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PECULIAR ABUNDANCES IN SOLAR PARTICLE EMISSIONS

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Abstract

In this paper we attempt to show that currently available data on solar flare particle abundances allows studies of abundance and enhancement patterns In particular we show that solar particles originate from regions of temperature around 6 x $10^5 K$ *We also take a look at the direct charge state measurements in small and large flares and show that it is possible to distinguish between the coronal and photospheric components of solar flares We then deduce the thermal conditions that must be existing during various stages of solar particle flare build up and release*

I Introduction

Last two decades of extensive studies of solar energetic particles have revealed a wealth of data While large flares have been studied on the time varying as well as nap shot basis (Armstrong et al, 1976; Scholer et al, 1978, Biswas et al, 1983, Crawford et al, 1975), the small flare studies on the other hand have been possible only after the advent of satellites which continuously monitor the solar particle fluxes (Mewaldt, 1980) The detailed observational features obtained by such studies are discussed elsewhere (Vahia, 1988) As a result of these studies, clear patterns have begun to emerge regarding the possible conditions that exist during solar particle flares and particle acceleration In this paper we shall briefly review the observational features of small and large events and try to derive the physical conditions in solar particle emission regions on the basis of these observations

II Observations

II 1 Small Flare Observations

Composition studies of small flares have been reported by McGuire et al, (1981) which show that the relative abundances for most of the elements are a function of time but C and Ne + Mg show little variation; a feature that has also been observed for large flares (Meyer, 1985, Vahia, 1987) Mason et al, (1986) have made an extensive compilation of small flare abundances and have found that the enhancement of heavier elements with respect to large flares is a monotonically increasing function of the nuclear charge There have also been attempts to determine the charge states of ~1 MeV/n He, O and Fe in small flares (Hovestadt et al, 1984) using electrostatic deflectors, a proportional counter and position sensitive detectors These studies (Figure 1) have shown that while He shows a mean charge state that corresponds to an ambient temperature less than ~ 8×10^5 K, the heavier ions show charge states that corresponds to a temperature ~ 2.5×10^6 K

II.2 Large Flare Composition

Rocket borne as well as satellite borne studies of large flare particles (Biswas et al, 1983, Meyer, 1985, Vahia et al, 1985) have shown that for most of the elements for which the measurements have been made, the relative abundances are a strong function

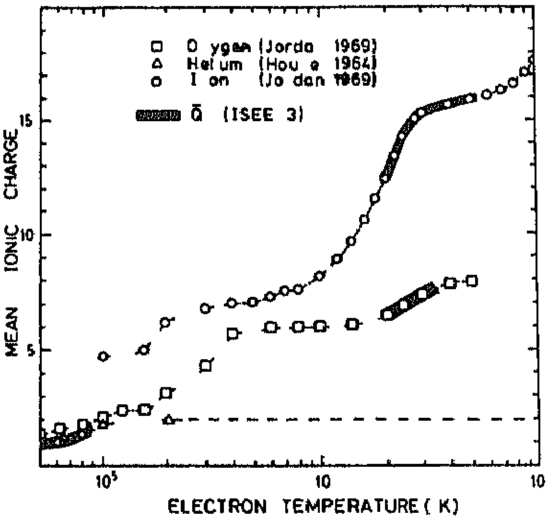

Fig. 1 Direct measurements of charge states of heavy ions in small flares and comparision with temperature (Hovestadt et al, 1984)

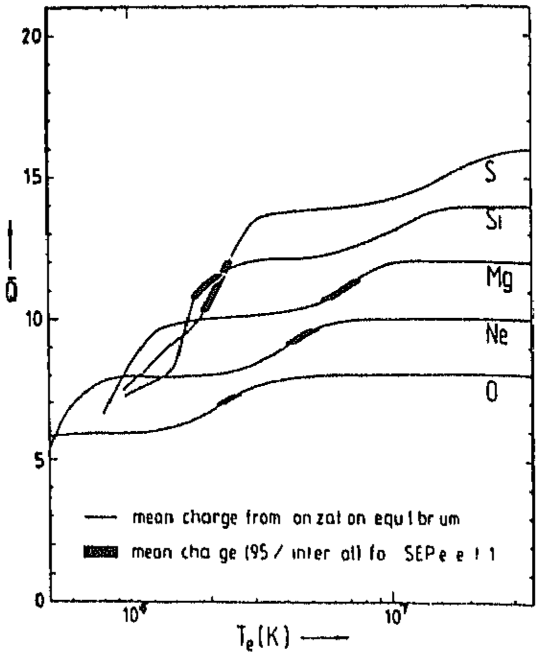

Fig. 2 Direct measurements of charge states of heavy ions in large flares and its comparison with temperature (Lunn et al, 1985)

