Imaging Challenges of Modern Astronomy and Astrophysics

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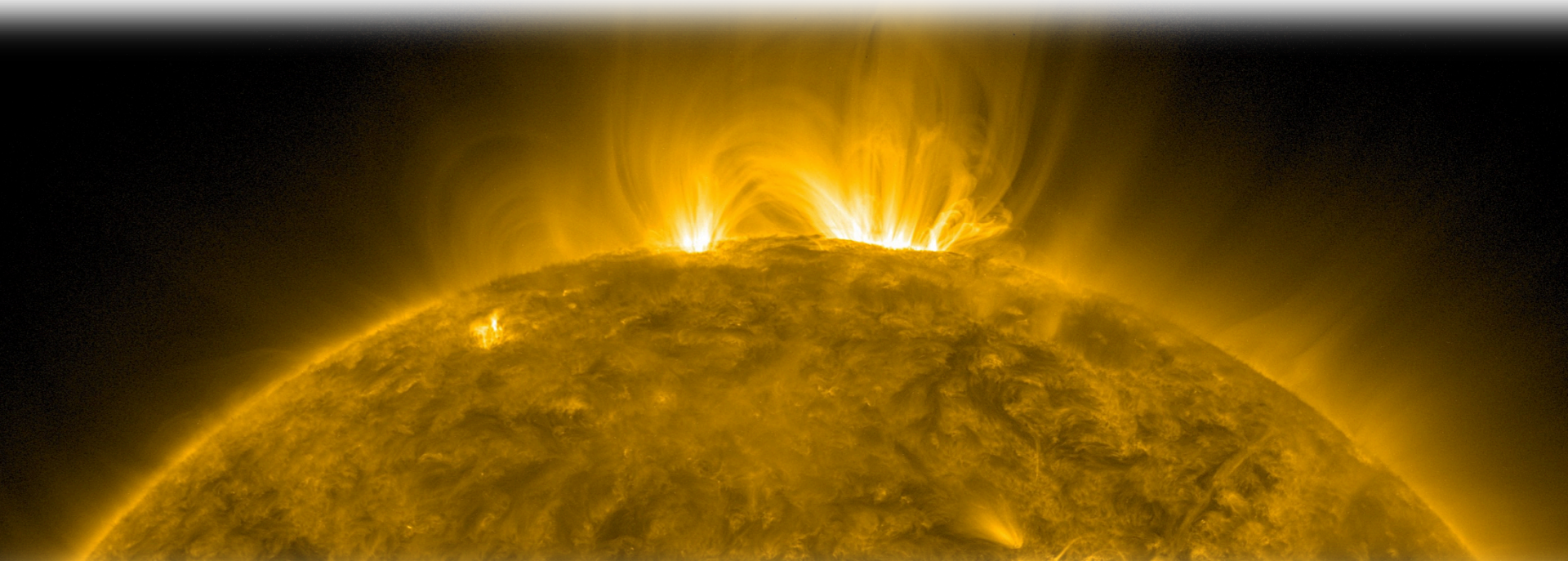
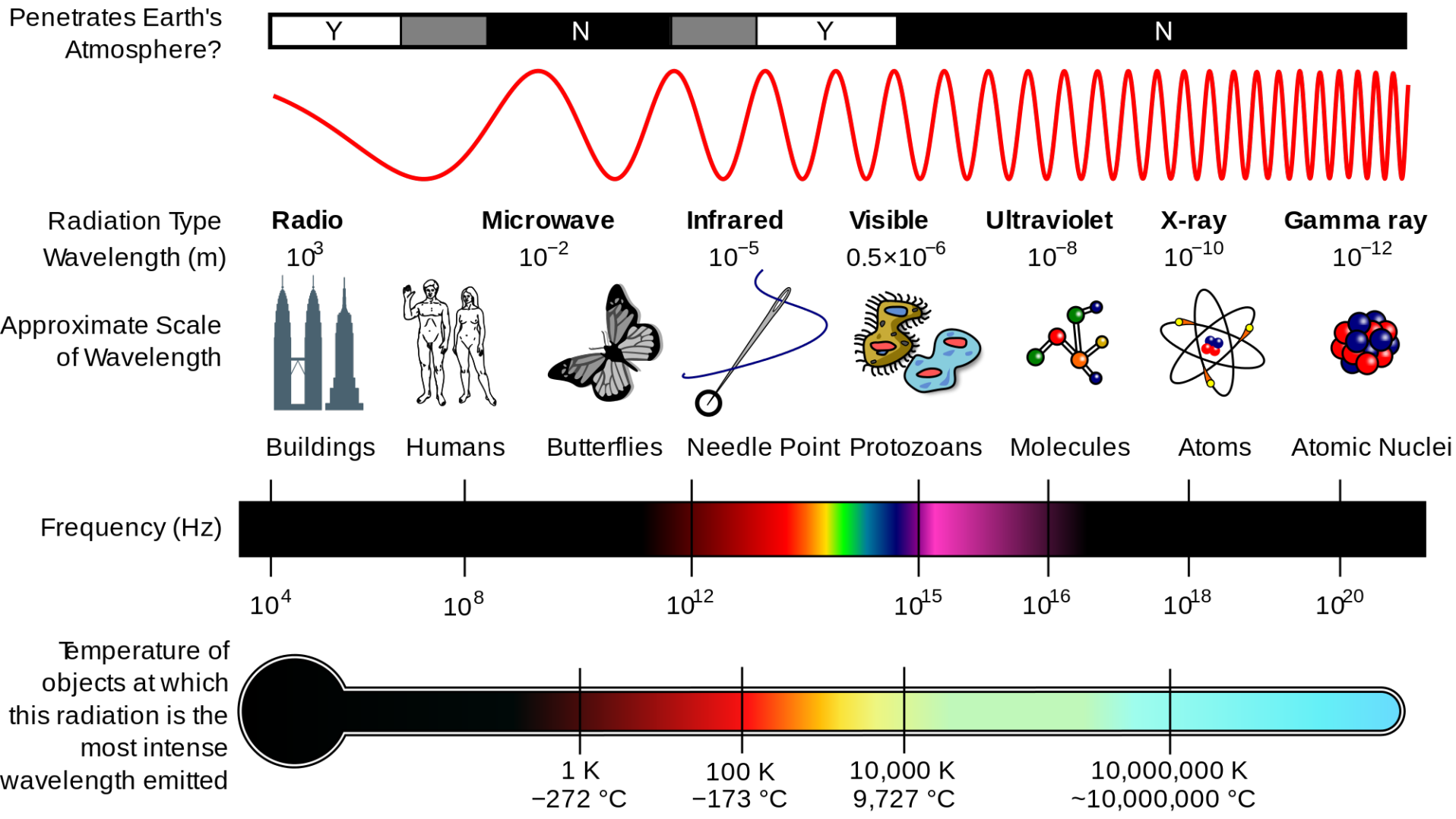
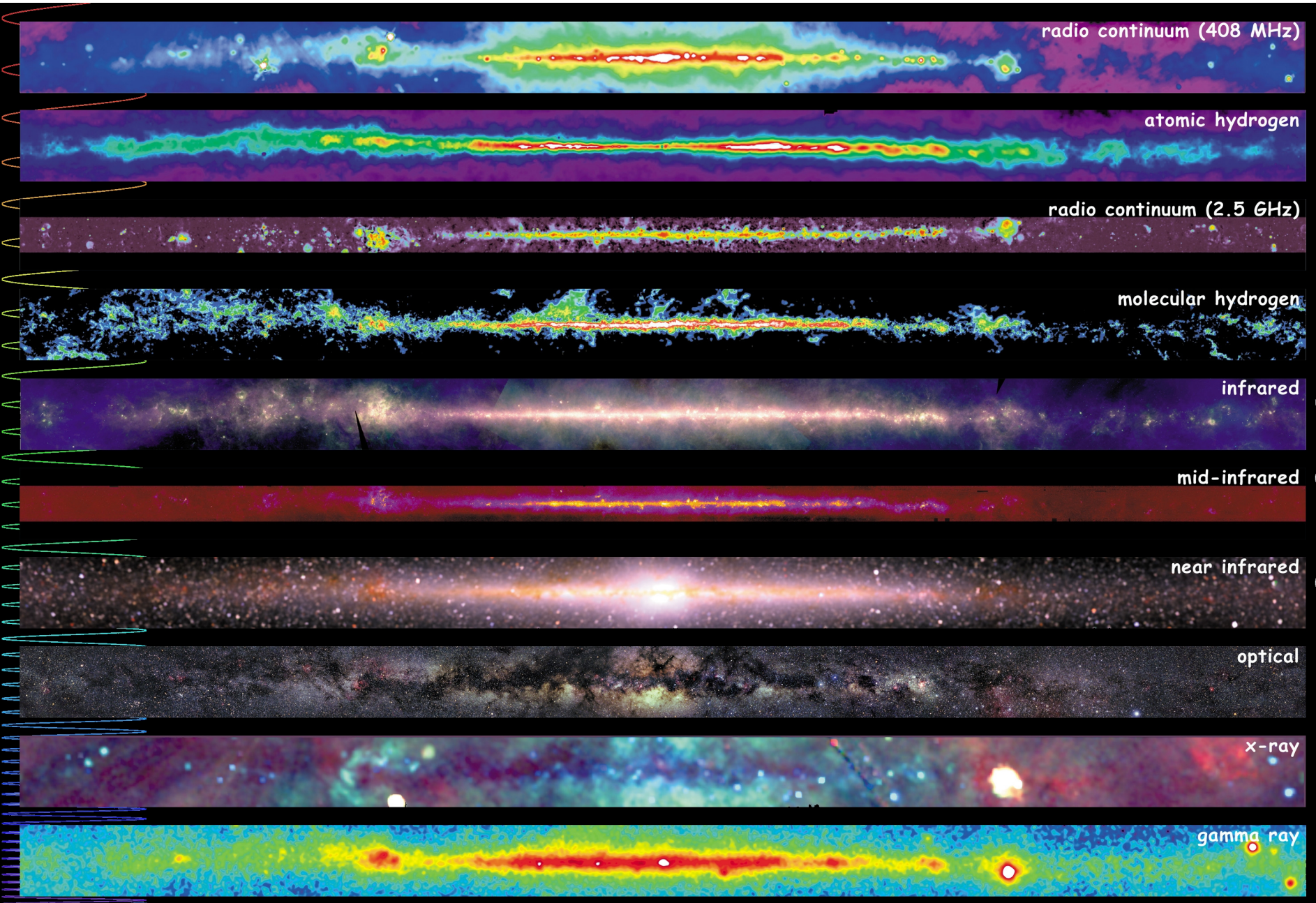
- Imaging in Astronomy and Astrophysics
- Why Focus on a Complex Sun?
- Solar Image Data
  - Disk Images
  - Coronagraphs
  - Indirect Imaging
- So what? Why Do We Care?
  - Break
- Solar Image Processing for Science
- Future Challenges
- Let's Talk

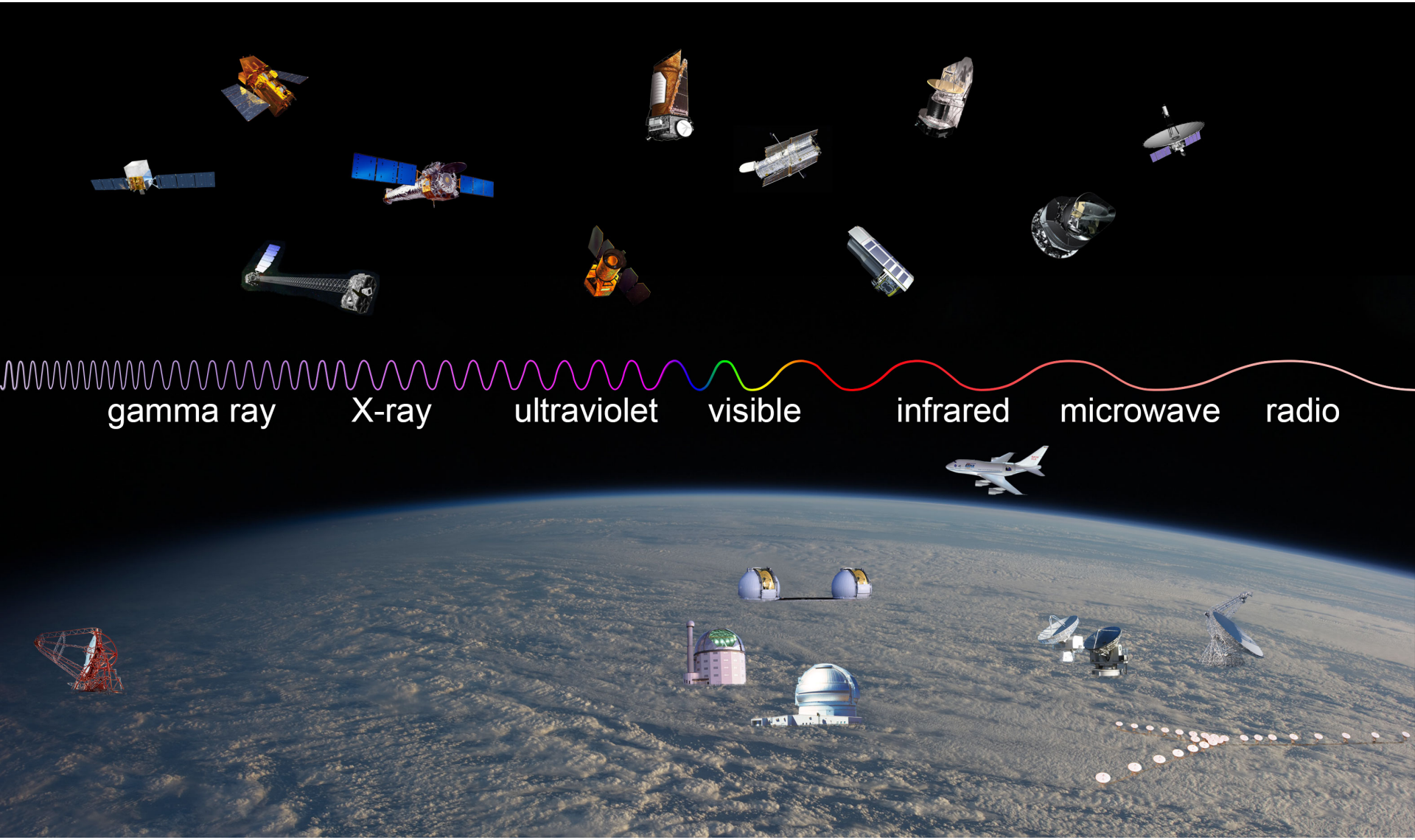
Imaging in Astronomy & Astrophysics



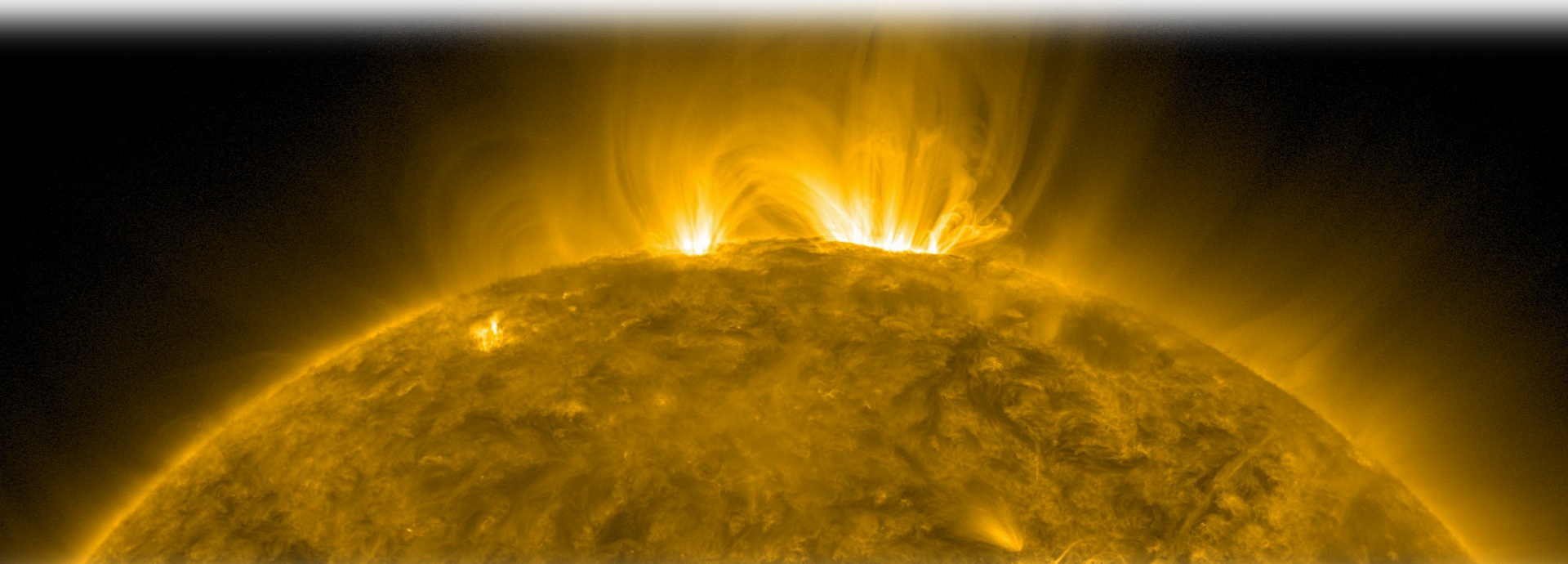

Penetrates Earth's Atmosphere?
Y
N
Y
N
Radiation Type
Wavelength (m)
Approximate Scale of Wavelength
Radio
10^{3}
Microwave
10^{-2}
Infrared
10^{-5}
Visible
0.5×10^{-6}
Ultraviolet
10^{-8}
X-ray
10^{-10}
Gamma ray
10^{-12}
Buildings
Humans
Butterflies
Needle Point
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
Temperature of objects at which this radiation is the most intense wavelength emitted
1 K
−272 °C
100 K
−173 °C
10,000 K
9,727 °C
10,000,000 K
~10,000,000 °C

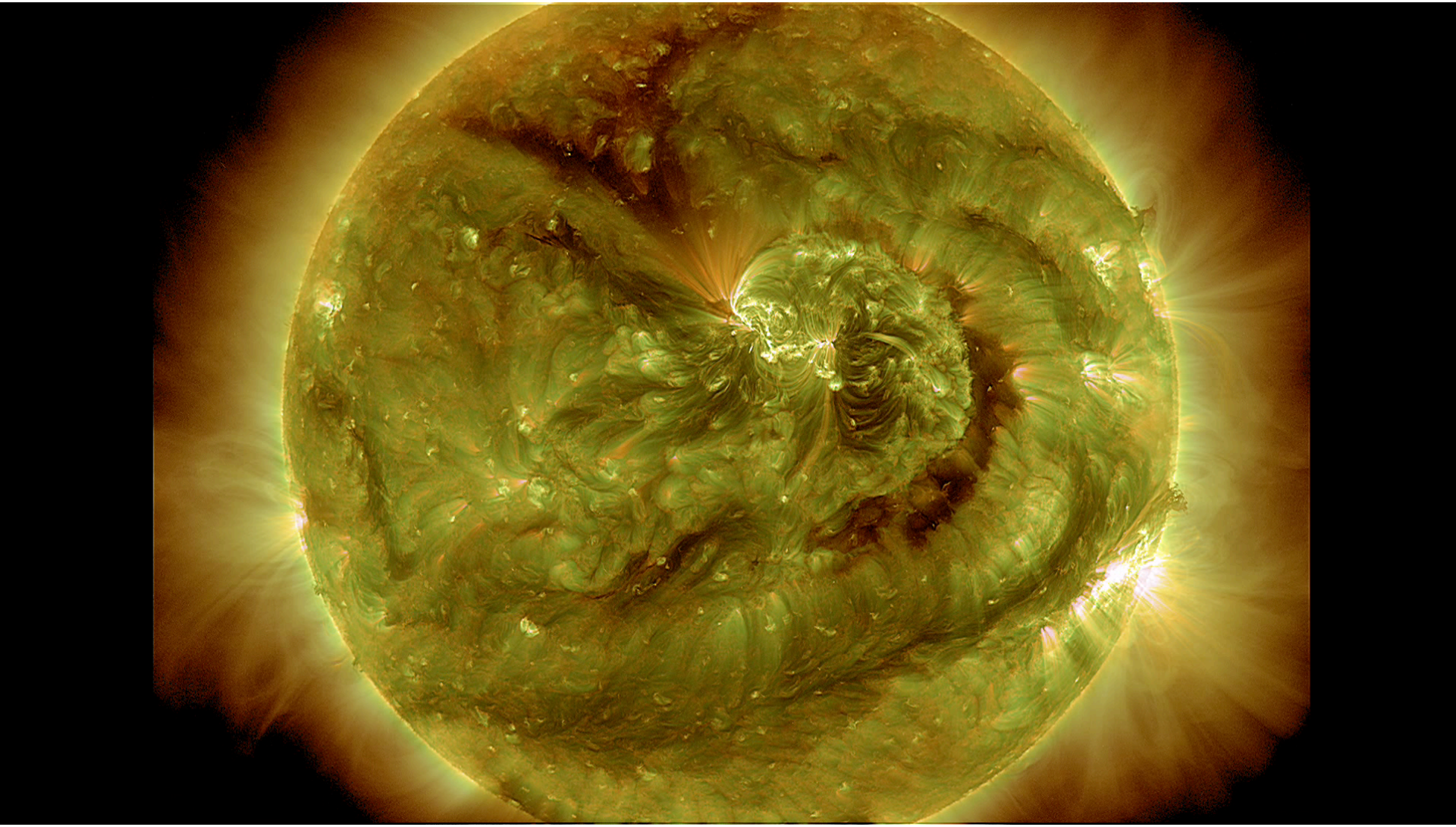

radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
http://adc.gsfc.nasa.gov/mw
NASA
Multiwavelength Milky Way

