Surveying Green Light: Impacts of Space Weather

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Summary of GPS Errors

Typical Error [m] (per satellites)	Standard GPS	Differential GPS
• Satellite Clocks	1.5	0
• Orbit Errors	2.5	0
• Ionosphere	5.0	0.4
• Troposphere	0.5	0.2
• Receiver Noise	0.3	0.3
• Multipath	0.6	0.6

The ionosphere is the largest source of error for Standard GPS and second largest for Differential GPS.

http://www.trimble.com/gps/howgps-error2.shtml#3

Ionosphere and Plasmasphere

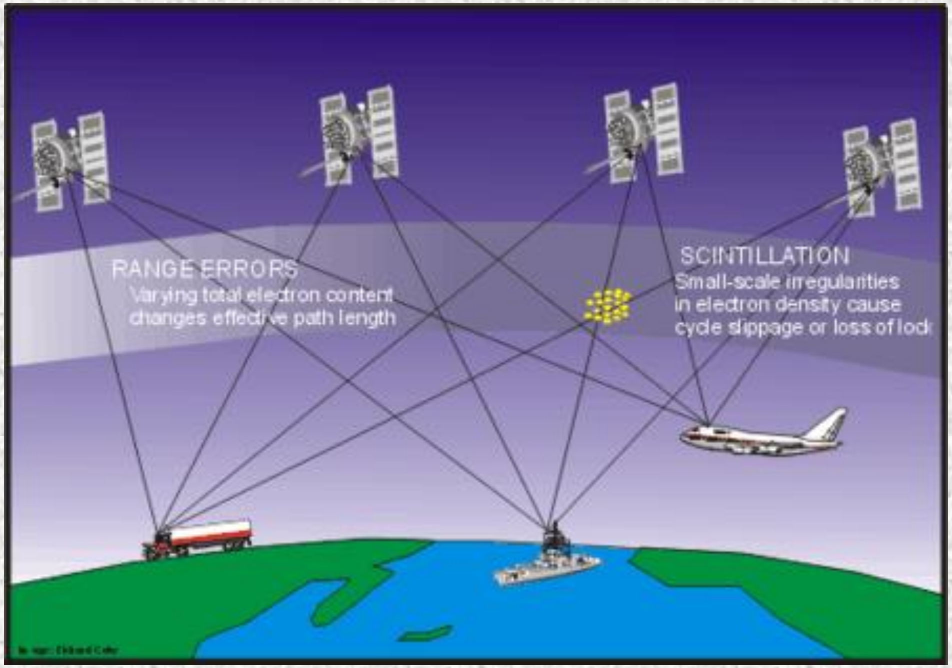
The ionosphere is that part of the upper atmosphere where free electrons occur in sufficient density to have an appreciable influence on the propagation of radio frequency electromagnetic waves.

Less than 1% of constituents ionized

Lower boundary at ~ 60 km
Upper boundary at ~ 1000 km

Plasmasphere extends to several R_E and includes the radiation belts and the ring current

