

Center for Magnetic Field Studies and Remote Sensing

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Proposal Summary

A. Overview

The Sun is our star and the source of life on earth. Studies of our star address both fundamental scientific issues and the most pragmatic concerns of our life on Earth. It is the Sun's magnetic field that make it such a dynamic star. The Sun and its extended magnetic field represent the largest scale field that we can resolve. Measuring this field has become an ever-more sophisticated venture requiring more complex instrumentation reflecting new technologies. Such instrumentation has allowed us ever deeper insight into the the fundamental nature of our star. This knowledge advances our understanding of how stars live their lives, and on a larger-scale, the solar magnetic field holds a key to understanding the role of magnetic fields in the evolution of galaxies and the universe itself. On a more pragmatic level, slight, but poorly understood gradual changes in the sun may well alter the climate of the Earth. For instance, about three hundred years ago the Sun was essentially unspotted for several decades and this corresponded to a time on Earth called "The Little Ice Age". Over the recent decades, ever-increasing numbers of space assets have been flown, and these assets are vulnerable to the effects of abrupt, and hard to predict, magnetic storms originating on the Sun. Such storms, broadly called "space weather" can destroy satellites and impact life on Earth by damaging the power grid and disrupting telecommunications and more.

To address these scientific and practical issues, we propose to establish an NSF Science and Technology Center (STC) to team universities, national centers and industrial partners with a common goal. This center will be built on both an expansion and tightening of existing interwoven connections. The center will focus on building and utilizing ground-based instrumentation needed to determine the fundamental

nature of the Sun's magnetic field and the short- and long-term changes in the Sun that impact life on Earth. Students will be deeply involved in our work and will greatly benefit from the exchange of resources among the center members, and others. Those educated through the center will have a broader and deeper experience that will benefit them and our society. Ground-based observational solar astronomy also presents a special situation for scientists who build instruments – the required instrumentation represents a sufficiently small project that a well-advised graduate student can handle all aspects of bringing to fruition a new instrument to measure properties of the Sun. Scientists with such training have special skills that are applicable across a wide range of fields. The experience of the students may be further broadened by extending it into internships with our industrial partners and involvement in incubation centers for the formation of small companies. The center will be deeply connected to the education of members of underserved groups.

These are laudable goals, but why is a center needed? Why can't our goals be accomplished in a traditional manner in which students take classes at some university, and are perhaps involved in the educational process for underserved groups, then builds some instrument for scientific measurement in pursuit of a Ph.D., and ultimately the graduate pursues a career at a university, national center or industry? The reasons that the traditional approach is not optimal in studies of the Sun by groups that build and use instruments has been carefully developed in several recent National Research Council (NRC) studies. These NRC studies have recognized the importance of ground-based observational solar astronomy and have strongly recommended an expansion of the field to include a new generation of solar telescopes – both optical and radio. The field also requires an infusion of scientists who are trained to build instru-

ments. To achieve these, we propose to form an NSF center that combines the universities that operate solar observatories and build the scientific hardware to enable frontier observations.

In the 1998 NRC report entitled “Ground-Based Solar Research: An Assessment and Strategy for the Future” developed a series of strategies to ensure a bright future for the field. There the report argued for a strong future for the study of the Sun, but expressed concern about “the current state of university-based instrumentation programs, which are widely seen as essential to future instrument development, as well as the reduced access of new researchers to hands-on observing experience. Existing instrumentation and training programs are few in number and rely on precarious grant-based funding.” That NRC report also argued that “centers and/or institutional consortia can play an important role in facilitating the creation of ‘critical-mass’-size programs of research.” In the 2001 NRC report entitled “Astronomy and Astrophysics in the New Millennium” a “systems approach to solar physics” is recommended to understanding the nature of the Sun’s magnetism, which requires a close collaboration among those tied to observations of the Sun. The 2002 NRC study entitled “The Sun to the Earth – and Beyond: A Decadal Research Strategy in Solar and Space Physics” argues that the community should come up with innovative ways to ensure that there are a “sufficient number of future scientists in solar and space physics” and there should be a strong effort in distance learning to optimize community resources.