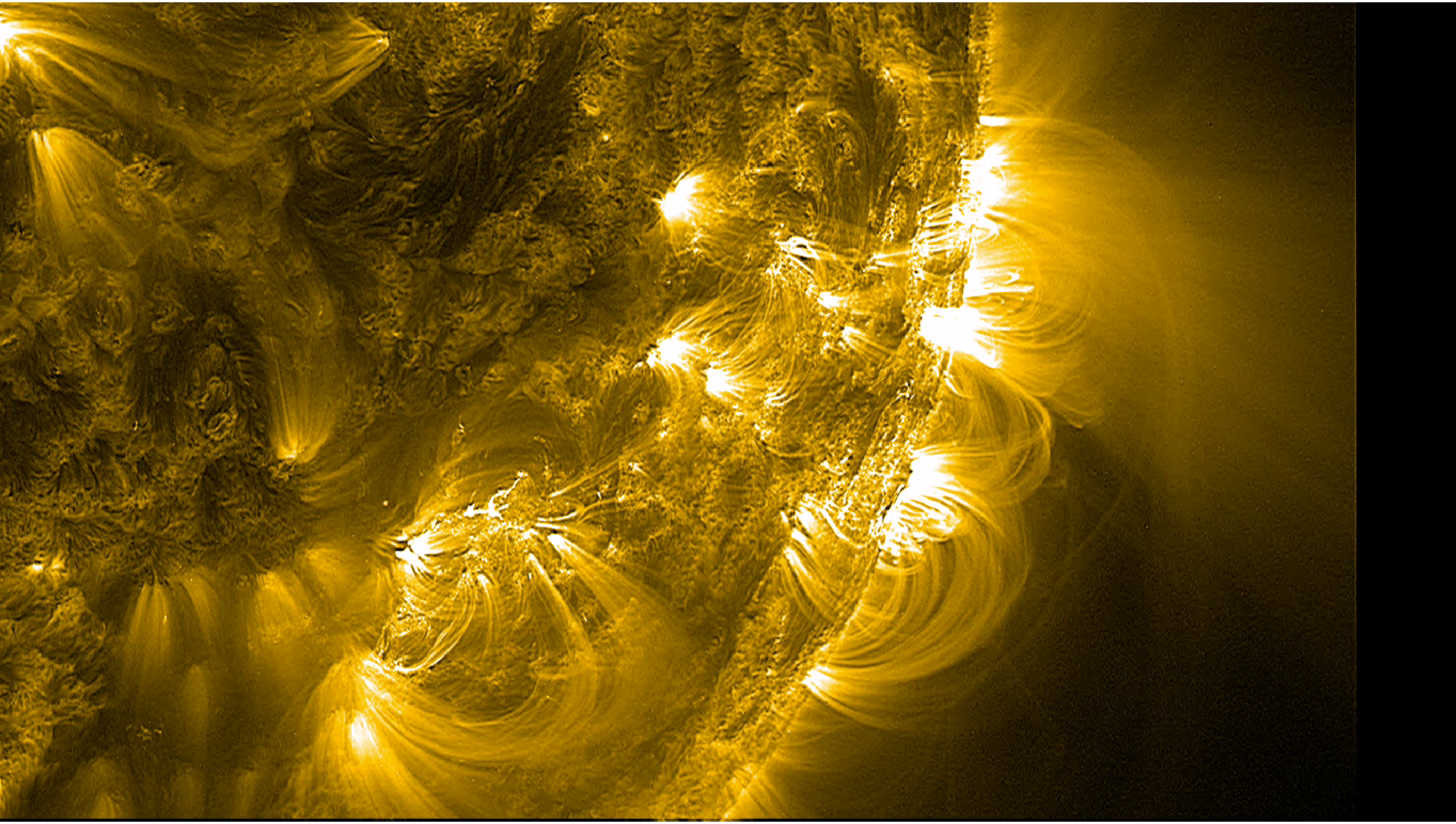

Radio
Microwave
Infrared
UV
X-Ray
Gamma Ray
Radio
60,000 nm
600 K
Infrared
1200-800 nm (10-3.6 um)
4,500 K
Optical
450-750 nm
6,000 K
Ultraviolet
400-200 nm
10,000 K
X-ray
100-10 nm
10,000,000 K
Multiwavelength Whirlpool Galaxy
COLD GAS: Radio waves reveal regions of gas cool enough for CO_2 molecules to exist.
COOL STARS: Infrared shows smaller cool red stars that make up most of the galaxy.
SOLAR STARS: Optical light comes from stars around the size of the Sun.
HOT STARS: Ultraviolet shows the larger hot blue stars that are less frequent in galaxies.
HOT GAS: X-rays are emitted from the hottest regions of gas where atoms are ionized.
COOL LOW ENERGY RADIATION
VISIBLE LIGHT
HOT HIGH ENERGY RADIATION


gamma ray
X-ray
ultraviolet
visible
infrared
microwave
radio

First, an introduction to the sun





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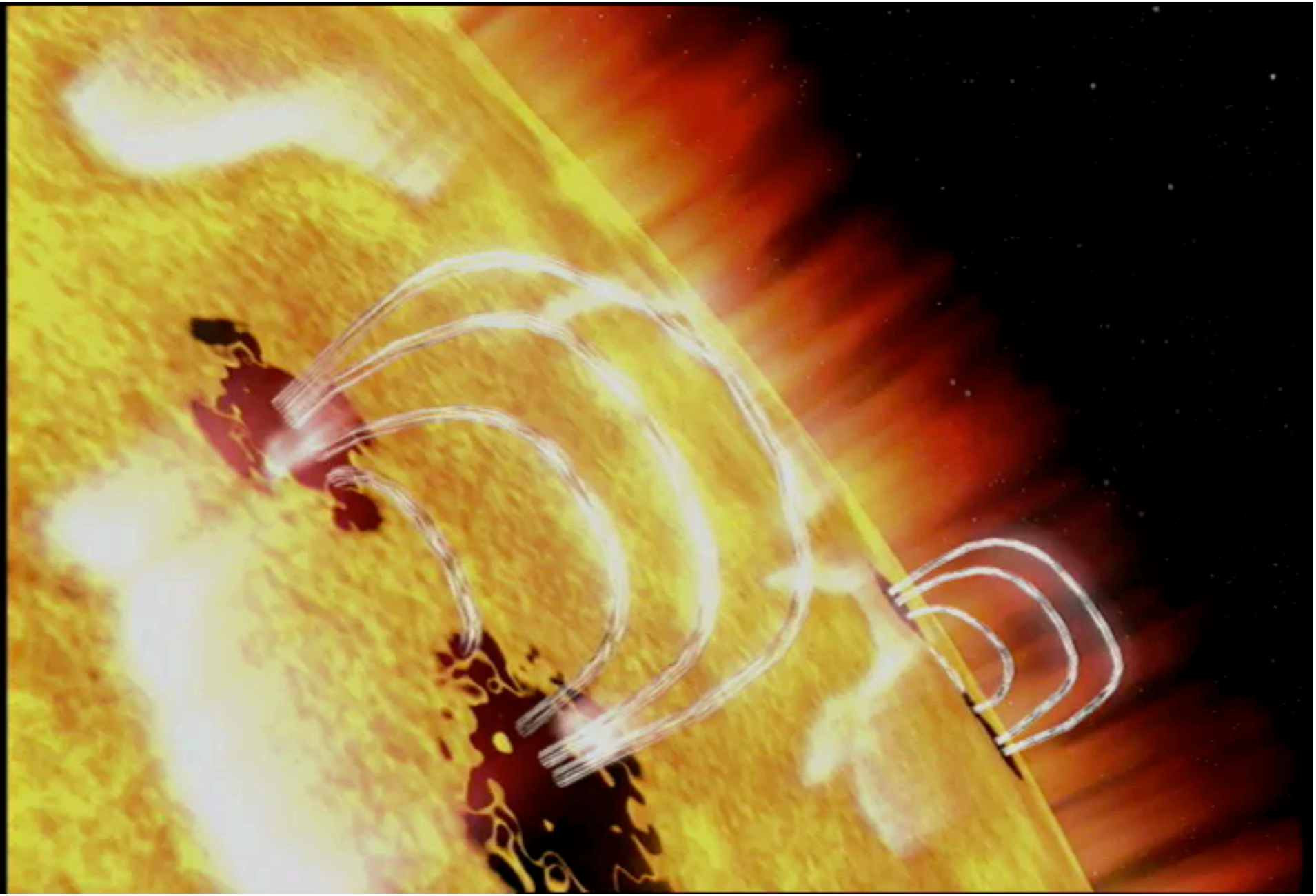
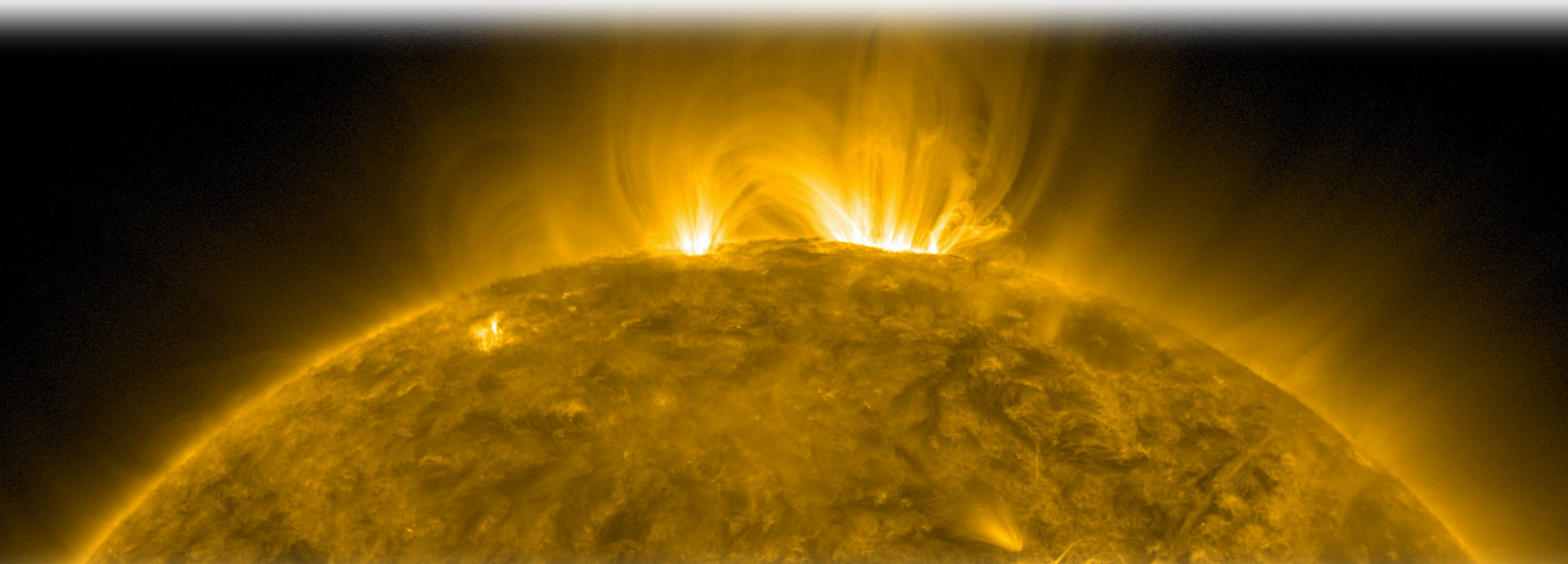
The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

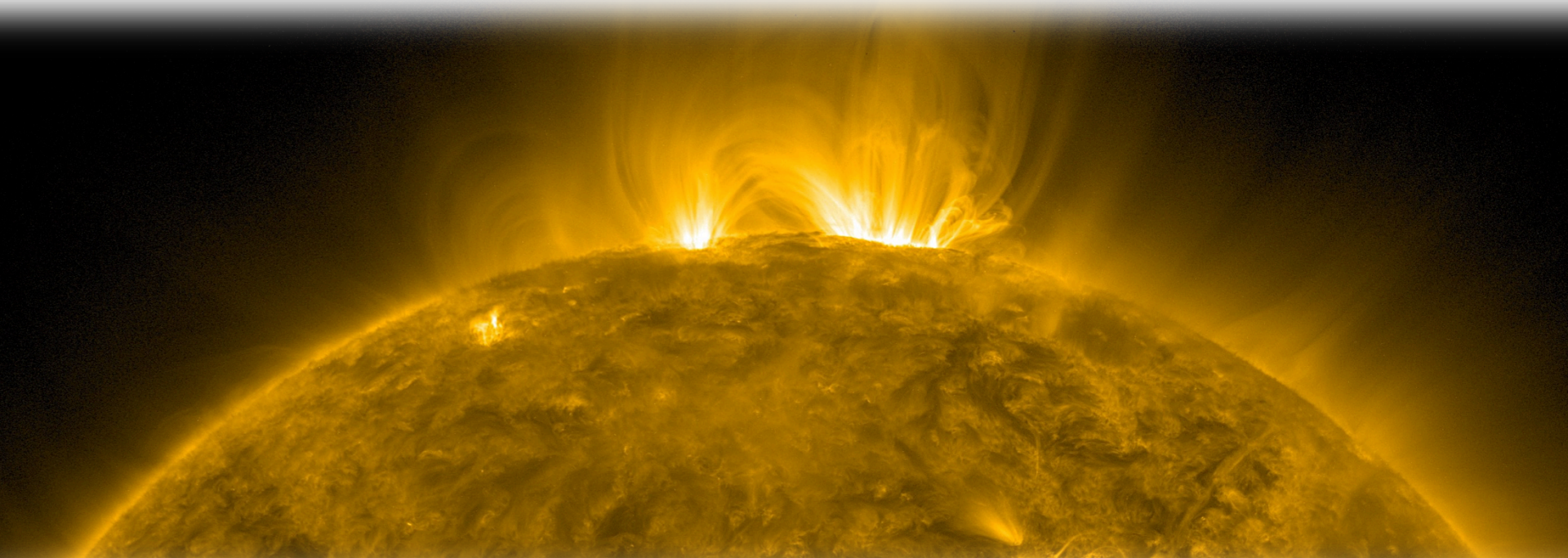
The combination of plasma, magnetic fields, and differential rotation is the key to the structure and dynamics of the sun.

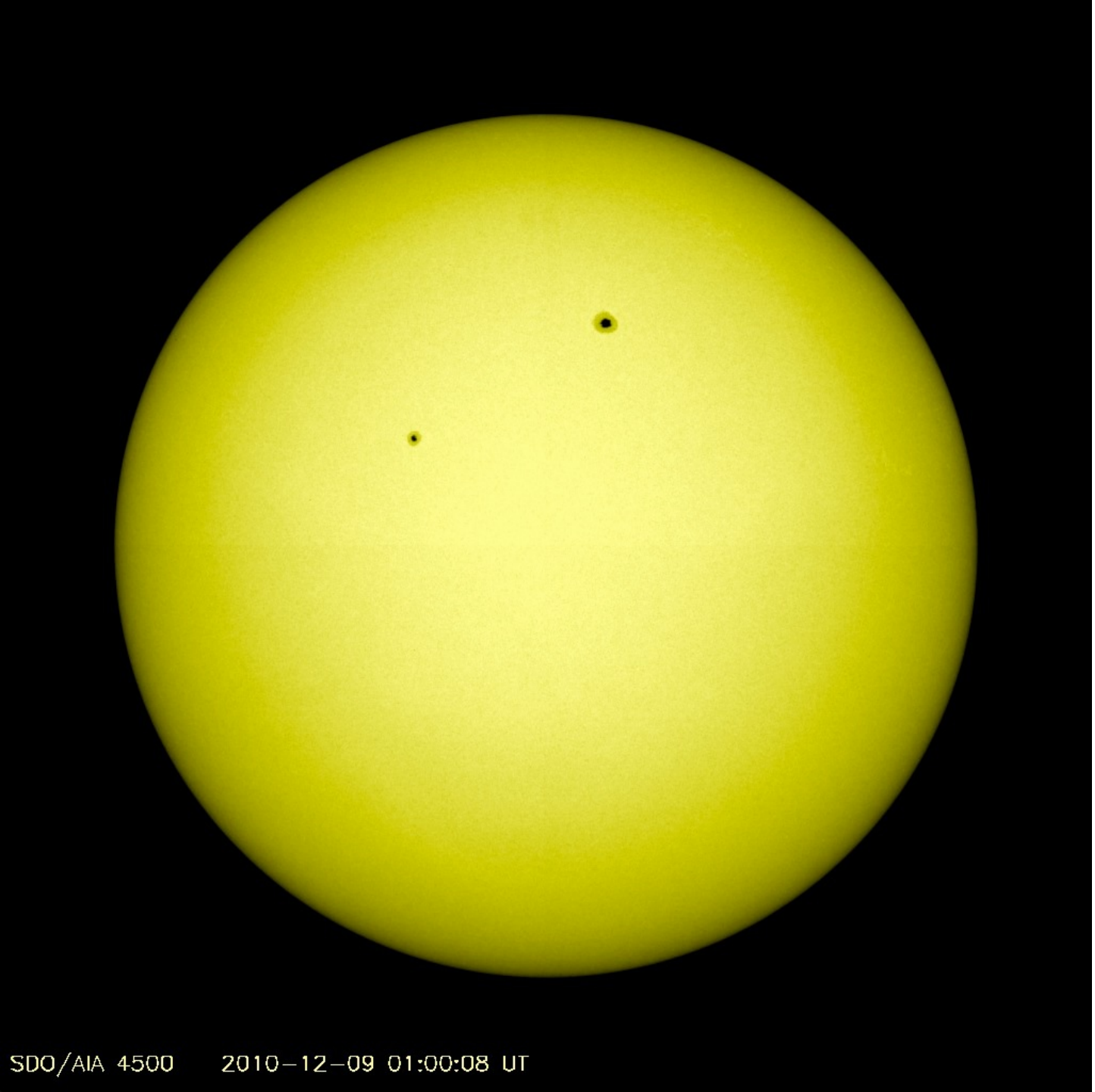


An Introduction to Solar Data

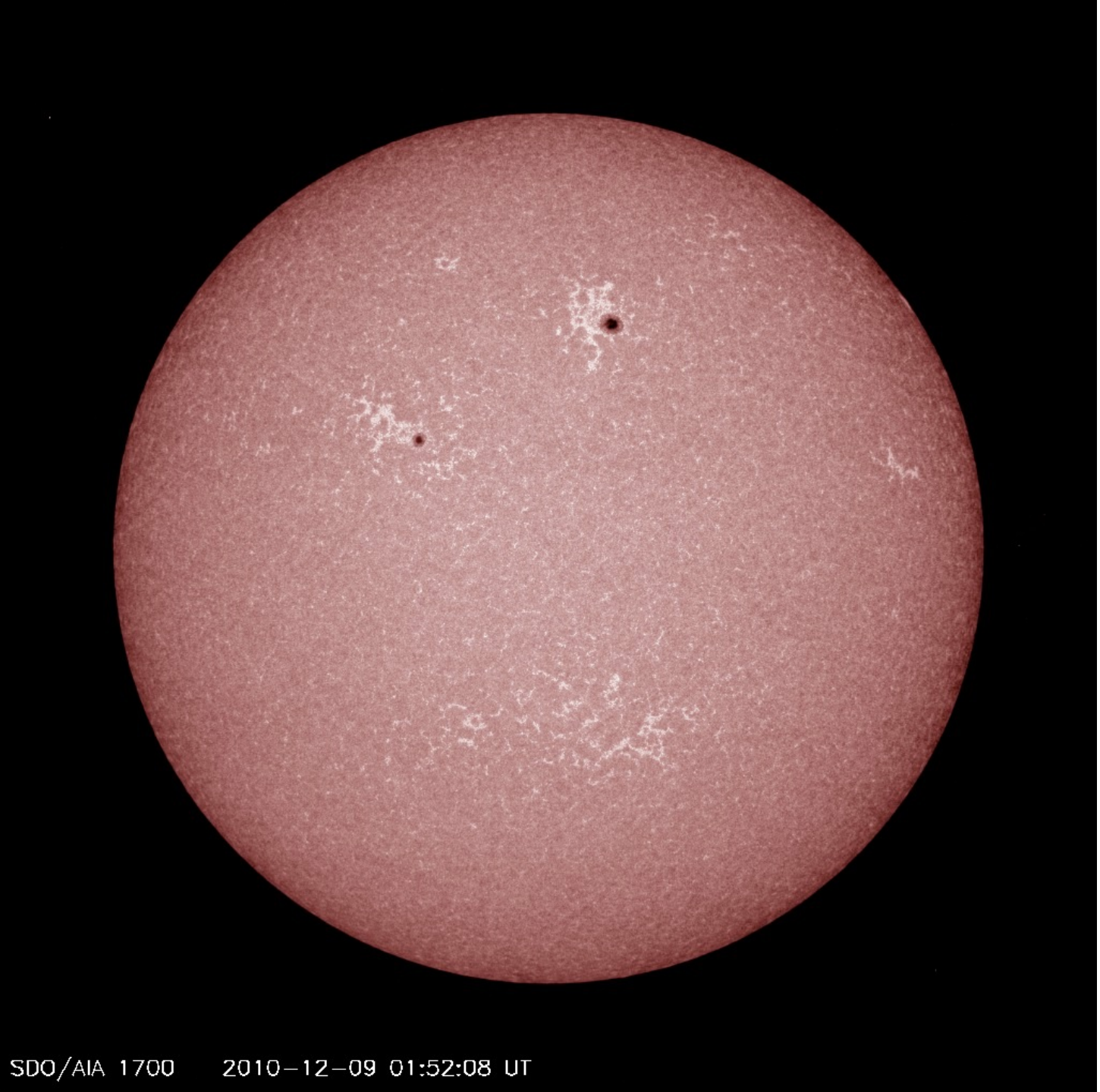


Disk Images (Visible, UV, EUV, X-ray)

