CONTENTS

CHAPTER 5: PAYLOAD DESCRIPTION AND PERFORMANCE 171

CHAPTER 6: DISCUSSION OF ROCKET RESULTS 213

CHAPTER 7: GALACTIC HALO CONTRIBUTION TO THE DIFFUSE X-RAY BACKGROUND 255

CHAPTER 8: THE EFFECT OF COSMIC X-RAYS ON THE IONOSPHERE 289

PUBLICATIONS 328

REFERENCES 329
CHAPTER FIVE
PAYLOAD DESCRIPTION AND PERFORMANCE

5.1 INTRODUCTION

This chapter includes the basic experimental aims, specification, peculiarities, and where applicable, performance and preliminary data analysis for each of the six UAT flights. Flights I and II were practically identical and are treated together. In discussion of the integrated but unlaunched V, VI payloads, emphasis is placed on accurate presentation of laboratory calibrations of the new counter types. These give insight into the counter operation and will be necessary for data analysis.

5.2 FLIGHTS I AND II

Two identical ancillary payloads, sited in multi-purpose rings were prepared for Skylarks SL426 (I) and SL425 (II). Four LND counters in each rocket were mounted in pairs to form two independent detection systems, A and B, each having an effective area of 22 cm² and facing in diametrically opposite directions in a plane normal to the
spin axis (i.e. along the + OZ rocket axes). Identical normal, vertical, rectangular fields of view (see 3.6.1) were used for all systems. The quoted experimental aims were "to survey the southern sky, in particular the Magellanic clouds and the galactic disc south of the galactic centre, for sources of X-rays in the energy range 2-8keV".

The detection system and flight parameters are summarized in table (5.1).

5.2.1 Discussion of the Detection Systems

The LND proportional counters have been described in Appendix C. Counter lifetimes, involving a gradual decrease in gain and worsening of energy resolution, had time-scales ranging from months to many years. Some of the worst examples were refilled with a 90% Xe, 10% CH₄ gas mixture two to three weeks prior to launch by Dr. A.G. Fenton. In all cases the deterioration in a time scale comparable with the flight duration, even in vacuum, were negligible. Pre-flight calibrations enabled amplifier gains and bias levels to be set within days of launch, and after this time, gains measured 15 minutes before launch were used to calculate the effective energy discrimination levels for each system. Systems A on both flights showed no gain deterioration after final adjustment; small correction was necessary for I, B and a much larger correction (corresponding
### TABLE 5.1

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<tr>
<th>Detector Summary</th>
<th>Flight I (A,B)</th>
<th>Flight II (A,B)</th>
<th>Comment</th>
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<tbody>
<tr>
<td>collimator (FWHM)</td>
<td>10.5° x 35°</td>
<td>as in I</td>
<td>Vertical (3.6.1)</td>
</tr>
<tr>
<td>effective area (cm²)</td>
<td>22 ( x 2)</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>window (mg cm⁻²)</td>
<td>14 (Be)</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>gas (mg cm⁻²)</td>
<td>29 (Xe - 10%CH₄)</td>
<td>&quot;</td>
<td>2&quot; depth at N.T.P.</td>
</tr>
<tr>
<td>nominal bias levels (keV)</td>
<td>2, 5, 8</td>
<td>&quot;</td>
<td>(5.2.1)</td>
</tr>
<tr>
<td>energy resolution</td>
<td>A</td>
<td>52, 81</td>
<td>individual counters</td>
</tr>
<tr>
<td>FWHM (5.9keV),%</td>
<td>B</td>
<td>100, 25</td>
<td>(2 per system)</td>
</tr>
<tr>
<td>veto efficiency</td>
<td>Vₑr ≈ .75 (p.h.a.)</td>
<td>as in I</td>
<td>(3.5.5)</td>
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</tbody>
</table>

### Flight Summary

<table>
<thead>
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<th>Flight Summary</th>
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</tr>
</thead>
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<tr>
<td>launch time (U.T.)</td>
<td>0032hr, 4 April, 1967</td>
<td>2236hr, 20 April, 1967</td>
</tr>
<tr>
<td>local time (C.S.T.)</td>
<td>1002am, &quot; &quot; &quot;</td>
<td>0806am, 21 &quot; &quot; &quot;</td>
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<tr>
<td>apogee (km)</td>
<td>219.9</td>
<td>218.6</td>
</tr>
<tr>
<td>time above 80km (sec)</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>spin rate (deg.sec⁻¹)</td>
<td>33.6</td>
<td>-28.2</td>
</tr>
<tr>
<td>precession rate (deg.sec⁻¹)</td>
<td>0.87</td>
<td>0.65</td>
</tr>
<tr>
<td>half cone angle (deg.)</td>
<td>66</td>
<td>66.3</td>
</tr>
<tr>
<td>co-ords. precession axis (RA, dec)</td>
<td>23hr, -79°</td>
<td>17.6hr, 22.8°</td>
</tr>
</tbody>
</table>
to a 27% gain change) for II, B.

Samples of the beryllium windows were broken out of each of the damaged counters after recovery and measured as discussed in Section 3.3. The measured thicknesses with a mean of about .0033 inches (15 mg cm$^{-2}$) were used in the data analysis.

Four full and two subswitched telemetry channels were available. The subswitched channels were halved and used to monitor the temperature of four thermistors mounted in the payload. These results are discussed in 2.7.3, and coupled with pre-flight calibrations of the electronics packages, implied that the overall gain of a detection system varied less than ± 5% due to temperature changes in flight. The electronics for each detection system differed from that described in section 4.3 (figure 4.2) in having only two channel pulse height analysis, 16 step staircases (n=4), and no anticoincidence rejection. Four sets of 16 step staircases, corresponding to the 2-5keV and 5-8keV count rates from A and B, were each sampled by one full telemetry channel (at 80 samples per second).

An instrumental difficulty, relating to a shift in one of the three bias levels in flight I after final adjustment, is discussed in section 5.2.3; apart from this everything functioned in the desired manner.
5.2.2 Discussion of the Attitude Solutions

UAT attitude solutions were obtained in the manner described in section 2.4.6. On both flights the diagonal and vertical sun slits continuously scanned the sun for two periods of about 100-150 seconds, one at the beginning and the other late in flight. For these periods the position of the $+OX$ axis in space was determined by triangulation from the sun and magnetic field positions, the two sections of precession cone so obtained were fitted to a circle on the celestial globe, and a constant precession rate assumed. British Aircraft Corporation (BAC) attitude solutions were also provided. A test of a particular solution was its ability to predict the times of sighting X-ray sources whose positions are accurately known (in these flights, Sco XR-1 and the sun). An additional criterion for flight I was the ability to give a consistent position for the new strong X-ray source, Cen XR-2, observed both at the beginning and end of flight.

In flight I, the sun and magnetic field positions were separated by only 33 degrees, and early in the flight the $+OX$ axis moved almost along the line passing through these positions. Thus small errors in determining the angles $S\hat{O}X$ and $M\hat{O}X$ produced large errors in the triangulated $OX$ position. The two sections of precession cone obtained in this manner did not lie on a circle, and the UAT solution,
based on a circle of best fit, did not give consistent positions for Cen XR-2, although the agreement for Sco XR-1 was within 1°. Three BaC solutions were provided, each an improvement on the one before. The third solution gave good agreement for the sun and consistent positions for Cen XR-2, but gave a Sco XR-1 position some 4° from the measured one. A program was written to rotate the BaC solution about the sun position to give better agreement with Sco XR-1. A rotation of 5° in a co-ordinate system with the sun at zenith gave an agreement of better than 1° for Sco XR-1.

For example, such a rotation could be associated with an error in magnetic field position of about 2°, and since uncertainties larger than this existed in UAT solutions, it was decided to use the rotated BaC solution with parameters listed in table (5.1).

Figure (5.1) shows the scan path over the sky of the OZ rocket axis (detection system A). The galactic longitude (l) and latitude (b) are plotted for each instant (0.1 sec) of flight, and the position at each second after launch is labelled immediately to the right of the trace. The collimator field is shown relative to the scan direction; it becomes distorted away from the centre of the Hammer "equal area" projection. The ground level horizon is shown at the time of launch; the rocket horizon at 80 Km is almost 10° below, and at apogee 15° below this. Source positions and
FIGURE 5.1: Flight I Attitude Solution
rough relative intensities (2-8keV) are taken from Mayer et al (1970) for the Sagittarius-Scorpius region, Giacconi et al (1967) for the Cygnus region, Chodil et al (1967b) for the Vela, Centaurus regions, Thomas et al (1969) for the July, 1969, source, this thesis for the Cetus and Cen XR-2 (Apr. 1967) positions and Friedman et al (1967) for other sources. Caution must be exercised in accepting the position or even the existence of sources shown with intensities < 0.5 photons cm⁻² sec⁻¹ and other such sources may exist in some of the above regions.

Flight II was launched at a time of much larger sun-magnetic field vector separation (65°). A well defined circular precession cone was evidenced by an excellent fit to the two sections obtained by triangulation. This circle passed very close to the anti-solar direction at +238 seconds (indicated by a complete loss of vertical sun slit data), and in order to interpolate the spin rate accurately over the period of no sun sightings, the times of "sighting" the centre of the precession cone were calculated for the periods for which sun slit data existed — the differences between successive "sightings" should have been constant throughout the flight. In fact the time differences indicated a gradual decrease from 13 seconds to 12.5 seconds and the interpolation was made allowing for a 4% despin between +100 and +400 seconds. A program, using the cone half angle, the
attitude of precession axis and the precession period
determined the rocket OYZ plane. The direction of look of
the counters in this plane were phased to the precession
axis "sightings". This solution predicted the Sco XR-1
position to within 2° (and, of necessity an accurate sun
position) and has no apparent inconsistencies. On the other
hand the BaC solution erred some 8° from the Sco XR-1
position and contained a similar discrepancy for the sun
position late in flight. The UAT solution with parameters
listed in table (5.1), was used for data analysis, and
figure (5.2) shows the sky area scanned by detection system
a. Ground level horizon and source positions are included.

The co-ordinate transformations employed in both
attitude solutions are generally applicable to rocket surveys
and are reproduced in appendix a.

5.2.3 Data Reduction

Photographic records of each staircase output were
manually digitalized to give the number of counts (or steps)
per 0.1 seconds throughout each flight. The first steps in
determining source positions and intensities are described
in sub-section 3.6.1 on collimators, for the case of slowly
spinning rockets. In both I and II, \( \alpha_s = 10.5^\circ \) and a
detector response to a single scan across a point source is
a triangle of base \( 2\alpha_s/\omega_s \approx 0.7 \) seconds. A least squares
FIGURE 5.2: Flight II Attitude Solution
fitting technique (Appendix B) was programmed to fit the correct triangular response to each set of 6 to 8 "digitalized" data points obviously representing a source. The program output comprised a maximum count rate $A_s$, its variance $V(A_s)$, time of peak $t_s$, and its variance $V(t_s)$, for the triangle of best fit. $A_s$ was interpreted as the number of source photons per second, modified only by the collimator response normal to the spin direction and the counter efficiency and energy resolution.

With a separation of successive scans $\leq$ about 10° (figures 5.1, 5.2) and collimator full width of 70° normal to the spin direction, an accessible and sufficiently strong source yielded a set of at least six successive sets of $A_s$, $t_s$ values for each detector system. The collimator response normal to the spin direction was assumed to be triangular with FWHM, $\alpha_p = 35°$ (a good approximation, see table 3.7). Then by using the attitude solutions to obtain the angular separation between successive scan paths at times of maximum source count rate, i.e. at each $t_s$, a "theoretical" response function of $A_s$ against $t_s$ was determined. For the Sco XR-1 response on I and the Cen XR-2 response on II, this response was triangular and symmetric and the least squares fitting technique used above was immediately applicable. However for the Cen XR-2 on I and Sco XR-1 on II, the relative phasing of spin and precession
resulted in a theoretical response function noticeably asymmetric, and non linear after the peak. In these cases an approximate response function was employed, and consisted of an asymmetric triangle, characterized by different "widths" before and after the peak.

The time of peak \( t_n \) resulting from these fits, was used to interpolate linearly between the positions representing neighbouring values of \( t_s \), so yielding an actual source position and its statistical variance. The ordinate \( A_p \) at \( t_p \) of the fitted response then gives the source intensity modified only by the energy dependent response of the counter.

The method of correcting for counter efficiency and energy resolution are described in section 3.4. As has been already mentioned, the energy resolution of the LND counters was poor. In flight I, where the counters had field forming electrodes to correct for end effects, the response to Fe\(^{55}\) X-rays was symmetrical but "smeared" out with FWHM \((5.9\text{keV})\) ranging from 30% to 100%. Thus the analysis of I data, employed a gaussian response with

\[
\sigma = 0.18(h\nu)^{1/2} + \{\text{FWHM}(5.9\text{keV}) - 18\} (h\nu)
\]

in equation (3.22). The term in curly brackets is a constant percentage added to bring the resolution up to that observed at 5.9keV. For flight II counters, the large end effects were incorporated by considering a gaussian component with \( \sigma \) similar to above for two thirds of the counts, and a
rectangular response from zero energy to hv for one third of the counts, in accord with observed Fe$^{55}$ pulse distributions. The convolution of source intensity, counter efficiency and gaussian (plus rectangular) response was numerically integrated for a wide range of source parameters, and for 0.1keV energy intervals (from 1 to 10keV) in a program written by Dr. Harries.

There remains the possibility that measurements of source spectra were influenced by a gain hysteresis effect due to the sun sightings. A possible effect is mentioned in 4.3.3. The maximum electronic charge collected at the anode on one scan of the sun (∼1/3 sec) is $10^{-6} - 10^{-7}$ coulomb. At least initially this is neutralized by charge from the last filter capacitor in a time of the order of $10^{-3}$ seconds, so that the electronic charge on the anode is smaller than, but a noticeable fraction of, the static anode charge $q = CV \overset{<}{\sim} 10^{-8}$ coulombs. Space charge acts on the gas gain to prevent the electronic charge from becoming comparable to the stored charge. The corresponding decrease in anode voltage is therefore small, say up to 1-10%, but this gives much larger changes in gas gain (see table 3.1). On the other hand the recovery time, after passing the sun, for a small voltage deviation is dominated by the last stages of the filter and in this case will be of the order 0.5 - 1 secs at the most. As can be seen from figures (5.1), (5.2), both
Sco XR-1 and Cen XR-2 are several seconds from the sun. In fact in flight II, when Cen XR-2 shows a decrease in intensity from I, Cen XR-2 is observed and measured on scans occurring some 150 seconds after the last sun sighting.

For Sco XR-1 an exponential spectrum similar to equation (1.5) was used, i.e.

\[
\frac{dN}{d(h\nu)} = K(h\nu)^{-1} \exp \left(-\frac{h\nu}{k}\right) \text{photons keV}^{-1} \text{cm}^{-2} \text{sec}^{-1} \quad (5.1)
\]

here \(k(\text{keV})\) represents the "temperature" of the source. The total 2-8 keV count rates obtained from the analysis were in good agreement between the two flights, and the ratio of \((2-5 \text{ keV})/(5-8 \text{ keV})\) counts in flight II indicated a source temperature in good agreement with those obtained on April 10 (Cooke et al., 1967) and May 18 (Chodil et al., 1967b).

However, the ratios obtained for Sco XR-1 (and also Cen XR-2) on flight I implied an unreasonably flat spectrum. Measurements on the recovered electronics indicated that (only) the middle bias level for flight I had changed since final calibration (presumably in the locking process) and that the I bias levels were in fact from 2-4.5 keV and 4.5-8 keV. Using these limits the ratio of low to high energy counts gave excellent agreement with the flight II Sco XR-1 temperature. (The slight dependence of this argument on the requirement for the two sightings of Sco XR-1, with equal 2-8 keV intensities, to record the same
temperature, is justified in spite of the now obvious variability of this source. This is evident from a study of all available Sco XR-1 measurements discussed in section 8).

5.2.4 Summary of Results

Between launch and about 40 to 50 Km on both I and II, all detector outputs gave a saturated response (\(<\, 16 \times 80\) counts per second), with the effect commencing first and persisting longest in the lower energy channels. This was most likely due to microphonic action in the detectors, associated with the thrust phase of the flight, as slight sensitivity to vibration was observed in preflight tests.

Above these altitudes and below 70 Km the count rate was approximately constant in time and from flight to flight, with equal counts in both energy intervals. This was attributed to primary cosmic rays and secondary charged particles and photons discussed in subsections (3.5.1), (3.5.2), and was assumed to be a constant contribution to the count-rate at higher altitudes.

Between 70 and 90 Km a marked increase in count was observed. The effect was most marked when detectors looked up out of the atmosphere and was strongest in the low energy (2-5 keV) channels. The possibility of the increase being due to low energy charged particles unable to penetrate below 70 Km was considered and thought unlikely, mainly because of
the insensitivity of the LND counter to such particles, discussed in section (3.5.3), and the magnetically quiet conditions during both flights. Also a search for a pitch angle distribution in the increased flux was unsuccessful, however as mentioned in (3.5.3), a small contribution from electrons is extremely difficult to separate from X-ray events. The difference in count rate when detectors looked up (but not at known point sources), and the count rate below 70 Km was taken to represent a diffuse X-ray flux. The large field of view and small area made it difficult to obtain sufficient data uncontaminated by point sources or horizon etc. to make a detailed study of the diffuse X-rays — no statistically significant flux variations (>20% - 30%) were found with galactic latitude. The combined data of both flights gave results compatible with a power law of the form

\[
\frac{dN}{d(h\nu)} = (19 \pm 3) h\nu^{-(1.75 \pm 0.3)} \text{photons keV}^{-1} \text{cm}^{-2} \text{sec}^{-1} \text{ster}^{-1}
\]

which is not significantly different from the result of Seward et al (1967), taken in a similar region of the galaxy. All available diffuse X-ray measurements are discussed in more detail in section 7.2.

The increase between 70 and 90 Km in detectors looking down into the atmosphere was only significant in the low energy channels, and varied with the sun direction. This
effect was explained in a very satisfactory manner by Dr. Harries, in terms of an albedo of scattered solar X-rays and solar-excited fluorescent X-rays from the atmosphere, and is discussed in detail elsewhere (e.g. Harries and Francey, 1968).

Above 90 km, X-rays from point sources, unattenuated by the atmosphere, were observed above the background of cosmic ray induced events and the diffuse X-rays. Sco XR-1 and Cen XR-2 were detected on at least seven consecutive scans by each detection system on both flights and so were subjected to detailed analysis.

The published UAT position for Cen XR-2

13.9 hr. RA, -64° dec
310° lII, -2.3° bII

is the mean position of the independent determinations from each flight. These, with statistical and estimated systematic errors are shown in figure 1 of Harries and Francey (1968), and result in approximately a 4° error circle. No attempt was made to combine statistical errors in the direction parallel to the scan, from neighbouring scans. As will be seen in Chapter 6, flight II offers a unique opportunity to obtain the Cen XR-2 galactic longitude to much greater accuracy, as a result both of combining statistical errors in the manner suggested and of scan directions allowing accurate determination of the position relative to Sco XR-1. The second factor markedly reduces
the dependence of the positional determination on the accuracy of the attitude solution. The resulting position has great significance in view of more recent X-ray surveys of the region.

The most outstanding results from these flights were

1. the discovery of Cen XR-2 in a region of sky for which a flux upper limit of approximately 1/100 th. that observed on flight I was claimed (Chodil et al., 1967b), and

2. the unique information on the Cen XR-2 spectrum variation on a time scale of three weeks, the first such information obtained for an X-ray source.

Examination of even the raw count rate totals indicated that whereas the Sco XR-1 flux was similar on both flights, the Cen XR-2 flux exhibited a marked decrease from I to II. Since the two channel pulse height analyser was unable to distinguish the actual shape of the spectrum (e.g. whether exponential, power law or blackbody), the results were first published in an exponential form, similar to equation (5.1), showing clearly the statistical significance of the measurements (Francey et al., 1967). Subsequent and more detailed spectral information on Cen XR-2 (Chodil et al., 1968b) is more compatible with a power law shape, (as are recent data by Rao et al., 1969a, for an object which has "reappeared" near the Cen XR-2 position). Assuming simple power law source spectra the UAT Cen XR-2 spectral data are given by
5.2

\[
\frac{dN}{d(h\nu)} (2-8 \text{ keV}) = (79 \pm 4) \ h\nu^{-2.12 \pm 0.15} \text{ ph. keV}^{-1} \text{ cm}^{-2} \text{ sec}^{-1} \tag{5.3}
\]

\[
\frac{dN}{d(h\nu)} (2-8 \text{ keV}) = (114\pm6) \ h\nu^{-2.75\pm0.25} \text{ ph. keV}^{-1} \text{ cm}^{-2} \text{ sec}^{-1} \tag{5.3a}
\]

Figure (5.3) shows the lines of best fit and included are the May 18 (1967) data of Chodil et al (dashed line). The dotted line shows the exponential Sco XR-1 spectrum at intensities representing both flights I and II. Also included are upper limits of LRL (28Sept67) and flight III (1Dec67, section 5.3) assuming a spectral index the same as the last sighting (\text{approx} -2.75).

The Sco XR-1 data are represented by

\[
\frac{dN}{d(h\nu)} (2-8 \text{ keV}) \approx (56\pm5) \ h\nu^{-1} \exp(-h\nu/4.5\pm0.5) \text{ ph. keV}^{-1} \text{ cm}^{-2} \text{ sec}^{-1} \tag{5.4}
\]

\[
\frac{dN}{d(h\nu)} (2-8 \text{ keV}) \approx (50\pm5) \ h\nu^{-1} \exp(-h\nu/4.5\pm0.5) \text{ ph. keV}^{-1} \text{ cm}^{-2} \text{ sec}^{-1} \tag{5.4a}
\]

A search for X-rays from the Magellanic clouds was one of the stated aims of these flights, and figure (5.1) shows a large number of scans close to the LMC position on flight I. Times of "sighting" the LMC were read from the attitude solution for 26 scans past the position (13 of which were by detector A and are shown in figure 5.1). Count rate data were arranged about these times and superposed. No significant count rate increase was observed implying a point
FIGURE 5.3: Variability of Cen XR-2 Spectrum (c.f. table 6.1). (Mean Apr-May Sco XR-1 spectrum included for comparison)
source flux upper limit (correcting for collimator transmission) of

\[ I_{\text{LMC}} < 0.2 \text{ counts cm}^{-2} \text{ sec}^{-1} \ (2-8 \text{ keV}) \]  \hspace{1cm} (5.5)

Recent evidence for an extended LMC X-ray source of 12° width and flux 0.2 photons cm\(^{-2}\) sec\(^{-1}\) over a significantly wider energy interval (1.5 - 10.5 keV), (Mark et al, 1969), would be undetectable on either of these flights.

