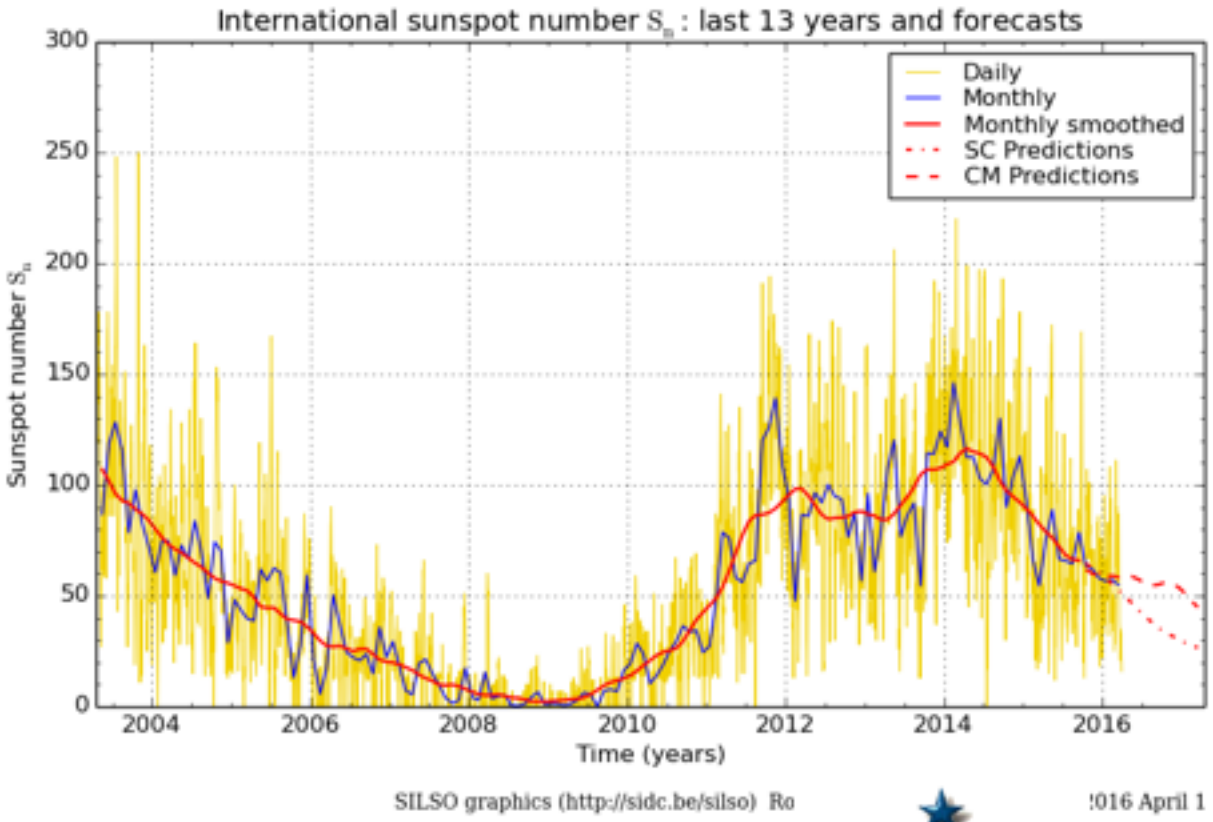
Tracing back Space Weather data from real-time to the distant past

David Berghmans
SIDC - Royal Observatory of Belgium

Tuesday April 5

“The new sunspot number in focus”

POSTER LON-5



Frederic Clette & Laure Lefevre
SIDC - Royal Observatory of Belgium

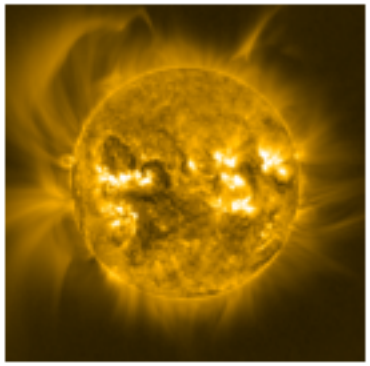
This talk

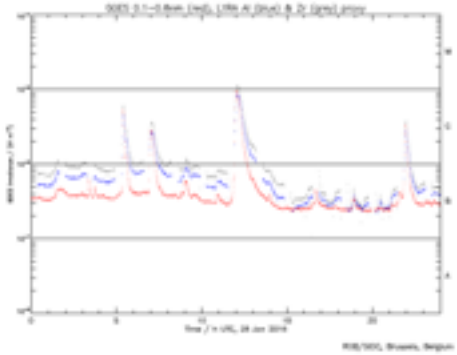
- Space Weather today
- Relation with Space Climate
- 60 years space age
  - coronal imaging
  - CME monitoring
  - flare monitoring
- What have we learned?

Hands-on

- the quiz
- Ilpo Virtanen: OMNIWeb & CDAWeb
- jHelioviewer

Space Weather





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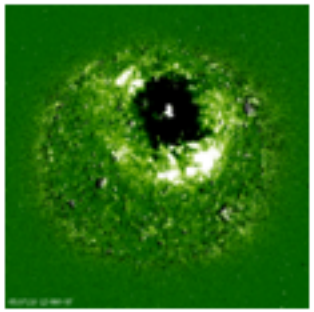
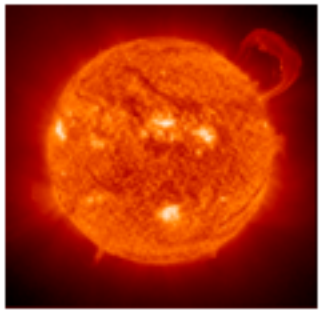
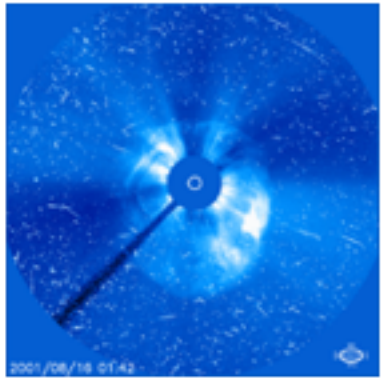
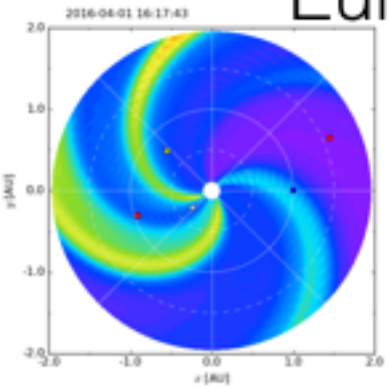




Euhforia

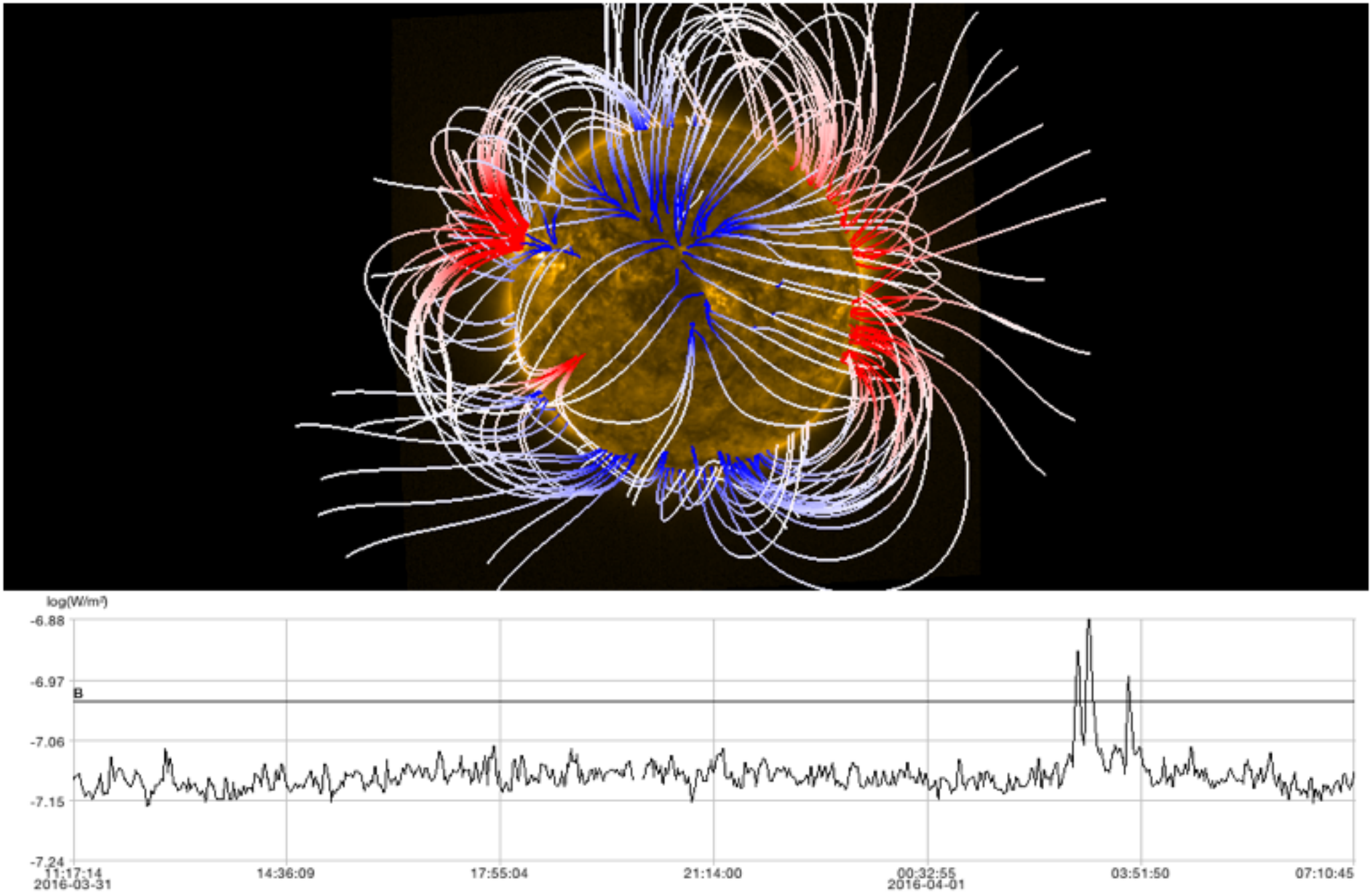
LASCO





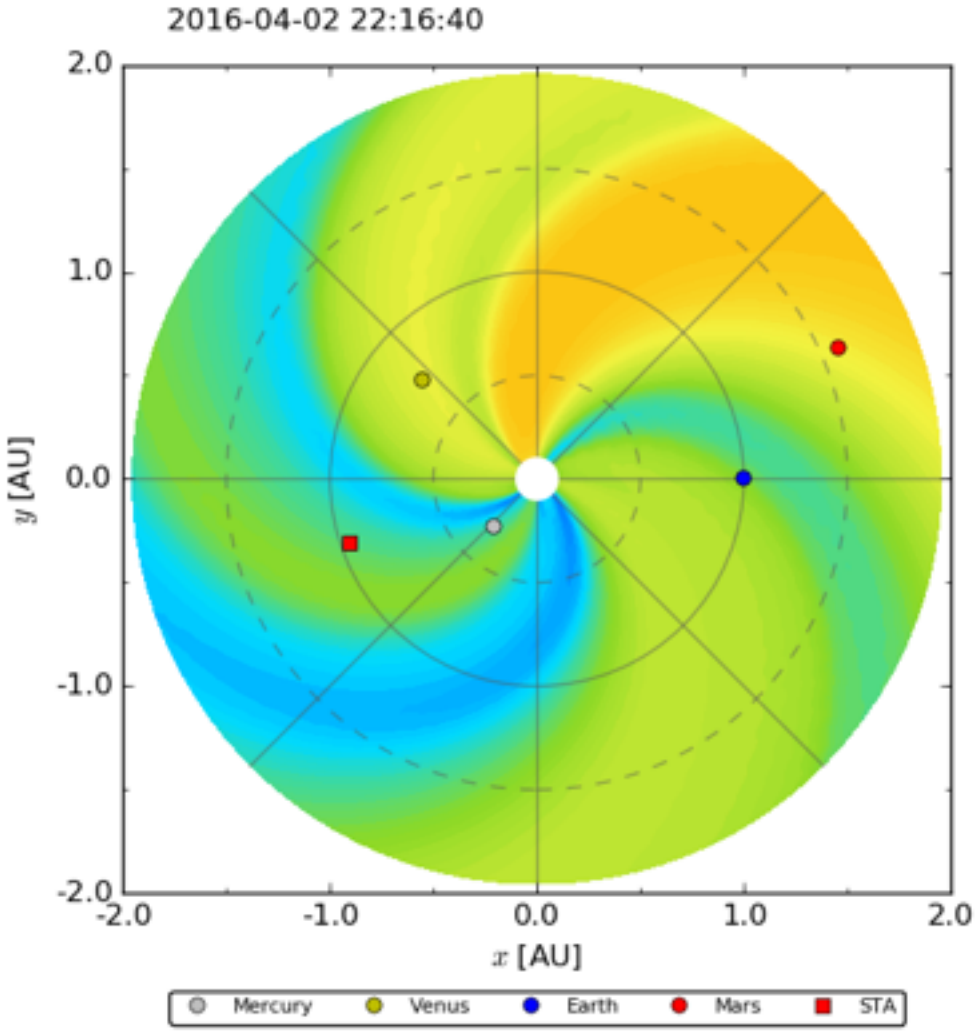
coronal imaging

LEVI

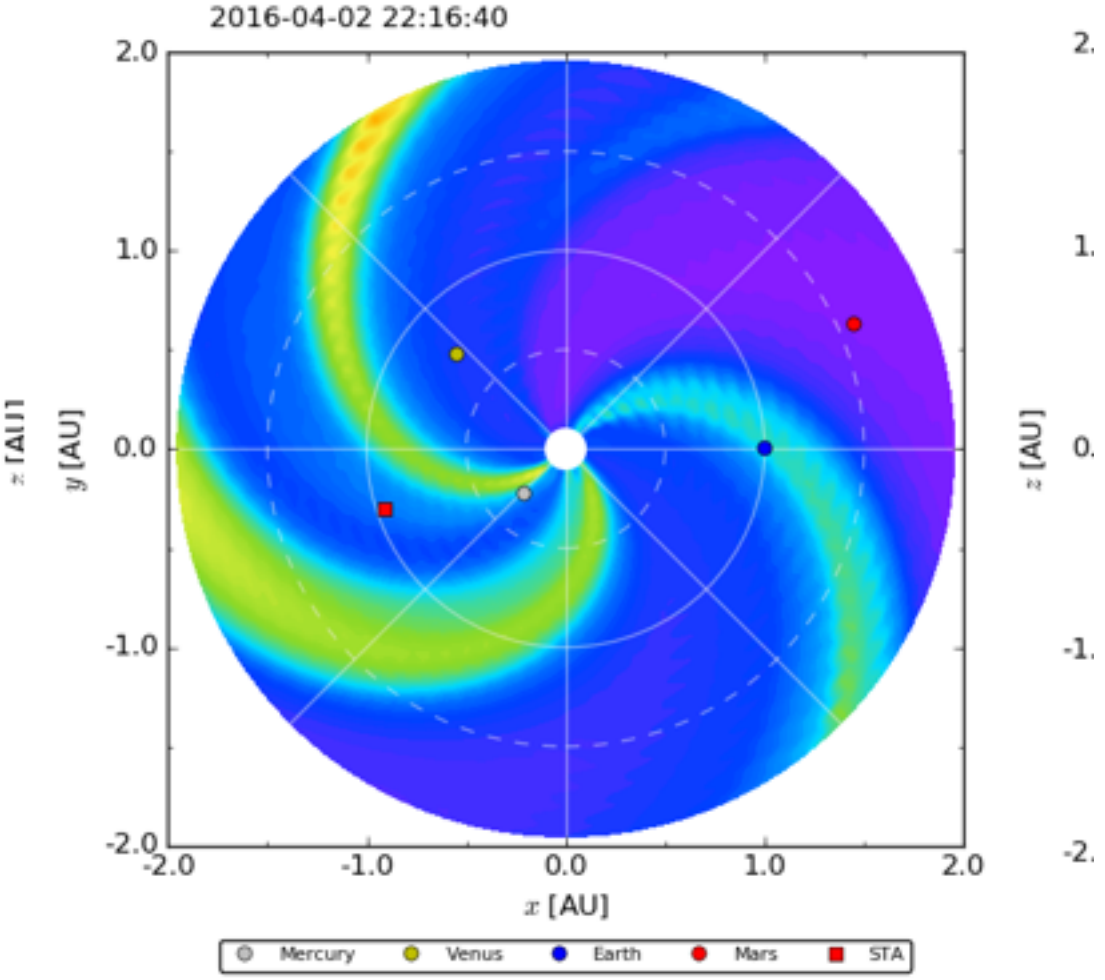


http://sidc.be/jhelioviewer

solar wind speed



solar wind density



Euhforia (Poedts et al)

INFO FROM SIDC - RWC BELGIUM 2016 Apr 01 12:30UTC

Solar flaring activity was limited to three B1 flares from NOAA 2526. No earth-directed coronal mass ejections (CMEs) have been observed over the last 2 days.

Quiet conditions are expected to continue.

Solar wind speed decreased from initial values near 450 km/s to values around 400 km/s by the end of the period. Bz varied between -3 and +3 nT. The interplanetary magnetic field was directed away from the Sun till about 08UT, then slightly towards between 08-12UT. Geomagnetic conditions were quiet.

Mostly quiet to unsettled geomagnetic conditions are expected until the arrival later today or tomorrow (2 April) of a sector boundary crossing and the co-rotating interaction region ahead of the wind stream of the small negative equatorial coronal hole. This may result in minor geomagnetic storming on 2 and 3 April, with a small chance on moderate storming on 2 April.

http://sidc.be

"**Space climate** is an interdisciplinary science that concentrates on the long-term change **(tens to thousands of years)** in the Sun and its effects in the heliosphere (region of space dominated by solar magnetic field), in the near-Earth space, atmosphere and climate. **Space weather** is concentrated on studying these things on shorter **time scales from hours to few days.**"

–Website University of Oulo

timescale	feature	impact	
billion years	stellar evolution	Armageddon	
?			**Space Climate**
centuries	grand minima	climate change?	
decades	solar cycle		
year	Earth orbital periode		
month	solar rotation	recurrent storms (CIRs)	**Space Weather**
day	Earth rotation	CME arrival	
hour	eruptions	SEP	
(sub)minutes	flare flashes	radio black-outs	

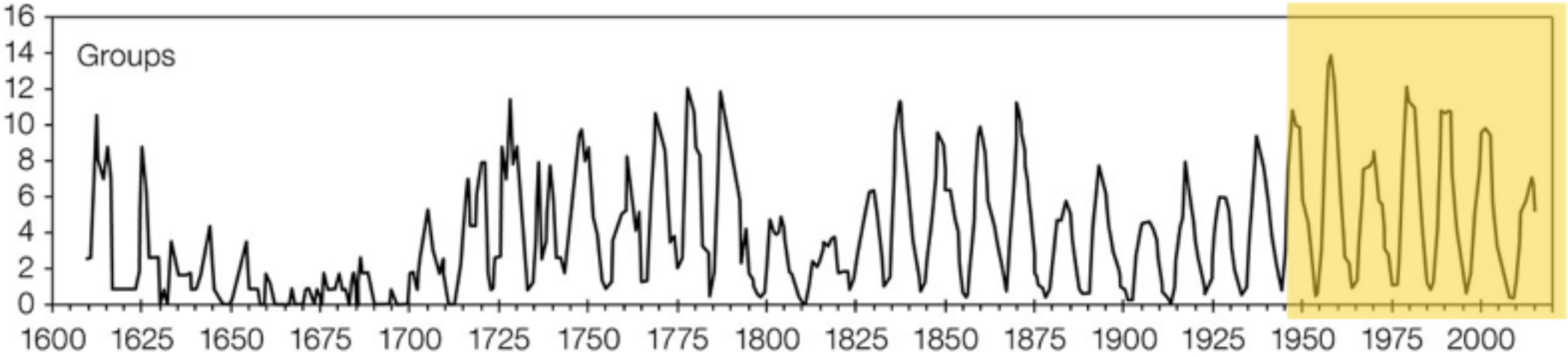
So why bother?

