

## Ground-Based Solar Facilities in the U.S.A.

Carsten Denker<sup>1,2</sup>, Dale E. Gary<sup>1</sup>, and Thomas R. Rimmele<sup>3</sup>

<sup>1</sup>New Jersey Institute of Technology, Newark, NJ 07102, U.S.A.

<sup>2</sup>Astrophysikalisches Institut Potsdam, D-14482 Potsdam, Germany

<sup>3</sup>National Solar Observatory/Sacramento Peak, Sunspot, NM 88349, U.S.A.

\**Email*: cdenker@adm.njit.edu

**Abstract.** In this review, we present the status of new ground-based facilities for optical and radio observations of the Sun in the United States. The 4-meter aperture Advanced Technology Solar Telescope (ATST) under the stewardship of the National Solar Observatory (NSO) has successfully completed its design phase and awaits funding approval. The 1.6-meter aperture New Solar Telescope (NST) at Big Bear Solar Observatory (BBSO) is currently under construction. Complementing these optical telescopes is the Frequency Agile Solar Radiotelescope (FASR) – an instrument for dynamic broadband imaging spectroscopy covering a multitude of radio frequencies from 50 MHz to 20 GHz. Imaging spectroscopy and polarimetry are common features of these telescopes, which will provide new insight regarding the evolution and nature of solar magnetic fields. High-resolution observations of solar activity, bridging the solar atmosphere from the photosphere to the corona, will be obtained with a dedicated suite of instruments. Special emphasis of this review will be put on the interplay between instrumentation and scientific discovery.

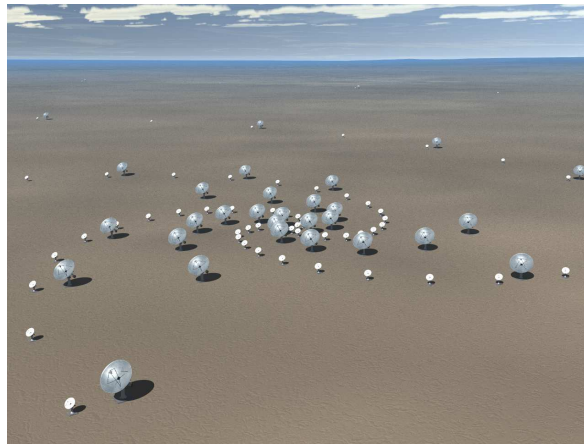
### 1 Introduction

Astronomy, astrophysics and solar physics in the United States are periodically evaluated by panels of the National Research Council (Parker 1998; McKee & Taylor 2001; Lanzerotti 2003). In the latest review, the Panel on the Sun and Heliospheric Physics as part of the Solar and Space Physics Decadal Survey (Lanzerotti 2003) identified and prioritized four science questions for new research initiatives in solar and heliospheric physics: (1) What physical processes are responsible for coronal heating and solar wind acceleration, and what controls the development and evolution of the solar wind in the innermost heliosphere. (2) What determines the magnetic structure of the Sun and its evolution in time, and what physical processes determine how and where magnetic flux emerges from beneath the photosphere? (3) What is the physics of explosive energy release in the solar atmosphere, and how do the resulting heliospheric disturbances evolve in space and time? (4) What is the physical nature of the outer heliosphere, and how does the heliosphere interact with the galaxy? The unique combination and research thrusts of the three U.S. ground-based initiatives FASR (Gary 2003; Bastian 2003), NST (Denker et al. 2006), and ATST (Rimmele et al. 2003; Keil et al. 2004a; Oschmann et al. 2004; Rimmele et al. 2005; Wagner et al. 2006) in collaboration with many other national and international programs will undoubtedly advance solar and heliospheric physics across this broad theme in the years to come. These major initiatives are also well-aligned with current and future space missions.

