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A HIGHLY X-RAY–VARIABLE ACTIVE GALACTIC NUCLEUS NEAR M101: A MICROLENSING CANDIDATE

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ABSTRACT

The X-ray selected active galaxy 1E 1403+5439 has been found to increase its X-ray flux by a factor 5.5 ± 1.9 over an interval of 161 days. No other X-ray selected emission line active galaxy has been observed to vary by such a large factor. The X-ray source 1E 1403+5439 lies $\sim 18'$ ($\approx 1.3 R_{25}$) from the center of the large spiral galaxy M101. This proximity suggests that gravitational microlensing may be responsible for the extraordinary variability of this active galaxy.

Subject headings: galaxies: individual (M101) — galaxies: nuclei — galaxies: X-rays — gravitational lenses

I. INTRODUCTION

Large and rapid flux variations in quasars were one of the earliest signs of the extraordinary energy densities in these objects (Kinman 1968). Variability provided the strongest argument against normal stellar processes accounting for the quasar continuum. However, it now seems that large amplitude variations (>factor 1.5) are quite rare (Keel and Allen 1988; Pica *et al.* 1987). For this reason, the rare examples of active galactic nuclei (AGNs) which do exhibit variations well beyond this level have become worthy of note. This paper reports the discovery of a factor ~ 5 X-ray variation in an X-ray selected AGN: 1E 1403+5439 which lies near to the normal galaxy M101 in the sky.

II. OBSERVATIONS

The normal galaxy M101 (NGC 5457) was observed by the *Einstein Observatory* Imaging Proportional Counter (IPC, Giacconi *et al.* 1979, Gorenstein, Harnden, and Fabricant 1981) on two occasions separated by ~ 6 months (1979 January 6 and 1979 June 16, 161 days apart). Trinchieri, Fabbiano, and Romaine (1989) report on these observations in detail. One of the sources seen in these two observations is of particular interest: M101/X-9 (=1E 1403+5439). The X-ray (IPC) position of 1E 1403+5439 is (R.A. = $14^h03^m27\overset{s}{.}3$, decl. = $54°39'39''$). 1E 1403+5439 was identified with an AGN at a redshift $z = 0.082$, with a magnitude of 16.8 mag $\pm$ 0.3 mag (POSS magnitude) by Margon, Downes, and Chanan (1985).

This source was present in the first *Einstein IPC* observations at $4.4 \pm 1.4 \times 10^{-3}$ counts s^{-1} (Fig. 1[*a*]) in the standard IPC Broad band (Harnden *et al.* 1984). By the time of the second observation it had increased its count rate to $24.0 \pm 3.0 \times 10^{-3}$ counts s^{-1} (Fig. 1[*b*]), an increase of a factor 5.5 ± 1.9. The difference in the count rate detected in the two observations is significant at about the 6 σ level (Trinchieri, Fabbiano, and Romaine 1990). In both observations, the source was clear of the IPC window support structure which occults off-axis regions of the detector. Other systematic instrumental effects that could produce a spurious flux variation are unlikely, since both a flux increase and decrease is observed in two other sources in the M101 field.

In its bright state 1E 1403+5439 has a flux of 3.5×10^{-13} erg cm^{-2} s^{-1} (0.2–4.0 keV), implying an X-ray luminosity of 2.2×10^{43} ergs^{-1} (for a Galactic column density of 1.2×10^{20} atoms cm^{-2}, Stark *et al.* 1984, a power-law energy index of 1.0, [similar to those of both radio-quiet optically selected quasars, Wilkes and Elvis 1987, and X-ray selected quasars, Maccacaro *et al.* 1988], and $H_0 = 50$ km s^{-1} Mpc^{-1}). This X-ray luminosity is typical of type 1 Seyfert galaxies (see e.g., Kriss, Canizares, and Ricker 1980).

III. DISCUSSION

While X-ray flux variations on scales of several months are fairly common in quasars, they are, in almost all cases, of much smaller amplitude. In the study by Zamorani *et al.* (1984), nine out of 12 optically and radio selected quasars observed over this time interval showed significant variations (with limits for nonvarying sources being typically $\sim 20\%$). X-ray selected AGN are quite possibly less commonly variable. Maccacaro, Garilli, and Mereghetti (1987) report that, out of 41 *X-ray selected* AGNs, only five are variable, even though their objects were observed with similar time coverage to the Zamorami *et al.* quasars. The amplitude of the variations are slightly larger than in the Zamorani *et al.* sample, but are still only in the range 1.4–2.8. Only one source, with a variability factor 4.4 ± 1.7, is similar to our source. (But this source is partially affected by the IPC ribs so that this amplitude is suspect.) Larger X-ray variations in AGNs can be found more readily by selecting objects carefully. A sample of known radio variable quasars (Henriksen, Marshall, and Mushotzky 1984) produced three objects in which factor of 2 changes on six month time scales were seen, out of a total of 14 objects observed more than once. Even in this sample though no variability amplitudes similar to 1E 1403+5439 were found. The factor 5 variation observed in 1E 1403+5439 thus makes this an unusual object among X-ray selected AGNs. Branduardi-Raymont *et al.* (1989) have reported one other X-ray selected violent variable AGNs, however this is *optically* variable. Their AGN (EXO 033041−2613.1, "Gepu") faded by >3 mag optically in just over 2 yr.

