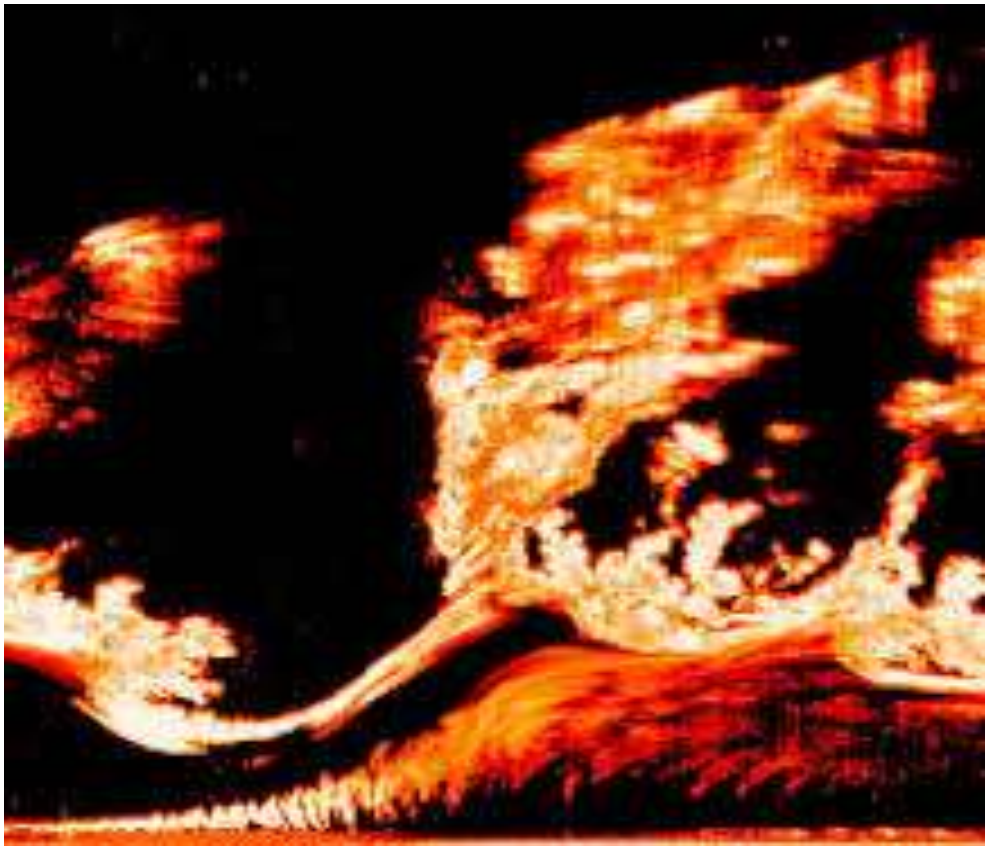
Storms in Earth's ionosphere



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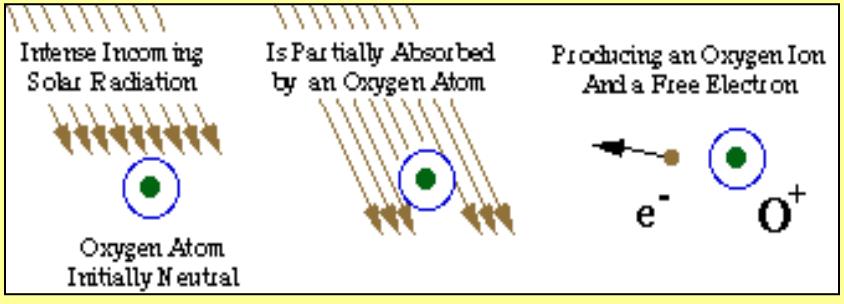
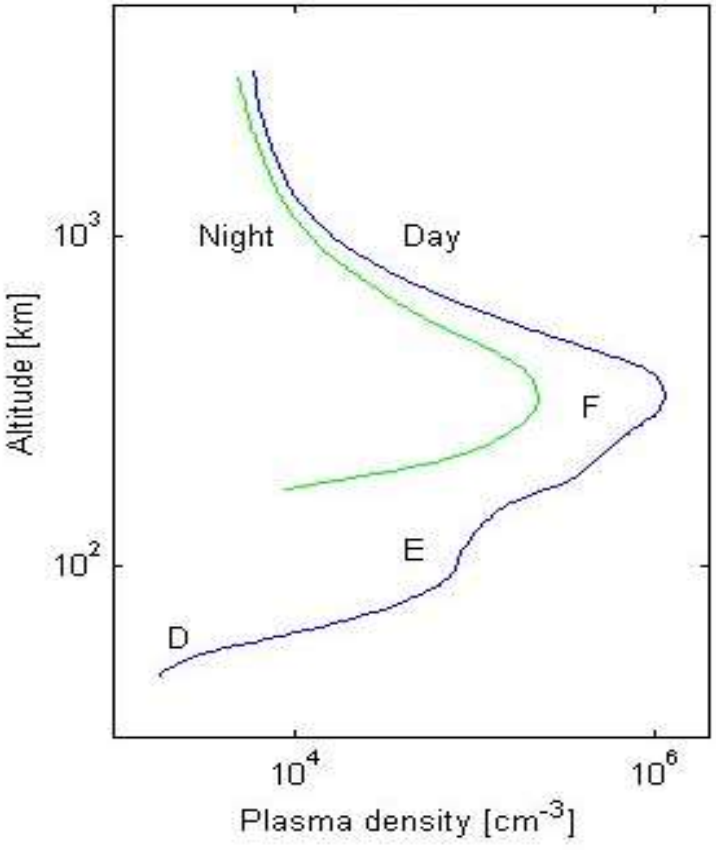
Earth's Ionosphere

