Recent Solar Eclipse Coronal Observations

Jay Pasachoff
Williams College–Hopkins Observatory
Williamstown, Massachusetts
Visiting Serge Koutchmy (IAP) and Frédéric Baudin
Institut d'Astrophysique Spatial

https://www.ias.u-psud.fr/fr/le-laboratoire/seminaires/seminaires-2017-2018

NSF NATIONAL GEOGRAPHIC NASA SIGMA XI THE SCIENTIFIC RESEARCH SOCIETY Williams

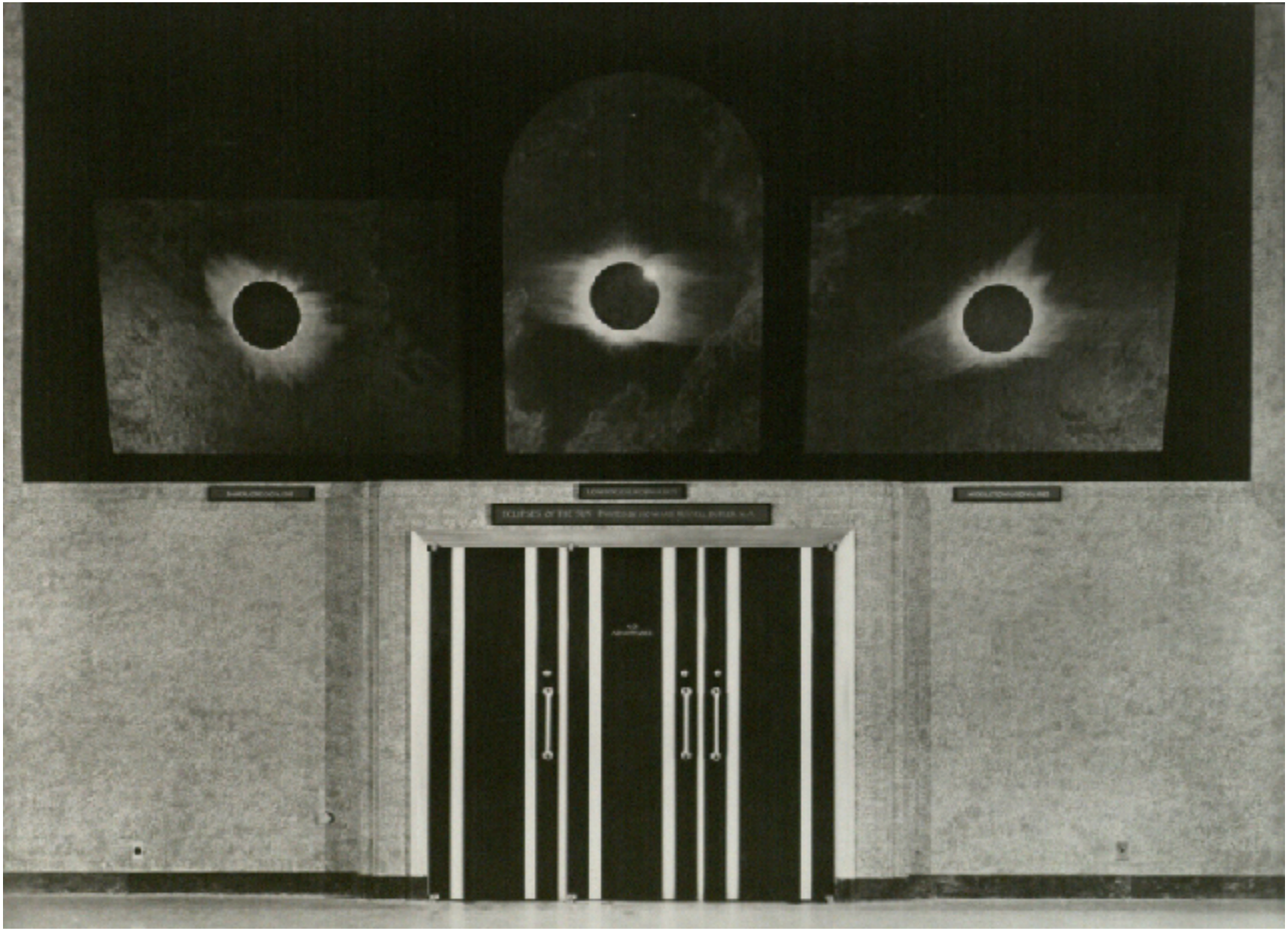
From our observing site
campus of Willamette University
Salem, Oregon

Major support from the Solar Terrestrial Program, Atmospheric and Geospace Sciences Division, National Science Foundation;
additional support: Committee for Research and Exploration, National Geographic Society

Additional student support from the Massachusetts NASA Space Grant Consortium; Sigma Xi; the Clare Booth Luce Foundation; and Williams College

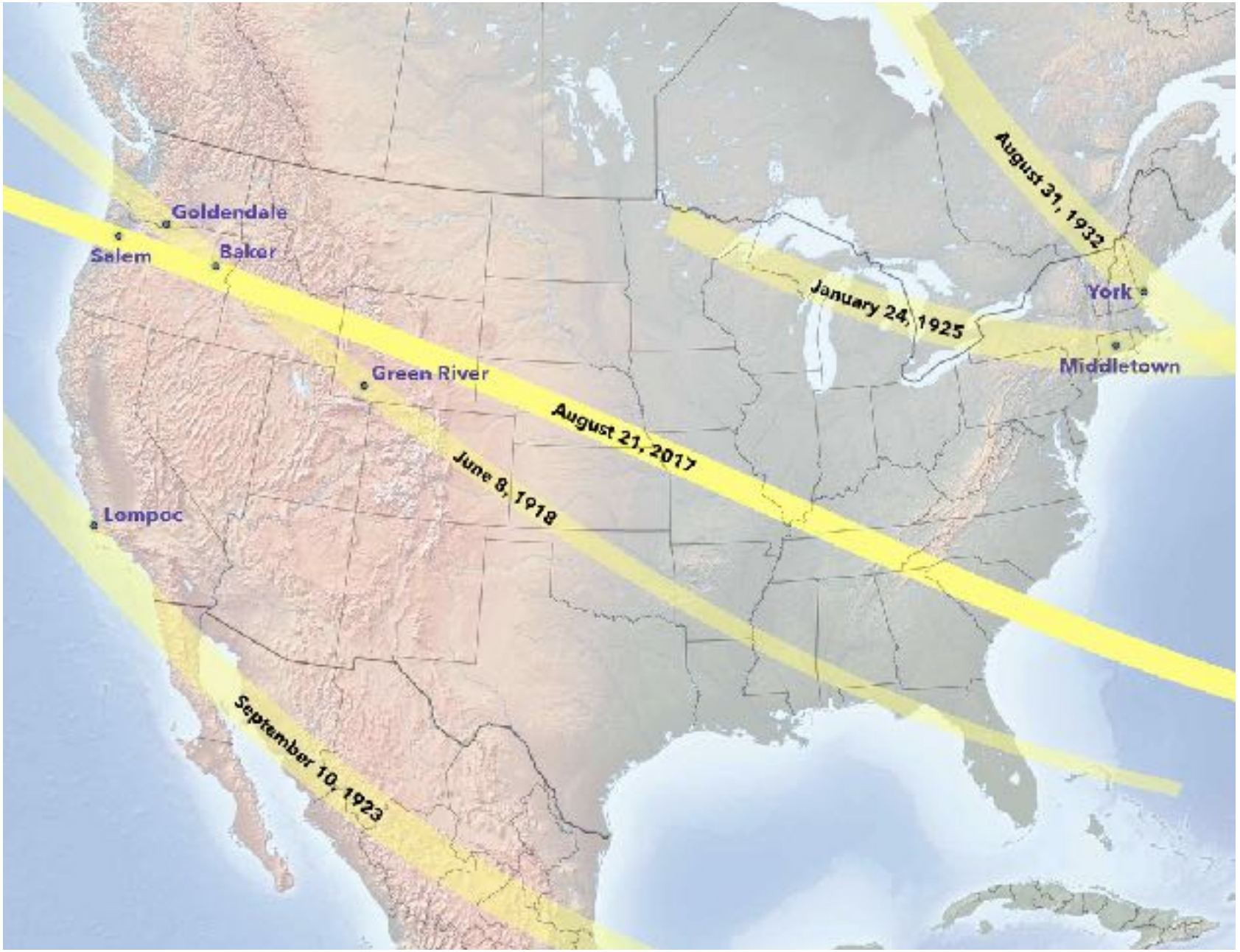
Our composite image from Salem with 68 individual images included

Jay Pasachoff, Vojtech Rusin, Roman Vanur, and the Williams College Solar Eclipse Expedition



The larger eclipse paintings of 1918, 1923 and 1925 at their previous location at the American Museum of Natural History.
Credit : American Museum of Natural History


Goldendale
Baker
Green River
Lompoc
York
Middletown
August 31, 1932
January 24, 1925
June 8, 1918
September 10, 1923


Goldendale
Salem
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Green River
Lompoc
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Middletown
August 31, 1932
January 24, 1925
August 21, 2017
June 8, 1918
September 10, 1923

A color photograph of the June 8, 1918, solar eclipse painting. The corona and prominences can be seen through the thin clouds at the USNO station, Baker, Oregon.
Credit : American Museum of Natural History

Sept 10, 1923, solar eclipse as seen from Lompoc, California. The painting shows the diamond ring effect. Near the top of the painting is Venus. Credit : American Museum of Natural History

The eclipse as seen from Middletown, Connecticut, on Jan 24, 1925.
Credit : American Museum of Natural History

Panel sizes: left panel: 173 x 248 cm (68 x 98 in.); center panel: 234 x 165 cm (92 x 65 in.); right panel: 170 x 241 cm (67 x 95 in.)

At bottom right of left panel: H.R. **Butler** © Baker, Ore. June 8 1918"; other two panels unsigned.

For reproduction of this painting, see the folded plate issued as supplement to *Natural History*, v. 26, no. 4 (July/Aug. 1926)

*We thank **Thomas Baione**, Harold Boeschenstein Director of the Department of Library Services of the American Museum of Natural History for arranging for new photography of the murals.*

The eclipse as seen from York, Maine, on Aug 31, 1932.
Credit : Princeton University Art Museum

Total solar eclipse of August 21, 2017

Eclipse magnitude is the maximum fraction of the Sun's diameter occulted by the Moon

Times given are for the moment of the local greatest eclipse

18:00 UT = 11 a.m. PDT = 12 p.m. MDT = 1 p.m. CDT = 2 p.m. EDT

Map by Michael Zeiler, January 2015

Calculations by Xavier Jubier, xjubier.free.fr

Predictors by Fred Espenak, eclipsewise.com

From our observing site
campus of Willamette University
Salem, Oregon

Scientific colleagues:
Ron Dantowitz, Clay Center Observatory
Daniel Seaton ‘01, NOAA and U Colorado CIRES
Vojtech Rusin, Slovakian Academy of Sciences
John Seiradakis, Aristotle U, Thessaloniki
Aristeidis Voulgaris, Aristotle U, Thessaloniki
Marcos Peñaloza-Murillo, U de los Andes, Venezuela

Williams College undergraduates:
Erin Meadors ‘20
Cielo Perez ’19
Brendan Rousseau ‘19
Ross Yu ‘19
Declan Daly ‘20
Connor Marti ‘20
Christian Lockwood ‘20
Charles Ide ‘20

Graduate students:
Allen Davis ’14 (now Yale U)
Muzhou Lu ‘13 (now U Colorado, Boulder)
David Sliski (now U Penn)
Amy Steele ‘08 (now U Maryland)
Duane Lee ’01 (Ph.D. Columbia)
(Vanderbilt U; newly MIT)
Marcus Freeman ‘08 (Ph.D. RIT)

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additional alumni scientists
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(Ph.D. Columbia)
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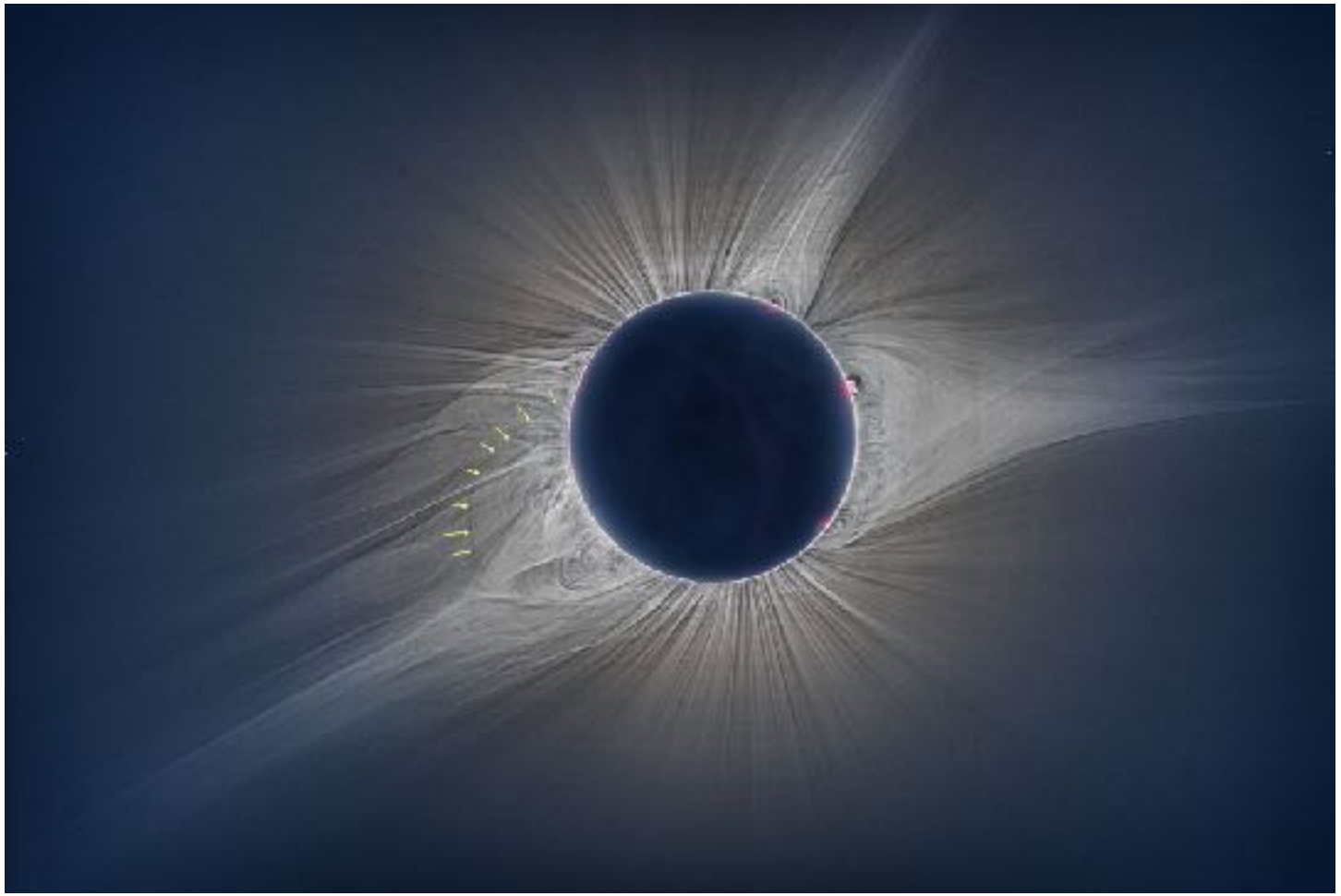
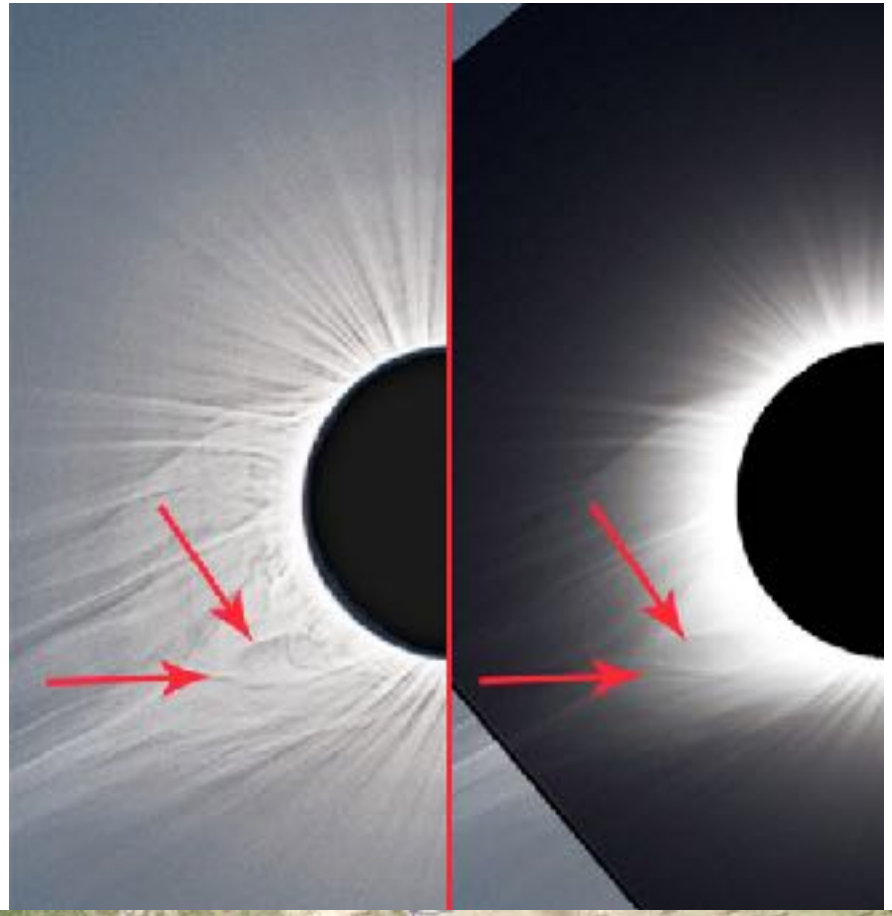
Above:
Chinese team

Above:
Williams College team

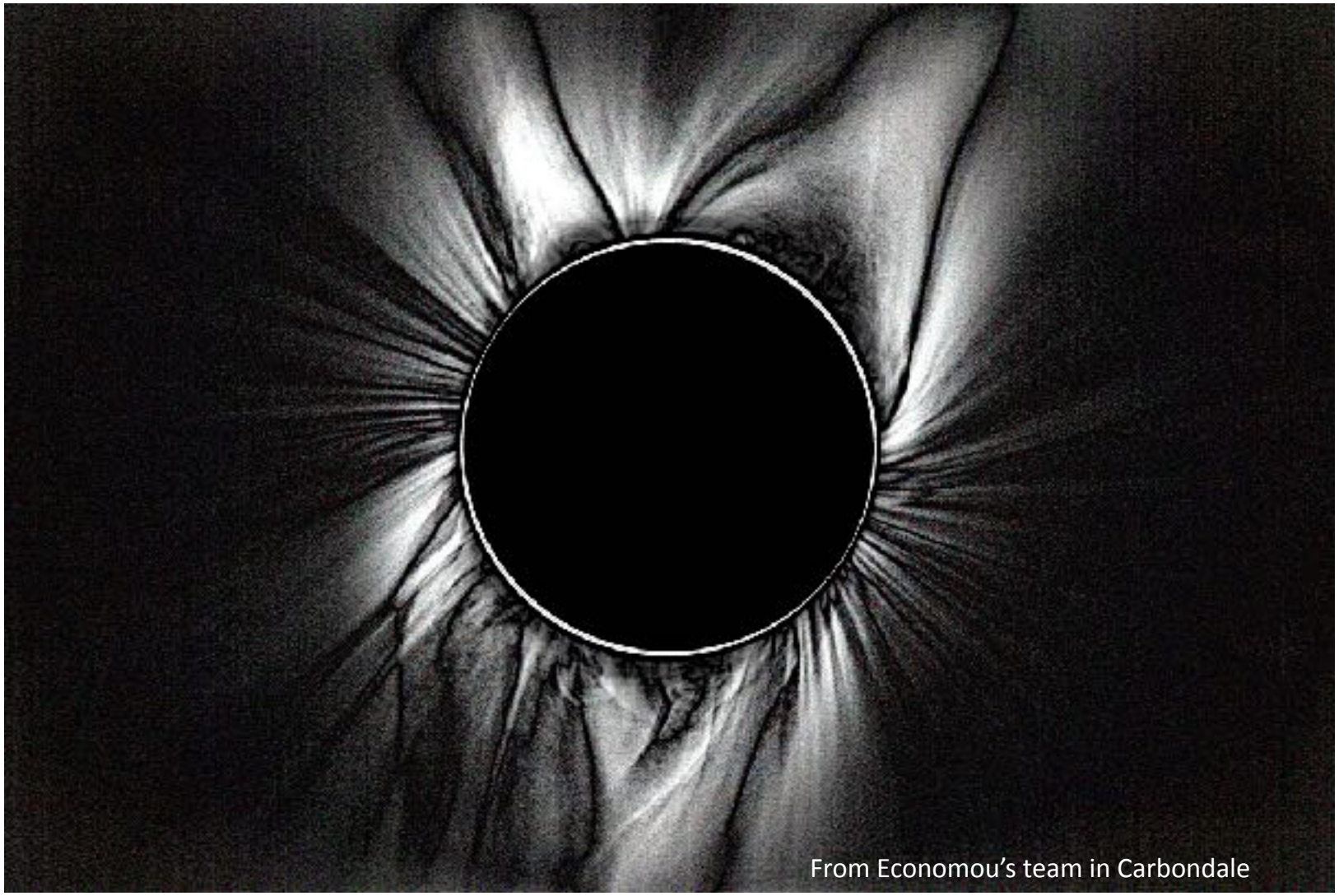
Below:
Japanese team
Based at Kyoto Obs.



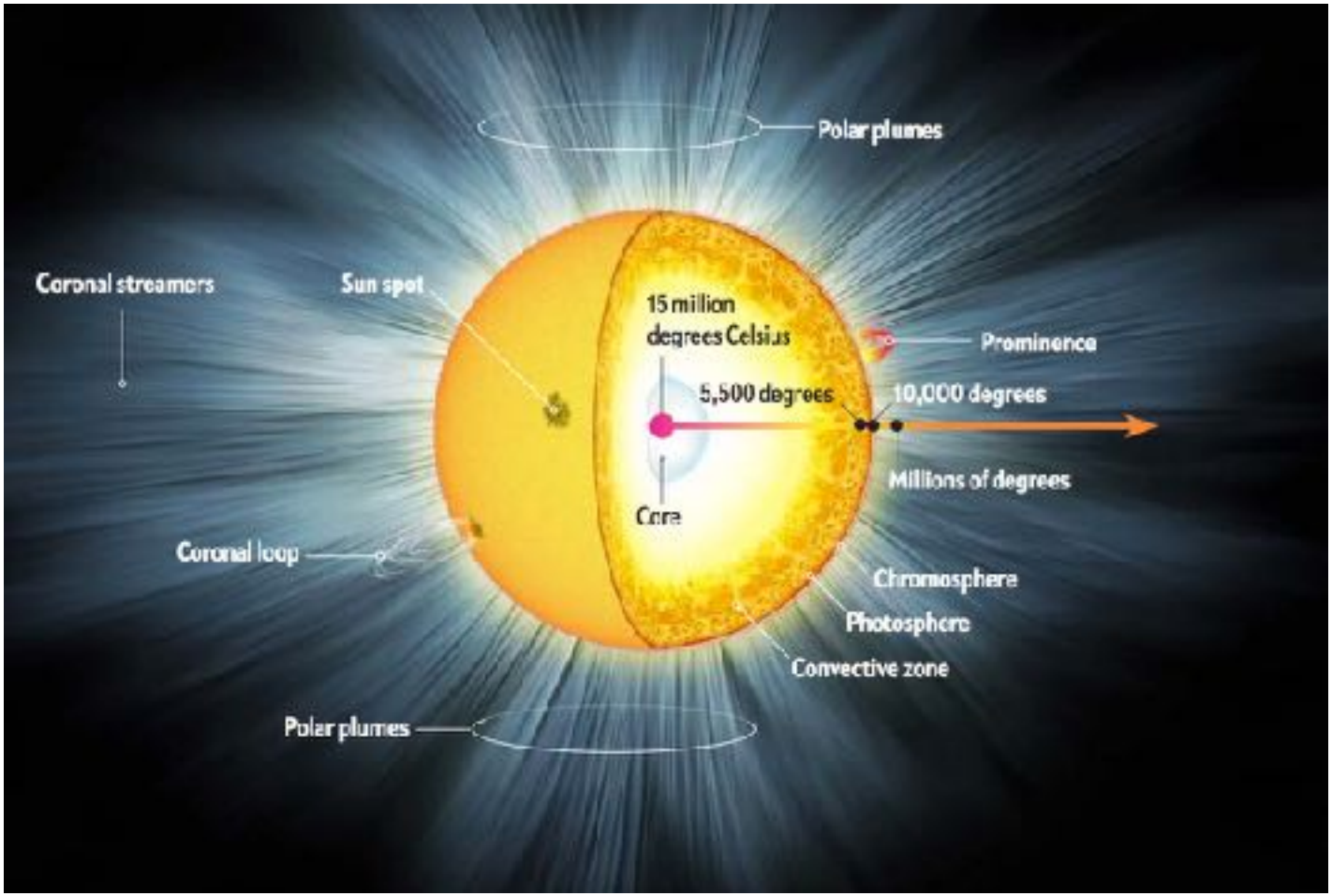
Comparison: Salem vs. Carbondale



Science Visualization Studio, NASA's Goddard Space Flight Center, and USRA; https://svs.gfsc.nasa.gov/eclipse2017


From Economou's team in Carbondale

From ”The Great American Eclipse of 2017”
by Jay Pasachoff, *Scientific American*, August 2017



