relatively large uncertainty of this earlier value, little can be inferred about the radio spectrum from Sco X—1 from these two measurements. In addition, the time variation reported herein would indicate that spectral information should be derived from simultaneous measurements at different wavelengths, unless long-term mean values can be regarded as stable and meaningful.

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1 Andrew, B. H. and Purton, C. R., *Nature*, **218**, 855 (1968).
2 Sandage, A. R., Osmer, P., Giacconi, R., Gorenstein, P., Gursky, H., Waters, J., Bradt, H., Garmire, G., Sreekantan, B. V., Oda, M., Osawa, K. and Jugaku, J., *Ap. J.*, **146**, 316 (1966).
3 Gursky, H., Giacconi, R., Gorenstein, P., Waters, J., Oda, M., Bradt, H., Garmire, G. and Sreekantan, B. V., *Ap. J.*, **146**, 310 (1966).
4 Gursky, H., Giacconi, R., Gorenstein, P., Waters, J., Oda, M., Bradt, H., Garmire, G. and Sreekantan, B. V., *Ap. J.*, **144**, 1249 (1966).
5 Mook, D. E., *Ap. J. (Letters)*, **150**, L25 (1967).
6 Stepien, K., *Ap. J. (Letters)*, **151**, L15 (1968).
7 Hiltner, W. A. and Mook, D. E., *Ap. J. (Letters)*, **150**, L23 (1967).
8 Lewin, W. H. G., Clark, G. W. and Smith, W. B., *Ap. J.*, *(Letters)*, **152**, L55 (1968).
Lewin, W. H. G., Clark, G. W. and Smith, W. B., *Ap. J. (Letters)*, **150**, L153 (1967).

The Development of UAT Rocket Instrumentation for X-ray Astronomy

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The Universities of Adelaide and Tasmania (UAT) have now collaborated in the preparation of four experiments on British Skylark rockets. Two independent X-ray detectors of total sensitive area 40 cm^2 were flown on each of two rocket flights launched in April, 1967. The most significant result of these measurements was the discovery of Cen XR-2 and the measurement of the variation in its intensity and spectrum.[1] The third flight, launched in December 1967, carried three X-ray detectors of total area 140 cm^2. One of the main results from this flight, evidence for a new X-ray source at high galactic latitude, will be presented in the following paper.[2]

The fourth experiment, scheduled for launching from Woomera in December 1968, and referred to as Flight IV in the remainder of this paper, is partially illustrated in Figure 1.* Three pairs of identical 'back-to-back' detectors are mounted beneath an ejectable nose cone. In addition, a modified version of the instrument flown on the third flight is included below the nose cone. Total sensitive detection area is 2100 cm^2.

The detectors used in all these experiments are gas-filled proportional counters with thin 'windows' of beryllium or of the organic films polypropylene or polyethylene terephthalate (the latter obtainable from ICI as 'Melinex'). X-ray photons passing through a collimator and penetrating the window have a high probability of being absorbed in the counter gas by the photoelectric effect, provided their energies are less than about 10-12 keV. The ionization thus produced in the counter gas is proportional to the energy of the X-ray photon and, when the counter is operated in the proportional region, the voltage pulse produced at the anode is also proportional to the photon energy. The basic principles of the detector system and the associated electronics are illustrated in Figure 2.

