The Variety of Optical Pulses from Lightning

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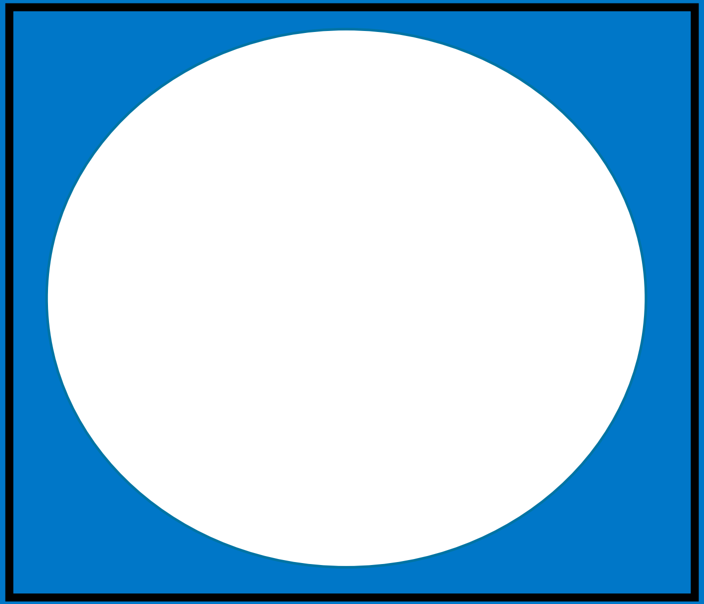
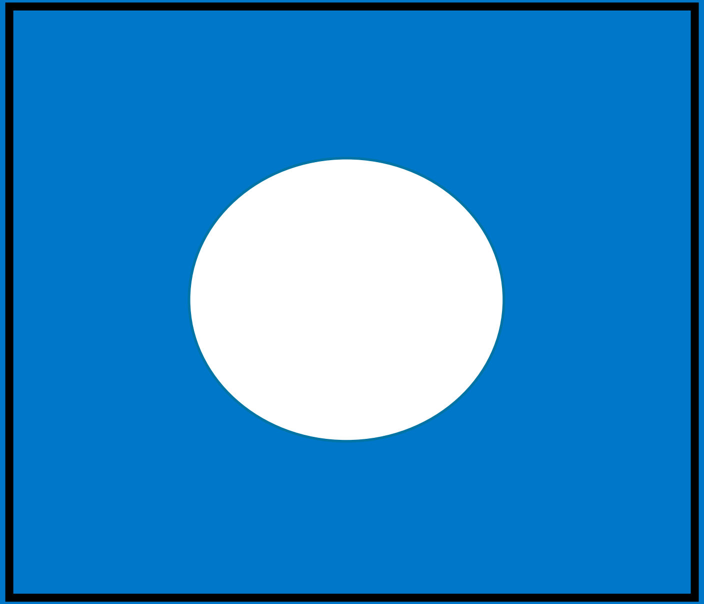
We know GLM can struggle to detect smaller pulses…

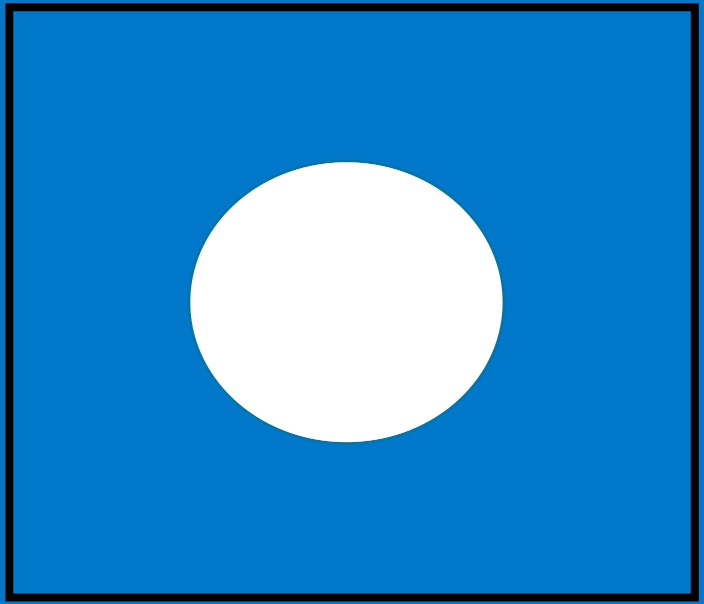


If lightning optical emission is bright enough, and it (mostly) fills the pixel, it will be detected.

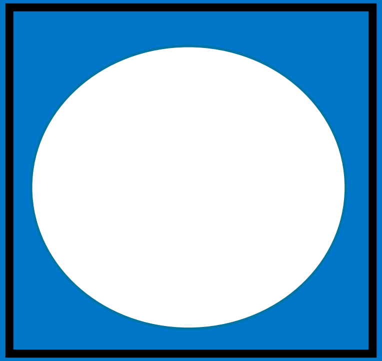


If lightning optical emission is smaller such that it underfills the pixel, it *might* not be detected.

Possible solution: have smaller pixels.

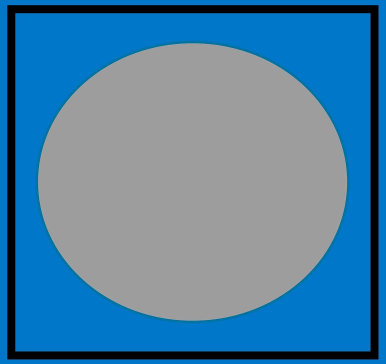


If lightning optical emission is smaller, and it underfills the pixel, it *might* not be detected.

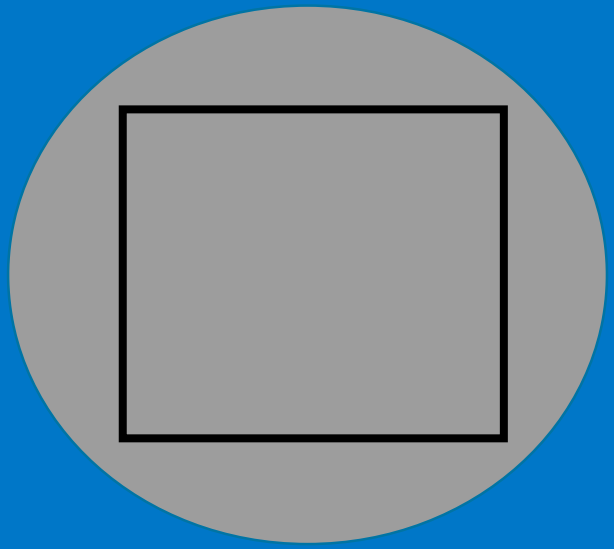


A smaller pixel has a better chance of (mostly) filling the pixel, and hence, the optical emission is more likely to be detected.

