THE SEARCH FOR ABSORPTION OF 1 KEV X-RAYS BY THE SMALL MAGELLANIC CLOUD

Prepared for
Dr. Burrows, Astrophysicist
Pennsylvania State University
State College, Pennsylvania

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Prepared by
Brad Marazas, Senior Astrophysics major
Pennsylvania State University
State College, Pennsylvania
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ABSTRACT

The contribution of the extragalactic component of the diffuse background to the 1 keV energy band remains unknown. An effective way to ascertain this contribution is to measure the absorption of the extragalactic component by the neutral hydrogen in the Small Magellanic Cloud with an instrument capable of eliminating point sources from the X-ray data that compensate for absorption. The Image Proportional Counter data from the Einstein observatory can be used for this purpose. Additionally, any extended emission must also be eliminated. The resulting source free data can be compared to the neutral hydrogen and the amount of absorption can then be obtained when compared to the diffuse flux away from the SMC. However, due to other types of radiation contaminating the X-ray data, a true measure of the X-ray absorption was not obtained.

INTRODUCTION

Currently the fraction of the diffuse X-ray background below 2 keV that is of extragalactic origin is unknown. At energies greater than 2 keV, it is presumed that the diffuse background is completely of extragalactic origin because it is isotropic in nature. From 2 to 10 keV, its spectrum is closely represented by an 11 $E^{-1.4}$ photons cm^{-2} s^{-1} sr^{-1} keV^{-1} power law (Bunner et al. 1979).

A possible way to separate these components is to measure the shadowing of the X-rays by an extragalactic object and compare it to measurements of the unabsorbed X-ray background in order to find out where the power law spectrum turns over. A good candidate to be used for observing X-ray shadowing is the Small Magellanic Cloud (SMC). This is because the compact distribution of the neutral hydrogen has a sufficiently high enough column density to be able to absorb soft X-rays below 2 keV.

McCammon et al (1971) attempted to measure the absorption of the soft X-ray background flux below 284 eV by the SMC with a proportional counter on a sounding rocket. The experiment consisted of 5 12 degree scans spaced 2.5 degrees apart with a rate of 0.4 degrees/s. The aspect was determined to within a degree and a half and the proportional counter output pulses for all counted events were telemeterd 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.

21 cm measurements of the columnar hydrogen density were used

to calculate the models of the expected soft X-ray absorption. The data McCammon et al (1971) used for the galaxy and the outer and central regions of the SMC were taken from McGee et al (1966), Hindman et al (1963), and Hindman (1967) respectively. The effective X-ray absorption cross-sections used to calculate optical depth were obtained from Brown and Gould (1970).

The results of their experiment were divided into 4 models. In the first mode all the flux was assumed to be extragalactic and is represented by the solid line in Figure 1A: Absorption of X-ray flux. McCammon et al (1971) determined that at most 25% of the flux could have this origin. The dashed lines indicate a refinement to this model consisting of the assumption that the neutral hydrogen is clumped into clouds with an average thickness of 8 x 10^{20}H cm^{-2} and 20 x 10^{20}H cm^{-2}. The dot dash line indicates absorption due to the earths atmosphere (USSA. 1966). Figure 1B shows the absorption model if the local hydrogen densities are assumed to be zero. Figure 1C represents a model where the soft X-ray flux originates outside of the local velocity hydrogen distribution but closer than the SMC. The assumed hydrogen cloud thickness was 8 x 10^{20} cm^{-2}. It can be seen that the data does not fit any of these models.

If the power law spectrum that fits the data in the interval from 2 to 10 keV is extrapolated to the 120 - 284 ev range, only one sixth of the observed flux can be accounted for, even if there is no absorption. A fourth model devised by McCammon et al (1971) to explain this is based on the assumption that the other five

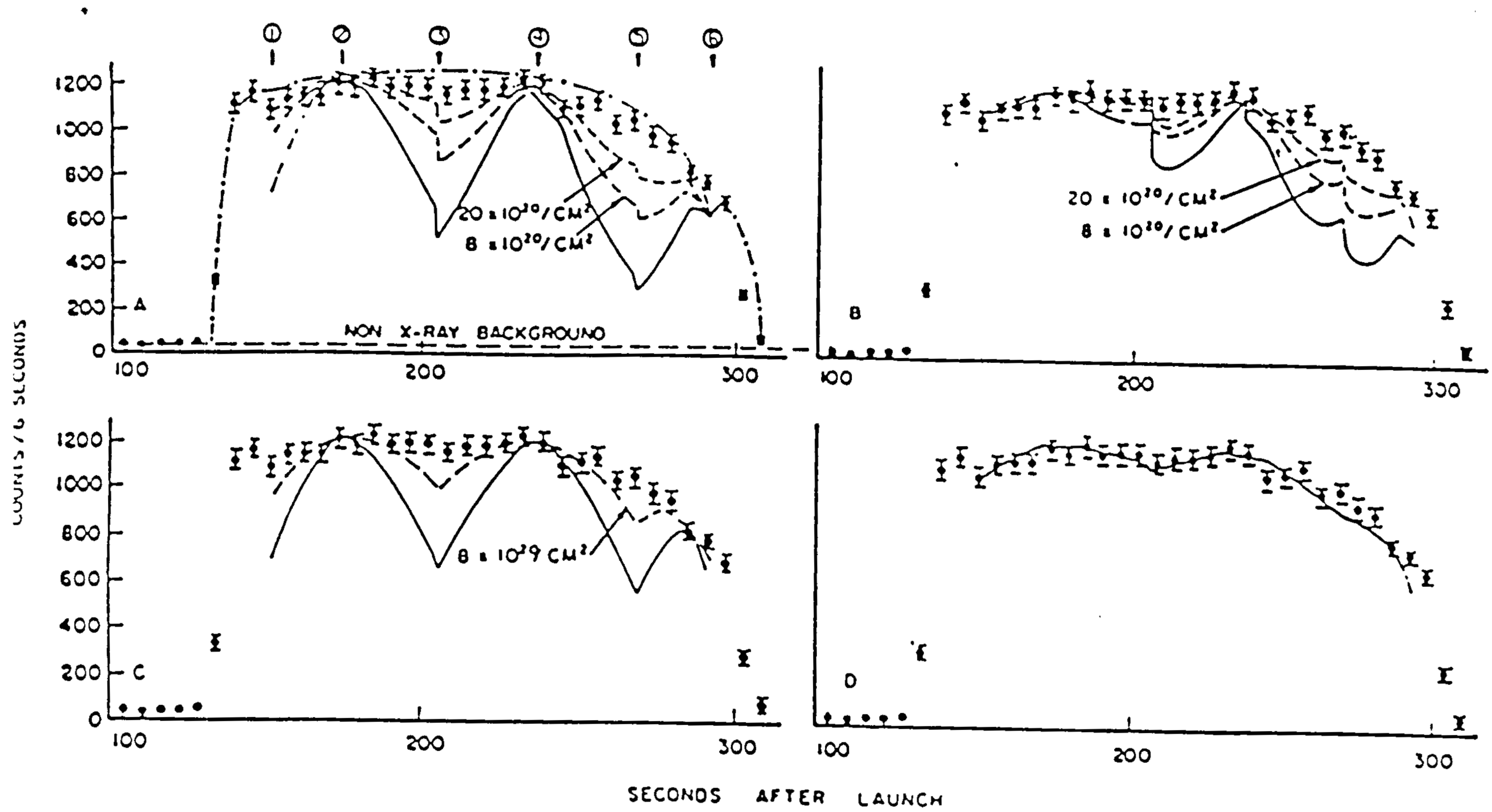

Figure 1: Absorption of X-ray flux.
(McCammon et al. 1971)

sixths of the observed flux are from a very local isotropic 0.3 keV component which is absorbed by only the earths atmosphere. This model is shown in Figure 1D. The data fit the model well, but other observations pertaining to the added local component (Bunner et al. 1971) suggest that this model is not an accurate representation of the local diffuse distribution. It was observed that the flux between 0.1 and 0.3 keV in the galactic plane is less than 30% of the flux at high altitudes. This implies that the added component is not as local as assumed in model 4, but that it must originate from a sufficiently distant point such that it is greatly absorbed by the gas in the galactic plane.