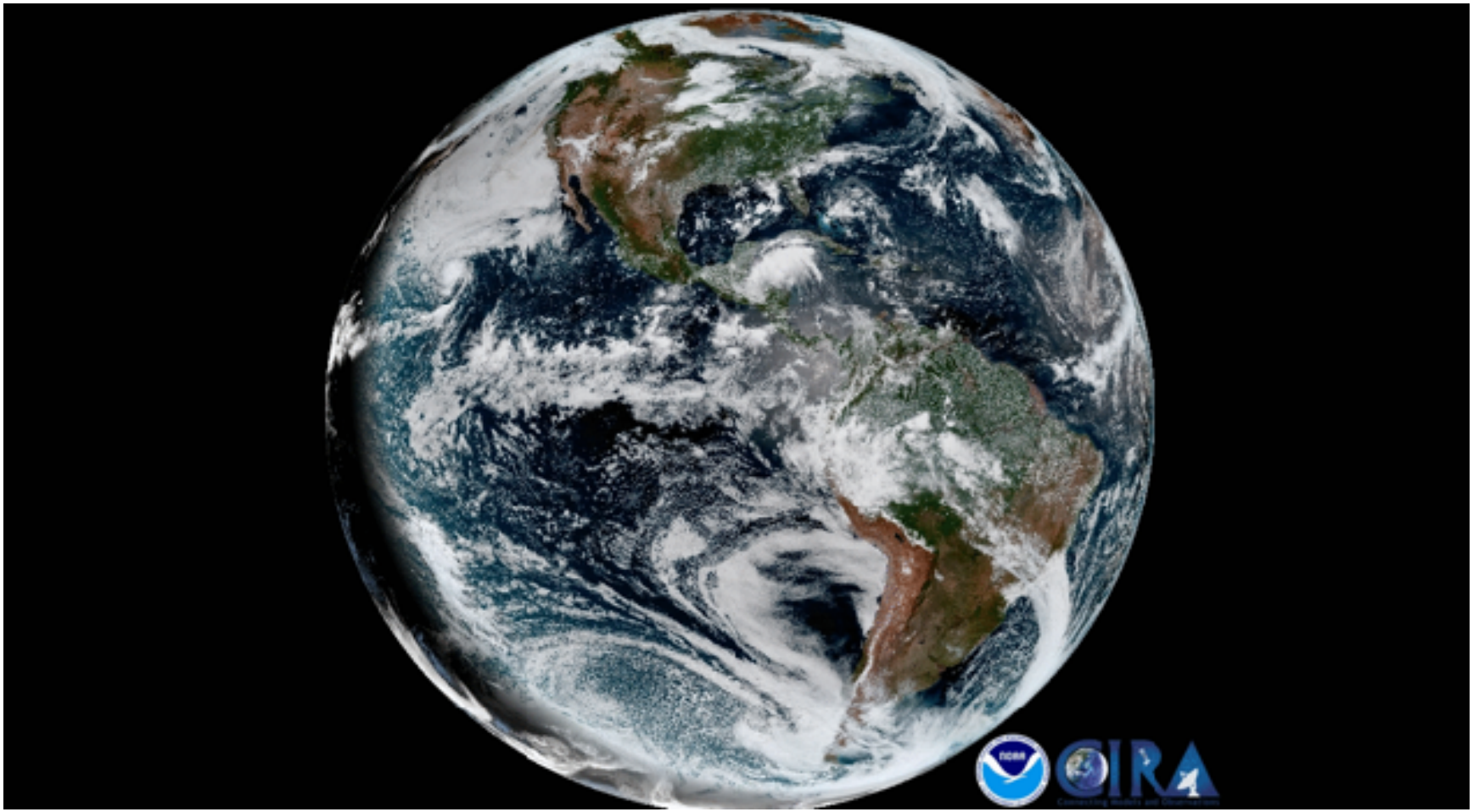
The Great American Eclipse 2017

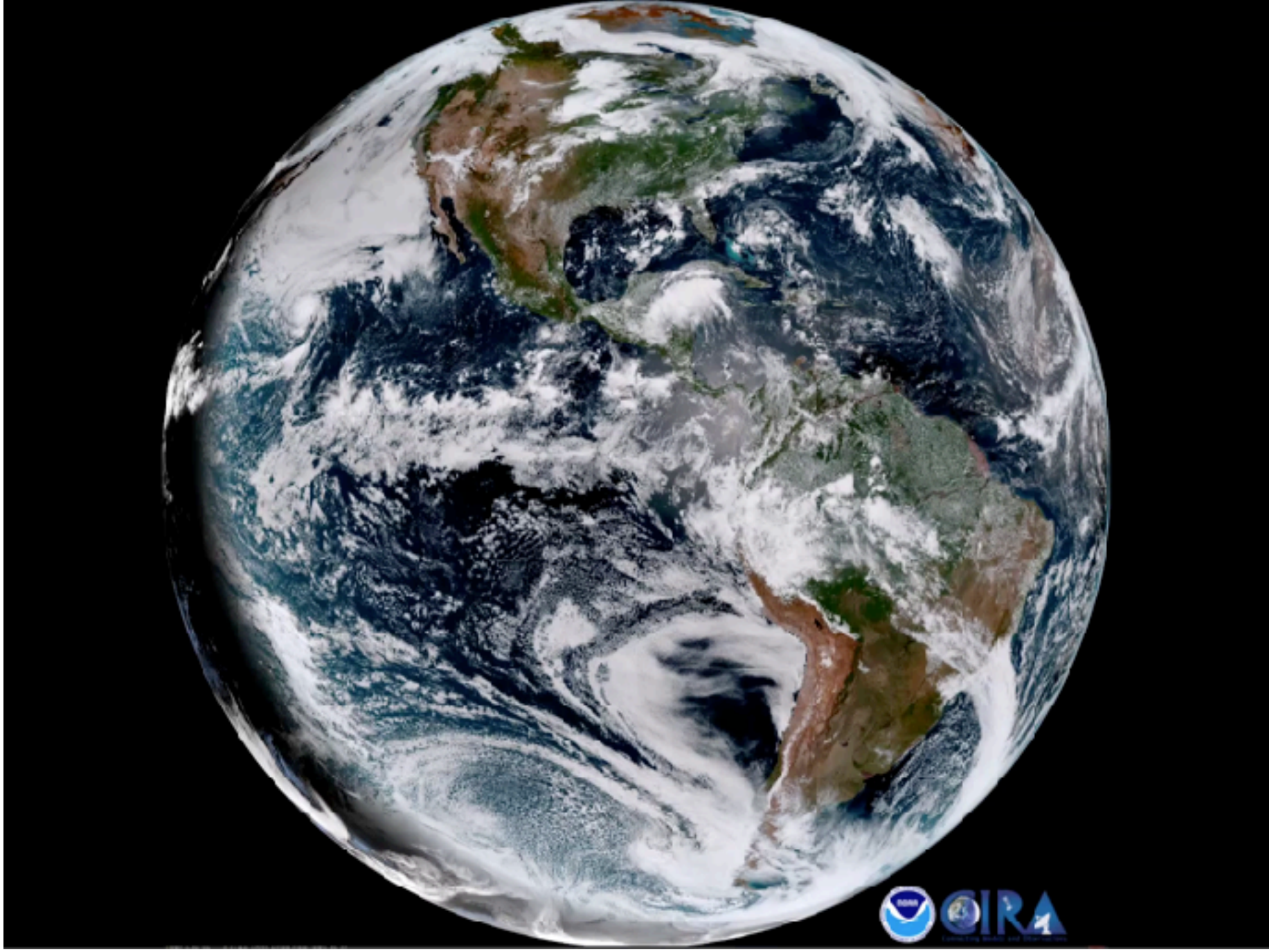
Photos by Jay Pasachoff and the Williams College Eclipse Expedition

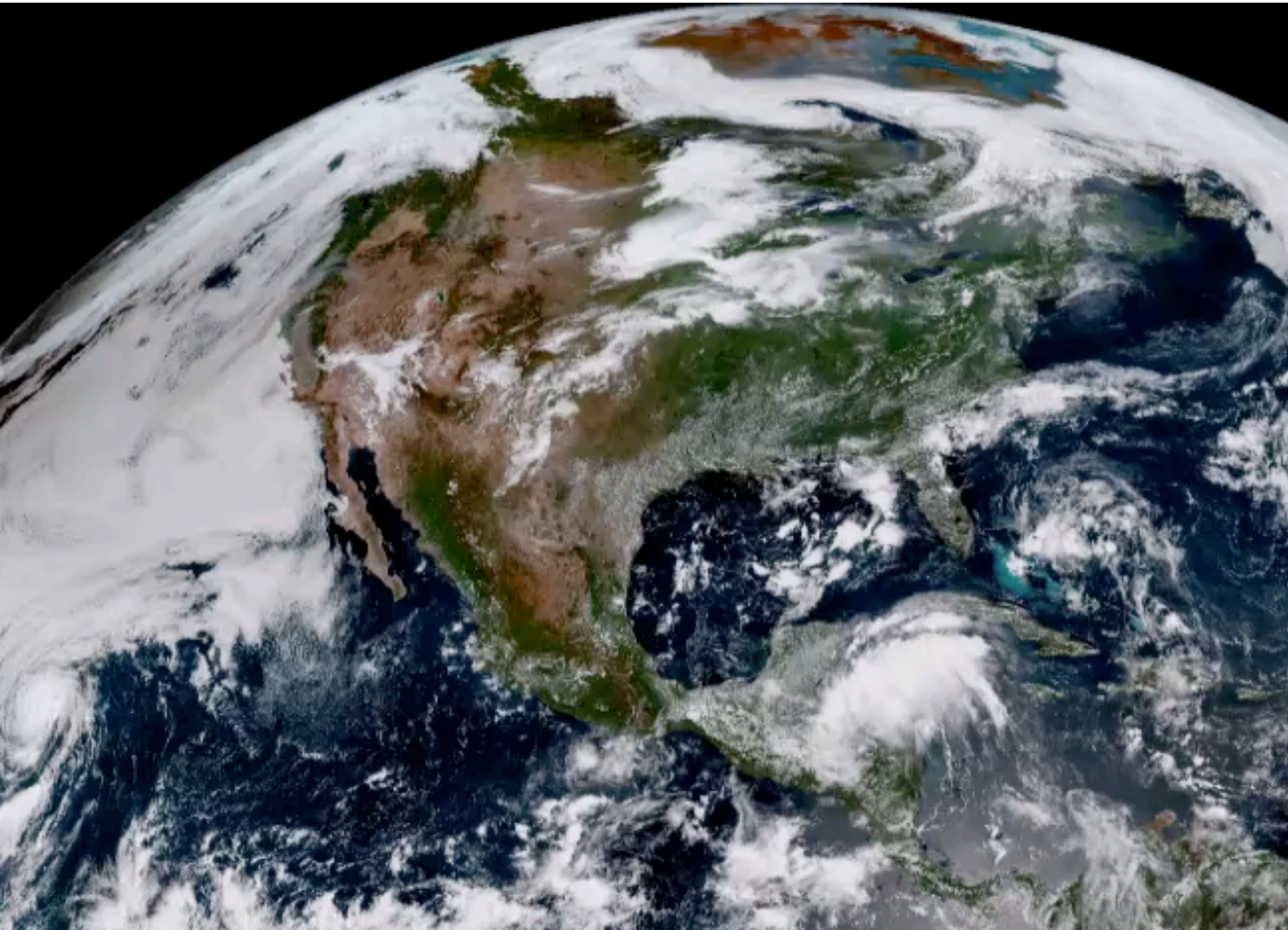
Composite by Christian Lockwood

Astronomy Picture of the Day, 27 September 2017

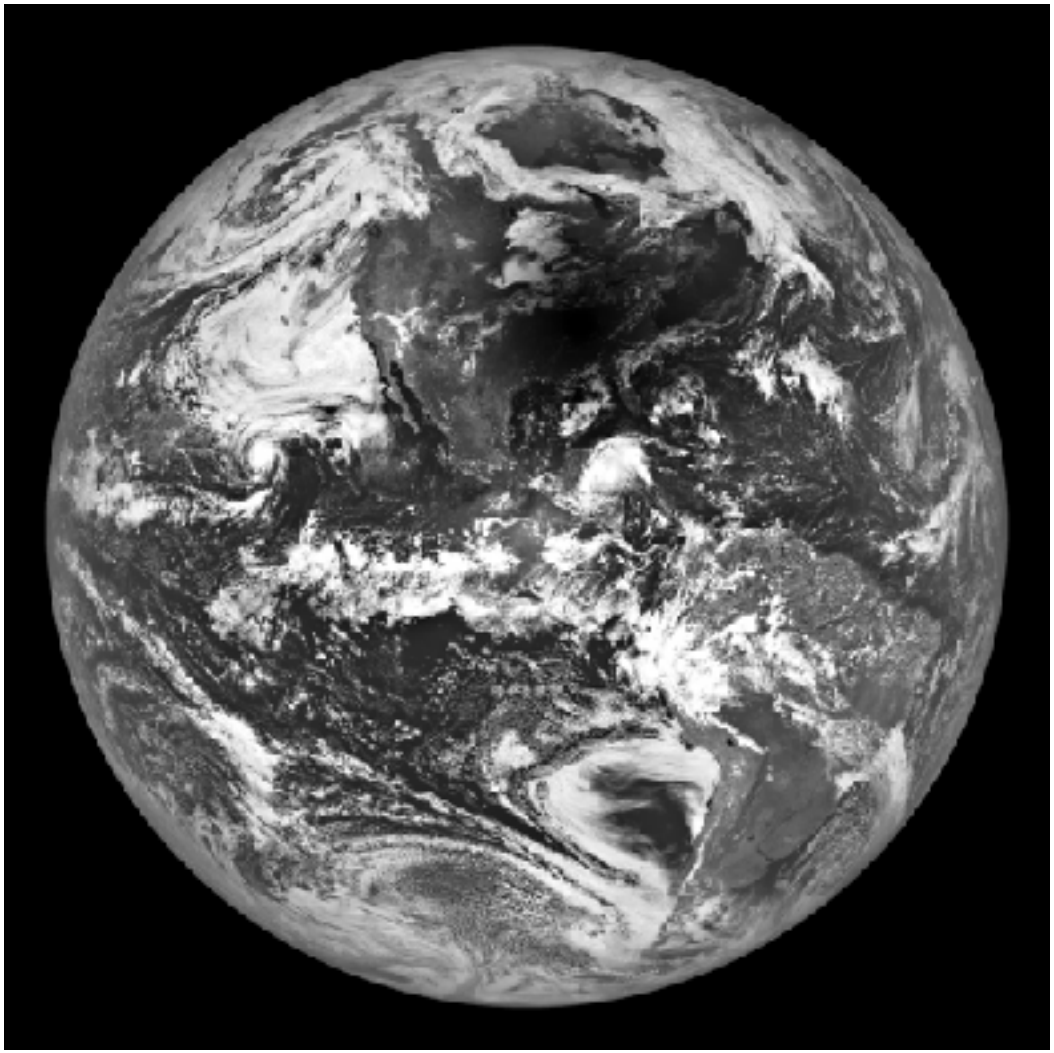
GOES-16




CIRA



Lunar Reconnaissance Orbiter

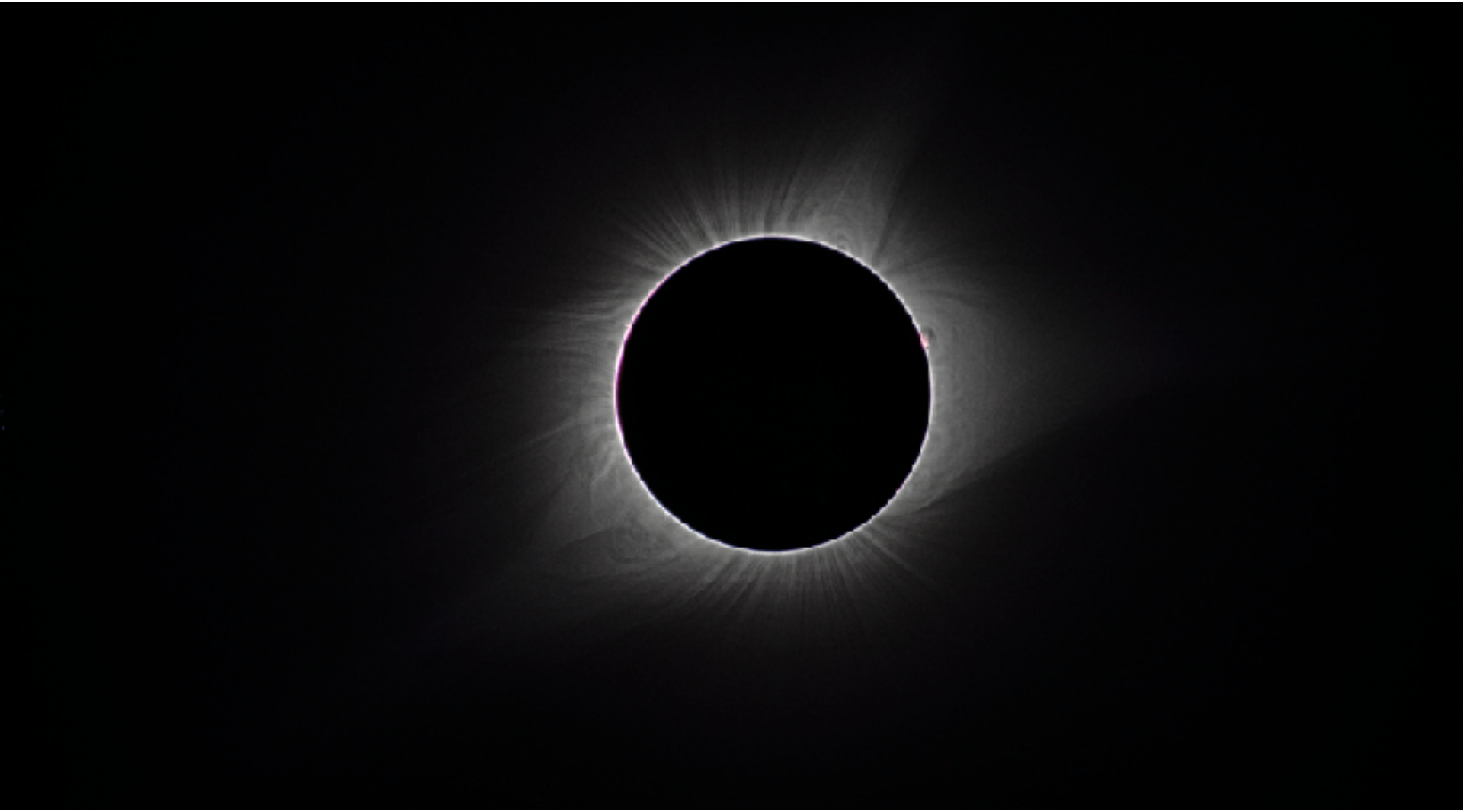


NASA / GSFC / Arizona State Univ. / LRO

International Space Station eclipse view
(NASA/ESA)

Balloon view of Wyoming/Nebraska during the eclipse.
Credit: Earth to Sky Calculus/Josh Stansfield

The camera, a Panasonic GH4, belonged to professional photographer Josh Stansfield. He helped students launch the balloon from Ft. Laramie, Wyoming, and later processed these images after the payload was recovered from its landing site in Nebraska.

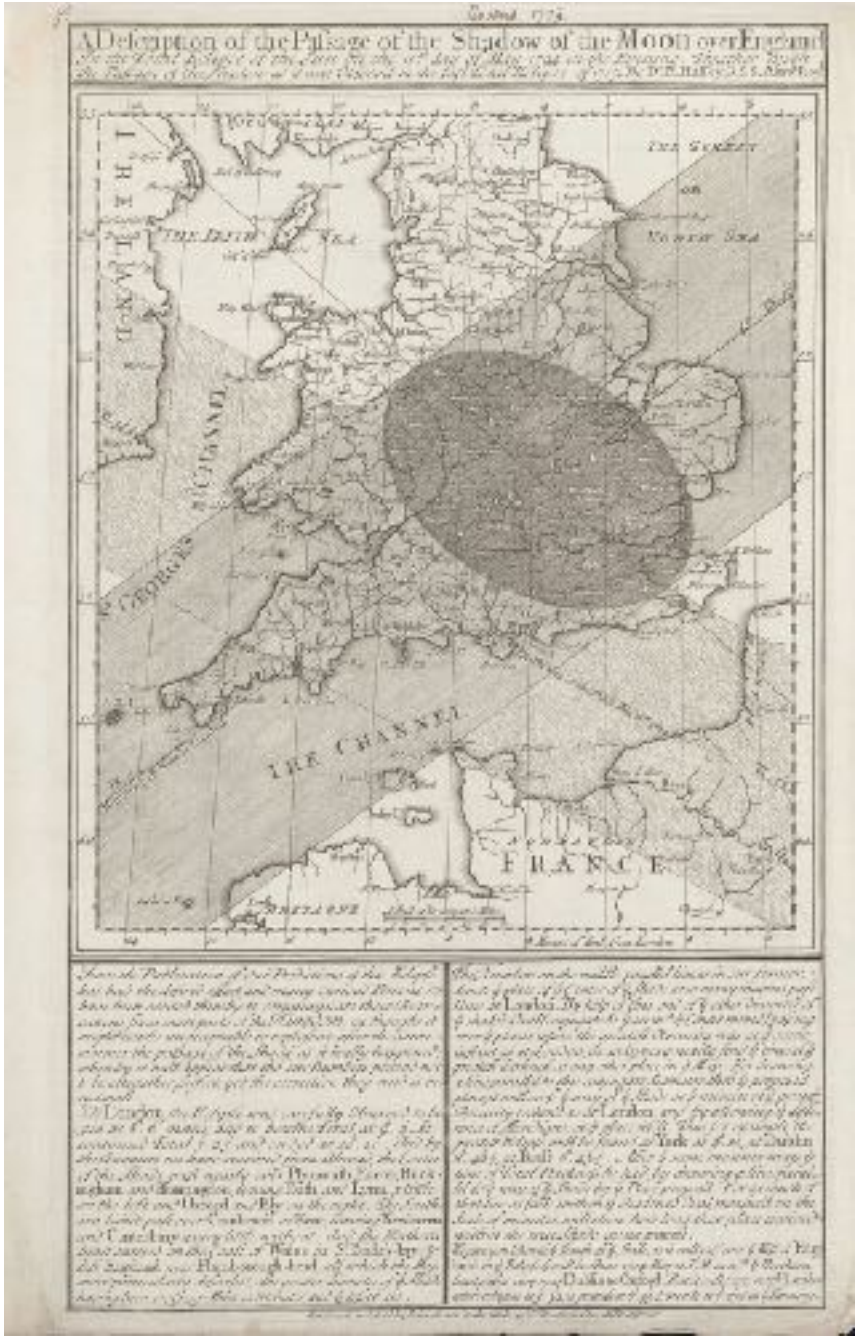


Edmond Halley map, 1715

Edmond Halley's map predicting the eclipse of 1715, and requesting crowdsourcing of observations. His predictions were within 20 miles and 4 minutes of the actual path and time.

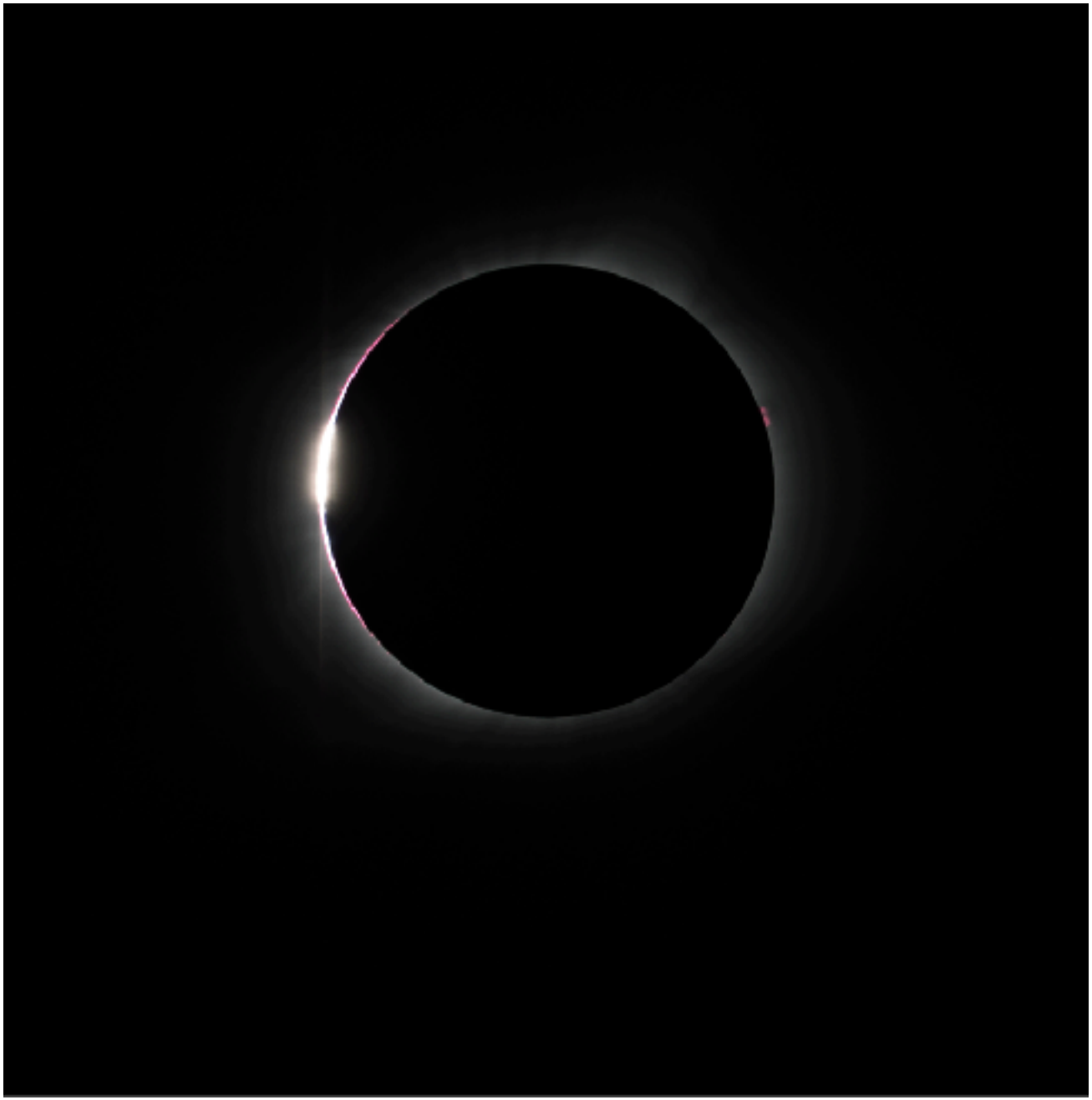
Collection of Jay and Naomi Pasachoff

Halley map
1715/1724



Harvard University, Houghton Library, hyde_eb7_h1552_715d2b_0001

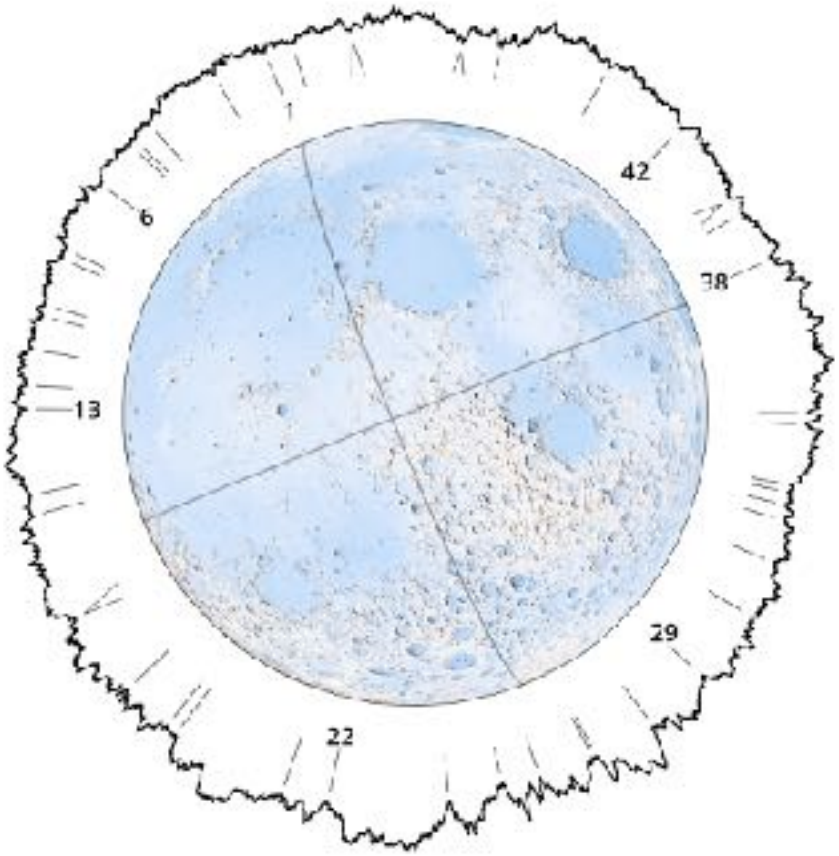
Baily’s beads on ingress



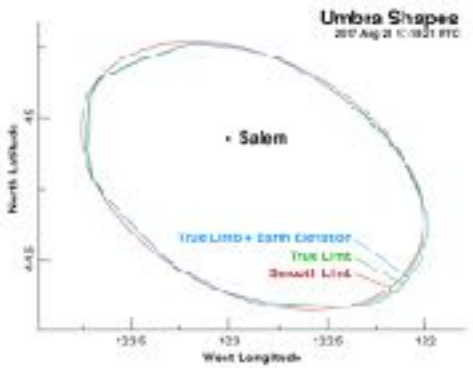
Our observations vs. *Solar Eclipse Maestro* predictions

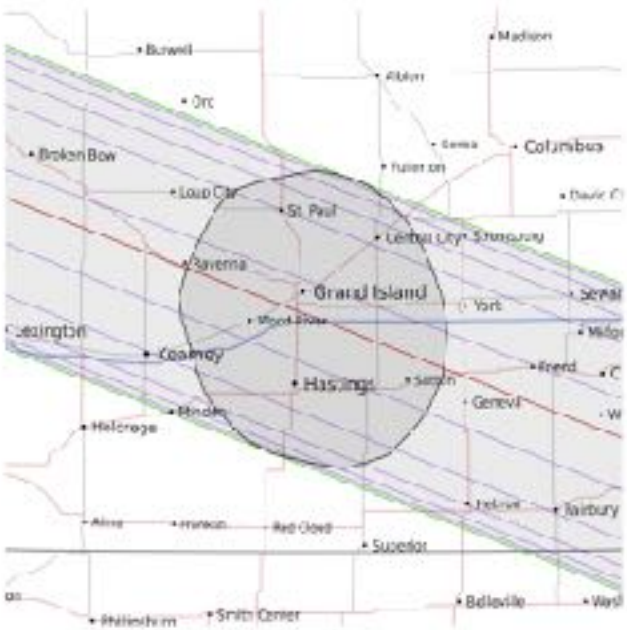
Using Xavier M. Jubier's *Solar Eclipse Maestro*

