Cometary sputtering on Mars: Comet C/2013 A1 (Siding Spring) encounter

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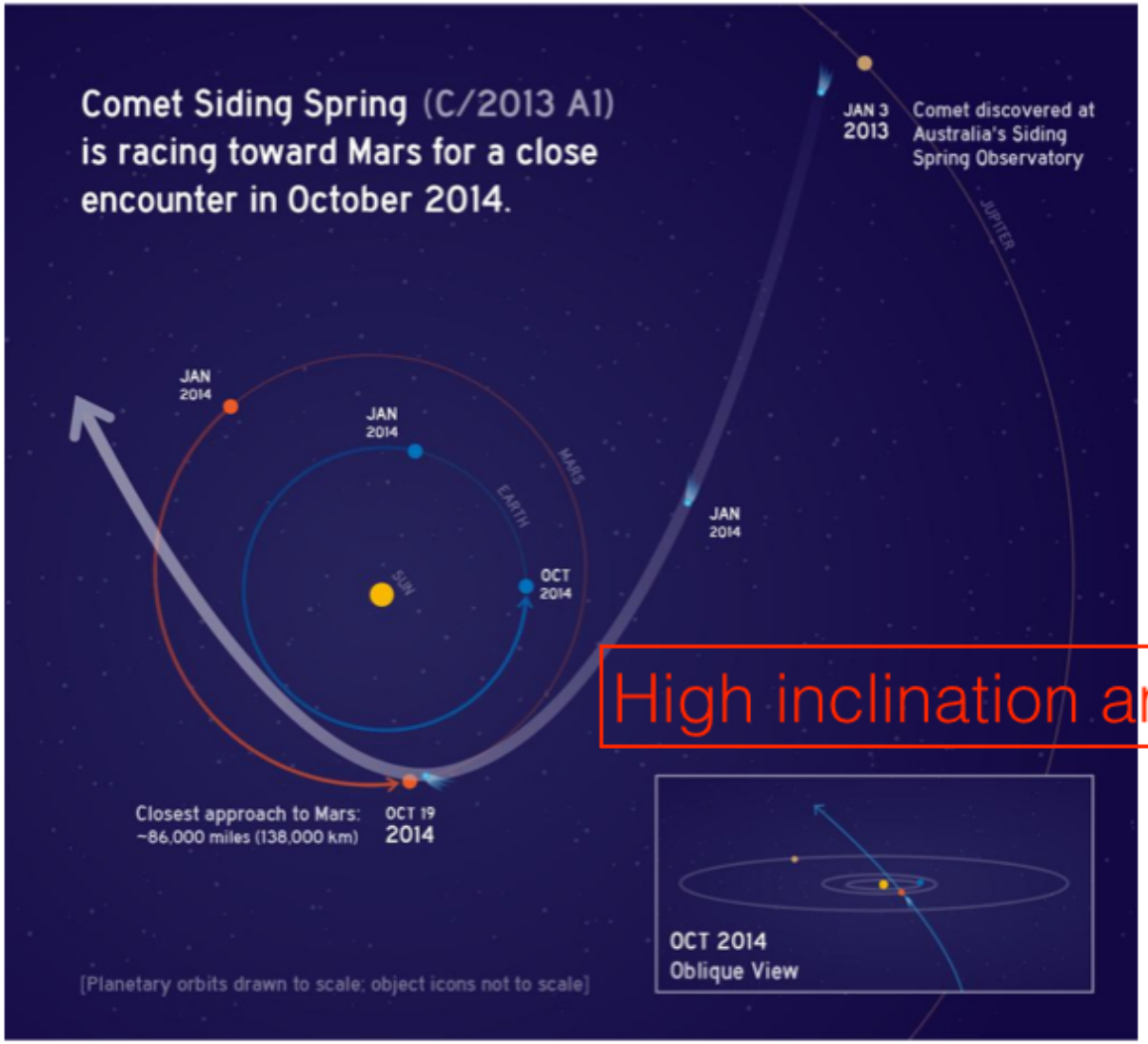
Siding Spring encounter

- Comet Siding Spring will encounter Mars on October 19, 2014.
- The velocity respect Mars is about 56 km/s and the close approach (CA) distance is between 116,000 and 169,000 km.
- The sub-comet location at CA is (latitude, west longitude) = (-8.6, 22.4), corresponding to solar local time of 5:30AM.
- Interaction duration is about one hour.

(From R. Yelle, et al., 2014)

Siding Spring orbit



High inclination angle ~ 129°

http://mars.nasa.gov/comets/sidingspring/

Assumptions of the extended coma

- Assume the cometary density near Mars as

$$n(r) = \frac{Q_c}{4\pi r^2 V_c}$$

- where Q_c is the H_2O production rates (10^{28} s^{-1}), r is the cometary distance (130,000 km), and V_c is the ejection velocity of H_2O (1 km/s).

