# Supplementary Materials

## Sets of chemical reactions

**Table S1**. Main chemical reactions in blue jets. The rate coefficients are in units of $s^{-1}$ for uni-molecular, $cm^3 s^{-1}$ for two-body reaction, and $cm^6 s^{-1}$ for three-body reactions. T is the gas temperature in Kelvin. M stands for $N_2$ and $O_2$ molecule.

| No. | Reaction | Rate coefficient | Reference |
|---|---|---|---|
| Electron attachment | | | |
| 1 | $e^- + O_3 \rightarrow O_2^- + O$ | $10^{-9}$ | 3 |
| 2 | $e^- + O_3 \rightarrow O^- + O_2$ | $10^{-11}$ | 3 |
| 3 | $e^- + O_3 + O_2 \rightarrow O_3^- + O_2$ | $10^{-31}$ | 2 |
| 4 | $e^- + NO \xrightarrow{M} NO^-$ | $10^{-30}$ | 3 |
| 5 | $e^- + NO_2 \rightarrow NO_2^-$ | $3 \times 10^{-11}$ | 3 |
| 6 | $e^- + NO_2 \rightarrow O^- + NO$ | $10^{-11}$ | 3 |
| Electron detachment | | | |
| 1 | $O_2^- + O \rightarrow e^- + O_3$ | $1.5 \times 10^{-10}$ | 3 |
| 2 | $O_2^- + N \rightarrow e^- + NO_2$ | $5 \times 10^{-10}$ | 3 |
| 3 | $O^- + O_2(a) \rightarrow e^- + O_3$ | $3 \times 10^{-10}$ | 3 |
| 4 | $O^- + N_2 \rightarrow e^- + N_2O$ | $10^{-12}$ | 2 |
| 5 | $O^- + N \rightarrow e^- + NO$ | $2.6 \times 10^{-10}$ | 3 |
| 6 | $O^- + O_2 \rightarrow e^- + O_3$ | $5 \times 10^{-15}$ | 3 |
| 7 | $O^- + NO \rightarrow e^- + NO_2$ | $2.6 \times 10^{-10}$ | 3 |
| 8 | $O^- + O_3 \rightarrow e^- + O_2 + O_2$ | $5 \times 10^{-10} \times (T/300)^{0.5}$ | 5 |
| 9 | $O_3^- + O \rightarrow e^- + O_2 + O_2$ | $3 \times 10^{-10}$ | 3 |
| 10 | $O_3^- + O_3 \rightarrow e^- + 3O_2$ | $10^{-10}$ | 2 |
| 11 | $NO^- + N_2O \rightarrow e^- + NO + N_2O$ | $5.1 \times 10^{-12}$ | 2 |
| 12 | $NO^- + NO \rightarrow e^- + NO + NO$ | $5 \times 10^{-12}$ | 2 |
| 13 | $NO_2^- + O \rightarrow e^- + NO_3$ | $10^{-12}$ | 3 |

| | Associative and Penning ionization | | |
|---|---|---|---|
| 1 | $N(^2P) + O \rightarrow e^- + NO^+$ | $10^{-11}$ | 2 |
| | Positive ion chemistry | | |
| 1 | $N_2^+ + O \rightarrow NO^+ + N$ | $1.3 \times 10^{-10} \times (T/300)^{-0.5}$ | 3 |
| 2 | $N_2^+ + O_3 \rightarrow O_2^+ + O + N_2$ | $10^{-10}$ | 3 |
| 3 | $N_2^+ + N_2O \rightarrow N_2O^+ + N_2$ | $5 \times 10^{-10}$ | 3 |
| 4 | $N_2^+ + N_2O \rightarrow NO^+ + N + N_2$ | $4 \times 10^{-10}$ | 3 |
