How using the spectral response of instruments in flaring conditions affects the modelling of the impact of flares on the ionization rate in the ionospheric D-region

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Objectives

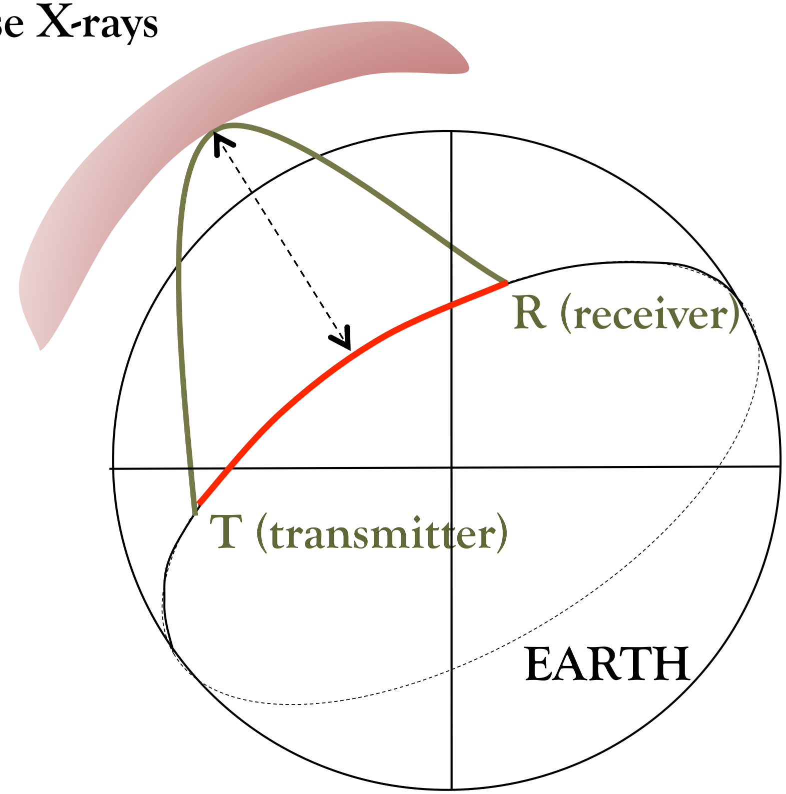
- To assess the impact of solar flares on the lower ionosphere: 50-100 Km height
- Mean:
  - combine space-based irradiance measurements and Earth-VLF transmission
  - understand how the response of the various instruments affect the measurements
  - compare our estimation of electron density to models (LWPC from Naval Ocean System Center)

Radiowave propagation

(Supported by NOSC **LWPC**)

D region (50-100 km):

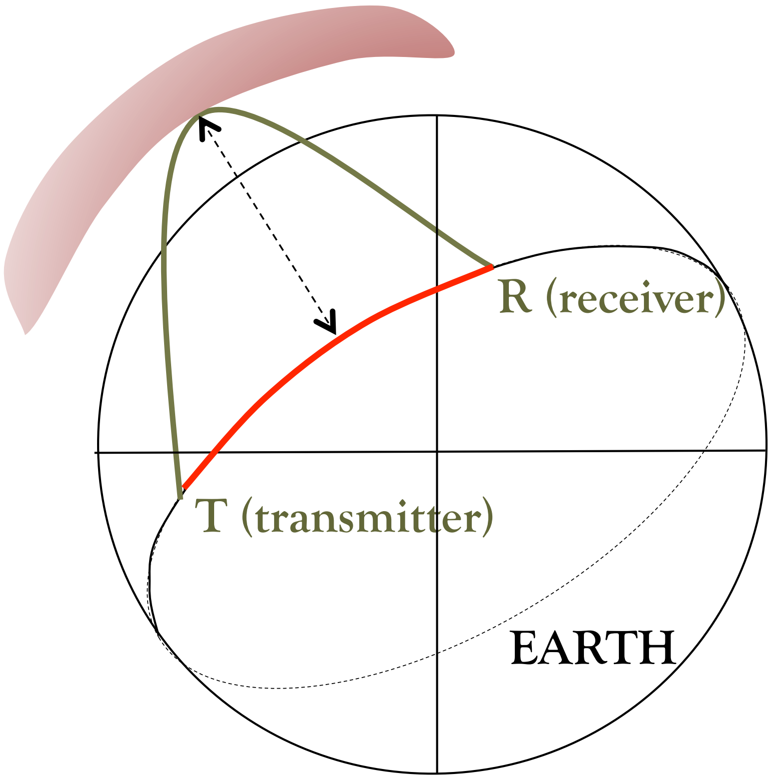
- **reflects radio waves with frequencies < 30 kHz (VLF)**
- **produced by lyman-α and during solar flares by the intense X-rays**



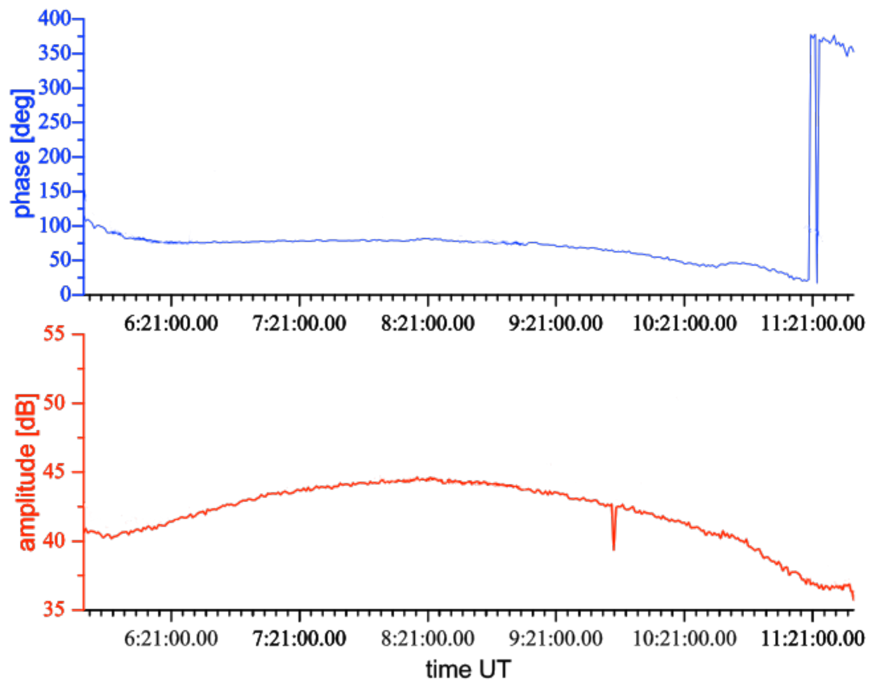
Transmitter:
North-West Cape / 19.8 kHz (21.S,114.2 E)

