National Centers for Environmental Information (NCEI)

AMS Short Course

GOES-R Preview for Users

Space Weather

W.F. Denig

National Centers for Environmental Information (NCEI)

NOAA/NESDIS

Boulder, Colorado

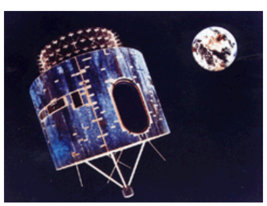
22 January 2017

Before GOES – Early Satellites

SOLar RADiation (SOLRAD, 1960-1976) – Determined relationship between solar x-rays and radio-wave fadeouts. Non operational.

Vela Hotel (She Watches Over, 1963-1971) – 1963 Partial Test Ban Treaty compliance but detected solar events.

Advanced Technology Satellites (ATS, 1966-1977) – Demonstrated utility of geosynchronous orbit for meteorological monitoring.



Synchronous Meteorological Satellites (1974-1979) – Immediate predecessor to GOES; Identical to GOES 1-3

Memorandum to David Johnson from George Benton (04 Mar 1969)

"I am pleased to submit to you in outline our firm requirements for operational space disturbance monitoring from the first GOES satellite. These are for operational monitoring of ***energetic protons, alpha particles and solar x-rays*** *in the 1 – 8 and 0.5 – 3 Angstrom bands."*

Dr. George Benton
ESSA Research Laboratories (ERL)

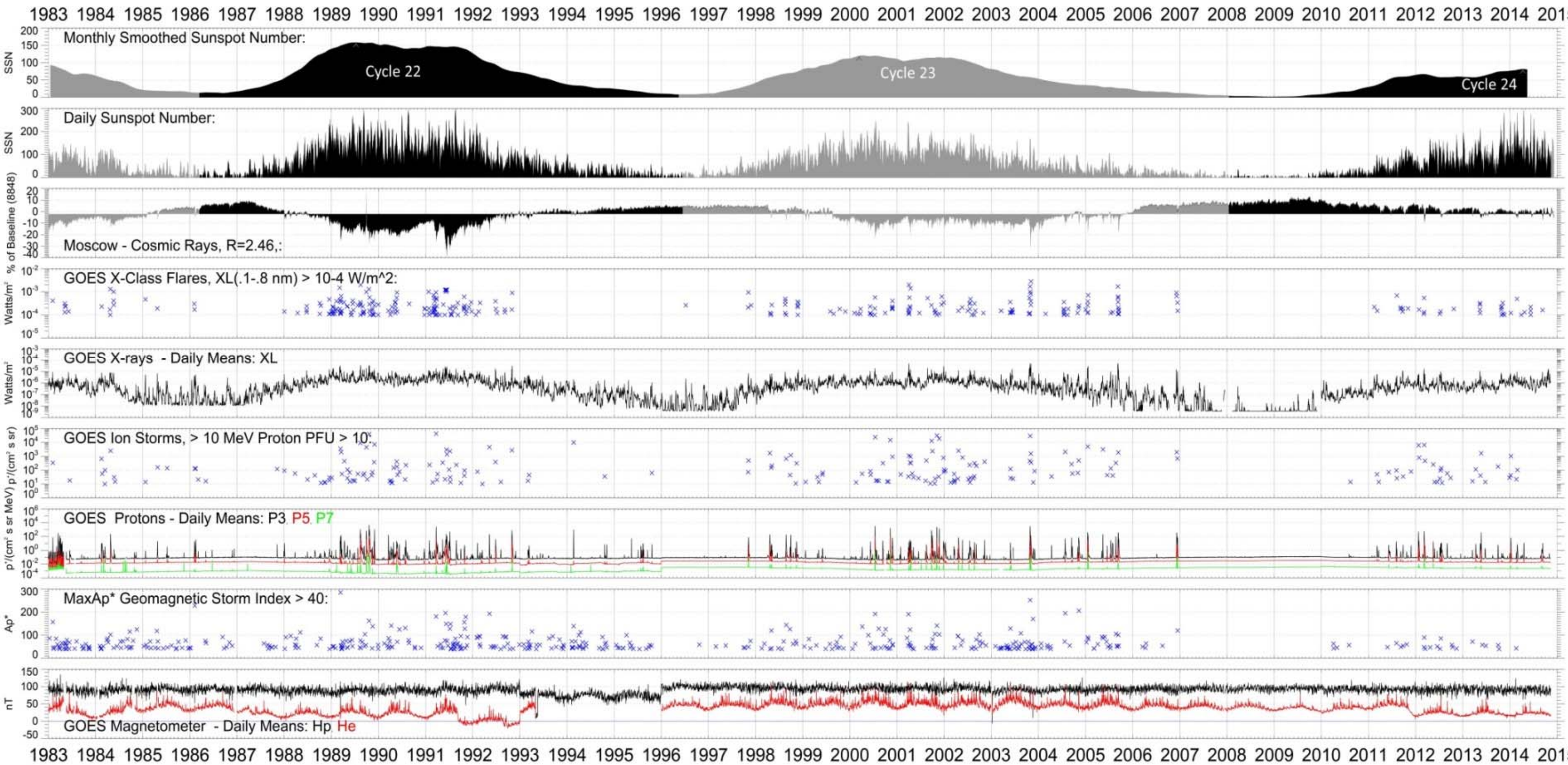
David Johnson
National Environmental Satellite Center (NESC)

(unsigned file copy, courtesy Dick Grubb)

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

GOES-R – 40+ Years of SWx

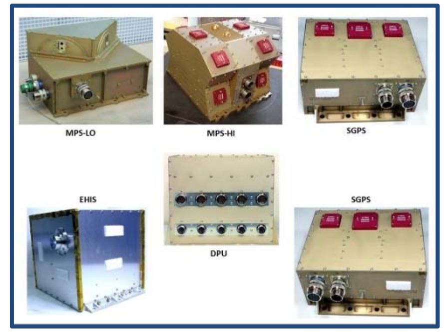
Space Environment Overview: 1983-01-01 - 2014-12-31



	Start Date	Max Date	End Date	C-Class Flares	M-Class Flares	X-Class Flares	Ion Storms	Mag Storms Ap* > 40
Solar Cycle 22	1986-03	1989-07	1996-06	12,447	2,021	151	73	191
Solar Cycle 23	1996-06	2000-03	2008-01	13,102	1,437	126	92	158
Solar Cycle 24 *	2008-01	2014-04	TBD	5,288	488	35	32	25

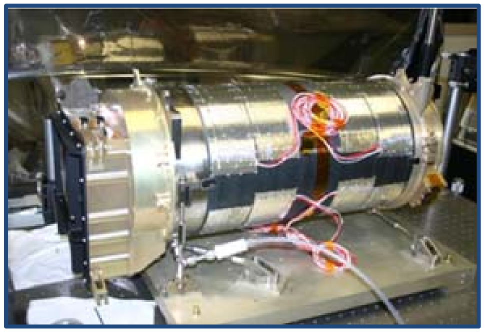
Space Weather Sensors

GOES-16



Space Environmental In-Situ Suite

(SEISS)



Solar Ultra-Violet Imager

(SUVI)

