Space Weather in Ionosphere and Thermosphere

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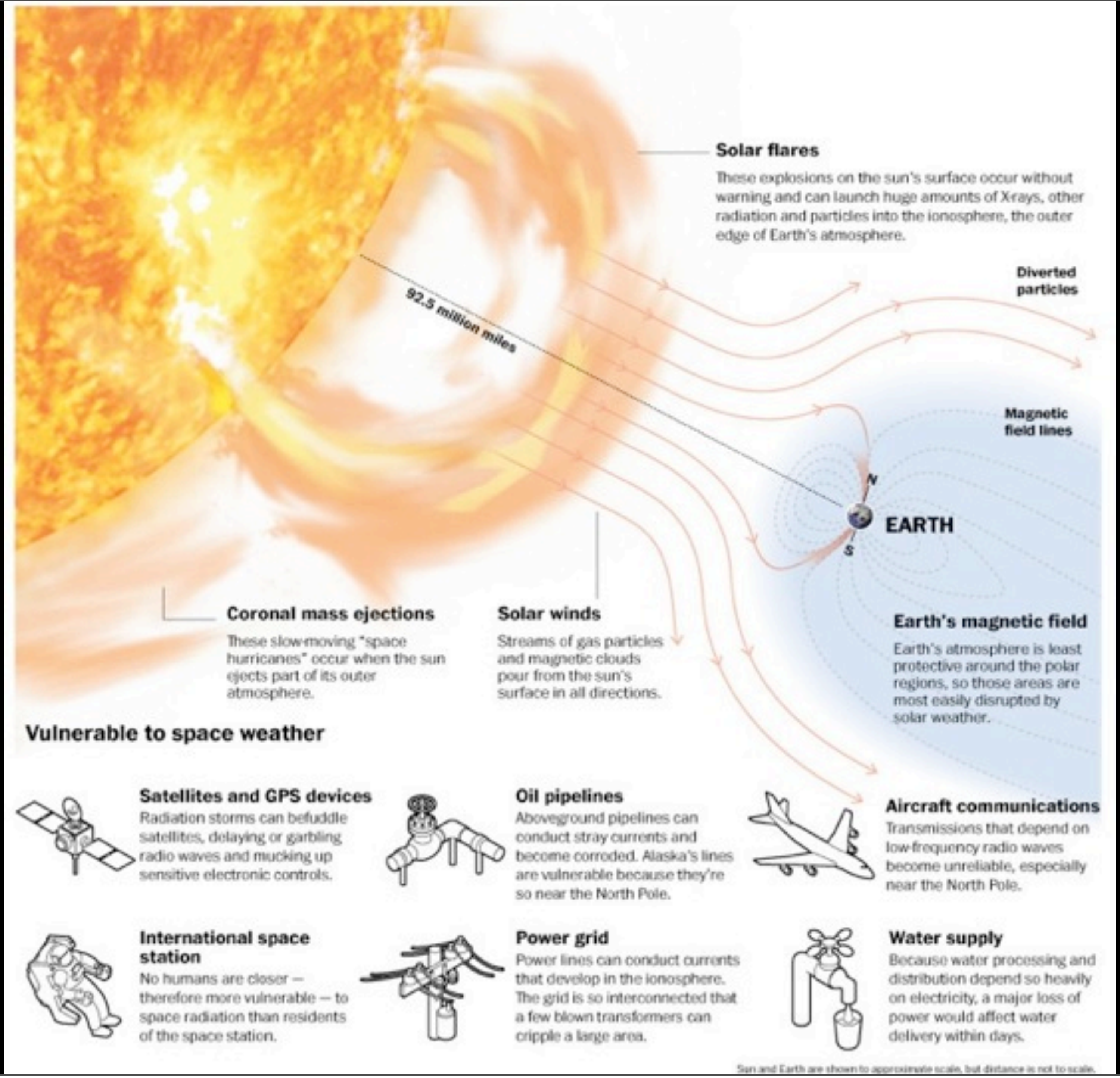
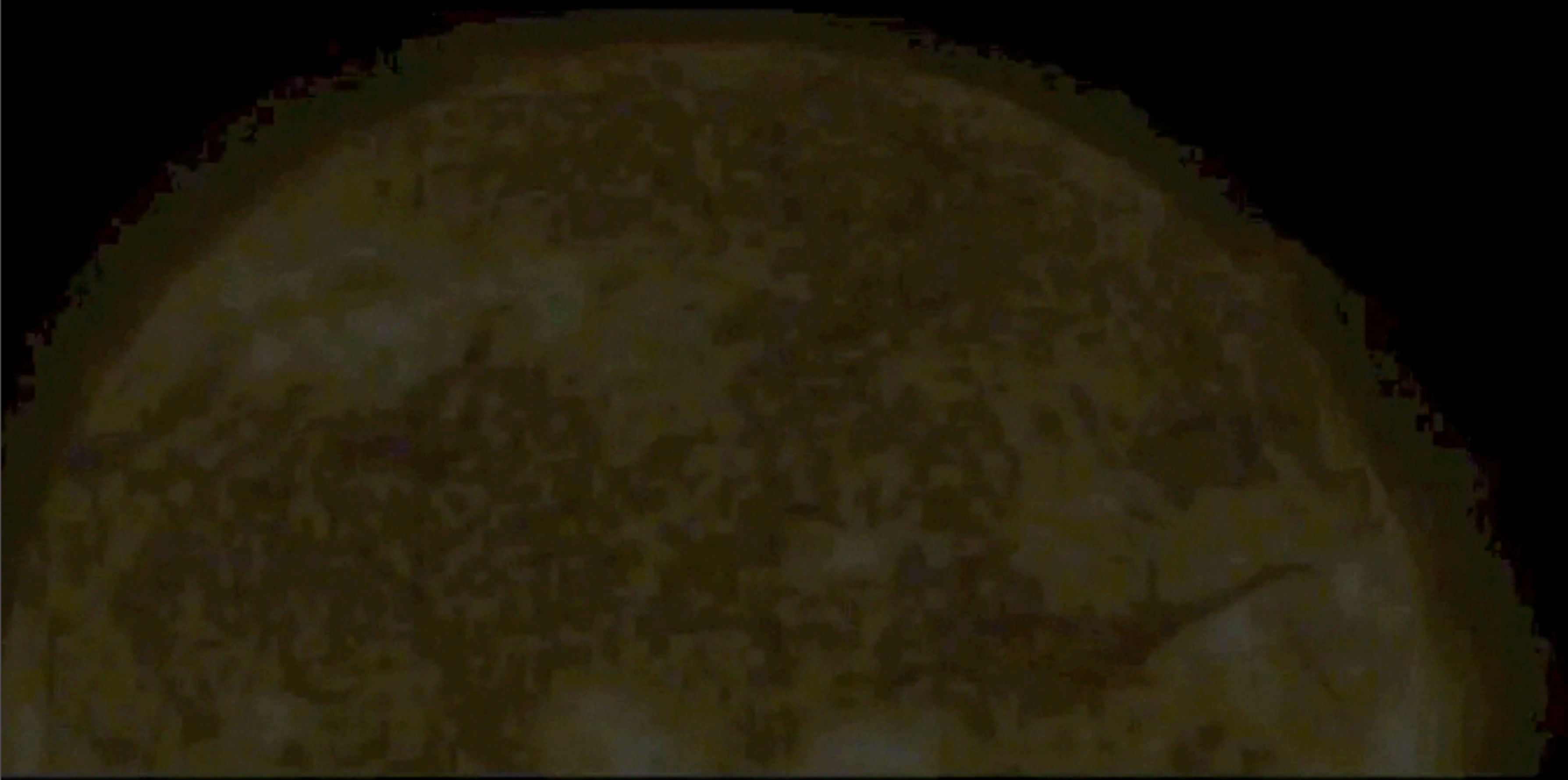
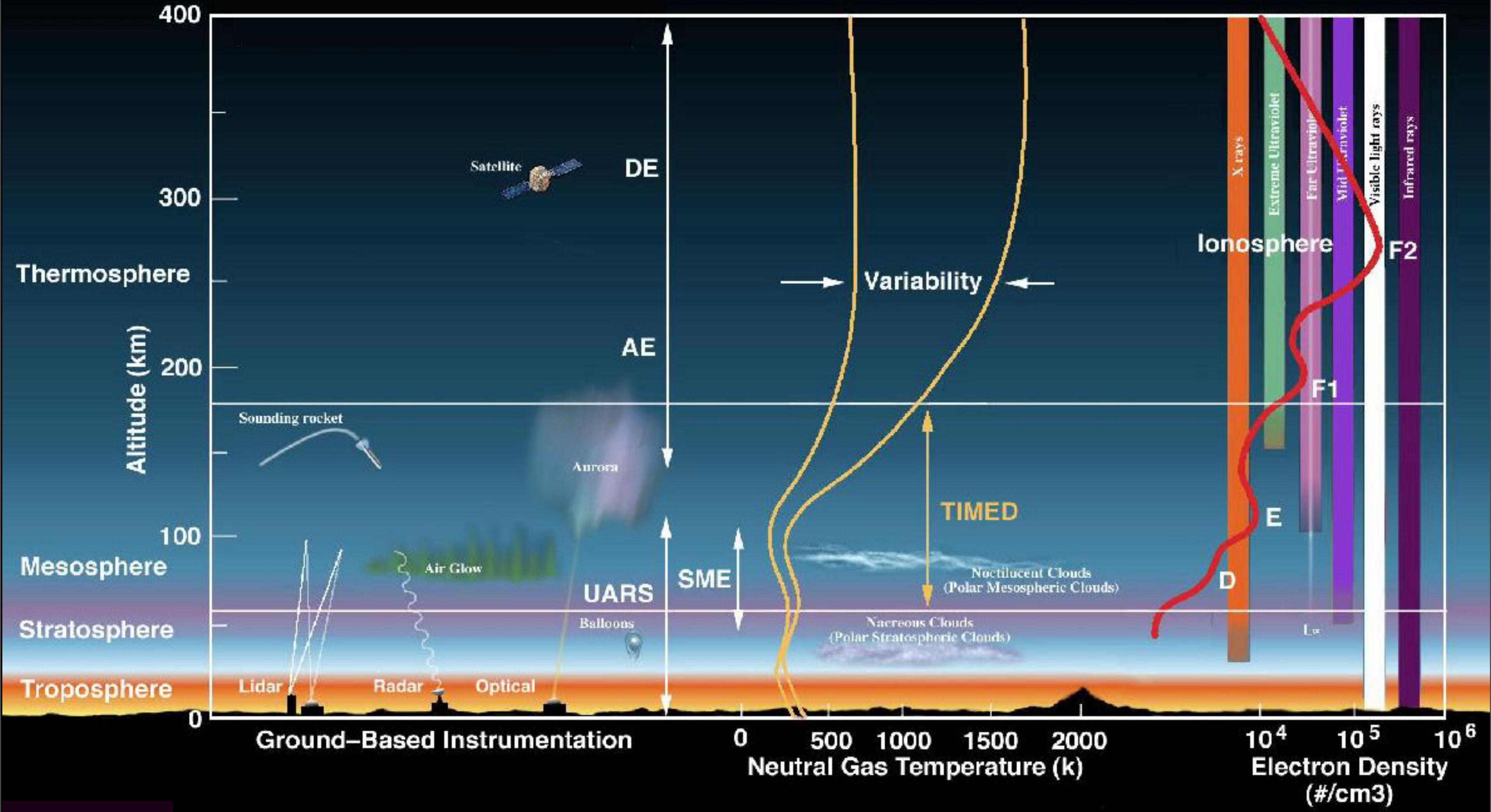
UAH 2013 Space Weather Summer School