- Two cases on the ionization of the coma:

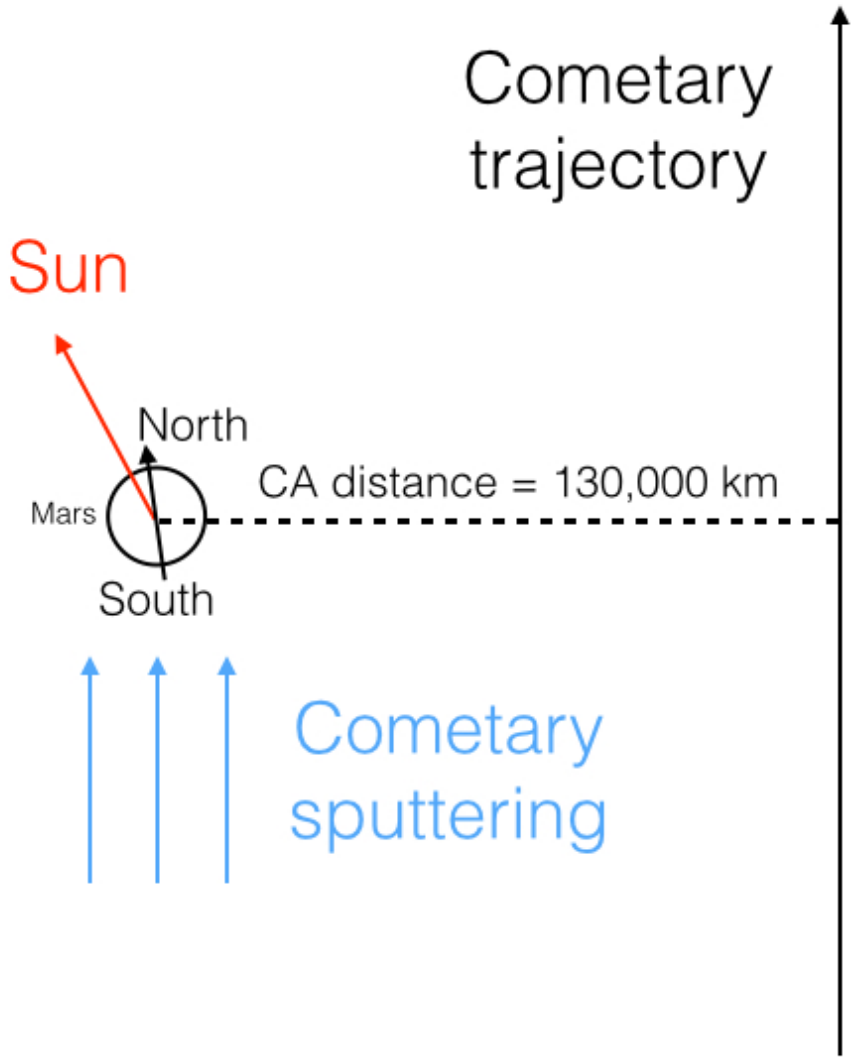
    1. No ionization near Mars. All cometary ejecta are not influenced by the electromagnetic fields near Mars, and incident to the upper atmosphere of Mars with velocity of 56 km/s. H_2O are replaced by incident O when the influences from the two attached H on the sputtering is negligible.

    2. Completely ionized near Mars (outer region of the coma). Impact rates of the cometary pickup O^+ (ionized from H_2O) are calculated with different solar wind (SW) conditions (provided by A. Rahmati at U. of Kansas).

Sputtering from neutral coma
- Time variation simulation -

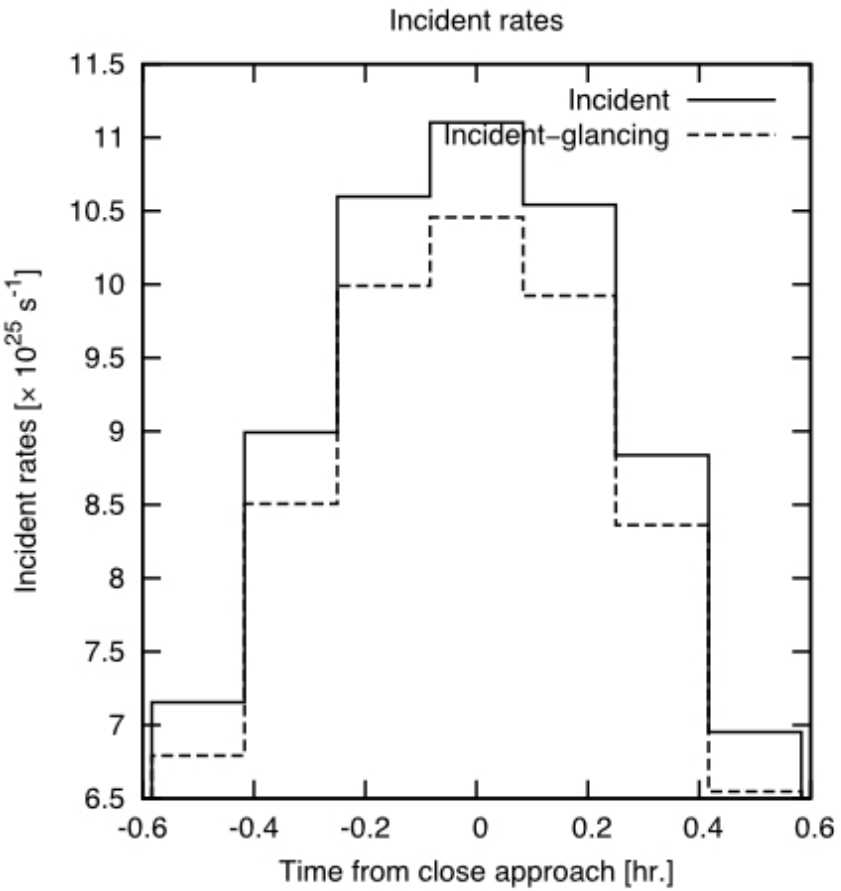
Assumption: No ionization for the neutral coma. All cometary ejecta are neutral H_2O (O).

