

## OBSERVING TIME PROPOSAL FORM FOR NEW SOLAR TELESCOPE (NST)

### Important Notes:

#### Two Proposal Submission Deadlines:

- 15 April 2015 for Session 1 (May 1 - June 30)
- 1 June 2015 for Session 2 (July 1 - 31 and September 15 - October 31)

1. Time window available for 2015: May 1 - July 31 and September 15 - October 31;
2. For the information of NST and BBSO, please visit <http://www.bbso.njit.edu>;
3. For the instrument information, feel free to contact Prof. Wenda Cao at [wcao@bbso.njit.edu](mailto:wcao@bbso.njit.edu);
4. Final decision on telescope allocation for session 1 and session 2 will be made no later than April 25 and June 15 2015, respectively by BBSO Telescope Allocation Committee (TAC). High priority may be given to the PIs who produced good scientific results from the previous observations, to the proposals with scientifically challenging and achievable objectives, and the observing proposal with coordinated observations.

**Make sure to submit your proposal in PDF format to Wenda Cao (TAC chair) via [wcao@bbso.njit.edu](mailto:wcao@bbso.njit.edu) before the deadlines**

Qualified internal and external applicants:

1. Internal applicants refer to the scientific staff residing at BBSO, scientists and students in NJIT's Center for Solar-Terrestrial Research, and BBSO partners.
2. External applicants refer to the scientists and students from the institutes or universities in USA recognized by NSF or NASA.
3. The PI must have a PhD degree or be a PhD student with the supervisor as the Co-I.

### Acknowledgement Requirement:

Please acknowledge BBSO and the instrument PIs in the paper relevant to this observation:  
*BBSO operation is supported by NJIT, US NSF AGS-1250818 and NASA NNX13AG14G*

# 1 General Information

## 1.1 Applicant Name and Affiliation

---

<b>PI:</b>	<b>Phil Goode</b>	New Jersey Institute of Technology
<b>Co-I*:</b>	<b>Dirk Schmidt, Jose Marino</b>	National Solar Observatory (and BBSO)
<b>Co-I*:</b>	<b>Nicolas Gorceix, Wenda Cao</b>	New Jersey Institute of Technology

---

\*Note that Co-Is have the same data access rights as the PI. Please coordinate data access among team members.

## 1.2 Proposal Information

---

- Renewal or continuation
- Linked to US NSF funding
- Linked to NASA funding
- Linked to a PhD thesis in preparation and led by a PhD student
- A coordinated observation with a ground-based telescope
- A coordinated observation with a space-based observatory (e.g. IRIS or Hinode)

## 1.3 Observing Conditions

---

- Good Seeing
- Sky Clarity
- Low Water Vapor
- Specific Solar Activity
- Quiet Sun Observation
- Solar Limb Tracking

## 1.4 Preferred Observing Date and Time\*

---

- Fixed Date: 21 Sept. - 2 Oct 2015
  - Flexible Date: 5 - 7 days
  - Fixed Observing Time: 18:20:45 UT - 19:00:05 UT
  - Suggested Observing Time: 16:30:00 UT - 22:30:00 UT
  - Observing Conditions Permitting
- 

\*Note that Fridays may be occupied for telescope engineering time.

## 2 Scientific Rationale

### 2.1 Title

#### MCAO Studies Using 1.6 m NST

### 2.2 Abstract

NSF-ATI is funding development of the NST's MCAO system bringing it from engineering first light to an operational system. This is the third two week run in this project. In the first run with a rough setup, we closed the loop and obtained MCAO corrected images with two DMs. We plan to do this with three DMs. For the second run in May 2015 we were largely shutout due to weather. We remain eager to test our new and more sophisticated setup. The goals are 1) determine the optimal order of DMs, in particular where in the sequence of DMs should one place the pupil DM - conventional wisdom says that the pupil DM comes first.; 2) we plan to test the order of the wavefront sensors (WFSs). To date the pupil WFS has been upstream of the two high altitude DMs. This choice is the subject of controversy and we need to know what is the optimal location of the DMs in the optical stream. 3) We plan to include a much more sophisticated reconstructor that will improve statistics; 4) observe with all three DMs. 2), 3) and 4) will benefit from good seeing. Again, our May 2015 run was mostly cloudy, so we need to make up that time.