But this assumes brightness is constant!



What if smaller area lightning discharges are less bright? **Then, smaller pixels may not be enough to detect these small discharges.**



To zeroth order, an overfilled pixel will detect the lightning discharge.

Caveat: As long as signal to noise ratio is large enough!

So, what is the phenomenology of lightning optical emission?

How does brightness vary with discharge area?

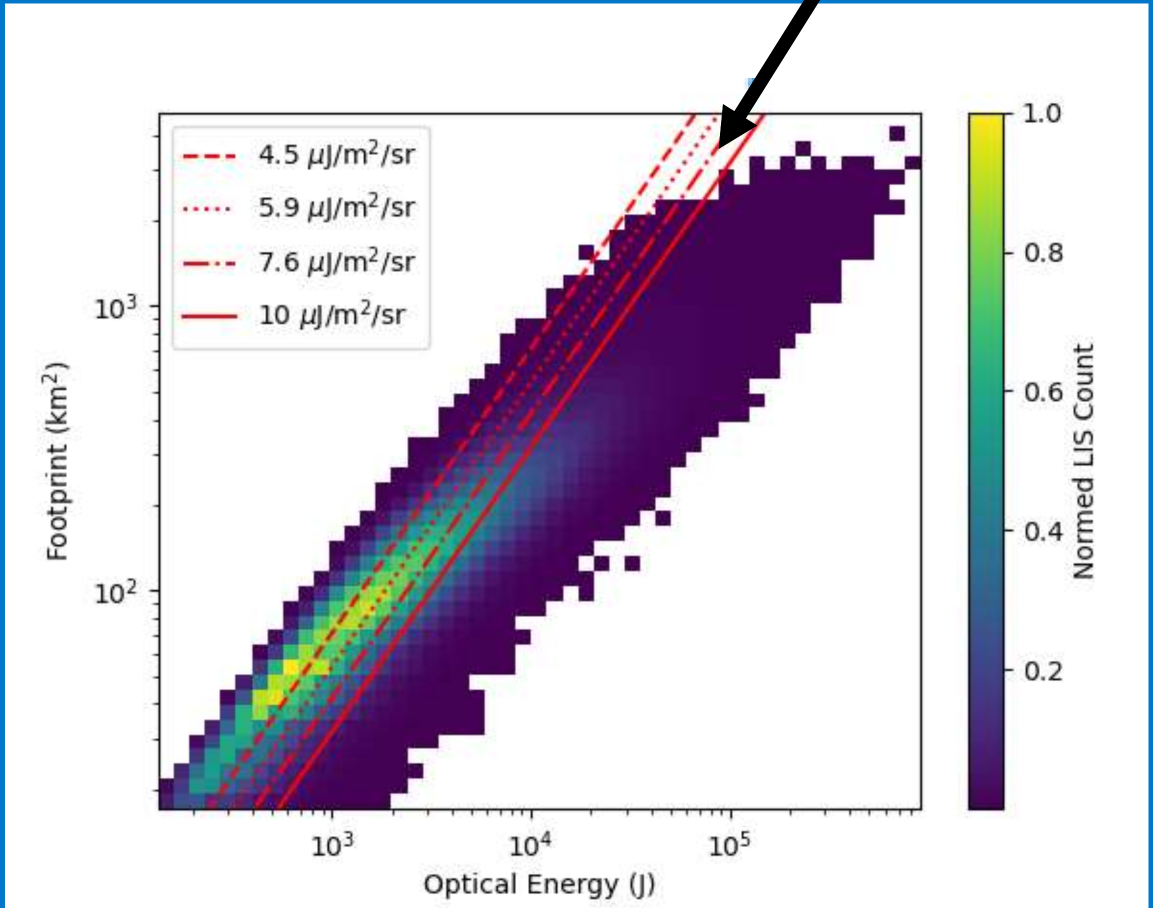
Lightning Optical Pulse Phenomenology

- To assess how various measurements of optical emission compare, we find the optical energy emitted from the cloud top following methods in Koshak (2017) and Bitzer and Koshak (2016).
- This allows us to readily compare measurements from various instruments:
  - GLM: Geostationary Lightning Mapper
  - ISS-LIS: International Space Station Lightning Imaging Sensor
  - FEGS: Fly's Eye GLM Simulator
  - MMIA: Modular Multispectral Imaging Array
- Despite the various design differences in pixel size, footprint, etc., optical energy emitted at cloud top is the common measurement.
- Analyzing the results in the 2D phase space of energy and area of lightning discharge gives us the phenomenology of optical pulses that we can use to inform and assess the design of lightning mappers.

