Santa Clara Valley CHAPTER

www.scvemc.org

Title : The Lightning Phenomenon

Guest Speaker : Marcos Rubinstein (DL)

Abstract: Lightning is one of the primary causes of damage and malfunction of telecommunication and power networks and one of the leading causes of weather-related deaths and injuries. Lightning is composed of numerous physical processes, of which only a few are visible to the naked eye. This lecture presents various aspects of the lightning phenomenon, its main processes and the technologies that have been developed to assess the parameters that are important for engineering and scientific applications. These parameters include the channel-base current and its associated electromagnetic fields. The measurement techniques for these parameters are intrinsically difficult due to the randomness of the phenomenon and to the harsh electromagnetic environment created by the lightning itself. Besides the measurement of the lightning parameters, warning and insurance applications require the real-time detection and location of the lightning strike point. The main classical and emerging lightning detection and location techniques, including those used in currently available commercial lightning location systems will be described in the lecture. The newly proposed Electromagnetic Time Reversal technique, which has the potential to revolutionize lightning location will also be presented.

Biography

Marcos Rubinstein (M'84-SM'11-F'14) received the Master's and Ph.D. degrees in electrical engineering from the University of Florida, Gainesville, FL, USA, in 1986 and 1991, respectively. In 1992, he joined the Swiss Federal Institute of Technology, Lausanne, Switzerland, where he was involved in the fields of electromagnetic compatibility and lightning location. From 1995 to 2000, he worked as a research engineer, project manager and program manager at Swisscom in the areas of numerical electromagnetics and EMC. In 2001, he moved to the University of Applied Sciences of Western Switzerland HES-SO, Yverdon-les-Bains, where he is currently a full Professor and head of the Advanced Communication Technologies Group. He is the author or coauthor of more than 200 scientific publications in reviewed journals and international conferences. He is also the coauthor of nine book chapters and the co-editor of a book. He served as the Editor-in-Chief of the Open Atmospheric Science Journal, and currently serves as an Associate Editor of the IEEE Transactions on Electromagnetic Compatibility. Prof. Rubinstein received the best Master's Thesis award from the University of Florida. He received the IEEE Achievement Award and he is a co-recipient of the NASA's Recognition for Innovative Technological Work award and the ICLP Karl Berger award. He is a Fellow of the IEEE and an EMP Fellow, a member of the Swiss Academy of Sciences and of the International Union of Radio Science. Following is summary of his presentation options.

The Lightning Phenomenon

Marcos Rubinstein

Outline

- What is lightning and the main lightning processes
- How are its parameters measured
- Lightning detection and location

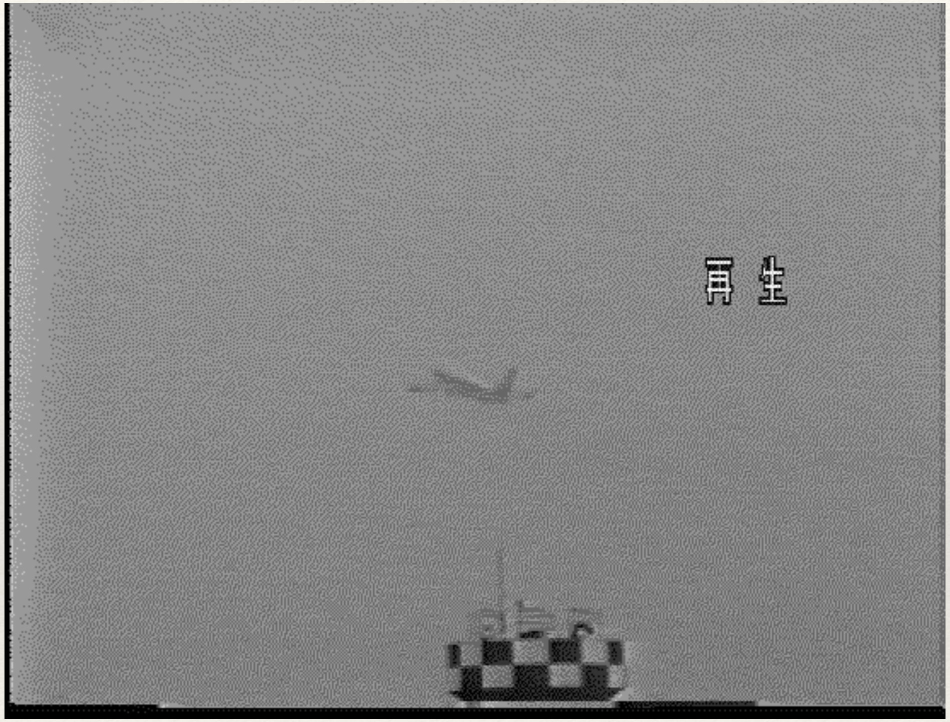
Lightning is a transient, high-current electric discharge whose path length is measured in kilometers

Lightning Effects

- About 30%-60% of all power outages annually are lightning-related, on average, with total costs approaching $1 billion dollars. (Source: EPRI)

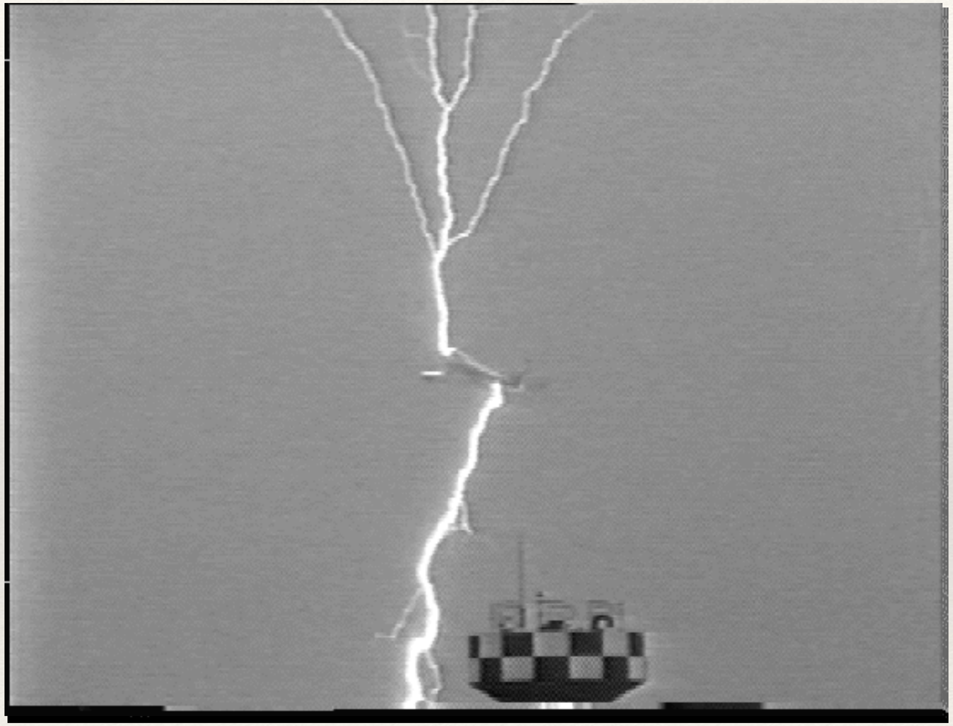
- Lightning strikes cost nearly $1 billion in insured losses in 2012 (source: Insurance Information Institute)

Lightning initiation by an aircraft



Kamatzu Airforce Base, Japan

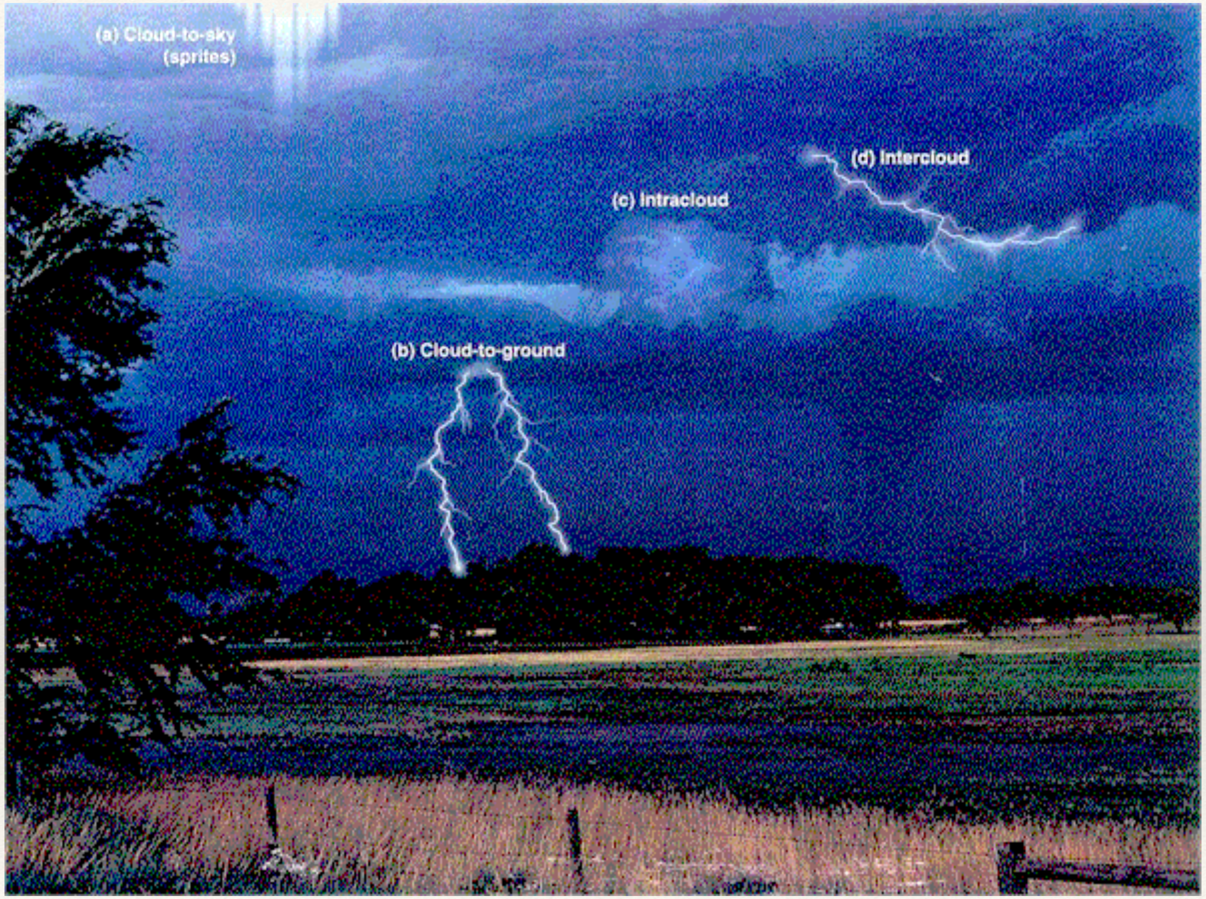
Lightning initiation by an aircraft



Kamatzu Airforce Base, Japan

Cattle Killed by Step or Touch Potential

Major Types of Lightning

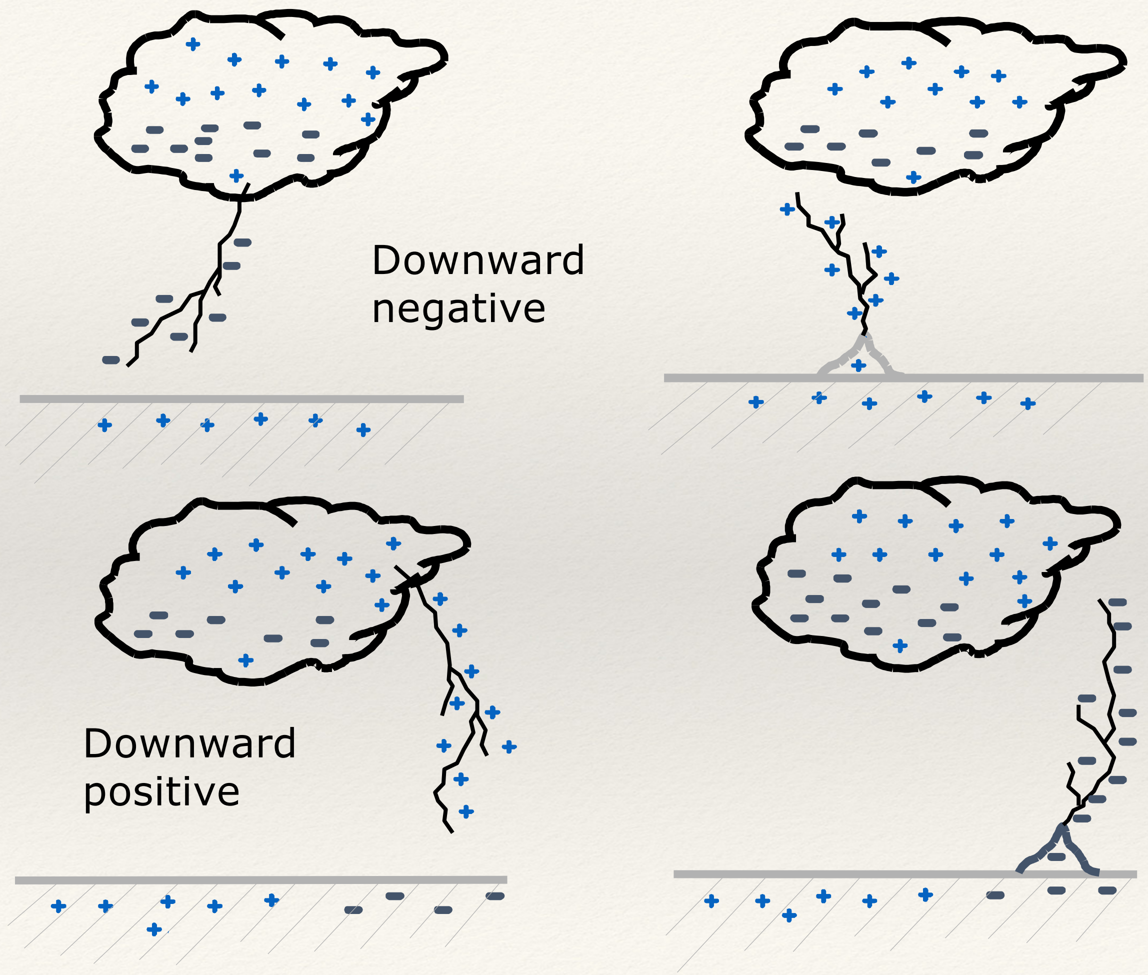


A complete lightning is called a “lightning flash”

