Photometric properties of quiet Sun observed with the DKIST and HINODE

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Abstract

The variability of irradiance is primarily influenced by surface magnetism, such as sunspots, faculae, and network structures. Each of these features contributes differently to the overall variability. However, the impact of small magnetic elements, which are commonly observed in high-resolution images of the solar photosphere but remain unresolved in full-disk images used for irradiance modeling, is still a topic of debate. Understanding the influence of these small magnetic elements to the overall brightness, particularly in quiet regions, is fundamental to understanding irradiance fluctuations over decadal and longer temporal scales. We investigate the brightness of small-size magnetic elements using very high spatial resolution spectro-polarimetric observations acquired at different spectral ranges with the National Science Foundations Daniel K. Inouye Solar Telescope (DKIST) and with HINODE/SOT. Our results are compared to 3D MHD Small Solar Dynamo simulations obtained with the MURaM code.

DKIST Observations

DKIST Observations were acquired on July 7, 2022 during the Cycle 1 ofDKIST Operations Commissioning Phase. Two quiet-sun regions were observed with the ViSP in the FeI 630.1/630.2 nm, CaIIH and Ca II 854.2 nm ranges and with the VBI blue continuum (450.4 nm). We present here results obtained from the preliminary analysis of data acquired in the FeI spectral range only.

Seeing conditions were variable, with several moments of r0=17 cm.

We present here results obtained on a 16"x23" region from Target 2.

By selecting a very quiet area in Target 1 we estimated:

Spectropolarimetric sensitivity = 0.001 x Ic (continuum intensity)

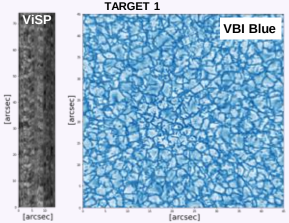
cross-talk I→V,Q,U = 0.00335, 0.00641 , -0.00335

By comparing with the quiet sun (QS) solar atlas we found:

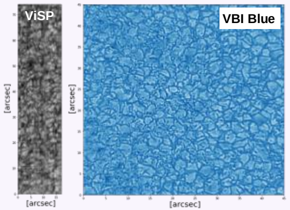
Spectral resolution = 2pm

Scattered light level = 2% of Ic.

TARGET 1



TARGET 2

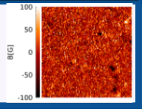


ViSP map in FeI 630.1 nm nearby continuum (left) and example of VBI frames (right) for Target 1 (top) and Target 2 (bottom). VBI images were post-processed using the Speckle Reconstruction technique (Wöger et al. 2021). Each image results from the reconstruction of 80-frames.

HINODE Observations

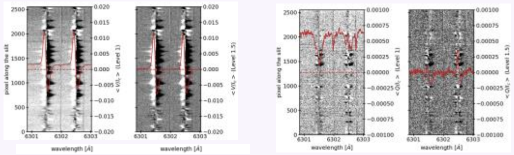
Hinode observations were acquired with SOT/SP on December 19, 2007, they are part of the irradiance program HOP 79. Here we use the scan performed at disk center on a 56'' x 164 '' quiet Sun region. The spectral resolution is 2.15 pm/px in the spectral range between 630.08 and 630.32 nm. The pixel size is 0.16'' along the spectrograph slit and the scan step is 0.1476''. We use the level-1 data provided by the CSAC database of the High Altitude Observatory.

Image on the left shows as an example a 5.1" x 5.1 " region of the line-of-sight magnetic field derived from HINODE/SOT observations.



DKIST data post-processing

The Level 1 ViSP data require further post-processing beyond the standard data reduction before they can be analysed. This includes correction for residual crosstalk and wavelength/flux calibration.



We used the *ad hoc* crosstalk correction method developed by Jaeggli et al. (2022, *ApJ* 930, 132). This effectively removed the continuum polarization offset and the imprint of the telluric lines from the spectra (see also da Silva Santos et al., 2023, arXiv:2308.10983).

The figure shows Stokes Q and V for a given slit position of the ViSP raster before (left) and after (right) crosstalk correction. The solid red curves show averaged spectra.

We have determined the spectral dispersion (0.0013 nm/px) and performed the wavelength/flux calibration by comparing the mean spectrum with the QS solar atlas.