### 2.3 Short Summary of the Request

We have re-designed the MCAO setup and this superior design has been implemented to make it easy to swap between classic single mirror AO and MCAO and to address various handling issues, as well as testing the various possible MCAO configurations for the DMs and WFSs.

The proposed September 2015 observations have three fundamental objectives that are essential for solar MCAO project, in general and the BBSO MCAO project in particular.

First, we need to test DM1 and DM2 on-sky after their being re-polishing over the Summer of 2015. They need to be polished with electrical bias to increase the Strehl of each by about 50%.

Second, the plans include using the on-axis WFS in the MCAO focus while relocating one DM to the pupil downstream of the high-altitude DMs (see Figure 1, scheme B). Setup A is the MCAO setup used in Feb. 2015 observations. This configuration raises two questions. First, is this the best configuration possible? Second, the WFS for the pupil DM is upstream of the high altitude DMs. Is this good, bad, right or wrong? For this run, we propose to test configuration B (weathered out in May 2015). The configuration B setup is shown in Figure 2 as set up during the May 2015 run. Now the pupil DM is last in the optical path and both WFSs are downstream of all DMs. This will be the very first test of this configuration, and GREGOR cannot test this configuration. One can argue for or against this type of configuration, but only experimentation will tell. Again, this configuration implies advantages and disadvantages