Because no absorption was observed, McCammon et al (1971) reasoned that the 120 - 284 eV diffuse background flux was of local origin.

In 1973 McCammon et al (1976), because of the uncertainty and low resolution of their neutral hydrogen maps, made a more detailed survey of the neutral hydrogen near the SMC.

The new survey consisted of drift scans with a $0^{\circ}.8$ resolution at declination intervals of $1^{\circ}15'$ by the Parks 18m telescope. The 64 7 km/s channels ranged from -140 km/s to 300 km/s, thus allowing simultaneous coverage of the galactic component near zero radial velocity and the SMC gas at 200 km/s. The gas profiles were 25 km/s FWHM, the estimated minimum detectable column density was 8×10^{18} H cm^{-2} and the minimum detectable area under the high velocity profiles was about 3×10^{19}H cm^{-2}, which is about 0.12 optical depths for 0.25 keV X-rays. With this new survey, McCammon et al (1976) felt their measurements were accurate to within 20% of the absolute column densities and that there was no evidence for clumping of interstellar gas that would affect X-ray absorption.

All models which consisted of the assumptions that all the 0.25 keV flux is of extragalactic origin and is isotropic in nature did not fit the data, so a two component model was assumed. One component was extragalactic and the other component was local and absorbed by only the earths atmosphere.

The final conclusions that McCammon et al (1976) arrived at were that the 21 cm observations near the SMC showed no evidence of small scale structure that would affect the soft X-ray absorption. They arrived at an upper limit of 300 photons $(cm^{2}$ s sr keV$)^{-1}$ for the 0.25 keV flux incident on the galaxy if the interstellar gas absorbs normally and the local component is isotropically distributed. They also considered assumptions varied to an extreme case where the local flux is distributed to allow the greatest possible extragalactic flux. They then arrived at an upper limit of 900 photons $(cm^{2}$ s sr keV$)^{-1}$. Under either of these assumptions the local flux has to be greater than 160 photons at 0.25 keV. This is greater than the flux observed near the galactic plane and is not explained by their simple two component model where local X-ray emission is proportional to interstellar hydrogen density and thus, no sufficient evidence was obtained for an extragalactic component of the 0.25 keV flux.

At 1 keV the diffuse background is no longer isotropic and its observed intensity is 1.5 times greater than that expected in regions of low galactic HI column density when the 11 $E^{-1.4}$ power law is extrapolated into that energy range (Bunner et al. 1979).

To gain a better understanding of the contributions of the galactic and extragalactic components of the diffuse background below 2 keV, Bunner et al (1979) used the soft X-ray instrument on OSO-8 to observe the diffuse background also in the vicinity of the SMC. The experiment used forward axis proportional counter detectors with hexagonal honeycomb collimators that were sensitive from 0.15 to 6 keV in nine broad energy bands with a field of view of 3° (FWHM) at 1 keV (Bunner, 1978). Also, observations were made when SMC X-1 was in eclipse to avoid contamination of data.

The observed count rate in the energy range .8 to 1.5 keV at intervals of 1° along the scan path is shown in Figure 2: Observed count rate. The solid line shows the predicted count rate for a two component model. This model used the 21 cm neutral hydrogen density maps of the SMC from McCammon et al (1976) and the X-ray absorption cross-section of Brown and Gould (1970). A decrease of 0.083 counts/sec was expected, but a change of +0.004 +/- 0.014 was observed.

Bunner et al (1979) came up with three possible explanations of why absorption was not observed. The first explanation was a possible depletion of metal abundances, anything heavier than H or He. This would require an absorption dip of 0.047 counts/sec which is greater than the observed absorption. The second explanation was possible emission by the SMC of soft X-rays

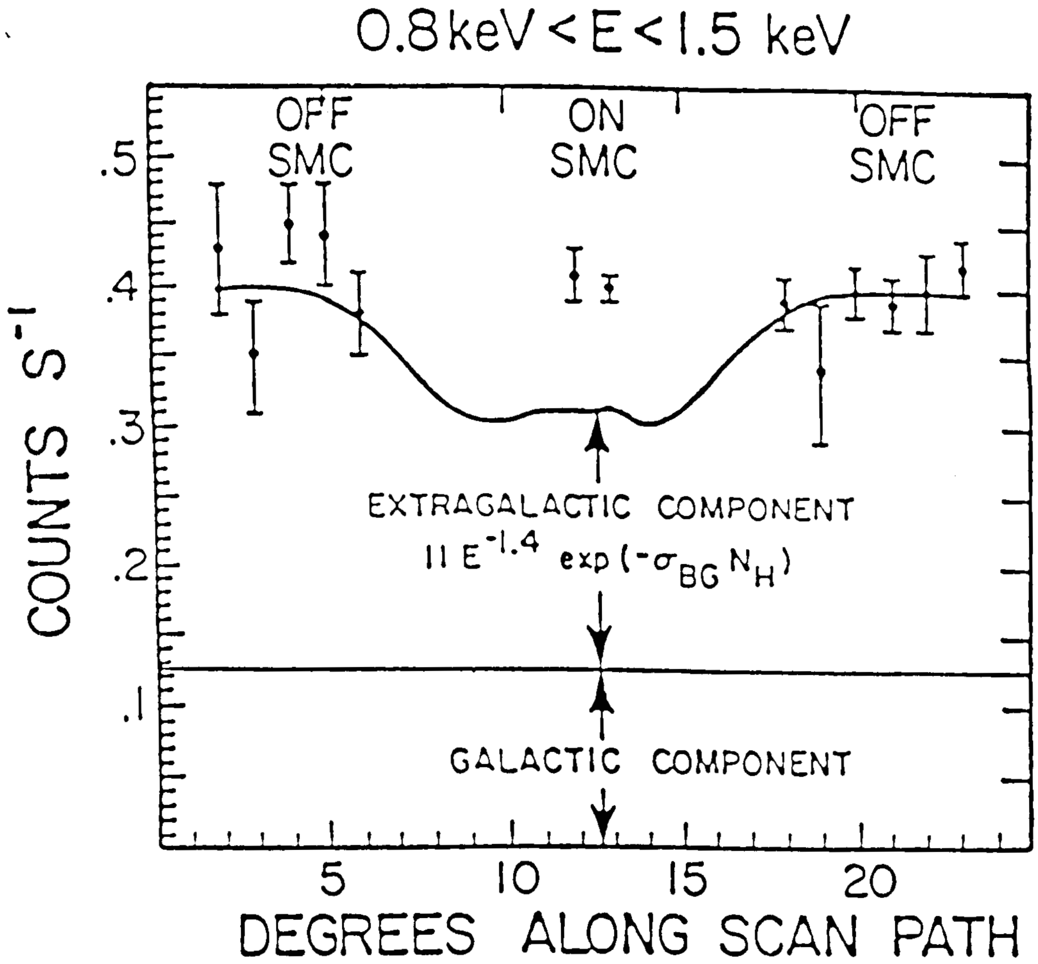

Figure 2: Observed count rate.
(Bunner et al. 1979)

exactly compensating for the expected absorption. They reasoned this could occur in two possible ways: by diffuse emission from the SMC interstellar medium; or by emission from unresolved point sources. The first possibility seemed unlikely because the mass of the SMC is such that it is too small to gravitationally bind a hot interstellar medium of the required temperature of 2×10^{6} K to produce the necessary flux; also the 0.8 - 1.5 keV energy band is dominated by Iron and Nickel which is depleted in the SMC and thus could not be high enough to successfully compensate for the lacking absorption. The second possibility seemed also unlikely because the intensity required for SMC X-1, X-2, and X-3 to fill in for the expected absorption in the 0.8 - 1.5 keV band would also require an excess emission in the 3 - 6 keV band, which is not seen. The third explanation was possible variations in the component fractions in the 0.8 to 1.5 keV energy range. These variations included: a 20% upward flux in the cosmic $E^{-1.4}$ intensity in the vicinity of the SMC in order to compensate for the absorption; a 40% upward fluctuation in the galactic 1 keV component in the direction of the SMC, thus filling in the expected absorption; and the extrapolation of the 11 $E^{-1.4}$ power law to 1 keV being inaccurate such that below 2 keV less than 35% of the observed 0.8 to 1.5 keV flux is actually of extragalactic origin.

