Kodaikanal Obs Bull (1988) 9 117 124

PARTICLE EMISSION FROM SUN

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Abstract

Recent results on various aspects of solar energetic particles are reviewed A possible grain component of the polar particles is discussed in brief The plasma component namely the solar wind and the solar energetic particle composition is evaluated Composition studies of solar wind are reviewed The solar energetic particle flares are separated into large and small flare composition Elemental and isotopic composition are listed so as to compare with the other measurements Present status of theoretical studies is reviewed Long term variations are also mentioned

I Introduction

Particle emission from the Sun has three possible components namely, a) Grains, b) Solar Wind and c) Solar Energetic Particles Of these, the first component is only suggested to be originating from the sun and clear experimental evidence of its solar origin is yet to be established The other two components are the plasma component of the solar particles They are magnetically accelerated from the sun and detailed studies over the past two decades have revealed some important clues about their composition, origin and acceleration They have also been studied in order to get clues to the understanding of various processes of the sun We shall discuss each of these components below In this review we restrict ourselves to the various experimental results in the field Interpretation of this data in terms is attempted elsewhere (Vahia, 1988)

II General Features of Solar Particles

II 1 Possible grain component

There have been various studies of the interplanetary grains of 10^{18} to 10^{3} g in near earth as well as interplanetary space (for an extensive review see eg McDonnell, 1978, Walker, 1985, Wood et al 1985) These studies have shown that below 10^{11} g there exists a distinct component of the grains which comes from the direction of the sun These grains with their age less than 10^{4} years have fluxes higher than the interstellar fluxes by an order of magnitude They are suggested to originate from the Sun Direct studies of their composition by Hemenway et al (1972) have shown that they have an excess of high atomic weight material and a deficiency of low atomic weight material Isobe et al (1985) have made polarisation studies of the outer corona during a total solar eclipse in specialised wavelengths to study the light scattering by the grains They have concluded that a distinct grain ring exists around the sun between 4 and 5 solar radii

All these studies indicate that there exists a distinct component of interplanetary grains which probably originates from the sun However, detailed studies of time variabilities and other properties of the grains is needed before any definite statement can be made

II.2 Solar Wind

Solar wind consi ts of purely diffusing particles that have mean kinetic energy greater than the required escape energy from the solar surface It consist of low energy streams with velocity between ~ 300 800 kms/sec (energy ~ 1 10 KeV/n) Two to four major high speed and low speed streams typically sweep past the earth during each solar rotation At 1 AU from the sun their density generally varies between 1 and 20 protons/cc (with p alpha 1 0 005) in rough anticorrelation with the speed Local density peaks are commonly observed on the leading edges of the high speed streamers The proton temperature usually varies between 10^4 and 5×10^5K roughly in phase with the speed variation The thermal speeds corresponding to these temperatures are about a factor of 10 smaller than the flow speeds so that the solar wind protons form a fairly well collimated ion beam

The electron beam distribution is most successfully characterised by the superposition of two thermal populations, the major component has the temperature of $1\ 25 \times 10^5$K and the minor component has the temperature of about 8×10^5K

The heavy element composition studies have been made only for a few elements like He C, O and Ne and it has been found that their relative abundances are similar to the low energy (~ 1 5 MeV/n) solar energetic particle compo ition (Bochsler et al 1986) There have also been some preliminary isotopic composition measurements which agree with the spectroscopically determined ratios for the solar corona (cf Mewaldt and Stone, 1987)

The solar wind is a magnetised plasma Because of the high electrical conductivity, the solar magnetic field is frozen into the expanding coronal plasma to form the interplanetary magnetic field The field magnitude usually in the range of 1 to 20×10^{-5}Gauss The azimuth angle between the radial vector and the stream (also called the Parker Spiral angle) commonly fluctuates between 135 deg and 315 deg with the field pointing out of (135 deg) or towards (315 deg) the sun along the Parker spiral

A detailed discussion of various aspects of the solar wind can be found in Neugebauer (1981), Steinitz and Eyni (1980) and Eyni and Steinitz (1981)

