

The NASA/MSFC Solar Instrumentation Program



Amy Winebarger
Ken Kobayashi
Laurel Rachmeler
David McKenzie
Patrick Champey
*Jonathan Cirtain

Genevieve Vigil
Brent Beabout
Dyana Beabout
Harlan Haight
William Hogue
Jonathan Pryor
**and many more

Solar Instrumentation Programs at MSFC

SOUNDING ROCKETS

- **SUMI** (J. Cirtain, PI)
 - Launched from WSMR on July 2012
- **Hi-C 1** (J. Cirtain, PI)
 - Launched from WSMR on July 11, 2012
- **Hi-C 2** (J. Cirtain, PI)
 - Launched from WSMR on July 27, 2016
- **Hi-C 2.1** (A. Winebarger, PI)
 - Launched from WSMR on May 29, 2018
- **CLASP 1** (A. Winebarger, PI)
 - Launched from WSMR on September 3, 2015
- **CLASP 2** (D. McKenzie, PI)
 - Scheduled to launch Spring, 2018
- **MaGIXS** (A. Winebarger, PI)
 - Scheduled to launch in August 2019

OPERATIONAL
FLOWN
FUNDED
PROPOSED

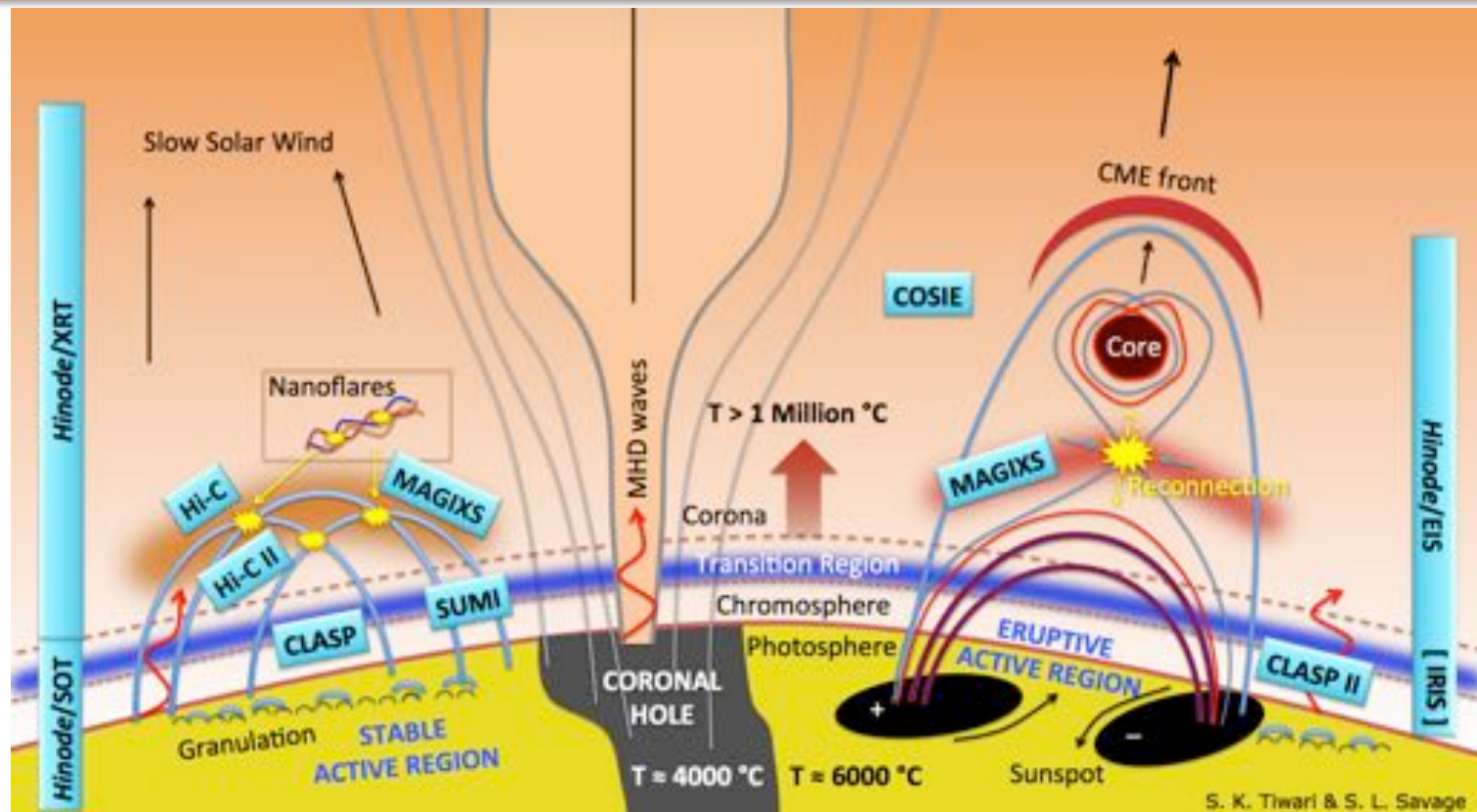
HINODE (Solar B)

- SOT: Solar Optical Telescope
- XRT: X-Ray Telescope
- EIS: EUV Imaging Spectrometer

COSIE

- Coronal Spectrographic Imager in the EUV

Targeted Science



Solar Instrumentation Programs at MSFC

SOUNDING ROCKETS

- **SUMI** (J. Cirtain, PI)
 - Launched from WSMR on July 2012
- **Hi-C 1** (J. Cirtain, PI)
 - Launched from WSMR on July 11, 2012
- **Hi-C 2** (J. Cirtain, PI)
 - Launched from WSMR on July 27, 2016
- **Hi-C 2.1** (A. Winebarger, PI)
 - Launched from WSMR on May 29, 2018
- **CLASP 1** (A. Winebarger, PI)
 - Launched from WSMR on September 3, 2015
- **CLASP 2** (D. McKenzie, PI)
 - Scheduled to launch Spring, 2018
- **MaGIXS** (A. Winebarger, PI)
 - Scheduled to launch in August 2019

OPERATIONAL
FLOWN
FUNDED
PROPOSED

HINODE (Solar B)

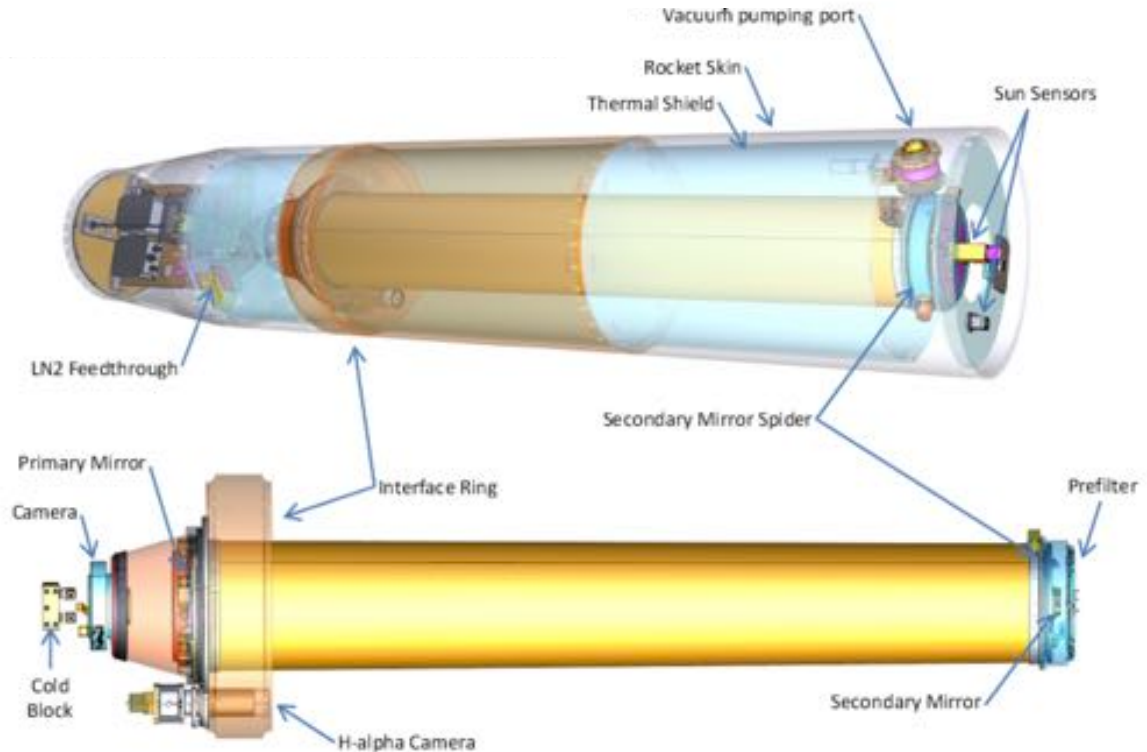
- SOT: Solar Optical Telescope
- XRT: X-Ray Telescope
- EIS: EUV Imaging Spectrometer

COSIE

- Coronal Spectrographic Imager in the EUV

Hi-C: High-resolution Coronal imager

- Telescope design capable of $\sim 0.2\text{-}0.3''$ (~ 150 km) spatial resolution imaging of the corona.
- Requires high rocket pointing stability to achieve resolution goal (Sparcs system).
- Capable of high-cadence observations through rapid CCD readout duration (~ 2 seconds) and data storage system.



Hi-C 1: High-resolution Coronal imager

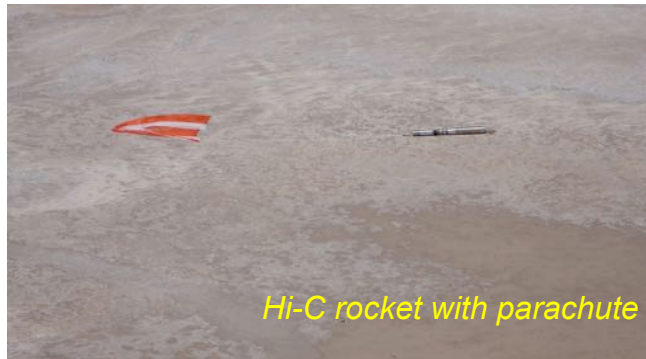
*Hi-C 1 Launch
White Sands, NM
July 11, 2012*



Hi-C recovery team



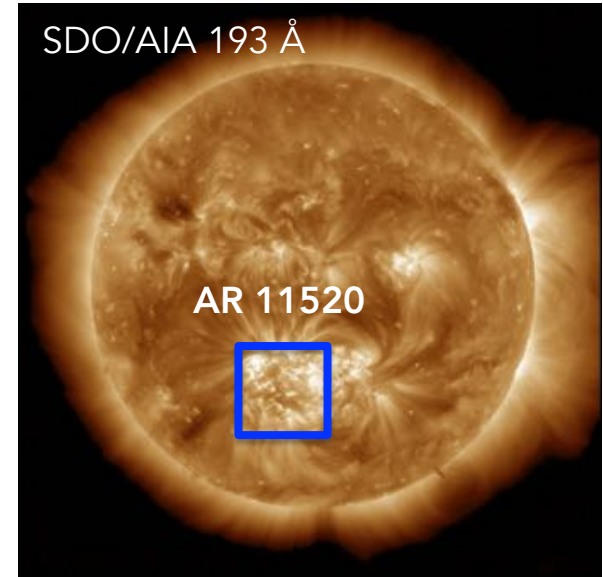
Hi-C rocket with parachute



Data available via the Virtual Solar Observatory (VSO).

Guidebooks available at hic.msfc.nasa.gov.

SDO/AIA 193 Å



AR 11520

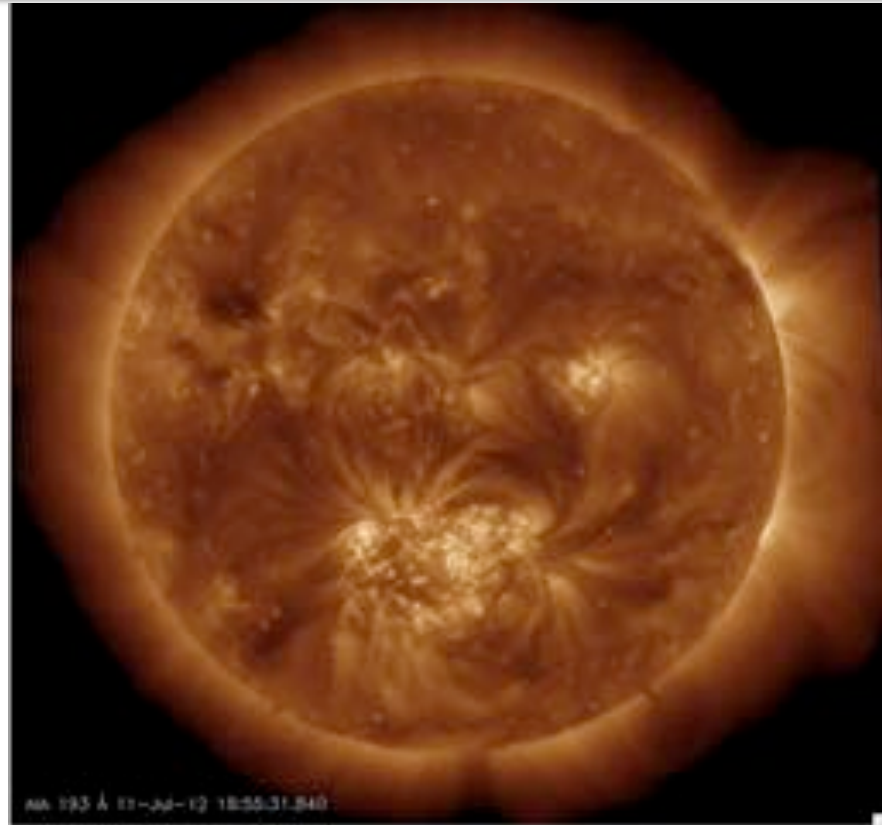
Hi-C 1: High-resolution Coronal imager

Bandpass – 193 Å

26 publications for 5 minutes of data!