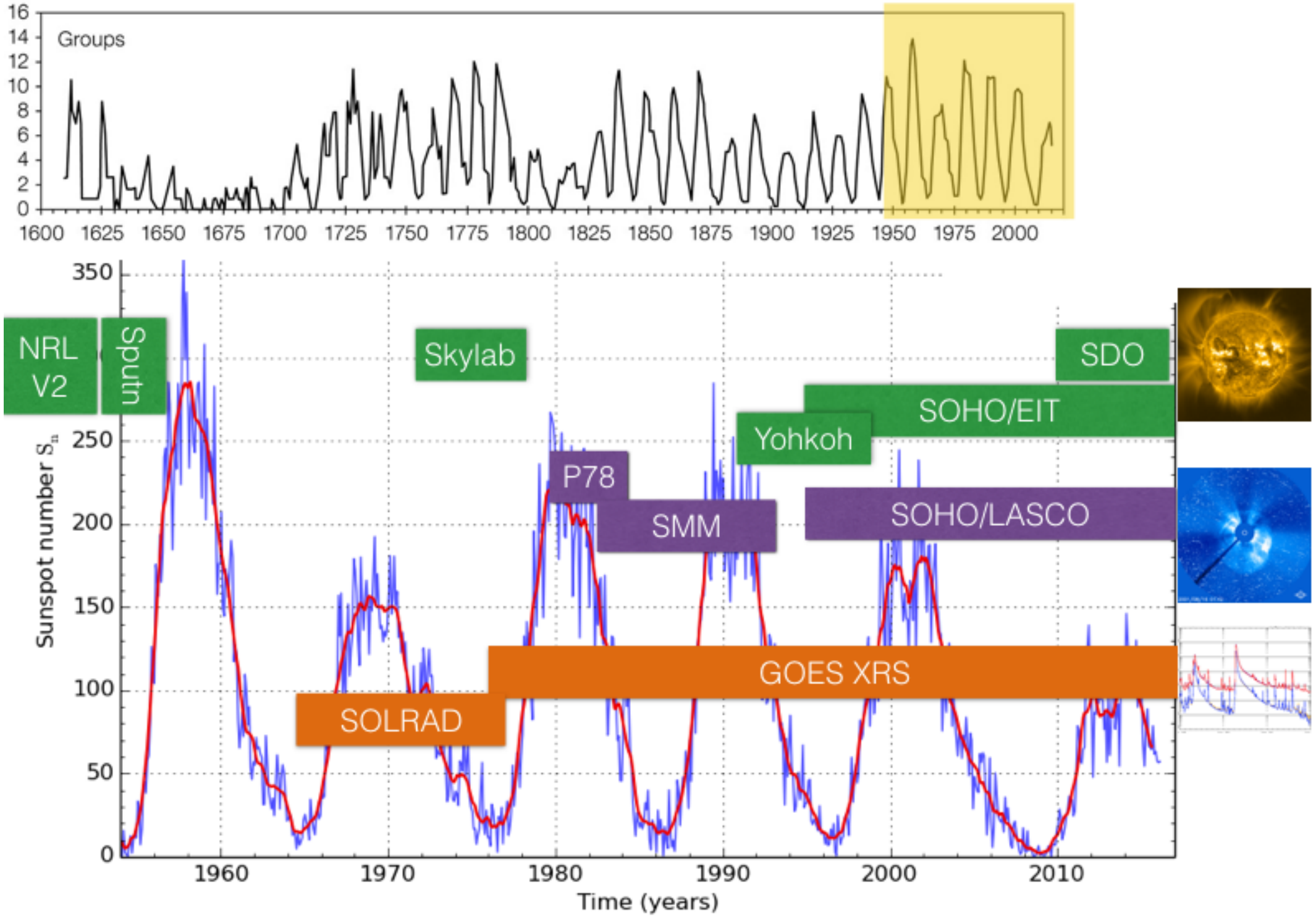
space climate is good for space weather
large scale statistics (=space climate) are essential references when making short term forecasts (=space weather)

space weather is good for space climate
real-time space weather data accumulates since the beginning of the space age untill it becomes relevant for space climate

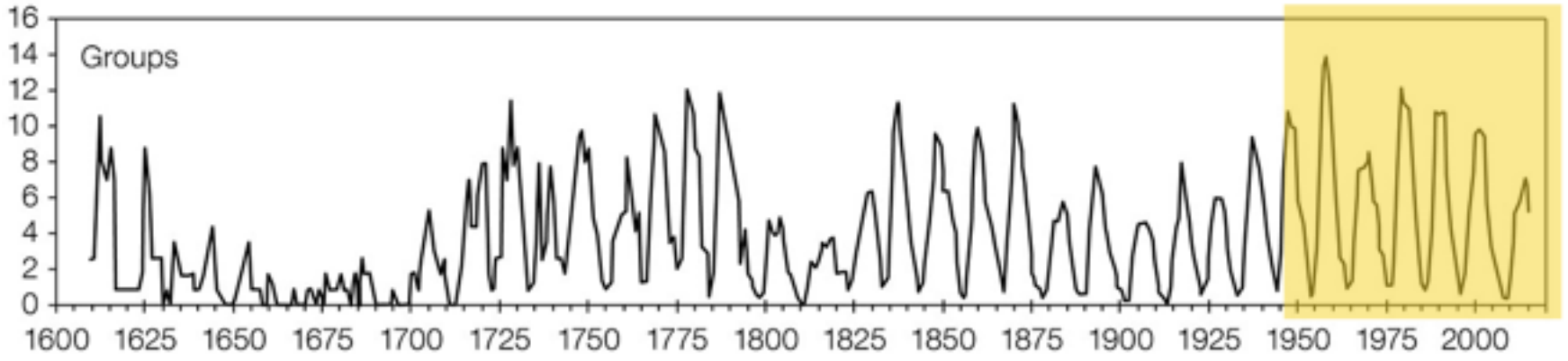

WIKIPEDIA: The Space Age began […] on October 4, 1957, with the launch of Sputnik 1 by the Soviet Union. This was the world's first artificial satellite, orbiting the Earth in 98.1 minutes and weighing 83 kg.

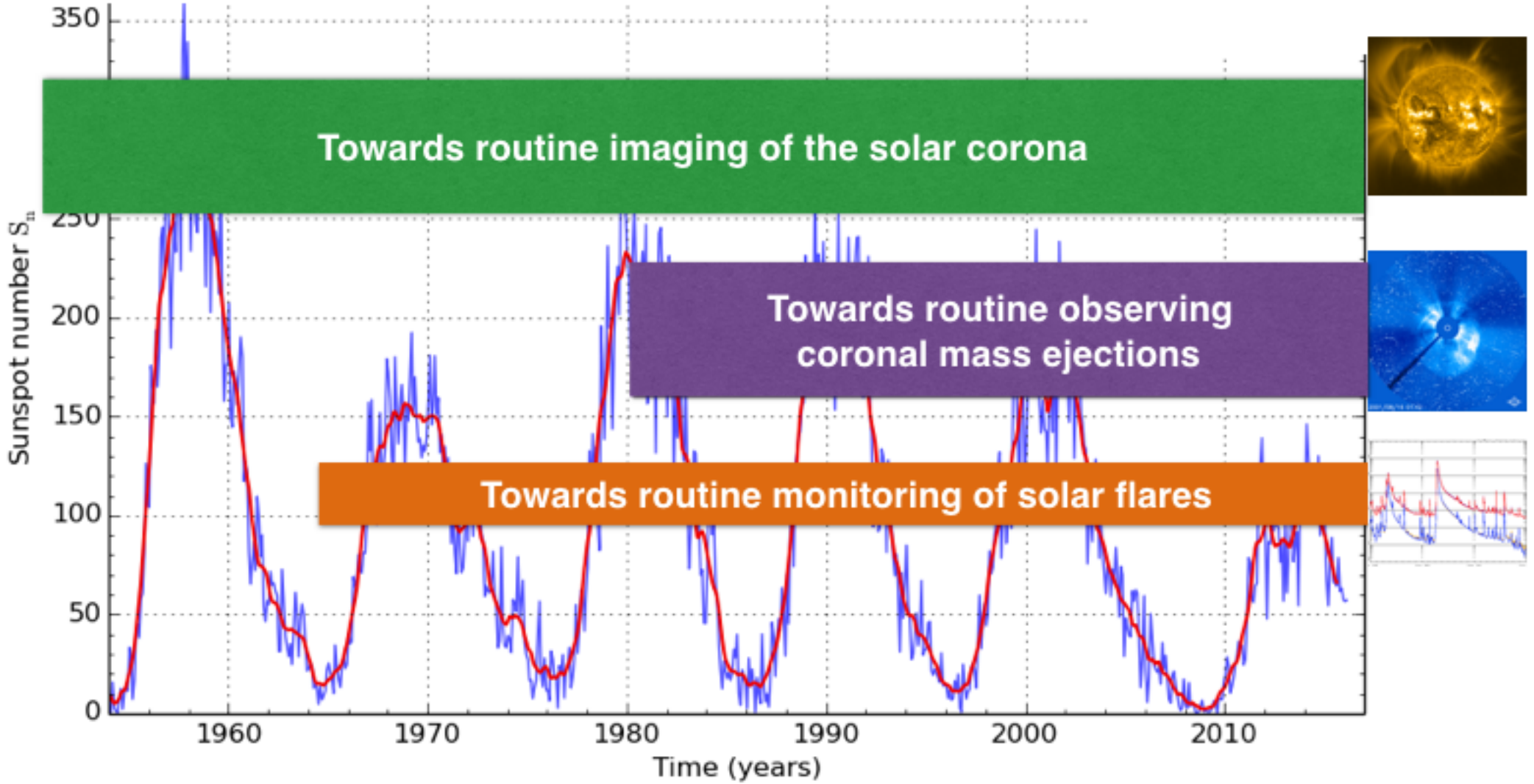
~60 years Space Age





SILSO graphics (http://sidc.be/silso) Royal Observatory of Belgium 2016 March 1



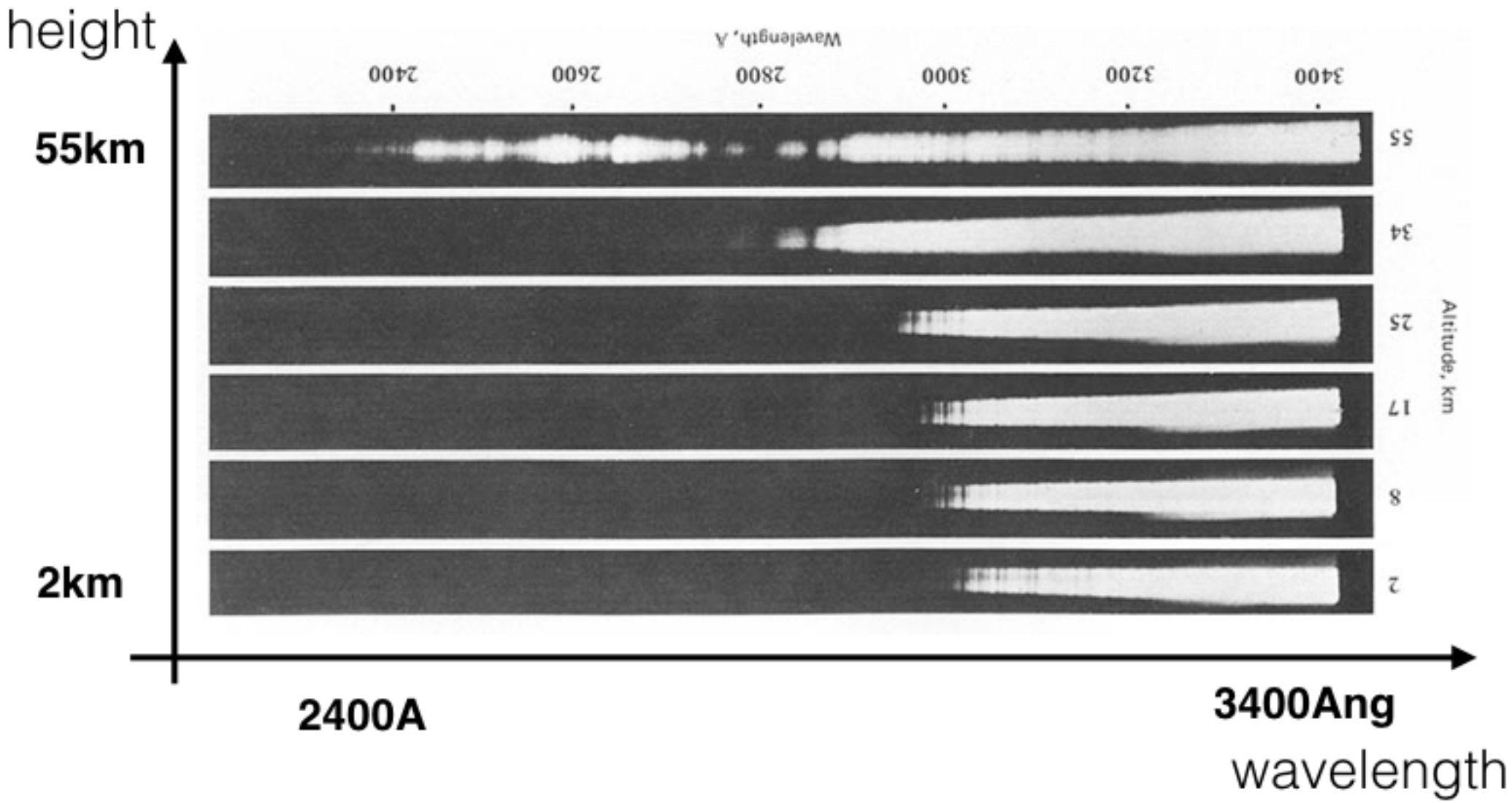


SILSO graphics (http://sidc.be/silso) Royal Observatory of Belgium 2016 March 1

Towards routine imaging of the hot corona


V2-rocket
technology

NRL experiment:
Spectrograph flown on V2-rocket in 1946

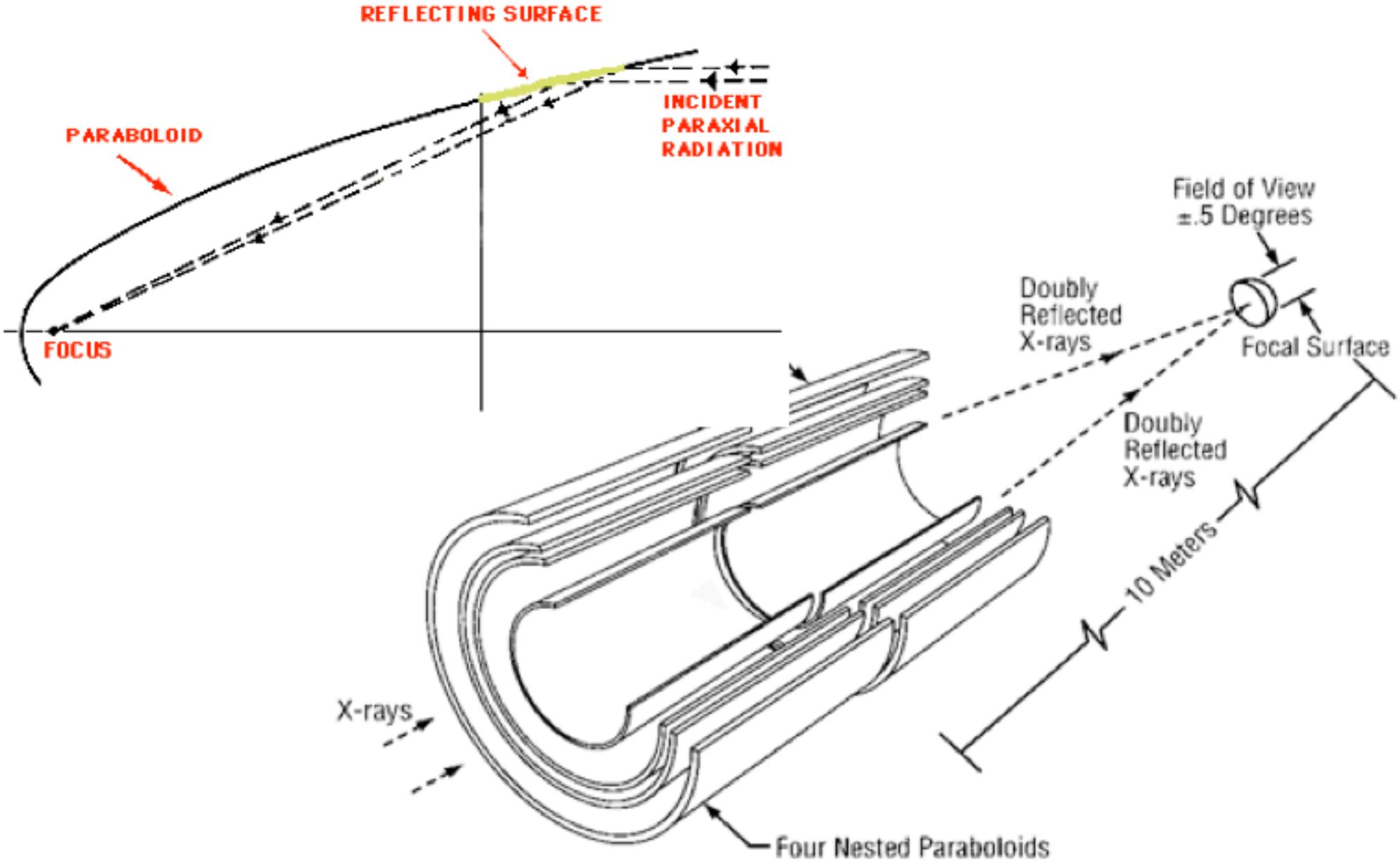


Tousey (1967) ApJ, 149, 239

Pinhole camera flown in 1960

Friedman (1963) IAUS, 16, 45

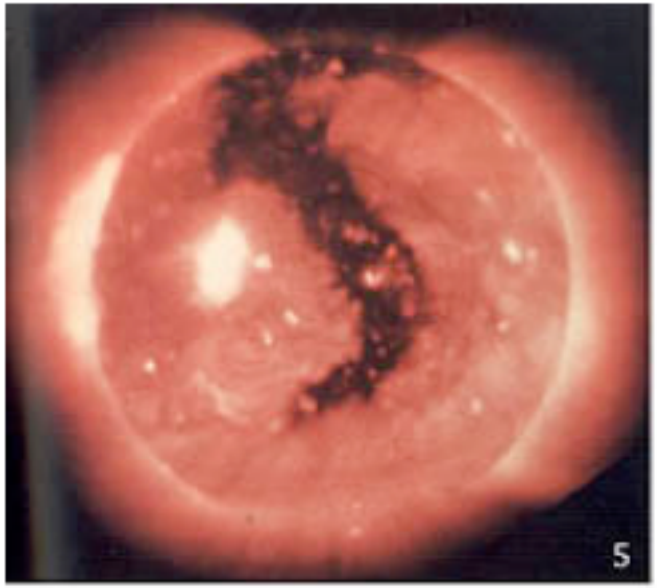
reflecting X-rays is hard



XMM mirrors during tests at Centre Spatial de Liege

Skylab (1973-74)

http://history.nasa.gov/SP-402/ch1.htm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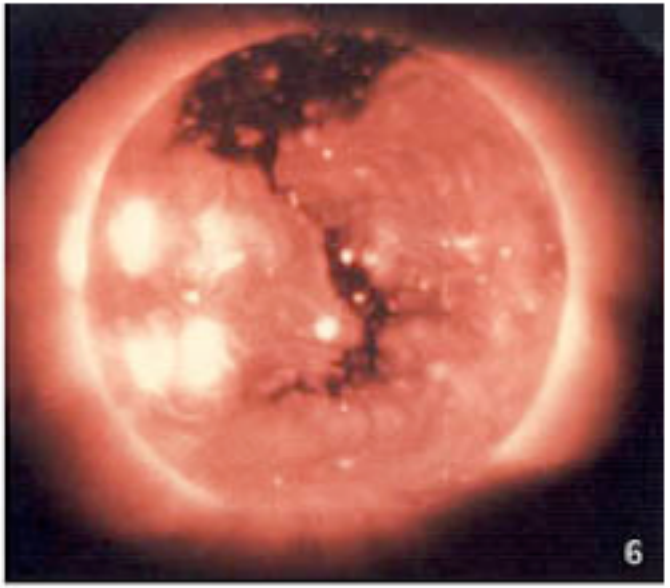
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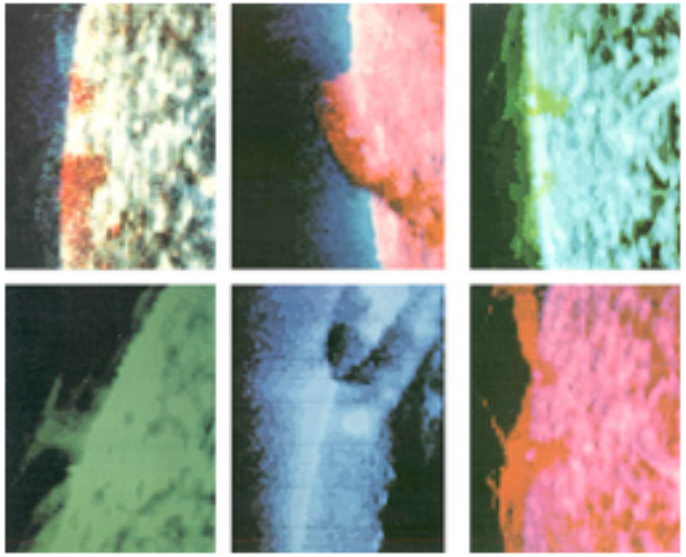

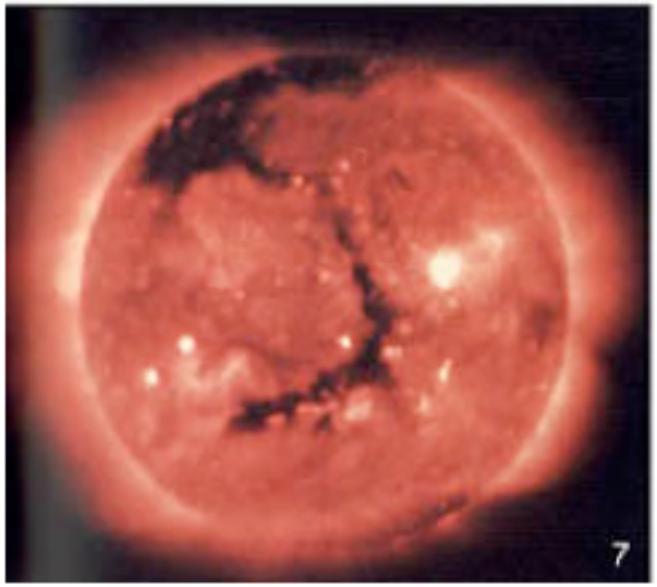
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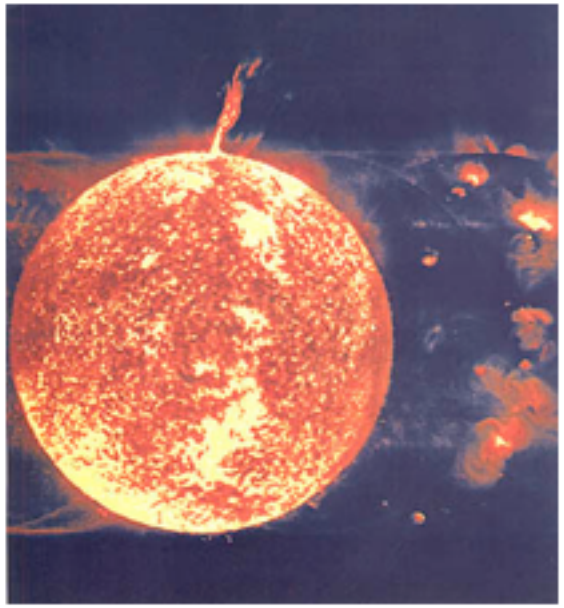
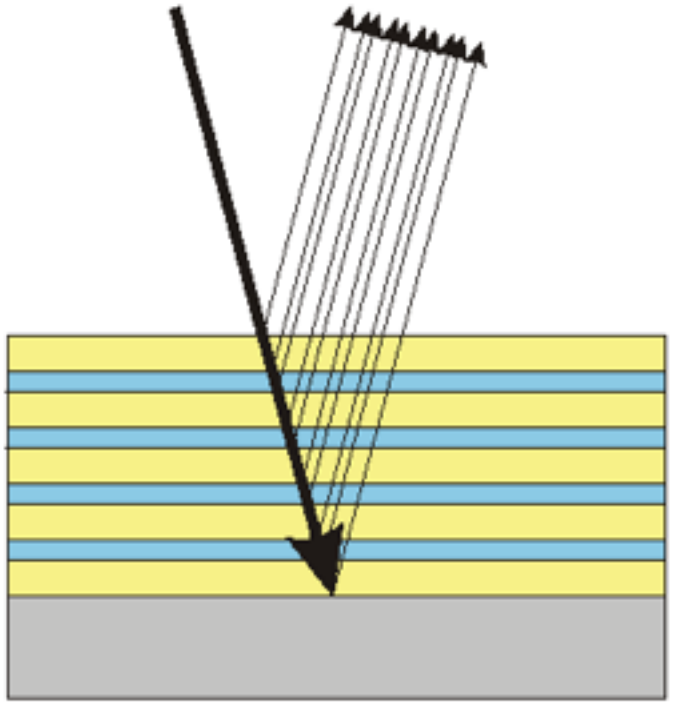
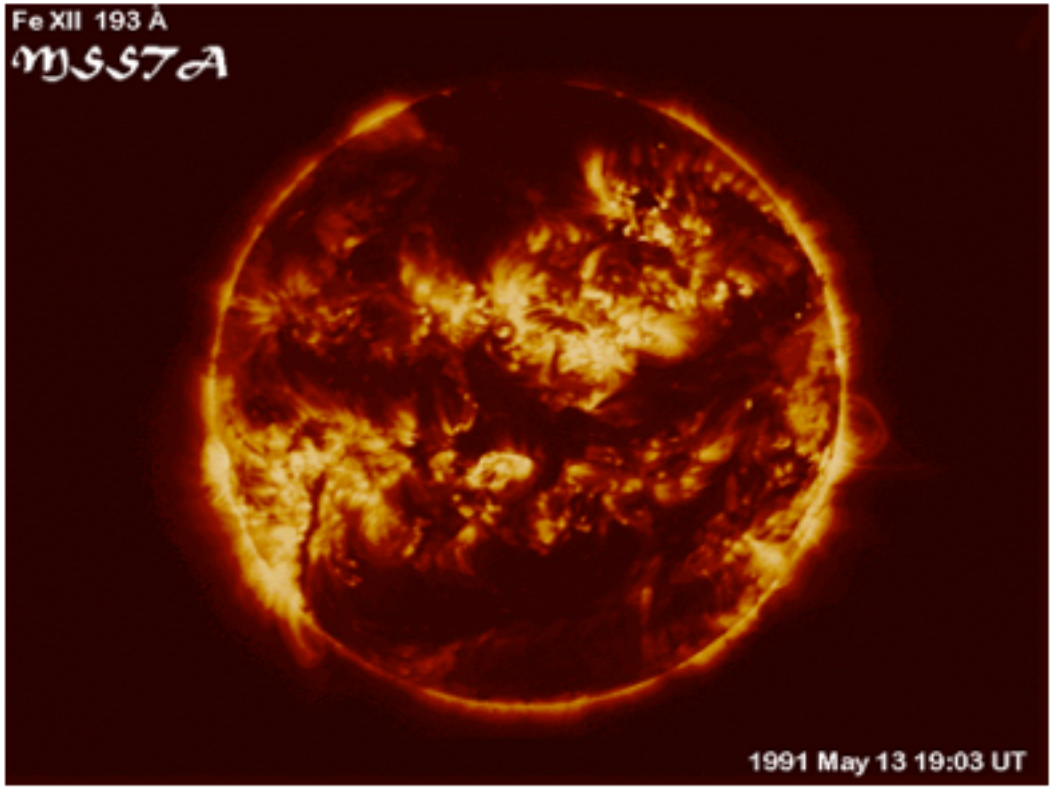


