Spatial behavior of D-region plasma parameters during the dominant influence of Lyα line after a solar X-ray flare

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  - D-region
  - monitoring

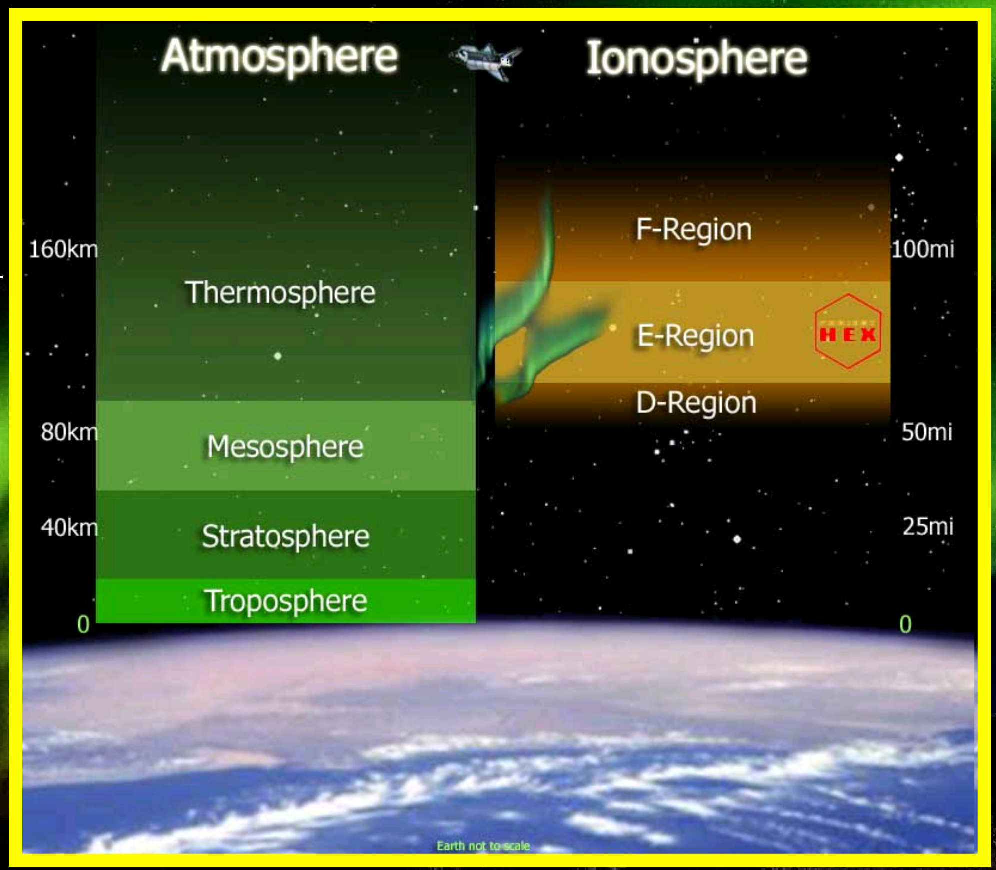
- **Motivation**
- **Observation**
- **Modeling**

  - electron density
  - photoionization rate induced by Lyα photons
  - effective recombination coefficient
  - electron temperature

- **Summary**

Introduction

- **The lowest ionospheric layer – D-region**



Introduction

- **The lowest ionospheric layer – D-region**
- **Influences: from the outer space and Earth**