Lightning Phenomenology – ISS-LIS

Diagonal lines are lines of constant radiant energy density, i.e., brightness

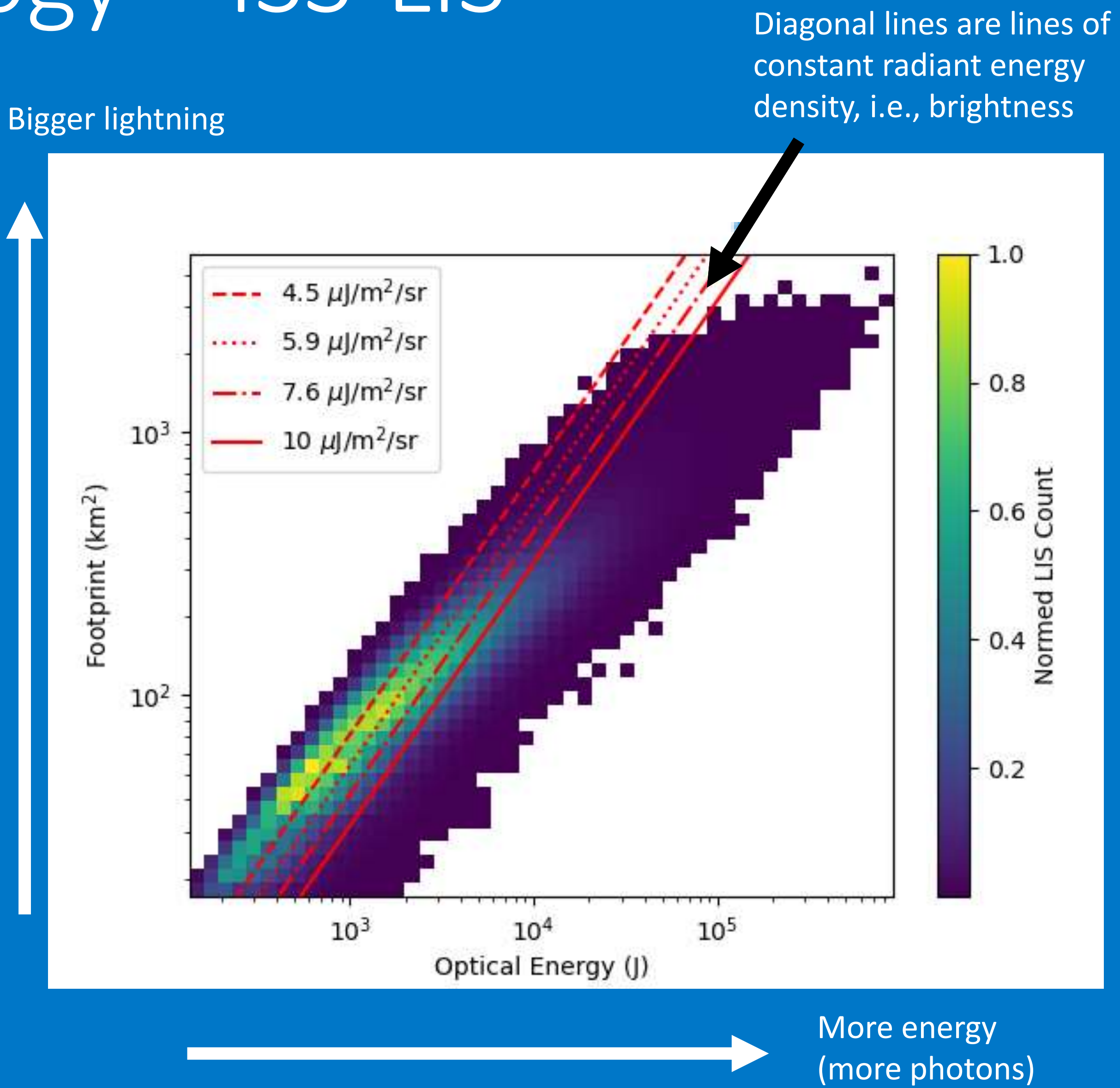
Bigger lightning



More energy
(more photons)

Lightning Phenomenology – ISS-LIS

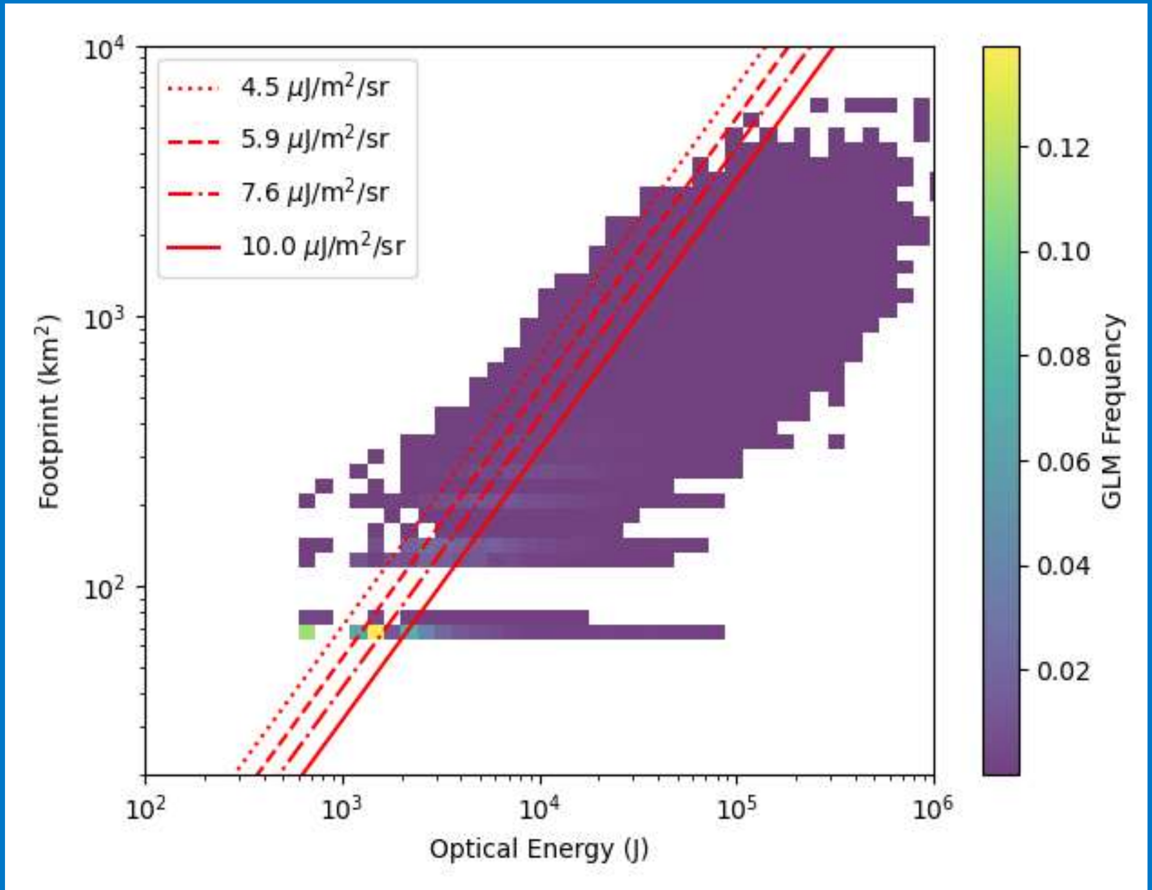
- The distribution of optical pulses detected by ISS-LIS shows pulses span several orders of magnitude and energy.
- The distribution has a larger slope than the lines of constant radiant energy density, i.e., bigger pulses tend to be brighter.
- Conversely, ***the smaller the pulse, the smaller the radiant energy density***.
  - Detection limit lines up with a 2.9 μJ/m^2/sr radiant energy density, similar to Zhang et al. (2019)*



- Zhang, D., K. L. Cummins, P. Bitzer, and W. J. Koshak (2019), Evaluation of the performance characteristics of the lightning imaging sensor, Journal of Atmospheric and Oceanic Technology, doi:10.1175/JTECH-D-18-0173.1.

