The scientific and educational environment sections of the University of Colorado's bid to host the Directorate Site of the National Solar Observatory:

Coupling Research and Education in Solar and Space Physics with the NSO in Boulder

Abstract

We propose that the headquarters of the National Solar Observatory (NSO) be relocated to the campus of the University of Colorado at Boulder (CU) and maintain close academic relationships with the departments of Astrophysical and Planetary Sciences (APS), Physics, and Aerospace Engineering Sciences (AES). We see the NSO headquarters consolidation in the context of one of the key challenges of the twenty-first century: developing a deeper understanding of the dynamics and magnetism of the Sun and its role in heliospheric variability in order to sustain a technological and exploratory presence in space. Boulder provides a vibrant environment for collaborative efforts towards this end. It is home to the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), and a large branch of the National Institute of Standards and Technology (NIST), as well as many smaller science organizations with active solar and space physics programs. The NSO would significantly broaden the solar capabilities of this unique research environment.

The benefits of NSO's relocation to Boulder extend beyond the significant research synergies anticipated. The fundamental mission of CU is education, and a vital component of that mission is the training of the next generation of solar and space physicists and engineers. It is here that there remains a critical gap in the nation's solar and space physics efforts, and in meeting this need the partnership between CU and the consolidated NSO headquarters can be transformational. To that end, CU is committed to significant faculty and fellowship augmentation to sustain its partnership with the NSO. Impact on students is the primary yardstick by which we measure the benefit of the presence of the NSO headquarters on the Boulder campus.

The Boulder area provides an attractive physical environment for the NSO. The proposed location for the NSO headquarters is a site within CU's East Campus Research Park, located a short 5-minute drive or 15-minute walk from the main Boulder campus. The site is adjacent to CU's Laboratory for Atmospheric and Space Physics (LASP) and Center for Astrophysics and Space Astronomy (CASA) institutes, which have similar physical space and infrastructure needs as NSO. Computational and data service facilities are similarly located in the research park ensuring high volume/speed internet connectivity. Convenient travel from CU to Maui and the rest of the U.S. minimizes logistical complexities for operation of the Advanced Technology Solar Telescope (ATST).

Our bid to host the NSO headquarters includes these key components:

- A synergistic research environment of diverse institutes (described in §2) offering a broad range of collaborative opportunities to NSO scientists in solar and space physics, astrophysics, data management and mining, and instrument design and engineering, including local aerospace expertise to bridge ground- and space-based capabilities.
- CU's commitment to significant academic augmentation (detailed in §4) to sustain an ongoing solar and space physics educational effort, including five new faculty lines (three full and two half appointments, the latter jointly with NSO), two new graduate student fellowships, one new postdoctoral fellowship, and the development of a Collaborative Graduate Education Program (CGEP) jointly with the New Jersey Institute of Technology (NJIT) and the University of Hawaii (UH).
- State of the art facilities and infrastructure including high-end space, laboratory, computational, and data management resources and support, available on a schedule meeting NSO's needs.

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1. Project Summary

The anticipated consolidation of most of the National Solar Observatory (NSO) scientific and technical staff at a single headquarters site, while simultaneously maintaining a key presence on Maui to support instrument development and telescope operations, should provide benefits which extend well beyond essential operational and management efficiency. The move, which entails significant disruption for the staff, should in the end enhance the NSO's scientific and technical capabilities, augment the broader solar and space physics community, and serve to increase the NSO's role in education and the promotion of workforce diversity. These goals are best met within a rich academic and technological environment with ready access to skilled engineers, scientists, and students, as well as essential hardware and computational lab resources. The University of Colorado at Boulder (CU) provides such an environment, and the campus is fully committed to helping make headquarters consolidation a successful endeavor for the NSO in the broadest sense.

1.1 Scientific and Educational Benefits to the Nation's Solar and Space Physics Efforts

We see the NSO headquarters move as an unprecedented opportunity for CU, the broader Boulder, national, and international solar and space physics communities, and the NSO to synergistically combine and focus their capabilities to meet one of the key scientific challenges of the twenty-first century, namely developing a deeper understanding of the dynamics and magnetism of the Sun as a star and its role in heliospheric variability in order to support a technological and exploratory presence in space.

1.1.1 Frontiers in Heliophysics

Following the onset of the space age, this century will likely see an ever-increasing technological and human presence in space, and continued and deepened societal dependence on these activities for functions as vital as telecommunications and transportation. The reliability of space-based technological systems and continued exploration will depend upon fundamental scientific advances in our understanding of the heliospheric environment and its short- and long-term variability in response to solar magnetic activity. These in turn will likely lead, over the coming century, to forecast capabilities in support of extended human activity, biological and/or technological, over vast regions of the solar heliosphere.

Central to those efforts will be detailed knowledge of the magnetohydrodynamical operation of the Sun, its radiative and particulate variability, and how these couple to planetary magnetic fields and atmospheres. The NSO's ATST will lie at the observational core of these scientific advances, hosting preeminent ground-based solar instrumentation for decades to come. This capability, combined with space-born instrumentation, petascale to exascale computing resources, and anticipated algorithmic developments in solvers, data assimilation, mining, analysis and visualization, will facilitate modeling advances on a scale heretofore unseen. The challenge will be to bring these resources and the scientists focused on them together to advance our understanding of what is fundamentally a cross-disciplinary highly-coupled nonlinear system, in the process transforming both our physical understanding and how that understanding is gained.

Similar critical advances were made over the past half-century in numerical weather prediction. These were facilitated by research support for individual scientists, groups, and graduate programs, as well as focused efforts at national centers such as the National Center for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration (NOAA). We suggest that the scientific synergies and educational opportunities accompanying a move of NSO headquarters to Boulder, if carefully anticipated, would similarly transform the national solar and space physics effort to meet critical needs of the twenty-first century.

1.1.2 Next Generation of Space Scientists and Engineers

Underlying this challenge is the urgent need to educate the next generation of solar and space scientists and engineers, and meeting that need has the strongest possible Boulder campus support. To that end, in conjunction with the NSO headquarters relocation, CU plans (§4.1) to augment its faculty with two joint (with the NSO) and three full faculty appointments, to be rostered in the Astrophysical and Planetary Sciences (APS), Physics, or Aerospace Engineering Sciences (AES) departments. One of the full appointments will be a three-year termed appointment to be successively and competitively filled by members of the broad solar and space physics community. This will provide significant ongoing opportunities to the community to bring leading developments, detailed experience and expertise, and fresh perspectives to bear upon the education of the next generation of solar and space physicists.

To cement the educational thrust, CU will award each year up to two 3-year graduate student fellowships and one 2-year postdoctoral fellowship to outstanding incoming candidates in solar and space physics. One of these positions will be specifically dedicated to solar instrumentation, a significant unmet educational need of the community. These investments will make ongoing contributions to the invigoration of solar and space physics education, with impact well beyond the headquarters relocation to the CU campus.

