THE ASTROPHYSICAL JOURNAL, 226: L111–L114, 1978 December 15

NGC 2110: AN X-RAY/RADIO GALAXY WITH ELLIPTICAL(?) MORPHOLOGY

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Received 1978 August 2; accepted 1978 September 7

ABSTRACT

We report the detection of X-ray emission from NGC 2110, which is cataloged as an elliptical galaxy. Optical observations show Seyfert type 2 emission lines from the nucleus, a galactocentric redshift of 0.0071 ± 0.0003, and a resolved (~4″) nonstellar optical nucleus. The 2–11 keV X-ray luminosity at the redshift distance (43 Mpc) is 1.2×10^{43} ergs s^{-1}. Radio observations yield flux densities of 0.24 and 0.13 Jy at 1.48 and 4.88 GHz, respectively, from a nuclear region also resolved at ~3″. The known (about six) X-ray–emitting, high-excitation, narrow-emission-line ($\lesssim$1000 km s^{-1}) galaxies appear to be nearby ($1500 < cz < 2500$ km s^{-1}) examples of the Seyfert type 2 phenomenon.

Subject headings: galaxies: nuclei — galaxies: Seyfert — X-rays: sources

I. INTRODUCTION

Compact extragalactic objects of several types are known to exhibit X-ray emission: (1) the nuclei of ~20 Seyfert type 1 galaxies (e.g., Tananbaum *et al.* 1978; Schnopper *et al.* 1977; Elvis *et al.* 1978); (2) three QSOs, 3C 273, MR 2251−178, and 0241+622 (Bowyer *et al.* 1970; Kellogg *et al.* 1971; Ricker *et al.* 1978; Apparao *et al.* 1978); (3) the nucleus of the giant radio galaxy Cen A (Delvaille, Epstein, and Schnopper 1978, and references therein; Doxsey *et al.* 1977); (4) two BL Lacertae objects, Mrk 421 and Mrk 501 (Cooke *et al.* 1978; Marshall and Jernigan 1978; Forman *et al.* 1978; Schwartz *et al.* 1978); and (5) about six narrow-emission-line ($\lesssim$1000 km s^{-1}) galaxies, NGC 5506, 7582, 2992, A0945−30 = MCG-5-23-16, and possibly NGC 1365 and M82 (Ward *et al.* 1978 and references therein; Schnopper *et al.* 1978; Dower *et al.* 1978). The compact nature of X-ray sources in each of these classes has been demonstrated through X-ray variability on time scales ranging from years to possibly hours (see references above).

The narrow-emission-line galaxies exhibit spiral and irregular morphologies, X-ray luminosities of 10^{41} to 10^{43} ergs s^{-1} (Ward *et al.* 1978), and 21 cm radio luminosities, where known, of 10^{38} to 10^{39} ergs s^{-1} GHz^{-1} (10^{21} to 10^{22} W Hz^{-1} sr^{-1}; de Bruyn and Wilson 1976; Kellermann 1964; Glass 1973). In this *Letter* we report the discovery, through its X-ray emission, of another example of this class but yet of a different kind because of its apparently elliptical morphology.

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II. X-RAY OBSERVATIONS

The X-ray observations were carried out 1978 January 17–23 with the *SAS 3* rotating modulation collimators (Doxsey *et al.* 1976) and yielded a net exposure of 103,000 s. The objective of the observation was the measurement (Bradt and Kelley 1979) of the precise position of the weak X-ray source 4U 0531−05 associated with M42, the Orion Nebula (den Boggende *et al.* 1978, and references therein). A previously unreported source was detected, within the 12° × 12° (FWHM) field of view, at a strength of 2.5 ± 0.3 μJy (averaged over 2–11 keV; 1.0 μJy = 0.24×10^{-11} ergs cm^{-2} s^{-1} keV^{-1}). The new source was clearly evident in each of the two independent modulation collimators (2′.3 and 4′.5 FWHM) at significances of 6 and 8 standard deviations, respectively, and is located ~5° from M42.