| 5 | $N_2^+ + NO \rightarrow NO^+ + N_2$ | $3.3 \times 10^{-10}$ | 3 |
| 6 | $N_3^+ + O_2 \rightarrow NO_2^+ + N_2$ | $4.4 \times 10^{-11}$ | 3 |
| 7 | $N_3^+ + NO \rightarrow N_2O^+ + N_2$ | $7 \times 10^{-11} \times (T/300)^{0.5}$ | 5 |
| 8 | $N_3^+ + NO \rightarrow NO^+ + N + N_2$ | $7 \times 10^{-11}$ | 3 |
| 9 | $N_3^+ + NO \rightarrow N_2O^+ + N_2$ | $7 \times 10^{-11}$ | 3 |
| 10 | $N_4^+ + NO \rightarrow NO^+ + N_2 + N_2$ | $4 \times 10^{-10}$ | 3 |
| 11 | $N^+ + O \xrightarrow{M} NO^+$ | $10^{-29}$ | 3 |
| 12 | $N^+ + O_3 \rightarrow NO^+ + O_2$ | $5 \times 10^{-10}$ | 3 |
| 13 | $N^+ + O_2 \rightarrow NO^+ + O$ | $5 \times 10^{-11} \times (T/300)^{0.5}$ | 5 |
| 14 | $N^+ + O_2 \rightarrow NO^+ + O(^1D)$ | $2 \times 10^{-10} \times (T/300)^{0.5}$ | 5 |
| 15 | $N^+ + O_2 \rightarrow O^+ + NO$ | $2.8 \times 10^{-11}$ | 3 |
| 16 | $N^+ + NO \rightarrow NO^+ + N$ | $8 \times 10^{-10}$ | 3 |
| 17 | $N^+ + NO \rightarrow N_2^+ + O$ | $3 \times 10^{-12}$ | 3 |
| 18 | $N^+ + NO \rightarrow O^+ + N_2$ | $10^{-12}$ | 3 |
| 19 | $N^+ + N_2O \rightarrow NO^+ + N_2$ | $5.5 \times 10^{-10}$ | 3 |
| 20 | $O_2^+ + N_2 \rightarrow NO^+ + NO$ | $4 \times 10^{-21} \times (T/300)^{-2}$ | 6 |
| 21 | $O_2^+ + N \rightarrow NO^+ + O$ | $1.2 \times 10^{-10}$ | 3 |
| 22 | $O_2^+ + NO \rightarrow NO^+ + O_2$ | $4.4 \times 10^{-10}$ | 3 |
| 23 | $O_2^+ + NO_2 \rightarrow NO_2^+ + O_2$ | $6.6 \times 10^{-10}$ | 3 |

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|---|---|---|---|
| 24 | $O_2^+ + NO_2 \rightarrow NO^+ + O_3$ | $10^{-11}$ | 3 |
| 25 | $O_4^+ + O \rightarrow O_2^+ + O_3$ | $3 \times 10^{-10}$ | 3 |
| 26 | $O_4^+ + NO \rightarrow NO^+ + O_2 + O_2$ | $10^{-10}$ | 3 |
| 27 | $O^+ + N \overset{M}{\rightarrow} NO^+$ | $10^{-29}$ | 3 |
| 28 | $O^+ + N_2 \rightarrow NO^+ + N$ | $1.2 \times 10^{-12} \times (T/300)^{-1}$ | 5 |
| 29 | $O^+ + N_2 \overset{M}{\rightarrow} NO^+ + N$ | $6 \times 10^{-29} \times (T/300)^{-2}$ | 3 |
| 30 | $O^+ + NO_2 \rightarrow NO_2^+ + O$ | $1.6 \times 10^{-9}$ | 3 |
| 31 | $O^+ + NO \rightarrow NO^+ + O$ | $2.4 \times 10^{-11}$ | 3 |
| 32 | $O^+ + NO \rightarrow O_2^+ + N$ | $3 \times 10^{-12}$ | 3 |
| 33 | $O^+ + N_2O \rightarrow N_2O^+ + O$ | $4 \times 10^{-10}$ | 3 |