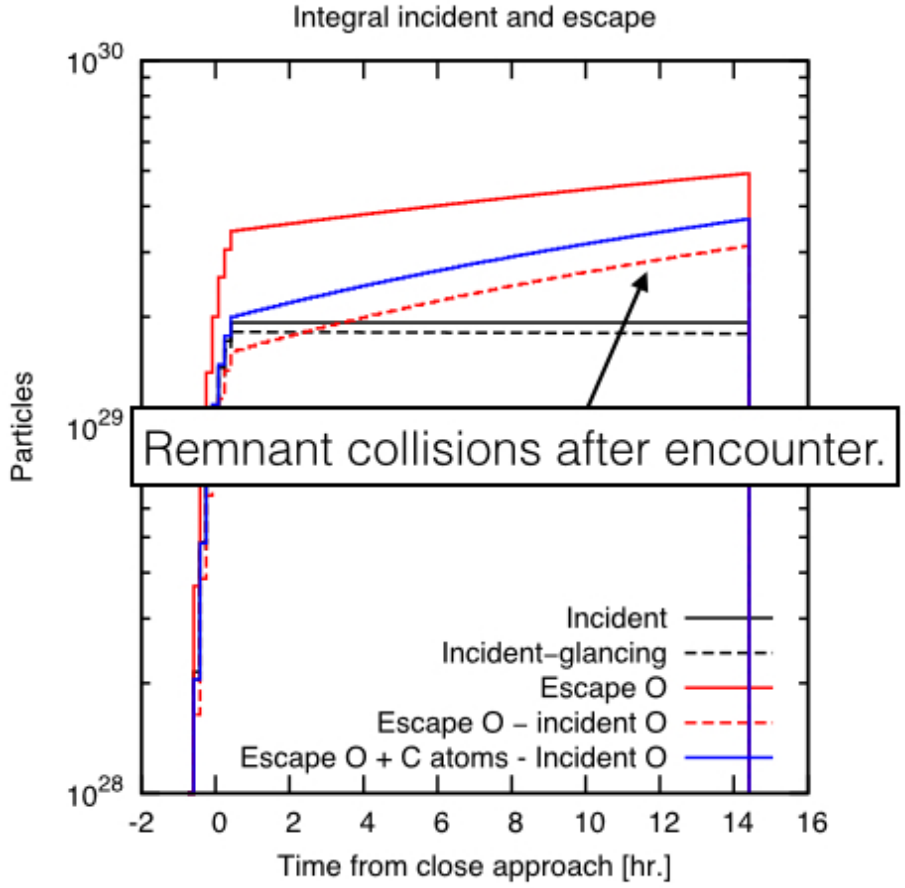
Cometary trajectory



- Time variation calculation includes the rotation of Mars and the Coriolis forces when tracing the sputtered neutrals.
- The comet encounters Mars from south to north due to high inclination of its orbit. Complexity of the cometary trajectory (including Mars' gravity, etc.) is not considered.

