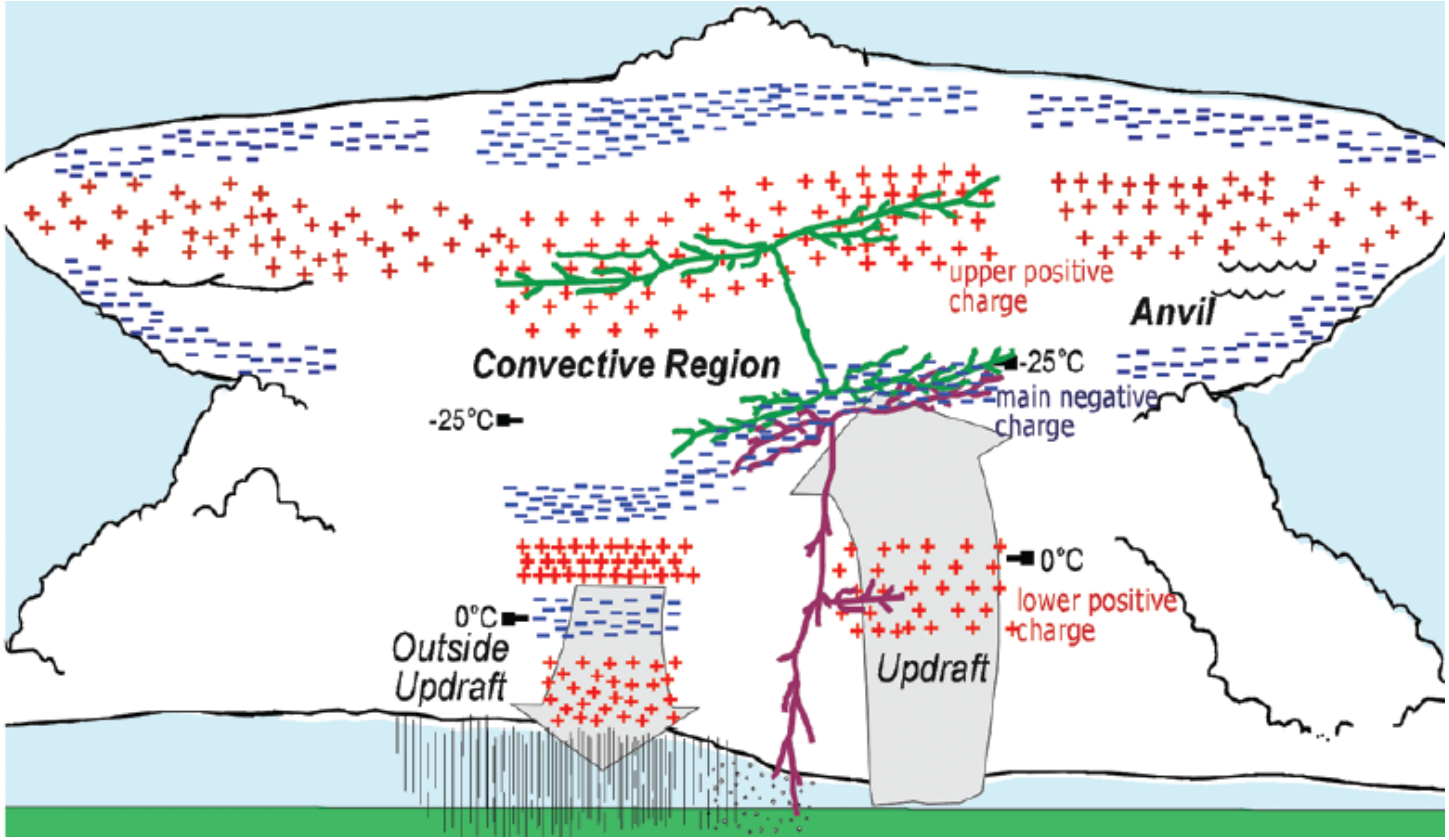
The origin of lightning

Casper Rutjes

Introduction



Balloon measurements

photos from: Langmuir Lab, central New Mexico, 1999 (Marshall, Stolzenburg et al.)

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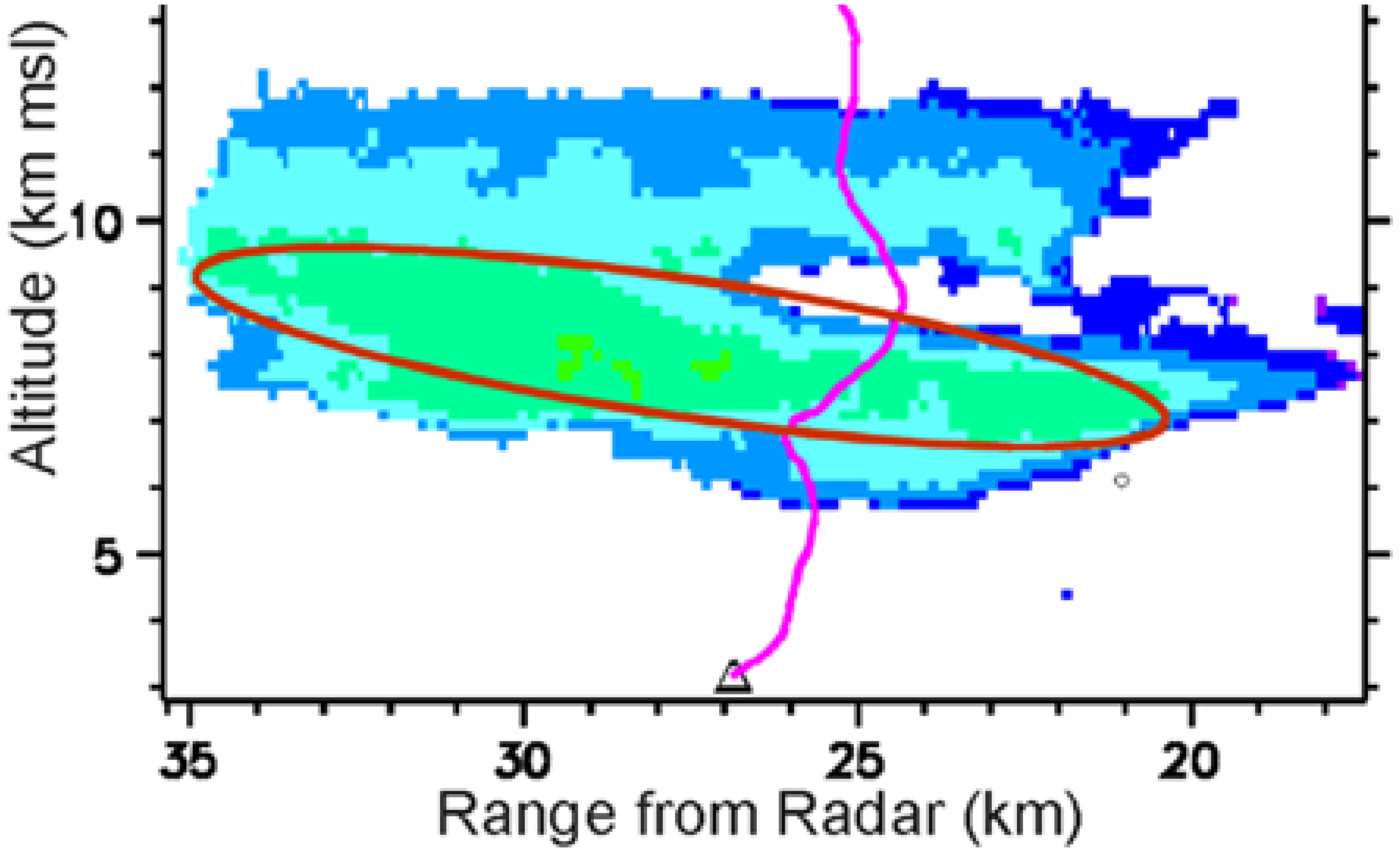
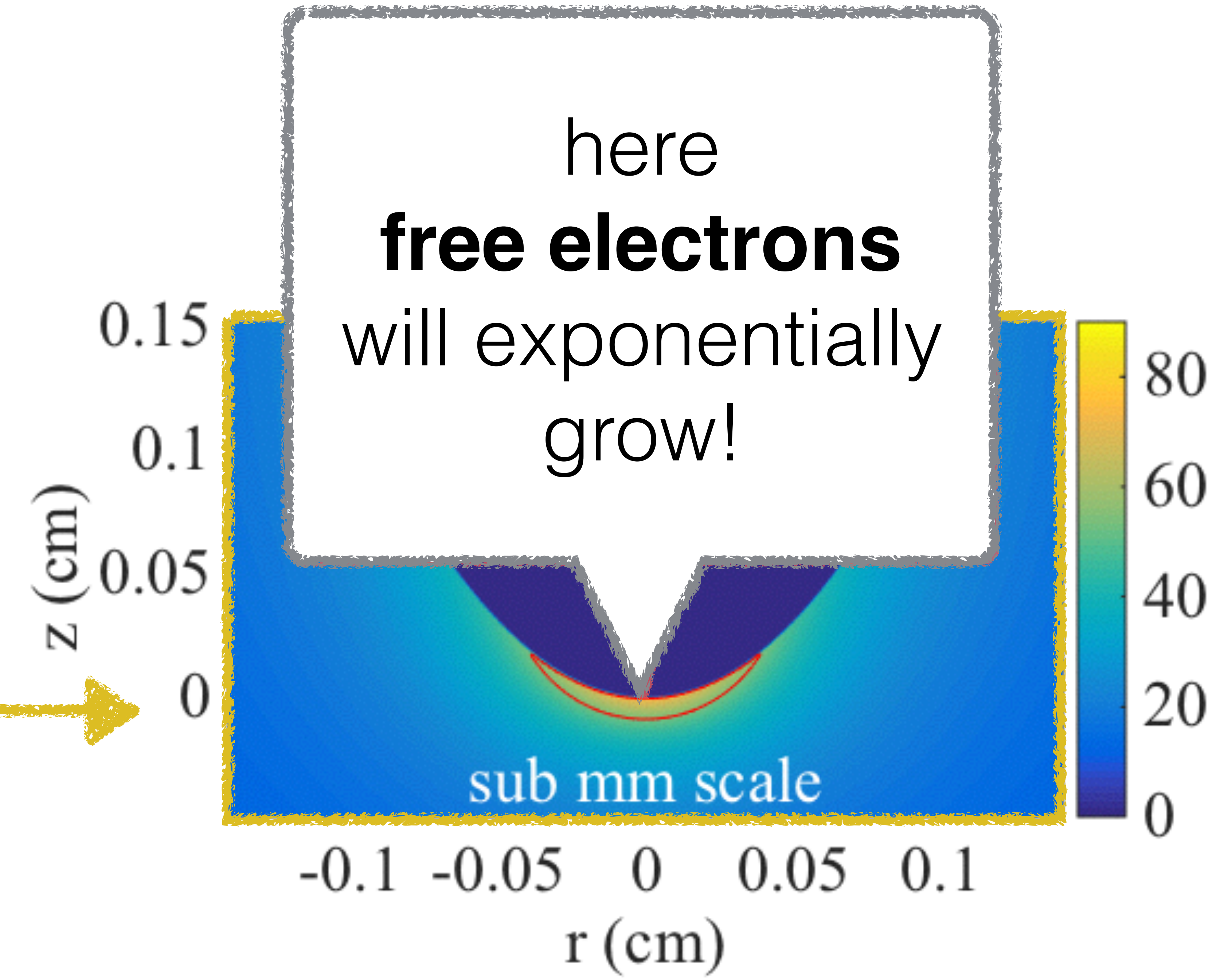