Lightning Phenomenology – GLM

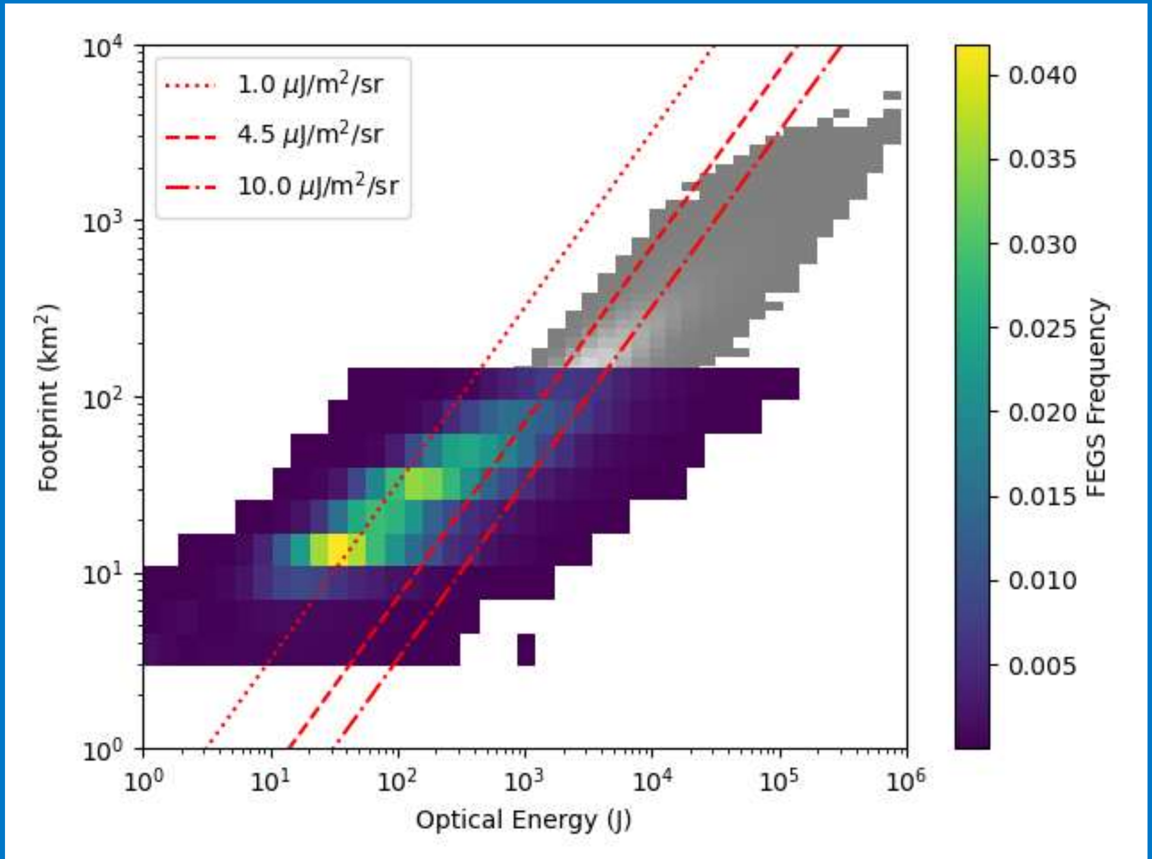
- The distribution of optical pulses detected by GLM shows a similar trend: bigger pulses are brighter or, **the smaller the pulse, the smaller the radiant energy density**.
- Further, the distribution from GLM contains many small pulses (minimum reportable area from GLM is ~64km^{2}).
- Since the ISS-LIS distribution does not show a similar "pile up", this suggests GLM is detecting discharges that are smaller than a GLM pixel.



GLM is sensitive enough to detect discharges smaller than a pixel footprint.

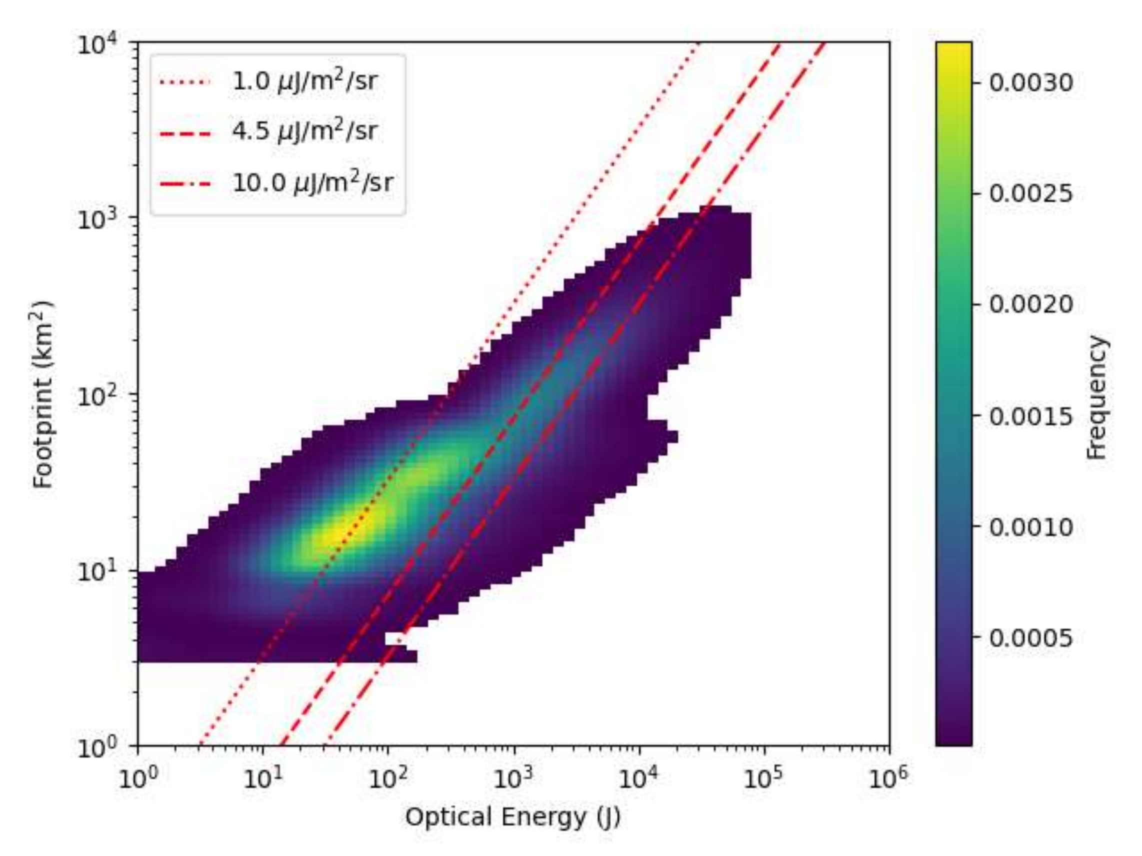
Lightning Phenomenology – FEGS

- FEGS can provide information about the distribution of smaller pulses.
  - Once again, the distribution shows that smaller pulses have less radiant energy density.
- **Smaller pixel size isn't sufficient to detect these smaller pulses – sensitivity matters!**
  - 75% of FEGS pulses have a radiant energy density less than 4.5 μJ/m^2/sr.
  - If the detectable radiant energy density is greater than this, these pulses will not be detected – no matter the pixel size.



