ELECTRIC FIELD MEASUREMENTS IN SOLAR FLARES

ZHENDA ZHANG* and RAYMOND N. SMARTT
National Solar Observatory**, National Optical Astronomy Observatories,
Sunspot, NM 88349, U.S.A.

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Abstract. Measurements of solar flare spectra have allowed the electric field strengths in two flares to be determined, using the Inglis–Teller formula. Further, an independently estimated value for the electron density has allowed the two components of this field, that is, the interionic component and the external component that arises, for example, through plasma instabilities, to be separately extracted. External electric field strengths ~ 0.5 kV cm$^{-1}$ for a limb flare and ~ 1.3 kV cm$^{-1}$ for a white-light flare are found. Estimates of electric fields strengths generated by the resistive magnetic tearing instability indicate that this process could account for a significant part of the electric field if pre-existing magnetic field strengths in the flaring regions are characterized by a few kilogauss. Other plasma processes probably contribute measurably as well.

1. Introduction

In recent years a number of workers have used a nonthermal model to describe the impulsive phase of a flare. In this model, electrons are accelerated by the action of some nonthermal process, such as a direct electric field or plasma turbulence, and are injected downwards into the solar atmosphere. The electron beam and its associated return current are considered to be largely stable to the generation of plasma turbulence, and thus the beam thermalizes by Coulomb collisions deep in the atmosphere, producing enhanced thermal emission (e.g., EUV, H$_\alpha$) at these depths (see, for example, Syrovatskii and Shmeleva, 1972; Brown, 1973; Brown et al., 1978; Emslie et al., 1978; Priest, 1981). Therefore, determination of electric field strengths in solar flares could be of fundamental importance in understanding the complex phenomena that occur in flaring regions.

Spectroscopic signatures of strong electric fields are line broadening and shifts due to the linear and quadratic Stark effects, respectively. Observations of the high Balmer lines in solar flares have shown that line widths increase significantly with increasing principal quantum number beyond about $H_{10}$ (e.g., Švestka and Fritzová-Švestková, 1967), but the effect of external electric fields (as opposed to the interionic field) on the line broadening has been neglected in such studies. Spicer and Davis (1975), Bakshi and Kalman (1976), Tsytovich (1973), and Galdetskii and Oks (1984) suggested that Stark broadening might be increased (for a given electron density) in a plasma which is driven unstable by shock waves or by energetic particle beams which generate turbulent fields. It is reasonable to expect that various plasma instability mechanisms occur during the

* Permanent address: Department of Astronomy, Nanjing University, Nanjing, People's Republic of China.
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flare process, which would give rise to significant turbulent electric fields. These fields would substantially affect the line shape through the Stark effect, in a way qualitatively different from the simple Holtsmark broadening. Davis (1977) has measured electric fields in solar flares using the Stark effect, based on intensity ratios of allowed and forbidden neutral helium triplet lines. He has obtained electric field strengths as high as 700 V cm\(^{-1}\) in flaring regions, the fields originating, he suggests, predominantly from nonthermal plasma waves. Jordan et al. (1980) have also estimated electric fields based on line shifts of high order SiI lines in sunspots.

In this paper we will discuss measurements of the electric field strength in flaring regions as derived from flare spectra and compare these with the electric field strengths that would arise from plasma instabilities if present in the flare plasma.

2. Measurement of Flare Electric Fields

As pointed out above, Stark broadening, both linear and the subtle quadratic component, can be used to estimate the electric field strength in a flare region. The two components of this total field, that due to the external field as produced, for example, by plasma instabilities, and the interionic field, can, at least in principle, be evaluated separately (Rust and Emslie, 1979). However, as discussed below, the possibility of extracting the separate components is conditional on determining the electron density in the flare region by a method independent of the Stark effect. To determine the total electric field, the continuum merging of the Balmer series in the flare spectra is measured and applied to the Inglis–Teller formula (Inglis and Teller, 1939):

\[
\log E = 6.757 - 5 \log n_{\text{max}},
\]

where \(E\) is the total electric field strength (V cm\(^{-1}\)) and \(n_{\text{max}}\) is the principal quantum number of the last resolvable Balmer line. The interionic component (involving the contributions of the ions and electrons), \(E_{i,e}\), of \(E\) is described by \(E_{i,e} = 2.3 e N_e^5\), which is obtained from Equations (1) and (10), where \(N_e\) is the electron density, and \(e\) is the electron charge in e.s.u. Hence, if an independent estimate of \(N_e\) can be made, a value for the external electric field, \(E_e = \sqrt{E^2 - E_{i,e}^2}\), can be obtained. We point out, however, that implicit in much of the treatment below is that the flare region is uniform. This is presumably not the case, and any consequent error in the derived values remains uncertain.

2.1. Observations

Our observations consist of the spectra of two flares: one is a nominal limb flare (importance 1N, location N09 E90 (as reported in Solar Geophysical Data)) which occurred between 21:35 and 21:47 UT on July 16, 1970, with H\(\alpha\) maximum occurring at 21:38 UT; the other is a white-light flare (importance 2B, location S 10 E 55) which occurred between 13:26 and 13:36 UT on June 4, 1982, with H\(\alpha\) maximum occurring at 13:31 UT. The spectra were obtained with the universal spectrograph and 40-cm coronagraph at Sacramento Peak Observatory. The spectra include the wavelength