all measured electric fields are too low
to start classical breakdown

figure: Stolzenburg & Marshall. *Space Sc.Rev.* 137.1-4 (2008): 355-372.

Droplets and ice particles



increases the electric field (potentially above breakdown), but only very locally

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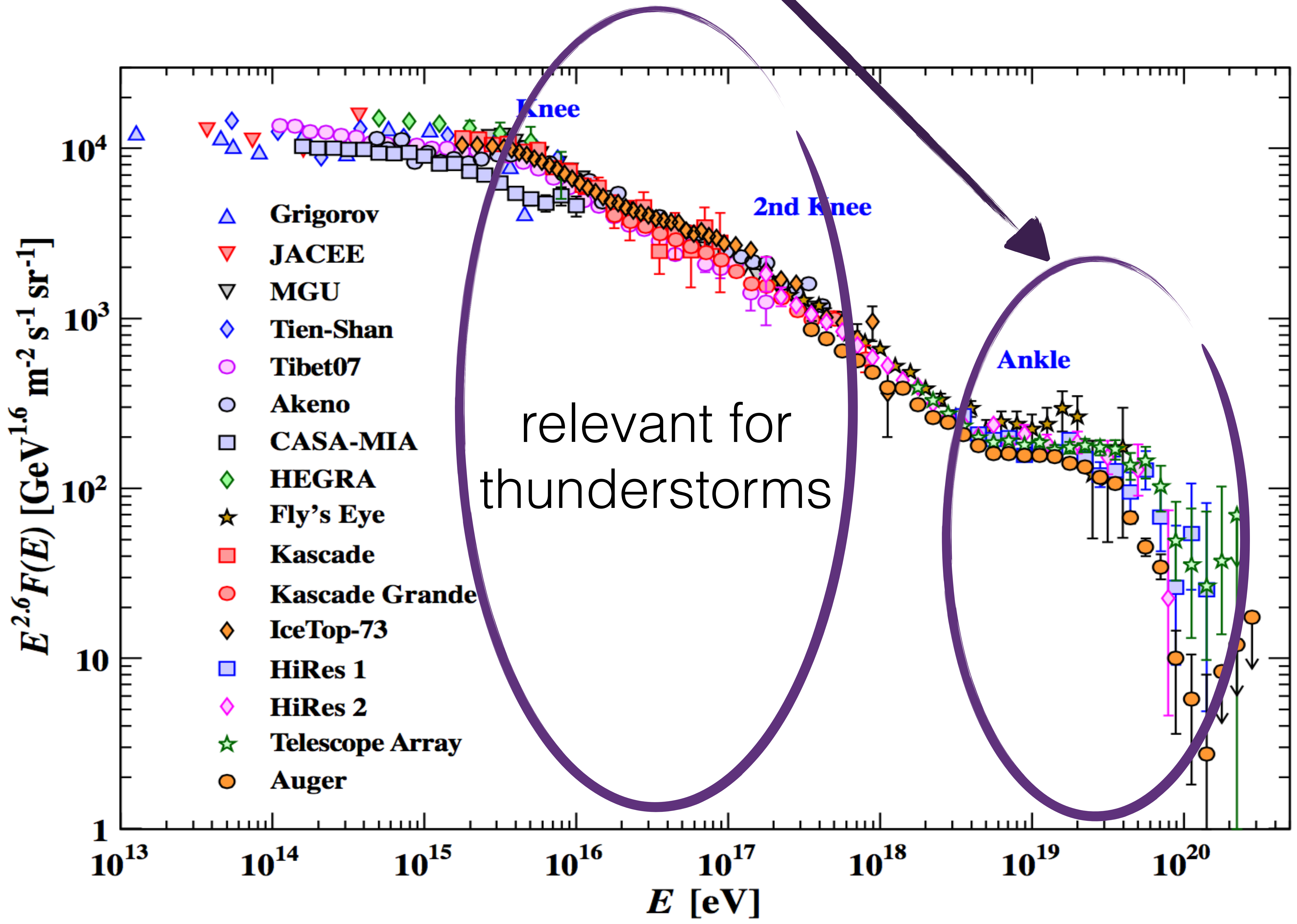

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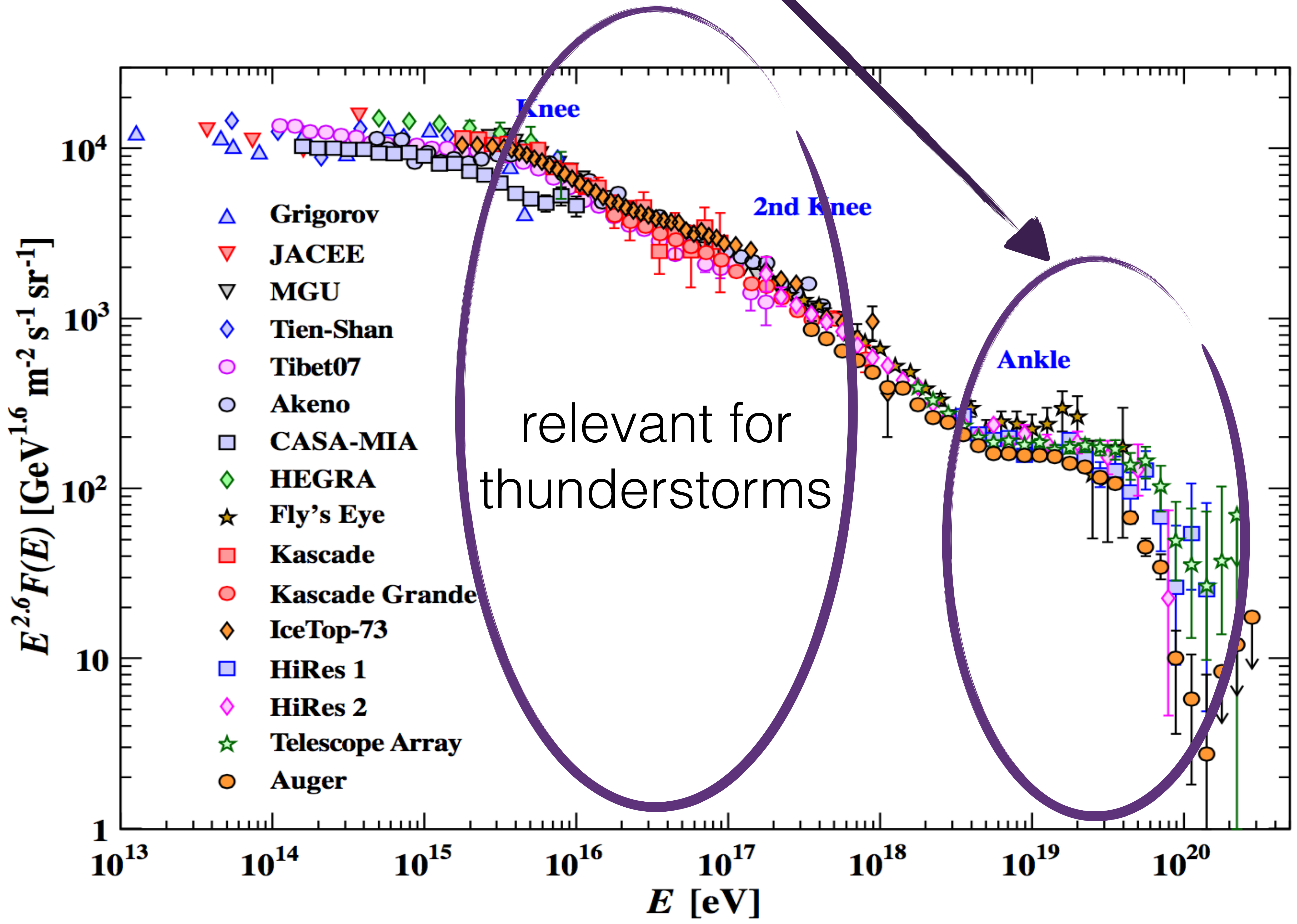


Free electrons by cosmic rays

Intermezzo;

Footprint of shower changes due to the thunderstorm.

New way of probing electric fields!

