Modeling Studies of Optical Properties of Sprite Streamers and Their Chemical Effects On the Upper Atmosphere

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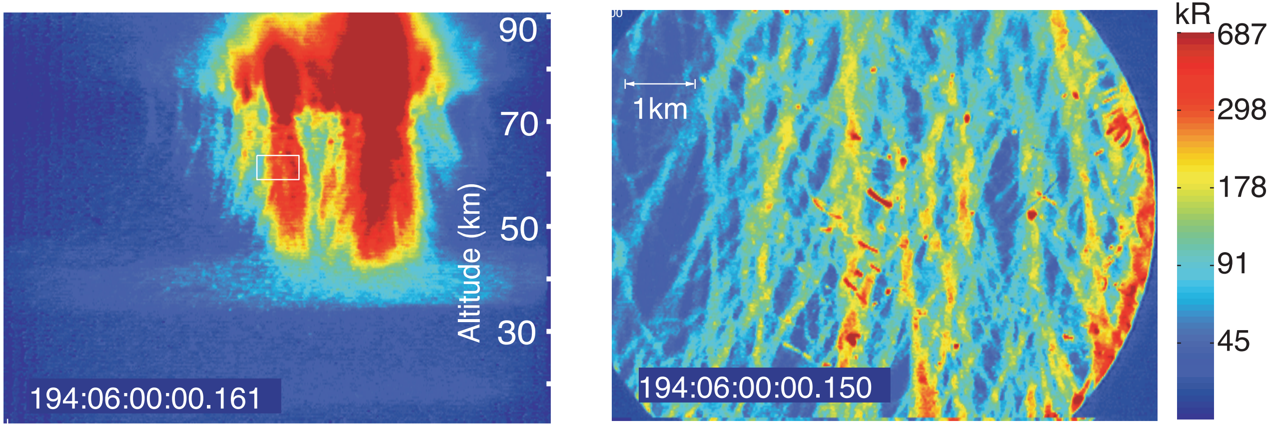
Streamer Structure of Sprites

- Filamentary structures of sprites:



[*Gerken et al.*, GRL, 27(17), 2637, 2000]

- Four major emission band systems of sprites:

Emission Band System	Transition	Excitation Energy Threshold (eV)	Lifetime at 70 km Alt.	Quenching Alt. (km)
$1PN_2$	$N_2(B^3\Pi_g)\rightarrow N_2(A^3\Sigma_u^+)$	$\sim$7.35	5.4 μs	$\sim$53
$2PN_2$	$N_2(C^3\Pi_u)\rightarrow N_2(B^3\Pi_g)$	$\sim$11	50 ns	$\sim$30
LBH N_2	$N_2(a^1\Pi_g)\rightarrow N_2(X^1\Sigma_g^+)$	$\sim$8.55	14 μs	$\sim$77
$1NN_2^+$	$N_2^+(B^2\Sigma_u^+)\rightarrow N_2^+(X^2\Sigma_g^+)$	$\sim$18.8	69 ns	$\sim$48

Observation of NO-γ Emissions in Laboratory Experiments

- Laboratory experiments at ground pressure suggest that NO-γ emissions can be generated during streamer discharges, which have a wavelength range overlapping with that of N_2 LBH emissions [e.g., *Simek et al.*, J. Phys. D: Appl. Phys., 35, 1998; *Tochikubo and Teich*, Jpn. J. Appl. Phys., 39, 2000].

