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OBSERVATION OF THE X-RAY SOURCE SCO X-1 FROM SKYLAB

By Robert M. Wilson
Space Sciences Laboratory

February 1977

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George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

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16. ABSTRACT

An attempt was made to observe the discrete X-ray source Sco X-1 with ATM instrumentation on 20 September 1973 between 0856 and 0920 UT. This report presents the results of analysis of the X-ray data obtained with the ATM/S-056 X-ray event analyzer, in particular the flux observed with the 1.71 to 4.96 keV counter. No photographic image of the source was obtained because Sco X-1 was outside the field of view of the X-ray telescope.

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OBSERVATION OF THE X-RAY SOURCE SCO X-1 FROM SKYLAB

I. INTRODUCTION

During the second manned Skylab mission (SL3), the opportunity arose to utilize Apollo Telescope Mount (ATM) instrumentation in the observation of the X-ray source Sco X-1. This report describes the findings based on observations performed with the ATM/S-056 X-ray telescope experiment.

The S-056 experiment consisted of two separate instruments: an X-ray telescope (X-RT) which obtained photographic images of X-ray emitters (generally, the Sun) through any of five metallic X-ray transmission filters with varying exposure, and an X-ray event analyzer (X-REA) which included two proportional-counter, pulse-height analyzer systems that recorded X-ray emanations in the 1.71 to 4.96 keV (2.5 to 7.25 Å) and 0.62 to 2.03 keV (6.1 to 20 Å) spectral regions with 2.5 s temporal resolution. Detailed descriptions of these instruments are available elsewhere [1-4]. In addition, Wilson [5] and deLoach et al.[1] have discussed the calibration and orbital performance of the instruments, and a report[2] has been prepared for the National Space Science Data Center.

II. OBSERVATION

On 20 September 1973 (Day of Year 263, Mission Day 55), following the solar observational period denoted day cycle 833, the Skylab was maneuvered in an attempt to observe the X-ray source Sco X-1 with the ATM instruments. The source was available to the ATM instruments for the period 0853 to 0946 UT, as

1. deLoach, A. C.; Hoover, R. B.; Wilson, R. M.; Milligan, J. E.; and Underwood, J. H.: The Skylab ATM/S-056 Solar X-Ray Telescope: Design and Performance, NASA TN, 197⁻ (in preparation).

2. User's Guide to the Data Obtained by the Skylab/ATM NASA Marshall Space Flight Center/The Aerospace Corporation S-056 X-Ray Experiment, NASA TM, 1977 (in preparation).

determined by orbital and pointing restrictions. At approximately 0852 UT, the ATM thermal shield doors were cycled open and monitoring of the night-sky X-ray emission with the X-REA instrument proceeded. At approximately 0856 UT, the X-REA beryllium counter (1.71 to 4.96 keV) acquired the source, and at approximately 0907 UT a single exposure (frame number 5710) through filter 4 (bandpass: 6 to 16 Å) of 762 s duration began. The thermal shield doors were cycled close at 0923 UT, following completion of the ATM observations which were terminated at approximately 0920 UT.

Figure 1 illustrates the 1 min averaged flux profiles for the 1.71 to 4.96 keV (beryllium counter) and 0.62 to 2.03 keV (aluminum counter) spectral regions during the Sco X-1 maneuver and observation. The fluxes are plotted in terms of relative units, where the number 1 represents average counter background, due principally to particles. One observes a substantial increase in counting rate with the beryllium counter, suggesting acquisition of Sco X-1 at that moment (0852 UT). No such increase is noted in the aluminum counter counting rate, indicating perhaps that either the source was not within its field of view (FOV), the Sco X-1 counting rate in the 0.62 to 2.03 keV band was substantially lower than expected from previous studies, or the aluminum counter's sensitivity was severely reduced. These possibilities will be discussed in the next section. Certainly, the lack of "sudden increase" in the counting rate for the aluminum counter implies that its flux profile is due entirely to particle radiation. Thus, the average background, plotted as the dashed line in Figure 1, for the aluminum counter is simply the average of all the data points over the 0826 to 0930 UT time interval. Also shown in Figure 1 is the spectral hardness index (i.e., the ratio of the beryllium counter total counts to the aluminum counter total counts)[3] for the periods when the counts were due strictly to particles. This period covers 0826 to 0855 UT and 0921 to 0930 UT. No photographic image of the source has been revealed.