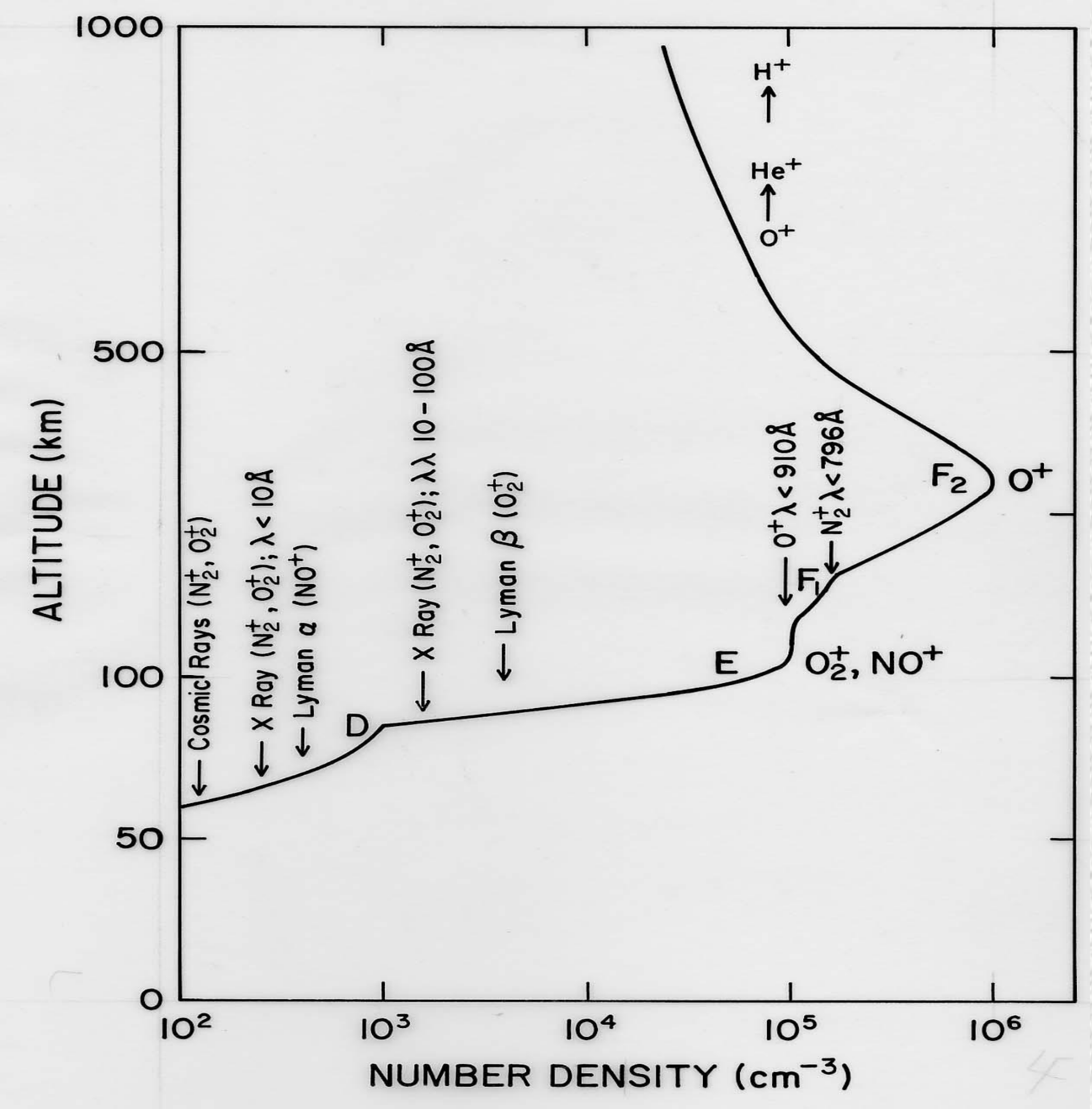
Ionospheric Effects on GPS



-The ionosphere introduces a variable time delay in the propagation of signals from the satellite to the receiver, which affects positioning.

-The delay calculation requires modeling the electron density along the pass of the signal.

Electron\Ion Density Profile



Ionospheric Effects

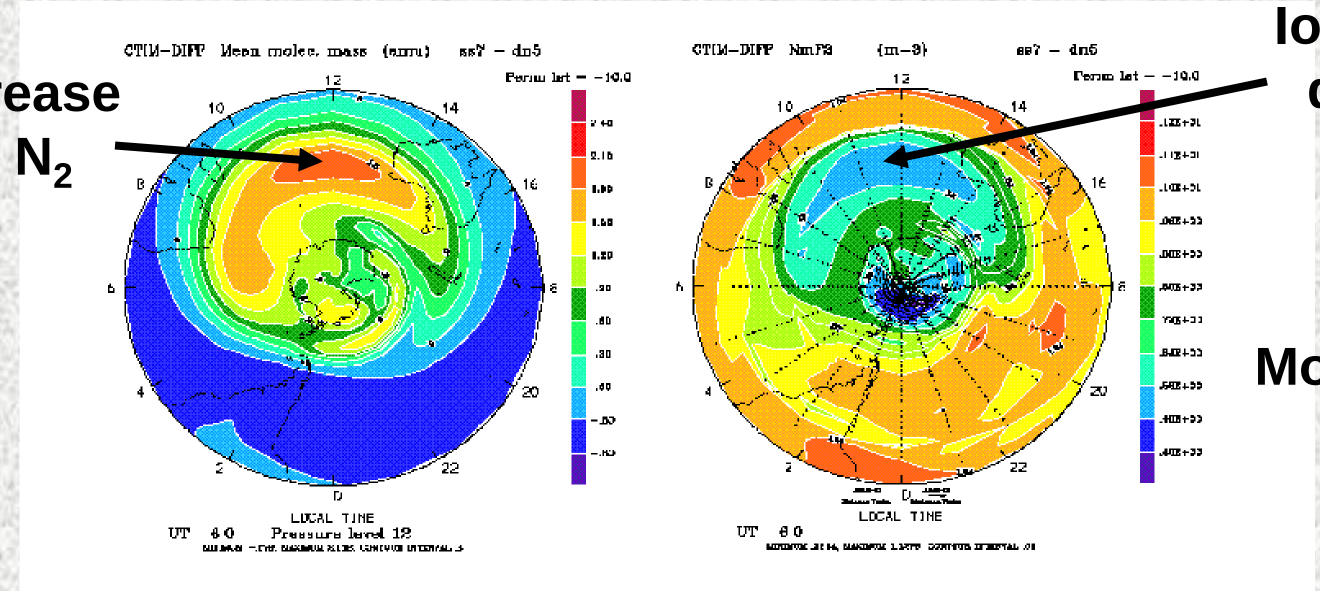
- Neutral composition
  - Affects production and loss of ionization
  - Can vary on several hours time-scales during storms

- Neutral Winds
  - Redistribute plasma paralell to B field
  - Change charged particle life times
  - Have time scales of about one hour

- Electric fields
  - Redistribute plasma perpendicular to B field
  - Change charged particle life times
  - Have time scales of minutes