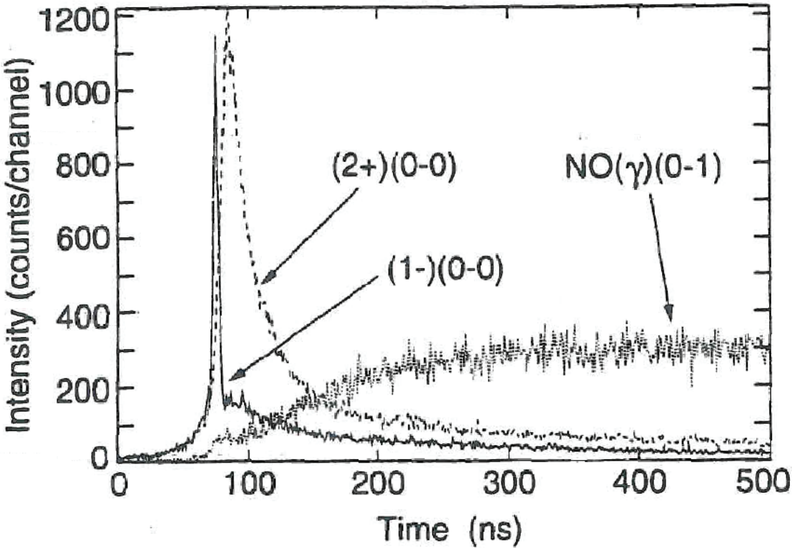


Figure 1: Time histories of $2PN_2$, $1NN_2^+$ and NO-γ from repetitive positive streamer discharge (365 hPa N_2 + 10 hPa O_2) [*Tochikubo and Teich*, 2000].

NO Chemistry for Sprite Streamers

- Important species involved in NO chemistry: N_2, O_2, $N(^2D)$, $O(^3P)$, $N_2(A^3\Sigma_u^+)$, $NO(X^2\Pi_r)$, and $NO(A^2\Sigma^+)$

Reaction process or index	Reaction	Rate Coefficient [$f(E/N)$ denotes function of reduced electric field]
Electron collision reactions		
1	$e + N_2 \rightarrow e + N(^4S) + N(^2D)$	$f(E/N)$
2	$e + O_2 \rightarrow e + O(^3P) + O(^3P)$	$f(E/N)$
3	$e + N_2 \rightarrow e + N_2(A^3\Sigma_u^+)$	$f(E/N)$
4	$e + N_2 \rightarrow e + N_2(B^3\Pi_g)$	$f(E/N)$
5	$e + N_2 \rightarrow e + N_2(C^3\Pi_u)$	$f(E/N)$
6	$e + NO(X^2\Pi_r) \rightarrow e + NO(A^2\Sigma^+)$	$f(E/N)$
Chemical reactions		
7	$N(^2D) + O_2 \rightarrow NO(X^2\Pi_r) + O(^3P)$	5.20×10^{-18} m^3s^{-1}
8	$N_2(A^3\Sigma_u^+) + O(^3P) \rightarrow NO(X^2\Pi_r) + N(^2D)$	7×10^{-18} m^3s^{-1}
9	$N(^2D) + NO \rightarrow N_2 + O(^3P)$	6.0×10^{-17} m^3s^{-1}
Excitation		
10	$N_2(A^3\Sigma_u^+) + NO(X^2\Pi_r) \rightarrow NO(A^2\Sigma^+) + N_2(X^1\Sigma_g^+)$	8.75×10^{-17} m^3s^{-1}
Quenching		
11	$N(^2D) + N_2 \rightarrow N(^4S) + N_2$	1.70×10^{-20} m^3s^{-1}
12	$N_2(A^3\Sigma_u^+) + O_2 \rightarrow N_2 + O_2$	8.75×10^{-19} m^3s^{-1}
13	$N_2(A^3\Sigma_u^+) + O_2 \rightarrow N_2 + 2O(^3P)$	1.63×10^{-18} m^3s^{-1}
14	$NO(A^2\Sigma^+) + O_2 \rightarrow NO(X^2\Pi_r) + O_2$	1.62×10^{-16} m^3s^{-1}
Radiative transition		
15	$N_2(B^3\Pi_g) \rightarrow N_2(A^3\Sigma_u^+) + h\nu$	1.7×10^5 s^{-1}
16	$N_2(C^3\Pi_u) \rightarrow N_2(B^3\Pi_g) + h\nu$	$2.0 \times 10^7 s^{-1}$
17	$NO(A^2\Sigma^+) \rightarrow NO(X^2\Pi_r) + h\nu$	5×10^6 s^{-1}

NO-γ Band Emissions

- The transition leading to NO-γ emissions:
  $NO(A^2\Sigma^+) \rightarrow NO(X^2\Pi_r) + h\nu$.
  The excitation energy threshold for $NO(A^2\Sigma^+)$ is 5.45 eV.