X-rays were detected from the galactic centre region but were not resolved into point sources. The total fluxes observed were consistent with the results of Friedman et al (1967) and more recently those of Mayer et al. (1970). Both rockets scanned the Cygnus region; the large number of flight II scans over the region permits sufficient superposition to get significant responses, which in the light of more recent data are quite meaningful and are discussed in Chapter 6. Finally the sun was scanned and on every occasion saturated the relevant telemetry output. This placed a lower limit of 2000 counts sec\(^{-1}\) between 2-8 keV on the solar flux; the analysis of atmospheric albedo yielded a solar flux of about \(10^6\) photons cm\(^{-2}\) sec\(^{-1}\).

5.3 FLIGHT III

A third ancillary experiment was accepted for inclusion on an engineering round, SL 422A. Limited finance and
preparation time influenced design and major considerations were

(1) the existence of a complete set of unused I and II hardware, and

(2) the immediate availability of a ring not requiring milling for apertures, i.e. the standard base ring.

Three independent detection systems A, B and C were employed with UAT BR counters in A and B, and two refurbished flight II LND counters in C. The engineering tests included a new parachute for head recovery, plus a rocket "spin up" system to reduce impact dispersion. It was anticipated that the initial imparted spin would damp out after 5 seconds and not affect the motion of the rocket above the atmosphere. However both this factor plus a greater likelihood of inertial asymmetries than in a newly designed rocket, meant there was no guarantee of the ideal survey motion experienced on flights I and II.

The UAT purpose was again a survey one, as well as an inflight test of the new counters. Although UAT had no influence on launch time, it was hoped to once more scan the Cen XR-2 and Sco XR-1 positions. Table (5.2) summarizes the detection system and flight parameters, which are discussed below.
### Table 5.2

**FLIGHT III**

<table>
<thead>
<tr>
<th>Detector Summary</th>
<th>System A</th>
<th>System B *</th>
<th>System C</th>
</tr>
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<tbody>
<tr>
<td>collimator (FWHM)</td>
<td>$4.2^\circ \times 36.85^\circ$ (vert.)</td>
<td>$4.5^\circ$ (hexagonal)</td>
<td>($4.1^\circ \times 35^\circ$ (vert.) $4.1^\circ \times 35^\circ$ (45° diag.)</td>
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<tr>
<td>effective area (cm$^2$)</td>
<td>43.9</td>
<td>87.0</td>
<td>2 x 11.7</td>
</tr>
<tr>
<td>window (mg cm$^{-2}$)</td>
<td>23 (Be)</td>
<td>1.77, $\text{C}_1\text{H}_2\text{O}_4$</td>
<td>23 (Be)</td>
</tr>
<tr>
<td>gas (mg cm$^{-2}$)</td>
<td>4.8 (P-10)</td>
<td>4.82 (P-10)</td>
<td>29 (Xe -10%CH$_4$)</td>
</tr>
<tr>
<td>bias settings (keV)</td>
<td>2, 3, 2, 4, 5, 6, 8</td>
<td>2, 3, 2, 4, 5, 6, 8</td>
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<tr>
<td>energy resolution</td>
<td>25</td>
<td>17.5</td>
<td>100, 35</td>
</tr>
<tr>
<td>FWHM (5.9 keV)</td>
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<td></td>
</tr>
<tr>
<td>veto efficiency</td>
<td>$V_c \approx 0.76$ (a/c)</td>
<td>$V_c \approx 0.76$ (a/c)</td>
<td>$V_c \approx 0.75$ (p.h.a.)</td>
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**Flight Summary**

<table>
<thead>
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<th>Value</th>
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<td>launch time (U.T.)</td>
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<td>local time (C.S.T.)</td>
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<td>apogee (km)</td>
<td>181</td>
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<tr>
<td>time above 80 km (sec)</td>
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<tr>
<td>spin rate (deg. sec$^{-1}$)</td>
<td>15.9</td>
</tr>
<tr>
<td>precession rate (deg. sec$^{-1}$)</td>
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</tr>
<tr>
<td>half cone angle (deg.)</td>
<td>~90</td>
</tr>
<tr>
<td>co-ords of precession axis</td>
<td>2 hr., - 61°</td>
</tr>
</tbody>
</table>

(* in-flight calibration)
5.3.1 Discussion of Detection Systems

To give flexibility in the event of an unexpected rocket motion and to enable better source resolution, and flux and position estimates, a wide range of collimator types was employed. The A collimator was similar to the type on flights I and II. System B used a honeycomb collimator giving good resolution normal to the spin direction, useful in a cluttered star field or with a rocket motion implying a large number of scans over a restricted region. Separate and identically constructed collimators were placed over the two counters of system C (one vertically and the other diagonally (at 45°), see 3.6.1} and the counter outputs monitored separately.

System A electronics comprised 4 channel pulse height analysis, and anticoincidence rejection and differed from that shown in figure (4.2) only in the number scalers, (n). The 2-3.2 keV and 3.2-4.5 keV outputs were on 32 step staircases (n=5), each sampled by a full telemetry (TM) channel. The 4.5-6 keV and 6-8 keV outputs used 16 step staircases on half TM channels, (i.e. the total system A X-ray output was monitored on 3 TM channels). A further half TM channel carried an 8 step (n=3) guard count rate.

System B incorporated inflight calibration in the form of a small (~400 counts sec⁻¹) Fe⁵⁵ source permanently irradiating the guard counter. Since only guard pulses
occurring in coincidence with, or less than 8 µsec after an X-ray pulse were vetoed, the number of random rejections was about 0.3% of the X-ray count rate. A shielded "Ledex" switch at the counter allowed the X and G outputs to be reversed on command, i.e. the G output was analysed in the 4 channel pha for the duration of the command, permitting location of the Fe$^{55}$ peak. The Ledex calibrations occurred only for times when the rocket was below 70 Km (e.g. see section 2.8). In all other respects the B electronics were identical to those in system A. An unusual feature in the B counter was the 0.5 mil Melinex window exposure during launch. The excellent support and heat shielding provided by the honeycomb collimator in laboratory tests indicated that the use of exposed plastic windows might be feasible, and in view of the high cost of beryllium, was incorporated, with future flights in mind.

The separate outputs from the C1 and C2 counters were monitored in single 2-8 keV energy channels, in each case a half TM channel sampling an 8 step staircase. A combined C1 and C2 output was prescaled by $2^5$ before being sampled as an eight step staircase with half a TM channel. With a total scaling factor of $2^8$ it was hoped to obtain an approximate measure of the sun X-ray flux as a further check on the X-ray albedo theory mentioned in 5.2.4.
Although all three systems yielded some information, there were some disappointing aspects of this flight. The gain of the B counter decreased rapidly after the final flush (at launch -20 min.). The gas valve on plumbing was immediately suspect, but because of the ancillary status of the experiment it was not possible to interrupt the countdown sequence to allow rectification. The counter still responded, with reduced gain, to the calibration source at 70 Km on descent. However a leak which tended to decrease gain at ground level may well have implied an increase in gain above the atmosphere if the counter pressure decreased, so that considerable uncertainty exists in the detailed behaviour of system B. The effectiveness of system A was also reduced, this time by an abnormally high guard count rate which saturated the TM (320 cts/sec) and appeared to reduce the efficiency of the X counter due to random rejections. This has been a most puzzling feature since this system functioned normally on recovery; it is possible that physical movement of electronics or foreign matter during launch initiated EMT discharge which cured itself on impact.

Interpretation of the data from both A and B might have been vastly simplified by an inflight cross reference between these and the C detector (which functioned normally), as would have been provided by a sighting of the sun, Sco XR-1.
or other relatively strong X-ray sources. The unusual rocket motion, described below, prevented the detectors from scanning any strong source.

5.3.2 Discussion of Attitude Solutions

The rocket motion above the atmosphere was such that at no time did the diagonal sunslits sight the sun, although the vertical slits gave a response throughout most of the flight. This information plus the slow spin rate implied large precession cone angle and slow precession rate. In addition to this, the Z magnetometer functioned incorrectly and prevented an inflight magnetometer calibration which would have given information on the cone angle. Finally since the X-ray detectors at no stage scanned the position of a strong source, no additional aids or accuracy criteria existed.

Mr. Barnden obtained an approximate attitude solution using the remaining magnetometer data plus vertical sunslits, and this was used for data analysis. The solution was in substantial agreement with a recent, more detailed BaC solution whose authors make the following comments. "The solution ...... fits the sun cell data to a r.m.s. error of 0.72 degees, suggesting an overall accuracy of ±1.5 degrees. .......we have assumed a cone angle of 90° although we have no means of proving this because of the small movement in precession ........ checked as far as possible and feel
reasonably sure that it is a valid solution". The parameters of this solution are listed in table (5.2) and the path of the (+OZ -π/6) rocket axis, corresponding to system C, is shown against galactic longitude and latitude in figure (5.4). The ground level horizon and source positions are indicated.

5.3.3 Data Reduction and Results

Although no obvious sources were apparent on flight records, as might be expected from figure (5.4), the high scan density over previously poorly scanned regions near the South galactic pole was sufficient reason to digitalize all data into 0.1 second count rates, as for flights I, II. The most obvious method of analysis, in view of the rocket motion was to superpose successive scans, and using this procedure Mr. Barnden isolated a noticeable deviation above the background for the C vertical collimator counter, using 5 scans. The C diagonal collimator data were then searched keeping in mind the relative peak phasing for an off axis source, and the most significant count rate deviation was obtained adding three of the above scans. Summing all the data from system C a peak 3.6 standard deviations above the mean background level was obtained, where the total counts due to peak and background over a time representing the FWHM of the collimator response have been compared with the established background level as in 5.2.4. Using the separation of peak
FIGURE 5.4: Flight III Attitude Solution
times between vertical and diagonal collimators for this situation gives a likely source position of 2.0hrs RA, -6° DEC ($l^{\text{II}} = 164^\circ$, $b^{\text{II}} = -62^\circ$), in the constellation Cetus.

This means that the B detector, with honeycomb collimator, would have seen the source only on the first scan, if at all, and no confirmatory information was obtained from it. The A detector with vertical collimator viewed the source on at least 5 scans, hampered however by an unknown reduction in sensitivity due to the high guard rate. Adding a detector scans about the "source" position yields a peak 2.0σ above the mean background level.

Since this position was scanned on previous UAT flights, both the I and II records were re-examined. As seen in figure (5.1) the source and sun positions are unresolved by the 10.5° FWHM collimators of I. In II, figure (5.2), four scans were added about the source position and over the FWHM of the response function a peak 2.7σ above the mean background level obtained.

Both the III-C and II peaks imply a Cetus source with intensity about 1.5 photon cm$^{-2}$sec$^{-1}$ over 2-8 keV. Adding the peak rates, normal errors according to the relation

$$\sigma = (\sigma_1^2 + \sigma_2^2 + \sigma_3^2)^{\frac{1}{2}},$$

and mean background levels for the three sightings, the significance of the peak increases to 4.6σ above the mean background. Since the response on any one scan is ill-
defined, an error circle of 15° radius about the above position is quoted, incorporating the collimator full width and attitude uncertainties. A search of the literature to 1969 yielded no flight with comparable sensitivity in this region, with the majority of spin stabilized and attitude controlled rockets concentrating on the more prolific source regions in the galactic disc.

A second important result from flight III comes from the large number of scans close to the Cen XR-2 position, whose angular separation from the scan paths implies a mean vertical collimator transmission 55% that for a scan right over the source. Using the detector C results and assuming a spectrum of similar shape to that observed on 18 May, 6 months earlier (see figure 5.3), an upper limit of

\[ \dot{I}_{\text{Cen XR-2}} \leq 1 \text{ photon cm}^{-2} \text{ sec}^{-1} (2-8 \text{ keV}) \]  

(5.7)

is obtained. This upper limit is greater than one obtained by Chodil et al (1968) September 28, 1967, of 0.5 photons cm\(^{-2}\) sec\(^{-1}\) (2-10 keV), however in view of the variability of this source, discussed in the next chapter, it retains significance.

5.4 FLIGHT IV

In January, 1969, the flight IV payload was totally destroyed 40 seconds after launch due to a vehicle
malfunction (portrayed in a spectacular fashion in Appendix C). The rocket, SL 781, was primarily launched to flight test the new, powerful Goldfinch boost motor and from the UAT view this implied greater acceleration and vibration, but a heavier payload for the same apogee.

UAT were given a primary status on this rocket and weight, space, power and telemetry allowances vastly exceeded anything available before or since. The detector details are summarized in table (5.3). The use of a large number of independent detection systems, all calibrated throughout flight (below 70 Km and for 5 seconds at apogee), and with variations in window type, area, collimator shapes etc. from one to the other, is obviously a good way to avoid systematic errors. Unhampered by normal payload restrictions, this experiment would have provided a unique opportunity to obtain absolute X-ray measurements of a large number of sources (for a well behaved flight I, II type motion) plus information on possible systematic errors.

A point source survey was the principal UAT objective, and the great advantages of 7-9 independent point source sightings per scan, with the detector variety listed, can be inferred from discussions of the following flights. Also, as an aid in determining accurate attitude, an additional sun cell, aligned with the collimators and covering the +OX rocket direction, plus cameras to photograph the horizon
<table>
<thead>
<tr>
<th>Detection System</th>
<th>Collimator FWHM (deg.)</th>
<th>Eff. area (cm²)</th>
<th>Window (mg cm⁻²)</th>
<th>Gas (20°C) (mg cm⁻²)</th>
<th>Bias Levels (keV)</th>
<th>Energy Res. FWHM (5.9keV)</th>
<th>Background Rej. Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1*</td>
<td>4.5 (hexag.)</td>
<td>570</td>
<td>0.9(C₁₀H₁₈O₄)ₙ</td>
<td>7.6, P-10</td>
<td>1, 2, 3, 4, 5, 6,</td>
<td>17%</td>
<td>V&lt;sub&gt;εr&lt;/sub&gt; = .94 (guard)</td>
</tr>
<tr>
<td>NC-A2*</td>
<td>&quot;</td>
<td>&quot;</td>
<td>1.45(CH₂)ₙ</td>
<td>7, 8, 12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NC-B1*</td>
<td>2.7x33 (vert.)</td>
<td>220</td>
<td>0.9(C₁₀H₁₈O₄)ₙ</td>
<td>6.0, P-10</td>
<td>1, 2.5, 4, 6, 10</td>
<td>&quot;</td>
<td>V&lt;sub&gt;εr&lt;/sub&gt; = .78 &quot;</td>
</tr>
<tr>
<td>NC-B2*</td>
<td>&quot;</td>
<td>&quot;</td>
<td>1.45(CH₂)ₙ</td>
<td>3.8, P-10</td>
<td>25, 30, 1.50</td>
<td>&quot;</td>
<td>V&lt;sub&gt;εr&lt;/sub&gt; = .75 &quot;</td>
</tr>
<tr>
<td>NC-C1*</td>
<td>5 x 36 (vert.)</td>
<td>60</td>
<td>0.89(CH₂)ₙ</td>
<td>3.8, P-10</td>
<td>2, 8</td>
<td>20%</td>
<td>V&lt;sub&gt;εr&lt;/sub&gt; ≃ .75 &quot;</td>
</tr>
<tr>
<td>NC-C2*</td>
<td>&quot;</td>
<td>&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BR-A*</td>
<td>4 x 37 (vert.)</td>
<td>65</td>
<td>12.5 Be</td>
<td>as in flight III</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BR-B*</td>
<td>4.5 (hexag.)</td>
<td>87.0</td>
<td>1.77(C₁₀H₁₈O₄)ₙ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BR-C1*</td>
<td>3 x 35 (vert.)</td>
<td>30</td>
<td>23 Be</td>
<td>4.0, P-10</td>
<td>2, 8</td>
<td>20%</td>
<td>V&lt;sub&gt;εr&lt;/sub&gt; ≃ .75 &quot;</td>
</tr>
<tr>
<td>BR-C2*</td>
<td>3 x 35 (diag.)</td>
<td>29.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>35 x 35</td>
<td>1.5</td>
<td>9 Be</td>
<td>&gt;2 (electrons &gt; 85keV)</td>
<td>30%</td>
<td>V&lt;sub&gt;εr&lt;/sub&gt; = 1.0 &quot;</td>
<td></td>
</tr>
<tr>
<td>EL-B</td>
<td>&quot; (gap of 1500 gauss magnet)</td>
<td>1.5</td>
<td></td>
<td>&gt;2 (electrons &gt; 250keV)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(* in-flight calibration)
were included in the UAT payload.

Secondary aims of the flight were more unusual and deserve special mention.

1. Though these collimator shapes were better suited to a point source rather than diffuse X-ray survey, the comparison of results from counters with similar collimators and different areas and vice versa, provides valuable information on the diffuse radiation. The exact composition of the diffuse count rate was to be probed firstly using a prescaled BR-C output (as in flight III) to measure the sun flux and obtain more information on the atmospheric albedo, discovered in flights I and II. (This is important if the diffuse flux is obtained by an "up-down" difference, a method frequently employed by other authors). Secondly, the possibility of low energy electron contamination (discussed in 3.5.3), was to be investigated using a technique similar to O'Brien, i.e. a magnetic "broom" was included over one of two identical counters (in this case proportional counters with a common gas volume). Electrons < 250keV were prevented from entering the counter with the magnet, otherwise sensitive to < 80keV electrons. In addition the comparison of "diffuse" counts from each side of the NC-A or NC-B counters would have provided information on electron contamination — the transmission of the two windows by low energy X-rays are similar, e.g. at 2keV, \( \frac{I}{I_0} \) Melinex \( \approx 0.73 \)
and \( I/I_0 \) Propafilm \( \approx 0.70 \), however the electron transmission depends mainly on the mass of the windows, and electrons with energy \( E \geq 23 \text{keV} \) penetrate the Melinex and with \( E \geq 30 \text{keV} \), the Propafilm. The pulse height analyser permits only a narrow "slice" of the electron spectrum above these limits to be sampled (~5keV, and slightly narrower for the Propafilm), thus a difference in count rate would have resulted from the presence of a steep electron spectrum.

(2) The NC-C counters were to probe a relatively new area of investigation, the cosmic X-ray fluxes below 0.28keV. The 40G Propafilm, employed for the first time in a cosmic X-ray detector to the author's knowledge, provided reasonable efficiencies below 0.28keV (Francey et al, 1969, also figure 3.5), without resort to special window supporting meshes etc. The solar induced fluorescence of the atmosphere which saturated the low energy detectors of Grader et al (1969) would have been far less serious, in this case, since the Propafilm transmission efficiencies for 0.50keV oxygen and 0.38keV nitrogen \( \text{K}\alpha \) X-rays are less than \( 10^{-2}\% \). The detector gain was to be monitored in flight. As in all other calibrated detectors a "fail-safe" calibration method was employed in which an Fe\(^{55}\) source was permanently mounted over a small beryllium window in the wall surrounding each gas volume. X-rays were prevented from entering the window by an intervening, spring loaded, aluminium shutter which
could be held open only in the presence of a +28v pulse from the rocket bus. In this case the NC-C amplifier gains were simultaneously divided by a fixed factor (~2.5) to bring the amplifier output into the pulse height analyser range (0.25keV to 3keV).

The only information salvaged from the flight was obtained from telemetry records during free fall of the head from about 2 Km. These showed that all counters were functioning normally and in particular that large areas of thin plastic windows and long thin anodes in the new counters had withstood accelerations, vibration, and buffeting (due to premature nose cone ejection) in excess of that expected on a normal flight.

5.5 FLIGHTS V AND VI

Flights V and VI are the first of a program of UAT "X-patrol" experiments. With the cessation of engineering rounds prepared and launched in Australia by WRE, a major consideration in the X-patrol proposal was minimization of costs of U.K. integration for ancillary UAT payloads. A continuation of a survey program was proposed with enough payload flexibility to cover the general aims of

(1) a study of point source variability, or

(2) an investigation of possible anisotropies in the
diffuse X-ray background, at short notice, depending on launch time and rocket motion. Motivation for these studies is discussed generally in Chapter 1.

The development of large thin window counters with markedly improved background rejection efficiency and adaptation of electronics to handle despun or spun up rockets are the only significant changes from earlier payloads. Ease of changing collimators on the detectors allows emphasis to be placed on a particular source, or a background survey.

Both V and VI rockets (SL728, SL 727 respectively) have spin rates about 3 revs. sec⁻¹ and UaT have no control of launch time. The detector details are summarized in tables (5.4), (5.5) with flight V incorporating one new T8 detector, plus NC counters similar to those on IV. Flight VI has two T8 detectors.