Additionally, we outline a Collaborative Graduate Education Program in solar and space physics (§4.2). This program, initially joint with New Jersey Institute of Technology (NJIT) and University of Hawaii (UH), will use high-definition telepresence technology to broaden the course work available to graduate students in the solar and space physics. The lectures will originate variously at CU, NJIT, and UH, be taught by faculty and scientists at the universities, NSO, the High Altitude Observatory (HAO) of NCAR, or the Space Weather Prediction Center (SWPC) of NOAA, and be accessible to both local graduate students, those at the partner sites, and those at Minority Serving Institutions (MSIs). We expect that these efforts will not only enable a sensible quorum of students and faculty for classes that may not be practical given a strictly local audience, but also enable research collaboration and co-supervision across institutions. We envision the program growing to include other interested universities in due course.

1.2 Benefits of Collocation to the NSO, CU, and the Boulder Community

1.2.1 Boulder Solar and Space Physics Environment

The Boulder community offers a vibrant high-tech environment in which to achieve the goals of the NSO headquarters move. HAO, a division within NCAR, is specifically devoted to solar-terrestrial research and modeling (§2.5). NOAA houses SWPC, which aims to both take research results and transform them into operational tools and focus research activities on the needs of operations (§2.6). In addition, Boulder is home to the nonprofit research institutes Southwest Research Institute (SwRI, §2.8) and Colorado Research Associates (CoRA), a division of NorthWest Research Associates (NWRA, §2.7), and the nonprofit public corporation Space Sciences Institute. SwRI focuses on planetary and solar physics, CoRA conducts basic and applied research in terrestrial atmospheric, planetary, and solar physics, while the Space Sciences Institute concentrates on planetary research and education/public outreach. Boulder is also the home of Ball Aerospace Corporation, a very successful space hardware company. Nearby communities along the Front Range host other large and small aerospace firms including Lockheed Martin Astronautics, Raytheon, and Boeing.

By establishing its headquarters at CU in Boulder, NSO would enter an exceptional research and teaching environment, with a wide array of opportunities for the staff and affiliated faculty members to collaborate with scientists and engineers both within and beyond CU in solar, astro, and space physics, and space weather research and applications.

The physical facilities anticipated for the headquarters include high quality office and laboratory space and computing and network connectivity, with significant potential for additional leveraged resources, including, for example, machine shop, clean room, and light feed capabilities. The CU environment provides high-caliber students at all levels eager for research and employment opportunities, and the geographic and cultural environment of the Colorado Front Range contributes to high retention rates for scientific, engineering, and technical staff.

1.2.2 NSO's Role in Coupling Research and Education

Given the facilities and organizations listed above, how would the NSO's coming here make a difference at CU and in the Boulder community?

Solar physics once had a stronger presence in many university faculties across the nation (CalTech, Stanford, Chicago, etc.) and at CU in Boulder. While CU has consistently maintained an active solar program for decades, there has been, here as elsewhere, some erosion of this faculty presence due to a shift in focus toward other research areas. At the same time, advances in both ground- and space-based observations, the consequent scientific explosion in helioseismology, ultraviolet and x-ray imaging, spectropolarimetry, and in situ particle and field measurements, and a new appreciation of the importance of solar variability to the space environment, has brought to the fore the critical need to train the next generation of scientists. This led the Solar and Space Physics 2003 Decadal Survey to recommend increased faculty support for solar and space physics programs. The NSF offered such support in the form of academic bridging positions, one of which resulted in a new faculty line in the APS department at CU. This, however, was just a first step in the rebuilding of a robust solar and space physics program at CU. In particular, attracting top quality graduate students and training of the next generation of solar and space physicists require meeting research and education needs at undergraduate, graduate, and postdoctoral levels. Class size constraints and faculty oversubscription make any subcritical academic program difficult to sustain. Engagement of the NSO staff in graduate student supervision, classroom lecturing, and research collaboration, both on campus and through the Collaborative Graduate Education Program we outline in §4.2, will contribute significantly to addressing these needs.

Moreover, the NSO has played a key role in the renaissance of solar physics in the past decades, and will clearly have a lead role with the ATST into the next decades. The staff's expertise in advanced instrumentation, synoptic facilities, data analysis and modeling, and education and outreach, ensure that the NSO headquarters move would bring new and unique capabilities to Boulder (§2.9). For example, NSO's leadership in ground-based instrumentation and instrument development would complement Boulder-area strengths in spacecraft hardware, and we envision a new faculty position and graduate student fellowship in solar instrumentation to support ongoing vitality in this critical area. Additionally, the NSO's research strengths in spectropolarimetry, helioseismology, radiative transfer, and others, would enhance and extend those ongoing in Boulder. Geographically close cross-collaborations, between solar and stellar astrophysicists, high-resolution solar observations and turbulence theorists, helio and asteroseismologists, adaptive optics and remote sensing instrumentalists, to name just a few, promise, through proximity, unique and otherwise difficult to sustain interdisciplinary efforts and advances.

By leveraging university/lab/industry synergies, the move of the NSO headquarters to the CU campus would: strengthen CU and the NSO scientifically and technically, transform the education and training of a new generation of solar and space scientists, forge links between unique ground- and space-based instrumentation capabilities, and advance our understanding at the frontiers of heliophysics.

2. Boulder Solar and Space Physics Community

The Boulder scientific community is involved in observational, modeling, data analysis, and theoretical efforts over a broad range of solar and space physics specialties. These include helioseismology of the Sun's interior, solar dynamo modeling, magnetohydrodynamic turbulence, chromospheric dynamics, solar radiative variability, coronal heating and reconfiguration, solar wind shocks, plasma processes in planetary magnetospheres, the chemistry and energetics of the planetary atmospheres, and others. Research activities are distributed over a range of institutions including university academic departments, government laboratories, nonprofit research institutes, and private corporations.

2.1 Boulder Solar Alliance (BSA)

To facilitate cross collaboration among these diverse efforts, the community formed the Boulder Solar Alliance (BSA) six years ago. We envision the NSO joining and playing an important role in this consortium, contributing substantially to its dual objectives of furthering new and existing scientific collaborations and harnessing the research environment in the service of solar and space physics education. The goal of the BSA is to advance solar and space physics objectives by fostering interactions between groups, supporting innovation, and pursuing local and national opportunities. To this end the executive committee of the BSA, which includes directors and senior scientists of NOAA's SWPC, NCAR's HAO, CU's Laboratory for Atmospheric and Space Physics (LASP) and JILA, SwRI, and CoRA, meets monthly. These meetings are an important venue for the exchange of information between institutions, the development of plans and programs fostering interactions between research groups, and the articulation of the advocacy objectives of the solar and space physics community at national and international levels.

The BSA also aims to bring the expertise and experience of research scientists in the region to bear on the education of the next generation of solar and space physicists. It is an active forum in an ongoing effort to refine the content of the solar and space physics program at CU across departments, as well as to facilitate research scientist involvement in the classroom. Overall, the BSA has proven to be a viable organizational model, enabling researchers to work across academic, government, and private institutions with minimal administrative overhead. Specifically, the BSA has been instrumental in supporting the LASP Research Experience for Undergraduates (REU) program and organizing an annual Boulder Solar Day workshop, which brings together 80 plus scientists from the Colorado–New Mexico–Arizona solar community to discuss current research and future collaborations.