Regional Composition Changes and Ion Density

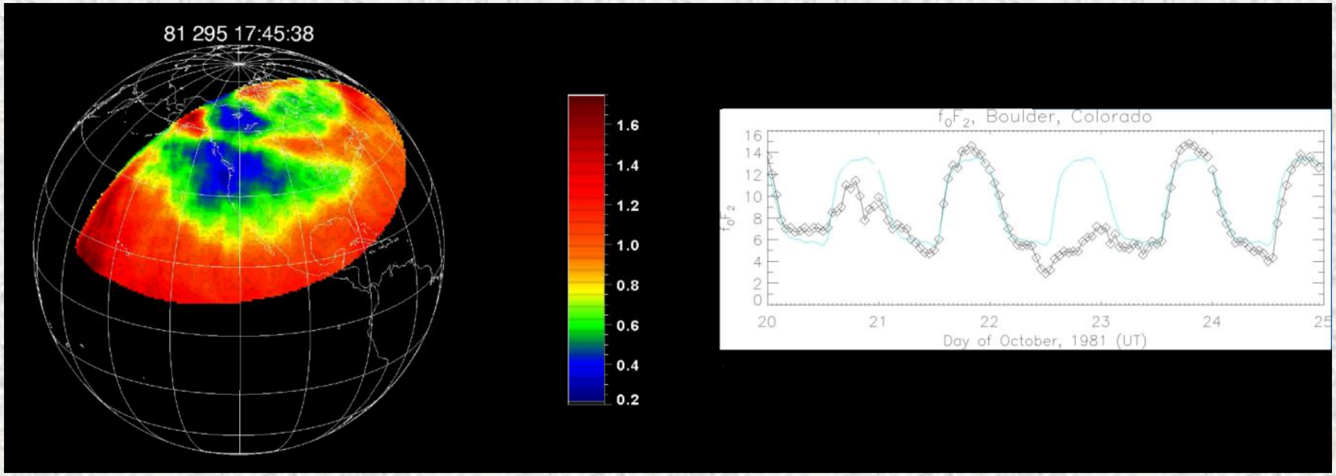
Increase in N_2



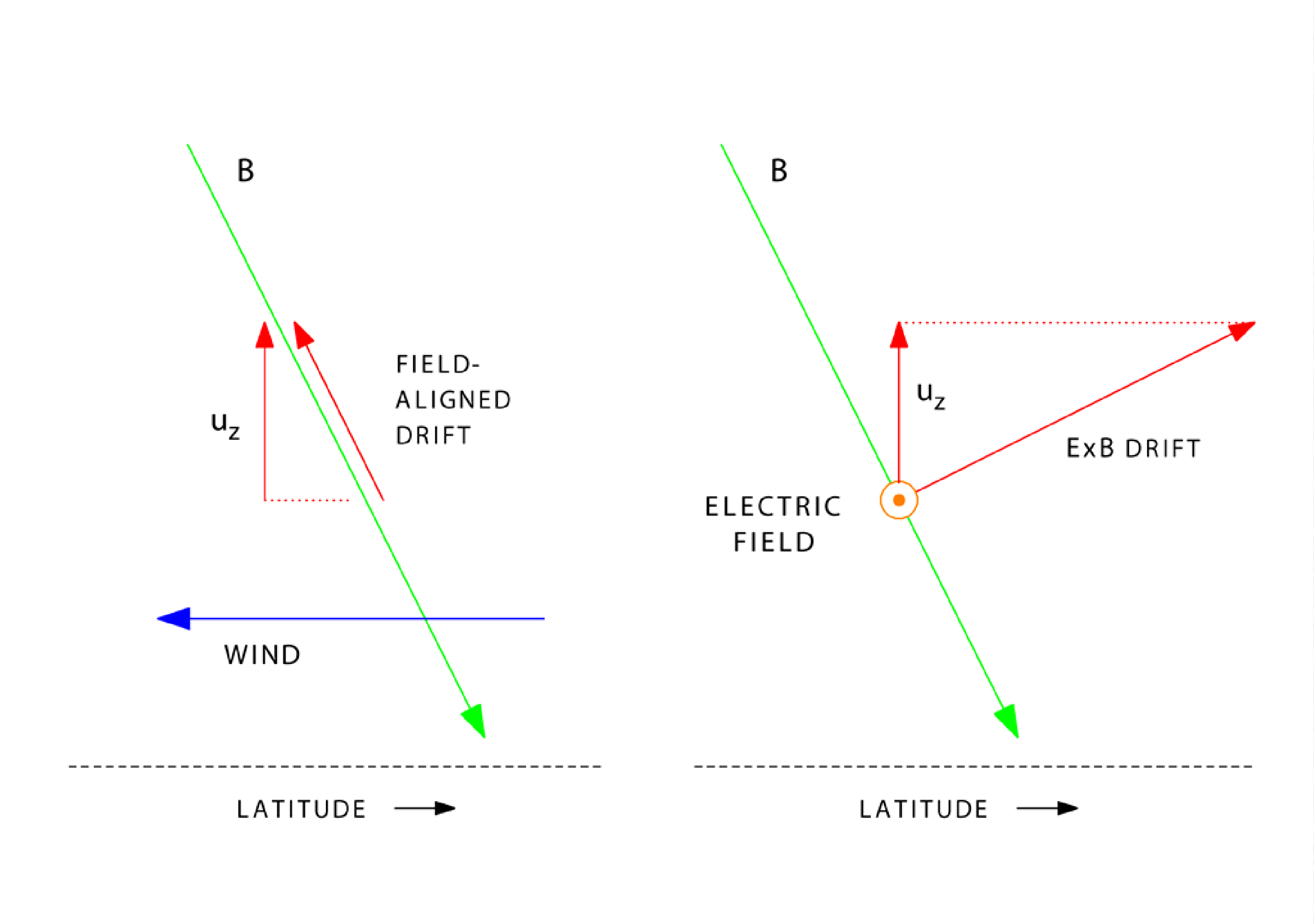
Ionospheric depletion

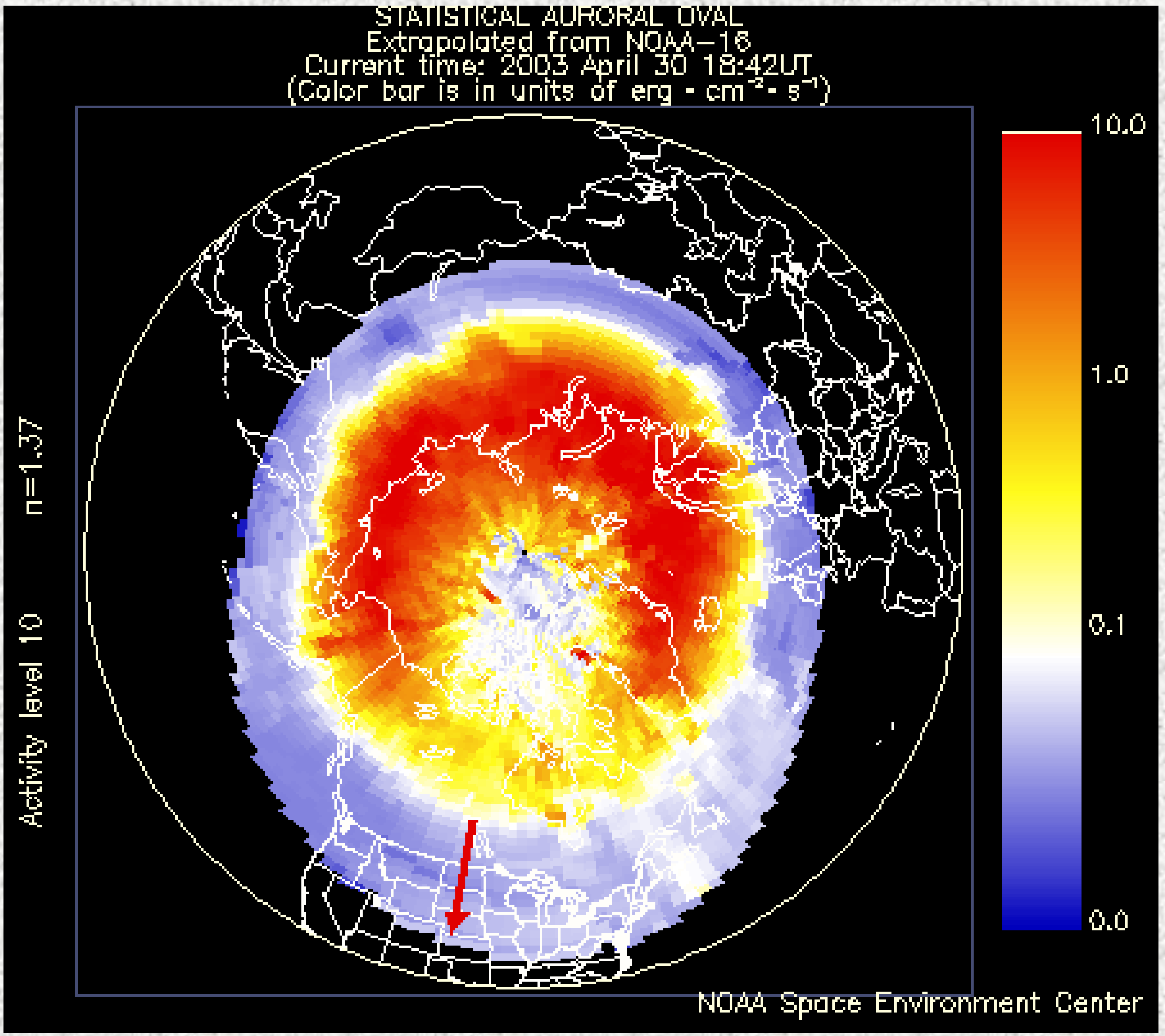
Modeling

Observations: Paxton et al. 2001



Wind & Electric Field Effects





Integrated particle power 5 - 100 GW on minutes time scales

http://www.sel.noaa.gov/pmap/pmapN.html

Ionospheric Corrections

- Need to model the ionosphere to compute corrections
- Empirical climatological models: Klobuchar coefficients
- Physics based numerical models: CTIPe, TIE-GCM
- Data assimilation schemes: US-TEC, GAIM

