Living With A Star
Ionosphere-Thermosphere Storm Probes
An update from the community

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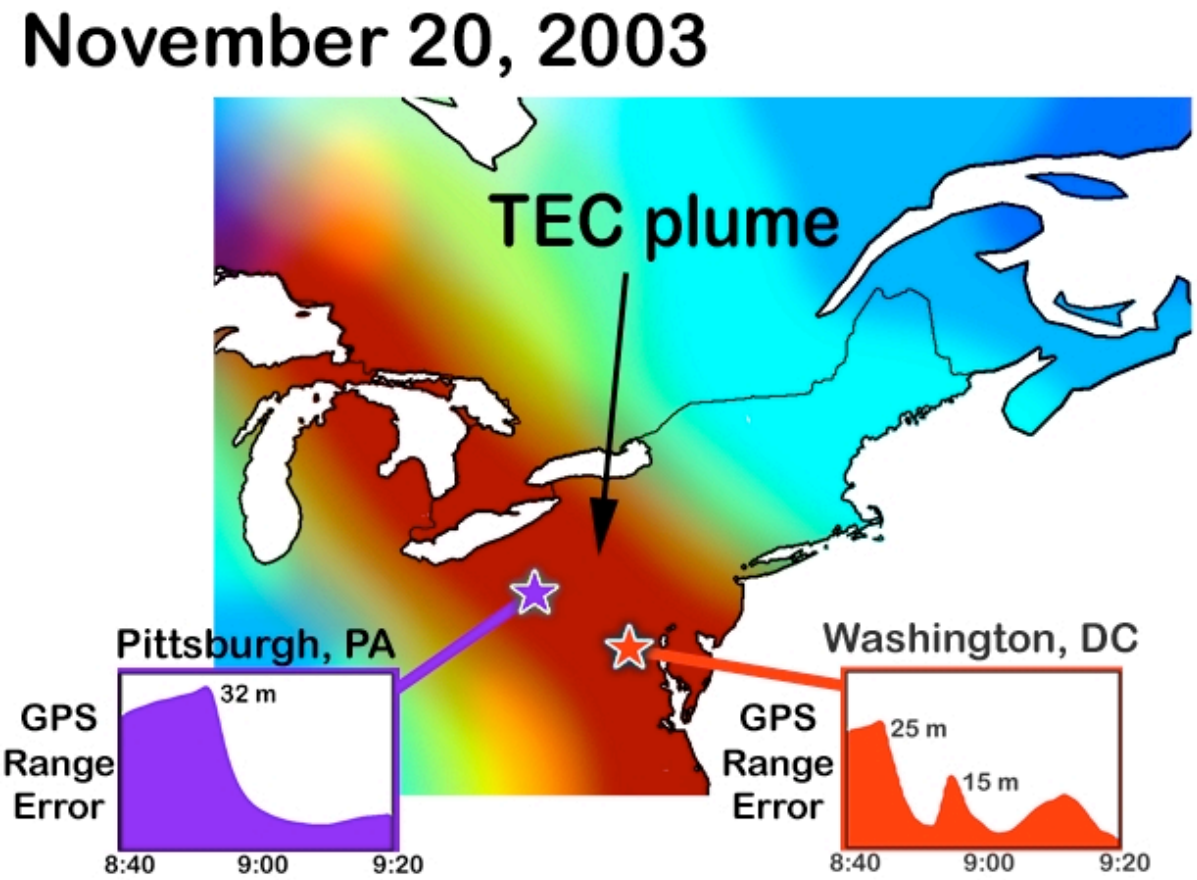
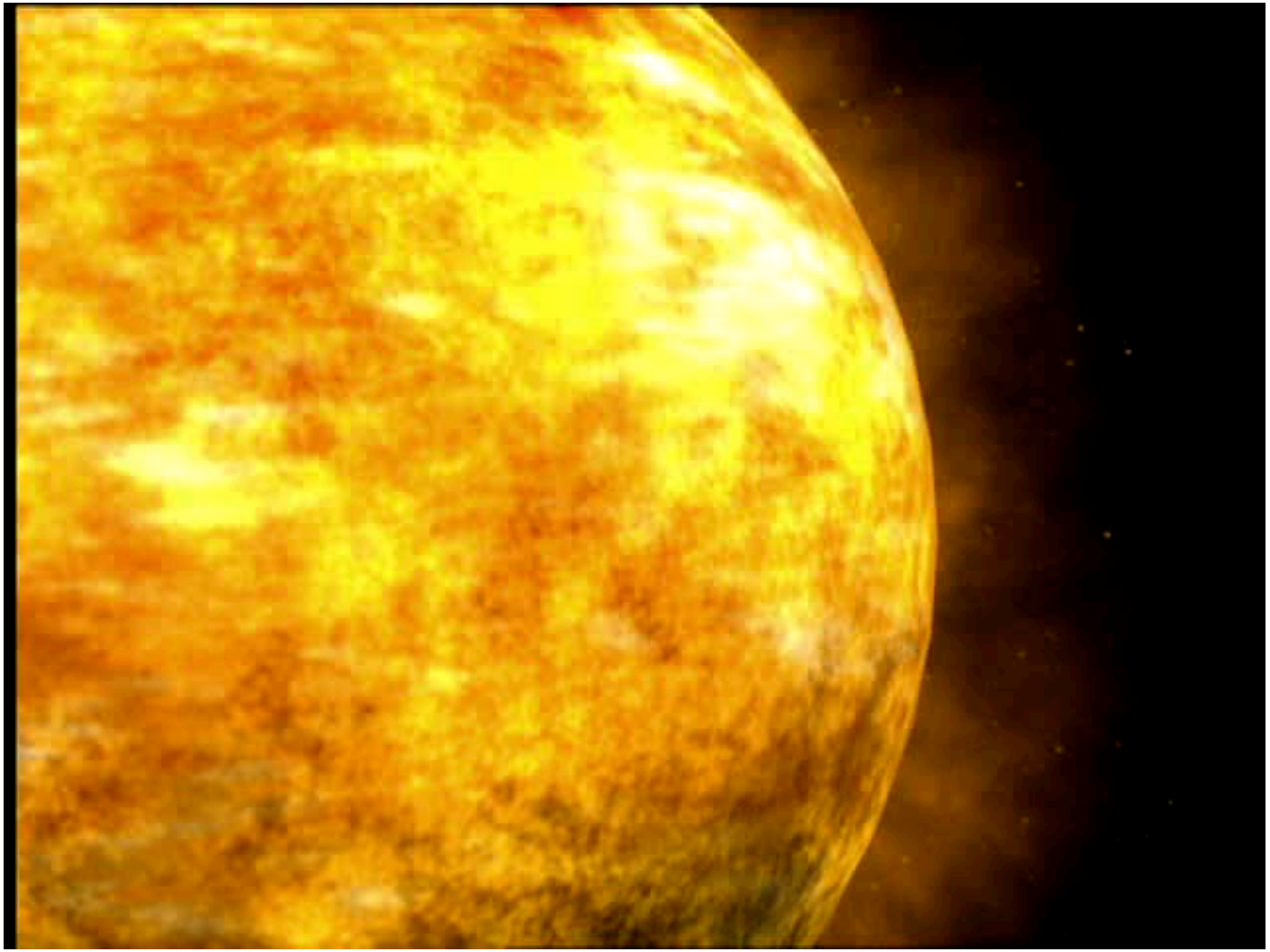
…and the broader geospace community

