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Synoptic Observing at Big Bear Solar Observatory

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Abstract. Synoptic solar observations in the chromospheric absorption lines Ca II K and Hα have a long tradition at Big Bear Solar Observatory (BBSO). The advent of the New Solar Telescope (NST) will shift the focus of BBSO's synoptic observing program toward high-resolution observations. We present an overview of the telescopes and instrumentation and show some of the most recent results. This includes Ca II K data to track solar irradiance variations, Hα full-disk data to monitor eruptive events, Dopplergrams from two-dimensional spectroscopy, as well as image restorations of diffraction-limited quality.

1. Introduction

One of the unique characteristics of BBSO is its location. The observatory is located on a small island in Big Bear Lake (Fig. 1), which is connected to the northern shore of the lake by a 300 m causeway. The lake with a surface area of 12 km^2 follows the east-west orientation of Big Bear Valley in the San Bernardino Mountains of Southern California. The observatory was established in 1969 as the result of a comprehensive site survey conducted in 1965 (Zirin and Mosher 1988) by California Institute of Technology. The survey concluded that the best seeing conditions were encountered in the proximity of lakes or close to oceans. The water acts as a heat reservoir and provides a natural temperature inversion, which effectively suppresses air turbulence and ground-layer seeing. These findings are also supported by the recent site survey (Hill et al. 2004, 2006) for the Advanced Technology Solar Telescope (ATST, Rimmele et al. 2005; Wagner et al. 2006).

Historically, BBSO has conducted synoptic observations of solar activity. The almost flat seeing profile from sunrise to sunset with a median Fried-parameter r_0 exceeding 6 cm makes this lake-site observatory ideal to monitor solar active regions for solar eruptive phenomena such as flare, filament and prominence eruptions, and signatures of Coronal Mass Ejections (CMEs). These types of events are important in the context of space science and space weather forecasting (Gallagher et al. 2002a). An early implementation of a flare prediction system was "Bearalerts" (Zirin and Marquette 1991), an electronic mail system, which reported the rapid development of certain active regions based on magnetic field topology and Hα morphology. The Active Region Monitor (ARM, Gallagher et al. 2002b) was developed at BBSO as the web-based successor of

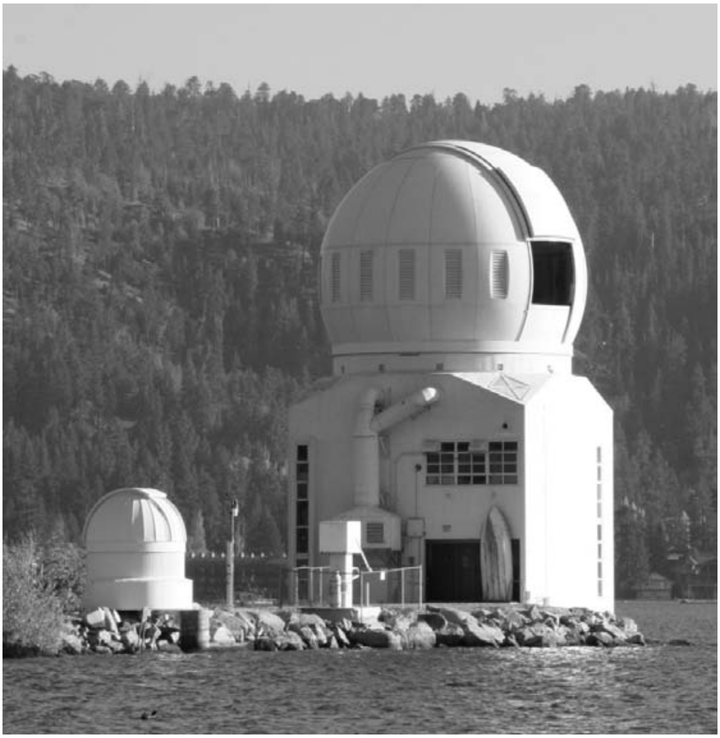

Figure 1. Big Bear Solar Observatory.

Bearalerts and is now operated independently (`http://solarmonitor.org`) at NASA Goddard Space Flight Center's Solar Data Analysis Center (SDAC).

