# Future Satellites With in Situ Probes to Address Critical Space Weather and Science Requirements in the Earth's Ionosphere/Thermosphere

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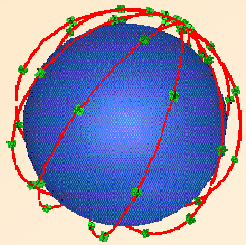
# Theme

- **Critical regions of Earth's upper atmosphere have not been sampled or sampled rather poorly even by single satellite missions.**
  - ***–Understanding requires simultaneous sampling of ionosphere-thermosphere (I-T) systems***
  - ***–State of this system has important environmental consequences along with basic science needs***
- **Multiple satellite missions are ultimately needed to address the structured and dynamic I-T system, but even a single spacecraft mission well configured would help solve many of our concerns.**

# Consequences of Ionosphere-Thermosphere

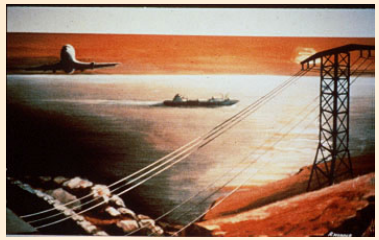
**The dissipation of magnetosphere energy is manifest in the appearance of aurora.**

***Need satellite measurements below $F_{max}$***



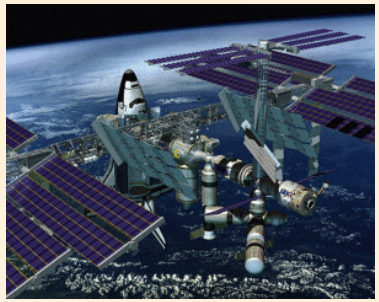
**Charged particle distributions contain irregularities that disrupt navigation and communication signals.**

***Need satellites that resolve local time structures, equator and middle latitudes, F layer.***



**Horizontal closure currents induce electric fields and currents at the Earth's surface.**

***Need satellite measurements below $F_{max}$***



**Neutral atmosphere perturbations affect the orbits of small and large vehicles.**

***Need global scale measurements at diverse altitudes.***

# 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.**
  ***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.**

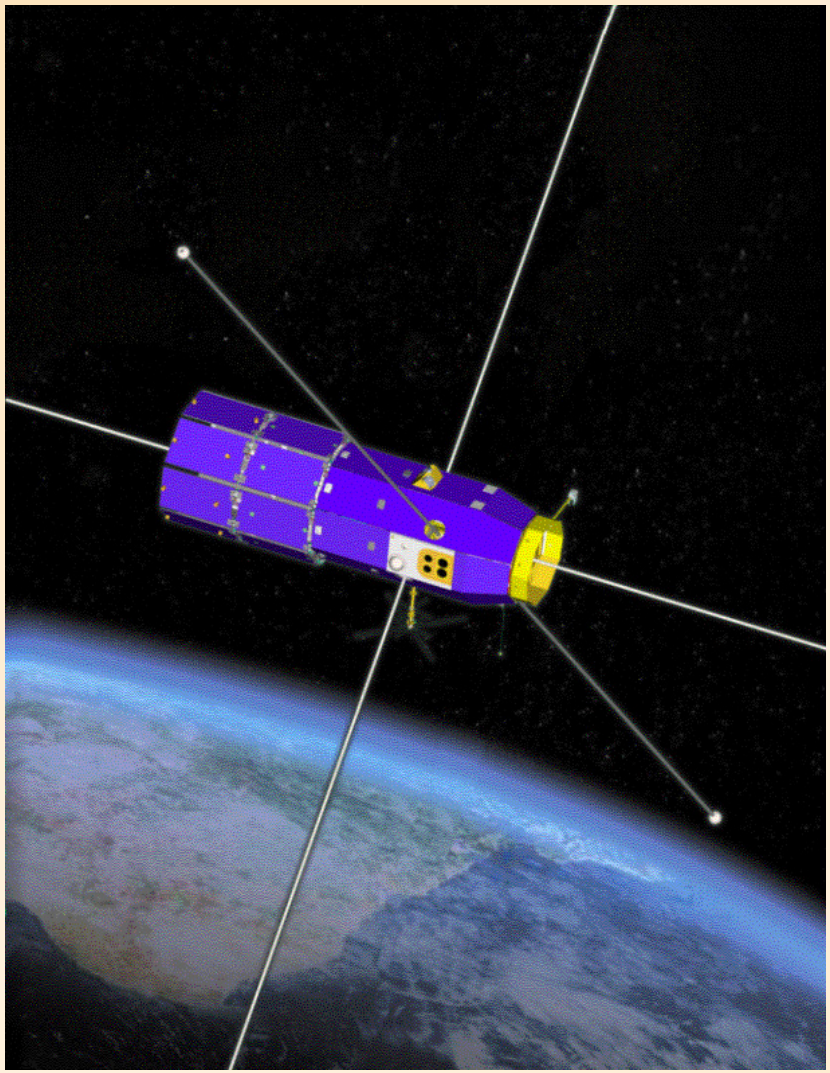
*-25 Years Since Last Extensive I-T Mission-*

# Planned NASA Involvement in I-T Missions

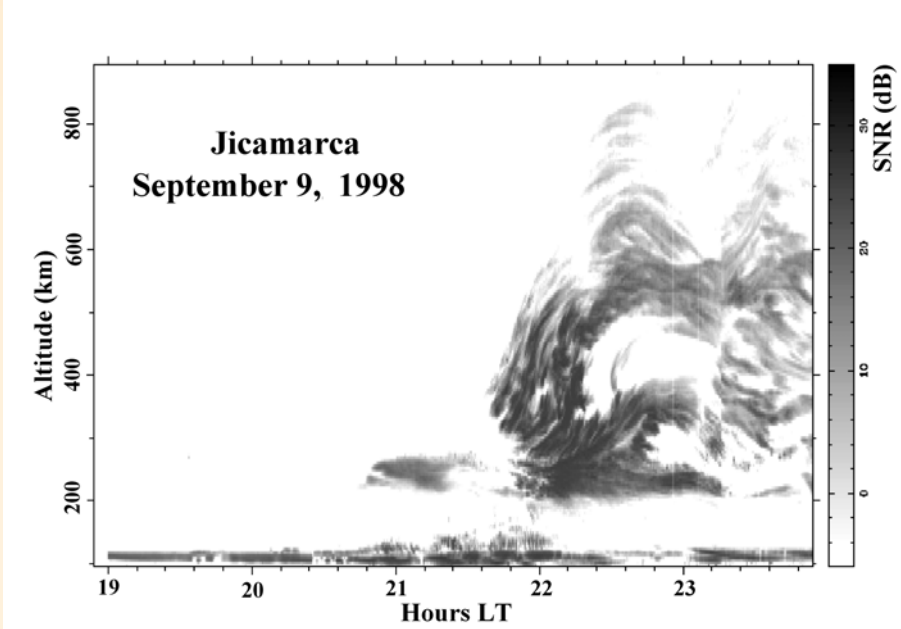
- ***Communications/Navigation Outage Forecast System (C/NOFS);*** **USAF mission; NASA provides instruments**
- ***Ionosphere-Thermosphere Storm Probes (I-TSP*****) Part of Living with a Star Program; science geared to human needs.**
- ***Geospace Electrodynamics Connections (GEC*****)**