Science highlights:

- Braided loops triggering energy release through magnetic reconnection
 - (*Cirtain et al. 2013, Nature*)
- Subflare triggers
- Nanoflare heating
- Loop sub-structure
- Moss dynamics
- Penumbral jets
- Flows along filament threads
- MHD waves



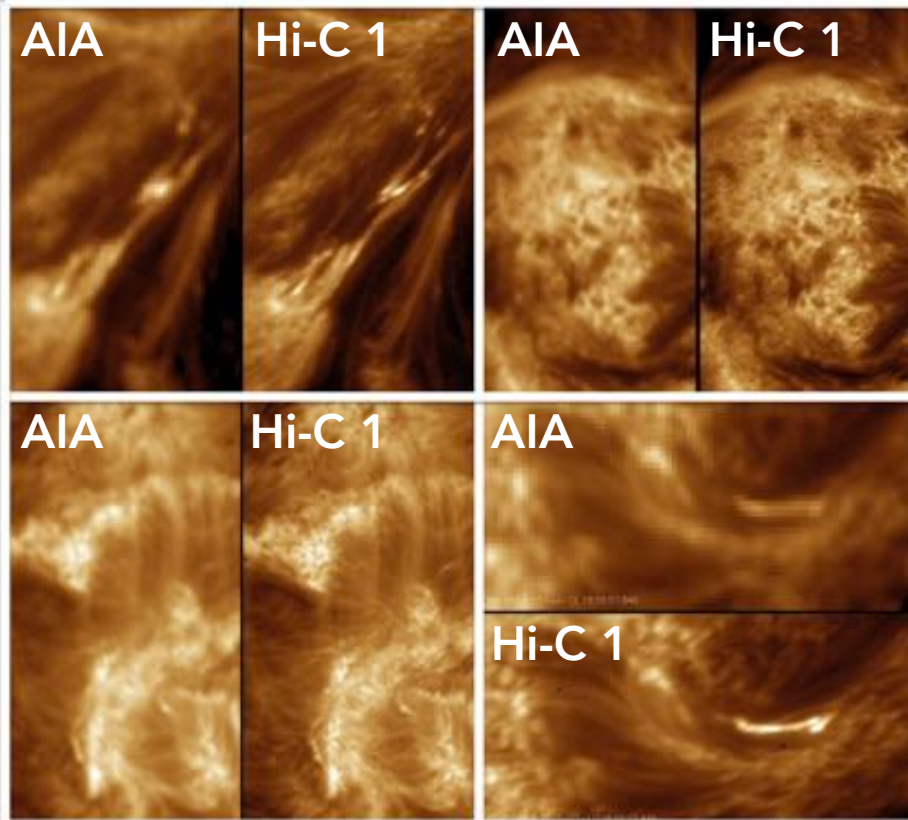
Hi-C 1: High-resolution Coronal imager

Bandpass – 193 Å [TEMPS]

26 publications for 5 minutes of data! [SITE]

Science highlights:

- Braided loops triggering energy release through magnetic reconnection
 - (*Cirtain et al. 2013, Nature*)
- Subflare triggers
- Nanoflare heating
- Loop sub-structure
- Moss dynamics
- Penumbral jets
- Flows along filament threads
- MHD waves



Solar Instrumentation Programs at MSFC

SOUNDING ROCKETS

- **SUMI** (J. Cirtain, PI)
 - Launched from WSMR on July 2012
- **Hi-C 1** (J. Cirtain, PI)
 - Launched from WSMR on July 11, 2012
- **Hi-C 2** (J. Cirtain, PI)
 - Launched from WSMR on July 27, 2016
- **Hi-C 2.1** (A. Winebarger, PI)
 - Launched from WSMR on May 29, 2018
- **CLASP 1** (A. Winebarger, PI)
 - Launched from WSMR on September 3, 2015
- **CLASP 2** (D. McKenzie, PI)
 - Scheduled to launch Spring, 2018
- **MaGIXS** (A. Winebarger, PI)
 - Scheduled to launch in August 2019

OPERATIONAL
FLOWN
FUNDED
PROPOSED

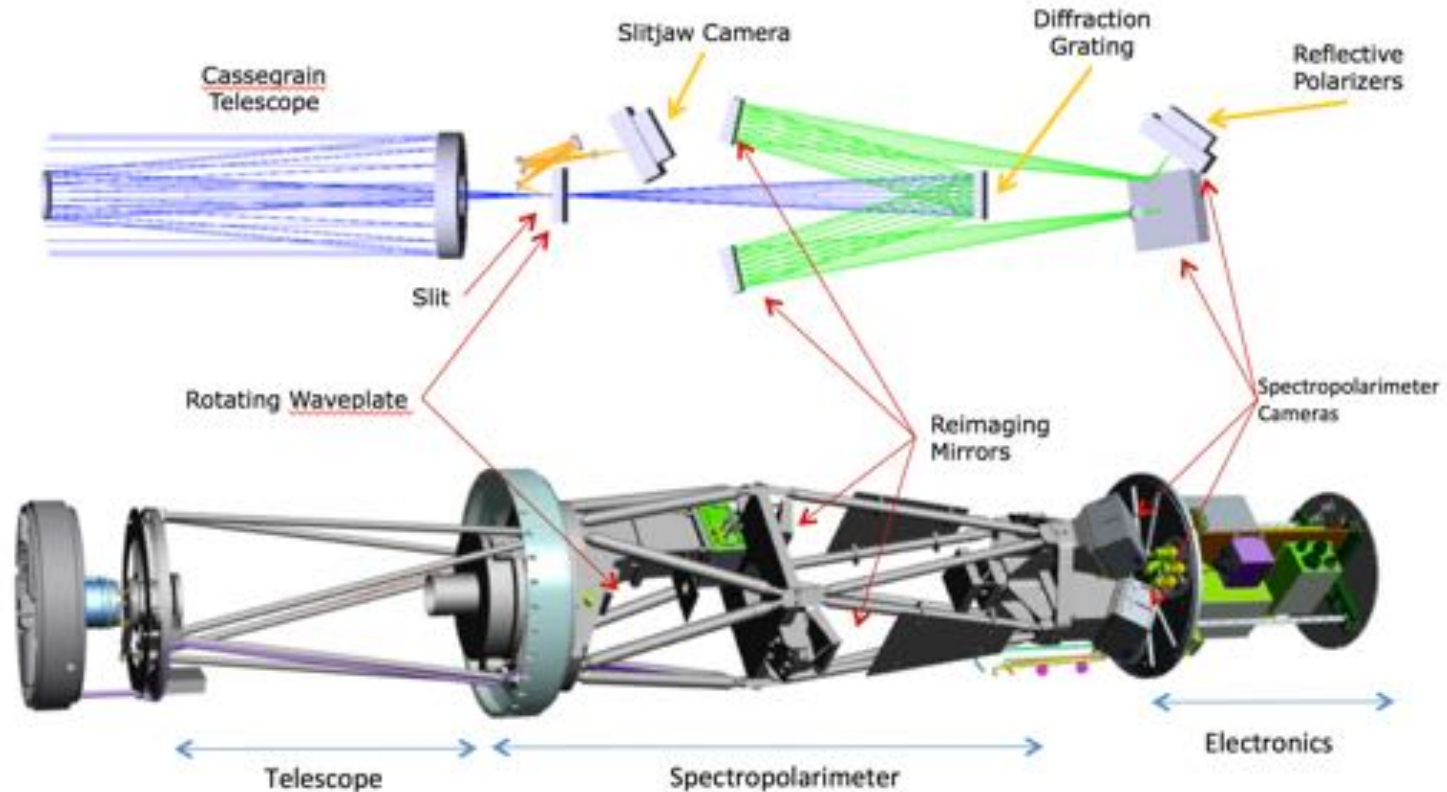
HINODE (Solar B)

- SOT: Solar Optical Telescope
- XRT: X-Ray Telescope
- EIS: EUV Imaging Spectrometer

COSIE

- Coronal Spectrographic Imager in the EUV

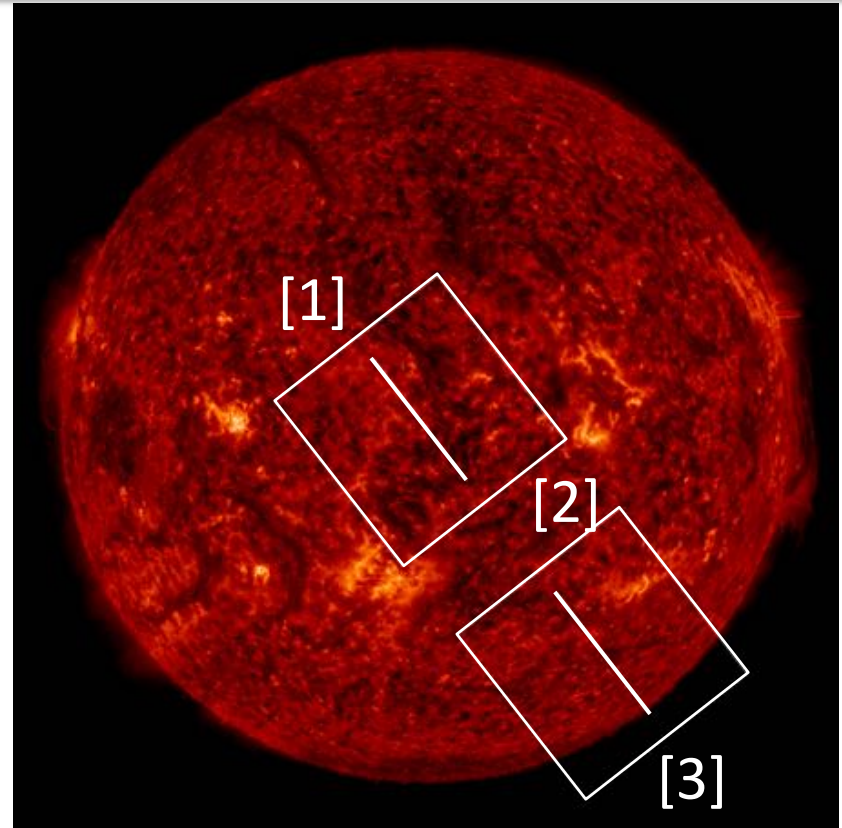
CLASP 1: Chromospheric Lyman-Alpha Spectropolarimeter



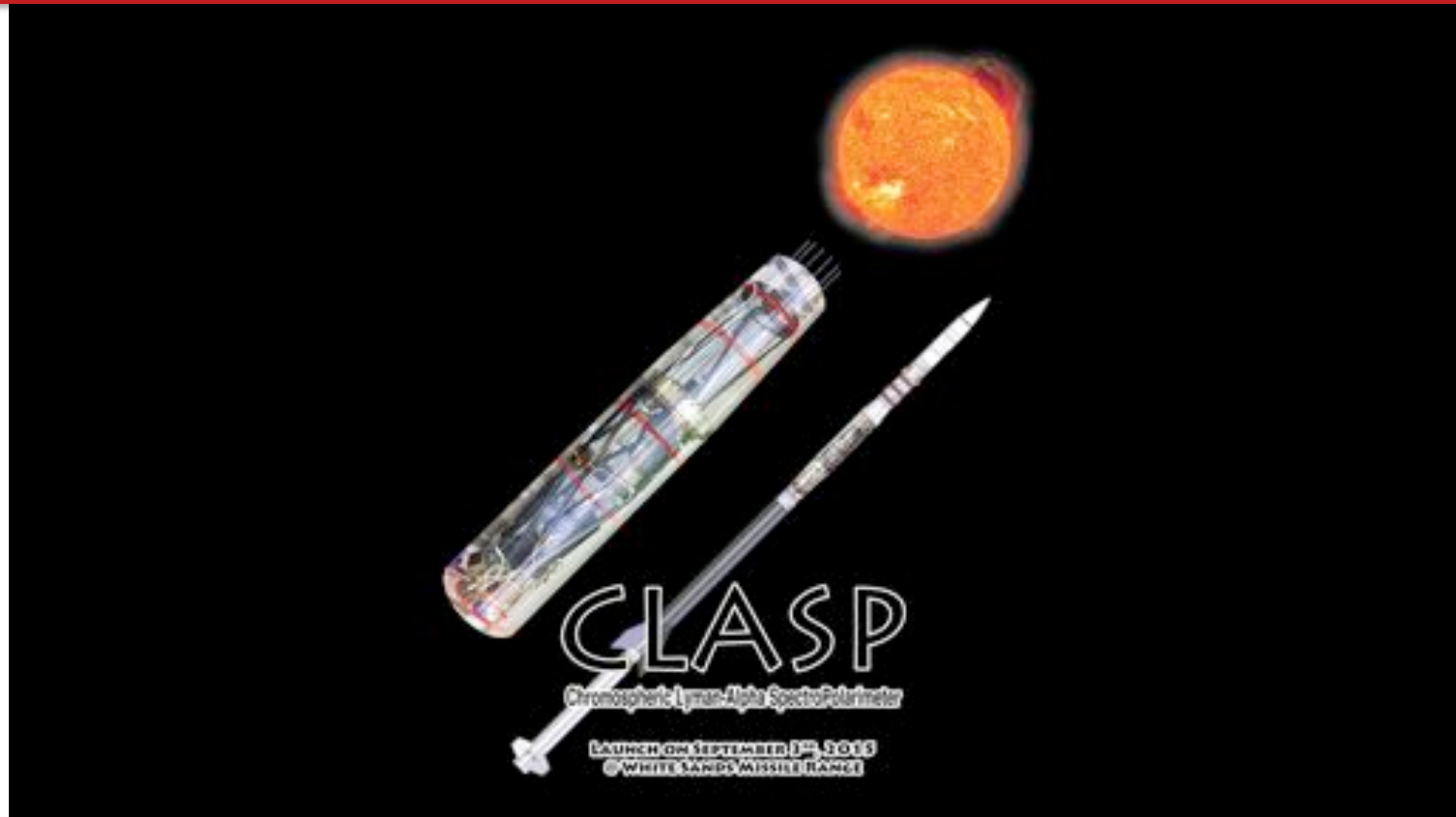
CLASP 1: Chromospheric Lyman-Alpha Spectropolarimeter

Objective: Use the polarization to infer the chromospheric thermal structure and magnetic field.

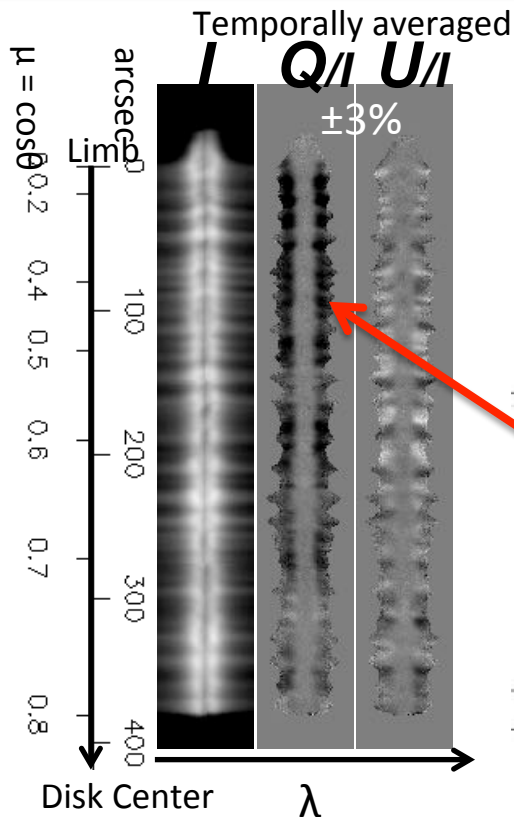
- Requires accurate calibration
- Requires advanced theoretical modeling for interpretation



CLASP 1: Chromospheric Lyman-Alpha Spectropolarimeter

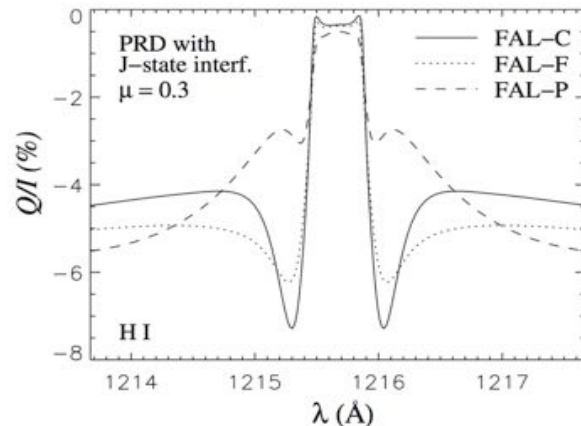
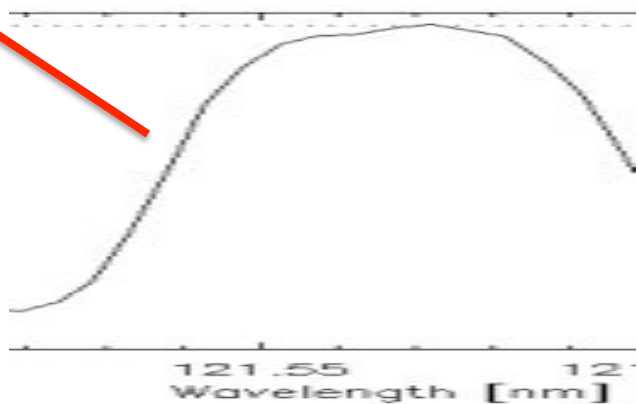


CLASP 1: Chromospheric Lyman-Alpha Spectropolarimeter



Further calibrations/investigations are required, but the initial results are...