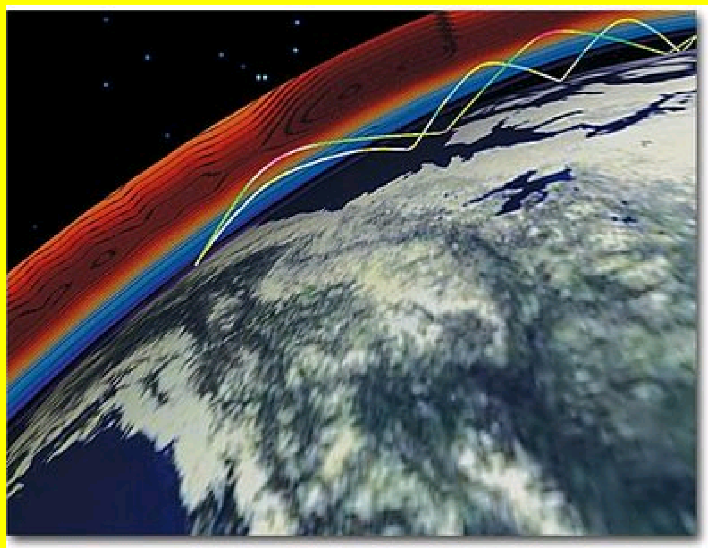
The most Important source of

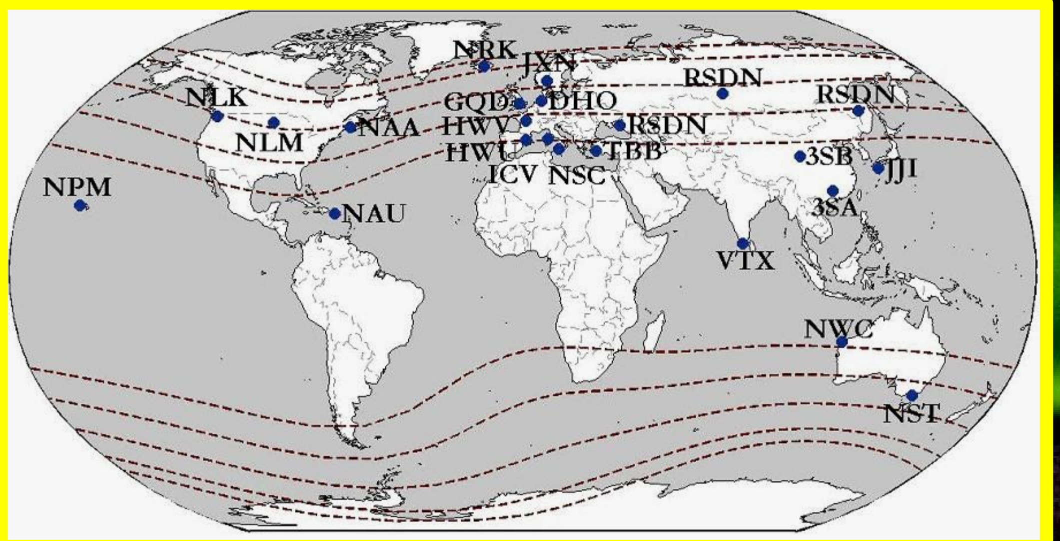
ionization during unperturbed period – **Solar hydrogen Ly-α radiation**

sudden ionization – **Solar X-ray flare**

Introduction

- **The lowest ionospheric layer – D-region**
- **Influences: from the space and Earth**
- **Monitoring: VLF/LF radio waves, radars, rocket**





- continual emission and monitoring
- good time resolution (less than 1 s)
- large analyzed space

Motivation

Lyα line is very important for D-region dynamics – dominant role in the upper D-region ionization in absence of strong sudden disturbances

Development of procedures for modeling of upper D-region plasma parameters when we can consider ionization as photoionization caused by Lyα line

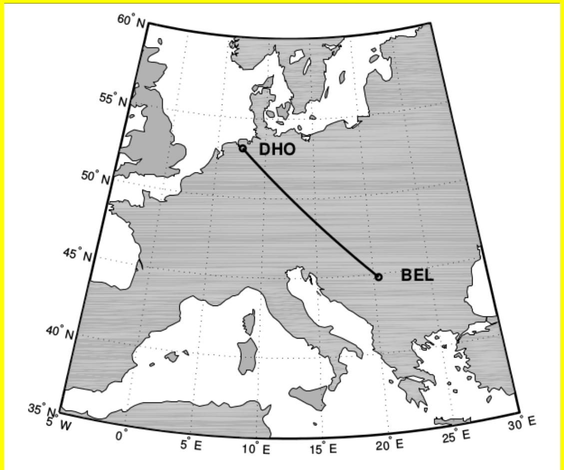
QUIET PERIODS

Modeling of Lyα photoionization rate (ASR and SCSLSA 2013) which is used to calculations of plasma parameters in quiet conditions

RELAXATION PERIODS

HOW D-REGION PARAMETERS RELAX AFTER STRONG INFLUENCES WHEN Lyα IS DOMINANT SOURCE OF IONIZATION?