Ionosphere is the region of the atmosphere in which free electrons exist in sufficient quantities to affect the propagation of radio waves.

- Begins at about 60 km and extends up to about 1000 km
- Produced by X-rays and UV radiation from the Sun

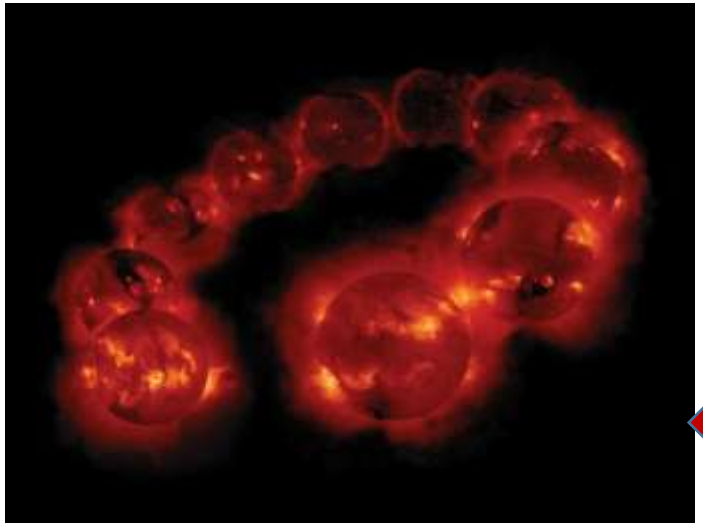


- Reverse process is *Recombination*
- Controlled by chemical composition and transport by neutral winds



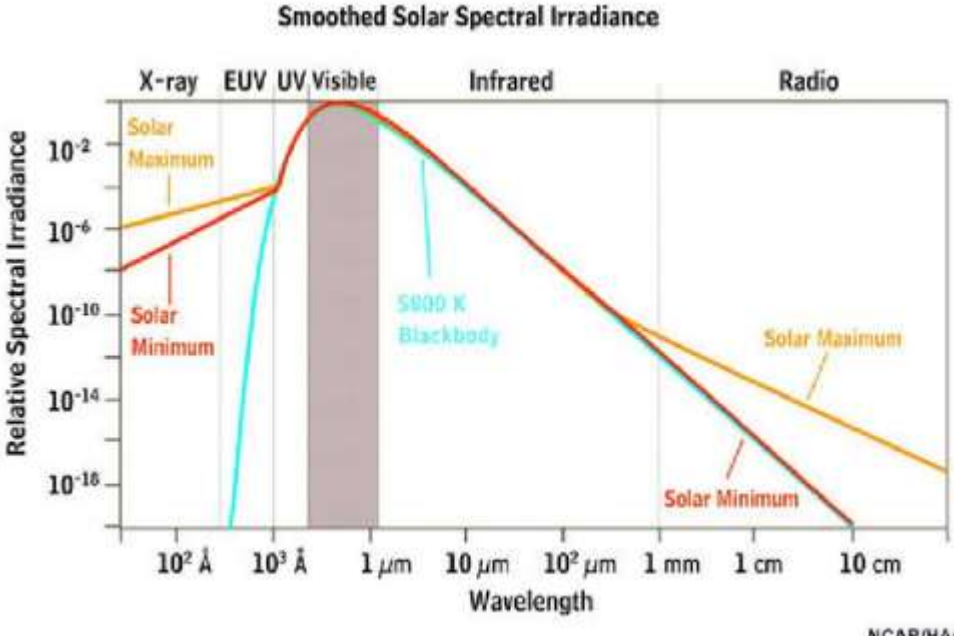
F Layer is most dense and highly variable.