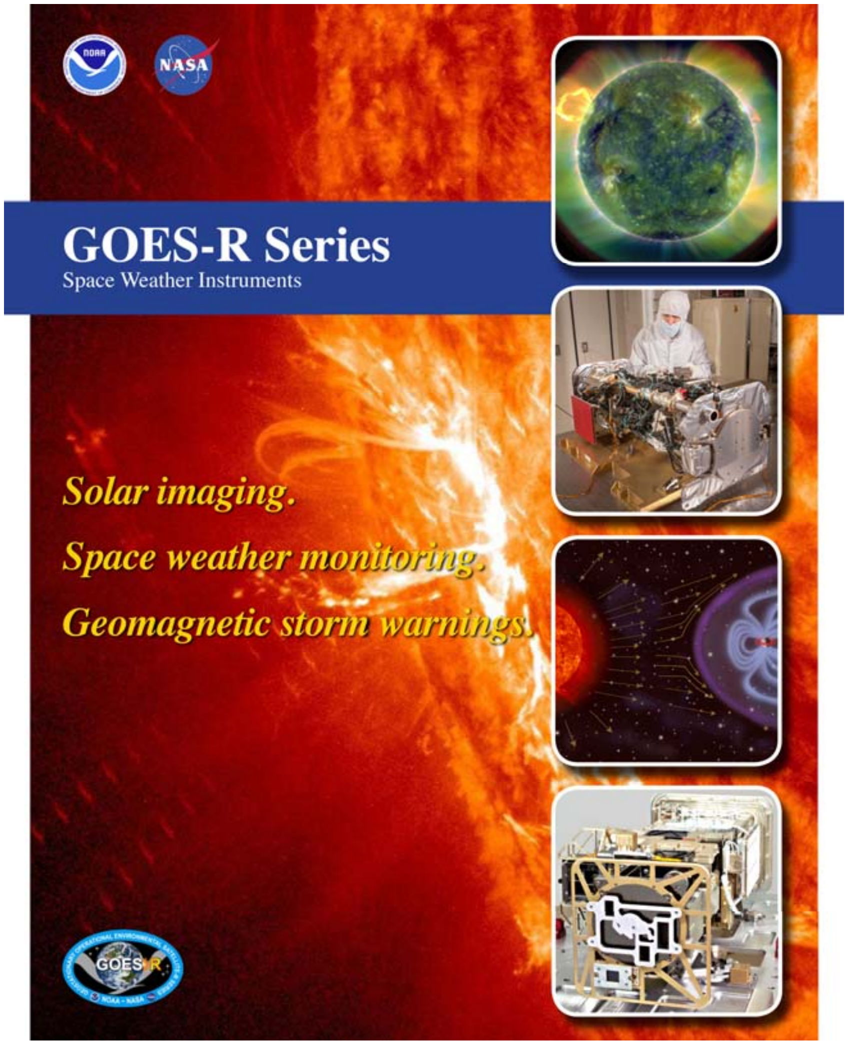
Magnetometer

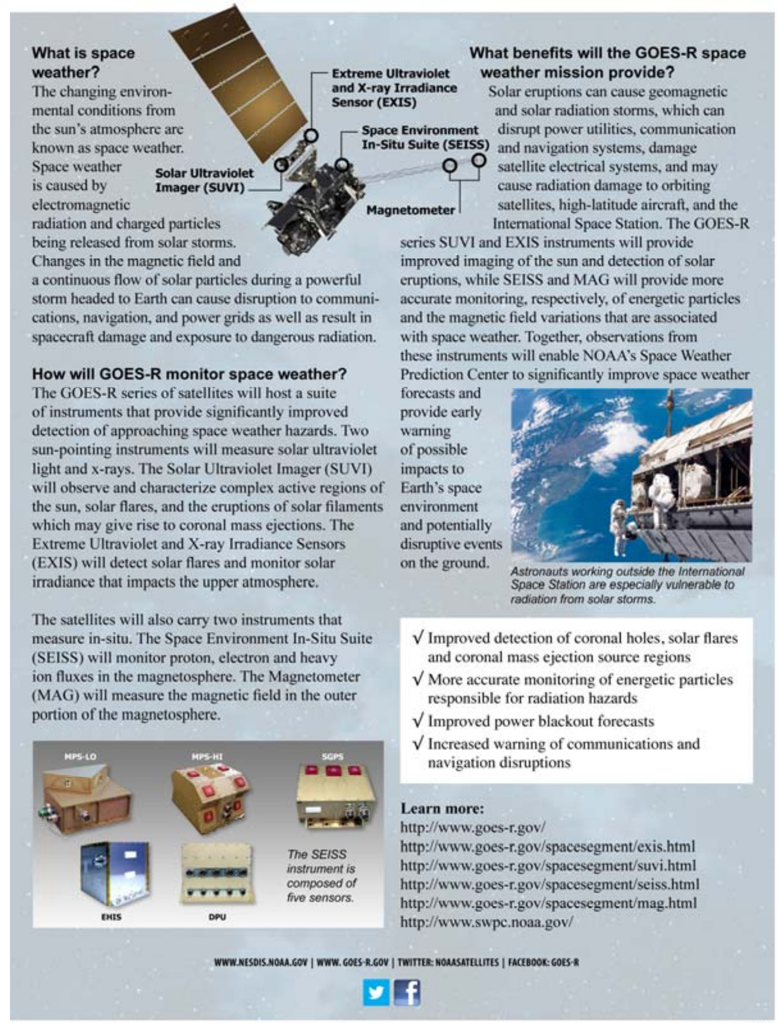
MAG

EUV and X-ray Irradiance Sensors

(EXIS)

GOES-16 SWx Handout





What is space weather?
The changing environmental conditions from the sun's atmosphere are known as space weather. Space weather is caused by electromagnetic radiation and charged particles being released from solar storms. Changes in the magnetic field and a continuous flow of solar particles during a powerful storm headed to Earth can cause disruption to communications, navigation, and power grids as well as result in spacecraft damage and exposure to dangerous radiation.

How will GOES-R monitor space weather?
The GOES-R series of satellites will host a suite of instruments that provide significantly improved detection of approaching space weather hazards. Two sun-pointing instruments will measure solar ultraviolet light and x-rays. The Solar Ultraviolet Imager (SUVI) will observe and characterize complex active regions of the sun, solar flares, and the eruptions of solar filaments which may give rise to coronal mass ejections. The Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS) will detect solar flares and monitor solar irradiance that impacts the upper atmosphere.

The satellites will also carry two instruments that measure in-situ. The Space Environment In-Situ Suite (SEISS) will monitor proton, electron and heavy ion fluxes in the magnetosphere. The Magnetometer (MAG) will measure the magnetic field in the outer portion of the magnetosphere.

The SEISS instrument is composed of five sensors.

What benefits will the GOES-R space weather mission provide?
Solar eruptions can cause geomagnetic and solar radiation storms, which can disrupt power utilities, communication and navigation systems, damage satellite electrical systems, and may cause radiation damage to orbiting satellites, high-latitude aircraft, and the International Space Station. The GOES-R series SUVI and EXIS instruments will provide improved imaging of the sun and detection of solar eruptions, while SEISS and MAG will provide more accurate monitoring, respectively, of energetic particles and the magnetic field variations that are associated with space weather. Together, observations from these instruments will enable NOAA's Space Weather Prediction Center to significantly improve space weather forecasts and provide early warning of possible impacts to Earth's space environment and potentially disruptive events on the ground.

Astronauts working outside the International Space Station are especially vulnerable to radiation from solar storms.

- √ Improved detection of coronal holes, solar flares and coronal mass ejection source regions
- √ More accurate monitoring of energetic particles responsible for radiation hazards
- √ Improved power blackout forecasts
- √ Increased warning of communications and navigation disruptions

Learn more:
http://www.goes-r.gov/
http://www.goes-r.gov/spacesegment/exis.html
http://www.goes-r.gov/spacesegment/suvi.html
http://www.goes-r.gov/spacesegment/seiss.html
http://www.goes-r.gov/spacesegment/mag.html
http://www.swpc.noaa.gov/

WWW.NESDIS.NOAA.GOV | WWW.GOES-R.GOV | TWITTER: NOAASATELLITES | FACEBOOK: GOES-R

10/2015

Why EXIS?

EUV and X-ray Irradiance Sensors (EXIS/EUVS & EXIS/XRS)

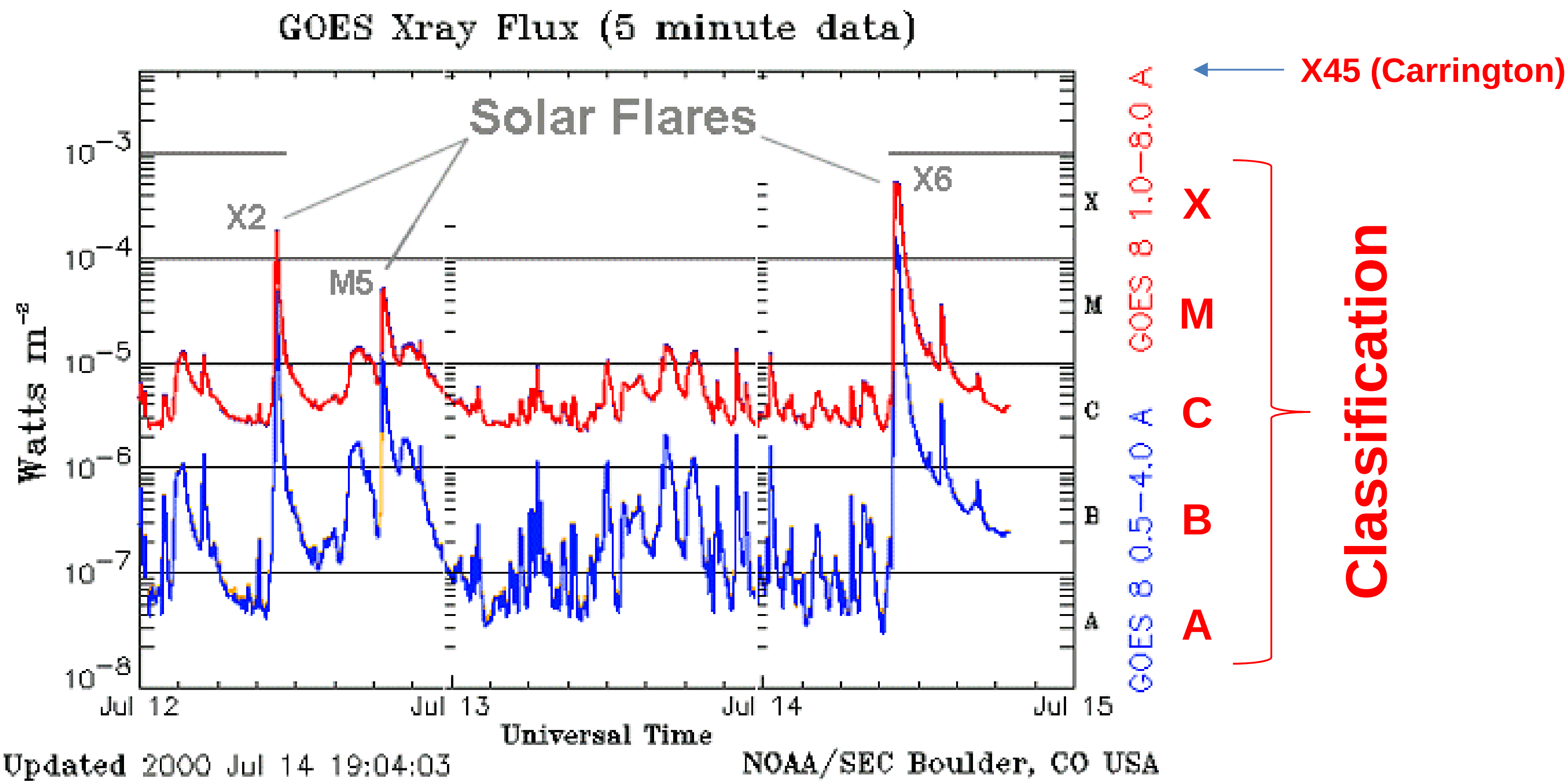
X-Ray irradiance /// solar flare monitoring

EXIS/XRS measures the background x-ray solar irradiance and detects solar flares that disrupt communications, reduce navigational accuracy, affecting satellites, high altitude airlines and power grids on Earth.

Extreme UltraViolet (EUV) solar irradiance

NOAA requires the real-time monitoring of the solar irradiance variability that controls the variability of the terrestrial upper atmosphere (ionosphere and thermosphere). This requirement supports NOAA's space weather operations and is implemented with XRS and EUVS.