Calculations based on NASA's Lunar Reconnaissance Orbiter



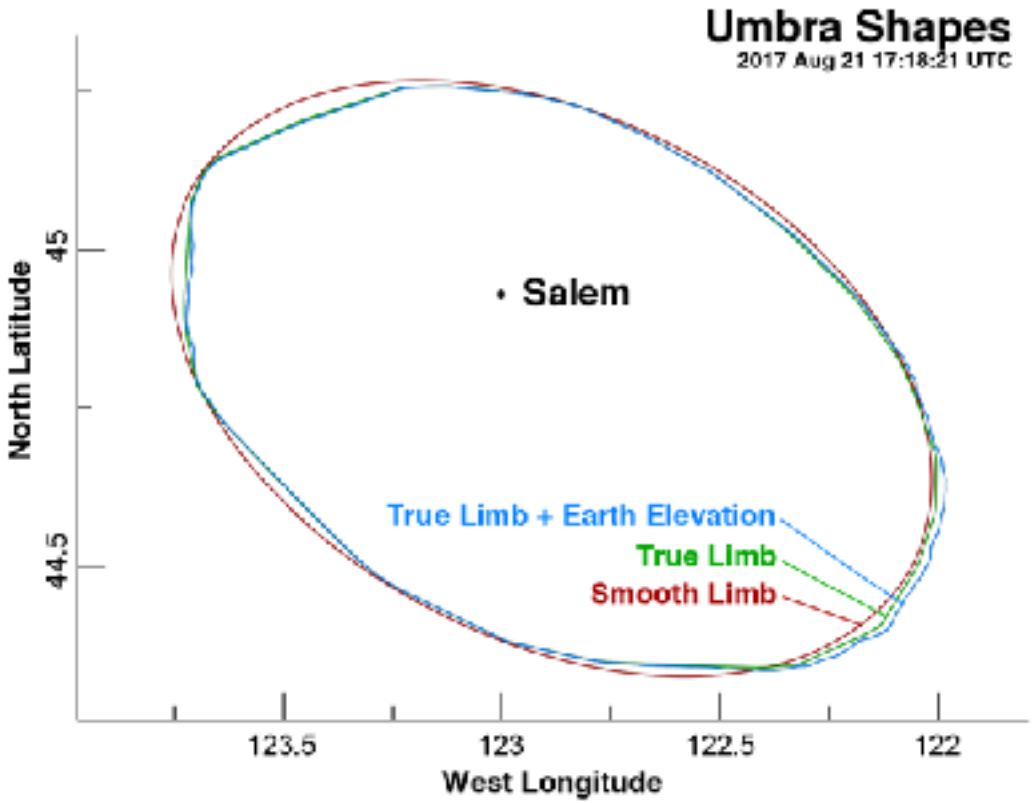
Science Visualization Studio, NASA's Goddard Space Flight Center, and USRA; https://svs.gfsc.nasa.gov/eclipse2017



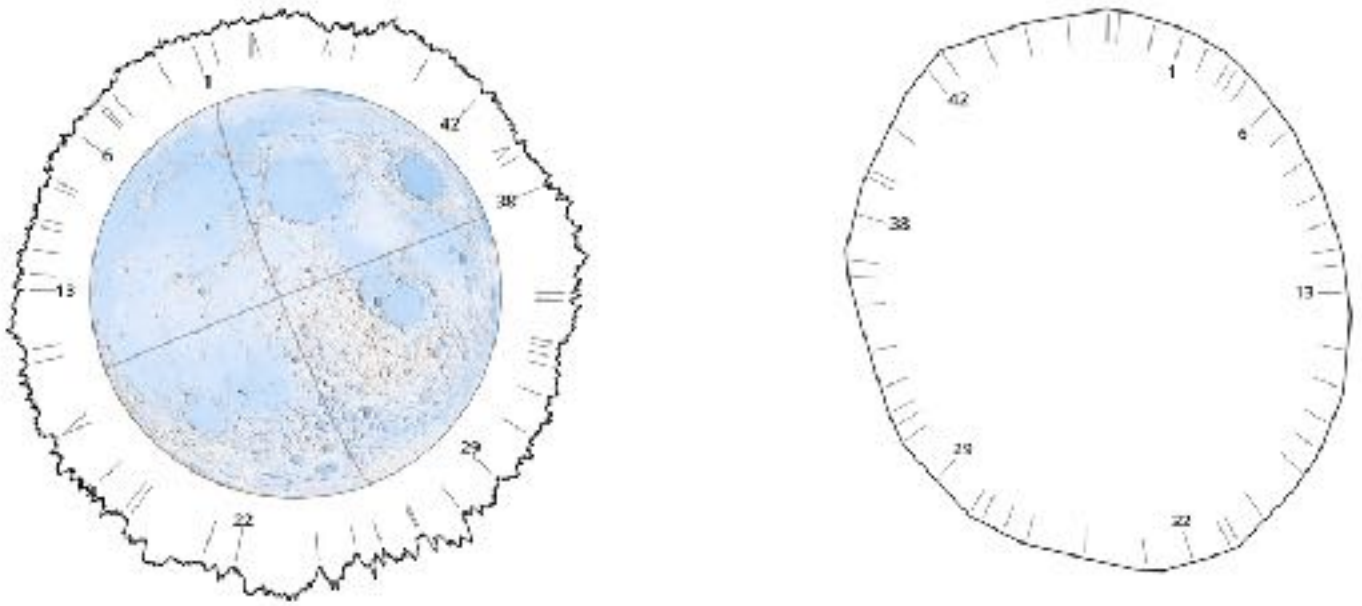


The shape of the umbra on the ground is the locus of all points on the surface of the Earth at which the photosphere of the Sun is completely blocked by the Moon. The nominal calculation of this shape (left) assumes that the Moon is smooth and that all observers are at sea level. Accounting for the limb of the Moon (green) produces a polygonal umbra shape. Accounting for Earth terrain tends to shift the shape toward the Sun's azimuth by approximately $h\cot(a)$, where h is the height of the observer and a is the azimuth of the Sun. In the left figure, the umbra is over Salem, Oregon, and its leading (eastern) edge has begun to interact with the higher elevations of the Cascades. In the figure to its right, the position corresponds to the adjacent map of Nebraska.

Calculation using NASA's Lunar Reconnaissance Orbiter 3D mapping

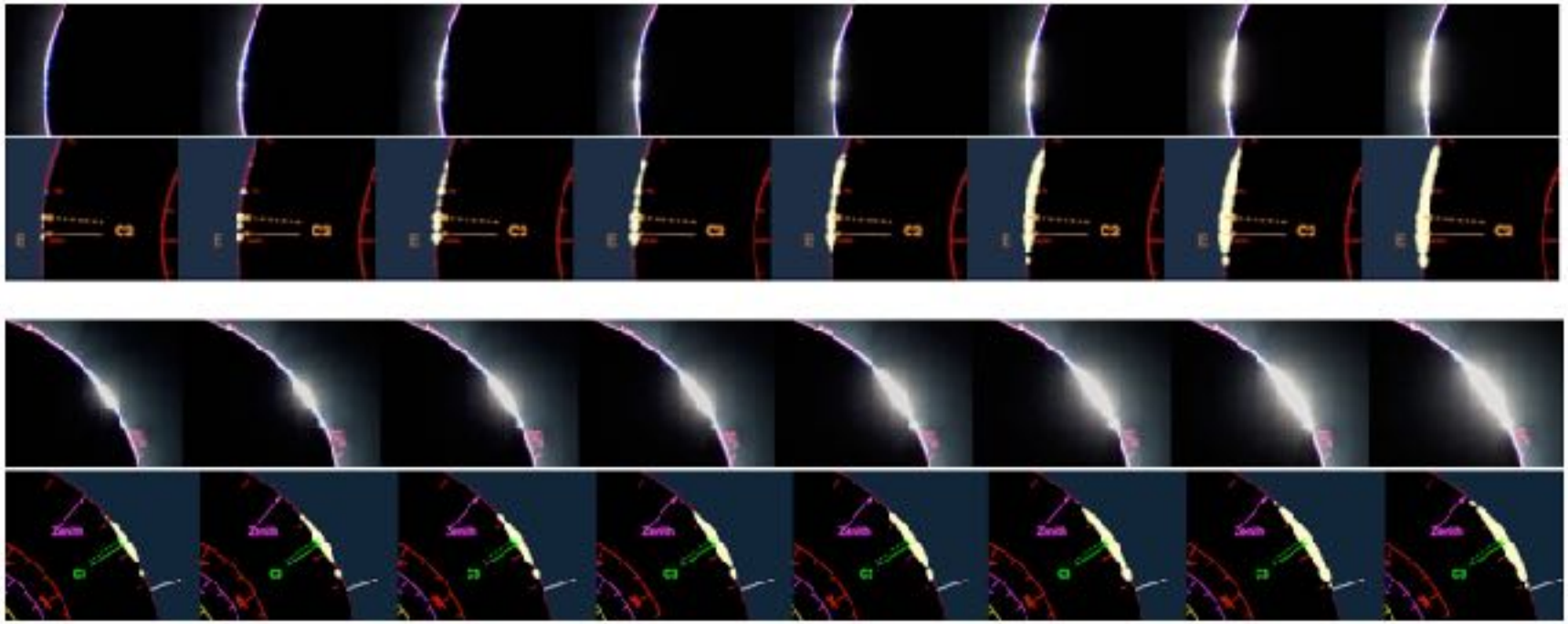


Calculations by Ernie Wright, Science Visualization Studio, NASA/GSFC



The limb of the Moon (left) produces a polygonal umbra shape on the Earth's surface (right). Each side of the polygon corresponds to a single valley on the lunar limb, either the last valley admitting photospheric light prior to second contact, or the first valley admitting sunlight just after third contact. Here, with 18,000 points equally spaced in position angle around the limb, the umbra is determined by just 49 points, some of which are labeled. The correspondence between umbra edges and limb points allows the position angle of the diamond ring and the last Baily's bead to be predicted. Observers at a particular edge, where two umbra polygon sides meet, see a first or last Baily's bead in the corresponding valley on the lunar limb. At 18:00:00 UTC on August 21, 2017, the umbra is in eastern Nebraska. The location was chosen for this figure to minimize the additional effects of Earth elevation. The lunar limb profile is magnified 32x.

Baily's beads: Visualization by Xavier Jubier compared with our observations

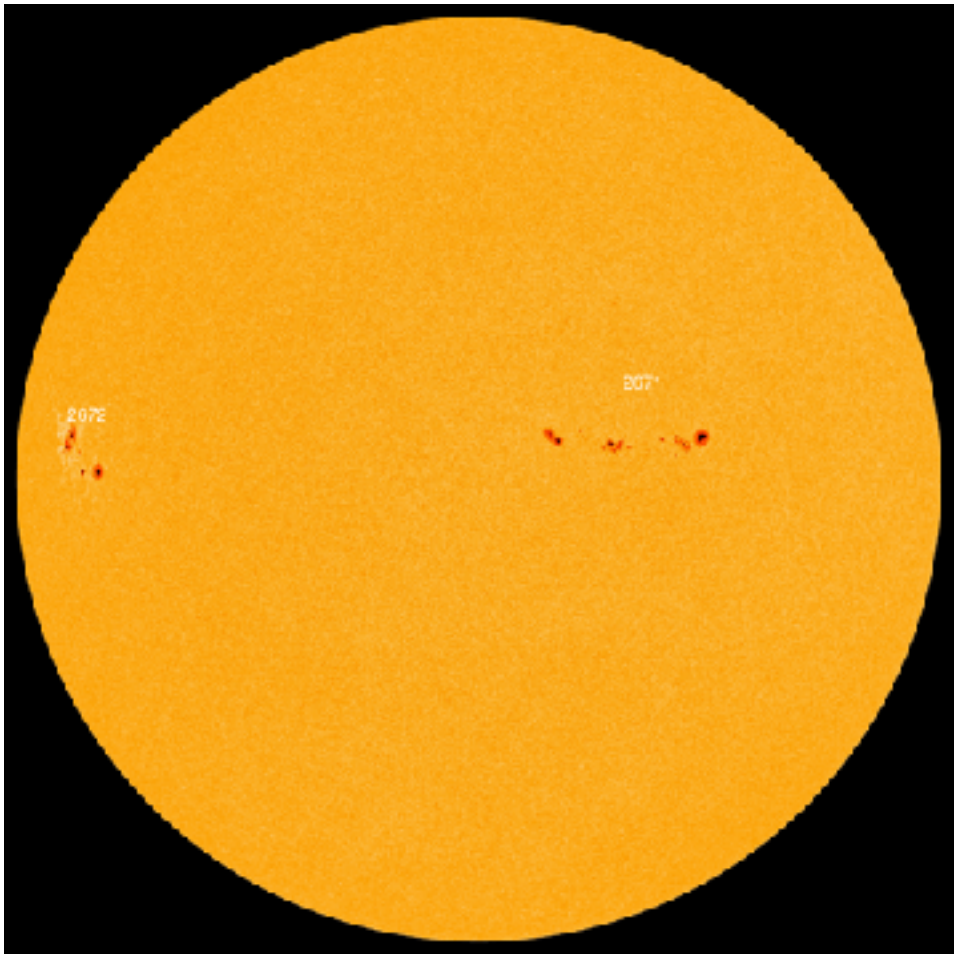


Using Xavier Jubier's *Solar Eclipse Maestro*

Jay M. Pasachoff, Xavier Jubier, and Ernest T. Wright, "Syzygy Information: Lunar Limb Profiles at Total Eclipses of the Decade," 49th Meeting of the Division of Planetary Sciences, American Astronomical Society, Provo, 417.17.

- **The solar radius used for eclipse predictions**
- The IAU 2015 value—695,700 km is 959.22” at 1 au—is more of a conversion factor than a true photospheric solar radius to be used for solar-eclipse predictions. To succeed in making eclipse-totality predictions valid to a fraction of a second, that is one of the issues that need to be understood and tackled.
- The IAU 1976 value is the one derived by Auwers in 1891 and this is the value all solar-eclipse predictions use by default: 959.63” at 1 au or 696,000 km. http://adsabs.harvard.edu/full/1980MitAG..48...59L
- This webpage does a summary: https://en.wikipedia.org/wiki/IAU_(1976)_System_of_Astronomical_Constants
- So, if we were using the IAU 2015 resolution conversion factor for solar-eclipse predictions, then the totality duration would be even longer, up to two seconds longer, than with the IAU 1976 value, which gives a duration that is already far too long!
  We now have everything to show that the true photospheric solar radius is indeed even larger than the IAU 1976 value, not smaller. Work with Solar Eclipse Maestro and other eclipse simulators show that with either the IAU 1976 or 2015 solar radius values, it is meaningless to correct for the true lunar limb profile.
- 959.98” at 1 au ±0.02” is Xavier Jubier’s suggested true photospheric solar radius; from the preliminary study for TSE 2017, it remains the best value.

From NASA's Solar Dynamics Observatory
Helioseismic Magnetic Imager (HMI)



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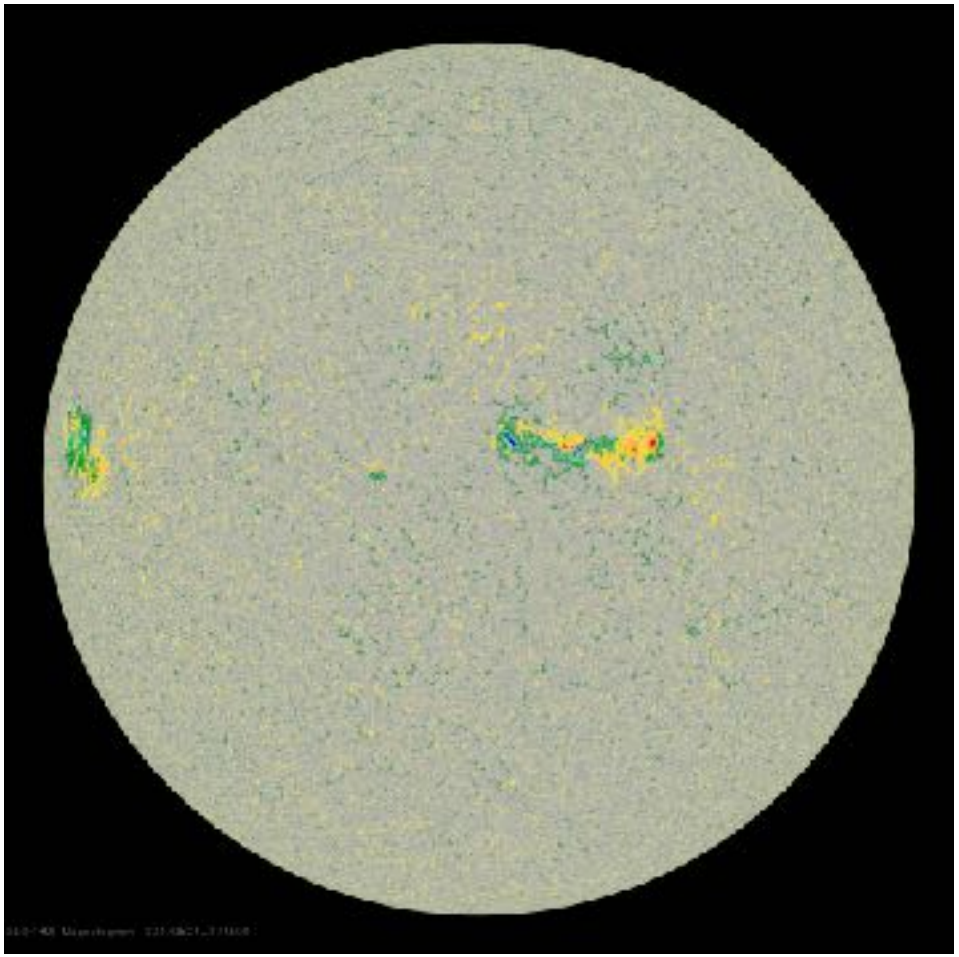
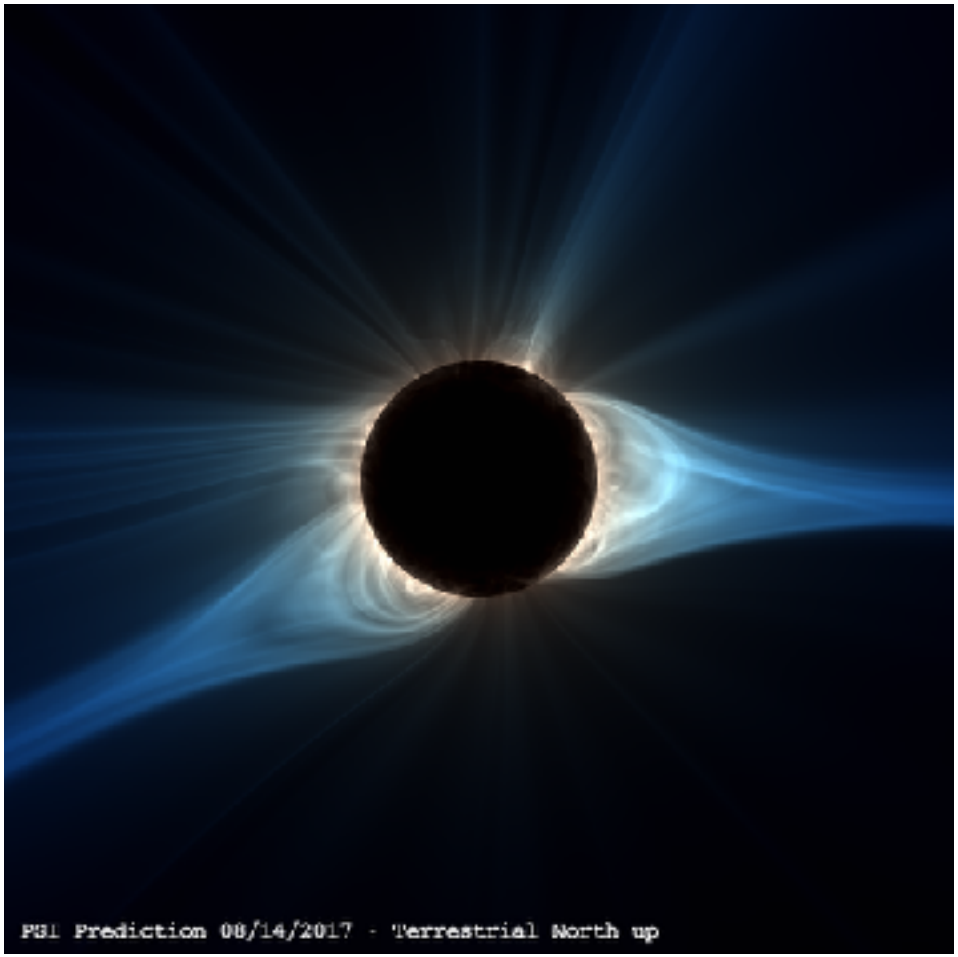
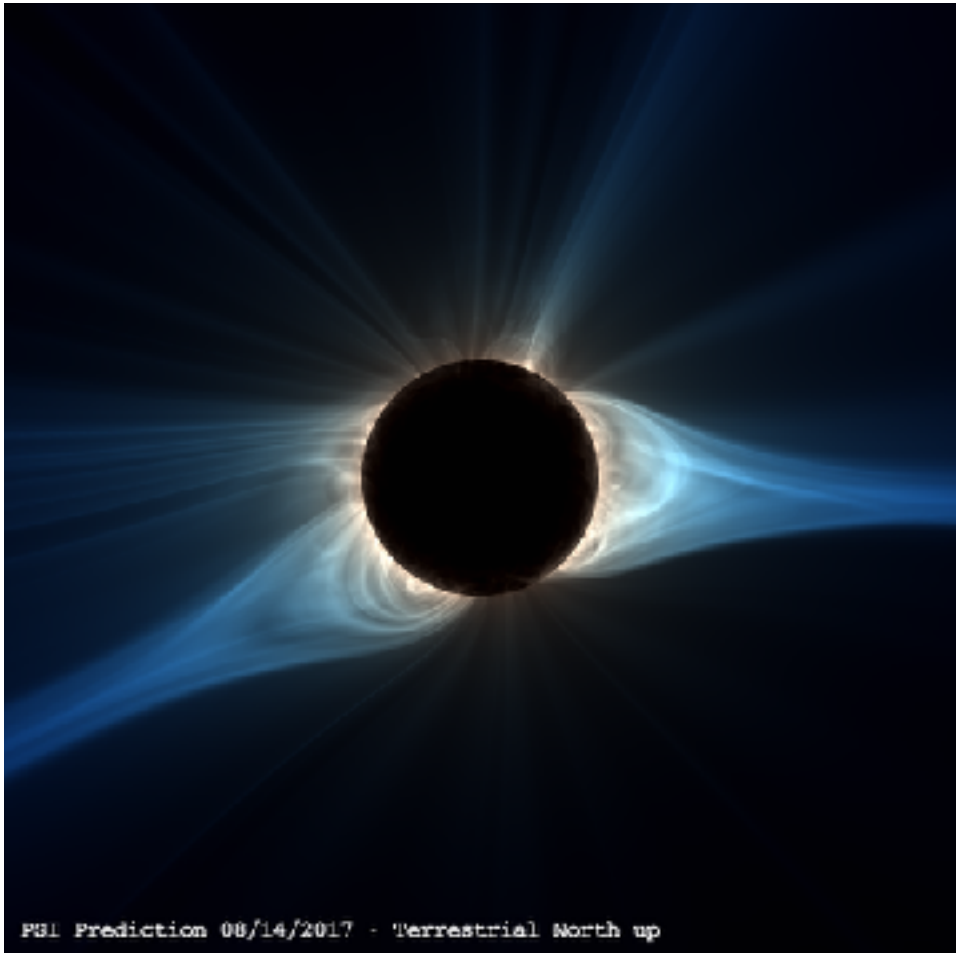


Predictive Science, Inc.
courtesy of Connor Down, Zoran Mikic, John Linker, et al.



Our observations (left); Predictive Science prediction (right)



Our coronal oscillation experiment joint with M. J. Person (MIT)

science goal: distinguishing among predictions of coronal heating theories

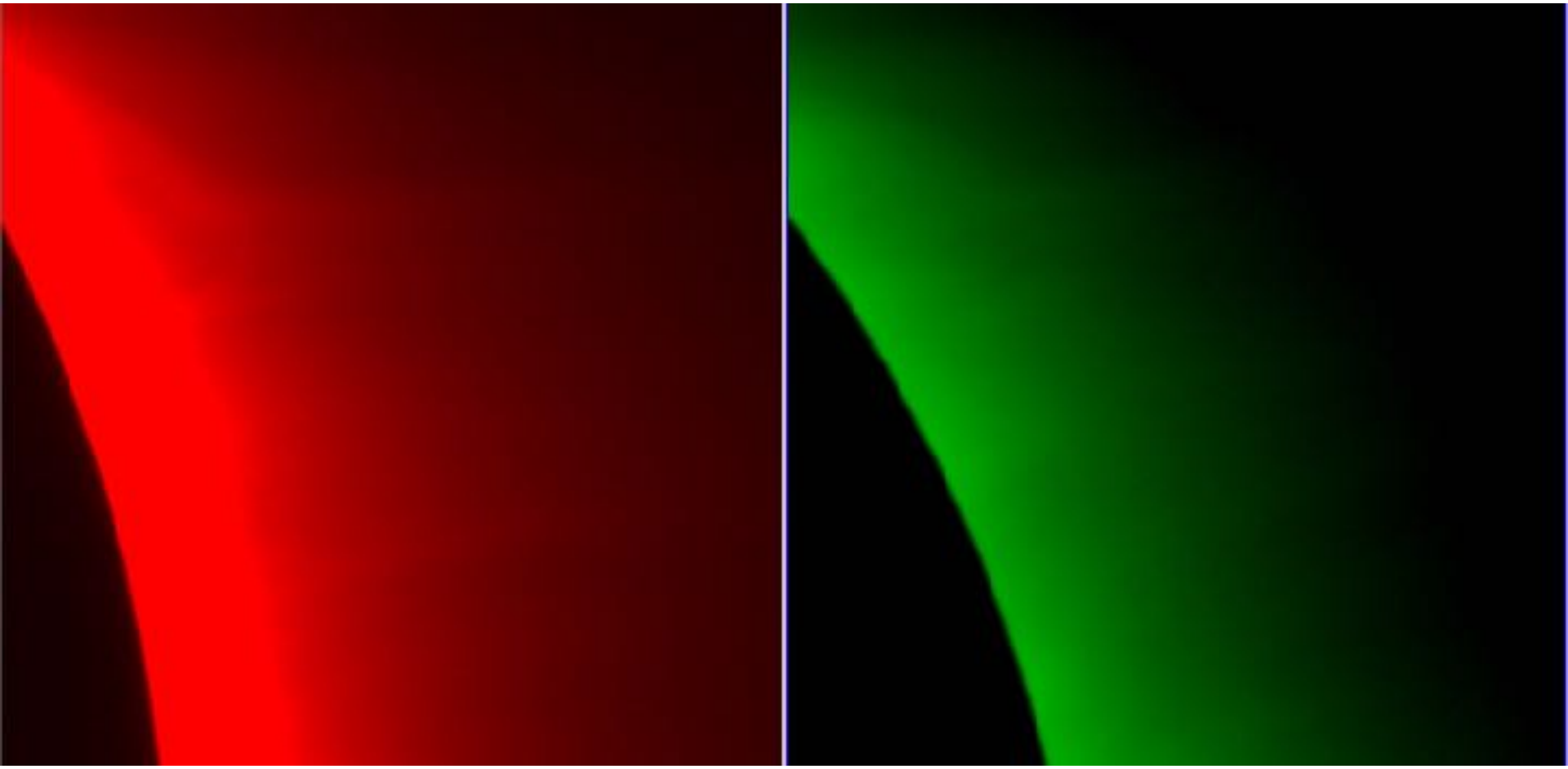
Measuring the power spectrum of oscillations in the coronal red (5303 Å=[Fe XIV]) and green (6374 Å=Fe X]), as well as a continuum channel.

