



NSF's National Solar Observatory

Daniel K Inouye Solar Telescope



DKIST Science Support Center



The National Science Foundations'
Daniel K Inouye Solar Telescope



NSF's Daniel K. Inouye Solar Telescope (DKIST)



- The 4m DKIST on Haleakalā, HI is the world's largest solar telescope!
- The construction and operations of DKIST are funded by the National Science Foundation
- Partner contributions from:
 - Germany – Visible Tunable Filter, pursuing Data Center Mirror in Germany
 - UK - high speed, large format cameras



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- Facility and instrument overview
 - Science Objectives - examples
 - Efforts to organize and prepare the community for DKIST
 - Construction Status
 - First Light results
 - Remaining work
 - Transition to Operations

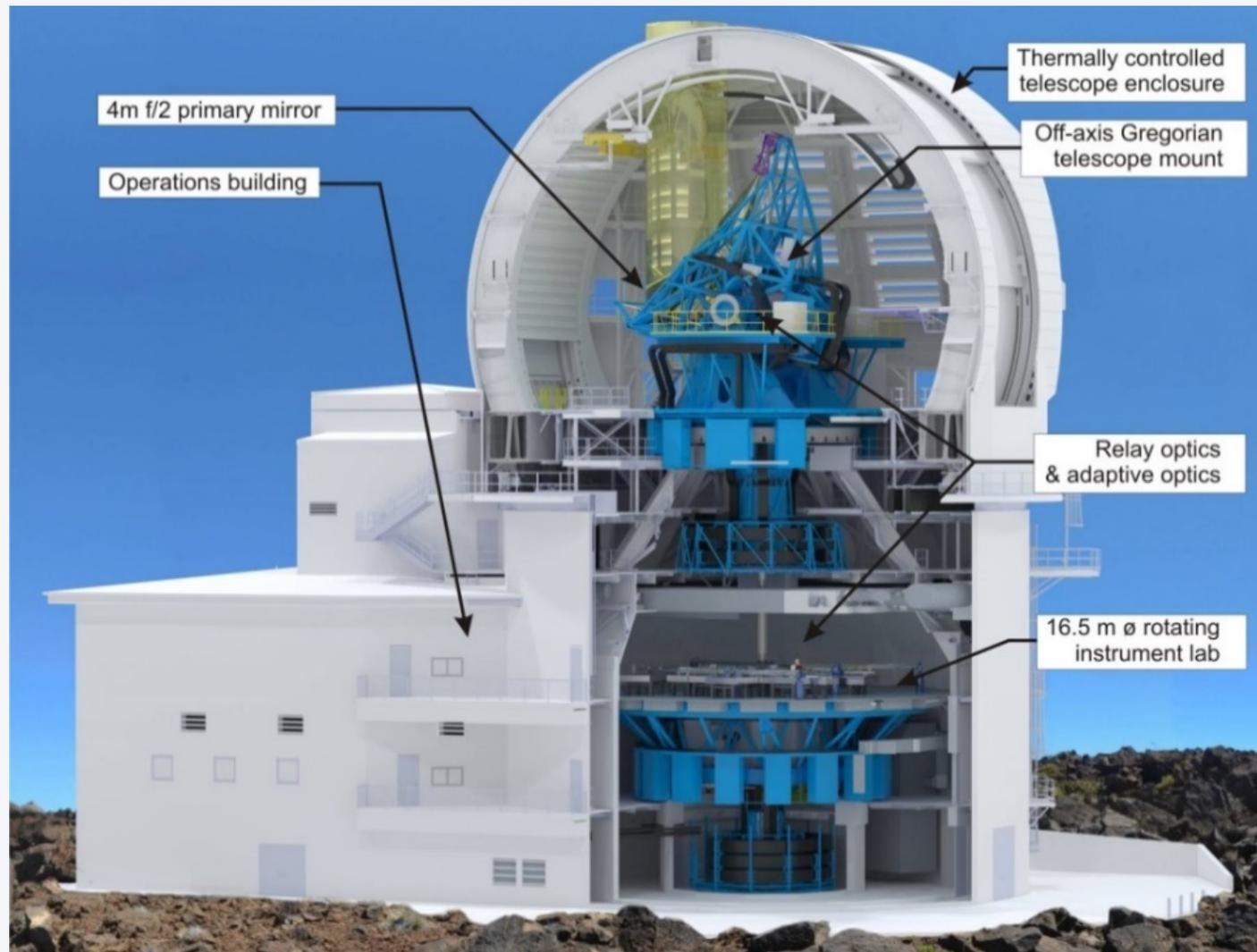


DKIST in a nutshell

- Four-meter aperture
- Off axis design
- Most advanced solar adaptive optics to enable high resolution observations
- Coronagraph to enable coronal magnetometry
- 5 Facility-class instruments
- Data output: 3 Pb/year served fully calibrated to the community. Open access after short proprietary period
- Lifetime: two magnetic cycles (2x22years)
- At a site that has excellent seeing and coronal skies

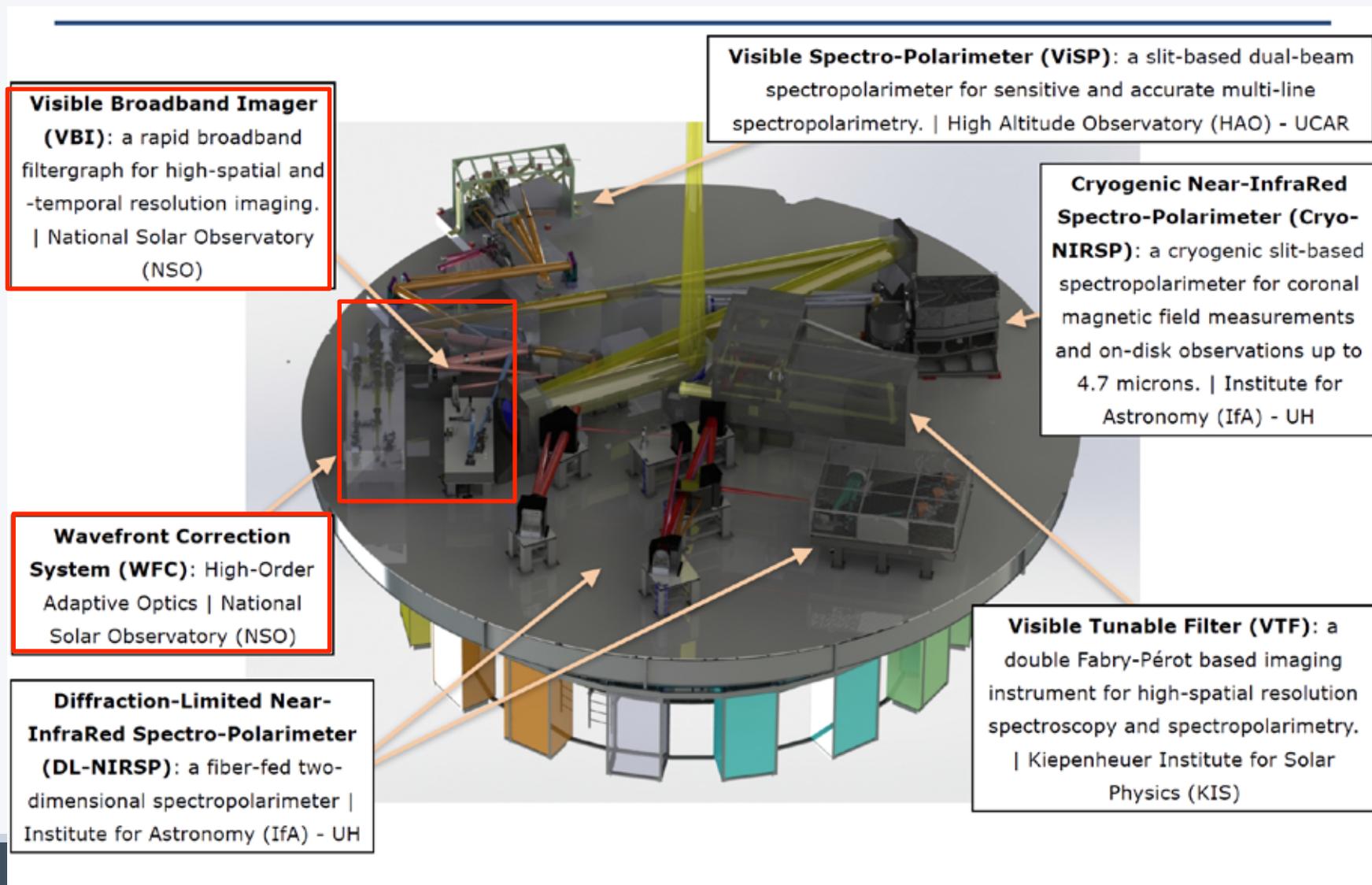
Spatial Resolution (25km@500nm)