Figure 2 depicts the counts, in relative units, due to Sco X-1 as observed in the 1.71 to 4.96 keV band. It results from differencing the calculated particle counts from the observed counts, which includes the particle counts and the Sco X-1 counts. The dashed line represents the average value of all the data points in the interval 0857 to 0919 UT.

3. Both counters separated their pulses into various energy bins. The totals for each counter, then, are the sum of all the individual counts in each counter's energy bins.

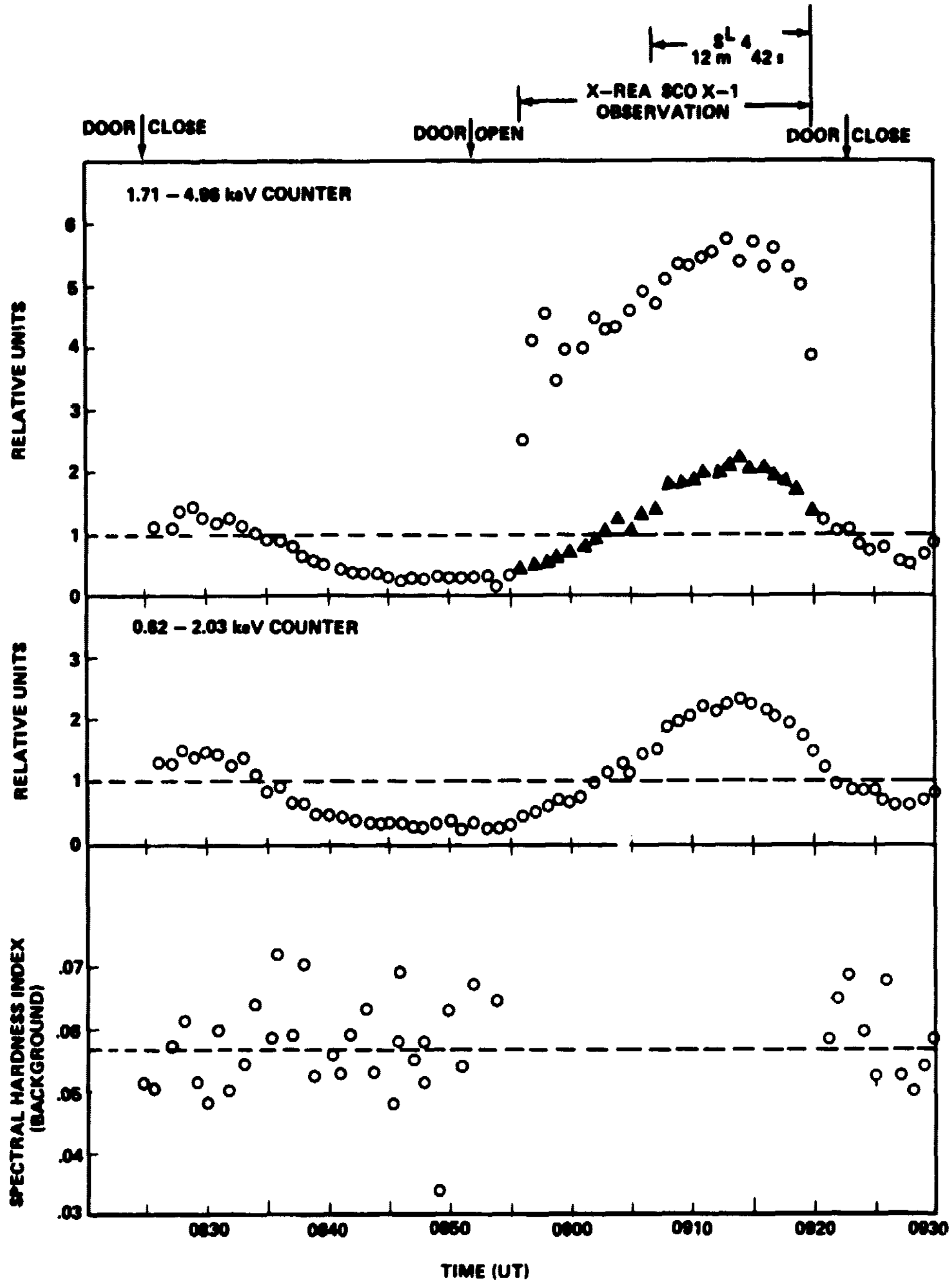

Figure 1. 20 September 1973 Sco X-1 observation, 0826 to 0930 UT. [Shown are observed (O) values for both X-REA counters, in relative units, where 1 equals average