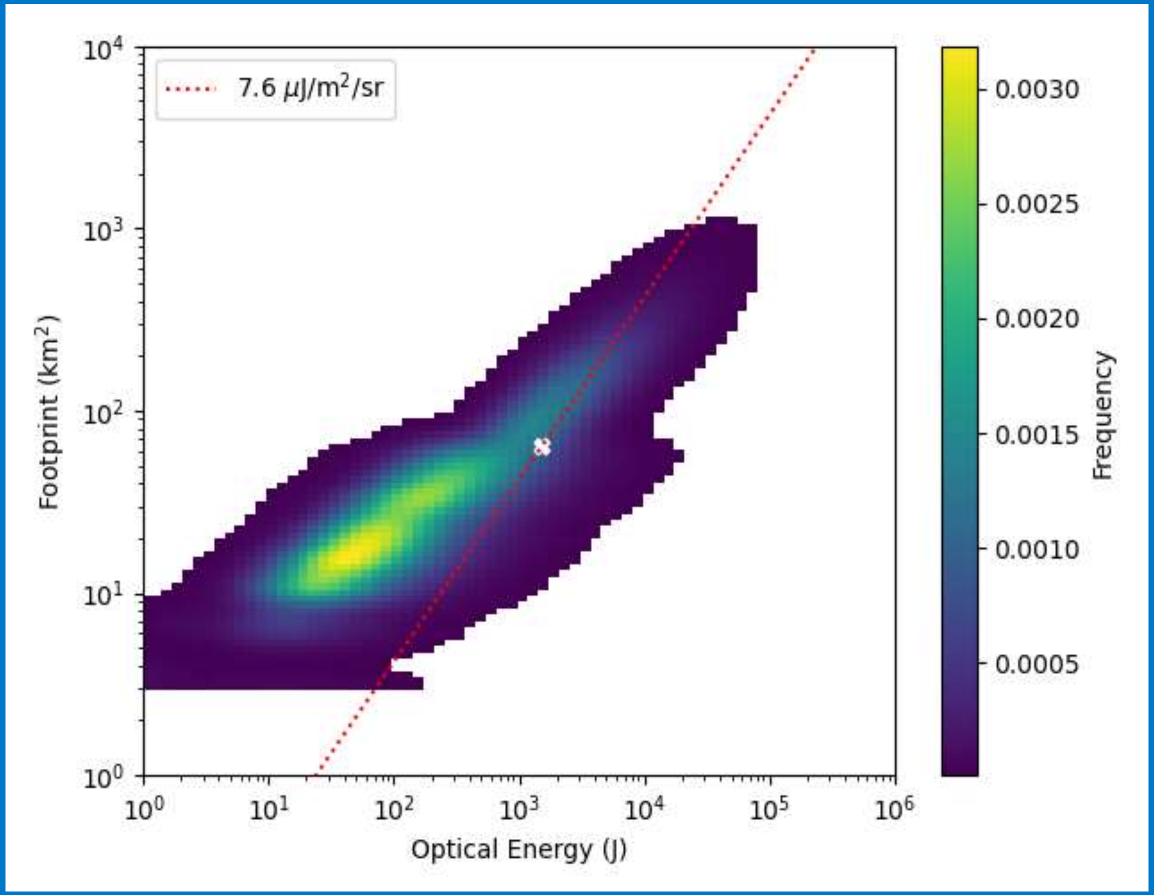
Lightning Phenomenology – optical pulses

- By using several sensors, we can build a more complete picture of the phenomenology of optical pulses from lightning.
- **FEGS, LIS and GLM agree: smaller pulses have a lower radiant energy density than larger pulses.**
    - Or, smaller pulses are *even dimmer* than you might expect just from their smaller size.
    - While decreasing pixel size helps with detection, the smaller and dimmer pulses also require an improvement in sensitivity.
    - Data from MMIA follows the same distribution!



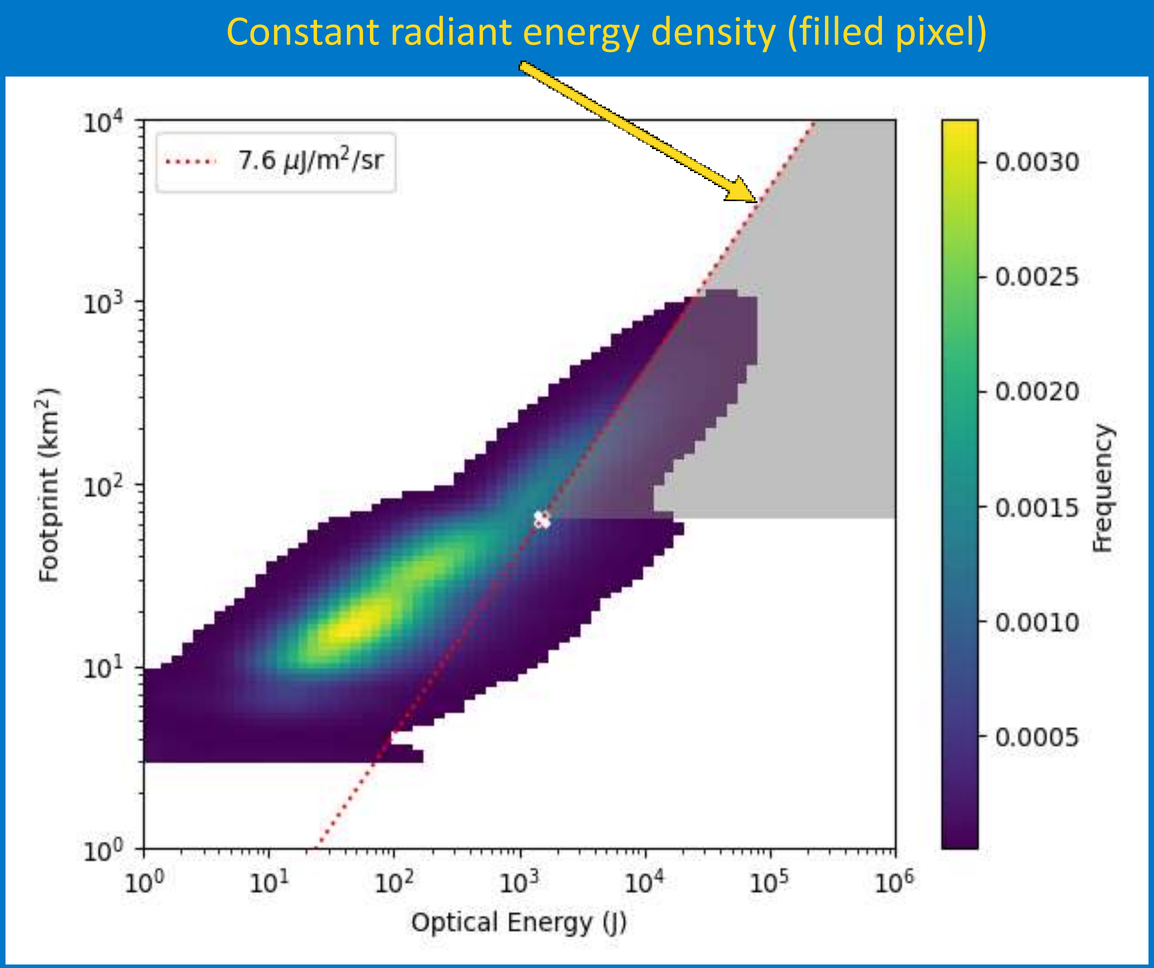
Lightning Phenomenology – optical pulses

- For a given radiant energy density (sensitivity) and pulse area (ground sample distance), we can determine how many pulses would be detected.