Types of Cloud-to-Ground lightning

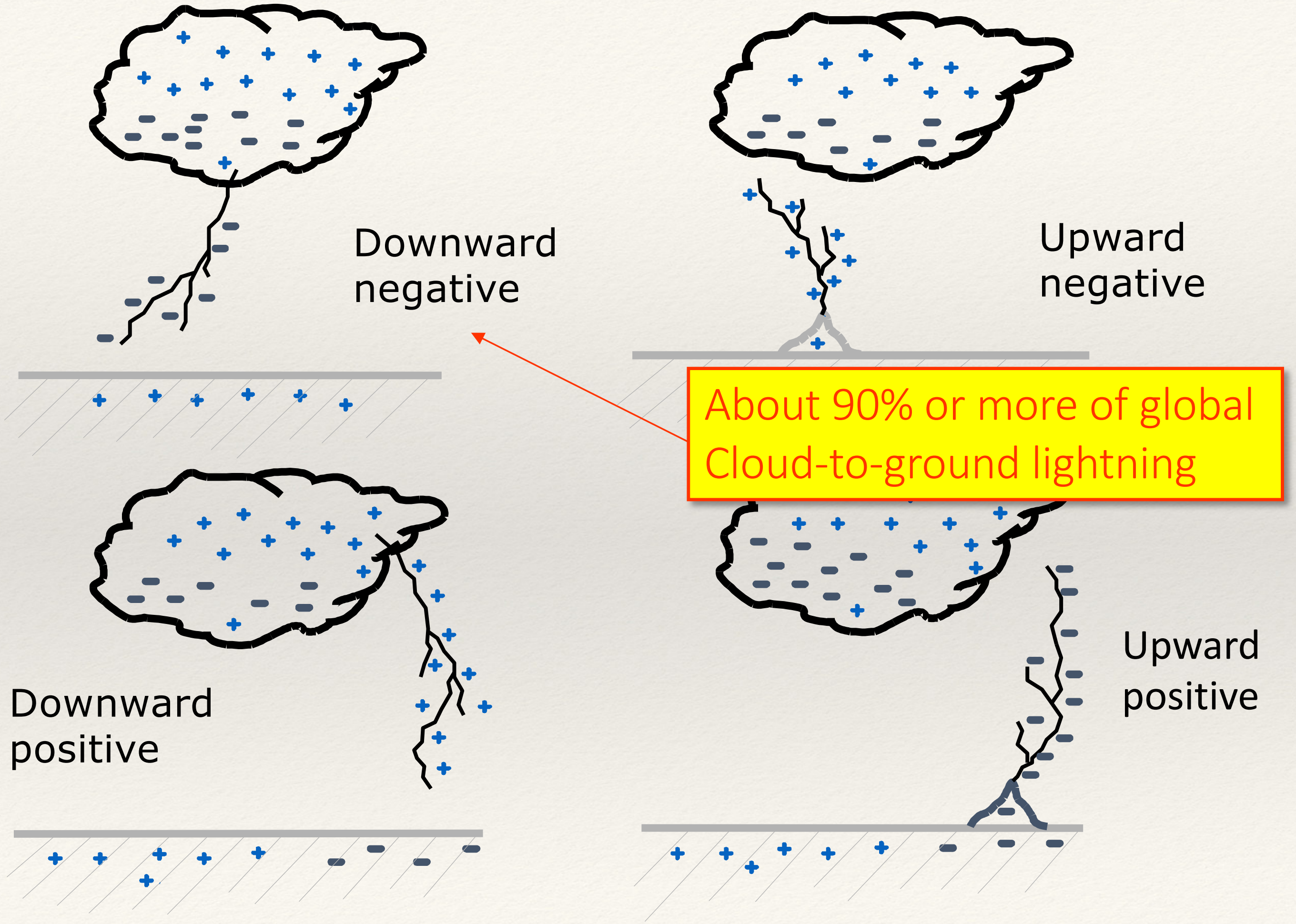
Both of these types can transfer either positive or negative charge to the ground.

