

A. Proposal Summary

From 1969 to 1995, Big Bear Solar Observatory (BBSO) recorded all the observations on 35 mm film before switching to digital imaging. The data includes full-disk observations from the 8 inch telescope and high resolution observations from the 10 and 26 inch telescopes. The cadence of observations ranged from 10 seconds to 1 minute. BBSO has an excellent clear sky fraction. The data sets cover two and half solar cycles and thousands of flares, and spans the entire operational period of the Solar Maximum Mission (SMM; February 1980–December 1989) and partially, the Compton Gamma Ray Observatory (CGRO; April 1991–June 2000) and Yohkoh (August 1991–December 2001). It was very difficult to make the data publicly accessible, and its scientific capability was never fully explored. We propose to digitize these films, archive them in the BBSO public domain, and carry out targeted research on the relationship among magnetic reconnection in two ribbon flares, filament acceleration, and the power spectra of accelerated flare electrons.

More specifically, the data to be digitized includes full-disk $H\alpha$ images and high resolution images $H\alpha$ and He I D3 images. The digitization will be done using a commercial film digitizer, the Sigma 67. It can digitize at a rate of 15 frames per minute automatically. Full-disk data will all be digitized to create a synoptic data base. All flares and filament eruptions will be automatically detected and cataloged using artificial intelligence methods that have been developed and implemented at BBSO. High resolution film data will be digitized according to events selected by the full-disk data.

The digitized data will be archived and completely open to the community. Because of the usage of 2000 points-per-inch (ppi) digitization of the films, the resolution of digitized data will have compatible, perhaps better resolution, in some cases, than the current BBSO digital images. Despite of some obvious limitations of the film data, the long-term coverage and high quality of the data should have very broad applications for many statistical studies. We will concentrate on the following two targeted research projects:

(1) Recently, we have developed programs to automatically detect filament eruptions and flares, and track ribbon motions of two ribbon flares using $H\alpha$ data. We further derived magnetic reconnection rate, in the term of electric field in the reconnecting current sheet (RCS), based on the ribbon separation speed and corresponding line-of-sight magnetograms. Based on limited events, we have found specific correlation among reconnection rate, flare emissions, and mass (filament and CME) acceleration. This study will be enhanced when the data sample is expanded significantly by including digitized film data and corresponding Kitt Peak magnetograms.

(2) Motivated by recent theoretical work, we will use hard X-ray (HXR) spectral index, which can be derived using data of SMM/Hard X-ray Burst Spectrometer (HXRBS), CGRO/Burst and Transient Source Experiment (BATSE), and Yohkoh/Wide Band Spectrometer (WBS), as a probe to diagnose electron acceleration during flares. We will study the possible temporal correlation between the electric field in the RCS and the spectral index of detected HXRs, which will help us to better understand the electron acceleration mechanism. This study will be complementary to the on-going research of comparing BBSO digital data and HXR spectra obtained with the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), but expanding the data base significantly.

Scientific Merit: The digitization project will provide 27 years of BBSO data to the community. All the flares and filament eruptions will be cataloged with movie clips. The digitized data will enable us to enhance our study of the magnetic reconnection process associated with flares and coronal mass ejections (CMEs) and make other related studies possible. Our research is aimed at the key SHINE goals: understanding initiation of CMEs and electron acceleration in flares.

Broad Impact: The study of a large number of past events will aid forecasting of solar eruptive events in the future. This is a key element in space weather prediction. In addition, this proposal has a strong education component: A Ph.D. student and at least 3 undergraduate students will participate in film digitization and research using the digitized data.

B. Project Description

B.1. Film Digitization and Archiving

Over the past several decades, BBSO has made significant contribution to observing and studying solar activities. From its establishment in 1969 to 1995, all the data were recorded on 35 mm films. Although the researchers in the group and visitors have used the data and published many papers, due to the difficulty of accessing film data and lack of image alignment and intensity normalization, its scientific capability was never fully explored. The films have been stored in a film library at Caltech. However, Caltech mandated that the films be moved out and afterwards, they were shipped to NJIT. We realize that the films will start to deteriorate in the current storage environment, and we may lose this valuable data set for good if they are not preserved or have their contents transferred. Therefore, we propose to digitize these films and explore their scientific usage. Table 1 gives a summary of film data to be digitized. The numbers of images are estimated by counting number of rolls of films.