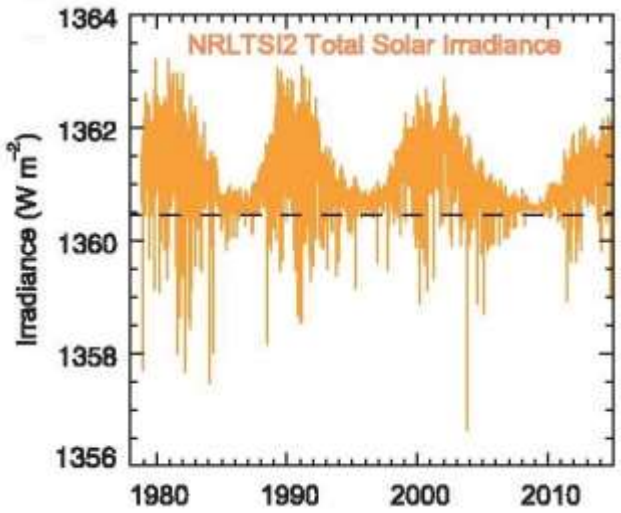
Variation in electromagnetic radiation from the Sun



Active regions on the Sun, which are associated with strong magnetic fields often lead to solar flares with enhanced X-ray and EUV radiation. Sun's activity follows a cycle of about 11 years.

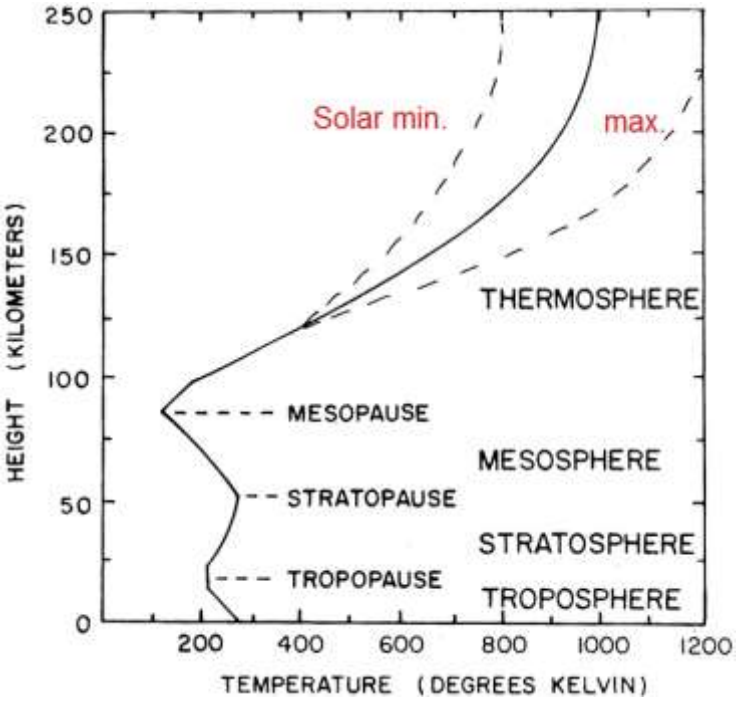
Annual soft X-ray images of the Sun from Yohkoh satellite show dramatic changes during a solar cycle (Courtesy of NASA)



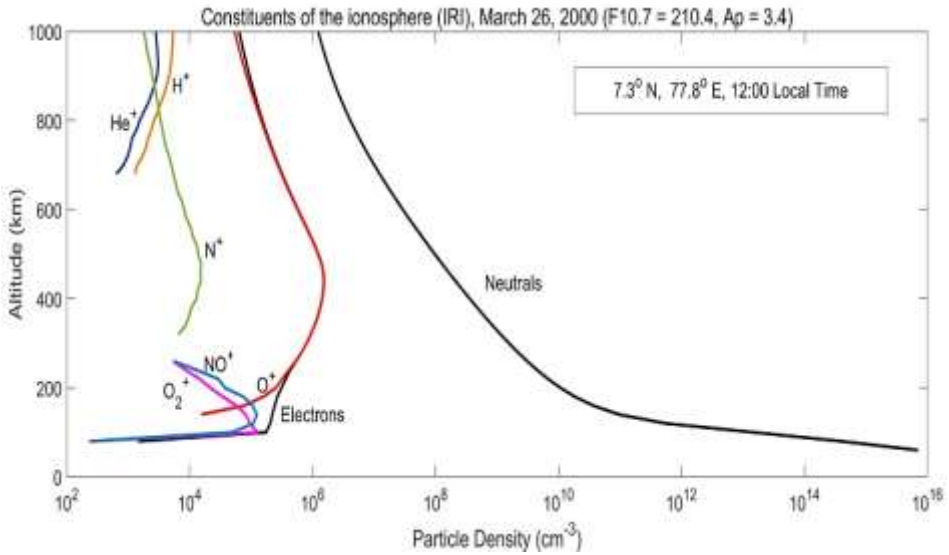


(Coddington et al., BAMS, 2016)

