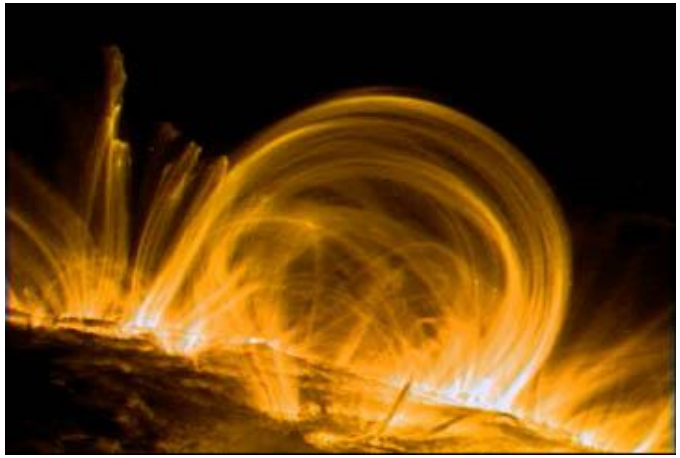


INTRODUCTION TO SOLAR WEATHER & HF PROPAGATION

Lewis Thompson

W5IFQ

2 JAN 2024

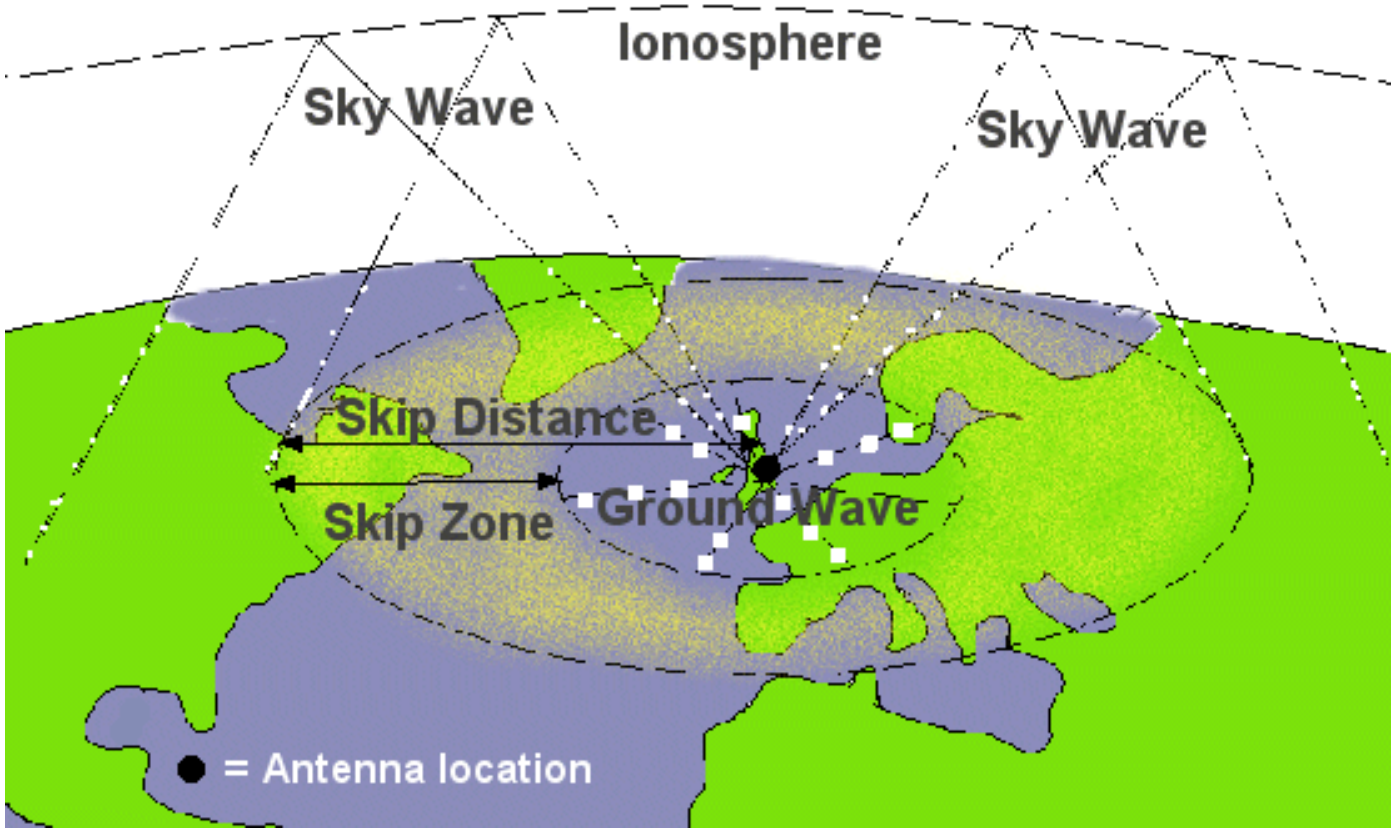
Outline

- Ionospheric propagation
  - NVIS
  - Long-Range
  - Frequency Selection (Critical Frequency & MUF)
  - Propagation modeling
- Solar Weather
  - Ionosphere (Solar Flux, Sun Spot Number)
  - Earth's Geomagnetic Field
  - Solar Flares
  - CME
  - Proton Event

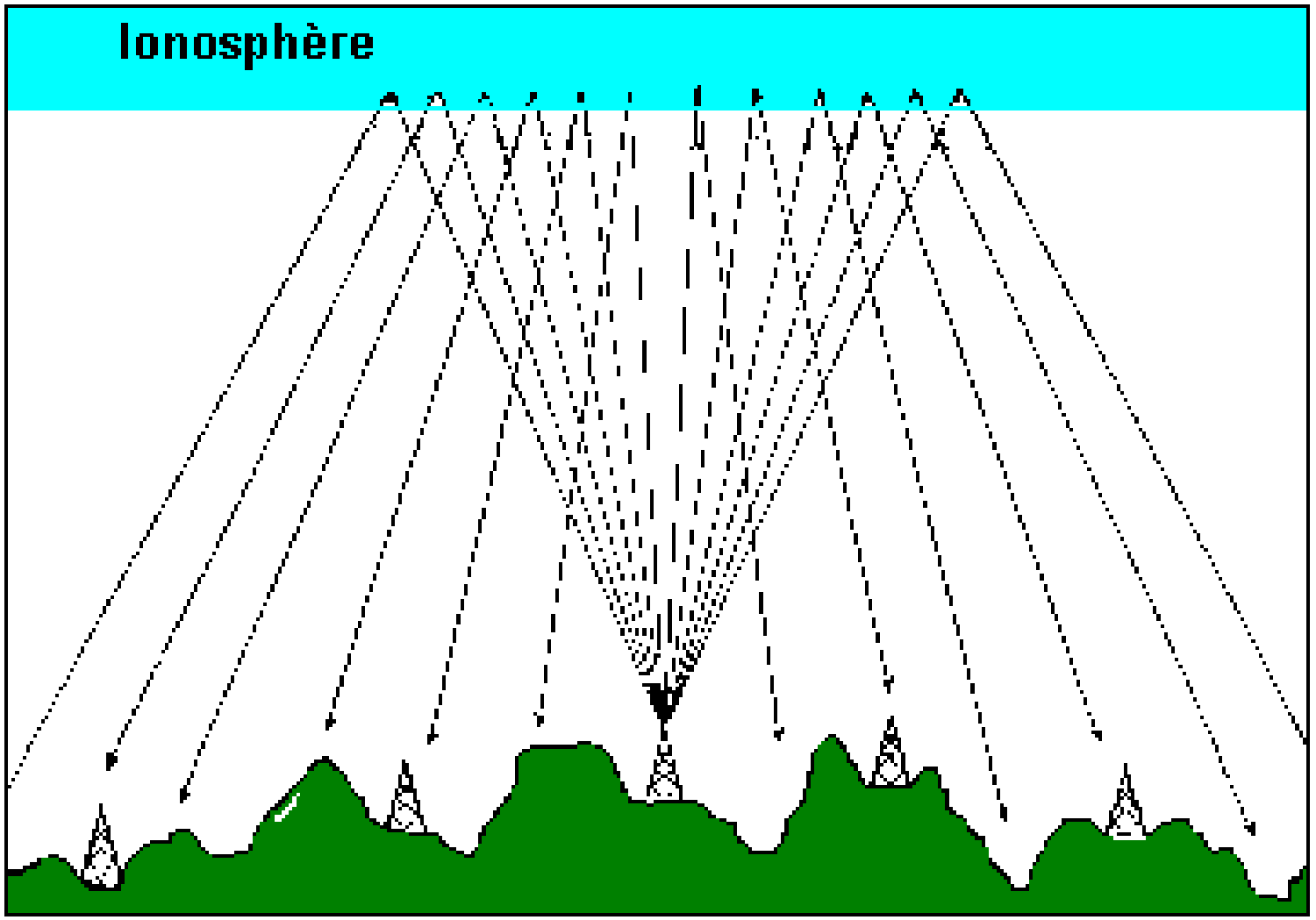
HF Propagation Modes
(3 – 30 MHz)

- Free Space – Line of sight
- Ground Wave – Follows Earth's curvature
- Ionospheric Skip (Affected by Solar Wx)
  - Long Distance with a "skip-zone"
  - NVIS (Near Vertical Incidence Sky Wave)

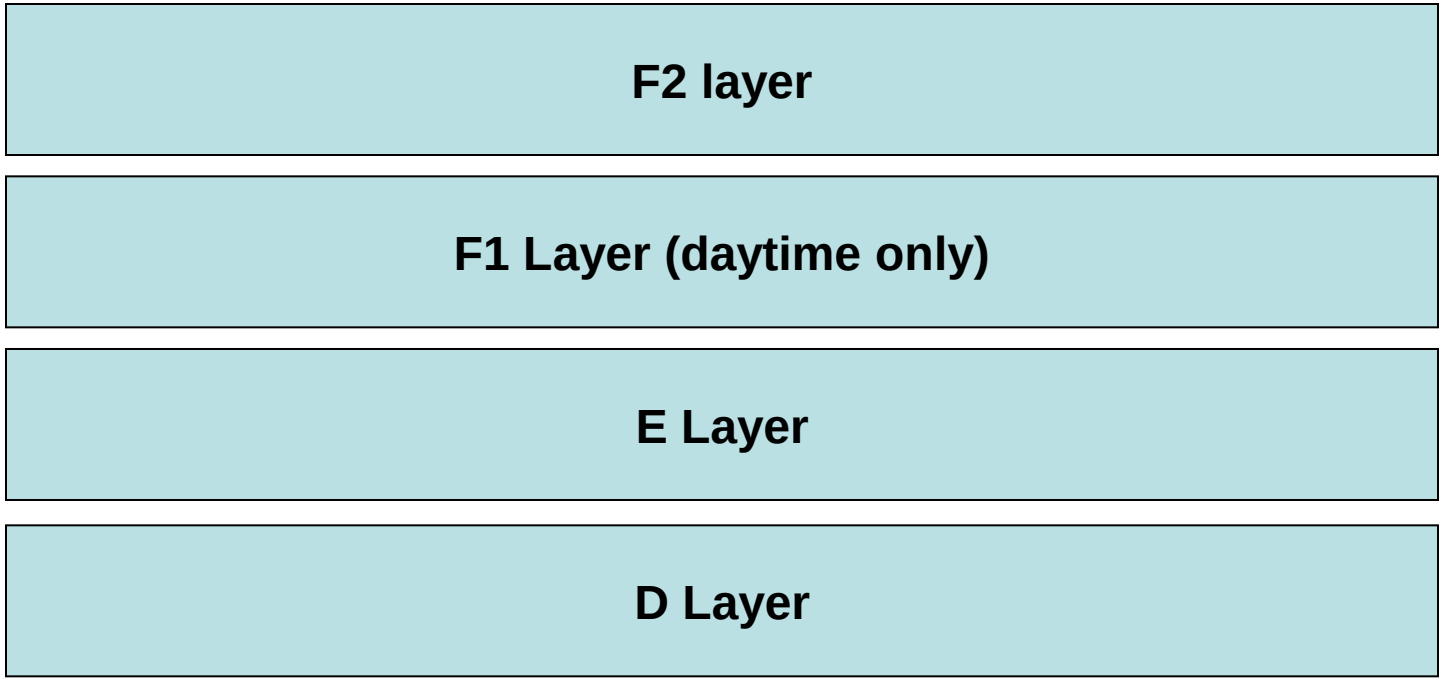
Long Distance Sky Wave



NVIS Propagation

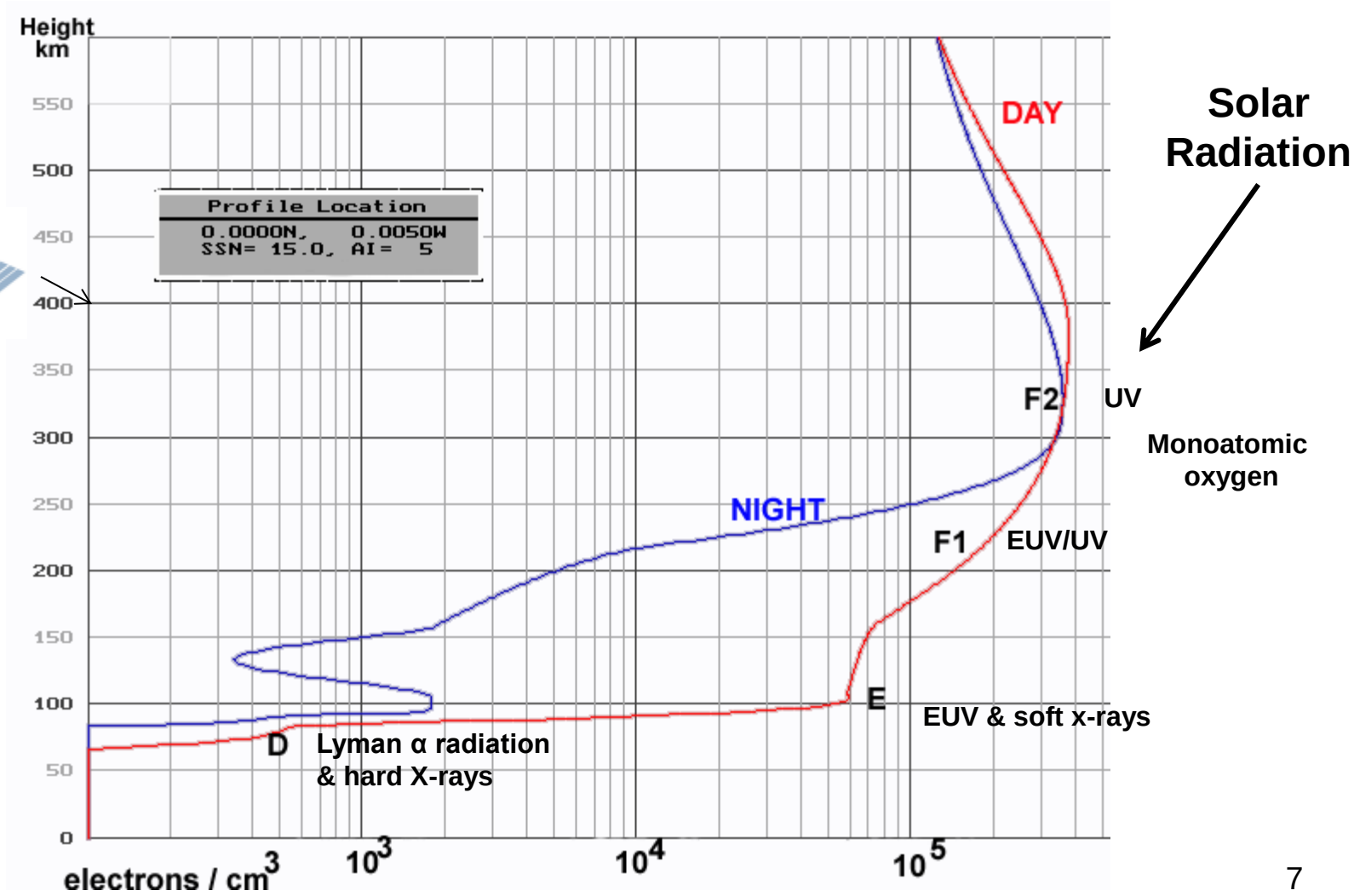


IONOSPHERE



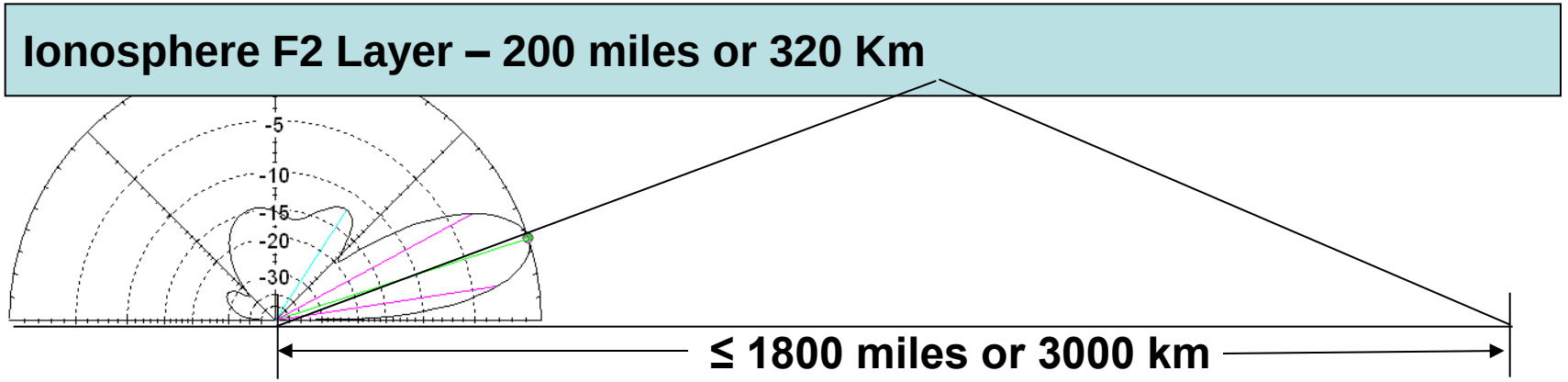
Ionosphere Structure

Gravity



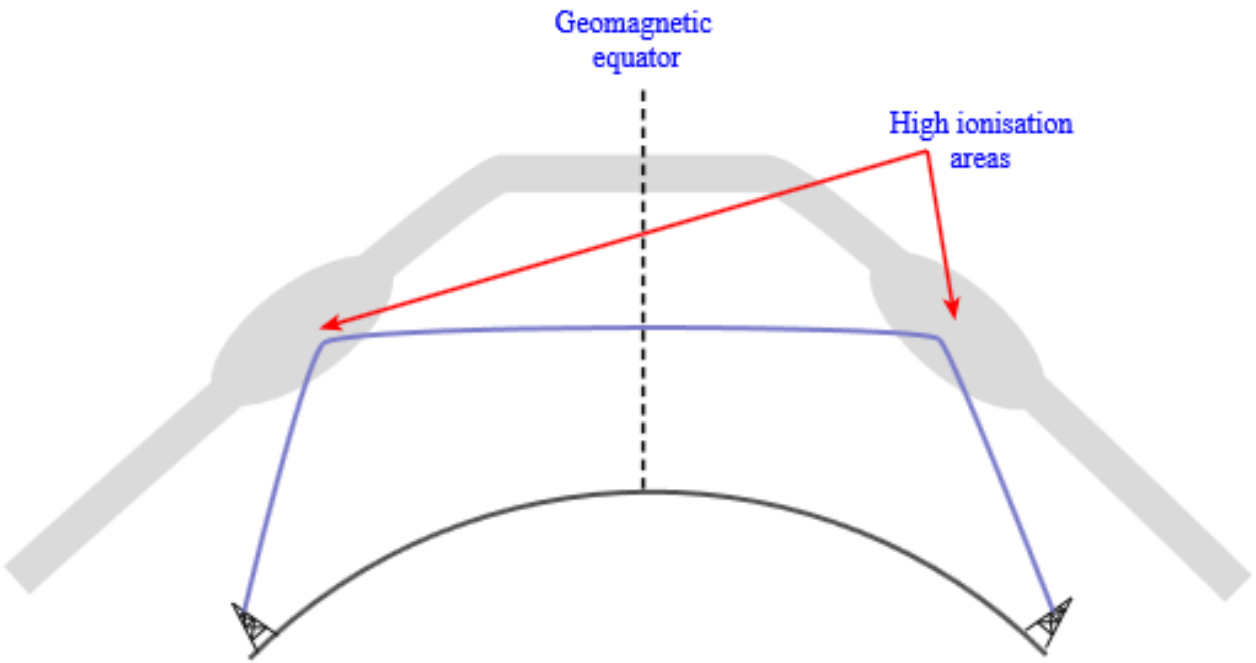
Solar Radiation

TYPICAL LONG-RANGE PROPAGATION



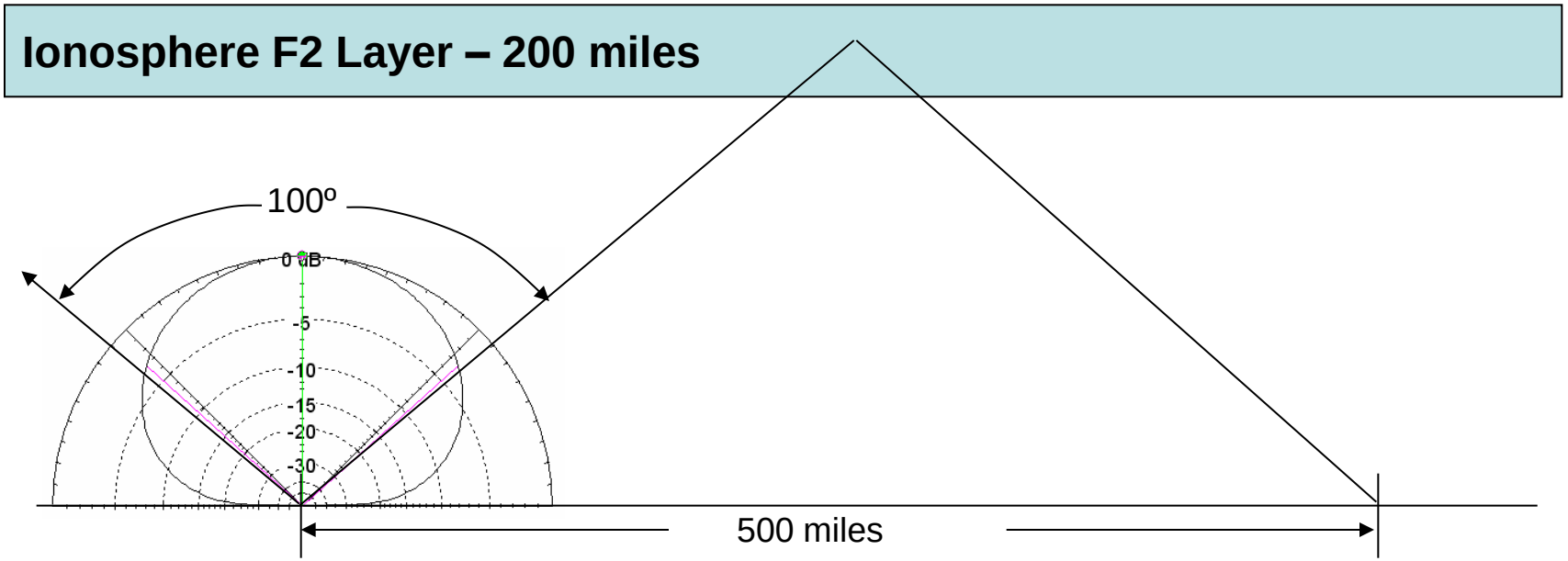
Both F2 & E layers propagation can be involved in multiple reflection circuits.

Transequatorial Propagation (TEP)



Mode of operation of transequatorial propagation, TEP

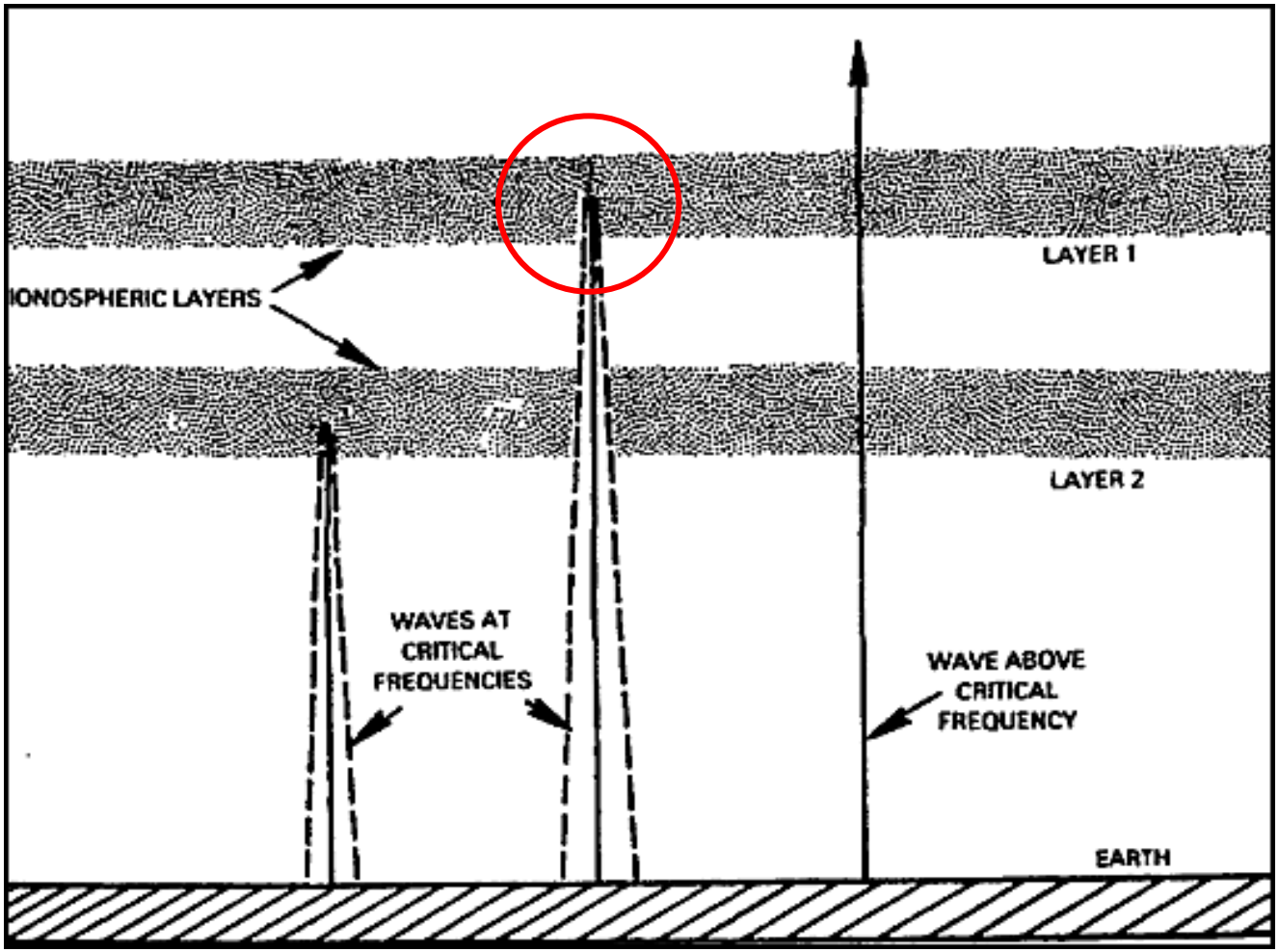
NVIS PROPAGATION



Only F2 layer propagation can provide necessary range

NVIS Frequency Selection

- Must operate at or below the local Critical Frequency (CF)

