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Advanced Technology Solar Telescope

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Abstract High-resolution studies of the Sun's magnetic fields are needed for a better understanding of the fundamental processes responsible for solar variability. The generation of magnetic fields through dynamo processes, the amplification of fields through the interaction with plasma flows, and the destruction of fields are poorly understood. There is incomplete insight into physical mechanisms responsible for chromospheric and coronal structure and heating, causes of variations in the radiative output of the Sun, and mechanisms that trigger flares and coronal mass ejections. Progress in answering these critical questions requires study of the interaction of the magnetic field and convection with a resolution sufficient to observe scale fundamental to these processes. The planned 4 m aperture ATST will be a unique scientific tool, with excellent angular resolution, a large wavelength range, and low scattered light. With its integrated adaptive optics, the ATST will achieve a spatial resolution nearly 10 times better than any existing solar telescope. The ATST design and development phase began in 2001 and it is now ready to begin construction in 2009.

Keywords High resolution solar observations · Solar magnetic fields · Solar dynamo · Solar telescope design

1 ATST Science

Magnetic fields control the inconstant Sun. The key to understanding solar variability rests with understanding all aspects of these magnetic fields. In a way, magnetic fields are the dark energy problem of solar physics. Only in the solar photosphere to we have direct measurements with some degree of accuracy. But even in the photosphere, the magnetic fields change so rapidly that current telescopes cannot resolve many aspects of the field, before it has evolved and the bulk of the field may exist on scales that have not been

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resolved. In higher atmospheric layers our current ability to accurately measure the magnetic field is rudimentary at best.

The photosphere is a crucial region where energy is readily transformed from convective motion into thermal and magnetic energy, and electromagnetic radiation. The energy stored in magnetic fields is eventually dissipated at higher layers of the solar atmosphere, sometimes in the form of violent flares and coronal mass ejections (CMEs) that ultimately affect the Earth and drive space weather. The photosphere, the chromosphere, transition region, and the corona are connected through the magnetic field, and therefore, have to be treated as one system, rather than as individual layers. The ATST is a crucial tool to understand this complex, interconnected physical system. Some of the scientific problems the ATST will address include the origin and generation of magnetic fields, magnetic activity and instability, chromospheric and coronal structure and heating, and sources of solar irradiance variability. A complete description of ATST science and is synergism with space missions is available at http://atst.nso.edu/science/. Below we give a brief summary.

While global dynamo models attempt to explain large-scale solar magnetic fields, the role of small-scale turbulent dynamo action at the solar surface is not understood and many questions remain: How do strong fields and weak fields interact? Does the weak-field component have a large-scale structure? What is the small-scale structure of the global component? How are both generated? How do they disappear? How do they contribute to chromospheric/coronal magnetism and heating? The ATST will address these questions by resolving individual magnetic flux concentrations and observing their emergence and dynamics. It will measure distribution functions of field strength, field direction and flux tube sizes and compare these with theoretical models. The ATST will observe plasma motions and related them to the magnetic field dynamics. ATSTs high time-cadence, high spatial resolution vector magnetograms will provide crucial information about evolution of magnetic field twist during flux emergence. To detect helicity "pumping" by Alfven waves will require a computation of electric currents inside individual flux tubes—a task well outside the scope of existing ground-based telescopes or existing and future space instruments. ATST will provide ultra-high resolution vector magnetograms allowing direct observational test of the hypothesized local dynamo. In addition, the high resolution and high time-cadence white-light images will allow direct comparison of kinetic helicity of local dynamo flows and helicity of magnetic fields generated by these flows.

Small scale flux may be the dominate form taken by the magnetic field and could be a major contributor to the energy balance of the atmospheric, in particular heating of the outer atmospheric layers and a source of energy for the solar wind. Addressing these issues requires simultaneous vector magnetometry in multiple layers of the solar atmosphere and drives the temporal resolution requirements to periods as short as a second or less. ATST will achieve the resolution and photon flux required to investigate the role of flux annihilation and MHD wave modes in generating and transporting energy to the outer solar atmosphere. ATST will provide direct measurements of magnetic flux cancellation rates in the quiet sun from magnetograms that have 16 times better resolution (pixel area) or 30 times better sensitivity (or a compromise between the two) with the 4 m ATST than with the current largest solar telescopes. The ATST will provide spectroscopic observations of sufficient resolution to study the formation, internal structure, interactions with convection, and disappearance of flux tubes and what role they play in the heating of the outer atmosphere.

Sunspots are the ideal objects for testing magnetohydrodynamic theory under astrophysical conditions. Explaining their complexity represents a strong challenge and many aspects of the behavior are not understood. The ATST will be the first telescope able to collect precision polarimetric data with a temporal cadence necessary to capture the evolution of sunspot fine structure and finally understand its physical origin. In sunspot umbrae and penumbrae, optical observations are plagued by contamination of scattered light from the bright surrounding photosphere. The ATST is carefully designed to allow observations of high resolution and low scattered light. In addition, the 4 m aperture will allow high-resolution observations in the infrared (e.g., 0.08 arcsec at 1.6 μm), where scattered light is less of a problem and much more accurate magnetic field fine-structure determination is possible. For the first time we will have magnetic field strength measurements directly from a fully split Zeeman line at this very high spatial resolution. An important goal for the ATST will be to study origins and mechanisms of solar activity such as the small-scale and rapid processes in solar flares and configurations leading to flares and CMEs. The ATST will also provide a new set of tools, in particular in the infrared, to measure magnetic fields at higher layers of the atmosphere. There is limited observational evidence that the distribution of electric currents and current helicity inside an active region varies with flares. Highly uniform sequences of high-resolution vector magnetograms of an active region before and after a flare are required to address this important issue. In order to clearly discriminate between existing models and develop a sound understanding of magnetic configurations that lead to CMEs, ATST will provide accurate magnetic field measurements in the chromosphere and corona. In particular, ATST will perform prominence magnetic field measurements and measurements of magnetic fields in the coronal helmets.