A.1 The Genesis of the Center

At the outset, the center will arise from a teaming of universities active in observational ground-based solar astronomy and developing requisite instrumentation: New Jersey Institute of Technology (NJIT), University of Hawaii

(UH), Stanford University, University of Maryland, UC Berkeley, and Prairie View A&M (PVAM); national centers in ground-based solar astronomy: the National Solar Observatory (NSO), National Radio Astronomical Observatories (NRAO) and High Altitude Observatory (HAO); and interested third parties: Rockwell, Apogee, Lucent Technologies, Edmund Scientific and the NJIT Enterprise Development Center, Inc. Of course, the center will encompass more members, but for our purposes here the initial partners illustrate how the center will work. The center will be built around a profound strengthening of initial, natural connections that have evolved over time.

A.1.1 The University Connections

A natural connection has evolved between New Jersey Institute of Technology (NJIT)/Big Bear Solar Observatory (BBSO) and the University of Hawaii (UH) because the two are the US universities operating solar optical observatories that build the PI-class instrumentation required to keep the US at the leading edge in ground-based optical solar astronomy. Both teams train PhD students who build the instrumentation required to keep the small US university community at the leading edge of observational solar astronomy. The connection between NJIT and UH is reflected in the several joint scientific projects like DoD funded infrared instrumentation (DURIP), space weather studies (MURI) and most recently the teaming of our expertises for the NST project to build a 1.6 m open aperture solar telescope at BBSO. As well, the BBSO/Caltech group is using a UH infrared spectrograph in climate studies focussed on the greenhouse gas spectrum of the Earth. Codifying the NJIT/UH relation within the framework of an NSF Center would bind and strengthen the eastern and western-most frontiers of solar astronomy. Scientifically, combining joint instrumentation interests with overlapping regions of obser-

vation (BBSO/photosphere&chromosphere and UH/chromosphere&corona) has great synergy. Both NJIT and UH are co-I's on the upcoming NASA Solar Dynamics Observatory (SDO) mission on which Stanford is a PI institution. The SDO will be significant in the aforementioned studies. Through the NST, NJIT has a working relation with PVAM, which built its own ground-based solar observatory. These scientific synergies are further advanced by the ground-based radio observatory that NJIT operates – Owens Valley Solar Array (OVSA).

OVSA is the only solar-dedicated radio array in the world that combines a broad spectral coverage with spatial resolution to allow the use of microwave imaging spectroscopy. The power of such an approach is widely recognized, and has led several NRC committees and international gatherings of experts in solar radio physics to recommend the construction of a much larger array (the Frequency Agile Solar Radiotelescope, or FASR) based on the principles used at OVSA. The main driver is the development of the FASR by a consortium of institutions including universities NJIT, University of Maryland (UMd), and UC Berkeley (UCB), national observatories (NRAO, NSO), industrial partners (Lucent, PSI).

A.1.2 The National Centers

Both NJIT and UH are co-PIs on the NSF funded 4 m class Advanced Technology Solar Telescope (ATST) Design&Development project, which connects the universities to the National Solar Observatory (NSO) –the lead institution on the ATST. The ATST project, common interests in the infrared and the corona connect the High Altitude Observatory (HAO). This center would be a resource for ATST instrumentation, while training the students who would be the true beneficiaries of the ATST. Both NJIT and UH team members have produced a significant number of PhD students who are well-grounded both in science and making

the instrumentation necessary to do the science. We view this connection to be one that can help seed other university programs and further expand the center. BBSO already has a further close tie to NSO with a joint NSF funded program to implement adaptive optics at both observatories and two NJIT PhD students doing thesis work at NSO. Further, the FASR project also binds together NJIT, NRAO and NSO.

Additionally, NJIT and UH serve on the ATST Advisory Committee. Another level of the connection would be an expanded REU program. Right now, both NJIT and UH have REU students, but there is no linkage to each other, or to NSO, HAO or NRAO. This would change. As well, NJIT is located in inner city Newark and has significant educational connections with the community, including to the Newark Planetarium. The center will be deeply involved in minority/underrepresented group education. We have a summer program involving the usage of our small, on-campus by students in the these programs, but the center would greatly expand this effort.

A.1.3 Industrial Affiliates

B. The Science

What is broadly called solar physics includes the study of the Sun from its center out to the Earth, including climate and space weather, and beyond to the edge of the solar system. Our center is focussed on the ground-based observatories – optical and radio – that are so essential in this enterprise.

