Service-Mode Observations for Ground-Based Solar Physics

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Abstract. There are significant advantages in combining \textit{Hinode} observations with ground-based instruments that can observe additional spectral diagnostics at higher data rates and with greater flexibility. However, ground-based observations, because of the random effects of weather and seeing as well as the complexities data analysis due to changing instrumental configurations, have traditionally been less efficient than satellite observations in producing useful datasets. Future large ground-based telescopes will need to find new ways to optimize both their operational efficiency and scientific output.

We have begun experimenting with service-mode or queue-mode observations at the Dunn Solar Telescope using the Interferometric Bidimensional Spectrometer (IBIS) as part of joint \textit{Hinode} campaigns. We describe our experiences and the advantages of such an observing mode for solar physics.

1. Ground-Based Solar Observations

Even with the many important space-based observatories, ground-based instruments will continue to provide unique observations unavailable from space, primarily because of the availability of higher spatial resolution or light collecting power, the much greater data rates that can be achieved, and the higher level of flexibility, for example in real-time targeting or instrument upgrades.

High-resolution solar observations are characterized by observing programs full of tradeoffs that are made based on the specific scientific goal\textsuperscript{1}. Limitations on instrumentation, detectors, terrestrial atmosphere, and photon flux require decisions on observed wavelengths, image scale, cadence, and coverage, as examples. Since high-resolution observations have limited fields of view, the particular target on the solar surface must be selected, taking into account both the rotation of the Sun as well as the overall evolution of structures on timescales of hours.

\textsuperscript{1} While ground-based observations come in many forms, we concentrate on high-resolution observations in the visible and infrared regimes since there are many prominent facilities catering to such usage and they constitute a significant portion of the expenditures for ground-based solar physics.
Principal investigators submit observing proposals that describe their scientific goals and their choices for the tradeoffs outlined above. They also specify the type of solar structures required for their observing program. Successful proposals are generally assigned fixed periods of one to two weeks at the telescope, usually many months in advance. A portion of the “observing” time is dedicated to instrumental setup particular the specific program, often because major modifications to the instrumental configuration are desired (and allowed). For a variety of reasons, one or more of the proposers are typically present at the telescope during the full observing run. Often they are required to actually setup the instrumentation and perform observational tasks, or at least to make further choices on the observational setup in near real-time. They also perform immediate quality assurance, both in terms of monitoring the immediate conditions (i.e. the “seeing”) and checking the acquired data. Finally, given the rapid variability of the Sun, often the selection of the target requires direct visualization of the structures present at the time of the observations.

This mode of observation, commonly referred to as “classical-mode” or “visitor-mode” in astronomy, has long been the standard in solar physics. This laboratory concept, allowing scientists to manipulate instruments to construct ad hoc configurations, indeed offers a high level of flexibility in the instrumental setup and observational sequences, while providing for straightforward planning of telescope operations. It allows selected scientists to (eventually) become proficient in instrumental and observational techniques.

Clearly, however, there are many drawbacks to such an approach. The investigators must invest time and money traveling to the observatory and must labor to become proficient in the operation and intricacies of the instrumentation. They are also expected to perform their own data reduction with limited software packages and documentation. All this is for an uncertain gain given the vagaries of the weather and solar conditions. Time is lost changing setups between programs, and there is little opportunity to adapt the observational schedule to the immediate conditions. Only a few dozen observing programs can be carried out in a year, and even then the chance of successful execution remains low. All these limitations tightly constrain the scientific output of ground-based telescopes to just 10–20 papers per year.

2. Service-Mode Observations

Experience at ground-based nighttime facilities has shown that new approaches, such as service-mode observing, can offer significant gains in observational efficiency and scientific output. Service-mode operations, also known as queue or dynamic scheduling, are based on the definition of a prioritized list of observing programs by an allocation committee, and then the selection by telescope staff of the appropriate program to be run given the actual observing conditions (Silva 2002). Both VLT (Comerón et al. 2006) and Gemini (Puxley & Jørgensen 2006) perform a significant amount of their observations in such a mode (50% and 90%, respectively) and future facilities like ALMA will be operated exclusively in this mode. Given the dynamic nature of the scheduling, investigators are typically not present at the telescope when their observing program is executed.
The transition from classical to service-mode observations undertaken in nighttime astronomy during the 90’s was driven by the need to improve the efficiency and scientific output of new large facilities with high total costs (Robson 1996). In fact, the flexible scheduling not only allows more programs to be run, but also ensures that the highest ranked proposals have the best chance of being completed. An essential advantage is that it improves the odds that the moments of above-average atmospheric conditions are used for programs requiring the best conditions. This mode also facilitates observations of targets of opportunity and programs requiring observations spread over many weeks or months.

Solar physics is facing a very similar situation as it moves toward the construction of large-aperture solar telescopes such as ATST and EST. These facilities will be expensive and will require commensurate annual operational budgets. With costs comparable to current 8–10 meter telescopes, they will be expected to achieve a similar level of scientific output, namely resulting in upwards of 50–100 papers published per year using data from the telescope. To achieve this goal it will be crucial to increase the number of observing programs that are run each year in concert with a broadening the currently limited user-base for ground-based solar observations.