The ATST will also address many problems in chromospheric and coronal structure and heating. The ATST will have an unprecedented multi-spectral imaging capability with which true three-dimensional mapping will become routine. Simultaneous observations will regularly be conducted at more than one wavelength in the whole range of near-ultraviolet, visible, and infrared. Because the optical path in the ATST is fully reflective it is the first big telescope that will be able to observe at all these wavelengths. Its coronal capability will allow it to map coronal fields and plasma properties of coronal loops and structures

2 Design

The Advanced Technology Solar Telescope (ATST) is the first major instrument designed by the astronomical community in all of its aspects as a tool for magnetic remote sensing. ATST is an off-axis all-reflecting Gregorian telescope. The off-axis design gives the best stray-light performance, which is critical for coronal observations. The all-reflecting characteristic is the only solution that allows observations at wavelengths from 300 nm to 12 microns, often with multiple instruments observing simultaneously. Its collecting area, spatial resolution, wavelength performance, and integral focal plane instrumentation are all targeted for understanding how magnetic fields affect the physical properties of the Sun. Its 4 m aperture will provide the collecting area needed to obtain photon fluxes that allow the rapid measurement of the magnetic field and the spatial resolution (0.023" at 400 nm) needed to probe the field at its fundamental scales. Adaptive optics is integrated into the design and the AO system feeds and integral set of focal plane instrumentation.

Figure 1 shows the various components of the ATST design. The light from the off-axis, active, parabolic primary is focused on a heat stop that reflects all of the light, except for a 3–5 arcsec field of view which passes through to the active secondary mirror. It is

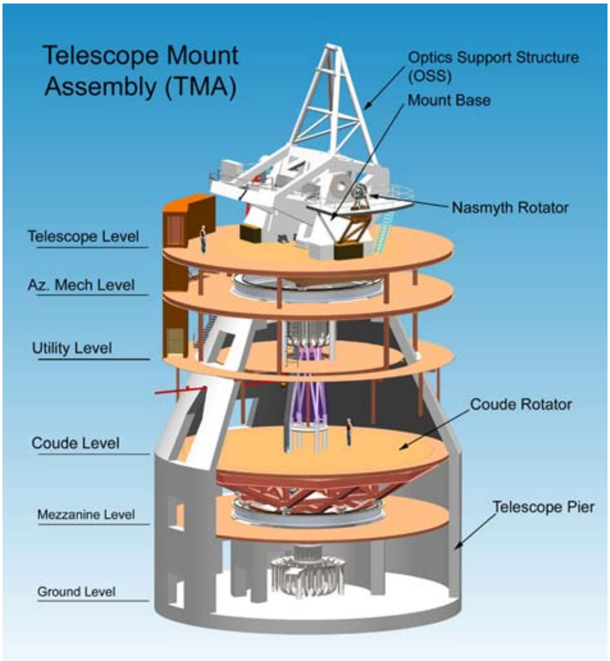

Fig. 1 Cut away showing subsystems of the ATST

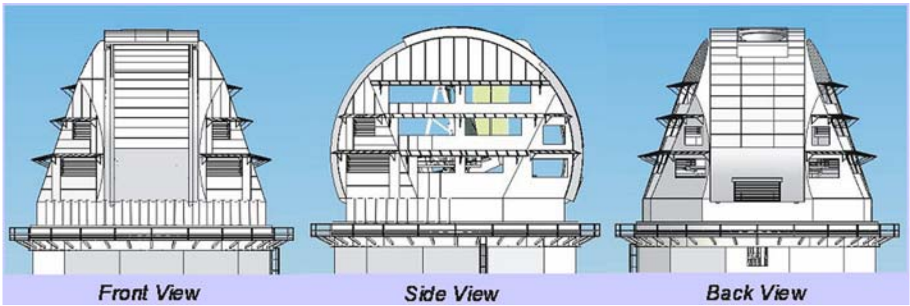

Fig. 2 Views of the ATST enclosure

then reflected to a Gregorian focus and relayed downward to a coud platform where a fast tip-tilt mirror and the adaptive optics system can feed several instruments. First light instruments include a set of visible light broad-band filters, visible-light and infrared spectropolarimeters, and visible and infrared narrow-band tunable filters. The enclosure is a hybrid design (Fig. 2) that allows controlled flushing of the air across the mirror, while protecting the mirror from shake and ripple due to high winds. After thoroughly investigating seeing, sky clarity, and weather at six sites, Haleakala was proposed as the site that would meet all of the ATST scientific criteria for high-resolution imaging and coronal observations. Figure 3 is a rendition of how ATST will look at the Haleakala site.

Fig. 3 A rendition of the ATST on Haleakala by Tom Kekona, K. C. Environmental Inc., Original photo by Frank Rizzo

3 Status

The ATST passed its preliminary design review in the fall of 2006. The National Science Board considered the project in August of 2007 and recommended ATST be considered by the NSF director for inclusion in the NSF budget at his discretion. The project is now preparing for a 2009 construction start. We anticipate a final baseline review in the fall of 2008 or early 2009. The final environmental impact statement required for building the ATST on the Haleakala site should be published this winter and the associated record of decision is expected in the spring of 2008. ATST still seeks partnerships for telescope construction, instrumentation, and operations. An International Advisory Council was formed in December 2006. Membership remains open and interested parties should contact skeil@nso.edu. More detail on design is available in Rimmele et al. (2005), Wagner et al. (2006). A discussion of the unique scientific capabilities of the ATST is given in Rimmele et al. (2006).

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