Polarimetry (accuracy: 5×10^{-4} ; sensitivity: $> 10^{-(4-5)}$)



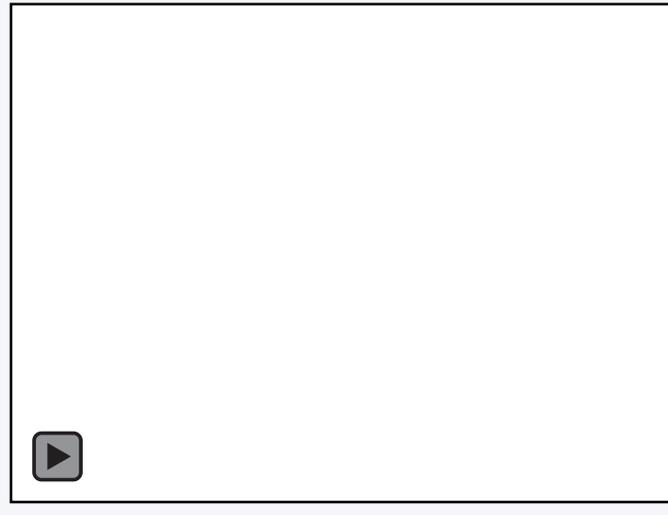
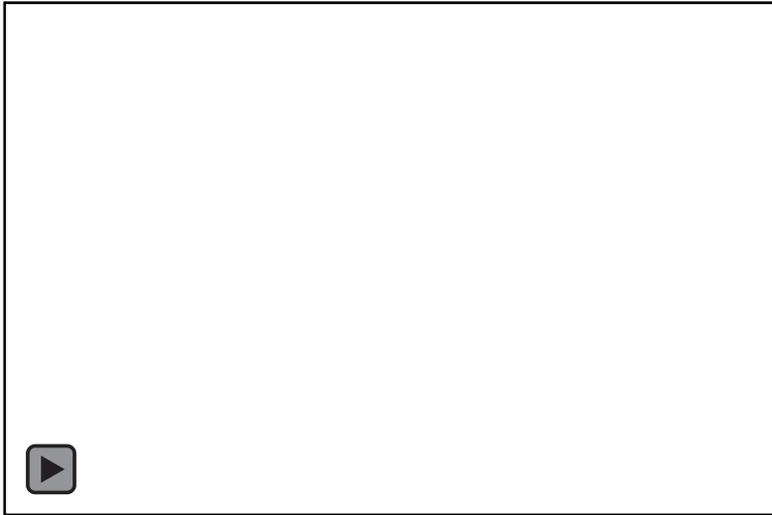


DKIST Instruments – a highly capable observing system! UV to 5 micron spectro-polarimetry



Science Goal: Verification of Models

Need: Resolution and Sensitivity.



Rempel, HAO
MHD Model resolution:
10-20km
Observations have been
lacking ! So far ...

\mathcal{D}'

$$\begin{aligned} SNR &\approx 10^4 \\ \phi_{px} &\leq 0.1 \text{ arcsec} \\ t_{\text{exp}} &\approx 10 \text{ s} \end{aligned}$$

à

\mathcal{D}

4m minimum aperture

$$D = \frac{SNR}{\sqrt{0.7 N 10^{-0.4 m} \tau \Delta \lambda Q \phi_{px}^2 t_{\text{exp}}}}$$

Observations are often photon starved!

SDO Flares & CMEs solar drivers of space weather

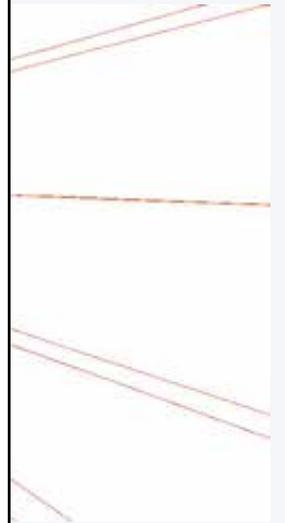
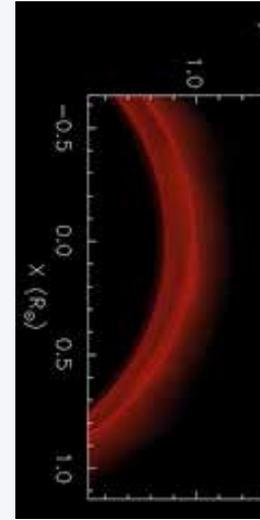
Goal: Understand the underlying physics well enough to improve models & predictive capabilities!