Incident rates and sputtering escape rates

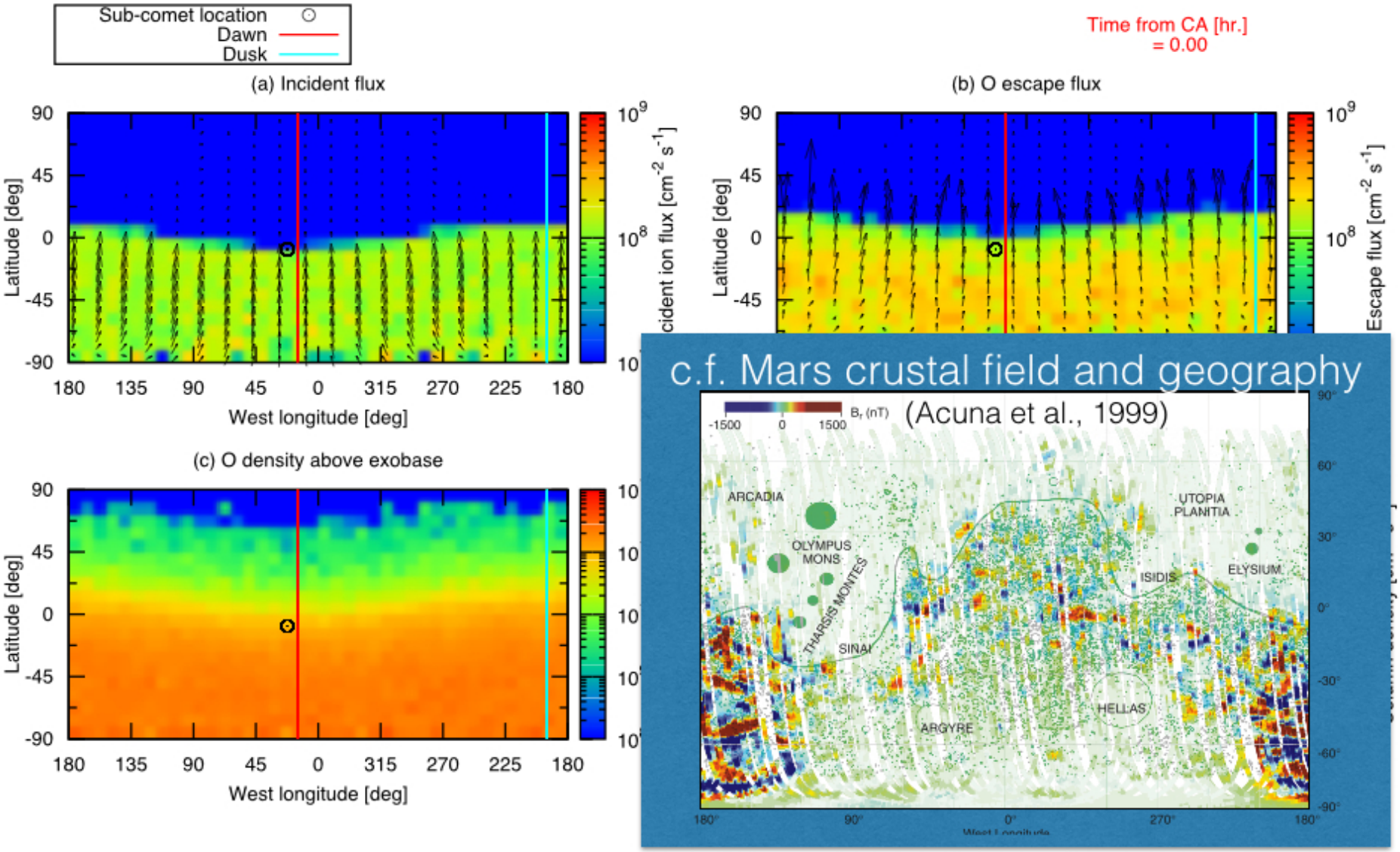




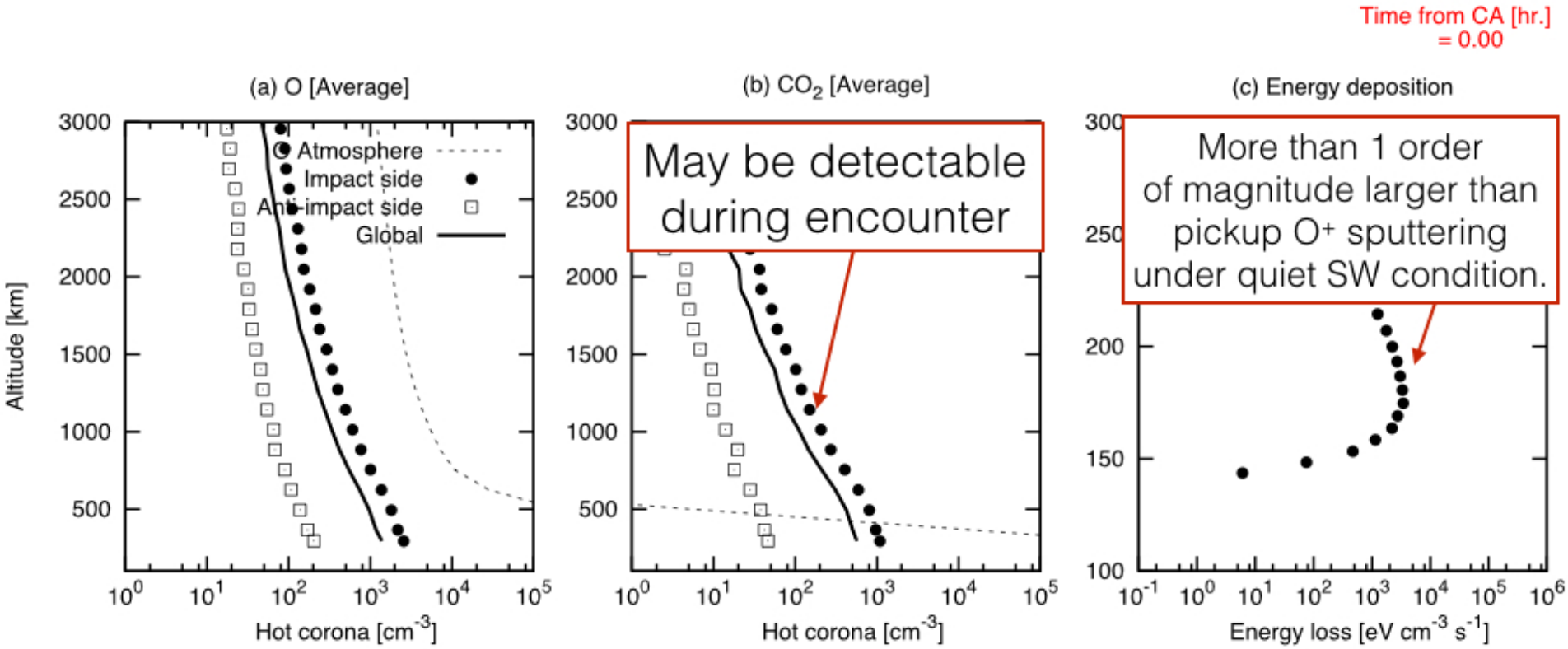
- Encounter (incident) duration = 70 min.
- Total incident particles = 1.9×10^{29}