Receiver:
Belgrade AbsPAL
Measures phase and amplitude disturbances (44.85 N, 20.38 E)

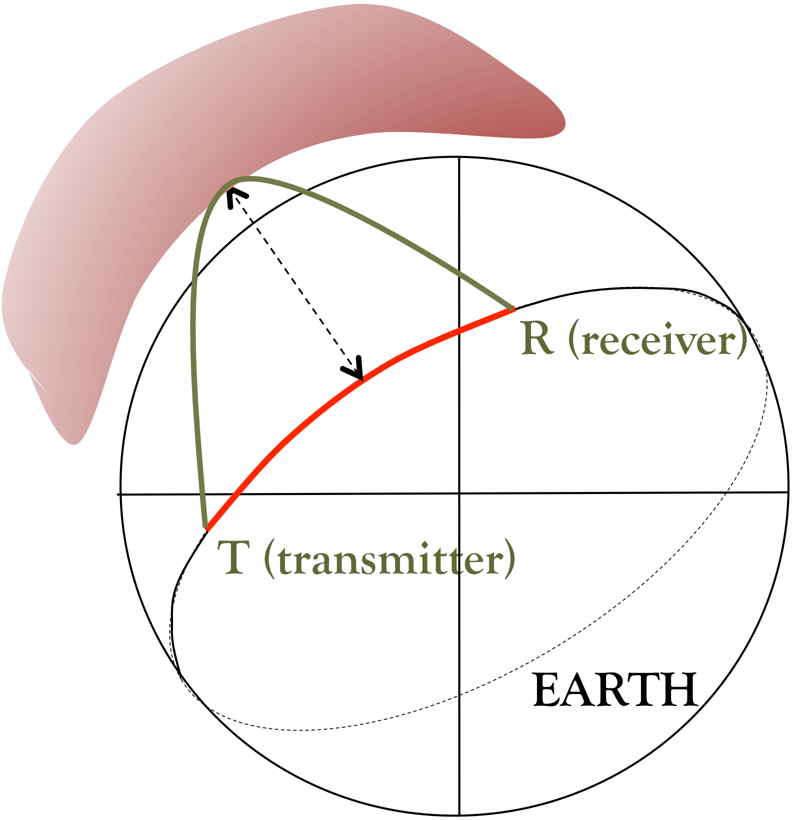
Flare impact on radiowave propagation



Measured variations of phase and amplitude on the **NWC-Bgd** path on a quiet day 2011/02/22 and on a flare active day 2011/02/18.



Flare impact on radiowave propagation



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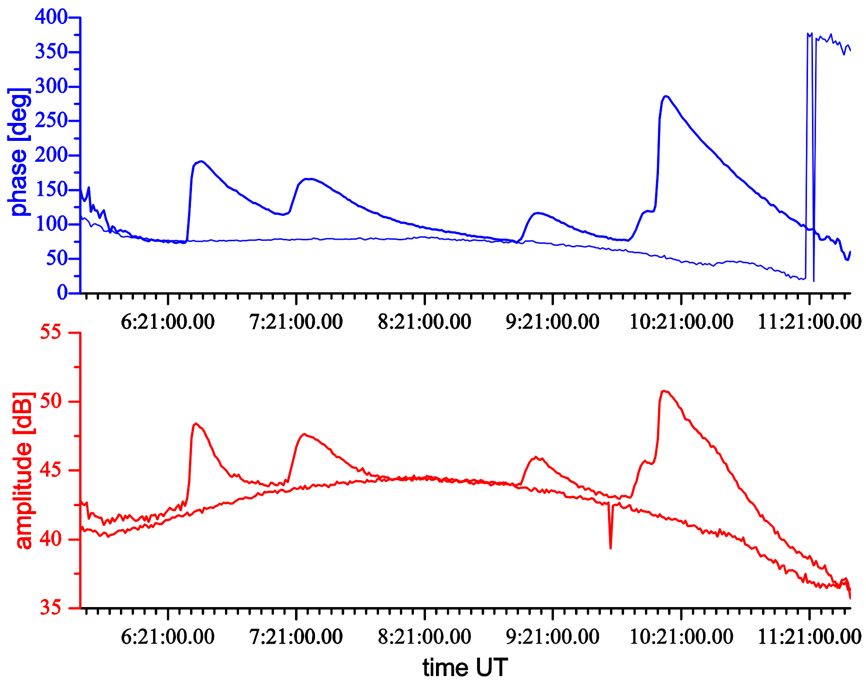
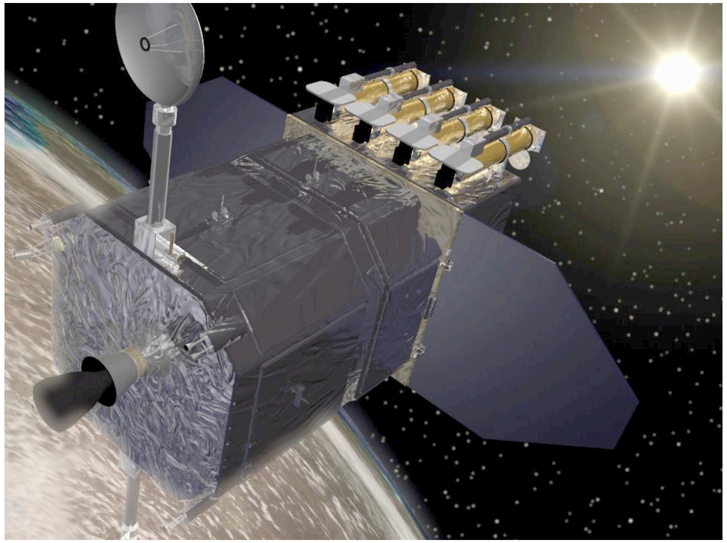


