THE ASTROPHYSICAL JOURNAL, 246:L11–L14, 1981 May 15

X-RAY OBSERVATIONS OF NGC 7582 AND THE GRUS QUARTET WITH THE *EINSTEIN* OBSERVATORY

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Received 1980 July 18; accepted 1981 February 12

ABSTRACT

Observations with the Imaging Proportional Counter reveal that three of the four galaxies in the Grus Quartet are X-ray emitters (NGC 7552, 7582, 7590). The strongest is the narrow emission line galaxy (NELG) NGC 7582, and we confirm, also using data from the Monitor Proportional Counter, that the variable 2A 2315−428 consists essentially of this galaxy only. In the spectrum of this galaxy evidence is found of a large photoelectric cutoff, with the corresponding N_H lying between 5 and 10×10^{22} cm^{-2}. It is shown that both the interstellar medium and the narrow emission line gas of this galaxy are unlikely to be the main causes of the cutoff. By analogy with NGC 4151, where the variable cutoff is attributed to the broad line emitting gas, N_H is found to be compatible with the upper limits that can be placed on the strength of broad line components in NGC 7582 and could therefore represent the first indirect evidence of very high velocity gas in the nuclei of NELGs. A crucial test to be pursued is time variability in the cutoff.

The X-ray flux from NGC 7552 is variable, therefore probably coming from a compact nuclear region. The properties of NGC 7552 and 7590 are briefly discussed, and further optical studies are suggested.

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

I. INTRODUCTION

The four spiral galaxies NGC 7582, 7552, 7590, and 7599 belong to an association in Grus (Shobbrook 1966*a*, *b*) and form the so-called Grus Quartet. Ward *et al.* (1978) identified the variable X-ray source 2A 2315−428 with one of them, NGC 7582, a narrow emission line galaxy with a strong infrared excess and a "nonthermal" optical-UV continuum (Glass 1973; Ward *et al.* 1980; Clavel *et al.* 1980). On the basis of the extinction suffered by its nuclear light, Ward *et al.* (1978, 1980) predicted a photoelectric cutoff in the X-ray spectrum around 1 keV. NGC 7552 also has strong emission lines, but the degree of excitation is smaller than in NGC 7582, and there is no evidence in its optical spectrum of a substantial nonthermal component of the continuum (Alloin and Kunth 1979; Ward *et al.* 1980). It has, however, an IR luminosity comparable to that of NGC 7582.

The purpose of these observations, made with the Imaging Proportional Counter (IPC) on the *Einstein* Observatory, which is sensitive to the soft X-rays (∼0.1–4.0 keV) and has a resolving power of about 2′, was twofold: (1) to isolate the X-ray flux of NGC 7582 from nearby sources, which might contaminate the 2A flux, and look for a low-energy cutoff in its spectrum and (2) to explore the possibility of X-ray emission from the other members of the quartet, in particular NGC 7552. The observational results are presented in § II and discussed in § III, where a distance to the group of 30 Mpc ($H_0 = 50$) has been adopted.

II. THE OBSERVATIONAL RESULTS

Two IPC images centered on NGC 7582 were obtained the 1979 November 21 (1700 s) and the 1980 May 15 (2600 s). A third IPC image centered 23′.5 N-E of NGC 7582 and obtained 1980 June 6 (2000 s) was kindly given to us by C. Jones and W. Forman. During the IPC exposures, counts were recorded from the Monitor Proportional Counter (MPC), which is sensitive in the range 2–10 keV. For a description of the instruments, see Giacconi *et al.* (1979) and Grindlay *et al.* (1980).

In the first two images, all four Grus galaxies are within the field of view (60′×60′), although NGC 7552

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TABLE 1

X-RAY SOURCES IN THE NGC 7582 FIELD

SOURCE[a]	FLUX (0.2–3.5 keV)(10^{-12} ergs cm^{-2} s^{-1}) 1979 Nov. 21	1980 May 5	1980 June 6	IDENTIFICATION
1E 231327−4250.9	1.0 ±0.23	<0.32[b]	out of image	NGC 7552
1E 231540−4238.5	3.87±0.39	2.99±0.30	1.05±0.32	NGC 7582
1E 231611−4230.8	0.37±0.11	0.25±0.08	<0.47[b]	NGC 7590
1E 231619−4223.3	4.10±0.34	3.18±0.24	3.37±0.24	brightest member of distant group
Mpc flux (2–10 keV)(10^{-12} ergs cm s^{-1}) ...	31±6	36±7	...	...