In the following sections, we will describe the individual telescopes at BBSO and their science objectives. A cluster of telescopes (65 cm vacuum reflector, 25 cm reflector, Singer Hα full-disk telescope, photometric full-disk telescope, and Earthshine telescope) share the same equatorial mount. However, the 65 cm and 25 cm telescopes can be individually pointed. An overview of the synoptic observing and instrumentation program at BBSO was previously presented in Goode et al. (2003b).

2. Hα Full-Disk Telescope

The Hα full-disk telescope was built by Boller and Chivens under contract to Singer-General Precision in Binghamton, New York. Hence, it was called the Singer telescope. It consists of a 22 cm singlet lens, which is stopped down to 15 cm to deliver an unvignetted image of the Sun through Lyot filter manufactured by Halle in Berlin, Germany. A special coating of the singlet lens restricts the transmitted sunlight to a 30 nm spectral window centered at Hα. A narrow-band interference filter selects the correct order of the Lyot filter, which has a bandpass of 0.05 nm. The birefringent filter can be manually tuned to

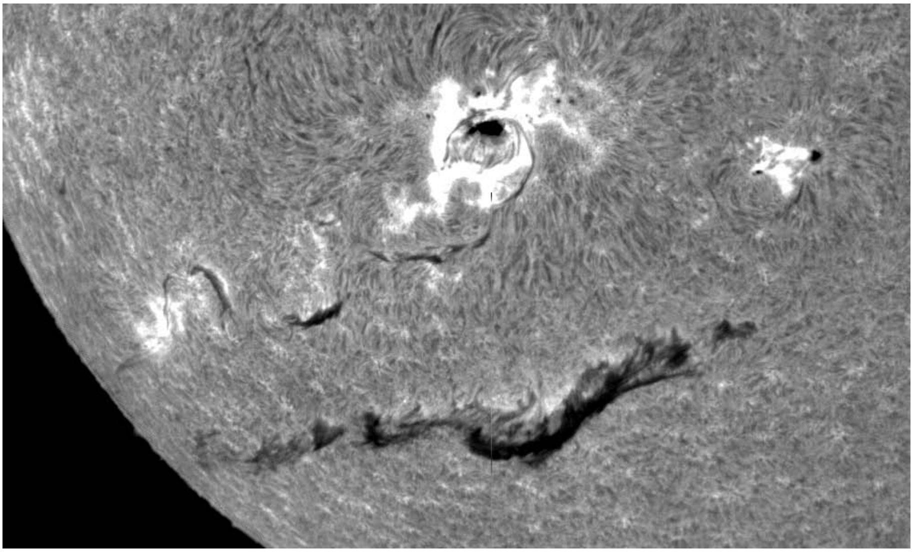

Figure 2. Partial view of an Hα full-disk filtergram showing a filament eruption on June 11, 2003.

Hα $\pm$ 0.1 nm so that Hα line wing images can be taken in dedicated observing runs (e.g., Moreton waves). A weak field lens in front of the Lyot filter and a re-imaging lens after the filter provide an 18 mm solar full-disk image at the final focus.

Digital data was taken with this system since 1996. First with a Kodak 4.2 CCD camera and later with an Apogee KX4 CCD camera. However, the detector characteristics are very similar. In both cases, the images have 2k $\times$ 2k pixel and the imaging cadence is typically one minute. Considering the good and stable seeing conditions at BBSO, the full-disk images usually have a spatial resolution close to the nominal $2''$ (see Fig. 2). All data are carefully calibrated and a limb-darkening function is computed to provide contrast-enhanced full-disk images (Denker et al. 1998). The data processing has been standardized for all BBSO full-disk images. Sample images and movies are posted on a daily basis on the world wide web (`http://www.bbso.njit.edu`).

A detailed description of the Singer Hα full-disk telescope and the data processing is given in (Denker et al. 1998). The Singer telescope is also part of the Global Hα Network (GHN, Steinegger et al. 2000), which is a collaboration between BBSO, Observatoire de Paris in France, Kanzelhöhe Solar Observatory in Austria, Catania Astrophysical Observatory in Italy, Yunnan Astronomical Observatory in China, and Huairou Solar Observatory in China.