Telescope	Time Period	Approximate FOV	Wavelengths	Number of Images	% to be Digitized
8 inch	1971 to 1995	Full Disk	H α	2 million	100%
10 inch	1969 to 1995	400'' \times 300''	H α , VMG, He I D3	8 million	10%
26 inch	1973 to 1995	200'' \times 150''	H α , WL, He I D3	6 million	10%

Table 1: Summary of BBSO Film Data

BBSO is well-known for its excellent observing conditions, namely the constant excellent seeing and long periods of continuous sunshine. Historically, the observations have been done with three different telescopes (see Table 1). Most of the observations were carried out in H α wavelengths, both in line center and the red/blue wings. Video magnetograms obtained with the videomagnetograph (VMG) system using the 6103 Å Ca I line with the 10 inch telescope were recorded in the film from 1973 to 1984. He I D3 observations were another important and unique feature of BBSO for electron density diagnosis, since D3 intensity turns from absorption to emission as the electron column density increases during flares (Zirin, 1980). Figure 1 shows two sample images of BBSO film observations, the famous “seahorse flare” on August 7, 1972 and a quiescent prominence. The 10 and 26 inch telescopes each had three observing benches controlled by flip mirrors, and therefore, high resolution images were normally obtained at six wavelengths. A typical set up was as follows: 10 inch: H α blue wing, red wing, and VMG; 26 inch: H α line center, D3, and white-light (WL). Scope of digitization is also listed in Table 1. All the full-disk and 10% of high resolution data will be digitized over the next four years. About 3 million of images will be generated.

Because of the large data volume, the digitization and archiving require high speed and a high degree of automation. We investigated the available commercial digitizers and found that Durst Sigma 67 with 300-foot external feed will be the most suitable one. We will first digitize full-disk images, using which filament/prominence eruptions and flares will be automatically detected (Qu et al. 2003, 2004, 2005) and movie clips will be created. Based on selected events from full-disk data, specifically chosen high resolution images will be digitized. Since we will use 2000 ppi digitization resolution, the pixel resolution of full-disk data will be below 1'', comparable to the contemporary BBSO data with the 2K by 2K digital camera. For high resolution data, the pixel resolution could be as high as 0.07'', matching the diffraction limit of BBSO’s 26 inch telescope.

We had investigated the possibility of sending out the films to professional photo shops. There were two major problems that made this option not feasible: (1) It costs at least 50 cents for each frame, thus it is too expensive, and (2) Data archiving and further data processing are difficult and inflexible. As we will discuss later, our digitization will be done by undergraduate students, who are supervised by PI and a Ph.D. student.

The digitized data will be integrated into the existing data archive of BBSO Global H α Network (GHN; Steinegger et al. 2000) that started to operate in 2000. The six stations are BBSO, Kanzelhöhe Solar Observatory (KSO) in Austria, Yunnan Astronomical Observatory and Beijing Observatory in China, Catania

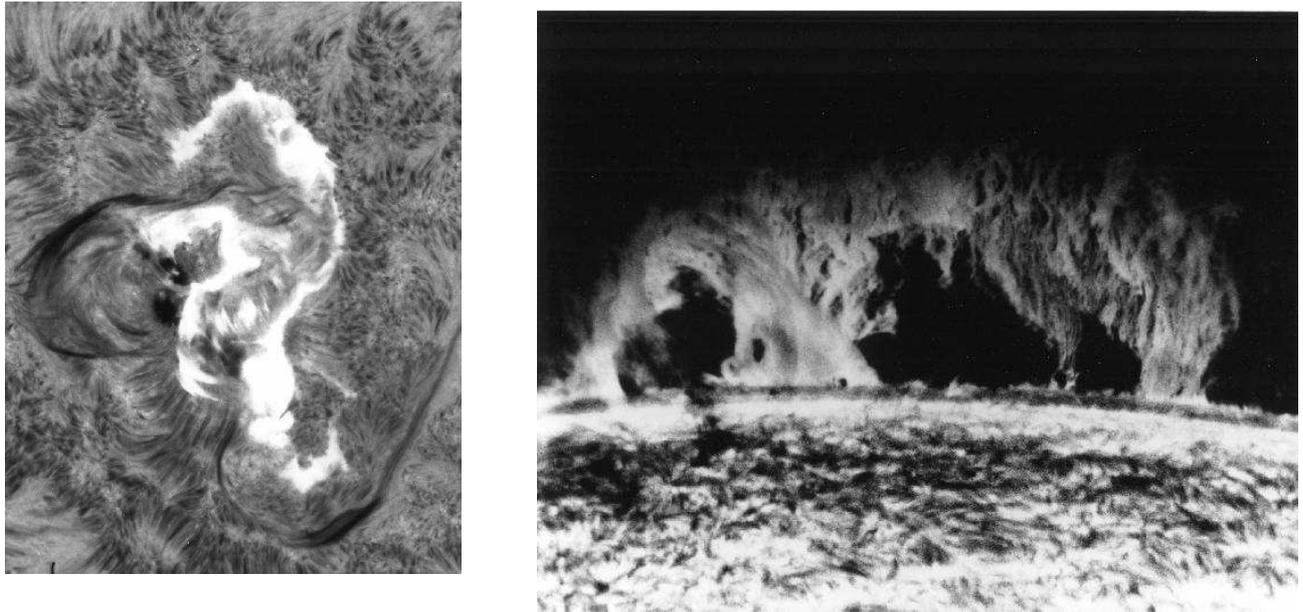


Figure 1: Sample images of BBSO film data. *Left panel:* The great “seahorse flare” on August 7, 1972 observed in $H\alpha$ blue wing. *Right panel:* a quiescent prominence in 1970.

