The enigmatic soft X-ray NLS1
RX J0134.2–4258

Dirk Grupe\textsuperscript{a,1}, Karen M. Leighly\textsuperscript{b}, Hans-Christoph Thomas\textsuperscript{c}, Sally A. Laurent-Muehleisen\textsuperscript{d}

\textsuperscript{a}Max-Planck-Institut für extraterrestrische Physik, Giessenbachstr., D-85748 Garching, Germany
\textsuperscript{b}Columbia Astrophysics Lab., 550 West 120th St., New York, NY 10027, USA
\textsuperscript{c}MPI Für Astrophysik, karl-Schwarzschild-Str. 1, D-85748 Garching, Germany
\textsuperscript{d}UC-Davis and IGPP/LLNL, 7000 East Ave. Livermore, CA 94550, USA

Abstract

We report the discovery and analysis of the follow-up \textit{ROSAT} pointed observation, an \textit{ASCA} observation and optical and radio observations of the enigmatic Narrow-Line Seyfert 1 galaxy RX J0134.2–4258. While its spectrum was one of the softest observed from an AGN during the \textit{ROSAT} All-Sky Survey, its spectrum was found to be dramatically harder during a pointed observation although the count rate remained constant. In the pointed observation we found that the spectrum is softer when it is fainter, and spectral fitting demonstrates that it is the hard component that is variable. The \textit{ASCA} observation confirms the presence of a hard X-ray power law, the slope of which is rather flat compared with other NLS1s. Survey and follow-up radio observations reveal that RX J0134.2–4258 is also unusual in that it is a member of the rare class of radio-loud NLS1s, and, with $R=71$, it holds the current record for the largest radio-to-optical ratio in NLS1s. We discuss possible scenarios to explain its strange behaviour.

\textit{Key words:} accretion, active galaxies, individual: RX J0134.2–4258

1 Introduction

One of the most interesting results from \textit{ROSAT} observations of AGN was the discovery of several X-ray transient AGN. These objects were detected

\footnote{E-mail: dgrupe@mpe.mpg.de}
to be bright soft X-ray sources during the *ROSAT* All Sky Survey (RASS), but follow-up observations revealed large amplitude decreases in flux by up to two orders of magnitude. RX J0134.2−4258 also exhibited X-ray transience, but the behavior was somewhat different. During the RASS, it was found to have one of the steepest spectra exhibited by an AGN. During the follow-up pointed observation about two years later, the spectrum was much flatter. We report the results of a study of this object using *ROSAT*, *ASCA*, optical and radio observations; details can be found in Grupe et al. (2000, A&A, in press).

2 Observations

RX J0134.2−4258 was discovered during the RASS. Optical spectroscopic observations showed that the object at the center of the RASS error circle is a NLS1 at a redshift of 0.237. Based on a small sample of 15 objects, Ulvestad et al. 1995 reported that NLS1s are generally weak radio sources. As discussed by E. Moran in these proceedings, this is not always the case. We discovered that RX J0134.2−4258 is a moderately strong radio source. In the Parkes-MIT-NRAO (PMN) radio catalog its flux density is 55 ± 9 mJy at 4.85 GHz, and a VLA observation measures a flux density of 25 ± 1 mJy at 8.4 GHz. We infer that the radio spectral index is rather steep (1.4) and/or that it is a variable radio source. Comparison of the 8.4 GHz radio flux with the optical spectrum reveals that RX J0134.2−4258 is radio-loud: the radio to optical ratio R=71, and the luminosity is log(\(P\)) = 25.3 WHz−1.

**Spectral Variability Observed by ROSAT:** The RASS observation revealed that the X-ray spectrum of RX J0134.2−4258 is very steep and practically no photons were detected above 1 keV. The inferred photon index was \(\alpha_x = 6.9 \pm 2.9\); poor statistics prevented more complex modeling. The follow-up pointed observation found that the count rate from RX J0134.2−4258 had not changed substantially. However, the spectrum was significantly harder. A power law model with Galactic absorption did not describe the spectrum adequately. While the poor energy resolution of the *ROSAT* PSPC means that we cannot definitively determine the origin of the spectral complexity, we favor a model with a power law plus a soft component, where \(\alpha_x = 1.04 \pm 1.22\) and \(kT = 14 \pm 7\) eV.

RX J0134.2−4258 was variable during the pointed observation. The pointed observation was split into 6 intervals (OBIs). The third OBI has significantly lower flux, and the hardness ratio analysis showed that the spectrum was temporarily much softer as well. The spectral variability on short time scales observed during the pointed observation seems to be similar to the long time-
scale variability observed between the RASS and the pointed observation; that is, both are produced by a large amplitude change in the hard X-rays, while the soft X-rays remained nearly constant.