Two celestial positions, separated by 26″, were obtained from the two collimators. The average position (Table 1), precise to 40″ (90% confidence; Doxsey

TABLE 1

CELESTIAL POSITIONS

	α(1950)	δ(1950)	Error Circle Radius (90% confidence)
X-ray	$05^h49^m45^s.8$	−7°27′55″	40″
Optical nucleus	05 49 46.4	−7 28 06	4″
Radio	05 49 46.4	−7 28 03	1″.5

et al. 1977), lies 14″ from the centroid of the elliptical galaxy NGC 2110 (Fig. 1 [Pl. L9]). This galaxy has an extent of ∼40″ × 55″ on the Palomar Sky Survey and is classified as elliptical in the RNGC (Sulentic and Tifft 1973).

A relatively hard 2–11 keV energy spectrum ($\alpha = 0.1 \pm 0.3$) is indicated by the counting rates in the two energy channels (Table 2). The 2–11 keV X-ray luminosity is $L_x = 1.2 \times 10^{43}$ ergs s^{-1} for the redshift distance (see below) of 43 Mpc ($H_0 = 50$). In an earlier (1977 November) and somewhat less sensitive (60,000 s) observation, the flux density from this celestial position was consistent with the 1978 January value given in Table 2.

III. OPTICAL OBSERVATIONS

Spectrophotometry of the nucleus of NGC 2110 was performed at the McGraw-Hill Observatory with the Mark II photon-counting spectrometer with a 4″ diameter aperture in 1978 February and March (by A. K. and J. M.). Photographic spectra were taken at the ESO 3.6 m telescope in 1978 March (by J. vP.). The spectra show permitted and forbidden emission lines of approximately equal breadth with full widths at half-maximum intensity of 400–500 km s^{-1} as follows: Hα, Hβ, Hγ, Hδ, [O III] λλ4363, 4959, 5007 (the latter much stronger than Hβ), He II λ4686, [Ne III] λλ3868, 3696, strong [O I] λ6300, [O II] λ3727, [N II] λλ6547, 6583, [S II] λλ4071, 6716, 6731, and [N I] λ5199. Also present in the spectra are absorption lines due to the underlying galaxy: G-band, Mg I *b*, Na I D, and a broad feature near λ6230 due to TiO and many blended lines of Fe I and Ca I. We find a galactocentric redshift of 0.0071 ± 0.0003.

The emission-line features of the spectrum of NGC 2110 are quite similar in their relative strengths and widths to those of NGC 5506, 2992, and 7582 (Wilson *et al.* 1976; Ward *et al.* 1978). However, compared with these galaxies, NGC 2110 has a galactic continuum which is significantly more intense relative to the strengths of the emission lines.

TABLE 2

FLUX DENSITIES AND LUMINOSITIES

A.

Frequency (Hz)	Flux Density (Jy)
1.480×10^{9}	$0.24\ (+0.08, -0.04)$
4.885×10^{9}	0.13 ± 0.04
5.5×10^{14}	3.0×10^{-3}*
0.5–1.5×10^{18} (2–6 keV)	$(2.6\pm0.3)\times10^{-6}$
1.5–2.8×10^{18} (6–11 keV)	$(2.4\pm0.5)\times10^{-6}$

B.

Frequency Band	Luminosity
Radio (1.5 GHz)	5×10^{38} ergs s^{-1} GHz^{-1}
Optical (0.45–0.55 μm)	1.4×10^{42} ergs s^{-1}
X-ray (2–11 keV)	1.2×10^{43} ergs s^{-1}

* From counting rate meter: $m_v \sim 15.2$ ($M_v \sim -18.0$) in 4″ diameter aperture.

