Study of small scale plasma irregularities in the ionosphere

Đorđe Stevanović

Overview

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2. Space weather
3. Ionosphere and its effects
4. Case study
   a. Instruments
   b. Ionospheric plasma irregularities
   c. EISCAT measurements
5. Conclusion

1. Global Navigation Satellite Systems

Global Navigation Satellite System

- Network of satellites with global coverage that continuously transmit encoded information enabling precise positioning on Earth

- Active GNSS systems:
  1) Global Positioning System (GPS)
  2) Globaln'naya Navigatsivannaya Sputnikovaya Sistema (GLONASS)

- In developing phase:
  1) Galileo (EU)
  2) COMPASS (China)

Global Navigation Satellite System

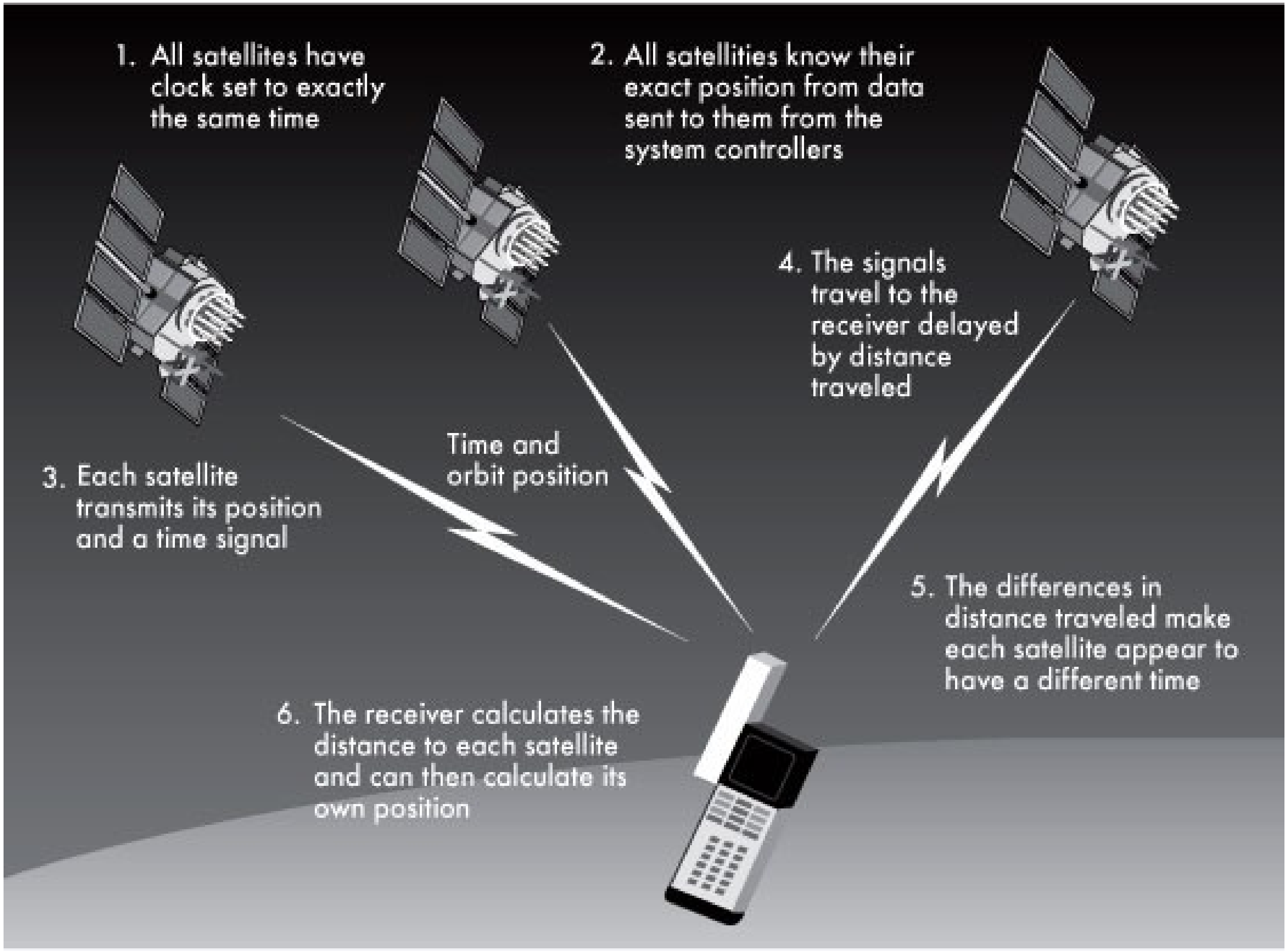
- The GNSS satellites transmit codes generated by atomic clocks, navigation messages and system-status information
- Signals are modulated on two carrier frequencies L1 on 1.57542 GHz and L2 on 1.2276 GHz
- The original GPS design contained two ranging codes:
  - Coarse/Acquisition or C/A code, available to the public
  - Precision or P-code, usually reserved for military applications

Global Navigation Satellite System

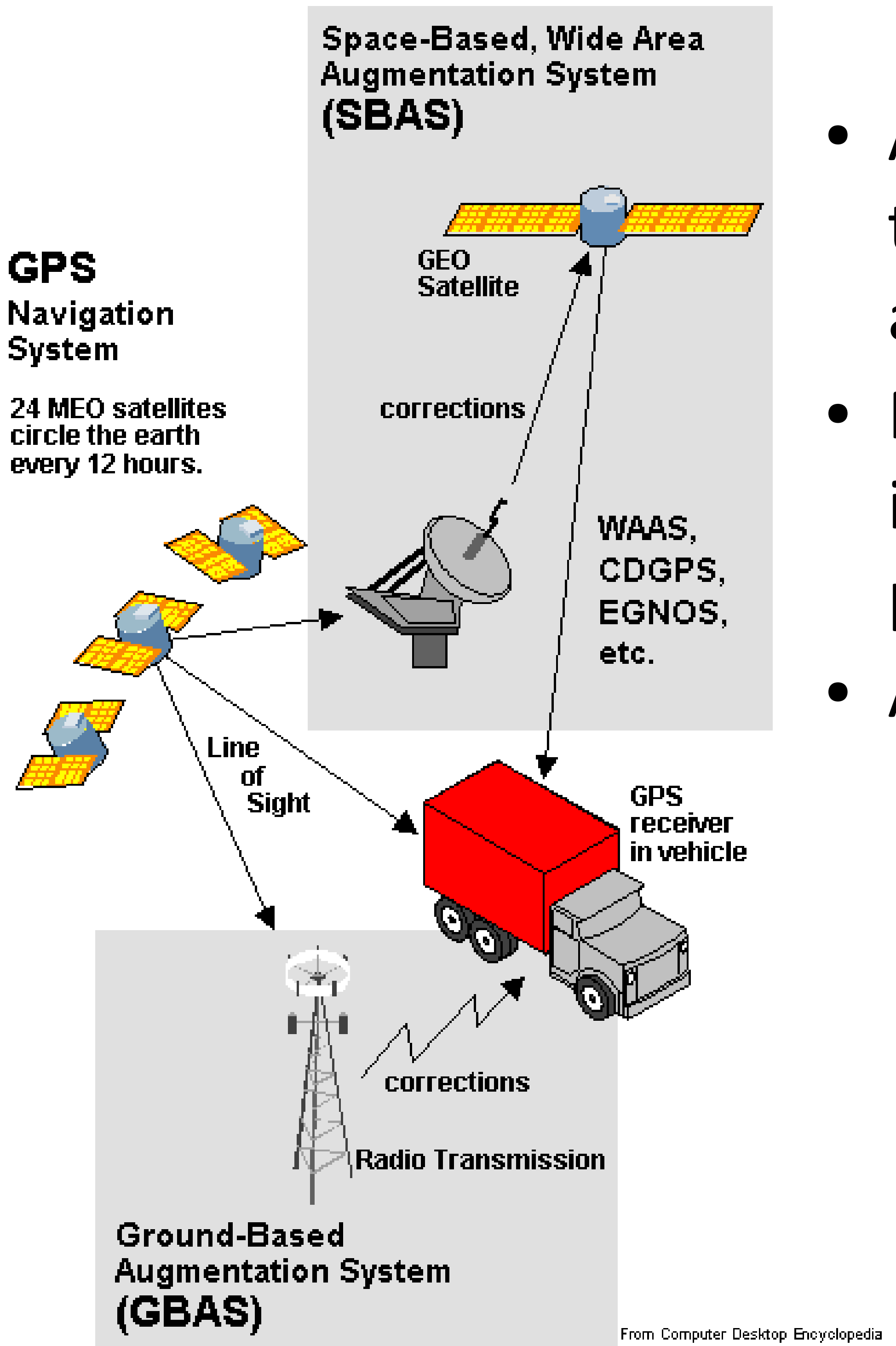
- Baseline constellation of about 24 to 30 satellites on orbital height of 19000 to 24000 km
- Orbit time period of about 12 hours to cover every area on Earth with at least 4 satellites
- New and modernized systems are developing, because GPS satellites do not sufficiently cover all regions
- Development of new signals for more accurate positioning, safety and commercial services (L5, L1C, E1, E5)

Global Navigation Satellite System

- How it works:



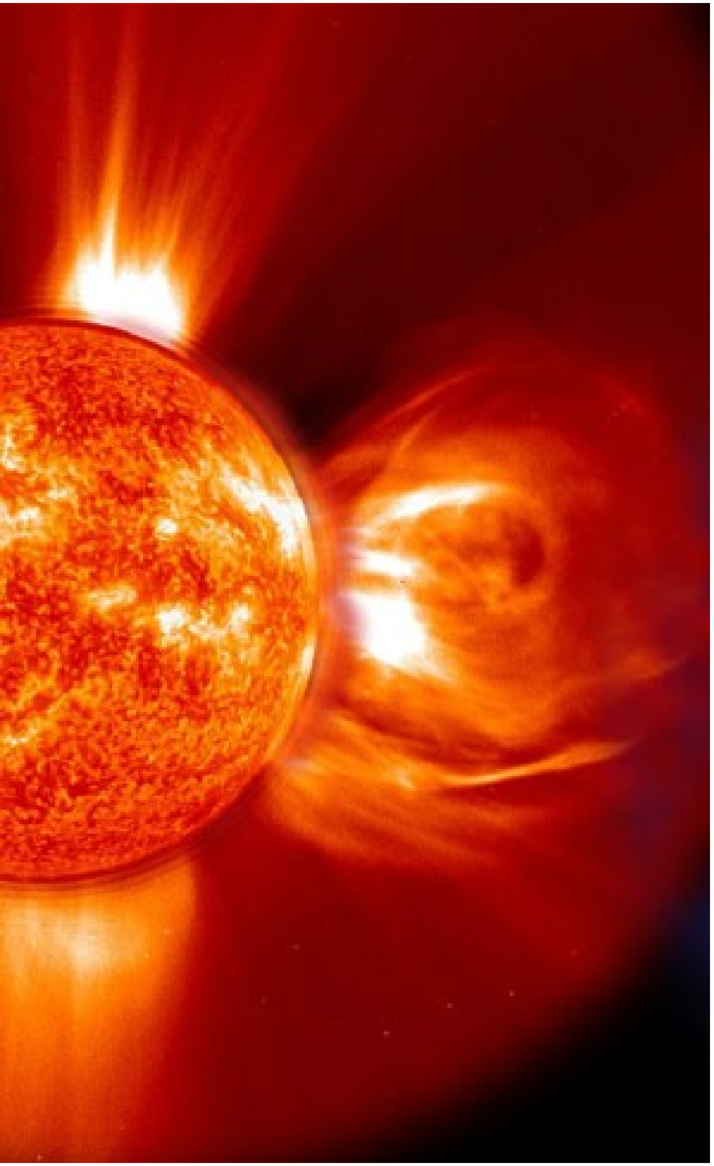
http://www.aero.org/education/primers/gps/howgpsworks.html