www.proba2.sidc.be

Zr channel of LYRA: 1-2 + 6-20nm

lasp.colorado.edu/home/eve/



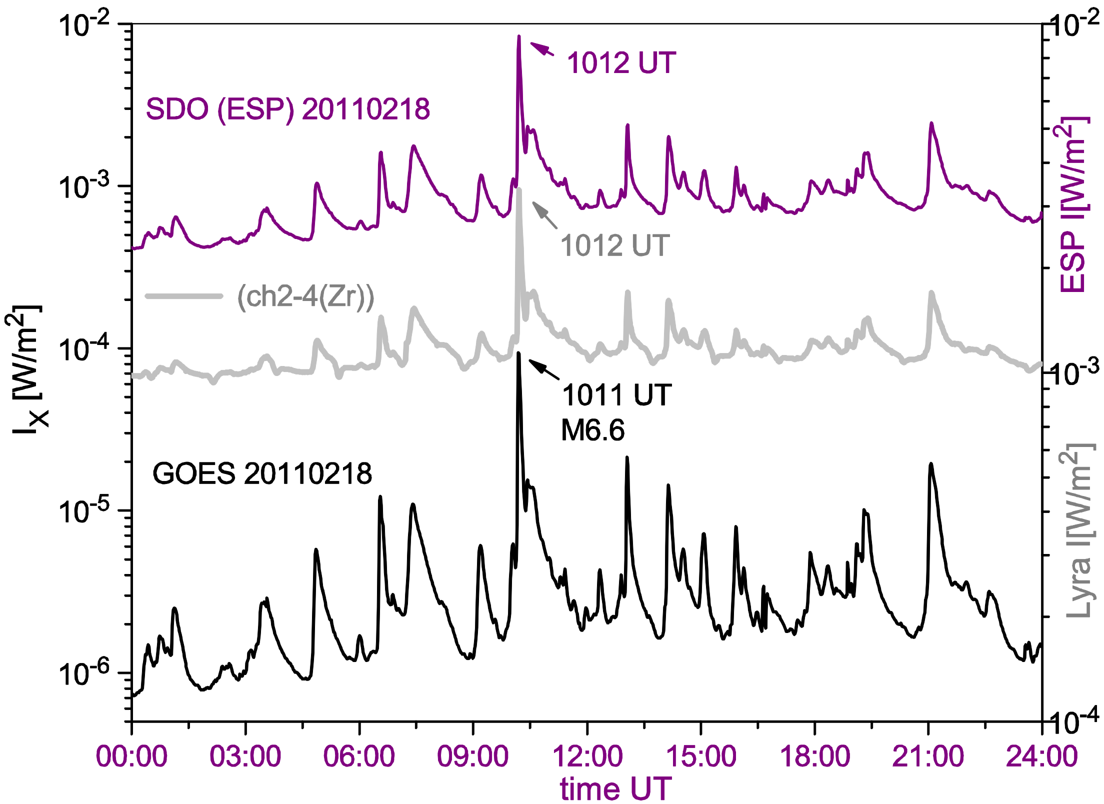
Channel 1 of EVE: 0.1-7nm

www.swpc.noaa.gov

GOES: 0.1-0.8nm

Observations of solar flares

2011/02/18 highly active day



SDO/ESP

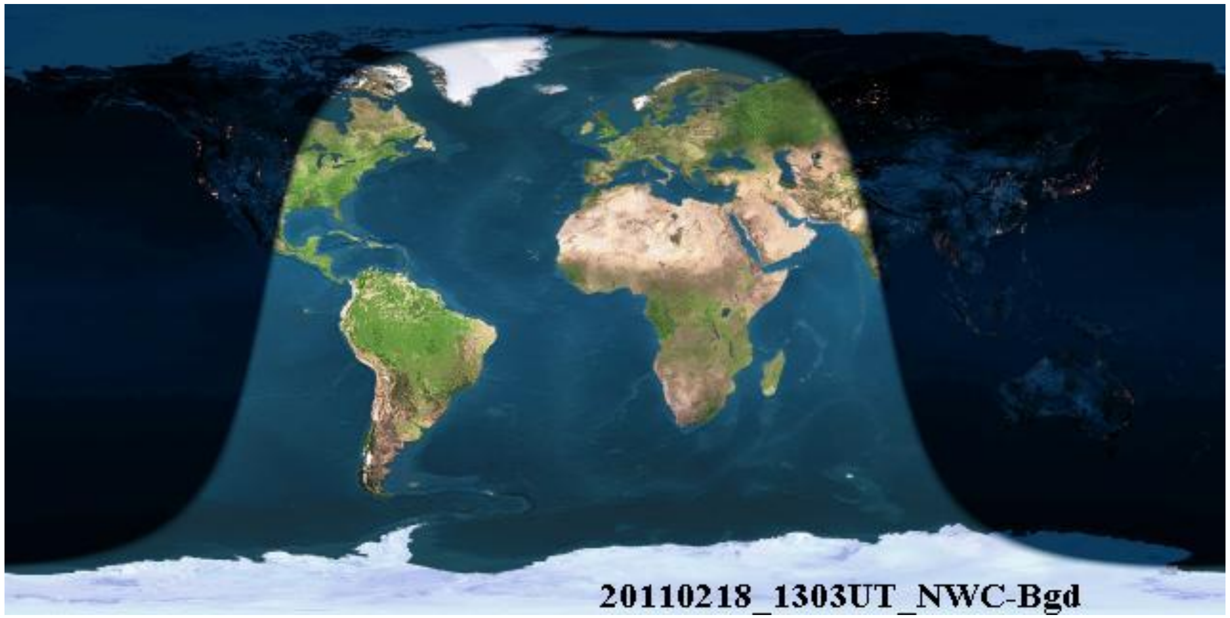
PROBA2/
LYRA

GOES

VLF observability of flares needs a **sunlit** signal path

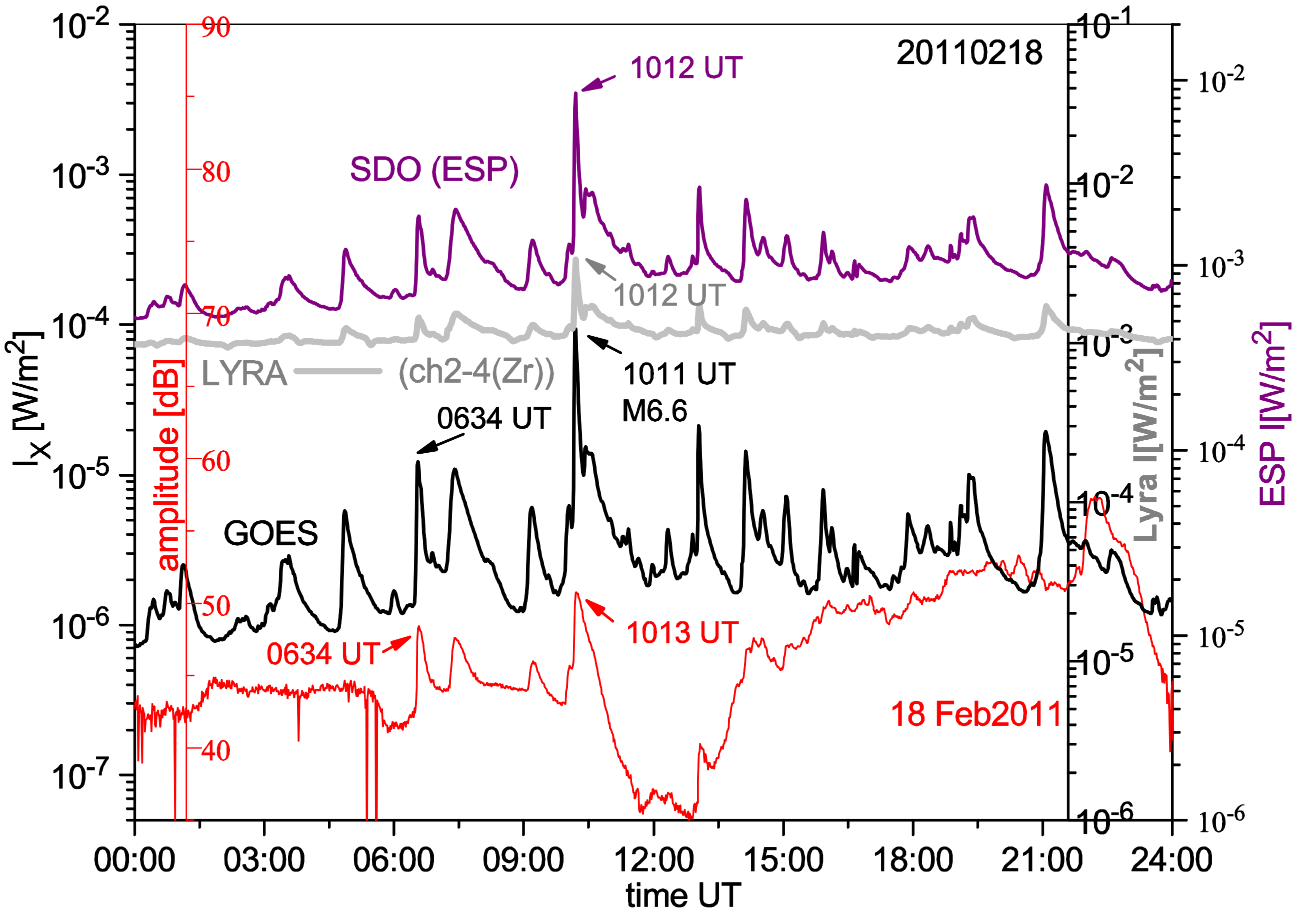
M6.6_1011 UT

M1.4_1303 UT



In correlation with VLF observations from Earth

2011/02/18



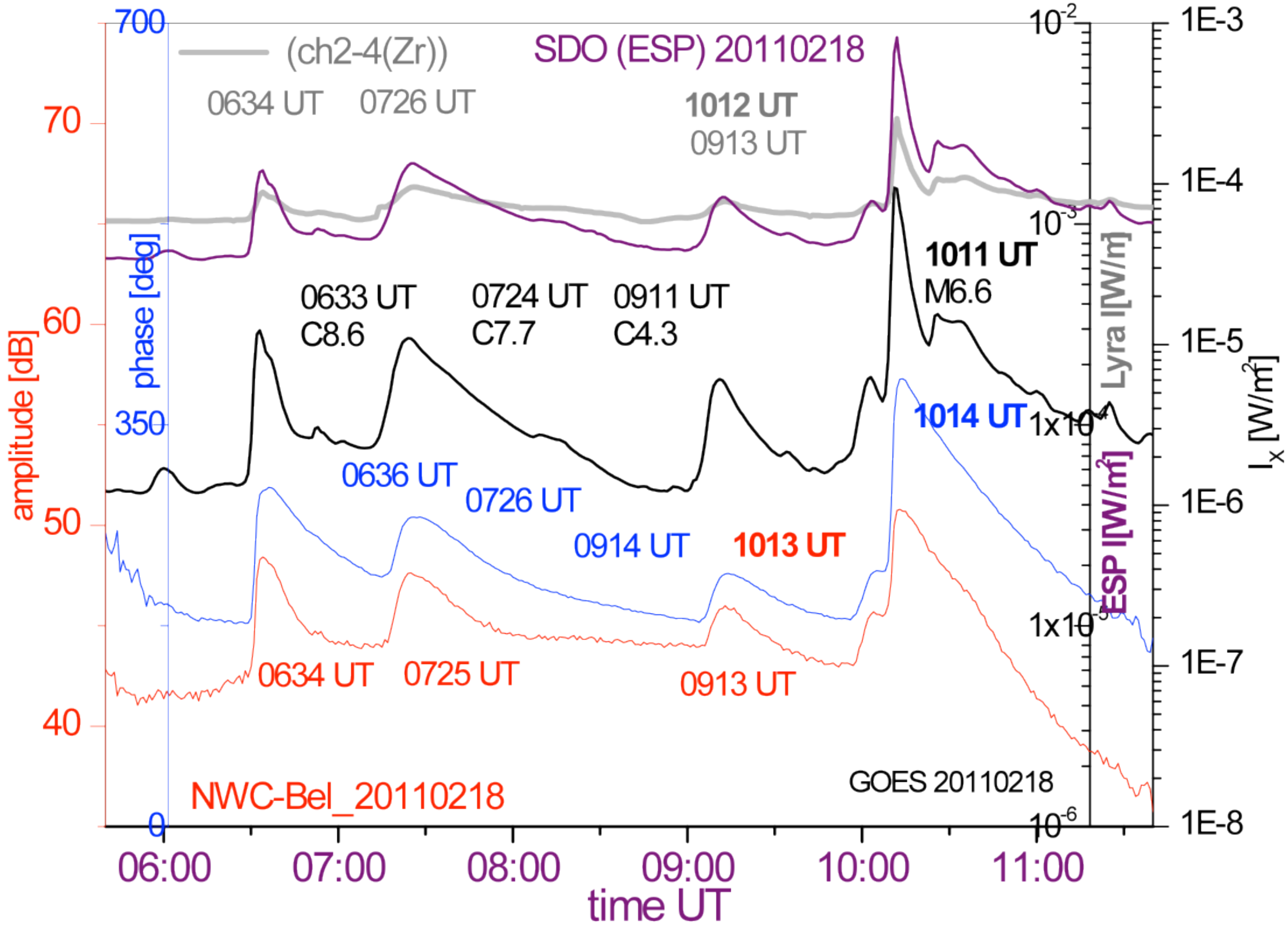
SDO/ESP

PROBA2/
LYRA

GOES

VLF amplitude

Observations of solar flares



SDO/ESP

PROBA2/
LYRA

GOES

VLF phase

VLF amplitude

Observations of solar flares