EXIS/XRS Product



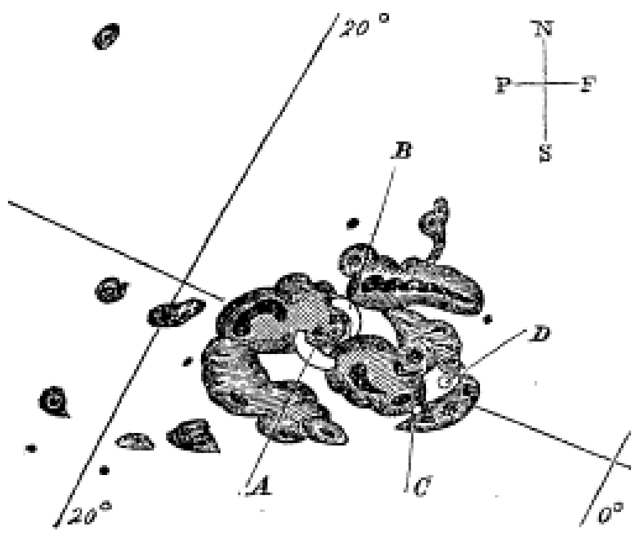
Note: Solar x-ray flares observed above the background solar irradiance.

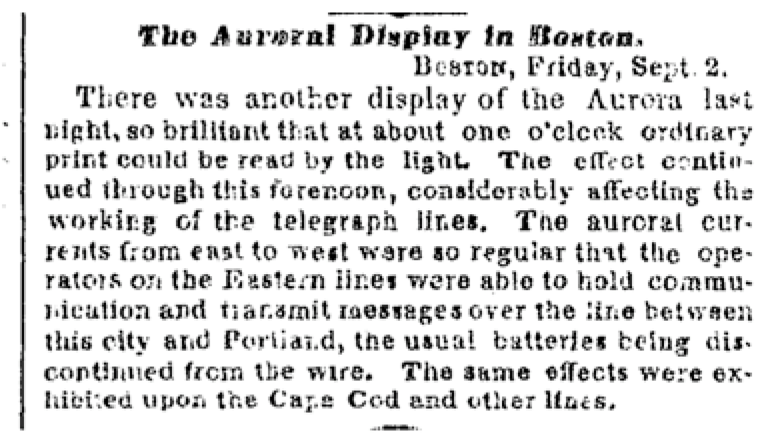
Letters to the right of the image are the classifications

The Carrington Event (1859)

Carrington Event

The Carrington event was an extreme geomagnetic storm that was both awe inspiring and impactful on the technology system of the day; that is, the telegraph. The event was trigger by a massive solar flare on 01-Sep of estimated **X45** intensity. A high-speed Coronal Mass Ejection (CME) slammed into the earth some 19 hours later resulting in an extreme geomagnetic storm. A storm of similar intensity would have a debilitating impact on today's high technology systems.




The Auroral Display in Boston.

Boston, Friday, Sept. 2.

There was another display of the Aurora last night, so brilliant that at about one o'clock ordinary print could be read by the light. The effect continued through this forenoon, considerably affecting the working of the telegraph lines. The auroral currents from east to west were so regular that the operators on the Eastern lines were able to hold communication and transmit messages over the line between this city and Portland, the usual batteries being discontinued from the wire. The same effects were exhibited upon the Cape Cod and other lines.

The New York Times
Published: September 3, 1859

White House Action

"White House is preparing for catastrophic solar flares which could wipe out power around the world for months

- ***Massive electromagnetic pulse caused by solar flares could bring an end to modern civilization as we know it***
- ***Extreme space weather event could wipe out power for months and render cellphones and internet useless***
- ***One study estimates that in the U.S. alone it could cost the fragile economy up to $2.6 trillion***
- ***Now the White House are preparing for the threat after a major solar flare narrowly missed the Earth in 2012***
- ***Strategy includes improving prediction abilities as forecasters only have 15-60 minutes warning to protect energy grids"***

EXIS Key Requirements

	Parameter	Requirement	Design
X-Rays	XRS λ Range	0.05 nm – 0.8 nm	0.05 nm – 0.8 nm
	XRS Dynamic Range	10^{-9} W/m^2 – 10^{-3} W/m^2	10^{-5} W/m^2 – 10^{-3} W/m^2
	XRS SNR	1:1 over 10 min. average	>30:1 over 10 min. average
	XRS Data Product Accuracy	≤20% over mission life	14% over mission life
	XRS Cadence	≤3 sec	3 sec
EUV	EUVS λ Range	5 - 127 nm	5-127 nm (data product)
	EUVS $\Delta\lambda$ Resolution	From 5 to 35 nm: 10 nm bins From 35 to 115 nm: 40 nm bins L-α (121.6 nm): 10 nm (FWHM)	5 – 115 nm; 5 nm bins 117 127; 10nm bin
	EUVS SNR	1:1 over 10 min. average	>20:1 over 10 min. average
	EUVS Data Product Accuracy	≤20% over mission life	18% over mission life
	EUVS Cadence	≤30 sec	27 sec

NOAA Space Weather Scales

Radio Blackouts

The NOAA Radio Blackout Scale is directly driven by EXIS/XRS measurements. Scale varies from Minor R1 (<M5) to Extreme (>X20)

Radio Blackouts

Scale	Description	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
R 5	Extreme	**HF Radio:** Complete HF (high frequency) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. **Navigation:** Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 (2×10^{-3})	Less than 1 per cycle
R 4	Severe	**HF Radio:** HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. **Navigation:** Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	**HF Radio:** Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. **Navigation:** Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	**HF Radio:** Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. **Navigation:** Degradation of low-frequency navigation signals for tens of minutes.	M5 (5×10^{-5})	350 per cycle (300 days per cycle)
R 1	Minor	**HF Radio:** Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. **Navigation:** Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

Why SEISS?

Energetic Charged Particles

The information provided by SEISS is critical for assessing the electrostatic discharge (ESD) risk and radiation hazard to astronauts and satellites

MPS-LO – Magnetospheric Particle Sensor Low
e^- & p^+; 30 eV – 30 keV

MPS-HI – Magnetospheric Particle Sensor High
e^-; 50 keV – 4 MeV; >2 MeV integral
p^+; 80 keV – 10 MeV

SGPS – Solar & Galactic Particle Sensor
p^+; 1 MeV – 500 MeV; >500 MeV integral

EHIS – Energetic Heavy Ion Sensor (10 – 100 MeV/nucleon)

My God – Space is Radioactive[1]

Bursts Of Cosmic Rays Imperil Space Travelers

BERKELEY, Calif. (AP)—Another potentially deadly radiation hazard for space travelers was reported today by researchers who sampled the upper air of the arctic region with instrument-carrying balloons.

During periods of solar flares the investigators found that the top of the earth's atmosphere near the polar region was showered with stupendous bursts of cosmic rays.

This radiation was 10,000 to100,000 times above normal, said Dr. Robert A. Brown, physicist, and Ray D'Arcy, graduate student, of the University of California.

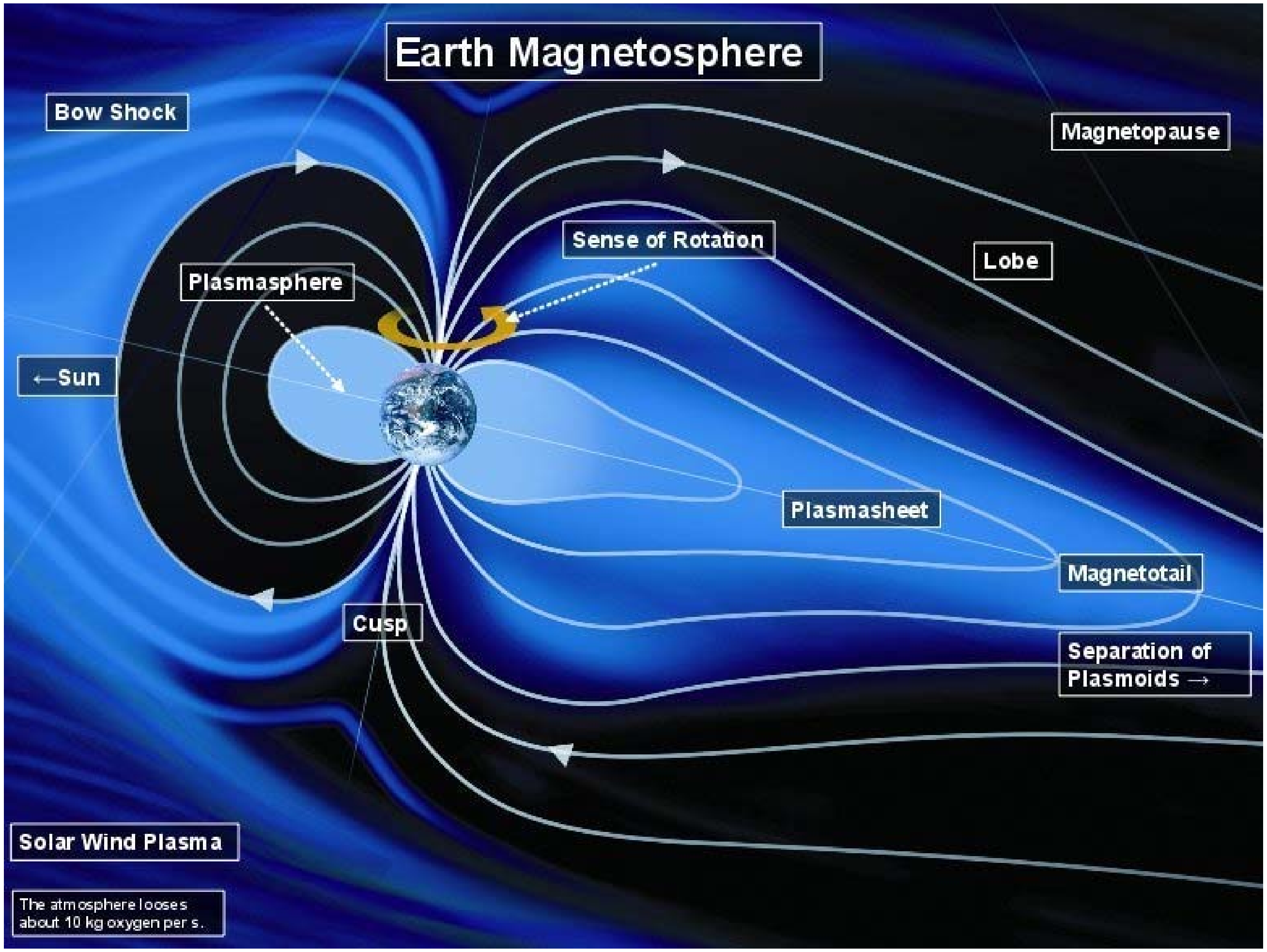
Dr. Brown made his report after returning here from College, Alaska, where the balloon flights were made. Cosmic rays are more intense in the polar areas because they encounter less interference there from the earth's magnetic field.

