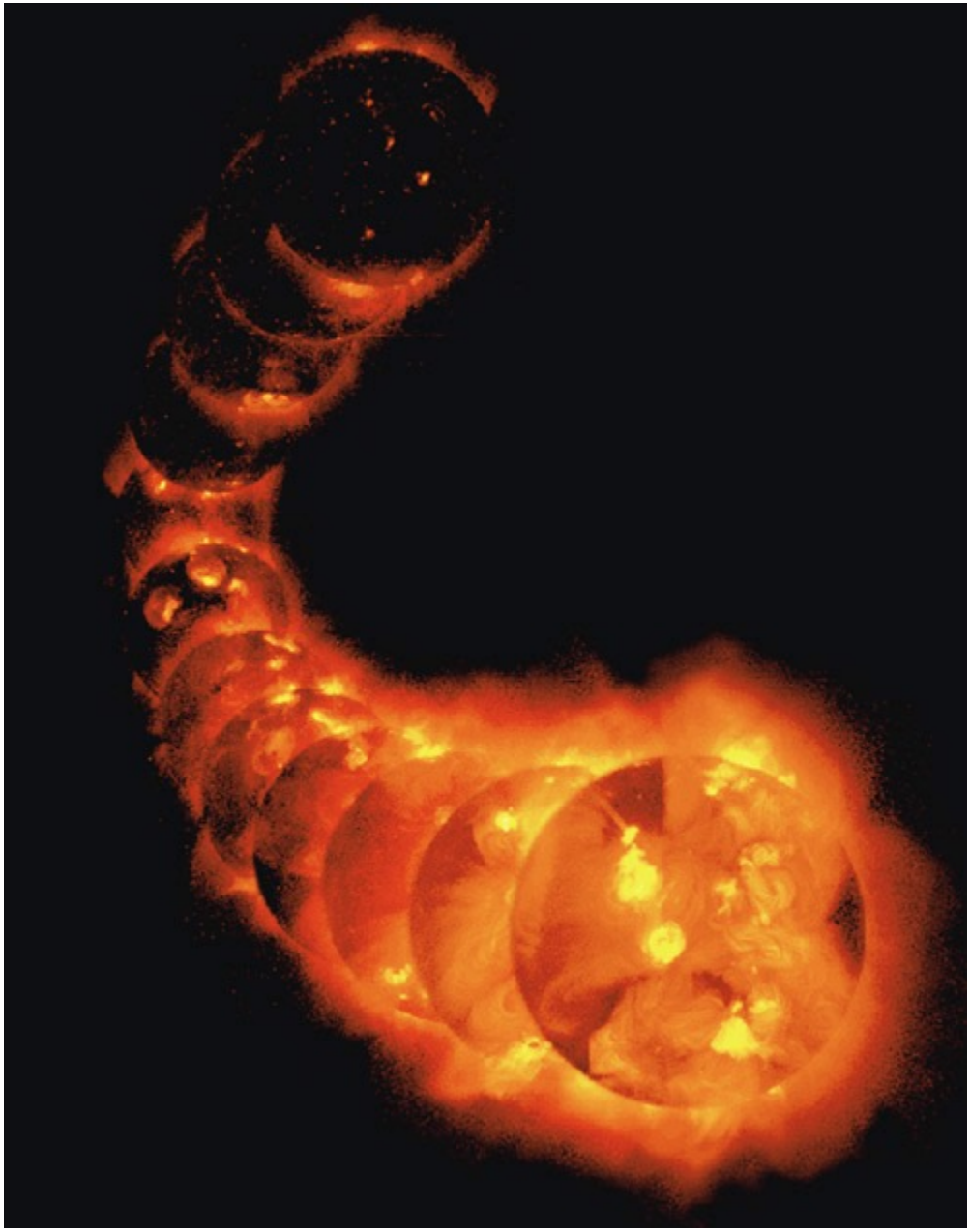
The Sun

I. **Basic Features**
   Mass, Size, Elemental make-up, 8 major Parts: CRCPCTCW

II. **Quiet Sun**
   Continuous Features, Energy Production, Fusion Rx's

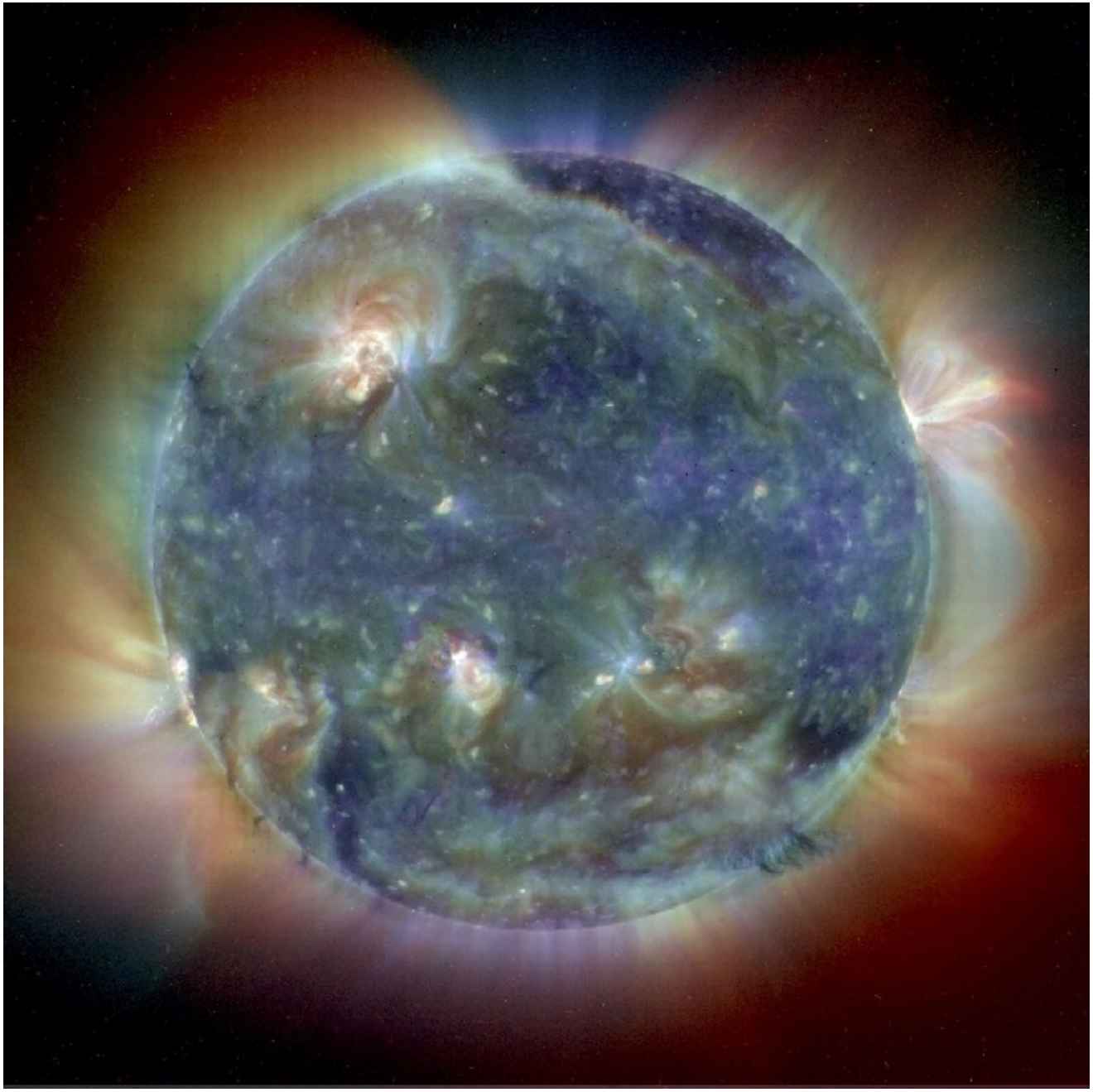
III. Active Sun
   Solar Cycle, Sunspots, Transient Features, Magnetic Dynamo

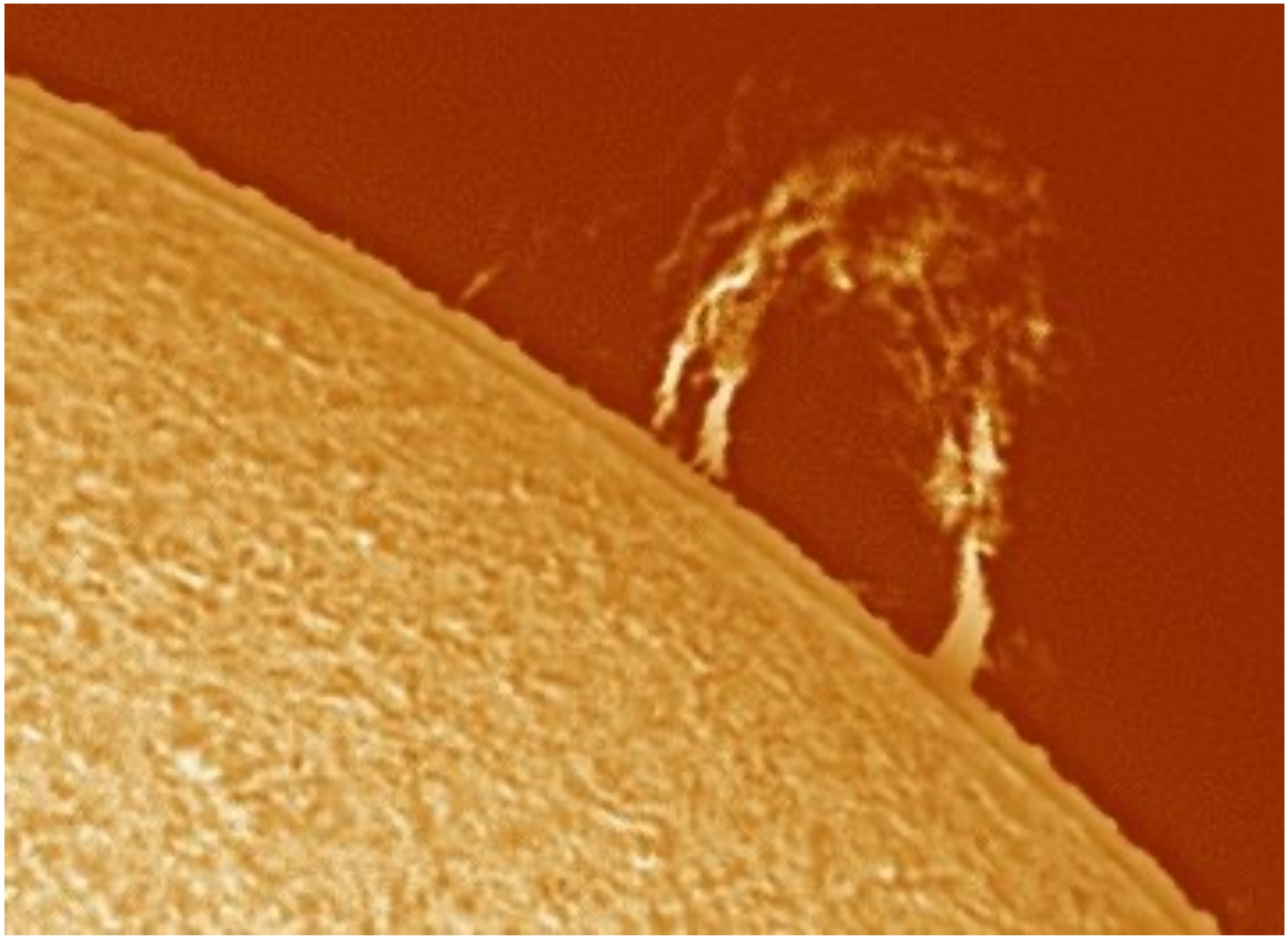
	The student will be able to:	HW:
1	Describe the overall structure of the Sun in terms of its core, radiation zone, convection zone, photosphere, chromosphere, transition zone, corona, and solar wind.	1 – 8
2	Describe the basic properties and composition of each part of the Sun listed above.	
3	Explain and describe granulation and supergranulation.	
4	Explain what is meant by helioseismology and describe how it has yielded information about the Sun's structure.	9, 10
5	Define, explain, and state the approximate values of the solar constant and the Sun's luminosity.	11 – 19
6	Describe mechanisms by which energy is transported from the core of the Sun to its exterior.	
7	Explain the process by which the Sun produces energy – fusion and relate this to the law of conservation of mass and energy and the strong nuclear force.	
8	Describe and explain the steps of the proton-proton chain in terms of reactions involving fundamental and subatomic particles.	
9	Describe efforts to obtain experimental evidence of the fusion process thought to power the Sun including measurements of solar neutrinos.	
10	Compare and contrast the concepts quiet Sun and active Sun.	20 – 23
11	Describe the appearance of sunspots and explain their formation in terms of the Sun's magnetic field.	
12	Define and explain the following concepts: sunspot cycle, solar cycle, solar minimum, and solar maximum.	
13	Describe and explain active regions of the Sun including prominences, and flares, spicules, and coronal mass ejections.	



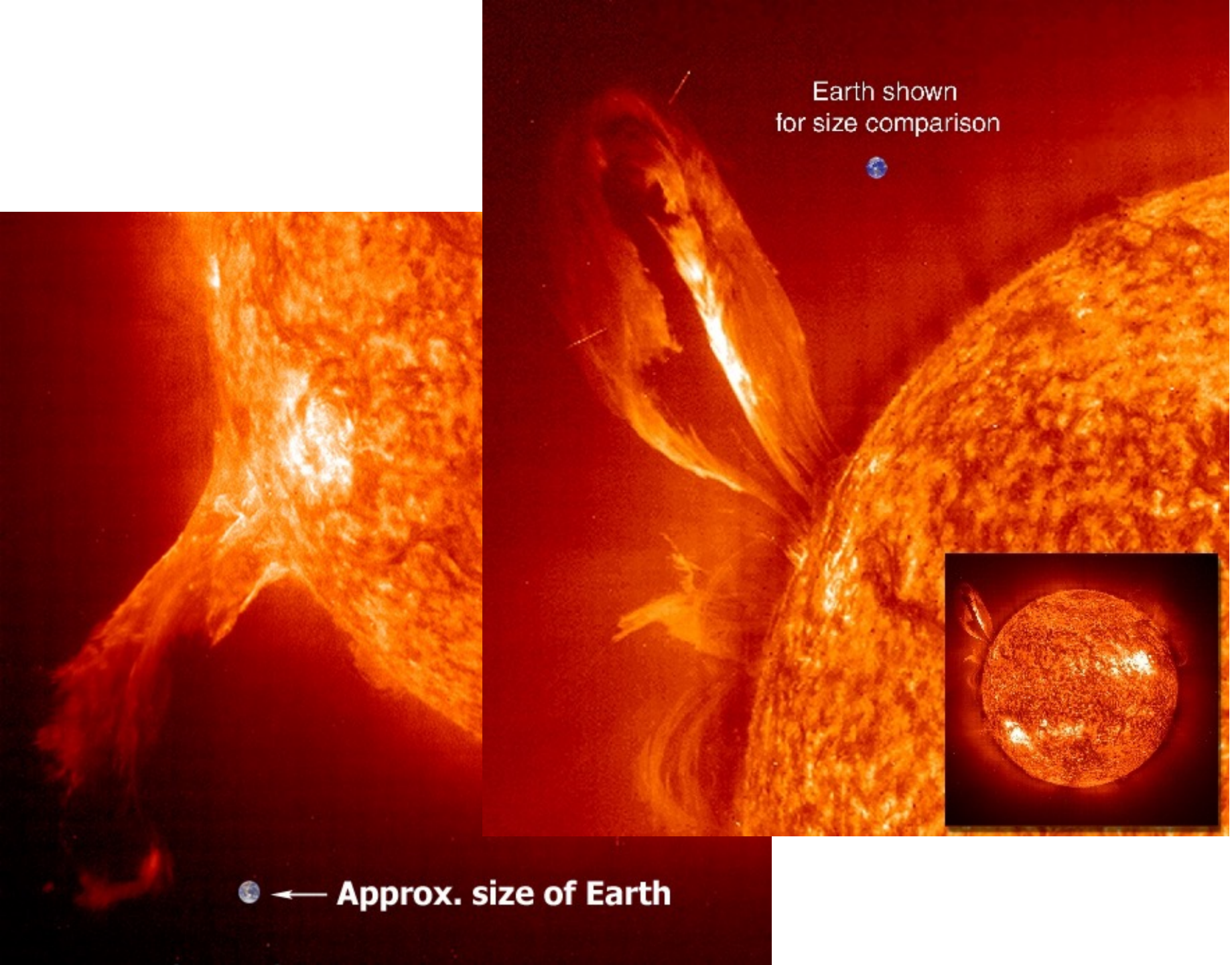
The sun displays various forms of "activity": sunspots, flares, prominences, CME's, et. The frequency of these activities varies in a cyclical fashion.