O+C atomic yields ~ 2
⇒ Escape > incident

Global sputtering evolution (see movie “Mars_comet_Tvar_2D.mp4”)



Sputtered corona and energy deposition (see movie “Mars_comet_Tvar_1D.mp4”)



- After encounter, sputtered density supplied from lower altitude vanishes and the slope of the density become steeper with time.
- The density at anti-impact side become equivalent to the impact side at ~ 1.5hr. after CA.

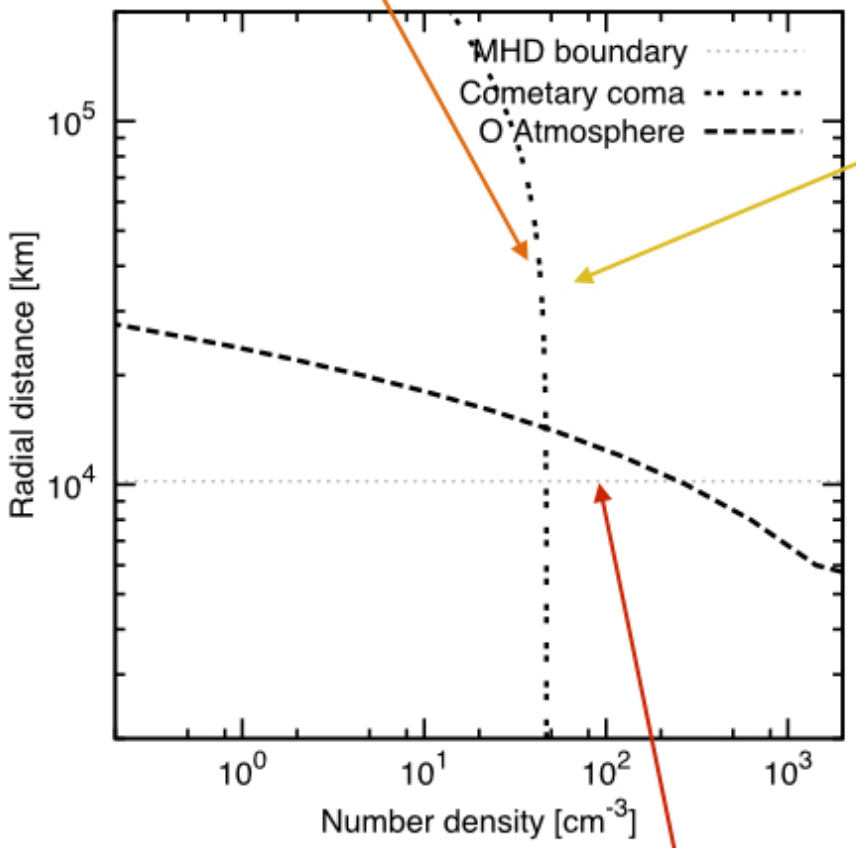
Sputtering from ionized coma
- Fixed time simulation at CA-

Assumption: Completely ionization from H_2O to O^+.

Pickup O^+ sputtering under influences of solar wind.

