

Solar Flare Impacts on Lower Ionosphere

A statistical study

Laura A. Hayes

Oscar O'Hara, Sophie Murray & Peter Gallagher

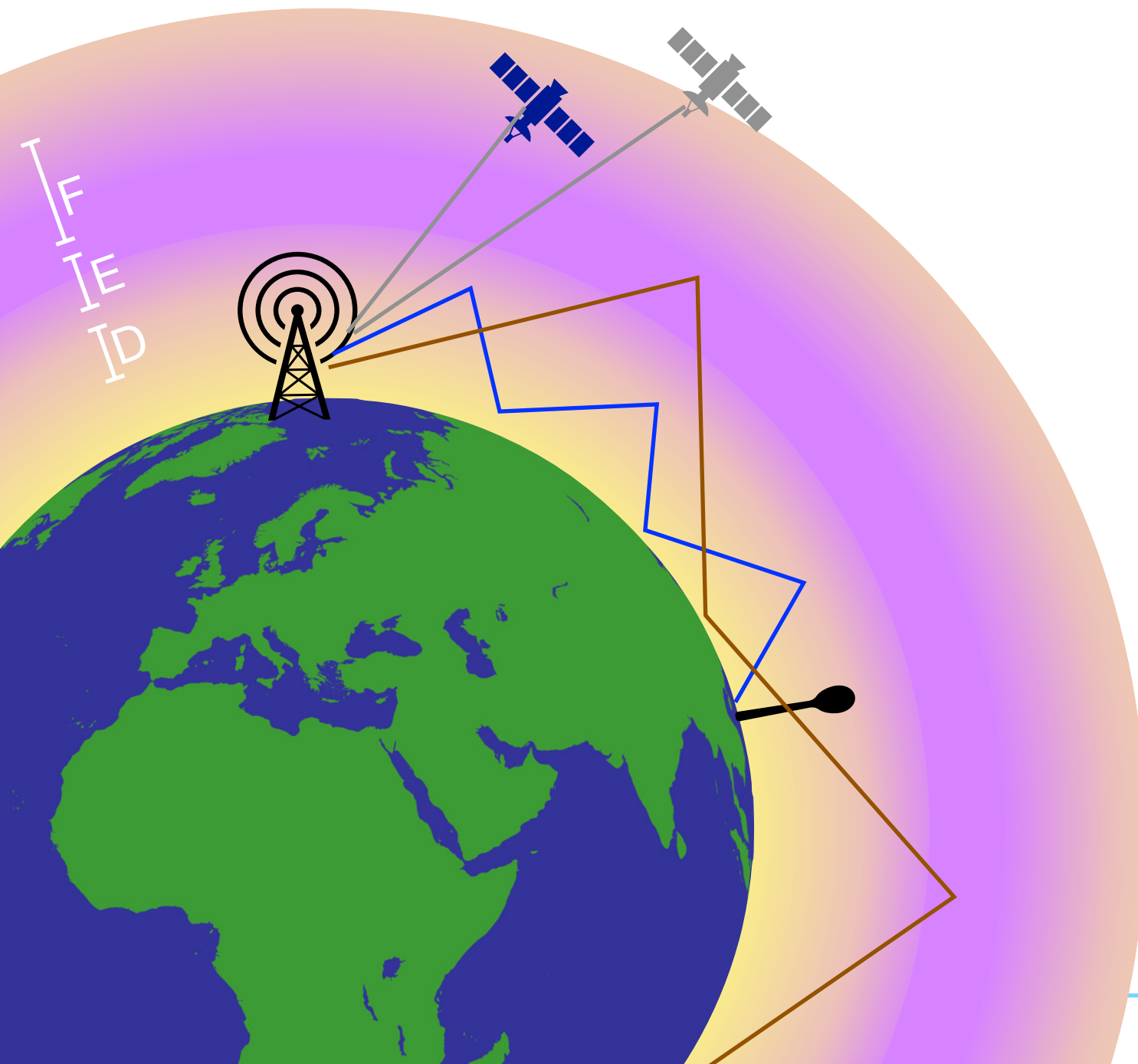
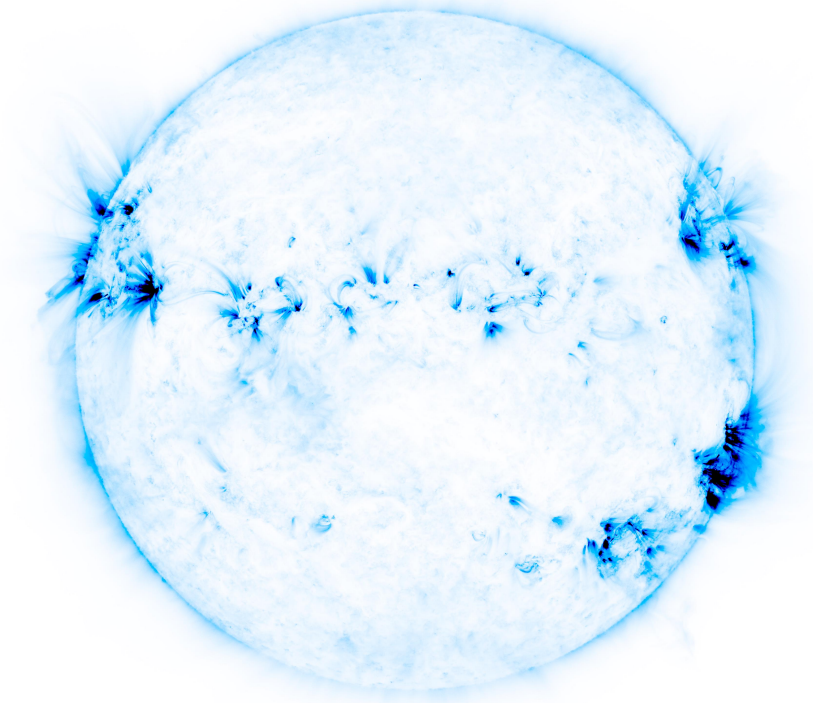
ESPM-16 Sept 7 2021