B.1 Solar Magnetism from Optical Observatories

The observed magnetic field of the sun is generally regarded as being composed of conglomerations of individual fibers (or “fluxtubes”, as they are also known), and establishing the na-

ture of the individual fibers, and hence the fundamental nature of the field, depends on critical magnetic observations with higher spatial resolution. Many believe that individual fluxtubes have cross sections of order 100 km. To advance, the field requires higher resolution telescopes to explore spatial scales as small as 50 km and test flux models of fibers and tubes. Understanding this small-scale solar activity is at the heart of understanding large-scale solar activity and the origins of space weather. Further, we need to resolve the field in three dimensions – measuring it from the solar surface, through the photosphere through the chromosphere and into the fiery hot corona.

In the near future, there ground-based solar observatories in the U.S. will have apertures that are several times larger than current sub-meter class telescopes. These coupled with adaptive optics, which is now coming into its own in solar physics, much higher resolution observations are possible. Further, new technologies in filters and cameras make revolutionary advances in our understanding of the Sun possible. In the remainder of this subsection, we briefly discuss some significant, outstanding problems that the center will be able to address with the aforementioned new instrumentation.

B.1.1 High Resolution, High Cadence Studies of Solar Flares

With solar telescopes in the 1.5 m class, the improved resolution would allow flare imagery and spectroscopy that would otherwise be beyond our reach. High cadence X-ray and microwave observations have revealed a temporal (sub-second) fine structure in solar flares, called elementary flare bursts. These may be attributed to the fine structure in coronal magnetic fields, which are related to the aggregation of photospheric magnetic fields into “magnetic knots”.

B.1.2 Structure and Evolution of Magnetic Fields in Flaring Active Regions

The new telescopes with their leading edge instrumentation would enable us to address questions like: (a) What is the role of the evolution of the photospheric magnetic field in triggering solar flares, and what is the relationship between the magnetic configuration and the properties of flares? (b) How do electric currents evolve, and what is their relationship to particle precipitation?

It is generally accepted that the energy released in solar flares is stored in stressed magnetic fields. So, the study of magnetic fields is a very important component of flare science. This concept of energy release has motivated many attempts to detect flare-induced changes in the magnetic fields of active regions. So far, no one has detected, in any consistent way, the changes in magnetic fields associated with solar flares. The inconsistency of the results is due to observational limitations. We cannot get high temporal and spatial resolution and high polarization accuracy at the same time, with existing telescopes/instruments.

B.1.3 Dynamics of Kilogauss Flux Tubes

One of the major breakthroughs in solar physics during the last 40 years has been the discovery that most photospheric magnetic flux that is measurable in visible light, via Zeeman polarization, appears outside of sunspots in the form of small scale flux concentrations with field strengths of typically 1 to 2 kG. Evolving from this discovery is the picture of small fluxtubes with typical sizes of a few tens to a few 100 kilometers, as building blocks of plage and network magnetic fields. Sophisticated Magneto-HydroDynamic (MHD) models now offer a variety of predictions that need to be tested. Also, precise measurements are necessary in order to define boundary conditions for these models.

The main questions about the dynamic be-

havior and structure of small scale kilo-Gauss fluxtubes, which need to be addressed with larger aperture solar telescopes, concern the formation of photospheric flux concentrations with field strength above the equipartition field strength, and the dynamic interaction with the turbulent photospheric atmosphere. How are fluxtubes formed and how do they evolve? What is the lifetime of a fluxtube? How do the fluxtubes interact with turbulent flows in the photosphere? The observational verification of the process(es) that leads to kilo-Gauss flux concentration in the solar photosphere, where the equipartition field strength is only about 500 G, is a fundamental problem in solar and stellar physics that needs to be solved, and better than 100 km resolution is critical to resolve this problem.

Understanding the dynamic interaction of photospheric flux concentrations with turbulent granulation is essential in order to estimate the total energy flux that is transmitted/channelled by small-scale fluxtubes into the higher atmosphere.