Phys. Rev. Lett. 114 , 165001 (2015)

nature Science

The New York Times nrc.nl

Radiotelescope LOFAR
Drente Netherlands

E. field + Ice particle + Free electrons

From the initial conditions to discharge inception
is a non-linear time-dependent problem

drift **diffusion** **reaction**

electrons $$\partial_t n_e = \nabla \cdot (\mu \vec{E} n_e + D \nabla n_e) + (\alpha - \eta)\mu E n_e + S_{\mathrm{ph}}$$

ions $$\partial_t n_i = (\alpha - \eta)\mu E n_e + S_{\mathrm{ph}}$$

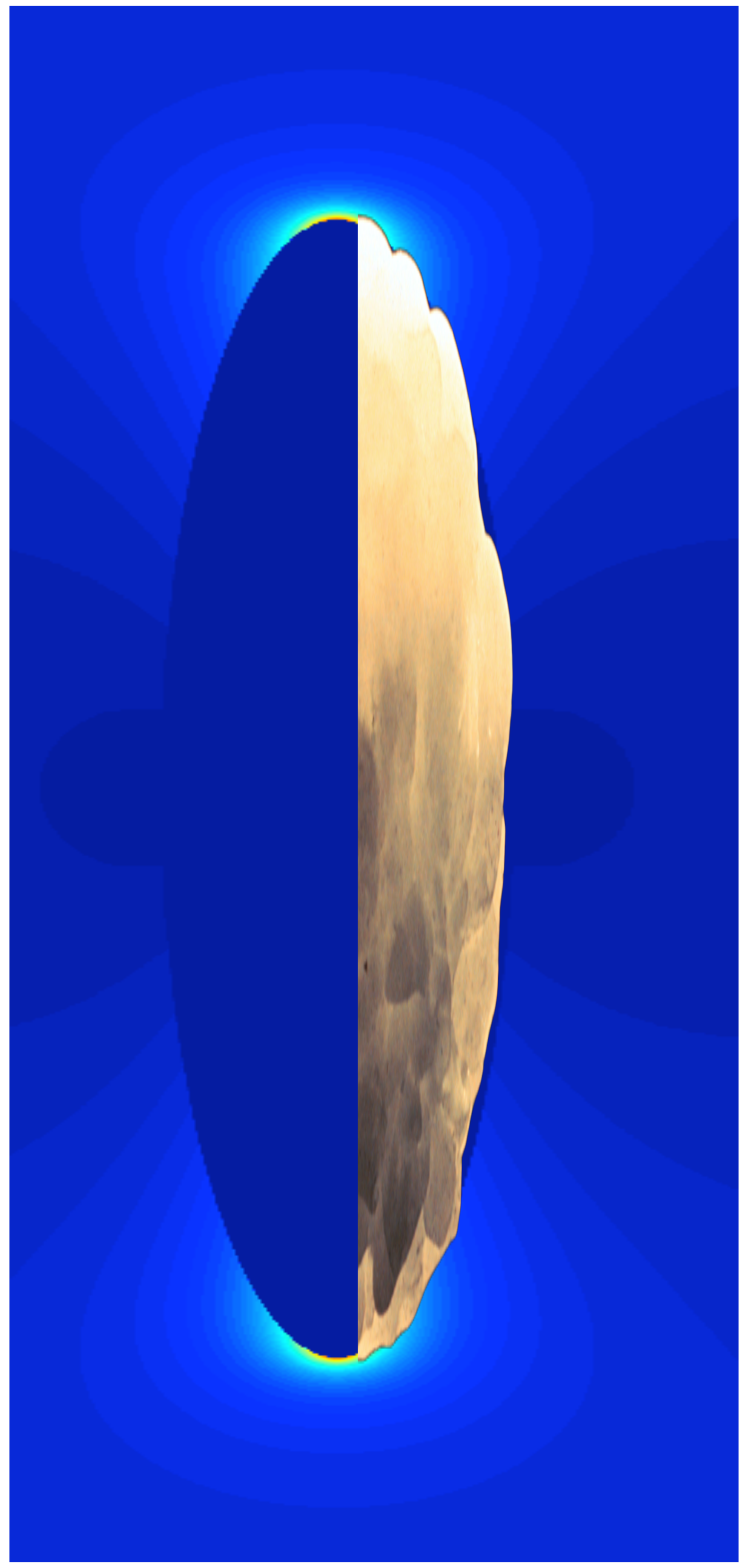
electric potential $$\nabla(\epsilon \nabla \phi) = \frac{e}{\epsilon_0}(n_i - n_e)$$

electric field $$\vec{E} = -\nabla \phi$$

E. field + Ice particle + Free electrons

Shown case: 0.7 x 6 cm length, Field 15% breakdown,
altitude 5.5 km, background electron density 10^2 cm^{-3}

