2017 Total Solar Eclipse across North America: Early Research Findings

TAPR DCC
September 14, 2018

P. J. Erickson, L. P. Goncharenko, S.-R. Zhang, A. J. Coster
MIT Haystack Observatory
and many other research community members

EXPERIENCE THE 2017 ECLIPSE ACROSS AMERICA
AUGUST 21, 2017

Credit: S. Habbal, M. Druckmüller and P. Aniol

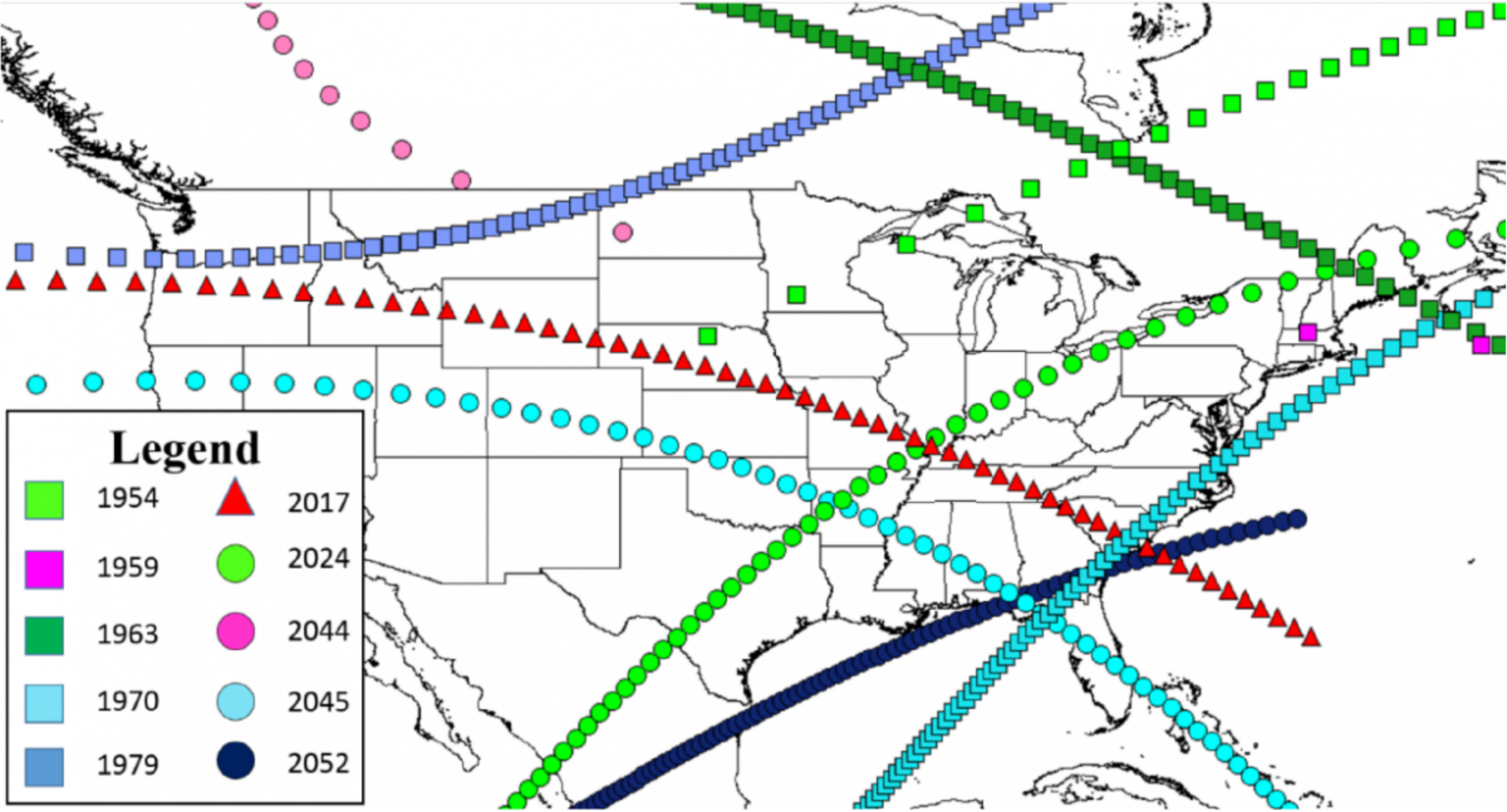
Eclipse Countdown Until First Contact in Oregon August 21, 2017 UT

8 weeks, 6 days, 4 hours, and 26 minutes left

TOTAL SOLAR ECLIPSE

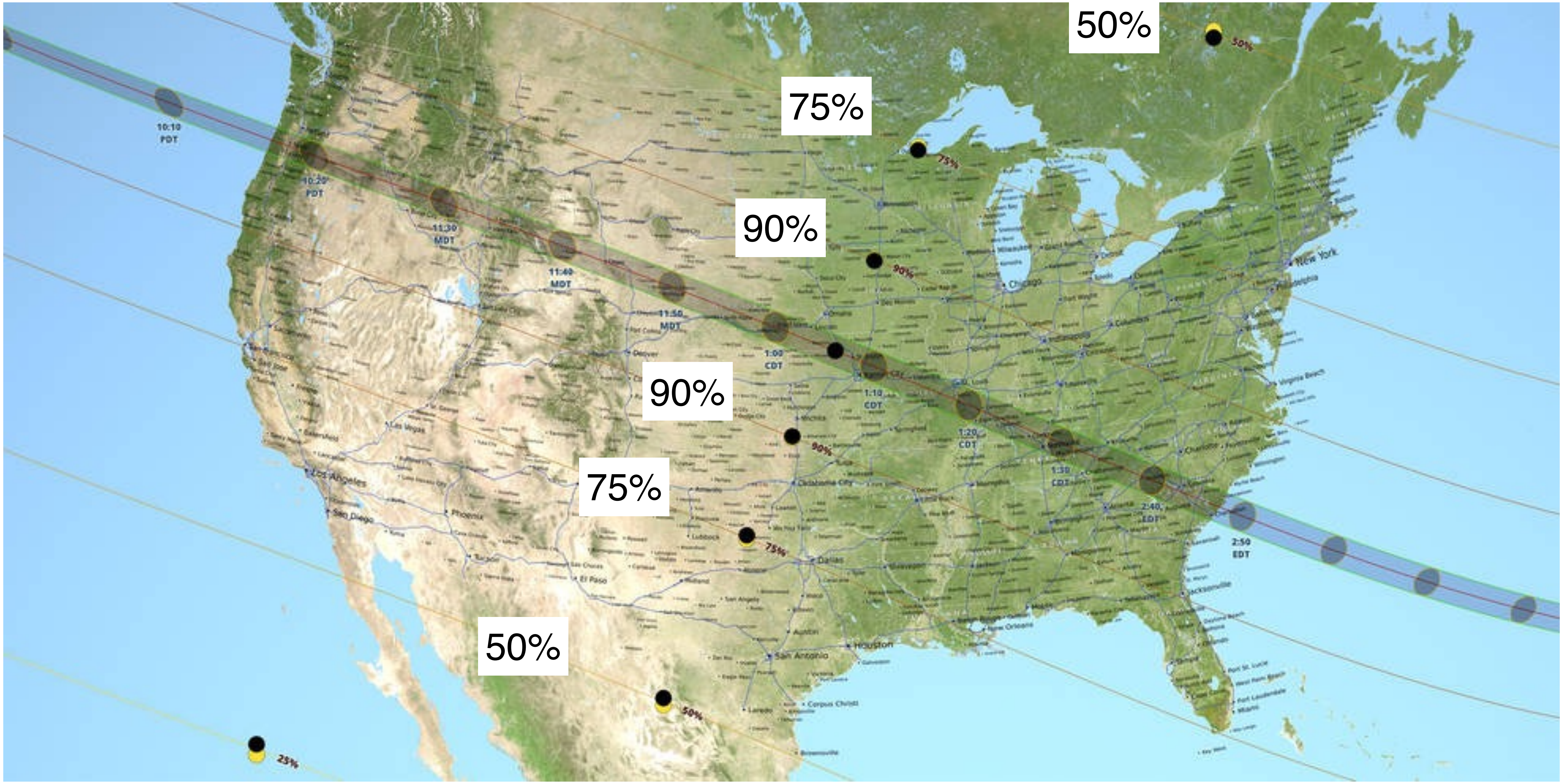
On Monday, August 21, 2017, all of North America will be treated to an eclipse of the sun. Anyone within the path of totality can see one of nature's most awe inspiring sights - a total solar eclipse. This path, where the moon will completely cover the sun and the sun's tenuous atmosphere - the corona - can be seen, will stretch from Salem, Oregon to Charleston, South Carolina. Observers outside this

Map of All Eclipses over Continental US From 1950-2052



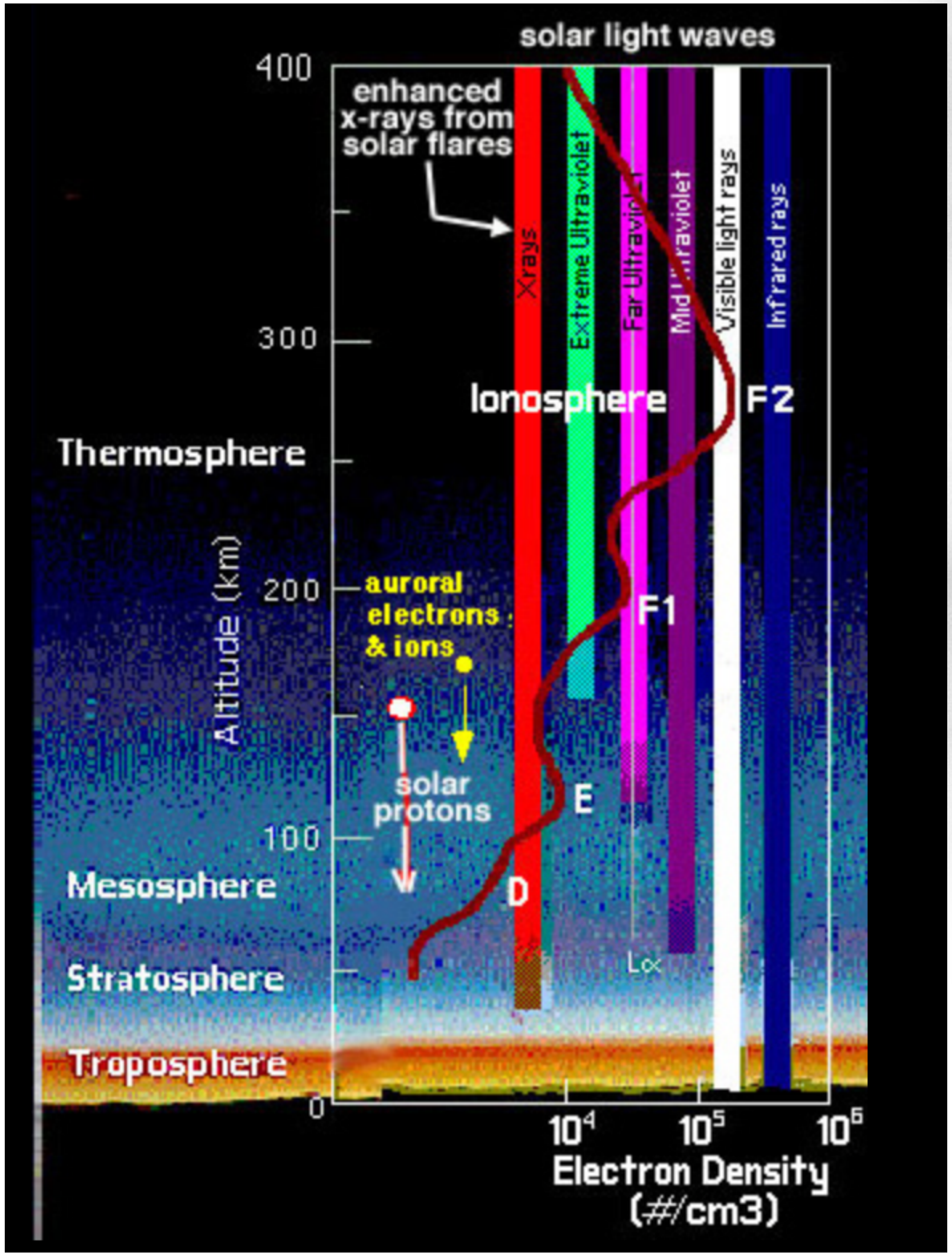
2017 Eclipse Totality Track

(Ernie Wright, NASA GSFC)

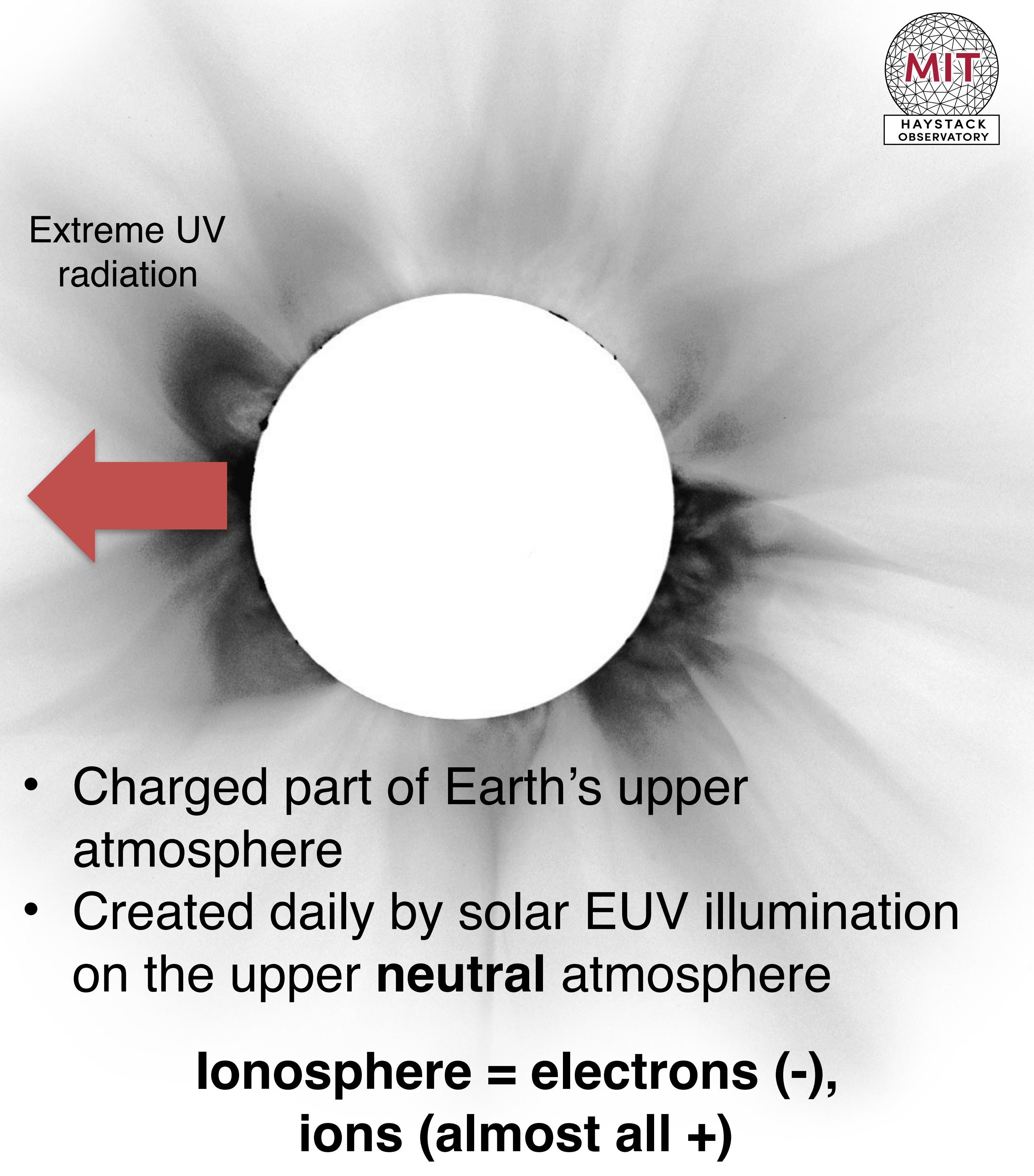


Penumbral (partial) shadow: very important

Ionospheric Basics



(Windows on the Universe)