2.2 University of Colorado in Host Role

The University of Colorado in Boulder (CU) is the lead organization in this bid to host NSO, and we are proposing to site the headquarters on the university campus, in close proximity to both laboratory and engineering facilities and academic activities. This environment will facilitate daily exchanges between the NSO and the CU community. Strengthening the proposed activities is the close geographic proximity of national laboratories, nonprofit research institutes, and private corporations. In addition, CU proposes a close partnership with the New Jersey Institute of Technology (NJIT) and the University of Hawaii (UH). They will play an important part in the development of a distributed Collaborative Graduate Education Program (CGEP) in solar and space physics. Both have a keen interest in this activity and have pledged resources toward this joint effort. We also envision broad future participation by other universities from across the country once the groundwork is in place, should this bid be successful.

The Boulder campus of CU is the flagship teaching and research campus of the state university system. Presently over 29,000 students are enrolled in its graduate and undergraduate programs. The campus is noted for the quality of its physical sciences departments. The National Research Council ranks CU Boulder's astrophysics and astronomy program (which includes planetary and space physics) among the top four to eight in the nation, its aerospace engineering department (which has a strong upper atmosphere component) as number one, and so too in first place is the Atomic, Molecular, and Optical Physics (AMO) program of the Physics department and JILA.

NSF ranks CU in the top five among public institutions in federal funded research, and places CU in the top ten among all research universities. CU Boulder ranks first among public institutions and third overall in NASA funding. In FY 2009, CU-Boulder received more than $420M in sponsored research funds with over $120M of that in space-related research. This success is partly linked to the Boulder campus system of interdisciplinary research institutes that support and encourage cross-departmental studies. Two of these institutes, JILA and LASP, are home to scientific groups engaged in solar and space physics research.

2.2.1 NSO Site in Close Proximity to LASP

We propose that the NSO be housed in close physical proximity to LASP, thereby enabling convenient use of some technical facilities (such as clean rooms and precision machine shops, as needed). LASP, as a research entity, covers the fields of solar and space physics most broadly on campus, with the largest concentration at CU of tenure and research scientists in the discipline. Research efforts include planetary and atmospheric science, magnetohydrodynamic (MHD) modeling, solar influences on the terrestrial atmosphere and climate, and space plasma physics. LASP has over 350 professional staff and over 160 student employees. Students are involved in many aspects of LASP's activities, ranging from instrument design to data analysis to mission operations. Of the professional staff, about 70 are PhD scientists and of those, 16 are tenured or tenure-track faculty members. Seven of the faculty are in the solar and space physics disciplines; four (Baker, Bagenal, Ergun, Rast) are rostered in APS, two (Li, Sternovsky) in AES, and one (Horanyi) in Physics. LASP currently supports over 40 PhD students, with about 10 pursuing research in solar and space physics.

LASP has a long history of involvement in solar and space physics missions, such as in building and operating some of the primary instruments on the OSO-8 and SMM missions focused on the Sun, emphasizing UV spectroscopy. The latest solar instrument is the Extreme Ultraviolet Variability Experiment (EVE) on the recently launched Solar Dynamics Observatory (SDO). LASP is currently building flight instruments for the Radiation Belt Storm Probes mission, the LADEE mission to the Moon, the Mars Atmosphere and Volatile Evolution (MAVEN) mission to Mars, the GOES-R mission, and the Total Solar Irradiance Sensor. In pursuing space-based assets, LASP has worked closely with ground-based observations to establish broad wavelength solar coverage that is calibrated with care.

2.2.2 Participating Role of JILA

JILA (formerly the Joint Institute for Laboratory Astrophysics) is a physical science institute operated jointly by CU Boulder and the National Institute of Standards and Technology (NIST), with a focus on fundamental physical processes that have bearing on astrophysics, atomic and molecular physics, chemical physics, biophysics, optical physics and precision measurements. Sited on the CU campus, about half of its senior staff of 29 fellows comes from the Quantum Physics and the Time & Frequency divisions of NIST, and the other half from five CU departments, including APS and Physics. There are about 50 postdocs and 110 graduate students working within JILA, leading to an overall staff size of about 240. JILA is prominent in the study of the interaction of light with matter in many guises, with this leading to the award of three Nobel prizes in physics in the past ten years, two MacArthur fellowships, and to seven of the fellows becoming members of the National Academy of Sciences.

The astrophysicists within JILA (Armitage, Begelman, Hamilton, Hindman, Linsky, McCray, Perna, Toomre), also holding appointments in APS, work on diverse aspects bridging stars, galaxies and cosmology. The research by Hindman, Linsky and Toomre has concentrated on solar and stellar physics, including radiative processes and line formation in stellar atmospheres, helioseismology, and magnetic dynamo and convection theory. Thus NSO and JILA have close working relations on the GONG project and keen overlapping interests in the high-resolution observations of the magnetic and dynamic structures to be studied with ATST. Given that other JILA scientists have major interests in adaptive optics, nanotechnology, stabilized laser systems, and frequency standards, we foresee a range of possible interactions between NSO and JILA.

2.2.3 Participating Role of AeroSpace Initiative

The AeroSpace Systems Science and Engineering Initiative (AS^3E) at CU is a cross-disciplinary campus-wide enterprise. The participating campus units are AES, APS, the Cooperative Institute for Research in the Environmental Sciences (CIRES), the Institute of Arctic and Alpine Research, and LASP. Its broad goal is to integrate efforts now spread across these units to address major science and engineering challenges such as the changing Earth climate system and technological survivability in the harsh geospace environment. Its primary emphasis is to focus the development and engineering of aerospace vehicle-sensor systems toward the solution of these challenges, thus explicitly integrating aerospace engineering with earth and space sciences. Led by the AES department, this effort has a significant space weather component. Its engineering thrust complements and bridges the solar and space weather science research goals of APS and LASP and the forecast needs of SWPC, while its focus on space science sensors and remote sensing make it of direct relevance to advanced instrumentation.

2.3 New Jersey Institute of Technology (NJIT) Partnership Role in Bid

The partnership between the New Jersey Institute of Technology (NJIT) and CU significantly strengthens this bid to host NSO. NJIT operates the Big Bear Solar Observatory (BBSO), including the New Solar Telescope (NST), a 1.6 m off-axis instrument that is currently the world's largest aperture solar telescope and a prototype for the ATST. The NST is the ideal telescope to provide the solar community leading-edge observations in the interim between the phase-out of current NSO facilities and full commissioning of the ATST, and the partnership forged through the NSO headquarters move will couple this capability directly to that transition. The BBSO is already collaborating with the NSO in building multi-conjugate adaptive optics hardware and a fully cryogenic near infrared spectrograph for the NST. Both of these instruments will be unique and provide guidance for downstream ATST instrumentation. BBSO's experience with the NST, coupled with CU's experience with space missions, will provide a unique collaborative environment for future instrument development and potential insight into technical management issues for the NSO with ATST. Moreover, NJIT shares with NSO and CU a deep commitment to the education of the next generation of solar and space physicists. The training of new solar astronomers and instrumentalists will benefit tremendously from direct NST access.