The first two explanations were ruled out because the energy maps of Fried et al (1979) in the energy intervals from 0.1 to 2 keV implied that the galactic diffuse background intensity is constant over the OSO-8 scan path or shows a slight deficit in the direction of the SMC. The third explanation could not be ruled out by any of the soft X-rays studies done up to that point.

Seward and Mitchell (1981) attempted to make new X-ray maps of the SMC with the hope, among other things, of uncovering new soft X-ray sources that could produce enough soft X-rays to fill in the expected absorption dip in the 0.8 - 1.5 keV energy range of Bunner et al (1979). This experiment was different than previous mapping attempts because the Einstein observatory, which was equipped with an Imaging Proportional Counter (IPC), was build specifically for measuring soft X-rays. The sensitivity was greatest at and below 2 keV and fell off drastically above 3 keV dropping off to zero above 5 keV. Previous mapping attempts used instruments sensitive to sources between 2 and 10 keV. The spatial resolution of the IPC was 1'.

The new soft X-ray sources that Seward and Mitchell (1981) found provide a flux of 10^{-11} ergs cm^{-2} s^{-1}, which is about 0.6 counts/sec. They suggested that this is comparable to the flux needed to fill in for the lacking absorption in the SMC in the 0.8 to 1.5 keV energy range.

However, it is not known how these new sources correspond to the OSO-8 data of Bunner et al. (1979), that is, what contribution the 0.6 counts/sec make to the flux that may fill in for the expected absorption.

The best way to get true measure of contribution that the extragalactic X-rays make to the 1 keV energy band is to measure the absorption of the extragalactic component by the SMC, for reasons previously stated, with an instrument that has the ability of eliminating point sources from the X-ray data. Additionally, any extended emission must also be eliminated as this also adds to the compensating X-rays which mask absorption. The IPC fields created by the Einstein observatory can be used effectively for this purpose. The remaining diffuse flux can then be compared to the neutral hydrogen in the SMC to ascertain the amount of absorption when compared to measurements of the diffuse flux off the SMC.

II. INFORMATION ON DATA USED

The IPC data of the SMC produced by the Einstein observatory (Seward and Michell. 1981) that I used for this analysis is archival data obtained from NASA's Guest Investigator Program. It consisted of two main parts, contour maps and corresponding strip charts for each of 65 fields that the SMC was divided into. The contour maps were of the X-ray sources detected along the line of sight of the SMC. The levels of contour depended on the intensity of the X-ray source. The strip charts contained many different data windows. The only windows that were of importance to my analysis were as follows: VG-FLAG, which is a representation of the viewing geometry of the satellite indirectly indicating how clean the data is, with a setting of 1 being the cleanest; IMAGE, which when ON means the detector was locked on target and taking data; PI-SOFT, which is the count rate in the soft X-ray band (energy range from .12 to 1.2 keV); and PI-HARD, which is the count rate in the hard X-ray band (energy range from 1.2 to 120 keV). The hard and soft band source free count rates and the position coordinates for each field are stored in the data file XDETECT. Maps of the low and high velocity neutral hydrogen in the SMC are stored in the data files NH1.DAT and NH2.DAT respectively.

III. INFORMATION ABOUT DETECTORS

The Einstein observatory was launched in 1978 and among other types of detectors carried an Imaging Proportional Counter (IPC). This instrument is a position sensitive proportional counter with moderate spatial and spectral resolution. The counter body houses electrodes in a density-regulated gas mixture of Argon, Xenon, and CO_2. The electrodes consist of a plane of anode wires situated between two planes of cathode wires. Through avalanching, the cathode receives induced signals from the anode. Rise time measurements of the induced signals allow the determination of the Y-Z coordinates of events to a precision of 1mm. This corresponds to a precision of 1' over the central 60' x 60' of the field of view. The centroid of the signal from a point source can be determined to 1'. The gain of approximately 10^5, which is required to obtain this resolution, is obtained by having the anode at a potential of 3600 volts and the cathode at 900 volts. Processing of anode signals, that is, event timing and pulse height analysis, provides 63 microseconds time resolution and 32 channels of energy resolution over the 0.1 - 4.5 keV energy range.

There is also a background counter located in the same counter body below the IPC electrodes covering the same area. Its signals are in anticoincidence, thus providing background rejection for the IPC (Giaconni et al. 1979). There is a complication caused by the ribs supporting the detector window. There are four ribs set up in a tic-tac-toe pattern each 3' wide. The central square is 38' on a side. These ribs unfortunately shadow part of the detector, such that a weak source under a rib would not be detected. A strong source or a moderately strong supernova remnant under a rib, however, would not be completely shadowed. It was estimated that due to reduced sensitivity at the edges of fields and the shadowing of the detector, that approximately 93% of the intended area was actually observed (Seward and Mitchell. 1981).

IV. INFORMATION ON DATA PROCESSING

As mentioned earlier, the IPC fields from the Einstein observatory are such that X-ray point sources can be easily identified and removed. This was done by standard REV 1 data reprocessing. This reprocessing included a search for all sources within the field of view, spectral fits of strong point-like sources in the central four arc minutes of the the detector, and a source location accuracy within the ribs of 20 arc seconds (NASA. 1983). The source free diffuse background rates for both the hard and soft bands and there positions in the vicinity of the SMC are stored in the data file XDETECT.

V. ANALYSIS TECHNIQUE USED AND OUTLINE OF PROCEDURE FOLLOWED

As mentioned above, the point sources were removed by the standard Rev 1 data processing. The work left to be done was the analysis of the IPC data in order to find any extended emission regions and eliminate them. There is no way to remove the extended emission regions from a particular field, so the entire field containing that emission must be eliminated. The next step in the analysis is to produce a plot of the X-ray intensity vs. NH column density. From this plot, how the X-ray intensity changes as a function of increasing neutral hydrogen column density can be determined. The expected outcome of this plot is an exponential decrease in intensity with increasing column density. The reason for this can be seen in equation 1:

$$I = I_o \times EXP(-@H_H) \qquad \text{Eq. 1.}$$

where I_o is the incident unabsorbed X-ray intensity, I is the X-ray intensity after absorption, @ is the absorption cross-section coefficient, and H_H is the neutral hydrogen column density. As the neutral hydrogen column density increases, X-ray intensity exponentially decreases. A plot of this type indicates absorption. The final step in the analysis is to ascertain what fraction of diffuse background is extragalactic. This is done by using a nonlinear regression program and equation 2:

$$I_B = I_L + I_E EXP(-@N_H) \qquad \text{Eq. 2.}$$

where I_B is the intensity of the total diffuse background, I_L is the intensity of the local component, and I_E is the intensity of programs are located on the P.S.U. Astronomy department's computer system.