3. Photometric Full-Disk Telescope

The photometric full-disk telescope is a simple refractor with an aperture of 12.5 cm diameter (stopped down to 6.5 cm). Full-disk images in Ca II K line at

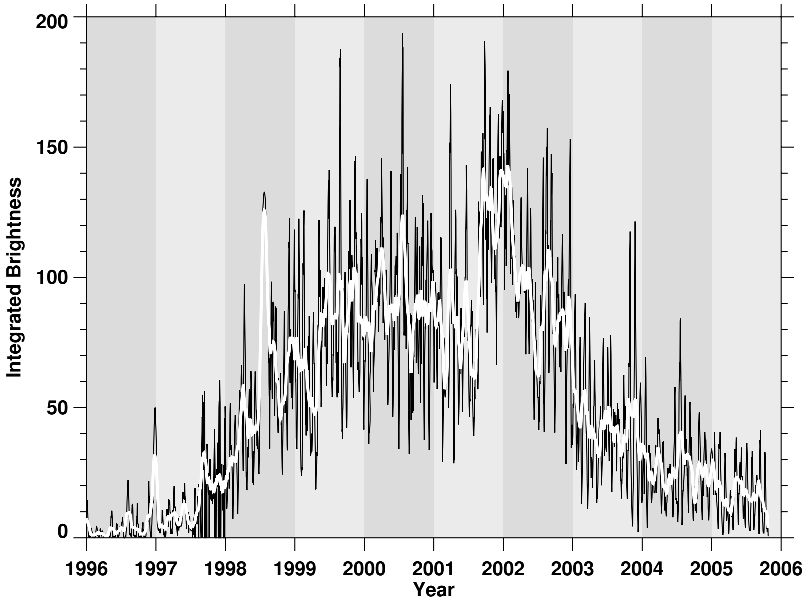

Figure 3. Ca II K brightness index for solar cycle No. 23.

393.3 nm and green continuum at 520 nm are taken once a day. Occasionally, G-band full-disk images are taken as well. A Daystar filter restricts the band-pass of the Ca II K line images to 0.15 nm. Ca II K full-disk filtergrams were observed at BBSO since 1981. Digital data acquisition started in 1996. A blue-sensitive, Lumigen coated Kodak 1.4i MegaPlus CCD camera record 1k × 1k pixel filtergrams.

Based on these filtergrams, daily indices are computed (Johannesson et al. 1995, 1998) to track the solar irradiance variability, which can be attributed to bright magnetic features (Lean et al. 1998). In Fig. 3, we show one of these brightness indices covering solar cycle No. 23 from 1996 until the end of 2005. Ca II K observations allow us to monitor ultraviolet irradiance variability of the Sun (Warren et al. 1996) and can reproduce other irradiance indices (e.g., Ly-α), which would otherwise only be accessible from space (Johannesson et al. 1995, 1998). Since the data coverage is more than 25 years, the BBSO Ca II K data presents a valuable reference point for ground- and space-based observations of solar irradiance variability. Since a continuation of this program beyond 2006 seems unlikely, we are currently preparing a summary of the observations and a description of the data products, which will be published in a forthcoming paper (Naqvi et al. 2007).

4. Digital Vector Magnetograph

The main instrument on the 25 cm refractor is the Digital Vector Magnetograph (DVMG, Spirock et al. 2001). In addition, a computer controlled mirror system can direct the light to two side benches with Lyot filters, which typically observed the Sun in the chromospheric absorption lines Hα and Ca II K. All camera system have a field-of-view (FOV) of about $300'' \times 300''$ and 512×512 pixel. The cadence for active region observations is typically one minute.

First attempts to convert the now obsolete video magnetograph system (Varsik 1995) to a digital system were described in Wang et al. (1998). This also includes a discussion of image selection, alignment and restoration, and other techniques to improve the sensitivity and spatial resolution of magnetograms. The current system uses a combination of ferro-electric crystal and nematic liquid crystals to obtain vector magnetograms in the Ca I line at 610.3 nm. The DVMG is a filter-based magnetograph using a Lyot filter with a bandpass of 0.025 nm. Images in different polarization states are accumulated at a rate of 30 Hz with a 12-bit Dalsa 1M15 CCD camera to minimize seeing-induced cross-talk. Typically, 100 are integrated for longitudinal magnetograms of active regions. This number increases to 1000 for quiet Sun observations or measurements of transverse fields.