  **Part of Solar Terrestrial Probe Science Program.**

# Communications/Navigation Outage Forecast System (C/NOFS)



*13$^{o}$ inclination, 375 X 710 km*




- Science focus is turbulence of the equatorial ionosphere that disrupts radio wave navigation and communications.
- Objective is to detect active scintillation regions and forecast them 3-6 hours in advance.
- Measure plasma densities, temperatures, E-fields, neutral and ion velocities

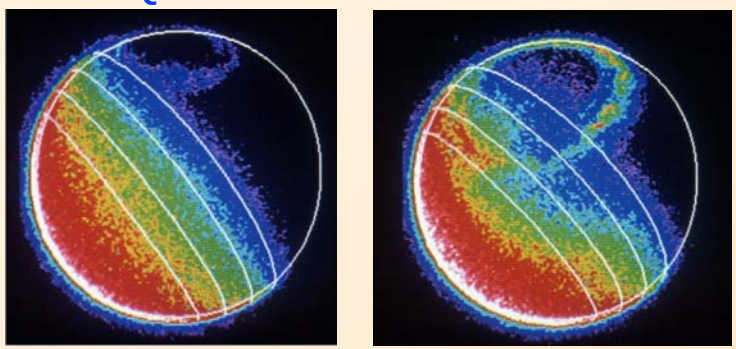
# Solar Variability Impacts

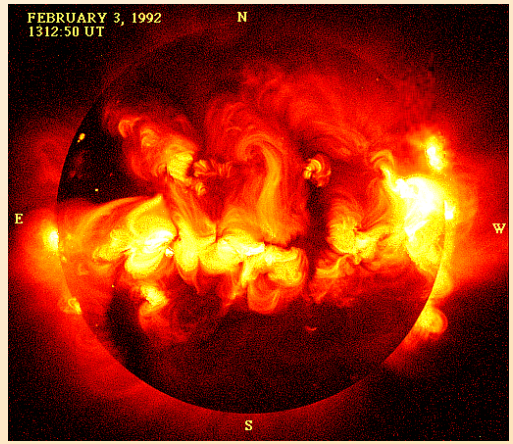
**Need to Improve our Prediction of Space Weather Effects at all Latitudes**

**Understand the effects of solar flares and EUV variations in addition to auroral heating on communication systems through modification of the ionosphere.**

**Better determination of atmospheric drag changes and satellite tracking due to solar EUV variability and geomagnetic storms.**

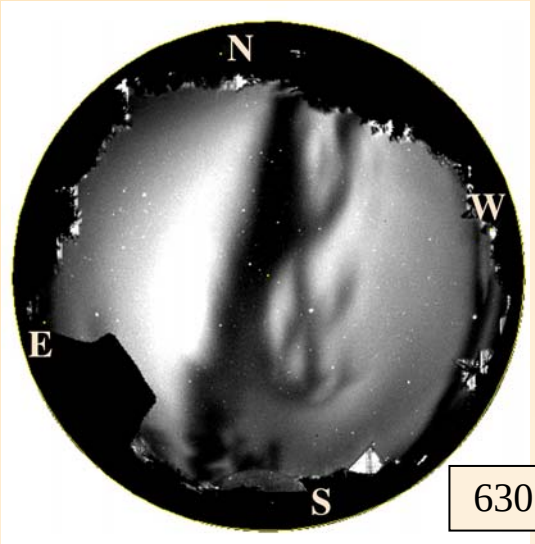
Quiet Active






Earth UV Images indicating the change of composition as solar flare activity increases

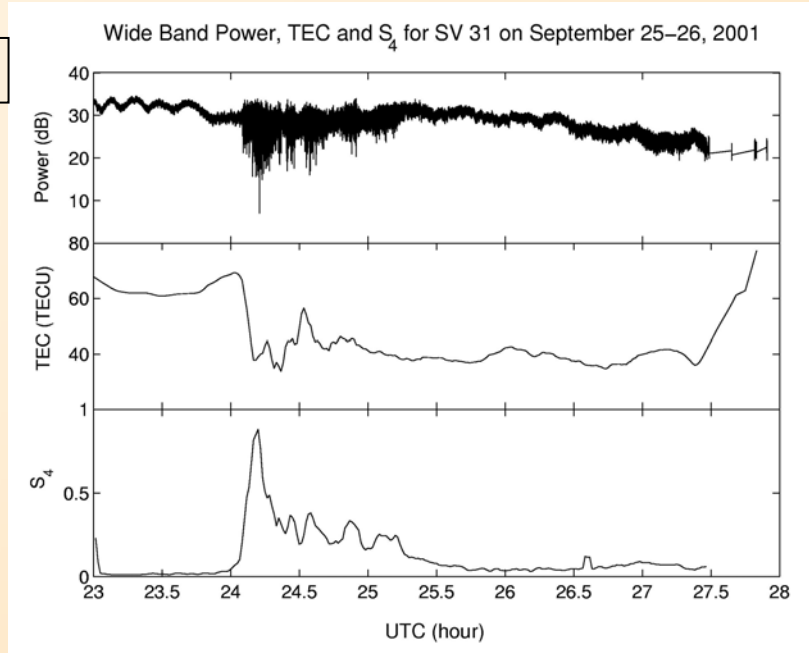
# Midlatitude Ionospheric Irregularities Also Affect GPS Navigation and Satellite Communications



