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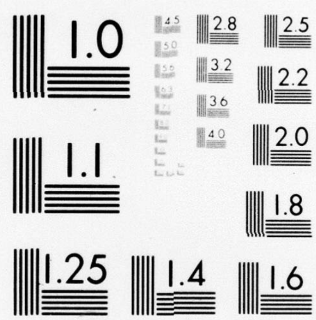

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REPORT SAMSO-TR-77-140

K-Shell X-Ray Fluxes at Satellite Altitude From Proton Precipitation

Space Sciences Laboratory
The Ivan A. Getting Laboratories
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15 July 1977

Interim Report

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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A sample calculation is presented of K-shell x-ray emission resulting from energetic proton precipitation into the upper atmosphere. It is found that intense fluxes of K-shell x-rays at low satellite altitudes can result from observed fluxes of precipitating protons.

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CONTENTS

FIGURES

1. INTRODUCTION

Luhmann and Blake (1977) have presented sample calculations of the soft bremsstrahlung and K-shell x-rays (0.10 keV to 10 keV) present at low satellite altitude resulting from the precipitation of electrons into the upper atmosphere. Since proton precipitation occurs also, it is of interest to determine if such precipitation results in a detectable x-ray signal. It happens that the proton bremsstrahlung cross-section is negligible but the cross-section for producing K-shell x-rays by proton impact upon nitrogen and oxygen is significant above a few tens of keV.

In this paper a sample calculation is presented based upon a satellite measurement of proton precipitation. The general question of the detectability of x-rays from proton precipitation is discussed briefly.

2. CALCULATIONS

The cross-section for the production of K-shell x-rays by protons impinging upon oxygen, nitrogen and argon are required for the calculation. Measured cross sections have been presented by Hart et al. (1969) for protons with energies between 20 keV and 100 keV impinging on oxygen. Data are available also for the production of K-shell x-rays by protons with energies between 15 keV and 1900 keV impacting carbon, magnesium and other heavier elements (Khan et al., 1965). In the absence of measurements, these latter data were used in concert with well-understood theoretical principles (Merzbacher and Lewis, 1958; Madison and Merzbacher, 1975) to provide the cross-sections for K-shell x-ray production by protons with energies from 20 keV to 700 keV impinging upon nitrogen, oxygen and argon.

The calculation was performed as described in Luhmann and Blake (1977) by substituting the proton K-shell cross-sections described above for the electron cross-sections given by Tawara et al. (1973), replacing an electron range-energy relationship by one for protons, and deleting the bremsstrahlung formalism.

The cross-sections used in the calculation are shown in Figure 1. It is clear from Figure 1 that proton energies of several tens of keV are required to excite appreciable K-shell emission in oxygen and nitrogen and that hundreds of keV are required in the case of argon.