Societal Impact



A large plume of total electron content crossed the US on November 20, disrupting GPS and other technological systems

Geospace Storms



Where Geospace Science Stands Today

- **Characterization of ionospheric behavior has changed dramatically in the past 10 years**
  - Including mid-latitudes
- **We can now identify large to meso-scale plasma structures that vary over time scales of minutes to hours**
- **New phenomenology has been discovered**

Missing:

- **The right observations at the right locations to achieve *understanding* of what is observed**

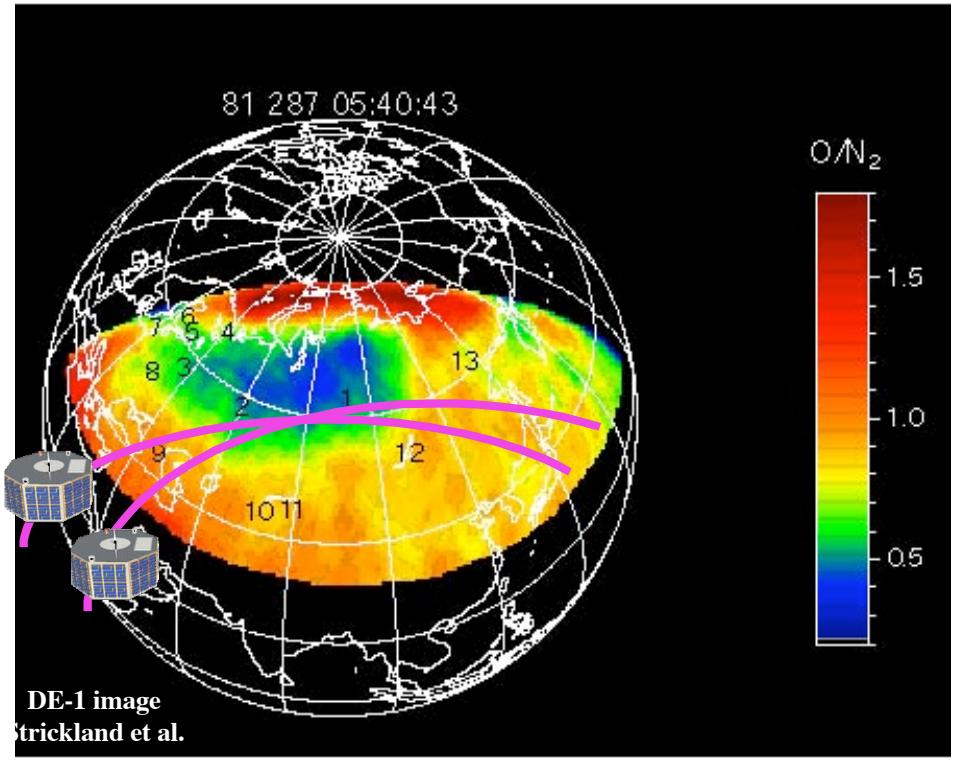
Highest scientific priority:

- **Achieving understanding**

Approach: Ionosphere-Thermosphere Storm Probes

- **Targets understanding of structures and dynamics of ionosphere and neutral atmosphere that significantly impact human activities**
- **Simultaneous neutral and plasma measurements to understand fundamental processes at work**
- **ITSP is a unique asset that covers all local times**
- **Multiple spacecraft to resolve critical spatial scales at middle latitudes for first time**
- **Analogy: sending probes to the heliospheric environment despite copious amounts of remote sensing data**
  - Remote sensing data is an important resource
  - Need remains to sample directly the relevant environment

Ionosphere-Thermosphere Storm Probes: Two Satellites



- **Orbit:** ***Nominally 450 km; allowed to drag down to 400 km; includes propulsion***
  - *Near peak ion density*
  - *60º inclination: for mid-latitudes*
  - *Separated 10º-20º in mean local time*
  - *Variety of local times*
- **Orientation:** ***non-spinning***
- **Core Measurements:**

  Plasma density, altitude profile, fluctuations

  DC Electric Field

  Neutral composition/temperature

  Neutral wind

  Scintillation spectra
- **Complementary:**

  Broad FOV remote sensing of I-T Regions

  Simultaneous Solar EUV measurements.

The Ionosphere-Thermosphere Region: Physics

- **Warning: ionospheric plasmas governed by *collisional magnetohydrodynamics***
- **Electrical conductivity is finite (*not* infinite)**
- **The plasma is lightly ionized (*not* fully ionized)**
- **The ionosphere-thermosphere system is physically distinct from rarefied regions such as the magnetosphere and solar wind**
- **The interaction between an idealized MHD fluid and a collisional, lightly ionized plasma represents fundamental physics important for planetary atmospheres**
  - A debate rages

Prioritized Science Objectives
GMDT Report May 2002

1 - Understand the acceleration, global distribution, and variability of energetic electrons and ions in the inner magnetosphere.

2A - Determine the effects of long and short term variability of the Sun on the global-scale behavior of the ionospheric electron density.

2B - Determine the solar and geospace causes of small scale ionospheric density irregularities in the 100 to 1000 km altitude range.

3A - Determine the effects of solar and geospace variability on the atmosphere enabling an improved specification of the neutral density in the thermosphere.