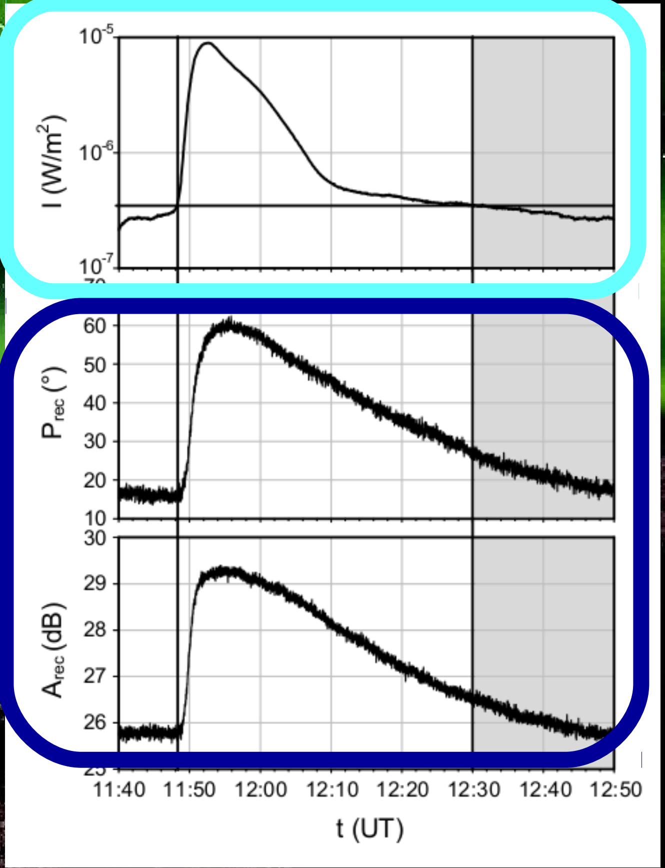
Observations and experimental setup



EXAMPLE
Solar X-ray flare occurred on May 5, 2010

GOES-14 satellite in wavelengths domain 0.1 nm - 0.8 nm

STANFORD – AWESOME (Atmospheric Weather Electromagnetic System for Observation Modeling and Education)



Reaction of phase (middle panel) and amplitude (bottom panel) of the VLF signal emitted by the DHO transmitter located in Germany and received by the AWESOME receiver in Serbia.

Modeling

Electron density dynamics

$$\frac{dN(\vec{r},t)}{dt} = \mathcal{G}(\vec{r},t) - \mathcal{L}(\vec{r},t)$$

$$\frac{dN(\vec{r},t)}{dt} = \kappa(\vec{r},t)I^{sat}(t) + \mathcal{P}_r(\vec{r},t) + \mathcal{C}(\vec{r},t) - \xi_L(\vec{r},t)N^2(\vec{r},t)$$

RELAXATION PERIOD (70 km – 80 km)

Electron gain processes: hydrogen Lyα photons from the Sun

Electron loss processes: recombinations

$$\frac{dN(\vec{r},t)}{dt} = \mathcal{G}_0(\vec{r},t) - \alpha_{eff}(\vec{r},t)N(\vec{r},t)$$

Observations + numerical modeling

$$\frac{dN(\vec{r},t)}{dt} = \mathcal{G}_0(\vec{r},t) - \alpha_{eff}(\vec{r},t)\, N^2(\vec{r},t)$$

analytical procedures

Electron density
Rate of Lyα photons induced photoionization
Effective recombination coefficient
Temperature

Electron density

Rate of Lyα photons induced photoionization

Effective recombination coefficient

Temperature

Electron density

- **Wait's model of ionosphere:**
  reflection height *H'(t)*
  sharpness *β(t)*

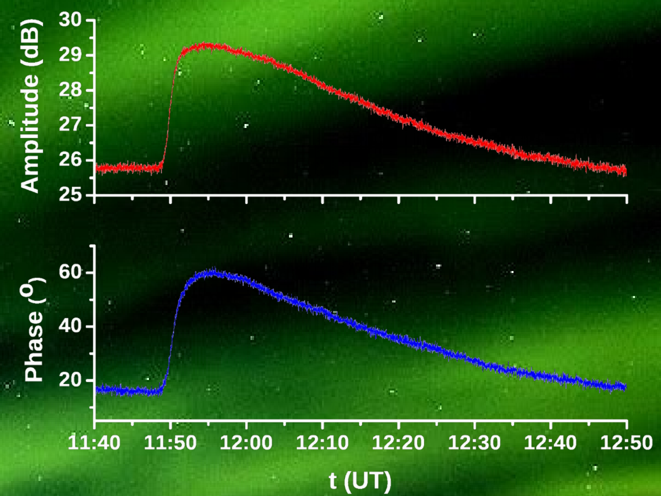
$$N(h,t) = 1.43 \cdot 10^{13} e^{-\beta(t)H'(t)} e^{(\beta(t)-0.15)h}$$

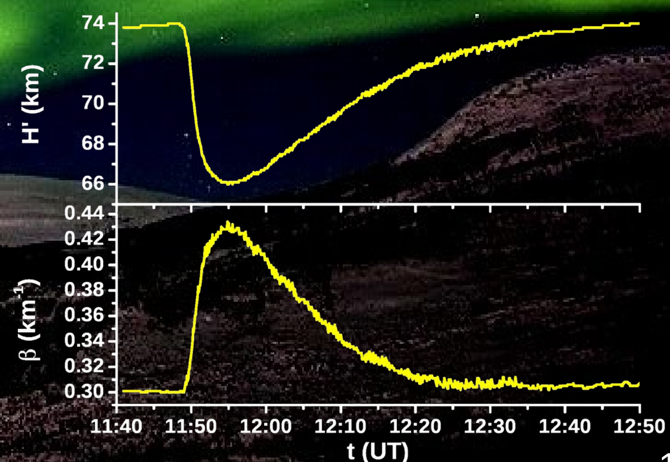
- **Numerical program for simulation of the VLF signal propagation: Long-Wave Propagation Capability (LWPC) - USA National Oceanic and Atmospheric Administration (NOAA)**