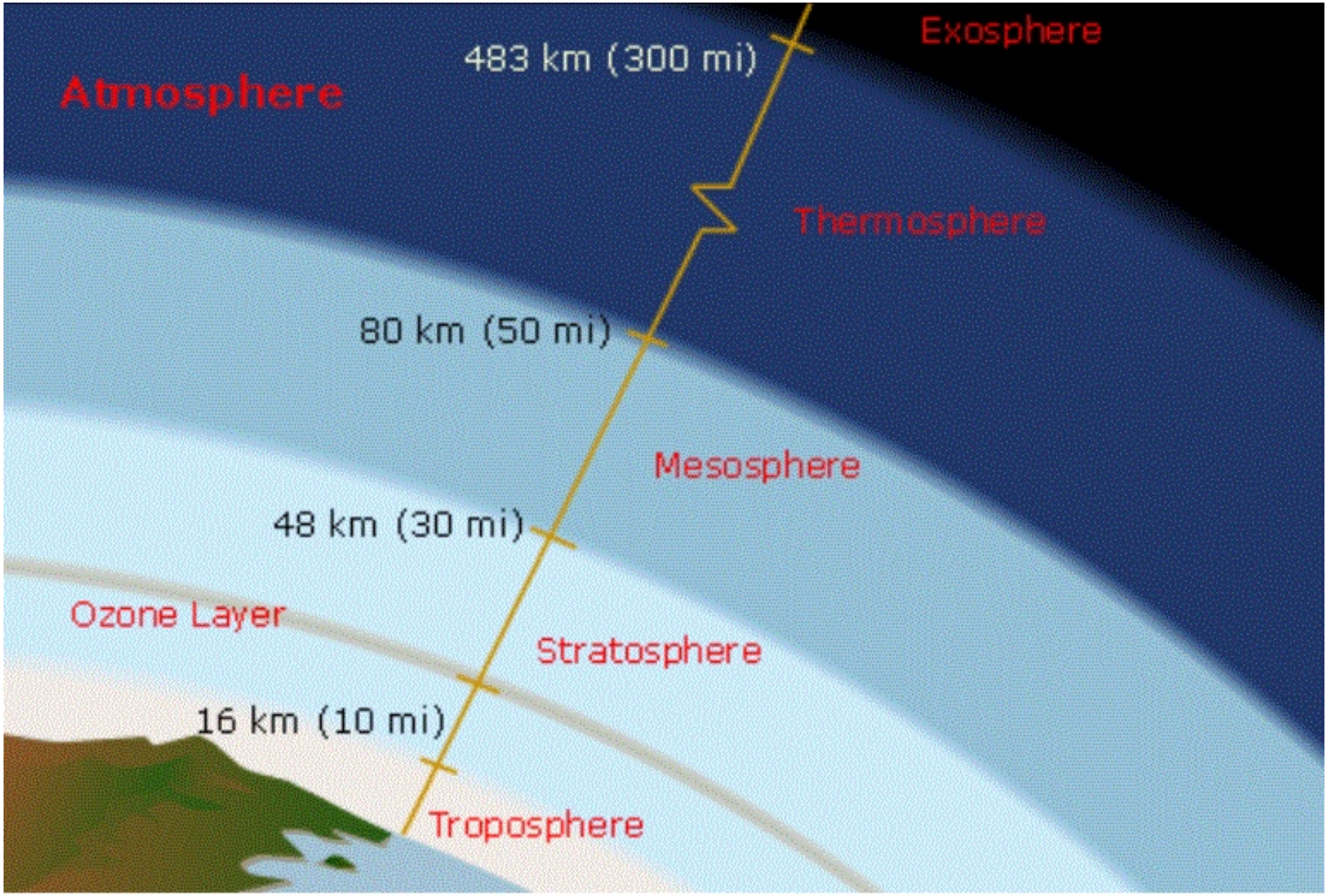


- Charged part of Earth's upper atmosphere
- Created daily by solar EUV illumination on the upper **neutral** atmosphere

Ionosphere = electrons (-), ions (almost all +)

Earth’s Ionosphere and Its Relation To The Atmosphere

Our planet’s neutral atmosphere..

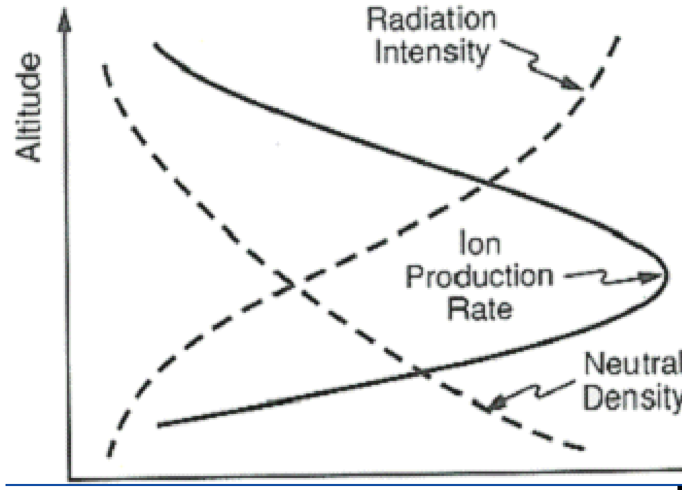


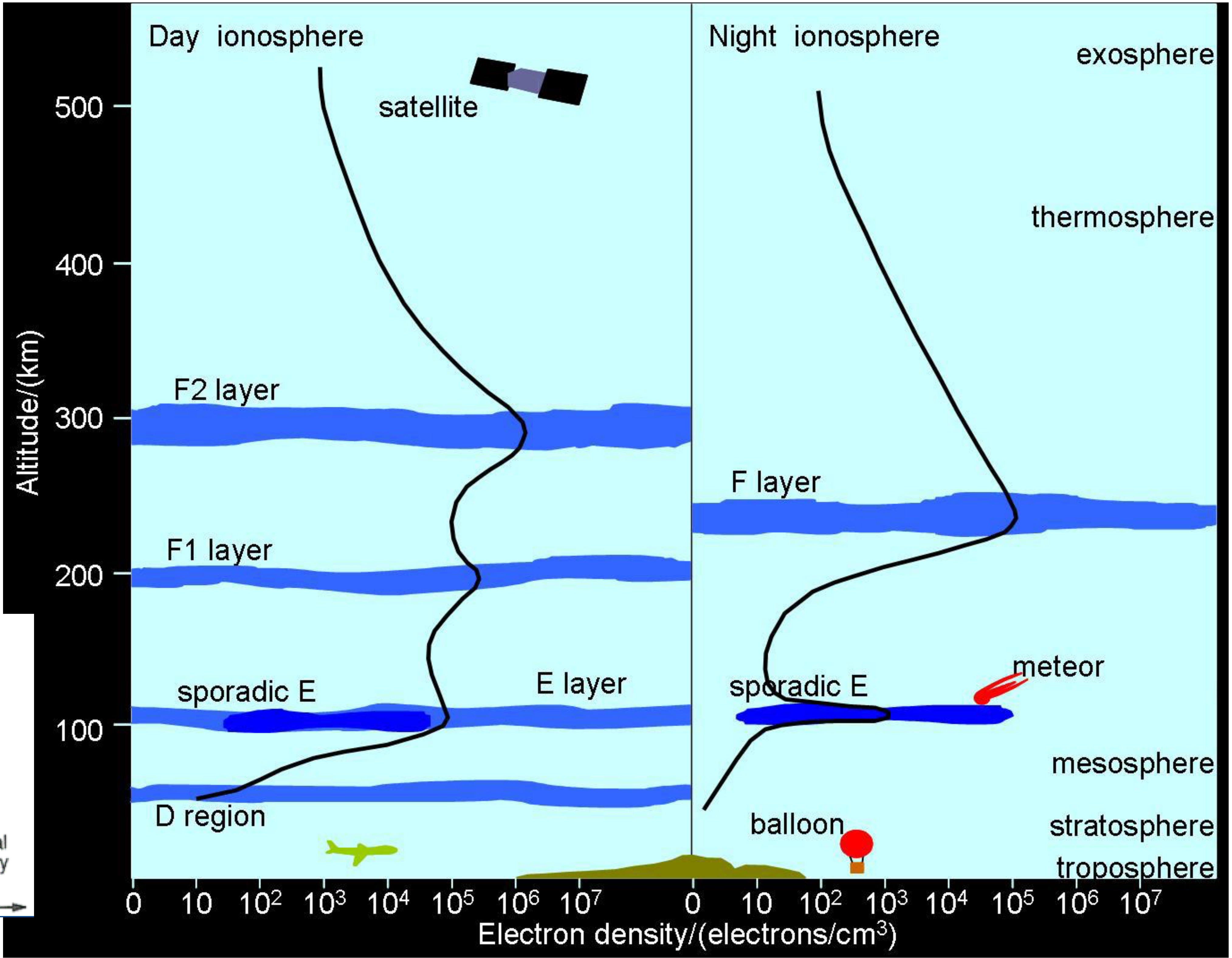
http://www.sws.bom.gov.au/Educational/1/2/5

Earth's Ionosphere and Its Relation To The Atmosphere

.. is the source for the ionosphere.

Sun's EUV rays ionize the neutral gas.





http://www.sws.bom.gov.au/Educational/1/2/5

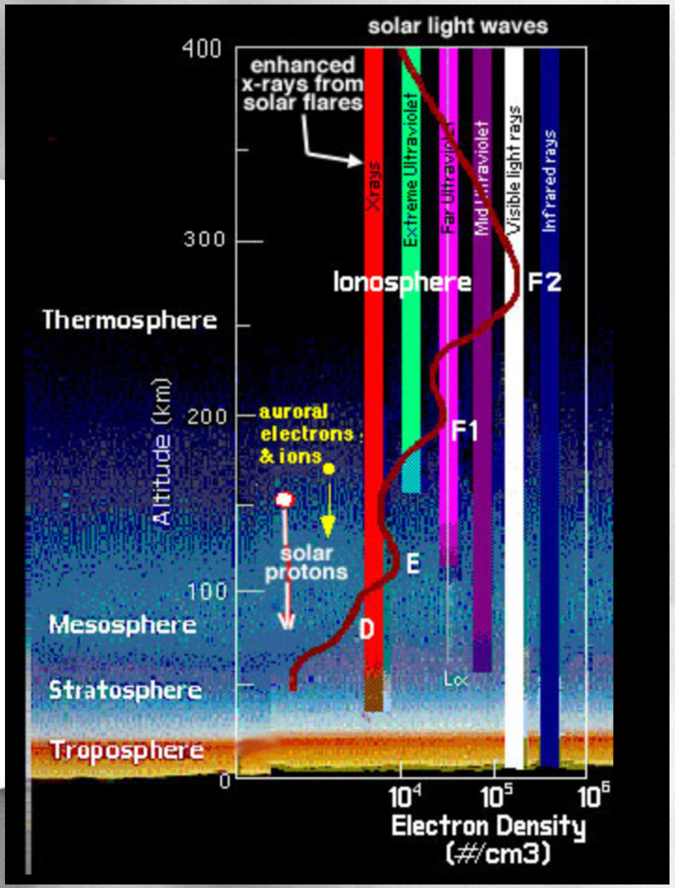
What's Important About the 2017 Eclipse?

$$dN/dt = E(t)\,q(t) - \alpha N^2$$ E layer

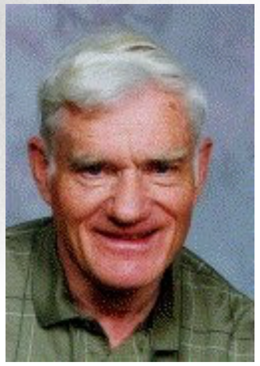
$$dN/dt = E(t)\,q(t) - \beta N$$ F2 layer