Models can provide both specification and forecast

The ionosphere is highly variable in space and time

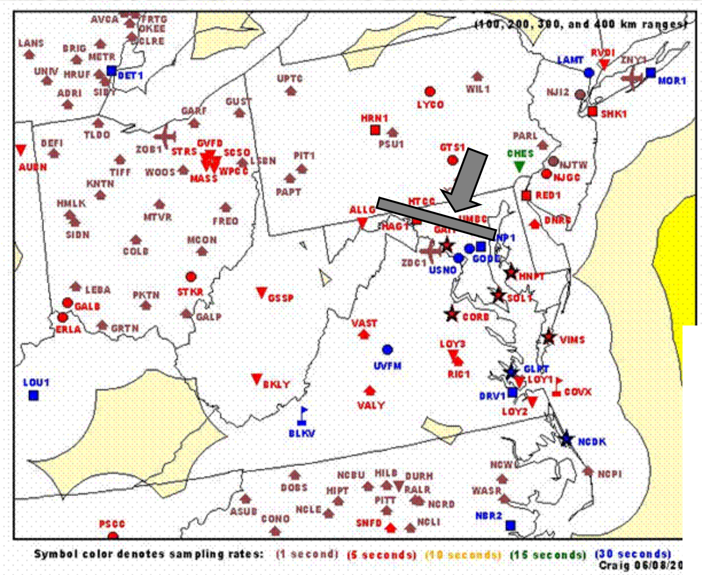
New Products

- Gradient Detection

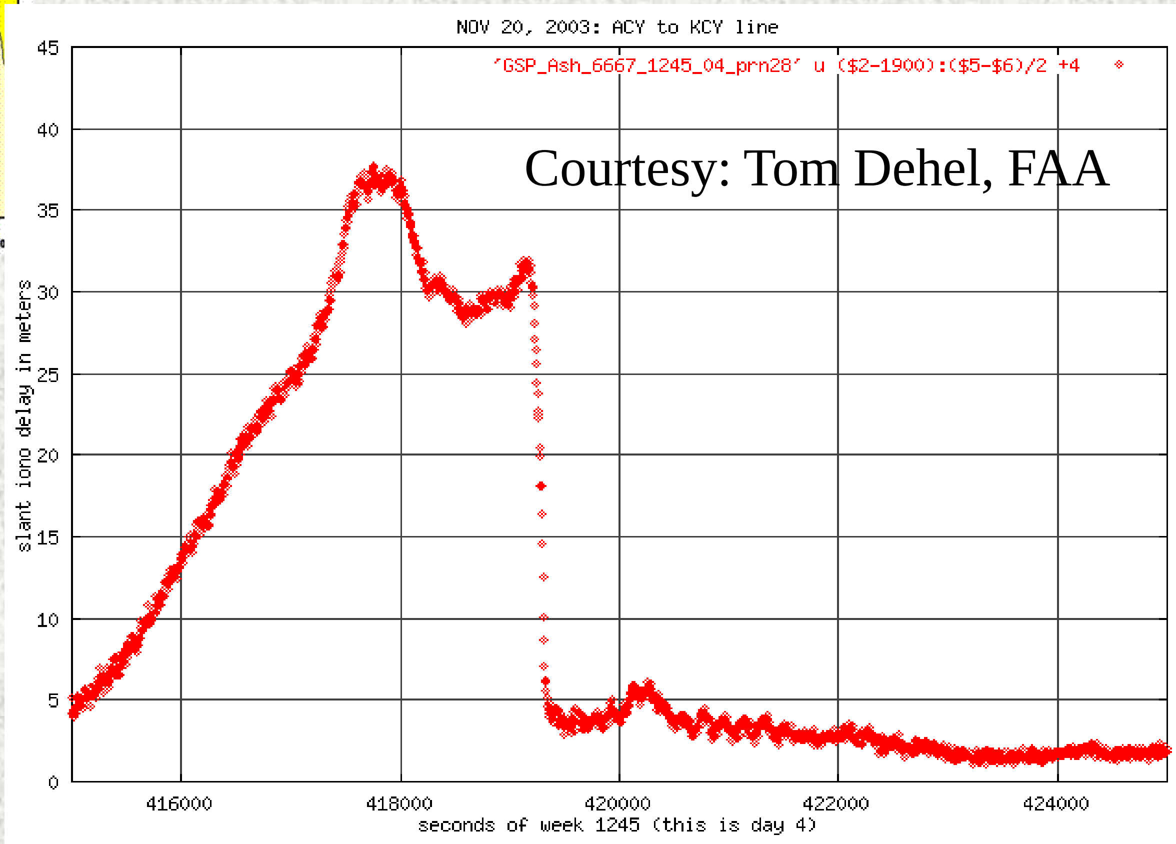
- OPUS Ionospheric Correction Function

Gradient Detection

Fall 2003 stationary “walls” of TEC



TEC “walls”:
130 TEC units over 50 km
20 m of GPS delay;
walls move 100 to 500 m/s



Background/Rationale

- NGS was running US-TEC in 3-day latent mode
- As the space weather agency, SWPC to provide ionospheric correctors
- Avoid the need to continue to update ionospheric activities at NGS every time SWPC makes an improvement to services
- SWPC is the natural place for providing the service of characterizing the ionosphere

Proposal

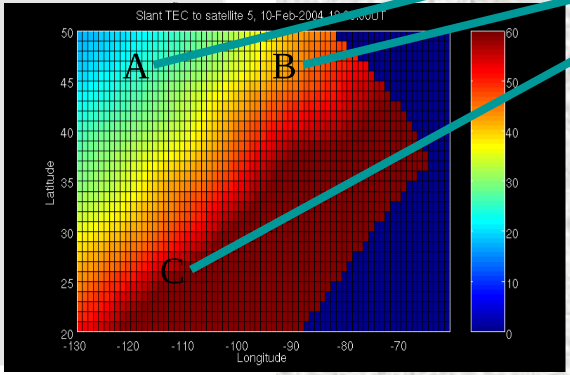
- SWPC to provide a web-based customer application for providing ionospheric correctors from a user specified list of options
- User submits a RINEX file over a particular interval
- SWPC either uses “best-available” model to evaluate correctors or user specified model (e.g. US-TEC, GAIM, IRI, rtIRI, ….)
- Return RINEX file to user with correctors inserted
- Next version of RINEX format has place for corrector

Ionosphere Correction for NGS

	Same system as used for attitude.	

SYS / # / OBS TYPES	- Satellite system code (G/R/E/S)
	- Number of different observation types for the specified satellite system
	- Observation descriptors:
	  - Type
	  - Band
	  - Attribute
	
	Use continuation line(s) for more than 13 observation descriptors.
	
	In mixed files: Repeat for each satellite system.
	
	These records should precede any **SYS / SCALE FACTOR** records (see below).
	
