Perturbation of the Mars Atmosphere by Comet C/2013 A1

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Comet C/2013 A1 (Siding Spring) will have a close encounter with Mars on October 19, 2014. Traveling on a highly inclined, 129 degree, hyperbolic orbit, this comet will encounter Mars with a relative velocity of about 56 $\mathrm{km\,s^{-1}}$ and a close approach distance between 116,000 and 169,000 km [JPL Small-Body Database]. The extended coma will impinge upon the upper atmosphere of Mars for about one hour. The flux of mass and energy incident upon the atmosphere will be considerable if the comet is active. This provides the opportunity to study the upper atmosphere of Mars at a unique time that could provide insight into physical processes that are difficult to investigate in normal circumstances. The physical consequences of the transit of a planet through a cometary coma have not previously been studied. Moreover, the near-collision with Siding Spring may affect the atmosphere so that the set of spacecraft currently investigating Mars may view a perturbed rather than normal atmosphere.

The thermosphere of Mars is rich in O and it is unlikely that the contributions from the comet could significantly alter the O inventory. The H abundance in the unperturbed atmosphere is much smaller and the cometary contribution can be significant. Temperatures can also be strongly affected because of the large kinetic energy of the impacting molecules. The flux of mass and energy into the martian atmosphere depends on the H_2O production rate, which vary from 10^{26} to 10^{30} molecules $\mathrm{s^{-1}}$ at 1.4 AU. Rates below 10^{27} $\mathrm{s^{-1}}$ have little effect on the Martian atmosphere and for rates larger than 10^{29} $\mathrm{s^{-1}}$ the perturbation to the atmosphere is so extreme that the models used here are probably no longer valid.

We adopt a simple model for the spherical expansion of the coma to estimate the fluxes incident upon the atmosphere. With this model the fluxes of H and energy into the atmosphere are

$$F_H = \frac{PV}{\pi r^2 U}, \qquad F_E = \frac{m_{H_2O} P V^3}{2\pi r^2 U}.$$

A production rate of $P = 10^{28}$ $\mathrm{s^{-1}}$, $U = 1\ \mathrm{km\,s^{-1}}$, $r = 130,000$ km and $V = 56\ \mathrm{km\,s^{-1}}$ gives values at the closest approach of $N = 47$ $\mathrm{cm^{-3}}$, $F_H = 5.2 \times 10^8$ $\mathrm{cm^{-2}\,s^{-1}}$, and $F_E = 1.2 \times 10^{-1}$ $\mathrm{erg\,cm^{-2}\,s^{-1}}$. The time-integrated values for the H and energy input are $3.7{\times}10^{12}$ $\mathrm{cm^{-2}}$ and $8.7{\times}10^2$ $\mathrm{erg\,cm^{-2}}$.

Calculations are based on the aeronomical model described in Yelle (2014) Figure 1 shows the comet's energy flux at Mars and the resulting thermal evolution of the atmosphere for a comet production rate of 10^{28} $\mathrm{s^{-1}}$. Peak temperatures occur 25 minutes after closest approach and are elevated by about 32 K relative to the unperturbed atmosphere. The heating drops rapidly after the comet passes Mars with a time constant of roughly one hour; however, the atmosphere's response lags considerably taking about 2.2 hours to decrease by a factor of e.

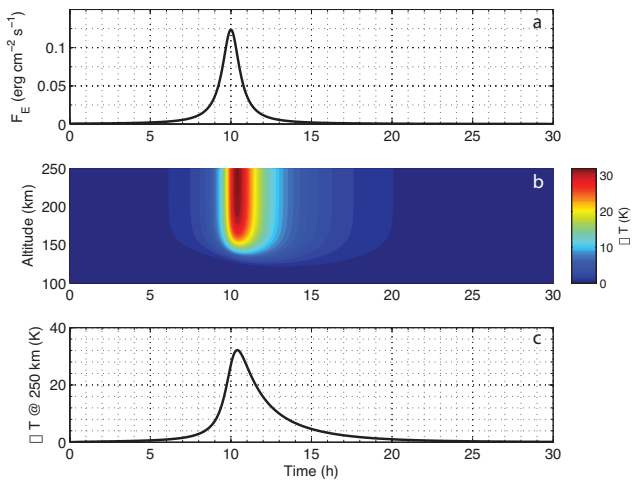

Figure 1: Calculations of the time evolution of atmospheric temperature for an H_2O production rate 10^{28} s^{-1} a) The incident energy flux from the comet as a function of time. b) The temperature perturbation induced by the cometary input as a function of altitude and time. c) The temperature perturbation at an altitude of 250 km as a function of time.

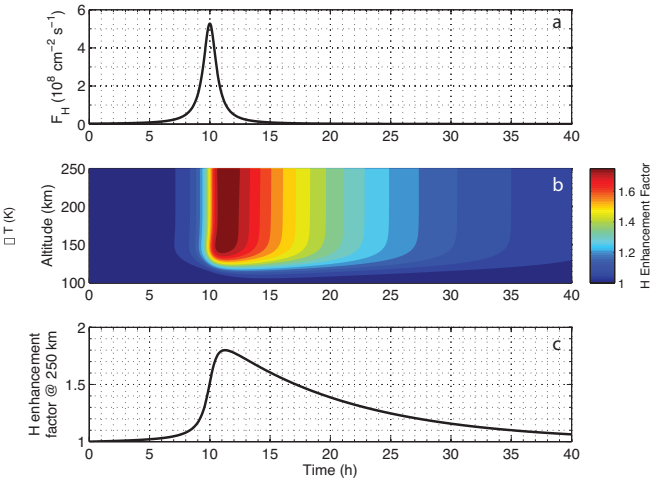

Figure 2: Calculations of the time evolution of H density for an H_2O production rate 10^{28} s^{-1} a) The incident H flux from the comet as a function of time. b) The ratio of H density in the perturbed atmosphere to the steady-state atmospheric model induced as a function of altitude and time. c) The ratio of H densities in the perturbed and unperturbed atmosphere at an altitude of 250 km as a function of time.

Heating due to the comet is confined to altitudes above ∼150 km and is balanced primarily by thermal conduction, which transports the energy downward to ∼130 km where it is radiated away by CO_2. The temperature profile is essentially isothermal above 160 km because of the efficiency with which thermal conduction redistributes energy. Temperatures are unperturbed below 130 km because the energy from the comet never reaches those levels.

Figure 2 shows the evolution of H density in the upper atmosphere. The maximum enhancement in H densities is a factor of 1.8 at 77 minutes after closest approach. The density perturbation decays away with an e-folding time of 11.8 hours. During the encounter, H flows primarily upward. At the time of the peak H density perturbation the maximum upward and downward fluxes are 1.2×10^8 $cm^{-2}\,s^{-1}$ and 4.0×10^7 $cm^{-2}\,s^{-1}$, respectively. However, it is more difficult to diffuse downward, through higher density, and the downward fluxes persist for a longer time. Integrated over time the net enhancement in the H escape rate due to cometary input is estimated to be 5×10^{29} atoms while 7×10^{29} atoms flow to the lower atmosphere.

References

Yelle, R. V., and A. Mahieux and S. Morrisson and V. Vuitton and S. Horst 2014. Perturbation of the Mars Atmosphere by the Near-Collision with Comet C/2013 A1 (Siding Spring). *Icarus in press.*