Eclipse obscuration function

Normal production function



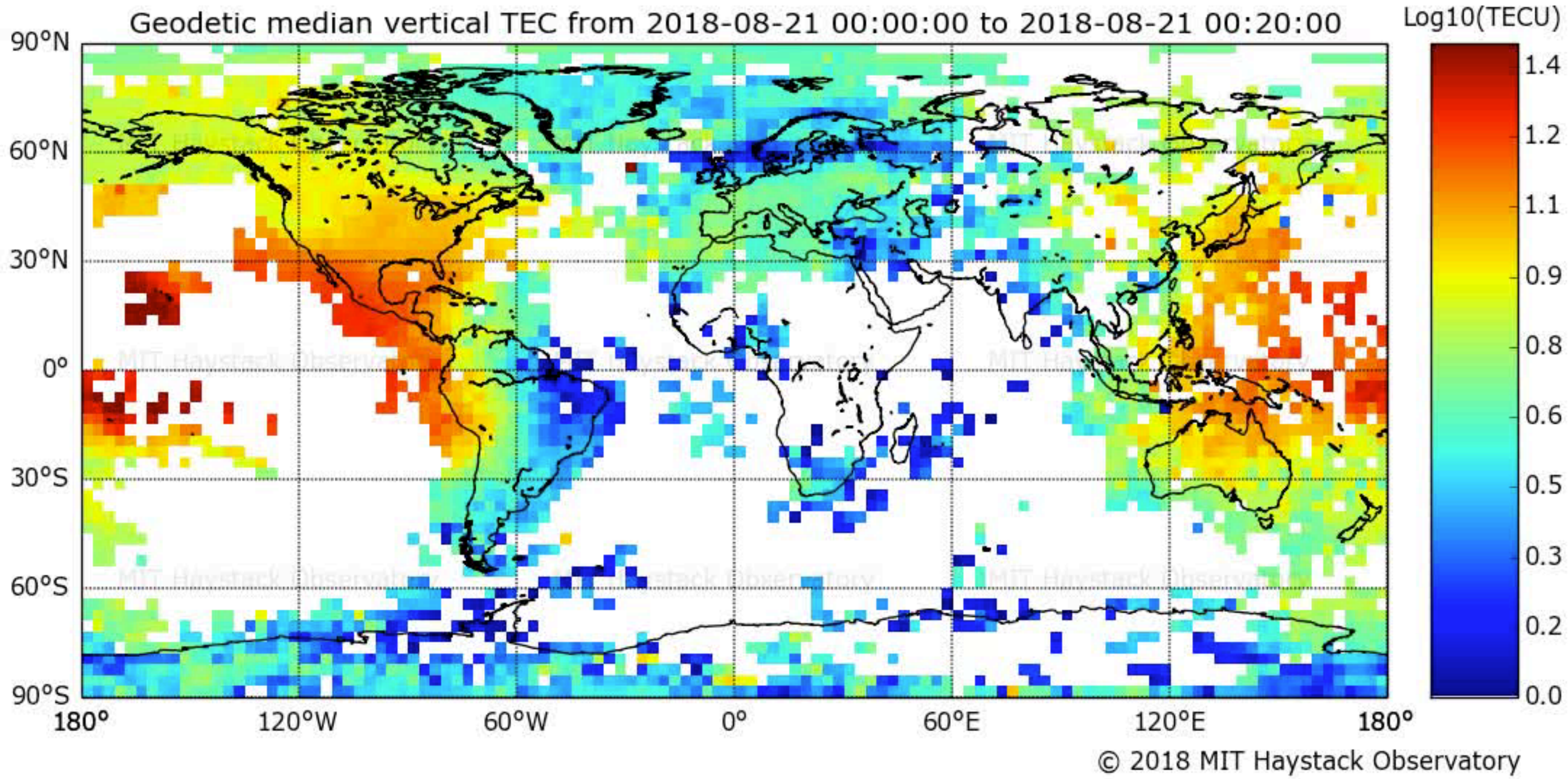
"Observations during a solar eclipse offer a special opportunity for studying both the solar ionizing radiations and the earth's ionosphere" - H. Rishbeth in 1968!



The Ultimate Active Experiment!

The Ionosphere Is Naturally Complex

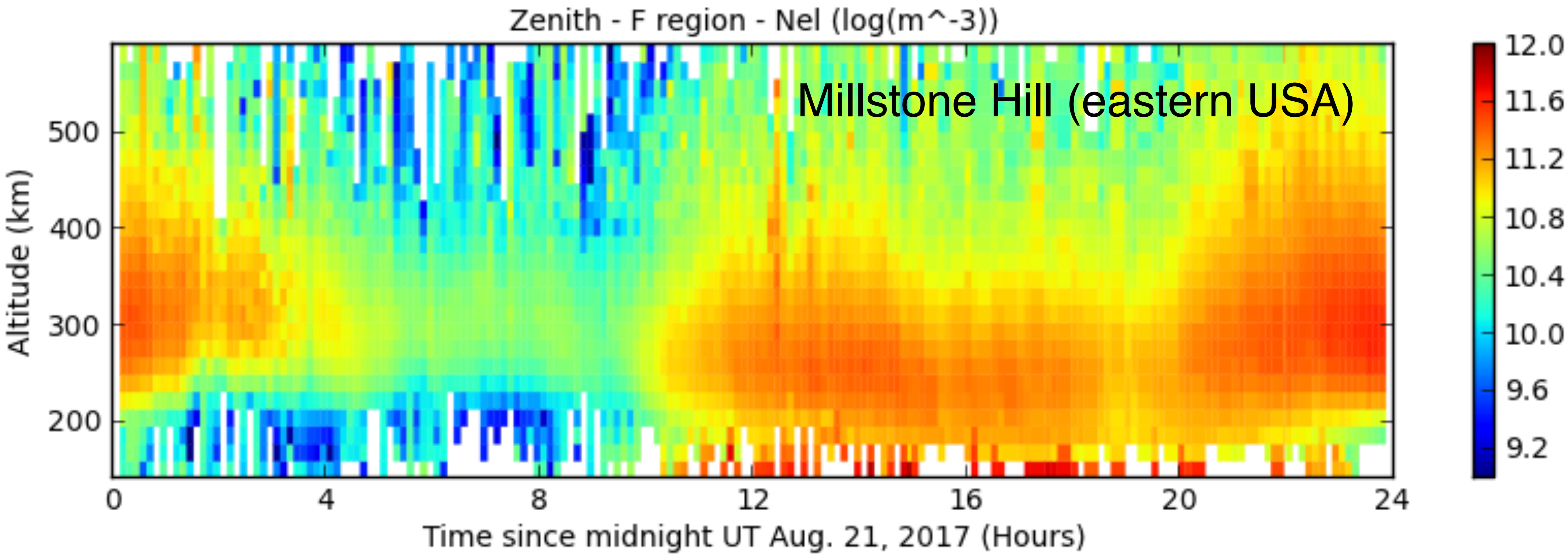
(red = more electrons, blue = less)



Varies in Space, Time: Space Weather

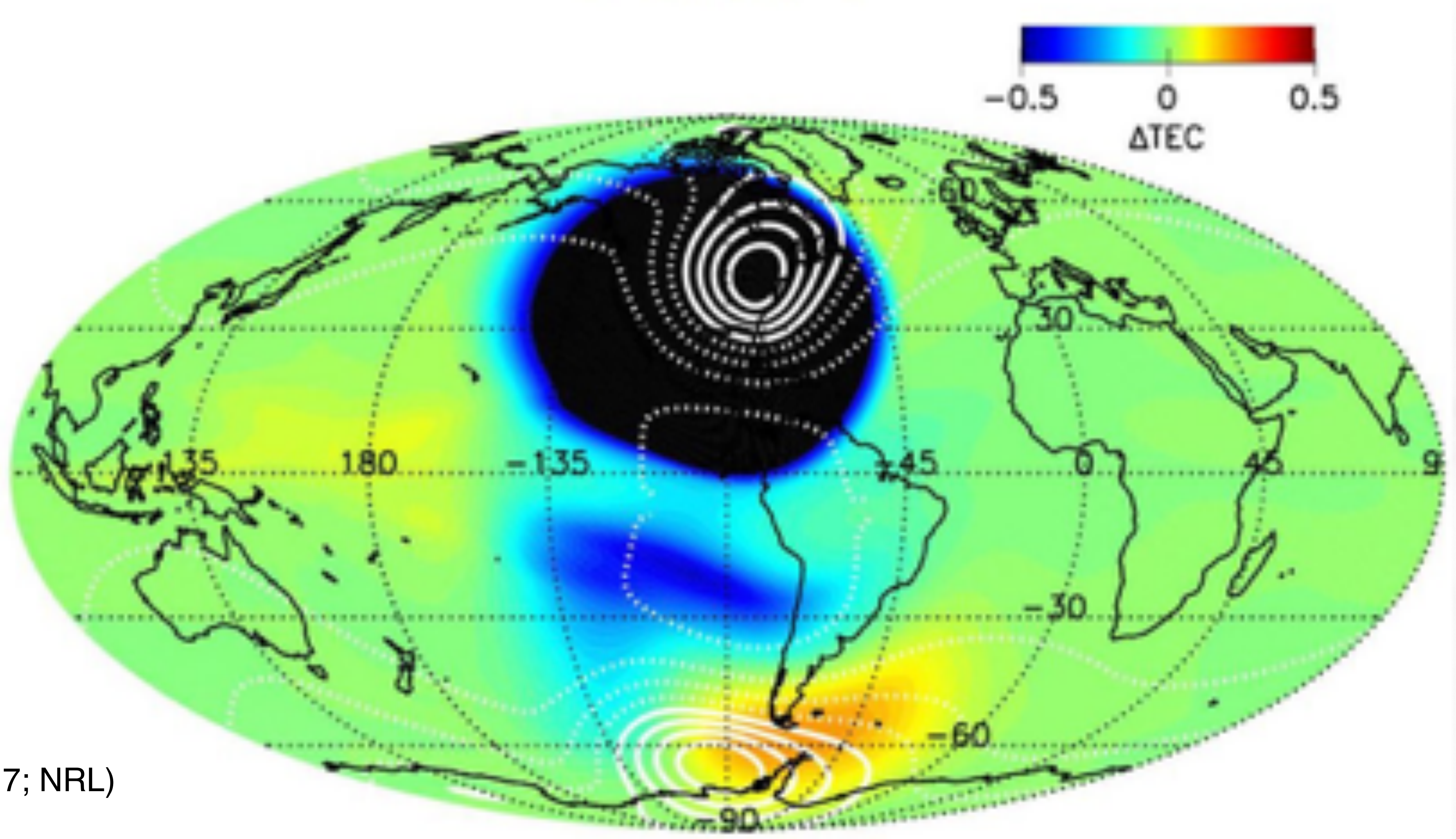
The Ionosphere Is Naturally Complex

(red = more electrons, blue = less)



Varies in Altitude: Space Weather

Advance Predictions: What Should The 2017 Eclipse Do?

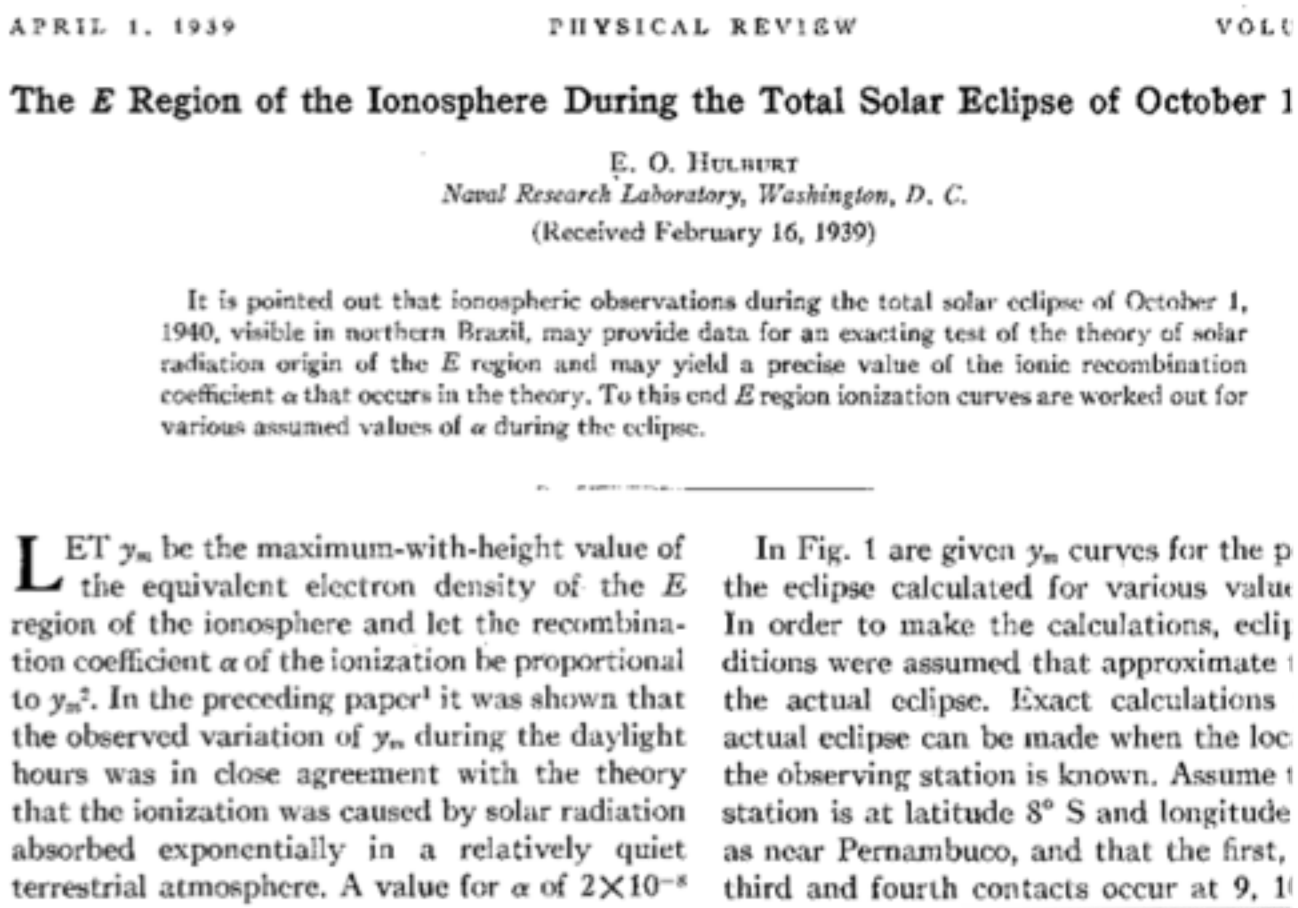


(Joe Huba, 2017; NRL)

Modeled effects on electron density

Both hemispheres affected (electrical coupling)

Previous Eclipse Research Example



APRIL 1, 1939 PHYSICAL REVIEW VOLU

The *E* Region of the Ionosphere During the Total Solar Eclipse of October 1

E. O. Hulburt
Naval Research Laboratory, Washington, D. C.
(Received February 16, 1939)

It is pointed out that ionospheric observations during the total solar eclipse of October 1, 1940, visible in northern Brazil, may provide data for an exacting test of the theory of solar radiation origin of the *E* region and may yield a precise value of the ionic recombination coefficient α that occurs in the theory. To this end *E* region ionization curves are worked out for various assumed values of α during the eclipse.