The experimenters put up a balloon immediately after the University of Alaska detected a solar flare. A solar flare is a sudden brightening of the sun's surface in the vicinity of a sunspot.

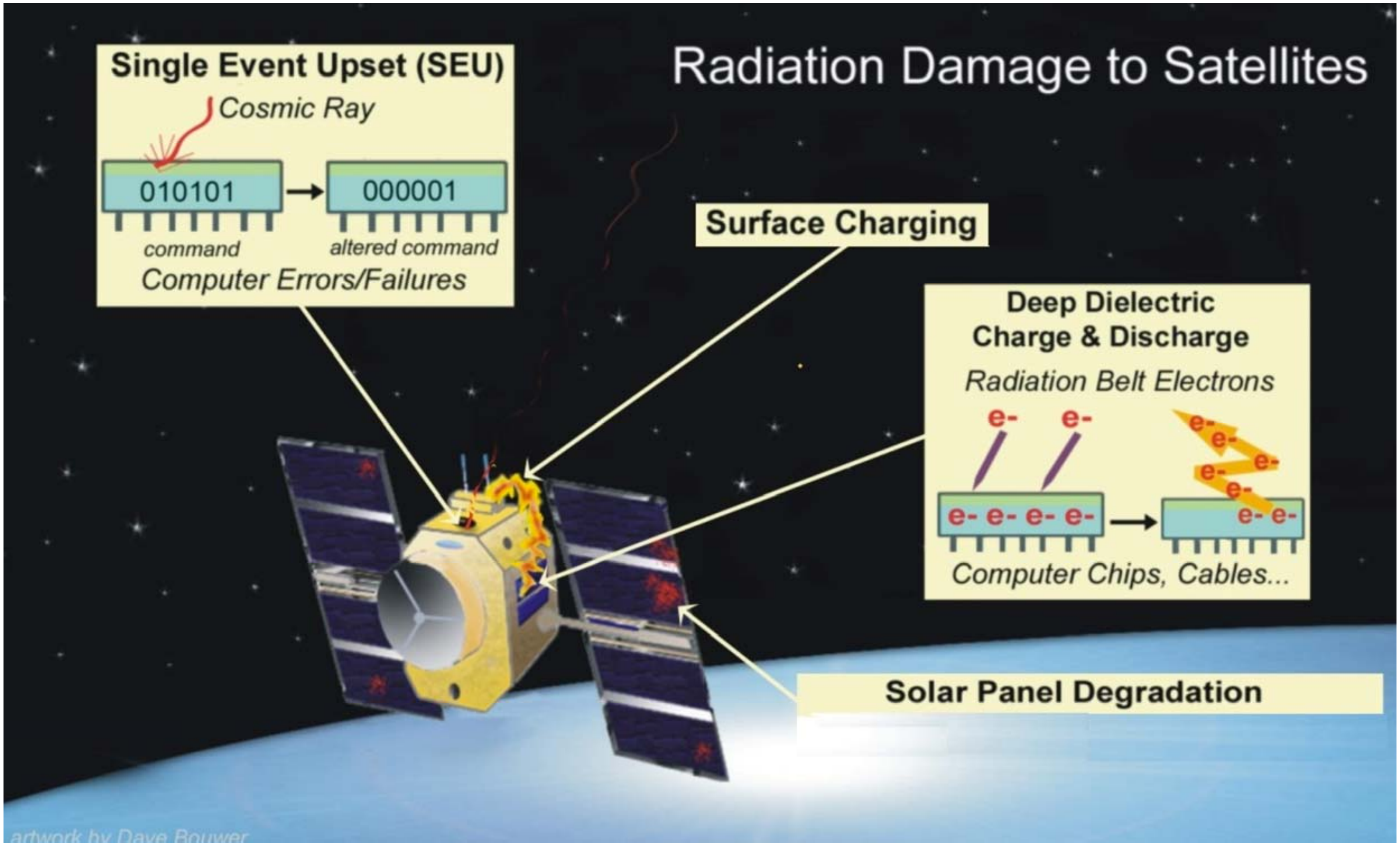
Alice Lon

[1]Credited to Van Allen (or team)

Charged Particles in the Geospace



Spacecraft Charging



NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NOAA Space Weather Scales

Radiation Storms

The NOAA Radiation Storm Scale is directly driven by SEISS/MPS-HI measurements. Scale varies from Minor (S1) to Extreme (S5)

Solar Radiation Storms

Scale	Description	Effect	Physical measure (Flux level of >= 10 MeV particles)	Average Frequency (1 cycle = 11 years)
S 5	Extreme	**Biological:** Unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** Satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. **Other systems:** Complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	**Biological:** Unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** May experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. **Other systems:** Blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	**Biological:** Radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** Single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. **Other systems:** Degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	**Biological:** Passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk. **Satellite operations:** Infrequent single-event upsets possible. **Other systems:** Small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	Minor	**Biological:** None. **Satellite operations:** None. **Other systems:** Minor impacts on HF radio in the polar regions.	10	50 per cycle

Why MAG?

Geomagnetic storm alerts/warnings

Geomagnetic field measurements are important for providing alerts and warnings to many customers, including satellite operators and power utilities.

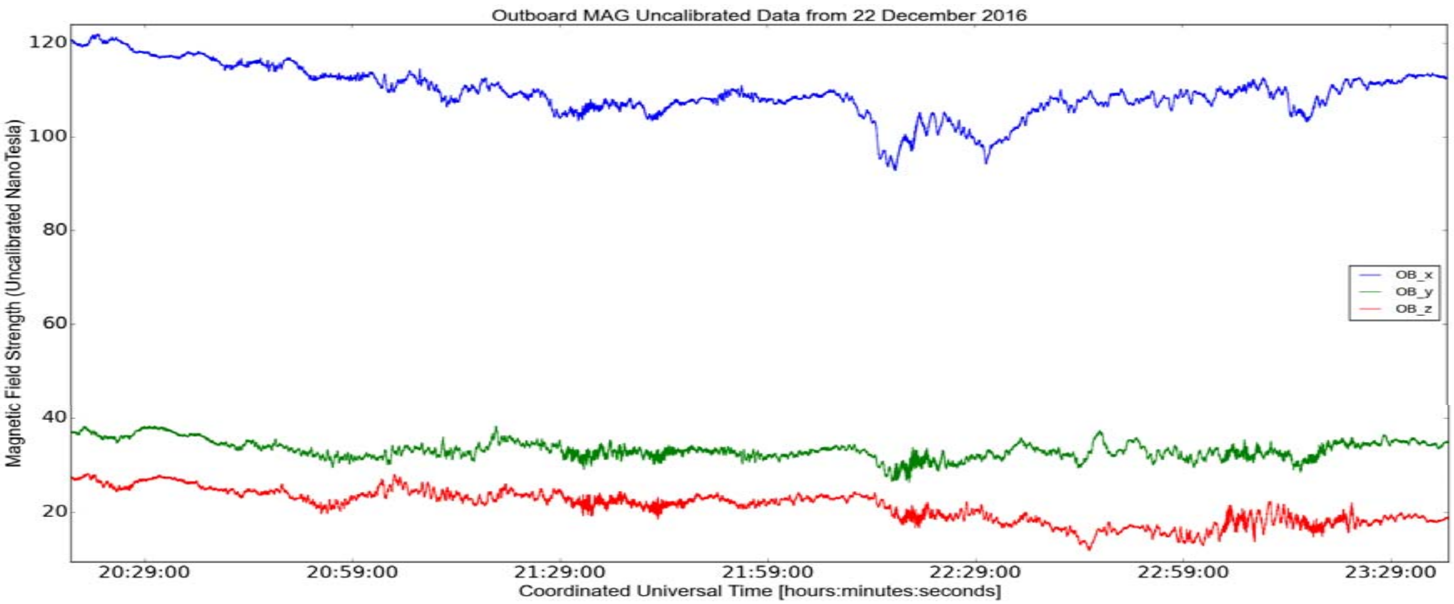
Research

GOES Magnetometer data are also important in research, being among the most widely used spacecraft data by the national and international research community.

Note: MAG data also vital for correct interpretation of SEISS charged particle data.

GOES-16 MAG – Initial Data Release

Preliminary non-operational data undergoing on-orbit testing.