Astrophysical Observatory (CAO) in Italy, and Observatoire de Paris, Section de Meudon. When all combined, we will have an archive of 36 years full-disk digital data. As we describe in Table 2, our Level 1 data will include all the $H\alpha$ full-disk images that are all aligned and intensity normalized. Level 2 data will include the clipped events of flares, filament eruptions, and new flux emergence. Level 3 data will include physical quantities of flares and filament eruptions, such as flare ribbon separation speed and filament trajectory (see § B.2.1). We anticipate that digitization of full-disk data will be completed in 18 months. Digitization of 10% carefully selected high resolution data will take additional 24 months.

Data Level	Data Description
Level 1	All $H\alpha$ Full-Disk Images
Level 2	Partial Image Sequences of Flares, Filament Eruptions, and Emerging Flux Regions
Level 3	Properties of Flares and Filament Eruptions

Table 2: Archiving Structure of Digitized Data

Although we will follow our digitization plan as outlined above, we will inform the community how researchers can request specific events/dates to be digitized. We will provide such a service in a timely fashion.

B.2. Research with the Digitized Data

The digitized data are suitable for many different research projects. However, we will first concentrate on the following two scientific objectives. These will be supplementary to the Ph.D. project of a graduate student using recent digital data. The essential goal of the research is to understand the relationship among magnetic reconnection, filament acceleration, and flare electron distribution using a large data sample. As flares and filament eruptions are closely related to CMEs (e.g., Qiu et al. 2004), our research is certainly relevant to the key SHINE goals: understanding the initiation of CMEs and electron acceleration in flares. At the end of this section, we will briefly list other potential research projects.

B.2.1. The Relationship between the Rate of Magnetic Reconnection and Acceleration of Filaments

It is generally agreed that magnetic reconnection plays an important role in driving solar eruptions (filament eruptions and CMEs), as well as giving rise to intense heating that accounts for the associated flares (Lin et al. 2003). In the standard magnetic reconnection geometry above bipolar active regions (e.g., Priest & Forbes 2002), the electric field E_{rec} in RCS above the newly formed loop system can be derived by measuring the flare ribbon expansion speed V_r and the normal component of the magnetic field B_n swept by the flare ribbons: $E_{rec} = V_r B_n$ (Forbes & Priest 1984). Upon integration of the electric field over the ribbon length l , the electric potential drop, or equivalently, the rate of reconnecting magnetic flux ϕ_{rec} can be further inferred as another important measure of magnetic reconnection: $\phi_{rec} = \int E_{rec} dl = \frac{\partial}{\partial t} \int B_n da$, where da is the newly brightened area swept by the flare ribbons.

These theoretical ideas opened a new area of study — the role of magnetic reconnection in the early stage of large-scale solar eruptions. In our recent studies on solar eruptive events consisting of CMEs, erupting filaments, and flares, we found evident temporal correlations and magnitude scaling relationships between the kinetic properties of filaments/CMEs and magnetic reconnection rate inferred from flare observations (Wang et al. 2003, Qiu et al. 2004; Jing et al. 2005). As an example, Figure 2 shows a snapshot of an M1.0 flare observed at KSO on 2000 September 12 and corresponding MDI magnetogram, with the evolution of flare ribbons being marked. It also shows the temporal evolution of the rising motion of the filament and CME, as compared with that of E_{rec} and ϕ_{rec} . The good temporal correlation among E_{rec} , ϕ_{rec} , and mass (filament and CME) acceleration clearly indicates that the physical link between the evolution of flares and CMEs is magnetic reconnection.

Figure 3 displays scatter plots of the reconnection rate (E_{rec} and ϕ_{rec}) versus the acceleration of filaments in a logarithmic scale based on a sample of 13 well observed events. All values refer to their maxima that were found in each event. A specific linear correlation between filament acceleration and reconnection rates is demonstrated, but needs many more events to confirm. Furthermore, Qiu & Yurchyshyn (2005) found that there is a scaling relationship between total reconnection flux and velocities of CMEs (see Figure 4). Therefore, monitoring the magnetic reconnection is essential in determining the kinetics of CMEs.

