Sprites
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Sprite Models of Initiation
¬ Conventional Breakdown Model (Pasko et al. 1997)
¬ Other Contributing Factors: Meteoritic Dust (Zabotin and Wright 2001), neutral density depletions by gravity waves (Pasko et al. 1997)
Conventional Breakdown Model

Positive Charge Reservoir Depleted but Shielding Layer remains over a longer timescale

Rapid charge transfer by +CG reduces positive charge reservoir but Shielding Layer remains over a longer timescale

Generates sustained intense quasi-electrostatic fields at mesospheric altitudes that are able to heat and ionize the background medium, initiating a sprite
Conventional Breakdown Model

Magnitude of quasi-electrostatic field at high altitudes is approximately proportional to the charge moment change.

Runaway Breakdown Model

- Pre-existing high energy electrons (produced by cosmic rays) are excited by the quasi-electrostatic field.
- Such electrons have a mean free path approximately 100 times longer than low-energy electrons.
- Collisions can have a cascading effect of high energy electrons that grows exponentially and produce optical emissions.
- Requires a weaker quasi-electrostatic field than the conventional breakdown model. Can occur under electric fields an order of magnitude lower than the dielectric strength.
Runaway Breakdown Model

At certain high energy levels, the stopping power (friction) decreases with increasing electron energy. Thus, high energy electrons tend to accelerate and "runaway".

Varieties of Sprites

• Columniform Sprite (C-sprites): thin, vertical elongated columns of light (single or multiple); typically short time delay from parent CG
• Carrot Sprites: heart-shaped central body with numerous protruding convulsed tendrils; long time delay from parent CG
• Jellyfish Sprites: much larger in volume with overlaying canopy above downward tendrils
• Angle Sprites: bifurcated columns with bright channels extending diagonally

Sprite Climatology and Meteorology

• When and where do sprites occur in relation to the parent thunderstorm?
• What are the detailed characteristics of TLE parent flashes?
• Why don’t all types of high CME CG flashes produce sprites?
We’ve established that a quasi electrostatic field in the upper atmosphere that reaches breakdown values may lead to sprite formation.

Draining of positive charge by large (lots of charge lowered and long continuing current) +CG flashes enhances this upper atmosphere field to breakdown values.

Impulse charge moment changes (iCMCs) have been shown to predict a sprite occurrence well.

Implications of the physics of positive vs. negative flashes for sprite production


\[ \int I(t) dt = \int_0^t dQ(t) \]

\( t = \) function of time

\( \text{Greater current} \rightarrow \text{greater iCMC} \)

Total CMC in sprite producing +CGs often exceeds 500 C km after ~10ms → points to common occurrence of “long-delayed” sprites

Lyons et al. (2009)

iCMCs and sprites

\[ \text{iCMC} = \text{return stroke current} + \text{initial part of continuing current (in general)} \]

\[ \text{TOTAL CMC of } \sim 500 \text{ C km taken to be a typical threshold for sprite ignition – long continuing current needed to achieve this} \]

\[ \text{Total CMC in sprite producing +CGs often exceeds 500 C km after } \sim 10 \text{ms } \rightarrow \text{points to common occurrence of “long-delayed” sprites} \]

Lyons et al. (2009)

iCMC and sprite climatology

*Delay time = time between parent flash and sprite*

TLE Delay Time vs. Parent Positive CG Peak Current

Lyons et al. (2009)
For 2007 warm season, negative iCMC values with magnitude > 1 C km greatly outnumber positive ones. But, positive iCMC values > 500 C km greatly outnumber negative ones. Suggests dominance of positive sprite-producing CGs. A long continuing current is more likely for a +CG flash.

Sprite producing storms: case study 20 June 2007

Lyons et al. (2009)
Sprite parent lightning
Lang et al. (2010) show how +CG flashes of various characteristics can initiate a sprite.

Comparing 9 May and 20 June 2007 cases (small MCS-MCV vs. large MCC):

Table 6: Mean Values for Various Parameters Associated With TLE-Parent Flashes for 20 June 2007, 9 May 2007, and 19 July 2007

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Total No. Flashes</td>
<td>7</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Vertical Multiflash Time</td>
<td>6.1</td>
<td>24.9</td>
<td>11.3</td>
</tr>
<tr>
<td>First Lightning (TS)</td>
<td>22.9</td>
<td>25.0</td>
<td>NA</td>
</tr>
<tr>
<td>Total Current (MA)</td>
<td>1.15</td>
<td>2.1</td>
<td>2.7</td>
</tr>
<tr>
<td>Total Current in TS (MA)</td>
<td>1.01</td>
<td>0.84</td>
<td>NA</td>
</tr>
<tr>
<td>Flash Altitude (km)</td>
<td>78.0</td>
<td>82.1</td>
<td>46.4</td>
</tr>
</tbody>
</table>

For 20 June case, TLE production better tracked intensity of convection – flashes initiated at higher levels in TS due to advection of charge from upper positive region in convection.

One such discharge was nearly 300 km long, 5.6 s duration; initiated in convective core and discharged into stratiform region.

Challenges accepted theory of sprite production via discharge near the melting level in widespread stratiform of weakening MCSs.

Lang et al. (2010), Lyons et al. (2009)

Lack of sprites generated by -CGs

The continuing current problem:
Most sprites tend to occur > 10 ms after parent CG flash, suggesting importance of continuing current in developing large total CMC (draining sufficient charge).
-CGs may have comparable iCMC values but shorter continuing currents.
A higher breakdown threshold for negative CGs?

Lyons et al. (2009)
Discussion

- How can a high CMC –CG flash produce a sprite at all?
- How does draining of negative charge enhance the upper-atmosphere electric field? Is this an explanation for the relative lack of –CG produced sprites?
- If sprites are thought to be caused by standard electrostatic breakdown, what leads to the crazy shapes and colors?