Approaches to Optimize Scientific Productivity of Ground-based Solar Telescopes

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Summary

This white paper seeks to emphasize the scientific and strategic value to the solar physics community of scientific programs that combine physical diagnostics from multiple regimes of the solar atmosphere. High-resolution, ground-based observations provide a range of observational details of the lower solar atmosphere, that could profitably be combined with simultaneous transition region and coronal observations, and compared to simulated observables from the increasingly realistic magneto-hydrodynamic (MHD) simulations. Notable advances could be made with existing instrumentation and would serve to prepare and foster the community for the Advanced Technology Solar Telescope (ATST). Support for development of robust, user-friendly data-reduction pipelines for ground-based instruments and service-mode operations are key elements in lowering the barriers of entry for non-traditional users of ground-based telescopes.

Recommendations

The challenge is to develop a strong US community, including multiple universities, that is able to make use of the unique capabilities of ground-based observations to perform innovative science covering a broad range of topics. This robust community will be crucial to producing the significant and sustained scientific output necessary for upcoming facilities such as ATST.

To achieve this, we encourage funding agencies to provide support for:

a) meetings, exchange programs, and outreach to the community with the goal to identify and foster scientific investigations that can contribute to a comprehensive picture of the dynamic solar atmosphere, including comparisons of observations with MHD simulation results;
b) data analysis workshops that will help familiarize the broader community, especially university students and young researchers, with the present capabilities and techniques in ground-based solar physics;
c) university-based studentships and post-doctoral fellowships that encourage the use of multi-wavelength diagnostics for transversal studies of the solar atmosphere;
d) the development of pathfinding observational and instrumental programs using existing telescopes and facilities (including NSO's Dunn Solar Telescope and NJIT's New Solar Telescope) in preparation for ATST;

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e) the development of robust, well-calibrated data reduction pipelines to provide users with direct access to science-ready data;
f) experimentation with service-mode operations with existing high-resolution solar facilities, in preparation for its full implementation in the ATST operations.

The motivation for supporting such efforts as a viable approach to achieving new scientific insights and increased productivity from existing and future ground-based solar telescopes is outlined below.

Systems approach to the solar atmosphere

The solar atmosphere is characterized by multiple transitions in physical conditions as the density, temperature, and ionization degree vary by orders of magnitude over distances of only a few thousand kilometers or less. The pervasive solar magnetic field, present even in the quieter areas, interacts with convection and plasma motions to structure and dynamically heat the outer regions of the solar atmosphere (chromosphere, transition region, and corona) and accelerate the solar wind, in ways still not fully understood. Coupling between several mechanisms, including wave–mode conversion (Bogdan et al. 2003, Straus et al. 2008), non-linear processes caused by the density gradients (e.g. magneto-acoustic shocks, Hansteen et al. 2006), or the release of magnetic energy at small scales (De Pontieu et al. 2009; Edmonson et al. 2010) results in an intricate chain of processes producing the upward propagation and dissipation of non-radiative energy in the Sun's outer atmosphere.

Real progress in understanding this complex environment will only come from a "systems approach", in which complementary observations diagnosing different physical regimes are simultaneously obtained in order to encompass the full complexity of the magnetized plasma and its dynamic behavior. Our ability to pursue such an approach is facilitated by the current availability of powerful observational and theoretical tools: space missions like Hinode and SDO have been designed to explore at once multiple regions of the solar atmosphere, and 3D, MHD numerical simulations spanning the top of the convection zone all the way to the corona are becoming increasingly realistic.

The large apertures and large data fluxes available with ground-based telescopes in the visible, infrared, and millimeter wavelengths represent a crucial asset for this system approach, as they allow the acquisition of the most accurate observations in terms of spectral diagnostics, polarimetric accuracy, and spatio-temporal resolution of the lower solar atmosphere. These properties are essential for example to understand magneto-convection phenomena operating in the solar photosphere, such as the small-scale surface dynamo (Voegler & Schessler 2007) or the formation of pores and sunspots (Leka & Steiner 2001; Rempel et al. 2009). Ground-based facilities also provide the most efficient access to diagnostics of the chromosphere (van Noort & Rouppe van der Voort 2006; Cauzzi et al. 2008; Rouppe van der Voort et al. 2009), an atmospheric region that is increasingly understood as a crucial interface between the photospheric "source" of energy and mass and the resulting coronal structure (see also the white paper by McIntosh et al 2010). In particular, the measure of the intensity and topology of the chromospheric magnetic field at high resolution, currently possible only with ground-based instrumentation (e.g. Socas Navarro 2005; Casini et al. 2009; Judge et al. 2010), holds promise of providing meaningful boundary conditions for the extrapolation of such fields in the corona, and hence an understanding of the mechanisms leading to the heating and accelerating of plasma in the corona and the solar wind.