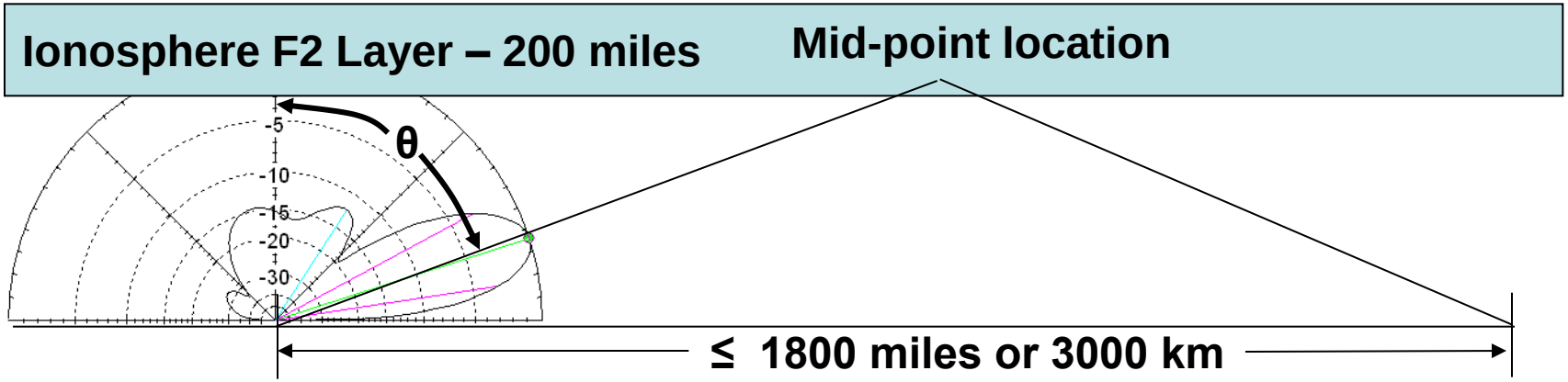


Critical Frequency

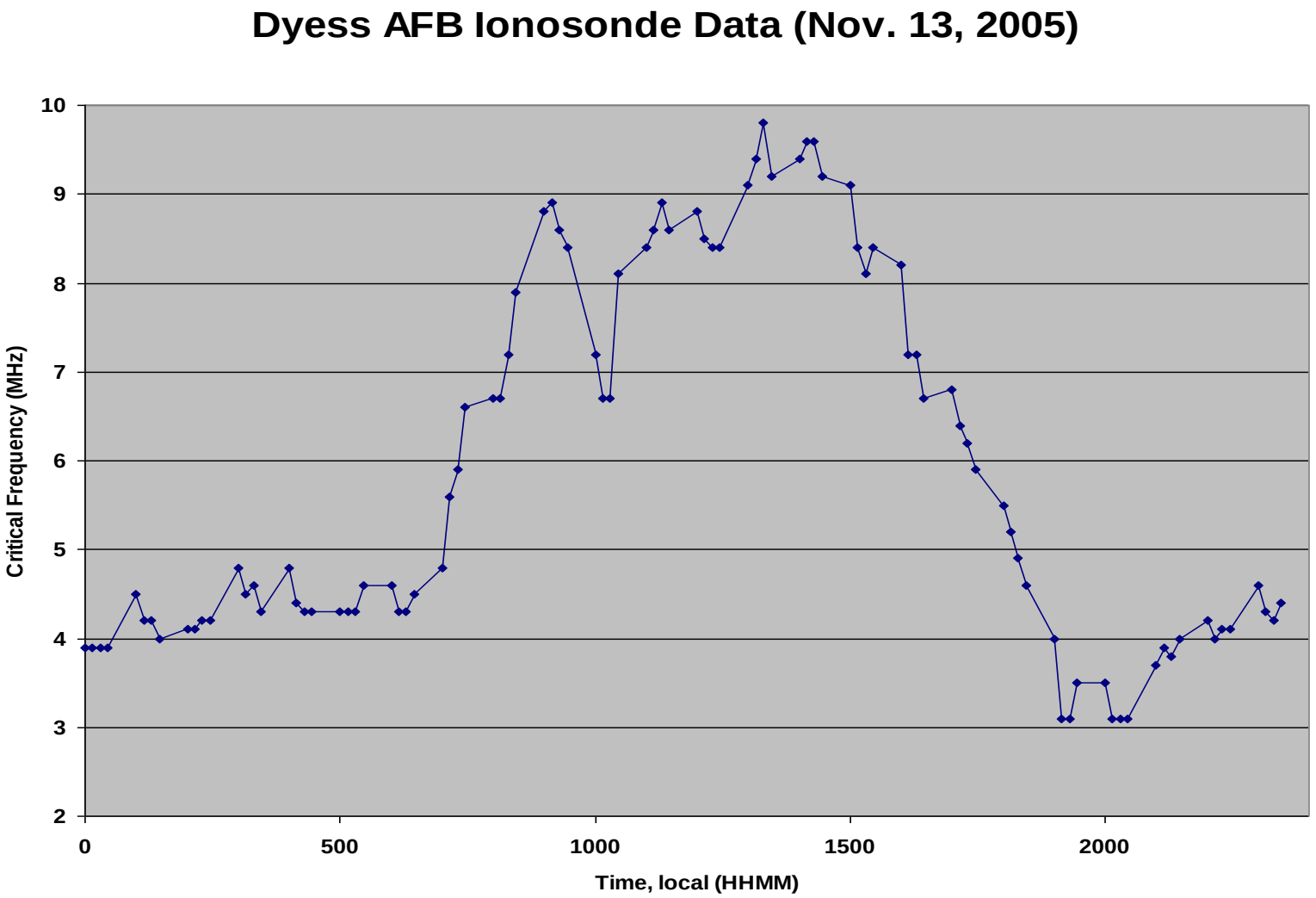
- Critical Frequency increases with increased ionization of F-layer
  - Time of day
  - Time of year
  - Time of the 11-year sun spot cycle

Maximum Useable Frequency (MUF)

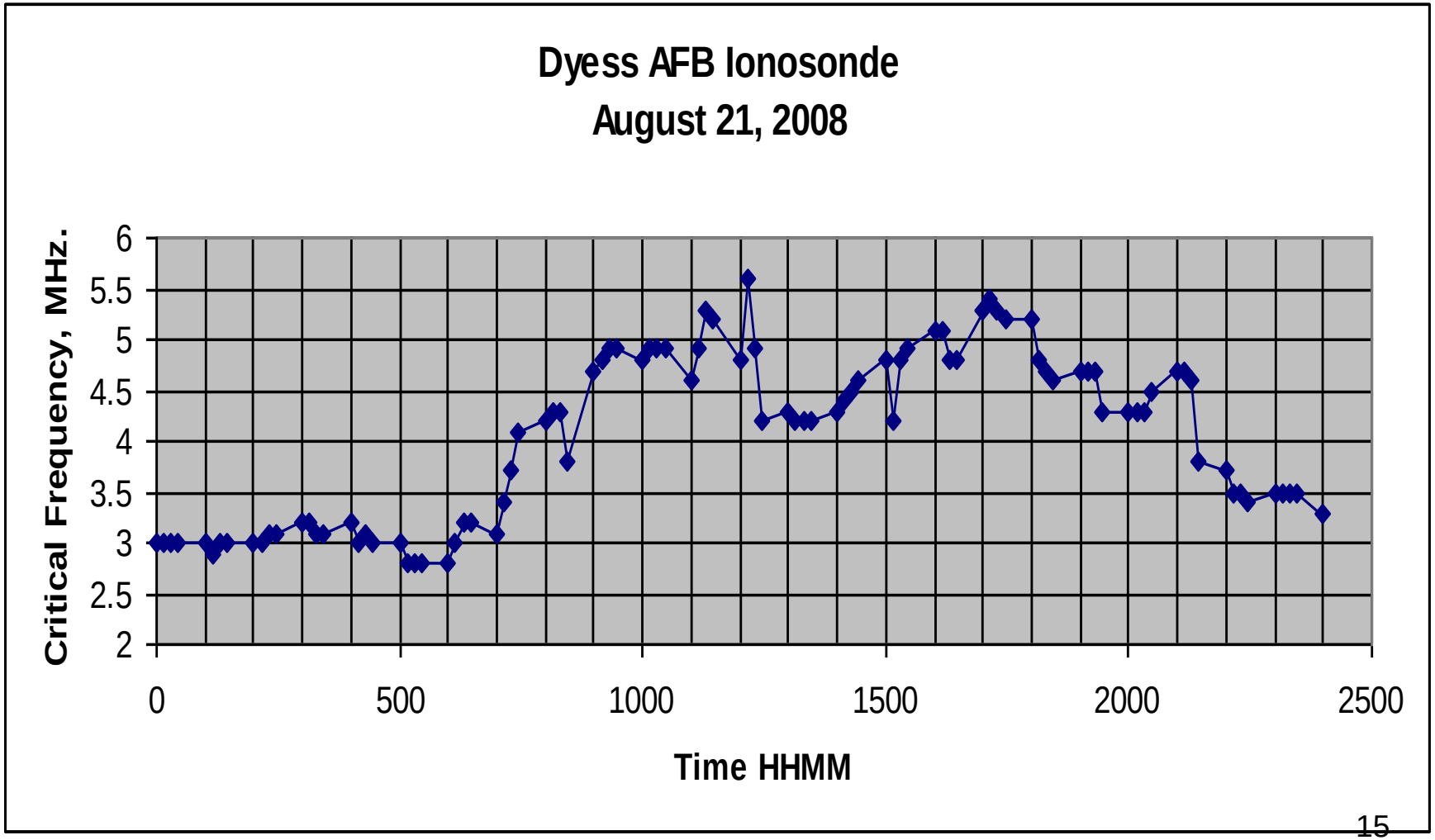
- MUF (Maximum Useable Frequency) is CF/cosθ, where θ is the angle from the take-off beam to vertical.



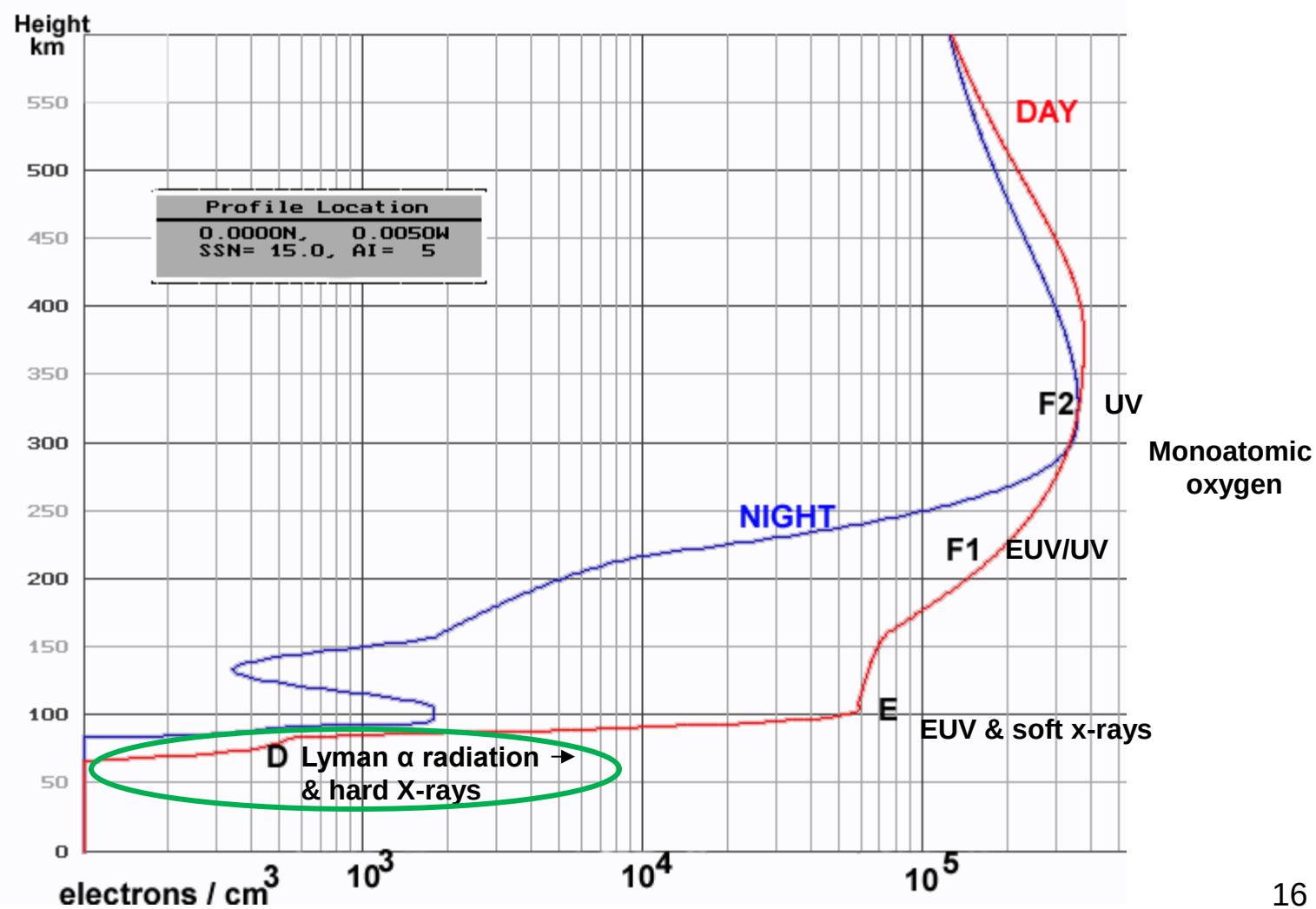
Critical Frequency
(During Sun Spot Cycle 23)



Critical Frequency
(Between Cycles 23 & 24)

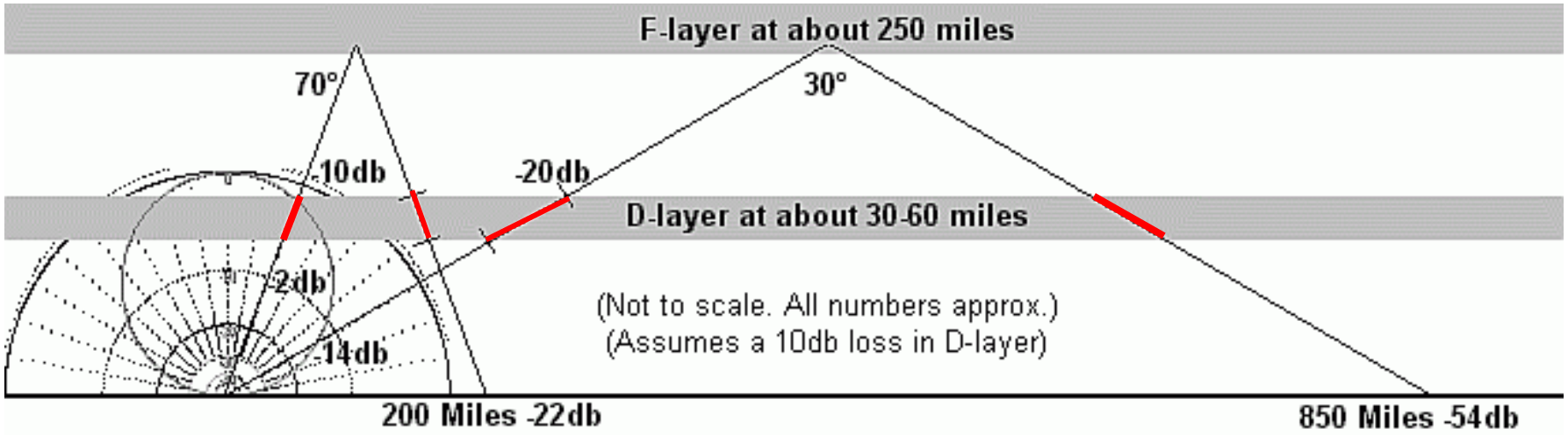


Lowest Useable Frequency (D-Layer Absorption)



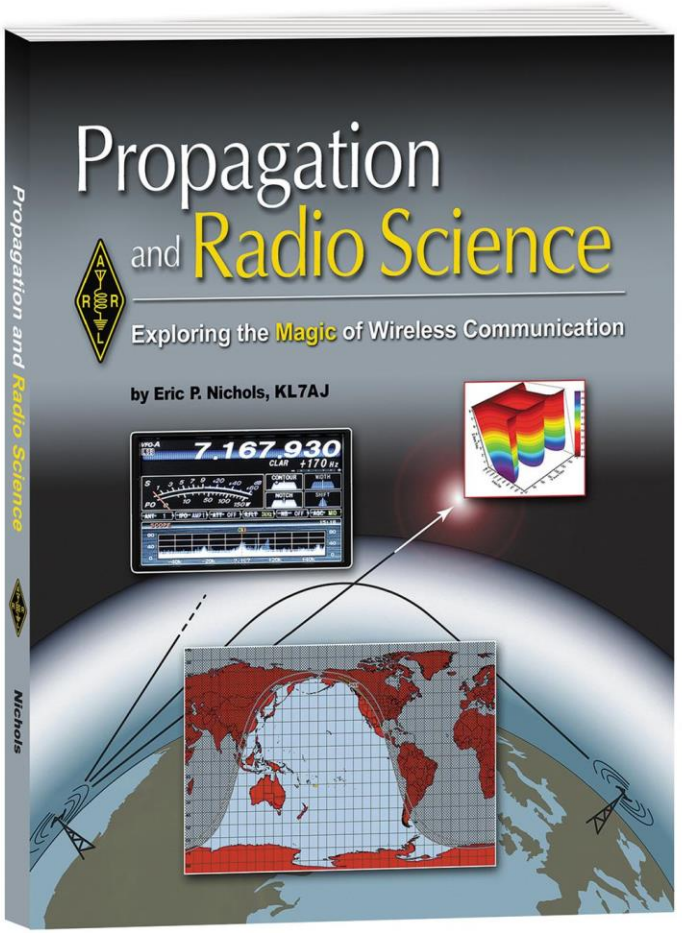
Lowest Usable Frequency (LUF)

- Controlled by D-Layer absorption
- Day-time effect (Gray-Line)
- Function of transmit power and mode of operation
- Absorption is a function of $1/f^2$



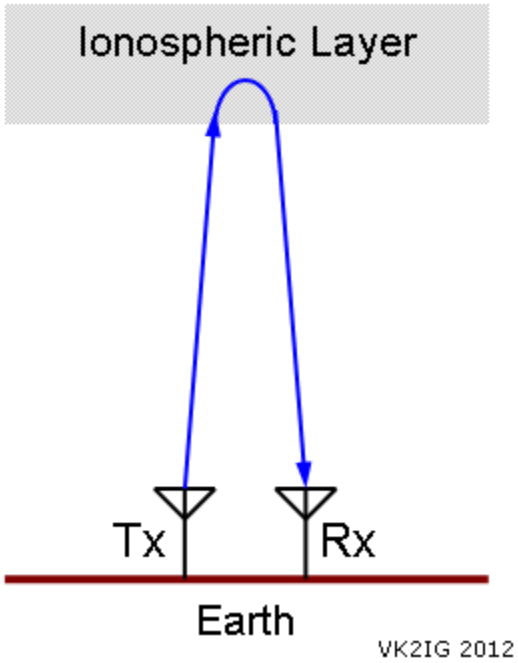
Ionosonde Use

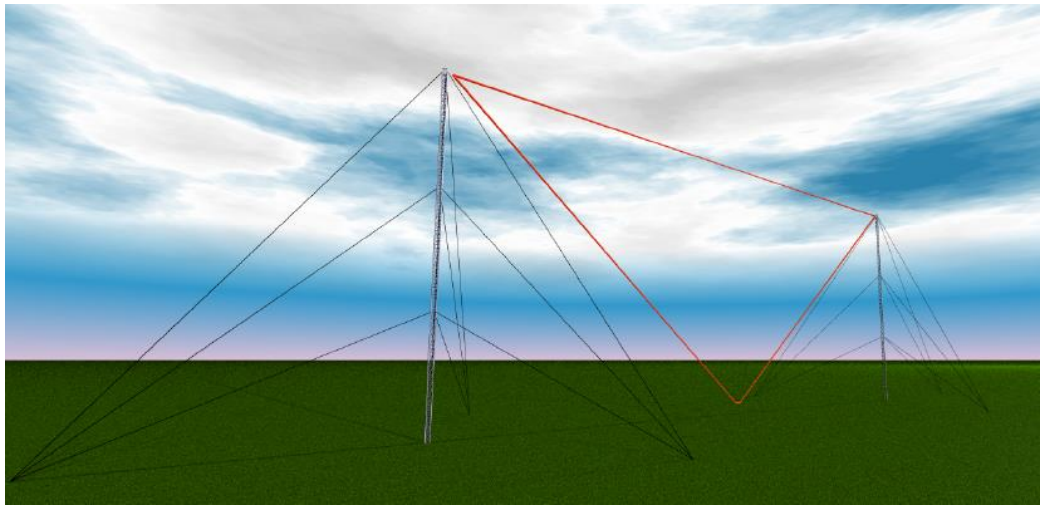
“Whether you plan on just using the Ionosphere, or wish to make a meaningful contribution to understanding the ionosphere… Every radio amateur should know how to read an ionogram”.



By Eric Pl Nichols, KL7AJ

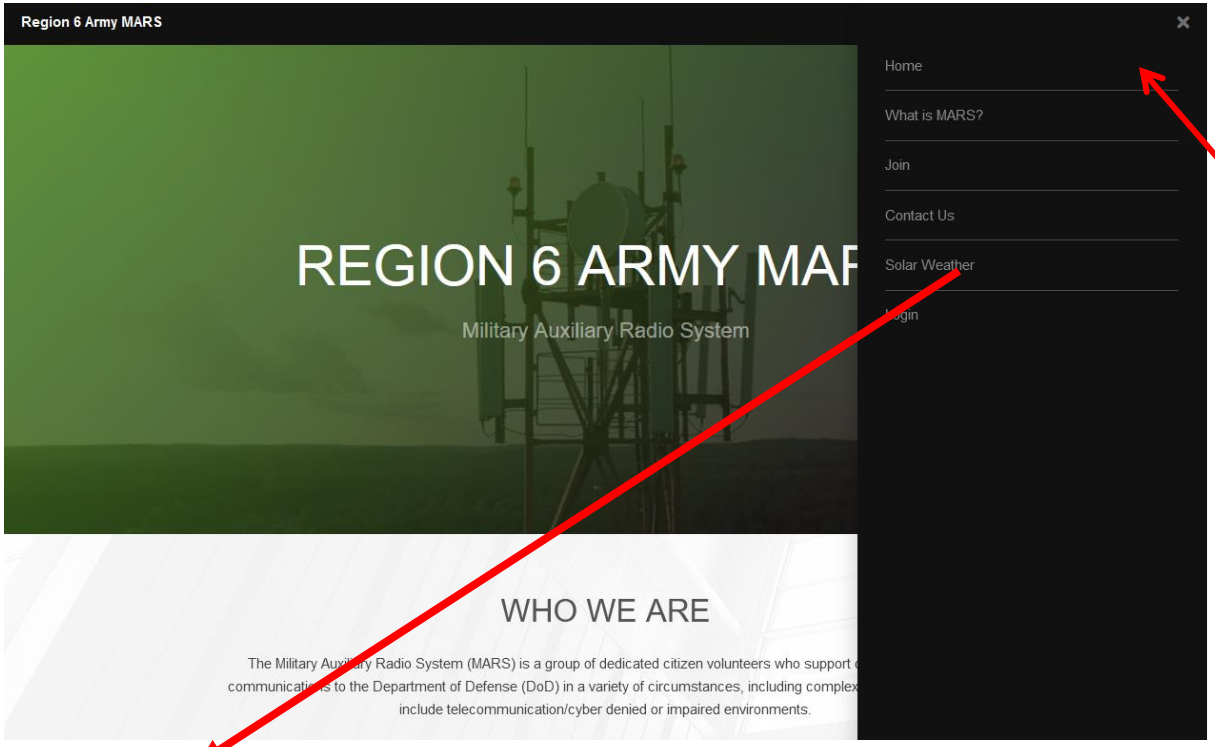
Austin Ionosonde





Ionosonde Locations

Ionosonde Data



Menu

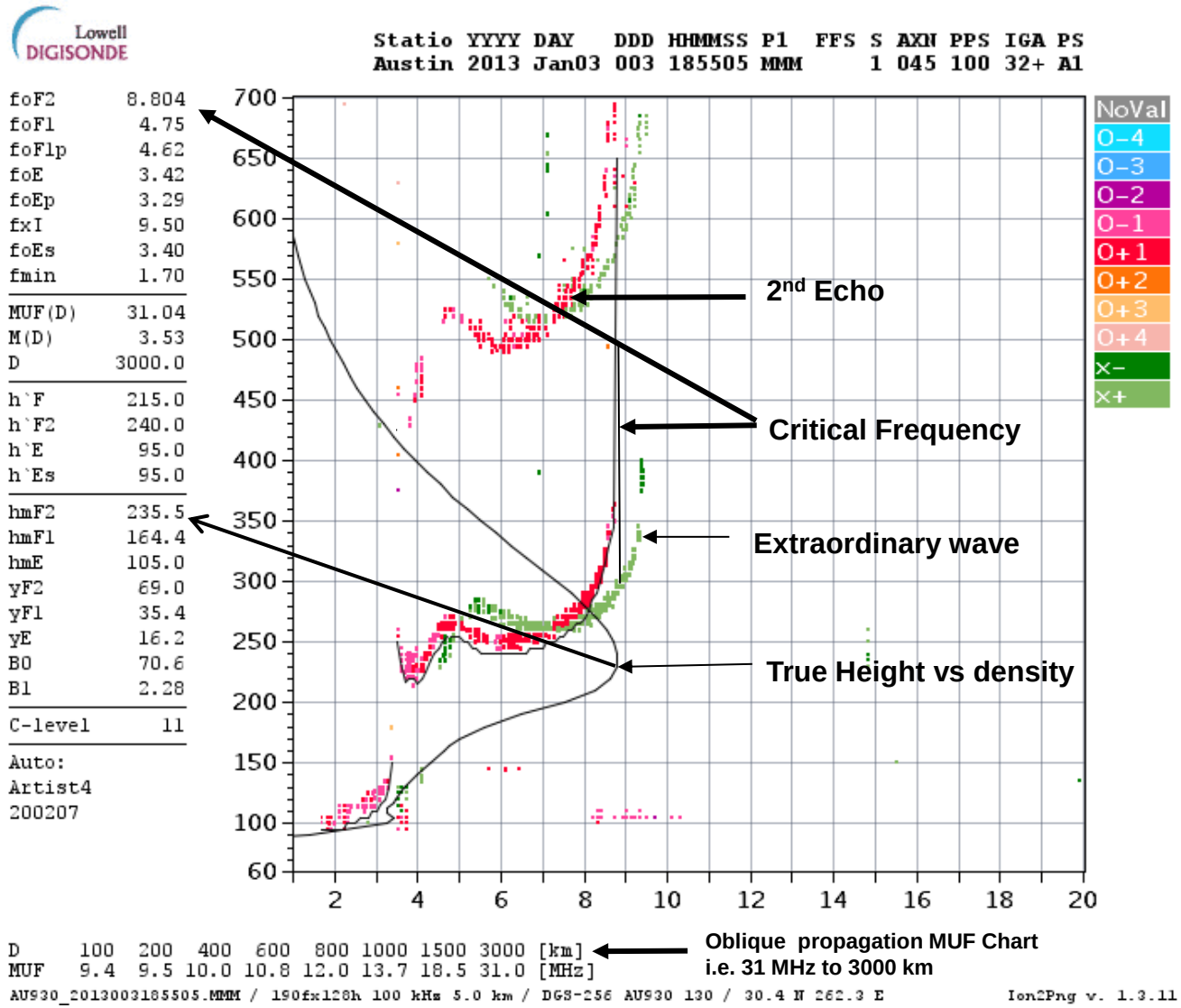
Solar Weather

Other Solar Weather Links of Interest

All Ionosondes →

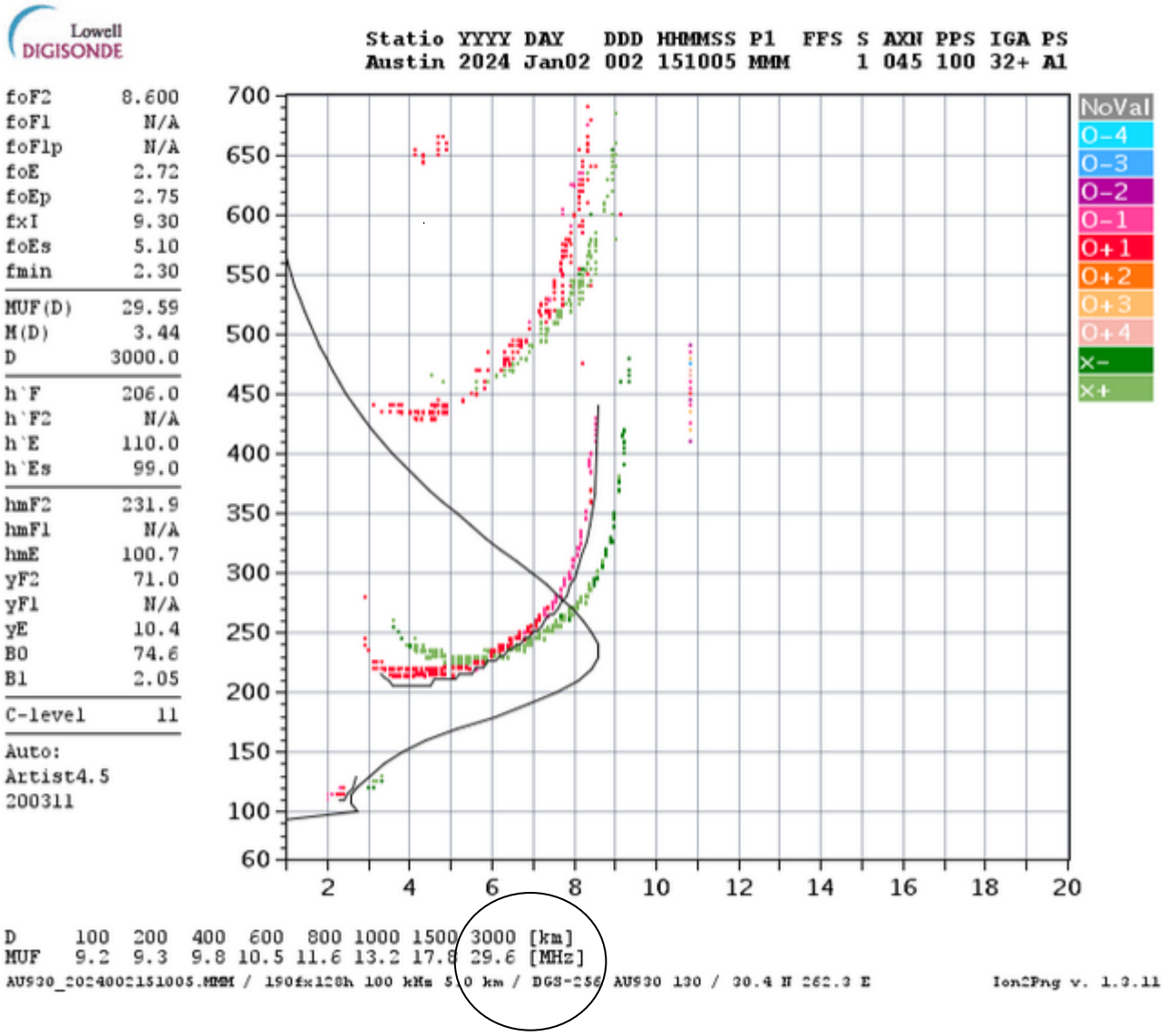
- DIDBase - Select Station List then EGLIN then year/month/day/time for Ionosonde plot.
- NOAA Solar Weather - Solar Weather plots of Kp and X-Ray and other solar emissions.
- Solen Solar Weather - Good general solar forecast from an individual.
- Solar Ham - SolarHam provides real time solar news, as well as consolidated data from various sources.