Hinode



Fan et al



Cheung

NATURE ASTRONOMY



LETTERS

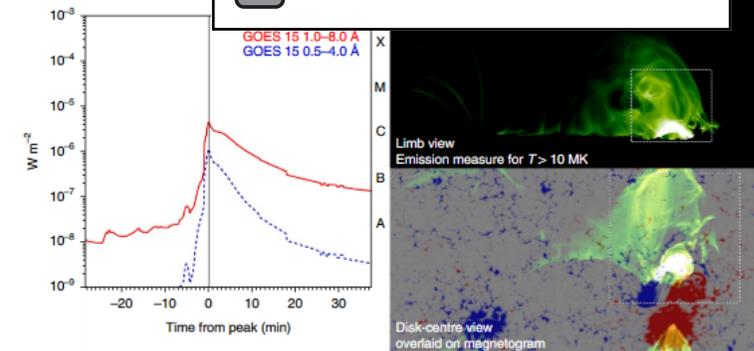


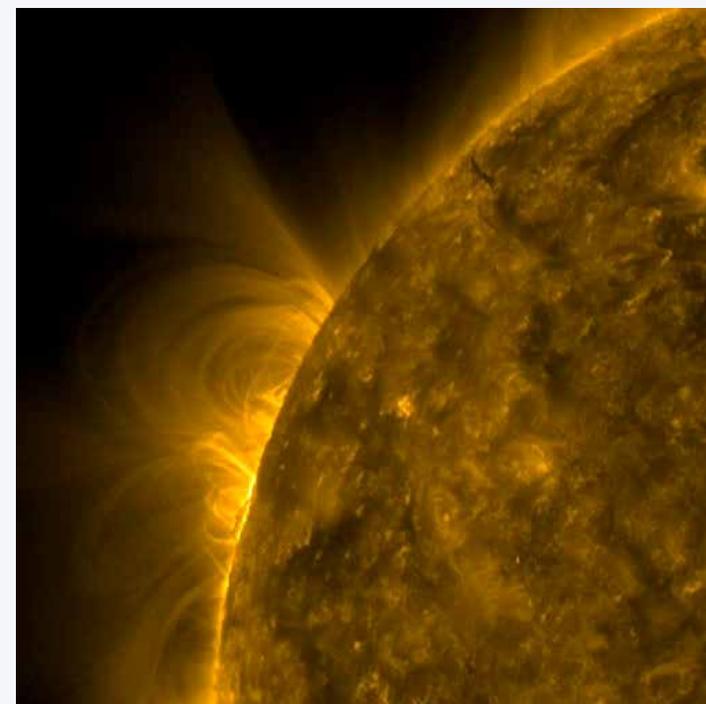
Fig. 1 | Synthetic X-ray flux time profiles and associated hot plasma. Left: synthetic time profiles of X-ray fluxes as would be measured by the long- (1.0–8.0 Å, solid red) and short-wavelength (0.5–4.0 Å, dashed blue) X-ray channels of the GOES 15 satellite. The corresponding NOAA flare class designation is indicated on the right by the letters A, B, C, M and X. The peak flux in the long-wavelength channel gives a GOES flare classification of C4. Right: simulated disk-centre (bottom; overlaid on a magnetogram) and limb views (top; emission measure of plasma with $T \geq 10$ million K, shown with increasing values as black < green < white) of flare plasma at the time ($t=0$) during the peak of the X-ray flux. The hottest loops connect the opposite polarities of the parasitic bipolar emerging flux region north of the negative (red) polarity sunspot. These loops are heated by the energy released by the strong magnetic fields that have undergone reconnection. The dashed boxes in the disk-centre and limb view panels indicate the regions shown in Figs. 2 and 3, respectively.



Science Goal: Measuring Coronal Magnetic Fields

SDO

- ▷ The Problem:
- ▷ **Coronal Intensity** : $10^{-(5-6)} I_{\text{disk}}$
- ▷ **Polarimetric signal** : $10^{-(3-4)} I_{\text{corona}}$
- ▷ **4m aperture: DKIST as light bucket!**
- ▷ **~1" resolution**
- ▷ **low scattered light!**
- ▷ **IR diagnostics!**



Lin et al. Solar-C,
Haleakala



DKIST measures the 3D magnetic field structure

Photospheric field:

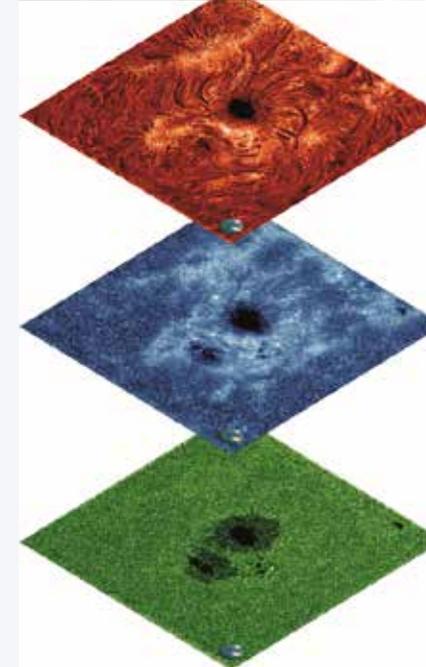
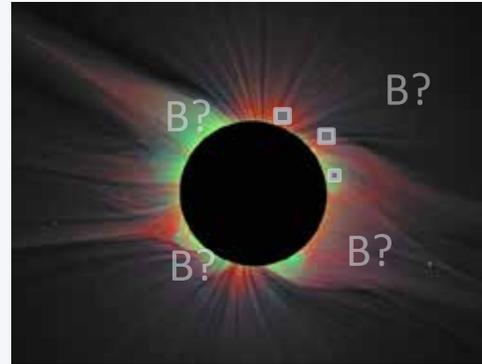
- FeI 525 nm, FeI 630.2nm,
- FeI 1.56 micron lines

Chromospheric field:

- CaII 854.2nm,
- HeI 1083.0nm

Coronal field:

- FeXIII 1.0747, SiIX 3.9 micron



Goal: Obtain maximum on observational information!

Requires:

- Combining multiple instruments in a coordinated fashion.
- Coordination with e.g. space assets SO, PSP,...

Consequence:

- Observing experiments are complex, produce large amounts of data
- Experiment preparation time & resources are significant
- Experiment preparation & execution requires significant science resources
- Data rates & "handling" effort are significant



Multi-messenger Astrophysics of the Sun

Working together to study the Sun

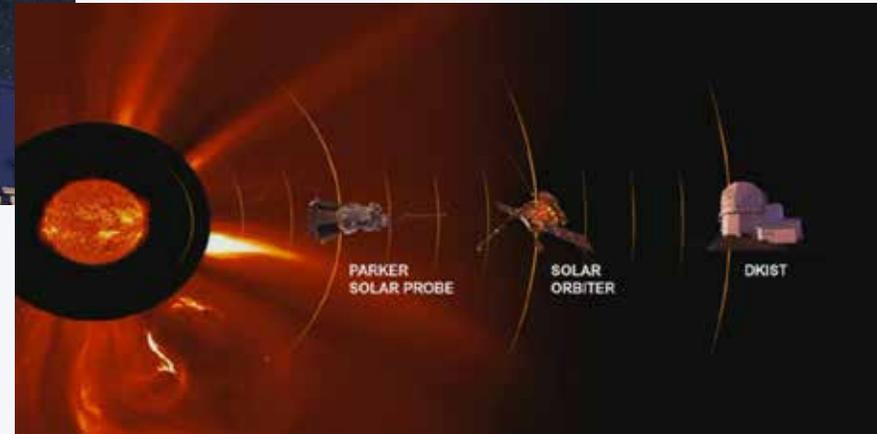
SOLAR ORBITER
Space-based: Remote sensing of photons and in-situ particles and fields
Orbit: Will fly within 0.28 AU of the Sun.
Out of the ecliptic orbits inclined by 30 degrees
The ESA/NASA Solar Orbiter will examine how the Sun creates the vast bubble of charged particles blown by the solar wind into the interstellar medium, known as the heliosphere.

PARKER SOLAR PROBE
Space-based: In-situ particles and fields
Orbit: Will fly within .04 AU of the Sun
NASA's Parker Solar Probe will provide a statistical survey of the Sun's outer corona, tracing the flow of energy and exploring what accelerates and heats the solar wind.

