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Kinetics of CO_2 and nitrogen oxides in air plasmas produced by the action of sprites and halos in the Earth mesosphere

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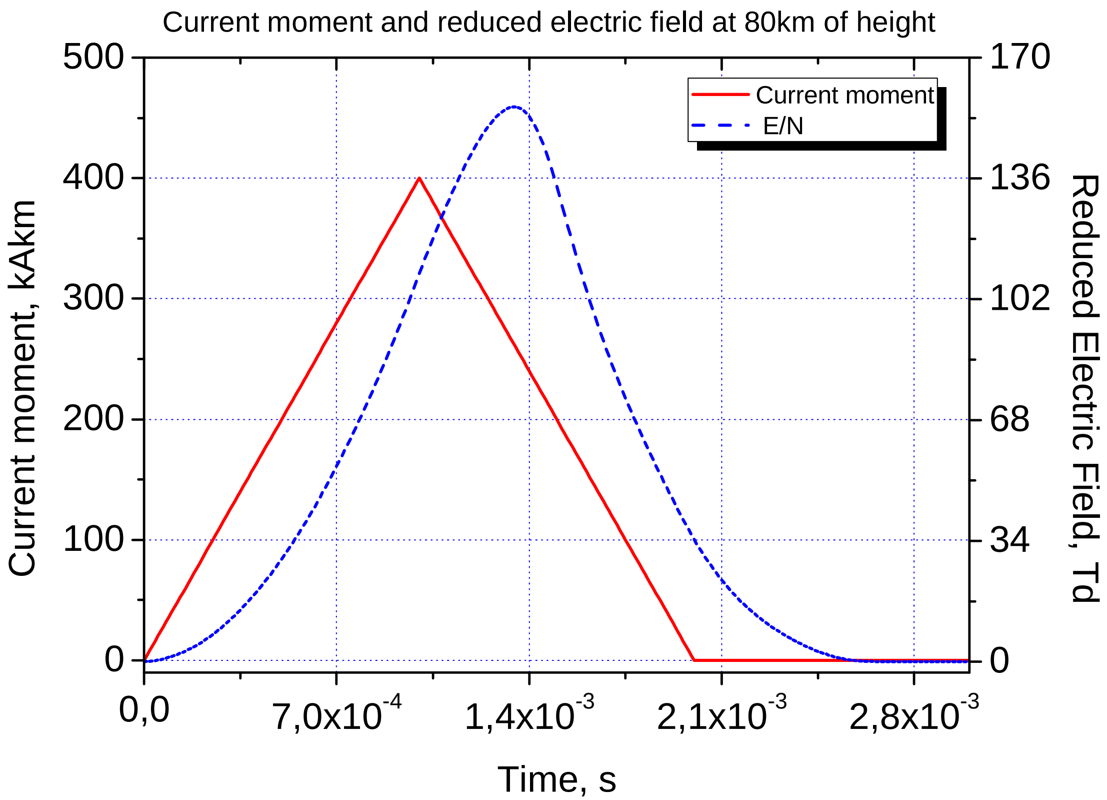
1. MOTIVATION AND OBJETIVES

1. Impact of sprite streamers and halos in the electron density

➡ Conductivity ➡ Streamer propagation



2. Contributions of the sprites and halos to the IR emission (14.9 μm and 4.26 μm of CO_2)

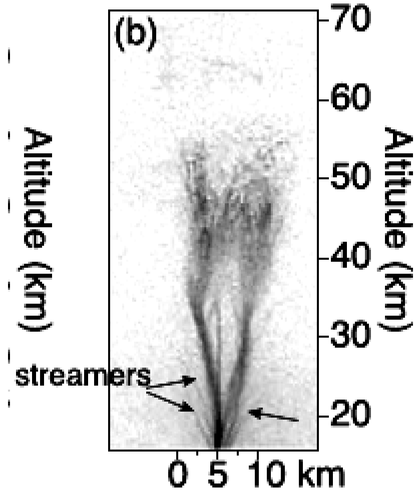
Picard *et al*. (GRL 1997) estimated that electrons could excite N_2 and CO_2 vibrationally which radiative decay could produce IR emission (4.26 μm of the $CO_2(00^01)$) detectable from space platforms.

3. Influence of the sprites and halos in the concentrations of NO_x , N_2O and $CO_2(v)$

Nitrogen oxides are very important species in the mesospheric chemical evolution (N_2O particularly). Gordillo-Vázquez (JPD 2008) obtained a significant increase in the concentration of the NO_x and two orders of magnitud in the N_2O concentration under the streamer electric field influence.
Sentman *et al.* (JGR2008) predicted an increase of the 50% in the NO density.

4. Possible upper atmosphere gas heating due to TLEs action

Gas heating mechanisms in the mesosphere under the sprite influence are not well known. In 1998, Pasko *et al.* (GRL 1998a) estimated a heating of $\Delta T/T \approx 2 - 0.2$ % (50-60 km) under the action of streamer electric field. this gas heating could also be possible in the stratosphere and lower mesosphere under the action of Blue Jets and Gigantic Jets.
(Riousset *et al.* JGR 2010).



