

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

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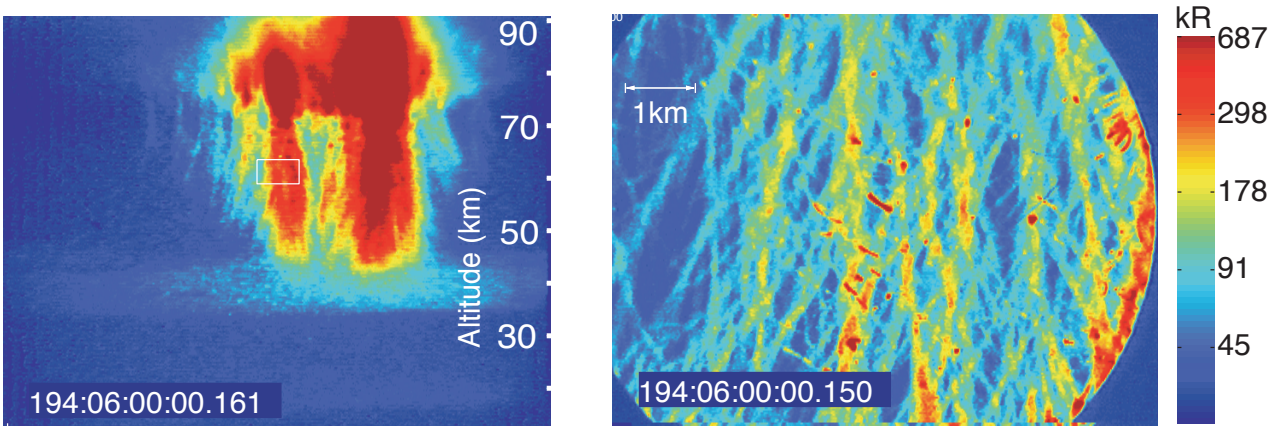
Ningyu Liu

Department of Electrical Engineering  
Communications and Space Sciences Laboratory  
The Pennsylvania State University  
University Park, PA 16802

Advisor: Victor P. Pasko

## 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 <sub>2</sub>	N <sub>2</sub> (B <sup>3</sup> Π <sub>g</sub> )→N <sub>2</sub> (A <sup>3</sup> Σ <sub>u</sub> <sup>+</sup> )	~7.35	5.4 μs	~53
2PN <sub>2</sub>	N <sub>2</sub> (C <sup>3</sup> Π <sub>u</sub> )→N <sub>2</sub> (B <sup>3</sup> Π <sub>g</sub> )	~11	50 ns	~30
LBH N <sub>2</sub>	N <sub>2</sub> (a <sup>1</sup> Π <sub>g</sub> )→N <sub>2</sub> (X <sup>1</sup> Σ <sub>g</sub> <sup>+</sup> )	~8.55	14 μs	~77
1NN <sub>2</sub> <sup>+</sup>	N <sub>2</sub> <sup>+</sup> (B <sup>2</sup> Σ <sub>u</sub> <sup>+</sup> )→N <sub>2</sub> <sup>+</sup> (X <sup>2</sup> Σ <sub>g</sub> <sup>+</sup> )	~18.8	69 ns	~48

## Observation of NO- $\gamma$ Emissions in Laboratory Experiments

- Laboratory experiments at ground pressure suggest that NO- $\gamma$  emissions can be generated during streamer discharges, which have a wavelength range overlapping with that of N<sub>2</sub> LBH emissions [e.g., *Simek et al.*, J. Phys. D: Appl. Phys., 35, 1998; *Tochikubo and Teich*, Jpn. J. Appl. Phys., 39, 2000].

