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OBSERVATION OF X-RAY EMISSION FROM M31

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ABSTRACT

We have observed X-ray emission from M31 in the 0.5–5.0 keV band, using rocket-borne proportional counters. The integrated flux corresponds to $(2.2 \pm 0.6) \times 10^{39}$ ergs s^{-1} at M31, and is confined chiefly to a region coinciding with the optical image of the galaxy. The spectrum has a slope similar to the bright Galactic X-ray sources. The intensity, spectral, and spatial data suggest that the bulk of X-ray emission from M31, and by inference from most normal galaxies, is due to a small group of highly luminous sources, in agreement with the Galactic X-ray luminosity function.

Subject headings: galaxies, individual — spectra, X-ray — X-ray sources

The bulk of extragalactic X-ray astronomy has thus far been concerned with the study of unusual objects or clusters of galaxies. However, the observation in the X-ray band of normal individual galaxies is crucial to our understanding of many properties of Milky Way galactic X-ray emission. In this paper we report observations of the Andromeda Nebula, M31, in the 0.5–5.0 keV band.

The data were obtained by two thin-window proportional counters carried aboard a Black Brant VC sounding rocket fired from White Sands Missile Range, New Mexico, on 1973 February 10 at 0408 UT. Parameters of the two detectors are given in table 1. An attitude control system (ACS) pointed the payload at M31 and surrounding background points for 129 s, during which time the vehicle was at altitudes of 182–217 km. The aspect of the X-ray detectors with respect to the celestial sphere was obtained from star field photographs taken by an onboard 35-mm camera, star transits in an ultraviolet telescope of the type described by Holberg, Bowyer, and Lampton (1973), and telemetered ACS performance data. With the aid of an optical star-tracker, the ACS performed a series of preprogrammed maneuvers which included two 25-s background observations centered at points 4° west and 3° north of M31, respectively, followed by a 42-s observation of the galaxy itself. During this observation, the aspect data indicate that the detector fields-of-view were centered on a point $(30 \pm 5)'$ north and $(12 \pm 5)'$ east of the nucleus, whose 4^m image is visible on certain of the aspect photographs. The slat collimator of the XR2 detector was inclined to the major axis of M31 by 55°. In this pointing configuration, the half-power beam of XR1 encompassed ~0.75 of the projected disk of the galaxy, while XR2 saw only the northeastern limb, or ~0.4 of the disk. The XR1 beam is shown on a plate of this region of sky in figure 1.

Count-rate data telemetered by the two detectors during these maneuvers appear in table 1. The two background scans agreed in each counter in the indicated bandpasses to within 1 σ and have been summed in the table. It is apparent that M31 is seen in XR1 at a level 3.9 σ above the background, while XR2 sees only a 1.3 σ excess; the joint probability of such positive fluctuations appearing simultaneously by chance in both counters is 5×10^{-6}. The XR1 net count rate of (4.1 ± 1.1) counts per second (cps) corresponds to a flux at Earth of $(4.2 \pm 1.1) \times 10^{-11}$ ergs cm^{-2} s^{-1} in the 0.5–4.1 keV band, or $(2.2 \pm 0.6) \times 10^{39}$ ergs s^{-1} at the distance of M31.

We can use the difference in net count rates in our two detectors, together with their known sensitivities and background count rates, to derive additional

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TABLE 1
INSTRUMENTAL AND OBSERVATIONAL PARAMETERS

Parameter	XR1	XR2
Window	85 $\mu g\ cm^{-2}$ polypropylene 35 $\mu g\ cm^{-2}$ carbon	254 $\mu g\ cm^{-2}$ Kimfol 23 $\mu g\ cm^{-2}$ carbon
Gas	215 mm propane	400 mm argon/methane
Sensitivity (≥5%)	3–34 Å, 44–125 Å	1–22 Å, 44–80 Å
Effective area (cm^2)	633	585
Collimation (FWHM)	2°05 × 2°46	1°11 × 5°0
Background count rate (cps)	21.5 ± 0.7 (0.5–4.1 keV)	14.6 ± 0.5 (0.7–5.2 keV)
M31 count rate (cps)	25.6 ± 0.8 (0.5–4.1 keV)	15.6 ± 0.6 (0.7–5.2 keV)

information on the location and spatial distribution of the observed X-rays. Although such inferences cannot yield a unique model, all but the simplest interpretation of the data would require a flux distribution which is asymmetric with respect to the M31 nucleus, a possibility which we consider unlikely on physical grounds. We conclude from this analysis that the X-ray emission emanates chiefly from the immediate vicinity of the optical image of the galaxy, rather than from an extended region surrounding but centered on M31. For example, we can rule out the scenario that the observed emission is due to a disk of radius 2° centered on the nucleus; an isothermal sphere responsible for the flux must have core radius less than 3°. Thus the X-ray major axis of M31 does not exceed its optical counterpart by more than 70 percent, and may well be substantially less; our data are equally compatible with a point nuclear source.

