spectral Fitting

The spectrum was fitted in the 4–20 keV range to a power law with low energy absorption. A narrow emission line and an absorption edge of iron were also included in our model function. The photoelectric absorption cross sections of cold matter and iron were taken from Brown and Gould (1970) as well as McMaster et al. (1970), respectively. The complete model had 7 free parameters, resulting in an acceptable

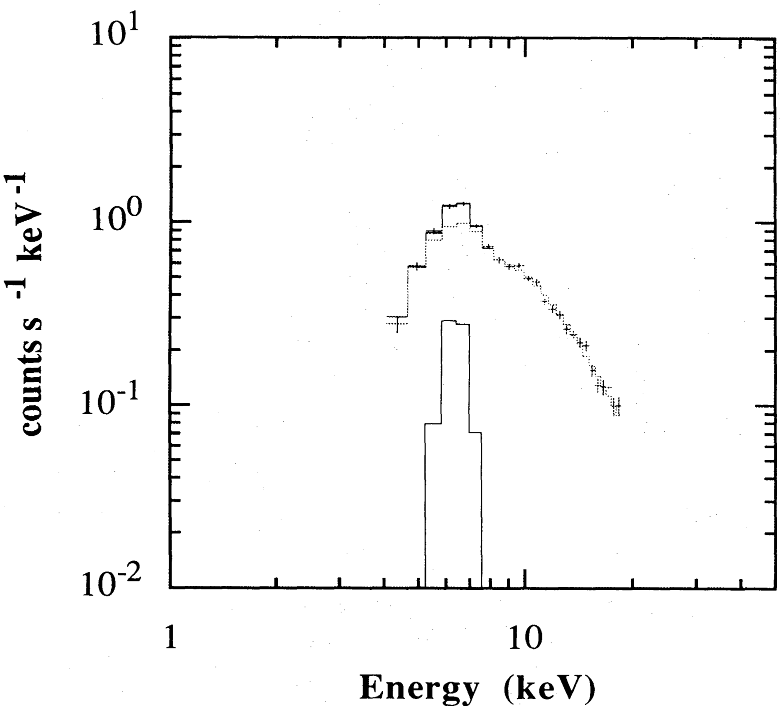

Fig. 1. LAC pulse height spectrum of NGC 4507. The histograms show the best-fit model as described in the text.

fit ($\chi^2 = 21$ for 18 degrees of freedom); the best-fit parameters are listed in the table. The photon index and hydrogen column density were $1.34^{+0.28}_{-0.25}$ and $(4.9 \pm 0.7) \times 10^{23}$ cm^{-2}, respectively. The equivalent width of the iron line was 420^{+100}_{-110} eV and the absorbing iron column density (N_{Fe}) was $(1.7 \pm 0.1) \times 10^{19}$ cm^{-2} (equivalent to a neutral hydrogen column density of 5.2×10^{23} cm^{-2} assuming cosmic abundances), respectively. The centroid of the emission line was $6.23^{+0.13}_{-0.10}$ keV and the edge energy was $7.37^{+0.19}_{-0.21}$ keV, respectively. The observed energy flux in the 2–10 keV band was 1.6×10^{-11} erg s^{-1} cm^{-2}, and the unabsorbed flux 6.6×10^{-11} erg s^{-1} cm^{-2}. This implies an intrinsic 2–10 keV luminosity of 3.2×10^{43} ergs s^{-1} (D=65 Mpc).

The low-energy cut-off in the spectrum may also be explained by reflection from cold material (e.g., Pounds et al. 1989; Matsuoka et al. 1990; Piro et al. 1990). We therefore tried to fit the X-ray spectrum with a reflection model, but had to reject it (a χ^2 value of 449 for 21 degrees of freedom). We further tried to estimate the maximum contribution of any reflection component using as model the sum of the absorbed direct component and the reflection component. The upper limit to the reflection component was 50% of the total flux at the 90% confidence level.

2.2. Timing Analysis

We made a light curve of NGC 4507 in the 4.5–20 keV band. Since the spectrum of NGC 4507 shows a low-energy cut-off, we did not include the counting rate below 4.5 keV. The light curve shown in figure 2 has a time resolution of 128 s. The data were consistent with a constant flux for all time scales between 10^2–3.6×10^4 s at the

Table 1. The results of spectral fitting.

Flux a) (erg s^{-1} cm^{-2})	Γ b)	N_H c) ($\times 10^{23}$ cm^{-2})	E.W.$_{Fe}$ d) (eV)	Energy e) (keV)	N_{HFe} f) ($\times 10^{23}$ cm^{-2})	Energy g) (keV)	χ^2 (D.O.F.)
1.6×10^{-11}	$1.34^{+0.28}_{-0.25}$	4.9 ± 0.7	420^{+100}_{-110}	$6.23^{+0.13}_{-0.10}$	5.2 ± 0.2	$7.37^{+0.19}_{-0.21}$	21.0 (18)

Notes: Errors are 90% confidence limits. a) observed flux in the 2–10 keV band. b) photon index. c) column density. d) equivalent width. e) energy of the iron line corrected for the redshift. f) $N_{HFe} = N_{Fe} \cdot 10^{4.48}$. g) energy of the iron edge corrected for the redshift.