NJIT has several faculty members who teach graduate/advanced courses that will broaden curricular offerings in the new Collaborative Graduate Education Program in solar and space physics proposed as part of this bid. These faculty are rostered in the Center for Solar

Terrestrial Research (CSTR) at NJIT. The primary mission of the CSTR is to observe and model the solar system environment from the Sun to the Earth. To achieve this goal, CSTR operates several significant and unique ground-based facilities, including BBSO, the Owens Valley Solar Array, and Automated Geophysical Observatories across Antarctica. CSTR faculty are also involved as co- or principal investigators of space projects. CSTR membership has grown to six senior faculty, including five regular faculty (Cao, Gary, Gerrard, Goode, and Wang) and one research faculty member (Lanzerotti). Lanzerotti and Gerrard bring a strong near-terrestrial component to CSTR, giving NJIT a group whose studies span the regime from the Sun to the Earth. CSTR has 15 PhD researchers (nine in Newark and six at BBSO). Additionally, NJIT will be hiring a new faculty member with expertise in ground-based solar observations as part of this effort.

2.4 University of Hawaii (UH) Partnership Role in Bid

The Institute for Astronomy at the University of Hawaii (UH) has a total of about 350 scientists and staff on three different islands. There are six PhD faculty and staff, four post-docs, and three graduate students pursuing solar studies. The Haleakala observatory is one of the longest running university solar observatories in the country, and continuing its tradition for producing experimental and instrumental scientists is an important goal of the IfA in Manoa and Maui. The IfA on Maui and its Advanced Technology Research Center (ATRC) is the heart of the solar instrument program. The 14000 sq. ft. ATRC has about 5000 sq. ft. of instrument laboratory space and $4M of research equipment infrastructure. The ATRC is a focus for the design, development, and testing of advanced remote sensing optical and infrared instrumentation. For example, $5M of first-light ATST optical and IR instruments are now under development, while 5 other optical and IR instruments are currently in various stages of development at the ATRC. The IfA/Maui is the local host for the ATST and is a strong partner with the NSO in the conceptual design and completion of the ATST. The IfA plays a leading role in the development of ground-based optical and infrared spectropolarimetry for solar and stellar studies. The IfA also has a significant stake in large optical telescope for nighttime studies of other Sun-like stars. On Haleakala the IfA controls 10 percent of the 3.7m AEOS telescope, and operates the 2m PanSTARRS system. New nighttime telescopes like the off-axis PLANETS 2m and the 1m Harlingten telescopes will be available for stellar studies before ATST first light.

UH is committed to a partnership with the NSO headquarters host institution independent of the final headquarters bid outcome. Partnership with CU provides significant research and educational opportunities. Research areas of common and complementary interest at the two universities include the interface between solar and stellar astrophysics, solar and stellar spectropolarimetry, the environments of young stellar systems, and the environments of extra-solar planets. These all will potentially benefit from future ATST observations, and collaborative study in these areas will extend the impact of discoveries made about the Sun by including broader astrophysical implications.

UH has a strong interest in extending the scientific and educational impact of the NSO's operations in Hawaii well beyond caretaking of the ATST and its data on Maui. To that end the collaboration with CU focuses on integrating collaborative research projects and education through the proposed Collaborative Graduate Education Program in solar and space physics. In support of these goals, IfA expects new solar/stellar faculty positions. The IfA/Maui has also expanded its teaching role to include the new UH Maui College Engineering technology program, thereby bringing the local Maui UH program into the fore as a 4-year college and positioning IfA/Maui as a strong local partner in both research-oriented and broader-education and workforce development initiatives.

2.5 High Altitude Observatory (HAO) as Asset in Boulder

The High Altitude Observatory (HAO) of NCAR conducts fundamental and applied research in solar physics and solar-terrestrial interactions, designs and builds instrumentation for solar and upper atmosphere observations, and operates the Mauna Loa Solar Observatory on Hawaii. HAO and the NSO share a history of collaboration spanning several decades. Most notable is the joint work that has enabled NSO to provide the solar community with cutting-edge instrumentation for spectropolarimetric observations of the solar atmosphere. These efforts are ongoing, with HAO contributing critically to the definition of the ATST polarization package and responsible for the design, construction, and deployment of the Visible Spectro-Polarimeter (ViSP) focal plane instrument. HAO is deeply involved in the development of community inversion codes for polarimetric data, to infer the magnetic and thermodynamic structure of the solar atmosphere from the data. Several of these codes are currently being used to process data from the Spectro-Polarimeter for the Infrared and Optical Regions (SPINOR) operating on the Dunn Solar Telescope, and it is expected that they will evolve into a critical suite of data handling tools for the ATST.

In addition to instrumentation projects, HAO and NSO have a long history of collaboration on the scientific interpretation of solar observations through the interplay between forward modeling and data analysis. These have included comparisons between forward modeled subsurface flows and those inferred from GONG helioseismic data and are being extended to detailed modeling of active regions. Recently HAO has made substantial progress in MHD modeling of sunspots. Computer simulations have been advanced to the point where they provide a consistent picture of sunspot fine structure and the origin of the Evershed flow. The models have reached a degree of realism at which direct comparison with the wealth of high-resolution spectropolarimetric observations is meaningful and necessary for progress. Recently, collaboration along these lines was established between NSO and HAO, and even closer collaboration on a day-by-day basis may be required once high-resolution data from ATST is available. This would allow 3-D MHD simulations to be used in conjunction with high-resolution observations to provide a consistent picture of the subsurface flows and magnetic structures via data assimilation and guided simulation.

HAO is committed to collaboration with and support of the NSO and the headquarters host institution independent of the bid outcome. Collaborations would benefit through geographical proximity should that location be at CU. As an example, there is a long-standing collaboration between HAO and CU in efforts to understand the physical origin of solar spectral irradiance variations and their influence on the Earth's upper atmosphere. LASP-led space missions make high accuracy measurements of the solar disk integrated irradiance. These are combined with magnetic structure information provided by HAO's Precision Solar Photometric Telescope (PSPT) full-disk imagery. Those facilitate interpretation of the variations and allow synthesis of the solar spectral output. That in turn or the measurements directly, particularly at ultraviolet wavelengths, can be used in models of the upper terrestrial atmosphere developed at HAO. Future incorporation of high-resolution ATST observations to understand and model variance at sub-pixel-resolution would further refine our understanding and bring the NSO in as a third partner. This is just one example of the type of cross-institutional cross-disciplinary synergistic activities that can be achieved quite readily with geographic co-locality.