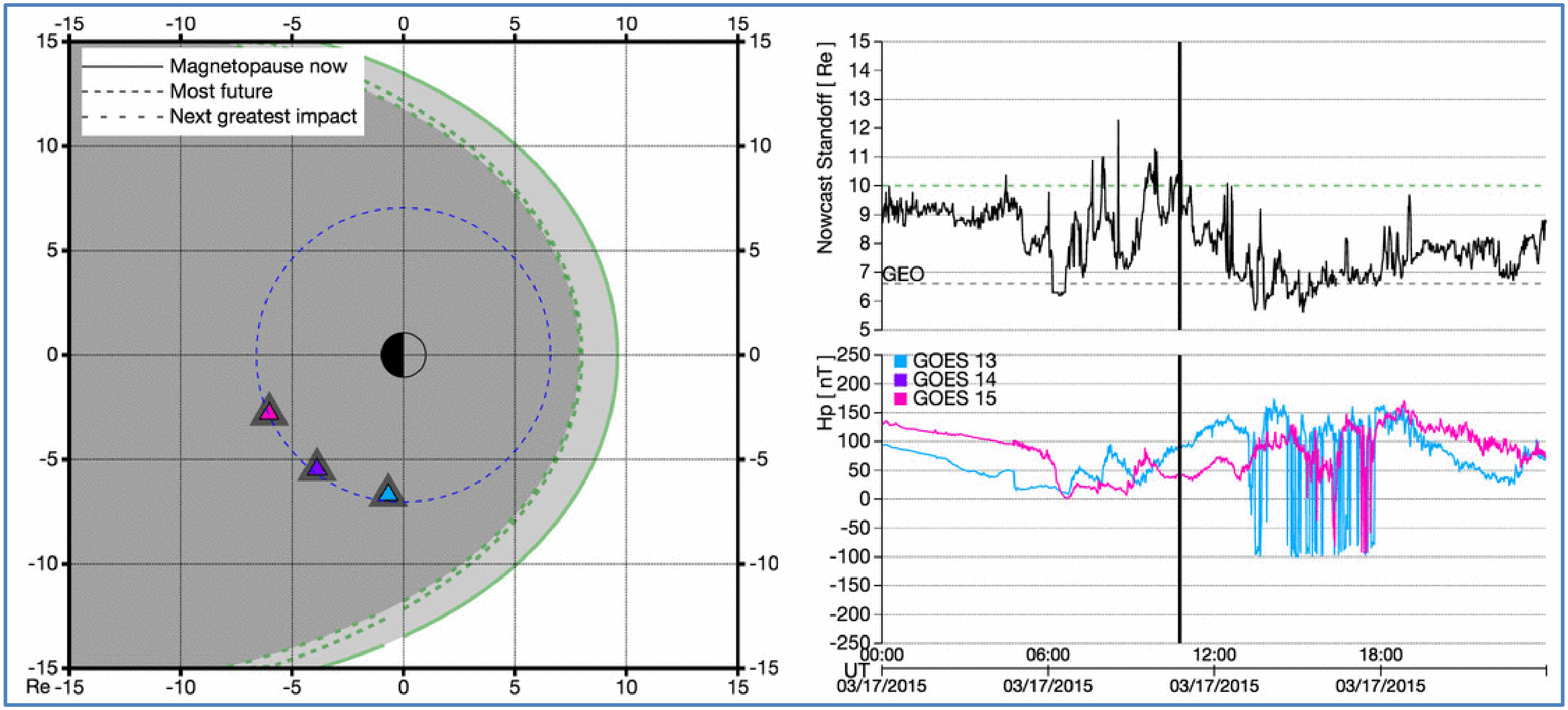


LINK

Text: Earth's geomagnetic field acts as a shield, protecting us from hazardous incoming solar radiation. Geomagnetic storms, caused by eruptions on the surface of the sun, can interfere with communications and navigation systems, cause damage to satellites, cause health risks to astronauts, and threaten power utilities. When a solar flare occurs, GOES-16 will tell space weather forecasters where it happened on the sun and how strong it was. Using that information, forecasters can determine if the explosion of energy is coming towards Earth or not.

See: Loto'aniu et al, "The GOES-R Spacecraft Mission Series Magnetometer" (Monday AM)

Magnetopause Crossing



GOES-16 MAG measurements combined with a DSCOVR-driven model of the magnetopause location are used to determine when GEO satellites are exposed to the interplanetary space environment.

Why SUVI?

Solar region characterization

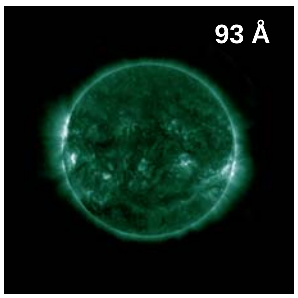
SUVI will observe and characterize complex active regions of the sun, solar flares, and the eruptions of solar filaments which may give rise to coronal mass ejections.

Solar flares and eruptive events

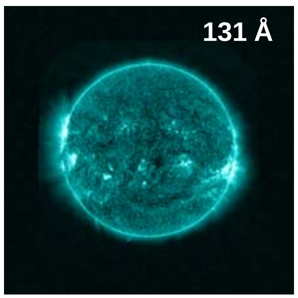
SUVI observations of solar flares and solar eruptions will provide an early warning of possible impacts to Earth's space environment and enable better forecasting of potentially disruptive events on the ground.

SUVI Overview

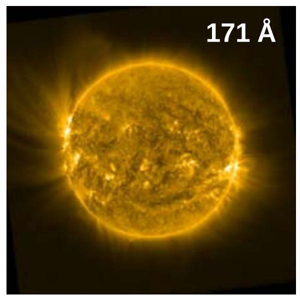
GOES-16 shifts current x-ray imagery to the ultraviolet for improved solar feature characterization. Wavelength bands are comparable to SDO/AIA.



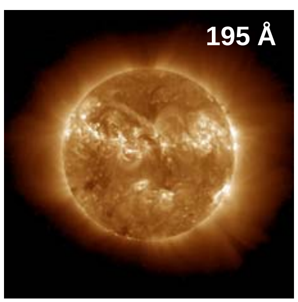
Flaring Regions (Fe XVIII)



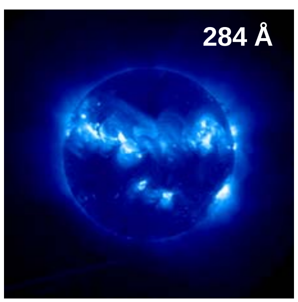
Flaring Regions (Fe VIII / XX / XXIII)



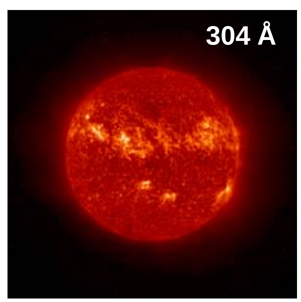
Transition Region (Fe IX)



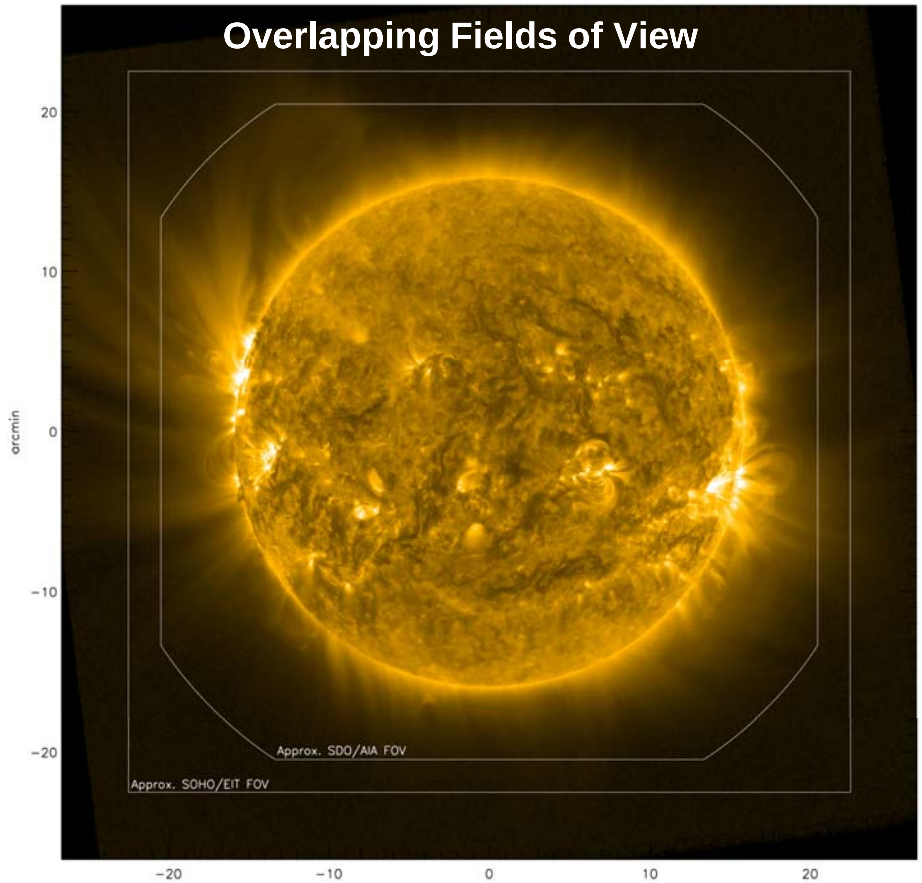
Corona (Fe XII / XXIV)



Flaring Regions (Fe XV)



Chromosphere (He II)



Simulated SUVI image at 171 Angstroms (Fe IX)
Transition Region (chromosphere-corona)

SUVI Operational Requirements

- Locate coronal holes for geometric storm forecasts
- Detect and locate solar flares for forecasts of solar energetic particle events related to flares
- Monitor changes in the corona that indicate coronal mass ejections (CMEs)
- Analyze active region complexity for flare forecasts

