Natural disasters and low ionospheric disturbances detected by Belgrade VLF/LF receiver station

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Luka Č. Popović, Vladimir M. Čadež,
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Hazards SoS, Petnica, 2019

Content

- VLF/LF radio signals - low ionospheric observations
- Description of research in Serbia (disturbance detections and modelling)
- Ionosphere and natural disasters:
  - connections
  - Influence of D-region disturbances on remote sensing

Observations

3 kHz – 30 kHz VLF
30 kHz – 300 kHz LF

Time resolution of data

0.001 s – 1 s
1 Hz - 1 kHz

Size:
several tens of GB/day
several TB/year

- <u>Continuous receiving</u>
  - Detections of unperiodical perturbations
  - Periodical variations: diurnal, seasonal, solar cycle

- <u>High time resolution</u>
  - Detection of short-term disturbances and relevant events and phenomena

- <u>Global experimental setup – transmitter and receiver networks</u>
  - Analyses of large part of the low ionosphere
  - Detection of local perturbations

Belgrade VLF/LF receiver station

AbsPAL | **AWESOME**

During this period we have collected a large database containing a written information about numerous low ionospheric responses to different natural and human induced events.

0.1 s | **0.02 s**

Research

DETECTION OF LOW IONOSPHERIC DISTURBANCES

MODELING OF PLASMA PARAMETERS

Detection of low ionospheric disturbances

DEVELOPMENT OF PROCEDURES FOR DETECTIONS OF DISTURBANCES

DETECTION OF IONOSPHERIC DISTURBANCES IN PERIOD AROUND EVENTS

- **Detection of short-term disturbances – statistical study**

Nina, A., S. Simić, V. A. Srećković and L. Č. Popović (2015), Detection of short-term response of the low ionosphere on gamma ray bursts, Geophys. Res. Lett., 42, 8250–8261, doi:10.1002/2015GL065726.

- **Detection of hydrodynamic waves**

Nina, A. and V. M. Čadež (2013), Detection of acoustic-gravity waves in lower ionosphere by VLF radio waves, Geophys. Res. Lett., 40, 4803–4807, doi:10.1002/grl.50931.

Detection of low ionospheric disturbances

DEVELOPMENT OF PROCEDURES FOR DETECTIONS OF DISTURBANCES

DETECTION OF IONOSPHERIC DISTURBANCES IN PERIOD AROUND EVENTS

- Detection of mid-term disturbances in periods around tropical depression beginnings

Nina, A., S. Simić, V. A. Srećković and L. Č. Popović (2015), Detection of short-term response of the low ionosphere on gamma ray bursts, Geophys. Res. Lett., 42, 8250–8261, doi:10.1002/2015GL065726.

- Detection of disturbances in periods around the earthquakes

Nina, A. and V. M. Čadež (2013), Detection of acoustic-gravity waves in lower ionosphere by VLF radio waves, Geophys. Res. Lett., 40, 4803–4807, doi:10.1002/grl.50931.

Modelling

Wait, J. R. and Spies, K. P. (1964). Characteristics of the Earth-ionosphere waveguide for VLF radio waves. NBS Technical Note 300, National Bureau of Standards, Boulder, CO.

[1] Ferguson, J. A. (1998). Computer Programs for Assessment of Long-Wavelength Radio Communications, Version 2.0., 0, Space and Naval Warfare Systems Center, San Diego.