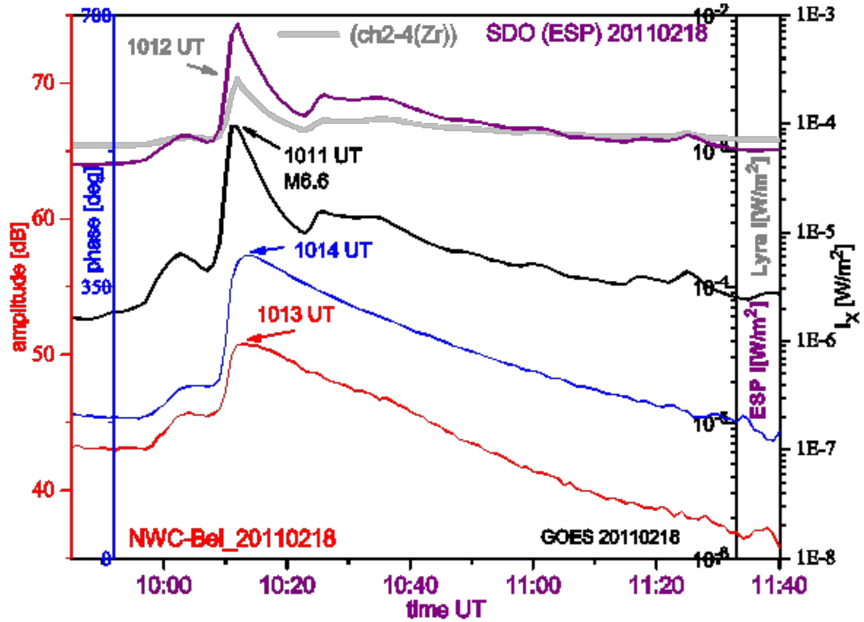
$\Delta t > 0$ ➡

Time delay (*Appleton,1953*, Journal of Atm. Terrestrial Physics *JATP, 3, 282*) "sluggishness"
(time shift of maximum N with respect to regular diurnal flux at $\chi=0$)

$$I(A_{max}) \equiv I(N_{max})$$

$$\Delta t_{A,P} = t_{A,P_{max}} - t_{I_{max}} = t(N_{max}) - t(I_{max})$$

2011/02/18 10:11 UT M6.6



	Δt A (min)	Δt P (min)
ESP	1	2
LYRA	1	2
GOES	2	3

Modelling the induced electron density enhancement

$$\frac{dN(t)}{dt} = q(t) - \alpha N^2(t)$$

With $q(t) = kI(t)\cos(\chi)$

- N = electron density
- q = electron production rate
- α = effective electron recombination coefficient
- χ = solar zenith angle
- k = number of e-i pairs produced per unit energy per unit path length

Determination of α

Time delay, Appleton relation, but for the **active** ionosphere:

$$N(I_{max}) = \frac{1}{2\alpha\ \Delta t} \qquad N_{max} \approx N(I_{max}) + \left.\frac{\partial N}{\partial t}\right|_{I_{max}} \Delta t \qquad (1)$$

$$\frac{dN(t)}{dt} = q - \alpha N^2 \longrightarrow N_{max} = \sqrt{\frac{kI(N_{max})\cos\chi}{\alpha}} \qquad (2)$$

Agreement of (1) and (2) yields: $\boxed{k\alpha\cos\chi = const.}$

Determination of q

$$q(t) = k(h)I(t)$$

I can be measured => q and k pertains to the bandpass of the instrument

Measurements: only available for limited time periods

$\Rightarrow$ use of several instruments

$\Rightarrow$ comparison of several bandpasses

If we know k(h), we know α and q(t)