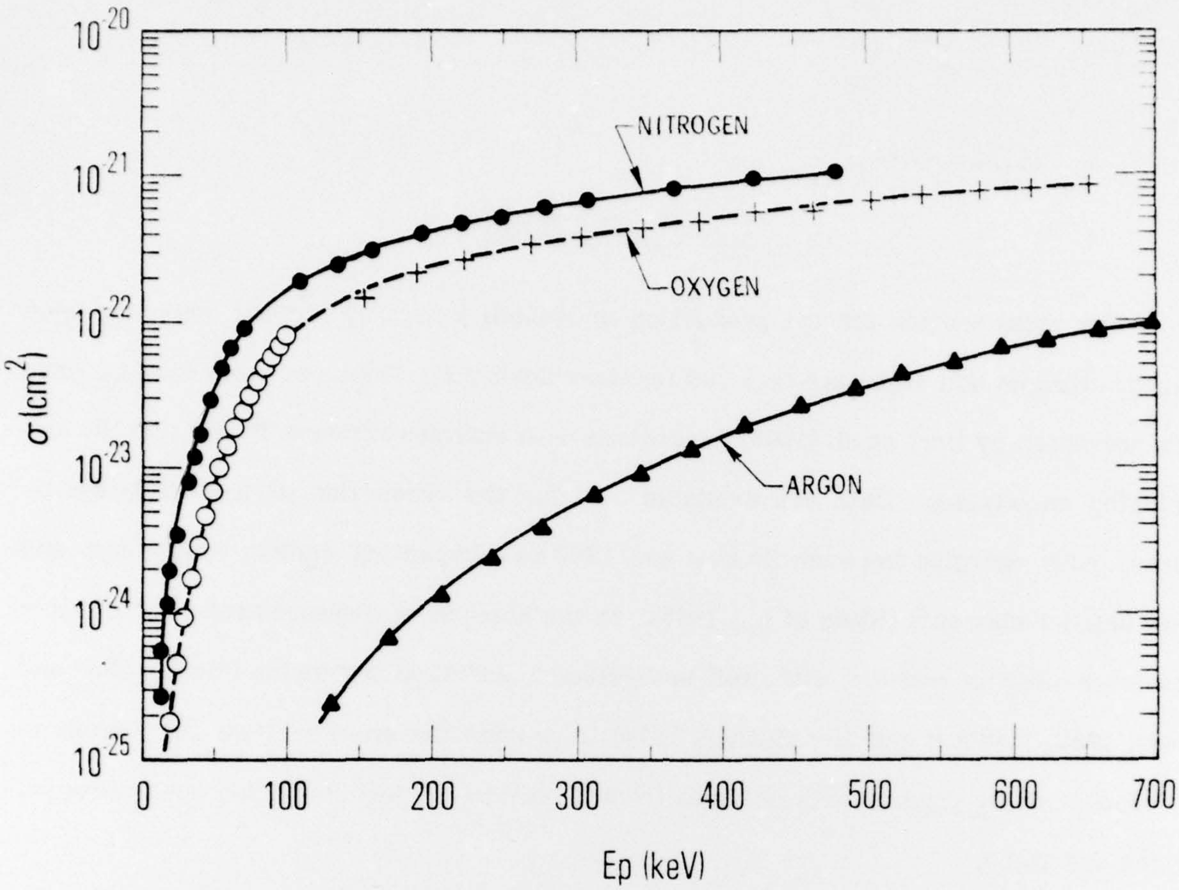

Fig. 1. K-Shell X-Ray Cross-Sections (p,x).

The proton precipitation flux, spectra and pitch-angle distribution used in this sample calculation were observed during the solar particle event which began on 11 April 1969; the specific data were obtained at 75570 sec UT on 14 April. These measurements are described in detail by Blake and Vampola (1974). Figures 2 and 3 are adapted from their paper. Figure 2 shows the measured proton and electron fluxes during a polar cap transverse by the OV1-19 satellite. The proton energy spectrum observed at 75570 sec UT is shown in Figure 3. Note that at the location of the peak proton precipitation intensities, the energetic electron ($E > 100$ keV) precipitation is nil. Unfortunately, no measurements of auroral energy electrons were made aboard the spacecraft, and thus possible K-shell x-ray emission due to auroral electron precipitation cannot be calculated.

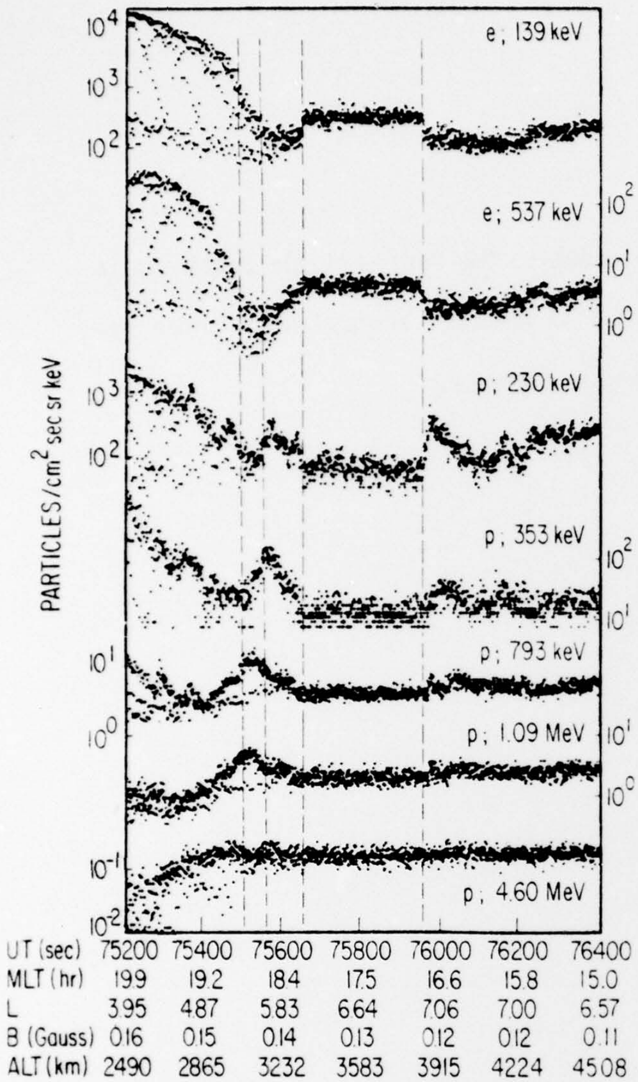

Fig. 2. Satellite Measurements of Proton and Electron Fluxes on 14 April 1969.