5.5.1 Corrections for Collimators

The fast spin rate implies small precession cone angles (table 2.1) and thus a large number of scans around a narrow band of the sky. Both rockets carry combination vertical-diagonal collimators to assist in source location (section 3.6). One side of the V-NC counter has a vertical collimator tilted 20° towards the rocket +OX axis to allow greater sky coverage. Response functions have been measured as described
### TABLE 5.4

**FLIGHTS V, VI  COLLIMATOR PROPERTIES**

<table>
<thead>
<tr>
<th>Detector Type (3.6.3)</th>
<th>Collimator</th>
<th>Spin Direction</th>
<th>Perp. Spin Dirn.</th>
</tr>
</thead>
<tbody>
<tr>
<td>V - NC A1 vertical</td>
<td></td>
<td>$\alpha_s (^\circ)$</td>
<td>$T_s (%)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.20</td>
<td>83.0</td>
</tr>
<tr>
<td>- NC A2 tilted (20°)</td>
<td></td>
<td>3.60</td>
<td>77.0</td>
</tr>
<tr>
<td>- T8 diagonal(33.5°)</td>
<td></td>
<td>4.50</td>
<td>84.5</td>
</tr>
<tr>
<td>VI - T8 A vertical</td>
<td></td>
<td>3.40</td>
<td>80.6</td>
</tr>
<tr>
<td>- T8 B diagonal(33.5°)</td>
<td></td>
<td>4.50</td>
<td>84.5</td>
</tr>
</tbody>
</table>

(*) see 5.5.1
### TABLE 5.5

**FLIGHTS V, VI DETECTION SYSTEMS**

<table>
<thead>
<tr>
<th>Detection System</th>
<th>Eff. area (cm²)</th>
<th>Window (mg cm⁻²)</th>
<th>Gas (20°C) (mg cm⁻²)</th>
<th>Bias Levels keV</th>
<th>Energy Res. FWHM (5.9keV)</th>
<th>Backg. Rej. Eff. V&lt;sub&gt;cr&lt;/sub&gt;</th>
<th>V(Co⁶⁰)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V- NC A1</td>
<td>442</td>
<td>0.91 (CH₄)ₙ</td>
<td>7.6, (P-10)</td>
<td>1.2, 3.5, 4, 6, 9</td>
<td>17.5%</td>
<td>.84</td>
<td>negligible</td>
</tr>
<tr>
<td>- NC A2</td>
<td>442</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>.84</td>
<td>&quot;</td>
</tr>
<tr>
<td>- NC B (Pulsar detector prepared by University of Adelaide)</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>- T8</td>
<td>349</td>
<td>0.91 (CH₄)ₙ</td>
<td>(7.6, (P-10) + guard 11.7)</td>
<td>1.2, 2.5, 4, 6, 9</td>
<td>17.5%</td>
<td>0.75*</td>
<td>0.75*</td>
</tr>
<tr>
<td>VI-T8 A</td>
<td>338</td>
<td>&quot;</td>
<td>as for V-T8</td>
<td>as for V-T8</td>
<td>as for V-T8</td>
<td>.93*</td>
<td>0.9*</td>
</tr>
<tr>
<td>- T8 B</td>
<td>349</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td></td>
</tr>
</tbody>
</table>

(* see 5.5.4)
in 4.4.6, table (5.4) summarizes the parameters of best fit triangles to the measured results. The maximum transmission $T_s$ and differences from the true response $\delta_s$ are incorporated into the effective window areas quoted in table (5.5). (In actual data analysis the spin direction triangle will be convolved with the telemetry sampling time as described in section 3.6). The data for best fit triangles in the direction perpendicular to the spin may not be required for these spun up rockets, with direct reference to the measured collimator response giving the desired information. This is given for the T8 vertical collimator in figure (4.8) and is shown for the two NC collimators in figure (5.5). As indicated in table (5.4) the tilted collimator is asymmetric about the peak which is $70^\circ$ from $+OX$. (The change in slope of measured points for angles $>40^\circ$ is due to the light beam intersecting the collimator outside wall and is not a real effect.)

The response of the diagonal collimators is given by equation (3.32a), and has been measured only in the spin direction. The collimator cell size is similar to that for the T8 vertical collimator, i.e. $w = 0.17$ ins; $l = 1.735$ ins; $d = 2.50$ ins and the measurement is in good agreement with (3.32a). The response along the collimator long axis, which is of interest here, is similar to that shown for the T8 vertical.
FIGURE 5.5: Calibration of NC Collimators. (a) NC Vertical response in Spin and Perpendicular directions. (b) ditto, NC Tilted (20° toward +Ox).
5.5.2 Effective Area

The effective areas of table (5.5) have been obtained from the total window areas by subtracting

1. the area blocked by the collimator housing (mainly in the region of end effects, 4.4.3)
2. the area blocked by reinforcing collimator plates and cross bars (assumed circular and close to the window)
3. the edge area of counter baffles if they do not coincide with collimator plates or bars.

The remainder is multiplied by $T_5$, the maximum transmission of the best fit triangle to the spin direction collimator response, and adjusted by the small percentage $\delta_5$ to account for the difference in area between the triangle and measured response. Note that a negative $\delta_5$ implies an underestimation of source intensity, and to account for this requires division of the measured rate by a smaller area. Correction for window obscuration by the T8 bay aperture and NC mounting rods must be included in the table (5.5) values, prior to use.

5.5.3 Calibration

The NC counters are calibrated, on command, with a "fail safe" ledex arrangement as described for the IV-NC detectors. In the T8 counters the guards are permanently irradiated with a small Fe$^{55}$ source (~400 cts/sec), as with the III-PR detectors. In this case each guard output is pulse height
analysed and continuously monitored on four low speed telemetry channels (four quarter channels) giving continuous inflight calibration of the counter. The guard bias levels are included in table (5.5).

5.5.4 Background Rejection

The $V_{cr}$ efficiencies are calculated using equation (3.29), with the exception that the flight V T8 counter $V_{cr}$ is adjusted to account for measured dead regions in the guard (see section 4.5). For the flight VI T8 counters the full $V_{cr}$ values are listed in anticipation of remedial measures presently being applied and tested in these counters.

As an indication of the effectiveness of rejection of nuclear collision induced background, the mean rejection efficiencies when counters are subjected to Co$^{60}$ gamma rays are included (see 4.4.7). Anticipated improvement in the T8 rejection efficiency is again included for the flight VI counters.

5.5.5 Launch

Flight V was successfully launched 09.07 hrs. UT, 16 Apr 1970. All counters, except NC-B appeared to have functioned normally except for a gain decrease caused by the detectors scanning over the sun (see 4.3.3). Data analysis is proceeding.
Flight VI was successfully launched 00.30 hrs. UT, 10 July 1970. Preliminary data indicates that both T8 counters functioned in the desired manner.
CHAPTER SIX
DISCUSSION OF ROCKET RESULTS

6.1 INTRODUCTION

While the nature of X-ray sources remains obscure, continuous re-appraisal of early results in the light of more recent (and sometimes more sophisticated) observations can place restrictions on interpretations arising from the latter, as is the case here.

6.2 LOCATION OF CENTAURUS XR-2

A history of the reported observations of Cen XR-2 is given by Harries (1968). This is extended in table (6.1), and the positional information emphasized. The different intensity measurements are compared and discussed more fully in section 8.4.3. There is a general overall tendency to decrease at both rocket (see also figure 5.3) and balloon energies strongly suggesting a common origin. A "reappearance" at rocket energies in Nov. 68 and an apparent conflict in the Jan-Feb. 1968 results of UCSD and Buselli may indicate a more complicated variation. (The
<table>
<thead>
<tr>
<th>Date</th>
<th>Group</th>
<th>Vehicle</th>
<th>Energy keV</th>
<th>Flux $\text{ergs cm}^{-2}s^{-1}$</th>
<th>Power Law</th>
<th>Collimator FWHM</th>
<th>Celestial Coord.</th>
<th>Galactic Coord.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>28Oct65</td>
<td>LRL(G)</td>
<td>RS</td>
<td>2-10</td>
<td>$\leq 2.1\times10^{-9}$</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13Dec66</td>
<td>Bowyer</td>
<td>RD</td>
<td>1.5-8</td>
<td>&quot;strong&quot;</td>
<td>-</td>
<td>-</td>
<td>&quot;within 10° of UAT&quot;</td>
<td>-</td>
</tr>
<tr>
<td>4Apr67</td>
<td>UAT</td>
<td>RD</td>
<td>2-8</td>
<td>1.5,0-7</td>
<td>1.15</td>
<td>10.5 x 35</td>
<td>208±6</td>
<td>63±3</td>
</tr>
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<td>10Apr67</td>
<td>LEIC</td>
<td>RD</td>
<td>2-5</td>
<td>1.6,0-7</td>
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<td>30 x 30</td>
<td>200±4</td>
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</tr>
<tr>
<td>20Apr67</td>
<td>UAT</td>
<td>RD</td>
<td>2-8</td>
<td>1.0,0-7</td>
<td>1.75</td>
<td>10.5 x 35</td>
<td>210±6</td>
<td>-6.5±3</td>
</tr>
<tr>
<td>18May67</td>
<td>LRL(C)</td>
<td>RS</td>
<td>2-8</td>
<td>2.6,0-8</td>
<td>2.8</td>
<td>10 x 30</td>
<td>201±5</td>
<td>-62±2.5</td>
</tr>
<tr>
<td>28Sep67</td>
<td>LRL(C)</td>
<td>RS</td>
<td>2-5</td>
<td>$\leq 3.1\times10^{-9}$</td>
<td>-</td>
<td>(vert &amp; diag)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>15Oct67</td>
<td>MIT</td>
<td>B</td>
<td>20-52</td>
<td>$\leq 4.1\times10^{-9}$</td>
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<td>13° circular</td>
<td>196.5±3</td>
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</tr>
<tr>
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<td>B</td>
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<td>2.6,0-9</td>
<td>-</td>
<td>17.5° &quot;</td>
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<td>-6.5±3</td>
</tr>
<tr>
<td>17Nov67</td>
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<td>S</td>
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<td>23° &quot;</td>
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<td>-</td>
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<tr>
<td>21Nov67</td>
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<td>S</td>
<td>10-30</td>
<td>$\leq 5.1\times10^{-9}$</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1Dec67</td>
<td>UAT</td>
<td>RD</td>
<td>2-8</td>
<td>$\leq 5.1\times10^{-9}$</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jan-Feb68</td>
<td>UCSD</td>
<td>S</td>
<td>10-30</td>
<td>$\leq$ thresh</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>29Feb68</td>
<td>Buselli</td>
<td>B</td>
<td>30-40</td>
<td>$\leq 7.1\times10^{-10}$</td>
<td>-</td>
<td>10 x 30</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12Jun68</td>
<td>LEIC</td>
<td>RD</td>
<td>2-5</td>
<td>$\leq 1.1\times10^{-9}$</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3Nov68</td>
<td>FRL</td>
<td>RS</td>
<td>2-20</td>
<td>1.5,0-8</td>
<td>1.2</td>
<td>8.7 x 17.2</td>
<td>201±2</td>
<td>-62.5±2</td>
</tr>
<tr>
<td>7Nov68</td>
<td>FRL</td>
<td>RS</td>
<td>2-20</td>
<td>2.3,0-8</td>
<td>0.9</td>
<td>8.7 x 17.2</td>
<td>201±2</td>
<td>-62.5±2</td>
</tr>
</tbody>
</table>

**IDENTIFICATION**

<table>
<thead>
<tr>
<th>Identification</th>
<th>RA</th>
<th>Dec</th>
<th>Galactic Coord.*</th>
</tr>
</thead>
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<tr>
<td>Cen B</td>
<td>202.95</td>
<td>-60.30</td>
<td>309.74 1.58</td>
</tr>
<tr>
<td>NGC 5189</td>
<td>202.50</td>
<td>-65.80</td>
<td>307.19 -3.53</td>
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<td>WX Cen</td>
<td>197.25</td>
<td>-63.12</td>
<td>305.26 -0.61</td>
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<tr>
<td>Kes 17</td>
<td>195.8</td>
<td>-62.4</td>
<td>-</td>
</tr>
</tbody>
</table>
sighting by Bowyer et al on 13 Dec. 1966, has been reported without evidence and, because of grave difficulties experienced by these authors in producing an attitude solution, also for reasons discussed below and in Chapter 8, is not accepted).

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6.2.1 Rocket Observations

The first four rocket sightings of Cen XR-2 in 1967 almost certainly refer to one and the same predominant object despite the scatter in reported locations. This is because no source of comparable intensity has been observed from this region (within $\sim 30^\circ$), before or since, and the time scale of the intensity decrease is in excellent agreement
with that of the only similar variable, Cen XR-4 (July 1969), (see figure 6.3). The alternative is that there are two or more normally unobservable but strongly flaring X-ray stars in the region with flare time scales < month, an unlikely one in view of the relatively stable behaviour of the majority of sources. Accepting that there is a single point source, the scatter in reported positions 4 Apr, 10 Apr, 20 Apr, 18 May, 1967, must represent systematic attitude errors greatly exceeding the quoted ones and the method of estimating errors must be questioned.

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(1) the gross features of the rocket motions, shown in figures (5.1, 5.2), are in agreement with BwC least squares solutions using data from standard three-axes magnetometers and four sets of sunslits, and quite independent UAT determinations from the same data.

(2) Confirmation of attitude solutions during portions of the flights come from X-ray sightings of the sun and Sco XR-1. For Sco XR-1 this requires that the statistical significance of the source count rate allows accurate determination in the scan direction and the rocket motion allows the determination "perpendicular" to the scan direction.
\textbf{TABLE 6.1}

\textbf{OBSERVATIONS OF CENTAURUS XR-2}

<table>
<thead>
<tr>
<th>Source</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>LRL(C)</td>
<td>Grader et al (1966)</td>
</tr>
<tr>
<td>Bowyer</td>
<td>Bowyer et al (1968)</td>
</tr>
<tr>
<td>UAT</td>
<td>this thesis, sections 5.2.4, 5.3.3</td>
</tr>
<tr>
<td>LRL(C)</td>
<td>Chodil et al (1968b)</td>
</tr>
<tr>
<td>MIT</td>
<td>Lewin et al (1968b),</td>
</tr>
<tr>
<td>UCSD</td>
<td>Peterson (1969)</td>
</tr>
<tr>
<td>Buselli</td>
<td>Buselli (1968)</td>
</tr>
<tr>
<td>PRL</td>
<td>Rao et al (1969a)</td>
</tr>
</tbody>
</table>

\textbf{RS} - spun up rocket  
\textbf{RD} - despun rocket (see 2.4.6)  
\textbf{B} - balloon  
\textbf{S} - satellite

\*b\textsuperscript{II} error is similar to dec. error, and l\textsuperscript{II} error is approximately half the r.a. error in this region.

\** for more accurate position see below.
<table>
<thead>
<tr>
<th>Date</th>
<th>Group</th>
<th>Vehicle</th>
<th>Energy keV</th>
<th>Flux erg cm(^{-2}) s(^{-1})</th>
<th>Power Law Index</th>
<th>Collimator FWHM</th>
<th>Celestial Coord.</th>
<th>Galactic Coord.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>28Oct65</td>
<td>LRL(G)</td>
<td>RS</td>
<td>2-10</td>
<td>&lt; 2.4 x 10(^{-3})</td>
<td>2.2</td>
<td>30 x 30</td>
<td>208.5 ± 6</td>
<td>63.5 ± 3</td>
</tr>
<tr>
<td>13Dec66</td>
<td>Bowyer</td>
<td>RD</td>
<td>1.5-8</td>
<td>&quot;strong&quot;</td>
<td>2.2</td>
<td>30 x 30</td>
<td>208.5 ± 6</td>
<td>63.5 ± 3</td>
</tr>
<tr>
<td>4Apr67</td>
<td>UAT</td>
<td>RD</td>
<td>2-8</td>
<td>1.5 x 10^7</td>
<td>1.2</td>
<td>10.5 x 35</td>
<td>210.5 ± 6</td>
<td>64.5 ± 3</td>
</tr>
<tr>
<td>10Apr67</td>
<td>LEIC</td>
<td>RD</td>
<td>2-5</td>
<td>1.6 x 10^7</td>
<td>1.75</td>
<td>10.5 x 35</td>
<td>210.5 ± 6</td>
<td>64.5 ± 3</td>
</tr>
<tr>
<td>20Apr67</td>
<td>UAT</td>
<td>RD</td>
<td>2-8</td>
<td>1.0 x 10^7</td>
<td>1.75</td>
<td>10.5 x 35</td>
<td>210.5 ± 6</td>
<td>64.5 ± 3</td>
</tr>
<tr>
<td>18May67</td>
<td>LRL(C)</td>
<td>RS</td>
<td>2-8</td>
<td>2.6 x 10^8</td>
<td>2.8</td>
<td>10 x 30</td>
<td>201 ± 5</td>
<td>62.5 ± 3</td>
</tr>
<tr>
<td>28Sep67</td>
<td>LRL(C)</td>
<td>RS</td>
<td>2-5</td>
<td>&lt; 2 x 10^−9</td>
<td></td>
<td>10 x 30</td>
<td>201 ± 5</td>
<td>62.5 ± 3</td>
</tr>
<tr>
<td>15Oct67</td>
<td>MIT</td>
<td>B</td>
<td>20-52</td>
<td>&lt; 4 x 10^−9</td>
<td></td>
<td>10 x 30</td>
<td>201 ± 5</td>
<td>62.5 ± 3</td>
</tr>
<tr>
<td>24Oct67</td>
<td>MIT</td>
<td>B</td>
<td>20-52</td>
<td>2.6 x 10^9</td>
<td></td>
<td>10 x 30</td>
<td>201 ± 5</td>
<td>62.5 ± 3</td>
</tr>
<tr>
<td>17Nov67</td>
<td>UCSD</td>
<td>S</td>
<td>10-30</td>
<td>5.2 x 10^−9</td>
<td>1.44</td>
<td>230°</td>
<td></td>
<td></td>
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<tr>
<td>21Nov67</td>
<td>UCSD</td>
<td>S</td>
<td>10-30</td>
<td>5.2 x 10^−9</td>
<td>1.44</td>
<td>230°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan-Feb68</td>
<td>UCSD</td>
<td>S</td>
<td>10-30</td>
<td>&lt; thresh</td>
<td></td>
<td>10 x 30</td>
<td>201 ± 5</td>
<td>62.5 ± 3</td>
</tr>
<tr>
<td>29Feb68</td>
<td>Buselli</td>
<td>B</td>
<td>30-40</td>
<td>&lt; 7 x 10^−10</td>
<td></td>
<td>10 x 30</td>
<td>201 ± 5</td>
<td>62.5 ± 3</td>
</tr>
<tr>
<td>12Jun68</td>
<td>LEIC</td>
<td>RD</td>
<td>2-5</td>
<td>&lt; 1 x 10^−9</td>
<td></td>
<td>10 x 30</td>
<td>201 ± 5</td>
<td>62.5 ± 3</td>
</tr>
<tr>
<td>3Nov68</td>
<td>PRL</td>
<td>RS</td>
<td>2-20</td>
<td>1.5 x 10^8</td>
<td>1.2</td>
<td>8.7 x 17.2</td>
<td>201 ± 2</td>
<td>62.5 ± 3</td>
</tr>
<tr>
<td>7Nov68</td>
<td>PRL</td>
<td>RS</td>
<td>2-20</td>
<td>2.3 x 10^8</td>
<td>0.9</td>
<td>8.7 x 17.2</td>
<td>201 ± 2</td>
<td>62.5 ± 3</td>
</tr>
</tbody>
</table>

**IDENTIFICATION**

- Cen B  
- NGC 5189  
- WX Cen  
- Kes 17
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(3) For both Sco XR-1 and Cen XR-2, the high count rates and precessing motion on both flights permitted location to within 1-3° relative to the rocket axes.

(4) The final attitude solutions gave good agreement in the independent assessments of the Cen XR-2 position, and of course were forced to fit the sun and Sco XR-1 X-ray positions. Fortunately the Cen XR-2 sightings occurred at times close to either a Sco XR-1 or sun sighting on all occasions.

(In addition flight II gives excellent agreement with reported positions of other galactic X-ray sources, see section 6.3, below).

The April 10, data of Leicester University were also obtained from a despun Skylark rocket launched from Woomera, and the following comments can be made:

(1) The rocket was launched at night and attitude was determined with reference to only the magnetometers of the standard instrumentation, plus an horizon sensor in an accompanying experiment (B. Cooke, private communication).

(2) The 30° x 30° collimator is far from ideal for a positional determination, and while a strong source such as Cen XR-2 (10 Apr, 1967) would allow a reasonably accurate statistical fit to the collimator response function in the scan direction, in general it is very difficult to eliminate contamination from other sources. A large count rate
discontinuity at the horizon, a result of the large sensitivity to diffuse X-rays with this collimator, is also capable of confusing results.

(3) Sco XR-1, which along with the sun provided an accurate inflight attitude calibration on the UAT flights, was on the horizon. Its position could be gauged accurately only if there were scans parallel to the horizon (and thus only in galactic latitude). Although Tau XR-1 was sighted on three separate occasions it was also near the horizon and in any case the statistical accuracy of peak response location (with this weaker source) would be considerably worse than for Sco XR-1 or Cen XR-2.

The LRL data of May 18, represent a markedly different situation with respect to attitude solution. The rocket had negligible precession and high spin rate, \( \sim 5 \text{ rev sec}^{-1} \). The X-ray detectors made a large number of scans around the horizon during which time the galactic disc from Scorpius - Centaurus, through Vela to Taurus arced above the horizon (forming an angle of about 20° with the horizon). Aspect determination is considerably simplified from the despun case. It can be determined from a magnetometer giving the spin rate, and phased relative to the sightings of known strong X-ray sources. The solution is assisted by crossed X-ray collimators, giving a measure of the elevation of the
stronger sources off the (rocket) horizon.

Points relevant to the present discussion are:

(1) In order to obtain a significant number of counts from weaker sources all scans are superposed giving a single count rate profile per detector for the whole flight. For this flight peaks due to both Sco XR-1 and Tau XR-1 provided phasing information.

(2) The Cen XR-2 peak obtained from the superposition is unresolved from nearby sources, despite a similar collimator FWHM to UaT. This is a result both of the angle of the scans to the galactic disc (giving poorer resolution to sources distributed in galactic longitude than scans along the disc) and the very much reduced Cen XR-2 intensity relative to contaminating sources. Some subjective judgment is required on the relative intensities and positions of sources near Cen XR-2, particularly since one of them Cen XR-3, has only been reported on this flight.

In all four cases it appears as if there are ambiguities and uncertainties capable of explaining the scatter in observed location. The discussion tends to favour the UaT results on the grounds of good statistical location of the Cen XR-2 count rate peak with a minimum of confusion due to known sources, a check of the attitude solutions in the periods of interest, and the good agreement between the two independent solutions. Possibly the greater access to UaT
data contributes to this bias, but in any case the more accurate assessment of Cen XR-2 galactic longitude, described below does not depend on a choice between these alternate positions or attitude solutions.

The other rocket flights mentioned in table (6.1) were made by PRL, 3 Nov, 7 Nov, 68. Both represent situations practically the same as LRL in regards rocket motion and altitude determination, with the exception that there were no crossed collimators (and in which case the small declination errors are surprising). The requirement for the observed count rate deviation to be due to the same source as the apr. 67 one is far less demanding.

