Problems in lightning physics - the role of polarity asymmetry

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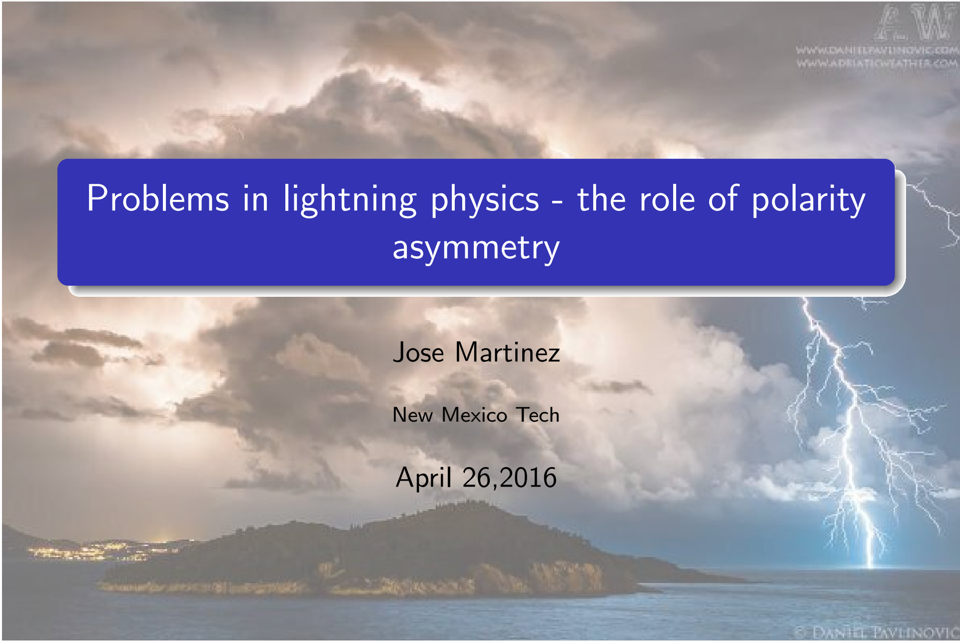
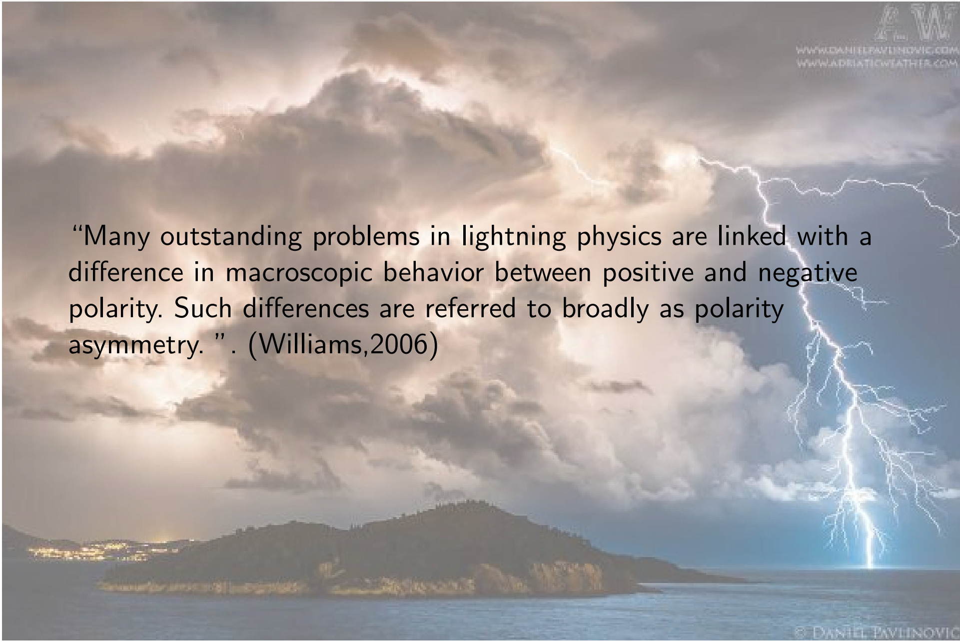
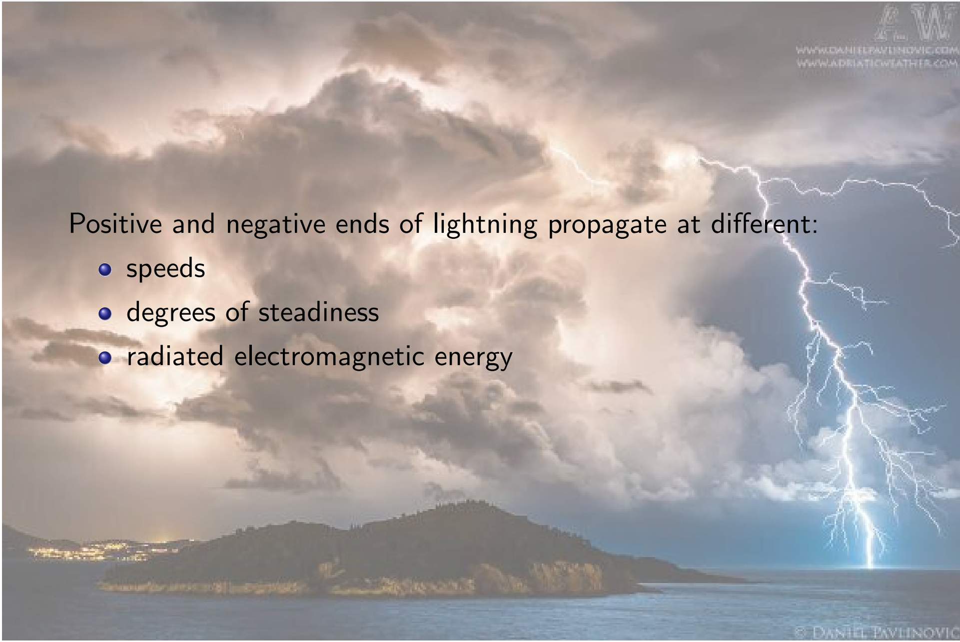