	The following observation descriptors are defined in RINEX Version 3.00:
	
	Type: C = Code / Pseudorange
	L = Phase
	D = Doppler
	S = Raw signal strength
	I = Ionosphere phase delay
	X = Receiver channel numbers
	Band: 1 = L1 (GPS,SBAS)
	G1 (GLO)
	E2-L1-E1 (GAL)
	2 = L2 (GPS)
	G2 (GLO)
	5 = L5 (GPS,SBAS)
		A1,
		2X,I3,
		
		13(1X,A3)
		
		6X,
		13(1X,A3)

US-TEC slant TEC provides ionospheric correctors for RINEX files



Sat. 29

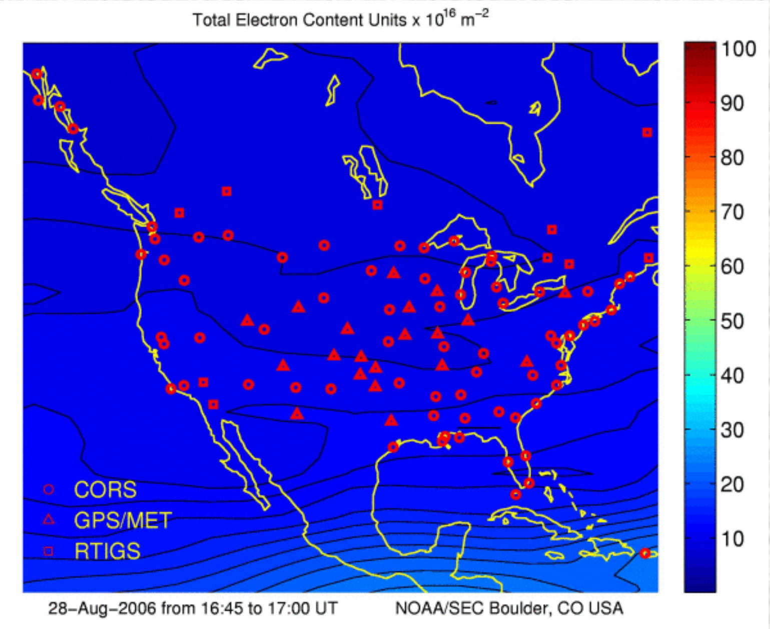
USTEC Product

http://www.swpc.noaa.gov/ustec

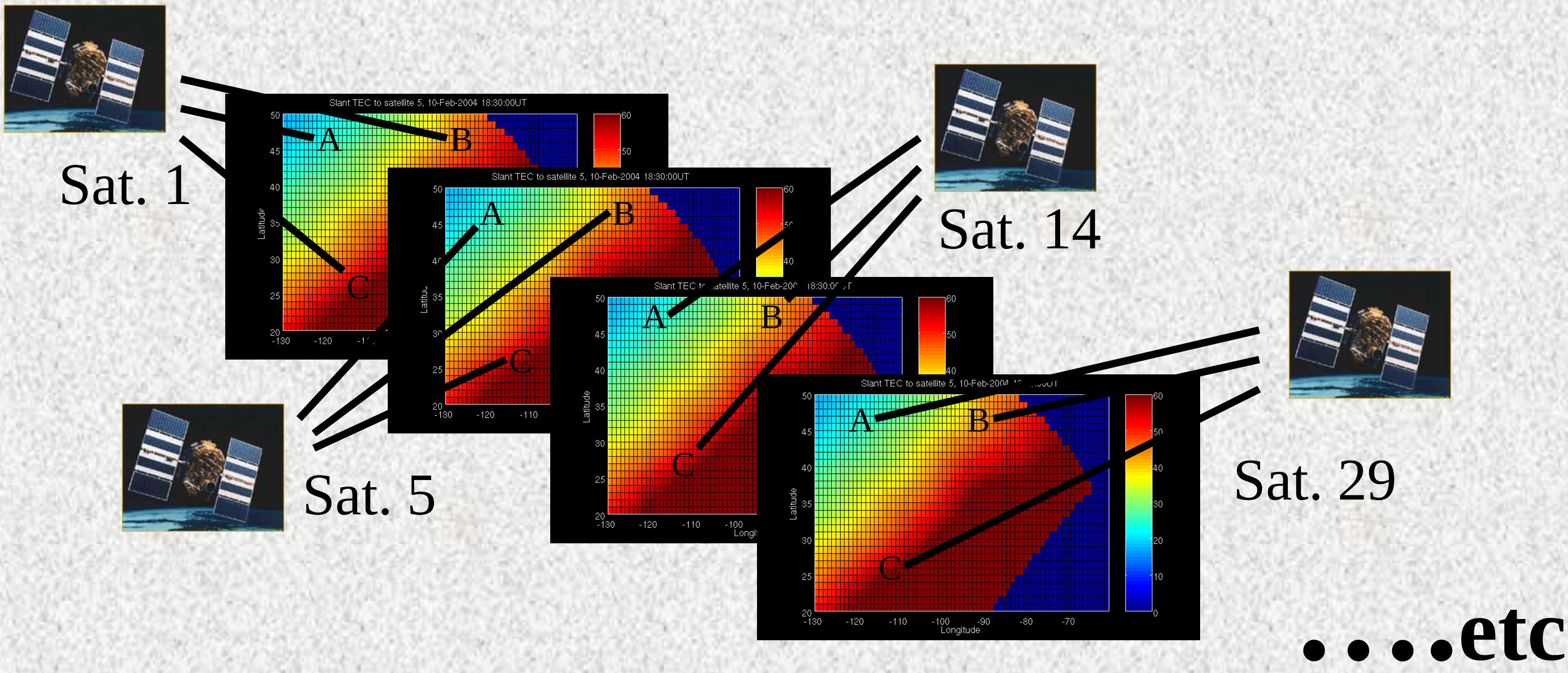
- Current NOAA capability for characterizing the total number of free electrons (TEC) in the ionosphere, with parallel input data streams for reliability
- Since 2004, a product characterizing the ionospheric TEC over the continental US (CONUS) has been running in real-time at NOAA's Space Environment Center (SEC)
- The ionospheric data assimilation model uses a Kalman filter and ingests ground-based GPS data to produce 2-D maps of total electron content over the CONUS
- Product evolved from a collaboration between SEC and NOAA's National Geodetic Survey (NGS), National Geophysical Data Center (NGDC), and Forecast Systems Laboratory (FSL)