6.2.2 Balloon and Satellite Observations

The MIT balloon flight on 15 Oct, 1967, represents the best positional determination for the source observed at energies above 10keV. This flight has both a smaller field of view and better counting statistics than later ones (the latter being partly due to maximum observed source intensity on this date). The attitude determination, done with reference to a magnetometer and sun sensor is claimed to give the direction of telescope axes to within 1° throughout the flight for the 15 Oct. case, and presumably Sco XR-1 X-rays provided an inflight attitude check. These factors plus the agreement with position determined on the 24 Oct 67, MIT
6.2 balloon flight give considerable weight to the location reported by MIT for the high energy object.

The statistics for the Buselli sighting do not allow an accurate positional determination (G. Buselli, private communication) and this is possibly also the case for the UCSD results, (OSO III) which quote the MIT position but give no discussion or errors.

6.2.3 Identification

Identification with optical or radio objects is greatly hampered by the proximity of the source or sources to the galactic plane. Nevertheless table (6.1) includes the positions of four prominent objects in the region. Cen B is a strong radio source regarded by Shklovsky as a supernova remnant 185 (Poveda and Woltjer, 1968); Kes 17 is a non thermal radio source, a possible supernova remnant, Milne (1970). The optical objects in planetary nebula NGC 5189, and WX Cen were suggested as identifications of Cen XR-2 by Feast (1967), Blanco et al (1968), and Eggen et al (1968) respectively.

6.2.4 Cen XR-2 (Apr.67) Galactic Longitude

Flight II offers a unique opportunity of determining the galactic longitude of Cen XR-2. Accepting figure (5.2) as a reasonable representation of a rocket motion it can be seen that there are several scans essentially parallel to the galactic disc in this region, and many of these also pass
The approach employed here is to use the approximate attitude solution to predict the single scan count rate profiles expected from Sco XR-1 plus a single point Cen XR-2 source at the various positions quoted in table (6.1). These are compared directly with the observed "raw" count rates. Second order effects due to the incorrect attitude solution and contamination by known weak sources are allowed for in the interpretation of the compared results.

Figure (6.1) shows a series of 11 consecutive scans by detection system A over the region of interest. These have been obtained from the attitude solution as follows; the galactic co-ordinates of the directions in the rocket XZ plane (remembering that OX is the spin axis and ± OZ the detector axes), at 0°, ± 15°, ± 30° from the −OZ(A) axis have been evaluated and plotted every 0.1 seconds of the scan. (With a mean spin period of 12.55 seconds during this part of the flight, this corresponds approximately to every 2.87° of galactic longitude). The time of maximum response to a given source within the 70° full width of the collimator long field of view can then be predicted to an accuracy of about .01 seconds. This is illustrated in figure (6.1) for only two short periods of scan 21, where the dashed lines were obtained by joining the 0°, ± 15°, ± 30° points by a smooth curve. Open circles show the various Cen XR-2 positions (the
FIGURE 6.1: Positions of Cen XR-2. Eleven scans of Flight II detector A giving accurate position of Cen XR-2 relative to Sco XR-1. Dashes are collimator long axis each 0.1 seconds of scan 21.
UT mean position, section 5.2.4, is used). Closed circles indicate other sources. As in figure (5.2), the circle size is a rough indication of source intensity.

Columns (3)-(5) of table 6.2(a) list the predicted times of sightings of Sco XR-1, and the Cen XR-2 positions of UAT and MIT (the extremes in galactic longitude). Also included in brackets are the angular separations of the source positions from the predicted scan paths at the time of sighting.

The times of occurrence of count rate peaks, obtained from the least squares fitting technique of Appendix B, are given in columns (6), (7) of table 6.2(a). Note that the fitting of the triangular collimator response has been restricted to scans for which the source position lies within the FWHM ($\alpha_p = 35^0$) of the collimator long axis, and that for reasons discussed in 5.2.1 the statistical significance of detector B results are generally inferior to those collected with A.

The differences between the count rate peak times and predicted peak times are collected into table 6.2(b). The errors combine the standard deviations in the count rate peak position and the estimated $\pm 0.01$ second predicted response. Apart from a tendency to increase near the end of the flight (perhaps associated with gradual re-entry) the differences indicate no obvious systematic trends and the consistency of
### Table 6.2(a)

**Flight II Times of Source Maximum Response**

<table>
<thead>
<tr>
<th>Scan</th>
<th>Detector</th>
<th>Predicted from Attitude Solution</th>
<th>Count Rate Peak Time ($\pm \sigma$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sco XR-1</td>
<td>Cen XR-2: UAT</td>
</tr>
<tr>
<td>16</td>
<td>A</td>
<td>273.20 ($-20^\circ$)</td>
<td>273.41</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>279.40 ($-17^\circ$)</td>
<td>279.68</td>
</tr>
<tr>
<td>17</td>
<td>A</td>
<td>285.76 ($-13^\circ$)</td>
<td>285.97</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>292.04 ($-9^\circ$)</td>
<td>292.24</td>
</tr>
<tr>
<td>18</td>
<td>A</td>
<td>298.32 ($-5^\circ$)</td>
<td>298.51</td>
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<tr>
<td></td>
<td>B</td>
<td>304.60 ($-1^\circ$)</td>
<td>304.78</td>
</tr>
<tr>
<td>19</td>
<td>A</td>
<td>310.86 ($2^\circ$)</td>
<td>311.05</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>317.13 ($6^\circ$)</td>
<td>317.32</td>
</tr>
<tr>
<td>20</td>
<td>A</td>
<td>321.74 ($-18^\circ$)</td>
<td>323.40 ($10^\circ$)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>328.01 ($-15^\circ$)</td>
<td>329.67 ($14^\circ$)</td>
</tr>
<tr>
<td>21</td>
<td>A</td>
<td>334.30 ($-13^\circ$)</td>
<td>335.90 ($17^\circ$)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>340.57 ($-10^\circ$)</td>
<td>342.16 ($20^\circ$)</td>
</tr>
<tr>
<td>22</td>
<td>A</td>
<td>346.84 ($-7^\circ$)</td>
<td>348.41 ($24^\circ$)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>353.10 ($-5^\circ$)</td>
<td>354.230 $\pm$ 0.013</td>
</tr>
<tr>
<td>23</td>
<td>A</td>
<td>359.36 ($-3^\circ$)</td>
<td>360.91 ($-1^\circ$)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>365.62 ($-1^\circ$)</td>
<td>366.310 $\pm$ 0.012</td>
</tr>
<tr>
<td>24</td>
<td>A</td>
<td>371.85 ($2^\circ$)</td>
<td>373.45 ($3^\circ$)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>378.09 ($3^\circ$)</td>
<td>379.500 $\pm$ 0.014</td>
</tr>
<tr>
<td>25</td>
<td>A</td>
<td>384.33 ($5^\circ$)</td>
<td>386.89 ($7^\circ$)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>390.57 ($7^\circ$)</td>
<td>392.050 $\pm$ 0.013</td>
</tr>
<tr>
<td>26</td>
<td>A</td>
<td>396.81 ($10^\circ$)</td>
<td>402.05 ($12^\circ$)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>403.05 ($12^\circ$)</td>
<td>RF - Recording Failure</td>
</tr>
</tbody>
</table>
TABLE 6.2(b)

PREDICTED TIME MINUS COUNT RATE PEAK TIME

<table>
<thead>
<tr>
<th>Scan</th>
<th>Detector</th>
<th>Sco XR-1</th>
<th>Cen XR-2 (UAT)</th>
<th>Cen XR-2 (MIT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>A</td>
<td>-0.04 ± 0.02</td>
<td>+0.24 ± 0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>+0.01 &quot;</td>
<td>+0.22 &quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>+0.03 &quot;</td>
<td>+0.23 &quot;</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>A</td>
<td>-0.01 &quot;</td>
<td>+0.18 &quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>+0.06 &quot;</td>
<td>+0.24 &quot;</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>A</td>
<td>+0.05 &quot;</td>
<td>+0.24 &quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>+0.03 &quot;</td>
<td>+0.21 &quot;</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>A</td>
<td>+0.05 &quot;</td>
<td>+0.25 &quot;</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>(Gal. Centre)</td>
<td>-0.03 &quot;</td>
<td>+0.17 &quot;</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>A</td>
<td>+0.06 ± 0.02</td>
<td>+0.02 &quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>+0.06 ± 0.02</td>
<td>(outside FWHM)</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>A</td>
<td>+0.05 ± 0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>R.F.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>A</td>
<td>+0.05 ± 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>+0.01 ± 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>A</td>
<td>+0.03 ± 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>+0.09 ± 0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>A</td>
<td>+0.07 ± 0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>+0.07 ± 0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>A</td>
<td>+0.09 ± 0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>weighted mean</td>
<td>+0.044 ± 0.004</td>
<td>+0.017 ± 0.006</td>
<td>+0.220 ± 0.006</td>
</tr>
</tbody>
</table>
the values is emphasized in figure (6.2). This shows the
detector A raw count rate histograms along with the collimator
response best fits to the Sco XR-1, Cen XR-2 peaks. The times
of predicted response are clearly indicated. For each source
position the weighted mean of the differences of table 6.2(b)
have been obtained and are included in the table.

In the case of Sco XR-1, the mean difference is +.044
seconds. This is not entirely due to the errors in attitude
solution. For example using the source positions and
intensities for the galactic centre region given by Mayer
et al (1970), then for scan 21a the contribution of the
Sagittarius and Scorpius sources to the anticipated Sco XR-1
peak results in a slight broadening and a shift in mean
position -.015 seconds. Inspection of figure (6.1) shows
how this shift towards the Sagittarius sources tends to
persist even as the relative Sco XR-1 intensity increases,
since the contribution by the other Scorpius sources
quickly diminishes. Accepting a -.015 ± .007 second shift as
encompassing this "second order" source contamination
effect, leaves an attitude solution error along the scan
direction of

+.029 ± .008 seconds.

This implies that the U.T Cen XR-2 position used in the
analysis, i.e. with l II = 310.5°, is in error by the angle
swept out by the rocket in (.029 - .017) = .012 ± .010 secs.
FIGURE 6.2: Count Rate profiles corresponding to Scans 16–24 of Figure (6.1). Least squares fits to Sco XR-1, Cen XR-2 peaks are compared to peak positions predicted from both UAT, MIT source positions.
Since the scan paths are very nearly parallel to the galactic disc in the region and (certainly for scan 19) move at 
$\frac{360}{12.55} = 28.7^\circ$ of galactic longitude sec$^{-1}$ in the 
direction of decreasing longitude, this implies a Cen XR-2 
(Apr. 67) position of

$$l_{\text{Cen XR-2 (Apr. 67)}}^{\text{II}} = 310.0 \pm 0.3^\circ$$ \hspace{1cm} (6.1)

The MIT position with $l = 304.9 \pm 1.5^\circ$ is clearly 
excluded, as was obvious from the raw count rate data of 
figure (6.2). Accepting the MIT position for the object 
detected in hard X-rays, presumably the same object as that 
seen by UCSD (Nov. 67) and Buselli (Feb. 68), implies that 
these hard X-rays come from a quite different region of 
space than Cen XR-2 (Apr. 67), i.e. Cen XR-2 (Apr. 67) and 
Cen XR-2 (Oct. 67) are different objects despite similarities 
in behaviour with respect to variability.

Error bars on the LRL position very nearly overlap 
those in equation (6.1). The direction of LRL scans does not 
permit good resolution of their Cen XR-2 position and the 
UAT one, and a small error in their determination of the 
source separation from the scan plane would reduce the 
differences in galactic longitude. The position of the 
Cen XR-3 source, reported by LRL and unresolved from their 
Cen XR-2 peak, was scanned and resolved on flight II. The 
published intensity of $0.7 \times$ counter efficiency (2.1-9.5 keV)
can be meaningfully applied to the UAT counters which have practically identical window-gas combination. Count rate data within a FWHM of the predicted peak time for Cen XR-3 were added for six scans 18 A,B, 19 A,B, 20 A,B giving a total of 70 counts compared with the expected background rate of $59.2 \pm 2$ counts (derived from $\sim 20$ seconds of data away from known X-ray sources). In the observation time, the measured rate exceeds the mean background rate by just over 1σ, which is not considered significant. Using the LRL intensity a total of $\sim 100$ counts would have been expected, i.e. a significant $3\sigma$ response. These data indicate that Cen XR-3, if it exists, is weaker (or was weaker on 20 April, 1967) than reported by LRL. Cooke et al (1969) report the suggestion of a source at this longitude but $b^{\prime\prime} \approx -15^\circ$, not incompatible with UAT results, but still implying an incorrect extraction of LRL Cen XR-2 data.

The Leicester position error bars do not overlap the flight II longitude, even though there is no doubt that both flights saw the same strong source. As already mentioned, it is not difficult to imagine systematic errors in attitude solution within the limits of published information which could explain the difference. A similar uncertainty can be considered in the case of the PRL data, though it is equally likely that Cen XR-2 (Nov.68) is associated with the MIT object.
The identification of Cen XR-2 (Apr.67) can be definitely excluded in the cases of Kes 17, WX Cen and NGC 5189, but not in the case of Cen B. Cen B is at the limit of the UAT error bars in the $b^\parallel$ direction ($\sim 3^\circ$). There are no data on the variability of radio emission, though observations over more than 10 years at a variety of frequencies have seen the source as strong. Hamilton and Haynes (1968) by comparing the 10MHz intensity with earlier high frequency measurements conclude that Cen B is $< 2.3$ kpc from the solar system. Note that the identification of MIT's Cen XR-2 (Oct.1967) with WX Cen is still a possibility.

6.3 MODELS OF CEN XR-2

6.3.1 Cen XR-4 (Jul 69)

Interest in Cen XR-2 has been revived not only by the unexpected MIT and PRL reports but also by the observations from Vela satellites 5a, 5B of the sudden appearance and gradual disappearance of Cen XR-4. Figure (6.3) is reproduced from Evans et al (1970) showing the behaviour of Cen XR-4 as monitored by the 3-12 keV scintillators, each with two channel pulse height analysis. The times of two independent observations of Cen XR-4, discussed below, are included. The intensity variation of Cen XR-2 is directly compared with the Cen XR-4 count rate data by Evans et al by normalizing to the
peak count rate; the resulting crosses show striking agreement with the Cen XR-4 count rates. Included also is a measure of the relative behaviour of a hardness ratio for Cen XR-2, obtained by integrating the best fit spectra (figure 5.3) between 2-5 and 5-8 keV and plotting the ratio of high to low energy fluxes. Because of the markedly different spectral responses of the different detectors, no attempt is made to normalize to the Vela hardness ratio. It is tempting to attribute both sources to a common astrophysical process, but first differences in the reported behaviour must be discussed.

The spectral information on Cen XR-2 comes from LRL, 18 May, 67. Their data, like that of UAT, are fitted by any of the forms given in equations (1.4), (1.5), (1.8), however the power law dependence gives the best fit. The MIT and PRL spectra are also both more compatible with a power law but as seen above, do not necessarily refer to the same object. The obvious contamination of the LRL data by other peaks may have influenced the spectral shape, particularly if contaminating spectra were markedly different from that of Cen XR-2. Cen XR-4, on the other hand, was observed by rocket on 7 Aug, 69 by Kitamura et al (1969) who report an exponential shape practically identical to that of Sco XR-1, observed on the same flight. If their characteristic temperature (kT=7keV) was obtained using a simple exponential
without Gaunt factor (see equations 1.5, 1.6) then this is an unusually high temperature for Sco XR-1 and the data cannot be simply extrapolated to explain the balloon results of Thomas et al (1969), taken on 25 Aug.69, a much softer spectrum being required. The apparent conflict between the three sets of data is very likely systematic in origin, but may indicate a high energy cut-off or break in the Cen XR-4 spectrum, or a spectral variability in a time short c.f. 3 days, the interval between successive Vela sightings.

While the April-May 1967 data show that Cen XR-2 is decidedly "non-isothermal", an isothermal character is indicated by the Vela data for Cen XR-4 after the first week. Criticism might be levelled at the comparison of UAT and LRL temperatures particularly with the possibility of source contamination affecting the LRL data, and it could be argued that the temperature of Cen XR-2 changed sharply about 4 Apr.67 and only slowly afterwards. By comparison with Cen XR-4 this implies a Cen XR-2 age of only a week or so on 4 Apr.

Evans et al see a similarity between the intensity decrease in Cen XR-4 and the light output from nova of the DQ Herculis type. The light intensity decreases a mean of 0.25 - 0.30 magnitudes per day until 60 to 120 days after onset, when a much sharper decay occurs to a deep minimum. There is then a second increase to a reduced maximum
followed by a slow decay and Evans et al point to the MIT and PRL observations of a reappearance of Cen XR-2 as evidence of this behaviour. As seen above, this is certainly not the case if these X-rays originate in the MIT, PRL positions. (Also, the intensity decrease of Cen XR-4 appears in fact to be very nearly linear with time, and the implications of this are mentioned below). There is no object similar to the radio source Cen B within 10° of Cen XR-4.

6.3.2 Models of Cen XR-2 (Apr 67), Cen XR-4 (Jul 69)

The model of Cen XR-2 which has received most prominence is a highly idealized one, requiring the expansion and cooling of a thin hot plasma (Manley, 1967, Chodil et al 1968, Edwards 1968, Harries 1968). In brief the spectral and intensity data for 4 Apr, 20 Apr and 18 May, 1967, are used in equation (1.6) to obtain a temperature T, and emission measure $n_e^2 V/d^2$ (assuming a hydrogenic plasma), on each date. Assuming a constant mass plasma ($n_e V = \text{const.}$) at fixed distance from the solar system implies that the measured fluxes depend only on T, and the inverse of the volume, $V^{-1}$. Manley assumed an isothermal source so that for a constant expansion velocity (assumed to be the velocity of sound in the plasma, $V \sim 5,000$ cm sec$^{-1}$) the measured flux from a spherical plasma is proportional to $t^{-3}$, t in seconds.
The other authors incorporate the measured temperatures to arrive at essentially the same result, i.e., a plasma radius expanding from $\sim 3.10^{14}$ cm on 4 Apr 67 with $t^3$ dependence. A doubling of the plasma volume between 4 Apr. and 18 May then implies an age on 4 Apr of about 4 months, the cooling implies a flux change slightly slower than in $t^{-3}$. By comparing the total radiated bremsstrahlung, from (1.6),

$$\frac{dE}{dt} = 1.43_{10} - 27 \ n_e^2 T^2 V \ \text{ergs/sec},$$

with the thermal energy content of the plasma

$$E = 3 n_e k T V = 4.14_{10} - 16 n_e T V \ \text{ergs},$$

then gives a measure of $n_e$. Harries uses the measured values of $T$, $V$ to obtain $\gamma$ in the expression $TV^{\gamma-1} = \text{const}$. In an adiabatic expansion of spherically symmetric particles, $\gamma = 1.67$ and the measured 2.1 is taken to indicate 39% of the cooling is due to radiated photons, the rest to expansion. This gives $n_e \sim 9_{10} 7 \ \text{cm}^{-3}$. Using $n_e V$ in $n_e^2 V/d^2$ implies a distance $d = 0.5 \ \text{kpc}$.

Edwards comments on the difficulty in maintaining steady gas expansion through gravitational constraint at the high temperatures and goes on to suggest heating of a gas envelope by an adiabatic strong shock moving radially outwards. To fit the Cen XR-2 data requires conservation of the quantity $(n_e^2 V/T)$ during expansion, and this is constant for a shock propagating into a non uniform gas density $n$, varying as $(\text{radius})^{-2}$. The X-radiation is shown to originate in a thin
shell of thickness $\Delta R \sim R/4$, where $R \propto t^{2/3}$ is the radius of
the shock front. As above, this model gives $R \sim 3.0 \times 10^4$ cm on
4 Apr but at this time the source is only about two weeks old
and the intensity suggests a distance of 0.3 kpc.

Finally Manley (1968) combines the uniform expansion
(approximately isothermal) with a shock wave model to
explain the cool (Apr - May 67) and delayed hot (Oct 67)
Cen XR-2 radiation respectively. Since the evidence above
strongly suggests that these two sources are spatially
resolved, this elaborate hypothesis does not appear to be
required as yet.

A criticism affecting all of these hot plasma models
relates to the expected optical luminosity. The Edwards
model is based on the behaviour of recurrent nova, and he
predicts an optical outburst of 4th magnitude in March-April
1967. The other models are also suggestive of nova and an
ejected plasma at the suggested temperatures should be
highly luminous. The lack of observation of optical nova in
the vicinity of Cen XR-2 has been excused on the basis of
possible obscuration by dust since this is in the direction of
the local spiral arm. If Cen XR-4 is taken as a second
example of the process, the further lack of optical activity
(particularly in view of the 20° separation off the galactic
disc in this case) throws some doubt on the nova models.
(The tacit assumption is that a nova outburst would have been
detected, either directly or by subsequent comparison of optical plates of the respective regions).

A striking feature of the count rate behaviour of Cen XR-4, pointed out by Evans et al, is the marked deviation from a simple $t^{-n}$ dependence, required by the simple models above. For the nova models to survive (and the similarity of the Cen XR-4 variation to date, with the DQ Herculis type novae deserves further investigation), more convincing evidence for the lack of observed optical activity is required. As well, more complicated models for X-ray emission are necessary. For example some self absorption in the source might immediately explain some of the observed features, such as the initial change in hardness ratio of Cen XR-4. (As pointed out by Manley, a plasma with the mass associated with the Cen XR-2 model, when compressed to within a radius $\sim 10^{14}$cm, can no longer be considered optically thin).

Prompted by the non luminous character of Sco XR-1, Prendergast and Burbidge (1968) develop the model for plasma heating by mass accretion between binary members of an old nova, as discussed in 1.6.2. They suggest that the Cen XR-2 variability might be the result of a large variation in the mass transfer between the members. Despite possible difficulties with optical thickness as pointed out by Manley
and Olbert (1969), mass accretion between members of a binary pair has some attractive features, for example the count rate behaviour of Cen XR-4 is very nearly linear with time, as might be anticipated from the eclipsing of an emitting region. Temperature variations may occur with a non-isothermal emitting region (e.g. Cen XR-2). The Cameron (1969) accretion model, comprising an optically thick ring of matter about a white dwarf would exhibit similar properties. Such X-ray sources might be expected to reappear when the system is suitably oriented and sufficient accretion occurs.