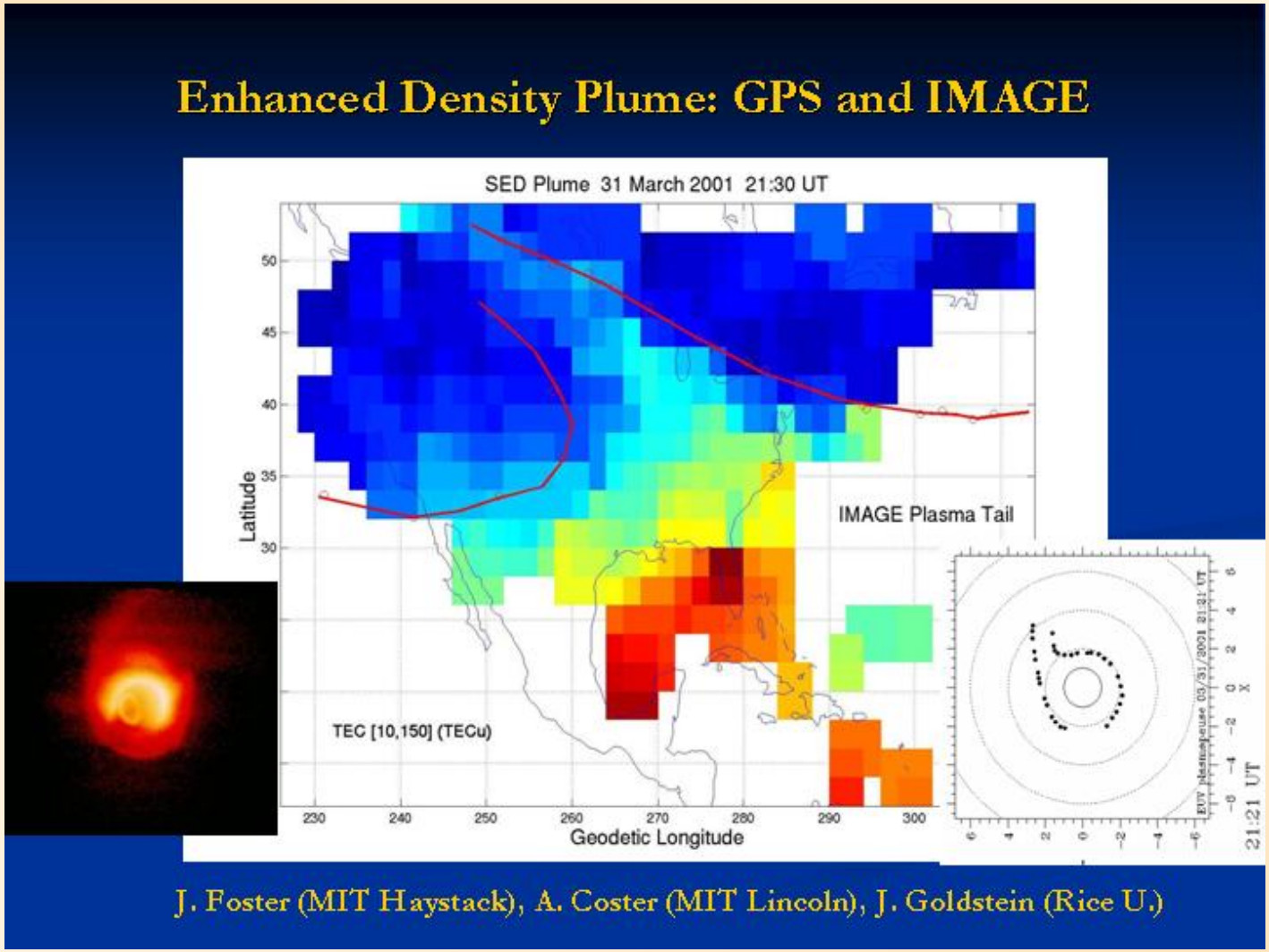

630 nm airglow emissions Arecibo

•Large-scale mid-latitude depletions contain strong irregularities and ionospheric density gradients similar to equatorial spread-F (ESF).

•There is a lack of basic in-situ measurements by multiple satellites (particularly neutral winds and neutral atmosphere)



# Middle Latitude Structures

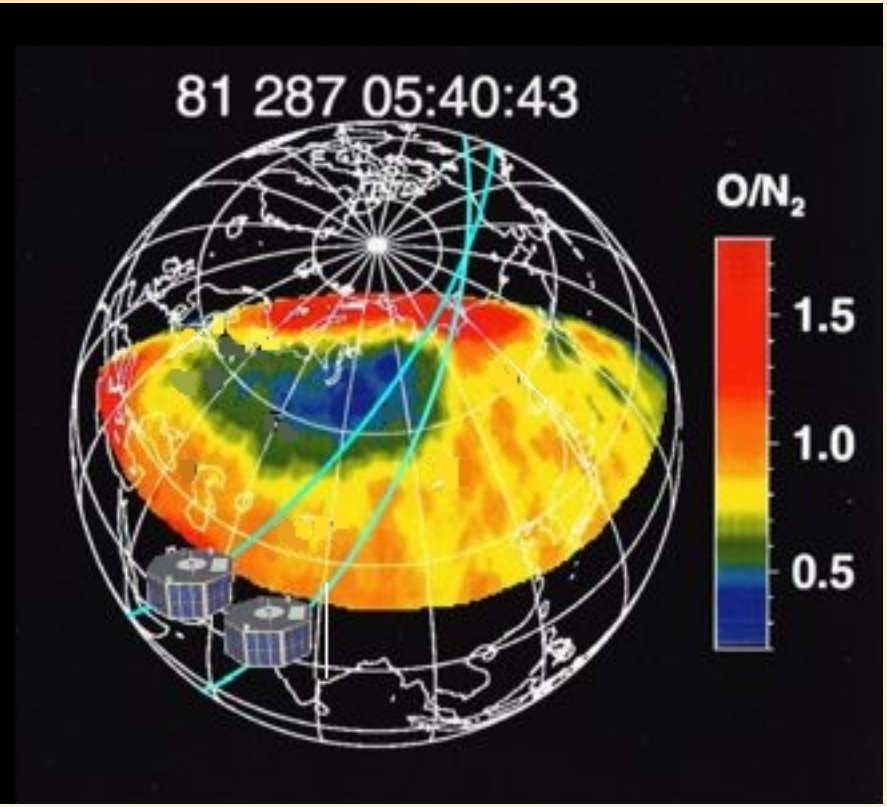



Over 40 events have been identified since the original discovery

# I-T Storm Probe Satellites - A NASA Living with a Star Mission

## Focus on Middle Latitude Processes that Have Societal Implications

***Two Spacecraft***




***Orbits:***

- *~ 450 km circular orbits*
- *60º inclination*
- *10-20º longitude separation, orbiting side by side*