MSSTA & NIXT (1990)



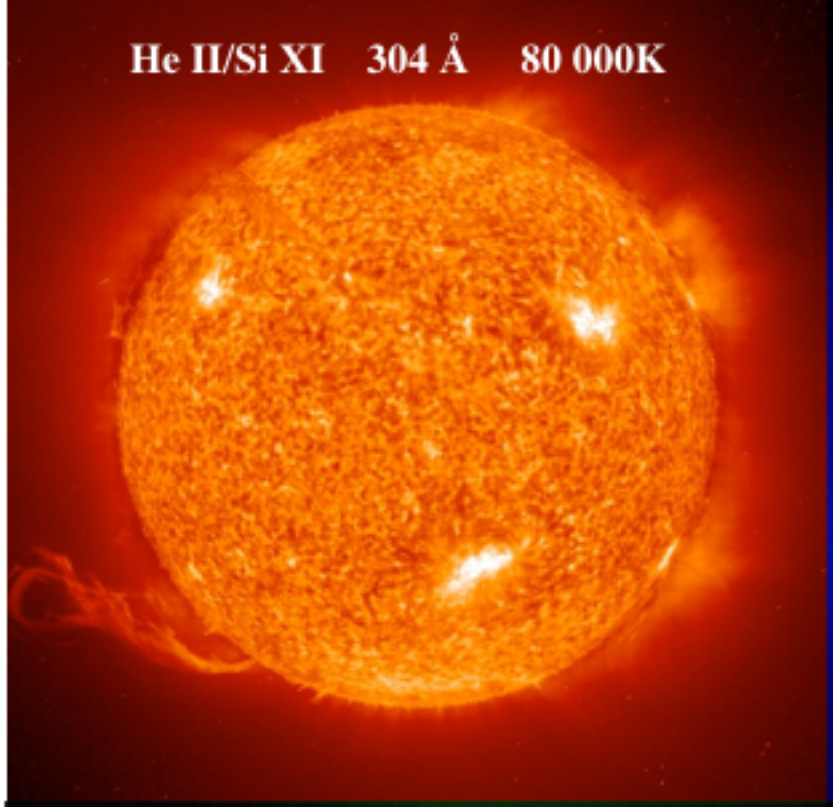


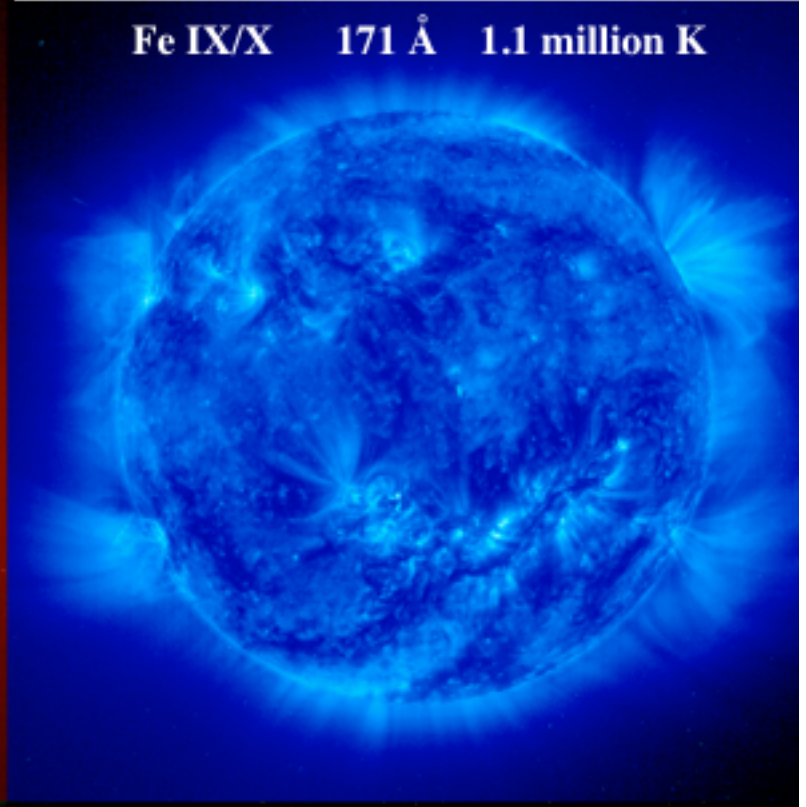
http://solarscience.msfc.nasa.gov/MSSTA.shtml

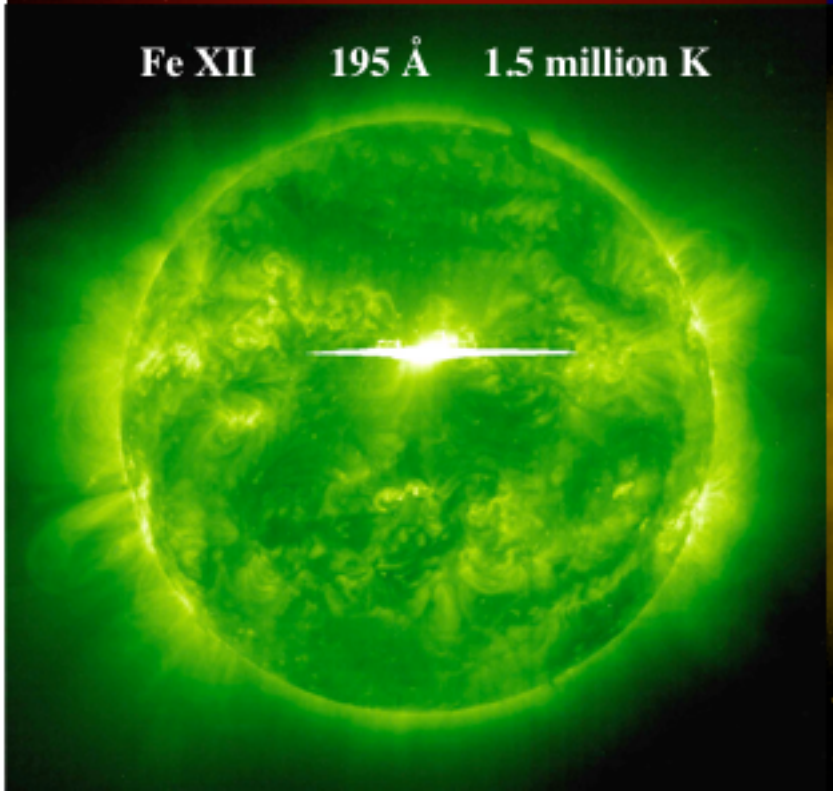
onboard SOHO

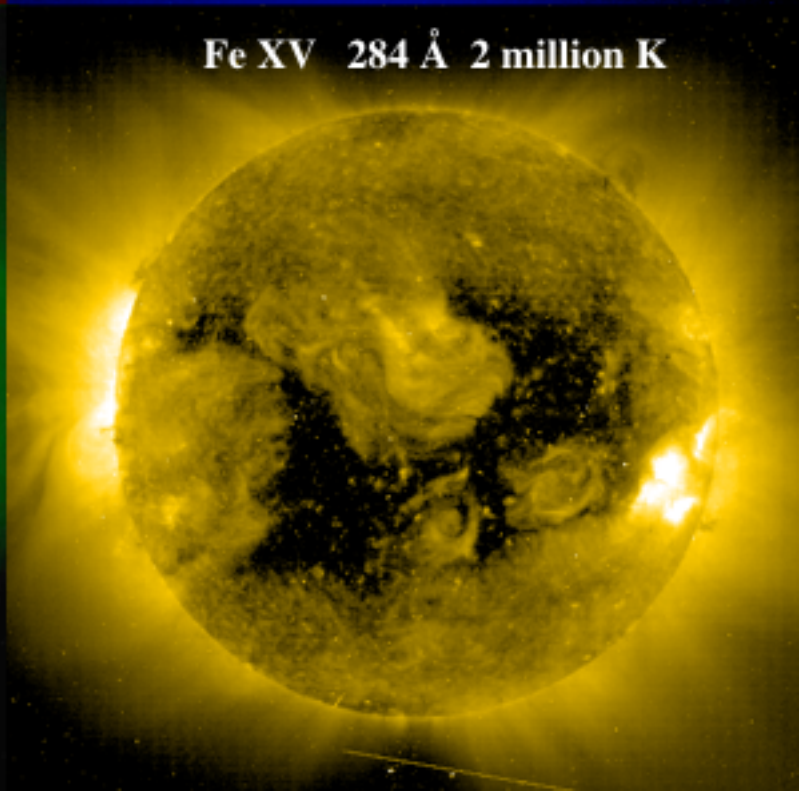
EIT

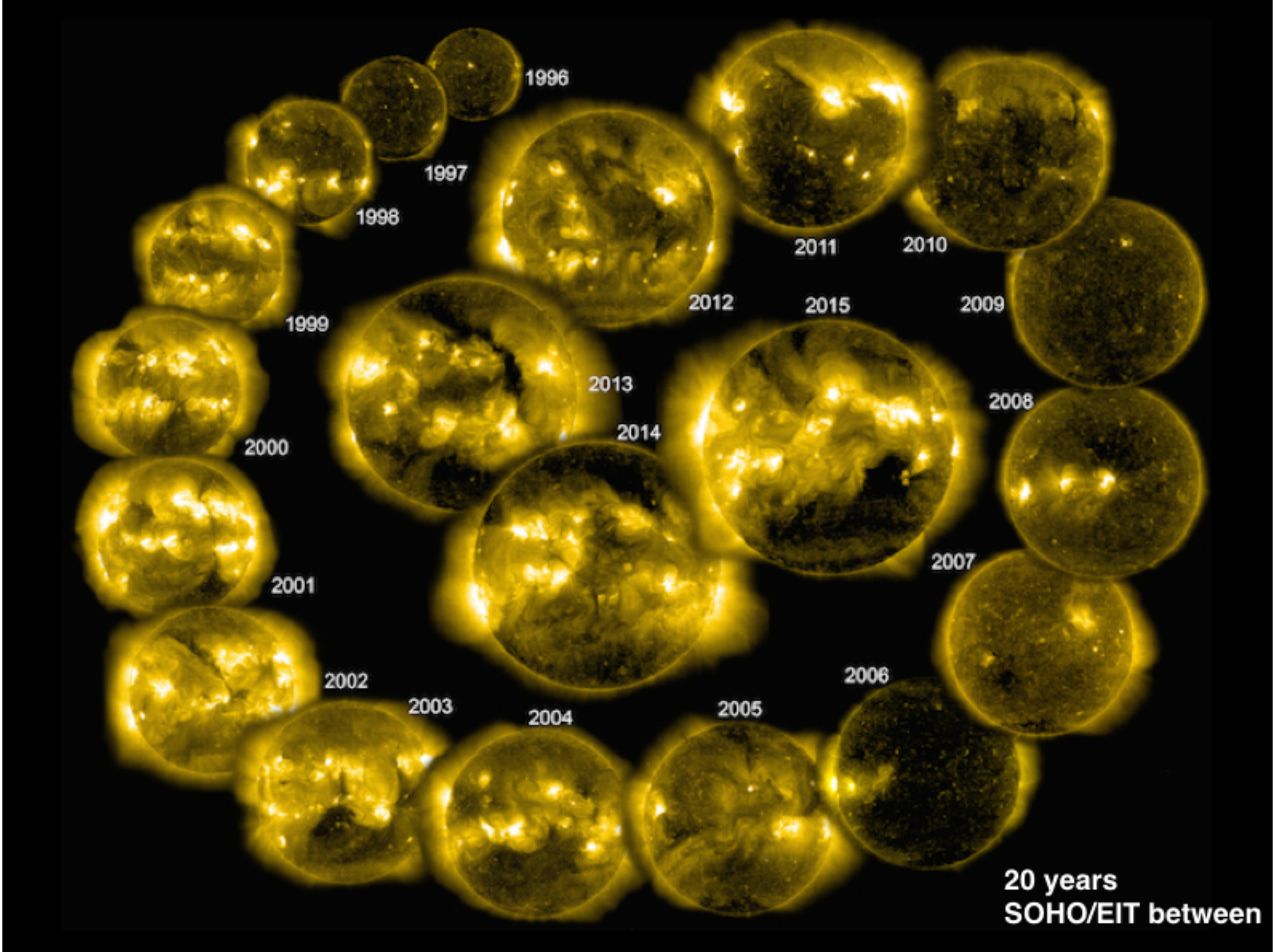
1995-present







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20 years
SOHO/EIT between

Britain's best-selling astronomy magazine

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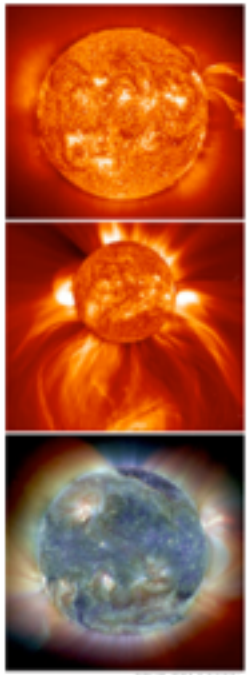
SCIENCE JOURNAL
By ROBERT LEE HOTZ

Digital Age Means We Must Care More About Space Weather

September 28, 2007; Page B3

A moody, middle-age star, our sun has an explosive temperament. Power surges that flare from its roiling magnetic fields send outbursts of charged particles, radio static and X-rays across the 93 million miles to Earth. With little warning, these cosmic tsunamis of energy periodically have disabled commercial satellites, overloaded power grid transformers, blacked out radio communications and sent space-station astronauts scrambling for radiation shelter.



Space weather forecasters are bracing for a new season of intense sunspot activity that could begin by March and peak in 2012 -- and they worry that outages and damage could be even greater this time because the world has become increasingly dependent on wireless and cellular electronic networks. We are, therefore, even more susceptible to these sudden gales of solar wind.

"We are set up for a nasty surprise," said Thomas Bogdan, director of the federal Space Environment Center in Boulder, Colo., the largest of 13 international space weather warning centers. "There are going to be impacts on all these services in the next few years."

Worries about solar storms are as old as the telegraph. When 19th-century entrepreneurs first started stringing long-distance wires across the U.S., they discovered that the lines attracted so much electricity during peak solar activity that the system could run without batteries and telegraph operators risked electrocution.

FORUM

VOTE ON THE CENTURY'S 10 HOTTEST SKY EVENTS

SPECIAL ISSUE

Astronomy

'UFO' on NASA camera

By TIM UPTON

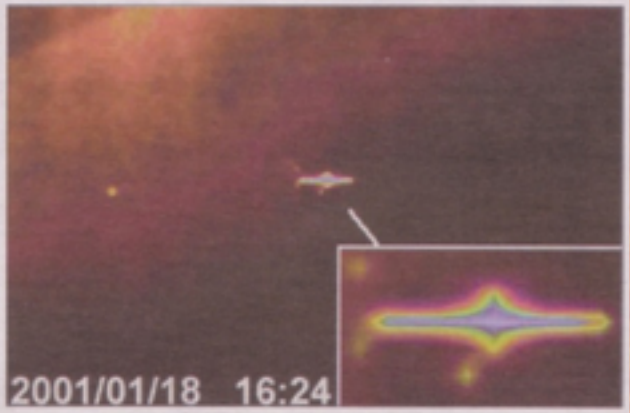
WASHINGTON: The object is certainly unidentified and appears to be flying.

Whether this enlarged image really shows a UFO piloted by aliens remains to be seen. But according to the people who released it this photo and hundreds like it are the best evidence yet of the existence of spacecraft from other worlds.

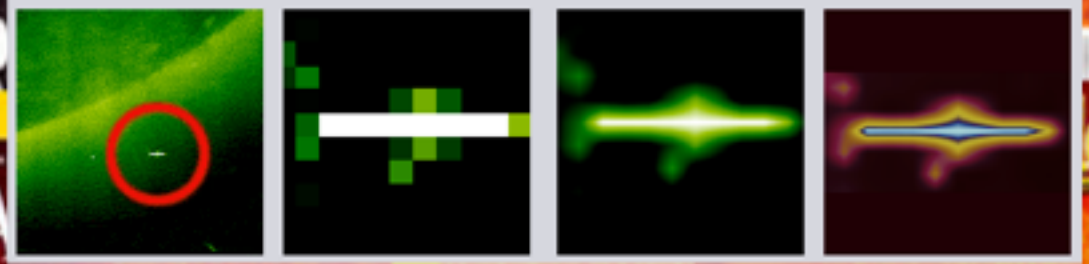
UFO investigators say the image was captured by the Solar and Heliospheric Observatory (SOHO), a NASA satellite that was launched in 1996 to observe the sun. Since then, it is said, SOHO has captured hundreds of images of UFOs moving along a kind of alien superhighway.

SOHO is more than 1.5 million kilometres from Earth, with its camera trained towards the sun. Experts say the photographed objects are likely to be only hundreds of kilometres from its lenses.

Graham Birdsall, editor of *UFO* magazine, said: "The images are irrefutable in that they are from official satellites owned by NASA. They resemble the kind of spacecraft we used to see in sci-fi films like *Star Trek*."



UTTERLY ALIEN: The image investigators say shows a UFO.