$$\Delta A_{LWPC} = \Delta A_{exp}$$

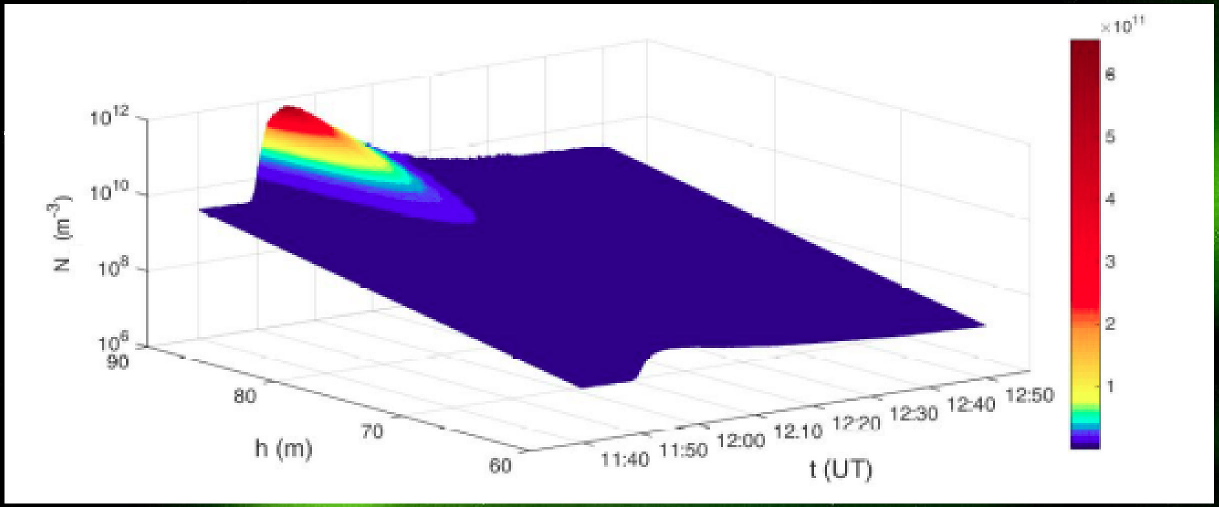
$$\Delta P_{LWPC} = \Delta P_{exp}$$

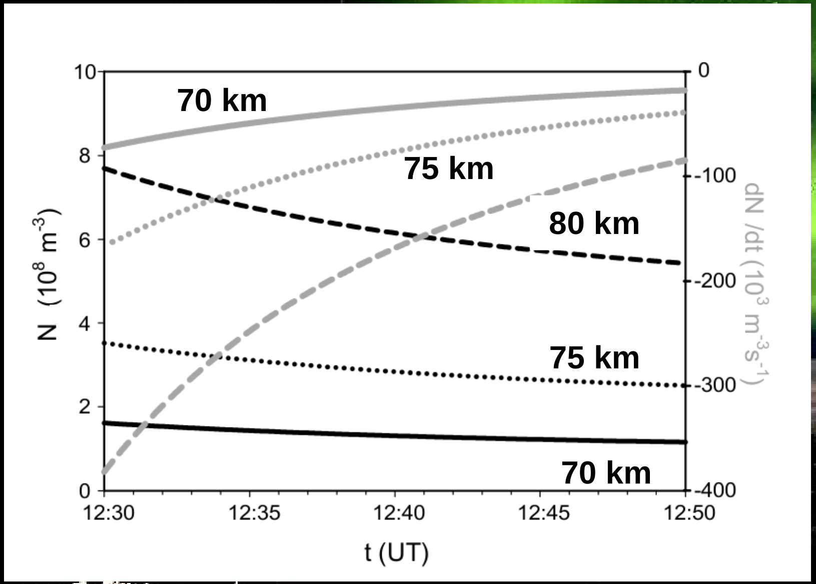
- **Recorded signal amplitude and phase**





Electron density





- **Intensity of electron density variations increases with altitude**
- **Gradient of the electron density increase with altitude**
- **Saturation occurs earlier at lower altitudes**

Electron density

Rate of Lyα photons induced photoionization

Effective recombination coefficient

Temperature

Rate of Lyα photons induced photoionization

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Serbia

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Electron production by solar Ly-α line radiation in the ionospheric D-region

