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GROUND BASED SYNOPTIC INSTRUMENTATION FOR SOLAR OBSERVATIONS (POSTPRINT)

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14. ABSTRACT
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Ground Based Synoptic Instrumentation for Solar Observations

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Abstract

We will describe the status of current ground-based solar spectroscopic and imaging instruments used in solar observations. We will describe the advantages and disadvantages of using these two classes of instruments with examples drawn from the Improved Solar Optical Observing Network (ISOON) and Synoptic Long Term Investigations of the Sun (SOLIS) Network. Besides instrumental requirements and lessons learned from existing ground-based instruments, this talk will also focus on the future needs and requirements of ground-based solar optical observations.

1. Introduction

Targeted active region observations of the Sun are often driven by the research in a specific area of solar physics. In contrast, sustained long-term synoptic observations will lead to a global understanding of solar phenomena, and provide a snap-shot of the Sun in the context of stellar astrophysics, helps in forecasting solar phenomena. Historically, one could trace daily recordings of all visible sunspots leading to discovery of the solar cycle by Heinrich Schwabe[1] and the first solar flare observed by Richard Carrington[2] to his systematic observations of sunspots. Here, we provide glimpses of a contextual snapshot appropriate to this discussion. The synoptic observations have revealed coronal phenomena such as Moreton[3] and EIT waves[4], sympathetic flares[5], and as a most recent example, sequential chromospheric brightennings[6] (SCBs) associated with the reconnection in the corona taking place in the course of a coronal mass ejection (CME) eruption. Synoptic observations are indispensible in studies of long-term effects pertinent to variation in solar radiative output[7], space weather and space climate[8], as well as for understanding the physics of global processes taking place on our nearest star such as, for example, the solar dynamo (see e. g. Jones et al. [9]) . The main-stay of such observations has been ground-based, for a considerably long time. Synoptic recordings of spectroheliograms taken in Ca II K line by observatories at Kodaikanal (India), Mount Wilson (USA), Kislovodsk (Russia) have allowed for the development of proxies for UV and EUV flux and subsequently comparisons with the global variations in temperature on earth over the last 100-plus years (e.g., Foukal et al. 2009[7]). Full disk longitudinal magnetograms recorded from 1975-2002 by the National Solar Observatory (NSO) at Kitt Peak contain a wealth of information about various solar phenomena during different phases of several solar cycles. Since 2003, this data set is continued by the Vector Stokes Magnetograph, one of three instruments comprising the Solar Optical Long-term Investigation of the Sun (SOLIS)[10-11] Earlier synoptic programs were based on observing full disk of the Sun in hydrogen Hα spectral line (e.g., NSO at Sacramento Peak in USA, Kislovodsk High Altitude Station of Pulkovo Observatory and Sayan Observatory near Irkutsk in Russia) are now supported by modern instruments such as Improved Solar Observing Optical Network (ISOON)[12]. Separately, a network of six identical instruments was developed

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by the Global Oscillation Network Group ([13]GONG) to study subphotospheric properties of solar activity using methods of helioseismology.

This article reviews existing ground-based facilities for synoptic long-term observations of the Sun, with an emphasis on two major initiatives: SOLIS and ISOON. Although we concentrate on the ground-based facilities, in Section 2, we briefly compare ground-based and space-borne synoptic programs. Section 3 provides a brief summary of existing ground based networks/major facilities, and Section 4 offers a more detailed description of ISOON and SOLIS. Section 5 concludes this article with the discussion of future needs for the synoptic ground-based solar facilities.

2. Ground-based and space-borne synoptic programs

2a. Scientific Comparisons

Regular, reliable and consistent long-term spectroscopic imaging in a few spectral lines forms the basis of solar synoptic programs. Some of these are achieved by spectroscopic imagers, such a tunable birefingent filters, Fabry-Perot Filters or simply band -limited filters or in some combination, thereof [12, 13]. Others are achieved by scanning spectrographs [10, 11]. There are compromises with each method. Tunable filters scan the spectral dimension temporally, with compromises on fluctuations due to intensities partially corrected by comparing mean spectral line profiles within the data set to high-resolution solar atlas spectra, and sometimes, compensating for astronomical "seeing" by spatial sub-image correlation (de-stretching). Spectrographs scan the solar image, spatially in the temporal domain, with some partial correction due to intensity changes by apriori knowledge of the solar limb-darkening correction. Both methods hamper whole sun simultaneous determination of the surface magnetic field, which is partially mitigated by rapid cameras. Many of these difficulties are eliminated by space borne instruments such as SOHO[14]/MDI and the SDO [15-16]/AIA and HMI Instruments. Other developments include the use o f a slit-less spectrograph[19], which derives spectral and spatial information from a combination of images taken in three different spectrograph orders, or multi-slit instruments, for example, FIRS[20].

2b. Logistical Comparisons

In the past, ground-based instruments were individual PI-based, located in different countries, and the commonality of the discipline for synoptic solar physics globally wrested in principally data sharing between members of the scientific community. While space borne instruments have had significant data-quality advantages over ground-based instruments, it takes several decades to plan missions, with multi-country international agreements, and prohibitive costs beyond the realm of individual national observatories. The significant improvement in data quality has also been due to advanced detectors, stable orbital platforms and missions, whose life time have lasted about a decade, even though they have been planned for a few years. Uniformity of data quality from space-based missions has been unprecedented.

Ground based systems are attractive because of distributed costs over several observatories spread across nations. Such a situation permits uninterrupted solar monitoring, overcoming barriers that constrain centrally focused observatories, particularly space based missions. A significant step towards understanding solar physics comes from uniform solar imaging data obtained from various instruments, spread globally, and observed from different geographic longitudes. The NSO's GONG instrument provides a good example of such ground-based data. The USAF's Solar Observing Optical Network (SOON) has also been providing a fairly uniform data source of ground-based solar observations via the NOAA/Space Weather Predictions Center. Recent advances in optical instrumentation such as the Improved SOON (ISOON) and SOLIS Observatories have proved the usefulness of ground-based synoptic data for making newer discoveries, in conjunction with space based data, such as those from SOHO and SDO.