LET y_m be the maximum-with-height value of the equivalent electron density of the *E* region of the ionosphere and let the recombination coefficient α of the ionization be proportional to y_m^2. In the preceding paper[1] it was shown that the observed variation of y_m during the daylight hours was in close agreement with the theory that the ionization was caused by solar radiation absorbed exponentially in a relatively quiet terrestrial atmosphere. A value for α of 2×10^{-8}

In Fig. 1 are given y_m curves for the p
the eclipse calculated for various valu
In order to make the calculations, ecli
ditions were assumed that approximate
the actual eclipse. Exact calculations
actual eclipse can be made when the loc
the observing station is known. Assume t
station is at latitude 8° S and longitude
as near Pernambuco, and that the first,
third and fourth contacts occur at 9, 1

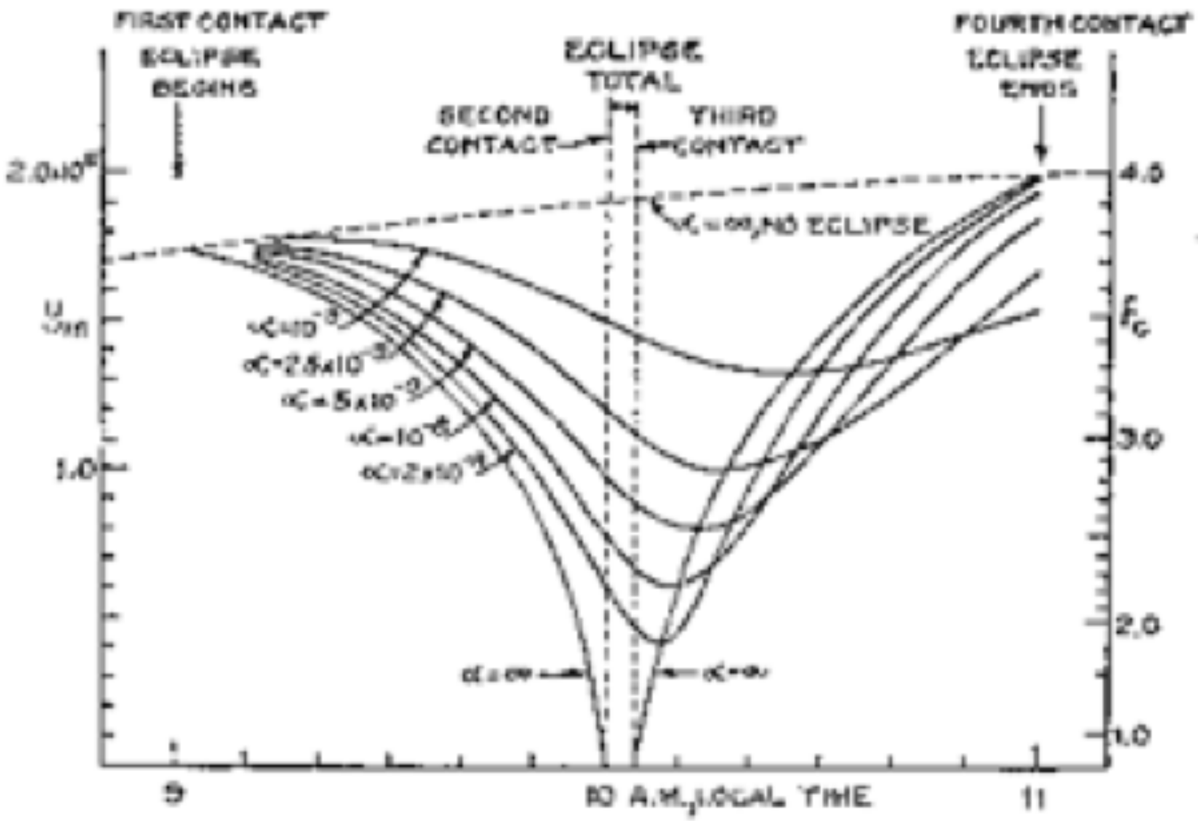


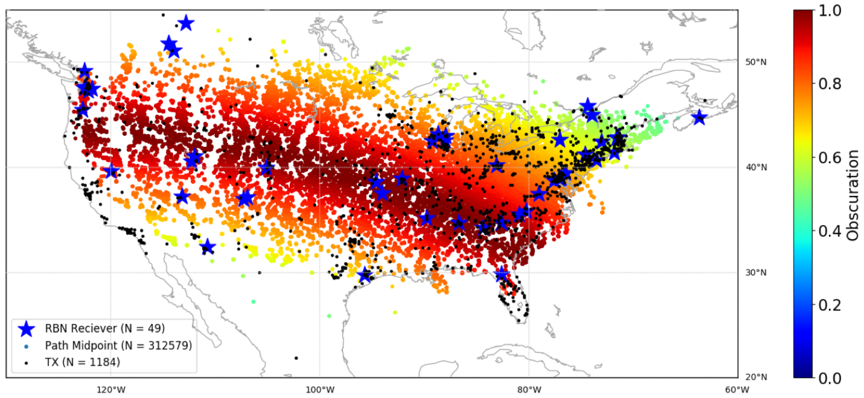
Fig. 1. Theoretical ionization of *E* region at Pernambuco, Brazil, during the eclipse of October 1, 1940.

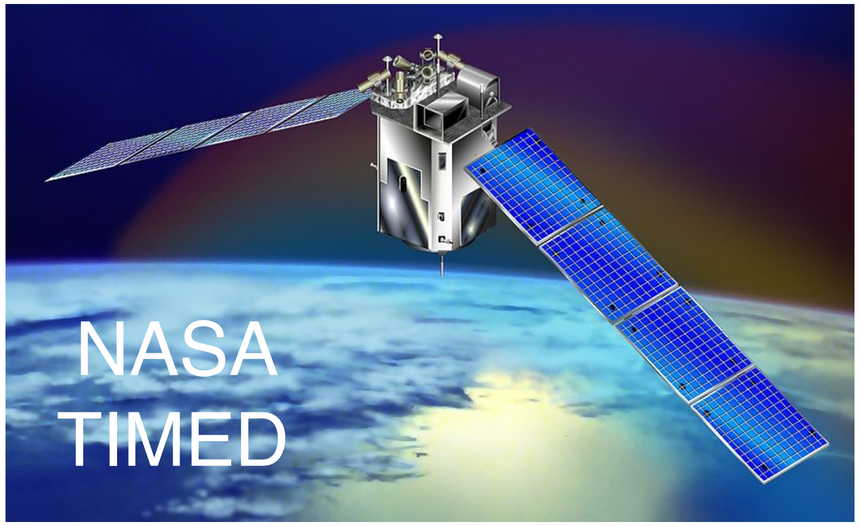
Density reductions, waves, significant cooling..
but observations were mostly few and limited.
Use modern tools and observations!

What Was New for the 2017 Eclipse?

HamSCI

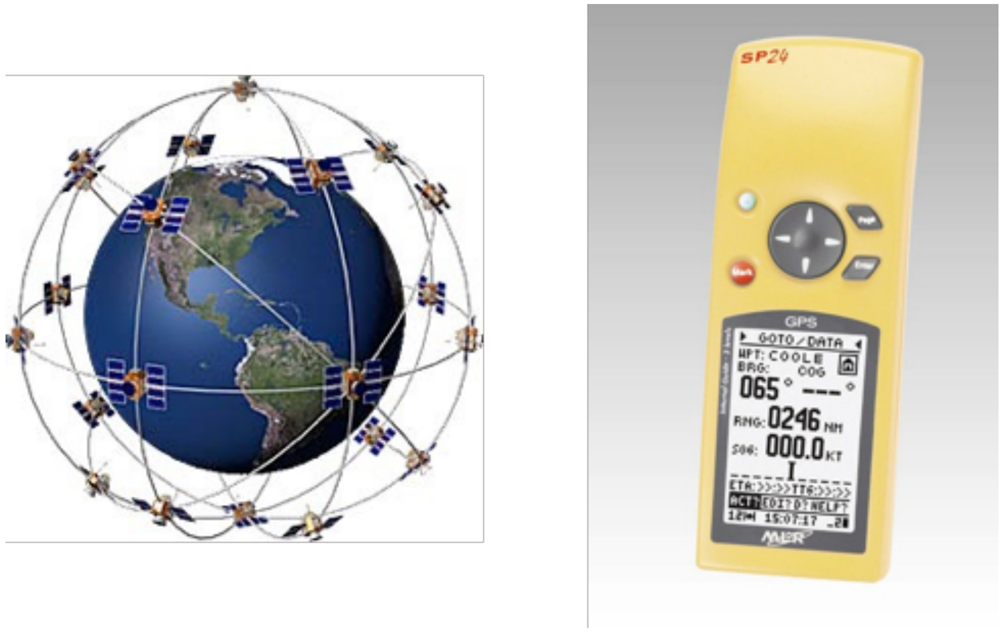
http://hamsci.org





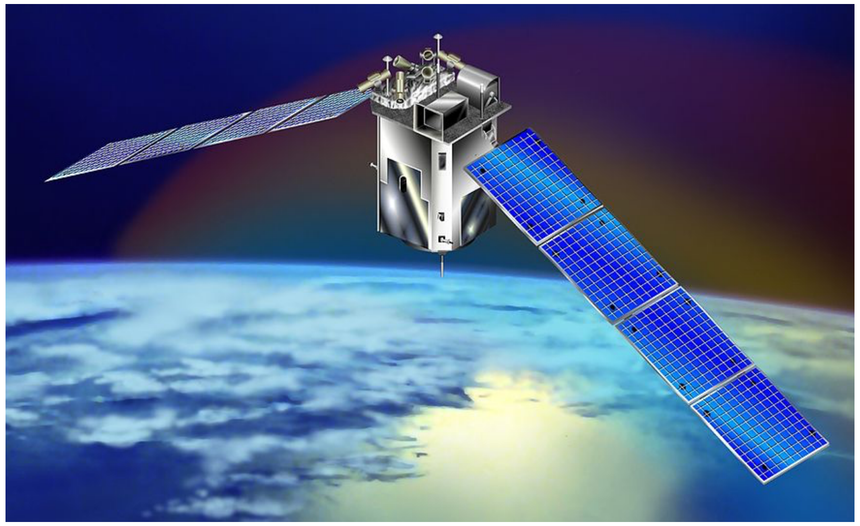
Precise ground-based ionosphere monitoring (radars), combined with satellite overflights **and crowd-sourced ham data!**

Tools for Ionospheric Observations



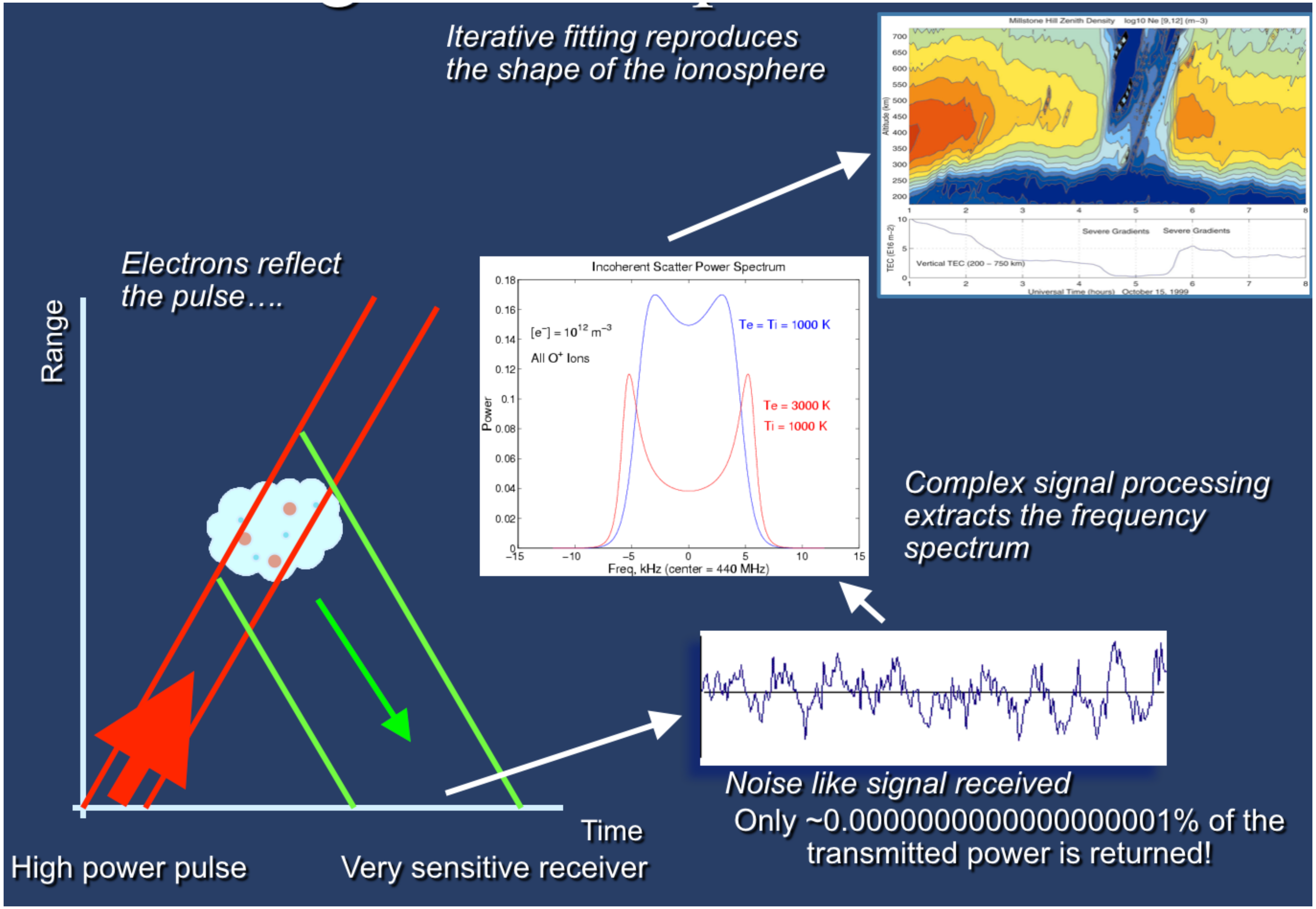
GNSS Receivers
(Ionospheric information!)

Large Ground-based
Ionospheric Radars



Orbiting satellites
(Neutral atmosphere information)

Ionospheric Radars



Iterative fitting reproduces the shape of the ionosphere

Electrons reflect the pulse….

