CHANDRA OBSERVATIONS OF NGC 4698: A SEYFERT 2 GALAXY WITH NO ABSORPTION

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Received 2003 February 24; accepted 2003 May 22

ABSTRACT

We present Chandra ACIS-S observations of the enigmatic Seyfert 2 galaxy NGC 4698. This object, together with several other bona fide Seyfert 2 galaxies, shows no absorption in the low spatial resolution ASCA data, in contrast to the standard unification models. Our Chandra observations of NGC 4698 probe directly the nucleus, allowing us to check whether nearby sources contaminate the ASCA spectrum. Indeed, the Chandra observations show that the ASCA spectrum is dominated by two nearby AGNs. The X-ray flux of NGC 4698 is dominated by a nuclear source with luminosity $L_{0.1-8\,\text{keV}} \approx 10^{39}\,\text{ergs}\,\text{s}^{-1}$, coincident with the radio nucleus. Its spectrum is well represented by a power law, $\Gamma \approx 2.2$, obscured by a small column density of $5 \times 10^{20}\,\text{cm}^{-2}$, suggesting that NGC 4698 is an atypical Seyfert galaxy. On the basis of its low luminosity, we then interpret NGC 4698 as a Seyfert galaxy that lacks a broad-line region.

Subject headings: galaxies: active — galaxies: individual (NGC 4698) — galaxies: nuclei — quasars: general

1. INTRODUCTION

Seyfert galaxies are roughly divided into those presenting broad emission lines ($>1000\,\text{km}\,\text{s}^{-1}$; Seyfert 1) in their spectra and those having only narrow lines (Seyfert 2). In the standard active galactic nucleus (AGN) unification models (see Antonucci 1993 for a review), the two types of Seyfert galaxies are intrinsically identical, with their differences being an orientation effect. In particular, an accretion disk produces the UV continuum that ionizes the surrounding gas: the broad-line region (BLR) and the narrow-line region (NLR), at distances typically less than 0.1 and less than 100 pc, respectively (see, e.g., Robson 1996). Then, a Seyfert galaxy is classified as type 2 if our line of sight toward the nucleus intercepts an obscuring screen, the so-called torus, which blocks the BLR. There have been several observations supporting these simple unification models. Ground-breaking optical studies have detected broad lines in polarized light in NGC 1068, demonstrating that a hidden BLR is present in this Seyfert 2 galaxy (Antonucci & Miller 1985). Similarly, IR observations showed the existence of obscured BLRs in several Seyfert 2 galaxies (Veilleux, Goodrich, & Hill 1997). Further evidence supporting the unification models comes from X-ray observations of Seyfert 2 galaxies that show large amounts of obscuration, typically above $10^{23}\,\text{cm}^{-2}$ (see, e.g., Smith & Done 1996; Turner et al. 1997).

However, some questions arise regarding whether the unification models can be applied to all Seyfert galaxies. Polarimetry studies have shown that a significant fraction of Seyfert 2 galaxies appear to lack a hidden BLR (Moran et al. 2000; Tran 2001). A correlation with luminosity is observed, in the sense that the less luminous Seyfert nuclei are those missing a BLR (Tran 2001; Lumsden & Alexander 2001). Moreover, ASCA observations of some Seyfert 2 galaxies show that these do not present intrinsic X-ray absorption: NGC 3147 (Ptak et al. 1996), NGC 7590 (Bassani et al. 1999), and NGC 4698 (Pappa et al. 2001). Recently, Panessa & Bassani (2002) added several more candidates to this list. One has to be cautious in identifying candidate “unabsorbed Seyfert 2 galaxies,” as the optical spectroscopy may not be of sufficient quality to classify them as bona fide Seyfert 2 galaxies. Furthermore, some of the objects may be Compton-thick; i.e., the transmitted component below 10 keV is completely absorbed. Then, in the ASCA 1–10 keV band we would observe only the scattered, unabsorbed component. The lack of a strong Fe line at 6.4 keV, as well as the high ratio of the broadband hard X-ray to [O iii] line emission (the latter comes from the NLR and thus represents an isotropic measurement of the luminosity; see, e.g., Alonso-Herrero, Ward, & Kotilainen 1997), can be used to discriminate against the Compton-thick model. Finally, the ASCA point-spread function (PSF) is large ($3''$ half-power diameter), and hence the observed X-ray emission may be contaminated by other nearby sources or the integrated emission of the host galaxy. This confusion problem is particularly important in the low-luminosity Seyfert galaxies, where the energy output of a few strong, ultraluminous X-ray (ULX) sources may rival the luminosity of the nucleus (see, e.g., Ho et al. 2001).