The above results confirm the importance of magnetic reconnection in the early stage of fast CMEs, and show potential of forecasting CME speed from flare observations. CME speed is important for space weather predictions. Earlier, Lindsay et al. (1999) concluded that interplanetary magnetic fields (IMF) with larger maximum magnitudes are associated with high-speed CMEs. A recent study of IMF by Yurchyshyn et al. (2005) suggests that both the magnitudes of the hourly averaged B_z component and the total IMF B_{tot} are scaled by the speed of CMEs launched around the solar disk center. Therefore, knowing the CME speed in advance may improve our predictive capabilities. Although our film data to be digitized did not have good corresponding CME observations, the derived magnetic reconnection rate and associated filament acceleration will shed light on understanding the early stage of CME acceleration.

The major difficulty in our previous studies was the lack of a large data sample. Restrictions of event selection include that the flares need to be within 30° away from disk center, the two ribbons need to be well defined, and the filament can be tracked. In order to improve the statistical significance of the magnitude scaling correlations we previously obtained, extended database including many more events will be included. We have been using and will continue to use GHN full-disk images as the primary data source to track the flare ribbon expansion and the filament rising motion. These $H\alpha$ observations are suitable because of their high-cadence (one or more image frames per minute), high-resolution ($\sim 1''/\text{pixel}$), and superior detail and contrast (Martin 1989; Steinegger et al. 2000). However, modern digital data only cover events within about one solar cycle. Therefore, our digitized data will be highly complementary in expanding the database. Meanwhile, we will use Kitt Peak full-disk magnetograms to obtain the necessary magnetic information, since the SOHO MDI magnetograms became routinely available after 1996. The archive of Kitt Peak includes 512-channel daily magnetograms from 1974 to 1992. After 1992, it was upgraded to a spectromagnetograph system with higher