 @laura_hayess

 hayesla@tcd.ie

Earth's Ionosphere

Linked to the Sun

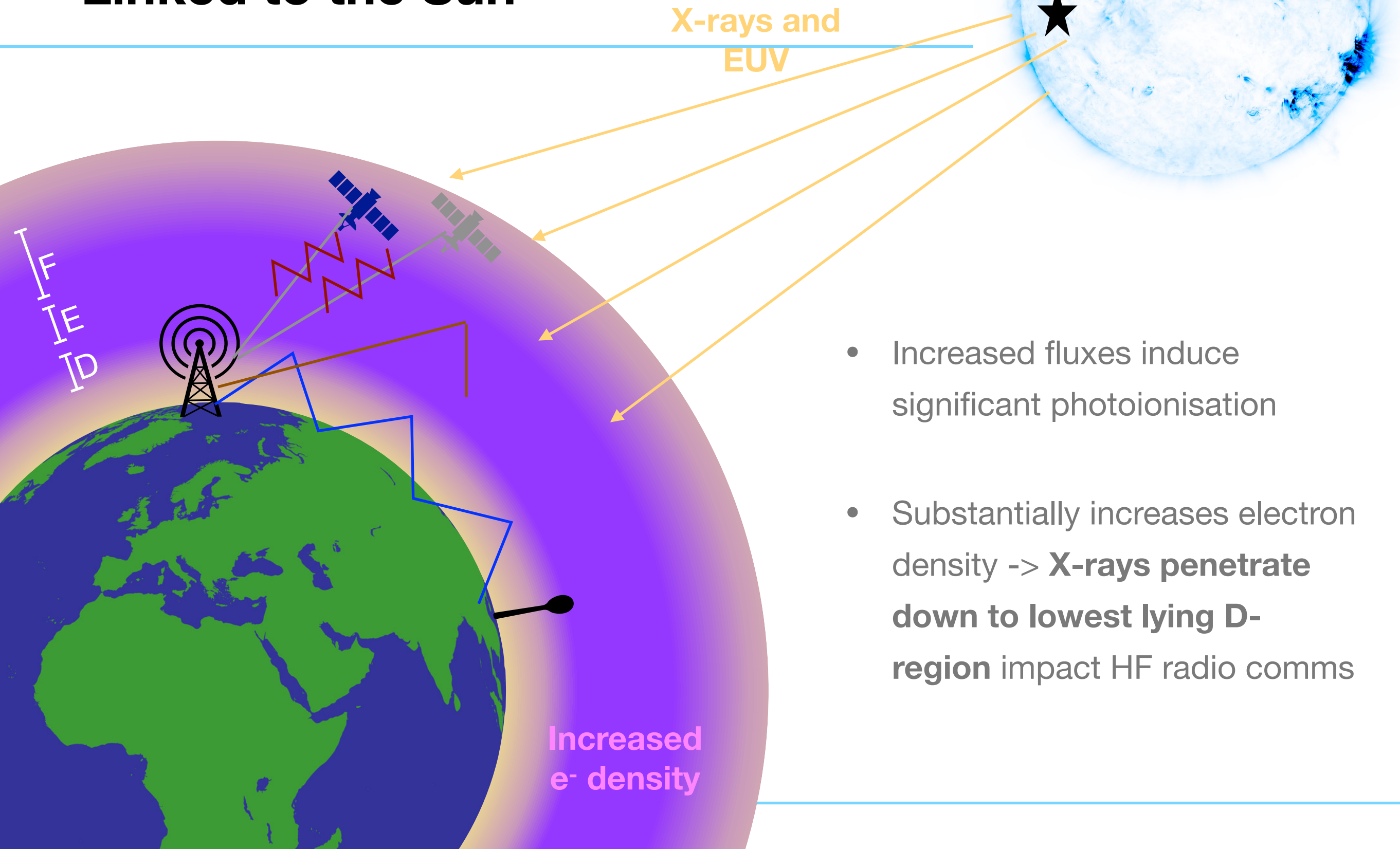


- Ionosphere plays a governing role in radio communications (e.g. GPS, HF comms)
- Critical frequency in which wave will reflect is dependent on the electron density N_e