II 3 Solar Energetic Particles

With the peak flux around 1 to 5 MeV/n, this is a more energetic component of the solar particles The solar energetic particles are a periodic and widely varying in intensity The emission is usually well correlated with electromagnetic disturbances such as H (alpha) flares etc Thus these are often referred to as solar flare particles However an observation of an electromagnetic di turbance is neither necessary nor sufficient for the emission of solar energetic particles

Unlike the solar wind, they carry with them an appreciable flux of heavy elements of Z > 1 Since magnetic disturbances are known to exist in the region of solar paticle emissions, these particles become sensitive tools for the study of flare conditions (Vahia, 1988) These particles mainly provide three kinds of informations 1) Properties of the interplanetary space like the magnetic field configuration and field perturbation, 2) the acceleration processes in solar flares and 3) particle abundances on the solar surface

The most interesting realisation of these studies has been the identification of two kinds of solar energetic particle events called small events and large events The main distinguishing feature between the two is the fact that the former are low flux events accompanied by little or no electromagnetic activity The increase over the ambient flux is also by small amounts in the former case compared to several orders of magnitude increases in the fluxes and extensive electromagnetic activity that accompanies the large flares We discuss each of these below

II.3 1 Small Flares Since the advent of satellites and continuous monitoring of the solar particle , a new component of the solar energetic particles has been identified (see eg McGuire et al 1981) This component, studied mainly for its heavy ion fluxes has shown distinct peculiarities For example, compared to large flares the He^3/He^4 ratio in such flares can be enhanced by upto a factor of 1000 Unlike the large flares the absolute fluxes in such events are small However, the abundance peculiarities may continue over several days and abundances of various elements show differing behaviour (figure 1) In particular, unlike in the case of large flares, in the small flares the relative abundances of various elements do not reach the photospheric value even at high energies (figure 2) This has been attributed to possible special selectivities that effect the particle composition at isotopic levels because of their varying charge to mass ratio (cf Ramadurai 1988) There have also been studies of other heavy ions in such flares and this shows an increase in large flare to small flare component with nuclear charge (figure 3) (Mason et al, 1986) Various mechanisms have been suggested for their origin involving various aspects of magnetohydrodynamics Ramadurai (1988) has discussed the e problems elsewhere in this volume and we shall not discuss these further over here

Hovestadt et al (1984) have attempted to measure directly the charge states of the 0 4 to 1 MeV/n particles in small flares using electrostatic deflectors They have found that while He has charge states that correspond to an ambient temperature less than 8 x 10 K O and Fe show charge states corresponding to an ambient temperature $\sim 2 \times 10^6$ K

II 3 2 Large Flares Large flare emission is characterised by 2 to 5 orders of magnitude rise in particle fluxes within a short time span of a few minutes They have been associated with large electromagnetic events on the solar surface and the flux increases typically 8 to 12 hour after the electromagnetic event Detailed compositional studies have identified different mechanisms that operate on the electron, proton, alpha particles and heavy ions in accelerating them

Various studies of the problem and alpha particle spectra have shown that Bessel function and exponential spectrum in rigidity best fit the observations (Formann et al, 1986) The electron spectrum on the other hand shows a break at around 100 KeV and can be well fitted by two power laws in energy with index of 1 1 and 3 6 below and above 100 KeV respectively This is probably the effect of higher susceptibility of electrons to various energy loss processes (Formann et al, 1986)

The acceleration patterns in heavy ions are much more complex due to the fact that heavy ions can show varying charge states depending on the number of electrons associated with the nuclei A standard method of studying the heavy ions is to study the relative abundances of various elements with respect to oxygen (or silicon) at specific energies One can then compare the relative abundances of various elements to the relative abundances of the sun This is a very powerful way of analysing the changes in the abundances at various energies and the causes for the same The energies are also usually defined on per nucleon basis so that at a given energy all particles independent of their mass would have the same velocity In figure 4 (Biswas et al, 1983) the variation of enhancement factor (relative abundances in an event at a specific energy normalised to the relative abundances in the photosphere) with energy is plotted for various elements The most striking feature of such a study is that while at low energies the relative abundances may be different, at energies above ~ 25 x MeV/n they tend to have values similar to the photospheric abundances (i e enhancements = 1) However, for some elements the relative abundances tend to remain similar to the photospheric value right from low energies upto high energies This can be understood in terms of variations of charge states with energy Empirical studies on the variation of charge states with energy in a plasma show that particles tend to loose all their orbiting electrons by the energy of ~ 25 MeV/n Hence above this energy various species with similar charge to mass ratio are accelerated in similar quantities and hence show the same abundance patterns as the ambient medium One consequence of this has been to attempt to derive abundance patterns of solar energetic particles based on the first ionisation potential of