B.1.4 Heating of the Upper Atmosphere

Recently, there have been some significant advances in the research on the origin of coronal heating. New, larger aperture solar telescopes will enable us to make breakthroughs on this sixty year old problem because we will provide direct measurements of magnetic reconnection rates in the quiet sun with magnetograms that are an order of magnitude more precise. Some years ago, Parker (1988) proposed that the X-ray corona is due to a continuous nanoflaring process. The energy source of these nanoflares is from the random motion of footpoints. So the observations of footpoint motions associated with all the above events is essential. We know that such footpoint motion is hard to observe and characterize in lower resolution observations with the current system. We plan to detect and characterize such footpoint motions

with 0.1'' spatial resolution, using real-time reconstructed images.

B.2 Solar Magnetism from Radio Observatories

OVSA is a unique facility for radio observations of the Sun. OVSA continues to be improved. The latest improvement is an upgrade of the feeds and front-end system to provide full circular polarization measurements. At present such measurements are only possible on some combinations of antennas, and then with rather large uncertainties. The new improvements, with funding from NASA, will be completed by 2005 and will allow for full circular polarization with significantly better calibration and precision. FASR is the future for radio observations of the Sun, and is based on the principles used at OVSA. The power of solar-dedicated operation is that (1) solar radio bursts can be observed in sufficiently large numbers to allow meaningful statistical studies of the general properties of such bursts and (2) joint observations of bursts with space-based and ground-based instruments can be made with regularity, yielding many well-observed events for detailed individual study.

The solar radio spectrum is due to several emission mechanisms at different frequency ranges, and although there is tremendous diagnostic power in the radio spectrum, sufficient spectral resolution is needed to distinguish the different spectral components. The brightness of the emission is key to the diagnostic power, but to determine brightness requires that the sources be spatially resolved. So the combination of imaging and spectroscopy is essential, and this is what OVSA uniquely provides. The main contribution to the radio spectrum in the range 1-18 GHz is due to gyroresonance emission, which has the nice property of being both optically thick at high frequencies and optically thin at low frequencies. Since the radio opac-

ity and emissivity of electrons accelerated in solar flares depends differently on the plasma and particle parameters, having both thin and thick emission yields powerful diagnostics. From the dynamic changes in the radio spectrum one can deduce the changing electron energy distribution and constrain the plasma parameters of density and magnetic field strength in the flaring region. Comparison with hard X-ray and other data in other wavelength ranges allows especially tight constraints on the environment of solar flares.

In addition to flares, one can deduce the structure of the corona above active regions, including temperature, density, and magnetic field strength. OVSA has made some of the best constrained characterizations of the fall-off of magnetic field above sunspots, helping to establish the structure of strong-field regions as a function of height.

B.3 Space Weather – Effects of the Sun on Technology and Society

It has been recognized since the development of the electromagnetic telegraph in the first half of the 19th century that the Sun can be a source of severe disruptions to critical technical systems on Earth. The recently completed Decadal Survey of solar and space physics (The Sun to the Earth - and Beyond, National Academies Press, 2003) prominently discussed - and included in the prioritization process for defining and rank-ordering new initiatives for the field for the next decade - the many practical applications of the research (this research area has come to be identified as “space weather”). Indeed, an entire chapter (Chapter 5, Effects of the Solar and Space Environment on Technology and Society) was devoted to the numerous engineering, science, and public policy challenges that the research field faces currently, and will face in the future. The five Challenges for space weather research that are identified in the Sur-

vey are classified under the categories of

- The National Space Weather Program
- Monitoring the solar-terrestrial environment
- Transition from research to operation
- Data acquisition and availability
- Public and private sectors in space weather applications

Studies of the Sun using state of the art instrumentation and data handling are critical aspects of the research in each of these “challenge” areas.

The Sun is the driving source for all of the disturbances of the near-Earth space environment that can affect many modern technologies, both those on Earth’s surface and those that fly in space. However, each technology that might potentially be affected by a disturbance from the Sun has to be individually examined to ascertain the specific disturbances in the solar-terrestrial system that can cause the vulnerability to a specific technical system. Most of the current research - both modeling and data-taking - that is directed towards the practical uses of solar and space physics research involves the study of the transition of solar disturbances from their solar launching to their propagation through the interplanetary medium to their impacts on Earth’s space environment - the magnetosphere and the ionosphere. Indeed, most of the studies of the Sun, and especially the Sun’s magnetic fields, are directed toward the configurations that can launch disturbances into the heliosphere. Few, if any, of the present forefront research efforts (excellent as they are) in space weather - especially the several very large modeling activities - address the physics of the magnetic fields on the Sun that give rise to solar disturbances that by themselves can produce effects on technologies at Earth.