$$f_{critical} \propto \sqrt{N_e}$$

Earth's Ionosphere

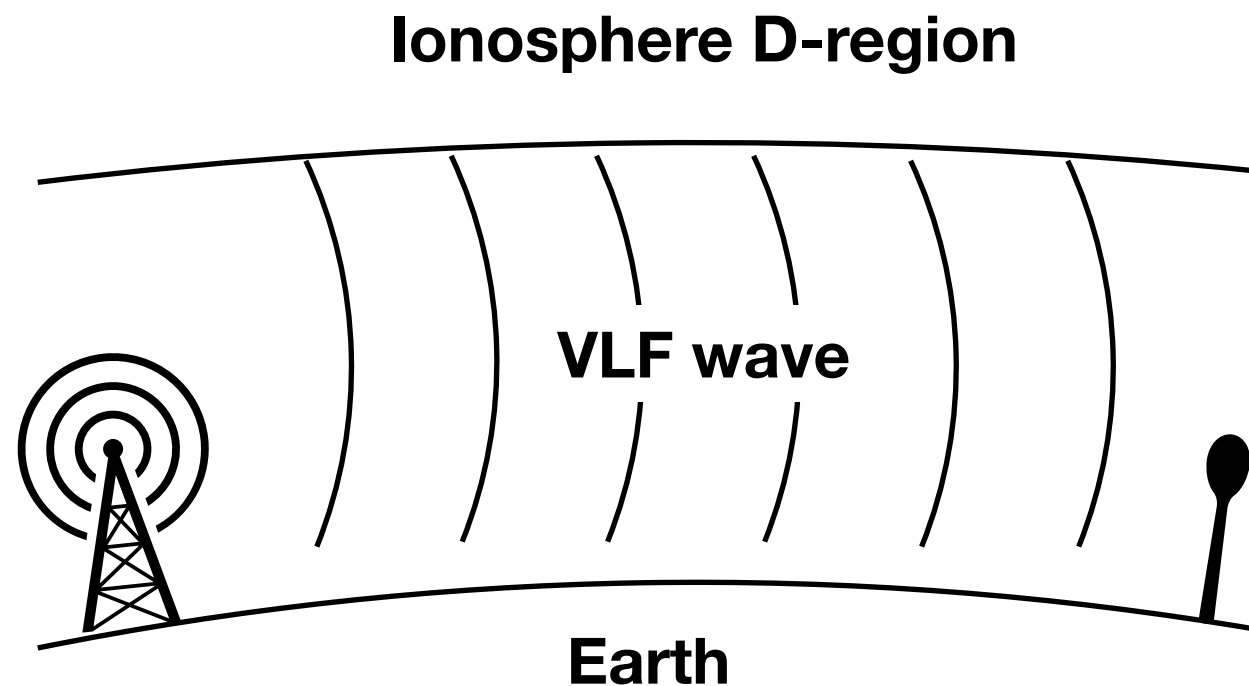
Linked to the Sun



Solar flare impacts on D-region

Lowest lying region

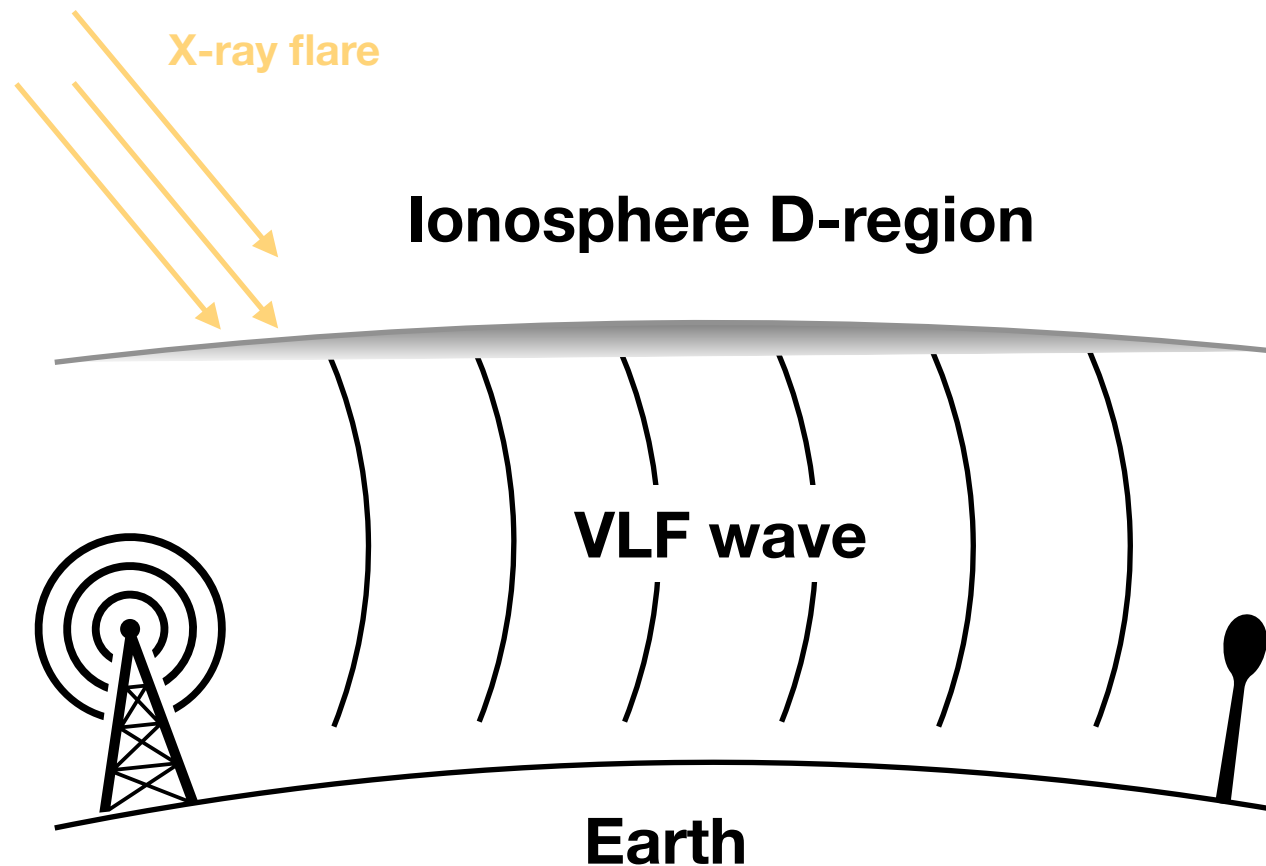
- D-region formed during the day by Lyman- α (121.6nm) acting on neutral Nitric Oxide (minor constituent)



- Very Low Frequency (VLF 3-30kHz) waves propagate in wave-guide
- Large (1MW) Navy transmitters are used for global submarine comms!

Solar flare impacts on D-region

Lowest lying region



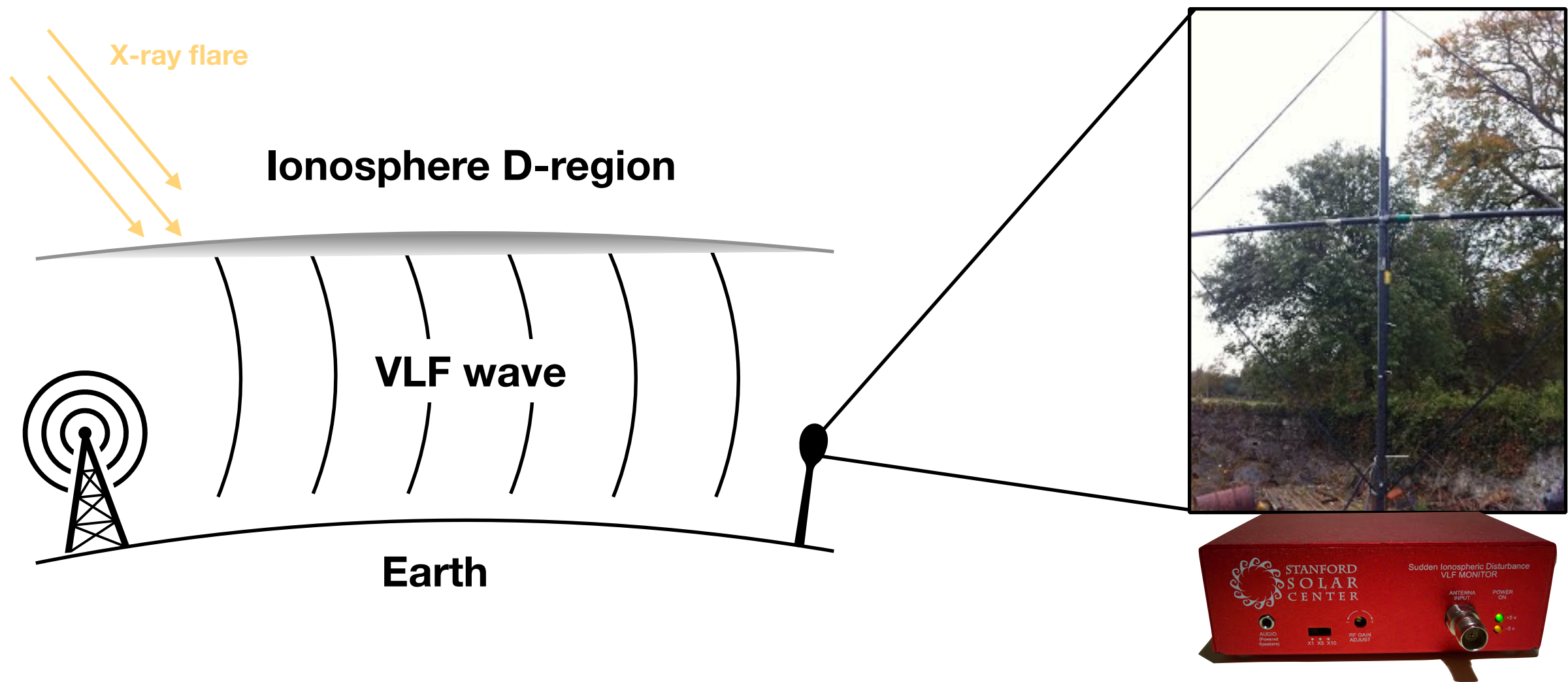
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- D-region formed during the day by Lyman- α (121.6nm) acting on neutral Nitric Oxide (minor constituent)
- During flare X-rays $< 1\text{nm}$ ionise N_2 and O_2 (dominant particles)

