Chandra Observations of the NLS1 RX J2217.9–5941

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ABSTRACT

We report the results of two Chandra ACIS-S observations from February and August 2003 of the highly X-ray variable Narrow-Line Seyfert 1 galaxy RX J2217.9–5941. Observations spanning the time from the ROSAT All Sky Survey (RASS) through an ASCA observation in 1998 indicate apparently monotonically decreasing flux by a factor of 30. The Chandra observations reveal increased emission over that seen in ASCA, supporting a persistent variability rather than an X-ray outburst event. However, the cause of the strong X-ray variability remains unclear. Our Chandra observations confirm the steep soft X-ray spectrum in the 0.2-2.0 keV band found during the ROSAT All-Sky Survey observation ($\alpha_X=2.7$). The spectral shape of the source appears to be variable with the spectrum becoming softer when the source becomes fainter. Best fitting models to the data include an absorbed broken power law, a blackbody plus power law, and a power law with partial covering absorption. The latter model suggests a variable partial-covering absorber in the line of sight which can explain in part the variability seen in RX J2217.9–5941. We suggest that there might be a population of Narrow Line Seyfert 1 galaxies which are at least at times highly absorbed.

Subject headings: galaxies: active - quasars:general - quasars: individual (RX J2217.9–5941)

1. Introduction

With the launch of the X-ray satellite ROSAT (Trümper 1982) the X-ray energy range down to 0.1 keV became accessible for the first time. During its half-year ROSAT All-Sky Survey (RASS, Voges et al. (1999)) a large number of sources with steep X-ray spectra were detected (Thomas et al. (1998); Beuermann et al. (1999); Schweppe et al. (2000)). About one third to one half of these sources are AGN. Grupe (1996) and Grupe et al. (1998a, 2004b) found that about 50% of these bright soft X-ray selected AGN are Narrow-Line Seyfert 1 galaxies (NLS1s). These sources were originally defined by their optical properties (Osterbrock & Pogge (1985); Goodrich (1989)) and they turned out to be the class of AGN with the steepest X-ray spectra (e.g. Stephens (1989); Puchnarewicz et al. (1992); Boller et al. (1996); Grupe (1996); Laor et al (1997); Brandt et al.
The most extreme case of X-ray variability found among galactic nuclei is X-ray transience (e.g. Gezari et al. 2003; Komossa 2002; Komossa et al. 2004; Donley et al. 2002; Vaughan et al. 2004; Halpern et al. 2004) in which a source appears bright in the X-ray sky only once and becomes very faint by factors of up to several thousand in later years.

In the case of X-ray outbursts seen in inactive galaxies such as RX J1624.9+7554 (Grupe et al. 1999a; Halpern et al. 2004), RX J1242.6–1119 (Komossa & Greiner 1999; Komossa et al. 2004), and RX J1420+5334 (Greiner et al. 2000) the most plausible explanation is the tidal-disruption-of-a-star scenario as suggested by Frank & Rees (1976) and Rees (1988). In the case of the outburst observed in the Seyfert 2 galaxies IC 3599 (Grupe et al. 1995a; Brandt et al. 1995) and NGC 5905 (Komossa & Bade 1999) the nuclear activity in these sources suggests that besides the tidal disruption of a star scenario, it could as well be an instability in the accretion disk that caused the dramatic increase in the X-ray flux.

The situation is somewhat different in the NLS1 WPVS 007 (Grupe et al. 1995b). Here the X-ray flux during the RASS agreed with that expected from its optical flux suggesting that the high X-ray flux seen during the RASS was not caused by an outburst. Nevertheless, the source almost vanished from the X-ray sky in later HRI and Chandra observations (Grupe et al. 2001a) and Vaughan et al. (2004, respectively). A possible explanation of this behavior is a change in the accretion disk temperature (Grupe et al. 1995b).