Before discussing these major projects in detail, some of the other U.S. ground-based projects should be briefly mentioned. The Global Oscillation Network Group (GONG, Harvey et al. 1996) is a world-wide network of six observing stations to study the internal structure and dynamics of the Sun using helioseismology. In particular, the Sun’s “five minute” oscillations are determined from Doppler velocities, which are measured in the Ni I line at 676.8 nm with a polarizing Michelson interferometer. Synoptic Optical Long-term Investigations of the Sun (SOLIS, Keller et al. 2003) is a synoptic facility to understand the solar activity cycle and monitor solar irradiance changes. The SOLIS instrument suite consists of a Vector Spectromagnetograph (VSM), a Full Disk Patrol (FDP) instrument and a Integrated Sunlight Spectrometer (ISS). Another instrument for synoptic studies of the Sun is the Optical Solar Patrol Network (OSPAN), formerly known as the Improved Solar Observing Optical Network (ISOON, Neidig et al. 1998). OSPAN data products include  $H\alpha$ , He I 1083.0 nm and red continuum full-disk images as well as line-of-sight magnetograms in the Ca I line at 612.2 nm. Future instruments include the Coronal Solar Magnetism Observatory (COSMO), a meter-class coronagraph, which has been proposed by the High-Altitude Observatory. COSMO would replace the existing Mauna Loa Solar Observatory operated by the National Center for Atmospheric Research.

## 2 Frequency Agile Solar Radiotelescope

FASR (Figure 1) is an instrument dedicated to solar observations with a field-of-view encompassing the entire solar disk. Broadband imaging spectro-polarimetry will be used to study the solar atmosphere (White et al. 2003) from the middle chromosphere to the corona (about one solar radius above the surface). The FASR array is a three-armed logarithmic spiral with self-similar scaling containing a total of 200 individual antennas. The array consists of 100 antennas with dish sizes of 2 m, 60 antennas with dish sizes of 6 m and 40 log-periodic dipoles.



**Figure 1.** Frequency Agile Solar Radiotelescope.

The longest baseline is about 5 km. Thus, a roughly circular area with same diameter is required for the future FASR site. Other site characteristics include low levels of radio frequency interference (RFI) over the entire band from 50 MHz to 20 GHz and a benign environment to minimize corrosion and ease maintenance (Gary & Keller 2003).

The array will observe low frequency radio emission from 50 MHz to 20 GHz, which originates predominantly in the solar corona. Bremsstrahlung or free-free radiation, gyrosynchrotron radiation and plasma radiation are the three most important emission mechanisms in this frequency range. The lower frequency boundary is close to the electron plasma

frequency of the ionosphere above an observer. Thus, it defines the observing window for ground-based radio observations.

The Sun's radio signal is highly variable. The brightness can change by orders of magnitude on extremely short time-scales. Therefore, FASR has to combine a large dynamic range with high-temporal resolution. The time resolution is about 10 ms from 100 MHz to 3 GHz and about 100 ms for frequencies larger than 3 GHz. The spectral resolution ranges from 0.1% in the low frequency part to 1% in the high frequency part of the spectrum.

The instrument has the ability to measure the polarization state of the full Stokes vector. However, the Stokes- $I$  and  $-V$  components are more important, since strong differential Faraday rotation in the corona will obscure any intrinsic linear polarization measured in Stokes- $Q$  and  $-U$ . True coronal magnetograms are the end product of imaging spectro-polarimetry with FASR. The only other access to coronal magnetic fields is given by optical observations in the near-infrared, which is one of the ATST's main objective.

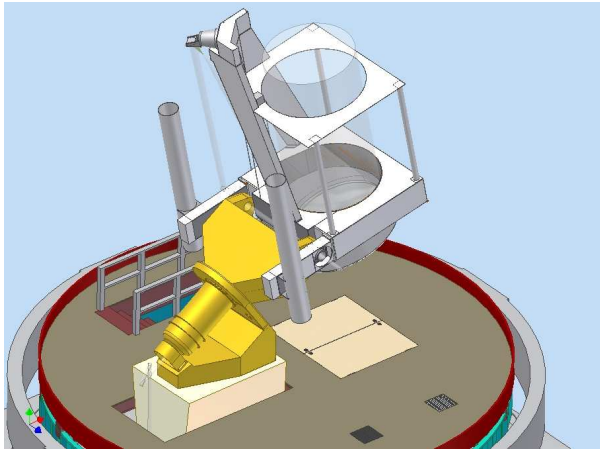
One of FASR's science goals is to obtain a more detailed understanding of the elusive nature of solar radio bursts (Bastian 2004). The character of the bursts strongly depends on frequency. The duration of radio bursts is relatively short lasting only about 5 min to 15 min. Bursts below about 3 GHz are characterized by a frequency shift of the emission with time, usually from high to low frequencies. For example, the frequency drift is much faster for Type III than for Type II bursts. The cause of Type III radio bursts are beams of non-thermal electrons with energies in the range from a few to 100 keV. The propagation speed of electrons in the beams can reach a few tenths of the speed of light. In contrast to these emissions, the dominant emission mechanisms for Type IV radio bursts are plasma and gyrosynchrotron radiation. The various forms of broad-band emissions are typically associated with flares. Type II and IV radio bursts and CMEs are closely associated. Fast CME-driven or flare-associated ejecta and blast waves such as Moreton or EIT waves produce shocks, which in turn are responsible for Type II radio bursts.