Training: Helioviewer.org

Training: Helioviewer

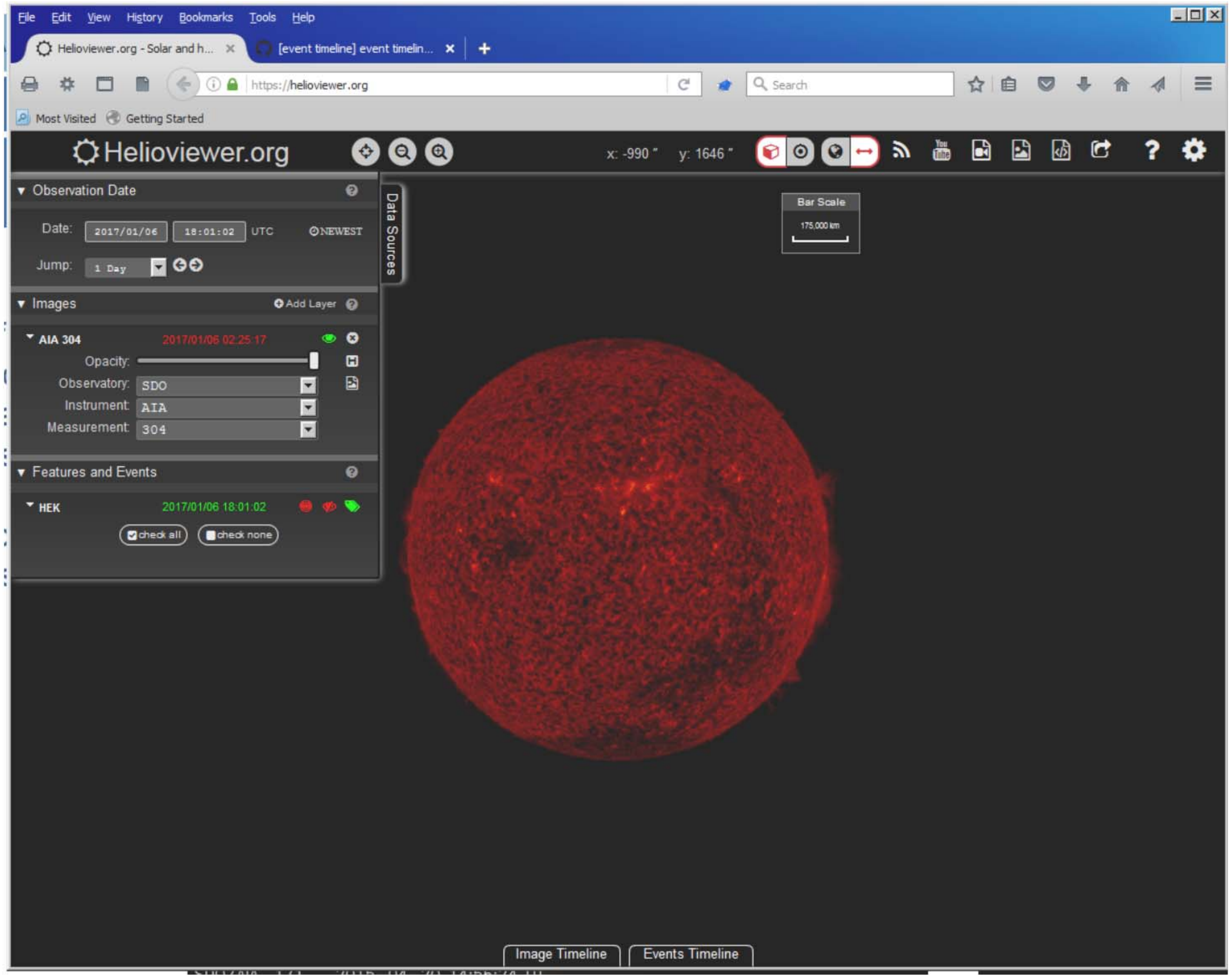
Hosted by NASA/ESA

Satellites

- SDO/AIA
- SOHO
- STEREO A/B
- PROBA2
- Yohkoh
- Hinode
- TRACE

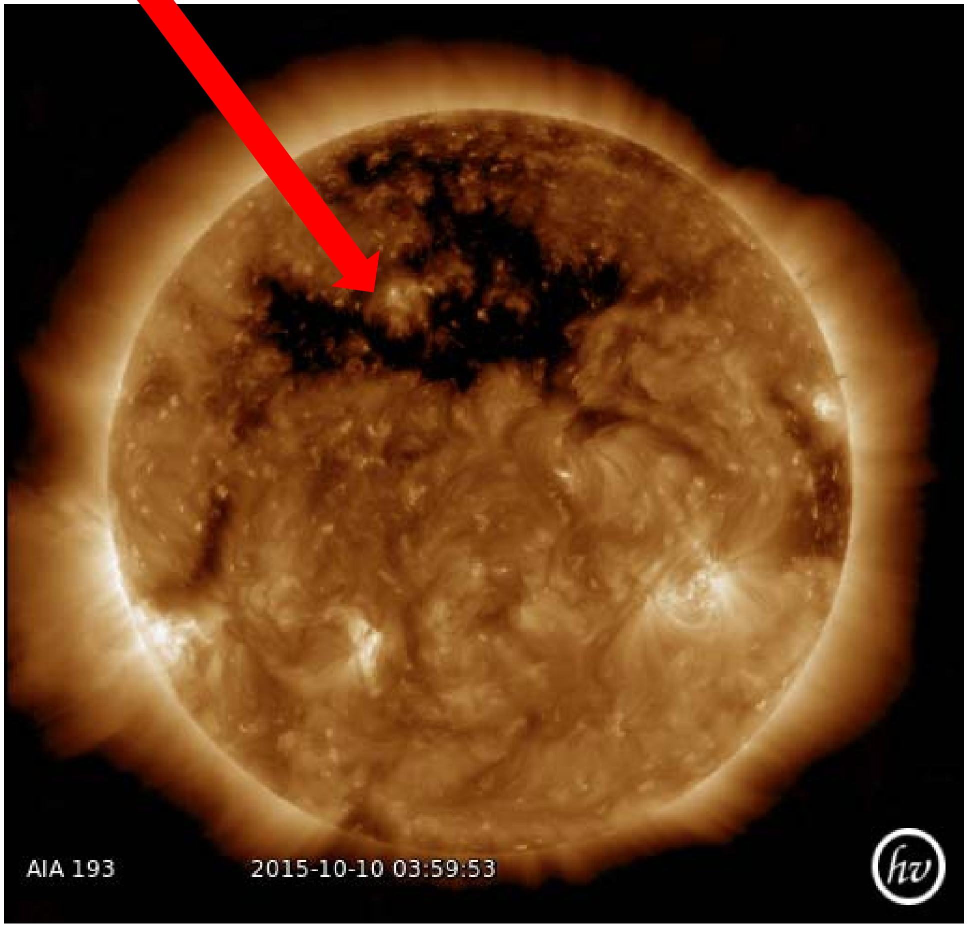
Services

- Images
- Movies
- Features



Coronal Hole (image)

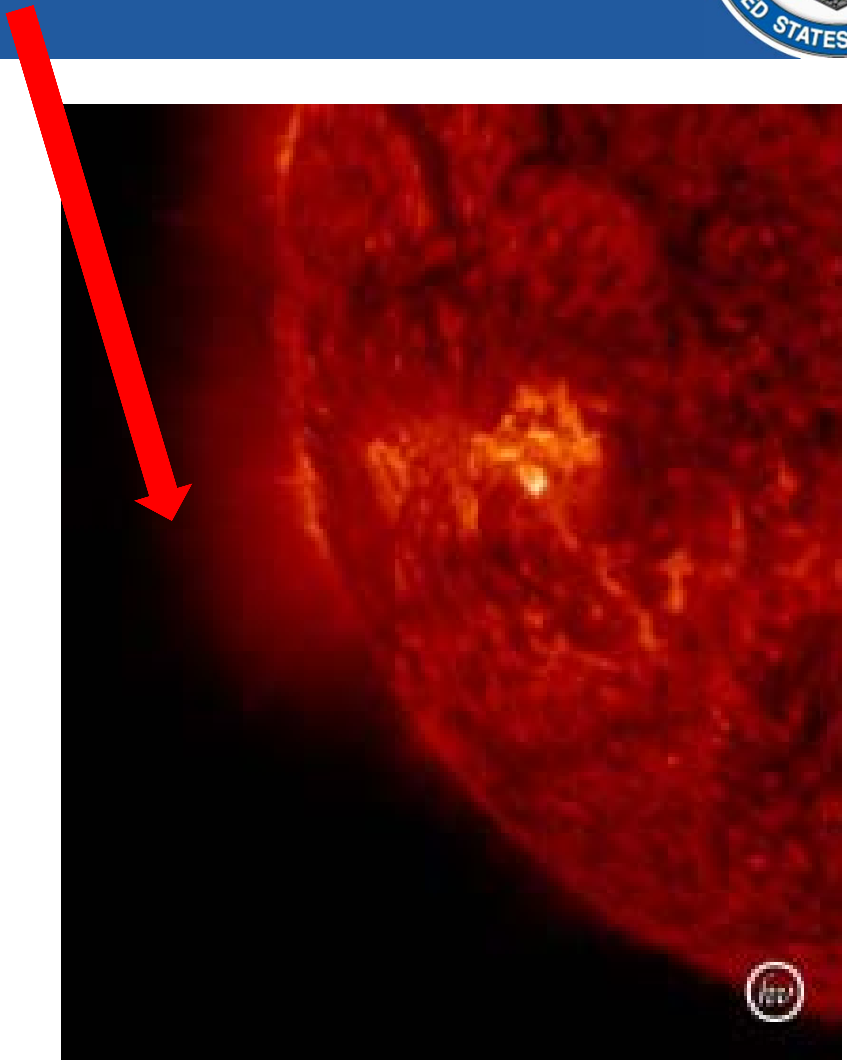
The dark area across the top of the sun in this image is a **coronal hole**, a region on the sun where the magnetic field is open to interplanetary space, sending coronal material speeding out in what is called a high-speed solar wind stream. The high-speed solar wind originating from this coronal hole, created a geomagnetic storm near earth that resulted in several nights of auroras.