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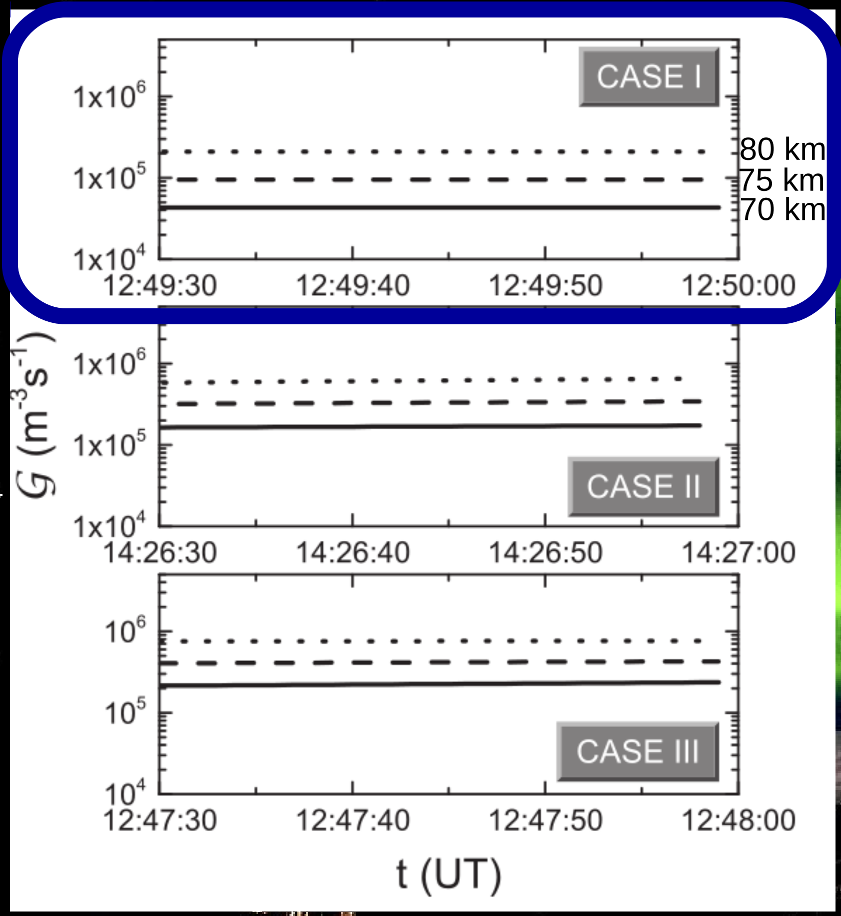
PROCEDURE

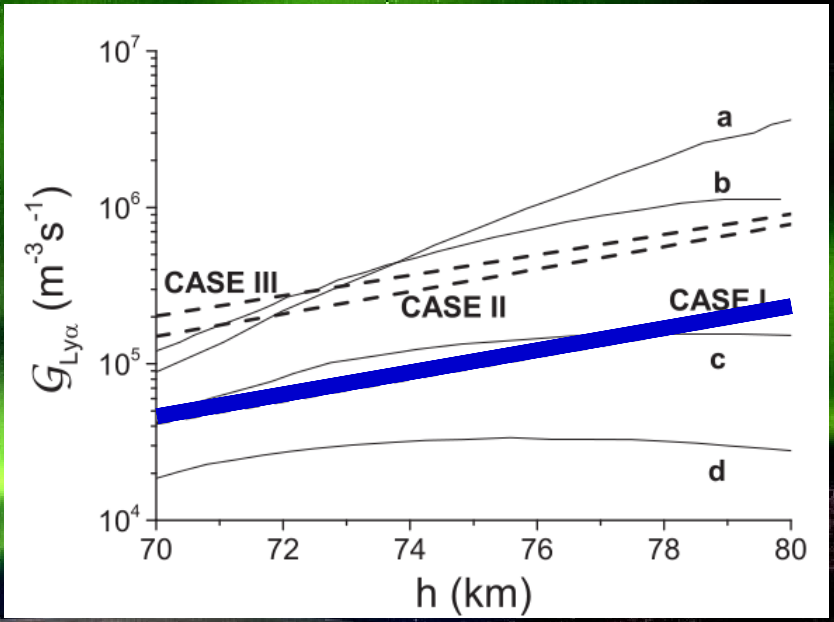
- **Considered time period is divided in short (1 s long lasting) time periods**
- **G_0 and α_{eff} are considered as time constant within these short periods**

$$\frac{dN(\vec{r},t)}{dt} = \mathcal{G}_0(\vec{r},t) - \alpha_{eff}(\vec{r},t)N(\vec{r},t)$$