Determination of q

- Traditionally, I is measured by GOES (narrow bandpass)
- Other instruments with larger bandpasses can be used as well, if we have an idea of the spectral behavior of k and the solar irradiance over the bandpass

  => we estimate the ionization efficiency over the bandpass of the instrument by

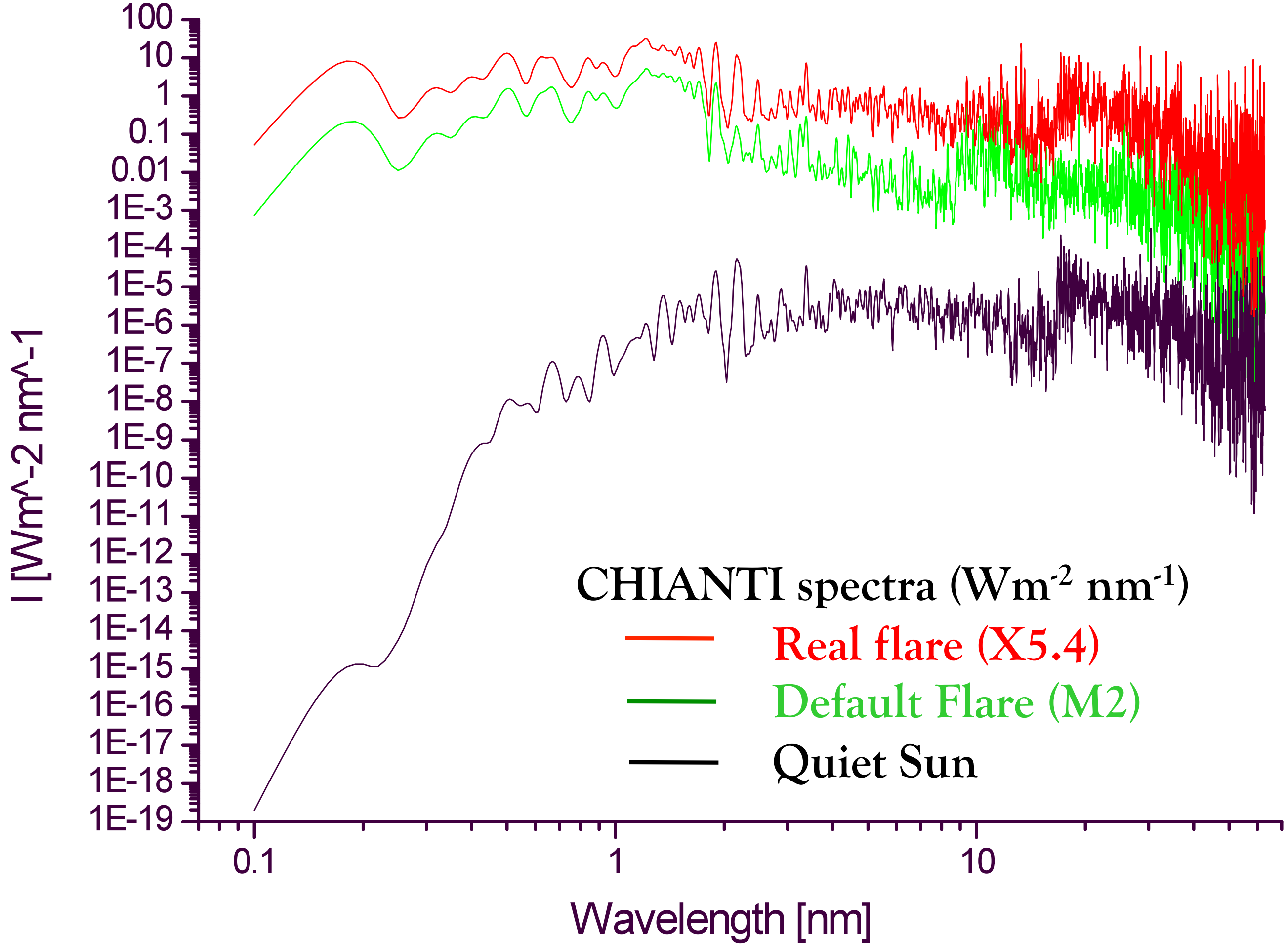
$$k(h) = \frac{\int_{\lambda_1}^{\lambda_2} k_\lambda(\lambda, h) \; I_\lambda^{(Ch)}(\lambda) \; d\lambda}{\int_{\lambda_1}^{\lambda_2} I_\lambda^{(Ch)} d\lambda}$$

where $I_\lambda^{(Ch)}$ is the CHIANTI modeled spectral irradiance at flare conditions and λ_1 and λ_2 determine the relevant wavelength domain.