The data were taken at 3 Hz using our POETS: Portable Occultation, Eclipse, and Transit Systems (NASA instrumentation grant from 2004); next observation: a 12th mag star by Triton on October 4

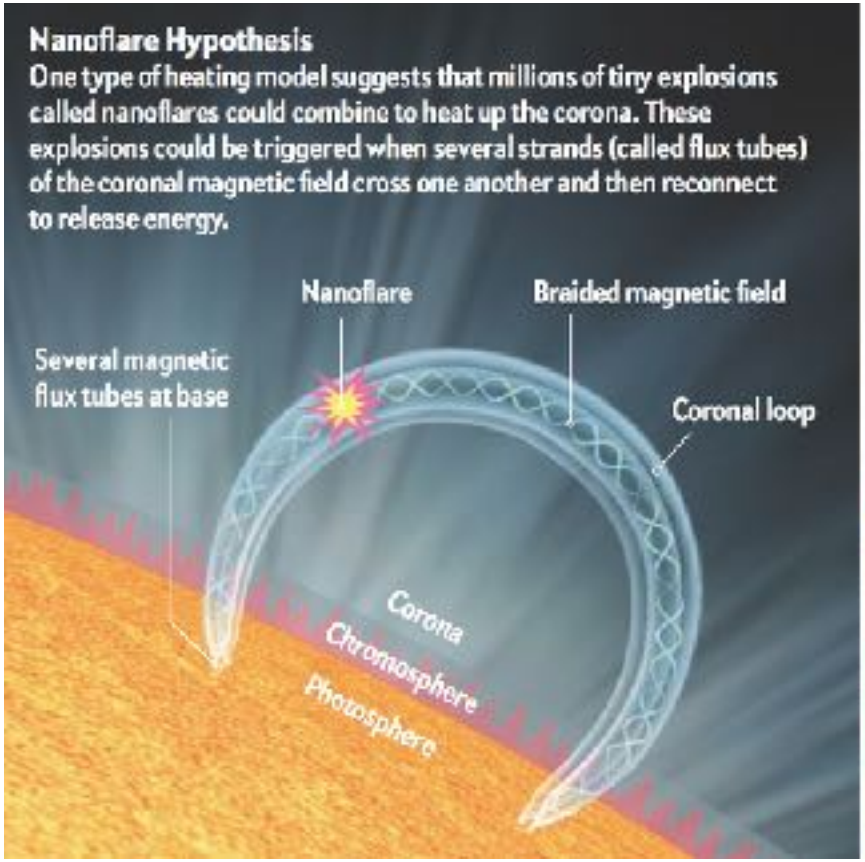
We used twin 8” carbon-fiber (to minimize the focus change in the eclipse’s atmospheric cooling) telescopes and a Losmandy mount (thanks to N. Liepins, Willamette U, and Michael Taylor, Williams College Science Shop)

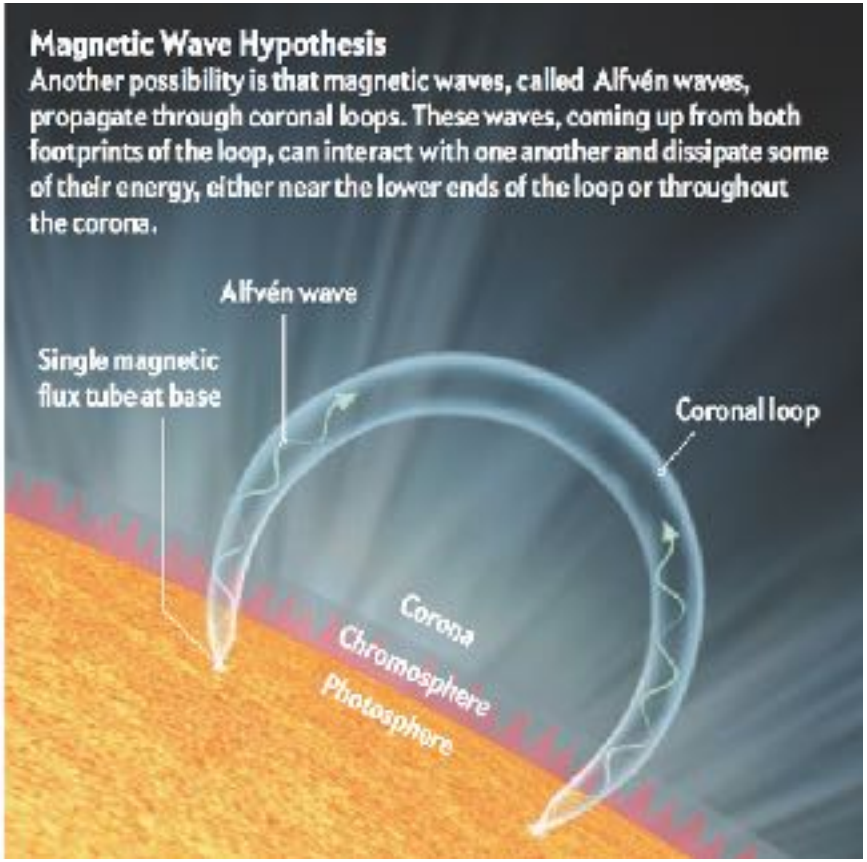
3 Hz, coronal red and green lines (3 Å filters)

Obviously: movies and analysis to come



From ”The Great American Eclipse of 2017”
by Jay Pasachoff, *Scientific American*, August 2017

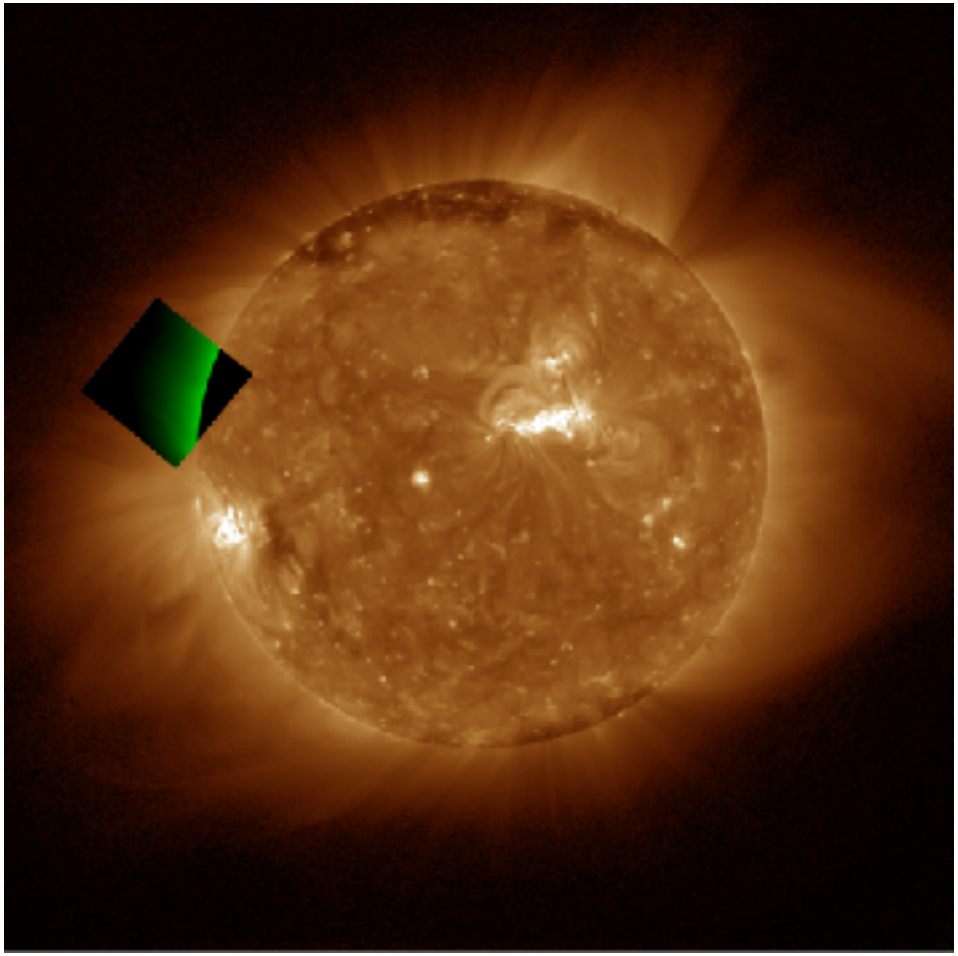




Composites with SUVI (Solar Ultraviolet Imager) on GOES-16

center: SUVI (Dan Seaton, NOAA/CIRES-UColorado)

eclipse: Pasachoff/Person(MIT)/NSF/NGS

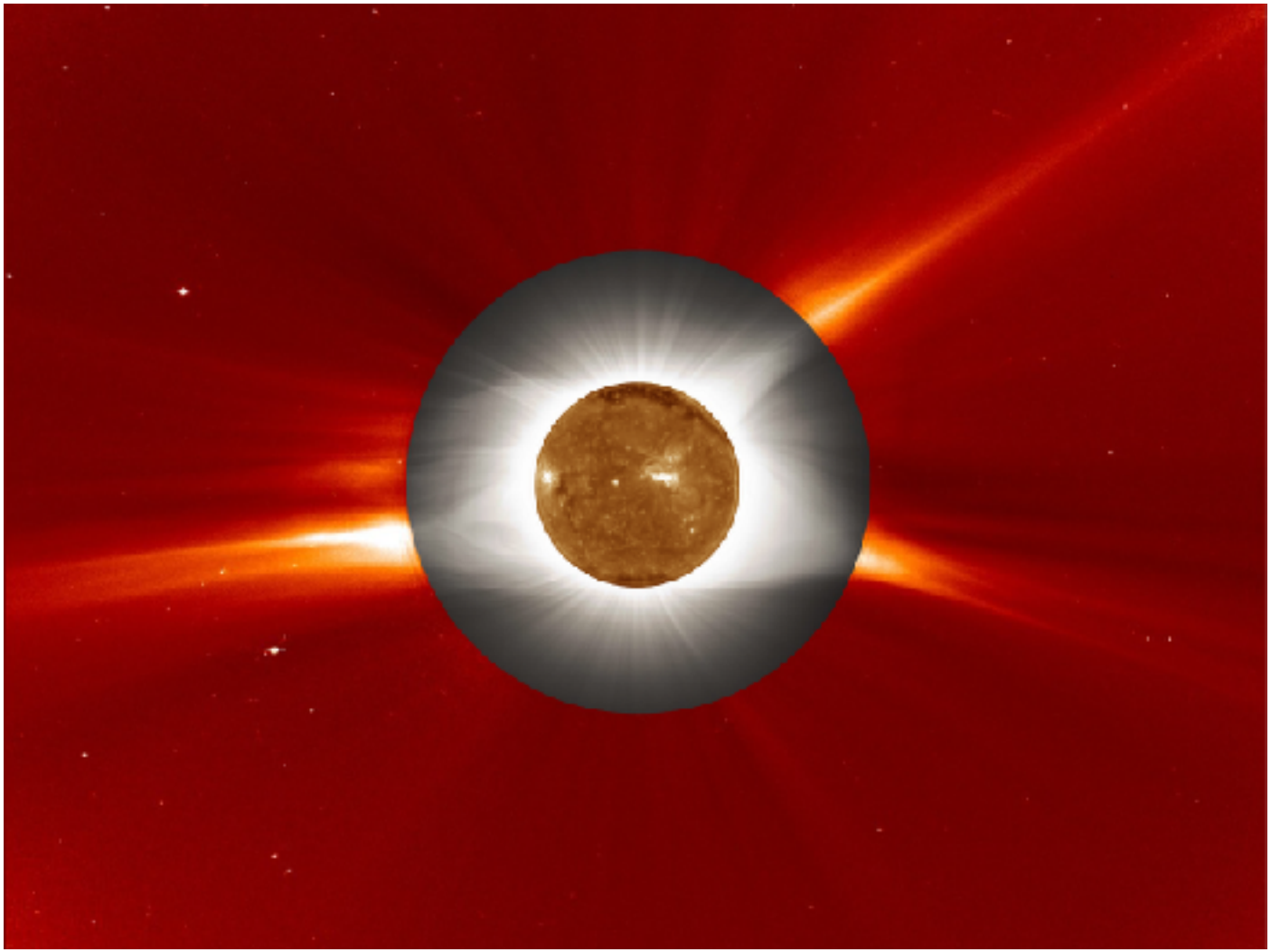


Composites with SUVI (Solar Ultraviolet Imager) on GOES-16

center: SUVI (Dan Seaton, NOAA/CIRES-UColorado), 195 Å

eclipse: Pasachoff/Dantowitz/NSF/NGS

outer: Outer: LASCO/NASA/NRL/SoHO:ESA

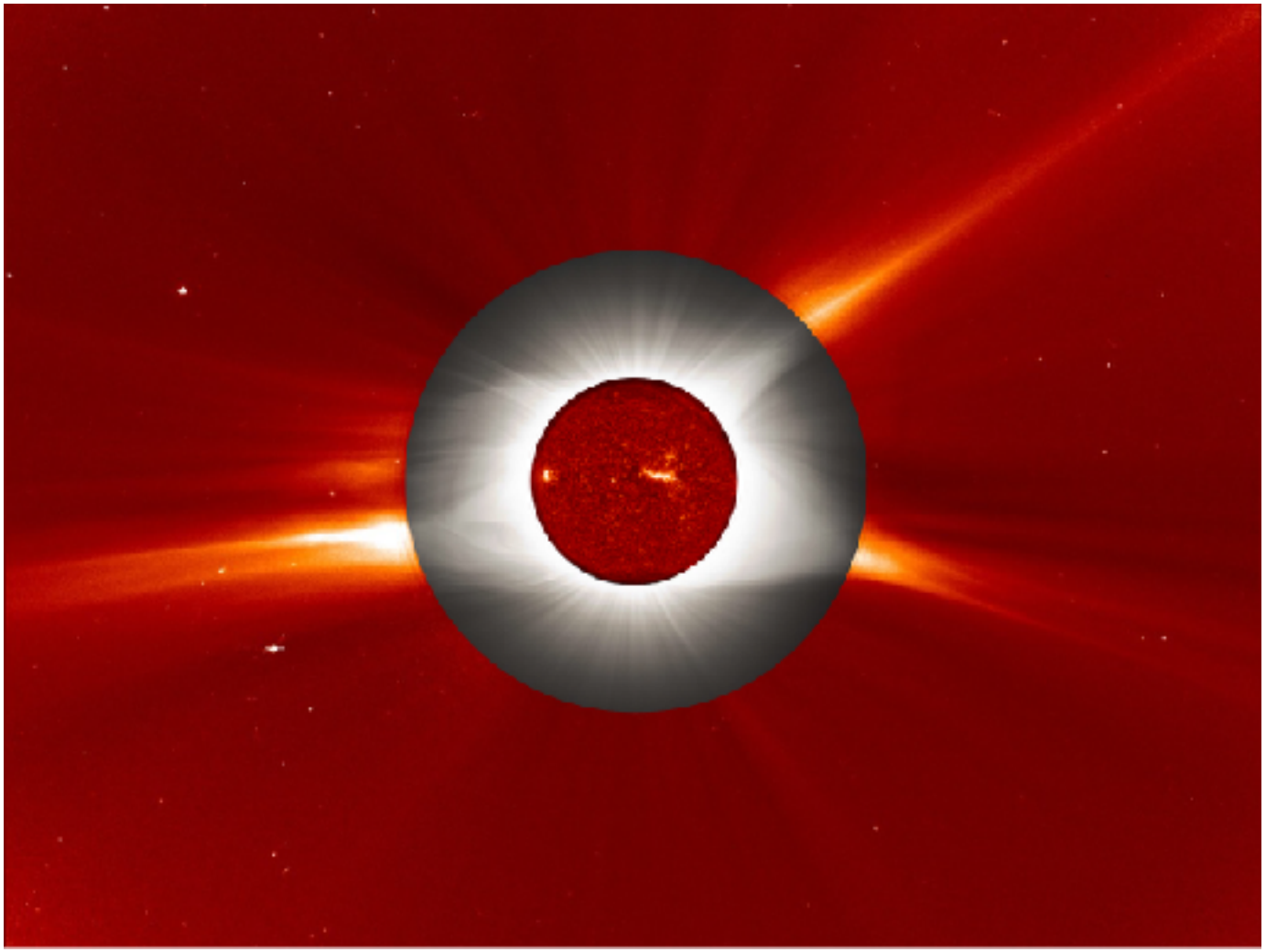


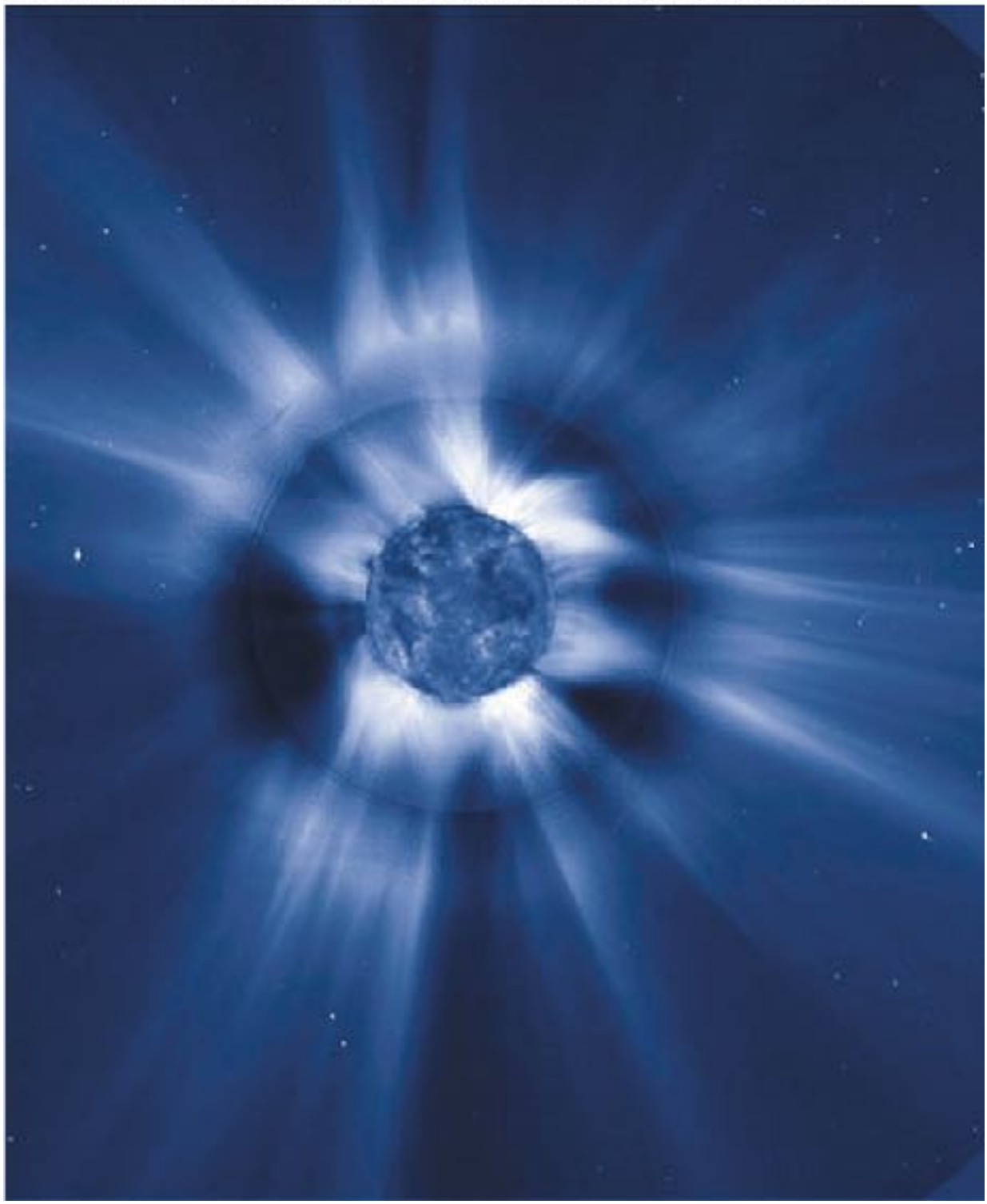
Composites with SUVI (Solar Ultraviolet Imager) on GOES-16

center: SUVI (Dan Seaton, NOAA/CIRES-UColorado), He 304 Å

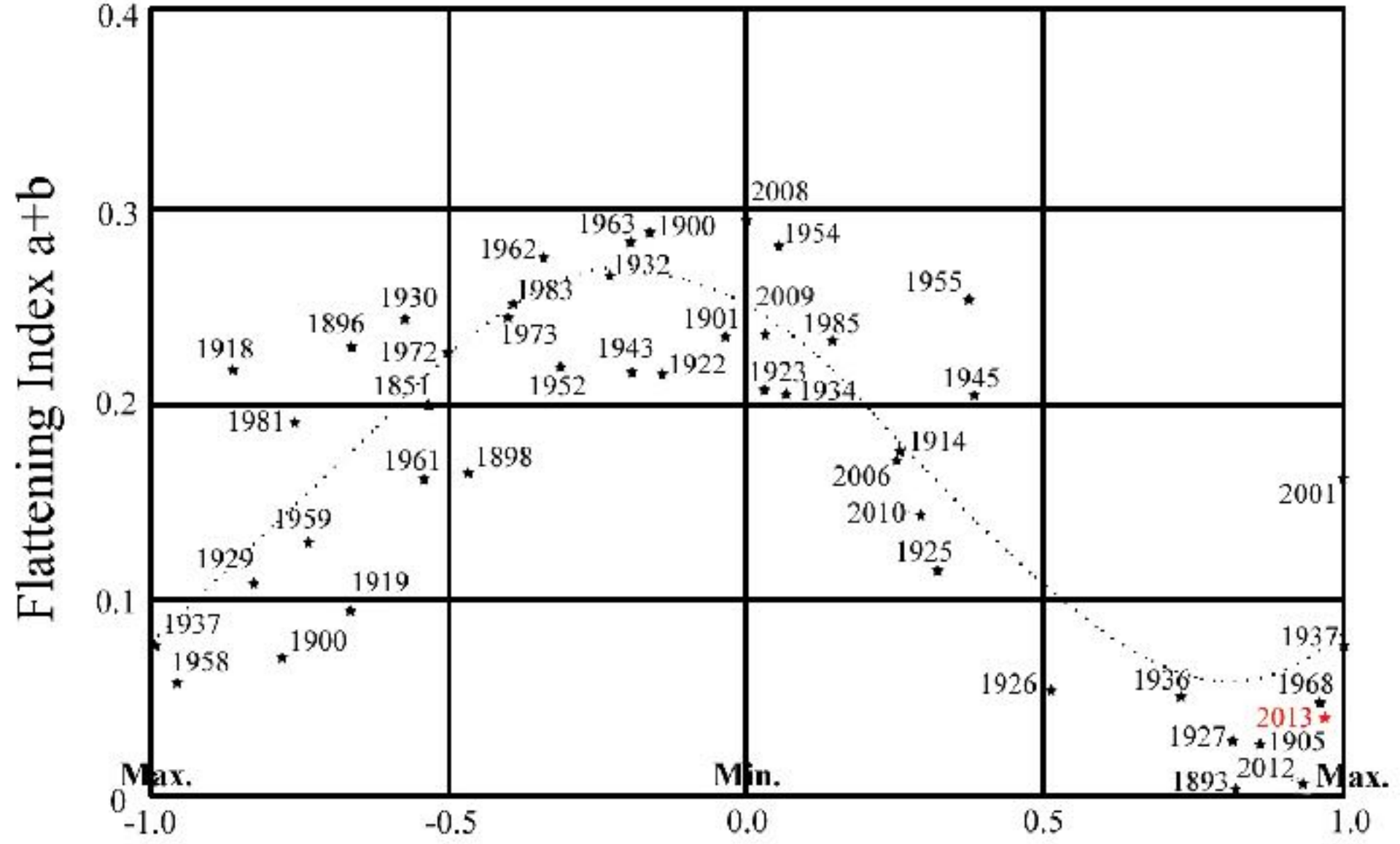
eclipse: Pasachoff/Dantowitz/NSF/NGS

outer: Outer: LASCO/NASA/NRL/SoHO:ESA





The 1999 solar eclipse composite at solar maximum


Flattening Index a+b
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0.3
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0.1
0
-1.0
-0.5
0.0
0.5
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Max.
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2008
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1962
1954
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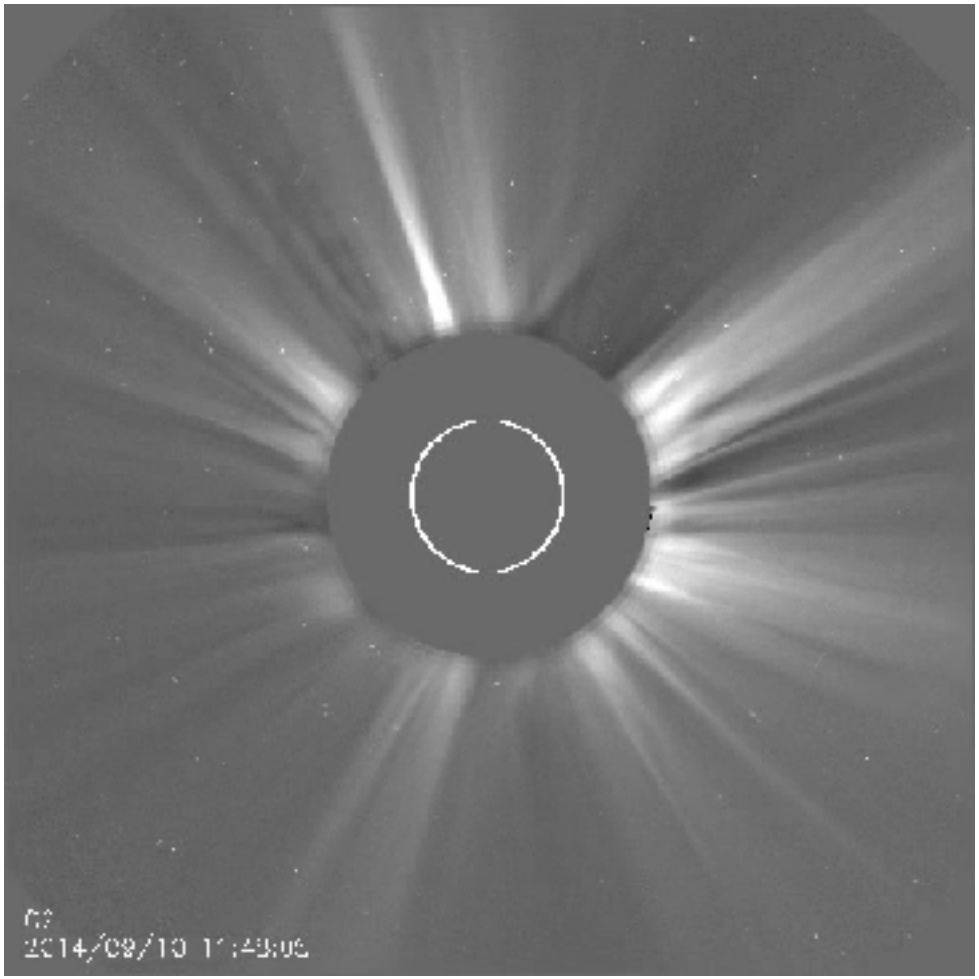
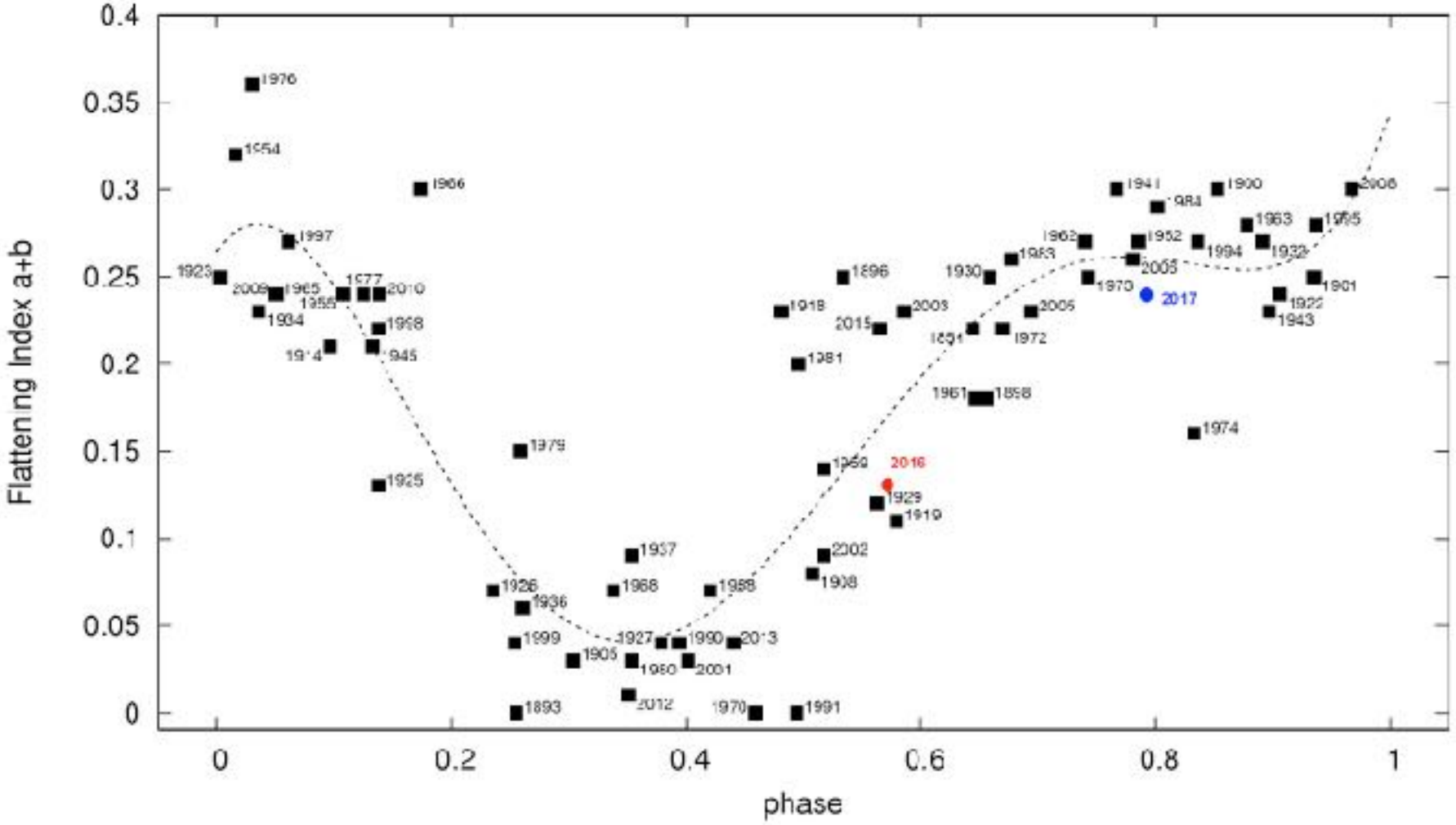
1905
1893
2012

