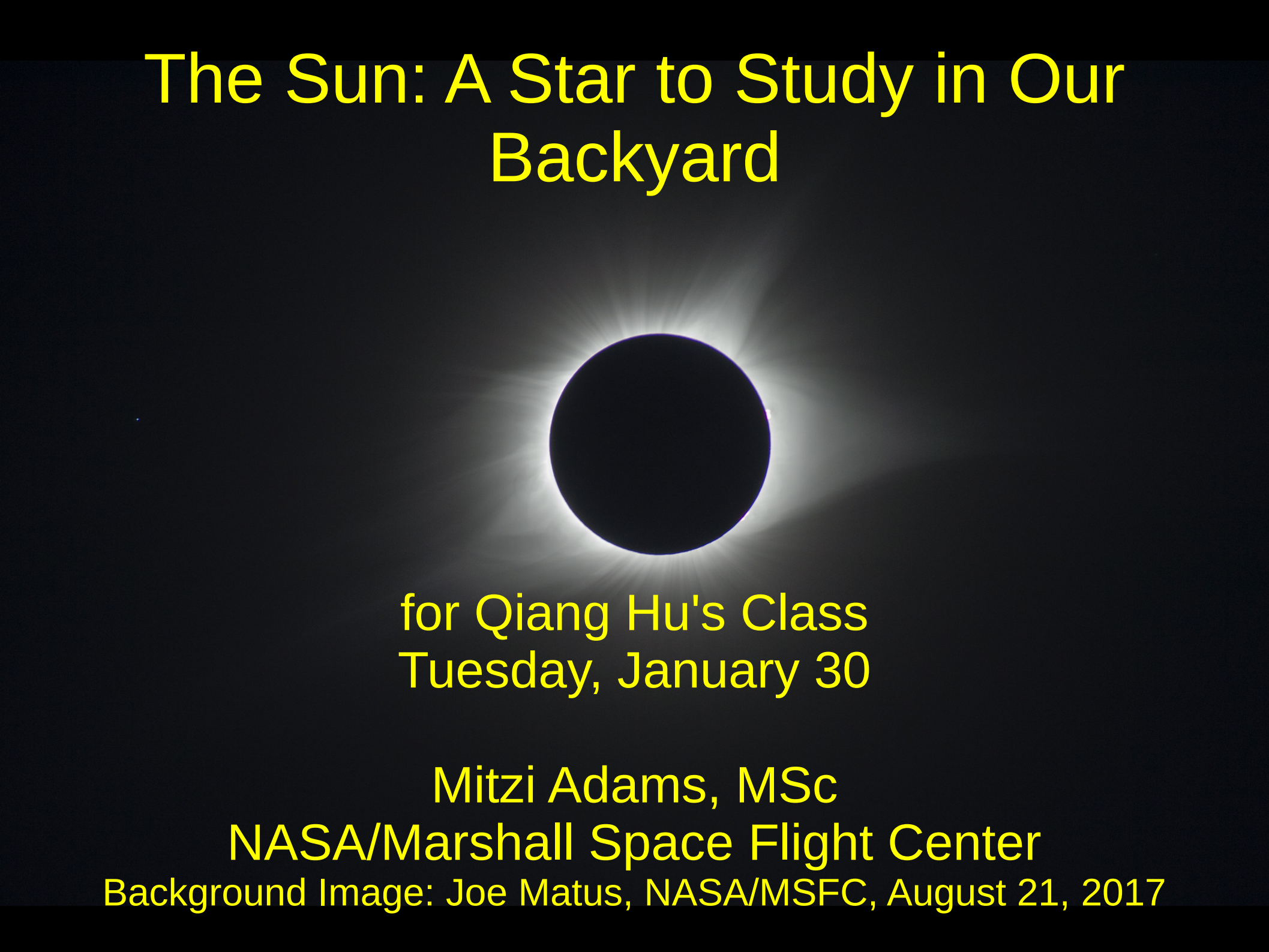
The Sun: A Star to Study in Our Backyard



for Qiang Hu's Class
Tuesday, January 30

Mitzi Adams, MSc
NASA/Marshall Space Flight Center

Background Image: Joe Matus, NASA/MSFC, August 21, 2017

Outline

- A bit of history
- The Sun vs. a couple of stars
  - What is a Star?
  - What is the Sun like?
- Eclipse 2017
- Solar Eruptions
- Jets in Coronal Holes

First Contact, August 21, 2017 Solar Eclipse

Image Credit: Mitzi Adams, NASA/MSFC, August 21, 2017
from Clarksville, Tennessee

History

Maria Mitchell: Educating Future Scientists

- Discovered a comet in 1847 at age 29
- First woman elected to the American Academy of Arts and Sciences (1848)
- First woman elected to the American Association for the Advancement of Science (1850)

- First professor hired at new Vassar College (1865)
- Co-founded the Association for the Advancement of Women (1973)

Maria Mitchell: Her Legacy - Her Students

Mary Watson Whitney -- Succeeded M. Mitchell as Chair of Astronomy Department and Director of Observatory and Educator

Mary Watson Whitney, 1847-1921, Professor of Astronomy at Vassar College, and first President of the Alumnae Association

Antonia Maury -- Became one of Edward Pickering's “computers” published in 1897 a catalogue of stellar spectra -- first observatory publication credited to a woman

Image Credit: Vassar College Special Collections Library

Edward Pickering and the “Computers” at Harvard Observatory

At Harvard College Observatory,
13 May, 1913

Image Credit: Licenced under Public Domain via Wikipedia Commons - http://commons.wikipedia.org)

William Pickering and his “computers”
Antonia Maury on the far left with back to camera
Annie Cannon on far right

Image Credit: Vassar College Special Collections Library

Annie Cannon and Spectral Classifications

Annie Cannon (image from 1895) classified spectra of more than 425,000 stars

Image Credit: Harvard College Observatory

The Sun vs. a Couple of Stars

What is a Star?

- Energy Production
- Differences
- H-R Diagram

What is the Sun like?

- Structure
- Surface Features
- Magnetic Fields
- The Solar Cycle
- Solar Eruptions

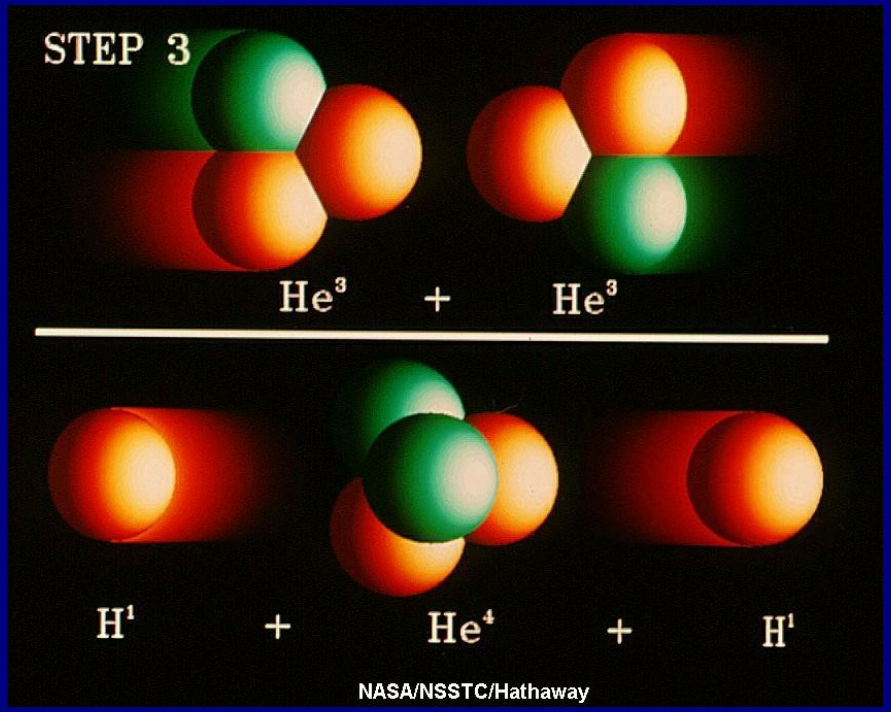
What is a Star?

What is a Star? -- Energy Production

A star is an astrophysical body that produces its own light by thermonuclear reactions in its core.

For solar-type stars, this is the proton-proton chain

1. Two protons collide, form deuterium, a positron, and a neutrino.



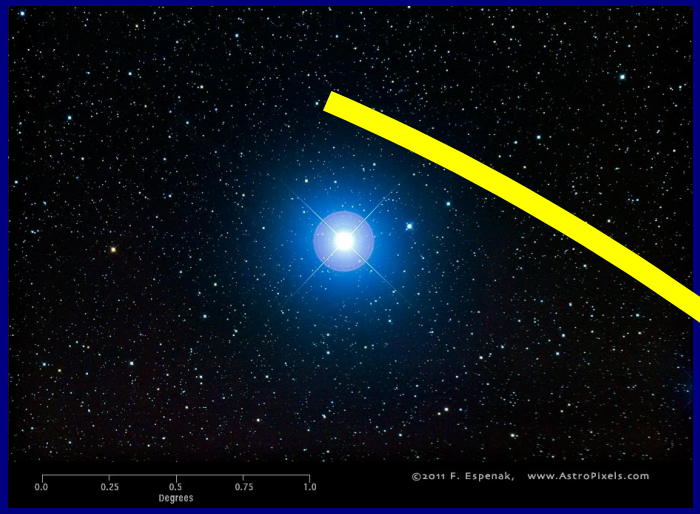
2. A proton collides with the deuterium, forming helium-3 and a gamma ray

3. Two He-3s collide to form He-4 plus two protons.

Basically, Hydrogen converts to Helium

(High-mass stars, greater than about 2 solar masses use a different procedure, the CNO cycle.)

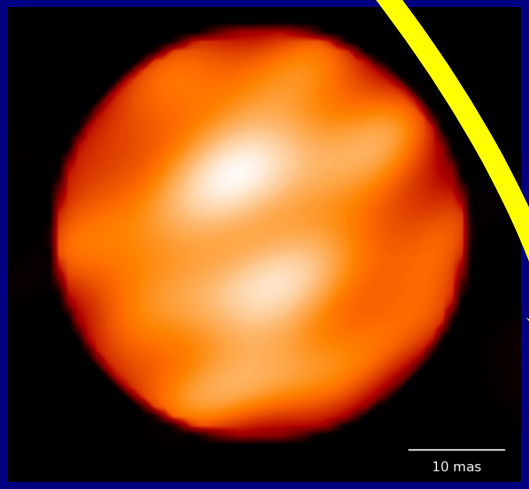
What is a Star? -- Differences



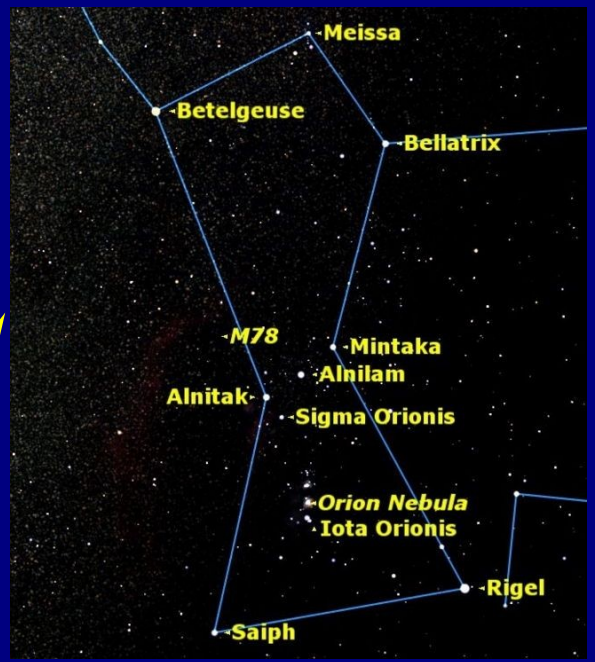
Rigel: A blue-white star, about 8600 ly away, 12,000 K, 80 $R_{\odot}$, 23 $M_{\odot}$, 8 million years old.

Aging

Our Sun: A yellow star, ~8 lm away, 6,000 K, ~700,000 km (432,000 mi), 2 x 10^{30} kg, 4.5 billion years old, ~ 5M yr left.