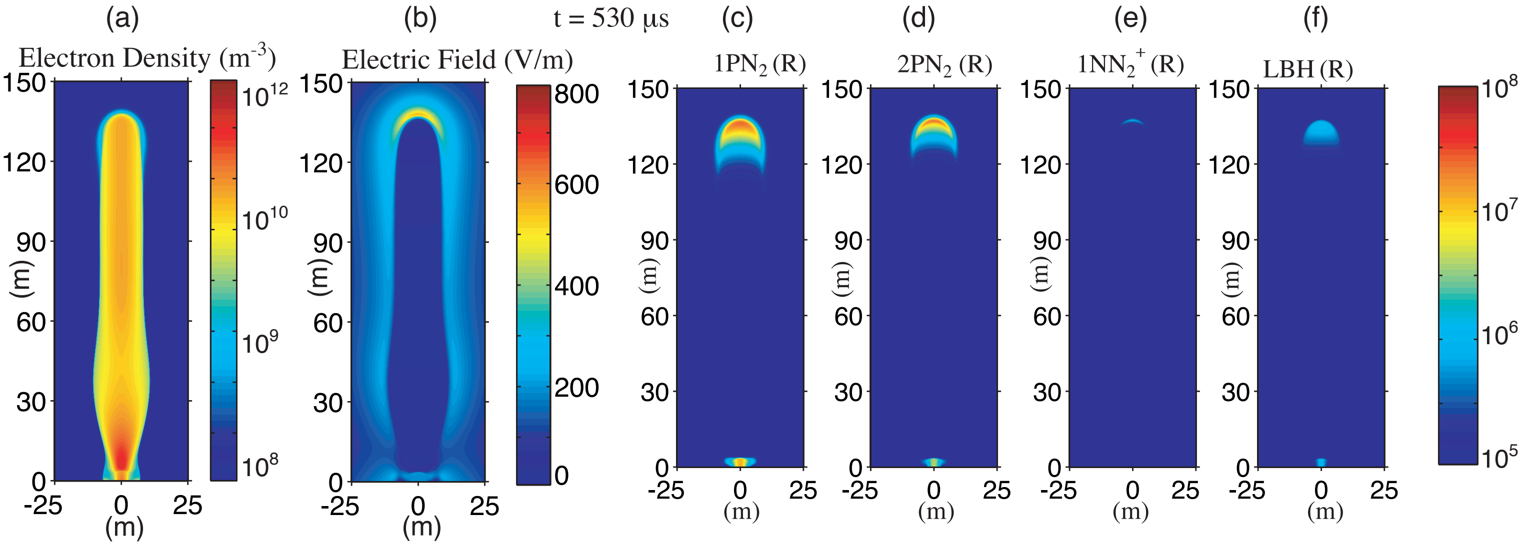
- The radiative transition rate (Einstein coefficient):
  $A_k = 5 \times 10^6\ s^{-1}$.

- The excited state $NO(A^2\Sigma^+)$ is mainly produced by resonant energy transfer:
  $N_2(A^3\Sigma_u^+) + NO(X^2\Pi_r) \rightarrow NO(A^2\Sigma^+) + N_2(X^1\Sigma_g^+)$. The direct excitation by electron impact plays a minor role.

- The dominant quenching process of excited state $NO(A^2\Sigma^+)$:
  $NO(A^2\Sigma^+) + O_2 \rightarrow NO(X^2\Pi_r) + O_2$, which has a rate constant $1.62\times10^{-16}\ m^3/s$. The resulting quenching altitude is $\sim$30 km.