SpaceFlight

The Magazine of Astronautics and Outer Space

OGRAPHIC

un bursts

HOT NEWS FROM OUR STORMY STAR

En cadeau le CD-Rom du Soleil vu par Soho

400 images 100 vidéos

pour PC et Mac

CIEL & espace

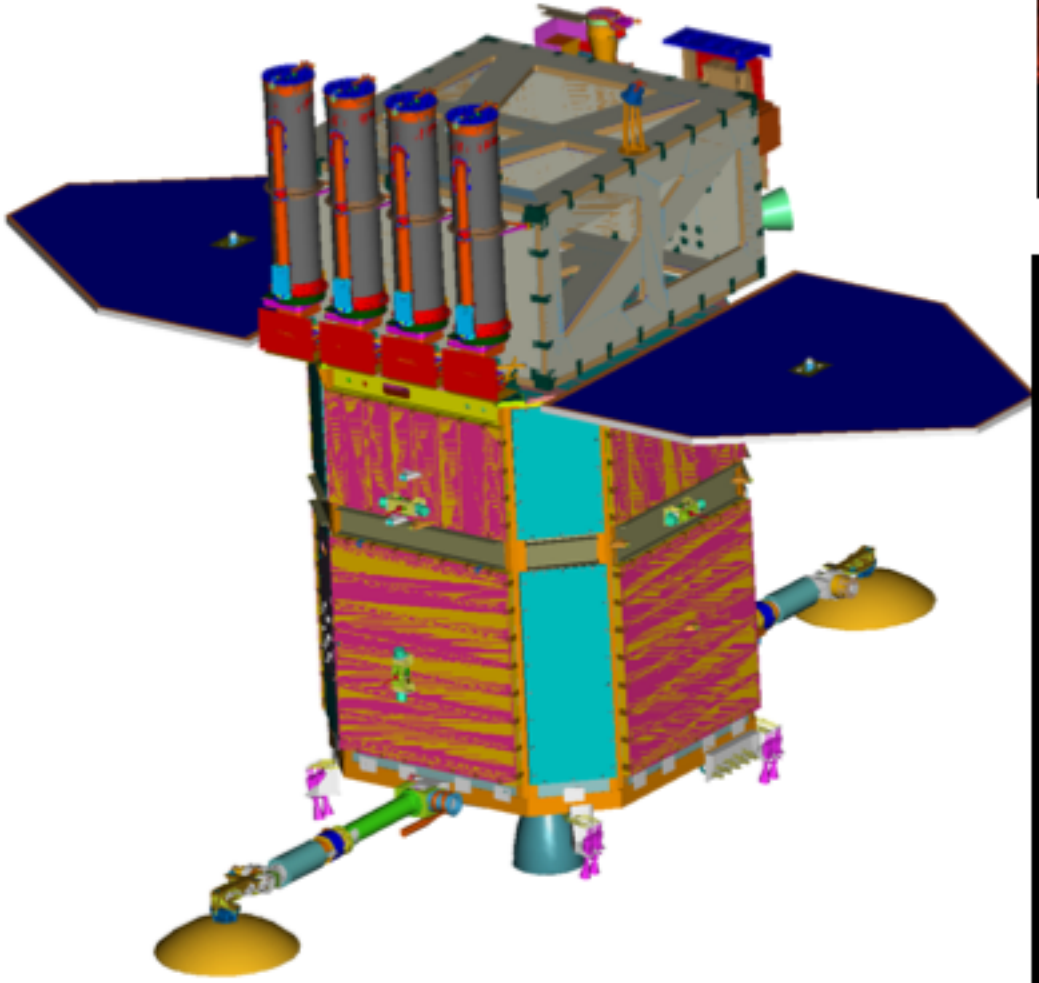
L'événement de l'année

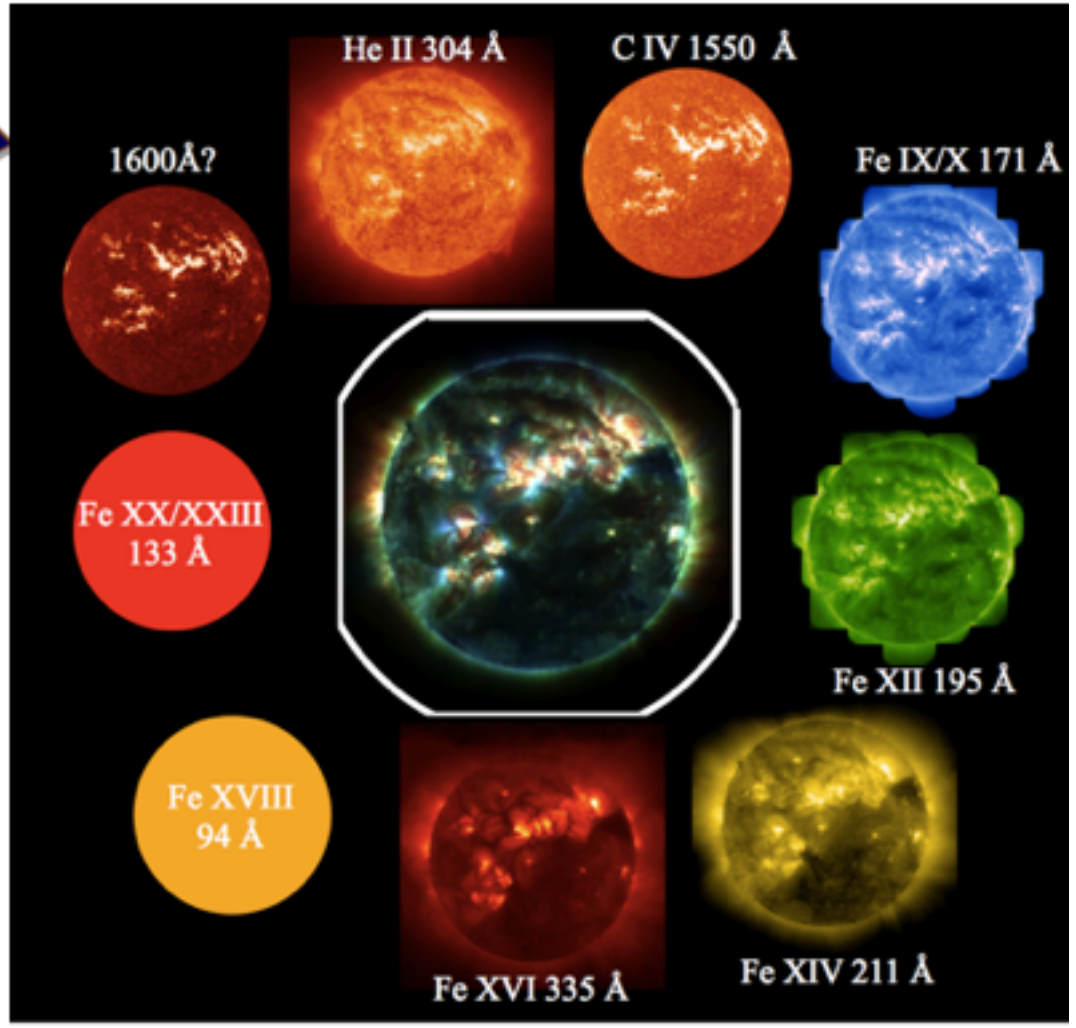
Les Rencontres du ciel et de l'espace

Colères du Soleil

Quelles

since 2010



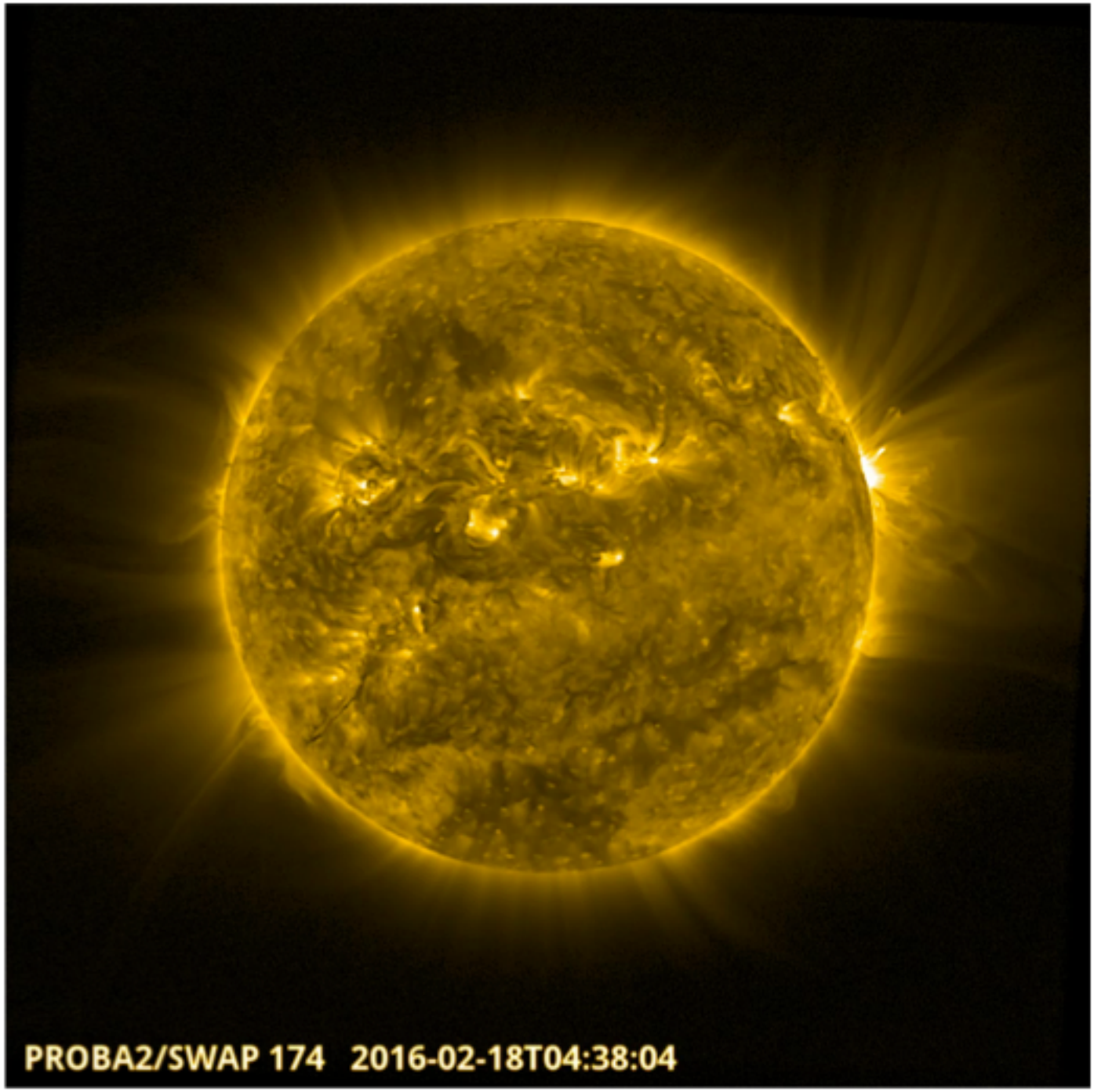


http://aia.lmsal.com

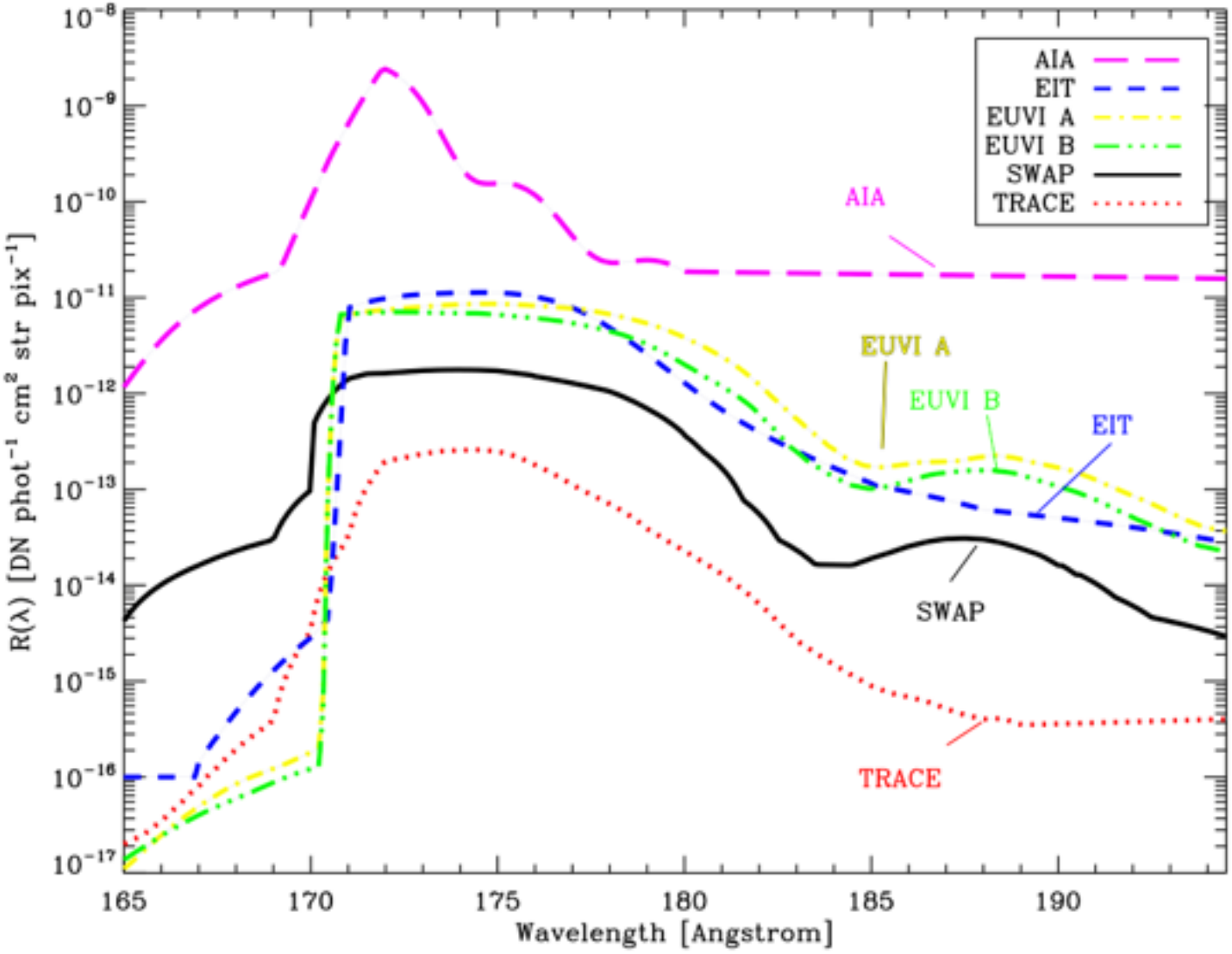
Atmospheric Imaging Assembly (AIA)

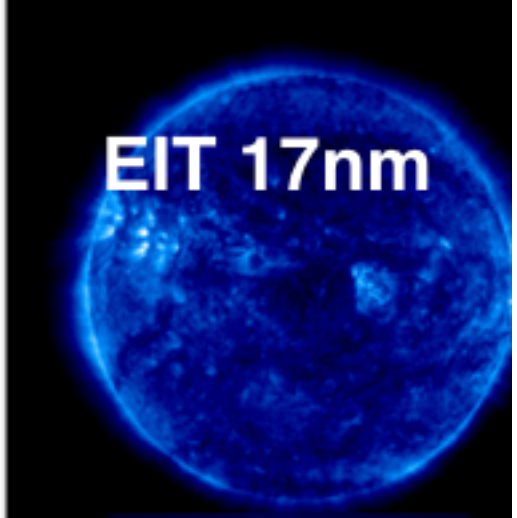
SWAP onboard PROBA2

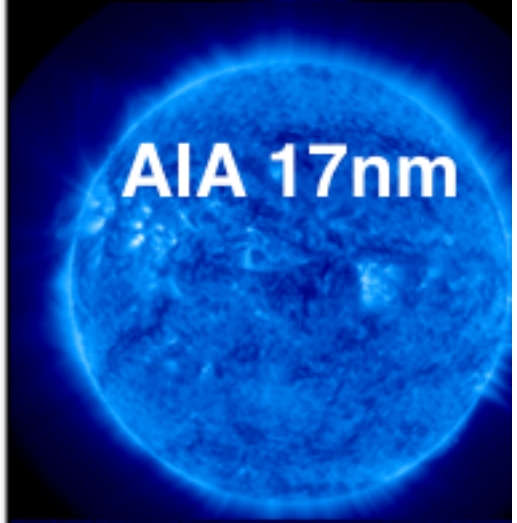
http://proba2.sidc.be

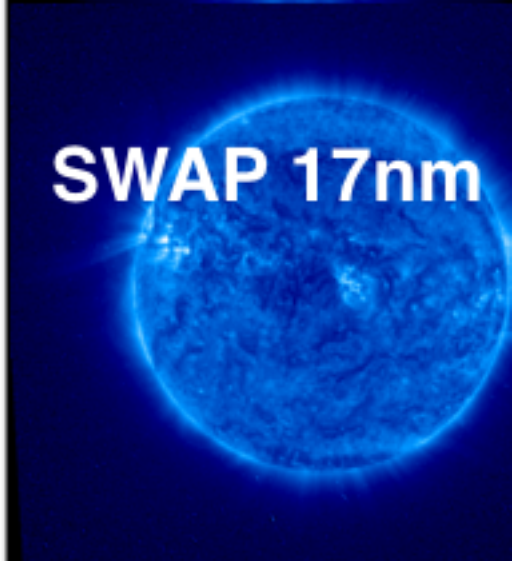


Coronal EUV images differ in the details

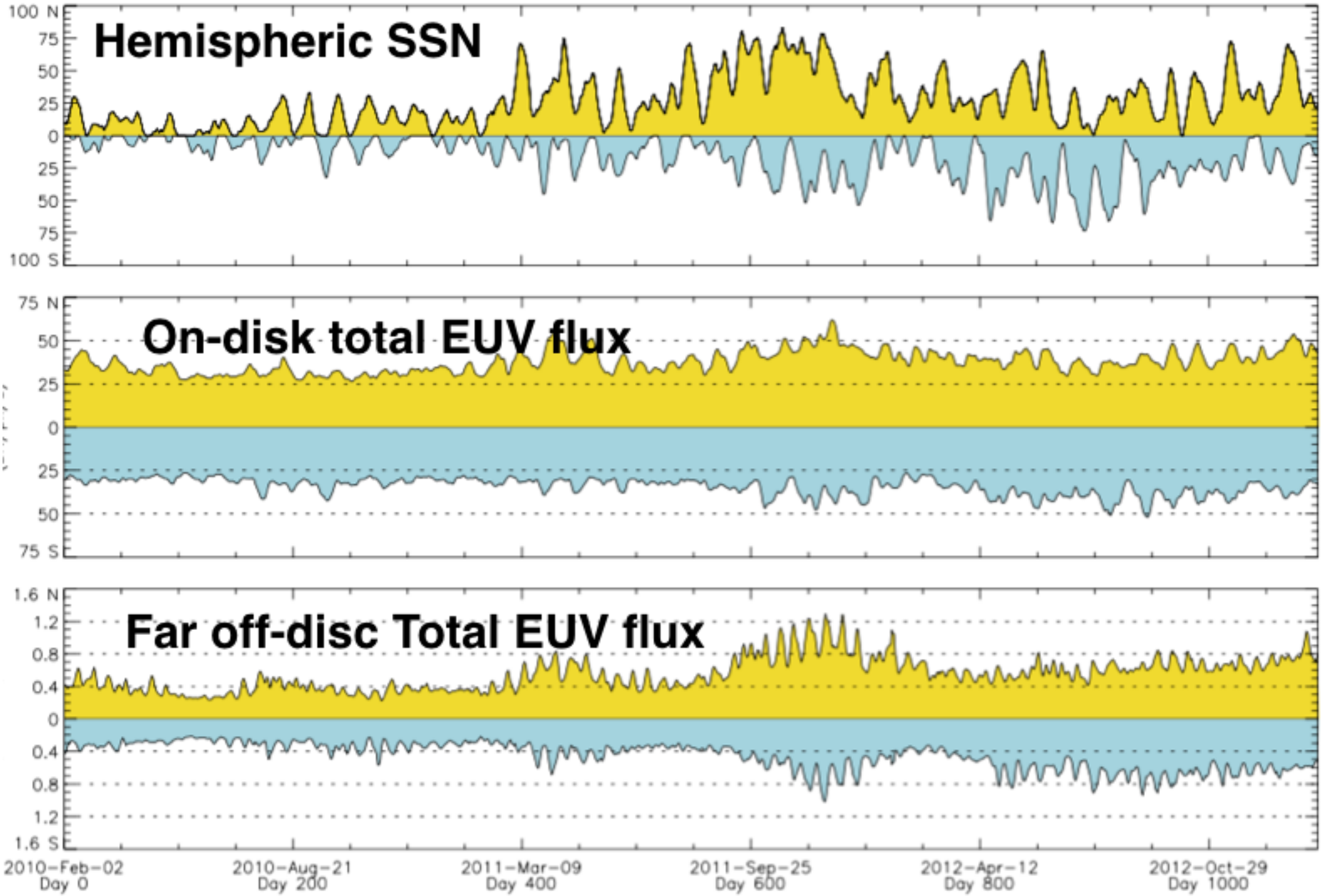








Claire Raftery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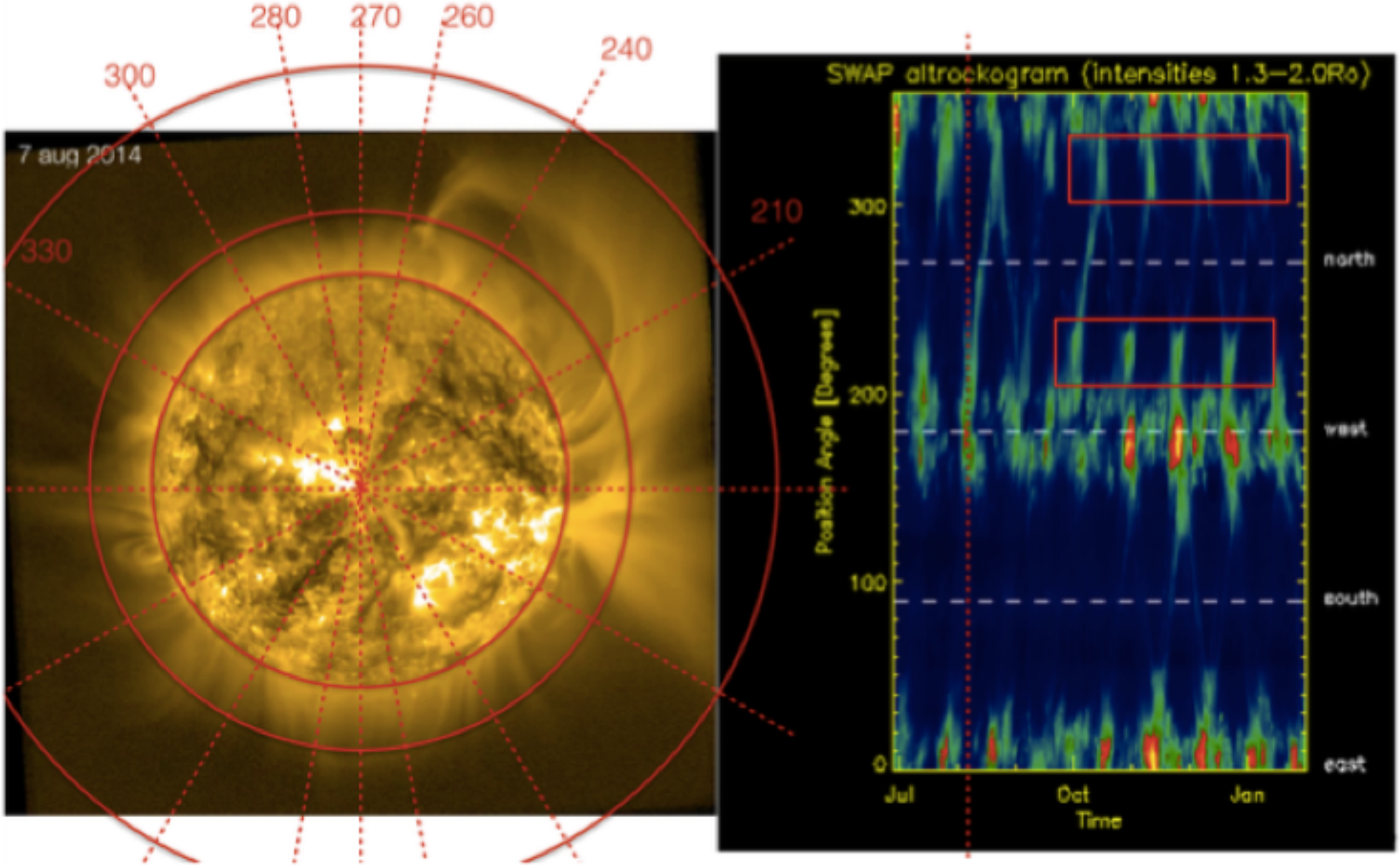
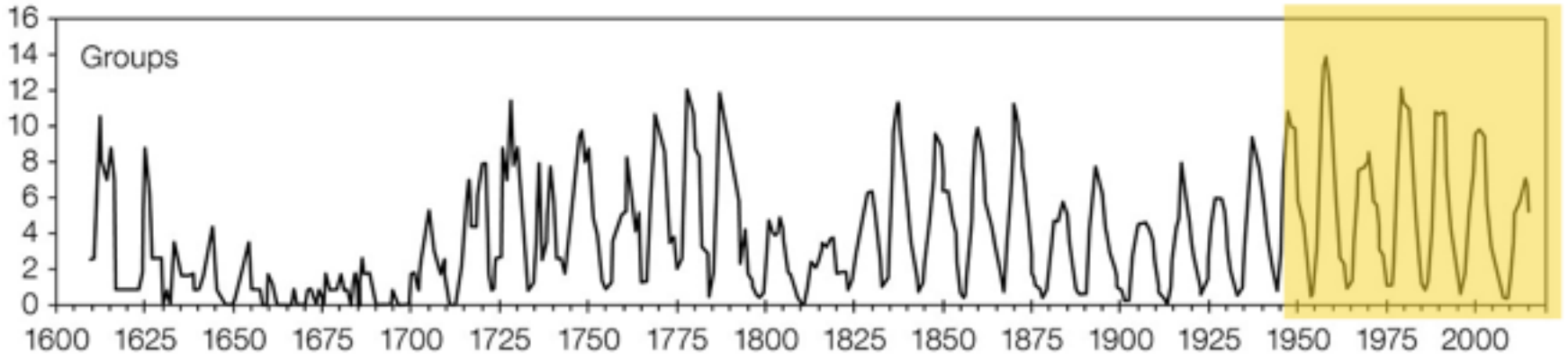
2012-Oct-29
Day 1000