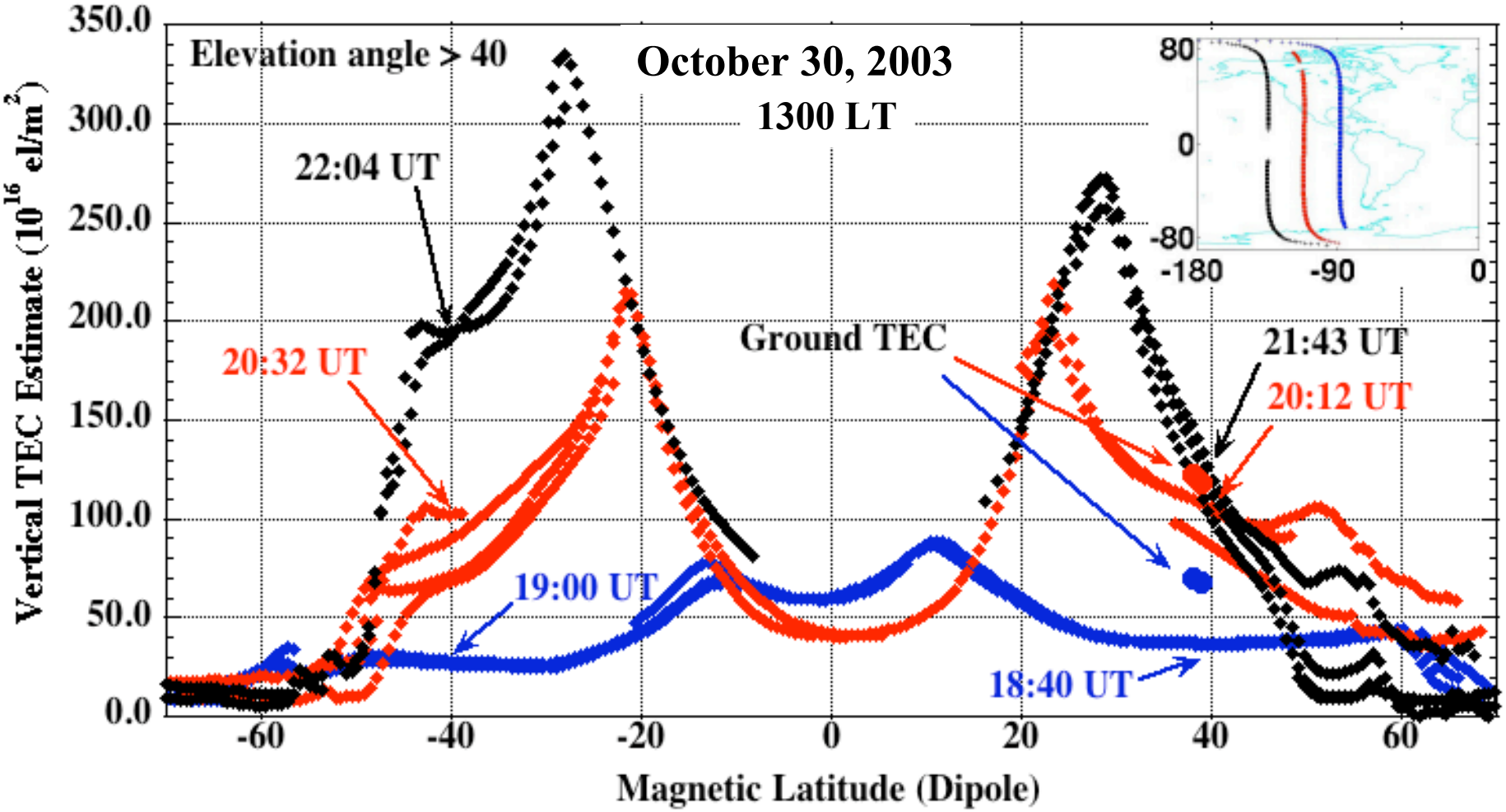
3B - Understand how solar variability and the geospace response determine the distribution of electric currents connecting the magnetosphere to the ionosphere.

4- Determine the quantitative relationship between very energetic electron and ion fluxes in the interplanetary medium and their fluxes at low altitude, particularly the geomagnetic cut-offs.

5 - Quantify the geospace drivers that potentially affect ozone and climate.

Large Ionization Changes During Storms

CHAMP (TEC above 400 km altitude)



Mannucci et al., GRL 2005

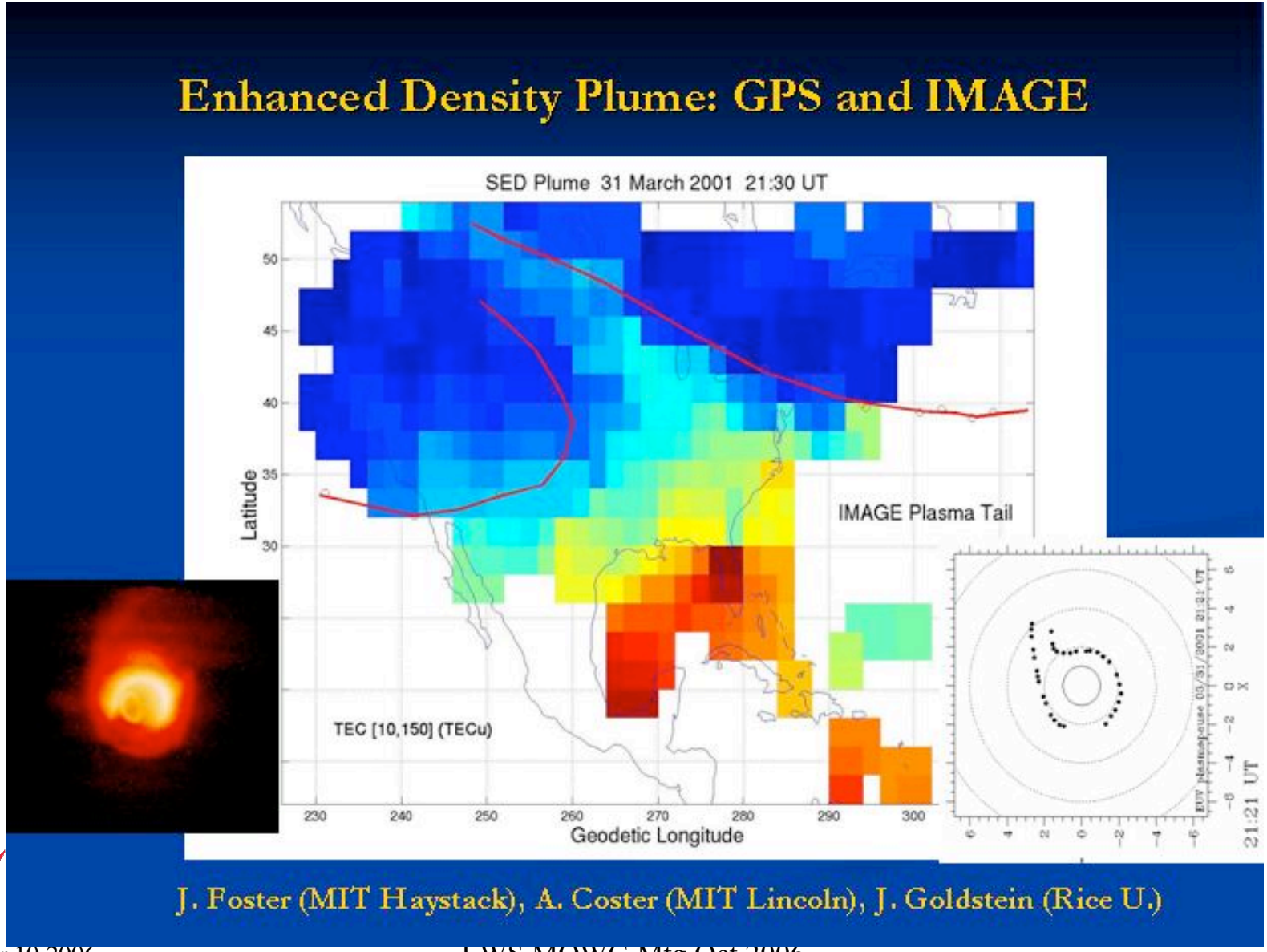
Understanding "Prompt" Ionization Increases

- **What is the role of electric fields in determining these increases?**
- **How are neutral wind perturbations modulating the response?**
  - Winds and electric fields are linked via dynamo action and ion-neutral drag
- **How do the responses vary with storm intensity or IMF conditions?**

⇐ITSP will simultaneously measure electric fields, winds and the electron density response to answer these questions