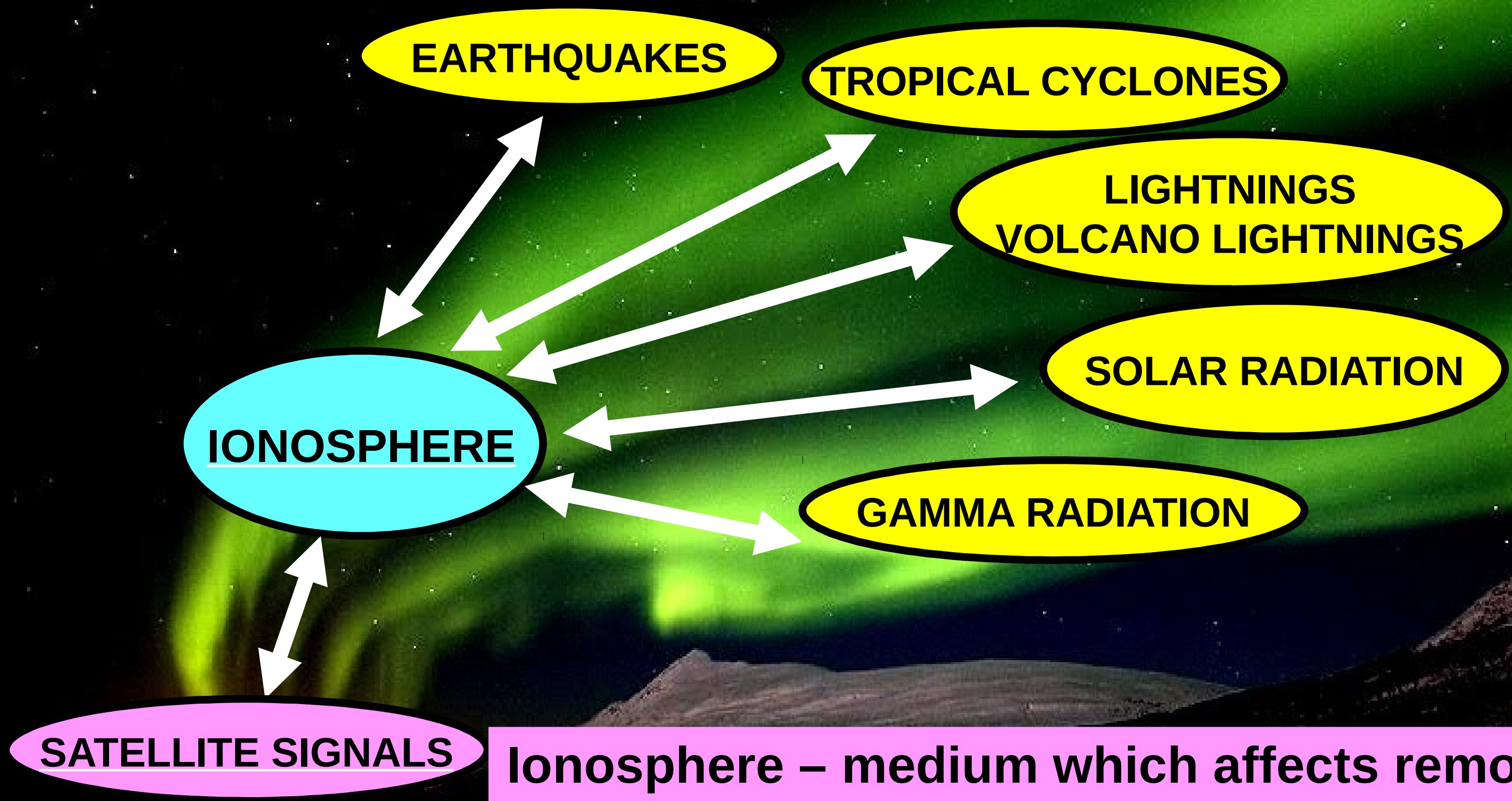
[2] Nina, A. (2014). PhD Dissertation, Faculty of Physics, University of Belgrade, Belgrade, Serbia

[3]Thomson, N. R. (1993). Experimental daytime VLF ionospheric parameters. Journal of Atmospheric and Terrestrial Physics, 55:173–184.

- HORIZONTAL UNIFORM IONOSPHERE
- EXPONENTIAL Ne ALTITUDE DISTRIBUTION
- SOLAR X-RAY FLARE

Ionosphere – natural disasters: two fold connection

Ionospheric disturbances connected with disasters



Ionosphere – medium which affects remote sensing of natural disasters by satellites

Ionospheric disturbances connected with disasters

Ionosphere – medium which affects remote sensing of natural disasters by satellites

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Earthquakes - ionosphere
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COST Action ELECTRONET

Paper in preparation - Science of the Total Environment

Analysis of the low ionospheric disturbances in period around the Kraljevo earthquake occurred on November 3, 2010

Aleksandra Nina[*,a], Sergey Pulinets[b],, Giovanni Nico[c,d], Srdjan Mitrović[e], Milan Radovanović[f,g] and Luka Č. Popović[h,i]

- Amplitude noises
- Short-term amplitude peaks (spikes)
- Hydrodynamic waves

Three proceedings

- Terminator times


Cyclones - ionosphere
Hazards SoS, Petnica, 2019

Advances in Space Research 60 (2017) 1866–1877

Low ionospheric reactions on tropical depressions prior hurricanes

Aleksandra Nina [a,*], Milan Radovanović [b,c], Boško Milovanović [b], Andjelka Kovačević [d], Jovan Bajčetić [e], Luka Č. Popović [d,f]

