Monte Carlo Modelling of Hot Particle Coronae

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Monte Carlo Model

Goal

- 3D Monte Carlo model of hot particle coronae of terrestrial planets
- Investigation of the evolution of the hot particle corona (in view of the interaction of the early solar wind with planetary atmospheres/coronae)

Monte Carlo Model

Neutral Atmosphere

CO_2, O, O_2, N_2 …

Ions + Electrons

CO_2^+, O^+, O_2^+, N_2^+, …

Major Source of Suprathermal Atoms in Upper Atmosphere: Dissociative Recombination of Molecular Ions

Assumption:
ions are in ground vibrational level

$O_2^+ + e \rightarrow O(^3P) + O(^3P) + 6.96$ eV	br = 0.22
$O_2^+ + e \rightarrow O(^3P) + O(^1D) + 5.00$ eV	br = 0.42
$O_2^+ + e \rightarrow O(^1D) + O(^1D) + 3.02$ eV	br = 0.31
$O_2^+ + e \rightarrow O(^1D) + O(^1S) + 0.80$ eV	br = 0.05

[Kella et al., 1997]

→ Flux of hot oxygen at the exobase

Oxygen exosphere above exobase

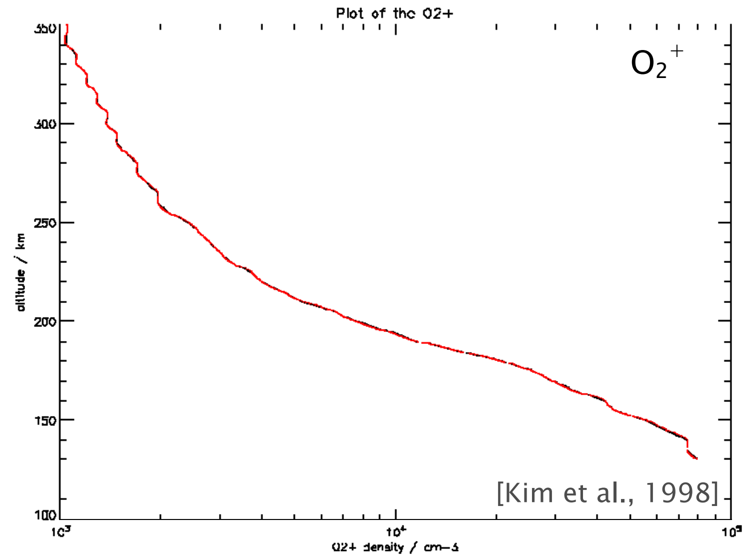
Monte Carlo Model

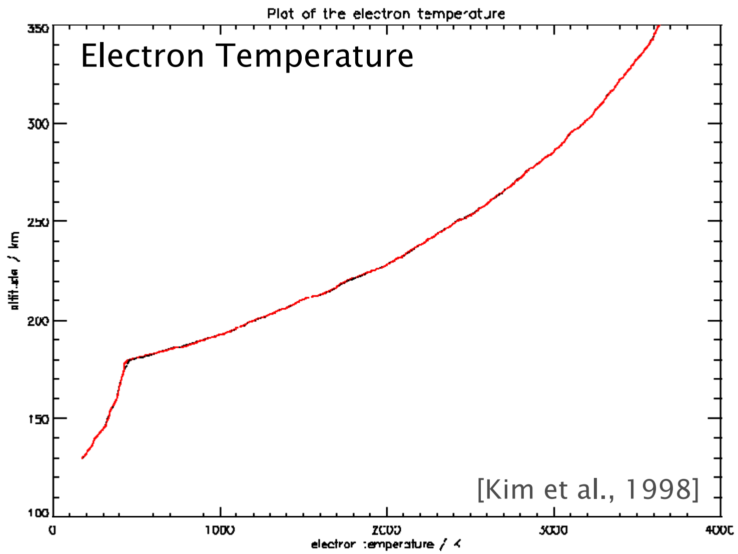
Production Rate of Oxygen

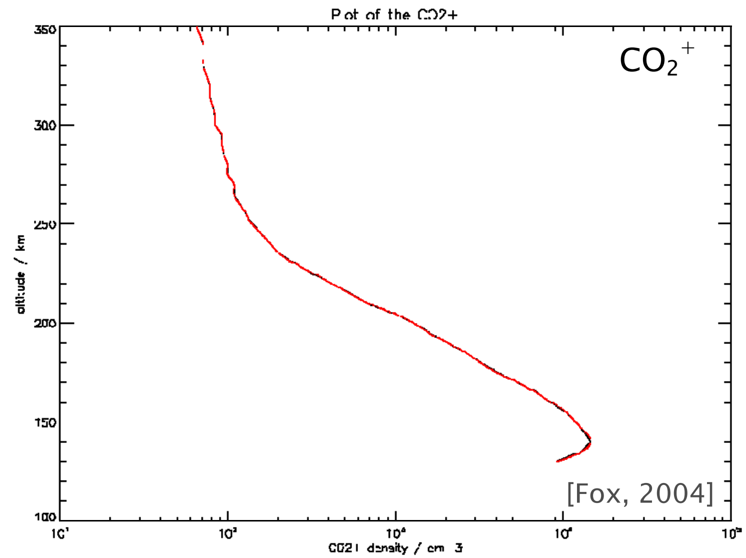
Rate coefficient

[Mehr & Bondi, 1969; Alge et al., 1983]

$$k = \begin{cases} 1.95 \times 10^{-7} \left(\frac{300}{T_e}\right)^{0.7}, & T_e < 1200 \text{ K} \\ 7.38 \times 10^{-8} \left(\frac{1200}{T_e}\right)^{0.56}, & T_e \geq 1200 \text{ K} \end{cases}$$