- A few % of polarization in the wing, and a few of 0.1 % in the core.
- A clear C-to-L variation in the wing of Q/I.
- Small-scale structures along the slit.
- Q/I profile is essentially consistent with the model prediction.
- This Hanle effect is the only way to consistently measure the magnetic fields everywhere in the chromosphere.



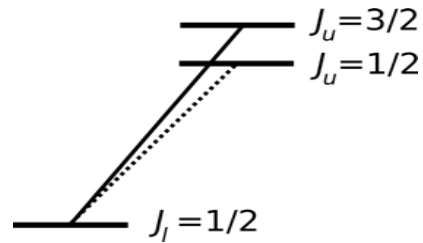
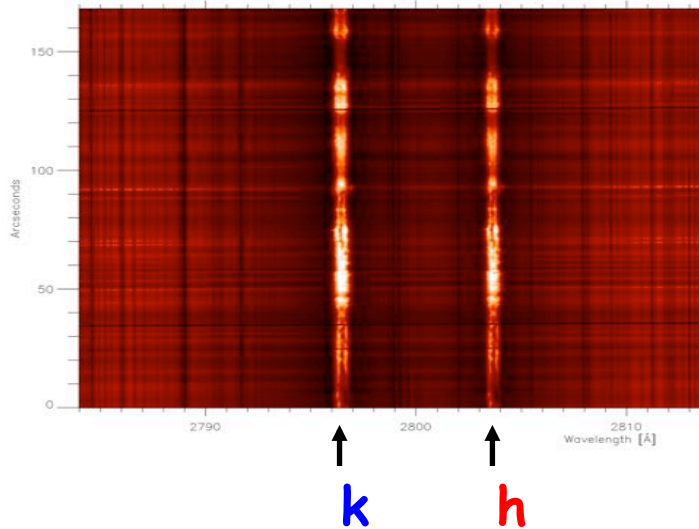
Belluzzi et al. 2012

CLASP 2

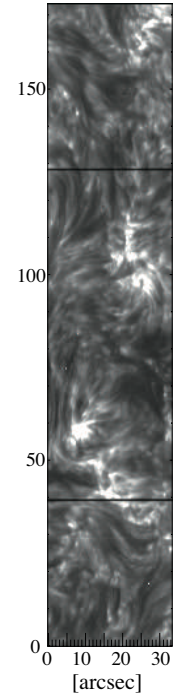
Schedule to fly Spring 2018.

CLASP 2 proposes to change the wavelength to Mg II h&k, another set of magnetically sensitive spectral lines in the UV at ~ 280 nm.

Need to explore multiple lines to determine which is best for routine measurements....



Observing target:
QS and plage (if available)



Mg II h&k line core image obtained by IRIS

Solar Instrumentation Programs at MSFC

SOUNDING ROCKETS

- **SUMI** (J. Cirtain, PI)
 - Launched from WSMR on July 2012
- **Hi-C 1** (J. Cirtain, PI)
 - Launched from WSMR on July 11, 2012
- **Hi-C 2** (J. Cirtain, PI)
 - Launched from WSMR on July 27, 2016
- **Hi-C 2.1** (A. Winebarger, PI)
 - Launched from WSMR on May 29, 2018
- **CLASP 1** (A. Winebarger, PI)
 - Launched from WSMR on September 3, 2015
- **CLASP 2** (D. McKenzie, PI)
 - Scheduled to launch Spring, 2018
- **MaGIXS** (A. Winebarger, PI)
 - Scheduled to launch in August 2019

OPERATIONAL
FLOWN
FUNDED
PROPOSED

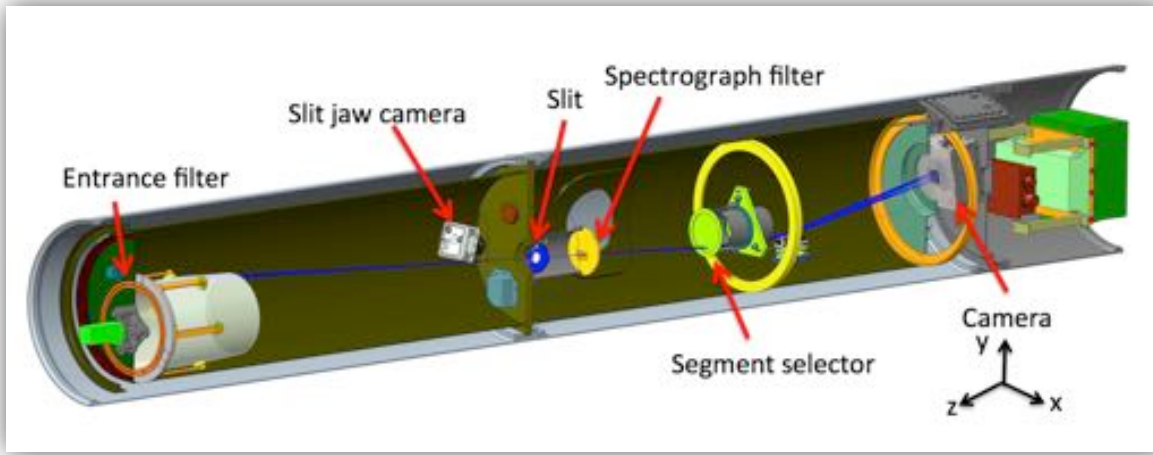
HINODE (Solar B)

- SOT: Solar Optical Telescope
- XRT: X-Ray Telescope
- EIS: EUV Imaging Spectrometer

COSIE

- Coronal Spectrographic Imager in the EUV

MaGIXS: Marshall Grazing Incidence X-ray Spectrometer



Scheduled to launch
August 2019.

Telescope: Wolter Type-I
Effective Focal Length ~ 1 m

Slit jaw imaging system for pointing and co-alignment

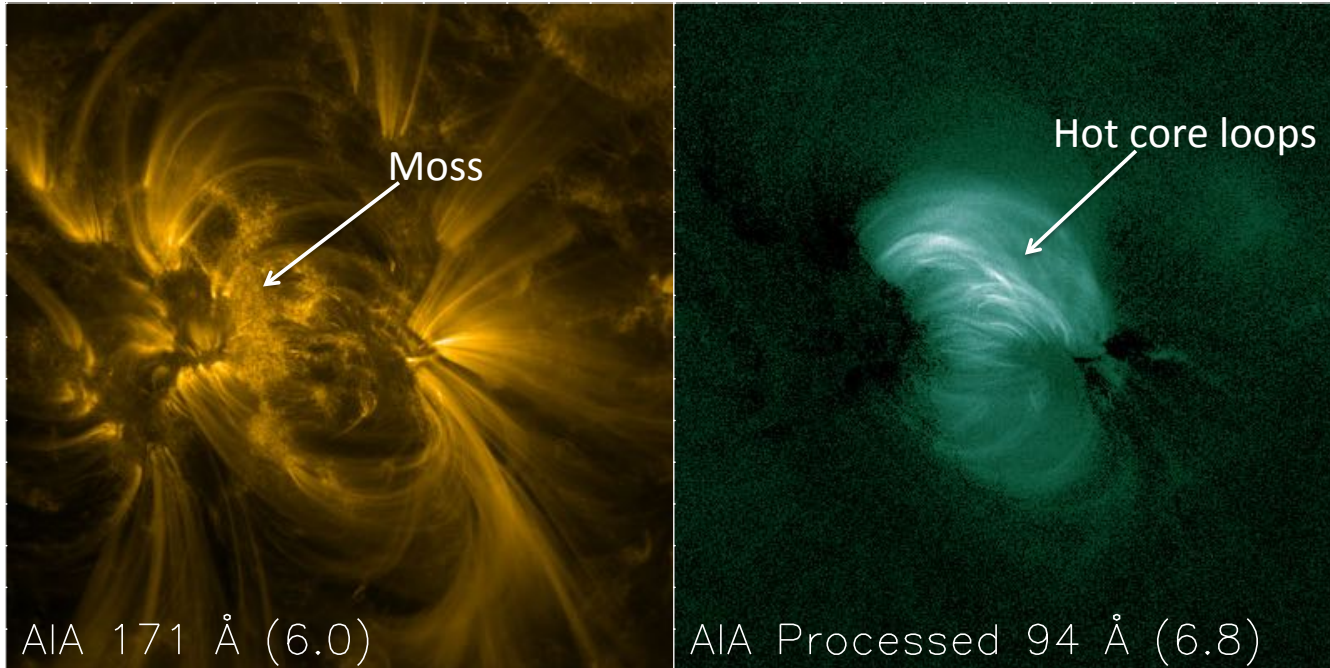
Detector : Low noise, 2kx1k frame transfer

Spectrograph: Two matched parabolic mirrors + Grating
6.0 - 24.0 Å (0.5 - 2.0 keV)
11 mÅ / pixel
2.8 arcsec / pixel

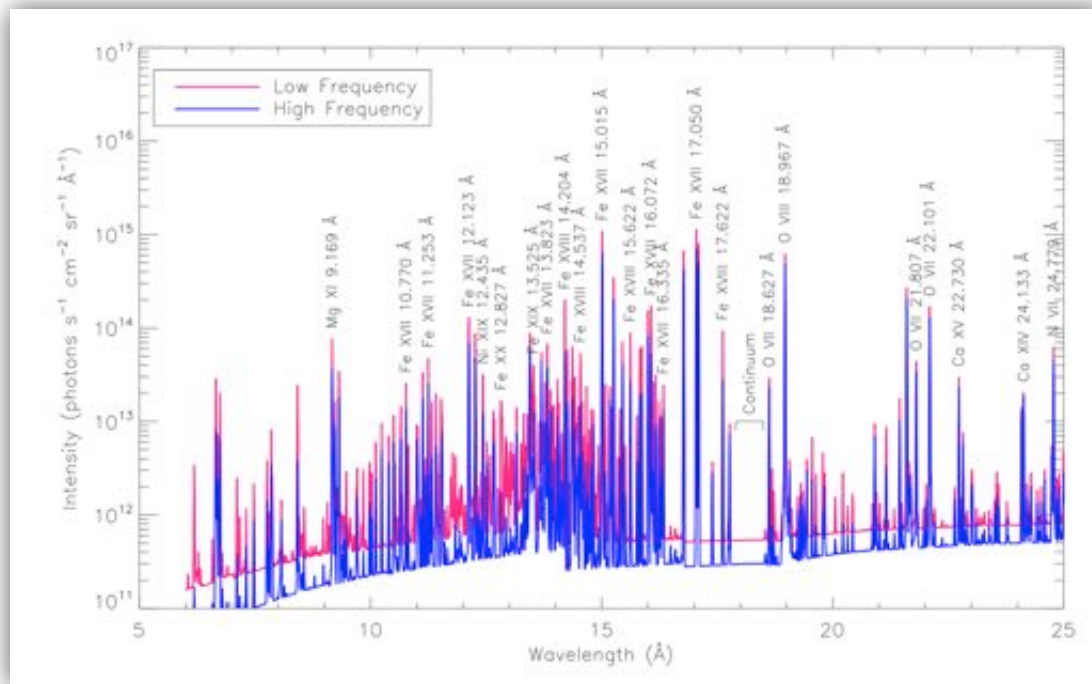
Grating: Blazed Planar Varied Line Space

MaGIXS: Marshall Grazing Incidence X-ray Spectrometer

Science Goal: Determine the frequency of heating in active region cores.
Is heating sporadic (nanoflares) or frequent (waves)?

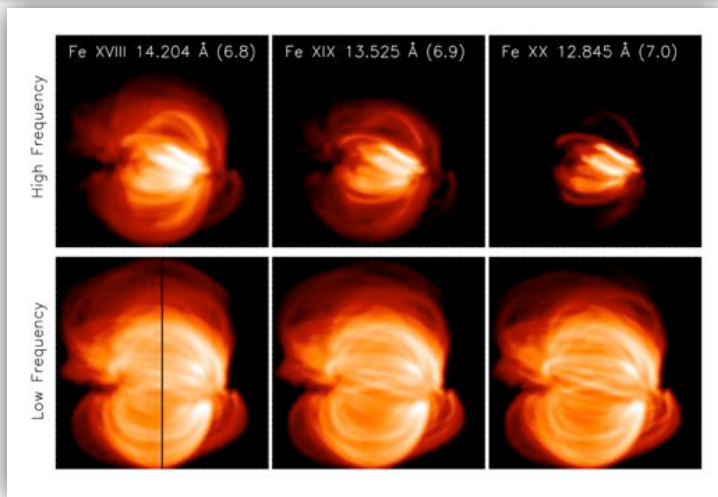


MaGIXS: Marshall Grazing Incidence X-ray Spectrometer



Simulated spectra from a single spatial position along the MaGIXS slit.

MaGIXS: Marshall Grazing Incidence X-ray Spectrometer



Simulated MaGIXS spectra

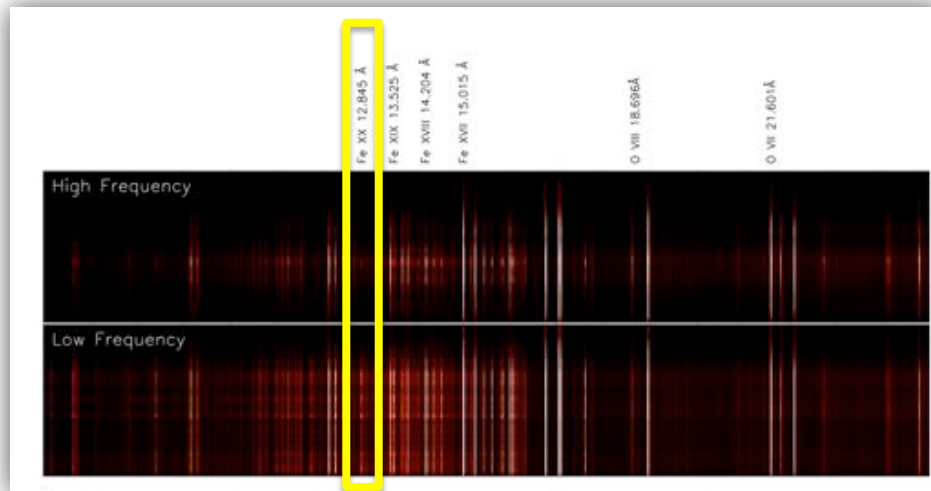
Biggest difference in Fe XX (12.845 Å).

Multiple high temperature spectra lines necessary for interpretation.

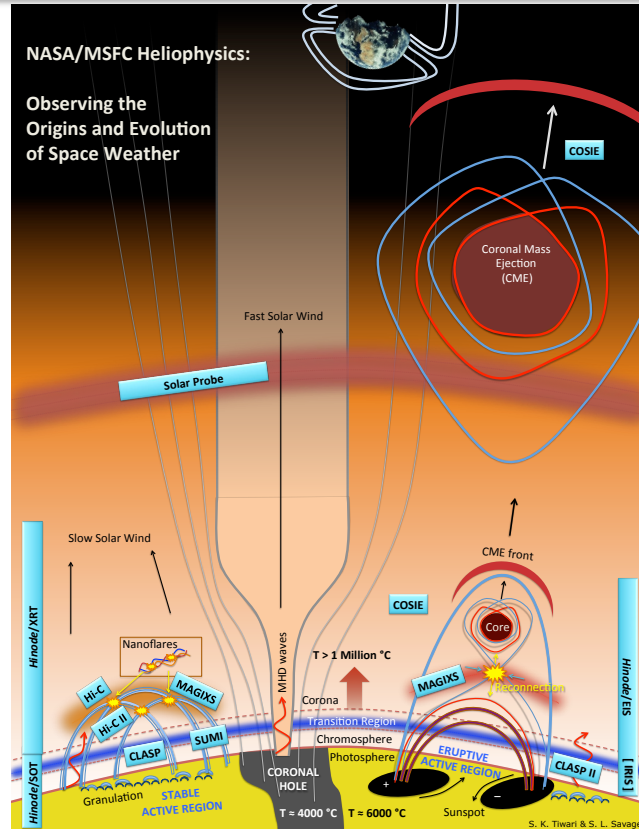
Simulated active region core
using 0-D EBTEL:

- Random heating events
- Heating event cadence 1575 s
versus 6300 s

Expected emission quite different at higher temperature lines.