- Augmentation systems - techniques used to improve the accuracy of positioning information
- Rely on external information being integrated into the calculation process
- Augmentation systems:
  - Wide Area Augmentation System (WAAS)
  - Differential GPS (DGPS)
  - Inertial Navigation Systems (INS)
  - Assisted GPS (A-GPS)

2. Space weather

Space weather



- High coronal temperatures cause a continuous outflow of plasma from the corona – **solar wind**
- *Solar flares, prominences and coronal mass ejections* create storms of radiation, fluctuating magnetic fields, and swarms of energetic particles
- Solar plasma travels outward through the Solar System with the solar wind

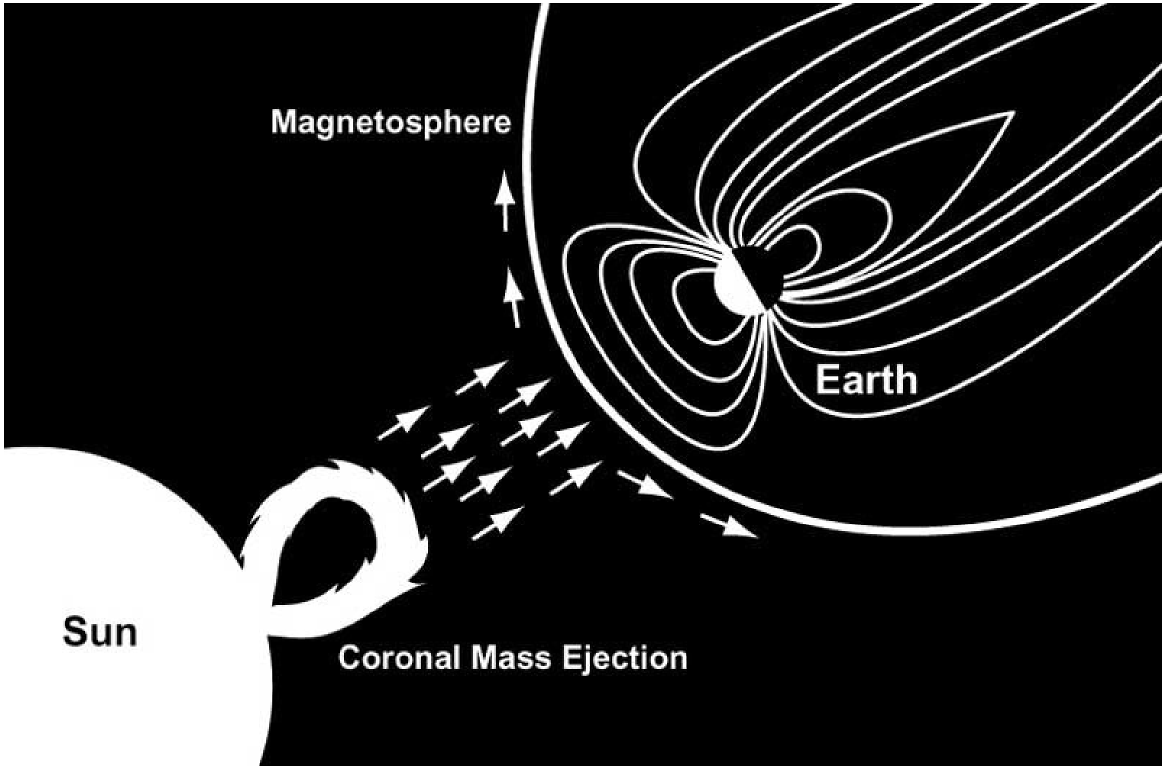
http://stevequayle.com/News.alert/06_Cosmic/060512.solar.2012.html

Space weather

- Speed and pressure of solar wind changes all the time
- Space is filled with magnetic fields, which control the motions of charged particles
- The strengths and directions of the magnetic fields often shift
- Changes in radiation, the solar wind, magnetic fields, and other factors make up **space weather**

Space weather

- Solar plasma interacts with Earth's magnetic field, creating Earth's radiation belts and the auroras
- Earth is surrounded by a magnetic cavity called the "magnetosphere"

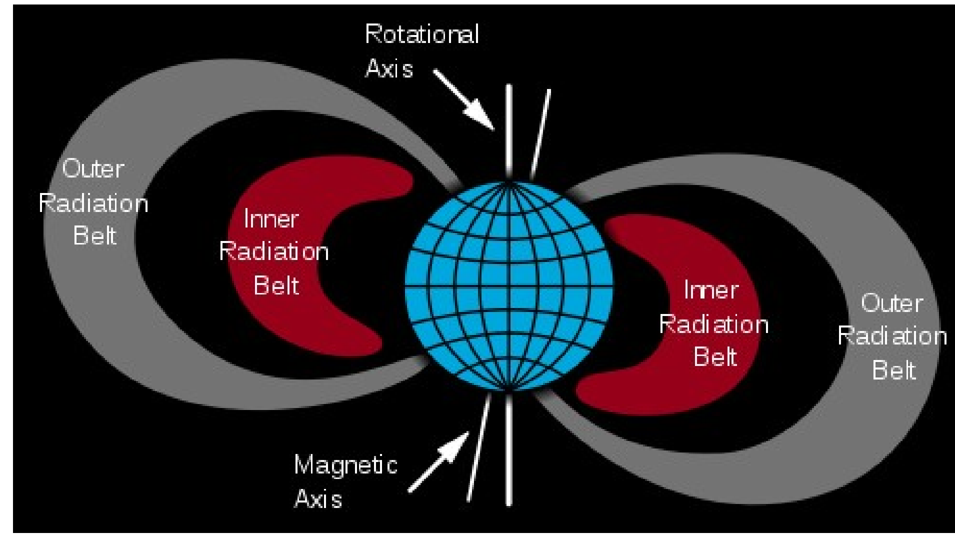


http://spaceplace.nasa.gov/spaceweather/

Space weather

- Aurora - collision of energetic charged particles with neutral Oxygen atoms and molecules in the high altitude atmosphere

http://www.nuitsacrees.fr/DP/Jokusarlon1_2000.jpg



http://en.wikipedia.org/wiki/Van_Allen_radiation_belt

- Radiation belts are made up of charged particles traped by magnetic field

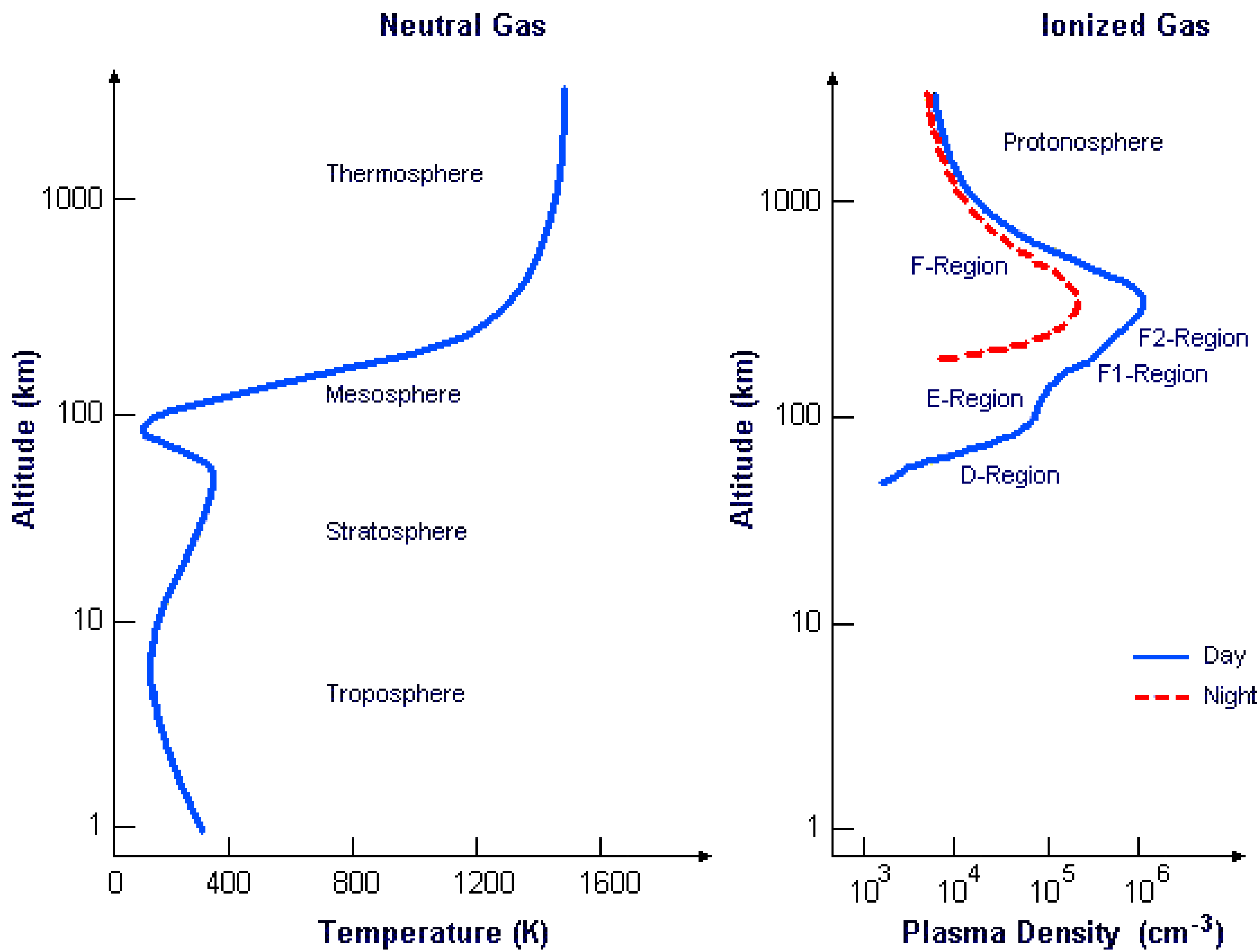
3. Ionosphere and its effects

Ionosphere

- The ionosphere is a layer of the upper atmosphere ionized by radiation from the sun
  - From 50 km to about 1,200 to 1,600 km
  - Ionization mostly due to extreme UV, but also hard and soft X-rays, and other radiations
  - Several layers (D, E, F1, F2) depending on different chemical composition
- One of most important atmospheric layers for radio signal propagation:
  - Radio wave signal diffract from the ionosphere
  - GNSS (microwave) signals penetrate through the ionosphere

