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The Density and Thickness of Quiescent Prominences

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[Abstract] The electron density was determined for a number of quiescent prominences at various positions from the Stark effect. It was found that the intensity ratio of MgI emission lines to SrII lines is independent of the observed electron density in the range of $10^{10.2}$—$10^{11.4}$cm^{-3}. This contrasts with Landman's (1984) theoretical expectation that the ratio is proportional to the electron density. From the intensity of Balmer lines and the electron density, it is inferred that the true diameter of a thread in prominences of high electron density may be smaller than 0.2". The averaged total number density of hydrogen N_H was found to be $3\text{-}6\times10^{11}$cm^{-3}, leading to a total gas pressure of P_g=0.6 dyn cm^{-2} and a total density of $\sim1\times10^{-12}$gcm^{-3}. Landman's large value of $N_H\sim6\times10^{12}$ and $P_g\sim6$ may have resulted either from the fact that he has treated very bright prominences and/or from the derivation of the high electron density for all prominences he studied.

Recently Landman (1983,1984, and 1985) has shown from intensity ratios of various lines that the mean electron density of quiescent prominences is Ne$\sim10^{11.3}$cm^{-3} and the total gas pressure of 3-6 dyn cm^{-2} with the total number density of hydrogen $N_H\sim5\times10^{12}$cm^{-3} and with the ionization ratio of hydrogen (N_{HII}/N_{HI}) of $\sim$0.09 (see also Nikaido and Kawaguchi, 1983). The Landman's values of N_H and the gas pressure are more than one order of magnitude larger than the previous values (Hirayama, 1979, p.14). See also discussions on the older values by Landman (1983).

In order to inspect this problem, first I have determined the electron density from the hydrogen-Stark effect using an unpublished extensive table of line intensities and widths of prominences (32000 lines in total) which I observed with the 40cm coronagraph at Sacramento Peak Observatory in 1969 (Hirayama, 1972, Paper I). The method of determining the electron density, which takes the ion contribution to the broadening into account, is described in Hirayama (1971). Figure 8 of Paper I shows examples, where 1/e-widths of Balmer lines are plotted against principal quantum number, and it is easy to

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distinguish, say, between $N_e = 10^{10.3}$ and $10^{11.2}$. In the case of a post-flare loop, a high electron density of $N_e = 10^{12}$ cm^{-3} was obtained with the same method (see Fig. 9 of Paper I).

The result is the following (Hirayama, 1985): the average electron denisty was found to be $10^{11.02} cm^{-3}$ for five hedgerow quiescent prominences at 57 different positions, and $10^{10.48} cm^{-3}$ for two curtain-like old quiescent prominences at six different positions. The maximum value was $10^{11.4} cm^{-3}$, and if $N_e \leq 10^{10.0}$ the determination becomes difficult. If lines up to H28 are observed, the electron density can be derived when $N_e \geq 10^{10.2}$.

