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A new narrow-line Seyfert 1 galaxy: RX J1236.9+2656

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Abstract. We report identification of a narrow-line Seyfert 1 galaxy RX J1236.9+2656. X-ray emission from the NLS1 galaxy undergoes long-term variability with 0.1–2.0 keV flux changing by a factor of ~ 2 within $\sim 3\,\mathrm{yr}$. The $ROSAT$ PSPC spectrum of RX J1236.9+2656 is well represented by a power-law of $\Gamma_X = 3.7^{+0.5}_{-0.3}$ absorbed by matter in our own Galaxy ($\mathrm{N_H} = 1.33 \times 10^{20}\ \mathrm{cm^{-2}}$). Intrinsic soft X-ray luminosity of the NLS1 galaxy is estimated to be $\sim 1.5 \times 10^{43}\ \mathrm{erg\ s^{-1}}$ in the energy band of 0.1–$2.0\ \mathrm{keV}$. The optical spectrum of RX J1236.9+2656 is typical of NLS1 galaxies and shows narrow Balmer emission lines ($1100\ \mathrm{km\,s^{-1}}$ < FWHM < $1700\ \mathrm{km\,s^{-1}}$) of H$\beta$, H$\alpha$, and forbidden lines of [O III] and [N II]. Fe II multiplets, usually present in optical spectra of NLS1 galaxies, are also detected in RX J1236.9+2656.

Key words: galaxies: active – galaxies: individual: RX J1236.9+2656 – galaxies: nuclei – X-rays: galaxies

1. Introduction

Narrow-line Seyfert 1 (NLS1) galaxies are considered to be a special class of "normal" Seyfert 1 galaxies because of their peculiar properties that distinguish them from the latter class. They are characterized by their optical spectra having permitted lines that are narrower than those found in the normal Seyfert 1 galaxies, e.g., full width at half maximum (FWHM) of Hβ line is $\lesssim 2000\ \mathrm{km\,s^{-1}}$, relatively weak forbidden lines, $\frac{[OIII]\lambda 5007}{H\beta} < 3$ (Osterbrock & Pogge 1985), and strong Fe II emission. NLS1 galaxies also have distinctive soft X-ray properties as well. They show steep soft X-ray spectrum with little or no absorption above the Galactic value (Grupe et al. 1998). They often show rapid and large amplitude as well as long-term X-ray variability (Boller et al. 1993; Brandt et al. 1995; Grupe et al. 1995a,b). In spite of the dominance of soft X-ray emission, soft X-ray luminosity of NLS1 galaxies are similar to those of normal Seyfert 1s. $ASCA$ observations show that the hard X-ray (2–10 keV) continua of NLS1s are also steeper than those of normal Seyfert 1s with broader Hβ FWHM (Brandt et al. 1997; Leighly 1999b). NLS1 galaxies also show more variability in hard X-rays than the normal Seyfert 1s (Leighly, 1999a). The spectral energy distribution (SED) from far-infrared (FIR) to X-rays of NLS1 galaxies appears to be similar to that of broad-line Seyfert 1 galaxies. However, the UV luminosity of NLS1 galaxies tends to be smaller than those of Seyfert 1s (Rodríguez-Pascual et al. 1997).

Optical spectroscopy of ultra-soft X-ray sources discovered with $Einstein$, and $ROSAT$ has been an efficient way to identify NLS1 galaxies (e.g., Puchnarewicz et al. 1992; Grupe et al. 1998). As part of our programme to optically identify and study in detail the counterparts of the ultra-soft sources in the catalogue of Singh et al. (1995), we have discovered a NLS1 galaxy RX J1236.9+2656. The basic parameters of RX J1236.9+2656 are given in Table 1. Throughout this note, luminosities are calculated assuming an isotropic emission, a Hubble constant of $H_0 = 75\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$ and a deceleration parameter of $q_0 = 0$ unless otherwise specified.

Table 1. Basic parameters of RX J1236.9+2656.

Position[1]:	$\alpha(J2000) = 12^h\ 36^m\ 57.0^s$
	$\delta(J2000) = +26°\ 56'\ 50.0''$.
Redshift[1]:	z = 0.225 ± .001.
Magnitude[2]:	B = 18.2, V = 17.1.