VII. RESULTS

In an attempt to locate any possible extended emission regions in the SMC, I examined each of the contour maps that were made, paying attention to the levels of contour each mapped image had. Any images with one level of contour were simply noise and ignored. Any image with prominent sources having two levels of contour that were not already eliminated by the standard Rev 1 data processing, I marked as questionable and eliminated from the XDETECT data file, since they could be caused either by extended emission or by fluctuations in the background noise. These fields included: I591, I593, I597, I603, I609, I619, I624, I1091, I3925, I3926, and I5247. Any image with three or more levels of contour were in all cases point sources. These point sources were already accounted for and eliminated by the standard Rev 1 data processing.

In order to see if there were any fluctuations in the background rate over time, which is an indication of some type of emission, either source fluctuations or fluctuations in the background which could be interpreted as extended emission, I examined the strip charts for each field. Of all the data contained on the strip charts, the only data that I used was that which had VG-FLAG set on 1, as this was the cleanest data.

For each strip chart, I examined the plots paying specific attention to the soft X-ray emission since these are the X-rays which are absorbed by neutral hydrogen. The criteria I used to decide if a particular area was exhibiting significant fluctuations was as follows: the soft band count rate displayed significant spikes above the background, consistently increased above the background, or was consistently greater than the background rate by any noticeable amount. I also examined the hard band count rate making sure there were no drastic fluctuations above the background. There were many cases where there were 3 or 4 prominent single spikes in the hard X-ray band readout, but I attributed this to minor fluctuations in background noise. The only field that exhibited any fluctuation in the soft band was field I5247. This field is shown in Figure 3: Field I5247 in the row marked PI-SOFT. An example of a field I felt did not exhibit any fluctuations is shown in Figure 4: Field I5430, also in the row labeled PI-SOFT. The data windows between the vertical lines in both these figures indicate the data which was useful, VG-FlAG equal to 1 and IMAGE ON. It can be seen in Figure 4: Field I5430 that over time the background rate remains constant indicating that there are no detectable sources or extended emission present, while in Figure 3: Field I5247 it is obvious that in the PI-SOFT window the background rate is fluctuating over time, indicating some type of emission.

After determining that field I5247 showed signs of some type of emission, I eliminated its corresponding hard and soft band count rates and position coordinates from the XDETECT data file.