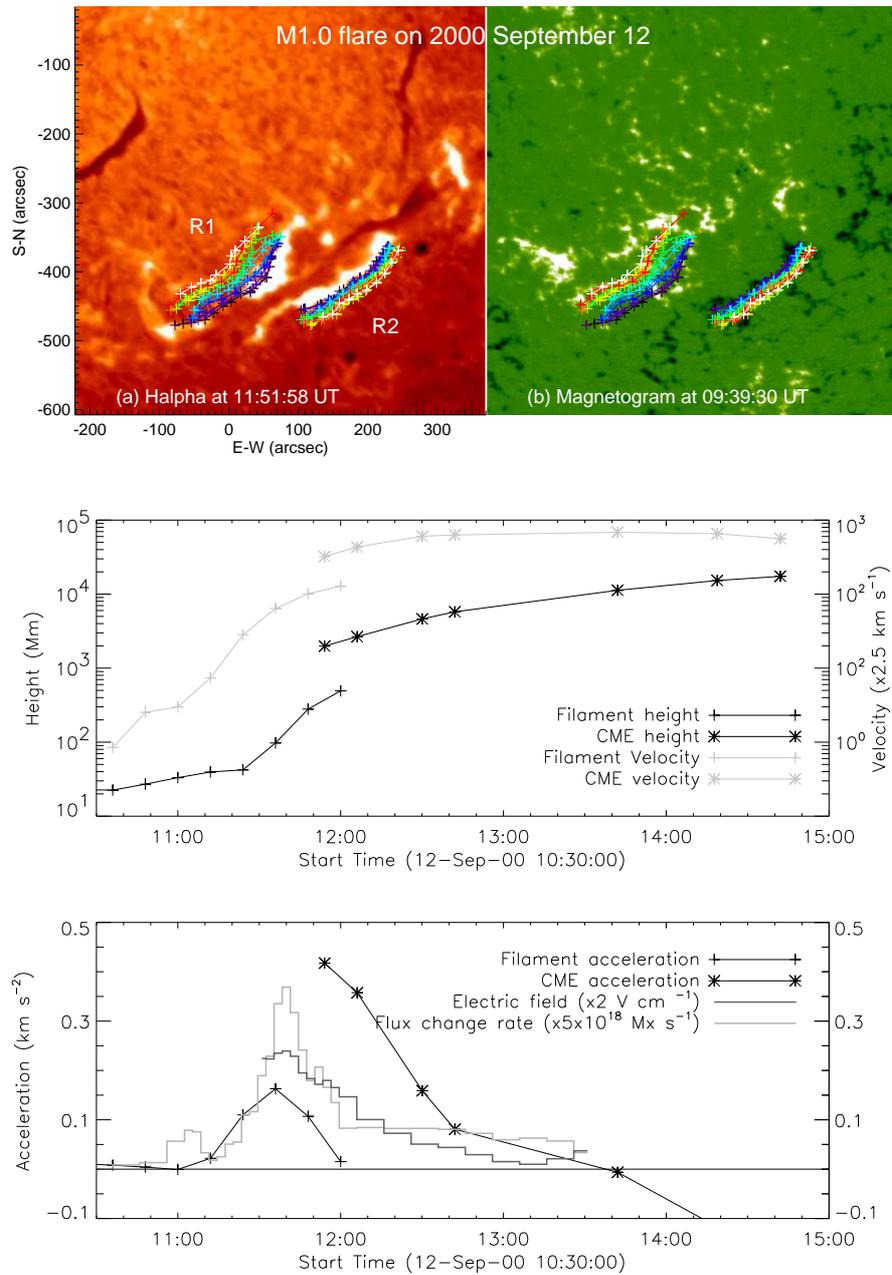


Figure 2: Evolution of flare, filament, and CME in the 2000 September 12 M1.0 event. *Top panels:* A snapshot of the flare in H α observed by KSO and a preflare MDI magnetogram, superposed with the trajectories of the ribbon fronts (plus signs). The colored lines from purple to white indicate fronts of ribbons from 11:00 to 13:00 UT. *Middle panel:* Measured heights and deduced velocities of the filament and CME. *Bottom panel:* Deduced acceleration of the filament and CME, compared with E_{rec} and ϕ_{rec} (Qiu et al. 2004).

Figure 3: *Top*: Scatter plot of maximum filament acceleration vs. maximum ϕ_{rec} ; *Bottom*: Scatter plot of maximum filament acceleration vs. maximum E_{rec} . Error bars attached to each sign indicate the uncertainty of the measurement (Jing et al. 2005).

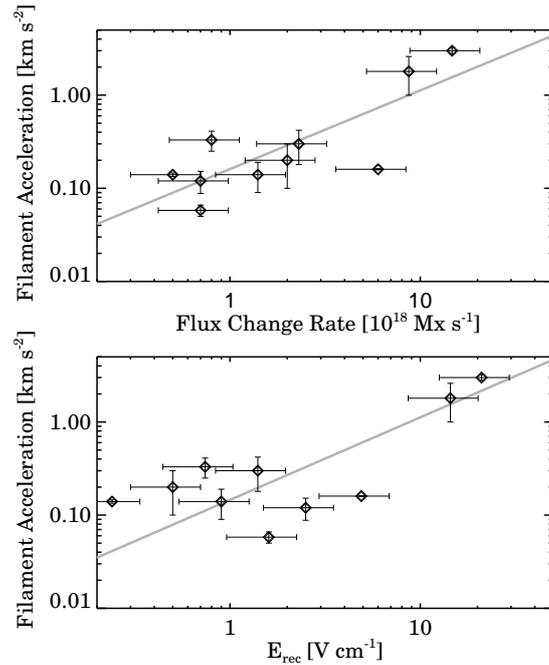
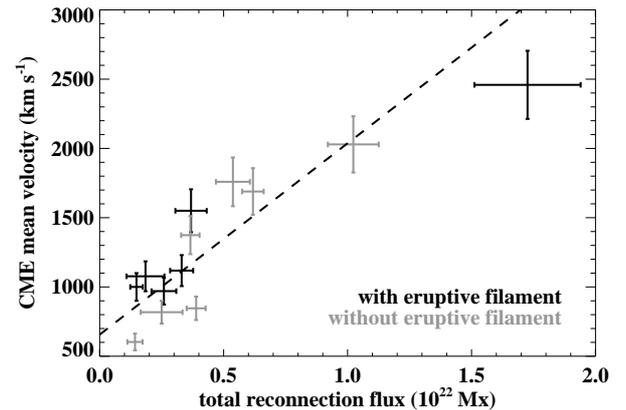


Figure 4: Scatter plot of CME velocities vs. total reconnection flux for 13 events. Dark and gray colors indicate events associated with erupting and non-erupting filaments, respectively. The dashed guideline shows the least-squares linear fit to the data points (Qiu & Yurchyshyn 2005).



resolution and polarization accuracy. We note that Kitt Peak provides one magnetogram per day, therefore, there is a time difference up to 8 hours between the time of an observed flare at BBSO and the time that a magnetogram is obtained. We will correct for the effect of solar rotation, however, the field evolution will affect the accuracy of the derived magnetic reconnection rate. We estimated that the errors in calculating magnetic reconnection rates could be in the order of 10%.