The physical conditions near the energy release site can be accessed by radio observations (see e.g., Gary & Keller 2004, for a detailed introduction to solar radiophysics), since they can accurately measure the plasma and gyrosynchrotron radiation produced by non-thermal electrons. The interaction of electron beams with a fixed electron number density at a given location can be studied with imaging spectroscopy. Images sampled at different frequencies hold the information on the electron beam trajectory. In the case of decimetric Type III radio bursts, it allows to discern between upward and downward beam trajectories. Thus, energy release sites can be connected to beam trajectories and to coronal magnetic field topology, which yields a comprehensive picture of eruptive phenomena in the chromosphere and corona.

Advances in broadband devices, digital circuitry and computing power have made FASR feasible. These technological innovations have played the same critical role in solar radiophysics as advances in adaptive optics (AO) for optical telescopes. Several key FASR components are currently being developed, which include some prototyping efforts to mitigate risks. These studies are funded as PI-type grants to individual members of the FASR project. The overall design and development (D&D) is funded by the Advanced Instrumentation and Technology program of the Astronomical Sciences Division (AST) within the National Science Foundation (NSF). Several strategies are investigated on how to implement FASR, once the D&D studies are successfully completed. One option is to build a scaled-down prototype with about 10% of the antennas, which could be funded within NSF AST.

### 3 New Solar Telescope at Big Bear Solar Observatory

The proximity of the Sun allows us to study surface structure in fine detail. Even if observed with the largest telescopes, almost all of the other stars remain point sources. The recent quest for solar telescopes with apertures larger than one meter can be traced to two technological breakthroughs: solar AO (Rimmele 2000) and an open telescope design and its first successful implementation, the Dutch Open Telescope (DOT, Rutten et al. 2004). These advances in technology help to overcome the limitations posed



**Figure 2.** New Solar Telescope at Big Bear Solar Observatory.

by Earth's turbulent atmosphere. Observations close to the diffraction limit of this new generation of telescopes are now feasible and will provide the first glimpse at the intrinsic scales of magneto-convection, which are only 100 km or less on the solar surface.

NST (Figure 2) is 1.6-meter, off-axis Gregorian telescope replacing a number of older solar telescopes at BBSO. The project is a collaboration between BBSO, the Korean Astronomical Observatory (KAO) and Institute for Astronomy at the University of Hawai'i. All major contracts for design and fabrication of NST are in place and construction of components is well underway. BBSO is ideally suited for campaign-style solar observations. NST will provide unprecedented times-series with high-spatial and high-temporal resolution. Both are required to follow the dynamics of active regions and eruptive phenomena on the Sun. Synoptic observations and space weather-related studies have historically been one of the research focusses at BBSO (Gallagher et al. 2002).

The old metal dome at BBSO was replaced in March 2006 with a larger 10 m diameter, 5/8 fiberglass sphere manufactured by MFG Ratech. The design is based on the dome for the Southern Astrophysical Research (SOAR) telescope (Teran et al. 2000). Fourteen vent gates with automated, proportional positioned dampers are spaced around the equator of the dome to control the air flow across the open structure telescope. DFM Engineering supplies the equatorial mount, telescope tube, primary mirror (M1) cell, positioning actuators and M1 supports, the optical support structure, pointing control system, mounts and mirrors for M3 through M5, and M1 handling equipment. An unbalanced system was developed to meet the overall mass requirement imposed by the existing pier. Unbalanced moments are taken up by the declination (DEC) drive system. The center-of-gravity about the right ascension (RA) axis will vary with RA position. This will be compensated by a pair of moving 1/2 ton counter-weights located in tubes near the DEC axis (see Figure 2).