Riousset *et al.* (JGR 2010)

2. MODEL

Chemical species over 90 (N_2 , O_2 , CO_2 , Ar, …)
Over 800 processes (ionization, EDF-dependent, V-V, V-T, …)
We solve the equations that control chemical processes

$$\frac{\partial n_i}{\partial t} = G_i - L_i \tag{1}$$

Coupled with the steady-state Boltzmann transport equation

$$\left(\frac{eE(t)}{m_e} \nabla_v \right) f(v,t) = \left(\frac{\partial f}{\partial t} \right)_{collisions} \tag{2}$$

In the halo and lightning case, we solve in self-consistent way the total current conservation equation

$$\varepsilon_0 \frac{dE}{dt} = -\sigma E + J_T(t) \tag{3}$$

This system needs to meet the condition of charge conservation

$$\sum_j n_j^+ = n_e + \sum_k n_k^- \qquad (4)$$

We also implement the gas heating equation (energy conservation).

$$P_{ext} = P_{elec} + P_{gas} + P_{chem} + P_{rad} \qquad (5)$$

$$e n_e v_e E = \frac{3}{2}\frac{d(n_e T_e)}{dt} + \frac{1}{\gamma - 1}\frac{d(n T_{gas})}{dt} + \sum_i Q_i \frac{dn_i}{dt} - \sum_i n_i A_{ij}^{eff} h \upsilon_{ij}$$

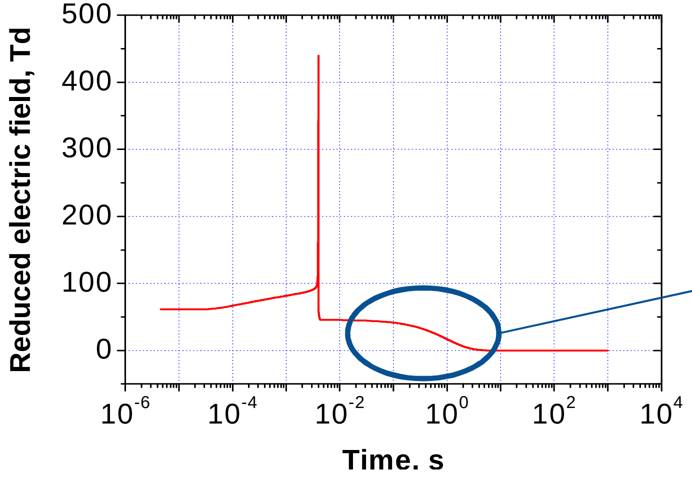
. STAGES OF THE SIMULATION

1º "Relaxation" of the species to E/N ~ 0, at t = 10^6 s (fit the rate of ionization by cosmic rays). We search the equilibrium of the initial concentration of the species.

2º Chemical effects of tropospheric lightning in the mesosphere based in the Luque and Gordillo-Vázquez model (Nature Geoscience 2011) → Halo.

$$\varepsilon_o \frac{dE}{dt} = -\sigma E + J_T(t)$$

3º Input from streamer electric field (Luque and Ebert, GRL2010)



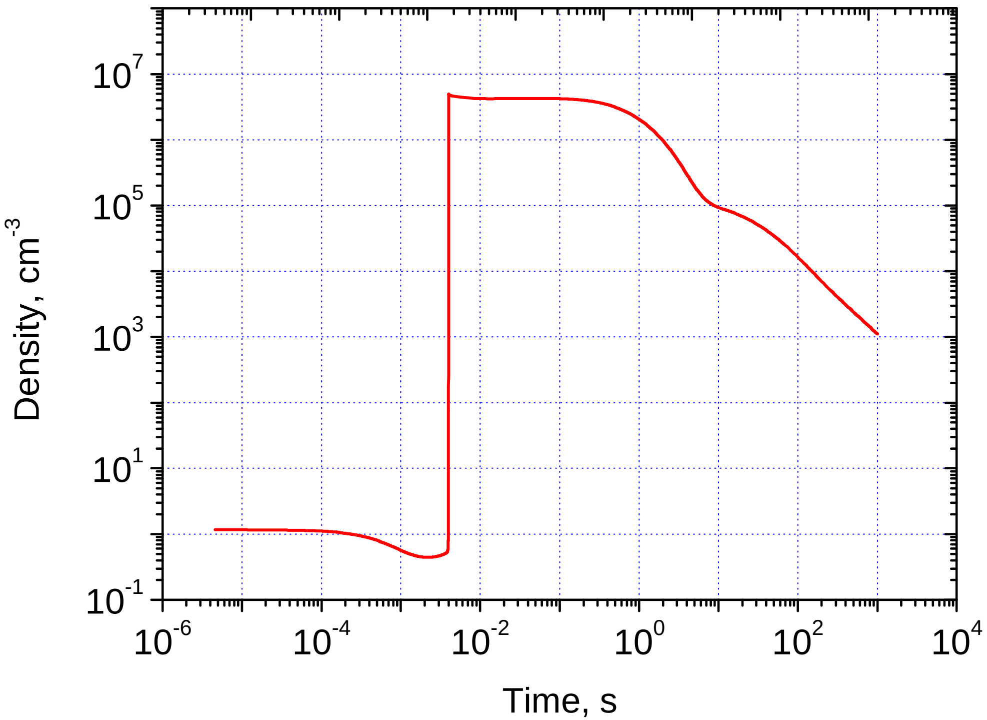
The decay of the E/N is parametrized

$$E_{tail} \propto e^{-t/\tau}$$

4. RESULTS

4.1 Electron density

Streamer (75 km)