3. Brief summary of existing ground-based networks/major facilities

Modern synoptic-type observations of the Sun began during the late-1950 – early 1960's periods, in several countries around the globe. The beginning of the active exploitation of the low-Earth orbit (LEO) for civilian and military use, and human space exploration led to the realization of a need for a forecasting of solar activity, especially solar flares and filament eruptions. As a result, the first networks of solar observing stations were established in USA (USAF's Solar Observing Optical Network, SOON) and USSR (under auspices of the Soviet Academy of Sciences). Initially, the stations in both networks were equipped with a (near-) identical set of instruments for optical and (in some cases) radio observations. Typical synoptic observations included visual and/or photographic data taken in H-alpha and Ca II K line, sunspot and filament drawings, various parameters characterizing the chromospheric plages and sunspots, as well as the magnetic field strength of major sunspots. Individual stations had reported their observations to a central office, which used these data to issue a daily forecast of solar activity. In addition, a synthesis of observations from the stations was published in monthly publications such as the "Solar-Geophysical Data" (http://www.ngdc.noaa.gov/stp/solar/sgd.html) and the "Bulletin Solnechnye Dannye" (translated from Russian as the "Bulletin of Solar Data", http://www.gao.spb.ru/english/database/sd/index.htm).

Several new networks aimed at synoptic observations and/or a specific scientific field of research has been established throughout the world. In late 1990's the National Solar Observatory led the development of a network of five identical instruments for studying the solar pulsations nicknamed the GONG for the Global Oscillation Network Group (http://gong.nso.edu/). In late 2010, the GONG instruments were upgraded to record the full disk Hα images using relatively broad-band non-tunable H-alpha filters.

In the late 1990's, the National Solar Observatory (NSO) developed the Precision Solar Photometric Telescope (PSPT) for measuring the variability in the solar radiative output in a framework of the National Science Foundation (NSF) Radiative Inputs from Sun to Earth (RISE) program. Two out of three instruments scheduled to be built are now in operation, one at the Osservatorio Astronomico di Roma (http://www.mporzio.astro.it/solare/Ilpsptdiroma_eng.htm), and at the other at Mauna Loa Solar Observatory (MLSO, http://mlso.hao.ucar.edu/). The PSPT takes the full-disk (2K x 2K) images with high photometric precision in the blue (4094 Å) and red (6071 Å) continuum, and the core and wings of CaII K (3934 Å) spectral line.

In 2000, the New Jersey Institute of Technology (NJIT) spearheaded the creation of the Global High Resolution Hα Network comprised of nine stations in six countries (http://swrl.njit.edu/ghn_web/). Full disk Hα images are recorded using instruments with different aperture as well as spectral and spatial sampling. Currently, both tunable and non-tunable filters are employed in these observations.

4. Improved Solar Observing Optical Network (ISOON)

Imaging filters in narrow spectral bands such as Hα, CaIIK line (3933.7 A), or white-light and narrow-band continuum measures have been the mainstay for synoptic observations. The Hα spectral line particularly useful diagnostic because it is formed in a layer where the balance between magnetic fields and hydrodynamic forces appear to be the most competitive. As a result, the Hα spectral line is most sensitive to magnetic field energy changes and thermodynamic influences on the solar atmosphere, a prevalent condition during energy release during a solar magnetic reconnection process in the lower atmosphere. The table below illustrates a need for monitoring active space weather, as used by ISOON[12, 17].

Spectral Line	~ Solar Atmospheric location	Relevant synoptic activity
Hα	~500 – 10^5 km Chromospheric monitor	Flares, Plages, filament and prominence eruptions, Moreton waves, solar cycle monitoring
Hα wings (+ or – 0.4 A)	Lower Chromosphere ~ 500-1000 km	Doppler motions due to flares, surges, filament eruptions, speeds of eruptions Moreton waves
Continuum @ 6300 A	True continuum lowest layer <10 km surface	Sunspot area, sunspot number counts, white-light flares, white-light plages
HeI 10830 A	Cold corona ~	Prominences,

	10000K	flares, and upper magnetic structures

Table 1: List of spectral lines and their origin, as observed with ISOON

ISOON System Specifications: The optical system for the ISOON telescope is as follows:

- Telescope:
  - 250-mm aperture, polar-axis, evacuated refractor, primary focal length 5000 mm
- Instrumentation:
  - Dual Fabry-Perot filters (150 mm aperture)
  - Polarization analyzer (Stokes I, Q, U, and V are observable)
- Detector:
  - 2048 x 2048 CCD, cooled, 12-bit, 14 micron pixels, 200,000 electron well depth
- Magnetograph:
  - Full-spectral line longitudinal Zeeman using FeI 6302.5 Å line, upgradable to vector
- Standard Wavelengths Observed:
  - Hydrogen-alpha, tunable to +/- 4 Å
  - Magnetic field (Calcium 6305.5 Å)
  - Continuum (vicinity of 6300 Å)
- Bandpass:
  - 0.08 A (0.1 - 0.25 A threshold, depending on observing mode and effective aperture)
- Pixel Size:
  - 1.1 arcsec full disk mode
  - 0.32 arcsec high resolution mode
- Standard Cadence:
  - 1 Hα image per minute
- Photometric Accuracy:
  - Better than 5% over the field, 4096 intensity levels

The optical train in the ISOON telescope consists of a 25 cm (full resolution) aperture, that is stopped down to a 15.24 cm aperture to accommodate a 37 arcseconds field-of-view, which encompasses observing the full solar disk plus 15% of radius extending off the solar disk. The pre-filtering spectral element in the ISOON system is a 3-5 Å filters in the central range of the spectral list in Table 1. A pair of tunable Fabry-Perot Etalons, in a telecentric configuration results in an effective band-pass of 80 m Å (in Hα), provides a high fidelity spectral filtering. With the high throughput the entire system is able to provide imaging snapshots of the Sun, with exposure time as short as 6-20 milliseconds that freezes terrestrial scintillation and turbulence.