Space Weather Illustrated





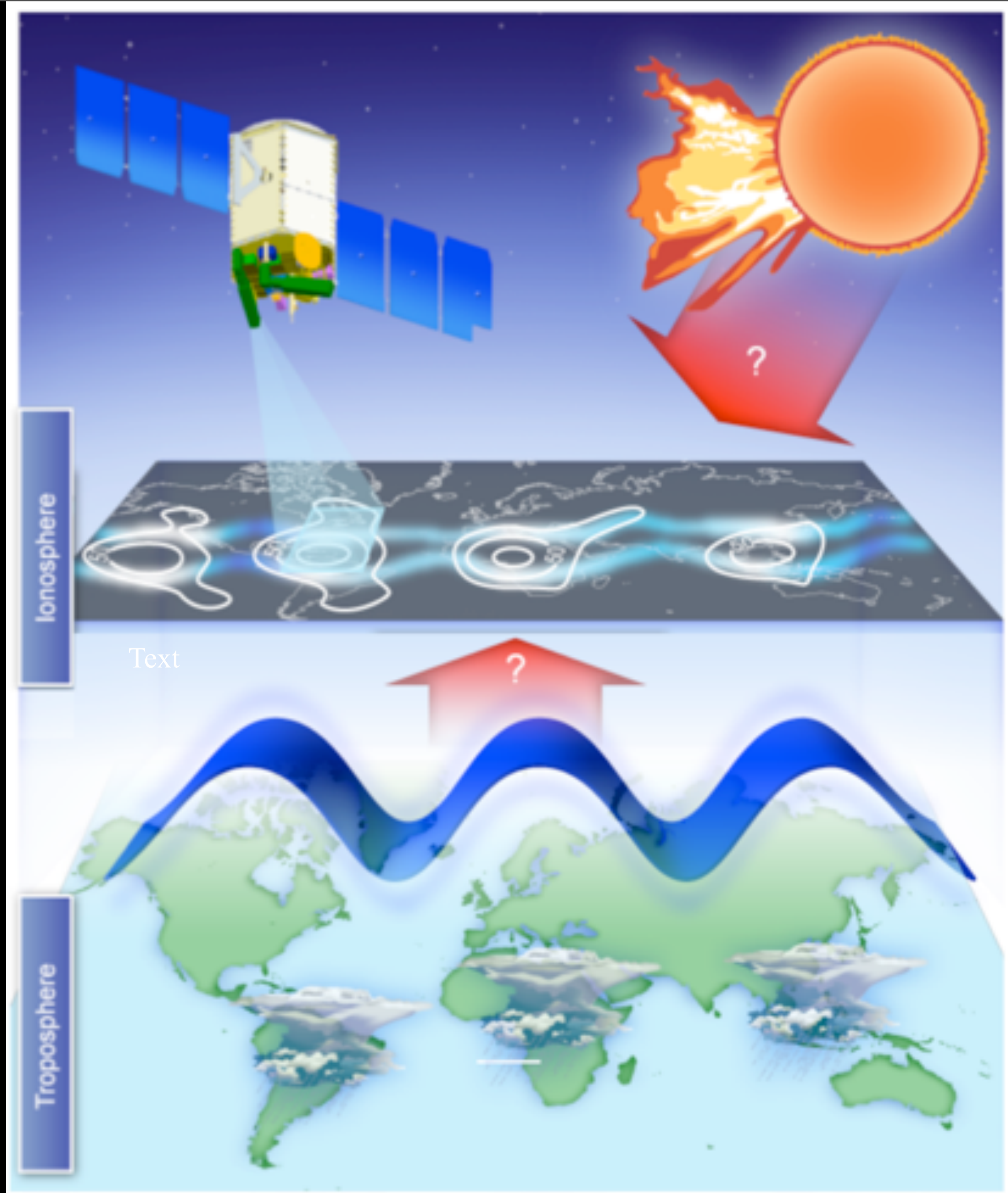
Ionosphere - Thermosphere Overview



The ionosphere is the densest plasma between the Earth and Sun, and is traditionally believed to be mainly influenced by forcing from **above** (solar radiation, solar wind/ magnetosphere)

Recent scientific results show that the ionosphere is strongly influenced by forces acting from **below**.