Monte Carlo Model

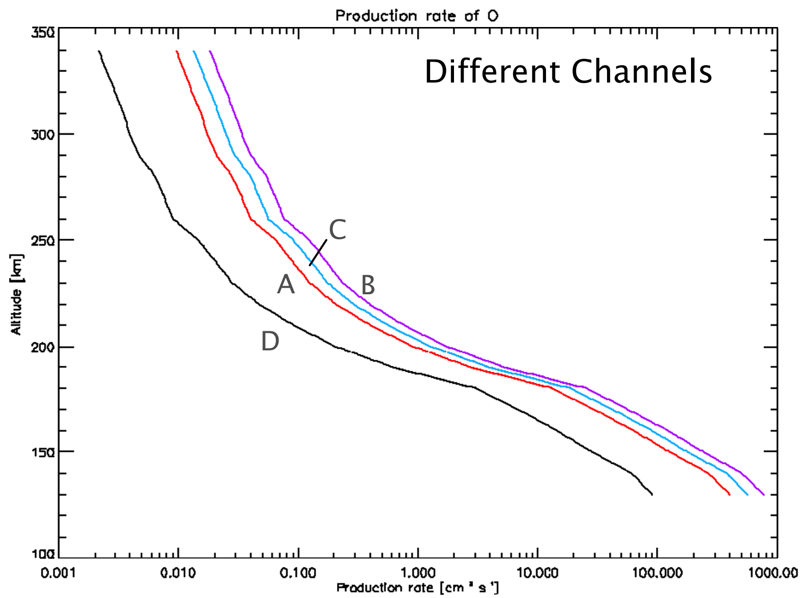
Production Rate of Oxygen

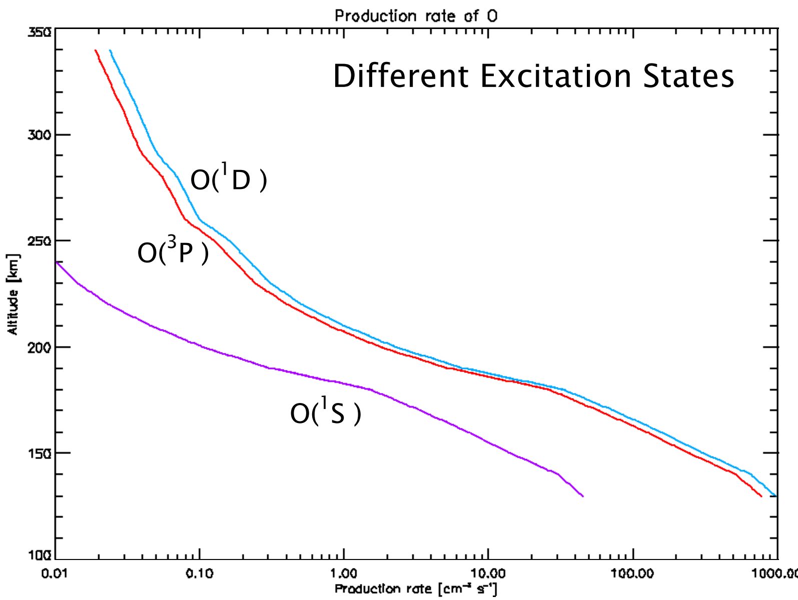
A: $O_2^+ + e \rightarrow O(^3P) + O(^3P) + 6.96$ eV

B: $O_2^+ + e \rightarrow O(^3P) + O(^1D) + 5.00$ eV

C: $O_2^+ + e \rightarrow O(^1D) + O(^1D) + 3.02$ eV