Creation processes

$e + N_2 \rightarrow N_2^+ + e + e$

$e + O_2 \rightarrow O_2^+ + e + e$

$O^- + N_2 \rightarrow N_2O + e$

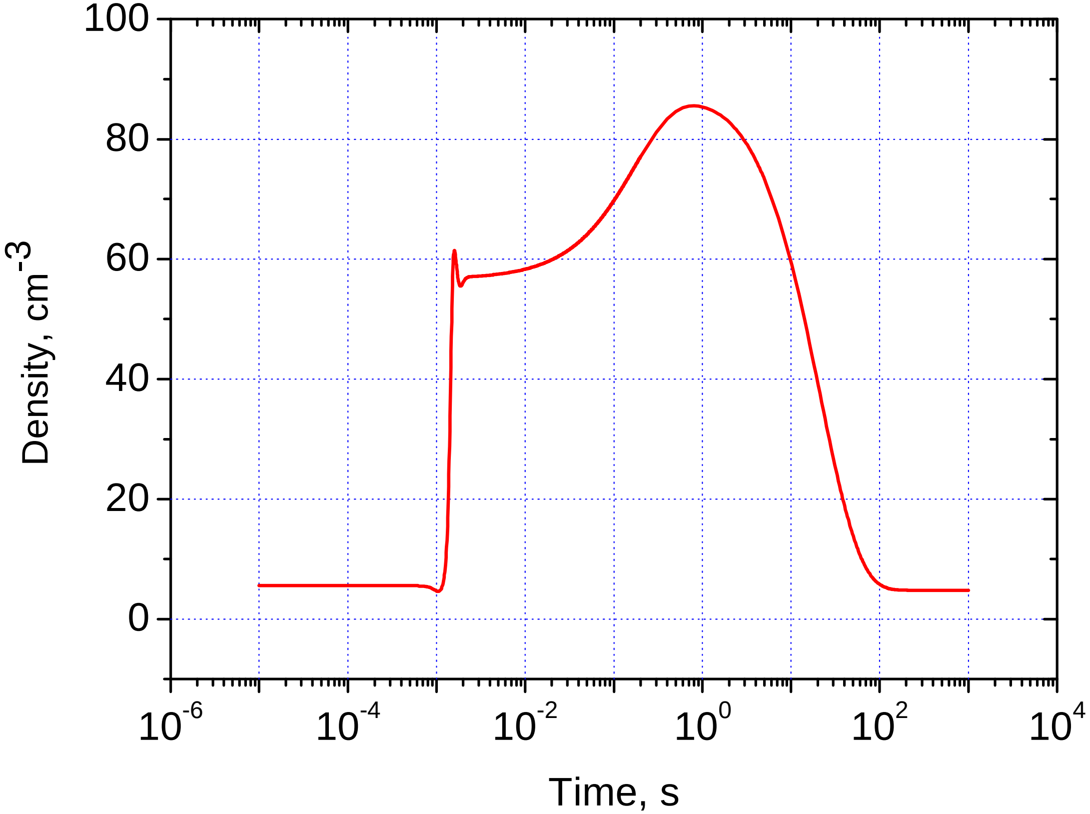
Removal processes

$e + O_2 + N_2 \rightarrow O_2^- + N_2$

$e + O_2 + O_2 \rightarrow O_2^- + O_2$

$e + O_2 \rightarrow O + O^-$

Halo (80 km)