cylindrical symmetric approximation



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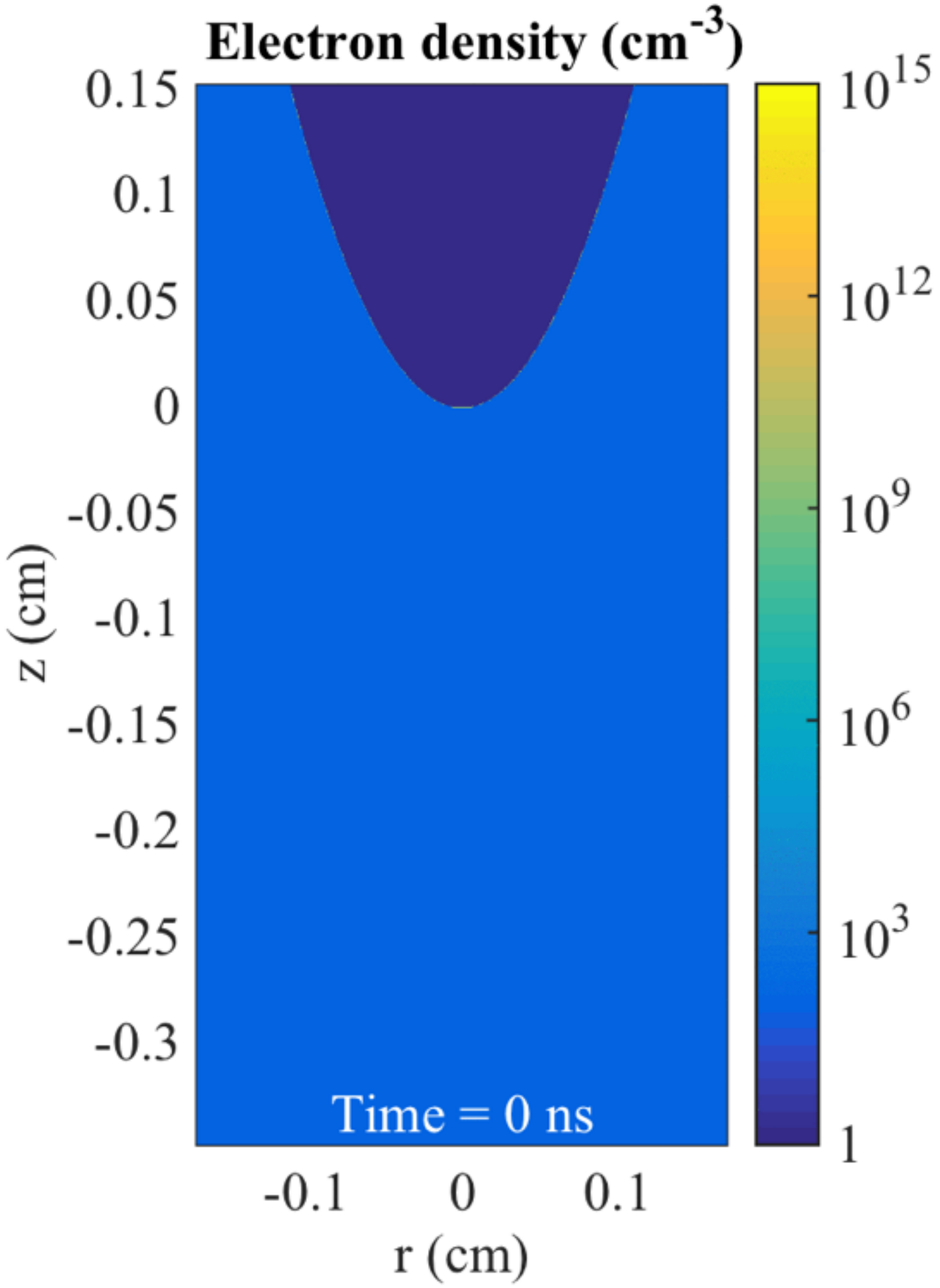
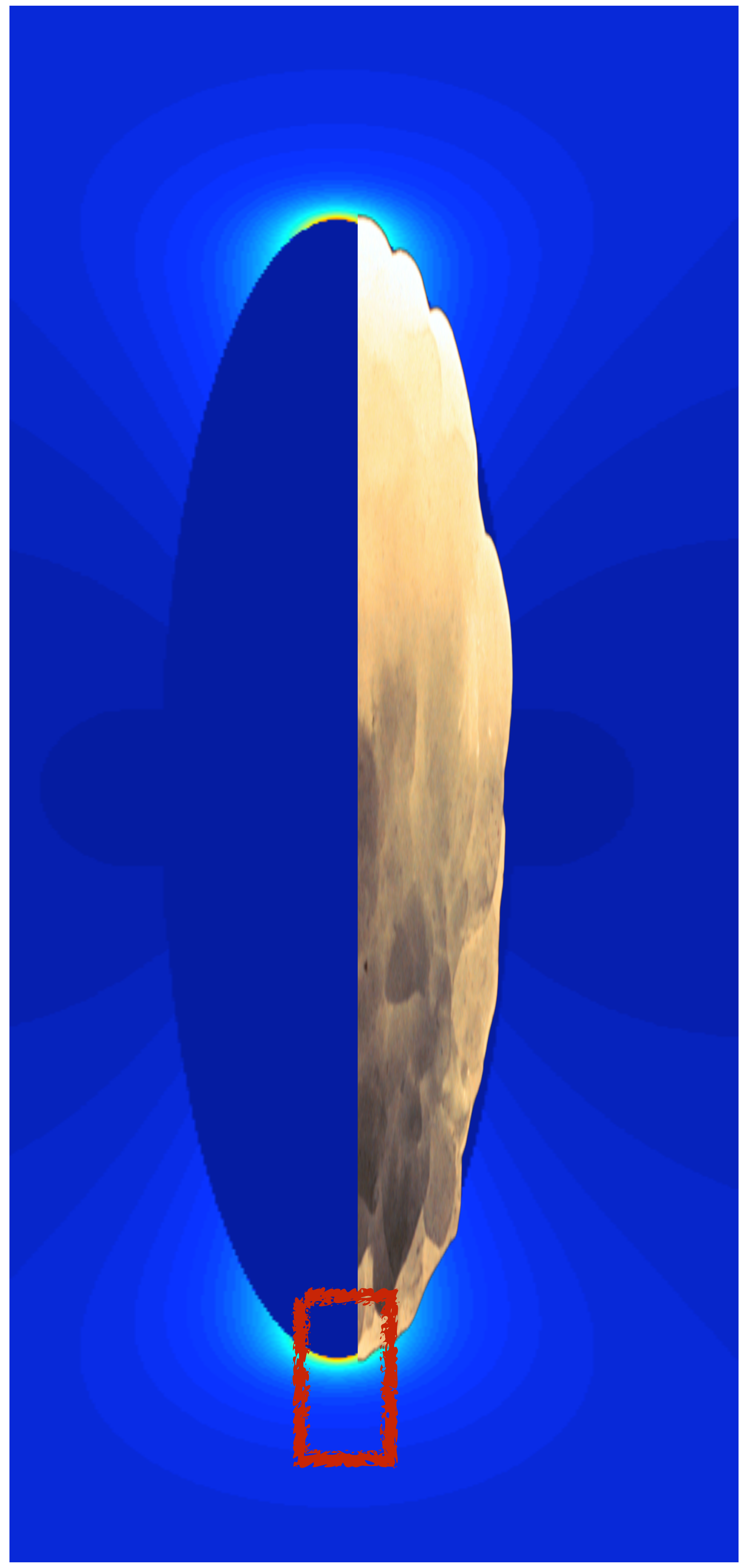
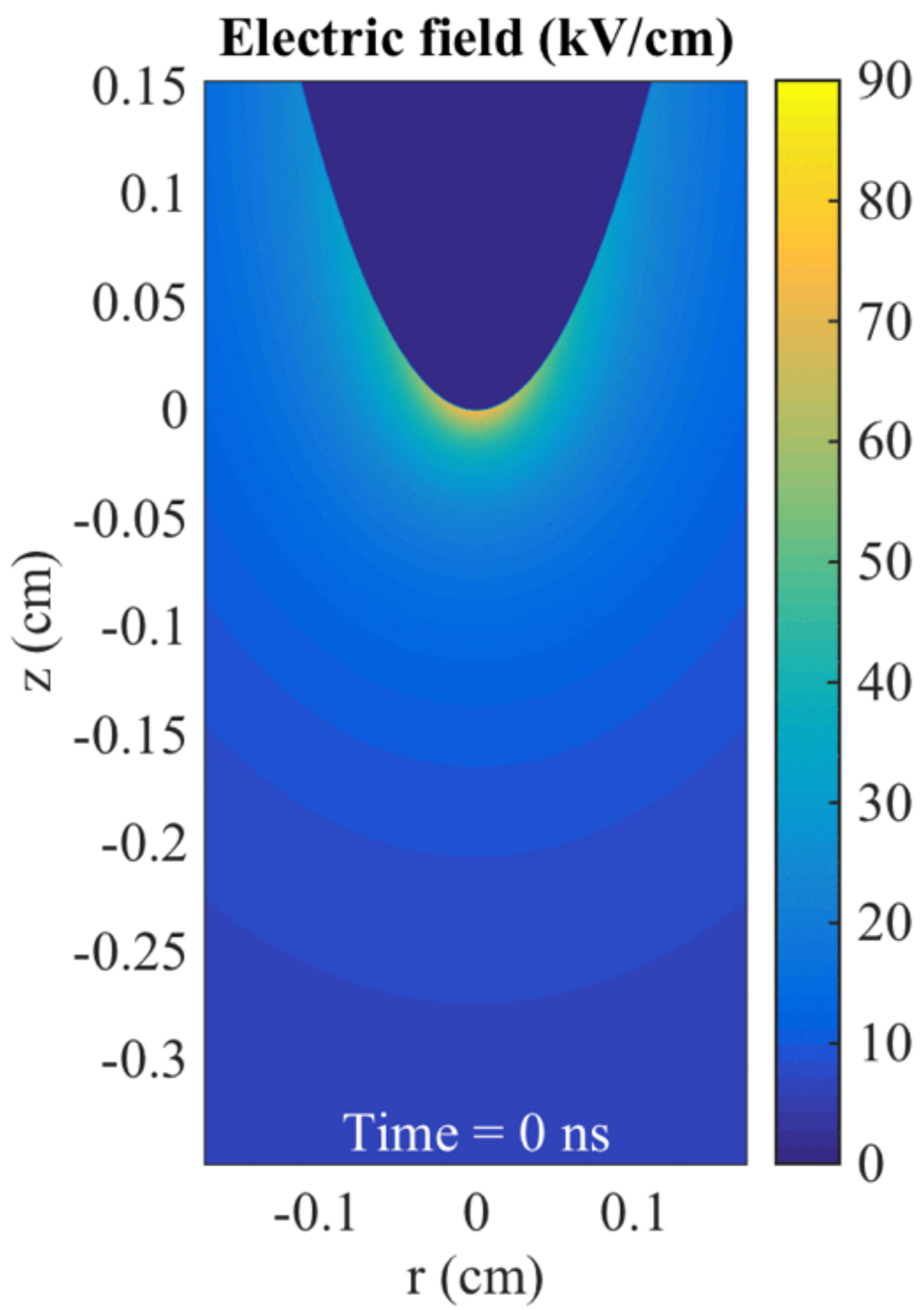


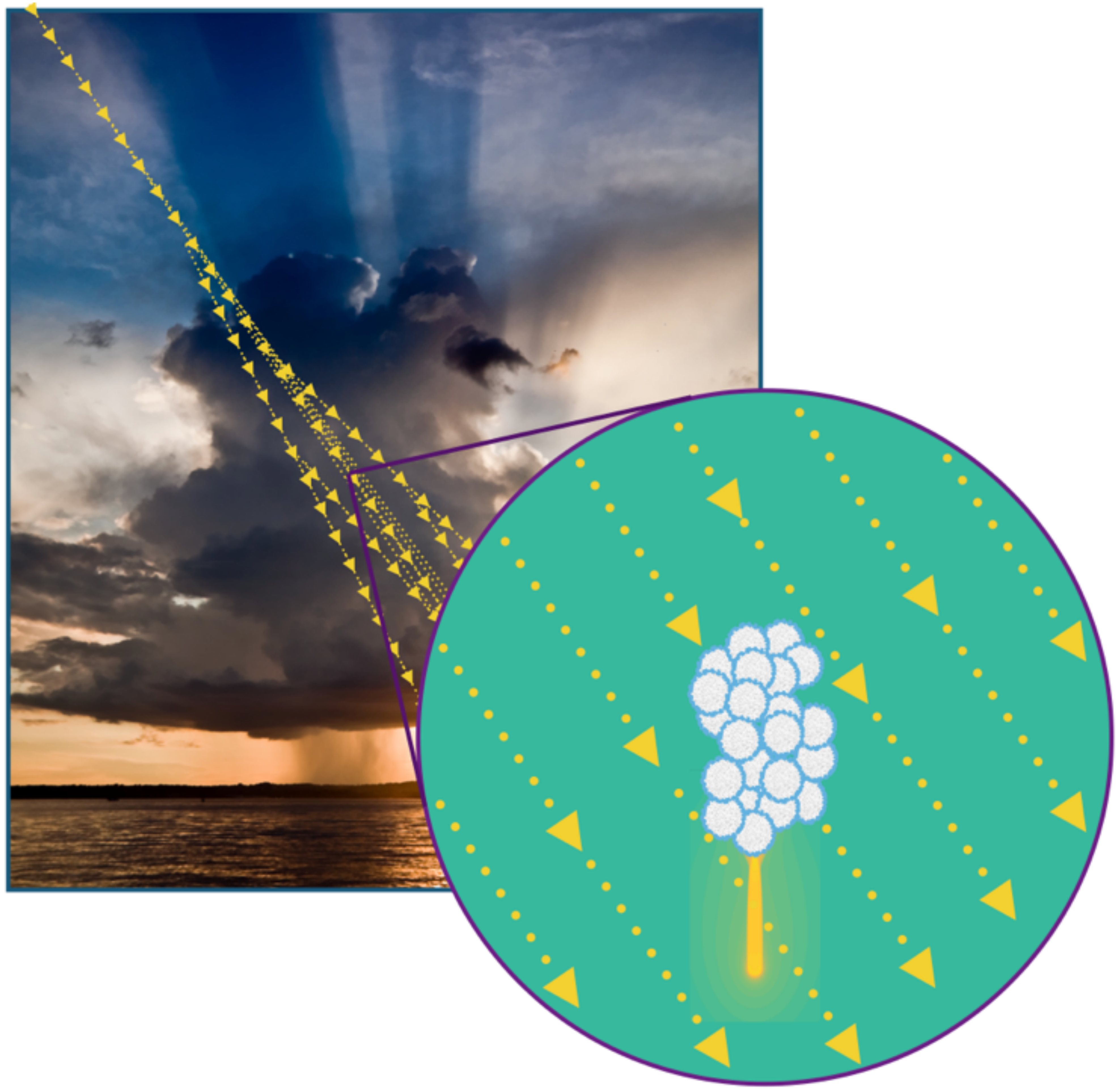




PRL 115, 015002 (2015) PHYSICAL REVIEW LETTERS week ending 3 JULY 2015

Prediction of Lightning Inception by Large Ice Particles and Extensive Air Showers

