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A SEARCH FOR ABSORPTION OF THE SOFT X-RAY DIFFUSE FLUX BY THE SMALL MAGELLANIC CLOUD

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ABSTRACT

An upper limit of 25 percent is placed on the fraction of the observed 120–284-eV X-ray flux that originates beyond the Small Magellanic Cloud if 21-cm measurements of total columnar hydrogen density and the effective absorption cross-sections of Brown and Gould are assumed. This result is still consistent with the extragalactic origin of an $E^{-1.4}$ extrapolation of the isotropic X-ray background observed above 2 keV. The excess flux cannot all originate outside of even the local-velocity gas unless an extremely clumpy model of the gas distribution is accepted.

Several groups have reported an X-ray background flux below 284 eV in excess of that predicted from an extrapolation of the isotropic power-law spectrum observed at higher energies (Henry *et al.* 1968; Baxter, Wilson, and Green 1969; Bunner *et al.* 1969; Hayakawa *et al.* 1970*a;* Shukla and Wilson 1971; Bunner *et al.* 1971). Since the extragalactic origin of such an excess could have cosmological implications (Henry *et al.* 1968), it is desirable to determine whether these X-rays do in fact originate outside the Galaxy. A definitive demonstration that this is the case would be to observe absorption of the X-ray flux by an extragalactic object. The results of an attempt to measure the absorption of the soft X-ray background by the Small Magellanic Cloud are reported here.

The experiment was flown from Woomera, South Australia, on an Aerobee 150 sounding rocket at 18:00 GMT on 1970 June 2. The inertial attitude control system was programmed to make a raster scan centered on the Small Magellanic Cloud (SMC) and comprised five 12° scans spaced 2°.5 apart. The actual scan path is shown in Figure 1. Although the 35-mm aspect camera failed to operate, magnetometer data and two source crossings, one very near the SMC, enabled the aspect to be determined within a degree and a half. Scan rates were about 0°.4 s^{-1}. Amplitudes of the proportional-counter output pulses for all non-vetoed events were telemetered with a resolution equivalent to 8 eV in the pulse-height interval 0.09–1.8 keV and with 50-eV resolution to 11 keV. Calibration by a 5.9-keV source every 30 seconds during the flight verified overall gain stability within 5 percent.

Models for the expected soft X-ray absorption have been calculated using 21-cm measurements of columnar hydrogen density. Data for the Galaxy and for the outer and central regions of the SMC have been taken from McGee, Milton, and Wolfe (1966), Hindman, Kerr, and McGee (1963), and Hindman (1967), respectively. The effective X-ray absorption cross-sections of Brown and Gould (1970) were used to calculate optical depth. Another estimate of these cross-sections by Bell and Kingston (1968) would predict even more absorption, largely due to their higher assumed relative abundance of helium. Interstellar gas transmission was folded with the collimator response on a very fine spatial grid. The source spectrum $11\ E^{-1.4} + 180\ E^{-1} \exp(-E/0.3)$ photons (cm^2 s sterad keV)$^{-1}$ was assumed. While this is not a perfect fit to the data at all energies, it does provide the total intensity observed below 284 eV. The off-axis transmission of the aluminum honeycomb collimators is a function of energy, since the efficiency of reflection from the aluminum increases sharply with wavelength, but the measured collimator response at 180 eV was used for all energies in the calculations. Since this is the broadest possible effective response, it tends to predict a lower limit to

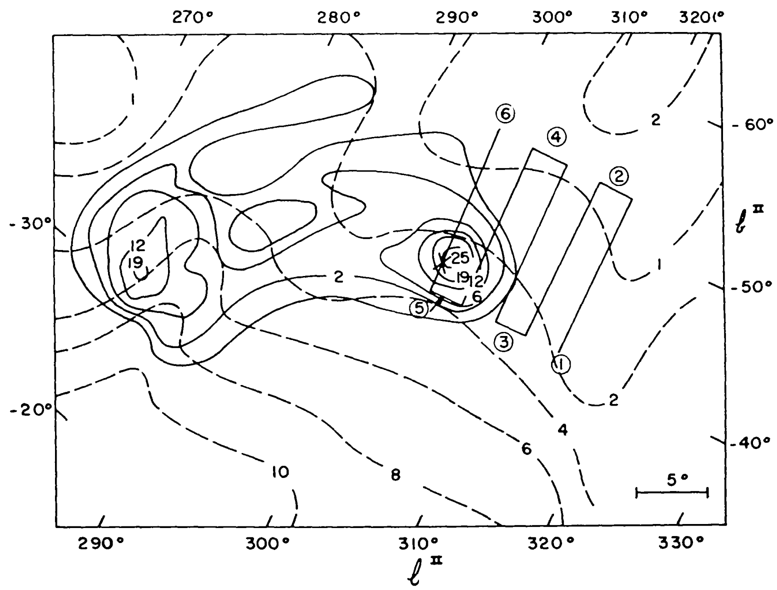

FIG. 1.—Scan path of this experiment superposed on a smoothed representation of the hydrogen distribution. Dashed contours are galactic H I. Solid contours are for H I associated with the Magellanic Clouds. Units are 10^{20} H cm^{-2}. Circled numbers 2–5 indicate rapidly scanned connecting segments. The fields of view of the X-ray detectors were 6° and 10° FWHM at 180 eV and were roughly circular. The cross marks the location of a weak point source probably associated with the SMC.

the absorption. In fact, the predicted absorption depth is not affected markedly either by the choice of a source function or by small changes in the collimator response.