The ISOON prototype was designed and constructed as a joint collaboration between the USAF/AFRL and the National Solar Observatory. ISOON was funded by the USAF.

Optical Design

The optical design is by Dr. Richard B. Dunn (http://nsosp.nso.edu/isoon/desciption.html). ISOON operates exclusively as a narrow band (0.1 Å) filtergraph, and is built around a telecentric optical configuration for optimum performance of the system's two Fabry-Perot filters. The Fabry-Perot filters are designed with coatings allowing tunable performance over the range 6,000 to 11,000 A, although the tunable ranges are limited to about 8 A within any particular prefilter selection. A maximum of four interchangeable prefilters, centered on the wavelength of interest, can be accommodated in the system.

The ISOON optical system includes five lenses, all of fused silica. None are corrected for chromatic aberration. The system overall is diffraction limited for all wavelengths in the tunable range. The magnifier lens and first field lens are mounted on a movable stage which, in combination with the movable Cooke triplet lens, provides a zoom and focus system that simultaneously corrects for chromatic focus effects and maintains a constant solar diameter throughout the year. The magnifier lens is interchangeable, allowing the selection of either full sun (on 1.1 arcsec pixels) or limited field of view at increased magnification (0.32 arcsec pixels). Spatial resolution in the recorded image is limited by detector pixelation in all configurations. A polarization analyzer is inserted into the beam for magnetic field measurements.

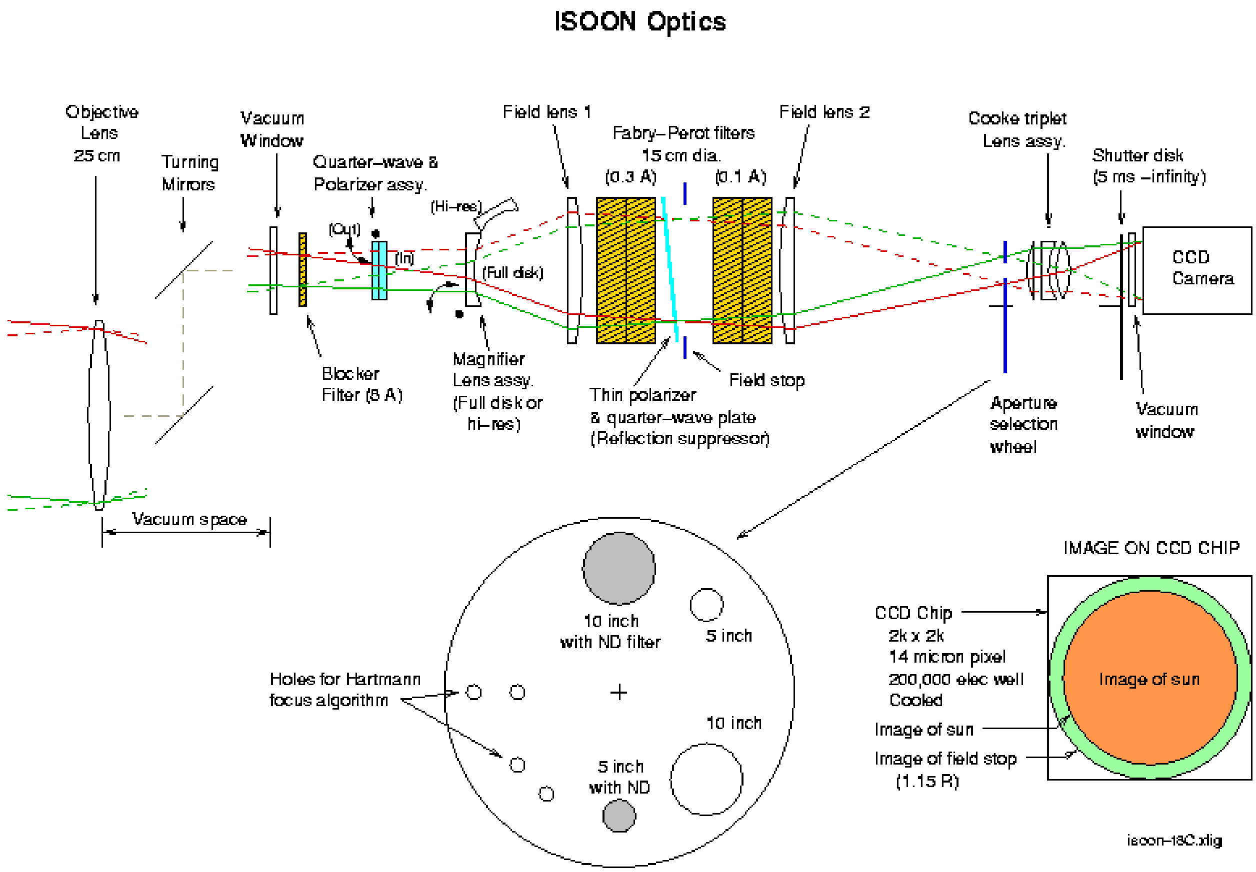

Figure 1: The optical configuration of the ISOON system

Image Processing

ISOON digital images are processed in a series of steps that produce a standard solar diameter (1781 pixels) and orientation (P-angle correction to obtain solar north at top) on a circular field of view of diameter 2048 pixels (1.15 solar diameters). Off-pointing to 0.5 solar radii above the solar limb in any direction is a program option for tracking ejecta. All images are presented in FITS format within the ISOON system and are converted to JPEG on the web pages.

Flatfielding:

Intensity variations over the field that are introduced by defects in the optical system are removed by a flatfielding process[17] that uses two orthogonal constant-speed scans (in right ascension and declination) of the Sun's image across the detector with the shutter open. Although these scans are performed quickly, a neutral density filter is inserted at the aperture selection wheel to prevent detector saturation. Flatfielding is performed every 30 minutes in each wavelength and optical configuration that is being used.