Targeted Science



Solar Instrumentation Programs at MSFC

SOUNDING ROCKETS

- **SUMI** (J. Cirtain, PI)
 - Launched from WSMR on July 2012
- **Hi-C 1** (J. Cirtain, PI)
 - Launched from WSMR on July 11, 2012
- **Hi-C 2** (J. Cirtain, PI)
 - Launched from WSMR on July 27, 2016
- **Hi-C 2.1** (A. Winebarger, PI)
 - Launched from WSMR on May 29, 2018
- **CLASP 1** (A. Winebarger, PI)
 - Launched from WSMR on September 3, 2015
- **CLASP 2** (D. McKenzie, PI)
 - Scheduled to launch Spring, 2018
- **MaGIXS** (A. Winebarger, PI)
 - Scheduled to launch in August 2019

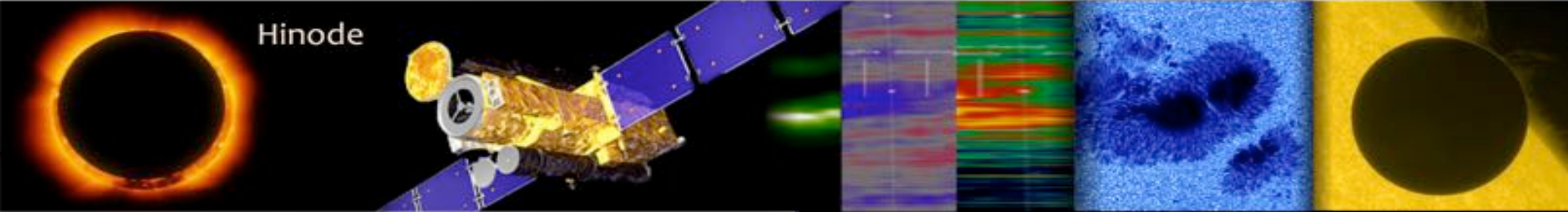
OPERATIONAL
FLOWN
FUNDED
PROPOSED

HINODE (Solar B)

- SOT: Solar Optical Telescope
- XRT: X-Ray Telescope
- EIS: EUV Imaging Spectrometer

COSIE

- Coronal Spectrographic Imager in the EUV

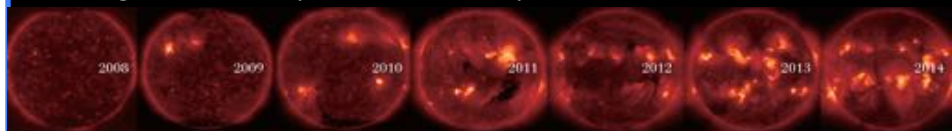


Hinode

Hinode, Japanese for "Sunrise" and formerly Solar-B, is a collaboration with space agency partners from Japan, the US, the UK, and Europe.

- Developed through Solar Terrestrial Probes Program
- US Program Office and Science Mgmt through NASA/MSFC
- Instrument US PI Institutions:
 - Lockheed Martin Solar and Astrophysics Laboratory (LMSAL)
 - Harvard-Smithsonian Center for Astrophysics (SAO/CFA)
 - Naval Research Laboratory (NRL)

XRT long baseline study of solar variability

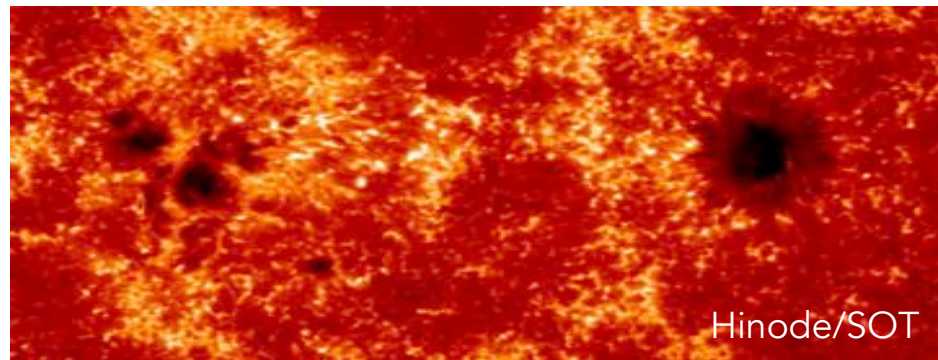


Prioritized Science Goals

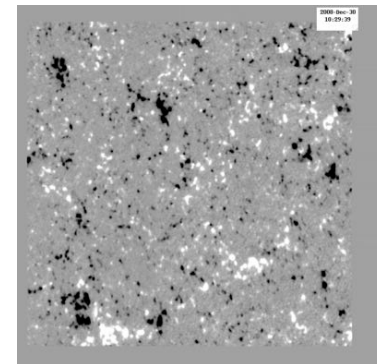
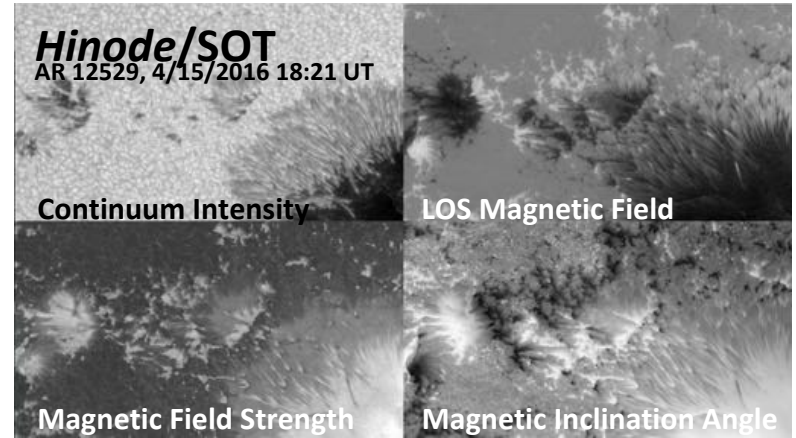
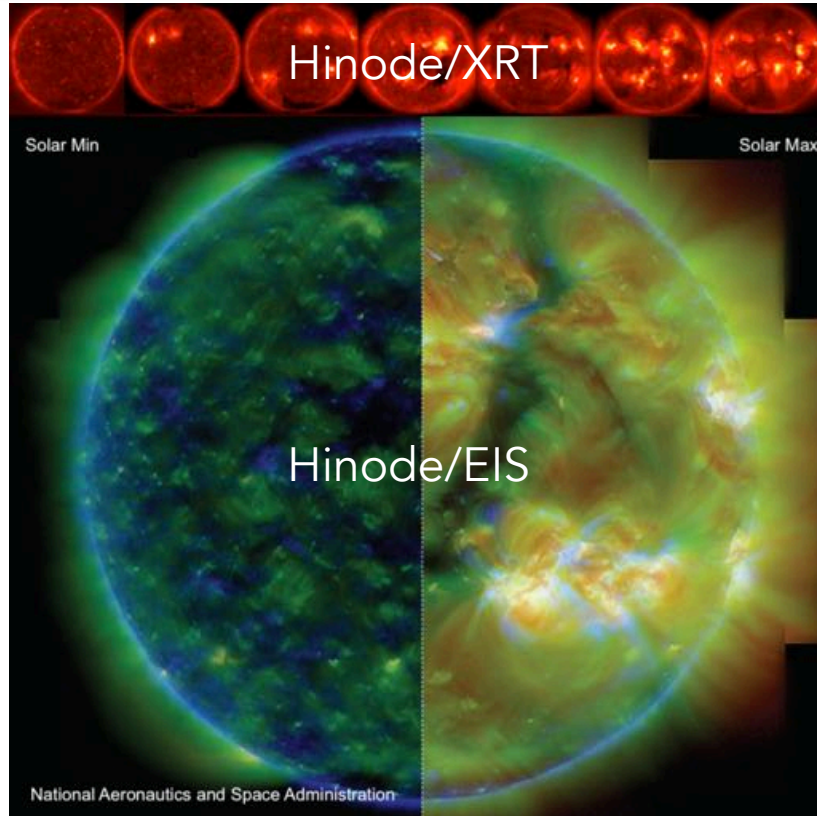
- Study the sources and evolution of highly energetic dynamic events.
- Characterize cross-scale magnetic field topology and stability.
- Trace mass and energy flow from the photosphere to the corona.
- Continue long term synoptic support to quantify cycle variability.

Instrumentation

1. SOT – Solar Optical Telescope (surface/magnetic fields)
 - Spectro-polarimeter (SP) & Filtergram (FG – no longer in use as of March 2016)
2. EIS – Extreme ultraviolet Imaging Spectrometer (atmosphere/spectra – plasma diagnostics)
3. XRT – (Soft) X-Ray Telescope (coronal activity – long baseline synoptics)



Hinode: formerly Solar B; "Sunrise"



Solar Instrumentation Programs at MSFC

SOUNDING ROCKETS

- **SUMI** (J. Cirtain, PI)
 - Launched from WSMR on July 2012
- **Hi-C 1** (J. Cirtain, PI)
 - Launched from WSMR on July 11, 2012
- **Hi-C 2** (J. Cirtain, PI)
 - Launched from WSMR on July 27, 2016
- **Hi-C 2.1** (A. Winebarger, PI)
 - Launched from WSMR on May 29, 2018
- **CLASP 1** (A. Winebarger, PI)
 - Launched from WSMR on September 3, 2015
- **CLASP 2** (D. McKenzie, PI)
 - Scheduled to launch Spring, 2018
- **MaGIXS** (A. Winebarger, PI)
 - Scheduled to launch in August 2019

OPERATIONAL
FLOWN
FUNDED
PROPOSED

HINODE (Solar B)

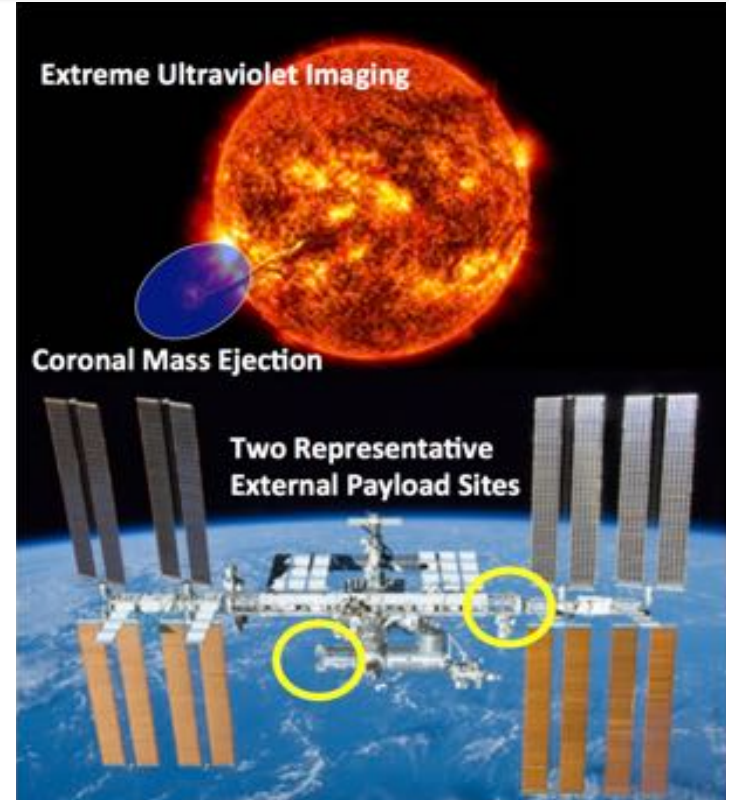
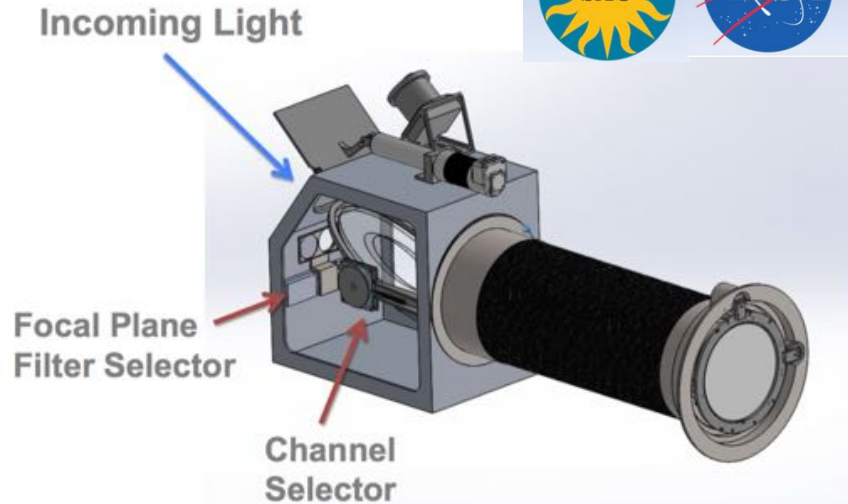
- SOT: Solar Optical Telescope
- XRT: X-Ray Telescope
- EIS: EUV Imaging Spectrometer

COSIE

- Coronal Spectrographic Imager in the EUV

COSIE: Coronal Spectrographic Imager in the EUV

Mission of Opportunity instrument being proposed for placement on the International Space Station to enhance our understanding of the dynamics of the Transition Corona and to provide improved detection and tracking of solar eruptive events for space weather research.



Solar Instrumentation Programs at MSFC

SOUNDING ROCKETS

- **SUMI** (J. Cirtain, PI)
 - Launched from WSMR on July 2012
- **Hi-C 1** (J. Cirtain, PI)
 - Launched from WSMR on July 11, 2012
- **Hi-C 2** (J. Cirtain, PI)
 - Launched from WSMR on July 27, 2016
- **Hi-C 2.1** (A. Winebarger, PI)
 - Launched from WSMR on May 29, 2018
- **CLASP 1** (A. Winebarger, PI)
 - Launched from WSMR on September 3, 2015
- **CLASP 2** (D. McKenzie, PI)
 - Scheduled to launch Spring, 2018
- **MaGIXS** (A. Winebarger, PI)
 - Scheduled to launch in August 2019

OPERATIONAL
FLOWN
FUNDED
PROPOSED

HINODE (Solar B)

- SOT: Solar Optical Telescope
- XRT: X-Ray Telescope
- EIS: EUV Imaging Spectrometer

COSIE

- Coronal Spectrographic Imager in the EUV

...