Pickup O^+ from Mars corona and comet

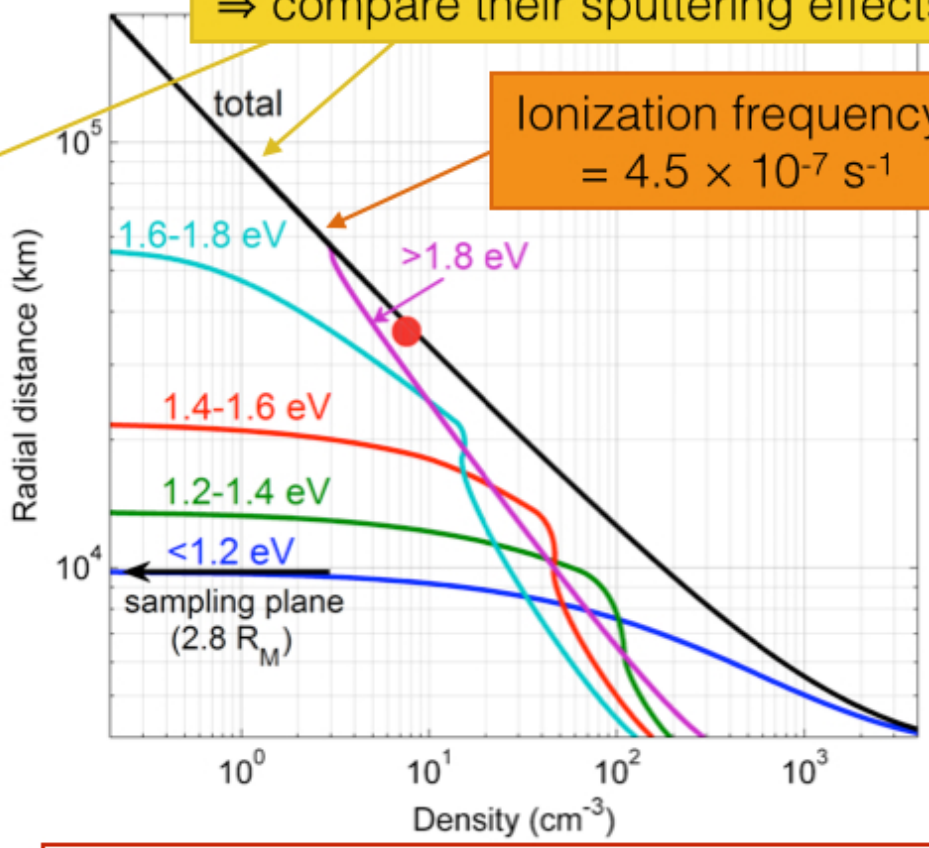
Assume completely ionized



MHD + Pickup ion:
Simulation box boundary at $3R_M$

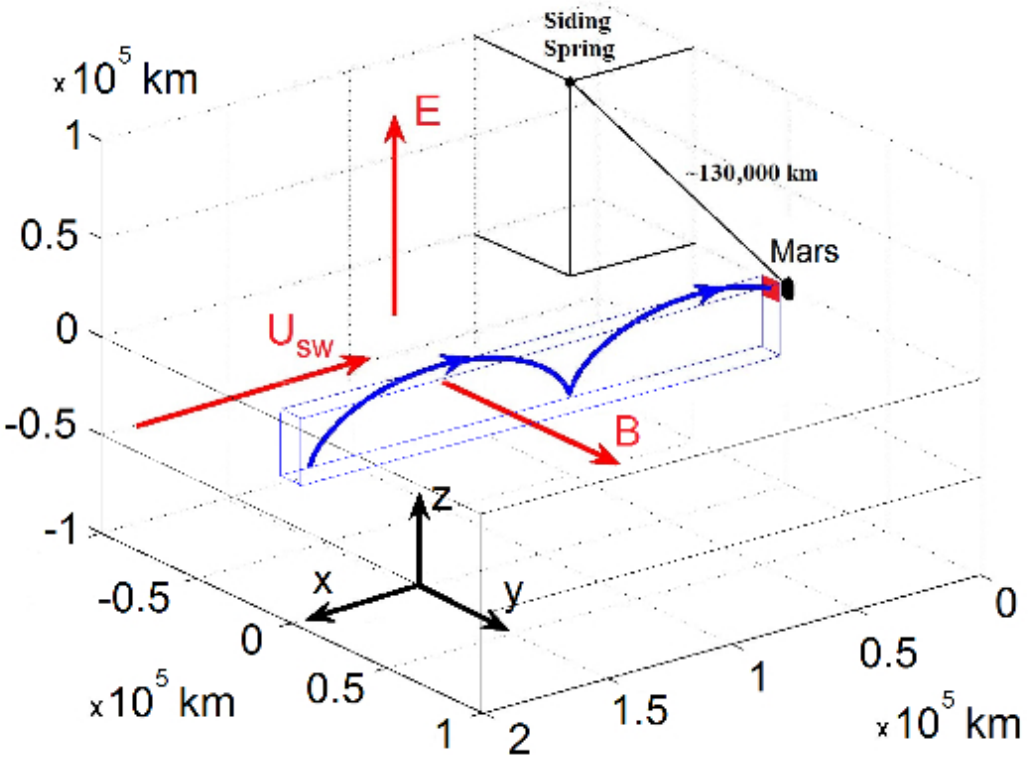
O from cometary coma > O corona
at higher altitude.
⇒ compare their sputtering effects.

Ionization frequency
$= 4.5 \times 10^{-7}$ s^{-1}



O corona from SDMC and two-stream method
from dissociative recombination of O_2^+
(from A. Rahmati et al., *submitted to JGR*)

Pickup O+ from higher altitudes



- Trace pickup O+ under the influences of solar wind. No interactions between Mars, comet, and the solar wind are considered.