Solar x-rays and ultraviolet emissions have long been known to produce changes in Earth's ionosphere, changes that can seriously effect radio transmissions that use the ionosphere for signal reflection and propagation. Solar radio noise across a wide frequency band (including into the GHz range) have long been know to affect the reception of radar signals in antenna that may be directed toward the Sun at the time of a burst. With the increasing importance of wireless communications in the civil sector over the last decade, it has become recognized that solar radio noise bursts can also affect the quality of this technology as well.

Such solar emissions (x-rays to radio) are sometimes, but not always, associated with solar disturbances that eventually will reach Earth's environment after propagating through the interplanetary medium. But these disturbances (x-rays to radio) reach Earth at the speed of light, and so systems operators do not have the relative luxury of up to a day in delay for a solar-produced effect to propagate to Earth. Such radar and radio systems operators must respond immediately to potential threats to their systems.

These two examples demonstrate that specific studies of the Sun that are directed to research that can potentially predict, hours or a day in advance, solar conditions that will lead to a x-ray or radio outburst could be critically valuable for technical systems operators in both the civil and the public (largely military) sectors of society. Research on the fine-scale (temporal and spatial) structure of Sun's magnetic fields in solar active regions, or potentially active regions, can provide the essential tools that are needed for such predictive capability. The organized research that will be conducted in this Center, coordinating the research efforts of key solar research establishments in the U.S., as well as several principal international organizations, will significantly facilitate the development of new predictive tools for practical use.

B.4 Climate

It is important to know whether there is an on-going global change in the earth's climate. To answer this, one needs precise, global/integrated measures of relevant quantities. The earth's climate is driven by the net sunlight deposited in the terrestrial atmosphere, and so, is critically sensitive to the solar irradiance and the earth's albedo. Precise measurements of the solar irradiance have been made by various satellites and using ground-based proxies (for a review, see Fröhlich, 2000, and references therein). The spectrum of efforts to determine the earth's global albedo is not so rich. There have been efforts using systems of satellites (Buratti et al., 1997, and references therein), but virtually no efforts from the ground. Nonetheless, the earth's energy balance is determined in large part by its global albedo – the fraction of the incident sunlight that is directly reflected back into space without altering the internal energy budget of the atmosphere. The earth's surface, aerosols in the atmosphere, and clouds all reflect some of the incoming solar short-wavelength radiation, preventing that energy from warming the planet.

It has been known for some time that the so-called solar constant varies by about 0.1% over the solar cycle. It is conventional wisdom that a 0.1% change is about several times too small to be climatologically significant over a solar cycle (Lean, 1997). Still, there is strong terrestrial evidence of a solar cycle going back more than 100,000 years (Ram and Stoltz, 1999). If the 0.1% increase in the mean solar irradiance between the mid-1980s and 1990 were typical, then one is led to consider more carefully the possibility of a variation in the earth's albedo arising from, perhaps, an indirect effect of the solar cycle associated with the solar wind. The Earth's reflectance is not so well-studied and seems to show considerable variation, Goode et al. (2001). From BBSO, the Earth's reflectance has have been precisely measured, in collabo-

ration with Caltech, over the last several years by observing the earthshine, but to best study the changes in the large-scale reflectance of the Earth we need a network of robot telescopes to measure the earthshine to provide an absolutely calibrated measure of the Earth's climate.

The same group has been measuring the spectrum of the earthshine from Mt. Palomar using the 60" telescope, and its Echelle spectrograph. These observations give the only large-scale measure of the spectrum of the other side of the Earth, and its variation. These data hold the promise of enabling us to determine the large-scale variation of the structure of the terrestrial atmosphere as well as the evolution of its content of greenhouse gasses. However, the spectral signatures of the greenhouse gasses are concentrated in the near infrared, and we have been using the AEOS telescope in Hawaii employing the University of Hawaii infrared spectrograph.