The galaxy has an elliptical appearance on the Palomar Sky Survey. However, on a deep blue plate (taken by P. Véron), we find the slightest suggestion of structure which, if real, could result in a different morphological classification. We also find the nucleus of NGC 2110 to be resolved on short-exposure plates provided by P. Véron and also by W. Liller (Fig. 1), and on the ESO photographic spectrum. The extent of the continuum and the line emission in the latter is estimated to be ∼4″. We point out that the nuclei of NGC 5506 ($z = 0.0061$) and NGC 7582 ($z = 0.0049$) also appear to be optically resolved (Wilson *et al.* 1976; Ward *et al.* 1978). A complete analysis of these optical data will be presented elsewhere.

IV. RADIO OBSERVATIONS

On 1978 April 21, following the X-ray and optical identification of NGC 2110, observations at 1.480 and 4.885 GHz were carried out at the VLA (the Very Large Array of the National Radio Astronomy Observatory). At this time, the VLA consisted of 10 antennas, at the higher frequency, most of which were on the SW arm, with a maximum spacing of 180,000 wavelengths. At the lower frequency, six of the antennas were used. The observations were distributed in four brief segments at each frequency; the equivalent beam at the higher frequency was approximately 1″ by 12″ full width at half-power, with a position angle of 55° for maximum resolution.

The observations show a source, located to a precision of 1″.5 (Table 1), 3″.0 from the position of the optical nucleus. This agreement is well within the 4″ accuracy of the optical measurement. The measured fluxes (Table 2) from the source indicate a nonthermal spectrum with a spectral index $\alpha = 0.5$. The source 3C 120 was used as a flux calibrator. The flux measurements are believed to be accurate to 30%, with the principal uncertainties arising from systematic effects in the VLA system, which is still in a state of development. The source exhibits an extension of approximately 3″ in the direction of maximum resolution. In the direction of minimum resolution, no extension was measurable.

V. DISCUSSION

The optical spectrum of the NGC 2110 nucleus is indistinguishable from that of a Seyfert type 2 (Sy 2) galaxy (see Koski 1978). As we have noted, it is similar to the spectra of several of the other X-ray–emitting narrow-emission-line galaxies mentioned above. NGC 2110 and the other four galaxies with secure X-ray identifications all have high [O III] λ5007/Hβ intensity ratios indicative of the high excitation associated with Sy 2 galaxies (Weedman 1977). In at least two cases, NGC 5506 and A0945−30 (Wilson *et al.* 1976; Schnopper *et al.* 1978), the galaxies were not classified as Sy 2 because of their relatively narrow line widths (200 and 400 km s^{-1} FWHM, respectively; see Weedman 1977). Rubin (1978) now reports broad wings (>1500 km s^{-1}, FWZI) for the permitted and forbidden lines of NGC 5506 and classifies it as Sy 2. The very narrow emission