[1] Present work
[2] US Naval Observatory (USNO) catalogue

2. X-ray observation, analysis and results

The region of the sky containing the source, RX J1236.9+2656, was observed seven times with the $ROSAT$ (Trümper 1983) Position Sensitive Proportional Counter (PSPC) during 1991–1993 and twice with the High Resolution Imager (HRI) (Pfeffermann et al. 1987) in 1996 June–July. The exposure times were in the range $1420\ \mathrm{s} - 5422\ \mathrm{s}$ for the PSPC observations while the two HRI observations were carried out with longer exposure times ($14545\ \mathrm{s}$ and $16738\ \mathrm{s}$). The offset of the source from the field center was $\sim 17'$ for each of the PSPC and HRI observations.

⋆ Based on observations with the Apache Point Observatory (APO) 3.5m telescope, which is owned and operated by the Astrophysical Research Consortium (ARC).

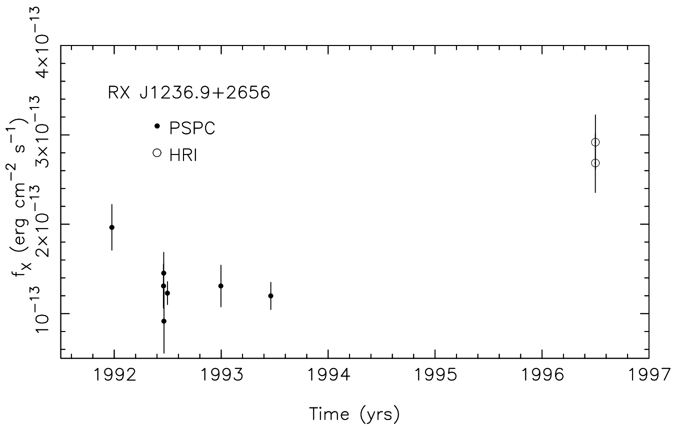

Fig. 1. Long-term $ROSAT$ light curve of RX J1236.9+2656. The observed flux in the energy band of 0.1–2.0 keV has been plotted.

The X-ray source, RX J1236.9+2656, was identified by overlaying the contours of high resolution X-ray images obtained from $ROSAT$ HRI observations onto optical images obtained from the Digital Sky Survey (DSS). No other X-ray source, within the angular spread comparable to the point spread function of $ROSAT$ HRI, was seen in the overlays. Therefore, X-ray emission from RX J1236.9+2656 is not contaminated by emission from any other source. HRI count rates for RX J1236.9+2656 were obtained using a circle of radius $50''$ for the source and an annulus of inner circle radius $60''$ and width $60''$ for background. The HRI count rates thus estimated are $(1.14 \pm 0.14) \times 10^{-2}$ and $(1.23 \pm 0.13) \times 10^{-2}$ count s^{-1} for the two observations. The spatial resolution with the PSPC at an offset of $16.5'$ is $\sim 40''$ (half power radius) (Hasinger et al. 1993). Therefore, PSPC count rates for RX J1236.9+2656 were obtained using a circle of radius $2.5'$ for the source and 7 nearby circular regions of radii $2.25'$ for background. The PSPC count rates are $(3.53 \pm 0.46) \times 10^{-2}$, $(3.19 \pm 0.57) \times 10^{-2}$, $(3.19{\pm}0.60){\times}10^{-2}$, $(3.54{\pm}0.57){\times}10^{-2}$, $(2.23{\pm}0.87){\times}10^{-2}$, $(3.26 \pm 0.34) \times 10^{-2}$, and $(3.15 \pm 0.40) \times 10^{-2}$ count s^{-1} for the 7 PSPC observations.

In order to investigate the time variability of soft X-ray emission from RX J1236.9+2656, we extracted light curves from the $ROSAT$ PSPC observations using the same source and the background regions as described above and in the PSPC energy band of 0.1–2.4 keV containing all the X-ray photons. The background subtractions were carried out after appropriately scaling the background light curves to have the same area as the source extraction area. The light curves of RX J1236.9+2656 do not show short-term variability during the PSPC observations. However, on a longer time scale of months to years, variability is clearly detected in the X-ray flux measurements plotted in Fig. 1. The observed flux in the energy band 0.1–2.0 keV, estimated from the best fit spectral model (see below), increased by about a factor of 2 within ~ 3 yr.

