EXTENSION OF THE SOLAR LIMB AT SUB-MILLIMETER AND MILLIMETER WAVELENGTHS

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(received 3 February, 1992; in revised form 13 April, 1992)

ABSTRACT

Solar limb scanning at 5 wavelengths from 0.35 to 2 mm on the JCMT has revealed significant limb extension which increases rapidly with wavelength, in agreement with other measurements. This appears to be related to the increasing opacity of overlapping spicules which appear to become optically thick at about 1mm.

1. INTRODUCTION

The source heights of solar far IR and millimeter radiation extend over the high photosphere and low chromosphere. Measurements at these wavelengths are relatively easily interpreted and have proven of great value in the study of these regions. Since the opacity is dominated by H^-, the spectrum is predominantly continuum and is assumed to be formed in thermodynamic equilibrium. Radiometrically calibrated spectral measurements provide estimates of brightness temperature over a relatively wide height range which contains the important inversion in temperature at the temperature minimum (Vernazza, Avrett and Loeser, 1983). In contrast, observations of other radiations whose source heights occur in this region such as the UV continuum, which is hard to identify against a plethora of lines, and strong Fraunhofer lines, are more difficult to interpret.

Unfortunately, radiometric far-IR measurements at disk center (e.g. Boreiko and Clark, 1987) provide only a dependence of brightness temperature on optical depth and give no direct measurement of height within the atmosphere. Interpretation of these data in terms of height have depended upon unreliable assumptions related to hydrostatic equilibrium within this atmosphere. Also, these spectral measurements have been made with limited spatial resolution from small-aperture balloon or aircraft-borne telescopes and provide only a spatially averaged measurement over relatively large areas of an atmosphere which contains obvious structure, including the spicular chromospheric network.

In contrast, the method of limb scanning, particularly to high resolution in solar eclipses (e.g. Lindsey et al., 1986, 1992, Roellig et al., 1991), provides direct information on the source distribution with height. Such intensity measurements still represent an average over a structured atmosphere, namely the spicular forest embedded in a tenuous corona. Nevertheless, these measurements appear to be amenable to interpretation by statistical modeling of the expected structure (e.g. Braun and

Solar Physics **140**: 393–396, 1992.

Lindsey, 1987, Lindsey and Jefferies, 1990), from which new distributions of electron density and temperature within spicules have been derived.

An important result which has emerged from limb scans, and one which has been incorporated into the above modeling, is the significant extension of the limb of the Sun at these wavelengths, well beyond the prediction of most homogeneous atmospheric models of the chromosphere (Vernazza et al.,1981). The purpose of this short note is to present new data on this limb extension, obtained by exploiting the superb observing conditions of Mauna Kea and the high angular resolution of the 15-m. James Clerk Maxwell Telescope to scan the solar limb, and to compare these data with a range of recent interferometric and eclipse observations.

2. OBSERVATIONS

The present data were taken over a period of a few minutes under excellent observing conditions on Feb. 6th, 1990 with the facility bolometric detector UKT14 (Duncan et al 1990) mounted at the JCMT f/35 Nasmyth f/35 focus. The limb scans shown in Figure 1 were taken by differential photometry at effective wavelengths of 0.35, 0.45, 0.8, 1.1 and 1.92 mm. respectively, across the north limb of the sun. This limb was found to be free of activity from Hα photographs taken a few hours earlier.

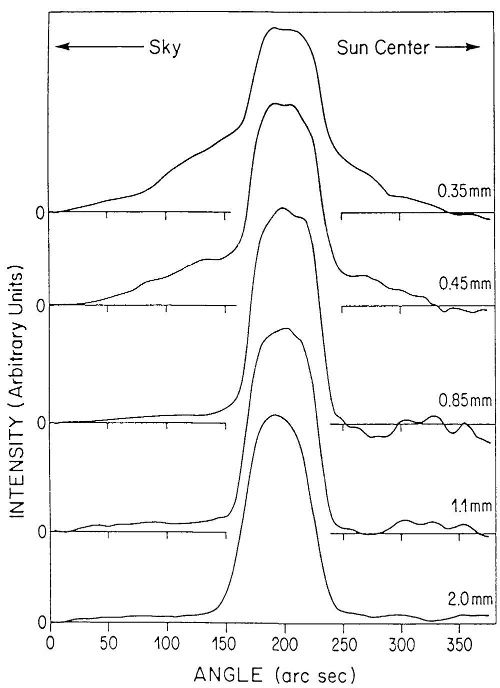

Fig.1 Differential Limb Scans.

The telescope was scanned over a range of 370 arc seconds in 5 arc second steps at 1 step per second, with the telescope secondary chopping 60 arc seconds in the direction of scan. The effective telescope beam-widths are governed by diffraction and by deviation of the composite mirror surface from that of a perfect mirror. Overall widths of the central peaks were determined from these scans to be about 11 arc seconds for the shorter wavelengths and 26 arc seconds for the two longer wavelengths. The scans clearly show the sharp rise to full intensity as the detector sensitivity peak crosses the solar limb, a clear indication of the excellent quality of the JCMT mirror. There is also evidence of a significant wing on the beam, at least at the shorter wavelengths with the mirror under solar illumination.

