

**02 INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS(PI/PD) and
co-PRINCIPAL INVESTIGATORS/co-PROJECT DIRECTORS**

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PI/PD Name: Philip Goode

Gender: Male Female
Ethnicity: (Choose one response) Hispanic or Latino Not Hispanic or Latino

Race:
(Select one or more)
 American Indian or Alaska Native
 Asian
 Black or African American
 Native Hawaiian or Other Pacific Islander
 White

Disability Status:
(Select one or more)
 Hearing Impairment
 Visual Impairment
 Mobility/Orthopedic Impairment
 Other
 None

Citizenship: (Choose one) U.S. Citizen Permanent Resident Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name):

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project

Ethnicity Definition:

Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.

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Native Hawaiian or Other Pacific Islander. A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands.

White. A person having origins in any of the original peoples of Europe, the Middle East, or North Africa.

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PI/PD Name: Thomas Berkefeld

Gender: Male Female
Ethnicity: (Choose one response) Hispanic or Latino Not Hispanic or Latino

Race:
(Select one or more)
 American Indian or Alaska Native
 Asian
 Black or African American
 Native Hawaiian or Other Pacific Islander
 White

Disability Status:
(Select one or more)
 Hearing Impairment
 Visual Impairment
 Mobility/Orthopedic Impairment
 Other
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PI/PD Name: Wenda Cao

Gender: Male Female
Ethnicity: (Choose one response) Hispanic or Latino Not Hispanic or Latino

Race:
(Select one or more) American Indian or Alaska Native
 Asian
 Black or African American
 Native Hawaiian or Other Pacific Islander
 White

Disability Status:
(Select one or more) Hearing Impairment
 Visual Impairment
 Mobility/Orthopedic Impairment
 Other
 None

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PI/PD Name: Jose Marino

Gender: Male Female
Ethnicity: (Choose one response) Hispanic or Latino Not Hispanic or Latino

Race:
(Select one or more)
 American Indian or Alaska Native
 Asian
 Black or African American
 Native Hawaiian or Other Pacific Islander
 White

Disability Status:
(Select one or more)
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 Visual Impairment
 Mobility/Orthopedic Impairment
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PI/PD Name: Thomas R Rimmele

Gender: Male Female
Ethnicity: (Choose one response) Hispanic or Latino Not Hispanic or Latino

Race:
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List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:

Spiro Antiochos, NRL
Thomas Ayres, University of Colorado
Tom Bogdan, NOAA
James Chen, NRL
Len Fisk, University of Michigan
George Fisher, UC Berkeley
Bernhard Fleck, ESA
Leon Golub, Harvard
Joe Gurman, GSFC
Hugh Hudson, UC Berkeley
James Klimchuk, NRL
Alexander Kosovichev, Stanford
Jeff Kuhn, University of Hawaii
Bob Lin, UC Berkeley
Dana Longcope, Montana State
Nariaki Nitta, LMSAL
Eric Priest, St. Andrew University
Robert Rutten, University of Utrecht
Phil Scherrer, Stanford
Steve Tomczyk, High Altitude Observatory
Thomas Zurbuchen, University of Michigan

REVIEWERS NOT TO INCLUDE:

Not Listed

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 09-29					FOR NSF USE ONLY	
NSF 09-561			08/10/09		NSF PROPOSAL NUMBER	
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)					0959187	
AST - MAJOR RESEARCH INSTRUMENTATION						
DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION	
08/10/2009	3	03020000 AST	1189	075162990	09/04/2009 10:01am S	
EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)		SHOW PREVIOUS AWARD NO. IF THIS IS <input type="checkbox"/> A RENEWAL <input type="checkbox"/> AN ACCOMPLISHMENT-BASED RENEWAL		IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES <input type="checkbox"/> NO <input checked="" type="checkbox"/> IF YES, LIST ACRONYM(S)		
226000910						
NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE			ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE			
New Jersey Institute of Technology			323 DOCTOR MARTIN LUTHER Newark, NJ 07102-1982			
AWARDEE ORGANIZATION CODE (IF KNOWN)						
0026211000						
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE			ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE			
PERFORMING ORGANIZATION CODE (IF KNOWN)						
IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)		<input type="checkbox"/> SMALL BUSINESS <input type="checkbox"/> FOR-PROFIT ORGANIZATION		<input type="checkbox"/> MINORITY BUSINESS <input type="checkbox"/> WOMAN-OWNED BUSINESS		<input type="checkbox"/> IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE
TITLE OF PROPOSED PROJECT MRI: Development of Multi-Conjugate Adaptive Optics for the 1.6 Meter Solar Telescope in Big Bear						
REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE			
\$ 2,375,052	36 months	03/01/10				
CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW						
<input type="checkbox"/> BEGINNING INVESTIGATOR (GPG I.G.2)		<input type="checkbox"/> HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number _____				
<input type="checkbox"/> DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)		Exemption Subsection _____ or IRB App. Date _____				
<input type="checkbox"/> PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D., II.C.1.d)		<input type="checkbox"/> INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)				
<input type="checkbox"/> HISTORIC PLACES (GPG II.C.2.j)		_____				
<input type="checkbox"/> EAGER* (GPG II.D.2) <input type="checkbox"/> RAPID** (GPG II.D.1)		<input type="checkbox"/> HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)				
<input type="checkbox"/> VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date _____		PHS Animal Welfare Assurance Number _____				
PI/PD DEPARTMENT			PI/PD POSTAL ADDRESS			
Department of Physics			323 Dr. Martin Luther King Jr. Boulevard			
PI/PD FAX NUMBER			Newark, NJ 07102			
973-596-3617			United States			
NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address		
PI/PD NAME Philip Goode	PhD	1969	973-596-3565	pgoode@bbso.njit.edu		
CO-PI/PD Thomas Berkefeld	DPhil	1998	761-319-8166	berke@kis.uni-freiburg.de		
CO-PI/PD Wenda Cao	PhD	2001	973-596-5301	wcao@bbso.njit.edu		
CO-PI/PD Jose Marino	PhD	2007	352-392-3516	marinoj@astro.ufl.edu		
CO-PI/PD Thomas R Rimmele	PhD	1993	575-434-7022	trimmele@nso.edu		

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the Authorized Organizational Representative or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), nondiscrimination, and flood hazard insurance (when applicable) as set forth in the NSF Proposal & Award Policies & Procedures Guide, Part I: the Grant Proposal Guide (GPG) (NSF 09-29). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

Conflict of Interest Certification

In addition, if the applicant institution employs more than fifty persons, by electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.A; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency?

Yes

No

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Grant Proposal Guide.

Certification Regarding Lobbying

The following certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding \$100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding \$150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

- (1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
- (2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure of Lobbying Activities," in accordance with its instructions.
- (3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than \$10,000 and not more than \$100,000 for each such failure.

Certification Regarding Nondiscrimination

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative is providing the Certification Regarding Nondiscrimination contained in Exhibit II-6 of the Grant Proposal Guide.

Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:

- (1) community in which that area is located participates in the national flood insurance program; and
- (2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:

- (1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
- (2) for other NSF Grants when more than \$25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE		SIGNATURE	DATE
NAME Maxine Kahn		Electronic Signature	Aug 10 2009 7:52AM
TELEPHONE NUMBER 973-596-3428	ELECTRONIC MAIL ADDRESS srard@njit.edu	FAX NUMBER 973-596-6056	

* EAGER - EARly-concept Grants for Exploratory Research

** RAPID - Grants for Rapid Response Research

Project Summary

Solar adaptive optics has become indispensable at ground based solar telescopes. Driven by the quest for ever higher spatial resolution observations of the Sun, solar adaptive optics hardware has been developed and systems routinely operate at major ground based solar telescopes. *Here we propose, in collaboration with the National Solar Observatory (NSO), to develop a Multi-conjugate Adaptive Optics (MCAO) system for the 1.6 m off-axis New Solar Telescope (NST) at Big Bear Solar Observatory (BBSO) that will expand the field of view (FOV) of diffraction limited observations by about an order of magnitude to at least 1 arcmin. The expansion of the diffraction limited FOV will be sufficient to cover entire active regions enabling critical spectroscopic and polarimetric observations, which include, for instance, flares that may occur at anytime and anywhere in an active region.* Therefore, the proposed MCAO system will eliminate a major limitation of conventional AO systems, the small isoplanatic patch, and, thus provide the tool to effectively study, with unprecedented spatial resolution, fundamental scientific questions like the onset and evolution of flares, flare triggering mechanisms, magnetic reconnection events and many other dynamic solar phenomena that require diffraction limited observations over an extended FOV with the requisite high temporal cadence. *The MCAO hardware will enable the NST to achieve its full scientific potential, while also serving as a pathfinder for the ATST MCAO project. Construction of the off-axis ATST (Advanced Technology Solar Telescope) will begin in 2010 and will be fully commissioned in 2017. Initial solar MCAO on-sky experiments provided proof-of-concept at the Dunn Solar Telescope (DST) and the German VTT on the Canaries demonstrating MCAO's ability to extend the corrected FOV. Thus, it is the right time to focus on the development and scientific utilization of MCAO as a critical enabling technology of the future.* The operational experience with solar MCAO at the NST, and thoroughly characterizing its performance will be absolutely essential for the next generation solar telescope, the 4 m aperture ATST, which undoubtedly will revolutionize solar astronomy. As well, we plan to work with a separately funded KIS (Kiepenheuer Institute, Germany, that will be operating, GREGOR, its own 1.5 m on-axis solar tele-

scope) team to perform both the required controlled MCAO laboratory experiments and continue vital on-sky MCAO experiments with the plan being to implement MCAO, in the timeframe of this proposal, on the NST and GREGOR and ultimately on the ATST soon after it has been commissioned.

Earlier, BBSO and NSO collaborated in the implementation of two AO-76 systems (76-subaperture, 97-element deformable mirror) for the now retired BBSO 0.6 m telescope and the NSO 0.7 m DST, respectively. These systems have served the solar community for many years now and their impact on scientific productivity of the BBSO and NSO facilities has been tremendous. The current high-resolution solar telescopes, such as the DST, are in the one-meter class and utilize AO for >95% of the observing time to achieve the diffraction limit at visible and near infrared wavelengths. Solar AO has revitalized ground-based solar astronomy at existing telescopes. A high order 349 actuator conventional AO system for the NST is currently under development involving the same experienced team that developed the AO-76 and successfully demonstrated MCAO for solar application at the DST. In sum, we address two required criteria:

(1) Intellectual merit: MCAO will enable the NST to provide the community the highest resolution, diffraction limited data over a large FOV to probe the fundamental character of the extended object that is our dynamic star. Over the next decade, NSO will build and begin operating the ATST, the flagship telescope for the solar community. MCAO experiments and their hardware implementation on the NST will be an essential pathfinder for the more complicated ATST MCAO. After the ATST is on-line, the NST will continue to be a critical telescope in making campaign-style observations.

(2) Broader Impact: The development of the proposed MCAO system will be a BBSO, NSO and KIS collaboration, and will continue BBSO's decade long tradition of training the next generation of scientists who build instruments. The resulting data from the upgraded NST will be used in many Ph.D. theses. Further, the testing and development of solar MCAO systems is relevant for nighttime telescopes. Our data, and a substantial portion of NST observing will be open to the community.

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A. Project Description

A.1 Overview

Adaptive Optics (AO) has revolutionized solar astronomy by providing diffraction limited observations of our nearest star. Since the deployment of conventional AO hardware at major solar telescopes, significant progress has been made in our understanding of the complex MHD processes that drive solar activity. These highly successful AO developments have delivered the enabling technology for the development and construction of large aperture solar telescopes such as the New Solar Telescope (NST) and the Advanced Technology Solar Telescope (ATST).

A severe limitation of conventional AO is its ability to fully correct only the seeing aberrations within the isoplanatic patch. Anisoplanatism causes the quality of the AO correction to gradually decline away from the diffraction limit with distance from the chosen lock center. As a consequence, the Strehl ratio decreases. The Strehl is the ratio of the maximum intensity in the AO corrected image to that in the diffraction limited image in the focal plane. For short exposures, i.e., broad-band imaging, post-processing such as speckle reconstruction may restore contrast to the conventional AO corrected images. Arguably, however, the most exciting science requires long exposure spectroscopy and polarimetry over an extended field-of-view (FOV).

In the visible, conventional AO limits the corrected FOV to about $10''$ or less. In contrast, a sunspot or active region extends typically over 1-2 arcmin. In order to capture the dynamic temporal evolution of sunspot structures on the relevant spatial scales, one requires spatial resolution of $0''.1$ or less. Flares can occur “unannounced” anywhere in the extended FOV. Flare trigger mechanisms operate rapidly and on the smallest spatial scales. Their location within the FOV is difficult, if not impossible to predict. Thus, we are led directly to a requirement for diffraction limited resolution over a FOV of 1-2 arcmin.

A single cell of supergranular convection, the convective flow pattern that reflects the organization of the magnetic network of the Sun, is of order $30''$ in diameter. In order to study dynamic, magnetic reconnection events in the network boundaries, one requires diffraction limited resolution over a FOV that covers at least 2-3 network cells, i.e., $60''$ - $90''$ in spatial ex-

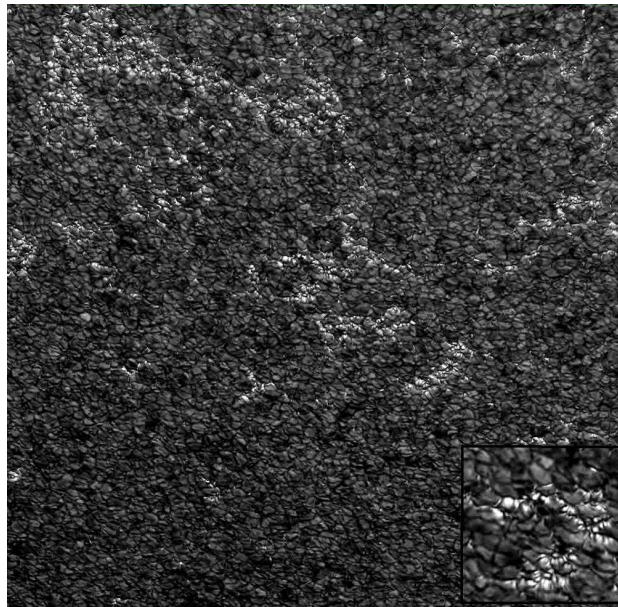


Figure 1: Granular field observed in G-band at the DST using AO-76 and speckle reconstruction. The box in the lower right corner is a magnified cutout illustrating the G-band bright points at the center of the FOV.

tent. The vast majority of solar observing programs would benefit tremendously from diffraction limited resolution over an extended FOV.

Figure 1 shows an image of solar granulation and embedded magnetic G-band bright points observed near the limb of the Sun. The FOV is approximately $120'' \times 120''$. This diffraction limited image was recorded at the Dunn Solar Telescope (DST) with high order AO and post-processed using speckle interferometry. Post-processing is required to achieve the uniform, diffraction limited imaging over such an extended FOV. However, speckle interferometry, as well as other post facto restoration methods typically rely on short exposure imaging, which cannot be utilized when quantitative spectroscopy and polarimetry are performed, i.e., long exposures are required.

The Sun is a natural target for extended object wavefront sensing; any number of “target stars” can be made from the 2-D structure of the Sun by using correlations from Shack-Hartmann wavefront sensing, which is the technique being used in our approach to solar AO. Implementing operational solar Multi-Conjugate Adaptive Optics (MCAO) is an essential, but challenging task that faces the NST, GREGOR (the 1.5 m on-axis solar telescope being built by our partners at the Kiepenheuer Institute in Ger-

many (KIS) for deployment in Tenerife, Spain) and ultimately the ATST.

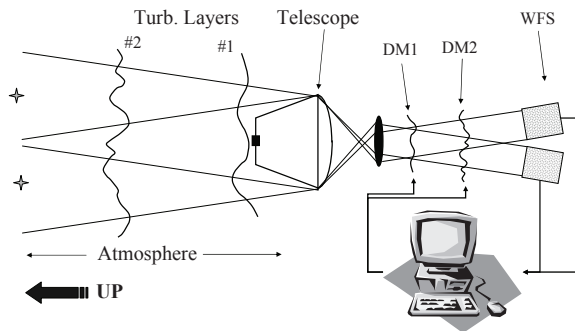


Figure 2: Cartoon illustration of MCAO wavefront sensing due to F. Rigaut from CfAO Lectures.

MCAO provides the much needed real-time diffraction limited imaging over an extended FOV. In the simplest view of MCAO, one has two, or more, deformable mirrors (DM's) to correct anisoplanatism with each DM being conjugated to a different layer of atmospheric turbulence (see cartoon in Figure 2). MCAO is now a demonstrated technique for correcting atmospheric turbulence over a FOV (Ragazzoni et al. 1999, Tokovinin et al. 2001, Ellerbroek et al. 2003). The recent results from the ESO MAD system, which uses natural guide stars, demonstrated the power of MCAO for scientific discovery even with a demonstrator system. Wavefront sensing in nighttime MCAO is difficult because for general use, multiple laser guide stars (LGSs) are needed for tomographic wavefront reconstruction. Thus, to accurately reconstruct 3-D turbulence, generally a number of LGSs are needed. The GEMINI SOUTH MCAO system uses five LGSs and three natural guide stars.