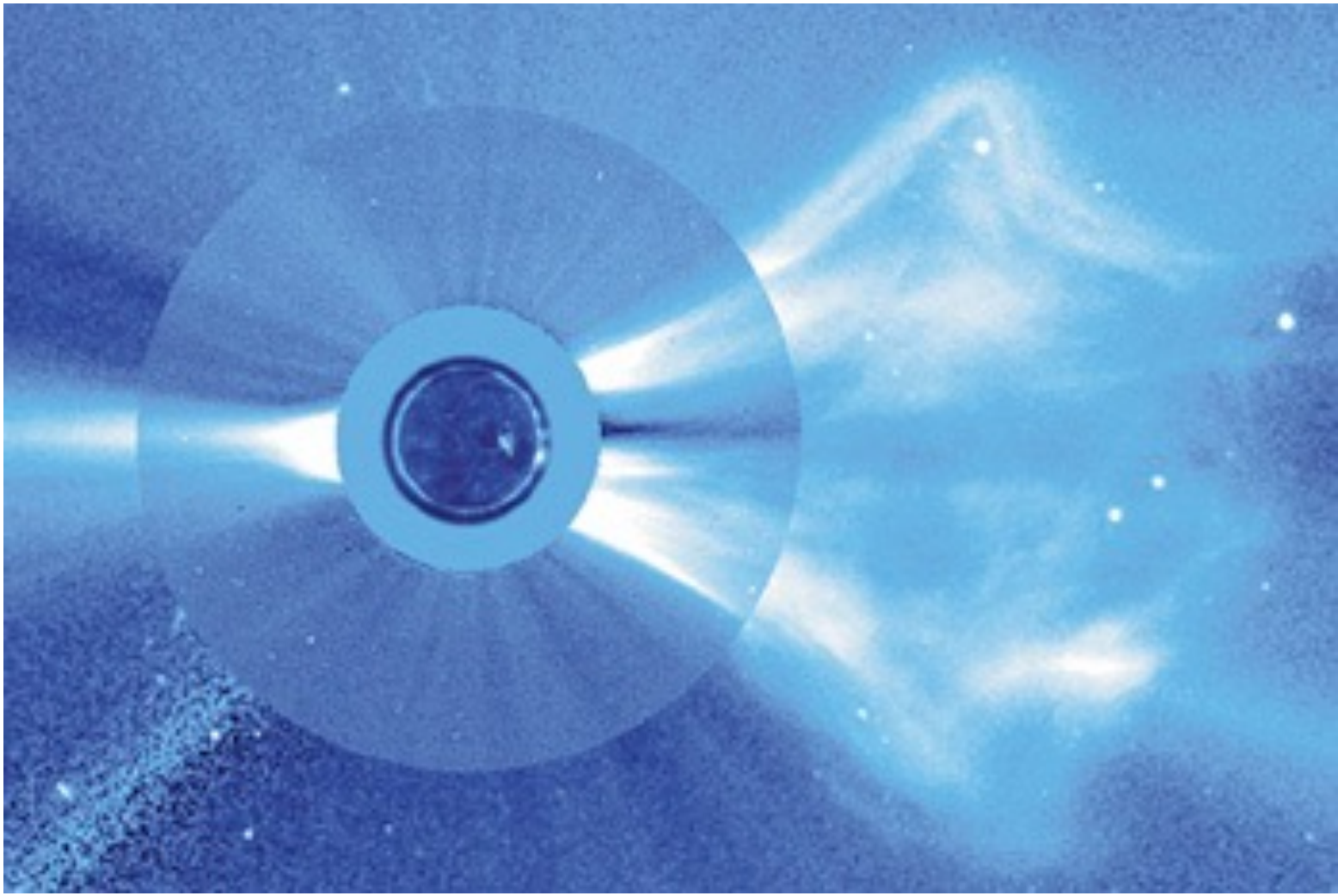
This x-ray image runs from "solar minimum" to "solar maximum" – a span of about 5.5 years.



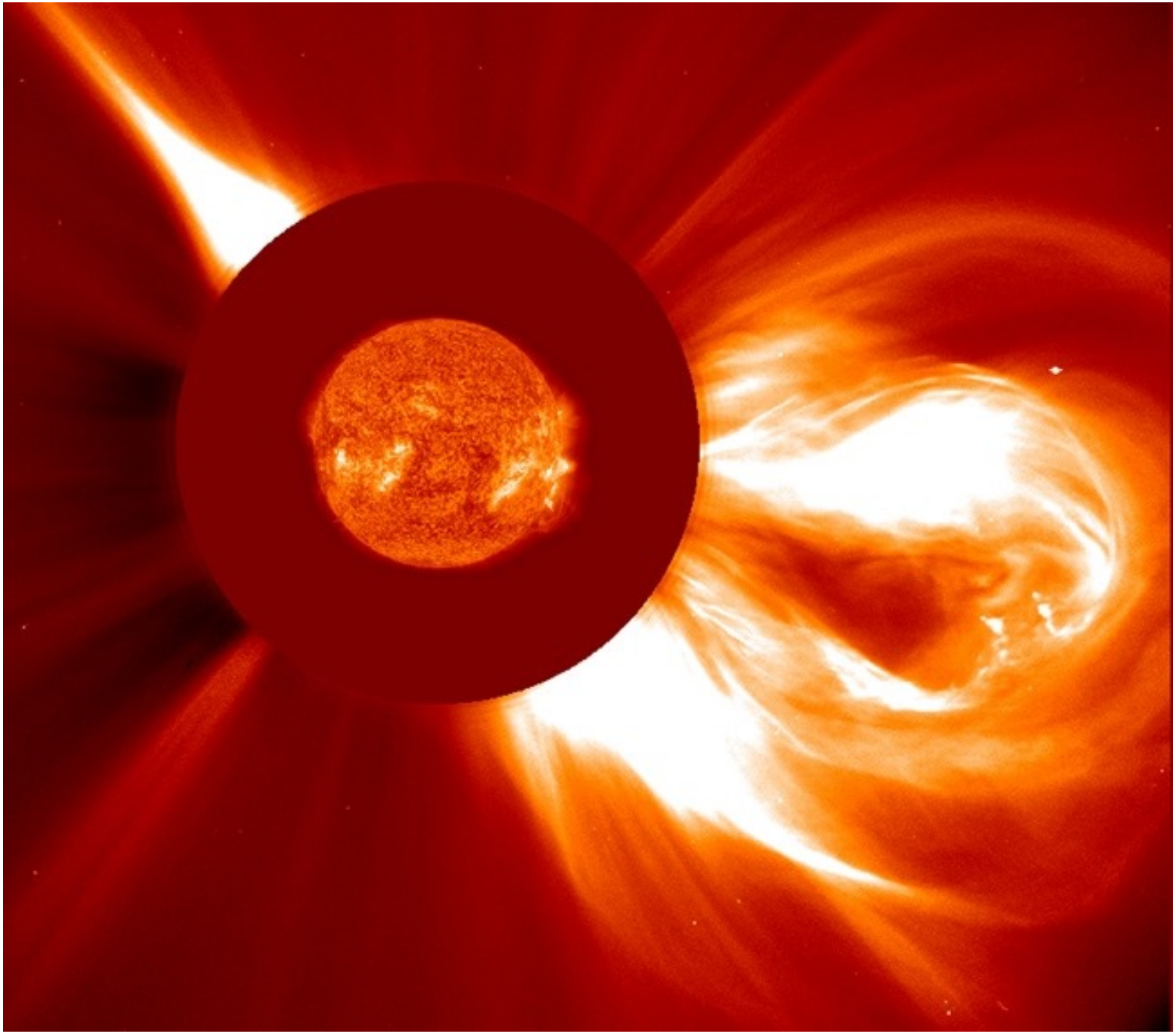


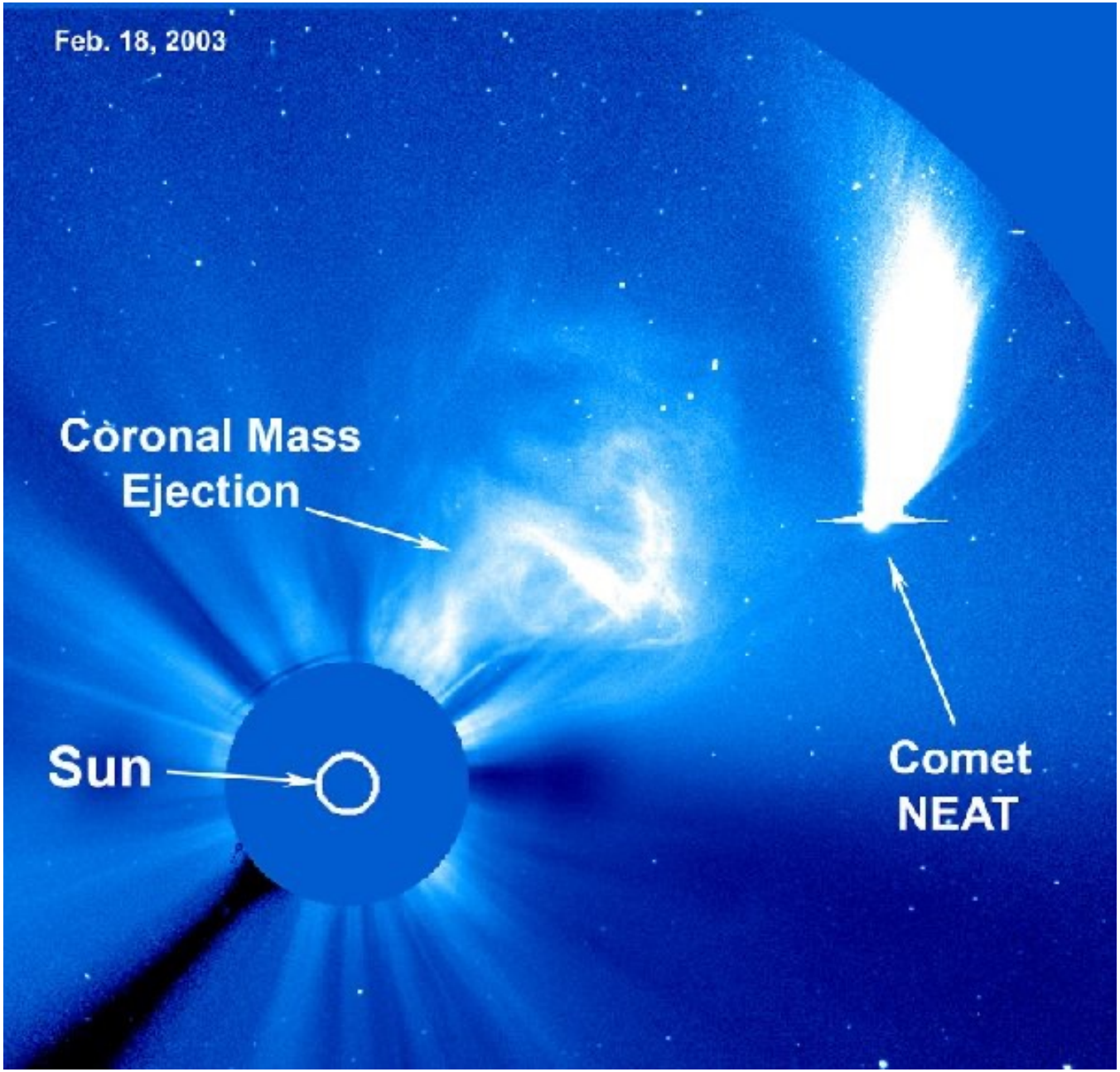
Solar Prominence – a sheet of glowing gas ejected from an active region of the photosphere.


Earth shown
for size comparison
Approx. size of Earth

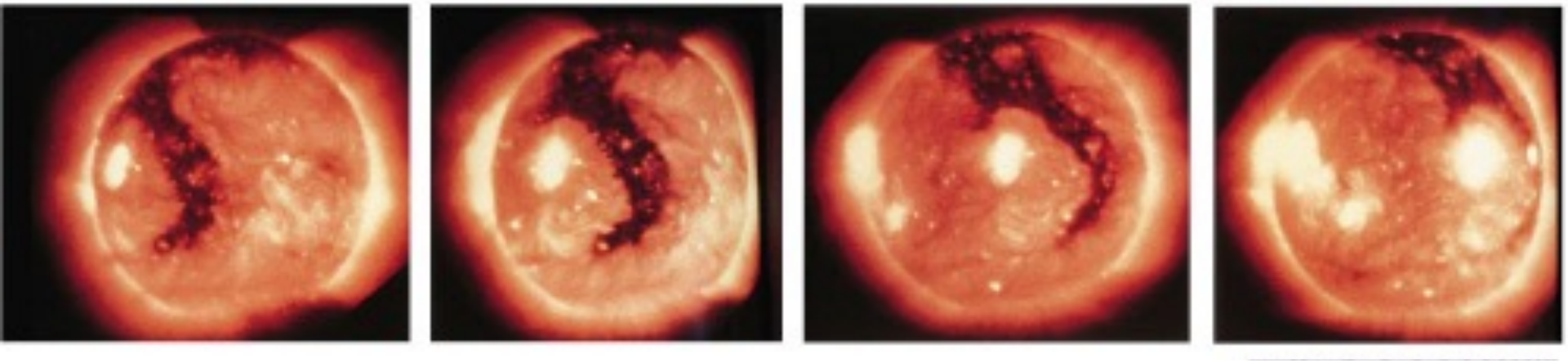


Coronal Mass Ejection (CME) is an exploding “bubble of gas” in the corona that releases particles into space.

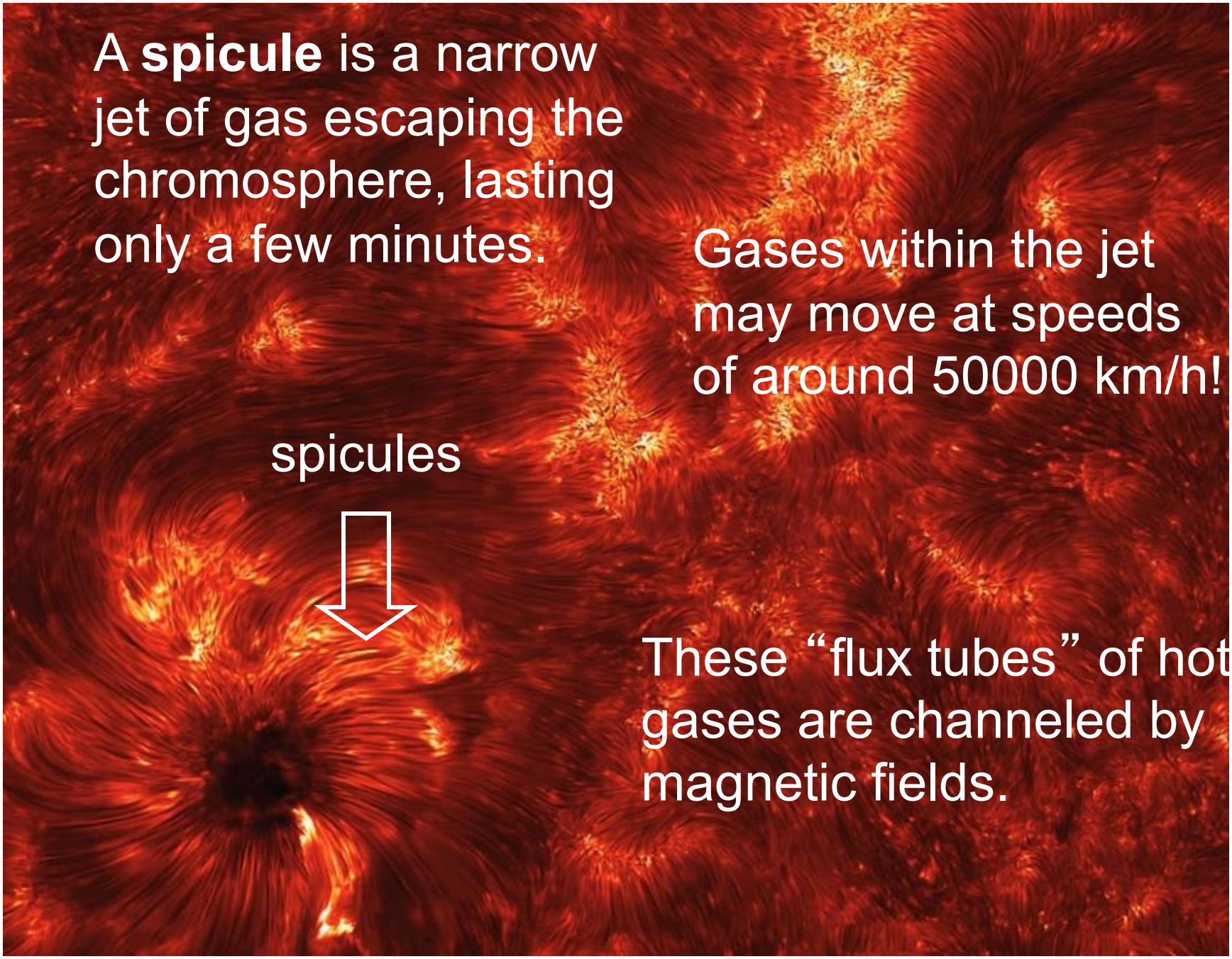



Feb. 18, 2003
Coronal Mass Ejection
Sun
Comet NEAT

Coronal Holes



A **coronal hole** is a region of the corona where material is escaping into space. These regions are usually near the poles of the Sun and are centered along open magnetic field lines.



