HIGH RESOLUTION STUDIES OF THE STRUCTURE OF THE SOLAR ATMOSPHERE

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Principal Investigator

Shadia R. Habbal

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Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

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HIGH RESOLUTIONS STUDIES OF THE STRUCTURE OF THE SOLAR ATMOSPHERE

ANNUAL REPORT

1. Introduction

During this second year we pursued the analysis, image enhancement and processing of an extensive set of the EUV/*Skylab* data in search of empirical characteristics of coronal heating in different scale magnetic regions on the Sun. Student involvement included Martina Arndt, Gretchen McPhee and Jennifer Yeh.

2. Summary of Accomplished Research Projects

2.1 Characteristics of the Temporal Variability of the Emission from Active Regions

By applying an image enhancement algorithm based on MaD MAXII, an algorithm originally suggested by Koutchmy et al (Proceedings of the 9th Sacramento Peak Summer Symposium, 1987), to the active region, we were able to show very clearly the discrete and localized nature of the variable emission. (The algorithm replaces each pixel in an image by the second derivative of the intensity, maximized over eight directions. Several levels of block-average smoothing may be applied prior to the derivative, and the results may be blended to emphasize features at various scales.) We found that the variable emission in an active region occurs preferentially around the footpoints (Figure 1).

We also studied the temperature dependence of the variable emission in active regions. We found that the magnitude and spatial density of the variability is temperature dependent with a peak around 10^5 K. This temperature dependence is very similar in a flaring or nonflaring region (Figure 2). These results suggest that the small scale field is greatly responsible for the variable emission of the solar atmosphere, and that flares are probably the tail end of the manifestation of this variability.

2.2 Studies of the Small Scale Structure at the Solar Limb in Coronal Holes

The image enhancement algorithm was also applied to limb observations in a coronal hole (Figure 3). For these data we find that there is a fine scale structure, with a characteristic spatial scale of 10", extending from the solar limb outwards into the corona (Figure 3). In addition, we find that different temperature fine structures which have the same spatial characteristic scale are not cospatial.

The application of this algorithm to images made simultaneously at different wavelengths at the limb clearly separated two different parts: a thin region where the limb brightening occurs, even in the coronal image of Mg X, and a fine structure extending above the limb. Measurements of the location of the limb in different spectral lines show that the limb defined by either the C III or O VI emission is about 5" above the Ly α limb, thus confirming previous measurements by Huber et al. (Ap. J. 194, L15, 1974). However, this technique enabled us to detect the limb in Mg X and to show for the first time that the height of the Mg X limb is 5" above the C III and O VI limb, and about 10" above the Ly α limb.

We also processed a time sequence of these images (Figure 5). We found that the filamentary structure extending above the limb was extremely dynamic, with indications of interaction between neighboring structures. A movie made with a series of images, taken every 2 minutes, shows the continuous interaction between the filamentary structures, forming short-lived arch-like structures, with the occasional expulsion of material. Although different temperature plasmas coexist in the field of view, the dynamic behavior of each seems to be quite different. The most dynamic events occur at the location of the macrospicules. Such events could be a reflection of the dynamic nature of the coronal magnetic field.

2.3 Inference of Coronal Temperatures

Line intensity ratios from EUV/*Skylab* limb observations in a coronal hole were used to infer the temperature across a coronal hole (Figure 6). We showed that the coronal base temperature, which is a critical parameter for solar wind models, cannot be determined with existing observations, to an accuracy better than 5×10^5 K. We also showed that line of sight effects can be significant in altering inferences of coronal hole temperatures.

2.4 Empirical Determination of the Helium Abundance in the Inner Corona

We have developed a very simple technique for the inference of the helium abundance in the inner corona from existing observations of spectral lines from which density and temperature can be inferred. The results given in Figure 7, for two different data sets, show that the helium abundance at the coronal base could be significantly high, i.e. the ratio of helium to proton density is at least 0.3, but drops very rapidly with heliocentric distance to interplanetary values of 0.05. This technique should be particularly valuable when data from SOHO become available.

2.5 Acquisition of Coordinated Ground-Based Observations

Two sets of internationally coordinated ground-based observations were obtained. The first on April 10, 11 and 12, 1993, coincided with the shuttle launch of the Spartan 201 Ultraviolet Coronagraph, the second was on July 22 and 23, 1993. The goal of both observational experiments was to study the solar wind from its source region into interplanetary space, from coronal holes and quiet regions. The ground-based instruments involved were the Very Large Array (VLA), the EISCAT radar system in Scandinavia to obtain Interplanetary Scintillation (IPS) measurements, and Sacramento Peak Observatory. Coordinated observations with YOHKOH, the X-ray satellite, were also obtained.

3. Publications and Presentations

3.1 Publications

R. Esser, S. R. Habbal and M. B. Arndt, "Temperature measurements in the inner corona", Proceedings of the first SOHO Workshop, Anapolis, Maryland, ESA SP-348, November, 1992.