<u>Creation processes</u>

$e + N_2 \rightarrow N_2^+ + e + e$

$e + O_2 \rightarrow O_2^+ + e + e$

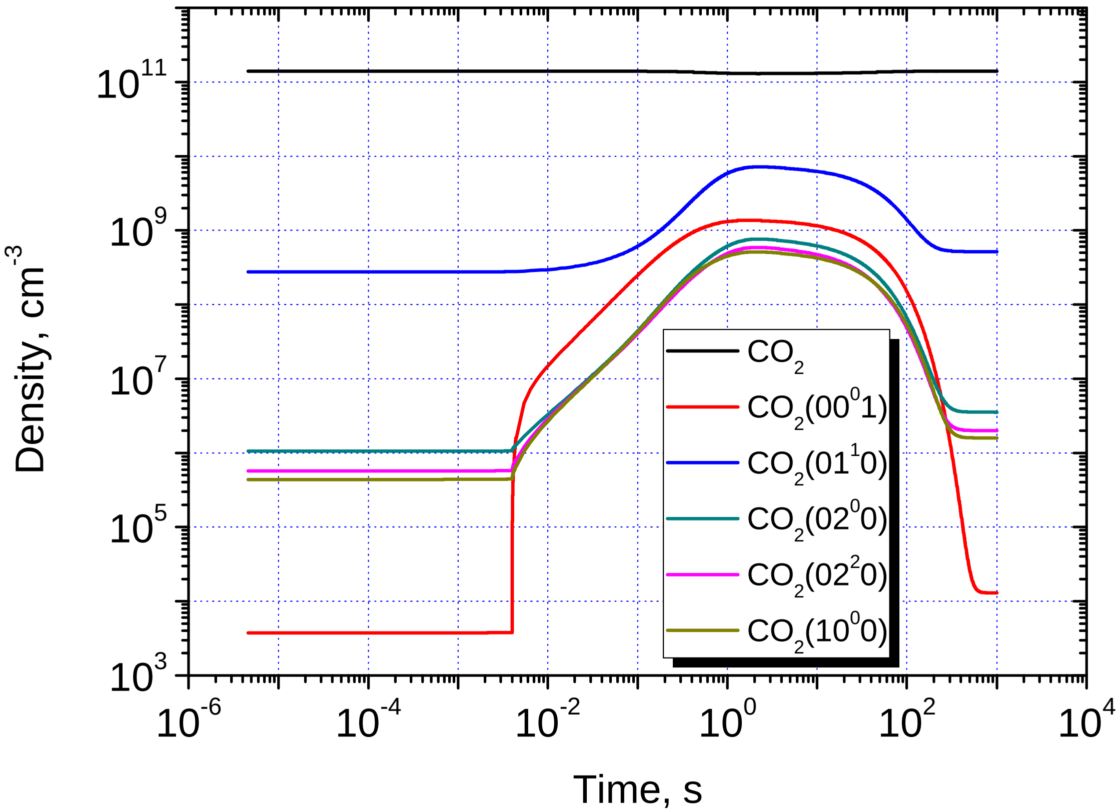
$O^- + N_2 \rightarrow N_2O + e$

<u>Removal processes</u>

$e + O_3 \rightarrow O^- + O_2$

4.2 CO_2 emission levels

Streamer (75 km)



Creation processes

$e + CO_2 \rightarrow CO_2(00^01) + e$

$N_2(X^1\Sigma_g^+, v=1) + CO_2 \rightarrow N_2 + CO_2(00^01)$

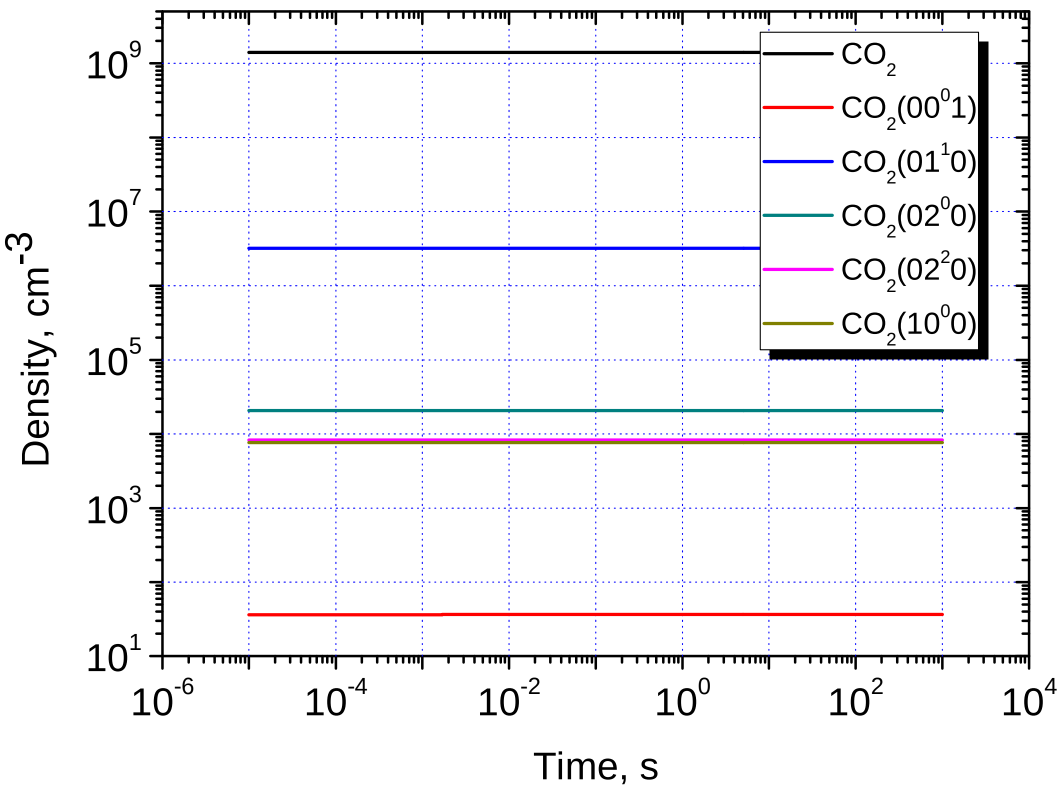
$e + CO_2 \rightarrow CO_2(01^10) + e$

Removal processes

$CO_2(00^01) \rightarrow CO_2 + h\nu\ (4.26\ \mu m)$

$CO_2(01^10) \rightarrow CO_2 + h\nu\ (14.9\ \mu m)$

Halo (80 km)