Models in which X-rays are emitted from a cooling neutron star can be criticized on similar grounds to the nova models, though more severely. A neutron star is expected to result from a super nova explosion the optical and radio evidence for which would almost certainly have been reported. Also, a neutron star cools principally by neutrino emission and Wolf (1966) gives the temperature T at time t (secs) after an initial very high temperature ($\gtrsim 10^{10}$K) in the form $T \propto t^{1/6}$ K. Harries has shown the Cen XR-2 intensity data (including the 28 Sept 67 upper limit) to be incompatible with neutron star cooling and this is even more evident for Cen XR-4.

The spectral shape and time dependence of X-rays resulting from the injection of a variety of electron spectra into a magnetic field, impulsively at $t = 0$ or at some later
6.3 time, or continuously, or at variable rate, are considered by Tucker (1967). Situations encompassing Fermi acceleration of the electrons and expansion of a tenuous plasma containing the field are also considered. For example injection of an electron spectrum \( \frac{dN}{dE} = kE^{-n} \) electrons cm\(^{-2}\) sec\(^{-1}\) keV\(^{-1}\) at \( t = 0 \), gives a photon spectrum

\[
\frac{dN}{d(h\nu)} \propto \begin{cases} 
(h\nu)^{1-n/2} & , \nu < \nu_b \\
\nu^{-n/2} \left( h\nu \right)^{-2n+1} & , \nu \gg \nu_b
\end{cases}
\]

where \( \nu_b = 1.1 \times 10^{9} \) Hz, and electrons lose energy by synchrotron radiation alone. Here \( H \) (gauss) is the mean magnetic field strength, and \( t \) is measured in years. Harries (using the above equations close to \( \nu_b \)) obtains good agreement with the Cen XR-2 data using \( H \sim 10^{-3} \) gauss, \( n = 3.3 \), and an age on 4 Apr 67 of \( \sim 3 \) weeks. The "temperature" change is a result of \( \nu_b \) moving through the observed frequency range between 4 Apr and 18 May. Obviously a system can be engineered to fit the Cen XR-4 data, for example the energy loss rate can be adjusted by an increasing magnetic field due to a plasma contraction, or by an electron acceleration process similar to that described by Manley and Olbert (1969), see 1.6.2. Without more intimate knowledge of the astrophysical situations which give such conditions, a detailed analysis is not warranted.
6.4. CYGNUS - SERPENS SOURCES

As mentioned in 1.6.3 some controversy still exists on the variability of sources in the Cygnus and galactic centre regions. The flight II scans, used above to obtain an accurate Cen XR-2 position, also passed along the galactic plane from Cassiopeia (on the horizon), through Cygnus to the galactic centre (see figure 5.2). The convergence and intersection of the scans permits sufficient superposition to imply significant responses from anticipated weak sources. The galactic centre sources and a group in Cassiopeia-Cepheus are unresolved by the 10.5° collimator FWHM, and the discussion is therefore restricted to galactic longitudes

\[ 20^0 < l^{II} < 100^0 \]

The Cygnus sources are also unresolved by the collimator; however resolution is assisted by early scans which pass over the Cygnus region in a direction perpendicular to the plane, and by the fact that Cyg XR-1, Cyg XR-2 are resolved in both directions and have always been reported to be much more intense than others nearby. The results for this flight can be meaningfully compared with more accurate surveys of the region.

6.4.1 High Resolution Surveys

By far the most accurate and comprehensive survey of the galactic disc in this longitude range to date, was made
from rocket by American Science and Engineering (ASE) on 11 October 1966. (Giacconi et al. 1967, Gorenstein et al. 1967, Gursky et al. 1967). Detectors with vertical and tilted $1^\circ \times 4.0^\circ$ FWHM collimators (3.6.1) were scanned slowly along the galactic plane from Scorpius to Cygnus, and manoeuvred in a complex but controlled fashion over the Cygnus region. Attitude to within $\sim 2'$ arc was provided by 1 sec interval photographs of the star field. Proportional counters with beryllium windows of nominally the same thickness as used by UAT allow comparison of the relative count rates of sources with those obtained on flight II. Large window area (\~800 cm$^2$) and relatively long observing time imply good counting statistics.

Only six sources were detected in $20^\circ < \alpha < 90^\circ$ and within about $\pm 15^\circ$ of the galactic disc, these are given in table 6.3. Sources not observed but previously reported in surveys with inferior angular resolution include Cyg A, Cyg XR-4 and Vul XR-1 (see Giacconi et al. 1967). With intensities at upper limits set by Giacconi et al, these would not have been observable on flight II and are not considered further.
### TABLE 6.3

**POSITION AND INTENSITY OF ASE(11OCT66) CYGNUS-SERPENS SOURCES**

<table>
<thead>
<tr>
<th>Source</th>
<th>Position I (degrees)</th>
<th>Position II (degrees)</th>
<th>Intensity (2-5 keV)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>GX+36.3</td>
<td>36.3 ± 0.2</td>
<td>9 ± 8</td>
<td>0.15</td>
<td>ScoXR-1 (Friedman et al, 1967)</td>
</tr>
<tr>
<td>GX+48.7</td>
<td>48.7 ± 0.2</td>
<td>0 ± 15</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>Cyg X-1</td>
<td>71.4*</td>
<td>3.1*</td>
<td>0.40</td>
<td>CygXR-1 (&quot;&quot;&quot;&quot;)</td>
</tr>
<tr>
<td>Cyg X-3</td>
<td>80.0*</td>
<td>0.7*</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Cyg X-4</td>
<td>82.9*</td>
<td>-6.4*</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Cyg X-2</td>
<td>87.4*</td>
<td>-11.3*</td>
<td>0.36</td>
<td>CygXR-2 (&quot;&quot;&quot;&quot;)</td>
</tr>
</tbody>
</table>

(*errors ± 20', see Giacconi et al, 1967)

(** Friedman, gives \( b^{\text{II}} = 3.3 \pm 4.0^\circ \) )

A second rocket flight yielding accurate and reliable X-ray data in the region was launched by Naval Research Laboratories (NRL) on 7 September, 1967 (Meekins et al 1969). A 220 cm² 0.5 mil Mylar windowed proportional counter with 10⁰ FWHM honeycomb collimator was held in each of the Cyg XR-1, Cyg XR-2 directions for ~41 seconds, as part of a series of inflight manoeuvres over the sky. The hold positions excluded any contribution from other known sources. Meekins et al point out the following:

1. A fit of ASE spectral shape to NRL Cyg XR-1 data implies a 26% increase in absolute intensity from 11Oct66 to 7Sept67, a slight spectral hardening is also indicated. These changes may be significant.
Similarly a 50% increase in Cyg X-2 intensity is indicated. The ratio of Cyg X-1/Cyg X-2 intensities (2-5 keV) are

\[
\text{nSE (11Oct66)} = 1.11 \quad (6.2a) \\
\text{NRL (27Sept67)} = 0.92 \quad (6.2b)
\]

The measured spectra of Cyg X-1, -2 and -3 (Gorenstein et al) show Cyg X-2 with a steeper spectral shape than Cyg X-1 which in turn is steeper than Cyg X-3. Without entering into a discussion on whether the flattening is due to hot sources or interstellar absorption or both, it is recorded that measurement over 2-8 keV will give a 20% and 25% increase in intensity of Cyg X-1, Cyg X-3 counts respectively relative to Cyg X-2, when compared to 2-5 keV data. This fact is required because data on weaker sources of table 6.3 are only published in 2-5 keV, whereas the total 2-8 keV UAT data are used below, to give good statistics.

6.4.2 Flight II results

Count rate data (per 0.1 sec) for 10 scans by detector A (figure 5.2) and 9 by detector B, symmetrically located about the galactic plane, were arranged about the times of "sighting" GX 36.3 (these times were obtained from the attitude solution in the manner described in 6.2.4). The count rates were simply added and the resulting histogram is plotted against galactic longitude in figure 6.4(a).
FIGURE 6.4: Cygnus-Serpens Sources: (a) Superposition of scan counts parallel to galactic plane (figure 5.2). (b) Superposition approx. normal to plane. Arrows indicate known source positions.
dashed line represents the mean sky background, obtained from 20 seconds of data collected for $b^{\text{II}} < -30^\circ$ and away from known source positions and the horizon. The galactic longitudes of the sources listed in table (6.3), and others, are indicated by arrows, however because of the changing orientation of the scan lines relative to the galactic plane, only sources close to $b^{\text{II}} = 0^\circ$ are expected to give count rate peaks at these positions.

Two peaks, each of width $\sim 0.7$ secs (the time representing the full width of the collimator in the scan direction) are clearly resolved and correspond roughly to Cyg X-2, Cyg X-1. The number of counts under each represent $\sim 8\sigma$ increase above the mean background level. That the majority of counts is indeed compatible with only two strong source regions near the Cyg X-1, Cyg X-2 positions is shown in figure 6.4(b). This is the super-position of count rates from 13 scans (A and B, including scans 3 to 9 of figure 5.2) roughly perpendicular to the galactic plane and therefore plotted against galactic latitude. (The dotted lines are predicted responses from the sources discussed in the analysis, below). The super-position is arranged about the predicted times of sighting Cyg X-1 which distorts the response expected from Cyg X-2. For this reason and because of possible source contamination with the $70^\circ$ collimator full width lying along the plane, these data are not used further in estimating source intensities.
6.4

Proceeding with the analysis of data of figure 6.4(a), the assumption is made that the UAT count rate comprises contributions from only those sources listed in table 6.3 for \(25^\circ < \Gamma < 100^\circ\). The shapes and positions of responses to sources in the Cyg X-2, Cyg X-1, GX 48.7 and GX 36.3 positions can be predicted using the attitude solution, (because of the convergence of scan paths this can be done for the last two despite uncertainties in their latitude, and Cyg X-2 is the only source for which the collimator triangular shape is seriously distorted). These response functions are shown as dotted "triangles" where in the case of GX 48.7, GX 36.3, they have been normalized to the counts in excess of the mean background within the collimator full widths (counts in the 0.2 sec overlap are equally divided).

For the Cygnus sources, an average angular separation of the scan paths from each source has been obtained from the attitude solution. These are applied to the collimator response function \(\alpha_p = 35^\circ\) giving a collimator efficiency for each source, which can be directly applied to the total count rates to obtain source intensity in counts cm\(^{-2}\)sec\(^{-1}\).

Making a further assumption that Cyg X-3, Cyg X-4 have the same intensities relative to Cyg X-2 as reported by ASE, and incorporating the collimator correction then allows the four Cygnus response functions to be normalized to the observed count rates. The sum of the normalized response functions is
shown in figure 6.4(a) to be good representation of the data (dot-dashed line). Cyg X-2 was chosen as the standard simply because it is better resolved from Cyg X-3 than is Cyg X-1. Table 6.4 gives the collimator efficiencies and 2-8 keV intensities, normalized to the 2-5 keV aSE intensity of Cyg X-2.

TABLE 6.4

INTENSITY OF FLIGHT II CYGNUS-SERPENS SOURCES

<table>
<thead>
<tr>
<th>Source</th>
<th>Collimator Efficiency</th>
<th>Normalized Intensity (2-8keV) counts cm⁻² sec⁻¹</th>
<th>R = ( \frac{UAT(2-8keV)}{ASE(2-5keV)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>GX 36.3</td>
<td>0.91</td>
<td>( 0.11 \pm 0.03 )</td>
<td>( 0.73 \pm 0.35 )</td>
</tr>
<tr>
<td>GX 48.7</td>
<td>e</td>
<td>( (0.06 \pm 0.04)/e )</td>
<td>( 0.37 \pm 0.29 \times 10^{-5} \pm 47)</td>
</tr>
<tr>
<td>Cyg X-1</td>
<td>0.69</td>
<td>( 0.24 \pm 0.06 )</td>
<td>( 0.60 \pm 0.21 )</td>
</tr>
<tr>
<td>X-3</td>
<td>0.67</td>
<td>( 0.13 \pm 0.05 )</td>
<td></td>
</tr>
<tr>
<td>X-4</td>
<td>0.60</td>
<td>( 0.05 \pm 0.05 )</td>
<td></td>
</tr>
<tr>
<td>X-2</td>
<td>0.52</td>
<td>( 0.36 \pm 0.08 )</td>
<td>( 1.00 \pm 0.33 )</td>
</tr>
</tbody>
</table>

* (see text)

Intensity errors are derived as follows:

If \( B \) represents the true average count rate due to background,

\[ b_{tb} = \text{number of b.g. counts observed in } t_b (\sim 20 \text{ secs}); \]

\( (s+b)t_s = \text{number of source plus b.g. counts recorded in a time } t_s \text{ representing the FWHM of the response function}; \]

then the true average source count rate

\[ S = s + \frac{b}{\sqrt{t_s}} + \frac{b}{t_b} \]
In the case of the ratio $R$, errors have been obtained by arbitrarily assuming a ± 10% error in the ASE Cyg X-1, Cyg X-2 intensities, and a ± 20% error for the weaker sources.

The relative Cyg X-1/Cyg X-2 intensity is incompatible with that obtained by ASE, and by comparison with equations (6.2a,b) is

$$\text{UAT (20 Apr 67)} \quad 0.67 \pm 0.31 \quad (6.2c)$$

When it is remembered that observations over 2-8keV will increase the intensities of Cyg X-1, Cyg X-3 by 20%, 25% respectively, relative to Cyg X-2, the (2-5keV) ratio will be reduced to less than 0.5, which is also incompatible with the NRL value.

The GX 36.3 data show an intensity decrease relative to Cyg X-2 but this is not statistically significant. In any case the agreement is improved by taking $b^{\text{II}}$ closer to the suggested ASE position than the $b^{\text{II}} = 3.3^\circ$ employed above. The ratio $R$ for GX 48.7 is quoted between limits corresponding to maximum collimator efficiency of 0.91 and minimum of 0.6 set by the ASE position $b^{\text{II}} = 0 \pm 15^\circ$.

6.4.3 Conclusions

Under the assumptions that Cyg X-2 is constant in intensity from 110ct66 to 20apr67 and that source spectral shapes are relatively invariant, it can be concluded that
(1) either Cyg X-1 has decreased in intensity (2-8keV) by \( \sim 40\% \), or Cyg X-3 has dramatically decreased in intensity (2-8keV), (or both);

(2) GX 48.7 has decreased in intensity (\( \geq 50\% \)) or its galactic latitude is \( |b^{II}| > 15^\circ \);

(3) GX 36.3 is constant in intensity (to within \( \sim 30\% \)).

If on the other hand a variation in Cyg X-2 alone has caused the difference in equations (6.2a), (6.2c) then

(1) Cyg X-2 has increased in intensity \( \sim 40\% \) (and would appear to have decreased again to explain (6.2b);

(2) for Cyg X-3, Cyg X-4 constant relative to Cyg X-1, GX 48.7 can be close to the plane and GX 36.3 is still consistent with a time invariant source.

If the simplest explanation is the correct one, then a variation in Cyg X-2 alone is favoured, particularly since its variability appears to be established between the ASE, NRL flights while that of Cyg X-1 is not established beyond doubt by these flights. This type of variation in Cyg X-2 is similar to that observed in Sco XR-1, and strengthens the case for the identification of Cyg X-2 with an optical object which is similar to that identified with Sco XR-1 (Giacconi et al 1967).

On the other hand Cyg X-1 has long been claimed to vary at rocket energies, see Chodil (1968c), and is apparently an
established variable at balloon energies, see Bingham and Clark (1969). It is worth re-emphasizing that the early rocket surveys were in general incapable of resolving the four ASE Cygnus sources. All have been analysed allowing for contributions from minor sources in positions different from those of Cyg X-3, Cyg X-4 or with no allowance for such sources.

In addition detectors with quite different spectral sensitivities have been used for intensity comparisons, when Cyg X-1, Cyg X-2, Cyg X-3 have been shown by ASE to have markedly different spectral shapes. These criticisms might also apply to some of the balloon results. There appears to be no marked correlation between the balloon and rocket intensity variations for Cyg X-1, indicative of systematic errors, a variability on a time scale of the order of weeks or less, or a source in which the 1-10keV and 20-50 keV emission processes are unconnected.

6.5 Cetus

Data from flights II, III were used in section 5.3.3 to present strong though not unassailable evidence for an X-ray source in Cetus. This puts the Cetus source among a class of other unconfirmed X-ray sources at high galactic latitude, e.g. Leo XR-1 (Friedman et al 1967), and sources
near 3C273 (Friedman and Byram, 1967) Crater (B. Cooke private communication), and the Large Magellanic Cloud (Mark et al. 1969b). One object, Vir XR-1, has been observed on a number of flights and its position suggests identification with M87 (Bradt et al, 1967). M87, 3C273 and LMC are extra galactic objects and confirmation of X-radiation from such objects and the identified other sources at high galactic latitude will have great bearing on the theories of origin of the diffuse X-rays, in particular whether or not the diffuse radiation is the sum of a large number of unresolved galactic or extra galactic discrete X-ray sources.

*Note in Proof: Dr. B.G. Wilson, University of Calgary, claims to have observed a strong source in this region in a recent rocket flight. Further details are not yet available. (Private Communication, July, 1970).*
CHAPTER SEVEN

GALACTIC HALO CONTRIBUTION TO THE DIFFUSE X-RAY BACKGROUND

7.1 INTRODUCTION

Section 1.6.4 summarizes a wide variety of mechanisms suggested as possible origins of the diffuse X-ray flux. No single mechanism explains all the features of the observed spectrum within limits imposed by present knowledge of such things as the cosmic ray spectra, magnetic fields and low energy photon densities, in galactic and extra galactic space. In fact it is not unreasonable to expect appreciable contributions from a number of different processes.

The low frequency radio background and the extra terrestrial electron spectrum are both thought to contain information on galactic processes. Extensive new radio data, and new electron and interstellar magnetic field strength estimates have prompted a reassessment (c.f. Felton and Morrison, 1966) of the possibility of a galactic X-ray contribution. Emphasis has been placed on similarities in the shapes of the electron, radio and X-ray spectra which might be taken as indicating some common origin. The chapter includes and extends work published by Hamilton and Francey (1969).
7.2 X-RAYS

7.2.1 Experimental Data

Observations of the diffuse cosmic X- and gamma ray spectrum are summarized in figure (7.1). There is noticeable steepening of the spectrum below about 1keV and above about 40keV. Between 1keV and $10^3\text{keV}$, the data are shown fitted by spectra of the form

$$\frac{dN}{d(hv)} = \text{const.}(hv)^{-(\alpha+1)} \text{photons (cm}^2\text{sec ster keV)}^{-1}$$

where $\alpha$ is the spectral index of the corresponding energy spectrum, and is given by

$$\begin{align*}
\alpha &= 0.5, \quad 1 < hv < 40 \text{ keV.} \\
\alpha &= 1.4, \quad 40 < hv < 1000 \text{ keV.}
\end{align*}$$

(7.1a)

The "reasonable" fit above 40keV becomes an excellent one if it is accepted that all the scintillator data (20-100 keV) should be adjusted in a manner suggested by Trombka (1970). (For instance an incident power law photon spectrum with spectral index $(\alpha + 1) = 1.5$ is shown to produce a pulse height spectrum, 60-100 keV, with index 1.7). There is evidence for a spectral feature at 1MeV and/or a spectral break to agree with the tentative 100MeV results. Both require further verification.

Below 40keV, and entering the domain of rocket borne proportional counter measurements (<15keV), the scatter in the data is pronounced. There is obviously a marked spectral
FIGURE 7.1: Summary of Diffuse X-ray Observations
break below about 1keV. With possible galactic structure in mind, the 1.5-15 keV observations for which directional and spectral information are available are summarized in table (7.1) and figure (7.2).

Problems in comparing data from different experiments arise from uncertainties in detector efficiency and background correction. The possibility of electron contamination (section 3.5.3) is perhaps the most serious and it may be significant that the observations of Green et al and Baxter et al, giving among the highest 3.6keV intensities, were from rockets launched at high geomagnetic latitude. The observations in regions 1,2,3,4 are considered to be the most reliable in view of the sophistication of detection systems and controlled rocket motions which extend the viewing time. On the other hand the programmed motion often removes the capability of detecting a pitch angle distribution and thus a steady electron precipitation; in this respect the thick beryllium windows of counters employed in regions 3 were the least sensitive to electrons and also record one of the lowest intensities. The apparent discrepancy in regions 4 and 7 may come from serious inflight difficulties experienced during observations in the latter.

Intensity variations (during a single flight) between the various galactic latitudes in regions 1,3 and 4 were reported to be less than 5%, 10% and 8% respectively.
### TABLE 7.1

ROCKET OBSERVATIONS OF THE DIFFUSE X-RAY BACKGROUND

<table>
<thead>
<tr>
<th>Region Observed (fig.7.4)</th>
<th>Energy Range (keV)</th>
<th>Spectral Index $\alpha$</th>
<th>Approx. Intensity at 3.6keV*</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2-20</td>
<td>0.35</td>
<td>6.6</td>
<td>Boldt et al (1969b)</td>
</tr>
<tr>
<td>2</td>
<td>1.5-8</td>
<td>0.4</td>
<td>7.5</td>
<td>Henry et al (1968)</td>
</tr>
<tr>
<td>3a</td>
<td>4-15</td>
<td>0.69</td>
<td>3.9</td>
<td>Seward et al (1967)</td>
</tr>
<tr>
<td>3b</td>
<td>4-15</td>
<td>0.73</td>
<td>4.8</td>
<td>Seward et al (1967)</td>
</tr>
<tr>
<td>4</td>
<td>1-13</td>
<td>0.70</td>
<td>5.1</td>
<td>Gorenstein et al (1969)</td>
</tr>
<tr>
<td>5</td>
<td>2-10</td>
<td>0.68</td>
<td>6.3</td>
<td>Green et al (1968)</td>
</tr>
<tr>
<td>6</td>
<td>1.5-4</td>
<td>~0.5</td>
<td>8.6</td>
<td>Baxter et al (1969)</td>
</tr>
<tr>
<td>7</td>
<td>2-10</td>
<td>0.3</td>
<td>4.2</td>
<td>Boldt et al (1969a)</td>
</tr>
</tbody>
</table>

* keV(keV cm² sec ster)

* *keV(keV cm² sec ster)*⁻¹
FIGURE 7.2: Areas of Sky covered in Rocket Observations of Diffuse X-rays
Perhaps the most significant background observations to date have recently been reported by Schwartz (1970). Using a single calibrated scintillator on OSH-III, statistically significant 10-50keV count rates were obtained over practically the whole sky in the course of one year. Due consideration was given to electron precipitation, claimed to be widespread. Schwartz arrives at two conclusions important in the present context;

(1) a spectral break occurs at $38 \pm 4$ keV. This is the first confirmation of a break in a single set of data and the position is in agreement with that used in equation (7.1a). (There is some controversy on the break position however (Gorenstein et al, 1969, Bleeker and Deerenberg, 1970), which possibly might be related to the direction of observation, and requires further investigation.)