The development of MCAO for existing solar telescopes and, in particular, for the next generation large aperture solar telescopes is stated as a top priority in the US adaptive optics roadmap (see http://aura-astronomy.org/nv/AO_Roadmap_2008_Final.pdf). The Sun is an ideal object for the development of MCAO since solar structures provides “multiple guide stars” with any desired configuration. It is therefore not surprising that the first successful on-the-sky MCAO experiments were performed at the DST and at the German VTT (Vacuum Tower Telescope) on the Canary Islands. However, further development is needed in order to provide operational solar MCAO at the NST

in Big Bear, and ultimately at the large ATST on Haleakala. *The roadmap further states that MCAO development must progress beyond these initial proof-of-concept experiments and should include laboratory experiments and on-sky demonstrations under controlled or well-characterized conditions, as well as quantitative performance analysis and comparison to model predictions. With our proposal, we respond fully to the US AO roadmap and propose to implement its goals for studies of the Sun.*

We propose to develop and install a high order MCAO system at the Big Bear Solar Observatory (BBSO) 1.6 m NST. Whereas, the DST will serve as the initial development platform, the primary goal is to develop a well-characterized, operational MCAO that will greatly enhance the capabilities of the NST and lead to new, otherwise unobtainable discoveries. *The project is a collaboration between NJIT (New Jersey Institute of Technology), NSO (National Solar Observatory), and KIS and will lead to operational MCAO systems at the currently largest aperture solar telescopes in the world, the NST, as well as its German counterpart GREGOR. This MCAO development effort is also an important pathfinder for providing the 4 m ATST with an MCAO system in the not too distant future. Although, BBSO is a university run observatory, the community will have access to the MCAO equipped NST through an open proposal process (discussed in Section B.7)*

Thomas Rimmele (NSO and NJIT research professor), Phil Goode (BBSO/NJIT), and Wenda Cao (BBSO/NJIT) are the PI team of NSF-AST-ATI-0905279 AO project to replace our 97 actuator DM with a 349 actuator DM, so the NST can take diffraction limited observations over a single isoplanatic patch in visible light. The 97 actuator DM was sufficient for the old BBSO telescope, but the NST has three times the aperture of the telescope it replaces. José Marino is a new member of the PI team. He earned a Ph.D. in Physics from NJIT for work in AO under the supervision of Rimmele. Rimmele (PI) and Goode were part of the PI team that built the 97 actuator AO systems on the DST and in BBSO (NSF-ATM-0079482). As well, KIS collaborated on both of these AO projects. Two senior members of the KIS MCAO team, Thomas Berkefeld and Dirk Soltau, are new members of the lead team on this proposal, and their work is supported by German funding sources,

so that NSF investments in this MCAO project are further leveraged. A myriad of papers have been published using the DST and BBSO 97 actuator DM AO systems (to cite just two: Rimmele, 2004; Cao et al., 2006).

A.2 Previous MCAO Experiments and Limitations

The initial solar MCAO work performed at NSO (Langlois et al. 2004, Rimmele et al. 2006a) and at KIS (Berkefeld et al. 2006) provided proof-of-concept with on-sky experiments at the DST and the German VTT in the Canaries. Both experiments demonstrated MCAO’s capability of expanding the corrected FOV. The DST MCAO experiments used two DMs and a MCAO wavefront sensor with three guide regions (small $\sim 10'' \times 10''$ areas, which serve the same purpose as guide stars for the extended object that is our star). Lacking dedicated hardware, these experiments utilized existing hardware from the conventional DST AO systems (Rimmele et al. 2008). Due to constraints of the existing hardware, only three guide regions and a limited number of subapertures (21 per guide region) could be implemented with a reasonable bandwidth. However, since daytime seeing is often dominated by strong ground-layer turbulence, a high order correction of the ground-layer is crucial. The 76 subaperture conventional AO system (97 actuator DM) at the 76 cm DST can correct between 60 and 70 KL (Karhunen-Loeve) modes, and thus is able to provide a good correction for most seeing conditions. By limiting the ground-layer correction to only 21 subapertures, MCAO work was, in practice, limited to the very best seeing conditions only.

Another severe practical limitation was the fact that in order to set up the MCAO experiment, the two operational conventional AO systems had to be disassembled to provide the parts such as DMs and wavefront sensor equipment for the MCAO. Likewise, a complete and time consuming re-assembly and alignment of the conventional AO systems was necessary after completion of the MCAO experiment. Given the high demand for observing time at the DST, this situation was not viable or sustainable.

The DST now has a dedicated MCAO bench for easier and faster and somewhat more permanent implementation of the MCAO experiment. The first stage consists of the high order AO system with 76

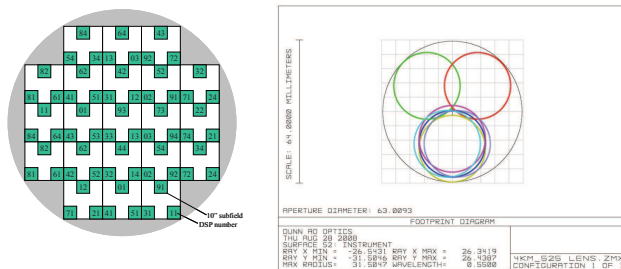


Figure 3: Guide region and WFS geometry on the left. The wavefront sensor camera of the MCAO stage reads out three 20×20 pixel ($10'' \times 10''$) fields arranged in a triangular pattern from within a $52'' \times 52''$ FOV. The separation between guide regions can be adjusted by simply reprogramming the WFS camera. For the experiment described here, the diagonal distance between the centers of the guide regions was about $30''$. The beam footprints of the center field points at an altitude of 4 km are shown as circles within the meta-pupil on the right. Each of these footprints is sampled with 21 subapertures as shown on the left. The multiple, overlapping circles for one of the fields indicate the coverage caused by the extended field of a guide region.

subapertures and its 97 actuator DM (DM1) conjugated to ground-level. This system is used for normal science operations at the DST. The second stage uses a second 97 actuator DM (DM2) that can be conjugated to an adjustable altitude between 2 and 10 km. The wavefront sensor of the MCAO stage uses up to four (4) off-axis guide regions to track granulation, or other solar structures. DM2 was on loan from the BBSO during the construction of the NST and is now installed at the NST. We used modal reconstruction algorithms for both DMs and successfully and stably locked the MCAO system on artificial objects (slides), for which turbulence screens are generated directly in front of the DMs, as well as solar structures. We varied the height of the upper conjugate between 2 km and 7 km. We recorded strictly simultaneous images after the pupil DM1, and after the upper layer DM2. Comparing these images allowed us to qualitatively evaluate the performance of the MCAO stage and directly compare to conventional AO. In addition, we recorded wavefront sensor telemetry data for both closed and open loop cases.

The wavefront sensor of the MCAO stage that follows the ground-layer AO utilizes 3-4 guide regions of about $10'' \times 10''$ each. The triangular arrangement of the three (3) guide-region setup is shown in Figure 3. The pupil footprints of the guide regions at altitude of

4 km above the telescope are plotted with respect to the meta-pupil.

The spare wavefront sensor camera and processing unit of the high order AO system were used for the second stage of the MCAO experiment. The camera can easily be reprogrammed to accommodate the arrangement of multiple FOVs.

On-sky experiments were performed under unknown atmospheric conditions, i.e., no information about the $C_n^2(h)$ seeing profile above the telescope was available during the experiments. Hence, a detailed comparison of MCAO performance with model predictions is impossible. Furthermore, optimization of parameters such as DM conjugate positions and control algorithms could not be performed. However, for any operational solar MCAO, it is crucial to determine how well the achieved and expected performances compare, and under what conditions and operational parameters. This is one of the first goals of the proposed BBSO MCAO effort.

Nevertheless, the DST MCAO experiment can be characterized as extremely successful. A stable control loop was achieved on solar granulation. We were able to correct up to 21 KL modes with DM2 conjugated to 4 km. Bursts of 50 -100 digital $1k \times 1k$ images with an exposure time of 10 ms were recorded after ground-layer AO correction and after the MCAO correction, respectively. The images were recorded strictly simultaneously. The observing wavelength was 510 nm (9 nm FWHM) for both channels. During these MCAO test runs, DM2 was positioned to conjugate heights of 2, 4, 5 and 7 km, respectively. The best results were achieved with the DM2 at 4 and 5 km conjugates, which is not surprising given the result of our solar SLODAR (SLOpe Detection And Ranging) measurements at the DST site, which indicate a dominant turbulence layer at an apparent altitude of about 4 km. The image bursts were processed in two ways. A local correlation algorithm was applied to obtain residual image motion within the extended FOV of about $60''$ diameter. Residual image motion is easily computed from granulation images, and is an indicator of the degree of correction obtained. Alternatively, a speckle reconstruction algorithm was applied, which also outputs residual image motion. The results of both methods were nearly identical.

Figures 4 and 5 show two sets of residual image motion maps. The granulation image in the back-

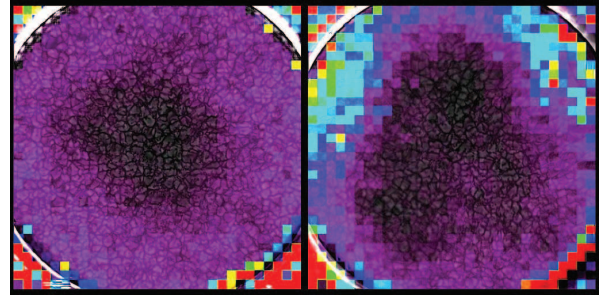


Figure 4: Maps of residual image motion measured with conventional AO (left) and the MCAO (right). Dark areas in these images indicate good correction. The circular FOV is about 1 arcmin. These results were obtained with the MCAO experiment at the DST using the *three* guide region configuration shown in Figure 3 and clearly demonstrate the MCAO's capability to increase the corrected FOV.

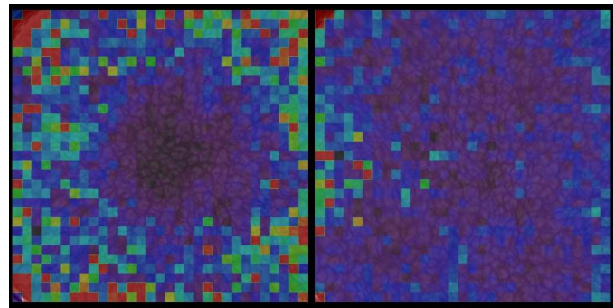


Figure 5: Maps of residual image motion for a *four* guide region configuration. This figure is similar to what is seen in figure 4 but the square FOV is about $45'' \times 45''$ and a different color scaling has been applied to the residual image motion maps. These very recent results indicate that a uniform correction can be achieved over an extended FOV.

ground of each map is the speckle reconstruction of the corresponding burst of images. Dark areas in these images indicate low residual image motion and hence good correction. The images on the right were recorded after DM2 and demonstrate the ability of the MCAO stage to provide an increased diameter of the corrected FOV compared to that of conventional AO. The MCAO corrects to a level better than $0''.01$ rms within a triangular shaped FOV of about $40''$, compared to typically less than $10''$ for the conventional AO. In Figure 4, the configuration shown in Figure 3 was used. The location of the three guide regions is clearly reflected in the residual image motion maps, since the correction is maximal at these locations. Image motion is actually increased by the MCAO stage in the corners of the FOV where the three (3) guide-

region wavefront sensor does not provide any information. Use of a more sophisticated control algorithm and more guide regions, as we plan to use for the BBSO NST MCAO, should alleviate this problem. This can already be seen in more recent results shown in Figure 5 where four guide regions were used for the MCAO wavefront sensor, and already a more uniform correction was achieved over the 1 arcmin FOV shown in this example.

B. Proposed Work

B.1 Overview of Implementation at the NST

In early 2009 at BBSO, first light science observations were made with BBSO’s NST, which is a 1.6 m clear aperture, off-axis telescope. The new telescope will have its operational 97 actuator DM based AO system replaced with our conventional, 349 actuator-based AO within the next year. Building on this 349 actuator system, we propose to upgrade to a three (3) DM MCAO system that offers an essential and significant improvement in ground-based high angular resolution capabilities that will substantially enhance our continuing program to understand photospheric magneto-convection and chromospheric dynamics. These are the drivers for what is broadly called space weather – an important problem, which impacts human technologies and life on Earth. The NST project is described in detail in <http://www.bbsso.njit.edu/newtelescope>.

The NST has an off-axis Gregorian configuration consisting of a parabolic primary, heat-stop, elliptical secondary and diagonal flats. The focal ratio of the primary mirror is $f/2.4$, and the final ratio is $f/50$. The working wavelength range covers from 0.39 to 1.7 μm in the Coudé Lab beneath the telescope and all wavelengths including the far infrared at the Nasmyth focus on the dome floor. We emphasize that both the NST and ATST are off-axis designs. A first scientific light NST image taken in the TiO band at 710 nm is shown in Figure 6.

The DST experiments and similar experiments at the German VTT telescope on Tenerife have demonstrated the feasibility and power of solar MCAO and its ability to extend the corrected FOV significantly. These demonstrate our team’s technical abilities and give us the confidence that we can upgrade the con-

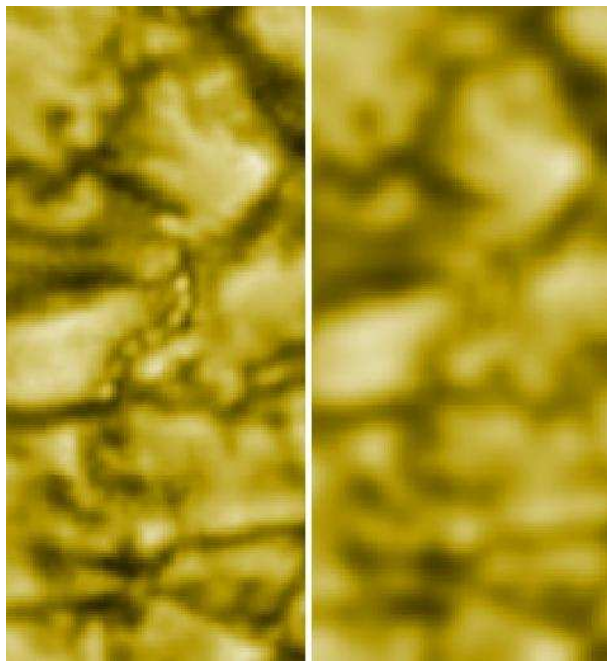


Figure 6: NST images with a FOV of $4'' \times 2''$ from March 30, 2009 are shown. Left: A reconstructed image in which seven bright points appear side-by-side in a dark lane at the center of the FOV. These bright points are thought to be associated with magnetic field concentrations and are each about $0.1''$ in diameter. Right: The same image degraded to the resolution of the old BBSO 0.6 m aperture telescope in which the beads cannot be seen.

ventional AO-349 currently under construction for the NST to an MCAO system. As well, we propose to join the nascent MCAO efforts in the KIS laboratories, further broadening our basis of expertise.

The NSO MCAO experiment at the DST uses a two (2) DM configuration, while the KIS laboratory setup that will eventually move to GREGOR implements a three (3) DM system. Both teams have extensive lab and on-sky experience with two (2) DM MCAO. KIS and NJIT/NSO/UF (University of Florida) teams have agreed to use the KIS three (3) DM system as a development platform. Lab experiments will be conducted at the KIS labs in Freiburg, while on-sky experiments will be conducted at the DST. The NSO MCAO bench optics will be modified to accommodate the KIS MCAO for on-sky MCAO experimentation. The DST provides the stable and well-supported development environment required for this effort. In this way, both teams will collaborate on hardware and software development, as well as analysis and characterization of system performance making optimal use

of resources at all partner institutes.

The teams have agreed to exchange personnel for joint work on the DST MCAO bench and the KIS lab setup. Initial joint MCAO experiment observing runs were already performed during 2008/2009. Building on these ties and following joint work with the KIS lab setup we plan to perform three MCAO observing campaigns at the DST during 2010 using the KIS three (3) DM MCAO setup. The KIS hardware will be shipped to the DST capitalizing on the common lab and on-sky bench on the DST (rather than shipping from KIS to Tenerife). The existing DST optical setup can be easily modified to accommodate one additional DM. The optical design also allows adjustment of conjugate heights of the two upper layer DMs.

Performance simulations that are to be compared to actual system performance achieved will be carried out jointly by team members at NSO and KIS. There is extensive experience in the area of MCAO simulations at NSO and UF. KIS intends to expand on its current capabilities in support of the GREGOR MCAO project and the European Solar Telescope (EST) effort. *Again, by joining these efforts, we will form a critical mass and make optimal use of resources and avoid duplication of effort.*

B.2 NST MCAO design parameters and expected performance

The goal of the proposed work is to implement an operational MCAO system on the NST. The median seeing at BBSO is about $r_0 = 6$ cm at $0.5 \mu\text{m}$ (see the ATST site survey, <http://atst.nso.edu/site> for details), but periods of excellent seeing with the Fried parameter, r_0 , being significantly larger than 10 cm do occur. The $C_n^2(h)$ profile at the site contains the crucial information for designing the MCAO and for modeling its expected performance. The ATST site survey provided measurements of $C_n^2(h)$ at BBSO. Unfortunately those measurements have very coarse height resolution, in particular, for the upper atmospheric layers. However, the site survey revealed that ground-layer turbulence, which dominates the daytime seeing at mountain sites is significantly suppressed at the BBSO lake site. While at a mountain site, 70-95 % of the seeing may be located near the ground, whereas at BBSO only about 50-70 % of the turbulence is near the ground. This makes MCAO relatively more important for the BBSO NST.

Measuring the $C_n^2(h)$ profile with sufficient resolution to be able to optimally design the MCAO system is a first important step in the proposed work. We will use a method that is similar to the well-known SLODAR (Wilson 2002; Butterley et al. 2006) approach used for point-sources, but it has been adapted for solar application (Waldmann et al. 2007, 2008). The method uses a wide FOV Shack-Hartmann wavefront sensor operating on solar granulation and evaluates the covariance of image shifts that have been measured with different subapertures of a Shack-Hartmann wavefront sensor at different points in the FOV. We plan to implement such a device at the NST to obtain online $C_n^2(h)$ measurements during normal operations. The device is fairly simple, consisting of a wide field wavefront sensor that uses a FOV of about 1 arcmin. A 10×10 lenslet array forms wide field images of 16 cm subapertures. Bursts of these images are recorded on a $2K \times 2K$ camera and processed on a PC. Software to analyze these data has been developed (Waldmann et. al 2009).