Solar physics would be well served by the flexible scheduling of service-mode observations. The success of many scientific programs requires simultaneously satisfying at least two conditions that both have significant temporal variability — acceptable atmospheric conditions and suitable solar features. Achieving the necessary intersection of these two parameters is arguably more critical than the presence of the investigator at the telescope. If the observing program has been well defined in advance, one remaining element possibly requiring investigator input at the time of the observations is the selection of the target. This is different from many nighttime observations because the structures on the solar surface are rapidly evolving and high-resolution instruments tend to have small fields-of-view that cover only a portion of features such as active regions or filaments. The presence of a resident astronomer at the telescope and the possibility of real-time feedback from the investigator may nonetheless allow for reliable choice of target in the majority of cases.

As an additional advantage, the ability to switch observing programs as the seeing conditions vary during the day, for example performing coronal or IR observations in the afternoon, would allow for an efficient usage of the sunlight hours. It will be imperative to develop science programs that can be productively carried out even during periods of “sub-optimal” seeing conditions. Long-term programs, such as high-resolution synoptic observations, would also be enabled by dynamic scheduling.

Supporting service-mode operations requires an extensive support infrastructure throughout the facility, extending from the observation planning and program execution through data processing and delivery. In a planning phase, investigators will need to provide a full description of their program requirements and the desired observational setup. Mechanisms must be put in place to smoothly manage the experiment queue. Additional or more highly trained staff may be needed to support such an approach. There are certainly additional costs involved with the implementation of such a system. However, given the
significant baseline operation expenses, improvements in the efficiency of the facility will probably be well worth their incremental costs.

This mode of operation also places certain demands on the instrumentation. It must be possible to adapt to different observing programs within a short period of time. The calibration sequences must be well defined and able to be shared, if possible, among different observing programs. Having common data acquisition procedures allows for the development of a standard reduction pipeline able to produce usable data for a wide range of potential users.

Some of the greatest problems associated with the transition to service-mode scheduling may not be technical, but cultural [Padman 1996]. Current users of solar telescopes will have to be satisfied at times with less hands-on time at the telescope. Members of the community who don’t currently use ground-based data need to be encouraged to become “customers” of these facilities. Open access to ground-based data, as is standard with many satellites, can also aid in increasing the usage of the facility. The more uniform approach to data acquisition and calibration inherent in service-mode observations can greatly improve the ability to effectively share acquired data among different researchers.

3. Service-Mode Tests with Hinode

Spacecraft, by their nature, typically operate using a dynamically scheduled approach. This is indeed the case with the Hinode satellite [Kosugi et al. 2007], which is also notable because the SOT has a suite of instruments with similar capabilities to those of high-resolution ground-based telescopes [Tsuneta et al. 2008]. These instruments have a broad group of users from a variety of backgrounds and a high rate of scientific output (we note that Hinode data analysis is greatly simplified by not having to contend with the variability of the terrestrial atmosphere). This serves as an indication of the viability of using a similar scheduling approach for ground-based telescopes.

The Interferometric Bidimensional Spectrometer (IBIS; Cavallini 2006) installed at the Dunn Solar Telescope (DST) appears well suited to support service-mode type observations. The instrument can be tailored to different observational programs with simple changes of configuration files and software controls, without any hardware modification. The characteristics of IBIS are well calibrated and the resident observers are able to efficiently operate the instrument even in the absence of the investigators. Finally, the data reduction process is well understood and a standard data reduction pipeline is under development. Previous tests using a queue of backup observing programs to be run during otherwise unused time have also been carried out previously using the Diffraction-Limited Spectropolarimeter (DLSP; Sankarasubramanian et al. 2004).

Because the IBIS imaging spectroscopy of the chromospheric Hα and Ca II 854.2 nm lines is highly complementary to the Hinode data, the service-mode observations were scheduled as part of two coordinated campaigns in April and July 2008. During these periods, five separate observing programs were run, with the different programs being chosen on the basis of the solar features present.

The principal investigators provided requests for the desired spectral lines and sampling, but none were present at the telescope. Ground-based observations are subject to variable seeing conditions, so not all of these datasets were
of acceptable quality. Several of the better datasets have been fully reduced and provided to the investigators and the results from these observations are expected to be published in the future.

4. Conclusions

We have shown that service-mode observations at a ground-based telescope, given instruments well adapted to such use, are feasible and may be a more efficient means to provide some users with high-resolution data. Many scientists may not have the time or observational experience to commit to an observing run at a ground-based telescope within the traditional framework. Service-mode scheduling gives more highly rated programs a better chance of being executed. Such dynamic scheduling would ensure that programs are only run when their pre-defined conditions, both in the terrestrial and solar atmosphere, are satisfied.

We believe such an approach will be crucial for future large-aperture solar telescopes such as ATST and EST. The systems needed to support such a scheduling approach are best designed as an integrated part of such an observatory. There is still much to be learned on the best ways to schedule and perform such observations. Some can be drawn from the nighttime practices, but there are many aspects that are particular to solar observations which require further experimentation. It is not clear, for example, how involved the investigator needs to be in the detailed choice of the target at the time of observation.

Experience at nighttime facilities has shown that it takes some time for a community to become familiar with the advantages and tradeoffs that are inherent in service-mode observing but in the end this approach is generally broadly endorsed \(\text{[Comerón et al. 2006]}\). By introducing this model to the community now, its wider application in the initial operational phases of these new facilities may proceed more smoothly. All of this argues for continued trials of service-mode scheduling at existing solar facilities.

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