Cloud-to-Ground Lightning

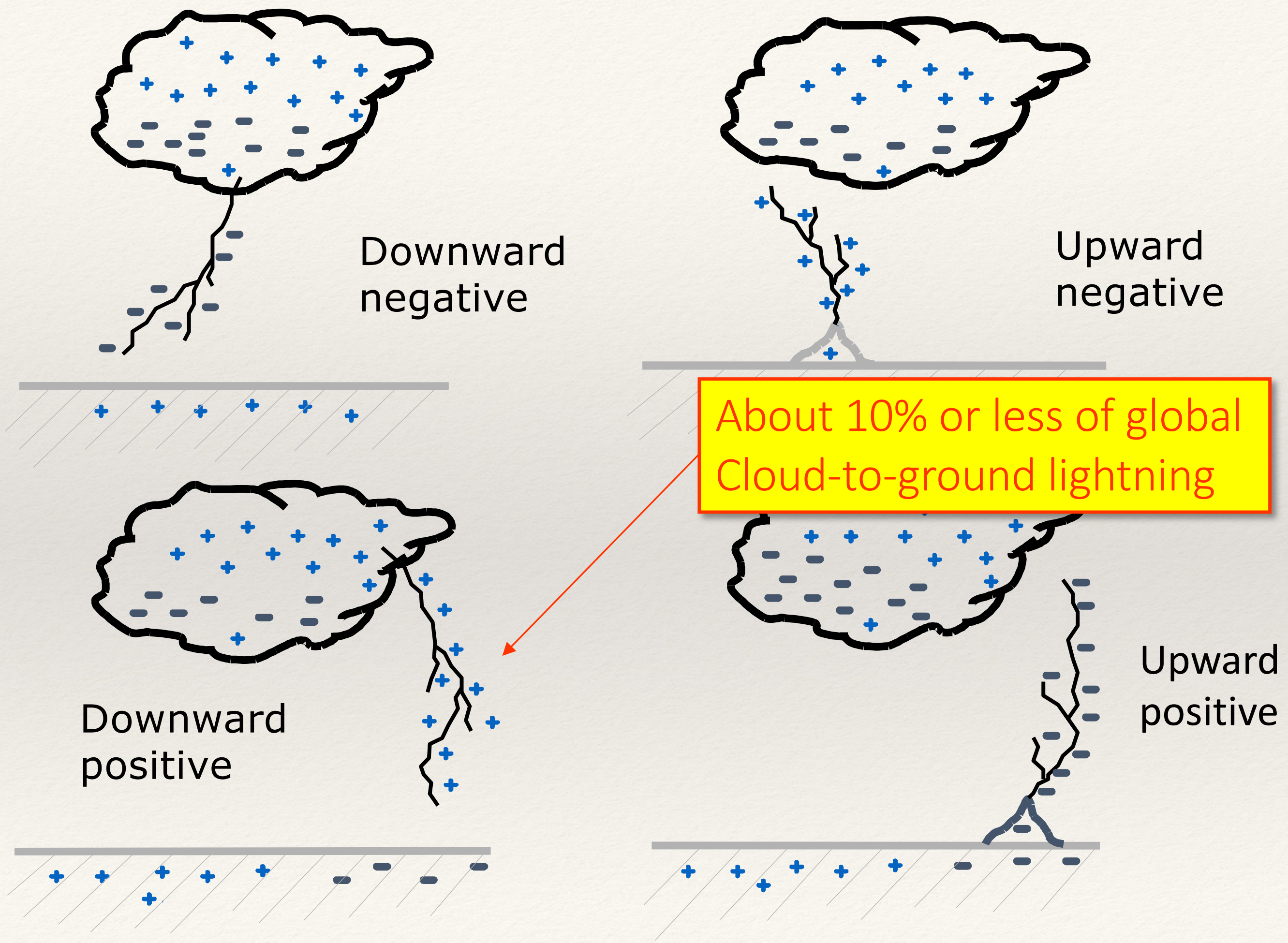


Adapted from Berger, 1977

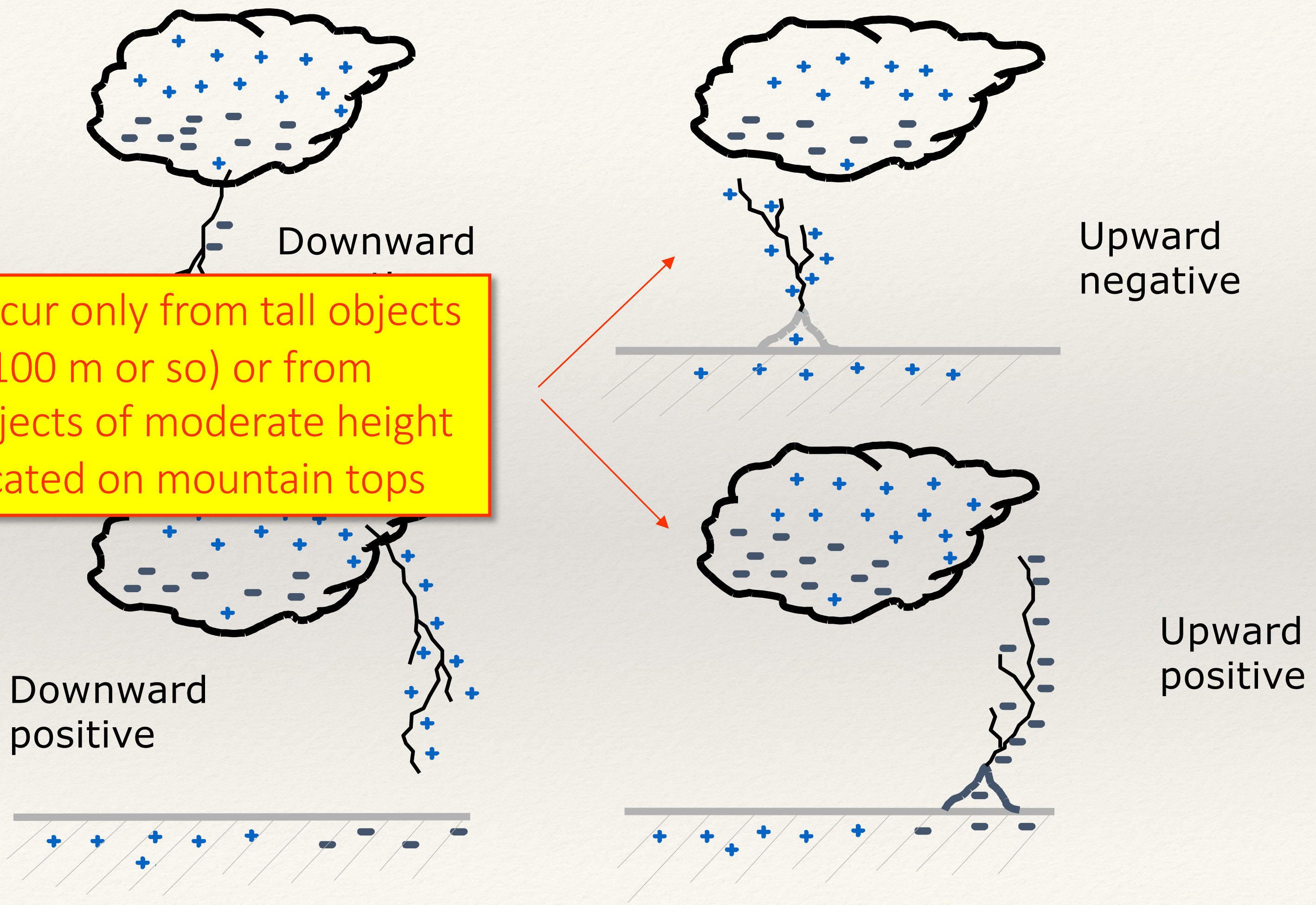
Cloud-to-Ground Lightning



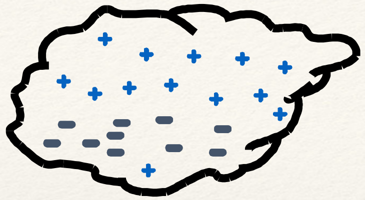
Cloud-to-Ground Lightning



Cloud-to-Ground Lightning

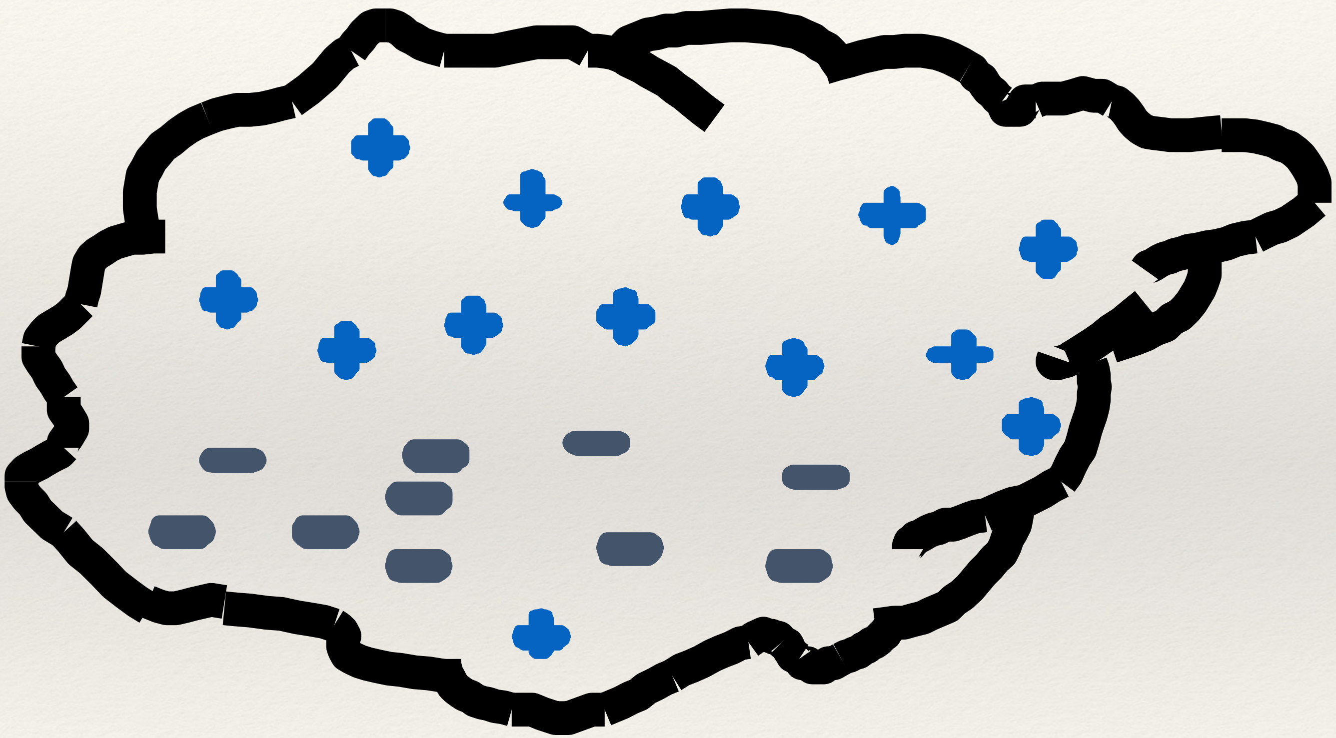


Cloud-to-Ground Lightning

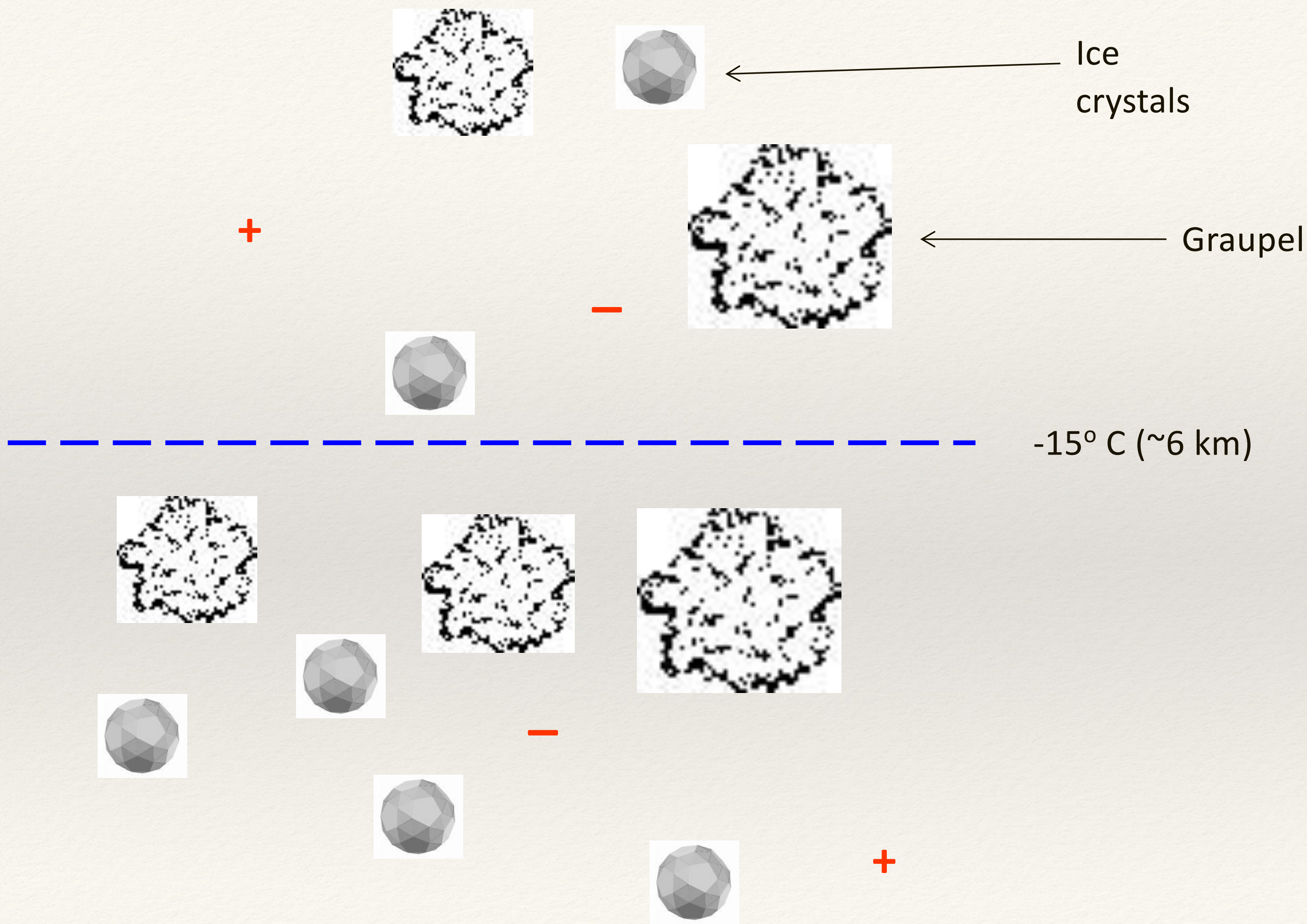


Adapted from Berger, 1977

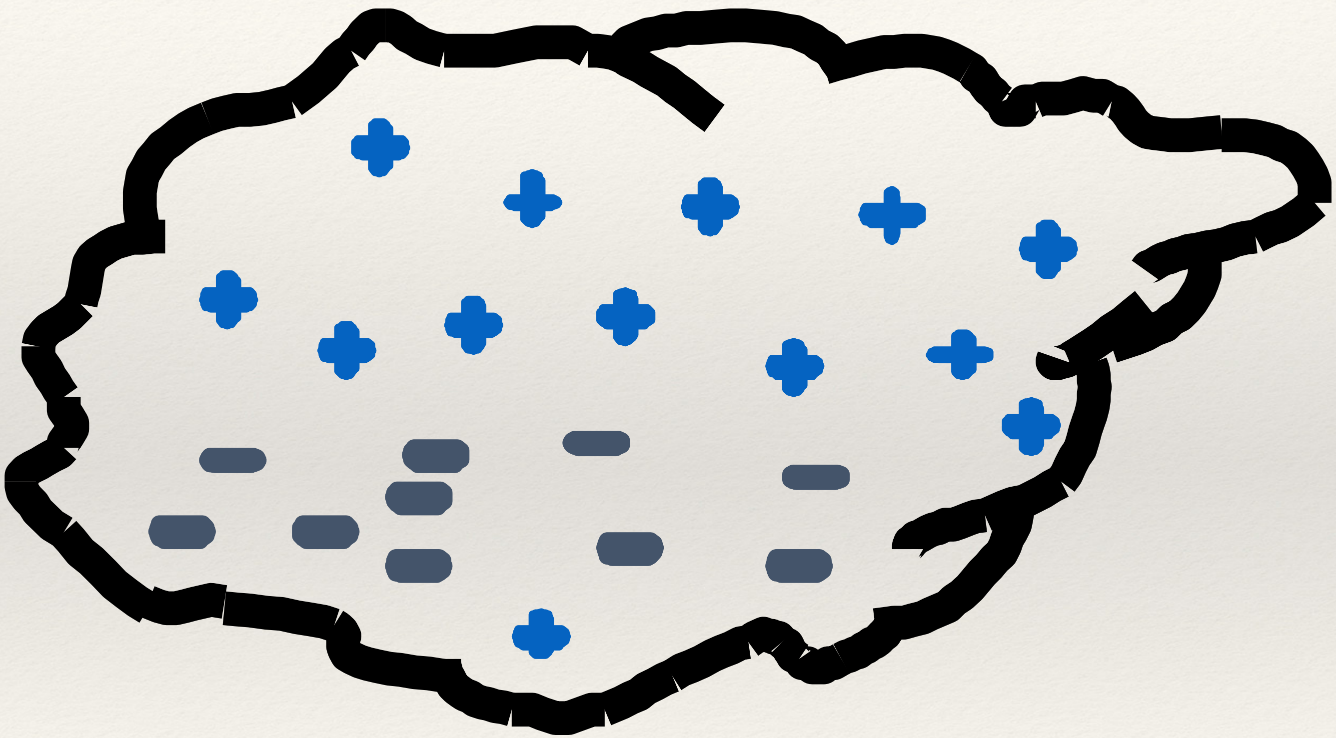
