## I. Summary

A consortium of six major, internationally-recognized research universities, New Jersey Institute of Technology (NJIT), University of Maryland (UMd), University of New Hampshire (UNH), California Institute of Technology (Caltech), University of Alabama in Huntsville (UAH), and University of Michigan (UM), plus an industrial laboratory (Lucent Technologies) and two government laboratories (Naval Research Laboratory and Air Force Phillips Research Laboratory), are proposing a comprehensive and unique suite of solar-terrestrial measurements and modeling that will significantly advance the state of knowledge of the nature of space weather. Space weather, as defined in the FY 2001 MURI Topic #29, can significantly, and negatively, impact DoD operations as well as civilian tele-communication facilities and electric power grid. Our team has unique observational capabilities, with dedicated state-of-art solar optical and radio telescopes. Our unique U.S. solar observational resources will be combined with measurements from additional instruments (associated with consortium members and other groups) that are flying in the heliosphere and in the earth's magnetosphere. The data to be acquired will be analyzed, synthesized, and modeled by consortium members who rank among the most internationally-recognized space plasma theorists. The central theme of our proposal is to use our unique solar data, along with space-based solar and heliospheric data to forecast and predict the initiation of space weather events, follow their propagation and development in the heliosphere, and predict their likely impact on the near-earth environment.

We propose to utilize NJIT's existing, unique optical and radio observing facilities at Big Bear Solar Observatory (BBSO) and Owens Valley Radio Observatory (OVRO), which includes our various magnetographs, our global H-alpha network, and the OVSA and SRBL instruments for microwave imaging spectroscopy. We also propose to extend our ground-based observations of the Sun to 24-h coverage in two key areas – microwave radio spectroscopy and optical vector magnetograpy – with world-wide networks. For heliospheric observations, we will rely on spacecraft data from SOHO, Wind, Ulysses, and ACE.

Using the expertise of our team, we will emphasize: (1) 3-D magnetic structure before and after major events from observation and modeling, (2) the physical cause of and correlations among different types of solar activity (flares, filament eruptions, and Coronal Mass Ejections (CMEs), (3) prediction and/or forecasting of solar activity, (4) real-time prediction of properties of magnetic clouds resulting from CMEs, (5) study of coronal and IP shock waves and energetic particles, to understand and perhaps forecast >10 MeV proton (SEP) events, and (6) prediction of likelihood and magnitude of geomagnetic storms. As an independent check of the particular models of filament eruptions, we will also include a laboratory component to simulate filament eruptions. The laboratory "data" will be closely compared with the results of observations and models. The above components will enable us to understand the underlying physics of CMEs, and will provide tools to predict geomagnetic disturbances and SEP events.


## II. The Science Team

1) From NJIT, which operates BBSO and the Solar Array at OVRO, the members are Philip Goode, Director, BBSO, Distinguished Professor of Physics; Haimin Wang, Associate Director, BBSO, Professor of Physics; and Dale Gary, Director, OVSA, Associate Professor of Physics

2) Paul Bellan, Professor of Applied Physics at Caltech does laboratory modeling and theory of filament destabilization.

3) Terry Forbes, Research Professor at UNH does MHD Modeling of filament eruptions, flares, and magnetic reconnection

4) Mukul Kundu, Professor of Astronomy at UMd, and Stephen White, Research Associate at UMd, do radio observations, modeling, and interpretation of radio data from mm to m wavelengths

5) S.T. Wu, Director, CSPAR, Distinguished Professor, UAH, does modeling of CMEs and the solar wind.

6) Thomas Zurbuchen, Research Scientist at UMich, combines space-based experiment and theory in heliospheric research.

7) From Naval Research Lab, James Chen, Research Physicist, who does CME modeling, magnetic cloud modeling, and the prediction of geomagnetic storms; and Simon Plunkett, Research Physicist and Staff Scientist for LASCO (and SECCHI) coronographs.

8) Louis J.Lanzerotti, Distinguished Member of Technical Staff, Lucent Technologies, with expertise in heliospheric research.