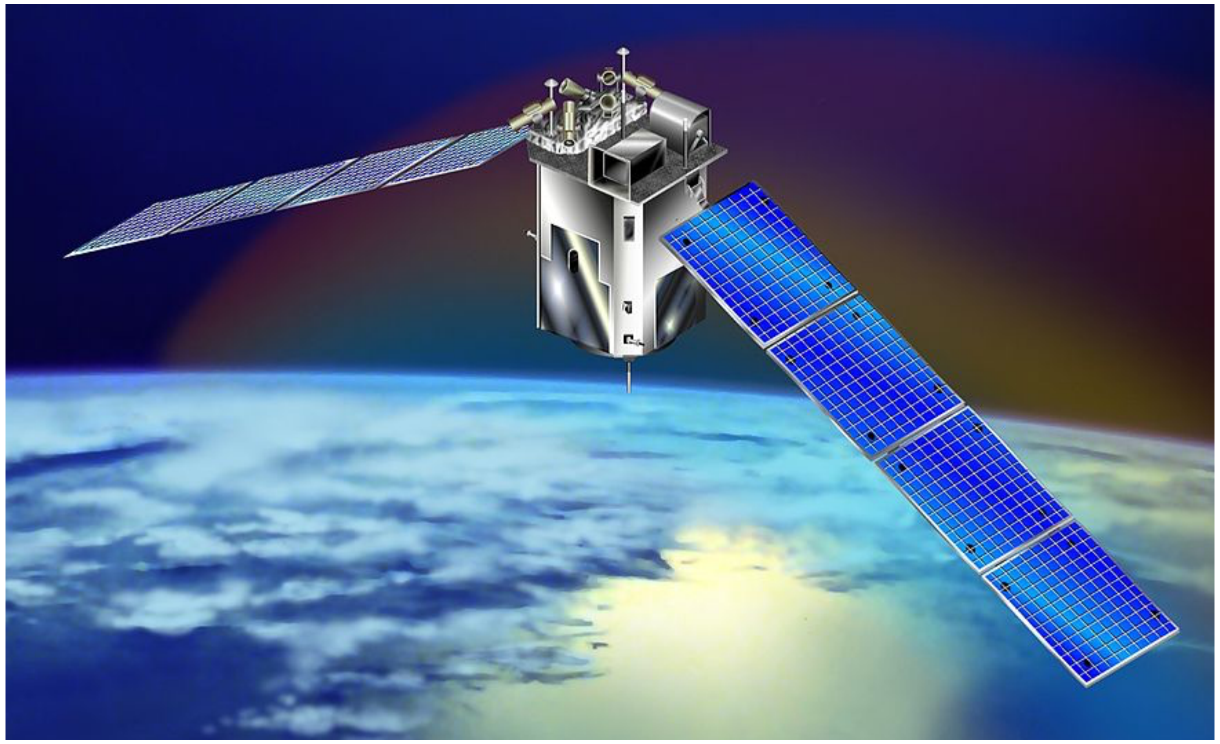
Complex signal processing extracts the frequency spectrum

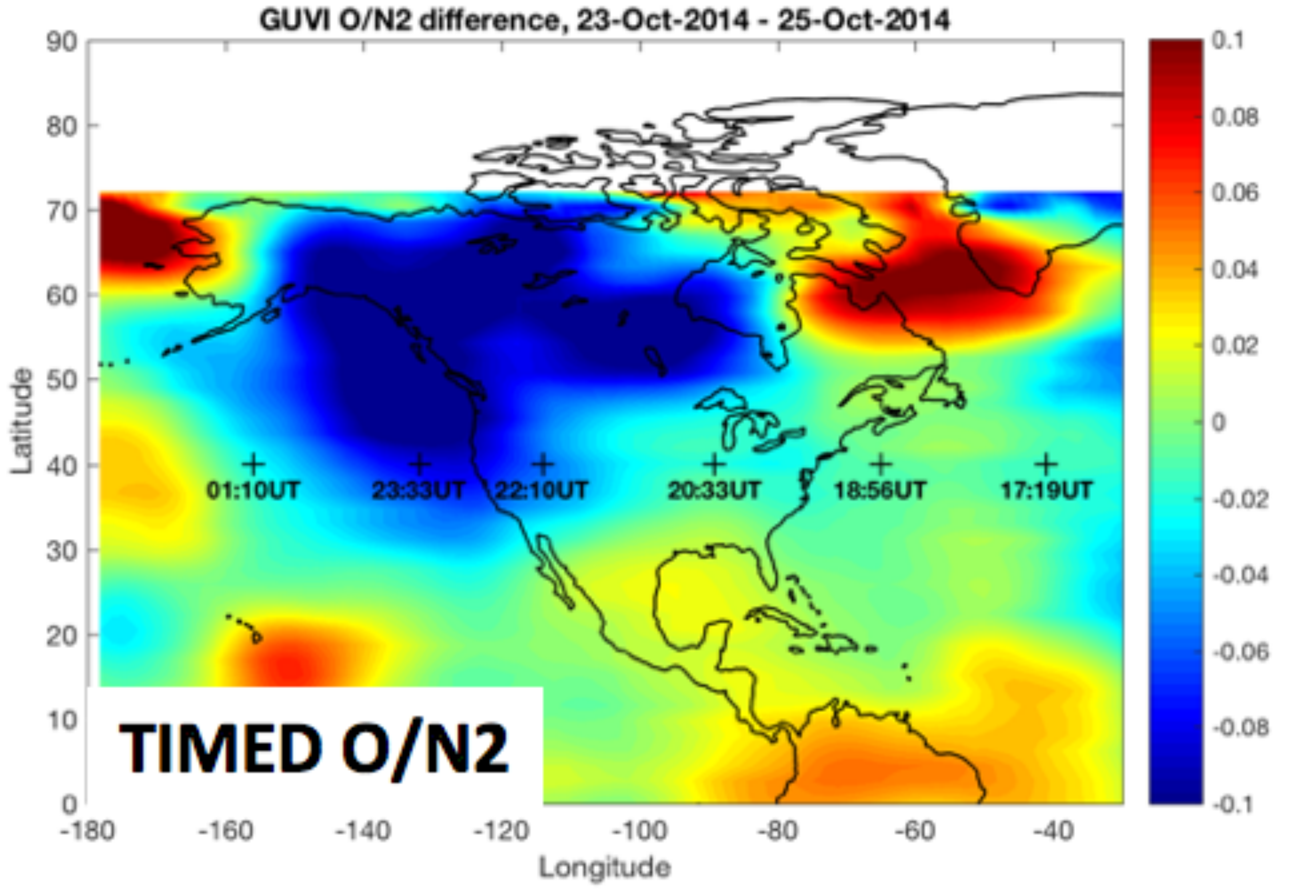
Noise like signal received

Only ~0.0000000000000000001% of the transmitted power is returned!

NASA TIMED Satellite

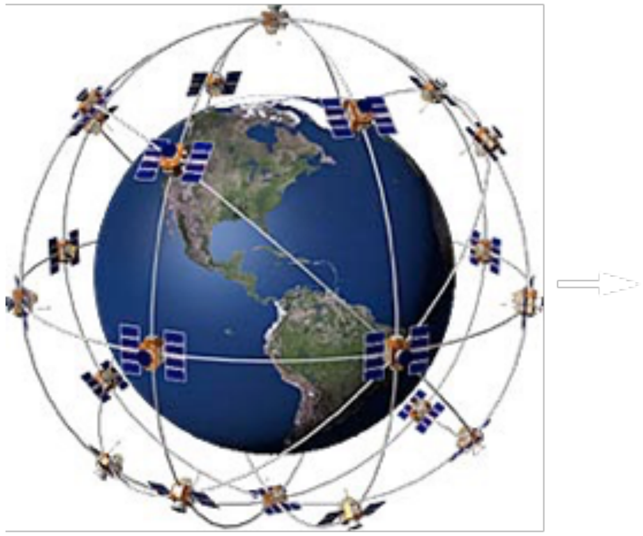
Blue = weaker ionospheric source, red = stronger

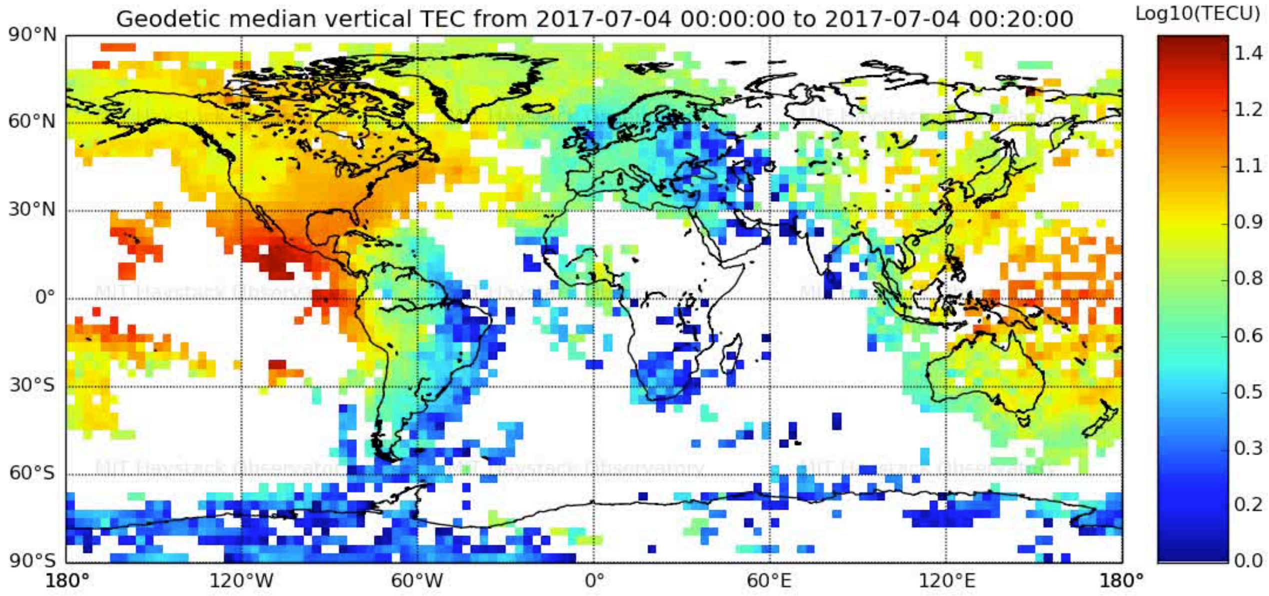




Satellite optical data gives a global picture of the neutral atmosphere **(source of the ionosphere)**

Global Navigation Satellite System (GNSS)





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GNSS data has ionospheric information

Processing can extract global ionospheric maps

University of Colorado **Boulder**

CEDAR Workshop
June 19-23, 2017
Keystone, CO

Studying the D-region ionosphere response to the total solar eclipse through data and modeling

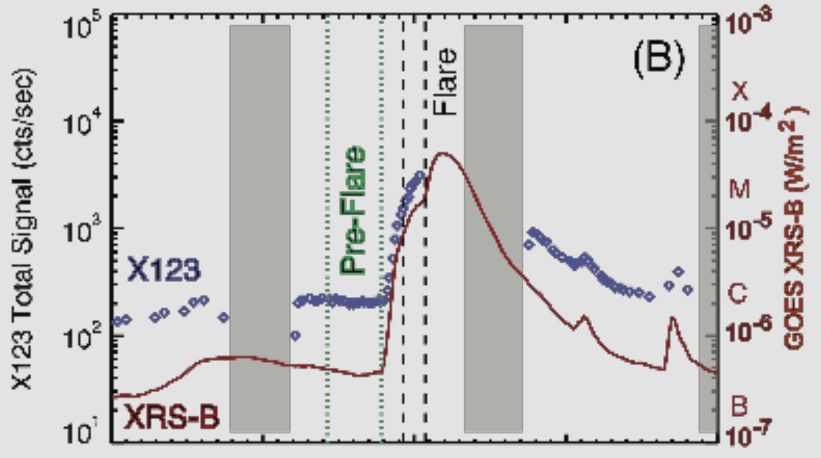
Robert A. Marshall[1]

[1]. Aerospace Engineering Sciences, University of Colorado Boulder, Boulder, CO

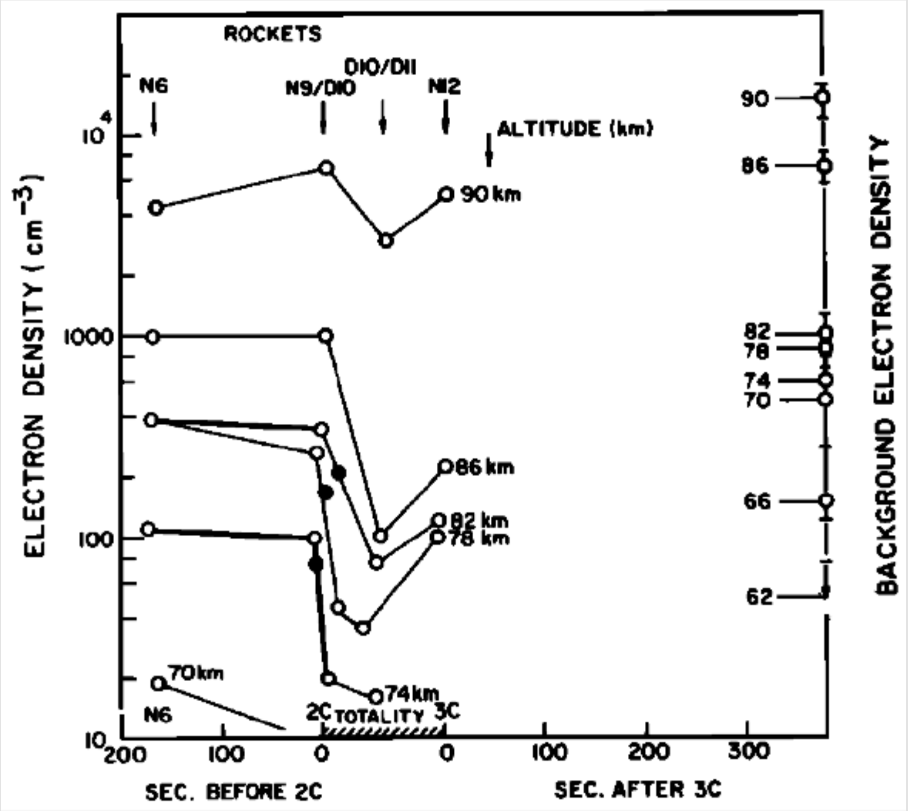
D-region response to Total Solar Eclipse

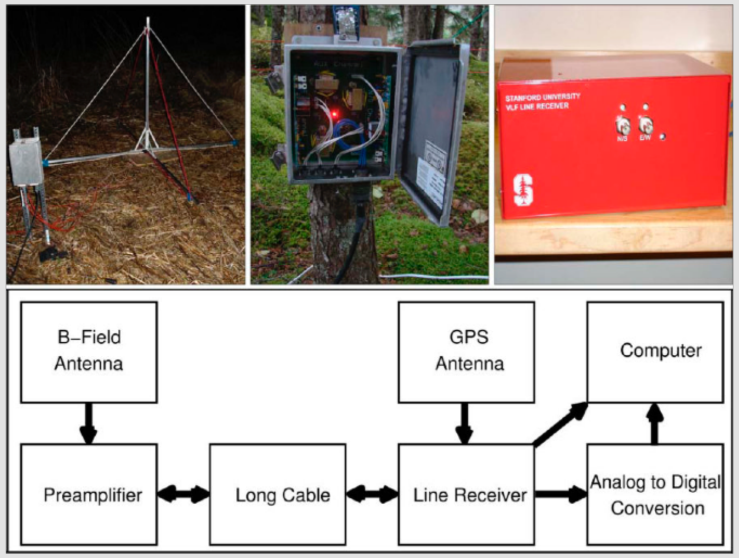
- **Eclipse 2017 provides a unique opportunity to study the D-region when the sun is "turned off"**
- **SQ: What are the contributions of solar Lyman-alpha, EUV, soft X-rays, and hard X-rays to the production of D-region ionization?**

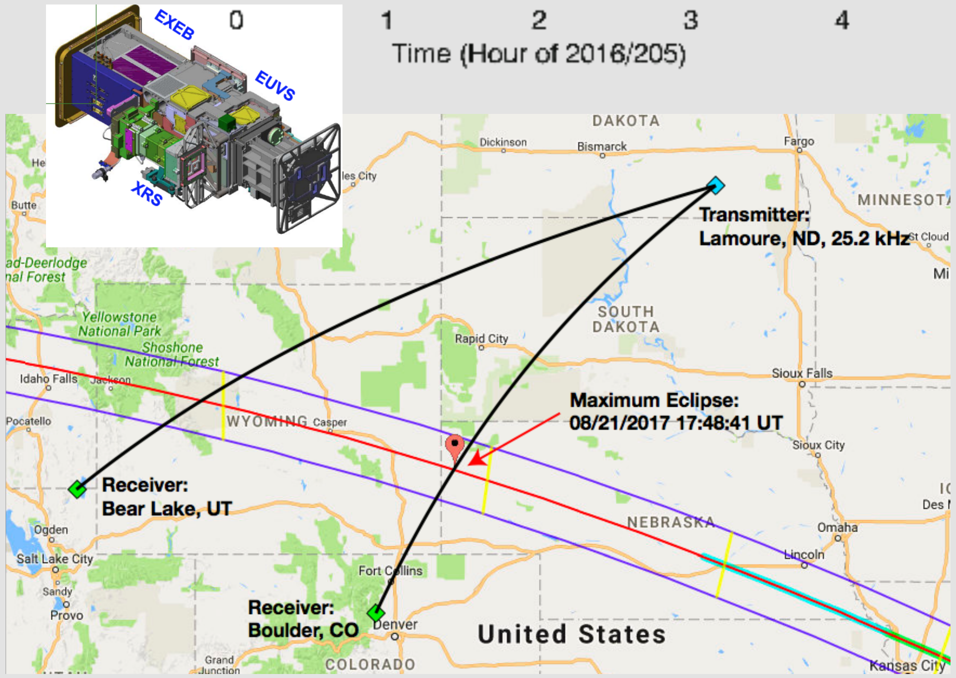
We use a combination of spacecraft ionizing radiation data, subionospheric VLF measurements, and chemistry and propagation modeling to quantify the effects of the eclipse on the D-region ionosphere.