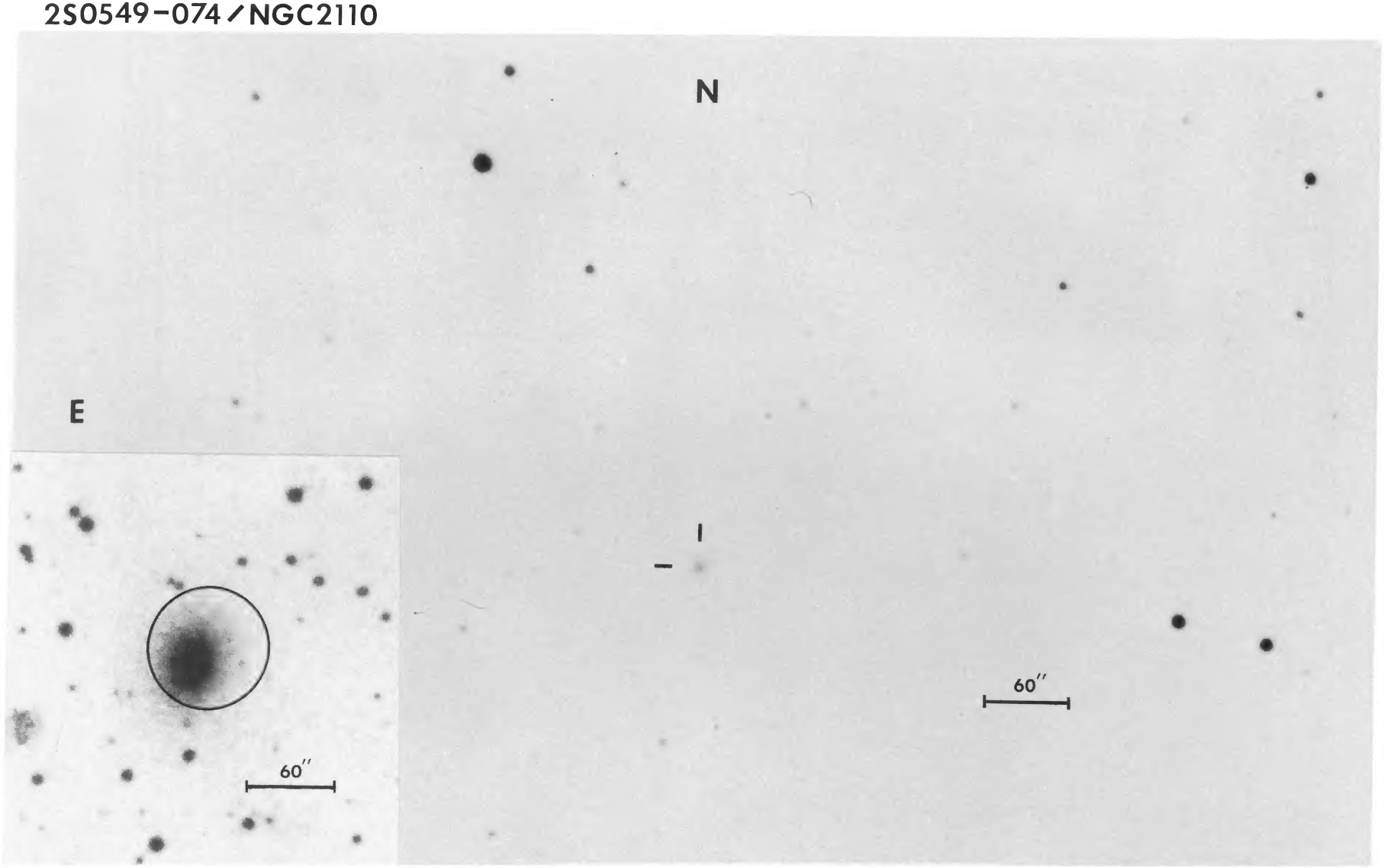

FIG. 1.—Short-exposure blue plate (provided by W. Liller) taken at the Harvard Agassiz 1.5 m telescope to illustrate the resolved nucleus of NGC 2110. *Inset*, Palomar Observatory Sky Survey (© National Geographic Society) red print of NGC 2110 with 40″ radius (90% confidence) X-ray error region shown. Note that the scale factors of the two prints are about equal.

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lines of A0945−30 appear to be unique among these galaxies.

These X-ray–emitting galaxies, as a class, are much closer to the Sun ($1470 < cz < 2500$ km s^{-1}, excluding M82 at 3 Mpc) than are the 16 cataloged Sy 2 galaxies ($1090 < cz < 15{,}300$ km s^{-1}, with only two below 2500 km s^{-1}: NGC 1068 at 1090 km s^{-1} and NGC 6764 at 2405 km s^{-1}; Weedman 1977). The resolved optical nuclei of NGC 2110, NGC 5506, and NGC 7582 may simply reflect this proximity. We note that the emission lines of the closest Sy 2 (NGC 1068) are spatially resolved at $\sim 8''$ (Walker 1968).