(2) there is an upper limit of 3-5% on a halo anisotropy, above 10keV.

Three related factors (already implied from section 3.5.3) cause hesitation in extrapolating this isotropy to 1keV and attributing the scatter in rocket observations to electron precipitation, one being the short time scale (minutes) of the reported strong precipitation events. The second is the relative insensitivity of the proportional count to electrons and finally pitch angle distributions (befitting steady precipitation) have often been considered
but never reported from X-ray astronomy flights. Re-analysis of the individual rocket data in light of new electron data might be fruitful.

We can conclude here either that the diffuse X-rays are isotropic (and therefore most likely extragalactic) and there are large systematic or background induced errors in the measurements (with implication of widespread frequent electron precipitation and steep electron spectra), or that there are X-ray anisotropies particularly at low energies indicating an appreciable galactic contribution. From the latter point of view a difference in spectral index between rocket observations representing the northern galactic halo

\[(\alpha_N)_{x-ray} \sim 0.4 \quad (7.2a)\]

and those containing a significant contribution from the south

\[(\alpha_S)_{x-ray} \sim 0.7 \quad (7.2b)\]

is most evident from table (7.1), figure (7.2). Since it is possible to imagine some situations in which a difference in spectral index will be more obvious than a measured count rate difference over a selected energy range, equations (7.2) are noted for comparison with extra-terrestrial electron and radio spectra. Before doing this the properties of the most likely galactic X-ray production mechanism, the inverse Compton effect, are summarized.
7.2.2 The Inverse Compton Effect

An accurate calculation of the spectrum of inverse Compton scattered photons is given by Jones (1967) who shows that the \( \delta \)-function approximation for scattering by a single electron, employed in the convenient treatment of Felten and Morrison (1966), is a good one. Following the latter, the electron spectrum is expressed in the form

\[
n(\gamma) \, d\gamma = n_0 \gamma^{-3} \, d\gamma \quad \text{electrons cm}^{-3} \quad (7.3)
\]

for electrons with

\[
\gamma = (1 - \beta^2)^{-\frac{1}{2}}
\]

in the range \( d\gamma \). Here \( \beta \) is the ratio of electron velocity to the speed of light. (For electron energy \( E = 1 \text{GeV} \), \( \gamma = 1970 \)).

For an ambient photon population with mean photon energy \( \bar{\epsilon} \) which is isotropic, the mean energy of a scattered photon is

\[
\bar{h\nu} = \frac{4}{3} \gamma^2 \bar{\epsilon}
\]

and for a black-body distribution of ambient photons at temperature \( T \) (degK): \( \bar{\epsilon} = 2.7 \, k \, T \) so that

\[
\bar{h\nu} = 3.1_{10}^{-4} \, \gamma^2 \, T \, \text{eV}
\]

\[
= 1.18 \, E^2 \, T \, \text{keV} \quad (7.4)
\]

for \( E \) in GeV.

If the electrons are also isotropic, the specific intensity received at Earth in a given direction which includes a length \( R \) of the electron-photon field region is

\[
I(h\nu) \approx 10^3 \, (56.9)^{3-n} \, n_0 R \rho \, T^{(n-3)/2} \, h\nu^{(1-n)/2} \
eV. \ (eV \ cm^2 \ sec \ ster)^{-1} \quad (7.5)
\]
where \( \rho \), the energy density of the ambient photons, is given by
\[
\rho = \frac{4\pi T^4}{c}, \quad \sigma = \text{Stefan Boltzmann constant},
\]
\( 3.5 \times 10^7 \text{ eV} (\text{cm sec deg}^4)^{-1} \), and \( R \) is in light years
(\( = R \times 9.46_{10} \text{ cm} \)).

Thus the X-ray spectral index, \( \alpha \), of the last subsection is related to the electron spectral index \( m \), in equation (7.3) by
\[
\alpha_{\text{inv. com}} = \frac{(m - 1)}{2}
\]  
(7.6)

(Assuming equations 7.2 represent real differences, attributable to a halo origin, then electron spectra with \( m = 1.8, \ m = 2.4 \) would be expected in the north and south).

7.3 THE RADIO BACKGROUND

7.3.1 Observations

Hamilton (1969) carried out a critical and comprehensive review of low resolution radio observations in the directions of the galactic poles. The results, corresponding to references 1 to 19 of Hamilton and Francey (1969), are included in figure (7.3). The brightness \( B \), is derived from
\[
B = \frac{2kT}{\lambda^2} \quad \text{Watts (MHz ster)}^{-1}
\]  
(7.7)

where \( k = \text{Boltzman's constant}, \ 1.38_{10} \text{ joule deg}^{-1} \).

\( T = \text{temperature, degK.} \)

\( \lambda = \text{wavelength, metres.} \)
FIGURE 7.3: Summary of Diffuse Radio Observations in the Galactic Pole Directions. Bars indicate extrapolation to Pole Directions using PTS survey (see text).
The brightness scales of the north and south data are displaced an order of magnitude to aid comparison.

High frequency data (references 20 to 25) are included in figure (7.3) taken from:

20 Pauliny-Toth and Shakeshaft (1962)
21 Howell and Shakeshaft (1967)
22 Price (1969)
23 Pelyushenko and Stankevich (1969)
24 Wall, Chu and Yen (1970)
25 Rohan and Soden (1970)

In all these cases (and also the 404 MHz data of reference 11), a contribution due to a universal microwave black-body radiation has been subtracted out. Measurements on the black-body temperature range from the original estimate of 3 degK (Penzias and Wilson, 1966) down to 2.5 degK used by Pelyushenko and Stankevich (23). The pair of parallel lines superposed onto the northern halo data of figure (7.3) represents the microwave background for these two temperature limits, and apart from the points (23), a 2.7 degK radiation has been subtracted (see Boynton et al, 1968).

Because of the magnitude of both the atmospheric and cosmic temperatures relative to the galactic temperatures reported by Pelyushenko and Stankevich, the points (23) are taken with considerable reserve (and are indicated with large error bars).
Pauliny-Toth and Shakeshaft (PTS, 20) published 404 MHz temperature contours covering most of the sky, combining their own data about the north pole with measurements by other authors. The upper limit of the plotted point (20) in figure (7.3), north pole, corresponds to the temperature with a base line correction of -4.5 degK as suggested by Price (1969). For each of the plotted points (21) to (24), the upper limit is that published by the respective author (minus 2.7 degK) for regions removed but near the galactic poles (usually the celestial poles). The lower limit is that predicted at the galactic pole (minus 2.7 degK) using the relative brightnesses at 404 MHz taken from the PTS surveys. In all cases the lower limits are probably the more correct estimates of pole brightness.

The differences in 10-200 MHz spectral shape between the north and south are very marked and are shown fitted by a power law, similar to equation (7.1), with

\begin{align}
(\alpha_N)_{\text{radio}} & \sim 0.4 \quad (7.8a) \\
(\alpha_S)_{\text{radio}} & \sim 0.6 \quad (7.8b)
\end{align}

(the resemblance to equations 7.2a,b is striking). The north and south brightnesses are similar above 200 MHz, so that at 10 MHz the south is approximately two times brighter than the north. The power law with \( \alpha = 0.4 \) obviously does not include the very high frequency northern points and the evidence for a
spectral break at about 200 MHz is very good. In contrast, the data are accurately described by a single power law, with the scant high frequency data indicating the absence of a spectral break between 10 and 400 MHz.

Evidence for a galactic halo comes from radio observations around 80 MHz (Baldwin, 1955, Mills, 1959). A model for the Southern halo by Hamilton (1969) is unique in that extensive high resolution surveys at 2.1, 4.7, 10, 30, 85 and 153 MHz have permitted an accurate definition of the galactic disc component (low frequency absorption in the disc distinguishing it from more tenuous regions). Unfortunately similar data at the low frequencies are not available for the north, a consequence of the non-existence of relatively "transmitter-free" regions with anomalously low ionospheric critical frequencies similar to Hobart. (The quality of present satellite results, apparently plagued by exospheric emissions, is poor). The Hamilton halo is presented in figure (7.4) as contours of constant \( A \), for an integrated extra-disc emission

\[
\varepsilon(\nu) = A \nu^{-\alpha}
\]

normalized to 100 at the south galactic pole. (Northern points are distorted, most likely due to presence of Cen A). Dotted lines show a model ellipsoid of revolution with uniform emissivity throughout, and with dimensions chosen to fit the high latitude measurements. The relative dimensions
FIGURE 7.4: The Hamilton Halo. Emissivity measure, normalized to 100 in the South Galactic Pole direction.
of the ellipsoid are quite accurately defined by the data (allowing for a slight increase in emissivity towards the galactic centre); the absolute dimensions are defined by the solar distance, currently thought to be 10 kpc. Using this gives,

- a major axis (in the galactic plane) of 29.2 kpc,
- and minor axis (normal to the plane) of 26.6 kpc.

A solar distance of 8 kpc, as used by both Baldwin and Mills, decreases the size of the present model proportionally.

### 7.3.2 Synchrotron Emission

The measured diffuse radio emission is generally assumed to be of galactic origin, for reasons which include the measured anisotropy as above, calculations on possible cosmological models (Payne, 1969 and private communication) and a single direct measurement at 20 MHz limiting the extragalactic emission (Shain, 1959). All three methods arrive at an upper limit of about 10% for an extragalactic contribution. The shape of the spectrum above 100-200 MHz, as indicated in the northern halo data of figure (7.3) is further indirect evidence for a predominantly galactic origin. An extragalactic radio spectrum is assumed to arise from the superposition of spectra from unresolved point sources. Spectra of resolved extragalactic sources show no evidence for a uniform spectral bend necessary to explain a diffuse spectral discontinuity.
Galactic radio spectra are described in terms of synchrotron emission of relativistic electrons in a galactic magnetic field. A complete treatment of the synchrotron process is given by Westfold (1959) and more recently by Ginzburg and Syrovatskii (1964), who introduce a characteristic frequency

\[ \nu_c \approx 16.1 B_\perp E^2 \text{ MHz} \]  

(7.9)

where \( E \) is the electron energy, \( \text{GeV} \)

\( B_\perp \) is the component of magnetic flux density normal to the electron velocity, \( \mu \text{G} \).

The power radiated by a single electron is given by

\[ P(\nu) = 2.34 \times 10^{-29} B_\perp F(\nu/\nu_c) \]

where \( F \) is a modified Bessel function tabulated by Westfold.

For an electron spectrum of number density \( n(E) dE \), in a randomly oriented field, the synchrotron emission will have no net polarization (as observed) and will be isotropic.

The synchrotron emissivity is given by

\[ \epsilon(\nu) \approx 2.34 \times 10^{-35} B_\perp \int n(E) F \left( \frac{\nu}{16.1 B_\perp E^2} \right) dE \]

watts \( \text{m}^{-3} \text{Hz}^{-1} \)  

(7.10)

For an electron spectrum, (see equation 7.3),

\[ n(E) dE = N_0 E^{-s} dE \]  

(7.10a)

and assuming all the radiation occurs at the characteristic frequency \( \nu_c \), it can be shown (Mills, 1964) that

\[ \epsilon(\nu) \propto B_\perp \nu^{1+s} \nu^{1-s} \]
or \[ \varepsilon(\nu) \propto \nu^{\alpha_{\text{synch}}} \] where \[ \alpha_{\text{synch}} = (m-1)/2 \] (7.11)

This can be compared with equation (7.6) for the inverse Compton effect, and gives added significance to the correspondence between north and south radio and X-ray spectral indices.

The radio measurements give a total radiation, \( S(\text{Watts m}^{-2}\text{Hz}^{-1}\text{ster}^{-1}) \), in a given direction, which is related to the emissivity by

\[
S(\nu) = \frac{1}{4\pi} \int_0^L \varepsilon(\nu) \, dl = \frac{\varepsilon L}{4\pi} \tag{7.12}
\]

assuming uniform isotropic emissivity along the total path length \( L \) through the halo.

7.4 INTERSTELLAR MAGNETIC FIELDS

Direct information on interstellar magnetic fields comes from measurements on Zeeman splitting of the 21 cm hydrogen line and from Faraday rotation measures on extragalactic and pulsar radio sources. Veerschuur (1969) obtains fields ranging from \( 0.55 \, \mu\text{G} \) to \( > 20 \, \mu\text{G} \) from Zeeman splitting measurements in various spiral arm directions. The strong fields are associated with "amplification" in dense interstellar clouds and excluding these, limits on field strengths much less than \( 10\mu\text{G} \) are established. Berge and Seielstad (1967) obtain Faraday rotation measures for extra-
galactic sources as a function of galactic latitude; an
interpretation of their results in terms of a field aligned
with the galactic disc gives
\[ \int n_e B \, dr \approx 20 \text{ cm}^{-3} \mu \text{G pc}. \]
for the direction of the galactic pole. Radhakrishnan (1969)
summarizes the Faraday rotation measures on pulsars, for
which the dispersion also gives \( \int n_e \, dr \). Using a model for
the dispersing electrons given by Mills (1969) implies
\[ \int n_e \, dr \approx 10 \left[ \text{ cosec } b \right] \text{ cm}^{-3} \text{pc}. \]
Thus in the direction of the poles, these two equations imply
a mean line-of-sight field in the disc, \( B \sim 2\mu \text{G} \).

Two phenomena must be kept in mind, one is cloud
structure (which might amplify the field as suggested by
Veerschuur) and secondly (for the Faraday measurements) any
large scale field reversals will tend to cancel the rotation
measure. If we accept \( 2\mu \text{G} \) as a reasonable estimate of \( B \) in
the disc, a corresponding halo field might be expected to be
considerably less than \( 2\mu \text{G} \). Independent evidence for a
mean field strength (halo plus disc) with \( B \| \sim 0.3 - 1\mu \text{G} \)
in the direction of the north galactic pole is presented in
section 7.6. (For a randomly oriented field in the haloes
\( \langle B^2 \rangle \approx \frac{2}{3} B^2 \).)
Estimates of an interstellar electron spectrum hinge on measurements made close to earth in the range

\[ 2.5_{10} \leq E \leq 500 \, \text{GeV} \]

Ignoring various interpretative lines, the data are summarized in figure (7.5), adapted from Faneslow et al (1969). Recently published 1968 data between \(3_{10} \leq 2 \) and 1 GeV, and \( > 100 \) GeV have been included, taken from a review by Pal (1969). In following general discussions, the review of Pal and others by Meyer (1969), Webber (1968) have been the principal sources of information.

**Solar modulation** obviously plays a big part in the \(3_{10} \leq 2\) to 1-2 GeV spectrum but apparently not outside these limits. The spectral flattening in this energy interval is very reminiscent of the behaviour of protons and He nuclei. Controversy on the demodulation procedure is normally restricted to the electron data \( < 2 \) GeV, however even above this energy there are difficulties. For example Webber shows that to explain the radio emission from the galaxy using a demodulated electron spectrum requires line of sight averaged field strength \( B_\perp = 7_{10} \mu \text{G} \), significantly higher than that suggested in the previous section (unless there is a large scale field reversal.)
FIGURE 7.5: Summary of measurements of Electrons near earth. (Right hand scale and E² lines allow prediction of mean Inverse Compton energy and/or characteristic synchrotron frequency.)
An alternative method of obtaining the interstellar electron spectrum starts with the observed galactic radio emission (e.g. Felten, 1965). Independent information on the relative values of the two unknowns, the electron density and magnetic field strength, is usually obtained by requiring a pressure equilibrium between the field and cosmic rays in the haloes (Shklovsky, 1960). That this leads to similar problems has long been recognized and for example Hamilton (1969) shows that the data from the southern halo require either an electron to proton ratio of $\sim 50\%$ (c.f. $\leq 1\%$ near earth), or again field strengths ($B_B$) of about $6 \mu G$.

Because of such difficulties, the emphasis here is placed on the shape of the electron spectrum, and in particular on what Pal calls "the favourite occupation ....... of kink hunting". The assumption is that discontinuities in the interstellar spectrum, whatever their cause, will be apparent also in radio and perhaps X-ray spectra. The data of figure (7.5) above 1-2 GeV are shown represented by the "best fit" power law. The choice of a basic power law shape is not required by any astrophysical argument except for a general tendency of cosmic ray observations to be described in this form. For example Anand et al (1968), fit a smoothly varying function to the data about 1-10 GeV. Also the quality of the data might not warrant such attention and for example it is normal practice to fit the data above 2-3 GeV.
and below $\sim 100\, \text{GeV}$ by a single power law (Faneslow et al., 1969). For the moment, accepting these "best" fit lines gives an electron spectrum (see equation 7.3)

$$n(E) \, dE = n_0 \, E^{-m} \, dE \, (\text{m}^2 \, \text{sec ster})^{-1}$$

where

$$n_0 = 33.7, \quad m = 1.74 \quad \text{for} \quad E < 4.5 \, \text{GeV}$$

$$n_0 = 190, \quad m = 2.89 \quad 4.5 < E < 35 \, \text{GeV}$$

$$n_0 = 11.5, \quad m = 2.4 \quad 35 < E \leq 200 \, \text{GeV}$$

(7.13)

Possible causes of breaks in the electron spectrum are discussed by Pal, Felten and Morrison (1966) and others. Of particular importance here are energy losses from a galactic electron spectrum due to synchrotron and/or inverse Compton radiation. For an equilibrium situation, the electron storage time (between source and observer) is given by

$$\tau = \frac{E}{dE/dt} \propto \frac{1}{bE}$$

(7.14)

$b$ is proportional to the energy density of the background radiation ($\rho$) in the case of Compton losses, or to the energy density of the magnetic field ($B^2/8\pi$) for synchrotron losses. For an injected power law electron spectrum of exponent $m$, and for residence times exponentially distributed with mean time $\tau$, the spectrum steepens to $m + 1$ above an electron energy $(b\tau)^{-1}$.

The charge composition of the electrons measured near earth is considered significant to this problem. Measurements
in the energy range 0.5 - 10 GeV give a 10 fold negatron excess, widely accepted as an indication that these electrons are directly accelerated. An increasing positron ratio towards lower energies is taken to represent an increasing contribution of "secondary" electrons resulting from interactions of the primary cosmic rays in the interstellar medium (i.e. $\pi \rightarrow \mu \rightarrow e$ decay). A tentative result indicating positron excess above 10GeV (Daniel and Stephens, 1966) is interesting but requires further verification.

A break "upwards" in the electron spectrum as indicated at $\sim 35$GeV in figure (7.5) can only be the result of an alternative production mechanism. In this respect the inconclusive report of a high energy positron excess, receives new significance. (If this particular kink is ignored or attributed to experimental causes, the consequence in the present context is to move the 4.5GeV break to slightly lower energies).

7.6 COMPARISON OF DATA

The similarity of spectral indices in the 1-15 keV X-ray and 10 - 100 MHz radio data has already been noted, including corresponding differences between north and south galactic halo spectra (equations 7.2, 7.8).
Equations (7.4), (7.9) can be used to estimate the portions of the electron spectrum of interest for the cases of inverse Compton X-rays and synchrotron radio waves respectively. For convenience, these are included on figure (7.5) by relabelling the right hand scale to read keV OR MHz, depending on whether a mean Compton photon, \( \bar{\nu} \), OR the characteristic synchrotron frequency, \( \nu_c \), is being discussed. Dashes show \( \nu_c \) for 0.5, 1.0, 5.0 \( \mu \)G fields. Dots show \( \bar{\nu} \) for 2.7, 8, 5000 degK black-body fields. The reason for including the 8 degK is discussed briefly at the end of the section, the 5000 degK is taken to represent starlight. For example 10 to 100 MHz radio waves are obtained from a magnetic field with \( B_\perp = 1 \mu \)G from electrons of \( \sim 0.8 \leq E \leq \sim 2.5 \) GeV. These electrons will produce X-rays with \( 2 \leq \nu \leq 25 \) keV from a 2.7 degK blackbody field or \( 5 \leq \nu \leq 40 \) MeV from starlight.

As a preliminary measure, the \( \nu_c, \bar{\nu} \) corresponding to electron energies at break positions can also be used to estimate possible break positions in the radio and X-ray spectra. The results are again striking, e.g. a 4.5 GeV electron gives a characteristic synchrotron frequency of 200 MHz for \( B_\perp = 1 \mu \) G and a mean Compton energy \( \sim 60 \) keV for a 2.7 degK ambient field (c.f. figures 7.3, 7.1). In addition the decrease in electron spectral index at 35 GeV
implies a decrease in X-ray spectral index at ~ 4.10 3 keV and is of the right magnitude to explain the 100 MeV data of figure (7.1).

Because of the smeared and asymmetrical distribution of the synchrotron or inverse Compton radiation from a mono-energetic electron spectrum it is not at all obvious that the preliminary measure of predicting breaks is valid. For this reason the electron spectrum represented by equation (7.14), (extended down to 0.2GeV and up to 300GeV) has been inserted into equation (7.10) and numerically integrated. The integration is achieved using a series representation of the tabulated Westfold values of the modified Bessel function \( F(v/v_c) \). An Algol program incorporating the method was developed and tested by Dr. Hamilton and was kindly made available for the present purpose. The resulting emissivities are shown in figure (7.6), normalized to the northern radio data at 20-30 MHz. Normalization factors relative to that at \( B_\perp = 1 \mu G \) are

<table>
<thead>
<tr>
<th>Field ( B_\perp, \mu G )</th>
<th>Normalization Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.38</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2.5</td>
<td>3.6</td>
</tr>
<tr>
<td>5.0</td>
<td>9.7</td>
</tr>
<tr>
<td>10.0</td>
<td>26</td>
</tr>
</tbody>
</table>
FIGURE 7.6: Synchrotron Spectra predicted from Observed Electron Spectrum, normalized to North Galactic Pole Radio data.
7.6

For an observed brightness in the north pole direction, figure (7.3), of

\[ S(10 \text{ MHz})_N = 5.5 \times 10^{-21} \text{ Wm}^{-2}\text{Hz}^{-1}\text{ster}^{-1} \]

and a total path length through the halo in the pole direction similar to that observed in the south i.e.

\[ L = 10 \text{ kpc} = 3.08 \times 10^{20} \text{ m}. \]

implies from equation (7.12), that

\[ \epsilon(1\text{OMHz})_N = 2.2 \times 10^{-4} \text{ Wm}^{-3}\text{Hz}^{-1}. \]

The emissivity calculated above for a 1\mu G field was

\[ \epsilon'(1\text{OMHz}) = 4.5 \times 10^{-4} \text{ Wm}^{-3}\text{Hz}^{-1}. \]

In other words to explain the intensity of the radio emission implies \( \sim 5 \) times more electrons than observed near earth or alternatively the same electron spectrum and a field with \( B_\perp \sim 3\mu G \). This field is not too unreasonable at first sight and e.g. is similar to the value used by Sironi (1969) from similar arguments, but not so well selected radio data. Sironi goes on to claim support for this field on preliminary evidence for a radio spectral steepening above 200 MHz and an electron break at 3GeV. As can be seen from figure (7.6) a break in the radio spectrum can only be interpreted in terms of a value of \( B < 2.5\mu G \) with the present interpretation of the electron spectrum. Remembering that the lower limits of the bars representing data above 200 MHz are more likely to be the correct values the northern halo field can be limited to
7.6

\[ 0.3 < B < 1 \mu \text{G} \quad (7.15) \]

(If the electron spectrum break is shifted to lower energies, \( B \perp \) is increased, e.g. by comparison with the \( v_c \) curve in figure (7.5) a 2GeV electron break requires \( B \perp \sim 5 \mu \text{G} \).)