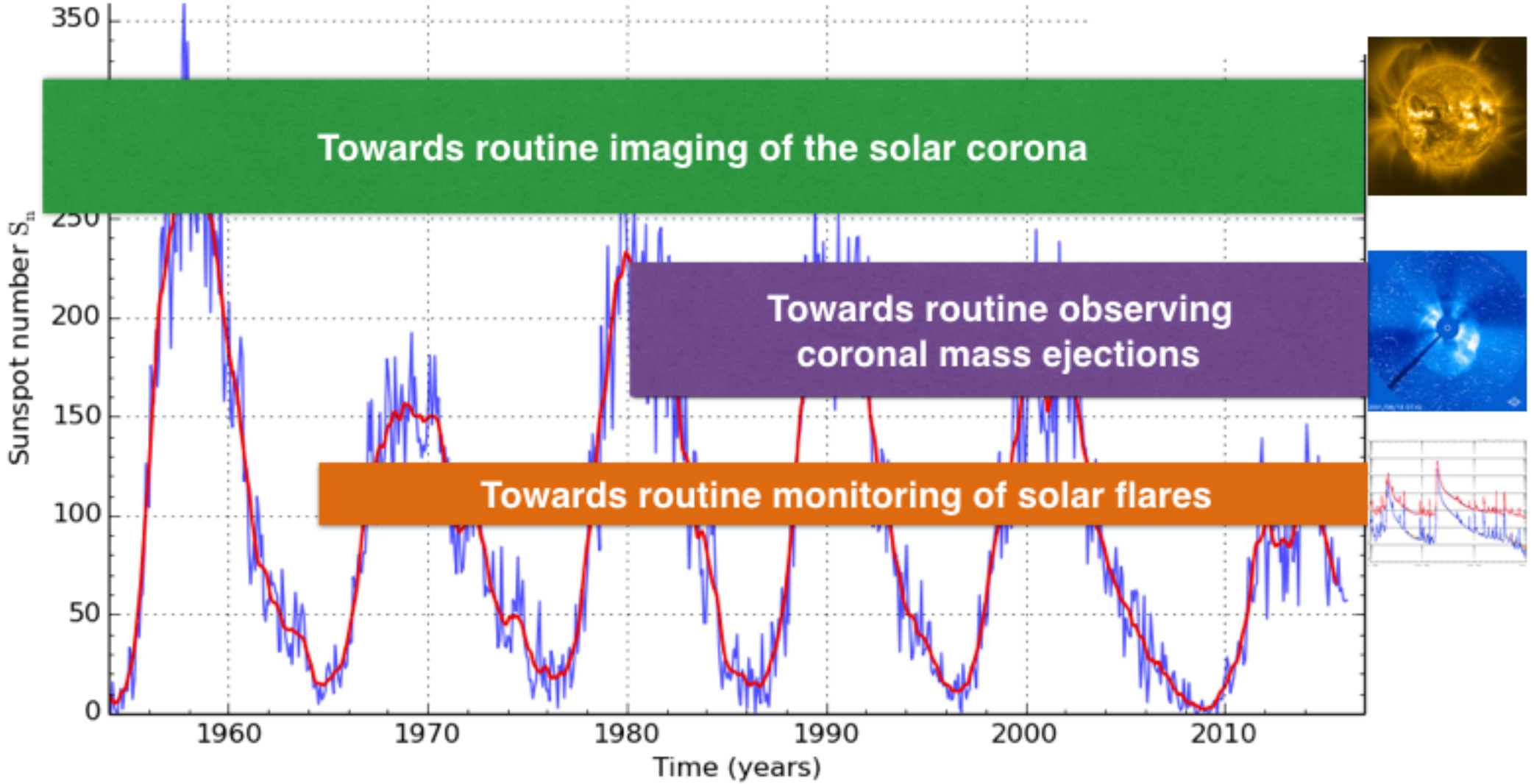
Poster COR-1 (De Groof et al)
Unexpectedly Long lived Coronal Structures



Coronal images for space climate?

- different technologies on different missions
- similar telescopes differ in spectral bandpasses
- poor and unstable calibration
- differences in resolution, field of view, cadence, exposure time
- underused data-sets: breakthrough opportunities





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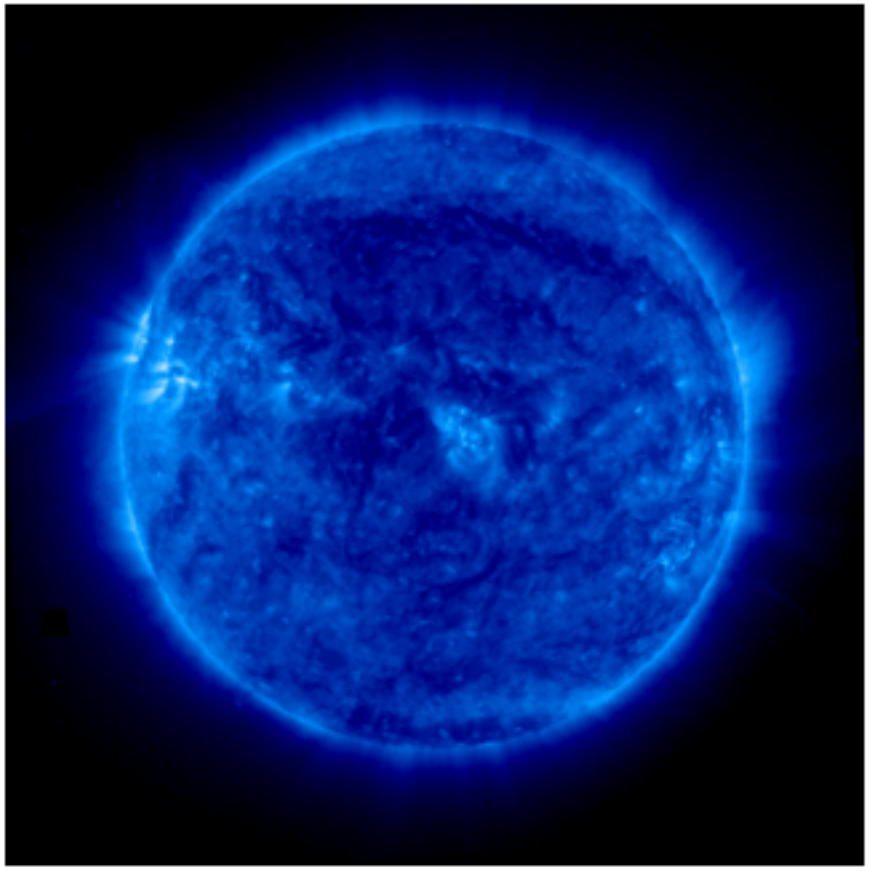
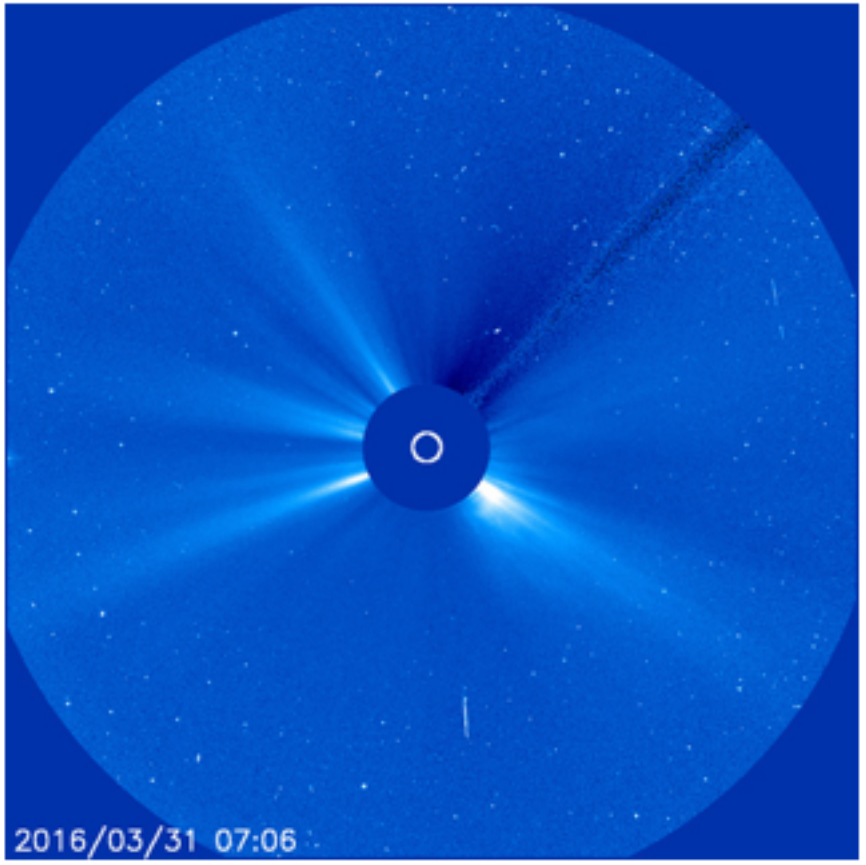
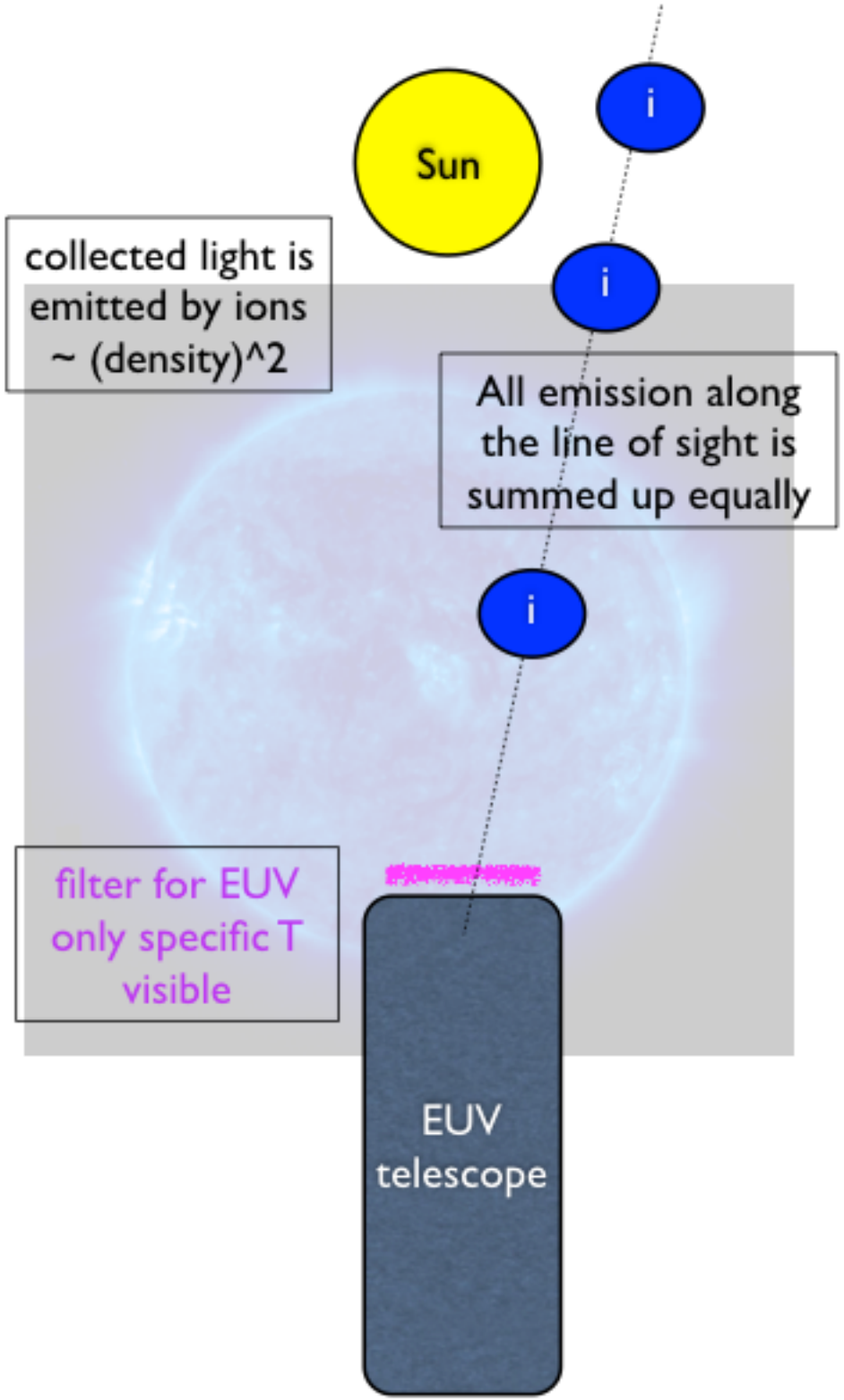
Towards routine imaging of coronal mass ejections (CMEs)

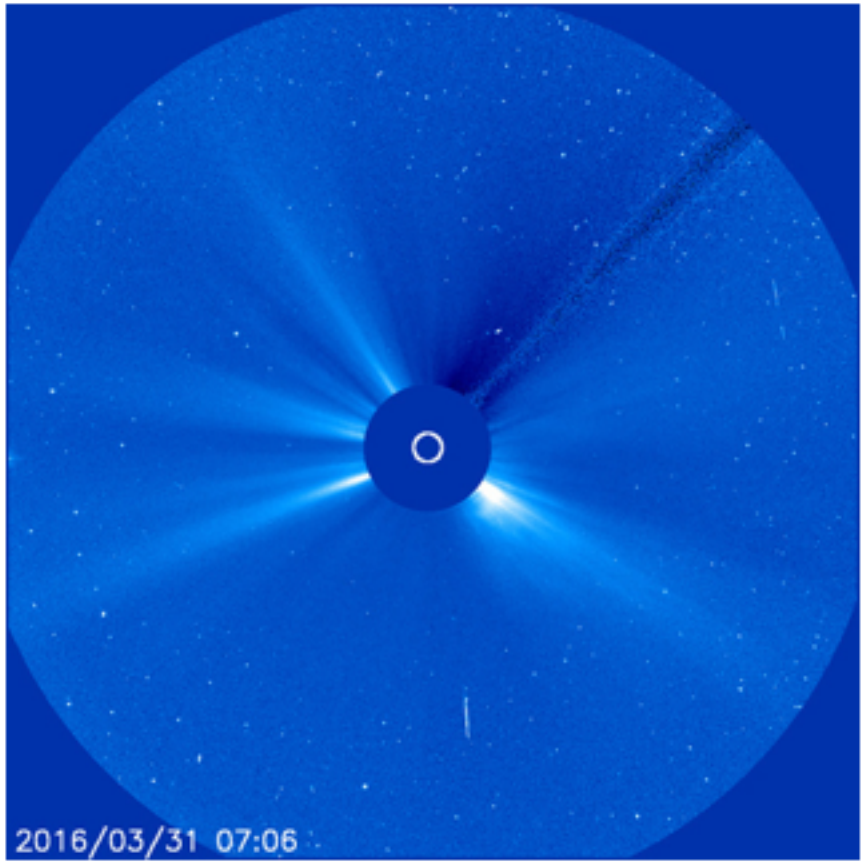


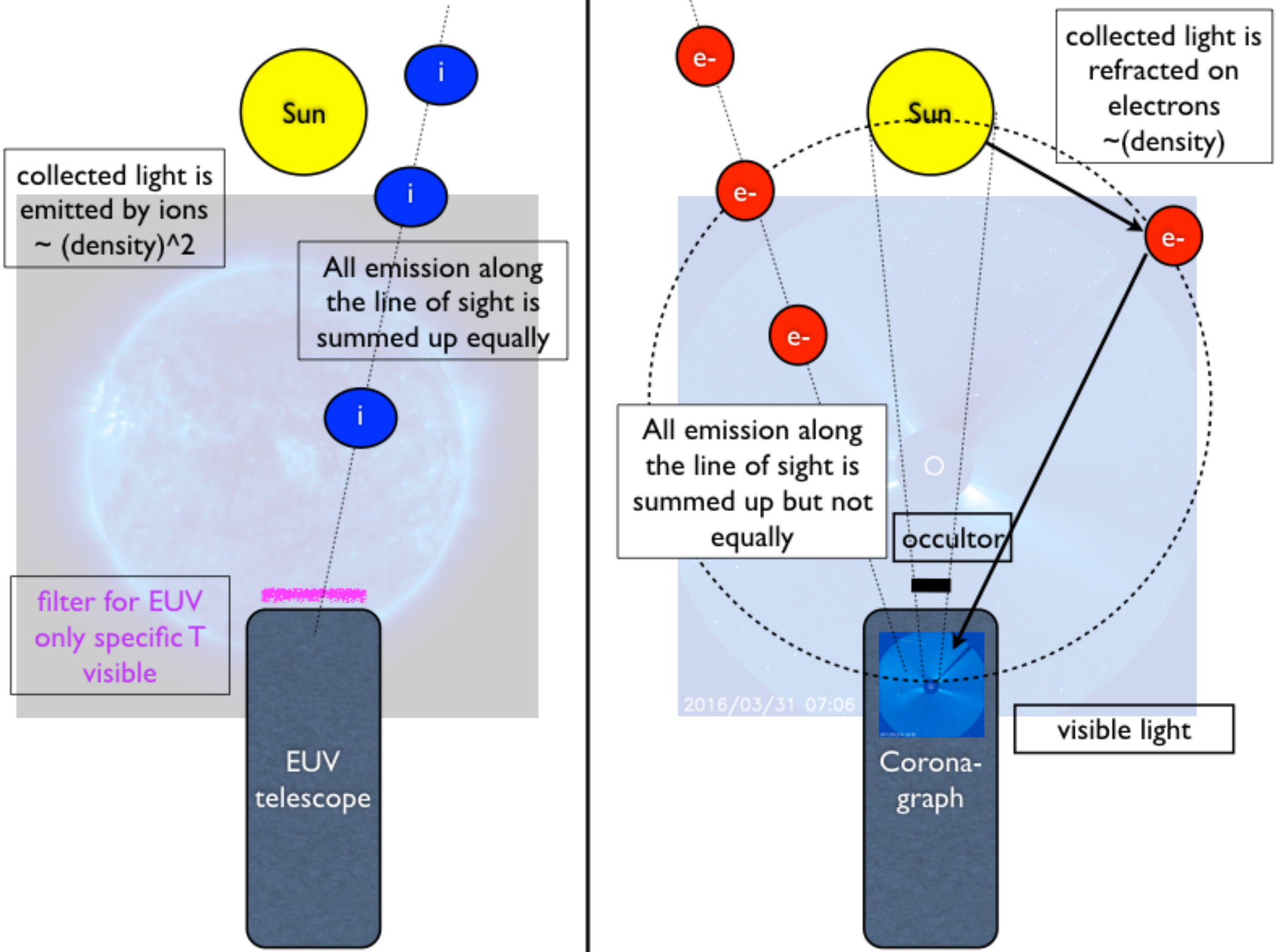
SOHO/EIT

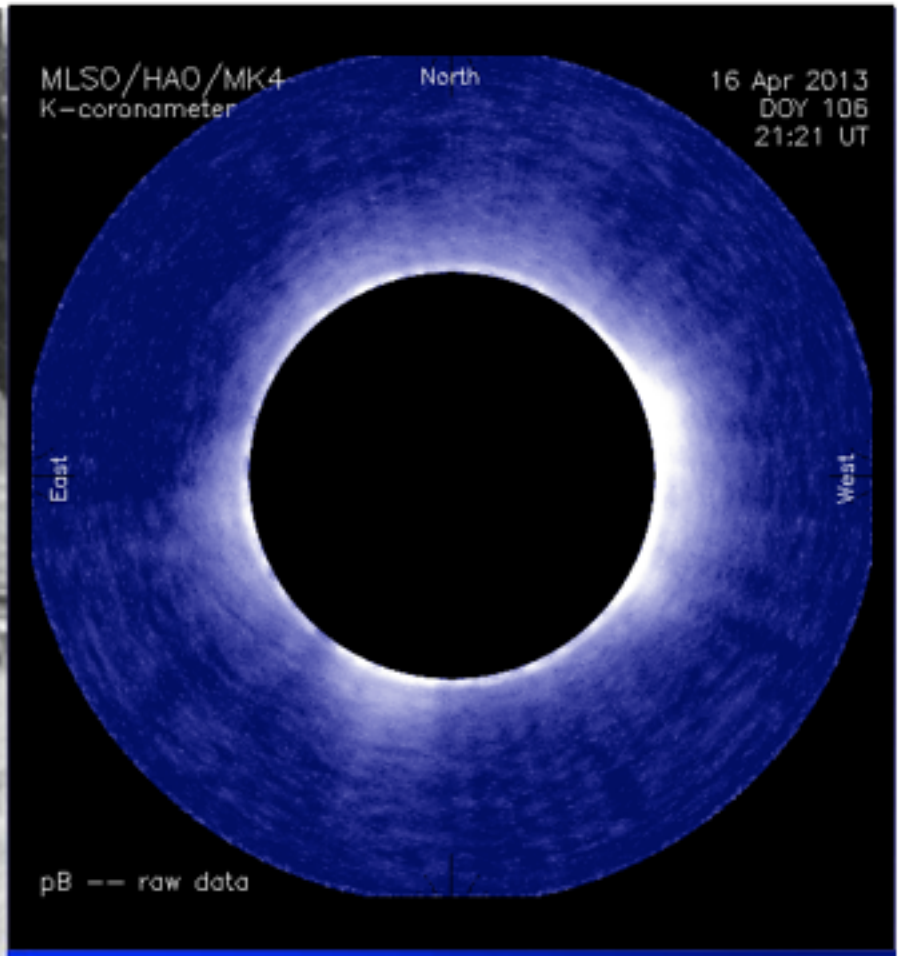


SOHO/LASCO


Sun
i
i
i
collected light is emitted by ions ~ (density)^2
All emission along the line of sight is summed up equally
filter for EUV only specific T visible
EUV telescope