S. R. Habbal, R. Esser and M. B. Arndt, "How reliable are coronal hole temperatures deduced from observations", *Ap. J.*, **413**, 1993.

R. Esser and S. R. Habbal, "Effect of overestimating the density relative to the Ly α intensity on the velocities derived from Doppler dimming", to appear in *Solar Phys*, 1993.

S. R. Habbal and R. Esser, "Empirical limits on the helium abundance in coronal holes below 1.5 $R_\odot$ ", to appear in *Ap. J. Lett.*, 1993.

S. R. Habbal, R. Esser and Y. Q. Hu, "Standing shocks in a two-fluid solar wind model", submitted to *J. Geophys. Res.*, August 1993.

M. B. Arndt, S. R. Habbal, and M. Karovska, "Discrete and localized nature of the variable emission from active regions", submitted to *Solar Phys.*, August 1993.

M. Karovska and F. Blundell, "The fine structure at the limb in a coronal hole", submitted to Ap. J, August 1993.

M. Karovska, M. Arndt and S. R. Habbal, "Spatial and temporal variability of the emission at the limb in a coronal hole", in preparation.

3.2 Conference Presentations

M. Karovska, S. R. Habbal and F. Blundell, "Fine structure at the limb in a coronal hole", 181st AAS Meeting, Phoenix, Arizona, January 1993.

M. Karovska, "Exploring the dynamical structure at the limb in a coronal hole, 24th Solar Physics Division Meeting, Stanford, CA, July 1993.

M. Karovska and H. Hudson, 1993, "Determining point spread response functions from space Using blind iterative deconvolution algorithm", *New look at the Sun with Emphasis on Advanced Observations of Coronal Dynamics and Flares* Symposium, Kofu, Japan, September 1993

M. Karovska and M. B. Arndt, "The fine scale structure of the solar limb in a coronal hole", *New look at the Sun with Emphasis on Advanced Observations of Coronal Dynamics and Flares* Symposium, Kofu, Japan, 1993.

3.3 Invited Talks

S. R. Habbal, "The small scale magnetic field of the Sun and its connection to coronal heating", Physics Colloquium, U. Mass, Dartmouth, November, 1992.

S. R. Habbal, "Observationai characteristics of coronal heating mechanisms", University of Cincinnati Physics Colloquium, January 28, 1993.

S. R. Habbal, "Unraveling some of the puzzles of coronal heating", Harvard-Smithsonian Center for Astrophysics Colloquium, March 11, 1993.

4. Future Projects

We will be concentrating on several research projects which involve data analysis, image processing and theoretical modelling:

Comparison of the temperature in coronal holes and the quiet sun: the implication for solar wind models. We will pursue our analysis of the extensive set from the EUV/*Skylab* data of limb and disk observations. These studies will be complemented by theoretical solar wind models that are also being developed.

The energy spectrum of the variability of the emission in active regions, the quiet sun, and coronal holes. This study will involve the application of the analysis techniques developed so far to an extensive set from the EUV/*Skylab* and other ground based multi wavelength data.

Studies of the fine scale structure in the quiet sun and active regions. We will continue to apply the two image processing techniques IDCON and MaD MAXII which we have been using, and have proven to be very successful, on a large data set to establish the difference, if any, between the fine scale structure in large and small scale magnetic structures such as active regions and coronal bright points, the quiet Sun and corona holes. The goal is to find a characteristic underlying scale for the magnetic field structures.

Model radio emission in the presence of structure in the quiet sun and active regions. With the acquisition of three data sets of coordinated observations, we can pursue more successfully the inference of plasma parameters from radio observations. In particular, the coronal magnetic field is one of the parameters that can, at present, only be inferred from the radio emission.