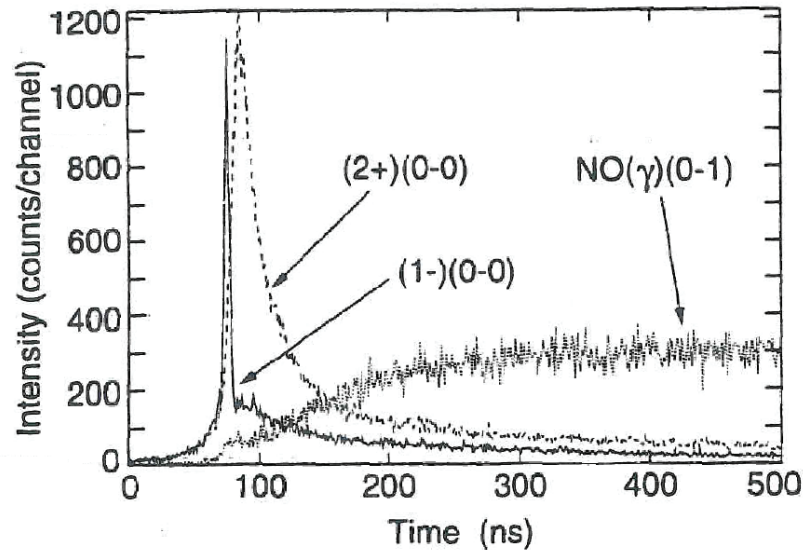


Figure 1: Time histories of  $2PN_2$ ,  $1NN_2^+$  and NO- $\gamma$  from repetitive positive streamer discharge (365 hPa N<sub>2</sub> + 10 hPa O<sub>2</sub>) [*Tochikubo and Teich*, 2000].

# NO Chemistry for Sprite Streamers

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- 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	$N(^2D) + O_2 \rightarrow NO(X^2\Pi_r) + O(^3P)$	$5.20 \times 10^{-18} \text{ m}^3\text{s}^{-1}$
8	$N_2(A^3\Sigma_u^+) + O(^3P) \rightarrow NO(X^2\Pi_r) + N(^2D)$	$7 \times 10^{-18} \text{ m}^3\text{s}^{-1}$
9	$N(^2D) + NO \rightarrow N_2 + O(^3P)$	$6.0 \times 10^{-17} \text{ m}^3\text{s}^{-1}$
Excitation		
10	$N_2(A^3\Sigma_u^+) + NO(X^2\Pi_r) \rightarrow NO(A^2\Sigma^+) + N_2(X^1\Sigma_g^+)$	$8.75 \times 10^{-17} \text{ m}^3\text{s}^{-1}$
Quenching		
11	$N(^2D) + N_2 \rightarrow N(^4S) + N_2$	$1.70 \times 10^{-20} \text{ m}^3\text{s}^{-1}$
12	$N_2(A^3\Sigma_u^+) + O_2 \rightarrow N_2 + O_2$	$8.75 \times 10^{-19} \text{ m}^3\text{s}^{-1}$
13	$N_2(A^3\Sigma_u^+) + O_2 \rightarrow N_2 + 2O(^3P)$	$1.63 \times 10^{-18} \text{ m}^3\text{s}^{-1}$
14	$NO(A^2\Sigma^+) + O_2 \rightarrow NO(X^2\Pi_r) + O_2$	$1.62 \times 10^{-16} \text{ m}^3\text{s}^{-1}$
Radiative transition		
15	$N_2(B^3\Pi_g) \rightarrow N_2(A^3\Sigma_u^+) + h\nu$	$1.7 \times 10^5 \text{ s}^{-1}$
16	$N_2(C^3\Pi_u) \rightarrow N_2(B^3\Pi_g) + h\nu$	$2.0 \times 10^7 \text{ s}^{-1}$
17	$NO(A^2\Sigma^+) \rightarrow NO(X^2\Pi_r) + h\nu$	$5 \times 10^6 \text{ s}^{-1}$

## NO- $\gamma$ Band Emissions

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- The transition leading to NO- $\gamma$  emissions:

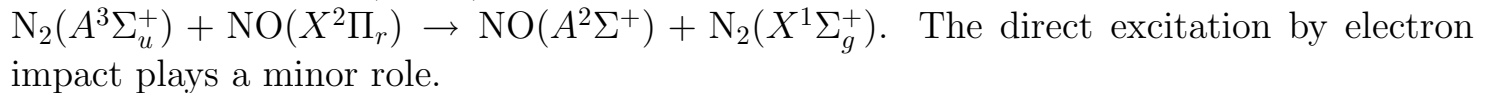


The excitation energy threshold for NO( $A^2\Sigma^+$ ) is 5.45 eV.

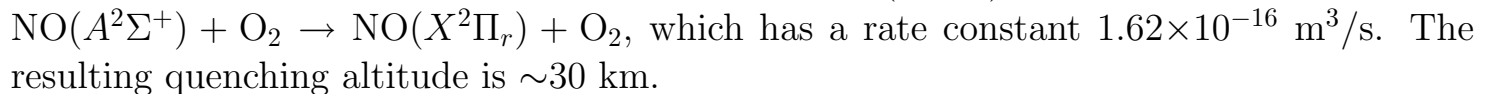
- The radiative transition rate (Einstein coefficient):

$$A_k = 5 \times 10^6 \text{ s}^{-1}.$$

- The excited state NO( $A^2\Sigma^+$ ) is mainly produced by resonant energy transfer:

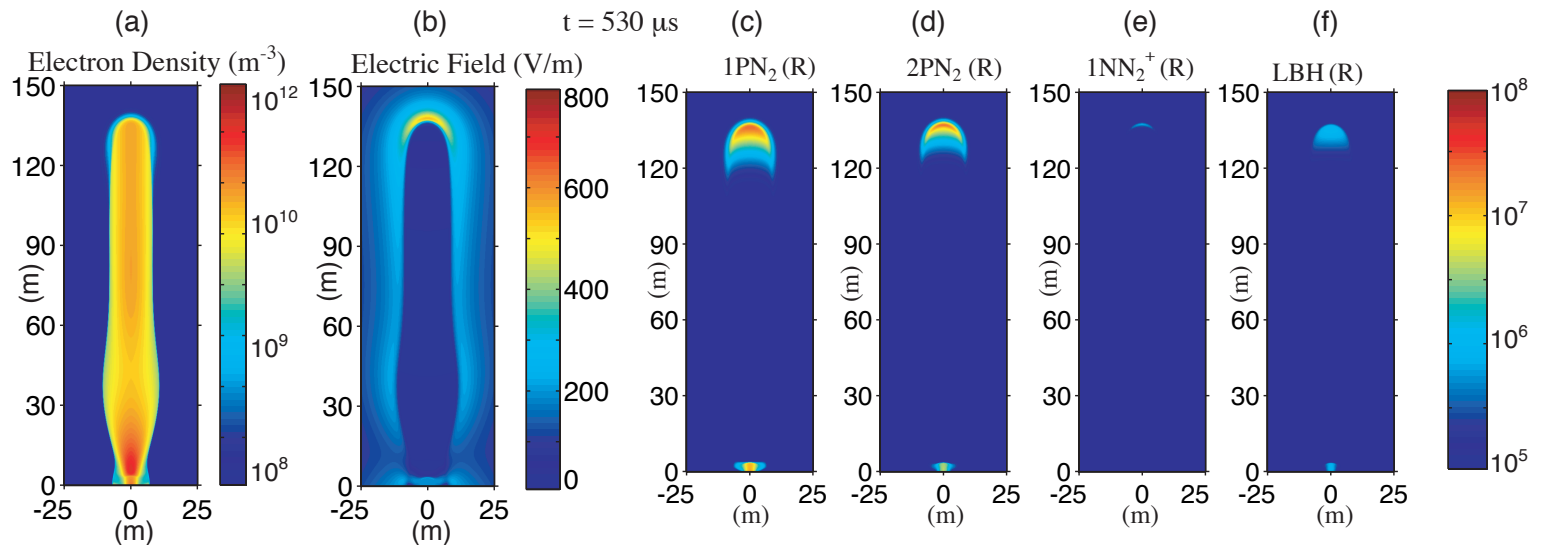


- The dominant quenching process of excited state NO( $A^2\Sigma^+$ ):



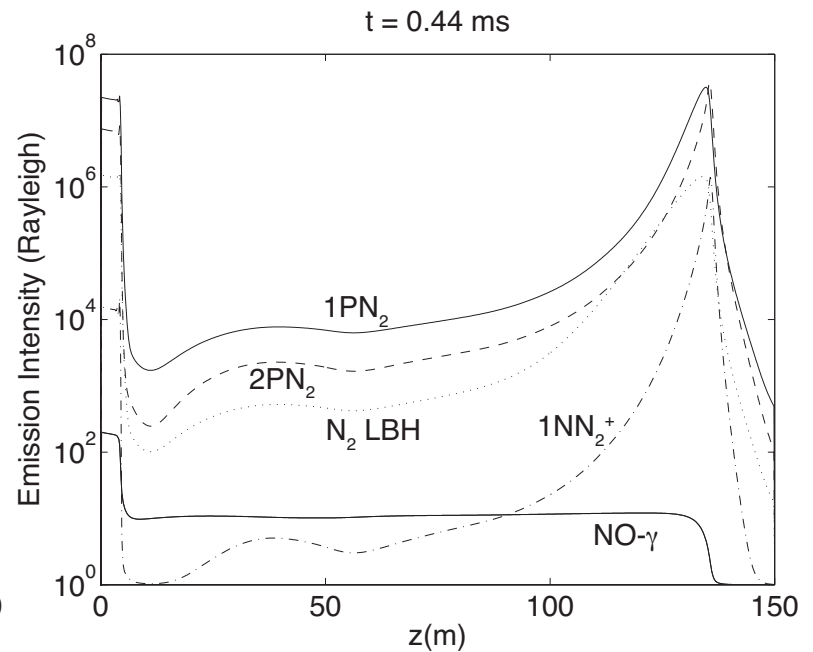
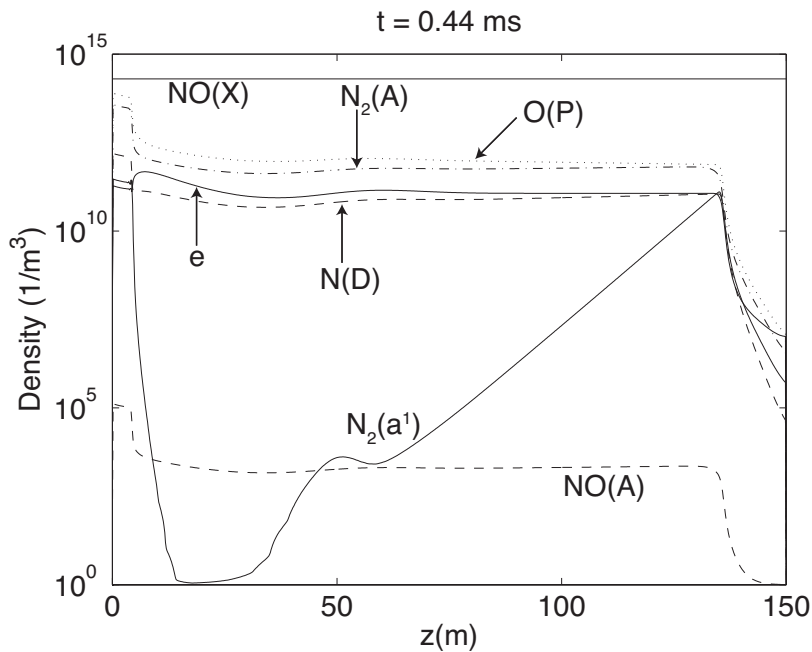
# Streamer Model