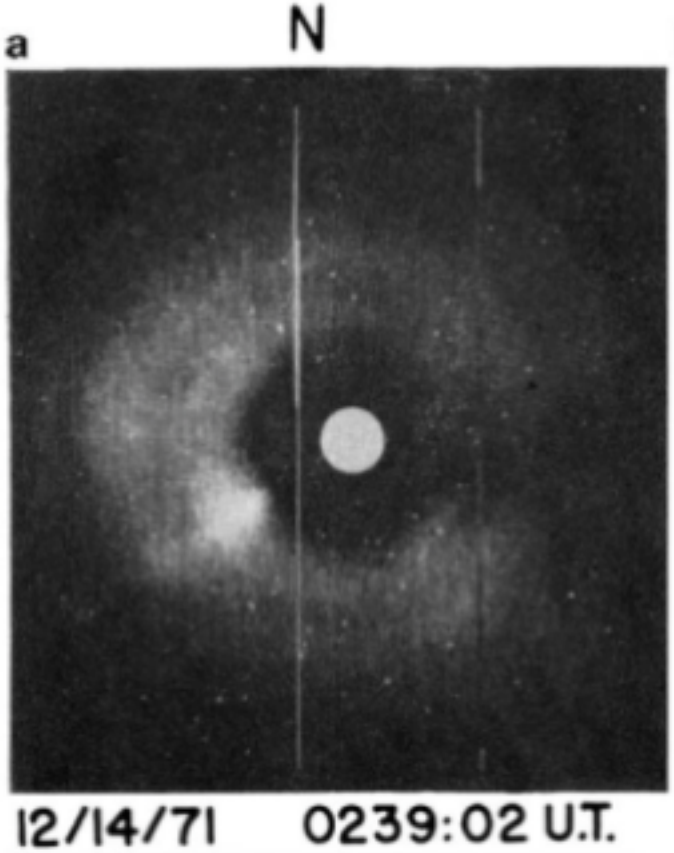

2016/03/31 07:06


Sun
i
i
i
collected light is emitted by ions ~ (density)^2
All emission along the line of sight is summed up equally
filter for EUV only specific T visible
EUV telescope
e-
e-
e-
Sun
e-
collected light is refracted on electrons ~(density)
All emission along the line of sight is summed up but not equally
occultor
2016/03/31 07:06
visible light
Corona-graph

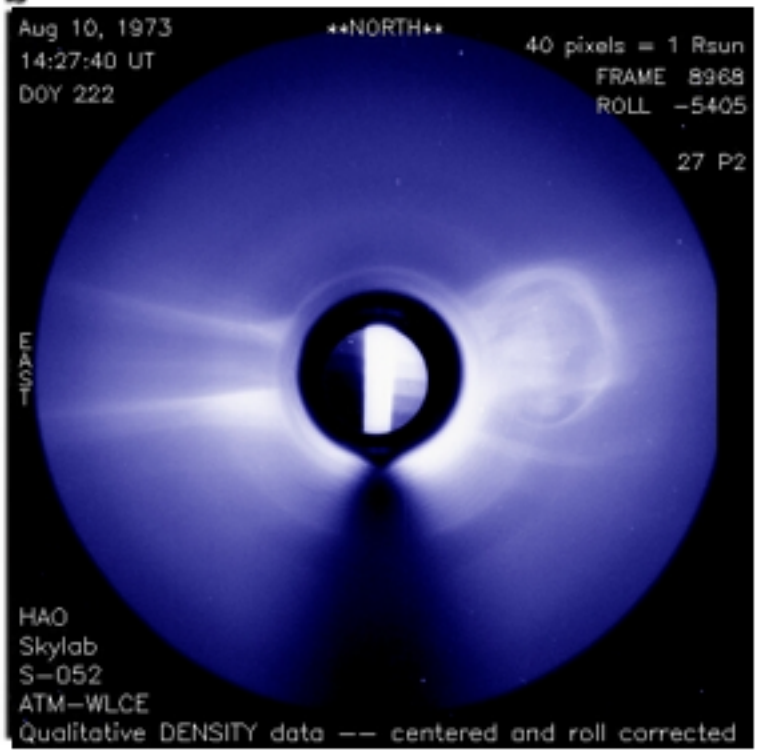


Bernard Lyot, 1939, at Pic du Midi
French Astronomer
Inventor of the Coronagraph

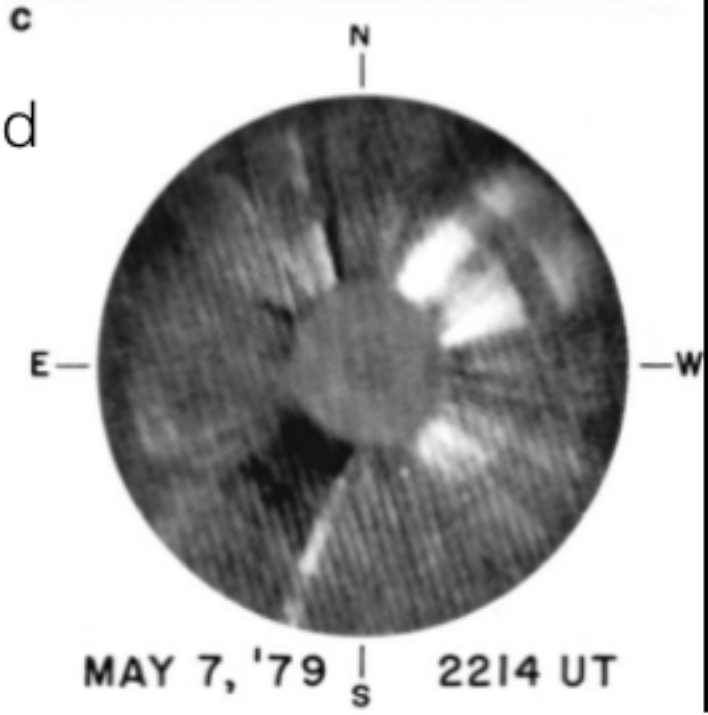
OSO-7
Dec 1971



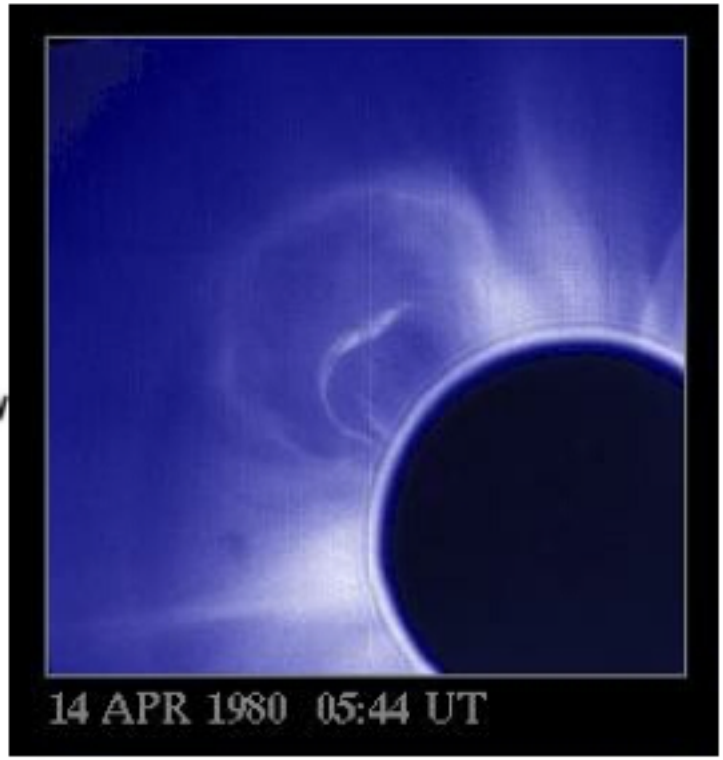
Skylab
Aug 1973

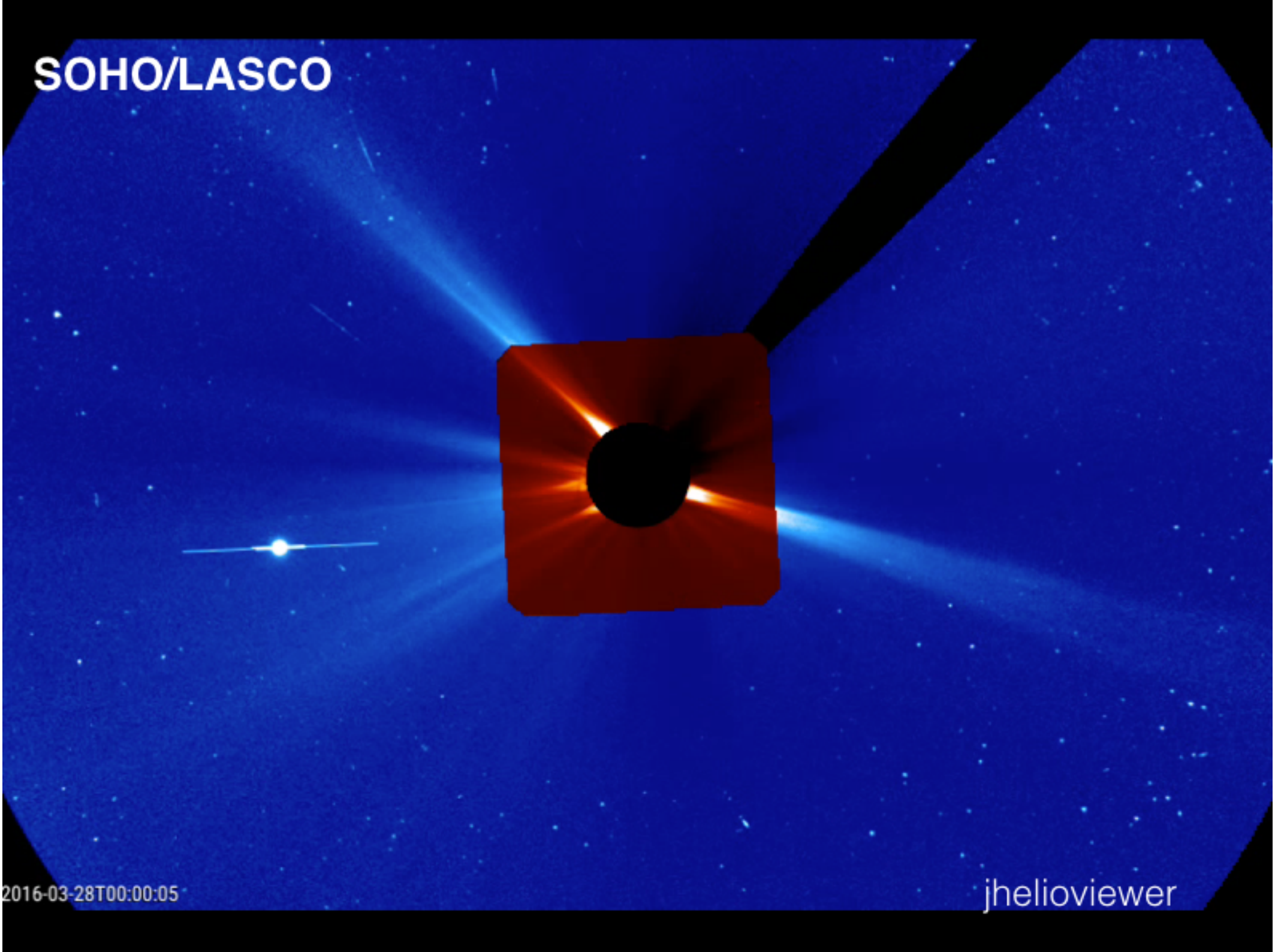


P78/Solwind
May 1979



SMM/C/P
April 1980

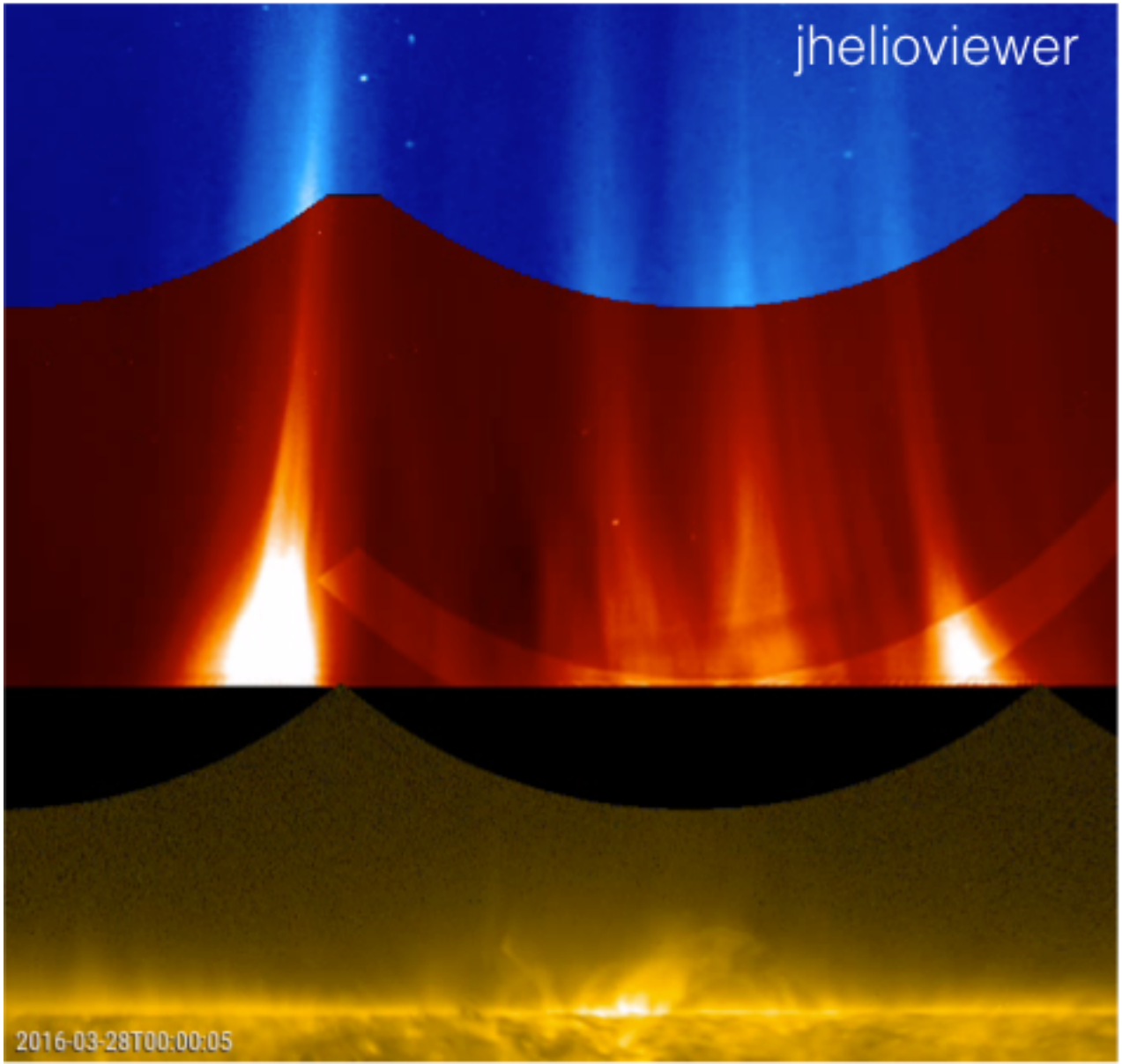


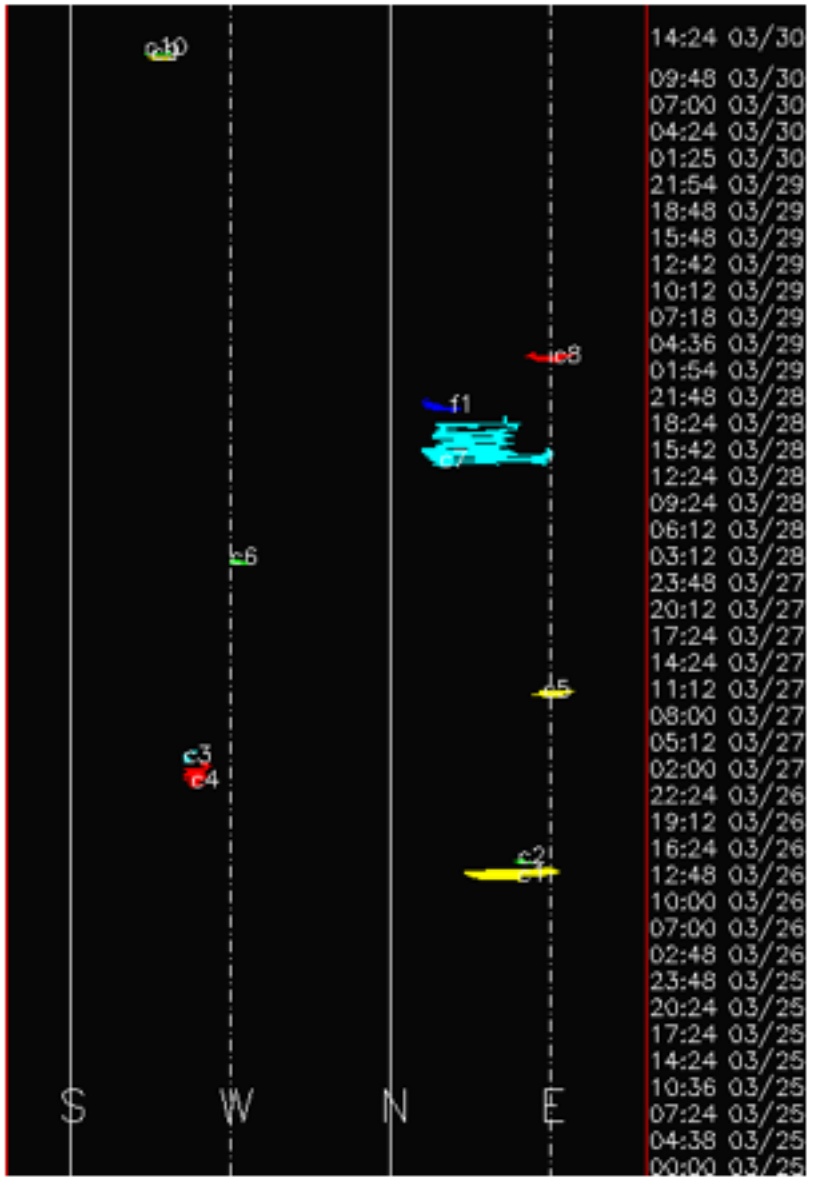

SOHO/LASCO
2016-03-28T00:00:05
jhelioviewer

CACTUS 2.5.0

A software package for 'Computer Aided CME Tracking'

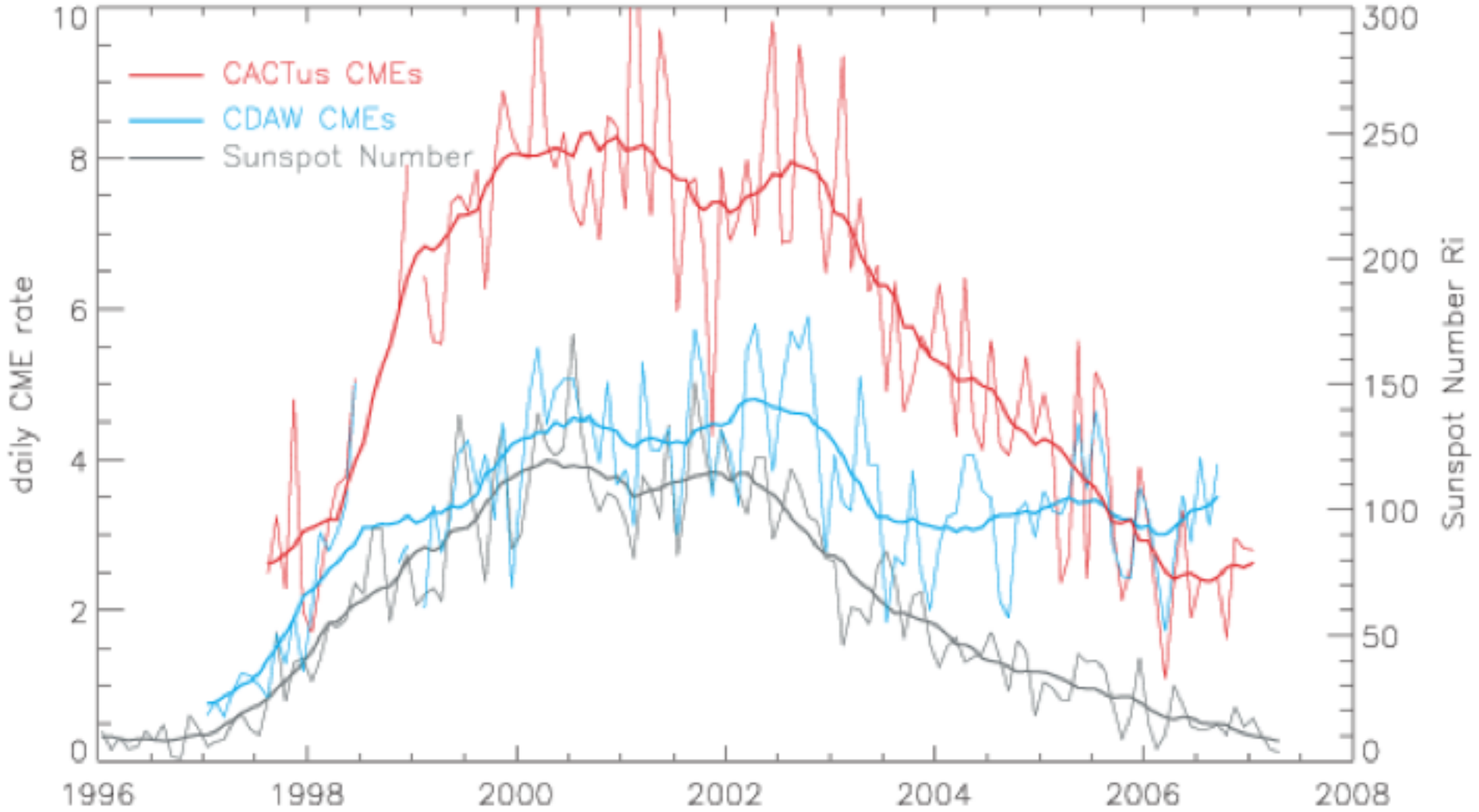
# CME	t0	dt0	pa	da	v	dv	minv	maxv	halo?
0007	2016/03/28 16:00	06	055	072	0182	0044	0103	0256	