DKI SOLAR TELESCOPE
Earth-based: Remote sensing of photons
Orbit: 1 AU
The NSF's Daniel K. Inouye Solar Telescope, the world's largest solar telescope, indirectly measures the magnetic fields to create maps of the corona and better understand how and why the corona heats up so dramatically.

NSO AURA NSF

From solar surface, through the heliosphere, to the magnetosphere?





DKIST is a proposal driven facility

- Community **PIs or PI Teams** develop and submit proposals
 - Formulate specific science objective
 - Develop and submit detailed Observing Plan
 - Instrument combination & modes for each instrument
 - Observing requirements and procedures
 - Special calibration requirements and procedures
- Call for proposals every 6 months (4months for OCP)
- TAC review process with science and technical review

Note: Developing an observing proposal constitutes a significant intellectual investment > short (6 months) data proprietary period as proposed by DSPAC.

Open Access after 6 months PP!



Preparing the Community for DKIST -Critical Science Plan

- Community has developed pre-proposals
 - CSP workshops organized by science topic
 - NSO/DKIST provided tools and assistance to aide
 - Instrument performance calculators
 - Data rate estimator
 - Tool to assess feasibility of instrument combinations
 - Some 300 pre-proposals prepared already
- **Goal: proactively organize and prepare the community (with emphasis on US) for DKIST science**



Critical Science Plan

DKIST Critical Science Plan

The DKIST Critical Science Plan (CSP) will define the community-driven critical science goals for the first two years of DKIST operations. Its overall aim is to be ready, by start of operations, to execute a set of observations that take full advantage of the DKIST capabilities to address critical compelling science. In the process, the CSP effort will help refine data handling procedures and science operations.

The Critical Science Plan is currently being formulated with the help of the DKIST Science Working Group, building up from a comprehensive set of Piled Science Use Cases (SUCs), which detail the scientific goals and the DKIST instrumental configuration required to achieve them. A large fraction of the solar community has already been involved in this bottom-up effort, most notably via participation in the series of Critical Science Workshops organized by NSO in the 2017-2018 timeframe.

Please note that all the CSP related activities are aimed at helping the community to familiarize with the DKIST capabilities, and prepare for first light efforts. They do not preclude submission of observing proposals by individuals and teams directly to the DKIST Time Allocation Committee, and all observing proposals will be evaluated on an equal footing.

Any scientist that wants to contribute to the CSP is welcome to do so, by submitting a Science Use Case. Five broad Research Areas have been identified as the "building blocks" of the CSP, and need to be referenced to when writing the Science Use Cases.

Research Areas

Magnetohydrodynamics and Dynamo Processes (MHD&DP)

Flares and Eruptive Activity (F&EA)

Magnetic Connectivity and Energy Flows in the Solar Atmosphere (MC, M&EF)

Long-Term Studies of the Sun (LTS)

Special Topics and Broader Implications (ST)



Contact

DKISTCSP@nsso.edu
Mark Rast, CU Boulder
Gianna Cauzzi, NSO

Science Use Cases

How to Submit a Science Use Case

DKIST Instruments

- VBI
- VISP
- VTF
- DL-NIRSP
- Cryo-NIRSP

CSP Resources

CSP documents, downloads, and presentations

CSP Workshops

CSP workshop pages

Workshop Topics and Dates

Note that the Critical Science Plan Development workshops are planned as one or two components, as described below. Note that participation to the workshop is by invitation only. Questions and comments can be directed to the single workshop organizers, or to Y. Yan, Director, Plan 5, Facility M, RAS.



Magnetic Reconnection and Reconfiguration

(B. Morota, Y. Kazekawa)
Aims to develop Science Use Cases investigating magnetic reconnection of the solar atmosphere, on reconfiguration during reconnection, and the resulting waves and flows.

Workshop dates:
13 - 15 November 2017
(Huntsville, AL)
26 - 28 February 2018
(Nagoya, Japan)

[Read More](#)



Magnetic Connectivity

(D. Schmitz, E. Magdalenic)
Aims to develop Science Use Cases that leverage DKIST's polar fields and multi-scale capabilities to understand the magnetic structure and energy transfer through the solar atmosphere.

Workshop dates:
8 - 10 January 2018
(Washington, DC)

[Read More](#)



Photospheric Magnetic Fields

(C. Fischer, N. Beloborodov)
Aims to develop Science Use Cases that leverage DKIST's high resolution polarimetric capabilities to study the structure and dynamic evolution of magnetic fields at the photosphere.

Workshop dates:
18 - 19 January 2018
(Freiburg, Germany)

[Read More](#)



Joint Science with Solar Orbiter and Parker Solar Probe

(J. Harris, V. Andrus, A. Youssoufi)
Aims to develop Science Use Cases that benefit from or require joint observations with Solar Orbiter (SO) and Parker Solar Probe (PSP).

Workshop dates:
13 - 15 March 2018
(Lanark, MT)

[Read More](#)



Wave Generation and Propagation

(S. Suuthi, S. Malherbe)
Aims to develop Science Use Cases that leverage DKIST's high resolution and heliostats to understand wave generation, mode conversion, and energy dissipation in the chromosphere and corona.

Workshop dates:
9 - 11 April 2018
(Newcastle upon Tyne, UK)
5 - 7 December 2018
(Lee Creek, NM)

[Read More](#)



Flares and Eruptive Phenomena

(J. Bratslavsky, L. Fleckner)
Aims to develop Science Use Cases that leverage DKIST's multi-wavelength capabilities to probe the energetics of flares over multiple heights, while simultaneously mapping the evolution of the magnetic field.

Workshop dates:
15 - 17 May 2018
(Houston, TX)

[Read More](#)



Coronal Science Frontiers

(J. Kuhn, T. Schud, M.P. Mirek)
Aims to develop Science Use Cases that leverage DKIST's revolutionary coronal capabilities to address the understanding of the coronal magnetic and thermal structure, its energy content, and its role in solar eruptive behavior.

Workshop dates:
June 27-29, 2018
(Fribourg, SW)

[Read More](#)



Broader Implications

(S. Longcope, M. Rast)
Aims to develop Science Use Cases that leverage DKIST's unique capabilities and address fundamental questions such as outbursts, reconnection, particle acceleration, and plasma instabilities.

Workshop dates:
July 16-20, 2018
(Bismarck, MT)

[Read More](#)



Long-Term Studies

(L. Peter)
Aims to develop Science Use Cases that require systematic use of DKIST to address questions requiring high resolution observations taken regularly over long periods.