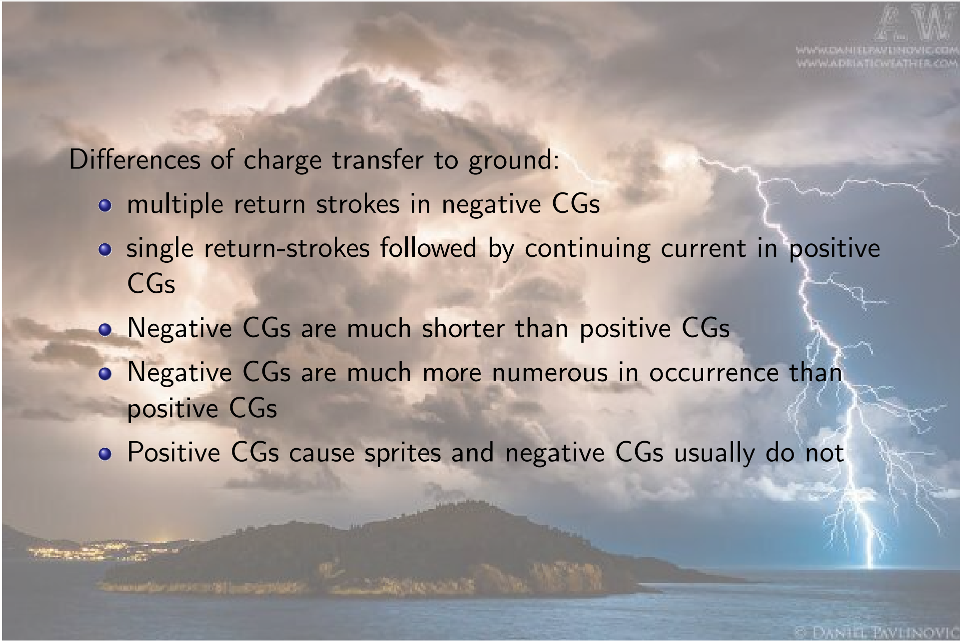


"Many outstanding problems in lightning physics are linked with a difference in macroscopic behavior between positive and negative polarity. Such differences are referred to broadly as polarity asymmetry. ". (Williams,2006)



Positive and negative ends of lightning propagate at different:

- speeds
- degrees of steadiness
- radiated electromagnetic energy



Differences of charge transfer to ground:

- multiple return strokes in negative CGs
- single return-strokes followed by continuing current in positive CGs
- Negative CGs are much shorter than positive CGs
- Negative CGs are much more numerous in occurrence than positive CGs
- Positive CGs cause sprites and negative CGs usually do not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- Williams believes these asymetries are rooted in difference in mobility between electrons and heavier positive ions
- Leader development is not unidirectional as Simpson believed. Rather it is bidirectional as Jensen (1933) believed and Mazur (1989) better documented.