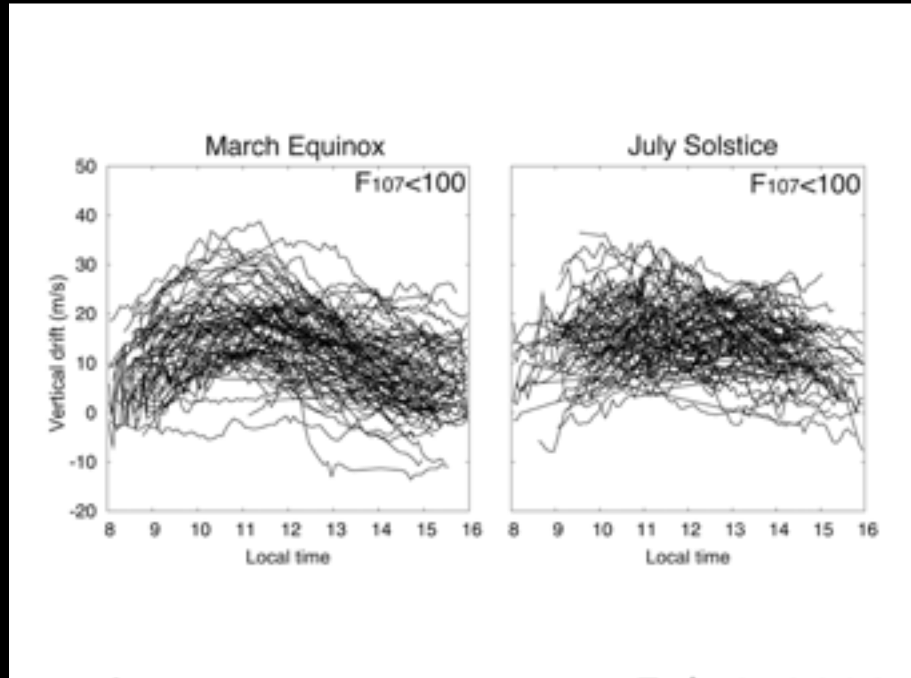
Research remains to be done:
How competing influences from above and below shape our space environment.

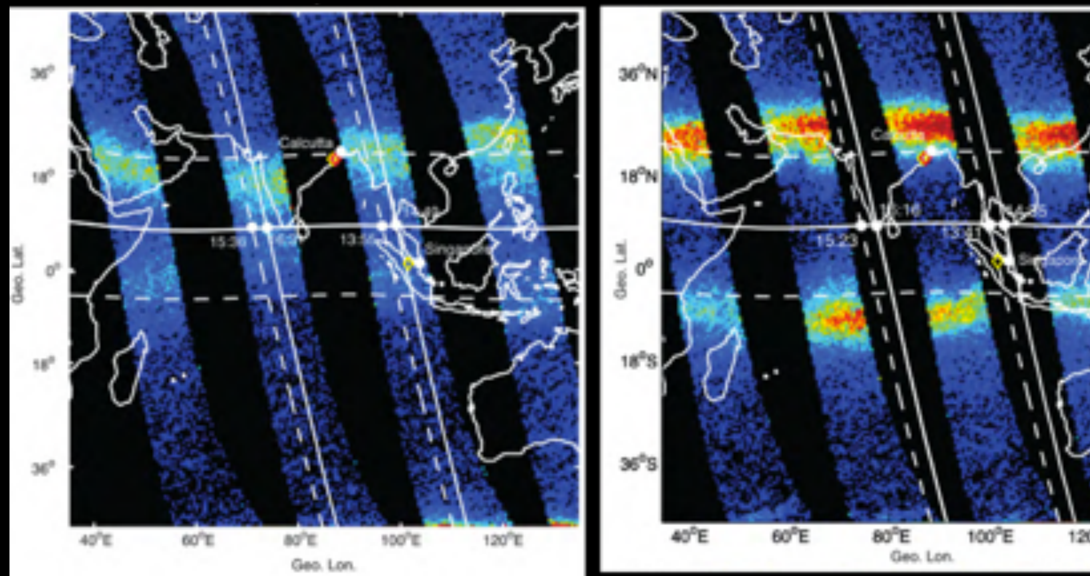


Courtesy: ICON

The daytime ionosphere exhibits significant variability in its motion and density.
the source of these changes: unknown

likely originates with modulation of
neutral and/or ionized state variables along the magnetic field - need to be determined