- **Set of two equations with two unknown values G_0 and α_{eff}**

Rate of Lyα photons induced photoionization





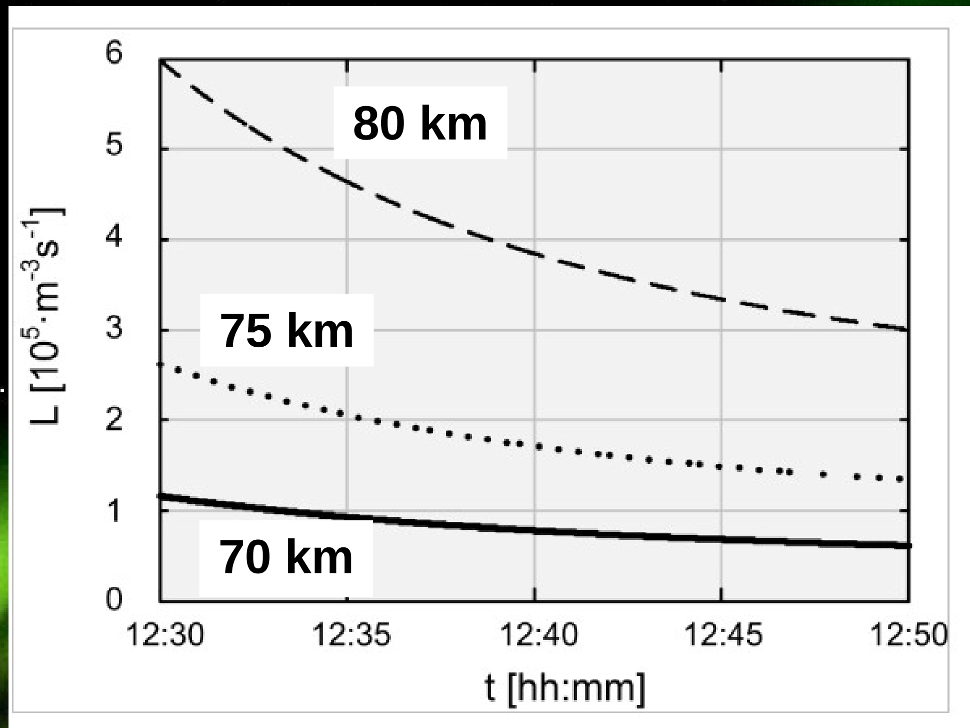
Electron density

Rate of Lyα photons induced photoionization

Effective recombination coefficient

Temperature

$$\frac{dN\ (\vec{r},t)}{dt} = \mathcal{G}_0(\vec{r},t) - \alpha_{eff}(\vec{r},t)N^2(\vec{r},t)$$

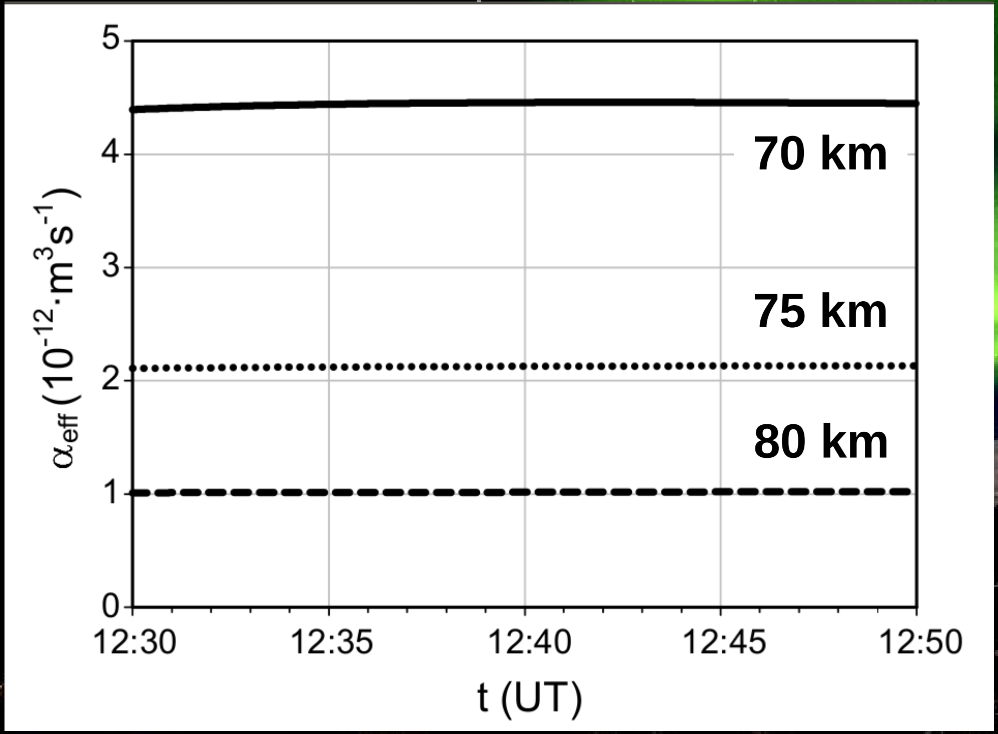


Which parameter has a greater impact on electron loss processes?