Here, we discuss Chandra observations of NGC 4698. NGC 4698, at a distance of 16.8 Mpc, belongs to the spectroscopic sample of nearby galaxies of Ho, Filippenko, & Sargent (1997). The excellent-quality nuclear spectra obtained ($2'' \times 4''$ slit) make the Seyfert 2 classification for this galaxy highly certain. Pappa et al. (2001) observed NGC 4698 with ASCA. Their best-fit model is an unobscured $[(9 \pm 4) \times 10^{20}\,\text{cm}^{-2}]$ power law ($\Gamma \approx 1.91 \pm 0.12$) with a luminosity of $L_{2-10\,\text{keV}} \approx 2 \times 10^{40}\,\text{ergs}\,\text{s}^{-1}$, No Fe K line is detected, with the upper limit on equivalent width being $\sim 0.4\,\text{keV}$ at the 90% confidence level. The absence of a strong Fe K line, as well as the high value of the $fX/f_{\text{[O iii]}}$ ratio, suggested that NGC 4698 is not a Compton-thick object. However, the spectrum measured by ASCA may be contaminated by other nearby sources that mask the true nuclear emission. The excellent spatial resolution of Chandra allows us to obtain a direct view of the nuclear region without any confusion problems.
2. OBSERVATIONS AND DATA REDUCTION

NGC 4698 was observed on 2002 June 16 (observation ID 3008), using the Advanced CCD Imaging Spectrometer, ACIS-S, on board *Chandra* (Weisskopf, O’Dell, & van Speybroeck 1996). The back-side–illuminated ACIS-S3 CCD was on the aim point, providing a spatial resolution of 0.5 and minimizing charge transfer inefficiency (CTI) problems. In order to minimize pileup, the observation was performed in half-subarray mode. In this mode the field of view is 4.1 × 8.3, which covers the whole galaxy. We use the type 2 event file (including only grades 0, 2, 3, 4, and 6) provided by the standard pipeline processing, after discarding periods of high background. The resulting exposure time is 29,726 s. Images, spectra, and light curves have been created using the CIAO, version 2.2, software. The imaging and timing analysis were performed using the SHERPA software. For the spectral fitting we use the XSPEC, version 11, software package.

3. ANALYSIS

3.1. Imaging

Three strong sources are detected by *Chandra* in the vicinity of NGC 4698. The detected sources, together with the ASCA GIS contours, are shown in Figure 1. The cross gives the position of the central source, which is spatially coincident with the optical center of the galaxy, and therefore we identify it as the nucleus. The nuclear source is also coincident with a faint radio source detected by Ho & Ulvestad (2001) at equatorial coordinates α = 12h48m22.92, δ = +08°29′14″5 (J2000.0). Its radio flux density was 0.23 mJy at 6 cm, corresponding to a radio power of ∼10^{19} W Hz^{-1}. RX J1248.4+0831 (source 1 in Fig. 1), originally detected in the ROSAT All-Sky Survey, was identified as a redshift z = 0.12 AGN (Bade et al. 1998). J124825.9+08302 is a radio source (denoted as source 2 in Fig. 1), detected by Ho & Ulvestad (2001), having a flux density of 0.8 mJy at 6 cm. Recently, Foschini et al. (2002) identified this source as a probable BL Lac object at a redshift of z = 0.43. Since the latter sources are ∼6 and ∼4 times brighter than the nucleus of NGC 4698 in the 0.3–8.0 keV band (Table 1), respectively, the ASCA spectrum is dominated by them instead of the NGC 4698 nucleus. Although the ASCA data cannot give an uncontaminated spectrum of the nucleus because of their limited spatial resolution, Pappa et al. (2001) assumed that all the X-ray emission observed by ASCA arises from NGC 4698 and failed to discuss the possible contamination from the nearby ROSAT source.