For analyzing the X-ray spectra of RX J1236.9+2656, we choose 3 PSPC spectra corresponding to those observations for which the exposure times were greater than 3000 s. These observations were carried out on 1991 December 15, 1992 June 30, and 1993 June 17. Photon energy spectra of RX J1236.9+2656 were accumulated from their PSPC observations using the same source and background regions as stated above. $ROSAT$ PSPC pulse height data were appropriately re-grouped to improve the statistics.

We used the XSPEC spectral analysis package to fit the data with spectral models. Appropriate ancillary response file was used to account for the off-axis position of the source. An appropriate response matrix was used to define the energy response of the PSPC.

Each of the 3 PSPC spectra was first fitted with a redshifted power-law model absorbed by an intervening medium with absorption cross-sections as given by Balucinska-Church & McCammon (1992) and using the method of χ^2-minimization. The photon index (Γ_X) was found to be very steep in all the cases. It was found that the absorbing column density in each case is similar within errors to the Galactic value ($N_H = 1.33 \times 10^{20}$ cm^{-2}) measured from 21-cm radio observations (Dickey & Lockman 1990) along the direction of the source, indicating that all the X-ray absorption is due to matter in our own Galaxy. Therefore, we have fitted the power-law models to these spectra after fixing the neutral hydrogen column density to the Galactic value. The best-fit minimum χ^2_ν and the power-law index do not change significantly from those obtained while varying the N_H. The photon indices obtained for fixed N_H are, however, better constrained. The values for Γ_X are $3.0^{+0.5}_{-0.4}$, $4.2^{+1.2}_{-0.7}$, and $4.2^{+2.0}_{-0.7}$ for the spectra observed on 1991 Dec 15, 1992 June 30, and 1993 June 17, respectively, and are quite similar within the errors for all three spectra. The errors quoted, here and below, were calculated at the 90% confidence level based on χ^2_{min}+2.71. In order to better constrain the model parameters, we have fitted the above model to the three spectra jointly. The best-fit photon index is now $4.0^{+0.5}_{-0.5}$. The observed flux, based on the best-fit model parameters, is estimated to be 1.4×10^{-13} erg cm^{-2} s^{-1} in the energy band of 0.1–2.0 keV. In the same energy band the intrinsic soft X-ray luminosity, corrected for Galactic absorption, of RX J1236.9+2656 is calculated to be 1.6×10^{43} erg s^{-1}.

We have also analyzed all the 7 PSPC spectra jointly. The best-fit phton index is $3.7^{+0.3}_{-0.5}$ which is similar to that obtained for the 3 PSPC observations above. Thus, it is clear that all available PSPC spectral data of RX J1236.9+2656 are well represented by a power-law of photon index $3.7^{+0.3}_{-0.5}$ absorbed by the matter in our own Galaxy. We have also fitted redshifted blackbody models, absorbed by an intervening medium, to the three PSPC spectra (exposure times $>$ 3000 s) of RX J1236.9+2656 taken jointly as well as all the 7 data taken jointly. The absorbing column density derived from the model fit was lower than the Galactic value in that direction, indicating that the blackbody is not a suitable model. We then fixed the absorbing column to the Galactic value and carried out the joint fitting. The temperature thus obtained, $kT = 79^{+13}_{-24}$ eV, reflects the ultra-soft nature of RX J1236.9+2656.

We have calculated the $ROSAT$ HRI flux of RX J1236.9+2656 using the best-fit model parameters obtained from best-fit to all the 7 spectral data ($\Gamma_X = 3.7$, $N_H = 1.33 \times 10^{19}$ cm^{-2}). The observed HRI fluxes are