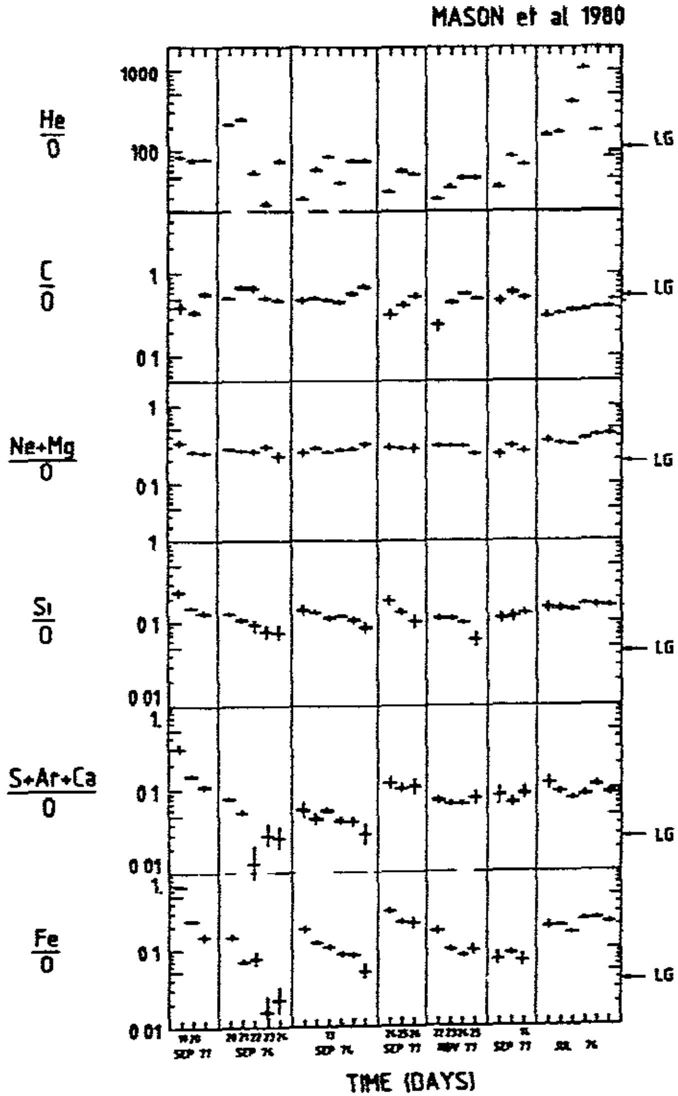

Fig 1 Variation of relative abundances with time for small flares (Mason et al 1980) LG denotes the value of the ratio in the local galactic material