Effective recombination coefficient

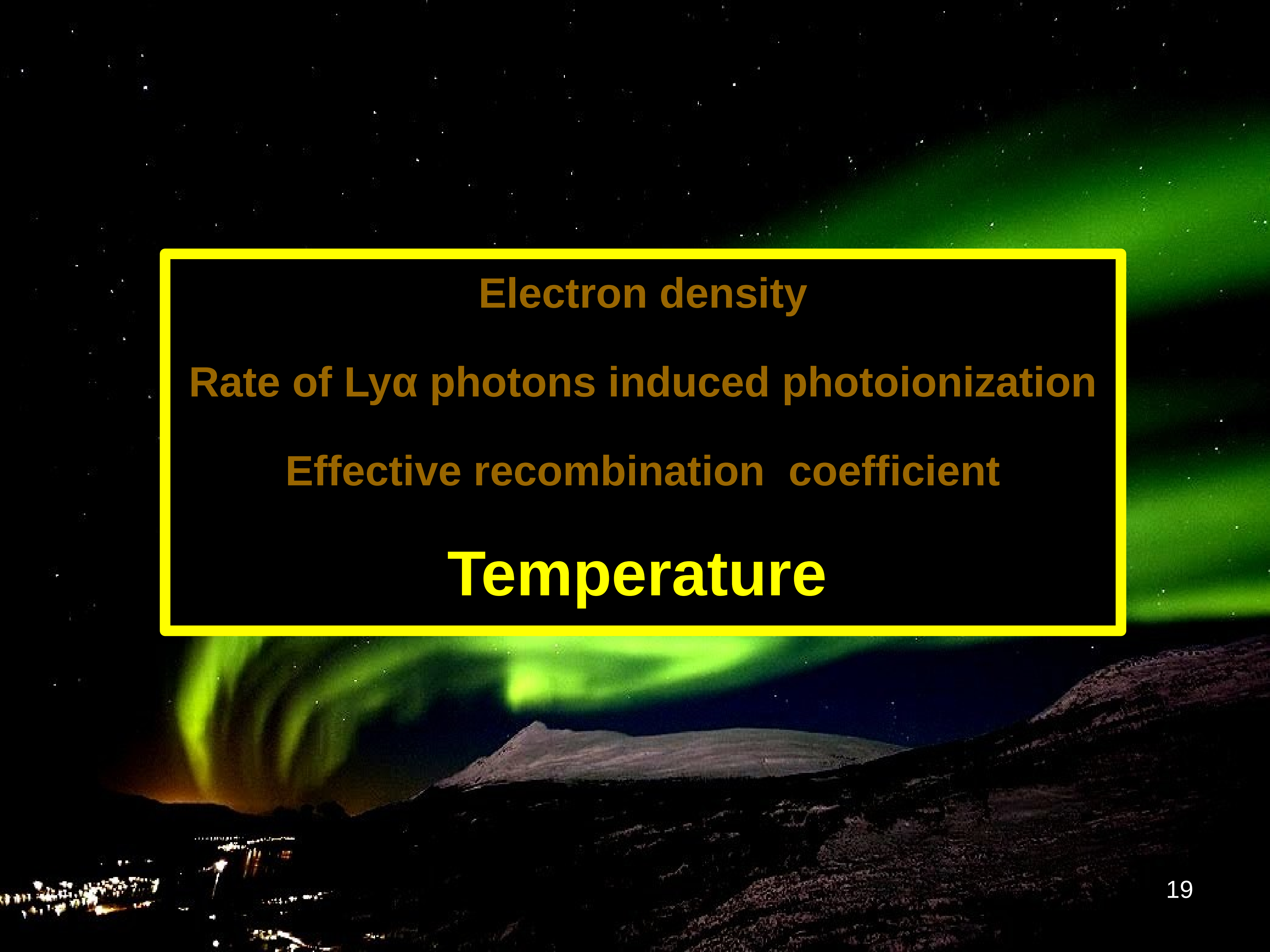
$$\frac{dN\ (\vec{r},t)}{dt} = \mathcal{G}_0(\vec{r},t) - \alpha_{eff}(\vec{r},t)N^2(\vec{r},t)$$

$$\alpha_{eff}(h,t) = \frac{\mathcal{G}_0(h,t) - \frac{dN\ (h,t)}{dt}}{N^2(h,t)}$$



- **The effective recombination coefficient decreases with altitude**
- **Gradient of the electron density decrease with altitude**
- **Saturation occurs earlier at higher altitudes**

Variations of the electron density is more important for electron loss rate than variations of effective Recombination coefficient


Electron density
Rate of Lyα photons induced photoionization
Effective recombination coefficient
Temperature

Temperature

- **Dominant influence of recombination in electron loss processes at considered altitude domain**

$$\alpha_{eff} = \frac{1}{N_e}\sum_i \alpha_i N_i$$

$$\alpha_i = C_i \cdot (T_e/300)^{D_i}$$

- **Dominant influence of clasters**

$$\alpha_{eff} = \alpha_{Claster}(1 + \sum_{i'} r_{\alpha_i}^{Claster} r_{N_i}^{Claster})$$