Workshop dates:
9-11 October, 2018
(Boulder, CO)

[Read More](#)



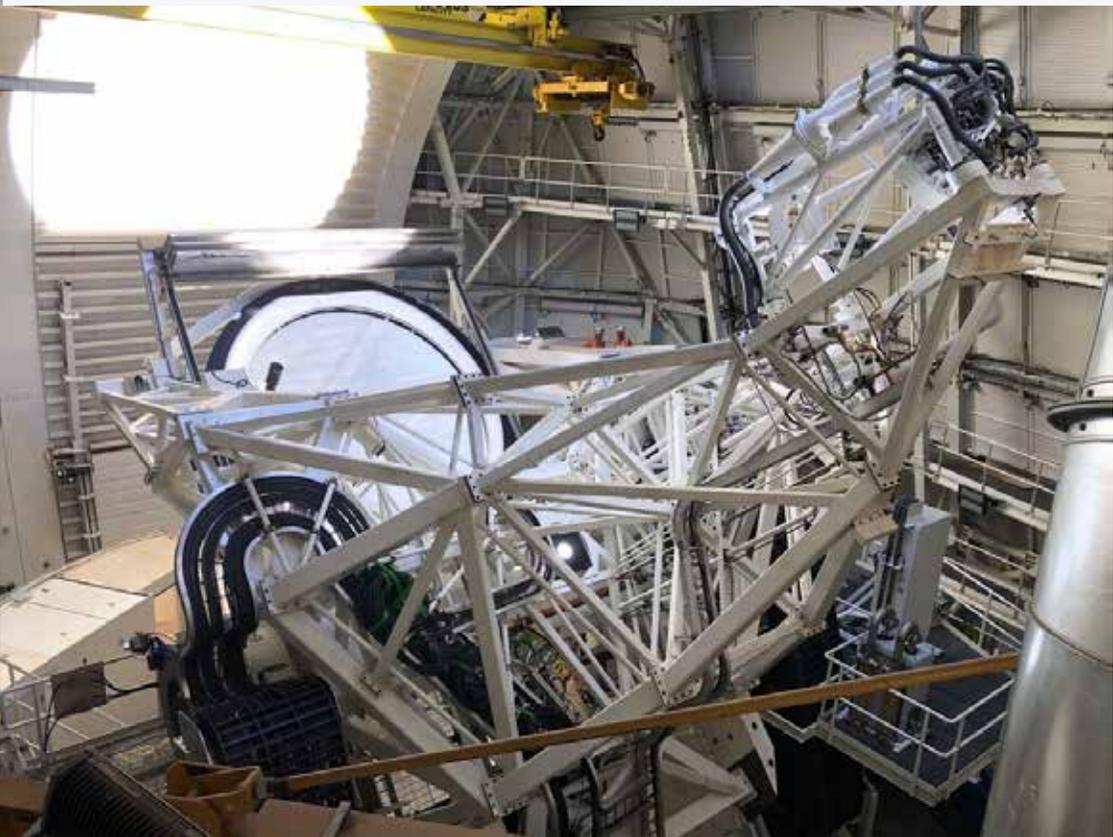


Outreach to stellar, exo-planet, heliophysics communities

- Presence at AAS (townhall), AGU, Solar Orbiter, PSP, HINODE, SOLAR-C workshops, visits to university astronomy departments
- Topical Workshops:
 - **Exoplanet Transit Spectroscopy** e-Workshop 2019 ,Boulder October 23 and 24, 2019
 - MK Symposium - **From Solar Physics to Exoplanets** ,Feb 26-28 2020 at NCAR in Boulder: future directions in solar physics, the solar-stellar connection, exoplanets and modeling of exoplanet atmospheres.
 - SHINE: **Multi-messenger Heliophysics with DKIST, PSP and SO**: Defining the Upcoming Opportunities
 - CSP Workshop 13 – 15 March 2018 Laurel, MD: **Joint Science with Solar Orbiter and Parker Solar Probe**
 - CSP Workshop Jul 18-20, 2018 Bozeman, MT **Broader Implications**
“leverage DKIST’s unique spatial and spectral resolution capabilities to address fundamental processes such as turbulence, reconnection, particle acceleration and plasma instabilities.”