The Simpson (1926) model

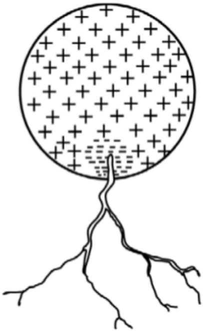


Figure 4. Simpson's (1926) picture of lightning as a single-ended tree, progressing out of positive charge regions, based on experience with laboratory experiments on positive streamers. Later observations by Jensen (1933) and others refuted this picture and supported a double-ended tree for lightning.

The Bi-directional leader

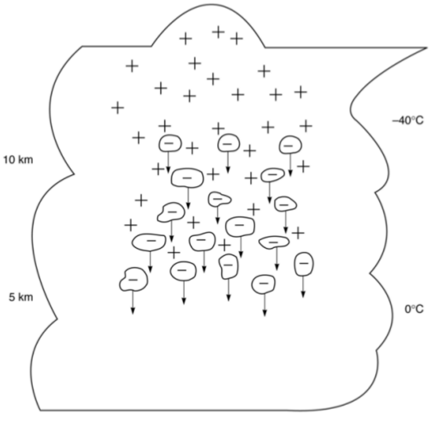


Figure 1. Thundercloud with typical positive dipole structure, maintained by differential motions of ice particles under gravity. The subsidiary pocket of lower positive charge beneath the main negative charge is not depicted here.

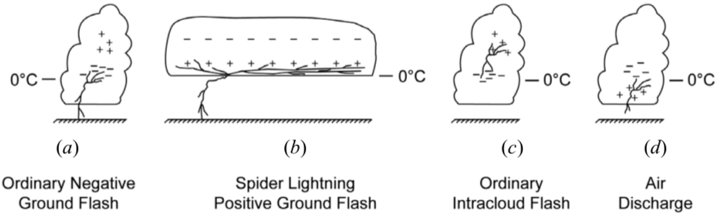
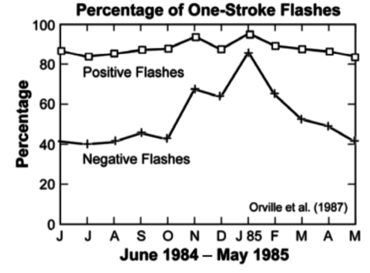


Figure 2. Common lightning types, all examples of double-ended 'trees' in thunderclouds: (*a*) negative CG lightning in an isolated thundercloud, (*b*) positive CG lightning in stratiform precipitation of a mesoscale convective system, (*c*) intracloud lightning in isolated thundercloud, and (*d*) air discharge in an isolated thundercloud.

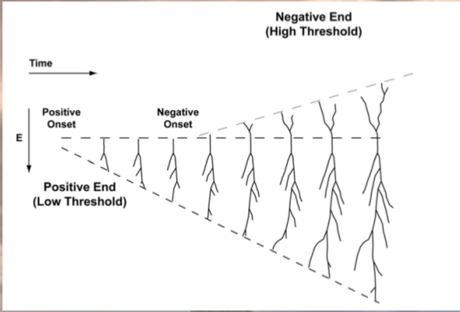
View of NLDN on PA

Observations from the US National Lightning Detection Network (NLDN) [...] show a pronounced asymmetry in the stroke multiplicity with season for negative and positive ground flashes (Orville et al 1987).