Spectral irradiance

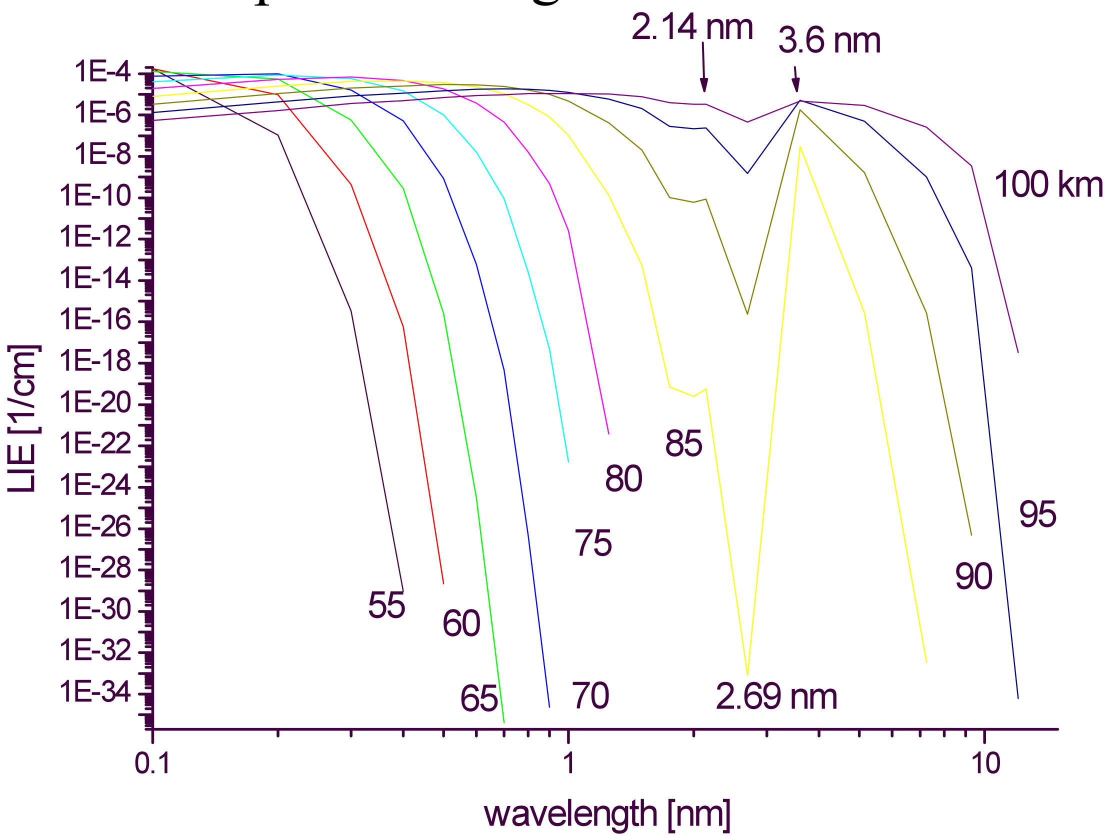
- We used the default flare spectrum from CHIANTI

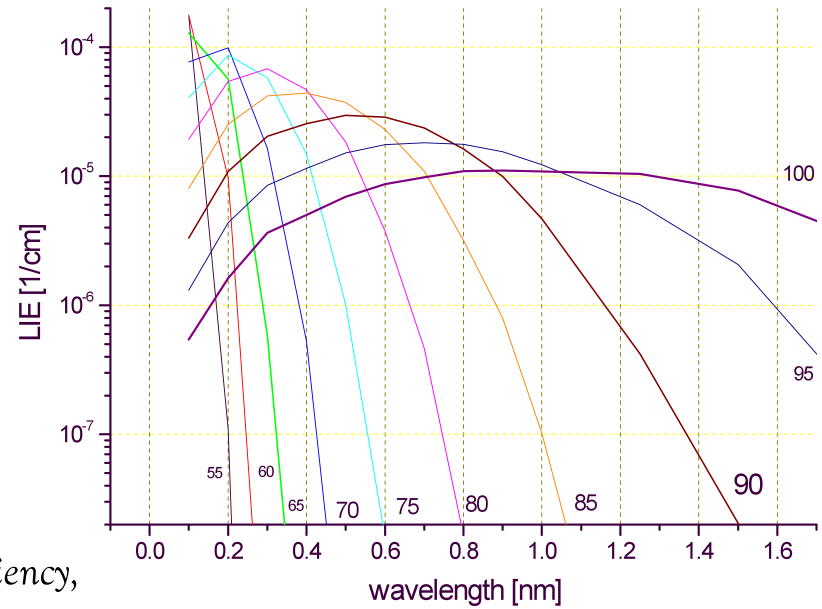
Severe changes in the spectral irradiance wavelength dependence for quiet and flare conditions



Determination of k

LIE [1/cm] - the number of electron ion pairs per one photon per unit length.