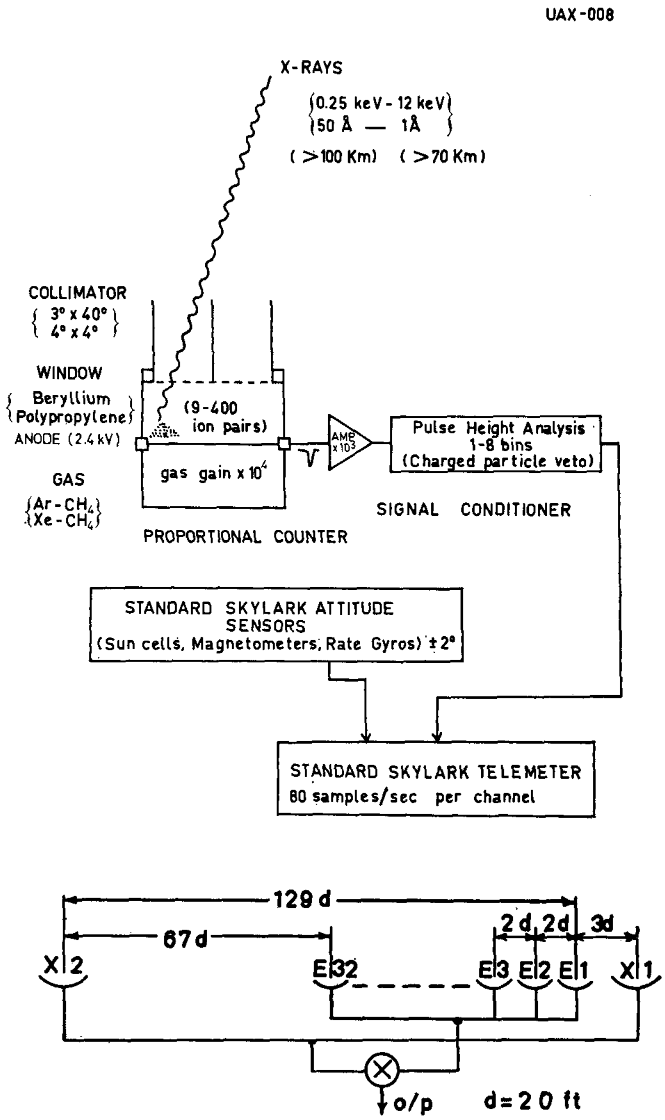

Figure 2. Basic UAT Skylark experiment, illustrating typical detector and rocket limitations.

The programme is aimed at providing information on the following aspects of X-ray astronomy : (i) the discovery and location of new sources of X-rays, (ii) the intensities and spectra of known and new discrete X-ray sources, (iii) variations in the intensities and spectra of these sources, and (iv) the nature of the 'diffuse X-ray flux'.

Each of these aims will be discussed briefly with particular reference to Flight IV.

(i) The discovery and location of new X-ray sources can result from either scanning regions of sky with improved sensitivity or from scanning an area of sky in which an

*See Plate IX.

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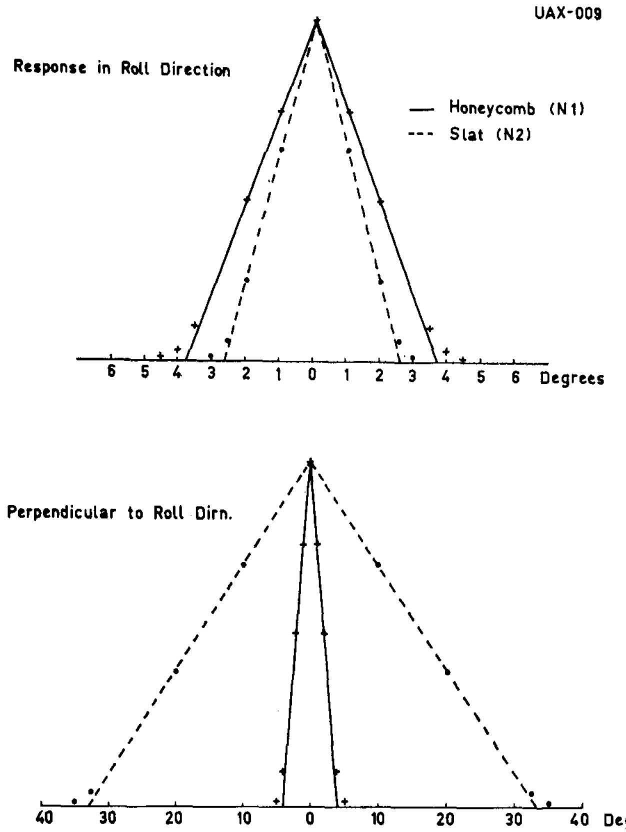

Figure 3. Measured collimator responses of the N1 and N2 detectors.

X-ray flare has occurred (Cen XR-2 being the one conclusive example of this type of phenomenon).

On Flight IV, besides the major increases in sensitivity to point sources due to the increased area, the contribution to the observed counting rates of cosmic ray charged particles is minimized by vetoing all pulses from either side of a pair of 'back-to-back' detectors which coincide with pulses from the other side. It is estimated that this will result in the rejection of 80% of pulses due to charged particles.

The point source sensitivity of the largest area pair of nose cone detectors is further enhanced by using a collimator of small acceptance angle (4°FWHM); resulting in a reduced response to the diffuse X-ray background. These improvements should result in the detection (in a single scan with one of the N1 counters in Figure 1) of a source whose intensity is 1/200 the intensity of Sco XR-1 compared with 1/20 of Sco XR-1 in the first two flights.