C. Education

The education of the next generation of scientists who build instrumentation is an essential part of the scientific enterprise. There are challenges and opportunities for those who observe the Sun-Earth system from the ground. The challenge is that there are small groups of students at several universities, which has made it difficult to ensure a thorough education for the students. This problem is made more difficult because the students from one institution can be spread among several locations. For instance, NJIT has Ph.D. students located on campus, at BBSO and at NSO. The opportunity is that video-conferencing technologies make distance learning comparable to the classroom experience. Further, NSO and HAO have expert scientific staff who could teach to students dispersed over several locations. It is easy to imagine an NSO course on radiative transport theory that is taken simultaneously by local students, stu-

dents at NJIT, BBSO, UH, HAO, etc. Such educational opportunities will be at the heart of this proposal. As well, the center broadens the possibilities for REU students, as well.

It is often argued that the early teen age years are the best time to interest people in becoming scientists and that the scientific enterprise would be strengthened by a better representation of members of underserved groups. This problem also presents us an opportunity. Stanford, UH (?), PVAM(?) and NJIT all run Upward Bound programs, and each has some involvement of the local Sun-Earth team. These efforts have a natural appeal to the students. But imagine a class prepared for Stanford that is also shown live at NJIT, PVAM and UH. This we propose as part of center function.

C.1 Education at NJIT

BBSO graduated 4 Ph. D. students from 2001 to 2003. We currently have 11 Ph. D. students (including 3 women), and 3 of the 11 will graduate in 2003. Generally, each student builds the additional instrumentation necessary for his/her Ph. D. work. This broadens the education of the student, while strengthening the observatory. The typical new instrument needed by a solar observatory constitutes a small enough project that one graduate student can handle all aspects of its development. Our typical student will receive a Ph. D. in Applied Physics, Electrical and Computer Engineering or Computer Science. Such training prepares our students for a scientific career, while ensuring broader career opportunities. Our most recent graduate, Jingshan Wang, is now leading an IR optics group in a New Jersey company.

C.2 Education at ...

D. The Center

D.1 Center Advisory Committee

The Center will have an external advisory committee. We anticipate that function like that already in operation for BBSO/OVSA, which has an unpaid, outside Advisory Board meeting bi-annually to critique observatory efforts. The current members of the board are Len Fisk (University of Michigan, Chair), Steve Koonin (Caltech), Jeff Kuhn (University of Hawaii), and Carl Shrijver (Lockheed/Martin).

E. Instrumentation Projects

E.1 New Telescope at BBSO

BBSO/NJIT, in collaboration with the University of Hawaii (UH), is upgrading BBSO by replacing its principal 65 cm aperture telescope with a modern, off-axis 1.6 m clear aperture instrument. The new telescope offers a significant improvement in ground-based infrared and high angular resolution capabilities, and enhances our continuing program to understand photospheric magneto-convection and chromospheric dynamics. These are the drivers of space weather. This New Solar Telescope (NST) will use the existing BBSO equatorial mount and observatory building, which will be modified (including a new dome to support the open design to accept the larger open telescope structure). The NST optical and software control design will be similar to the existing SOLARC (UH) and the planned Advanced Technology Solar Telescope (ATST) facility led by the NSO – all three are off-axis designs.

E.2 Adaptive Optics

NJIT is midway through a three year grant from NSF-MRI to build two high order adaptive optics (AO) systems (76 element AO systems), one for BBSO's 65 cm telescope and the other for the 76 cm Dunn Solar Telescope at NSO/SP. Dr. Thomas Rimmele of NSO, as a research professor at NJIT, is the PI for the project. The high order AO system is based on the lessons learned from the successful low order one developed and made operational under the leadership of Rimmele. The NSO/SP system has already enjoyed a highly successful engineering first light. The BBSO high order AO system will be in regular operation in the middle of 2004, and it will greatly aid BBSO's high resolution observations, and BBSO's ability to complement/supplement scientific data from other ground-based solar observatories and from NASA missions.