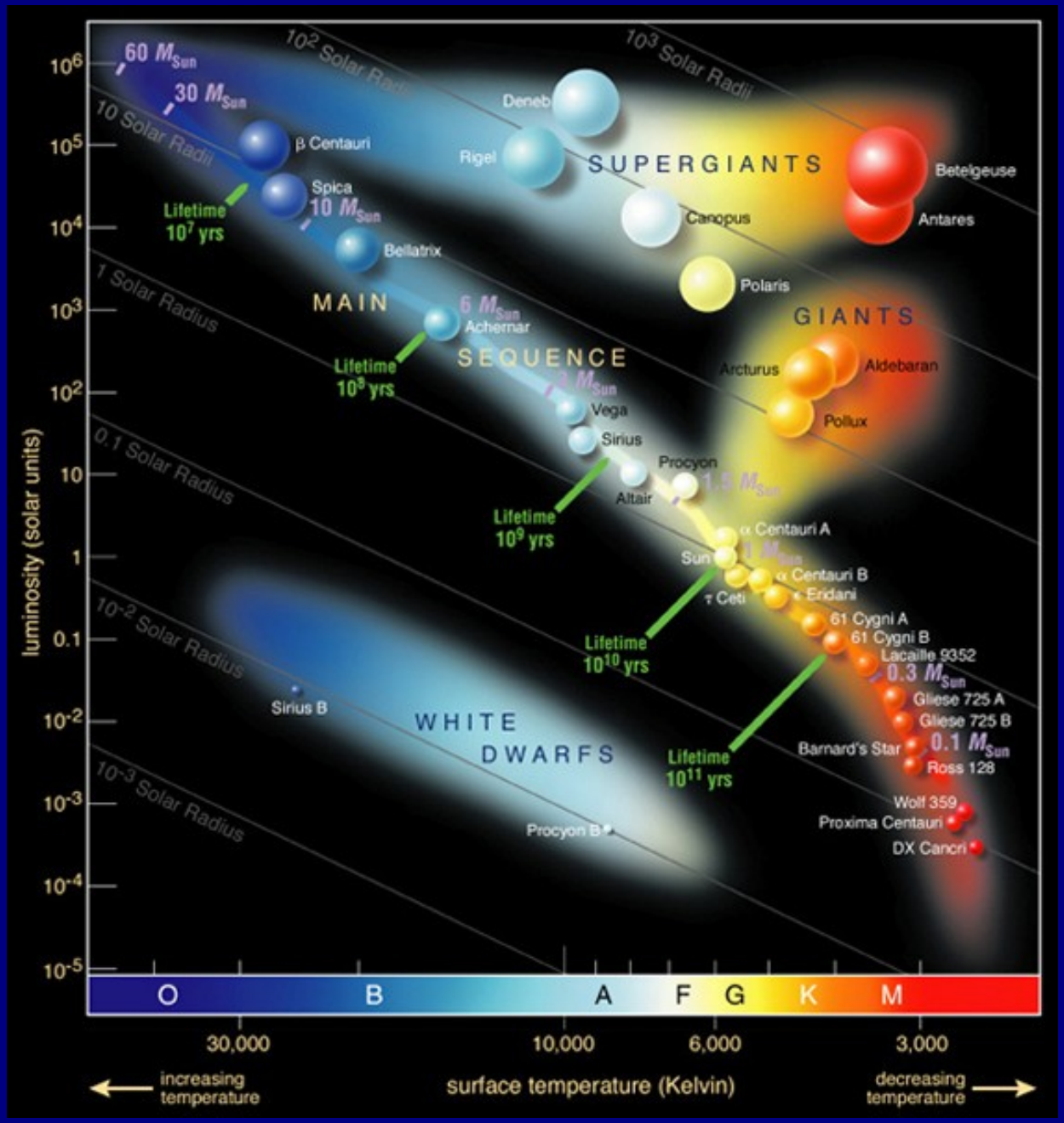
Betelgeuse: A red-giant star, about 650 ly away, 3500 K, 862 $R_{\odot}$, 20 $M_{\odot}$, 8.5 million years old, ~100,000 years left .



Brightness

Color

Hertzsprung-Russell Diagram



α-Cen-A is G2,
α-Cen-B is K1,
Proxima (α-Cen-C) is M6, 4.2 ly

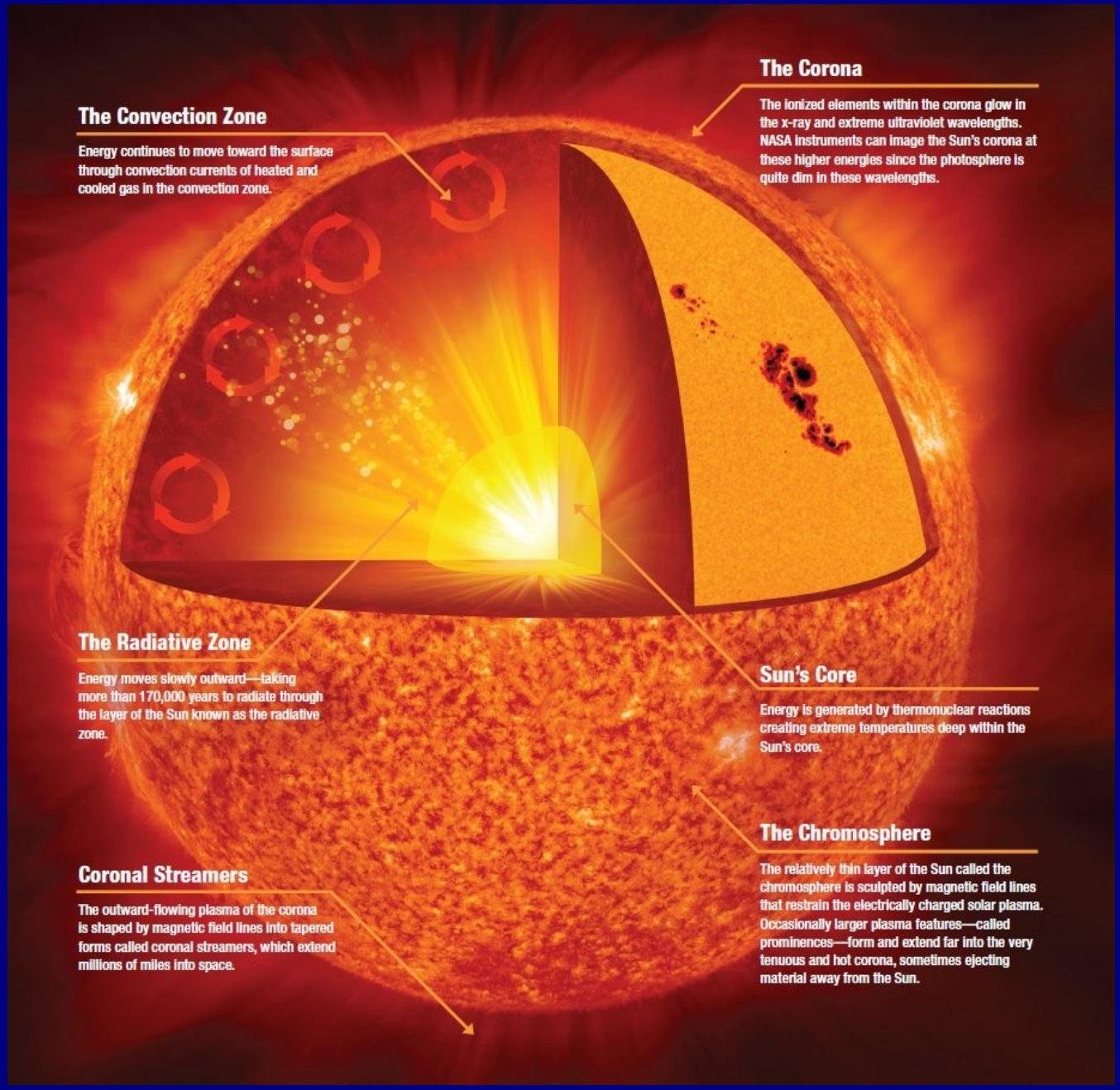
Sun is G2
8.5 light minutes away

Betelgeuse is M2
643 ly

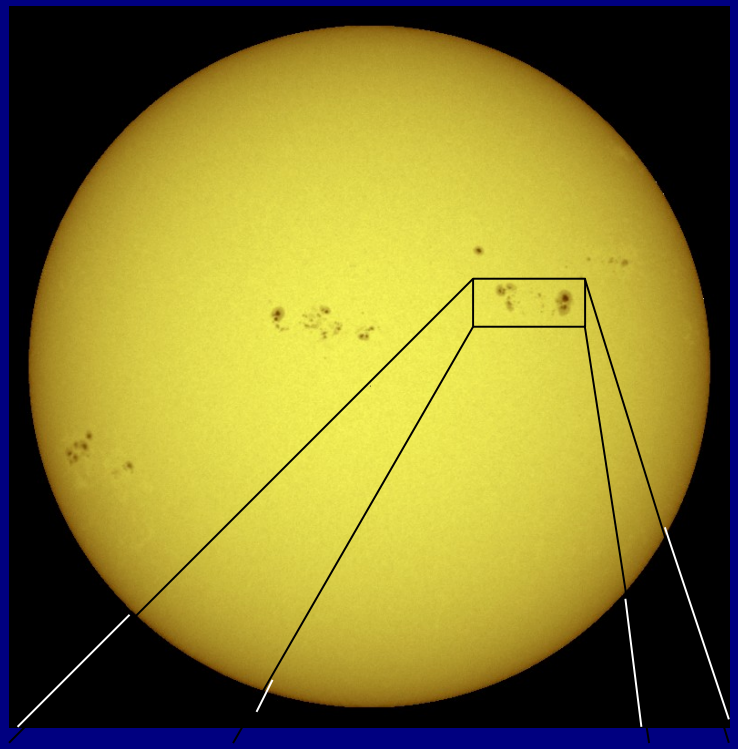
Rigel is B8
860 ly

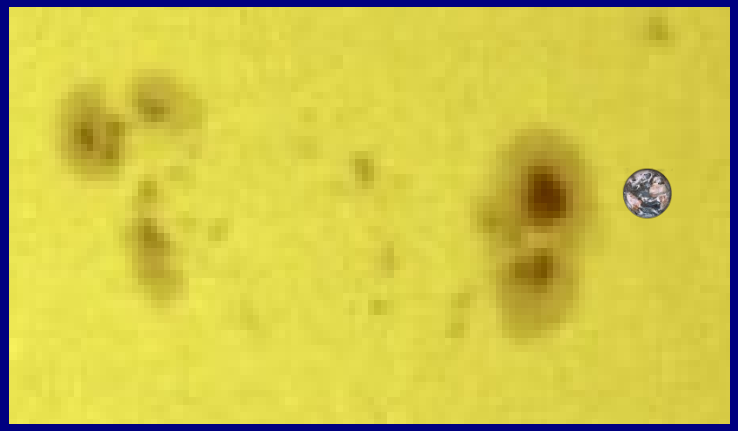
What is the Sun like?

The Sun: Structure



The Sun: Surface Features - Sunspots



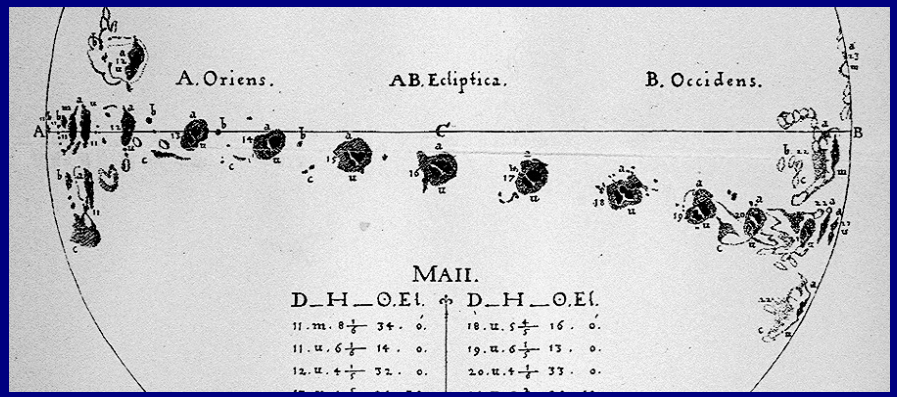


Sunspots are regions that are cooler than their surroundings, produced by strong magnetic fields.