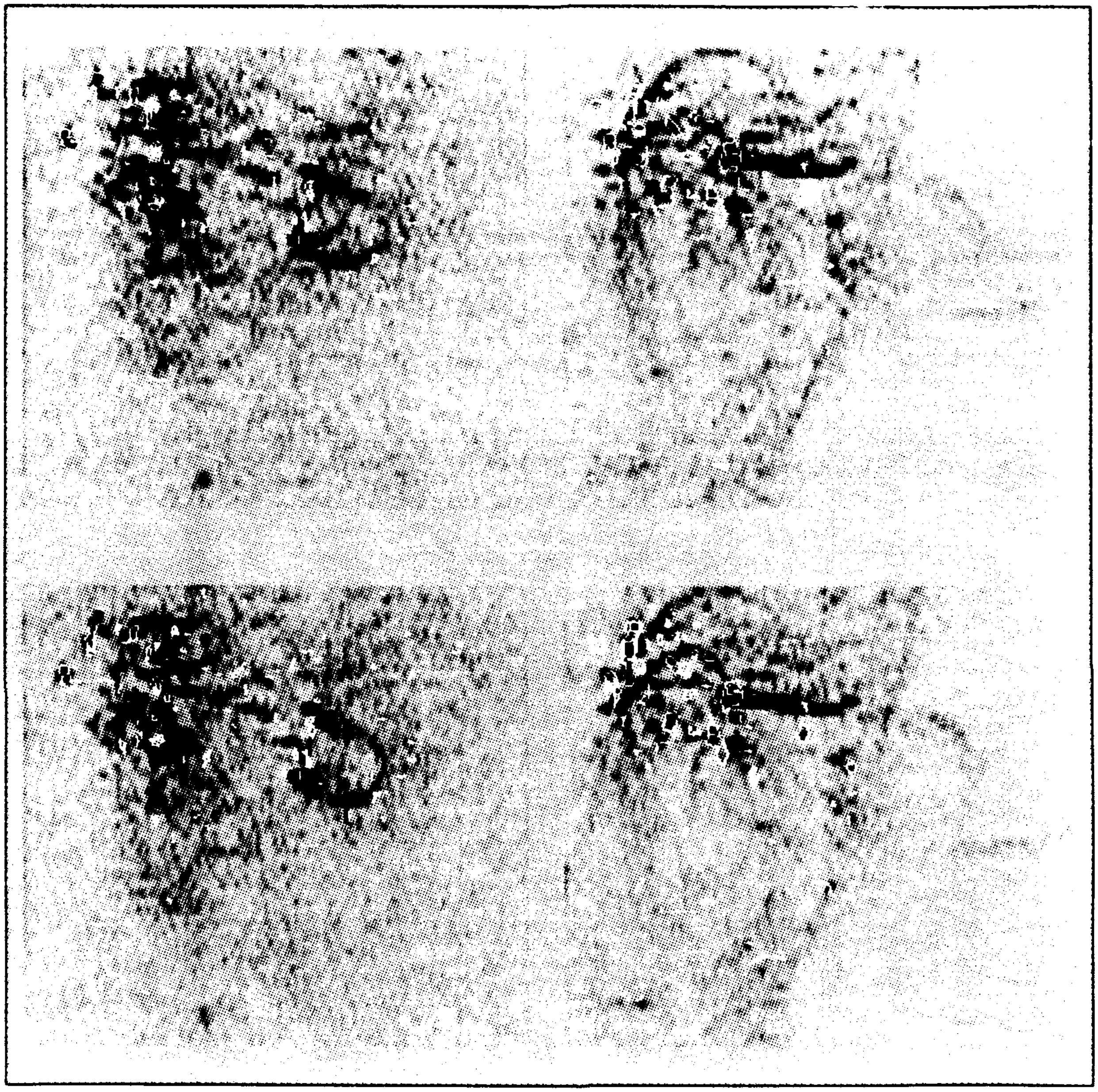


Figure 1: Active regions on the disk and near the limb, observed simultaneously in Ne VII (right panels) and Si XII (left panels), at 9:04 and 9:10 UT on 23 November 1973, with the EUV spectrometer on *Skylab*. The peak formation temperature of these two spectral lines is 7×10^5 and 1.8×10^6 K respectively. The images are processed with MaD MAXII. The contours indicate the location of the significant variability.