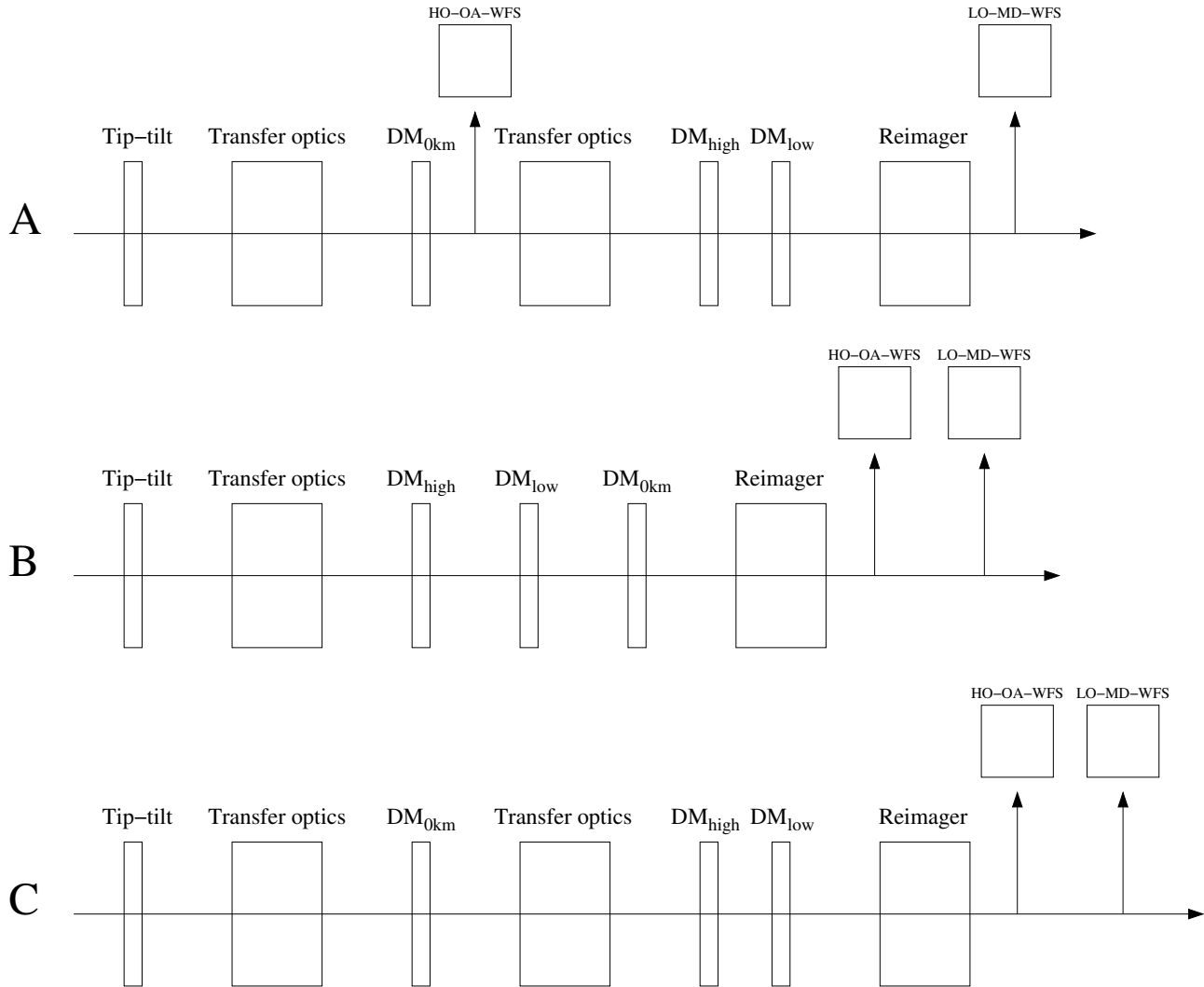


Figure 1: Wavefront correction and sensing schemes usable in NST MCAO. Each scheme deploys a deformable mirror (DM) in a pupil image and two DMs conjugate to high-altitude turbulence. Two wavefront sensors (WFS) are used at a time, a high-order on-axis WFS (HO-AO-WFS) and a low-order multi-directional WFS (LO-MD-WFS).

over the configuration that has been used so far. It will be the first ever on-Sun experiment of its kind, and hence is very exciting and important because it addresses the basic optical configuration of a solar MCAO system. We will decide during the run when, and whether to switch back to the prior configuration for a comparison based on the degree of success, as well as the effects of seeing and weather conditions. If time permits, we will also try C, which is like A except both WFSs are downstream of all DMs. There are vociferous arguments in the AO community between proponents of setup A and C, but only experiment will answer the question for solar MCAO.

The third goal is to test a fundamental modification in the reconstructor. We plan on using a statistical reconstruction matrix that Jose Marino has been using in his simulations. This method adds additional regularizations to the inversion and aims for minimization of the mean square error by taking the turbulence strength and the measurement errors into account. It is important, but difficult to determine these parameters for a real system. We also hope to