Coupling of the Ionosphere with the neutral upper atmosphere

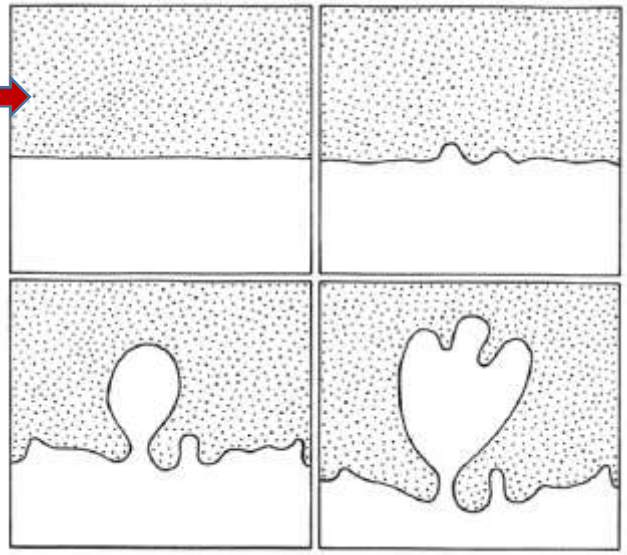


The upper atmosphere extending from 100 km to 600 km (thermosphere) expands during solar maximum and contracts during solar minimum



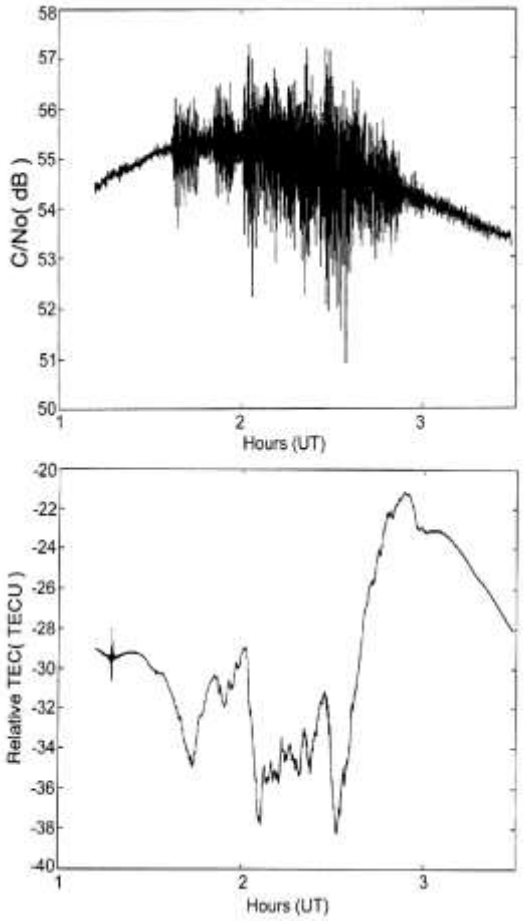
The upper atmosphere is only partially ionized. Number density of neutral particles is much greater than that of charged particles. Collisions of charged particles with neutrals compete with the effect of Earth's magnetic field to control the dynamics of ionospheric plasma.

Equatorial plasma bubbles and their effect on radio signals



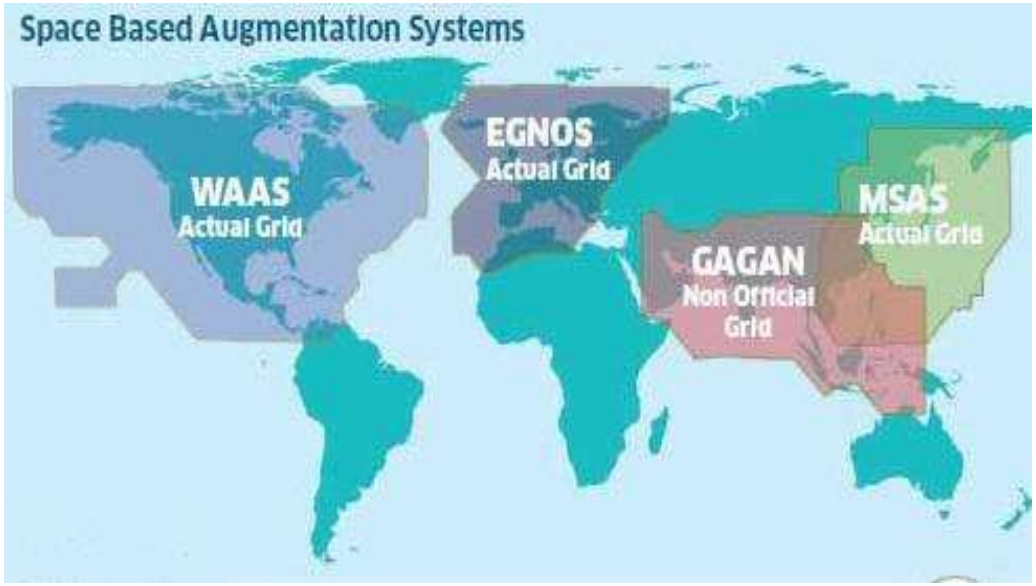
In the equatorial ionosphere, the more dense F region rests above an ionospheric layer of lower density – an unstable situation!