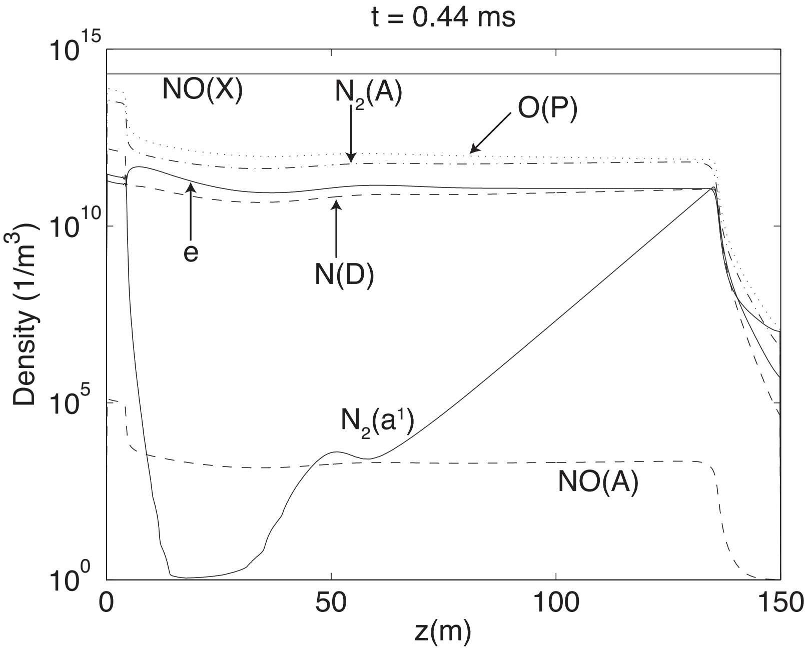
Streamer Model

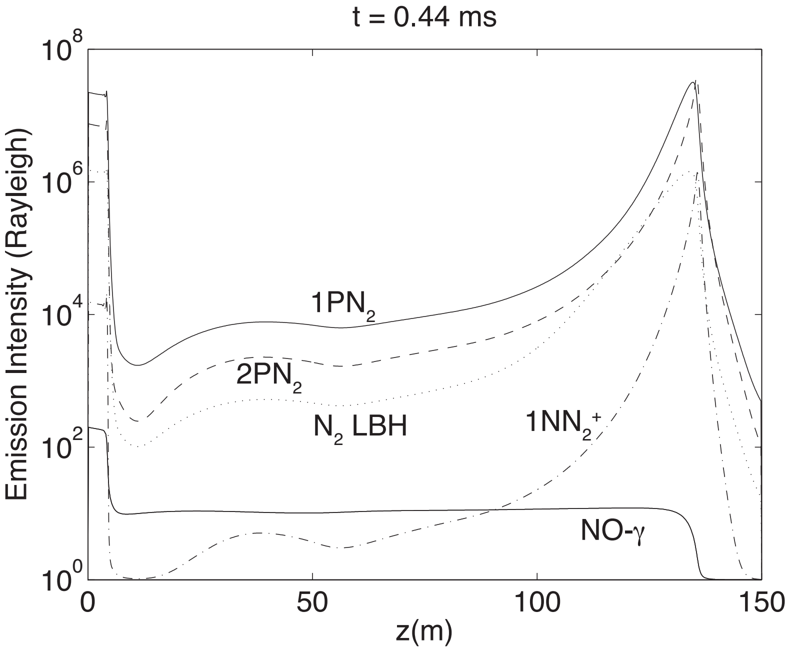
- Modeling results for a sprite streamer developing in an ambient field $E_0 = 5\times \mathrm{N}_{70}/\mathrm{N}_0$ kV/cm, where N_{70} and N_0 are air densities at 70 km and 0 km altitude, respectively.