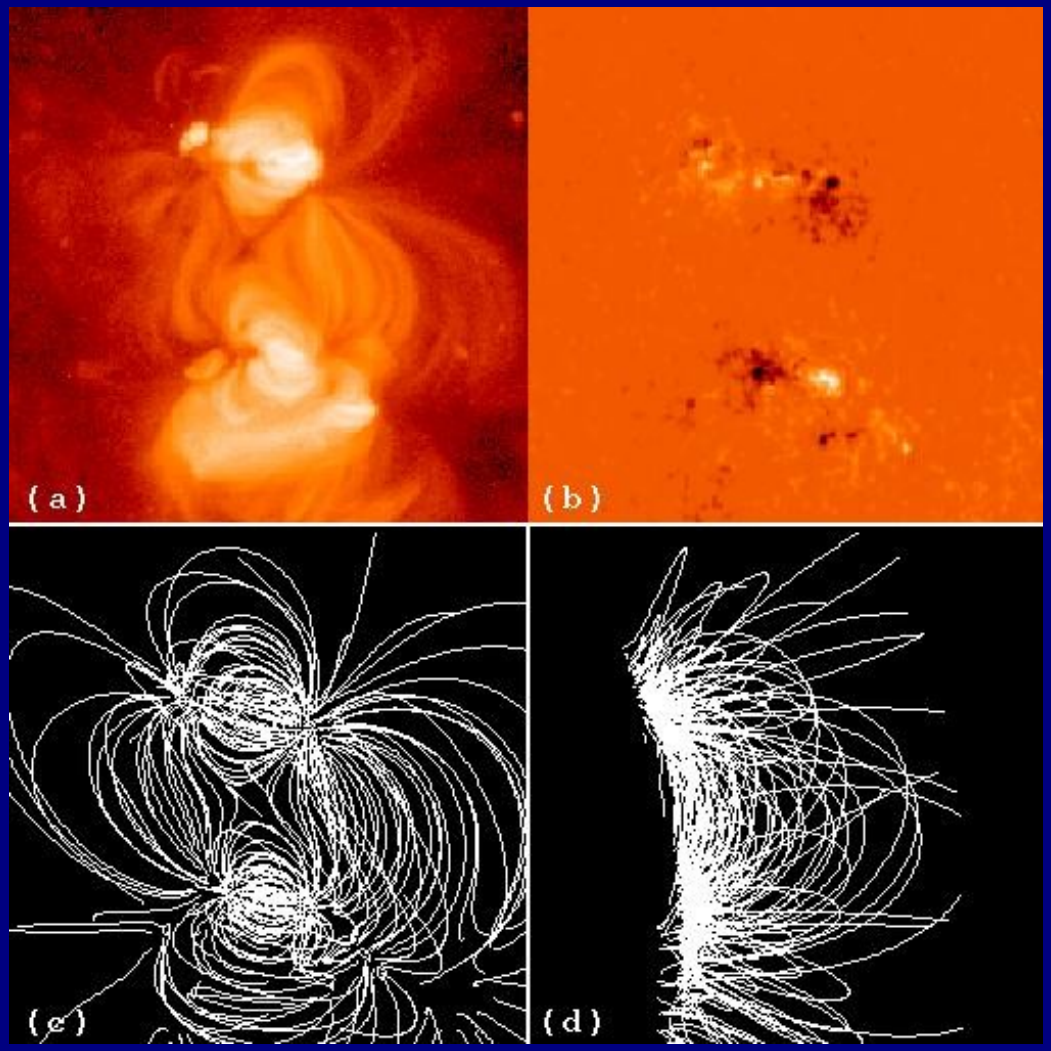
Sunspots have an Umbra surrounded by the lighter Penumbra.

Sunspots usually appear in groups, with lifetimes of days or weeks.

The earliest sunspot observations (c. 1609) indicated that the Sun rotates once in about 27 days.



The Sun: Sunspot - Magnetic Fields



(a) Yohkoh Soft X-ray Telescope, Corona
4 Jan, 1994 7:35 UT

(b) Line-of-Sight magnetic field from Kitt Peak National Observatory at 16:31 UT

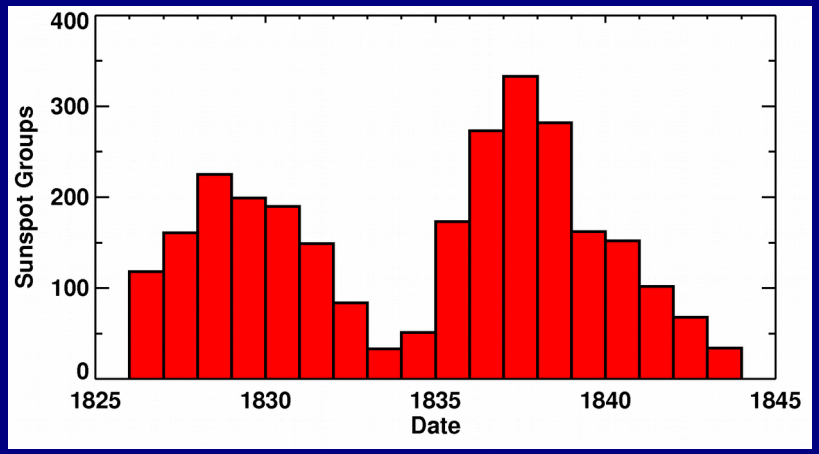
(c), (d) Extrapolated Magnetic Field

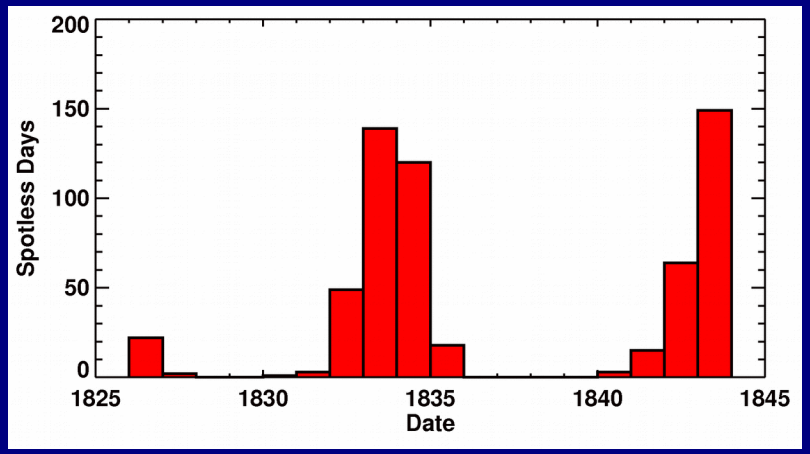
The Sun: Sunspot Cycle Discovery

Sunspots observed > 230 years
1844 Heinrich Schwabe, amateur astronomer, Dessau, Germany

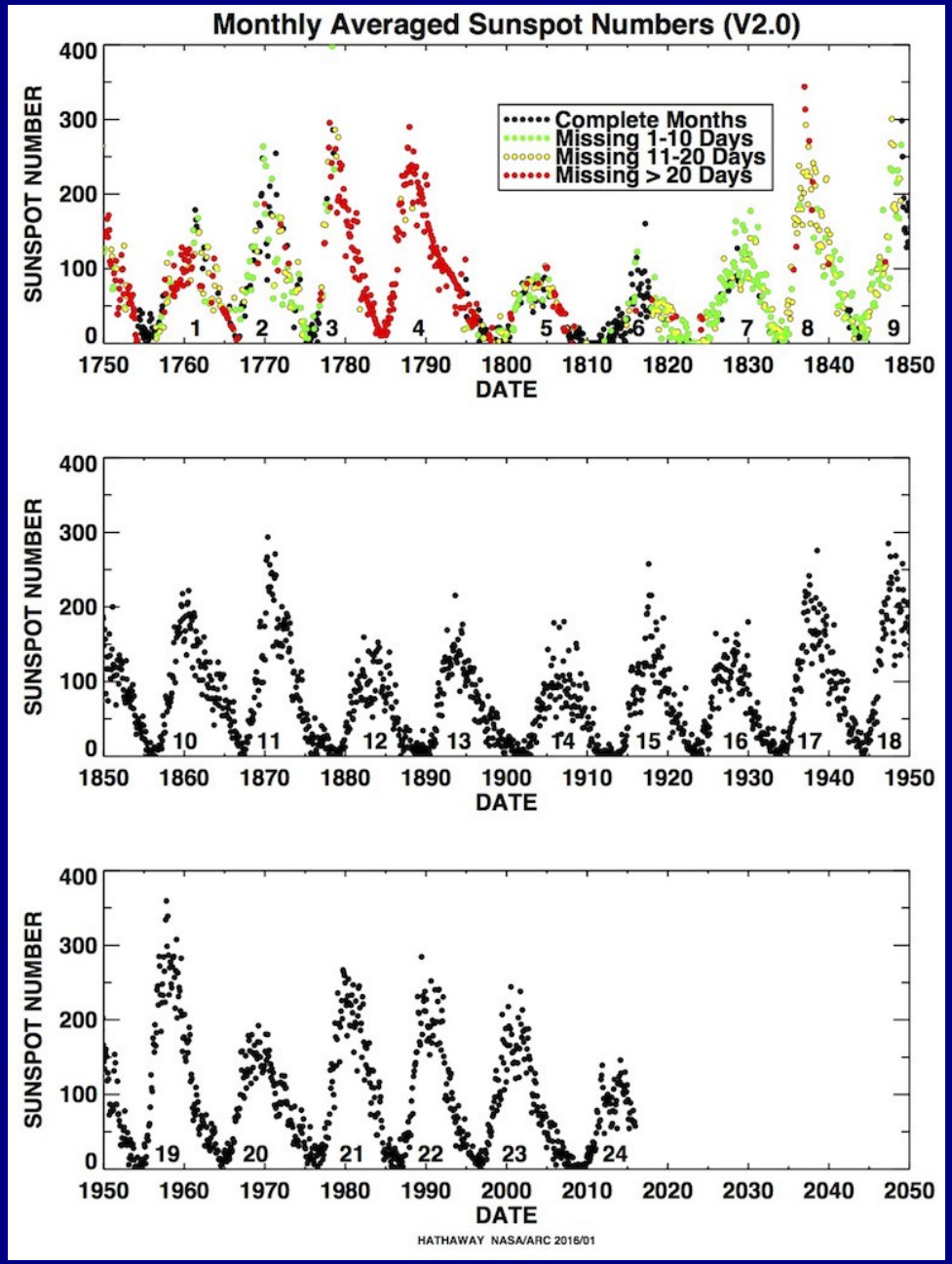
Cycle: increase and decrease over ~10-years
- number of sunspot groups and the
- number of days without sunspots