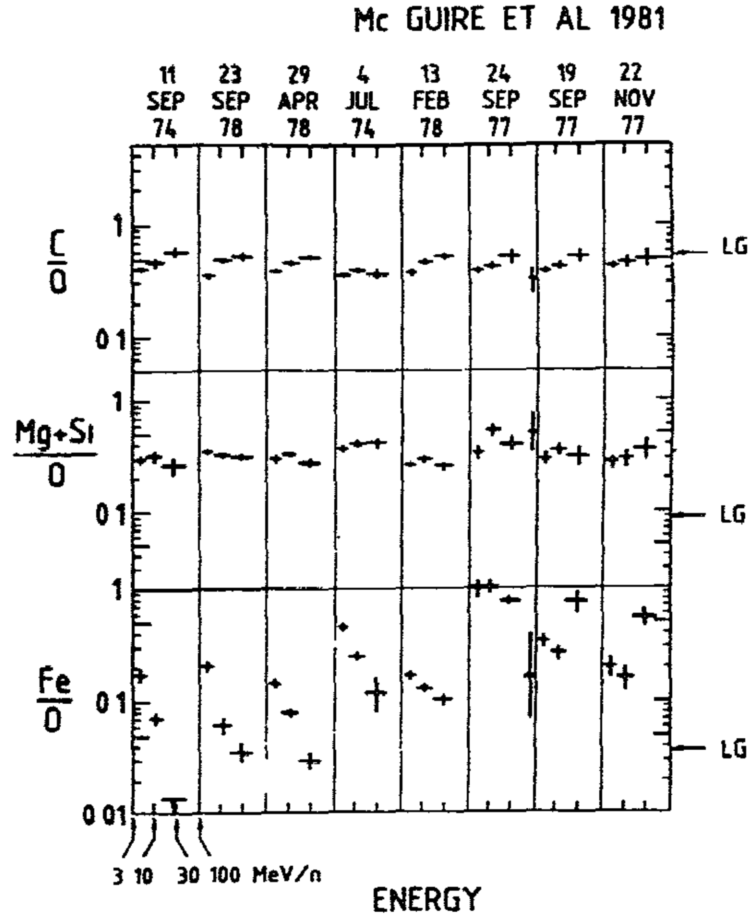

Fig 2 Variation of relative abundances with energy for small flares (McGuire et al 1981) LG denotes the value of the ratio in the local galactic material

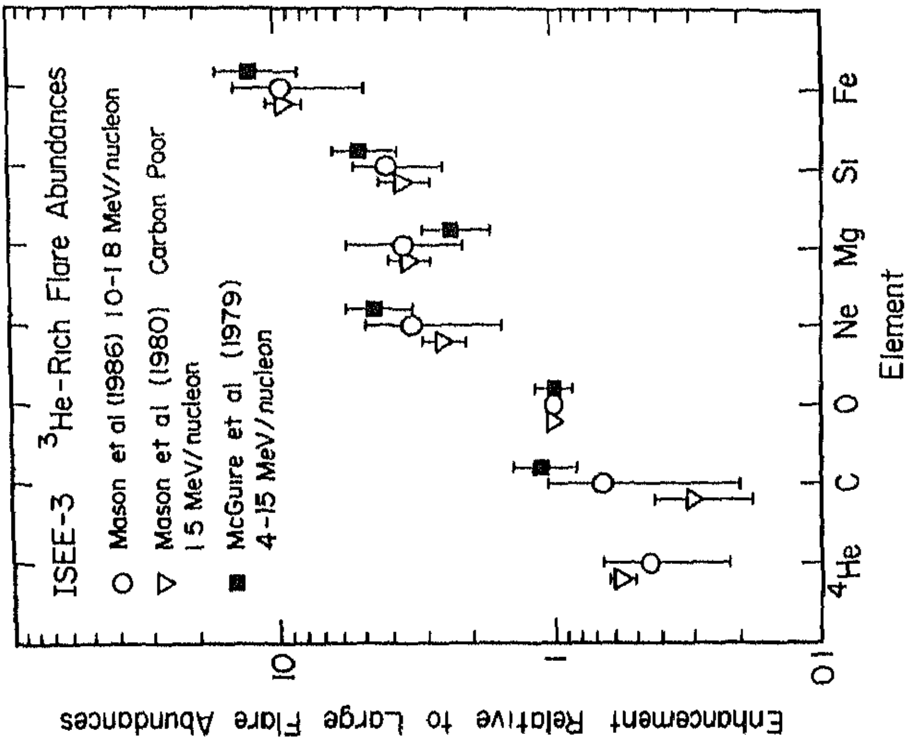

Fig.3 Variation in the small flare to large flare abundance ratio with nuclear species (Mason et al, 1986)