Storm Enhanced Densities

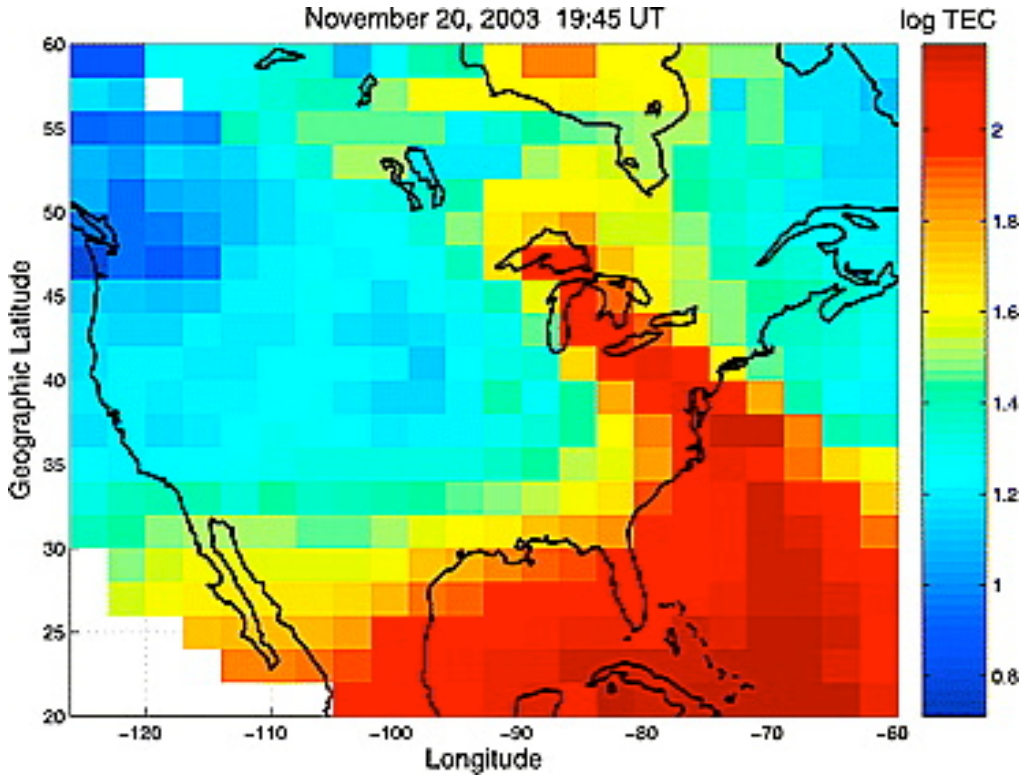
Enhanced Density Plume: GPS and IMAGE



J. Foster (MIT Haystack), A. Coster (MIT Lincoln), J. Goldstein (Rice U.)

Variability 4: Inner Magnetospheric Electric Fields

Foster et al, JGR, 2005



GPS TEC data

Dusk effect

The expansion of the convection pattern can transport middle latitude plasma to high latitudes.

Here plasma from below 50 degrees magnetic is transported poleward and across the high latitude regions.

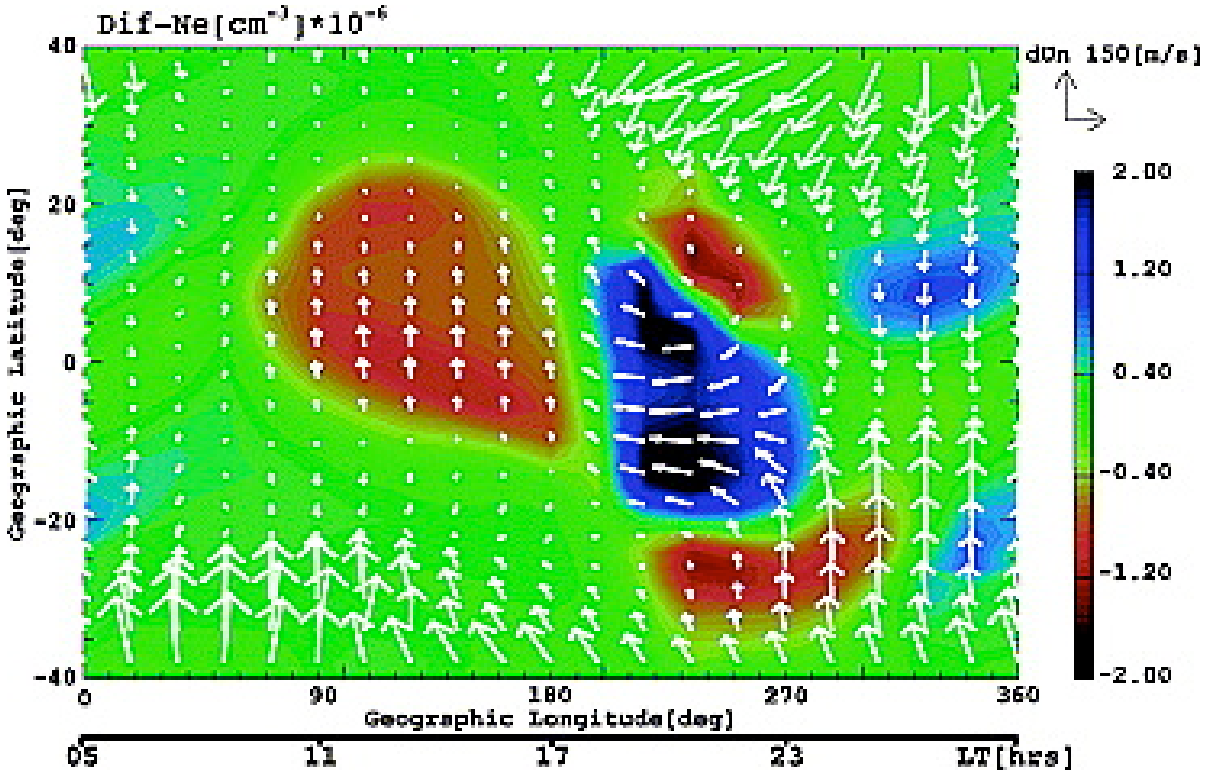
This feature would not be easily visible if there were not a high density reservoir from which the plasma were extracted. (**where does this come from ?)**

Understanding TEC Plumes

- **What is the physical link between electron density structure and plasmaspheric plume structure?**
  - Are winds playing a role in addition to electric fields?
- **How do the driving mechanisms vary over plume length scales?**
- **Are plumes observed at other longitudes? How do the physical drivers vary with longitude?**

⇑ **ITSP will provide comprehensive *in situ* measurements that will address these questions for the first time**