In order to obtain a baseline design that enables us to estimate the scope of the effort and the required resources, we used an approximated $C_n^2(h)$ profiles derived in the following way. The ATST site survey reliably measured $C_n^2(h)$ for the first 500 m above the telescope. The high altitude $C_n^2(h)$ profile was approximated by using 1) Mauna Kea $C_n^2(h)$ profiles (Rimmele 2006b), 2) a C_n^2 profile that was measured for Mt. Graham (Milton et al. 2003) and 3) a $C_n^2(h)$ profile measured at Mt. Palomar (courtesy R. Dekany 2009, priv. comm.). We will refer to these profiles as BBSO/MK, BBSO/MG and BBSO/MP profiles, respectively. The BBSO/MP profiles can be expected to closely match the actual BBSO profile because of the close proximity of BBSO to Mt. Palomar. The performance of a baseline MCAO configuration was simulated using CIBOLA (Co-variance, Incorporating Basic Option for Linear, Analysis by Ellerbroek). The baseline design uses three (3) DMs and a minimum of seven (7) granular guide regions. The DM conjugate heights vary for the different $C_n^2(h)$ profiles. For example, for the BBSO/MK profile the DMs are conjugated to 0 km, 4 km and 13 km and have 349 actuators, 349 actuators and 97 actuators, respectively. This order may change in BBSO depending on C_n^2 measurements and experimentation. The solar MCAO wavefront sensor is equivalent to the star-oriented night-

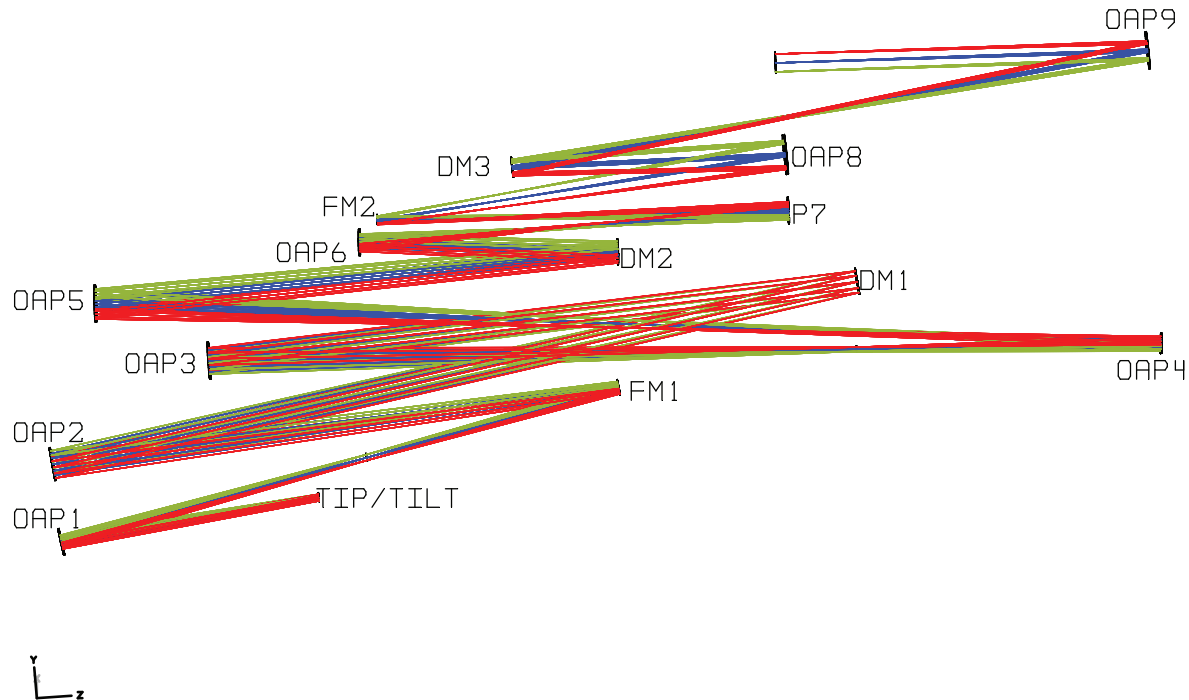


Figure 7: The design of Coudé Room optics for MCAO for the NST.

time version. However, since solar granulation is used a “guide-star”, we can easily select any “guide-star” configuration and increase the number of guide stars or guide regions to improve uniformity of the Strehl across the FOV. The use of natural guide stars in solar MCAO avoids the complexity of laser guide star systems of night time MCAO, and issues such as the cone-effect. The modeled baseline MCAO system has six guide regions arranged in a circular configuration with an additional guide region in the center of the 90'' diameter FOV.

The Strehl ratio is generally used to quantify the performance of an AO or MCAO system. The CIBOLA calculations show that the baseline NST system in BBSO can be expected to achieve Strehl ratios of about $S = 0.5$ across the 90'' FOV. The Strehl variations are moderate with S varying between $S = 0.6$ and $S = 0.45$. Strehl uniformity can be improved by adding additional guide regions. The idealized case where the turbulence is assumed to be located in three discrete layers (0, 3.4, 13.3 km) with the 3 DMs conjugated to these layers results in Strehl of between 0.65 and 0.74 across the FOV. The performance goal driven by the science requirements is to achieve an average Strehl of $S = 0.5$ across the FOV.

We expect to be able to further optimize the MCAO

baseline design once the actual $C_n^2(h)$ profile is measured. However, we do not expect significant changes in the baseline system design. This is indicated by comparing the CIBOLA results from the BBSO/MK $C_n^2(h)$ profile with the results from the BBSO/MG and BBSO/MP profiles. Similar performance can be achieved for these profiles with the baseline system and with adjustments to the DM conjugate heights.

B.3 The optical design of the NST MCAO

The preliminary optical design of the MCAO system shown in Figure 7 is composed of three parts corresponding to the three different altitude conjugations. The first part is built on the BBSO AO-308 system. AO-308 and the MCAO design are identical up to OAP3 (off-axis parabola). The only difference is the tilt of this latter component optimized for a better performance in the new system. The pupil of the telescope is formed on the tip/tilt mirror and on the Deformable Mirror (DM1 with 349 actuators and a clear aperture of 100 mm diameter). The second part conjugates DM2 (also with 349 actuators) to 4 km. OAP4 sends the 4 km altitude conjugate to infinity and OAP5 collimates the beam and images the 4 km conjugate onto DM2. BBSO already owns OAP4 and OAP5. The third part conjugates the smaller format DM3 (97

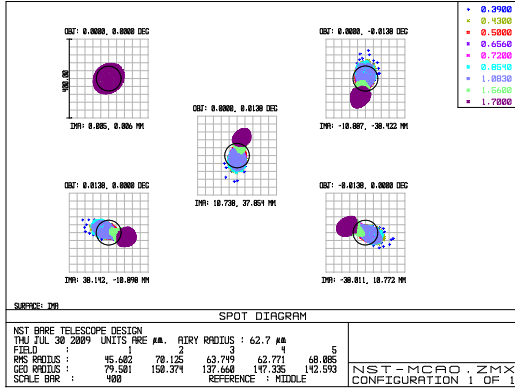


Figure 8: Spot diagram for MCAO showing near diffraction-limited image quality for $0.5 \mu\text{m}$, which is a shorter wavelength than used in our polarimeters. The circles are the Airy disks (diffraction limit disks) for $0.5 \mu\text{m}$ light. The spots are not fully confined to the Airy disk, but narrow-band wavelength observations, which are the norm at BBSO, will be diffraction limited.

actuators) to 13 km. P7 (on-axis Parabola) sends the 13 km altitude conjugate to infinity and OAP8 collimates the beam and images the 13 km conjugate onto DM3. The spot diagram for the design is shown in Figure 8 reveals diffraction limited performance for the narrow-band observations that we plan.

The overall length of the system is 4.3 m and could be reduced to 3 m by adding fold mirrors around OAP4 and OAP9 to make the system fit on a vertical optical table. However, we consider this design to be preliminary and expect that the design will be simplified and optimized during the initial design phase.

The requirements for the optics of the NST MCAO design shown in Figure 7 were also driven by the facts that the optics must relay the NST focal plane image to the Coudé Lab (beneath the telescope), which is about 3 m below the NST’s Gregorian focal plane and the FOV for the optics must be $90''$ in diameter, so that we realize as wide a field of view as is consistent with the downstream, Fabry-Pérot based polarimeters.

To deliver optimal optical performance, some of the optical components in the AO relay path will have to be custom-designed and manufactured. Figure 7 shows the optical layout of the design excluding the wavefront sensor (WFS). The optical concept is preliminary and will be finalized during the initial design phase and frozen after the Critical Design Review in Year Two of the project.

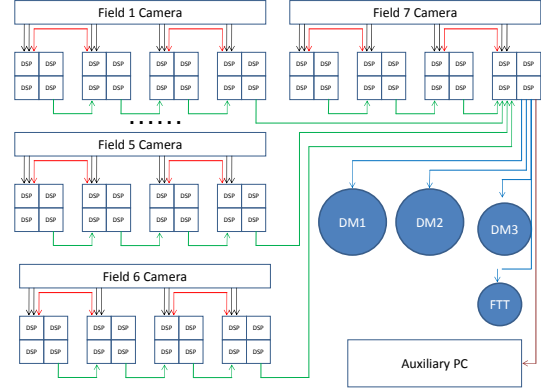


Figure 9: Functional block diagram of the DSP based WFS and the reconstruction unit of the MCAO system.

B.4 Electronic, computing and mechanical systems

The principal system components for the baseline MCAO system are: seven (7) correlating Shack-Hartmann WFS; a wavefront reconstructor and three (3) DMs. Figure 9 shows a block diagram of the MCAO hardware. The baseline wavefront sensor configuration samples with 20 subapertures across the 1.6 m entrance aperture for a total of 308 subapertures. A significant difference from the previously deployed approach is that instead of imaging a large (in this case $90'' \times 90''$) FOV through a single, wide-field lenslet array and onto a single wavefront detector and processing only the much smaller regions of interest (guide regions), the guide regions are now split or separated optically and re-imaged onto a number (baseline is 7) of narrow-field wavefront sensors. This design choice is motivated by a trade between optical complexity and wavefront sensor camera complexity and associated programmatic risk. Imaging all subapertures and the full field containing the seven guide regions onto a single detector would have required an extremely large detector of order 3000×3000 pixels with a required frame rate of 2000 fps. Such technology is not available at this point in time and a custom development would be expensive and carry significant risk. We avoid this cost and risk with the approach shown in Figure 10. The optical split into the seven (7) wavefront sensor channels, which are now duplicates of the conventional AO wavefront sensor that has already been designed for the BBSO high or-

der, AO-308 system. The added optical complexity is very moderate. The guide regions can be picked off in, or near an image plane using a pick-off mirror assembly. The required square field stop mask would be placed in the prime focal plane of the wavefront sensor channel. Alternatively, the light can be split into a collimated path, as is shown in Figure 11, and identical images of the full FOV are imaged. The smaller guide regions are then re-imaged through the lenslet array. The latter approach appears to have lower complexity and would be easier to implement. Since the wavefront sensor channel uses broad-band light, sufficient photon flux is available in the WFS channel so as to divide the beam multiple times.

The technology developed for the conventional AO-308 can be directly applied to the MCAO effort. The cameras that will be used are the same that we use for the conventional AO-308. Each of the seven MCAO Phantom V7.3 cameras will feed images to 15 DSPs on two DSP boards. The 14 DSP boards in two cPCI chassis will receive the images from the seven cameras, determine the subaperture image shifts and perform the reconstruction. The results will be passed to a fifteenth DSP board where the servo algorithms will take place for the three DMs. The fifteenth DSP board is interfaced to the three DMs through LVDS (low voltage differential signaling) via the DSP board's FPGAs (field programmable gate arrays).

The interface between the Phantom V7.3 cameras and the DSPs is mostly software and once developed for one camera can be copied for the other six. Bittware, Inc. is currently developing the required interface for the AO-308. This work is expected to be directly applicable to the MCAO interfaces and software modifications that are required to synchronize cameras will be contracted to Bittware, Inc. The cameras will be synchronized to each other through an external signal generated by one of the cameras.

Among the many issues of software development, the reconstruction matrix (to convert from wavefront information to the movements of the actuators) needs to be made. For the electronics part, we plan to perform the following tasks: (1) design and construct an interface to connect the WFS camera and the DSP board; (2) design and construct an interface to connect the DSP and tip/tilt; (3) design and construct an interface to connect the DSP and the DM. As in our AO-308 project, the skeletal interface will be built by

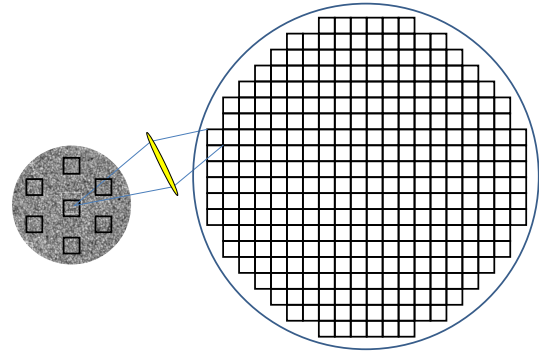


Figure 10: Schematic demonstrating MCAO wavefront sensing approach for solar application.

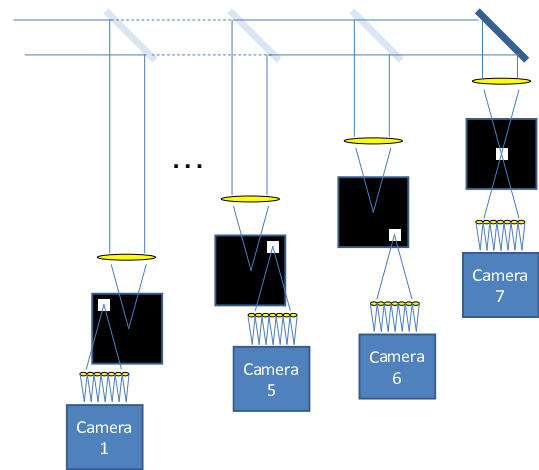


Figure 11: Multiple wavefront sensor channels for solar MCAO. The individual channels are duplicates of the conventional AO-308 wavefront sensor.

Bittware with a subcontract from this grant, and will need to be tailored within the team to fit our needs. Nonetheless, these are very time-consuming efforts requiring great care. Our experience with the two AO-76 and AO-308 systems will pay off here.

In addition to the international solar MCAO collaboration described here, we are in contact with several night-time MCAO efforts, such as GEMINI, ESO MAD and ONERA and will incorporate their valuable experience, in particular, in the area of reconstruction and control, into the NST MCAO effort. During a recent meeting with members at ONERA/Paris plans were discussed for ONERA members to use the DST MCAO to implement ONERA control algorithms and evaluate their performance.

B.5 Science drivers for an MCAO-equipped NST and NST instrumentation

BBSO's AO-308 (349-element DM) system can achieve 50 km resolution at 500 nm with a Strehl above 0.5 (more than sufficient for polarimetry) more than half of the time but with a less than $\sim 10''$ diffraction limited FOV under nominal BBSO seeing conditions. However, typical NST observing campaigns require diffraction limited observations that cover more like $100''$ because in a typical campaign, one might be tracking an active region replete with dynamical events, like flares, that may originate anywhere in the FOV. The events typically originate on small spatial scales with sub-second timescales. Thus, MCAO fed spectro-polarimetric hardware is essential to obtain diffraction limited across an entire active region. Often, events are seen in one place in an active region and are preceding and/or followed by other events elsewhere in the region. Therefore, with MCAO, campaigns can usefully follow the evolution of magnetic fields and flows for several hours continuously with sufficient Strehl. Extended FOV, sub-arcsec resolution will be a unique feature of MCAO equipped NST, and it will remain as a potent instrument to be used in its campaign mode for the study and monitoring of solar activity and space weather, even after the ATST is built. The following scientific objectives reflect such a unique capability.

The polarimetric hardware that will be fed MCAO light on the NST has already been built and tested, and the fully outfitted NST was designed to meet our science goals.

B.5.1 The hardware: near infrared (NIR) and visible imaging vector magnetograph systems

To achieve the highest spatial resolution with the NST, we have developed polarimetric instrumentation in visible light, which is a Visible Imaging Magnetograph system (VIM) that is tunable from 400 to 700 nm with a bandpass of 0.01nm (Denker and Tritschler, 2005). The principal optical elements of this state-of-the-art system are an interference filter set and a Fabry-Pérot interferometer, which enable one to perform full vector Stokes polarimetry over the $\sim 100''$ FOV. This system has achieved its first light at BBSO in 2007. With MCAO correction, the NST will

achieve diffraction limited images with a spatial resolution of about 50 km, when observations are made at 500 nm (better than three times the resolution possible in the NIR with the NST). Still, there are advantages to NIR vector polarimetry, especially the considerably larger Zeeman splitting, which enables one to separate the magnetic field from the magnetic flux over the FOV.

BBSO has built and employed several generations of NIR imaging systems. The most recent and significant part of our IR instrumentation was the development of a narrow bandpass filter system, which combines a Lyot filter and an IR Fabry-Pérot interferometer – the IR Imaging vector Magnetograph (IRIM). The Lyot filter has a bandpass of 2.5 \AA at $1.56 \mu\text{m}$, giving us a 2.5 \AA wide prefilter (narrower than the 5.5 \AA free spectral range of the IR Fabry-Pérot). The Lyot filter was designed as part of the Ph. D. thesis of a now graduated student. At present, this Lyot filter is being replaced by a second Fabry-Pérot interferometer to increase the light feed, which is not so critical for VIM. We have obtained and implemented a large format IR CMOS camera ($1k \times 1k$, 30 frames/s) from Rockwell Scientific Imaging (now Teledyne). We enjoyed a very successful first scientific light of the full IRIM hardware system in November 2004 at NSO on the DST and in July 2005 at BBSO (Cao et al., 2006). The strength of the IRIM is its magnetic extreme sensitivity, which allows us to study weak and small-scale magnetic fields in the quiet Sun. In active regions, it enables accurate measurements avoiding Zeeman saturation of the traditional filter-based magnetograph systems. Both magnetic field strength and the filling factor have already been derived from fitting the Stokes V profiles (Cao et al., 2006).

B.5.2 Science Drivers for the AO Equipped NST

We need to develop MCAO as soon as possible for the following scientific reasons: (1) Solar activity maximum is anticipated in about three to four years, and the full resolution NST would play a significant role in the study of solar activity. (2) The NST will support a number of solar missions, STEREO, Hinode, and SDO (to be launched later this year).

