What Can Elves Tell Us About Very Strong Lightning?

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Kevin-Druis Merenda

Lawrence Wiencke

APS April Meeting

Denver, CO

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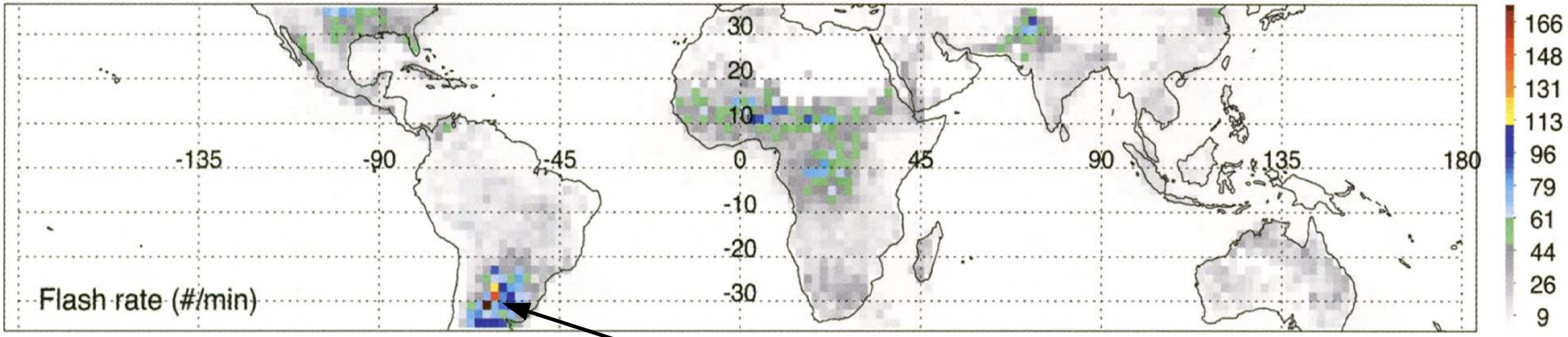
PIERRE AUGER OBSERVATORY

1) Argentina has some of the world's strongest lightning.
2) The Pierre Auger Cosmic Ray Observatory happens to monitor this region.
3) Lightning can be dangerous, so it is important to study.



[1] E. J. Zipser et al., "WHERE ARE THE MOST INTENSE THUNDERSTORMS ON EARTH?," Bull. Am. Meteorol. Soc., vol. 87, no. 8, pp. 1057–1072, Aug. 2006.

WHAT IS THE AUGER OBSERVATORY?

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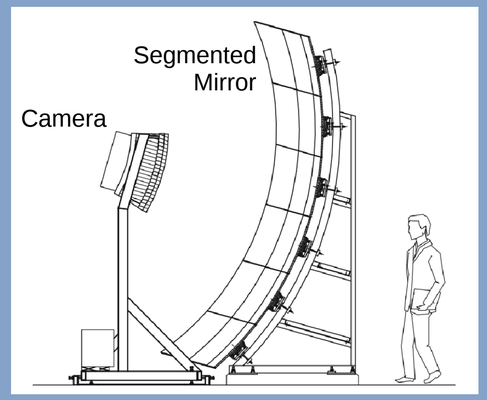
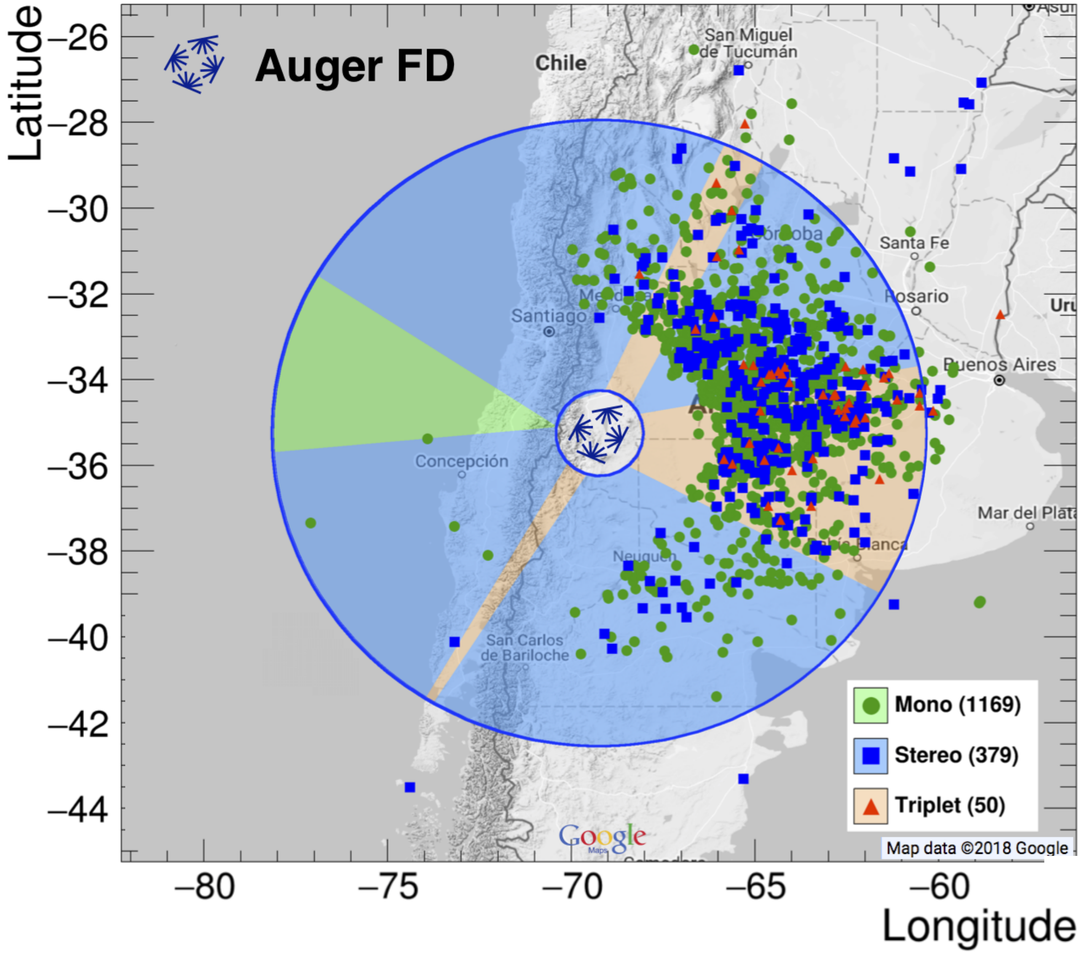
- The Fluorescence Detector of the Pierre Auger Observatory (Auger FD) records UV fluorescence from cosmic-ray air showers.
- FD made up of four sites with six telescopes each (24 total).

Auger FD Telescope



- Each camera has 440 PMTs and 10 MHz acquisition rate.