D: $O_2^+ + e \rightarrow O(^1D) + O(^1S) + 0.80$ eV





Monte Carlo Model

Energy Distribution

Velocity/Energy Distributions of Reaction Products

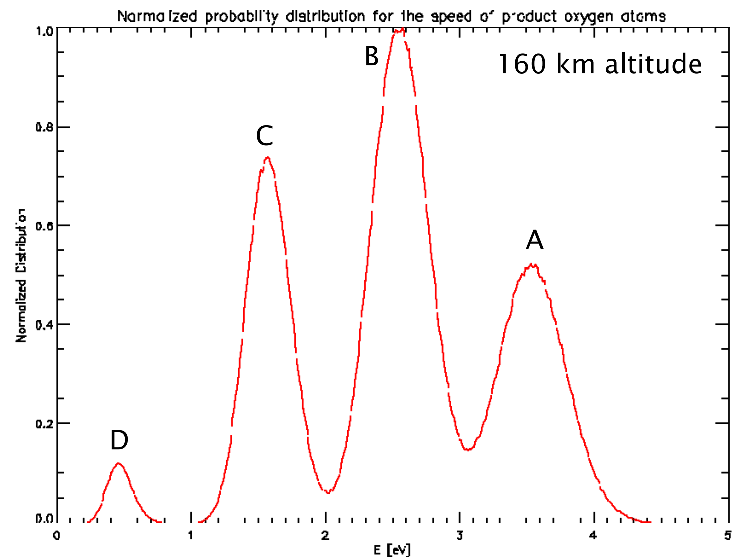
A: $O_2^+ + e \rightarrow O(^3P) + O(^3P) + 6.96$ eV

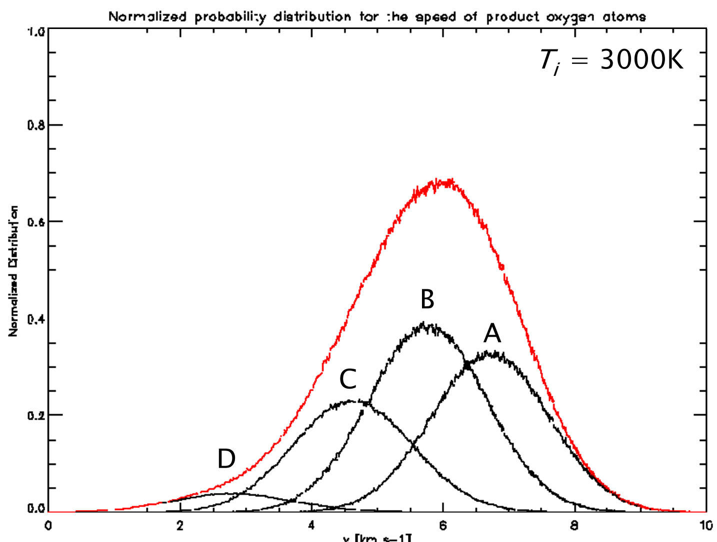
B: $O_2^+ + e \rightarrow O(^3P) + O(^1D) + 5.00$ eV