Below we briefly describe some of the science goals that we have planned to meet with MCAO corrected light feeding our existing hardware:

(a) High cadence, high resolution studies of solar flares

One of the most important but not well-understood areas in flare research is the fine temporal and spatial structure of flares, so called “elementary bursts” (see Sturrock, 1989 for a review). The 1.6 m telescope will obtain high resolution, high cadence images of flares. Such observations will provide details of electron precipitation on fine temporal and spatial scales. We expect to learn if, and how the individual sub-second peaks in the hard X-ray and microwave time profiles correlate with the rapid precipitation along various flux loops. Xu and Cao (2006) presented the very first high resolution observations of an X10 white-light flare (from solar active region NOAA 10486 obtained with the DST on 2003 October 29, with AO-76). The study demonstrated the potential for new scientific results when high resolution photospheric observations are combined with hard X-ray imaging and spectroscopic observations; however, even with a resolution approaching 100 km, the flare ribbons were not resolved. We anticipate that NST with MCAO will provide new and basic insight into this problem because, in part, we will be able to observe, at the diffraction limit remote, but correlated events in the FOV that precede and/or follow the flare.

(b) Structure and evolution of magnetic fields and flow fields in flaring active regions

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. Until very recently, no one has detected, in any consistent way, the changes in magnetic fields associated with solar flares. The BBSO group first saw signs of these changes using BBSO, TRACE and MDI one-minute cadence data (Spirock et al., 2002; Wang et al., 2002, 2004; Liu et al., 2005). The inconsistency among 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. NST equipped with MCAO will provide much more reliable, and higher quality measurements of vector magnetic fields. A consistently high Strehl ratio over the extended FOV will ensure that the detected field variations will not be due

to variation in seeing conditions. More specific scientific questions to be answered are: (1) What are the relative and absolute roles of the evolution of the local and nearby photospheric magnetic fields in triggering solar flares, and what is the relationship between the evolving magnetic configuration and the properties of flares? (2) How do electric currents, derived from the field, evolve, and what is their relationship to particle precipitation?

(c) Dynamics of Kilogauss Flux Tubes

Understanding the dynamic behavior and structure of small scale kilo-Gauss fluxtubes is a primary scientific goal. The key issues are the formation of photospheric flux concentrations having field strength above the equipartition field strength and the dynamic interaction with the turbulent photospheric atmosphere. Understanding the dynamic interaction of photospheric flux concentrations with turbulent granulation is also essential in order to estimate the total energy flux that is transmitted/channelled by small-scale fluxtubes into the higher atmosphere. The key questions are: How are fluxtubes formed and how do they evolve? What is the lifetime of a fluxtube? How do fluxtubes interact with the turbulent flows in the photosphere? The observational determination 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 50 to 100 km resolution is critical to resolve this problem. In the shorter term, multi-wavelength investigations ultimately using NST and satellite data to study this problem will advance our understanding of flux tube physics. Here MCAO will provide much more diffraction limited data, and thereby increasing our chances finding the odd event that facilitates new insights.

B.6 Education, Research Training and Mentoring

NJIT has a diverse student body in an urban environment, with a large minority student population. BBSO highly prizes its special role in the education of the next generation of scientists who build instruments. We currently have six PhD students, including 2 US citizens, who will receive PhD’s from NJIT in various fields: applied physics, electrical and computer engineering, and computer science. The very best NJIT

students are attracted to the BBSO program. The typical student designs and builds the instruments used to make his/her PhD measurements in BBSO, although this is not possible for the NST MCAO Project. However, José Marino earned his Ph.D. from NJIT in adaptive optics and will be working on this project as a postdoctoral associate. He will be primarily mentored by Thomas Rimmele (his thesis advisor) who has been guiding his work in adaptive optics and MCAO, in particular, since Marino graduated. He resides at the University of Florida (UF) and his support in our MCAO project will come from the subcontract to NSO. Marino will spend extended periods where the MCAO experiments are on-going. He has a close relation with nearly all members of the team, but is advised on a nearly daily basis by Rimmele. The second postdoctoral associate will be a new hire and will split time between NSO and BBSO. He/she will be mentored in the same manner as Marino and will work on MCAO experiments, integration and testing at the DST and NST, and do performance characterization of the MCAO system. He/she will benefit from collaboration with the full team in this essential task in the MCAO project. The mentoring of the two postdoctoral associates is also discussed in the Supplemental Documents appendage to this proposal.

The resulting data from the MCAO will be important sources for graduate and undergraduate research. The NST will also become a teaching tool for optics, mechanics, computer control and solar physics.

B.7 Data and Telescope Time

Since NJIT began operating BBSO, its telescope time and data have been open to the community. Many scientists have had observing time. Further, several PhD students from around the world have used BBSO data as a central part of their work on their theses. Data requests come to BBSO on a daily basis from around the world. We are an active participant in the Virtual Solar Observatory (VSO). Users of our telescopes and data are only asked to acknowledge BBSO in their resulting publications. Many observers have used our data to help plan their observing campaigns.

The observing time of the first, next generation solar telescope in the US, the NST, will be oversubscribed because of its much improved scientific capability compared to the old 0.6 m telescope, especially after it is equipped with MCAO. We will con-

tinue our open observing time and open data policies. We plan to make a portion of observing time available to the community. The Telescope Allocation Committee will rank the proposals and allocate time. NST data will be on line immediately, if it is not part of a special observing program. A web page describing all the requests will ensure that researchers will not duplicate their data analysis efforts.

B.8 Personnel Management Plan and Timelines

During the building of the NST, we have assembled a strong instrumentation team at BBSO. The commissioning phase of the NST began in January 2009. As a part of this phase, some members of the NST team have been shifted to the AO-308 project and will be shifted to the MCAO project. The implementation of AO-76 and then AO-308 are, in fact, part of the commissioning phase, and involve the same NSO team along with the BBSO team, as well, we maintain our close connection with our KIS colleagues in AO. In fact, BBSO and NSO have a decade-long history of working together beginning with AO-76. The AO installations on the NST are not part of the work proposed here even though they are significant precursors to MCAO. AO-76 will be operational beginning as of this writing and will be in operation in the Fall of 2009. The hardware purchases for AO-308 are being made at present and the MCAO team is already involved in this. The major efforts in the AO-308 project would only overlap with the first year of the MCAO project when BBSO seeing will be characterized and the conceptual design of the MCAO system will be made. Near the end of the first year of the work proposed here, the purchase of the MCAO hardware will be made following the conceptual design review. Meanwhile, in the first year of the MCAO project, lab and initial on-sky experiments will continue using the two DM system in place at the DST (BBSO will be implementing its AO-308 at this time). Early in the first year, the KIS three DM MCAO system (Berkefeld et al. 2006) will be transferred to the DST along with some personnel to do further lab and on-sky experimentation. During the second year, two of the DMs in the German system will be upgraded by being replaced by the two 349 actuator DMs (one purchased here and the other from the BBSO AO-308 system) for a series of experiments. Since the DM diameters are

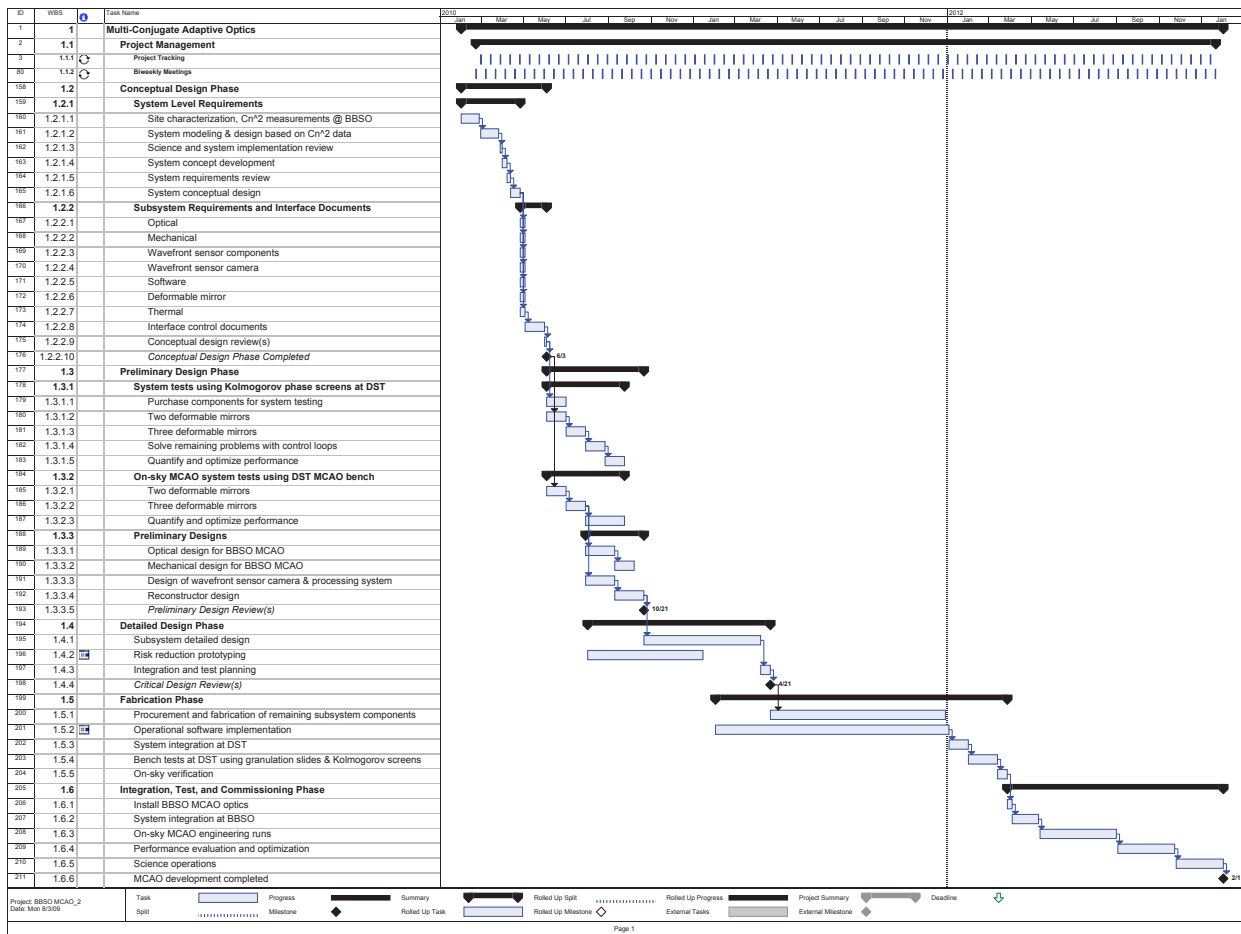


Figure 12: The Gantt Chart showing the Schedule for the MCAO Project. Details of MCAO tasks are given in Table 1.

comparable, only minor changes in the optical setup will be required.

We already have our experienced team in place to do the proposed work and we risk losing essential staff and our momentum by delaying the start of the MCAO project. Goode and Rimmele will manage and coordinate the diverse elements of the project. Goode is in BBSO about half of each year, so he can provide hands-on leadership, as well as coordinating the joint efforts between NSO and BBSO. Rimmele will oversee the MCAO activities at Sac Peak including the lab and on-sky experiments and will supervise Marino and a second, new post-doc who will spend most of his/her time at NSO early in the project. Nicolas Gorceix, the BBSO optical engineer, has done the MCAO optical designs shown in this proposal. He

will also be the Project Manager, and split his time between Big Bear and Sac Peak. A standard project review process that includes expert reviewers from the AO/MCAO community will be used for the MCAO effort. Rimmele will closely work with Kit Richards and a Software Engineer (new hire) on the interfacing of the WFS cameras, the DSP's and DM control; and Gorceix and the new postdoc will work on the analysis of the WFS data to optimize the system. Kit Richards at NSO will guide the software development, which is primarily DSP control. He will supervise the new Software Engineer who will be in residence at NSO/SP, and who will perform the majority of the MCAO DSP software programming and integration of components, such as cameras, DSP systems, and DMs. Jose Marino at the University of

Table 1: Tasks and Assignments for the MCAO Project.

Year	Task	Person(s) In Charge
Year 1	Overall Management and Coordination	Goode and Rimmele
	Project Management	Gorceix
	C_n^2 Measurements in Big Bear	Gorceix and Cao
	Subsystem requirements	Rimmele and Gorceix
	Lab MCAO development on DST	Rimmele and Marino
	On-sky MCAO tests on DST	Rimmele and Marino
	Review and Purchase Most Major Hardware	Rimmele and Goode
Year 2	Overall Management and Coordination	Goode and Rimmele
	Project Management	Gorceix
	Final Optical Design	Gorceix and Rimmele
	Final Design Review	Rimmele, Gorceix and Goode
	Review and Purchase Remaining Major Hardware	Rimmele and Goode
	DSP Software	Richards and software engineer (TBD)
	DSP Hardware Integration	Richards and software engineer (TBD)
	System Integration on DST	Rimmele and Marino
Year 3	Overall Management and Coordination	Goode and Rimmele
	Project Management	Gorceix
	On-sky MCAO tests in Big Bear	Rimmele, Gorceix and Cao
	Software and electronics	Richards
	System integration of MCAO on NST	Gorceix, Cao and Rimmele
	First Regular Observations with MCAO	Team

Florida, Gainesville has been developing reconstruction algorithms for the DST MCAO experiments. He will collaborate closely with T. Berkefeld at KIS in order to develop optimal reconstruction and control for the GREGOR and NST MCAO systems. Co-PI and NJIT Assistant Professor, Wenda Cao, is well-experienced in the BBSO AO-76 AO-308 systems and was a key developer of the IRIM and VIM. He will be responsible for integrating these instruments into the MCAO.

In the Gantt chart in Figure 12 and in Table 1, we show the major proposed tasks of the MCAO project with timelines and key personnel associated with the tasks, respectively. A detailed vertical flow work breakdown along with a full-page version of the Gantt chart is shown in the Supplemental Documents section. Before the start of MCAO tests in BBSO, AO-308 corrected light will be fed to the Coudé Laboratory of the NST, and that light will also be fed to the IRIM and VIM systems for observations. The main tasks in the first year of the MCAO Project will be C_n^2 experiments in Big Bear, including ob-

servations, analysis and modeling, to determine the conjugate altitudes in the sky above the NST using the Waldmann method, as discussed in Section B.2. This effort will be immediately followed by specification of the MCAO system components. At the conclusion of this *Conceptual Design Phase*, the major MCAO hardware (DMs, cameras, DSPs) will be purchased (see the next section for details). It is already clear, though that we will need to purchase another 349 actuator DM (in addition to the 97 and 349 actuator DMs already purchased by BBSO). This will be purchased late in the first year, since it has a six month lead time. As well, we will purchase the DSPs and wavefront sensing cameras. In parallel, MCAO lab experiments will begin in earnest on the DST using two (between NSO and BBSO there are already two 97 actuator DMs and one 308 actuator DM) and three DMs (the KIS system). In this phase, BBSO will use its 97 actuator DM during a series of runs on the DST, and its 308 actuator DM otherwise, while the DST will alternate between MCAO on-sky experiments and regular observations. The primary goals

of the DST experiments will be to sharpen optical and mechanical designs, while solving control loop problems. The KIS three (3) DM MCAO setup will be implemented in three observing campaigns during the first half of 2010 to optimize reconstruction and control algorithms, as well as quantifying and optimizing the on-sky performance of the system. All of this is to optimize the design for the NST MCAO. The first year culminates with the detailed design phase that continues into the second year. Early in the second year, there will be a *Critical Design Review* that will lead to the purchase of the mirrors, lenses, beamsplitters, benches and mounts for the NST MCAO. Most of the second year will be dominated by the fabrication phase and system integration on the DST. The second year culminates in bench tests and on-sky verifications of the NST system on the DST. Again, because the DMs all have nearly the same diameter, minimal optical changes will be required in switching to the NST system DMs. The third year is dominated by installation, testing, optimizing the MCAO on the NST. This includes on-sky tests and culminates in first science observations with the MCAO on the NST, which should be a time near solar activity maximum.

B.9 Budget

The requested budget for the project is \$2,375 K from the NSF. Even though no match is required, to show NJIT's commitment to this project, NJIT will match with \$515 K including \$100 K for equipment. As well, NJIT/BBSO and NSO personnel will be working part-time on the MCAO Project with no charge to the project. The contribution here is difficult to know exactly, but it amounts to about 1 FTE. Equipment accounts for slightly more than half the total proposed. These include: 1) the Xinetics 349 actuator DM (\$275 K) and its Controller (\$175 K); 2) seven (7) Phantom V7.3 Camera System (\$380 K), which are the WFS cameras; 3) fifteen (15) Bittware Tiger-Sharc T2 DSP Boards T26U-OU-445-306-1177 plus cPCI chassis and SBC (\$350 K); 4) integrated link from the WFS camera to the DSPs and to the DM (and tip/tilt) requires modification of linking software Bittware developed for AO-308 (\$30 K); 5) control computers with SCSI bus, etc. and software (\$50 K); 6) mirrors, lenses, beamsplitters (\$60 K); 7) benches, (\$40 K); and 8) C_n^2 hardware (\$20 K). The total hardware cost for MCAO is \$1,380 K.

The remainder of the budget for the MCAO development is dominated by personnel costs including about three (3) FTEs per year over the three year project. This includes the subcontract to NSO, which is less than 20% of the requested funding. The tasks of these people are described in the body of the proposal. This includes 1 FTE for Nicolas Gorceix as optical engineer and project manager, 0.5 FTE for engineering work in year 3 in BBSO by Jeff Nenow (mechanical engineer) and Vlad Abramenko (electronics engineer). The budget also includes 2.5 FTE for a new postdoctoral associate who will perform the MCAO experiments under the supervision of Dr. Thomas Rimmele and work with Dr. Jose Marino. Finally, there is partial support (1 FTE) for the software engineer for testing and debugging the MCAO system, as well as work on the GUI. The subcontract to NSO includes 0.6 FTE of Kit Richards time to supervise software development by the new hire software engineer. The software engineer is 1.4 FTE at NSO (remainder of support from BBSO) for a total of 2.5 FTE, which are split between programming the DSPs (1 FTE), programming the GUI (1 FTE) and post install debug and modification (0.5 FTE). The last part of the subcontract is 1.5 FTE to support Dr. Jose Marino for reconstruction algorithms and controls.