background counts (equal to 2.42 counts cm^{-2} s^{-1} for 1.71 to 4.96 keV counter, and equal to 40.64 counts cm^{-2} s^{-1} for 0.62 to 2.03 keV counter), calculated (▲) 1.71 to 4.96 keV counter background counts, and observed (O) spectral hardness ratio (1.71 to 4.96 keV data to 0.62 to 2.03 keV data) during background intervals. Dashed lines indicate average values.]

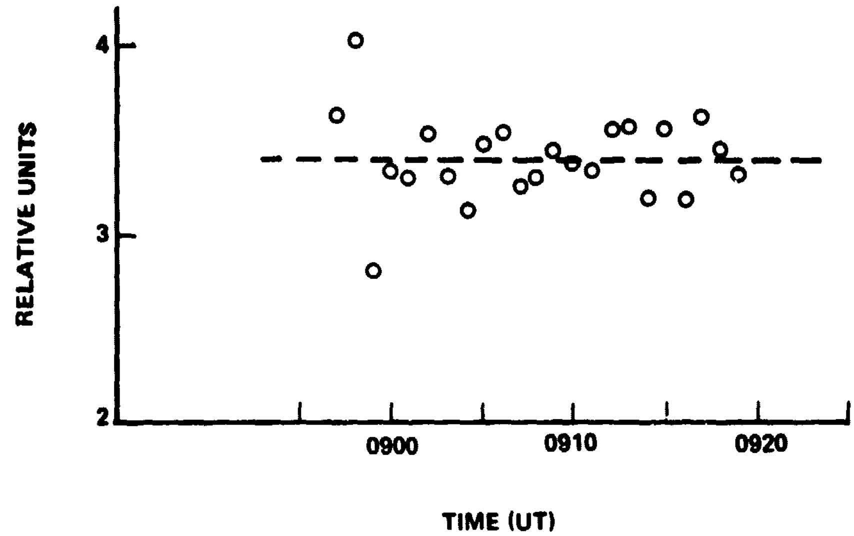

Figure 2. 20 September 1973 Sco X-1 observation, 0857 to 0919 UT, as observed with the X-REA 1.71 to 4.96 keV counter. [Values are in relative units (see Fig. 1) and represent differences between observed values in Figure 1 with corresponding calculated values. Dashed line represents the average value for the data points.]