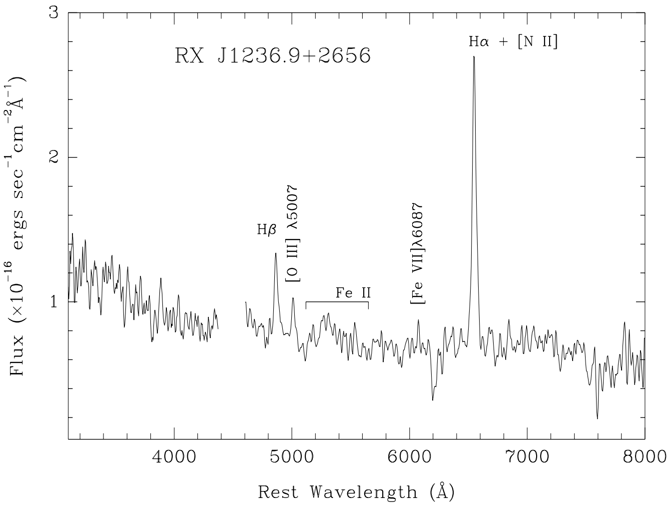

Fig. 2. Optical spectrum of RX J1236.9+2656. The gap around 4500 Å is due to the piece of the spectrum that was not covered due to the dichroic beam which splits the light into the blue and red spectrographs.

2.7×10^{-13} erg s^{-1} cm^{-2} and 2.9×10^{-13} erg s^{-1} cm^{-2} in the energy band of 0.1–2.0keV for the two HRI observations. The HRI fluxes are about a factor of two higher than the values obtained from the PSPC observations.

3. Optical spectroscopy

Low resolution optical spectroscopic observations of RX J1236.9+2656 were carried out at the 3.5m telescope of the Apache Point Observatory (APO) on the nights of 1995 April 25, 30 and 2000 January 6. The integrations ranged from 4–15 min, with the best spectrum obtained during the last observation. The Double Imaging Spectrograph (DIS) was used in low resolution mode with a $1.5''$ slit to obtain simultaneous blue and red spectra covering 3800–5300 Å in the blue and 5600–9900 Å in the red with a resolution of 14 Å.

The optical spectra were reduced using routines available within the IRAF[1] software. This included correcting the images using bias and flat fields, extracting sky-subtracted one-dimensional spectra and calibrating the wavelengths from He-NeAr lamps and the fluxes from standard stars. In the spectrum of RX J1236.9+2656, strong emission lines of Balmer Hα, Hβ, and the forbidden line [O III]λ5007 are readily observed. Using the peak wavelengths and the rest wavelengths of these lines, a redshift of 0.225 ± 0.001 was derived from the 2000 January spectrum. The observed spectrum was then corrected for this redshift and is shown in Fig. 2. The signal-to-noise ratio of the spectrum is ~ 7.6 measured from the dispersion in the continuum region 6900 Å $-$ 7200 Å. The continuum is observed to rise towards the blue end of the spectrum. Apart from the emission lines mentioned above, we have also identified Fe II emission between 5070–5600 Å and a forbidden line of [Fe VII]λ6087 (see Fig. 2). We have fitted Gaussian profiles to the strong emission lines using the profile fitting feature in the 'splot' task within IRAF. Due to the poor resolution of the spectrum, it was not possible to deblend the Hα, and [N II]$\lambda\lambda6548, 6584$ lines. A single Gaussian profile is not well fitted to the core of the Hα line and the FWHM is overestimated because of the presence of [N II]$\lambda\lambda6548, 6584$ lines. We also fitted a single Gaussian to the Hα after excluding the wings. In this case, the FWHM can be considered as a lower limit. Thus we derive the FWHM of the Hα line to be in the range of 1315–1692 km s^{-1}. The widths have been corrected for instrumental broadening by subtracting, in quadrature, the instrumental broadening (FWHM = 14 Å) from the observed FWHM. The Hα+[N II] flux is estimated to be 8.3×10^{-15} erg cm^{-2} s^{-1} by integrating the flux over the Hα+[N II] profile. The profile of the Balmer line Hβ is well fitted by a Lorentzian profile but poorly fitted with a Gaussian. The FWHMs of the best-fit Lorentzian and Gaussian profiles to the Hβ line are 1122 km s^{-1} and 1392 km s^{-1}, respectively. The observed widths of Hα and Hβ, and the presence of Fe II, [Fe VII] emission are characteristic of NLS1 galaxies. The flux of the Hβ line is estimated to be 2.0×10^{-15} erg cm^{-2} s^{-1}. Similarly the flux of the [O III]λ5007 line is calculated to be 7.6×10^{-16} erg cm^{-2} s^{-1}. Thus the ratio, $\frac{[OIII]\lambda5007}{H\beta}$ is only ~ 0.38.