FD Site



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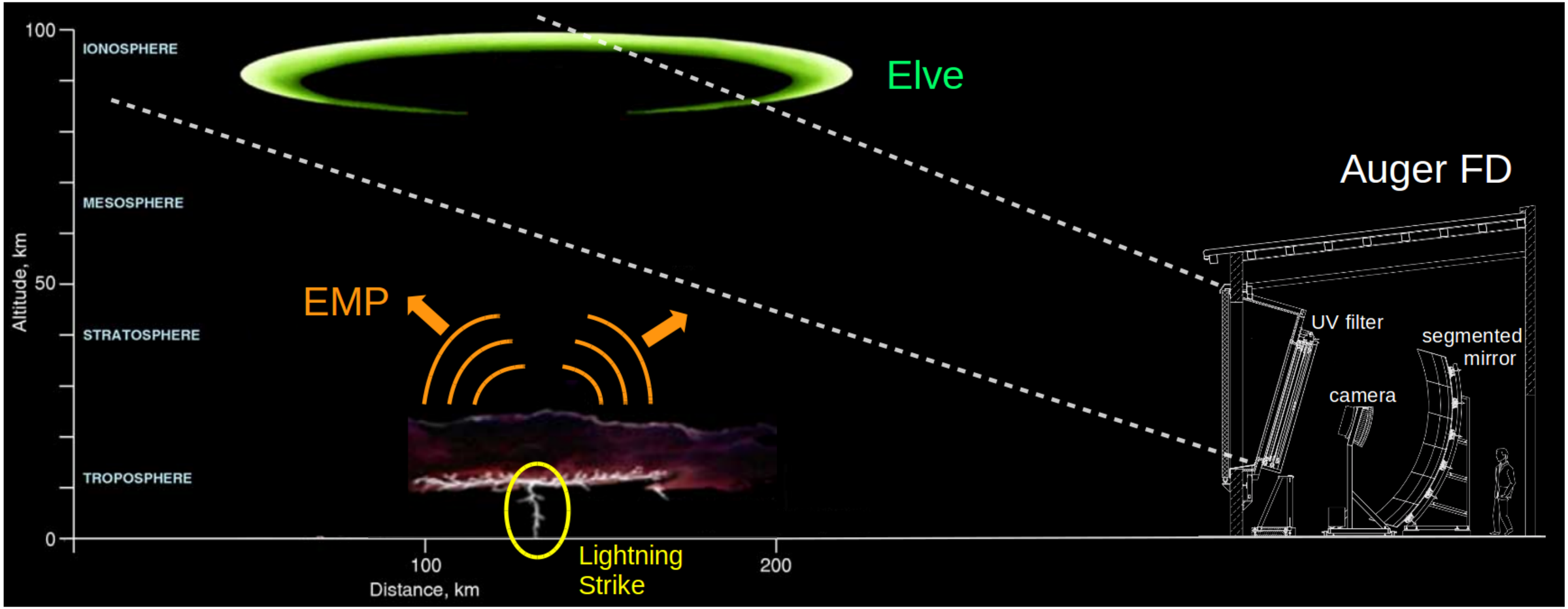
WHAT ARE ELVES?

- Elves are a class of transient luminous events that occur in the ionosphere over strong lightning.
- The fast current flow in lightning is modeled as a Hertzian dipole and creates an EMP.
- Elves are a result of the interaction between this EMP and the ionosphere.



[1] Warrilow, Chrissy. “Transient Luminous Events: Sprites, Jets and Elves Are Mysteries in the Sky (PHOTOS).” The Weather Channel, 27 Aug. 2014, weather.com/news/news/transient-luminous-events-mysteries-sky-20130731.

ELVE FORMATION PROCESS

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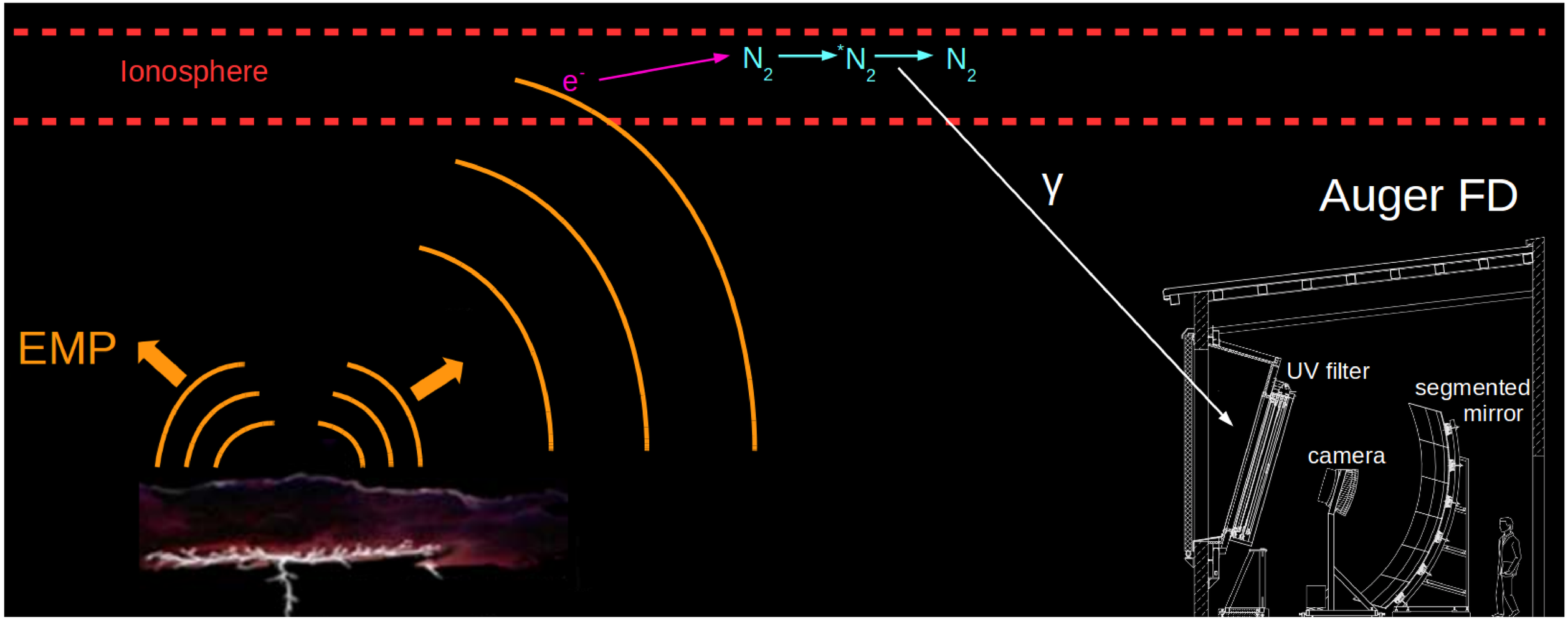