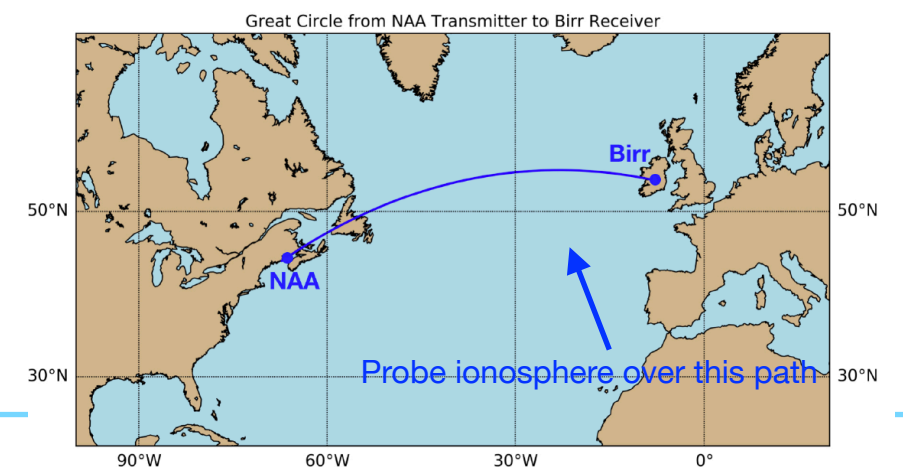
**Significantly changes
electron density =
changes propagation
conditions for VLF waves**