M1 has a 1.6 m clear aperture (1.7 m Zerodur blank with 10 cm thickness). The  $f$ -ratio of the 5.3-meter parent is  $f/0.73$ . The telescope optics are based on a Gregorian design with two additional flat mirrors to direct the light into the declination and coudé axes, respec-

tively. The M1  $f$ -ratio is  $f/2.4$  corresponding to a focal length of 4.1 m. The final  $f$ -ratio in the Gregorian focus is  $f/52$  and the effective focal length of the telescope is 83.2 m. The Steward Observatory at the University of Arizona is polishing M1 and is developing computer-generated hologram techniques required to produce 8.4-meter aperture, off-axis mirrors. M1 is a 1/5 scale test project for the Giant Magellan Telescope (Martin et al. 2004).

In addition to a large-aperture telescope, dedicated post-focus instruments have to be developed to exploit the capabilities of the new telescope. The NST post-focus instruments were tailored towards space weather and solar activity studies, i.e., preference was given to obtain high-spatial and high-temporal resolution data. Two imaging vector magnetographs for the visible and near-infrared wavelengths regions are currently being developed (Denker et al. 2003a,b) and have produced first science results. A scanning grating spectrograph with higher spectral resolution will be built by KAO. These instruments benefit from a high-order AO system, which was developed in a collaboration between NSO and BBSO (Rimmele 2000; Didkovsky et al. 2003; Ren et al. 2003; Rimmele et al. 2004a). According to the ATST site survey (Hill et al. 2004, 2006), the median Fried-parameter at BBSO  $r_0$  is about 6.0 cm, with about 1000 hours per year when the Fried-parameter  $r_0$  exceeds 7.0 cm. This indicates that AO-corrected data will be available for substantial periods of time. The special location of BBSO inside Big Bear Lake results in an almost flat profile of the Fried-parameter  $r_0$  with time. Thus, AO-corrected observations can be obtained from sunrise to sunset. As far as imaging is concerned, even higher correction can be achieved by combining AO and post-facto image correction (Denker et al. 2005). Considering that image restoration is no longer limited by computing resources (Denker et al. 2001), high-resolution observations can be routinely obtained, which is a necessity for space weather monitoring and forecast.

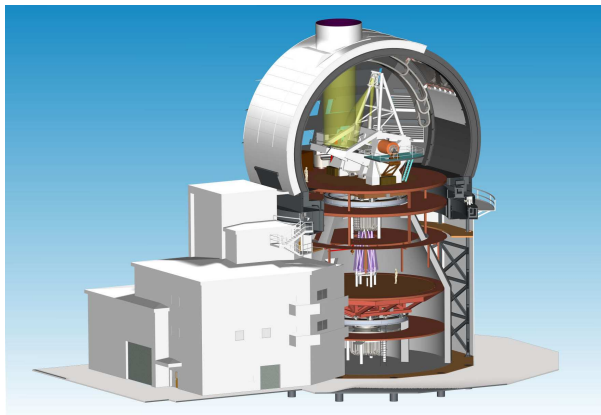
#### 4 Advanced Technology Solar Telescope

The ATST (Figure 3) is a 4-meter aperture, all-reflecting, off-axis Gregorian telescope with integrated AO. In 13 reflections, the light is directed from the Sun to a 16.4 m diameter, co-rotating coudé optical laboratory. The light path includes an upgrade option for multi-conjugate AO (Berkefeld et al. 2006; Rimmele et al. 2006). The telescope delivers a  $300''$  FOV to the Nasmyth observing station, which is unvignetted over  $240''$ . The FOV at the coudé observing station was reduced to  $120'' \times 120''$  to ease the optical design of the post-focus instrumentation and to achieve a Strehl ratio of 0.8 across the entire field. The polarization and calibration optics are integral parts of the ATST located at the Gregorian observing station and serve all post-focus instruments. The coudé optical laboratory provides ample space for multi-instrument set-ups and flexibility to integrate user instruments. The ATST project includes four facility-class, first-light instruments (Rimmele2004b).