These capabilities will only be accentuated with the arrival of the Advanced Technology Solar Telescope (ATST, Keil et al 2010), which in addition will possess coronagraphic capabilities to make possible direct measurements of the coronal magnetic field and unmatched spatial resolution for observations of coronal loop structures. Co-temporary new radio and millimeter facilities (ALMA, FASR) also will provide further, complementary diagnostics on the upper solar atmosphere.

Community Involvement

As mentioned before, multi-telescope observations have often been adopted as a fruitful venue of investigation for the solar atmosphere (e.g. the Joint Observing Programs of SOHO). Yet, while satellite data has become more accessible with the years (e.g. through the SOHO, RHESSI, and Hinode data centers), the increasingly complicated observing programs and data reduction schemes for ground-based data have made it a sometimes daunting task to analyze such observations. The striking high-resolution observations now being produced from ground-based instruments are generally the result of significant post-processing image reconstruction (van Noort et al. 2005; Woeger et al. 2008).

In order to increase the accessibility of ground-based data, developing more robust data reduction pipelines for high-resolution instruments appears mandatory. On the one hand, such a development would enable more multi-wavelength, transversal studies of the solar atmosphere. On the other, and more crucially, it would help attract more users for these instruments by drastically lowering the barriers-of-entry for the large portion of the community who are not familiar with the intricacies of reducing ground-based data. Even though well-calibrated data reduction pipelines are not trivial to develop, the delivery of reduced data has certainly contributed to the great productivity of recent space missions (the most famous example being the magnetic maps produced by MDI/SOHO), as well as the open data policy. While the stochastic nature of the atmospheric distortions certainly complicate the analysis of ground-based data, so far only few resources have been available for producing robust software packages for ground-based instruments. Presently such efforts are largely unfunded for ground-based facilities, but a relatively small investment in this direction would produce a significant return from existing and future instruments.

It is our conviction that more readily available ground-based data would greatly strengthen collaborations between the now distinct "high-resolution" and "coronal" communities. This would have great scientific and strategic value as the community prepares for the arrival of ATST, which will be a major investment in the US scientific infrastructure. Achieving a significant and sustained scientific output from the facility will demonstrate the robustness of the underlying community. Performance metrics for astronomical facilities, typically related to the number of papers published using data from a given telescope scaled to operational costs (Trimble & Ceja 2008, Simons 2009) indicate the need attract a sizable user base for ATST and its data products. It is expected that ATST will attract international users as well, but a strong participation of US researchers will be crucial.

Research specialized on high-resolution, ground-based observations is currently concentrated in a limited number of universities and research centers in the US. The challenge is to develop a diverse group of users, in multiple locations, able to perform innovative science covering a broad range of topics that will in the future make full use of ATST's observational capabilities. University programs should be encouraged that train students and young researchers in the skills needed for the analysis of ground-based data, especially solar spectroscopy. The NSO User's Committee recently recommended that there be "a conscious effort to train/involve/encourage wider US participation in the user community for [ATST]." Given that most scientists and programs are already heavily overextended, this goal might be best achieved by identifying research areas in which ground-based data can contribute to ongoing scientific studies.

It is easy to find examples. Simultaneous chromospheric and coronal data would help better identify the source of transition region explosive events and coronal jets (Reardon et al. 2008; McIntosh & De Pontieu 2009). Solar flares are best studied with information about both the chromospheric mass reservoir and the coronal energy release (Fletcher 2010). Ground-based observations are crucial in the validation and refinement of MHD simulations (e.g. Leenaarts et al 2009; Fang et al. 2010) and their extension into the plasma-physics domain. Chromospheric magnetic field measurements, currently available only from the ground, may provide one of the best sources of information on the coronal field configurations (see white paper by Judge, 2010). Measurements of the changes in the chromospheric magnetic fields before and after flares can be compared to theoretical models of reconnection invoking modifications in the field configuration.

Service-mode operations is a model in which observations are scheduled on a flexible, daily basis in order to optimally match the science programs to the current observing conditions, and thus does not require the PI's presence at the telescope. This approach is increasingly common at nighttime facilities (Jorgensen et al. 2010), but is not routinely offered at ground-based solar telescopes. Yet, its implementation will lower the investment of individual researchers in getting their desired datasets while increasing the overall efficiency and scientific productivity of the facility. Such an observing mode could be implemented and experimented with using existing ground-based facilities (e.g. Reardon et al. 2009) to increase the community's familiarity with this type of observation in preparation for ATST.