E.3 Visible Light Vector Magnetographs

BBSO is now building the Visible light Imaging vector Magnetograph (VIM) – which will use the Fabry-Pérot – will utilize the DVMG experience. The DVMG is part of the Ph. D. thesis work of Tom Spirock. With the VIM, BBSO will be able to make much more accurate and higher resolution measurements of the evolving magnetic fields in flare-producing active regions. The VIM will reside on the 65 cm telescope (and later, the 1.6m new telescope), with its Fabry-Pérot filter providing the spectral line profile and the full Stokes vector when observing photospheric magnetic fields. This improvement will preclude Zeeman saturation where the fields are strong (in sunspots), and it will also provide filling factors for weaker fields. The VIM is designed to operate at the diffraction limit of the 65 cm telescope covering a substantial field of view (FOV) of about $180'' \times 180''$ (and $180'' \times 180''$ for the NST, as

well). In addition, by selecting an appropriate interference filter, any spectral line in the range from 5500 Å to 7000 Å can be studied. The high transmission of the system (no Lyot filter) will also allow real-time image reconstruction of narrow band (~ 100 mÅ) filtergrams so that we can study, e.g., the H α fine structure with high spectral, temporal and spatial resolution.

E.4 Infrared Vector Magnetograph

One anticipates the greatest benefit of IR polarimetry to come in the measurement of magnetic fields because the atomic Zeeman splitting is considerably larger in the near IR (Zeeman splitting increases quadratically with wavelength), so that one can make much more precise measurements of the field and its evolution.

BBSO has developed a narrow bandpass filter system, which combines a Lyot filter and an IR Fabry-Pérot filter – the IR Imaging vector Magnetograph (IRIM). A recent Ph. D. graduate, Jingshan Wang completed the design of the Lyot filter. This one-of-a-kind Lyot filter will have a bandpass of 2.5 Å at 1.56 μ m, giving us a 2.5 Å wide prefilter (narrower than the 5 Å free spectral range of the IR Fabry-Pérot). This will solve the longstanding problem of constructing a filter-based IR magnetograph, while avoiding the complications of using a double etalon. At this time, regularly operating, stable dual etalon IR systems do not exist. The new and unique Lyot prefilter would be used in conjunction with our IR Fabry-Pérot filter. Then, polarimetry in the near IR will have the same reliability and stability as it now has for visible light. Note that the IR Lyot filter system will have about 20% transmission. IRIM's total transmission is about a factor of two less than that of a dual Fabry-Pérot instrument. However, unlike a dual Fabry-Pérot system, with its quite restricted FOV, our system can utilize almost the entire FOV of the 65 cm or 1.6 m telescopes ($180'' \times 180''$). Finally, a new detector technology (CMOS de-

vices) offers high quantum efficiency, so that we can take individual exposures well within the correlation time in the near IR (~ 100 ms). We are presently obtaining a large format IR CMOS camera ($\sim 1K \times 1K$, 30 fps from Rockwell Scientific Imaging). The strength of the IRIM is its extreme sensitivity and high spatial resolution, which allows us to study weak and small-scale magnetic fields in the quiet sun.

E.4.1 Global H α Network

BBSO has successfully established a five station H α observing network at BBSO, Kanzelhöhe Solar Observatory in Austria, Catania Astronomical Observatory in Italy and the Yunnan and Huairou Observatories in China. All five stations use the same kind of $2K \times 2K$ cameras, each with a pixel resolution of 1 arcsec and temporal resolution of 1 minute. The data are processed with the software that we developed over the last two years. This allows us to monitor solar activity round-the-clock, including real-time reports of all flux emergences, filament disappearances and flares – facilitating our predictions of flaring for each active region.

E.5 Real-Time Speckle Imaging

One of the difficulties in our high resolution observations is that each set of images takes hours of processing to construct a single diffraction limited image, using speckle imaging techniques. This effectively limits us to a short observing day (~ 2 hour) because the controlling computer's disk is filled by storing all the raw data, so the chances are slim of obtaining a sequence containing the long term evolution of an active region and catching flares during the observations. BBSO has established a 32-node parallel computing cluster, so that one can do real-time speckle reconstruction with a cadence of about 1 minute, and diffraction limited images will be achieved all the time during the entire observing period. This work is the thesis

project of an NJIT Ph. D. student. The real-time data will allow us to measure flow fields, which will complement vector magnetograms. Among other uses, it will advance efforts to forecast solar storms.