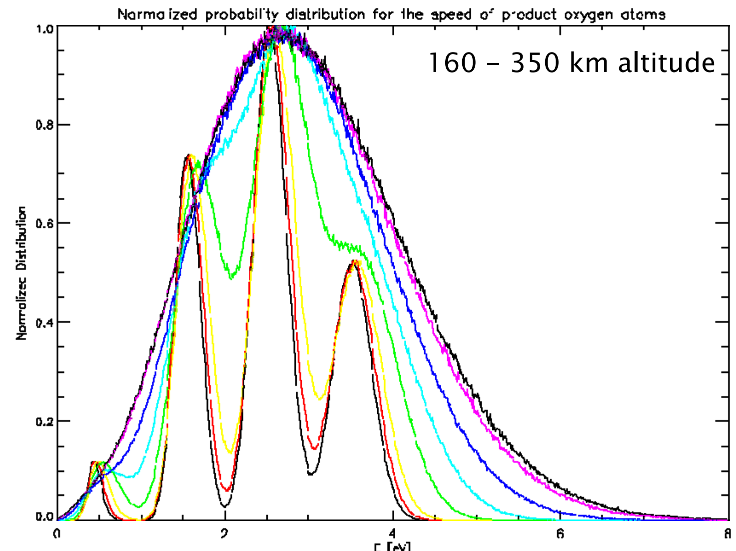
C: $O_2^+ + e \rightarrow O(^1D) + O(^1D) + 3.02$ eV