A perturbation on the bottom-side of the post-sunset equatorial F-region grows due to the Rayleigh-Taylor instability, and low-density equatorial plasma bubbles (EPBs) rise to the topside and develop structure.



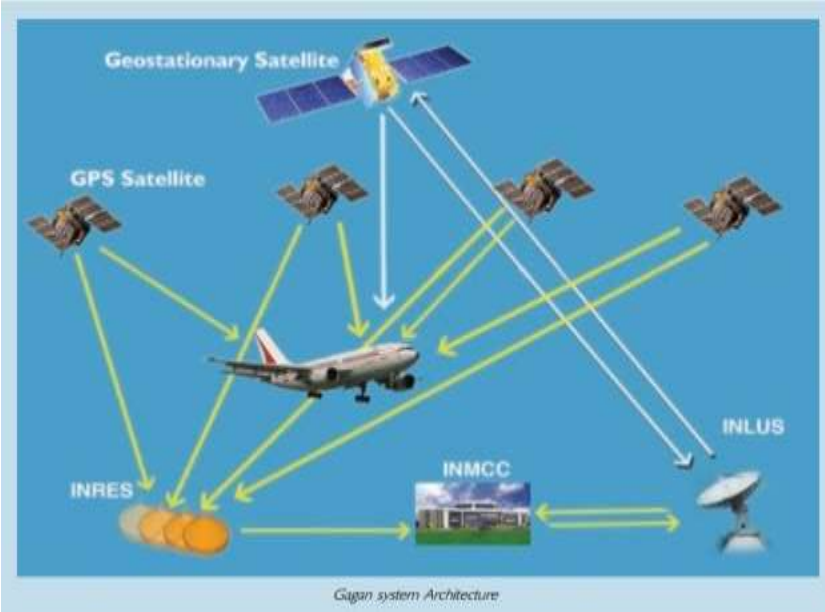
Irregular structures in the ionosphere of scale size ~ 300m cause fluctuations in the strength of a GPS signal.

Satellite based navigation systems



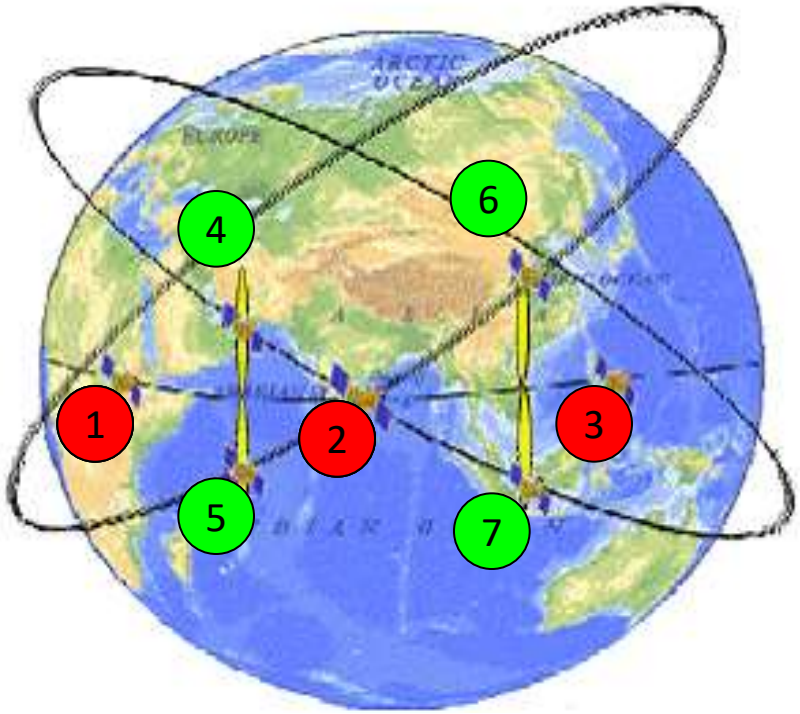
Uncertain spatial and temporal variations of ionospheric electron content causes positional errors due to the ionosphere to vary with space and time.

