OBSERVATIONS OF A SURGE PROMINENCE AS A CONTINUUM EVENT

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Abstract. Observations of a surge prominence event on 31 May 1971 are discussed. The continuum emission observed during the upward acceleration of the surge is attributed to the scattering of photospheric radiation by free electrons. The observed scattered light intensity amounts to a few times $10^{-5}$ that of the central disk intensity leading to a column density of $n_e L \approx 10^{20} \text{ cm}^{-2}$. The actual electron density when taking into account the presence of inhomogeneities is $n_e \approx 10^{12} \text{ cm}^{-3}$. The dynamic and morphological behaviour of the surge is considered.

1. Introduction

Three homologous surges were observed near the east limb of the Sun on May 31, 1971; this activity was observed with the Sacramento Peak Observatory’s 40 cm coronagraph by J. E. Coleman and L. B. Gilliam. The surges showed continuum emission over brief periods of time of a few minutes up to 20 minutes for the strongest event.

Weak continuum emission is sometimes seen in the spectra of prominences (Tandberg-Hanssen, 1974); it can be due to free-free or free-bound transitions, to $H^{-}$ or synchrotron emission or scattering. Because of the physical regime at play, electron scattering of photospheric radiation dominates. Becker (1959) obtained some time ago a rich collection of combined $\text{H}\alpha$ and white-light observations of the solar disc; he reported that surges seen on the disc appear as the best-defined and the clearest transient events seen in white light; appearing as absorbing features against the photosphere, their contrast is $\approx 5\%$. Becker also recalled white-light observations dating back to the last century by Trouvelot (1875) and Perry (1884) of transient absorption features behaving like surges and erupting filaments.

Ivanov–Kholodnyi (1960) has reviewed the methods to estimate electron density in prominences including the estimation of $n_e L$ from continuum radiation. The present observations allow us to follow the evolution of a surge as a continuum event simultaneously with $\text{H}\alpha$ and coronal line observations.

2. Observations

The observations consist of sequential filtergrams repeating every two minutes in $\text{H}\alpha$, $\lambda 5303 \text{ Å}$, $\lambda 6374 \text{ Å}$ and a continuum passband made from the reflecting slit jaws of the universal spectrograph attached to the 40-cm coronagraph. The
filtergrams with a passband of 1 Å were recorded on 103 AF 35 mm film as a skip-frame movie using a four-wavelength birefringent filter system designed by R. B. Dunn.

The first surge (Figures 1, 2) appeared in the continuum passband above the occulting disc at 1356 UT, grew more or less vertically, detached itself from the disc and vanished after 1414 UT; seen at Hα, it lasted longer (1340–1456 UT). The dynamics of the same event were studied by Roy (1973b). The surge coincided with a subflare (Solar-Geophysical Data) in McMath region 11352 at N02 E86, starting at 1353 UT, and ending at 1403 UT with maximum at 1355 UT.

Enhancement at the location of the surge is seen in filtergrams taken in the coronal red line Fe x λ6374 Å although it shows only faintly in the more complex green line Fe xiv λ5303 Å filtergrams. This agrees with the suggestion by Dunn (1971) that some bright features in loop tops and surge-like features observed on filtergrams taken in the high-excitation coronal lines are likely prominences showing in the continuum. Considering that (i) the surge is visible in filtergrams taken both in the coronal red and green lines, (ii) the observed intensity enhancement in the continuum window at λ6375 Å is 10 to 50 times the intensity of normal red line structures (Fort et al., 1973), and (iii) the intensity enhancement shows at exactly the same time and with identical morphology at Fe x λ6374 Å and λ6375 Å, it is unlikely that we observe a doppler-shifted Fe x feature. Furthermore, the absence of detectable microwave and soft X-ray emissions (Section 4) precludes the presence of a large volume of very hot material. Instead continuum emission by scattering of photospheric light by free electrons is a more likely interpretation.

