ROCKET OBSERVATIONS OF VIRGO XR-1

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Skylark 723, launched at 10.30 GMT on 12th June 1968 was an unstabilised rocket carrying two proportional counter detectors, each of 1385 cm^2 effective area. Detector C1 covered the energy range 1.4 to 2.5 keV and detector C2 the range 2.0 to 18 keV. The detector outputs were analysed into 4 and 9 energy channels respectively. The field of view of each detector was 28° and 4° (FWHM) with the greater collimator extension mounted parallel to the longitudinal rocket axis for C2 and $\frac{6}{10}$ of the C1 detector, the remaining $\frac{4}{10}$ of the C1 collimator being canted at 40° to the major axis. During the flight, the rocket spun at a constant rate of 75° per sec whilst the spin axis slowly precessed about a flat cone, thereby surveying some 80% of the visible sky. On 25 consecutive scans the Vir XR-1 source, which by chance lay near the precession axis, crossed the field of view of both detectors. The count rate profiles for twenty scans in which the source passed within 21° of the centre of the field of view have been added together for each detector, resulting in the totals shown in Figure 1. Significant peaks are seen in the position of Vir XR-1 for both detectors and these have been fitted with the measured transmission profiles of the respective collimators assuming

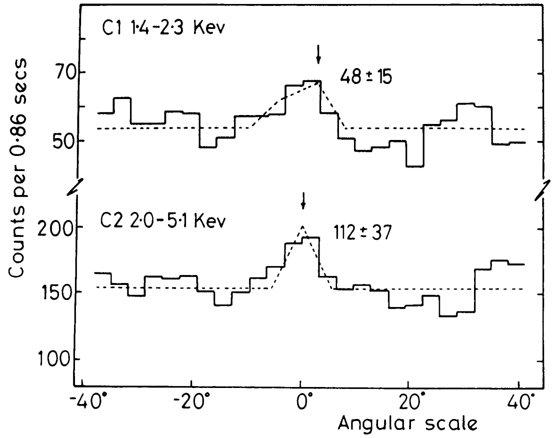

Fig. 1. The count rate histograms of each detector from the flight of 12th June. Data from 20 scans passing through the Virgo region have been added for each trace and the position of the Virgo XR-1 source is arrowed. The apparent 2° difference between the C1 and C2 peaks is in agreement with pre- and post-flight measurements of the relative detector alignment. Each count plotted is a running mean over two 3.2° intervals and corresponds to an accumulation time of 0.86 sec.

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parallel incident radiation. The peaks are consistent with the observation of X-rays from a single point source.*

Skylark 403, launched at 0605 GMT on 8th July, was equipped with a sun-pointing attitude control system and roll control was obtained by reference to magnetic field sensors. Two small X-ray proportional counters, each of 25 cm^2 effective area, were mounted, viewing at 76° to the sun-pointed rocket axis. The detectors were collimated to 20 arc min and 3.5° (FWHM) respectively (in a direction parallel to the longitudinal rocket axis), both having a 10° field of view in the rocket spin plane. During the 250 sec of stabilised flight, the two detectors were scanned four times, back and forth, across the region of sky containing the source Vir XR-1. The correct pointing was verified later by an on-board star camera. A systematic increase in count rate was observed in the direction of the source by the more coarsely collimated detector and the spectral analysis of these source counts has been used in the present paper. The finely collimated detector recorded no significant source counts, a result consistent with the flux measured by the other detector, and therefore no additional information can be given about the precise position of Vir XR-1.**

The spectral results of the two rocket experiments are summarised in Figure 2. The source counts from the June flight have been divided into seven energy channels and those from the July flight into two channels. The error bars on each individual point are quite large, owing to the limited counting statistics in a single channel, but the overall evidence for a continuously rising spectrum at least to 1.5 keV is good. This result is not in agreement with that of Bradt *et al.* [1] which indicated a flat photon spectrum near 2 keV and suggested that there might be significant absorption at this energy. It is noteworthy that the present data also indicate a source strength about three times as high as that found by Bradt *et al.*, and in better agreement with the measurements of the NRL group [2, 3]. The greater intensity recorded by the four NRL and Leicester experiments is in part consistent with the absence of a low energy cut-off in the Vir XR-1 spectrum since all four experiments had thin plastic window detectors, giving significantly greater sensitivity below 2.5 keV than the MIT groups beryllium window detectors. The intensity of the Vir XR-1 source from the present data is 1.5×10^{-9} ergs cm^2 sec in the energy range 1.5 to 5 keV.

Finally, it is interesting to speculate briefly on the proposed identification of Vir XR-1 with the radio galaxy M87 and, in particular, on the possibility that the X-radiation arises from synchrotron emission of the relativistic electrons in the optical jet. It is widely believed that both the 'core' radio emission and the polarised, blue continuum of M87 arise from synchrotron emission in the jet and Shklovskii [4] has suggested that the X-ray observation of Vir XR-1 represents an extension of this spectrum into the kilovolt range. The X-ray spectral data presented in Figure 2 are

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* It may be noted that the method of addition will tend to smooth out count rate peaks for any sources away from the Virgo region, but separate examination of the data has shown only one other discrete X-ray source in the high latitude sweep covered by the data of Figure 1. This is a weak source in Crater which gives rise to some excess counts to the left of the Virgo peak in Figure 1, particularly on the C1 trace. The Crater observation will be reported in a separate paper.