9) Michael Reiner, Research Scientist, Raytheon Corp., with expertise in solar and heliospheric radio physics.

10) Other domestic partners: From the Air Force Phillips Lab, Don Neidig, Principal Investigator of ISOON solar optical network, if the conflict of interest issue is resolved. We are negotiating with additional domestic partners in key areas. We are organizing an external advisory committee, the current members are: Art Poland NASA/GSFC, Ernie H. Hilner, NOAA and B.C. LOW, HAO. The committee can direct our efforts in the most critical and beneficial way.

11) International Partners: our current partners include Kanzelhohe Solar Observatory in Austria, Beijing Observatory and Yunnan Observatory in China. We are currently negotiating with other possible partners for radio and magnetograph sites. We plan to coordinate with Space Weather efforts in France through close cooperation with Monique Pick, Observatoire de Paris, (Meudon/Nancay).

## III. Instruments

1. Halpha Network

Based on our successful experience in making high resolution full disk Halpha observations at BBSO, and the urgent need to monitor the evolution of the solar chromosphere continuously during the solar maximum, we have deployed a network for Halpha full disk observations utilizing existing facilities at BBSO in California, Kanzelhohe Solar Observatory (KSO) in Austria, and Yunnan Observatory (YO) in China. Each of these observatories has over 300 sunny days a year, good seeing conditions, competent observing staffs, and well-established Halpha telescope systems. With this network, we can monitor solar chromospheric activity with 1$''$ pixel resolution and one minute cadence round-the-clock for most of the year, with the best available data quality. The network is operating normally.

2. Vector Magnetograph Network

BBSO and Huairou Observing Station (HSO) of Beijing Observatory have collaborated in round-the-clock vector magnetograph observations since 1988. Our night gap is 4-8 hours. Both stations have cadence of about 5 minutes and spatial resolution of about 1 aresec. We are currently seeking a third partner to form a 3-station vector magnetograph network. Tentatively, we will request a samll amount of funding ($25K) to set up a third station for vector magnetograph at KSO.

3. Radio Network

We are building a small (2 m) radio telescope, called the Solar Radio SpectroPolarimeter (SRSP), for obtaining 1-18 GHz radio spectra of solar bursts. The telescope is based on a similar system being deployed by the US Air Force called the Solar Radio Burst Locator (SRBL–see the web page at http://srblserver.caltech.edu/). The telescope that we are building, the SRSP, will be more sensitive to weak bursts and will record in two polarizations. Thus, it is complementary to the Air Force SRBL system, and its ability to record both circular polarizations makes it superior for the studies of space weather that we propose, since polarization is a key indicator of emission mechanism.

As an equipment procurement associated with this proposal, we propose to build two additional SRSP dishes to be placed in strategic locations, at existing radio sites, one in Europe and one in the Asia/Pacific region, to provide continuous 24-hour coverage of solar bursts.

4. Space Data

The combination of surface data discussed above with the direct imaging of CMEs from the LASCO/NRL team is a most important aspect of the proposal. STEREO, when it becomes available late in the target period, will extend and improve on LASCO. In addition, EIT will provide EUV imaging of eruptions in the low corona. MDI will provide continuous monitoring of photospheric longitudinal magnetic fields of the whole Sun.

Data from Wind, Ulysses, and ACE will be used, including magnetometer and particle detector data. These data provide in-situ measurements of the structure of magnetic clouds and particle properties. Data from the radio instruments on Ulysses and Wind will also be utilized for remote sensing of shocks and the heliospheric magnetic structure.

## IV. Scientific Objectives

Our scientific objectives are to forecast and predict the initiation of space weather events, follow their propagation and development in the heliosphere, and predict their likely impact on the near-earth environment. We divide them into two related parts: study of geo-effective CMEs and studies of SEP events.