The results of these calculations are shown with the observed data in Figure 2. For the solid curve in Figure 2*A* it has been assumed that all of the 120–284-eV flux originates beyond the SMC. A comparison of the data with this model leads to the estimate that less than 25 percent of the flux could have this origin. If it is further assumed that all the absorbing gas is clumped into clouds, the expected absorption is reduced as shown by the dashed curves for clouds of average thickness 8 and 20×10^{20} H cm^{-2}. Such cloud models would allow a larger fraction of the flux to be extragalactic, but even the more extreme one fails to make the data consistent with the assumption that all of the flux comes from beyond the SMC. The dot-dash line shows the part of the absorption due to the Earth's atmosphere (*USSA* 1966). Since columnar densities of hydrogen associated with the Galaxy are small in this region and it might be argued that they are questionable, models similar to those in Figure 2*A* were calculated for which local hydrogen densities were assumed to be zero. These are shown in Figure 2*B*, and still predict more absorption than is consistent with the data.

In Figure 2*C* it was assumed that the soft X-ray flux originates outside of the local-velocity hydrogen distribution but closer than the SMC, as if from an extended galactic halo. These models again are inconsistent with the data even for clumped gas distribution models with average cloud thicknesses as great as 8×10^{20} H cm^{-2}. Although the 21-cm survey in this region is not sufficiently detailed to exclude them, there is little evidence for clouds this thick at such high galactic latitudes. A more detailed survey near the South Galactic Pole (Dieter 1965) shows only "normal" clouds of about 2×10^{20} H cm^{-2} thickness.

Only one-sixth of the observed 120–284-eV flux can be accounted for by an extrapolation of the $11\,E^{-1.4}$ photons (cm^2 s sterad keV)$^{-1}$ spectrum that fits the data in the interval 1.5–10 keV, even if no absorption is assumed. Since there is good evidence that the

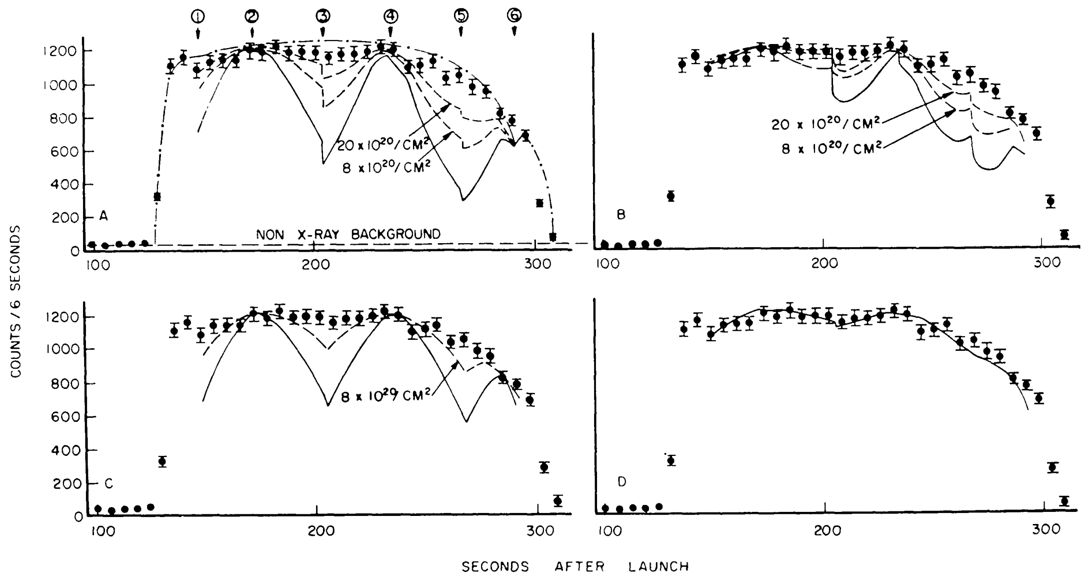

FIG. 2—Data points show total counting rate for all counters in the 120–450-eV pulse-height interval as a function of time during the flight. Circled numbers are points marked on the scan path in Fig. 1. The models shown in Fig. 2A assume that all the flux comes from beyond the SMC. *Solid curve,* absorption predicted if the gas is uniformly distributed. *Dashed curves,* cases where all the absorbing gas is clumped into clouds of 8 and 20×10^{20} H cm^{-2} thickness. Dot-dash curve includes only the effects of the Earth's atmosphere. For clarity, all models are normalized to the same point. Models in Fig. 2*B* assume absorption only by gas associated with the SMC, and those in Fig. 2*C* assume absorption only by gas associated with the Galaxy. Curve in Fig. 2*D* is the predicted absorption assuming that only an $E^{-1.4}$ photon spectrum fit to the 2–10-keV data is extragalactic, with the remainder of the observed flux coming from some local source.