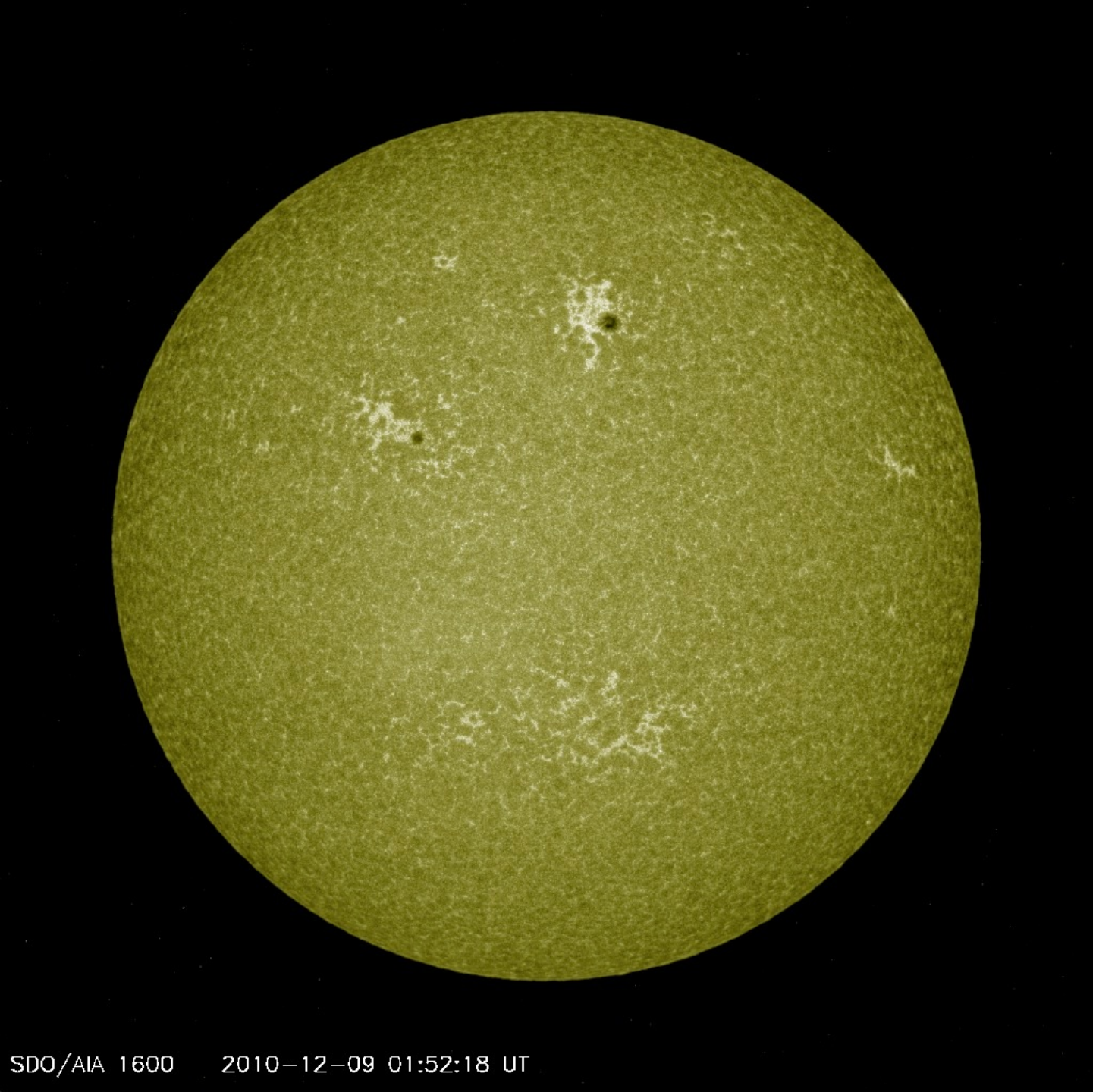




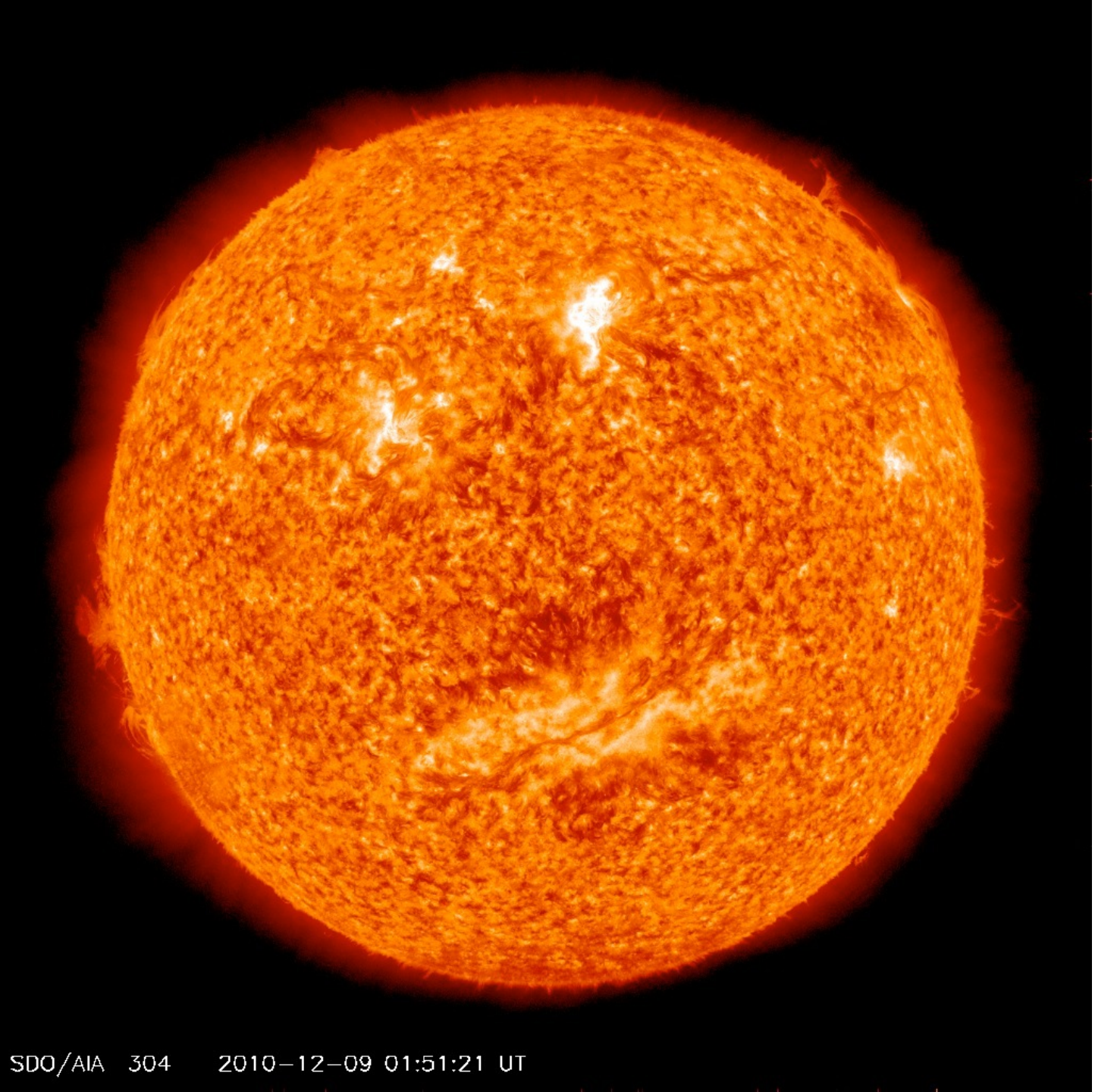
6000 K



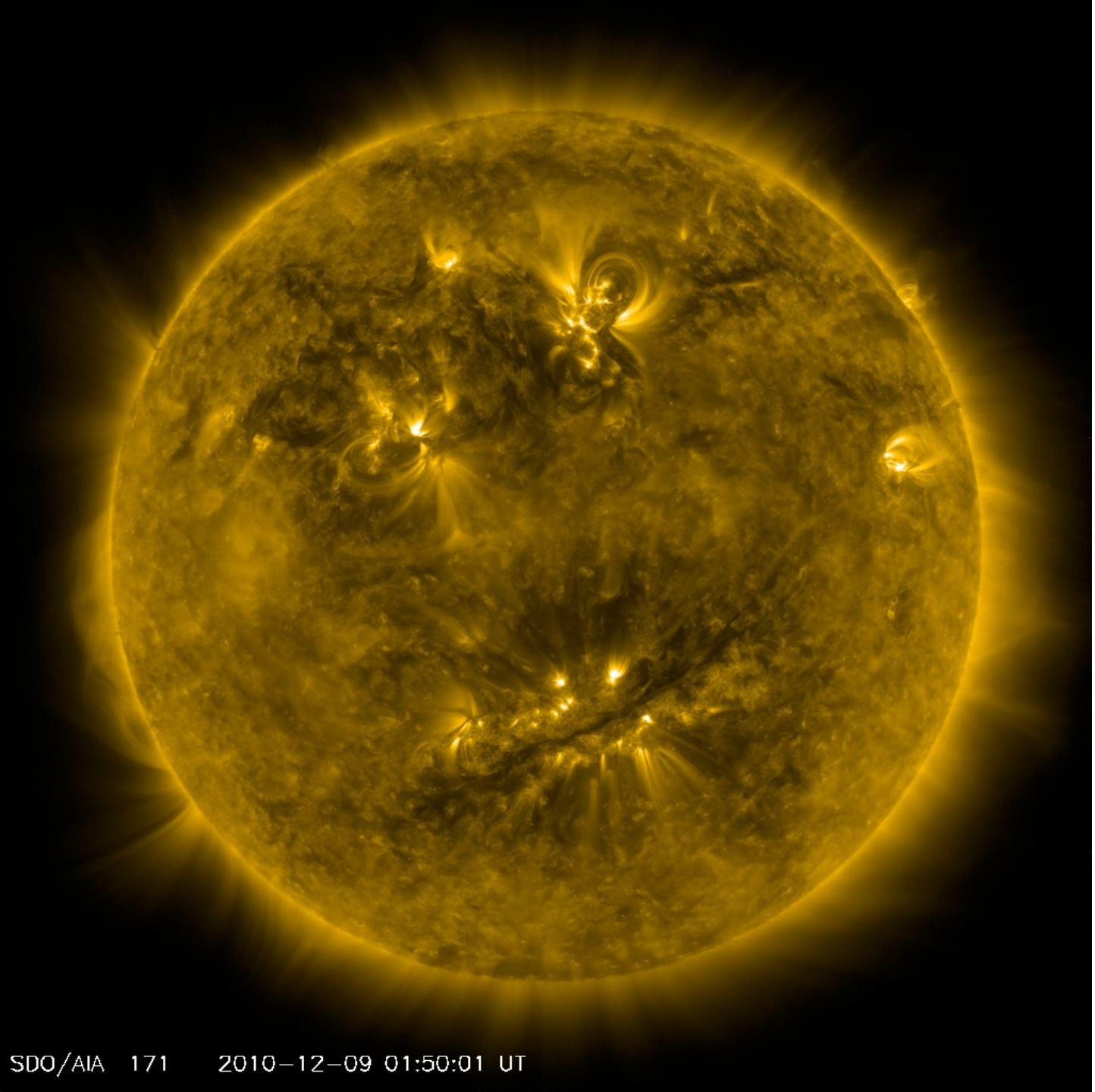
4500 K



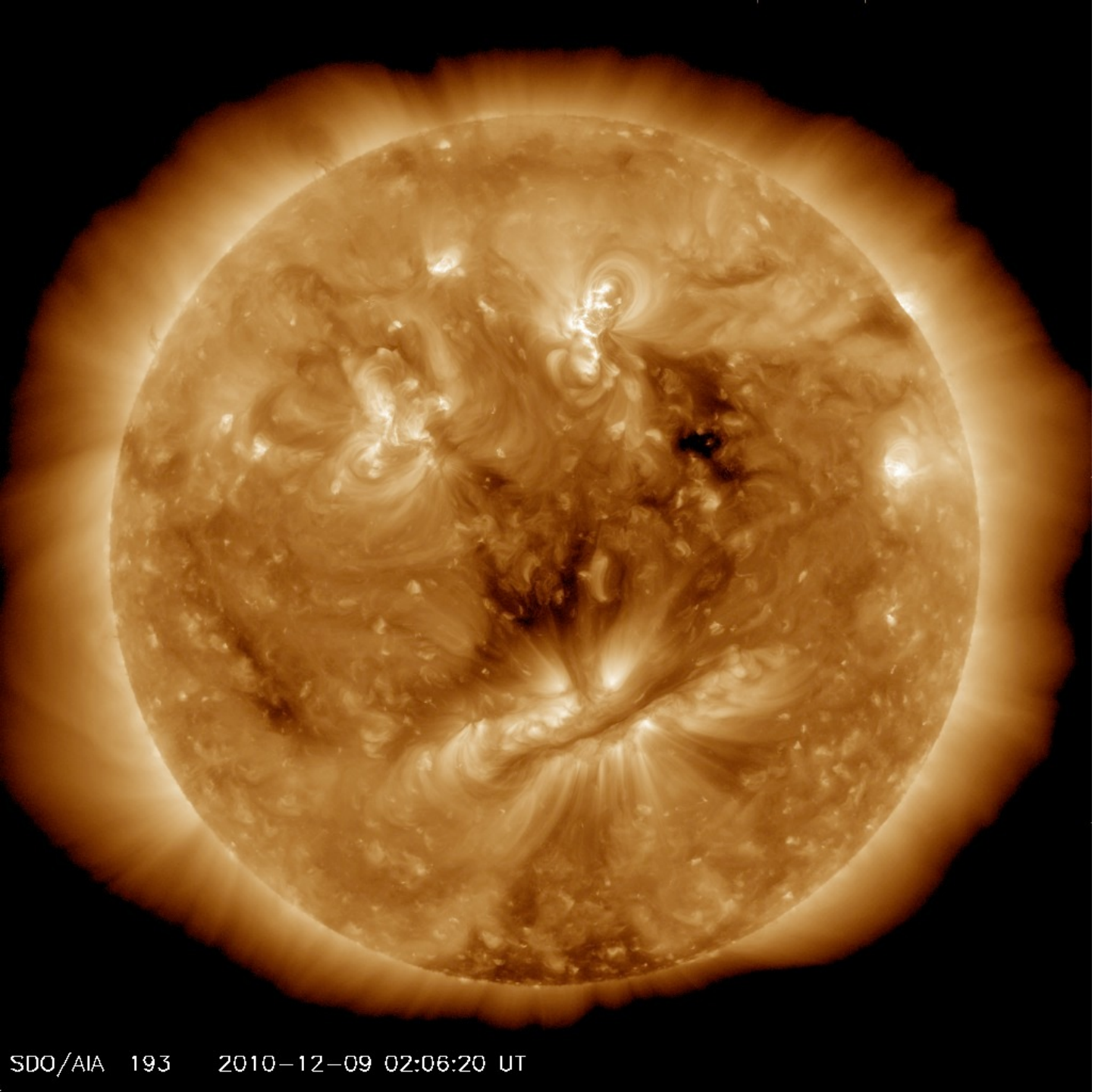
10,000 K



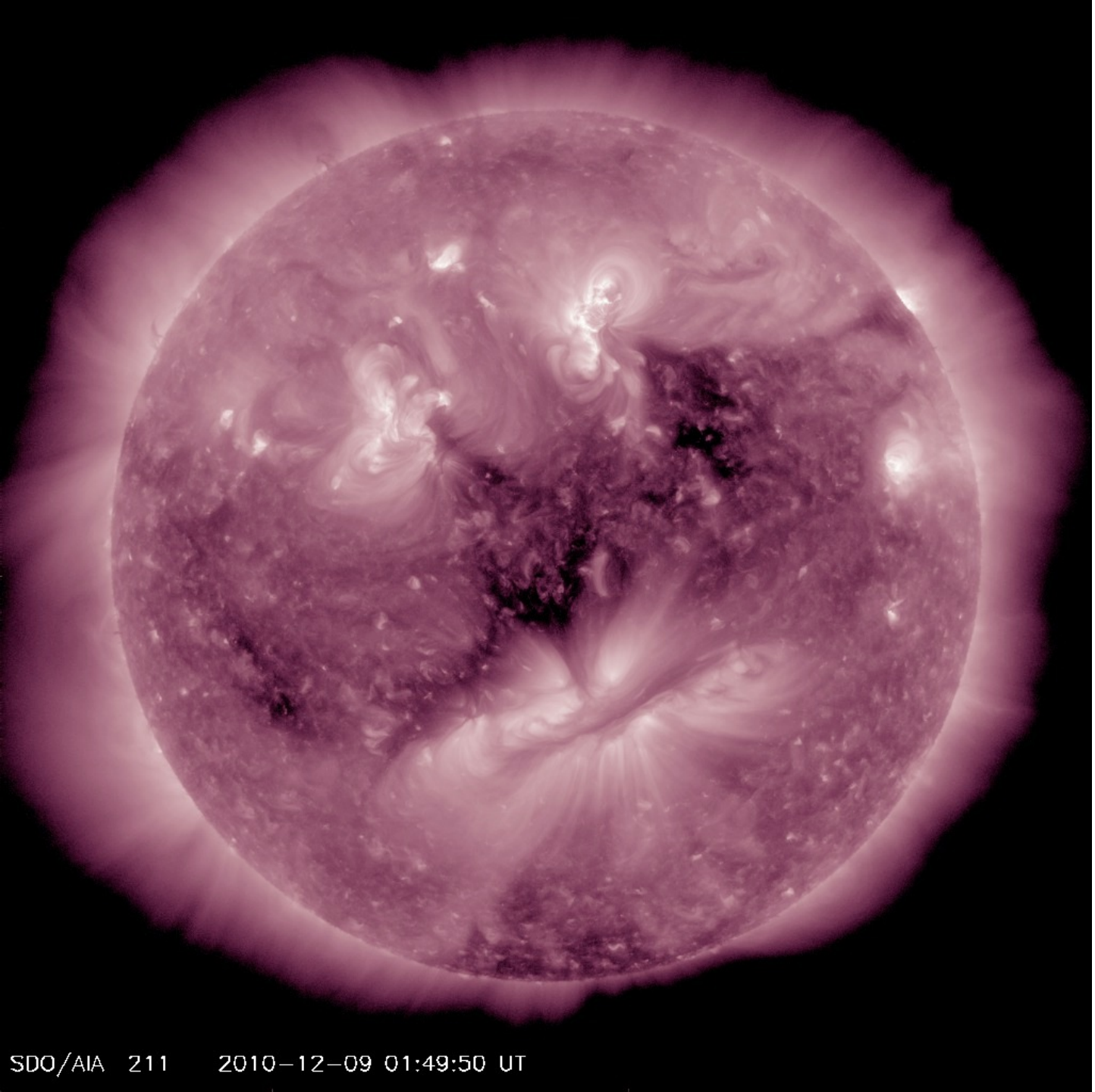
50,000 K



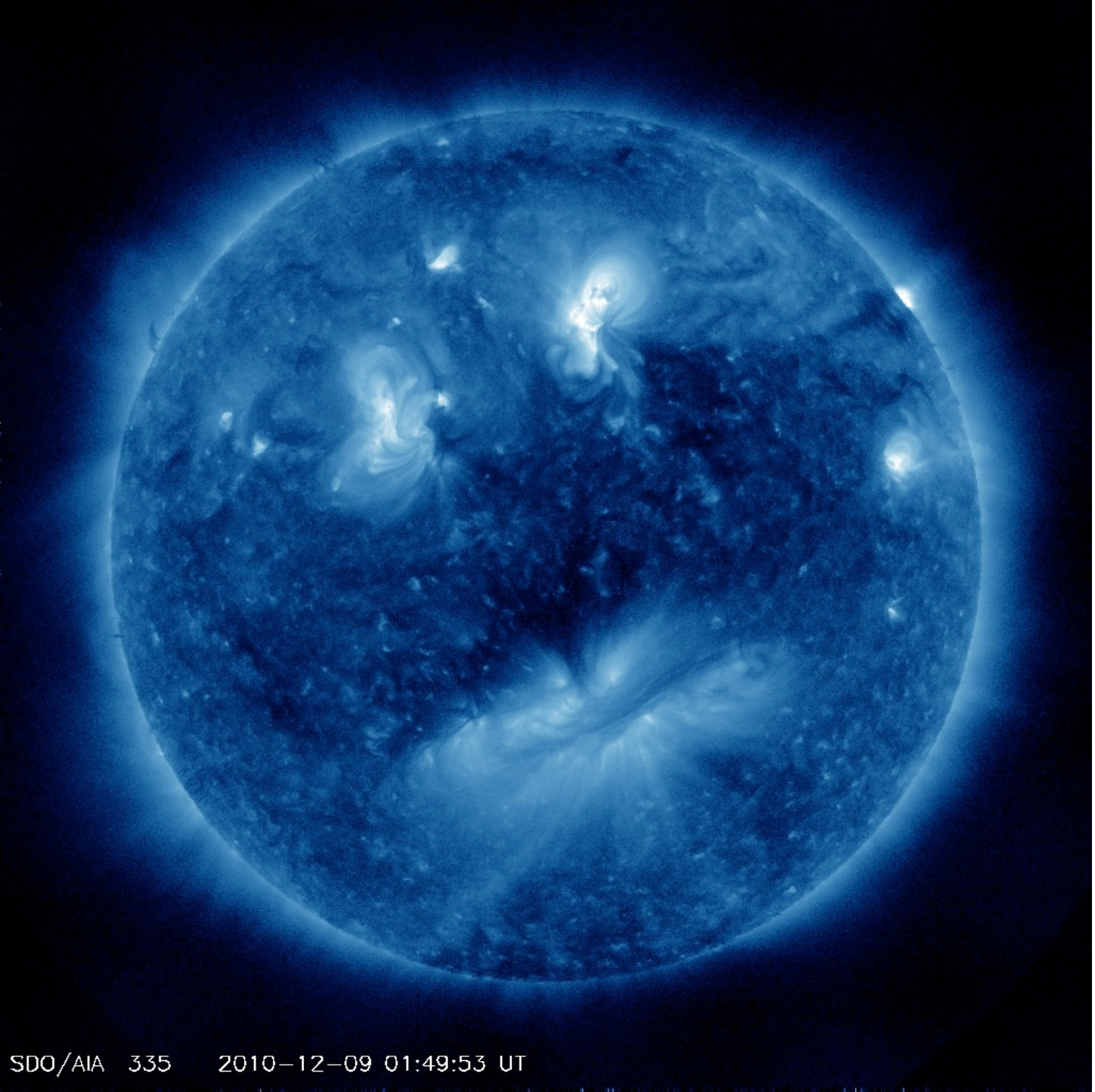
0.6 MK



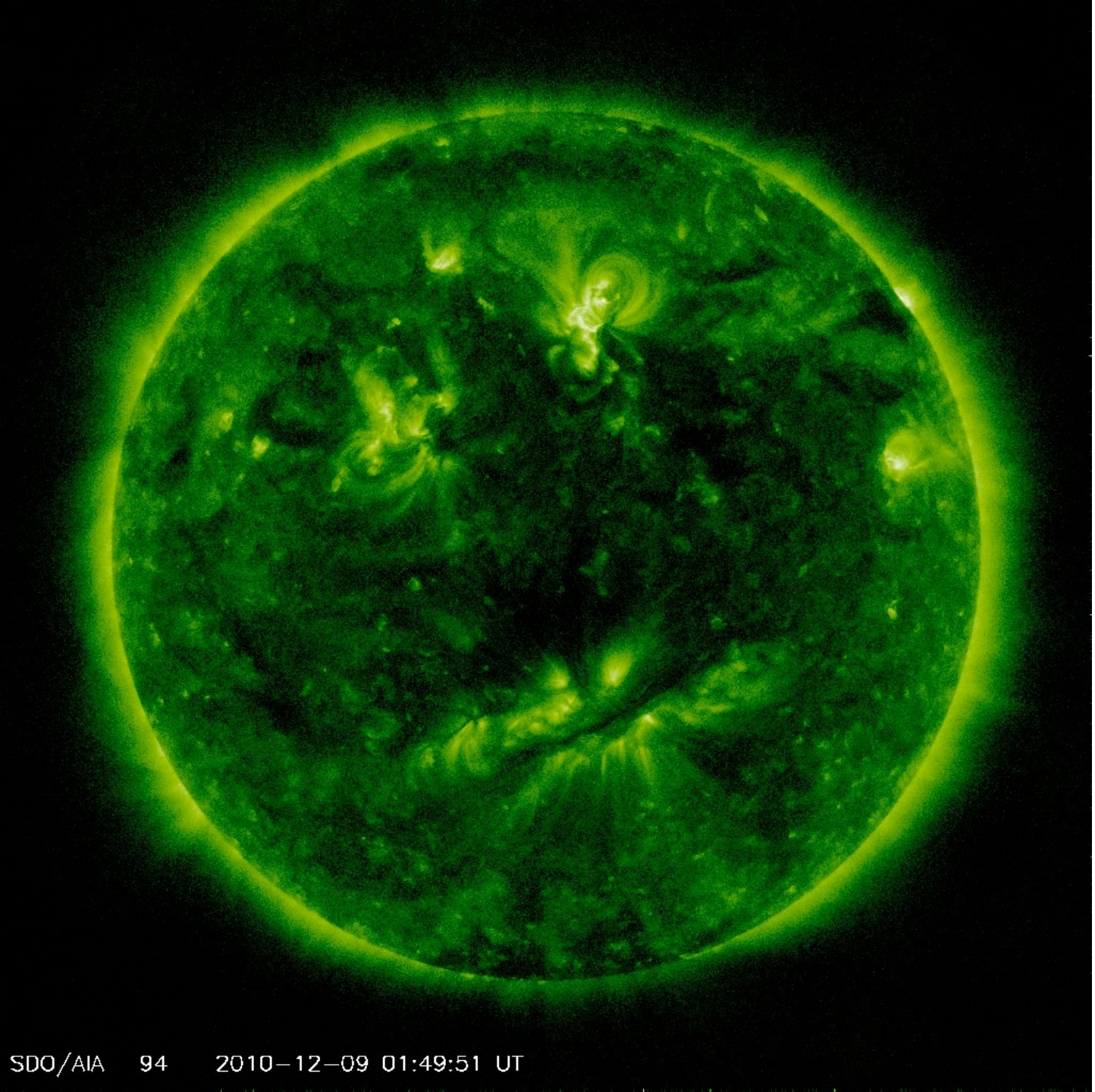
1 MK



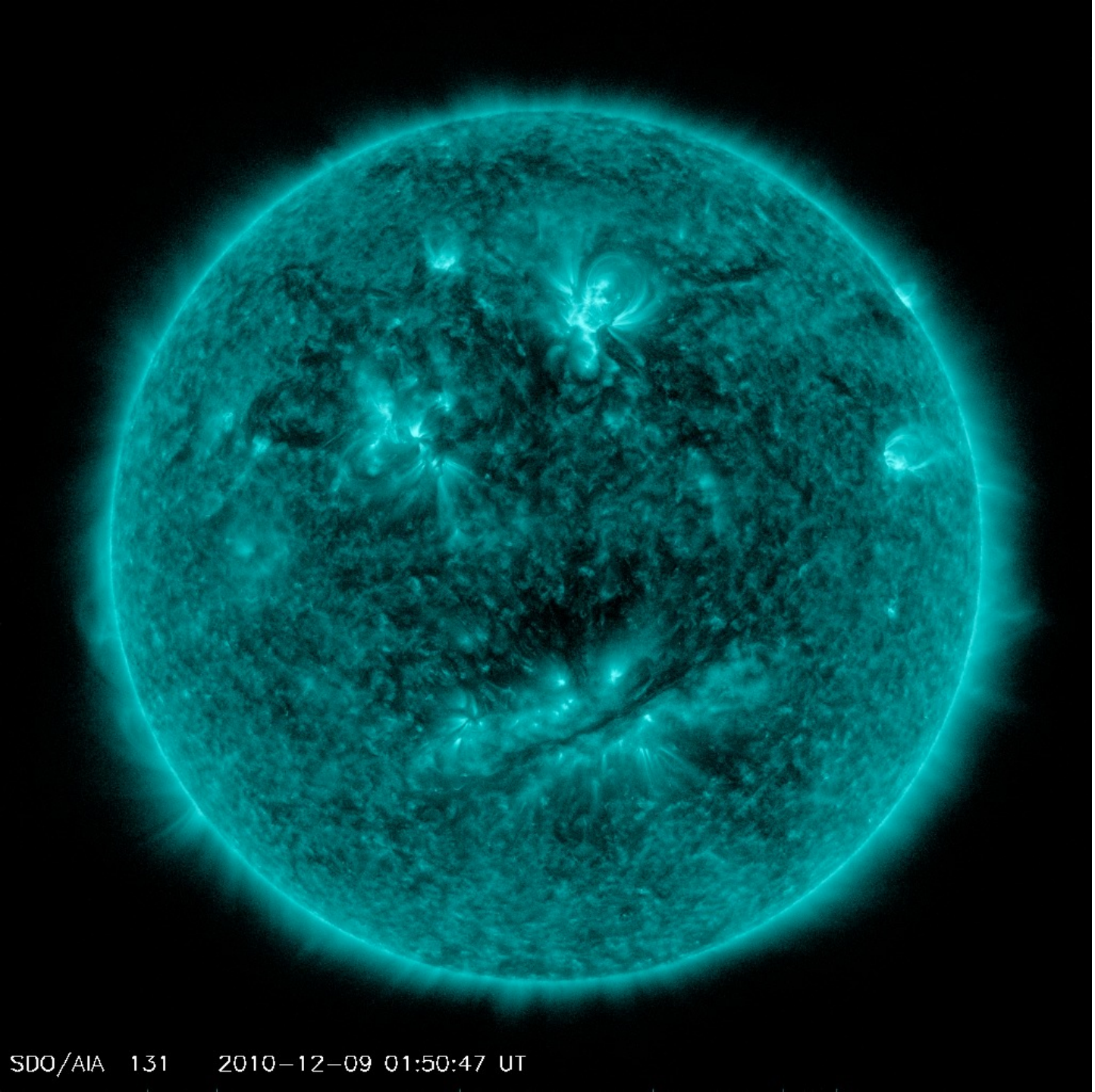
2 MK



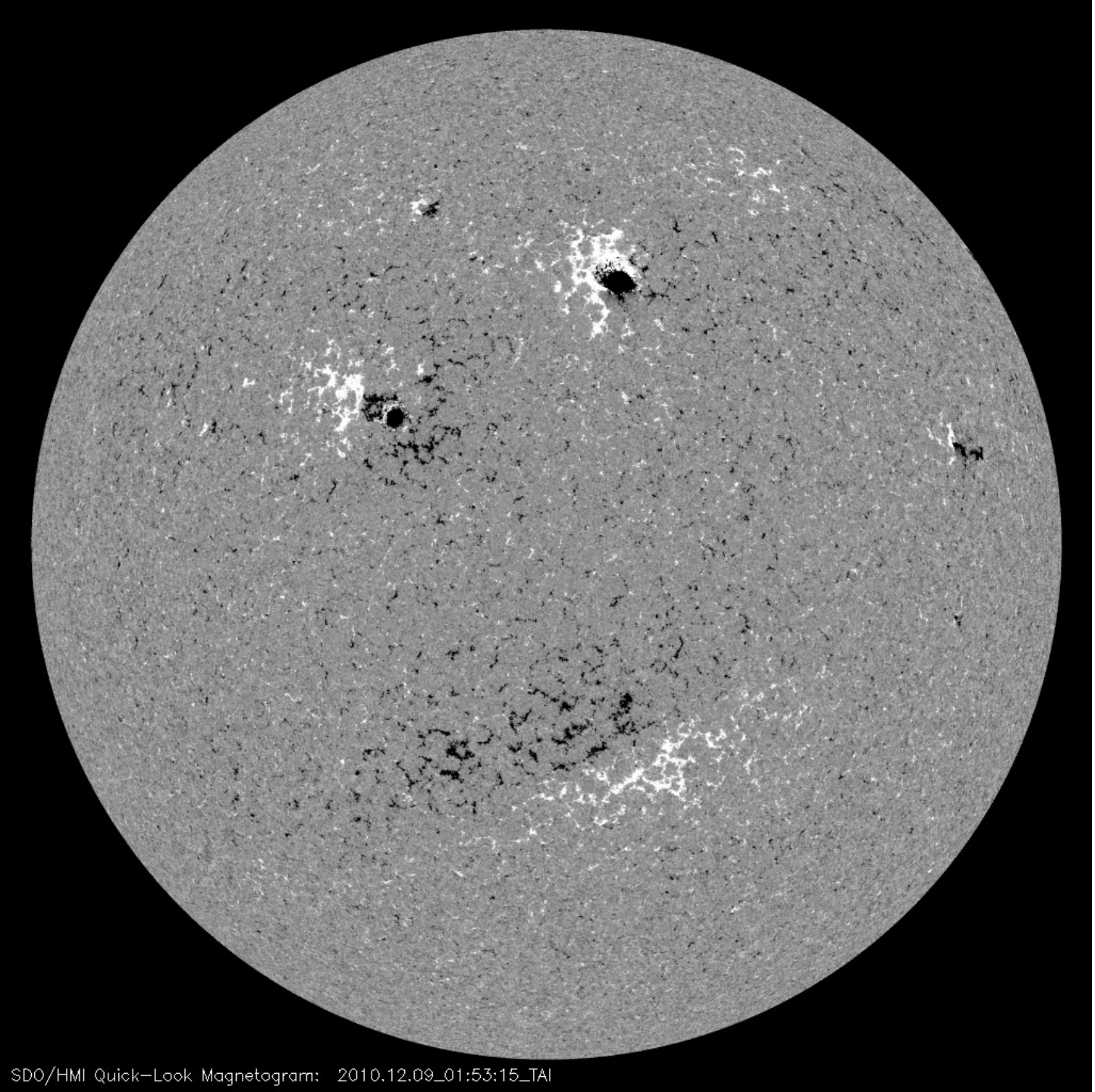