ROSAT and ASCA observations of the NLS1 RX J2217.9–5941 ($\alpha_{2000}=22h17m56.6s$, $\delta_{2000}=-59\arcdeg41.302\arcmin$, $z=0.160$) have shown this source is highly variable in X-rays (Grupe et al. 2001a; Grupe et al. 2001b). It was rather bright during the RASS with a mean count rate of CR=0.83 cts s$^{-1}$ in ROSAT’s Position Sensitive Proportional Counter (PSPC, Pfeffermann et al. 1987) and showed a decrease in its count rate by a factor of $\approx 12$ between the beginning and the end of its 2 day RASS coverage. Its X-ray loudness $\alpha_{ox}$ of RX J2217.9–5941 during the RASS agreed well with the value of Yuan et al. (1998) for objects of the same luminosity and redshift. After the RASS the source flux dramatically decreased in factors of about 30 in later ROSAT High Resolution Imager (HRI) and ASCA observations. Grupe et al. (2001b) suggested that the X-ray variability RX J2217.9–5941 could be explained by (a) persistent variability such as observed in e.g the NLS1 IRAS 13224–3809 (Boller et al. 1997; Gallo et al. 2004a), which is supported by the $\alpha_{ox}$ during the RASS, (b) a variable absorber, (c) an X-ray outburst such as seen in IC 3599, or (d) that RX J2217.9–5941 is an X-ray transient candidate in which a change in the accretion disk temperature has shifted the X-ray spectrum out of the observed energy window, similar to what has been suggested for the NLS1 WPVS 007 (Grupe et al. 1995b). In order to test this hypothesis we performed two 5ks ACIS-S observations with Chandra during guaranteed time observation time granted to the Max-Planck-Institute für extraterrestrische Physik in February and August 2003.

The outline of this paper is as follows: in §2 we describe the Chandra observations and the data reduction, in §3 we present the results of the temporal and spectral analysis, and in §4 we discuss possible origins of the variability observed in RX J2217.9–5941. Throughout the paper spectral indexes are denoted as energy spectral indexes with $F_{\nu} \propto \nu^{-\alpha}$. Luminosities are calculated assuming a Hubble constant of $H_0 = 75$ km s$^{-1}$Mpc$^{-1}$ and a deceleration parameter of $q_0 = 0.0$. All errors given in this paper refer to 1σ errors.

## 2. Observations

RX J2217.9–5941 was observed by Chandra on 2003-02-23 19:42 - 21:41 (UT) and 2003-08-16 18:38 - 20:25 (UT) for 4.7 and 5.1 ks with the back-illuminated ACIS-S CCD chip S3. The observations were performed in the Faint Mode with the standard frame time of 3.2s. Source photons were collected in a circular region with a radius $r=3\arcmin$ and background photons in an annulus with $\alpha_{ox}$ is the slope of a hypothetical power-law from 2500 Å to 2 keV; $\alpha_{ox}=0.384$ log ($L_{2500}/L_{2keV}$)

$\sigma$
an inner radius $r=4.3''$ and an outer radius $r=12''$. Spectra were extracted from the primary event files with CIAO version 3.0.2 and analyzed using XSPEC 11.2. The calibration database used was CALDB version 2.25. The response matrices and auxiliary response file for the effective area were created with the CIAO tasks mkrf and mkarf. The effective areas were corrected by the task apply_acis_corr in order to correct for contamination of a lubricant on the ACIS entrance window. The spectroscopic data were rebinned by GRPPHA to have least 20 photons per bin. For count rate conversion between the different X-ray missions, PIMMS 3.2 was used.

## Results

### 3.1. Source position

Chandra’s superior pointing accuracy and its spatial resolution enables us to measure the most accurate source position compared with other X-ray missions. From the February 2003 observation of RX J2217.9–5941 we measured the source positions to be \( \alpha = 22^h17^m56.63^s \) and \( \delta = -59^\circ41'31.2'' \) consistent within 1'' of the results of our HRI observation (Grupe et al. 2001b).

### 3.2. X-ray variability

The mean ACIS-S count rate in the 0.5-7.2 keV band during the February 2003 observation was CR=0.1258±0.0052 cts s⁻¹, and 0.0500±0.0031 cts s⁻¹ in the 0.5-3.6 keV range during the August 2003 observation. Figure 1 displays the long-term lightcurve of RX J2217.9–5941 including all X-ray observations performed on this source. Because the HRI observations do not provide spectral information and the ASCA spectral data have large uncertainties (Grupe et al. 2001b), the 0.2-2.0 rest frame luminosities of the HRI and ASCA observations were derived by using PIMMS assuming the X-ray spectral index of \( \alpha_X=2.7 \) and no significant spectral changes. The unabsorbed rest-frame 0.2-2.0 X-ray luminosities of the Chandra ACIS-S observations of log \( L_{0.2-2.0 \text{ keV}} = 36.95 \) [W] and 36.82 [W] (43.95 and 43.82 [ergs s⁻¹]) of the February and August 2003 observations, respectively.

We used the hardness ratio to look for spectral variability between the observations. For our purpose we define the hardness ratio as HR=(H-S)/(H+S) with the counts S in the soft band in the 0.5-1.0 keV and hard counts H in the 1.0-2.0 keV energy ranges. We used this particular definition to avoid any contribution in the February 2003 spectrum from a possible mis-calibration around 2.3 keV (see §3.3). Using this definition of the hardness ratio we found HR=−0.205±0.081 and HR=−0.492±0.092 during the February and August 2003 observation, respectively, suggesting a change in the X-ray spectrum in about half a year. The spectrum became softer with decreasing count rate. Note that also pileup causes the raw spectrum to become flatter. Because the February 2003 data are affected by pileup and the August data are not this could cause in part the variability we observe.