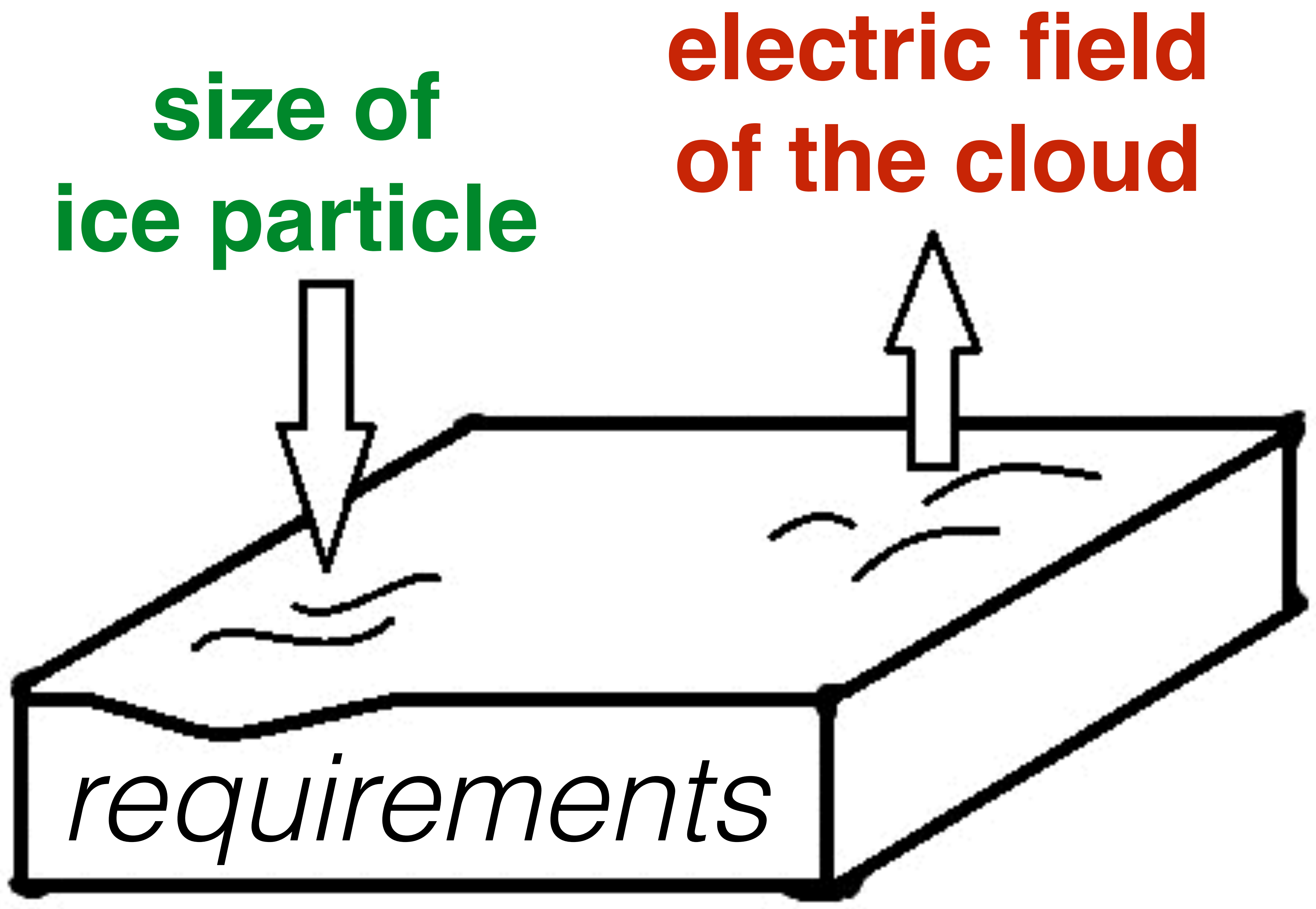
Anna Dubinova,[1,*] Casper Rutjes,[1,†] Ute Ebert,[1,2] Stijn Buitink,[3] Olaf Scholten,[3,4] and Gia Thi Ngoc Trinh[4]



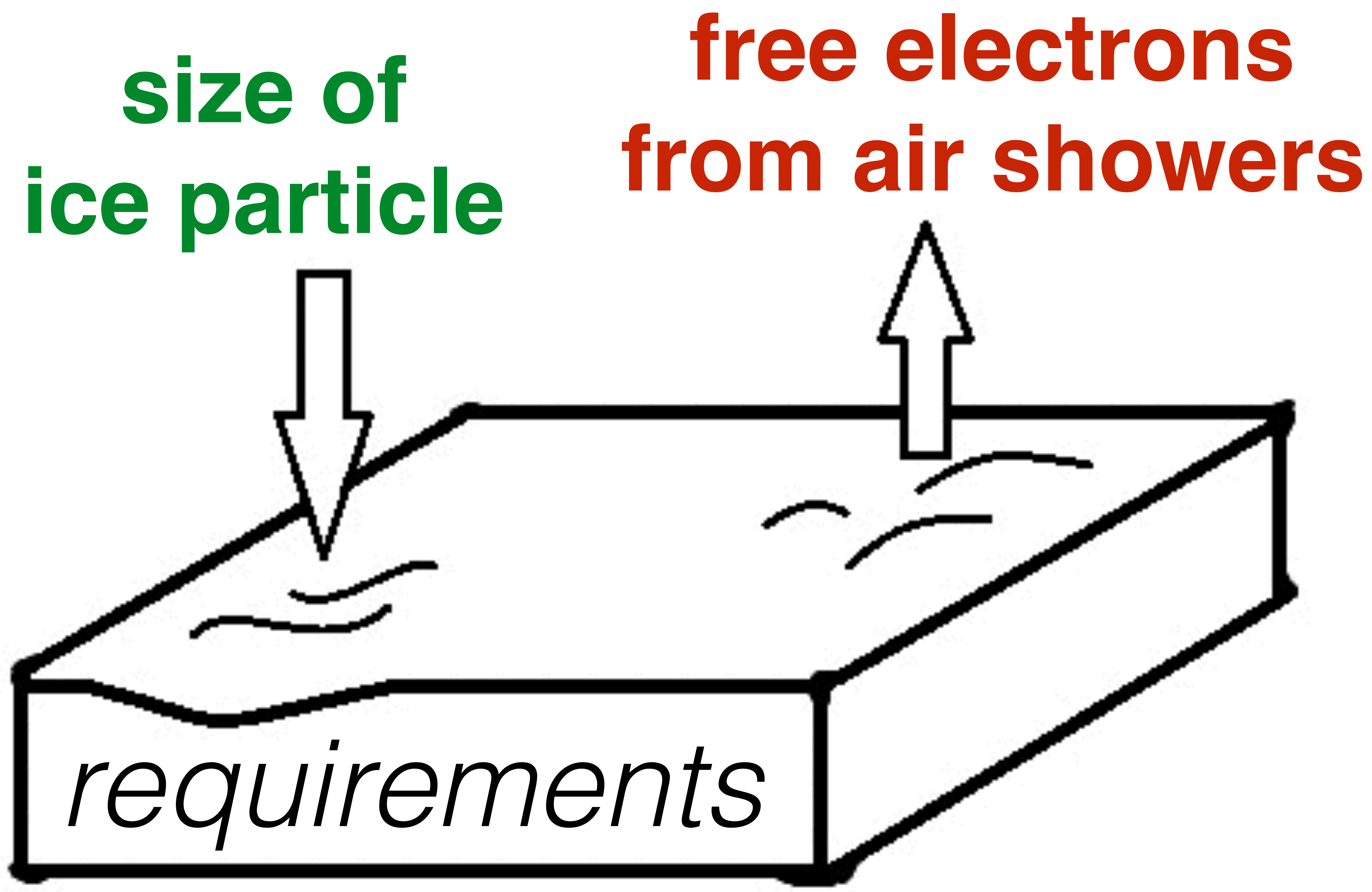
Inception from large ice particle (6 cm length) is possible; right conditions occur at least 5 times per km^2 per minute.

but is it possible to start from smaller ice particles (or droplets) and how often does that occur?

Smaller ice particles?