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- Rimmele, T., Richards, K., Roche, J. M., Hegwer, S. L., Hubbard, R. P., Hansen, E. R., Goodrich, B., Upton, R. S., 2006b, *The wavefront correction system for the Advanced Technology Solar Telescope*, SPIE, 6272, pp.627212
- Rimmele, T. R., Richards, K., Hegwer, S. L., Ren, D., Fletcher, S., Gregory, S., Didkovsky, L. V., Denker, C. J., Marquette, W., Marino, J. and Goode, P. R. 2003, *Solar Adaptive Optics: A Progress Report*, Proc. SPIE, 4839, 635-646
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- Waldmann, T., Berkefeld, T., & von der Lühe, O., 2007, in *Adaptive Optics: Analysis and Methods*, ed. Ellerbroek, B.L. (OSA)
- Waldmann, T., Berkefeld, T., & von der Lühe, O. 2008, in *Adaptive Optics Systems*, ed. Hubin, N., Max, C.E., Wizinowich, P. (SPIE)
- Waldman, T. A., Rimmele, T. R., Scharmer, G., and Berkefeld, T., 2009, A&A, in preparation

- Wang, H., Spirock, T. J., Qiu, J., Ji, H., Yurchyshyn, V., Moon, Y.-J., Denker, C. and Goode, P. R., 2002, *Rapid Changes of Magnetic Fields Associated with Six X-Class Flares*, Ap.J., 576, 497-504
- Wang, H., Liu, C., Qiu, J., Deng, N., Goode, P. R. and Denker, C., 2004, *Rapid Penumbra Decay Following Three X-Class Flares*, Ap.J. Letters, 601, L195-198
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- Wizinowich, P. L. and 11 others, 2004, *Adaptive Optics Developments at Keck Observatory*, SPIE, 5490, 1-11
- Xu, Y., Cao, W., Liu, C., Yang, G., Jing, J., Denker, C., Emslie, A.G., Wang, H., 2006, *High-Resolution Observation of Multiwavelength Emissions during Two X-Class White-Light Flares*, Ap.J., 641, 1210-1216

CURRICULUM VITAE

PHILIP R. GOODE

Address:

Department of Physics
New Jersey Institute of Tech. (NJIT)
Newark, New Jersey 07102

Big Bear Solar Observatory (BBSO)
Big Bear City, California 92314

Phone and E-mail:

Work:(973)596-3565
Home:(908)232-7907
pgoode@bbso.njit.edu

Work:(909)866-5791 x20
Home: (909)-866-0078

Education:

Ph.D. (Physics), February 1969
Rutgers, The State University

A.B. (Physics), June 1964
University of California, Berkeley

Present Positions:

1997- Director, Big Bear Solar Observatory, NJIT
Director, Center for Solar-Terrestrial Research, NJIT
1994- Distinguished Professor, Physics, NJIT

Thesis Advisor and Postdoctoral Advisors:

Larry Zamick, Daniel Koltun and J.B. French (deceased)

Recent Non-BBSO Collaborators

Carsten Denker, Leonid Didkovsky, Wojtek Dziembowski, Peter Gallagher, Stuart Jefferies, Haosheng Lin, Sara Martin, Alexei Pevtsov, Thomas Rimmele, Jesper Schou, Alexandra Tritschler, Harold Zirin

Ph.D. Students and Former Postdocs:

Wenda Cao, Jongchul Chae, Carsten Denker, Leonid Didkovsky, Peter Gallagher, Haisheng Ji, Yun Chun Jiang, Klaus Hartkorn, Scott Kleinman, Chang Liu, Pilar Montanes-Rodriguez, Yong-Jae Moon, Enric Palle-Bago, Jiong Qiu, Deqing Ren, Sergio Restaino, Thomas Rimmele, Thomas Spirock, Michael Steininger, Lou Strous, Alexandra Tritschler, John Varsik, Martin Woodard, Guo Yang, Vasyl Yurchyshyn

Synergistic Activities – Breadth of Activities:

Director of BBSO. Long experience in studies of magnetic fields, especially in combining ground-based data with satellite data to determine dynamic properties of the solar magnetic fields and space weather.

BBSO has strong instrumentation programs including building the NST, a 1.6 m clear aperture off-axis telescope,. Downstream instrumentation built and tested in BBSO include visible light and near infrared polarimeters, and high-order adaptive optics.

Twelve former students and/or postdocs have moved on to faculty/national center tenure track positions.

Synergistic Activities – Committees over Last Decade:

1999: NSF-AST Committee of Visitors
1999-2000: Solar Panel, Astronomy and Astrophysics Decadal Survey
2001-2002: Solar and Space Sciences Survey Committee
2001: Augustine Panel (Blue Ribbon Panel)
2001: NSF-AST: NOAO Management Recompetition Panel
2001: NSF-ATM: HAO Review
2003: NASA: Senior Review
2005-2008: AAS: Joseph Weber Award for Astronomical Instrumentation Committee
2005: NASA: Senior Review
2008: NASA: SMEX Review

THREE RELEVANT PUBLICATIONS

First Light of the Near-Infrared Narrow-Band Tunable Birefringent Filter at Big Bear Solar Observatory, Cao, W., Hartkorn, K., Ma, J. Xu, Y., Spirock, T., Wang, H., and Goode, P. R., 2006, Solar Physics, 238, 207.

Diffraction-limited Polarimetry from the Infrared Magnetograph at Big Bear Solar Observatory, Cao, W., Jing, J., Ma, J., Xu, Y., Wang, H. and Goode, P.R., 2006, PASP 118, 838.

High-Spatial-Resolution Imaging Combining High-Order Adaptive Optics, Frame Selection, and Speckle Masking Reconstruction, Denker, C., Mascarinas, D., Xu, Y., Cao, W., Yang, G., Wang, H., Goode, P. R., and Rimmele, T., 2005, Solar Physics, 227, 217.

Curriculum Vitae

Thomas Berkefeld
Kiepenheuer-Institut für Sonnenphysik
Schöneckstraße 6
79104 Freiburg

Phone: +49-761-3198-166
e-mail: berke@kis.uni-freiburg.de

PhD 1998 Max-Planck-Institut für Astronomie in Heidelberg.
Thesis advisor: Andreas Glindemann,

Positions:

1998-1999 Max-Planck-Institut für Astronomie in Heidelberg.
Postdoctoral Advisor: Andreas Glindemann,

1999- Staff Scientist with Tenure
Kiepenheuer-Institut fuer Sonnenphysik, Freiburg

Expertise: Adaptive optics system for GREGOR; MCAO development for German VTT and for GREGOR. Led wavefront control system development for the now successful SUNRISE balloon telescope.

Four Recent Publications:

- 1] Waldmann, T. A., Berkefeld, T. and van der Luhe, 2008, *Turbulence profiling using wide field of view Hartmann-Shack wavefront sensors*, SPIE, 7015, 154
- [2] Berkefeld, T., 2007, *Solar adaptive optics*, in Modern solar facilities - advanced solar science, p.107
- [3] Berkefeld, T., Soltau, D. and van der Luhe, 2006, *Multi-conjugate solar adaptive optics with the VTT and GREGOR*, SPIE, 6272, 627205
- [4] Berkefeld, T., Soltau, D. and van der Luhe, 2005, *Results of the multi-conjugate adaptive optics system at the German solar telescope, Tenerife*, SPIE, 5903, 219

CURRICULUM VITAE

Wenda Cao

Address:

Department of Physics
New Jersey Institute of Technology (NJIT)
Newark, NJ 07102-1982

Work: (973) 596 - 5301
Home: (908) 265 - 8404
Email: wcao@bbsso.njit.edu

Education

Ph.D., Astrophysics and Astronomical Instrument, August 2001
National Astronomical Observatories, Chinese Academy of Sciences, China
M.S., Solar Radio Physics, August 1995
Yunnan Astronomical Observatory, Chinese Academy of Sciences, China
B.S., Physics, July 1992
University of National Defense Science and Technology, China

Positions Held

2007-present	Assistant Professor, New Jersey Institute of Technology, Newark, NJ
2006-2007	Assistant Research Professor, New Jersey Institute of Technology, Newark, NJ
2003-2005	Post-Doctoral Fellow, New Jersey Institute of Technology, Newark, NJ
2002	Visiting Scientist, National Solar Observatory, Tucson, AZ
1998-2002	Associate Astronomer, National Astronomical Observatories, Chinese Academy of Sciences
1995-1998	Assistant Astronomer, Yunnan Astronomical Observatory, Chinese Academy of Sciences

Selected Recent Publications

- [1] Ning, Z., Cao, W.: *Spatial and Spectral Behaviors of Solar Flares Observed in Microwaves*, *Solar Phys.* 257, 335, 2009
- [2] Ning, Z., Cao, W., Goode, P. R.: *Periodicity of Twisting Motions in Sunspot Penumbra Filaments*, *Solar Phys.* 257, 251, 2009
- [3] Ning, Z., Cao, W., Huang, J., Huang, G., Yan, Y., Feng, H.: *Evidences of Chromospheric Evaporations in the December 1, 2004 Solar Flare*, *Astrophys. J.* 699, 15, 2009
- [4] Cao, W., Jing, J., Ma, J., Xu, Y., Wang, H., Goode, P. R.: *Diffraction-limited Polarimetry from the Infrared Imaging Magnetograph at Big Bear Solar Observatory*, *Publ. Astron. Soc. Pacific* 118, 838, 2007
- [5] Cao, W., Hartkorn, K., Ma, J., Xu, Y., Spirock, T., Wang, H., Goode, P. R.: *First Light of the Near-Infrared Narrow-Band Tunable Birefringent Filter at the Big Bear Solar Observatory*, *Solar Phys.* 238, 207, 2006
- [6] Xu, Y., Cao, W., Liu, C., Yang, G., Jing, J., Denker, C., Emslie, A. G., Wang, H.: *High-Resolution Observations of Multiwavelength Emissions during Two X-Class White-Light Flares*, *Astrophys. J.* 641, 1210, 2006
- [7] Cao, W., Xu, Y., Denkes, C., Wang, H.: *1024×1024 HgCdTe CMOS Camera for Infrared Imaging Magnetograph at the Big Bear Solar Observatory*, *Proc. SPIE* 5881, 245, 2005
- [8] Xu, Y., Cao, W., Ma, J., Hartkorn, K., Jing, J., Denker, C., Wang, H.: *Properties of Small Dark Features Observed in the Pure Near-Infrared and Visible Continua*, *Astrophys. J.* 628, L167, 2005

- [9] Cao, W., Denker, C., Wang, H., Ma, J., Qu, M., Wang, J., Goode, P. R.: *Characteristic Evaluation of a Near-Infrared Fabry-Perot Filter for Infrared Imaging Magnetograph (IRIM)*, *Proc. SPIE* 5171, 307, 2004
- [10] Xu, Y., Cao, W., Liu, C., Yang, G., Qiu, J., Jing, J., Denker, C., Wang, H.: *Near-Infrared Observations at 1.56 microns of the 2003 October 29 X10 White-Light Flare*, *Astrophys. J.* 607, L131, 2004
- [11] Yang, G., Xu, Y., Cao, W., Wang, H., Denker, C., Rimmele, T. R.: *Photospheric Shear Flows along the Magnetic Neutral Line of Active Region 10486 prior to an X10 Flare*, *Astrophys. J.* 617, L151, 2004
- [12] Matt, P. J., Cao, W., Walton, S., Chapman, G. and Livingston, W.: *Ti I 2231 nm Zeeman Splitting in a Sunspot*, *Solar Phys.* 213, 55, 2003
- [13] Matt, P. J., Cao, W., Walton, S., Chapman, G. and Livingston, W.: *Weak Infrared Molecular Lines Reveal Rapid Outflow in Cool Magnetic Sunspot Penumbra Fibrils*, *Astrophys. J.* 590, L119, 2003

Research Interests

Astronomical Instruments: Fabry-Pérot interferometer, birefringent Lyot filter, infrared and visible detectors, infrared and visible polarimeter.

Observation and Research: two-dimensional spectroscopy and polarimetry, infrared high resolution observations, temporal evolution of solar active regions, dynamics of small-scale magnetic fields, flares and filament eruptions.

Collaborators

Hugh, Hudson, Allen Gary, William Livingston, Matt Penn, Thomas Rimmele, Hector Socas-Navarro, Steven Tomczyk, Jiong Qiu

Memberships in Professional Societies

Solar Physics Division of the American Astronomical Society

International Astronomical Union

International Society for Optical Engineering

Research Activities

- Principal Investigator, *Developing High Resolution Infrared Instrumentation to Explore Solar Activity*, Sponsored by National Science Foundation
- Co-Principal Investigator, *MRI: Development of Cryogenic Infrared Spectrograph for the 1.6 Meter Solar Telescope in Big Bear*, Sponsored by National Science Foundation (PI, P. R. Goode)
- Co-Principal Investigator, *High Resolution Studies of Solar Activity with New Solar Telescope*, Sponsored by National Science Foundation (PI, P. R. Goode)
- Co-Principal Investigator: *Studies of Solar Activity with Coordinated Observation of New Solar Telescope and NASA Solar Physics Missions*, Sponsored by NASA (PI, P. R. Goode)
- Co-Principal Investigator, *First Light Infrared Observations with the 1.6 Meter Telescope in Big Bear: Origins of Space Weather*, Sponsored by Air Force (PI, P. R. Goode)
- Co-Principal Investigator, *Development of High-Order Adaptive Optics for 1.6 Meter Solar Telescope in Big Bear*, Sponsored by National Science Foundation (PI, P. R. Goode)

CURRICULUM VITAE

JOSE MARINO

Address:

Department of Astronomy
University of Florida
211 Bryant Space Science Center
PO Box 112055
Gainesville, FL, 32611-2055, USA

Phone: (352) 392-2052 ext. 227
marinoj@astro.ufl.edu

Education:

PhD. in Applied Physics, May 2007
New Jersey Institute of Technology, Newark, NJ

MSc. in Optoelectronics and Optical Information Processing, September 2000
Queen's University of Belfast, Belfast, UK

Degree in Physics, June 1999
Universitat de Barcelona, Barcelona, Spain

Present Position:

2008 – Post-doctoral Research Assistant at the University of Florida

Thesis Advisor and Postdoctoral Advisors:

Thomas Rimmele, Haimin Wang and Steve Eikenberry.

Recent Collaborators:

Friederich Wöger, Julian Christou, Laurent Jolissaint

Current Work Responsibilities:

Multi-Conjugate Adaptive Optics development for the Dunn Solar Telescope: develop MCAO control algorithms and simulate expected performance.

Participate in design of ATST wavefront control system: develop optimal reconstruction algorithms for the ATST high-order AO system, assist in develop error budgets.

Develop PSF reconstruction techniques for high-order AO.

Relevant Publications:

“Long exposure point spread function estimation from adaptive optics loop data: validation and results”, J. Marino, T. Rimmele, and J. Christou, Proceedings of SPIE 6272, 62723W (2006).

“The Evershed Flow: Flow Geometry and Its Temporal Evolution”, T. Rimmele and J. Marino, Ap. J. 646, 593-604 (2006).

Curriculum Vitae

Thomas R. Rimmele

Present Position:

Full Astronomer with tenure, National Solar Observatory

Research Professor, New Jersey Institute of Technology/Rutgers University

P.O. Box 62

National Solar Observatory

Sunspot, NM 88349-0003

work. (505) 434-7022

home: (505) 437-8609

FAX: (505) 434-7029

email: rimmele@nso.edu

Education:

1993 Ph.D., Physics, University of Freiburg, Germany

Positions Held:

1999 – present

Full Astronomer w/ tenure

1999 - present

Research Professor at NJIT/Rutgers

Nov. 1998 – Mar. 1999

Acting Director of NSO

1998

Awarded Tenure w/ AURA

1997 - 1999

Associate Astronomer, NOAO/NSO

1995 - 1997

Assistant Astronomer, NOAO/NSO

1993 - 1995

Post-Doctoral Fellow, New Jersey Institute of Technology

1989 - 1993

Scientific Staff Member at Kiepenheuer

Institut(KIS),Freiburg/Germany

1987 - 1988

Consultant at NSO

1986 - 1987

Research Assistant at Kiepenheuer Institut, Freiburg/Germany

Current Functions at NSO:

- Principle Investigator, solar adaptive optics program at NSO and NJIT/BBSO
- Project Scientist Advanced Technology Solar Telescope.
- Chief Scientist for Dunn Solar Telescope
- Co-Investigator, Solar-B FPP (PI, A. Title, Lockheed-Martin Advanced Technology Center).
- Member Center for Adaptive Optics, UC Santa Cruz .

Memberships in Professional Societies:

American Astronomical Society

Solar Physics Division

SPIE, The International Society for Optical Engineering

SPIE Adaptive Optics Working Group

OSA Optical Society of America - Chair of the Optical Systems for Earth, Air, and Space

Technical Group

Selected Recent Publications:

1. Rimmele, T. , “On the Relation between Umbral Dots, Dark-cored Filaments and Light Bridges.”, 2008, ApJ, 672, 684
2. Vecchio, A.; Cauzzi, G.; Reardon, K. P.; Janssen, K.; Rimmele, T.; 2007, “Solar atmospheric oscillations and the chromospheric magnetic topology”, A&A, 461L, 1
3. Rimmele, T.; Marino, J., 2006, “The Evershed Flow: Flow Geometry and Its Temporal Evolution”, ApJ, 646, 593
4. Rimmele, T.; Keil, S.; Wagner, J., 2006, “The unique scientific capabilities of the Advanced Technology Solar Telescope”, 36th COSPAR Scientific Assembly. Held 16 - 23 July 2004, in Beijing, China., p.3186
5. Rimmele, Thomas; Richards, Kit; Roche, Jacqueline; Hegwer, Steve; Tritschler, Alexandra, 2006, “Progress with solar multi-conjugate adaptive optics at NSO”, SPIE, 6272, 5
6. Rimmele, T.; Richards, K.; Roche, J. M.; Hegwer, S. L.; Hubbard, R. P.; Hansen, E. R.; Goodrich, B.; Upton, R. S., 2006, “The wavefront correction system for the Advanced Technology Solar Telescope”, SPIE, 6272, 33
7. Marino, J., Rimmele, T., Christou, J. “Long exposure point spread function estimation from adaptive optics loop data: validation and results.” Advances in Adaptive Optics II. Edited by Ellerbroek, Brent L.; Bonaccini Calia, Domenico. Proceedings of the SPIE, Volume 6272, pp. 62723W (2006).
8. Rimmele, T., ”Plasma Flows Observed in Magnetic Flux Concentrations and Sunspot Fine-Structure using Adaptive Optics”, ApJ, 604, 906 (2004)
9. Deng, N., Xu, Y., Yang, G., Cao, W., Liu, C., Rimmele, T.R., Wang, H., Denker, C., “Multiwavelength Study of Flow Fields in Flaring Super Active Region NOAA 10486.” Astrophysical Journal 644, 1278, (2006).
10. Moretto, G., Langlois, M., Rimmele, T., “Multiconjugation Optical Relay for an Off-Axis Solar Telescope”, PASP, 116, 819, (2004)

Thesis Advisor: E.H. Schroeter

Recent Collaborators: J. Marino, J. Christou, K. Reardon, G. Cauzzi, C. Denker, N. Deng, G. Moretto, M. Langlois, J. Roche, C. DeForest, H. Lin

Post-Doctoral Researchers supervised:

Woeger, F.	2007 – present
Marino, J.	2007 – present
Tritschler, A.	2006 – present
Sankarsubramaniam, K.	1999 – 2005
Langlois, M.	2001 – 2004
Krishnakumar V	1999 – 2001
Sigwarth, M.	2000 – 2002

Undergraduate and summer students supervised:

Tinker, J; Langhans, K.; Harold, E.; Benson, B.; Wang, F.; Roeser, M.; Beardsley, S.; Marino J.; Hartkorn K.; Yang C., Murray, L.; Simon, L.; Bierent, R., Bharti, L.