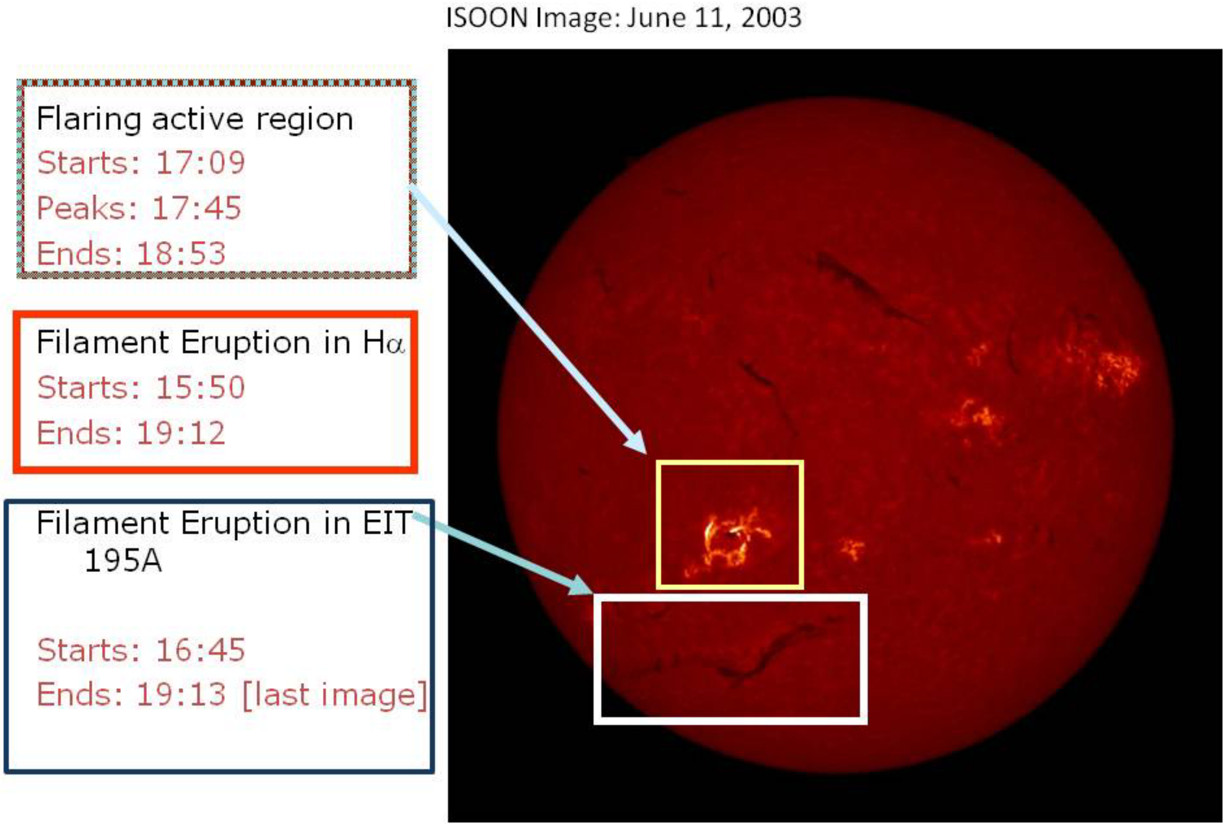

Figure 2: Example of ISOON image. This is a part of a sequence of observing showing a filament eruption and a flare

Magnetic field measurement:

We use the Zeeman circular polarization measured in the FeI 6302.5 Å spectral line (Lande g=2.5) profile. We measure the centroid measuring technique to obtain the wavelength position of the magnetic line in each (left and right) polarization state. The centroid is computed from images acquired at a number of wavelengths across the line. A separate set of flat-fields are determined for each spectral line image. The algorithm does not saturate in strong fields and is not sensitive to Doppler effects. Approximately 20-Gauss noise level (line of sight field) is obtained with 5 summations of profile differences in about 5 minutes of observing time (3 seconds of actual photon collection time).