2.5 MK



6 MK

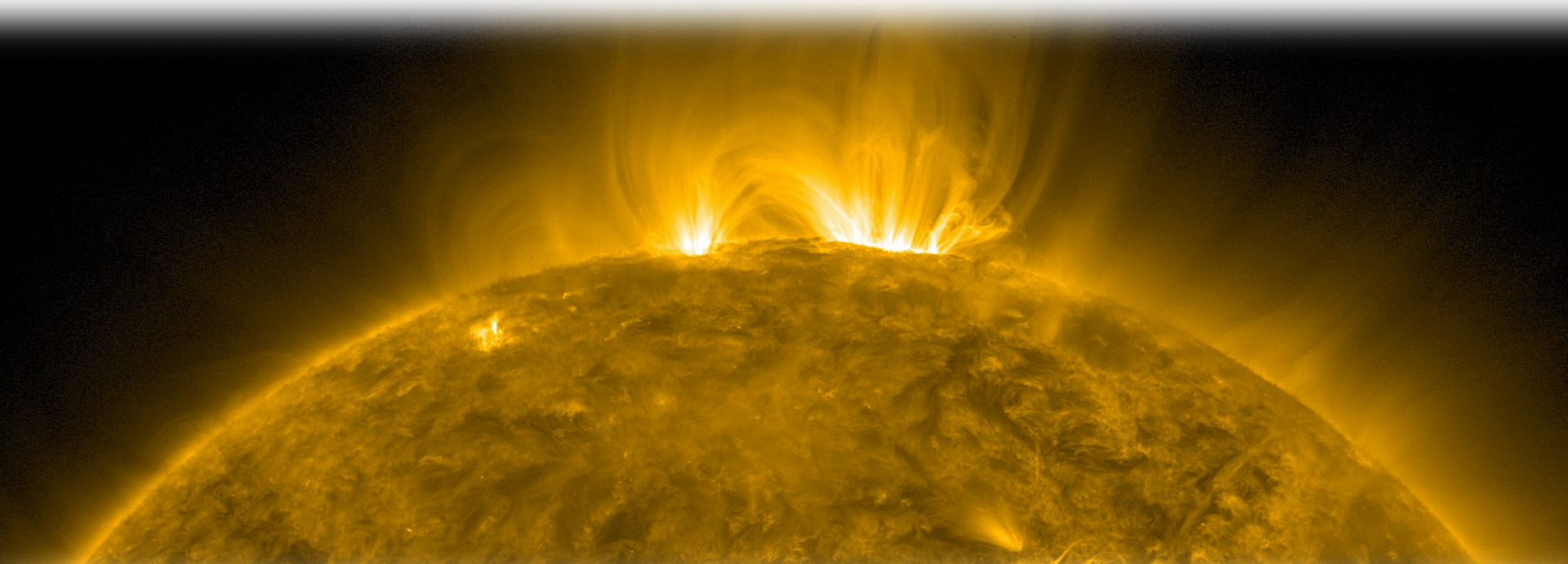


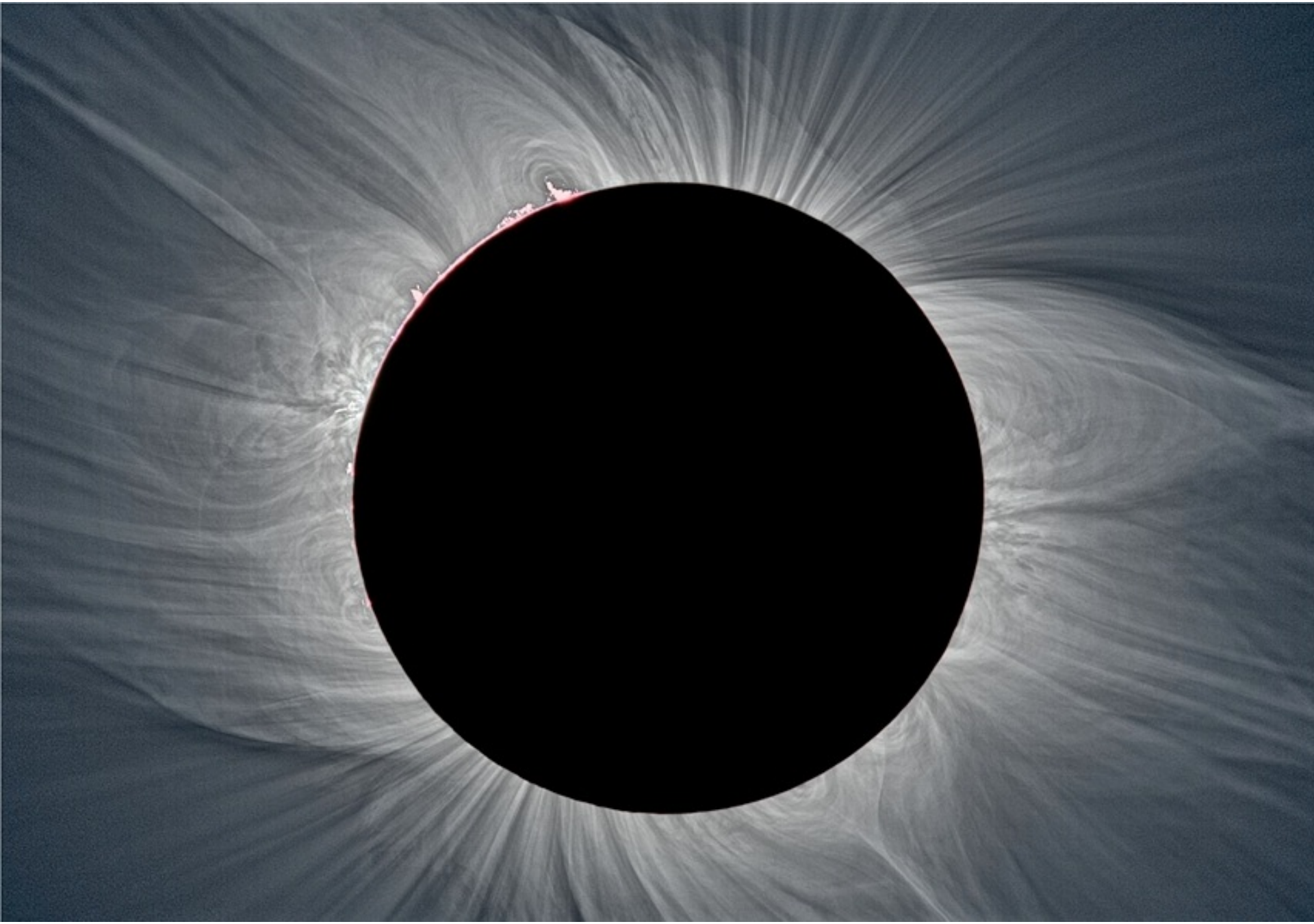
10 MK

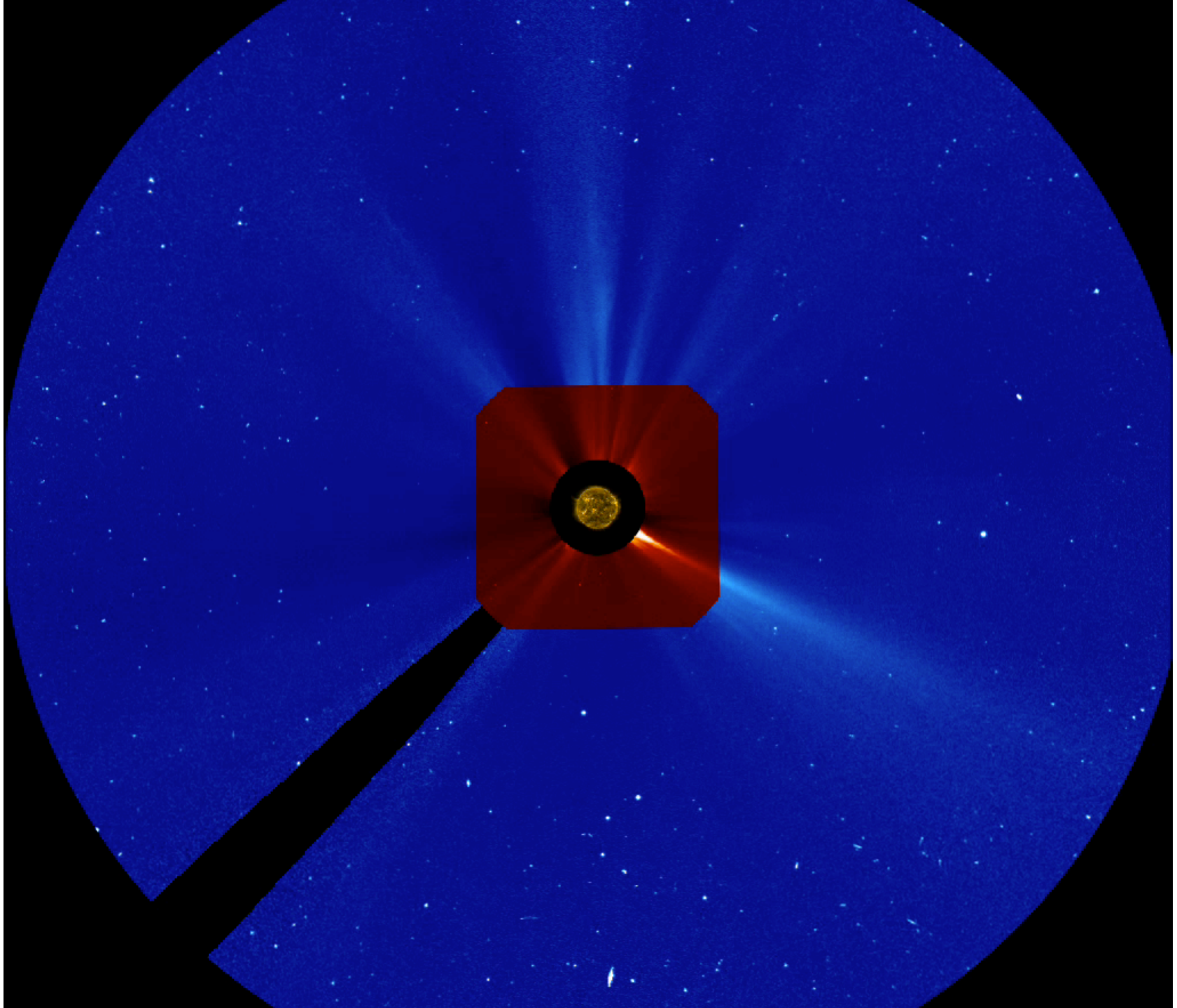


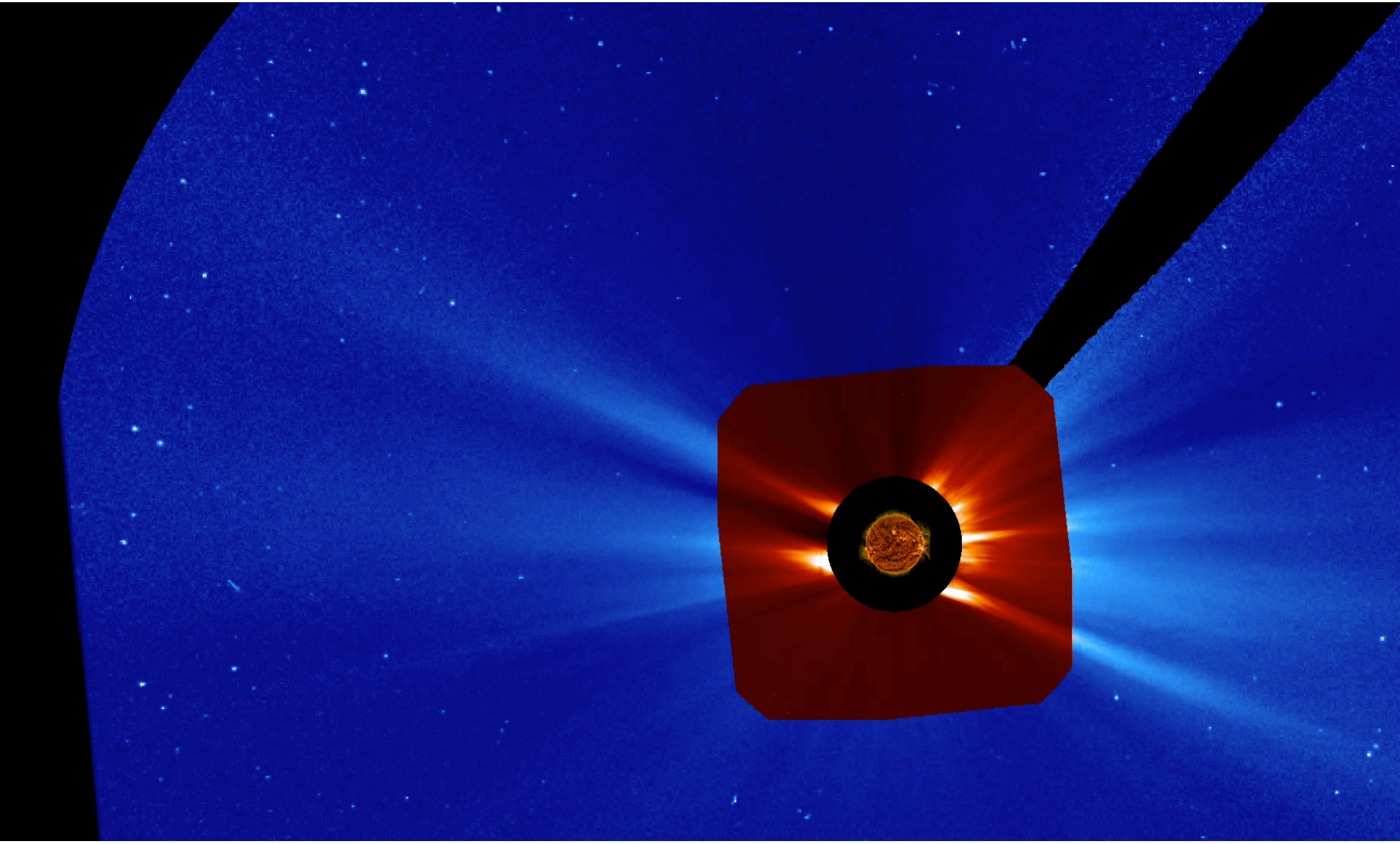
Magnetic Field

Coronographs

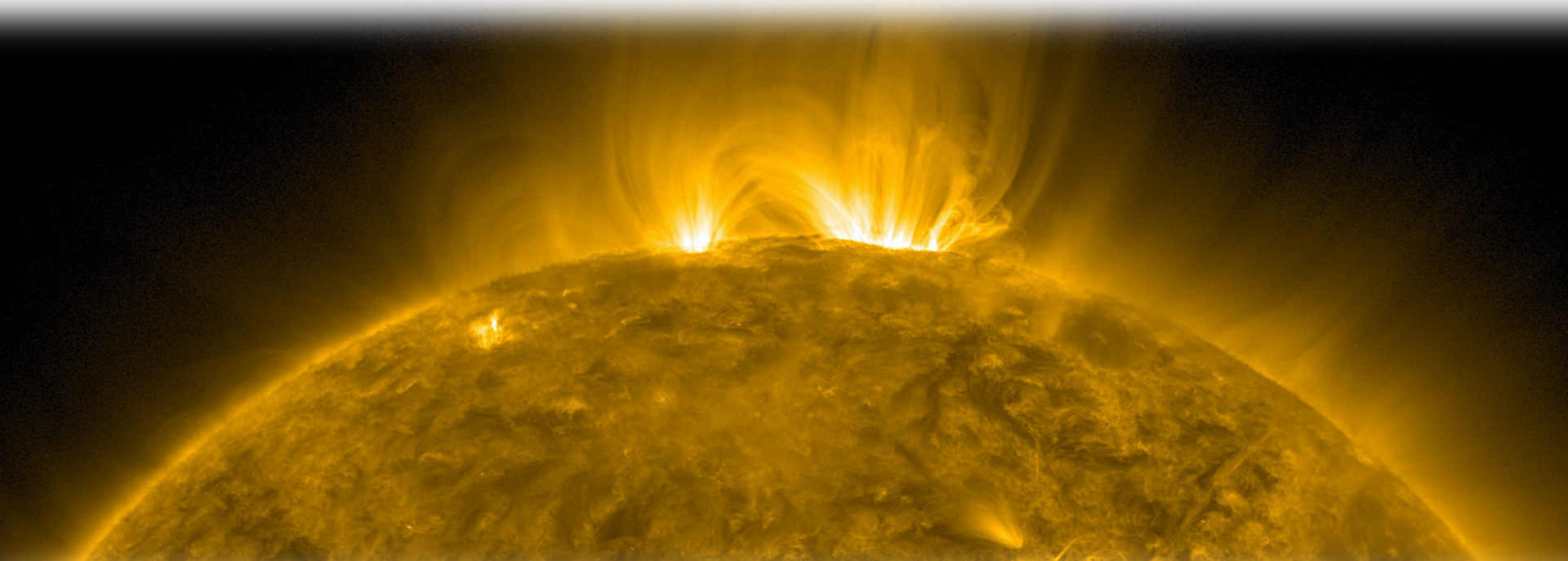




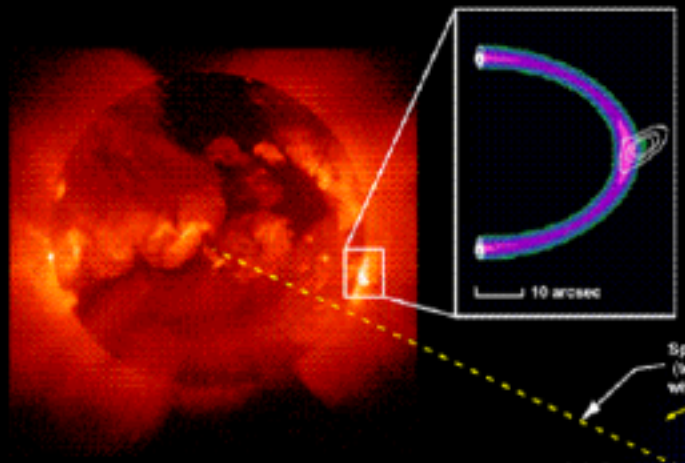


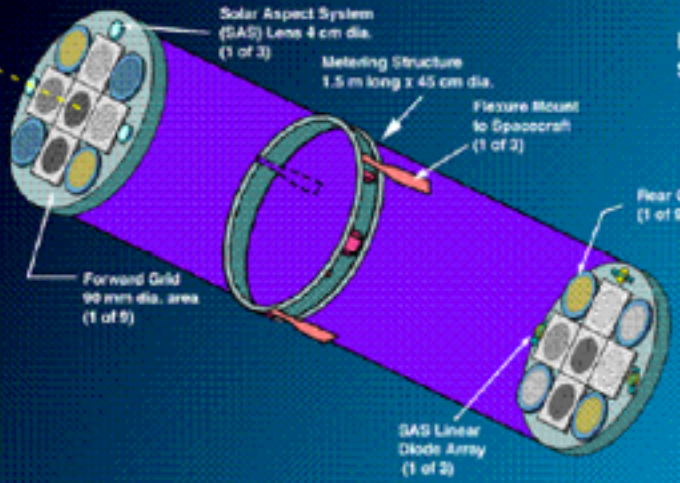


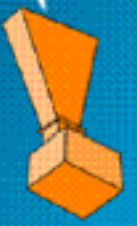
Indirect Imaging (Radio, X-ray, Gamma-ray