5. High-Resolution Observations

High-resolution observations, in particular two-dimensional imaging spectro-polarimetry, are the domain of ground-based solar observatories. This holds even more true in an era with 0.5-meter telescopes flying in space such as Hinode (Shimizu et al. 2004) and the next generation of synoptic space missions preparing for launch such as the Solar Dynamics Observatory.

Adaptive optics (AO) is a necessity to achieve a spatial resolution close to the diffraction limit of today's meter-class solar telescopes. Future large-aperture solar telescope would not even be possible without AO. The high-order AO system at the 65 cm reflector was developed by the National Solar Observatory (Rimmele et al. 2004) in collaboration with BBSO. Most of the hardware is identical to the twin system at the Dunn Solar Telescope in New Mexico. Only the optical design differs taking into account the equatorial mount of the Gregorian reflector and space limitations at BBSO (Didkovsky et al. 2003; Ren et al. 2003). A performance evaluation of the BBSO AO system is presented in Denker et al. (2007).

Even with AO correction, some high-order aberrations remain, which can be compensated with post-facto image restoration (e.g., Denker et al. 2005). In Denker et al. (2001), we have shown that speckle masking imaging in combination with distributed computing is capable to deliver restored images on time-scales comparable to the evolution time-scale on the Sun (about one minute). Furthermore, the image restoration techniques can be applied to two-dimensional spectro-polarimetry. Considering this fact and the superior photon efficiency, Fabry-Pérot based spectro-polarimeters are the first choice for modern solar telescopes. Two imaging spectro-polarimeters, one for the visible and one for the near infrared, have been developed at BBSO (Denker et al. 2003a,b). First science data have been obtained (see Fig. 4) and are currently being prepared for publication. The FOV of the instruments is about $80'' \times 80''$, which is sufficiently large to cover a sunspot. The spectral resolution is better than 0.01 nm and a typical wavelength scan takes about 20 s. These imaging instruments are ideally suited for solar activity studies.

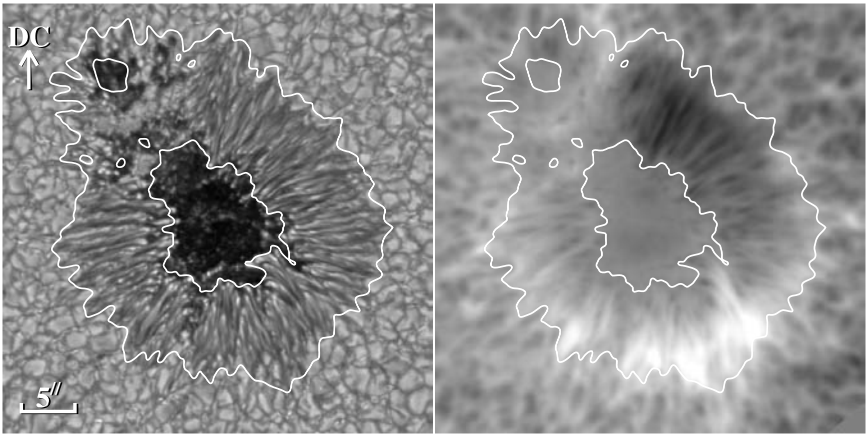

Figure 4. Image restoration using the speckle masking technique and corresponding Dopplergram obtained with two-dimensional spectroscopy. The white contour lines indicate the penumbra boundaries and the white arrow points toward disk center (DC).

6. New Solar Telescope

The New Solar Telescope (NST) project is a collaboration among BBSO, the Korean Astronomical Observatory (KAO) and Institute for Astronomy (IfA) at the University of Hawai'i (Goode et al. 2003a; Denker et al. 2006). The current telescope cluster will be replaced by a 1.6-meter aperture, off-axis Gregorian telescope with an open design. The telescope is currently under construction and all major contracts have been placed. A new 5/8-sphere dome has already been installed to accommodate the larger NST. The old telescopes will be removed in early 2007 and the telescope pier will be modified in preparation for the installation of NST in August 2007. Full operation is expected in 2008.