| 34 | $O^+ + N_2O \rightarrow NO^+ + NO$ | $2.3 \times 10^{-10}$ | 3 |
| 35 | $O^+ + N_2O \rightarrow O_2^+ + N_2$ | $2 \times 10^{-11}$ | 3 |
| 36 | $O^+ + O_3 \rightarrow O_2^+ + O_2$ | $10^{-10}$ | 3 |
| 37 | $NO_2^+ + NO \rightarrow NO^+ + NO_2$ | $2.9 \times 10^{-10}$ | 3 |
| 38 | $N_2O^+ + NO \rightarrow NO^+ + N_2O$ | $2.9 \times 10^{-10}$ | 3 |
| 39 | $NO^+ + O_3 \rightarrow NO_2^+ + O_2$ | $10^{-15}$ | 3 |
| 40 | $NO^+ + N_2O_5 \rightarrow NO_2^+ + 2NO_2$ | $5.9 \times 10^{-10}$ | 3 |
| 41 | $NO^+(N_2) \overset{M}{\rightarrow} NO^+ + N_2$ | $1.5 \times 10^{-8} \times (T/300)^{-5.3} \times \exp(-2093/T)$ | 6 |
| 42 | $NO^+(N_2) + O_2 \rightarrow NO^+ + N_2$ | $10^{-9}$ | 6 |
| 43 | $NO^+(O_2) + N_2 \rightarrow NO^+ + O_2$ | $10^{-9}$ | 6 |
| | Negative ion chemistry | | |
| 1 | $e^- + O_3 \rightarrow e^- + O_2 + O$ | $10^{-8}$ | 2 |
| 2 | $O^- + O_2 \rightarrow O_3^- + O$ | $5.3 \times 10^{-10}$ | 3 |
| 3 | $O^- + O_2 \overset{M}{\rightarrow} O_3^-$ | $1.1 \times 10^{-30} \times (T/300)^{-1}$ | 3 |
| 4 | $O_2^- + O_3 \rightarrow O_3^- + O_2$ | $4 \times 10^{-10}$ | 3 |
| 5 | $O_3^- + O \rightarrow O_2^- + O_2$ | $3.2 \times 10^{-10}$ | 3 |

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|---|---|---|---|
| 6 | $O_4^- + O \rightarrow O_3^- + O_2$ | $4 \times 10^{-10}$ | 3 |
| 7 | $O^- + NO \xrightarrow{M} NO_2^-$ | $10^{-29}$ | 3 |
| 8 | $O^- + NO_2 \rightarrow NO_2^- + O$ | $1.2 \times 10^{-9}$ | 3 |
| 9 | $O^- + N_2O \rightarrow NO^- + NO$ | $2 \times 10^{-10}$ | 3 |
| 10 | $O_2^- + NO_2 \rightarrow NO_2^- + O_2$ | $8 \times 10^{-10}$ | 3 |
| 11 | $O_3^- + NO \rightarrow NO_2^- + O_2$ | $2.6 \times 10^{-12}$ | 3 |
| 12 | $O_3^- + NO \rightarrow NO_3^- + O$ | $10^{-11}$ | 3 |
| 13 | $O_3^- + NO_2 \rightarrow NO_2^- + O_3$ | $7 \times 10^{-10}$ | 3 |
| 14 | $O_3^- + NO_2 \rightarrow NO_3^- + O_2$ | $2 \times 10^{-11}$ | 3 |
| 15 | $O_3^- + NO_3 \rightarrow NO_3^- + O_3$ | $5 \times 10^{-10}$ | 3 |
| 16 | $NO^- + O_2 \rightarrow O_2^- + NO$ | $5 \times 10^{-10}$ | 3 |
| 17 | $NO^- + NO_2 \rightarrow NO_2^- + NO$ | $7.4 \times 10^{-16}$ | 3 |
| 18 | $NO^- + N_2O \rightarrow NO_2^- + N_2$ | $2.8 \times 10^{-14}$ | 3 |
| 19 | $NO_2^- + O_3 \rightarrow NO_3^- + O_2$ | $1.8 \times 10^{-11}$ | 3 |