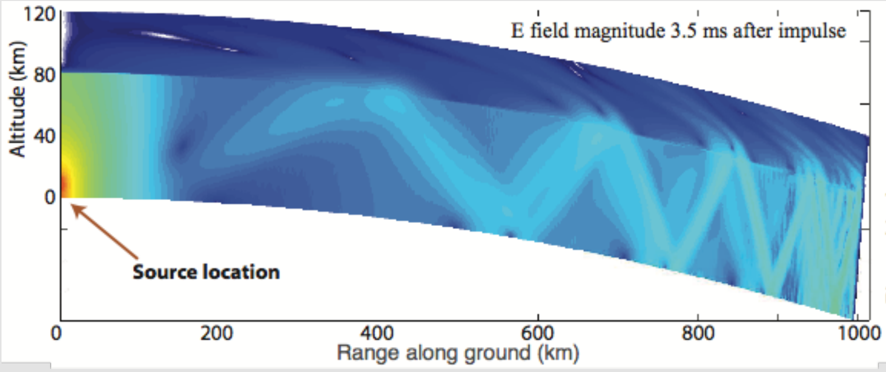


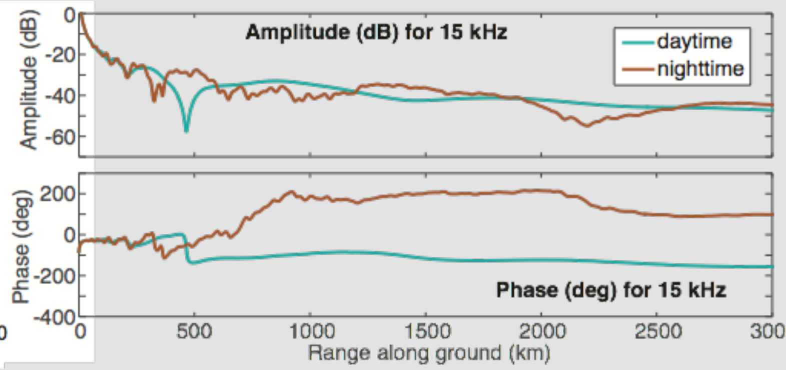
Previous study (Sears, 1981) used rocket experiments to measure electron density







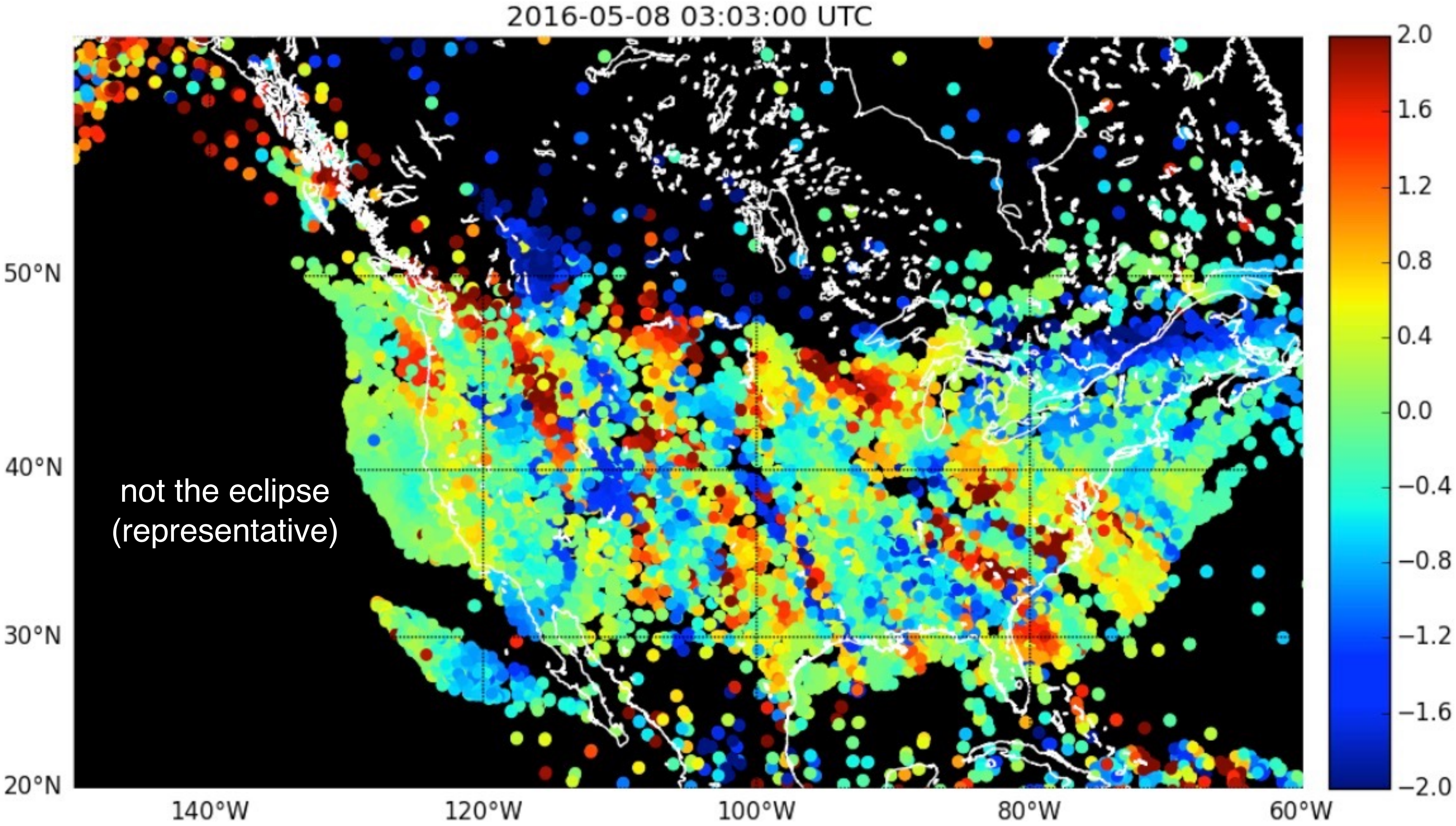




What Was New for the 2017 Eclipse?

GNSS based total electron content

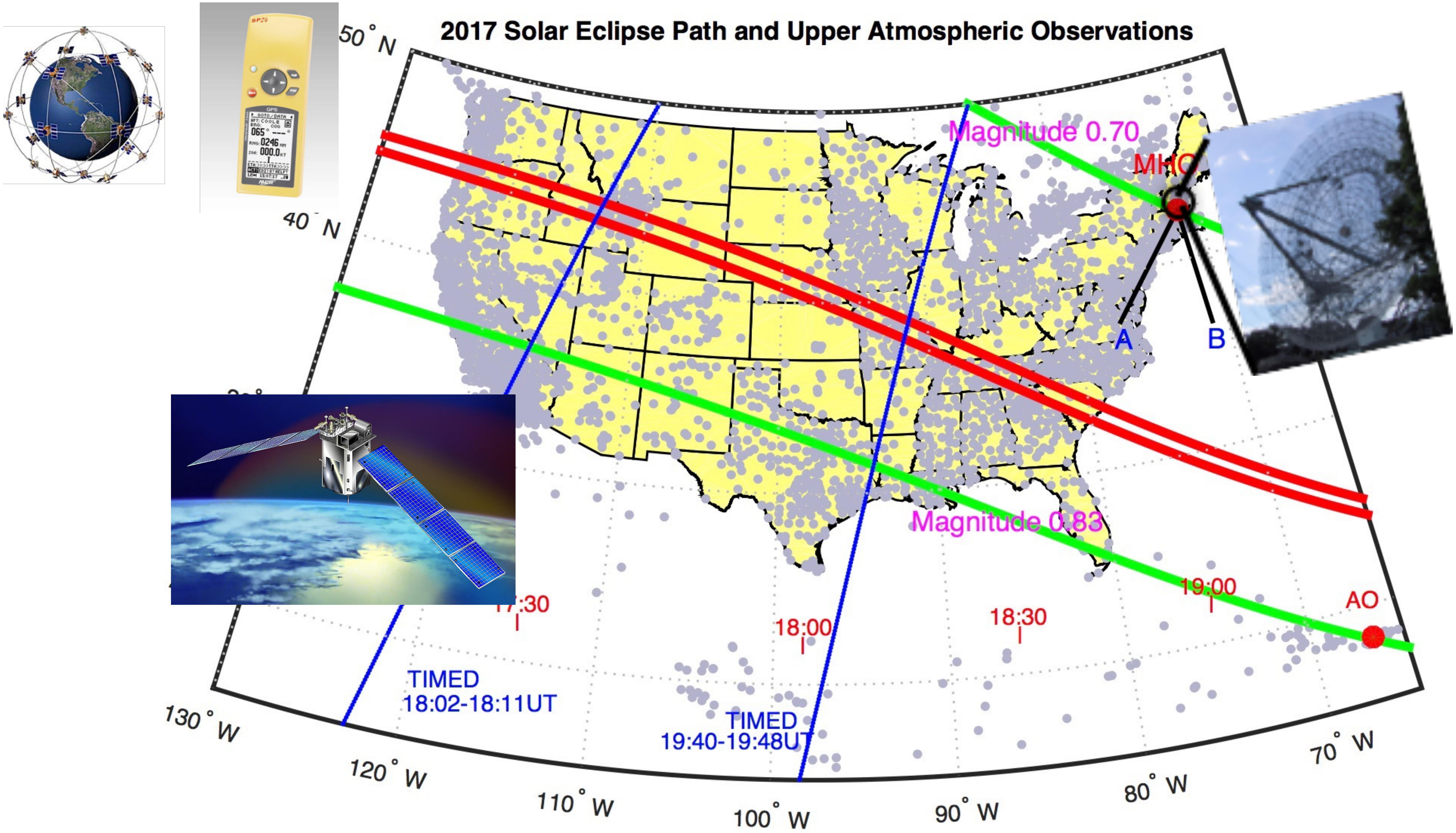
Differences from climate background



not the eclipse (representative)

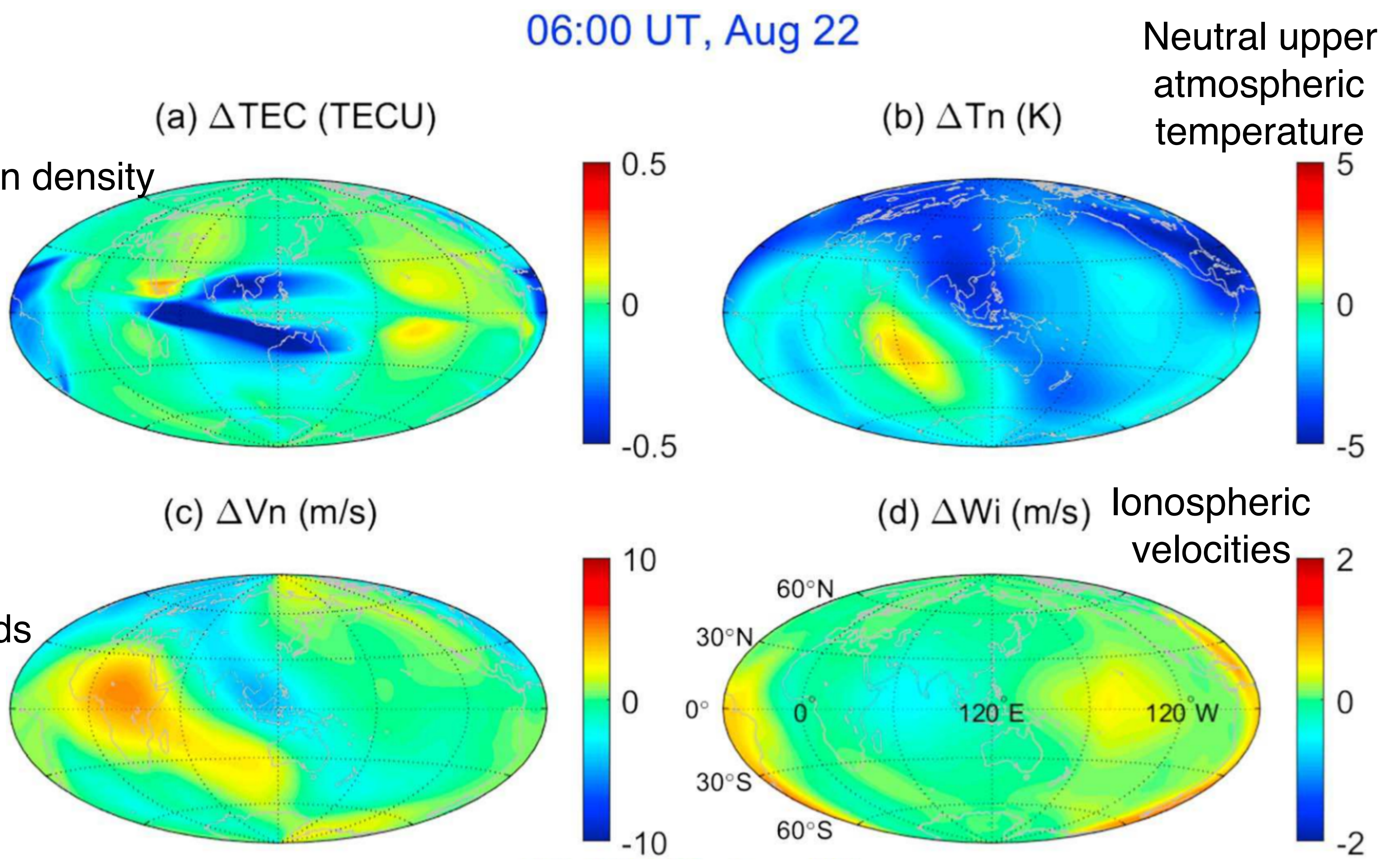
Much better distributed observing over the whole US (thank you, geologists!)