Separation of charge



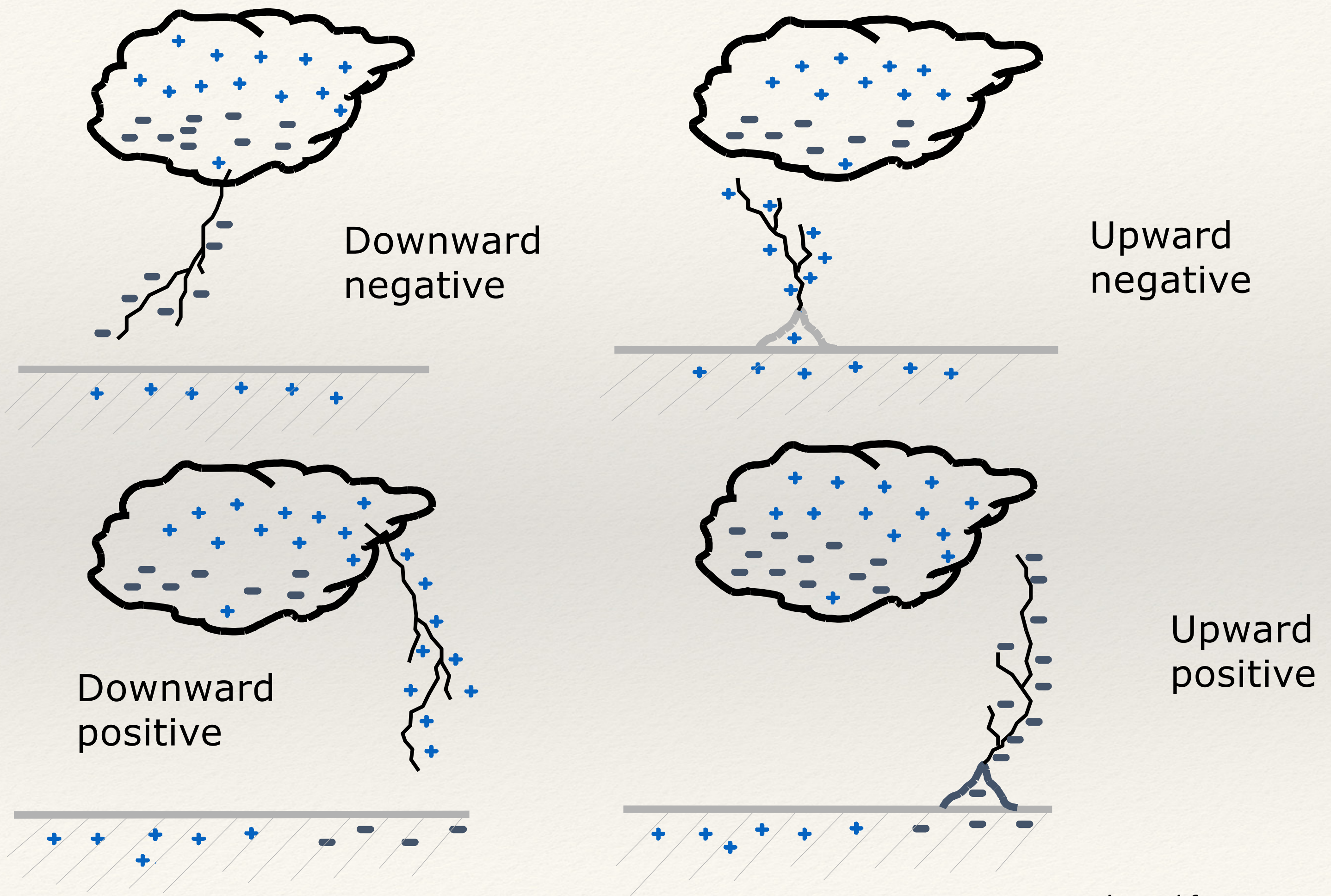
Separation of charge



Cloud-to-Ground Lightning

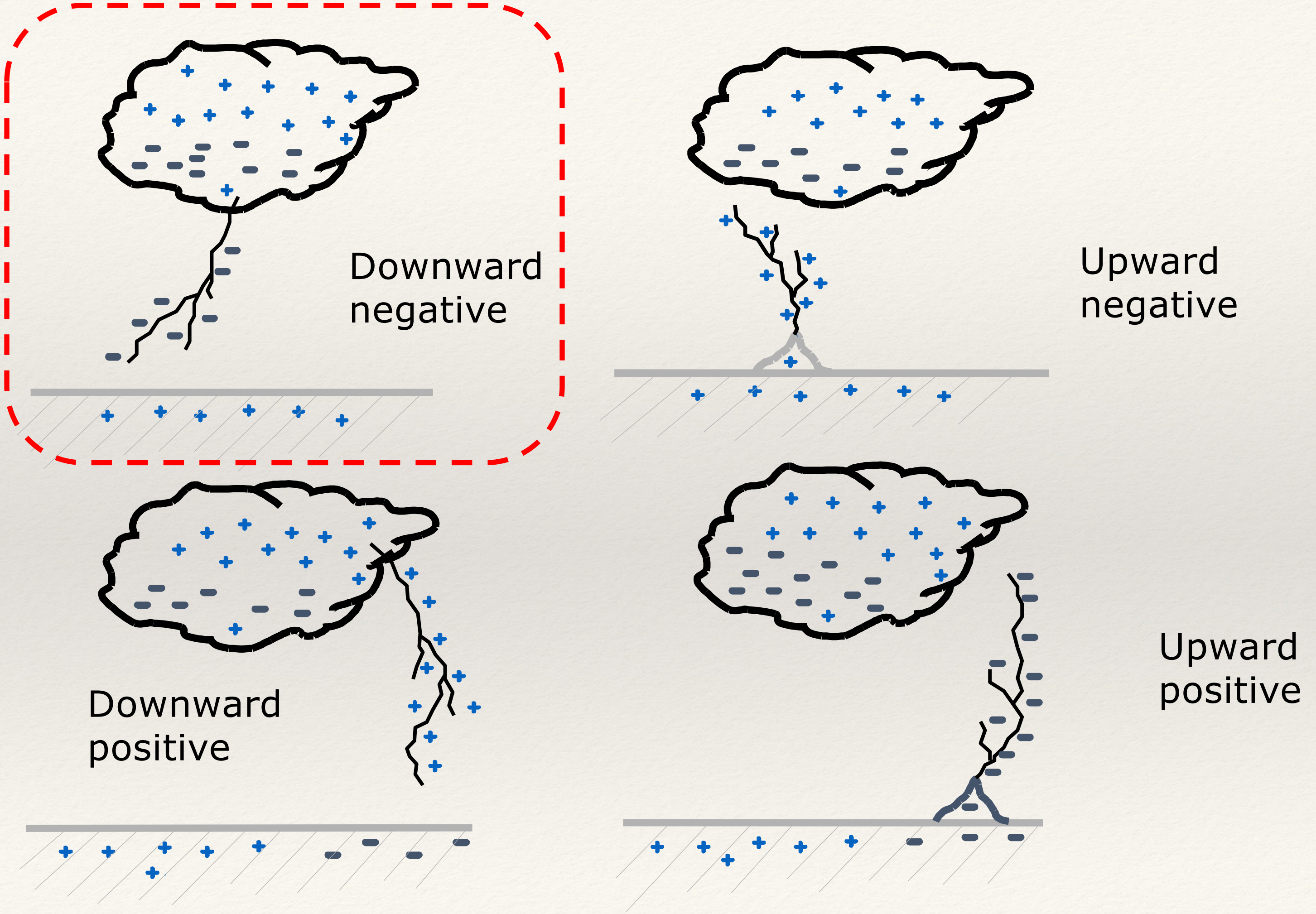


Cloud-to-Ground Lightning

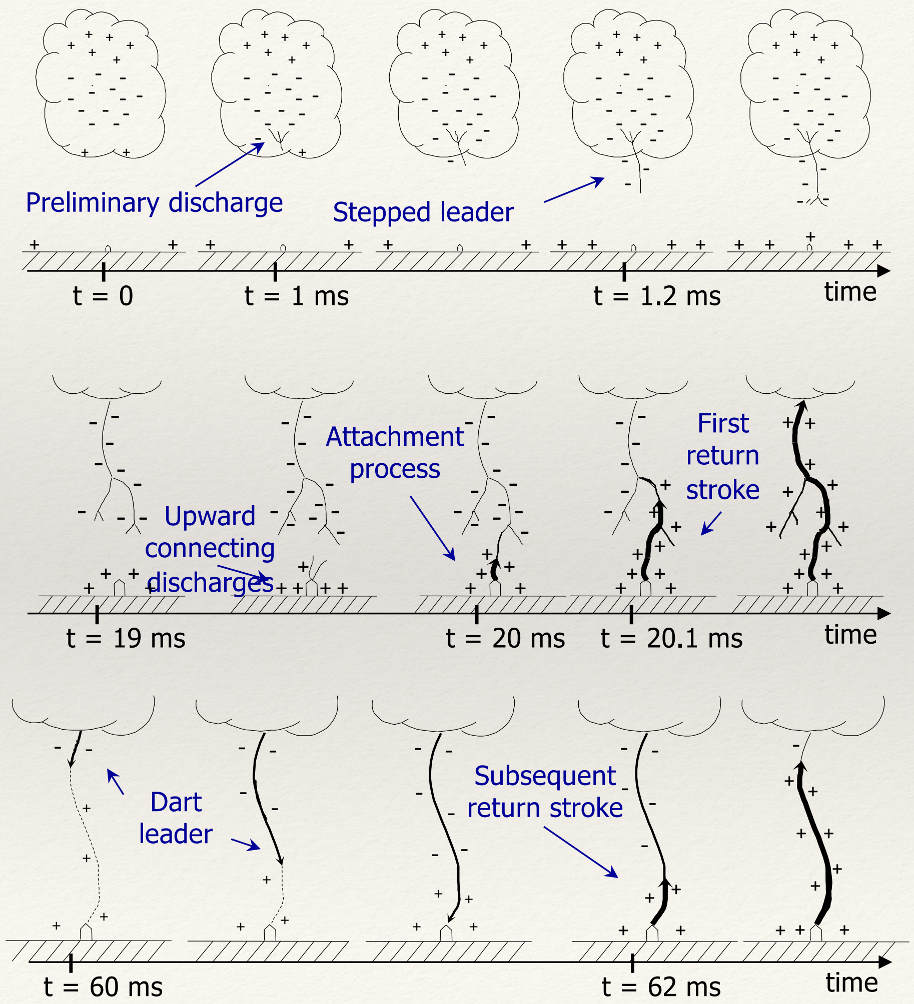


Adapted from Berger, 1977

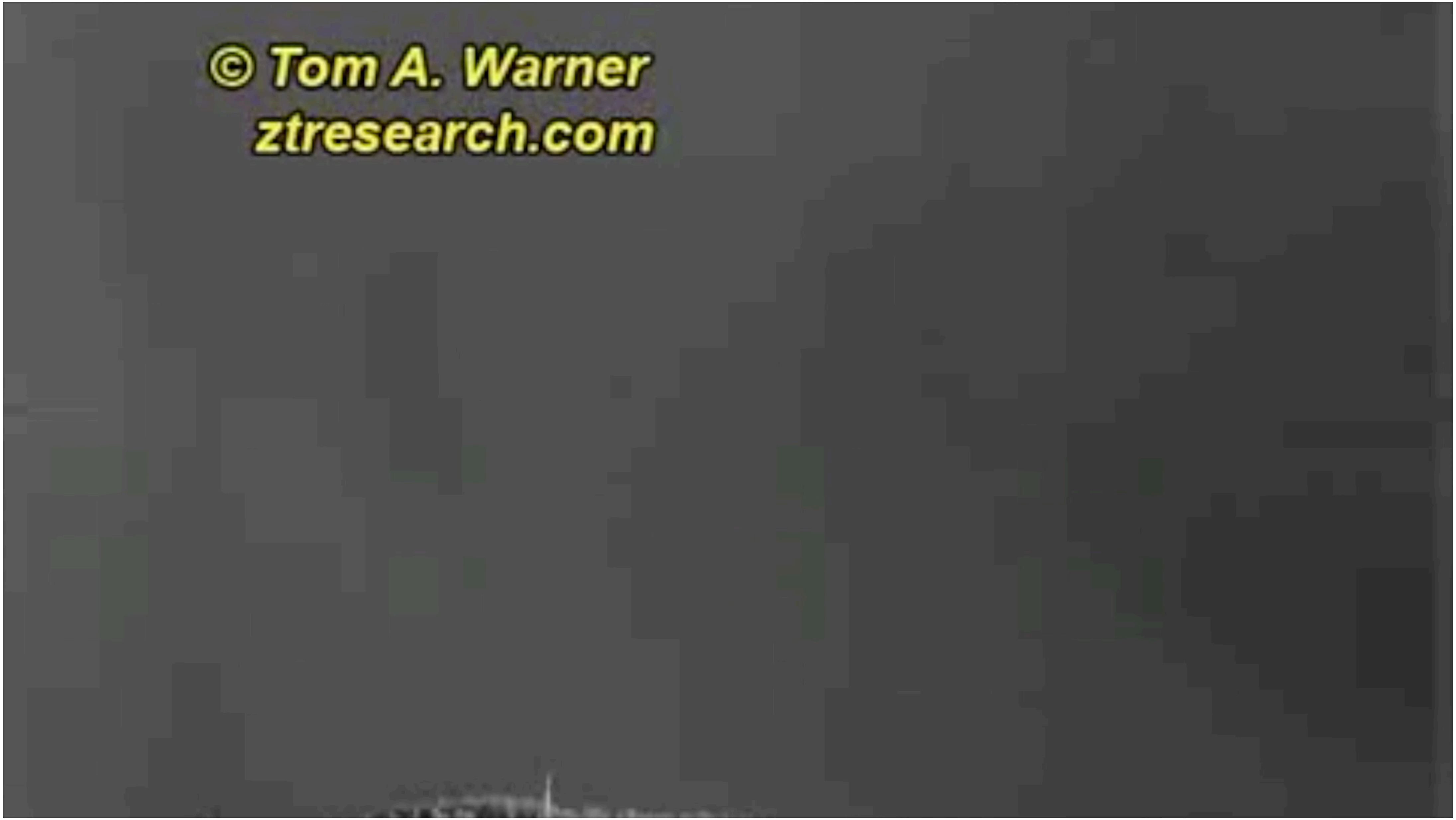
Cloud-to-Ground Lightning



Downward Negative Cloud-to-Ground Lightning



Adapted from Uman, 1987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ztresearch.com