The 2–10 keV X-ray luminosity of NGC 2110 is comparable to that of the other X-ray–emitting narrow-emission-line galaxies (2×10^{42} to 2×10^{43} ergs s^{-1}), except for M82, which is only about 4×10^{40} ergs s^{-1} if the identification with the X-ray source is correct (Ward *et al.* 1978). Searches for X-ray emission from the cataloged Sy 2 galaxies have yielded upper limits that range from 2×10^{44} down to 2×10^{42} ergs s^{-1}, with only four of the 16 limits below 1.0×10^{43} ergs s^{-1} (Elvis *et al.* 1978). Thus the present emission-line galaxies could well be examples of the Sy 2 phenomenon wherein X-rays are detected because these galaxies are closer than all but two of the cataloged Sy 2 galaxies and wherein some of the present objects may not meet an operational criterion for Sy 2 membership (e.g., line widths >500 km s^{-1} FWHM). In fact, the intense emission of X-rays from these galaxies may be a common element more indicative of the underlying energy generating processes than are the observed line widths.

X-ray upper limits for 17 other emission-line galaxies (Ward *et al.* 1978) indicate that even high-excitation nuclei, e.g., Tololo 1400−411 (Penston *et al.* 1977) and NGC 5643 (Martin 1976), can have luminosities of $\lesssim 5 \times 10^{41}$ ergs s^{-1}. Thus the luminosities of this class of X-ray emitters probably extend down to at least 10^{41} ergs s^{-1} (see M82 above).

The radio luminosity of NGC 2110 at 21 cm (4×10^{21} W Hz^{-1} sr^{-1}) is about a factor of 4 greater than that of M82, and about equal to those of NGC 5506 (de Bruyn and Wilson 1976) and NGC 7582 if the latter galaxy has been correctly identified with PKS 2315−426 (Glass 1973). The radio luminosity and spectral index are near the centers of the distributions for Sy 2 galaxies. The size ($\sim$700 pc) is also typical of Sy 2 galaxies and comparable to the extent of the forbidden-line emission regions (de Bruyn and Wilson 1978).

Since we found no evidence for variability in the NGC 2110 X-ray source, its compact nature has not yet been demonstrated. However, the variability in NGC 5506 (Stark, Bell-Burnell, and Culhane 1978), in A0945−30 (Schnopper *et al.* 1978), and possibly in NGC 7582 (Ward *et al.* 1978) clearly establishes the compact nature of this class of X-ray emitters.

The elliptical morphology of this galaxy, if confirmed, may be unique among known Seyfert galaxies (Adams 1977). It is also unusual among known X-ray–emitting galaxies. Until recently, M87 was the only other galaxy with evident elliptical morphology associated with an X-ray source. In this case, most, and possibly all, of the X-ray flux is emitted from an extended ($\gtrsim \frac{1}{2}^\circ$) region centered on M87 (Lea *et al.* 1973; Gorenstein *et al.* 1977). However, the two BL Lacertae objects, Mrk 421 and Mrk 501, recently identified convincingly as X-ray sources (Marshall and Jernigan 1978; Schwartz *et al.* 1978), are known to be associated with elliptical galaxies (Ulrich *et al.* 1975). The quiescent X-ray luminosities of these objects are an order of magnitude greater (2×10^{44} ergs s^{-1}; Schwartz *et al.* 1978, and references therein) than the most luminous of the narrow-emission-line galaxies. The X-ray luminosities of Sy 1 galaxies range from 4×10^{42} to 1.5×10^{45} ergs s^{-1}, while X-ray–emitting quasars range from 2×10^{44} to 1×10^{46} ergs s^{-1} (Apparao *et al.* 1978, and references therein). NGC 2110, another variant among the diverse types of compact extragalactic X-ray emitters, may play a role in the eventual understanding of the basic and possibly common energy-generating process in these objects.

We thank the staffs of the VLA, McGraw-Hill Observatory, ESO, and NASA GSFC for their support of this work. We particularly thank B. Cooke, R. Dower, R. Doxsey, W. A. Hiltner, G. MacAlpine, and H. Schnopper for helpful conversations, M. Johns for assistance with the McGraw-Hill optical observations, and W. Liller and P. Véron for providing plates of NGC 2110. The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation. The McGraw-Hill Observatory is operated jointly by the University of Michigan, Dartmouth College, and MIT. This work was supported in part by the National Aeronautics and Space Administration under contract NAS5-11450 and grant NGR 23-005-464.

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