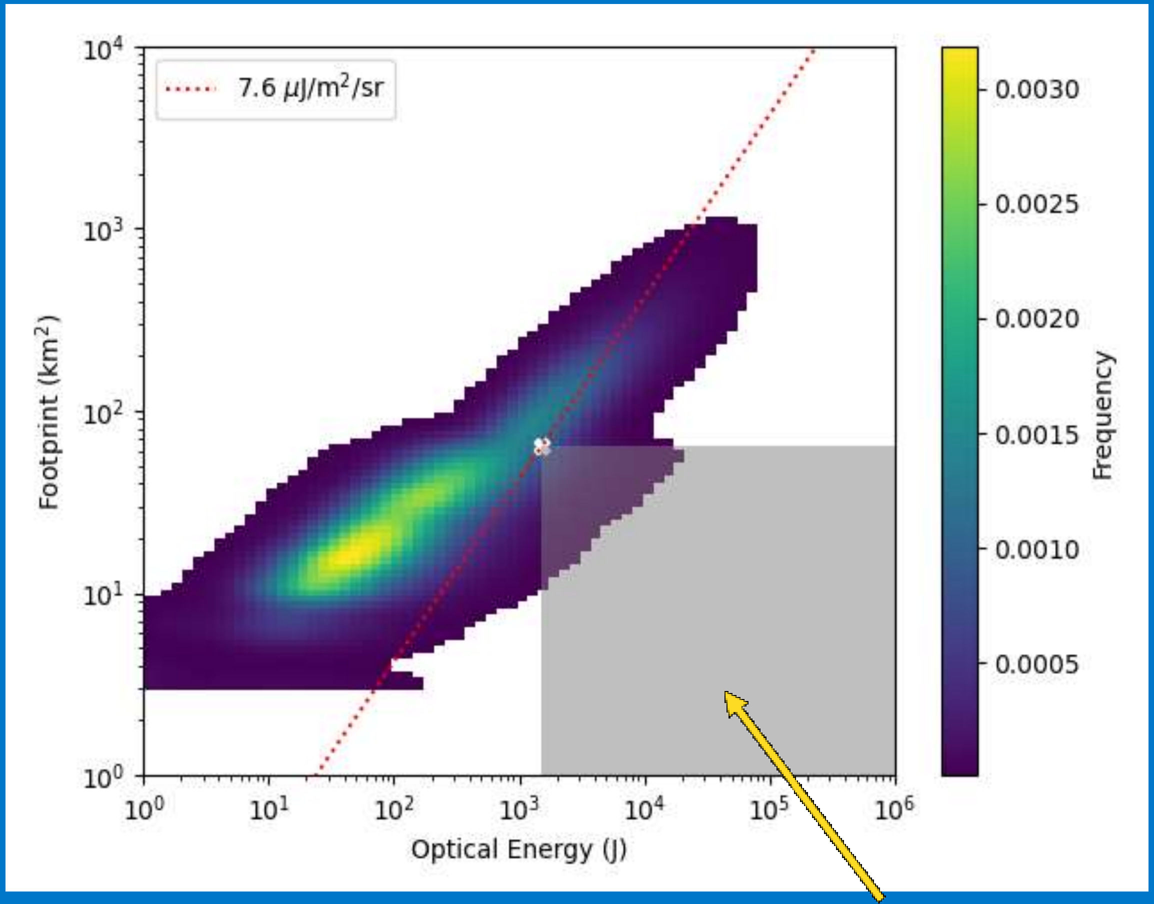
Lightning Phenomenology – optical pulses

- For a given radiant energy density (sensitivity) and pulse area (ground sample distance), we can determine how many pulses would be detected.
- Pulses that are greater than the radiant energy density and bigger than the pixel area are detected.



Lightning Phenomenology – optical pulses

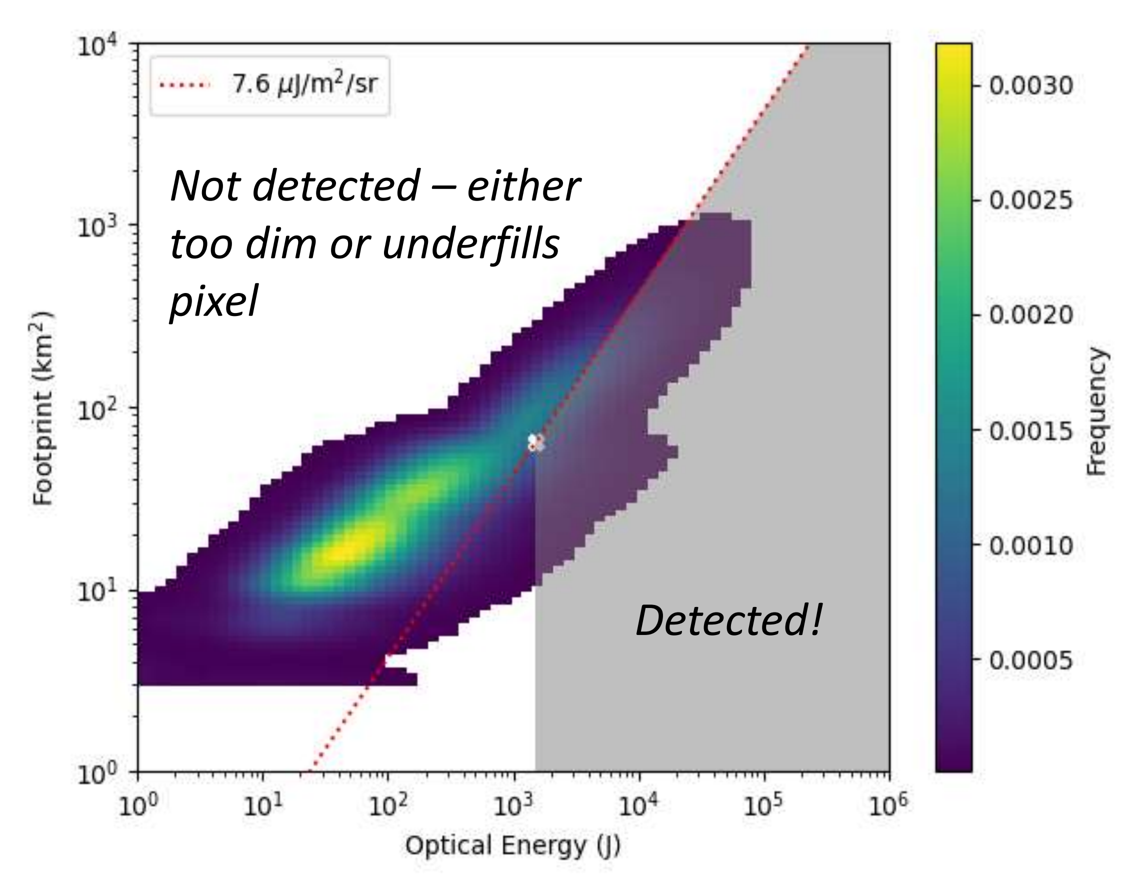
- For a given radiant energy density (sensitivity) and pulse area (ground sample distance), we can determine how many pulses would be detected.
- Pulses that are greater than the radiant energy density and bigger than the pixel area are detected.
- Below the pixel area, the pixel is underfilled, but energies of this value and greater are still detected.