Ionosphere and its effects

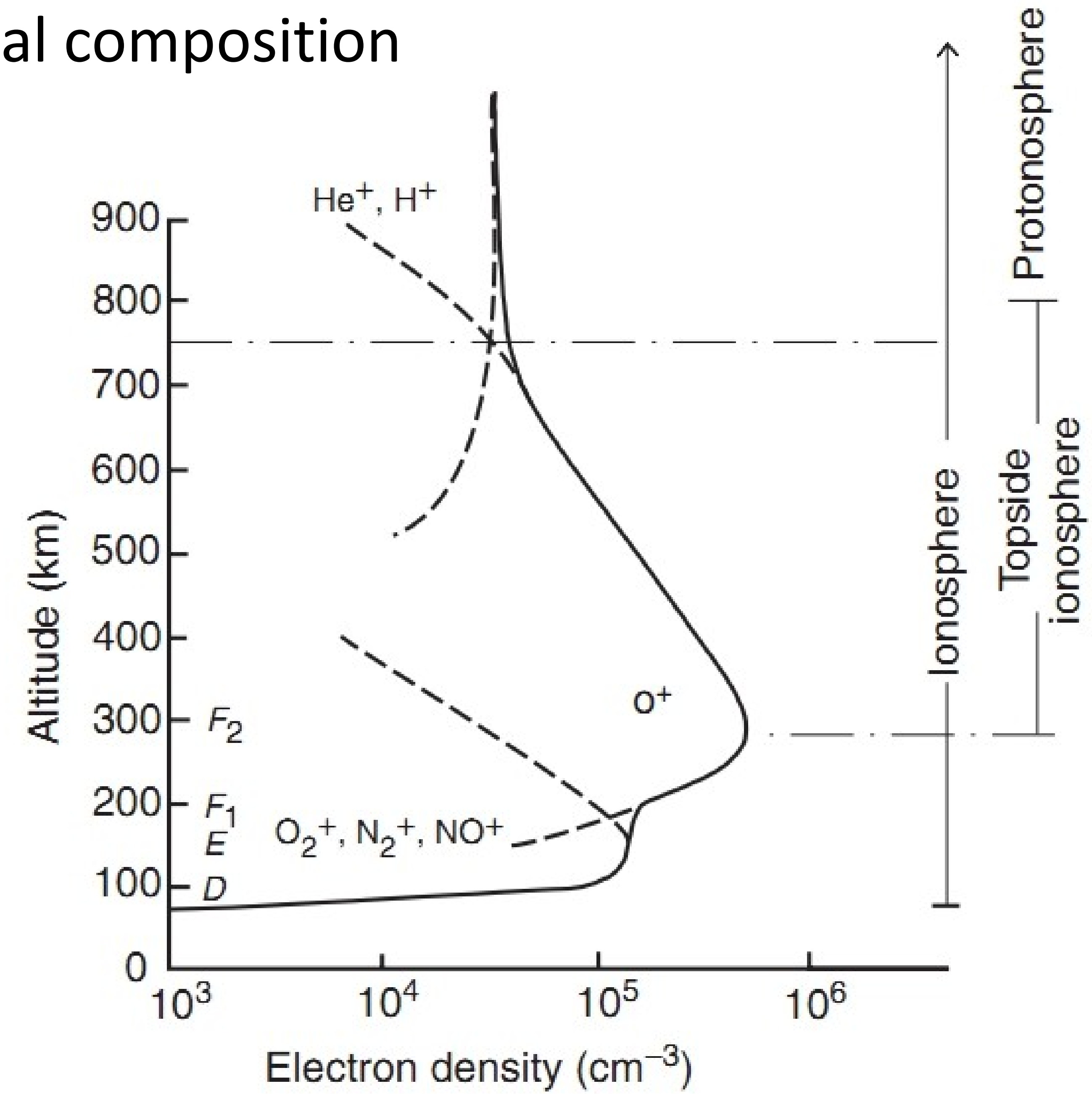
- Density profiles of free electrons in the ionosphere



http://www.astrosurf.com/luxorion/Radio/atmosphere-ionosphere.gif

Ionosphere and its effects

- Chemical composition



Banks,P.M., R.W.Schunk,and W.J.Raitt, The topside ionsophere: a region of dynamic transition,Annl. Rev. Earth Planet. Sci., **4**, 381,1976.

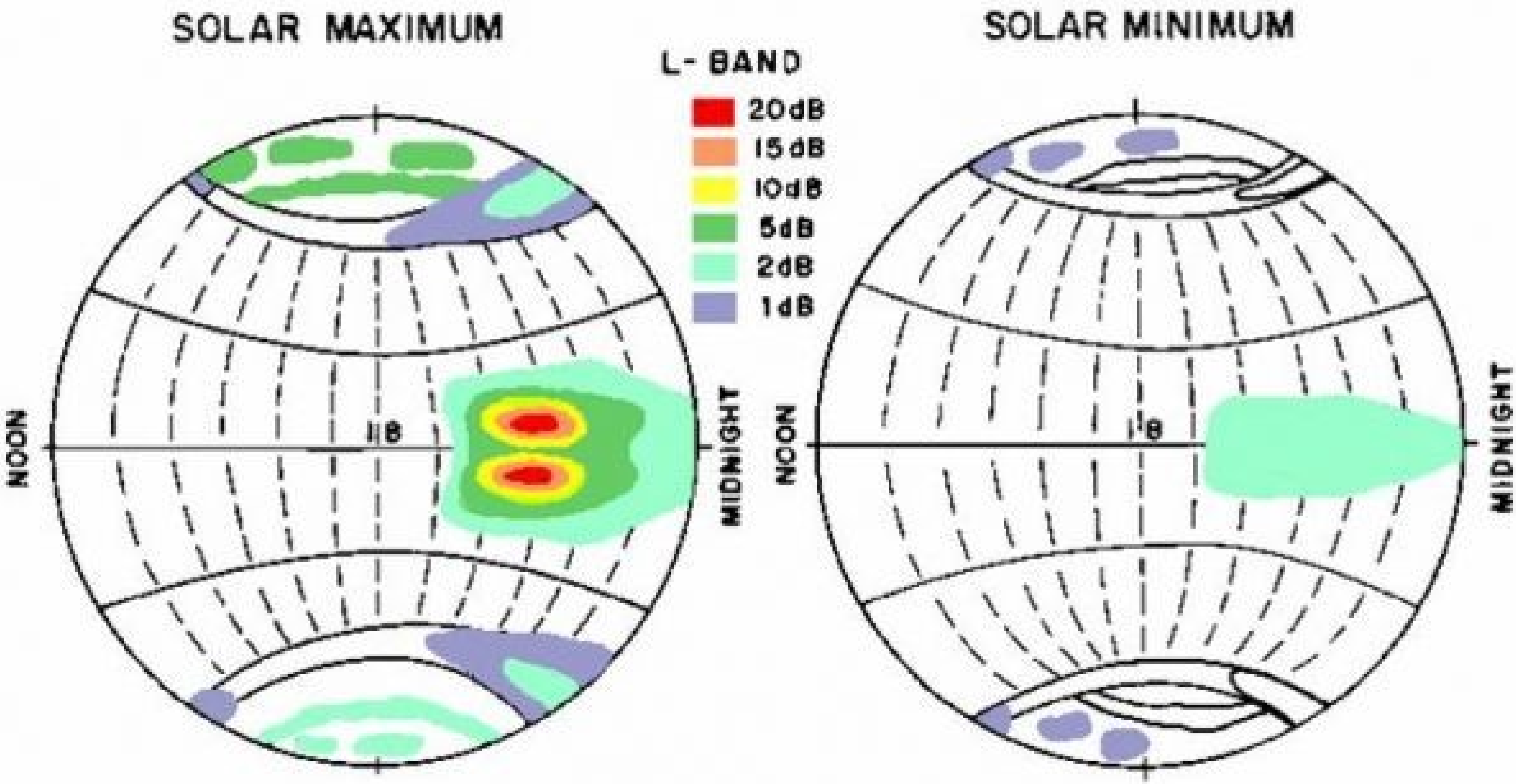
Ionosphere and its effects

- Ionospheric effects on GNSS signals are:
  - Phase and group delay
  - Doppler shift
  - Faraday rotation
  - Ray-path bending
  - Scintillations

Ionosphere and its effects

- Scintillations – irregular fluctuations in signal phase and amplitude during propagation through ionosphere
- Caused by small-scale fluctuations in the refractive index of the ionospheric medium by inhomogenities
- Ionospheric scintillation is primarily an equatorial and high-latitude ionospheric phenomenon - scintillation occur mainly in the F layer

Ionosphere and its effects



Basu, S. et al., J. Atmos. Terr. Phys, v.64, pp. 1745-1754, 2002

Ionosphere and its effects

- Scintillation indices:
  - for intensity:

$$S_4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}} \qquad SI = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

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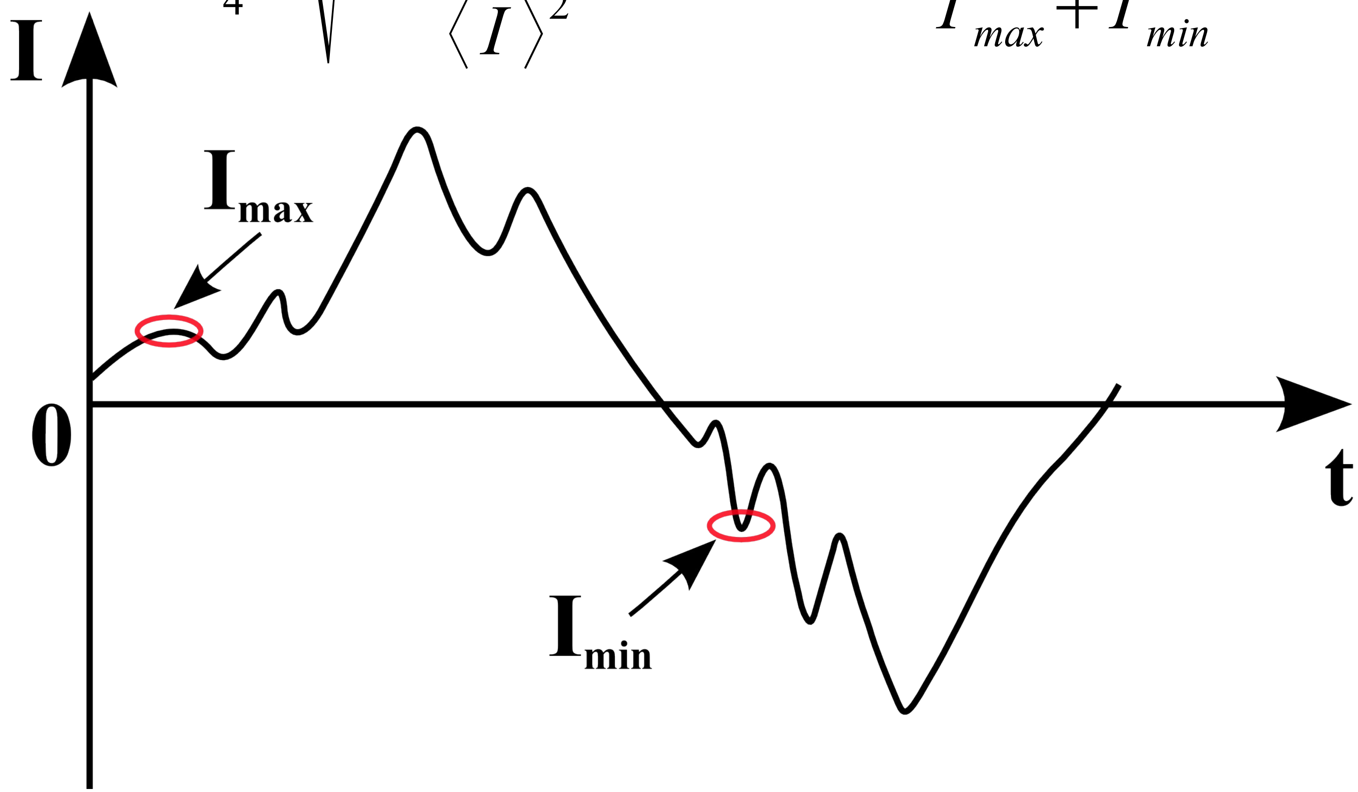