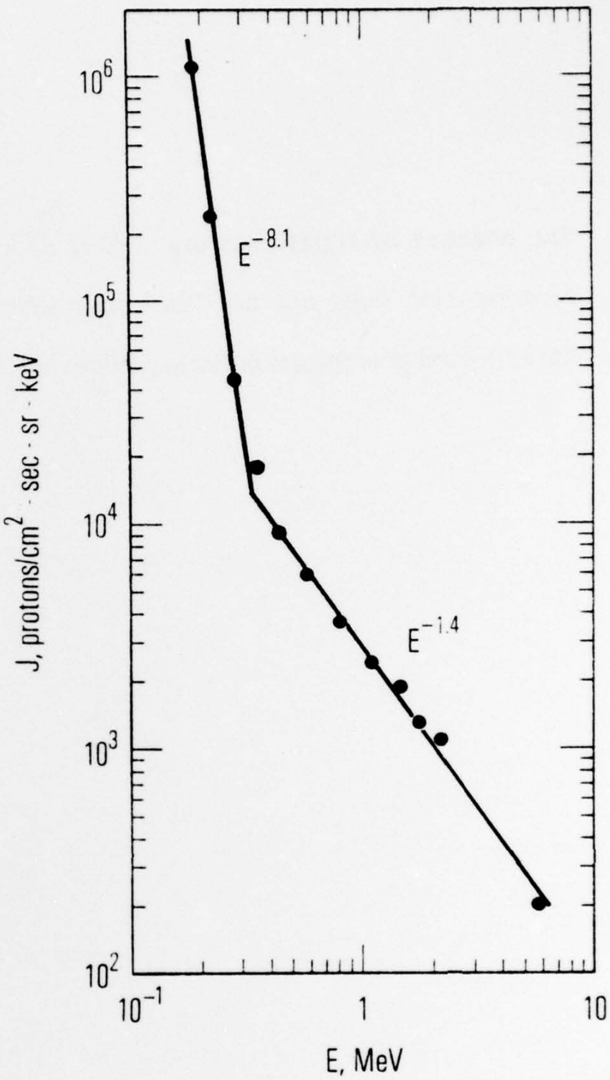

Fig. 3. Proton Energy Spectrum as observed at 75570 sec UT on 14 April 1969. (See Fig. 2.)

The present calculation yields the following K-shell x-ray fluxes at satellite altitude due to the observed proton spectrum shown in Figure 3:

Nitrogen:	$4 \times 10^7 cm^2$-sec;
Oxygen:	$2 \times 10^7/cm^2$-sec;
Argon:	$7 \times 10^{-2}/cm^2$-sec.

The absence of significant argon K-shell x-rays is due to the fact that the proton-argon cross-section does not become appreciable (Figure 1) until an energy where there was little proton precipitation during the event depicted in Figure 2.

3. DISCUSSION

It is clear from the energy dependence of the K-shell cross-sections that normal auroral-energy proton precipitation will not cause significant K-shell x-ray emission from upper atmospheric nitrogen or oxygen. However, the sample calculation does show that intense fluxes of K-shell x-rays from nitrogen and oxygen result from the more energetic proton precipitation events that have been observed. (It should be noted that the proton precipitation shown in Figure 2, although occurring during a solar-particle event, does not simply consist of solar protons. The protons were accelerated by magnetospheric processes. Whether or not they were solar protons, with energies well above typical solar wind energies before magnetospheric acceleration, could not be determined (Blake and Vampola, 1974)).

Since the protons generate no bremsstrahlung continuum, x-ray emission from precipitating protons and that from precipitating electrons differs in a readily detectable fashion. If only K-shell lines are present, the precipitation consists of protons, not electrons. The shape of the bremsstrahlung spectrum, if present, reveals some information about the spectrum of the precipitating energetic electrons (Imhof et al., 1975a, 1975b; Luhmann and Blake, 1977). Thus satellite x-ray measurements which span the energy range from ~ 300 eV to ~ 300 keV will permit remote sensing of electron and energetic proton precipitation.

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