The X-ray luminosity of the nuclear source is relatively low (L_X ∼ 10^{39} ergs s^{-1}; 0.3–8.0 keV), leaving open the possibility that it could be associated with an ULX (see Ward 2002 for a recent review). Nevertheless, the fact that the nuclear X-ray source is coincident with the radio and optical nucleus suggests that our source is most probably associated with the supermassive black hole at the center of NGC 4698. Moreover, the ratio of the X-ray to radio luminosity (see Terashima & Wilson 2003 for the definition) of the nuclear source in NGC 4698 is an order of magnitude lower than in the case of the ULX in NGC 5408, the only extragalactic X-ray binary emitting at ULX levels identified with a radio source (Kaaret et al. 2003). The value of the above ratio (∼10^{-6}) puts NGC 4698 clearly in the regime of radio-quiet AGNs.

Seven more X-ray sources are detected within or around NGC 4698 down to ∼2 × 10^{-15} ergs cm^{-2} s^{-1}. The details of all the above sources are given in Table 1. We give the name, equatorial coordinates (J2000.0), counts, absorbed flux, and luminosity (all in the total 0.3–8 keV band) in columns (1), (2), (3), (4), and (5), respectively. Counts were extracted from a 4 pixel (2″) radius circle. For the seven off-nuclear sources in NGC 4698, the conversion from count rate to flux was performed assuming a power-law spectrum of Γ = 1.9, consistent with the spectrum of low-mass X-ray binaries in nearby galaxies (see, e.g., Prestwich et al. 2003). We further assume that the above spectrum is only absorbed by the Galactic column density, N_H = 2 × 10^{20} cm^{-2} (Dickey & Lockman 1990). For the nucleus, RX J1248.4+0831, and
J124825.9+083021, we used the spectra derived from the spectral fits below. Luminosities are estimated assuming $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $q_0 = 0.5$, and $\Lambda = 0$.

We have fitted the two-dimensional spatial profile of the nuclear source with the SHERPA software. We use a radius of 2$''$ for our fit. Fitting a Gaussian profile, we obtain an FWHM of 1$''$. Background regions are taken from source-free regions on the same chip. Note, however, that the background contribution is practically negligible, with about 1 count in the above extraction radius. We group the data so that there are at least 15 counts per bin. The quoted errors to the best-fitting spectral parameters correspond to the 90% confidence level for one interesting parameter. We discard data below 0.3 keV because of the low response, as well as calibration uncertainties. In order to take into account the degradation of the ACIS quantum efficiency at low energies, we used the ACISABS model in the spectral fitting. We present in Table 2 spectral fits for the following sources:

### Table 1

| Name               | Equatorial Coordinates (J2000.0) | Counts | $\log f$ (0.3–8 keV) | $\log L$ (0.3–8 keV) |
|--------------------|----------------------------------|--------|----------------------|----------------------|
| Nucleus......................... | 12 48 22.9, +08 29 15           | 168    | −13.5               | 39.0                |
| CXU J124823.6+082844.............. | 12 48 23.6, +08 28 44          | 28     | −14.3               | 38.2                |
| CXU J124823.3+082901.............. | 12 48 23.3, +08 29 01          | 10     | −14.8               | 37.7                |
| CXU J124823.2+082915.............. | 12 48 23.2, +08 29 15          | 14     | −14.6               | 37.9                |
| CXU J124822.4+082917.............. | 12 48 22.2, +08 29 17          | 24     | −14.4               | 38.1                |
| CXU J124822.2+082926.............. | 12 48 22.2, +08 29 26          | 14     | −14.6               | 37.9                |
| CXU J124824.3+082754.............. | 12 48 24.3, +08 27 54          | 12     | −14.7               | 37.8                |
| CXU J124826.4+082955.............. | 12 48 26.4, +08 29 55          | 14     | −14.6               | 37.9                |
| RX J1248.4+0831..............     | 12 48 28.4, +08 31 12          | 986    | −12.6               | 42.8                |
| J124825.9+083021..............    | 12 48 25.9, +08 30 21          | 699    | −12.8               | 43.8                |