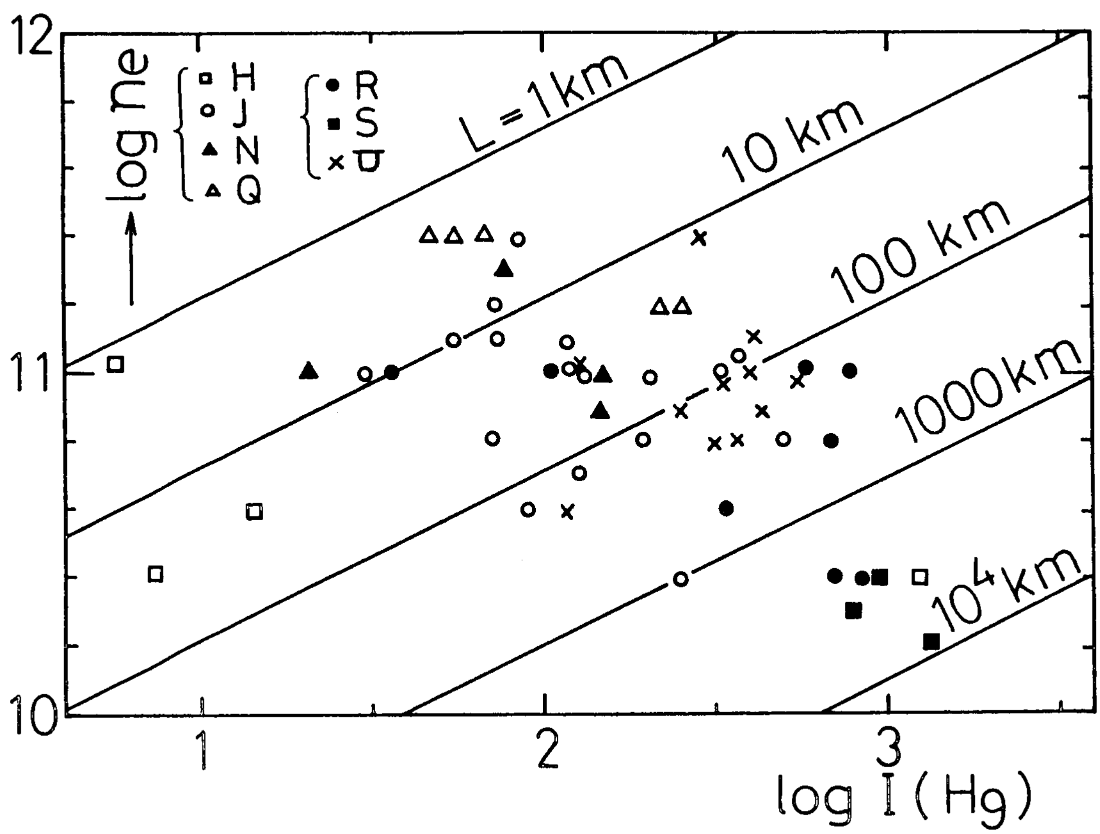

Fig. 1. The electron density from the Stark effect vs. the intensity of hydrogen Balmer line H9 (erg $cm^{-2}s^{-1}sr^{-1}$). Full lines: lines of constant effective geometrical length L.

Figure 1 shows the electron density, N_e, thus determined vs. the intensity of an optically thin Balmer line of H9, I(H9). Letters H,J,N,... refer to prominences listed in Table II of Paper I, and data from various heights and portions of each prominece were utilized. Using the average value of the whole sample of $N_e = 8.4 \times 10^{10}$, and with T=7000K, the emission measure $N_e^2 L$ and the effective length L can be determined from the average intensity of $I(H_9) = 240$: $N_e^2 L = 6.3 \times 10^{28} cm^{-5}$ and L=80km.

If one uses values from 6 points in the lower right corner of Figure 1, L becomes 4600km, and from 4 points having high N_e of $10^{11.4}$, one obtains an extremely low value of the effective length: L=2.4km. Larger L's are obtained for stable big quiescents, and low values of L are from low height, rather young quiescents, which lie perpendicular to the solar equator. Note that there are not many data points of lower intensity with lower electron density in Figure 1. This is simply because the electron density cannot be determined for these prominences.

Now we discuss the implications of the value of the effective geometrical length integrated along the line of sight, L. We assume that prominences consist of a number of long threads of a diameter ϕ of 300km (Dunn, 1960), and that they are, for simplicity, suspending vertically. Then L=10km means that the number of threads in a distance of 10" along the solar limb, n, is about unity: $n\pi(\phi/2)^2=L\times 10''$. Since the average L is 80km, n should be 8, the filling factor of $n\phi/10''$ being 0.3. However if L>200km, overlapping of threads in the line of sight must be occurring: $n\phi>10''$. If $L\leq 10$km as derived before in some cases, it means that the thread diameter should be smaller than 300km. This comes from the following consideration: we measured spectra with a 10" length of the microphotometer slit, and with a 10" step of raster scan. And the distribution of the total intensity of emission lines along the spectrograph slit which was placed parallel to the limb is found to be rather smooth. Since the seeing was probably better than 10", it means that there should be at least one thread within a distance of 10": $n\geq 1$. This requires that $\phi\leq 2(L\times 10''/\pi)^{1/2}$. For example $\phi\leq 150$km, if L=2.4km as found above. It is hoped to observe the thread diameter of less than 150km from the direct imaging.