### 3.3. Spectral analysis

At first we fitted an XSPEC power law model only to the data in the 0.5-2.0 observed energy range to be consistent with the ROSAT PSPC range. The results of these power law fits are listed in Table 1. In the February 2003 observation, the XSPEC PILEUP model of Davis (2001) is needed to model the spectrum correctly. This model takes into account the fact that the count rate of this object is sufficiently high that more than one photon is obtained in a single pixel during the nominal frame time of 3.2 seconds. This causes a change in the grades by a grade morphing parameter \( \alpha \) which determines the number of 'good grades' (see Davis (2001) for details) by number of good grades = \( \alpha^{(P-1)} \) where P is the number of piled up photons. For the August 2003 observation the count rate was low enough not to be significantly affected by pileup. The February and August 2003 data spectra are well-fitted by a simple power law with Galactic absorption (2.58×10²⁰ cm⁻²; Dickey & Lockman (1990)). The results of the spectral fits are listed in Table 1. Both observations confirm the steep X-ray spectrum of \( \alpha_X=2.7 \) that was found during the RASS observation (Grupe et al. 2001b).

The spectra seem to become more complicated towards higher energies (Figure 2). However, the February 2003 spectrum is, even though it is not a good fit, still consistent with a simple power law model. On the other hand, the August 2003 spectrum is not (Table1). The spectra were fitted with power law models with the X-ray spectral index left free and fixed to the value determined
in the 0.5-2.0 keV range. In all cases the spectra show a flattening towards higher X-ray energies. In a first approach to fit these spectra we used a broken power law with the absorption parameter fixed to the Galactic value. This model results in acceptable fits with a soft X-ray spectral index of $\alpha_{X}=2.58\pm0.61$ and $3.55\pm0.30$ for the February and August 2003 data, respectively (Table 1). This model suggests a soft X-ray excess above a hard X-ray spectrum with a flatter spectral index of $\alpha_{X} \approx 1.0$.

A partial-covering absorber can also potentially explain a flattening of the spectrum toward higher energies. This model has been successfully applied to the XMM data of several NLS1s (e.g. Boller et al. (2002, 2003) and Grupe et al. (2004c)). Applying a partial-covering absorber to the spectra of RX J2217.9–5941 also gives acceptable fits. A partial-covering absorber is also able to explain the variability observed in RX J2217.9–5941. However, one has to keep in mind that the quality especially of the August 2003 data do not constrain of the partial-covering absorber parameters, particularly when the X-ray slope is free to vary. The X-ray spectra from NLS1s are also frequently parameterized using a blackbody plus power law spectrum (e.g. Leighly (1999a)). However, this model does not improve the fits to the data (Table 1). The February 2003 data (Figure 2) also show strong residuals around 2.3 keV. This feature can be modeled by a Gaussian line which significantly improves the fit. However, the existence of a real emission line at this energy is rather uncertain. Aldcroft et al. (2003) reported a similar feature in their Chandra ACIS-S spectrum of 3C212 and concluded that the 'line' is most likely instrumental nature.

As mentioned in §3.2 there seems to be a change in the hardness ratios between the February and August data. In order to check whether this is real or just the effects of pileup we used the simultaneous fit to both data sets in XSPEC by applying a blackbody plus power law fit to the data as given in Table 1. The blackbody temperature and the power law index were fixed and the normalizations were left free. The changes in the normalization agree with results from the changes in the hardness ratios: While the normalization of the blackbody of the soft X-ray part decreases by a factor of about 2 between February and August 2003, the normalization of the power law decreased by a factor of about 5, suggesting also that the spectrum became softer when the source it became fainter.