A 2–6 keV X-ray source with a 1.6 σ error box of 15 deg^2 in this general area has been noted by Giacconi *et al.* (1974); this box is also shown in figure 1. Since there are 39 3U sources in the band $30 \geq |b| \geq 10$, or a density of 0.003 deg^{-2}, the fact that any one source falls in a 15 deg^2 box near M31 is significant only at the 2 σ level. The formal confidence that such a source is associated with M31 is considerably less than 2 σ if the *Uhuru* 3 σ error box area is employed and if the calculation is corrected for incomplete sky coverage by the satellite. Clark, Lewin, and Smith (1968) and Laros, Matteson, and Pelling (1973) have also reported upper limits to hard X-ray emission from this region.

In our experiment each proportional counter telemetered 64 channels of pulse-height information, and we have used the XR1 pulse-height data to derive the energy spectrum of M31. The technique used is that of Cruddace *et al.* (1972); the derived spectrum has been compared with power-law photon distributions of index n, subjected to photoelectric absorption. In figure 2 we present the observed spectrum incident at Earth, corrected for instrumental efficiency and resolution. The inset to the figure gives a 1 σ contour of constant probability for the least-squares fitting procedure, and all values of the free parameters (n, N_H) lying within this contour should be considered equally compatible with the data. The low observed flux level makes it difficult to accurately define the spectral parameters; however, several other constraints are available. The column density of galactic neutral hydrogen is known to be of order 7×10^{20} cm^{-2} (Tolbert 1971), and thus values $N_H \gtrsim 10^{21}$ in the observed X-ray spectrum are likely. If we require our observed flux, when extrapolated to the 2–10 keV band, to agree with that reported by Giacconi *et al.* (1974), we find that a spectrum of the form $F(E) = (0.023 \pm 0.006)E^{-2.4} \exp(-4 \times 10^{21} \sigma_{ISM})$ photons cm^{-2} s^{-1} keV^{-1} fits all the data, where σ_{ISM} is the photoelectric absorption cross-section of the interstellar medium to soft X-rays (Cruddace *et al.* 1974). We stress the possible systematic uncertainties of this spectrum; for example, the flux observed by Giacconi *et al.* may not be from M31, for reasons discussed previously.

We do not have sufficient source counts to subject our data to a statistically significant Fourier analysis; a source of 10 times the intrinsic flux of Cygnus X-1 if located in M31 could modulate at most 5 percent of the observed flux.

Our spatial data indicate that the bulk of the observed X-ray emission originates close to or coincident with the optical galaxy, and are thus consistent with a stellar origin, analogous to the situation we observe in our own Galaxy. Our spectral data point to another such similarity. The mean spectral index for 10 bright Galactic X-ray sources reported by Cruddace *et al.* (1972) is 2.5 ± 0.7; Hill *et al.* (1972) report 2.5 ± 1.6 for a separate sample of 11 bright sources. These values are quite close to that which we derive for the integrated M31 flux. Observed Galactic eclipsing binary X-ray sources, once suggested to have very flat spectra, also often show indices in this range (Baity *et al.* 1974).

Previous to the current data, very little information independent of galactic observations has been available on the nature of the X-ray emission of normal galaxies. Observations of the Magellanic Clouds (Price *et al.* 1971; Leong *et al.* 1971) are not relevant to this problem, since these objects are an order of magnitude less massive than our Galaxy or M31; in any case these data specifically indicate a drastic difference from the Milky Way, since $\gtrsim 90$ percent of the emission from the Small Magellanic Cloud is due to a single source. From a study of the Galactic X-ray luminosity function, Margon and Ostriker (1973) conclude that the X-ray emission of the Milky Way is dominated by a group of highly luminous sources. The intensity, spectral, and spatial data presented here for M31 are interpretable in this framework, and serve as independent evidence for the nature of the X-ray luminosity of normal galaxies.

Hunt and Sciama (1972) have noted that an ionized intergalactic medium accreting onto M31 will generate a diffuse soft X-ray flux within $\lesssim 6°$ of the galaxy. The models presented by these authors imply an observed flux of 0.1–1.0 cps in our XR1 detector, and less in XR2. Even if one disregards our marginal ability to detect these fluxes at a statistically significant level, verification of this model would require separation of this flux from that due to the soft component of the diffuse X-ray background. The X-ray background generates $\gtrsim 10$ times more counts than the predicted effect, is of extremely uncertain intrinsic flux and spectral shape at any given location, and is known to vary on spatial scales comparable to that of the predicted accretion effect. We therefore conclude that the flux from this process is probably unobservable by the current generation of experiments. However, our observations of the spatial variation of the $E < 0.5$ keV flux in the M31 region do provide constraints on the origin of the diffuse background (Gould and Sciama 1964), and these will be discussed elsewhere (Margon *et al.* 1974).