Creation processes

$N_2(X^1\Sigma_g^+, v=1) + CO_2 \rightarrow N_2 + CO_2(00^01)$

$N_2 + CO_2 \rightarrow N_2 + CO_2(01^10)$

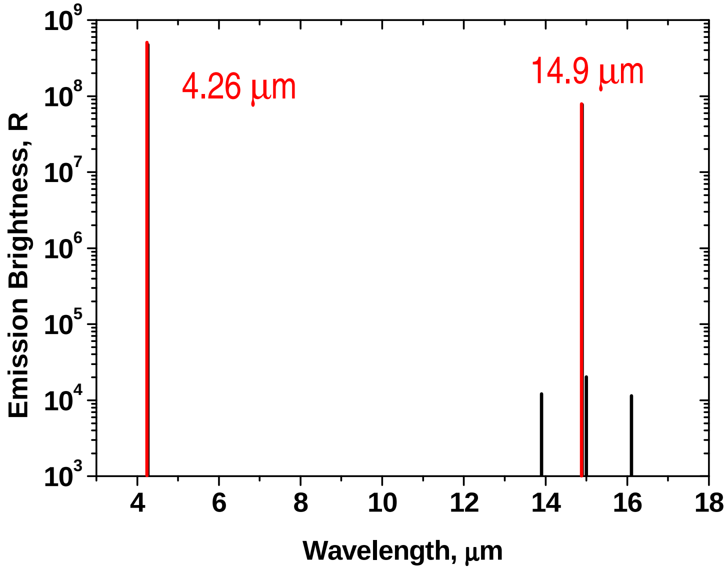
Removal processes

$CO_2(00^01) \rightarrow CO_2 + h\nu\ (4.26\ \mu m)$

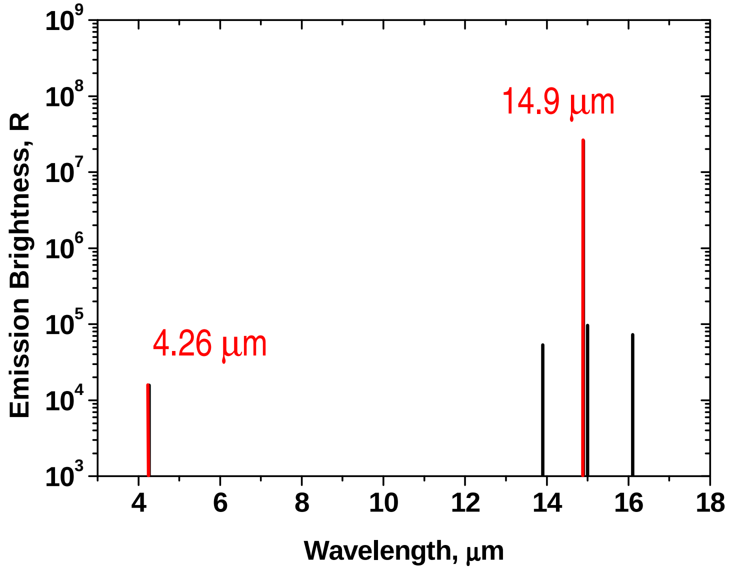
$CO_2(01^10) \rightarrow CO_2 + h\nu\ (14.9\ \mu m)$

Characterization of sprites by CO2 infrared spectra

Streamer (75 km)



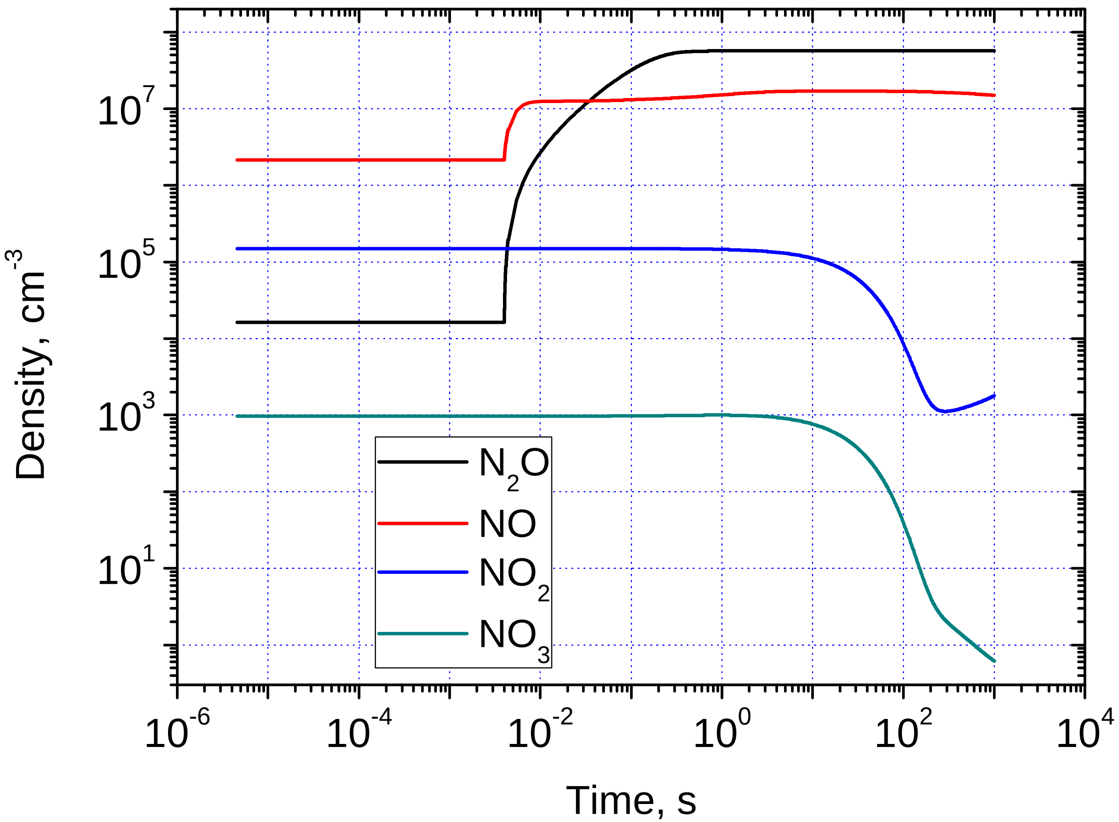
Halo (80 km)



$$ratio = \frac{I(4.26\mu m)}{I(14.9\mu m)} = 6.16$$

$$ratio = \frac{I(4.26\mu m)}{I(14.9\mu m)} = 6.09 \cdot 10^{-4}$$

Streamer (75 km)