Naval Research Laboratory
C2 coronagraph on SoHO (Russ Howard)



10 September 2014 coronal mass ejection


Flattening Index a+b
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0.3
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0.2
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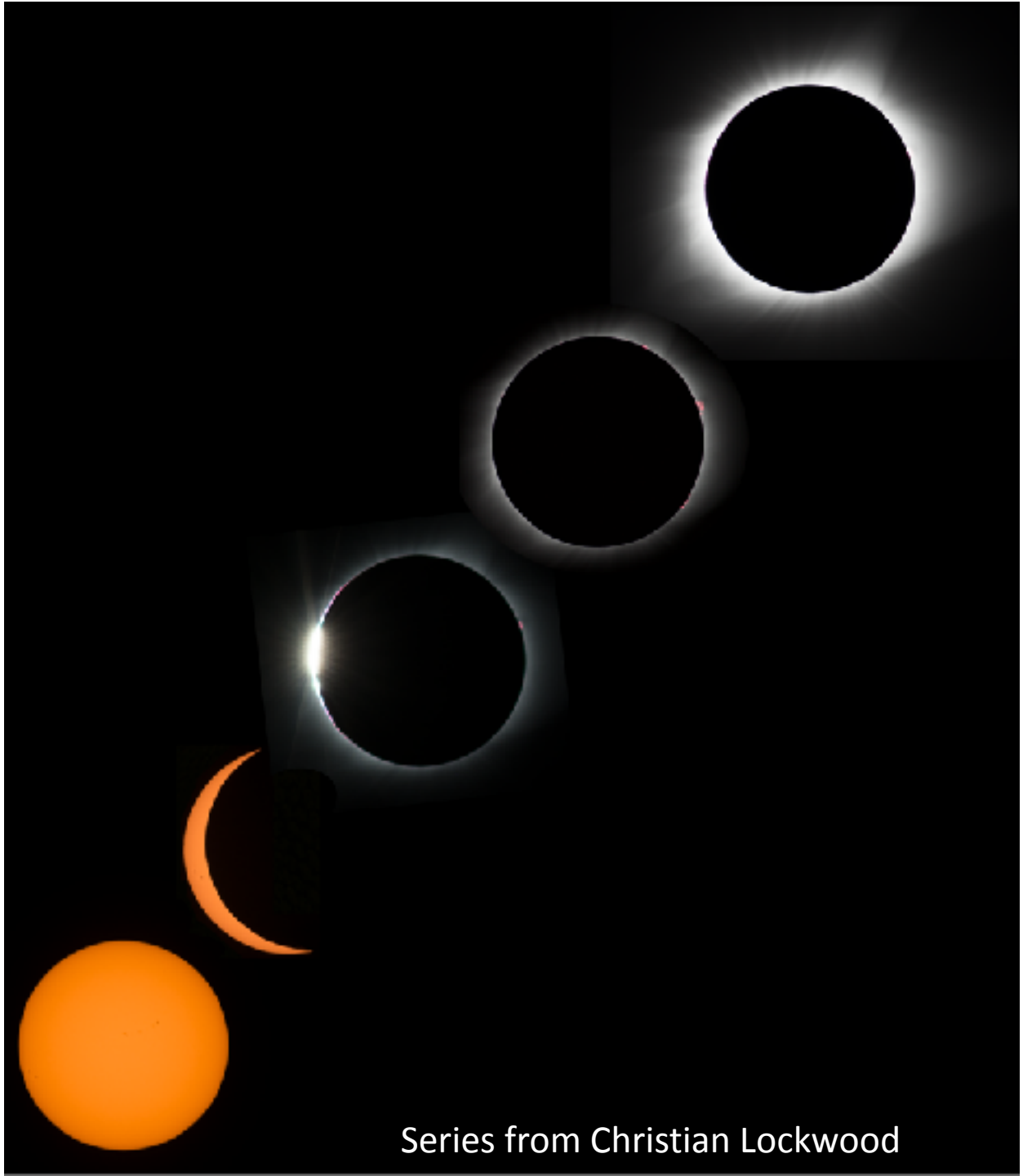
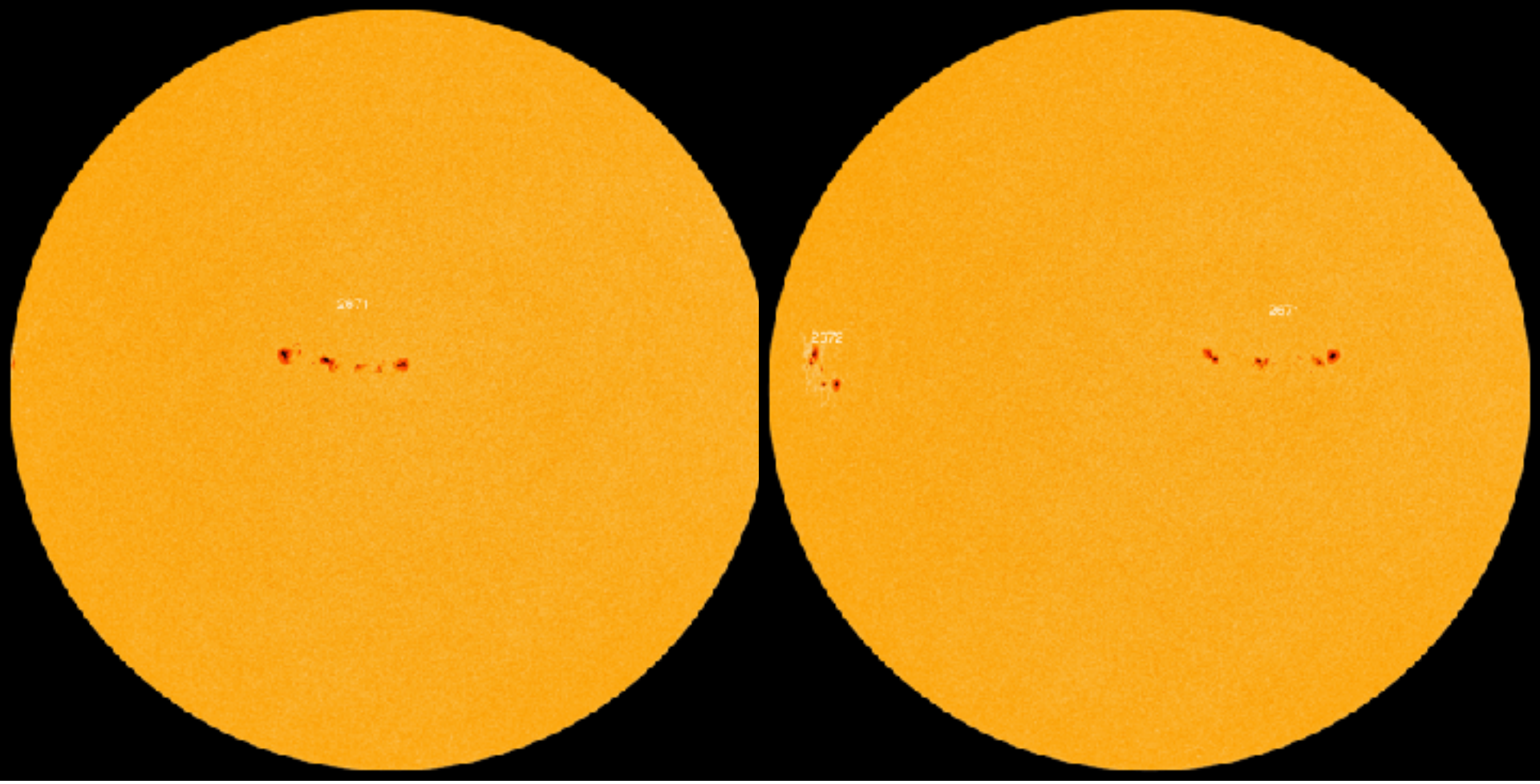
0.1
0.05
0
0
0.2
0.4
0.6
0.8
1
2016
2017



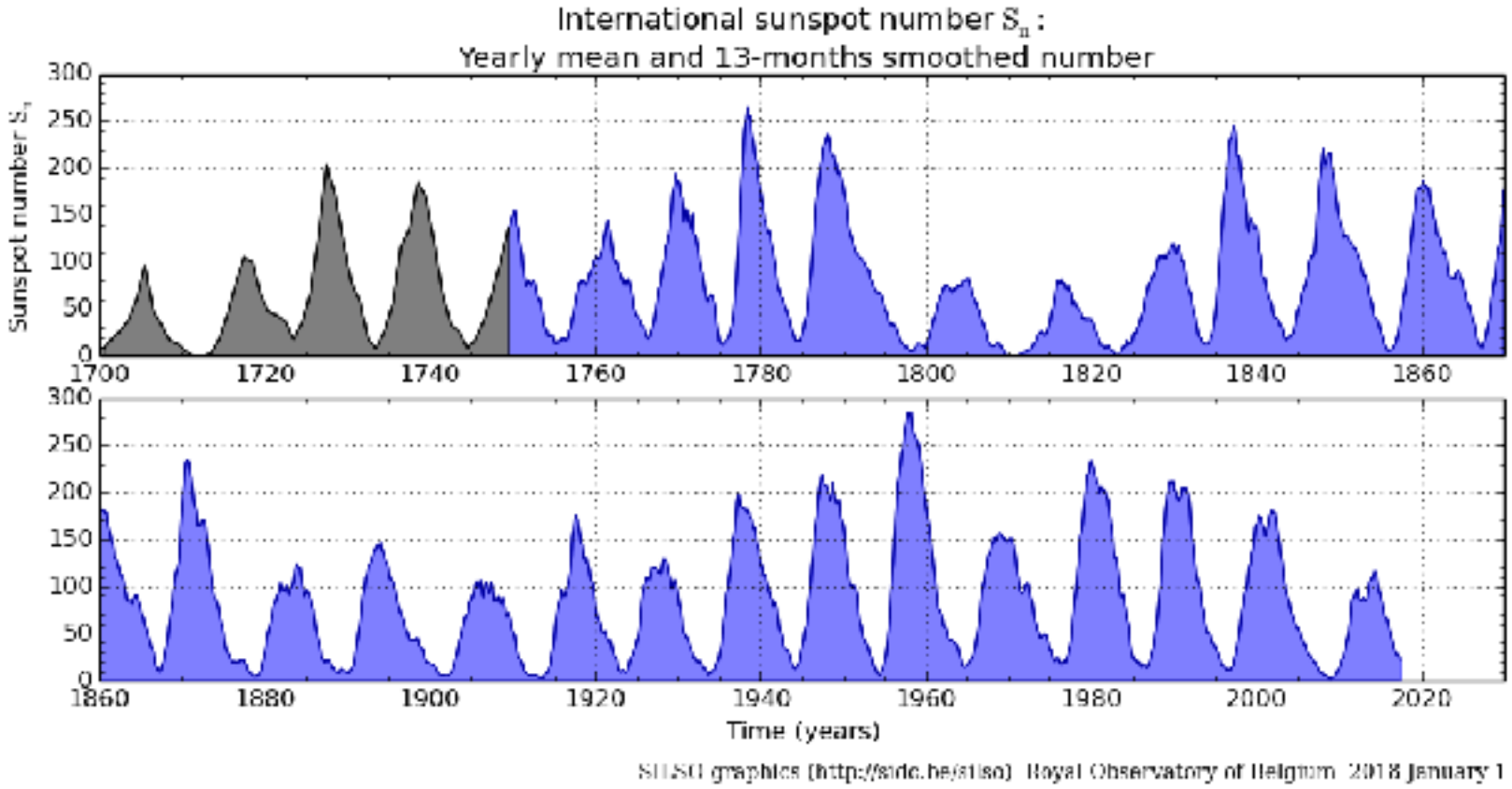
Series from Christian Lockwood

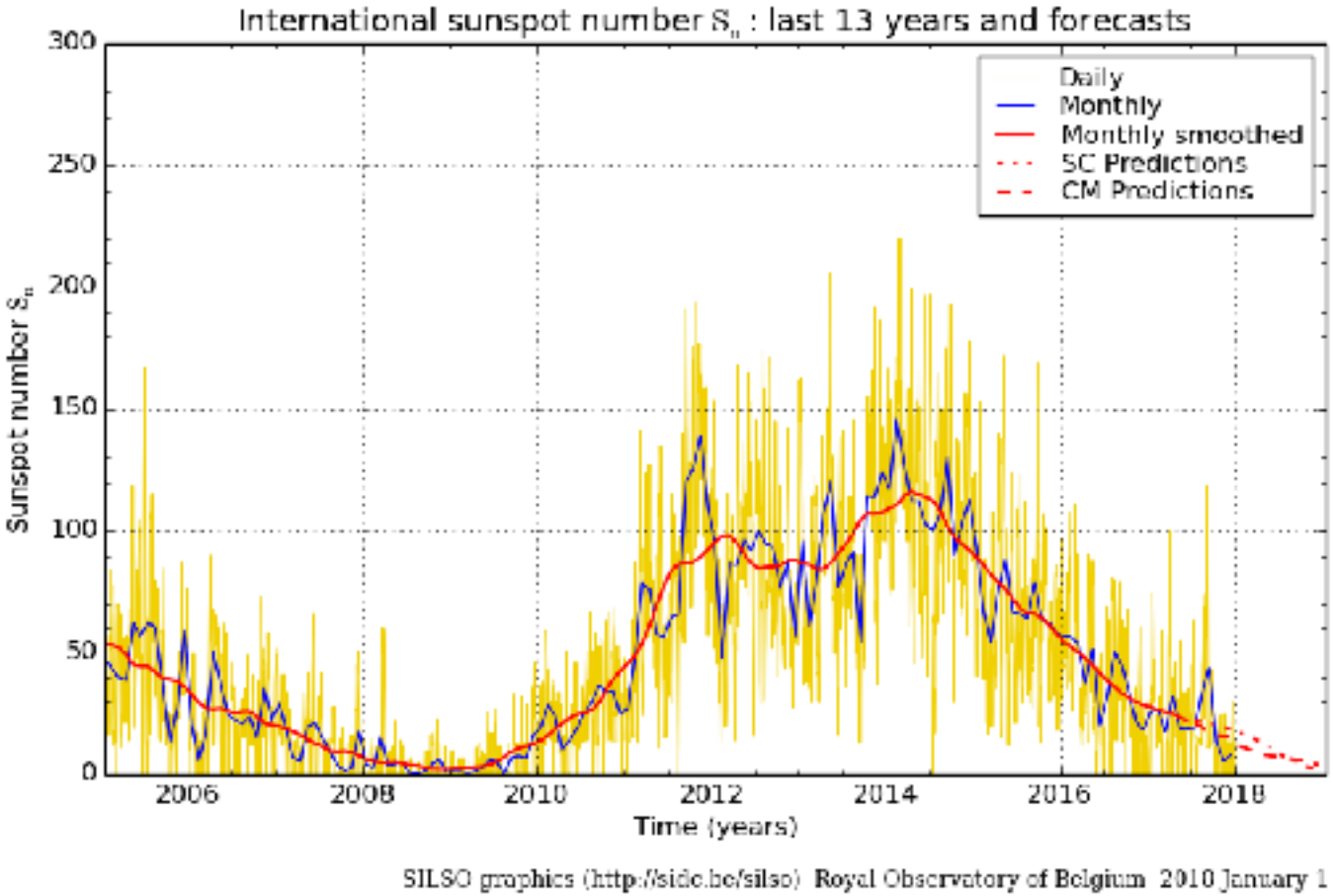


August 21

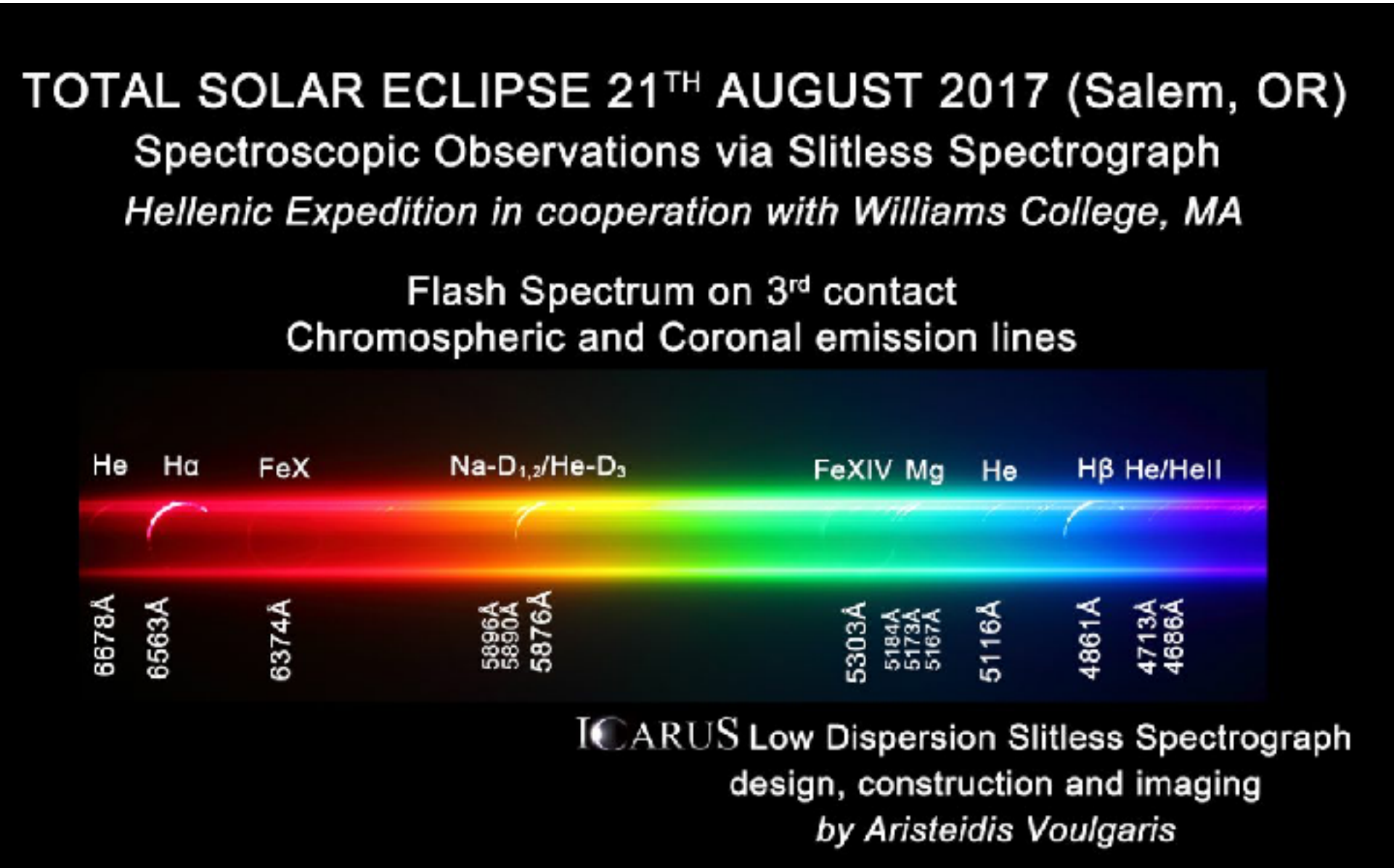
August 22

NASA's SDO/HMI

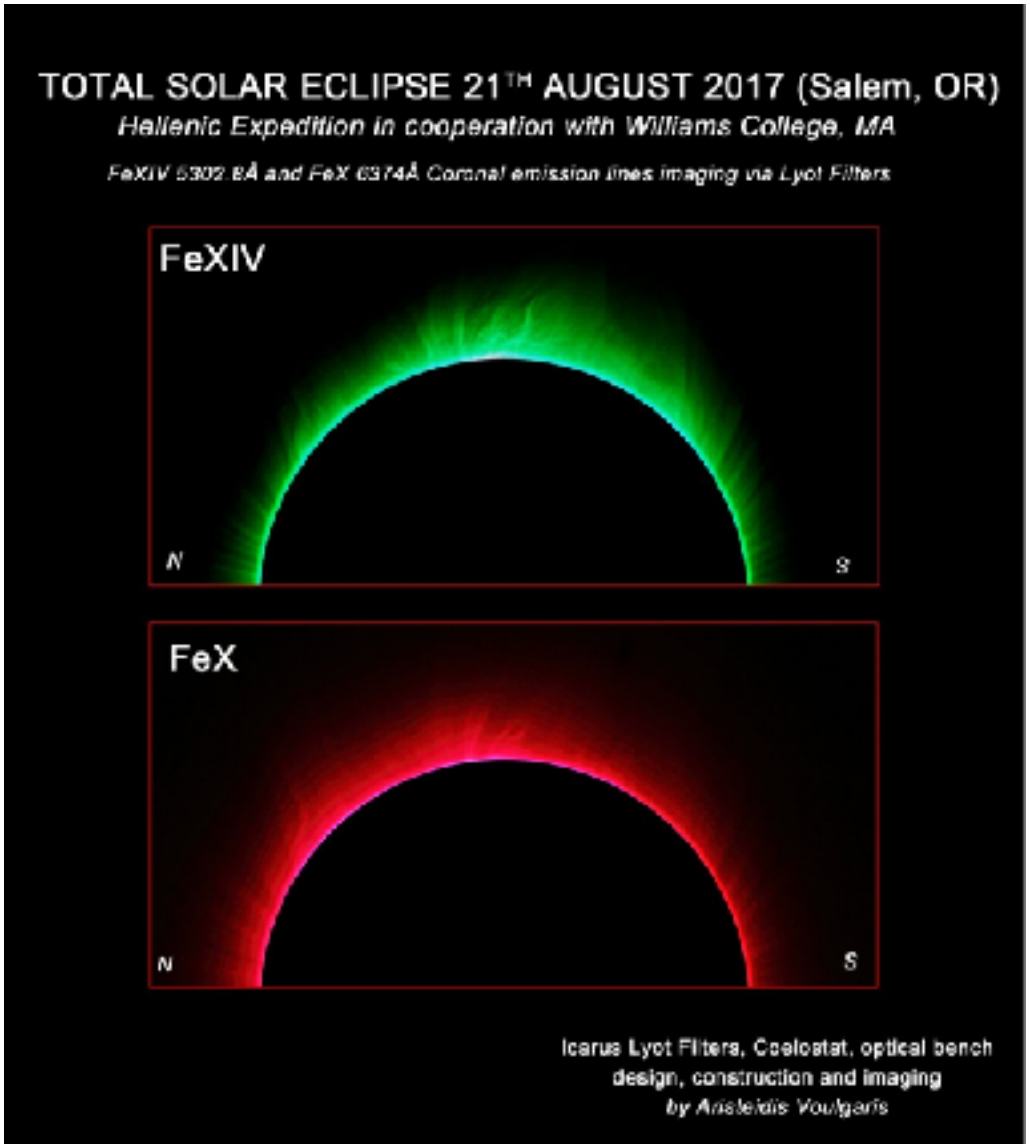

International sunspot number S_n :
Yearly mean and 13-months smoothed number
Sunspot number S_n
300
250
200
150
100
50
0
1700
1720
1740
1760
1780
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
Time (years)
SILSO graphics (http://sidc.be/silso) Royal Observatory of Belgium 2018 January 1

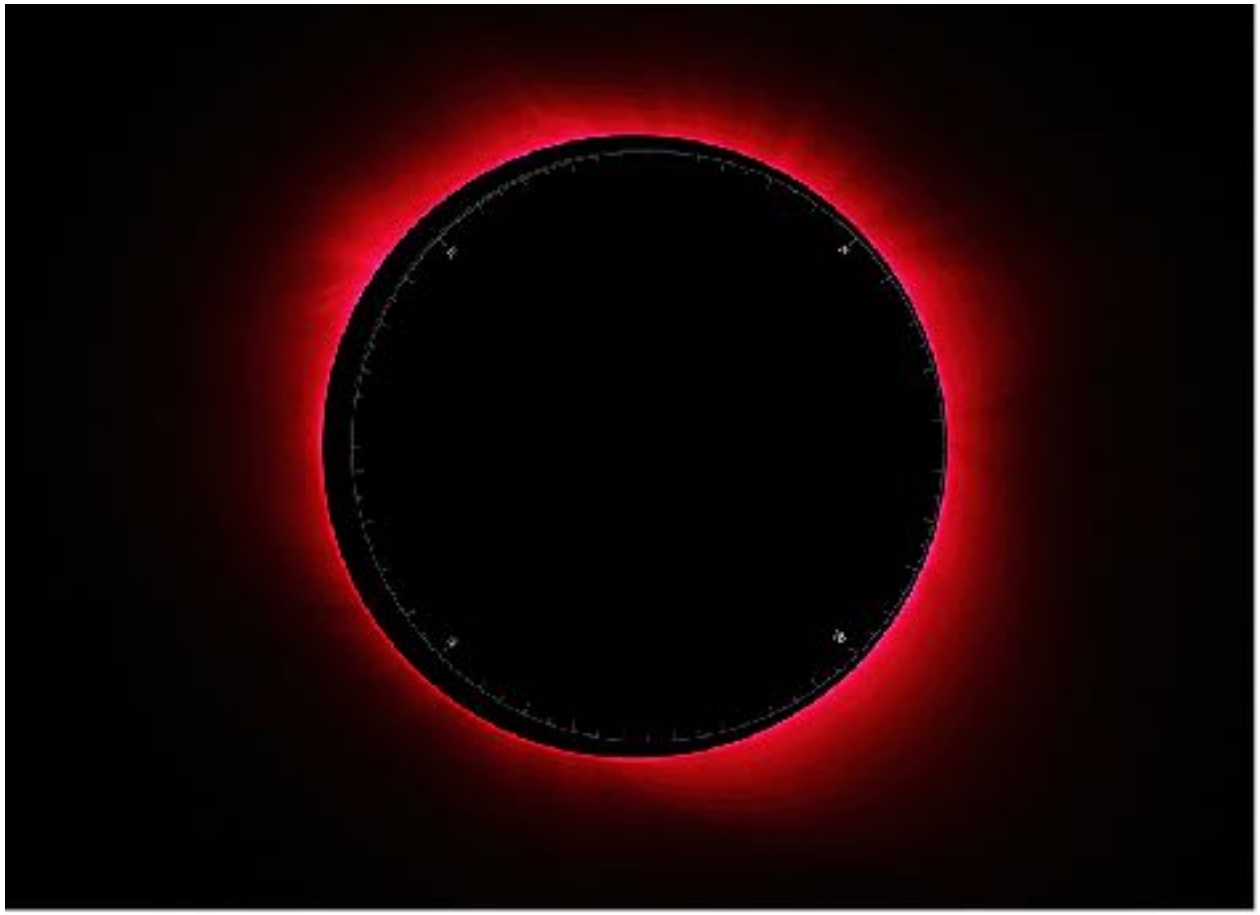

International sunspot number S_n : last 13 years and forecasts
Daily
Monthly
Monthly smoothed
SC Predictions
CM Predictions
Sunspot number S_n
300
250
200
150
100
50
0
2006
2008
2010
2012
2014
2016
2018
Time (years)
SILSO graphics (http://sidc.be/silso) Royal Observatory of Belgium 2010 January 1