Schwabe's data for 1826 to 1843





The Sun: 23 Full Cycles Observed

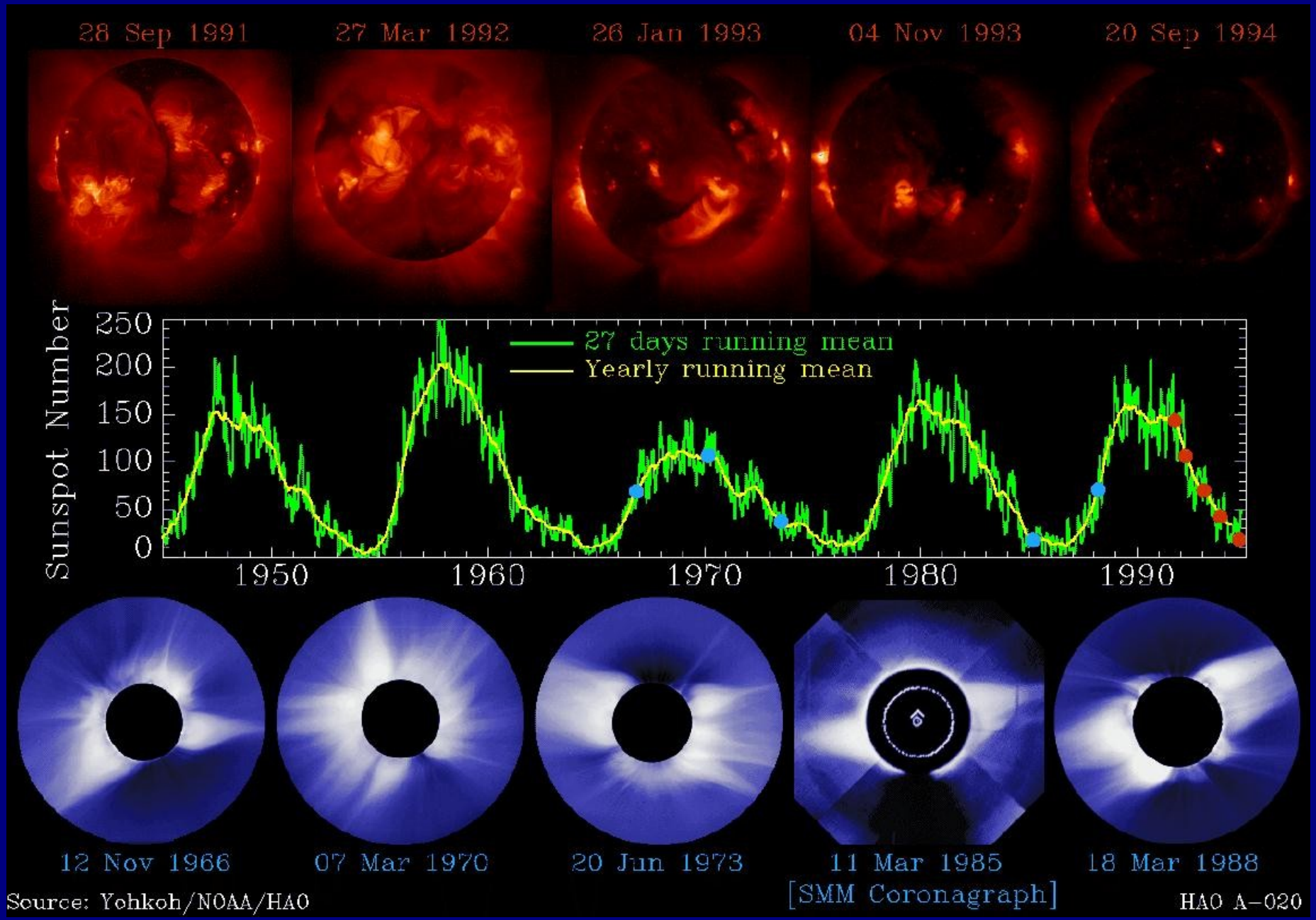


Rudolf Wolf 1849 -- "Relative" Sunspot Number = 10 times number sunspot groups + total distinct spots

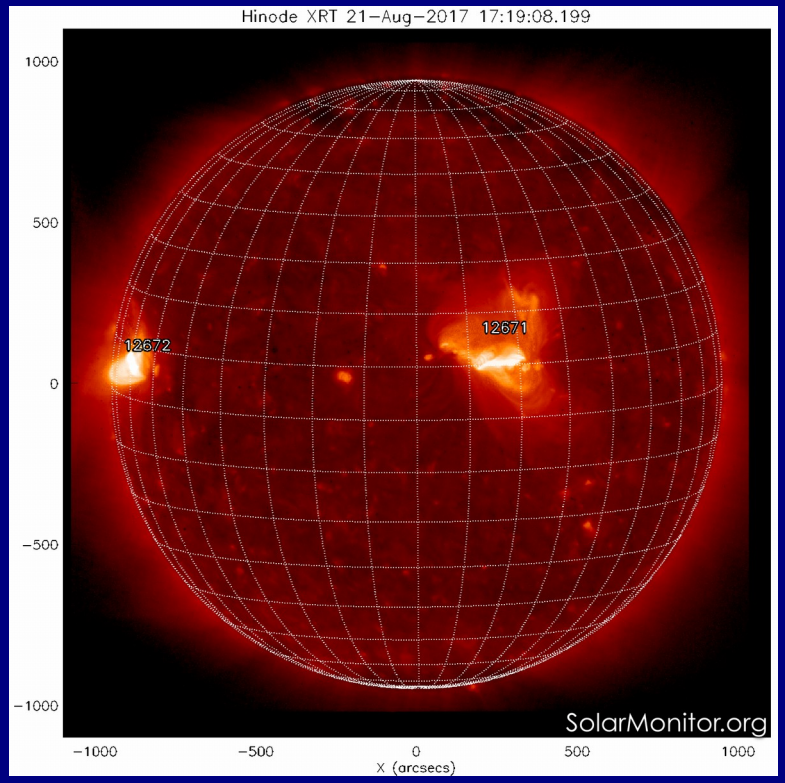
Average cycle: ~11 years, -2, +3

Average amplitude: ~100, with range from 50 to 200

The Corona and the Solar Cycle



The Corona “Now”
August 21, 2017



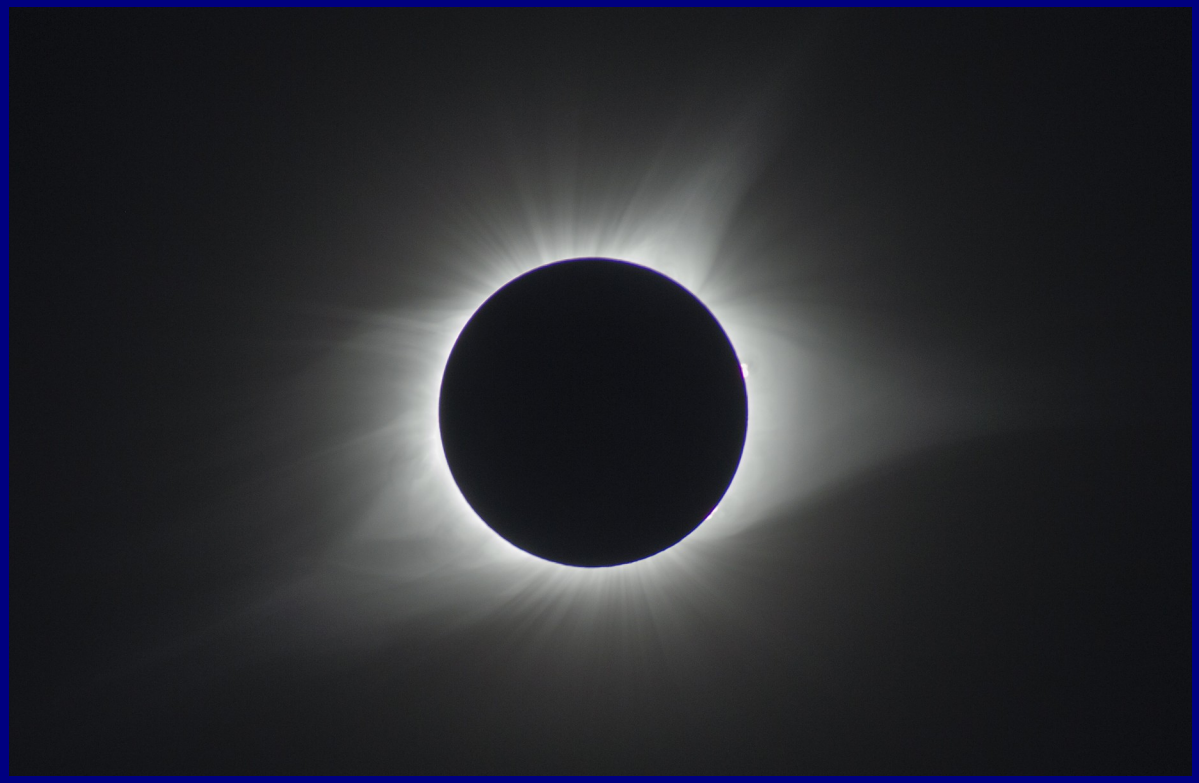


Image by Joe Matus, NASA/MSFC from Hopkinsville, KY

Total Solar EclipseAugust 21, 2017

Image Courtesy of Joe Matus, ST 24, NASA/MSFC

Partnerships

- U.S. Space and Rocket Center
- Austin Peay State University
- University of Alabama in Huntsville
- The Inspire Project
- Christian County Schools
- The City of Hopkinsville, KY
- Citizen CATE
- Tennessee Tech

Animal Behavior Observations: Cows, Bees, Crickets, Turtles

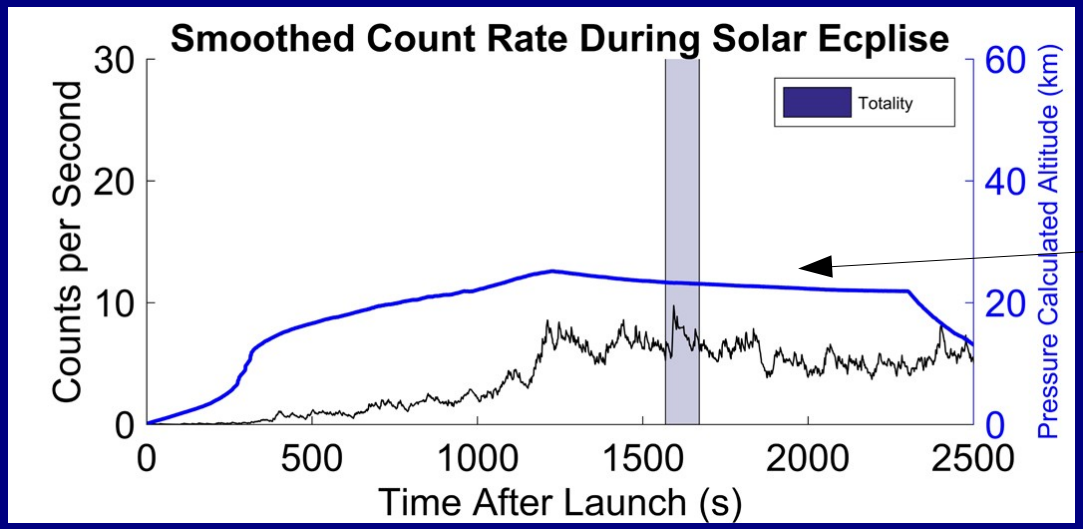
Totality (~13:30 CDT) Behavior

- 1 of 8 cows moved from shade tree
- 97% bees returned to hive, takeoffs 0.5 hr after totality
- 50% of crickets were active/chirping
- 40 turtles on pond bank, only 7 by 15:00 CDT

Montana State Balloon Project

50 Teams from across the nation flew payloads

Three teams at APSU:
APSU, Arkansas State, and UAH

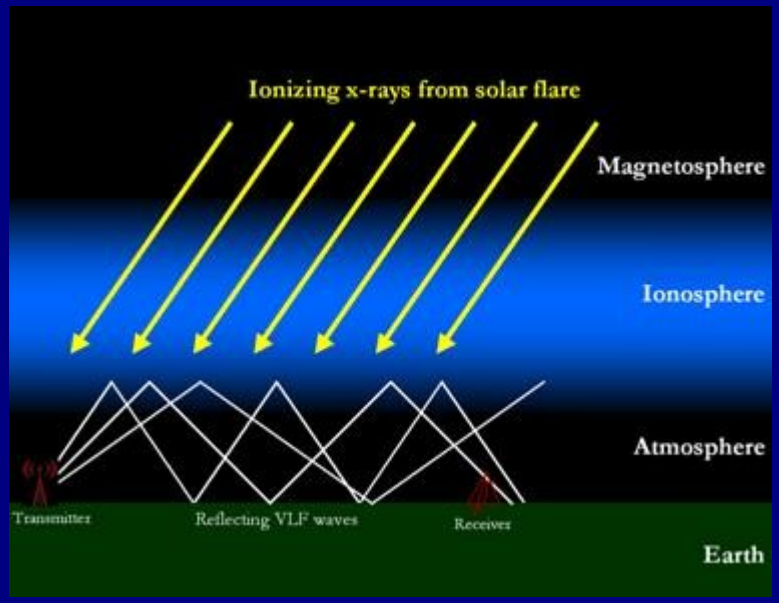


Note plateau in altitude

Payloads:
- Video-streaming camera
- Two pounds of hops for Straight to Ale Eclipse Brew
- Geiger counter, temperature, pressure