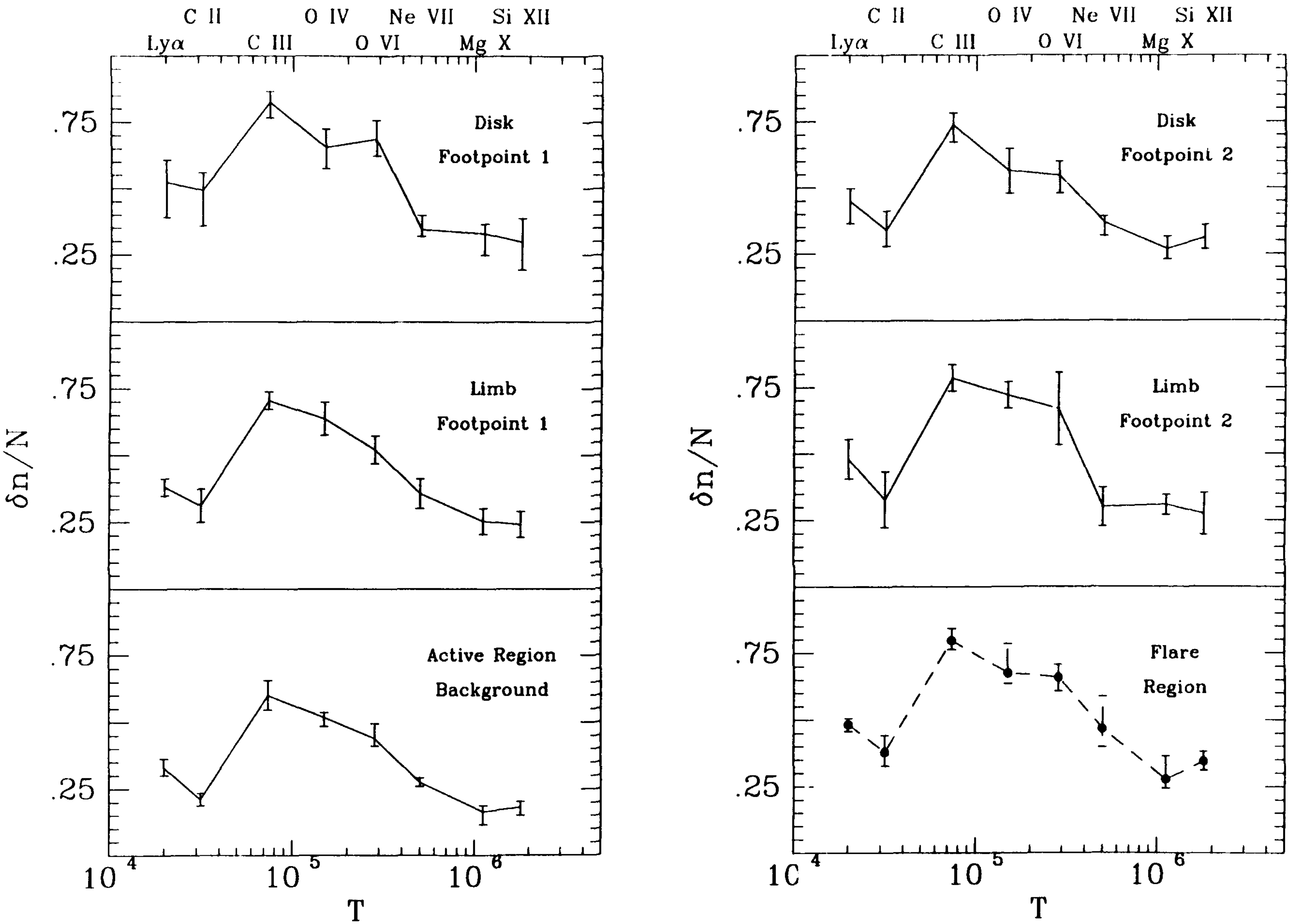
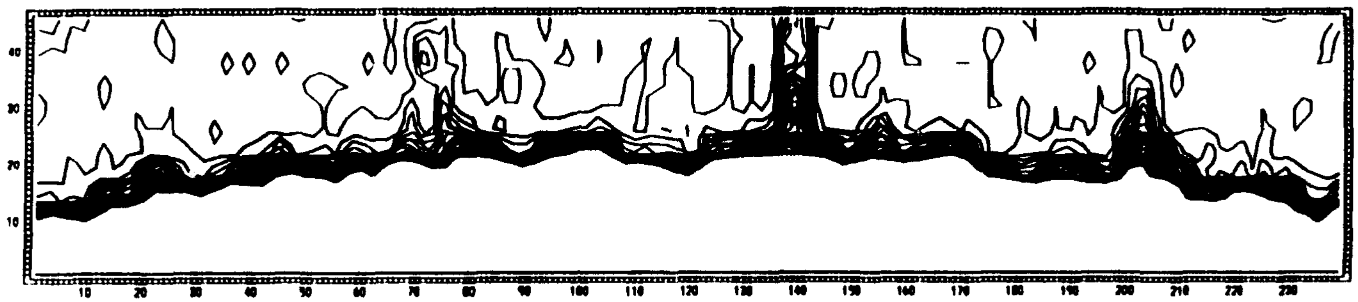


Figure 2: Variation of the spatial density of the variability, $\frac{\delta n}{N}$, as a function of temperature in different parts of the field of view of Figure 1. The dashed curve for the flare indicates that the flare occurred only during the simultaneous Si XII and the Ne VII observations. The 'error bars' represent the temporal spread in $\frac{\delta n}{N}$.

(a)



(b)