In summary, with the limited event samples analyzed to date, we had found scaling relationships of a certain magnitude between the magnetic reconnection rate and the kinetics of erupting filaments and CMEs. These pilot results need to be corroborated by including many more events. In order to achieve this goal, we plan to carry out research in the following steps:

(1) We will take advantage of our digitized data to explore a large number of events. We will also improve our automatic program that can align $H\alpha$ images with full-disk magnetograms, count all brightened pixels swept by flare ribbons in a sequence of consecutive $H\alpha$ images, map the newly brightened patches

onto the co-registered magnetograms, and measure the ribbon expansion velocity. This program, mainly based on “region growing”, “adaptive boundary-base”, and “morphological closing” methods, makes batch processing possible (Qu et al. 2003, 2004). In addition, we have developed software to detect and characterize filament and prominence eruptions (Qu et al. 2005; Fu et al. 2006).

(2) If the above mentioned correlation relationship can be solidly established, we will provide a real-time prediction of filament accelerations and its associated CME speeds, based on the real-time monitoring of flare ribbon separation. Of course, we may see events that do not follow the general scaling relationship, and we will then investigate the physical reasons for these exceptions.

BBSO is in the its final stage in building the 1.6m off-axis New Solar Telescope (NST). Analysis of archived data will provide guidance for planning NST observations, such as cadence and wavelength selection. Results from higher resolution NST observations will also provide corrections to the parameters that we derive from lower resolution observations.

B.2.2. Study of the Relationship Between the HXR Spectral Index and Electric Field in RCS

Besides the local magnetic reconnection rate (i.e., E_{rec}), another quantity related to electron acceleration during flares is the nonthermal spectral index. Nonthermal photons usually exhibit a power-law distribution in energy, i.e., $I(\varepsilon) \propto \varepsilon^{-\gamma}$. The power-law index γ thus can be directly associated with the energy distribution of the electron flux bombarding the target assuming the emission is bremsstrahlung. It can also be compared to theoretical models to identify the dominant acceleration process. Observationally, the temporal evolution of spectral index generally follows a “soft-hard-soft” pattern (Hudson & Fárník 2002) in the rising-peak-decay phase of flares, which indicates a direct correlation between the HXR flux and the spectral index. However, exceptions do exist. E.g., some flares showed continued hardening with time (Kiplinger 1995), which might be related to gradual and long-duration events with solar energetic particle production (Krucker & Hudson 2006). Grigis & Benz (2006) studied the “soft-hard-soft” evolution of the spectral features of the HXR emitted by suprathermal electrons, and suggested that stochastic acceleration may explain this spectral evolution of the loop-top HXR sources. Hence the study of the evolution of the spectral index furnishes an observational constraint on acceleration theories.

Since the energy released in a flare is generally believed to have been previously stored in the magnetic field and later unleashed through magnetic reconnection at some critical stage, the direct acceleration by the reconnection electric field is, therefore, one possible mechanism accounting for the high energy particles in solar flares. Recently, Woods et al. (2005) presented results of charged particle orbit calculations in prescribed electric and magnetic fields motivated by magnetic reconnection models. Their MHD simulation shows that an initially Maxwellian distribution function in the inflow region can develop a beam-like component in the outflow region. In relation to our study, in particular, they reported that in the case of a weaker maximum electric field, both a reduction in the possible energy gains and a steepening of the spectrum are expected, under the direct electric field acceleration in field-aligned electric fields. Specifically, the value of γ is ≈ 2.6 for $E = 1.0 \text{ V cm}^{-1}$ and ≈ 4 for $E = 0.1 \text{ V cm}^{-1}$. We note the E they suggested is much smaller than what is actually measured from ribbon motion, and we will seek to determine whether the theory can be expanded to cover a broader range. Nonetheless, it is scientifically worthwhile to seek the expected anti-correlation between a spectral index and the electric field in RCS using real flare observations.

We plot in Figure 5 the photon spectral index at the HXR peak time and the largest energy gain both derived from the spectral fitting versus the co-temporal E_{rec} for five events. The electric field is derived from recent BBSO and MDI data, while HXR spectral index is derived from RHESSI observations. Consistent with the simulations, we obtained a harder spectrum (smaller γ) and larger maximum energy gain when there is a larger E_{rec} . However, the same limitation in studying the relationship between filament dynamics and magnetic reconnection rate applies, it is hard to have a large number of well-observed events from the BBSO/RHESSI data base alone. Naturally, the usage of digitized data will be an important source to expand the sample of events.