Impact of Reduced Solar Irradiance on the Ionosphere

Character of the lower ionosphere not well understood



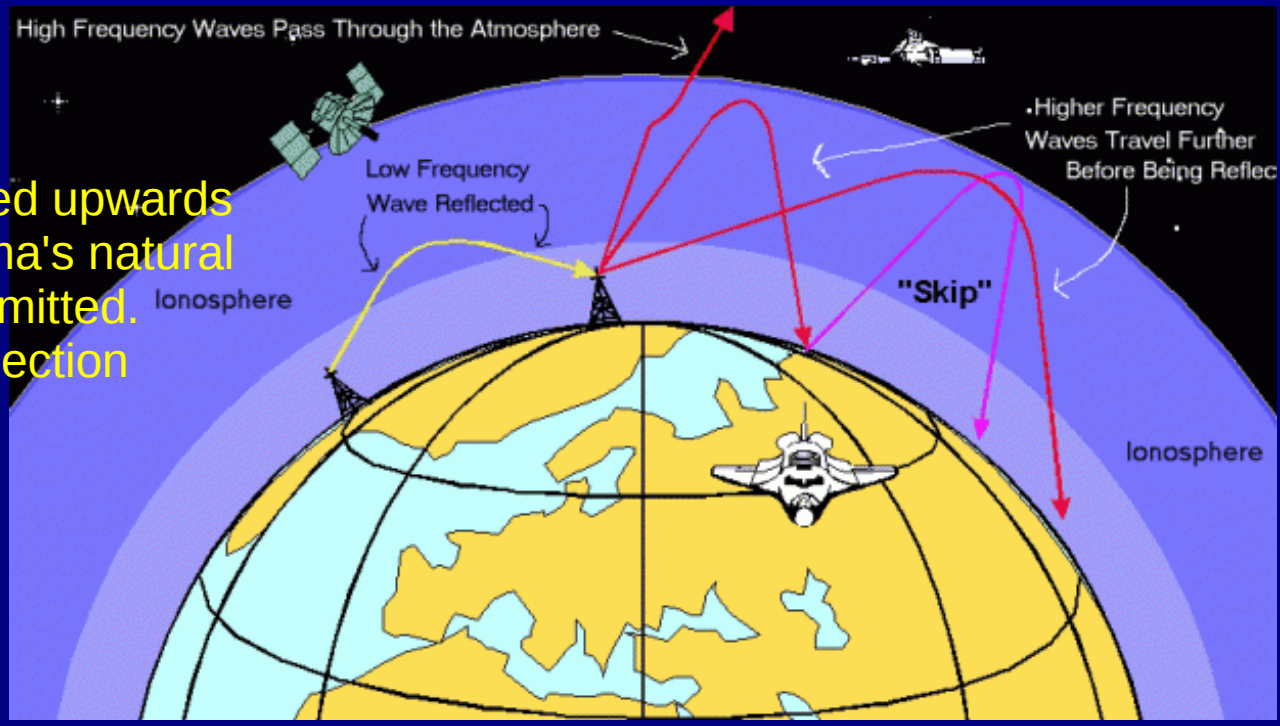
Physical Processes:

Solar radiation reduced

Ionosphere responds--ions recombine

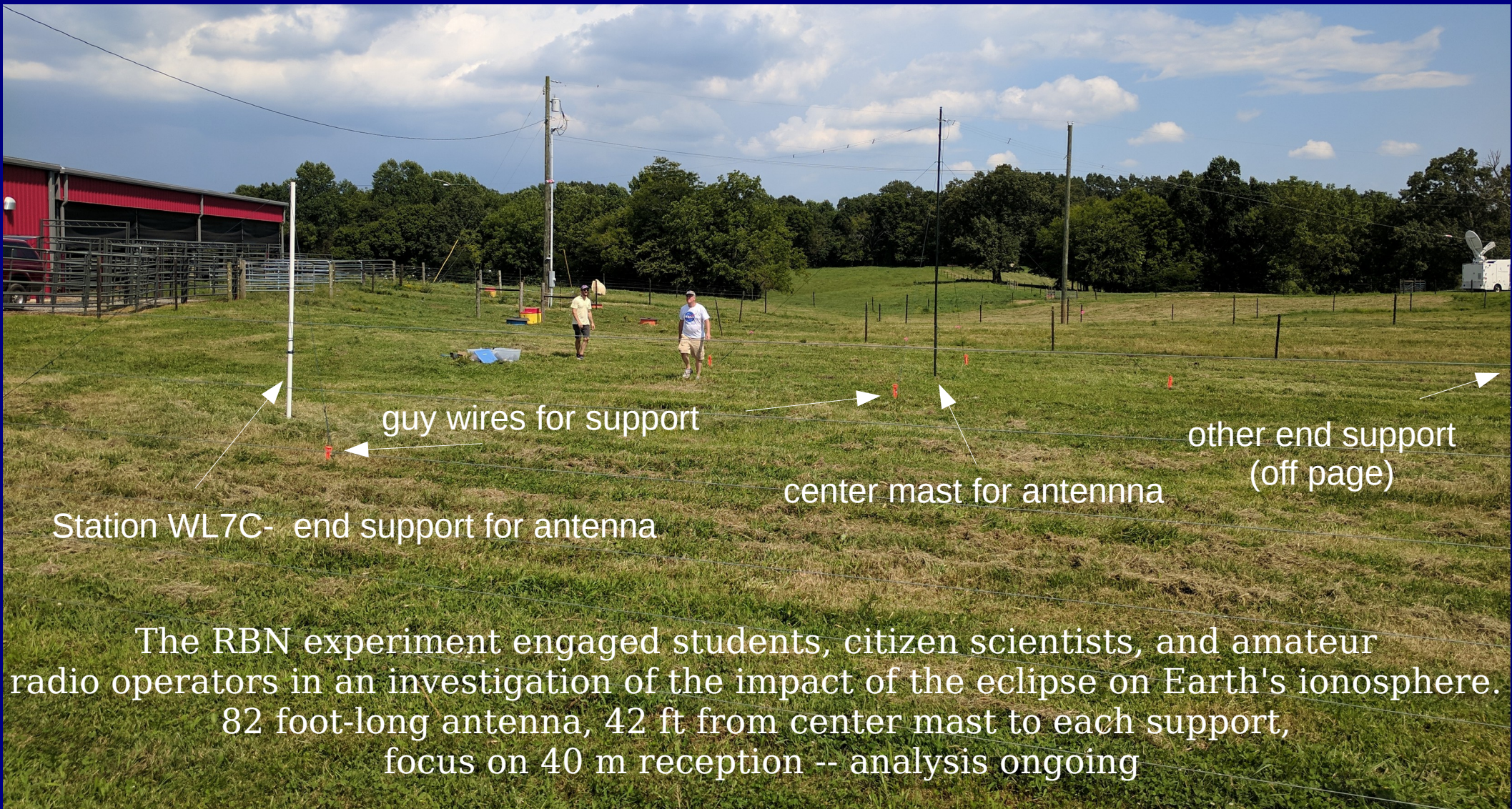
How quickly does the ionosphere recover?

Measurements: Radio signal transmitted upwards
A layer of electrons reflect, when plasma's natural oscillation frequency equals that transmitted.
Time-of-flight measured->Height of reflection
Plasma density
proportional
to frequency -> Plasma Density
as function of altitude



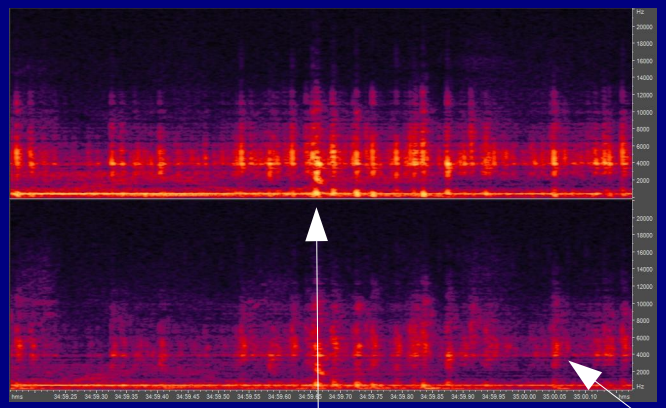
Reverse Beacon Network (RBN)

The RBN: an array of passive receivers that record radio links of amateur (ham) operators
(Frissell et al., 2014)

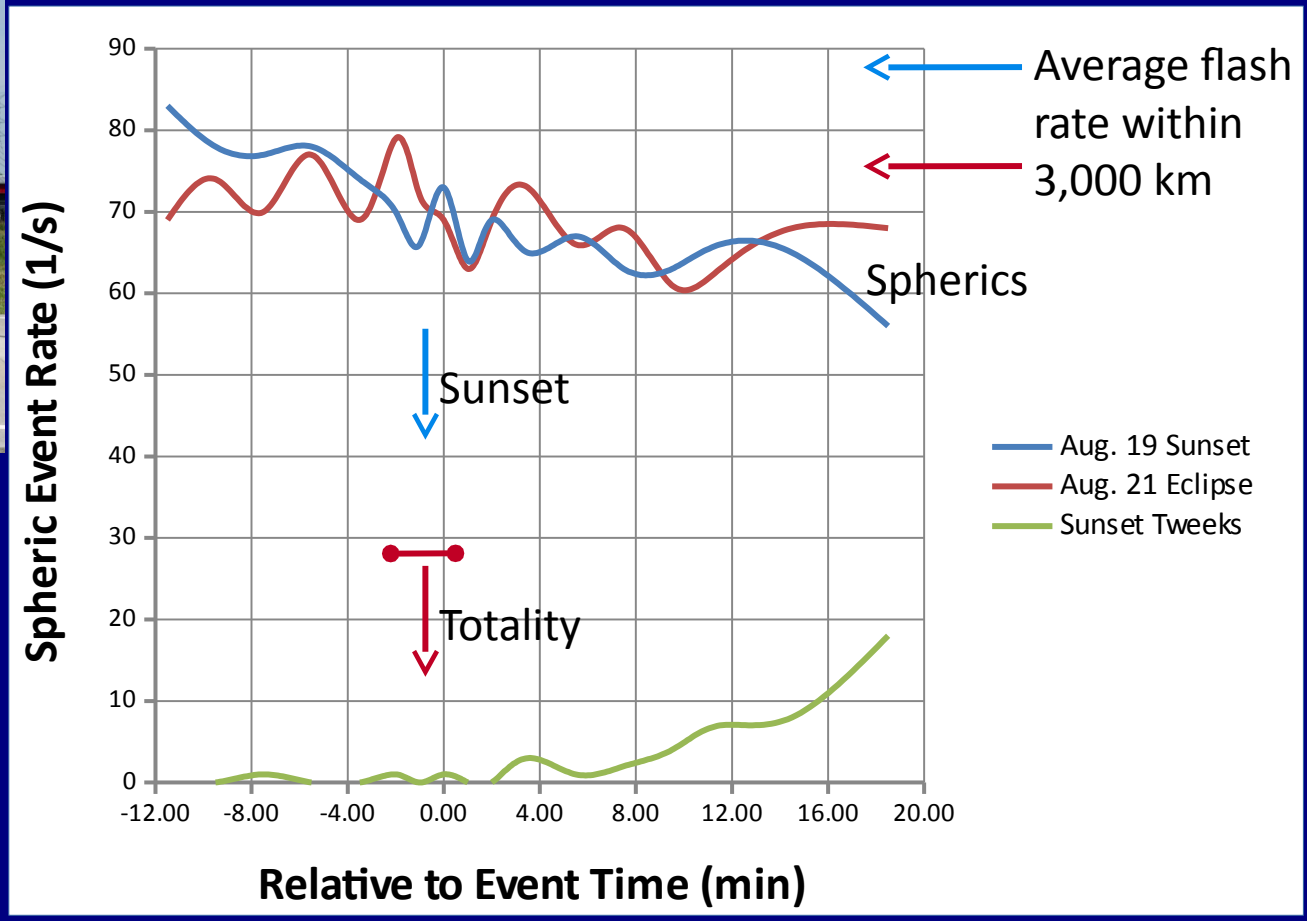


The RBN experiment engaged students, citizen scientists, and amateur radio operators in an investigation of the impact of the eclipse on Earth's ionosphere.
82 foot-long antenna, 42 ft from center mast to each support,
focus on 40 m reception -- analysis ongoing

