Final Scientific Report

on

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to

The University of Chicago

for

High Resolution Solar X-Ray Studies

in the period

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Abstract

This grant supported the construction of two high resolution solar X-Ray payloads and their launches on Aerobee rockets with SPARCS pointing systems. The payloads included 5 to 25Å X-Ray spectrometers, multiaperture X-Ray cameras, and command box attitude control inflight by means of a television image radioed to ground. Spatial resolution ranged from five arc minutes to ten arc seconds and spectral resolution ranged from 500 to 3000. Several laboratory tasks were completed in order to achieve the desired resolution. These included (1) development of techniques to align grid collimators, (2) studies of the spectrometric properties of crystals, (3) measurements of the absorption coefficients of various materials used in X-Ray spectrometers, (4) evaluation of the performance of multiaperture cameras, and (5) develooment of facilities adequate for these studies as well as for test and calibration of the rocket payloads themselves.

Rocket equipment malfuncitions and the low level of solar acitivity combined have so far prevented the attainment of our scientific objectives. The second payload, which has the greater data capability, is ready for launch at White Sands Missile Range as soon

as logistical and solar conditions permit.

Some technical results have been obtained. These include:

(1) Verification in the laboratory and in a rocket flight that a multiaperture camera can produce high resoltuion solar X-Ray pictures.

(2) Development of techniques for construction, alignment, and testing of grid collimators with nearly the theoretical ėtendu and collimation limited by diffraction (~10 arc sec FWHM at 10Å for a typical rocket payload length of 2m).

(3) Extension of the theory of X-Ray diffraction in crystals to the ultrasoft X-Ray region.

(4) Measurement of the spectrometric properties of KAP, ADP, and EDDT and comparison to theoretical predictions with very good agreement.

(5) Theoretical explanation of the anomolous reflectivity spike in KAP at 23.3Å, thus making it possible to use this feature for verification of the long wavelength solar continuum.

(6) Measurement of the absorption fine structure near the oxygen K-edge in materials used for X-Ray detector windows.

(7) Discovery and explanation of why the gas gain of proportional counters at sub-atmospheric pressures does not follow earlier theoretical predictions.

High Resolution Solar X-Ray Studies

1. Background

This research project was effectively started in 1970 with the objective of improving the spatial and spectral resolution of solar X-Ray observations and thereby to provide the data base for improved analysis of solar physics. Earlier measurements had shown the need for higher spectral resolution below 25Å to resolve the many lines from one another in crowded spectra, and to distinquish the types and scales of inhomogeneities that were apparent in broad band X-Ray photographs. There was also some evidence that at least occasional X-Ray spectra of active regions might contain non-thermal components.

2. Approach

A progressive approach was laid out and partially implemented. Initial measurements were planned to observe isolated active regions a few arc minutes in angular extent with spectral resolving power of ~1000. A first payload was built having five individual spectrometers to achieve a coherent set of data for analysis. This payload (A) also included a multiaperture camera whose purpose was to achieve 23 arc sec resolution photographsby taking advantage of the multiplexing concepts of communications theory.

Once these integrated active region data were in hand our approach included advancement to finer spatial resolution in the range 10 to 30 arc sec in order to probe the detailed structure within active regions. Simultaneous improvements in techniques to prepare crystal surfaces for X-Ray diffraction gave us the capability to achieve spectral resolving power $\sim$3000. A second payload (B) was constructed with these capabilities. It has three individual crystal spectrometers, a multiaperture camera capable of seven sec resolution, and a television camera system linked by telemetry to a ground based command box for active control of the solar field of observation during flight.

The third step in our approach was to replace one or more of the crystal spectrometers in payload B with plane grating spectrometers. This is still possible within the geometrical layout of the experiment but has not been implemented because detailed evaluations of the grating approach revealed that no improvement over crystals was feasible. Laboratory and analytic studies of this approach are being continued to determine under what condtions the plane grating approach should be employed.

Further steps that logically follow in any effort toward high resolution solar X-Ray studies include extension of the observing time by means of satellite spacecraft and extension to even finer spatial resolution when the Space Shuttle becomes availabe - it will permit the long telescope focal lengths and large spectrometer focussing circles required for simultaneous high spatial and spectral resolution.

3. Results

Rocket equipment malfuncitons twice prevented the acuisition of solar spectral data with payload A. This payload must be refurbished prior to any more launch attempts. Payload B is at White Sands Missile Range where we prepared for launch in January 1974 and again in February, but both times we cancelled because the solar active regions present were too small and faint to justify the launch. Another launch attmept is planned in the fall of 1974.

In laboratory and theroretical aspects of the program there have been some significant results, which are outlined in the following.

Multiaperture Cameras

A multiple pin-hole camera was designed in which the images from many holes are permitted to overlap on the film and the solar image is reconstructed by a post-development process that involves correlation or transform techniques. The basic idea is that a signal may be enhanced without loss of information by multiplexing and multichanneling simultaneously. Brown (1972) worked out the analysis of this approach and verified it in the laboratory with both visible and X-Ray sources. Blake, Burek, Fenimore and Puetter (1974) reported on the successful application to solar imagery. A camera of this type with 7 arc sec resolution is in payload B. Results to date indicate the technique is very good for objects with discrete uniform emitting points but becomes less useful as the source complexity increases. Thus, we expect it to be useful in revealing the sizes of individual active regions but not for the details within active regions.