[a]The source name gives the X-ray coordinates in hours, minutes, and seconds; degrees and arc minutes.

[b]3 σ upper limits.

is near the edge. In Table 1, we list four sources whose optical identification is illustrated in Fig. 1 (Plate L3). The first three sources are identified with NGC 7552, 7582, and 7590. The fourth one is the strongest in the soft X-rays and is identified with a background radio galaxy (M. Ward, private communication) which is the brightest member of a group. There is also a marginal evidence that this source might be extended ($\sim 1'.5$). Two more sources are seen near the detection limit, and detailed information on these, as well as on the background galaxy, will be presented elsewhere.

Significant evidence of variability is found for NGC 7582, which, in the third observation, was fainter by a factor of ~ 3 than in the previous ones, and for NGC 7552, which dropped below the detection limit in the second observation.

Figure 2 shows the IPC pulse height spectrum of the two strongest sources, NGC 7582 and the background source. The obvious difference between the two distributions can be quantified by means of the hardness ratio

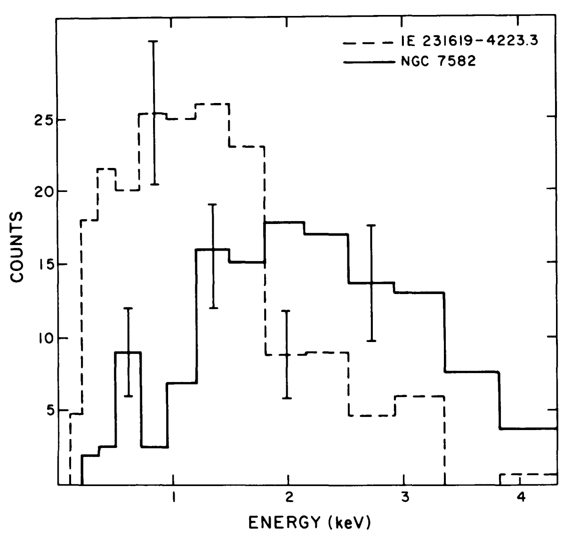

FIG. 2.—The IPC pulse height spectrum of the two strongest sources, from the 1980 May 15 observation.

[HR=counts (1.2–3.0 keV)/counts (0.5–1.2 keV)] (cf. Zamorani *et al.* 1981). The HRs in the three observations are consistent with a constant value, and their weighted mean is HR$=0.96\pm0.10$ for the background source and HR$=3.03\pm0.61$ for NGC 7582. In § III we shall demonstrate, using also the MPC data, that this difference is mainly due to a strong photoelectric cutoff in the spectrum of NGC 7582, but at present, unfortunately, calibration problems do not allow one to derive reliable spectral parameters from the pulse height spectrum. Furthermore, for the other two sources, the counts are too few even to obtain a meaningful value of HR. Therefore, in order to convert counts into flux, one has to make an assumption on the shape of the spectrum. The fluxes given in Table 1 have been obtained for a power law with a photoelectric cutoff. We adopted an energy spectral index $\alpha=-0.5$ and a cutoff energy $E_a=0.25$ keV, corresponding to a galactic column density $N_H=3\times10^{20}$ cm^{-2}, which is appropriate for the galactic latitude of our objects. For NGC 7582 only we adopted an additional intrinsic $N_H=8.8\times10^{22}$ cm^{-2}(E_a $=3.1$ keV), to be discussed in § III (the $E_a=N_H$ relationship used is from Brown and Gould 1970).

The errors in Table 1 are from counting statistics only. A change of ±1 in α produces a difference within $\pm20\%$ of the flux values quoted. For a thermal bremsstrahlung spectrum, which might be more appropriate for the background source, the flux given corresponds to $kT=10$ keV and would be smaller for lower temperatures, by 10% if $kT=2$ keV. Much more serious is the consequence of changing the intrinsic value of N_H for NGC 7582: for instance, with $E_a=1$ or 2 keV, the flux would be 1.75 or 1.40 times smaller than the one quoted.

For completeness, we report a 3 σ upper limit of 5×10^{-13} ergs cm^{-2} s^{-1} on the (0.2–3.5 keV) flux of NGC 7599.