This wing plays no part in the present interpretation but must be taken into account in any attempt to measure solar limb brightening functions by limb scanning (Lindsey and Roellig, 1991). The beam pattern from these data appears to consist of two central Gaussian components of 8 and 22 arc seconds FWHM respectively and a much wider "pedestal" with a FWHM of 230 arc seconds with a small but significant amplitude, especially at the shorter wavelengths.

Two methods were used to produce the present estimates of limb position. In the first, the half-intensity point on the sharp rising edge beyond the effect of the pedestal was measured while in the second, the position of maximum slope was determined mathematically. These methods yielded consistent results to better than 1 arc second. Since no absolute determination of the visible limb position is possible with this telescope, these data represent the limb positions measured with respect to the solar disk center as determined by the telescope pointing system. These positions are found to be within 1 arc second of the overlapping data of Roellig et al (1991) at 0.36 and 0.67mm and of Horne et al (1981) at 1.3mm.

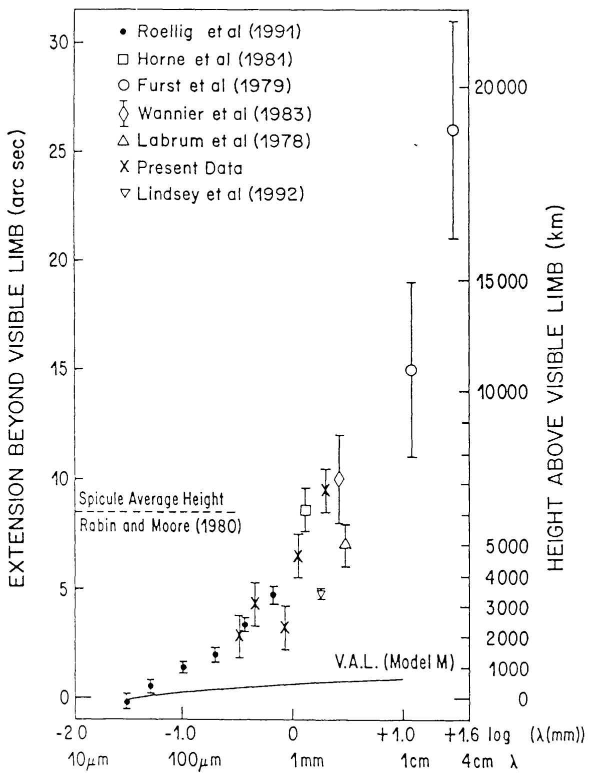

Fig.2 Solar Limb Extension as a Function of Wavelength

3. DISCUSSION OF THE DATA

The resultant solar limb extensions from these measurements are plotted against the logarithm of the wavelength in Figure 2, and are seen to be in good agreement with other data taken during eclipses or by interferometry in showing a distinct trend towards a larger solar diameter as wavelength increases. Also shown is the prediction of limb extension by the empirical, homogeneous solar atmosphere model M, of Vernazza, Avrett and Loeser (1981). It is clear that this type of model significantly underestimates the solar diameter at these wavelengths. More recent statistical modeling of the inhomogeneous spicular structure of this atmosphere (Hermans and Lindsey, 1986, Lindsey, 1987, Lindsey and Jefferies, 1990) has been successful in accounting for the limb extension and brightening measured in aircraft eclipse experiments.

The slope of this graph changes gradually between 0.8 and 1 mm, at about the average height of spicules in the solar atmosphere (Rabin and Moore (1980). It is tempting to suggest that the change in limb extension over the sub-mm range is caused by the slow increase in opacity of the spicular material (a point well made by Lindsey at al on the basis of their modeling) and that this material becomes opaque at a wavelength longward of 1 mm. Beyond this point, the increase in limb extension as seen by Furst et al.(1979) is most likely governed more by a rise in the opacity of inter-spicular coronal material than by the distribution of spicules.

4. CONCLUSIONS

Sub-millimeter and millimeter solar limb extensions of up to 10 arc seconds have been measured on the JCMT. These and other data show a significant increase in limb extension beyond that predicted by homogeneous atmospheric models. This appears to be related to the optical thickness of spicules and, at longer wavelengths, to the increased opacity of inter-spicular material.

Acknowledgements

It is a pleasure to thank the staff of the JCMT for their considerable efforts in support of these experiments and C.A.Lindsey for permission to include the recent solar eclipse data prior to publication. The James Clerk Maxwell Telescope is operated by the Royal Observatory Edinburgh on behalf of the Science and Engineering Council of the United Kingdom, the Netherlands Organisation for Scientific Research and the National Research Council of Canada.

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