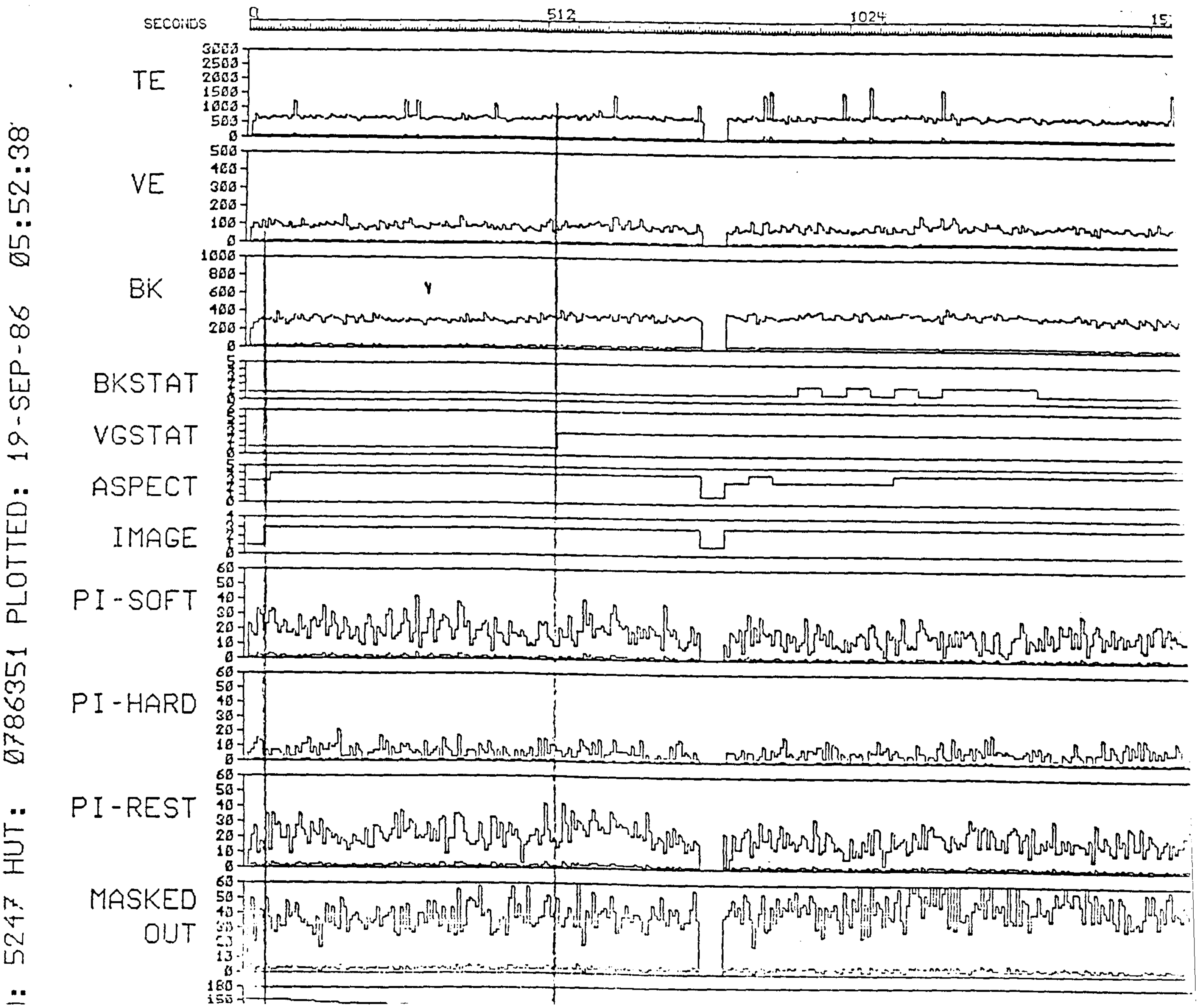

Figure 3: Field I5247

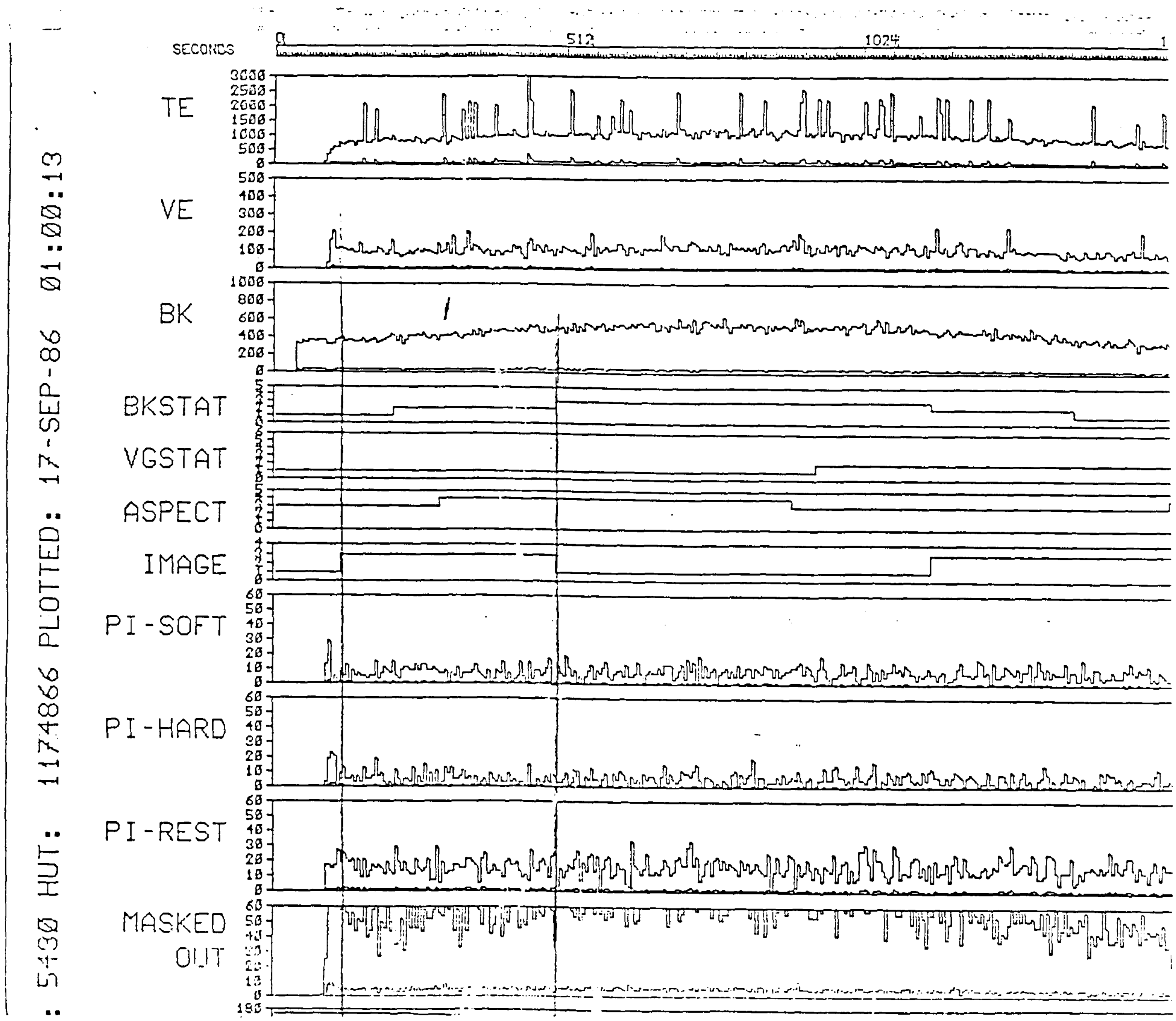

Figure 4: Field I5430

I next produced a plot of X-ray intensity vs. NH column density by first running the program AVGMAP which used the neutral hydrogen column density data files NH1.MAP and NH2.MAP and the X-ray data file XDETECT to produce the data files necessary for making the plot. I then ran the plotting program GRAFXY using the data files from AVGMAP to produce the actual plot. The expected outcome of the plot was an exponential drop in X-ray intensity as a function of increasing NH column density. Instead the plot was a very wide, seemingly random spread of points (see Figure 5: Scatter plot 1).

Since I did not obtain the expected result, I examined the program AVGMAP to ascertain why the plot was a random spread of points. I found that the program was processing the neutral hydrogen maps, stored in NH1.MAP and NH2.MAP, incorrectly. Specifically, AVGMAP was converting the sky coordinates of the neutral hydrogen maps to pixel coordinates incorrectly; thus producing inaccurate data files which were used by GRAFXY. Additionally, I found that the neutral hydrogen map stored in the NH2.MAP data file was not centered correctly as compared to the neutral hydrogen map stored in NH1.MAP and that the data in this file did not exactly correspond to the data in the table from which it was obtained, namely TABLE 2: NEUTRAL HYDROGEN COLUMN DENSITY of McCammon et al (1976).

I altered AVGMAP so that it would process the neutral hydrogen maps correctly. A printout of this program, AVGMAP4, is in APPENDIX A: PROGRAM AVGMAP4. I also wrote AVGFIX to correct the

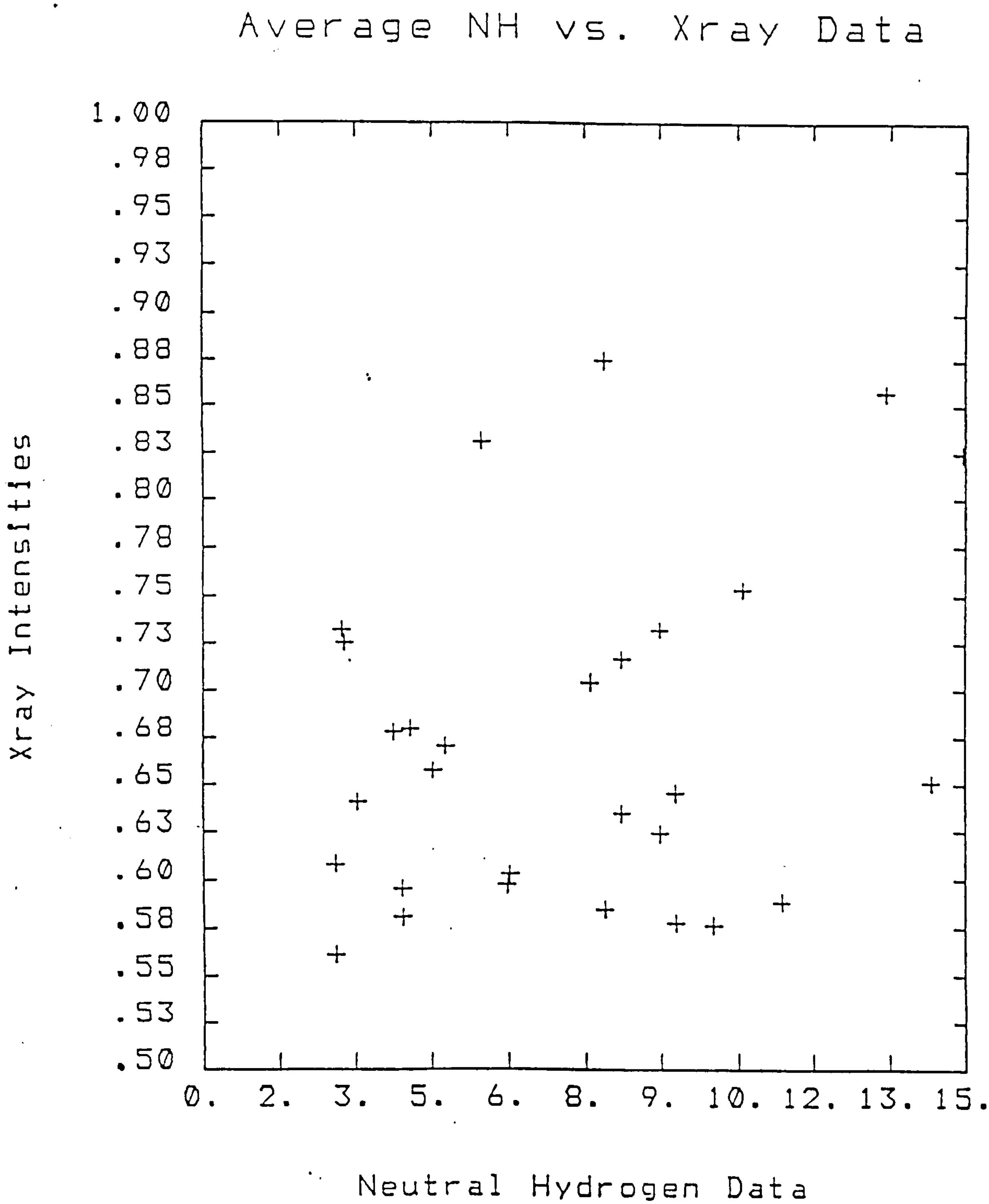

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Figure 5: Scatter plot 1

discrepances between NH2.MAP and TABLE 2: NEUTRAL HYDROGEN COLUMN DENSITY of McCammon et al (1976). A printout of AVGFIX is in APPENDIX B: PROGRAM AVGFIX.