HESSI Imaging Technique







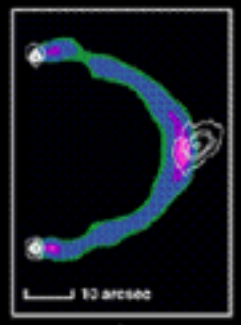
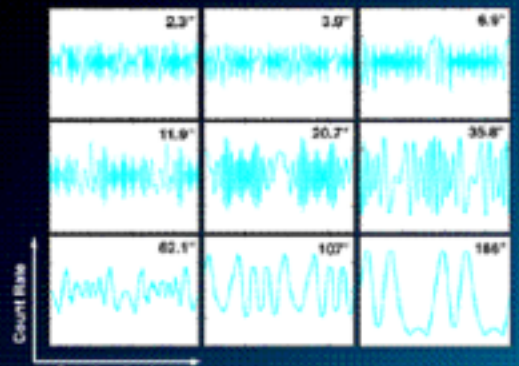
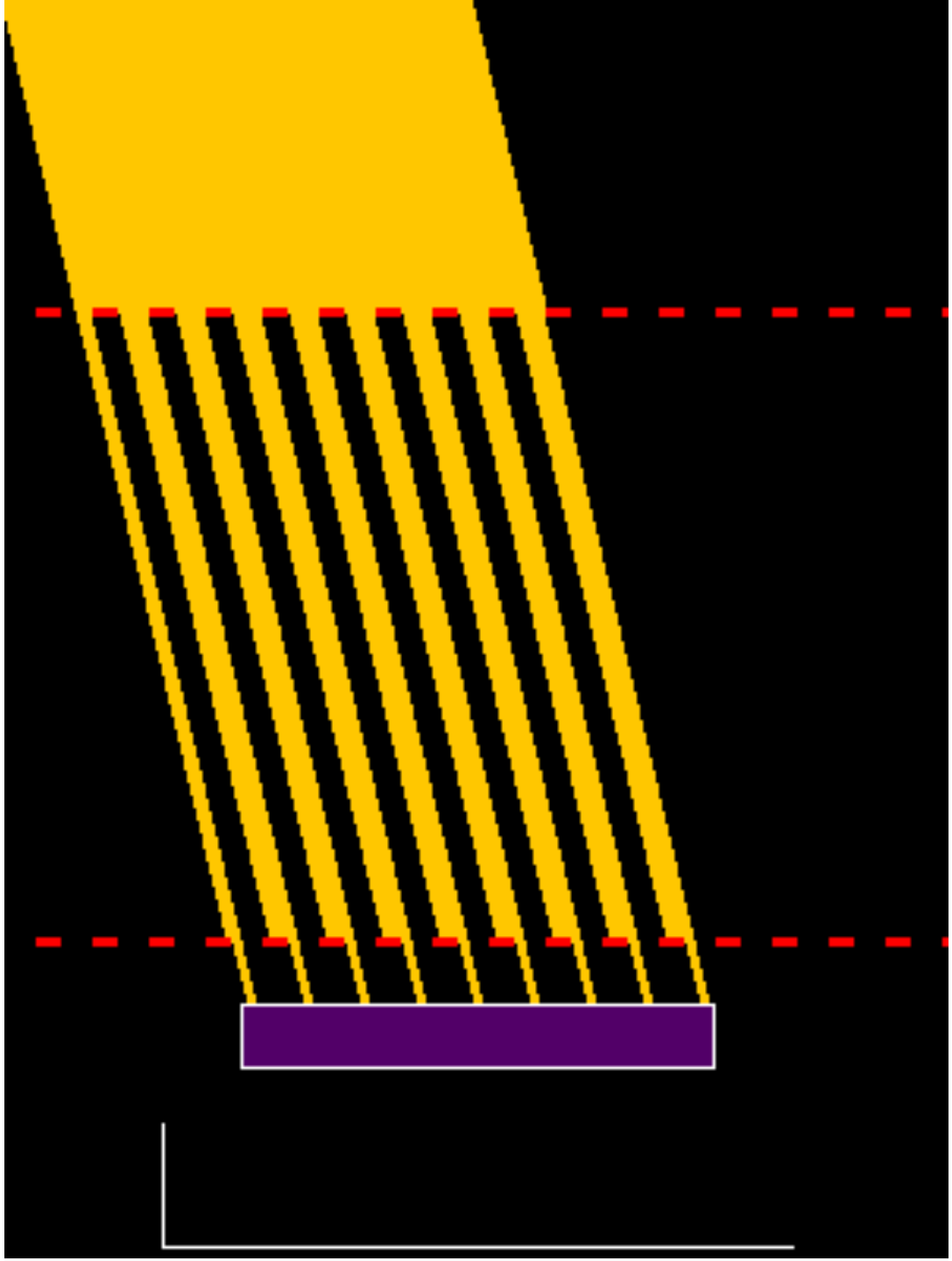