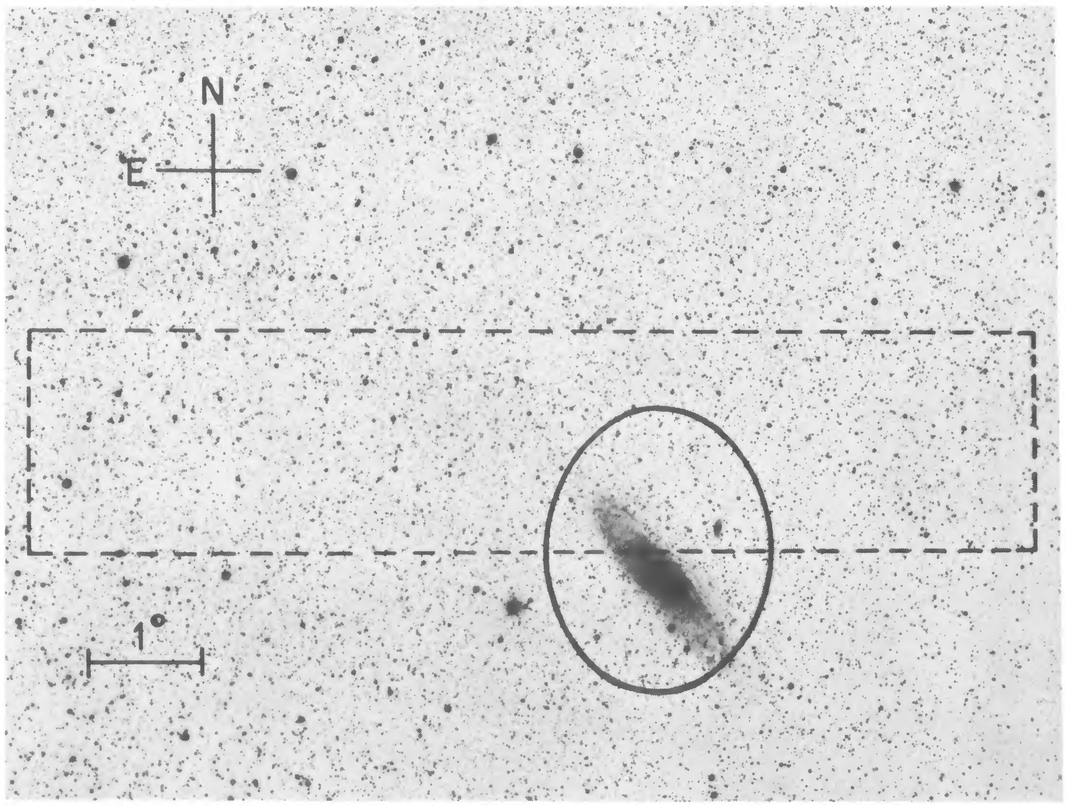

FIG. 1.—Plate of the M31 region, taken from the Lick Observatory *Sky Atlas*. *Solid line*, beam pattern of the XR1 propane proportional counter during the M31 observation described in the text. *Broken line*, 1.6 σ error box for a source noted by Giacconi *et al.* (1974).

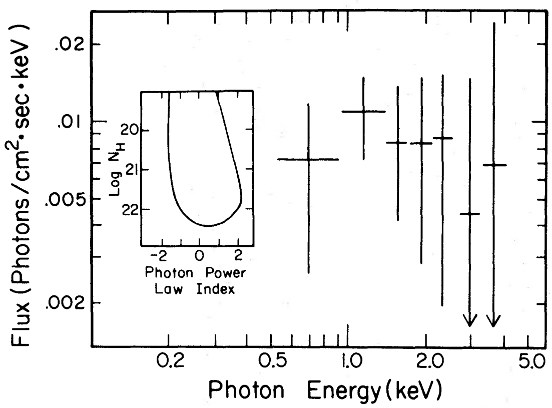

FIG. 2.—The X-ray spectrum of M31 observed in the XR1 detector. Error bars are $\pm 1\ \sigma$ statistical errors. *Inset*, contour where confidence of the least-squares fitting procedure drops to $e^{-0.5} = 0.607$ of the peak value.

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