D: $O_2^+ + e \rightarrow O(^1D) + O(^1S) + 0.80$ eV

Velocity vectors are assumed to be isotropically distributed







Monte Carlo Model

Collisions

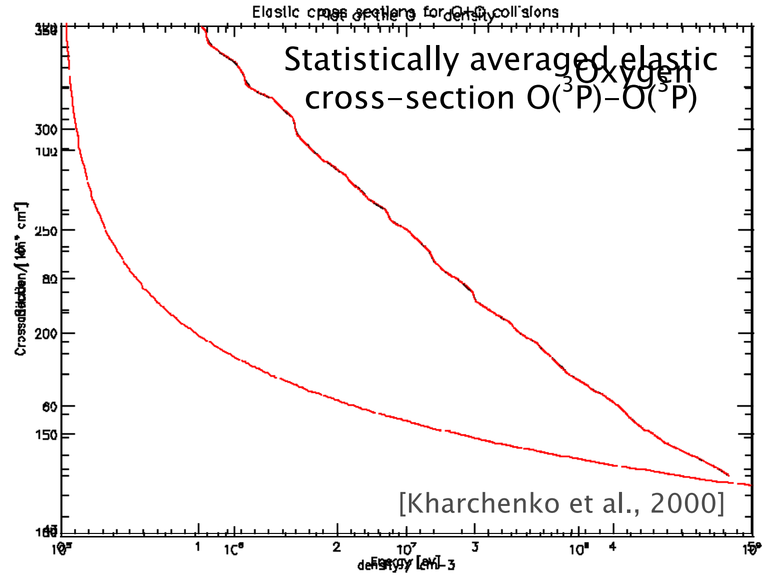
Collision Probability

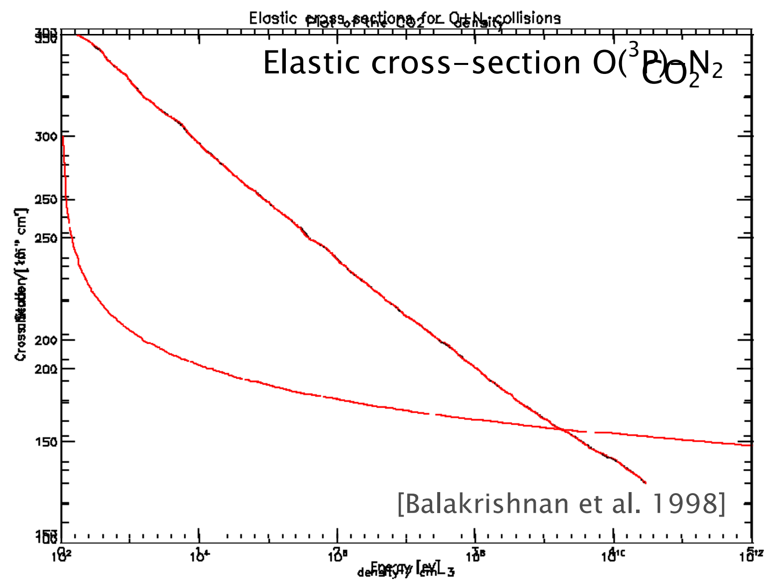
$$C_p = 1 - \exp\left(-\int_{z_1}^{z_2} \frac{dz}{l(z)}\right)$$

$$l(z) = \frac{1}{n(z)\,\sigma(E)}$$

n(z) : density of background gas

σ(z) : collision cross-section





[Kim et al., 1998]

Monte Carlo Model

Collisions

Energy Loss via Collisions

$$O_{th} + O_h(^3P, ^1D) \longrightarrow \begin{cases} O_{h'}(^3P) + O_{h''}(^3P, ^1D) & \text{elastic} \\ O_{h'}(^1D) + O_{h''}(^3P, ^1D) & \text{inelastic} \\ O_{h'}(^3P) + O_{h''}(^3P) + 1.97\text{eV} & \text{quenching} \end{cases}$$

$$CO_2 + O_h(^3P, ^1D, ^1S) \longrightarrow \begin{cases} O_{h'}(^3P, ^1D, ^1S) + CO_2 & \text{elastic} \\ O_{h'}(^3P, ^1D, ^1S) + CO_2^* & \text{inelastic} \\ O_{h'}(^3P) + CO_2 & \text{quenching} \end{cases}$$

Simple collision model

$$E_i = R_E \frac{4m_1 \cdot m_2}{(m_1 + m_2)^2} E_{i-1}$$

R_E: random number representing the collision type and effectiveness of energy transfer between colliding particles.

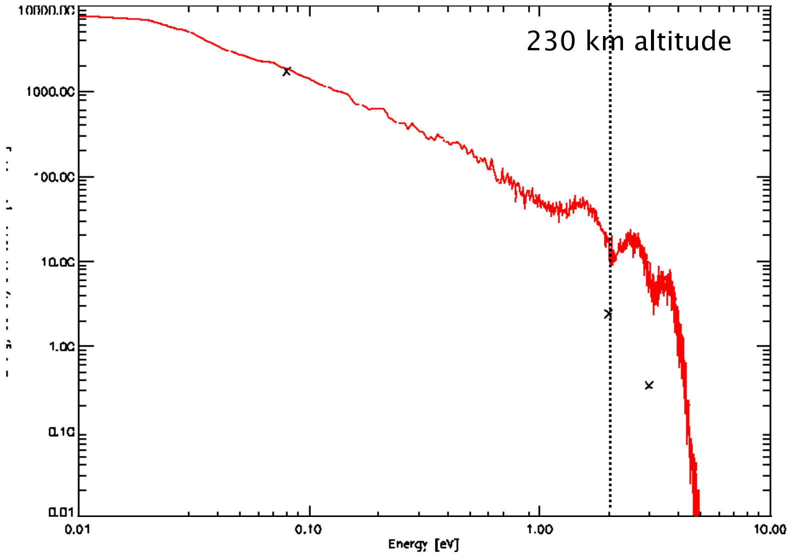
Angular dependence of the scattering cross sections is ignored