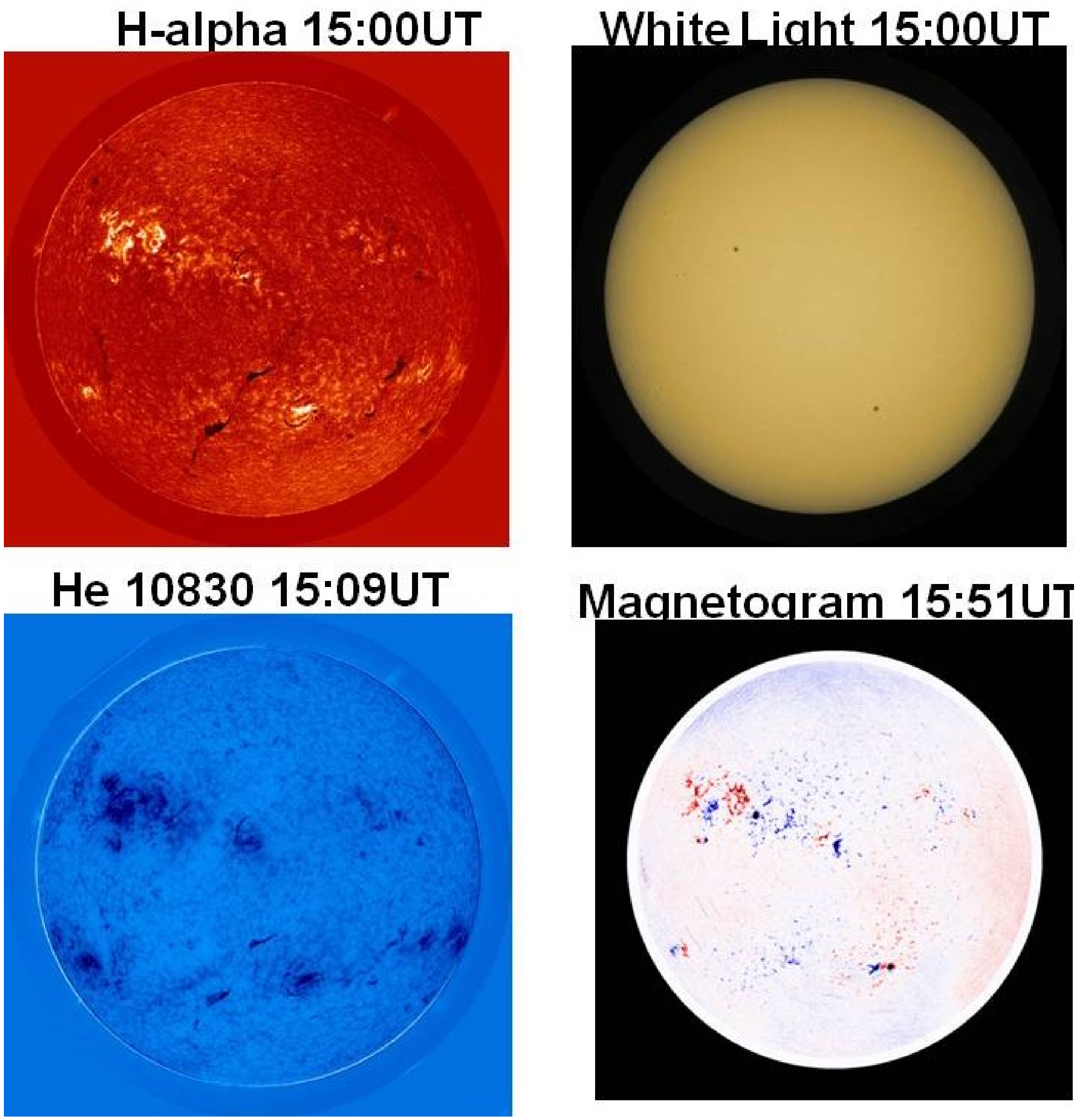

Figure 3: A sample series of ISOON images on July 15, 2011 (Ha line center, continuum, HeI 10830 Å and a magnetogram in FeI 6302.5 Å line)

These images demonstrate the viability of ISOON as a reliable solar imaging filter system to conduct synoptic observations of the Suns

The SOLIS Telescope System's VSM

The Synoptic Long-term investigations of the Sun (SOLIS) system is comprised of three different telescopes namely (a) a vector spectro-magnetograph (VSM) (b) a full-disk patrol imager (FDP) and (c) an integrated sunlight spectrometer (ISS).

Figure 4.the NSO's SOLIS telescope mounted atop the Kitt Peak Vacuum Telescope

To advance our understanding of long-term changes in solar activity, the National Solar Observatory (NSO) had designed and built a suite of instruments—the Synoptic Optical Long-term Investigations of the Sun (SOLIS). In a nutshell, SOLIS is composed of a single equatorial mount (Figure 4) carrying three telescopes: the 50 cm Vector Spectromagnetograph (VSM), the 14 cm Full-Disk Patrol (FDP), and the 8 mm Integrated Sunlight Spectrometer (ISS). The prototype system is located on top of the Kitt Peak Vacuum Telescope building (Figure 4; left), and the NSO Long Range Plan calls for a global network of two more VSMs to enable continuous solar observations. SOLIS instruments are designed to address three major questions: What causes the solar cycle? How is energy stored and released in the solar atmosphere? How do the solar radiative and non-radiative outputs vary in time? Current SOLIS data products include: daily full-disk vector and line-of-sight magnetograms in Fe I 6302.5 Å, chromospheric line-of-sight magnetograms in Ca II 8542 Å, full-disk images and derived maps of coronal holes in He I 10830 Å, and spectral observations of Sun-as-a-star in the wavelength range of 3500–11000 Å. SOLIS magnetic and helium observations by the VSM continue the historic synoptic data set from the NSO's Kitt Peak Vacuum Telescope facility collected during 1975–2002, and can be used to construct proxies characterizing solar irradiance and to bridge and calibrate the datasets taken with the space-borne instruments such as SOHO/MDI and SDO/HMI. Full-disk magnetograms and images observed by the VSM are used to construct synoptic maps of the Sun representing the entire solar surface for a selected rotation. These magnetograms find broad application in forecasting the solar-wind speed – one of the driving forces of space weather. For a detailed description of SOLIS see the references named above, and at http://solis.nso.edu/VSMOverview.html .

a) Vector Spectromagnetograph (VSM).

VSM is a Ritchey-Chrétien telescope with a 50 cm primary mirror and a two-lens field corrector. To minimize the internal seeing, the entrance of the telescope is protected by a thin (6 mm) fused silica window, and the whole telescope is filled with helium. A fan system circulates the helium to minimize the temperature gradients inside the telescope. The image of the Sun is built on the entrance slit of the Littrow spectrograph. The length of the slit covers 2048 arc seconds (angular diameter of the Sun varies between 1896 and 1962 arc seconds during the year). To compensate for the curvature of spectral lines in the spectrograph's focal plane, the spectrograph slit is slightly curved with radius of 258.77 mm. Scanning image by a curved slit result in a geometric distortion of the solar disk figure. This distortion is corrected at the data reduction stage.

The two polarization calibration packages (one for 6302 Å region and the other for 8542 Å region) are located in front of the spectrograph slit. Three separate LCD polarization modulators are placed on a mechanical slide behind the spectrograph entrance slit. Separate modulators are used for observing and deriving vector spectropolarimetry in FeI 630.15-630.25 nm wavelength range, and line-of-sight (circular) polarimetry in Fe I 6301.5-6302.5 Å, and Ca II 8542 Å wavelength ranges. A future upgrade for the full vector spectropolarimetry in Ca II 8542 Å is being considered. The appropriate modulator is mechanically moved into a beam when the observations at a specific spectral wavelength band are taken. The assembly holding the three modulators has an additional position which is used for non-polarimetric observations in HeI 10830 Å spectral line. The modulation scheme is based on one proposed by Gandorfer[21].