III. DISCUSSION

Since 1962, following its initial discovery which heralded the birth of a new branch of astronomy (cosmic X-ray astronomy), Sco X-1 has undergone extensive investigation [6]. Today, Sco X-1 is observed to be the strongest soft X-ray source (1-10 keV band) in the sky, being eclipsed only temporarily by occasional flashes from transient X-ray sources. Its X-ray emission measures approximately 10^3 times its visible and radio intensity. Its spectrum is consistent with that of an exponential function characteristic of a hot, optically thin plasma at 50×10^6 K radiating by thermal bremsstrahlung. It was the first discrete X-ray source to be identified,[4] being associated with a "peculiar," blue

4. Today, only about 40 X-ray sources have been identified with known radio or optical objects. Approximately 100 of the 161 observed sources are concentrated in the galactic plane. The remaining 60 or so sources are high-latitude sources, typically of a weaker nature [7].

star-like object of apparent magnitude 12.5. Optically, the source flickers continuously, with the flickering superimposed on other optical variations, including flares. X-ray variation has also been suggested [8]. Indeed, the nature of Sco X-1 remains largely a mystery [9-15].

The attempt to observe Sco X-1 during SL3 was of interest both scientifically and from an engineering point of view. Scientifically, it meant the possibility of simultaneous observation of a strong X-ray source with a large number of instruments over an extended spectral region. Also, it could result in the first X-ray photograph of an extra-solar X-ray source. From an engineering point of view, the exercise would give valuable information on the off-set pointing and maneuvering capability of a large Space Station for sources other than the Sun or Earth.[5]

Previous studies indicated Sco X-1 to have a flux of approximately 20 counts cm^{-2} s^{-1} (or photons cm^{-2} s^{-1}) in the 2-20 keV range, as deduced from UHURU [12], and about 40 counts cm^{-2} s^{-1} at 1 keV deduced from rocket observations [17]. The spectrum begins to flatten beyond 20 keV, and it appears to peak near 1 keV, falling rapidly at lower energies.[6] Thus, the intensity of the source was sufficient to allow its detection, provided the pointing was accurate and the instruments used to observe it were sensitive enough.

Failure to observe the source with the aluminum counter while seeing it with the beryllium counter indicates that either the source was emitting at a lower level than expected or the counter had become too insensitive. It cannot be attributed to an FOV problem, since the FOV of the aluminum counter was nearly twice that of the beryllium counter when the largest aperture hole size was in use (see Appendix).

The aluminum counter observed background count was approximately 12 counts cm^{-2} s^{-1} immediately prior to the acquisition of the source as evidenced by the beryllium counter flux profile (Fig. 1). Thus, a flux of 40 counts cm^{-2} s^{-1} at 1 keV should have resulted in an increase of about four times in the aluminum counter flux profile. This was not observed. Instead, the count rate appeared to slightly increase by a factor of approximately 2. The steady increase followed by a decline is attributed to particles rather than

5. Skylab was configured to operate in primarily two modes of spacecraft orientation: (a) solar inertial where the ATM was pointed at the Sun, and (b) Z-local vertical where Earth resources experiments could be trained upon the Earth [16].

6. A rather large flux has been observed at 0.28 keV (44 Å) stronger than anticipated [11].

variations of the X-ray emission in Sco X-1, although firm evidence for this explanation is lacking. Another reason for suspecting the influence of particles in the aluminum counter record is that after the Sco X-1 maneuver and observations, when the thermal shield door was closed, the count rate was higher than it was just prior to the Sco X-1 observation. Also, with the thermal shield door closed, both counters strongly mimic each other. This mimicking is no longer apparent during the Sco X-1 observation when the beryllium counters appeared to have acquired the source and the aluminum counters appeared to be reacting to variations in the particle flux.

The initial observations of Sco X-1 with the beryllium counter (~0857 UT; see Figs. 1 and 2)[7] show a jump of about nine times above the calculated background. The particle background apparently increased as the observation continued, resulting in a decrease of the signal-to-noise ratio. Figure 2 displays the Sco X-1 observation with the beryllium counter, where the data points are the differences between the observed beryllium flux profile (O) shown in Figure 1 and the calculated beryllium particle background (▲) also shown in Figure 1, based on the aluminum counter flux profile and the average spectral hardness index (= 0.057) calculated from the observed beryllium and aluminum counter flux profiles adjacent to the Sco X-1 observation. The variation in the Sco X-1 signal may be real but more likely is due to the coarseness of this analysis to determine particle background levels in the beryllium counter. It is tempting to explain the initial large variation (~0858 UT) in terms of an X-ray flare; however, the shortness of the time scale (< 2 min) makes this conclusion perhaps suspect.