Interactive NASA Space PhysicsIonosphere Radio Experiments (INSPIRE) Project



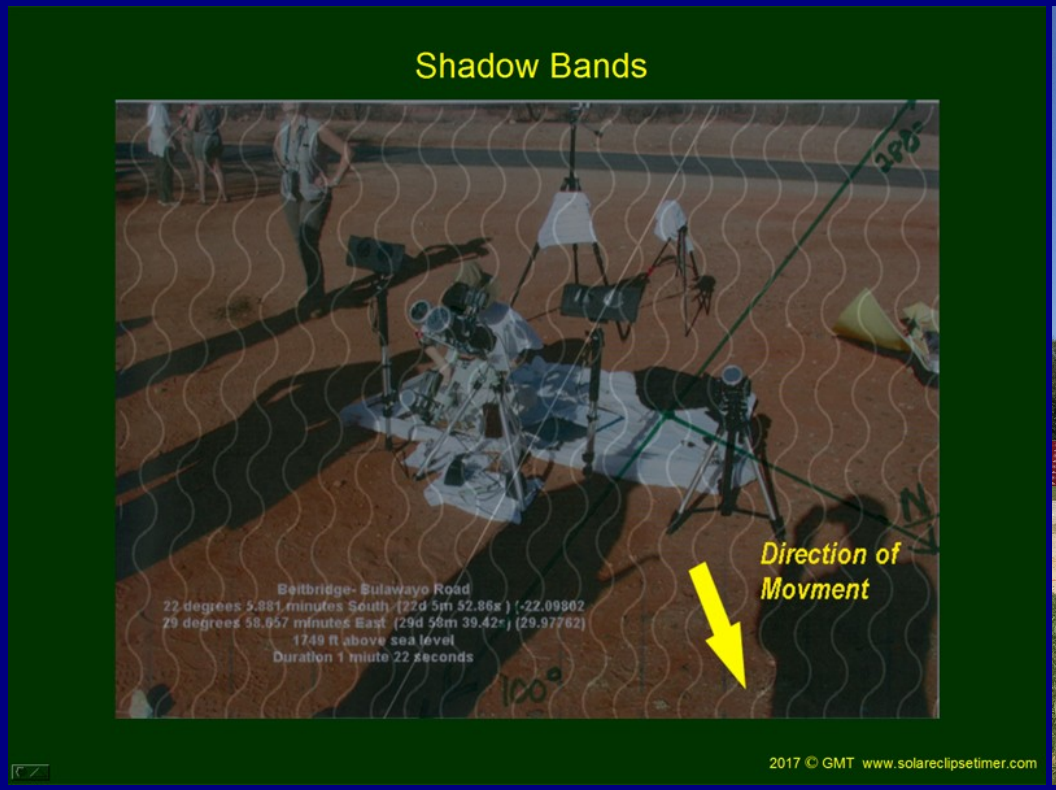
"Tweek" 08/19/2017 19:53 CDT



Spheric, caused by "nearby" lightning

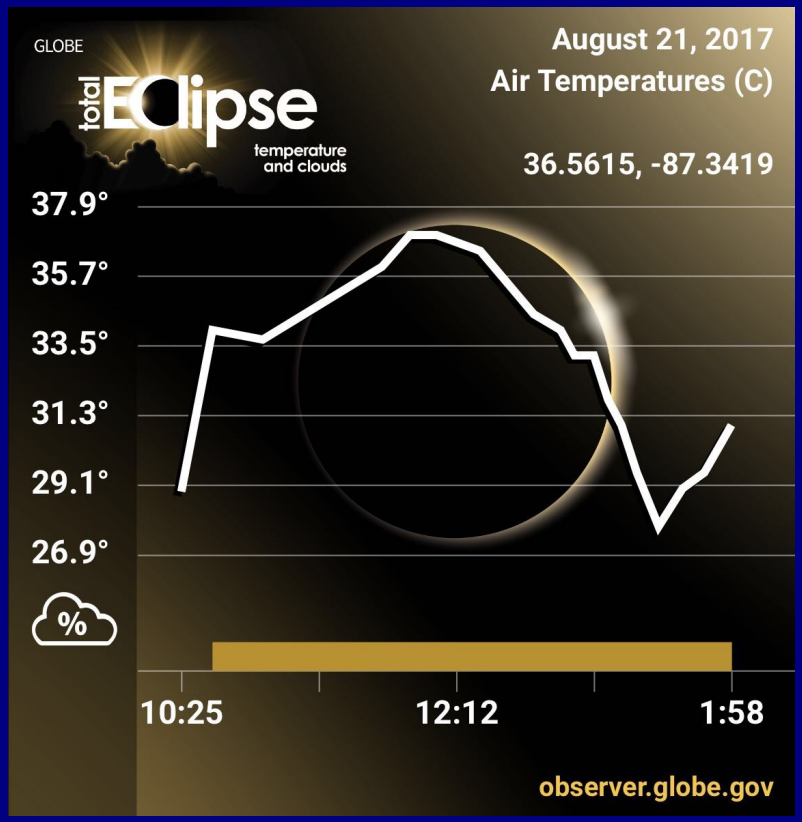
Shadow Bands

Hypothesis: Shadow bands will move in the direction of the path of totality.



Left Image Used with Permission from Dr. Gordon Telepun

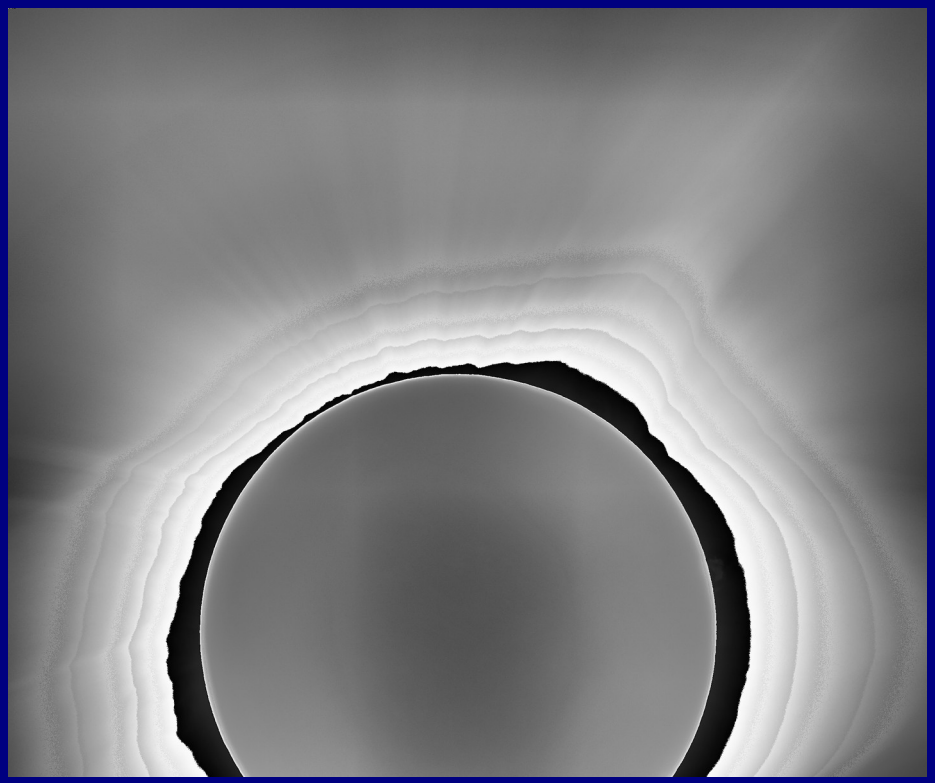
Air Temperature Changes for NASA's Global Learning and Observations to Benefit the Environment (GLOBE)



Air Temperature Changes at APSU Farm, TN. The minimum recorded was 27.8°C at 1:30 PM CDT... a 9.2°C Drop!

Citizen Continental-America Telescopic Eclipse Experiment (CATE)

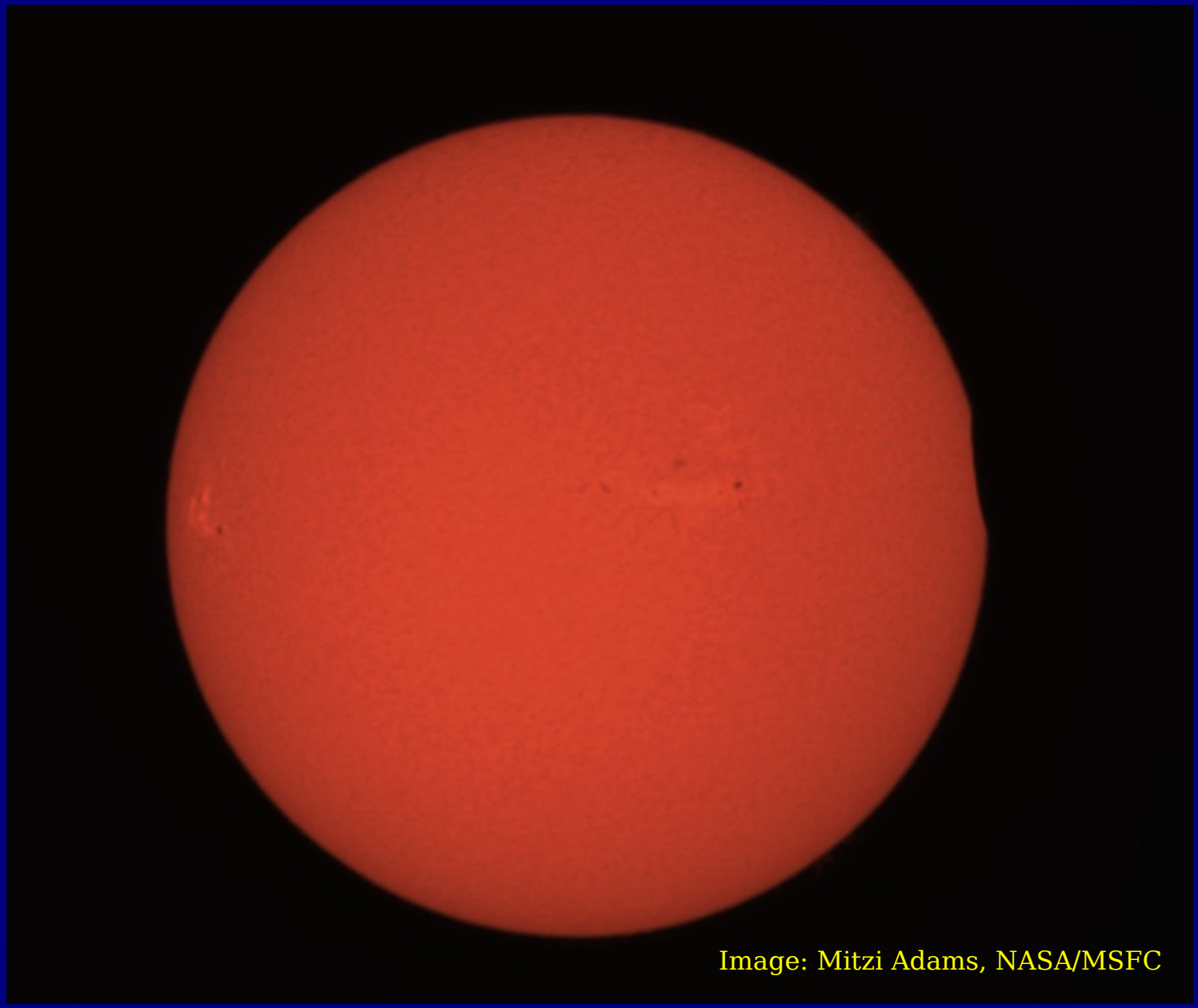
62 Sites Across Country Using
Identical Equipment
Obtained Data