Solar Instrumentation Programs at MSFC

SOUNDING ROCKETS

- **SUMI** (J. Cirtain, PI)
 - Launched from WSMR on July 2012
- **Hi-C 1** (J. Cirtain, PI)
 - Launched from WSMR on July 11, 2012
- **Hi-C 2** (J. Cirtain, PI)
 - Launched from WSMR on July 27, 2016
- **Hi-C 2.1** (A. Winebarger, PI)
 - Launched from WSMR on May 29, 2018
- **CLASP 1** (A. Winebarger, PI)
 - Launched from WSMR on September 3, 2015
- **CLASP 2** (D. McKenzie, PI)
 - Scheduled to launch Spring, 2018
- **MaGIXS** (A. Winebarger, PI)
 - Scheduled to launch in August 2019

OPERATIONAL
FLOWN
FUNDED
PROPOSED

HINODE (Solar B)

- SOT: Solar Optical Telescope
- XRT: X-Ray Telescope
- EIS: EUV Imaging Spectrometer

COSIE

- Coronal Spectrographic Imager in the EUV

Preview of First Results from Hi-C 2.1



PS: Sabrina Savage (MSFC)

PI: Amy Winebarger (MSFC)

IS: Laurel Rachmeler (MSFC)



Science Team:

David Brooks (GMU)
Jonathan Cirtain (BWXT)
Ken Kobayashi (MSFC)
Scott McIntosh (HAO)
David McKenzie (MSFC)

Leon Golub (SAO)
Robert Walsh (UCLAN)
Bart DePontieu (LMSAL)

Richard Morton (Northumbria)
Hardi Peter (MPS)
Paola Testa (SAO)
Sanjiv Tiwari (BAERI)
Harry Warren (NRL)



Hi-C 2: High-resolution Coronal imager

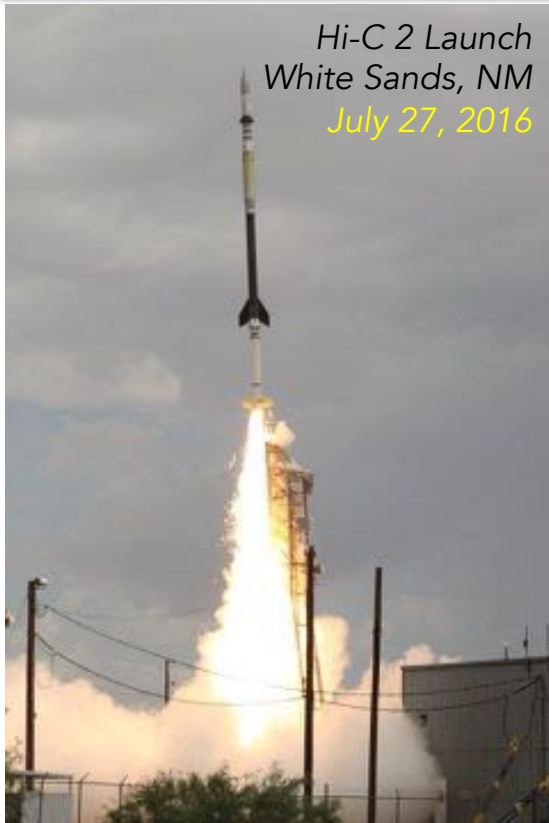
*Hi-C 2 Launch
White Sands, NM
July 27, 2016*

Hi-C 2 mirror recoated to explore the important Chromospheric-Coronal Connection by targeting specific candidates likely to contribute to coronal heating:

1. Type II spicules
2. Hot active region core loops

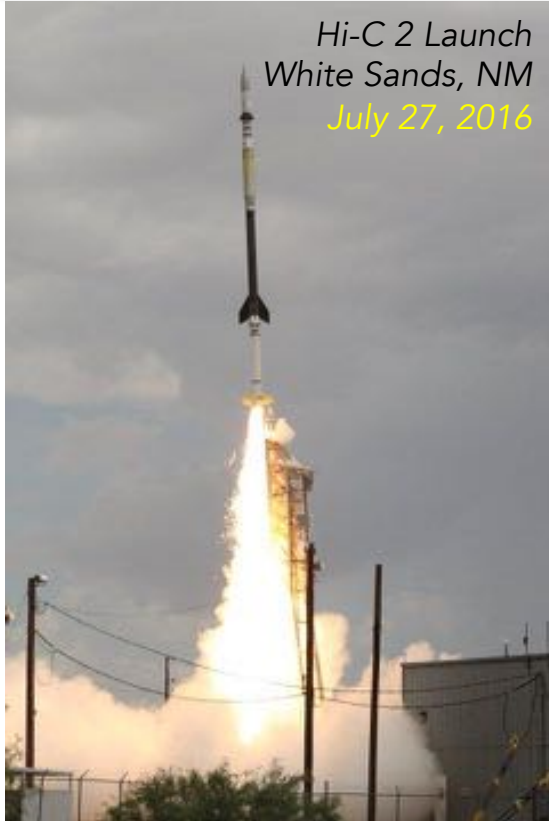
Updates for re-flight:

- Cooler bandpass centered on **172 Å**
- Significant improvement in camera quality (new MSFC-build designed for super low noise)
- **IRIS!**

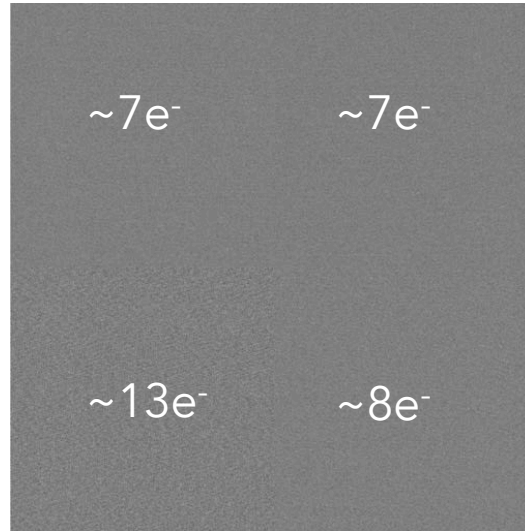


Hi-C 2: High-resolution Coronal imager

*Hi-C 2 Launch
White Sands, NM
July 27, 2016*



Fantastic flight performance
verification of the low-noise
MSFC-built camera.



Hi-C **2.1**: High-resolution Coronal imager

Cleaned up

Checked alignment

Upgraded cooling system

Added Hall Effect Sensor

Re-proposed

Hi-C **2.1**: High-resolution Coronal imager

3.5 months after ATP....

Hi-C 2.1: High-resolution Coronal imager

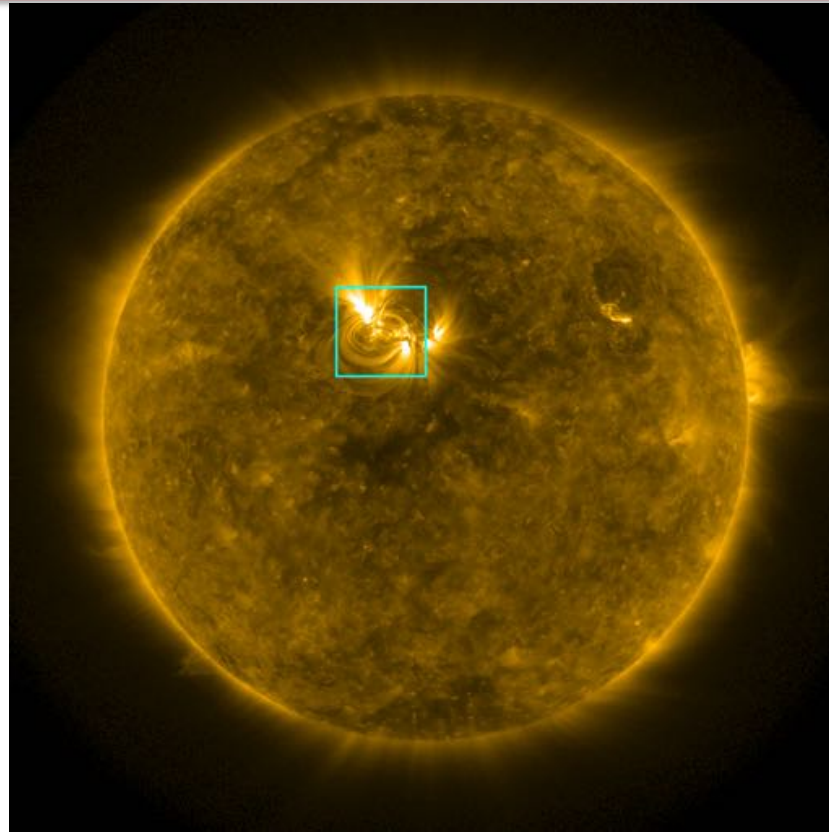
Hi-C 2.1 Launch
White Sands, NM
May 29, 2018