Ionosphere and its effects

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  - for phase

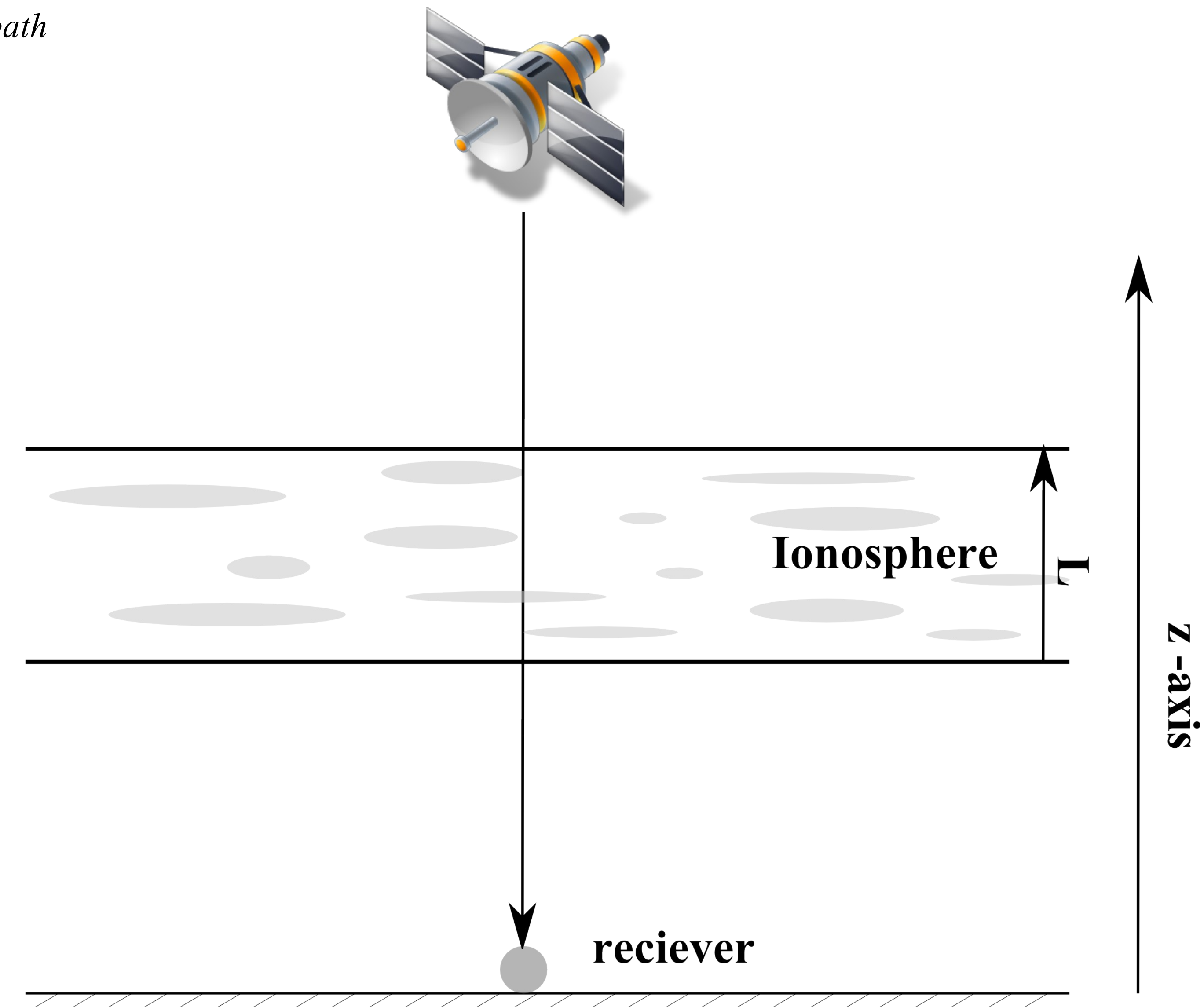
$$\sigma_\phi^2=\langle\phi^2\rangle-\langle\phi\rangle^2$$

Ionosphere and its effects

- The total ionospheric profile is the superposition of different layers, with different chemical composition
- Changes in GNSS signals during propagation and penetration through the ionosphere are being followed and measured every day by network of GNSS monitors
- Various parameters are being used to describe fluctuations in GNSS signals
- Total electron content (TEC) - total number of electrons present along a path between two points

Ionosphere and its effects

$$TEC = \int_{raypath} N_e(x, y, z) \cdot dz$$, [10^{16} electrons/m² = 1 TEC unit (TECU)]



Ionosphere and its effects

- Alternative way for calculating TEC:

$$TEC = \frac{1}{40.3}\left(\frac{f_1 f_2}{f_1 - f_2}\right)\left(P_2 - P_1\right)$$

f_1, f_2- L1 and L2 band frequencies

P_1, P_2- L1 and L2 band pseudoranges

- Simplified pseudorange equation:

$$P_r^s = c\left(t_r - t^s\right)$$

Ionosphere and its effects

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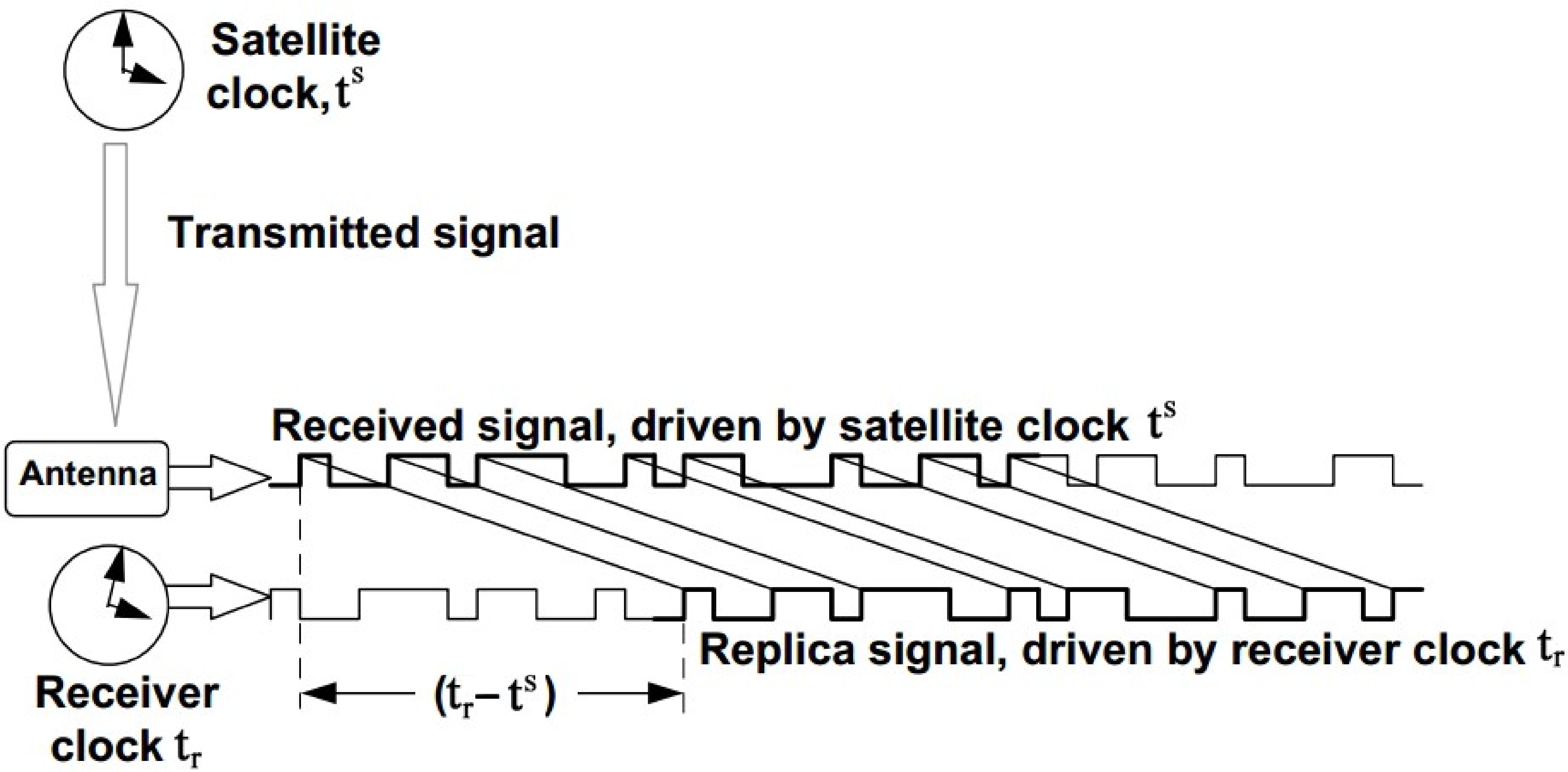


Geoffrey Blewitt, "Basics of the GPS Technique: Observation Equations", 1997

Ionosphere and its effects

- The state of the ionosphere varies:
  - with degree of exposure to the solar radiation
    - Daily
    - Seasonally
  - on solar activity
    - Solar maximum versus solar minimum (≈11 year cycle)
    - Geomagnetic conditions: quiet versus storm
      - Sudden bursts of solar energy can cause magnetic storms and other irregularities
  - on the magnetic latitude