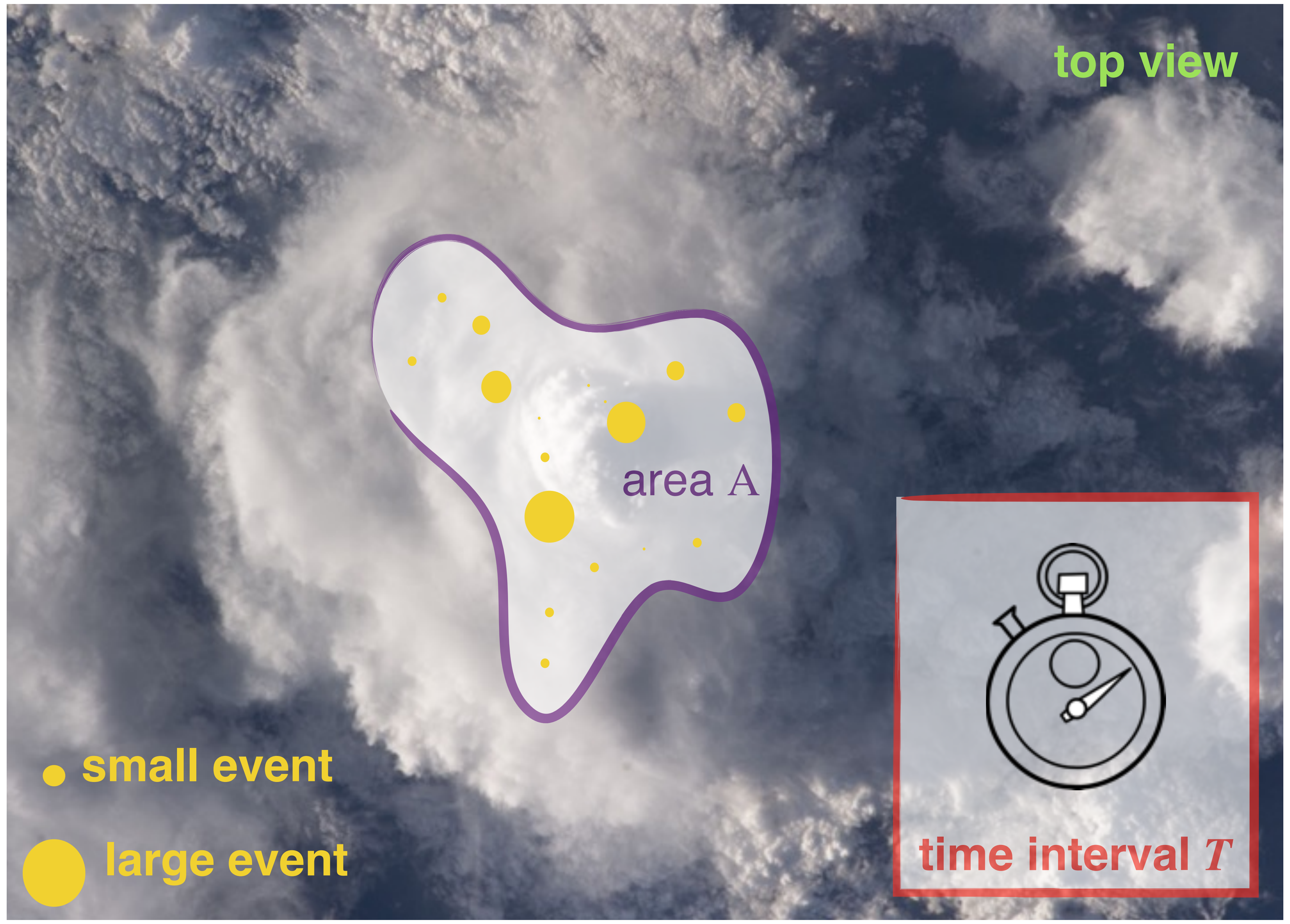


?? maybe the balloons just went to the wrong places ??



?? maybe there are rare events of cosmic showers ??

Extensive air shower - rare event analysis

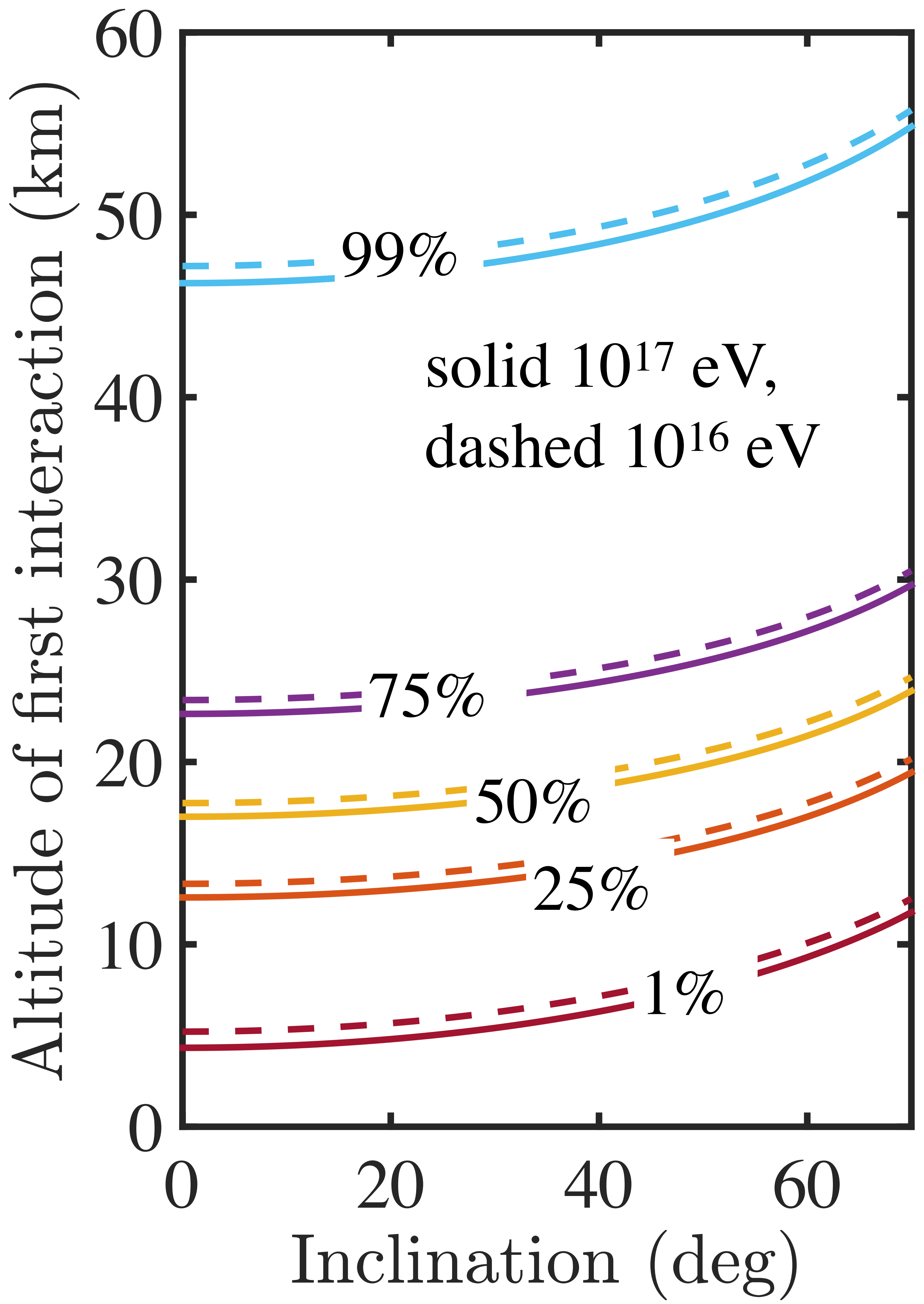


The number of events k
Poisson distributed.

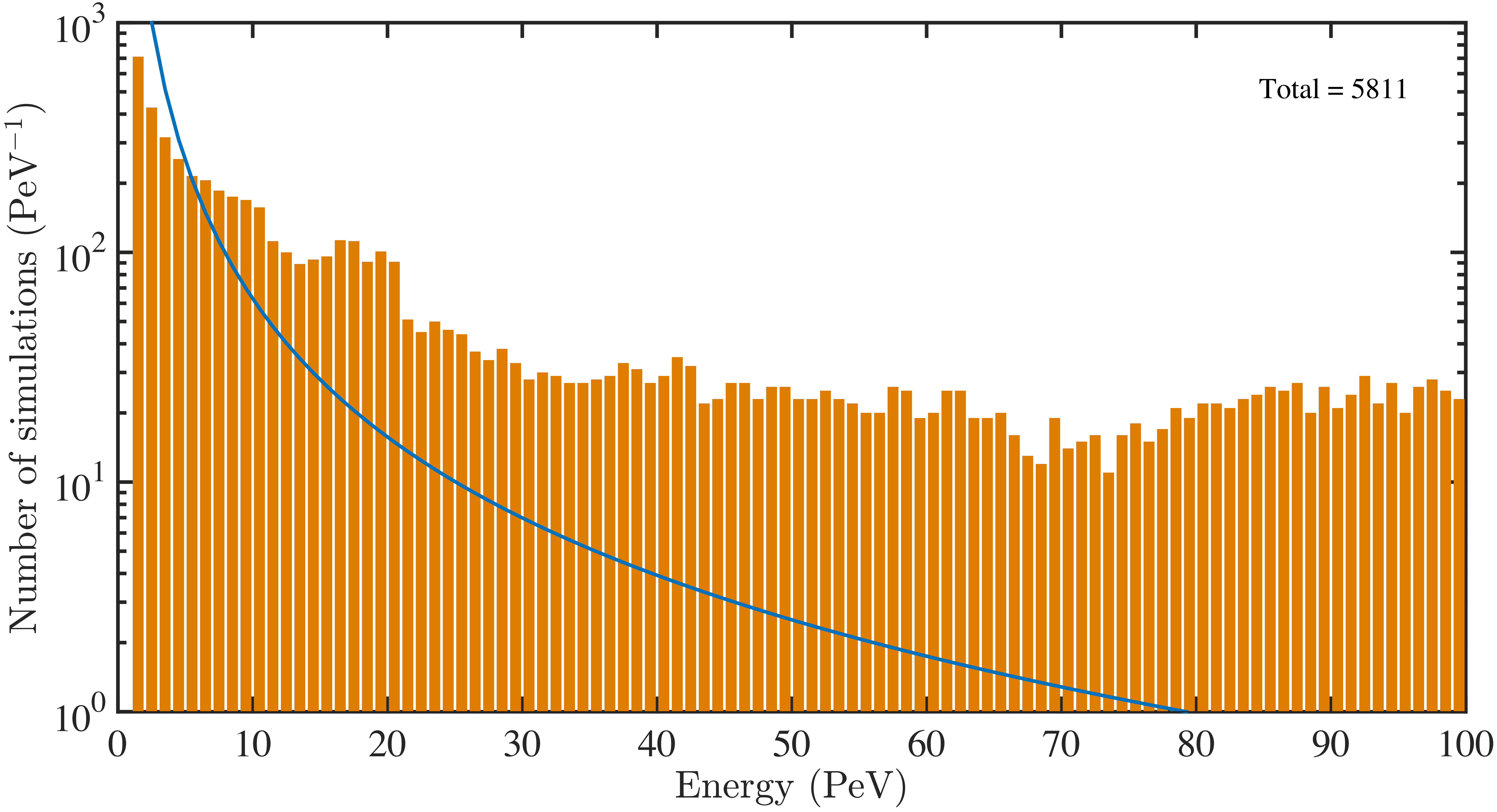
$$P(k) = \frac{\lambda^k e^{-\lambda}}{k!}$$