Aris Voulgaris, as part of the Williams College Expedition

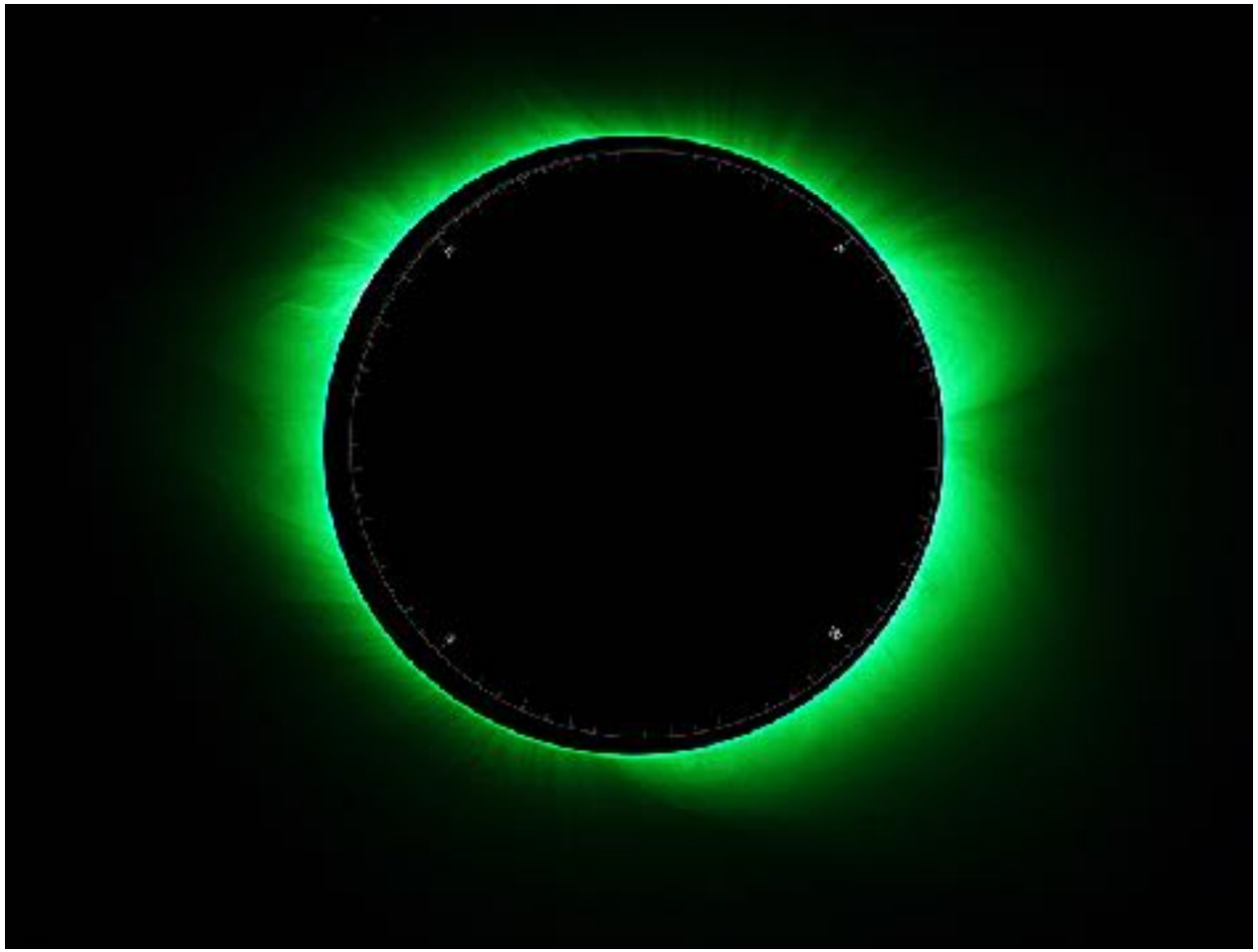


Aris Voulgaris, as part of the Williams College Expedition

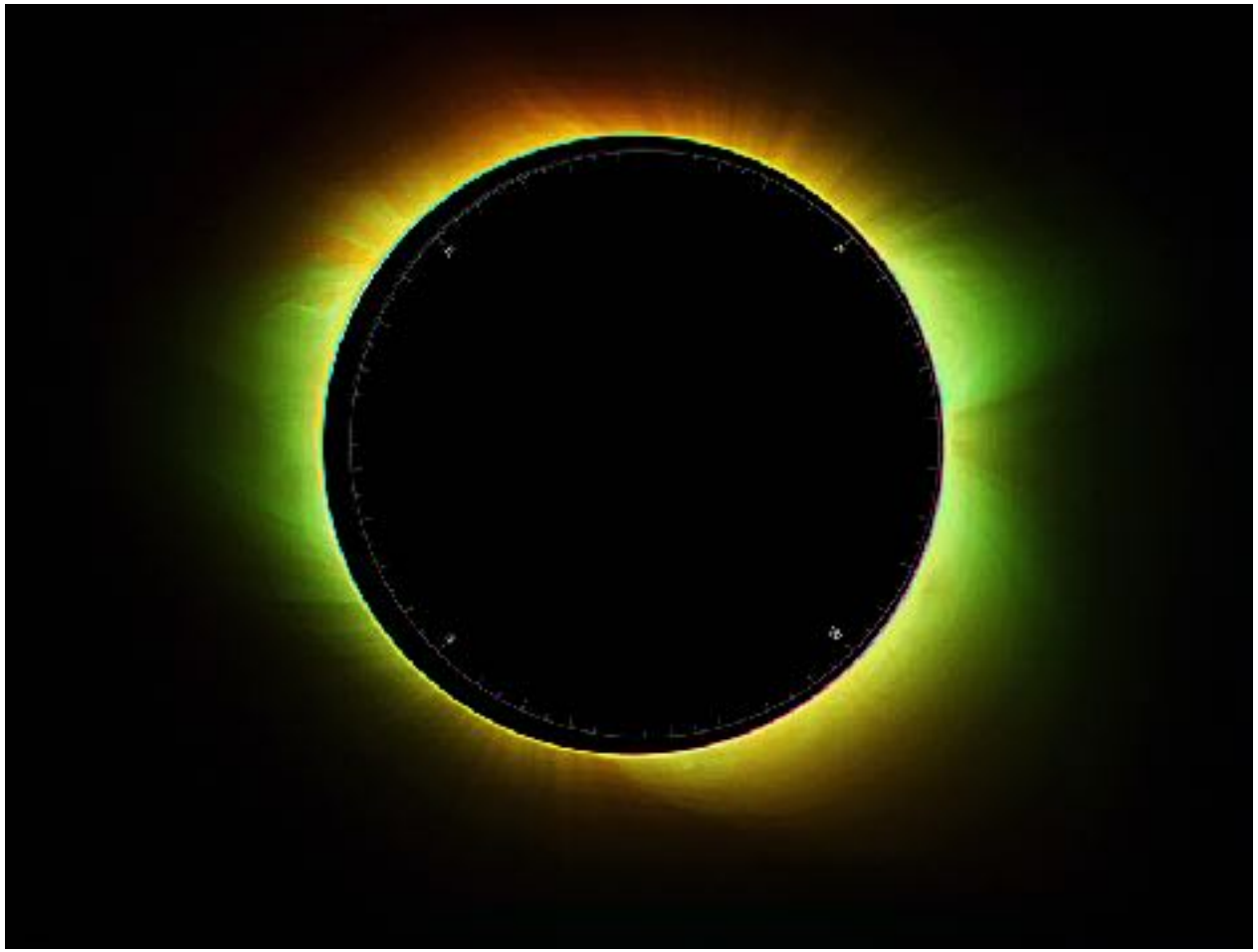




Computer analysis by Tim Nagle-McNaughton ‘18

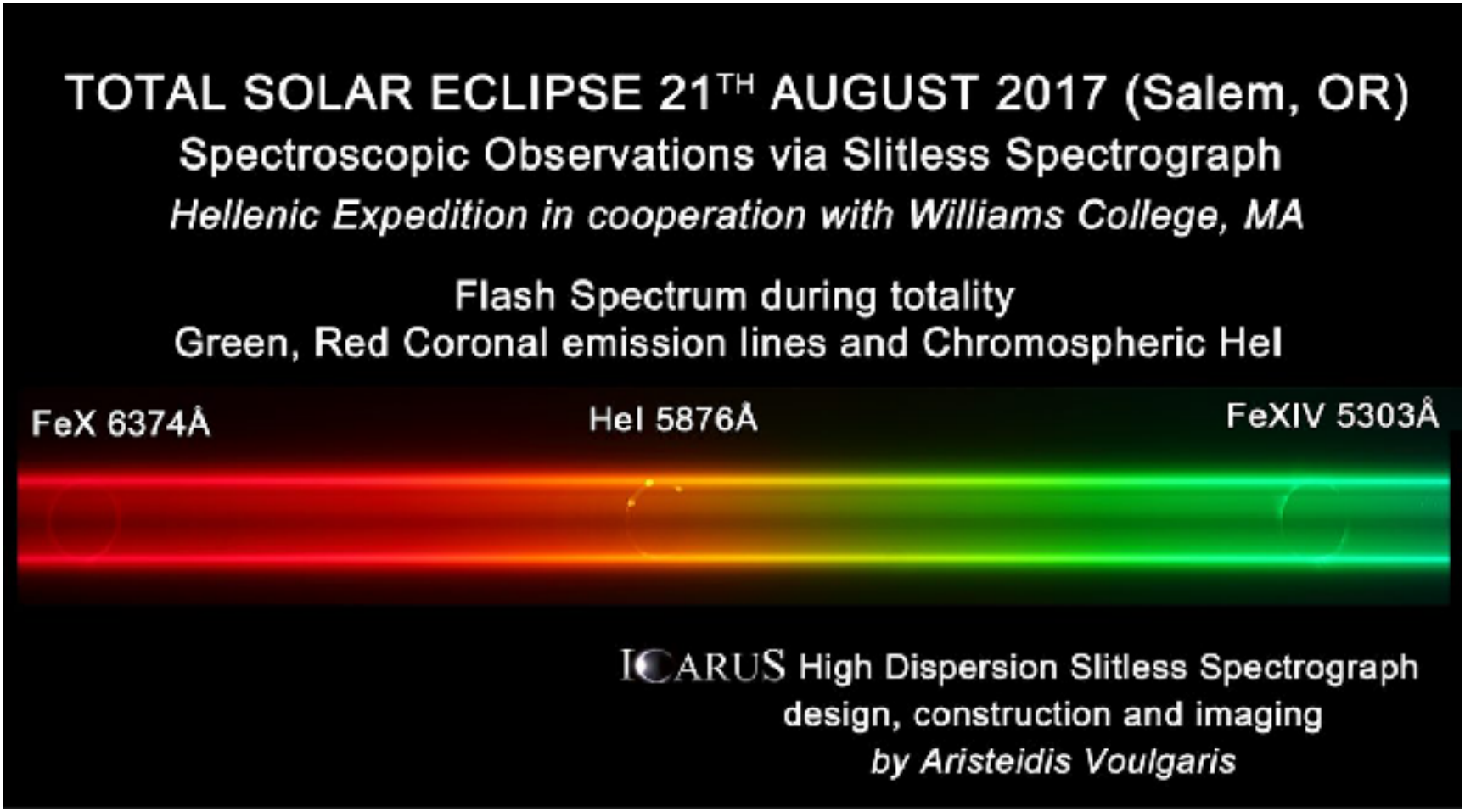


Computer analysis by Tim Nagle-McNaughton ‘18



Computer analysis by Tim Nagle-McNaughton ‘18

Aris Voulgaris, as part of the Williams College Expedition

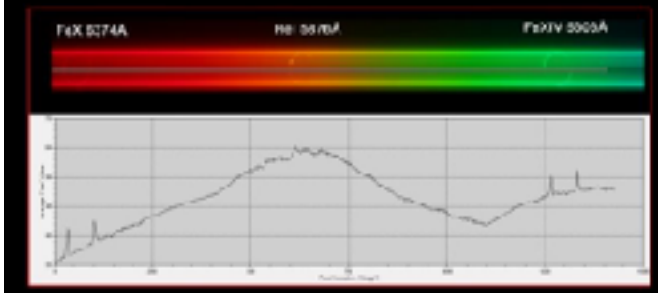


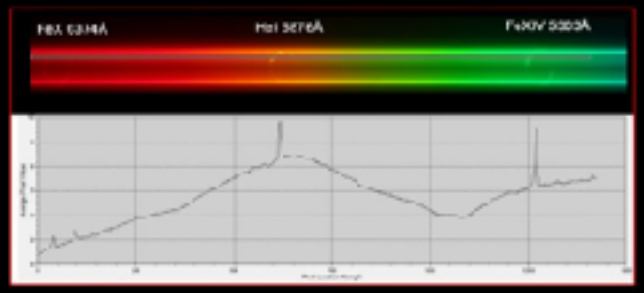
TOTAL SOLAR ECLIPSE 21TH AUGUST 2017 (Salem, OR)

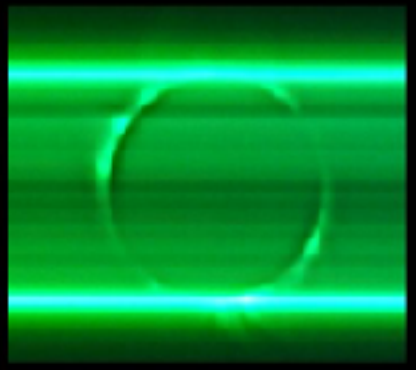
Spectroscopic Observations via Slitless Spectrograph in Green and Coronal lines

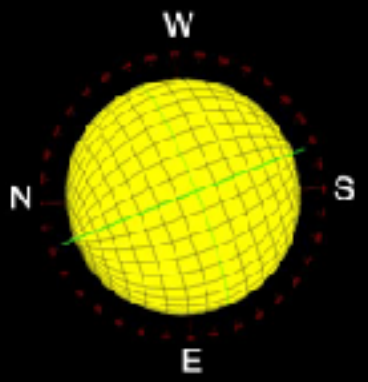
Hellenic Expedition in cooperation with Williams College, MA

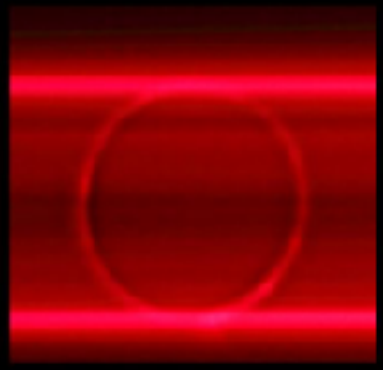
Flash Spectrum during totality
Green and Red Coronal emission lines



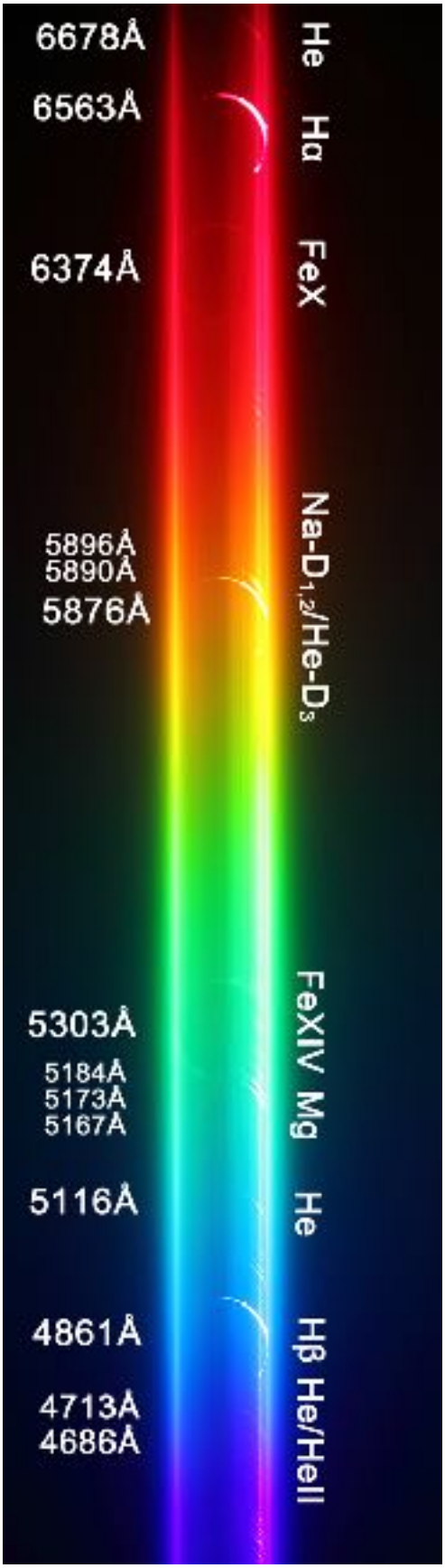


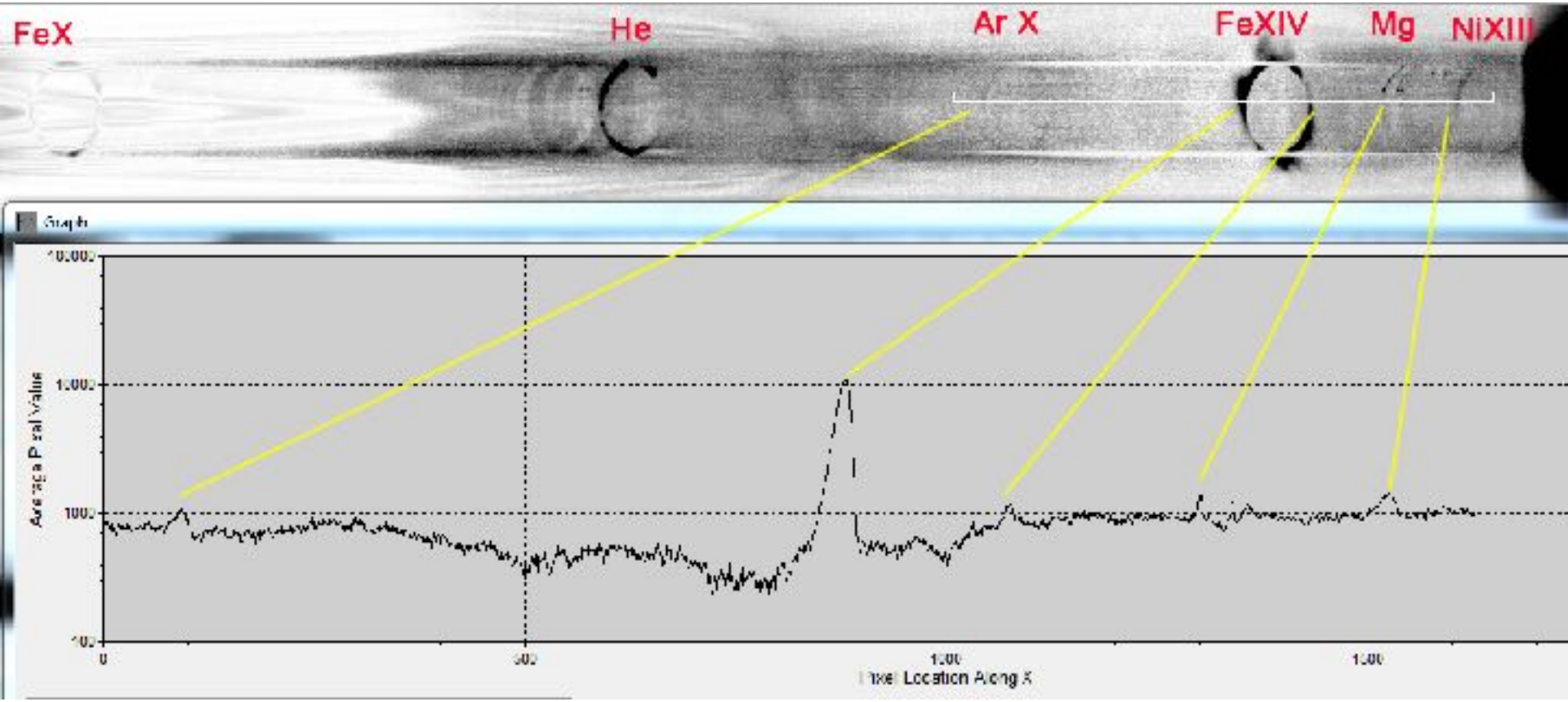


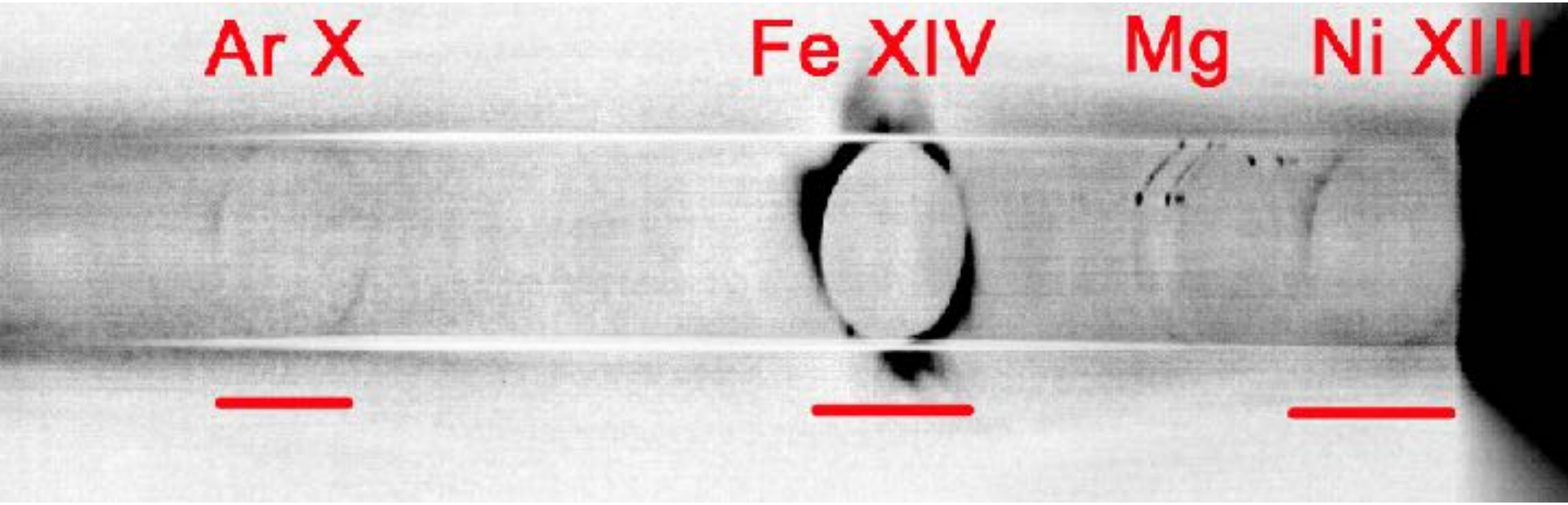


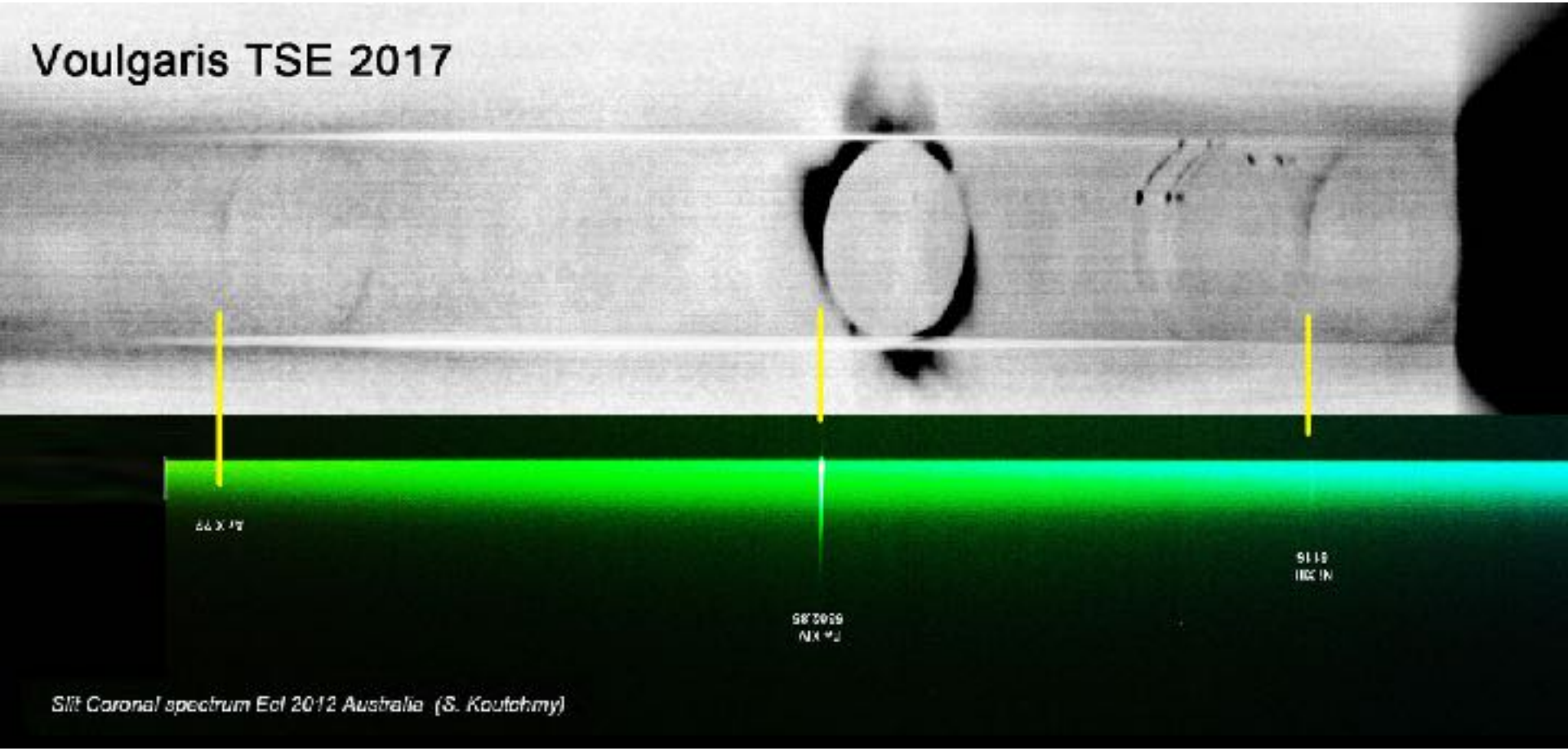


ICARUS High Resolution Slitless Spectrograph
design, construction and imaging
by Aristeidis Voulgaris


6678Å
6563Å
6374Å
5896Å
5890Å
5876Å
5303Å
5184Å
5173Å
5167Å
5116Å
4861Å
4713Å
4686Å
He
Hα
FeX
Na-D1,2/He-D3
FeXIV Mg
He
Hβ He/HeII


FeX
He
Ar X
FeXIV
Mg
NiXIII
Graph
10,000
1,000
100
-100
Average Pixel Value
0
500
1,000
1,500
Pixel Location Along X