| 20 | $NO_2^- + NO_2 \rightarrow NO_3^- + NO$ | $4 \times 10^{-12}$ | 3 |
| 21 | $NO_2^- + NO_3 \rightarrow NO_3^- + NO_2$ | $5 \times 10^{-10}$ | 3 |
| 22 | $NO_3^- + NO \rightarrow NO_2^- + NO_2$ | $3 \times 10^{-15}$ | 3 |
| Electron-ion recombination | | | |
| 1 | $e^- + NO^+ \xrightarrow{M} NO$ | $6 \times 10^{-27} \times (T/300)^{-1.5}$ | 3 |
| 2 | $e^- + NO^+ \rightarrow N + O$ | $4 \times 10^{-7} \times (T/300)^{-1.5}$ | 3 |
| 3 | $e^- + NO^+ \rightarrow N(^2D) + O$ | $3 \times 10^{-7} \times (T/300)^{-1}$ | 3 |
| 4 | $e^- + NO^+(N_2) \rightarrow NO + N_2$ | $1.3 \times 10^{-6} \times (T/300)^{-0.5}$ | 3 |
| 5 | $e^- + NO^+(O_2) \rightarrow NO + O_2$ | $1.3 \times 10^{-6} \times (T/300)^{-0.5}$ | 3 |
| 6 | $e^- + NO_2^+ \rightarrow NO + O$ | $2 \times 10^{-7} \times (T/300)^{-0.5}$ | 3 |
| 7 | $e^- + N_2O^+ \rightarrow O + N_2$ | $1.3 \times 10^{-6} \times (T/300)^{-0.5}$ | 3 |
| Neutral chemistry | | | |

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|---|---|---|---|
| 1 | $N + O_2 \rightarrow NO + O$ | $1.5 \times 10^{-11} \times \exp(-3600/T)$ | 4 |
| 2 | $N + O_3 \rightarrow NO + O_2$ | $10^{-16}$ | 4 |
| 3 | $N + NO \rightarrow N_2 + O$ | $2.1 \times 10^{-11} \times \exp(-100/T)$ | 4 |
| 4 | $N + NO_2 \rightarrow N_2O + O$ | $3 \times 10^{-12}$ | 3 |
| 5 | $N + NO_2 \rightarrow NO + NO$ | $2.3 \times 10^{-12}$ | 3 |
| 6 | $N + NO_2 \rightarrow N_2 + 2O$ | $9.1 \times 10^{-13}$ | 3 |
| 7 | $N + NO_2 \rightarrow N_2 + O_2$ | $7 \times 10^{-13}$ | 3 |
| 8 | $N + O \overset{M}{\rightarrow} NO$ | $1.76 \times 10^{-31} \times T^{-0.5}$ | 3 |
| 9 | $O + O_3 \rightarrow O_2 + O_2$ | $8 \times 10^{-12} \times \exp(-2060/T)$ | 4 |
| 10 | $O + NO_2 \rightarrow NO + O_2$ | $5.1 \times 10^{-12} \times \exp(210/T)$ | 4 |
| 11 | $O + NO_3 \rightarrow NO_2 + O_2$ | $10^{-11}$ | 4 |
| 12 | $O + O_2 \overset{M}{\rightarrow} O_3$ | $6 \times 10^{-34} \times (T/300)^{-2.4}$ | 4 |
| 13 | $O + NO \overset{M}{\rightarrow} NO_2$ | $9 \times 10^{-32} \times (T/300)^{-1.5}$ | 4 |
| 14 | $O + O_3 + O_2 \rightarrow O_3 + O_3 + O_2$ | $1.5 \times 10^{-34} \times \exp(750/T)$ | 2 |
| 15 | $O + O + O_2 \rightarrow O_2 + O_3 + O$ | $2.15 \times 10^{-34} \times \exp(345/T)$ | 2 |
| 16 | $O + NO_2 \overset{M}{\rightarrow} NO_3$ | $2.5 \times 10^{-31} \times (T/300)^{-1.8}$ | 4 |