Training: Sensor: SDO/AIA
Type: Image
Date: 2015/10/10
Time: 03:59:53
Wavelength: 193 Å
https://helioviewer.org/

Solar Flare (movie)

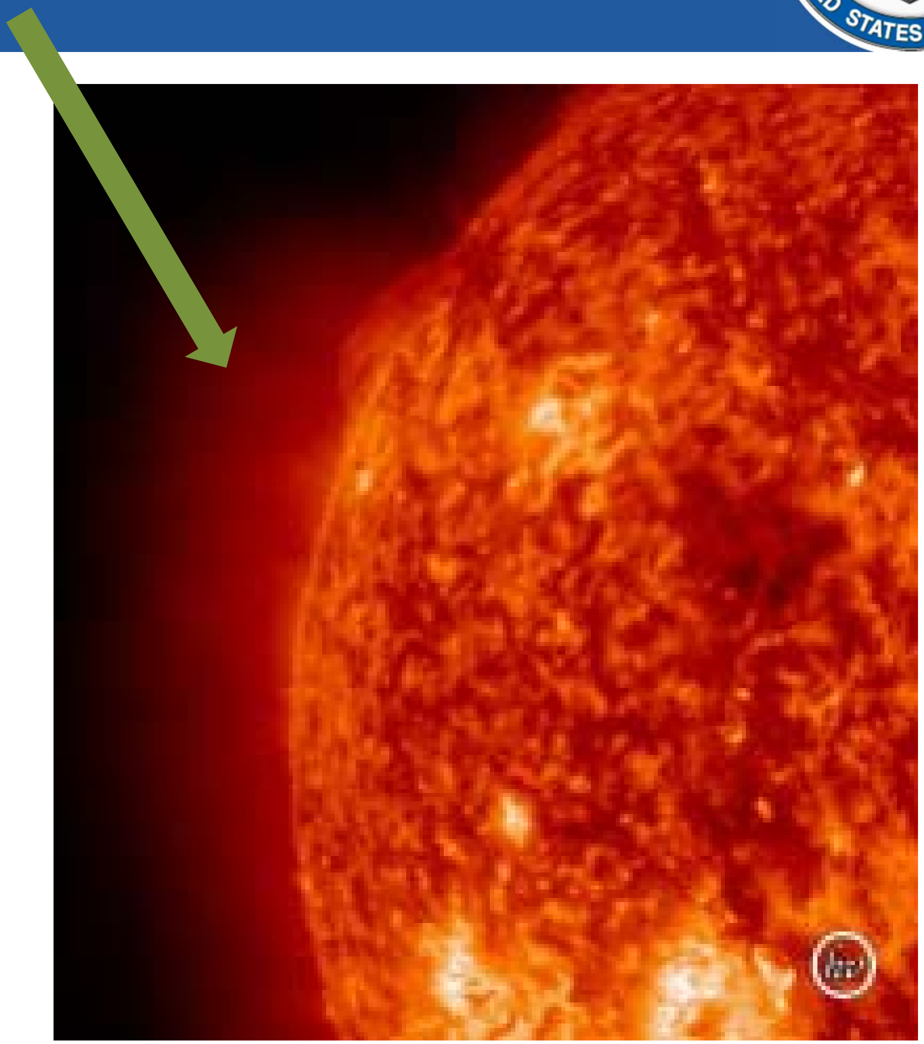
A **solar flare** is defined as a sudden, rapid, and intense variation in brightness. A solar flare occurs when magnetic energy that has built up in the solar atmosphere is suddenly released. Radiation is emitted across virtually the entire electromagnetic spectrum



Training: Sensor: SDO/AIA
Type: Movie
Date: 2015/10/16
Start: 12:45:06
End: 13:44:54
Wavelength: 304 Å
https://helioviewer.org/

Coronal Mass Ejection (Movie)

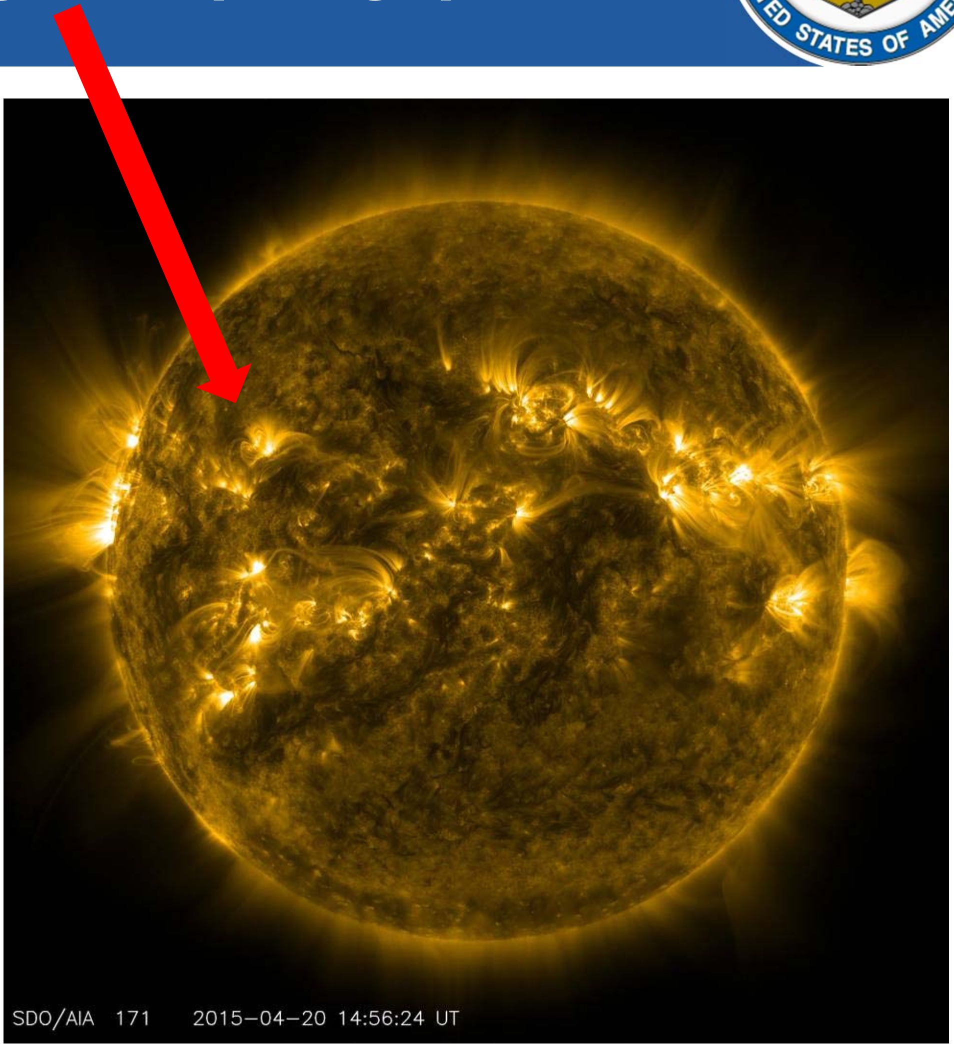
A **coronal mass ejection** (or **CME**) is a giant cloud of solar plasma drenched with magnetic field lines that is blown away from the sun during strong, long-duration solar flares and filament eruptions.



Training: Sensor: SDO/AIA
Type: Movie
Date: 2013/05/01
Start: 02:30:31
End: 03:29:55
Wavelength: 304 Å
https://helioviewer.org/

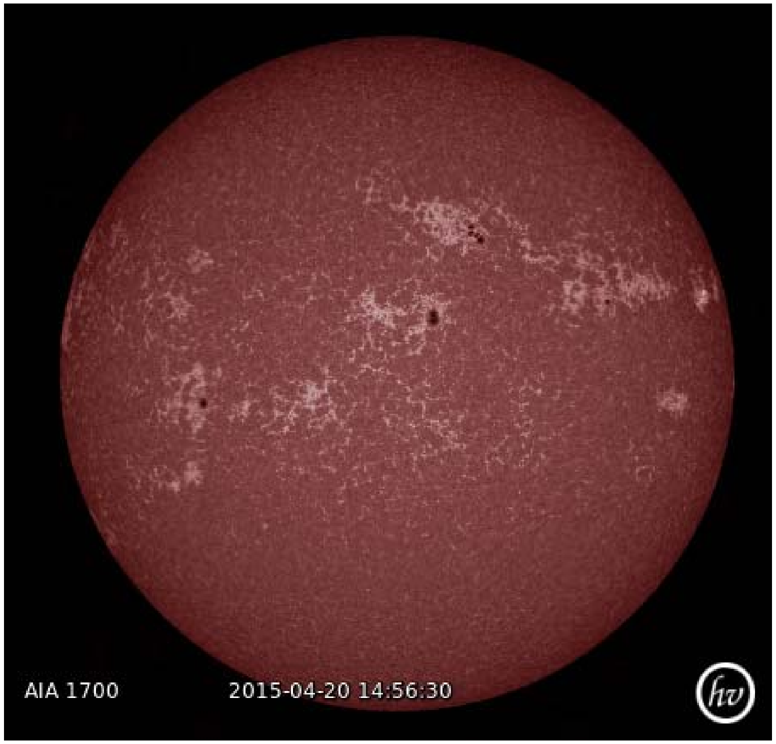
Active Regions (Image)

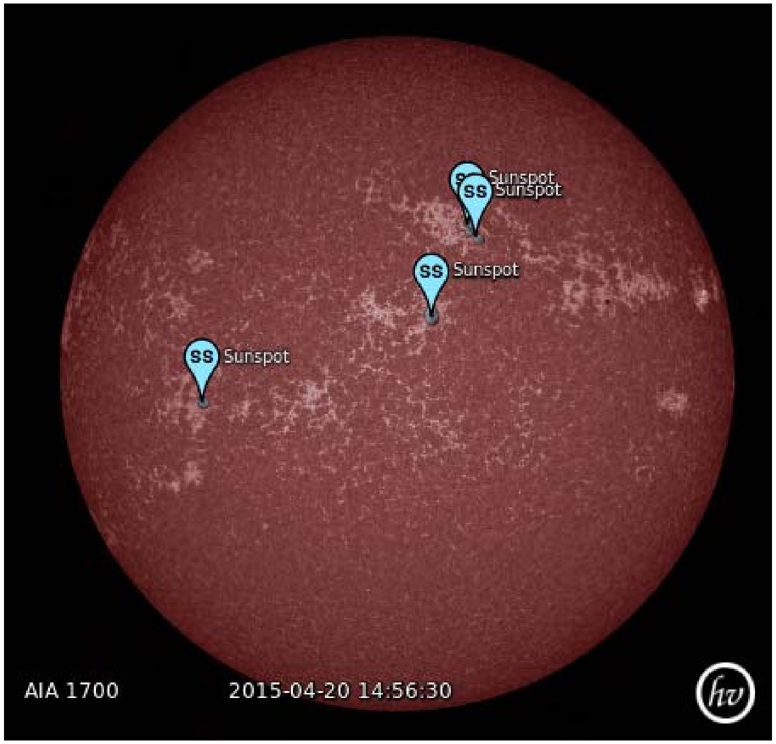
Active regions on the Sun are places where the Sun's magnetic field is disturbed. These regions frequently spawn various types of solar activity, including explosive "solar storms" such as solar flares and coronal mass ejections (CME). Dark sunspots are visual indicators of active regions.