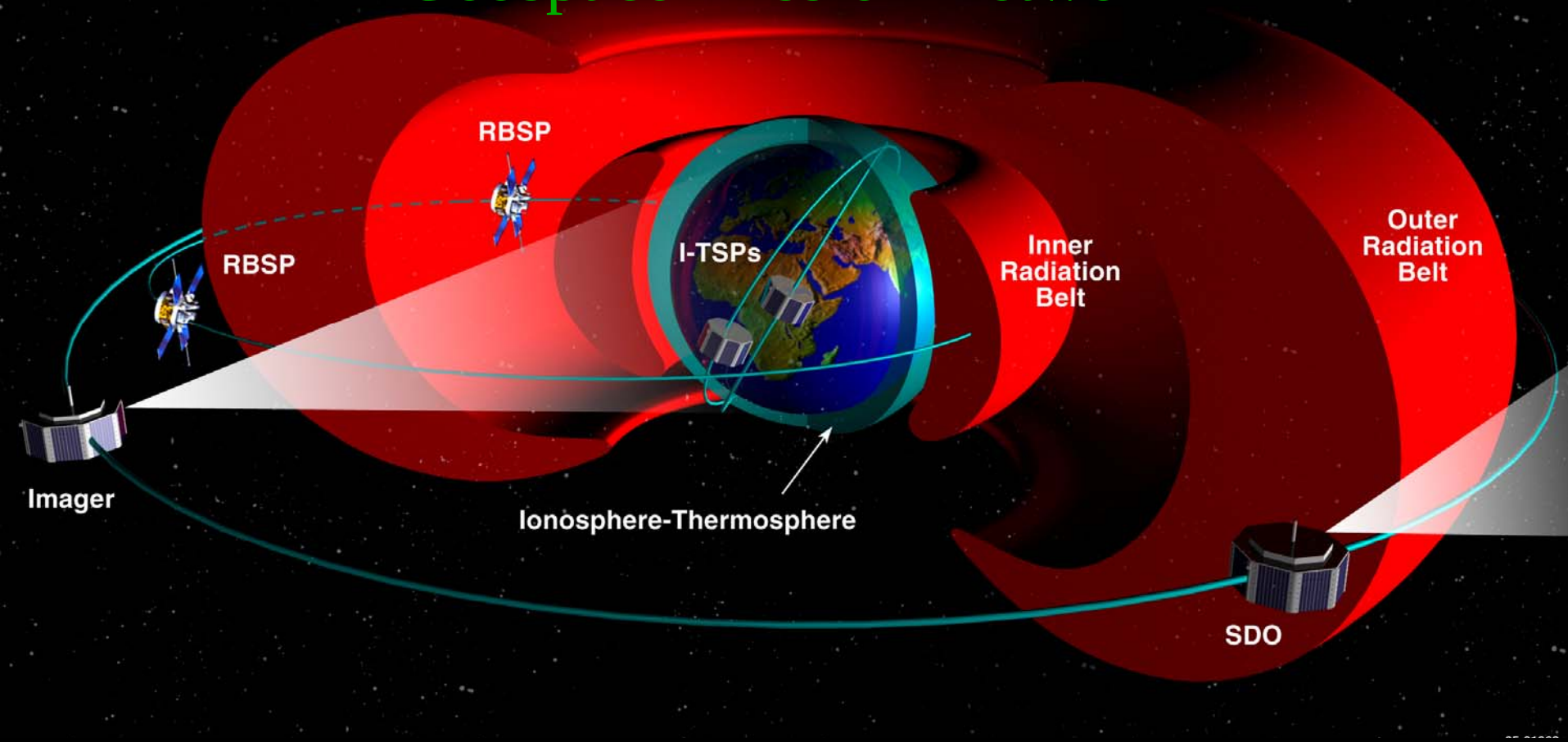
***Measurements:***

- *Ion/neutral winds, temperatures and concentrations*
- *Electric field*
- *Scintillations*
- *GPS*

# I-TSP Science Goals

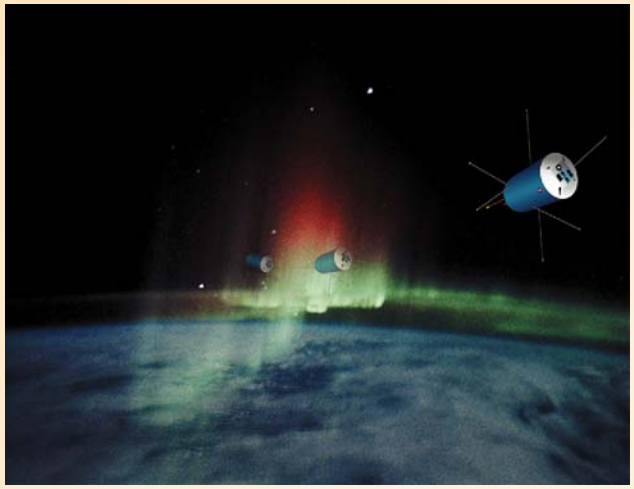
- **Determine the effects of long and short term variability of the Sun on the global-scale behavior of the ionospheric electron density.**
- **Determine the solar and geospace causes of small scale ionospheric density irregularities in the 100 to 1000 km altitude range.**