**ASCA Observation:** We observed RX J0134.2−4258 using ASCA for ∼ 45 ks. The object varied during the observation and the amplitude of variability was consistent with that of other NLS1s with similar hard X-ray luminosity (see Leighly 1999a). No spectral variability was detected.

The ASCA spectrum was adequately modeled with a power law and Galactic absorption. The energy index was 0.80 ± 0.09, a rather flat value compared with other NLS1s (e.g. Leighly 1999b). No evidence for absorption edges at 0.74 or 0.87 keV, appropriate for ionized oxygen in a warm absorber, was found. The optical depth upper limits are not strongly constraining (∼ 0.5); however, a large optical depth warm absorber is clearly ruled out. Similarly, no evidence for an iron line was found, with the EW upper limit for a narrow 6.4 keV (rest frame) line of 300 eV.

The spectrum from the ROSAT pointed observation and the ASCA spectrum were consistent with each other except for a normalization factor in the overlapping energy band. Therefore, we elected to model the spectra simultaneously. We found that the spectrum could not be modeled by a power law alone, but a power law plus soft excess model fit the spectra well.

**Optical observations:** An optical spectrum was obtained with the ESO 1.52m telescope during four nights in September 1995 for a total of 3.25 hours (see Grupe et al. 2000). The spectrum is typical of a Narrow-line Seyfert 1 galaxy with extreme FeII emission, weak [OIII] and a very blue optical continuum. We measured FWHM(Hβ)=900±100 and FWHM([OIII])=670±200 km s⁻¹. Its FeII/Hβ ratio (12.3) is the largest among our entire sample of soft X-ray selected AGN (Grupe et al. 1999).

3 Discussion

RX J0134.2−4258 showed extreme spectral variability between the RASS and the ROSAT pointed observation and also during the pointed observation. On both long and short time scales, the soft flux appeared to be constant, while the hard flux varied with large amplitude. Nothing exactly like this has ever been reported before, although behavior somewhat similar was observed from Mrk 766 whose spectral variability during the ROSAT pointed observations was also consistent with a non-variable soft component (Leighly et al. 1996). We explore possible origins of the spectral variability below; see Grupe et al. (2000) for details.
Warm Absorber: Komossa & Merrschweinchen (2000) speculate that the spectral variability between the RASS and pointed observation is due to a partially ionized (warm absorber) cloud traversing the line of sight. We find no evidence for a warm absorber in the ASCA spectra, however. Furthermore, we find that for reasonable parameters, the cloud scenario cannot explain the rather similar spectral variability observed on shorter time scales during the pointed observation, simply because for plausible source sizes and cloud velocities, the time scale of variability required is rather longer than observed.

Corona Loss and Recovery: The steep spectra observed from NLS1s imply that there must be energy released in the accretion disk to power the soft X-ray emission. Therefore, a hard X-ray emitting corona of energetic particles need not necessarily be present. It is possible that during the RASS, the hard X-ray emitting corona was absent, and it reappeared before the ROSAT pointed observation and the ASCA observation. A similar phenomenon may have been observed in NGC 4051; this object was found to be in a very low state recently, when the hard X-ray emitting power law was absent, and the spectrum was dominated by Compton reflection (Guainazzi et al. 1998).

Strengthening of the Radio Component: We discovered that RX J0134.2-4258 is a radio-loud NLS1 and that it has a flat hard X-ray spectrum compared with other NLS1s. Radio-loud objects are known to have flatter hard X-ray spectra and to be more powerful X-ray sources, possibly because of an extra contribution to the X-ray flux associated with the radio-emitting component. Thus, another possible explanation for the spectral variability is an increase in the component associated with the radio emission. We note, however, that RX J0134.2-4258 is a relatively weak radio source, and that the other two radio-loud NLS1s observed with ASCA have canonical steep hard X-ray spectra.

References

[1] D. Grupe, K. Beuermann, H.-C. Thomas, K. Mannheim, H.H. Fink, A&A \textbf{330}, 25 (1998a)
[2] D. Grupe, K. Beuermann, K. Mannheim, H.-C. Thomas, A&A \textbf{350}, 805 (1999a)
[3] D. Grupe, K.M. Leighly, H.-C. Thomas, S.A. Laurent-Muehleisen, A&A \textbf{in press} (2000) (also astro-ph/0001412)
[4] M. Guainazzi, F. Nicastro, F. Fiore, et al., MNRAS \textbf{301}, L1 (1998)
[5] K.M. Leighly, R.F. Mushotzky, T. Yaqoob, H. Kunieda, R. Edelson, ApJ \textbf{469}, 147 (1996)
[6] K.M. Leighly, ApJS \textbf{125}, 297 (1999a)
[7] K.M. Leighly, ApJS \textbf{125}, 317 (1999b)
[8] J.S. Ulvestad, R.R.J. Antonucci, R.W. Goodrich, AJ \textbf{109}, 81 (1995)