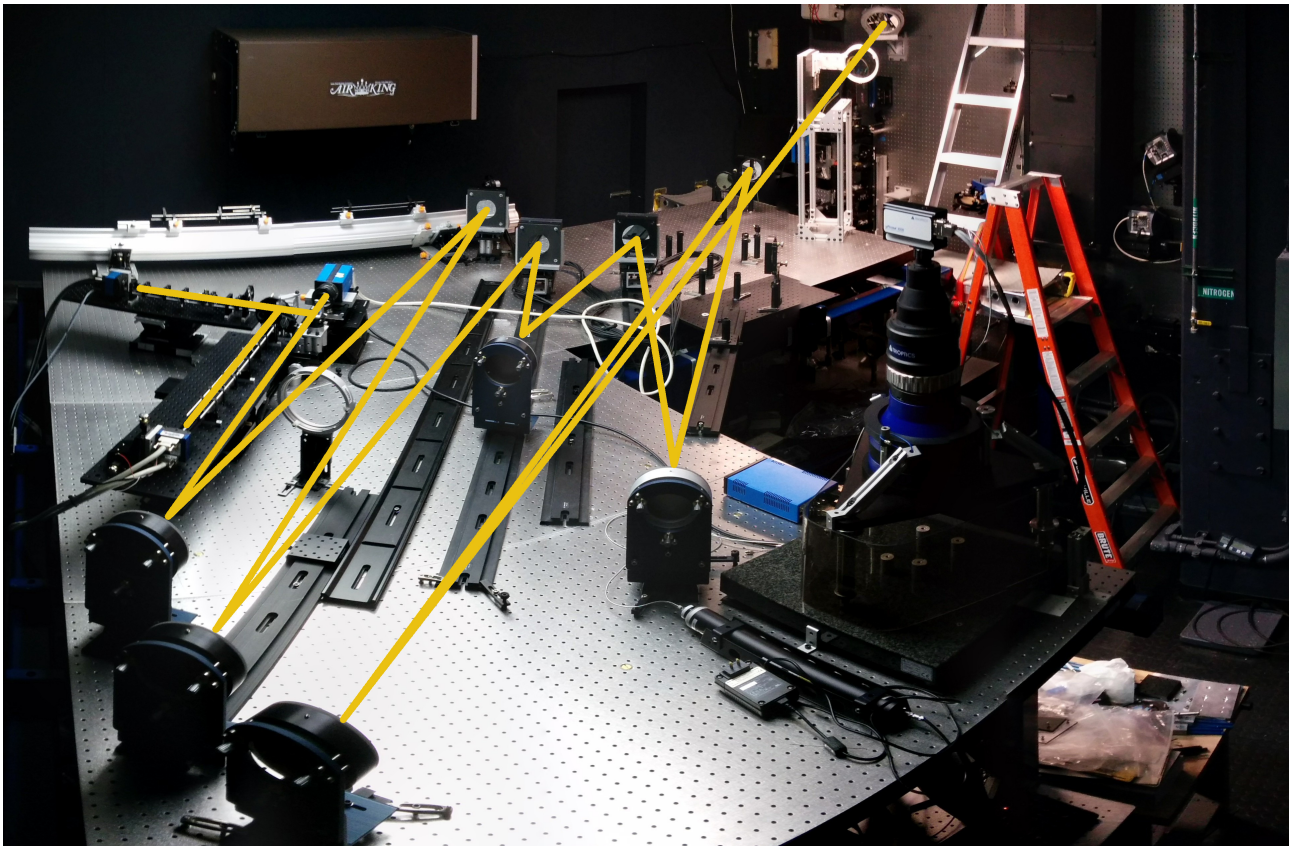


Figure 2: MCAO setup in the NST coude lab. The light comes in from the upper right of the figure and the three DMs are shown in the background with the leftmost one being the pupil DM. At the extreme left the two WFSs are shown 90 degrees apart and the science camera is blue.

benefit from good and more stable seeing and weather conditions.

As well, in the second part of what we propose here, we will push harder on including the third DM in the reconstruction. We have had marginal success in including the third DM, but success may come from a better reconstructor coupled with some good seeing and DMs with higher Strehl ratios.

We have had initial success in our MCAO runs in 2014. These were the first successful solar MCAO data at the NST. With the MCAO set up in configuration B but with only one high-altitude DM (the third DM was used for regular AO308 operations) we were able to compensate for static aberrations under lab conditions in April 2015. Now we are ready to move to the next step as detailed above and will benefit from good seeing.

We had long planned for two weeks of MCAO run in May, but that was mostly weathered-out.

We emphasize that MCAO is an essential technology for correcting the full field of view on solar observations, which in turn will enable one to make high-resolution, sub-second cadence diffraction limited observations of dynamical events like flares for the first time to elucidate phenomena that have been beyond our grasp.

At the end of the project, we plan to deliver classical AO (operational already) that is quickly switched to MCAO.

## 2.4 Results from Previous NST Observations

In February 2015 we had the first successful MCAO run (2DMs) ever recorded. This motivates the observations proposed here.

## 2.5 List of Relevant Publications

Two MCAO Papers in SPIE Meeting in Montreal in June 2014:

Optical design of the Big Bear Solar Observatory's multi-conjugate adaptive optics system  
2014SPIE.9148E..50Z Zhang, Xianyu; Gorceix, Nicolas; Schmidt, Dirk; Goode, Philip R.; Cao, Wenda; Rimmele, Thomas R.; Coulter, Roy

The multi-conjugate adaptive optics system of the New Solar Telescope at Big Bear Solar Observatory  
2014SPIE.9148E..2US Schmidt, Dirk; Gorceix, Nicolas; Zhang, Xianyu; Marino, Jose; Coulter, Roy; Shumko, Sergey; Goode, Phil; Rimmele, Thomas; Berkefeld, Thomas

## 2.6 Expected Results

Address long standing issues about the optimal ordering of DMs and an improved reconstructor leading to better statistical results in MCAO.

# 3 Observing Program

Utilize the new, improved MCAO Setup we have in place and record data with science camera.

## 3.1 Instrumentation Requirements\*

- Adaptive Optics (AO-308)
- Broad-band Filter Imager (BFI)
- Fast Imaging Solar Spectrograph (FISS)
- Visible Imaging Spectrometer (VIS)
- Infrared Imaging Spectro-polarimeter (NIRIS)
- Cryogenic Infrared Spectrograph (CYRA)
- Other

\*Note that FISS and VIS can't be used simultaneously. CYRA can't operate with all other instruments simultaneously.

## **3.2 Observational Strategy**

Alternate placement of on-axis DM and reconstructors and record and determine post-facto the precision of the results from the DM order switching and the utility of the improved reconstructor.

The better the seeing the more useful the scheduled observations will be. So we need observations during good seeing season to motivate work through the winter in preparation for Summer 2016.