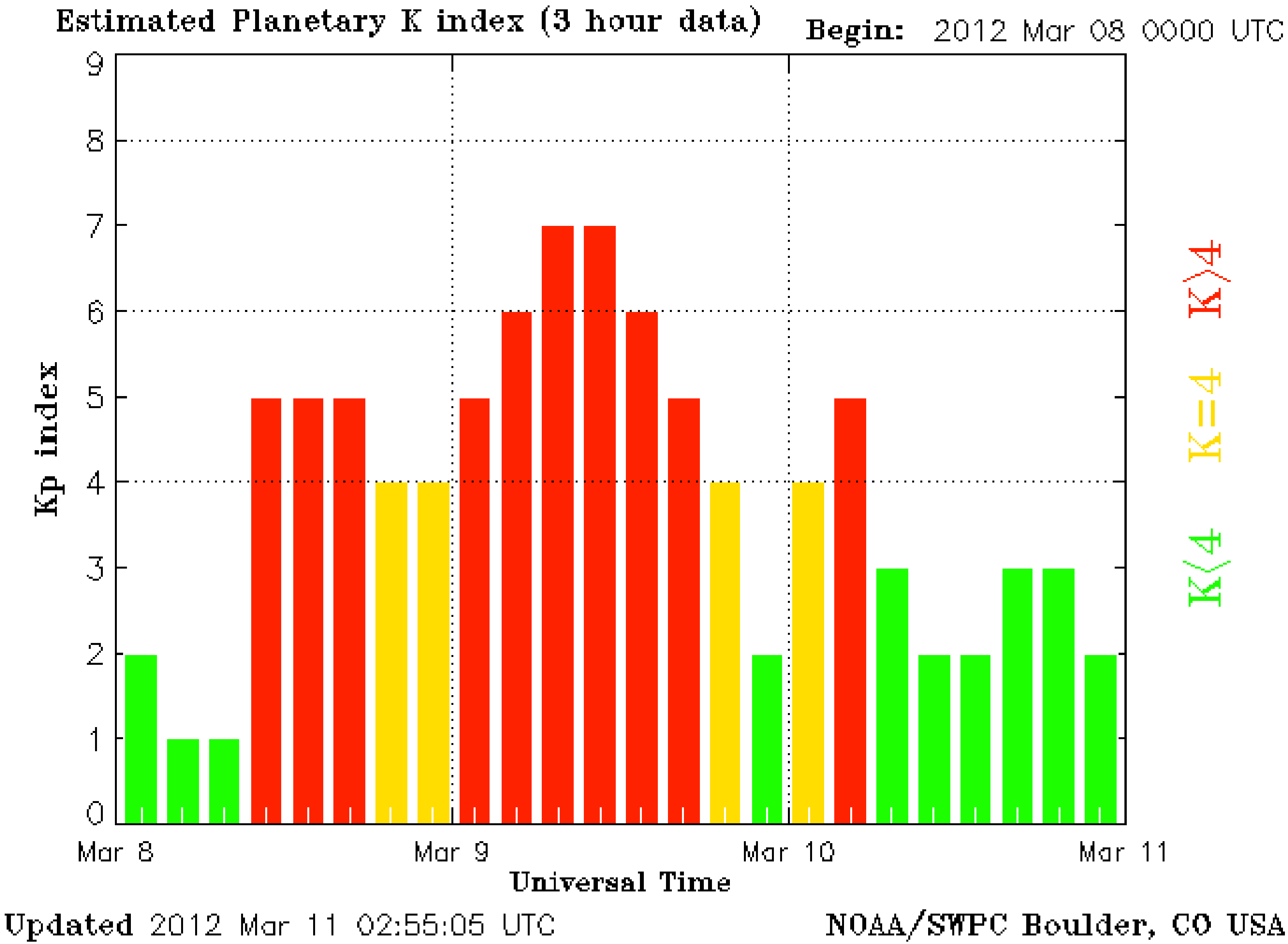
Ionosphere and its effects

- Infrequent bursts of energy at the surface of the sun (e.g., solar flares) can cause magnetic storms
  - Material and radiations ejected by the sun at very high speeds cause changes in the magnetic field of the Earth
  - Changes in the magnetic field are quantified by various “indices” measured and published daily (Kp, Dst, Ap)
- Magnetic storms can cause variations in TEC which translate into disruption for GNSS users
  - Intensity of these effects vary depending on the location and time of the observations

Ionosphere and its effects

- K index
  - Local measure of fluctuations in the horizontal component of earth's magnetic field at mid-latitude
  - Measured every 3 hours from data collected over 3-hour intervals
  - Range: 0-9 with 1/3 quantization
- Kp index
  - Small letter “p” stands for planetary
  - Computed from K indices reported by a number of observatories worldwide

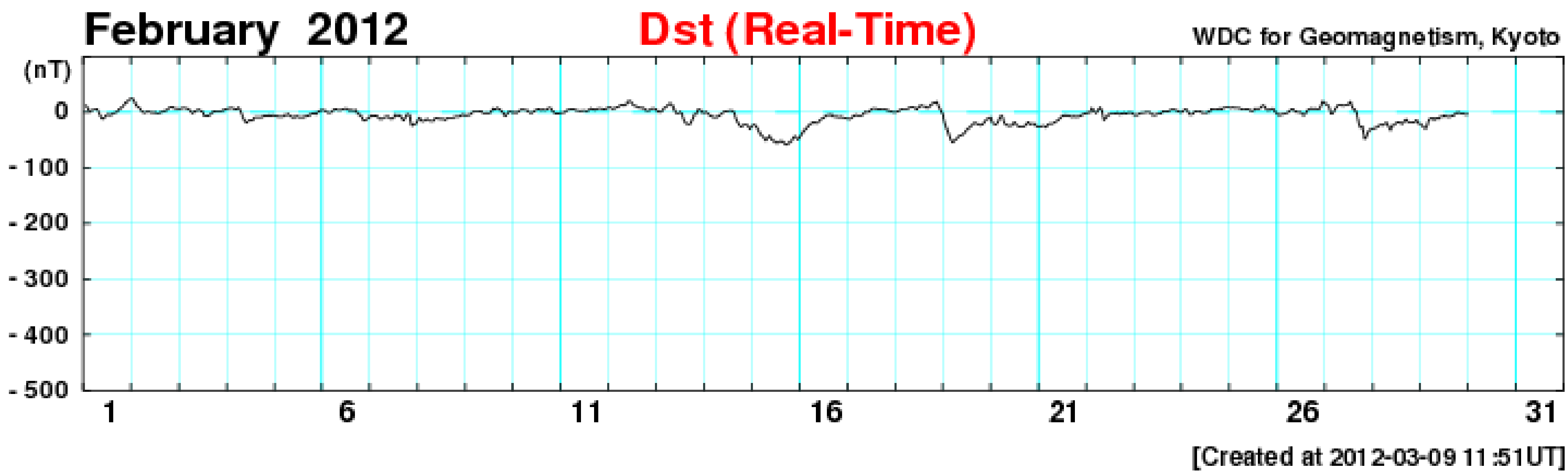
Ionosphere and its effects



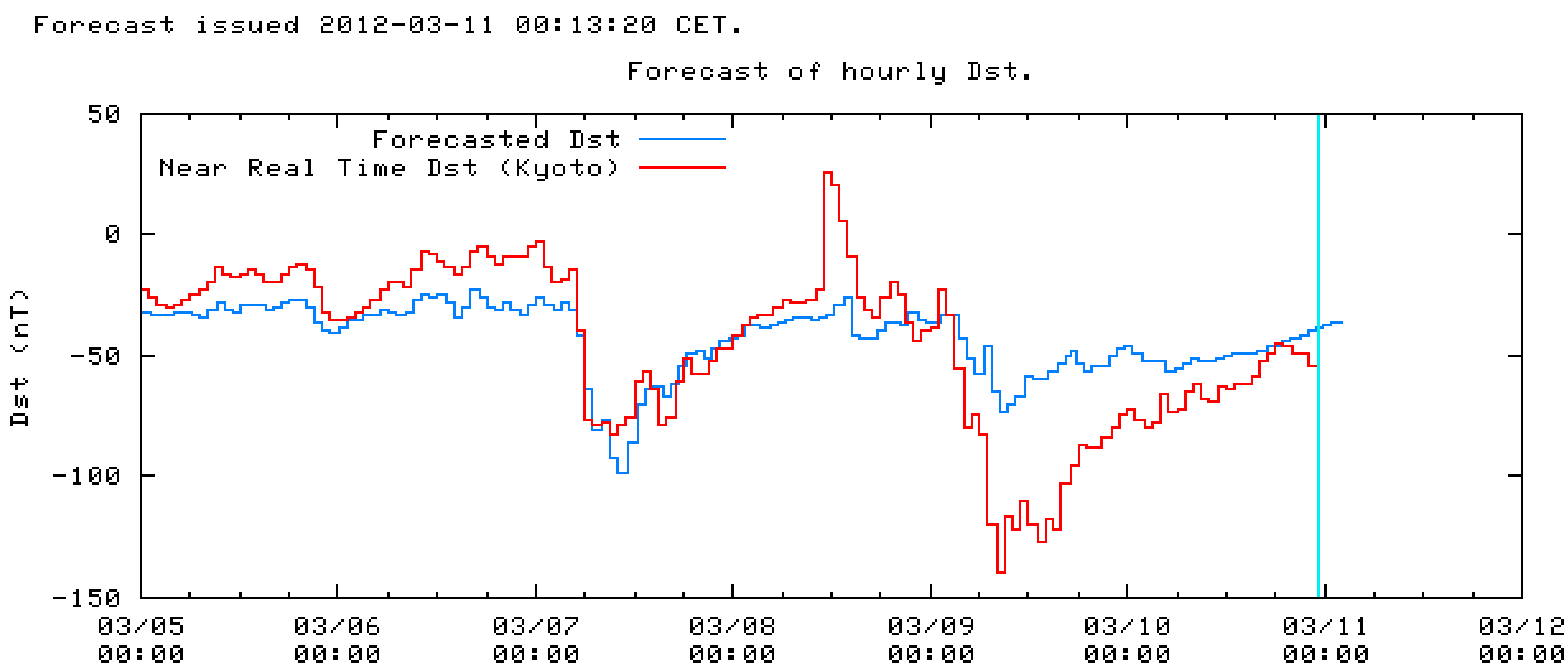
http://www.swpc.noaa.gov/ftpmenu/plots.html

Ionosphere and its effects

- Dst (disturbance storm time) index
  - Measure of fluctuations in the horizontal component of earth's magnetic field in the mid-latitude and equatorial region
  - A negative value indicates a storm is in progress
- Ap index
  - Measure of the general level of geomagnetic activity over the globe for a given UT day
  - Derived from measurements of the variation of the *ap* indices during a geomagnetic storm event