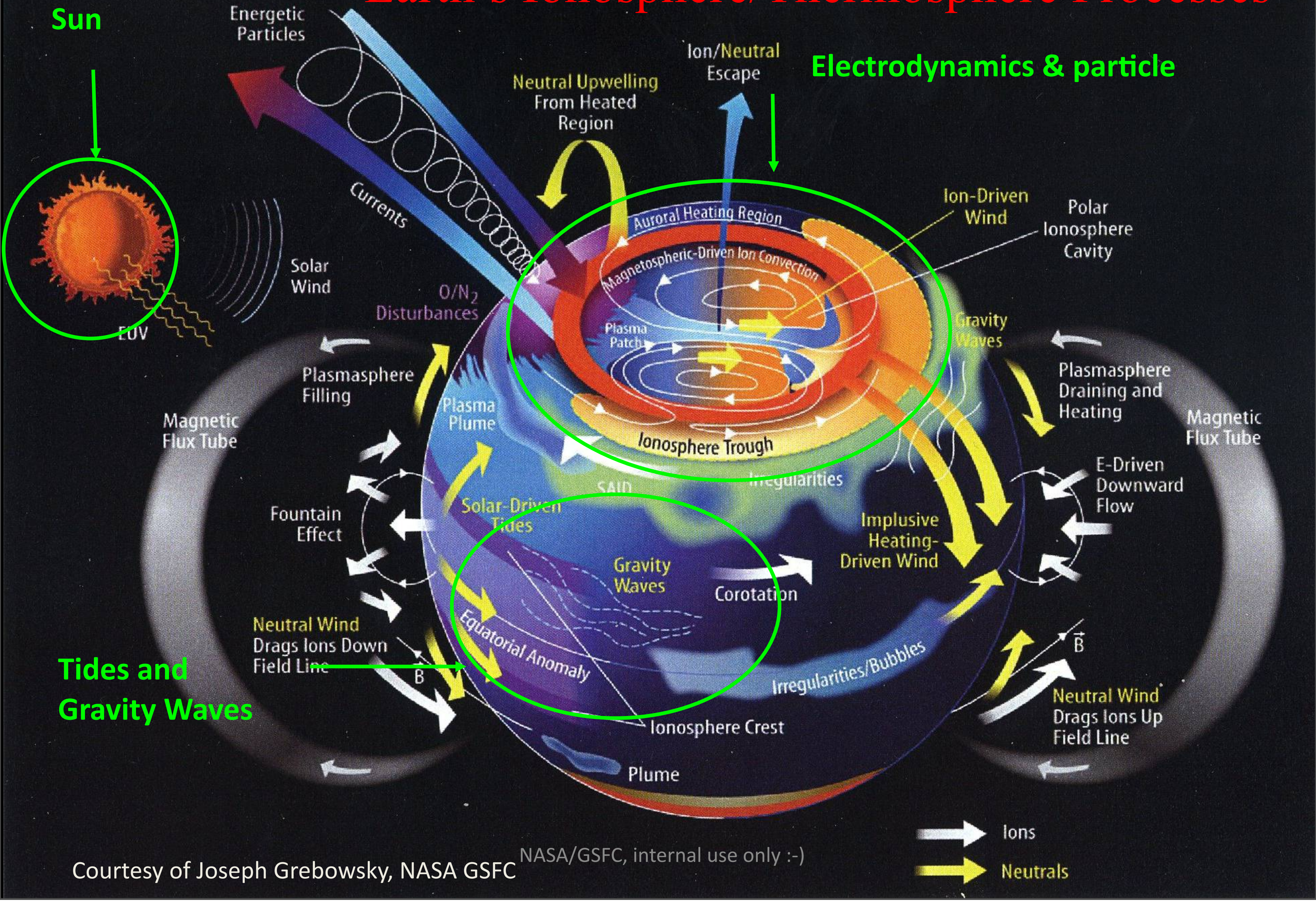




coupled ion-neutral dynamics

critical

Earth's Ionosphere/Thermosphere Processes



Space Weather Phenomena and Effects in the Ionosphere

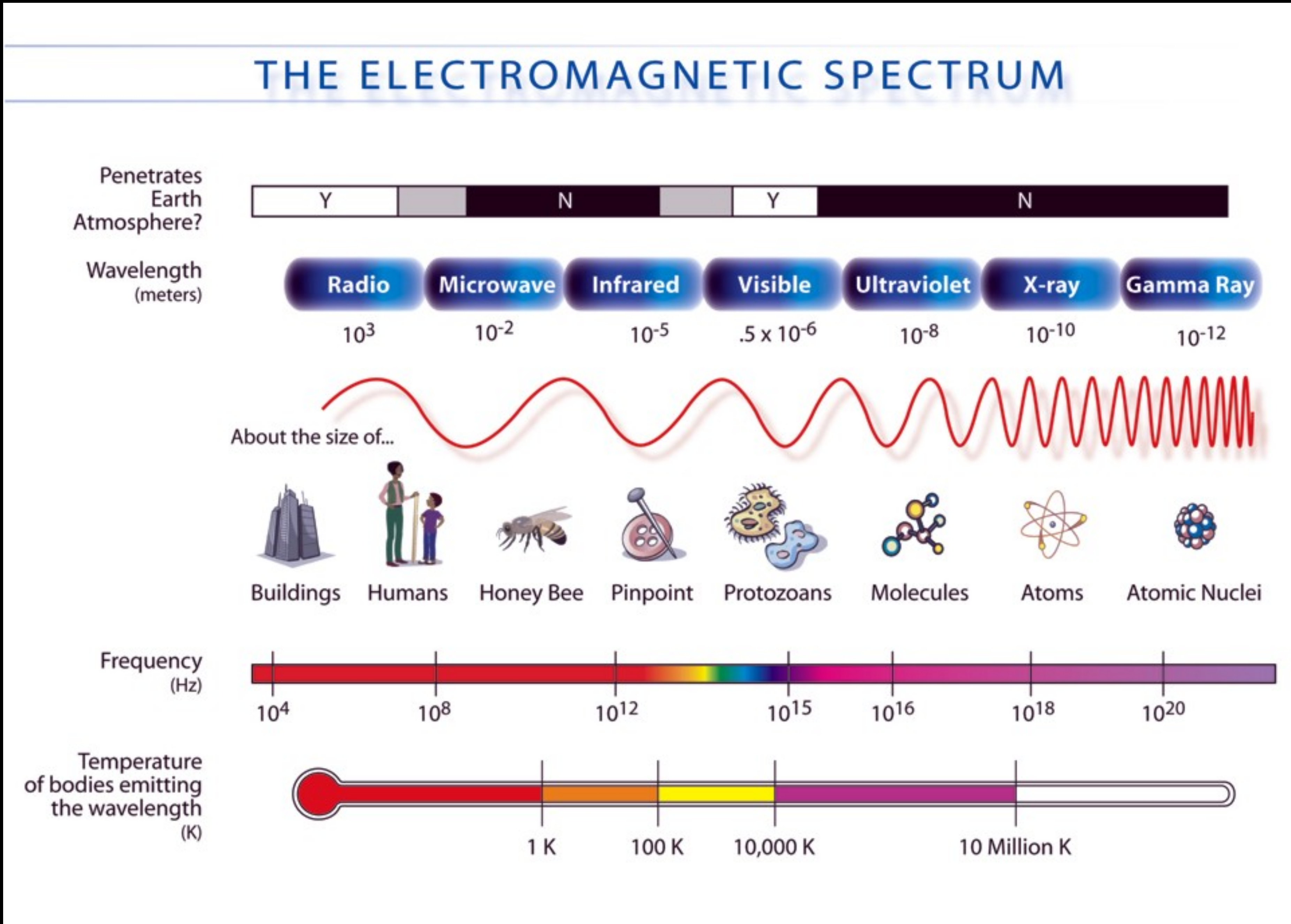
Aurora – hemispheric power (satellite charging, scintillation)

Satellite drag due to neutrals

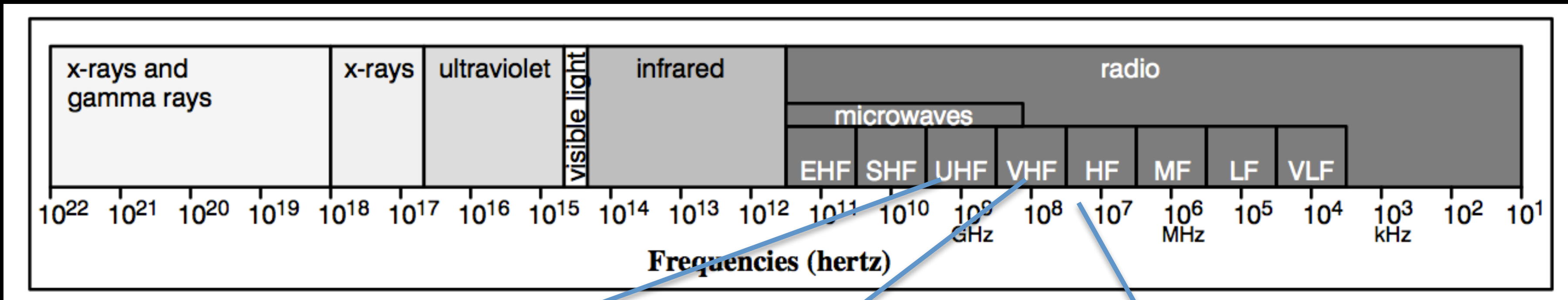
Equatorial bubbles/irregularities –scintillation, communication problems

Radio blackout -- solar flare

Polar Cap Absorption - solar energetic particles


THE ELECTROMAGNETIC SPECTRUM
Penetrates Earth Atmosphere?
Y
N
Y
N
Wavelength (meters)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^3
10^{-2}
10^{-5}
$.5 \times 10^{-6}$
10^{-8}
10^{-10}
10^{-12}
About the size of...
Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^4
10^8
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
Temperature of bodies emitting the wavelength (K)
1 K
100 K
10,000 K
10 Million K

Types of space weather events affecting nav and commu



UHF – GPS

- Energetic protons/ particles – via SEEs - affecting GPS satellites components
- Geomagnetic storms/ ionospheric storm - cause scintillations

VHF:

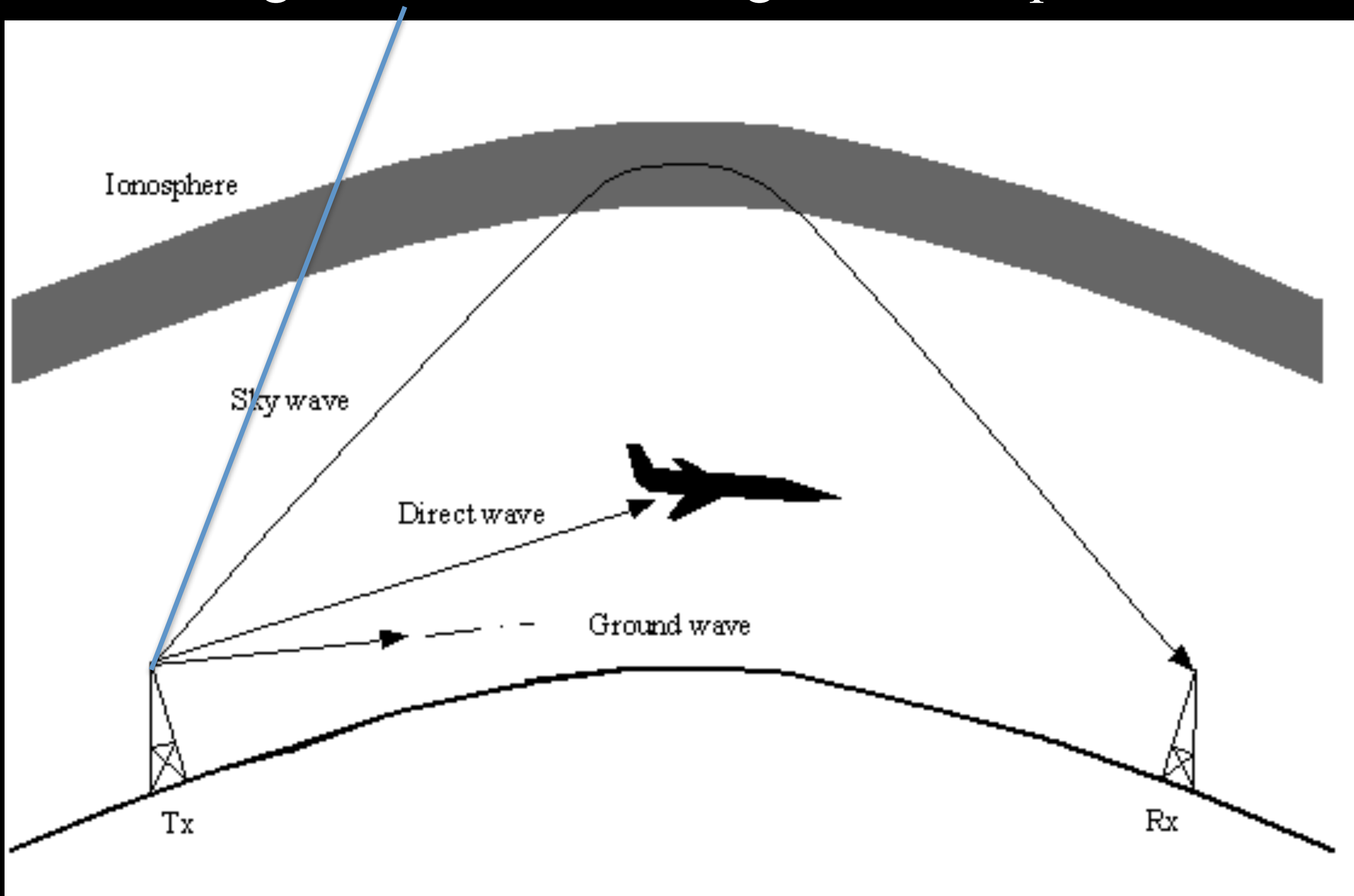
- Energetic protons - PCA
- Geomagnetic storms
- Solar radio emission associated with flare/CME

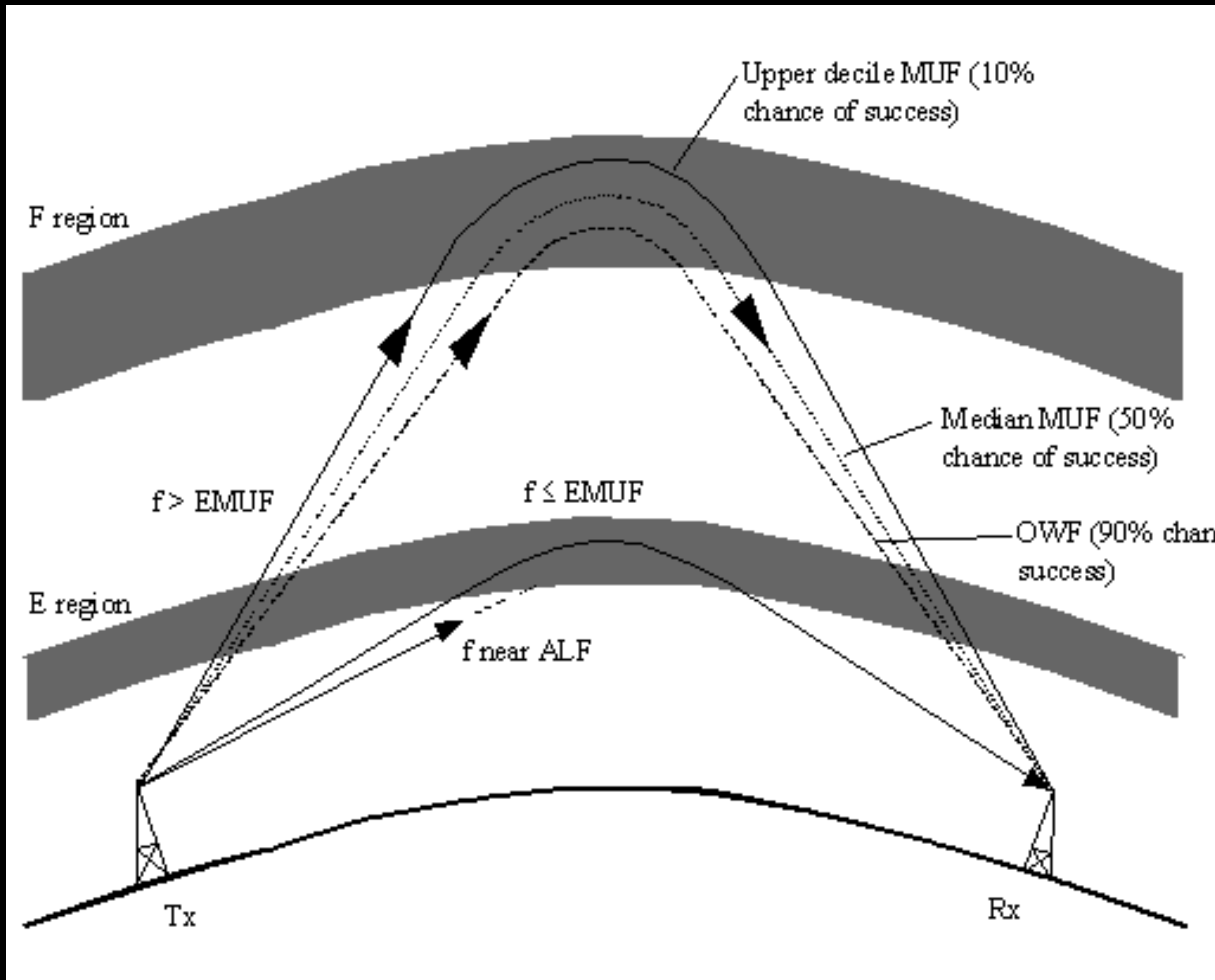
HF:

