Energy Release Processes in Solar Flares

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DECLARATION

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(c) Regularly submitted six monthly progress reports.
(d) Presented his work in the departmental committee.
(e) Published minimum of one research papers in a referred research journal.

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Countersigned by
Head of the Department
Dedicated to

My Family & Friends
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ABSTRACT

The study of multi-wavelength emission during solar flares has enormous potential towards understanding the underlying physical phenomena occurring in the solar atmosphere. Our Sun presents nearest laboratory to us where various plasma processes in the extremely severe magnetic environment occur. These processes need complete understanding with the help of continuous monitoring in view of their proximal hazards. Therefore, in general, the focus of this thesis is to understand the open issues in the energy release processes during solar flare using high temporal, spatial and spectral observations from various space and ground-based observatories.

Time evolution of emission from solar flare is categorized in three phases viz: precursor, impulsive and gradual. The impulsive and gradual phase of energy release in solar flares are studied in greater detail while the underlying processes causing the precursor phase is not yet explored owing to the lack of high spectral and temporal cadence observations. In order to explore the responsible underlying processes during the precursors and their role in producing impulsive phase, quantitative study is carried out employing multi-wavelength emission from fifty flares occurred during year 2003-2012. We do not find loop-top or foot-point hard X-ray (HXR) signatures during the precursor phase. Moreover, our investigation revealed thermal origin of the emitting plasma. A few of the well observed flares revealed the presence of coronal soft X-ray (SXR) sources during the precursor emission which suggests thermal conduction to be a possible mechanism of energy release. In addition, we find that main phase of all the flares can be fully explained by the CSHKP model. Based on this study, we propose a unified scheme for energy release during the precursor and main phases of emission.

The solar flare plasma is traditionally treated to be of isothermal nature. However, this assumption does not seem to be physically acceptable due to involvement of multiple-loop scenario having multiple temperatures as revealed
from the observations. In this regard, we study high cadence temporal and spectral mode observations of ten M-class flares observed by SOXS to study the isothermal or multi-thermal nature of the plasma. Firstly, we modeled the spectral evolution of the X-ray line and continuum flux during flares by integrating a series of isothermal plasma flux. The differential emission measure (DEM) power-law index of the integrated modeled flux, when compared with that obtained from fitting the observed X-ray spectra revealed flare plasma to be of multi-thermal nature. Moreover, energy-dependent timing delays of temporal evolution of X-ray emission have been studied. This study led to the estimation of thermal to non-thermal photon crossover energy (break energy).

Further, as the solar flare plasma cools simultaneously with the heating, we study the effect of cooling on Neupert effect, a causal relationship between SXR and HXR. This enabled us to propose a generalized Neupert relationship involving time-dependent exponentially cooling as previously suggested by Aschwanden (2005).

It has been widely accepted that the surplus energy released at the time of the flare and Coronal Mass Ejection (CME) in an active region is derived from the gradually stored energy from surrounding non-potential magnetic fields. However, the observations do not show any drastic change in the magnetic field at the time of the flare in an active region. Rather it has been revealed that stresses in the coronal magnetic fields may build up in response to the changes taking place at the photospheric level, such as sunspot rotation, flux emergence, submergence and cancellation. In this regard, we carried investigation of multi-wavelengths emission during a flare-CME system occurred on May 12, 1997. We quantify the temporal evolution of magnetic field parameters namely magnetic flux, gradient and sunspot rotation which revealed that free energy was being stored up into the corona several hours prior to the onset of flare. The slow low-layer magnetic reconnection was proposed to be responsible for the storage of magnetic free energy in the corona and the formation of a sigmoidal core field or a flux rope leading to the eventual
eruption. Further, magnetic-field gradient and sunspot rotation have shown continual increase till the flare event and then later decreased. Based on the observations and analysis we propose a qualitative model suggesting the mass ejections, filament eruption, CME and subsequent flare to be connected with one another in the framework of a solar eruption.

Akabane (1956) found the statistical behavior of power-law distribution of flare frequency versus respective energy released was found to be scale-invariant (see also, Dennis, 1985) etc. Jain and Bhatnagar (1983) correlated temporal evolutions of photospheric magnetic-field evolution with related X-ray and Hα emission and suggested a “Magnetic Complexity Number” as a cut-off magnetic field for flares of various intensities. As individual solar flare originates from a completely independent magnetic-field configuration from other flare, the aforesaid statistically independent behavior of flares has been posing questions on the understanding. Lu and Hamilton (1991) explained this by proposing solar coronal magnetic field which produces flare happens to be in a state of self-organized criticality (SOC; Bak et al., 1987). As the magnetic-field parameters are found to be a good proxy for build-up and trigger of flare energy release, we explore the SOC occurrence in the corona by employing photospheric magnetic-field and coronal X-ray flux. Firstly, we explored long-duration statistical photosphere-corona coupling through studying the active region independent full-disk magnetic-field parameters and co-temporal disk-integrated coronal X-ray flux. In addition to this, the relationship between flare-associated active region’s magnetic flux and coronal X-ray flux has been investigated. We found a strong power-law relationship between the photospheric magnetic flux and coronal X-ray flux in the former case. In the latter case also, power-law relationship between photospheric magnetic flux and coronal X-ray flux is found to hold. In addition, we have also noticed a photospheric magnetic flux over which the flare X-ray flux undergoes avalanche. This magnetic flux is termed as critical magnetic flux.
LIST OF PUBLICATIONS

1. Publications related to the thesis work

A. Referred Journal


B. Conference Proceedings


2. Other Publications