Collimators

We have developed techniques for the construction and alignement of X-Ray collimators with grids to the extent that the degree of collimation is limited by single slit diffraction. For a typical rocket payload of maximum length 2m it is feasible to employ collimators about 1 m long, in which case the unit is diffraction limited above 10Å. Collimators this fine can be built out of grids constructed with integrated circuit technology. They can be aligned so that the measured X-Ray transmission is 80-90 percent of theoretical and the angular response is nearly identical to theoretical predictions. Our technique permits a recheck of grid alignment anytime after the collimators are completed. Temperature sensitivity is not critical for a single unit, but the co-alignment of several collimators is quite sensitive to thermal and mechanical changes in a payload structure. A co-alignment tolerance of 10 arc sec can be maintained if extreme care is taken at the launch range. A description of the techniques and results will be published later.

Crystals

The spectrometric properties of crystals must be known before any solar physics analysis can be done from the solar X-Ray spectra. We have made measurements over the past few years on crystals used in solar studies. During this time we were keenly aware that systematic errors of several types had to be eliminated and we worried that some systematic errors might still be undetected in the measurements. Some theroretical guidelines were needed, but extensive literature searches showed no theoretical applications to the ultrasoft X-Ray region. Consequently, we extended the theory of X-Ray diffraction in crystals to cover KAP (Burek, Barrus and Blake 1974a). Since the crystal structure of EDDT was just determined last year the calculations have now been extended to cover EDDT and ADP (Burek 1974). Theory and experiment agree very well on reflectivities and resolving powers for KAP. We have also developed techniques (based on earlier work of Deslattes at NBS) to polish ADP and EDDT, both of which must be cut and ground to expose the desired planes. Reflectivity measurements show that we have made marked improvements toward restoring these crystal surfaces to near perfection. The most critical test, measurements of resolving power, are planned for later this year.

Detailed measurements with continuum sources have revealed structure in crystal reflectivity curves near the absorption edges of elements that make up the crystals. IN all cases treated so far (potassium and oxygen in KAP and phosphorus in ADP) the measurements are in very good agreement with theory. A noteworthy special case is the oxygen K edge in KAP. A reflectivity spike at 23.3Å has long been known and associated with anomolous dispersion. Recently, Burek has succeeded in reformulating the theory in such a way that the spike can be calculated. He has been able to match our observations quite well (Burek, Barrus and Blake 1974b).

These laboratory and theoretical results provide standards that will permit considerably improved X-Ray data analysis by all solar X-Ray groups in future experiments as well as some past experiments.

<u>Absorption Coefficients</u>

The reflectivity structure of crystals near absorption edges is only part of the overall problem of spectrometer efficiency calibration. Another important factor is the absorption coefficient structure near the absorprtion edges of elements in the materials used for detector windows and ultraviolet traps. We have studied this structure near the oxygen K-edge in Formvar, Parlodion, Kimfol and other plastic window materials. We discovered a characteristic structure including a small peak followed by a shallow minimum and a strong, broad peak to shorter wavelengths. A theoretical explanation is being sought.

Proportional Counter Gas Gain

During the preparation of detectors for our solar X-Ray payloads we set up a test sequence to establish operating parameters. Again, we sought theoretical guidelines to indicate how good our detectors were. Theories developed previously all proved inadequate to explain our measurements of gas gain at subatmospheric pressures. We introduced a correction term to previous theories and then obtained a good fit to measurements. We, also, suggested an explanation of the correction term, but further independent measurments of electron mobility in gases will be necessary before our suggestion can be confirmed. These results were published by Burek and Blake (1973).

X-Ray Calibration Facilities

Any high resolution solar X-Ray program must have a versatile X-Ray test and calibration capability in order to determine payload performance. Over the period of this grant we have built up such a facility, including X-Ray sources, calibration chambers, payload test chambers, and various jig systems for specific tests such as collimator angular response. The results reported above were only possible because of the existence of these facilities.

4. Grant Information

The NASA Technical Officer for this grant has been:

Dr. Goetz K. Oertel
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NASA Headquarters
Washington, D. C. 20546

This is the final report on this grant to the University of Chicago. The research program, including personnel and facilities, has been transferred to the Los Alamos Scientific Laboratory where it will be continued under a new grant.

Biographical Data - Principal Investigator

1959 BS Physics. Rensselaer Polytechnic Institute, Troy, New York. Assigned to Naval Research Laboratory as U.S. Navy Officer in scientific capacity. Worked on techniques to make x-ray photographs and x-ray spectra of the sun. Set up x-ray laboratory for calibration and testing of x-ray astronomy experiments.

1962 Released from active duty in Navy. Remained at NRL for another year as civilian scientist to complete solar x-ray experiments.

1963 Left NRL for graduate school. Thesis work concentrated on application of higher resolution techniques to x-ray spectroscopy. Set up a plasma machine as light source and built precision x-ray spectrometer. Measured wavelengths of He-like ions prominent in solar corona and determined crystal dispersion corrections that are necessary for precision measurements of solar spectra. Demonstrated that K -type transitions, discovered by NRL, could be used with L state transitions as an indicator of non-thermal character of solar x-ray bursts. All thesis work done at High Altitude Observatory in the program of Dr. L. L. House.

1968 Ph.D. University of Colorado

1968 Appointed Assistant Professor in the Department of Astronomy and the Enrico Fermi Institute of the University of Chicago. Started program in x-ray astronomy with emphasis on high resolution studies of the x-ray spectrum of the sun and cosmic x-ray sources.

1974 Staff Scientist at Los Alamos Scientific Laboratory in charge of rocket and satellite research program, including solar and cosmic x-rays and aeronomy.

Publications

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