I once again attempted to generate a plot of X-ray intensity vs. NH column density using GRAFXY and the new data files created by AVGMAP4 and the corrected version NH2.MAP. This plot again was not the expected exponential drop in X-ray intensity as a function of increasing NH column density, but a more closely packed spread of points (see Figure 6: Scatter plot 2).

In order to ascertain if the data points had any correlation, I ran the programs LINSTAT and PCORR. LISTAT produces a linear correlation coefficient R of 0 to 1, indicating the degree of linear correlation with a value of 1 indicating complete correlation. The value of R that I obtained was .098 for 44 data points. PCORR takes the number of data points and the value of R and calculates the probability of the data points being anticorrelated. The probability of anticorrelation for the 44 data points was 52.8%.

VIII. CONCLUSIONS

The purpose here was to find the contribution the extragalactic component of the diffuse background makes to the 1 keV energy band. However, I was not able to accomplish this goal. The X-ray intensity vs. NH column density plot that I obtained was not the expected exponential decrease in X-ray intensity as a function of increasing NH column density. The plot I did obtain

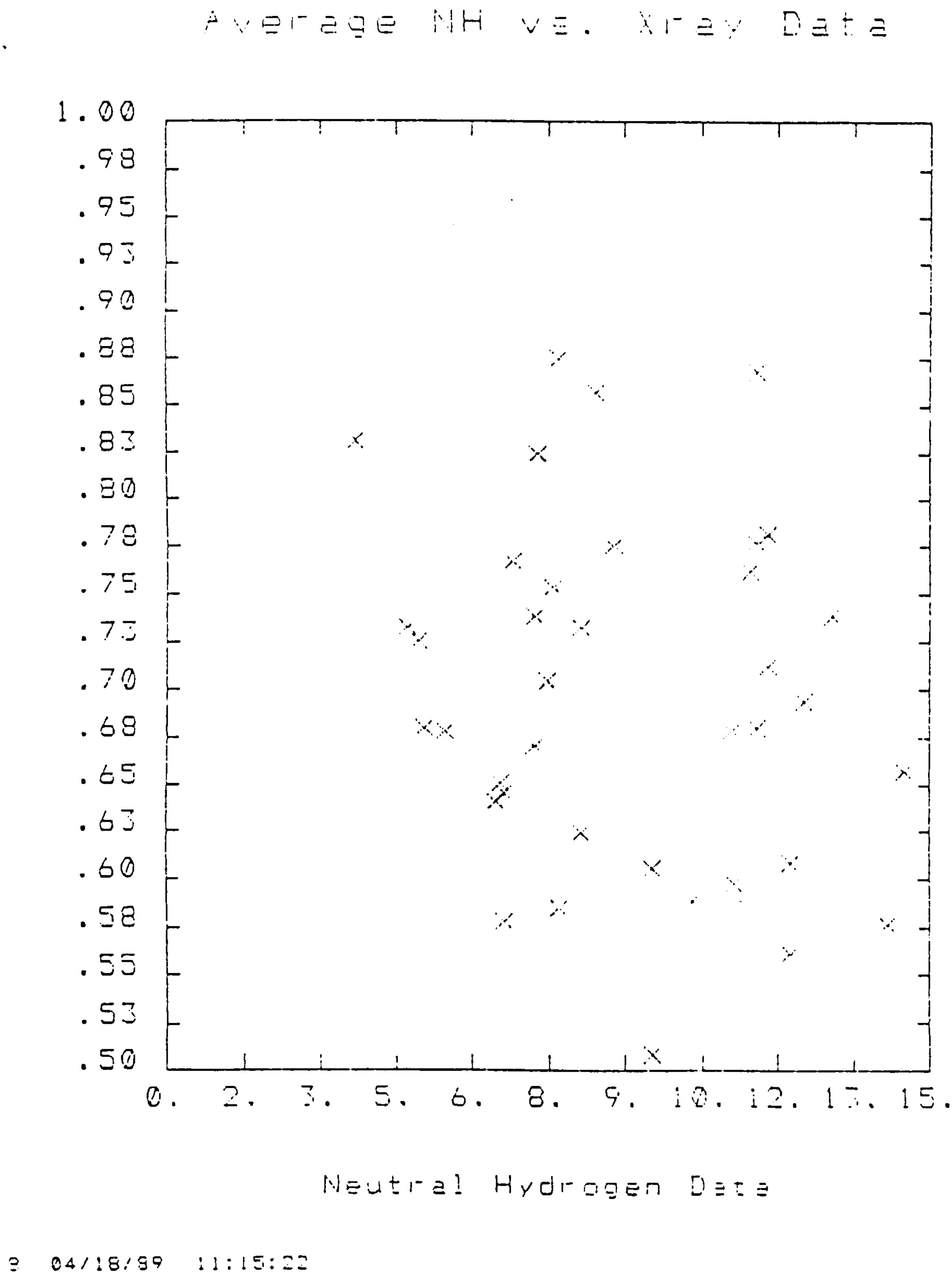

Figure 6: Scatter plot 2

made little sense and the output of LINSTAT and PCORR indicated that the data points were not closely correlated. Since the plot I obtained showed no evidence of X-ray absorption, or anything else for that matter, running a nonlinear regression program on the data would have been meaningless. From these results, I can only conclude that something is contaminating the X-ray data, such as some other ionizing radiation which was indistinguishable to the Imaging Proportional Counter; thus not allowing a true measure of X-ray intensity in the vicinity of the SMC.

To be able to use the procedure discussed in this paper to eliminate any extended emission that is masking the absorption in the SMC, a detector must be fabricated that can differentiate between different types of radiation so that an accurate measure of the X-ray intensity can be obtained.