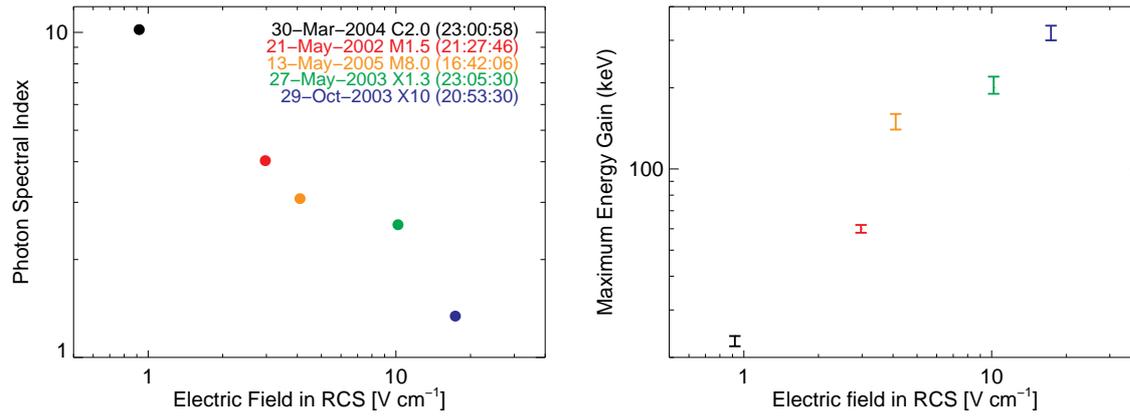


Figure 5: *Left Panel:* Photon spectral index γ at the HXR peak times (ordinates) of five well-observed two-ribbon flares vs. the co-temporal electric field strength in RCS (abscissa) measured by the ribbon expansion motion. *Right panel:* Maximum energy gain of these events vs. the electric field strength. Data points in the two plots both yield a correlation coefficient of 0.98.

Of course, RHESSI data were not available prior to 2002. While fortunately, high quality hard X-ray spectroscopic observations were obtained by the following three space missions.

(1) SMM was launched on 14 February 1980 during the peak of the solar cycle. Besides HXRBS, the payload included the Active Cavity Radiometer Irradiance Monitor, the Gamma-Ray Spectrometer, the soft X-Ray Polychromator, the Hard X-ray Imaging Spectrometer, and the Ultraviolet Spectrometer and Polarimeter. The mission ended on 2 December 1989.

Our key data will come from the HXRBS archive. The primary objective of HXRBS was to study hard X-ray spectra of solar flares on sub-second time scales. Events were pulse height analyzed in 15 channel energy spectra from 30–500 keV. The time resolution was 128 ms. Solar Data Analysis Center of NASA archived over 10,000 events observed by HXRBS.

(2) CGRO operated from April 1991 to June 2000. Although this was a high energy astrophysics mission, one of the payload instruments, BATSE, observed hard X-ray bursts of thousands solar flares, particularly in the earlier part of its mission. Therefore, a comparison of BBSO observations with the BATSE archive from 1991 to 1995 will compose an important component of our statistical study comparing the magnetic reconnection rate and HXR spectral index.

BATSE was the most sensitive all-sky hard X-ray and γ -ray detector system ever flown. It has two observational modes producing different data types, i.e., the 4-channel large area detectors (LAD) data and 256-channel spectroscopic detectors (SD) data. LAD HXR counts of large flares have been well-calibrated and archived in the BATSE home page. Thus, the power-law index is easy to derive. To achieve our scientific objective of a statistical study, LAD provides sufficient information for most of our events. SD data have higher spectral resolution, but the data processing is more difficult. We will use it only for some case studies. The PI had been a NASA CGRO fellow, and has extensive experience in handling BATSE data. The spectral fitting code SPEX was developed by Dr. Richard Schwartz, and has been evolved to handle modern RHESSI data.

(3) During an overlapping time period as the CGRO mission, the Yohkoh satellite was operational observing energetic phenomena taking place on the Sun, specifically solar flares in with X-ray and γ -ray emissions. The most relevant instrument for this study is the Wide Band Spectrometer (WBS) that consisted of three detectors: a soft X-ray, a hard X-ray, and a γ -ray spectrometer. They were designed to provide spectra across the full range of wavelengths from soft X-rays to γ -rays with a time resolution on the order of one second or better. WBS will be complementary to the LAD on BATSE. Again, the software package (SPEX) is quite mature to

handle the spectral fitting. The WBS flare catalog has been describe by Sato et al. (2006).

We understand that handling hard X-ray data requires substantial effort. The team has experience in handling RHESSI, CGRO, and Yohkoh data. The data archives for HXRBS, BATSE, and WBS are quite mature and events catalogs are readily available. Therefore, we are confident that automated codes can be written to extract power-law index of hard X-ray spectra.

By synthesizing the events to be analyzed, we will address the following questions:

- (1) **We will study the relationship between the HXR spectral index and the electric field E_{rec} in RCS.** We will also compare the results of observations and theoretical models such as that of Wood et al. (2005).
- (2) **We will investigate the temporal evolution of the spectral index and E_{rec} during selected individual events.** Does the conclusion also hold that a larger electric field corresponds to a harder spectrum? If not, what kind of factors (e.g., uncertainty in the ribbon velocity measurement, different electron acceleration mechanism) could contribute to the inconsistency? We will also address the observed delays between the peak of reconnection rate and peak of hard X-ray emissions (Xu et al., 2006).