4. Discussion

The main aspect of monitoring the NLS1 RX J2217.9–5941 with Chandra was to investigate whether the source is an X-ray transient AGN, such as WPVS 007 (Grupe et al. 1995b), or if it is simply a highly variable source that was observed in a bright state during the RASS and in fainter states in later ROSAT HRI and ASCA observations. Our new Chandra ACIS-S observations favor the latter scenario and support one of the speculations of Grupe et al. (2001b) that the variability found in RX J2217.9–5941 is most likely persistent. There is no indication from the Chandra observations that RX J2217.9–5941 is an X-ray transient AGN. The X-ray loudness of RX J2217.9–5941 during the RASS was $\alpha_{ox}=1.52$ (Grupe et al. 2001b) and agrees perfectly with the $\alpha_{ox}$ given by Yuan et al. (1998) for radio-quiet AGN with similar redshifts and luminosities as RX J2217.9–5941 which also supports the persistent variability nature of the source. This $\alpha_{ox}$ suggests also that the X-ray flux measured during the RASS is the 'normal', expected flux. Compared with the RASS observation, during the HRI and ASCA observations the optical to X-ray slope dropped to $\alpha_{ox}=2.0$. The optical spectra of RX J2217.9–5941 taken between 1992 and 1998 (Grupe et al. 2001b) do not suggest any optical variability. The remaining question about RX J2217.9–5941 is what causes the X-ray variability. There are two possible explanations, 1) intrinsic variability or 2) a variable cold absorber in the line of sight.

We also found in §3.2 that RX J2217.9–5941 is not only variable in flux, but also in its spectral shape. While most AGN become harder with decreasing flux (e.g. Gallo et al. (2004b); Dewangan et al. (2002); Lee et al. (2000); Chiang et al., (2000)) in RX J2217.9–5941 the source becomes softer when the flux decreases. Even though this is unusual, it is not unobserved in NLS1s: e.g. PKS 0558–504 (Gliozzi et al. 2001), RX J0134.2–4258 (Grupe et al. 2000) or 1H 0707–495 (Gallo et al. 2004c; Fabian et al. 2004). In the case
of the radio-loud object PKS 0558–504 Gliozzi et al. (2001) discussed the observed spectral variability in the contest of a contribution of a jet. This model can not be applied for RX J2217.9–5941, which is a radio-quiet source (Grupe et al. 2001b). In the case of RX J0134.2–4258 Grupe et al. (2000) excluded a warm absorber as the explanation for these findings, but discussed a change in the accretion disk corona as a possible explanation. Recently Wang et al. (2004) found that the corona becomes weak when the Eddington ratio increases. As a result the hard X-ray flux decreases with regards to the bolometric luminosity. In the case of 1H 0707–495, Fabian et al. (2004) explained the variability by ionized disk reflection. Both models may also explain the spectral behavior of RX J2217.9–5941, but for the current data it is not possible to draw final conclusions.

As an alternative the source can be intrinsically absorbed and this absorber is variable. It has been suggested by e.g. Abrassart & Czerny (2000) that clouds of neutral matter in the line of sight may cause the variability observed in X-ray in AGN. Such cold absorber has been suggested by e.g. McKernan & Yaqoob (1998) and Lamer et al (2003) to explain the X-ray variability of MCG–6–30–15 and NGC 3227. A simple cold absorber of neutral gas in RX J2217.9–5941 can cause the count rate to decrease as observed between the RASS and the pointed HRI observation in 1997 and 1998. Assuming the intrinsic spectrum did not change, it requires an absorption column of neutral gas of $8 \times 10^{20} \text{cm}^{-2}$ to account for the HRI count rate observed in 1997 and a column density of about $9 \times 10^{21} \text{cm}^{-2}$ to explain the second HRI observation assuming the intrinsic luminosity has not changed.

Most likely the absorber in RX J2217.9–5941 is a partial-covering absorber that blocks most of the X-rays but has 'leaks' either through parts of much lower column density in the absorber or by scattering (e.g. Grupe et al. 2004c). In the case of 1H 0707–495 Boller et al. (2002) and Tanaka et al. (2004) explained the X-ray spectrum by a partial-covering absorber which can explain the spectral variability in this source (Gallo et al. 2004c) which is similar to what we found in RX J2217.9–5941. Even though we can not put constraints on the absorber parameters the 0.5–7.2 February 2003 and 0.5–3.5 keV August 2003 data can be fitted by a power law model with partial-covering absorber, suggesting that the variability at least in part maybe due to a variable partial covering absorber in the line of sight.

When using partial-covering models as listed in Table 1 the unabsorbed fluxes in both observations are practically the same with rest frame fluxes of $-14.2 \text{[W m}^{-2}]$ ($-11.2 \text{[ergs s}^{-1} \text{cm}^{-2}]$). A partial-covering absorber may also be responsible for the X-ray transience found in the NLS1 WPVS 007 and might explain why no hard X-ray photons have been observed in this peculiar source (Grupe et al. 1995b). This raises the question if there is a population of NLS1s which is at least at times highly absorbed in X-rays. This hypothesis is supported by the findings of Williams et al. (2003) who studied 150 NLS1s selected from the Sloan Digital Sky Survey (SDSS, York et al. (2000)) and found that 10-20 sources were not detected by ROSAT. Their optical spectra did not show any differences to those of X-ray selected NLS1s. From Chandra follow-up observations of 17 of these sources, Williams et al. (2004) suggest that there is a population of NLS1s which are either intrinsically X-ray weak or are absorbed. The composite spectrum of Williams et al. (2004) does not show signs of intrinsic absorption, but the quality of these snap-shot Chandra observations did not allow any detailed spectral analysis in particular to check for the presence of a partial-covering absorber.