| 17 | $O + NO \rightarrow NO_2$ | $3.02 \times 10^{-11} \times (T/300)^{-0.75}$ | 2 |
| 18 | $NO + NO_3 \rightarrow NO_2 + NO_2$ | $1.5 \times 10^{-11} \times \exp(170/T)$ | 4 |
| 19 | $NO + O_3 \rightarrow NO_2 + O_2$ | $3 \times 10^{-12} \times \exp(-1500/T)$ | 4 |
| 20 | $NO_2 + O_3 \rightarrow NO_3 + O_2$ | $1.2 \times 10^{-13} \times \exp(-2450/T)$ | 4 |
| 21 | $NO_2 + NO_3 \rightarrow NO + NO_2 + O_2$ | $2.3 \times 10^{-13} \times \exp(-1600/T)$ | 9 |
| 22 | $NO_2 + NO_3 \overset{M}{\rightarrow} N_2O_5$ | $2.4 \times 10^{-30} \times (T/300)^{-3}$ | 4 |
| 23 | $NO_3 + NO_3 \rightarrow NO_2 + NO_2 + O_2$ | $8.5 \times 10^{-13} \times \exp(-2450/T)$ | 4 |
| 24 | $N(^2D) + O_2 \rightarrow NO + O$ | $1.5 \times 10^{-12} \times (T/300)^{0.5}$ | 3 |
| 25 | $N(^2D) + O_2 \rightarrow NO + O(^1D)$ | $6 \times 10^{-12} \times (T/300)^{0.5}$ | 3 |
| 26 | $N(^2D) + N_2O \rightarrow NO + N_2$ | $3.5 \times 10^{-12}$ | 2 |

| 27 | $N(^2D) + NO \rightarrow N_2 + O$ | $1.8 \times 10^{-10}$ | 2 |
|---|---|---|---|
| 28 | $N(^2D) + NO \rightarrow N_2O$ | $6 \times 10^{-11}$ | 3 |
| 29 | $N(^2P) + O_2 \rightarrow NO + O$ | $2.6 \times 10^{-12}$ | 3 |
| 30 | $N(^2P) + NO \rightarrow O + N_2$ | $3 \times 10^{-11}$ | 2 |
| 31 | $O(^1D) + O_3 \rightarrow 2O + O_2$ | $2.4 \times 10^{-10}$ | 4 |
| 32 | $O(^1D) + O_3 \rightarrow O_2 + O_2$ | $2.4 \times 10^{-10}$ | 4 |
| 33 | $O(^1D) + O_3 \rightarrow O + O_3$ | $2.4 \times 10^{-10}$ | 4 |
| 34 | $O(^1D) + N_2O \rightarrow NO + NO$ | $1.19 \times 10^{-10} \times \exp(20/T)$ | 4 |
| 35 | $O(^1D) + N_2O \rightarrow N_2 + O_2$ | $1.19 \times 10^{-10} \times \exp(20/T)$ | 4 |
| 36 | $O(^1D) + N_2O \rightarrow O + N_2O$ | $1.19 \times 10^{-10} \times \exp(20/T)$ | 4 |
| 37 | $O(^1D) + NO \rightarrow N + O_2$ | $1.7 \times 10^{-10}$ | 3 |
| 38 | $O(^1D) + NO_2 \rightarrow NO + O_2$ | $3 \times 10^{-10}$ | 2 |
| 39 | $O(^1S) + O_3 \rightarrow O(^1D) + O + O_2$ | $2.9 \times 10^{-10}$ | 3 |
| 40 | $O(^1S) + O_3 \rightarrow O_2 + O_2$ | $2.9 \times 10^{-10}$ | 3 |
| 41 | $O(^1S) + NO \rightarrow NO + O$ | $1.8 \times 10^{-10}$ | 3 |
| 42 | $O(^1S) + NO \rightarrow O(^1D) + NO$ | $3.2 \times 10^{-10}$ | 3 |