The image of spectra is formed near the spectrograph slit, where the focal beam-splitter splits the image of the spectrograph slit into two equal parts each of 1024 arcseconds long. Light from each part is reimaged to a separate CCD camera of 1024 x 512 pixels in size. The polarizing beam-splitters are located in front of each camera. With these optical arrangements, one camera is taking data from one solar hemisphere and the other camera records images of spectra from the other hemisphere. Both cameras are taking data in two orthogonal polarization states. Figure 5 shows example of spectra taken with the VSM.

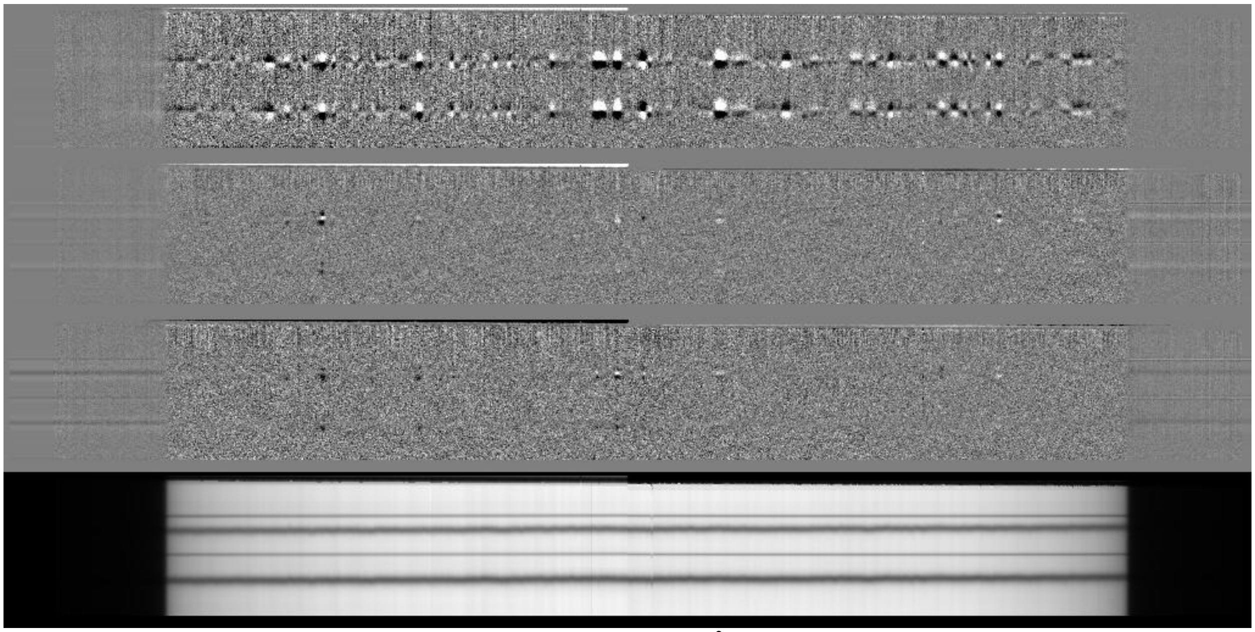

Figure 5. Example of spectra for Fe I 6301.5-6302.5 Å corresponding to Stokes parameters (top to bottom) V, Q, U, and I. Ghosts of spectra visible in three upper panels are residuals of a flat-field applied to the pixels corresponding to off- limb part of solar image for this scan line.

A full disk magnetogram is constructed by scanning the solar image, which is achieved by moving the telescope in declination. It takes about 0.6 seconds to record one scan line in FeI 6301-6302 Å region, and about 1.2 seconds for the Ca II 8542 Å line, which translates to about 20/40 minutes for a full disk magnetogram in the photospheric/chromospheric spectral lines. In addition to full disk, VSM can take a series of area scans by scanning portion of solar disk in the declination. Additional technical details on VSM can be found in [22] and at http://solis.nso.edu/VSMOverview.html.

In January 2010, the VSM was upgraded with new CCD cameras, which resulted in higher spatial resolution (smaller pixel size) and better signal-to-noise ratio. In the near future, a polarization modulator will be upgraded to expand the VSM capabilities to take full vector magnetic-field measurements in the chromosphere. This upgrade will make VSM the first chromospheric, full-disk vector magnetograph, and significantly advance our capabilities to study the topology of coronal magnetic fields, electric currents, and their effects on triggering solar flares.

The VSM provides the following data products (see Figure 6):

1. photospheric full-disk vector-magnetograms using the FeI 6301.5 and 6302.5 Å lines (field strength, azimuth, inclination, flux, Doppler velocity, continuum intensity)
2. chromospheric full-disk magnetograms using the CaII 8542 Å line (line-of-sight magnetic flux, Doppler velocity, line core intensity)

3. full-disk HeI 10830 Å line characteristics (equivalent width, continuum intensity, Doppler velocity, line depth, line asymmetry, Doppler width, Si line width, Si line depth, Si Doppler velocity)
4. photospheric full-disk longitudinal magnetograms using the FeI 6301.5 and 6302.5 Å lines (line-of-sight magnetic flux)