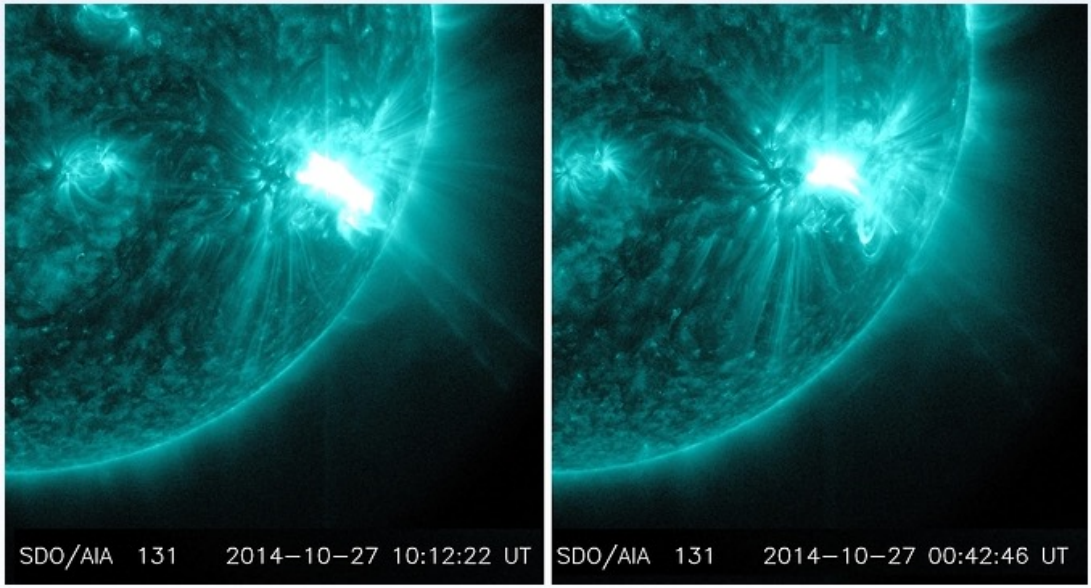
K. Reardon (Osservatorio Astrofisico di Arcetri, INAF) IBIS, DST, NSO

NASA's Solar Dynamics Observatory captured this image of an X2.0-class solar flare bursting off the lower right side of the sun on Oct. 27, 2014. The image shows a blend of extreme ultraviolet light with wavelengths of 131 and 171 Angstroms.

Image Credit: NASA/SDO

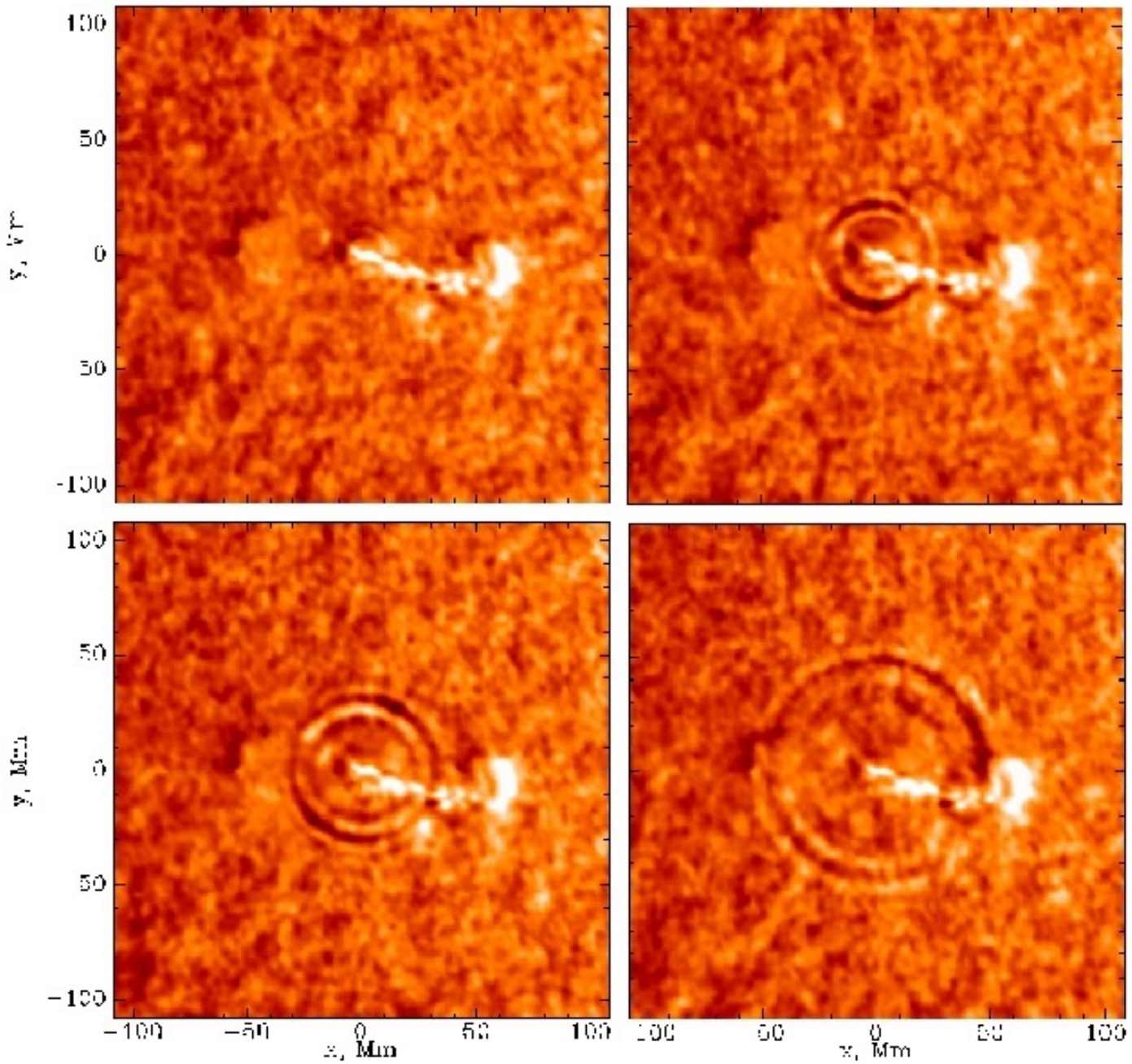
A **solar flare** is an intense burst of radiation that energizes gas in the solar atmosphere.

Scientists classify strength of flares as category *A*, *B*, *C*, *M*, or *X*, each being a factor of ten greater.

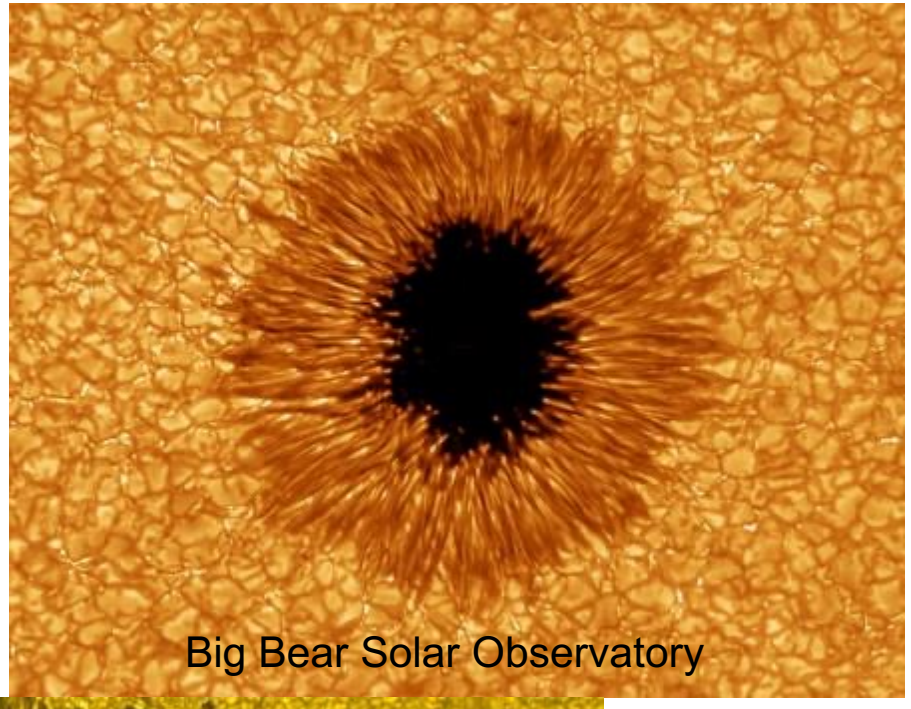


NASA's SDO captured images of two M-class flares erupting from the same region on the sun. The flare on the left peaked at 8:34 pm EDT on Oct. 26, 2014; the flare on the right peaked at 6:09 am EDT on Oct. 27, 2014. The images show EUV light of 131 Angstroms, which is typically colorized in teal.

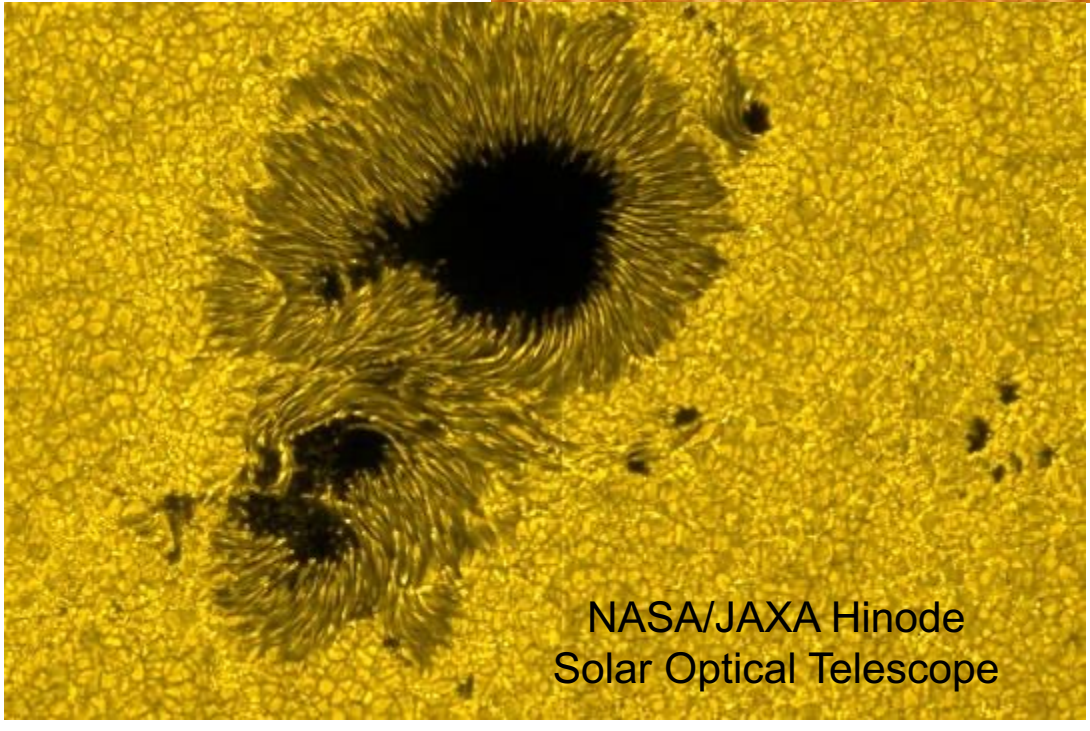
Image Credit: NASA/SDO


100
50
0
50
−100
y, Mm
−100
−50
0
50
100
x, Mm

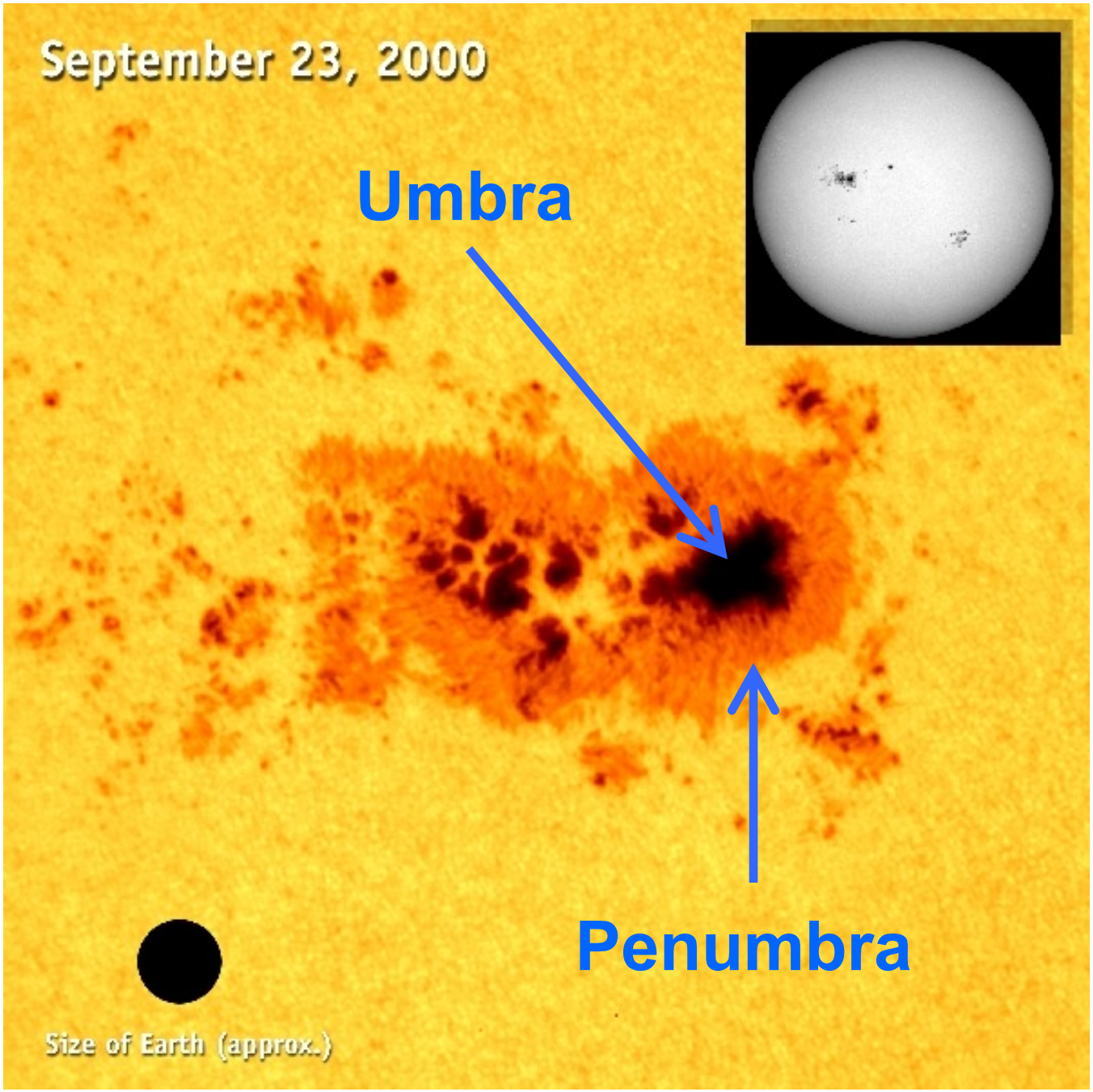
A **sunspot** is a *relatively* cool region of the photosphere – about 4500 K.