- Solar flares/x-ray
- Energetic protons - PCA
- Geomagnetic activities

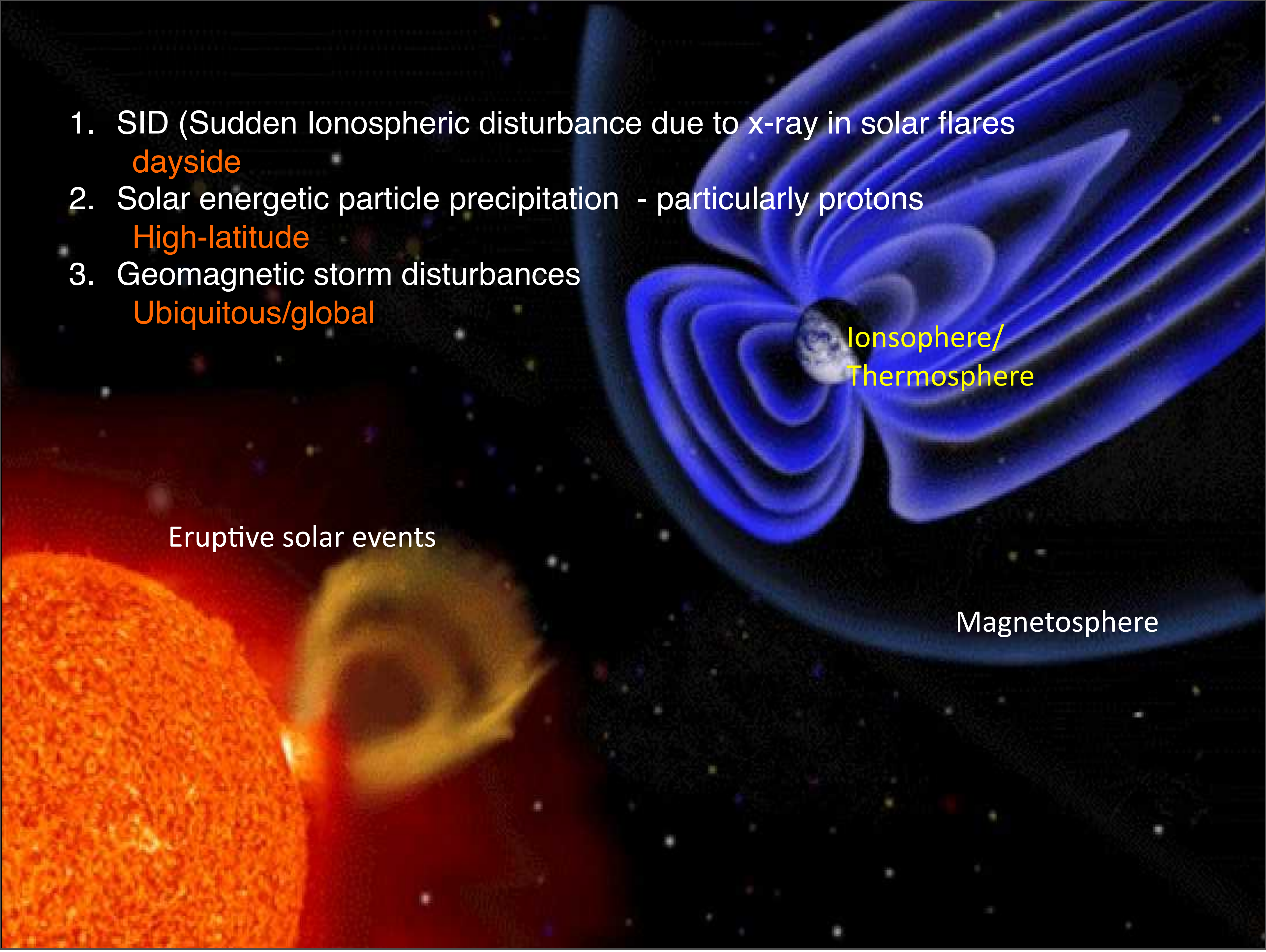
Signals of different types with different purposes

GPS signal: Penetrate through the ionosphere

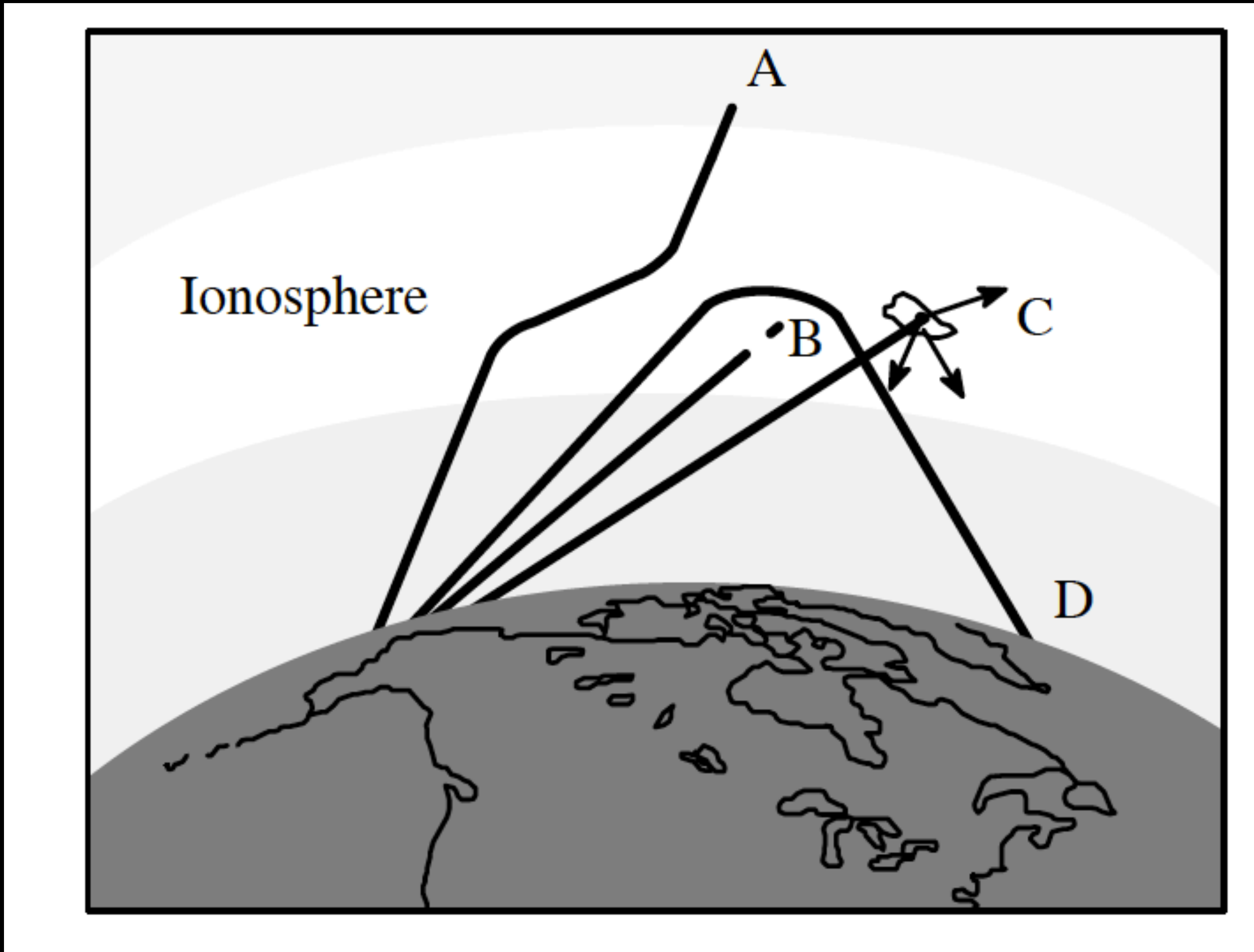




ALF: Absorption Limiting Freq.


1. SID (Sudden Ionospheric disturbance due to x-ray in solar flares
dayside
2. Solar energetic particle precipitation - particularly protons
High-latitude
3. Geomagnetic storm disturbances
Ubiquitous/global
Ionsophere/
Thermosphere
Eruptive solar events
Magnetosphere

Ionospheric impact on signal path



Could cause potential problems

Sudden Ionospheric Disturbances – solar x-ray

- ✓ An SID can affect very low frequencies (e.g., OMEGA) as a sudden phase anomaly (SPA) or a sudden enhancement of signal (SES).At HF, and sometimes at VHF, an SID may appear as a short-wave fade (SWF).
- ✓ May last from minutes to hours, depending upon the magnitude and duration of the flare.
- ✓ Absorption is greatest at lower frequencies, which are the first to be affected and the last to recover. Higher frequencies are normally less affected and may still be usable.

Radio blackout events

Solar Radio Emission affecting VHF

- Type II radio emission
- Type IV radio emission
- Solar flares also create a wide spectrum of radio noise; at VHF (and under unusual conditions at HF) this noise may interfere directly with a wanted signal.