GAGAN: GPS Aided GEO Augmented Navigation



A Category III landing requires horizontal accuracies of 3-4 m, vertical accuracy of ~ 1m

Space Segment - IRNSS (NAVIC)



3 Geostationary

1. GEO 32.5^{0}E
2. GEO 83.0^{0}E
3. GEO 131.5^{0}E

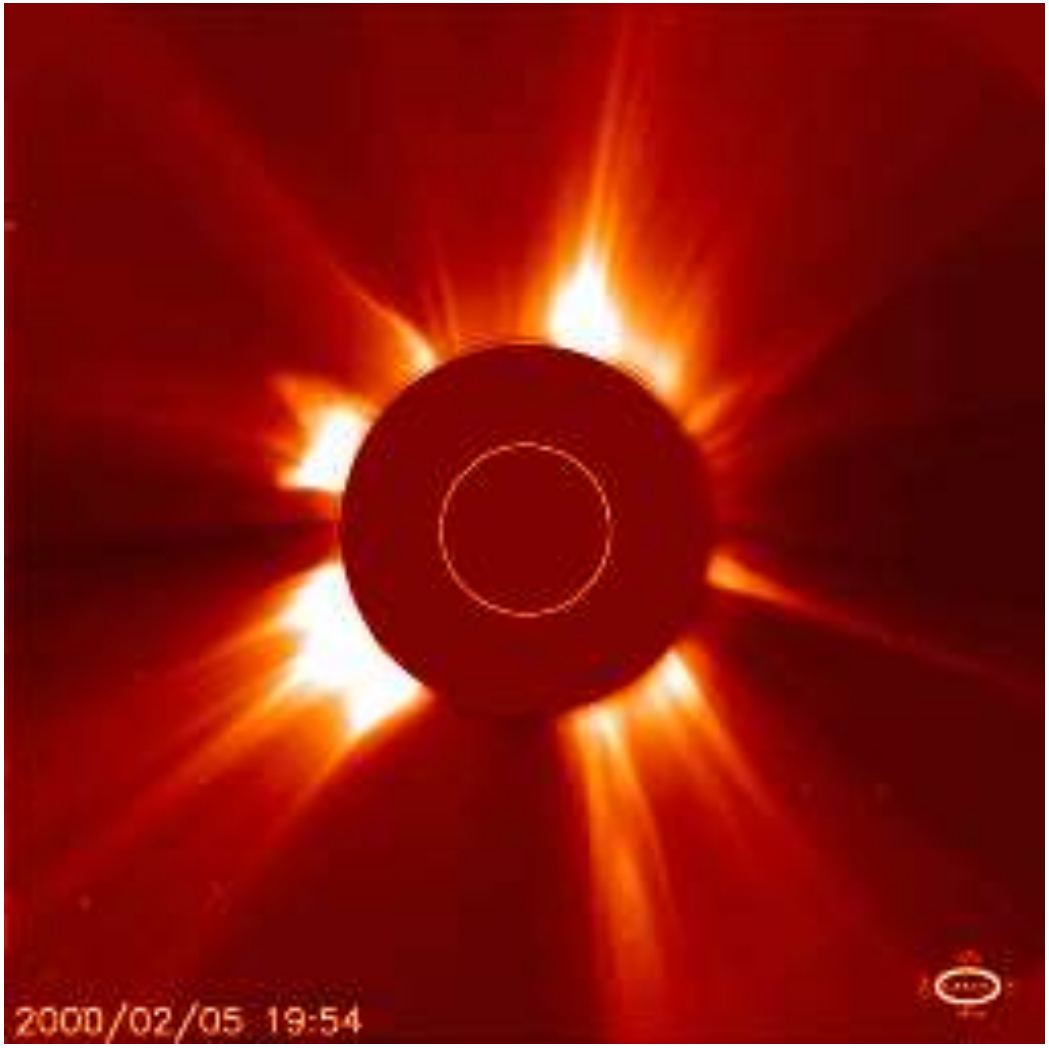
4 Geosynchronous (Inclination : 29^0)

4. GSO 55^{0}E
5. GSO 55^{0}E
6. GSO 111.75^{0}E
7. GSO 111.75^{0}E

All satellites transmit navigation signals in L5 (1176.45 MHz) and S (2492.03 MHz) frequencies and will be visible in service region for 24 hrs.

Source : ISRO

We live with a temperamental star!