Ionogram Interpretation



Austin Ionosonde –2 JAN 1510Z

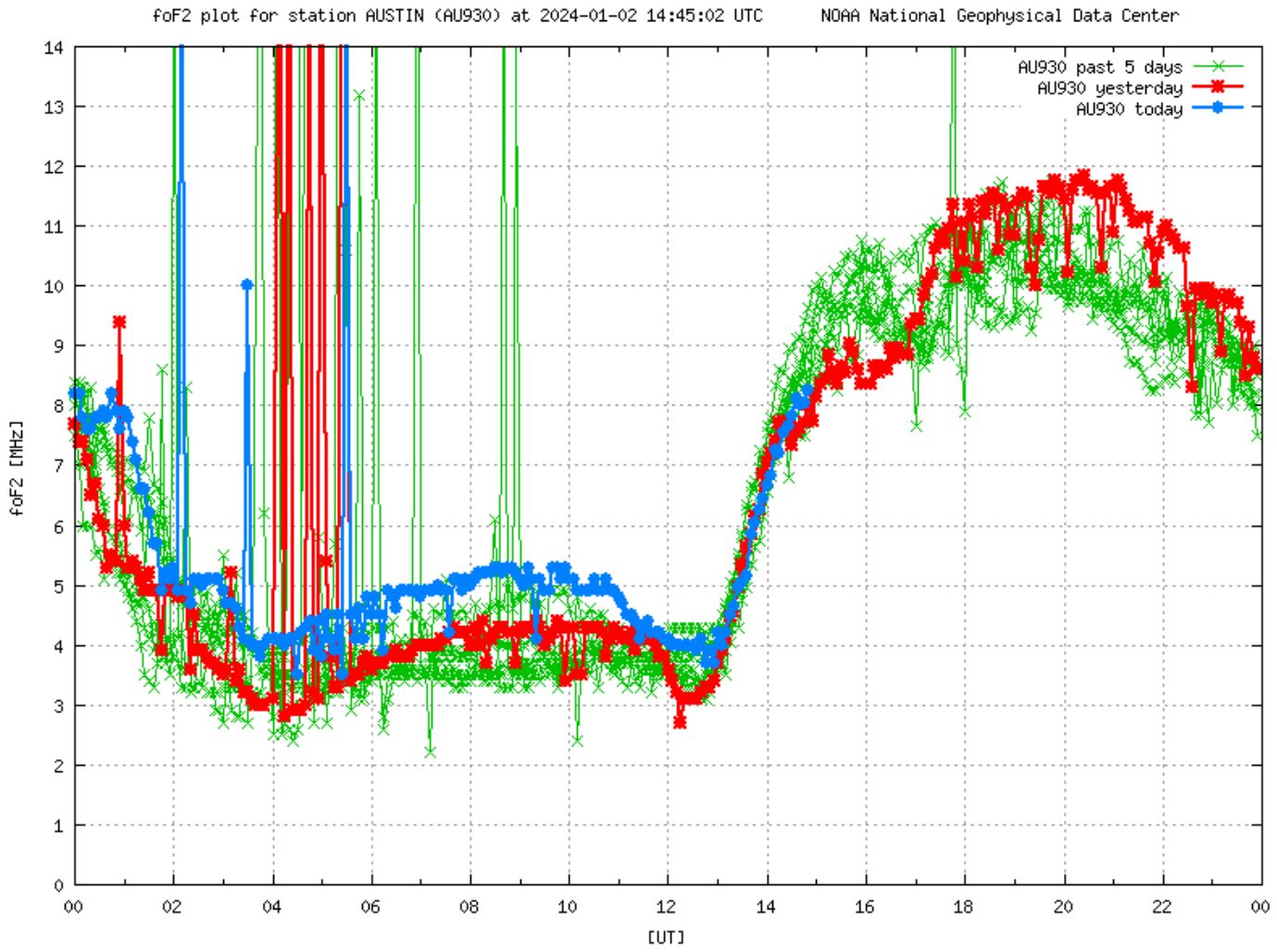
(Available every 5 minutes)



Austin Ionosonde foF2 Trend

(15 minute update from NOAA)

Critical Freq.

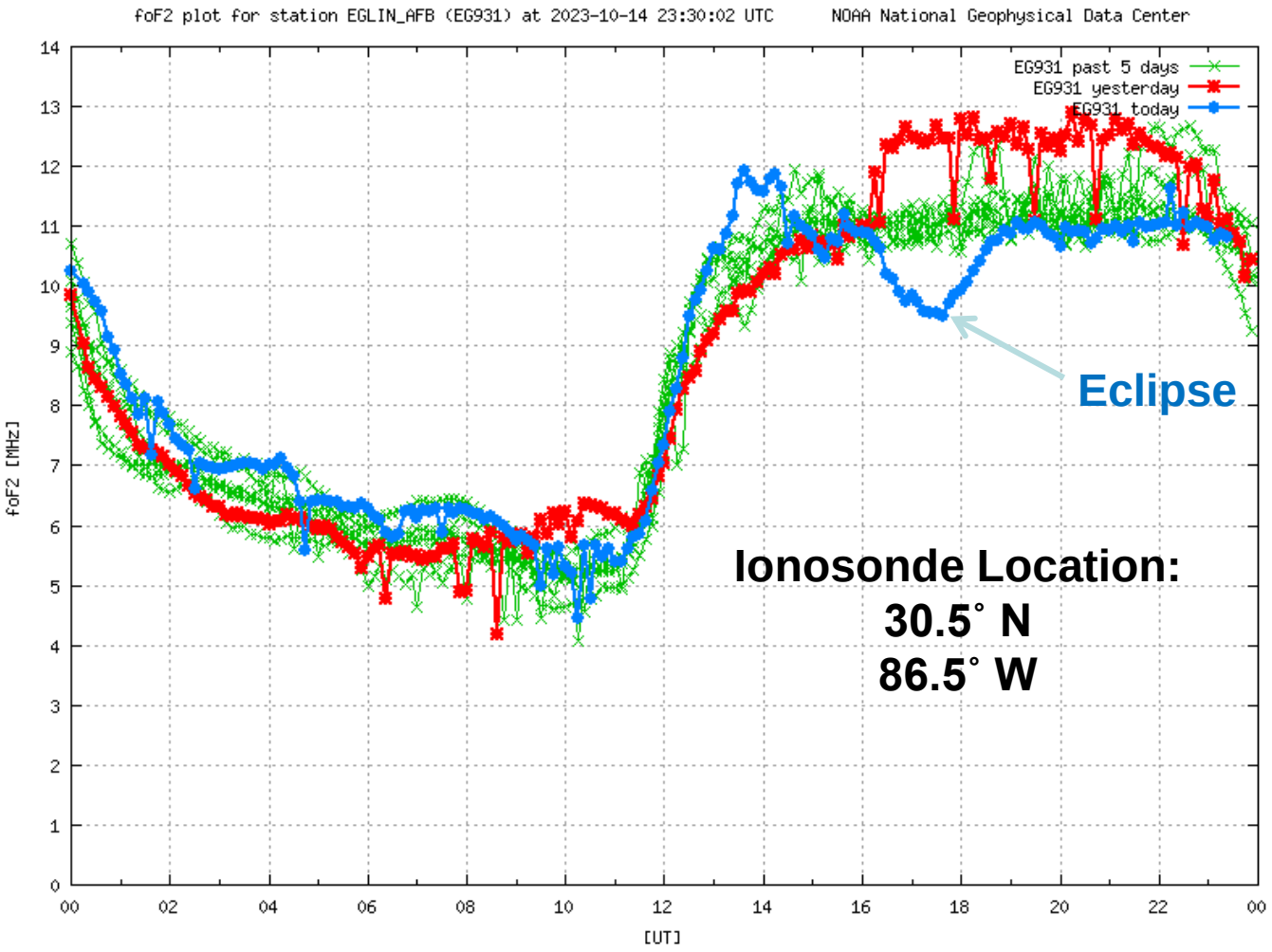


Propagation Effects of the Annular Eclipse – 14 Oct. 2023

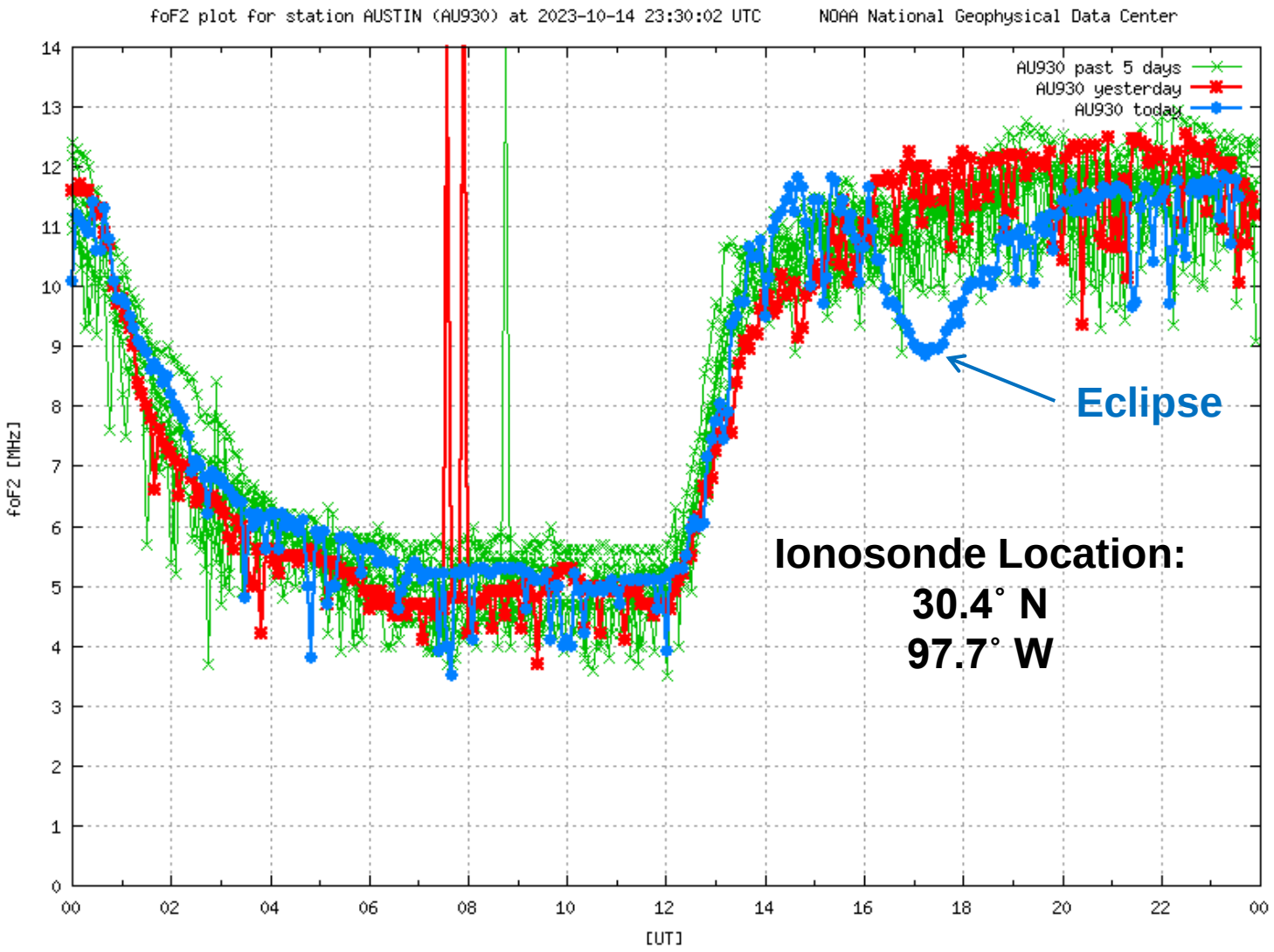
Path of Eclipse

CONUS Ionosonde Locations

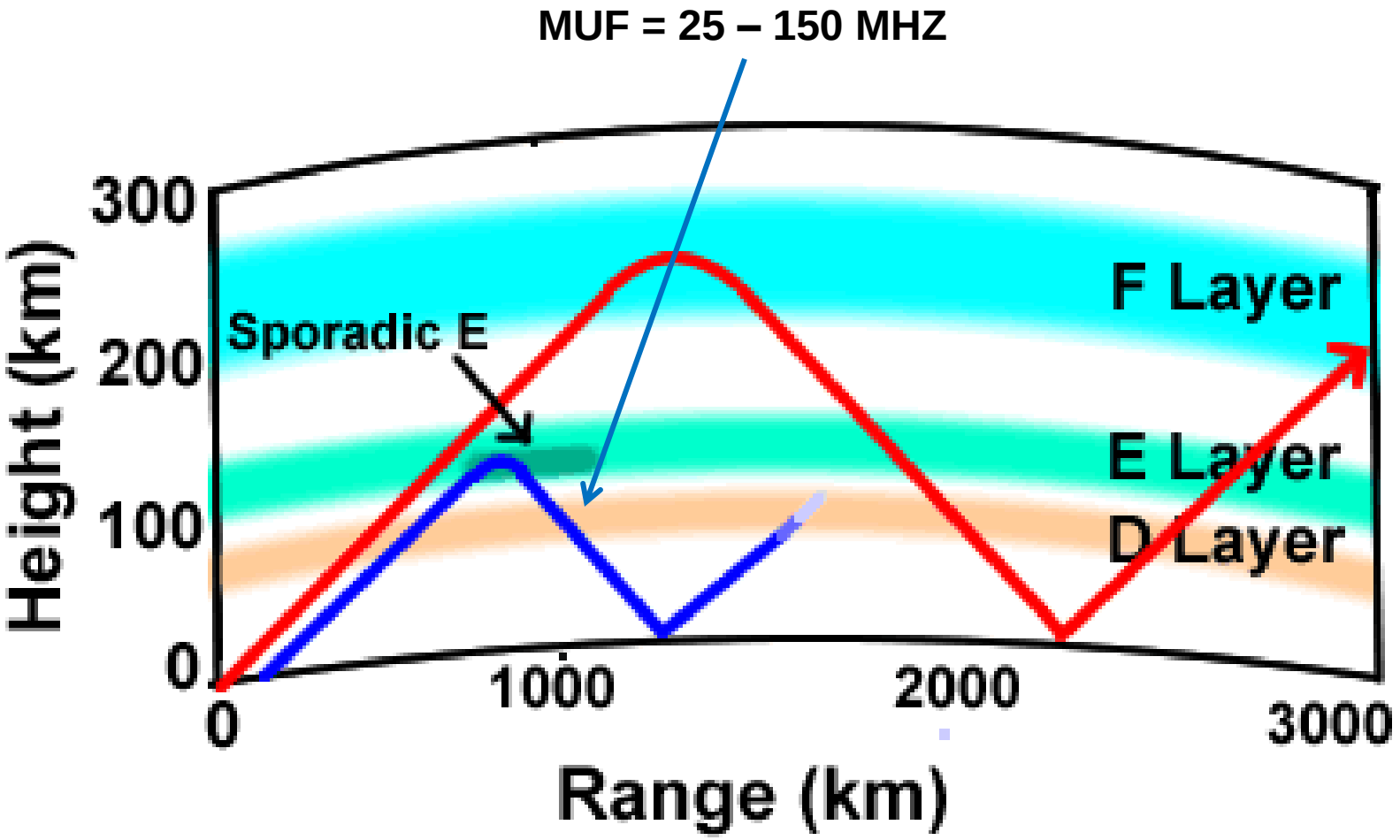
Eglin Ionosonde – foF2 Trend



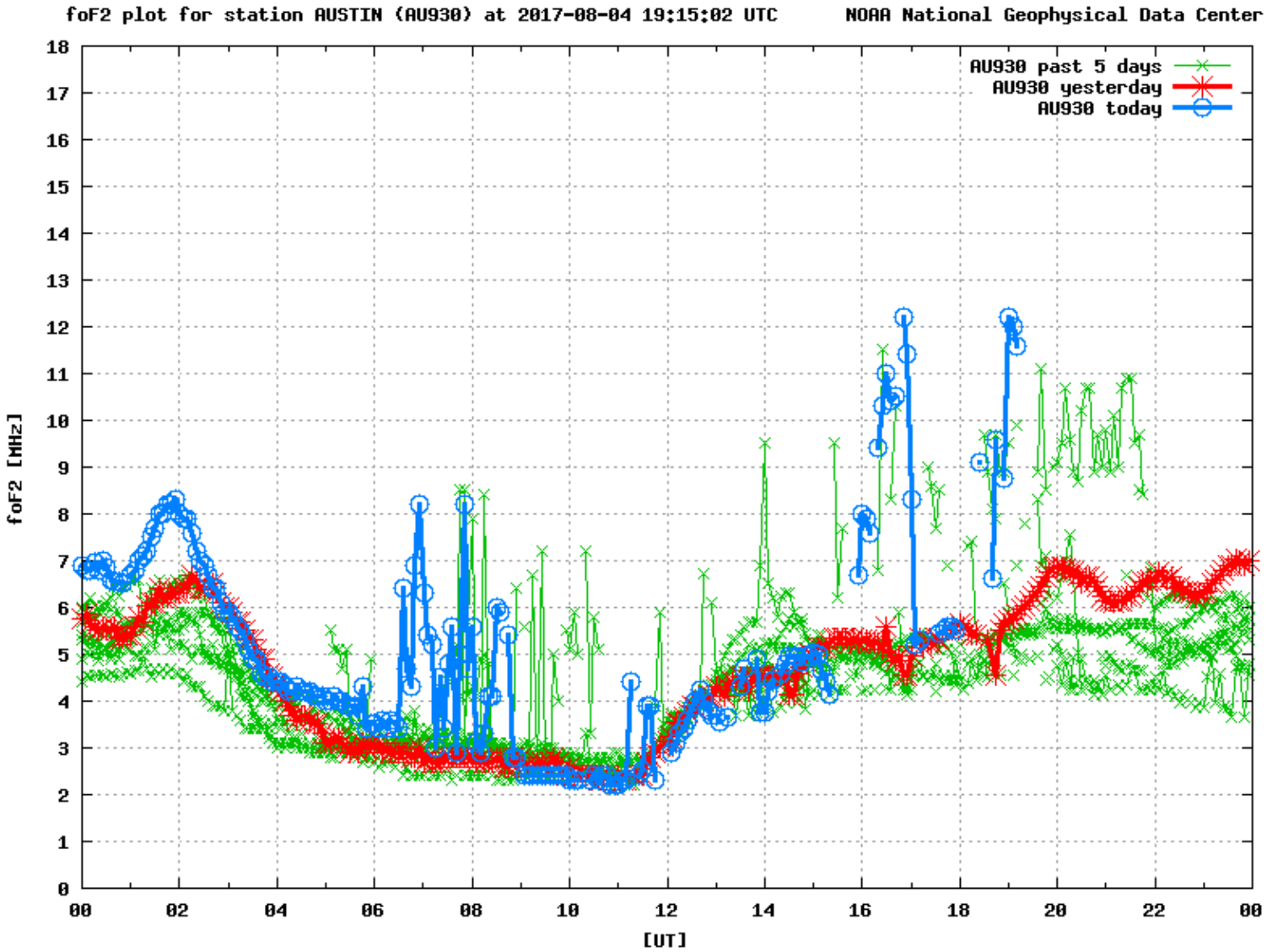
Austin Ionosonde – foF2 Trend



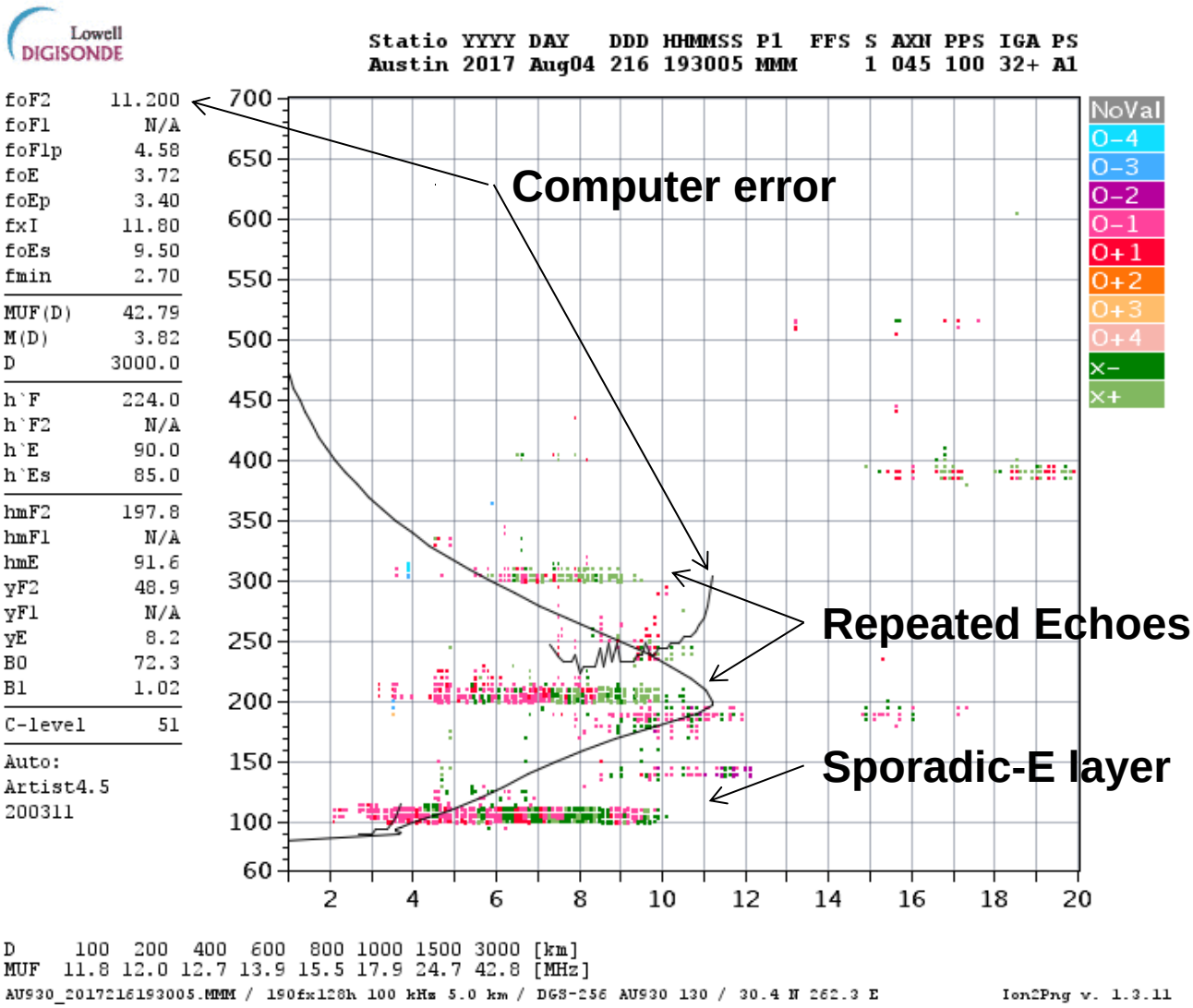
Sporadic–E Propagation



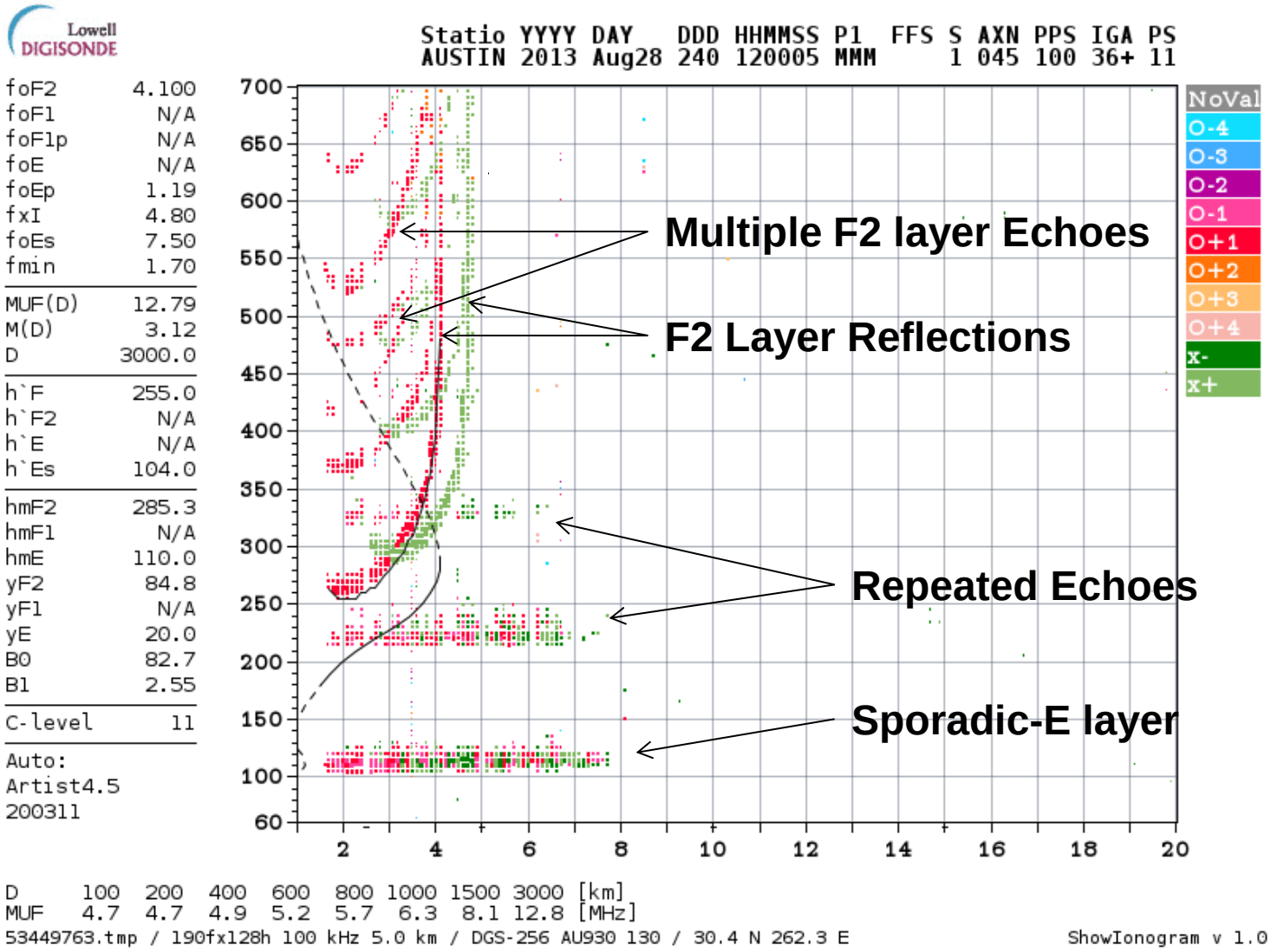
Blanketing Sporadic-E



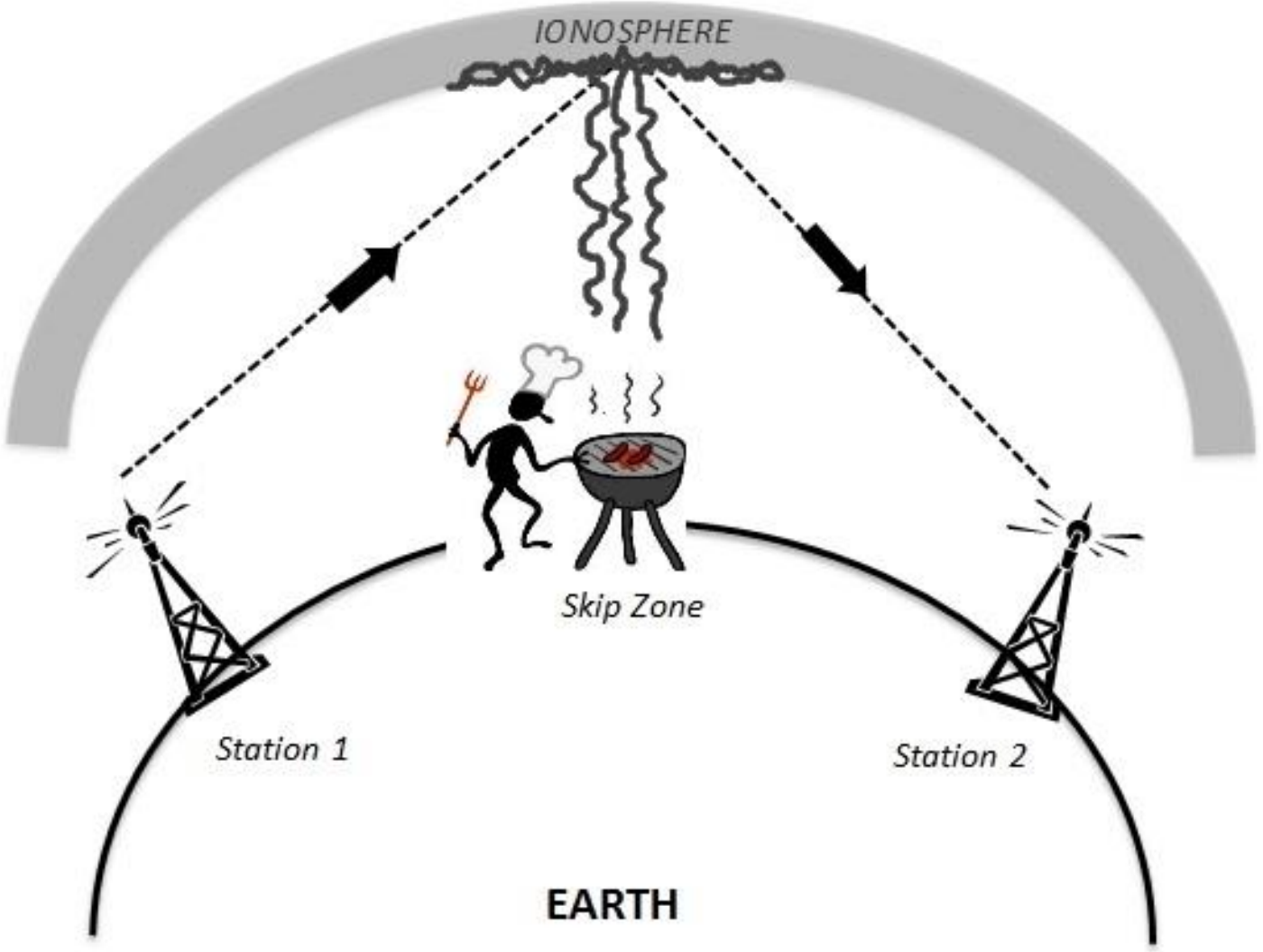
Ionogram During Sporadic-E



Return of F2 Layer Reflection



Formation of Sporadic E Propagation



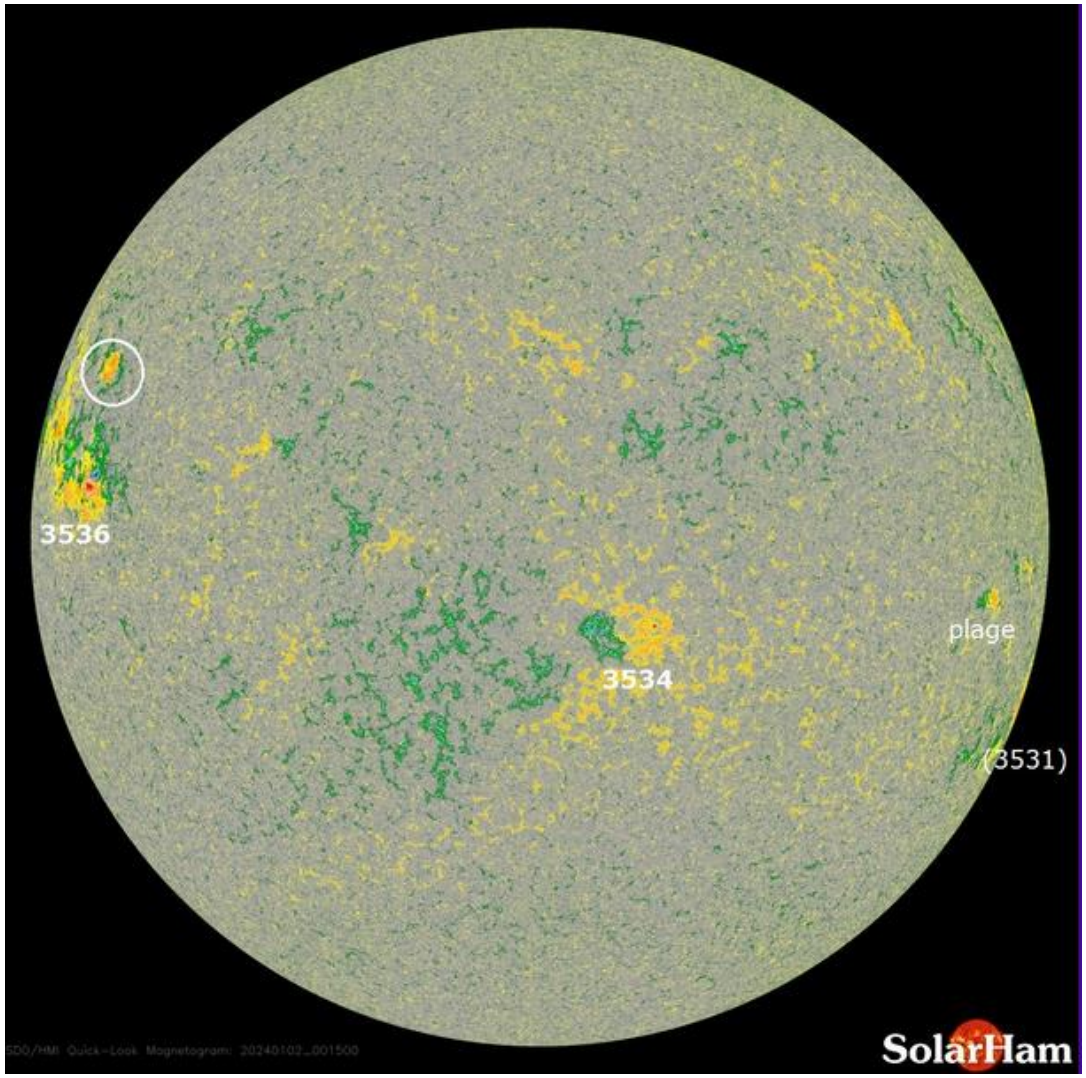
Propagation Prediction

- Rules of Thumb for Critical Frequency:
  - 2 to 4 MHz at night
  - 4 to 8 MHz in daytime
- Propagation prediction programs (not good for NVIS)
  - VOACAP - http://www.voacap.com/
  - Web information:
  - https://www.region6armymars.org/resources/solarweather.php
  - http://ulcar.uml.edu/DIDBase/
  - International Beacons - http://www.ncdxf.org/pages/beacons.html
    - Beacon Monitor - http://www.dxatlas.com/Faros/