We would like to thank Himel Gosh, Stefanie Komossa, and Luigi Gallo for comments and suggestions on the manuscript. We would also like to thank the anonymous referee for a fast and constructive referee’s report that significantly improved the paper. This research has made use of the NASA/IPAC Extra-galactic Database (NED) which is operated by the Jet Propulsion Laboratory, Caltech, under contract with the National Aeronautics and Space Administration. The ROSAT project was supported by the Bundesministerium für Bildung und Forschung (BMBF/DLR) and the Max-Planck-Society. This

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Note that Komossa & Meerschweinchen (2000) discussed the variability in RX J0134.2–4258 in the context of the presence of a warm absorber, however we did not find any evidence in the ASCA spectrum of RX J0134.2–4258 for such an absorber.
work was supported in part by NASA grant NAG5-9937.

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### Table 1

Spectral Fit parameters to the Chandra ACIS-S data of RX J2217.9–5941. The February 2003 data were corrected for pile up.

| Obs. | Model | E-range keV | $\alpha_X$ | $kT_{bb}$ keV | Pileup $\alpha$ | $E_{break}$ keV | $\alpha_{X,b}$ | $N_{H,pc}$ $10^{22}$cm$^{-2}$ | $t_{pc}$ | $\chi^2$/DOF |
|------|-------|-------------|------------|---------------|----------------|----------------|-------------|-----------------|-------|-------------|
| 02/03 | po$^1$ | 0.5-2.0 | 2.50±0.65 | — | 0.66±0.19 | — | — | — | — | 9.9/19 |
|      |       | 0.5-7.2 | 2.24±0.34 | — | 0.63±0.14 | — | — | — | — | 33.3/25 |
|      | zpcf po$^2$ | 0.5-7.2 | 2.50 (fix) | — | 0.63 (fix) | — | — | 15.2±7.5 | 0.80±0.03 | 27.7/25 |
|      | bknpo$^3$ | 0.5-7.2 | 2.56±0.61 | — | 0.66±0.14 | 1.97±0.88 | 0.94±1.02 | — | — | 26.9/23 |
|      | bb po$^4$ | 0.5-7.2 | — | 0.101±0.016 | 0.68±0.26 | — | 1.50±0.27 | — | — | 31.3/23 |
| 08/03 | po$^1$ | 0.5-2.0 | 3.38±0.26 | — | — | — | — | — | — | 6.9/8 |
|      | 0.5-3.6 | 2.95±0.29 | — | — | — | — | — | — | — | 28.6/10 |
|      | zpcf po$^2$ | 0.5-3.6 | 3.00 (fix) | — | — | — | — | — | — | 6.98±2.20 | 9.3/9 |
|      | bknpo$^3$ | 0.5-3.6 | 3.55±0.30 | — | — | 1.25±0.12 | 0.32±0.44 | — | — | 5.5/8 |
|      | bb po$^4$ | 0.5-9.6 | — | 0.098±0.008 | — | — | 0.23±0.42 | — | — | 4.8/8 |

$^1$ power law model with Galactic absorption fixed to 2.58 $10^{20}$cm$^{-2}$ Dickey & Lockman (1990)

$^2$ power law model with Galactic absorption fixed to 2.58 $10^{20}$cm$^{-2}$ Dickey & Lockman (1990) and partial-covering absorption

$^3$ broken power law model with Galactic absorption fixed to 2.58 $10^{20}$cm$^{-2}$ Dickey & Lockman (1990)

$^4$ blackbody plus power law model with galactic absorption fixed to 2.58 $10^{20}$cm$^{-2}$ Dickey & Lockman (1990)

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**Fig. 1.** Long-term light-curve of the 0.2-2.0 rest-frame X-ray luminosity of RX J2217.9–5941
Fig. 2.— power law fit with Galactic absorption to the February 2003 (left) and August 2003 (right) spectra of RX J2217.9-5941. The spectral slope was fixed to the values determined in the 0.5-2.0 keV range. (Table 1). Notice the flattening of spectra towards harder X-ray energies and the strong residuals around 2.3 keV in the February 2003 spectrum.