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SEMI-ANNUAL PROGRESS REPORT

FOR CONTRACT NASW-4814

CORONAL ABUNDANCES AND THEIR VARIATION

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Principal Investigator and Author:

Julia L.R. Saba (Lockheed Organization 91-3H)

Author's address (Lockheed Remote Site):

Code 682.2, NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

Institution address:

Lockheed Palo Alto Research Laboratory
Organization 91-30, Building 252
3251 Hanover Street
Palo Alto, California 93404

ABSTRACT

This contract supports the investigation of elemental abundances in the solar corona, principally through analysis of high-resolution soft X-ray spectra from the Flat Crystal Spectrometer on the *Solar Maximum Mission*. The goals of the study are a characterization of the mean values of relative abundances of elements accessible in the FCS data, and information on the extent and circumstances of their variability. This report is a summation of the data analysis and reporting activities which occurred during the months of June to December 1993.

Subject terms: Solar corona, X-ray spectra, elemental abundances, abundance variability

I. INTRODUCTION

This is the first semi-annual report for contract NASW-4814. The contract resulted from an award under NASA's Supporting Research & Technology Program after peer review of a proposal submitted by the Principal Investigator (PI) in August 1992 in response to NASA Reseach Announcement NRA-92-OSSA-10. Notification of the award was given in February 1993 and funding began in June 1993. The current investigation is a continuation and an extension of a pilot study of coronal abundances begun as a *Solar Maximum Mission* Guest Investigation (GI) by the same PI.

The contract supports an investigation of elemental abundances in the outer atmosphere of the Sun, principally through analysis of high-resolution soft X-ray spectra from the Flat Crystal Spectrometer (FCS) on the *Solar Maximum Mission (SMM)*, a NASA mission dedicated to solar observations from 1980 through 1989. This instrument acquired an excellent data base for studying the relative amounts of oxygen, neon, magnesium, and iron in solar active regions in various states of evolution and activity. The project includes analysis of this data base to decouple the effects of temperature and abundance, to assess different theoretical calculations of spectral line intensities for use in the study, and to account for the possible effects of opacity due to resonance scattering of certain bright lines. The goals of the study are a characterization of the mean values of relative abundances of elements accessible in the FCS data, information on the extent of their variability, identification of possible correlations of variability with active region properties, and clarification of a possible association between abundance variability and active region dynamics.

II. SCIENTIFIC BACKGROUND

Knowledge of solar elemental abundances is essential for correct interpretation of plasma diagnostic information from spectral and image data. Also, an assumed set of abundances is implicit in many aspects of astrophysical data analysis, such as calculations of energetics and radiative loss rates, and comparisons of relative emission in different wavebands to assess possible emission mechanisms. It has recently become apparent that a single set of abundances does not apply throughout the solar atmosphere, and that in some cases order of magnitude variability is found, so that many previous analyses must be reconsidered. In addition to these practical problems, it now appears that systematic differences in the average composition of the corona compared to the photosphere, and some details of coronal abundance variability might give important clues to the fundamental problems of coronal heating and mass supply.

A pattern is emerging that much of the observed variation in abundances between the photosphere and the solar wind and solar energetic particles (SEPs) is associated with the first ionization potential (FIP) of the elements, in the sense that elements with low FIP are enhanced in SEPs and the solar wind relative to high-FIP elements, as compared with photospheric composition. Although there is no convincing model yet available, the idea is that some element separation mechanism operates in a temperature regime of about 10,000 K where low-FIP elements are ionized while high-FIP elements remain neutral.

The *SMM* GI pilot study examined the behaviors of two low-FIP elements, Mg and Fe, and two high-FIP elements, O and Ne. A statistical analysis showed that the ratio of the low-FIP Fe to the high-FIP Ne appeared to vary by a factor of 5 or more, spanning a range which included the photospheric and the nominal coronal values. The other low-FIP/high-FIP ratios also seemed to vary at least between the photospheric and nominal coronal values and both the low-FIP/low-FIP ratio Fe/Mg and the high-FIP/high-FIP ratio O/Ne also showed significant variability. Several issues arose which needed to be addressed in a more extensive study before the work could progress. The present investigation has been attacking two of those issues.

III. CURRENT PROGRESS

A. Fe XVII Resonance Scattering

During the reporting period, 15 June to 15 December 1993, the PI has concentrated on diagnosing and understanding the role of resonance scattering of Fe XVII. The bright Fe XVII line at 15.01 Å, which featured heavily in the pilot study analysis was discovered by Schmelz, Saba, and Strong (1992 Astrophys. J., 398, L115) to be much more affected by resonance scattering than previous work by Rugge and McKenzie (1985 Astrophys. J., 297, 338) had suggested. At the center of bright active regions, where the abundance data were acquired, resonance scattering can deplete the observed flux in a line. The magnitude of the effect of resonance scattering and the impact on the derived abundance variability is being assessed in several ways. A fraction of the analysis was repeated using another Fe XVII line (at 16.78 Å) which is much less affected by scatter. In parallel, the various theoretical calculations available for the six bright Fe XVII lines covered by the FCS spectra are being examined with the assistance of Dr. Anand Bhatia at the Laboratory for Astronomy and Solar Physics at Goddard, who has made some of the calculations. At present comparing different pairs of the lines yield different answers. However, the initial analysis implies that resonance scattering cannot account for the bulk of the observed variability although it can introduce a systematic offset in the actual abundance ratios. Work on resonance scattering will continue in the next reporting period.

B. Diagnostic Tools

Work has begun on comparing the various temperature diagnostic line ratios available in the FCS data base. The most sensitive temperature diagnostic to use is a ratio of the Fe XVIII line at 14.24 Å with one of the Fe XVII lines. However, to make use of this ratio, one needs to have good values for the fractions of iron in the ionisation states $Fe^{+}17$ and $Fe^{+}16$. Unfortunately, the ionization balance calculations that predict these ion fractions as a function of temperature have recently come into question. New calculations have been proposed by Arnaud and Raymond (1992 Astrophys. J., 398, 394) as an improvement over the previous calculations of Arnaud and Rothenflug (1985 Astrophys. J. Suppl. Series, 60, 425), which were used in the pilot study. The two sets of calculations yield values of temperature for a given Fe XVIII/Fe XVII flux ratio, which translates into different relative abundance ratios for given values of flux ratios for the lines used in the study. An effort to compare the Fe XVIII/Fe XVII temperature diagnostic with diagnostics from the Mg XI and Ne IX triplets and with the ratio of Mg XII/Mg XI are underway. Although these ratios are less sensitive to temperature, they should give a handle on which of the two sets of iron ionization balance calculations are more consistent with the FCS data. Ongoing dialogues have also been established with several other groups who are comparing predictions of the iron ionization balance calculations with their own data or who are examining the calculations from first principles. This work will continue in the next reporting period. The goal is to be able to convert the various line flux ratios to relative abundance ratios by dividing out the temperature response.

IV. PRESENTATIONS:

During the reporting period, the following presentations were made under this contract, to report and publicize initial findings and to obtain feedback from the community to refine plans for future work:

SMM Flat Crystal Spectrometer Measurements of Solar Active Region Abundances: Variations on the FIP theme: J.L.R. Saba and K.T. Strong, 24th meeting of the Solar Physics Division of the A.A.S., Stanford, California, 13-16 July 1993.

An Abundance of New Information for Astrophysics from the Solar Corona: J.L.R. Saba, Laboratory for Astronomy & Solar Physics seminar at Goddard Space Flight Center, 30 September 1993.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT
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