Hi-C 2.1: High-resolution Coronal imager

2018 May 29
18:54 UT

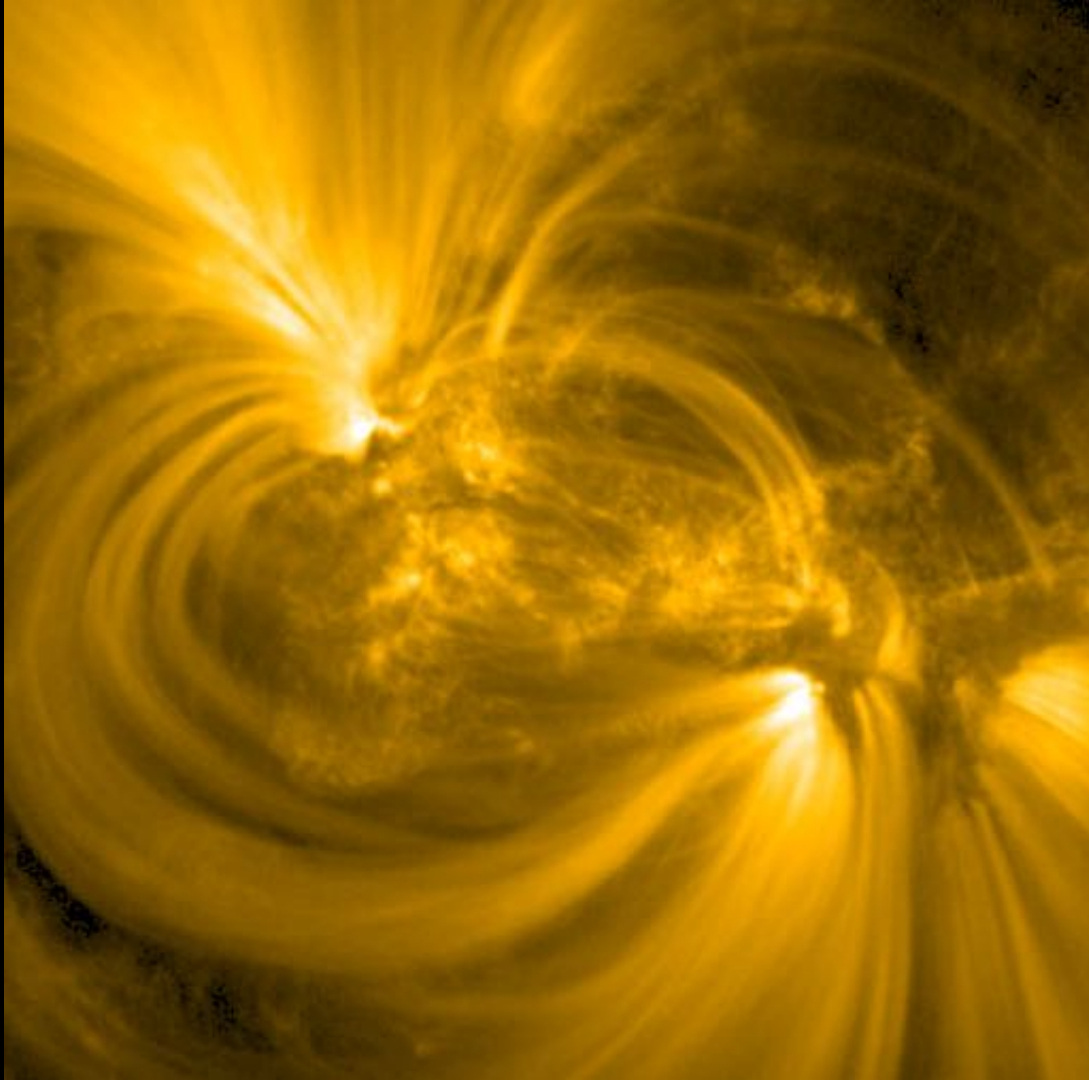
Target: AR 12712



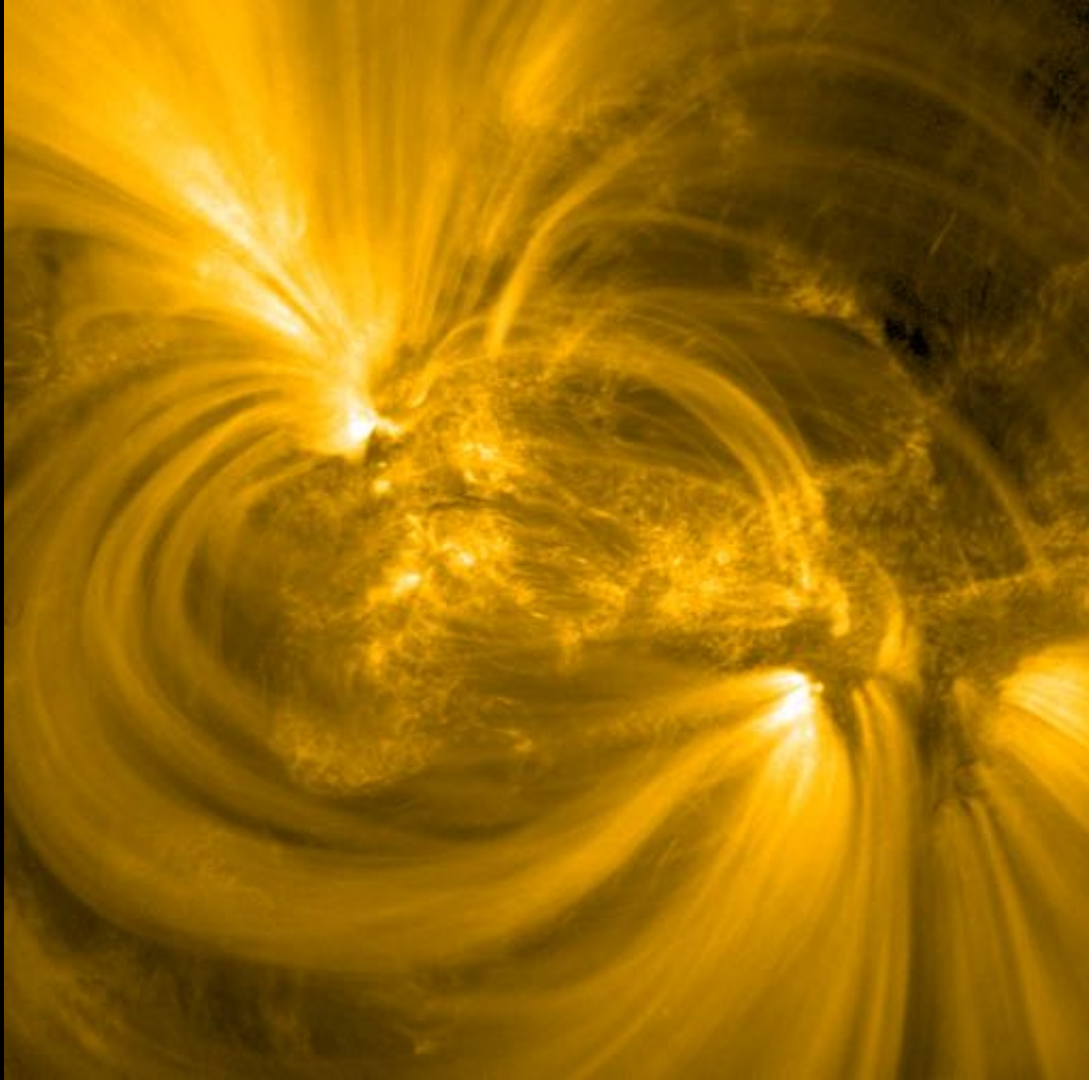
~ 15 minute flight

~ 5 minutes of solar
viewing data

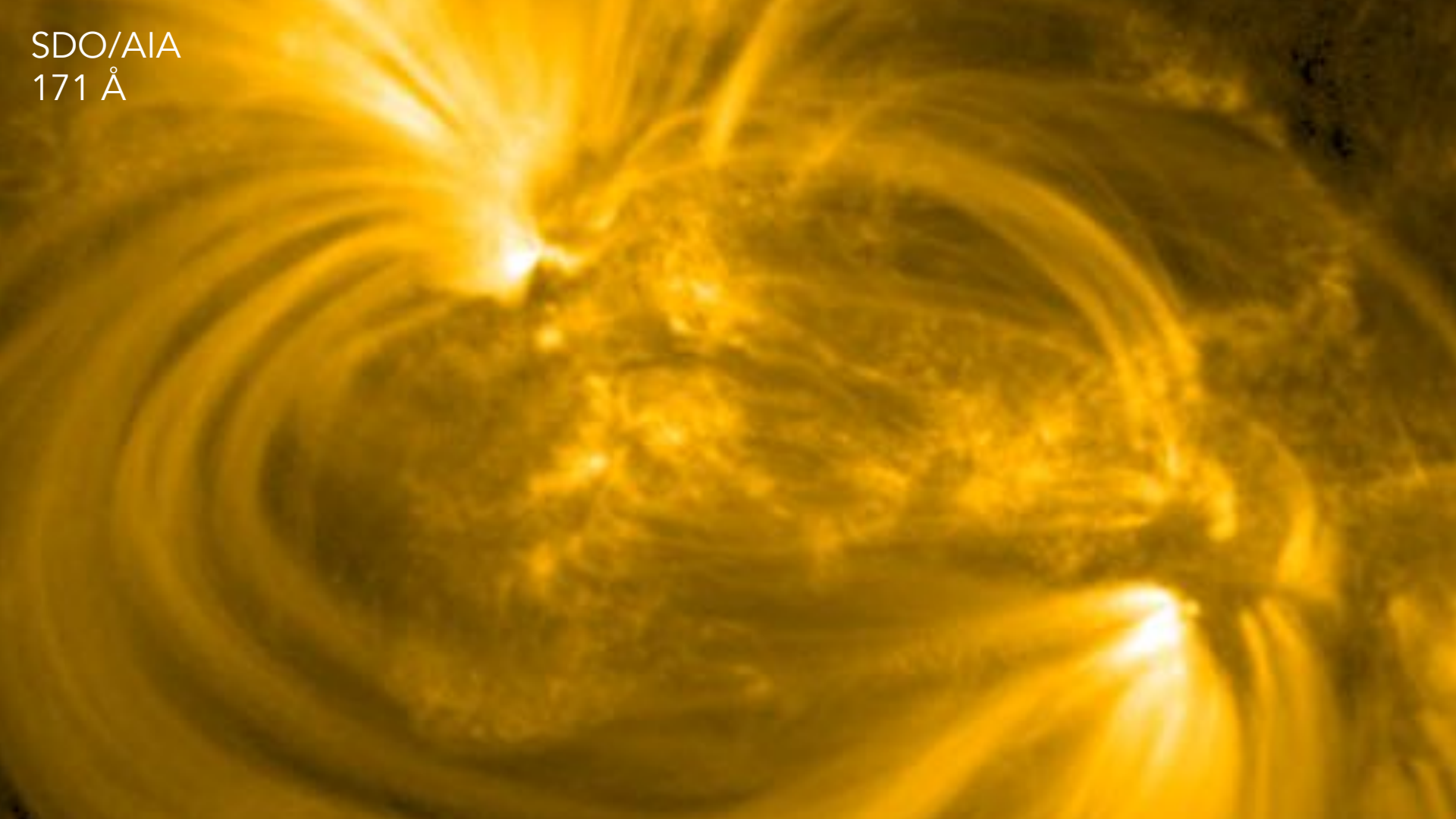
SDO/AIA
171 Å



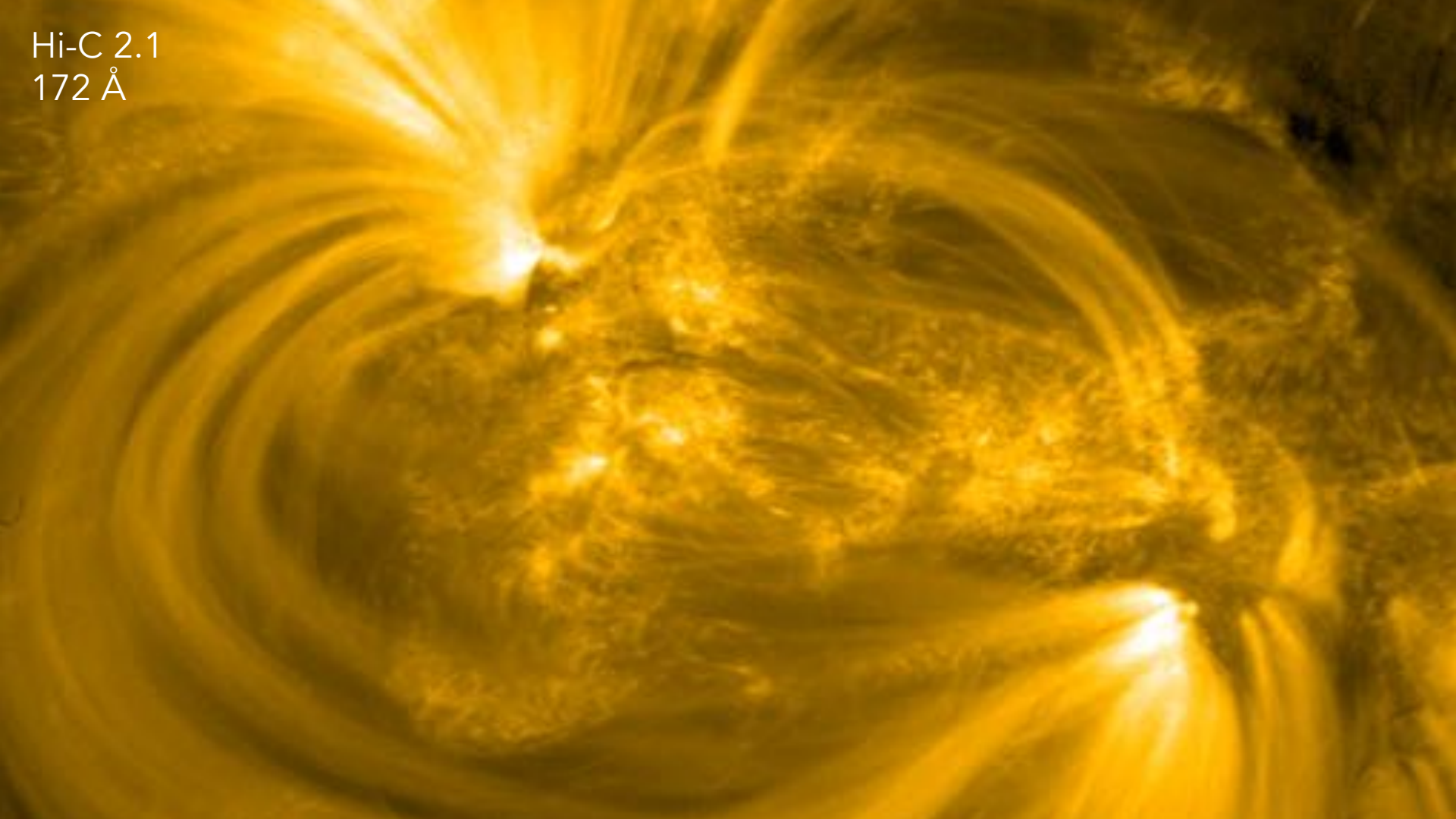
Hi-C 2.1
172 Å



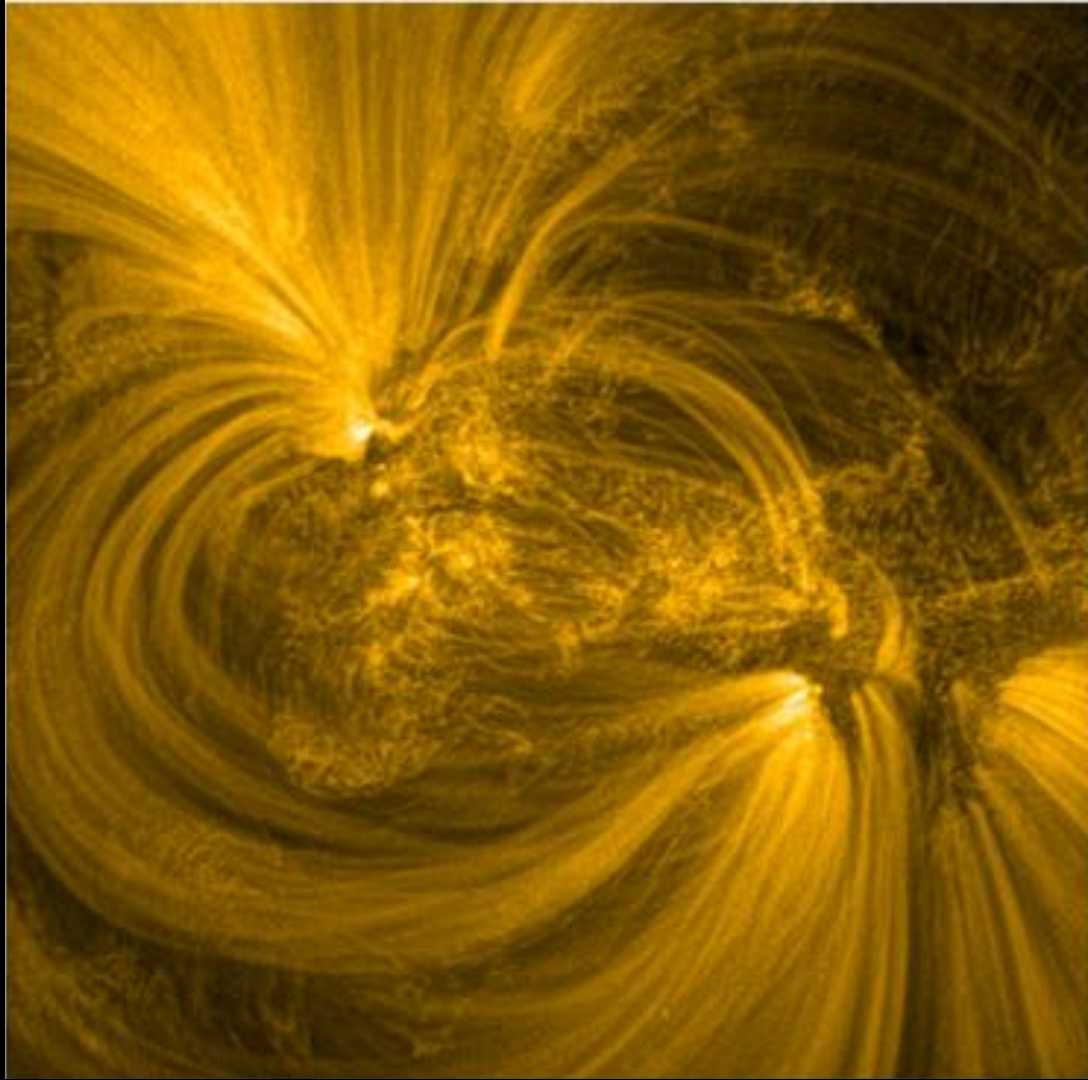
SDO/AIA
171 Å



Hi-C 2.1
172 Å

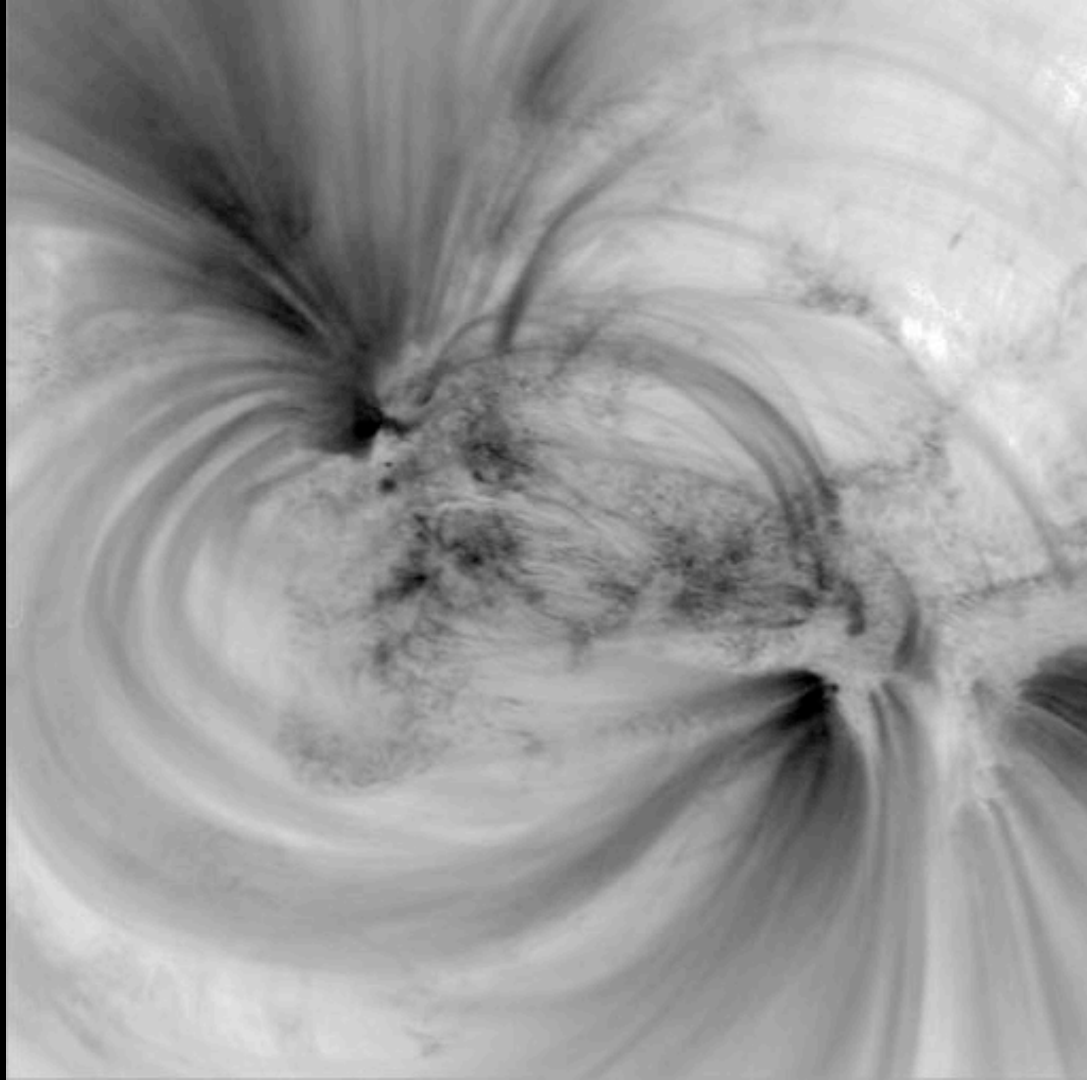


Hi-C 2.1
172 Å



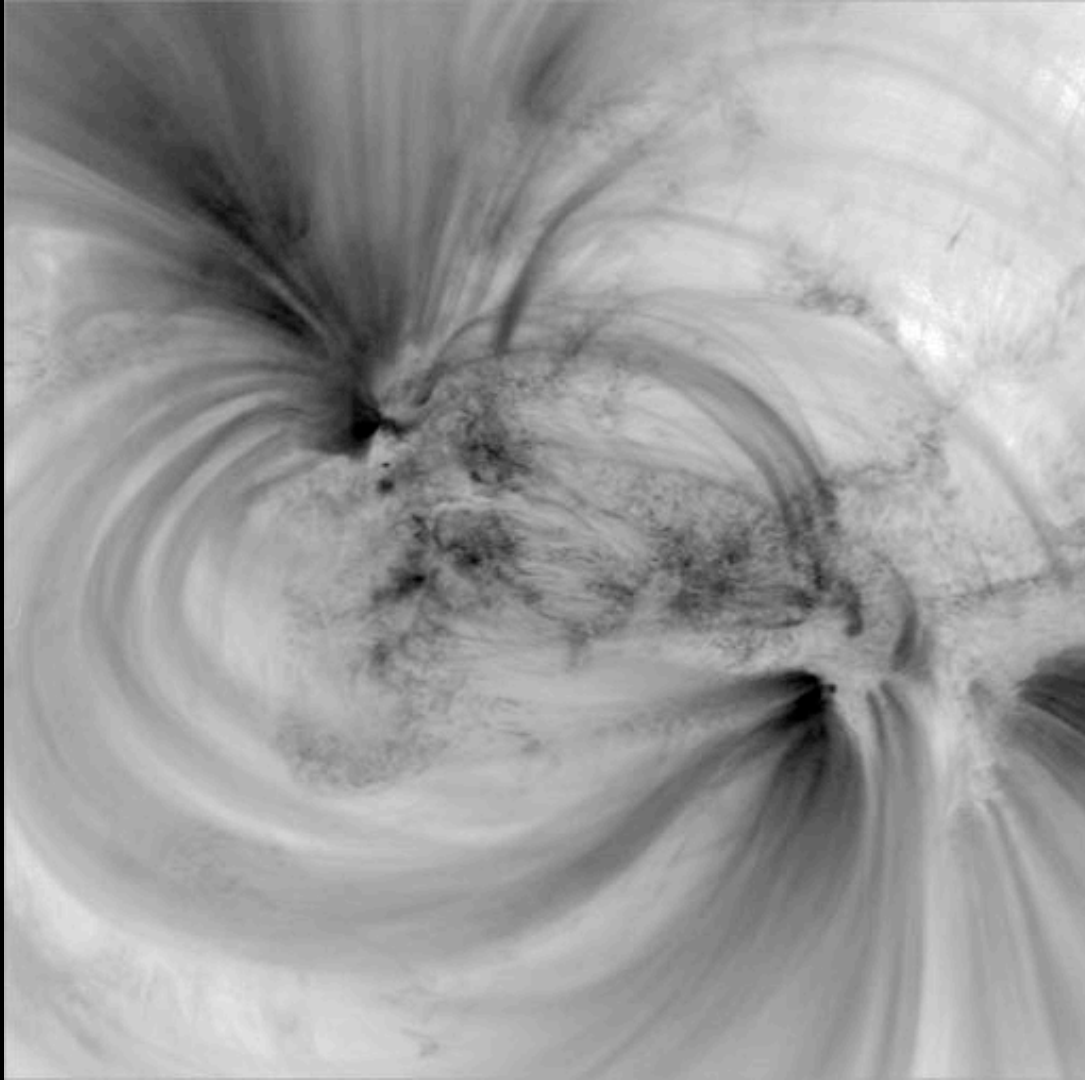
Sharpened

Hi-C 2.1
172 Å



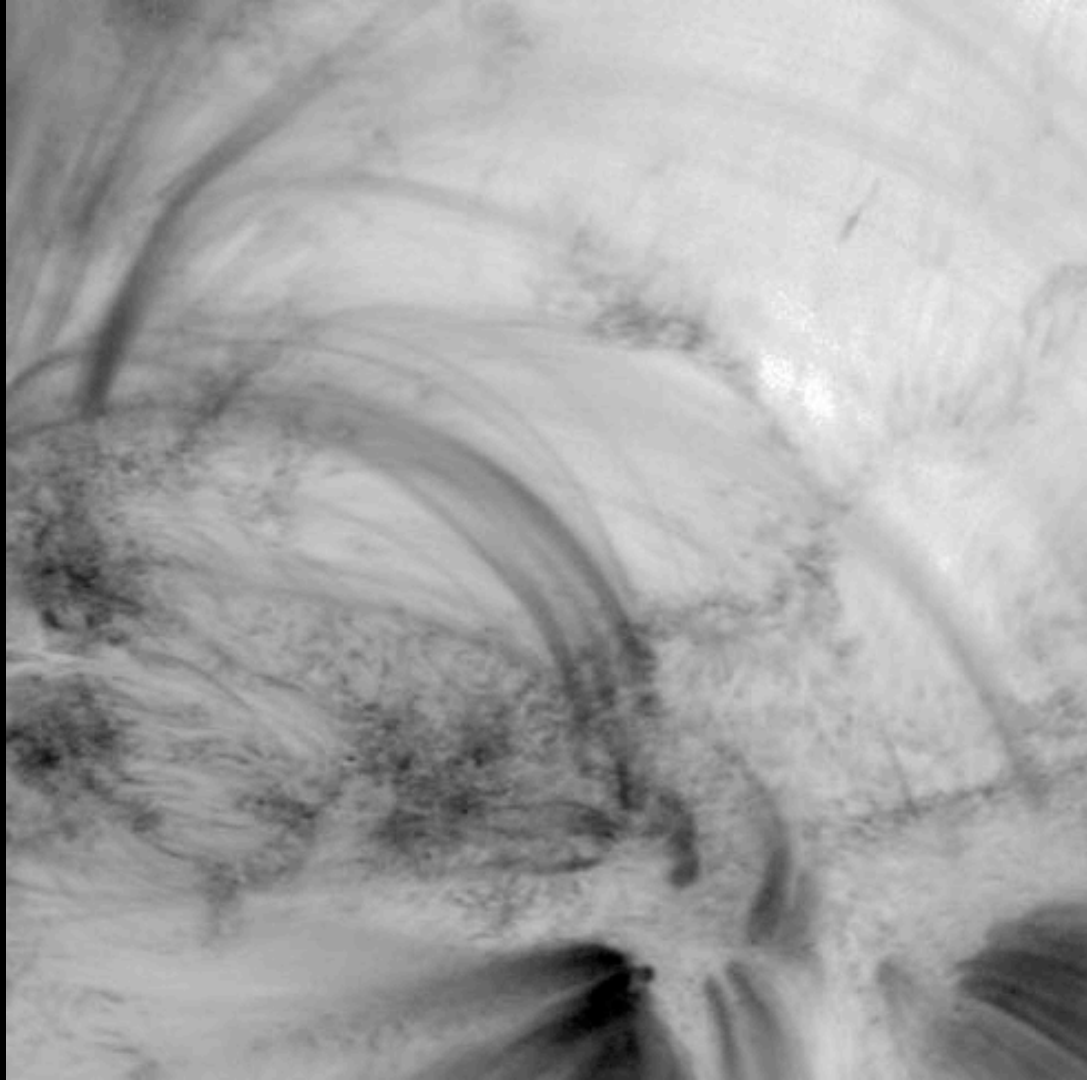