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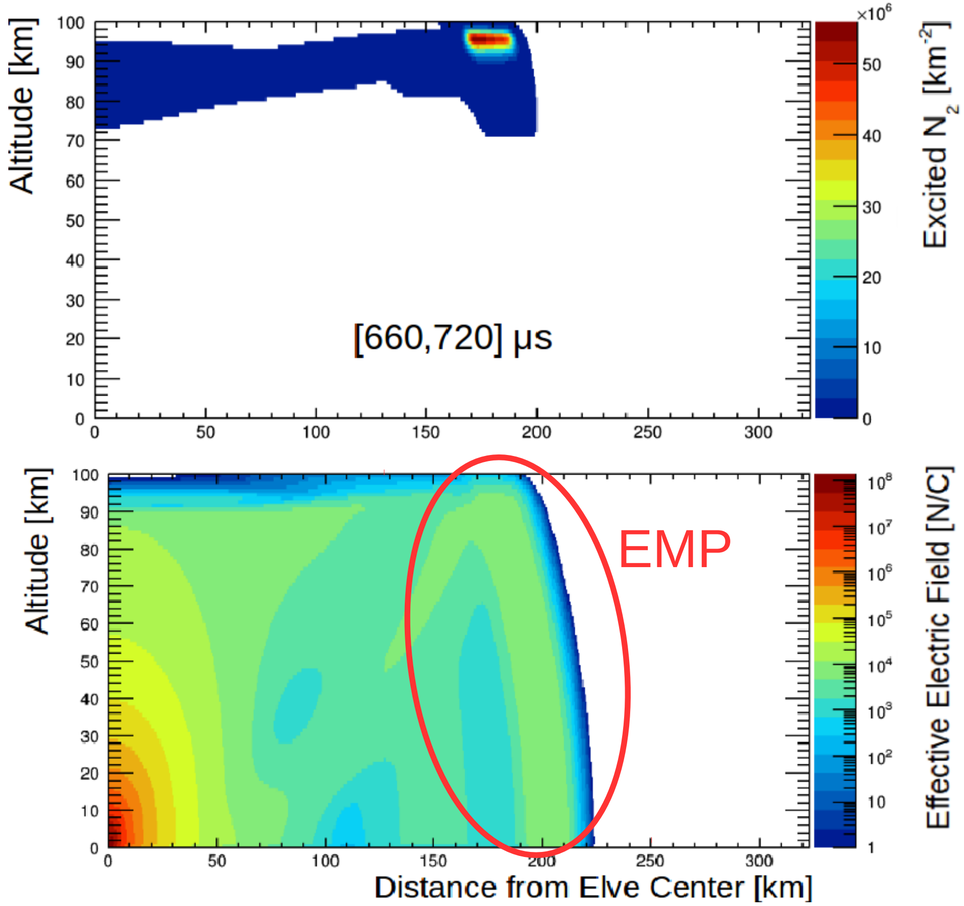
- Models the lightning strike, EMP, and interactions with the ionosphere.
- Numerical propagation of Maxwell's Equations and the Langevin equation.



Maxwell's Equations

$$\epsilon_0 \frac{\partial \mathbf{E}}{\partial t} = \nabla \times \mathbf{H} - \mathbf{J}_{\text{tot}}$$

$$\mu_0 \frac{\partial \mathbf{H}}{\partial t} = \nabla \times \mathbf{E}$$

[1] R. A. Marshall, "An improved model of the lightning electromagnetic field interaction with the D-region ionosphere," J. Geophys. Res. Sp. Phys., vol. 117, no. A3, p. n/a-n/a, Mar. 2012.

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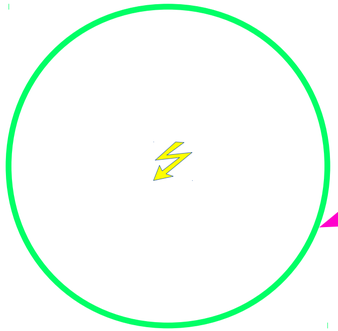
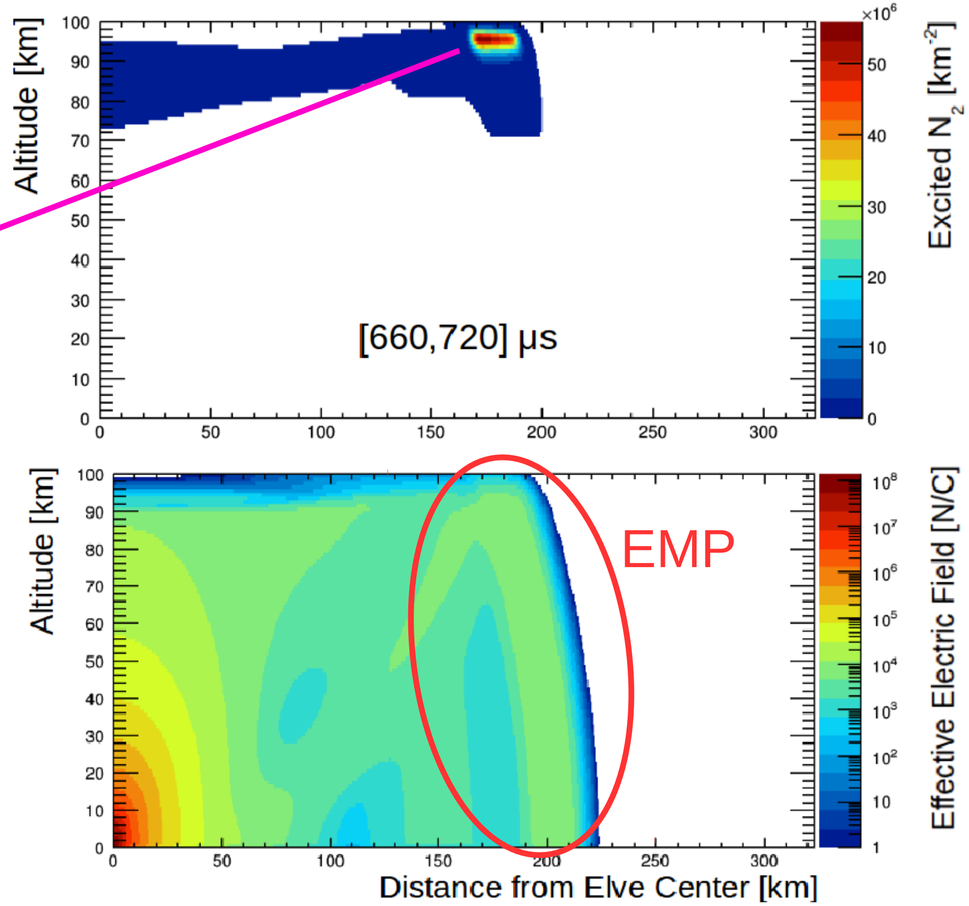
Elve seen from above