Solar energetic particles

Radiation Storms

- HF/VHF degradation in polar region (a.k.a. Polar Cap Absorption)
- Energetic particles have detrimental effects on the onboard systems of GPS satellites (SEE impacts on spacecraft component)
- Energetic particle events can persist for a few days at a time

Geomagnetic Storms

Global impacts

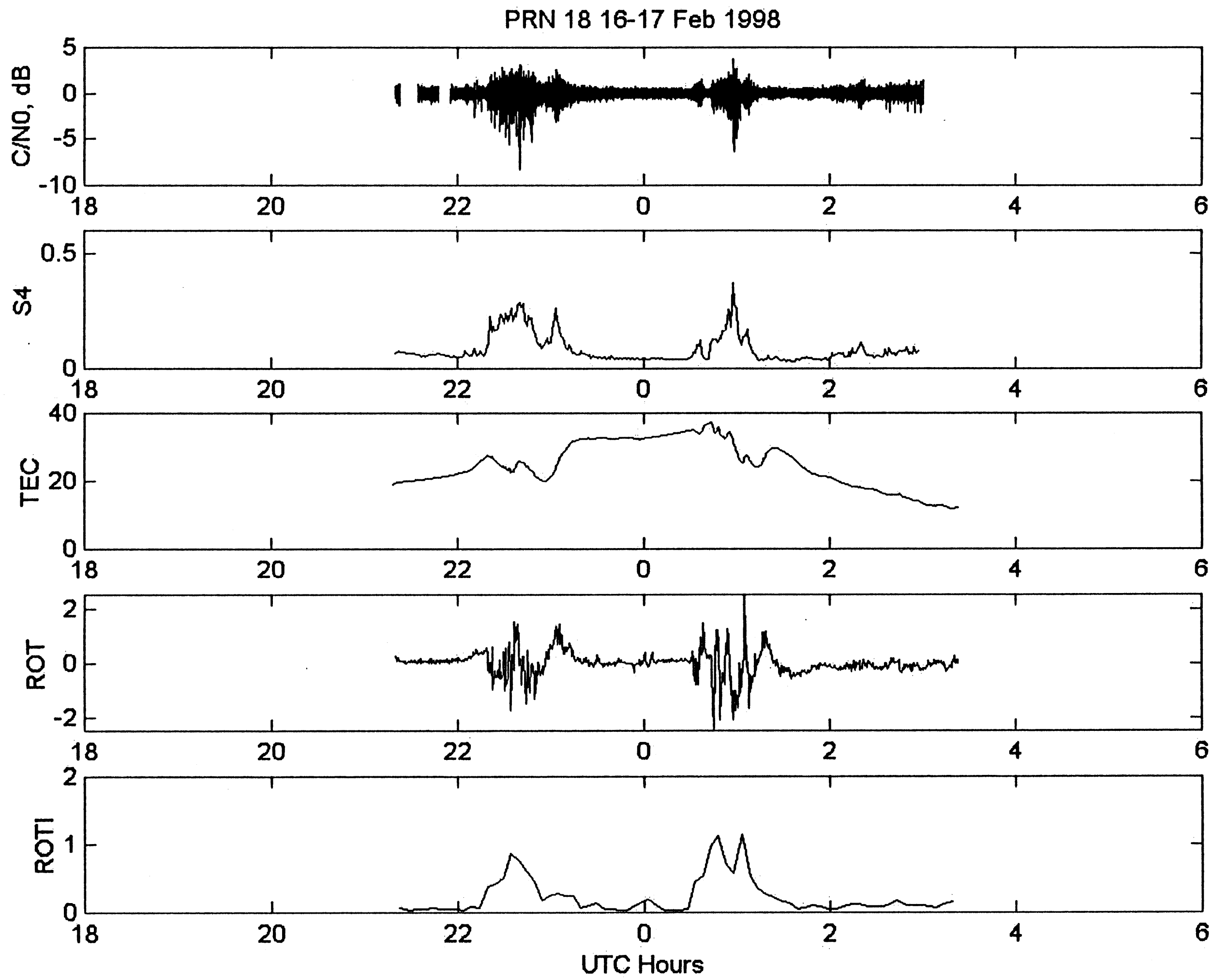
- CME storms
- CIR storms

Affect HF radio communication – especially when the signal passing through the auroral zone or ionospheric irregularities

GPS - scintillation

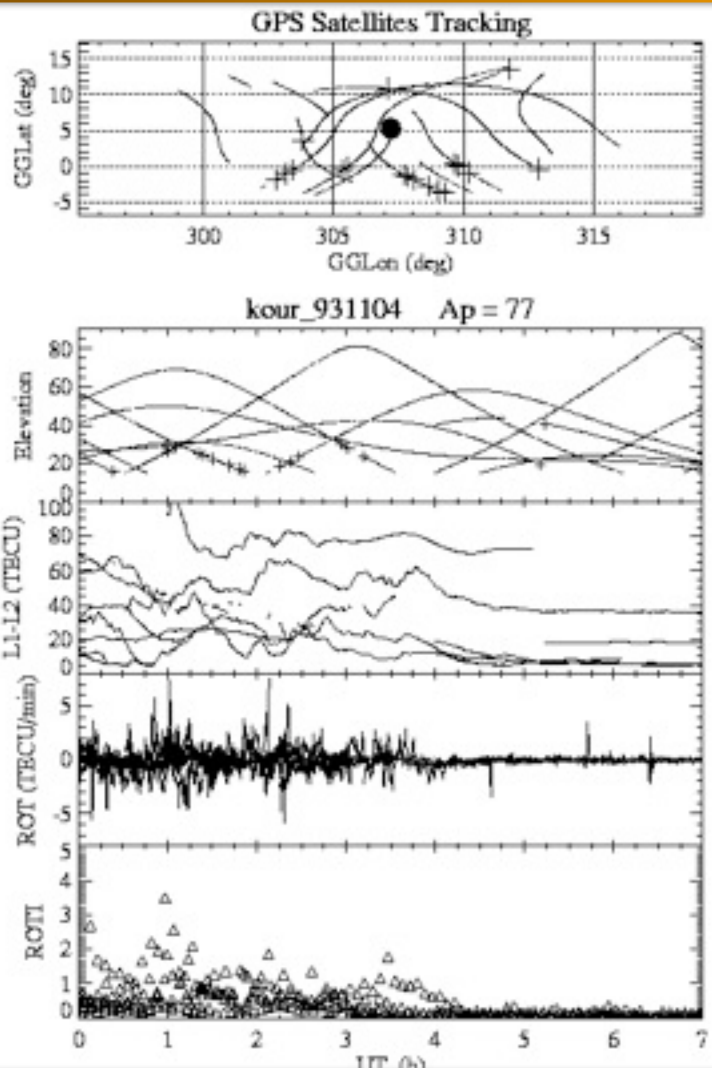
Geomagnetic storms may last several days, and ionospheric effects may last a day or two longer.