2.6 Space Weather Prediction Center (SWPC) as Asset in Boulder

The Space Weather Prediction Center (SWPC) of the NOAA uses solar and space physics understanding and observations to prepare and disseminate the nation's official space weather forecasts. With the rest of the National Weather Service, SWPC is a component of the National Critical Infrastructure system designated by the U.S. Department of Homeland Security. SWPC leverages the extensive pure and applied space science research and development supported by the NSF, NOAA, NASA, and the DoD. Transitioning research models and data streams into operations is a cornerstone of SWPC's program.

NOAA is exploring an initiative to develop a Space Weather Prediction Testbed that will work closely with the Community Coordinated Modeling Center, the Center for Integrated Space Weather Modeling, and the Air Force Research Laboratory to ensure the timely transfer of products and services from research into operations. SWPC now uses NSO data from GONG and SOLIS in its daily operations. When ATST observations enable good forecasts of flares and CMEs, SWPC will take advantage of those capabilities to better predict the timing and severity of events, such as flares, energetic particle increases, UV pulses, and coronal mass ejections, which cause space weather effects. The high-speed, multi-fiber Boulder Research Area Network (BRAN) links CU, NOAA, and NCAR, so that SWPC can easily receive all the NSO available data it requires for operational use and to refine and verify its models, enabling improved predictive capability in support of SWPC's primary mission. It can be anticipated that SWPC's desires for improved forecasts may influence targeted observation opportunities for the ATST. SWPC is the single place in the nation where solar physics is put to operational, economically important use. SWPC's practical operations complement and intertwine with the Boulder area's current strengths in space-based solar observations, theory, and modeling. They will do the same with NSO's ground-based solar science.

2.7 Colorado Research Associates (CoRA) of NWRA as Asset in Boulder

Colorado Research Associates (CoRA), a division of NWRA, has international research collaborations in helioseismology, magnetic structure and dynamics of active regions, mechanics of solar flares, diagnostics of large- and small-scale flows, space-weather, and space-weather forecasting. These programs tend to be highly interdisciplinary. Examples include the application of helioseismic techniques and data resources to the study of solar flares, and helioseismic imaging of activity on the Sun's far hemisphere and its use in solar irradiance forecasting. In both of these endeavors NSO/GONG collaborates intimately with NWRA and other institutions. Scientists at NWRA have long histories of interaction and collaboration with scientists at NSO. The proximity of NSO after relocation to Boulder will significantly benefit future collaborations via enhanced sharing of local resources and the facilitation of informal discussions, workshops, and seminars through which scientific collaborations prosper.

NWRA scientists have mentored undergraduate and graduate students of the NSO and other educational institutions in projects ranging from summer research assistantships to PhD theses. NSO attracts highly talented and motivated students from all over the world, and NSO's presence in Boulder would greatly facilitate the involvement of interested NWRA scientists with students working at NSO to the benefit of the NSO, scientists at NWRA, and the students.

2.8 Southwest Research Institute (SwRI) as Asset in Boulder

Southwest Research Institute (SwRI) is a not-for-profit company with roughly 3500 employees based in San Antonio, Texas, and an office in Boulder with roughly 60 scientists, engineers, project managers, and support staff. The SwRI/Boulder office has an active Solar Physics Group with leaders in the field of solar UV spectroscopy, magnetic feature tracking and modeling, and white light coronal studies. The underlying scientific theme of the group is understanding how the Sun produces its magnetic field and how ongoing changes in the surface magnetic field give rise to space weather effects throughout the heliosphere. Researchers engage the full range of activities, instrumentation to modeling, in pursuit of this goal.

Understanding the dynamics of magnetic field evolution on the Sun requires instrumentation that can extract information from the solar spectrum quickly and with high spatial resolution. SwRI/Boulder is involved with two prototype instruments – SHAZAM and RAISE – which take quite different approaches to measuring the solar spectrum. RAISE is an ultraviolet imaging spectrograph and SHAZAM is a high-speed Doppler magnetograph. RAISE looks toward future spacecraft instrumentation while SHAZAM provides proof of concept development and testing for a possible future ATST focal plane instrumentation. SwRI/Boulder researchers have also developed software algorithms to identify and track hundreds of thousands of magnetic features on the surface of the Sun simultaneously, determining their motion and history as they interact with one another. This software is currently being deployed as part of the data pipeline for NASA's Solar Dynamics Observatory, and will be used to identify new emerging flux regions on the Sun, with potential implications for space weather prediction. Complementary efforts use novel modeling techniques ("fluxons") to study solar magnetic field evolution particularly that relevant to understanding the magnetic instabilities underlying coronal mass ejections.

2.9 NSO's Unique Role in the Boulder Solar and Space Physics Community

The NSO headquarters move would bring a new and unique set of capabilities to Boulder that augment and extend existing strengths, allowing coordinated efforts to address key outstanding problems in heliophysics and key educational needs of the broader community. For example, the NSO's experience with a wide-array of ground-based solar instrumentation and long-standing instrument development expertise would complement the Boulder-area strengths in space-based solar observations. Through its REU, Summer Research Assistantship (SRA), and graduate student and postdoctoral fellowship programs, NSO is a well-established leader in the training of instrumentation scientists. These efforts couple well to ongoing instrumentation efforts in the APS and AES departments at CU, ranging from CubeSat and Space Grant Consortium activities at the undergraduate level to graduate student solar and astrophysical sounding rocket investigations. At least one-third of the APS faculty have primary or strong interests in instrumentation, and an expanded undergraduate and graduate instrumentation emphasis supported by a joint faculty position may be a key activity.

Other NSO critical scientific expertise includes spectropolarimetry, radiative transfer, and helioseismology, among others. These extend, augment, and enhance Boulder area efforts. The NSO's internationally recognized Adaptive Optics program is complementary to Boulder-area expertise and would add a very significant capability to the region's technical portfolio. The upcoming ATST diffraction-limited observations of the solar photosphere and polarization-limited observations of the corona, at resolutions unachievable by space born instrumentation in the near foreseeable future, have implications extending well beyond local small-scale solar dynamics and processes, and would couple well to ongoing efforts in Boulder to understand global processes including the dynamo, irradiance, and coronal reconfiguration. These processes ultimately depend on dynamics and properties of very small-scale fields and flows on the Sun, and successful modeling of global processes requires understanding the implications of small-scale contributions. The NSO's concerted efforts in high resolution solar physics will thus provide the scientific underpinning to the global scale observations and models that can be used to forecast heliospheric variability.

Establishing the NSO headquarters in Boulder would bring scientific expertise, augmentation and extension of solar and space physics educational efforts, and enhanced opportunities for CU/NASA/NSF/NOAA/industry research partnerships. These are all necessary to effectively span the range of scientific activities needed in the study of solar and space physics, train the next generation of solar and space scientists and engineers, and transform individual efforts into synergistic advances in fundamental interdisciplinary science with operational impact. They would also serve to enhance NSO's national and international scientific leadership.