The Visible-Light Broadband Imager (VBI, Uitenbroek et al. 2006) combines high-order AO with image restoration. Two channels, covering wavelength regions in the blue from 350 nm to 400 nm and in the red from 630 nm to 900 nm, are outfitted with fast, large-format CCD detectors for phase diversity and speckle imaging. The Visible Spectro-Polarimeter (ViSP, Elmore et al. 2005) is a medium dispersion spectrograph based on the horizontal spectrograph currently in operation at NSO's Dunn Solar Telescope. ViSP will carry out precision measurements of full state of polarization Simultaneously at diverse wavelengths in the visible from 380 nm to 900 nm. Fully resolved line profiles will provide quantitative

diagnostics of the magnetic field vector as a function of height in the solar atmosphere. The Visible Tunable Filter (VTF, Gary et al. 2003) is an imaging spectro-polarimeter (triple etalon Fabry-Pérot) covering the visible wavelength range from 450 nm to 750 nm. Its design was guided by the successful Telecentric Etalon Solar Spectrometer (TESOS Kentischer et al. 1998; Tritschler et al. 2002) of the Kiepenheuer Institut für Sonnenphysik in Freiburg, Germany. VTF will deliver Stokes spectro-polarimetry, accurate surface photometry, Doppler velocity measurements and transverse flows from feature tracking. High-cadence and the possibility of post-facto image restoration make VTF an ideal instrument study the dynamics of eruptive events and evolutionary changes of solar activity. The first light coronal instrument will be mounted at Nasmyth station and provide measurements of the coronal magnetic field. The operational mode of ATST will be quite different from current solar facilities. Instead of observer-defined instruments, the aforementioned suite of fixed facility instruments will provide standard data products and enable batch observing (Rimmele2004b).

The primary ATST mission is to perform high-resolution studies of the Sun's magnetic fields from the photosphere to the corona (Rimmele et al. 2003; Keil et al. 2004b). The term "high-resolution" in this context refers to the spatial, temporal and spectral (including polarization) domains in their entirety. Solar magnetic fields emerge and dissipate on spatial scales of just a few tens of kilometers. Starting with the dynamics of small-scale flux tubes and their amplifications by plasma flows,



**Figure 3.** Advanced Technology Solar Telescope.

sunspots and active regions are the next steps in merging and concentrating magnetic flux. The dynamics of sunspots occur on time-scale of just a few minutes. Magnetic reconnection above active regions can lead to violent eruptions in form of flares, filament/prominence eruption and coronal mass ejections (CMEs). Magnetic reconnection on smaller scales and/or wave phenomena are linked to heating of the corona. On longer time-scales the 11-year sunspot cycle is only one of the many signatures of the 22-year magnetic cycle of the Sun. In addition, to the more traditional spectro-polarimetric methods in the visible wavelength regime, technological advances have provided access to the near- and thermal-infrared. Site selection and instrument design with a special emphasis on scattered light performance give ATST infrared capabilities to directly measure coronal magnetic fields.

The ATST site survey has been a community effort to identify a location, which combines the best seeing and environmental conditions to fulfill the science goals of the ATST (Hill et al. 2004, 2006). This site survey has been the most extensive study of daytime seeing conditions so far. Initially, 72 candidate sites were selected and ranked according to feasibility, environmental conditions, and climate. Six sites were initially tested with an identical set of instruments (Beckers et al. 2003; Lin & Penn 2004; Socas-Navarro et al. 2005). These sites represented a large sample of geographical features: mountain sites, mountain-lake sites, and

mountain-island sites. After an interim comparison of the seeing conditions, the selection was narrowed to three sites (Big Bear Solar Observatory in Southern California, Observatorio Roque de los Muchachos on La Palma, Spain, and Mees Solar Observatory (MSO) on Haleakalā, Maui, Hawai'i). All finalist sites had about the same number of annual hours of seeing conditions with  $r_0 > 7$  cm (about 1000 hours), which confirmed their status as premier sites for solar observations. However, Haleakalā had the most annual hours (about 400 hours) of excellent seeing ( $r_0 > 12.0$  cm at a height of 28 m above ground). Haleakalā had also the most annual hours of low sky brightness required for coronal observations. Thus, MSO was chosen as the future ATST site.