APSU's Image: Telescope was bumped when removing solar filter

Tennessee Tech's Image

First Contact at APSU



In the Light of Hydrogen-alpha

Totality at APSU

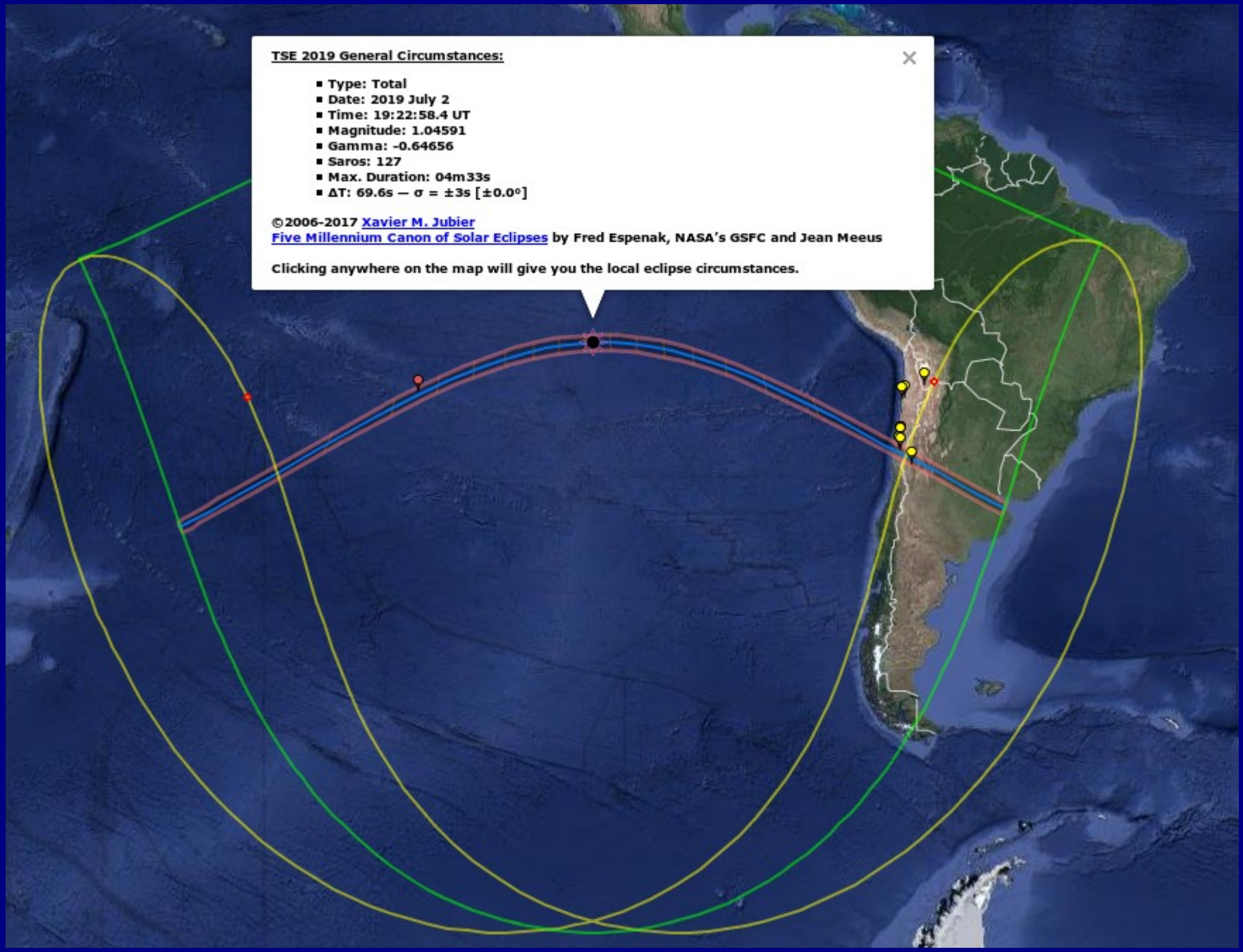
Totality at Hopkinsville, KY

Image from Dr. Jesse-Lee Dimech,
NASA NPP

Image from Joe Matus,
NASA/MSFC/ST24

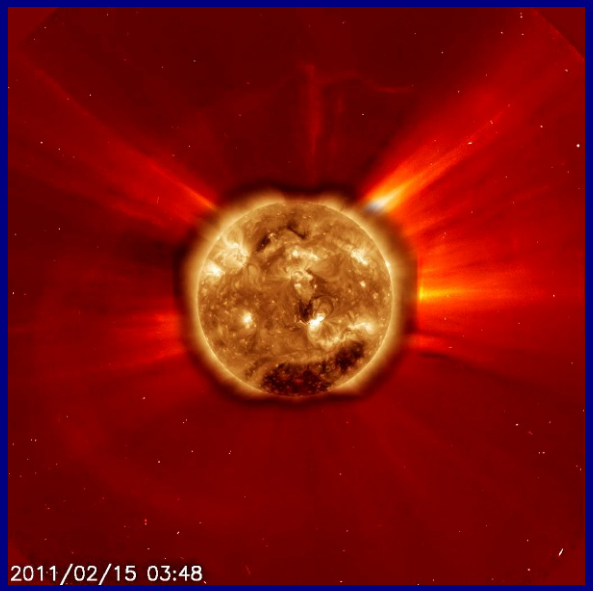
Images Used with Permission

Total Solar Eclipse July 2, 2019

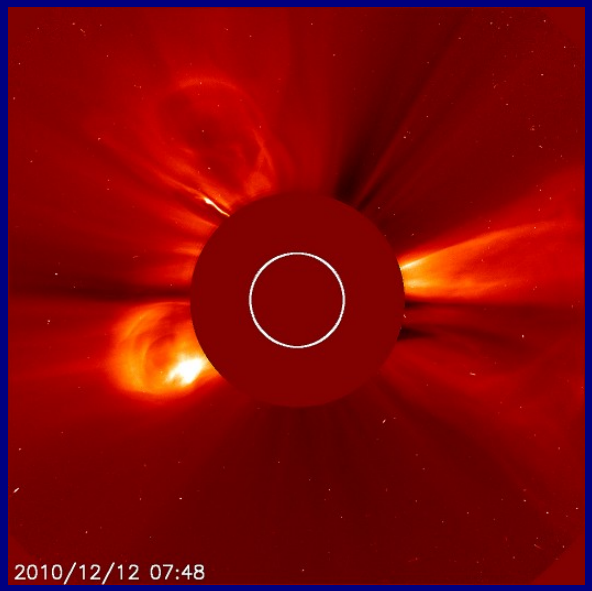


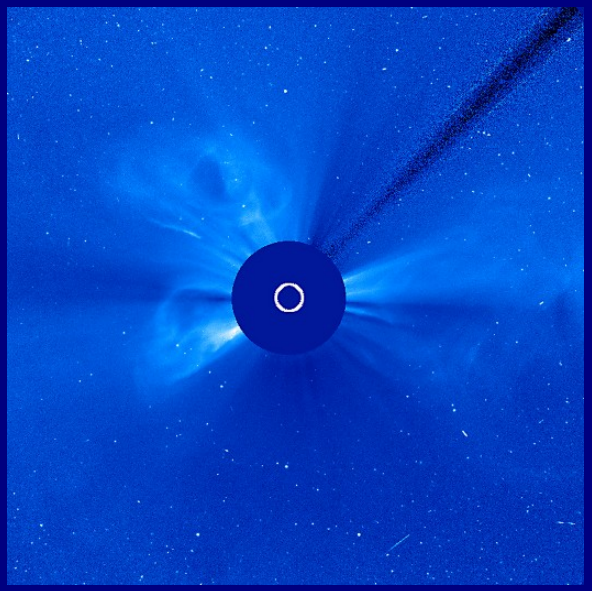
Solar Eruptions

Solar Eruptions



SDO plus Soho C2
X2-flare and halo CME

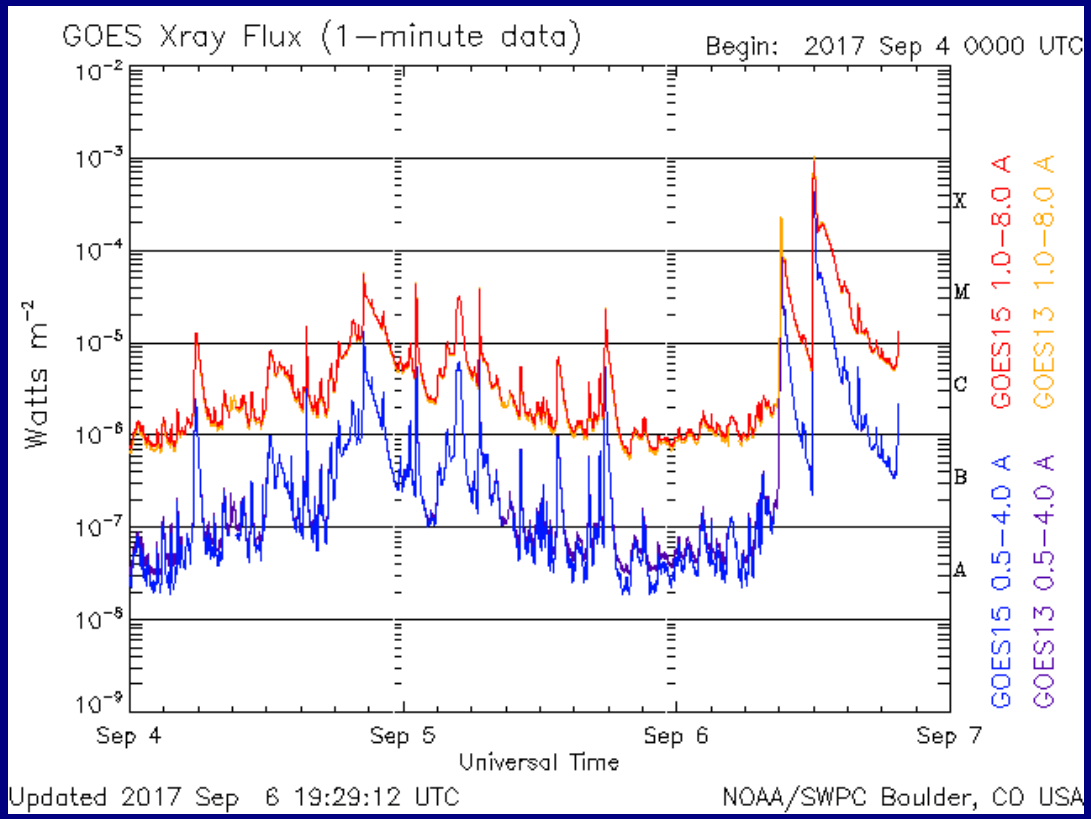


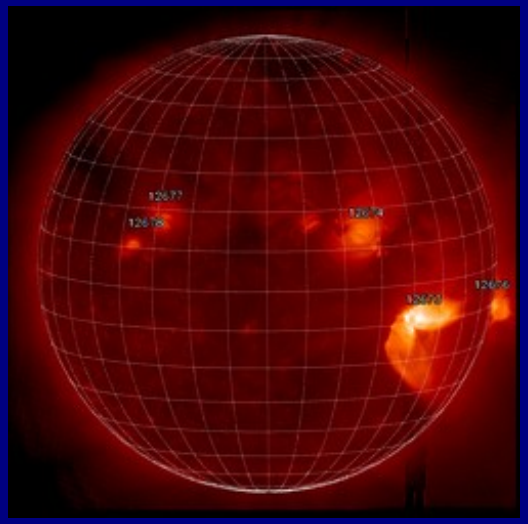


Three distinct CMEs
1. To right in both images, from a filament eruption,
2. From North Pole,
3. From far side of Sun.
All three eruptions happened within hours of each other.

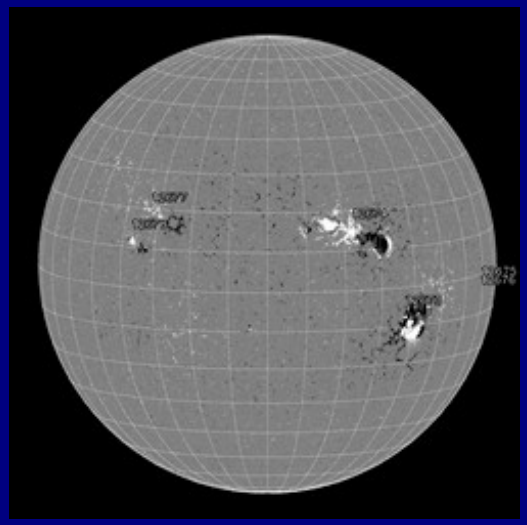
Image Credit:
SDO and
SOHO/LASCO

Solar Flare Classification





Sept. 6, 17:59UT
Hinode XRT
X9 flare



Sept. 6, 18:46 UT
SDO/HMI

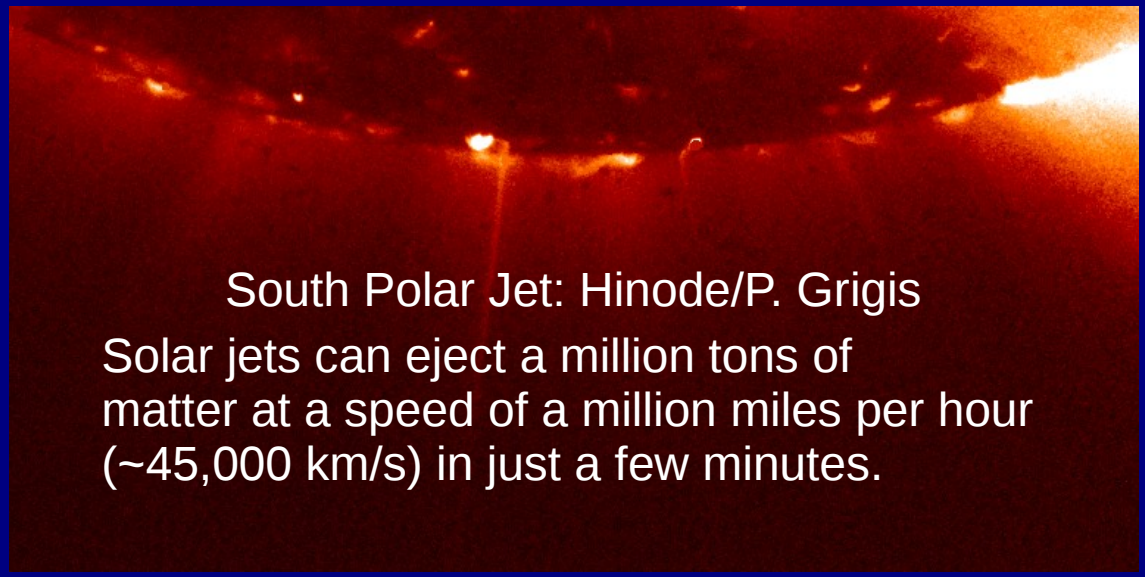
Coronal Jets

What is a Jet?