Further information comes from the MPC counts. They allow us to estimate the (2–10) keV flux in its $42'\times42'$ FWHM field of view. A significant net count rate was recorded only in the first two observations, when the instrument was pointed at NGC 7582. The

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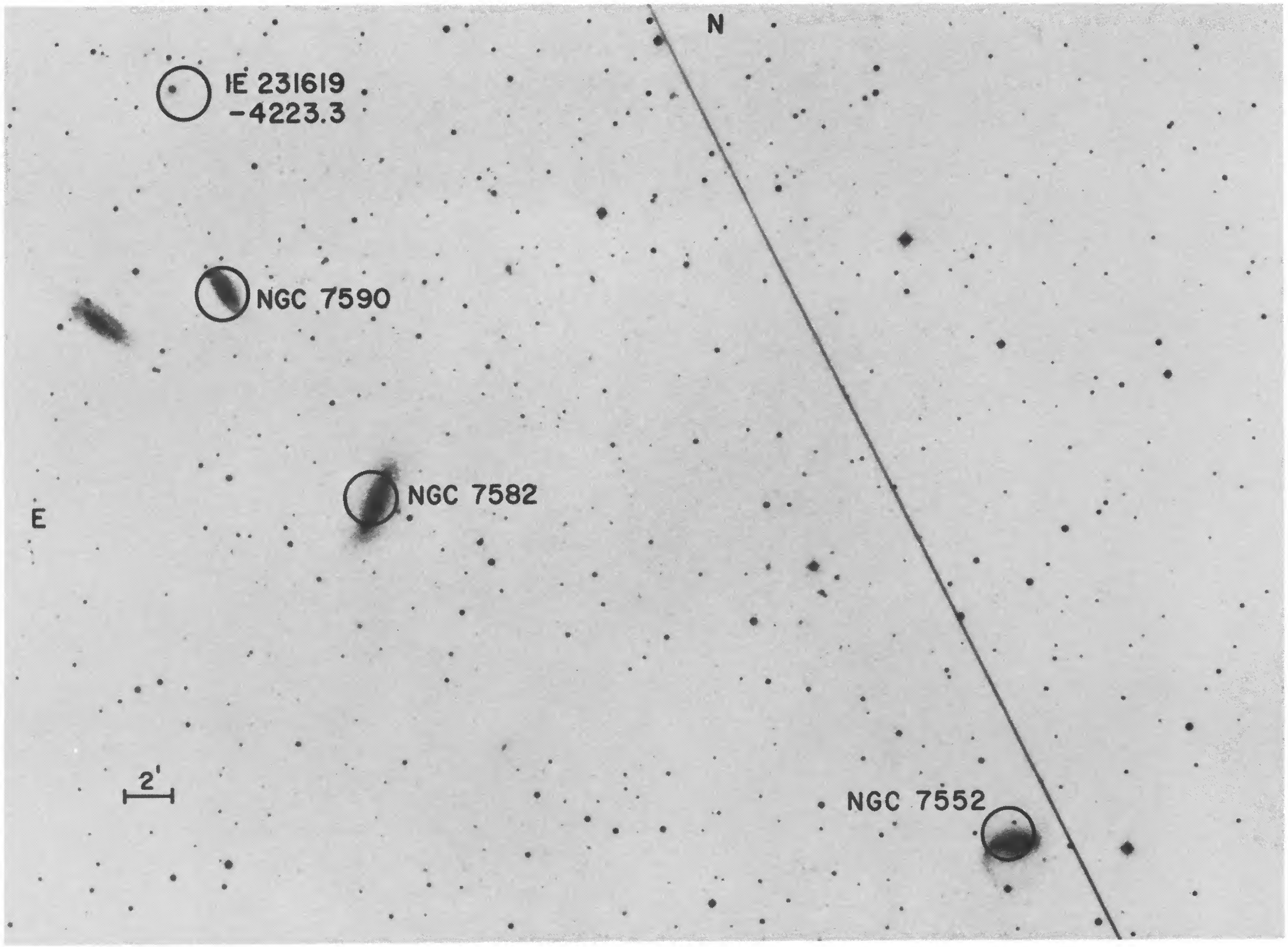

FIG. 1.—The position of the 4 sources in Table 1 plotted on a reproduction of the Palomar Sky Survey print (southern extension, courtesy National Geographic). The 90% confidence error circles are 1′ in radius.

MACCACARO and PEROLA (*see* page L12)

fluxes given at the bottom of Table 1 were obtained by best-fitting the PHA channel counts to a power law with photoelectric cutoff. Tests of the MPC performance on well-known constant sources (clusters) have been used to estimate the errors.