As might be expected from (7.11), the agreement in slope between the observed electron spectrum and 10-100 MHz northern data is excellent. On the other hand it is very difficult to extract an electron slope matching the southern radio data. If an energy dependent solar modulation argument is employed to steepen the electron spectrum around 2GeV, then the agreement with the northern data is destroyed.

Electron spectra derived from the radio data can be used to predict the intensity of X-rays resulting from inverse Compton collisions with 2.7 degK blackbody radiation \( (\rho = 0.24 \text{ eV cm}^{-3}) \). This is done in table (7.2) to allow comparison from north to south. In the pole directions the radio data and 2.7 degK field result in predicted X-ray fluxes up to about 6% of the observed flux. In directions away from the pole where \( R \) is large (e.g. \( R = 22 \text{ kpc}, \cos \theta = 0, \beta_\parallel = 30^\circ \)) the contribution may be as much as 12%. Hamilton and Francey (1969) predicted X-ray fluxes as much as 30% of the observed. This resulted mainly from using a spectral index \( m = 2.32 \) for the south, obtained from the data by correcting for the influence of the galactic disc, and also using \( T = 3 \) degK, \( (\rho = 0.4 \text{ eV cm}^{-3}) \). It is interesting that from the point of
### TABLE 7.2

CALCULATED X-RAY INTENSITIES FROM RADIO ELECTRONS AND 2.7 DEGK RADIATION IN HALOES

<table>
<thead>
<tr>
<th>Assumed Pole Dist.</th>
<th>North</th>
<th>South</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>R (cm)</td>
<td>3.08±10</td>
<td>3.08±20</td>
<td></td>
</tr>
<tr>
<td>Observed emissivity</td>
<td>2.24±10</td>
<td>4.5±40</td>
<td>7.12</td>
</tr>
<tr>
<td>$\alpha_{radio}$</td>
<td>0.4</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>$m$</td>
<td>1.8</td>
<td>2.2</td>
<td>7.11</td>
</tr>
<tr>
<td>$B_\perp \int E^{-1} dE$ at 10 MHz</td>
<td></td>
<td></td>
<td>7.10</td>
</tr>
<tr>
<td>$B_\perp = 0.7 \mu G$</td>
<td>0.85</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>$= 1.0 \mu G$</td>
<td>1.40</td>
<td>1.27</td>
<td></td>
</tr>
<tr>
<td>$n_0 (el.cm^{-3} y^{-1})$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.7)</td>
<td>4.9±10</td>
<td>2.4±10</td>
<td>7.10a</td>
</tr>
<tr>
<td>(1.0)</td>
<td>3.0±10</td>
<td>9.3±10</td>
<td>7.3</td>
</tr>
<tr>
<td>$I(3.6 \text{ keV})$</td>
<td>(630$n_0$R)</td>
<td>(30$n_0$R)</td>
<td></td>
</tr>
<tr>
<td>keV(keV cm$^2$ (0.7)</td>
<td>.10</td>
<td>.13</td>
<td>7.5</td>
</tr>
<tr>
<td>sec ster$^{-1}$ (1.0)</td>
<td>.06</td>
<td>.23</td>
<td></td>
</tr>
<tr>
<td>Observed $I (3.6)$</td>
<td>3.9 - 8.6</td>
<td>3.9-8.6</td>
<td>Table 7.1</td>
</tr>
</tbody>
</table>
view of X-ray isotropy, an increased electron flux indicated by the intensity of southern radio data is offset by the increased spectral index, in predicting X-ray intensities. The X-ray intensities of table (7.2) imply anisotropies at about the limit of present X-ray isotropy observations.

The submillimeter flux of $\sim 5 \times 10^{-9}$ Watts cm$^{-2}$ ster$^{-1}$ is discussed in 1.6.4. If this is isotropic it implies an energy density $\sim 12$ eV cm$^{-3}$ at a mean photon energy somewhere around $2 \times 10^{-3}$ eV (also the mean energy of an 8.3 degK blackbody). The electron fluxes used here then imply inverse Compton fluxes of the order of the observed flux.

7.7 CONCLUSIONS

This treatment is based principally on two pieces of evidence obtained from new high resolution and carefully selected low resolution radio data, and at variance with presently held views on galactic processes. These are

(1) the existence of a radio galactic halo, at least in the south;

(2) a marked difference in slope and intensity of the radio emission from the directions of the north and south galactic poles.

Also there is good evidence for a 200 MHz "break" in the northern radio spectrum, absent in the south, which gives
support to galactic origin or radio background. In a model of synchrotron emission from halo electrons and magnetic field, this puts limits on the halo field strength \( B_{\perp} \). At this point in particular, there is conflict with the treatment of Daniel and Stephens (see Pal). They use the charge composition of the measured electron spectrum to construct an interstellar spectrum comprising primary (galactic accelerated) and secondary (nuclear collision) electrons. The resultant electron spectrum shape is slowly varying, producing a similar radio spectrum. The present radio data, particularly in a comparison from north to south, do not support this view. If it did a markedly different accelerated spectrum from the south would be required.

The value of \( 0.3 < B_{\perp} < 1 \mu G \) is dependent on a break at 4.5 GeV in the electron spectrum near earth being also present in the northern halo. The relatively low \( B_{\perp} \) value is in line with recent estimates of low fields in the galactic disc.

In the present interpretation the difference in slope of radio data from north and south implies different electron spectra (possibly similar injection but different loss rates). An agreement in slope with the observed electron spectra near earth by only one of the two radio spectra then implies restricted access of halo electrons to the vicinity of the solar system (i.e., prior to solar modulation). The
discrepancy between the "radio electron" and observed electron intensities, which exist for both halo and disc models of the radio emission, is also removed if a halo model with "restricted access" is adopted. No satisfactory mechanism appears to exist to restrict electrons in this fashion.

From the point of view of both the magnitude and extent of the halo field, and anisotropies from north to south, the galactic field model of Piddington (1970), is attractive. In this model the spiral motion of the galaxy "sweeps up" an intergalactic field of $\sim 10^{-9}$ gauss and when the motion is at an angle to the intergalactic field direction, haloes are formed. These haloes are in a state of evolution, which also relaxes some pressure equilibrium requirements.

The shape of the X-ray data, from north to south and with the position of spectral breaks, is in excellent agreement with inverse Compton radiation from a $2.7\ \text{degK}$ field. On the other hand predicted X-ray intensities using electron spectra derived from the radio data amount to about $10\%$ or less of that measured. Also X-ray isotropy measurements appear to be an obstacle to a predominantly galactic origin, though anisotropies at the flux levels predicted here might become observable with better X-ray observations in selected directions (e.g. see figure 7.4).

The observed flux and spectral indices of X-rays can be explained if the submillimeter radiation of Shivanandan et al
(1968) is of galactic extent, in which case a break in the electron spectrum at 2GeV will produce a 40keV X-ray spectral break, if figure (7.5) can be validly used in this fashion. Again the isotropy measurements would appear to be restrictive.

The alternative to accepting a galactic explanation of the observed X-rays appears to be one of accepting widespread electron precipitation capable of contamination proportional counter X-ray observations. Careful observations of X-ray intensities in directions for which radio data are available (e.g. see figure 7.4), with particular attention to electron contamination, are required to resolve the question of halo X-ray anisotropies. Isotropy to within \( \sim 1\% \) in selected regions, for example representing large path length differences through the southern halo, will put severe restrictions on the interpretation of the radio data, or extent of photon fields in the galaxy.
8.1 INTRODUCTION

An ionospheric effect due to cosmic X-rays has been reported by Edwards, Burtt and Knox (1969) who correlate a night-time phase advance of 20 kHz radio signals with the transit over the VLF propagation path (Boulder to Wellington) of the strong source Sco XR-1 during the period 1965 to 1968. Preliminary calculations, based on a measured spectrum for Sco XR-1 and another for the diffuse cosmic X-ray background indicate that these X-rays can be the dominant night-time ionizing radiation at about 80 km. Edwards (1969) also reports a small ionospheric effect due to Cen XR-2. The effect of Sco XR-1 on the field strength of 164 kHz VLF radio waves from Tashkent received at Ahmedabad between 1960 and 1963 is reported by Ananthakrishnan and Ramanathan (1969). Very recently, Burgess and Jones (1969) find no evidence for a celestial X-ray effect on 10.2 kHz waves between Trinidad and Ottawa, 1966 to 1968. However, they do find evidence for large semi-annual variations which "seem to originate from density changes in the 85-90 km level".
In the short history of X-ray astronomy Sco XR-1 has, except for two brief occasions, been the most dominant stellar source of X-rays, in the 1.5 - 15 keV energy range. Variations in its X-ray intensity with time scales ranging from minutes to many years have been reported. The possibility of studying the history of the source prior to its "discovery", already apparently realized by the data of Ananthakrishnan and Ramanathan, is of immense interest. Both Cen XR-2 ( apr67) and Cen XR-4 (Jul69) have had intensities comparable to Sco XR-1 for brief periods, and the possibility of monitoring such objects in the past, present and future by ground-based equipment is again very attractive.

On the other hand, if the cosmic X-rays provide a dominant and stable (or at least predictable) source of electron production at about 80 km, they may be a valuable tool in the study of the night-time ionospheric processes since the effective "loss rate" of electrons from the night-time atmosphere appears to vary from a near constant value of about $2\times10^{-7}$ cm$^3$ sec$^{-1}$ above 90 km to greater than $10^{-3}$cm$^3$ sec$^{-1}$ near 80 km (Mitra, 1968), and the night-time reflection height for VLF waves propagated over long distances is in this altitude range (Wait, 1963).

Calculations of the electron production rates in the lower ionosphere due to the diffuse X-ray background and galactic point sources with emphasis on possible variations in
the parameters describing the source spectra are carried out in this chapter as a preliminary step in investigating the application of this technique. These rates are compared with electron production rates obtained from recent information on galactic cosmic rays and night-time Lyman alpha. The content of this chapter has been accepted for publication in J.G.R., September 1970.

8.2 CALCULATION OF ELECTRON PRODUCTION RATES

From figures (1.2a,b) the approximate levels in the atmosphere where a vertically incident beam of X-rays (with energy $E$ keV) is attenuated to $e^{-1}$ of the primary intensity are as follows:

<table>
<thead>
<tr>
<th>$E$ (keV)</th>
<th>Altitude (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>0.4</td>
<td>97</td>
</tr>
<tr>
<td>0.25</td>
<td>105</td>
</tr>
</tbody>
</table>

The altitude range of interest here lies between 60 and 100 km and more particularly between about 75 and 90 km. In what follows, the small X-ray fluxes greater than 10keV will not be considered. Between 10 and 1 keV the dominant attenuation process is photoelectric absorption (see section 3.1.1). Between 1 and 0.4 keV (corresponding to the nitrogen
absorption edge), the X-rays are absorbed above the region of interest. At energies just less than the nitrogen edge, photoelectric absorption above 90 km still accounts for more than 90% of the incident X-rays and the contribution at these energies will be mentioned only briefly.

Recall that the energy in a photon beam undergoing photoelectric absorption is shared between ejected photoelectrons and excitation of the residual atom, with subsequent emission from the atom of characteristic X-rays or Auger electrons. Nitrogen, oxygen and argon produce characteristic K X-rays at energies 0.39, 0.53 and 3.2 keV with fluorescent yields of .0015, .0022 and .13 respectively (Fink et al, 1966). For example, 13% of only those photoelectric collisions between argon atoms and X-rays with energies greater than the argon K shell energy (and which produce a K shell vacancy) result in the emission of 3.2keV X-rays. At densities representative of 80 km, a 3.2keV X-ray is "absorbed" in about 5 km, 0.39keV and 0.53keV X-rays, and the photo- and Auger electrons in less than 1 km. The energy lost from the beam is therefore effectively spent in producing electrons in the region of the collisions.

The energy absorption per unit volume from a monoenergetic beam of X-rays of intensity I (keV cm⁻² sec⁻¹) in a path dx (cm) of absorber is

\[ \frac{dI}{dx} = \mu p I \quad \text{keV cm}^{-3} \text{sec}^{-1} \]
where $p$ is the density ($g \, cm^{-3}$) and $\mu$ the mass absorption coefficient (= the photoelectric linear attenuation coefficient/density, $cm^2 \, g^{-1}$), of the absorber. The electron production rate in a volume element at altitude $h$ km is then

$$q(h) = \mu \, p(h) \, I(h)/W \, \text{electrons cm}^{-3} \text{sec}^{-1} \quad (8.1)$$

where $W = 0.035 \, keV$ (Snell, 1962) is the average energy for the production of an ion pair, and $I(h)$ is related to the primary source intensity $I_\infty$ and the mass of atmosphere between the volume and the source (see section 1.3). This has been described by

$$I(h) = I_\infty \exp\left[-\mu \int_h^\infty \frac{p(H)}{\cos z'} \, dH\right]$$

A reasonable approximation to a curved atmosphere (for $H > h$ and zenith angle $z < 90^\circ$) is obtained by using a "local" zenith angle $z'$ at $H$, related to $z$ at $h$ by

$$\cos z' = \left[1 - \left(\frac{R + h}{R + H} \sin z\right)^2\right]^{1/2},$$

$R$ being the earth radius ($= 6371$ km).

For a continuous source spectrum of the form

$$J(E) \, dE = K \, f(E) \, d\bar{E} \quad \text{keV cm}^{-2} \text{sec}^{-1},$$

the electron production rate at $h$ due to $X$-rays between $E_1$ and $E_2$ keV from a source at zenith angle $z$ is, from equation 8.1,

$$q(h) = \frac{\rho(h)K}{W} \int_{E_1}^{E_2} \mu(E) \, f(E) \exp\left(-\mu(E) \int_h^{b'} \rho(H) \right) \left[1 - \left(\frac{R + h}{R + H} \sin z\right)^2\right]^{1/2} d\bar{E} \quad \text{electrons cm}^{-3} \text{sec}^{-1} \quad (8.2)$$
If we assume that the diffuse X-ray background is isotropic and is described by

$$J(E)dE.d\Omega = K f(E)dE.d\Omega \text{ keV cm}^2 \text{sec}^{-1} \text{ster}^{-1}.$$

then \( q(h) \) is obtained by integrating the contribution per element of solid angle \( d\Omega \) over the zenith angles \( z \) and azimuths \( \theta = 0 \) to \( 2\pi \). Since \( d\Omega = \sin z.d\theta.dz \), then

$$q(h) \propto \frac{2\pi q(h)K}{W} \int_{E_1}^{E_2} \mu(E)f(E) \int_0^\theta \sin z \exp\left\{ -\mu(E) \int_h^h \rho(H) \right\} d\theta \text{electrons cm}^2 \text{sec}^{-1} (8.3)$$

Excellent fits of a continuous function to standard atmospheric densities (including selected perturbations) over the range 60 to 250 km (\( h' \)) are obtained in the form

$$\ln \rho = \sum_{i=0}^m a_i h^i, \text{ for } m \simeq 10$$

The photoelectric mass absorption coefficient for air can be adequately represented over restricted energy ranges by curves of the form

$$\mu(E) = AE^{-B}$$

See figure 1.2(b).

Equations (8.2) and (8.3) were numerically integrated to obtain the results reported in the following sections.
8.3 VARIATIONS IN ELECTRON PRODUCTION

The three sources of ionization considered here are the cosmic X-rays, the galactic cosmic rays and hydrogen Lyman radiation (solar and galactic). In a selected region of the atmosphere, perturbations in the night-time electron production rate will depend on the following:

(1) Time variations, in the source, of intensity and/or energy dependence of the ionizing radiation. Point X-ray sources are in this category; Lyman alpha and beta, scattering from the geocorona would be expected to vary with sunspot activity.

(2) Variations, due to the earth's rotation, in the positions of point or anisotropic galactic sources relative to the selected region of the atmosphere. Point X-ray sources are included along with possible anisotropic galactic diffuse X-ray and ultra violet emissions. Scattered solar Lyman radiation will depend on the anti-solar direction.

(3) Modulation of the source flux in interplanetary space; this results in the 11-year cycle in galactic cosmic ray intensity.

(4) Variations in the earth's magnetosphere. The low energy galactic cosmic rays are preferentially screened by the magnetic field introducing latitude and solar activity effects. Also variations in the hydrogen content in a geocorona will modulate the scattered Lyman radiation.
Each of these variations is discussed in more detail under the relevant headings in following sections. A final source of variation to be discussed here is (5) the variation in time and with altitude of the density of the absorbing constituent of the earth's atmosphere.

All three sources ionize at a rate \( q(h) \) in a form similar to equation (8.1), where \( \mu/W \) is independent of the physical state of the absorber. For the X-rays we have seen that a photon is completely absorbed to produce ions, so that \( J \) is dependent on the mass of atmosphere already traversed above \( h \), i.e. while absorption of the primary beam is small

\[
q(h) \propto \rho(h)
\]

and at lower altitudes where absorption becomes appreciable, \( q(h) \) varies approximately as

\[
q(h) \propto \rho(h) \exp \{-\rho(h)\}
\]

However, for the corpuscular radiation, \( J \) is effectively independent of \( h \), since only a small fraction of the particle energy is lost in ionization, i.e.

\[
q(h) \propto \rho(h)
\]

The effect of density variations on \( q(h) \) due to the representative diffuse X-ray spectrum of Gorenstein, Kellogg and Gursky (1969) are illustrated in figure (8.1). The result for the mean CIRA (1965) density curve is compared to those
for the extreme curves (see section 1.3). The dotted curve is the result for the U.S. Standard atmosphere (1962). The relative invariance of \( q(h) \) with density between 80 and 90 km for this type of radiation is a most interesting feature. For example, unless extremely localized, the semi annual density variations suggested by Burgess and Jones (1969) will produce a marked effect only when X-rays are not the principal ionizing agent. Further indication of the variations due to density in \( q(h) \) for the Lyman radiation and cosmic rays is included in the relevant sections. (In the case of Lyman alpha, whereas \( O_2 \) is the main absorber, only trace concentrations of nitric oxide are believed to be ionized, i.e. \( q(h) \propto \rho(NO).\exp\{-\rho(O_2)\} \), and above 80 km, \( \rho(NO) \) is a critical factor.) All other X-ray results reported here will use the mean CIRA (1965) atmosphere.

8.4 X-RAY SOURCES

8.4.1 The Diffuse Flux

Even with the possibility of galactic contributions to the diffuse X-ray background discussed in the previous chapter, the general tendency to isotropy already established plus the extreme improbability of temporal variations above the atmosphere make this the most constant source of D-region ionization.
The 2-10 keV data are adequately described by a simple power law,

\[ J(E) = KE^{-k} \text{ keV cm}^{-2} \text{ sec}^{-1} \text{ ster}^{-1} \]

(see 1.6.4). The data of Henry et al (1968), \((K \approx 12.5, k \approx 0.4)\) and Seward et al (1967), \((K \approx 9.5, k \approx 0.7)\) are taken to represent the range of the various observations. The electron production rates calculated from equation (8.3), assuming isotropy and with \(f(E) = E^{-k}\), are shown in figure (8.2). As an illustration of the energy dependence, the contributions of photons in the energy ranges 1-2 keV, 2-5 keV and 5-10 keV (dashed lines) are compared to the total 1-10 keV effect of the Seward et al spectrum.

At energies less than 1 keV, instrumental difficulties and uncertainties in background and absorption corrections increase and this is probably reflected in the order of magnitude differences in present estimates of the flux at 0.27 keV. The data of Henry et al (1968), obtained on the same rocket flight as above, represents an upper limit of such measurements. Arbitrarily assuming a sharp break in spectral index at 1.5 keV, so that the background energy spectrum passes through their point at 0.27 keV, the D-region ionization due to photoelectric absorption of this spectrum (between 0.25 and 0.4 keV) is shown as a dotted line in figure (8.2).
8.4

8.4.2 Sco XR-1

Sco XR-1, because of its consistent brightness, is the most intensely studied of the X-ray sources. Its identification, spectrum and possible nature have been discussed in section 1.6. Chodil et al (1968a) and Mark et al (1969a) have conducted a series of four simultaneous optical and X-ray observations of Sco XR-1 in which the measured X-ray intensity and the optical brightness (as indicated by the B magnitude) varied proportionally.