Creation processes of N_2O and NO

$O^- + N_2 \rightarrow N_2O + e$

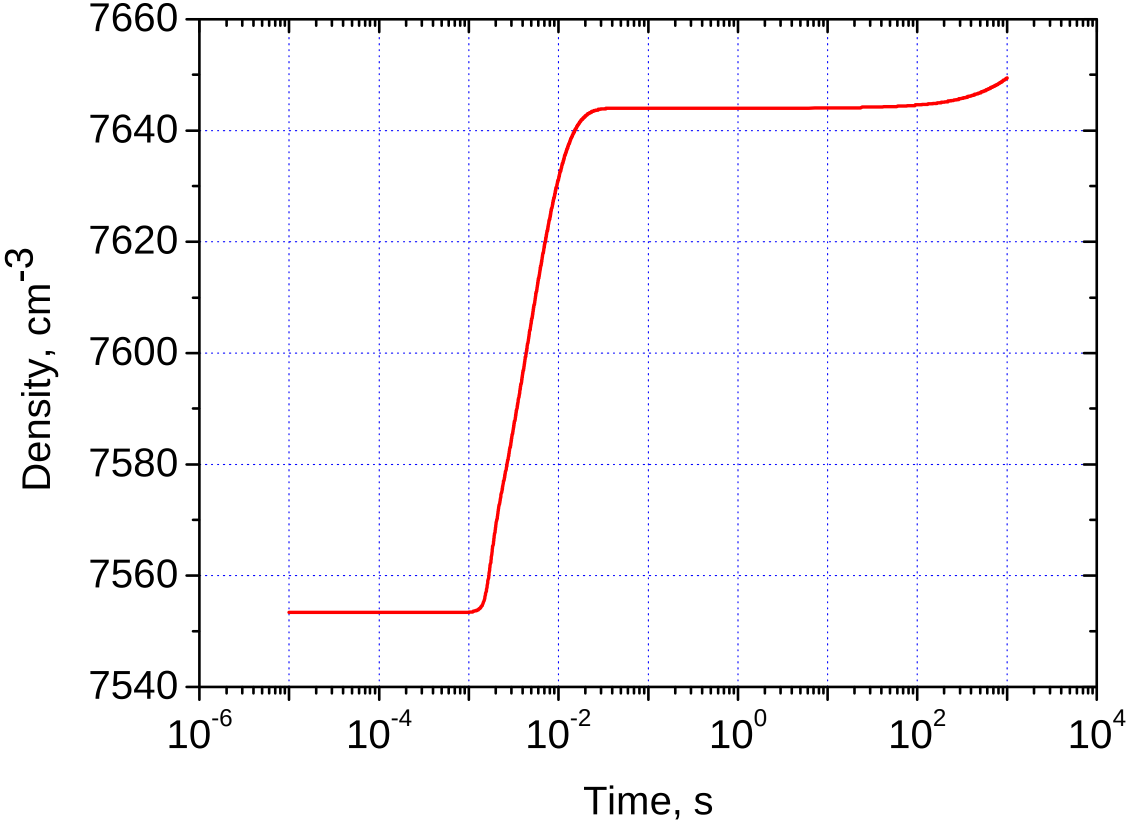
$e + N_2O_2^+ \rightarrow NO + NO$

Removal processes

$e + N_2O \rightarrow N_2 + O + e$

$N + NO \rightarrow N_2 + O$

Halo (80 km)