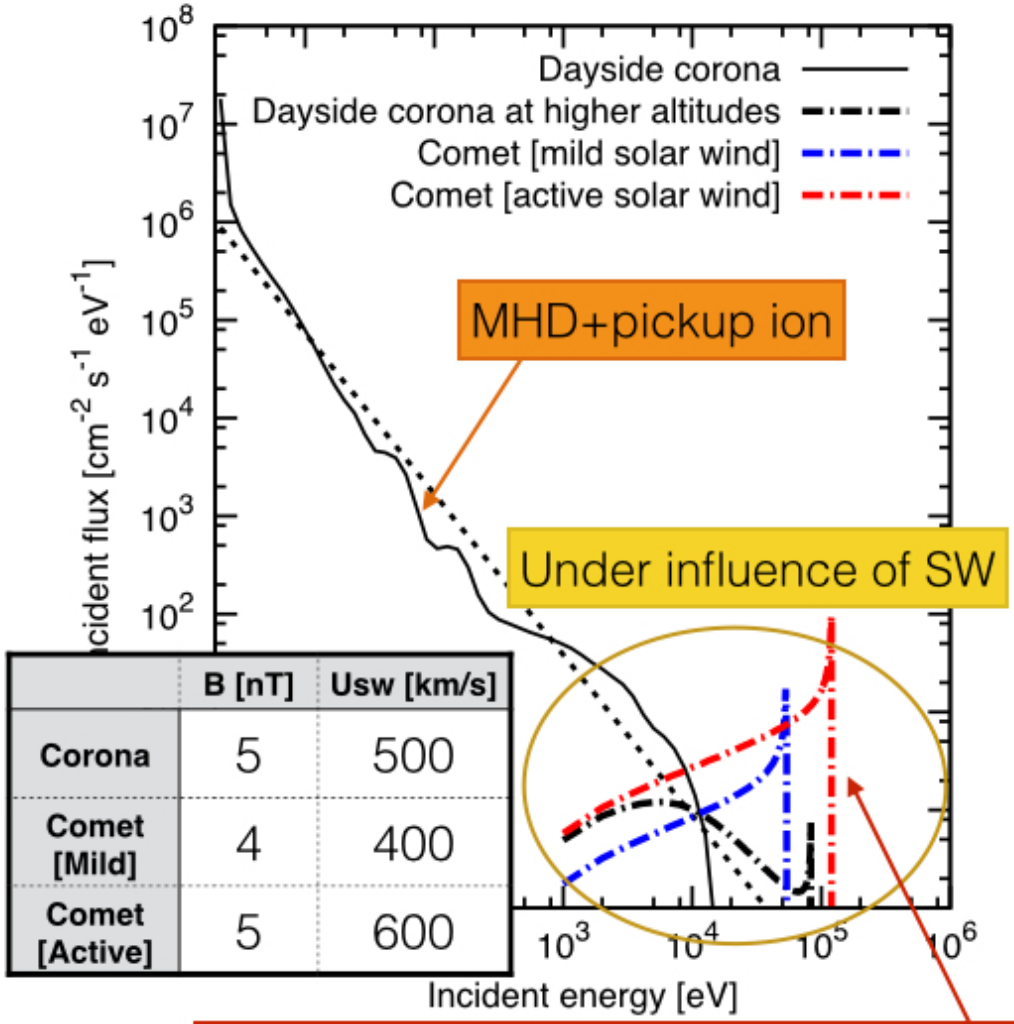
  ⇒ The mass loading effects from outer region of the coma and Mars O corona at higher altitudes might be negligible.

- Collect pickup O+ at altitude of 2000 km (right above the bow shock of Mars).

- Pickup O+ produced up to 10^6 km from the center of Mars is included.