Observational Coverage: The Big Picture



Selected Results
(Many more to come..)

Post-Eclipse Models: Effects Were Global!



Total electron density

Neutral upper atmospheric temperature

Neutral upper atmospheric winds

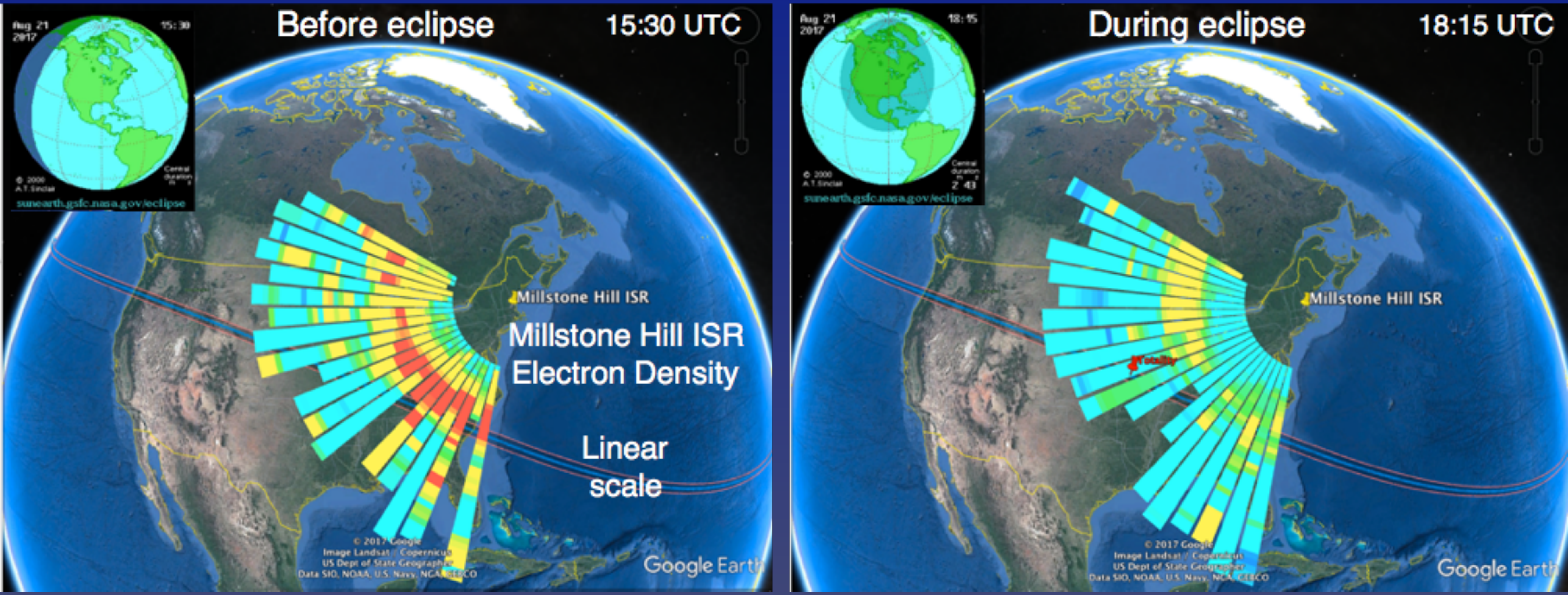
Ionospheric velocities

Lei et al, JGR, 2018

Figure 2. Global maps of differential TEC, neutral temperature, meridional winds (northward positive), and $E \times B$ vertical plasma drifts (upward positive) at pressure level 2 (~300 km) between the TIEGCM simulations with and without eclipse (with eclipse-without eclipse) at 06:00 UT on 22 August 2017, 9 hr after the eclipse ended.

Electron Density, Plasma Motions, Neutral Temperature, Neutral Winds
All Affected By The Eclipse - **Everywhere**

Ionospheric Changes Over North America During The 2017 Eclipse



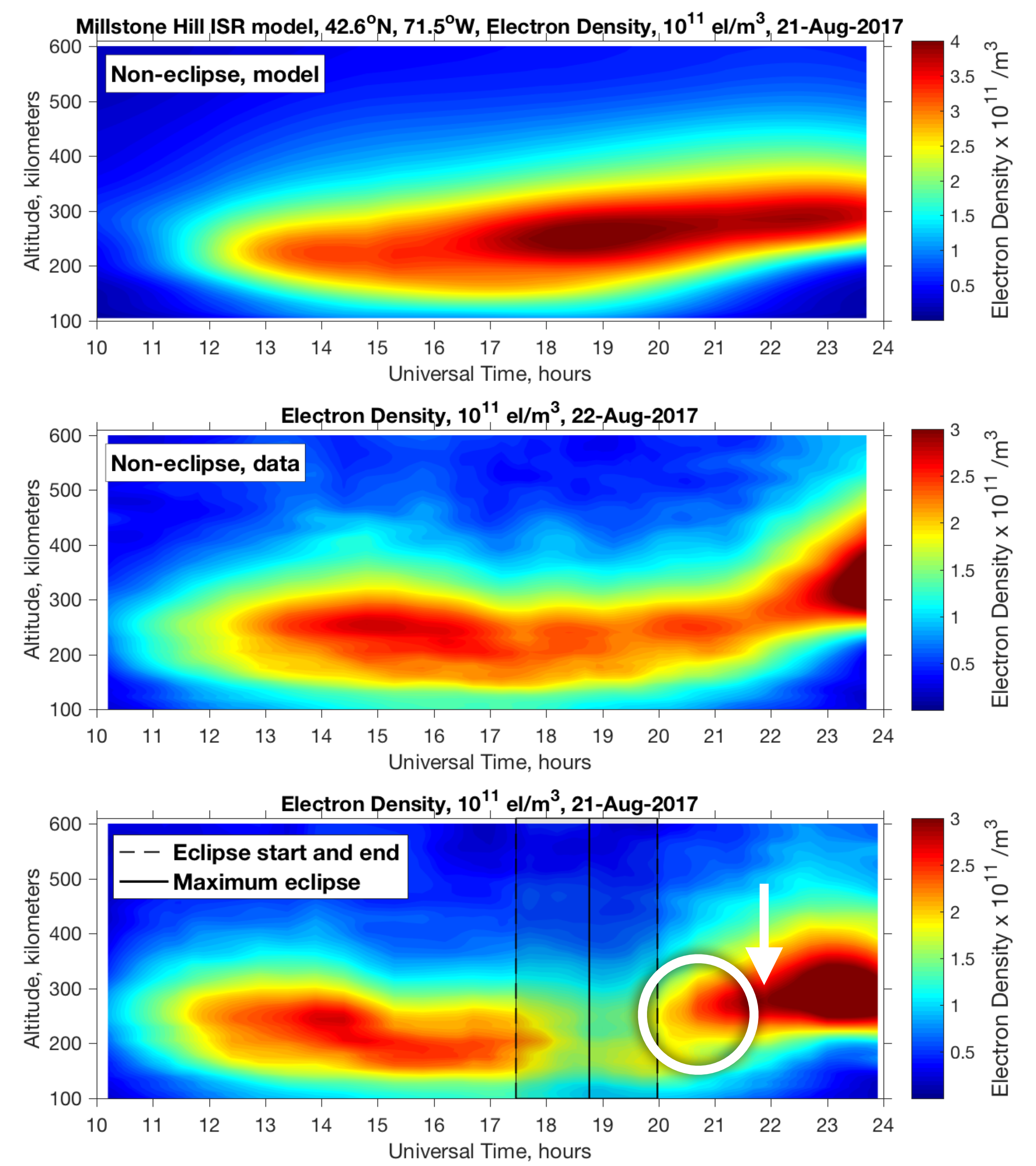
(figure: W. Rideout, MIT Haystack)

Millstone Hill Geospace Facility
Westford, MA, USA

Decrease in electron density during the eclipse by a factor of ~2

Ionospheric Changes Over Massachusetts During The 2017 Eclipse (>1000 km away from totality)

- Gradual decrease in electron density 100-600 km at eclipse start, more than 1000 km away from umbral shadow
- Quick recovery after eclipse
- Lower altitudes recovered faster than higher altitudes
- Natural space weather variations occurred even on non-eclipse day



Goncharenko, L. P., Erickson, P. J., Zhang, S.-R., Galkin, I., Coster, A. J., & Jonah, O. F. (2018). Ionospheric response to the solar eclipse of 21 August 2017 in Millstone Hill (42N) observations. Geophysical Research Letters, 45. https://doi.org/10.1029/2018GL077334

Eclipse Bow Waves In The Ionosphere?

Eclipse bow waves predicted by many studies (e.g. Chimonas [1970])

Did the 2017 Eclipse create bow wave structures?

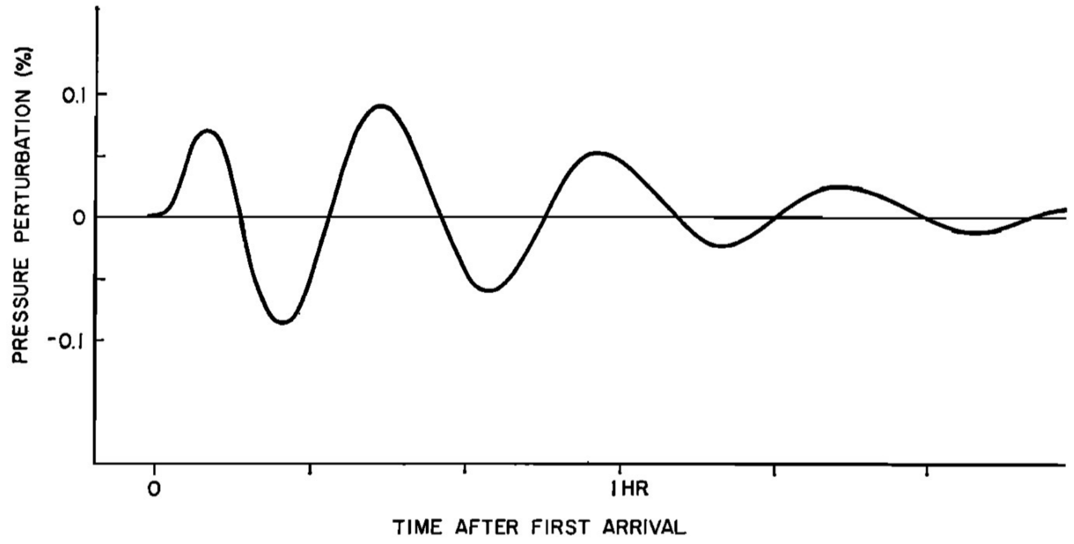
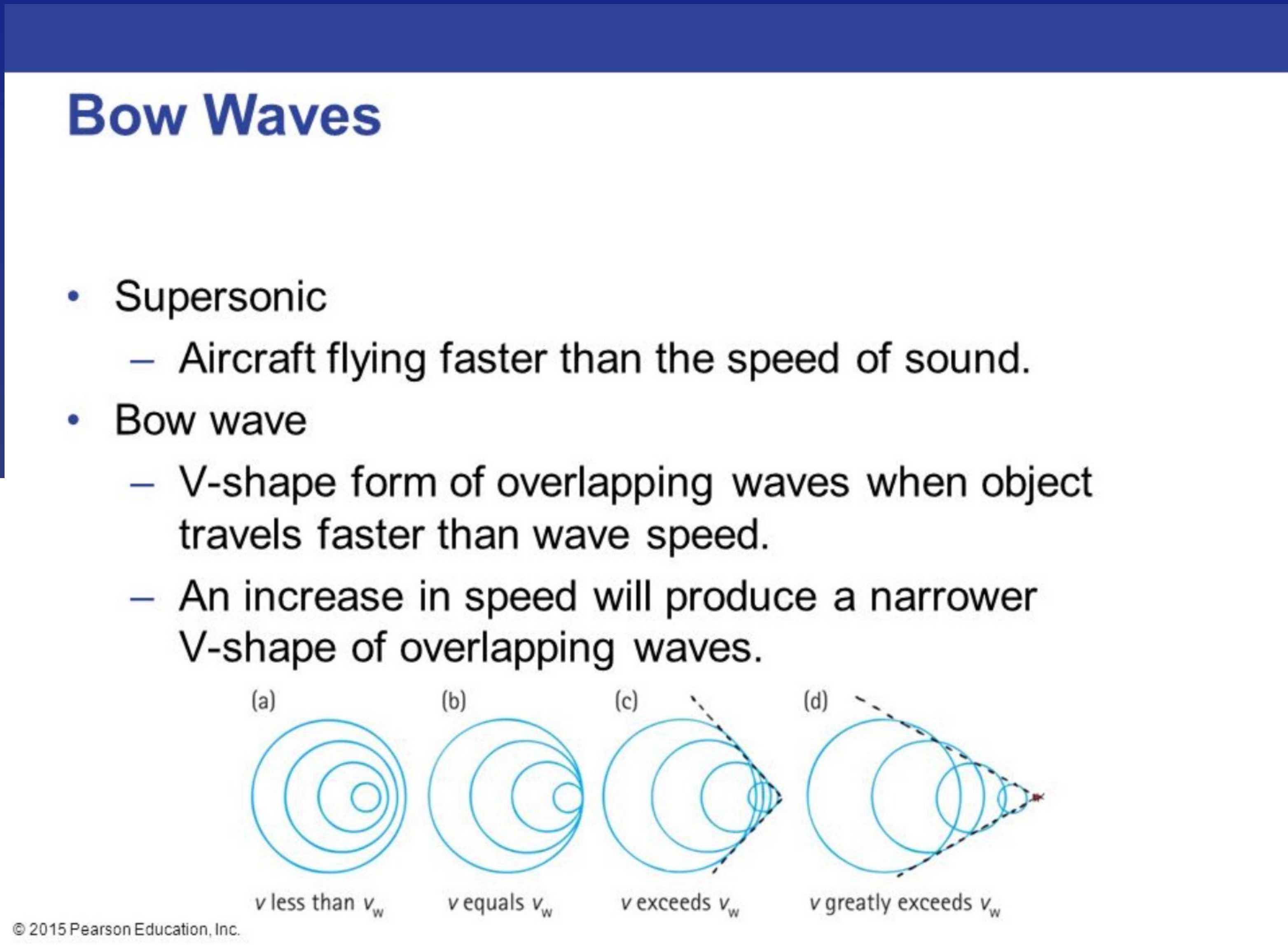


Fig. 2. The pressure perturbation bow wave caused by an eclipse, as computed from the theory of *Chimonas* [1970] for a point 5000 km off the axis of the eclipse path and 300 km above the earth's surface.