Solar flare impacts on D-region

Lowest lying region

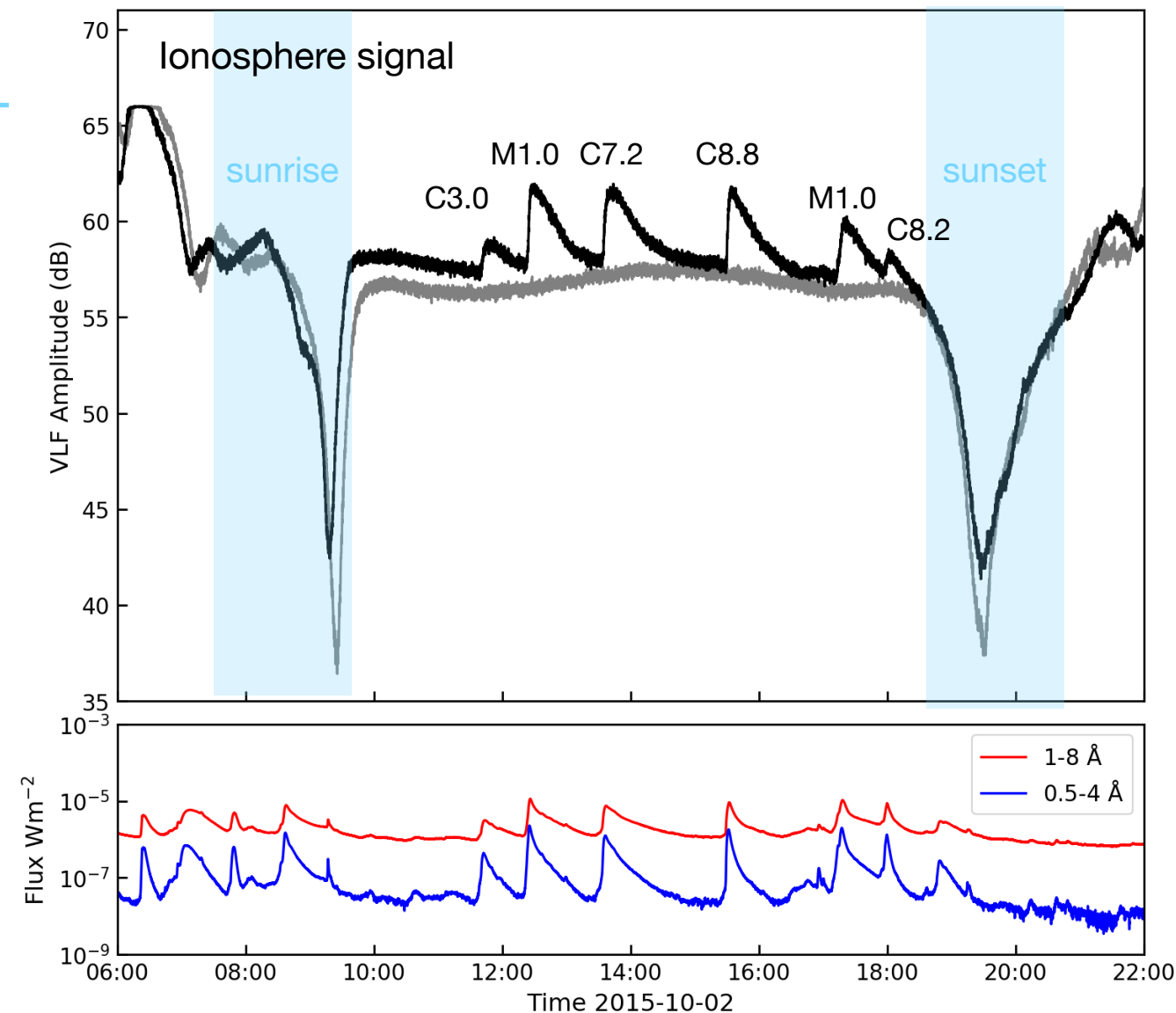
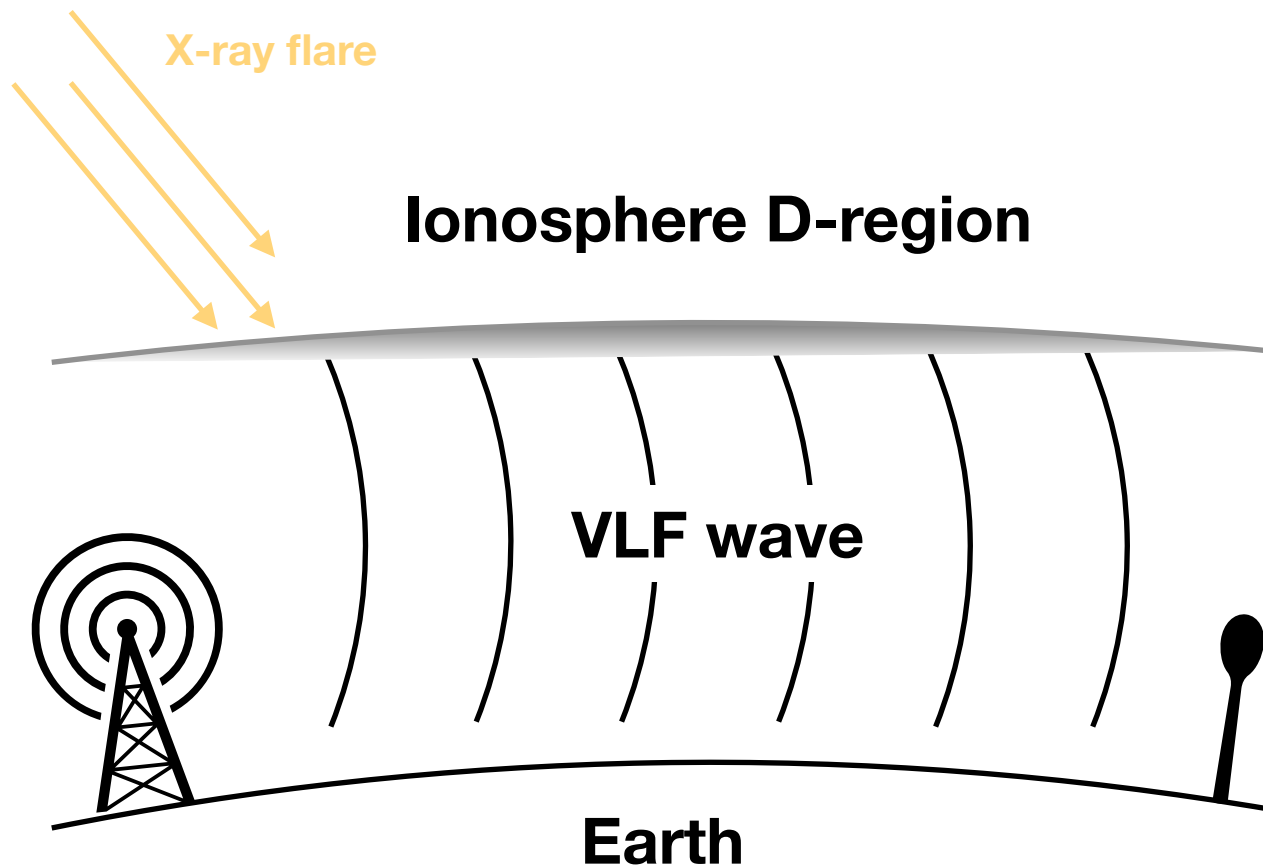


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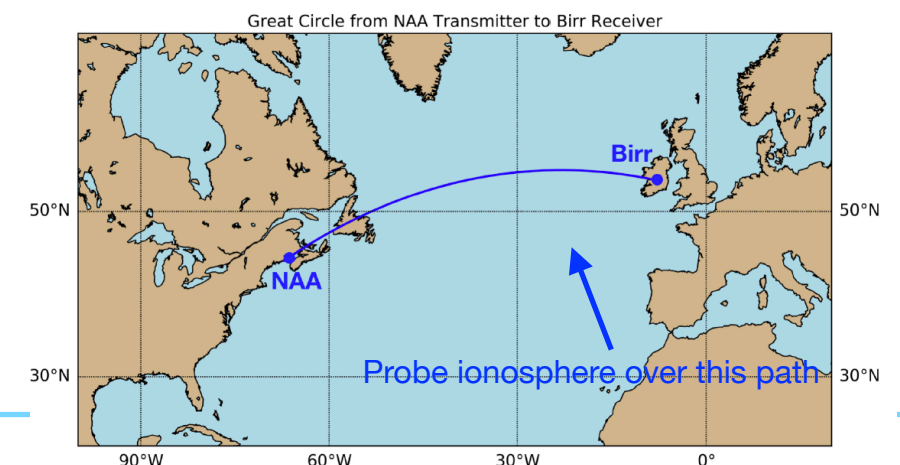