Constant energy (underfilled)

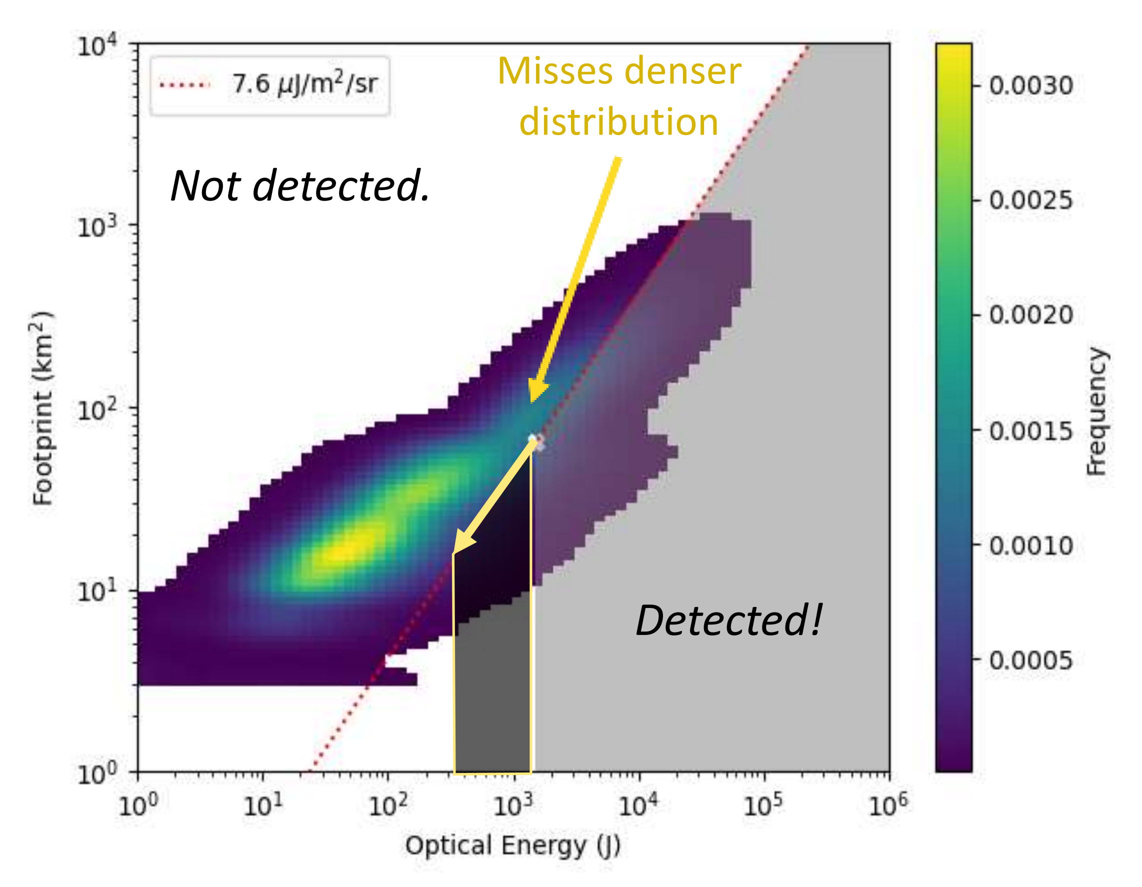
Lightning Phenomenology – optical pulses

- For a given radiant energy density (sensitivity) and pulse area (ground sample distance), we can determine how many pulses would be detected.
- Pulses that are greater than the radiant energy density and bigger than the pixel area are detected.
- Below the pixel area, the pixel is underfilled, but energies of this value and greater are still detected.
- The integration of the distribution to the right of the line yields the percent lightning detected.



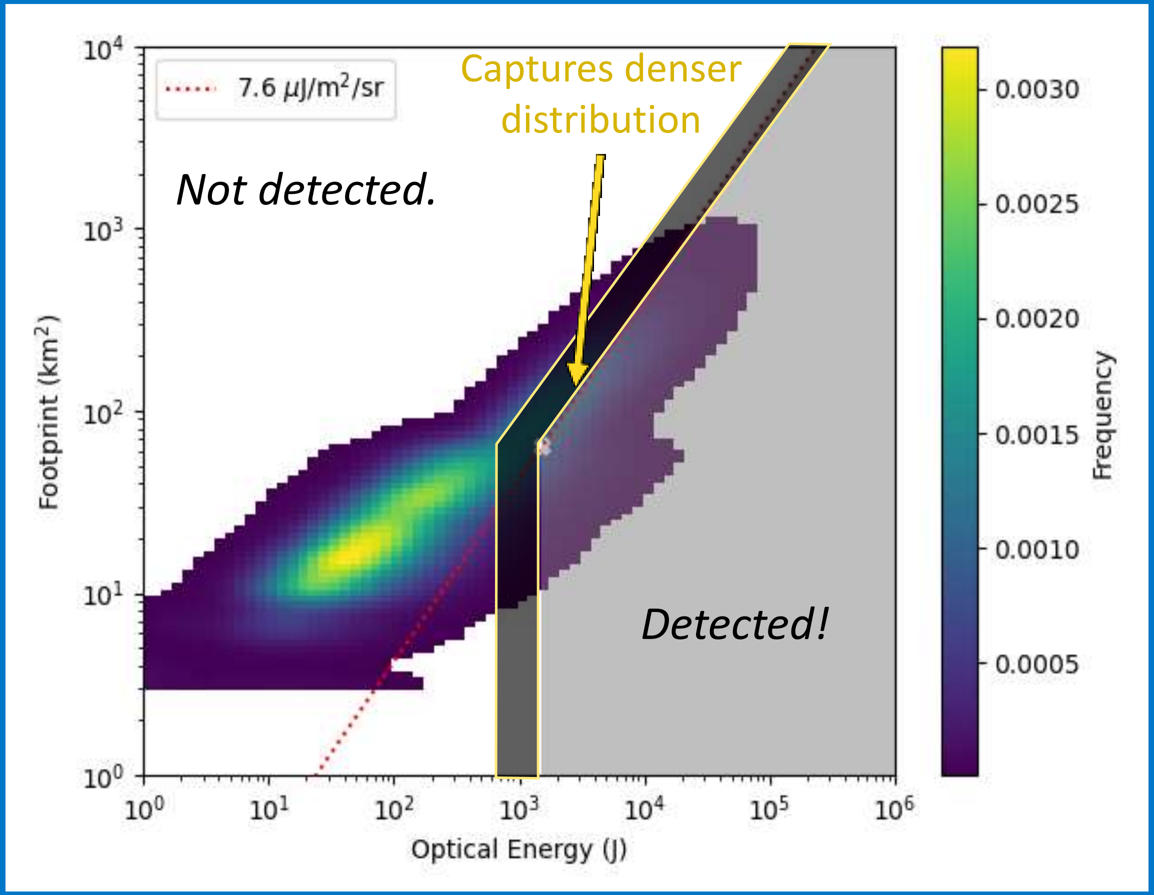
Lightning Phenomenology – optical pulses