JET / noun – plural noun: jets

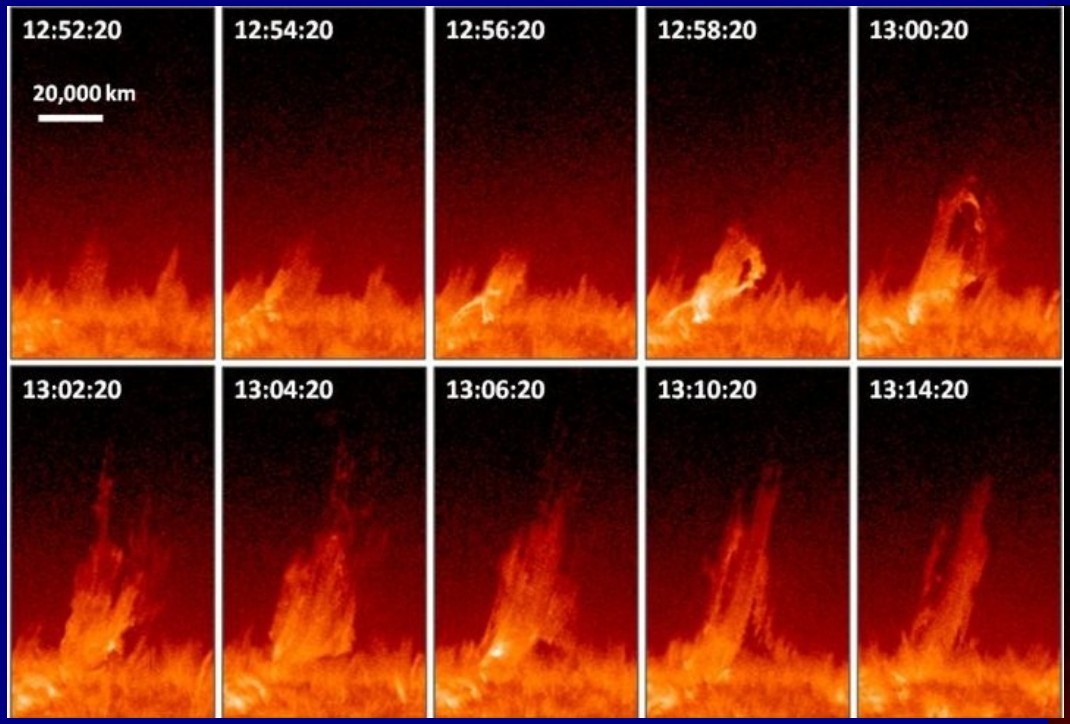
1. a rapid stream of liquid or gas forced out of a small opening."a high-pressure shower with pulsating jets", a nozzle or narrow opening for sending out a jet of liquid or gas."Agnes turned up the gas jet"

2. an aircraft powered by one or more jet engines."a private jet", “Astronauts fly T-38 jets.”



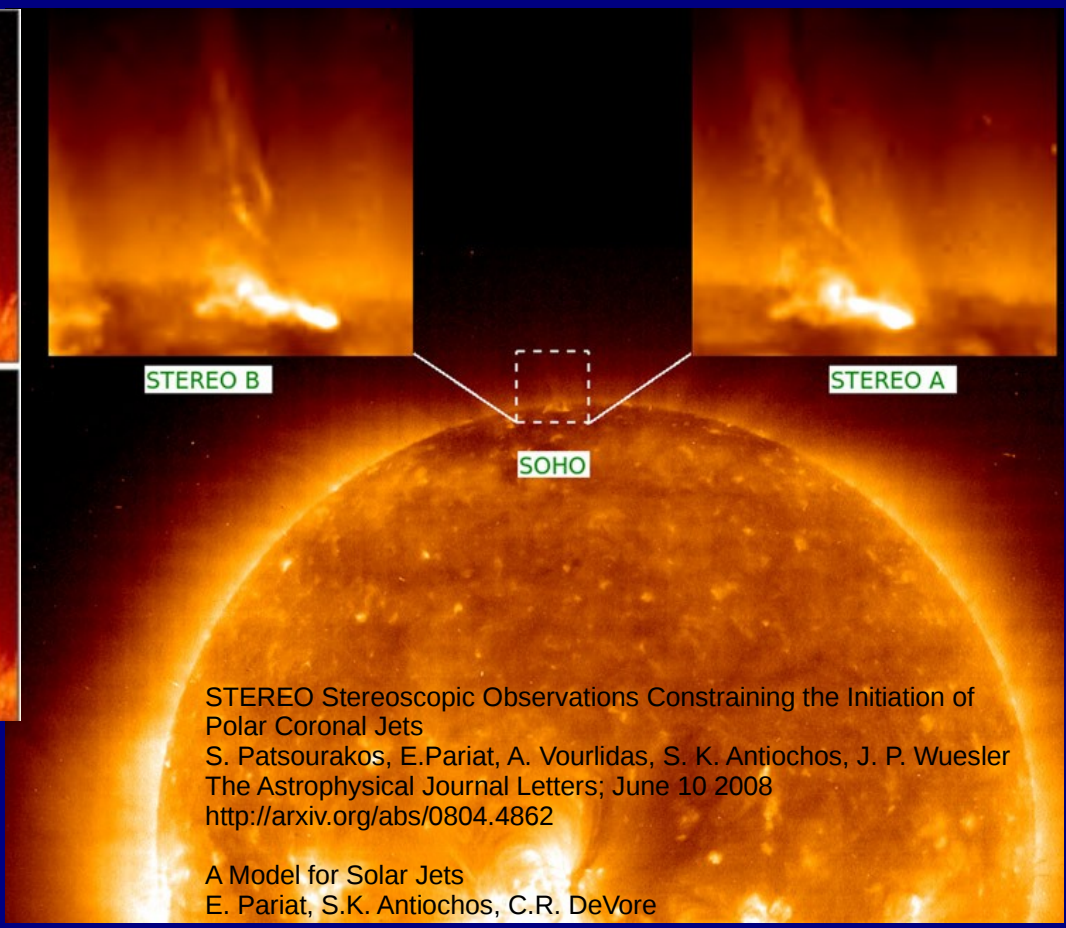
South Polar Jet: Hinode/P. Grigis

Solar jets can eject a million tons of matter at a speed of a million miles per hour (~45,000 km/s) in just a few minutes.



Above is an example of a “blowout” jet, from a northern polar coronal hole on 2010 October 2. The images are from SDO's AIA in 304 Å.

From: The Cool Component and the Dichotomy, Lateral Expansion, and Axial Rotation of Solar X-Ray Jets, R.L. Moore, *et al.,* **ApJ,** 768:134 2013 June 1



STEREO Stereoscopic Observations Constraining the Initiation of Polar Coronal Jets
S. Patsourakos, E.Pariat, A. Vourlidas, S. K. Antiochos, J. P. Wuesler
The Astrophysical Journal Letters; June 10 2008
http://arxiv.org/abs/0804.4862

A Model for Solar Jets
E. Pariat, S.K. Antiochos, C.R. DeVore

Jets in Coronal Holes

Coronal Holes in General (in X rays)

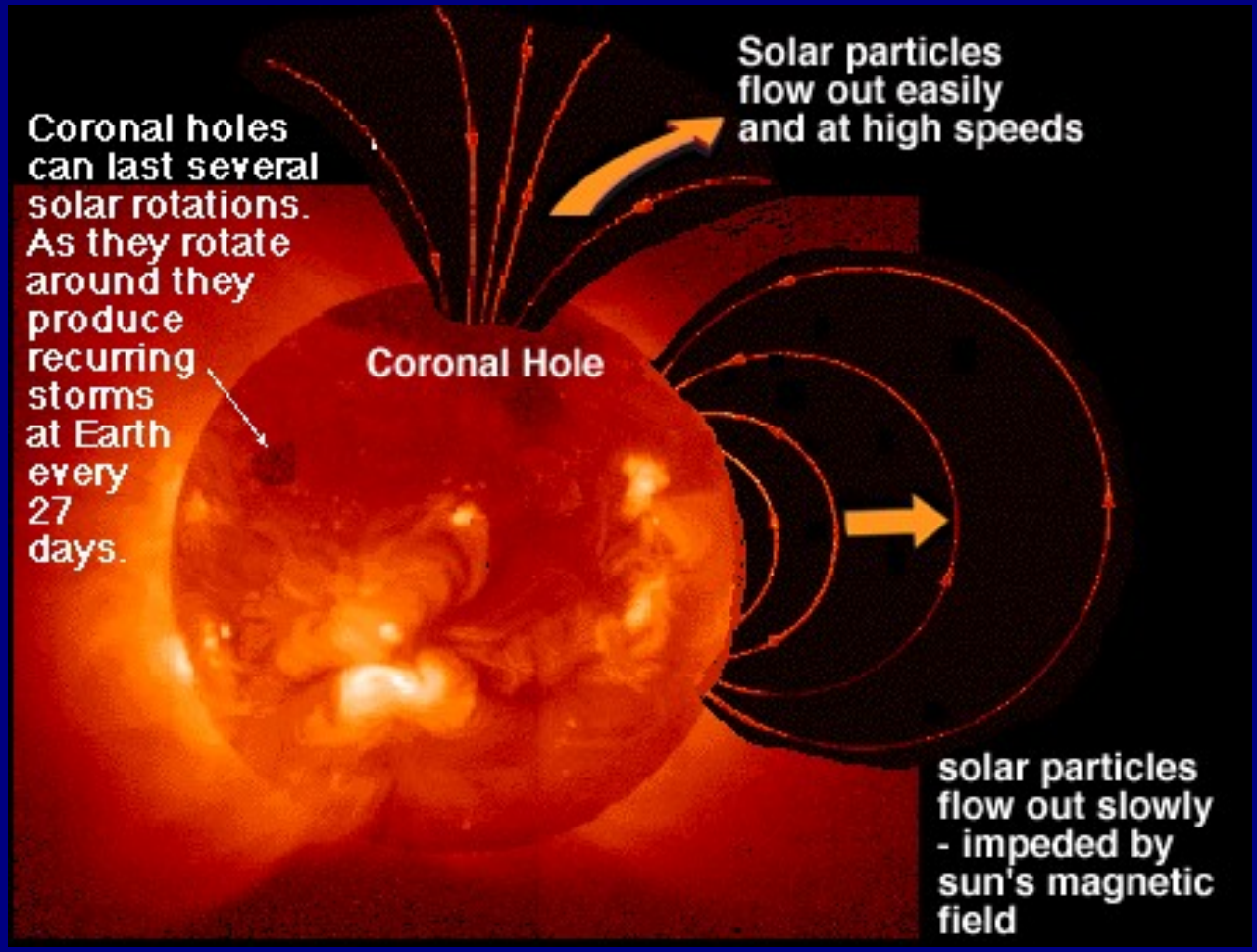


Image is from Windows to the Universe
http://www.windows2universe.org/spaceweather/coronal_hole_mag_field.html

Corona Holes in General (in EUV)