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X-RAY SPECTRA FROM SCORPIUS (SCO-XR-1) AND THE SUN OBSERVED ABOVE THE ATMOSPHERE*

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An important question which must be answered about the recently discovered stellar x-ray sources is the nature of the emission spectrum of these sources. Several experiments[1-5] have been performed in the past few years and a number of theoretical models[6,7] have been proposed to explain the observations. To obtain more precise information about the spectrum of the x-ray source in Scorpius (SCO-XR-1),[1] a proportional counter sensitive to photons with quantum energies between 2 and 20 keV was flown on a rocket. With this detector and a special telemetry system it was possible to measure the spectrum in this energy region with high resolution.

The counter employed in this experiment was a proportional gas counter filled with a 90%-10% xenon-methane mixture at atmospheric pressure; it had a resolution of 20% full width at half-maximum, at 5.9 keV. The counter window was made of 3-mil beryllium and had a rectangular shape with an area of 8.67 cm^2. Surrounding the counter (except over the window and over one end) was $\frac{1}{8}$ in. of plastic scintillator which was viewed by an RCA 4440 photomultiplier. This scintillator functioned as an anticoincidence shield against high-energy charged particles in cosmic rays. In addition, $\frac{1}{4}$-mil aluminized Mylar was placed over the counter window to protect the scintillator from light. The proportional counter was collimated to a transmission half-angle of ±10° in azimuth and ±45° in elevation, and it had a geometric factor of 3.41 cm^2 sr. The calculated efficiency of the proportional counter as a function of quantum energy is shown in Fig. 1.

The counter was mounted on an Honest John-Nike-Nike rocket which was launched on 12 June 1965 from Kauai, Hawaii. The launch time was 1515 hours UT, which was 39 minutes before local sunrise. At that time, the zenith coordinates were 22 hours right ascension and +22° declination. The rocket was launched towards an azimuth of 340° and 5° from the zenith and reached an altitude of 170 km. Apogee of the flight occurred at 160.0° W and 22.5° N at 1518 UT.

An Fe^{55}, Cd^{109} source was mounted on the inside of the nose cone for continual calibration during launch. The nose cone and this source were detached from the vehicle at an altitude of 88 km. Data were taken for the next 275 sec. The payload was spin-stabilized with a spin rate of 6.0 rev/sec, and was observed to precess in a cone of half-angle 3° with a frequency of 0.11 rev/sec. Therefore, the rocket spin vector pointed at a spot on the celestial sphere which traced out a circle of radius 3°, the center of which was located at 21 hours 50 min. right ascension and 27° declination. Scorpius was scanned every revolution during this time, and the x rays from the sun were detected during the 70-sec period centered on apogee during which the sun was high enough above the rocket's horizon so that atmospheric absorption did not completely attenuate the x rays. At apogee there was approximately 6×10^{-3} g/cm^2 of atmosphere between the counter and the sun.

Signals from the proportional counter were amplified and lengthened to 1.2 msec. This was done only with pulses not accompanied by

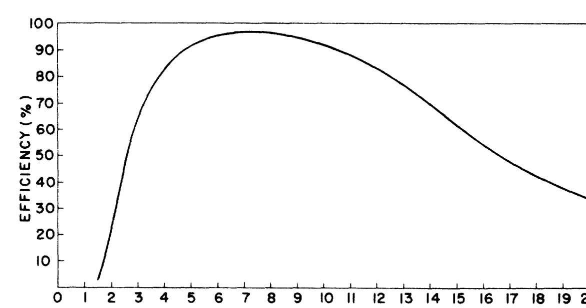

FIG. 1. Efficiency of Xe-CH_4-filled proportional counter as a function of x-ray energy.

a signal from the plastic scintillator. These wide pulses, which were still proportional in voltage to the energy of the x ray absorbed in the counter, were used to frequency-modulate a 70-kc/sec subcarrier oscillator which in turn frequency-modulated the carrier frequency and was telemetered to the ground. In this way it was possible to have the unmodified spectrum available for analysis on the ground. The electronic circuit which lengthened these signals introduced a dead time which for SCO-XR-1 was 55% at 2-3 keV, 23% at 5-6 keV, and 9% at 8-9 keV. The correction was negligible at higher energies. Gyros were installed in the payload to provide attitude information. In addition, a solar sensor provided azimuth information relative to the sun.

Figure 2 is a plot of counts greater than 1.7 keV versus azimuth during the 250 sec that the counter was above 104 km. The portion between channel 244 and "north" was scanned manually, and nothing above background was observed. Two sources are clearly visible. The peak in channel 80 (azimuth 255°) is caused by the x-ray source in Scorpius (SCO-XR-1). The moon was only 5 degrees from SCO-XR-1, but no detectable x-ray signal is expected from the moon.[1] The broadening of this signal toward the south is caused by other, weaker x-ray sources.[5] These are not resolved from the main peak because of the azimuthal angle of the collimator. The peak appearing in channel 228 (azimuth 60°) is caused by solar x rays. The crab nebula (Tau XR-1) was 3 degrees below the sun and therefore was shielded by about 20 g/cm^2 of atmosphere. The background counting rate is lower in the northwest than in the southeast, probably because the earth shields more of the solid angle viewed by the detector when the counter is oriented toward the northwest.