The NSF-funded ATST D&D efforts started in late 2001. In September 2005, ATST reached the readiness stage within NSF's Major Research Equipment and Facilities Construction program. Once the site decision was made, geotechnical studies were carried out at Haleakalā in early 2005. In parallel, an Environmental Impact Study (EIS) was initiated in 2005, which included several public hearings. The EIS process will be concluded by the end of 2006. As a result, the exterior shape and overall footprint of the ATST facility has advanced to the point, where it is now largely frozen. Since 2004, several NSF cost and design reviews were held and the preliminary design review was passed successfully in October 2006. The ATST is expected to be considered for a new start in spring of 2007 by the National Science Board, which is the U.S. science policy adviser to the President and the Congress. A positive recommendation could lead to an inclusion in the President's budget for fiscal year 2009. This would also signal the begin of the ATST construction. In this scenario, ATST would see first-light in 2012 and telescope and first light instrumentation would be fully commissioned by 2014. Current efforts focus on preparation for contracting of major ATST sub-systems to keep the project on target.

## 5 Conclusions

ATST, NST and FASR will obtain comprehensive observations of the Sun from its surface to the outer atmosphere. A systems approach is required, which integrates data of the photosphere, chromosphere and corona, to study the nature and evolution of magnetic fields, which are cause of many energetic phenomena such as flares, prominence/filament eruptions and CMEs. Acceleration of energetic particles, propagation of energetic and eruptive phenomena into the interplanetary medium and formation of coronal and interplanetary shocks are all topics, which rely on a detailed understanding of the near-Sun evolution of magnetic fields, thus, establishing a close connection between ATST, NST and FASR and space-based instruments studying the heliosphere and interplanetary medium. The synergies among these ground-based U.S. solar facilities will break new ground in solar physics and space science and bring us closer to answer some of the fundamental questions (Keil et al. 2004b): (1) What is the nature of solar magnetism? (2) How does magnetism control our star? (3) How can we model and predict the Sun's changing outputs that affect the Earth?

**Acknowledgements.** This work was supported by NSF under grants ATM 00-86999, ATM 02-36945, IIS ITR 03-24816, AST 03-52915 and AST MRI 00-79482 and by NASA under grant NAG 5-12782. The National Solar Observatory is operated by the Association of Universities for Research in Astronomy under a cooperative agreement with the National Science Foundation, for the benefit of the astronomical community.