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION New Jersey Institute of Technology				FOR NSF USE ONLY			
				PROPOSAL NO.	DURATION (months)		
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Philip Goode				AWARD NO.	Proposed	Granted	
A. SENIOR PERSONNEL: PI/PI, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)				NSF Funded Person-months		Funds Requested By proposer	Funds granted by NSF (if different)
				CAL	ACAD	SUMR	
1.	Philip Goode - none			0.00	0.00	0.00	\$ 0
2.	Thomas Berkefeld - none			0.00	0.00	0.00	0
3.	Wenda Cao - none			0.00	0.00	0.00	0
4.	Jose Marino - none			0.00	0.00	0.00	0
5.	Thomas R Rimmel - none			0.00	0.00	0.00	0
6.	(0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)			0.00	0.00	0.00	0
7.	(5) TOTAL SENIOR PERSONNEL (1 - 6)			0.00	0.00	0.00	0
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)							
1.	(1) POST DOCTORAL SCHOLARS			12.00	0.00	0.00	50,000
2.	(1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)			4.00	0.00	0.00	22,095
3.	(0) GRADUATE STUDENTS						0
4.	(0) UNDERGRADUATE STUDENTS						0
5.	(0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)						0
6.	(0) OTHER						0
TOTAL SALARIES AND WAGES (A + B)							72,095
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)							20,763
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)							92,858
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING \$5,000.)							
	15 Bittware TigerSharc T2 DSP Boards T26U-OU-445-306-1177, etc.		\$			350,000	
	7 Phantom V7.3 Camera System, which are the WFS cameras					380,000	
	C_n^2 Hardware					20,000	
	Others (See Budget Comments Page...)					530,000	
TOTAL EQUIPMENT							1,280,000
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)							4,000
2. FOREIGN							0
F. PARTICIPANT SUPPORT COSTS							
1.	STIPENDS \$ _____						0
2.	TRAVEL _____						0
3.	SUBSISTENCE _____						0
4.	OTHER _____						0
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS							0
G. OTHER DIRECT COSTS							
1.	MATERIALS AND SUPPLIES						1,000
2.	PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION						2,000
3.	CONSULTANT SERVICES						0
4.	COMPUTER SERVICES						0
5.	SUBAWARDS						233,176
6.	OTHER						0
TOTAL OTHER DIRECT COSTS							236,176
H. TOTAL DIRECT COSTS (A THROUGH G)							1,613,034
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)							
Personnel (Rate: 52.5000, Base: 92858) (Cont. on Comments Page)							
TOTAL INDIRECT COSTS (F&A)							65,550
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)							1,678,584
K. RESIDUAL FUNDS							0
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)							\$ 1,678,584 \$
M. COST SHARING PROPOSED LEVEL \$ 133,844				AGREED LEVEL IF DIFFERENT \$			
PI/PI NAME Philip Goode				FOR NSF USE ONLY			
ORG. REP. NAME* Maxine Kahn				INDIRECT COST RATE VERIFICATION			
		Date Checked	Date Of Rate Sheet	Initials - ORG			

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

**** D- Equipment**

Control computers with SCSI bus, etc.; Software (Amount: \$ 50000)

Link from WFS camera to the DSPs and to the DM from Bittware (Amount: \$ 30000)

Xinetics 349 actuator DM and its Controller (Amount: \$ 450000)

**** I- Indirect Costs**

Publications (Rate: 52.5000, Base 2000)

Subcontract (Rate: 52.5000, Base 25000)

Supplies (Rate: 52.5000, Base 1000)

Travel (Rate: 52.5000, Base 4000)

SUMMARY PROPOSAL BUDGET

YEAR **2**

ORGANIZATION New Jersey Institute of Technology				FOR NSF USE ONLY			
				PROPOSAL NO.	DURATION (months)		
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Philip Goode				AWARD NO.	Proposed	Granted	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)				NSF Funded Person-months		Funds Requested By proposer	Funds granted by NSF (if different)
				CAL	ACAD	SUMR	
1.	Philip Goode - none			0.00	0.00	0.00	\$ 0 \$
2.	Thomas Berkefeld - none			0.00	0.00	0.00	0
3.	Wenda Cao - none			0.00	0.00	0.00	0
4.	Jose Marino - none			0.00	0.00	0.00	0
5.	Thomas R Rimmele - none			0.00	0.00	0.00	0
6.	(0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)			0.00	0.00	0.00	0
7.	(5) TOTAL SENIOR PERSONNEL (1 - 6)			0.00	0.00	0.00	0
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)							
1.	(1) POST DOCTORAL SCHOLARS			12.00	0.00	0.00	51,750
2.	(2) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)			11.00	0.00	0.00	64,868
3.	(0) GRADUATE STUDENTS						0
4.	(0) UNDERGRADUATE STUDENTS						0
5.	(0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)						0
6.	(0) OTHER						0
TOTAL SALARIES AND WAGES (A + B)							116,618
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)							32,886
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)							149,504
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING \$5,000.)							
TOTAL EQUIPMENT							0
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)							4,000
2. FOREIGN							0
F. PARTICIPANT SUPPORT COSTS							
1.	STIPENDS \$ _____						0
2.	TRAVEL _____						0
3.	SUBSISTENCE _____						0
4.	OTHER _____						0
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS							0
G. OTHER DIRECT COSTS							
1.	MATERIALS AND SUPPLIES						1,000
2.	PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION						2,000
3.	CONSULTANT SERVICES						0
4.	COMPUTER SERVICES						0
5.	SUBAWARDS						132,231
6.	OTHER						0
TOTAL OTHER DIRECT COSTS							135,231
H. TOTAL DIRECT COSTS (A THROUGH G)							288,735
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Personnel (Rate: 53.0000, Base: 149504) (Cont. on Comments Page)							
TOTAL INDIRECT COSTS (F&A)							82,947
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)							371,682
K. RESIDUAL FUNDS							0
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)							\$ 371,682 \$
M. COST SHARING PROPOSED LEVEL \$ 238,335				AGREED LEVEL IF DIFFERENT \$			
PI/PD NAME Philip Goode				FOR NSF USE ONLY			
ORG. REP. NAME* Maxine Kahn				INDIRECT COST RATE VERIFICATION			
		Date Checked		Date Of Rate Sheet		Initials - ORG	

SUMMARY PROPOSAL BUDGET COMMENTS - Year 2

**** I- Indirect Costs**

Publications (Rate: 53.0000, Base 2000)

Supplies (Rate: 53.0000, Base 1000)

Travel (Rate: 53.0000, Base 4000)

SUMMARY PROPOSAL BUDGET

YEAR 3

ORGANIZATION New Jersey Institute of Technology				FOR NSF USE ONLY			
				PROPOSAL NO.	DURATION (months)		
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Philip Goode				AWARD NO.	Proposed	Granted	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)				NSF Funded Person-months		Funds Requested By proposer	Funds granted by NSF (if different)
				CAL	ACAD	SUMR	
1.	Philip Goode - none			0.00	0.00	0.00	\$ 0
2.	Thomas Berkefeld - none			0.00	0.00	0.00	0
3.	Wenda Cao - none			0.00	0.00	0.00	0
4.	Jose Marino - none			0.00	0.00	0.00	0
5.	Thomas R Rimmele - none			0.00	0.00	0.00	0
6.	(0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)			0.00	0.00	0.00	0
7.	(5) TOTAL SENIOR PERSONNEL (1 - 6)			0.00	0.00	0.00	0
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)							
1.	(1) POST DOCTORAL SCHOLARS			6.00	0.00	0.00	26,780
2.	(4) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)			16.00	0.00	0.00	85,787
3.	(0) GRADUATE STUDENTS						0
4.	(0) UNDERGRADUATE STUDENTS						0
5.	(0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)						0
6.	(0) OTHER						0
TOTAL SALARIES AND WAGES (A + B)							112,567
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)							31,744
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)							144,311
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING \$5,000.)							
TOTAL EQUIPMENT							0
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)							4,000
2. FOREIGN							0
F. PARTICIPANT SUPPORT COSTS							
1.	STIPENDS \$ _____						0
2.	TRAVEL _____						0
3.	SUBSISTENCE _____						0
4.	OTHER _____						0
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS							0
G. OTHER DIRECT COSTS							
1.	MATERIALS AND SUPPLIES						1,000
2.	PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION						2,000
3.	CONSULTANT SERVICES						0
4.	COMPUTER SERVICES						0
5.	SUBAWARDS						93,280
6.	OTHER						0
TOTAL OTHER DIRECT COSTS							96,280
H. TOTAL DIRECT COSTS (A THROUGH G)							244,591
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Personnel (Rate: 53.0000, Base: 144311) (Cont. on Comments Page)							
TOTAL INDIRECT COSTS (F&A)							80,195
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)							324,786
K. RESIDUAL FUNDS							0
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)							\$ 324,786 \$
M. COST SHARING PROPOSED LEVEL \$ 143,177				AGREED LEVEL IF DIFFERENT \$			
PI/PD NAME Philip Goode				FOR NSF USE ONLY			
ORG. REP. NAME* Maxine Kahn				INDIRECT COST RATE VERIFICATION			
		Date Checked		Date Of Rate Sheet		Initials - ORG	

SUMMARY PROPOSAL BUDGET COMMENTS - Year 3

**** I- Indirect Costs**

Publications (Rate: 53.0000, Base 2000)

Supplies (Rate: 53.0000, Base 1000)

Travel (Rate: 53.0000, Base 4000)

SUMMARY PROPOSAL BUDGET Cumulative

ORGANIZATION New Jersey Institute of Technology				FOR NSF USE ONLY		
				PROPOSAL NO.	DURATION (months)	
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Philip Goode				AWARD NO.	Proposed	Granted
					NSF Funded Person-months	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)				CAL	ACAD	SUMR
1. Philip Goode - none				0.00	0.00	0.00
2. Thomas Berkefeld - none				0.00	0.00	0.00
3. Wenda Cao - none				0.00	0.00	0.00
4. Jose Marino - none				0.00	0.00	0.00
5. Thomas R Rimmele - none				0.00	0.00	0.00
6. () OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)				0.00	0.00	0.00
7. (5) TOTAL SENIOR PERSONNEL (1 - 6)				0.00	0.00	0.00
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (3) POST DOCTORAL SCHOLARS				30.00	0.00	0.00
2. (7) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)				31.00	0.00	0.00
3. (0) GRADUATE STUDENTS						
4. (0) UNDERGRADUATE STUDENTS						
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)						
6. (0) OTHER						
TOTAL SALARIES AND WAGES (A + B)						301,280
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)						85,393
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)						386,673
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING \$5,000.)						
\$ 1,280,000						
TOTAL EQUIPMENT						1,280,000
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)						12,000
2. FOREIGN						0
F. PARTICIPANT SUPPORT COSTS						
1. STIPENDS \$ _____ 0						
2. TRAVEL _____ 0						
3. SUBSISTENCE _____ 0						
4. OTHER _____ 0						
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS						0
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES						3,000
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION						6,000
3. CONSULTANT SERVICES						0
4. COMPUTER SERVICES						0
5. SUBAWARDS						458,687
6. OTHER						0
TOTAL OTHER DIRECT COSTS						467,687
H. TOTAL DIRECT COSTS (A THROUGH G)						2,146,360
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)						
TOTAL INDIRECT COSTS (F&A)						228,692
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)						2,375,052
K. RESIDUAL FUNDS						0
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)						\$ 2,375,052
M. COST SHARING PROPOSED LEVEL \$ 515,356				AGREED LEVEL IF DIFFERENT \$		
PI/PD NAME Philip Goode				FOR NSF USE ONLY		
ORG. REP. NAME* Maxine Kahn				INDIRECT COST RATE VERIFICATION		
		Date Checked	Date Of Rate Sheet	Initials - ORG		

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Budget Justification Page

The requested budget for the project is \$2,375 K from the NSF. Even though no match is required, to show NJIT's commitment to this project, NJIT will match with \$515 K including \$100 K for equipment. As well, NJIT/BBSO and NSO personnel will be working part-time on the MCAO Project with no charge to the project. The contribution here is difficult to know exactly, but it amounts to about 1 FTE.

Equipment required for the MCAO system accounts for slightly more than half the total proposed. These include:

- 1) the Xinetics 349 actuator DM (\$275 K) and its Controller (\$175 K);
- 2) seven (7) Phantom V7.3 Camera System (\$380 K), which are the WFS cameras;
- 3) fifteen (15) Bittware TigerSharc T2 DSP Boards T26U-OU-445-306-1177, including cPCI chassis and SBC (\$350 K);
- 4) integrated link from the WFS camera to the DSPs and to the DM (and tip/tilt) requiring modification of linking software Bittware developed for AO-308 (\$30 K);
- 5) control computers with SCSI bus, etc. and software (\$50 K);
- 6) mirrors, lenses, beamsplitters (\$60 K);
- 7) benches, (\$40 K); and
- 8) C_n^2 hardware (\$20 K).

The total hardware cost for MCAO is \$1,380 K.

The remainder of the budget for the MCAO development is dominated by personnel costs including about three (3) FTEs per year over the three year project. This includes the subcontract to NSO, which is less than 20% of the requested funding. The tasks of these people are described in the body of the proposal. This includes 1 FTE for Nicolas Gorceix as optical engineer and project manager, 0.5 FTE for engineering work in year 3 in BBSO by Jeff Nenow (mechanical engineer) and Vlad Abramenko (electronics engineer). The budget also includes 2.5 FTE for a new postdoctoral associate who will perform the MCAO experiments under the supervision of Dr. Thomas Rimmele and work with Dr. Jose Marino. Finally, there is partial support (1 FTE) for the software engineer for testing and debugging the MCAO system, as well as work on the GUI.

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION AURA/National Optical Astronomy Observatories				FOR NSF USE ONLY		
				PROPOSAL NO.	DURATION (months)	
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Thomas R Rimmele				AWARD NO.	Proposed	Granted
					NSF Funded Person-months	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)				CAL	ACAD	SUMR
1. Thomas R Rimmele				0.00	0.00	0.00
2.						
3.						
4.						
5.						
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)				0.00	0.00	0.00
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)				0.00	0.00	0.00
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (1) POST DOCTORAL SCHOLARS				12.00	0.00	0.00
2. (2) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)				12.00	0.00	0.00
3. (0) GRADUATE STUDENTS						0
4. (0) UNDERGRADUATE STUDENTS						0
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)						0
6. (0) OTHER						0
TOTAL SALARIES AND WAGES (A + B)						108,323
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)						40,862
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)						149,185
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING \$5,000.)						
TOTAL EQUIPMENT						0
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)						0
2. FOREIGN						0
F. PARTICIPANT SUPPORT COSTS						
1. STIPENDS \$ _____				0		
2. TRAVEL _____				0		
3. SUBSISTENCE _____				0		
4. OTHER _____				0		
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS						0
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES						0
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION						0
3. CONSULTANT SERVICES						0
4. COMPUTER SERVICES						0
5. SUBAWARDS						0
6. OTHER						0
TOTAL OTHER DIRECT COSTS						0
H. TOTAL DIRECT COSTS (A THROUGH G)						149,185
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Personnel (Rate: 56.3000, Base: 149185)						
TOTAL INDIRECT COSTS (F&A)						83,991
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)						233,176
K. RESIDUAL FUNDS						0
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)						\$ 233,176 \$
M. COST SHARING PROPOSED LEVEL \$ 0				AGREED LEVEL IF DIFFERENT \$		
PI/PD NAME Thomas R Rimmele				FOR NSF USE ONLY		
ORG. REP. NAME* Maxine Kahn				INDIRECT COST RATE VERIFICATION		
		Date Checked	Date Of Rate Sheet	Initials - ORG		