Winds and Ion Density Perturbations

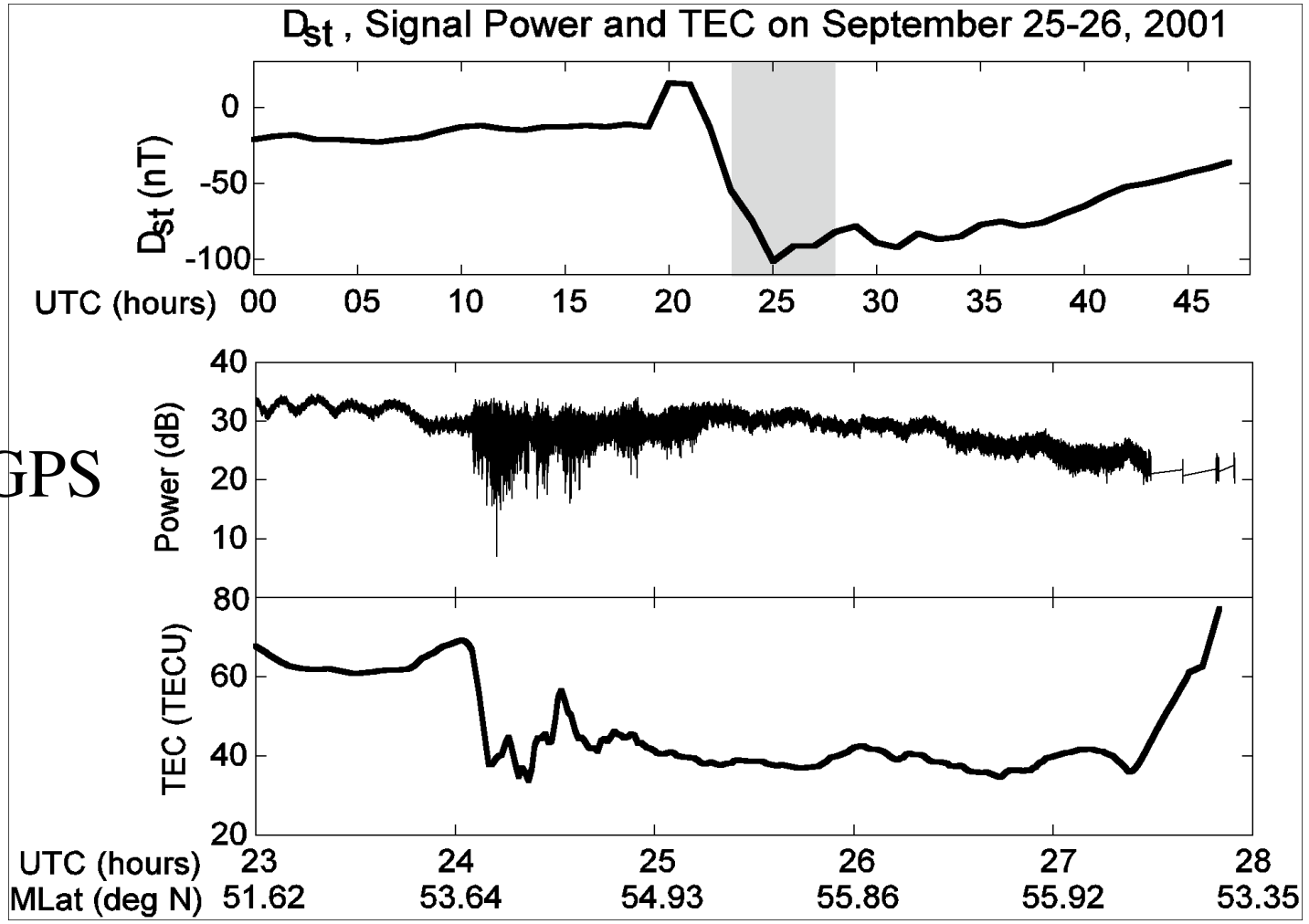


Muruyama et al, GRL, 2005

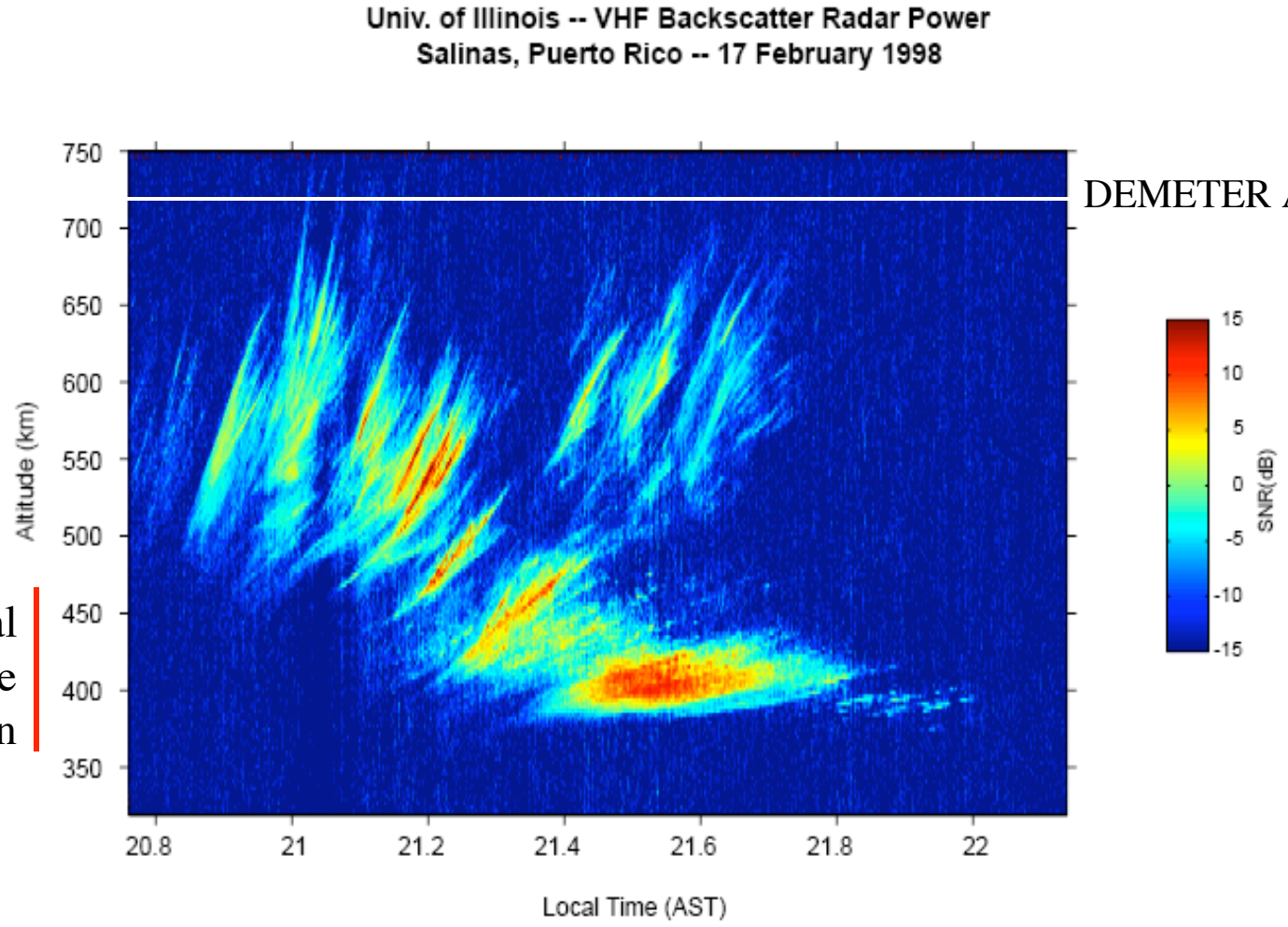
- **Model run showing electron density perturbations superposed over wind perturbations**
  - Dynamo and direct electric fields also playing a role
- **Plasma density perturbations will modify the winds**
- **Composition changes accompany wind perturbations**

⇒ **ITSP will provide accurate, simultaneous measurements of winds, electric fields, and compositional changes needed to understand how these quantities interact**

Mid-Latitude Scintillations at Ithaca, NY



Radar measurements of mid-latitude, ionospheric irregularities during a magnetic storm.



