(NASA-CR-170920) THE MODELLING OF THE SOLAR UPPER PHOTOSPHERE AND LOWER CHROMOSPHERE BASED UPON ATM DATA Final Technical Report (Hawaii Univ., Honolulu.) 10 p HC A02/MF A01 CSCL 03B G3/92

N84-12021

Unclas 44523

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER

FINAL TECHNICAL REPORT

NAS 8 33219

The Modelling of the Solar Upper Photosphere and Lower Chromosphere Based Upon ATM Data

James N. Heasley
Principal Investigator

Institute for Astronomy
University of Hawaii
2444 Dole Street
Honolulu, Hawaii 96822

Prepared for:

George C. Marshall Space Flight Center
Marshall Space Flight Center
Alabama 35812

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Final Technical Report

The scientific objective of this guest investigator program was to use spectral data obtained by the S082B experiment aboard Skylab to critically evaluate existing models of the solar upper photosphere and lower chromosphere and, where possible, to use these spectral diagnostics to develop new solar models. Research associate Dr. Diane Roussel-Dupre spent the period 12 November to 3 December 1979 at the Naval Research Laboratory in Washington, D.C. digitizing photographic spectra. This data has served as the basis for several investigations pertaining to the goals of this research program. These individual studies are described below.

At the time the original ATM guest investigator proposal was submitted one problem which was identified was the differences in models of the upper photosphere and temperature minimum region depending on whether the spectral diagnostics used in developing the model were continua (see, e.g., Vernazza, Avrett and Loeser 1976) or spectral lines (see, e.g., Ayres and Linsky 1976 or Heasley and Allen 1979). Heasley et al. 1981 presented new observations of the Al I autoionization doublet λ1932 and λ1936 and used non-LTE spectrum synthesis calculations to study the line formation of these features in the solar atmosphere. The non-LTE effects were found to be important for the line formation although the results were most sensitive to the "missing opacity" in the solar ultraviolet. The theoretical profiles for continuum based models (like the VAL) which have cool temperature minima (T ~ 4100 K) gave Al I profiles in good agreement with the ATM spectra while the models with hotter temperature minima, T ~ 4500 K (Ayres and Linsky 1976) predicted the Al I doublet to be somewhat weaker than observed.

ATM observations of the C I multiplets at λ1560 and λ1657 were reported by Roussel-Dupre and Heasley (1980). Previous work by Shine et al. (1978) using full-disk average profiles obtained from OSO-8 showed these lines to be sensitive to the magnitude of nonthermal broadening present in the lower chromosphere. The ATM spectra were found to be in reasonable qualitative agreement with the Shine et al. calculations for the VAL model atmosphere. These results represent the most complete observations of the C I multiplets to date, including the profiles in supergranuale cells, chromospheric network, and the overall center-to-limb behavior of the lines. Further theoretical calculations were attempted at the University of Hawaii Computer Center but proved to be computationally prohibitive due to the complex nature of the blending problems in the non-LTE calculations.

The major efforts supported by this guest investigator contract were directed toward using the solar H I Lyman α line as a diagnostic of the lower to middle chromosphere. This work represented a natural extension of Roussel-Dupre's thesis work at the University of Colorado, and required the reduction of the quiet sun Lyman α profiles from the ATM photographic spectra and the appropriate theoretical modelling.

The H I Lyman α line profiles obtained from the Skylab S082B films were presented by Roussel-Dupre (1981, 1982). These data represent the most detailed Lyman α profiles currently available and extend from the line center to over 6 Å into the line wings. Profile variations from center-to-limb, at different heights above the limb, and over cell and network boundaries were illustrated.

The Lyman α core exhibits weak or no limb darkening, while the line wings show weak limb darkening. Above the limb the line core has essentially constant integrated intensity and width up to + 12" and may result from resonance scattering of chromospheric radiation by coronal neutral hydrogen or from spicules. On the disk, intensities in the line core appear to correlate well with the H α network. The Lyman α wing intensities, however, appear to correlate better with the intensities seen in transition region lines. The average of profiles acquired over the cell and network region is similar to profiles obtained in the cell.

Roussel-Dupre (1982b) has recently completed a theoretical investigation of the Lyman α line formation in the solar chromosphere. Her calculations include a new form for the redistribution function that includes the effects of collisional coupling between different energy states. Frequencies in the Lyman α line wing 0.5 to 6 Å from the line center are shown to span the entire chromosphere in their height of formations. The line wing's usefulness as a diagnostic probe is limited by a large thermalization length, a result of almost coherent scattering outside of the doppler core.

Comparing Lyman α calculations for the Vernazza, Avrett and Loeser (1981) solar models, which were developed largely on the measurements from the Skylab S055 experiment, with the Lyman α profiles obtained under this guest investigator contract, Roussel-Dupre finds good agreement in integrated core intensities, in the line wing shape, and the normalized center-to-limb behavior. The absolute wing intensities calculated for these models, however, are a factor of 4 too small. In addition, there is no justification from the multilevel analysis to decrease the amount of coherent scattering in the wings to the value $\gamma = 0.98$ suggested by Vernazza, Avrett and Loeser (1981).

Roussel-Dupre makes several suggestions for future calculations which might improve the agreement between the observed and computed profiles. She believes that the strong collisional correlation correction terms to the redistribution function, which have been estimated to be small and hence deleted from the current formulations, may be important. Including one estimate of these terms resulted in a 40% increase in the computed line wing intensities.

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