Harries (private communication) has (4.3 day averaged) X-ray count rate data on Sco XR-1 from late May to mid August and around September 28, 1967, from an IMP satellite. Despite poor statistics, there is evidence for a significant flux increase (≤4.3 days duration) around June 10, and a general overall increase in flux over the 2½ months continuous data. The latter result is in agreement with data above 20keV obtained from three balloon flights by Overbeck and Tananbaum (1968) in which the June 26-27 flux was approximately twice that observed on May 16 and May 25, 1967. A short-term flare of only 20 mins duration has been reported at "balloon" energies by Lewin et al (1968a) and a similar activity by Agrawal et al (1969). Finally Rao et al (1969b) point out that the rocket observations over the period 1965 to 1968 indicate a gradual overall decrease in intensity of Sco XR-1.
All of the available proportional counter data have, where possible, been represented in the form

\[ J(E) = K \exp\left(-\frac{E}{k}\right) \text{keV}\cdot\text{keV}^{-1}\text{cm}^{-2}\text{sec}^{-1} \]

(see section 1.6.2, equation 1.5). The majority of data are accurately described by this equation over the range of observations. Energy fluxes in the ranges 2-5 keV and 5-10 keV (i.e. \(\int_2^5 J(E) dE\) and \(\int_5^{10} J(E) dE\)) are plotted in figure (8.3a) as a function of time. The author has taken the liberty to "normalize" the 2.7-5.9 keV and 6-8.6 keV count rate data of Harries by replotting his curves, to pass through the 2-5 keV and 5-10 keV data points of Rappaport et al (1969a) obtained on July 7, 1967. As a rough rule in interpreting figure (8.3a), more weight has been given to more recent observations, and in comparing data from different flights more emphasis has been placed on data from the same group of experimenters.

The data of the Livermore Research Laboratories (LRL) group (solid circles) give a good example of the overall "decay" of Sco XR-1, and include the lowest observed plasma temperature on September 29, 1967. The highest plasma temperature was measured by the American Science and Engineering (ASE) group on March 8, 1966. Figure (8.3b) shows \(q(h)\) for these cases and a 0° zenith. The effect with zenith angle is shown for the May 18, 1967, LRL spectrum, in Figure (8.3c).
8.4.3 Cen XR-2 (Apr. 67)

Figure (8.4a) summarizes the history of the proportional counter observations of Cen XR-2 (see also table 6.1). The 2-5 keV energy fluxes \( \int_{2}^{5} E^{-k} dE \) are plotted. The data of Rao et al (1969a) reporting a "reappearance" of low energy X-rays from this region of the sky, are included.

The electron production rates corresponding to the measured spectra on April 4, 20, and May 18, 1967, and November 3, 1968, are shown in figure (8.4b). Because of the high declination of Cen XR-2 (-64°), the results are shown for a 40° zenith (the 80 km production rate must be increased by approximately 13% for 0° zenith). If the intensity measurement of Cooke et al (1967) represents the peak intensity of Cen XR-2, then the maximum ionospheric effect is approximately that shown for April 4. However, uncertainties in the observations do not preclude a steadily decreasing intensity through the April data points.

By quite arbitrarily assigning some features of the source Cen XR-4 to Cen XR-2 (namely the steadily increasing spectral index through peak intensity and a 5-day increase to a peak approximately twice Sco XR-1, see figure 6.3) a possible sequence for ionospheric effects of such sources can be described. Thus, the plausible effects at peak intensity (March 22) and half peak intensity (March 19) are
8.4

included as dotted lines on figure (8.4b). The effect of decreasing spectral "hardness" is most noticeable; and would complicate any direct interpretation from ionospheric records.

8.4.4 Crab Nebula, Galactic Centre

Tau XR-1, at approximately 1/8 the 2-10 keV Sco XR-1 intensity, represents the second most intense of the "long term" galactic sources. Its spectrum has been measured by Chodil et al (1967b), Gorenstein et al (1969) and Boldt et al (1969a). These data span 15 months and are in good agreement. The last of these spectra, in the form

\[ J(E) = 8.6E^{-0.93} \text{ keV cm}^{-2} \text{ sec}^{-1} \]

is used here.

About a dozen sources lie close to the galactic plane (± 3°) and within about ± 15° of the galactic centre (see figure 5.1). Individual spectra measured by Gursky et al (1967) and Rappaport et al (1969) show examples of both power law and exponential spectra similar to, or softer than the "mean" Sco XR-1 spectrum (k = 5keV); there is a general tendency for a depletion of photons less than 3keV, presumably due to interstellar or "self" absorption. Thus an integrated spectrum of exponential form and with a temperature of 6.5keV ("harder" than Sco XR-1) is used here. (This value is compatible with flight I and II data for an
8.4. The number and 2-5 keV fluxes of sources is obtained from Gorenstein et al (1967). Electron production rates for these sources, and for Tau XR-1, all at 0° zenith, are plotted in figure (8.5).

8.5 GALACTIC COSMIC RAYS

The D-region ionization due to galactic cosmic rays has been investigated by Webber (1962), and in more detail by Velinov (1968). The data of Velinov are used in figure (8.6) to illustrate the variation in q(h) with geomagnetic latitude (λₘ), solar activity and season. At these altitudes the air density is greater in summer than in winter and the seasonal effect is much more pronounced at high latitudes. Also the effect with solar activity is small at the equator and more pronounced at higher latitudes. The largest effect over the earth's surface is the variation of q(h) with geomagnetic latitude, an effect normally described in terms of a "cut-off rigidity", Rₖ (momentum per unit charge). Particles with rigidities less than Rₖ are deflected by the geomagnetic field and do not reach the atmosphere. Rₖ varies approximately as \(\cos^4\lambdaₘ\), and because of the steep spectrum and greater ionizing capability of the low energy cosmic rays, q(h) varies very approximately as \((\cos^4\lambdaₘ)^{-1}\).
8.6 HYDROGEN LYMAN RADIATION

Prediction of night-time D-region ionization rates due to Lyman radiation is extremely difficult owing to lack of data on fluxes and atmospheric composition at these altitudes. At the same time, rough calculations included below indicate that a thorough understanding of this aspect will be necessary preparatory to using this region of the ionosphere for the study of X-ray sources, or alternatively using the effect of X-ray sources to study the ionosphere.

The origin of a night-time flux of Lyman alpha (Lyman), measured on a number of occasions by rocket has caused considerable controversy. Tinsley (1969) discusses the controversies and interprets measured flux contours in terms of solar Lyman multiply scattered from a geocorona, with the isophotes centred about a minimum near the antisolar direction. Departures from contours predicted for pure geocoronal scattering are ascribed to emission from gaseous nebula associated with the Milky Way. The flux of \( \phi_0 \) of Lyman will be considered for the cases

\[ \phi_0 \approx (1-1.5) \times 10^{-3} \text{ergs cm}^{-2} \text{sec}^{-1} \text{ster}^{-1} \]

and \( \phi_0 \approx (3-5) \times 10^{-3} \text{ergs cm}^{-2} \text{sec}^{-1} \text{ster}^{-1} \)

geocoronal scattering at solar minimum, and also of the order of a Milky Way component, geocoronal scattering at solar maximum,
with the lower number in each case referring to the antisolar direction. These figures are consistent with the observations discussed by Tinsley.

The Lα incident on the atmosphere is absorbed by O\textsubscript{2} with an absorption cross-section of $10^{-20} \text{cm}^{-2}$ in the narrow "window" at 1216 Å (Watanabe, 1958). The low energy per photon of the Lα prevents ionization of the more common atmospheric species and it is thought that nitric oxide is the main source of electrons. The photoionization cross-section of NO at 1216 Å is $2 \times 10^{-18} \text{cm}^2$ (Watanabe, 1954).

Mitra (1968) discusses the conflicting evidence on the concentration of nitric oxide in the D-layer, and arrives at an expression for the number density,

$$n(\text{NO}) = 0.4 \exp(-\frac{3700}{T}) n(\text{O}_2) + (5 \times 10^{-7}) n(0) \quad (8.4)$$

which is in agreement with data from ionospheric and photochemical methods but in considerable disagreement with a direct observation of NO airglow on a number of rocket flights by Barth (1966). Mitra points to a strong temperature dependence in (8.4) and to the fact that one of Barth's flights corresponded to a day of abnormal D-region warming. However, Pearce (1969) on a rocket flight in which simultaneous measurements of temperature were obtained, found nitrogen oxide concentrations exceeding those of Barth, and accompanied by temperatures much less than the CIRA extreme. The rocket measurements were obtained in twilight, and Pearce
suggests that the reaction \( \text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2 \), with a time constant of 3-5 hours (using night-time ozone densities predicted by Hunt, 1966) will result in the removal of NO during the night. Popoff and Whitten (1969) rule out the possibility of an observable cosmic X-ray effect on the ionosphere on the basis of the direct measurements of NO, in conflict with the data of Edwards and Ananthakrishnan et al. They do not consider the possibility of variation in NO concentration after sunset.

Figure (8.7) shows the electron production rates for isotropic fluxes of \( \phi_0 = 1, 0-3 \) and \( 5, 0-3 \) ergs cm\(^{-2}\) sec\(^{-1}\) ster\(^{-1}\) on the CIRA mean atmosphere using NO concentrations given by (8.4). The dashed curves are for the CIRA extreme atmospheres (maximum positive deviations of density \{applied to both \( n(\text{O}_2) \) and \( n(\text{O}) \)\} corresponding to maximum negative deviation in temperature, and vice versa), and with \( \phi_0 = 1, 0-3 \). Above about 70-75 km, the \( q(h) \) profile corresponds to the NO profile, below 70-75 km absorption by \( \text{O}_2 \) dominates. In the "mean" curves and the maximum positive density deviation curve above 90 km, the profile is determined by \( n(\text{O}) \), while for the negative deviation curve, the temperature term of (4) dominates.

Figure (8.7) also shows \( q(h) \) for the twilight nitric oxide concentration given by Pearce (1969) again for \( \phi_0 = 1, 0-3 \).
The first night-time observation of Lyman beta (Lβ) has been made by Young et al (1968) who observed an emission rate of 5-10 rayleighs above 215 km. The ionization due to this flux is shown for the CIR: mean and extreme atmospheres in figure (8.7), as dotted lines. The Lyman beta is absorbed in O₂ with a cross-section of 1.52 \times 10^{-18} \text{ cm}^2, and ionizes O₂ with an efficiency of 0.64 (Samson and Cairns, 1964). The Lβ profile will also be subject to a solar cycle variation of about a factor of 2 (Meier, 1969).

8.7 VLF TECHNIQUES

An increase in electron production rate implies an increased electron population (dependent on the effective recombination rate) and also some fluorescence of the atmosphere as a result of recombination processes. Ground based detection of optical or infra-red fluorescence in the D-region is in general hampered by large amounts of similar fluorescence from higher in the ionosphere, but within the line of sight of the detector. VLF radio waves transmitted from the surface of the earth, however are reflected at the relatively rapid changes in electron density in the D-region, which at night occur about the height of the X-ray perturbations predicted in the previous subsections. Edwards (1969) and ananthakrishnan and Ramanathan (1969) both use
VLF waves propagated over long distances to observe the effect of Sco XR-1, the former employing measurements of the phase change in the signal the latter changes in the field strength.

Wait and Walters (1963a,b,c) have studied the reflection of vertically polarized VLF waves at high oblique incidence, off horizontally stratified layers of an inhomogeneous isotropic medium whose effective conductivity varies smoothly with height. The undisturbed conductivity profile is given in terms of the conductivity parameter $1/L(Z)$ where

$$1/L(Z) = \exp (\beta Z)/L$$  \hspace{1cm} (8.5)

$\beta$ is a gradient parameter, $Z$ the height above a reference level $Z = 0$ and $L$ is a constant which for VLF is given by

$$L \approx \frac{\omega w}{\omega_0^2}$$

Here $\omega$ is the angular frequency, $\omega_0$ the plasma frequency and $\nu$ the collision frequency.

In general

$$1/L(Z) \propto N(Z)/\nu(Z)$$  \hspace{1cm} (8.6)

where the electron density at altitude $h = (\text{ref. level} + Z)$, for an electron production rate $q$ and loss rate $\psi$ is

$$N(h) = \left\{ \frac{q(h)}{\psi} \right\}^{\frac{1}{2}}$$  \hspace{1cm} (8.7)

Wait and Walters (1963b) have introduced a Gaussian perturbation in electron density,

$$\Delta N(Z) = \Delta N_0 \exp \left\{ -\left( \frac{Z - F}{D} \right)^2 \right\}$$
and assuming a collision frequency profile of the form

\[ v(z) = v_0 \exp(-\beta z/2) \]

(8.8)

obtain a conductivity profile

\[ \frac{1}{L_z} = \frac{1}{L(0)} \left[ \exp(\beta z) + \frac{\Delta N_A}{N_0} \exp \left[ \frac{\beta z}{2} - \left(\frac{z-F}{D}\right)^2 \right] \right]. \]

This is used to calculate and plot the reflection coefficient and phase angle for the case of 20kHz waves {implying \( L(0) = 0.5, \beta = 0.3 \text{km}^{-1} \)} with a range of values for the spread \( D \), and height \( F \) of the perturbation. The reflection coefficient depends on the angle of incidence onto the reflecting layer and values around \( 80^\circ \) are included, appropriate to propagation of VLF over long distances. The results apply to daytime conditions, but at night (8.8) decreases much more rapidly with height (Mitra, 1968). General features of the results applicable at night, and also in the case of a hyperbolic perturbation (Wait and Walters, 1963c), are

1. the magnitude of the reflection coefficient may either increase or decrease within the expected ranges of the parameters
2. the phase angle is only affected in a manner corresponding to a lowering of the reflection height.

Measurements of phase angle therefore provide a more satisfactory means of detecting a disturbance, particularly if superposition of records is necessary.

Even in the absence of the sharp night time recombination profile the exponential perturbation is
generally applicable because of interstellar absorption. In view of the night time recombination, a narrow disturbance (D = 2 km) is used here in applying Wait and Walters results to obtain a rough estimate of the magnitude of the expected VLF effect. In the absence of Lyman alpha effects, (figure 8.7) and for reflection near the equator (figure 8.6) Sco X-1 would have produced a $\Delta N_0/N_0 = 2$ in 1965 (figures 8.1, 8.3b). The phase then increases about 50° from the undisturbed wave. This corresponds to approximately 7 μsec in a 20kHz wave compared to a typical diurnal phase variation of around 100 μsec amplitude.

Records of the phase and field strength of VLF signals received at Melbourne from NLK/NFG(18.6kHz), Washington DC, were kindly provided by the Defence Standards Laboratories, Victoria, for the period July-August, 1969. These were inspected for an effect due to Cen XR-4. Unfortunately the transit times of the source over the propagation path correspond to the "sunset phase" of the records (when Lyman alpha is expected to dominate a cosmic X-ray effect in the D-region). The records are disturbed about the dates and times of Cen XR-4 birth and transit. The absence of a "quiet time curve" and of a familiarity with the types of disturbance (including instrumental) frequently seen on the records precludes any definite statement on a cosmic X-ray effect at this time.
8.8 CONCLUSIONS

(1) The diffuse X-ray background is an extremely constant source of ionization between 80 and 90 km. The source will be stable in time but may contain some small anisotropies over the galaxy. There is no interplanetary modulation and the electron production profile is practically independent of atmospheric density variations in this altitude range (assuming that the density at, e.g. 80 km, varies in the same fashion as the integrated densities immediately above 80 km). The contribution to the total electron population in this altitude range is nearly a factor of 4 greater than that due to galactic cosmic rays near the equator, and, depending on season and solar activity, becomes equal to the cosmic ray contribution at geomagnetic latitudes between 35 and 45°.

(2) The strong source Sco XR-1 produces electrons at a peak rate which has exceeded that due to the diffuse flux since 1965, for source zenith angles less than about 20-40°. The X-ray flux has exhibited a steady over-all decline in intensity so that at the present time the ionospheric effect of Sco XR-1 at zenith and the diffuse X-ray flux should be very similar. An ionospheric effect due to Sco XR-1 was apparently observed in 1960 (Ananthakrishnan and Ramanathan, 1969) prior to its discovery by rocket. If the source continued to increase in intensity going back in time, the
effect should be even more pronounced, and (subject to factors discussed below) early ionospheric records may even contain a nova-like appearance of X-rays. Short term "flares" have apparently been observed, superimposed upon the overall decline. Such "flares" appear to be associated with changes in spectral "hardness" of the source with a corresponding change in height of the peak electron production.

(3) On two occasions since 1967, X-ray sources have "flared" to brightnesses greater than or equal to that of Sco XR-1. A characteristic sudden appearance of such sources plus gradual decline should facilitate ionospheric detection, however direct interpretation from such records will be hampered by variations with time of the source spectral "hardness".

(4) All other recorded cosmic X-ray sources give ionospheric effects small compared with the diffuse X-ray background plus cosmic rays.

(5) The Lyman alpha production is critically dependent on the atmospheric nitric oxide profile and its variations. At concentrations of NO obtained from direct observations at twilight, the reaction

\[ \text{L} \alpha + \text{NO} \rightarrow \text{NO}^+ + e^- \]

will dominate electron production above 70 km and will exceed the night time X-ray contributions between 80 and
90 km by more than an order of magnitude. The observation of ionospheric effects due to X-ray sources implies that the night time NO concentration is very much smaller than the measured values, at least during portion of most nights. If a nitric oxide concentration similar to that given by Mitra, 1968, applied during portion of the night, and a major part of the Lyman alpha is of solar origin, then winter temperatures at solar maximum will result in electron production rates at 85 km exceeding that due to the diffuse background by as much as a factor of 5, while the production in the "mean" atmosphere never exceeds that due to the diffuse flux at this altitude.

(6) Electron production due to Lyman beta has little effect below 90 km but is quite important above this altitude.

(7) Obviously, the observations and interpretation of night time ionospheric effects associated with the altitudes 80 to 90 km must be made with due consideration to a large number of factors, e.g.

latitude (low cosmic ray fluxes and small seasonal density variations are associated with low latitudes);
galactic co-ordinates of the zenith (associated with galactic sources of X-rays and Lyman radiation);
local time (small Lyman fluxes are associated with the anti-
solar direction, small nitric oxide concentrations are
apparently associated with the late hours of night, and
there will be diurnal variations in other constituents,
including hydrogen in the geocorona, Anderson and Francis,
1966);
season (affecting the atmospheric densities and temperature,
particularly at high latitudes);
solar activity (sunspot maximum is associated with large
Lyman fluxes and small cosmic ray fluxes and vice versa,
and there will be some variation in atmospheric densities —
including hydrogen).
FIGURE CAPTIONS

FIGURE 8.1  The electron production rate $q(h)$, as a function of altitude for the diffuse X-ray spectrum of Gorenstein et al (1969), showing the effects of density variations in the atmosphere.

FIGURE 8.2  The $q(h)$ profile for different measurements of the diffuse X-ray spectrum. The separate contributions to the Seward et al (1967) spectrum of photons between 1-2 keV, 2-5 keV and 5-10 keV are shown by dashed lines. The dotted line shows an upper limit to the contribution of 0.25-0.4 keV photons.

FIGURE 8.3(b) The q(h) profiles for Sco XR-1 at 0° zenith using data of Chodil et al, and Mark et al, (LRL) and Gorenstein et al (ASE) from Figure 8.3(a). The solid lines are taken to represent a steady decline in Sco XR-1 intensity over 4 years, the dash and dot lines unusual spectra or flares.

FIGURE 8.3(c) The q(h) profiles for the 18May.67, LRL Sco XR-1 spectrum are shown as a function of source zenith angle.


FIGURE 8.4(b) The q(h) profiles for the observation of Cen XR-2 (solid lines) and for an arbitrary peak intensity (22 March 1967) and half peak intensity during increase (19 March 1967), (dashed lines). Zenith angle is 40°.

FIGURE 8.5 The q(h) profiles for Tau XR-1 and the Galactic centre group of X-ray sources, for a 0° zenith.

FIGURE 8.6 The q(h) profiles for galactic cosmic rays shown as a function of geomagnetic latitude (λs) and season (Velinov, 1968).
FIGURE 8.7  Estimates of $q(h)$ due to Lyman alpha and beta in the night time sky. The solid curves represent $I_\alpha$ estimates at solar maximum, and solar minimum (possibly similar to an anisotropic galactic contribution), using the nitric oxide intensity profile of Mitra (1968). The dashed curves correspond to this solar minimum profile for the CIRa extreme atmospheres. The dot-dash curve corresponds to solar minimum, with a nitric oxide concentration measured at twilight by Pearce (1969). The dotted curves are $q(h)$ profiles for a $I_\beta$ flux, as measured by Young et al (1968), on the CIRa mean and extreme atmospheres.
FIGURE 8.1 DIFFUSE X RAYS (DENSITY DEVIATIONS)
FIGURE 8.3(b)  SCO XR-1
(0° ZENITH)

Altitude
km.

ASE  8MAR 66.

LRL  29SEPT 67.

LRL:  9MAY 68.  18MAY 67.  28JUL 66.  2JUN 65.

q(h) electrons. cm^-3. sec^-1.
FIGURE 8.3(c) SCO XR-1
(18MAY 67)
FIGURE 8.4(a)
Figure 8.4(b) CEN XR-2
(40° Zenith)
FIGURE 8.5 TAU XR-1, GALACTIC CENTRE
(0° ZENITH)
Figure 8.6 Galactic Cosmic Rays
(Velinov, 1968)

- Solar max - summer
- Max - winter
- Min - summer
- Min - winter

Altitude (km)

$q(h)$ (electrons cm$^{-3}$ sec$^{-1}$)

Angles:
- $\lambda_m = 41^\circ$
- $\lambda_m = 0^\circ$


REFERENCES


Agrawal, P.C., Biswas, S., Gokhale, G.S., Iyengar, V.S.,
Kunte, P.K., Manchanda, R.K., and Sreekantan, B.V. 1969,
Nature, 224, 51.

Agrawal, P.C., Biswas, S., Gokhale, G.S., Iyengar, V.S.,
Kunte, P.K., Manchanda, R.K., and Sreekantan, B.V. 1969a,


Alkhazov, G.D., Komar, A.P., and Vorob'ev, A.A. 1967,

Allen, S.J.M., taken from CRC Handbook of Chemistry and Physics,

Aller, L.H. 1961, Abundance of the Elements, p 179,
Interscience, New York.


Council publication 1133, Washington D.C.


Diethorn, W. 1956, quoted from Williams and Sara (1962).


Herbert, P.J. 1967, "Determination of the Attitude of the Skylark Rocket in Free Space", presented to the A.I.A.A. Sounding Rocket Vehicle Technology Specialist Conference, Williamsburg, Virginia, U.S.A.


Kocharov, G.E., and Naidenov, V.O. 1964, presented at 14th All Union Conf. on Nucl. Spectroscopy, Tbilisi.


Snell, A.H. 1962, Nuclear Instruments and Their Uses, Volume 1, John Wiley and Sons Inc.


Symon, K.R. 1960, Mechanics, Addison-Wesley, Massachusetts.