- **Detection of deviation**
- **Determination of typical profiles of amplitude time evolutions that can be considered as deviation**

- **Detection of deviation**

$$\sigma_N(t) = \sqrt{\frac{1}{n_N(t)} \sum_{i=1}^{n_N(t)} (A_i(t) - A_{mN}(t))^2},$$

$$r(t) = \frac{\mathrm{abs}(\sigma_2(t) - \sigma_1(t))}{\sigma_1(t)}.$$

- The deviation of signal at time t in the day of a depression is significant if $r(t) \geqslant 100\%$.
- Deviation for the TD event is recorded if at least 50% of values $r(t)$ is significant within one hour.

In the case of 36 out of 41 TD events (88%)

- **Disturbances during daytime, nighttime and ST periods**
- **Before, during, after TD beginnings**

- **Typical profiles**

- **Three types of signal variations (80 %)**

MAIN CONCLUSIONS:
Possible connection of low ionospheric disturbances and TD

Pioneer study – the need for future research


γ radiation - ionosphere

Gamma-Ray Bursts (GRBs) are known as <u>THE MOST ENERGETIC PHENOMENA IN THE UNIVERSE.</u>

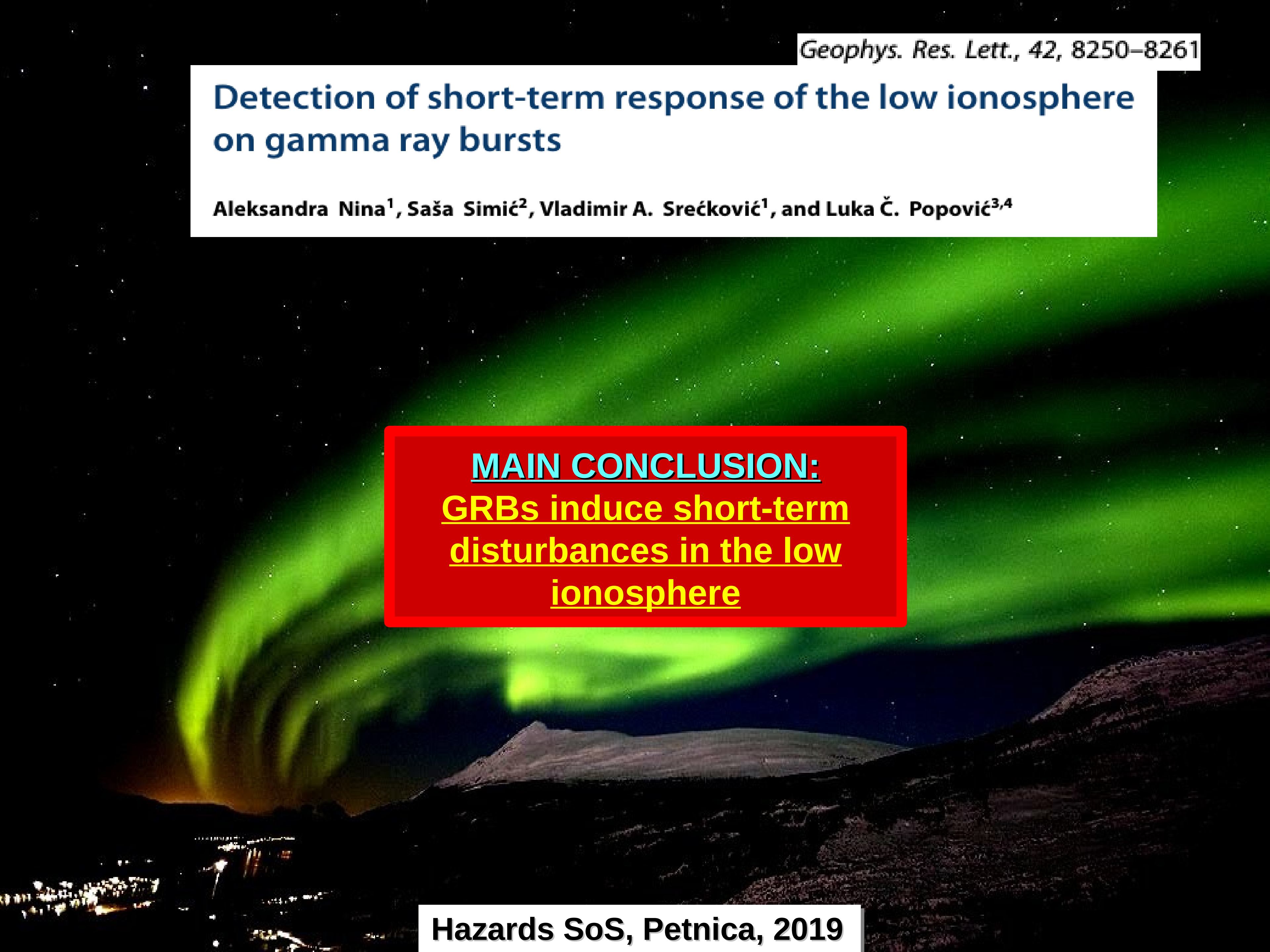
<u>Sources</u>: supernova explosions, collisions of celestial bodies such as neutron stars, white dwarfs, and Helium stars with black holes.