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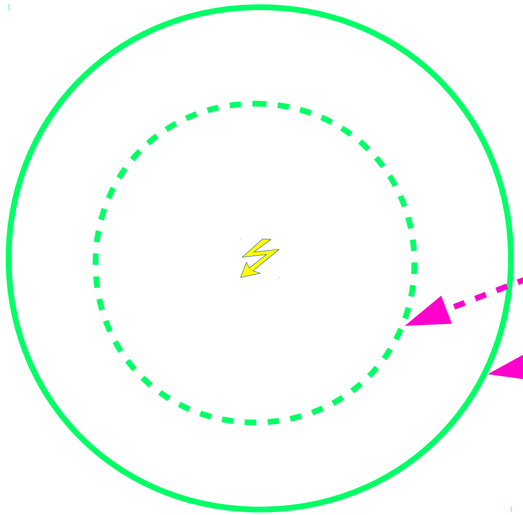

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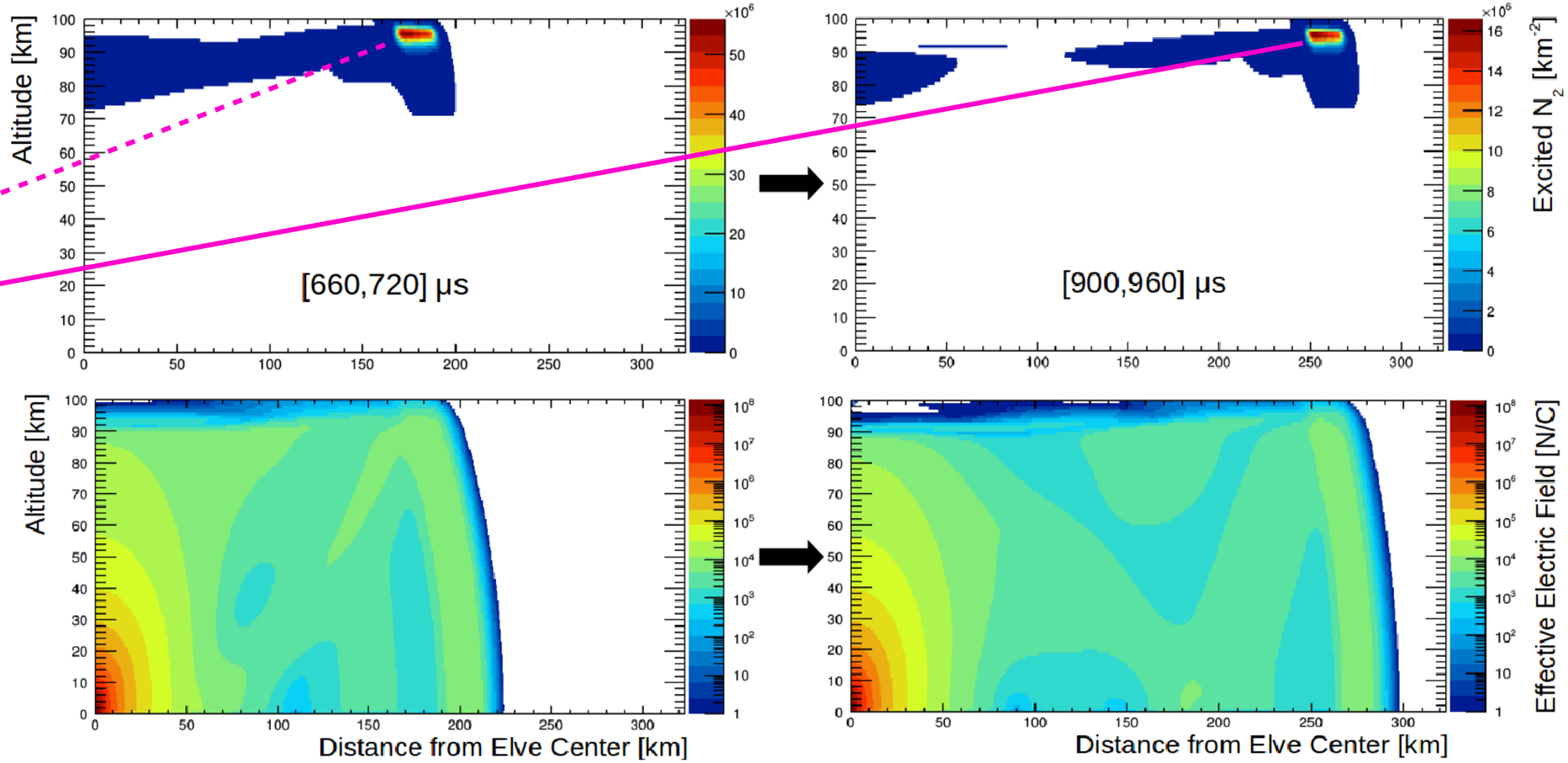