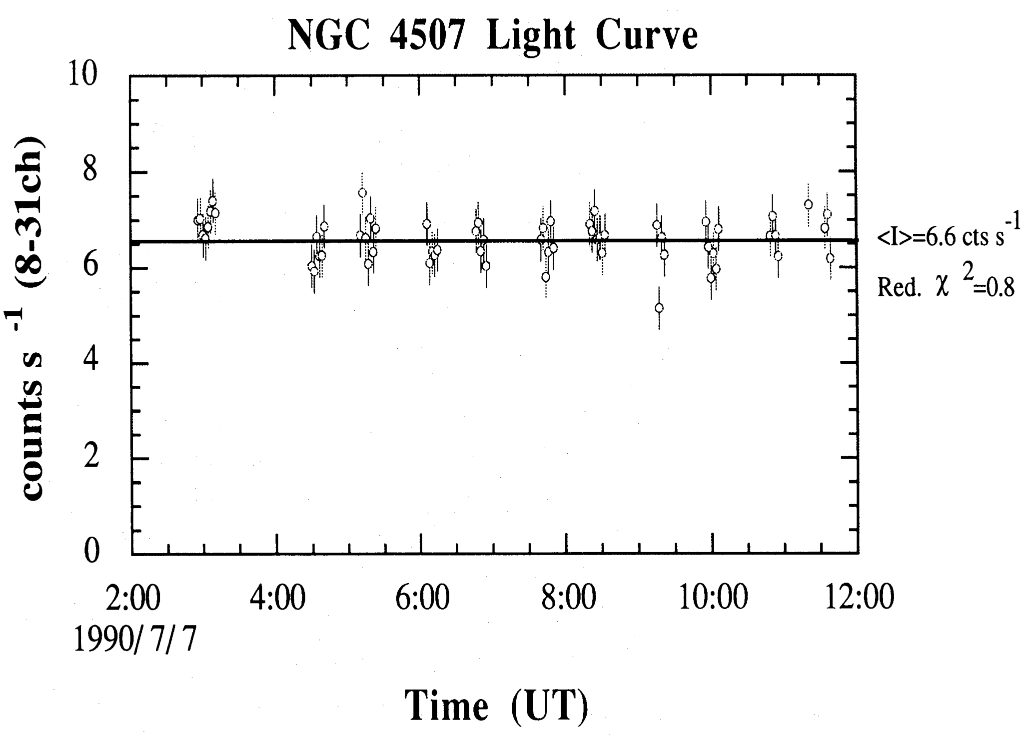

Fig. 2. Light curve for NGC 4507 in the 4.5–18.5 keV band. The binning time is 128 s. The solid line shows a mean intensity, <I>, of 6.6 counts s^{-1}.

~90% confidence level ($\chi^2 = 50$ for 62 degrees of freedom).

3. Discussion

NGC 4507 is a barred spiral galaxy, classified as SBab(rs)I, with a redshift of 0.01088 (Phillips et al. 1983). The visual magnitude is 13.6 and the optical coutinuum emission is strongly peaked at the nucleus. Highly excited lines appear in the spectrum of the inner regions up to a distance of about 2 kpc, as well as in the nucleus; the gas in the nucleus and inner region is photoionized by the non-stellar continuum from the active nucleus (Durret and Bergeron 1986).

We found that the continuum X-ray emission could be well described by a power law with a photon index of $1.34^{+0.28}_{-0.25}$ within the typical range for Seyfert 1 galaxies (Turner and Pounds 1989). The spectrum of NGC 4507 showed extremely large absorption with $N_H \sim 5 \times 10^{23}$ cm^{-2} at low energies and around the iron K-edge at $\sim$ 7 keV. The intrinsic 2–10 KeV luminosity (corrected for large absorption) is 3.2×10^{43} erg s^{-1}, which is also typical of Seyfert 1 galaxies. We thus conclude that the X-ray continuum emission originated from the same type of central engine as that found in Seyfert 1 galaxies. The major difference is only the presence of strong absorption.

We detected no significant time variability from NGC 4507 during a period of 3.6×10^4 s. This is consistent with the relationship between the variability time scale and the X-ray luminosity which was found by Barr and Mushotzky (1986).

From the measured iron edge energy, the ionization state of iron is 10 ± 6. This condition is satisfied if the ionization parameter ($\xi = L/nr^2$) is 25 using model 7 of Krolik and Kallman (1987). The ionization parameter $\xi \sim 25$ implies that the electron temperature is $\sim 10^5$ K and that elements heavier than He in the gas are not fully ionized. The low-energy cut-off due to the absorption arising from these lighter elements is consistent with the depth of the iron K-edge for the cosmic abundances of cold matter. The column density of the obscuring gas corresponds to Av $\sim$ 200 mag if a typical galactic dust-to-gas ratio (Seaton 1979) is used, and the gas is sufficiently thick to hide the central source and broad-line region in most wave bands other than that of hard X-rays.

The intensity of the iron line gives a constraint on the geometrical structure of the obscuring gas. We obtained an equivalent width of 420 ± 100 eV for NGC 4507. If the gas has full coverage with a spherical distribution, an equivalent width of 320 ± 80 eV is expected from the measured iron column density of $(1.7 \pm 0.1) \times 10^{19}$ cm^{-2} (Awaki et al. 1991b). The covering factor (f) would therefore be larger than 80%. The thick matter with a large covering factor can be attributed to a torus in the unified Seyfert model. In the host galaxy (NGC 4507), two components with a similar velocity dispersion and separated by 840 km s^{-1} have been observed in the strong emission lines of the nucleus (Durret and Bergeron 1986). This result may be explained by a collimation effect caused by the torus around the active nucleus, which produces an ionization cone near the nucleus (Pogge 1989).

The authors would like to express their thanks to all members of the Ginga team. Thanks are also due to Dr. J. S. Kaastra and Dr. M. Matsuoka for critical reading of the manuscript and comments. The data analysis was performed using the FACOM M380 computer of the High Energy Physics Laboratory of Nagoya University. This work was supported in part by the Scientific Research Fund of the Ministry of Education, Science and Culture under Grant No. 02952008 (H.A.).

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