Primary Product:

Real-time ionospheric maps of total electron content every 15 minutes. Currently uses about 100 real-time GPS stations from the CORS network



Slant-Path TEC Maps



Applications:

Ionospheric correction for single frequency GPS; NDGPS positioning; dual-frequency integer ambiguity resolution for rapid centimeter accuracy positioning

Validation Summary

Differential TEC:
Slant = 2.4 TEC units
Vertical = 1.7 TEC units

“Absolute” FORTE ray tracing:
Slant = 2.7 TEC units
Vertical = 1.9 TEC units

- Estimated USTEC slant path total electron content uncertainty < 3 TEC units (equivalent to about 45 cm of signal delay at L1 frequencies)

- Estimate USTEC vertical total electron content uncertainty < 2 TEC units (equivalent to about 30 cm of signal delay at L1 frequencies)

SWPC Ionosphere Goals

Improve USTEC

CONUS: Specification

US-TEC slant path total electron content uncertainty < 2 TECU

US-TEC vertical electron content uncertainty < 1 TECU

CONUS: Forecast

1 hour forecast as good as specification

3 hour forecast: uncertainty < 3 TEC units

6-12 hour forecasts

GPS User Tools

Color coded regional maps of ionosphere disturbance

Support vendors to produce color coded maps for specific applications

Conclusions

Ionospheric services are a fast growing area in Space Weather

SWPC is committed to offer improved products and tools

SWPC is ready to collaborate on:

Data
Models and model results
Research
Services

Solar Maximum is on the way (2012?)