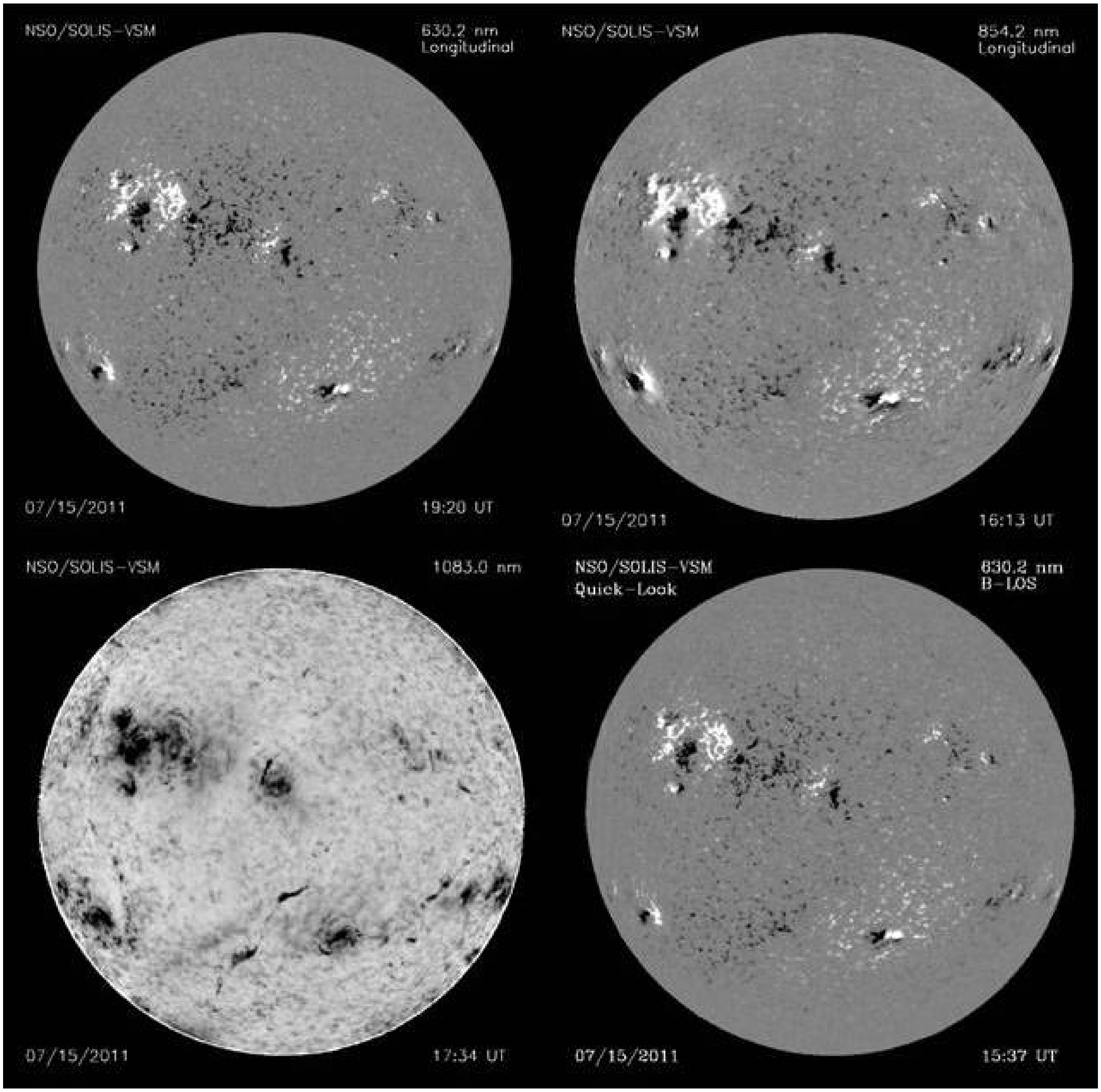

Figure 6: A sample series of SOLIS images on July 15, 2011 (FeI 6302.5 A line longitudinal, CaI 8542 line longitudinal, HeI 10830 and a LOS magnetogram in FeI 6302.5 A line)

b) The Integrated Sunlight Spectrometer (ISS).

The ISS is designed to obtain both high (R = 300,000) and moderate (R = 30,000) spectral resolution observations of the Sun as-a-star over a broad range of wavelengths of 3500–11000 Å. The optical feed for the ISS consists of an 8-mm diameter lens located on the side of main mount of VSM. The lens builds the image of the Sun on the input face of the fiber optic assembly, which transmits light to a McPherson 2-m Czerny-Turner double-pass spectrograph. The spectrograph is located in a temperature-controlled room inside the telescope tower. The use of the fiber optic feed insures the complete integration of the sight in angular and spatial directions as required for the Sun-as-a-star observations. The spectra are recorded using a back-illuminated 512 x 1024 CCD camera in the focal plane of the spectrograph. Further details on the observations and the data reduction pertaining to the ISS can be found in [23].

Currently, daily ISS synoptic observations include eight spectral bands centered at the CN band 3884.0 Å, Ca II H (3968.5 Å), CaII K (3933.7 Å), C I 5380 Å, Mn I 5394.1 Å, Hα 6562.8 Å, Ca II 8541.9 Å, and He II 10830.2 Å. These measurements are used to study changes in solar irradiance with the solar cycle and the response of different layers of the solar atmosphere to magnetic activity of the Sun. ISS observations are also employed to interpret and calibrate stellar measurements in terms of stellar activity and cycles.

Figure 7 displays the profiles of four spectral lines observed by the ISS on July 17, 2011.