Solar flare impacts on D-region

Lowest lying region



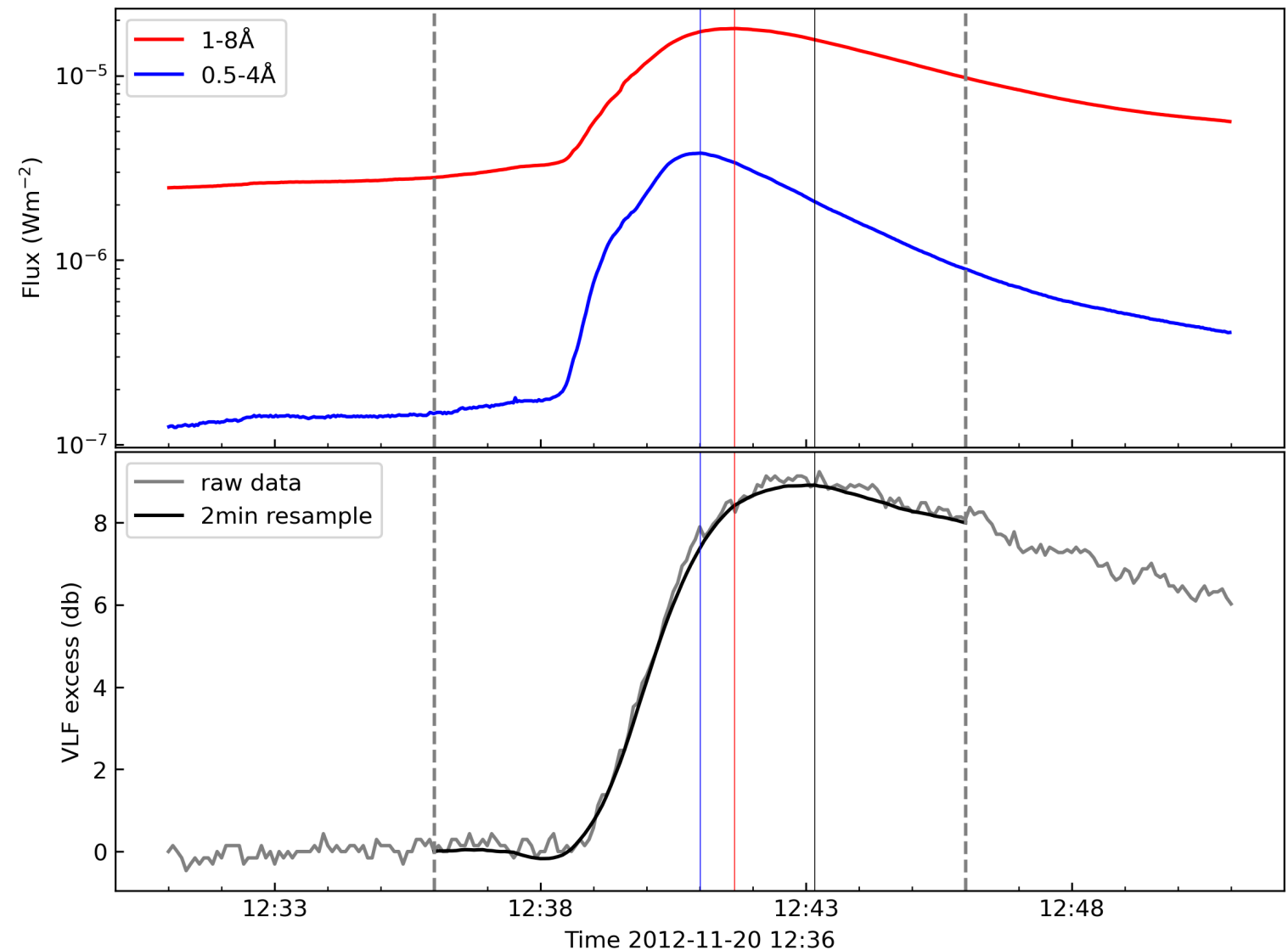
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Statistical Flare Analysis

Overview

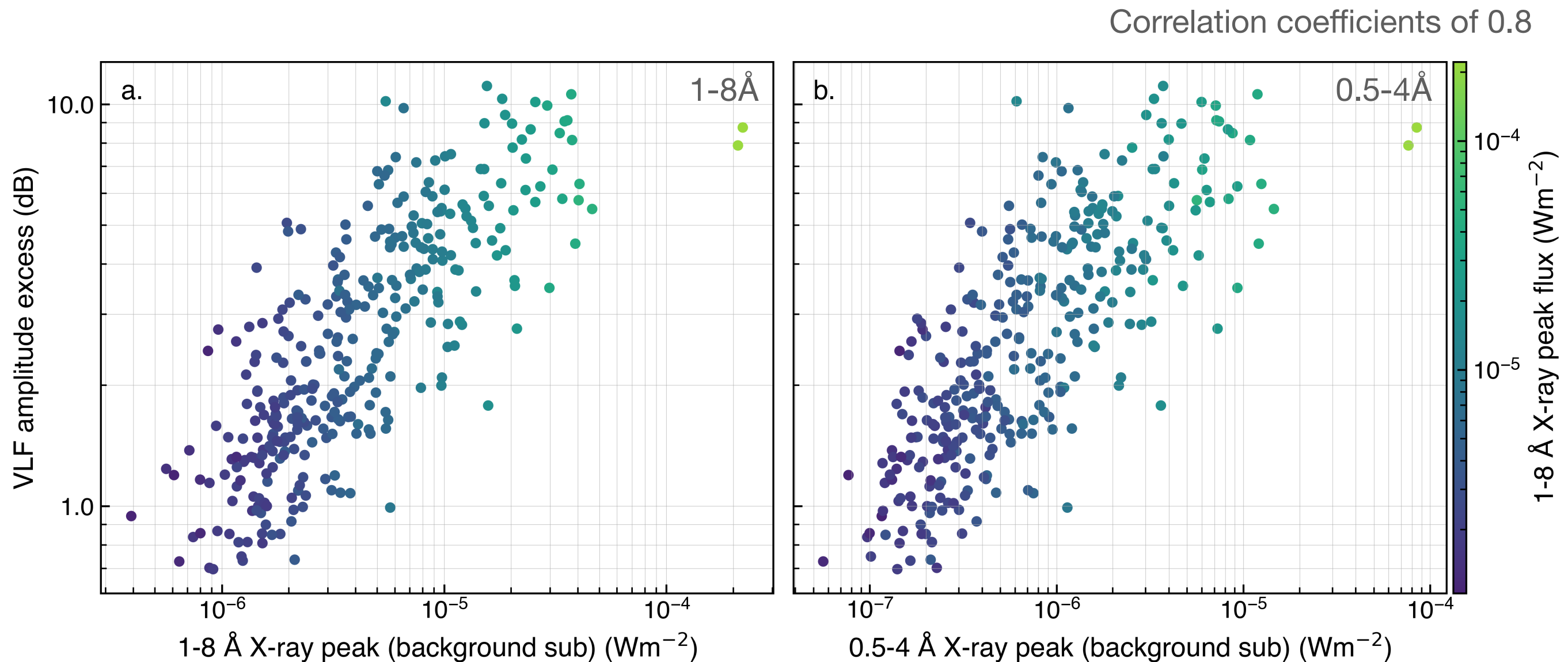
- VLF at Birr has been recording since 2012 - 2018
- Total of **342 flares of X, M, and C class** (missed many 😞) but still one of the largest statistical studies of VLF/flare analysis



- peak X-ray fluxes
- peak VLF amplitude (excess from background)
- time delays between X-ray and VLF