Sco X-1 was apparently fairly stable during the period of observation, showing small fluctuations which, as aforementioned, may be real or induced in the counter record. The average value above background in relative units is 3.4. Therefore, applying the observed average particle level (= 2.42 counts cm^{-2} s^{-1}), one observes (according to the beryllium counter) the Sco X-1 flux to be approximately 8.2 counts cm^{-2} s^{-1}. This value is too low by a factor of approximately 2.4, as compared to anticipated flux based on previous studies. Hence, either the source was emitting X-rays at a lower level than had been observed previously or the absolute calibration of the instrument during the latter part of SL3 is suspect. Indeed, the latter appears to be the case [5].

Since the measured flux of Sco X-1 at 1 keV (12.4 Å) is relatively high (~40 counts cm^{-2} s^{-1}), an X-ray photograph of the source should easily have been obtained, provided the pointing is accurate, an X-ray telescope is used,

7. The observation at 0856 UT is an average of non-Sco X-1 data and Sco X-1 data.

and the exposure is long enough. Thus, the 40 count cm^{-2} s^{-1} flux from a point source observed with the 14.66 cm^2 collecting area of the ATM/S-056 X-RT with an exposure of 762 s yields the enormous figure of approximately 4.5×10^5 photons incident on a single point on the film, assuming perfect filter transmission and telescope reflectivity. Correcting for filter transmission and telescope reflectivity[8] still yields the rather large figure of 4.5×10^4 photons incident on a point of the film (ignoring the telescope point-spread function). This is readily detectable; therefore, failure to observe an X-ray image of Sco X-1 on the film implies that the source lay outside the FOV of the telescope.[9]

Figure 3 illustrates the FOV's for the X-REA beryllium and aluminum counters and the X-RT. The smallest FOV is that of the X-RT and the largest is that of the aluminum counter. The implication of the data is that Sco X-1 lay within the middle circle but outside of the inner circle. Thus, the pointing of the ATM instruments was inaccurate by approximately 28.5 ± 9.5 arc min.

8. The filter used in the Sco X-1 observation was filter 4, a 2.54×10^{-3} cm thick beryllium material (~ 4.62 mg cm^{-2}) with a bandpass of 6 to 16 Å; the product of filter transmission and telescope reflectivity is ~0.1 at 12 Å.

9. Skylab did drift during the observation; however, the drift rate was sufficiently low so that, if the source were present in the FOV, a tiny track would still be evident. No track was noted. Also, since radio measurements indicate the possibility that the X-rays come from an extended source [11], Sco X-1 would not have left a readily detectable image. Thus, the conclusion that Sco X-1 lay outside the FOV of the X-RT is based on the assumption that it is a point source.

