LYMAN CONTINUUM OPTICAL DEPTH OF PROMINENCES DERIVED FROM EUV SPECTROHELIOGRAMS

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The two-dimensional distribution of the optical depth at the Lyman limit, τ_H, in three hedgerow prominences (P23, P28A, and P42) is derived from simultaneous spectroheliograms (5"x5" resolution) of C III λ977, Ly C λ896, and O IV λ554 observed with the Harvard experiment on Skylab.

We assume a multiple-slab model for the prominence. In this model the prominence is viewed as consisting of a number of cool ($T < 10^4$K) and identical slabs embedded in the hot ($T \approx 10^6$K) corona; at the surface of each slab is a transition zone of intermediate temperature. Then the observed intensity of C III λ977 and O IV λ554 will be

$$I(\mathrm{C\ III}) = 2NI_{\mathrm{C\ III}}, \tag{1}$$

and

$$I(\mathrm{O\ IV}) = I_{\mathrm{O\ IV}}\,[1-e^{-N\tau_1}+2\sum_{n=1}^{N} e^{-n\tau_1}]. \tag{2}$$

Here $I_{\mathrm{C\ III}}$ and $I_{\mathrm{O\ IV}}$ are the intensity of C III λ977 and O IV λ554 emitted by the transition zone at each surface of the slabs, N is the number of the slabs in the line of sight, and τ_1 is the optical depth of one slab in the Ly C at 554 Å.

We now assume that the total optical depth $N\tau_1$ is finite, but that the number of individual slabs is very large; i.e. the hot and cold regions of the prominence are intimately mixed. In the limit where N approaches infinity, we have

$$R \equiv \frac{I(\mathrm{C\ III})}{I(\mathrm{O\ IV})} = \frac{I_{\mathrm{C\ III}}}{I_{\mathrm{O\ IV}}}\ \frac{\tau_H(\lambda_1/\lambda_H)^3}{1-e^{-\tau_H(\lambda_1/\lambda_H)^3}}, \tag{3}$$

where $\lambda_1 = 554$ Å and $\lambda_H = 912$ Å. We note that the assumption $N \to \infty$ gives a lower limit for the optical depth. If the number of the slabs in the line of sight is greater than five, then the error in τ_H is less than 20%.

Now we can determine τ_H from Equation (3) using the observed intensity ratio R, provided that the ratio $I_{\mathrm{C\ III}}/I_{\mathrm{O\ IV}}$ is known. In order to determine $I_{\mathrm{C\ III}}/I_{\mathrm{O\ IV}}$

empirically for each of the prominences we use the Ly C spectroheliograms. Assuming the source function of the Ly C to be constant with depth and position in a prominence, we have the intensity of the Ly C at $\lambda 896$,

$$I(\text{Ly C}) = S_{\lambda_c}\left[1-e^{-\tau_H(\lambda_c/\lambda_H)^3}\right], \tag{4}$$

where S_{λ_c} is the source function of the Ly C at $\lambda_c = 896$ Å. From Equations (3) and (4) we have

$$\frac{d[\log I(\text{Ly C})]}{d[\log R]} = \frac{\tau_H(\lambda_c/\lambda_H)^3}{e^{\tau_H(\lambda_c/\lambda_H)^3}-1}\;\frac{e^{\tau_H(\lambda_1/\lambda_H)^3}-1}{e^{\tau_H(\lambda_1/\lambda_H)^3}-1-\tau_H(\lambda_1/\lambda_H)^3}\,. \tag{5}$$

The gradient $d[\log I(\text{Ly C})]/d[\log R]$ is independent of $I_{\text{C III}}/I_{\text{O IV}}$ and S_{λ_c}. For large τ_H (or R) the gradient has a value ≈ 0; it reaches a value of unity at $\tau_H = 2.46$ and then rapidly increases with decreasing τ_H (or R) for $\tau_H < 2.46$. The value of R at which the gradient becomes unity (R_1) will be found from a diagram of log I(Ly C) vs log R plotted for a number of positions in a prominence. Then we can find the numerical relation between τ_H and R, that is, the value of $I_{\text{C III}}/I_{\text{O IV}}$ for the prominence.

Figure 1 displays I(Ly C) as a function of R on a logarithmic scale for the three prominences. The points in Figure 1 are restricted to heights greater than 10" above the limb in order to avoid effects of chromospheric structures such as spicules, fibrils, and network walls along the line of sight. In Figure 1 we have illustrated theoretical curves (dashed lines) derived from Equations (3) and (4),