Statistical Flare Analysis

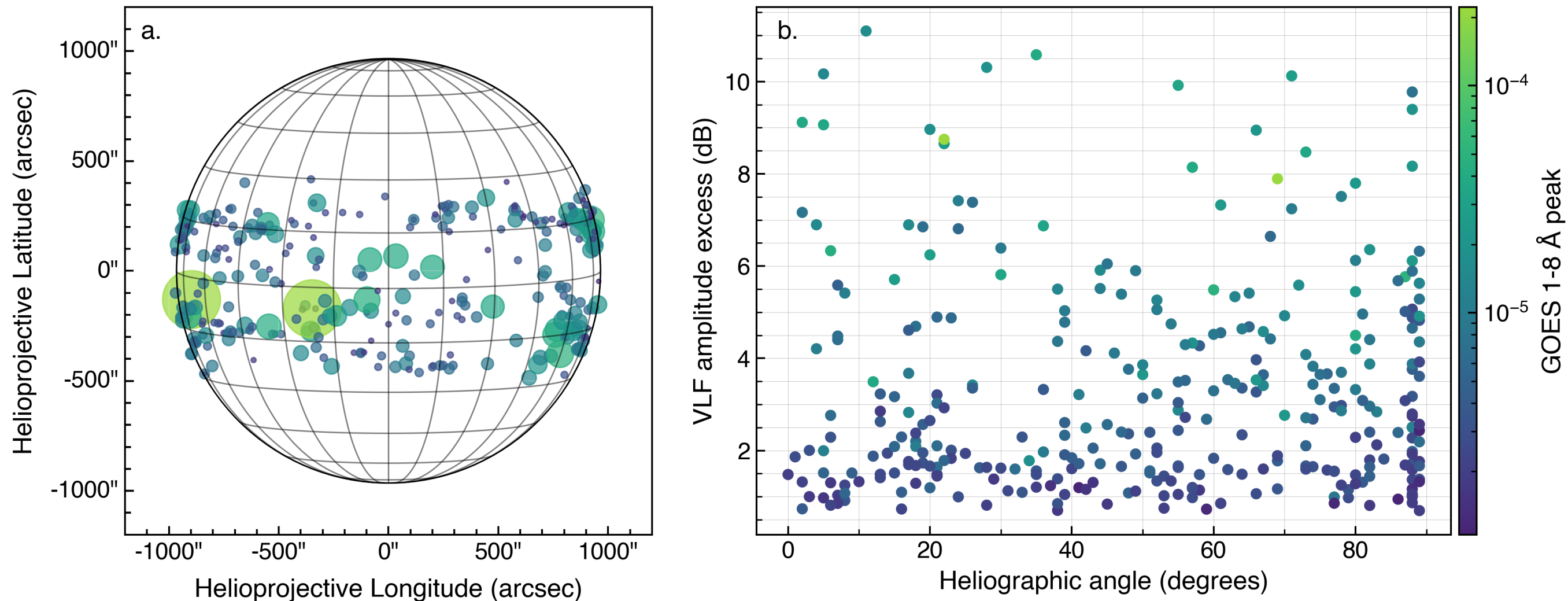
Flare flux and VLF amplitude



Larger X-ray flux \rightarrow larger the ionospheric response

Statistical Flare Analysis

Flare location and ionospheric response

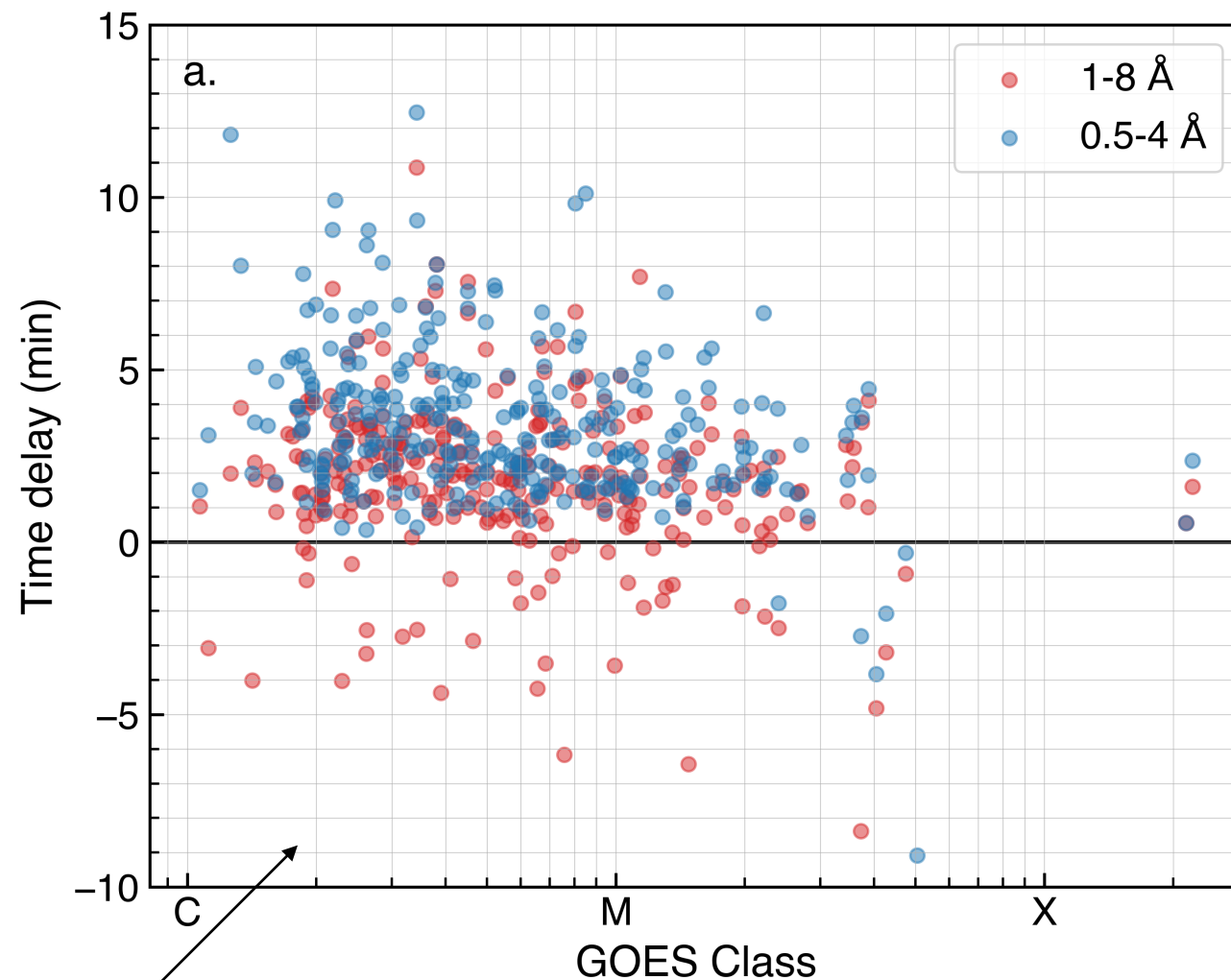
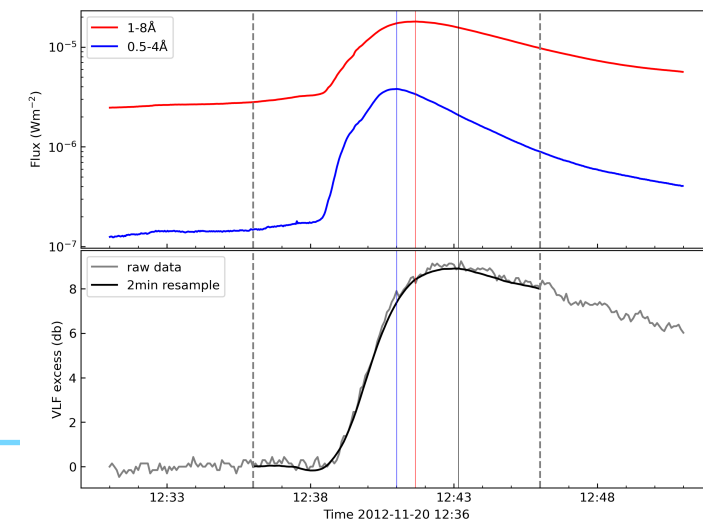