Status: First solar light in December 2019

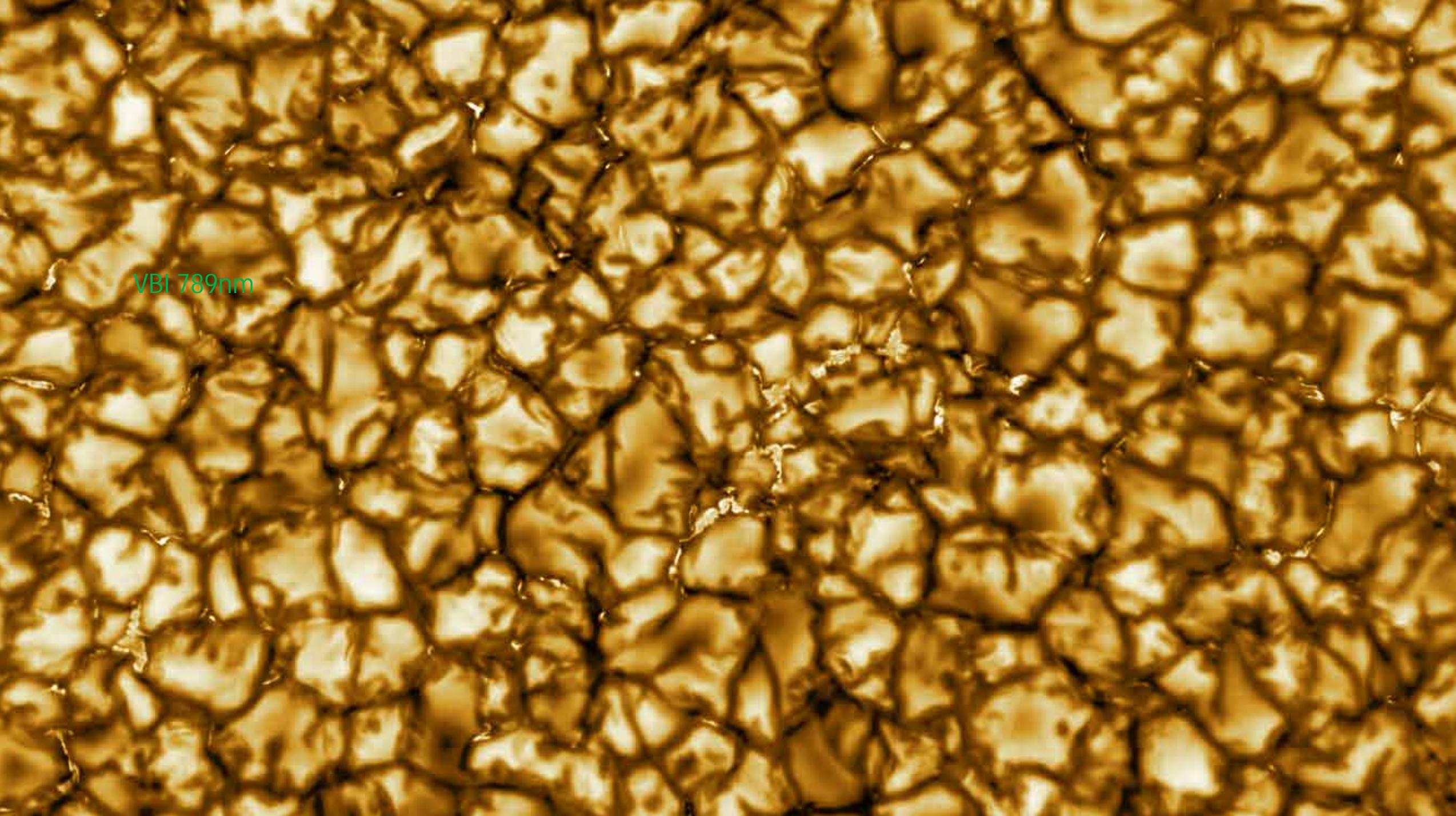


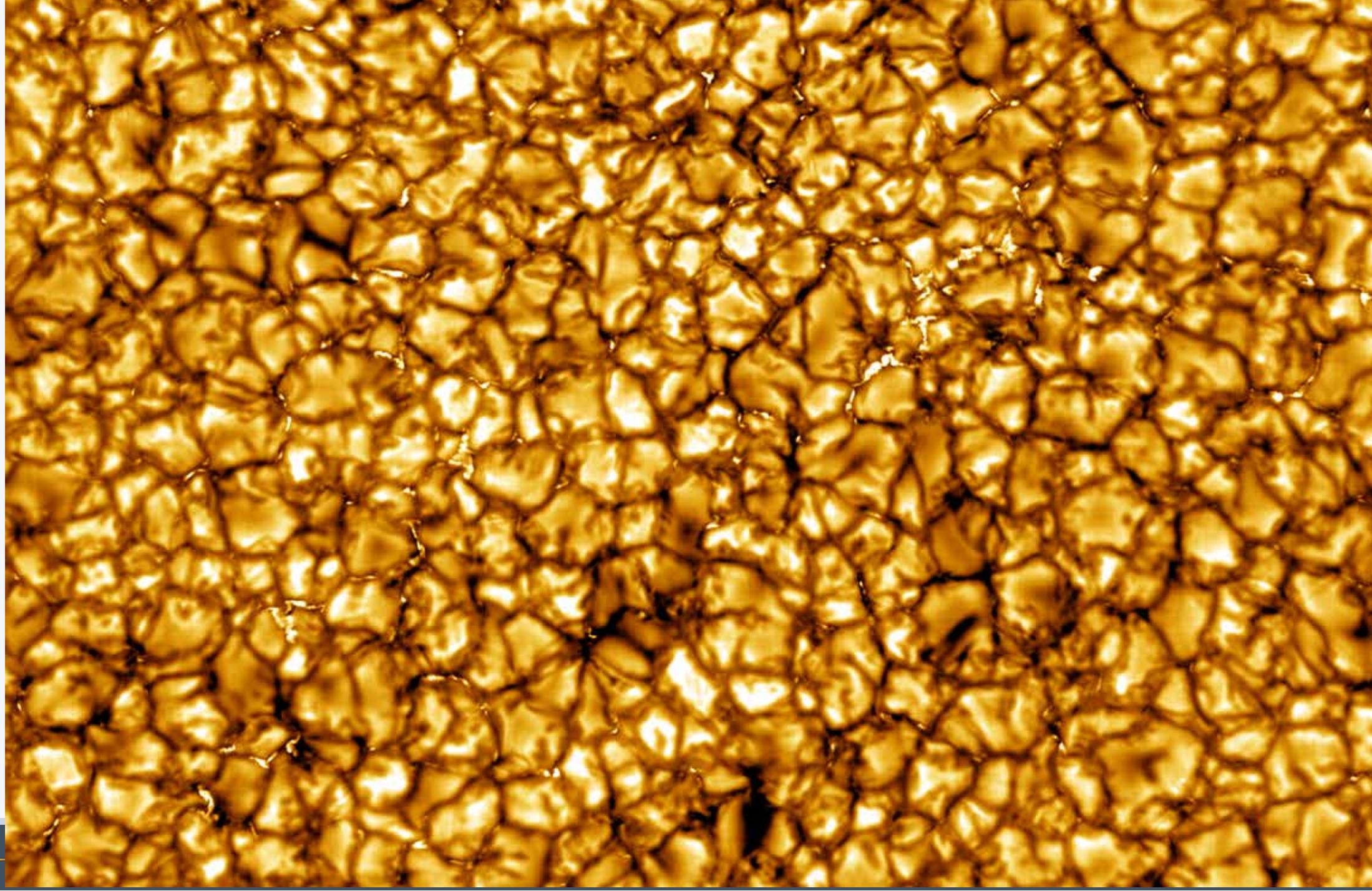


Coude Instrument Lab: First Light



VBI 789nm

The image shows a highly textured surface with a repeating pattern of irregular, rounded shapes, resembling a honeycomb or cellular structure. The overall color is a warm, golden-brown or tan. The lighting is directional, creating highlights on the raised portions of the cells and casting shadows in the recessed areas, which emphasizes the three-dimensional nature of the texture. The pattern is dense and covers the entire frame.





"All the News That's Fit to Print"

The New York Times

National Edition
Colorado: Partly sunny skies in the east. Cloudier skies in the west with periodic snow or flurries. High temperatures in the 30s and the 40s. Weather map appears on Page A32.

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The Sun's Churning Face

A telescope in Hawaii has captured the most detailed view yet, revealing cell-like "kernels," each about the size of Texas. Page A23.

NSO/NSF/AURA

Outside China, Racing to Halt Virus's Spread

By DENISE GRADY

Australians flown home from Wuhan, China, will be quarantined on an island for two weeks. Americans, also evacuated from Wuhan, will be "temporarily housed" on an air base in California. And in South Korea, the police have been empowered to detain

Plan Leaves Palestinians With Few Options

By DAVID M. HALBFINGER and ISABEL KERSHNER

JERUSALEM — For Mahmoud Abbas, the ailing octogenarian president of the Palestinian Authority, his life's work — a viable state side-by-side with Israel — is quickly slipping away. President Trump's Middle East plan deprives the Palestinians of nearly everything they had been fighting for: East Jerusalem as their national capital,

Bid That Favors Israel Deprives Abbas of All He's Fought For

that such a state would be forged through talks with the Israelis, years of failure, a weak and divided Palestinian leadership, and an Arab world that has largely moved on have all em-

With only muted reaction from Arab neighbors, a struggling Palestinian economy, little apparent appetite among Palestinians for a violent response and the United States having abandoned any pretense of neutral mediation, a proposal that might have been considered outlandish a decade ago landed with little serious opposition.