[courtesy, E. Kudeki]

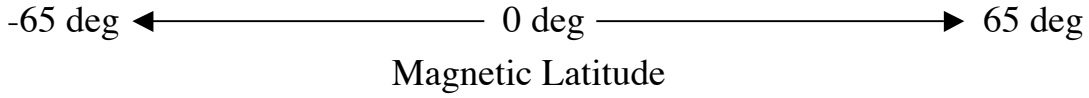
[See Swartz et al., 2000]

DEMETER -- 10 November 2004 -- Orbit 1904_1

720 km , 22.5 LT

Intense irregularities accompany density depletions, scatter radio waves.

Deep density depletions pervade mid and low latitudes during magnetic storm.



Data courtesy J.-J. Berthelier and J. Lebreton

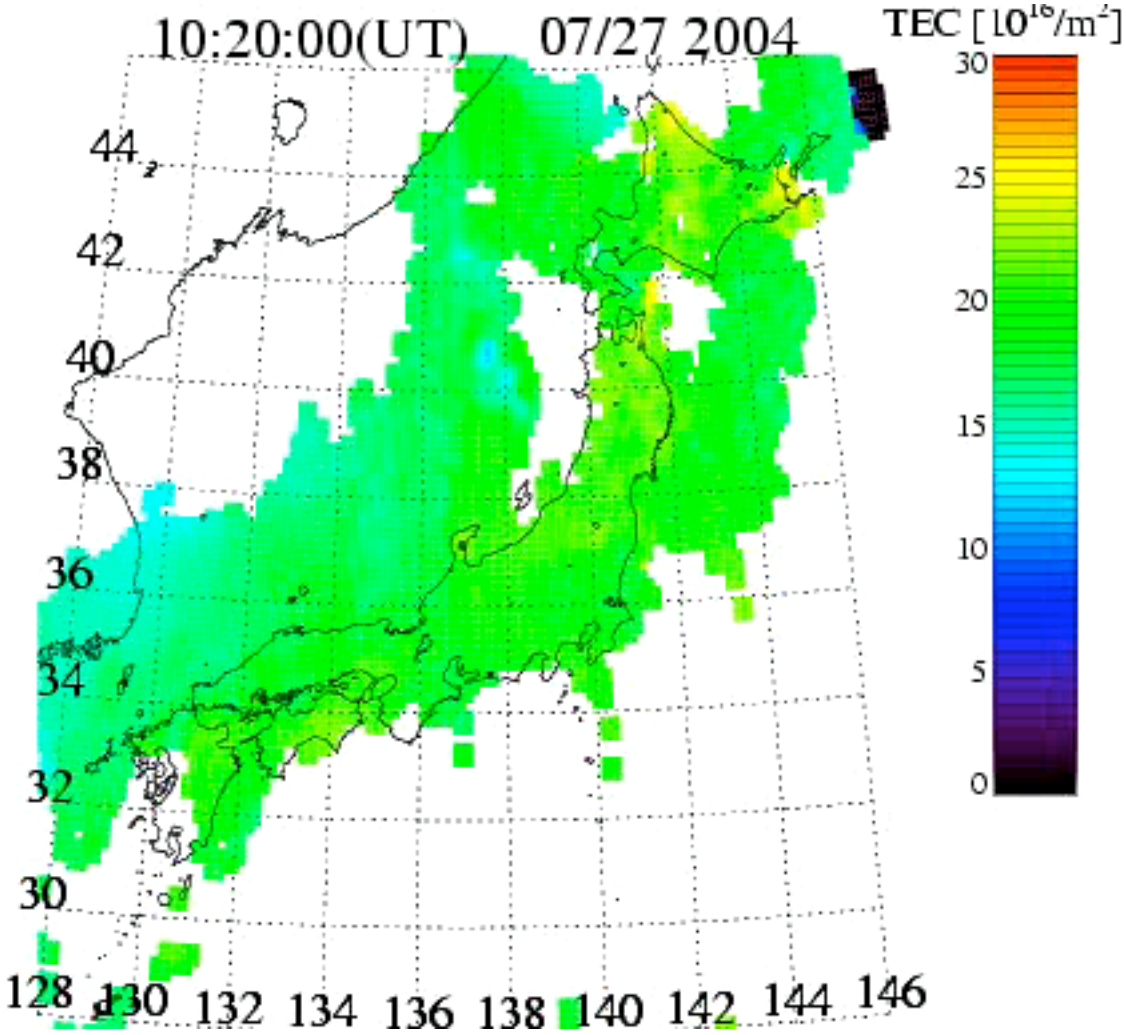
Science since Geospace Mission Definition Team Report 2002

- Characterization of the storm-time evolution of large-scale plasma density gradients
- The discovery of an association between equatorial electrodynamics and the appearance of large scale plasma gradients at middle latitudes.
- New nighttime irregularities and medium-scale traveling ionospheric disturbances

These discoveries support the contention that

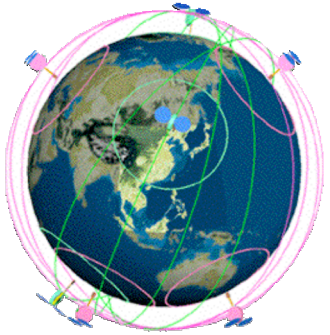
- The presence of large-scale gradients in electron density suggest spatial and temporal changes in electrodynamics, composition and /or dynamics (winds)
- This hypothesis is NOT TESTED and if true the nature of the spatial and temporal changes are UNKNOWN.