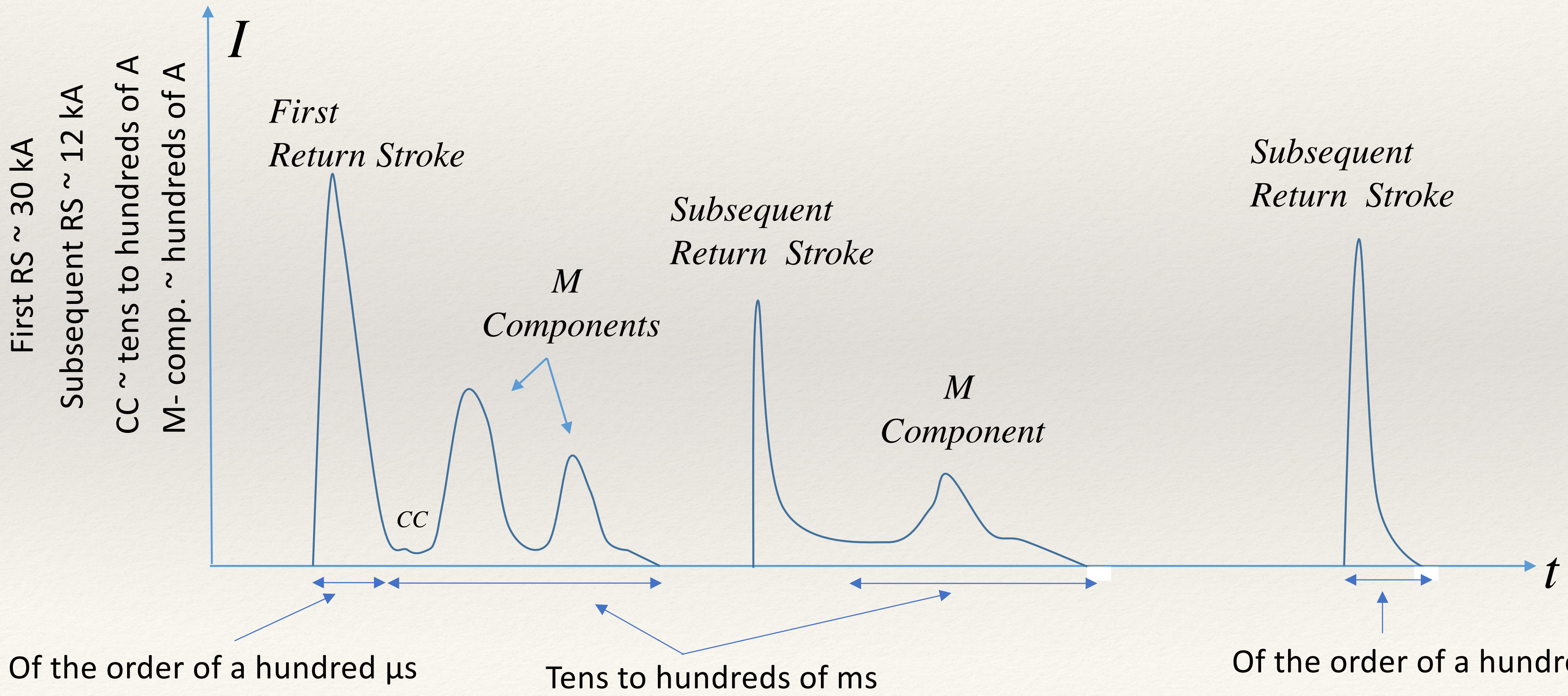
The three processes we saw in the video

- Stepped Leader
- Attachment process
- Return stroke

There are other processes in downward CG lightning

- Stepped Leader
- Attachment process
- Return stroke

Typical Channel-Base Current Waveform Associated with a Downward Negative Flash

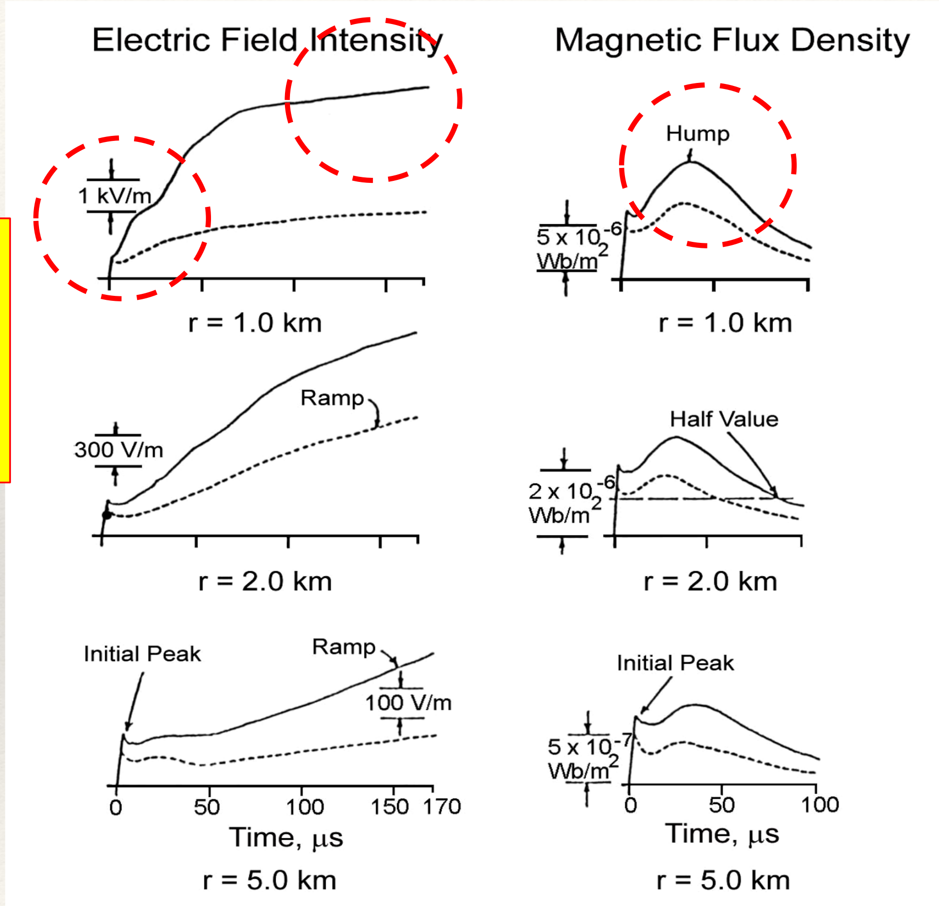


Lightning is a Very Long Antenna

Lightning Return-Stroke Fields: 1-5 km

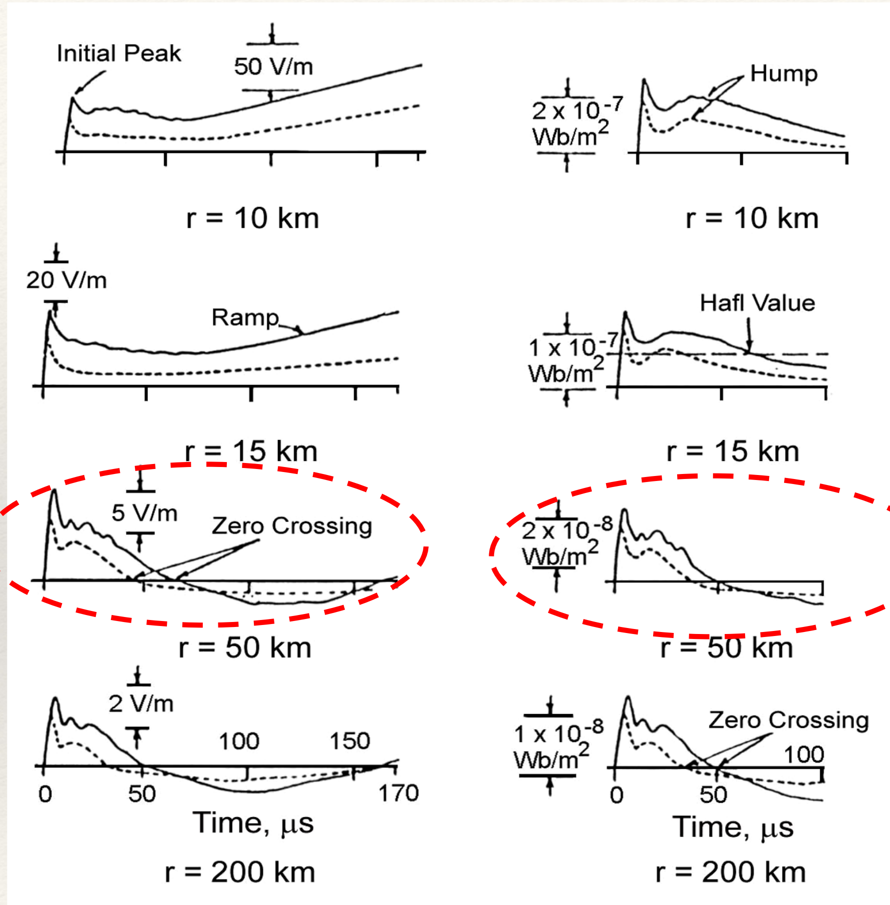
Solid Line:
First Strokes

Dashed Line:
Subsequent Strokes



Typical vertical electric field intensity (left column) and azimuthal magnetic flux density (right column) waveforms for first (solid line) and subsequent (dashed line) return strokes at distances of 1, 2 and 5 km. Adapted from Lin et al. (1979).

Lightning Return-Stroke Fields: 10-200 km

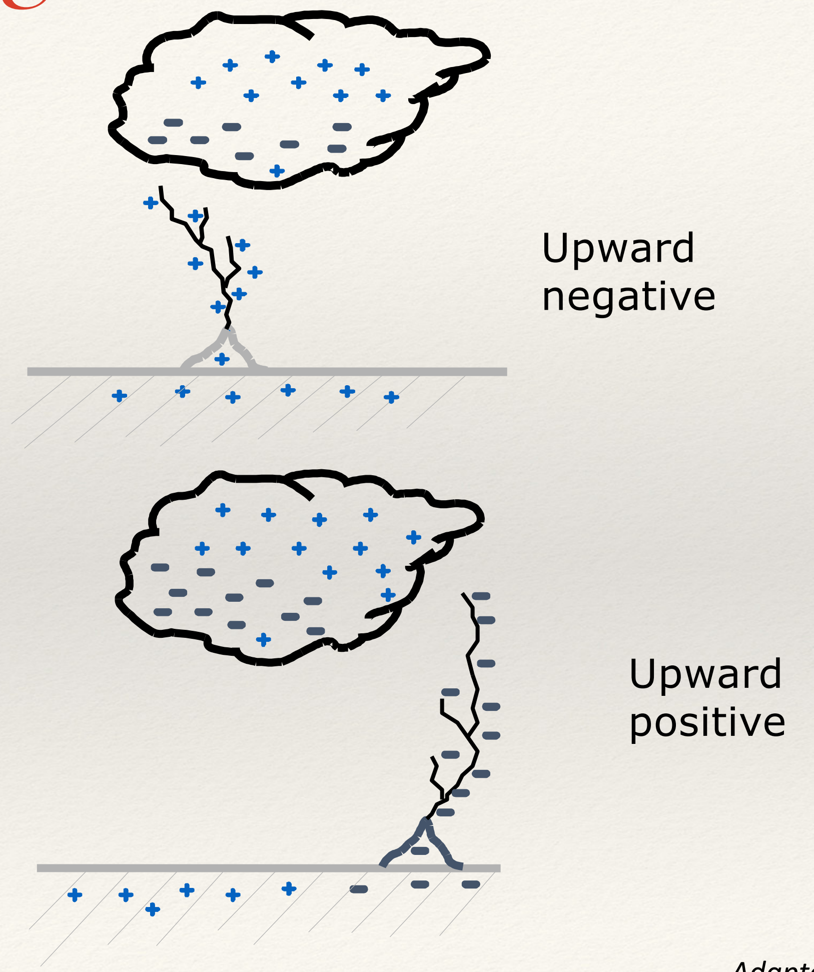


Typical vertical electric field intensity (left column) and azimuthal magnetic flux density (right column) waveforms for first (solid line) and subsequent (dashed line) return strokes at distances of 10, 15, 50, and 200 km. Adapted from Lin et al. (1979).

Upward Lightning

- Only from tall objects or from moderate height objects on mountains
- It is becoming more frequent
- Above a certain height, tall structures produce their own lightning