<u>Frequency of impact in the Earth’s atmosphere:</u> several times per month.

How much can a GRB event disturb the Earth atmosphere?

Fishman, G. J., and U. S. Inan (1988), Observation of an ionospheric disturbance caused by a gamma-ray burst, Nature, 331, 418

Inan, U. S., N. G. Lehtinen, R. C. Moore, K. Hurley, S. Boggs, D. M. Smith, and G. J. Fishman, Massive disturbance of the daytime lower ionosphere by the giant γ-ray flare from magnetar SGR 1806-20, Geophys. Res. Lett., 34, L08103, 2007



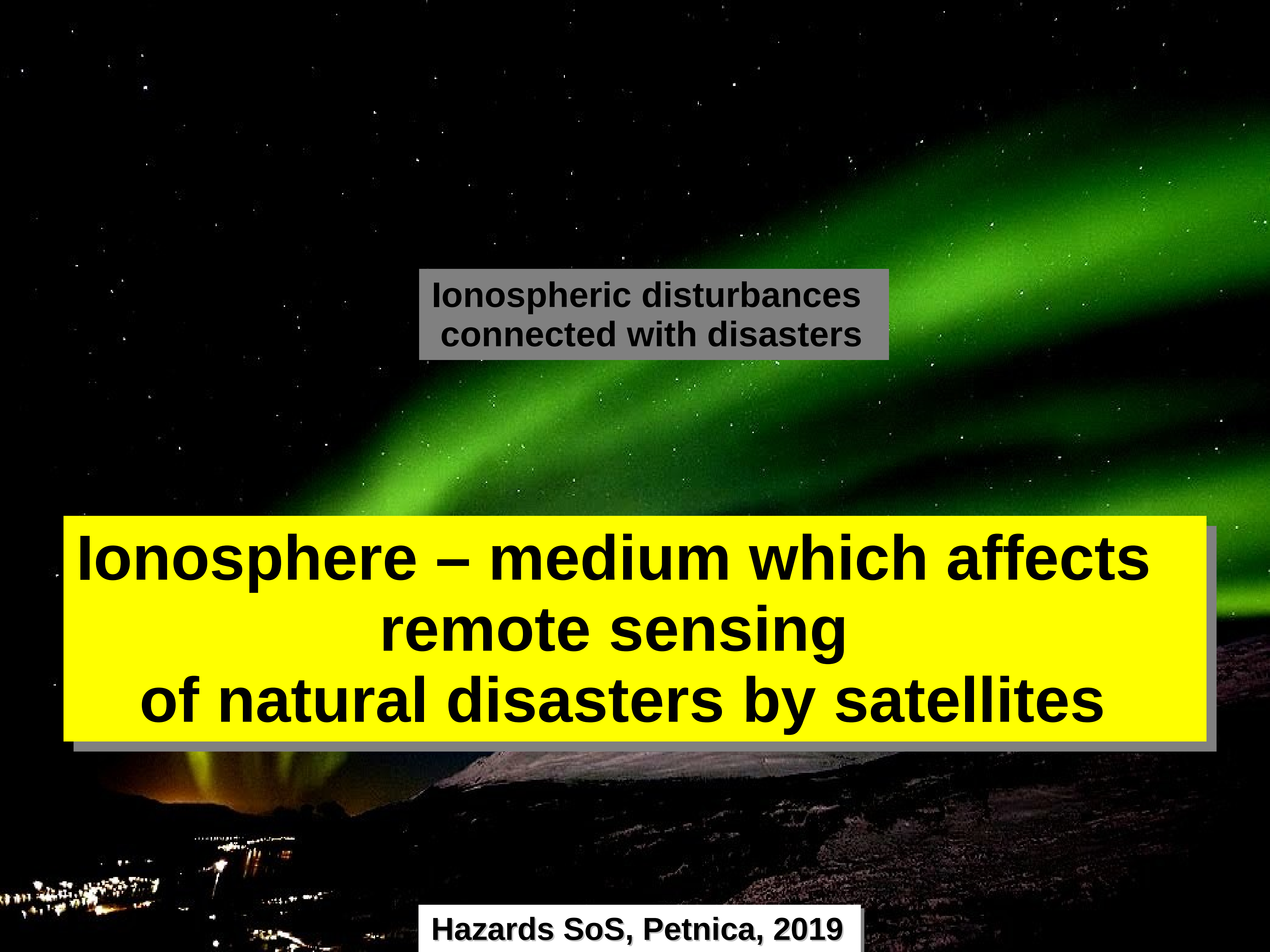
Geophys. Res. Lett., 42, 8250–8261

Detection of short-term response of the low ionosphere on gamma ray bursts

Aleksandra Nina[1], Saša Simić[2], Vladimir A. Srećković[1], and Luka Č. Popović[3,4]