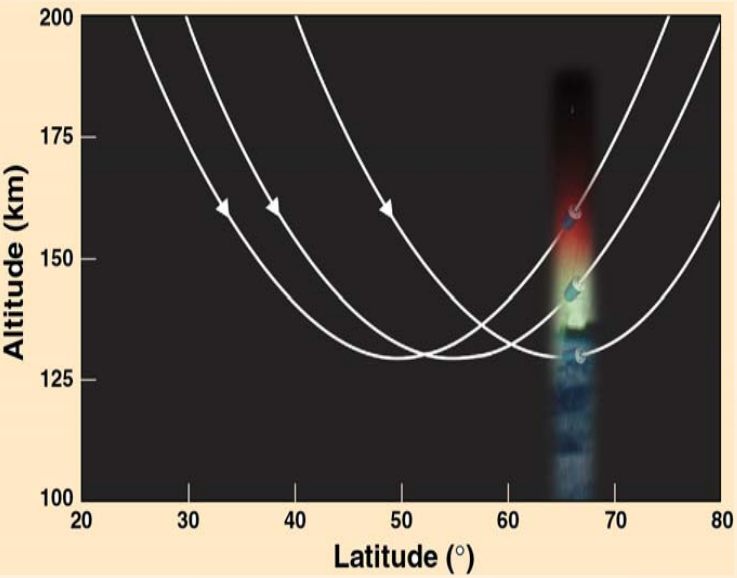
# Geospace Mission Network




- **Radiation Belt Storm Probes**
- **Ionosphere-Thermosphere Storm Probes**
- **EUV from Solar Dynamics Observatory (Extreme Ultraviolet Variability Experiment)**
- **Missions of Opportunity**
  - **Imager: $O/N_2$ and Electron Density**

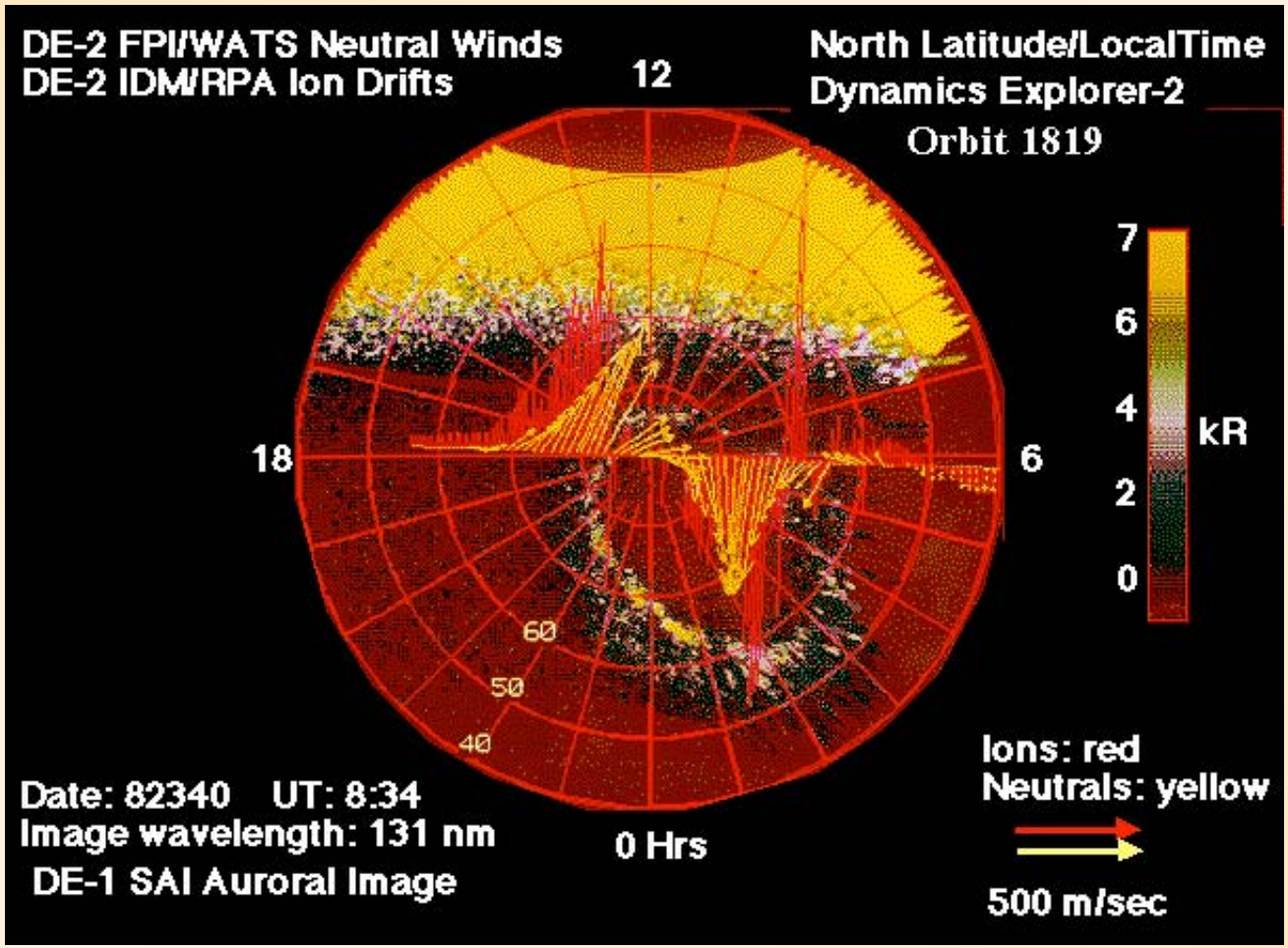
# GEOSPACE ELECTRODYNAMIC CONNECTIONS (GEC)






- **3-4 “dipping” spacecraft (nominal orbit 2000X200 km, 83$^{o}$ inclination, pearls-on-a-string) with dips below 130 km altitude.**
- **In-situ sensors measure all relevant ionosphere and thermosphere parameters (densities, velocities, temperatures, E, B, and energetic particles).**
- **Ability to adjust orbits to provide altitude snapshots.**