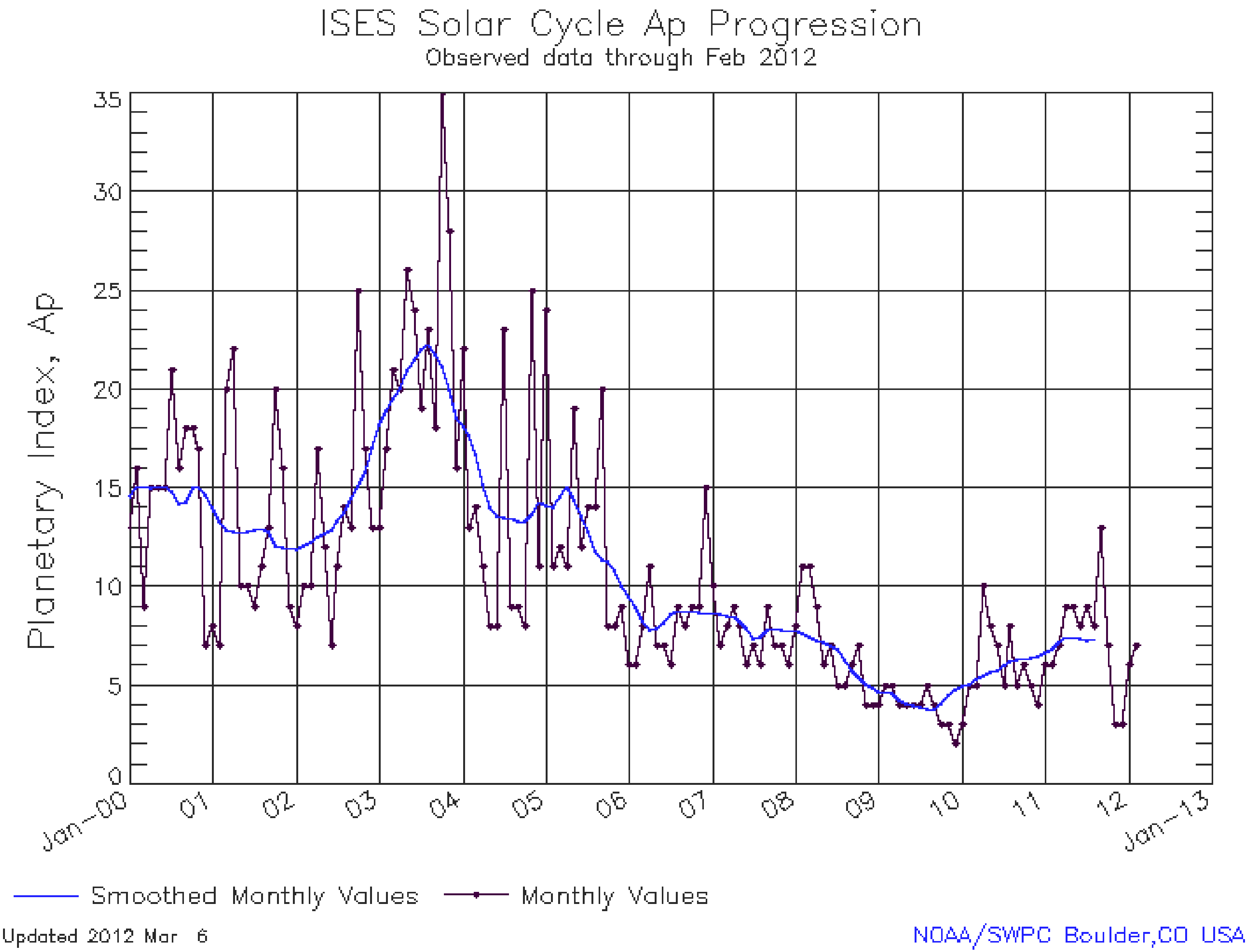


http://wdc.kugi.kyoto-u.ac.jp/dst_realtime/201202/index.html



http://rwc.lund.irf.se/rwc/dst/

Ionosphere and its effects



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

4. Case study

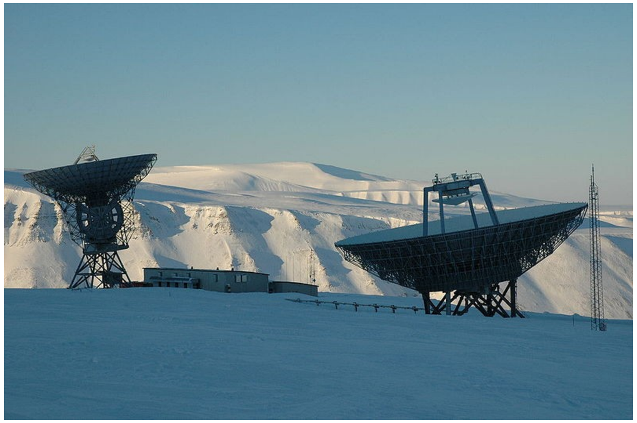
Instruments

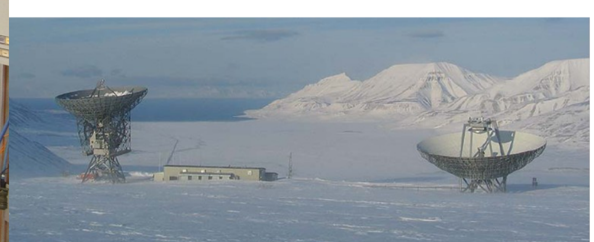
- Instruments for remout sensing of the irregularities in the ionosphere:
  - Magnetometer – provide information about electrodynamics that governs ionospheric motion
  - Ionosonde – provides geophysical parameters (critical frequencies, electron density profiles, ionospheric drift in some cases)
  - Incoherent scatter radar (ISR) – allows measurement of electron density, ion and electron temperature and velocity and plasma drifts

Ionospheric plasma irregularities

- Plasma irregularities:
  - Equatorial spread F layer and plasma bubbles
  - Sporadic E layer
  - Tides and gravity waves
  - Ionospheric storms
  - Traveling Ionospheric Disturbances (TIDs)
  - Polar arcs
  - Polar patches

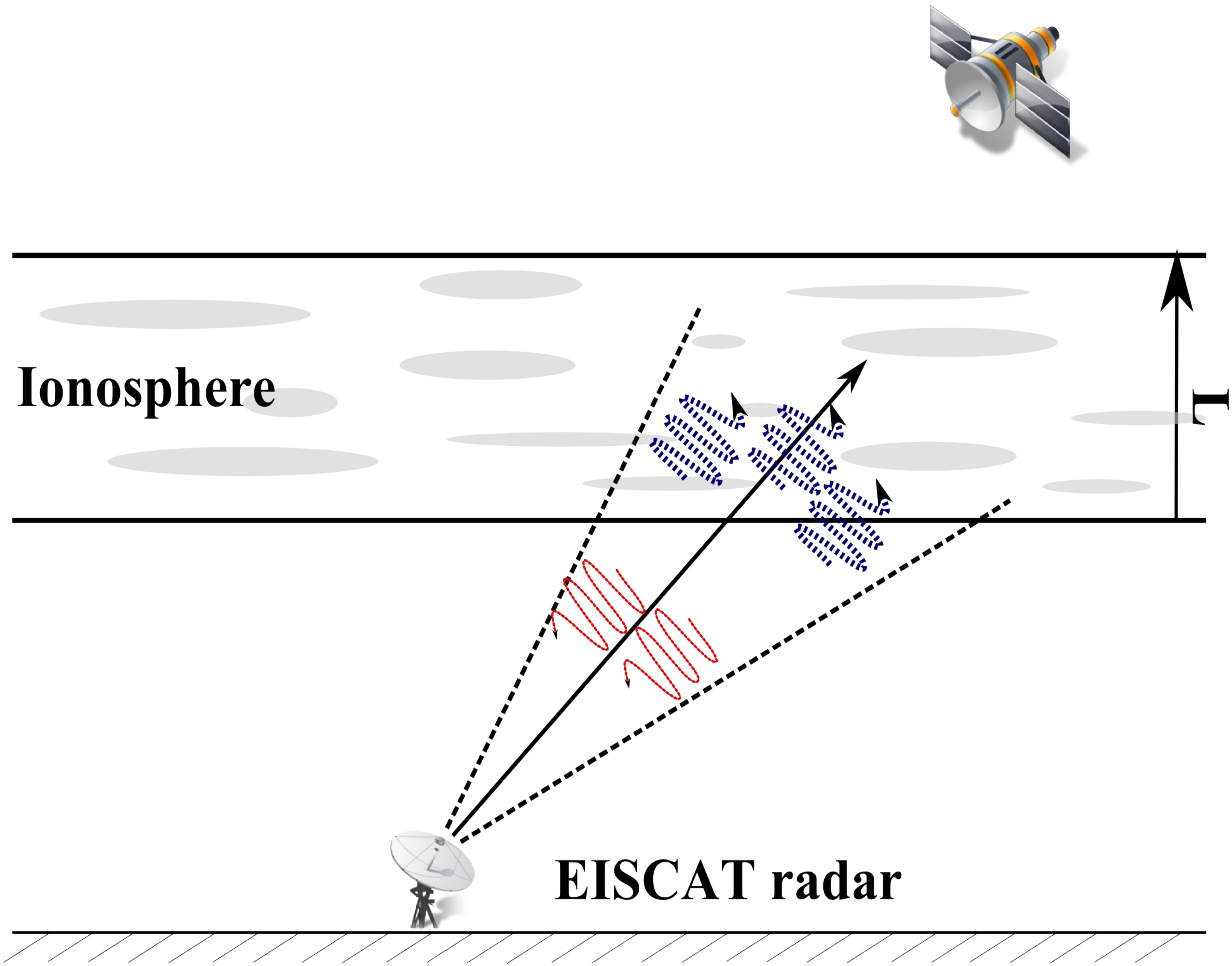
EISCAT measurements





- EISCAT incoherent scatter radar:
  - Emit powerful multi-mega-watt signals and recieves picowatt signals
  - A radar beam scattering off electrons in the ionospheric plasma creates an incoherent scatter echo
  - Transmiters are located in Tromsø and Svalbard, and recievers in Kiruna and Sodankyla

EISCAT measurements



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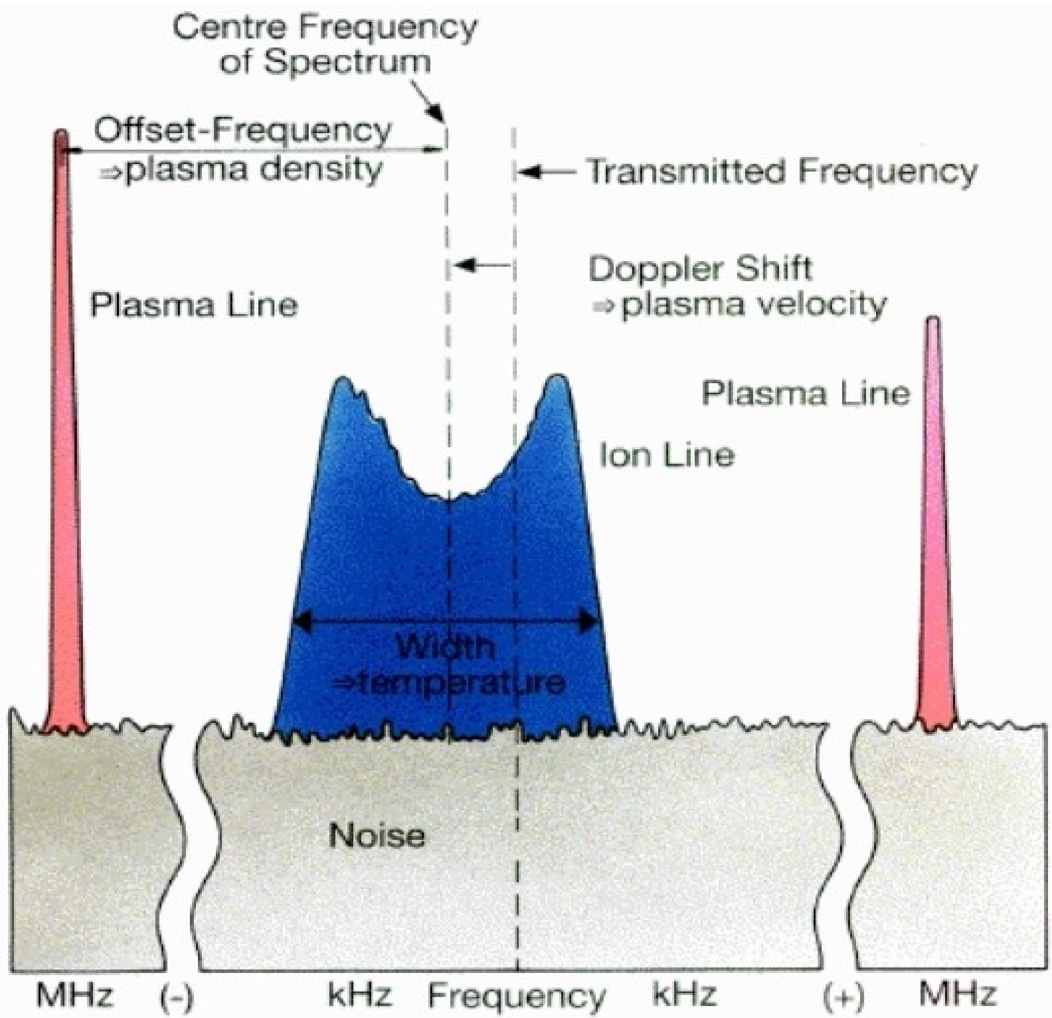