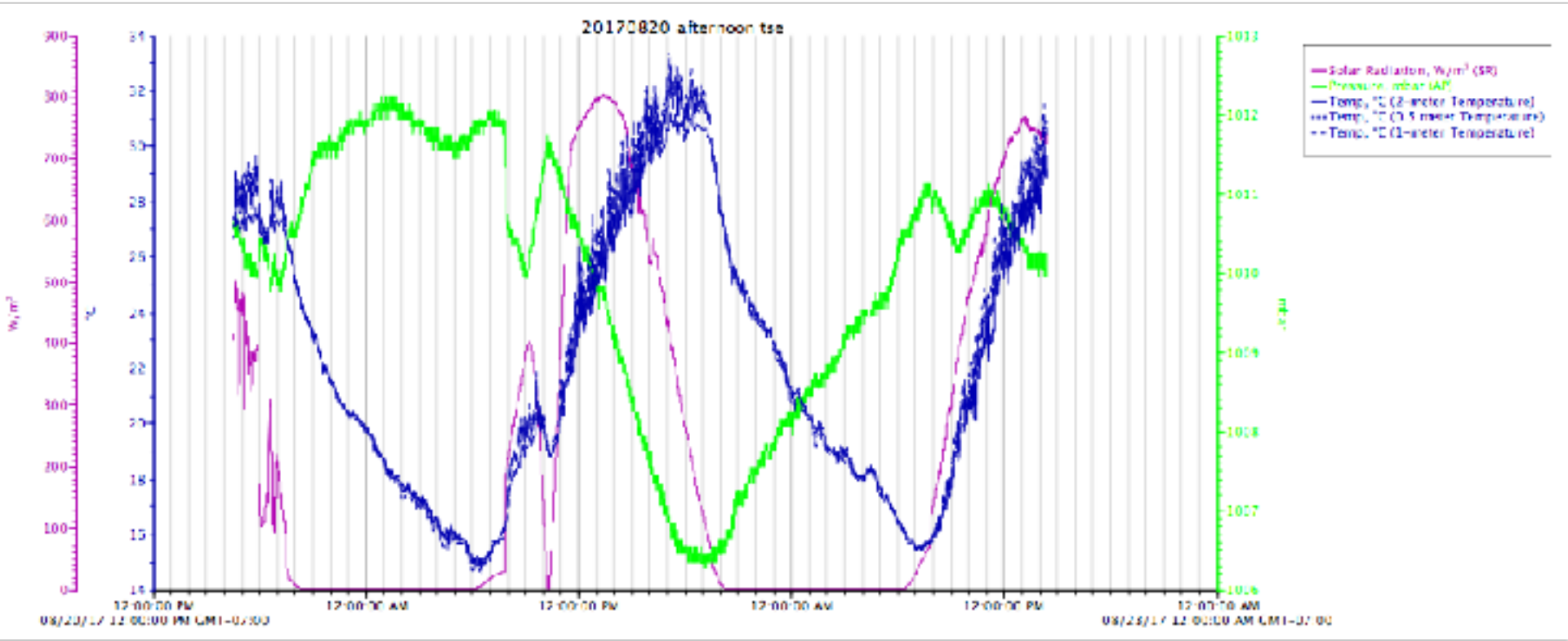

Ar X
Fe XIV
Mg
Ni XIII


Voulgaris TSE 2017
Slit Coronal spectrum Eclipse 2012 Australia (S. Koutchmy)

https://xkcd.com/1880/

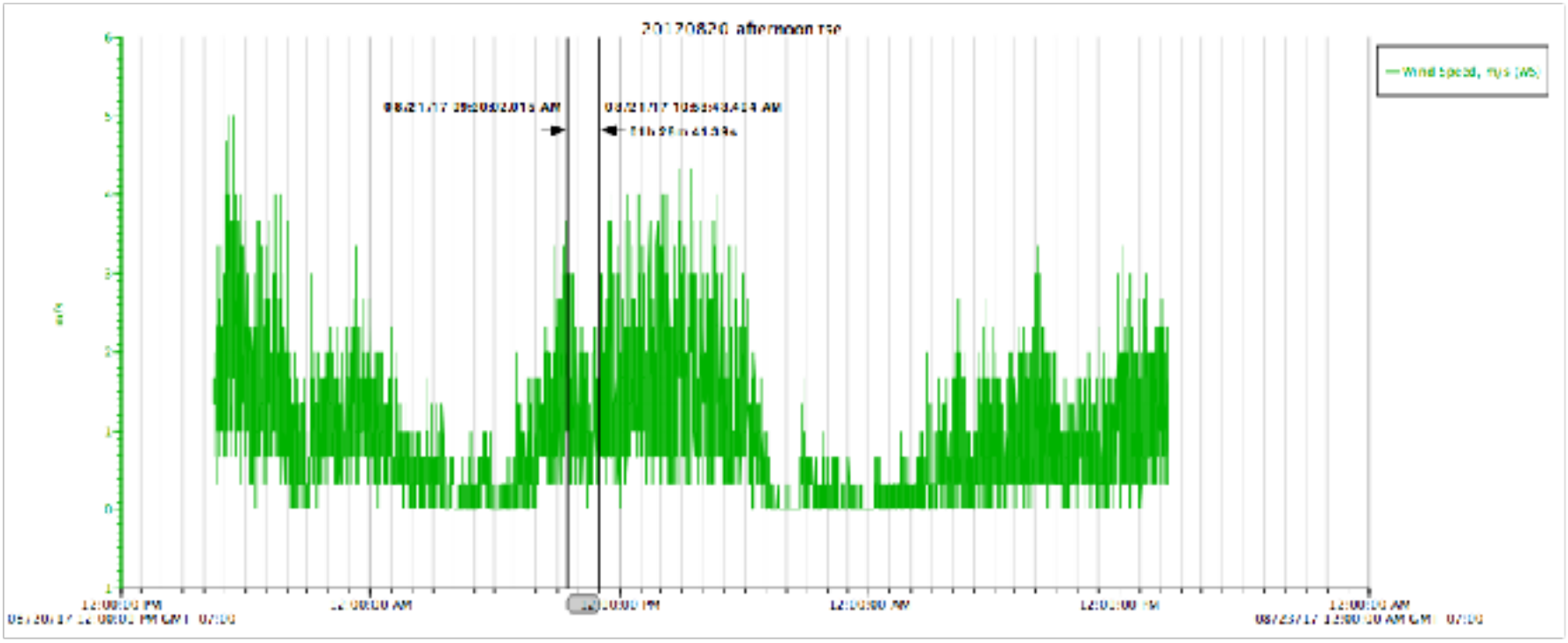
Terrestrial Atmosphere

Jay Pasachoff, Marcos Peñaloza-Murillo, Michael T Roman, Ross Yu, et al.

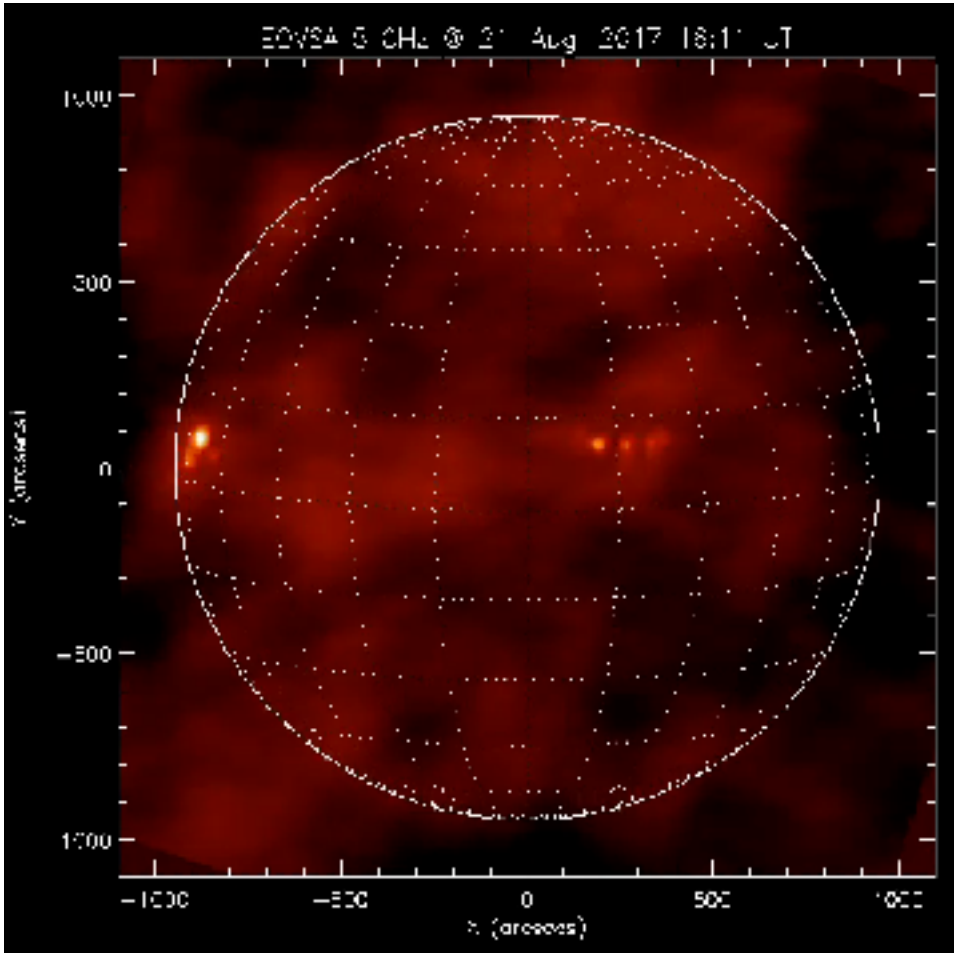


Terrestrial Atmosphere

Jay Pasachoff, Marcos Peñaloza-Murillo, Michael T Roman, Ross Yu, et al.



EOVSA: Expanded Owens Valley Solar Array



with Dale Gary, Bin Chen (NJIT) and Tim Bastian (NRAO); Natsuha Kuroda (NJIT)

EOVSA: Expanded Owens Valley Solar Array

cadence: 2 min; frequency synthesis ~3-8 GHz; 76% obscuration at 17:21 UTC

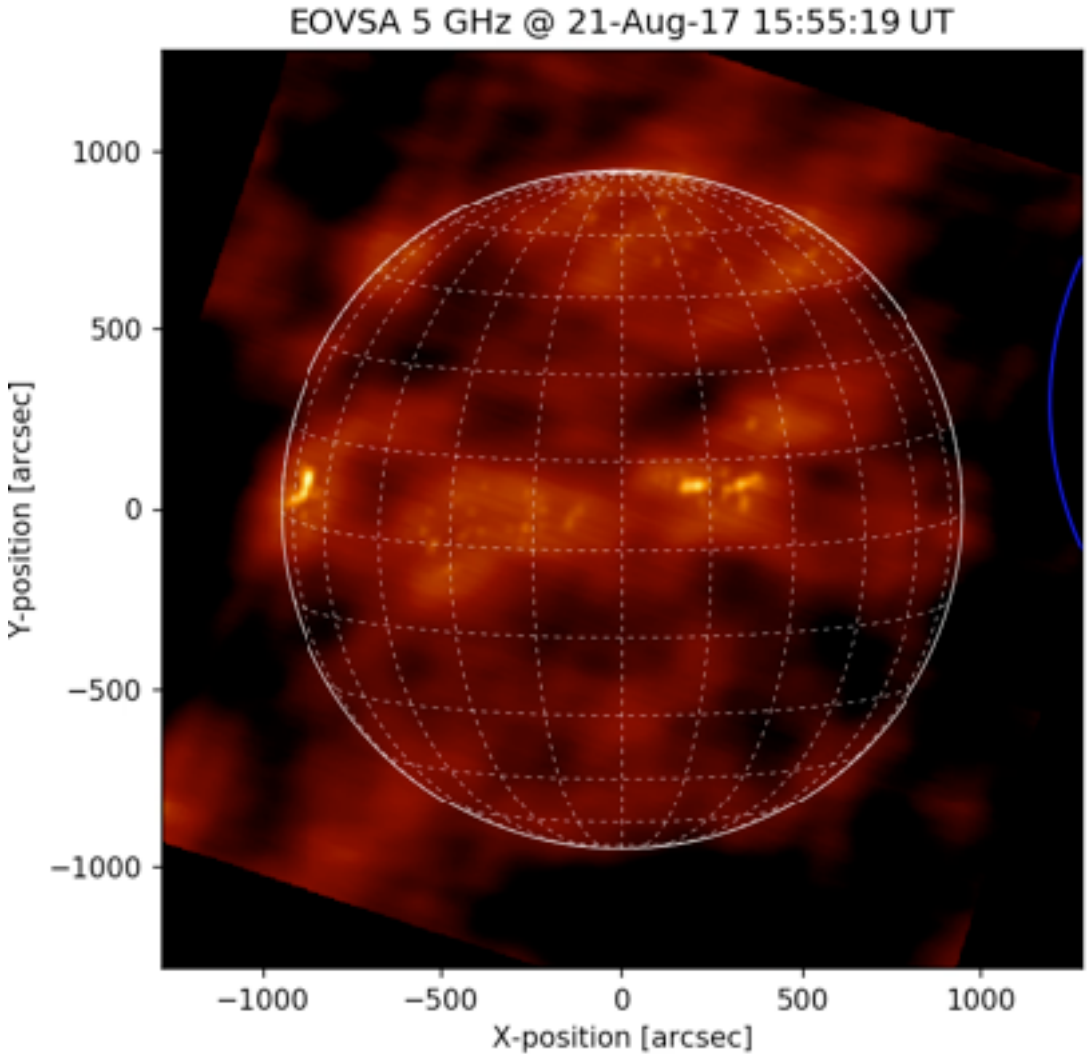


Image created by Bin Chen, Dale E. Gary, Sijie Yu (NJITO)

ASE May 20, 2012 –VLA, New Mexico

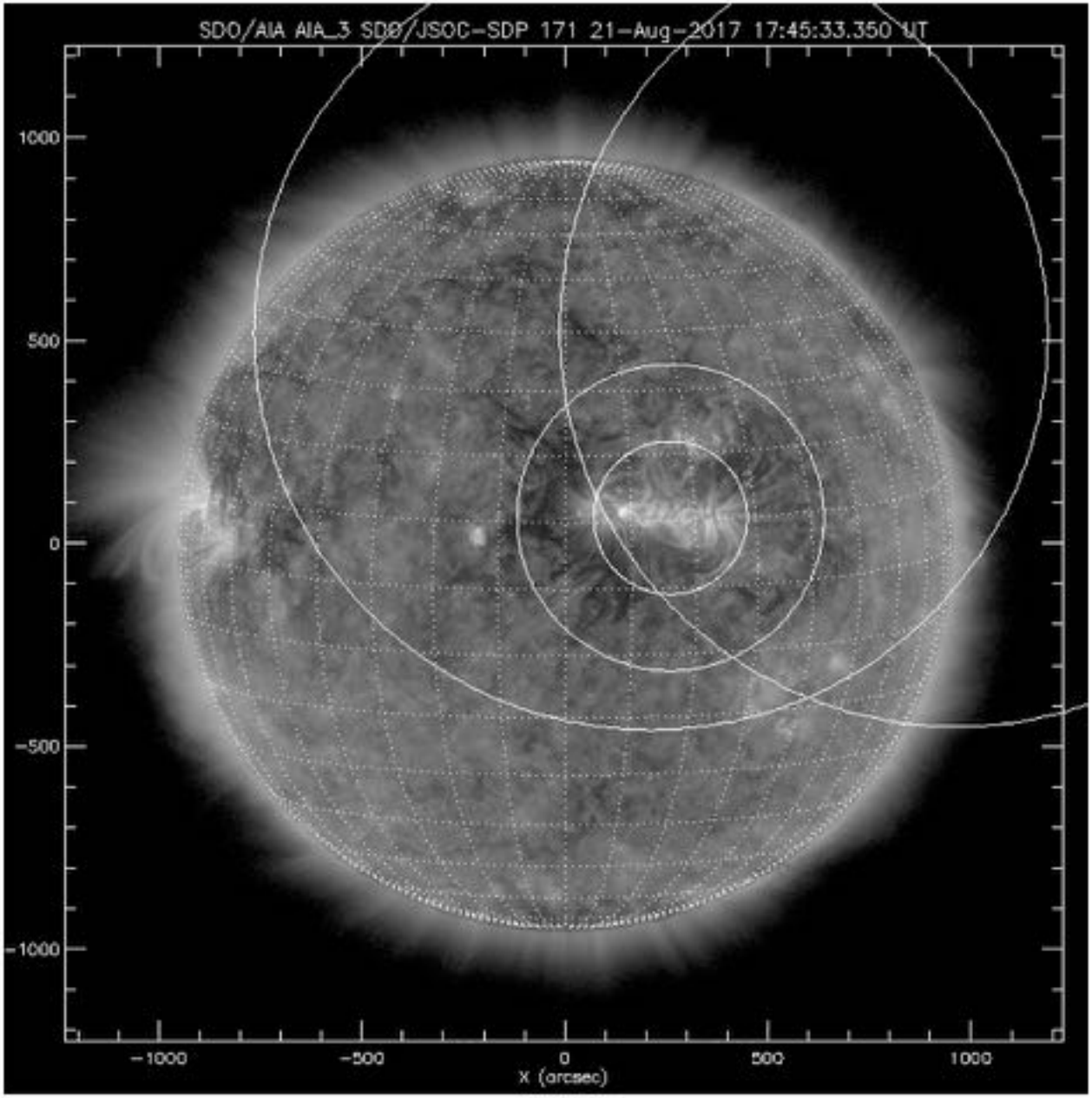
We had joint observing time for the August 21, 2017, eclipse with Dale Gary, Tim Bastian, Stephen White, Bin Chen

ASE May 20, 2012 –VLA, New Mexico

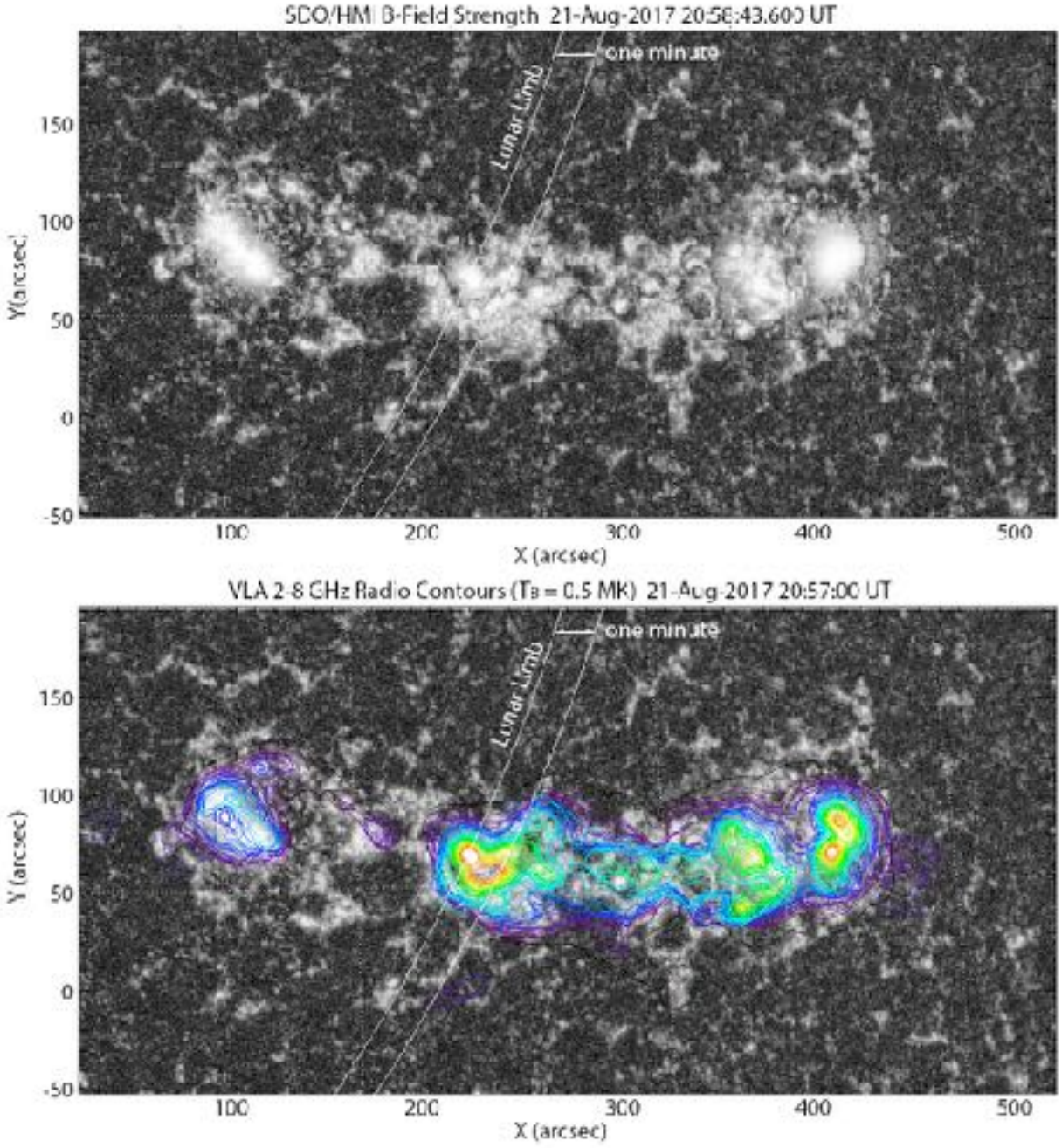
We had joint observing time for the August 21, 2017, eclipse with Dale Gary, Tim Bastian, Stephen White, Bin Chen

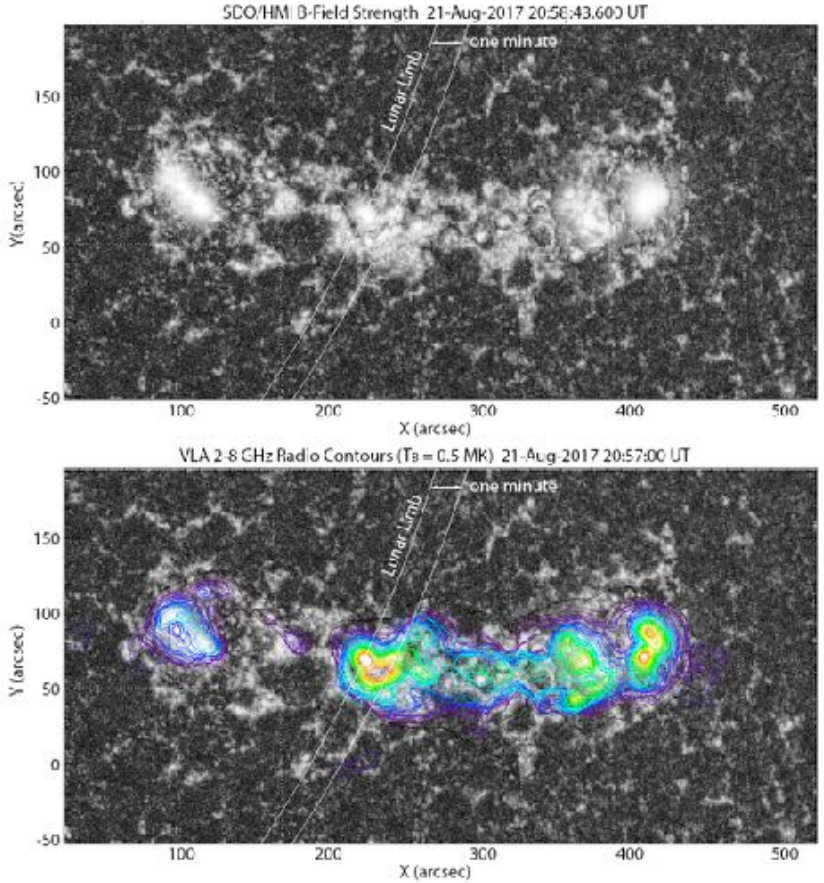
Drawing by Muzhou Lu

Target 1 ingress 17:00-17:34



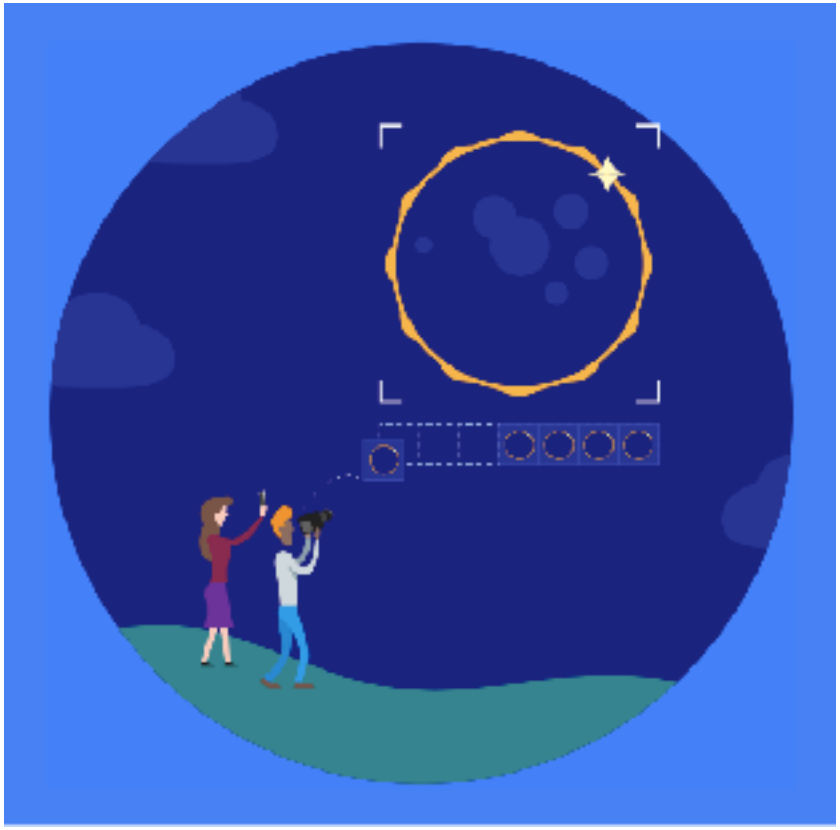
Joint work with Dale Gary and Bin Chen (NJIT) and Tim Bastian (NRAO)


SDO/HMI B-Field Strength 21-Aug-2017 20:58:43.600 UT
one minute
Lunar Limb
150
100
50
0
-50
Y(arcsec)
100
200
300
400
500
X (arcsec)
VLA 2-8 GHz Radio Contours (TB = 0.5 MK) 21-Aug-2017 20:57:00 UT
one minute
Lunar Limb
150
100
50
0
-50
Y (arcsec)
100
200
300
400
500
X (arcsec)



The Karl G. Jansky Very Large Array (VLA), teaming with the Expanded Owens Valley Solar Array (EOVSA) in California, captured the partial phases of the total solar eclipse that was visible across the continental US on August 21. The two complementary arrays provide multi-frequency images of solar active regions that can be used to measure the otherwise unknown magnetic field strength in the corona above sunspots, to compare with magnetic field measurements at the solar surface (upper panel of the figure). VLA measurements taken after the eclipse at 48 frequencies from 2-8 GHz are shown in the lower panel. The frequency of the radio emission, due to electrons spiraling in the hot, magnetized coronal plasma, is proportional to magnetic field strength so that lower-frequency emission (blue contours) come from larger, weaker-field areas while higher-frequency emission (red contours) come from the stronger-field areas in the core regions of the sunspots.

Megamovie Success!
We have an Archive!