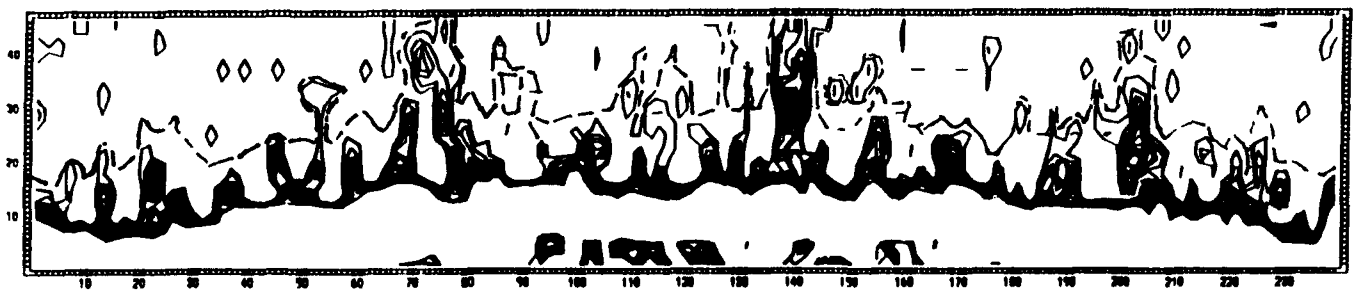


Figure 3. (a) A 300"x 65" section of the solar limb in a north polar coronal hole as observed in C III (977 Å) on 11 December 1973 by the EUV spectrometer on *Skylab*. (b) Same as (a) but processed using MaD MAXII. The dashed line corresponds to the lowest contour of the limb in the unprocessed image shown in (a). The contour levels in both panels were chosen in such a way to expose the weak emission at and off the limb. The strong disk emission appears as white. The MaD MAXII image exposes the filamentary structure at the limb with a characteristic spatial separation of about 10", and low-lying arch-like features. The structures extending vertically upwards are giant spicule-like features, also known as macrospicules.