- Modeling results for a sprite streamer developing in an ambient field  $E_0 = 5 \times N_{70}/N_0$  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

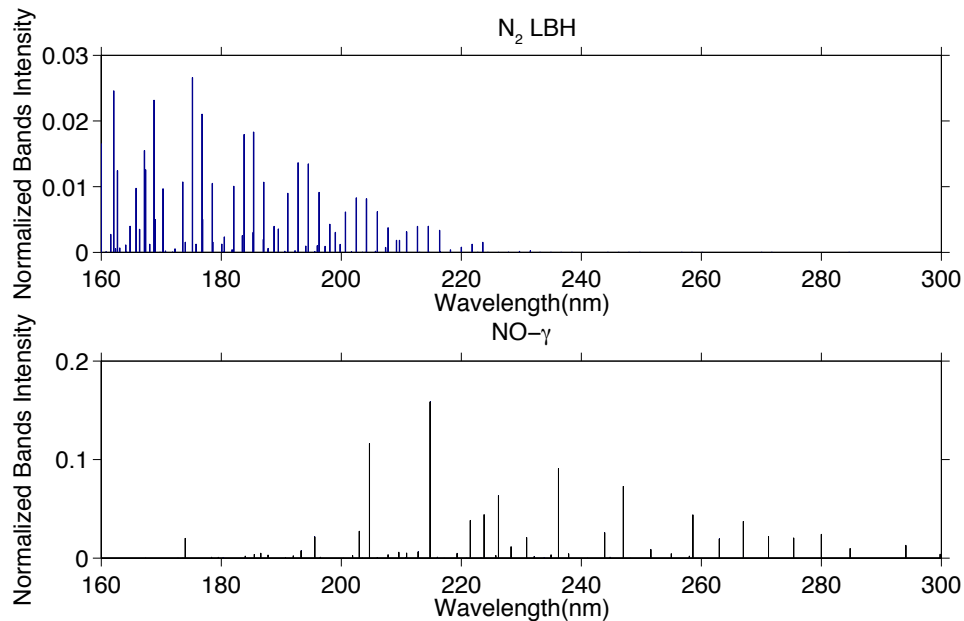
- $E_0 = 5 \times N_{70}/N_0$  kV/cm, where  $N_{70}$  and  $N_0$  are air densities at 70 km and 0 km altitude, respectively. The initial density of NO is set to be  $2 \times 10^{14}$   $1/m^3$  [Atreya, Adv. Space Res., 1, 127, 1981].



## Conclusions and Implications of This Work for Sprite Observations

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- The NO- $\gamma$  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<sub>2</sub> 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- $\gamma$  emissions from space.

## Publications and Conference Presentations to Date

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- Refereed Journal Papers:

- **Liu, N. Y.**, and V. P. Pasko, Modeling studies of NO- $\gamma$ emissions 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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