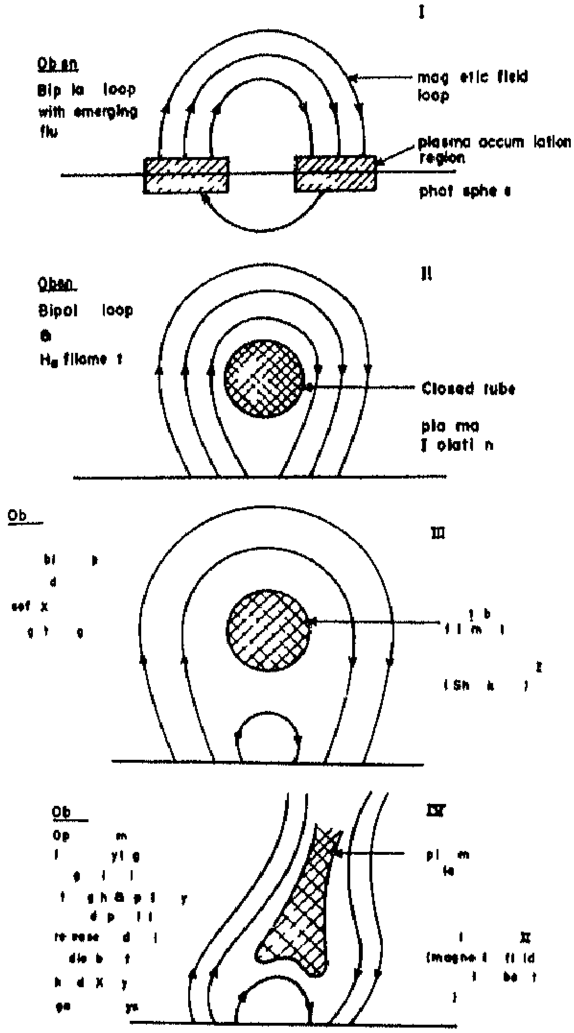

Fig. 3 Cartoon depicting the various stages of build up of a flare (see text) (Vahia and Rao, 1987)

of energy (Vahia 1988) In particular, the relative abundances are higher than the photospheric abundances at low energies and monotonically reach the photospheric value at energies above about 25 MeV/n This is especially so for Ne, Mg Si Ca, Ti, Cr, Fe and Ni where detailed spectra have been measured in several flares However the elements C N, Ne S and Ar show no excess over the photospheric value from very low energies (< 10 MeV/n) right upto high energies We discuss the importance of this conclusions in the next section Direct attempts to measure the charge states of solar energetic particles in large flares have shown that there seem to be two components corresponding to equilibrium temperatures of 2 x 10^6 K and 7 x 10^6 K (Luhn et al 1985) (figure 2)

III Discussion

Solar energetic particle events are predominantly associated with two ribbon flare and neutral line annihilation of the magnetic field (cf Priest, 1981) Hence any study of the morphology of flares must include the studies of the effects of the magnetic fields on charged particles For the rest of the discussion we take the sequence of events that lead to energetic particle emission as shown in figure 3 (Vahia 1986)

The solar flare region magnetic field behaviour can be summarised as shown in the figure A bipolar magnetic region in the photosphere can build up in strength through a plasma loop interaction and by absorbing the plasma from the surroundings (figure 3 I) As this loop becomes strong a plasma tube forms in the centre of the loop the cross section of which is shown in figure 3 II From considerations of stability, such a structure is unstable and would rise in the upper atmosphere thereby changing its energy content and magnetic field strength (figure 3 III) If the plasma energy in such a loop exceed the external pressure, an intense flare and particle flare would occur (figure 3 IV)

We shall now try to see what constraints can be put on the dynamics of such regions from the study of the solar energetic particles