As could be predicted from the distribution of the IPC counts (Fig. 2), NGC 7582 is the dominant contributor to the MPC counts detected in the first two observations. In fact, the null result in the third one, when NGC 7582 was about a factor of 3 dimmer (see the IPC flux) and attenuated by a factor of 2.3, while the background source was attenuated only by a factor of 1.2, allows us to place on the (2–10) keV flux of this source a 3 σ upper limit of 9×10^{-12} ergs cm^{-2} s^{-1}, which is consistent with its IPC flux for $\alpha\leq0$ or any value of kT. In the first two observations, when its attenuation factor was 1.6, at most 15% of the flux could then be contributed by this source. In conclusion, at least about 80% of the MPC flux in the first two observations must be assigned to NGC 7582. The two values are equal to the average intensity of 2A 2315−428 (Ward *et al.* 1978). These results confirm that the *Ariel 5* source consists essentially of NGC 7582.

III. DISCUSSION

a) *NGC 7582*

Despite the poor energy resolution and the limited statistics achieved, the spectral fit to the MPC data excludes $\alpha>0.0$ and $\alpha<-1.0$ at the 90% confidence level, with a best-fit value $\alpha=-0.5$. Furthermore, it shows evidence of a photoelectric cutoff around 3 keV, which provides the explanation for the large value of the ratio of the (2–10) keV to the (0.2–3.5) keV fluxes. At present, in fact, the most reliable estimate of E_a is obtained by fitting this ratio, allowing for the dependence on E_a of the fluxes derived from the net counts. Assuming 100% of the MPC flux as from NGC 7582, we find, for $\alpha=0.0$, $E_a=2.6(+0.3, -0.6)$ keV, or $N_{\rm H}=[5.3(+1.9, -2.3)]\times10^{22}$ cm^{-2}; for $\alpha=-0.5$, $E_a=3.1$ $(+0.3, -0.6)$ keV, or $N_{\rm H}=[8.8(+1.2, -2.6)]\times10^{22}$ cm^{-2}; for $\alpha=-0.1$, $E_a=3.4(+0.3, -0.4)$ keV, or $N_{\rm H}=[10.3(+6.1, -2.6)]\times10^{22}$ cm^{-2}. The uncertainties correspond roughly to the 90% confidence level.

The estimate of $N_{\rm H}$ can be compared with predictions based on information in the optical and ultraviolet bands. From the optical spectrum Ward *et al.* (1980) infer a value $A_V\approx1.3$ for the reddening of the continuum, in agreement with that measured from the strength of the 2200 Å extinction feature by Clavel *et al.* (1980). For the emission lines they deduce a larger value, $A_V\approx3.6$. The difference in A_V can be reasonably attributed to dust associated with the emitting gas, which, as typically occurs in active nuclei (e.g., Osterbrock 1978), can be very clumpy (filling factor $f\ll1$) and therefore can let the continuum shine through it with a reddening smaller than that suffered by the lines. In proposing this explanation Ward *et al.* (1980) actually suggest that the reddening of the continuum might be just due to the interstellar medium of NGC 7582, being this galaxy very dusty and seen almost edge-on.

A value of $N_{\rm H}$ can be predicted using the relationship between A_V and $N_{\rm H}$ for the interstellar medium of our galaxy. The one derived by Reina and Tarenghi (1973; also Gorenstein 1975) yields, for $A_V=1.3$, $N_{\rm H}=2.5\times10^{21}$ cm^{-2}, one order of magnitude less than the minimum compatible with the observed cutoff. This large discrepancy seems to exclude the interstellar medium of NGC 7582 as the main cause of the cutoff, but not necessarily the emission line gas itself, which could be characterized by a peculiarly low dust-to-gas ratio. However, we can also estimate an expectation value of $N_{\rm H}$ due to this gas from the intensity of its lines. Using the Hβ line (with $T\approx10^4$ K) and assuming spherical geometry, one finds

$$N_{\rm H}\approx fnR\approx2\times10^{24}n^{-1}R^{-2}L({\rm H}\beta), \qquad (1)$$

where n is the density within the clumps and R is the radius of the line emitting region. With L(Hβ) given in Table 2, $n\approx1.5\times10^3$ cm^{-3}, inferred by us from the [S II] ratio $I(\lambda6716)/I(\lambda6731)$ measured by Ward *et al.* (1980), and $R=150$ pc (corresponding to 1″, probably a lower limit since the nucleus appears marginally resolved on a blue plate inspected by Ward *et al.* 1978; with this value of R, $f\approx10^{-2}$) one obtains $N_{\rm H}\approx8\times10^{21}$ cm^{-2}, too small by at least a factor of 4. This result, although subject to uncertainties, indicates that the narrow line emitting gas is also unlikely to be the cause of the cutoff.