Figures 1a and 2a show the surge at Hα and in continuum. Vertical fiducial marks, not shown here, were used to establish the scale and the alignment. Figures 1b and 2b, c display isophotes obtained by photometric equidensitometry using Agfacontour film described by Gumeau (1975). Continuum isophotes showing the surge four minutes apart (Figures 2b, c) illustrate in a striking fashion the ascension and apparent squeezing out of the ejected material from the surface.

Two series of microphotometric tracings with a 100×254 μ slit (as seen at the film) were done: (a) a set of graded-height tracings crossing the surge approximately perpendicular to its long axis (Figure 3), and (b) a set of longitudinal tracings running along the main axis of the surge roughly normal to the Sun’s surface (Figure 4).

Because of the faintness of the continuum images (Figure 2a) the microphotometric recordings are noisy, except at the obvious location of the surge. The full circles in Figure 3 refer to the height (±3600 km) above the limb at which the tracing intersects the surge. In the continuum, the surge appears broadest and the most intense at 1404 UT (Figure 3). The rising background intensity along some of the tracings originates from the fact that the scan was run along a line
Fig. 1. (a) Hα filtergram of a solar surge on the east limb at position angle 90° on May 31st, 1971 (1404 UT). The solar disc is obscured by an occulting disc (Sacramento Peak Observatory). (b) Isophotes obtained by photographic equidensitometry.
Fig. 2. (a) Filtergram in the red continuum (6575 Å) of the same event as Figure 1 obtained with a narrow passband filter (1402 UT) (Sacramento Peak Observatory). (b) Isophotes of the surge in continuum emission at 1402 UT. (c) Isophotes of the surge in continuum four minutes later at 1406 UT.
tangent to a point away from the base of the surge, thus intersecting the scattered light at the edge of the occulting disc at low heights. Due to the difficulty of running the slit exactly along the surge, the tracings of Figure 4 are not as reliable as those of Figure 3. However they show the time behavior of the ascending continuum surge, appearing at the limb (1356 UT) and detaching itself from the limb (1402 UT). The velocity obtained by following the maximum density point (1402–1410 UT) is about 30 km s\(^{-1}\) compared to 30–60 km s\(^{-1}\) deduced from the moving tops of the corresponding H\(\alpha\) ejection. Figure 5 shows that the phase of continuum visibility corresponds to the fast rising phase seen at H\(\alpha\) when the material is apparently subjected to an upward acceleration (Roy, 1973b).
Fig. 4. Microphotometric tracings along the long axis of the surge showing the increasing growing continuum event above the limb (which is the area of large film density at low heights) and detaching itself from the Sun.
3. Analysis

The column density of scattering electrons is given by

\[ n_e L = \left( \sigma_e W \frac{I_{\text{ph}}}{I_i} \right)^{-1} \text{ cm}^{-2}, \]  

(1)

where \( I_{\text{ph}} / I_i \) is the ratio of the intensity of the scattered radiation to the intensity of the photospheric light, at center of the disc, \( W \) the dilution factor, \( \sigma_e \) the electron cross-section for Thomson scattering \( (6.6 \times 10^{-25} \text{ cm}^2) \) and \( L \) is the estimated path through the surge.

Since the continuum observation was obtained with a narrow passband, we used the wavelength dependent dilution factor given by Shklovskii (1965) as

\[ W_\lambda (r) = 0.5 \left\{ (1 - v) \left[ 1 - (1 - r^{-2})^{1/2} \right] + 0.5 v \left[ 1 - r(1 - r^{-2}) \ln \left( \frac{r + 1}{r - 1} \right)^{1/2} \right] \right\}, \]  

(2)
### TABLE I
Intensity and electron density in the surge

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<th>Time UT</th>
<th>Height(^a) (10^3) km</th>
<th>(L/L_{ph})^b (10^{-5})</th>
<th>(n_e L \times 10^{19}) cm(^{-2})</th>
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\(^a\) \(\pm 3.6 \times 10^3\) km.

\(^b\) Without the background removed; see text.