MAIN CONCLUSION:

GRBs induce short-term disturbances in the low ionosphere



Ionospheric disturbances connected with disasters

Ionosphere – medium which affects remote sensing of natural disasters by satellites

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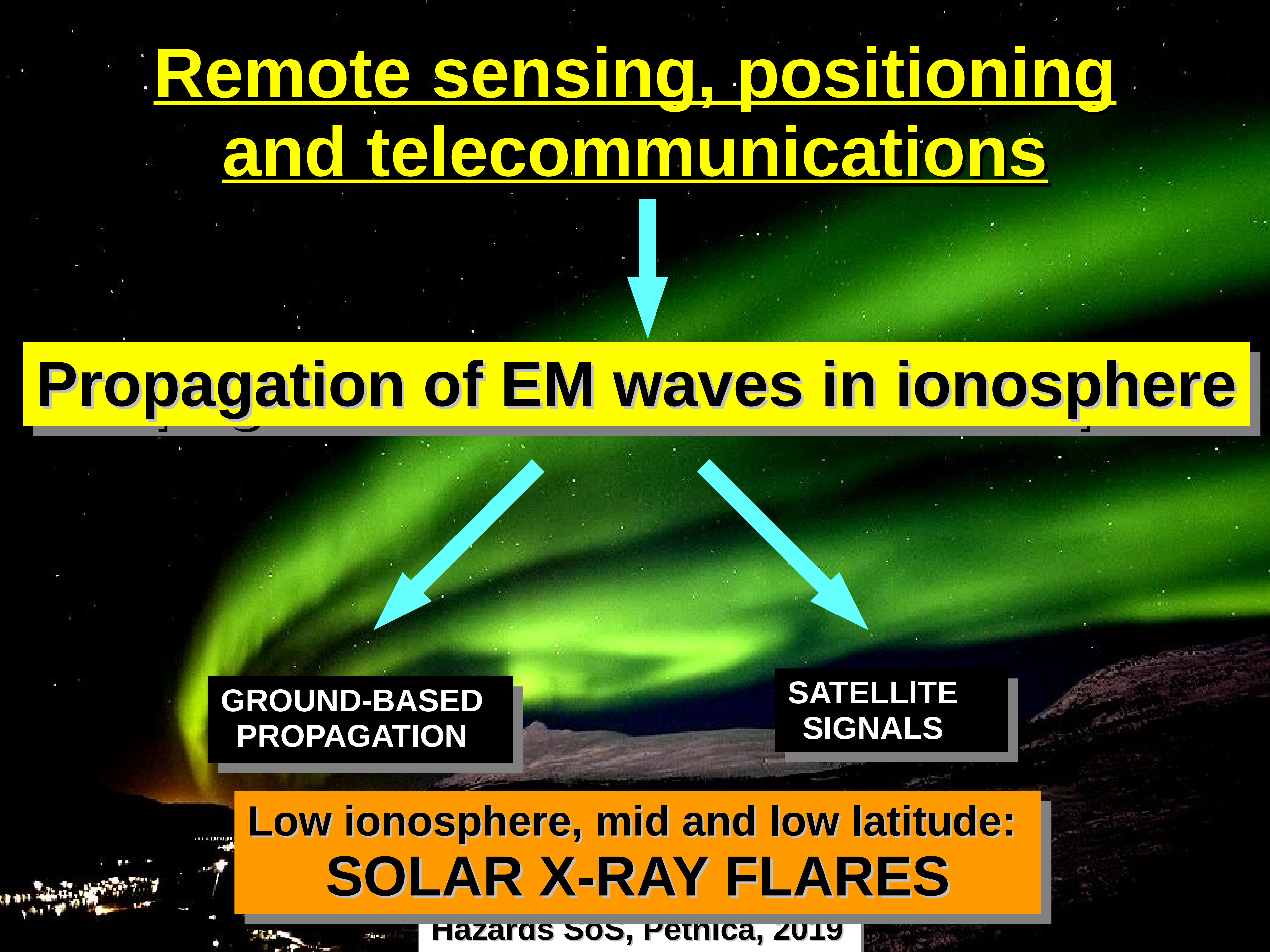
Remote sensing, positioning and telecommunications
Propagation of EM waves in ionosphere
GROUND-BASED PROPAGATION
SATELLITE SIGNALS
Low ionosphere, mid and low latitude:
SOLAR X-RAY FLARES
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- **Modelling of signal propagation significantly depends on the signal frequency *f* because of influence of the collision processes**