APPENDIX A: PROGRAM AVGMAP4

The following is a printout of the program AVGMAP4, which was used to reprocess neutral hydrogen maps and X-ray maps and produce data files. The reprocessing of the maps consisted of correcting mistakes in the conversion of sky coordinates to pixel coordinates so that the data files produced would be accurate. The data files produced were used by the plotting program GRAFXY to generate plots of X-ray intensity vs. NH column density.

```
C***************************************************************************
C
C  Name: AVGMAP4
C  Filename:  /usr/shue/prog/avgmap.for
C  Type: program
C
C  Language: FORTRAN 77
C  Purpose:  to read XDETECT.DAT file and NH2.MAP, NH1.MAP find corresponding
C             pixels between the maps, average the values of the NH maps and
C             create a plot of xray vs nh intensity
C
C    AVG1.MAP - uses 500 - 600 range files/ celestial coords.
C    AVG2.MAP - uses all files/ celestial coords.
C
C  Subroutines used:
C     (see the comment cards for xmap.for and cmaps.for)
C
C  Date: 1/28/87
C  Author:  David Shue
C  Modified:
C
C  Comments: altered version of AVGMAP to read in local files
C
C*****************************************************************************
C
      PROGRAM AVGMAP
C-----------------------------------------
C   variable declarations
C-----------------------------------------
      PARAMETER (NMAX=200, NAX=3, ID1=103, ID2=25)
      DIMENSION ARRAY1(ID1,ID2), ARRAY2(ID1,ID2), AVGNH1(NMAX),
     +          AVGXR1(NMAX), SIGX(NMAX), SIGY(NMAX), XX(4), YY(4),
     +          AVGNH2(NMAX), AVGXR2(NMAX)
      DIMENSION CRVAL1(NAX), CDELT1(NAX), CRPIX1(NAX), CROTA1(NAX),
     +          CRVAL2(NAX), CDELT2(NAX), CRPIX2(NAX), CROTA2(NAX),
     +          SMAP(IDIM1,IDIM2), SCALE(10)
      REAL      SRATE, SERROR, HRATE, HERROR, RA, DEC
      INTEGER*4 NAXISS(NAX), BITPIX, NAXIS
      integer row, col
      CHARACTER TYYPE*1, FILEIN*80, TYPE(5)*1, COORDS*3, HISTRY(5)*8
      CHARACTER*8 CTYPE1(NAX), CTYPE2(NAX)
      CHARACTER BUNIT1*8, OBJECT1*18, DATE1*8, DATOBS1*8, ORIGIN1*18,
     +          INSTRU1*18, OBSERV1*18,
```

```
     +            BUNIT2*8, OBJECT2*18, DATE2*8, DATOBS2*8, ORIGIN2*18,
     +            INSTRU2*18, OBSERV2*18
      CHARACTER*80 TITLE, XTITLE, YTITLE, FILENM, HEADER
      CHARACTER*1 ANSWER
C-----------------------------------------------------------------------
C   data statements to save space
C-----------------------------------------------------------------------
      DATA TYPE(1)/'L'/, TYPE(2)/'O'/, TYPE(4)/'F'/, TYPE(5)/'2'/
      DATA NX, NY, NZ /103,25,1/
      DATA SCALE(7)/1./, SCALE(8)/1./, SCALE(9)/-99./, SCALE(10)/0./
      DATA NAXISS/103,25,1/
C-----------------------------------------------------------------------
C  Define some variables
C-----------------------------------------------------------------------
      TYYPE   = 'L'
      ND1=ID1
      ND2=ID2
      NNN=NMAX
      NAXIS=NAX
      COORDS='CEL'
C--------------------------------------------------
C   zero arrays
C--------------------------------------------------
      DO 100 I=1,NNN
              AVGNH1(I)=0.0
              AVGXR1(I)=0.0
              AVGNH2(I)=0.0
              AVGXR2(I)=0.0
  100 CONTINUE
      DO 110 I=1,ND1
              DO 110 J=1,ND2
                      ARRAY1(I,J)=0.0
                      ARRAY2(I,J)=0.0
  110 CONTINUE
      PRINT*,'DO YOU WANT ARRAYS PRINTED, Y/N?'
      READ '(A)',ANSWER
C-----------------------------------------------------------------------
C   get data from NH1
C-----------------------------------------------------------------------
      FILEIN='NH1.MAP'
      write (*,*) 'calling getfts ',FILEIN
      CALL GETFTS (FILEIN,BITPIX,NAXIS,NAXISS,BSCALE,BZERO,BUNIT1,
     +           BLANK,DATAMX,DATAMN,EPOCH,OBJECT1,DATE1,DATOBS1,
```

```
     +          ORIGIN1,INSTRU1,OBSERV1,CRVAL1,CRPIX1,CDELT1,CTYPE1,
     +          CROTA1,ARRAY1,NX,NY,NZ,*750)
        IF (ANSWER .eq. 'y') THEN
                open(unit=21,file='array1.out',status='new')
                DO 111 row =1,103
                        write(21,101)(ARRAY1(row,col), col=1,25)
101                     format (25f8.4)
111             CONTINUE
                close(21)
        elseif (ANSWER .eq. 'n') then
                continue
        ENDIF
C-----------------------------------------------------------------------
C   get map from NH2
C-----------------------------------------------------------------------
        FILEIN='NH2.OUT'
        write (*,*) 'calling getfts ',FILEIN
        CALL GETFTS (FILEIN,BITPIX,NAXIS,NAXISS,BSCALE,BZERO,BUNIT2,
     +          BLANK,DATAMX,DATAMN,EPOCH,OBJECT2,DATE2,DATOBS2,
     +          ORIGIN2,INSTRU2,OBSERV2,CRVAL2,CRPIX2,CDELT2,CTYPE2,
     +          CROTA2,ARRAY2,NX,NY,NZ,*750)
        IF (ANSWER .eq. 'y') THEN
                open(unit=22,file='array2.out',status='new')
                DO 112 row =1,103
                        write(22,101)(ARRAY2(row,col), col=1,25)
112             CONTINUE
                close(22)
        elseif (ANSWER .eq. 'n') then
                continue
        ENDIF
C-----------------------
C  Read file
C-----------------------
        NNN=1
        KK=1
        CALL SLCTLU (131,LO)
        OPEN (UNIT=LO,FILE='xdetect.dat2',
     +       STATUS='OLD')
C
  120   CONTINUE
        READ (LO,*,END=130) IFILE, SRATE, SERROR, HRATE, HERROR, RA, DEC
        IF (IFILE .GT. 650) GOTO 120
C--------------------------------
```

```
C   determine pixel for rate
C----------------------------------
      XCD1=0.0
      YCD1=0.0
      XCD2=0.0
      YCD2=0.0
      IX=0.0
      IY=0.0
      MX1=0.0
      MY1=0.0
      MX2=0.0
      MY2=0.0
      CALL COPIX (CRVAL1,CRPIX1,CDELT1,RA,DEC,MX1,MY1,*730)
      CALL COPIX (CRVAL2,CRPIX2,CDELT2,RA,DEC,MX2,MY2,*730)
      print*,'ra,dec,mx1,my1,array1',ra,dec,mx1,my1,array1(mx1,my1)
      print*
      print*,'ra,dec,mx2,my2,array2',ra,dec,mx2,my2,array2(mx2,my2)
      print*
      AVGNH1(KK) = ARRAY1(MX1,MY1)+ARRAY2(MX2,MY2)
      AVGXR1(KK) = SRATE
      KK=KK+1
      GOTO 120
 130  CONTINUE
      REWIND (LO)
      KK1=KK
C------------------------------
C  do for second set of maps
C------------------------------
      NNN=NMAX
      KK=1
      DO 210 I=1,NNN
              AVGNH2(I)=0.0
              AVGXR2(I)=0.0
 210  CONTINUE
C------------------
C  Read file
C------------------
      NNN=2
 220  CONTINUE
      READ (LO,*,END=230) IFILE, SRATE, SERROR, HRATE, HERROR, RA, DEC
      IF (IFILE .EQ. 1091) GOTO 220
C-------------------------------
C   determine pixel for rate
```

```
C------------------------------
        XCD1=0.0
        YCD1=0.0
        XCD2=0.0
        YCD2=0.0
        IX=0.0
        IY=0.0
        MX1=0.0
        MY1=0.0
        MX2=0.0
        MY2=0.0
        CALL COPIX (CRVAL1,CRPIX1,CDELT1,RA,DEC,MX1,MY1,*730)
        CALL COPIX (CRVAL2,CRPIX2,CDELT2,RA,DEC,MX2,MY2,*730)
        AVGNH2(KK) = ARRAY1(MX1,MY1)+ARRAY2(MX2,MY2)
        AVGXR2(KK) = SRATE
        KK=KK+1
        GOTO 220
  230   CONTINUE
        KK2=KK
        CLOSE (LO)
C=====================================================================
C=====================================================================
C--------------------------------------------------
C    PLOTTING DATA
C--------------------------------------------------
        NSYMB = 0
        JDASH = 0
        NSKIP = 2
        XTITLE='Neutral Hydrogen Data'
        YTITLE='Xray Intensities'
        TITLE= 'Average NH vs. Xray Data '
C       WRITE (TITLE,8100) FILEIN
C 8100   FORMAT (A10,' vs. XRAY Data')
        DO 500 I=1,4
                XX(I)=0.
                YY(I)=0.
  500   CONTINUE
        XX(1) = 0.0
        XX(2) = 15.0
        YY(1) = 0.5
        YY(2) = 1.0
        DO 600 J=1,NNN
             SIGX(J)=0.
```

```
            SIGY(J)=0.
  600   CONTINUE
C-------------------------------------------------------------
        FILENM = 'avg1.map2'
C-------------------------------------------------------------
        WRITE (*,*)' Data being placed into data file ',FILENM
        CALL SLCTLU (2115,LUN)
        OPEN (UNIT=LUN, FILE=FILENM, STATUS='NEW')
        CALL WRDAT (LUN,TITLE,XTITLE,YTITLE,XX,YY,KK1,NSYMB,JDASH,
     +          NSKIP,AVGNH1,SIGX,AVGXR1,SIGY)
C
        CLOSE (LUN)
C-------------------------------------------------------------
        FILENM = 'avg2.map2'
C-------------------------------------------------------------
        WRITE (*,*)' Data being placed into data file ',FILENM
        CALL SLCTLU (2112,LUNO)
        OPEN (UNIT=LUNO, FILE=FILENM, STATUS='NEW')
        CALL WRDAT (LUNO,TITLE,XTITLE,YTITLE,XX,YY,KK2,NSYMB,JDASH,
     +          NSKIP,AVGNH2,SIGX,AVGXR2,SIGY)
C
        CLOSE (LUN)
C----------------------------------------------
C  end program and print execution messages
C----------------------------------------------
        STOP 'Normal program completion'
  700   WRITE (*,*) ' Error doing conversion in SKYPIX in sector ',NNN
        STOP 'Error in program completion'
  710   WRITE (*,*) ' Error doing map placement in PUTMAP in sector ',NNN
        STOP 'Error in program completion'
  720   STOP 'Error converting pixel in PIXCO '
  730   STOP 'Error in COPIX'
  750   STOP 'Error reading file in GETFTS'
        END
```