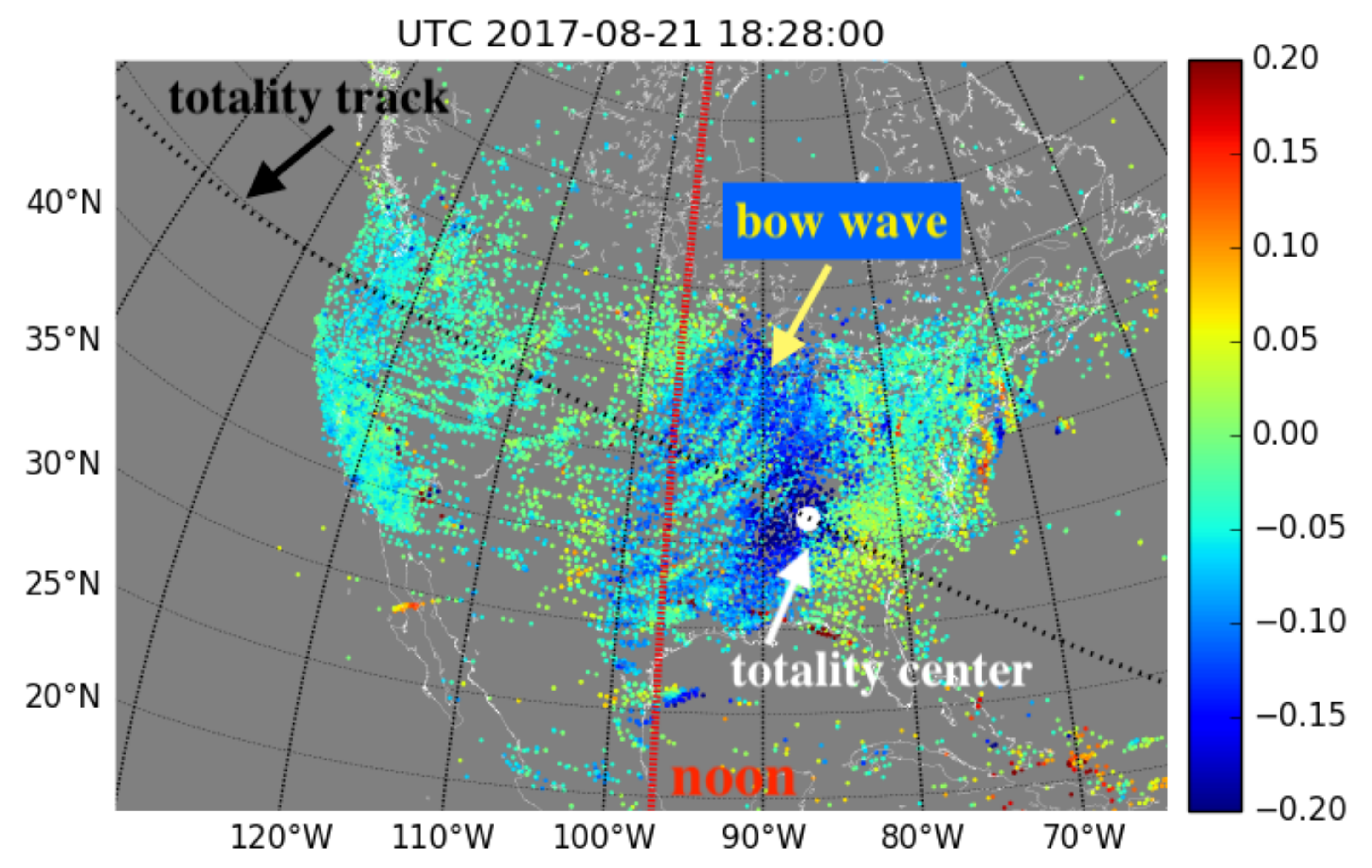
Bow Waves

- Supersonic
  - Aircraft flying faster than the speed of sound.
- Bow wave
  - V-shape form of overlapping waves when object travels faster than wave speed.
  - An increase in speed will produce a narrower V-shape of overlapping waves.

(a) v less than v_w
(b) v equals v_w
(c) v exceeds v_w
(d) v greatly exceeds v_w

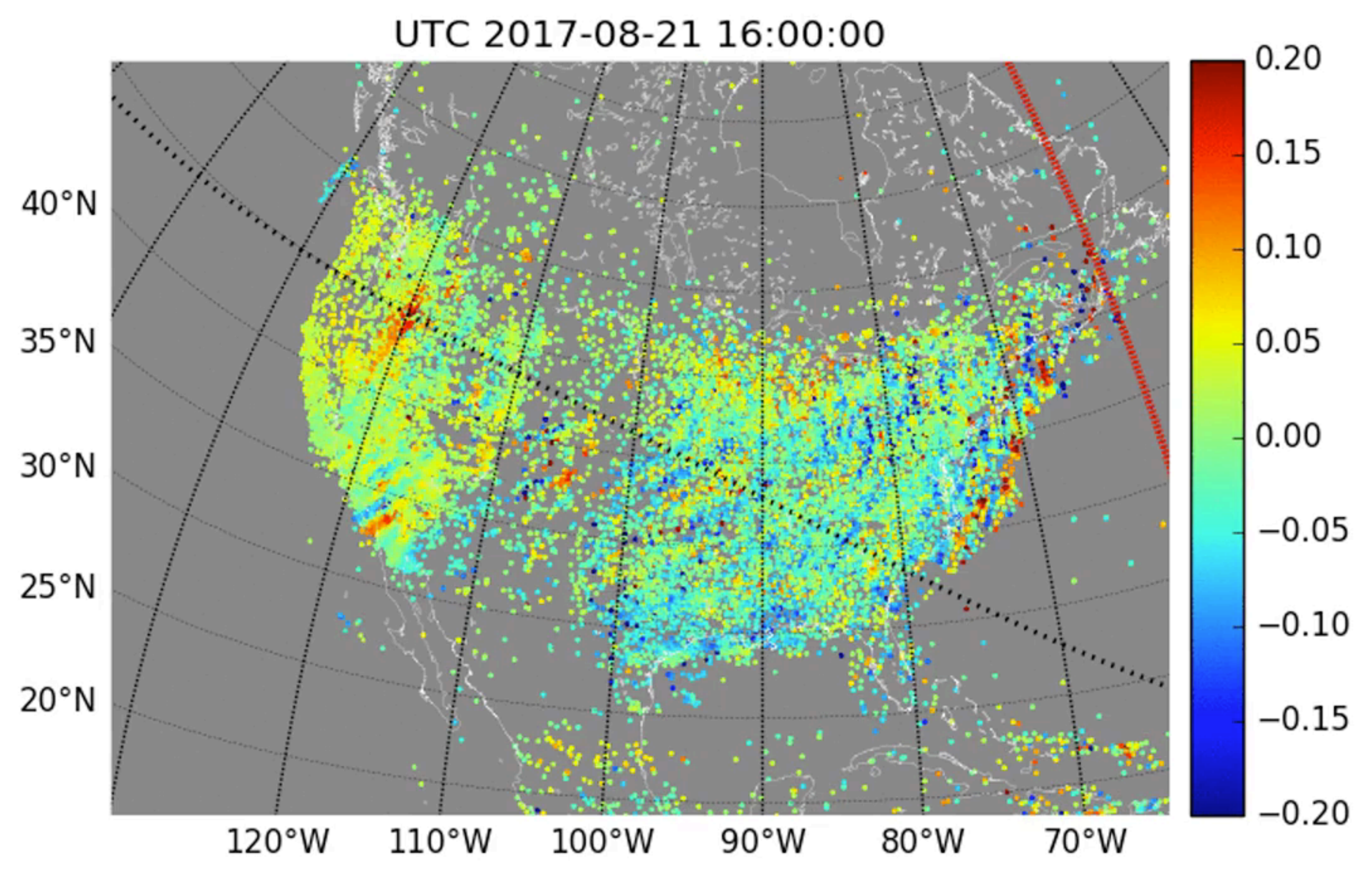
Ionospheric Bow Waves Seen Over Continental US During The 2017 Eclipse

- ★Differential total electron content maps = space weather in electron density
- ★**First unambiguous observations** of eclipse induced circular ionospheric bow waves
- ★Created by supersonic eclipse shadow moving across US
- ★Waves subsequently propagate at ~300 m/s speed along totality path



Zhang S.- R., P.J Erickson, L. Goncharenko, A.J. Coster, W. Rideout, and J. Vierinen (2017), Ionospheric bow waves and perturbations induced by the 21 August 2017 solar eclipse, Geophys. Res. Lett., 44, doi:10.1002/2017GL076054.

Ionospheric Bow Waves Seen Over Continental US During The 2017 Eclipse



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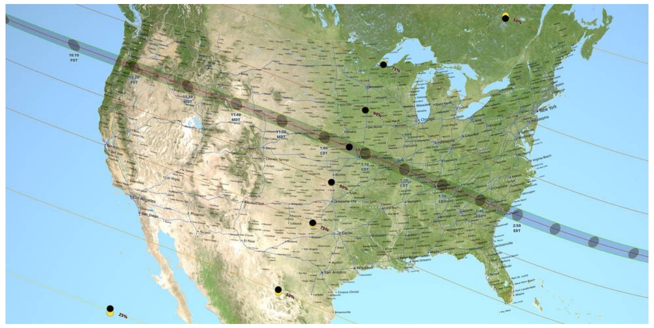
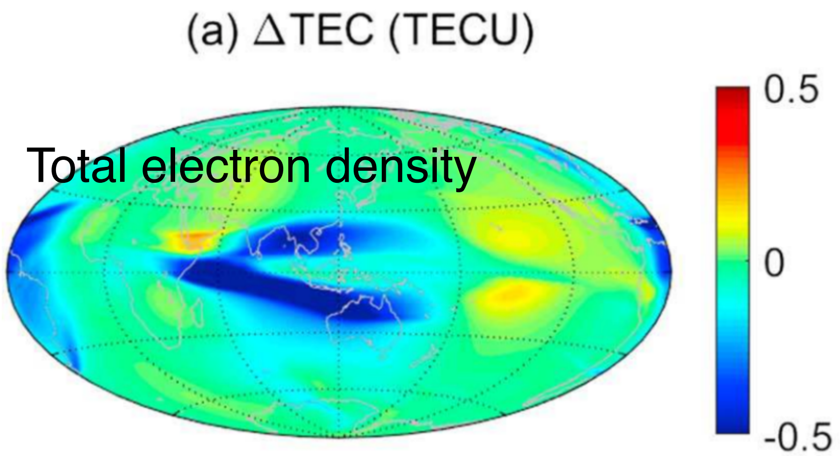
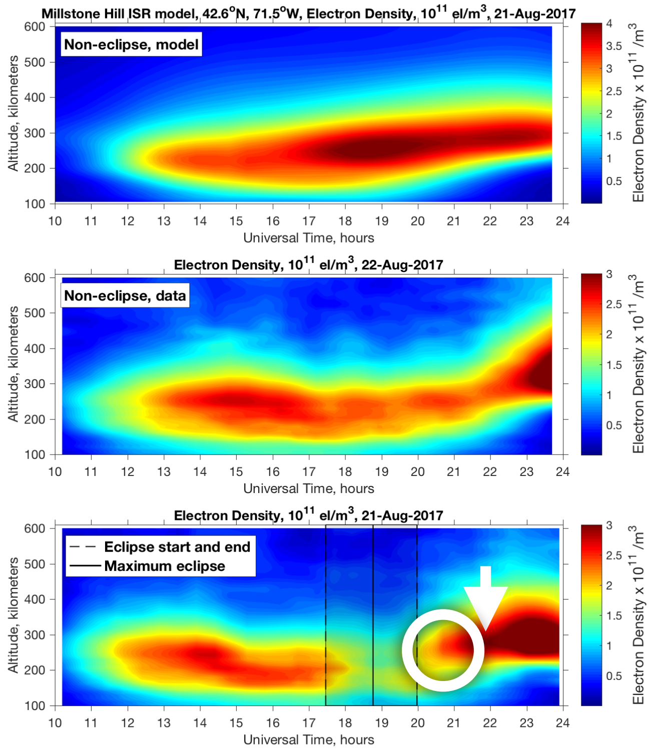
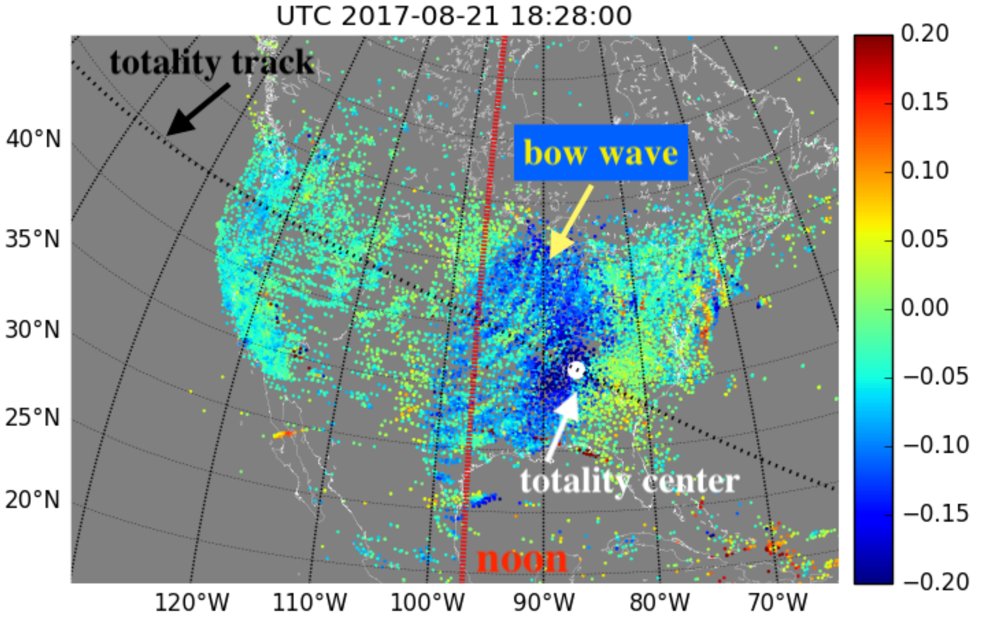
Summary



06:00 UT







Eclipses are a rich source of information about our planet’s dynamic atmosphere
Each eclipse provides vital information about basic and applied physics
Eclipses = Natural (and huge!) space weather experiment, provided by our sun
Modern instrumentation allows us to discover new knowledge about our environment

Non-traditional observation networks (ham radio!) have much to contribute - see W2NAF’s talk next.