OUTLINE

- Ionospheric propagation
  - NVIS
  - Long-Range
  - Frequency Selection (Critical Frequency & MUF)
  - Propagation modeling
- Solar Weather
  - Ionosphere (Solar Flux, Sun Spot Number)
  - Earth's Geomagnetic Field
  - Solar Flares
  - Proton Events
  - CME / Coronal Holes

Sun Spot Activity – 2 JAN 2024

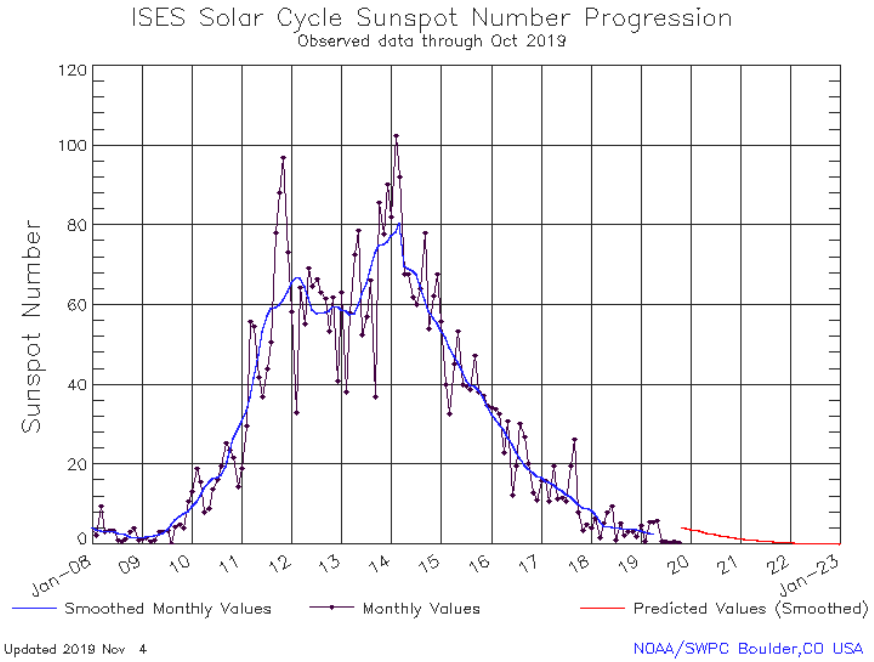


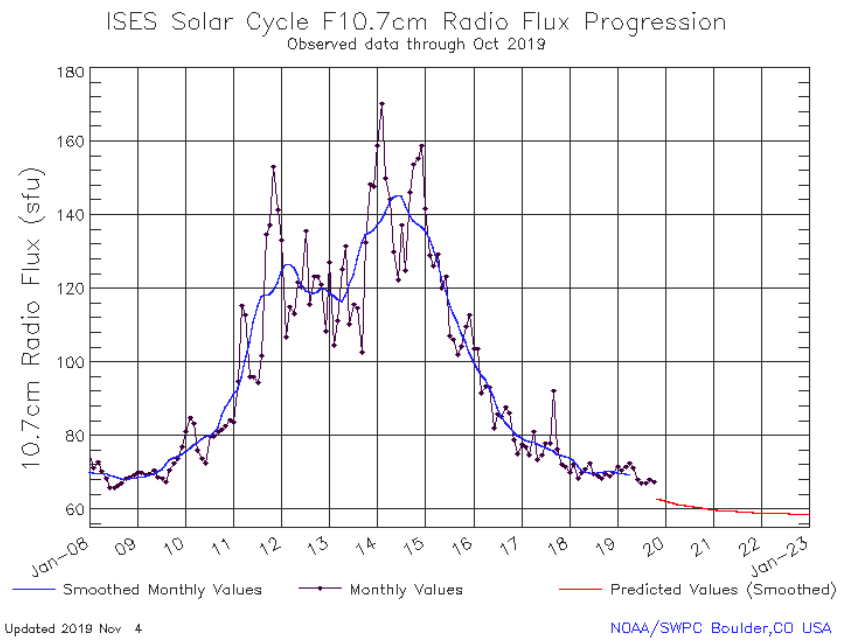
This Magnetogram uses Zeeman effect to measure polarity of magnetic fields on the Sun.

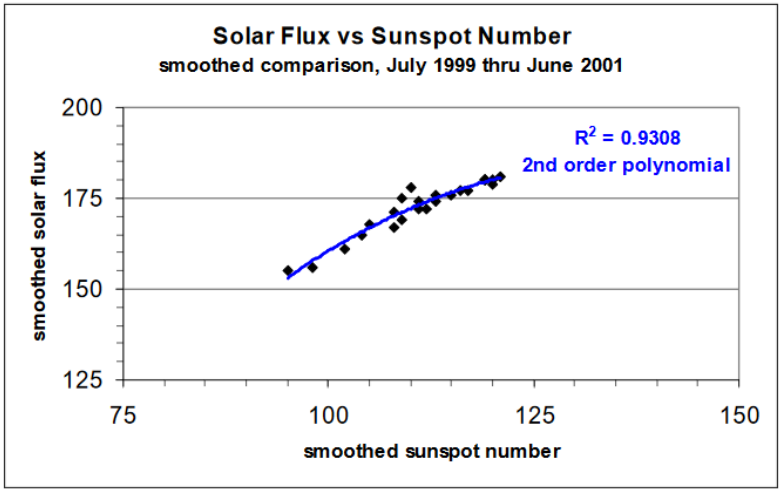
Solar Ionization Indicators

- **Sun Spot Number (SSN)** (Wolf or Zurich)
  - Special count of # of visible sun spots
  - Varies from 0 to 200+
  - 11-year cycle
  - 12 month running average produces best “fit” with propagation conditions.
  - Increased SSN leads to higher MUF
- **Solar Flux (SF)**
  - Measure of solar radio noise at 2800 MHz (10.7 cm)
  - Varies from 50 to 300
  - Increased SF leads to higher MUF
  - 11-year cycle
  - Does not exactly track propagation conditions

SSN & Solar Flux







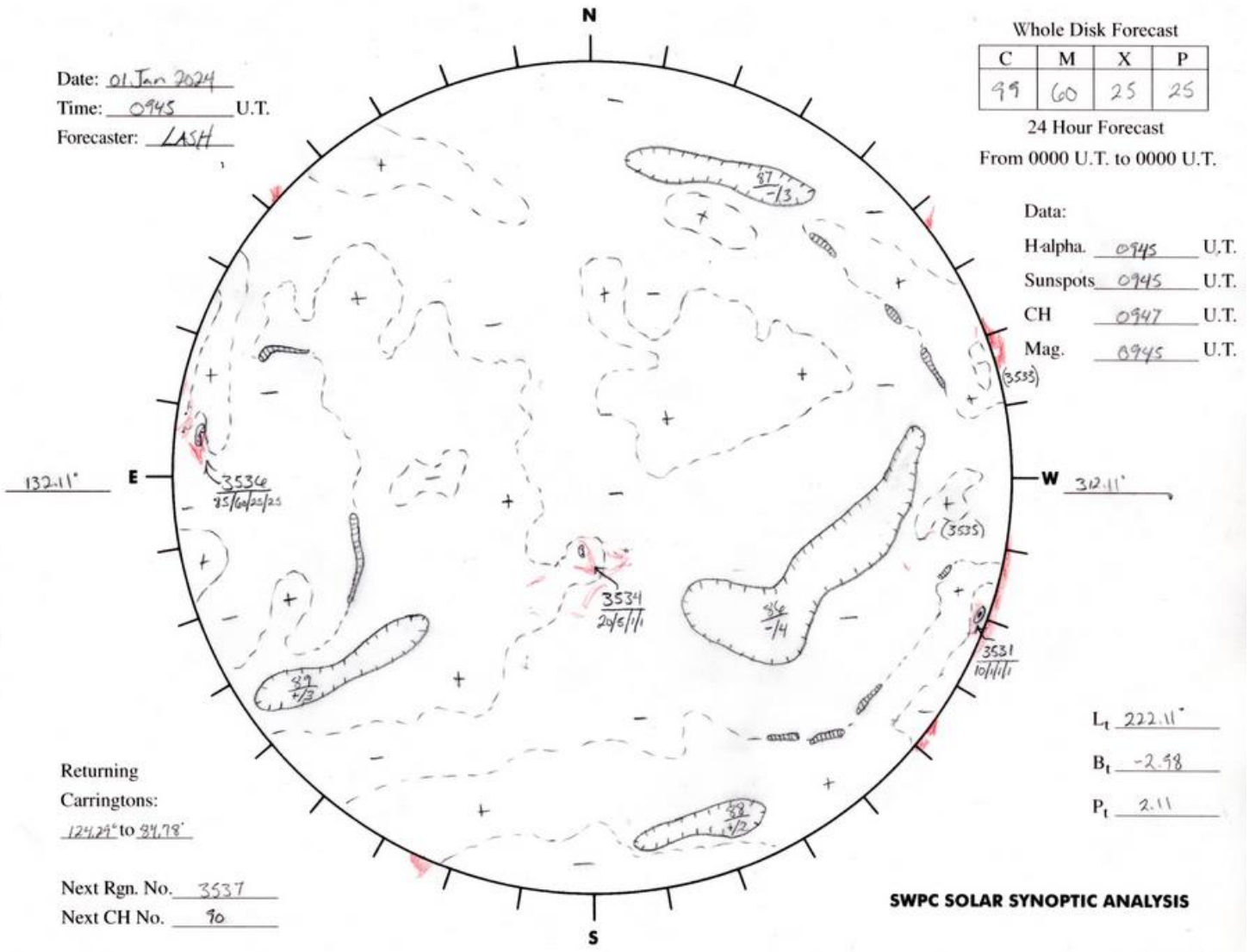
Sunspot Number

Visual count of Sunspots by observers:

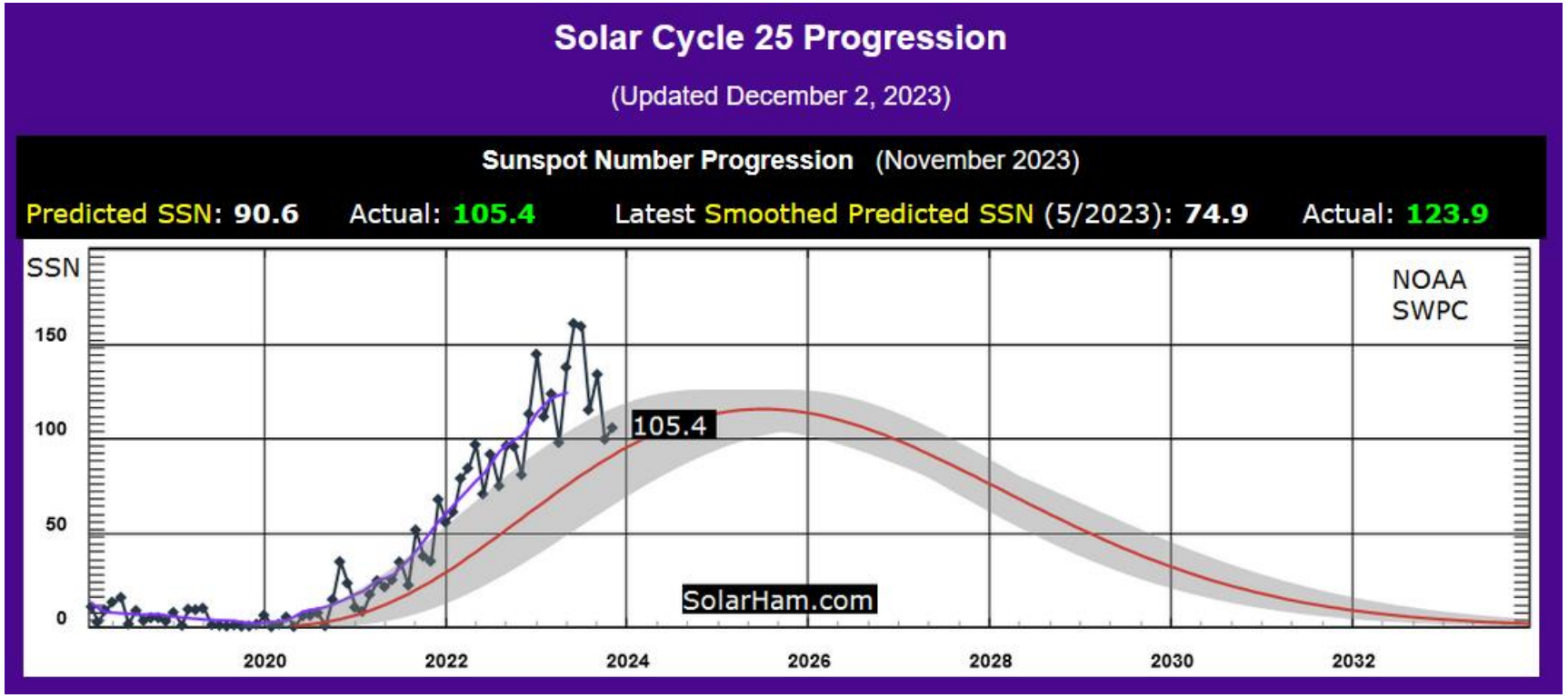
R = (10*G + S)*K
Where:
R = the sunspot number
G = the number of sunspot groups observed
S = the count of all sunspots in all groups
K = a scaling number to compensate for variables

Until 1980, traditionally, the sunspot number was essentially the Wolf number provided by the Zürich observatory, with some cross-validation relative to a network of supporting stations.
Since 1981, in Brussels, it was decided to derive the daily sunspot number from an average of all observations from a large worldwide network.

Sun Spot Analysis – 1 JAN 2024



Sun Spot Number Progress



SOLAR FLUX MEASUREMENTS

- **The various manifestations of solar activity are driven by the total amount of magnetic flux emerging through the photosphere into the chromosphere and corona, and its temporal and spatial distribution. For reasons not clearly understood, solar activity ebbs and flows over a cycle of about 11 years. The 10.7cm Solar Flux is a measurement of the integrated emission at 10.7cm wavelength from all sources present on the disc. It is almost completely thermal in origin, and directly related to the total amount of plasma trapped in the magnetic fields overlying active regions. This in turn is related to the amount of magnetic flux. A comparison made over more than a solar activity cycle show that there is indeed a linear correlation between the 10.7cm Solar Flux and the total photospheric magnetic flux in active regions.**

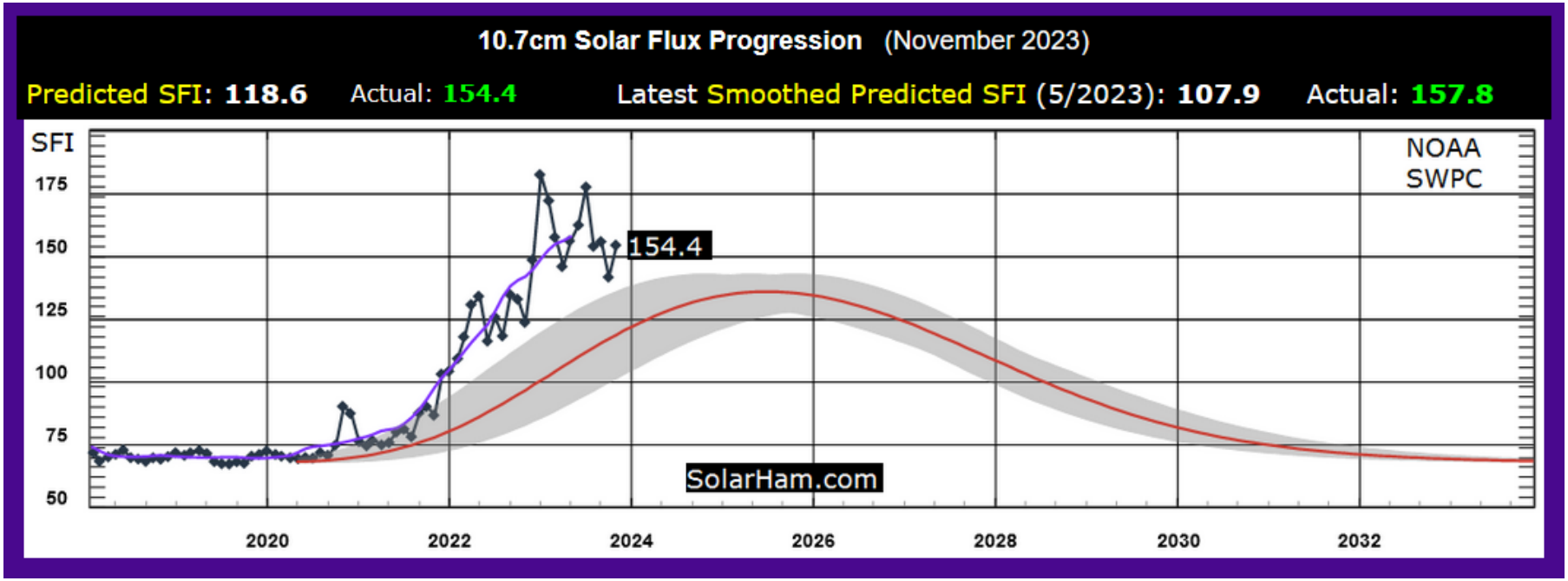
- **The 10.7cm Solar Flux, i.e., the solar flux density at 10.7cm wavelength is measured using two fully automated radio telescopes (called *Flux Monitors*), located at the Dominion Radio Astrophysical Observatory.**

- **The two instruments record the strength of the solar radio emission at 10.7cm wavelength each day for as long as the Sun is above the horizon. In addition, the instruments interrupt the continuous monitoring each day to make three precise measurements of the solar flux density. These measurements constitute the 10.7cm Solar Flux index.**

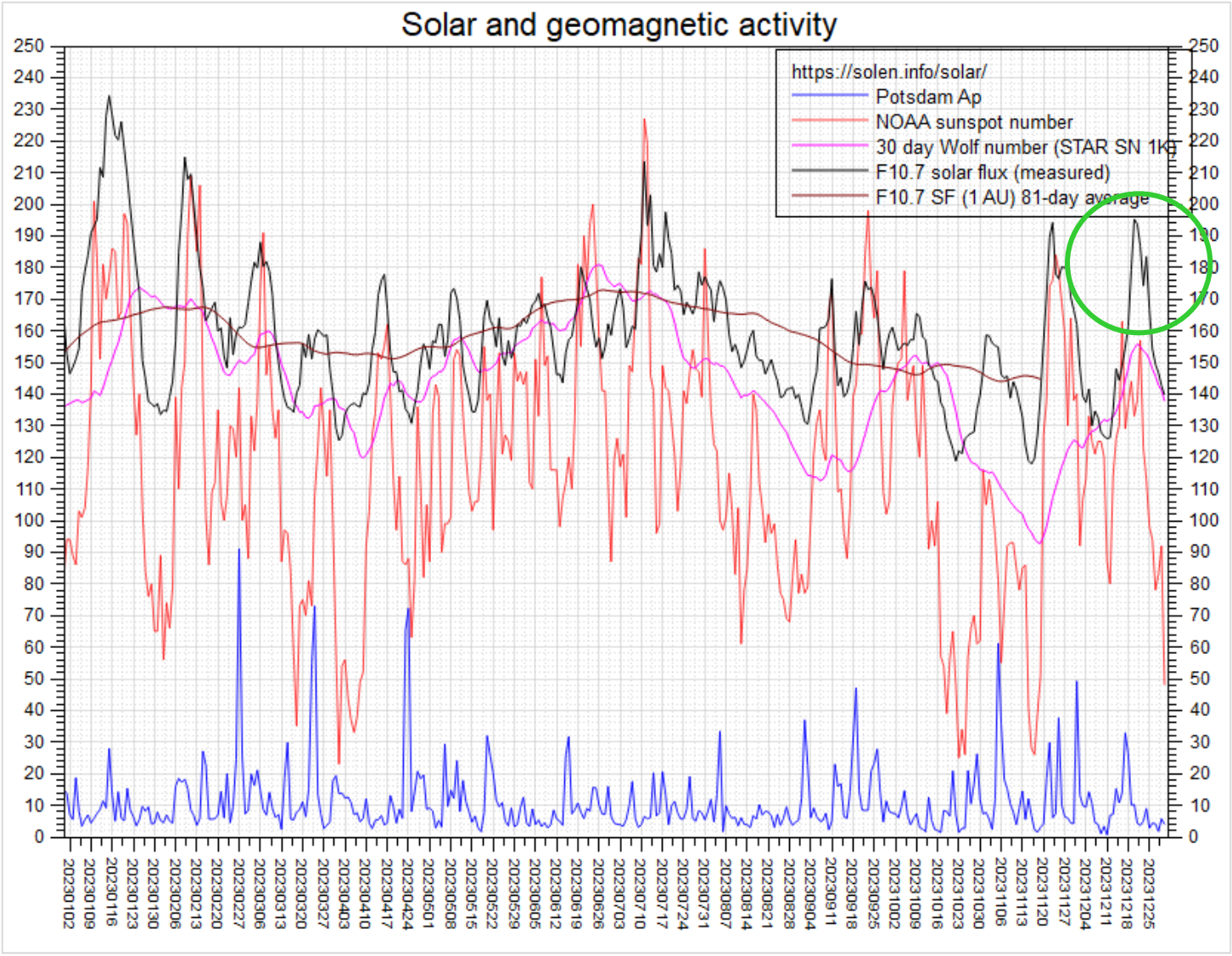
Solar Flux Monitor at Dominion Radio Astrophysical Observatory

Kaleden, British Columbia, Canada

Solar Flux


10.7cm Solar Flux Progression (November 2023)
Predicted SFI: 118.6 Actual: 154.4 Latest Smoothed Predicted SFI (5/2023): 107.9 Actual: 157.8
SFI
175
150
125
100
75
50
154.4
NOAA
SWPC
SolarHam.com
2020
2022
2024
2026
2028
2030
2032

SOLAR FLUX INDEX – 31 DEC 2023



Geomagnetic Indicators

- Geomagnetic Indices
  - Measure of Earth's geomagnetic activity
  - Increased activity means worse propagation
  - K_p : Planetary K index varies from 0 to 9 (3-hour average)
    - 0 to 1 – quiet conditions
    - 2 to 4 – some degradation to HF propagation
    - 5 to 6 – minor storm with further degradation to HF propagation
    - 6 to 9 – major storm leading to HF blackouts
  - Ap: Planetary A index varies 0 to 400 (average of four Kp)
    - Effectively yesterday's magnetic field variance

Kp – Index Measurements

K, Kp, and ap Indices

The **K-index** is quasi-logarithmic local index of the 3-hourly range in magnetic activity relative to an assumed quiet-day curve for a single geomagnetic observatory site. First introduced by J. Bartels in 1938, it consists of a single-digit 0 thru 9 for each 3-hour interval of the universal time day (UT).