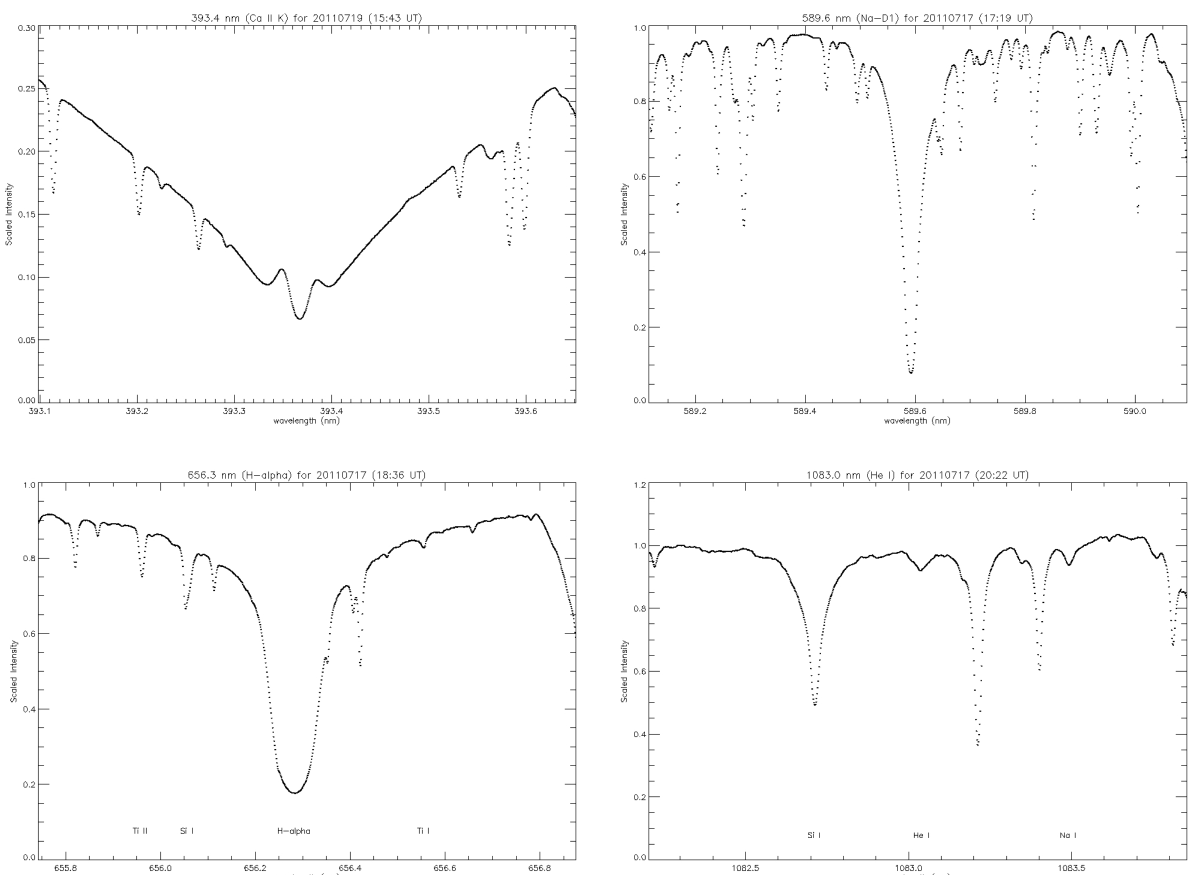

Figure 7: Example of four spectral line profiles observed by the ISS on July 17, 2011: (upper panel) Ca II K 3934 Å (left), Na D I 5896. Å (right) and (lower panel), Hα 6562.8 Å (left), and He I 10830 Å (right).

c) The Full Disk Patrol (FDP).

The FDP is a full-disk imager that uses tunable Lyot filters and a 2048 × 2048 CCD camera (about 1 arcseconds pixel size). It is designed to take observations with high temporal cadence (about ten seconds) in several selected spectral lines including Hα, Ca II K, He I 10830 Å, continuum (white light), and photospheric lines, as well as the capability of observing Doppler velocity maps. In June 2011, the FDP has been integrated to the SOLIS and is now going taking observations in the test mode. The FDP will provide crucial imaging data for space-weather forecasting, to help understand triggering and evolution of solar flares and coronal mass ejections, and it will also complement space-based X-ray and EUV observations.

5. Future Needs and Conclusions:

Ground-based synoptic observations are a sustainable main-stay for longer-term solar synoptic data. Full-disk patrol imagery, as obtained with ISOON and continuous magnetograms on a 5-15 minute cadence, similar to SOLIS are rather important. Space based measurements have come a long way in making solar observations much better, as evidenced by SOHO, STEREO and SDO missions, supported by NASA. Recent space-based measurements had adopted an open-data policy, which had proven to be extremely beneficial for the scientific research by enabling the research in a broad range of organizations and fostering the international collaboration. Space-based observations open spectral windows such as Extreme Ultraviolet, X-ray, and γ-ray that are not available from the ground. They also have a potential for a continuous observations uninterrupted by the day-night cycle and/or bad weather. Despite these advantages, the space-based instrumentation is inherently more expensive. The lifespan of the missions is typically limited by a few years, the instruments are not upgradable or repairable (with a few notable exceptions such as, for example, Hubble Space Telescope), and the major failures may have a severe impact on the operations (recent examples of solar missions include loss of communication with SOHO in 1997, limited downlink rate for Hinode, and failure of the power supply for Coronas-Photon mission. Ground-based observatories have the advantage of independent funding by individual countries and/or their observatories, and, since only the final data needs to be shared, pooled resources for a singular monolithic mission would be unnecessary.

We suggest that the next set of ground observatories aim for the following requirements. These are based on science and pragmatic needs: Most observatories have good astronomical seeing of ~ 0.5 arcseconds, or even better lasting for several hours, at some good part of the day. Since better resolution images gives us a good perspective, even if present only momentarily, this would be an important consideration. That results in covering the sun and an extended limb, at size of 4096x4096 pixels. Changing conditions on the sun before solar eruptions happen rapidly – of the order of seconds. However, cameras and processors that correct the images at 12-16 bit resolution will pragmatically help in getting a final image at least at 30-second cadence rate. Magnetic models of active regions require constraints of the magnetic fields in at many layers. Magnetic field observations are constrained by considerations such as: available spectral lines that are Zeeman sensitive, good polarization signal to noise, spectral coverage within the detector's spectral sensitivity, etc. At least one vector magnetic measurement, each in the photosphere, chromosphere and corona, respectively, will be necessary for advancing the science of eruptive solar forecasting. These requirements give rise to the following measurement requirements:

- 0.5 arc-second resolution and sampling
- 4096x4096 whole-sun images
- 30-second cadence
- Images: Hα, Hα off-band (+0.4 A, -0.4 A) CaII K line (3933 Å), continuum, HeI 10830Å, CaI 8542 Å, each at the above cadence.
- Magnetograms (both line-of-sight and full vector) at photosphere (6302 Å), chromosphere (8542 Å), and corona (10830 Å), at a 15-minute cadence
- Data processing and availability within 2-minutes of acquiring data

With little compromise in the need for high-cadence and near real-time data, and considerable data processing involved, separate imaging and magnetographs telescopes are necessary to avoid temporal sharing of the same light feed. Developing data driven models of solar activity for synoptic measurements must necessarily hinge on high-quality, consistent and reliable data. A round-the clock global network of telescopes, roughly separated by 60-80 degrees in terrestrial longitude will provide for good, consistent and overlapping coverage.

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