$$\Delta N_2O = 1.2\%$$

Creation process of N_2O

$N_2(A^3\Sigma_u+) + O_2 \rightarrow N_2O + O$

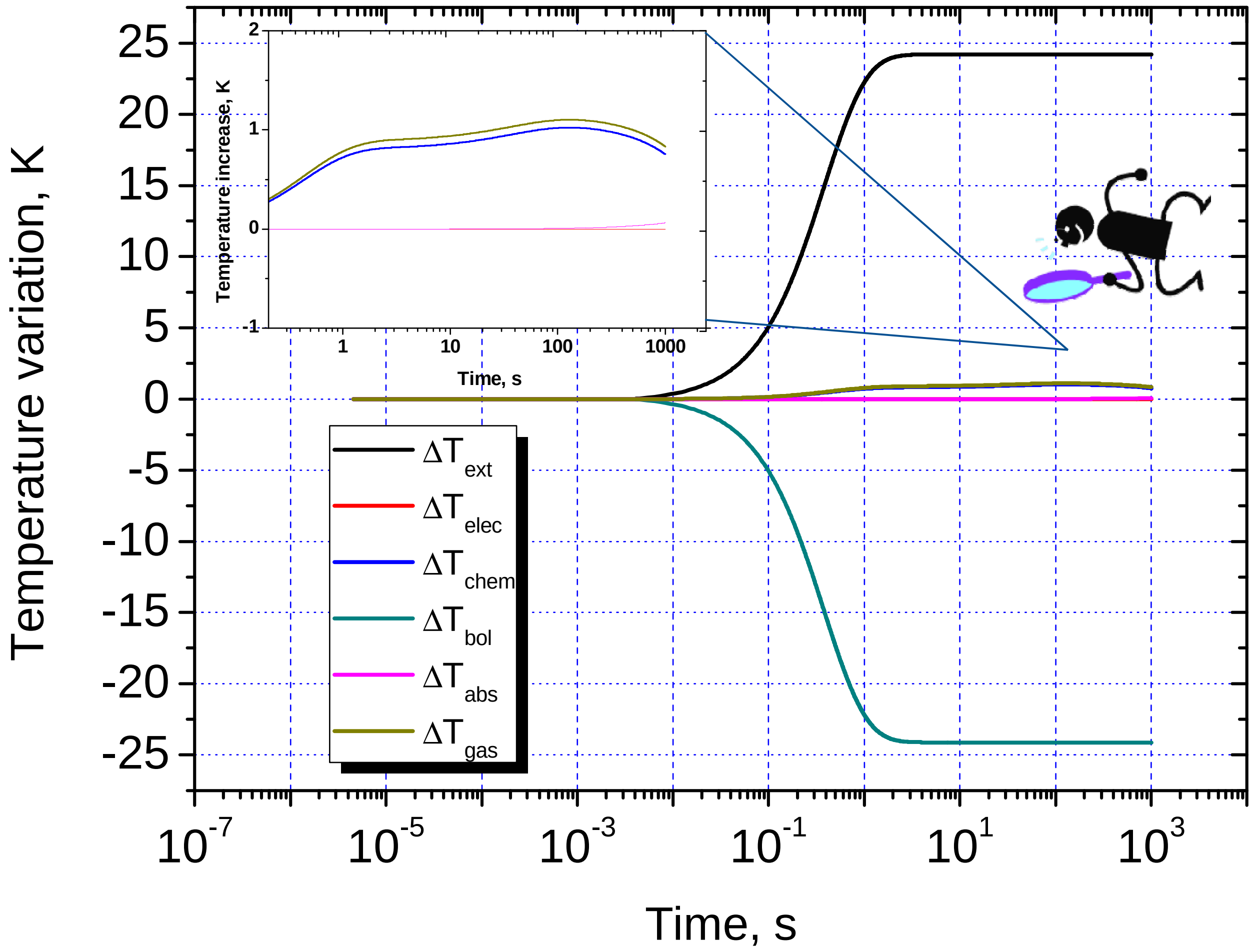
$N + NO_2 \rightarrow O + N_2O$

Removal process

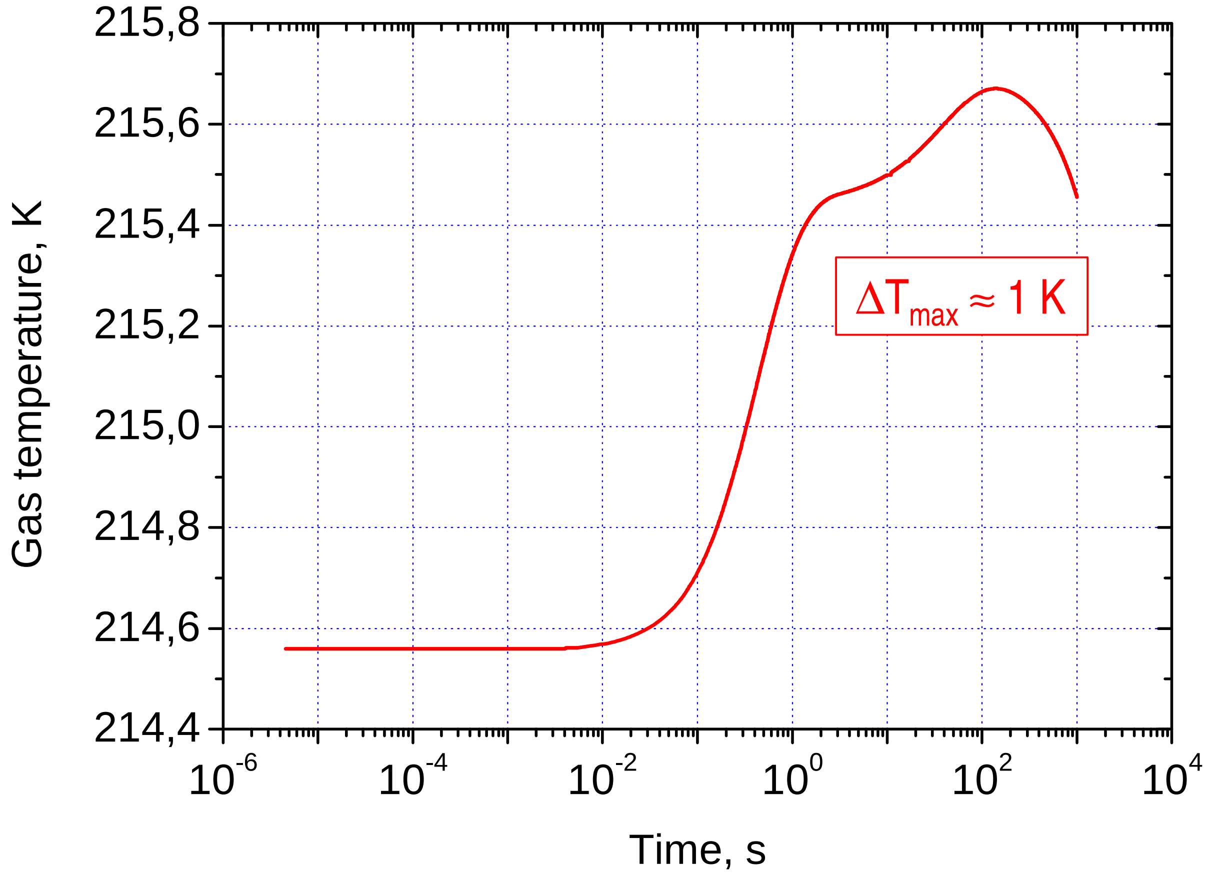
$O^- + N_2O \rightarrow NO^- + NO$

4.4 Mesospheric gas heating (75 km)

Energy balance



Gas heating (75 km)