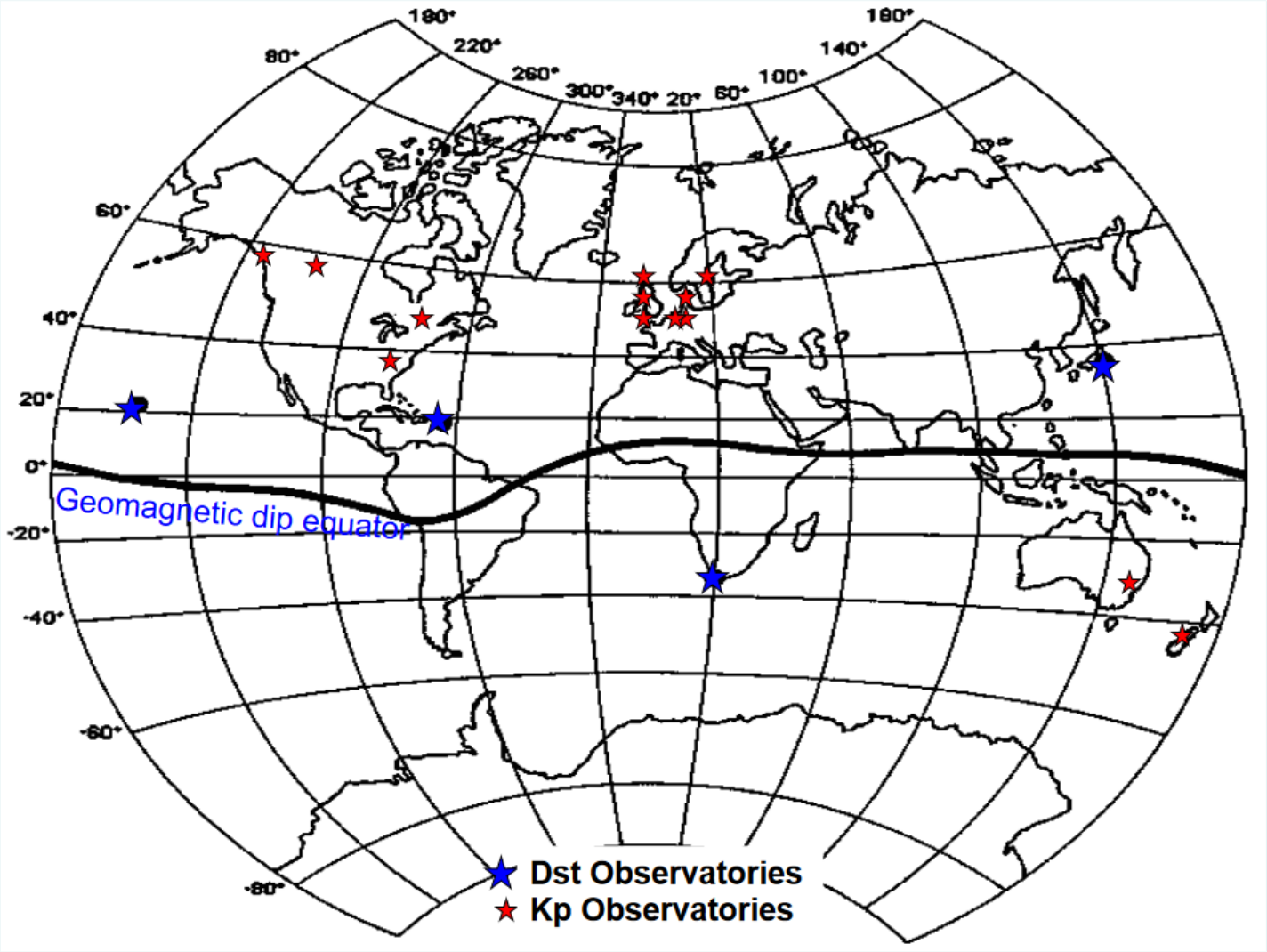
The planetary 3-hour-range index **Kp** is the mean standardized K-index from 13 geomagnetic observatories between 44 degrees and 60 degrees northern or southern geomagnetic latitude. The scale is O to 9 expressed in thirds of a unit, e.g. 5- is 4 2/3, 5 is 5 and 5+ is 5 1/3. This planetary index is designed to measure solar particle radiation by its magnetic effects. The 3-hourly **ap** (equivalent range) index is derived from the Kp index as follows:

The 13 Observatories used to compute official Kp

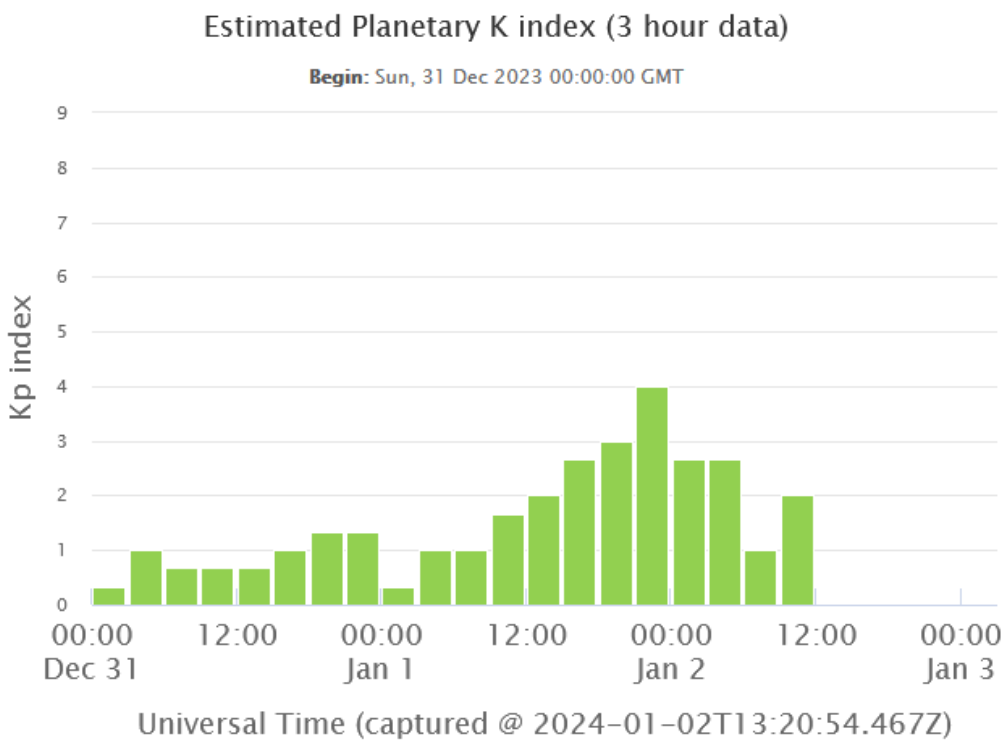
listed in order of geomagnetic latitude

Observatory					Geographic		Geomagnetic		
#	Code	Name	Location	Active	Lat.	Long.	Lat.*	Long.*	K=9
1	**LER**	**Lerwick**	**Scotland**	1932-actual	60°08'	358°49'	62.0°	89.2°	1000 nT
2	**MEA**	**Meanook**	**Canada**	1932-actual	54°37'	246°40'	61.7°	305.7°	1500 nT
3	**SIT**	**Sitka**	**Alaska (US)**	1932-actual	57°03'	224°40'	60.4°	279.8°	1000 nT
4	**ESK**	**Eskdalemuir**	**Scotland**	1932-actual	55°19'	356°48'	57.9°	83.9°	750 nT
5	LOV	Lovö	Sweden	1954-2004	59°21'	17°50'	57.9°	106.5°	600 nT
	UPS	**Uppsala**	**Sweden**	2004-actual	59°54'	17°21'	58.5°	106.4°	600 nT
6	AGN	Agincourt	Canada	1932-1969	43°47'	280°44'	54.1°	350.5°	600 nT
	OTT	**Ottawa**	**Canada**	1969-actual	45°24'	284°27'	55.8°	355.0°	750 nT
7	RSV	Rude Skov	Denmark	1932-1984	55°51'	12°27'	55.5°	99.4°	600 nT
	BFE	**Brorfelde**	**Denmark**	1984-actual	55°37'	11°40'	55.4°	98.6°	600 nT
8	ABN	Abinger	England	1932-1957	51°11'	359°37'	53.4°	84.5°	500 nT
	HAD	**Hartland**	**England**	1957-actual	50°58'	355°31'	54.0°	80.2°	500 nT
9	**WNG**	**Wingst**	**Germany**	1938-actual	53°45'	9°04'	54.1°	95.1°	500 nT
10	WIT	Witteveen	Netherland	1932-1988	52°49'	6°40'	53.7°	92.3°	500 nT
	NGK	**Niemegk**	**Germany**	1988-actual	52°04'	12°41'	51.9°	97.7°	500 nT
11	CLH	Cheltenham	USA	1932-1957	38°42'	283°12'	49.1°	353.8°	500 nT
	FRD	**Fredericksburg**	**USA**	1957-actual	38°12'	282°38'	48.6°	353.1°	500 nT
12	TOO	Toolangi	Australia	1972-1981	-37°32'	145°28'	-45.6°	223.0°	500 nT
	CNB	**Canberra**	**Australia**	1981-actual	-35°18'	149°00'	-42.9°	226.8°	450 nT
13	AML	Amberley	New Zealand	1932-1978	-43°09'	172°43'	-46.9°	254.1°	500 nT
	EYR	**Eyrewell**	**New Zealand**	1978-actual	-43°25'	172°21'	-47.2°	253.8°	500 nT

Kp and Dst Observatories



Planetary K index – 31 DEC – 2 JAN

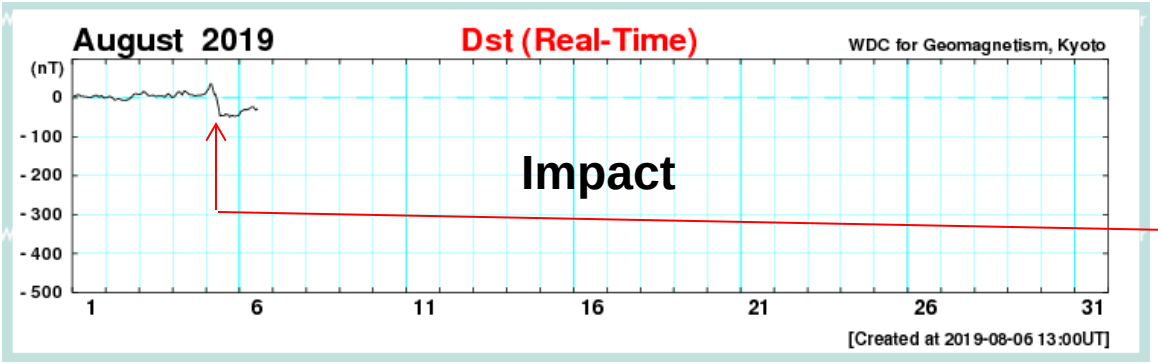


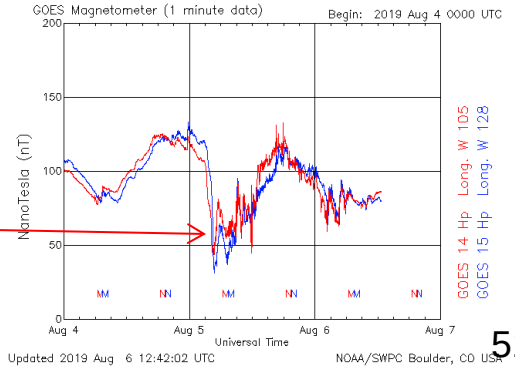
Generally, as planetary K-Index rises, critical frequency is suppressed.

K-Index	Effect
0-2	Inactive/Quiet, no impact on HF
3-4	Unsettled/Active, minor HF fade in higher latitudes
5-6	HF fade at higher latitudes
7-8	HF sporadic
9	HF impossible above 40M

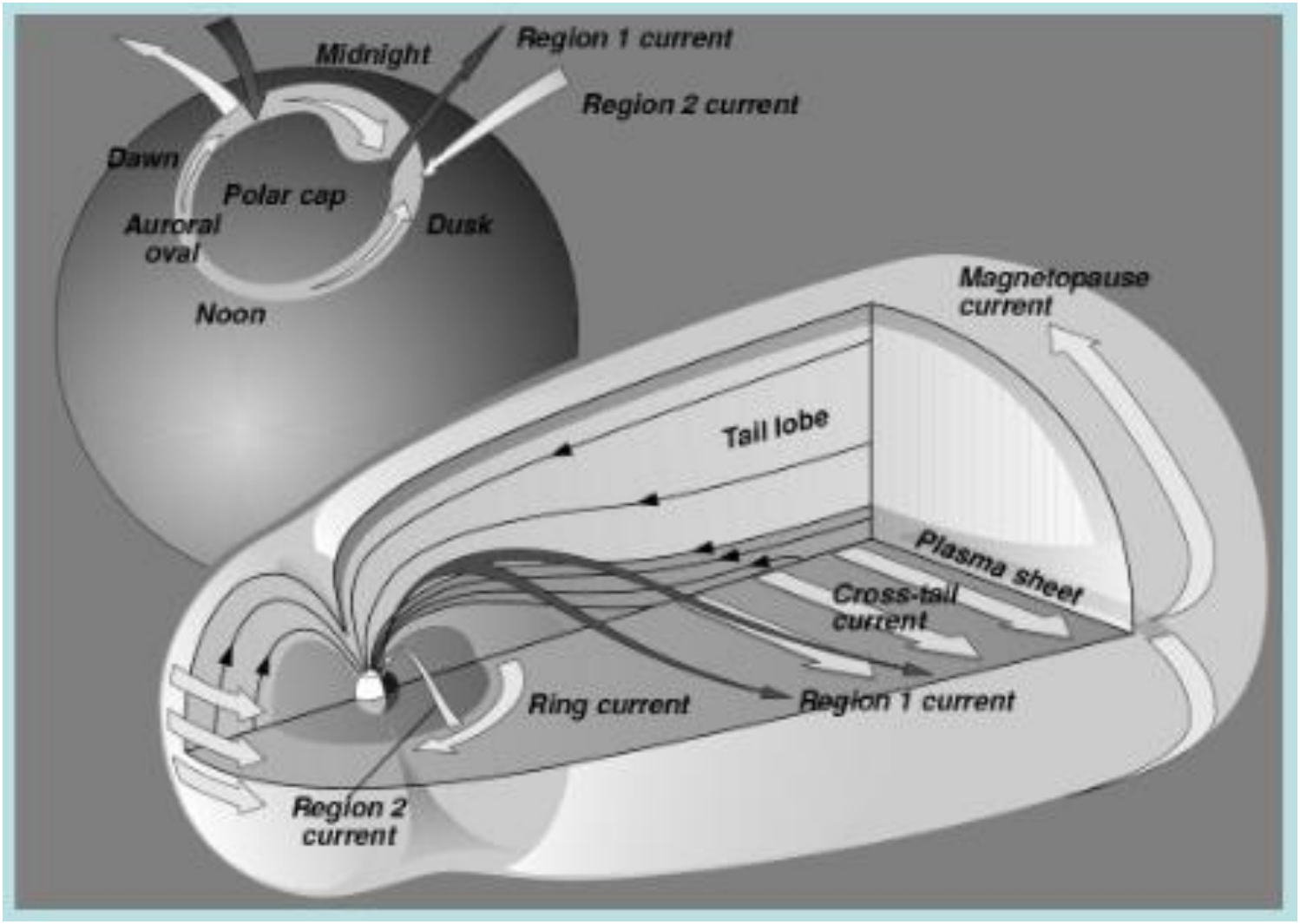
Dst Definition

- **The Dst (disturbance storm time) index provides a measure of the Earth's geomagnetic activity. It can be used to quantify the severity of magnetic storms.**
- **Dst, expressed in nanoteslas, is based on the average value of the horizontal component of the Earth's magnetic field measured hourly at four near-equatorial geomagnetic observatories.**
- **During a magnetic storm, the Dst shows a sudden rise, corresponding to the storm sudden commencement, and then decreases sharply as the ring current intensifies.**
- **Once the IMF turns northward again and the ring current begins to recover, the Dst begins a slow rise back to its quiet time level.**





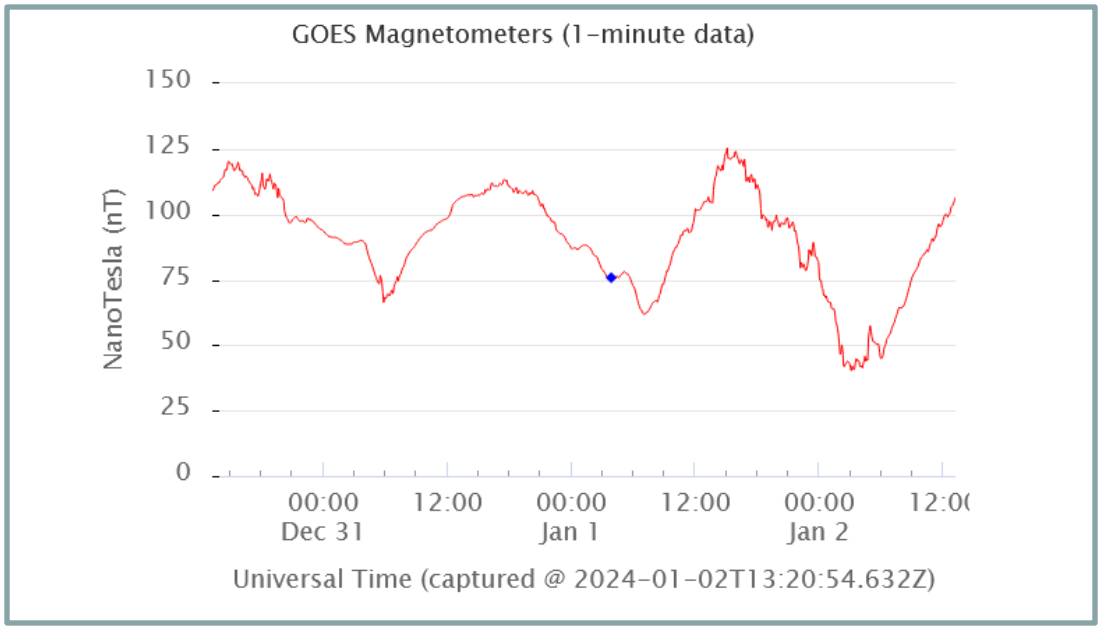
Ring Current



Geomagnetic Conditions: 2 JAN 2024

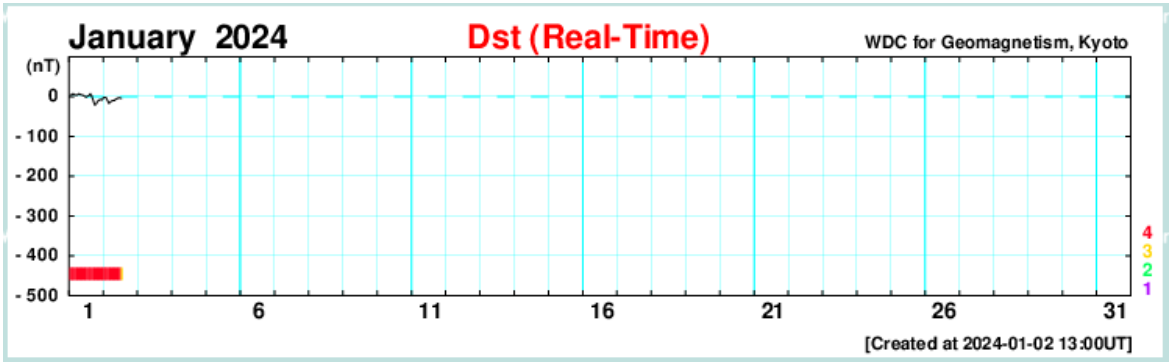
Solar wind:
Bz = -5 nT
speed = 405 km/sec
density = 8.3 protons/cm^3

(From – NOAA DSCOVR In L1, Lagrange Point)



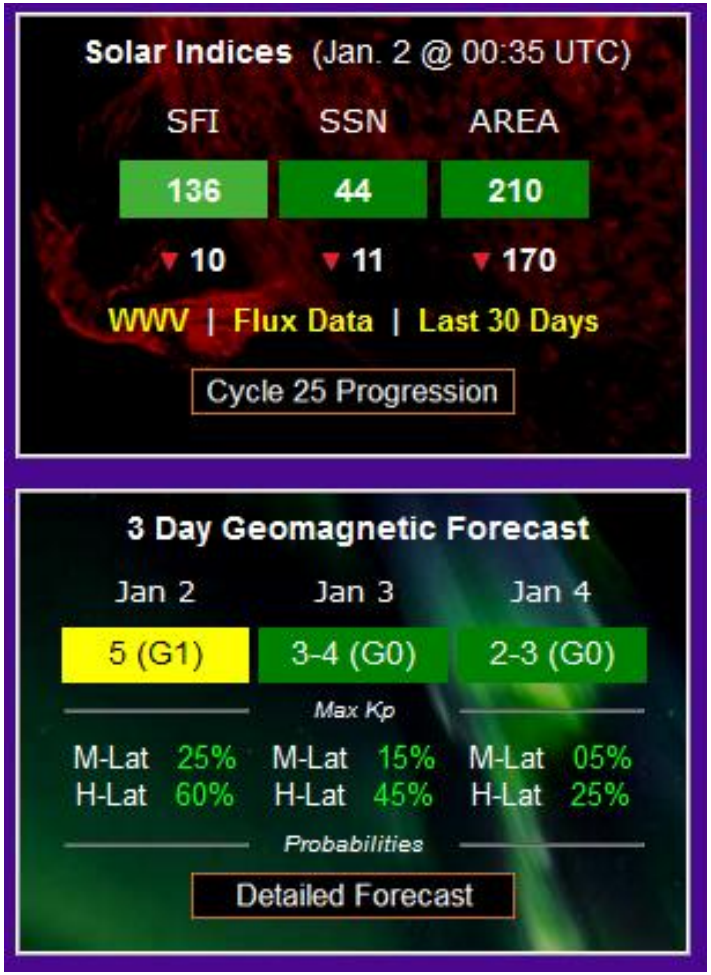
Dst = -5 nT (Ring Field)

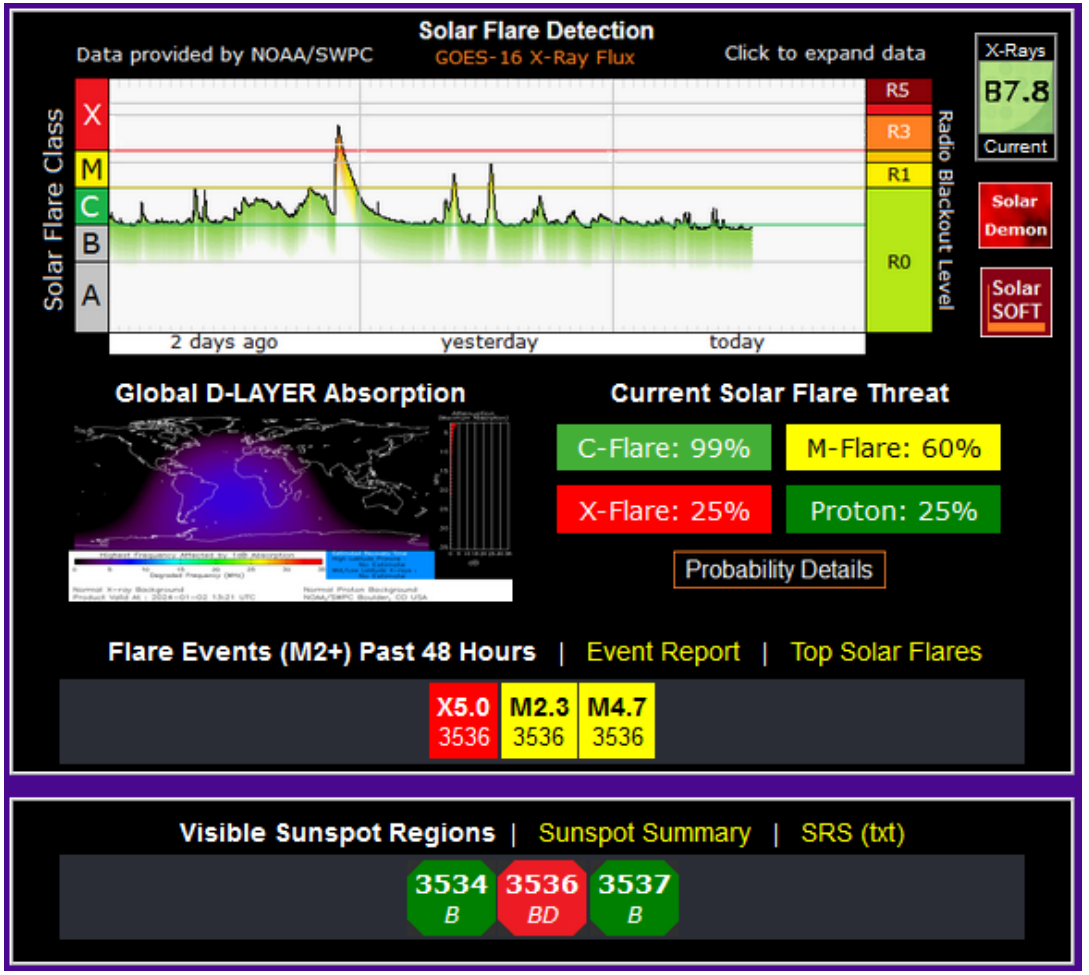
(From – Data Analysis Center For Geomagnetics and Space Magnetism – Kyoto University)



From – GOES 16
In geostationary orbit

SolarHam.org Forecast



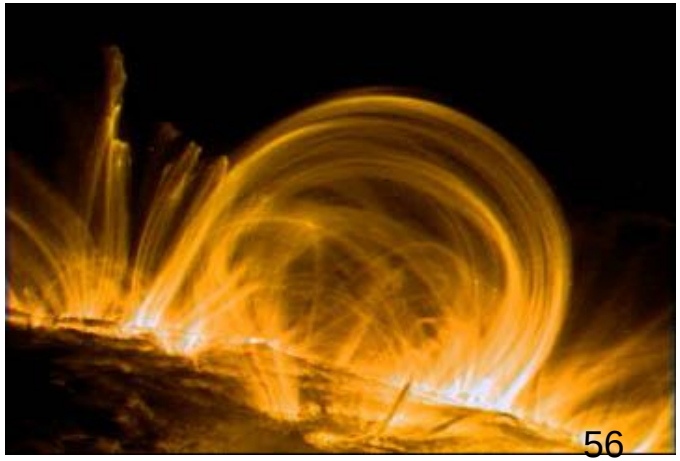


SOLAR EFFECTS ON PROPAGATION

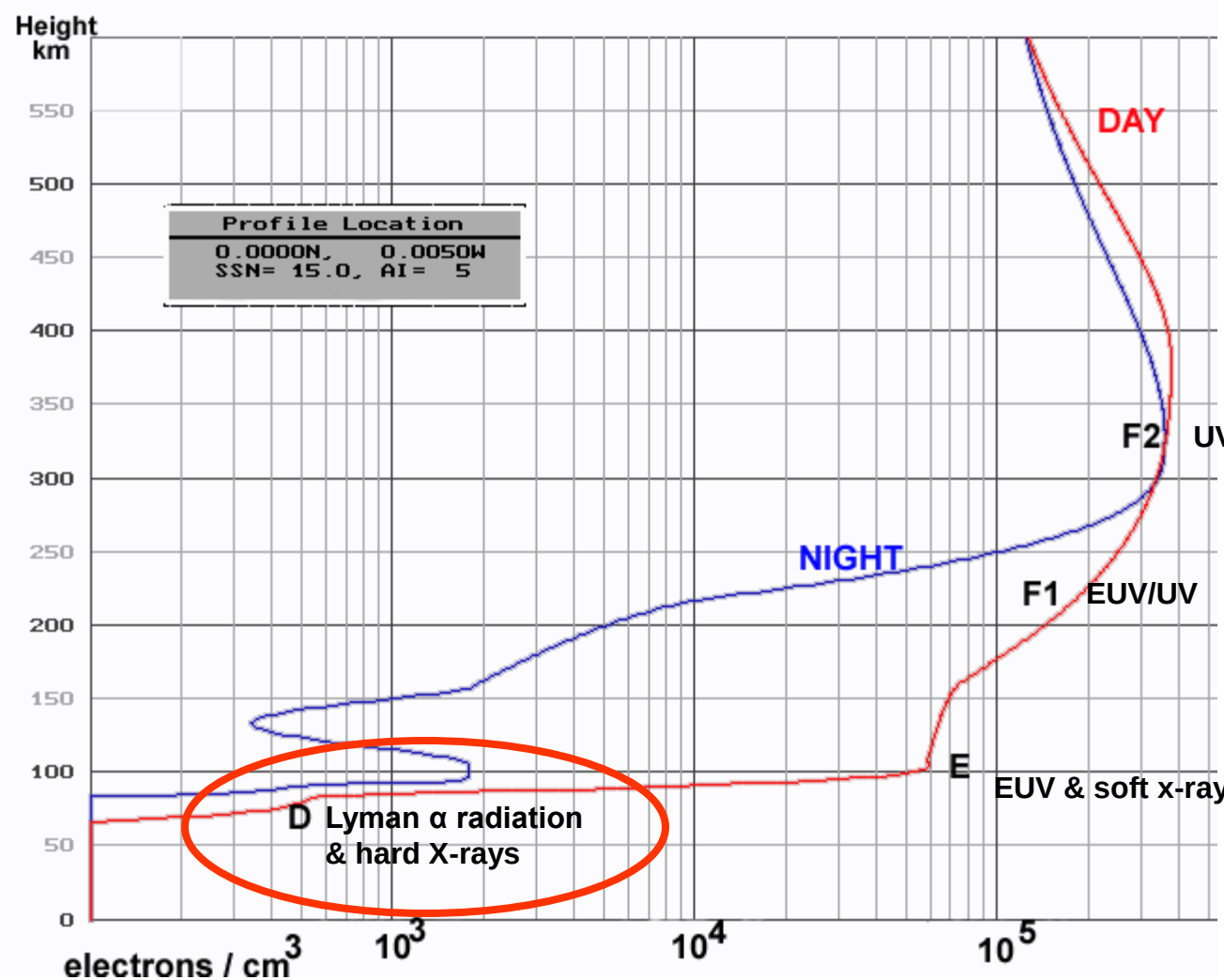
- Ultraviolet Radiation – Good
- X-Ray Radiation from Solar Flares – Bad
- Proton Events - Bad
- Corona Mass Ejections – Bad
- Coronal Holes – Bad

SOLAR FLARES (X-Rays)

- Radio Blackouts (8 minute arrival)
  - M or X class solar flare releasing X-rays
  - SID (Sudden Ionospheric Disturbance)
  - Caused by Extreme D-layer absorption
  - Day time effect