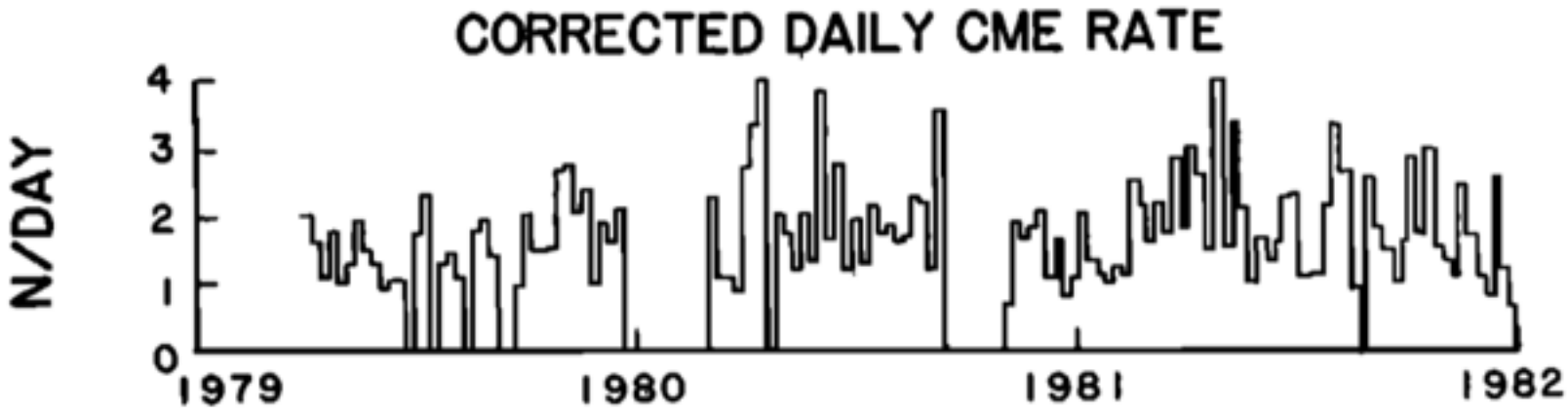


http://sidc.be/cactus

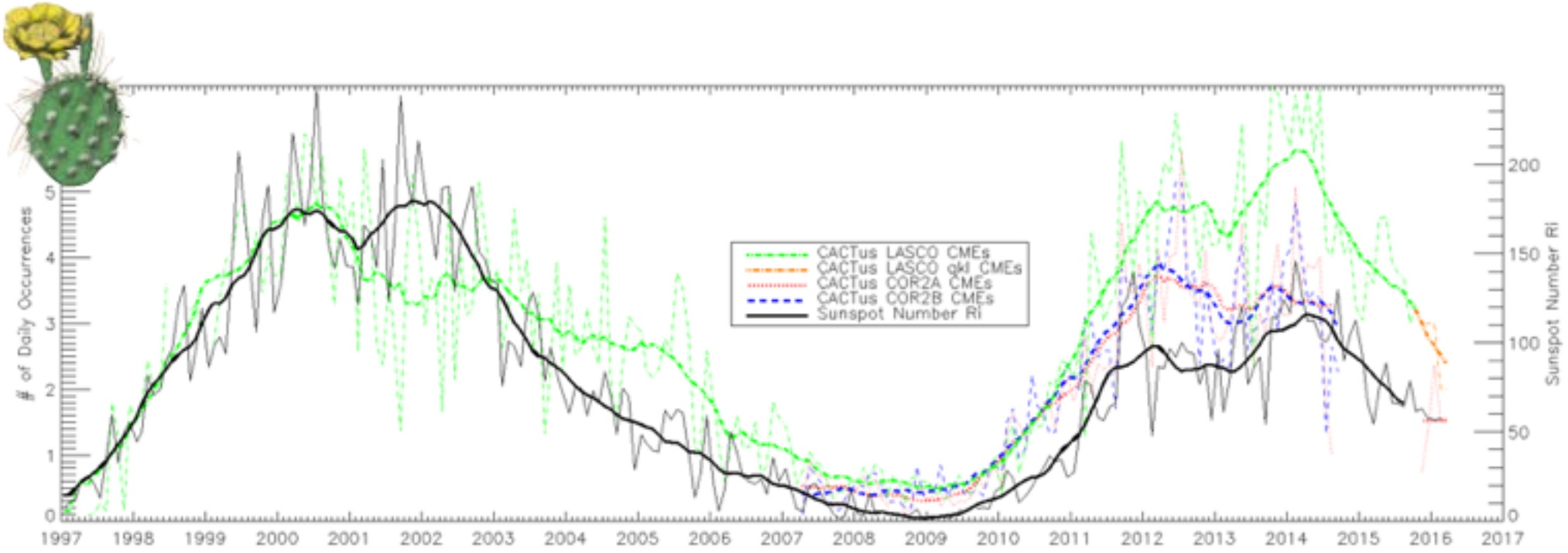
Robbrecht 2009 ApJ



CACTUS - generated by the software package "Computer Aided CME Tracking" (Automated).
ARTEMIS - generated by "Automatic Recognition of Transient Events and Marseille Inventory from Synoptic maps" (Automated)
CORIMP - generated by automatic detection of SOHO LASCO images (Automated).
CDAW Catalog - generated by visual manual methods (Manual).
NRL LASCO CME List - generated by operators (Manual).
COR1 CME Catalog - generated by the STEREO COR1 team (Manual)
HI1 Event List - generated by the STEREO HI1 UK team (Manual)



Howard 85

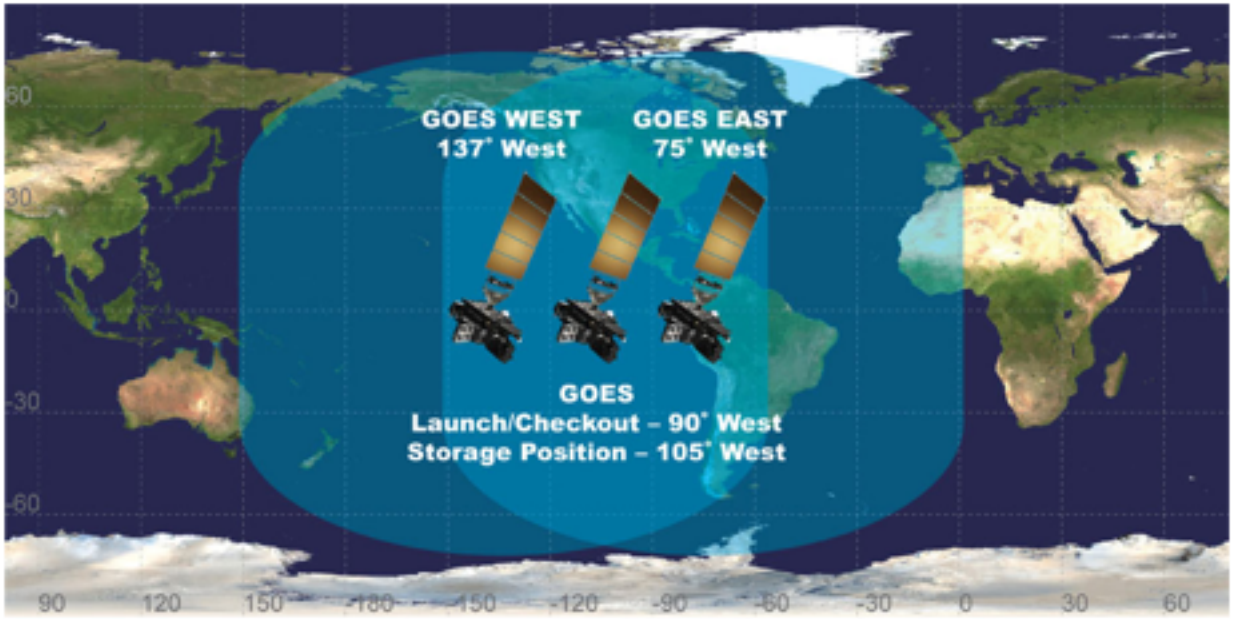


http://sidc.be/cactus/

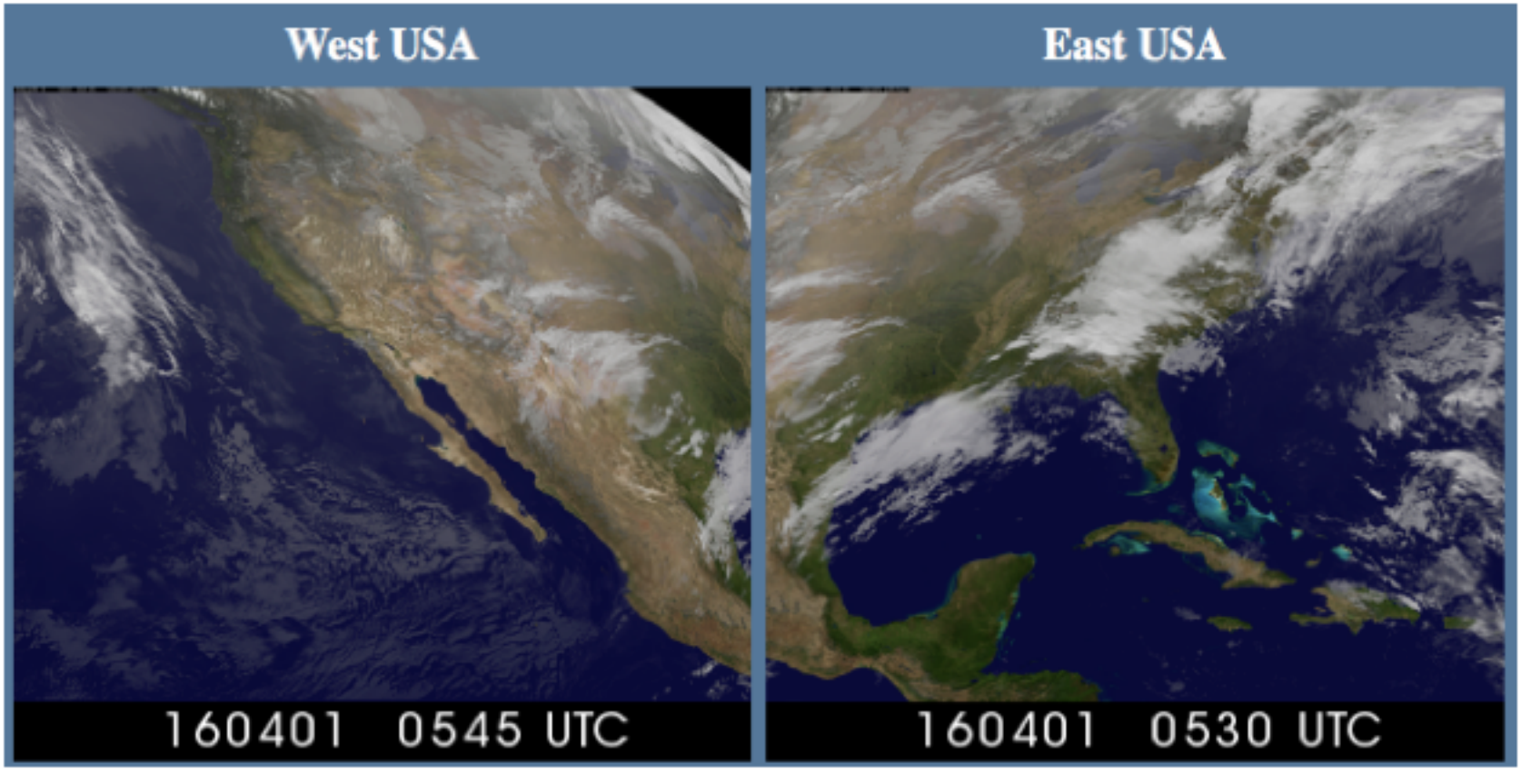
CME statistics for space climate?

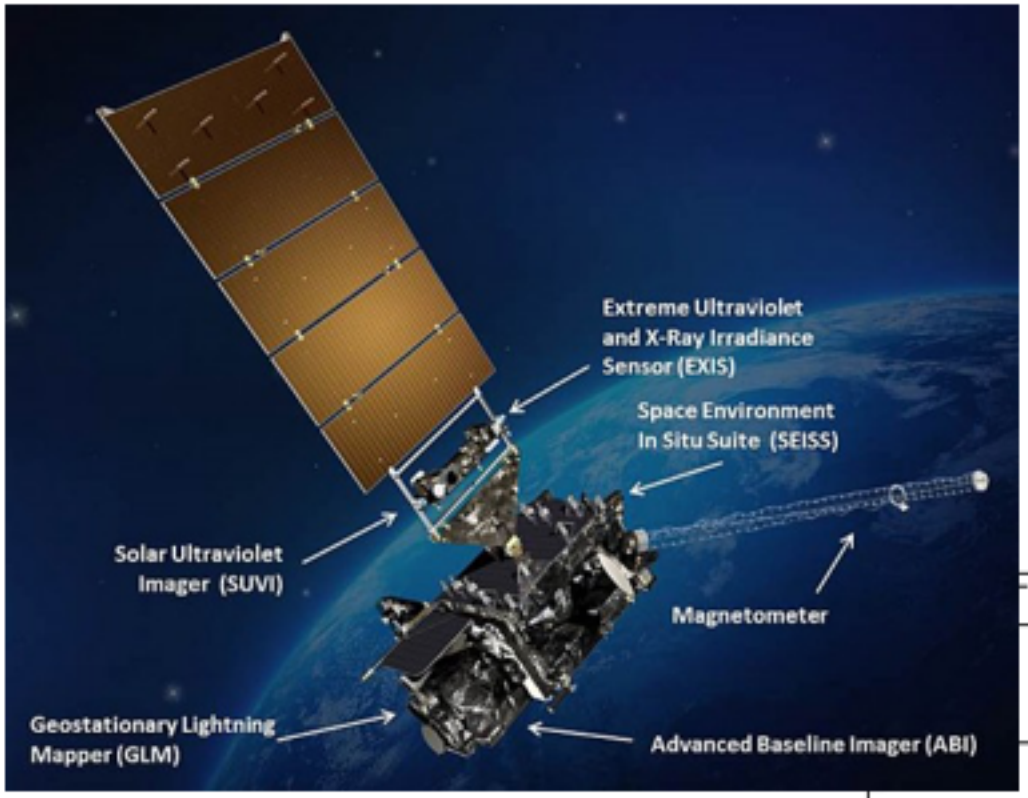
- CME rates hard to compared between instruments, affected by duty cycle, contrast and FOV
- SOHO/LASCO: 20 years of consistent high quality CME observations
- big data: feature recognition, computer vision, …
- data interpretation: what is a CME?

Towards routine flare observations



GOES weather satellites operated by NOAA

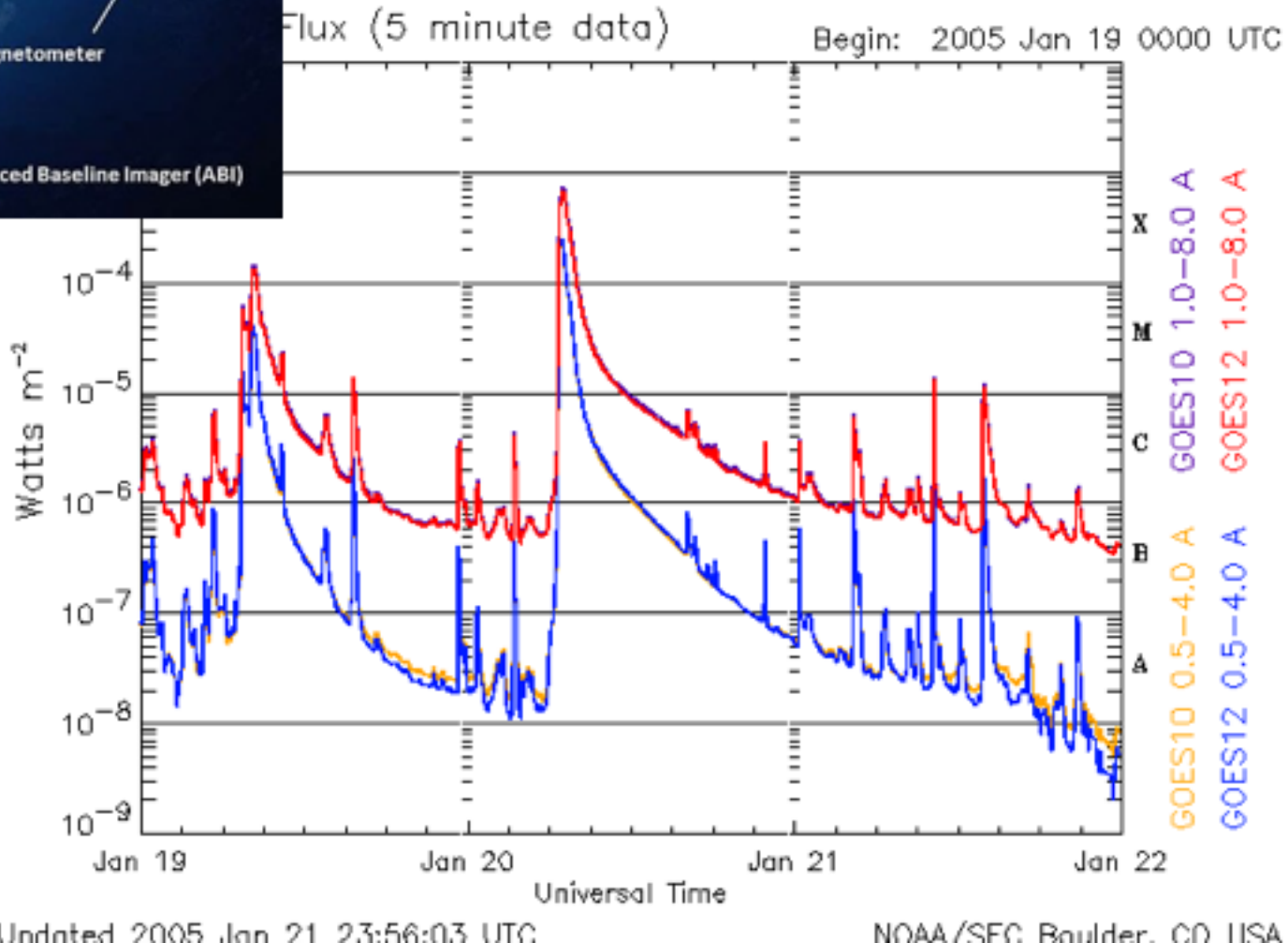


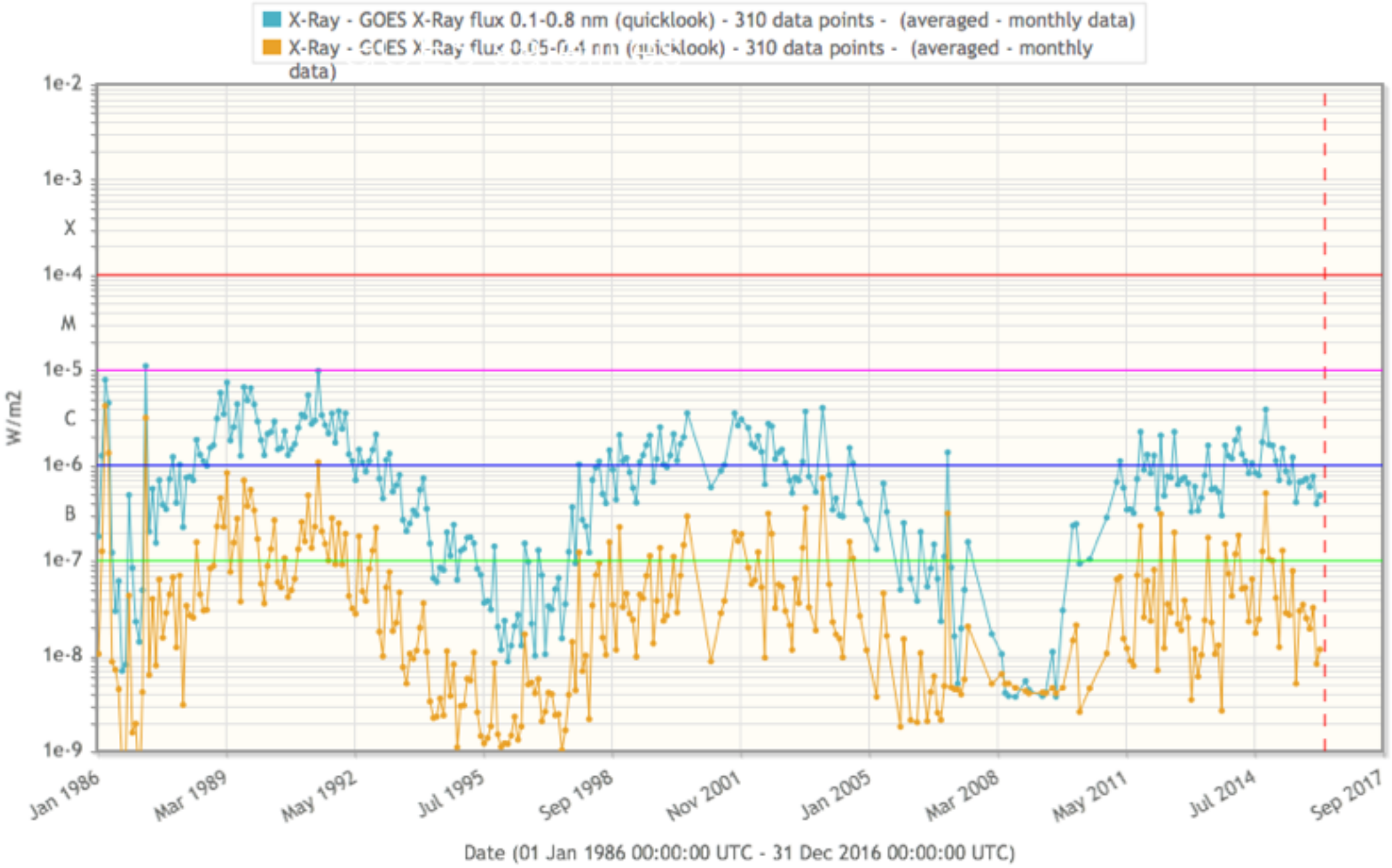


X-Ray Sensor (XRS)

http://www.swpc.noaa.gov

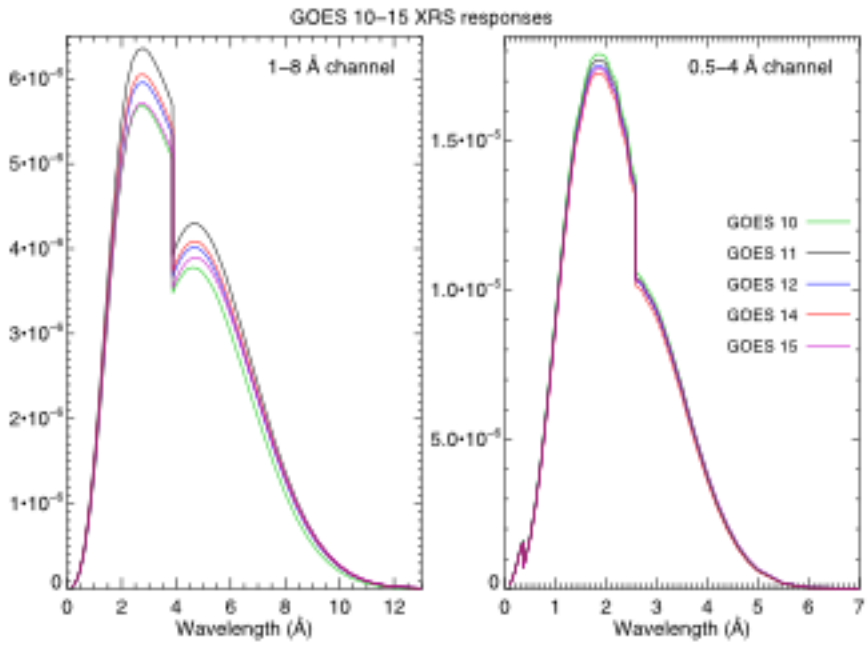
http://www.ngdc.gov





http://sidc.be/staff

bandpass shape
quiet stable



Satellite	Launch Date	XRS data start date	XRS data end date
GOES-15	2010-03-04	2010	present
GOES-14	2009-06-27	2009	present
GOES-13	2006-05-24	2014	present
GOES-12	2001-07-23	2003	2007
GOES-11	2000-05-03	2000	2008
GOES-10	1997-04-25	1998	2009
GOES-9	1995-05-23	1996	1998
GOES-8	1994-04-13	1995	2002
GOES-7	1987-02-26	1987	1996
GOES-6	1983-04-28	1983	1994
GOES-5	1981-05-22	1983	1987
GOES-4	1980-09-09	-	-
GOES-3	1978-06-15	1978	1980
GOES-2	1977-06-16	1977	1983
GOES-1	1975-10-16	1976	1977
SMS-2	1975-02-06	1974	1976
SMS-1	1974-05-17	1975	1975