Next we derive the total number density of hydrogen N_H by using the intensity ratio of H9 and MgI 3838. Since the ionization potential to MgIII is rather large (15.0eV), Mg is expected to be mostly in MgII, so that the intensity I(Mg3838) is proportional to $N_e N(\text{MgII}) L \propto N_e N_H L$. With the average observed value of I(3838)=55 erg $cm^{-2}s^{-1}sr^{-1}$ and with the above values of N_e and L, N_H is found to be $6\times 10^{11}cm^{-3}$ if one uses non-LTE calculations by Landman (1984, Table 2). $N_H=3\times 10^{11}$ is obtained, if one adopts Vernazza et al.'s computation (1981, Table 21, VALIII) near 7000K. Here we note that Mg3838 line is optically thin because the ratio of I(Mg3838)/I(Mg3832) was found to be independent of a wide range of values of I(Mg3838), and that the intensity ratio of I(Mg3838)/I(H9)($\sim$0.23) is also independent of I(H9). N_{HII}/N_{HI} then becomes $\sim$0.2 (from Landman's Table), or $\sim$0.4 (VALIII), and the optical depth at the head of the hydrogen Lyman continuum becomes $\sim$30 (Landman) or $\sim$10 (VALIII). These are not too far from older values (Hirayama, 1979). A factor of two difference in N_{HII}/N_{HI} from the Landman's value of 0.09 mainly comes from the difference of the observed intensity ratio of I(3838)/I(H9) $\sim$0.49. Landman's data are from very bright (or large thickness) prominences, and Landman's large N_H value simply comes from a rather large N_e of 2×10^{11} for every prominence he studied, which, in turn, may or may not be true (see below).

Landman claims that the intensity ratio of [I(Mg3838)+I(Mg3832)]/[2×I(SrII4077)] (abbreviated as I(Mg)/I(Sr)) is proportional to N_e in the range of $10^{10.5}$ — $10^{12.0}$cm^{-3}. Although it may be that I(Mg)/I(Sr)$\propto N_e$ holds for post-flare loops of high N_e (Foukal et al., 1986), quiescent prominences do not show this behavior as shown in Figure 2. Here