$$\lambda = FLUX \times AREA \times TIME$$

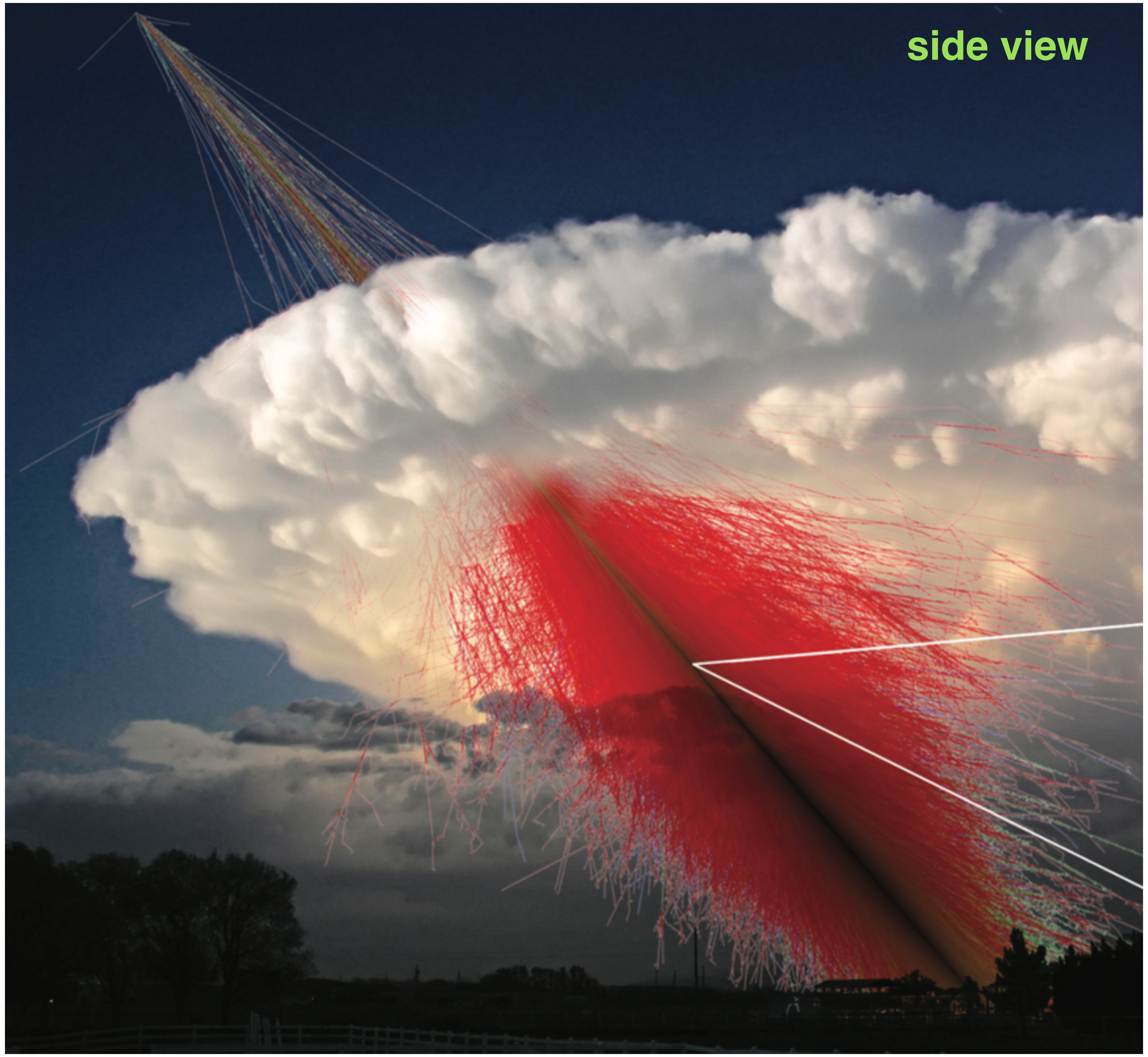
Per incoming cosmic particle
huge shower-to-shower fluctuations