1E 1403+5439 appears to be a normal radio-quiet AGN in every way except its extraordinary X-ray variability. With an absolute magnitude of $M_V = -21.7$, it is not luminous enough to qualify as a quasar on the criteria of Schmidt and Green (1983) and Veron-Cetty and Veron (1984) who both require

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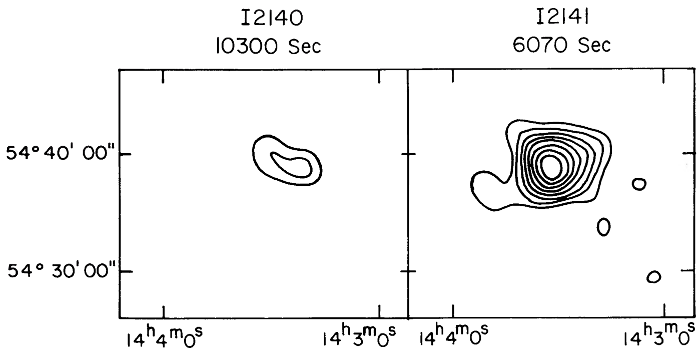

FIG. 1.—Isointensity contours of the X-ray source 1E 1403+5439 in the two IPC observations. The data have been smoothed with a Gaussian of $\sigma = 32''$ and have been background subtracted. The contours are linear in sigma, with the first contour at 2 σ above background.

$M_V < -23.0$. The AGN should thus be properly described as a type 1 Seyfert galaxy. 1E 1403+5439 has an X-ray-to-optical-flux ratio that is quite typical of radio-quiet quasars. This ratio is customarily defined via the nominal 2500 Å to 2 keV slope, $\alpha_{\rm OX}$. For 1E 1403+5439 $\alpha_{\rm OX} = 1.41$ (Margon, Downes, and Chanan 1985), close to the mean value for radio quiet quasars (Avni and Tananbaum 1986). A 5 GHz VLA radio measurement gives an upper limit of 0.8 mJy (5 σ, A. Wolter 1989, private communication). This implies a nominal slope from radio to optical, $\alpha_{\rm RO}$, of <0.0, typical of radio-quiet quasars. (To be classified as radio loud, a quasar conventionally needs $\alpha_{\rm RO} > 0.2$, Zamorani *et al.* 1981.) In the infrared, 1E 1403+5439 has normal *JHK* (1.2–2.2 μm) colors (Neugebauer *et al.* 1982). We have no information on the optical variability of the AGN.

Although it appears to be rare, there is no intrinsic difficulty in producing variability of this amplitude. For example one can define an efficiency parameter (Cavallo and Rees 1978) as $\epsilon = 4.72 \times 10^{-43}\ \Delta L/\Delta T$ which provides a lower limit on the conversion of accreting mass into luminosity. For 1E 1403+5439 ϵ has a value of $\sim 10^{-6}$, smaller than the values for the quasars in Zamorani *et al.* The normal emission line equivalent widths (Hα = 126 Å, Hβ = 41.5 Å, [on 1980 July 21], B. Margon and R. Downes 1989, private communication) and the existence of optical fuzz indicative of an underlying host galaxy (Malkan, Margon, and Chanan 1985), both suggest a normal Seyfert galaxy without strong relativistic beaming effects.

An alternative to varying the emission in 1E 1403+5439 is to change the absorbing column density toward it. A factor 5 increase in count rate could be produced by reducing the column density from $\sim 2 \times 10^{22}$ atoms cm^{-2} to the Galactic value in this direction, or from $\sim 5 \times 10^{22}$ atoms cm^{-2} to $\sim 1 \times 10^{22}$ atoms cm^{-2} (Harris 1984). Column densities of order 1–10 $\times 10^{22}$ atoms cm^{-2} are quite common in Seyfert 1 galaxies, particularly at low luminosities (Lawrence and Elvis 1982). Column density variations similar to the second example have been seen occasionally in Seyfert galaxies (e.g., Warwick, Pounds, and Turner 1988). The changes are normally presumed to be due to motions of "clouds" in the broad-line regions of the AGN (Reichert *et al.* 1985). Unfortunately, there are too few counts in the detections of the AGN to determine spectral parameters. In its bright state, it shows a hardness ratio HR = -0.08 ± 0.12 (defined as in Harnden *et al.* 1984). For the galactic line-of-sight column density, this corresponds to a power-law spectrum of $\alpha_E \sim 1$, quite normal for AGN (Maccacaro *et al.* 1988).

Since 1E 1403+5439 is normal in most regards, one may ask why it should show variability of an amplitude seen in no more than 1 in 40 X-ray selected AGN. The fact that 1E 1403+5439 is close on the sky to the nearby galaxy M101 ($\sim 18'$ from the galaxy's center, and $\sim 4'.5$ outside of the optical radius R_{25}, deVaucouleurs, deVaucouleurs, and Corwin 1976) may not be coincidental. Stellar mass objects in the haloes of galaxies can cause enhancements in the flux from background quasars through gravitational lensing, and the motion of the lensing object in the galaxy can induce large amplitude changes on a time scale of years (Canizares 1981). A six month time scale implies relatively small masses, $\sim 10^{-3}\ M_\odot$, (Gott 1981) for the lens.

New observations of this object could fill the wavelength gaps and archival data may provide sufficient variability data to test the plausibility of a microlensing explanation of the properties of this unusual X-ray variable AGN.

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