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Astrophysics Data Program

FINAL TECHNICAL REPORT FOR NASA GRANT NAG5-1362

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Abstract

Soft X-ray flux of extragalactic origin should be partially absorbed during passage through the Large Magellanic Cloud. Past attempts to measure this absorption have been frustrated by the LMC's intrinsic X-ray emission. We have developed new calibration techniques to enable precise (within 5%) measurement of the flux and spectrum of diffuse X-rays detected by the Einstein Observatory IPC. We use these techniques to measure the absorption of extragalactic flux by neutral gas in the LMC, and determine that at least 50% of the observed flux in the $.16 - 2$ keV band is of extragalactic origin.

1. Scientific Background

The existence of an X-ray background was discovered over 25 years ago (Giacconi et al. 1962). Nevertheless, although a great deal of theoretical and observational effort has been directed toward an understanding of this radiation and a great deal of data has been amassed, even the simplest questions regarding the physical processes underlying this flux remain a subject of vigorous scientific debate. Various workers have proposed that the XRB is emitted by a thermal plasma filling all of space and constituting an important component of the universe's total mass density (Field & Perrenod 1977), by an integrated ensemble of known types of X-ray emitting objects (Setti & Woltjer), by a hitherto unobserved period in the evolution of some class not X-ray bright in the current epoch such as normal galaxies (Bookbinder et al.), or by a completely new type of emission possibly based on new physics. In recent years observational work has concentrated on the measurement of the spectrum (Marshall et al. 1980) and the identification and study of classes of sources which are potentially significant contributors (Setti & Woltjer, Giacconi et al. 1979, Hamilton & Helfand 1987, etc.). Spectrophotometry has determined the flux and spectrum of the XRB over a broad band from 2 to 300 keV. Unfortunately, studies of faint point sources require X-ray imaging optics such as those used by the *Einstein* Observatory and ROSAT. and are therefore limited to energies below about 2 keV, a band in which spectrophotometry is both more uncertain and complicated by the presence of a substantial galactic component.(McCammon et al. 1983) Moreover, accurate spectrophotometry of the extragalactic XRB in this band has become more important as investigations of the spectral properties of known populations of contributors to the X-ray background have continued to point to an unnerving discrepancy between the spectra observed for putative contributors and the integrated spectrum of the XRB itself. All classes of object hitherto suggested as significant contributors which have been amenable to spectral study have shown themselves to have spectra significantly softer than that of the XRB (Mushotsky 1983 etc.). This has become a major constraint on theories of the XRB's origin (Giacconi and Zamorani 1987). In order to understand the contribution of observed populations to to the extragalactic background, more accurate photometry for the extragalactic X-ray flux in the .2-2 keV band is required. In particular a method for eliminating galactic contamination more reliable than simple arguments based on large scale morphology is necessary.

Because the isotropy of the extragalactic component to the XRB requires that it come from sources at a substantial distance from the galaxy, a straightforward way to measure the extragalactic contribution to the observed flux is to measure the change in flux along a line of sight which contains a known body of X-ray absorbing material. The closest extragalactic objects fulfilling this requirement are the Magellanic clouds. Therefore, in principle, an observation of the variation in X-ray flux as one scans across the Magellanic clouds provides a way to measure the nature of the absorption and thus the location of the observed X-ray flux's origin. Because this experiment involves observing a large section of the sky which contains an ample flux, it seemed well suited to the rocket borne detectors available in the early seventies. Groups at Wisconsin(McCammon et al.,1971) MIT(Rappaport et al.,1975) and Caltech (Long, Agrawal, and Garmire,1976) performed variations on this basic concept in a series of southern hemisphere rocket flights using collimated proportional counters scanning the area of the Magellanic Clouds for soft X-rays. While these experiments were successful in detecting X-ray emission from the Large Magellanic Cloud (MIT and Caltech) and measuring emission from the Small Magellanic Cloud (Wisconsin), their ability to make definitive statements about the effect of absorption was hampered by the difficulty of eliminating the effects of X-ray emission from within the clouds themselves. These experiments were able to identify only the brightest point sources. The effect of integrated flux from faint and diffuse sources would be to suppress any evidence of extinction. All of the rocket experiments found results which were consistent with the Magellanic Clouds absorbing no X-rays at all.

2. Procedure

To construct an accurately calibrated X-ray map of the Large Magellanic Cloud using the *Einstein* database, we took advantage of the fact that the *Einstein* IPC observed the LMC during 162 separate pointings. These pointings overlap irregularly, providing a mechanism for distinguishing between the effects of counter non-uniformities, variations in the particle background rate, and spatial variations in the X-ray sky. First we located and excised all pointlike, and therefore potentially variable, X-ray sources within the LMC. To determine the diffuse flux, we next constructed a mathematical model for the various sources of events in the *Einstein* IPC: cosmic rays, X-rays, a radiation leak internal to the spacecraft; and for the counter's response to those events as a function of counter position and time. Because the pointings overlapped so extensively, we were able to construct an overconstrained system of linear equations and solve these equations for, among other things, the diffuse flux across the face of the LMC. The technical details of this procedure are described in painful detail in Wu et al. 1991. A gray scale of the diffuse flux computed in this fashion is presented in Figure 1.