URL *eclipsemega.movie*

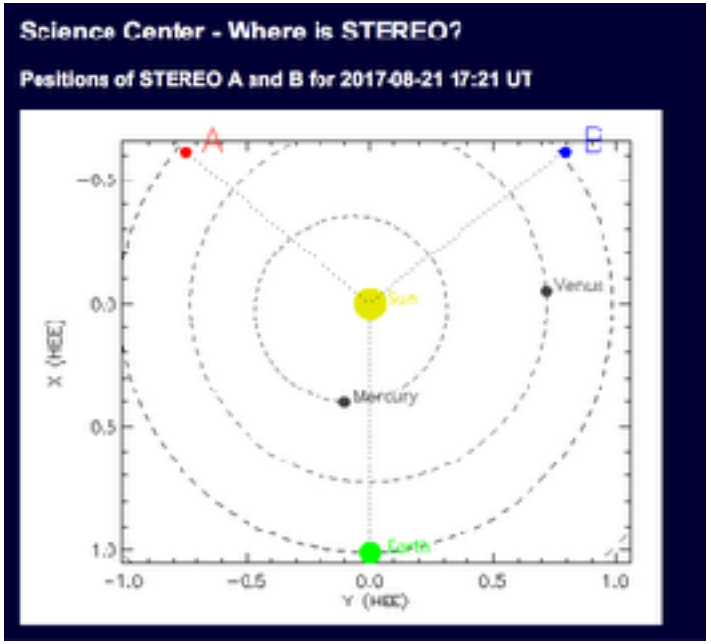
A Wyoming frame from Megamovie v.2

iphone plus 50x, Nebraska (Braxton Collier)

http://eclipsemega.movie/

Hudson, Hugh S., Scott W. McIntosh, Shaddia Habbal, Jay M. Pasachoff, and Laura Peticolas, 2011, "The U.S. Eclipse Megamovie in 2017: a white paper on a unique outreach event," a white paper: http://www.eclipse2017.org/2017/photo/mega_movie.htm

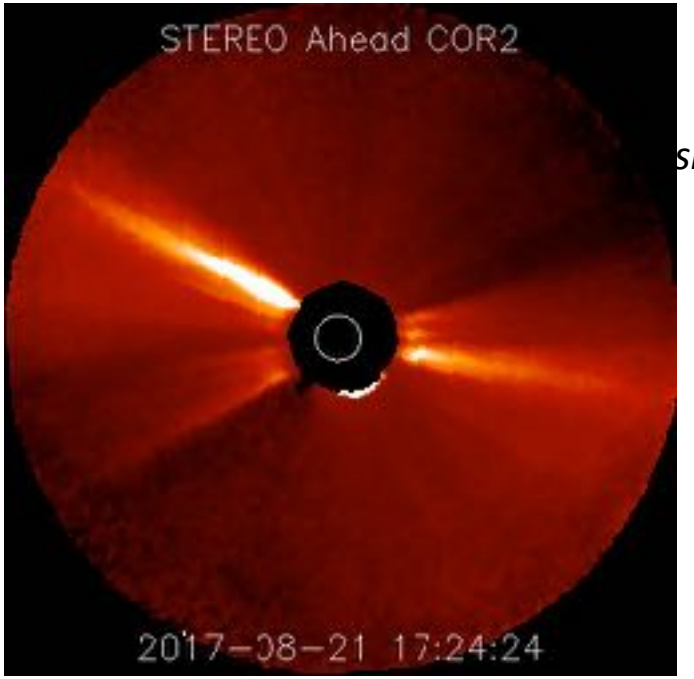
STEREO A COR2 Observations during Eclipse



View of corona from farside - Shows small ejection

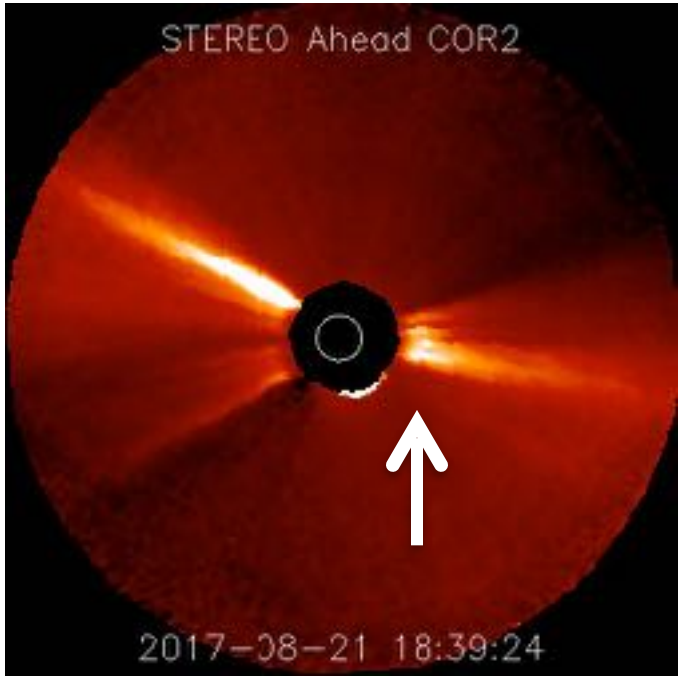
(showing space weather beacon data - high res available later via Stereo Science Center)

West Coast 17:24 UT



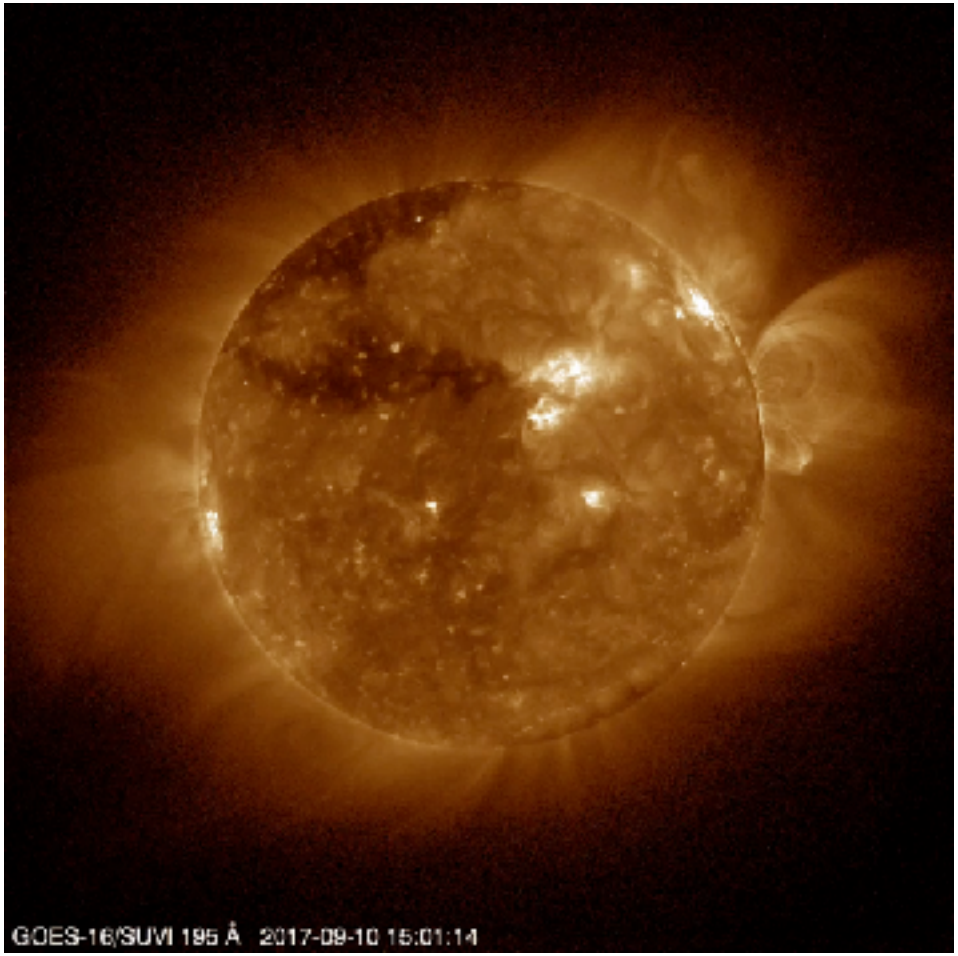
White circle shows size of Sun

East Coast 18:39 UT



Courtesy P. Liewer

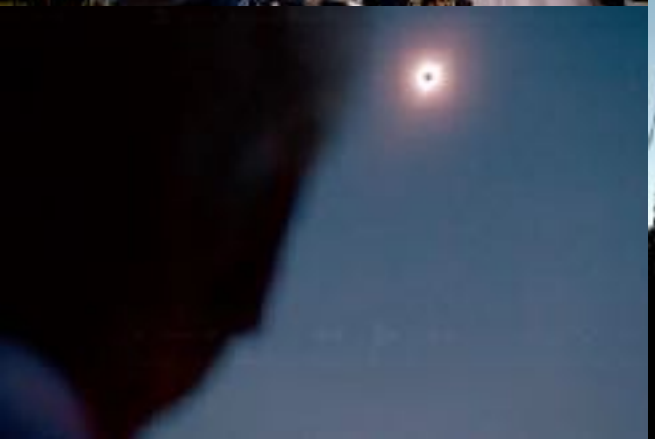
SUVI: Solar Ultraviolet Imager on GOES-16
September 20, 2017

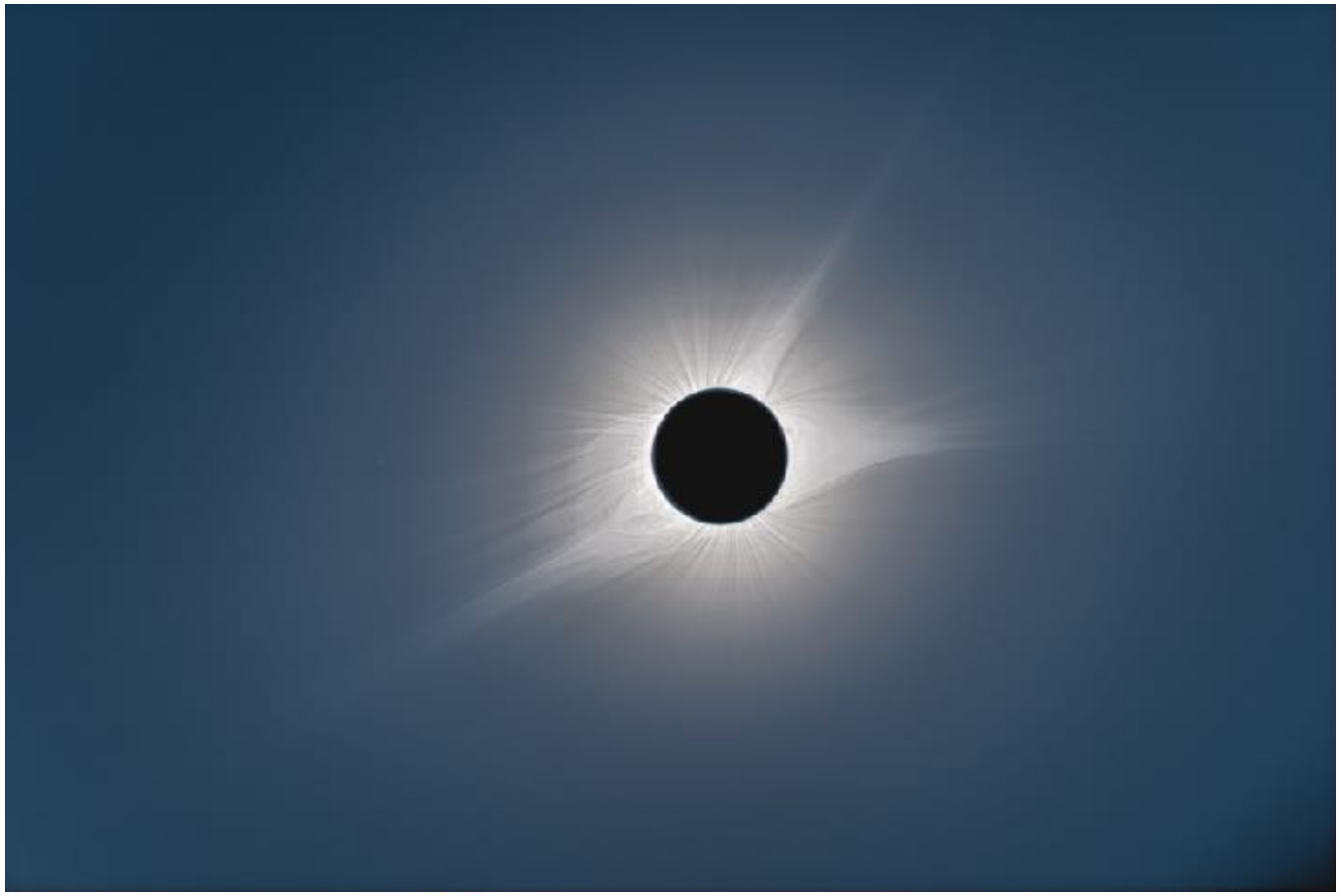


Dan Seaton ‘01

PBS NOVA
Eclipse Over America
https://nova.wistia.com/medias/py80aesc2x

Curiosity Stream
Eclipse Across America
http://curiositystream.com/eclipse





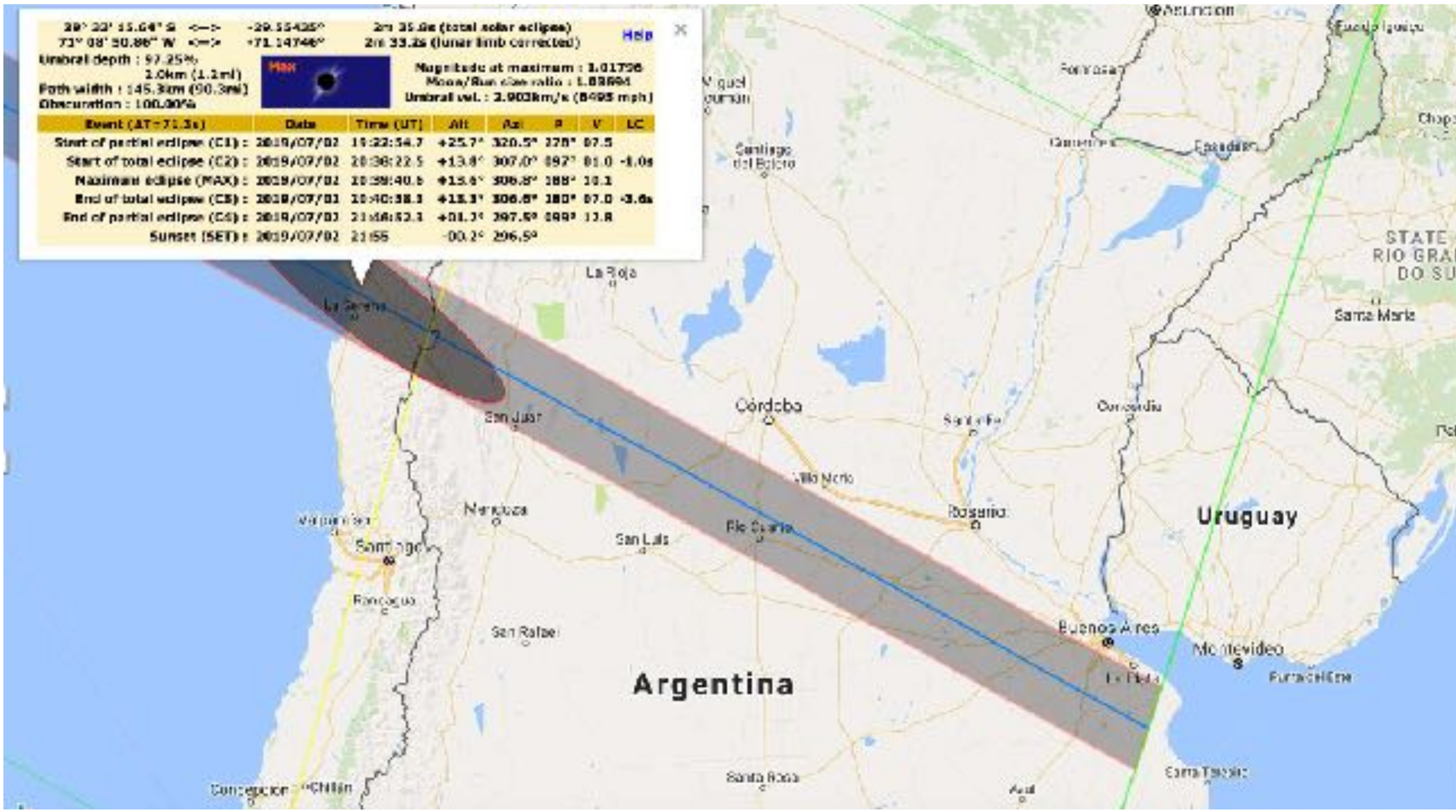
NSF NATIONAL GEOGRAPHIC NASA SIGMA XI THE SCIENTIFIC RESEARCH SOCIETY Williams

Information posted at

- http://totalsolareclipse.org

Our expedition was supported in large part by grants from the Committee for Research and Exploration of the National Geographic Society and from the Solar Terrestrial Program of the Atmospheric and Geospace Sciences Division of the National Science Foundation, with additional student support from the STP/AGS of NSF, the NASA Massachusetts Space Grant Consortium, the Sigma Xi honorary scientific society, the Clare Booth Luce Foundation studentship and the Freeman Foote Expeditionary Fund at Williams College, other Williams College funds, and U. Pennsylvania funds.

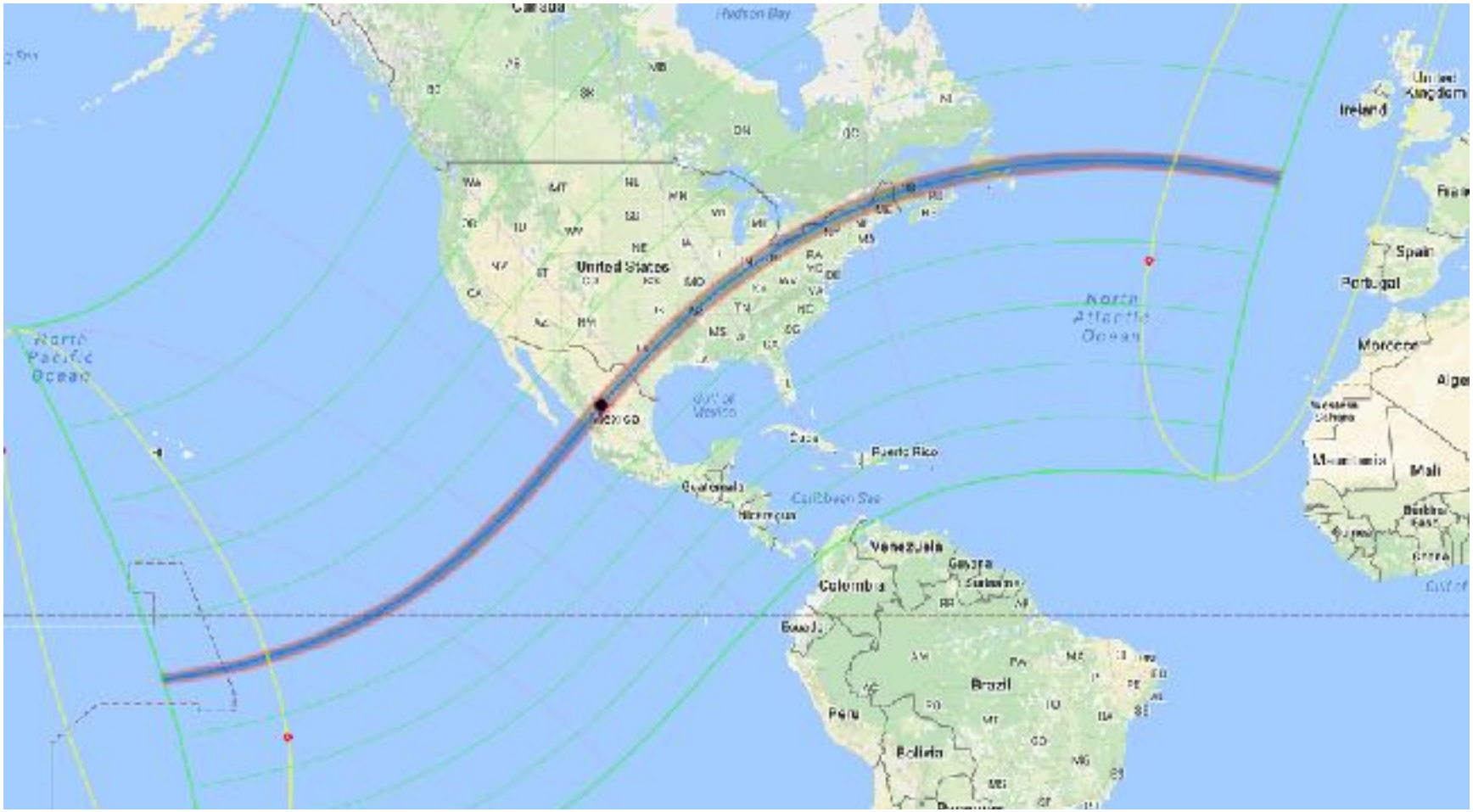
July 2, 2019



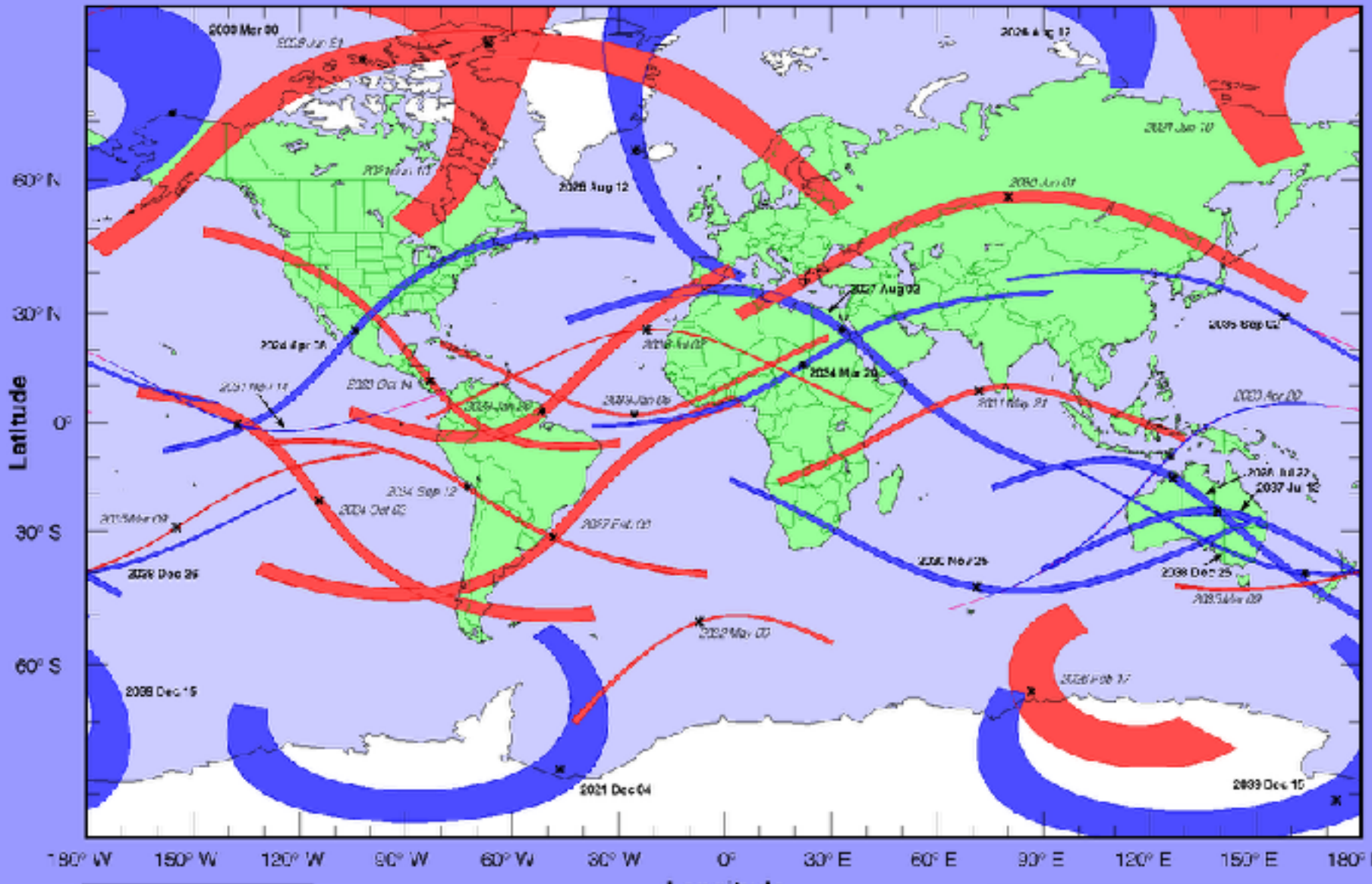
Help
Umbral depth : 97.25%
Path width : 145.3km (90.3mi)
Obscuration : 100.00%
Max
Magnitude at maximum : 1.01798
Event
Date
Time (UT)
Alt
Azi
P
V
LC
Start of partial eclipse (C1) :
Start of total eclipse (C2) :
Maximum eclipse (MAX) :
End of total eclipse (C3) :
End of partial eclipse (C4) :
Sunset (SET) :
2019/07/02
Asunción
Formosa
La Rioja
La Serena
San Juan
Córdoba
Santa Fe
Concordia
Villa María
Mendoza
Rosario
Uruguay
Valparaíso
Santiago
San Luis
Río Cuarto
Rancagua
San Rafael
Buenos Aires
Montevideo
La Plata
Argentina
Santa Rosa
Concepción
Chillán
Azul
Santa María

December 14, 2020

April 8, 2024


Hudson Bay
Ireland
United Kingdom
Spain
Portugal
United States
North Pacific Ocean
North Atlantic Ocean
Gulf of Mexico
Mexico
Cuba
Puerto Rico
Guatemala
Caribbean Sea
Venezuela
Colombia
Brazil
Peru
Bolivia
Mali

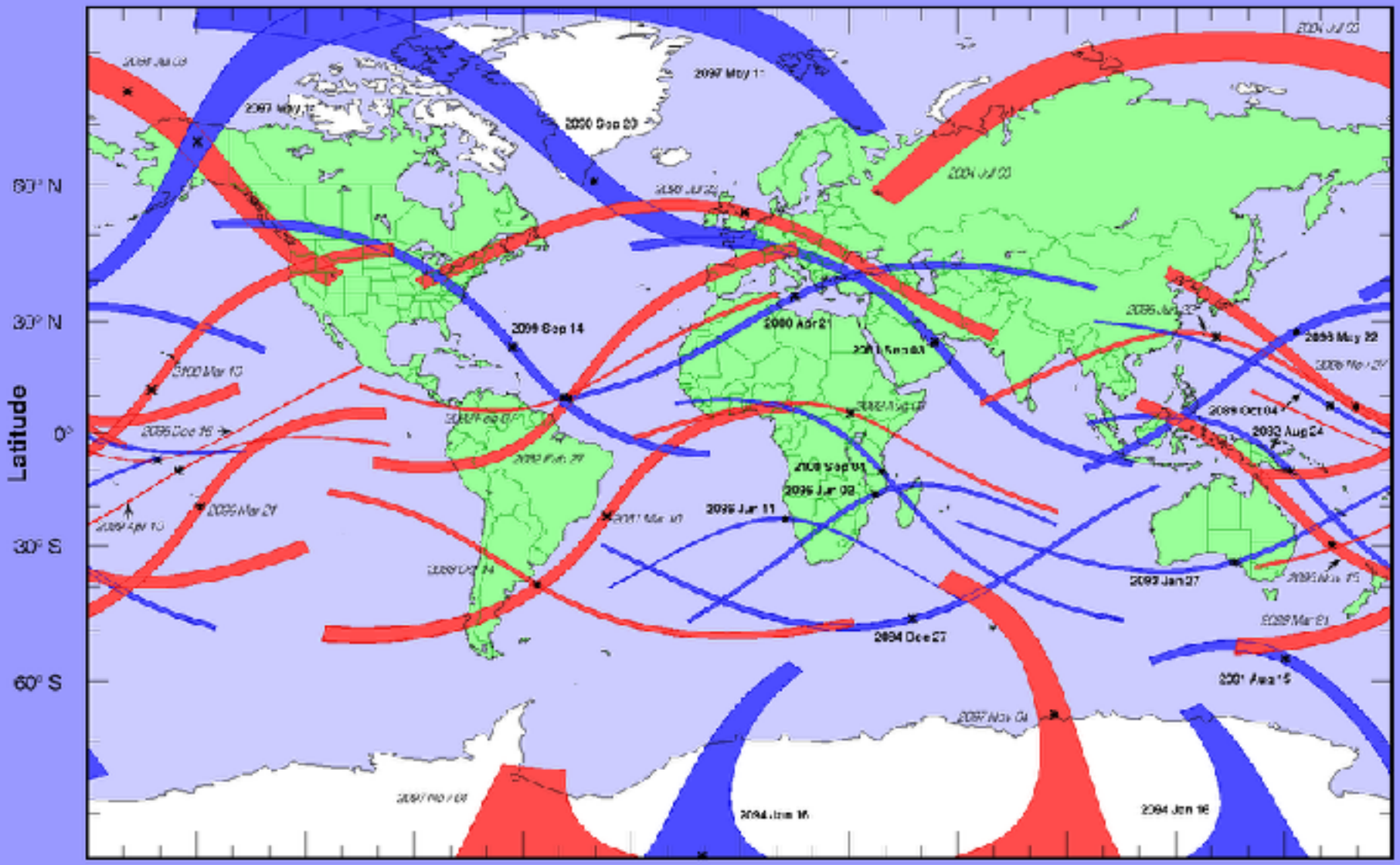
Total and Annular Solar Eclipse Paths: 2021 –2040



sunearth.gsfc.nasa.gov/eclipse/eclipse.html

Fred Espenak, NASA/GSFC - 2002 July

Total and Annular Solar Eclipse Paths: 2081–2100



sunearth.gsfc.nasa.gov/eclipse/eclipse.html

Fred Espenak, NASA/GSFC - 2002 July

Total solar eclipse of 3 September 2081, in 63+ years