No relationship between flare location on disk and D-region impacts

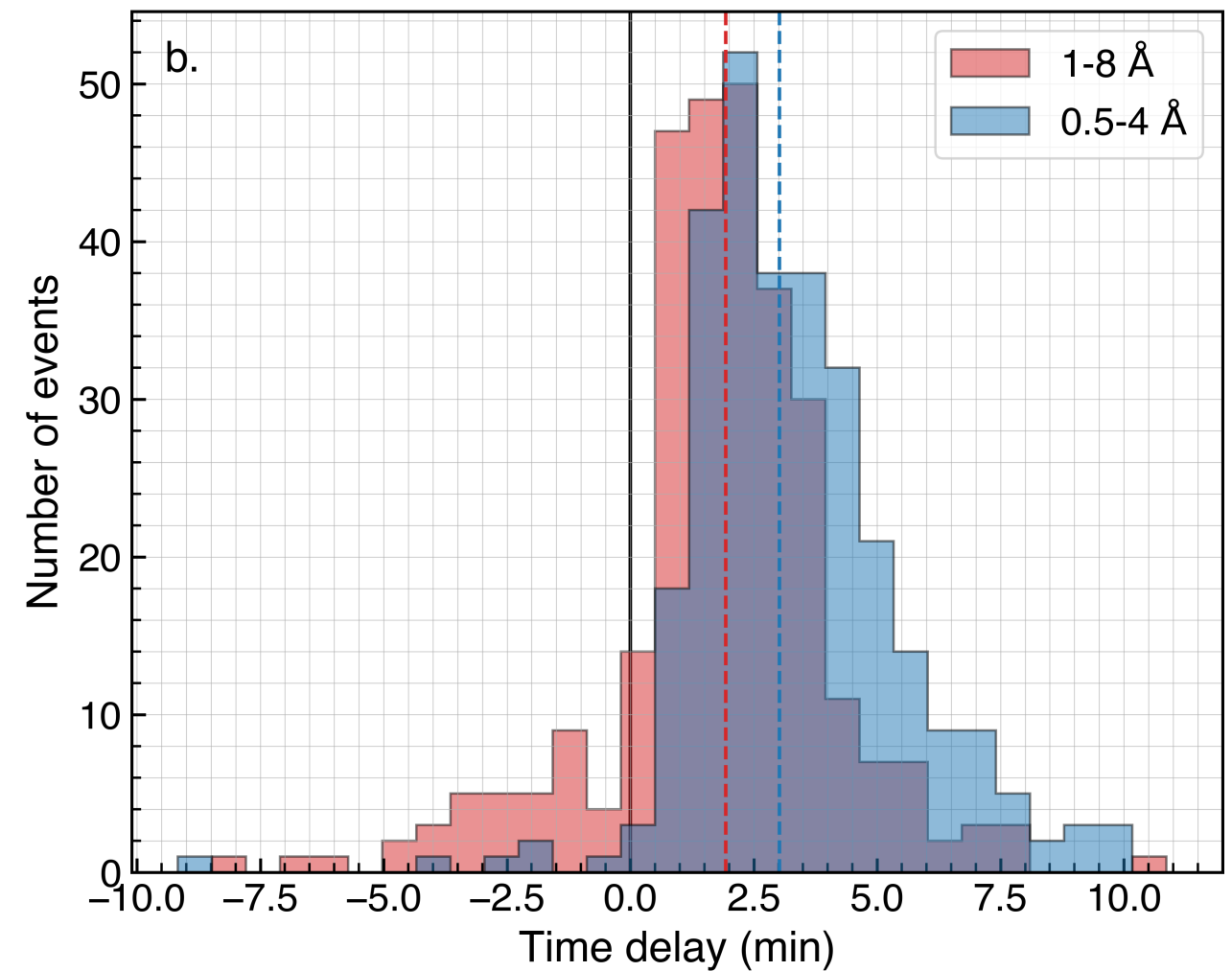
→ Rules out Lyman- α being a major factor
(centre to limb variation)

Statistical Flare Analysis

Time delay analysis



- Time delay analysis shows that sometimes VLF peak comes *before* 1-8Å in some cases



Time delays mean ~
3minutes

**How does the X-ray spectral components
affect ionospheric response?**

Statistical Flare Analysis

Conclusions

- Solar flare X-ray and EUV emission has a direct impact on Earth's lower ionosphere - *the lowest lying D-region is most impacted.*
- Statistical study of >300 flares shows **larger soft X-ray flux, larger the ionospheric response.**
- Unlike upper regions of the ionosphere, **there is no dependence on the D-region response to the location of the flare on disk.**
- Time-delay analysis reveals that harder X-rays also have a significant impact and that **the full spectral components of the flare should be considered in future works.**

Much work still to be done regarding spectral components of flares and their impacts!