# Neutrals and Ions Inter-coupled

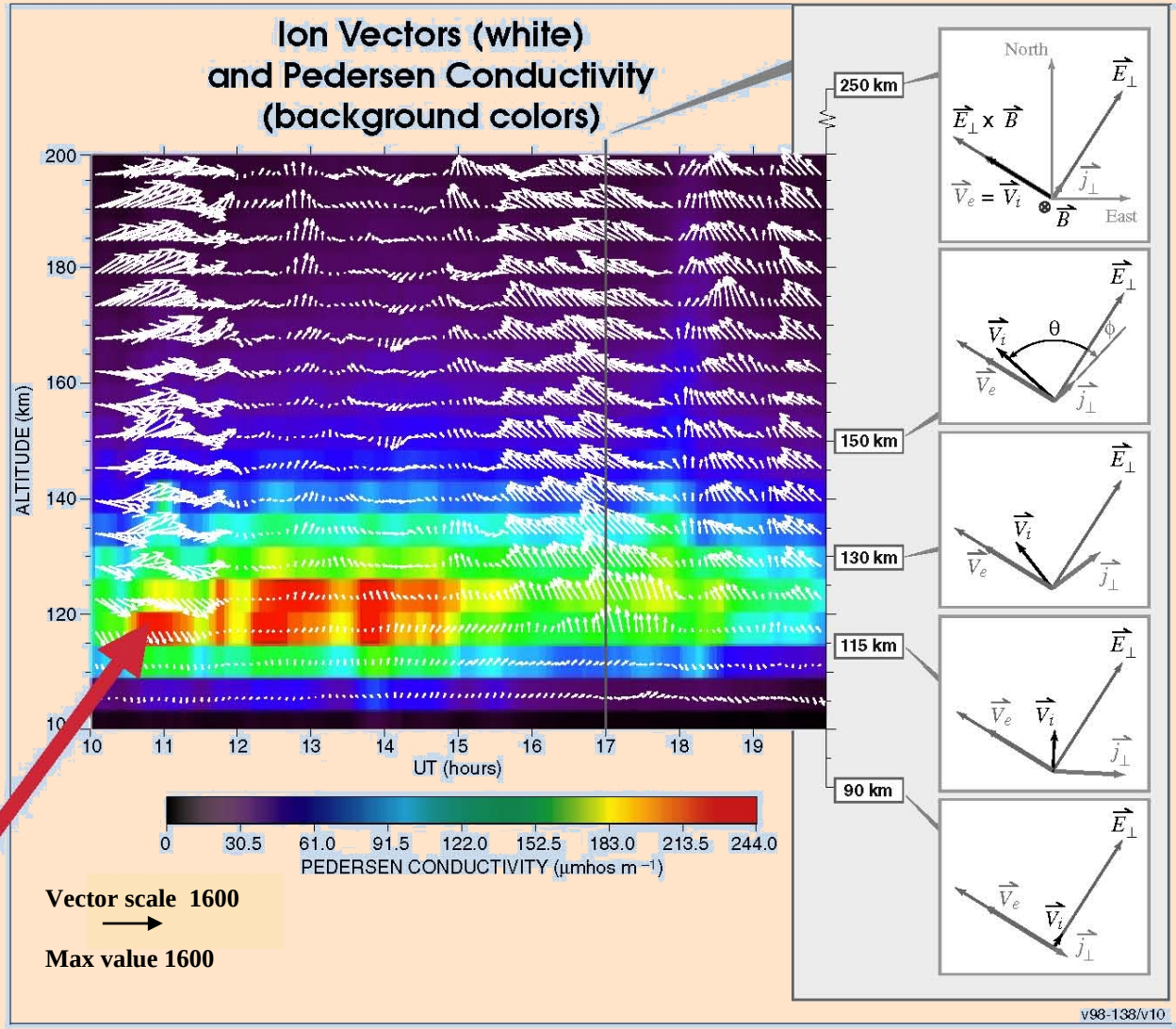


# WHY DIP TO 130 km?

## SONDRESTROM INCOHERENT SCATTER RADAR

Vector diagrams show ion motion and current at five altitudes for same time

- Ionosphere very conducting between 90 and 180 km
- Ion velocity vector departs by ~45° from the E ×B direction around 130 km

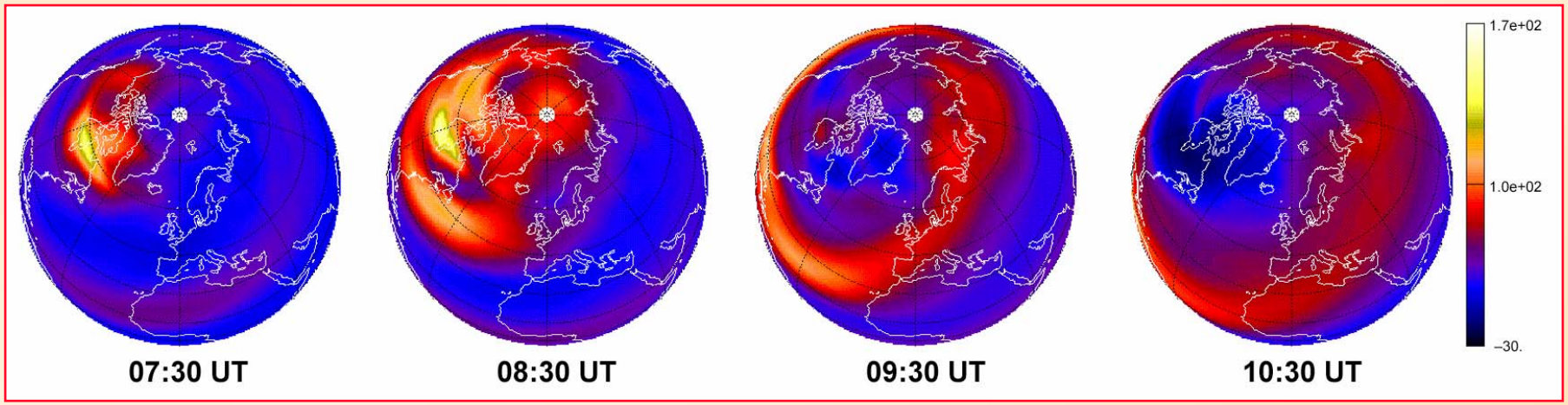



**Current Closure Region Overlaps 130 km - GEC's Approximate Targeted Altitude**

Jeff Thayer, June 1999

# Globally Traveling Ionospheric Disturbances

*"GEC will be able to track the initiation of such disturbances in small-scale heating regions in the auroral zone and track their evolution over increasingly larger scales."*




Changes in thermospheric neutral density of 300 km altitude. NCAR TIEGCM simulation of atmospheric response to January 11, 1997, magnetic storm. (Images courtesy of G. Lu/NCAR.)