The two pairs of smaller nose cone counters in Flight IV have a slot type collimator. The measured collimator responses for the nose cone counters in Flight IV are illustrated in Figure 3.

Source location relative to the rocket axes is obtained by a least-squares fitting technique of the count rate data to the collimator responses. The standard Skylark attitude sensors allow the rocket axes to be fixed to within $\pm 2°$ in favourable conditions (e.g. large separation of sun and magnetic vectors, consistent sun sighting etc.). In Flight IV, an additional UAT sun cell at 45° to the rocket zenith, plus two fish-eye cameras which will photograph the horizon at known times, together with a knowledge of the positions of known X-ray stars should permit this accuracy or better.

(ii) The spectral information on the first generation experiments was obtained from two channel pulse height analysis of the 2-8 keV detector responses. In Flight IV the energy range has been extended from 0.25 keV to 12 keV and multi-channel analysis of up to eight channels is included. This information for the nose cone detectors is illustrated in Figure 4. (Two of the detectors below the nose cone have similar efficiency, energy resolution and pulse height analysis as the N2 counters.) A 1 μ

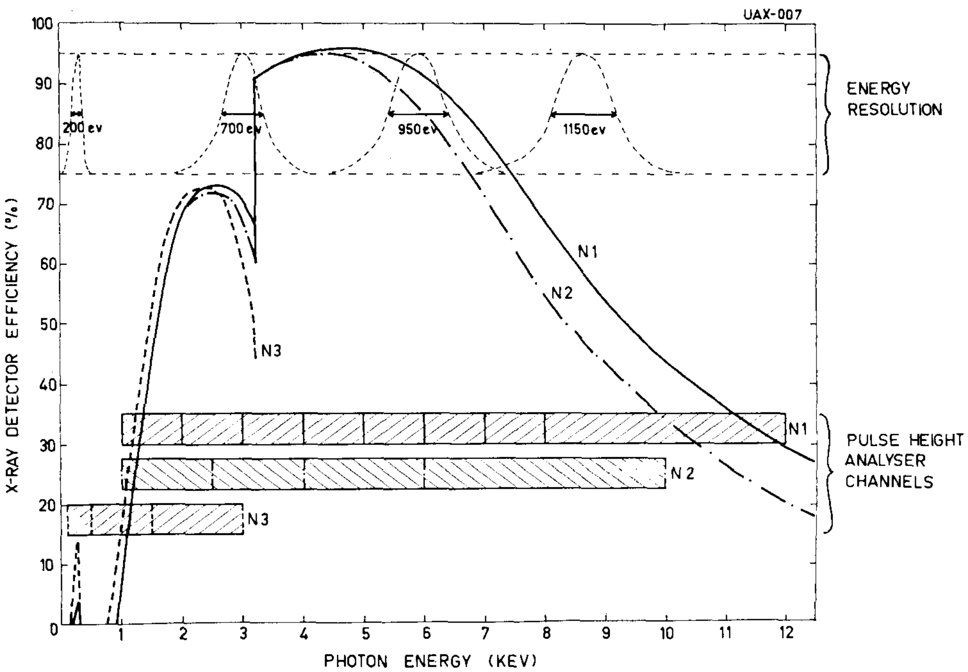

Figure 4. UAT Flight IV detector responses.

polypropylene window (plus 1000Å of aluminium) is used as a window on N3 and the carbon Kα absorption edge is used to permit measurement of X-rays $\leq$ 0.28 keV ($\geq$ 44Å). Emphasis has been placed on accurate pre- and in-flight calibration. Counter proportionality and energy resolution have been checked using radioactive photon emitters and X-ray fluorescence techniques. On the eight counters referred to above, small radioactive Fe^{55} samples (which emit Manganese Kα X-rays of 5.9 keV) have been included in the flight package and will illuminate the counters below 70 km on ascent and descent and for 5 seconds at apogee.

The intensity of the stronger sources is best obtained from the slat collimator detectors (N2, N3 and the two detectors below the nose cone) in which the count rate is not critically dependent on the collimator response. In all of the large area nose cone detectors, large dynamic count rate ranges have been achieved by UAT sub-commutation which is synchronous with the Skylark telemeter multiplexing.