\(^c\) \(\bar{n}_e\) is the density averaged over the whole path across the surge.

where \(r\) is the distance from the Sun’s center in solar radii and \(v\) is the coefficient of limb darkening given as \(v = 0.52\) for \(\lambda 6375\) Å (Allen, 1963). \(W_\lambda(r)\) varies from 0.37 at the limb down to 0.24 at \(5.6 \times 10^4\) km, the highest point where continuum emission is visible.

Column 4 of Table I gives the estimated electron column density, \(n_e L\), obtained from Figure 3. It was assumed that the actual intensity of the scattered light was equal to the measured intensity at the surge location minus the background intensity at the same height close to the surge. The background film density on the original film arises from the opal diffuser (transmission at \(\lambda 6570\) Å = 0.0387%), which is swung behind the objective; the ratio of mean background intensity near the surge to central disc intensity is about \(2.8 \pm 0.9 \times 10^{-5}\). The highest value at the surge \(I_s \approx 5 \times 10^{-5} I_{ph}\) was at 1400–1404 UT. Values of column electron density range between \(3 \times 10^{19}\) to \(1.2 \times 10^{20}\) cm\(^{-2}\).
4. Discussion

To estimate $n_e$, one must first determine $L$. Cylindrical symmetry is assumed and $L$ is taken as the width of the surge at the half-point between background and maximum density on the tracings of Figure 3. Because this procedure neglects the high degree of inhomogeneity of prominence plasma permeated by magnetic field, it gives only a lower limit to the electron density. We call it $n_e = \alpha n_e$ with $n_e$ being the actual density and $\alpha < 1$ is some 'wild' function of the inhomogeneity. The problem remains to establish the value of $\alpha$ by methods summarized by Ivanov-Kholodnyi (1964). The value of $\alpha$ ranges widely but we will use the more conservative value of Tandberg-Hanssen (1974) of $\alpha \approx \frac{1}{6}$ to $\frac{1}{3}$. The values of $n_e$ of Table I lead to an actual electron density ranging from a few times $10^{11} \text{cm}^{-3}$ to $1.7 \times 10^{12} \text{cm}^{-3}$. For a degree of ionization $0.7 < x < 0.9$ (Tandberg-Hanssen, 1974), a height of $5 \times 10^9 \text{cm}$ and a diameter of $10^9 \text{cm}$ (at 1404 UT), the emission measure is roughly $6 \times 10^{50} \text{cm}^{-3}$. With $\overline{n_H} \approx 2 \times 10^{11} \text{cm}^{-3}$, the total mass ejected is $5 \times 10^{15} \text{g}$, in agreement with Bruzek (1969) and Kirchner and Noyes (1971). For $V \approx 50 \text{km s}^{-1}$, the kinetic energy is about $6 \times 10^{28} \text{ergs}$, i.e. $4 \text{ergs} \text{cm}^{-3}$; this estimate is close to the one obtained by Kirchner and Noyes (1971) but much smaller than that quoted by Bruzek (1969). A magnetic field $B > 10G$ suffices to contain and channel the surge material.

The 2800 MHz radio flux recorded at the Algonquin Radio Observatory was below the background of $0.5 \times 10^{-22} \text{W m}^{-2} \text{s}^{-1} \text{Hz}^{-1}$ (Covington, 1975; private communication). No significant X-ray enhancement occurred during the surge event (there is a simultaneous particle event which likely accounts for a slight increase in the 8–20 Å channel of Solrad 9). Even with $\int n_e^2 \text{d}v > 10^{50} \text{cm}^{-3}$ this is not expected due to the low temperature of most of the surge material. Moreover, the absence of significant X-ray emission is consistent with the suggestion of Roy and Tang (1975) who explain that a surge with a small cross-section moving along magnetic fieldlines does not compress a large coronal volume such as seen in the expansion of an erupting filament.

5. Conclusion

The continuum emission observed with a narrow passband filter has been analyzed in terms of scattered photospheric radiation by free electrons. The deduced scattered intensity is a few times $10^{-5}$ the central disk density and the actual electron density $10^{11} < n_e \leq 10^{12} \text{cm}^{-3}$. The highest electron density occurs simultaneously with the phase of upward acceleration as well as the observation of an apparent squeezing out from the surface.

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References

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