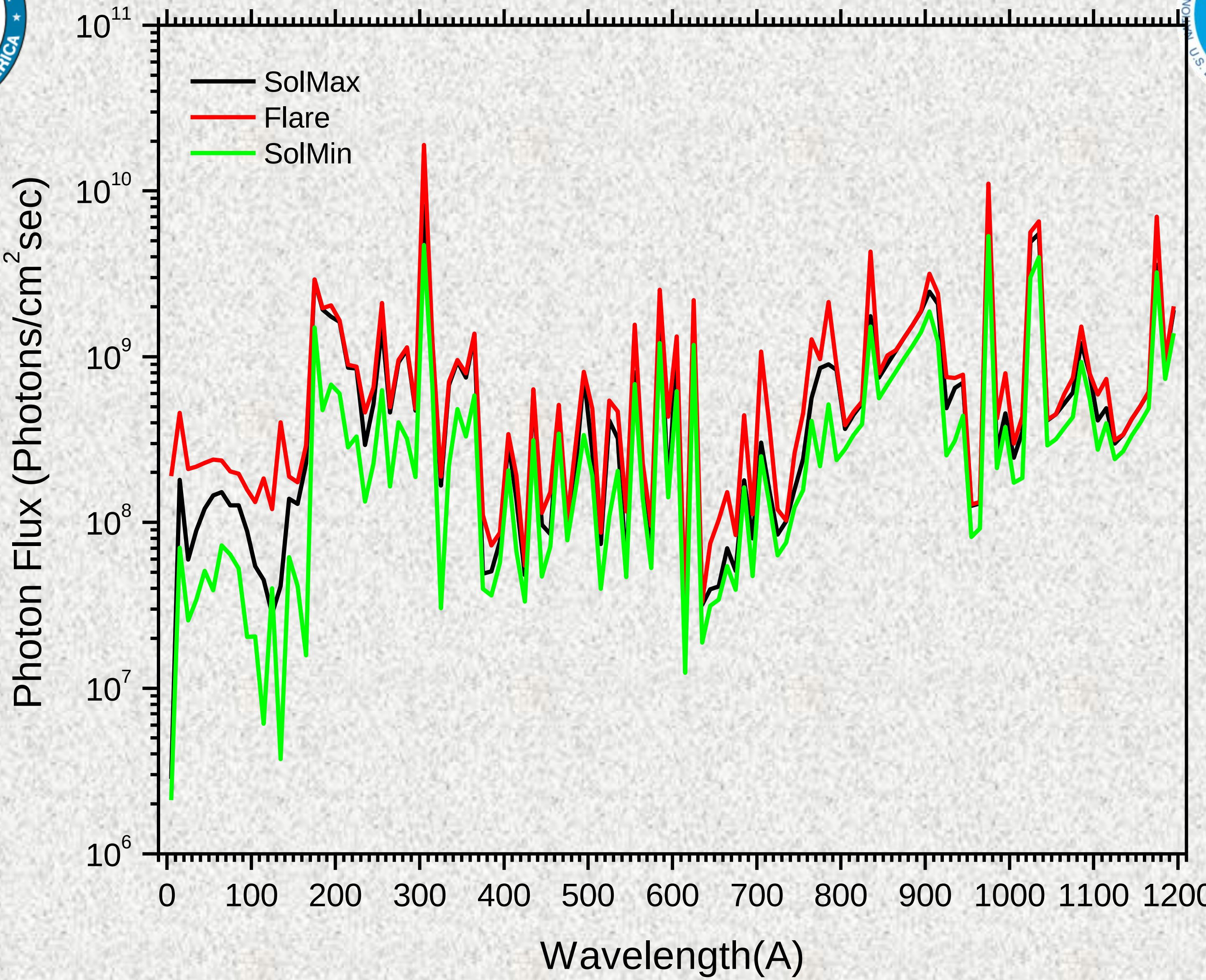
Ion Production

$$O + h\nu \rightarrow O^+ + e \quad (910.3\ \text{Å})$$

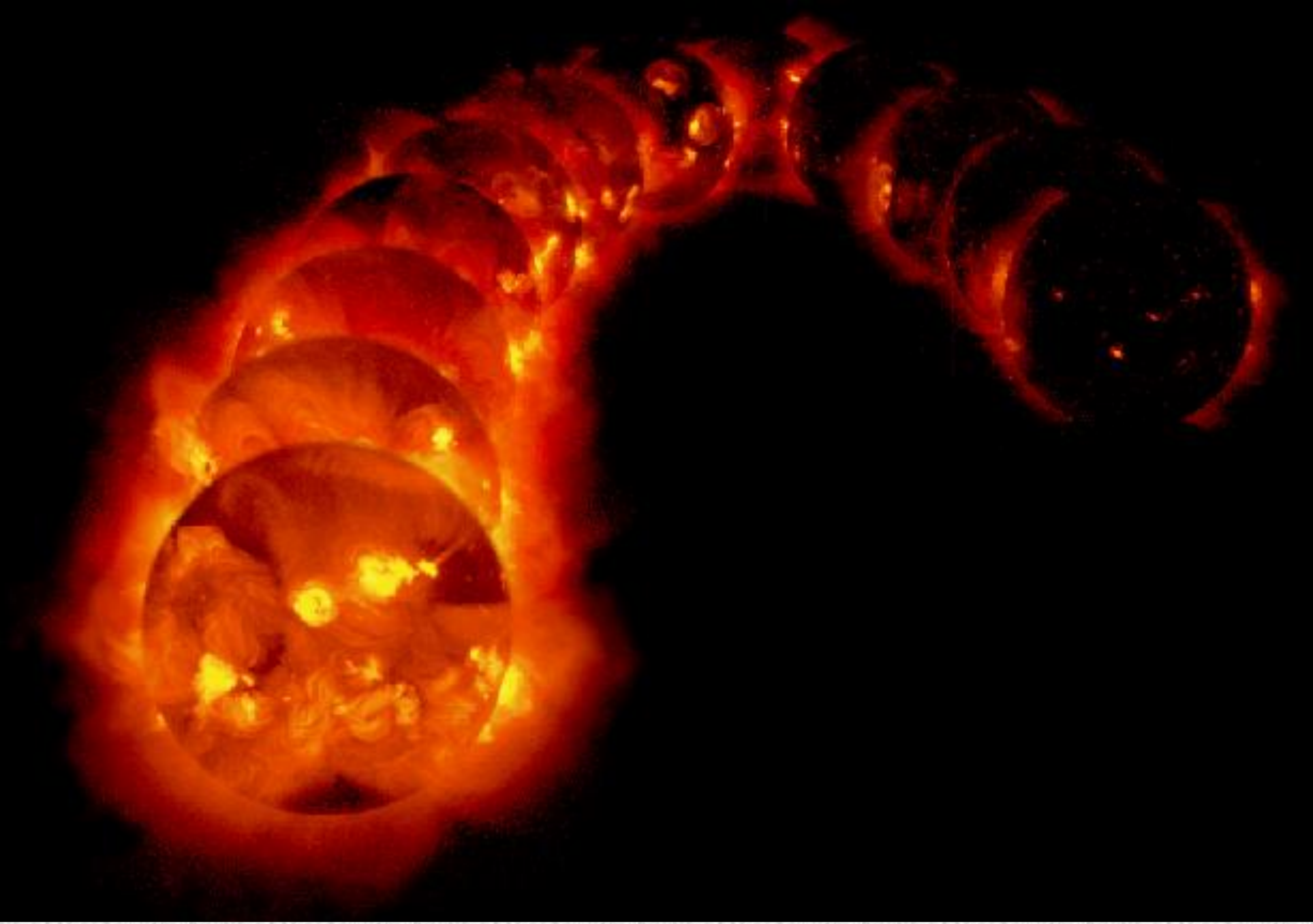
$$O_2 + h\nu \rightarrow O_2^+ + e \quad (1028\ \text{Å})$$

$$N_2 + h\nu \rightarrow N_2^+ + e \quad (795\ \text{Å})$$

NRLEUV Spectra



From Rodney Viereck, SEC



The solar x-ray images are from the Yohkoh mission of ISAS, Japan. The x-ray telescope was prepared by the Lockheed Palo Alto Research Laboratory, the National Astronomical Observatory of Japan, and the University of Tokyo with the support of NASA and ISAS. G.L. Slater and G.A. Linford