### IV.A Study of Geo-effective CMEs

1. We will use combined, high-resolution vector magnetograph data from BBSO and HSO (and possibly that from a third station) to observe the magnetic structure of solar active regions

almost continuously. With the observed vector magnetic fields as boundary conditions, we propose to carry out force-free extrapolations to obtain the 3-D magnetic configuration before and after major events that produce geo-effective CMEs. Based on the results of studying many events, we will develop tools to predict eruptions from continuous monitoring of magnetic fields. At the same time, we will learn the underlying physics of the events.

Different models will be tested and compared with observations. These include erupting flux model (Chen), MHD model (Wu) and Hybrid model (Forbes). We will test the streamer and flux-rope for the initiation of a cme, the observed vector magnetic field will be used as boundary conditions which should be able to give a quantitatvely description of the flux-rope, such as the length and strength of the flux-rope. In such a way, the critical field strength could be determined for the eruption to destablize the streamer to launch a cme. HERE NEEDS TO BE EXPANDED BY THEORISTS

As a test of how filament eruptions occur, Prof. Bellan (Caltech) will use pulse power experimental techniques to create laboratory scale filaments which replicate the complex three dimensional topological dynamics occurring on the sun. We intend to use the observational results to guide the laboratory studies and vice-versa. Also, the output of the theoretical modeling of filaments and CMEs will be tested in the laboratory where possible.

2. We will use the data from the H$\alpha$ network to provide real-time reports of all flux emergences, filament disappearances and flares. When a major event occurs, the morphology (such as the extent of flux emergence, the filament helicity) will be used as boundary conditions in models, to predict the magnetic field orientation in CMEs as they propage in heliosphere. The predictions will include the speed of the CME and magnetic structure of consequent magnetic clouds. The predictions will be checked by the magnetic cloud data observed by ACE and Wind. The large number of events will provide a useful tool to sort out which kind of flare/filament eruptions may have associated geo-effective events. The result will certainly be used as a forecast tool. The software that we develop will be coordinated with the ISOON team for use in their planned network coverage of the sun in H$\alpha$.

3. More subtle characteristics of radio phenomena, such as spatial characteristics of interacting magnetic loops, will be studied with the multi-frequency imaging data from OVSA, to shed light on the development of instabilities in the solar atmosphere that lead to interplanetary events. The goal is to understand these interactions and recognize the important pre-event geometries that signal the likelihood of activity.

4. We will compare the 1-18 GHz spectral characteristics of solar bursts with the metric radio events that are observed in Europe and the Asia/Pacific region. We will link solar radio events near the surface with type II/IV events seen in ground-based metric spectrographs that are clearly associated with CMEs and interplanetary shocks. We will also follow into interplanetary space those events that are observed with the radio spectrograph on the Wind spacecraft. We will seek signatures in such events, as well as magnetic geometries predicted by our heliospheric modeling, that are predictive of highly geo-effective CMEs and interplanetary shocks.

### IV.B Study of SEP Events

1. SEPs must be accelerated by interaction of CMEs with coronal and IP magnetic fields. Observations of the evolution of solar surface vector fields and 3-D modeling will enable us to

study the acceleration processes of flare particles, and investigate the role of such particles in SEP events. The SEP are likely accelerated by shock waves, but do seed particles from a flare play a role? How does the magnetic geometry affect the formation and acceleration properties of the shock? We will develop MHD and particle models to investigate these questions. The results from the models will be compared with observations from in-situ particle instruments on ACE, Ulysses and Wind, as well as radio observations.

2. The microwave spectral data will pertain to the high-energy component of solar flares, and diagnostics of the energy release region such as magnetic field and plasma parameters. We will use the microwave spectroscopic data to do a correlation analysis of microwave spectral characteristics with other characteristics such as optical, hard X-ray, and heliospheric (SEP) events. Successful correlation of robust characteristics in the radio spectra (e.g. spectral hardening through the burst) with later production of interplanetary protons will allow us to forecast when such damaging radiation may occur near the Earth. We anticipate that with a world-wide network we can give a warning minutes to hours ahead of the arrival of these particles.