Monte Carlo Model

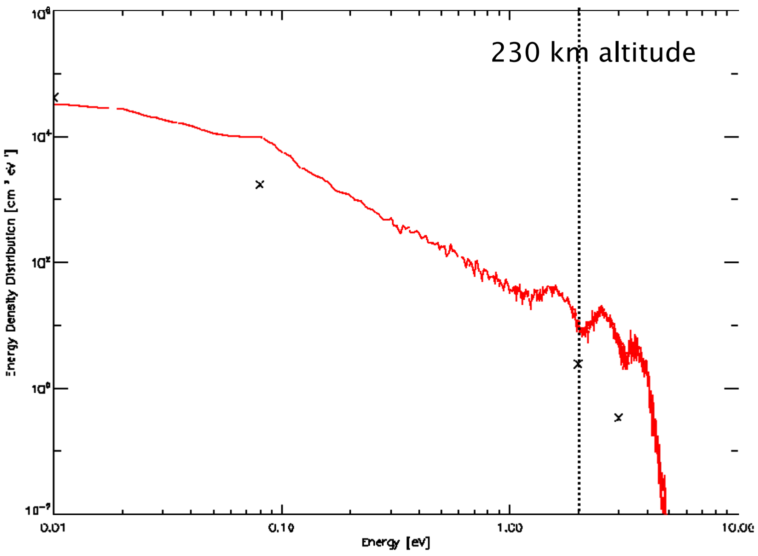
Energy Distributions

Energy Distribution at Exobase

Without secondary atoms



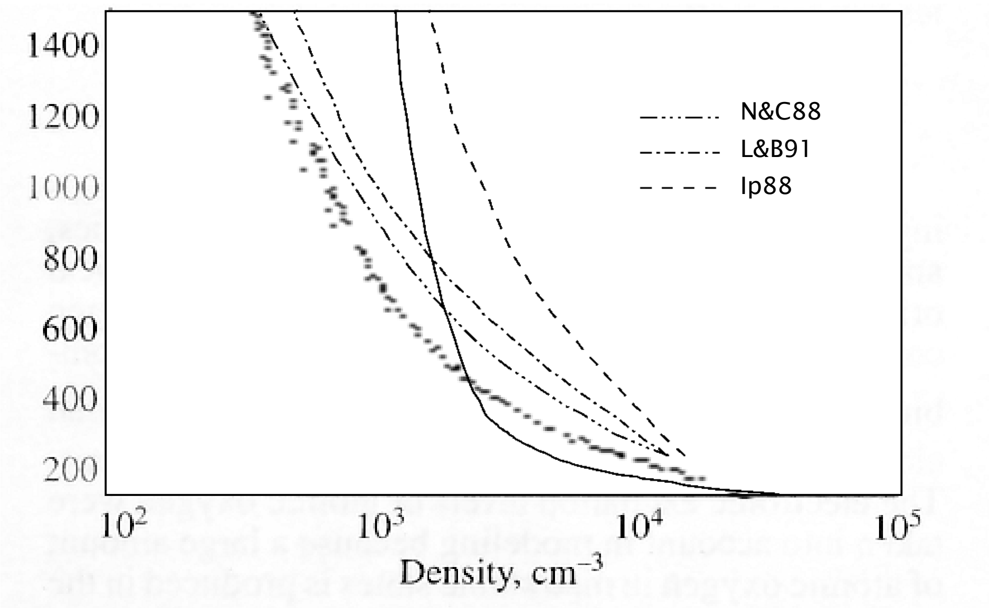
Secondary atoms included



Monte Carlo Model

Exosphere

Exosphere Density



[Krestyanikova & Shematovich, 2006]