A curved band running from roughly $05^h55^m - 69°20'$ to $05^h40^m - 70°40'$ is clearly seen to be deficient in X-ray emission. This corresponds to a region of relatively high neutral hydrogen column density (2×10^{21}). This region emits a mean flux $\sim 15\%$ lower than reference fields at the same galactic latitude but away from the LMC. This, of course, provides an absolute lower limit to the proportion of the X-ray flux in the $.16 - 3.5$ keV band of extragalactic origin. Assuming that the variation in X-ray count rate across this region is a result of variations in the X-ray emissivity of the LMC itself, we can calculate that at least 50% of the $.16 - 3.5$ keV emission is extragalactic.

In Figure 2 we display the residual X-ray count rates we derived for a slice along declination $-69°59'$, along with HI measurements of Rohlfs et al. (1984). Here we see some of the X-ray bright regions of the LMC as well. On small ($\sim 1°$ or 1 kpc) scales the X-ray emission and HI anticorrelate, although on the largest scale

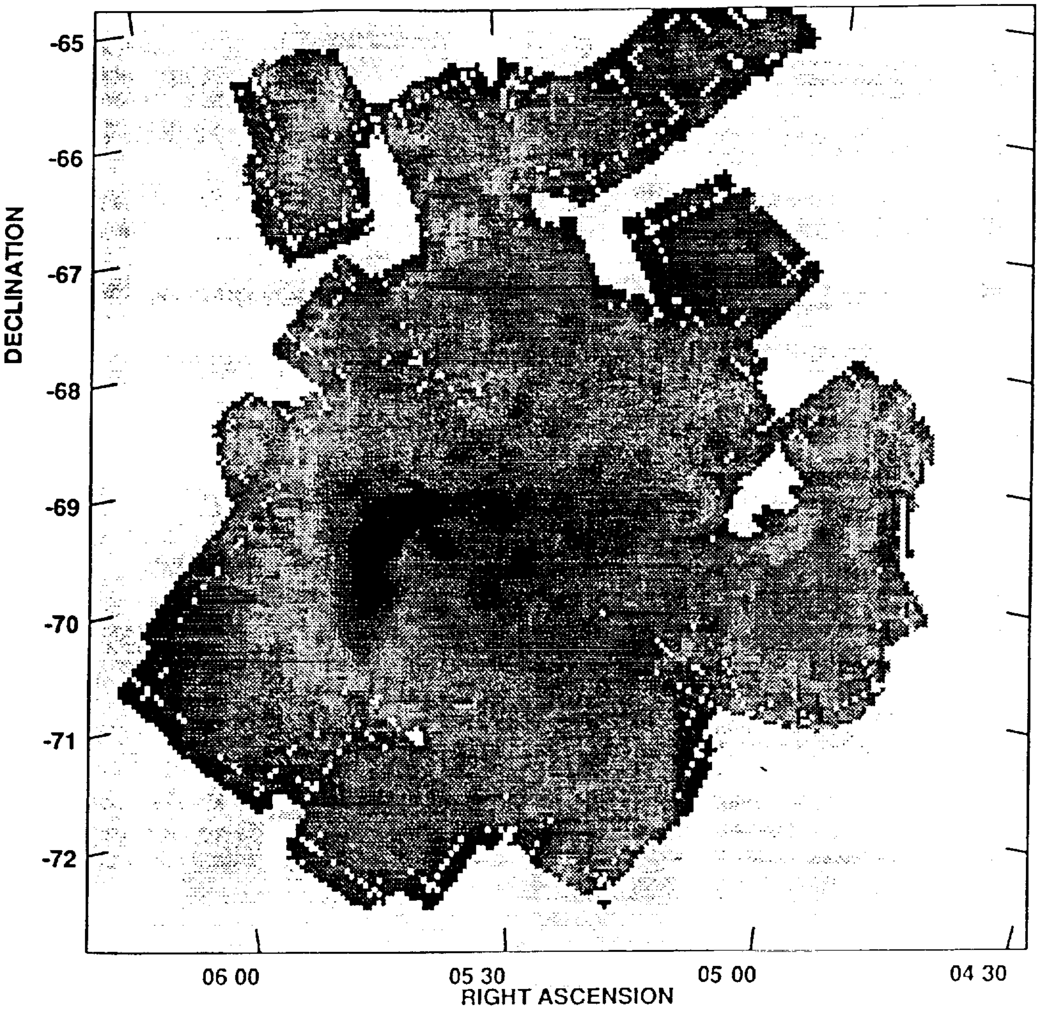

Figure 1, a gray scale representation of the diffuse X-ray flux in the direction of the LMC