power-law component above 1.5 keV is highly isotropic and probably extragalactic, a model was constructed in which an extrapolation of this spectrum below 284 eV was assumed to originate beyond the SMC. The remainder of the observed flux was supplied by an isotropic 0.3-keV free-free source assumed to be local and subject to absorption only by the Earth's atmosphere. The result of this model is shown by the solid line in Figure 2*D*. While the data are a reasonable fit to this model, the statistics are not good enough to require any absorption beyond that of the atmosphere.

We emphasize that the very local nature assumed for the added component, while consistent with these observations near the SMC, probably is not an accurate representation of its true distribution. Bowyer and Field (1969), Bunner *et al.* (1969), Hayakawa *et al.* (1970*a*), and Bunner *et al.* (1971) have observed that the flux between 0.1 and 0.3 keV in the galactic plane is less than 30 percent of the flux at high latitudes. Since the added component provides about five-sixths of the flux at high latitudes, most of it must come from sufficiently large distances that it is absorbed heavily by the gas in the galactic plane.

A point source was observed in the energy interval 1.0–10 keV at the position marked by a cross in Figure 1. This source also has been observed by groups at the Lawrence Radiation Laboratories and American Science and Engineering and is probably associated with the SMC. The source had an intensity of only about 0.08 photons cm^{-2} s^{-1}, and its spectrum could not be determined completely. The spectrum is sufficiently well determined in the 1–2-keV region, however, that absorption by more than 10×10^{20} H cm^{-2} is implied if a photon power-law spectrum is assumed with an index greater than 1.4. In this case there could be no significant contribution from the source at energies less than 284 eV to fill in the expected absorption of the SMC. Parenthetically, this would also suggest that either the source is heavily self-absorbed or it is embedded in the SMC, since our Galaxy contains at most 6×10^{20} H cm^{-2} in this direction. On the other hand, if the spectral index is less than 1.4, the source would contribute less than 10 percent of the flux observed at 120–284 eV even if no source absorption is assumed. In either case, it can have no fundamental effect on the above conclusions.

It might be argued that the entire SMC is a source of soft X-rays of whatever intensity and spatial distribution is needed to fill in the expected absorption by the SMC. But the region between points 2 and 4 on the scan path is sufficiently far from the SMC that it is unlikely that the galactic absorption predicted there would be affected strongly by such emission. Essentially the same conclusion still could be reached from data in this region alone.

Due to the apparent lack of absorption, it is important to establish that the observed counts in the 120–450-eV pulse-height interval are in fact due to X-rays of nonterrestrial origin. There are several arguments to support this supposition: (1) The absolute flux observed is within 20 percent of that seen at similar galactic latitudes on two previous flights (Bunner *et al.* 1969, 1971). (2) The shape of the pulse-height spectrum was similar to that observed in the laboratory: it peaks at the proper energy and falls off on both sides of this peak due to the X-ray transmission characteristics of the windows. This eliminates the possibility of significant ultraviolet contamination. (3) The calculations by Hayakawa *et al.* (1970*b*) of the intensity of scattered solar X-rays, well verified on several flights, predict less than 10^{-4} of the observed flux for this experiment. (4) The proportional counters are made up of two layers, the upper one being partially transparent to X-rays above 1.5 keV. A cross-vetoing arrangement guaranteed that telemetered counts in the lower counter were free from contamination by low-energy electrons that penetrated the windows. The portion of the counts in the upper counter above 1.5 keV due to such electrons was determined by subtracting the X-ray spectrum derived from the bottom counter. The resulting electron pulse-height spectrum was then extrapolated to the 120–450-eV region and found to contribute less than 5 percent of the observed counting rate. Since most of the electrons' energy is lost in the window, this extrapolation is across a very small logarithmic interval in the incident electron spectrum. (5) The variations in counting rate with altitude and zenith angle agreed very well with atmospheric absorption calculated from the *USSA* atmosphere and absorption coefficients of Henke *et al.* (1967). It is unlikely that this would be true if a large fraction of the counts were from bremsstrahlung or carbon fluorescent X-rays produced in the counter windows by a very large flux of 0.3–3-keV electrons.

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