Rather than fighting back, some Palestinian activists on Wednesday were saying the option may be breaking up the

ATTACKING BOLTON, REPUBLICANS PUSH TO SWIFTLY ACQUIT

Political Risks in Bid to Slam the Door

Confident They Can Block Witnesses

WASHINGTON — In the end, the impeachment calculation nearly all Senate Republicans are making would rather

By SHERYL GAY STOLBERG and MICHAEL D. SHEAR
WASHINGTON — The White

TRUMP ON TRIAL
CARL HULSE

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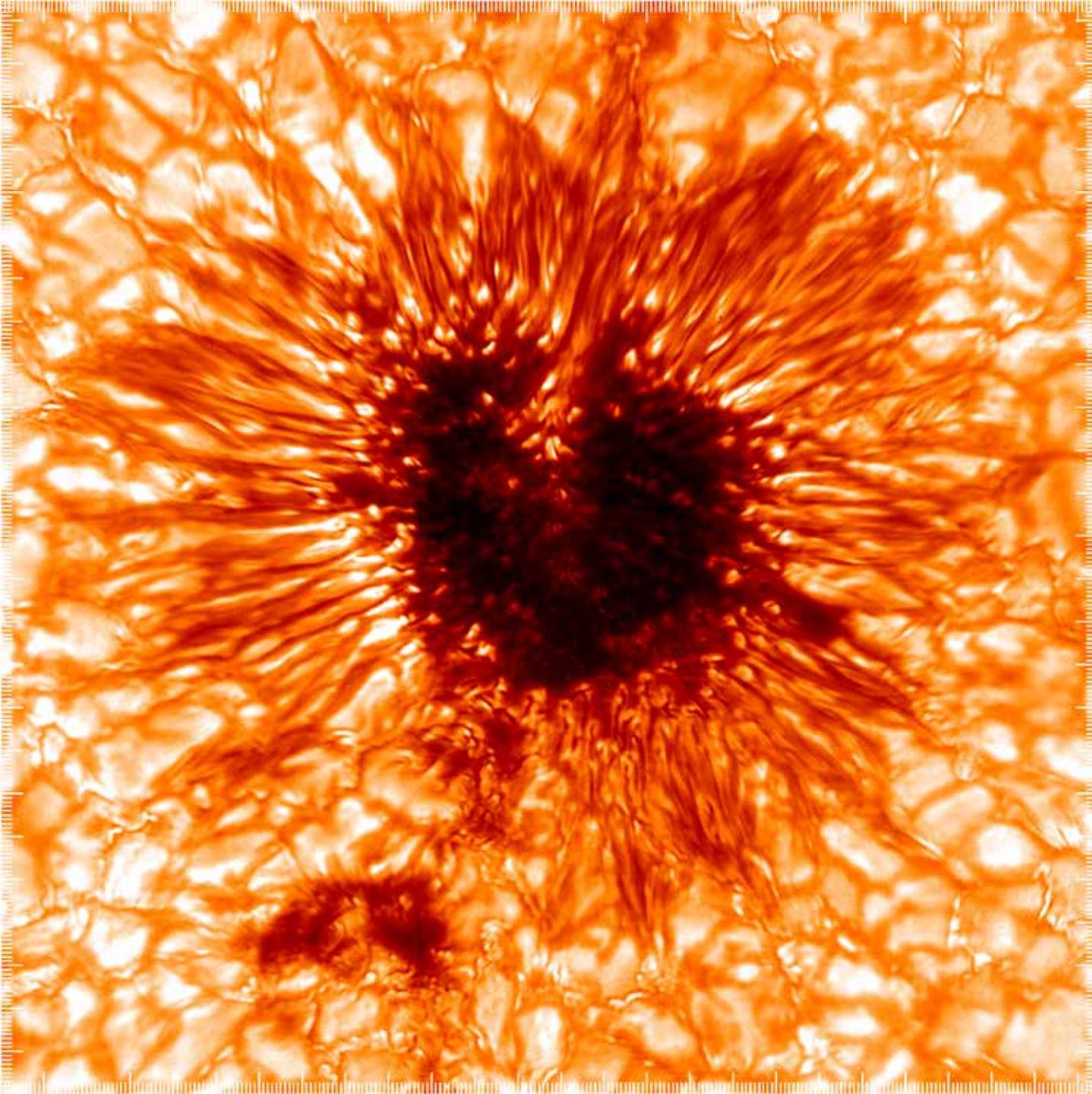
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witnesses would lead to prolonged court fights over executive privilege. They had heard more than enough evidence to reach a verdict. There was not enough evidence to show they needed more information. Allowing the House to force the Senate into a drawn-out impeachment trial would set a dangerous insti-

1.6 BILLION Impressions on social media alone

ERIN SCHAFF/THE NEW YORK TIMES
Senator Mitt Romney of Utah before Wednesday's session.

his forthcoming book, in which he wrote that the president refused to release military aid to Ukraine until its leaders committed to

Kudos to NSF, AURA and NSO EPO teams

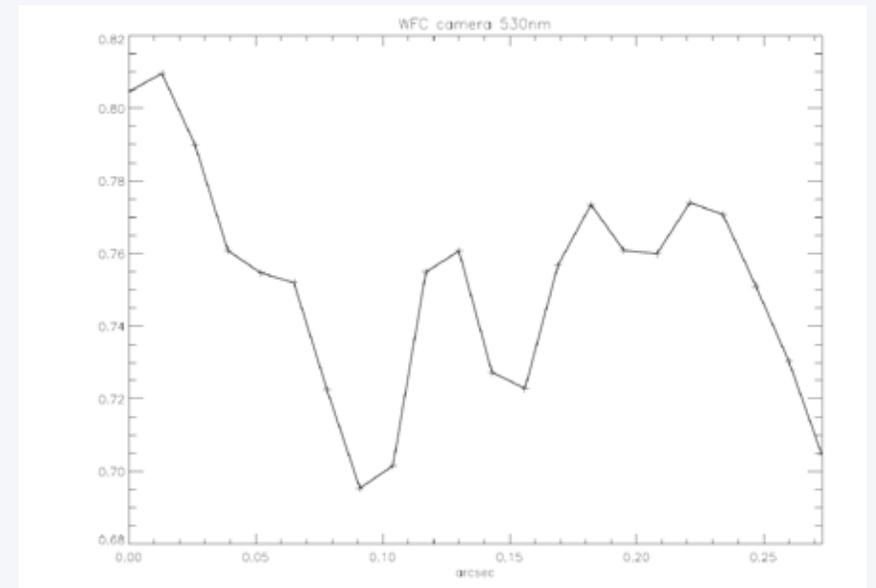


The First Sunspot Image

530 nm

Adaptive optics context viewer – not a science instrument

Diffraction limit in the visible achieved!



Significant Work remains to be done in the next several months!!



Visible Spectro-polarimeter (HAO)–
integration and testing close to
completion

CRYO NIRSP

DL-NIRSP

VBI
Adaptive
Optics

VISP

PolCal

VTF scheduled to arrive
from Germany Jan. 2021





Facility Thermal Systems – continue to be a challenge!



Ice Tanks

7.5 miles of cooling pipes





Transition to Operations – Operations Commissioning Phase (OCP)

- Preparing three (3) proposal calls ; 4 months proposal cycle
 - Simple instrument configuration at first (e.g. VBI, VISP for OCP1)
 - Ramping up to full complexity/capability (incl. VTF for OCP3)
- Implement and practice:
 - TAC process, observing time accounting
 - experiment generation using tools currently under development
 - service mode - Resident Scientists, Operators execute Observing Programs
 - **data center - calibration pipeline development**
- Technical Time: e.g. VTF integration, tuning of optical & thermal systems



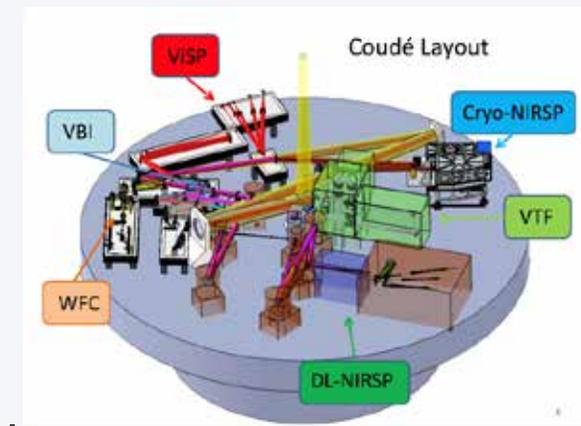
Operations Commissioning Phase(OCP)

- Shared Risk Period
- 1st OCP Proposal call release was scheduled for May, 1st, 2020
- 1st Proposal execution was planned for Oct, 1, 2020
- Will slip due to COVID situation!