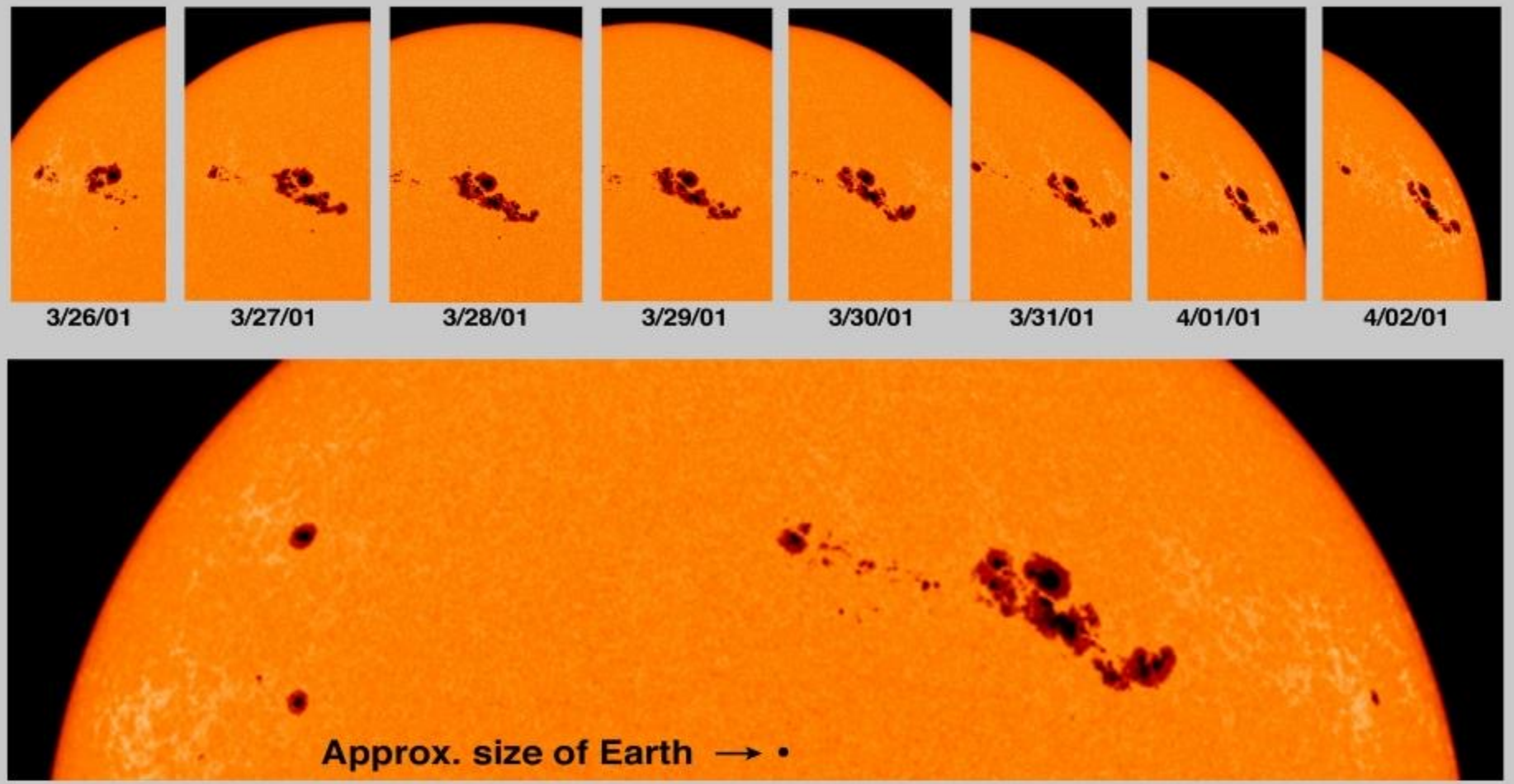


Big Bear Solar Observatory

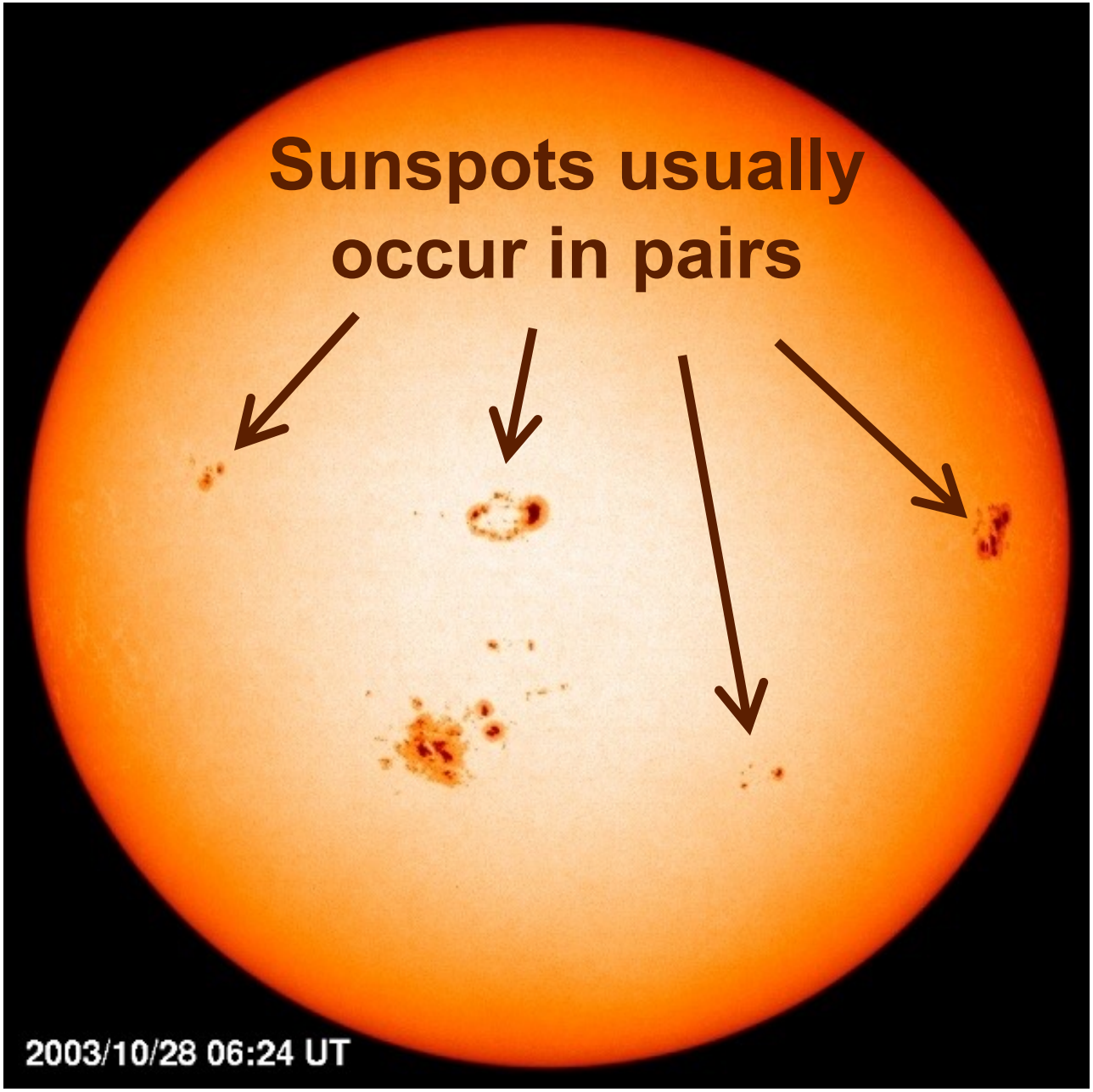


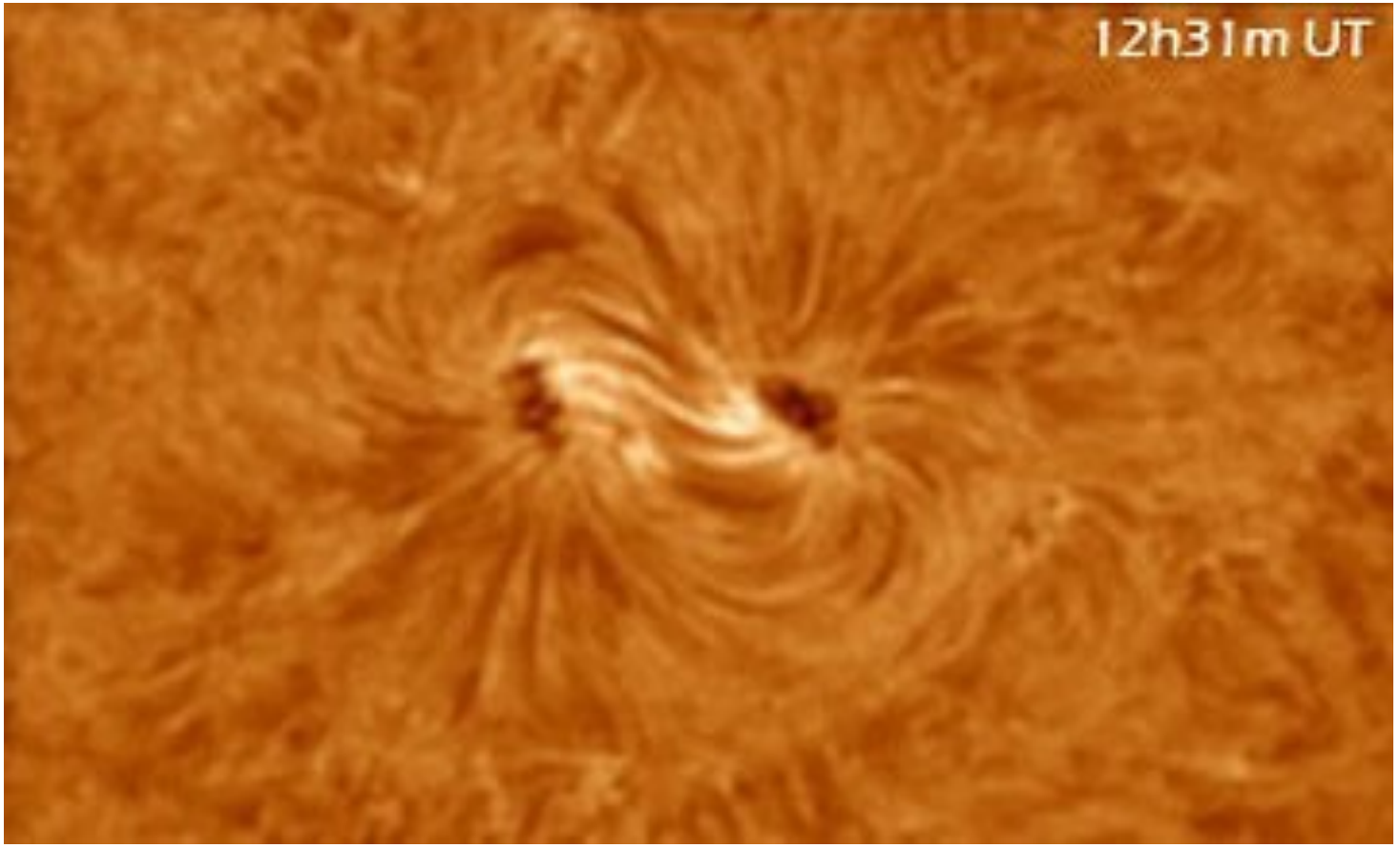
NASA/JAXA Hinode
Solar Optical Telescope


September 23, 2000
Umbra
Penumbra
Size of Earth (approx.)



March 30, 2001


Sunspots usually
occur in pairs
2003/10/28 06:24 UT



Formation of Sunspot Pair

Sunspot Number

- The "sunspot number" is related to the number of sunspots visible on the Sun.
- Since the number of sunspots is subjective, astronomers use the following formula:

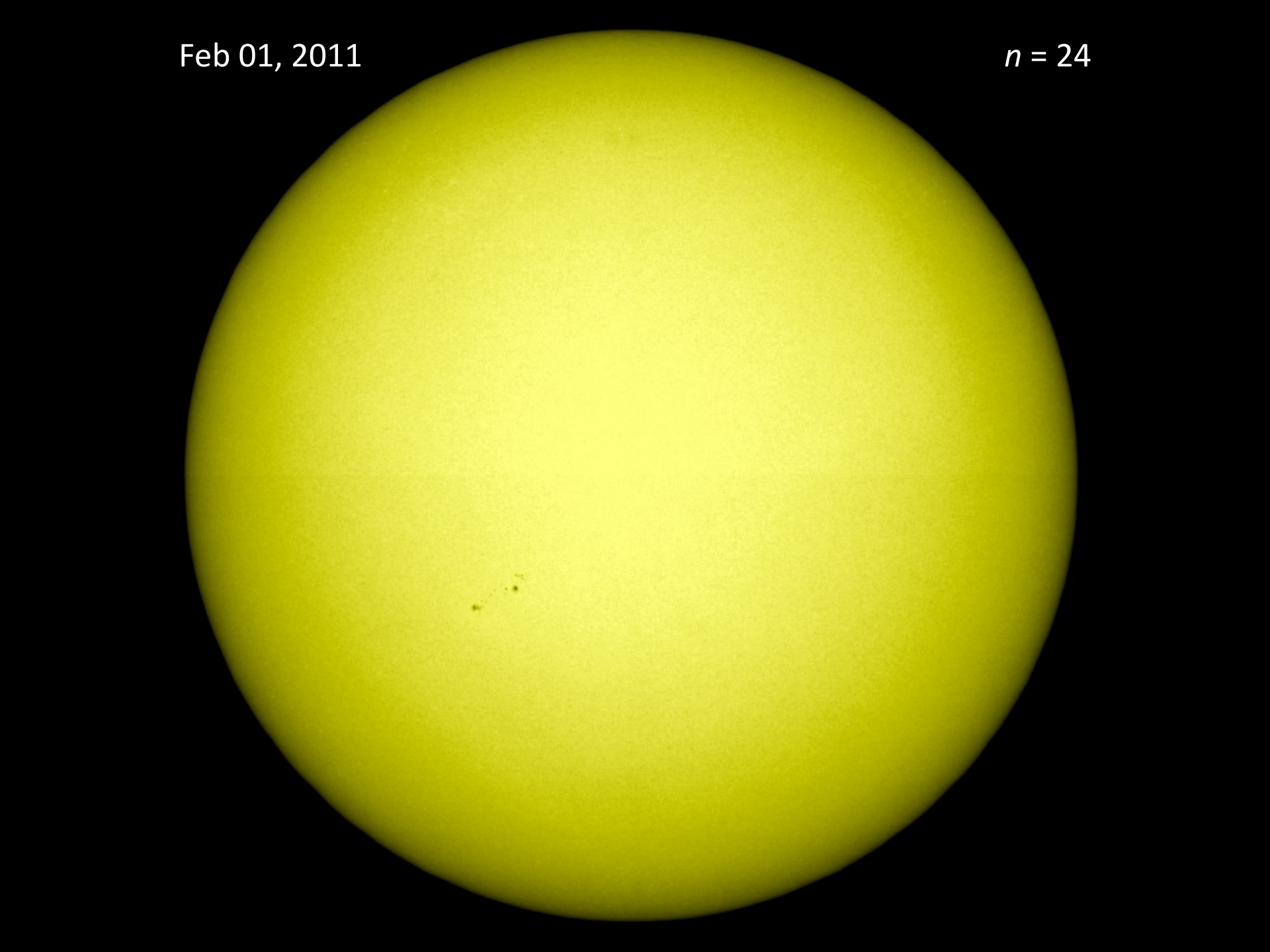
$$R = k(10g + s)$$

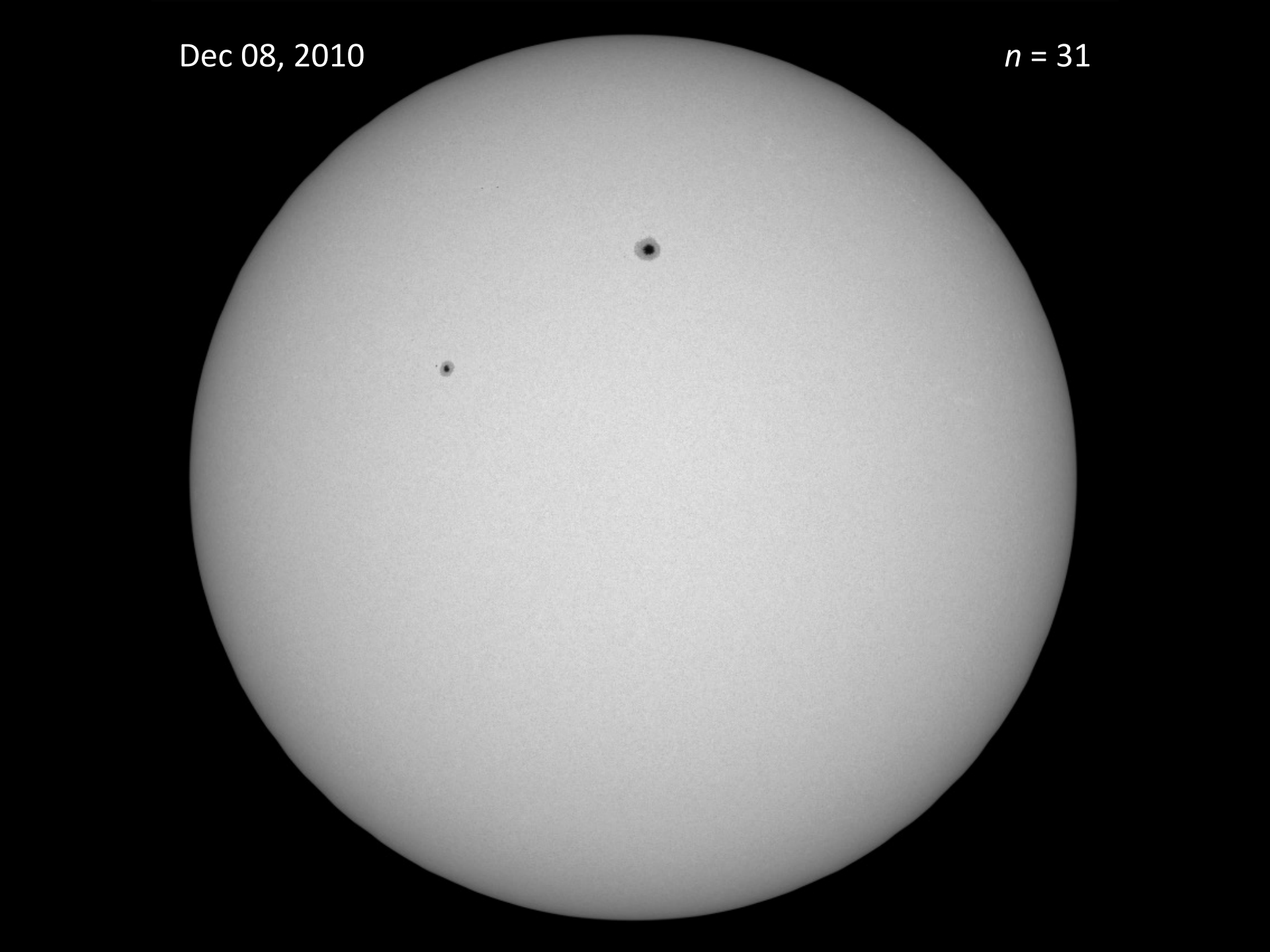
where: s = number of individual sunspots
g = number of sunspot groups
k = factor depending on location and instrumentation