$$\alpha_{eff} = C(T_e/300)^{-0.5}$$

- **C – time constant - unperturbed conditions**

$$C = \alpha_{eff}^0 (T_e^0/300)^{0.5}$$

T_e^0

IRI model

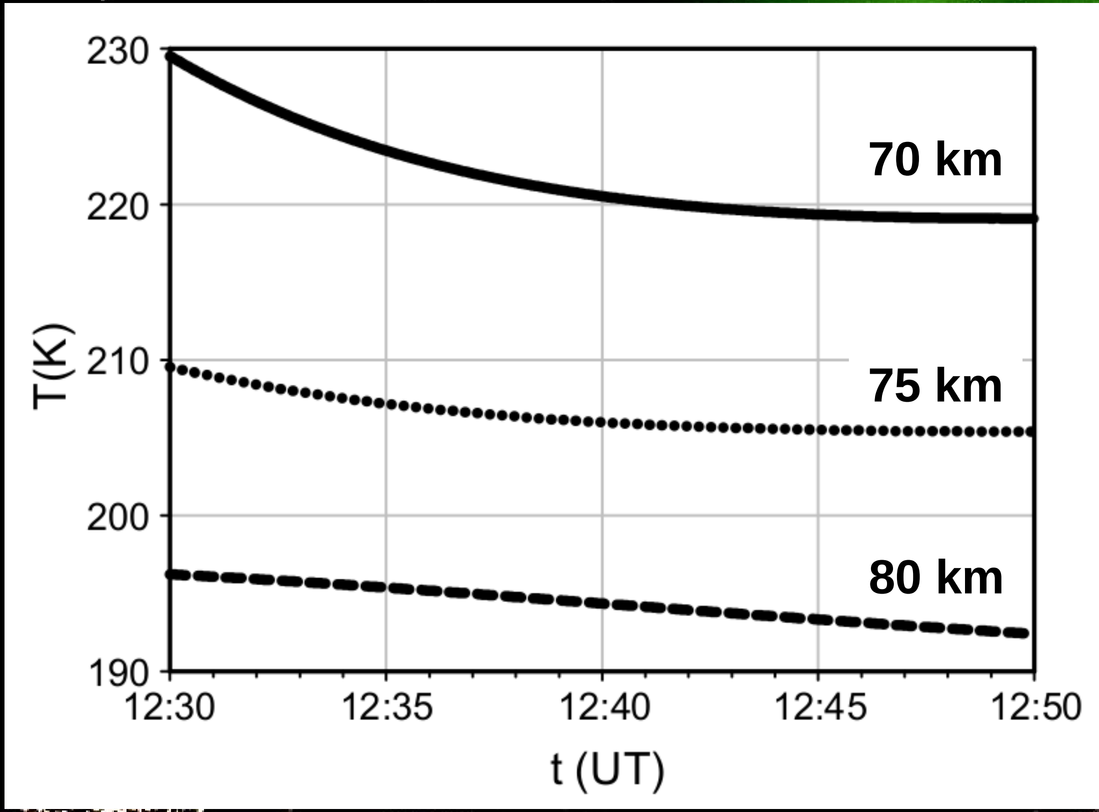
Ion	C_i (10^{-13})	D_i
N_2^+	1.8	-0.39
O_2^+	1.6	-0.55
NO^+	4.5	-0.83
$H^+(H_2O)_n$	5+20n	-0.5

Ratios of recombination coefficients and densities of ions i and claster – time constants at fixed h (variations are less than 1% in temperature range 190 K - 230 K)

Altitude (km)	$\mathcal{G}_0$ [20] $(m^{-3}s^{-1})$	T_e^0 [24] (K)	α_{eff}^0 $(10^{-12}m^3s^{-1})$	C (10^{-12})
70	41841	219.1	4.55	3.89
75	95000	205.4	2.13	1.76
80	215697	192.4	1.02	0.82

Temperature

$$T_e = 300(\alpha_{eff}/C)^{-0.5}$$



- **Temperature decreases with altitude**
- **Gradient of the temperature decrease with altitude**
- **Saturation occurs earlier at higher altitudes**

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IONOSPHERIC D-REGION TEMPERATURE RELAXATION AND ITS INFLUENCES ON RADIO SIGNAL PROPAGATION AFTER SOLAR X-FLARES OCCURRENCE

by

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Summary

- We analyzed ionospheric D-region plasma properties during relaxation period after solar X-ray flare when Lyα photons has dominant role in ionization processes

- We describe modeling of :

  - electron density
  - photoionization rate induced by Lyα photons
  - effective recombination coefficient
  - electron temperature

- The obtained final results show:

- Different tendencies in time evolutions and gradients of considered parameters
- Variations of the electron density are more important for the electron loss rate than variations of the effective recombination coefficient

Summary

OPEN QUESTIONS

- Relations between recombination and attachment processes during relaxation within entire D-region
- Analysis of influence of cosmic rays in the lower part of the D-region

UNIVERSAL NUMERICAL AND ANALYTICAL PROCEDURE

They can be applied on different data sets which can provide informations related to different locations and give us informations about influences of time period and geographical location on D-region plasma properties

IMPORTANCE FOR SCIENTIFIC RESEARCH IN GEOPHYSICS AND FOR PRACTICAL APPLICATIONS IN TELECOMMUNICATION


Thank you
for your
attention!