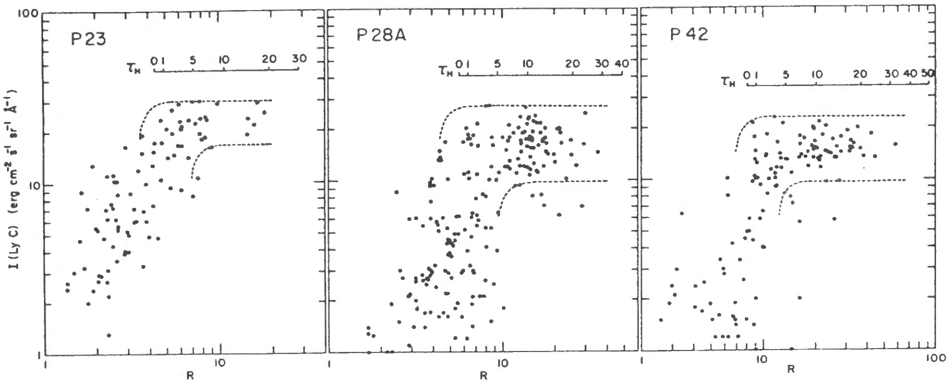

Fig. 1. Intensities of the Ly C at 896 Å as a function of R.

but choosing the parameters $I_{\mathrm{C\,III}}/I_{\mathrm{O\,IV}}$ and S_{λ_c} arbitrarily, so as to place the curves at locations corresponding to the outer and inner envelopes of the points for each prominence. From these curves we found a possible range of R_1. Given that the geometric mean of R_1 corresponds to $\tau_H = 2.46$, we can derive $I_{\mathrm{C\,III}}/I_{\mathrm{O\,IV}}$ for each prominence. These values for $I_{\mathrm{C\,III}}/I_{\mathrm{O\,IV}}$ can then be used with Equation (3) to calculate τ_H as a function of R. The latter relationships are given in Figure 1.

It is interesting that the three prominences have different values of $I_{\mathrm{C\,III}}/I_{\mathrm{O\,IV}}$: 4.3, 5.7, and 8.1 for P23, P28A, and P42, respectively. This may be due to differences in the structure of the transition zone of the prominence threads and of the region between the threads. On the other hand, Figure 1 shows a number of points which have values of R less than the lower limit $R_{\mathrm{min}} = I_{\mathrm{C\,III}}/I_{\mathrm{O\,IV}}$ predicted by this simple model. The points in question correspond to the positions near the edges of the prominences, rather than near their centers. In location near the edge of the prominence the slit filling factor for the Ly C emitting threads and their transition zones may be considerably less than unity. If we postulate the existance of hot ($T > 10^{5.5}$K) material between the threads, then this material would emit considerable O IV ($\log T_{\mathrm{max}} = 5.25$) compared to C III ($\log T_{\mathrm{max}} = 4.95$). This results in $R < R_{\mathrm{min}}$ for the positions near the edges of the prominences. In determinimg τ_H we assume that the positions with $R < R_{\mathrm{min}}$ are optically thin in the Ly C ($\tau_H < 1$).

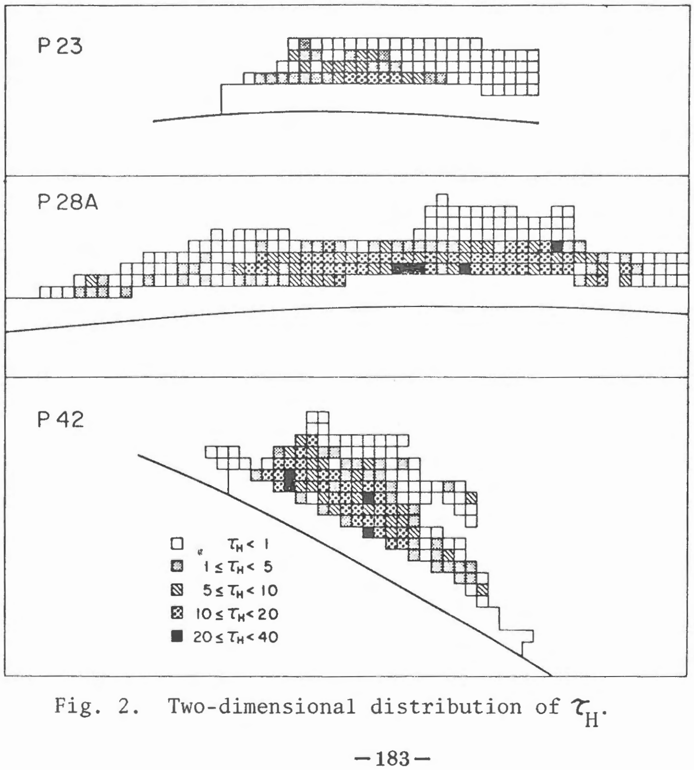

Fig. 2. Two-dimensional distribution of τ_H.

Figure 2 shows the two-dimensional distribution of τ_H for the three prominences at heights greater than 10" above the limb. A square in Figure 2 represents an area of 5"x5" ($\approx$ 3650x3650 km^2). The value of τ_H varies over a wide range at positions even in a single prominence. At the central part of the prominences where the opacity is largest τ_H reaches a maximum value of 30 to 50 for the three prominences when correction is made for the self-absorption effect of C III λ977. In general τ_H decreases with height in the prominences. Most positions near the outer boundary of the prominences are optically thin in the Ly C ($\tau_H < 1$).