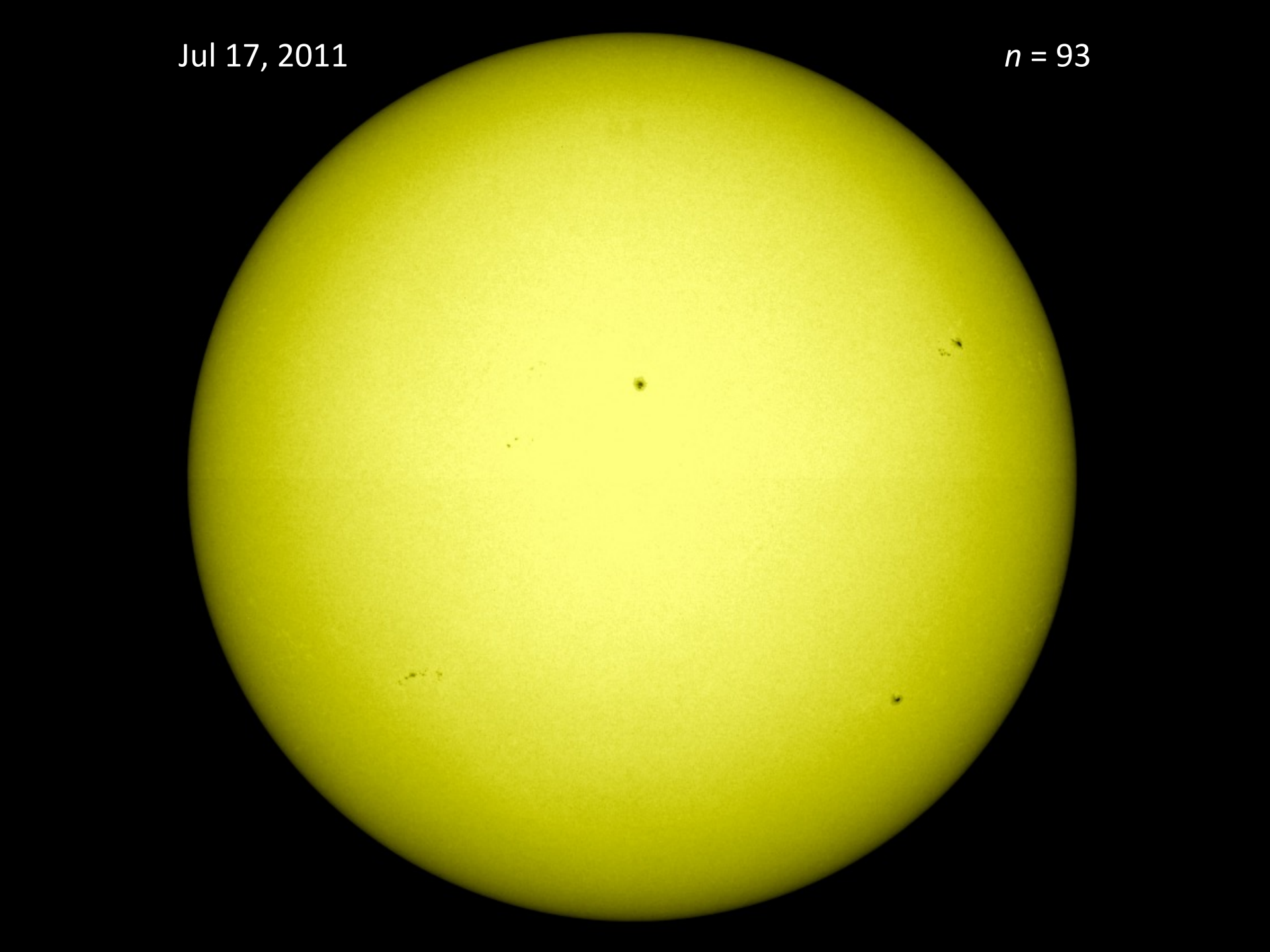
- Regular observations are tabulated and averaged to determine daily, monthly, and yearly values.

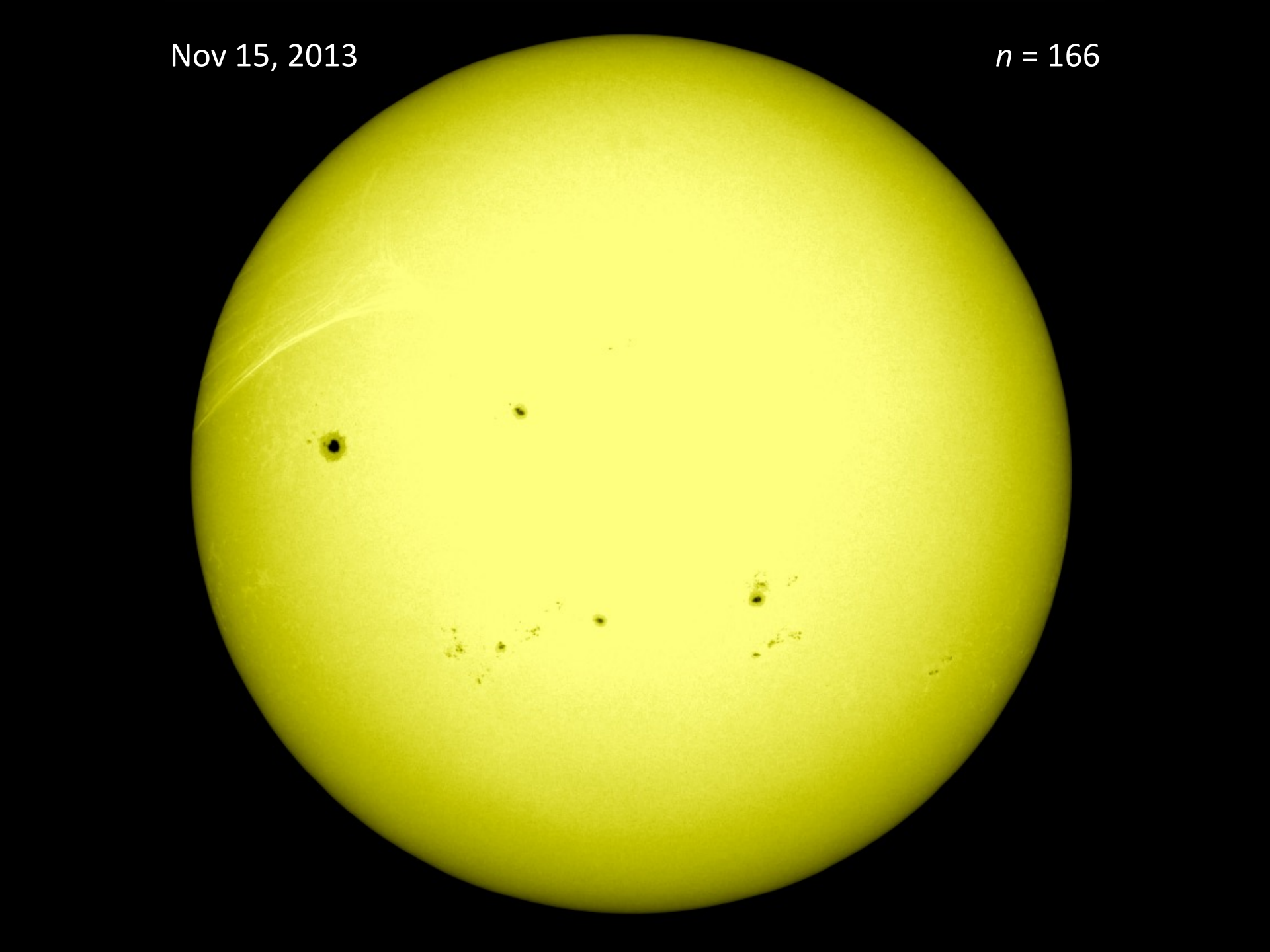
Sunspot Number

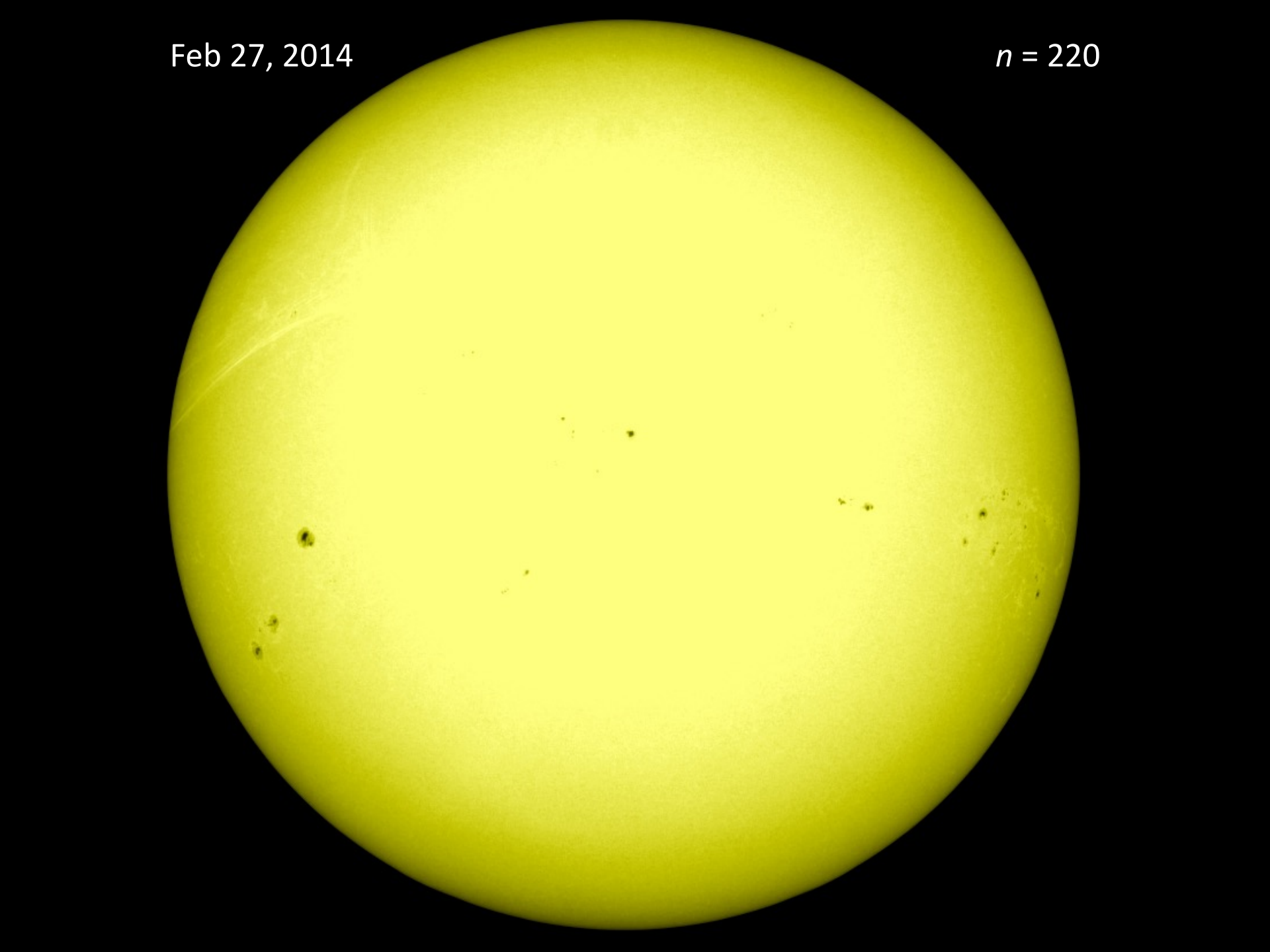
- There are two “standardized” sources: the “Boulder Sunspot Number” published by NOAA Space Environment Center and the “International Sunspot Number” published by the Solar Influences Data Center.
- As a rough “rule of thumb”, if you divide the sunspot number by 15 this is the number of sunspots visible when projecting an image of the Sun with a small telescope.