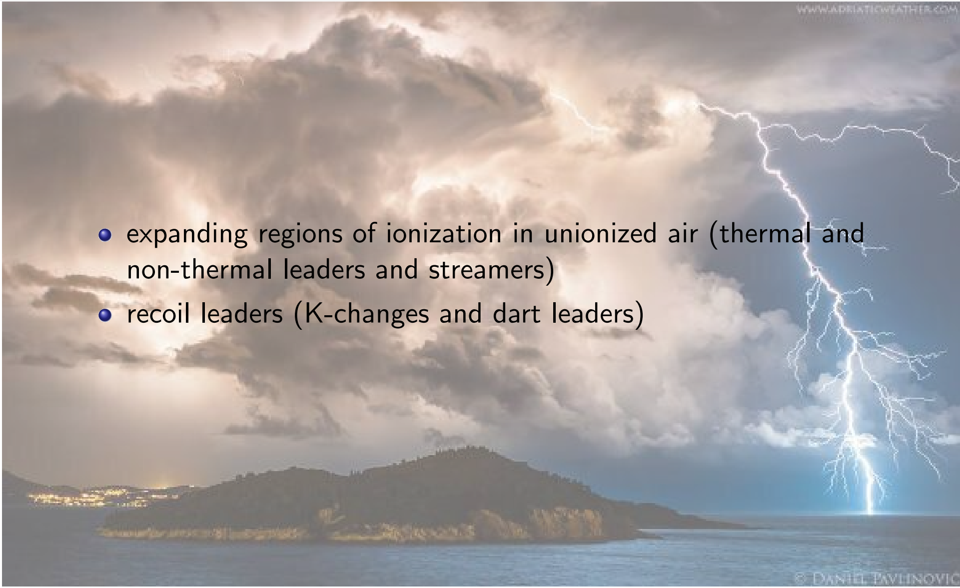
Positive ground flashes have a strong tendency to be single-stroke in all months, whereas negative flashes are more likely to contain multiple strokes.

The threshold field for positive streamers (at $P = 1000mb$) is $5 \times 10^5 Vm^{-1}$ (Griffiths and Phelps 1976) whereas the threshold for negative streamers is $10 \times 10^5 Vm^{-1}$, twice as large (Bazelyan and Raizer 2000).



The positive streamer begins first until the field at the initiation point is sufficiently large to launch a negative streamer in the opposite direction.

Breakdown categories in lightning

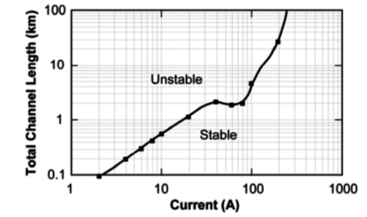


- expanding regions of ionization in unionized air (thermal and non-thermal leaders and streamers)
- recoil leaders (K-changes and dart leaders)

- Perhaps the most important physical parameter in the interpretation (below) of the general asymmetrical behaviour of CG lightning is the magnitude of the current in the leader channel.
- Current flow in the case of negative polarity is intermittent and erratic, in contrast to smooth behaviour for current in positive leaders.
- Numerous studies find that the VHF radiation from positive leaders is most often below the sensitivity of the receivers (Ron Thomas, 2005).

Instability criterion

The quantitative instability criterion is illustrated in two key lightning measurables, channel length L and channel current I:



Stability diagram for a lightning channel: unstable behaviour with current cutoff to the upper left of the stability line; stable behaviour with CC to the lower right of the stability line

The unstable condition can be understood as a nonlinear response to a decline in current -the channel resistance rises and the current in the arc declines still further until the channel cuts off entirely.