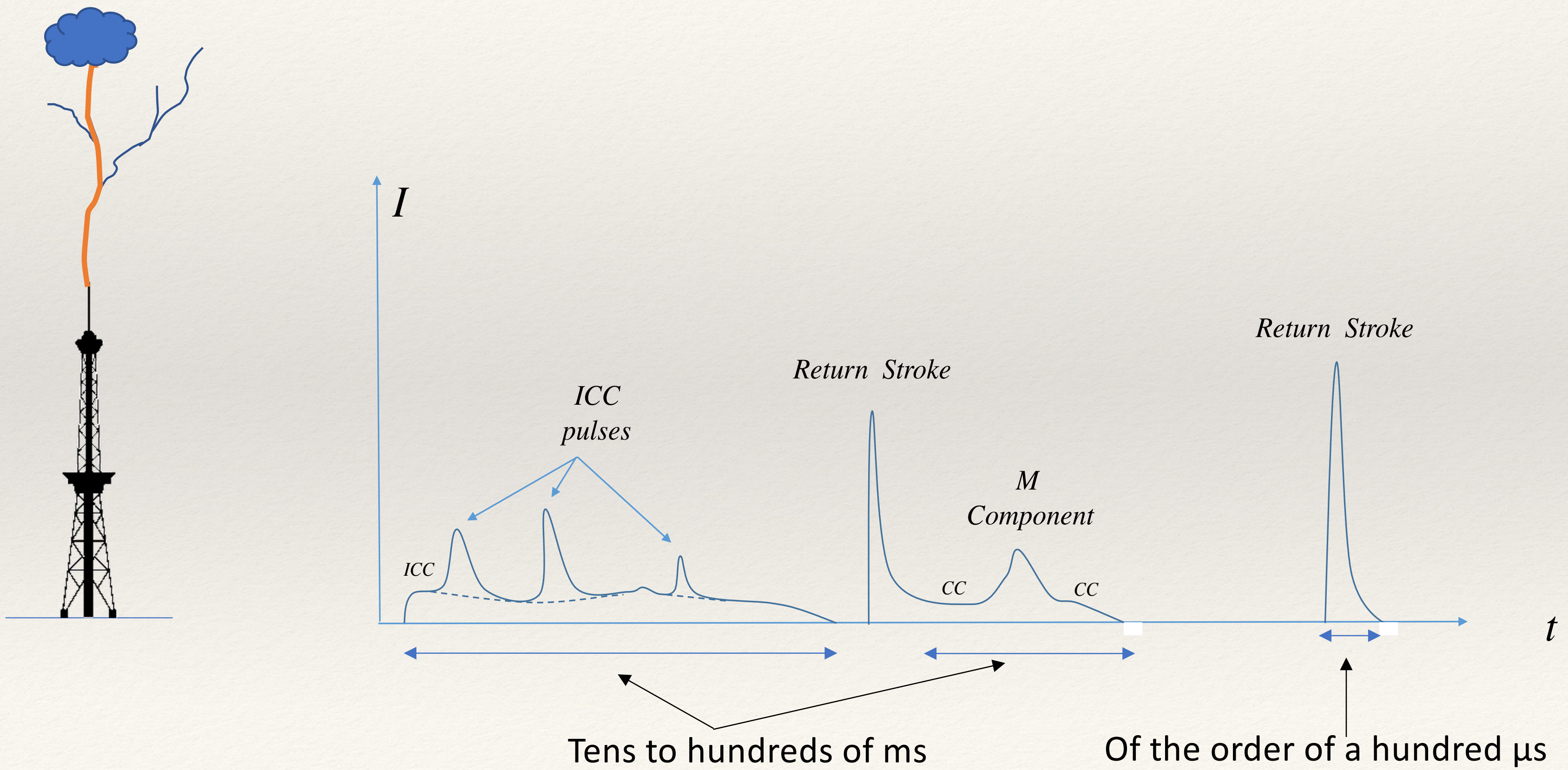
Upward Lightning



Adapted from Berger, 1977

High-Speed Video of Upward Lightning

Upward Negative Lightning



How are Lightning Measurements Made, Given its Inherent Randomness and Harsh EM environment?

Direct Channel-Base Measurements

- Artificially initiated lightning
  - Rocket-triggered
  - Laser triggered?
- Instrumented tall grounded objects
  - Towers, buildings, wind turbines

Rocket-Triggered Lightning

Launcher

Rockets

Camp Blanding, Florida

Camp Blnding, Florida

F. Rachidi and C.A. Nucci, 2005

Tall Grounded Objects

Slide courtesy of Prof. V. Rakov

Instrumented Towers Around the World

Eagle Nest	Morro do Cachimbo	Gaisberg	Säntis	Peissenberg	CN Tower	Skytree
25 m	60 m	100 m	124 m	160 m	553 m	634 m
2537 m ASL	1430 m ASL	1288 m ASL	2502 m ASL	940 m ASL	76 m ASL	37 m ASL

Slide courtesy of Prof. V. Rakov

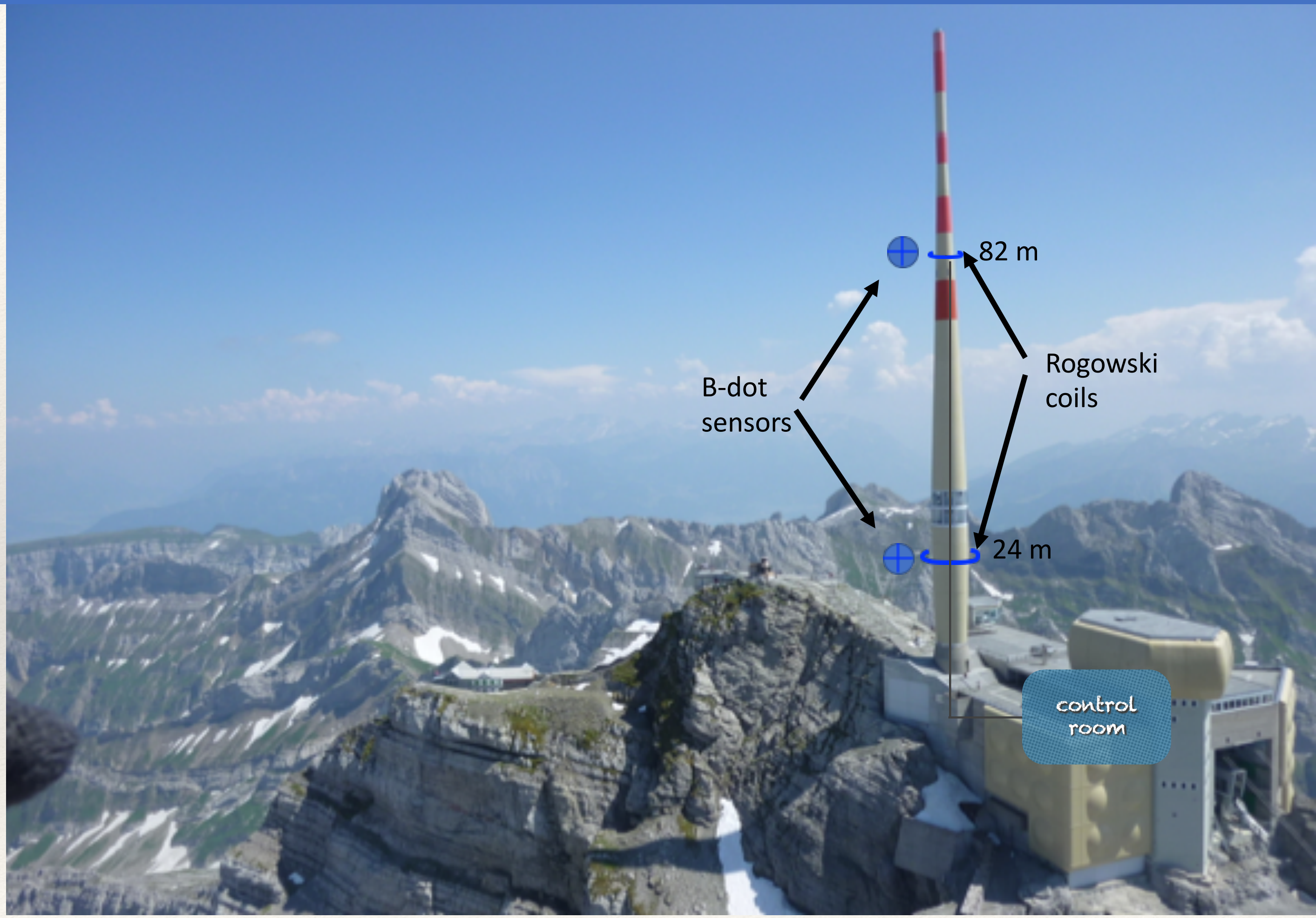
Säntis mountain: 2502 m; Säntis Tower: 123.5 m

- Instrumented in May 2010
- The highest lightning incidence (100+ times a year).

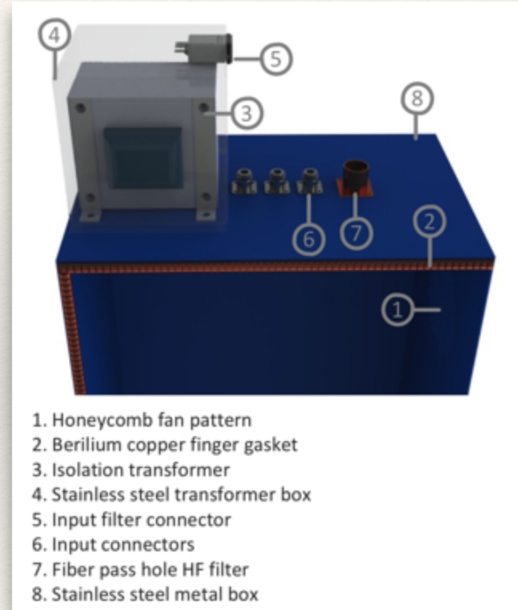
EMC Lab EPFL ECOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Hes·so Haute Ecole Spécialisée de Suisse occidentale University of Applied Sciences Western Switzerland

Säntis mountain: 2502 m;   Säntis Tower: 123.5 m

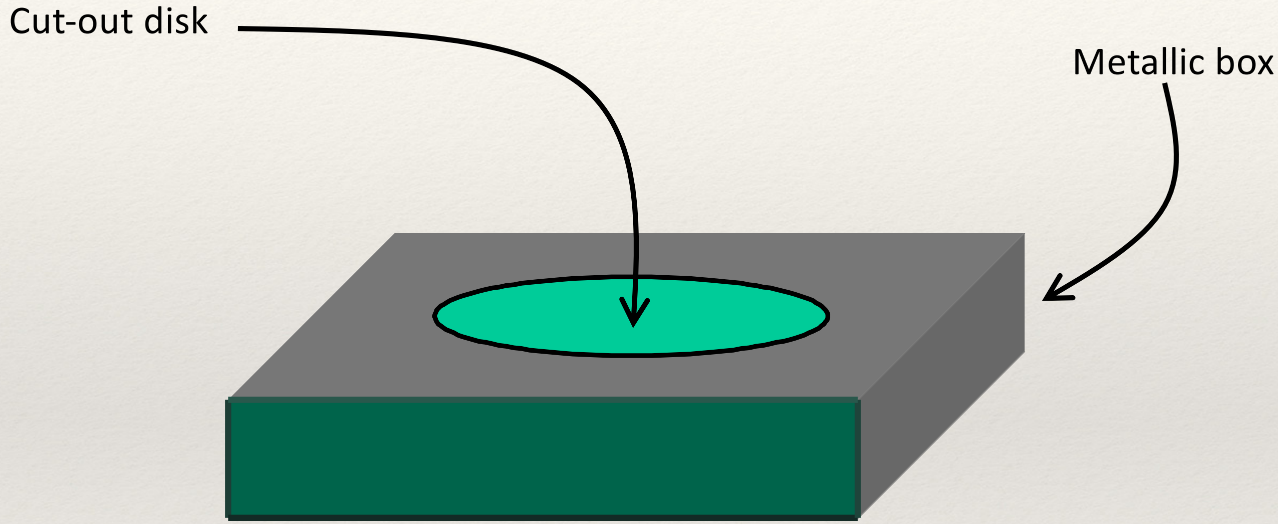


EMC Box Design

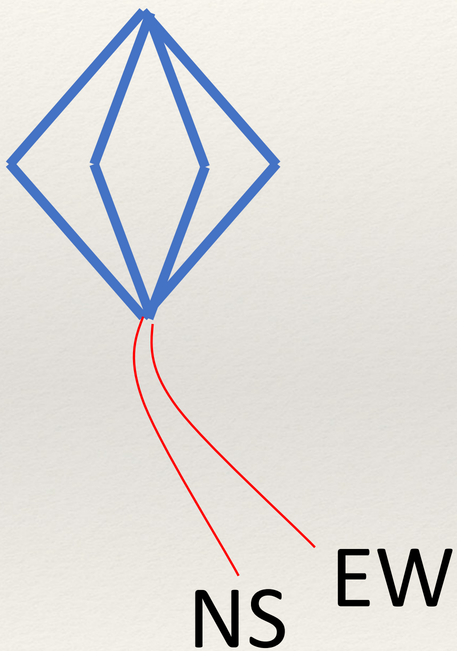


Equipment Installation

Flat-Plate Sensor for Electric Fields



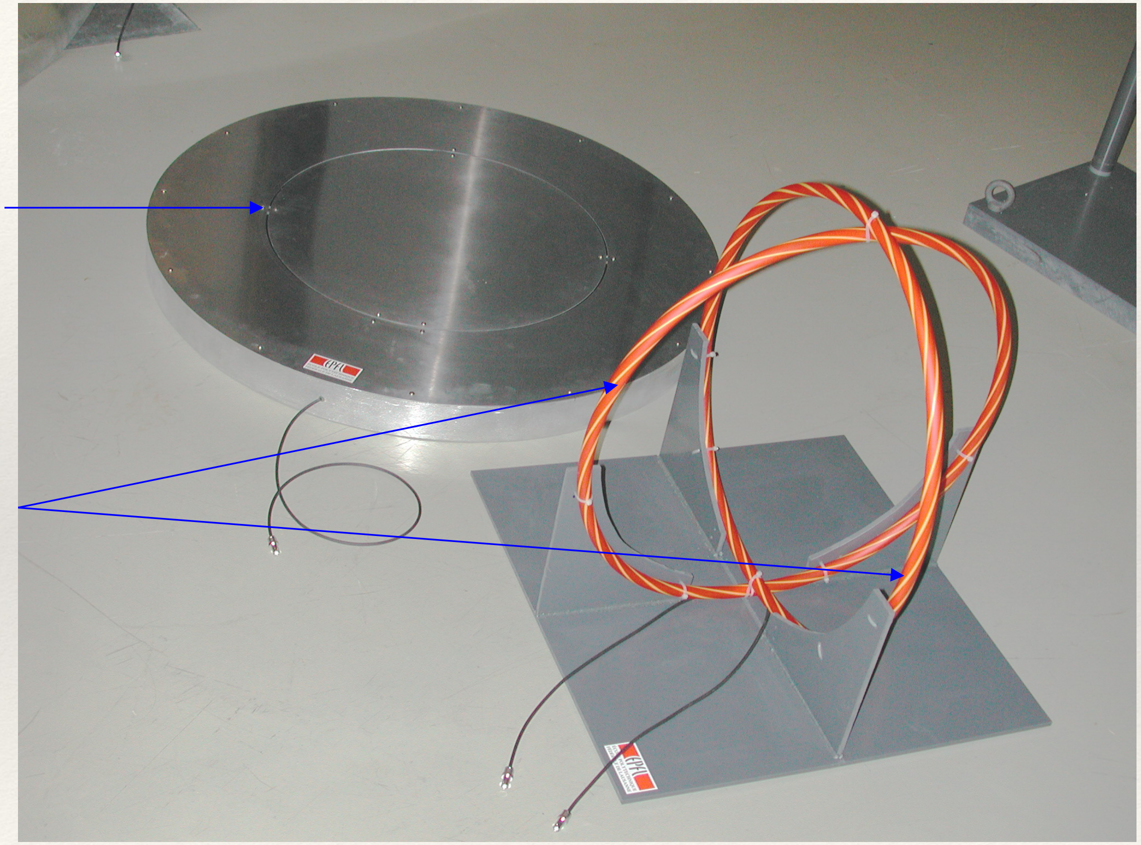
Cross-Loop Magnetic Field Sensor



Electric and Magnetic Fields

Flate-plate antenna
(vertical E-field)