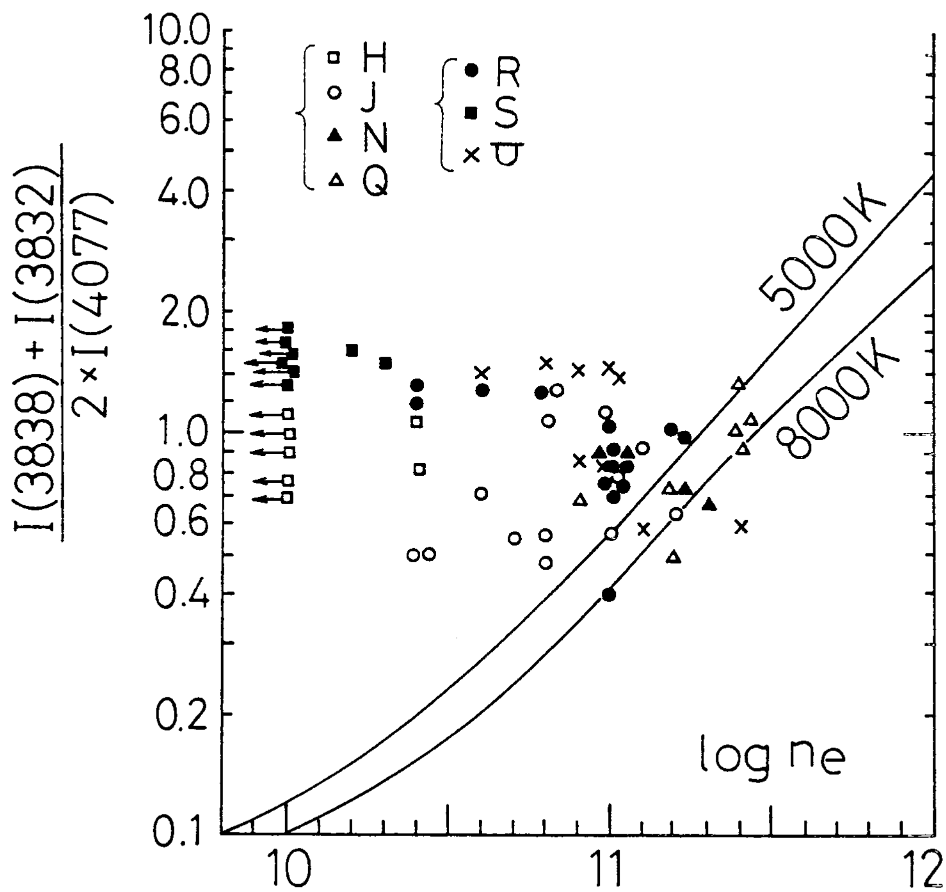

Fig. 2. Intensity ratio of metallic lines vs. electron density from the Stark effect. Full lines: Landman's calculation. Various symbols refer to prominences listed in Hirayama (1972).

I(Mg)/I(Sr) is plotted against the observed N_e obtained from the Stark effect, each data point being from a single exposure, and full lines are from Landman's calculation (Foukal et al., 1986, Fig. 4). If photoionizations of SrII to SrIII, which do not seem to be well-founded (see Landman, 1985), were much more effective, it may in principle be possible to obtain a constancy of the intensity ratio against N_e. The electron density may well be lower than $10^{10}cm^{-3}$ for much fainter portions of prominences (Bommier et al., 1986). I inspected the relation between I(Mg)/I(Sr) and I(Mg3838) to see if the ratio becomes lower when I(Mg3838) becomes very small. Here I included faint portions where the electron density cannot be determined from the Stark effect. While I(Mg3838) ranged from about 2-3 to 300 erg $cm^{-2}s^{-1}sr^{-1}$ (Landman's averaged value was 2800), the ratio changed only by a factor of 3: $I(Mg)/I(Sr)=[I(Mg3838)/10^2]^{0.22}$. So I would guess that something might be wrong with the calculation (probably of SrII), although low intensities do not necessarily ensure the low electron density. But it is difficult to doubt the existence of $N_e \sim 10^{10.0}$.

In conclusion, two points are worth mentioning. First the effective thickness L of quiescent prominences of low height is found to be only 10km or less, which is surprising. However this effective thickness can be converted to a thread diameter of 150km or less. On the other hand big, high altitude quiescent prominences showed L=5000km or so. This is not surprising, since the apparent length in the line of sight will easily exceed 10^5km. Second, there is a discrepancy between the eletron density found from the Stark effect and the intensity ratio of metallic lines. Further observations and calculations are needed to clarify this point.

The average physical quantities for the present data are $N_e=8.4\times10^{10}$, $N_H=3-6\times10^{11}$, $N_{HII}/N_{HI}=0.2-0.4$, and a filling factor of ~0.3, which implies that one 300km-diameter thread can be found every 1000km along the long axis of a quiescent prominence. Since the optical depth of the head of HI Lyc becomes less than 10 for a 300km thread, the maintenance of the temperature of 7000k by the incoming UV radiation below 912A will not be difficult. The average total gas pressure is found to be 0.6 dyn cm^{-2}, and the average total density of $1\times10^{-12}g\ cm^{-3}$ is derived by adopting the helium-to-hydrogen ratio of 10%.

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