4. Discussion

RX J1236.9+2656 is luminous in soft X-rays, with a rest frame intrinsic luminosity $\sim 1.6 \times 10^{43}$ erg s^{-1}, in the energy band of 0.1–2.0 keV. Seyfert 1 galaxies studied by Rush et al. (1996) span over 4 orders of magnitude in soft X-ray luminosity, from below 10^{42} erg s^{-1} to above 10^{46} erg s^{-1} in the energy band of 0.1–2.4 keV. Thus, the X-ray luminosity of RX J1236.9+2656 is similar to that of a Seyfert 1 galaxy. Assuming that the soft X-ray luminosity of RX J1236.9+2656 is about 10% of the bolometric luminosity, the lower limit to the mass of the central supermassive object or the Eddington mass is $\sim 10^6$ M$\odot$.

The galaxy RX J1236.9+2656 shows long-term variability – a change in intensity by a factor of ~ 2 within ~ 3 yr, another characteristic of NLS1 galaxies. Short-term (1000–100000 s) variability is not detected from RX J1236.9+2656 due to poor signal-to-noise ratio of the $ROSAT$ data.

The soft X-ray spectrum of RX J1236.9+2656 is steeper ($\Gamma_X \sim 3.7$) than those of normal Seyfert 1s [$< \Gamma_X >$ (90% range)$=$ 2.0–2.7], and similar to those of NLS1 galaxies [$< \Gamma_X >$(90% range)$=$ 2.3–3.7] (Grupe et al. 1998). Lack of intrinsic soft X-ray absorption over the Galactic value in RX J1236.9+2656 is similar to the results found in normal Seyfert 1s and NLS1 galaxies. The steeper power-law index and blackbody model fit to the PSPC spectra of RX J1236.9+2656 indicate an ultra-soft nature of this object. The derived temperature of the blackbody, $kT \sim 75$ eV, is similar to those found in NLS1 galaxies (Brandt & Boller 1998).

The optical spectrum of RX J1236.9+2656 appears to be typical of NLS1 galaxies. The FWHM of the Hβ line (in the

[1] IRAF (Image Reduction and Analysis Facility) is distributed by the National Optical Astronomy Observatories, which are operated by AURA, Inc., under cooperative agreement with the National Science Foundation.

range of 1122–1392 km s^{-1}) is narrower than those found in normal Seyfert 1s and is similar to those found in NLS1 galaxies ($\mathrm{FWHM}_{H\beta} \lesssim 2000\,\mathrm{km\,s^{-1}}$). The ratio $\frac{[OIII]\lambda 5007}{H\beta}$ (~ 0.38) for RX J1236.9+2656 indicates that forbidden lines are weak, similar to that observed from NLS1 galaxies ($\frac{[OIII]\lambda 5007}{H\beta} < 3.0$). An Fe II multiplet between 5070–5600 Å is also detected from RX J1236.9+2656. At blue wavelengths, there is an indication of the presence of an Fe II multiplet between 4435–4700 Å although our observation did not cover the multiplet fully. Thus the optical emission line parameters strongly suggest that RX J1236.9+2656 is a NLS1 galaxy. Furthermore, the position of RX J1236.9+2656 on the Γ_X–Hβ line width plane (Fig. 8 of Boller et al. 1996) is consistent with other NLS1 galaxies.

5. Conclusions

A narrow-line Seyfert 1 galaxy, RX J1236.9+2656, has been discovered based on the following soft X-ray and optical emission line properties: *(i) Steep soft X-ray spectrum (*$\Gamma \sim 3.7$*), high soft X-ray luminosity (*$1.6 \times 10^{43}\,\mathrm{erg\,s^{-1}}$*), the lack of intrinsic soft X-ray absorption, and X-ray variability. (ii) Narrow Balmer lines (FWHM*$< 2000\,\mathrm{km\,s^{-1}}$*), weak [O III]*$\lambda 5007$ *emission, and presence of Fe II multiplets.*

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