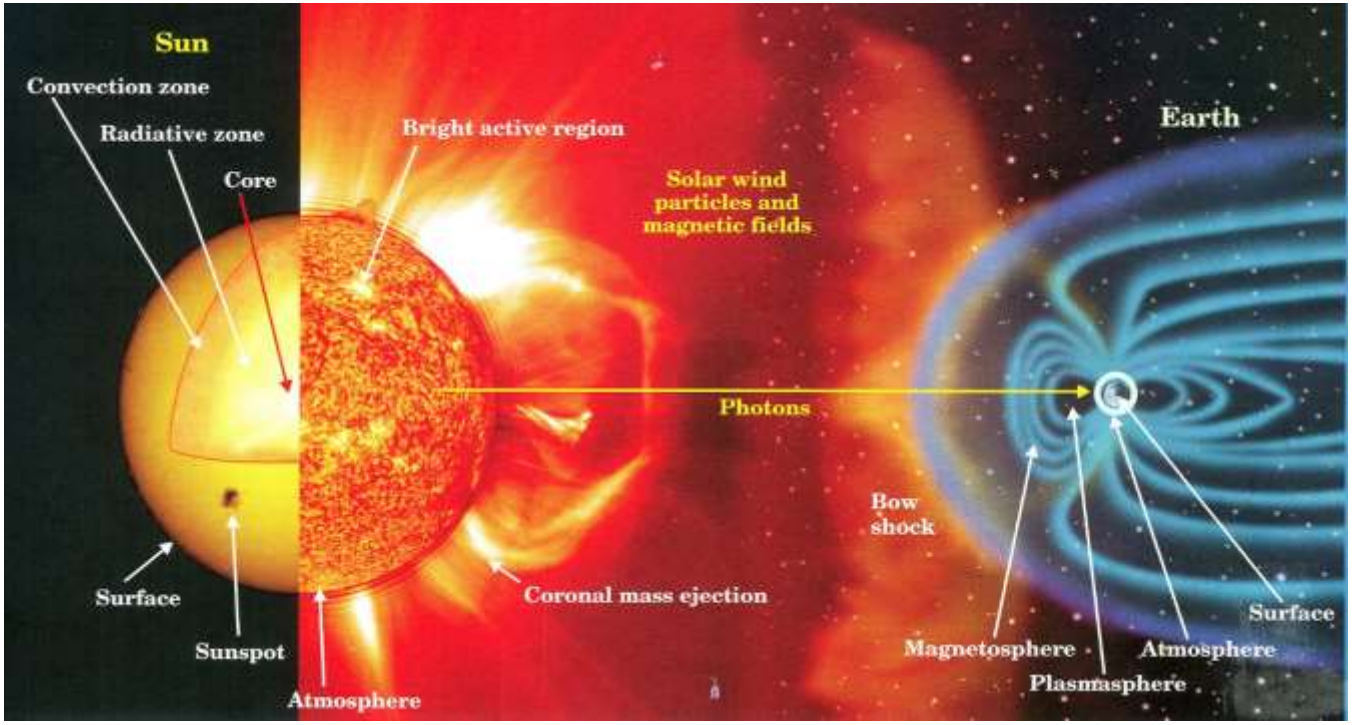


Courtesy of SOHO/LASCO consortium (ESA & NASA)

Coronal Mass Ejections (CMEs) are explosions in the Sun's corona that spew out solar particles. As much as 10^{13} kilograms of material can be ejected.

Large Angle and Spectrometric Coronagraph (LASCO) blocked light coming from the solar disk, in order to see the extremely faint emission from the corona of the sun

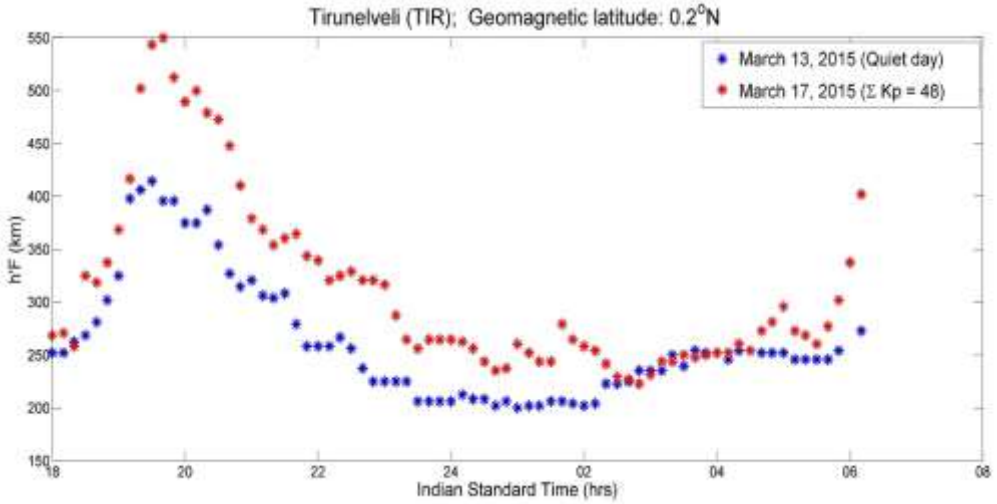
The Sun-Earth connected system



(J. Lean, Physics Today, 2005)