GROUND BASED SIGNAL PROPAGATION

Small f

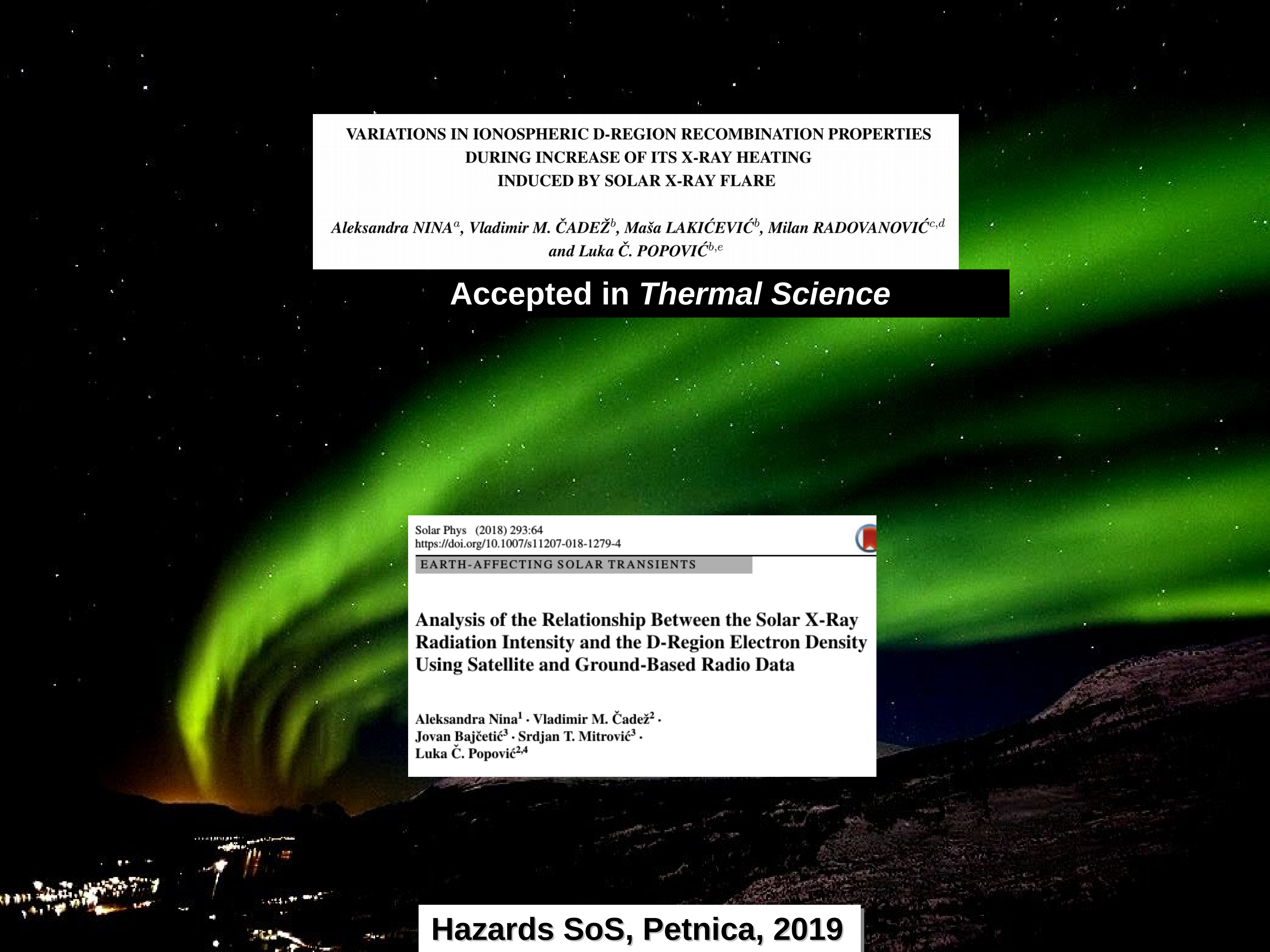
$$n(h,t) = \sqrt{1 - \frac{f_{\mathrm{p}}^2(h,t)}{f^2} \frac{1 + j\frac{\nu(h,t)}{2\pi f}}{1 + (\frac{\nu(h,t)}{2\pi f})^2}},$$