With Jitter

Hi-C 2.1
172 Å



Without Jitter
Sharpened

Hi-C 2.1
172 Å



Hi-C 2.1: What makes this instrument work?

HIGH SPATIAL RESOLUTION

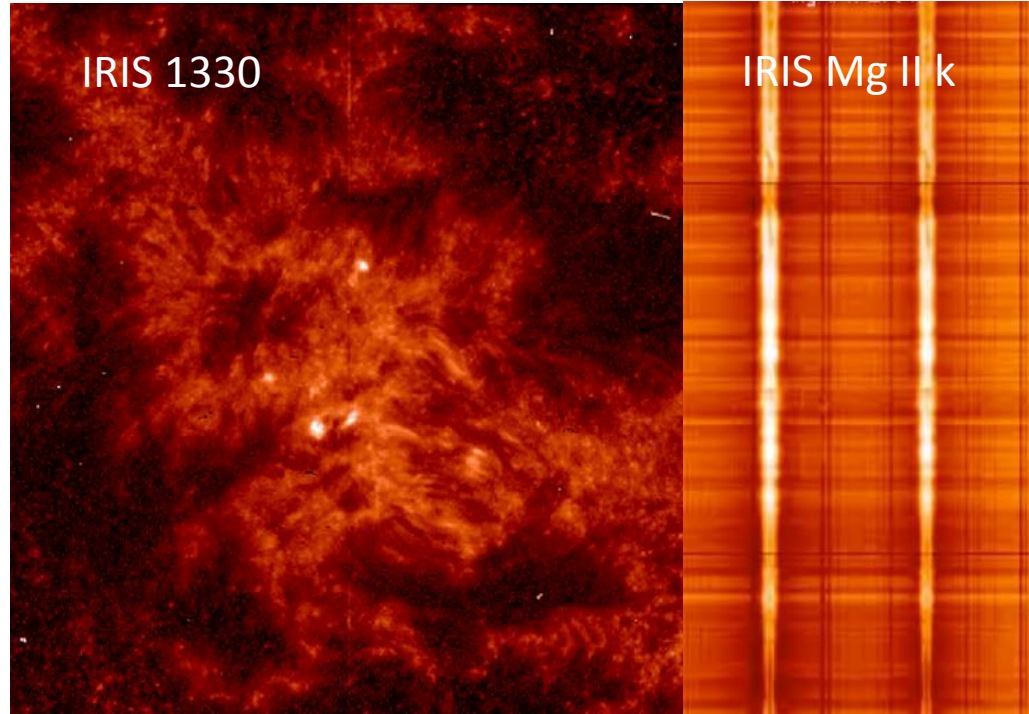
HIGH TEMPORAL RESOLUTION

LOW NOISE CAMERA

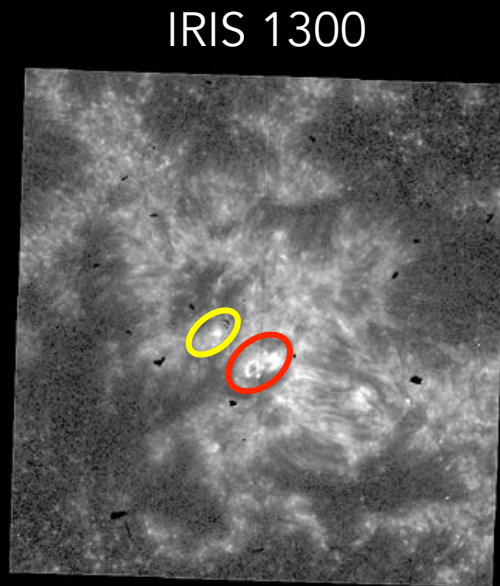
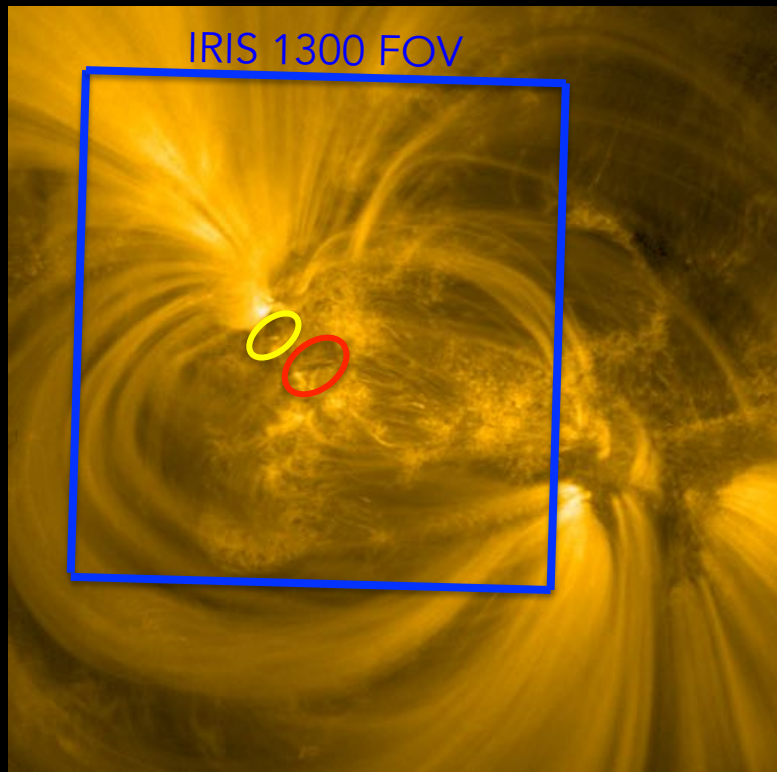
COORDINATED DATA SETS

IRIS coordinated data

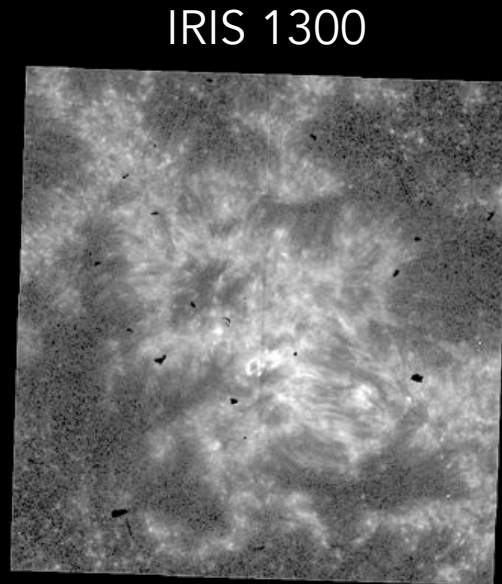
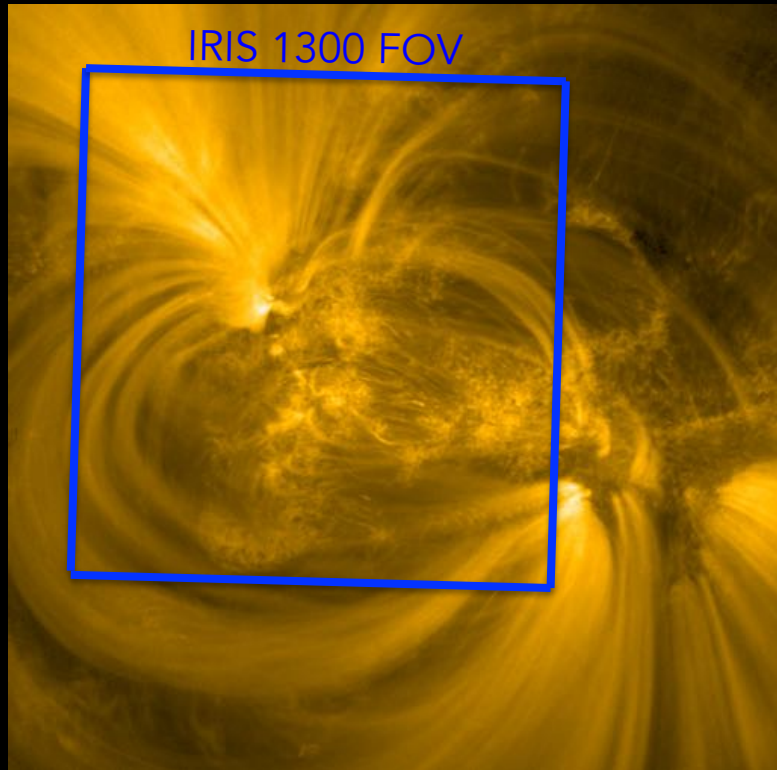
IRIS observations of a subset of the region at high resolution and spectra will be used to tie small features in the chromosphere to those in the corona.