Simulation Results for a Streamer at 70 km Altitude

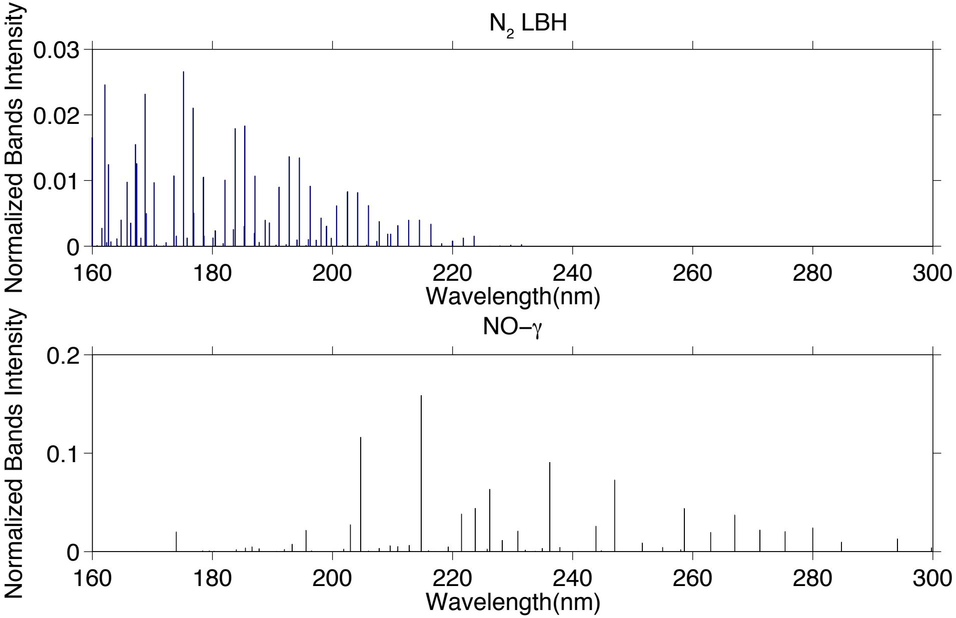
- $E_0 = 5\times \mathrm{N}_{70}/\mathrm{N}_0$ kV/cm, where N_{70} and N_0 are air densities at 70 km and 0 km altitude, respectively. The initial density of NO is set to be 2×10^{14} 1/m^3 [*Atreya*, Adv. Space Res., 1, 127, 1981].





Conclusions and Implications of This Work for Sprite Observations

- The NO-γ emissions from sprites are not observable for a wide bandwidth photometer.
- Strong bands of NO-gamma emissions are located in the wavelength range 240-260 nm in which N_2 LBH emissions are absent [*Vallance-Jones*, 1974, Tables 4.14 and 4.18, 1974].



- A dedicated narrow bandwidth photometer with the wavelength passband of 240–260 nm would be able to detect sprite NO-γ emissions from space.

Publications and Conference Presentations to Date

- Refereed Journal Papers:
  - **Liu, N. Y.**, and V. P. Pasko, Modeling studies of NO-γemissions of sprites, *Geophys. Res. Lett.*, accepted, 2007.
  - Bourdon, A., V. P. Pasko, **N. Y. Liu**, S. Celestin, P. Segur, and E. Marode, Efficient models for photoionization produced by non-thermal gas discharges in air based on radiative transfer and Helmholtz equations, *Plasma Sources Sci. Technol.*, in review, 2007.
- Conference Presentations:
  - **Liu, N. Y.**, and V. P. Pasko, NO Chemistry and NO-gamma Emissions Associated with Sprite Streamers, 2007 CEDAR workshop, *Poster Sessions Booklet*, p. 20, Santa Fe, NM, June 24–29, 2007.
  - Bourdon, A., V. P. Pasko, **N. Y. Liu**, S. Celestin, P. Segur, and E. Marode, Comparison of the classical integral model with Eddington approximation and Helmholtz equation based models for photoionization produced by non-thermal gas discharges in air, 2007 Aerospace Thematic Workshop: Fundamentals of Aerodynamic-Flow and Combustion Control by Plasmas, Varenna, Italy, May 28-31, 2007.
  - **(Invited) Liu, N. Y.**, and V. P. Pasko, The possibility of generation of NO-gamma emissions in sprite discharges, *Eos Trans. AGU*, 87(52), Fall Meet. Suppl., Abstract AE41A-06, 2006.

Acknowledgements

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