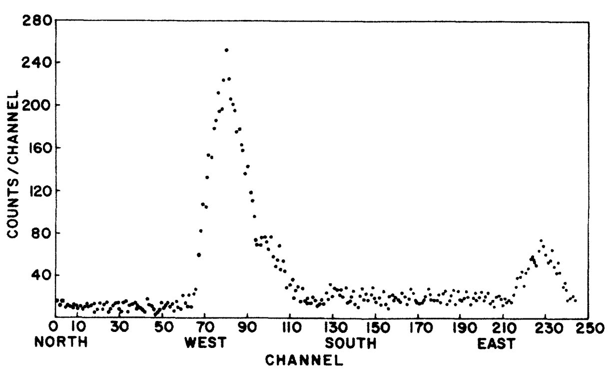

FIG. 2. Total number of x rays of energy greater than 1.7 keV observed above 104 km as a function of azimuth. Dead time in analyzing equipment causes the blank between channel 244 and "north." One channel is 1.32° of azimuth.

The spectral distribution of the radiation from SCO-XR-1 and the sun is shown in Fig. 3. Panel 3(a) shows the uncorrected SCO-XR-1 x-ray spectrum, and panel 3(b) shows this spectrum and the sun's when corrected for the counter efficiency, background, and system dead time. The sun's spectrum has also been corrected for atmospheric absorption. Low count rates are the main source of error at the high-energy part of the spectrum, and uncertainties in counter efficiency are the main source of error at the low-energy portion. The background spectrum observed when the counter points northwest is very similar to the SCO-XR-1 spectrum, except that the counting rate is, of course, much smaller. The corrected flux ob-

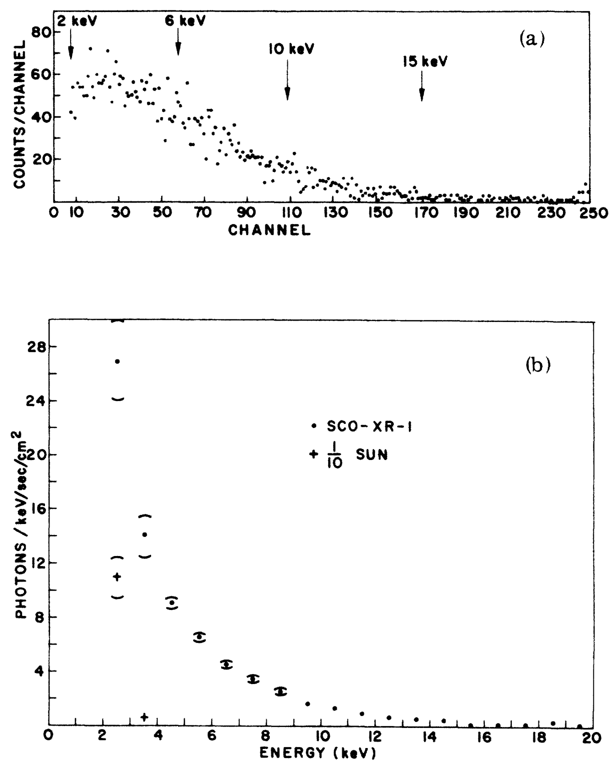

FIG. 3. (a) Uncorrected number of counts observed from SCO-XR-1 above 1.7 keV as plotted on a multichannel analyzer. (b) Spectrum of x-ray flux from SCO-XR-1 and the sun when corrected for counter efficiency, background, and system dead time. The sun's spectrum has also been corrected for atmospheric absorption.

served from the sun was approximately 118 photons sec^{-1} cm^{-2} (5.0×10^{-7} erg sec^{-1} cm^{-2}) with energies between 2 and 20 keV. This number is in reasonable agreement with the results expected for the quiet sun.[8] In the case of the Scorpius source (SCO-XR-1), the corrected flux is 74.6 photons sec^{-1} cm^{-2} (4.8×10^{-7} erg sec^{-1} cm^{-2}) with quantum energies between 2 and 20 keV. The cosmic-ray counting rate measured with the plastic scintillator was found to be in good agreement with previously measured values.

Significant differences are apparent in the spectrum observed from the sun and from SCO-XR-1. The solar spectrum is soft with only a small portion above 4 keV and has an energy distribution characteristic of the high-energy region of a bremsstrahlung spectrum at a temperature of 4.5×10^6 °K.

The Scorpius source, on the other hand, has a significant flux extending as high as 20 keV. Figure 4 is a plot of measured intensity of the source as a function of quantum energy. Included in this figure are calculated curves for synchrotron radiation for two different spectral indices[9] and bremsstrahlung for a Maxwellian energy

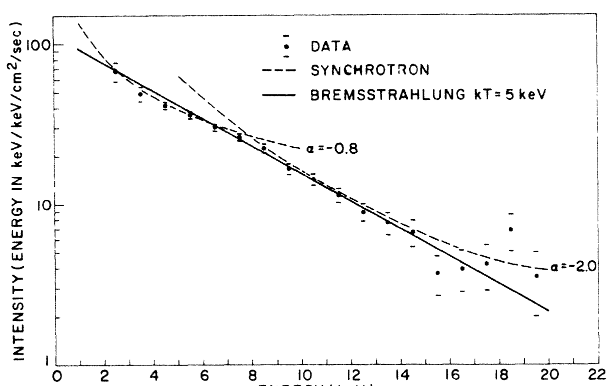

FIG. 4. Intensity of SCO-XR-1 as a function of quantum energy, including calculated intensities for synchrotron radiation and bremsstrahlung.

distribution.[10] It appears that a very good fit results for bremsstrahlung from a plasma at a temperature of about 5 keV (5.8×10^7 °K). To fit a synchrotron spectrum to the data, it is necessary to use a spectral index of approximately −0.8 between 2 and 8 keV and an index of −2 between 8 and 20 keV. Blackbody radiation from an object with a single temperature does not fit the measured data well. For low temperatures (<2 keV), the high-energy portion of a blackbody spectrum is too steep to fit the measured data, and for higher temperatures a peak develops in the blackbody spectrum which is not present in the measured data.

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