Current cutoff

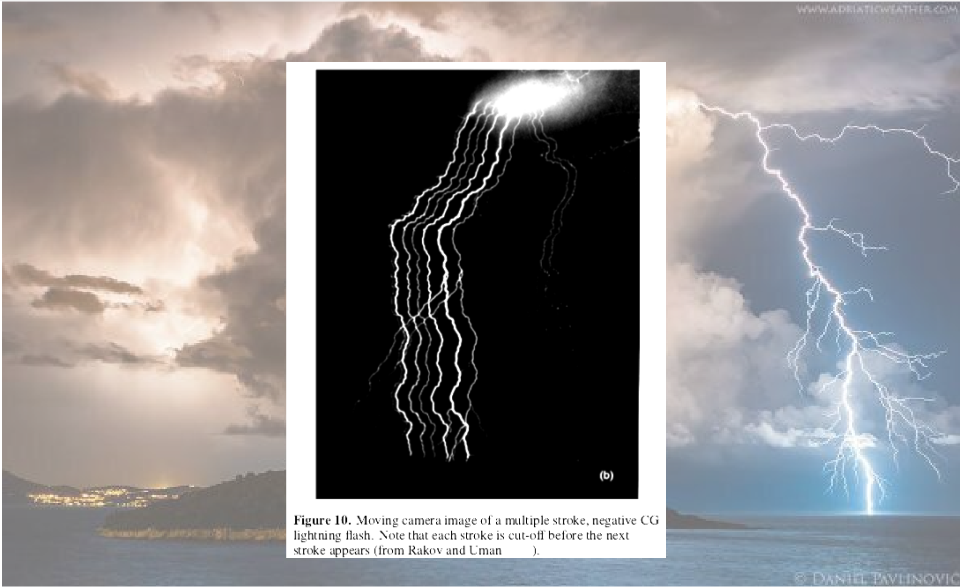
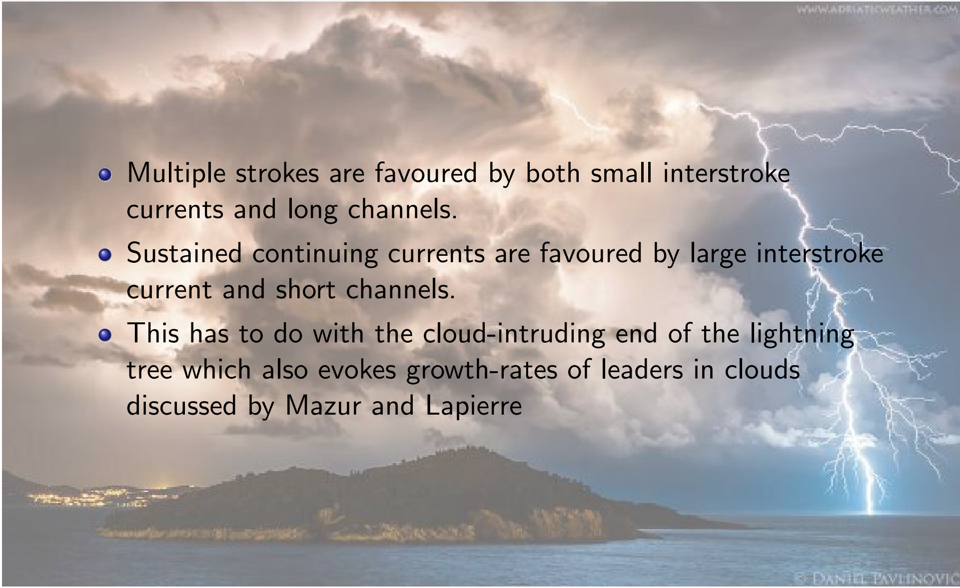


Figure 10. Moving camera image of a multiple stroke, negative CG lightning flash. Note that each stroke is cut-off before the next stroke appears (from Rakov and Uman).

Current cutoff

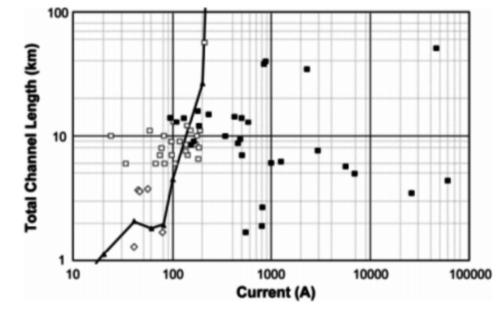
- Heckman (1992) predicts a stronger tendency for stable continuing current flow without cutoff (and subsequent) strokes when interstroke currents are large.
- In the case of positive CG lightning, the interstroke current is maintained by negative leader development into positively charged regions of the cloud.
- Heckman combines both thermodynamic constant *tau* and electronic constant *RC* to define cutoff frequency as stability criterion.

What does this mean?



- Multiple strokes are favoured by both small interstroke currents and long channels.
- Sustained continuing currents are favoured by large interstroke current and short channels.
- This has to do with the cloud-intruding end of the lightning tree which also evokes growth-rates of leaders in clouds discussed by Mazur and Lapierre

Results?



Stability diagram in comparison with observations on thunderclouds from the literature. Open squares represent scenarios with discrete strokes and without continuing current. Filled squares represent continuing current scenarios.