# GEC'S GOAL: ANSWER 3 QUESTIONS

- How does ionosphere-thermosphere system respond to and dynamically affect magnetosphere-ionosphere coupling?
- How are ion and neutral motions coupled through the global ionospheric wind dynamo?
- How does the ionosphere-thermosphere system provide closure paths for field-aligned currents?

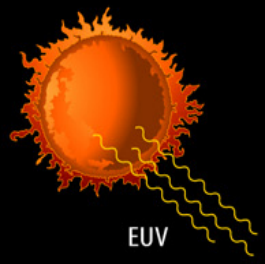
*Find the important temporal and spatial scales for e-m energy transfer and energy distribution and the cross-scale I-T-magnetosphere coupling processes.*

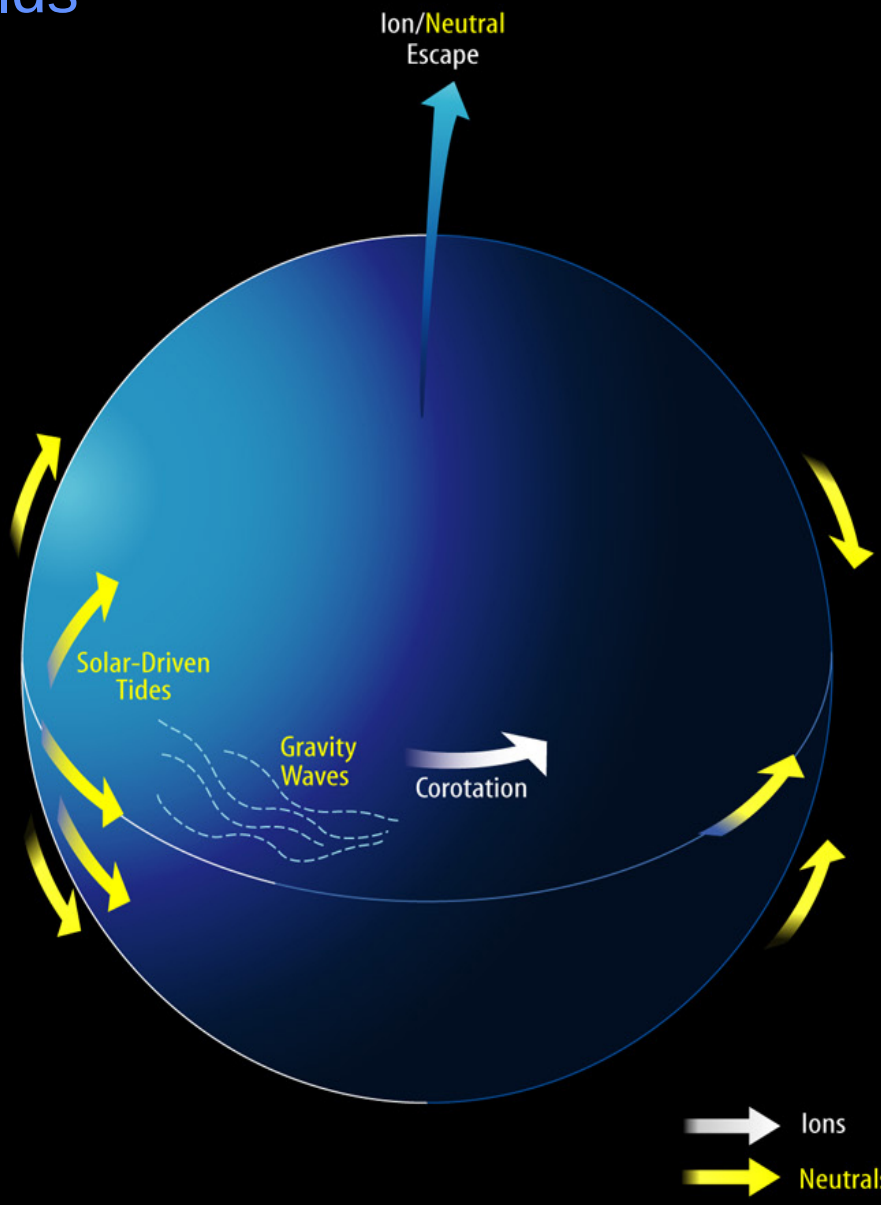
# Importance of All IT Missions

*SPATIO-TEMPORAL ASPECTS OF ION-NEUTRAL INTERACTIONS IN THE EARTH'S IONOSPHERE-THERMOSPHERE SYSTEM.*

"Ion-neutral interactions occur in all solar system settings and are fundamental to our understanding both of geospace and of other planetary environments"