Simulations

We employ 30 snapshots from small local-dynamo simulations of the solar photosphere obtained with the Max Planck University of Chicago Radiative MHD (MURaM) code (Vögler et al.2005, Rempel 2020). The simulations cover an area of 12X12 arcsec, with a sampling of 17 km and average magnetic field $\langle|B|\rangle_{\tau=1}$ = 75 G. Stokes parameters in the Fe I 630/1-630.2 nm lines were synthetized in NLTE using the RH code (Uitenbroek 2001). Emerging intensities were degraded to the DKIST's diffraction limit of 0.04 arcsec @ 630 nm, resampled to the pixel plate of observations and convolved with the ViSP instrument response function. SOT observations were emulated using the Modulation Transfer Function in Danilovic et al. 2008.

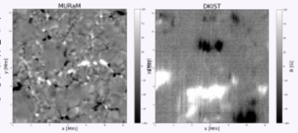
Magnetic field estimates

We are mostly interested in estimates of the magnetic field intensity along the line-of-sight B_{LOS}, which was estimated applying the Center of Gravity method on the Fe I 630.1 nm Stokes I and Stokes V profiles.

The B_{LOS} uncertainty in our measurements (estimated as the standard deviation of B_{LOS} in a very quiet area) is ~ **4 G.**

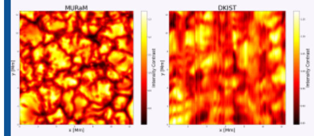
Results

Comparison of magnetic field line-of-sight intensity maps (B_{LOS}) obtained applying Milne-Eddington inversions to a MURaM snapshot (left), and DKIST observations (right). The DKIST field-of-view was cropped to match the field of view of the simulations. In both images the B_{LOS} is saturated at +/- 100 G.

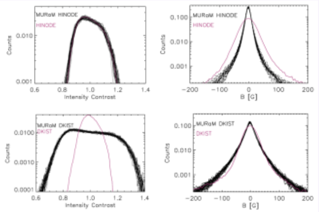


	<|B|> [G]	<B> [G]	Brms	Irms
MURaM DKIST	22	0.03	52	14%
DKIST obs.	22	-0.03	43	5.2%
MURaM HINODE	9	0.017	16.7	7.6%
HINODE obs.	23	1.44	42	7.8%

Table on the top compares the average properties of the magnetic field and of the intensity-rms-contrast (I_{rms}, defined as the ratio between the standard deviation and average values of the intensity) in the 630 nm continuum obtained from MURaM, and the DKIST and HINODE observations.

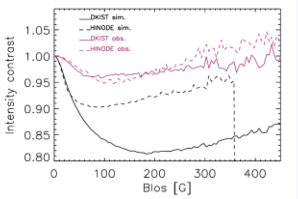


Comparison of maps of Intensity contrast (intensity normalized to the average Intensity in the field-of-view) at 630 nm continuum obtained with MURaM snapshot (left), and DKIST observations (right).



The Intensity contrast and the B_{LOS} distributions are compared in the left and right plots, respectively. The narrower distributions in the DKIST observations indicate that the spatial resolution of the ViSP data is less than the diffraction limit of the telescope @630nm suggests.

HINODE intenisty distributions are well matched by the simulations, while Blos is simulated narrower than the observed one.



Plot on the left shows that the I vs B_{LOS} curve presents the typical 'fish-hook' shape reported in the literature (Schnerr and Spruit 2011). The lower contrast and the lower B_{LOS} value of the position of minimum of the curve found in observations (~65 G) with respect to simulations (~100 G), are compatible even in this case with the fact that ViSP observations are not diffraction limited, while for HINODE might indicate a selection effect.

Conclusions

We performed a preliminary analysis of DKIST observations acquired on July 7, 2022 during Cycle 1 of the DKIST Operations Commissioning phase. We present here results obtained from ViSP observations at the FeI 630.1/630.2 nm spectral range. We found that the level 1 data provided by the DKIST Data Center are affected by residual cross-talk I-> U,V,Q and V-> Q,U, residual polarization in the continuum and low-frequency patterns (fringes) in the spatial domain. All these effects were compensated for in our data.

Comparison of observations with MURaM simulations degraded to the diffraction-limit of DKIST, indicate that the spatial resolution of ViSP data is lower than the diffraction-limit of the telescope. This is to be expected as typically diffraction limit is achieved by applying post-processing techniques.

The observed and simulated HINODE intensity distributions, and Irms are in very good agreement. However, the magnetic field properties of HINODE observations are not well reproduced, which points most likely to an area selection effect in the observations.