Madmax: H I, C III, O IV, O VI, Mg X 23:01 UT

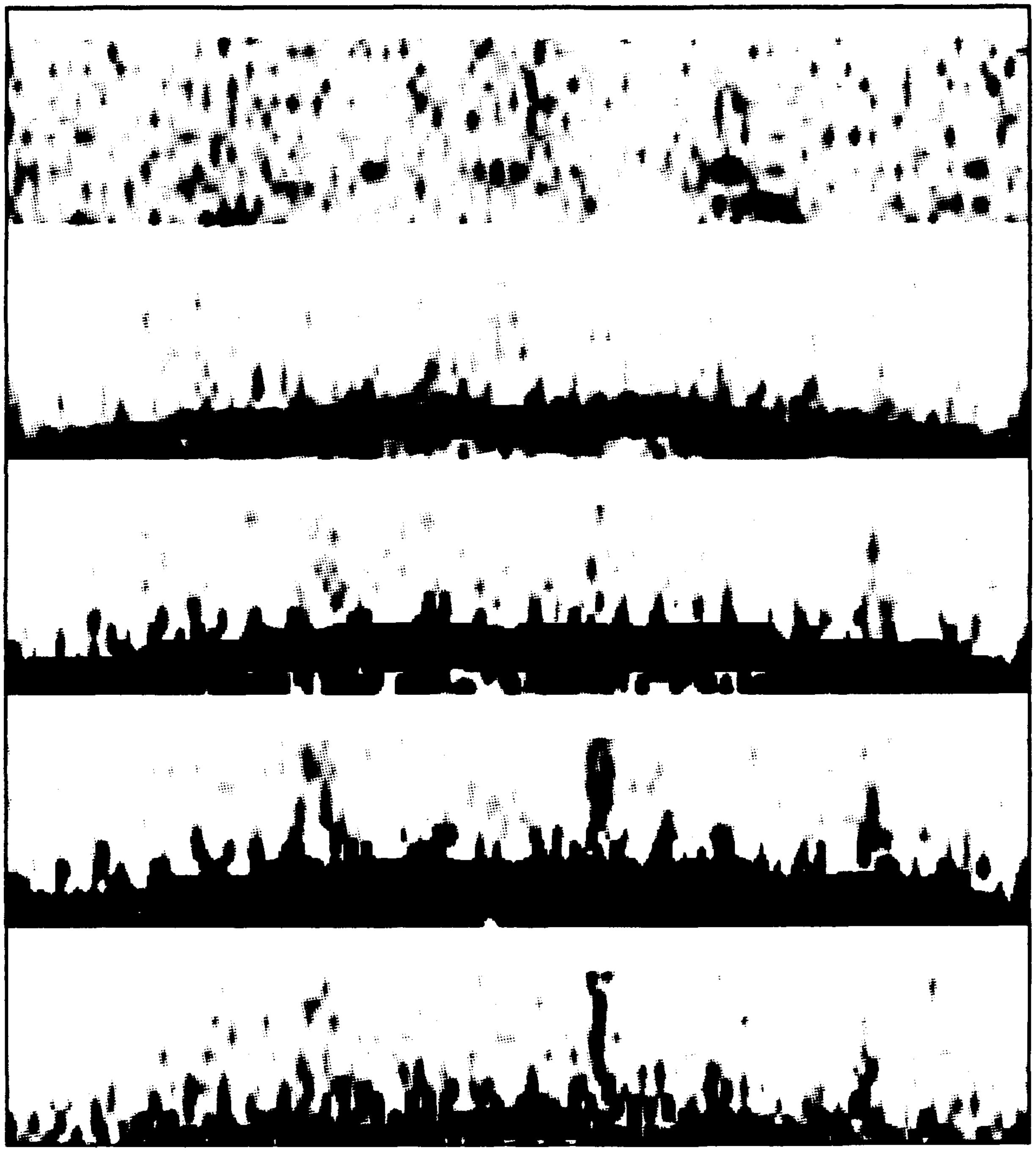


Figure 4. Same data as Figure 1 showing processed images of simultaneous and cospatial observations made (from top to bottom, in order of decreasing temperature) in Mg X, O VI, O IV, C III, and Lyα. The emission at higher temperatures (Mg X, O VI) is not cospatial with the emission at lower temperatures. This indicates the coexistence of different temperature plasmas in the field of view.

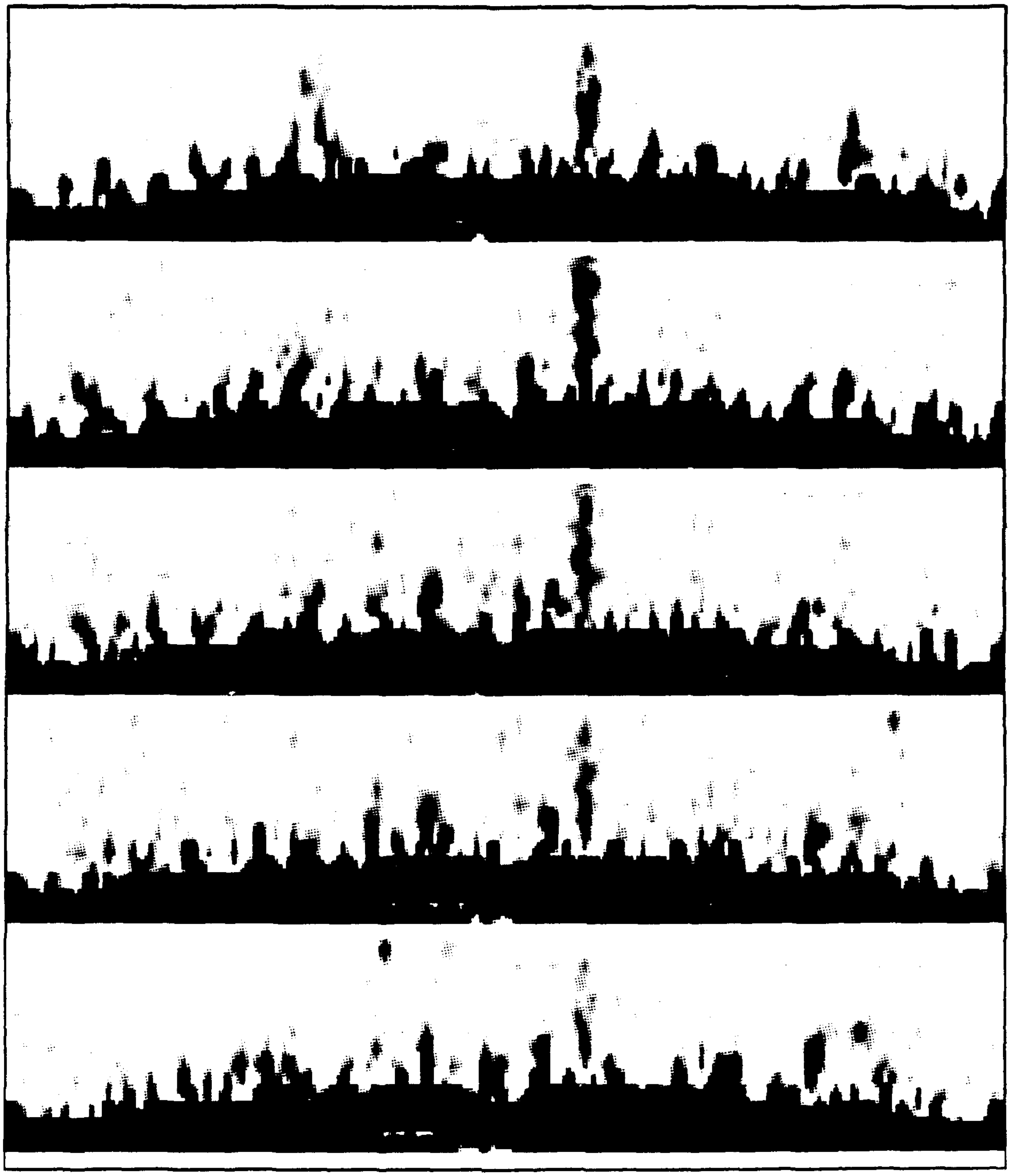


Figure 5. A selection of five consecutive processed C III MaD MAXII images, about 2 minutes apart, taken from a 40 minutes time sequence from the data of Figures 3 and 4, showing the dynamical evolution of the structures at the limb.