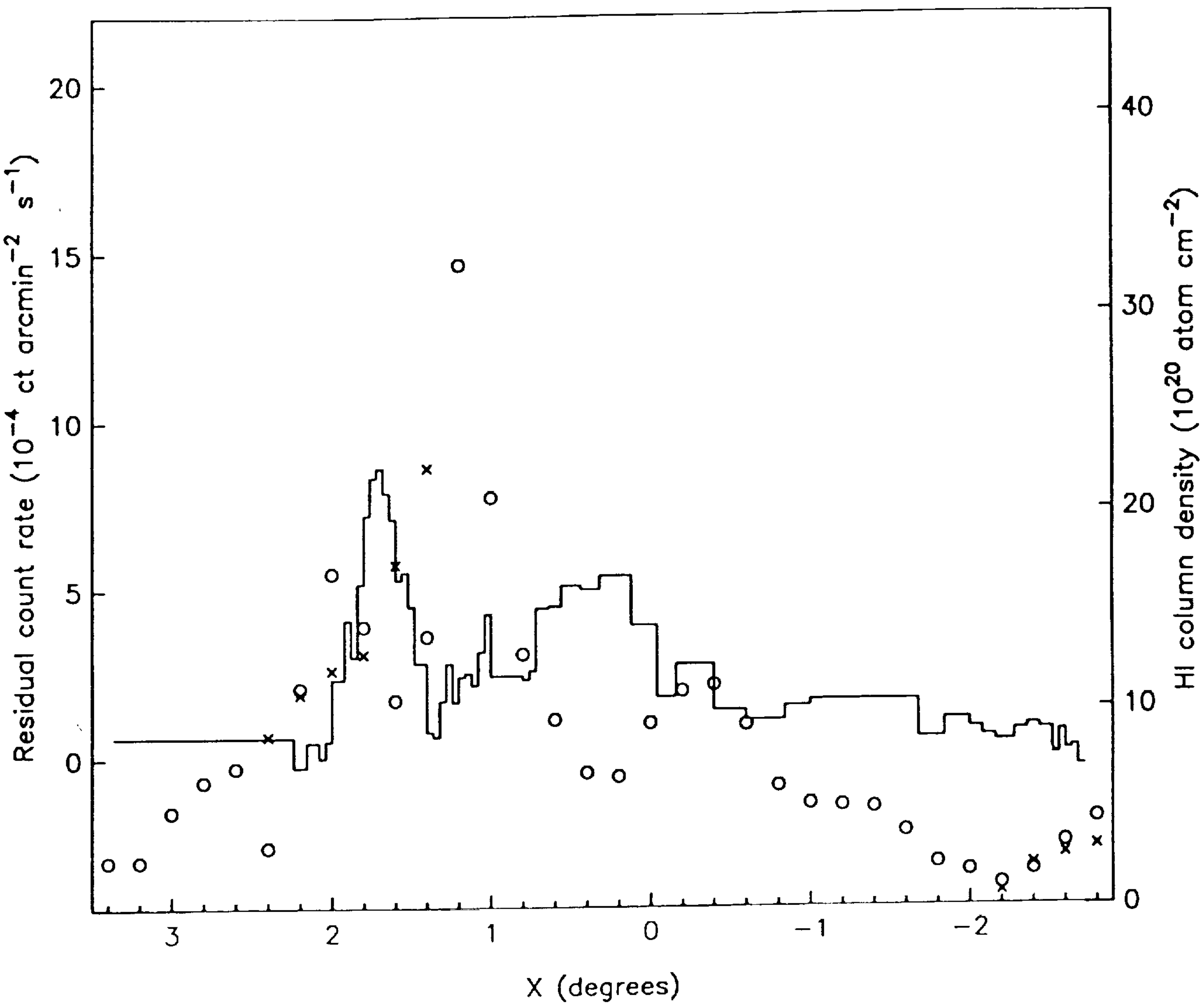

Figure 2

A plot of the surface brightness for the diffuse X-ray emission (solid curve) and the neutral hydrogen column density (open circles and crosses) in a slice 12' wide through the LMC at declination -69 59'. The X-axis (in units of degrees) refers to a coordinate aadopted by Rohlfs et al. (1984) and is centered on the optical center of the LMC bar.

they are correlated, i.e. they are both enhanced in the eastern part of the LMC (the left side of the graph) because that is simply where there is more material of all types. However, in the relatively X-ray bright region of the LMC shown on the left side of Figure 2 the anticorrelation is not a result of absorption but rather apparent displacement. Presumable the hot X-ray emitting gas is driving the cool neutral gas away from the regions of peak star formation. These results are presented in greater detail in Wang et al. 1991.

4. Conclusion

Variations in X-ray emission correlated with variations in HI column density are observed in the Large Magellanic Cloud. In the brighter regions of the cloud this is probably a result of the interaction of the hot interstellar medium with the cool gas. In the region where star formation is quiescent, absorption can be detected, giving a lower limit to the extragalactic component of the X-ray background of $\sim 50\%$. It should be possible to substantially refine both of these results as ROSAT survey data for the LMC become available.

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