**Note.**—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

**The nucleus of NGC 4698.**—A single–power-law fit gives a good fit to the data ($\chi^2$/dof = 5.8/9). The column density is $N_H = 5.5^{+0.6}_{-0.5} \times 10^{20}$ cm$^{-2}$, a factor of 2 above the Galactic value ($2.0 \times 10^{20}$ cm$^{-2}$; Dickey & Lockman 1990). This is much lower than the column densities encountered in typical Seyfert 2 galaxies (see, e.g., Smith & Done 1996; Turner et al. 1997). The photon index is $\Gamma = 2.18^{+0.28}_{-0.44}$. Unfortunately, our data are not of sufficient quality to check for the presence of an Fe K line at 6.4 keV. The spectrum of the source, together with the residuals from the best-fit power-law model, are given in Figure 2.

**RXJ1248.4+0831.**—The single–power-law fit yields a relatively poor fit to the data ($\chi^2$/dof = 75.8/55). The photon index is $\Gamma \sim 1.7$, while the column density is constrained to be less than $1.0 \times 10^{20}$ cm$^{-2}$. The photon index is characteristic of those of Seyfert 1 nuclei (Nandra & Pounds 1994). When we add a thermal Raymond-Smith component (Raymond & Smith 1977), absorbed only by the Galactic column, the fit is significantly improved ($\chi^2$/dof = 64.5/55). The temperature of the thermal component is $kT \sim 0.2$ keV. Then, the photon index becomes $\Gamma = 1.49 \pm 0.12$. The luminosity of the thermal component is $L_{0.3-2\text{keV}} \sim 6 \times 10^{41}$ ergs s$^{-1}$, or about 20% of the total luminosity in this band.

### Table 2

| Source            | $N_H$ ($\times 10^{20}$ cm$^{-2}$) | $\Gamma$ | $\chi^2$/dof |
|-------------------|-----------------------------------|----------|-------------|
| NGC 4698 nucleus   | $5^{+0.7}_{-0.5}$                 | 2.18$^{+0.28}_{-0.44}$ | 58.9         |
| RX J1248.4+0831     | $9^{+0.0}_{-0.0}$                 | 1.67$^{+0.08}_{-0.01}$ | 75.8/55      |
| J124825.9+083021    | $4 \pm 4$                        | 2.02$^{+0.11}_{-0.01}$ | 40.0/38      |

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3 See http://asc.harvard.edu/cal/Acis/Cal_prods/qeDeg.
Sources in the galaxy contribute about 40% of the total contribution of the NGC 4698 nucleus is very small, of the total 0.3–8 keV ASCA not probe the nucleus of NGC 4698. A pure, observed spectrum in the 2–10 keV band over the scattered component from the back side of the torus dominates the emission. A model in which the X-rays come through unabsorbed while the BLR is attenuated is rather unlikely. A warm absorber retaining dust could, in principle, attenuate the optical radiation while leaving intact the X-rays. Still, a warm absorber would imprint strong oxygen absorption features in the X-ray spectrum below 1 keV. Such absorption edges have not been seen in the spectrum of NGC 3147, while it is impossible to check for such features in the much poorer quality spectrum of NGC 4698. Another possible explanation for the lack of X-ray absorption in NGC 4698 and NGC 3147 is that we are simply viewing a Seyfert 1 nucleus that does not have a BLR. This is the pure Seyfert 2 model of Tran (1995). Recent models (see, e.g., Nicastro 2000; Laor 2003) suggest that a BLR cannot exist at low accretion rates. In particular, Nicastro (2000; see also Nicastro, Martocchia, & Matt 2003) advocates a model in which the BLR is associated with a wind coming from the accretion disk. In this model, the width of the broad lines depends on the accretion rate, in the sense that AGNs accreting at a much lower rate than their Eddington limit [<(1–4) × 10\(^{-3}\)\(M_{\text{Edd}}\)] should possess no BLR. Note, however, that the exact accretion rate limit depends on the accretion disk physics. Therefore, it may not be surprising that there are a few cases of low accretion rate AGNs with BLRs (see the discussion in Laor 2003).