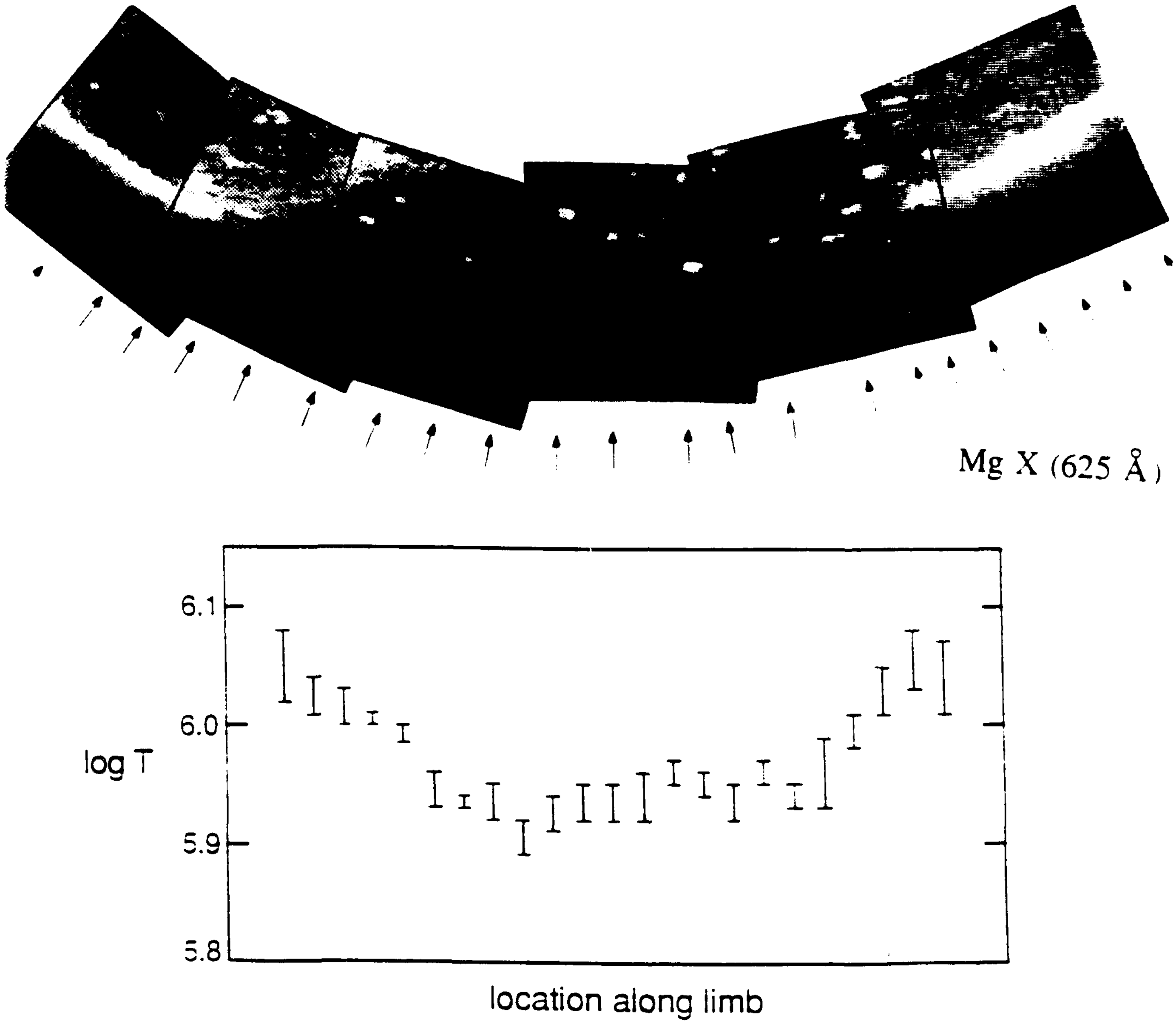


Figure 6. Temperature distribution across a south polar coronal hole and neighboring quiet regions as inferred from ratios of line intensities of Mg X, Ne VII and O VI (lower panel). The upper panel shows the composite image in Mg X, where the coronal hole is distinguished by the very low emission and is "dotted" with bright points. The composite was made from consecutive scans with *Skylab* on 11 December 1973. The arrows indicate the radial directions along which temperatures were inferred.