## References

- Bastian, T. S. 2004, P&SS, 52, 1381
- Bastian, T. S. 2003, Proc. SPIE, 4853, 98
- Beckers, J. M., Liu, Z., Jin, Z. 2003, Proc. SPIE, 4853, 273
- Berkefeld, T.; Soltau, D.; von der Lhe, O., Proc. SPIE, 6272, 4
- Denker, C., Goode, P. R., Ren, D. & 17 co-authors 2006, Proc. SPIE, 6267, 62670A
- Denker, C., Mascarinas, D., Xu, Y. & 5 co-authors 2005, Sol. Phys., 227, 217
- Denker, C., Didkovsky, L., Ma, J. & 5 co-authors 2003a, Astron. Nachr./Astron. Not., 324, 332
- Denker, C., Ma, J., Wang, H. & 4 co-authors 2003b, Proc. SPIE, 4853, 223
- Denker, C., Yang, G., & Wang, H. 2001, Sol. Phys., 202, 63
- Didkovsky, L. V., Dolgushyn, A., Marquette, W. H. & 10 co-authors 2003, Proc. SPIE, 4853, 630
- Elmore, D. F., Socas-Navarro, H., Card, G. L., & Streater, K. V. 2005, Proc. SPIE, 5901, 60
- Gallagher, P. T., Denker, C., Yurchyshyn, V. & 4 co-authors 2002, Ann. Geophys., 20, 1105
- Gary, D. E. & Keller, C. U. 2004, *Solar and Space Weather Radiophysics – Current Status and Future Developments*. Kluwer Academic Publishers, Dordrecht, The Netherlands
- Gary, D. E. 2003, J. Korean Astron. Soc., 36, 135
- Gary, D. E. & Keller, C. U. 2003, Proc. SPIE, 4853, 523
- Gary, G. A., Balasubramaniam, K. S., & Sigwarth, M. 2003, Proc. SPIE, 4853, 252
- Harvey, J. W., Hill, F., & Hubbard, R. & 14 co-authors 1996, Science, 533, 163
- Hill, F., Beckers, J., Brandt, P. & 18 co-authors 2006, Proc. SPIE, 6267, 62671T
- Hill, F., Beckers, J., Brandt, P. & 17 co-authors 2004, Proc. SPIE, 5489, 122
- Keil, S. L., Oschmann, J. M., Rimmele, T. R. & 8 co-authors 2004a, Proc. SPIE, 5489, 625
- Keil, S. L., Rimmele, T. R., Oschmann, J. M. & 4 co-authors 2004b, IAU Symp., 223, 581
- Keller, C. U., Harvey, J. W., & Giampapa, M. S. 2003, Proc. SPIE, 4853, 194
- Kentischer, T. J., Schmidt, W., Sigwarth, M., & Uexkuell, M. V. 1998, Astron. Astrophys., 340, 569
- Janzerotti, L. 2003, *The Sun to the Earth – and Beyond: A Decadal Research Strategy in Solar and Space Physics*. National Academy Press, Washington, DC
- Lin, H. & Penn, M. J. 2004, PASP, 116, 652
- Martin, H. M., Burge, J. H., Cueden, B. & 3 co-authors 2004, Proc. SPIE, 5494, 62
- McKee, C. & Taylor, J. 2001, *Astronomy and Astrophysics in the New Millennium*. National Academy Press, Washington, DC
- Neidig, D., Wiborg, P., Confer, M. & 17 co-authors 1998, ASP Conf. Ser., 140, 519
- Oschmann, J., Dalrymple, N., Warner, M. & 6 co-authors 2004, Proc. SPIE, 5171, 160
- Parker, E. N. 1998, *Ground-Based Solar Research: An Assessment and Strategy for the Future*. National Academy Press, Washington, DC
- Ren, D., Hegwer, S. L., Rimmele, T. R., Didkovsky, L. V., & Goode, P. R. 2003, Proc. SPIE, 4853, 630
- Rimmele, T.; Richards, K.; Roche, J.; Hegwer, S.; Tritschler, A., Proc. SPIE, 6272, 5
- Rimmele, T. R., Keil, S. L., Wagner, J. & 8 co-authors 2005, Proc. SPIE, 5901, 41
- Rimmele, T. R., Richards, K., Hegwer, S. & 10 co-authors 2004a, Proc. SPIE, 5171, 179
- Rimmele, T., Hubbard, R. P., Balasubramaniam, K. S. & 12 co-authors 2004b, Proc. SPIE, 5492, 944
- Rimmele, T. R., Keil, S. L., Keller, C. U. & 10 co-authors 2003, ASP Conf. Ser., 286, 3
- Rimmele, T. R. 2000, Proc. SPIE, 4007, 218
- Rutten, R. J., Hammerschlag, R. H., Bettonvil, F. C. M. & 2 co-authors 2004, A&A, 413, 1183
- Socas-Navarro, H., Beckers, J., Brandt, P. & 17 co-authors 2005, Publ. Astron. Soc. Pac., 117, 1296
- Teran, J. U., Porter, D. S., Hileman, E. A. & Neff, D. H. 2000, Proc. SPIE, 4004, 155
- Tritschler, A., Schmidt, W., Langhans, K., & Kentischer, T. J. 2002, Sol. Phys., 211, 17
- Uitenbroek, H., Tritschler, A., An, H. K., & Berger, T. 2006, Proc. SPIE, 6269, 193
- Wagner, J., Rimmele, T. R., Keil, S. L. & 12 co-authors 2006, Proc. SPIE, 6267, 626709
- White, S., Lee, J., Aschwanden, M. A., & Bastian, T. S. 2003, Proc. SPIE, 4853, 531