| 43 | $O(^1S) + N_2O \rightarrow N_2O + O$ | $6.3 \times 10^{-12}$ | 3 |
| 44 | $O(^1S) + N_2O \rightarrow O(^1D) + N_2O$ | $3.1 \times 10^{-12}$ | 3 |
| 45 | $O_2(a) + N \rightarrow O + NO$ | $2 \times 10^{-14} \times \exp(-600/T)$ | 3 |
| 46 | $O_2(a) + NO \rightarrow O + NO_2$ | $4.88 \times 10^{-18}$ | 2 |
| 47 | $O_2(a) + NO \rightarrow NO + O_2$ | $2.48 \times 10^{-17}$ | 7 |
| 48 | $O_2(a) + O_3 \rightarrow O(^1D) + O_2 + O_2$ | $5.2 \times 10^{-11} \times \exp(-2840/T)$ | 5 |
| 49 | $O_2(a) + O_3 \rightarrow O + O_2 + O_2$ | $5.2 \times 10^{-11} \times \exp(-2840/T)$ | 4 |
| 50 | $O_2(a) + O_2(a) + O_2 \rightarrow O_3 + O_3 + O_2$ | $10^{-31} \times (T/300)^{0.5}$ | 5 |
| 51 | $O_2(b) + O_3 \rightarrow 2O_2(a) + O$ | $3.5 \times 10^{-11} \times \exp(-135/T)$ | 4 |
| 52 | $O_2(b) + NO \rightarrow O_2(a) + NO$ | $4 \times 10^{-14}$ | 3 |

| | | | |
|---|---|---|---|
| 53 | $N_2(A) + O_2 \rightarrow N_2O + O$ | $7.8 \times 10^{-14}$ | 3 |
| 54 | $N_2(A) + O \rightarrow N(^2D) + NO$ | $7 \times 10^{-12}$ | 3 |
| 55 | $N_2(A) + NO \rightarrow N_2 + NO$ | $7 \times 10^{-11}$ | 3 |
| 56 | $N_2(A) + N_2O \rightarrow N_2 + N + NO$ | $10^{-11}$ | 3 |
| 57 | $N_2(B) + NO \rightarrow N_2(A) + NO$ | $2.4 \times 10^{-10}$ | 3 |
| 58 | $N_2(a'^1) + NO \rightarrow N_2 + N + O$ | $3.6 \times 10^{-10}$ | 3 |
| 59 | $N_2(a^1) + NO \rightarrow N_2 + N + O$ | $3.6 \times 10^{-10}$ | 2 |
| 60 | $O_3 \overset{hv}{\rightarrow} O_2 + O$ | $f(hv)$ | 1 |
| 61 | $O_3 \overset{hv}{\rightarrow} O_2 + O(^1D)$ | $f(hv)$ | 1 |
| 62 | $NO \overset{hv}{\rightarrow} N + O$ | $f(hv)$ | 1 |
| 63 | $NO_2 \overset{hv}{\rightarrow} NO + O$ | $f(hv)$ | 1 |
| 64 | $NO_3 \overset{hv}{\rightarrow} NO_2 + O$ | $f(hv)$ | 1 |
| 65 | $N_2O \overset{hv}{\rightarrow} O(^1D) + N_2$ | $f(hv)$ | 1 |
| Ion-ion recombination | | | |
| 1 | $A^- + (BC)^+ \rightarrow A + B + C$ | $10^{-7}$ | 3 |
| | $A^- = [O_3^-, NO^-, NO_2^-]$ and $(BC)^+ = [NO^+, NO_2^+, N_2O^+]$ | | |
| 2 | $O_3^- + A^+ \rightarrow 2O_2 + A$ | $10^{-7}$ | 3 |
| | $A^+ = [NO^+, NO_2^+, N_2O^+]$ | | |
| 3 | $A^- + B^+ \rightarrow A + B$ | $2 \times 10^{-7} \times (T/300)^{-0.5}$ | 3 |
| | $A^- = [O_3^-, NO^-, NO_2^-]$ and $B^+ = [NO_2^+, N_2O^+]$ | | |

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