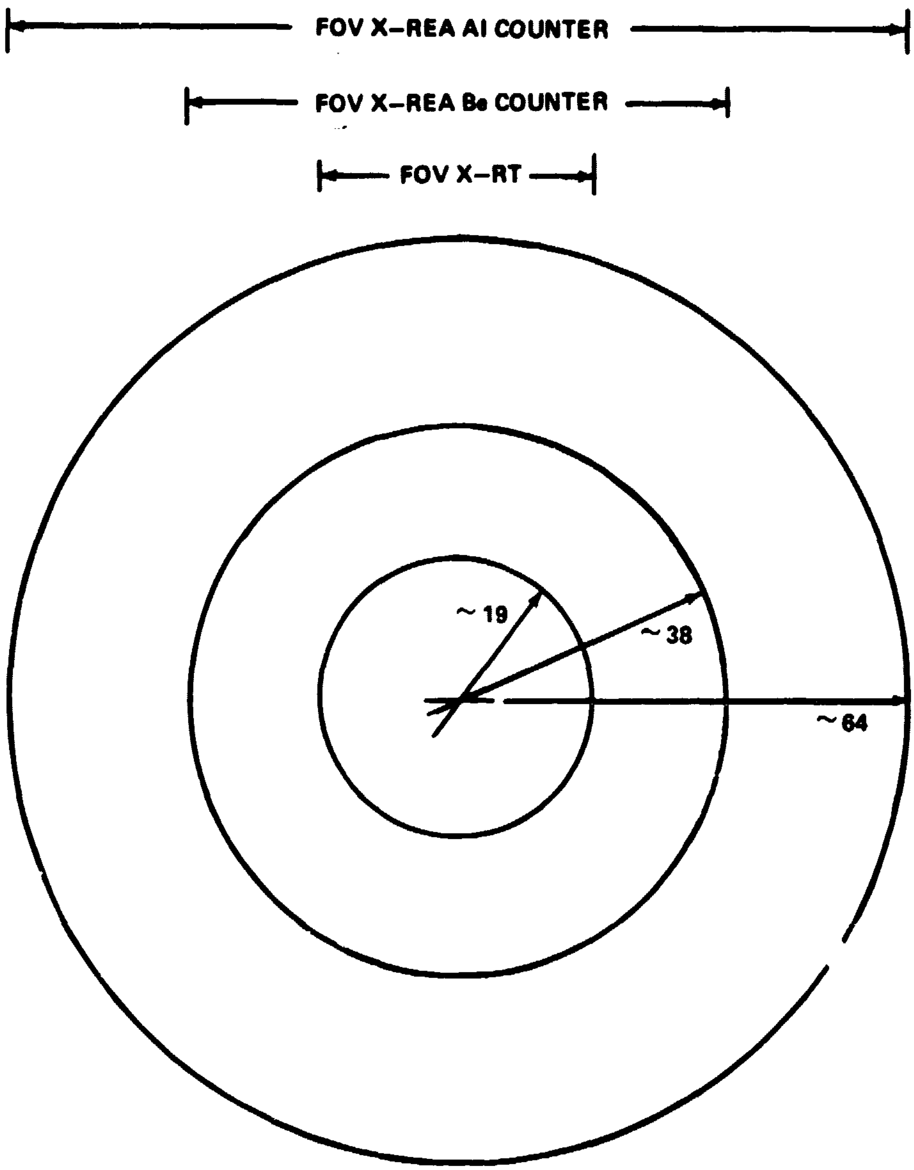

Figure 3. X-REA and X-RT field of view determinations. [Inner circle ($r \sim 19$ arc min, where r = radius of FOV circle) represents the X-RT FOV, middle circle ($r \sim 38$ arc min) the FOV of the 1.71 to 4.96 keV counter, and the largest circle ($r \sim 64$ arc min) the FOV of the 0.62 to 2.03 keV counter.]

APPENDIX

FIELD-OF-VIEW DETERMINATIONS

Since a nonsolar source of X-ray emission is under investigation, it is crucial to know the FOV of the instruments involved in the observation. The usable FOV of the X-ray telescope is 38 arc min (see footnote 2 in main text). The unobstructed or unobscured FOV's of the X-REA proportional counters are dependent on aperture wheel hole sizes. For the case of the 20 September 1973 Sco X-1 observation, both counters were in their largest hole size position (aperture 4).

The proportional counters view the night sky through three openings: the aperture wheel hole, the X-REA housing aperture, and the ATM aperture plate hole (Fig. A-1). Figure A-2 illustrates the approach used in the FOV determinations.