3. Current Solar and Space Physics Education at CU

The NSO would find a vibrant academic environment at CU, rich in collaborative opportunities to train the next generation of solar and space scientists. It would find unique opportunities to substantially enhance an academic program in astrophysical sciences, which started with the department of Astro-Geophysics and HAO at CU in the 1950s, was substantially broadened with LASP and solar and planetary missions in the 1970s and onward, and continues to evolve into maturity, covering much of astrophysics currently. NSO collaborations and joint appointments within CU's Astrophysical and Planetary Sciences (APS), Physics, and Aerospace Engineering Sciences (AES) departments would sustain important solar physics connections to both astrophysics and space weather applications, and bridge these disciplines.

3.1 Strong Graduate and Undergraduate Programs

Several CU Boulder departments are involved in solar and space physics, and relevant courses are currently taught across several departments at both the undergraduate and graduate level. These departments include:

- *Astrophysical and Planetary Sciences (APS)*: which houses both astrophysicists and planetary scientists, including solar and space physicists, a group with diverse interests and talents including observers, theorists, and instrumentationalists. The faculty are affiliated with the research institutes LASP and JILA or the Center for Astrophysics and Space Astronomy (CASA). Solar and space physics faculty members include Daniel Baker (space instrument design and calibration, space physics data analysis, and magnetospheric modeling), Fran Bagenal (magnetic fields and plasma environments of solar system objects mainly Jupiter, the Sun, other planets, comets and asteroids), Robert Ergun (space and astrophysical plasma studies), Mark Rast (solar convective dynamics and scale selection, turbulence, the excitation of the solar p-modes, and the origin of solar/stellar irradiance variations), and Juri Toomre (astrophysical fluid dynamics, with particular emphasis on nonlinear theories for compressible convection and dynamos in stars and helioseismology). The APS undergraduate program is now the largest in the nation, with two emphases, astronomy and astrophysics, and over 150 undergraduate majors. The National Research Council ranks the APS graduate program among the top four to eight in the nation.

- *Physics:* covers all branches of physics, and is home to the Center for Integrated Plasma Studies (CIPS). CIPS faculty includes John Cary (beam/accelerator physics, plasma physics, nonlinear dynamics, and computational physics), Martin Goldman (theoretical plasma physics and nonlinear dynamics), Mihaly Horanyi (dusty space and laboratory plasmas), Scott Parker (theory and simulation of plasma turbulence and transport, kinetic particle effects), Scott Robertson (laboratory dusty plasma experiments, ionospheric and space plasmas), and Dmitri Uzdensky (collisional and collisionless magnetic reconnection, solar corona, astrophysical accretion disk coronae). The National Research Council ranks the Physics department’s program in Atomic, Molecular, and Optical Physics (AMO) as top in the nation.

- *Aerospace Engineering Sciences (AES):* a leader in the training of future aerospace workers, AES has a graduate option in “Space Environment”. Faculty include Xinlin Li (dynamics of Earth's space environment, particularly in the magnetosphere), Jeffrey Forbes (theoretical dynamics and electrodynamics of Earth's mesosphere and lower thermosphere and ionosphere), and Jeffrey Thayer (upper atmosphere dynamics). The National Research Council ranks the AES program with its strong upper atmosphere component as number one in the nation.

Solar researchers from the broader Boulder science community have significant opportunities for graduate student mentoring, and the NSO staff will share in these opportunities. For example, over the past five years HAO and SWRI scientists have co-mentored with CU faculty 8 graduate students. A current focus of the CU Graduate School is meeting the computational challenges of the twenty-first century through the education of computational scientists. The university, as part of its strategic plan, is in the midst of implementing a cross-disciplinary cross-departmental initiative in Interdisciplinary Computational Science and Engineering (ICSE), which involves new faculty in departments across the campus. APS, Physics, and AES are all enthusiastic participants. The initiative has as its goal the increased effectiveness of computational science education across disciplines, and will be offering a range of graduate degrees. Both computational modeling and data access and visualization are strong components of this initiative, and thus it overlaps NSO's interests. Moreover, CU has major experience with prior Integrative Graduate Education and Research Traineeship (IGERT) programs funded competitively by the NSF, and we foresee organizing new IGERT efforts which leverage NSO capabilities and bridge APS, Physics, and AES faculty in solar and space physics.

Boulder scientists are also very committed to undergraduate solar and space physics education. As part of that program, a solar and space physics course is offered which aims to not only introduce the phenomenology of the heliosphere, but to use it as a context within which to illustrate the application of essential junior/senior level physics. NSO scientists, both those jointly and those singly appointed, would be welcome to teach parts of or that entire course. Development of new curricula, in for example solar observation, instrumentation, or modeling, would also be very welcome, and provide an opportunity to adapt and integrate material from NSO's Summer School in Solar Physics and Research Experience for Teachers (RET) programs into new or existing undergraduate classroom and laboratory course work. These efforts would address the needs of both the APS department's Astronomy (often K12 teaching bound) and Astrophysics (often graduate school bound) track students.

3.2 Research Opportunities for Undergraduates

Undergraduate education through research opportunities is a significant emphasis of the Boulder solar and space physics community. Not only are student employees involved in a wide range of projects (LASP currently has 80 undergraduates on its payroll working on projects ranging from instrument design to data analysis and mission operations), but the research experience is seen as an essential component of undergraduate education. Over the last four summers, the LASP run Research Experience for Undergraduates (REU) program in Solar and Space Physics has given 56 students (36 male, 20 female, 10 under-represented) an eight-week (1 classroom, 7 research) experience. Involvement beyond CU and LASP is critical to this endeavor. The BSA plays a role in scientific mentoring, with mentors from all member institutions involved; the four-year mentor totals (23 from LASP, 17 from HAO, 9 from NOAA, 4 from CoRA, and 3 from SwRI) reflect the number of staff scientists at the institutions. Future opportunities for both the LASP and the NSO, after the headquarters move, offer the possibility to redefine undergraduate programs as either expanded single or joint dual efforts, or some combination of these, in solar, space physics, and terrestrial impacts. The combination of NSO/BSA expertise would likely yield programs of unprecedented scope and quality.

Beyond the REU, undergraduates of all academic skill levels within the APS department at CU have a passionate desire for research experience. Some have GPAs below what is needed to be readily considered for admission into REU or graduate programs, or are not on a research scientist track, yet a research experience for these students provides a hands-on appreciation of, not only what research is, but how difficult meaningful scientific results are to attain. This experience may be particularly valuable for future K12 educators. To this end, a trial undergraduate research program was undertaken over the Spring 2010 semester. In short, 18 students were given the opportunity to conduct paid research while being simultaneously enrolled in classes. Mentors drawn from the APS teaching and research faculty individually supervised the students. Nearly all students and mentors responded to the experience positively. Concurrently, within LASP an NSF funded career-advising program, "Beyond Boulder," has been very successfully developed. The APS department is seeking ways to combine efforts into a single more permanent program that would include recruiting efforts, active mentoring to increase retention, particularly in the freshman and sophomore years, a research semester opportunity, and career advising, all with the aims of both enriching the undergraduate major experience and increasing the number of under-represented students entering the field. Collaboration with NSO and other Boulder-based solar and space physics institutions will be essential in making this happen, both for content and mentor participants.