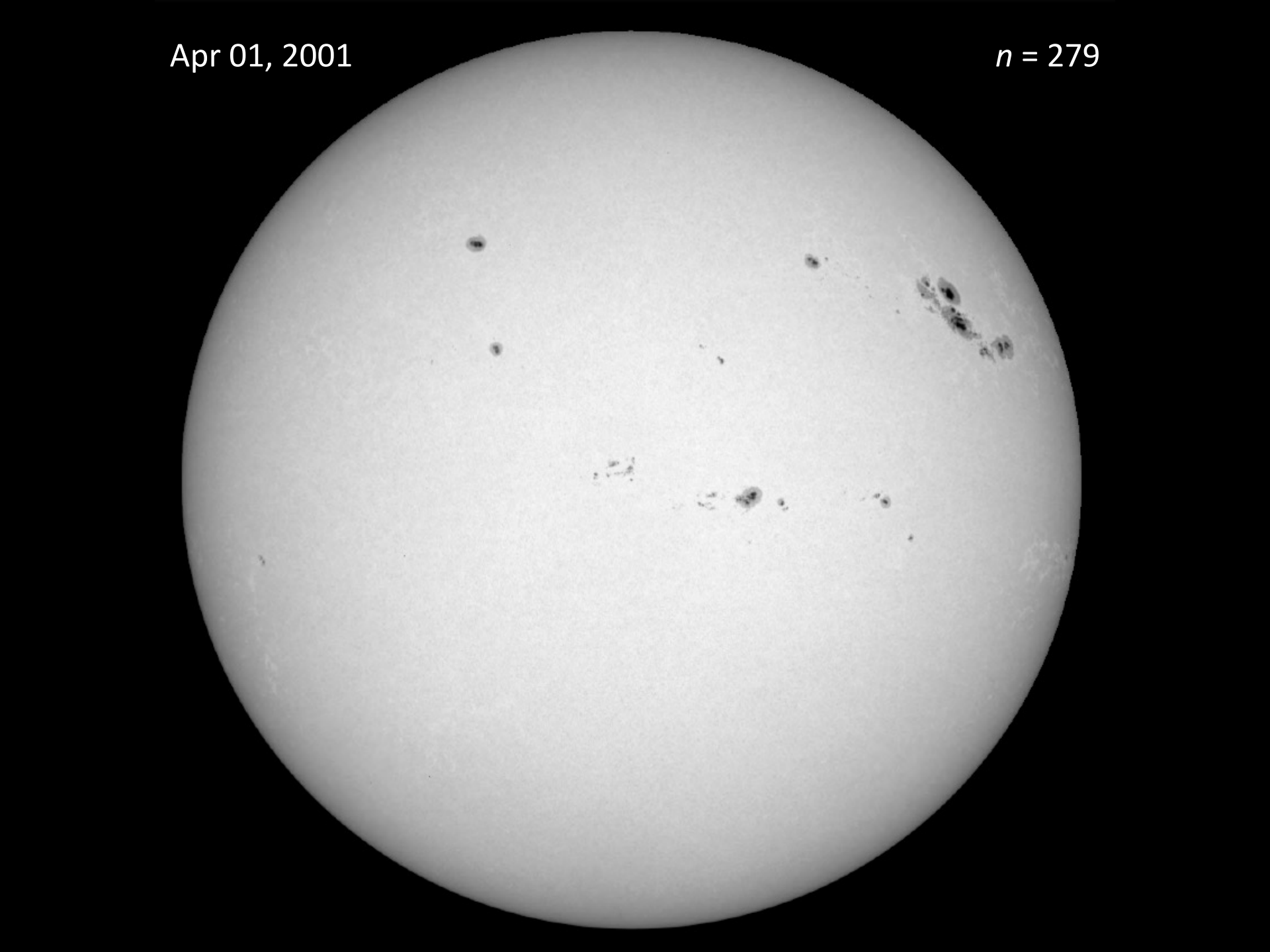

Feb 01, 2011
n = 24


Dec 08, 2010
n = 31


Jul 17, 2011
n = 93

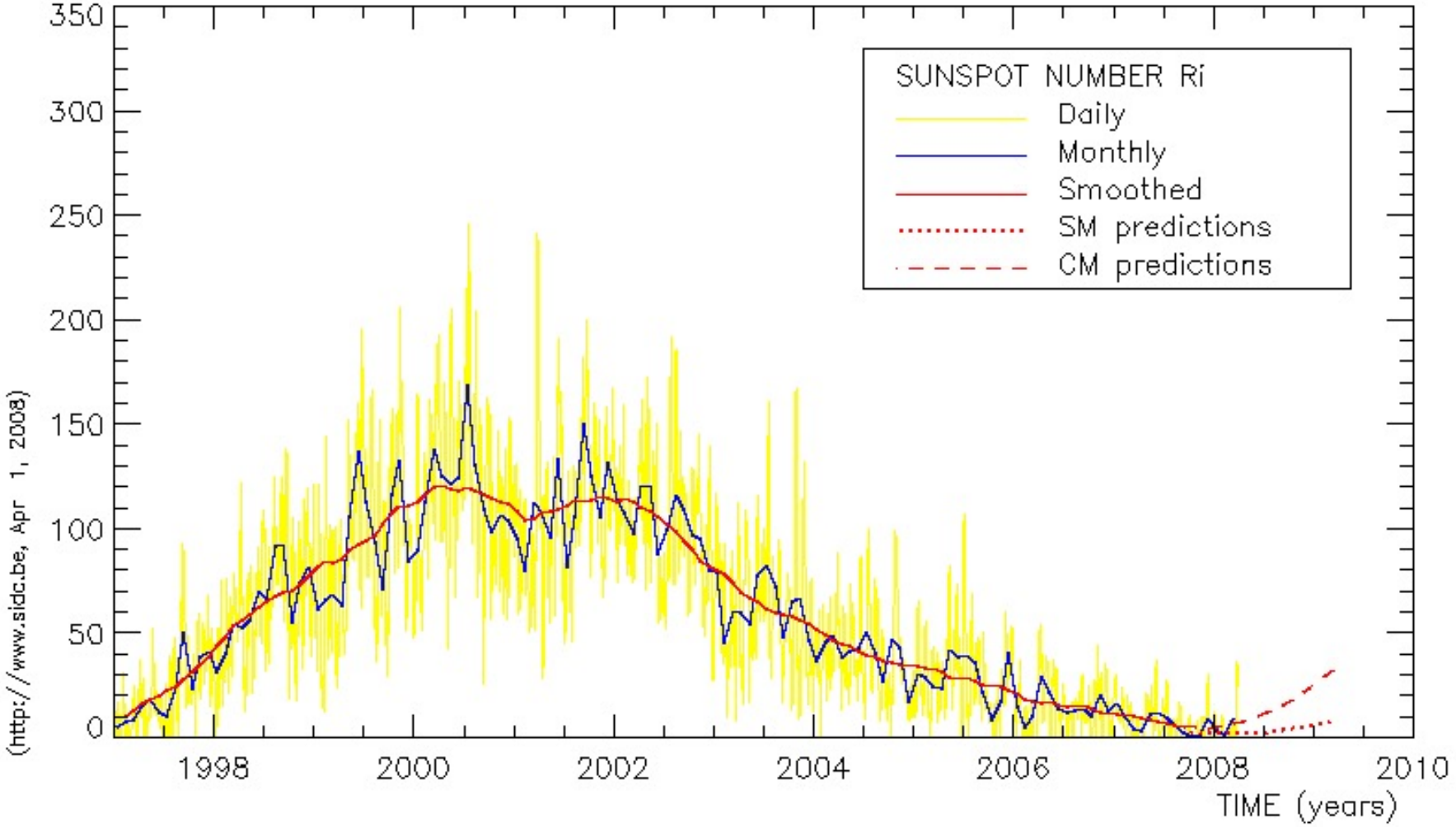

Nov 15, 2013
n = 166

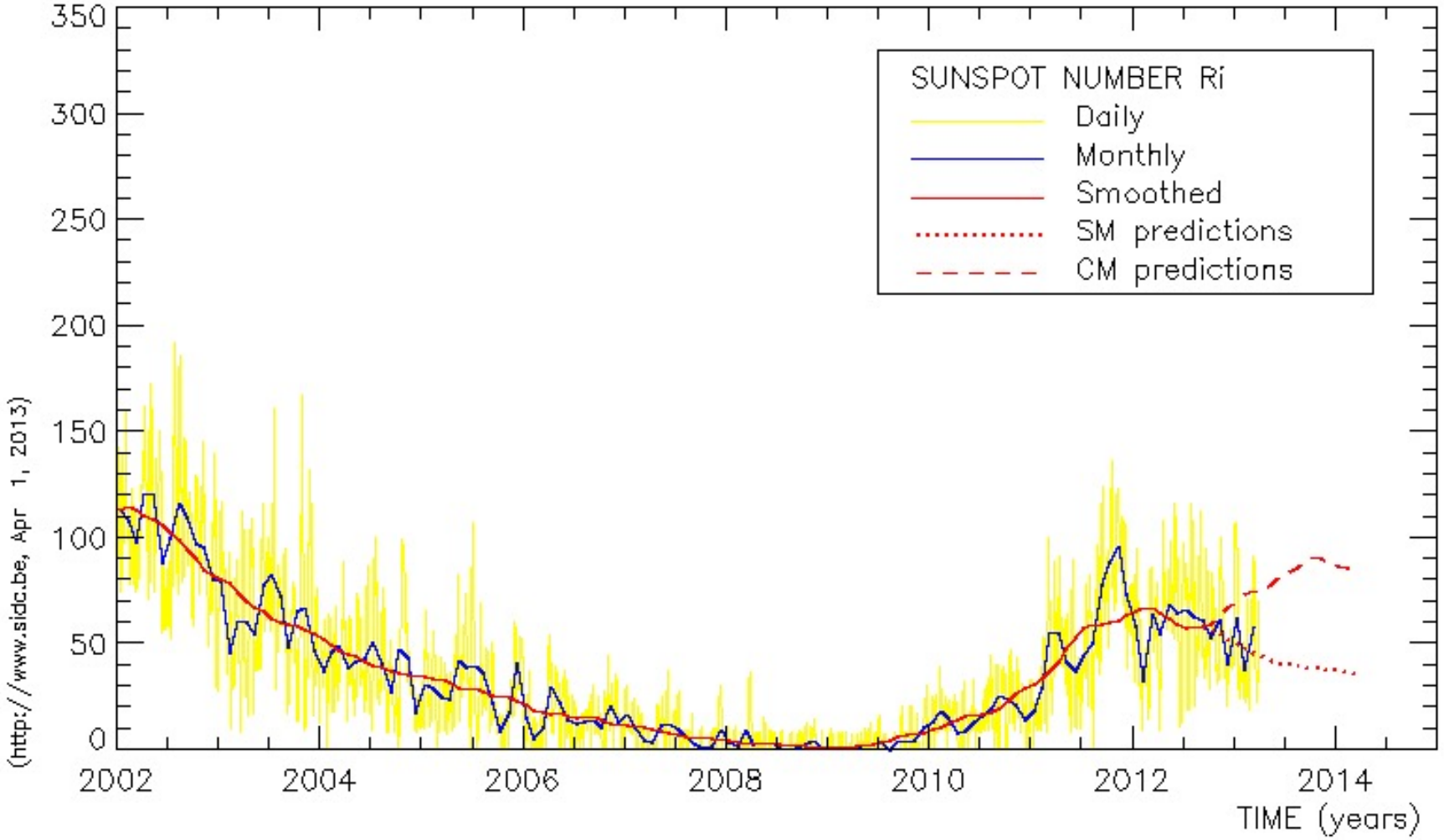

Feb 27, 2014
n = 220


Apr 01, 2001
n = 279

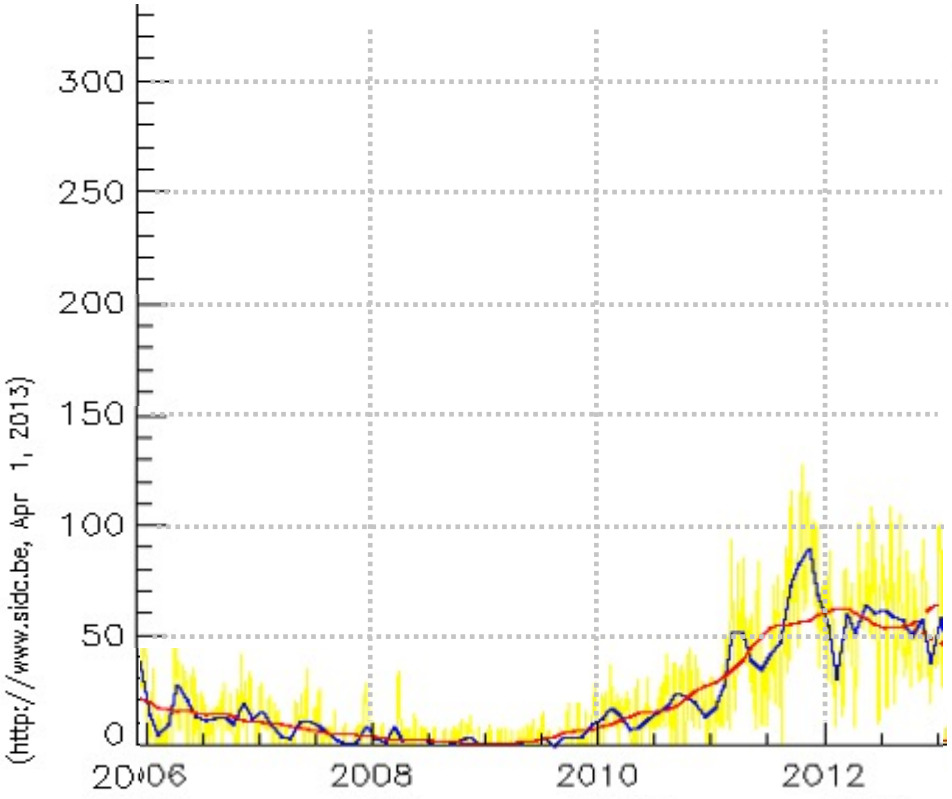
Sunspot Cycle

- The Sun is observed to undergo alternating periods of activity and relative calm.
- These alternating phases occur at regular intervals.
- Astronomers determine numbers of sunspots and measure other phenomena to track this cycle.
- You will explore this cycle on a worksheet…

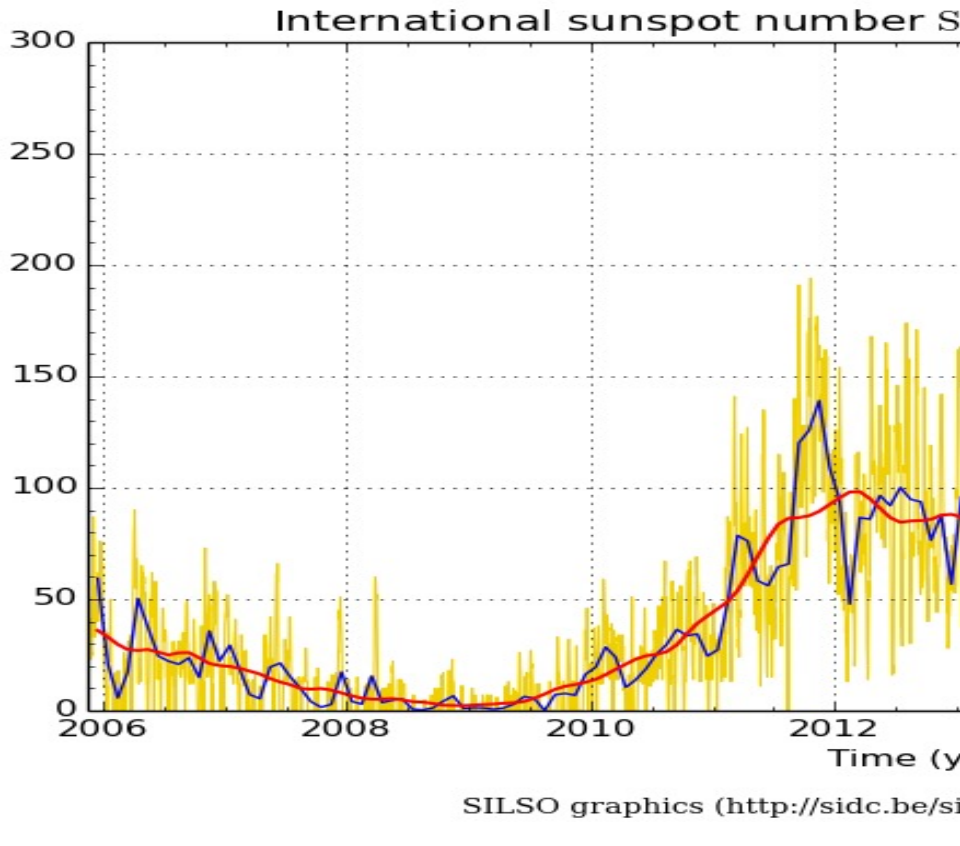

SUNSPOT NUMBER Ri
Daily
Monthly
Smoothed
SM predictions
CM predictions
350
300
250
200
150
100
50
0
1998
2000
2002
2004
2006
2008
2010
TIME (years)
(http://www.sidc.be, Apr 1, 2008)


SUNSPOT NUMBER Ri
Daily
Monthly
Smoothed
SM predictions
CM predictions
350
300
250
200
150
100
50
0
2002
2004
2006
2008
2010
2012
2014
TIME (years)
(http://www.sidc.be, Apr 1, 2013)

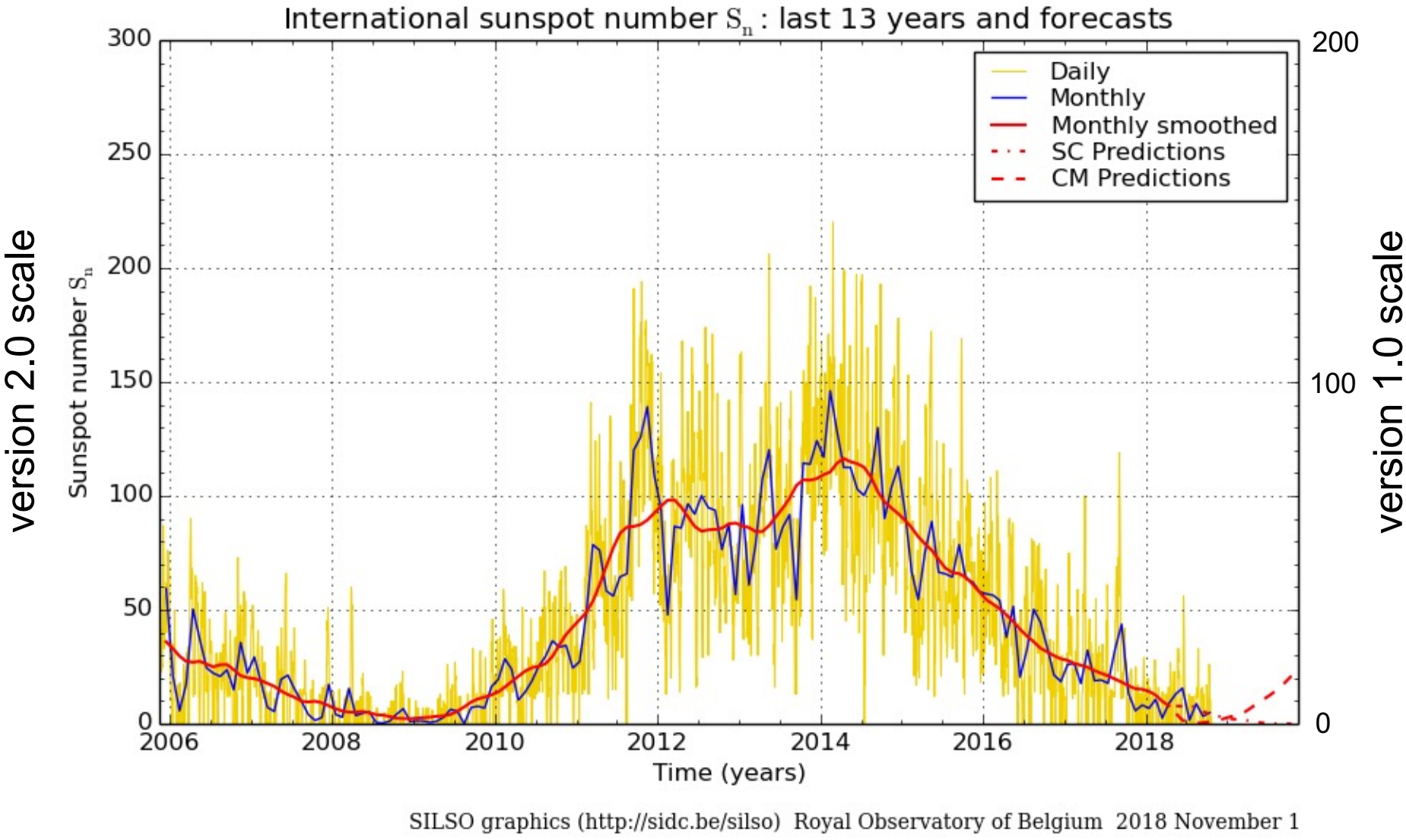
Version 1.0
(used prior to 2015)



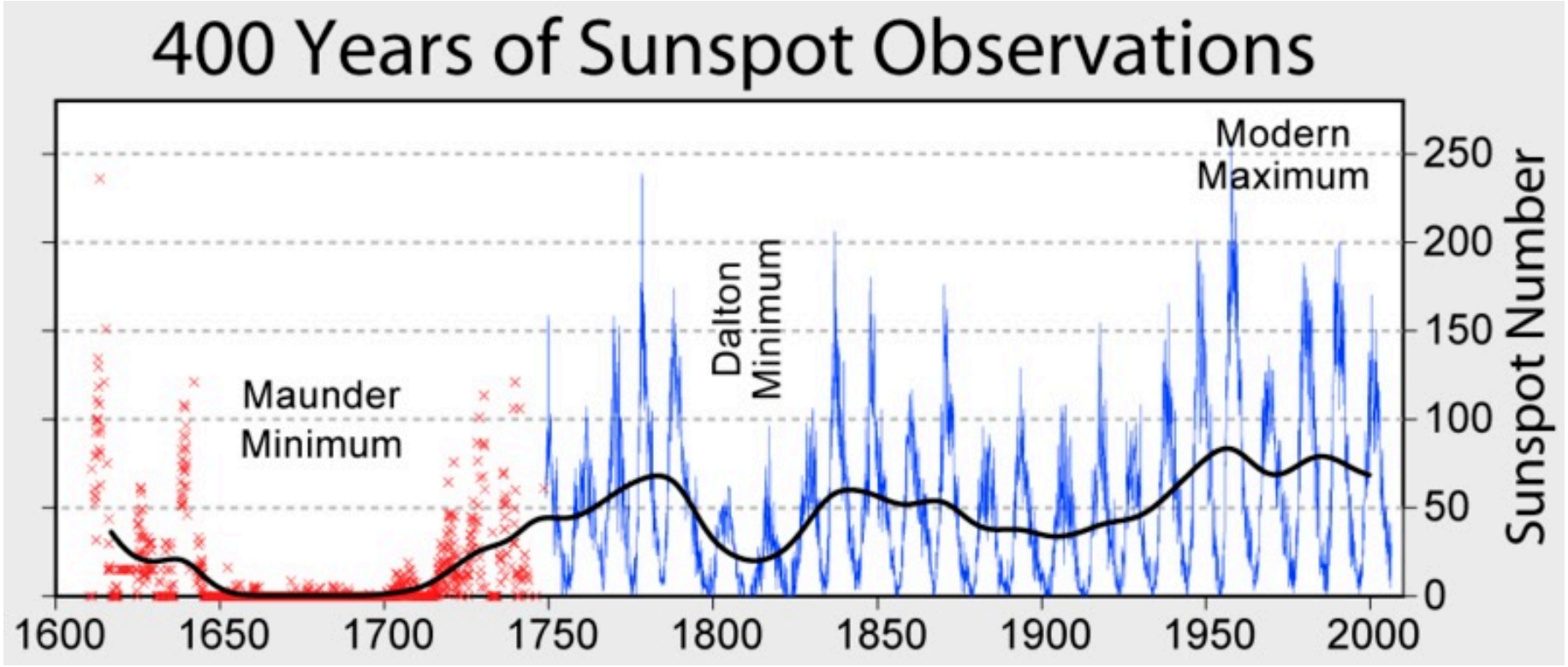
Version 2.0
(pattern is the same!)