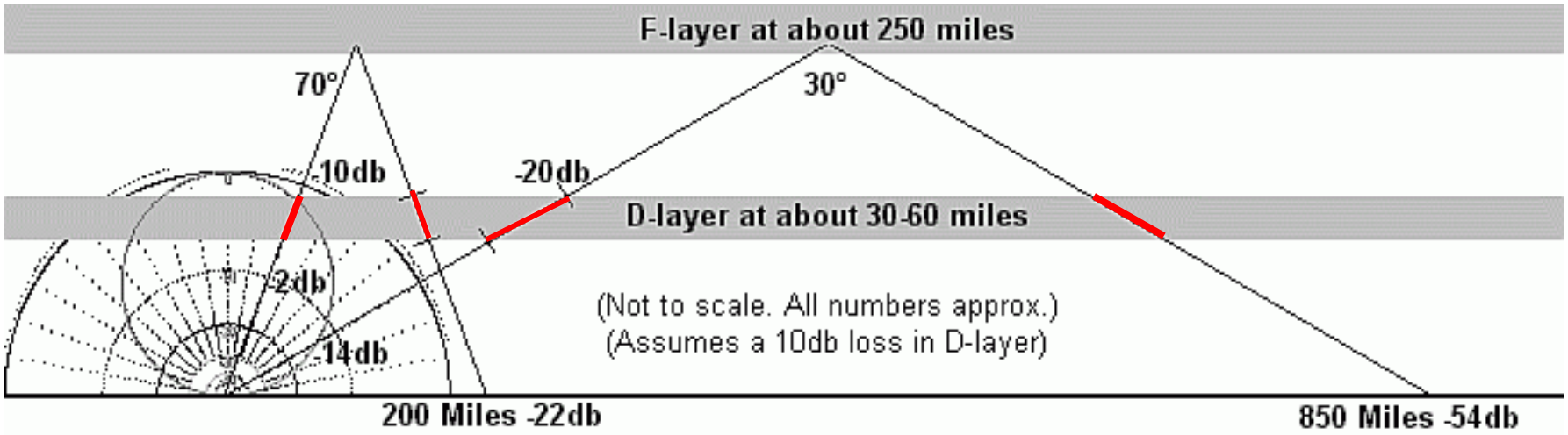


D-Layer Absorption

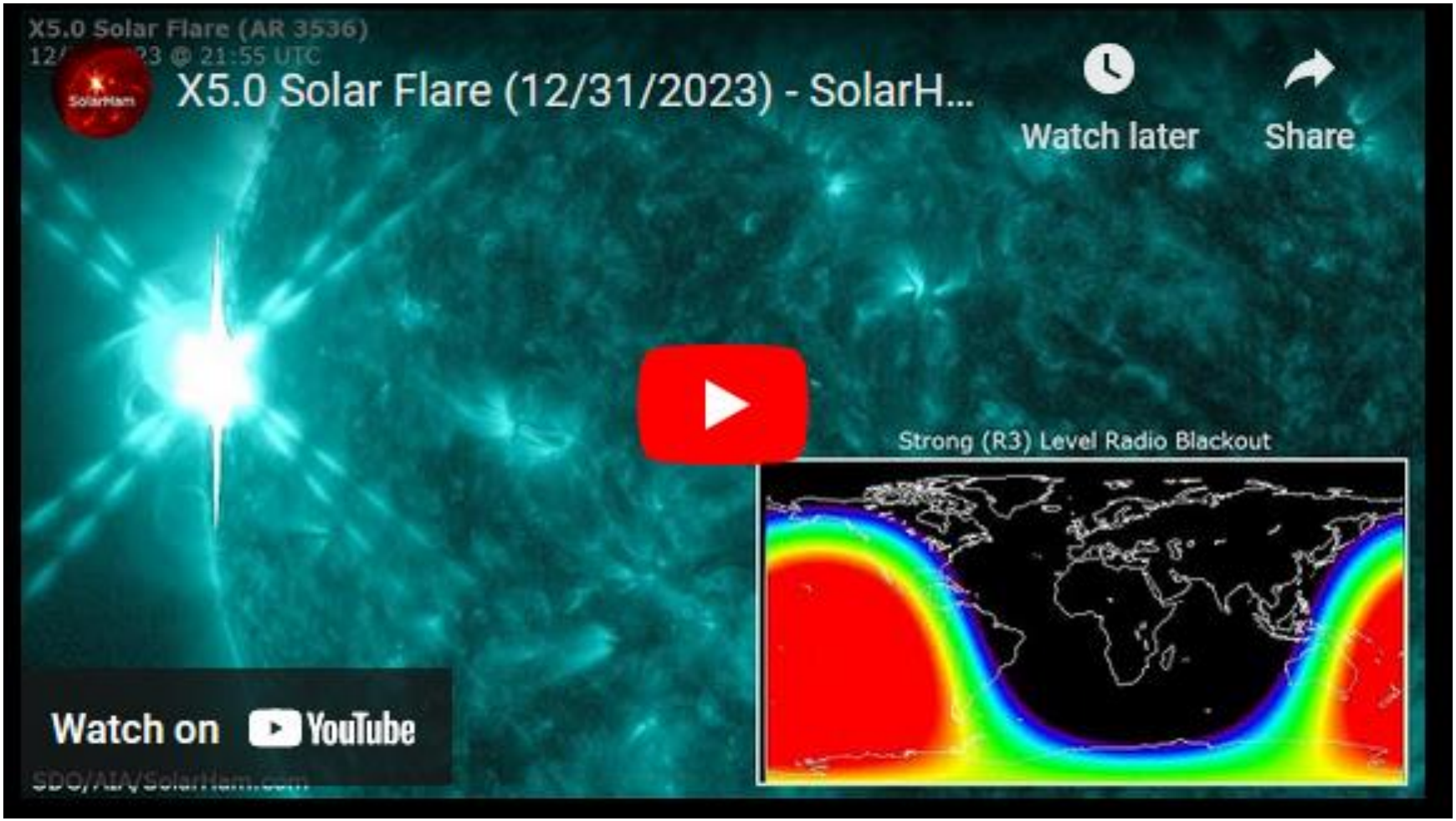


D-Layer Absorption

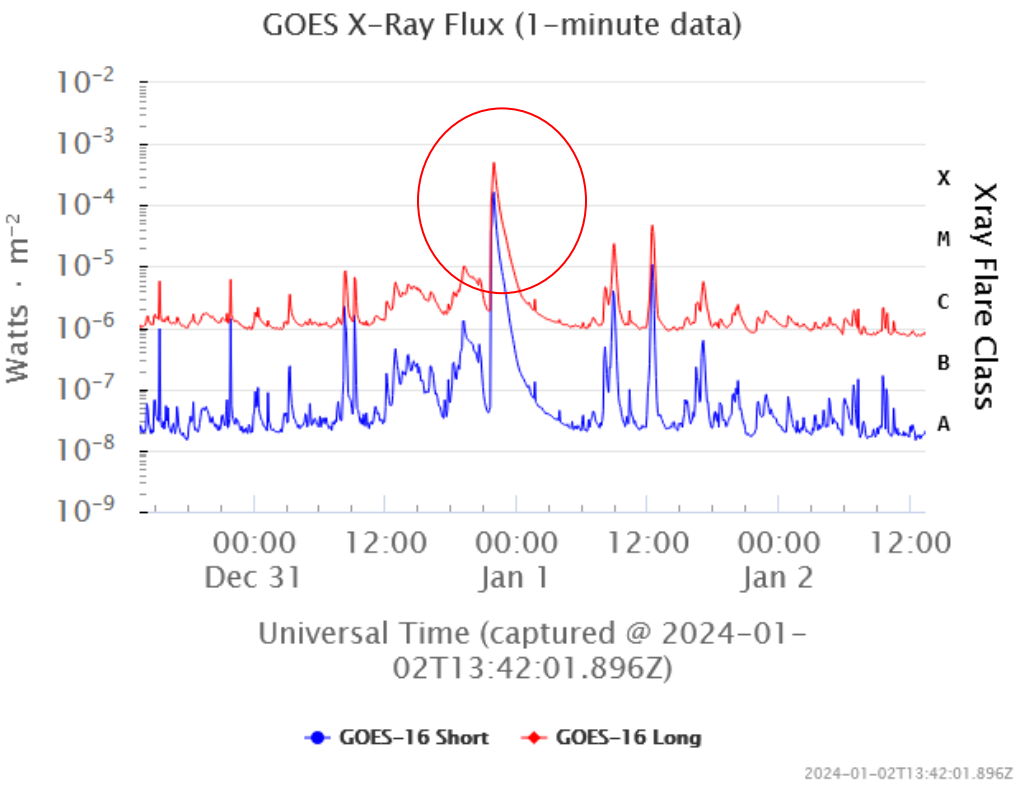
- Day-time effect
- Absorption is a function of $1/f^2$
- Can sometimes be compensated by power or bandwidth reduction



X5.0 Solar Flare – 31 DEC 2023



GOES X-Ray Flux – 31 DEC – 2 JAN



The X-ray radiation that ionizes the D-layer is the 1.0 - 8.0 A (red) plot. These measurements currently taken from the GOES 16 satelite.

Flare Category	Effect
A1-B9	No or minor impact on HF
C1	Low absorption of HF signals
M1	Occaisional loss of radio contact on sun-lit side
M5	Limited HF blackout for several minutes
X1	Wide area HF blackout for approx. 1 hr
X10	HF blackout over most of sun-lit side for 1-2 hrs
X20	Complete HF blackout of all sun-lit areas lasting hours

LASCO C3 - CME Departing Sun

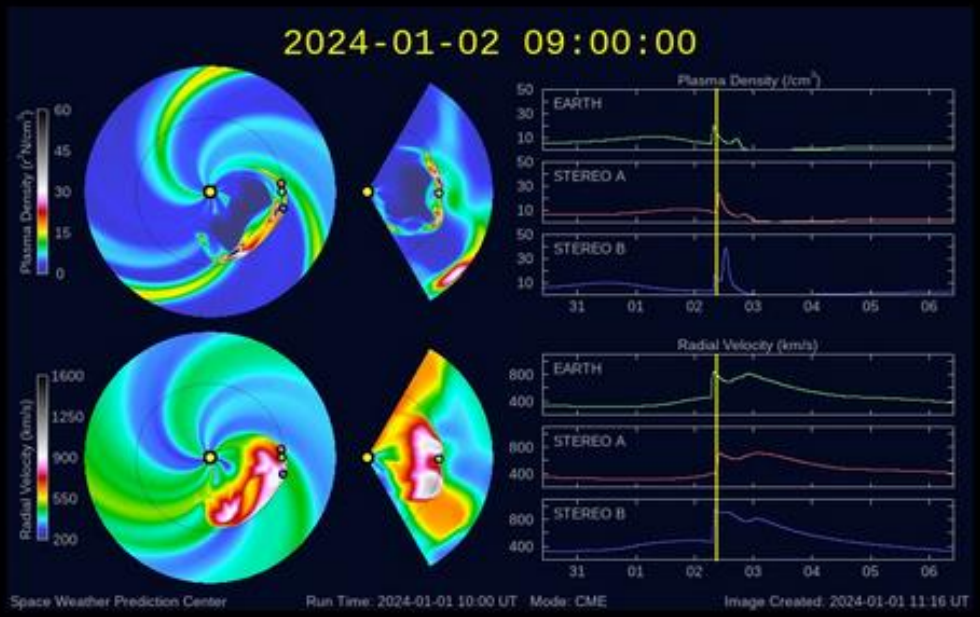
NOAA CME Tracking

Latest Space Weather News SolarHam News Archive

X5 CME Event Update

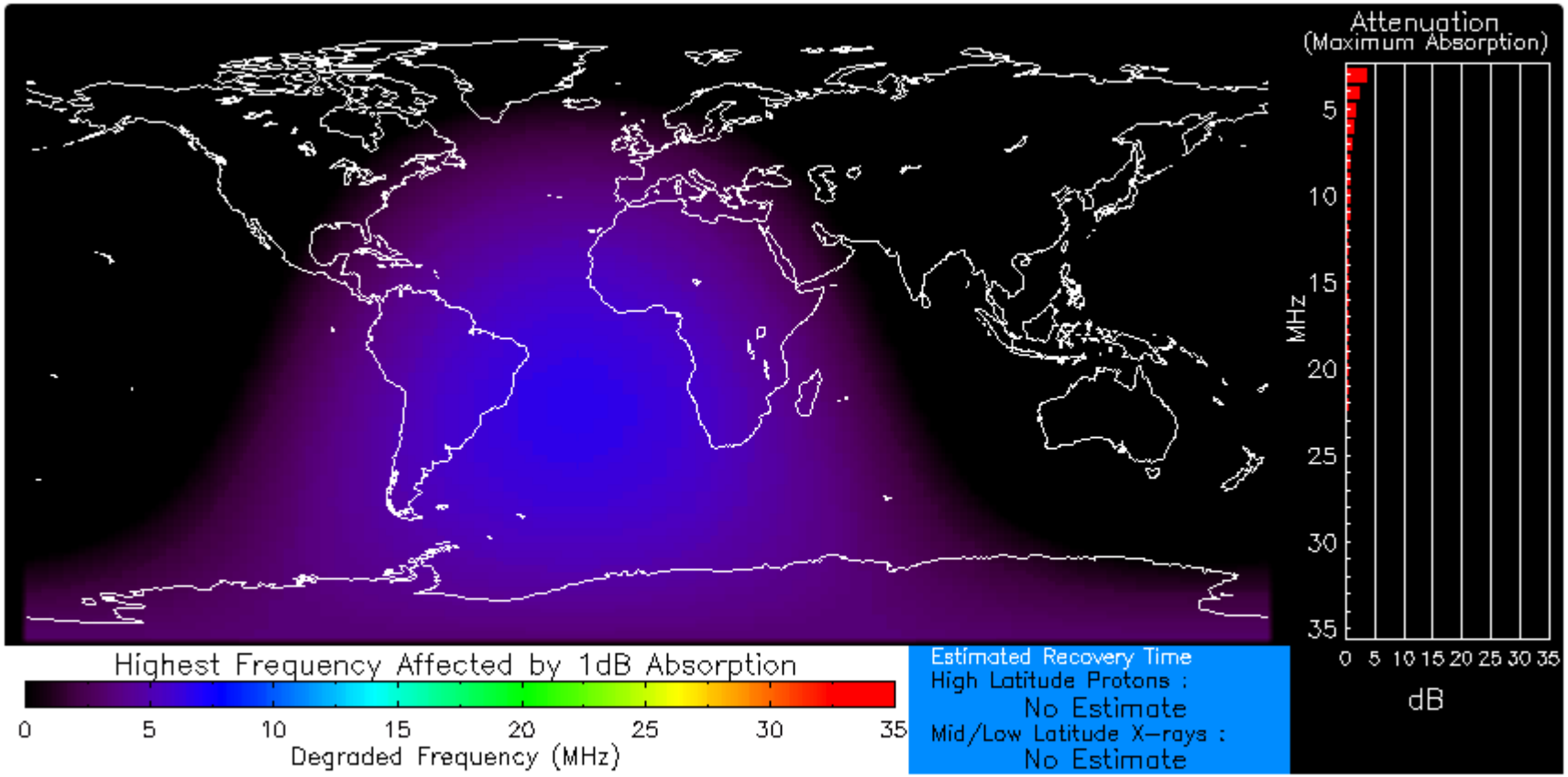
January 1, 2024 @ 18:40 UTC (Updated)

An official tracking model courtesy of NOAA/SWPC is now available for the X5.0 flare event. They are in fact calling for the extreme western edge of the associated CME to pass Earth by January 2nd. Geomagnetic storming will be possible should an impact be observed as predicted. Stay tuned for updates during the next 24 hours.



D-Region Absorption – 2 JAN

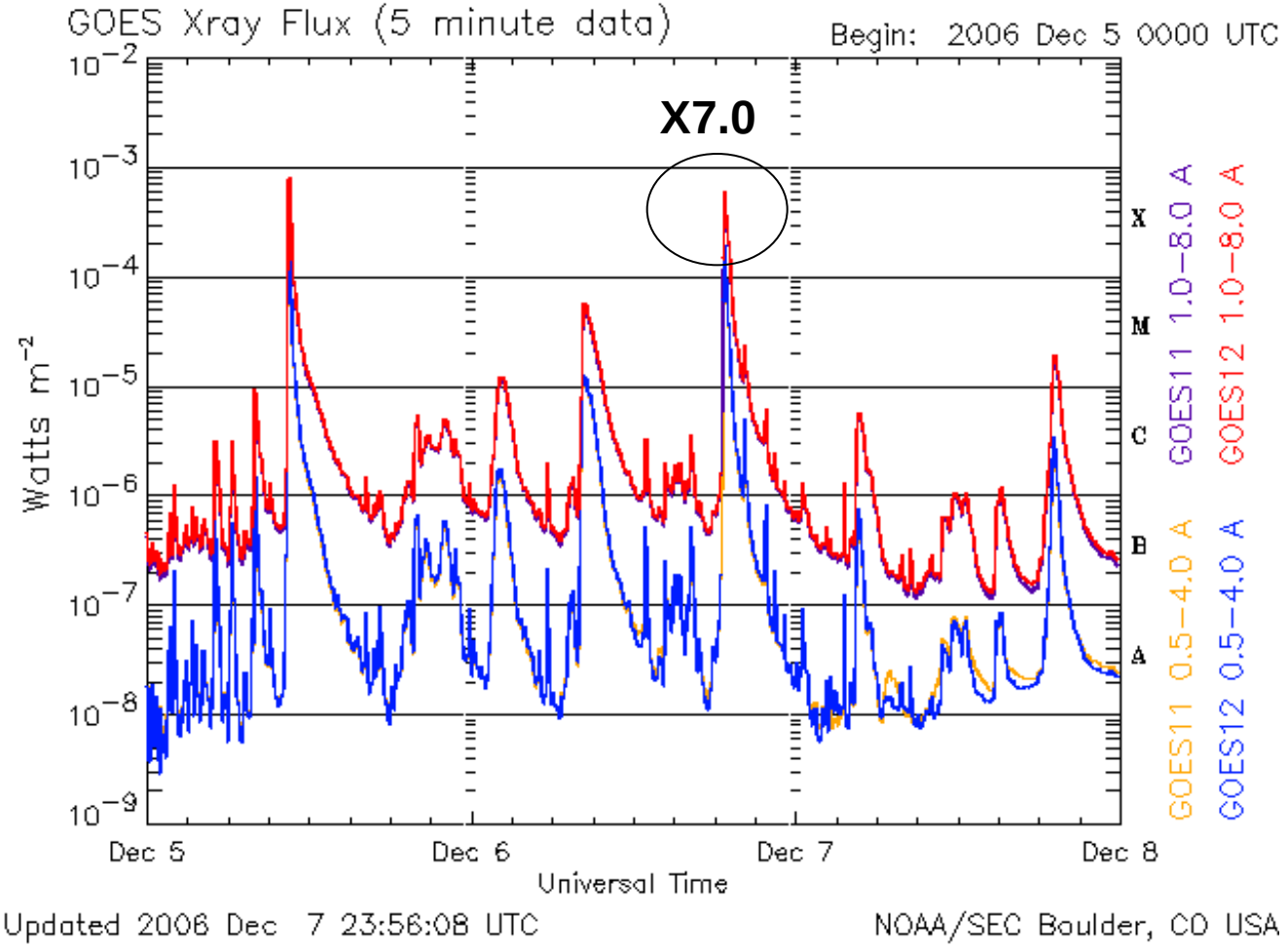
UNUSUAL D-REGION ABSORPTION PATTERNS



Normal X-ray Background
Product Valid At : 2024-01-02 13:24 UTC

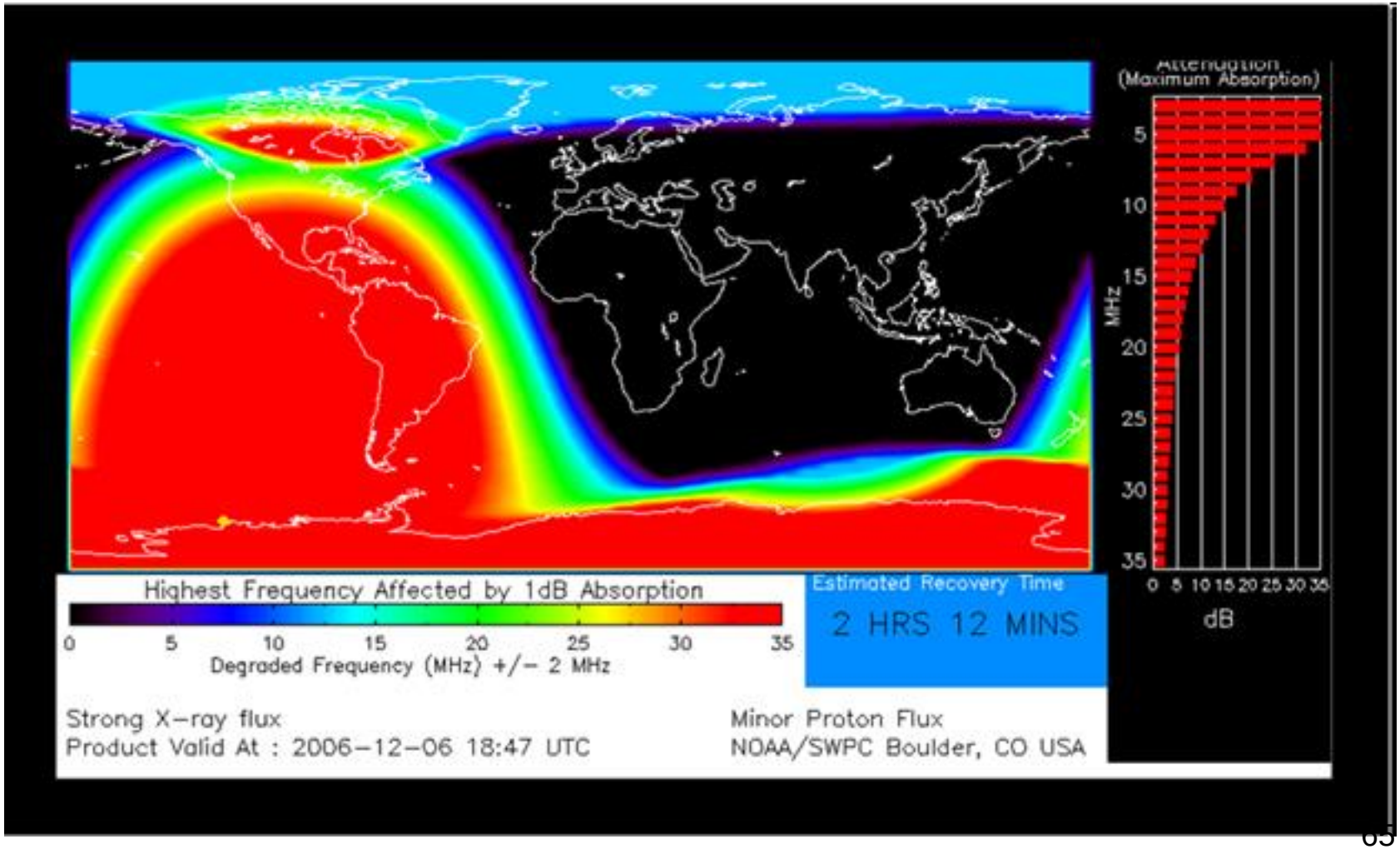
Normal Proton Background
NOAA/SWPC Boulder, CO USA

GOES X-Ray Flux (5-7 DEC 2006)



D-Absorption Prediction

(http://www.ngdc.noaa.gov/stp/drap/index.html)

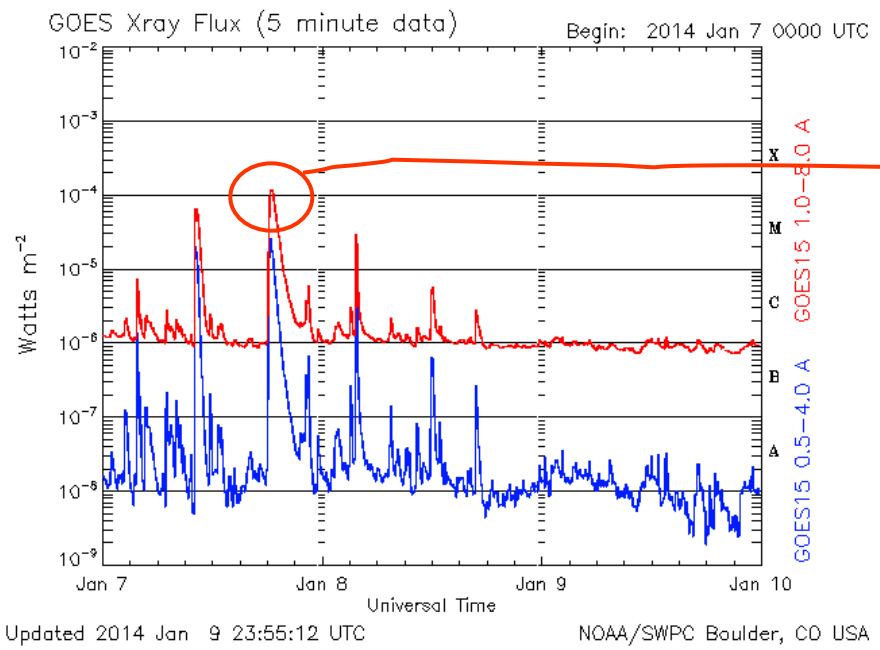


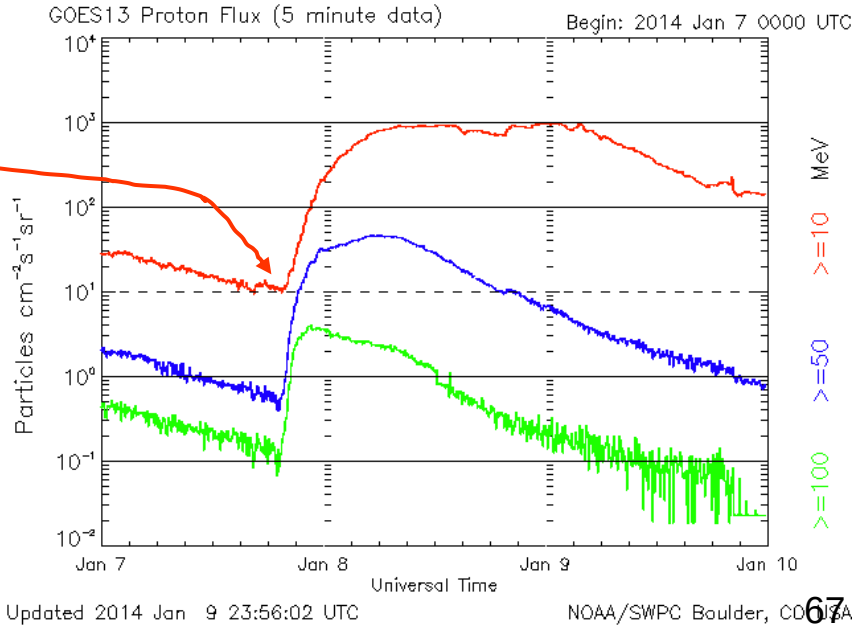
SOLAR EFFECTS ON PROPAGATION

- Ultraviolet Radiation – Good
- X-Ray Radiation from Solar Flares – Bad
- Proton Events – Bad for high Latitudes
- Corona Mass Ejections – Bad
- Coronal Holes – Bad

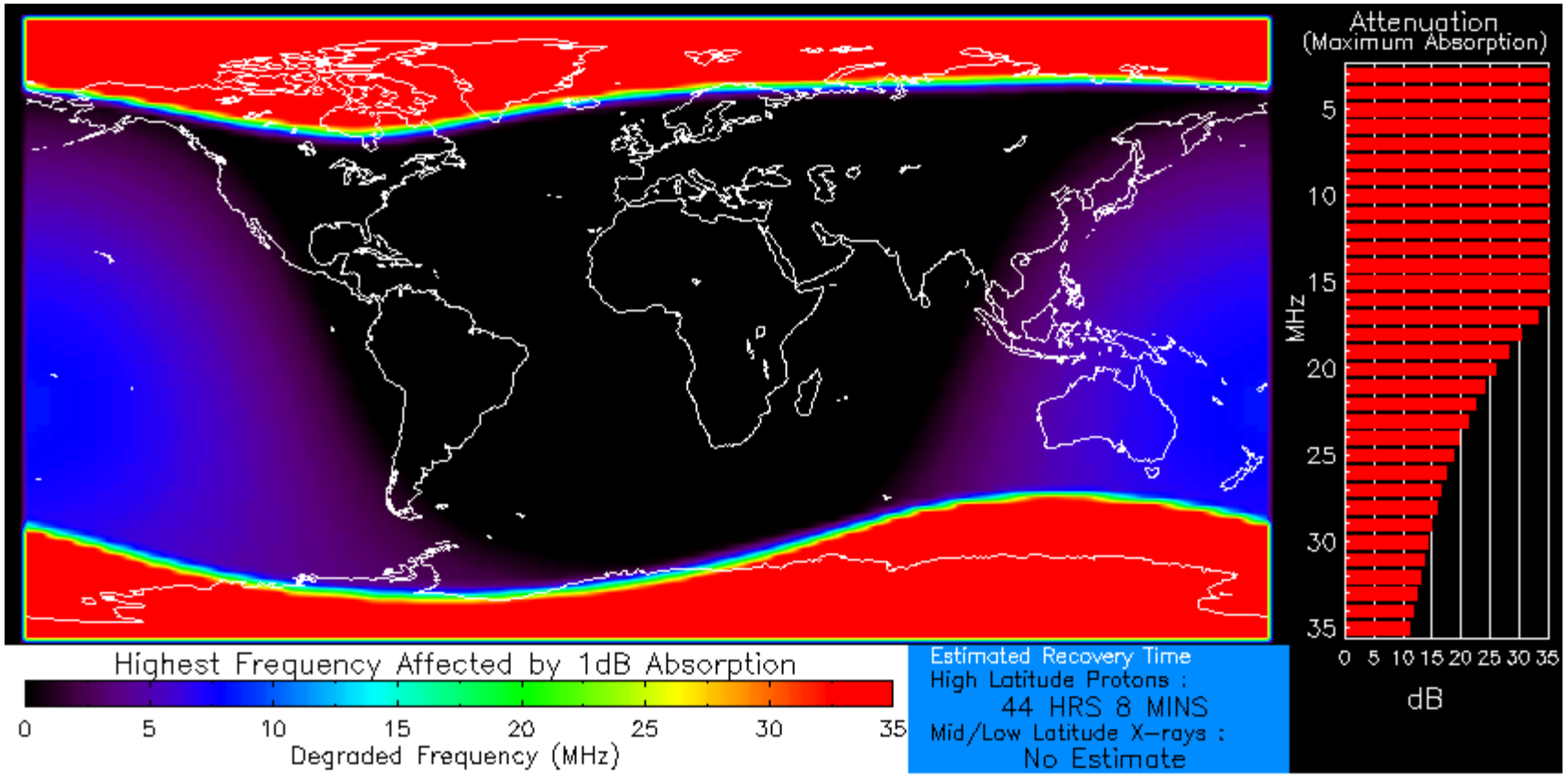
Proton Events

- Solar Radiation Storms (4 hours arrival after solar flare)
  - Caused by High energy Protons
  - Results in a PCA (Polar Cap Absorption)





Proton Event (D-Layer Absorption)