SUMMARY PROPOSAL BUDGET

YEAR **2**

ORGANIZATION AURA/National Optical Astronomy Observatories				FOR NSF USE ONLY			
				PROPOSAL NO.	DURATION (months)		
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Thomas R Rimmele				AWARD NO.	Proposed	Granted	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)				NSF Funded Person-months		Funds Requested By proposer	Funds granted by NSF (if different)
	CAL	ACAD	SUMR				
1. Thomas R Rimmele	0.00	0.00	0.00	\$	0	\$	
2.							
3.							
4.							
5.							
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00		0		
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00		0		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)							
1. (1) POST DOCTORAL SCHOLARS	6.00	0.00	0.00		25,000		
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	6.00	0.00	0.00		36,428		
3. (0) GRADUATE STUDENTS					0		
4. (0) UNDERGRADUATE STUDENTS					0		
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					0		
6. (0) OTHER					0		
TOTAL SALARIES AND WAGES (A + B)					61,428		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					23,172		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					84,600		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING \$5,000.)							
TOTAL EQUIPMENT					0		
E. TRAVEL							
1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)					0		
2. FOREIGN					0		
F. PARTICIPANT SUPPORT COSTS							
1. STIPENDS	\$		0				
2. TRAVEL			0				
3. SUBSISTENCE			0				
4. OTHER			0				
TOTAL NUMBER OF PARTICIPANTS (0)							
TOTAL PARTICIPANT COSTS					0		
G. OTHER DIRECT COSTS							
1. MATERIALS AND SUPPLIES					0		
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					0		
3. CONSULTANT SERVICES					0		
4. COMPUTER SERVICES					0		
5. SUBAWARDS					0		
6. OTHER					0		
TOTAL OTHER DIRECT COSTS					0		
H. TOTAL DIRECT COSTS (A THROUGH G)					84,600		
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Personnel (Rate: 56.3000, Base: 84600)							
TOTAL INDIRECT COSTS (F&A)					47,630		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)					132,230		
K. RESIDUAL FUNDS					0		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				\$	132,230	\$	
M. COST SHARING PROPOSED LEVEL \$ 0				AGREED LEVEL IF DIFFERENT \$			
PI/PD NAME Thomas R Rimmele				FOR NSF USE ONLY			
ORG. REP. NAME* Maxine Kahn				INDIRECT COST RATE VERIFICATION			
		Date Checked	Date Of Rate Sheet	Initials - ORG			

SUMMARY PROPOSAL BUDGET

YEAR 3

ORGANIZATION AURA/National Optical Astronomy Observatories				FOR NSF USE ONLY			
				PROPOSAL NO.	DURATION (months)		
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Thomas R Rimmele				AWARD NO.	Proposed	Granted	
A. SENIOR PERSONNEL: PI/PI, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)				NSF Funded Person-months		Funds Requested By proposer	Funds granted by NSF (if different)
				CAL	ACAD	SUMR	
1.	Thomas R Rimmele			0.00	0.00	0.00	\$ 0 \$
2.							
3.							
4.							
5.							
6.	(0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)			0.00	0.00	0.00	0
7.	(1) TOTAL SENIOR PERSONNEL (1 - 6)			0.00	0.00	0.00	0
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)							
1.	(0) POST DOCTORAL SCHOLARS			0.00	0.00	0.00	0
2.	(2) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)			8.00	0.00	0.00	43,334
3.	(0) GRADUATE STUDENTS						0
4.	(0) UNDERGRADUATE STUDENTS						0
5.	(0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)						0
6.	(0) OTHER						0
TOTAL SALARIES AND WAGES (A + B)							43,334
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)							16,347
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)							59,681
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING \$5,000.)							
TOTAL EQUIPMENT							0
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)							0
2. FOREIGN							0
F. PARTICIPANT SUPPORT COSTS							
1.	STIPENDS	\$	0				
2.	TRAVEL		0				
3.	SUBSISTENCE		0				
4.	OTHER		0				
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS							0
G. OTHER DIRECT COSTS							
1.	MATERIALS AND SUPPLIES						0
2.	PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION						0
3.	CONSULTANT SERVICES						0
4.	COMPUTER SERVICES						0
5.	SUBAWARDS						0
6.	OTHER						0
TOTAL OTHER DIRECT COSTS							0
H. TOTAL DIRECT COSTS (A THROUGH G)							59,681
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Personnel (Rate: 56.3000, Base: 59680)							
TOTAL INDIRECT COSTS (F&A)							33,600
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)							93,281
K. RESIDUAL FUNDS							0
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)							\$ 93,281 \$
M. COST SHARING PROPOSED LEVEL \$ 0				AGREED LEVEL IF DIFFERENT \$			
PI/PI NAME Thomas R Rimmele				FOR NSF USE ONLY			
ORG. REP. NAME* Maxine Kahn				INDIRECT COST RATE VERIFICATION			
		Date Checked	Date Of Rate Sheet	Initials - ORG			

SUMMARY PROPOSAL BUDGET Cumulative

ORGANIZATION AURA/National Optical Astronomy Observatories				FOR NSF USE ONLY			
				PROPOSAL NO.	DURATION (months)		
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Thomas R Rimmele				AWARD NO.	Proposed	Granted	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)				NSF Funded Person-months		Funds Requested By proposer	Funds granted by NSF (if different)
				CAL	ACAD	SUMR	
1. Thomas R Rimmele				0.00	0.00	0.00	\$ 0 \$
2.							
3.							
4.							
5.							
6. () OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)				0.00	0.00	0.00	0
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)				0.00	0.00	0.00	0
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)							
1. (2) POST DOCTORAL SCHOLARS				18.00	0.00	0.00	75,000
2. (5) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)				26.00	0.00	0.00	138,085
3. (0) GRADUATE STUDENTS							0
4. (0) UNDERGRADUATE STUDENTS							0
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)							0
6. (0) OTHER							0
TOTAL SALARIES AND WAGES (A + B)							213,085
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)							80,381
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)							293,466
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING \$5,000.)							
TOTAL EQUIPMENT							0
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)							0
2. FOREIGN							0
F. PARTICIPANT SUPPORT COSTS							
1. STIPENDS \$ _____				0			
2. TRAVEL _____				0			
3. SUBSISTENCE _____				0			
4. OTHER _____				0			
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS							0
G. OTHER DIRECT COSTS							
1. MATERIALS AND SUPPLIES							0
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION							0
3. CONSULTANT SERVICES							0
4. COMPUTER SERVICES							0
5. SUBAWARDS							0
6. OTHER							0
TOTAL OTHER DIRECT COSTS							0
H. TOTAL DIRECT COSTS (A THROUGH G)							293,466
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)							
TOTAL INDIRECT COSTS (F&A)							165,221
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)							458,687
K. RESIDUAL FUNDS							0
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)							\$ 458,687 \$
M. COST SHARING PROPOSED LEVEL \$ 0				AGREED LEVEL IF DIFFERENT \$			
PI/PD NAME Thomas R Rimmele				FOR NSF USE ONLY			
ORG. REP. NAME* Maxine Kahn				INDIRECT COST RATE VERIFICATION			
		Date Checked		Date Of Rate Sheet		Initials - ORG	

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Budget Justification Page

The requested budget for the project is \$2,375 K from the NSF with \$464 K (19% of total) to NSO. All these funds are for MCAO personnel. This includes 0.6 FTE of Kit Richards time to supervise software development by the new hire software engineer. The software engineer is 1.4 FTE at NSO (remainder of support from BBSO) for a total of 2.5 FTE, which are split between programming the DSPs (1 FTE), programming the GUI (1 FTE) and post install debug and modification (0.5 FTE). The last part of the subcontract is 1.5 FTE to support Dr. Jose Marino for reconstruction algorithms and controls.

New Jersey Institute of Technology
Big Bear Solar Observatory / Center for Solar-Terrestrial Research
Current Support
Principal Investigator: Philip R. Goode

CURRENT SUPPORT

Project/Proposal Title: **Studies of Solar Activity with Coordinated Observations of New Solar Telescope and NASA Solar Physics Mission**

Source of Support: **NASA**

Project Position: BBSO/NJIT

Total Award Amount: \$1.5M

Total Award Period: January 1, 2009 – December 31, 2011

Person-Months per Year Committed to the Project: 2.0 (Academic), 2.0 (Summer)

Project/Proposal Title: **First Light Infrared Observations with the 1.6 Meter Telescope in Big Bear: Origins of Space Weather**

Source of Support: **AFOSR**

Project Position: BBSO/NJIT

Total Award Amount: \$334,000

Total Award Period: January 1, 2009 – December 31, 2011

Person-Months per Year Committed to the Project: 0.3 (Calendar)

Project/Proposal Title: **ATI: Development of High-Order Adaptive Optics for the 1.6 Meter Solar Telescope in Big Bear**

Source of Support: **NSF**

Project Position: BBSO/NJIT

Total Award Amount: \$900,000

Total Award Period: July 1, 2009 – June 30, 2012

Person-Months per Year Committed to the Project: 1.0 (Calendar)

Project/Proposal Title: **MRI: Development of Cryogenic Infrared Spectrograph for the 1.6M Solar Telescope in Big Bear**

Source of Support: **NSF**

Project Position: BBSO/NJIT

Total Award Amount: \$1.3M

Total Award Period: July 1, 2009 – June 30, 2013

Person-Months per Year Committed to the Project: 1.0 (Calendar)

Project/Proposal Title: **High Resolution Studies of Solar Activity with New Solar Telescope**

Source of Support: **NSF – GEO/ATM**

Project Position: BBSO/NJIT

Total Award Amount: \$1.5M

Total Award Period: April 1, 2008 – March 31, 2013

Person-Months per Year Committed to the Project: 2.0 (Academic), 1.0 (Summer)

Project/Proposal Title: **Next Generation Synoptic Telescope for Innovative Space Weather Research**

Source of Support: **AFOSR**

Project Position: BBSO/NJIT

Total Award Amount: \$212,000

Total Award Period: June 1, 2008 – May 31, 2010

Person-Months per Year Committed to the Project: 0.2 (Calendar)

Project/Proposal Title: **Solar B_Phase E Support**
Source of Support: **Lockheed Martin Corp./NASA**
Project Position: BBSO
Total Award Amount: \$540,000
Total Award Period: November 1, 2006 – October 31, 2010
Person-Months per Year Committed to the Project: 0.3 (Calendar)

Project/Proposal Title: **Helioseismic and Magnetic Imager**
Source of Support: **Stanford University/NASA**
Project Position: BBSO
Total Award Amount: \$279,000
Total Award Period: May 1, 2005 – May 31, 2010
Person-Months per Year Committed to the Project: 0.2 (Calendar)

PENDING SUPPORT

Project/Proposal Title: **MRI: Development of Multi-Conjugate Adaptive Optics for the 1.6 M Solar Telescope in Big Bear**
Source of Support: **NSF**
Project Position: BBSO/NJIT
Total Amount: \$2,345 K
Total Award Period: February 1, 2010-January 31, 2013
Person-Months per Year Committed to the Project: 2.0 (Calendar)

3 Aug 2009

Kiepenheuer Insitut fuer Sonnenphysik
Current & Pending Support

Thomas Berkefeld

PENDING Co-PI SUPPORT

Project/Proposal Title: **MRI: Development of Multi-Conjugate Adaptive Optics for the 1.6
Meter Solar Telescope in Big Bear**

Source of Support: **NSF-MRI**

Project Position: **BBSO/NJIT**

Total Award Amount: \$2,345 K

Total Award Period: February 1, 2010 – January 31, 2013

Person-Months per Year Committed to the Project: 12 (Calendar in year 1), 6 (Calendar in year 2)

27 May 2009

New Jersey Institute of Technology
Big Bear Solar Observatory / Center for Solar-Terrestrial Research
Current & Pending Support
Wenda Cao

CURRENT PI SUPPORT

Project/Proposal Title: **Developing High Resolution Infrared Instrumentation to Explore Solar Activity**
Source of Support: **NSF – CAREER**
Project Position: NJIT
Total Award Amount: \$488,835
Total Award Period: February 1, 2009 – January 31, 2014
Person-Months per Year Committed to the Project: 1 (Academic), 1 (Summer)

CURRENT Co-PI SUPPORT

Project/Proposal Title: **High Resolution Studies of Solar Activity with New Solar Telescope**
Source of Support: **NSF – GEO/ATM**
Project Position: BBSO/NJIT
Total Award Amount: \$1.5M
Total Award Period: April 1, 2008 – March 31, 2013
Person-Months per Year Committed to the Project: 0 (Academic), 1 (Summer)

Project/Proposal Title: **Studies of Solar Activity with Coordinated Observation of New Solar Telescope and NASA Solar Physics Missions**
Source of Support: **NASA**
Project Position: BBSO/NJIT
Total Award Amount: \$1.5M
Total Award Period: January 1, 2009 – December 31, 2011
Person-Months per Year Committed to the Project: 0 (Academic), 1 (Summer)

Project/Proposal Title: **First Light Infrared Observations with the 1.6 Meter Telescope in Big Bear: Origins of Space Weather**
Source of Support: **AFOSR**
Project Position: BBSO/NJIT
Total Award Amount: \$334,019
Total Award Period: January 1, 2009 – December 31, 2011
Person-Months per Year Committed to the Project: 0.5 (Academic), 0 (Summer)

Project/Proposal Title: **ATI: Development of High-Order Adaptive Optics for 1.6 Meter Solar Telescope in Big Bear**
Source of Support: **NSF-AST/ATI**
Total Award Amount: \$895,792
Project Position: BBSO/NJIT
Total Award Period: June 1, 2009 – May 31, 2012
Person-Months per Year Committed to the Project: 1 (Academic), 0 (Summer)

Project/Proposal Title: **MRI: Development of Cryogenic Infrared Spectrograph for the 1.6
Meter Solar Telescope in Big Bear**

Source of Support: **NSF-MRI/ATM**

Total Award Amount: \$1.3M

Project Position: **BBSO/NJIT**

Total Award Period: July 1, 2009 – June 30, 2013

Person-Months per Year Committed to the Project: 1 (Academic), 0 (Summer)

PENDING Co-PI SUPPORT

Project/Proposal Title: **MRI: Development of Multi-Conjugate Adaptive Optics for the 1.6
Meter Solar Telescope in Big Bear**

Source of Support: **NSF-MRI**

Project Position: **BBSO/NJIT**

Total Award Amount: \$2,345 K

Total Award Period: February 1, 2010 – January 31, 2013

Person-Months per Year Committed to the Project: 1 (Academic), 0 (Summer)

3 Aug 2009

New Jersey Institute of Technology
Big Bear Solar Observatory / Center for Solar-Terrestrial Research
Current & Pending Support

José Marino

PENDING Co-PI SUPPORT

Project/Proposal Title: **MRI: Development of Multi-Conjugate Adaptive Optics for the 1.6
Meter Solar Telescope in Big Bear**

Source of Support: **NSF-MRI**

Project Position: **BBSO/NJIT**

Total Award Amount: **\$2,345 K**

Total Award Period: **February 1, 2010 – January 31, 2013**

Person-Months per Year Committed to the Project: **12 (Calendar in year 1), 6 (Calendar in year 2)**

Current and Pending Support

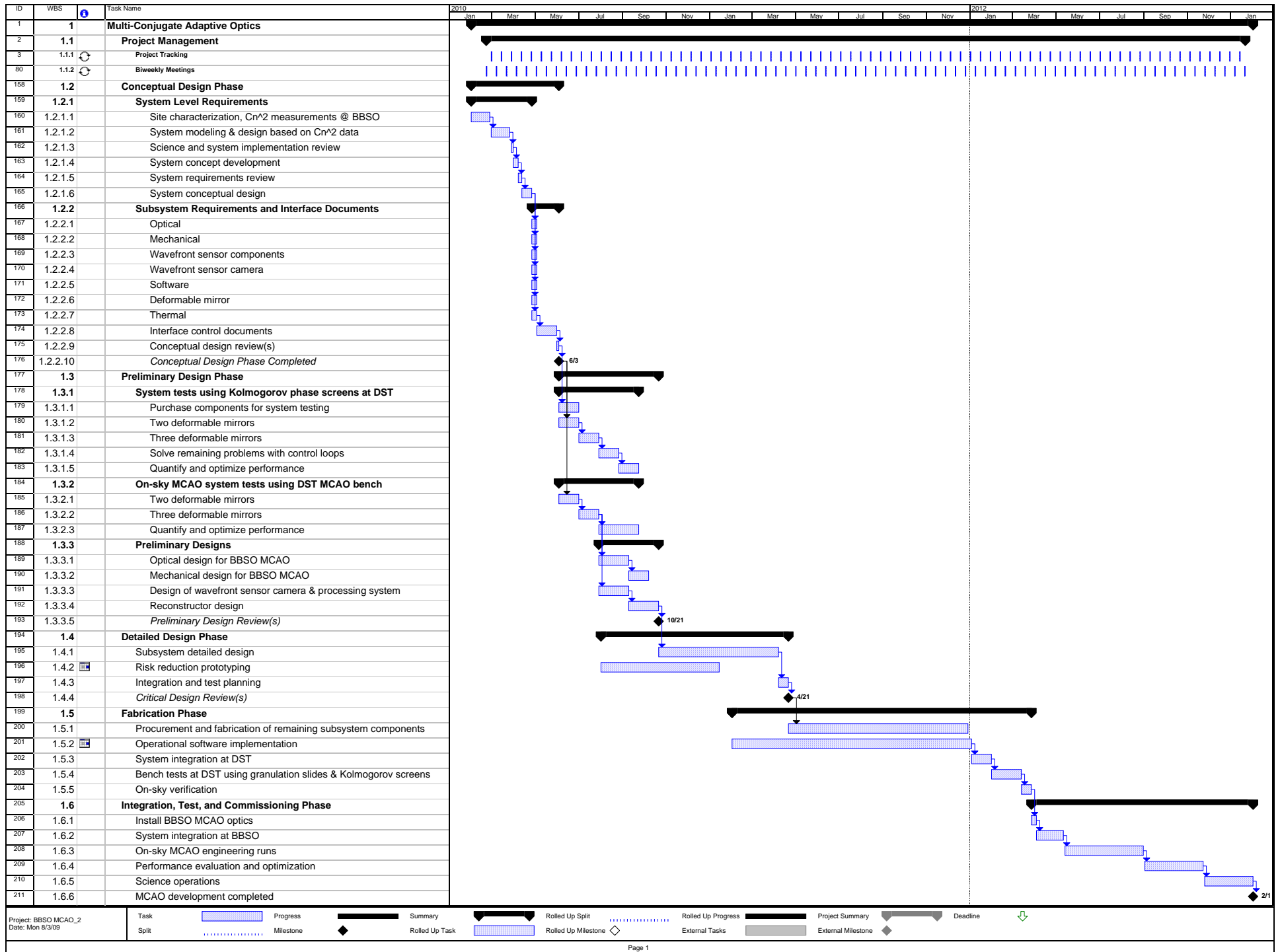
(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Thomas R. Rimmele	Other agencies (including NSF) to which this proposal has been/will be submitted. None
Support: <input checked="" type="checkbox"/> Current <input type="checkbox"/> Pending <input type="checkbox"/> Submission Planned in Near Future <input type="checkbox"/> *Transfer of Support	
Project/Proposal Title: Development of Infrared Instrumentation for High-Resolution and High-Precision Solar Magnetic Fields Observations	
Source of Support: National Science Foundation-MRI, ATM Division	
Total Award Amount: \$1,978,755.00 Total Award Period Covered: 08/01/04 – 07/31/09	
Location of Project: University of Hawaii & National Solar Observatory (Tucson & Sacramento Peak)	
Person-Months Per Year Committed to the Project. Cal: Acad: 1.20 Sumr:	
Support: <input type="checkbox"/> Current <input checked="" type="checkbox"/> Pending <input type="checkbox"/> Submission Planned in Near Future <input type="checkbox"/> *Transfer of Support	
Project/Proposal Title: Cooperative Agreement for the Management, Operation and the Maintenance of the Na-Astronomy Observatories (NOAO) and the National Solar Observatory (NSO)	
Source of Support: National Science Foundation, AST Division	
Total Award Amount: \$ 211,779,000.00 Total Award Period Covered: 04/01/09 – 03/31/14	
Location of Project: NSO Sites in Tucson, Arizona and Sunspot (Sacramento Peak), New Mexico	
Person-Months Per Year Committed to the Project. Cal: 12.0 Acad: Sumr:	
Support: <input type="checkbox"/> Current <input checked="" type="checkbox"/> Pending <input type="checkbox"/> Submission Planned in Near Future <input type="checkbox"/> *Transfer of Support	
Project/Proposal Title: Advanced Technology Solar Telescope (ATST) Construction Phase Proposal	
Source of Support: National Science Foundation	
Total Award Amount: \$253,721,000.00 Total Award Period Covered: 06/01/08 – 05/31/13	
Location of Project: NSO, NJIT/BBSO, Univ. of Hawaii, Univ. of Chicago, NCAR/HAO	
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:	
Support: <input type="checkbox"/> Current <input checked="" type="checkbox"/> Pending <input type="checkbox"/> Submission Planned in Near Future <input type="checkbox"/> *Transfer of Support	
Project/Proposal Title: Advanced Technology Solar Telescope (ATST) Construction Phase Proposal	
Source of Support: National SF	
Total Award Amount: \$253,721,000.00 Total Award Period Covered: 9 years, beginning 10/01/2009	
Location of Project: National Solar Observatory; NJIT/BBSO; Univ. of Hawaii; Univ of Chicago; NCAR/HAO	
Support: <input checked="" type="checkbox"/> Current <input type="checkbox"/> Pending <input type="checkbox"/> Submission Planned in Near Future <input type="checkbox"/> *Transfer of Support	
Project/Proposal Title: Development of High-Order Adaptive Optics for the 1.6 Meter Solar Telescope in Big Bear	
Source of Support: National Science Foundation, AST/ATI	
Total Award Amount: \$ 895,792.00 Total Award Period Covered: 06/01/09 – 05/31/12	
Location of Project: NJIT/BBSO	
Person-Months Per Year Committed to the Project. Cal: Acad: 1.0 Sumr:	