E.6 Synoptic Observations and Space Weather Forecasting

Synoptic observations and research will continue to be one of the primary scientific objectives of BBSO. Accumulated synoptic data sets provide important archives from which one can determine the long-term variation of the solar radiation field and magnetic field. The data sets also provide important information elucidating the physics of the solar cycle. For our purposes, we need synoptic observations that are contemporaneous with our high resolution observations. We require both because the solar phenomena that we propose to study may well have a small-scale origin, but also have a large-scale manifestation.

Accurate predictions of solar activity are most important for the safety of satellites and the protection of power grids and communications systems.

At least once a day, BBSO now provides Solar Activity Reports, which are a visible light survey of active regions. When warranted, BBSO also issues a BBSO Solar Warning forecasting rapid development and/or energetic solar flares in individual sunspot groups. When a flare is predicted, the forecast is right better than 90% of the time, and flares are rarely missed. BBSO also provides daily activity reports to the operation centers of solar missions to optimize their solar targeting. In addition to posting the reports and warnings on the BBSO web site, the warnings are sent via electronic mail to about 400 people who have requested them. BBSO has also developed the Active Region Monitor (ARM) and Flare Prediction System (FPS). They describe the real-time status of

each active region.

The scientific objectives of IR polarimetry are straightforward: in the active regions, it allows us to measure the magnetic fields accurately, so that the 3-D structure can be extrapolated based on these measurements. Processes, such as magnetic reconnection, can be studied in detail by following the evolution of the 3-D magnetic structure.

F. FASR

Solar radio physics in the U.S. was once pursued at a number of universities, and included spectroscopic, radiometric, and interferometric instrumentation. However, since the 1980's the involvement of universities in solar radio instrumentation has declined steadily, with the closure of the Fort Davis spectrometers, the Clark Lake radioheliograph, and numerous other facilities. As a result, the Owens Valley Solar Array is virtually the only remaining solar radio instrument in the U.S., and the technology on which it is based is now 20 years old. However, there are encouraging signs that this decline is beginning to be reversed due to new initiatives led by the universities. The main driver is the development of the Frequency Agile Solar Radiotelescope (FASR) by a consortium of institutions including universities (NJIT, University of Maryland, and UC Berkeley), national observatories (NRAO, NSO), industrial partners (Lucent, PSI), and international partners (Obs. Paris, ETH/Zurich). The FASR facility will use state-of-the-art technology, yet is a sufficiently small in scope that universities can play a major role in its design and construction. FASR will be the World's premiere solar radio facility for at least two decades after completion. It is designed to exploit the power of radio diagnostics for the quantitative measurement of the 3D structure of the extended solar atmosphere, including coronal magnetic fields, the study of particle acceleration and transport in

solar flares, and the detection and measurement of Coronal Mass Ejections (CMEs).

In addition, our partners at NRAO and University of Maryland plan to design and build a spectrograph system based on an updated Phoenix II spectrometer (0.1-4 GHz) and a clone of the Bruny Island system (3-90 MHz), to provide a modern radio spectrograph for the U.S. that will give much needed context measurements to aid in the interpretation of FASR imaging data.

A third solar radio project is the Solar Radio Spectropolarimeter (SRSP) based originally on the Solar Radio Burst Locator (SRBL) instrument prototyped by Caltech for the U.S. Air Force. The SRSP, built at NJIT for (and located at) Bell Laboratories (Lucent Technologies) is a frequency-agile system that monitors the Sun from 1-18 GHz, and is used also for environmental studies as input to wireless communication technologies. It is now planned to build a version of this system for use in Antarctica, and similar systems are being discussed for sites elsewhere in the world (Canada and South Korea).

All of these projects have their genesis in U.S. universities, but they are being pursued in separate, small pieces and are potentially more costly and less effective due to lack of dedicated infrastructure. Just as important is the necessarily low involvement of students due to the uncertainty of the funding and the lack of an integrated training program. We note that the technologies themselves, although focused on a seemingly restricted target of solar research, encompass a wide range of the most rapidly advancing areas of technology, including high-speed digital circuitry, analog and digital signal processing, broadband optical/electronic signal transmission, and massive computing, storage and database management.

We propose to invest in the infrastructure and create an integrated undergraduate and graduate training program in needed technologies to

support the current and future needs of the solar physics discipline.

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