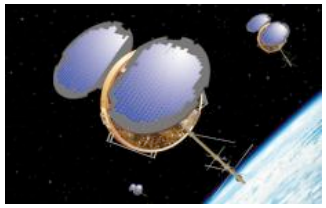
New Mid-Latitude Phenomena



Update: COSMIC

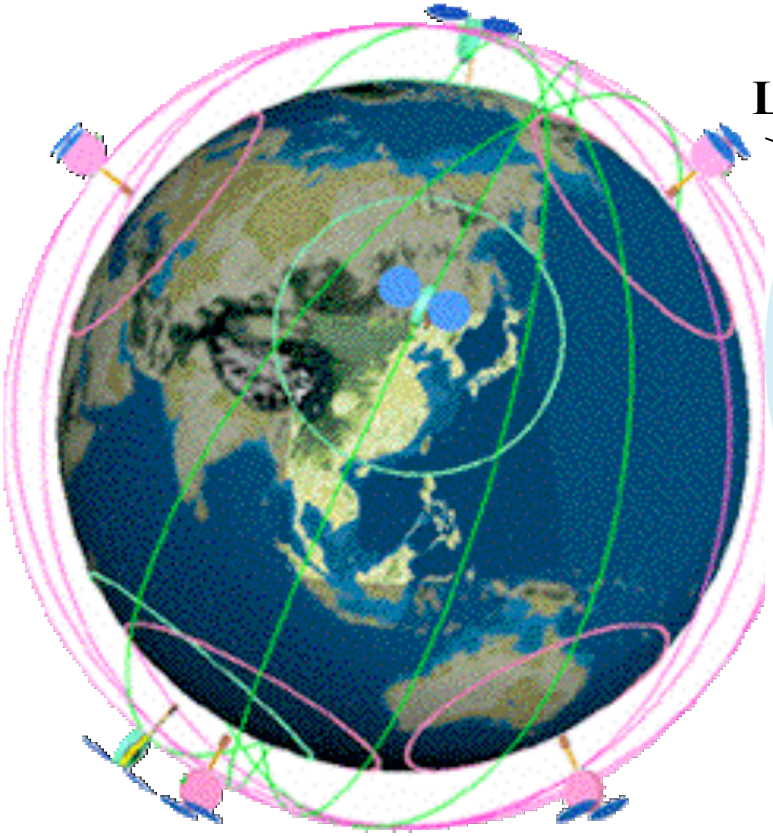
- **Successful launch April 14, 2006**
- **Six satellite constellation**
- **Initial configuration: single orbital plane**
- **Final configuration:**
  - 800 km altitude
  - Separate orbital planes
  - 72 degrees inclination
- **JPL-designed receiver**
- **Broad-Reach Engineering built**
- **Near real-time feed to NOAA**

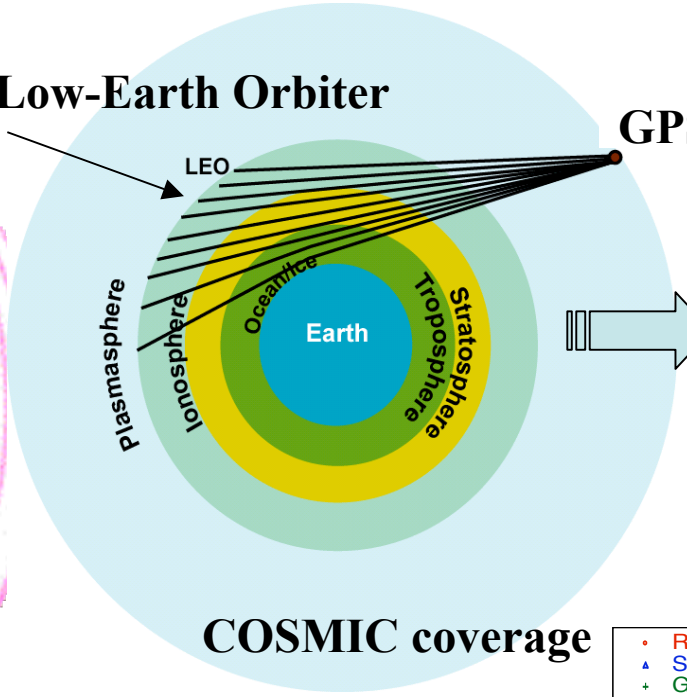


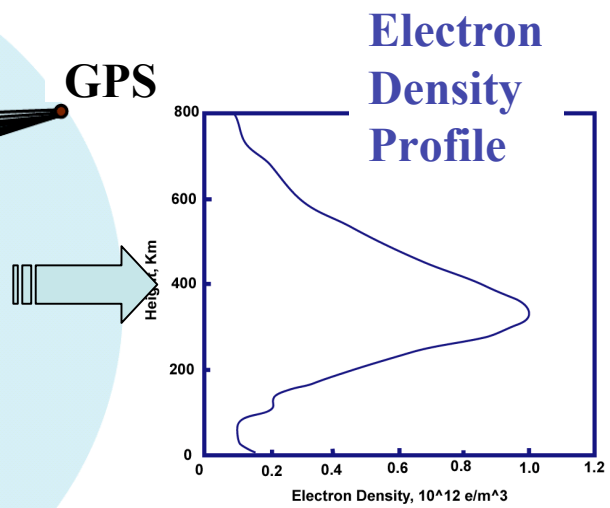


UCAR NSF NASA USAF NOAA NSPO ONR

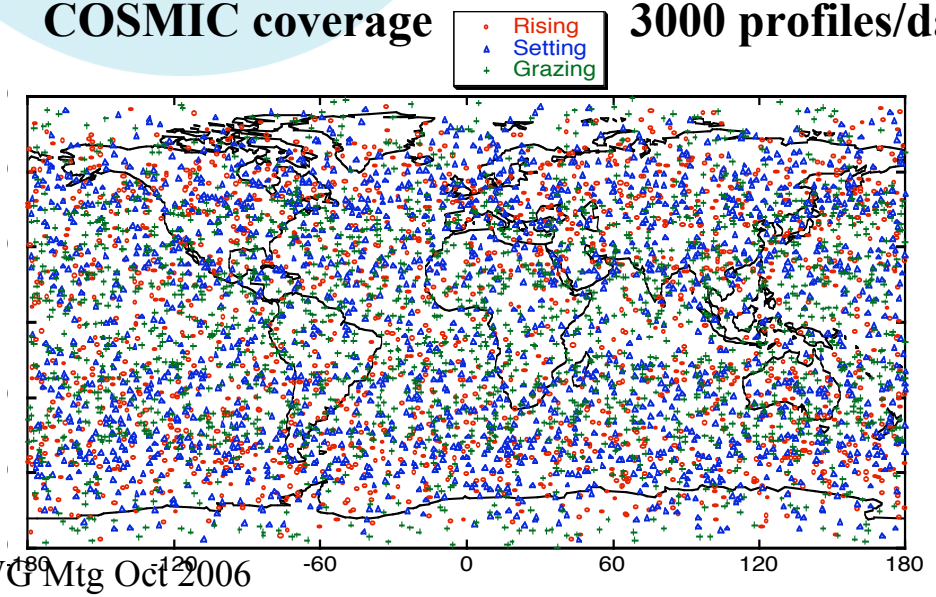
COSMIC Will Further Improve Characterization







COSMIC coverage



3000 profiles/day

COSMIC And Ionosphere-Theremosphere Science

- **COSMIC: more characterization (great!) but not understanding**
- **No in situ measurements**
- **Strong interest in COSMIC by data assimilation communities**
  - Improve electron density maps

- **Data available from UCAR**
- **JPL is planning space weather contribution**
- **COSMIC User's workshop planned Oct 16-18, 2006**

Recent Community Activities

- **CEDAR Community Workshop: "Ionosphere/Thermosphere Research From Space" (June 2006)**
- **Chapman Conference scheduled for January 2007**
- **COSMIC user's workshop October 2006**
- **Spring and Fall AGU sessions**
- **LWS Science workshop planned**
- **LWS CDAW scheduled (March 2007)**
- **A global disk imager was proposed for RBSP MOO**
  - Provides information about composition and electron density
  - Excellent for global context
- **C/NOFS will provide equatorial data (launch 2008)**