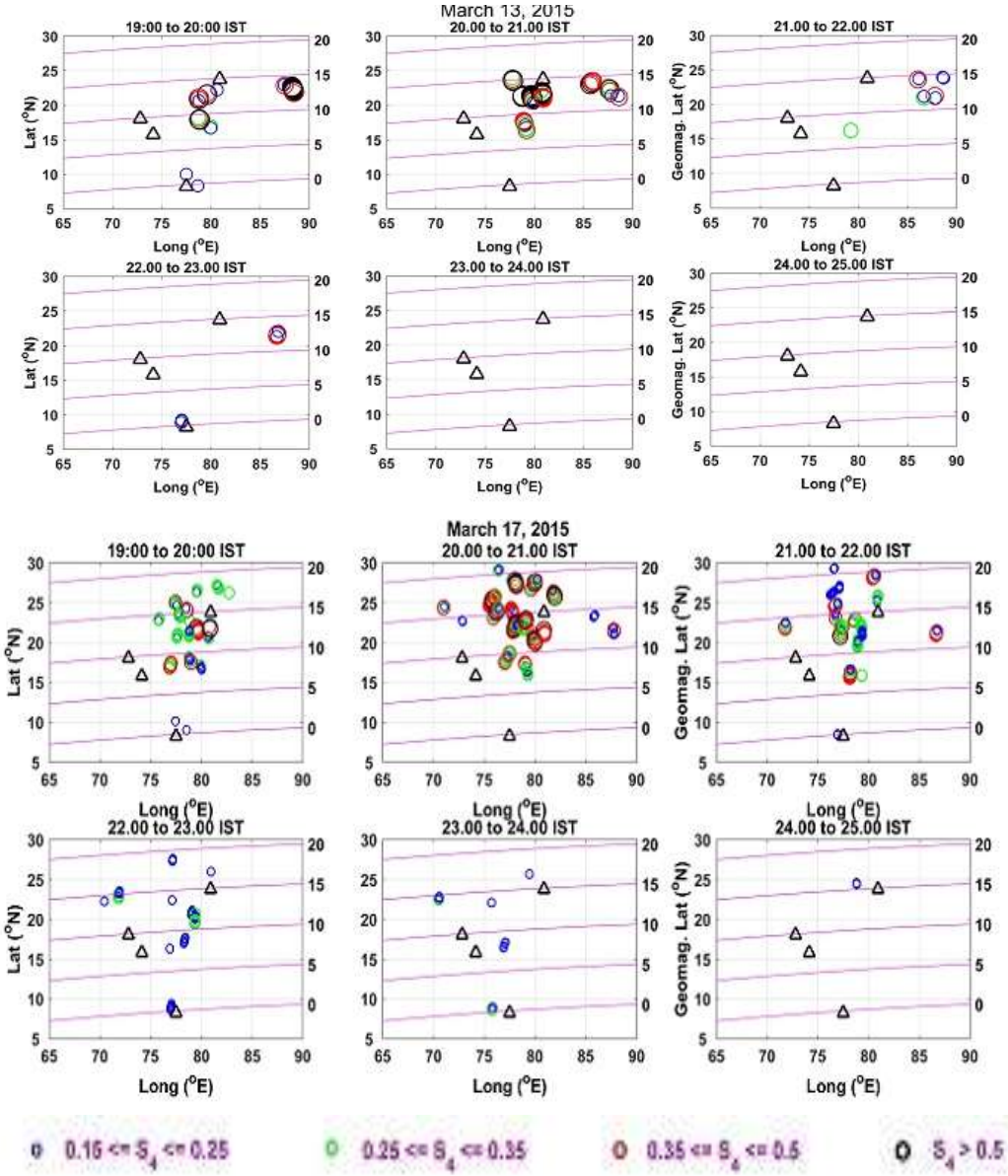
While solar UV and X-rays partially ionize Earth's upper atmosphere to create the ionosphere, charged particles in solar wind and CMEs are deflected by Earth's magnetic field.

Effect of a magnetic storm on the development of scintillation-producing irregularies



During a major geomagnetic storm of March 17, 2015, there was prompt penetration of a large eastward electric field of magnetospheric origin, into the equatorial ionosphere in the Indian longitude region, just after sunset. This caused the bottom-side of the equatorial F region to rise to an altitude of 550 km.

Spatial and temporal distribution of L-band scintillations on March 13 and March 17, 2015



A difference of ~150 km in the post sunset height rise of the equatorial F layer on March 13 and 17, has resulted in the EPBs reaching a maximum height above the geomagnetic equator on the night of March 17, which is ~ 300 km higher than that on March 13, 2015.

Consequently scintillations on GNSS (Global Navigation System Satellites) radio signals are recorded over a greater latitude range extending upto 30^{o} N!

Prediction of the occurrence of scintillations over the Indian region due to the development of equatorial plasma bubbles, referred to as a convective ionospheric storm, requires study of the following:

1. How does the equatorial ionosphere with the special geometry of the geomagnetic field respond to forcing from above and below?

2. How do the ambient conditions affect the growth of the equatorial plasma bubble and the development of scintillation-producing irregularities?

3. Propagation of the radio signals through different structures in the ionosphere.