APPENDIX B: PROGRAM AVGFIX

The following is a printout of the program used to correct mistakes in the neutral hydrogen column density maps of the SMC stored in the data file NH2.MAP. The problem was that the data in the file NH2.MAP did not exactly correspond to the data in TABLE 2: NEUTRAL HYDROGEN COLUMN DENSITY of McCammon et al (1976).

```
C*****************************************************************************
C
C  Name: AVGFIX
C  Filename:
C  Type: program
C
C  Language: FORTRAN 77
C  Purpose:  to fix the NH2.MAP data file
C
C  Subroutines used:
C     (see the comment cards for xmap.for and cmaps.for)
C
C  Date:
C  Author:
C  Modified:
C
C  Comments:
C
C*****************************************************************************
C
       PROGRAM AVGMAP
C------------------------------------------
C  variable declarations
C------------------------------------------
       PARAMETER (NMAX=200, NAX=3, ID1=103, ID2=25)
       DIMENSION ARRAY1(ID1,ID2), ARRAY2(ID1,ID2), AVGNH1(NMAX),
     +           AVGXR1(NMAX), SIGX(NMAX), SIGY(NMAX), XX(4), YY(4),
     +           AVGNH2(NMAX), AVGXR2(NMAX)
       DIMENSION CRVAL1(NAX), CDELT1(NAX), CRPIX1(NAX), CROTA1(NAX),
     +           CRVAL2(NAX), CDELT2(NAX), CRPIX2(NAX), CROTA2(NAX),
     +           SMAP(IDIM1,IDIM2), SCALE(10)
       REAL      SRATE, SERROR, HRATE, HERROR, RA, DEC
       INTEGER*4 NAXISS(NAX), BITPIX, NAXIS
       integer row, col
       CHARACTER TYYPE*1, FILEIN*80, TYPE(5)*1, COORDS*3, HISTRY(5)*8
       CHARACTER*8 CTYPE1(NAX), CTYPE2(NAX)
       CHARACTER BUNIT1*8, OBJECT1*18, DATE1*8, DATOBS1*8, ORIGIN1*18,
     +           INSTRU1*18, OBSERV1*18,
     +           BUNIT2*8, OBJECT2*18, DATE2*8, DATOBS2*8, ORIGIN2*18,
     +           INSTRU2*18, OBSERV2*18
       CHARACTER*80 TITLE, XTITLE, YTITLE, FILENM, HEADER
       character*80 FILOUT
       CHARACTER*1 ANSWER
```

```
C------------------------------------------------------------------------
C   data statements to save space
C------------------------------------------------------------------------
        DATA TYPE(1)/'L'/, TYPE(2)/'O'/, TYPE(4)/'F'/, TYPE(5)/'2'/
        DATA NX, NY, NZ /103,25,1/
        DATA SCALE(7)/1./, SCALE(8)/1./, SCALE(9)/-99./, SCALE(10)/0./
        DATA NAXISS/103,25,1/
C------------------------------------------------------------------------
C  Define some variables
C------------------------------------------------------------------------
        TYYPE   = 'L'
        ND1=ID1
        ND2=ID2
        NNN=NMAX
        NAXIS=NAX
        COORDS='CEL'
C---------------------------------------------------
C   zero arrays
C---------------------------------------------------
        DO 100 I=1,NNN
                AVGNH1(I)=0.0
                AVGXR1(I)=0.0
                AVGNH2(I)=0.0
                AVGXR2(I)=0.0
  100   CONTINUE
        DO 110 I=1,ND1
                DO 110 J=1,ND2
                        ARRAY1(I,J)=0.0
                        ARRAY2(I,J)=0.0
  110   CONTINUE
C------------------------------------------------------------------------
C   get data from NH1
C------------------------------------------------------------------------
        FILEIN='NH1.MAP'
        write (*,*) 'calling getfts ',FILEIN
        CALL GETFTS (FILEIN,BITPIX,NAXIS,NAXISS,BSCALE,BZERO,BUNIT1,
     +          BLANK,DATAMX,DATAMN,EPOCH,OBJECT1,DATE1,DATOBS1,
     +          ORIGIN1,INSTRU1,OBSERV1,CRVAL1,CRPIX1,CDELT1,CTYPE1,
     +          CROTA1,ARRAY1,NX,NY,NZ,*750)
C------------------------------------------------------------------------
C   get map from NH2
C------------------------------------------------------------------------
        FILEIN='NH2.OUT'
```

```
      FILOUT='NH2.OUT'
      write (*,*) 'calling getfts ',FILEIN
      CALL GETFTS (FILEIN,BITPIX,NAXIS,NAXISS,BSCALE,BZERO,BUNIT2,
     +          BLANK,DATAMX,DATAMN,EPOCH,OBJECT2,DATE2,DATOBS2,
     +          ORIGIN2,INSTRU2,OBSERV2,CRVAL2,CRPIX2,CDELT2,CTYPE2,
     +          CROTA2,ARRAY2,NX,NY,NZ,*750)
      IBGN = 1
      JBGN = 1
2857  write(*,*)'enter IX, IY, array2(IX, IY)'
      READ(*,*,END=2900)IX,IY, ARRAY2(IX,IY)
      GOTO 2857
2900  call PUTFTS (FILOUT,BITPIX,NAXIS,NAXISS,BSCALE,BZERO,BUNIT2,
     +             BLANK,DATAMX,DATAMN,
     +             OBJECT2,DATE2,DATOBS2,EPOCH,INSTRU2,OBSERV2,CRVAL2,
     +             CRPIX2,CDELT2,CTYPE2,CROTA,ARRAY2,NX,NY,NZ,IBGN,JBGN,*790)
C----------------------------------------------
C  end program and print execution messages
C----------------------------------------------
      STOP 'Normal program completion'
  700 WRITE (*,*) ' Error doing conversion in SKYPIX in sector ',NNN
      STOP 'Error in program completion'
  710 WRITE (*,*) ' Error doing map placement in PUTMAP in sector ',NNN
      STOP 'Error in program completion'
  720 STOP 'Error converting pixel in PIXCO '
  730 STOP 'Error in COPIX'
  750 STOP 'Error reading file in GETFTS'
  790 stop 'error in writing file in wrfits'
      END
```

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