7. Conclusions

The operation of NST significantly shifts the focus of BBSO's synoptic observing program. At the moment, there is no funding to replace the capabilities of the full-disk telescopes and the 25 cm refractor, which provided context information with moderate spatial resolution. Some of these capabilities exist at other observatories or on space missions such as the Solar and Heliospheric Observatory, Hinode, and the Solar Dynamics Observatory. Therefore, synoptic high-resolution observations and Earthshine observations (Pallé et al. 2004) will take precedence in the future. All high-resolution instruments described in the previous section can be adapted to fit NST. AO-corrected, two-dimensional spectropolarimetry in the visible and near infrared wavelength regions will become the main data source for solar activity and space weather studies at BBSO. These data will be complemented by high-resolution imaging using image restoration techiques such as speckle masking imaging.

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References

Denker, C., Tritschler, A., Rimmele, T. R., and 3 co-authors, 2007, PASP, submitted
Denker, C., Goode, P. R., Ren, D., and 17 co-authors, 2006, Proc. SPIE 6267, 62670A
Denker, C., Mascarinas, D., Xu, Y., and 5 co-authors, 2005, Solar Phys. 227, 217
Denker, C., Didkovsky, L., Ma, J., and 5 co-authors, 2003a, Astron. Nachr./Astron. Not. 324, 332
Denker, C., Ma, J., Wang, H., and 4 co-authors, 2003b, Proc. SPIE 4853, 223
Denker, C., Yang, G., Wang, H., 2001, Solar Phys. 202, 63
Denker, C., Johannesson, A., Marquette, W. H., and 3 co-authors, 1998, Solar Phys. 184, 87
Didkovsky, L. V., Dolgushyn, A., Marquette, W. H., and 10 co-authors, 2003, Proc. SPIE 4853, 630
Gallagher, P. T., Denker, C., Yurchyshyn, V., and 4 co-authors, 2002a, Ann. Geophys. 20, 1105
Gallagher, P. T., Moon, Y.-J., Wang, H., 2002b, Solar Phys. 209, 171
Goode, P. R., Denker, C., Didkovsky, L. I., and 2 co-authors, 2003a, J. Korean Astron. Soc. 36, 125
Goode, P. R., Denker, C., Wang, H., 2003b, Astrophys. Space Sci. Lib. 288, 137
Hill, F., Beckers, J., Brandt, P., and 18 co-authors, 2006, Proc. SPIE 6267, 62671T
Hill, F., Beckers, J., Brandt, P., and 17 co-authors, 2004, Proc. SPIE 5489, 625
Johannesson, A., Marquette, W. H., Zirin, H., 1998, Solar Phys. 177, 265
Johannesson, A., Marquette, W. H., Zirin, H., 1995, Solar Phys. 161, 201
Lean, J., Cook, J., Marquette, W. H., Johannesson, A., 1998. ApJ 492, 390
Naqvi, M. H., Denker, C., Marquette, W. H., Tritschler, A., 2007, Solar Phys. , in preparation
Pallé, E., Goode, P. R., Montañés-Rodríguez, P., Koonin, S. E., 2004 Science 304, 1299
Ren, D., Hegwer, S. L., Rimmele, T. R., and 2 co-authors, 2003, Proc. SPIE 4853, 630
Rimmele, T. R., Keil, S. L., Wagner, J., and 8 co-authors, 2005, Proc. SPIE 5901, 41
Rimmele, T. R., Richards, K., Hegwer, S., and 10 co-authors, 2004, Proc. SPIE 5171, 179
Shimizu, T., 2004, ASP Conf. Ser. 325, 3
Spirock, T., Denker, C., Chen, H., and 6 co-authors, 2001, ASP Conf. Proc. 236, 65
Steinegger, M., Denker, C., Goode, P. R., and 9 co-authors, 2000, ESA Conf. Proc. SP-463, 617
Varsik, J. R., 1995, Solar Phys. 161, 207
Wagner, J., Rimmele, T. R., Keil, S. L., and 12 co-authors, 2006, Proc. SPIE 6267, 626709
Wang, H., Denker, C., Spirock, T., and 7 co-authors, 1998, Solar Phys. 183, 1
Warren, H. P., Mariska, J. T., Lean, J., and 2 co-authors, 1996, Geophys. Res. Lett. 23, 2207
Zirin, H., Marquette, W. H., 1991, Solar Phys. 131, 149
Zirin, H., Mosher, J., 1988, Solar Phys. 115, 77