CEDAR Workshop

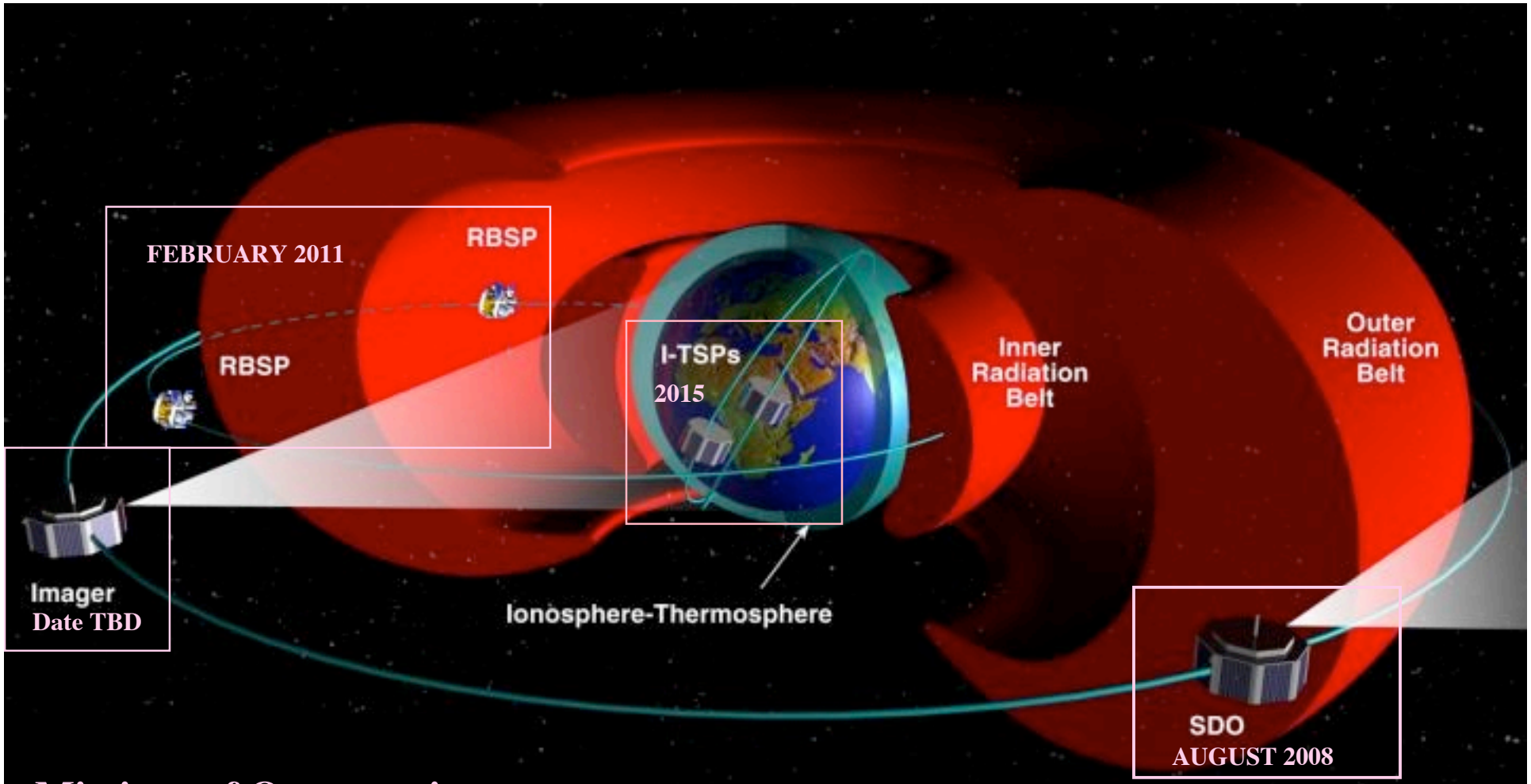
- **Community Workshop: "Ionosphere/Thermosphere Research From Space" (June 2006)**
  - Consensus: major science questions require simultaneous measurements of neutral and plasma dynamics
  - Multiple sources of variability interact on local and global scales
  - Variability caused by winds, electric fields, composition, dynamo, etc.
  - Progress requires remote and in-situ data coordinated among multiple platforms
  - Opportunities
    - **ITSP AO: Community eagerly anticipating release**
    - **RBSP AO: IT imager selection as MOO possible**
    - **Coincident Measurements from RBSP and SDO (EUV) expected**

Chapman Conference

- **"Mid-latitude Ionospheric Dynamics and Disturbances"**
- **Over 80 abstracts received**
- **Inter-disciplinary topics in a workshop format**
  - Characterization of Mid-latitude Ionosphere Storms
  - Ionospheric Waves, Irregularities, and User Needs
  - Ionospheric-Magnetospheric-Heliospheric Coupling
  - Coupling to High and Low Latitudes (dynamics)
- **Includes a session on future observational requirements**
- **LWS sponsorship gratefully acknowledged**

Issues and Concerns

- **ITSP coordination with other LWS elements is highly anticipated**
  - RBSP for inner magnetospheric electric fields
  - SDO for EUV
  - Imager mission of opportunity
  - Also benefits from C/NOFS
- **Community eagerly awaits ITSP AO**
  - Concerns about schedule
- **Concerns exist about maximum synergy**



- Missions of Opportunity
  Imager: O/N_2 and
  Electron Density

- Radiation Belt Storm Probes
- Ionosphere-Thermosphere Storm Probes
- EUV from Solar Dynamics Observatory
  (Extreme Ultraviolet Variability Experiment)

Ideally FUV (IMAGER), EUV (SDO) and E (RBSP) inputs for I-TSP Studies

Summary

- **The gap between what is observed and what is understood is widening**
  - Existence of dynamic meso-to-large scale structure is confirmed. Hypotheses are being formed.
- **Space-borne comprehensive in-situ measurements are critical to advance the science: *Ionosphere-Thermosphere Storm Probes***
- **The community is active in advancing the science through workshops and meetings**
- **The community is responding enthusiastically to mission opportunities**
- **The community eagerly anticipates an AO for ITSP**
- **Concerns exist regarding AO release date**

Constructive Discussion

BACKUP

NASA Instrumented Missions (Since 1973) Below 500 Km
With Both Neutral and Plasma Measurements

- ***Atmosphere Explorer Series*** **(focus was aeronomy).**
  AE-C **(1973-1978) 68.1^0 inclination; 30% duty cycle; Mostly solar minimum; *only* 15 sec averaged data was archived.**
  AE-D **(1975; only 4 months) 90.1^o inclination.**
  AE-E **(1975-1981) 19.7^o inclination.**
- ***Dynamics Explorer-2*** **(1981; 18 months) 90^o inclination; 16-36% duty cycle.**
- ***San Marco-D*** **(1988; 8 months) 3^o inclination; 6% duty cycle; neutral spectrometer/wind instrument failed after 1 month.**

-25 Years Since Last Comprehensive Mission-

The Ionosphere-Thermosphere Imager: Mission of Opportunity

- **Can provide spatial scales at mid-latitudes**
- **Measure global ionospheric neutral composition and temperature, conductivities, and electron density, and thermospheric variations.**
- **Distinguish from in-situ**
  - E.g. does not measure E fields or winds

⇒Imager + IT Storm probes: *first time we will understand large-to-meso scale variability!*