FoV calculations must be performed for each of the aforementioned "viewing" openings. In all cases, the known distances include DB, DE, and BC. Unknowns include AB (or AD, which equals AB + BD) and the angle α (which equals 1/2 FOV). One observes that triangles ABC and ADE are similar; therefore, AB (and hence AD) can be directly calculated:

$$AB = AD\left(\frac{BC}{DE}\right)$$

or, since AD = AB + BD

$$AB = BD\,\frac{\left(\frac{BC}{DE}\right)}{\left(1 - \frac{BC}{DE}\right)} \quad .$$

Knowing AB, one can calculate α :

$$\alpha = \arctan\left(\frac{BC}{AB}\right) \quad .$$

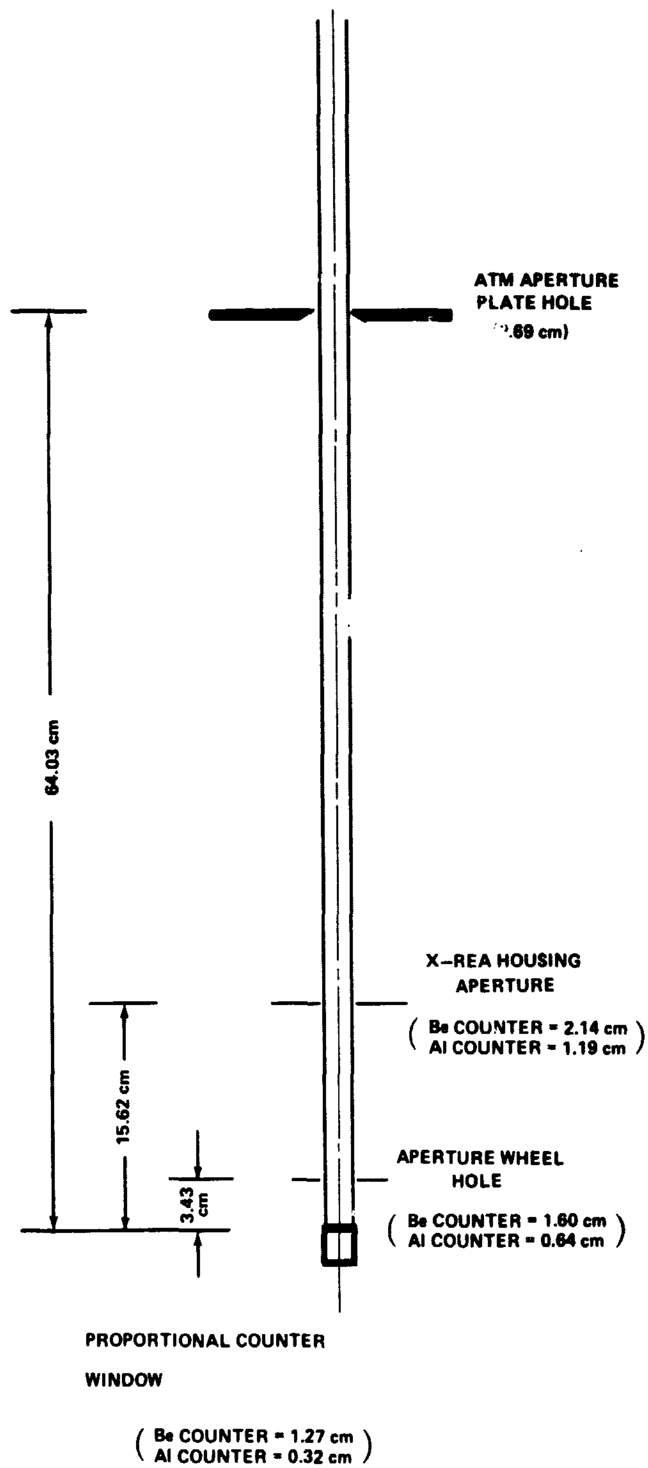

Figure A-1. X-REA dimensional representation. [Aperture wheel hole is the largest hole size (aperture 4) for the Sco X-1 observation.]