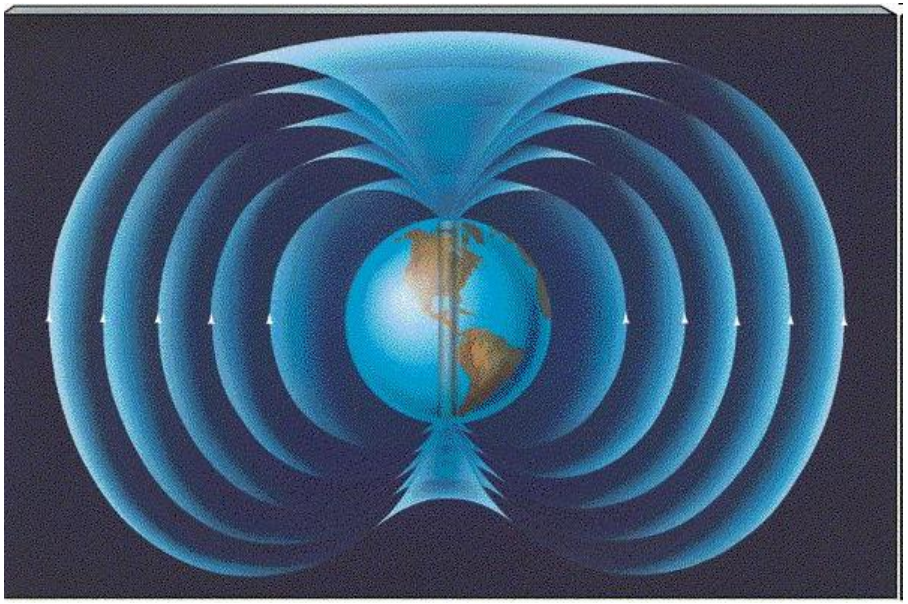
Normal X-ray Background
Product Valid At : 2014-01-09 00:00 UTC

Moderate Proton Flux
NOAA/SWPC Boulder, CO USA

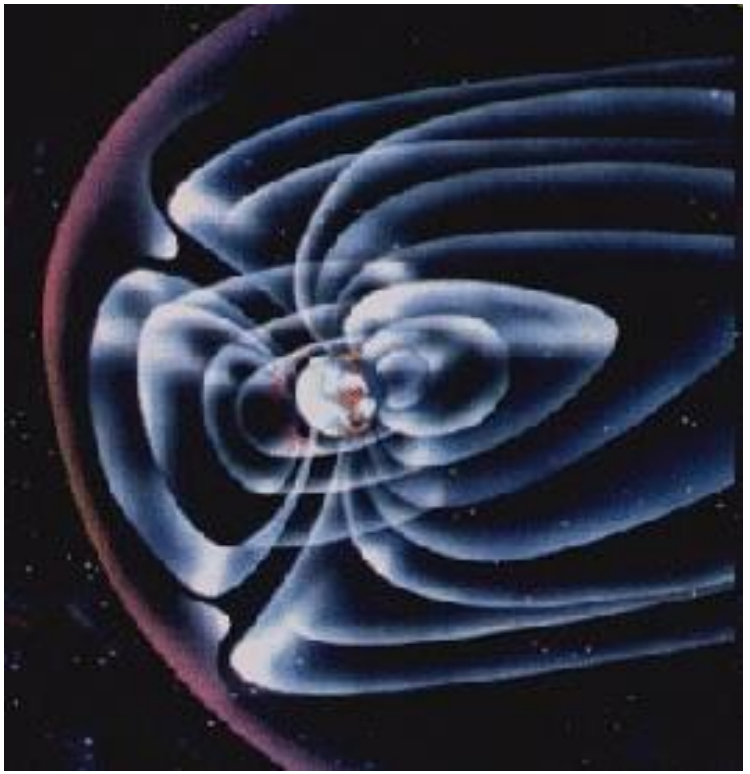
SOLAR EFFECTS ON PROPAGATION

- Ultraviolet Radiation – Good
- X-Ray Radiation from Solar Flares – Bad
- Proton Events - Bad
- Corona Mass Ejections – Bad
- Coronal Holes – Bad

EARTH'S MAGNETIC FIELD



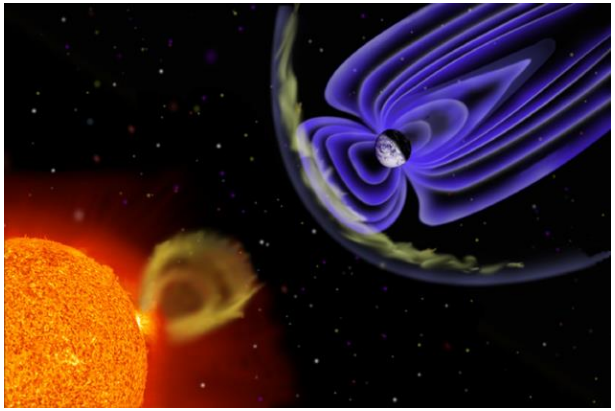
Without Solar Wind



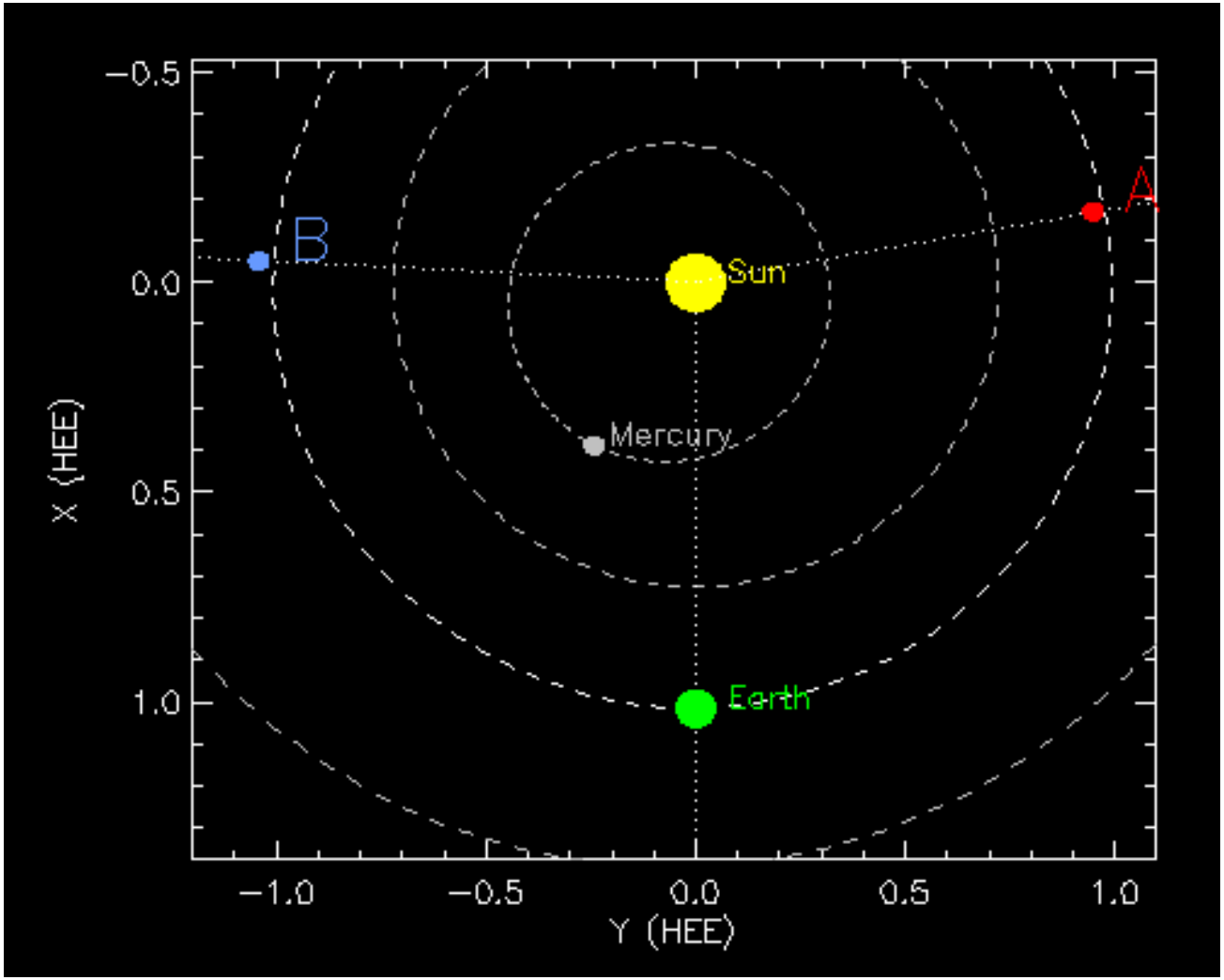
Actual Magnetic Field With Solar Wind

Coronal Mass Ejections

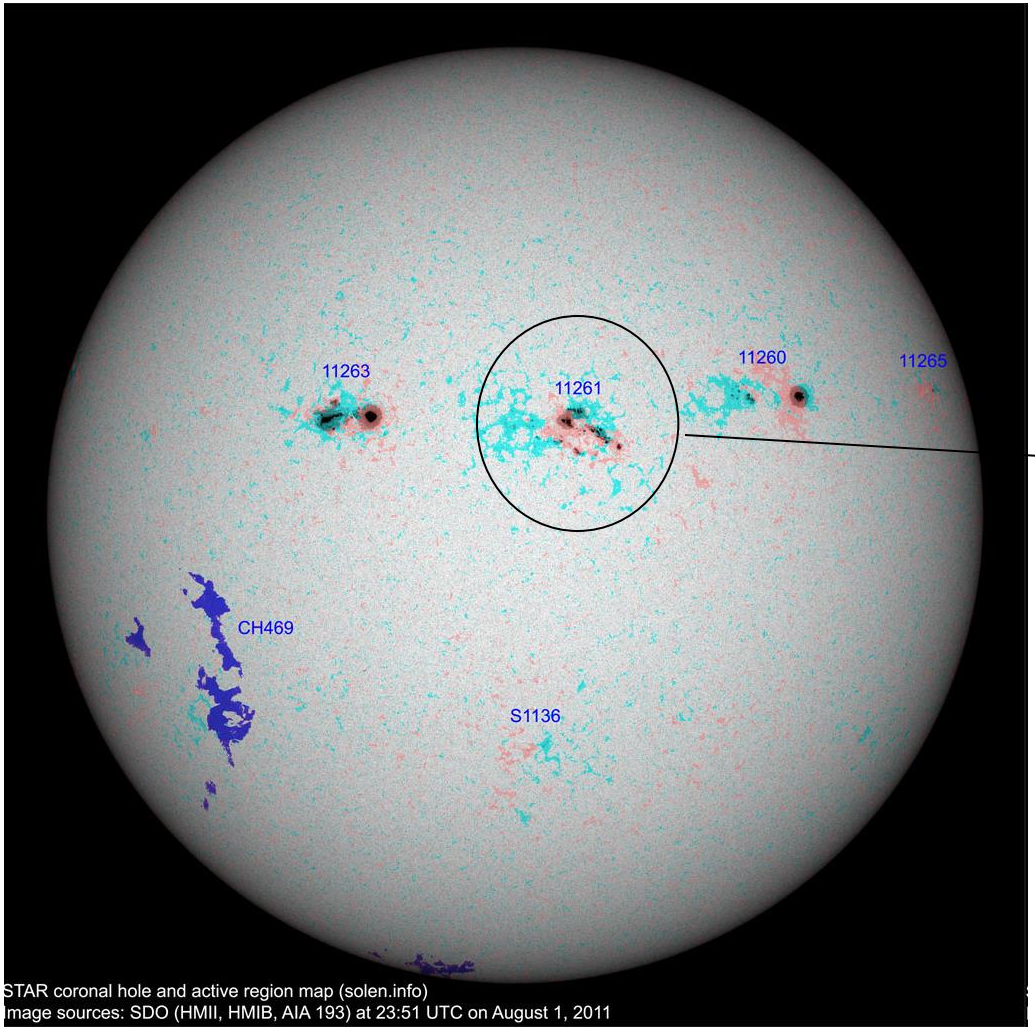
- Geomagnetic Storm causing Ionospheric Storm (1-3 day) Caused by CME (Corona Mass Ejection) or Coronal Hole
  - Depressed MUF and increased D absorption
  - Indicated by increased K and A indices
  - Severity of effects function of polarity of Bz
    - Bz South – more severe effects

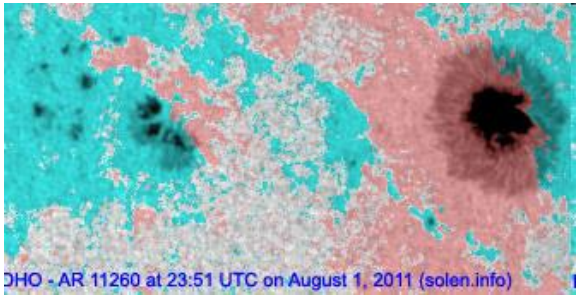


STEREO Satellite Pair
2 Aug 2011

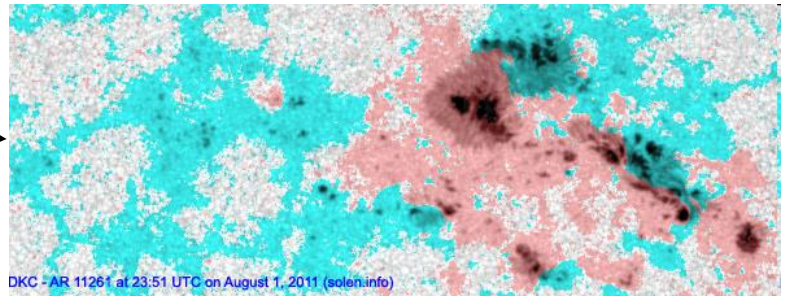


Sun Spots - Aug 2, 2011

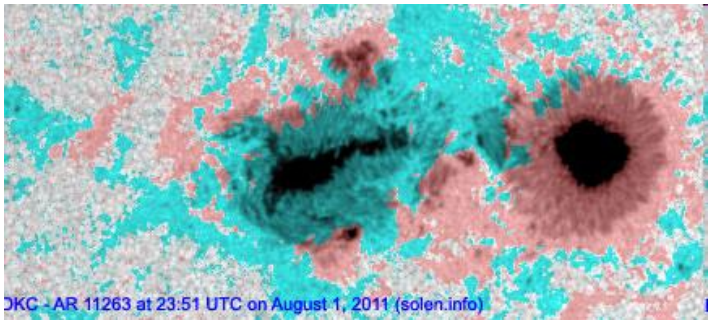




11260 SWPC Classification – EHO
Beta, Quiet and Stable



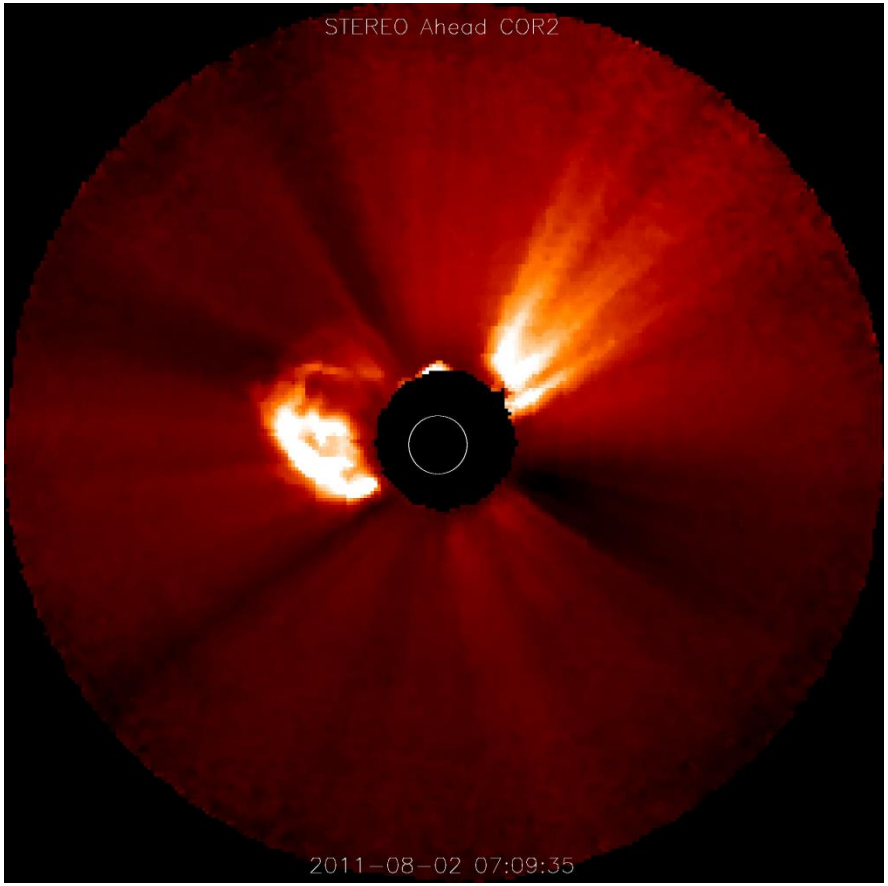
11261 SWPC Classification – FKC
Beta-Gamma-Delta, C, M, X Flares



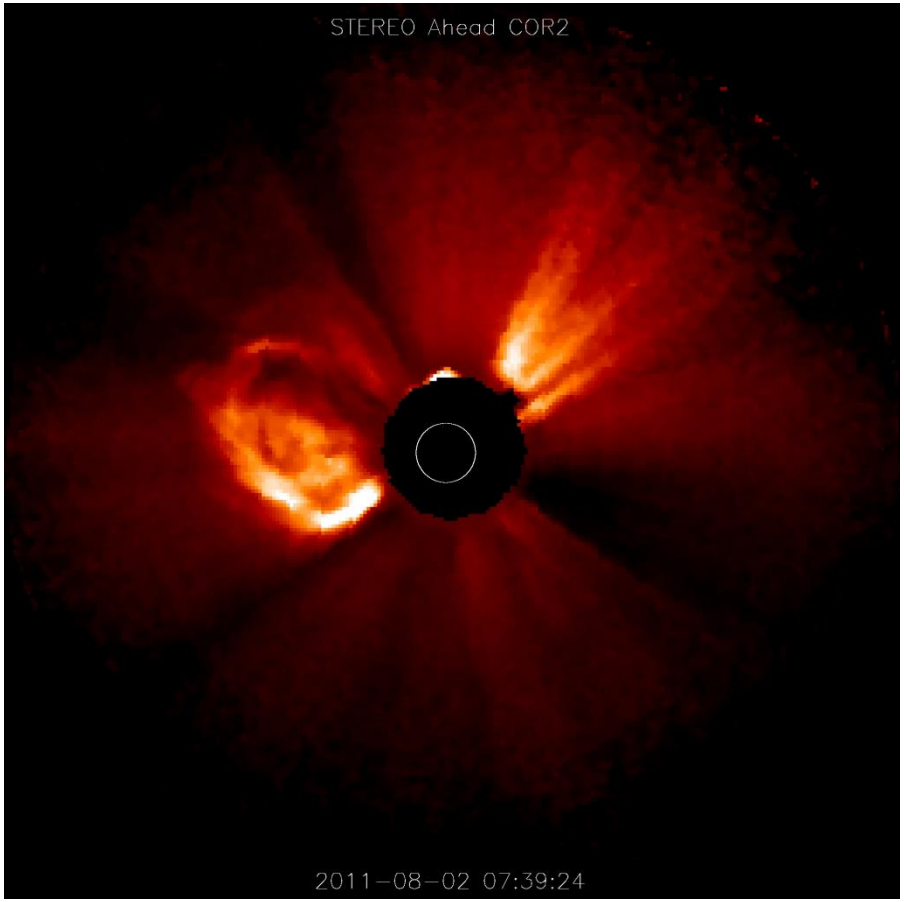
11263 SWPC Classification – DKC
Beta-Gamma-Delta, C, M, X flares

Sunspot 11261 CME

(long duration M1.4 event peaking at 06:19 UTC)

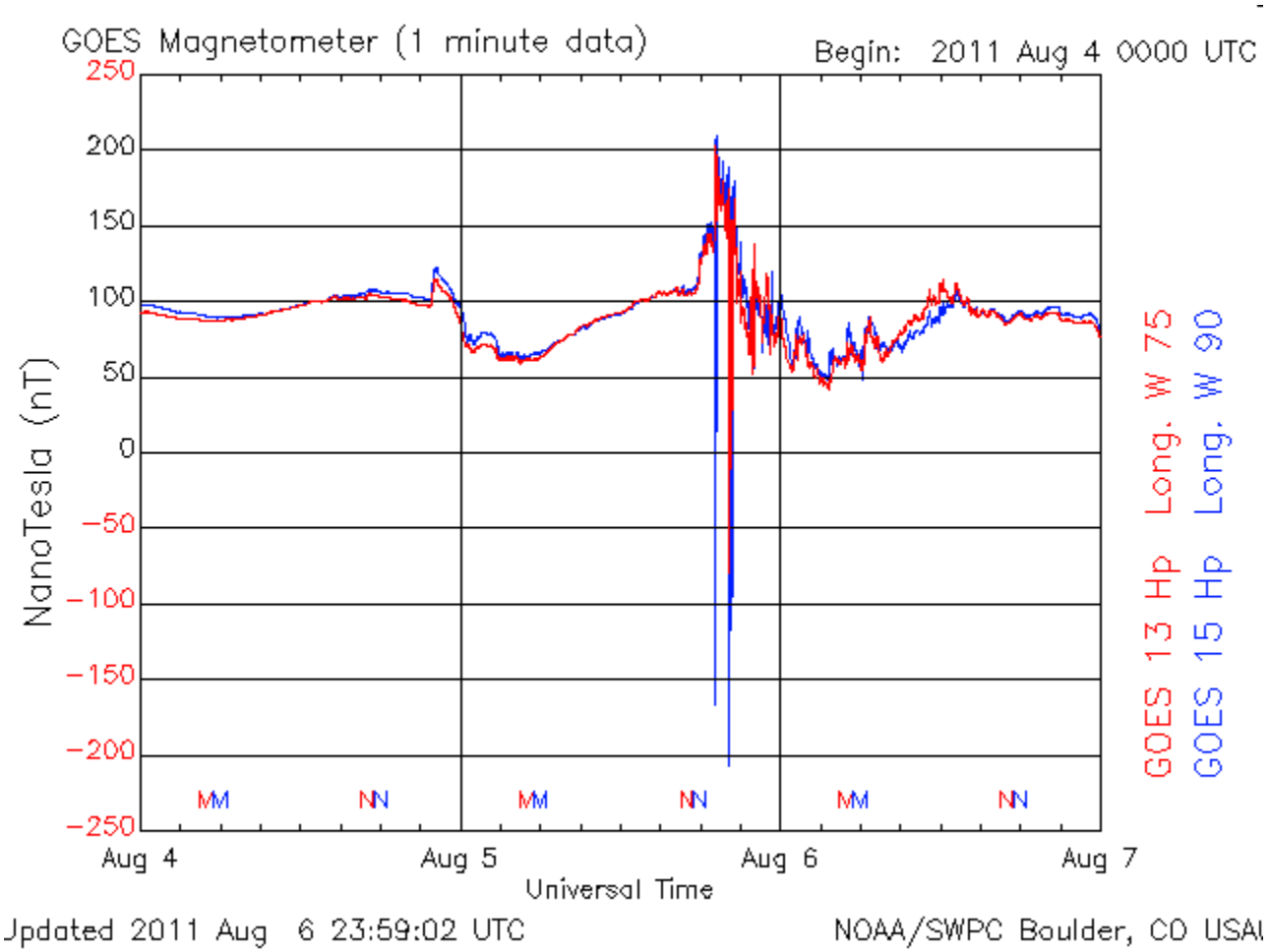


STEREO Ahead – 07:09Z

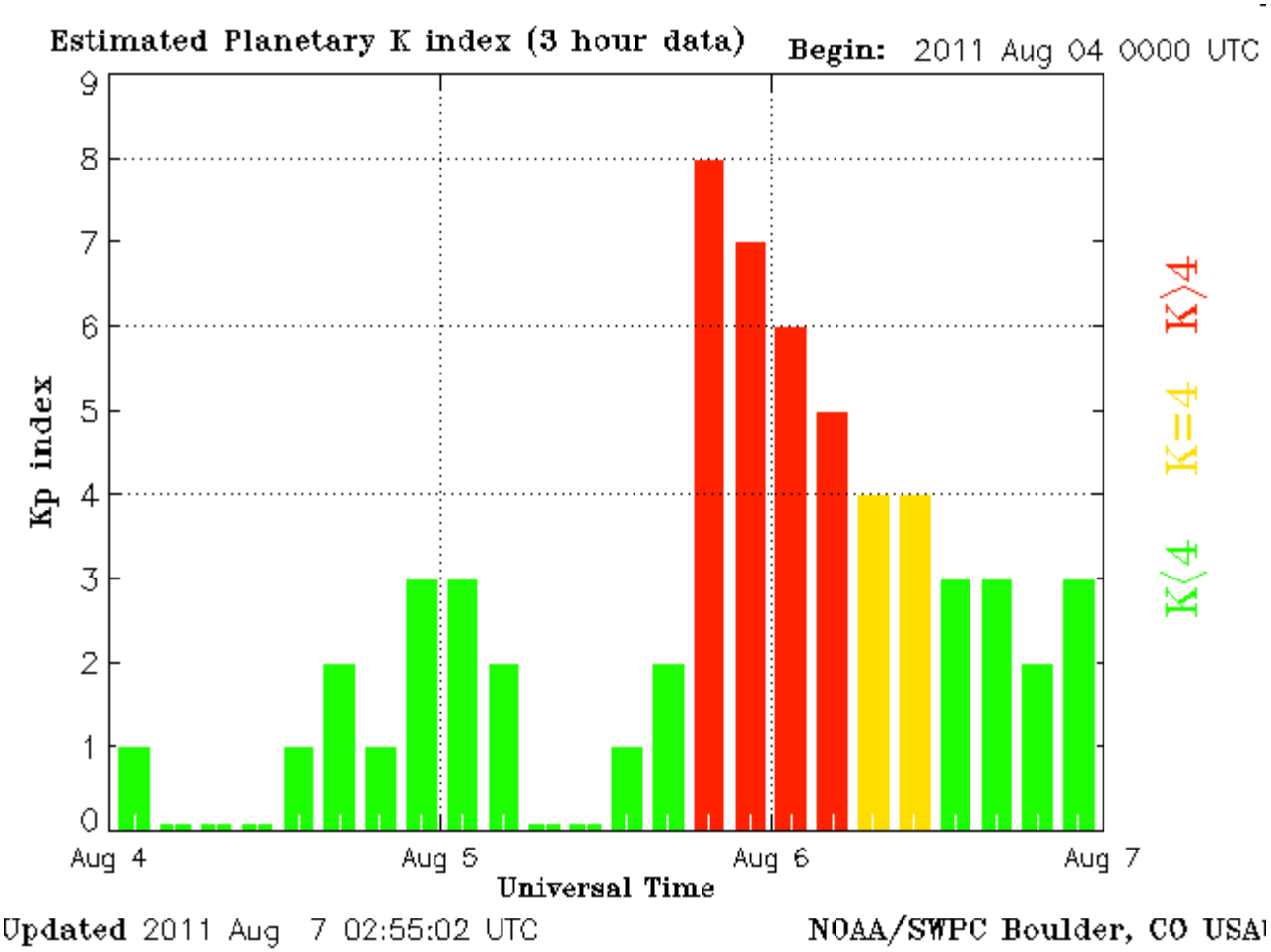


STEREO Ahead – 08:09Z

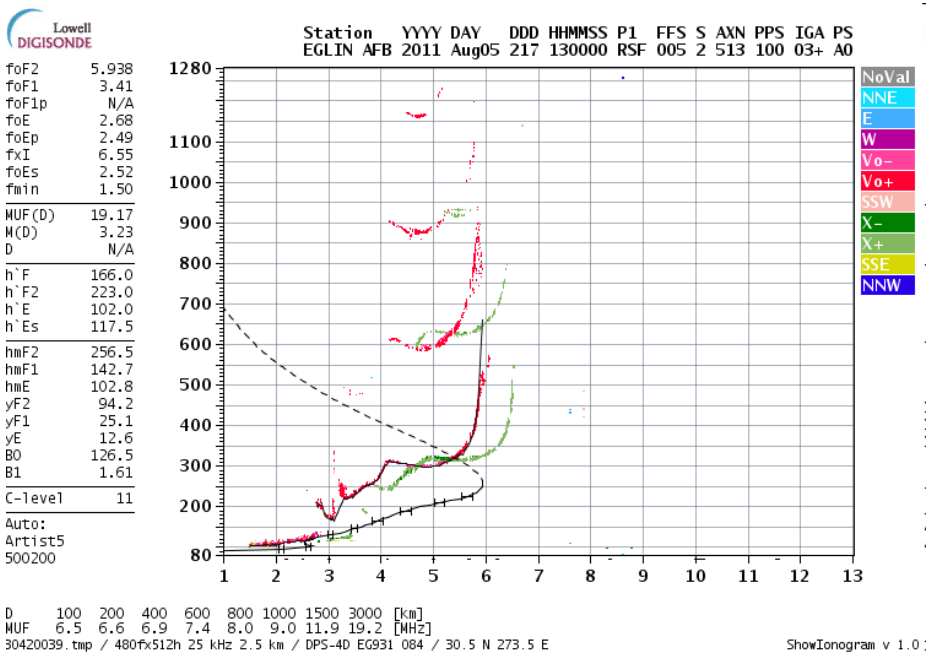
GOES Magnetometer (Arrival of 2 Aug. CME)

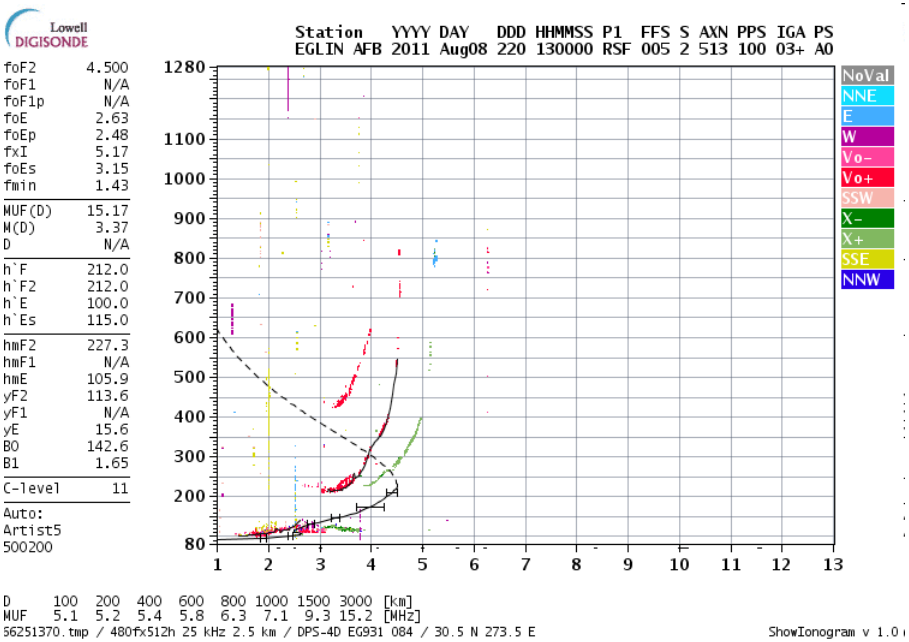


Planetary K Index (Arrival of 2 Aug CME)