SATELLITE SIGNAL PROPAGATION

Large f

$$n(h,t) = \sqrt{1 - \frac{f_{\mathrm{p}}^2(h,t)}{f^2}}$$

$$\nu = 1.7 \times 10^{-11}[\mathrm{N_2}]\mathrm{T_e} + 3.8 \times 10^{-10}[\mathrm{O_2}]\sqrt{\mathrm{T_e}} + 1.4 \times 10^{-10}[\mathrm{O}]\sqrt{\mathrm{T_e}},$$



VARIATIONS IN IONOSPHERIC D-REGION RECOMBINATION PROPERTIES DURING INCREASE OF ITS X-RAY HEATING INDUCED BY SOLAR X-RAY FLARE

Aleksandra NINA[a], Vladimir M. ČADEŽ[b], Maša LAKIĆEVIĆ[b], Milan RADOVANOVIĆ[c,d] and Luka Č. POPOVIĆ[b,e]

Accepted in *Thermal Science*

Solar Phys (2018) 293:64
https://doi.org/10.1007/s11207-018-1279-4

EARTH-AFFECTING SOLAR TRANSIENTS

Analysis of the Relationship Between the Solar X-Ray Radiation Intensity and the D-Region Electron Density Using Satellite and Ground-Based Radio Data

Aleksandra Nina[1] · Vladimir M. Čadež[2] · Jovan Bajčetić[3] · Srdjan T. Mitrović[3] · Luka Č. Popović[2,4]

Hazards SoS, Petnica, 2019

Upcoming research

- altitude distribution of photoionization maximum
- α_{eff} for whole time period
- T_e for whole time period
- ν for whole time period
- n for whole time period

Propagation path and other calculations

Positioning and Earth observations

Applications

- **Oceans and ice**
- **Changing lands**
- **Emergency response**

Monitoring hydrometeorological and geological events:
landslides, floods, earthquakes, wind and waves (they can be used to track the paths of oil slicks and other pollutants)

Satellite signal propagation

Source	Delay
Satellite orbit	2.5 – 5 cm
Satellite clock errors	up to 2 cm
Satellite hardware delay	1 m
Receiver hardware delay	up to 3 m
Ionospheric delay	3 – 5 m
Tropospheric delay	2.3 m
Multipath	6 cm
Phase center variation and offset	1 cm

Wautelet, G. (2013). Doctoral dissertation, University of Liège, Liège, Belgium and references therein