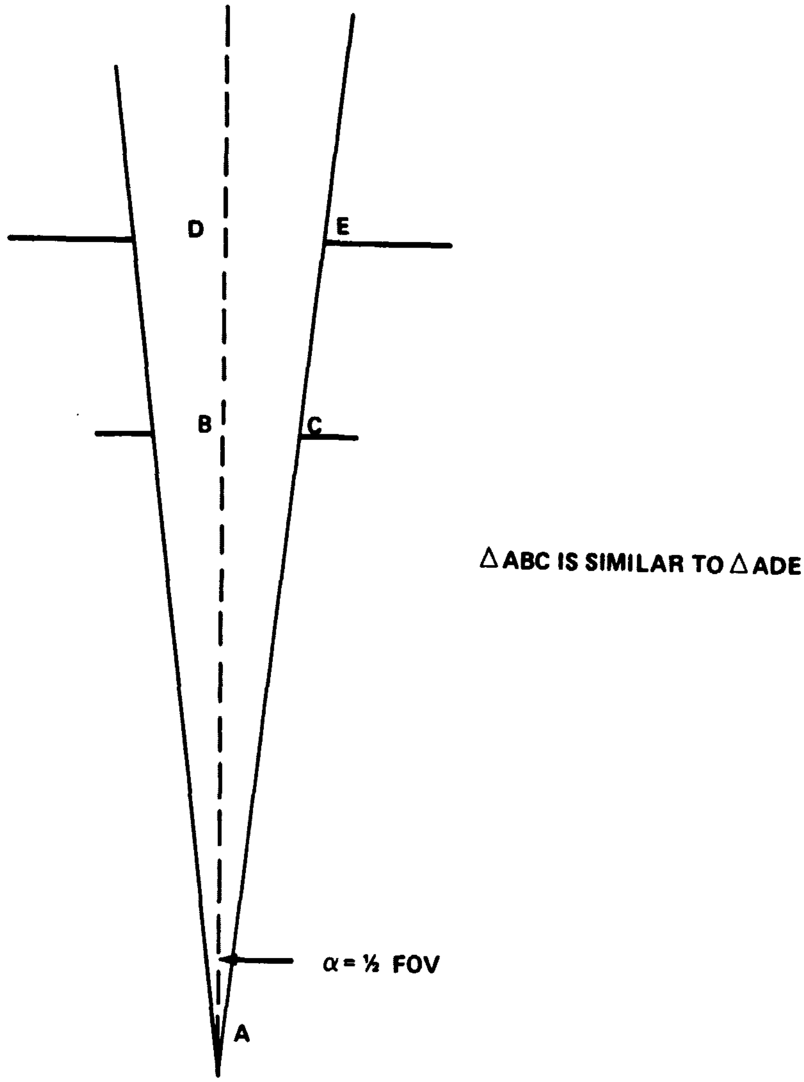

Figure A-2. Schematic showing method of approach in the determination of the unobscured FOV for the X-REA counters.

Table A-1 summaries results of the FOV calculations for the three viewing apertures. One observes that when the largest aperture position is used, regardless of counter, the determining factor for the FOV of that counter is its ATM aperture plate hole. Thus, t..e FOV for the beryllium counter is 76 arc min, and the FOV for the aluminum counter is 128 arc min.

TABLE A-1. SUMMARY OF X-REA FOV CALCULATIONS

Viewing Hole	Counter[a]	Hole-Size (cm) 2 DE	Separation Distance BD (cm)	Depth Distance AB (cm)	α = 1/2 FOV (arc min)
ATM Aperture Plate Hole	Beryllium	2.69	64.03	57.72	38.12
	Aluminum			8.61	63.88
X-REA Housing Aperture	Beryllium	2.14	15.62	23.25	94.61
	Aluminum	1.19		5.75	95.63
Aperture Wheel Hole (Aperture 4)	Beryllium	1.60	3.43	13.72	160.25
	Aluminum	0.64		3.43	160.25

a. Beryllium counter window is 1.27 cm in diameter; aluminum counter window is 0.32 cm in diameter. One-half of these diameters corresponds to BC for each counter FOV calculation.

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APPROVAL

OBSERVATION OF THE X-RAY SOURCE SCO X-1 FROM SKYLAB

By Robert M. Wilson

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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