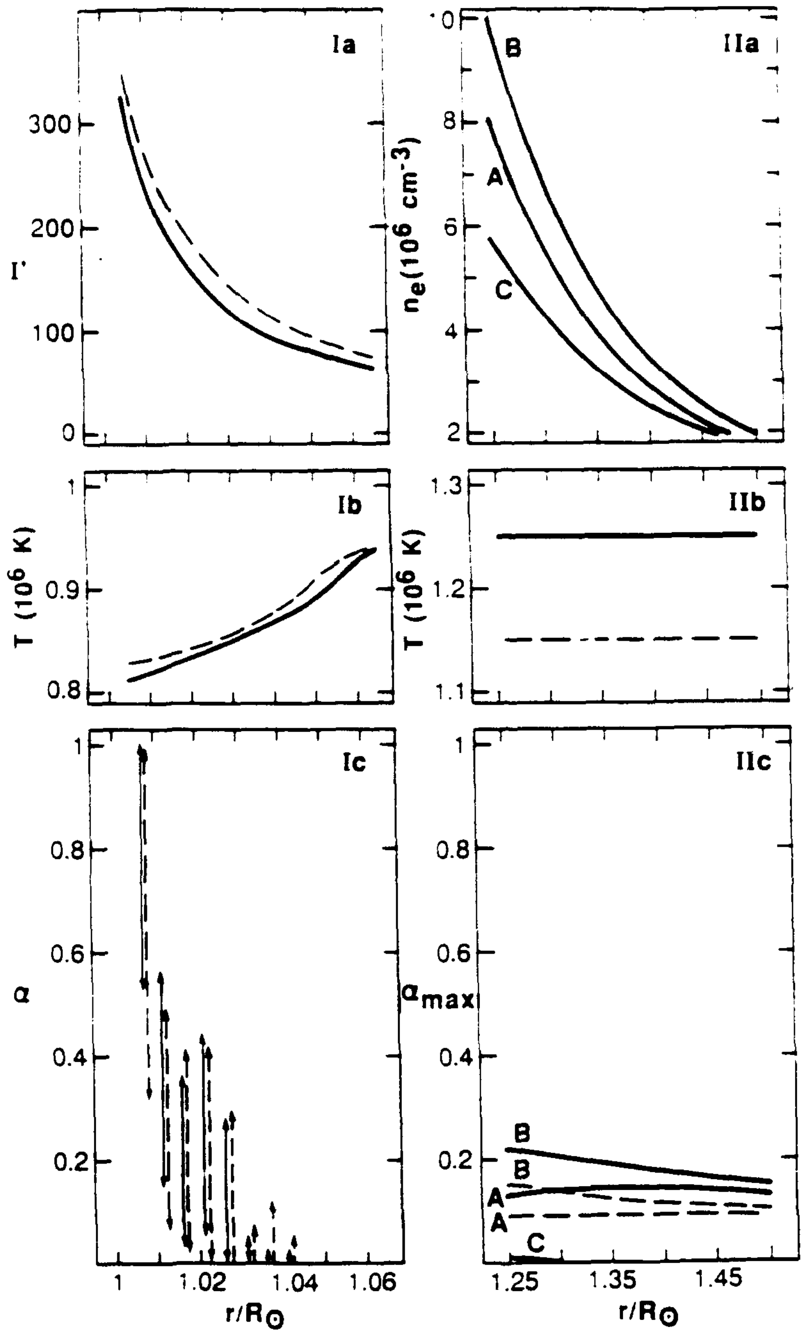


Figure 7. Panel Ia: average emission measure, I', for the range of empirical values derived from line intensities. Two different radial directions were chosen in a polar coronal hole, and the corresponding I' profiles are shown as a dashed and a solid line. Panel Ib: average temperature profiles corresponding to the two radial directions. Panel Ic: corresponding range of α. α_{min} was inferred from the data in Ia and Ib, while the maximum follows from assuming that $\alpha_{max} = 1$ at 1 $R_\odot$. Panel IIa: electron density profiles A, B and C of Lallement et al (1986). Panel IIb: constant temperatures of 1.15 and 1.25×10^6 K. Panel IIc: inferred α_{max} for 1.25×10^6 K (solid line) and 1.15×10^6 K (dashed line) for density profiles A, B and C. No solution exists for profile C when T = 1.15×10^6 K.

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Dr. Shadia R. Habbal

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Smithsonian Institution Astrophysical Observatory
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During this second year we pursued the analysis, image enhancement and processing of an extensive set of the EUV/*Skylab* data for the search of empirical characteristics of coronal heating in different scale magnetic regions on the Sun. Student involvement in our research projects included Martina Arndt, Gretchen McPhee and Jennifer Yeh. During this funding period we published three papers in refereed journals, one in a conference proceedings, submitted three papers to refereed journals, and have several manuscripts under preparation. We have also made two conference presentations and given three invited talks. Our future projects are continuations of our ongoing long term projects and include: (1) The comparison of the temperature in coronal holes and the quiet sun: the implication for solar wind models. (2) The energy spectrum of the variability of the emission in active regions, the quiet sun, and coronal holes. (3) Studies of the fine scale structure in the quiet sun and active regions. (4) Modeling the radio emission in the presence of structure in the quiet sun and active regions.

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