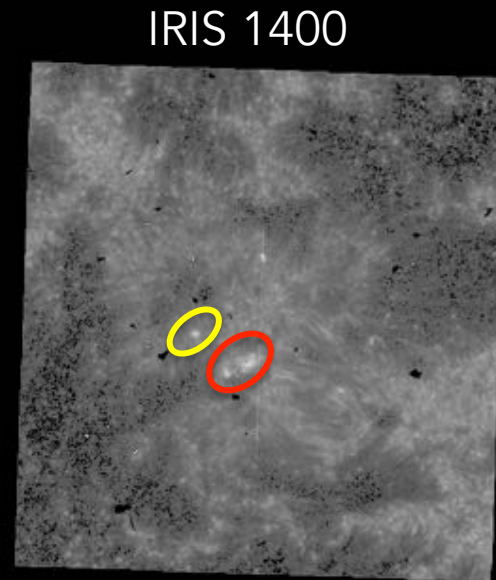
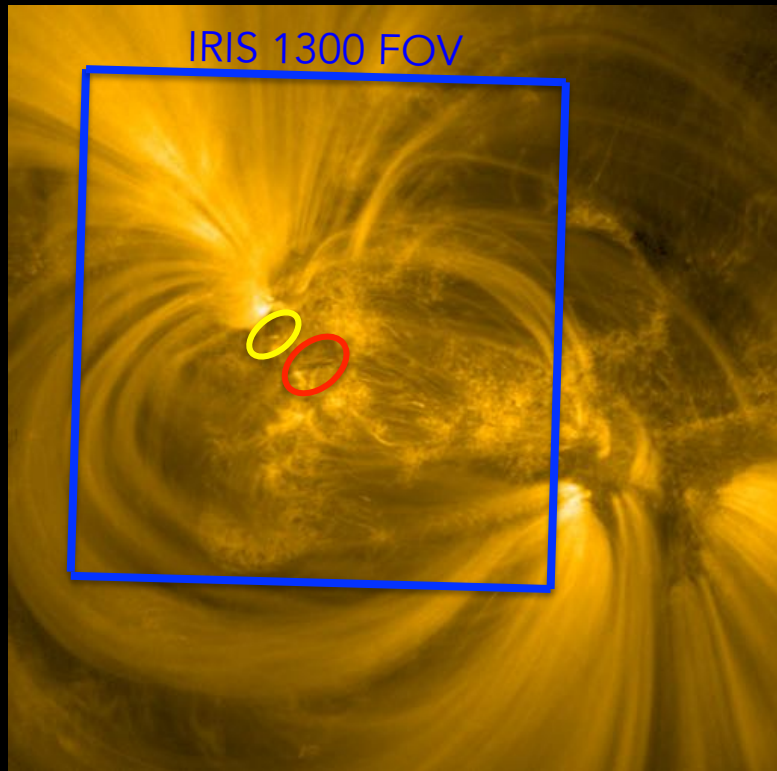
IRIS coordinated data



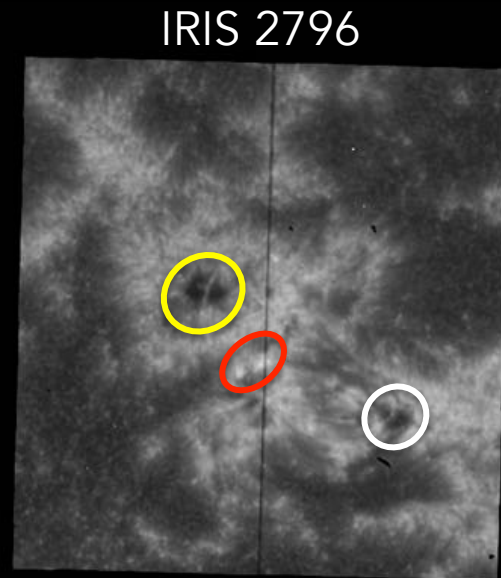
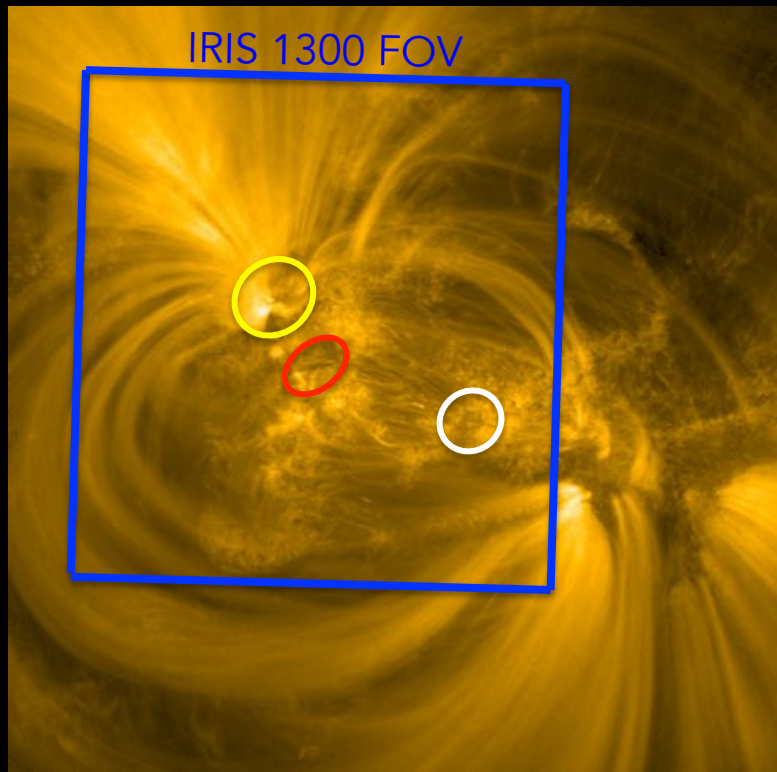
IRIS coordinated data



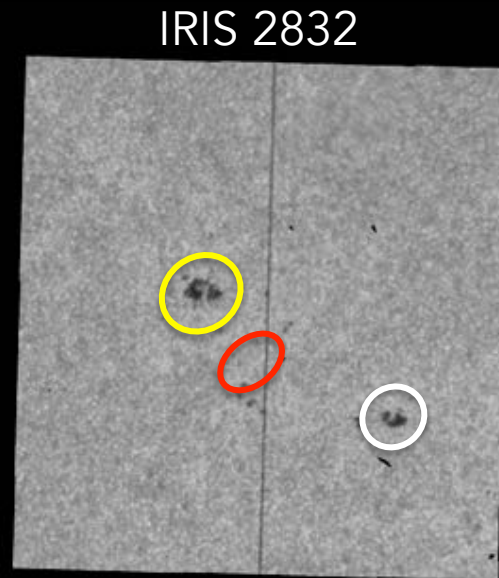
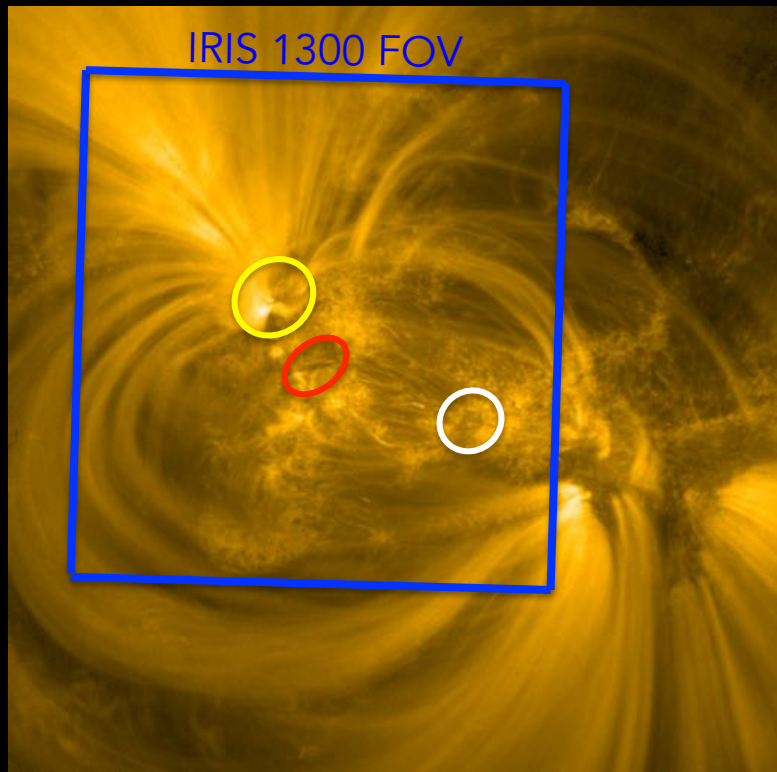
IRIS coordinated data



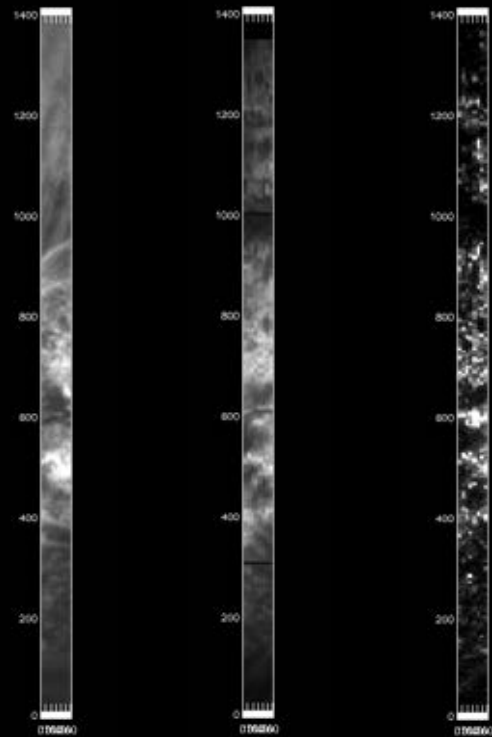
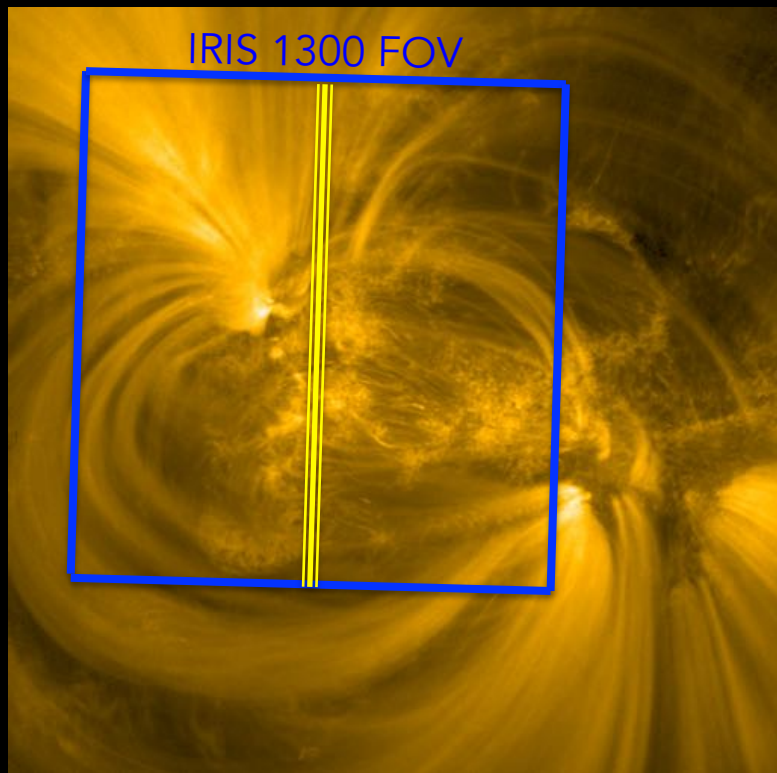
IRIS coordinated data



IRIS coordinated data



IRIS coordinated data



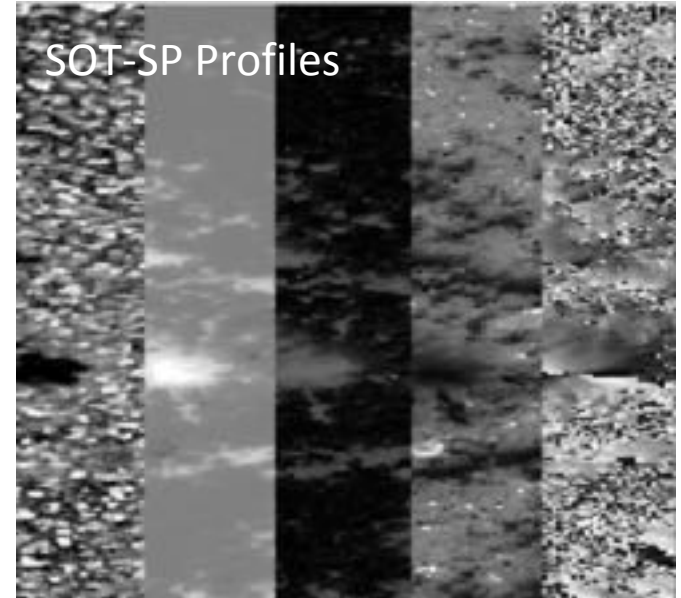
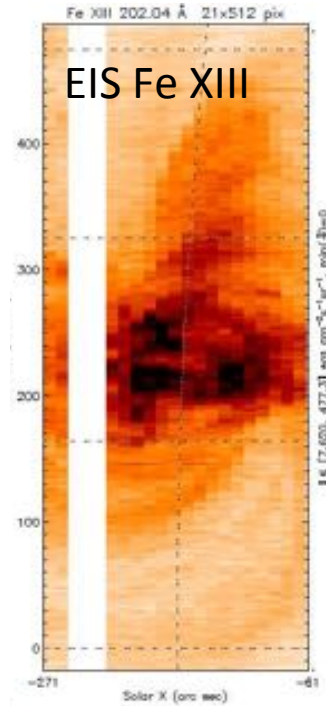
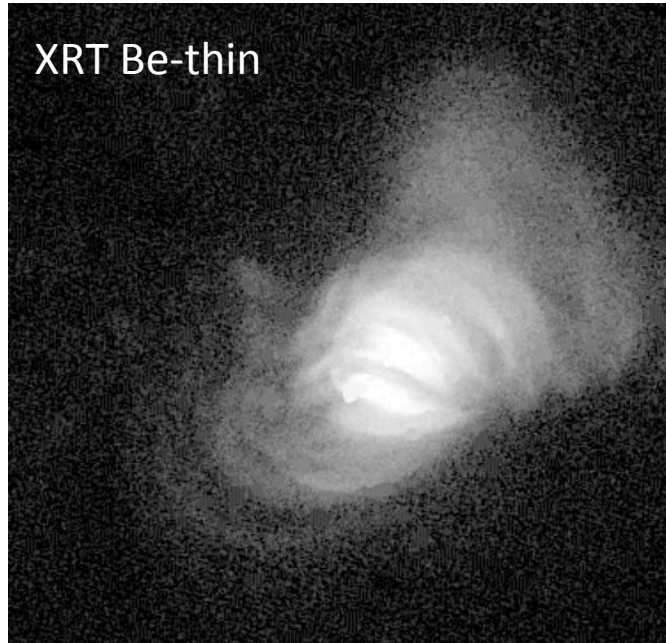
Hinode coordinated data

All three Hinode instruments successfully captured the Hi-C 2.1 region.

- XRT provides coronal context of the movement of hot plasma in the upper atmosphere above the Hi-C features.
 - EIS provides narrowband spectra of the hot coronal loops thereby precisely measuring plasma flow properties.
 - SOT-SP provides underlying magnetic field information to high precision.
-

Hinode coordinated data

All three Hinode instruments successfully captured the Hi-C 2.1 region.



Science topics being pursued

- Thin, stranded loops [width variations]
 - Flows between transition region, chromosphere, and corona
 - Spicules
 - Nano/microflares
 - Moss/Plage brightenings
 - Flows along loops
 - Waves
 - Mini-jets
 - Etc.
-

Additional Coordinated Data Sets

- NuSTAR
- BBSO
- Owens Valley
- NSO

** Special thanks for assisting with the coordinations goes out to:

L. Glesener,
K. Reardon,
B. Chen,
Y. Chai,
N. Karuda,
P. Antolin,
J. Leenaarts,
Gregal Visers

AGU plug

Add AGU session approved for highlighting suborbital results.

Hi-C 2.1 science results expected to be presented in this session!



FALL MEETING

Washington, D.C. | 10-14 Dec 2018

Thanks, and stay tuned....