Ionosonde Data
(24% drop in CF)

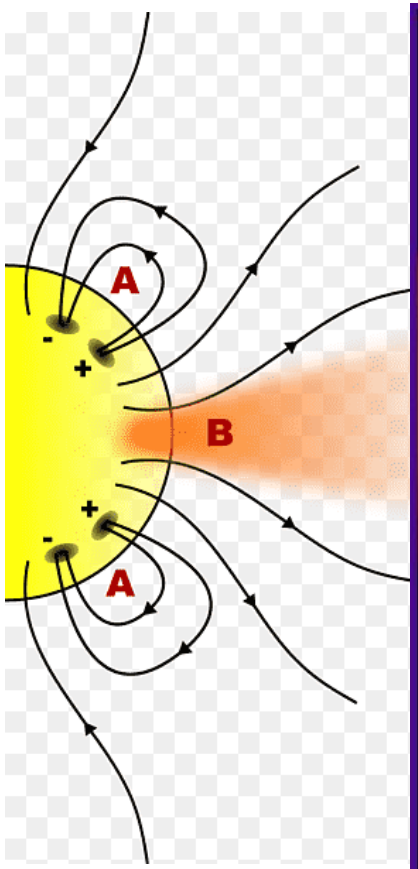




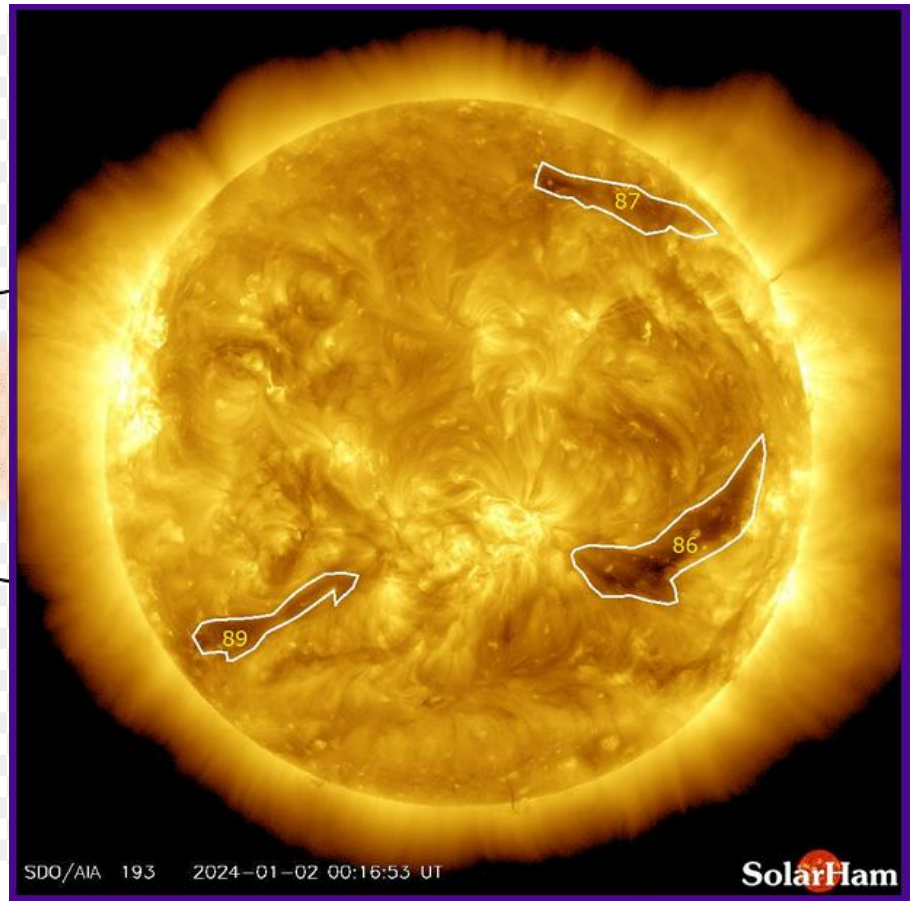
5 August 1300Z
(CF = 5.9 MHz - Normal)
(MUF = 19.2 MHz)

8 August 1300Z
(CF = 4.5 MHz)
(MUF = 15.2 MHz)

Coronal Hole Effect



Coronal Hole Map (Updated January 2, 2024)

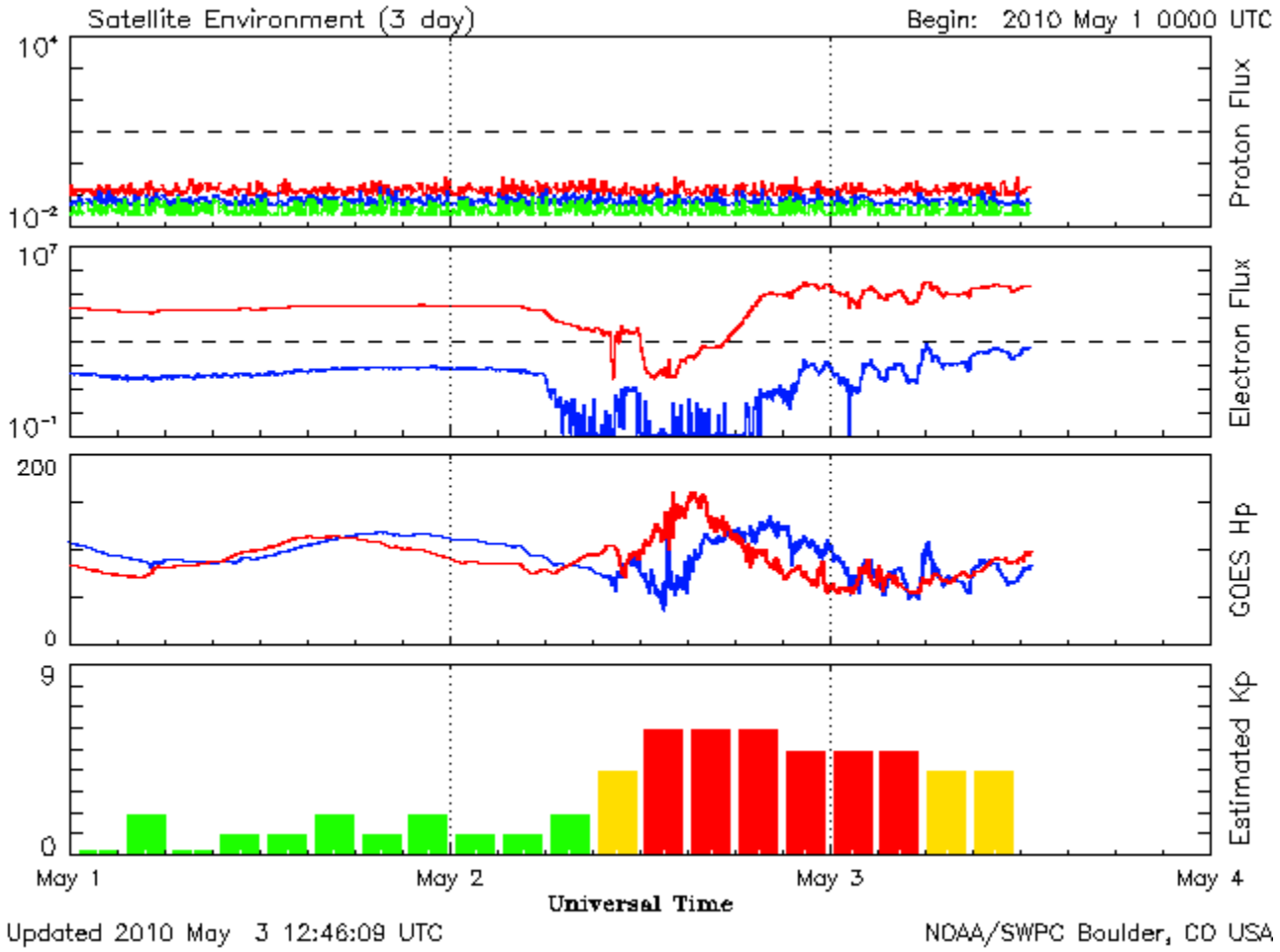


Analysis

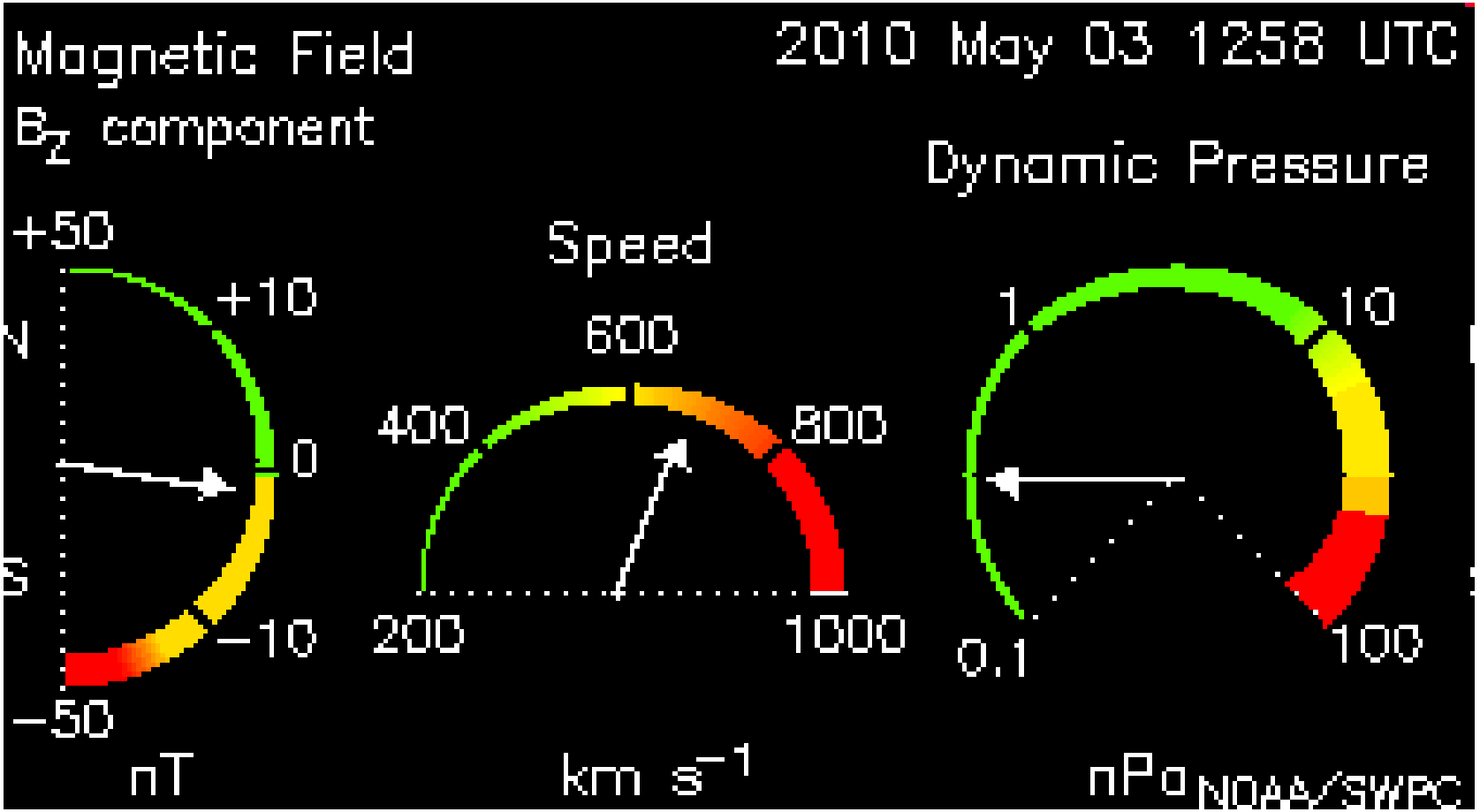
Coronal hole #86 is now turning away from Earth. A coronal hole stream containing sectors of southward Bz is currently moving past our planet.

Satellite Environment Plot

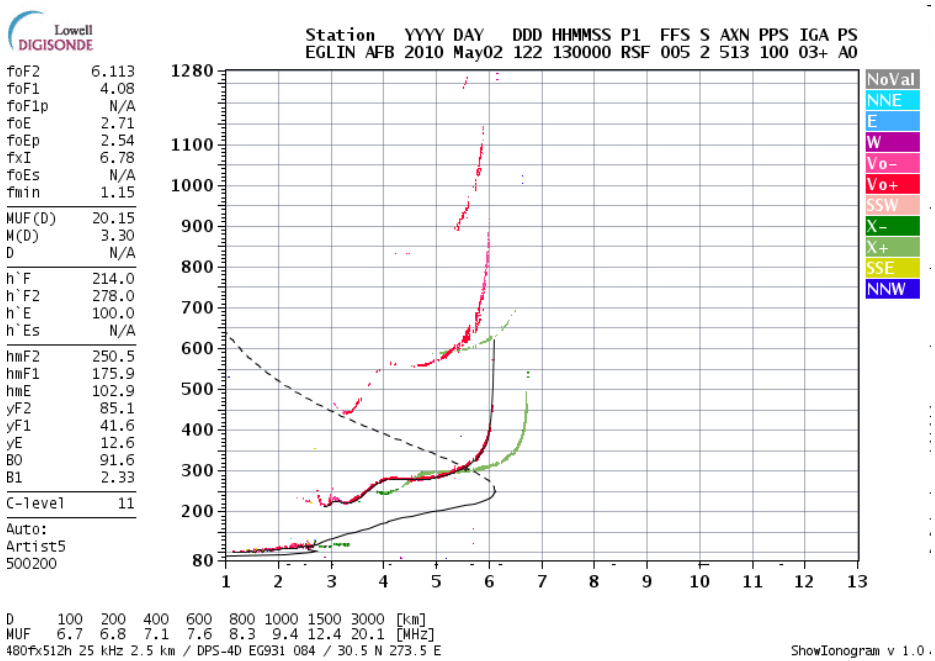
(Coronal Hole Event)

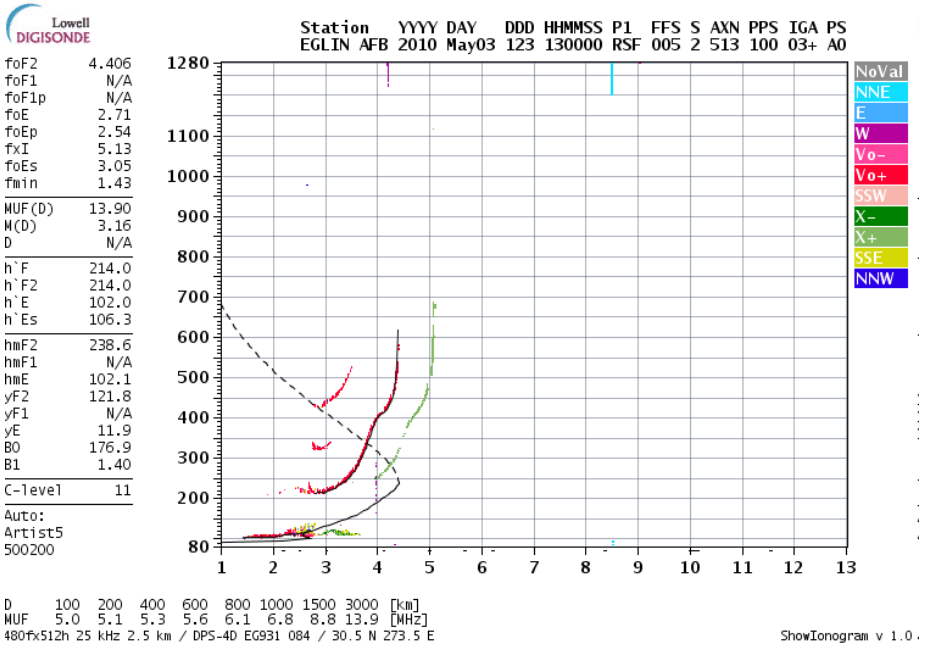


3 May Solar Wind (ACE Satellite)



Ionosonde Data
(28% drop in CF)



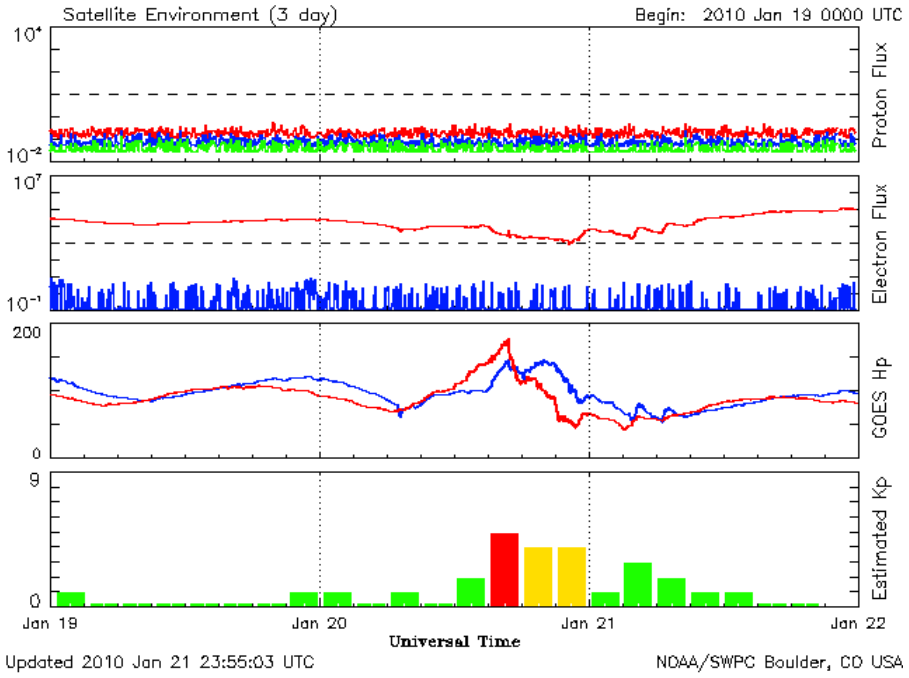


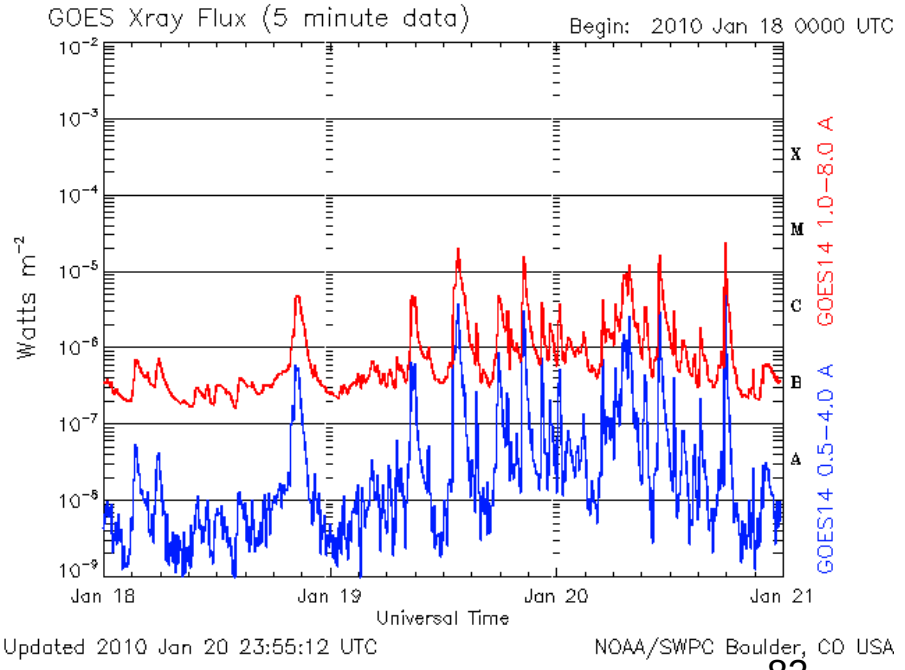
2 May 1300Z
(CF = 6.1 MHz - Normal)
(MUF = 20.1 MHz)

3 May 1300Z
(CF = 4.4 MHz)
(MUF = 13.9 MHz)

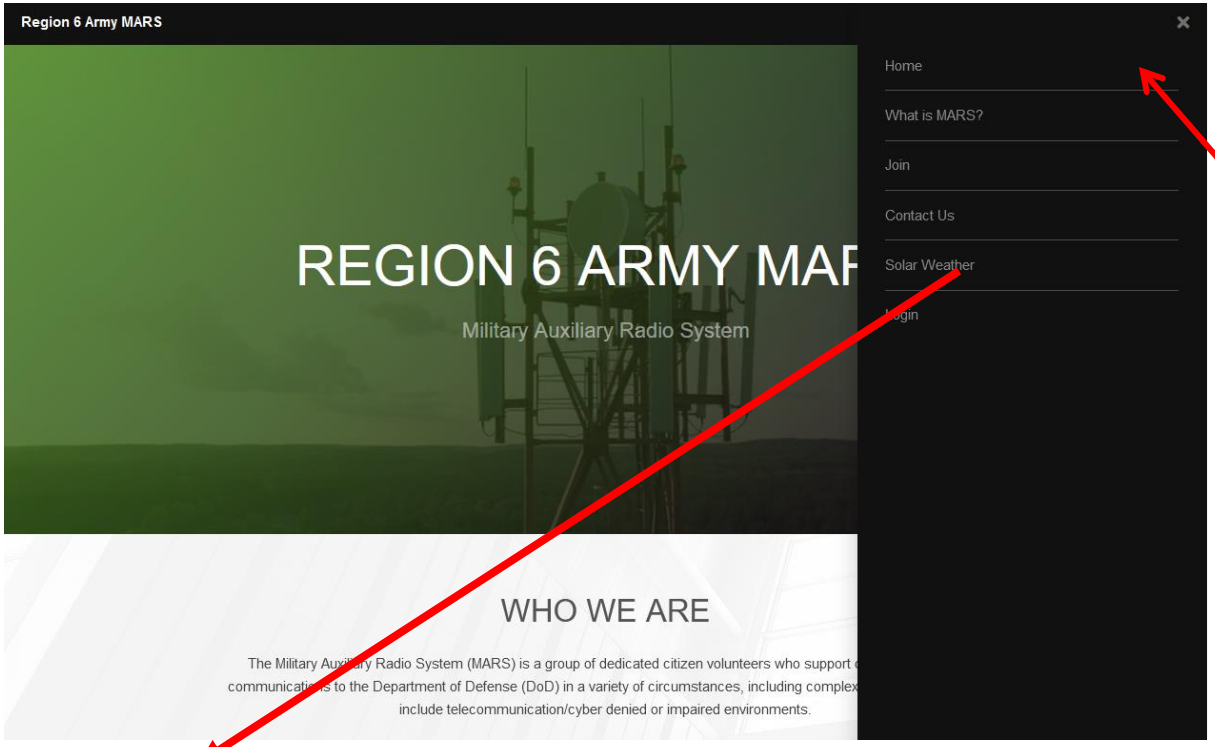
Solar & Geomagnetic Indicator Sources

- WWV – 2, 5, 10, 15, 20 MHz at 18’ pass each hour.
- Web site: http://www.swpc.noaa.gov/
- https://www.region6armymars.org/resources/solarweather.php





Solar Weather Sites



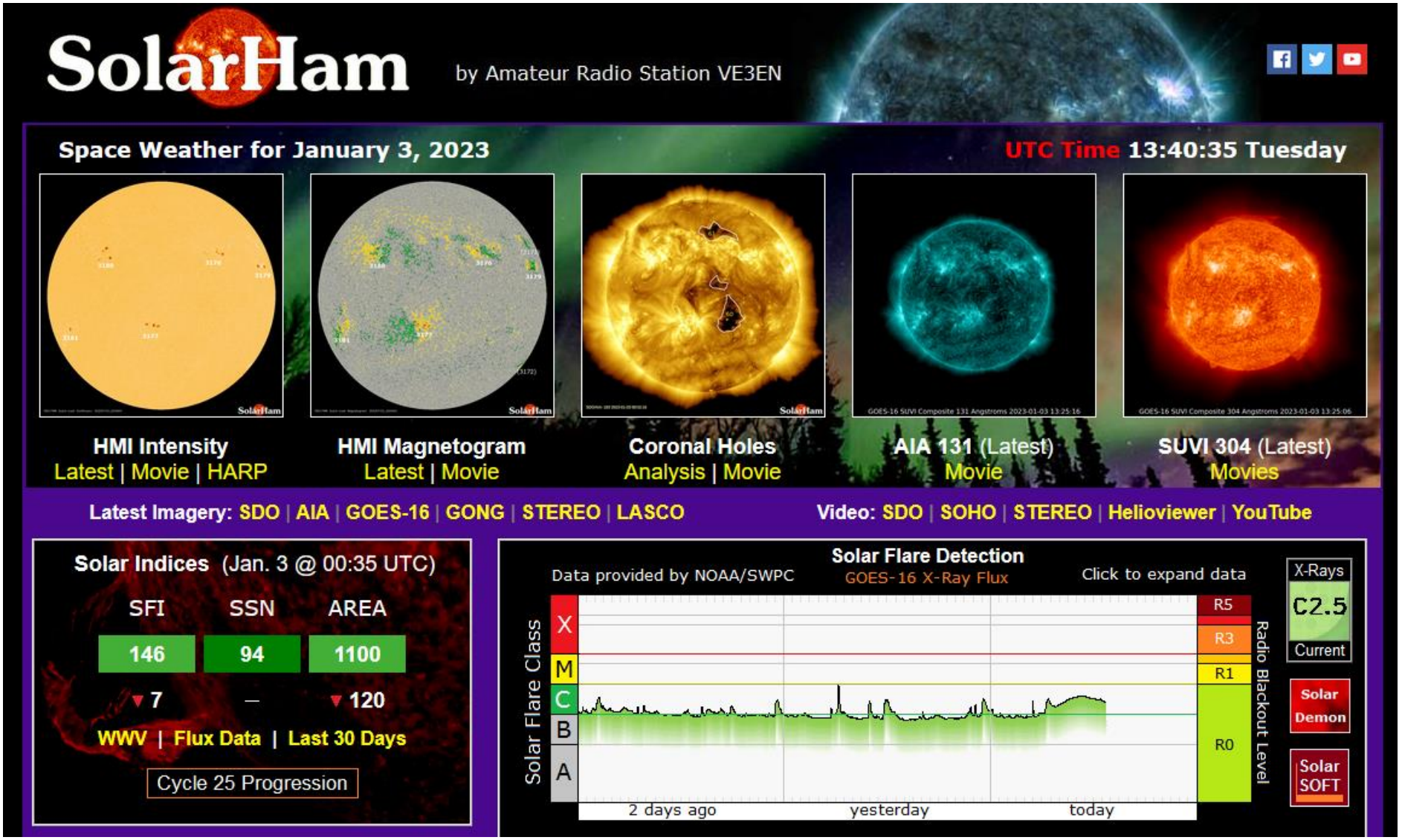
Menu

Solar Weather

Other Solar Weather Links of Interest

All Ionosondes →

- DIDBase - Select Station List then EGLIN then year/month/day/time for Ionosonde plot.
- NOAA Solar Weather - Solar Weather plots of Kp and X-Ray and other solar emissions.
- Solen Solar Weather - Good general solar forecast from an individual.
- Solar Ham - SolarHam provides real time solar news, as well as consolidated data from various sources.


SolarHam
by Amateur Radio Station VE3EN
Space Weather for January 3, 2023
UTC Time 13:40:35 Tuesday
HMI Intensity
Latest | Movie | HARP
HMI Magnetogram
Latest | Movie
Coronal Holes
Analysis | Movie
AIA 131 (Latest)
Movie
SUVI 304 (Latest)
Movies
Latest Imagery: SDO | AIA | GOES-16 | GONG | STEREO | LASCO
Video: SDO | SOHO | STEREO | Helioviewer | YouTube
Solar Indices (Jan. 3 @ 00:35 UTC)
SFI
SSN
AREA
146
94
1100
▼ 7
–
▼ 120
WWV | Flux Data | Last 30 Days
Cycle 25 Progression
Solar Flare Detection
Data provided by NOAA/SWPC
GOES-16 X-Ray Flux
Click to expand data
Solar Flare Class
X
M
C
B
A
R5
R3
R1
R0
Radio Blackout Level
2 days ago
yesterday
today
X-Rays
C2.5
Current
Solar Demon
Solar SOFT

spaceweather.com

News and information about the Sun-Earth environment

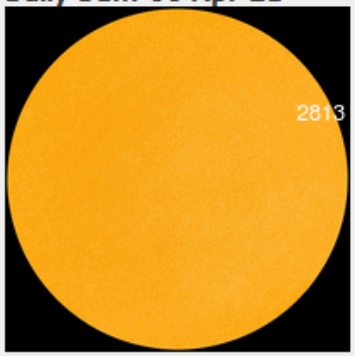
https://www.spaceweather.com/

Current Conditions

Solar wind
speed: **314.8** km/sec
density: **9.9** protons/cm^3
more data: ACE, DSCOVR
Updated: Today at 1225 UT

X-ray Solar Flares
6-hr max: **A1** 1027 UT Apr06
24-hr: **A1** 1515 UT Apr05
explanation | more data
Updated: Today at: 1230 UT

Daily Sun: 06 Apr 21



Sunspot AR2813 is decaying, and poses no threat for strong flares.
Credit: SDO/HMI

FLYING TO THE VOLCANO: Iceland's Geldingadalur volcano has turned into an popular tourist attraction---especially since auroras were sighted above the glowing lava. Early this morning, Tuesday, April 6th, Brian Emfinger saw auroras before he even reached the Reykjanes peninsula:

QUESTIONS?

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