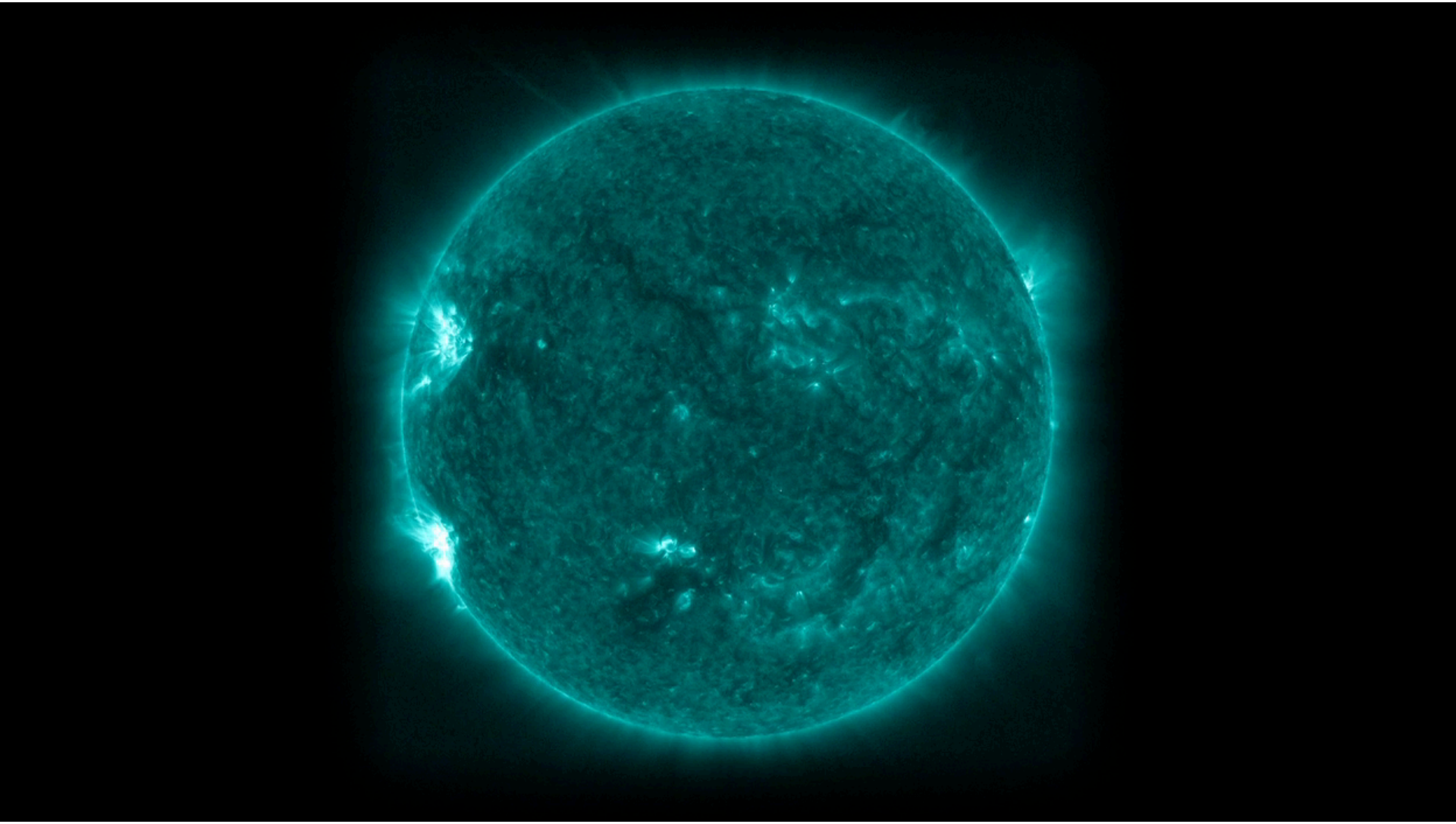
Image
Reconstruction

Count Rates in Each Detector for One Rotation

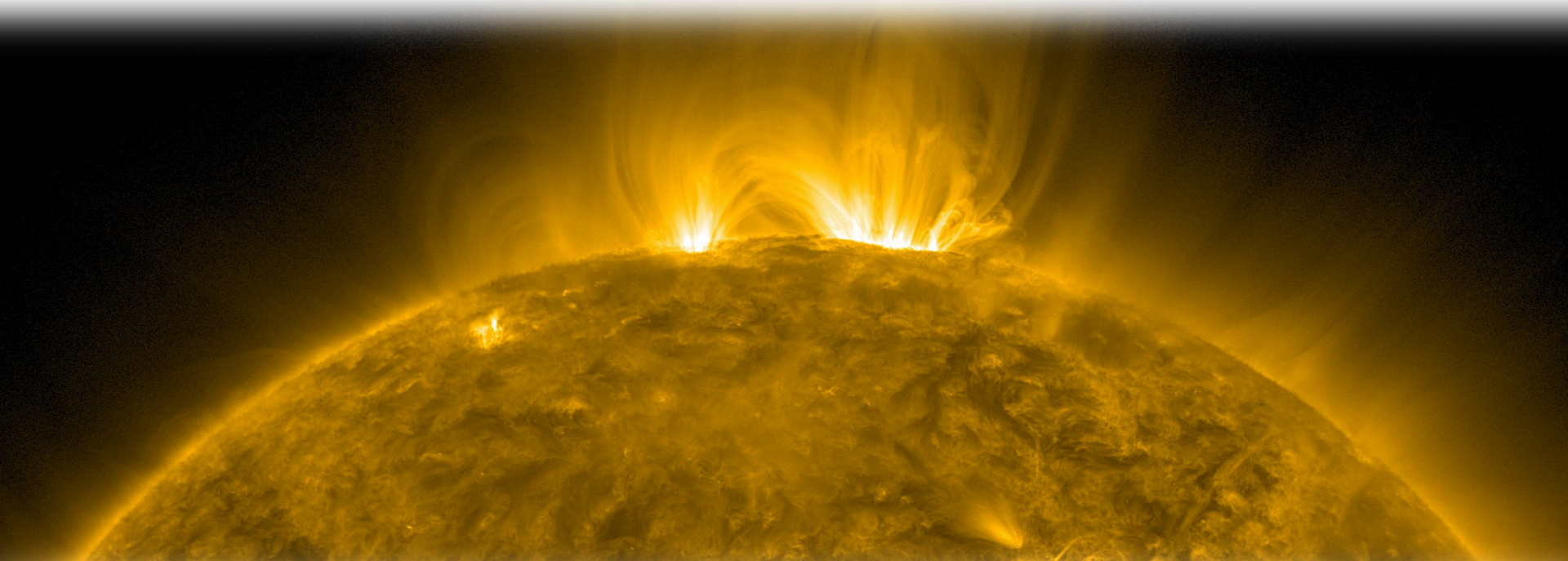


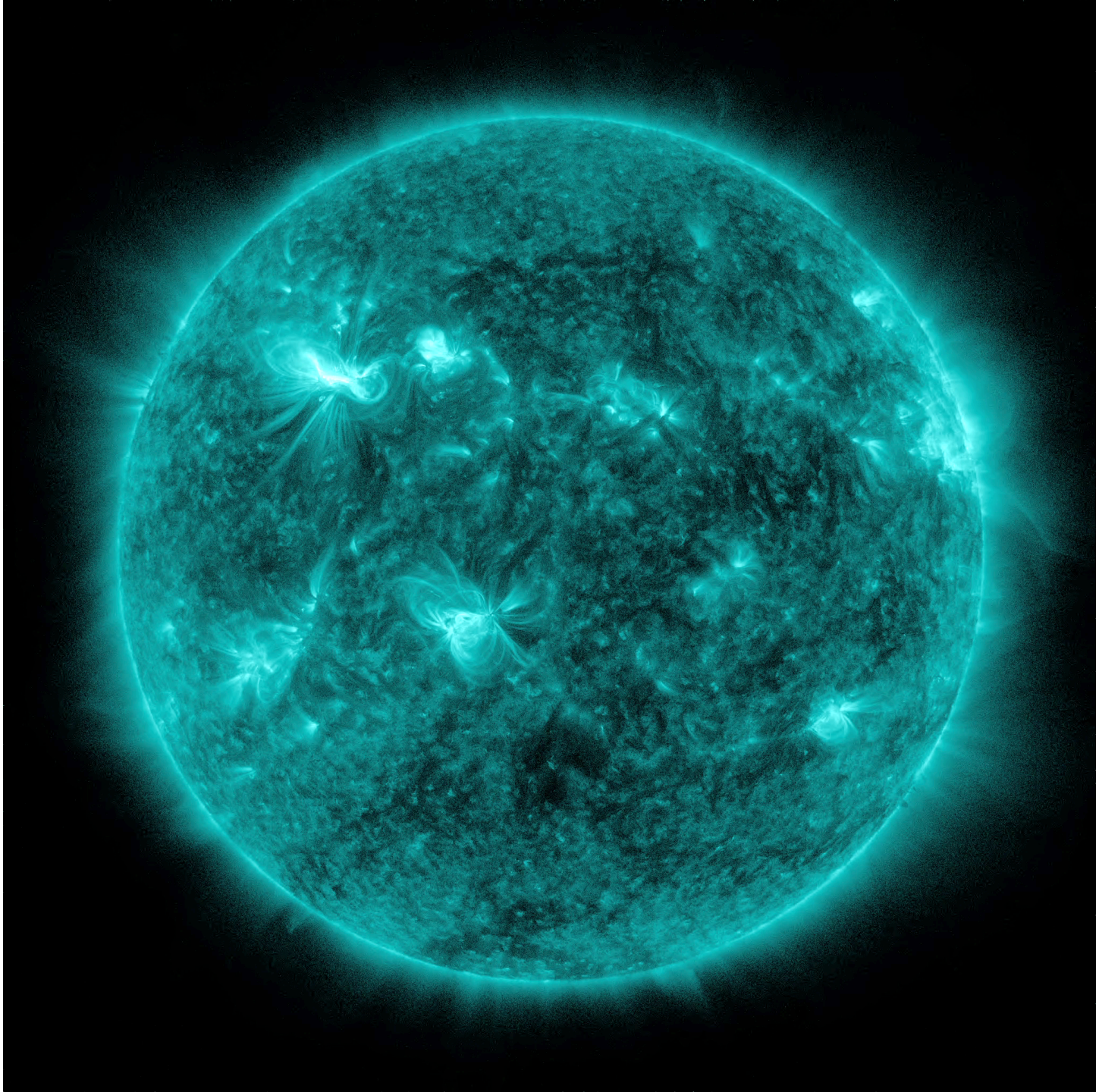
Time-Tagged
Detector Counts

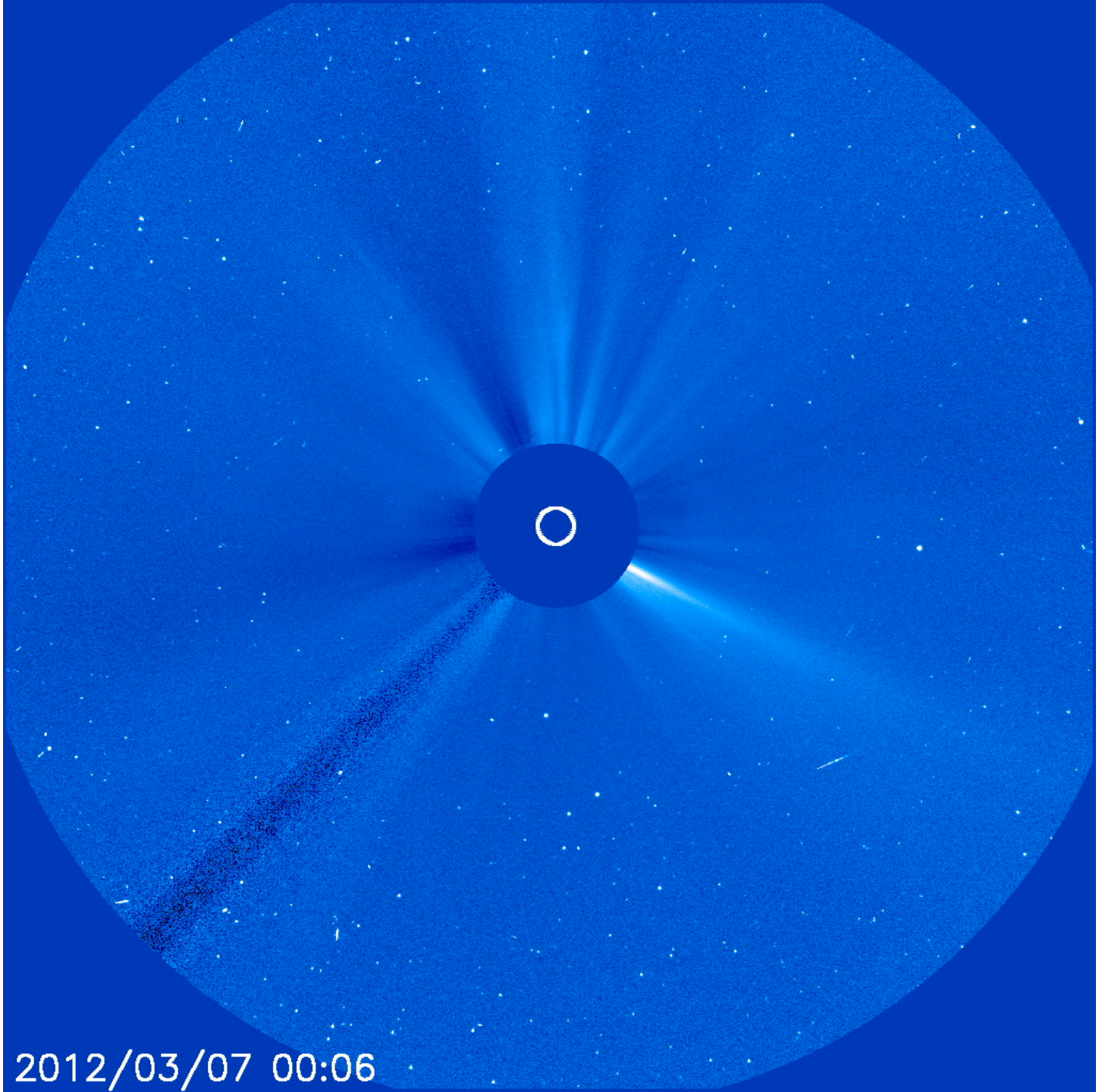


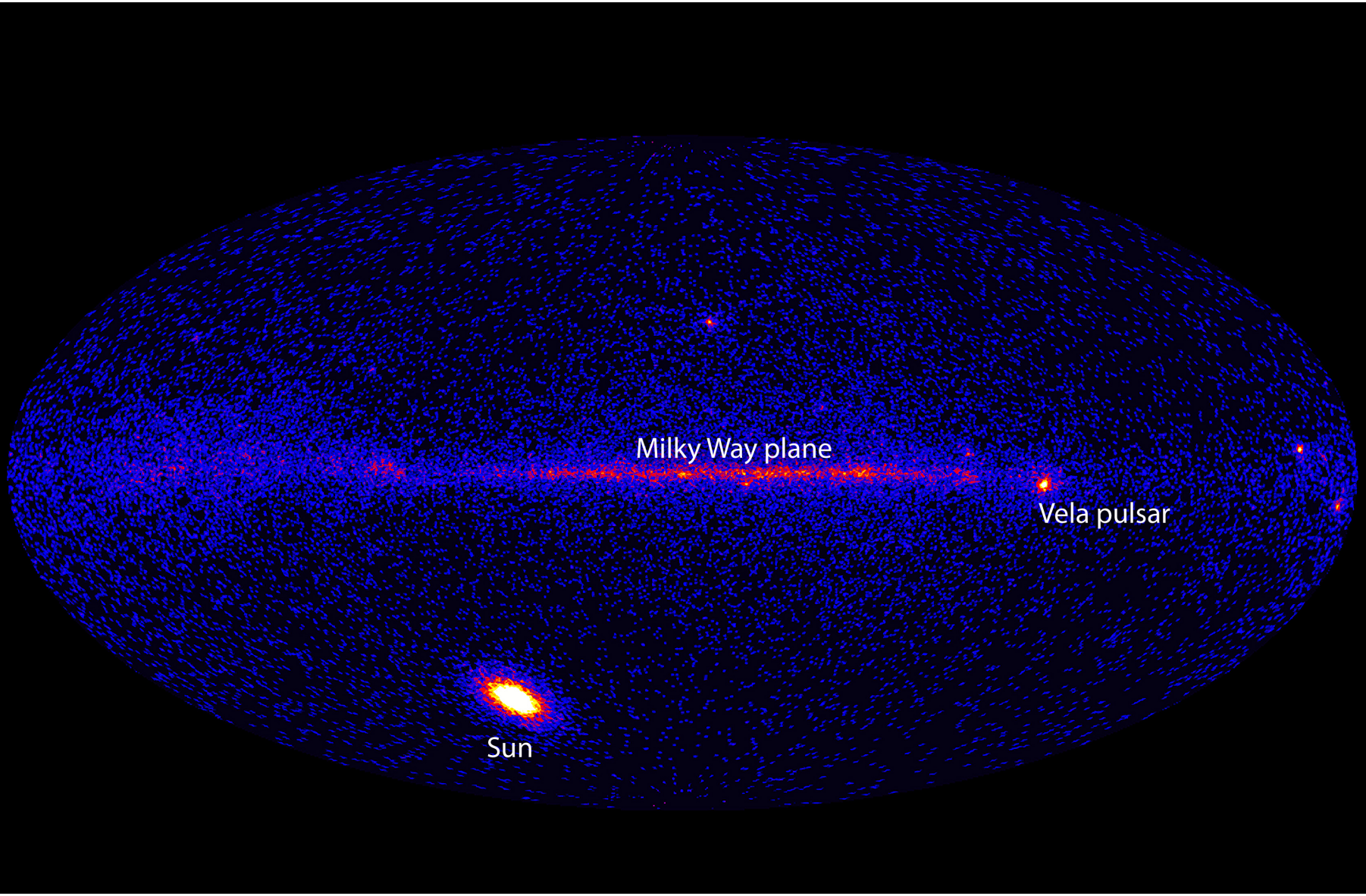


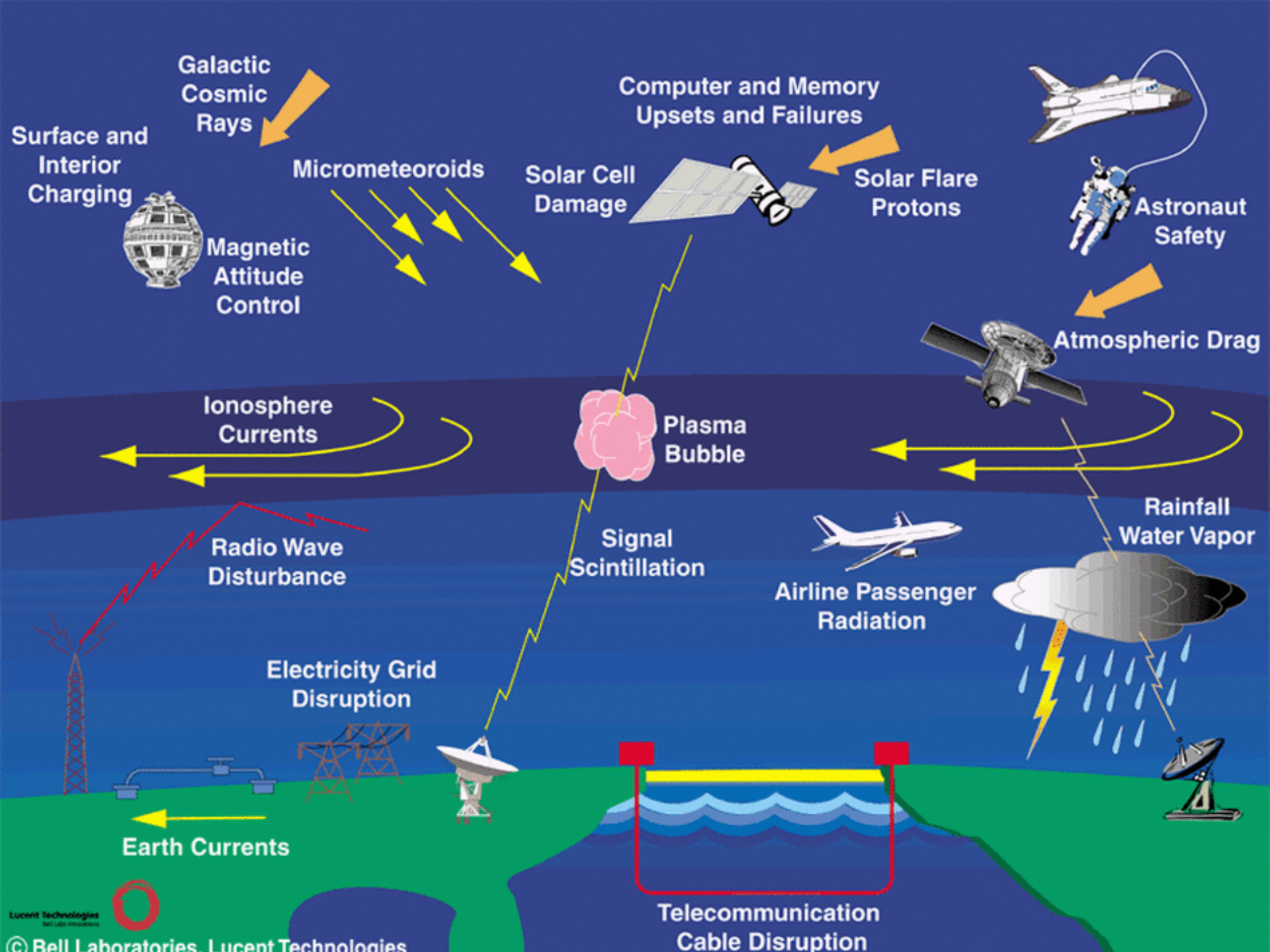
So What? Why Do We Care?






2012/03/07 00:06


Milky Way plane
Vela pulsar
Sun


Galactic Cosmic Rays
Surface and Interior Charging
Micrometeoroids
Magnetic Attitude Control
Computer and Memory Upsets and Failures
Solar Cell Damage
Solar Flare Protons
Astronaut Safety
Atmospheric Drag
Ionosphere Currents
Plasma Bubble
Rainfall Water Vapor
Radio Wave Disturbance
Signal Scintillation
Airline Passenger Radiation
Electricity Grid Disruption
Earth Currents
Telecommunication Cable Disruption
Lucent Technologies
© Bell Laboratories, Lucent Technologies

It’s not all bad.

Break

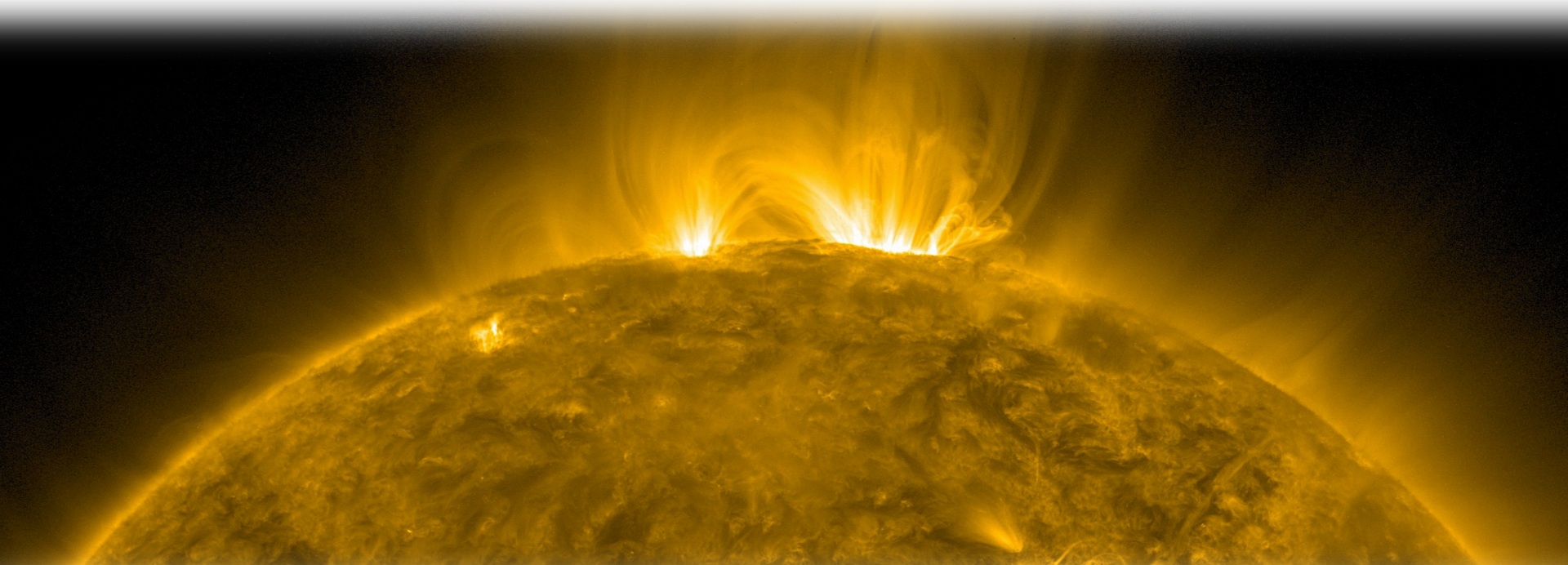


Image Processing for Science

The goal of image processing in heliophysics is to gain physical insight on the system.

How do flares erupt?

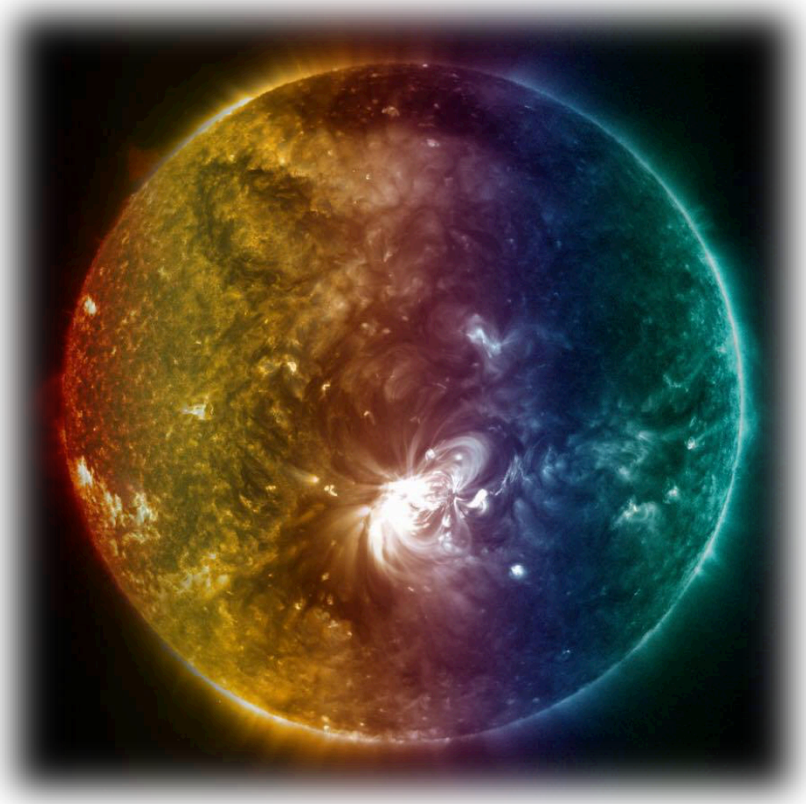
How big are coronal holes?

Where will magnetic field emerge?

What do active regions have in common?

What is signal and what is noise?

How do loops oscillate?

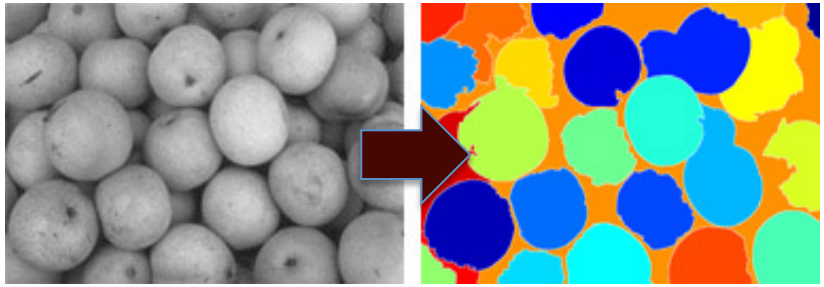


Types of Helio-Image Processing

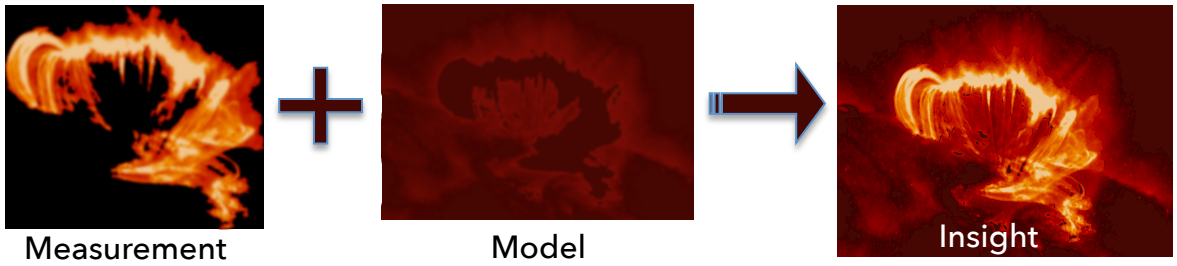
*This is not an exhaustive list, just a discussion.

Three main categories:

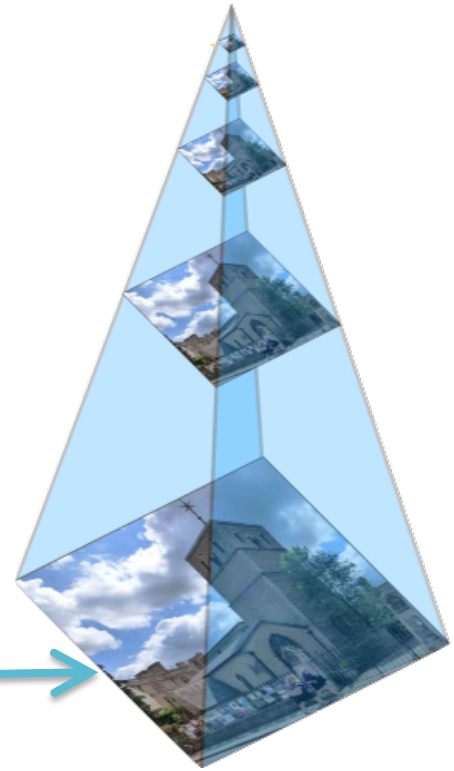
- Feature Segmentation and Classification



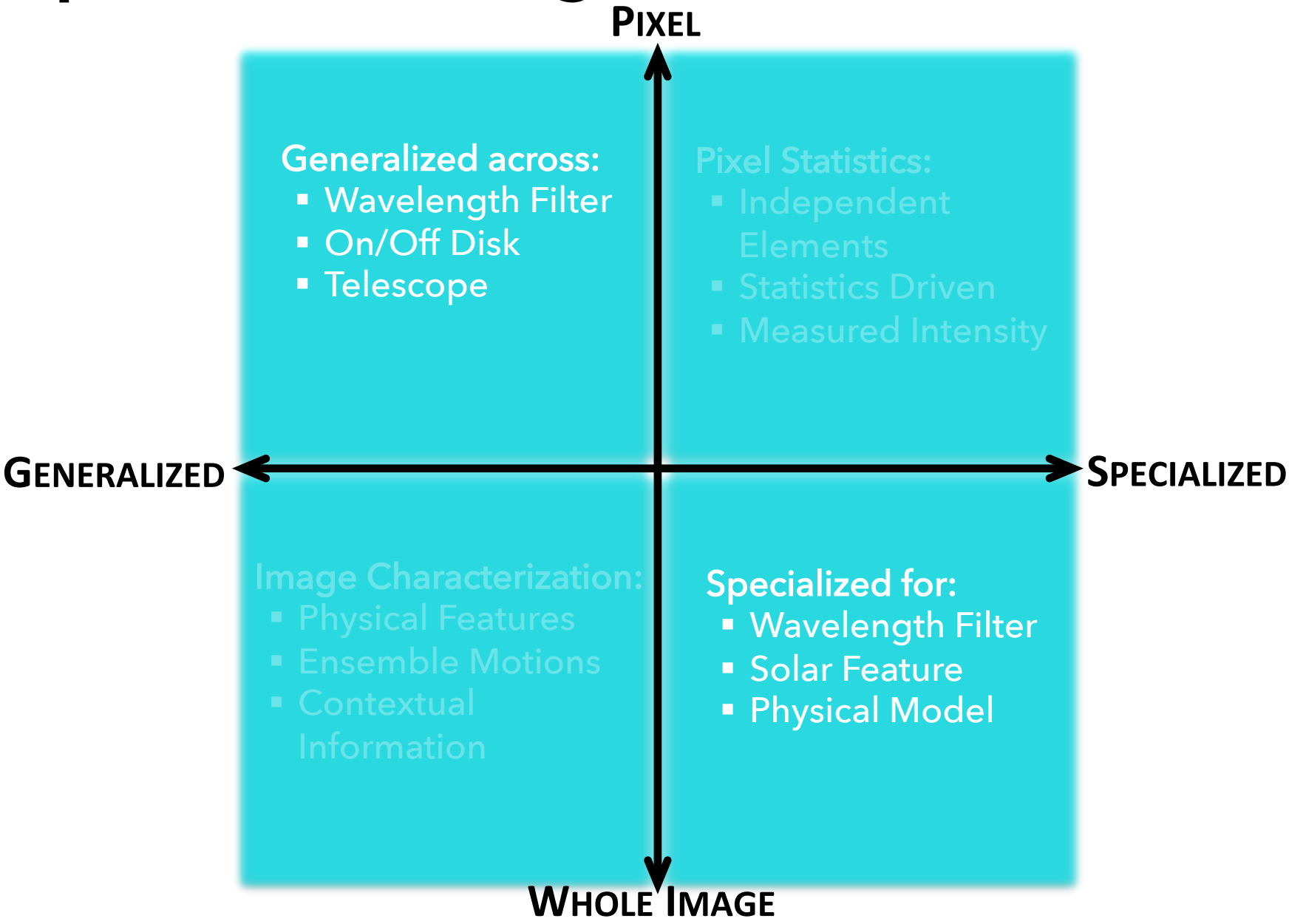
- Data Assimilation and Modeling



- Multi-Scale Processing

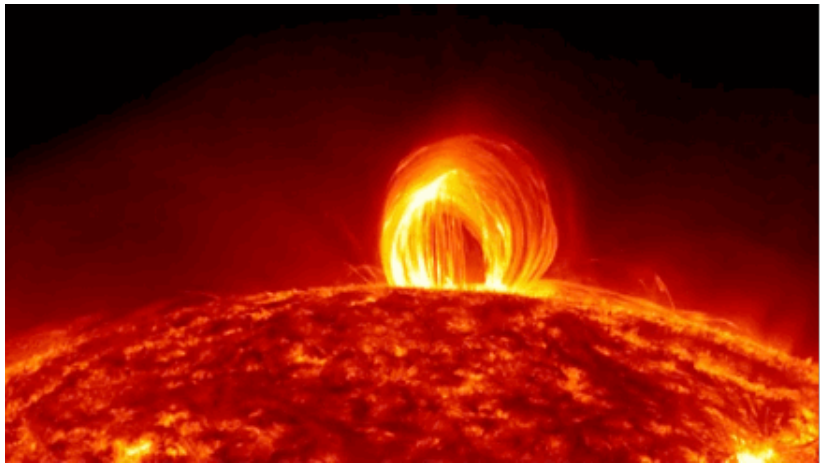


A Spectrum of Algorithms



Feature Segmentation and Classification

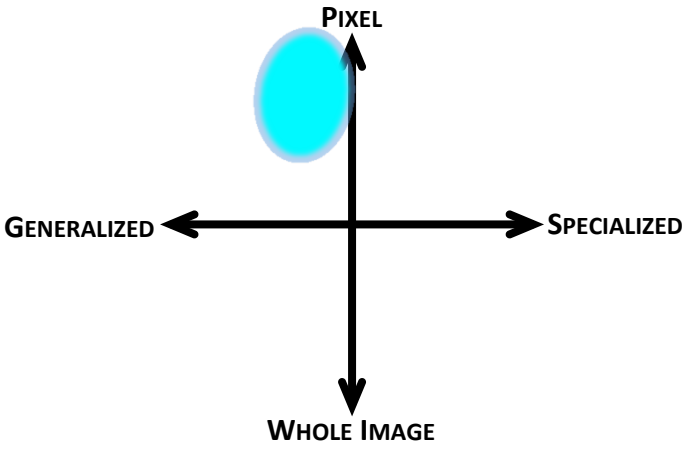
- Spatial Possibilistic Clustering Algorithm
  - SPoCA
- Active Contouring Without Edges
  - ACWE
- Solar Monitor Active Region Tracking
  - SMART



SPoCA

- Identification of Active Regions and Coronal Holes

- Designed to produce a catalog of events seen in EUV images.

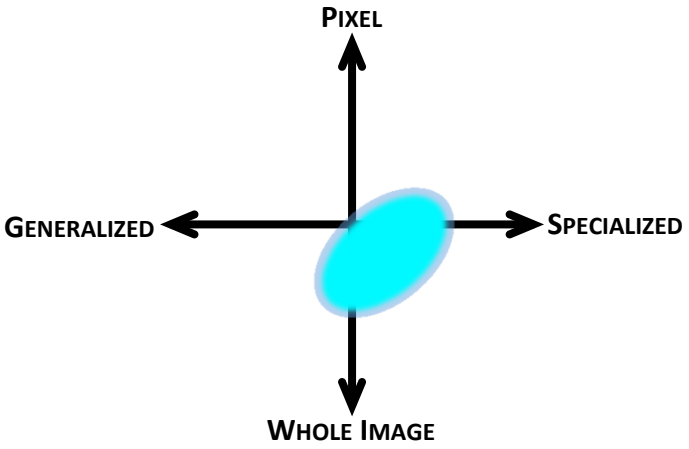


- Spatial Probabilistic clustering of pixel intensities.

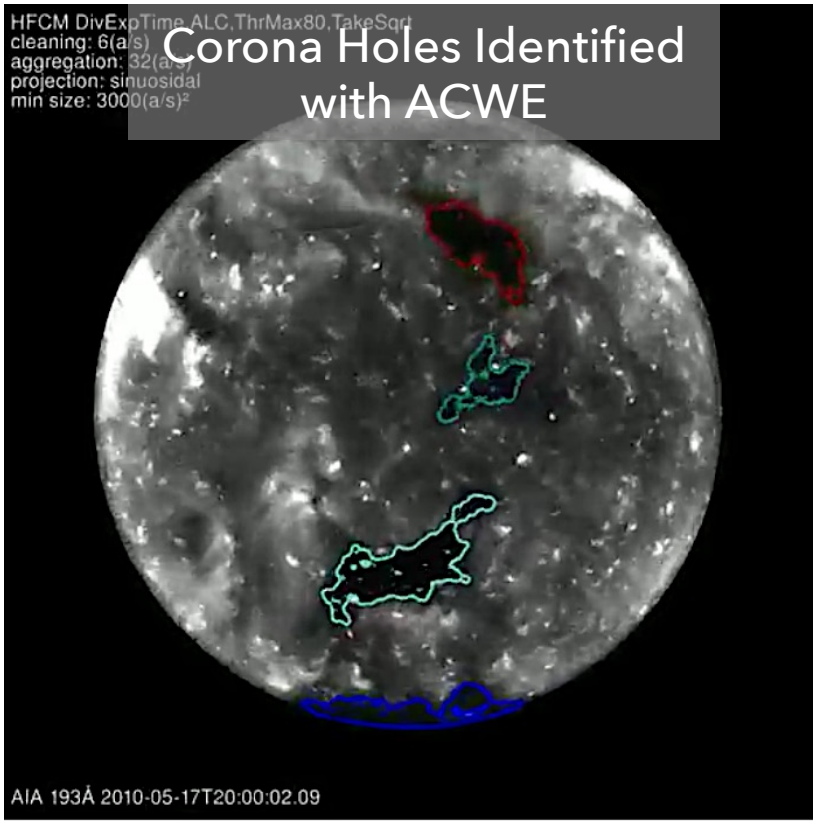
- Uses Fuzzy C-Means (FCM) algorithm for segmentation.