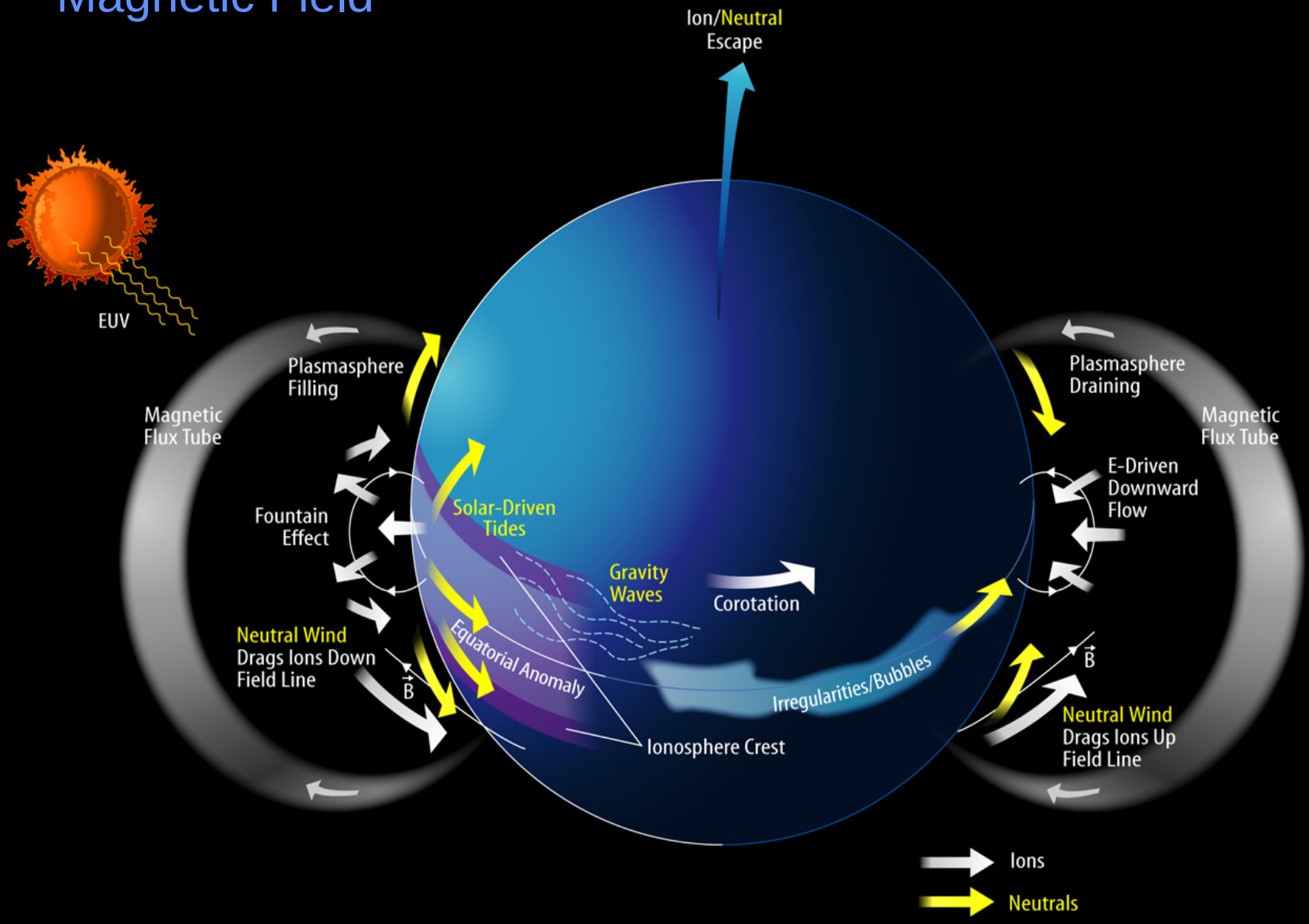
# Solar EUV Effects
# No Magnetic Fields




J. Grebowsky / NASA GSFC

# Addition of Earth's Magnetic Field

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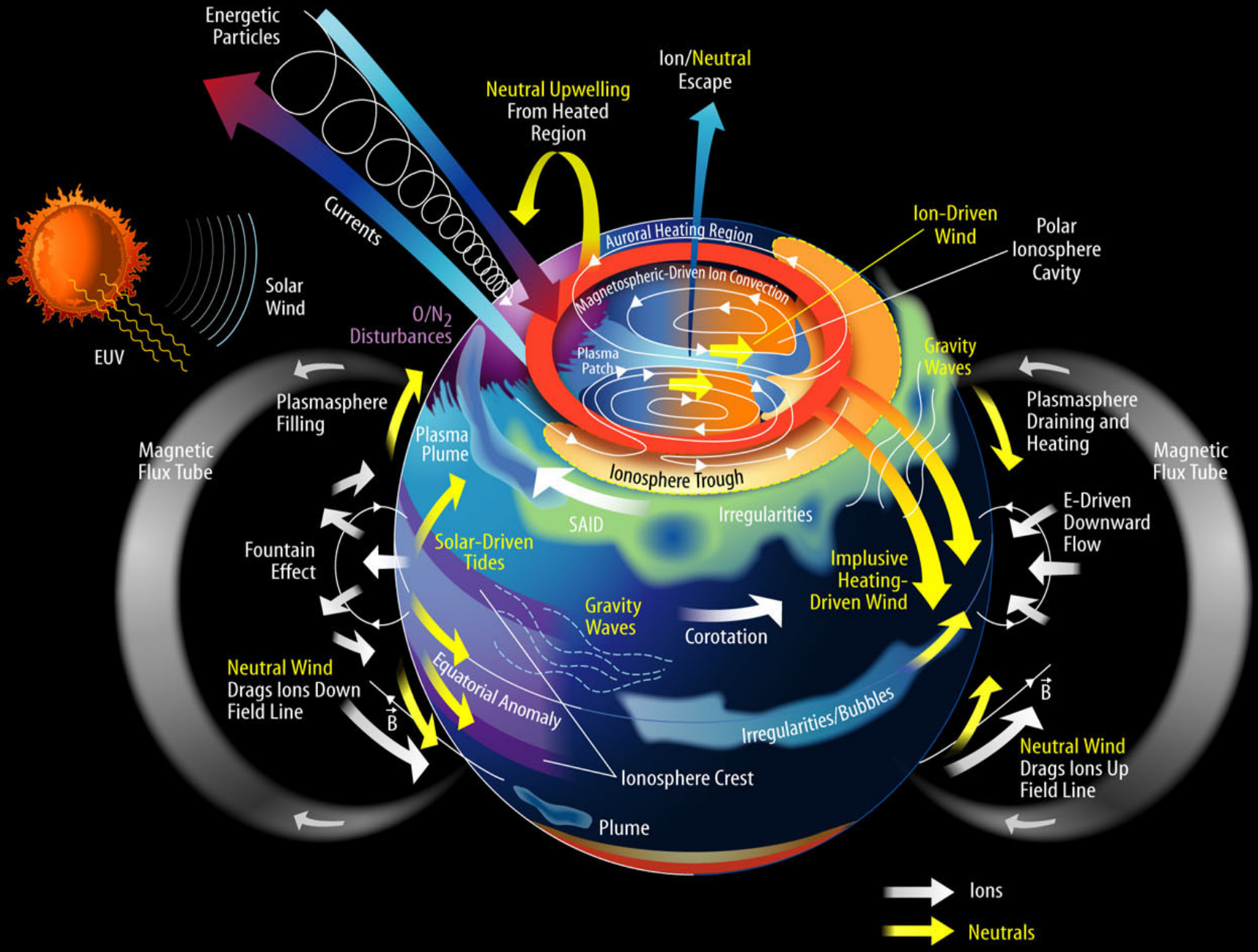
# Addition of Geomagnetic Storms

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