** This experiment was originally intended to observe the (briefly) much stronger source Cen XR-2.

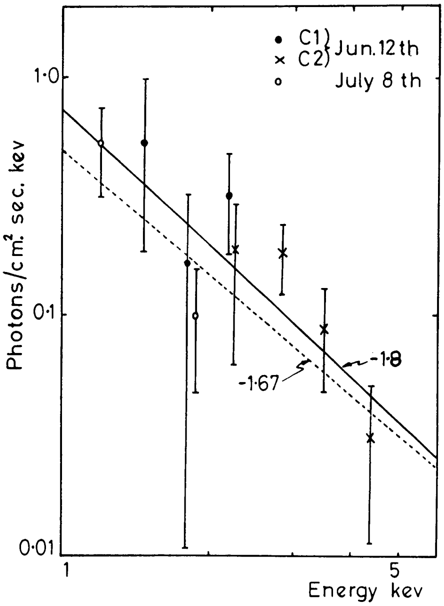

Fig. 2. The differential photon spectrum of Virgo XR-1 using the results of both rocket flights. Solid circles represent results from the C1 detector and crosses from the C2 detector of the June 12th flight. The full lines represent the best fit to all the data points and the dashed line the extrapolation of the core-radio spectrum.

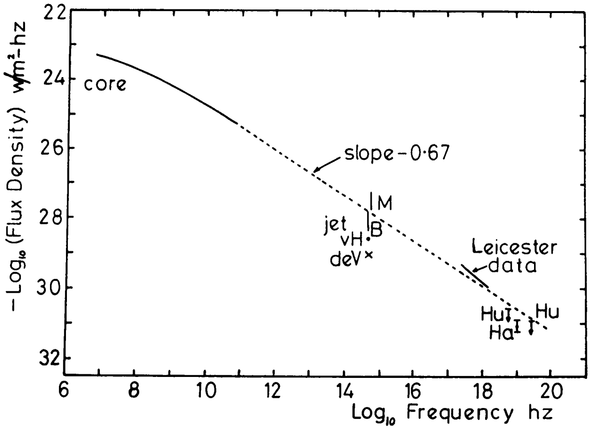

Fig. 3. The X-ray spectrum of Figure 2 is plotted together with the M87 core-radio spectrum extrapolated to high frequencies (after reference [6]), optical results from the M87 jet and some published high-energy X-ray data (see refs. [6–8]).

consistent with a power-law spectrum (though admittedly the energy band is insufficient to *prove* such a fit) as would be likely for a synchrotron source. More convincing, perhaps, is the evidence of Figure 3 in which the X-ray data have been plotted together with the M87 core-radio spectrum and various optical measurements of the jet. The overall fit to the extrapolated radio spectrum, with a power-law index of 0.67, is certainly remarkable over 9 decades of frequency. A well-known difficulty for the synchrotron mechanism, even at optical frequencies, is the short-lifetime of the radiating electrons. Shklovskii [5] and others have discussed a model in which a proton flux in the jet interacts with the ambient gas, producing a continuous supply of energetic electrons by ϱ-π-μ-e decays. As Felten [6] has pointed out, the occurrence of X-ray synchrotron emission would conflict with this model owing to the non-observation of 10^{13} eV γ-rays. Independent evidence against the secondary production model is provided by the absence of absorption in the X-ray spectrum, if this emission does indeed arise in the jet. Examination of Figure 2 indicates an optical depth at 1.5 keV of less than 0.5, corresponding to a neutral gas column of less than 5×10^{21} atoms (of cosmic abundance) per cm^2. The maximum gas density in a column 36 pc deep (0.5 arc sec [7, 8] is thus 100/cm^3, compared with 700/cm^3 necessary to prevent the jet being disrupted by its internal cosmic ray pressure [7].

In summary, it appears that the M87 jet is a source of intense optical and radio synchrotron emission, possibly extending up to X-ray frequencies. The latest optical studies [7, 8] show the optical emission arising mainly from three intense 'point sources', probably less than 1 arc sec in diameter and with some indication of fine structure. Moreover, there appears to be no evidence for the large gas densities required to confine the jet, either gravitationally or as the seat of ordered magnetic fields. We therefore propose a model analogous to, though on a much larger scale than that outlined recently by Burbidge and Hoyle for the Crab Nebula supernova remnant [9]. Thus in the case of M87, the visible radiation in the jet is envisaged to arise in the magnetospheres of massive, coherent fragments presumed to be thrown out from the galactic nucleus [10] perhaps a million years before. Continuous ejection from these fragments maintains the supply of energetic electrons and the required magnetic fields are anchored in the condensed objects. With this model, the absence of both optical emission lines and of X-ray absorption effects may be readily explained, whilst the electron lifetime and jet containment problems do not arise. The X-ray emission region might be very localised in each source and it is an intriguing possibility that the differences in measured flux referred to earlier could represent real variability.

Acknowledgements

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