L. J. Baddeley, "Running the EISCAT Mainland System for Dummies", 2007.

- Radar equation:

$$P_r = P_t \sigma_{radar} c \Delta T A_r / (8 \pi R^2)$$

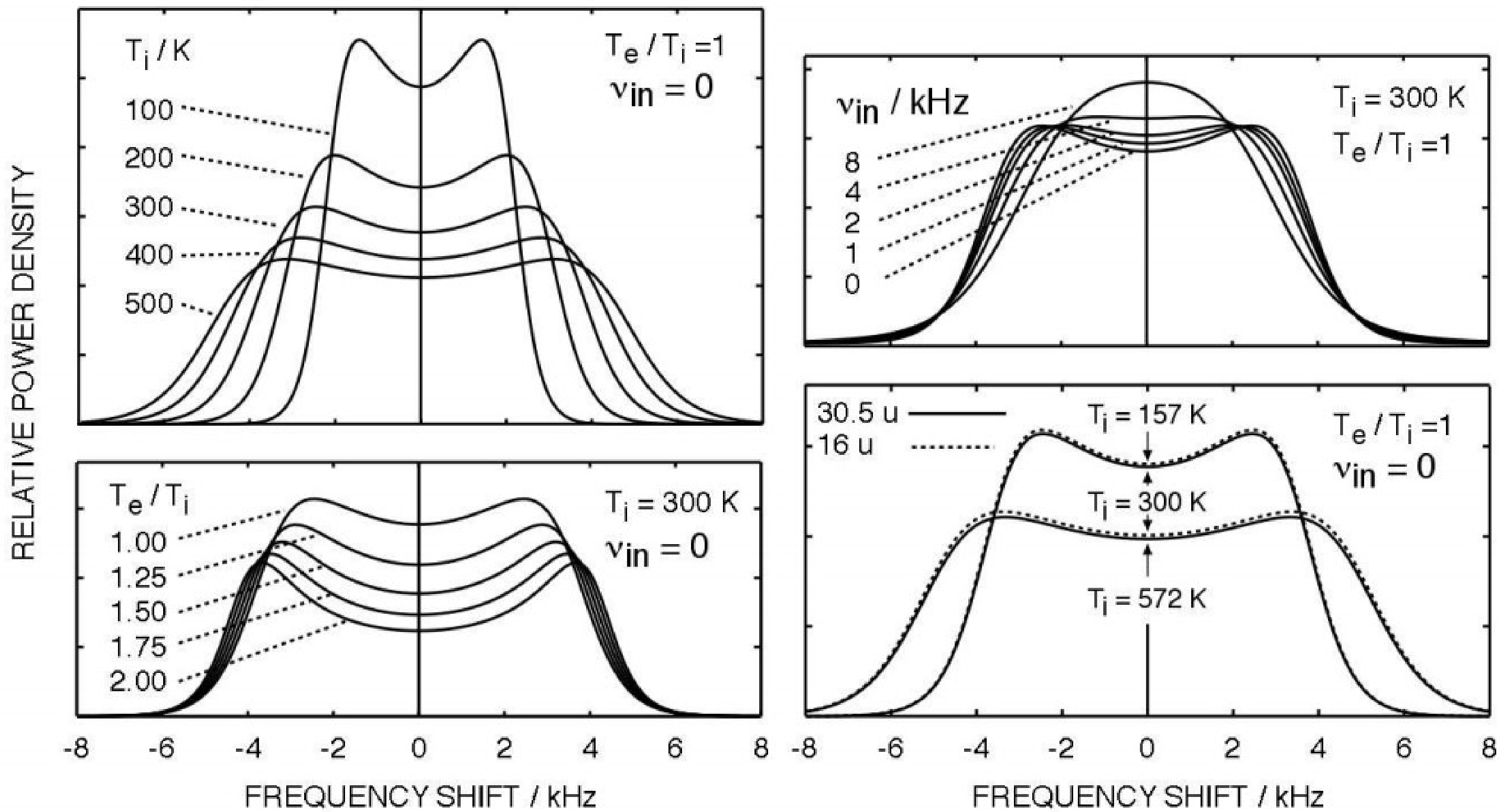
P_t - transmitter power

σ_{radar} - radar scattering cross section

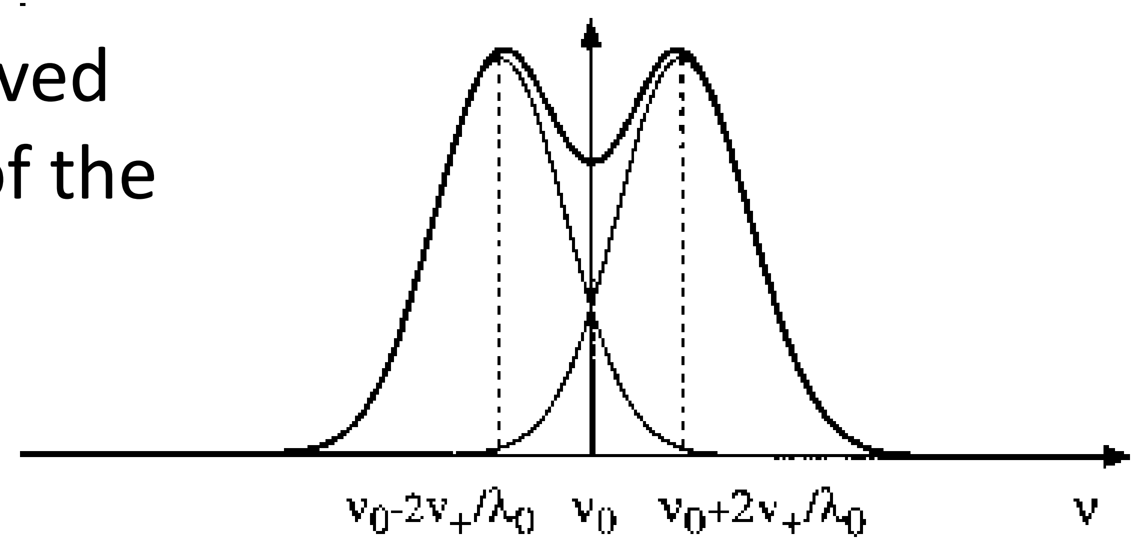
ΔT - transmited pulse length

A_r - effective receiving antenna area

R - distance from transmiter/receiver to scattered point

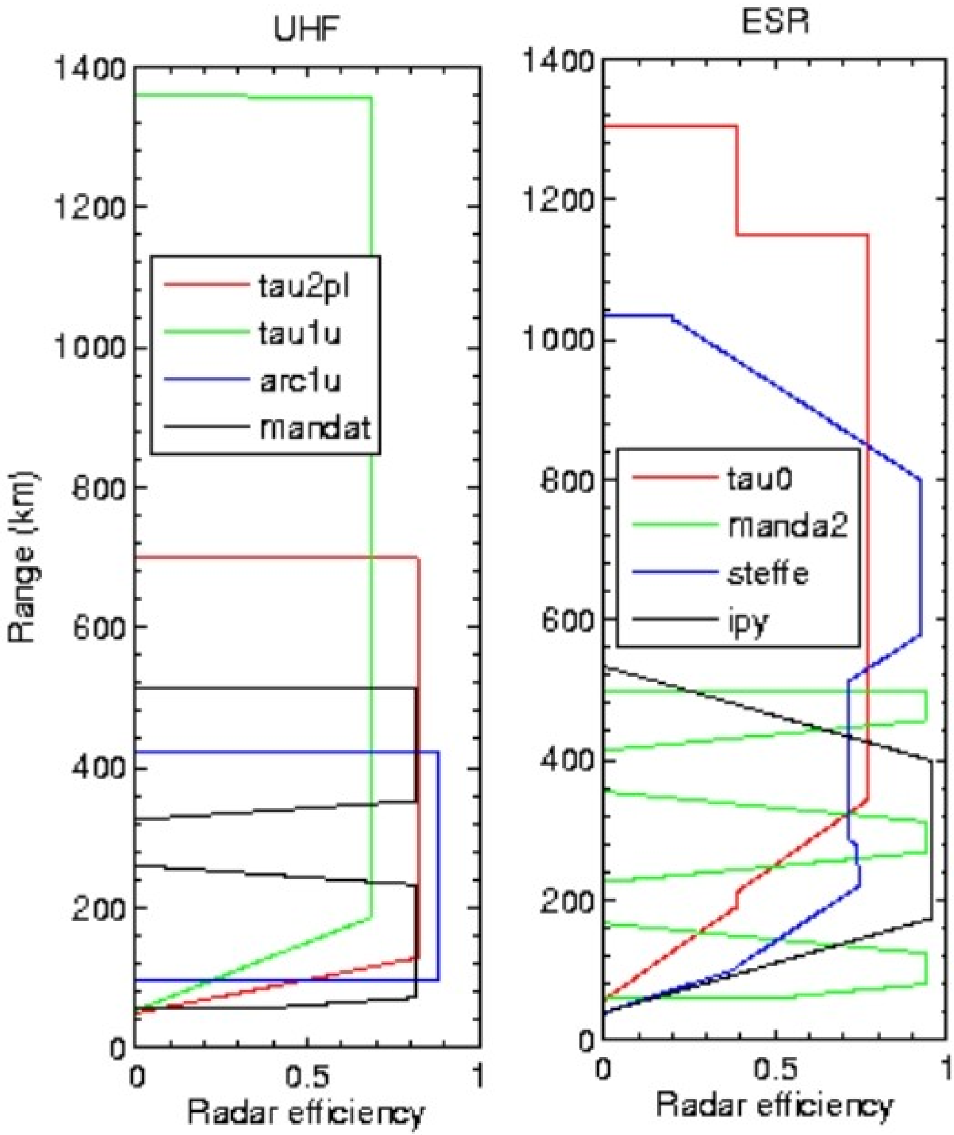


- Power spectrum of recieved signal and dependance of the ion line shape on plasma parameters