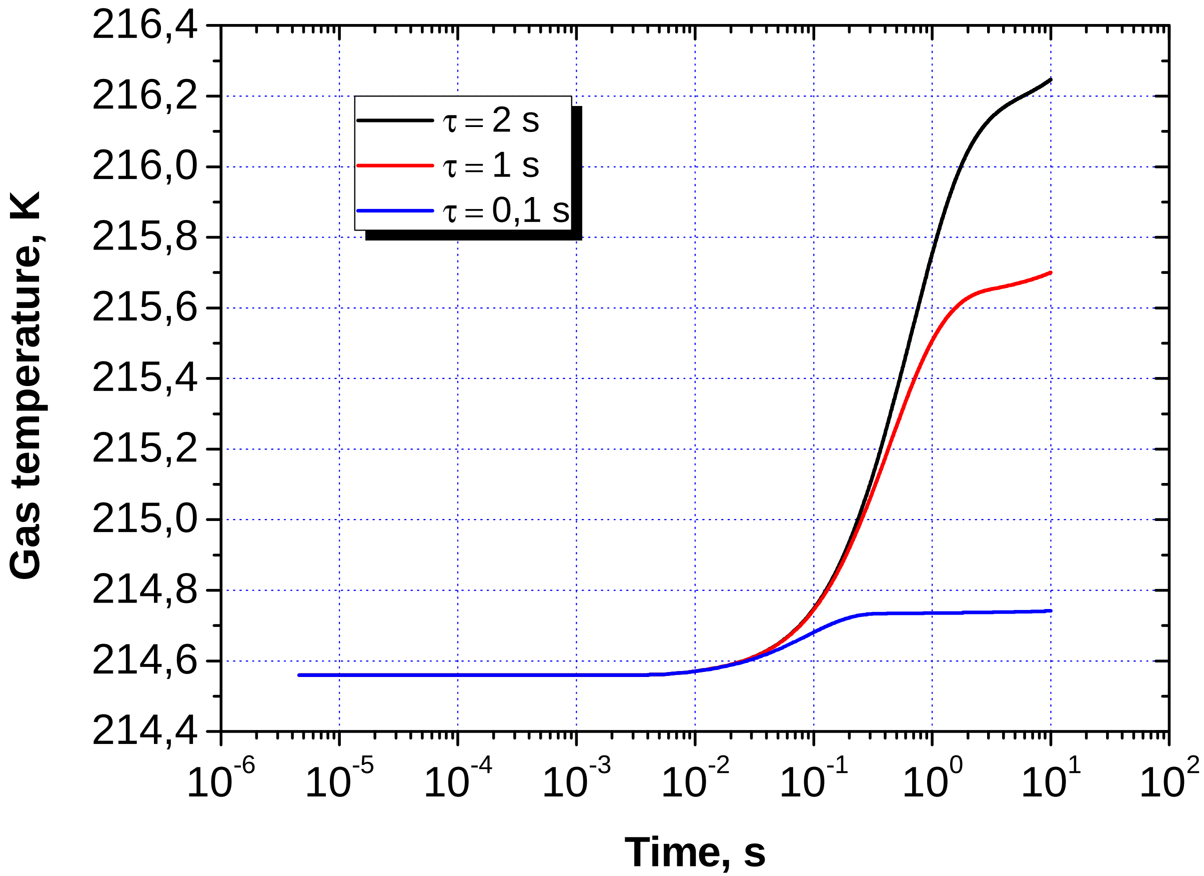


The top 10 processes that contribute to the maximum variation in temperature

Process	Temperature contribution (K)	Cumulative sum (K)
$CO_2(02^01) + N_2 \rightarrow CO_2(02^20) + N_2$	97.837	97.837
$CO_2(02^20) + N_2 \rightarrow CO_2(02^01) + N_2$	-97.821	0.015
$N_2(v2) + N_2 \rightarrow N_2(v1) + N_2(v1)$	5.255	5.271
$N_2(v1) + N_2(v1) \rightarrow N_2 + N_2(v2)$	-5.106	0.164
$N_2(rot) + M \rightarrow N_2 + M$	0.654	0.819
$N_2(v1) + CO_2 \rightarrow CO_2(00^01) + N_2$	-0.206	0.612
$CO_2(01^10) + N_2 \rightarrow CO_2 + N_2$	0.143	0.755
$CO_2(00^01) + N_2 \rightarrow CO_2 + N_2(v1)$	0.119	0.874
$CO_2 + N_2 \rightarrow CO_2(01^10) + N_2$	-0.105	0.769
$CO_2(02^00) + N_2 \rightarrow CO_2(01^10) + N_2$	0.025	0.79

These processes contribute in 71% to the maximum variation in temperature

The role of the reduced electric field "tail"



$$E_{tail} \propto e^{-t/\tau}$$

THANKS FOR YOUR ATTENTION !!!