- Energy dependent cross sections
- Different energy distribution of DR products
- Different treatment of collisions
- Effect of secondary atoms
- Smaller stepsize for determination of C_p

$$C_p = 1 - \exp\left(-\int_{z_1}^{z_2} \frac{dz}{l(z)}\right)$$

- Effect of 3D modelling

Monte Carlo Model

Number of Collisions

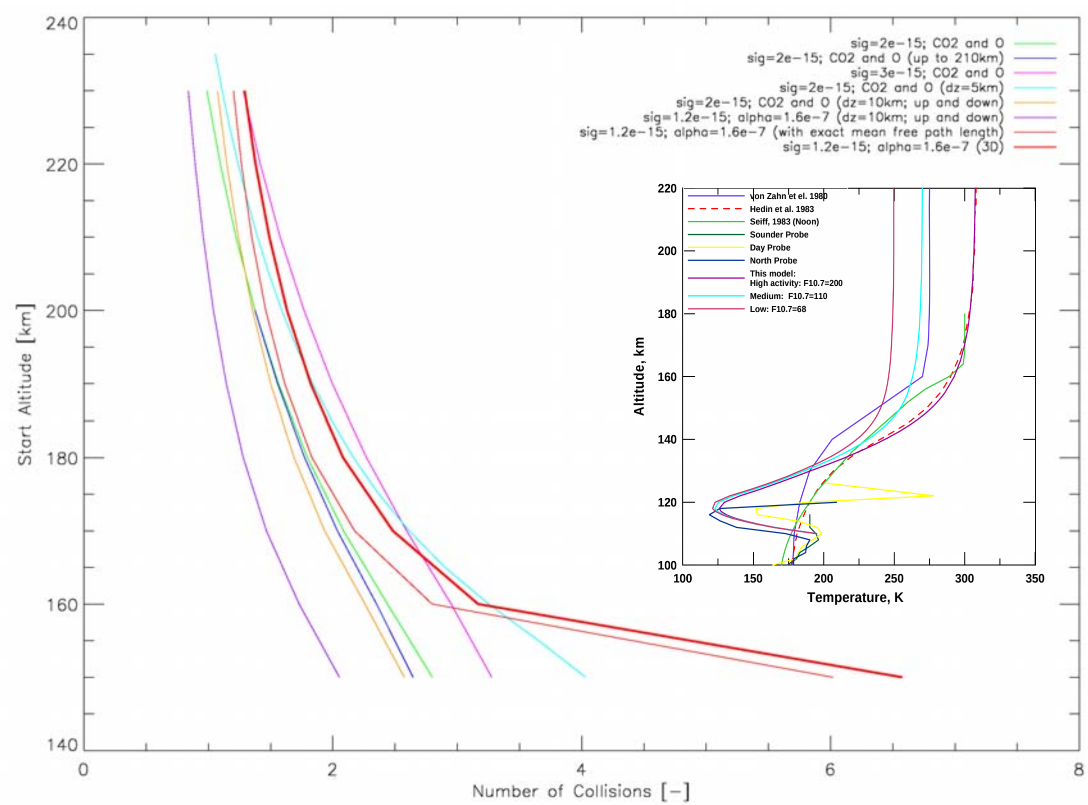


Fig. 2: Number of collisions depending on the simulation as a function of the start altitude of the traced particles. The insert shows the observed and modelled Venus thermosphere temperatures for low, moderate and high solar activity conditions.