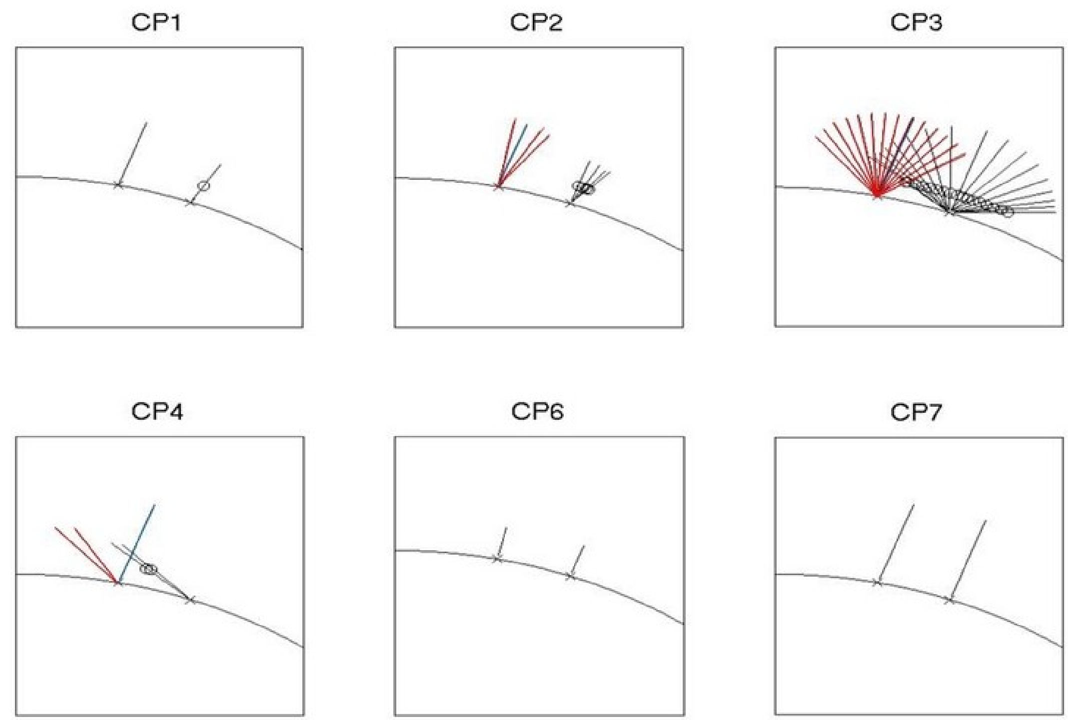


http://spaceweb.oulu.fi/education/NorFA97/EISCAT/expdesc.html

EISCAT measurements



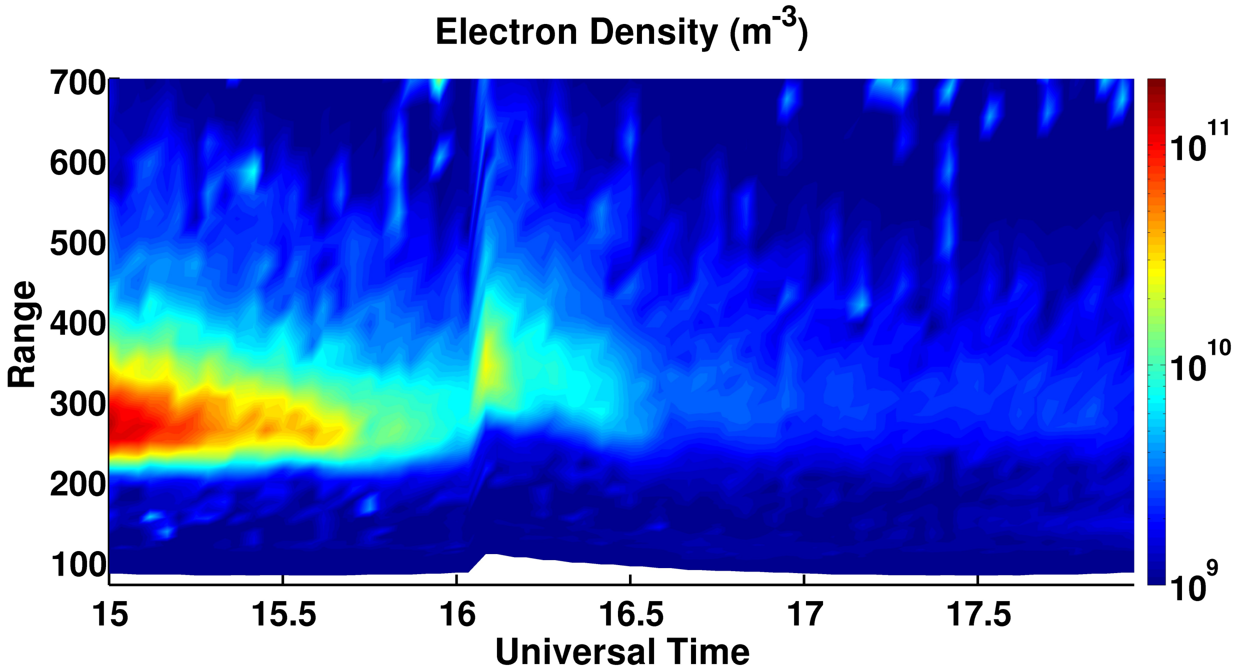
- Experiments for calculating plasma lines from raw data
- Scan patterns, which can be used in measurements:



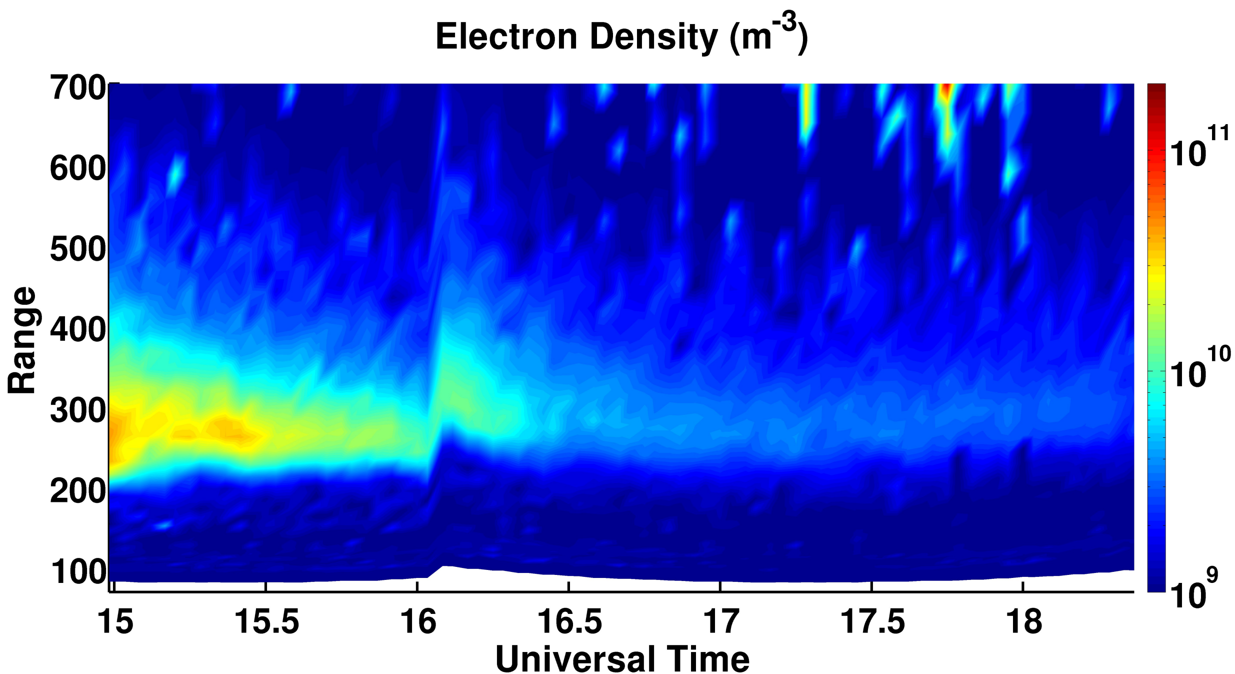
L. J. Baddeley, "Running the EISCAT Mainland System for Dummies", 2007.

http://www.eiscat.se/about/experiments2/scans

EISCAT measurements

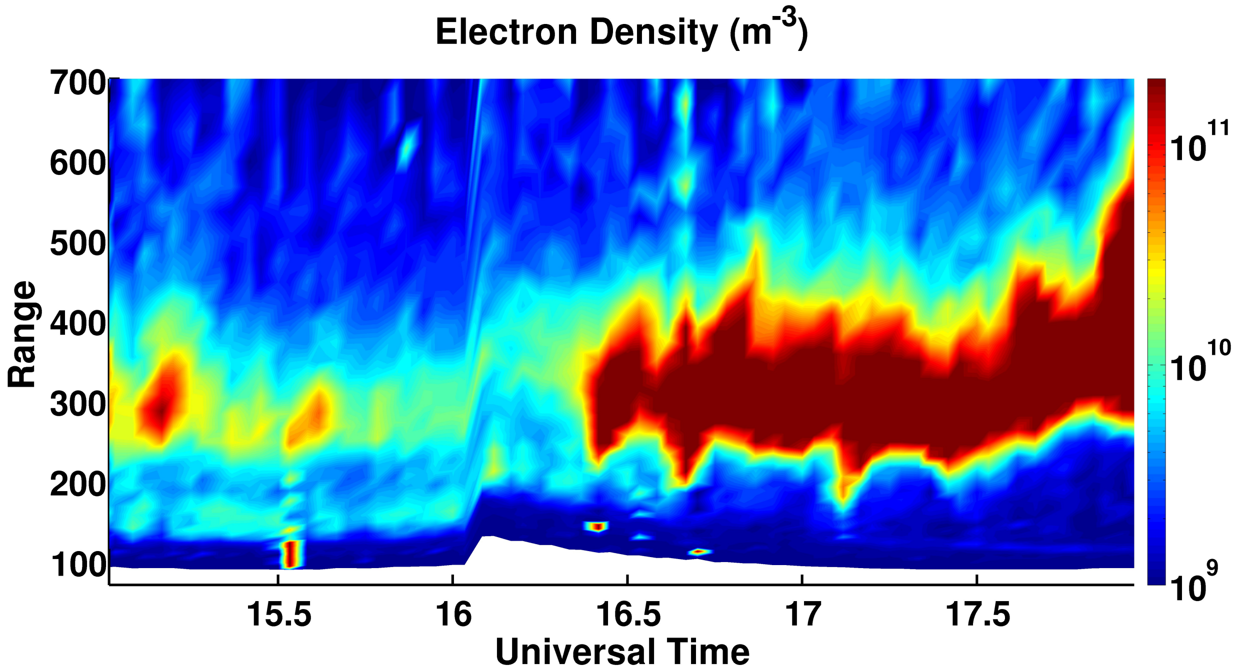


Tromsø data, 14.12.2011.

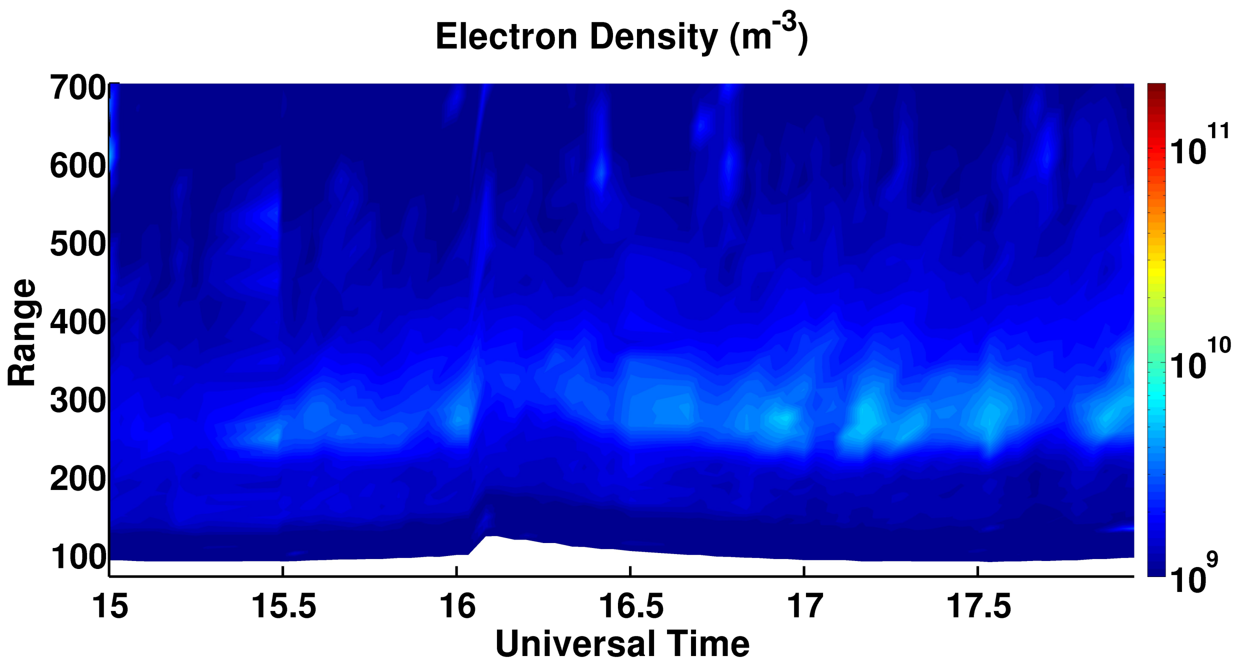


Tromsø data, 16.12.2011.

EISCAT measurements



Svalbard data, 14.12.2011.



Svalbard data, 16.12.2011.

5. Conclusion

Conclusion

- Small scale irregularities are not explored enough
- Discovering new metods for measuring and describing this type of irregularities
- The aim is prediction of all scales of irregularities and solving errors which can occure
- Improvement of physical and theoretical models of ionosphere and small scale irregularities
- Interaction with the project for the final prototype

Conclusion

- In addition to this scientific goals there is an idea to:
  - Enable server for collecting GPS monitors data from University of Nova Gorica and Ajdovščina and analzying it in daily, weekly and mounthly period
  - Web page for visualising analysed data from GPS monitors
- Attending courses, workshops and summer schools and interaction with experts in this field

Thank you for attention