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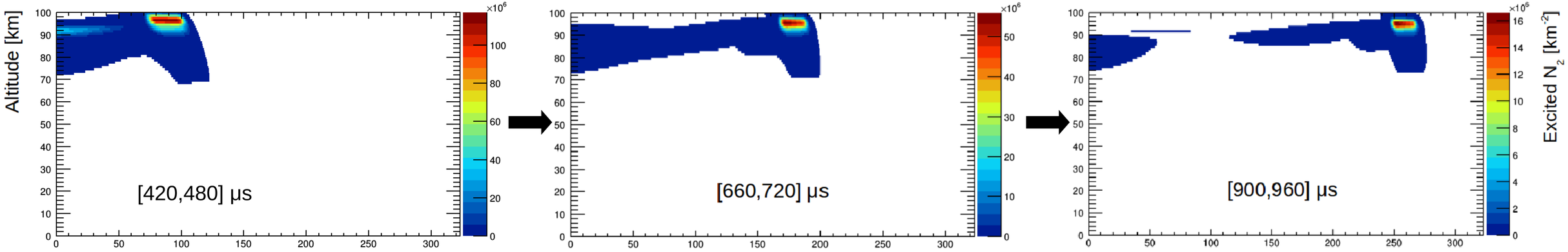
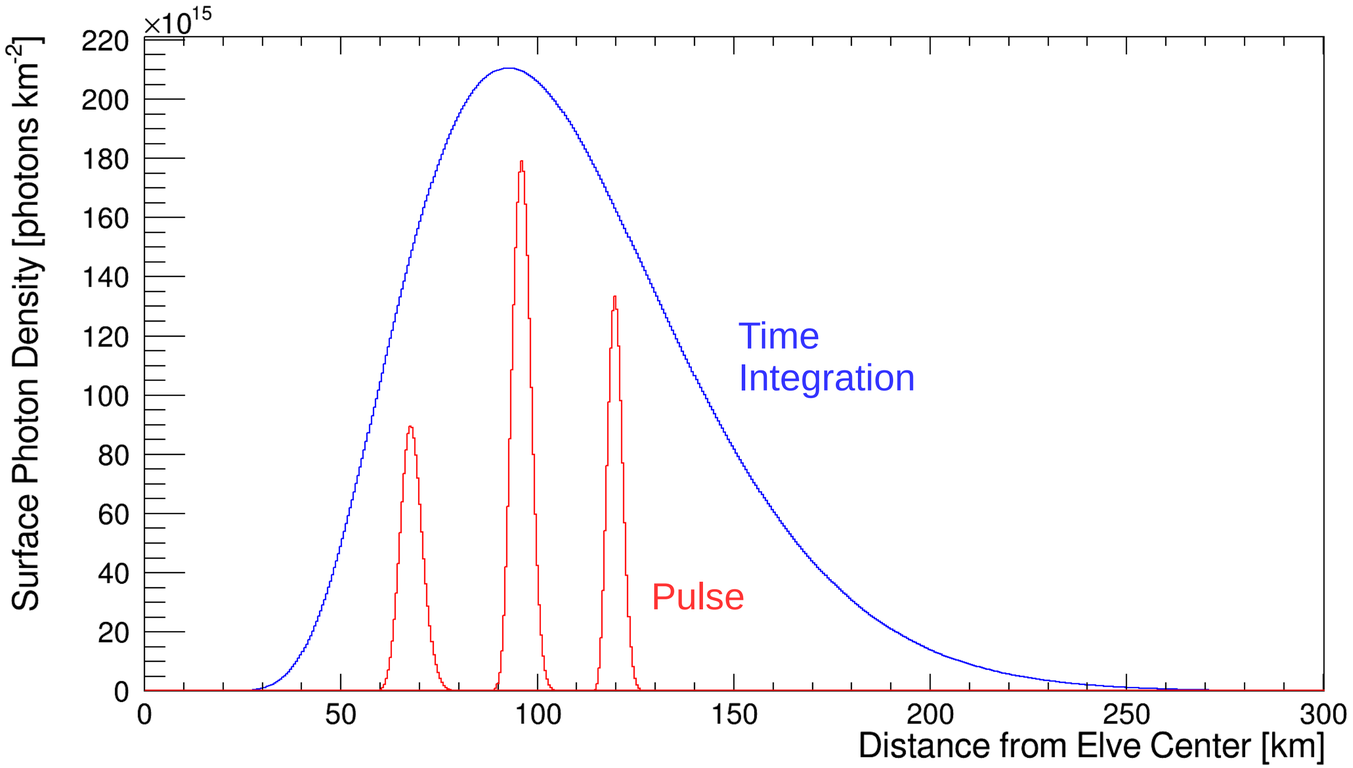
SURFACE PHOTON DENSITY



- Integrate excited nitrogen over **altitude** and **time**.
- This gives us **surface photon density**.
- Information reduced to two dimensions.



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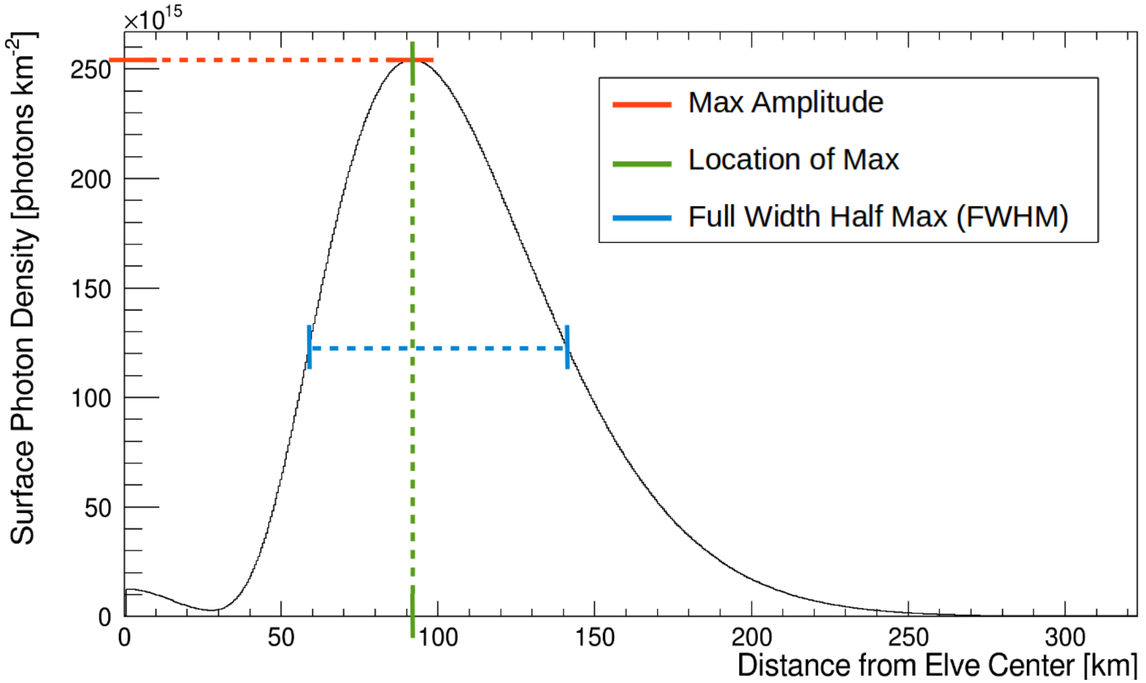
Which lightning parameters affect elve structure the most?

Simulation Input: Lightning and Atmospheric Parameters

Parameter	Parameter Name	Nominal Value	Reasonable Range
I_0	Peak Current	100 kA	30 kA to 300 kA
L_{ch}	Channel Length	6 km	3 km to 9 km
H_{Ion}	Height of Ionosphere Base	92 km	80 km to 98 km