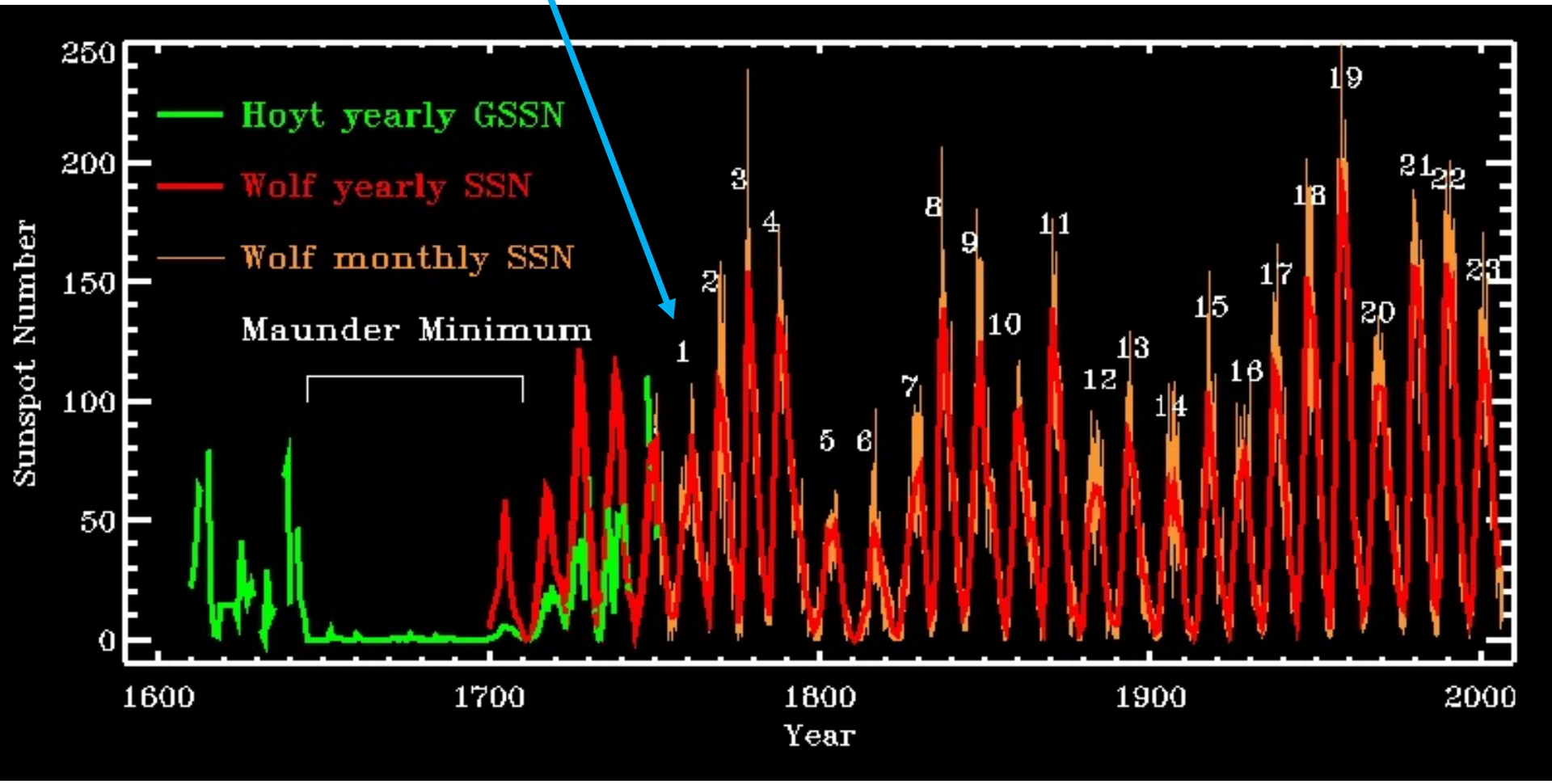
Sunspot Number 2.0: dropped conventional Zurich factor of 0.6
the new version is 1/0.6 = 1.67 times greater than before.

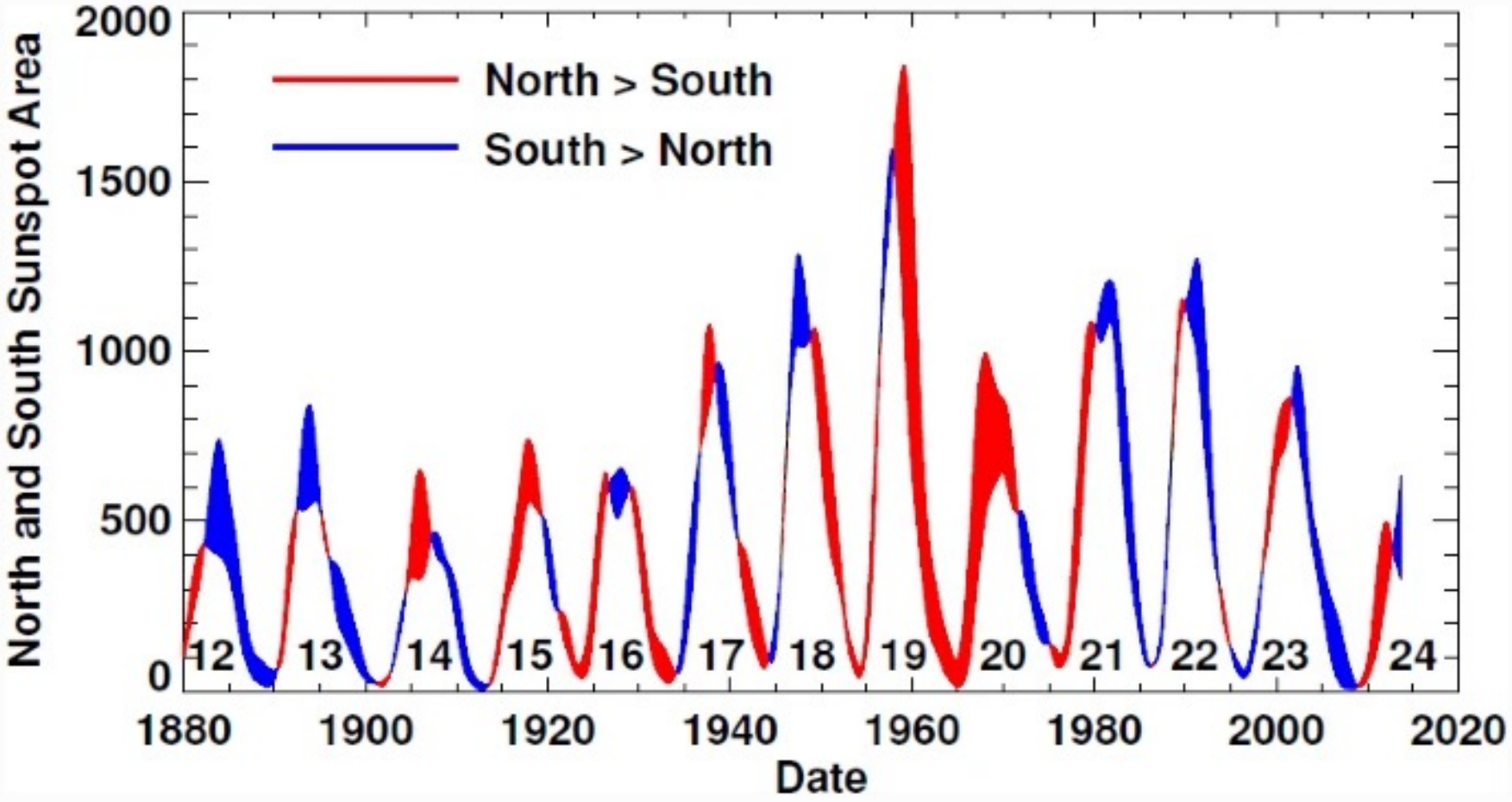


As shown above the pattern of activity is the same but the version 2.0 numbers are adjusted to a different scaling factor.

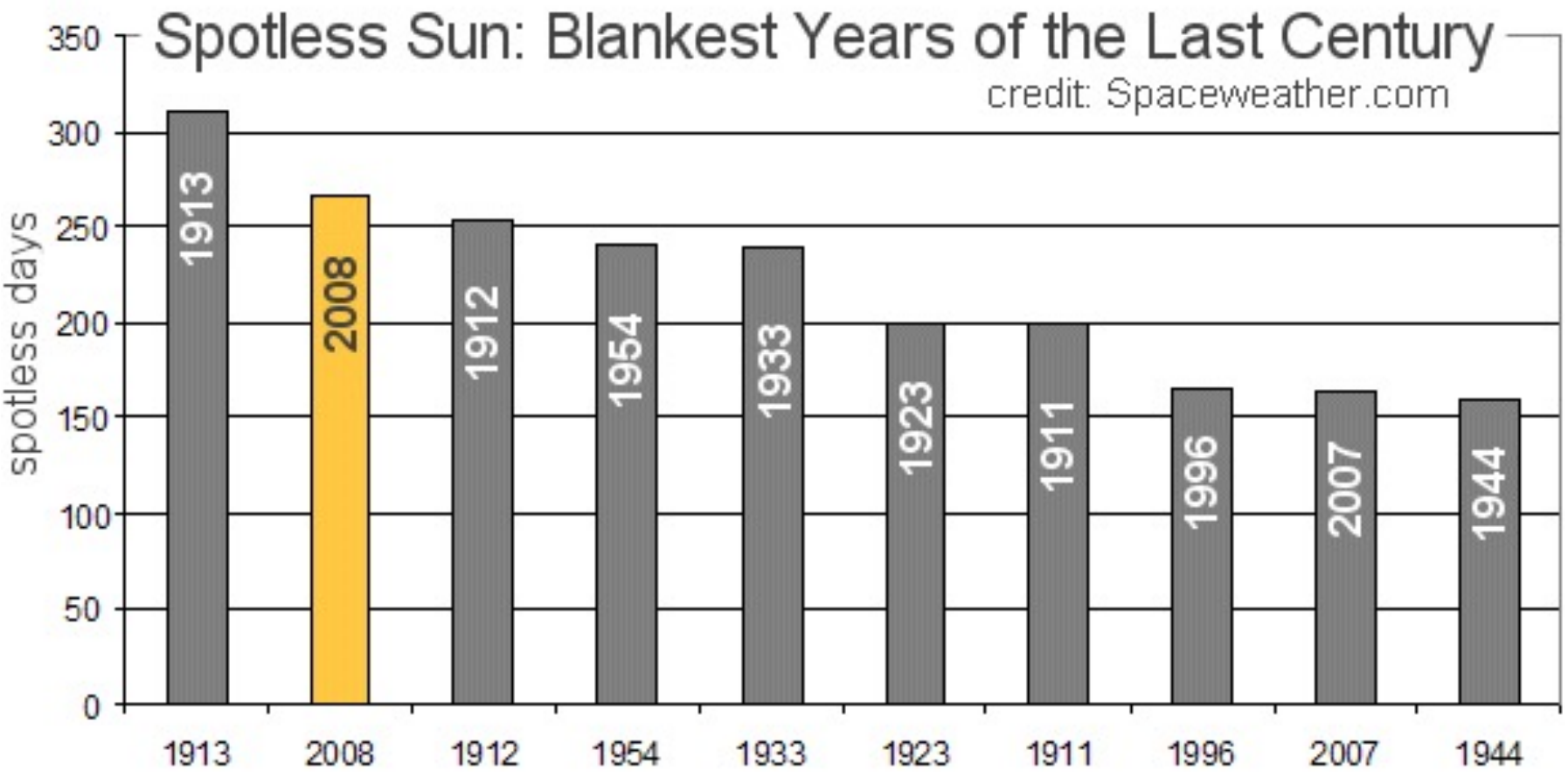

400 Years of Sunspot Observations
Modern
Maximum
Dalton
Minimum
Maunder
Minimum
250
200
150
100
50
0
Sunspot Number
1600
1650
1700
1750
1800
1850
1900
1950
2000

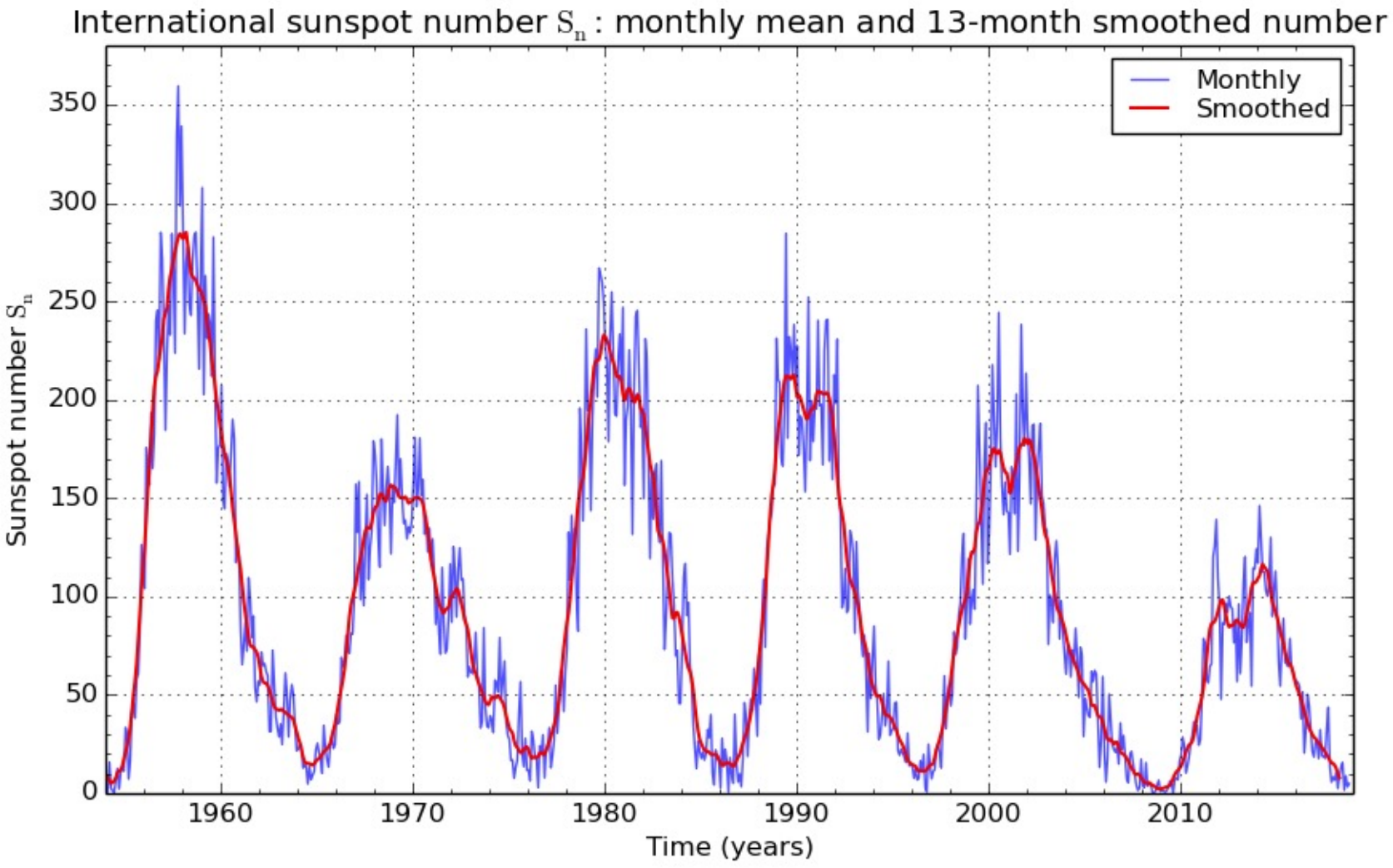
Sunspot cycles are numbered, starting with the cycle that began in 1756 and ended 1767 and continuing on through present time.