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.





Project: BBSO MCAO_2
Date: Mon 8/3/09

Task		Progress		Summary		Rolled Up Split		Rolled Up Progress		Project Summary		Deadline	
Split		Milestone		Rolled Up Task		Rolled Up Milestone		External Tasks		External Milestone			

Multi-Conjugate Adaptive Optics
1 | 0%

Project Management
1.1 | 0%

Conceptual Design Phase
1.2 | 0%

Preliminary Design Phase
1.3 | 0%

Detailed Design Phase
1.4 | 0%

Fabrication Phase
1.5 | 0%

Integration, Test, and Commissioning Phase
1.6 | 0%

Project Tracking
1.1.1 | 0%

Biweekly Meetings
1.1.2 | 0%

System Level Requirements
1.2.1 | 0%

Subsystem Requirements and Interface Documents
1.2.2 | 0%

System tests using Kolmogorov phase screens at DST
1.3.1 | 0%

On-sky MCAO system tests using DST MCAO bench
1.3.2 | 0%

Preliminary Designs
1.3.3 | 0%

Subsystem detailed design
1.4.1 | 0%

Risk reduction prototyping
1.4.2 | 0%

Integration and test planning
1.4.3 | 0%

Critical Design Review(s)
1.4.4 | 0%

Procurement and fabrication of remaining subsystem components
1.5.1 | 0%

Operational software implementation
1.5.2 | 0%

System integration at DST
1.5.3 | 0%

Bench tests at DST using granulation slides & Kolmogorov screens
1.5.4 | 0%

On-sky verification
1.5.5 | 0%

Install BBSO MCAO optics
1.6.1 | 0%

System integration at BBSO
1.6.2 | 0%

On-sky MCAO engineering runs
1.6.3 | 0%

Performance evaluation and optimization
1.6.4 | 0%

Science operations
1.6.5 | 0%

MCAO development completed
1.6.6 | 0%

Site characterization, Cn² measurements @ BBSO
1.2.1.1 | 0%

System modeling & design based on Cn² data
1.2.1.2 | 0%

Science and system implementation review
1.2.1.3 | 0%

System concept development
1.2.1.4 | 0%

System requirements review
1.2.1.5 | 0%

System conceptual design
1.2.1.6 | 0%

Optical
1.2.2.1 | 0%

Mechanical
1.2.2.2 | 0%

Wavefront sensor components
1.2.2.3 | 0%

Wavefront sensor camera
1.2.2.4 | 0%

Software
1.2.2.5 | 0%

Deformable mirror
1.2.2.6 | 0%

Thermal
1.2.2.7 | 0%

Interface control documents
1.2.2.8 | 0%

Conceptual design review(s)
1.2.2.9 | 0%

Conceptual Design Phase Completed
1.2.2.10 | 0%

Purchase components for system testing
1.3.1.1 | 0%

Two deformable mirrors
1.3.1.2 | 0%

Three deformable mirrors
1.3.1.3 | 0%

Solve remaining problems with control loops
1.3.1.4 | 0%

Quantify and optimize performance
1.3.1.5 | 0%

Two deformable mirrors
1.3.2.1 | 0%

Three deformable mirrors
1.3.2.2 | 0%

Quantify and optimize performance
1.3.2.3 | 0%

Optical design for BBSO MCAO
1.3.3.1 | 0%

Mechanical design for BBSO MCAO
1.3.3.2 | 0%

Design of wavefront sensor camera & processing system
1.3.3.3 | 0%

Reconstructor design
1.3.3.4 | 0%

Preliminary Design Review(s)
1.3.3.5 | 0%

Quote

100 Dey Road
Wayne, New Jersey
07470 USA
T: +1.973.696.4500
F: +1.973.696.0560
sales@
visionresearch.com



www.visionresearch.com

Quote ID : QU4530

Revision : 1

Page Number : Page 1 of 1

When remitting your order please use the Vision Research main office information to the left and reference the Quote ID above.

Sold To : CUS4000 Big Bear Observatory 40386 North Shore Lane Big Bear City, CA 92314 USA	Ship To : Big Bear Observatory 40386 North Shore Lane Big Bear City, CA 92314 USA
Quote Date: 8/4/2009 Expir. Date: Contact:	Currency Type : USD AR Terms: 1%-10; Net 30 Upon Approval

Line Nbr	Item ID Item Name / Cust Item ID	Taxable	Req Qty	Unit Price	GSA	Sales Tax Percent Sales Tax Amt	Extended Price
1	VRI-V7.3-2048MM-RTO PHANTOM, V7.3 MONOCHROME CAMERA, 2 GB MEMORY 1US SHUTTER, 14-BIT, PIV, RTO	No	7.00	\$53,675.0000		0.00% \$0.0000	\$375,725.00
Line Comments :		Includes real time output option.					
2	VRI-GF100-MTP CABLE, MULTI-MODE 50/125 12 FIBER OFNP MTP-F TO MTP-F GLASS FIBER FOR I3 (100 FT COIL) MAX 1500 FT	No	7.00	\$570.0000		0.00% \$0.0000	\$3,990.00
3	VRI-SC-V7.3-2YR SERVICE CONTRACT, TWO YEAR FOR V7.3	No	7.00	\$5,715.2000		0.00% \$0.0000	\$40,006.40
Line Comments :		Extended warranty/service contract. Extends standard warranty to 3 years (1 year warranty + 2 year extension). OPTION					

Total:	\$419,721.40
VAT Freight:	\$0.00
Total Extended Price:	\$419,721.40

Additional Instructions: Questions? Call Larry Vladic at 949-635-9053
larry.vladic@visionresearch.com

From: Price, Thomas R (Space Technology) <<mailto:Thomas.Price@ngc.com>>
To: Philip Goode <<mailto:pgoode@bbsso.njit.edu>>
Sent: Monday, November 03, 2008 11:12 AM
Subject: RE: Price Quote from Xinetics

Phil,

349ch mirror with 5mm actuator spacing	DMHD-349-S4	\$275,000
349ch Driver	EA349HVA48	\$175,000

577ch mirror with 5mm spacing	DMHD-577-S4	\$450,000
577ch Driver	EA577HV48	\$275,000

When purchasing a mirror with a Xinetics driver, there is a 1 year warranty on both units.

If you need more information feel free to contact me. We can also provide custom devices based on your application needs. We have some different technologies that may be a better fit to your application depending on the problem you are trying to solve. We can make some suggestions if you let us know what you are trying to do.

I have also attached catalog sheets for the mirrors and driver.

Regards,

Tom Price



August 5, 2009

9 Hills Avenue
Suite B
Concord, NH 03301
Phone: 603-226-0404
FAX: 603-226-6667

QUOTE # BUDGETARY ROM QUOTE 08-04-09

BittWare, Inc. is pleased to provide the following budgetary quotation for the following integrated system.

Item 1. Integrated System*	Quantity	Price
SY6U-NSO-001	1	\$349,702

*The Integrated System includes all of the following items.

Part #	Description	QTY
HardWare		
1	RS-EL-TBD Elma 12C, 19" Rack Mount, cPCI enclosure system, with 11 slot backplane, 64-bit 33MHz	2
2	RS-CO-P421/231-13 Concurrent cPCI SBC with 1.66 Ghz Dual Core Xeon CPUs, 4 GB DRAM	2
3	RS-CO-AD-CP1/DR1-73 Concurrent Disk Drive Fitting	2
4	RS-MS-WINDOWS-XP Microsoft Windows XP	2
5	RS-IDE-HDD-NHD-120GB 120GB IDE Notebook Hard Disk Drive	2
6	RS-CDR-DVD CD-R, DVD Drive	2
7	T26U-0U-4450-306-1177 Octal TS201 6U cPCI board, populated with Virtex Pro (30/6) and 256MB SDRAM per cluster (7 in one system 8 in another)	15
8	T26T-CUSTOM Custom Rear Transition Module for T2	15
9	RS-FJ-FPD-010R008-0E Fiber Connector from Fujitsu FPD-010R008-0E	14
10	RS-FC-FCP1925-2-0 Fiber Cable from Fiber Connection, Custom 50/125 10GbE MTP(f) 12F Plenum Ribbon Std pol. MTP Jumper - 2 Meters - 0 PKs	7
11	CAIB-0050 Infiniband Cables .5 meters	45
12	RS-EL-80-616CJB-00 ELMA Slot blocker	5
SoftWare		
1	BittWorks-Platinum-02 BittWork's Platinum Bundle includes BittWorks Gold (DSP21K-SF-32-01, VDSP-SF-Target, TS Libs Full) and VDSP++ and HPUSB-ICE	1

- 1) This Quotation includes standard product documentation.
- 2) Prices do not include shipping. FOB Origin.
- 3) Pricing assumes total system pricing.
- 4) Terms are 50% up front, 50% at delivery.
- 5) Delivery is 16-18 weeks ARO.
- 6) Pricing is currently based on ROM

Thank you for the opportunity to quote your application requirements. Please contact me if I can be of further assistance. This quote is valid for 30 days.

Sincerely,

Lacey Brown
(603) 226-0404x513
lbrown@bittware.com

Mentoring of Postdoctoral Associates in MCAO Development Project:

The MCAO Development Project will hire two postdoctoral associates. The first is Dr. Jose Marino who earned his Ph.D. from NJIT in adaptive optics. Jose will be working on this project as a postdoctoral associate. He will be primarily mentored by Thomas Rimmele (who served as his PhD thesis advisor) and has been guiding his work in adaptive optics and MCAO, in particular, since Dr. Marino graduated. He resides at the University of Florida and his support in our MCAO project will come from the subcontract to NSO. Marino will spend extended periods where the MCAO experiments are on-going. He has a close relation with nearly all members of the team, but has been advised on a nearly daily basis by Rimmele over the last several years (both before and after finishing his PhD). Marino will play a key role in the lab and on-sky MCAO experiments. He is developing skills that ensure a bright future as a scientist who builds instruments. The second postdoctoral associate will be a new hire and will split time between NSO and BBSO. He/she will be mentored in the same manner as Marino and will work on MCAO experiments, integration and testing at the DST and NST, and do performance characterization of the MCAO system. He/she will benefit from collaboration with the full team, as well as a close working interaction with Rimmele. in this essential task in the MCAO project.

The resulting data from the MCAO will be important sources for graduate and undergraduate research. The NST will also become a teaching tool for optics, mechanics, computer control and solar physics.



New Jersey Institute of Technology
University Heights
Newark, NJ 07102-1982
973.596.8449
973.596.6056 fax
sebastian@njit.edu

Donald H. Sebastian, Ph.D.
*Provost (Interim) and
Sr. Vice President for R&D*

August 5, 2009

Office of Integrative Activities National Science Foundation
Major Research Instrumentation Program
4201 Wilson Blvd. Arlington, VA 22230

Dear NSF Program Manager:

I am pleased to write on behalf of Professor Phil Goode's application to this year's special ARRA-funded National Science Foundation Major Research Instrumentation Program - Recovery & Reinvestment. His proposal entitled "MRI: Development of Multi-conjugate Adaptive Optics for the 1.6 M Solar Telescope in Big Bear" is an important extension to the capabilities of the newly commissioned optical telescope at our Big Bear Solar Observatory. It is currently the world's largest platform for ground-based observations of the sun and not only will this instrument add considerable enhancement to image quality and resolution, it will serve as a test bed for a variety of instrumentation concepts that will be integrated into the planned ATST. NJIT regards BBSO as its premier scientific research venue and has made millions of dollars of investment to transform the site to world-class status since acquiring it from Cal Tech in 1995. NJIT's commitment to its solar observatory is further reflected in the half-million dollar match, including \$100K for hardware for the project even though no match is required.

NJIT is one of three public, doctoral universities in the state of New Jersey. It offers the Ph.D. degree across nineteen different programs, graduating more than 50 Ph.D. candidates per year. Its annual research expenditures are over \$90M with Federal funding of over \$30M. This does not place it in the top 100 universities and thus NJIT is exempt from the cost-sharing requirement. The university enrollment is about 65% undergraduate, and although neither an MI nor HBCU, NJIT is one of the top 25 institutions in the country in the number of graduating engineers who are Hispanic and African American. We include undergraduate research experiences and rich capstone design projects as key elements of that undergraduate experience

Consequently, if granted this equipment will make a substantial improvement in NJIT's capabilities to conduct leading-edge research; it will be used to enhance our ability to offer research experiences for undergraduate students using leading-edge facilities; and it will broaden the participation in science and engineering research by women, underrepresented minorities and persons with disabilities. Please contact me if you need any additional data on our academic enterprise.

Thank you, and please contact me with any questions regarding institutional support for this request.

Sincerely,

A handwritten signature in black ink, appearing to read "D. Sebastian", written over a horizontal line.

Donald H. Sebastian, Ph.D.

Provost (Interim) & Sr. Vice President for Research & Development



NSO/Tucson
950 N. Cherry Avenue
P.O. Box 26732
Tucson, AZ 85726-6732
Ph. (520) 318-8294; Fax (520) 318-8278
Email: nso@noao.edu

NSO/Sunspot
P.O. Box 62
Sunspot, NM 88349-0062
Ph. (505) 434-7000
Fax (505) 434-7029 or 7079
Email: nso@sunspot.noao.edu

3 August 2009

Dr. Phil Goode, Director
Big Bear Solar Observatory (BBSO)
40386 North Shore Lane
Big Bear City, CA 92314-9672

Dr. Thomas Rimmele
POB 62
National Solar Observatory
Sunspot, NM 88349

Dear Phil and Thomas,

This is to confirm the commitment of the NSO to fulfill its obligations in connection with the proposal titled "MRI: Development of Multi-Conjugate Adaptive Optics for the 1.6 Meter Solar Telescope in Big Bear". The NST MCAO can be considered a valuable and important development effort for a future MCAO upgrade for the ATST. We are looking forward to collaborating with you on developing this important technology and implementing MCAO on the NST.

Sincerely yours,

A handwritten signature in black ink that reads "Stephen L. Keil".

Stephen L. Keil, Director
National Solar Observatory
Sunspot, NM 88349 (505 434-7039)

Kiepenheuer-Institut für Sonnenphysik | Schöneckstrasse 6 | 79104 Freiburg | Deutschland

Prof. Dr. Phil Goode
Director, Big Bear Solar Observatory
40386 N. Shore Lake
Big Bear City, CA 92314
USA

Schöneckstraße 6
79104 Freiburg im Breisgau
Deutschland
Telefon: +49 761 3198-0
Fax: +49 761 3198-111
E-Mail: ovdluhe@kis.uni-freiburg.de
Internet: www.kis.uni-freiburg.de

Freiburg, den 07.08.2009
Prof. Dr. Oskar von der Lüche

Dear Phil,

this is to confirm the commitment of the Kiepenheuer-Institut to fulfil its obligations in connection with the proposal to the National Science Foundation titled „MRI: Development of Multi-Conjugate Adaptive Optics for the 1.6 Meter Solar Telescope in Big Bear“.

We are looking forward to collaborating with you and with NSO on implementing multi-conjugate solar adaptive optics at the Big Bear and Gregor solar telescopes. With the Gregor MCAO getting ready for system tests at the optics laboratory of the Kiepenheuer-Institut, this is clearly the right time to strengthen our community by an intense exchange of experience, personnel and data. The NST and Gregor will be the first solar telescopes equipped with comprehensive adaptive optics which will revolutionize or field of experimental research.

Sincerely,



Prof. Dr. Oskar von der Lüche
Director