Revisiting the sprite

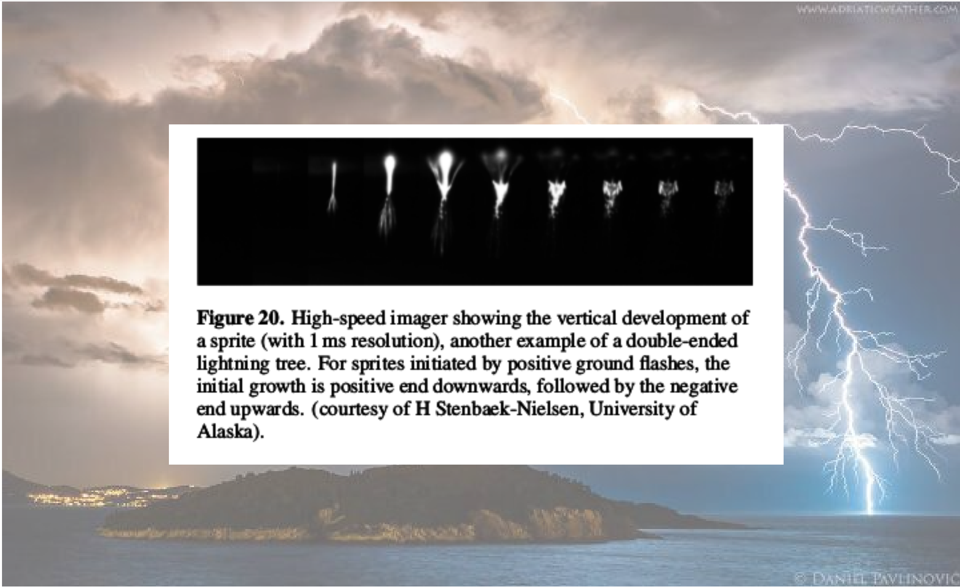


Figure 20. High-speed imager showing the vertical development of a sprite (with 1 ms resolution), another example of a double-ended lightning tree. For sprites initiated by positive ground flashes, the initial growth is positive end downwards, followed by the negative end upwards. (courtesy of H Stenbaek-Nielsen, University of Alaska).

Long and stable CC

Credits:Johnny Del Pastro. Queensland,Australia

What about bolts from the blue?

Credits:Jac Hagler. Mt Saleve,Switzerland

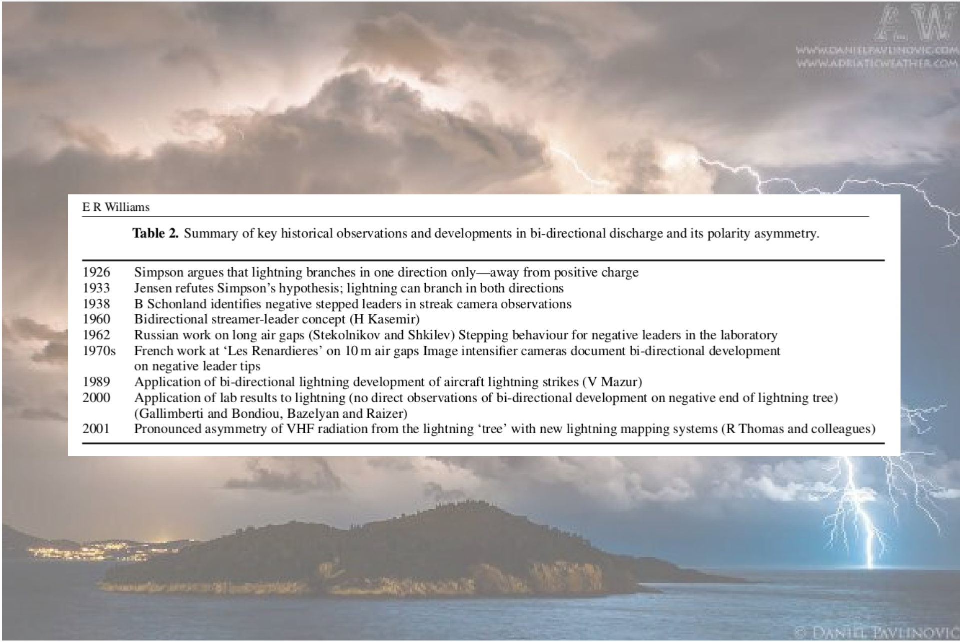


Table 2. Summary of key historical observations and developments in bi-directional discharge and its polarity asymmetry.

1926	Simpson argues that lightning branches in one direction only—away from positive charge
1933	Jensen refutes Simpson's hypothesis; lightning can branch in both directions
1938	B Schonland identifies negative stepped leaders in streak camera observations
1960	Bidirectional streamer-leader concept (H Kasemir)
1962	Russian work on long air gaps (Stekolnikov and Shkilev) Stepping behaviour for negative leaders in the laboratory
1970s	French work at 'Les Renardieres' on 10 m air gaps Image intensifier cameras document bi-directional development on negative leader tips
1989	Application of bi-directional lightning development of aircraft lightning strikes (V Mazur)
2000	Application of lab results to lightning (no direct observations of bi-directional development on negative end of lightning tree) (Gallimberti and Bondiou, Bazelyan and Raizer)
2001	Pronounced asymmetry of VHF radiation from the lightning 'tree' with new lightning mapping systems (R Thomas and colleagues)