Two loop antennas
(Horizontal H-field)

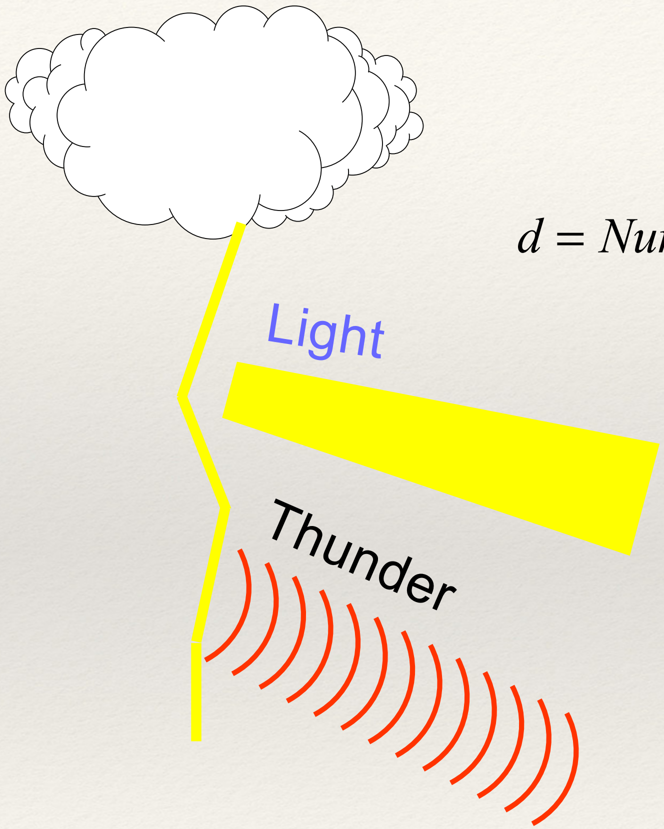


Slide courtesy of Prof. V. Rakov

How is Lightning Located?

- Well-known (patented) Time-to-Thunder
- Direction Finding (DF)
- Time of Arrival (TOA)
- Interferometry
- Peak Amplitude Method
- Field Component Methods
- Time reversal

Time to Thunder



The light is 1 million times faster than sound

$$d = Number\ of\ seconds \times Speed\ of\ sound$$

$$d = \frac{Number\ of\ seconds}{3}\quad km$$

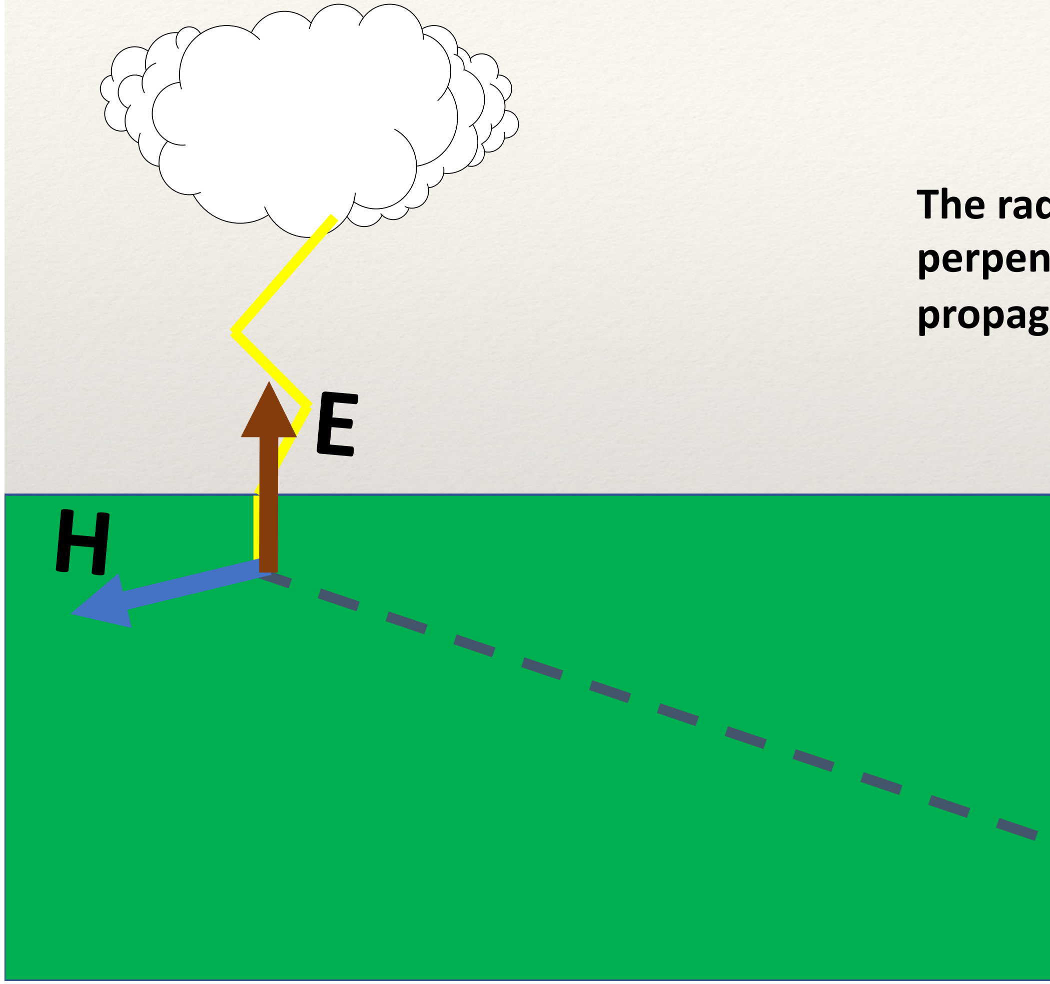
$$d = \frac{Number\ of\ seconds}{5}\ Miles$$

Time to Thunder

- Advantages:
  - Can be used as single station
  - It does not require any special equipment

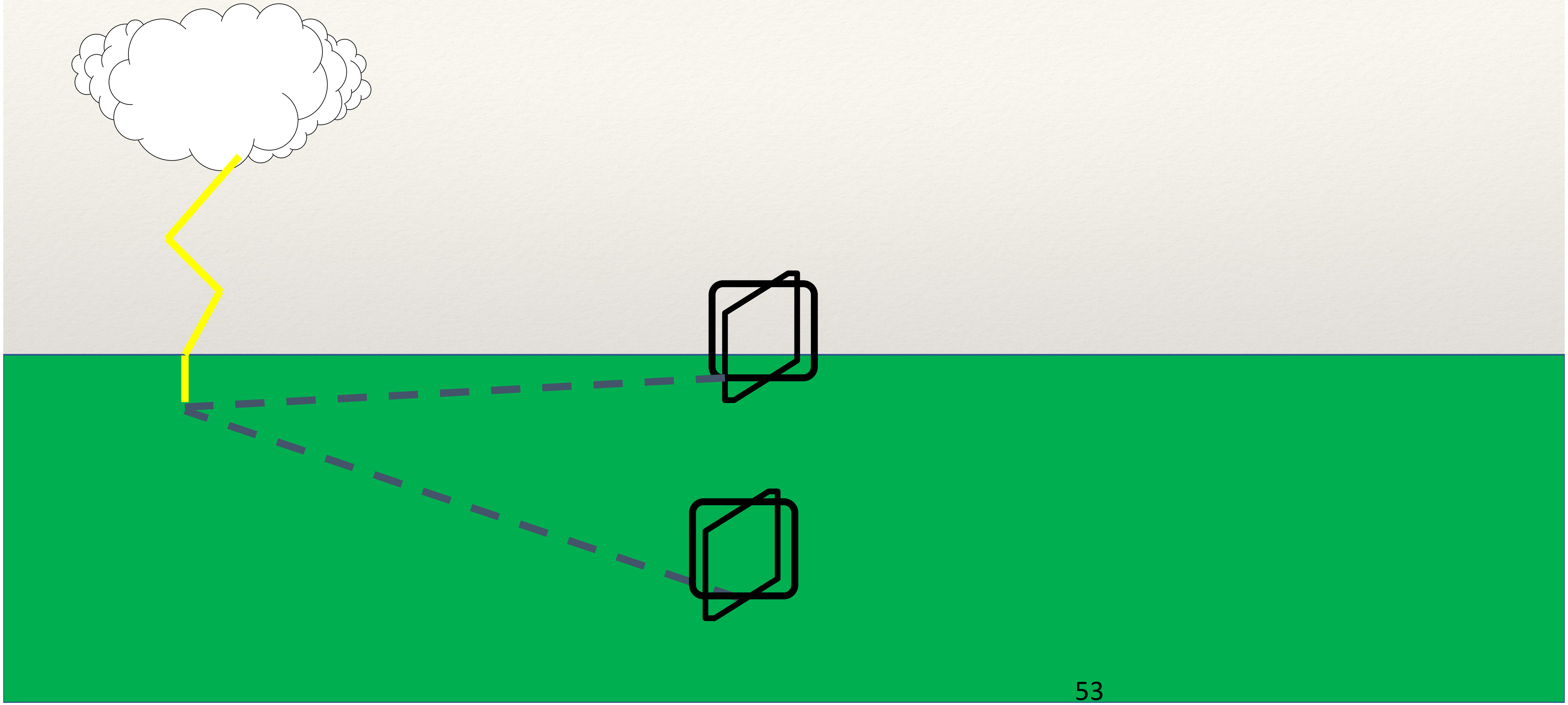
- Disadvantages:
  - Low accuracy
  - Limited range