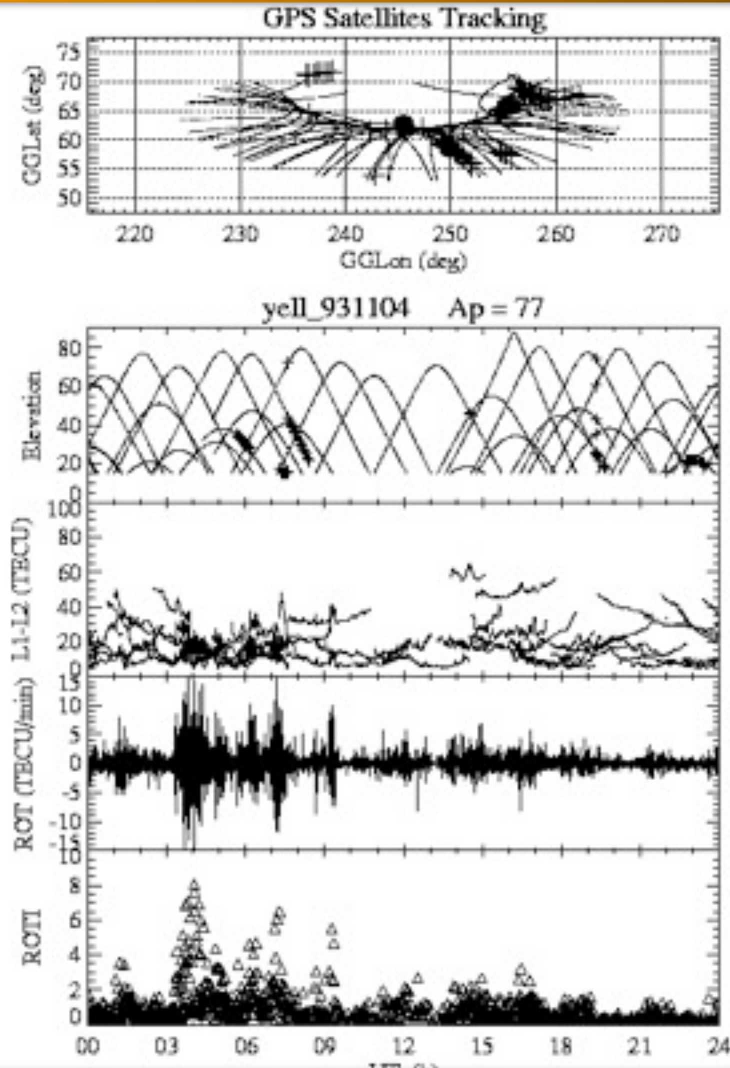
Scintillation



Basu et al., 1999

Phase Scintillation





Low Lat

High Lat

Ionospheric Scintillation Indices

$$S_4(f) = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}} \propto f^{-1.5}$$

$$\sigma_\phi(f) = \sqrt{\langle \phi^2 \rangle - \langle \phi \rangle^2} \propto f^{-1}$$

$$\mathrm{ROTI} = \sqrt{\langle \mathrm{ROT}^2 \rangle - \langle \mathrm{ROT} \rangle^2}$$

$$\mathrm{ROT} = C\frac{\Phi_I(t+\Delta t) - \Phi_I(t)}{\Delta t}$$

- **S_4 and σ_ϕ indices – amplitude and phase scintillation, respectively**
  - I – detrended signal intensity
  - ϕ – detrended signal phase
  - raw data is sampled at 20 or 10 ms (50 Hz or 100 Hz)
  - frequency dependent
  - Measurements of phase scintillation susceptible to local oscillator errors of transmitter and receiver
- **ROTI – Rate of TEC index**
  - ROT – detrended rate of TEC derived from dual-frequency phase data
  - ROT data sampled at 30 sec (or 1 s)
  - Not susceptible to local oscillator errors, in principle

Courtesy: Pi at JPL

Spacecraft Drag

- Spacecraft in LEO experience periods of increased drag that causes them to slow, lose altitude and finally reenter the atmosphere. Short-term drag effects are generally felt by spacecraft <1,000 km altitude.

- Drag increase is well correlated with solar Ultraviolet (UV) output and additional atmospheric heating that occurs during geomagnetic storms.

- Most drag models use radio flux at 10.7 cm wavelength as a proxy for solar UV flux. Kp is the index commonly used as a surrogate for short-term atmospheric heating due to geomagnetic storms. In general, 10.7 cm flux >250 solar flux units and Kp>=6 result in detectably increased drag on LEO spacecraft.

- Very high UV/10.7 cm flux and Kp values can result in extreme short-term increases in drag. During the great geomagnetic storm of 13-14 March 1989, tracking of thousands of space objects was lost. One LEO satellite lost over 30 kilometers of altitude, and hence significant lifetime, during this storm.

Satellite Drag

- Atmospheric drag magnitude: $a_{drag} = \frac{1}{2}\beta\rho v^2$

  $\beta = \frac{c_D A}{m}$ is ballistic coefficient

  ρ is atmospheric density

  $v \cong v_{sat}$

  Solar cycle and space weather have strong impact on neutral atmospheric density

  Increasing atmospheric drag impacts:

  - Frequency of "Drag Make-Up" maneuvers for satellite to stay in control box
  - Covariance

  Uncertainty in predicted atmospheric drag impacts:

  - Future satellite position predictions (next slide)

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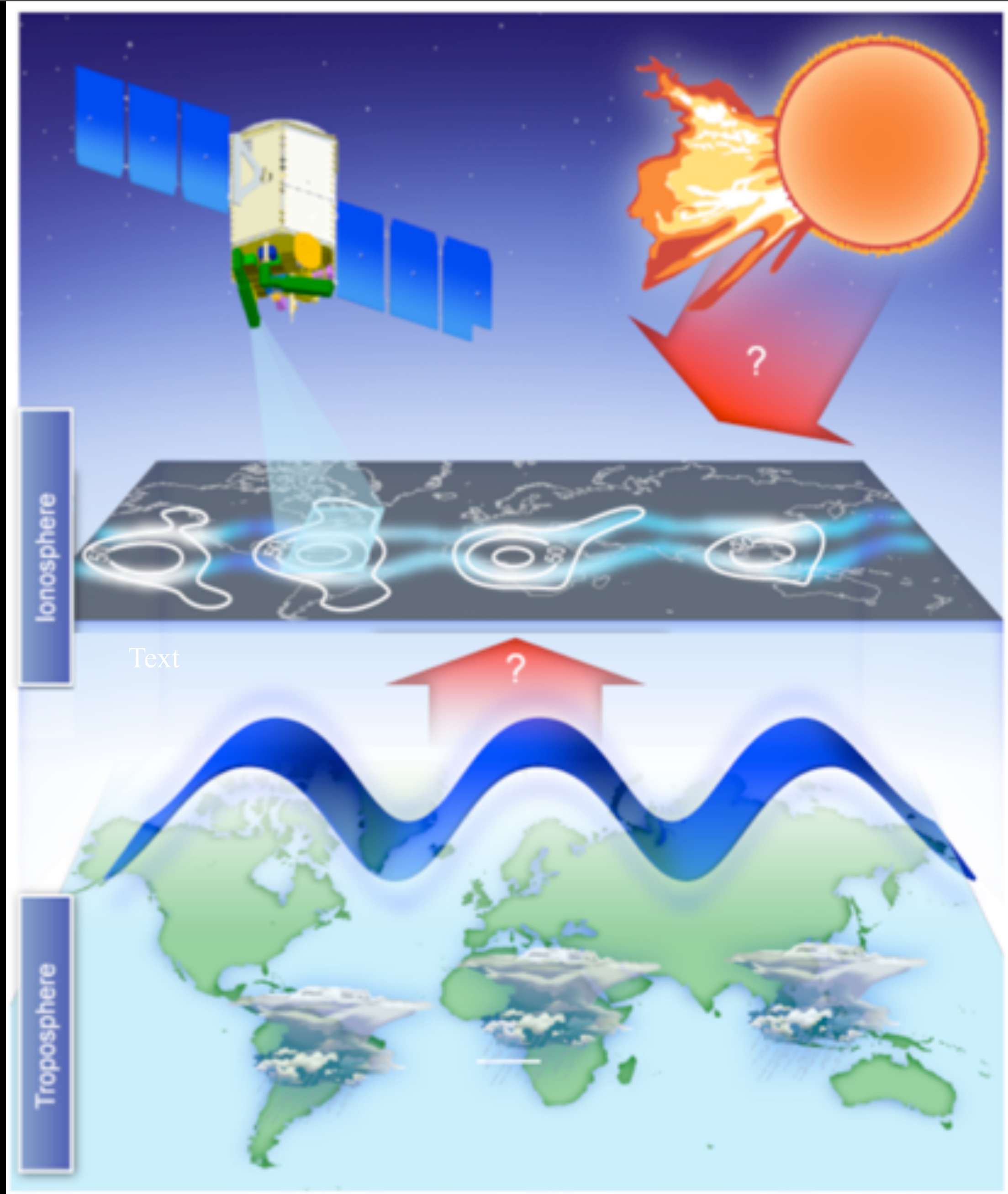

Courtesy: ICON