The accretion rate in the case of NGC 4698 can be easily estimated as follows. The observed velocity dispersion is 169 km s\(^{-1}\) (McElroy 1995; Corsini et al. 1999, estimate a somewhat lower value of 134 km s\(^{-1}\)). Then from the relation between the black hole mass and the velocity dispersion (see, e.g., Gebhardt et al. 2000), we find a black hole mass of \(M_{\text{BH}} \sim (2–8) \times 10^7 M_\odot\). In this estimate we take into account both the quoted errors in the relation of Gebhardt et al. (2000) and the variations between the different measurements of the velocity dispersion. Hence, the predicted Eddington luminosity is \(\sim (3–10) \times 10^{45} \text{ ergs s}^{-1}\). We estimate the bolometric luminosity by integrating the measured X-ray luminosity down to 100 \(\mu\)m, using a power-law energy spectrum of slope \(\alpha = 1\), characteristic of the broadband AGN spectrum (see, e.g., Robson 1996). This yields \(L_{\text{bol}} = 4 \times 10^{39} \text{ ergs s}^{-1}\). Note, however, that if we use instead the relation between the bolometric luminosity and the narrow H\(\alpha\) luminosity (see Laor 2003), we obtain \(L_{\text{bol}} = 4 \times 10^{40} \text{ ergs s}^{-1}\). Hence, \(L_{\text{bol}}/L_{\text{Edd}} \sim 4 \times 10^{-7}\) to \(1 \times 10^{-5}\). In the case of NGC 3147, we estimate a central mass of \((3–5) \times 10^8 M_\odot\), from the measured bulge velocity dispersion, 268 km s\(^{-1}\) (McElroy 1995). Therefore, the predicted Eddington luminosity is \(L_{\text{Edd}} = (4–6) \times 10^{46} \text{ ergs s}^{-1}\). Extrapolation of the X-ray emission down to 100 \(\mu\)m using \(\alpha = 1\) gives \(L_{\text{bol}} = 3 \times 10^{42} \text{ ergs s}^{-1}\); the narrow H\(\alpha\) luminosity gives instead \(L_{\text{bol}} = 3 \times 10^{44} \text{ ergs s}^{-1}\). Hence, \(L_{\text{bol}}/L_{\text{Edd}} \sim 5 \times 10^{-6}\) to \(1 \times 10^{-4}\). According to the theoretical models discussed earlier, these low accretion rates are totally consistent with an absent BLR.

Unfortunately, there are no polarimetry data for NGC 4698 or NGC 3147 available to search for the presence of a hidden BLR and therefore to test directly the above model. In the case of NGC 7590, which also has a low column density, where such data are available (Heisler, Lumsden, & Bailey 1997) no BLR is detected. Tran (2001) find that the Seyfert galaxies with no hidden BLR are those with the lowest luminosity. Therefore, it is possible that there is a link...
between the Seyfert 2 galaxies that present no absorption in their X-ray spectrum and those that lack a hidden BLR. However, in the samples of Tran (2001) and Lumsden & Alexander (2001), there are a few examples of Seyfert 2 galaxies without a BLR but with large amounts of X-ray absorption. This could be simply explained as an orientation effect in the standard unification model framework. Assuming that all AGNs with low accretion rate do possess a torus but have no BLR, objects like NGC 4698 that present no X-ray absorption must be viewed face-on, while the ones with absorption are viewed edge-on.

In conclusion, *Chandra* observations of NGC 4698 (and NGC 3147) confirm that these galaxies host nuclei that present very little X-ray absorption, although they are classified as Seyfert 2 galaxies by optical spectroscopy. This is in disagreement with the standard unification models, in which a dense obscuring screen is believed to block the BLR and to absorb the soft X-ray radiation. The most straightforward explanation is that NGC 4698 lacks a BLR. This could be in line with theoretical models in which the BLR clouds are not formed at low accretion rates, and it explains the low absorbing column density in other low-luminosity AGNs classified as type 2 on the basis of their optical spectra.

We thank Fabrizio Nicastro for many useful comments. This work has been supported by the NASA grant NAG G02-3127X.

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