C. Verbeeck, V. Delouille, B. Mampaey, and R. De Visscher: Astronomy and Astrophysics, 2014; 561, A29.

ACWE



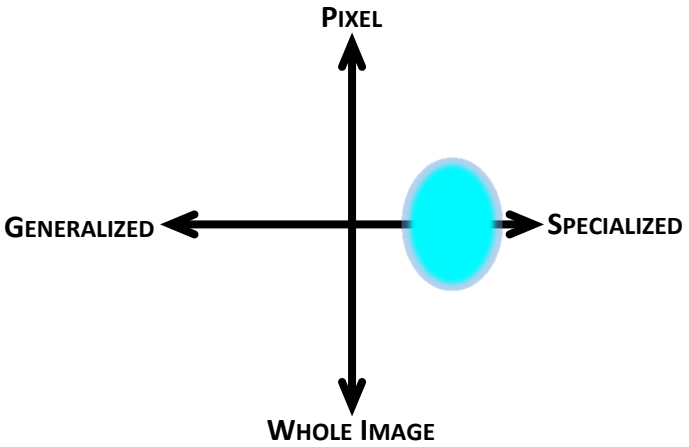
- Identification of the boundary of Coronal Holes.
- Create a self-consistent measurement across wavelength and mission.



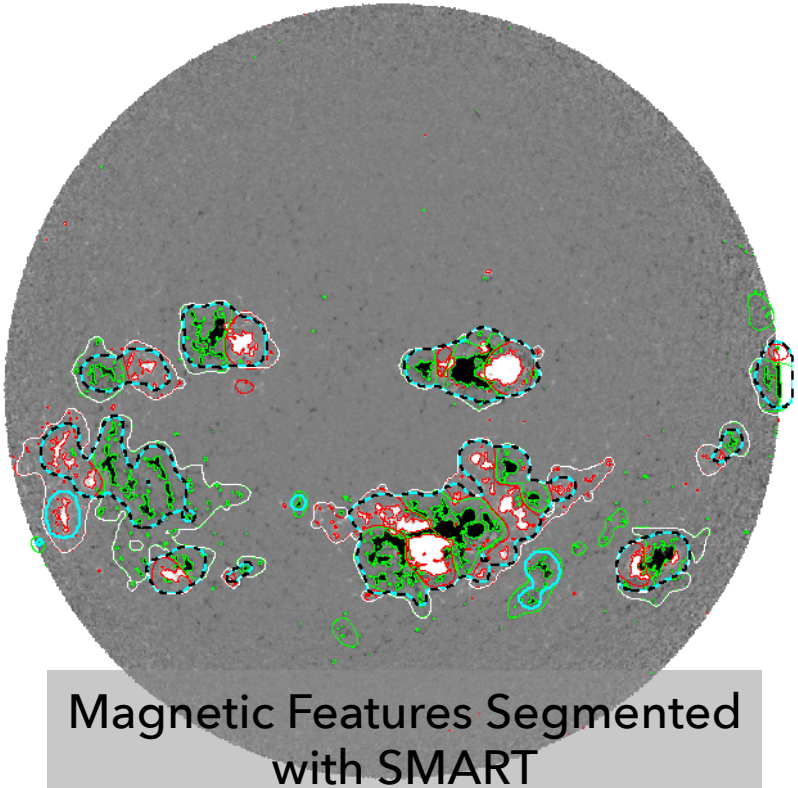
- Active contouring segmentation using an energy-minimization technique.
- Incorporates contextual information beyond intensity to determine a boundary.

M. Valluri, L. E. Boucheron, R. T. J. McAteer: Solar Physics, 2016; in press.

SMART



- Segments and tracks magnetic active regions across solar magetograms.
- Fully automated to run independently of user input.



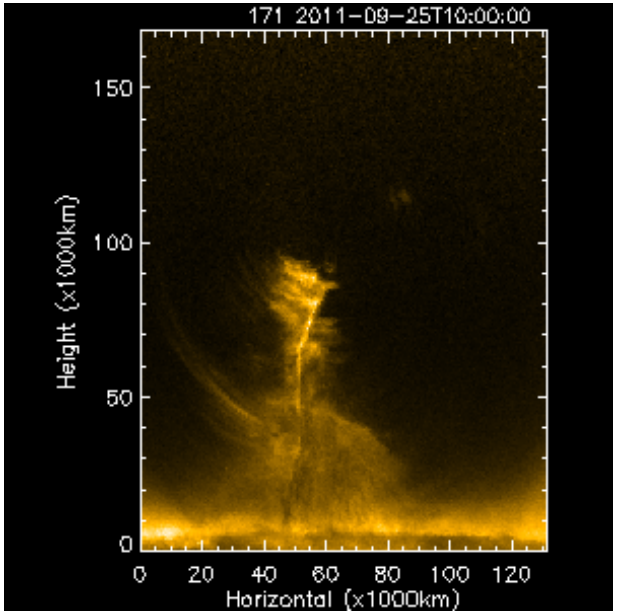
Magnetic Features Segmented with SMART

- Utilizes an iterative thresholding, smoothing, and subtraction method to create a consistent result.
- Tracked using a mathematical model for solar rotation.

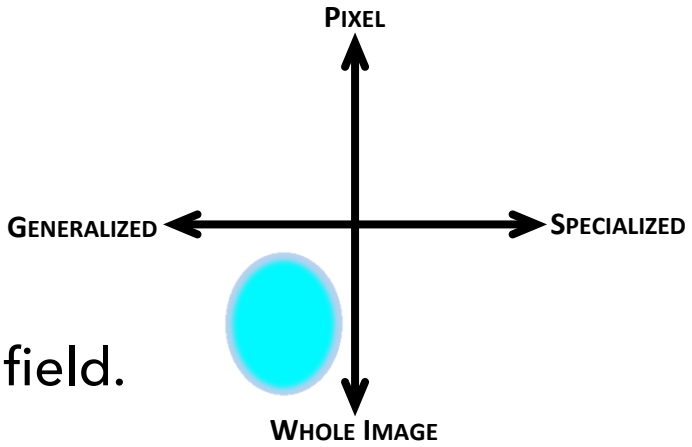
P.A. Higgins, P.T. Gallagher, R.T.J. McAteer, D.S. Bloomfield: Advances in Space Research, 2011; 47, 2105.

Data Assimilation and Modeling

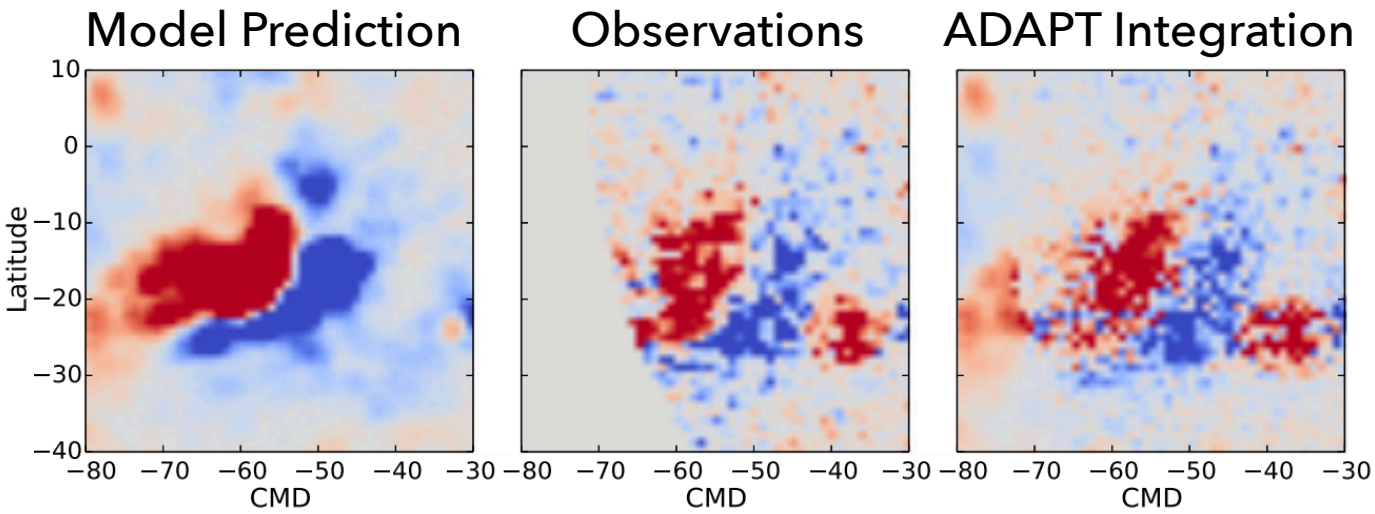
- Air Force Data Assimilative Photospheric Flux Transport
  - ADAPT
- Heliospheric Data Integration
  - HSDI
- Optical Flow 3D
  - OpFlow3D



ADAPT

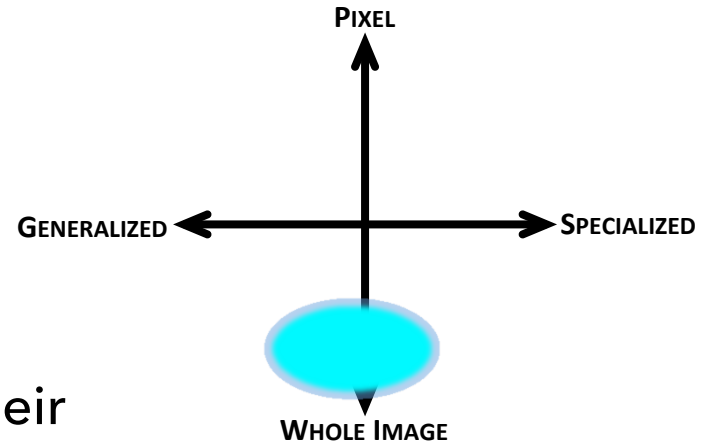


- Incorporate real-time magnetic field measurements into a model of the global field.
- Retain and propagate magnetic field measurements into the future.
- Uses localized Kalman Filtering to integrate the Model and Observations.
- Creates an ensemble of results that are folded together to better model the real conditions.

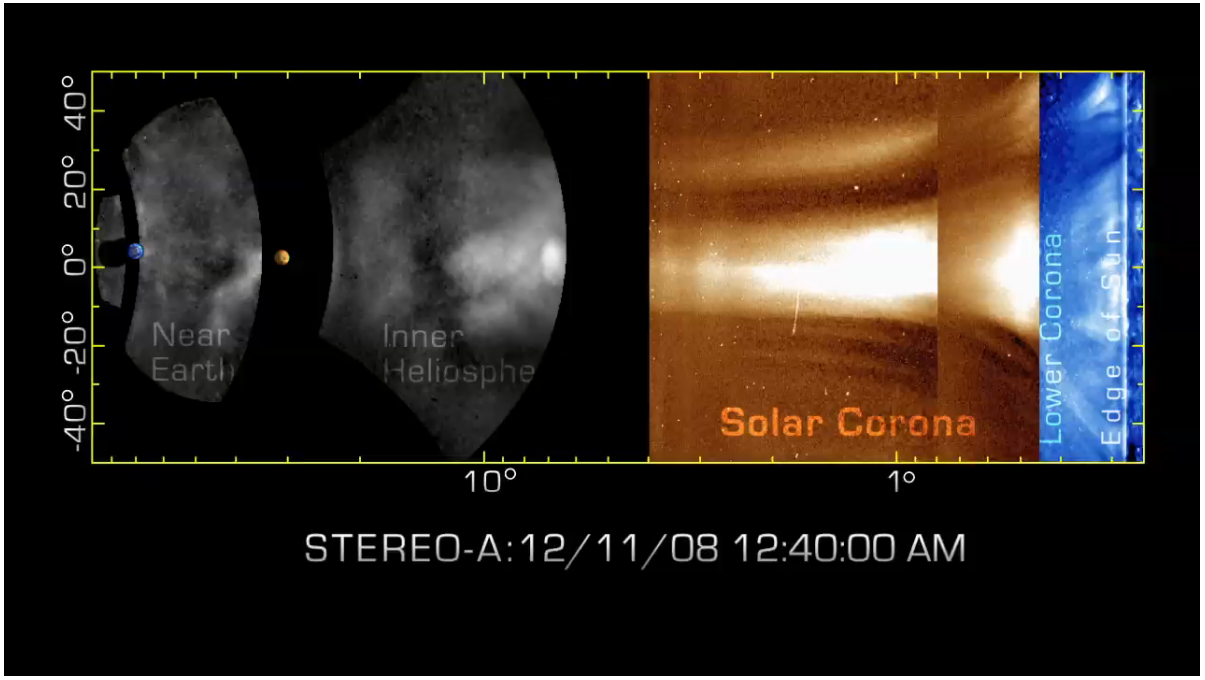


C. Nick Arge, Carl J. Henney, Josef Koller, C. Rich Compeau, Shawn Young, David MacKenzie, Alex Fay, and John W. Harvey: AIP Conference Proceedings, 2010; 1216, 343.

HSDI



- Integrates observations from 7 different cameras into one coherent measurement.
- Observes and maps solar eruptions from their source to the earth.
- Relies upon physical models of how light scatters off of particles to cross-calibrate images.

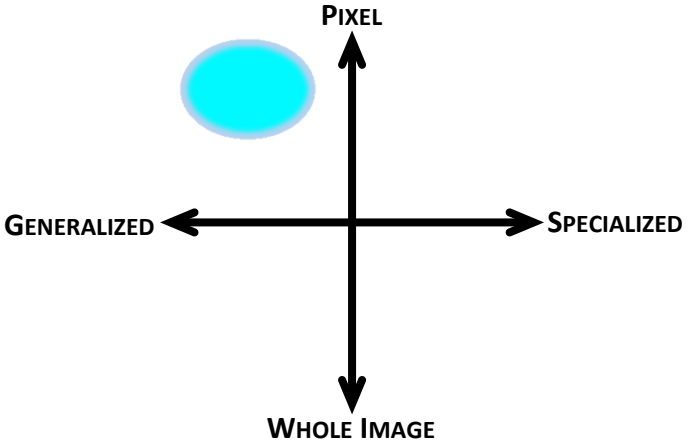


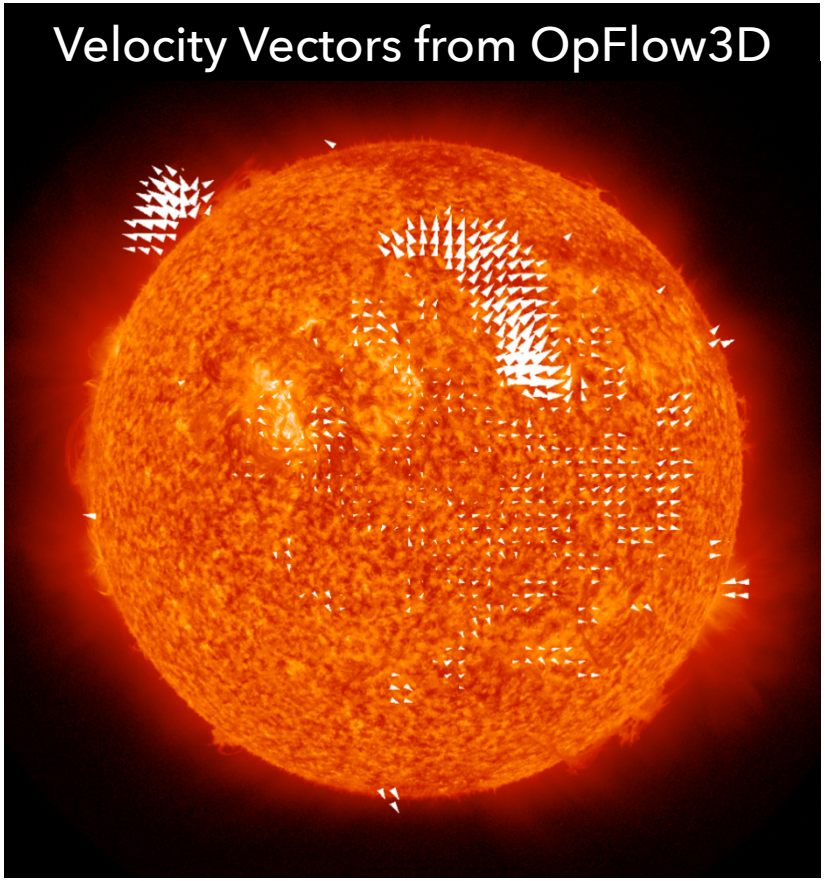
- Makes use of consistent feature morphology to calibrate against in situ measurements.

C. E. DeForest, T. A. Howard, and D. J. McComas: The Astrophysical Journal, 2013; 769, 43

OpFlow3D

- Tracks features the motion of various solar features using optical flow techniques.



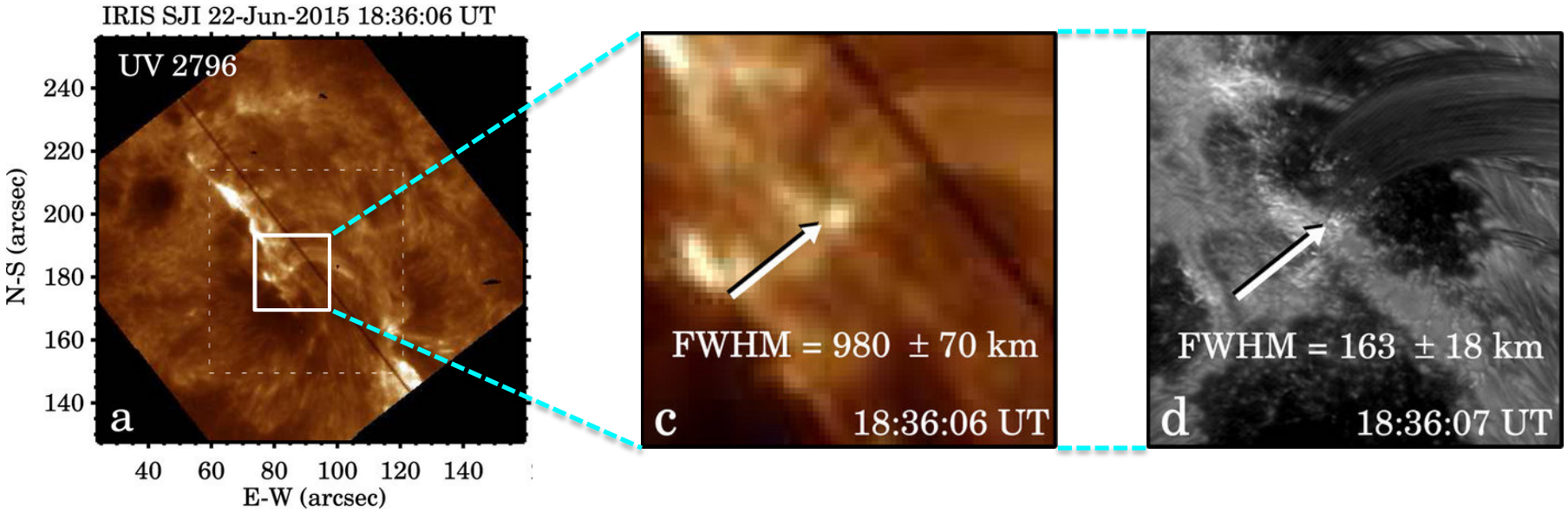


- Utilizes the different emission heights of the plasma to efficiently estimate plasma motions.
- Based upon discrete Fourier transforms of the spatial and temporal derivatives of the image.
- Mathematical formalism scalable to any solar data set.

Neal Hurlburt, Steve Jaffey: Earth Science Informatics, 2015; 8, 959.

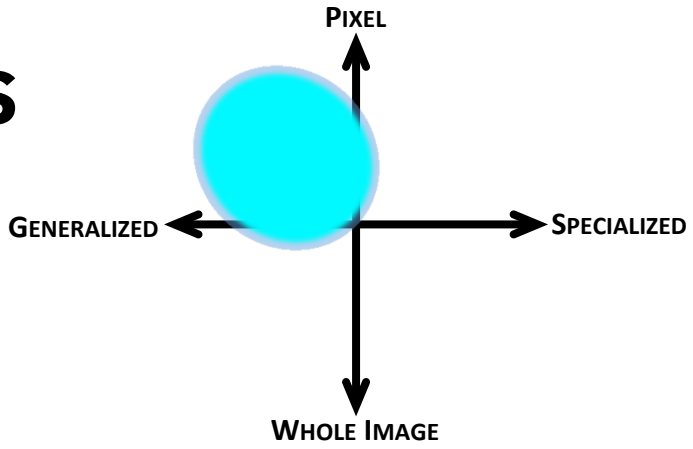
Multi-Scale Processing

- Wavelet & Curvelet Applications
- Multi-Dimensional Scaling
  - MDS
- Blind Noise Statistics

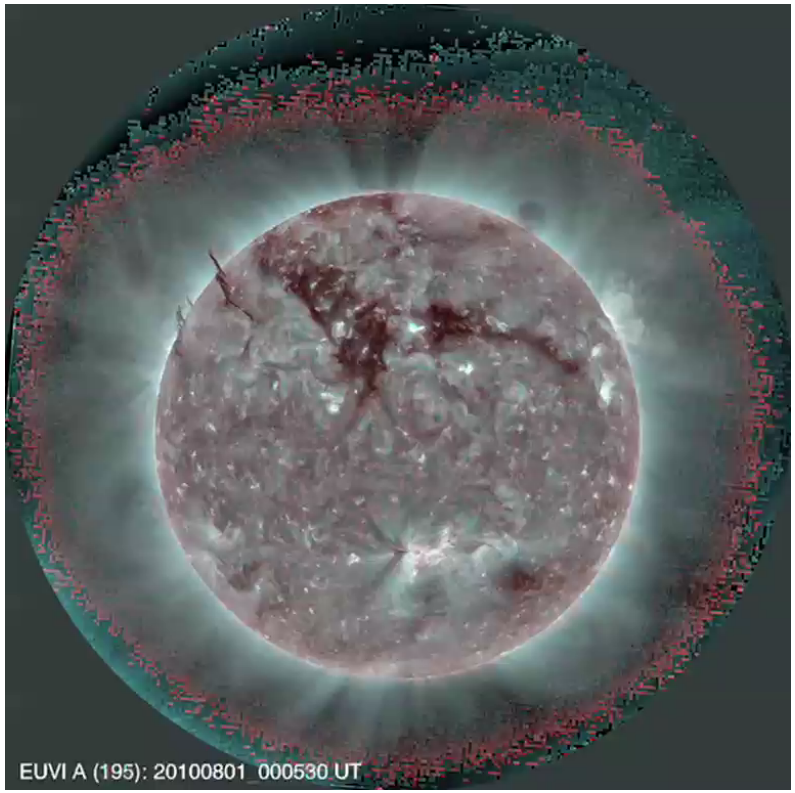


From Jin et al.: Nature 2016; 6, 24319.

Wavelets and Curvelets



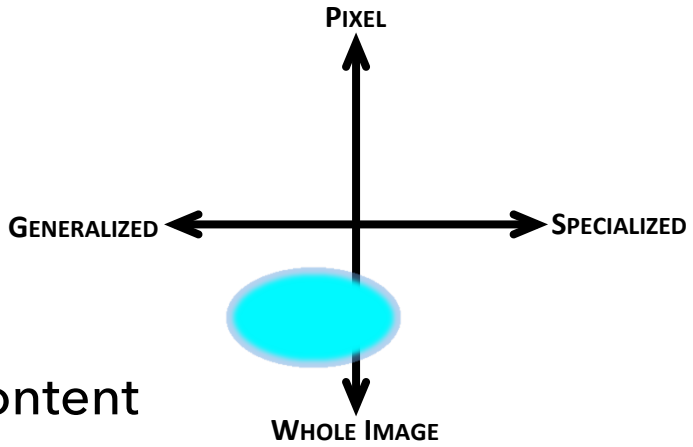
- Have been used for the last ~20 years in solar physics data analysis.
- Pipeline implementation for edge and feature enhancement.