3.3 Promotion of Workforce Diversity and Broadening Participation

The Boulder solar and space physics community has significant involvement in efforts to broaden the participation of under-represented groups in science and mathematics. NCAR runs an internship program Significant Opportunities in Atmospheric Research and Science (SOARS) that matches 20 undergraduate students with mentors in solar and atmospheric science for a 10-week research program for up to four summers. Since 1996, 129 students have participated in SOARS and with over 90% having gone onto graduate school, and the programs achievements were recognized through a Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring in 2001.

As part of the Colorado Diversity Initiative in science, math, and engineering, CU has a similar SMART (Summer Multicultural Access to Research Training) program covering a broader range of scientific disciplines including physics, astrophysics, and aerospace engineering, with a focus on scientific writing and oral presentation skills as well as research. It offers about 25 students per year a ten-week opportunity to conduct research under the guidance of a faculty mentor, present their projects, and participate in work-shops designed to strengthen their preparation for graduate school. Both the NCAR and CU programs would welcome and benefit from mentor participation by the NSO staff.

We have keen interest in broadening the base of students pursuing solar and space physics. The LASP REU program actively recruits students from under-represented and under-served groups, with some success (10 of 56 students so far). We foresee working closely with the NSO, building on its and our successes, in devising new strategies. Enabling Minority Serving Institution (MSI) participation in the new Collaborative Graduate Education Program (CGEP) is one proposed avenue (§4.2.1).

3.4 Educating K12 Science Teachers and Outreach to K12 Students

Another area of real synergistic potential is that between CU's Learning Assistant (LA) program, the APS department's Astronomy major emphasis, and NSO's Research Experience for Teachers (RET) program. The LA program trains talented undergraduate science majors interested in K12 teaching by pairing them with science faculty interested in the preparation of future teachers to create interactive environments in large-enrollment classes within which the students engage in collaborative problem solving. The LAs are hired to facilitate small-group interaction in large-enrollment courses, transforming undergraduate education and science teaching. LAs who decide to pursue a K12 teaching license are eligible for scholarship support. The Physics and APS departments at CU use LAs in their large introductory courses, and Physics has extended their participation to more advanced classes. The APS major has two tracks, one in Astronomy and one in Astrophysics. The Astronomy track is particularly intended for students more interested in K12 education than graduate school after graduation, and so couples tightly with the LA opportunity.

The research/inquiry-based teaching promoted by the LA program has similar goals to NSO's RET program. While the first aims at teacher training and the later addresses K12 teacher professional development after graduation, both strive to increase the effectiveness of K12 science education. As credentialed teachers in most states have ongoing professional development requirements, continuity between these efforts could have transformational benefits. The K12 educator trained as a LA could take back, as part of their professional development requirement in later years, state-of-the-art research experience gained in NSO's RET program, and communicate those experiences to their K12 students using the foundations of research/inquiry-based teaching laid in the CU LA program. While this is already possible across these programs, geographic co-locality would enable the programs to evolve in synch, each benefitting one from the other through close communication.

CU is committed to direct outreach to K12 students, through programs at institutes including LASP, the campus planetarium and museum, and individual departments. This is combined with a campus wide initiative to transform the K12 math and science education through course and curricular assessment and teacher preparation. A new program on campus, called Integrating STEM (iSTEM, Integrating Science, Technology, Engineering, and Math Education at Colorado), is a 5-year initiative to establish the CU as a national hub of STEM education research aimed at transforming STEM education methodologies using discipline-based education research. An early component, the implementation of CU Teach, which is a streamlined math and science teacher education program, is meeting with very strong and positive responses and has been nationally recognized as a model of teacher workforce preparation.

4. Proposed Educational Augmentations

CU is committed to a significant enhancement of its solar and space physics educational investments across departments, in concert with the NSO headquarters move onto campus.

4.1 New Faculty and Fellowships

With a broad aim to contribute to the overall health of solar and space physics nationally, these commitments include sustained fellowship and multi-year faculty opportunities as well as tenure-track positions.

Specifically, CU is committed to:

- Five new faculty lines (three full and two half appointments, latter jointly with NSO) in solar and space physics, all with open competitive searches to fill the positions. Some searches will initiate prior to the NSO headquarters relocation so that the appointments coincide with the move. Others will follow in the early years after relocation. Three of the positions will be full appointments by CU; the remaining two will be split, half by CU and half by NSO. It is expected that the appointments will be rostered in one of three academic departments, APS, Physics, or AES, depending on the appointee's primary academic interests, with an additional cross-disciplinary research institute affiliation.

- One of the full appointments will have a three-year term, to be competitively and successively filled by members of the broader solar and space physics community. This offers opportunities for community members to bring their expertise into the university environment. We envision that this appointee will not only engage in NSO/CU research collaborations, teaching, and academic mentoring, but will co-direct the new Collaborative Graduate Education Program we outline below. They will be expected to engage broadly with the Boulder solar and space physics community, outlining their plans at the time of application. We anticipate that the position will appeal to a diverse range of scientists: early career scientists eager to gain experience or later career scientists interested in sharing their experiences with students. Such a resource investment extends the impact of the headquarters move geographically and temporally, making a significant contribution to solar and space physics beyond Boulder.

- The other four appointments (two full and two half) will be tenure track positions to be filled in open academic searches conducted by CU with significant NSO involvement. It is anticipated that these appointments, along with the current faculty, will consolidate a major campus thrust in solar and space physics. They will be involved in all aspects of research and teaching from general education core science requirements at the lower division undergraduate level, through upper division undergraduate course work and research experience, to graduate student supervision and instruction. The new faculty will augment current cross-departmental interests and expertise in instrumentation, theory, modeling, and data analysis, bringing them to bear on the research challenges of solar and space physics and the training of the next generation of solar and space physicists. An example area of keen immediate interest is astronomical instrumentation, to which a joint appointment could contribute strong synergistic linkages between the NSO, APS, and AES, coupling current NSO ground based instrumentation and campus efforts, which include a strong graduate-student sounding-rocket program, expertise in space craft instrumentation and remote sensing, and undergraduate involvement in

LASP engineering, mission operations, CubeSat projects, and the Colorado Space Grant Consortium.

- To broaden the educational impact of the NSO headquarters move and contribute to the reinvigoration of solar and space physics education and the training of the next generation of solar and space physicists, CU will award each year up to two 3-year graduate student fellowships and one 2-year postdoctoral fellowship to outstanding incoming candidates in solar and space physics, solar astronomy, or instrumentation, with one of these positions specifically dedicated to solar instrumentation, as this is a significantly unmet educational need of the community. The fellowship holders will have a primary home in one academic department, but will engage in cross-disciplinary research with interdepartmental or inter-institutional supervision.