These considerations lead us to regard with favor an alternative explanation suggested by the analogy with the Seyfert galaxy NGC 4151, where the column density predictable from the extinction in the far UV is also far less than the one determined from the X-ray cutoff (Boksenberg *et al.* 1978; Penston *et al.* 1981). In NGC 4151 the X-ray column is seen to vary between a few times 10^{22} and 10^{23} cm^{-2} (Barr *et al.* 1977; Mushotzky *et al.* 1980), and this naturally suggests the identification of the absorbing material with the dense gas clouds ($n>10^7$ cm^{-3}) in the broad line region, whose size is probably ~0.025 pc (Anderson 1974). In the optical spectrum of NGC 7582, there is no direct evidence of broad line gas; however its existence cannot be excluded, since a broad Hβ component ($\gtrsim1000$ km s^{-1}) of the order of 0.1 times the intensity of the observed narrow one is not inconsistent with the available observational data. Such a broad line would be approximately 30 times weaker than in NGC 4151; hence, according to equation (1), for the same R also the same $N_{\rm H}$ is obtained in the two objects, provided that the density in NGC 7582 is also 30 times lower than in

TABLE 2

PROPERTIES OF THE GRUS QUARTET[a]

Galaxy	L(0.2–3.5 keV)[b] (ergs s^{-1})	L(Hβ)[c] (ergs s^{-1})	[O III]5007/Hβ	L(1.2–3.4 μ) (ergs s^{-1})	L(10–10^4 MHz) (ergs s^{-1})
NGC 7582 ...	3.5×10^{41}	1.2×10^{42}	2.6	2.4×10^{43}	2.9×10^{39}
NGC 7552 ...	1.0×10^{41}	2.8×10^{41}	0.4	3.3×10^{43}	3.3×10^{39}
NGC 7590 ...	3.2×10^{40}	...	...	3×10^{42}	9×10^{38}
NGC 7599 ...	$<5\times10^{40}$	...	...	...	6×10^{38}

[a]Optical data from Ward *et al.* 1980; radio data from Ward *et al.* 1980 and Wright 1974; infrared data from Glass 1973. Distance adopted 30 Mpc.

[b]For NGC 7582 and 7552, this is the maximum luminosity found in our observations.

[c]Corrected for extinction.

NGC 4151. A crucial test of this interpretation consists in looking for variability in the X-ray cutoff. If found, it would represent the first indirect evidence of the existence of substantial amounts of high-velocity gas also in the nuclei of narrow emission line galaxies.

b) *NGC 7552*

At the epoch of the first observation, this galaxy was only ~3.5 times fainter than NGC 7582 in the soft X-rays, but as much as ~25 times weaker in the (2–10) keV range, if we assume no intrinsic cutoff and $\alpha=-0.5$. A check of its medium energy flux requires an observation pointed on this galaxy. The second observation showed a decrease in intensity, thus proving that we are dealing with a compact nuclear source as in NGC 7582. Comparing other properties of the two galaxies (see Table 2), note that they have similar radio and infrared luminosities (the latter being remarkably large), but NGC 7552 has much smaller values of L(Hβ) and of the excitation parameter [O III]/Hβ. In addition, the nucleus of NGC 7552 is characterized by the presence of bright spots (Sersic 1973) and, according to Alloin and Kunth (1979), the ionizing continuum originates mainly from hot (young) stars in these spots, like in galactic H II regions. Our observation indicates the presence of a relatively weak nonthermal component of the continuum. A similar galaxy with a "hot spot" nucleus is NGC 1365, also a rather weak X-ray emitter (Ward *et al.* 1978). On short-exposure photographs of this galaxy, Veron *et al.* (1980) discovered a starlike blue nucleus, most likely to be identified with the nonthermal source. Such an investigation should be carried out also for NGC 7552.

c) *NGC 7590*

Martin (1976) describes the nucleus of NGC 7590 as stellar-like, reports the presence of weak emission lines, and puts it in the same excitation class as NGC 7582, on the basis of an eye estimate of the line intensity ratios. These properties, together with the moderately high X-ray luminosity, indicate that this object might be a weaker example of galaxies like NGC 7582. A detailed and quantitative spectrophotometry is obviously needed.

This work was done as part of a guest observing program with the *Einstein* Observatory. We wish to thank I. M. Gioia for the help provided in the data analysis, G. Zamorani and N. Panagia for a discussion, and the CFA staff for hospitality and assistance. We also wish to thank M. Ward for informing us of his results prior to publication. We acknowledge financial support from the Italian CNR.

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