- With this distribution, we can assess different sensitivity and pixel size designs to quantitively assess the amount of lightning that can be detected.
- For example, an instrument that maintains the same sensitivity but has pixels that are twice as small will detect 32% more lightning.
  - FOV averaged: 7.6 μJ/m^2/sr , 16 km^2
- For reference, the current Geostationary Lightning Mapper detects 4% more lightning than these specs.



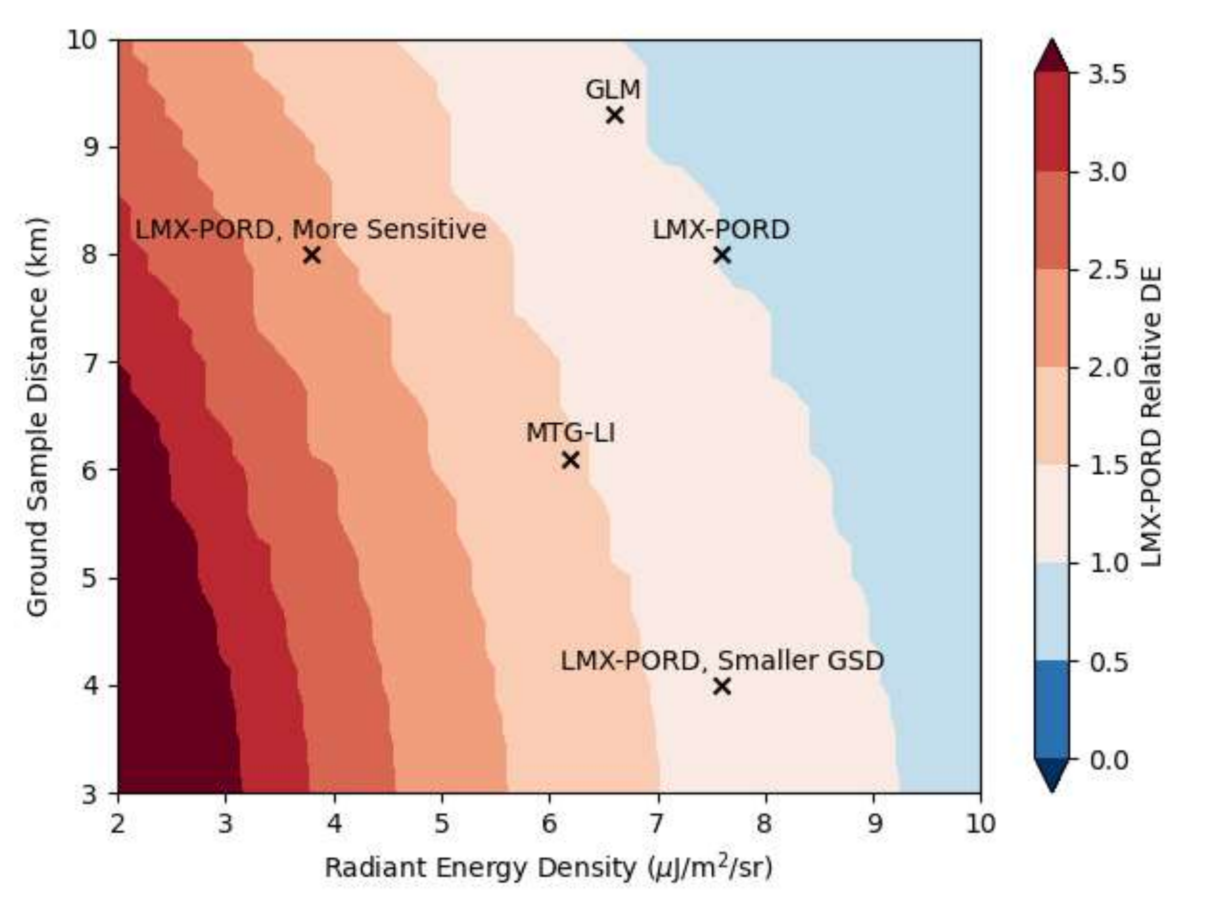
Lightning Phenomenology – optical pulses

- A design that maintains the same sensitivity but has pixels that are twice as small will detect 32% more lightning.
  - FOV averaged: 7.6 μJ/m²/sr , 16 km²
- A design that maintains the same pixel size but is ***twice as sensitive will detect 119% more lightning*****!**
  - FOV averaged: 3.8 μJ/m²/sr , 64 km²
- Decreasing pixel size does not yield as much performance improvement as increasing sensitivity!



Lightning Phenomenology – detection

- If we look at the parameter space of radiant energy density and ground sample distance (and not just selected samples), we see that the detection of lightning pulses is a strong function of radiant energy density.
    - In other words, for every combination of radiant energy density and ground sample distance, integrate the distribution to find percent lightning detected.
- The contours are largely vertical, until the very smallest radiant energies.



More sensitivity is more valuable than smaller pixels to see more lightning!

Take Home!

- Small lightning discharges are not as bright as larger lightning discharges.
- Starting from a baseline sensitivity and pixel size, an instrument with pixels twice as small will detect 32% more lightning.
- An instrument that is twice as sensitive will detect 119% more lightning!
    - Where we are in parameter space matters.