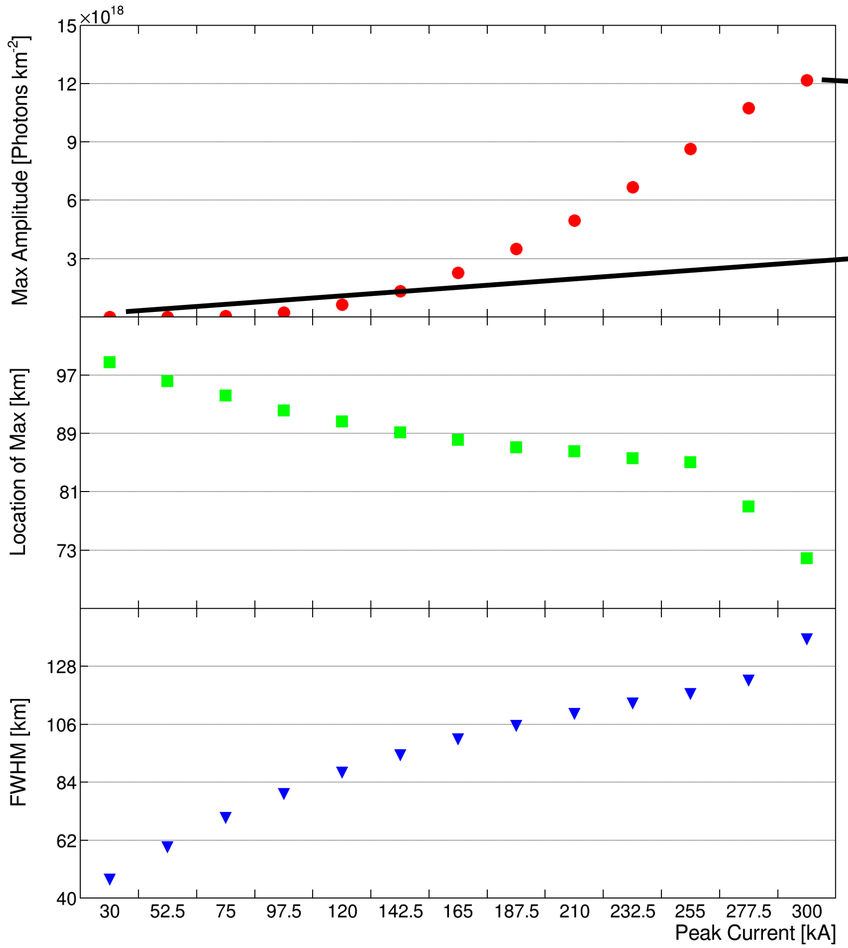
- Range of parameters selected through literature review and simulation study.
- Lightning parameters describe the flow of current in the lightning channel.
- Other parameters studied include: Rise Time, Fall Time, Return Stroke Speed, Continuing Current.

Simulation Output: Elve Parameters



- Want to quantitatively study simulated elves.
- Chosen metrics shown on plot.

Peak Current



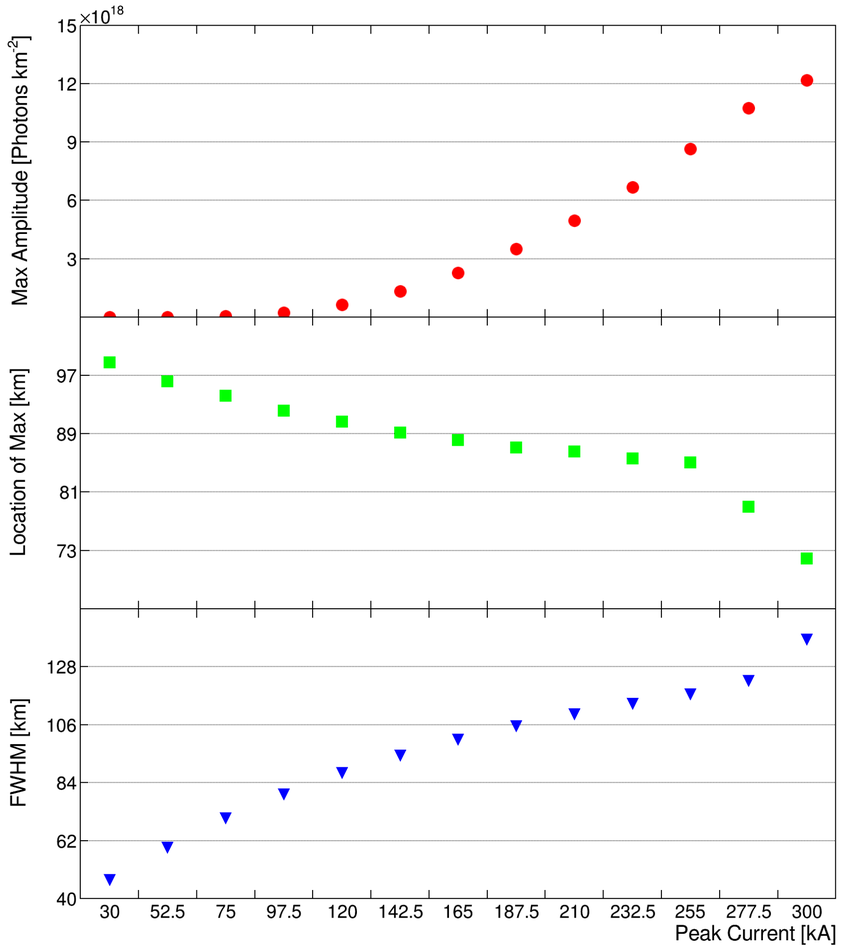
- Varying over peak current while keeping other parameters constant.
- Clearly sensitive to peak current.
- Note the sharp increase in amplitude @ 120 kA.

Sensitivity Ratio

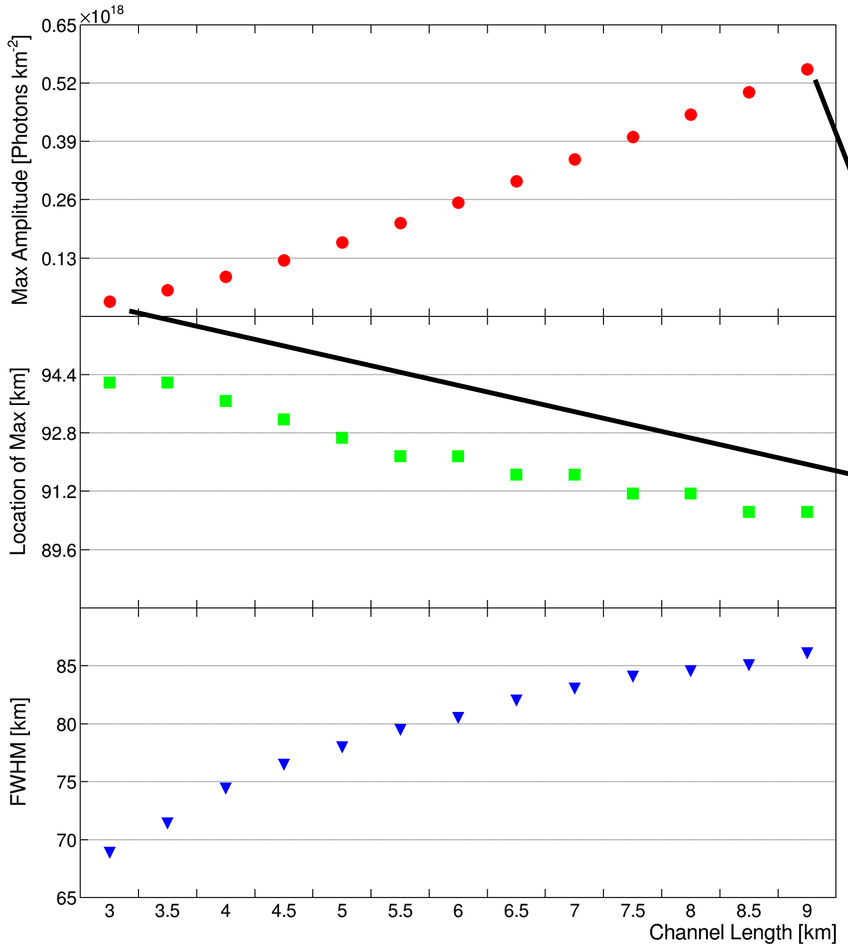
Peak Current:

$$\frac{\text{Maximum Value}}{\text{Minimum Value}} \approx \frac{10^{19}}{10^{11}} \approx 10^{8}$$

Peak Current



Channel Length



- Varying over channel length while keeping other parameters constant.