Newer generation

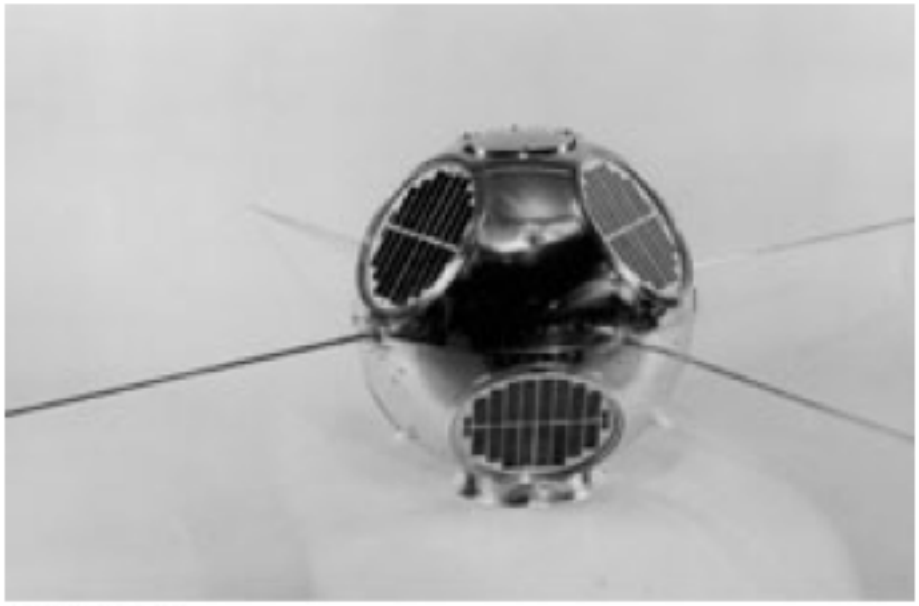
- 3-axis stabilised, shorter exposure times
- dynamic range extended to small flares
- scaling factors applied
- timestamps 1s off

Older generation

- spinning satellites, longer integration times
- no onboard clock (<3s off)

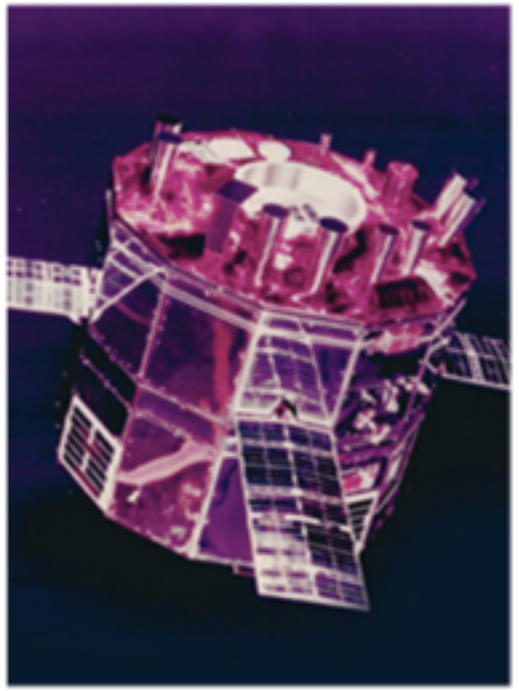
Satellite	Launch Date	XRS data start date	XRS data end date
GOES-15	2010-03-04	2010	present
GOES-14	2009-06-27	2009	present
GOES-13	2006-05-24	2014	present
GOES-12	2001-07-23	2003	2007
GOES-11	2000-05-03	2000	2008
GOES-10	1997-04-25	1998	2009
GOES-9	1995-05-23	1996	1998
GOES-8	1994-04-13	1995	2002
GOES-7	1987-02-26	1987	1996
GOES-6	1983-04-28	1983	1994
GOES-5	1981-05-22	1983	1987
GOES-4	1980-09-09	-	-
GOES-3	1978-06-15	1978	1980
GOES-2	1977-06-16	1977	1983
GOES-1	1975-10-16	1976	1977
SMS-2	1975-02-06	1974	1976
SMS-1	1974-05-17	1975	1975

Even older: SOLRAD (1965-1976)



SOLRAD I

Launched Nov 19, 1965



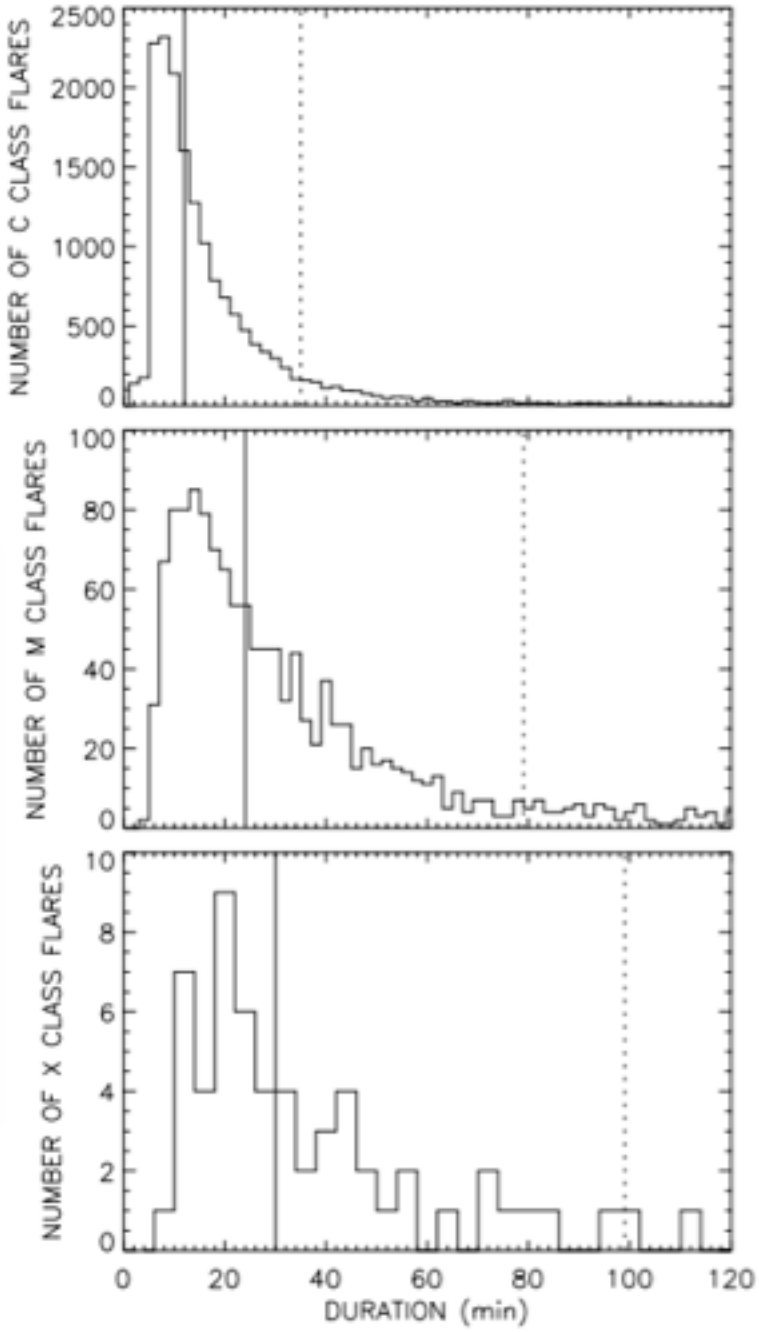
Solrad 10 (Explorer 44)

Launched July 8, 1971

ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SATELLITE_ENVIRONMENT/XRAY_BGND/docs/solrad.txt

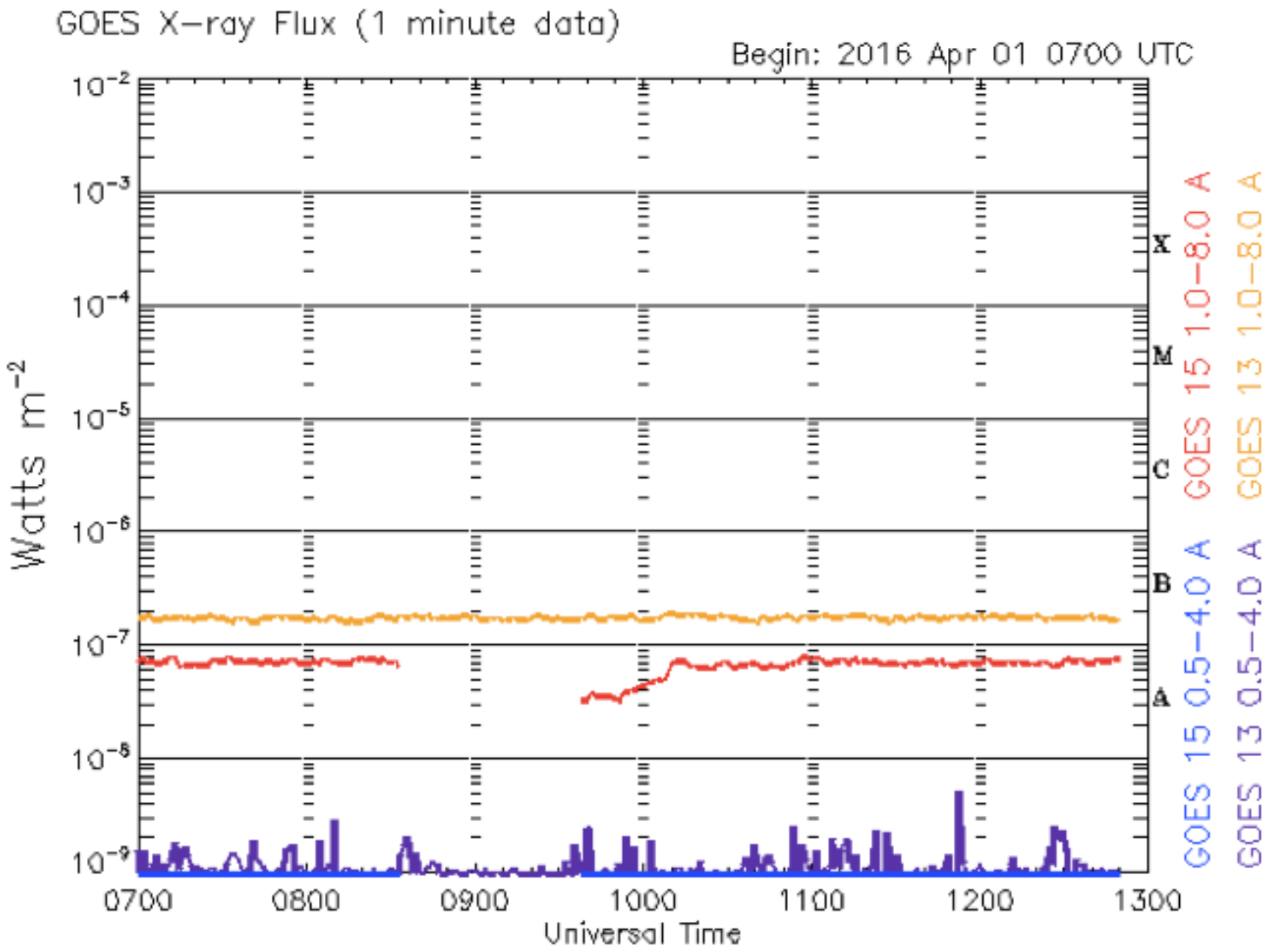
Table 1. The number of flare events for the different SXR flare classes (B, C, M, X) and the corresponding percentage values are listed. T denotes the total number of flares occurring in the selected period (1976–2000).

Class	No. events	No. (%)
B	11 558	23.4
C	32 784	66.4
M	4708	9.5
X	359	0.7
T	49 409	100.0

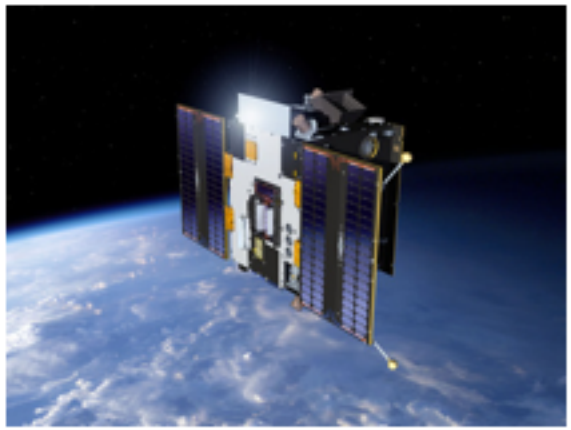


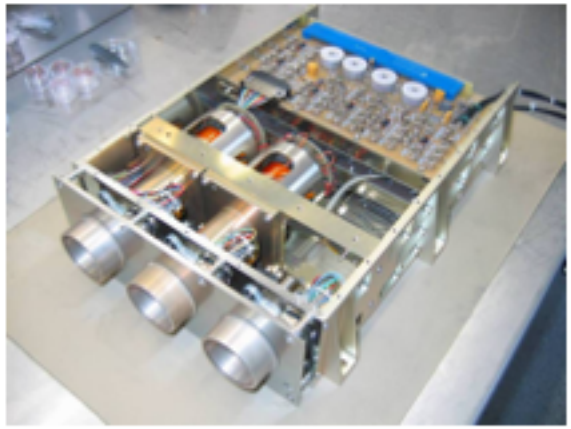
Veronig et al (2002)

data gaps

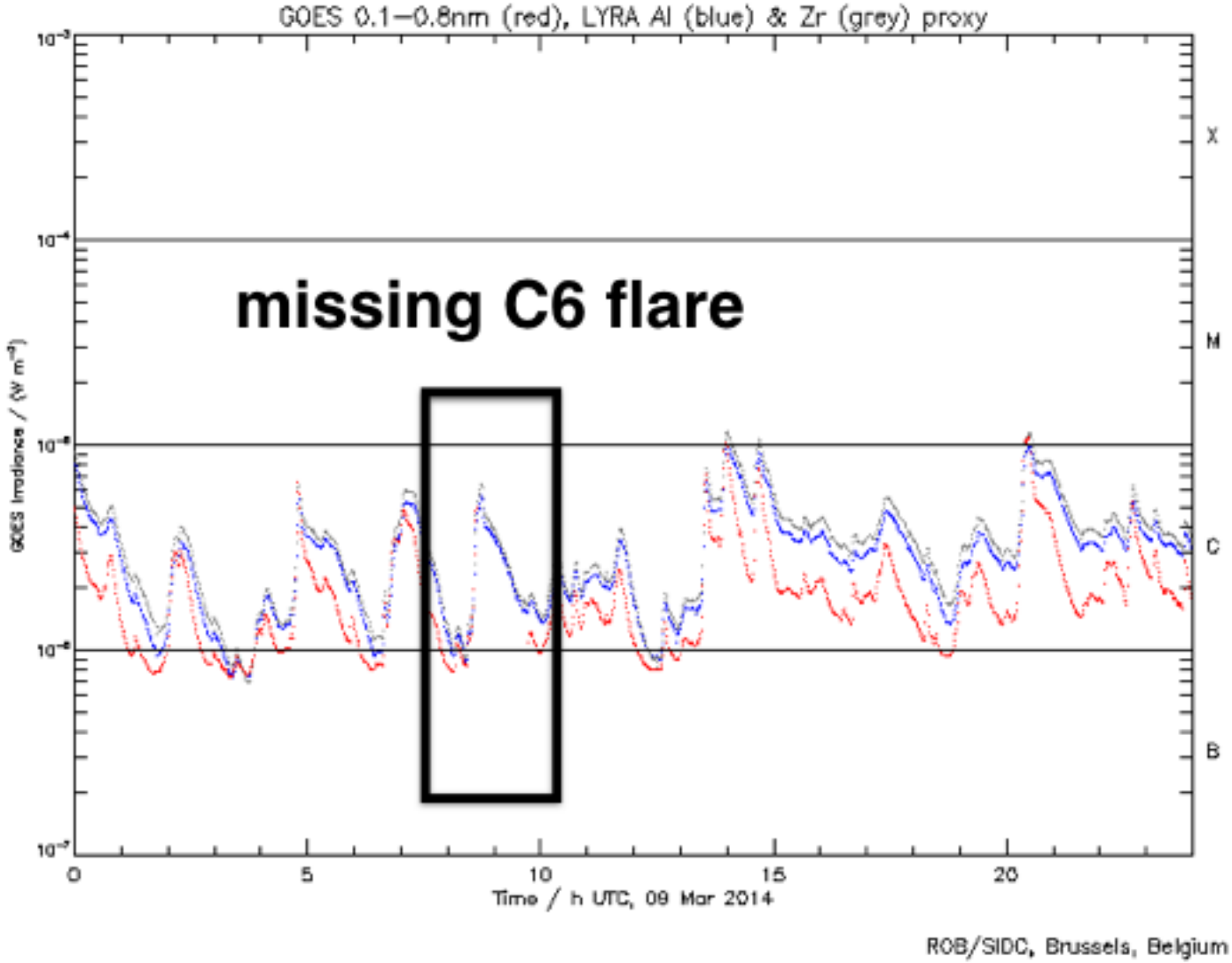

GOES X-ray Flux (1 minute data)
Begin: 2016 Apr 01 0700 UTC
Watts m-2
10-2
10-3
10-4
10-5
10-6
10-7
10-8
10-9
X
M
C
B
A
0700
0800
0900
1000
1100
1200
1300
Universal Time
GOES 15 1.0-8.0 A
GOES 13 1.0-8.0 A
GOES 15 0.5-4.0 A
GOES 13 0.5-4.0 A

LYRA onboard PROBA2



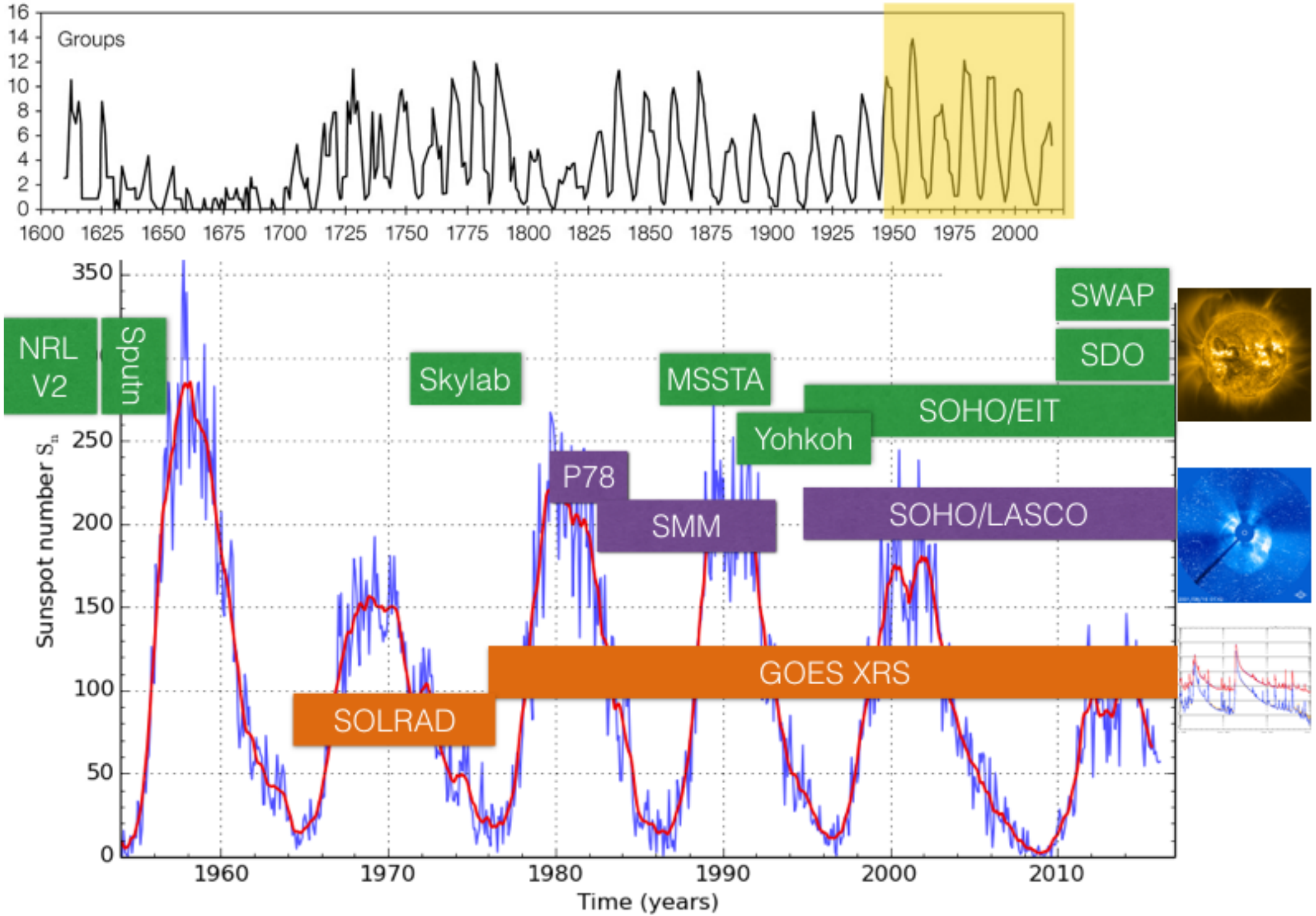


http://proba2.sidc.be/ssa



X-ray/flare monitoring for space climate?

- exceptionally long data series (1965 - >now) with relatively stable data quality
- no observation yet of ‘superflares’
- some flares are missed because of eclipses



SILSO graphics (http://sidc.be/silso) Royal Observatory of Belgium 2016 March 1

What have we learned?

- space data for space climate is limited to the last 70 years
- during this period, instrument design and performance was in full evolution
- GOES+SOLRAD soft X-rays data set covers 50 years
- imaging data sets are coherent for only last 20 years
- comparable older data sets exists but carefull intercalibration/interpretation is required.
- opportunities waiting to be harvested

“The world's longest-running experiments remind us that science is a marathon, not a sprint”

–Brian Owens (editorial nature.com)