Additionally, CU will:

- Make adjoint appointments to NSO scientific and engineering staff to facilitate collaboration, teaching, and mentoring.
- Expand honorarium teaching by members of the broader Boulder solar and space physics research community, particularly at the graduate level. This is especially important for broad Boulder solar and space physics community involvement in teaching.
- Support efforts to define a joint solar and space physics graduate curriculum between CU, NJIT and UH, to leverage existing and future human and facility resources by utilizing innovative distributed learning methods and technologies.

These educational commitments aim to benefit the future health of the US solar and space physics community. The NSO, its staff and assets, will play an important role in that future. The ATST will be the world's premier ground-based solar telescope, and the headquarters move to Boulder would couple that capability, and the synoptic capabilities of GONG and SOLIS, to the Boulder community's strengths in theory and modeling and mission oriented space-based observations, adding a state-of-the-art solar astronomy program and an historically outstanding heritage in the training of instrument scientists. The proposed educational resource additions, detailed above, would help bring the unique NSO resources to bear on the education of the next generation of solar and space physicists, at a time when space weather forecasting is playing an increasingly important role in protecting space assets and the training of young scientists in this area is most critical. CU recognizes this importance, as well as the broader astrophysical implications of understanding the magnetism and dynamics of a star like the Sun, and is committed to the material support outlined above.

4.2 Collaborative Graduate Education Program (CGEP) in Solar and Space Physics

The gradual decrease within our nation of faculty positions centered on solar, stellar, and space physics has largely come about because of strong pressures in many astronomy and astrophysics departments to explore new research areas that have blossomed over the past three or four decades. Stars and their evolution seem to be quite well understood when compared to other objects such as quasars, neutron stars, supernovae, dark matter, or the large-scale structure of the universe. Thus there has been noticeable erosion in the number of faculty working in solar and space physics at any given institution, though the overall number across the nation is quite substantial. At the same time the field of solar and space physics itself has blossomed. Modeling has moved well beyond one-dimensional stellar structure and evolution to detailed radiative-magnetohydrodynamic and plasma-process models, and hybrids of the two, and observations remote and in situ have pushed, and with the ATST and planned spacecraft instrumentation will continue to push the limits of spatial and spectral resolution. As a result, the research vibrancy and the intellectual promise of solar and space physics is very high, and so too is its relevance to societal concerns, as evidenced by the major investments that both NASA and NSF are making in the subject. Thus, there is a mismatch between the need for graduate level teaching in solar and space physics and the ability to meet that need at any single institution. The specialties making up the subject are quite broad, a sound education in the discipline requires graduate level instruction over the range of topics, and the faculty and students are distributed across universities. The teaching of graduate students entering the field within any given university could benefit from an approach that makes better use of the distributed skills.

We are proposing to initiate a new collaborative approach to the teaching of graduate courses and the supervision of thesis projects within the solar and space physics graduate programs being carried out at CU, NJIT, and UH, joined in this with active participation by NSO, HAO, and SWPC staff. It will use telepresence technology to bring students and faculty from different campuses together for research and classroom learning. We call this the Collaborative Graduate Education Program (CGEP) in solar and space physics. We anticipate that other university groups may join in this venture in the future, but will start by gaining necessary experience between these initial partners. We are committed to exploring this new approach to graduate education, which bridges the boundaries between individual universities and bolsters the efficiency with which course work can be taught and research goals can be achieved. We hope that as we gain experience with the approach it may evolve toward a model that on the national scene provides an additional way for students to make contact with broader solar and space physics research opportunities.

4.2.1 Co-teaching of Graduate Courses at CU, NJIT and UH

We plan to coordinate our graduate offering of courses at CU, NJIT and UH so that many elements of solar and space physics will be available on a two-year cycle, thereby fitting into the early training of our mutual graduate students before they enter into nearly full-time research. We shall make the courses available using advanced video-conferencing so that real-time interactions are possible and strongly encouraged, though we will also record the lecture material so that it can be reviewed or studied at later times via web tools. We plan to utilize software and hardware that provides high-quality telepresence to all participants, which is now feasible with moderate investment and the network connections available to all partners (an example of which is CISCO's TelePresence). In order to encourage interaction and even collaborative work on some of the course projects, it would be helpful if most of the students could get to know each other through participation in yearly summer schools or gatherings, such as the Heliophysics Summer School run with NASA support at HAO/UCAR or NSO's Summer Workshop. Reflecting our commitment to diversity, we plan to make these courses and opportunities available to, and enable participation by, Minority Serving Institutions (MSIs).

There are six to eight graduate courses that should be taught on a two-year cycle that encompass solar and space physics elements (in addition to the core courses in each department), augmented by more advance topics to be taught as appropriate. Some of the courses could be co-taught from two sites if this enhances the course content. As examples, these graduate courses could be a sampling of the following: 1: Space Plasma Physics, 2: Fluid Waves, Instabilities and Turbulence, 3: Radiative Transfer and Stellar Structure, 4: Coronal Physics and Dynamics, 5: Solar Instrumentation and Observations, 6: Solar MHD and Interior Dynamics, 7: Solar Wind and Structure of the Heliosphere, 8: Space Weather Modeling and Forecasting. Some of these courses may not be practical to a purely local audience, but would reach a sensible quorum if offered to students in our larger partnership. We anticipate that we begin by offering four courses per two year cycle within our collaborative approach, and then expand this suite with increased graduate enrollment and faculty appointments.

We expect that the lectures will originate variously at CU, NJIT and UH, will be accessible to both local graduate students and those at the partner sites, and be taught by faculty and scientists at the universities, NSO, HAO, or SWPC. There are some basic issues to be sorted out between the universities in terms of credit for graduate courses taken from the partners, how course charges are handled, and how faculty are made available and encouraged to participate in such a distributed graduate program. Our various administrations have indicated a real interest in resolving such matters concerning graduate school rules and compensation, and thus we foresee being able to establish such a distributed program. Some of these issues have been resolved by the Worldwide Universities Network, which involves 19 universities seeking to foster the exchange of faculty and students and accentuating the benefits of having access to experts across institutional and geographical boundaries. Their experiences in looking to establish a "virtual global university" should help us as we develop a coordinated approach to exploiting the distributed skills in solar and space physics of our institutional partners.

4.2.2 Co-supervision of Early-Career Researchers

Motivated by the complex and interdisciplinary nature of research at the forefront of solar and space physics, we plan to also encourage co-supervision of thesis research work where expert advice can be offered to the graduate students from faculty at partnering institutions. Teleconferencing on roughly a biweekly basis can, again, readily facilitate co-supervision, as suitable and desired, with technology allowing for high quality research interactions between graduate students and co-supervisors. Such co-supervision would be complemented by onsite visits, to allow early-career researchers to personally get to know their colleagues and appreciate the diverse research settings and approaches. To enable such co-supervision on a more formal basis, university and departmental regulations will have to be adjusted. There is clear interest in doing so at our partner sites.