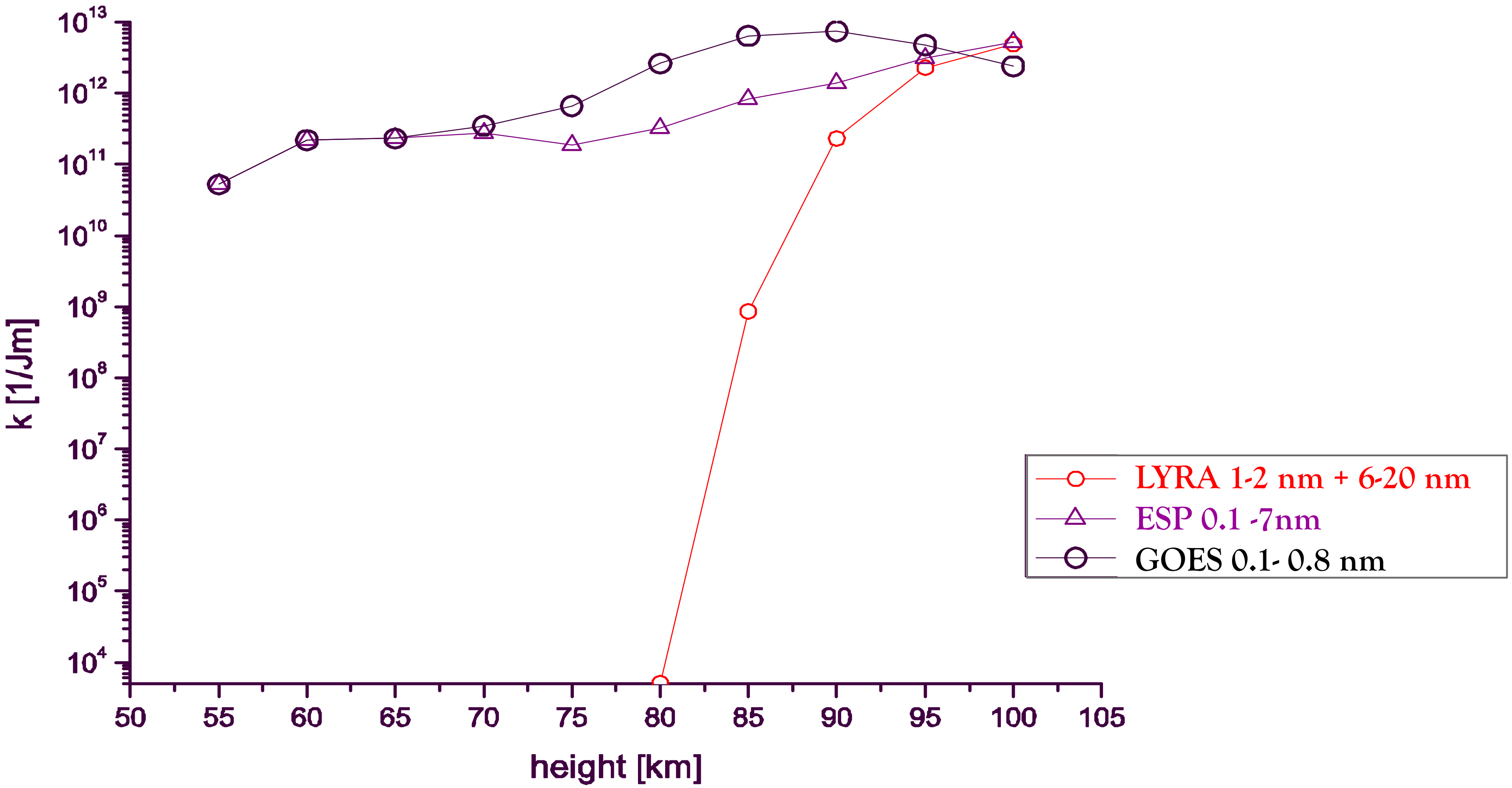


Ohshio M, et al. 1966 *Height distribution of local ionization efficiency*, Journal of the Radio Research Laboratories, *13, no 70, 245- 261*

LIE estimated over the altitude range 30-300 km and for wavelength from 0.01 to 137.5nm.

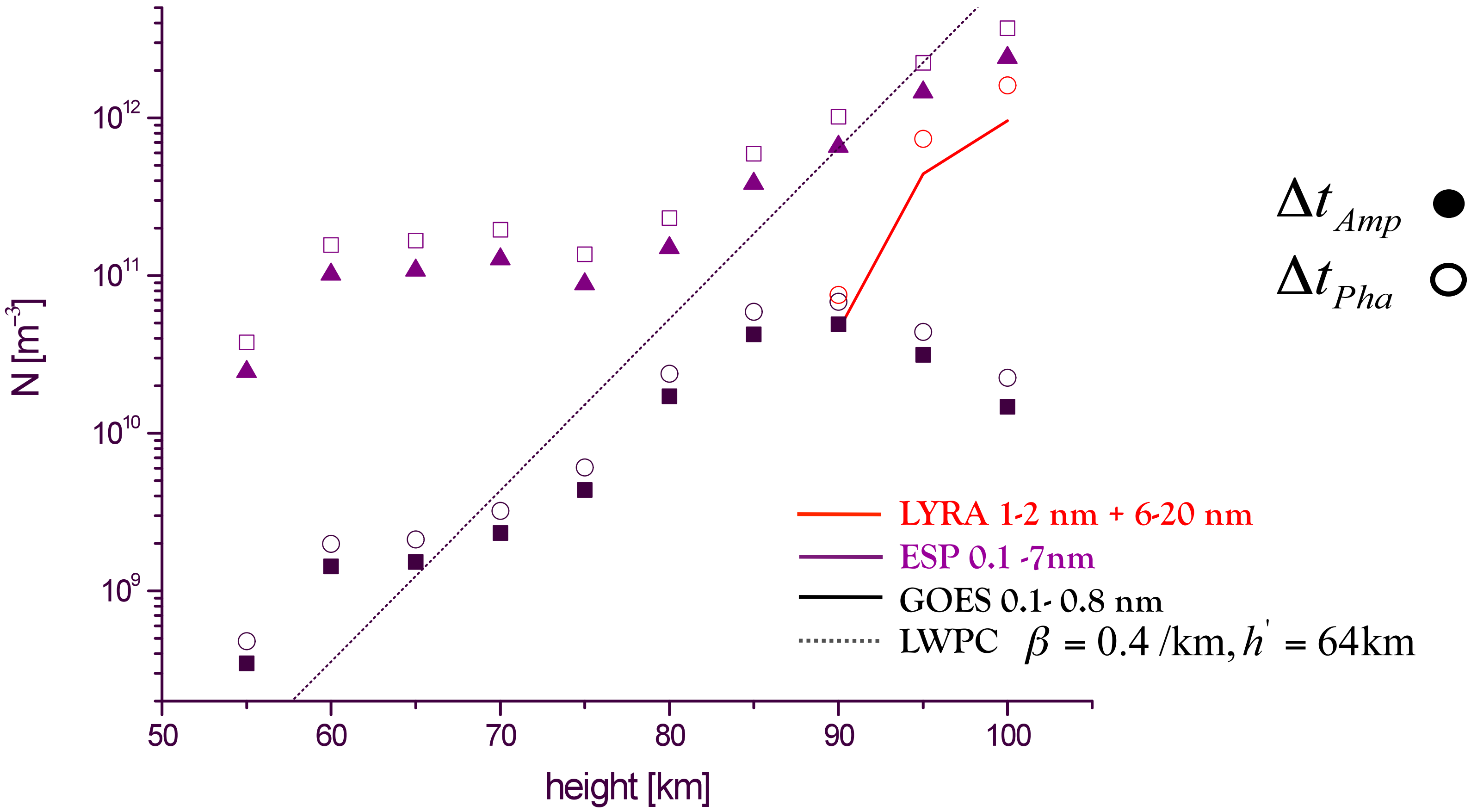
Results

Height distribution of ionization coefficient ***k***



Results: flare M6.6 18/02/2011

Height distribution of flare induced maximum electron density $\mathbf{N}_{\mathbf{max}}$



THANK YOU!!!

- To the PROBA2 Guest Investigator Programme
- To G. DelZanna and the CHIANTI team
- To the STCE/ROB
- To UNG

And the courageous audience attending the first talk of the morning!!!!