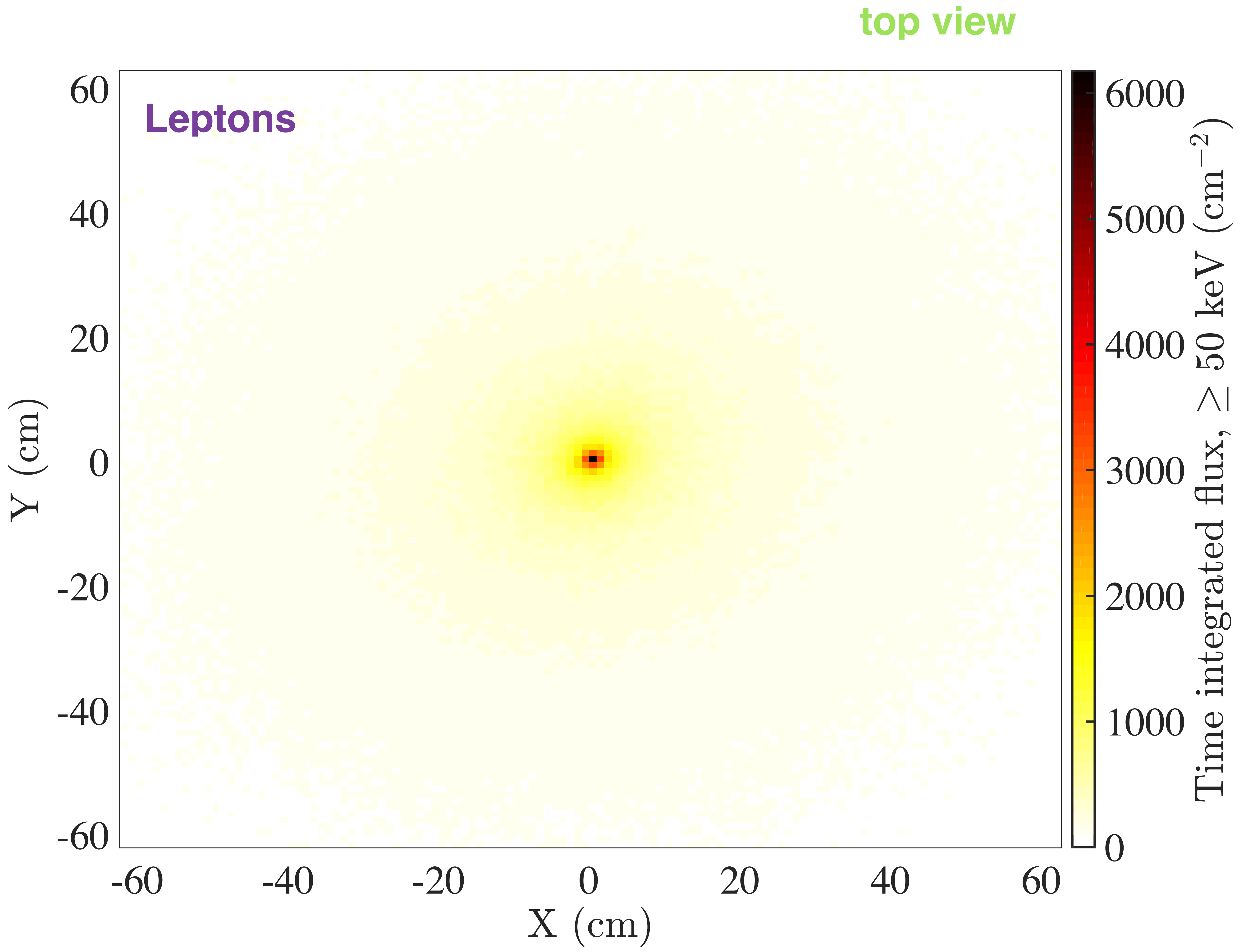


Computed dataset

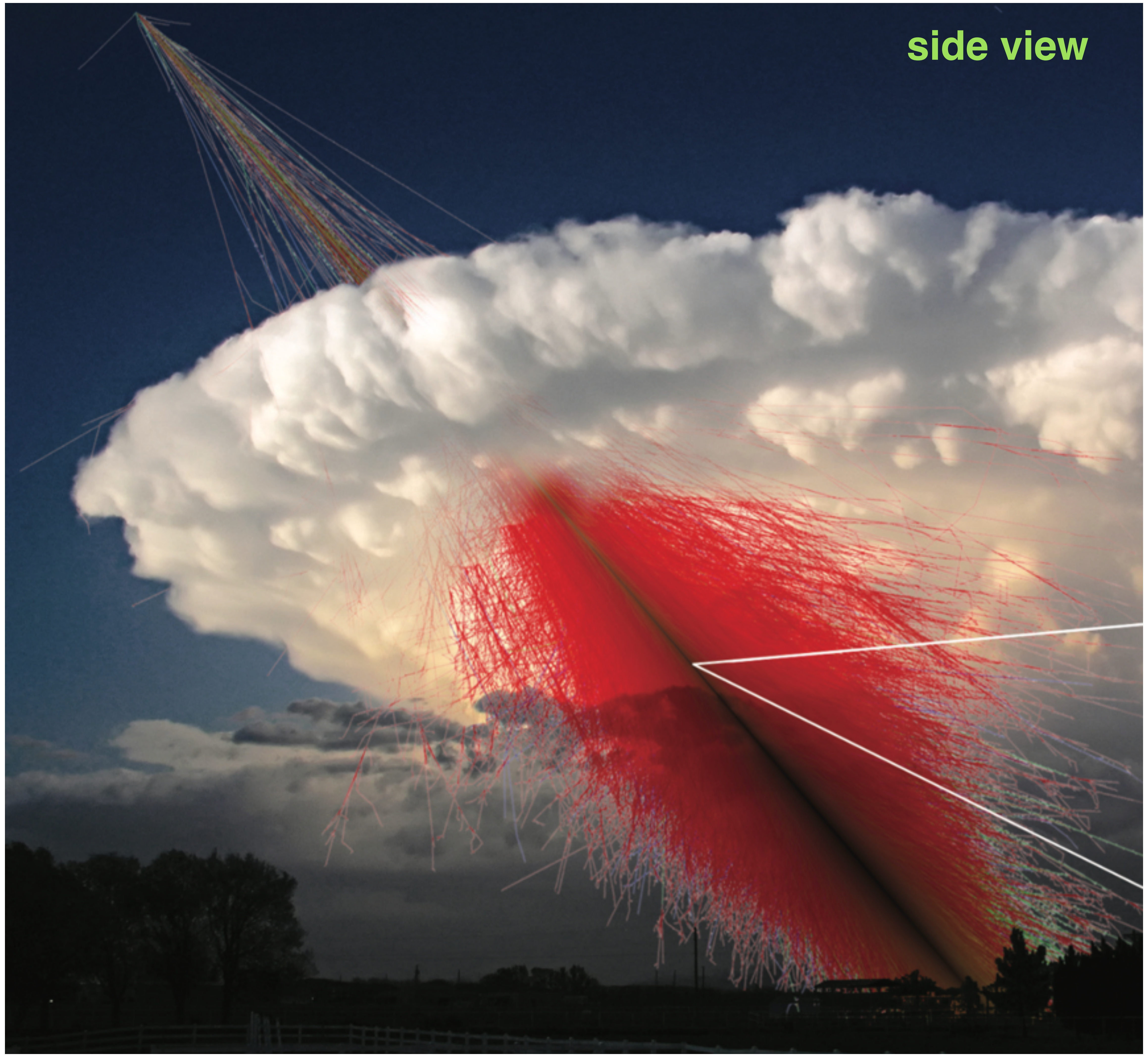


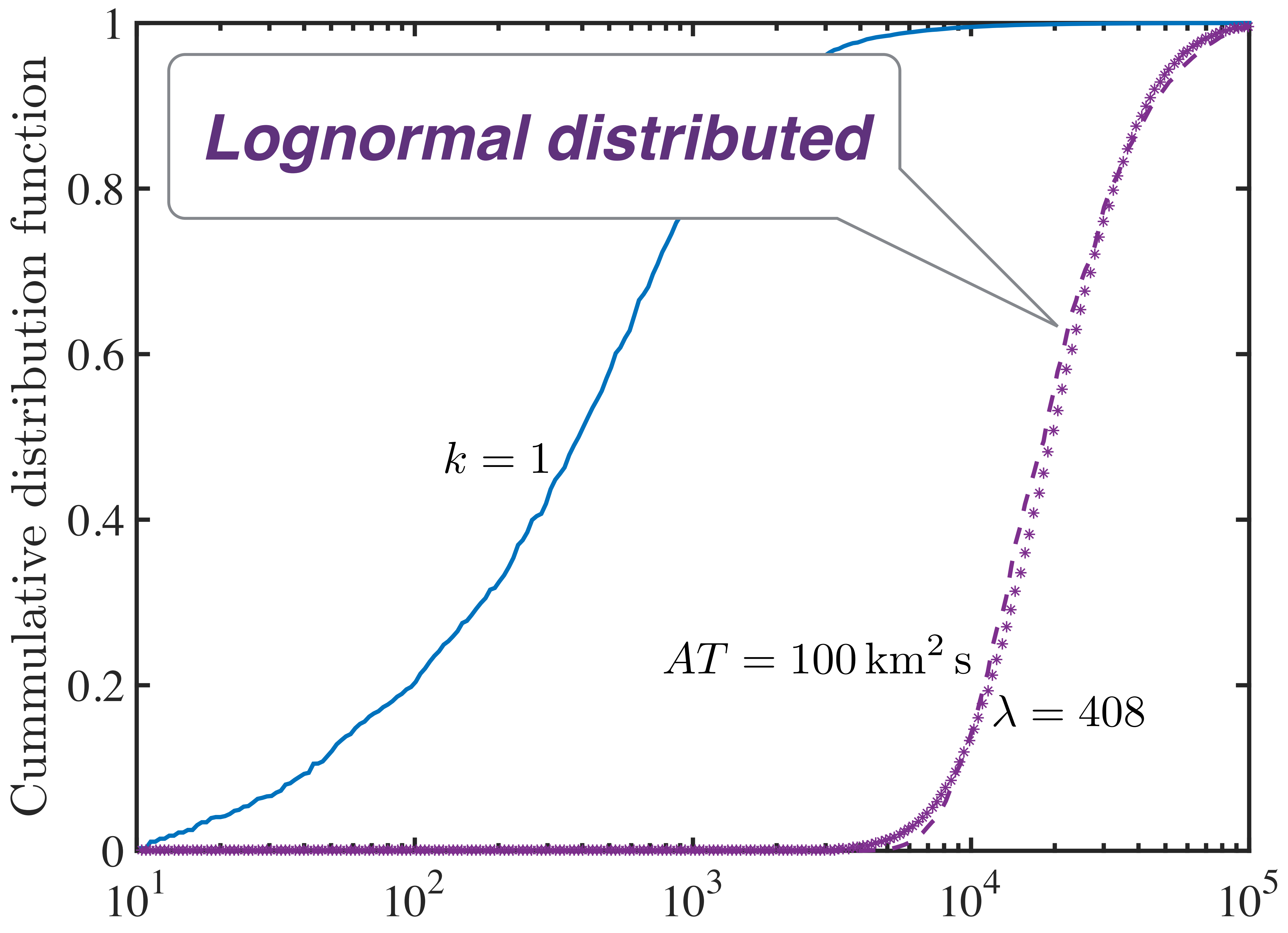
For each simulation





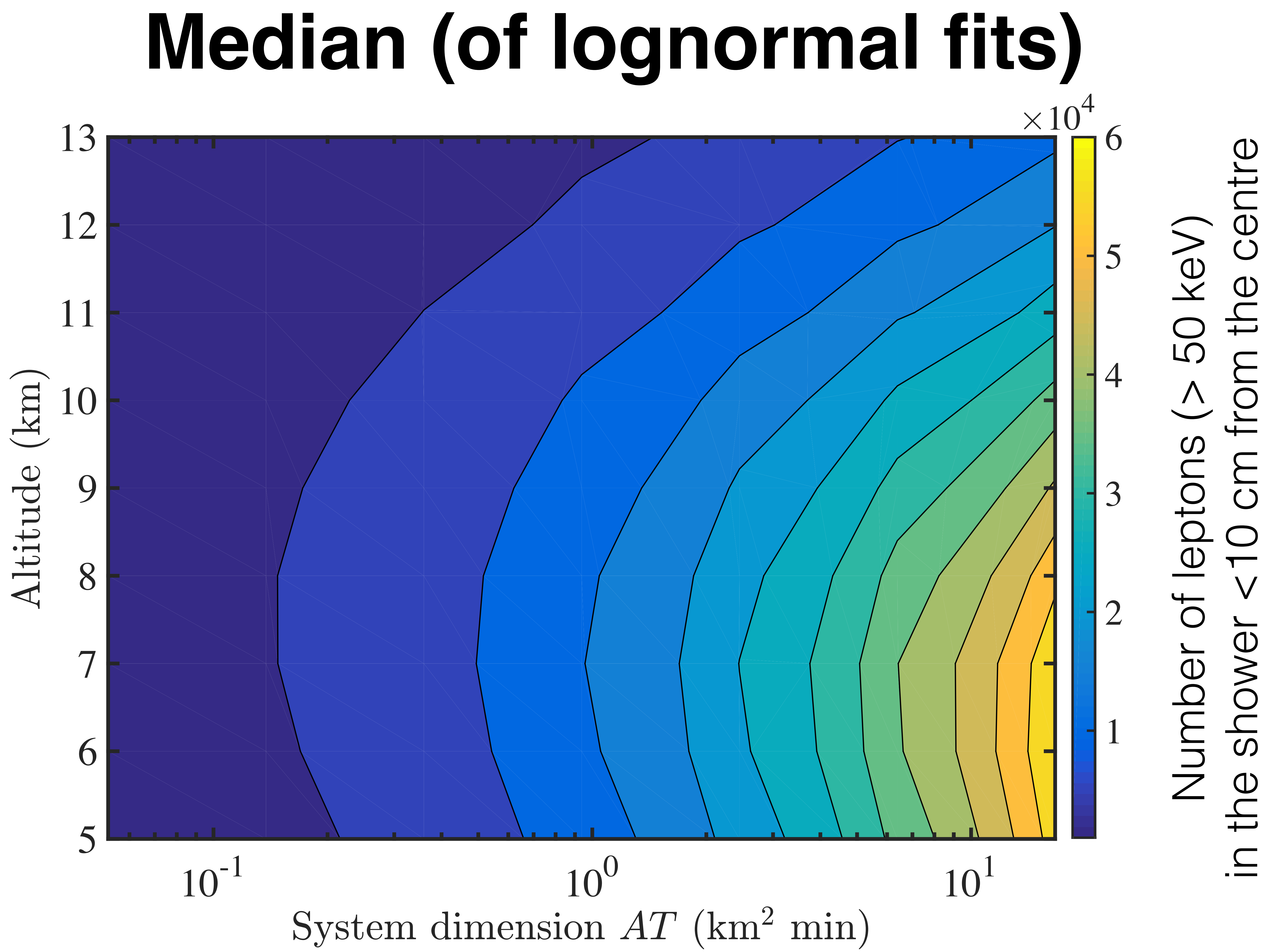
Probability distribution of the maximal output





Number of leptons (> 50 keV)
in the shower <10 cm from the centre

Probability distribution of the maximal output



Conclusions & outlook

- To start lighting:
  1. thundercloud E field
  2. ice particle
  3. free electrons

  } possible to start streamer, demonstrated for large ellipsoidal ice particles *Dubinova, Rutjes, Ebert et al. (2015)*

- Smaller ice particles? Lower fields? -> More free electrons!

- Maximal free electron density is lognormal distributed and very sensitive on system size.

- [Outlook] predict streamer inception near insulators (e.g. ice), in thunderstorms and high-voltage technology.