Monte Carlo Model

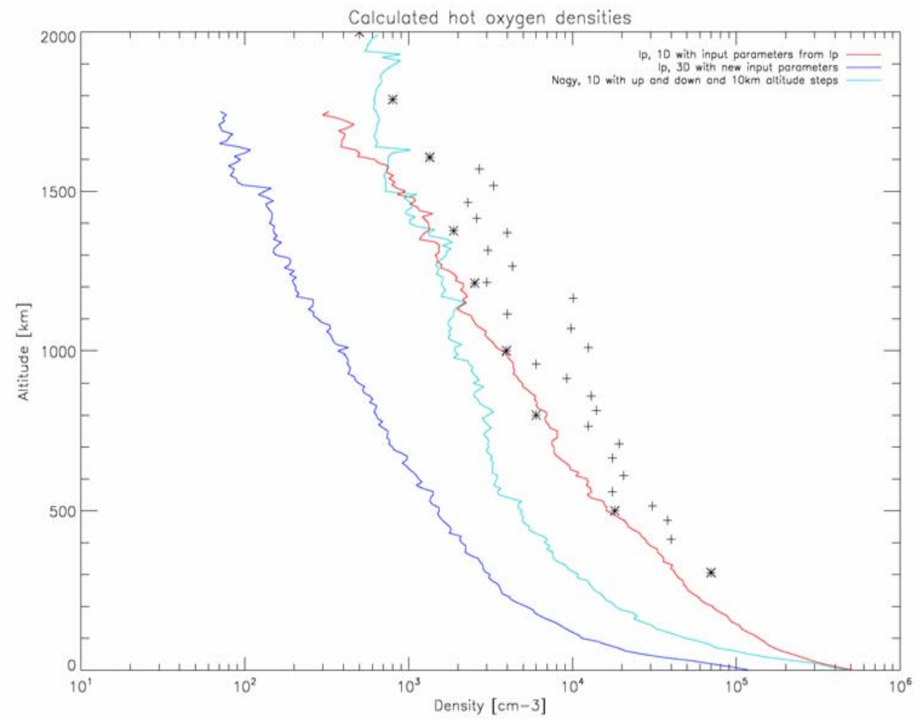


Fig. 3: Calculated hot oxygen density distribution. The (+) shows data points inferred from PVO OUVS airglow observations (Nagy et al., 1981), while the (*) correspond to PVO OUVS observations shown by Nagy et al. (1988). One should note that the figure shows only the hot O atom density. By adding the cold background component the total (cold + hot) O number densities below 400 km would be higher.

Monte Carlo Model

Improvements

- Implementation of correct cross-section for O-CO_2 collisions
- Consideration of angular dependence of the scattering cross sections (determines the rate of momentum transfer between hot particles and cool background gas; elastic scattering of suprathermal O atoms with energies < 5 eV is characterized by a distribution in small scattering angles [Kharchenko et al., 2000])
- Inclusion of quenching collisions (large amount of atomic O in metastable states)

3D-Exosphere at Venus

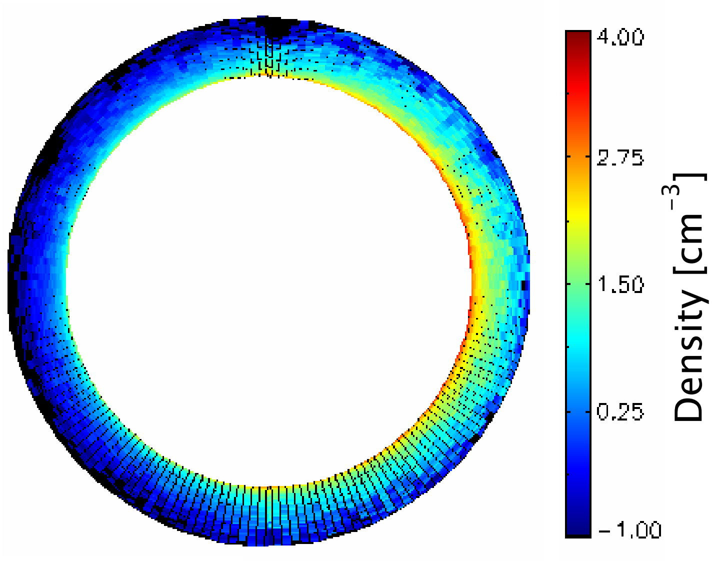


Fig. 5: Day and night exosphere oxygen density distribution of the 3D Monte Carlo simulation for high solar activity from 210 km up to 2000 km.