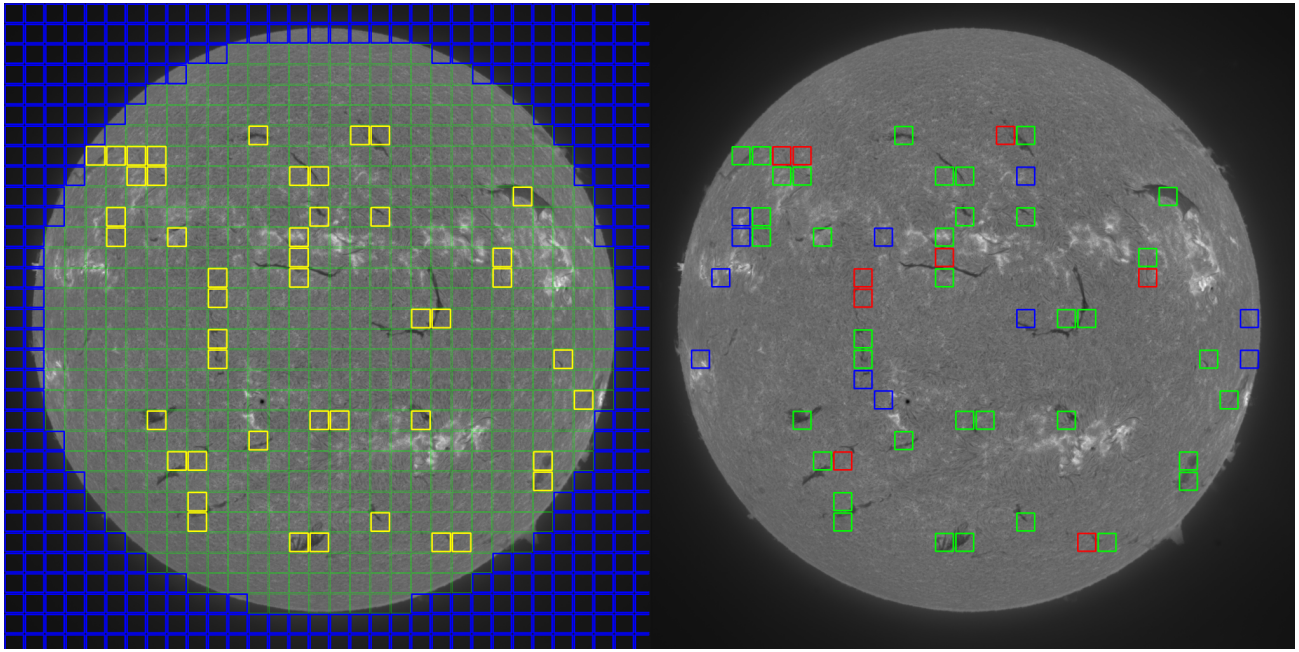
- Recent efforts include: CME edge detection, coronal loop oscillation enhancement, and helio-seismic applications.
- Curvelets are generally better suited to a solar image environment than wavelets.

Gallagher, P. T., C. A. Young, J. P. Byrne, and R. T. McAteer: Advances in Space Research, 2011; 47, 2118.

MDS

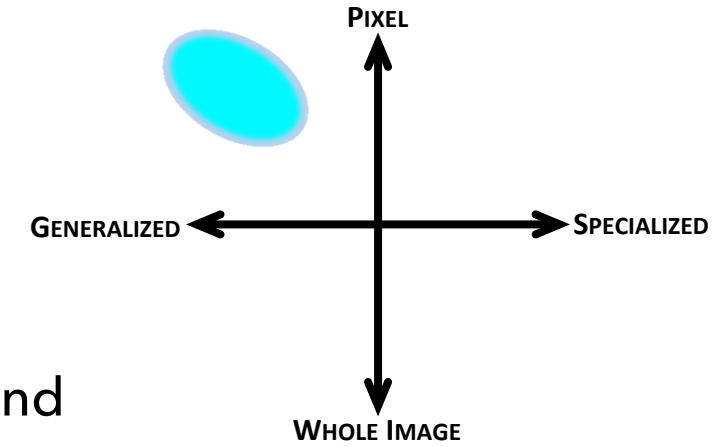


- Seeks to associate solar phenomena to similar events throughout time.
- Has the goal of producing an intelligent content cataloging and retrieval.
- Uses 10 parameters to form a feature vector across a 128 x 128 grid.
- Correlates vectors using an 18-parameter dissimilarity matrix and Support Vector Machines.



J. M. Banda , R. A. Angryk, P. C. H. Martens: Solar Physics, 2013; 288, 435.

Blind Noise Statistics



- Noise estimation and removal without a ground truth image.
- Evaluates contemporary noise estimation and mitigation techniques for the solar environment.
- Spatial and temporal frequency analysis is used to compare the effect of noise mitigation on solar features.

Original

Noise Mitigation

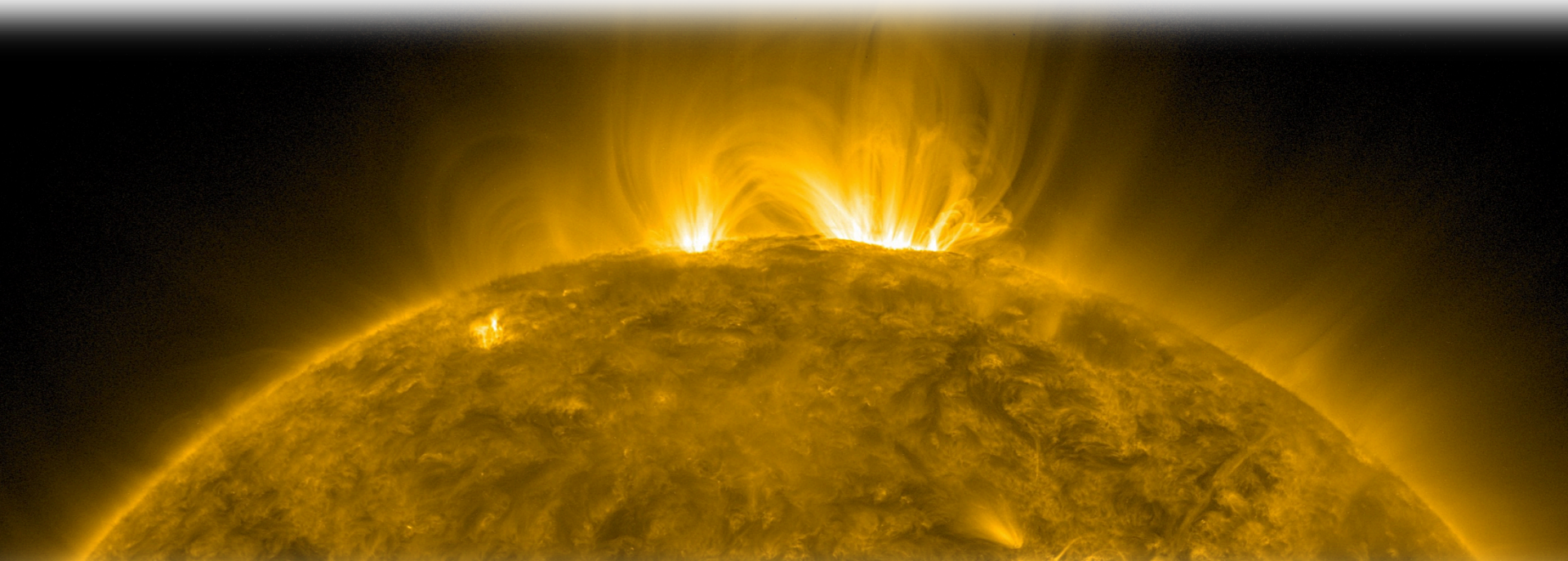
- All solar features and pixel noise are fundamentally linked in both space and time.

M. S. Kirk, J. Ireland, C. A. Young, W. D. Pesnell: Astrophysical Journal, 2016; in prep.

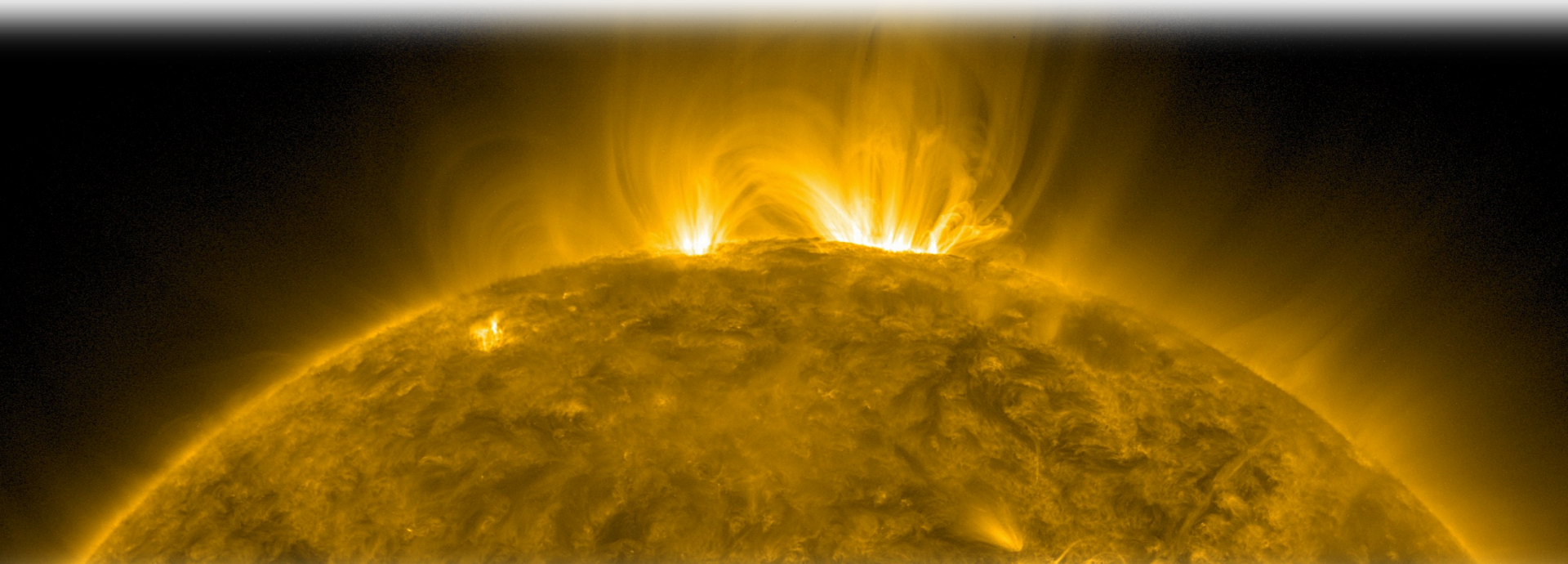
Current State of Helio Image Processing

- All scales (both space & time) exist in solar imaging.
- Current techniques are seeking to answer a Science Question (physics).
- Looking for ways to process large amounts of data.
- Solar images represent unique challenges.
- We always see unexpected features.

Future Challenges for the Field



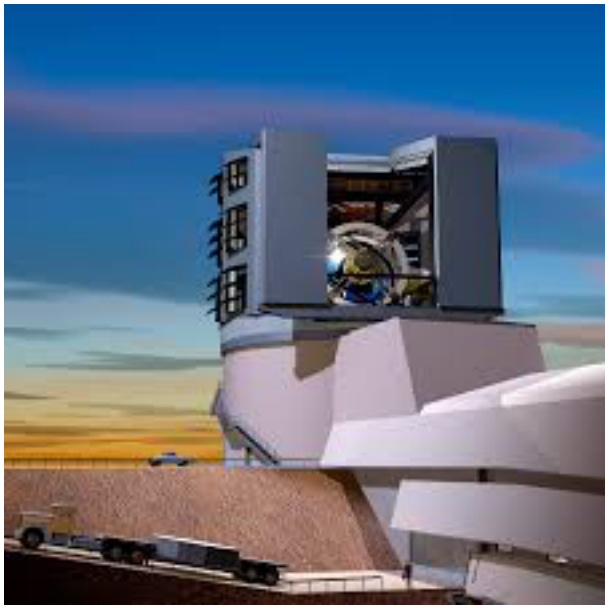
Big Data



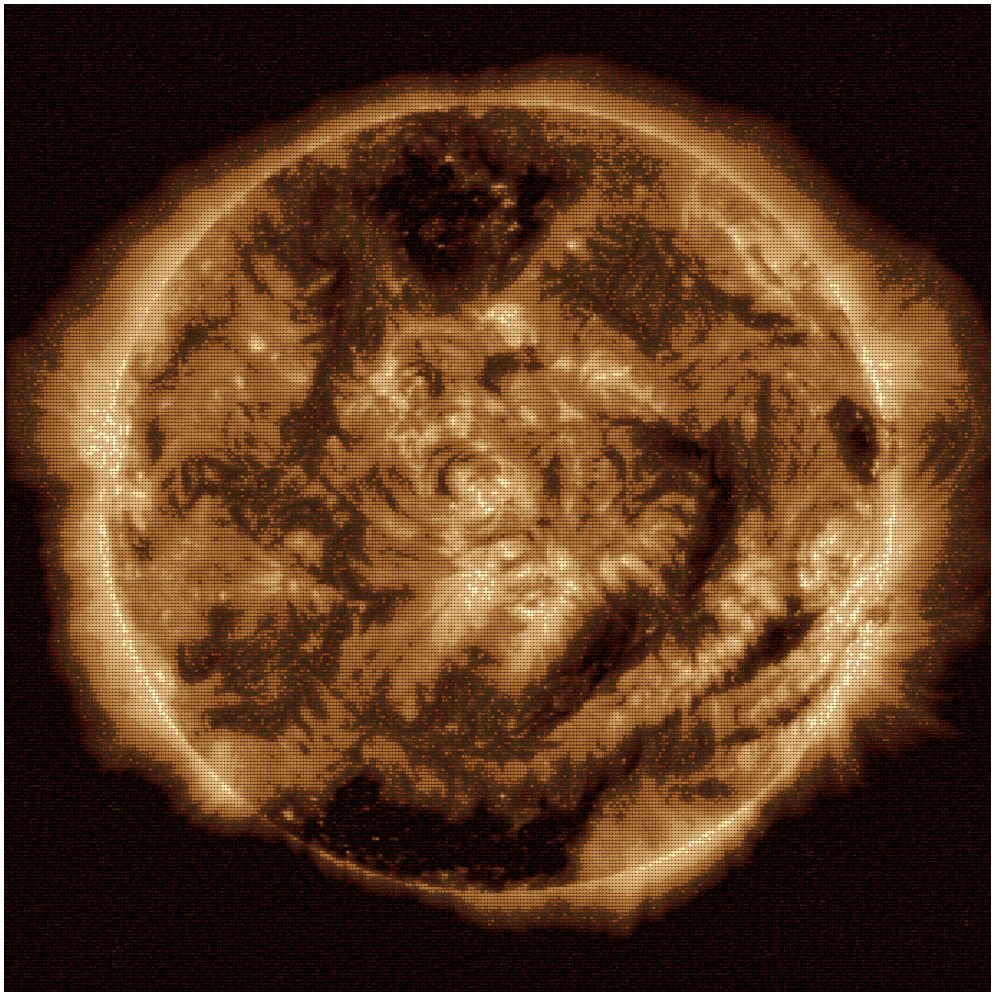
Solar Dynamics Observatory

Daniel K. Inouye Solar Telescope

Large Synoptic Survey Telescope



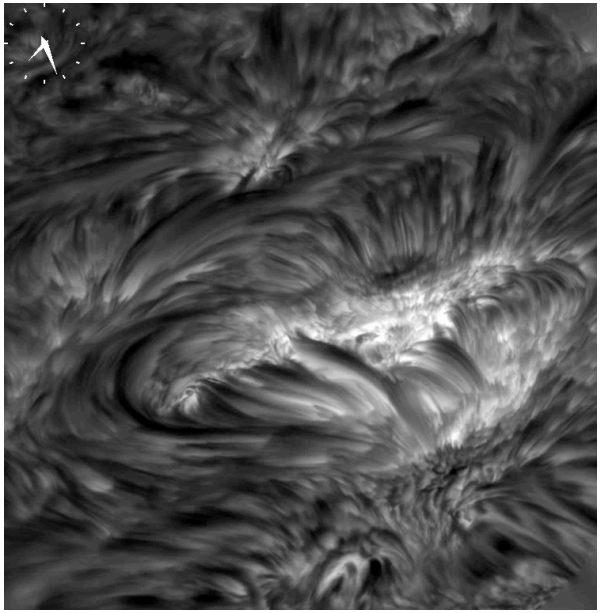
Solar Dynamics Observatory (SDO)



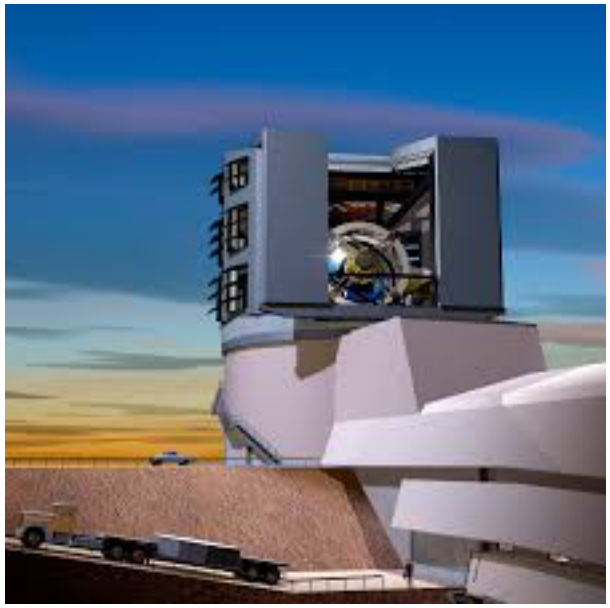
- 10 Wavelengths every 12 s
- 16 MPixel cameras
- ~2 TB/day
- ~0.7 PB/year

Daniel K. Inouye Solar Telescope (DKIST)

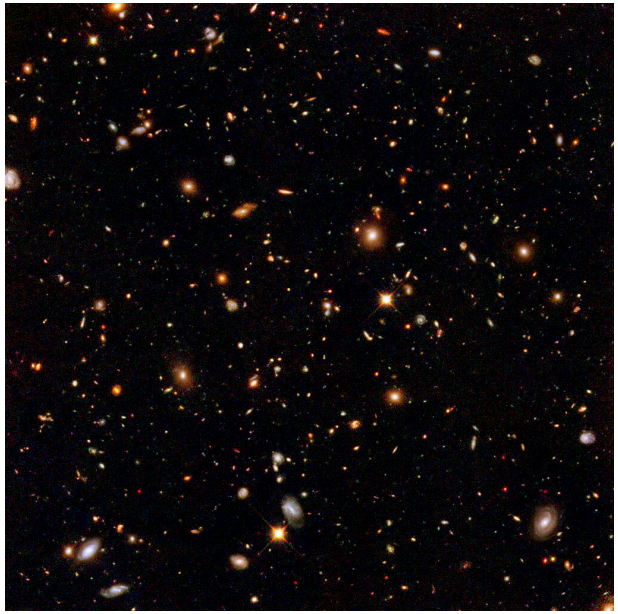
- Achieve the highest resolution possible of the solar surface
- Image features ~20km
- 4 meter telescope (1.6 m current)
- ~50 TB/day
- ~5 PB/year



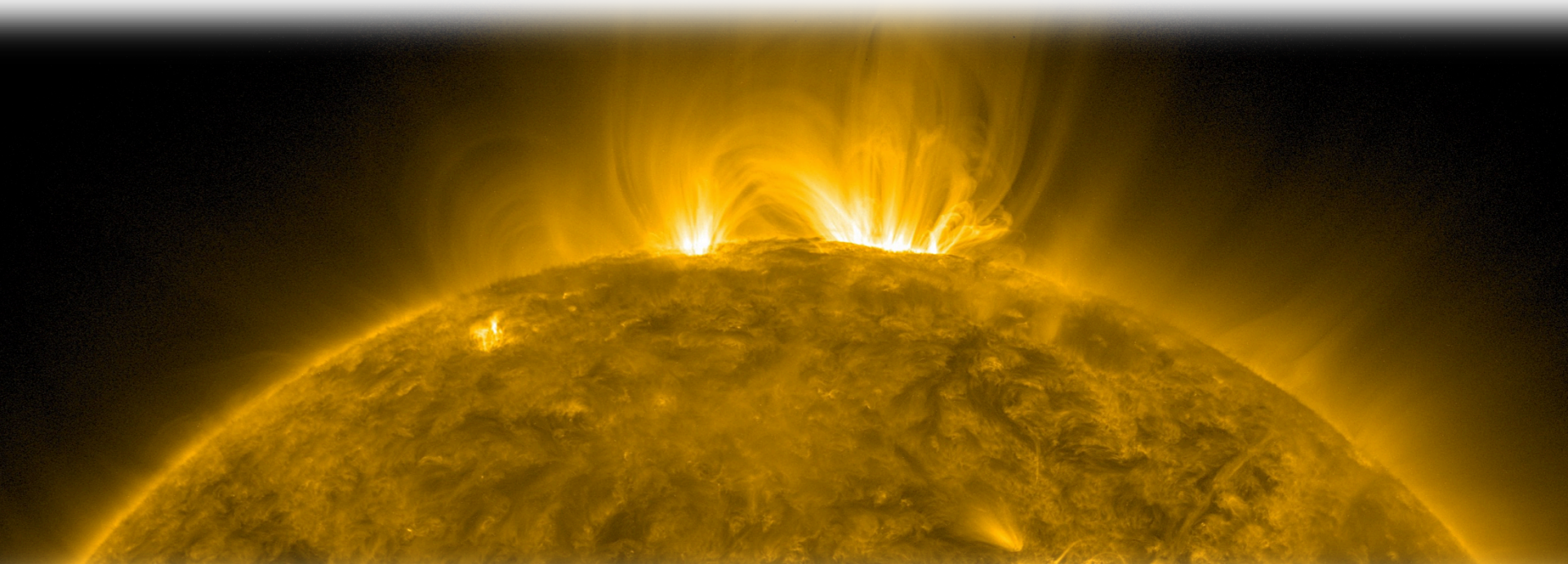
Large Synoptic Survey Telescope (LSST)



- Survey the entire sky every 3 days
- Create a complete 3D map
- 8.4 meter telescope
- 3.2 Gigapixel Camera
- ~50 TB/day
- ~5 PB/year



Multi-Instrument/Multi-Spacecraft Integration




Wind
Voyager
QuikSCAT
Stereo
ACRIMSAT
ERBS
EO-1
RHESSI
TOMS
TRMM
Geotail
ICESat-2
SOHO
Aqua
THEMIS
Landsat 7
TOPEX
TRACE
TIMED
CALIPSO
ACE
Terra
GRACE
SORCE
Cluster
POES
SDO
AIM
IMAGE
Aura
GOES
FAST
GPM
Polar
MMS
Solar-B
Aquarius
IBEX
NPP
TDRSS
LDCM
CloudSat
TWINS
(Instrument)
RBSP
Osiris-Rex
(Sample Return)
WMAP
Cassini
NuSTAR
JWST
WISE
HST
GALEX
New Horizons
Messenger
Spitzer
SWAS
Astro-H
IUE
RXTE
Galileo
Juno
Integral
MAVEN
EUVE
Pioneer
FUSE
Swift
COBE
Mars Science
Laboratory
Fermi
Compton
GRO
LADEE
LRO

Let’s talk!