B.2.3. Other Scientific Topics

Because of the commitment to digitize a huge amount of data, we can only focus on the two scientific topics outlined above. Both are closely related to SHINE goals. Nevertheless, the resulting archive can be used for many other important research topics. Such research can be done by us in the future or by anybody in the community. We list a few of them in this section.

- (1) The data can be used to study large amplitude, long period oscillation of filaments to understand the excitation, damping, and restoring force of the observed oscillations, and the possible relationship to the eruption of filaments (Jing et al. 2003, 2006). There are only a few such events studied so far.
- (2) A statistical study can also be done on the dynamics of filaments especially those in the sigmoidal active region during the initiation phase of flares. These filaments are important tracers of the sheared core field and can provide crucial information as how the sigmoidal fields erupt into CMEs (Moore & Sterling 2006; Liu et al. 2007).
- (3) The full-disk data can be used to systematically investigate the generation of Moreton waves and characterize their propagation (Liu et al. 2006). A natural question is what is special to only a small fraction of flares that have associated Moreton waves.
- (4) The full-disk data can also be used to study remote flare brightenings associated with many events (Wang 2005; Balasubramaniam et al. 2005; Liu et al. 2006), which is important to map out the initiation and subsequent disturbances of the flare/CME eruptions and large-scale magnetic field structures.
- (5) High resolution, as well as full-disk data, can be used to study small-scale activity, such as surges (Liu et al. 2005), Ellerman Bombs (Qiu et al. 2000), and microflares (Liu et al. 2004).
- (6) As the cadence of the film data is as high as 10 seconds, we will be able to study a large number of events with high cadence and high resolution to characterize the footpoint motion in the impulsive phase of flaring (Ji et al. 2004, 2006; Veronig et al. 2006). In particular, we will determine whether contracting motion of footpoints always occurs in the early stage of flares, and investigate the relationship between the extent of the contraction and the energy release of flares. Such motion is usually observed to occur in the first two minutes of a flare.
- (7) The data can be used to study the evolution of emerging flux regions (EFR) and the rules of EFR in developing into flare active regions. In particular, the twist and shear motions are found to be important characteristics in producing flares.

- (8) The statistical properties of filament disappearance can be established, in particular as a function of solar cycle. Evolution of polar crown filaments are particularly important to reveal the transition between two cycles.
- (9) Flare precursors can be statistically studied using $H\alpha$ data, such as pre-flare brightening and filament darkening.
- (10) Caltech was operation another important solar facility: the Solar Radio Array of Owens Valley Radio Observatory (OVRO). With imaging and spectroscopy capability in microwave, it covered many flares since 1982. The data are now all archived at NJIT. For the two major scientific topics in this proposal, OVRO data provides another important data source for the diagnosis of flare electrons and magnetic fields of the active regions.

C. Personnel and Management

PI Team

The project requires scientists to analyze data and people to handle tedious work. It will be carried out primarily by the following people.

PI Wang will oversee and coordinate efforts and participate in HXR data analysis.

Co-PI Goode will supervise the integration of digitized data into the data archive system at BBSO.

Co-PI Chang Liu will carry out the data analysis for the research topic 2: the reconnection rate and HXR spectral index. He will also assist PI in supervising the Ph.D. students and undergraduates.

A graduate student will devote 50% of his/her time to the project, to study the relationship between magnetic reconnection and filament eruptions (topic 1). He/She will also spend time to solve any problems in the digitization process that will be mainly carried out by undergraduates.

At least three undergraduate students will be hired from NJIT's Honors College. We had very good experience in working with these bright kids. Their primary duty is film digitization. We will ensure the maximal usage of the digitizer up to 12 hours a day, 7 days a week. However, these students are also involved in data archiving and statistical research in the topics listed in § B.2.3. By involving them in frontier research, they are more likely to choose solar physics as their field when move to graduate school. The planned digitization is feasible, as a roll of film will be automatically digitized in about 4 hours. Therefore, they can use a separate computer to process digitized data, while keep an eye on the digitizer.

This is a four-year proposal. We propose to spend the first 6 months to setup the equipment, streamline the digitization and data processing procedures. Over the next 18 months, we will finish digitizing all the full-disk data. In the final 24 months, we will digitize selected high resolution data. Statistical studies will be on-going. All the data and event movies will be available to the community by the end of the project.

Budget

In this proposal, we need to balance between the digitization of films and research using the data to meet the SHINE goal. The total budget is about \$400K. the rough breakdown of the financial resources to be used is:

Equipment: 10%;

Man Power for Research: 40%;

Man Power for Digitization: 40%;

Data Archiving 10%.

D. References Cited

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