As discussed in section II, C, N, O, Ne and S and Ar are not enhanced in a large variety of solar flares for which detailed studies are available Therefore, this must be taken to be a very fundamental condition of solar energetic particle emission region If the above listed elements are not to be enhanced with respect to their photospheric value, it implies that their charge to mass ratios are very similar to each other at the stage when the solar flare plasma is isolated from the ambient medium The standard deviation from the mean charge states for C, N, O and Ne together and S and Ar together against the log of temperature is shown in figure 4 (Vahia, 1987) It can be seen from the figure that if the plasma isolation occurs around log T of ~ 5 8 (T ~ 6 3 x 10^5 K) then the charge states of these elements would be very similar At this temperature, the charge states of other elements would be substantially different (Arnaud and Rothenflug, 1985, Vahia, 1987) Therefore, the solar flare plasma must be isolated at a temperature ~ 6 x 10^5 K This temperature is higher than that of the photosphere (~ 10^4 K) and less than the coronal temperature (2 x 10^6 K) Hence the basic loop structure must be in the upper chromosphere (or below the photosphere) (Vahia and Rao, 1987) It should be noted that the observed charge states near the earth are those that are modified by rapid acceleration during the particle release in the interplanetary medium Vahia and Rao (1987) have used the betatron mechanism to study the possible effects of the varying magnetic fields on such a plasma and find that the electronic field component of a simple time varying magnetic field can effectively accelerate particles They have also shown that a bipolar region can result into a particle flare if the density of the flare region is less than 10^7 p/cc otherwise the coulombian loss would absorb the energy and a pure electromagnetic flare would result

Since small flares are not associated with extensive electromagnetic activity, it can be assumed that such flares originate in regions of lower pressure so that by the time a flare reaches the configuration shown in figure 3 III, it becomes unstable and releases particles into the interplanetary medium while for large flares the stage of intense electromagnetic activity is required Under such a condition the charge states measured would show a distinct difference in their final charge states Mason et al (1986) have studied the heavy ion composition in small flares and have shown a pattern of small flare to large flare enhancement If this is compared with large flare to coronal abundances it turns out that the small flares to coronal abundance are very similar (Mason et al 1986 Meyer and Reeves 1977) in both the cases while the He^3 abundances are substantially different This is also reflected in the differences in the charge state measurements of He^3 and heavy ion by Hovestadt et al (1984) They have shown that while the He component has a temperature less than about 8×10^5 K the heavy ions have a temperature ~ 2×10^6 K (figure 1) In the large flare on the other hand, while a (coronal) component of temperature of 2×10^6 K is seen the other component has a temperature ~ 7×10^6 K (Luhn et al 1985) (figure 2) Hence, while the large flares have a distinct photospheric component which undergoes a rapid acceleration and shows temperature around that of large electromagnetic flares, small flares show no such component

This allows us to put temperature constraints on various stages depicted in figure 3 Since the basic material of flares shows photospheric composition at high energies (Biswas et al 1983), the temperature condition for stage 3 I must be around 1 10 x 10 K Since the large flare composition shows an isolation temperature of ~ 6×10^5 K (Vahia, 1987) the temperature during the stage depicted in figure 3 II must be around 4 8×10^5 K These loops are distinctly seen in corona and are often stable at temperatures around 2×10^6 K the loops depicted in figure 3 III should have a temperature around 2×10^6 K The stage depicted in figure 3 IV is the most energetic part of the solar flares and gives extensive X ray emission indicating a temperature around 7×10^6 K

IV Conclusions

Accurate studies of solar energetic particle abundance studies carry vital clues to the plasma field interactions in various stages of solar flares and suggest that solar energetic particles may be an important source of flare trigger

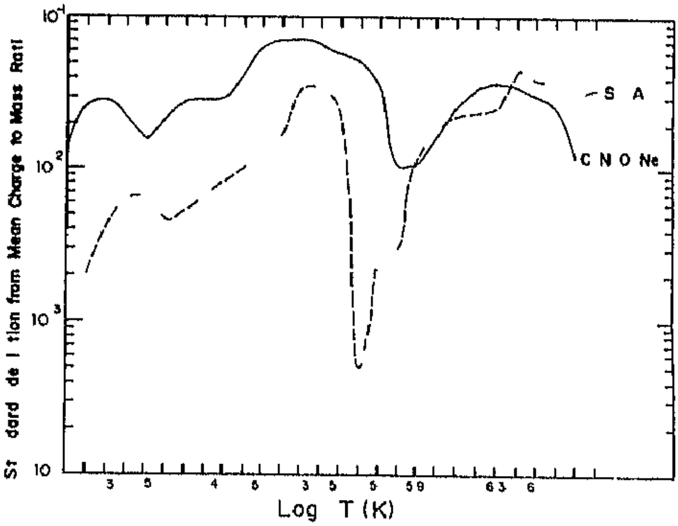

Fig.4 Standard deviation in mean charge states to mass ratios for C, N O and Ne together and S and Ar together against temperature (Vahia 1987) based on the calculations by Arnaud and Rothenflux (1985)

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