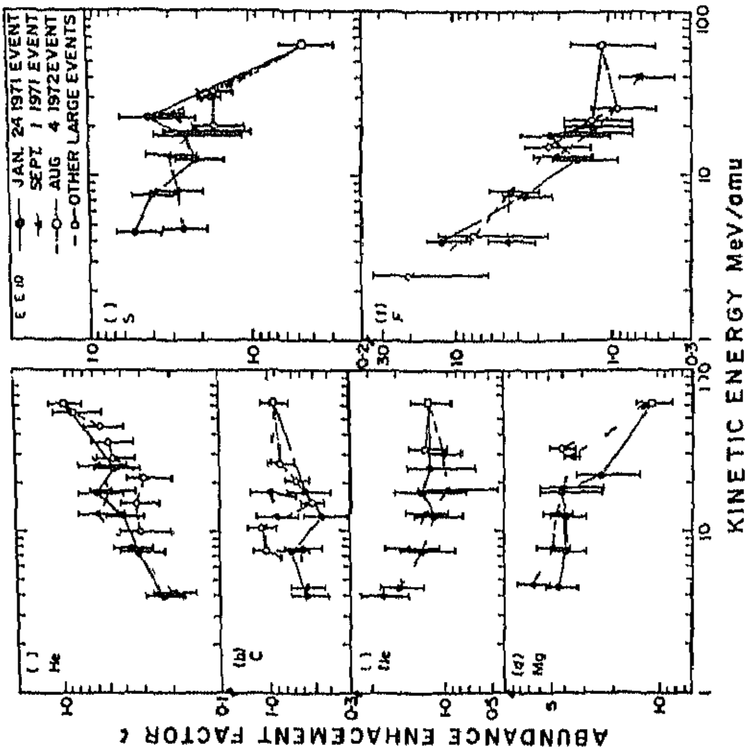

Fig.4 Variation in enhancement factor with energy for *various elements with energy* (Biswas et al 1983)

nuclei (cf Meyer, 1985 and references therein) This has shown that the elements with the first ionisation potential less than 9 eV tend to be enhanced by varying degree while those with the first ionisation potential higher than 9 eV are not enhanced However, since even at the photospheric temperatures the mean charge states are greater than 1, such correlations are only an approximation of the real situation The importance of classifying the enhancements on charge states is discussed elsewhere (Vahia 1987 1988)

In large flares isotopes of He, C, N, O, Mg and Ne have been measured between 0 4 to 1 MeV/n (Mewaldt and Stone, 1987) These results show that the isotopic abundances for Ne (Ne^{22}/Ne^{20}) are about a factor of two higher than those found in solar wind while other isotopic ratios are similar to solar wind abundances

There have been various studies to measure the charge states of cosmic solar energetic paticles (cf Hovestadt et al, 1984, Luhn et al, 1985) These studies using electro static field, a proportional counter and a positive sensitive solid state detector have been restricted to energies below about 1 MeV/n These studies have found that for the large flares there exist two components of temperatures around 2×10^6 K and 7×10^6 K The implications of this are discussed elsewhere (Vahia, 1988)

Various attempts have been made to theoretically understand particle acceleration in solar flares These have mainly concentrated on various aspects of magnetic field effects on charged particle Biswas and Vahia (1985) have reviewed some of the models in brief de Jager (1986) has extensively reviewed various aspects of solar flare particle acceleration from electromagnetic as well as particle characteristics Recently, Vahia (1986) has shown that betatron mechanism is very efficient in accelerating particles to high energies Droge and Schlickeiser (1986) have studied stochastic resonant scattering by hydrodynamic waves to accelerate particles Lee and Ryan (1986) have attempted to analytically study the time dependent coronal shock acceleration of solar energetic particles However, none of the models are in a position to allow detailed comparison with experimental results and therefore, selection of the most likely model is not possible yet

III. Long Term Variations

Over and above the studies of the solar energetic paticle events, there is a general trend and variability in the number of solar energetic particle events (deduced indirectly from the sunspot records and C^{14} dating) in various time interval in the past Since 1714 AD the variations in solar activity as measured by the records of the sunspot observations are known to follow an 11 year cycle along with the solar activity cycle Supporting evidence for this can be found in ancient records of Auroral light observations, rock sedimentations and polar cap ice depositions (see eg White, 1977 and Stuiver and Quay, 1980) Such studies give the Solar energetic particle flux variations over a period of time The main outcome of this has been that while the Solar activity cycle has been a continuous feature since 1714 AD, there were prolonged periods of solar quiet and extensive solar activity in earlier times There were at least three marked periods of solar quiets called the Mounder Minimum (1654 to 1714 AD), Sporer Minimum (1416 to 1534 AD) and Wolf Minimum (1282 to 1342 AD) named after the scientists who first identified them The cause of these solar variations are still not understood and they are apparently related to the problems of the origin of stellar magnetic fields

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