Direction Finding

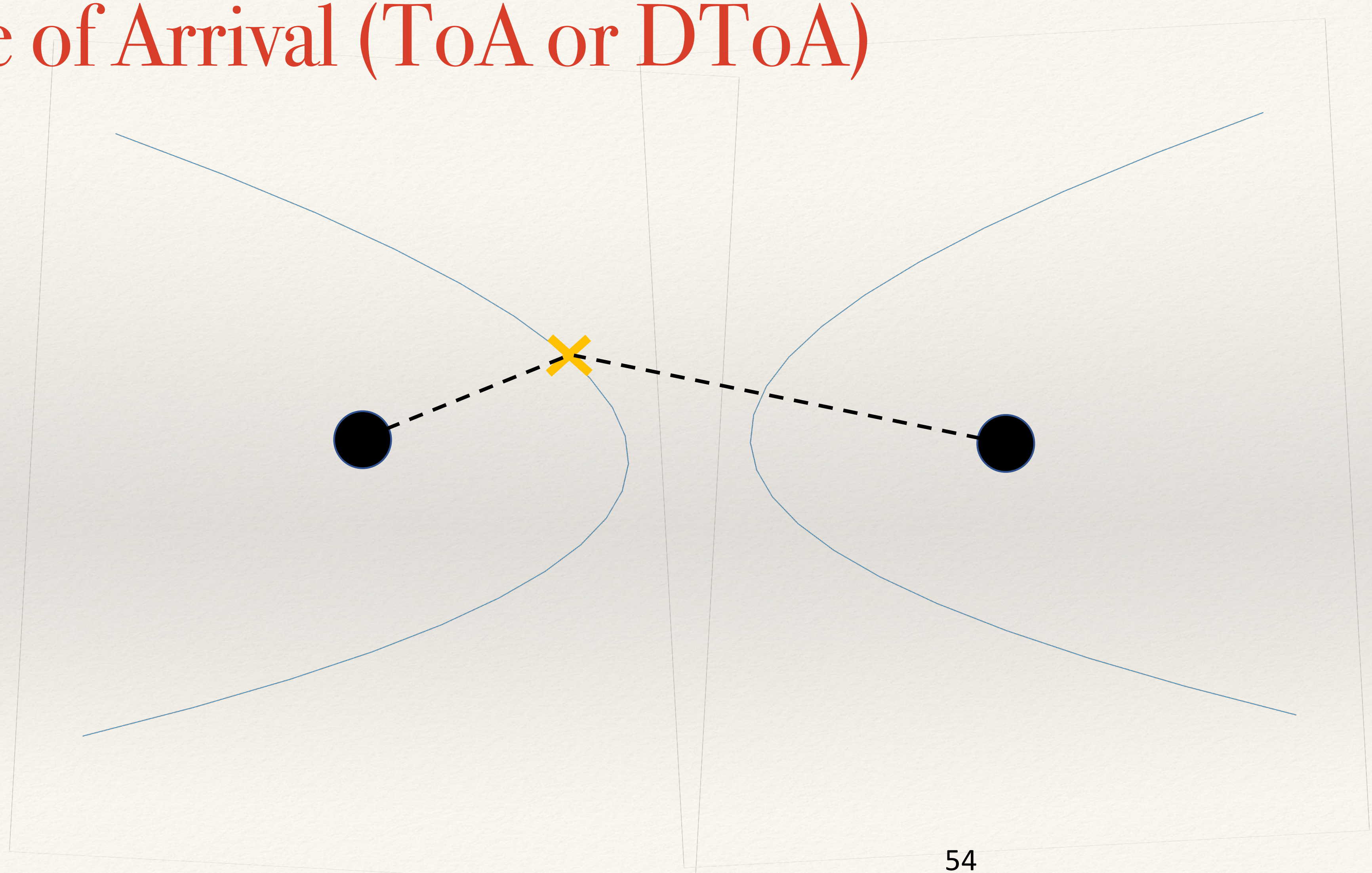


The radiated magnetic field is perpendicular to the direction of propagation

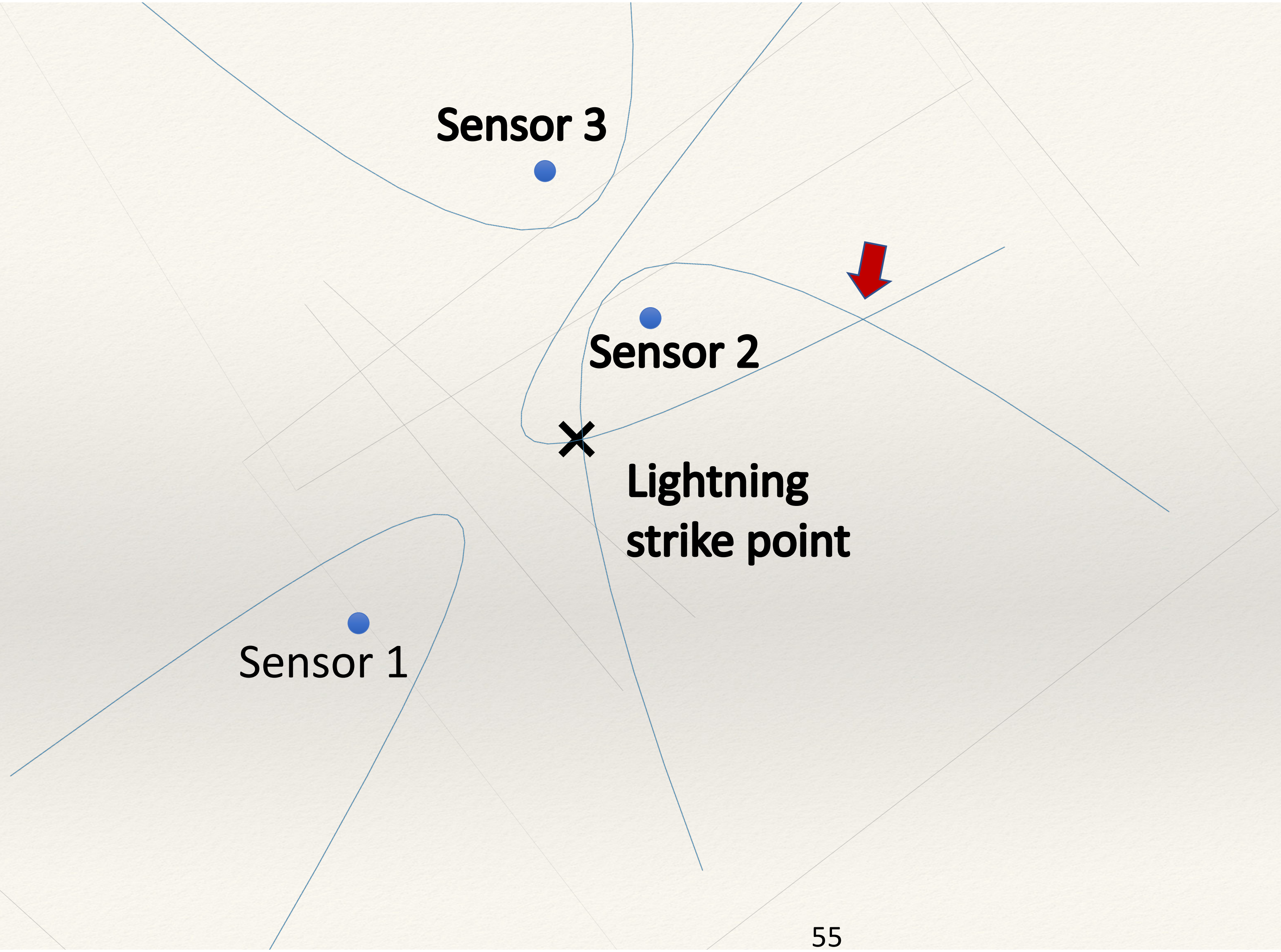
Direction Finding



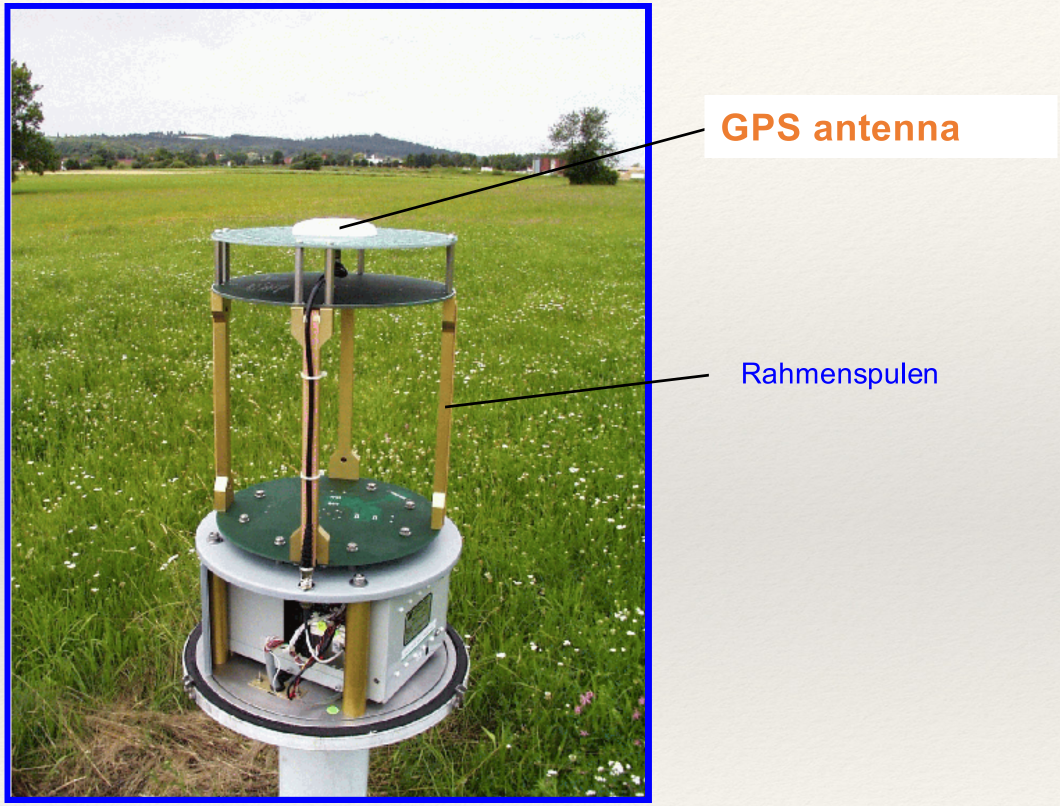
Time of Arrival (ToA or DToA)



ToA



Commercial LLS sensor



European Cooperation for Lightning Detection

ca. 164 Sensors (2019)

IMPACT 181T
IMPACT ES
IMPACT ESP
LPATS III
LPATS IV
LS 7000

www.euclid.at

Emerging LLS Technology: Time Reversal

Time Reversal Invariance

- It is the property of some laws of physics to remain invariant under the T-Symmetry Transformation
- The T-Symmetry Transformation:

$$T : t \rightarrow -t$$

Time-reversal Invariance of Maxwell's Equations

- Maxwell's equations in vacuum are time-reversal invariant

$$\nabla \cdot \left(\varepsilon(\vec{r}) \vec{E}(\vec{r},t) \right) = \rho(\vec{r},t)$$

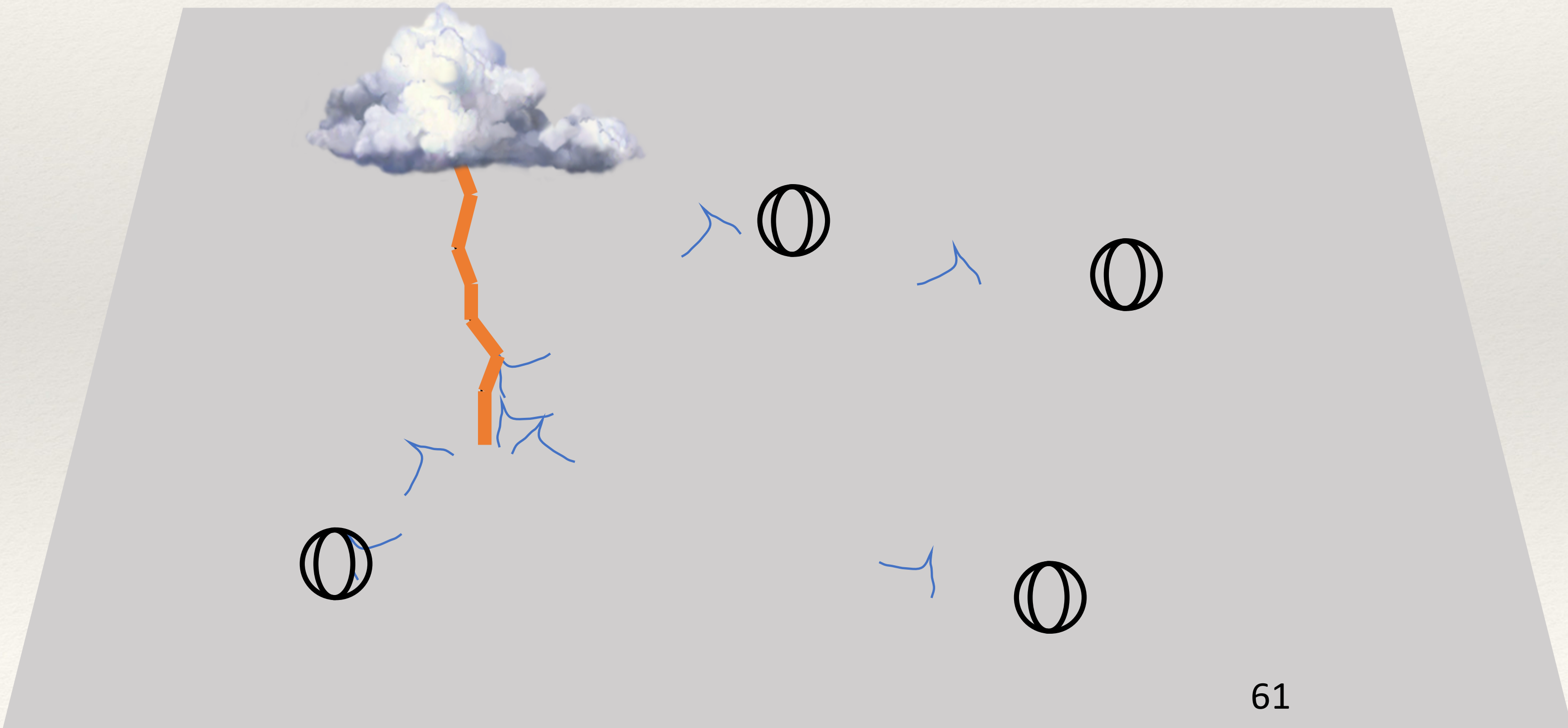
$$\nabla \cdot \left(\mu(\vec{r}) \vec{H}(\vec{r},t) \right) = 0$$

$$\nabla \times \vec{E}(\vec{r},t) = -\mu(\vec{r}) \frac{\partial \vec{H}(\vec{r},t)}{\partial t}$$

$$\nabla \times \vec{H}(\vec{r},t) = \varepsilon(\vec{r}) \frac{\partial \vec{E}(\vec{r},t)}{\partial t} + \vec{J}(\vec{r},t)$$

EMTR and Lightning Location

- Record magnetic field at sensors
- Time-reverse the measured field
- Transmit the time-reversed waveforms back into the medium by simulation
- Find the point of maximum constructive interference



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Thank you for your Attention!