(iii) The study of long-term variability of source intensity and spectra has been achieved by comparing results from different flights and with a variety of detection systems. Accurate calibrations and knowledge of detector and logic performances must be relied on. It is hoped that attention to these factors with a large number of independent detection systems on Flight IV will ensure dependable results.

(iv) Most measurements of the diffuse X-ray background have resulted from comparison of detector count rates when the detector points towards and away from the Earth (and not in the direction of known X-ray sources). A terrestrial X-ray albedo (of reflected solar X-rays) was discovered from results of our April 1967 flights[1] and must be considered in any such experiment. One of the detectors below the nose cone in Flight IV has a prescaled output to measure the solar X-ray flux and permit calculation of this albedo.

The results of our first flights also suggested the possibility of contamination of diffuse X-ray measurements by precipitated low energy electrons from the Van Allen belt, particularly at times of sunspot maximum. To this end, Flight IV also carries a small two-window proportional counter, with one of the windows being swept free of low energy electrons by a permanent magnet.

The great variety of collimator solid angles on Flight IV provides a considerable variation in sensitivity to a diffuse background flux, which will assist in accurate determinations of this flux.

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[1] Harries, J. R. and Francey, R. J., *Aust. J. Phys.*, **21**, 715 (1968).
[2] Barnden, L. R. and Francey, R. J., *Proc. ASA*, **1**, 236 (1969).

RADIATION THEORY

Stark Broadening in the Two-level Approximation

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The study of line-broadening mechanisms puts at our disposal an extremely useful tool for the investigation of physical conditions in plasmas, both stellar and laboratory.

In studying line-broadening, we usually make one of two approximations depending on the motion of the perturbing particles. If the perturbers are ions, their velocity is small and their interaction with the radiating atom is strong; we make the quasi-static approximation that all collisions are adiabatic, and, considering the ions as stationary, average over all possible configurations of the perturbers. For electrons on the other hand, their higher velocity means that the collision time, $\tau \sim \rho/v$, is of the order of the orbital period of the atomic electron. An impact theory which takes into account non-adiabatic collisions must be used to determine the electronic contribution to the width and shift.

From the impact theory, if we consider the duration of a collision to be negligible, it can be shown that the width and shift parameters, w and d, of a spectral line are given by[1]

$$w + \mathrm{i}d = 2\pi N \int_0^\infty v f(v)\mathrm{d}v \int_0^\infty \{1 - \langle u\,|S(\rho)|\,u\rangle\}_{\mathrm{av}}\,\rho\,\mathrm{d}\rho,$$

where $f(v)$ denotes the electron velocity distribution, ρ the impact parameter of collision, $\{\ \}_{\mathrm{av}}$ the average over angles of orientation between perturber and radiating atom, and $\langle u\,|S(\rho)|\,u\rangle$ the diagonal element of the S-matrix for the collision. The S-matrix element can be written as $\mathrm{e}^{-[\Gamma(\rho) + \mathrm{i}\eta(\rho)]}$.

In the GBKO theory,[2] on the other hand, the solution for the S-matrix is only taken to first order, which is equivalent to a first order expansion of the exponential term

$$\langle u\,|S(\rho)|\,u\rangle \approx 1 - (\Gamma + \mathrm{i}\eta).$$

The width and shift in the GBKO theory is expressed in terms of two functions, $a(z)$ and $b(z)$; the former diverges for small impact parameter.

A cut-off impact parameter, ρ_{min}, was introduced to obtain convergent solutions; this is the value of ρ at which the matrix elements of the interaction are of the order of unity. It is assumed that collisions with $\rho < \rho_{\mathrm{min}}$ (i.e. strong collisions) broaden according to the Lorentz theory. This choice of a cut-off has been criticized by van Regemorter,[3] who suggests that a separate cut-off be applied for each state which perturbs the upper level of the line under consideration.

In the limit of low temperatures (when the electron velocity is small and all collisions are adiabatic), the width and shift can be solved analytically to yield the Lindholm[4]-Foley[5] result. At high temperatures, these should be derived from the Bethe-Born formula for excitation cross-section. In order to reduce the GBKO expressions to these limits, arbitrary factors were introduced in both the strong and weak collision terms.

This rather unsatisfactory feature of the GBKO theory can be overcome if we do not expand the exponential function. We find we have the correct limiting cases (without the introduction of *ad hoc* factors) and no divergence for small impact parameters; there is also a more realistic variation for intermediate temperatures.