Training: Sensor: SDO/AIA
Type: Image
Date: 2015/04/20
Time: 14:56:24 UT
Wavelength: 171 Å
https://helioviewer.org/

Heliophysics Events Knowledge



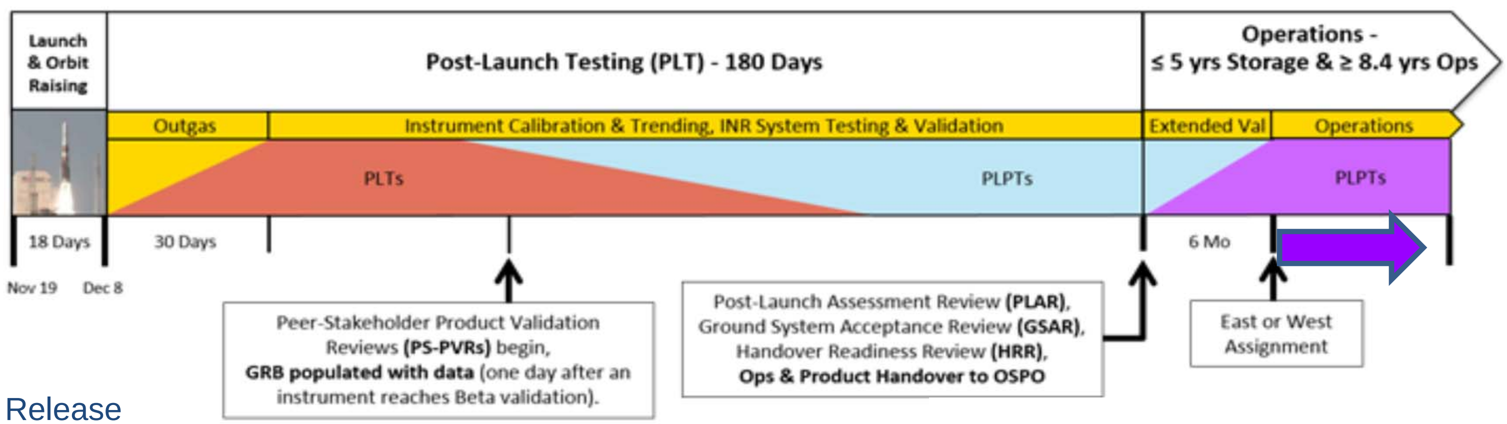


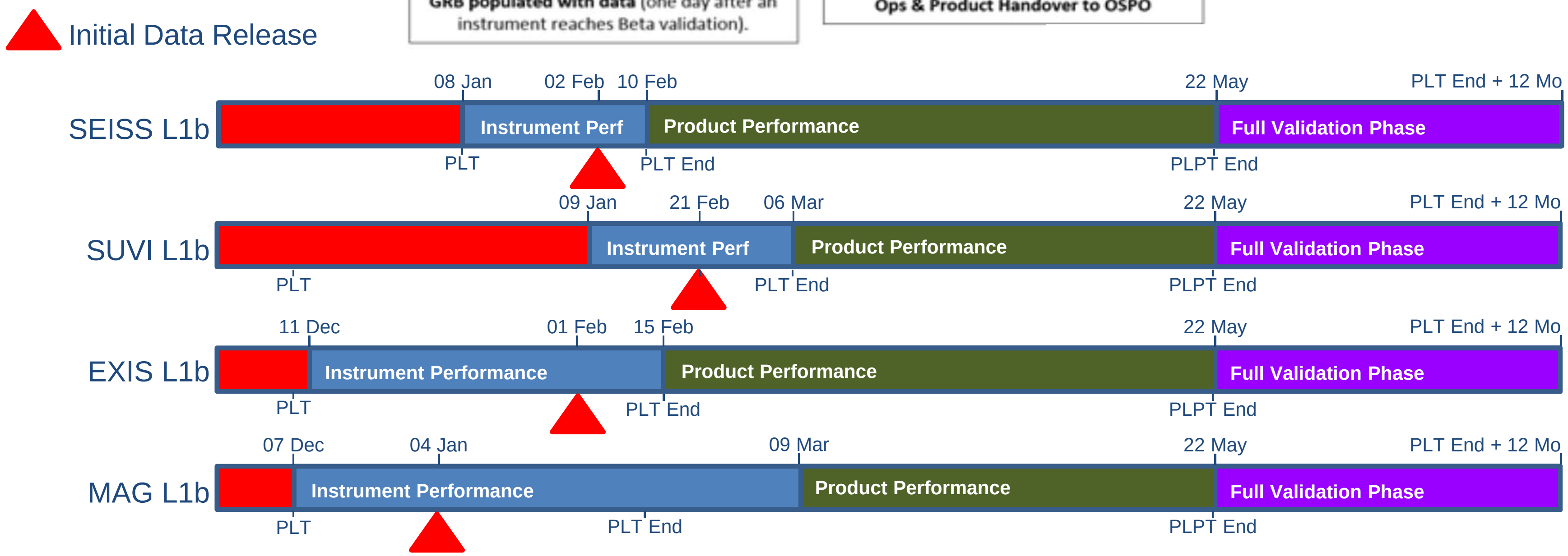
The Heliophysics Events Knowledgebase (HEK) is a source-agnostic catalog of solar features. HEK will be used within Helioviewer for GOES-16 solar imagery. *HEK is not real time – see SUVI L2+ thematic maps*.

Active Regions // Coronal Holes // Emerging Fluxes // Sunspots

Validation Schedule (L1b Products)

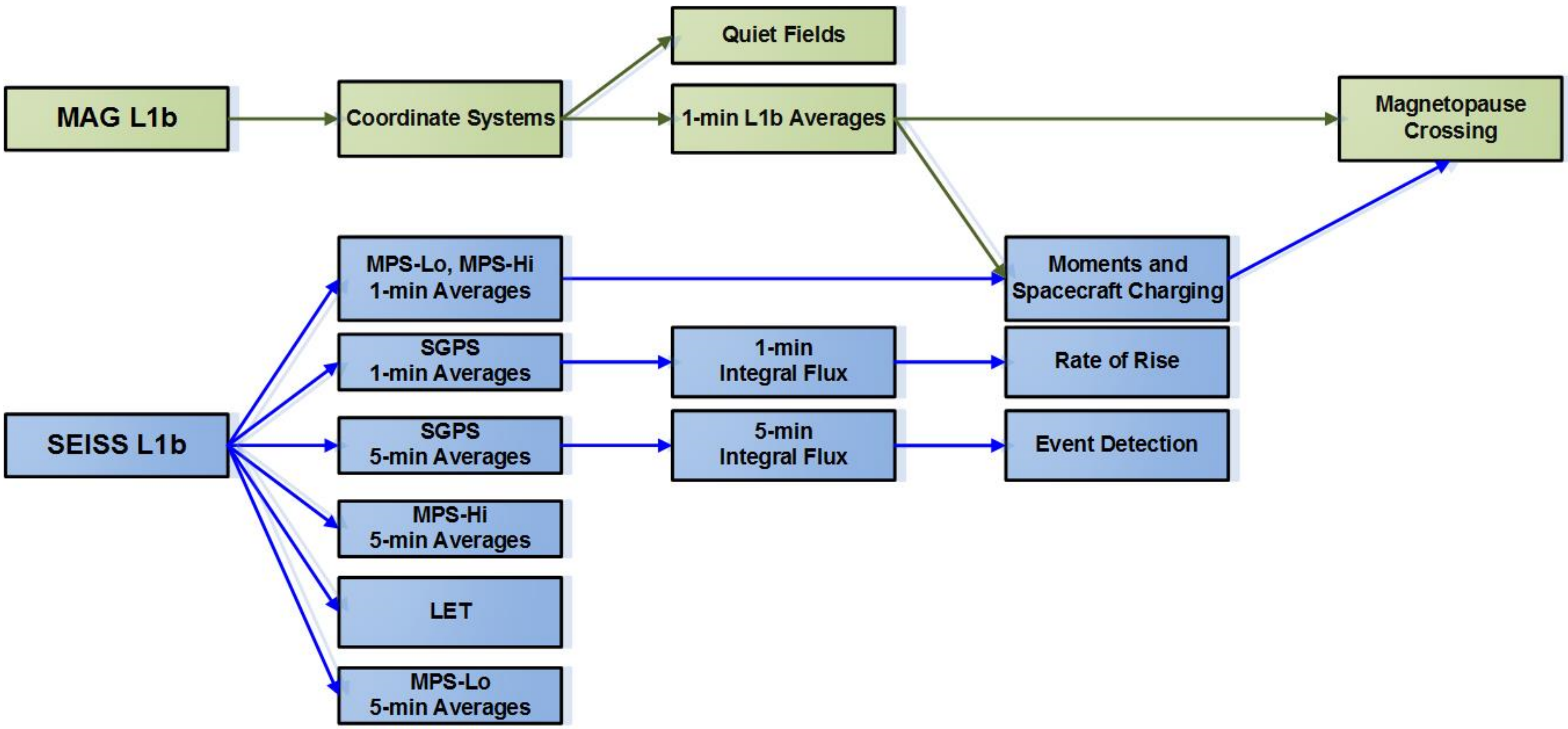
GOES-R Post-Launch Science Product Validation Schedule





L1b and L2+ SWx Products

+ SWx products are used operationally by the NWS Space Weather Prediction Center



L2+ Products for EXIS and SUVI not shown

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

GOES-R Space Weather Team