Sensitivity Ratio

Peak Current:

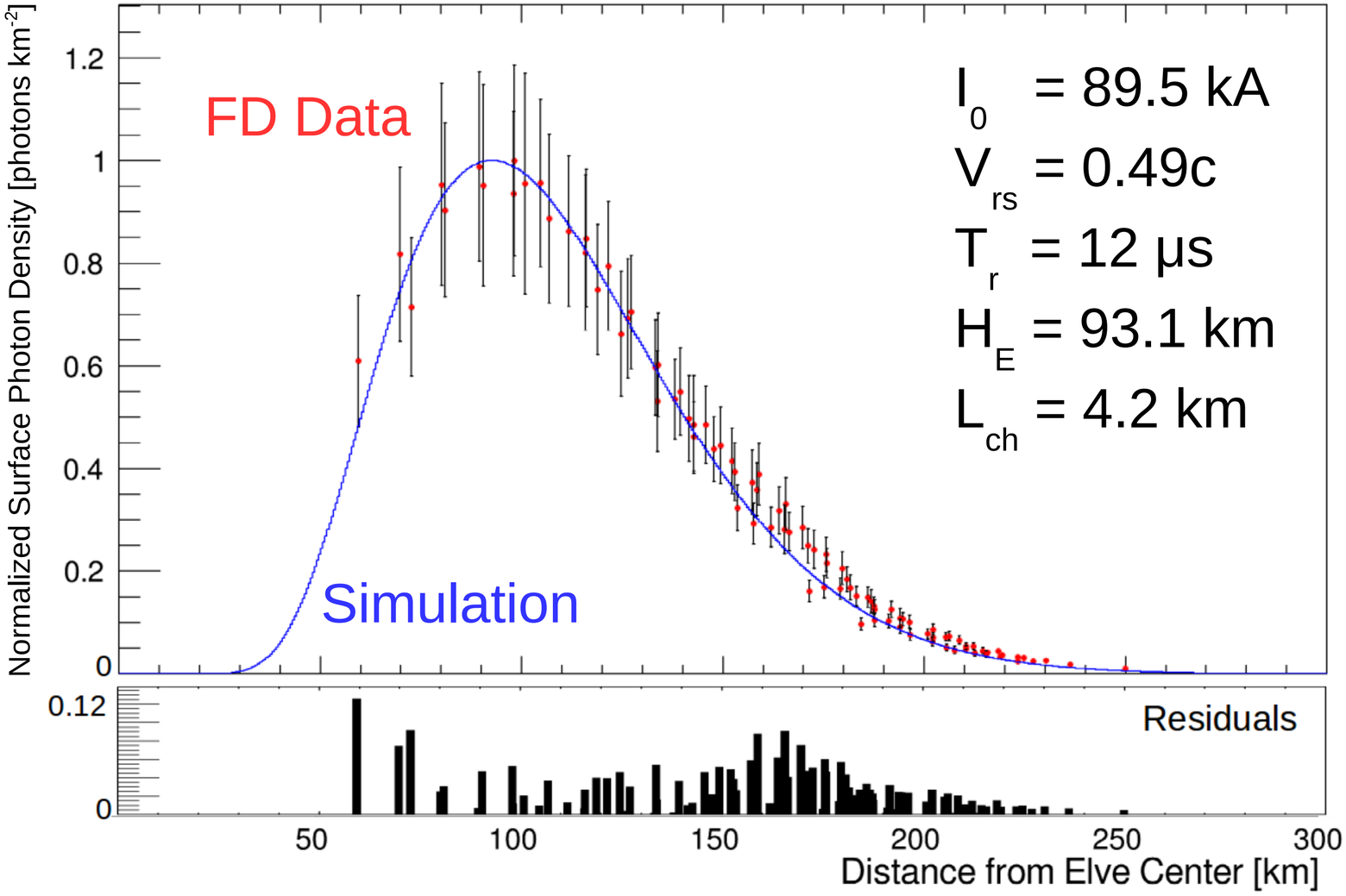
$$\frac{\text{Maximum Value}}{\text{Minimum Value}} \approx \frac{10^{19}}{10^{11}} \approx 10^{8}$$