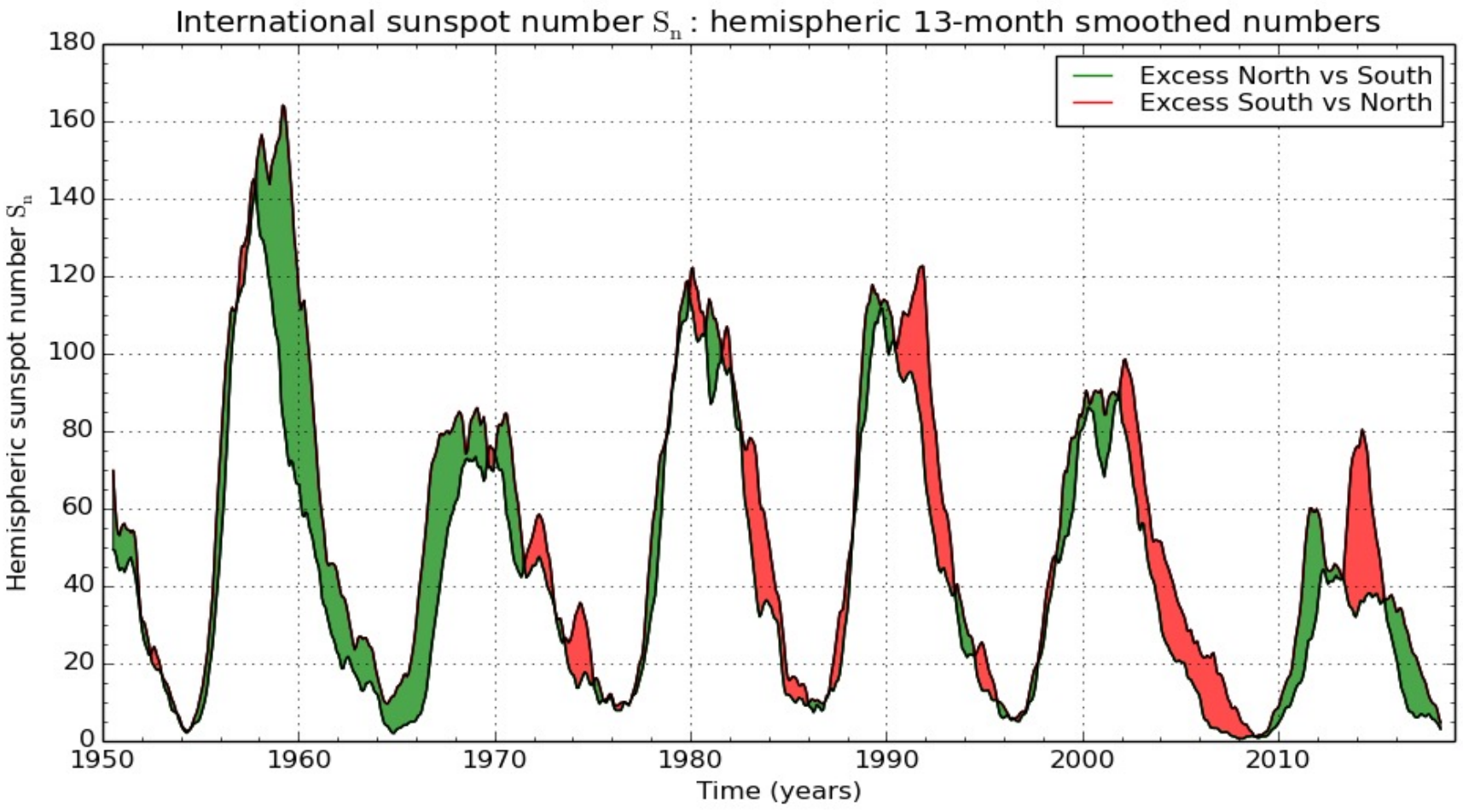




Smoothed monthly sunspot areas for northern and southern hemispheres separately. The difference between the two curves is filled in red if the north dominates or in blue if the south dominates.

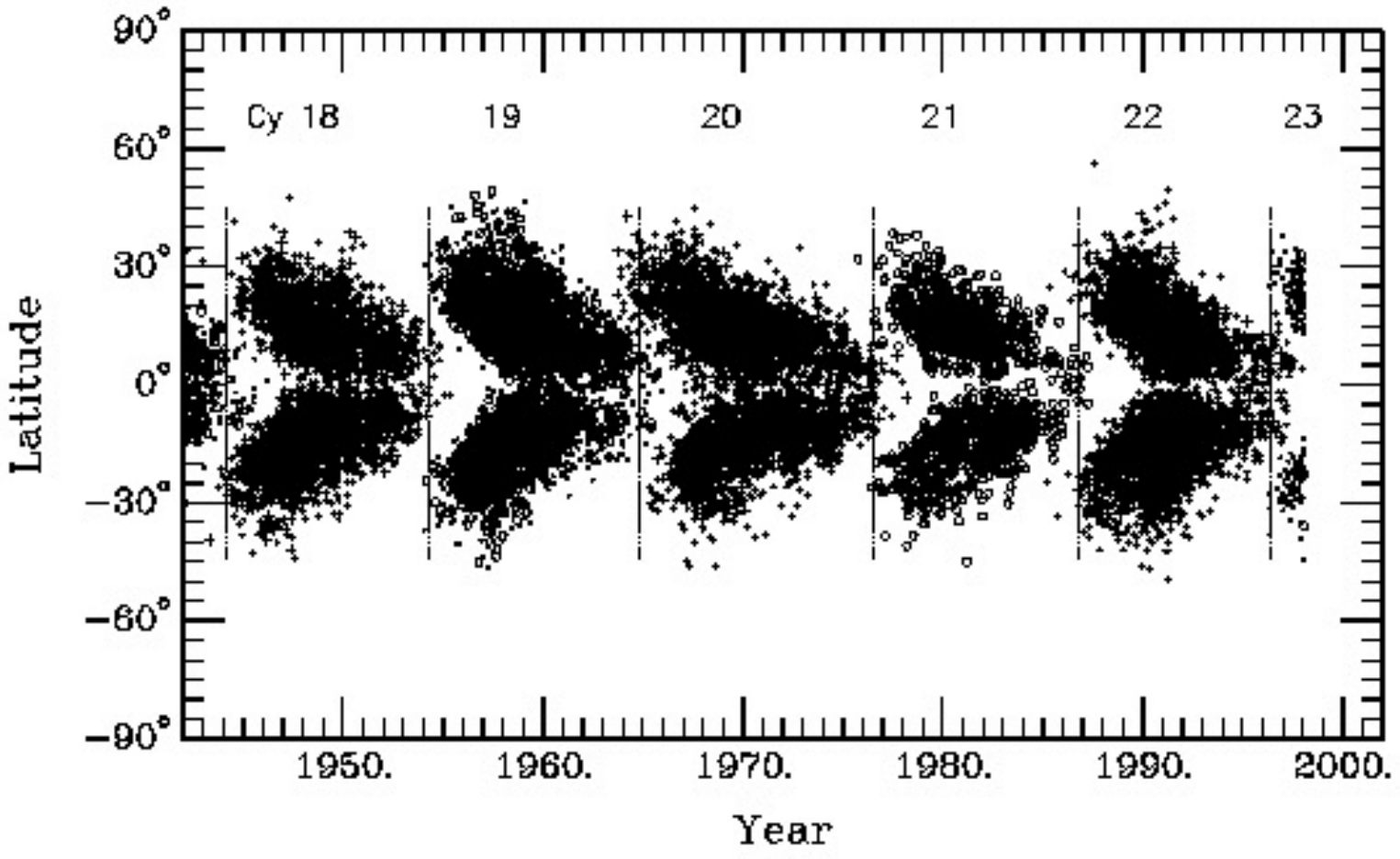

Spotless Sun: Blankest Years of the Last Century
credit: Spaceweather.com
spotless days
350
300
250
200
150
100
50
0
1913
2008
1912
1954
1933
1923
1911
1996
2007
1944


International sunspot number S_n : monthly mean and 13-month smoothed number
Monthly
Smoothed
Sunspot number S_n
0
50
100
150
200
250
300
350
1960
1970
1980
1990
2000
2010
Time (years)
SILSO graphics (http://sidc.be/silso) Royal Observatory of Belgium 2018 November 1

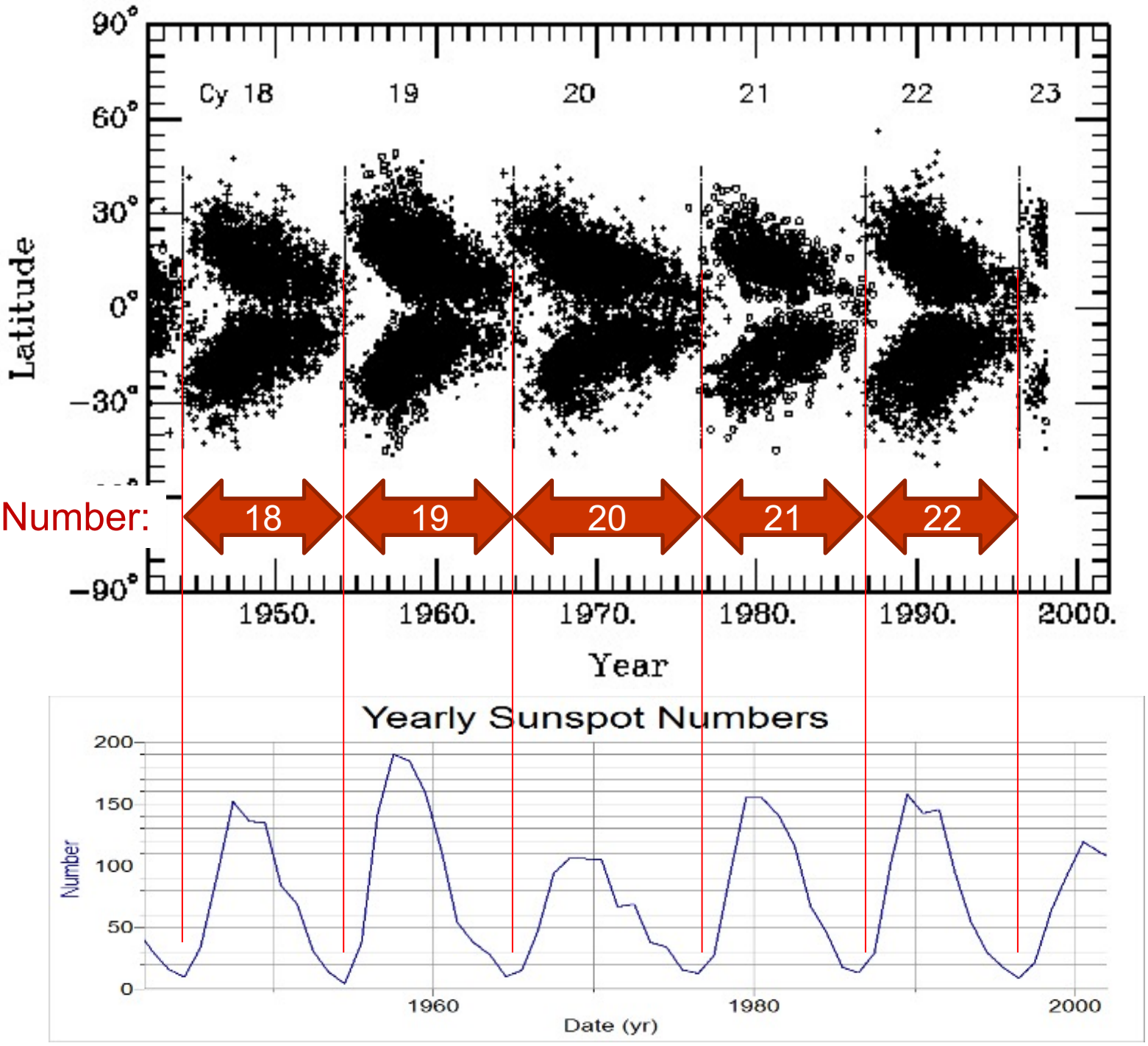

International sunspot number S_n : hemispheric 13-month smoothed numbers
Excess North vs South
Excess South vs North
Hemispheric sunspot number S_n
Time (years)
0
20
40
60
80
100
120
140
160
180
1950
1960
1970
1980
1990
2000
2010
SILSO graphics (http://sidc.be/silso) Royal Observatory of Belgium 2018 November 1

Use the Sunspot Data on Graphical Analysis

1. Using the Yearly values find the maximum and the minimum number – what years were these?
2. Using the Monthly values find the maximum and minimum number during the year 2000 and the month during which each occurred.
3. Starting at the year 1810, how many solar maxima have occurred since then? What is the average time for each up and down cycle?
4. Not every cycle has the same length – which ones in history were shortest? longest? how short/long?
5. Predict when the next maximum and the next minimum should occur.
6. Over the past 300 years are there any long term trends or patterns in the numbers?

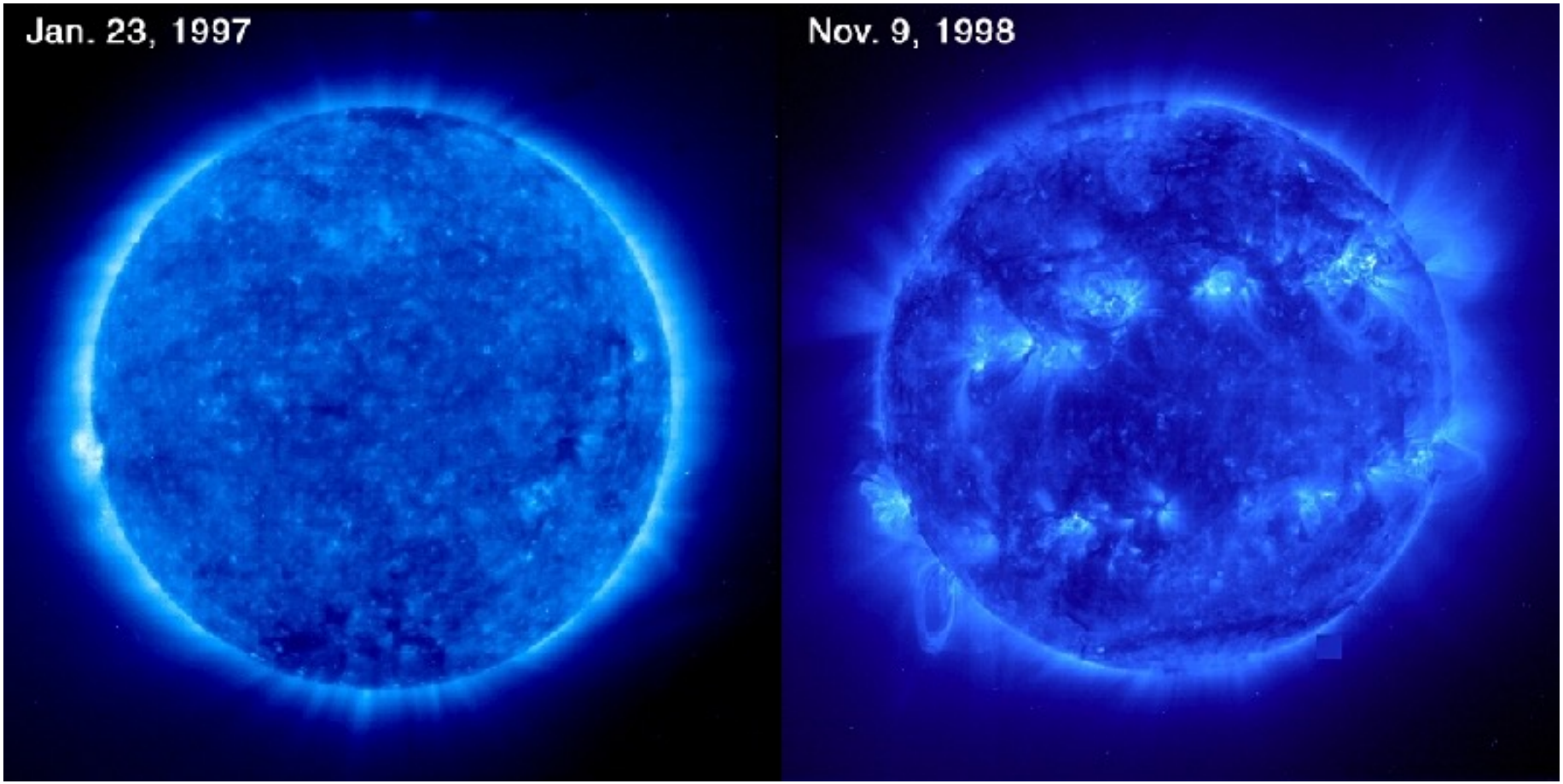


This is a “butterfly diagram”, which shows the latitude of sunspots with respect to time. At the beginning of each cycle sunspots tend to form at locations about 30 degrees north or south of the Sun’s equator. As the cycle continues sunspots tend to “migrate” and form closer to the equator at 0 degrees latitude.


Cy 18
19
20
21
22
23
90°
60°
30°
0°
−30°
−90°
Latitude
1950.
1960.
1970.
1980.
1990.
2000.
Year
Cycle Number:
18
19
20
21
22
Yearly Sunspot Numbers
200
150
100
50
0
Number
1960
1980
2000
Date (yr)

Sunspot Cycle

- The Sun is observed to undergo alternating periods of activity and relative calm.
- These alternating phases occur at regular intervals.
- Astronomers determine numbers of sunspots and measure other phenomena to track this cycle.
- The **sunspot cycle** is about 11 years, during which the number of sunspots varies from minimum to maximum and back to minimum.


Jan. 23, 1997
Nov. 9, 1998