Data Center – Challenges

- Complex facility, multiple instruments, multiple modes per instrument
- 8-10TBs (compressed) per day on average (Max ~60TB)
- Approximately 3 PB raw + 3 PB calibrated per year +(higher level products)
- Automated reduction pipelines are novel for complex ground-based data
- Long-term data curation for ground-based solar physics data of this complexity and variety is novel
- Planned 44-year lifetime (2 solar magnetic cycles)
 - Flexible system accommodating science, instrument and technological changes, replacing or upgrading software etc., without the need for frequent major redesign.

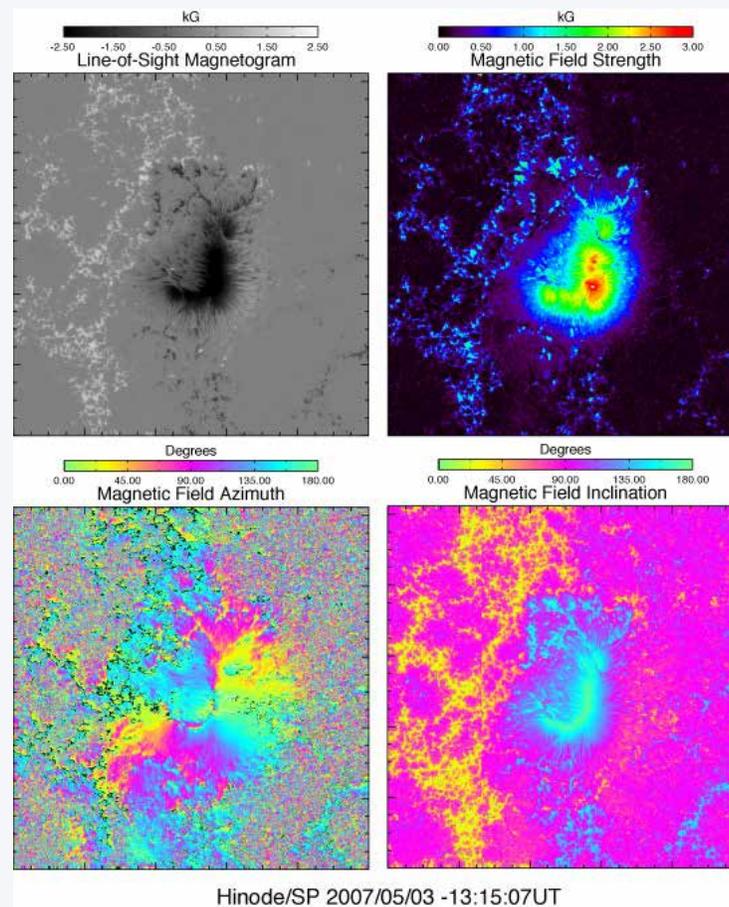




Data – Model comparison @ 8x resolution

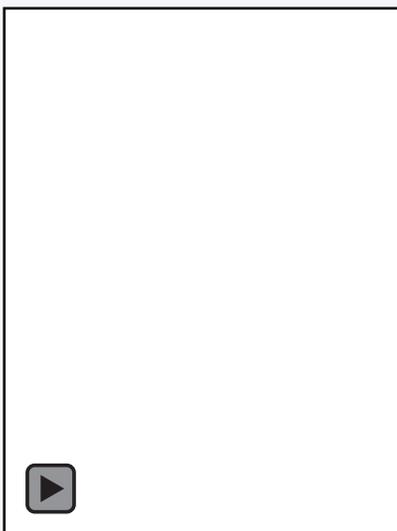
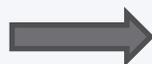


Level 2 Data
Physical Parameters



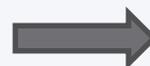
3 PB/year of Raw Data

Complex Calibrations



3PB/year of Calibrated Data
Demodulated, calibrated Stokes

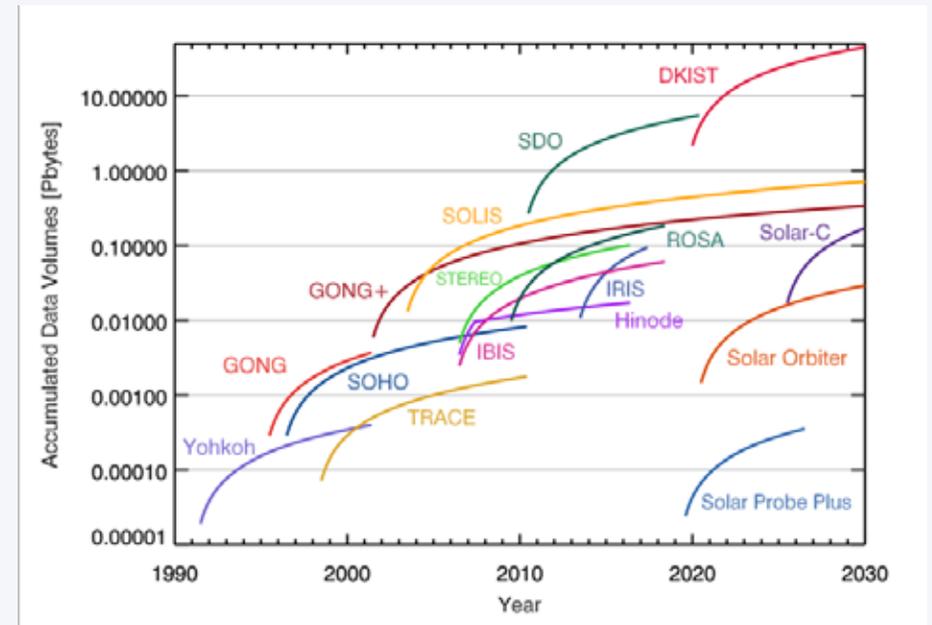
Inversion





Data Center Status

- Initial Infrastructure Design Software Development Completed
 - Web Search Portal currently in Development
- Production hardware being installed
- Implementing prototype instrument calibration pipelines
- Implementing pipeline infrastructure common to all pipelines





Schedule

Before COVID-19 -on schedule & budget:

- End of Major Construction June 30, 2020
- Project Handover-to-Operations July-Sep. 2020
- Operations Commissioning Phase Oct 2020 – Sep. 2021
- Full Operations Oct. 2021

◦ Impact of COVID-19 Situation:

- DKIST site construction halted and access to the DSSC offices closed to all non-essential personnel as of [March 17, 2020](#) for a period of two weeks with a plan to reevaluate [March 31](#)
- Since then Stay-at-Home order issued for Hawaii through [April 30, 2020](#)
- Only personnel needed to keep facility in safe and secure state allowed at summit and DSSC
- **DKIST construction critical path slipping day-for-day**