Channel Length

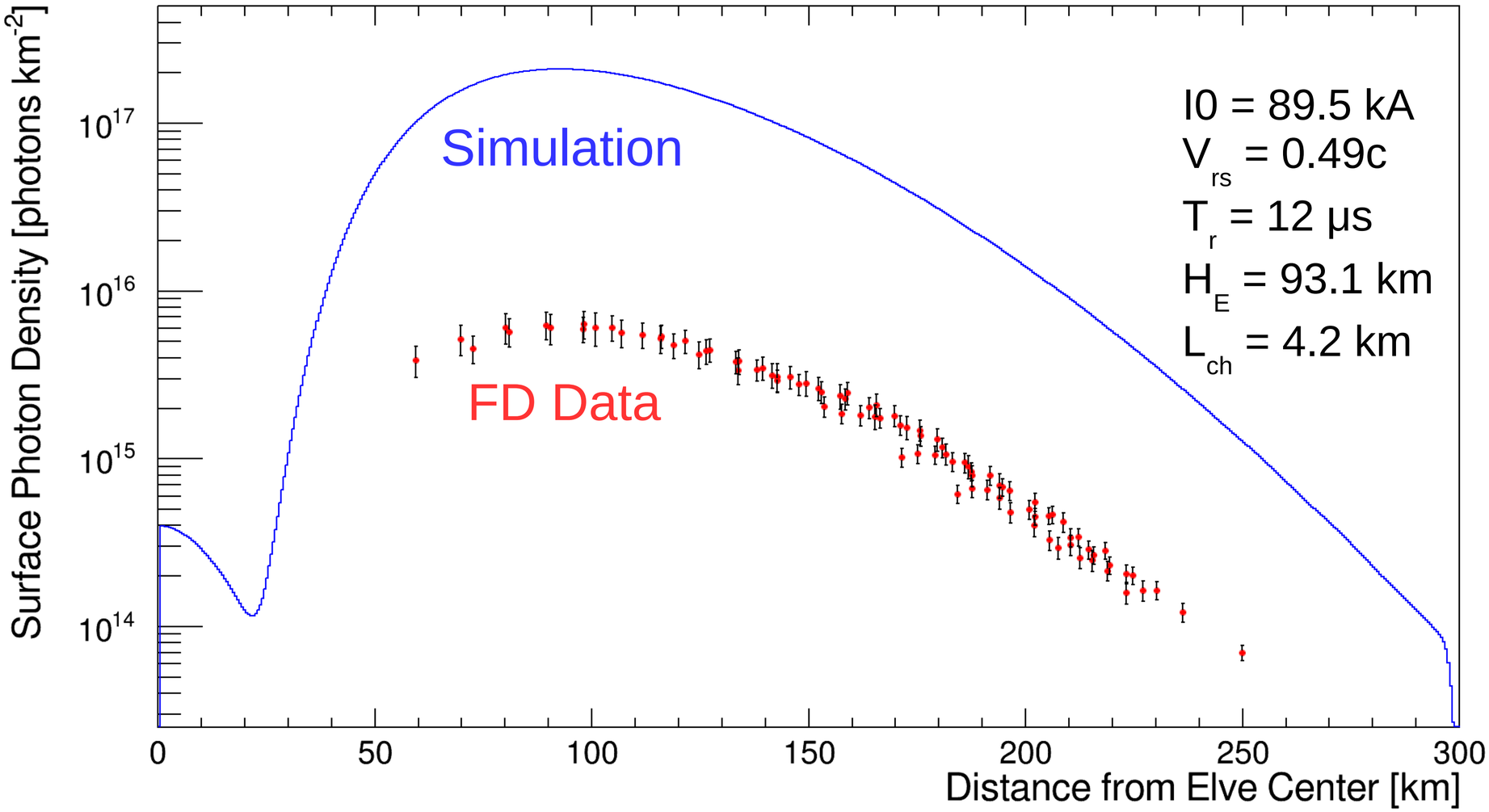
$$\frac{\text{Maximum Value}}{\text{Minimum Value}} \approx \frac{10^{17}}{10^{17}} \approx 1$$

Much more sensitive to Peak Current than Channel Length.

- Sensitivity study + X^2 minimization → attempt to match simulation to data.



- Each red dot is an FD pixel.
- Both plots are **normalized** to their respective maximums.
- Shape of simulation (Location of Max, FWHM) matches data well.
- Reduced X^2 with 51 DOF = 3.48311



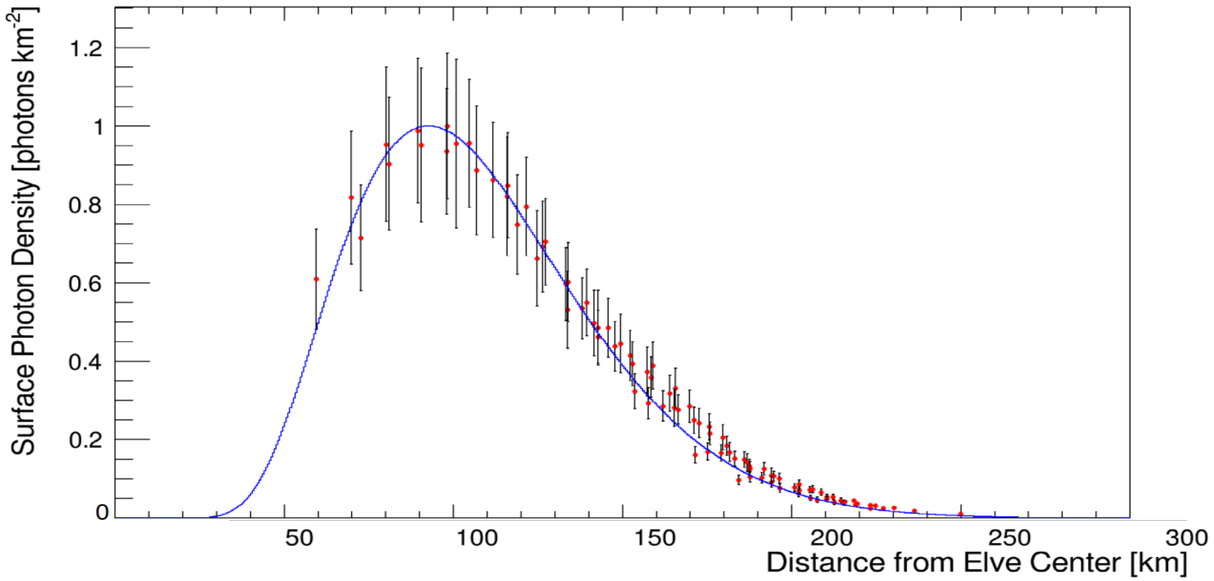
- Without normalization, Max Amplitude is off by ~2 orders of magnitude.
- Possible causes:
  1) Surface density reconstruction: revise atmospheric attenuation calculations
  2) EMP simulation

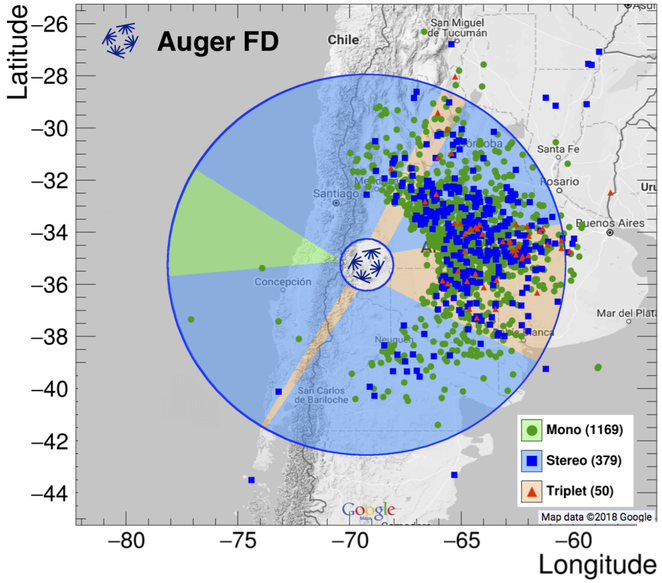
Big Picture Take-Aways

- Lightning can be dangerous, so it is important to study.
- We are using elves to look at lightning in a very novel way.

- Very bright elves means that peak current is greater than 120 kA.
- Better understanding of how lightning affects elve shape and amplitude.
- Simulation can create accurate surface density profiles.
- Problem with amplitude needs to be resolved.

Parameter	Sensitive to this Parameter?
Peak Current	Very
Channel Length	Somewhat
Return Stroke Speed	Very
Rise Time	Somewhat
Fall Time	No
Height of Ionosphere	Very
Continuing Current	No





Thank you - Questions?

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