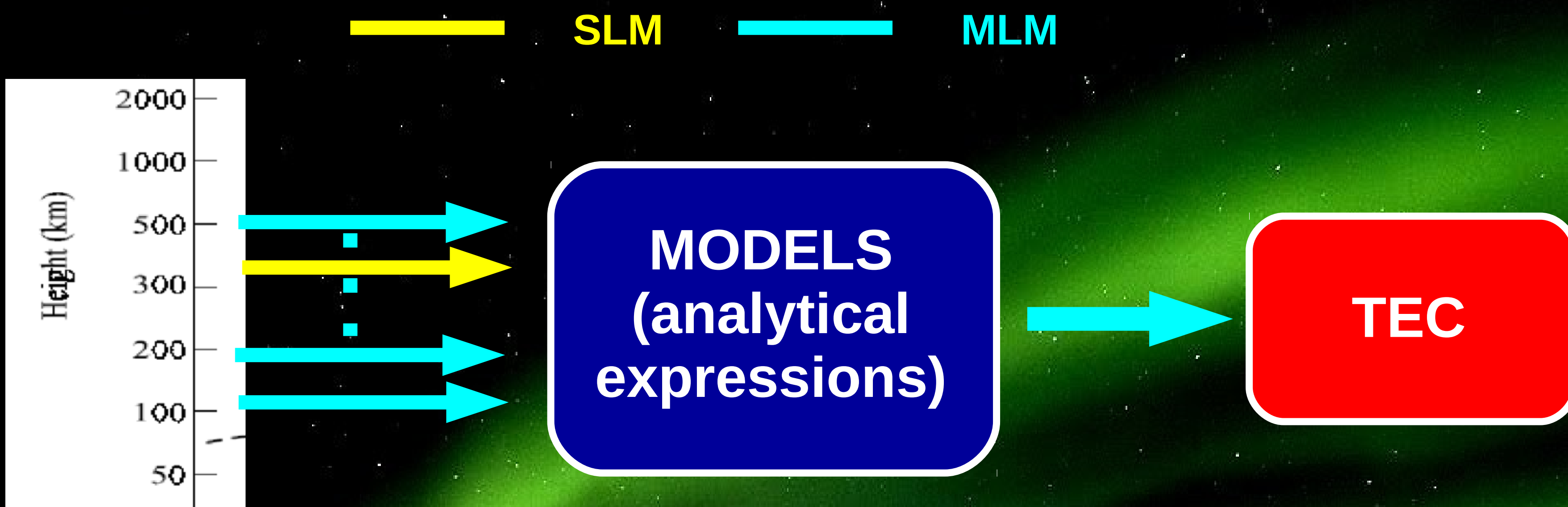
- **The ionosphere has the largest influence on the delay.**

- **The delay of 1 cm is included in modeling.**

Ionospheric influence on satellite signals: modelling and problems

- **Determination of ionospheric delay is based on calculation of the total electron content (TEC)**
- **Lack of data for the electron density with enough good space and time resolution: many approximations must be included in modelling of TEC.**
- **Approximations in the electron density space distribution:**
  - **SLM (it is assumed that all free electrons are concentrated in an infinitesimally thin layer at a fixed height in F-region)**
  - **MLM (for example up to the peak of the F2 layer, the NeQuick uses a profile formulation which includes five semi-Epstein layers (above 90 km) with modelled thickness parameters)**
  - **Models relevant for quiet conditions (IRI)**

TEC is number of electrons between satellite and receiver along a tube of 1 m^2 cross section



- Are these expressions applicable during intensive disturbances?
- Can local disturbances (localized altitude domain) be important?

Our study: Can the D-region delay be important for modelling?

Some events primarily disturbs the low ionosphere

D-region electron can be increase two orders of magnitude and input parameters are unchanged

Can the perturbed low ionosphere sufficiently affect the GNSS and SAR signals so that the inclusion of the D-region in models becomes necessary for measurements?

D-region contribution in delay

IEEE GEOSCIENCE AND REMOTE SENSING LETTERS

Accepted paper

GNSS and SAR signal delay in perturbed ionospheric D-region during solar X-ray flares

Aleksandra Nina, Giovanni Nico *Senior Member, IEEE,* Oleg Odalović, Vladimir M. Čadež, Miljana Todorović Drakul, Milan Radovanović and Luka Č. Popović

MAIN CONCLUSION

The perturbed D-region can significantly affect GNSS and SAR signals

Summary

- Analyses based on data collected by the Belgrade VLF/LF receiver station
- Detection of the low ionospheric variations in period of natural disasters and high energy EM radiation
- Influence of intensive low ionospheric disturbances on EM wave propagation – telecommunication, positioning, Eath observation

ASTRONOMERS
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...

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Magnetosphere
Ionosphere F-region
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...

Thank you for your attention!