Provided by Ali Rahmati

Pickup O^+ flux spectra

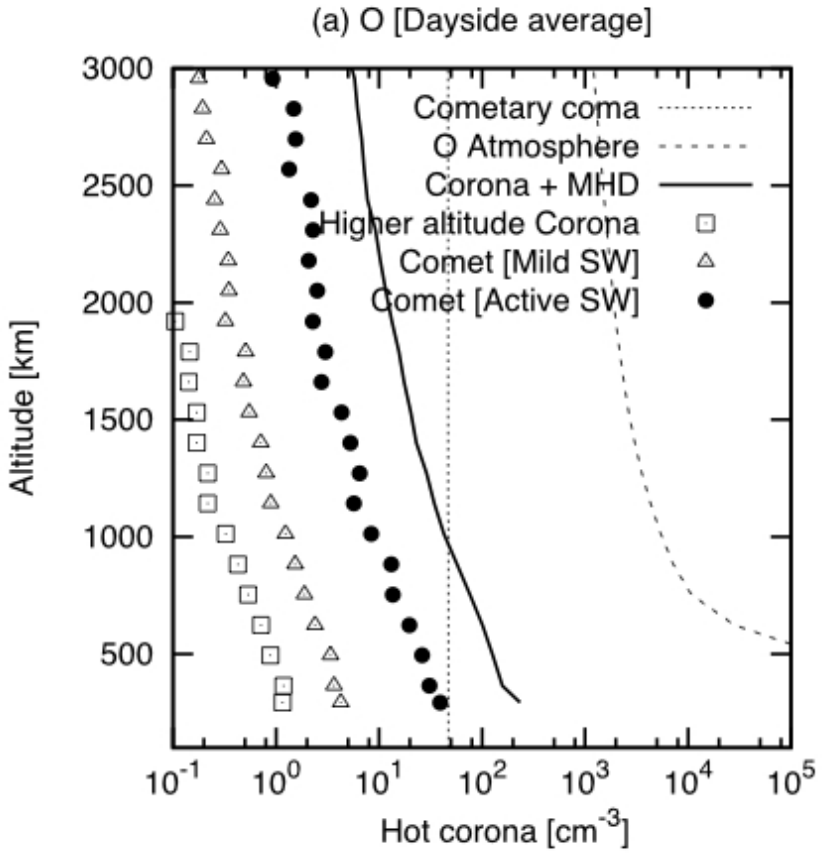


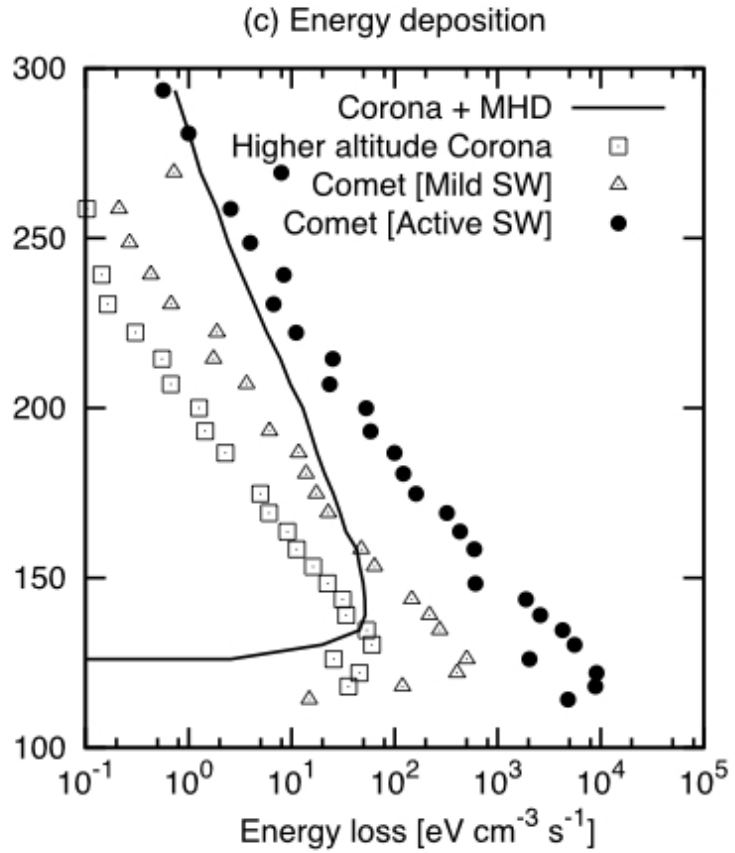
	B [nT]	Usw [km/s]
Corona	5	500
Comet [Mild]	4	400
Comet [Active]	5	600

- Although the pickup O^+ collected under simplified SW influences at 2000 km above surface may not completely represent those incidence to the upper atmosphere, they are likely to impact Mars due to their large energy. Reflections from the outward electric fields and surface crustal fields might be small.
- The spectrum for corona at higher altitudes completes a smooth decay slope after combining with those from MHD+pickup ion simulations.
- Assume they impact to the upper atmosphere.

Spikes due to acceleration of ion gyro-rations.

Sputtering from cometary pickup O^+





Because the flux from higher altitudes are relatively small, the sputtered hot corona density is also small.

Due to large energy, the energy deposition goes deeper to the atmosphere and is relatively larger than pickup O^+ sputtering under normal SW and Mars interactions.

Escape from cometary sputtering

Escape > Incident

		Incident O	Escape O	Escape O+C - Incident O
Siding spring with $Q_c = 10^{28}$ s^{-1} and CA at 130,000 km	**Neutral coma at CA**	1.1×10^{26} s^{-1}	2.0×10^{26} s^{-1}	1.2×10^{26} s^{-1}
	After 70 min. encounter (Neutral coma)	1.9×10^{29} part.	3.4×10^{29} part.	2.0×10^{29} part.
	Pickup O^+ [Mild SW]	1.1×10^{23} s^{-1}	3.4×10^{23} s^{-1}	3.2×10^{23} s^{-1}
	Pickup O^+ [Active SW]	1.2×10^{24} s^{-1}	3.0×10^{24} s^{-1}	2.5×10^{24} s^{-1}
Mars corona	**MHD+ pickup O^+**	1.1×10^{25} s^{-1}	1.8×10^{24} s^{-1}	2.0×10^{24} s^{-1}*
	Pickup O^+ from higher altitudes	2.8×10^{22} s^{-1}	9.1×10^{22} s^{-1}	1.1×10^{23} s^{-1}*

Escape rates can scale to any other Q_c and CA distance.

*No subtraction to incidents

Discussions

- Estimation of neutral coma density from Hansen et al. (2007) is

$$n_n(r) = \frac{Q_c}{4\pi r^2 V_c} \exp\left(-\frac{r}{\lambda}\right)$$

- With proposed ionization length scale $\lambda = 1.7 \times 10^6$ km at 1.3 AU, about 7% of coma will be ionized at 130,000 km.

Summary

- Due to large encountering velocity of comet Siding Spring, the sputtering effects from its coma can remove large amounts of the atmosphere instead of feeding gases to Mars.

- The sputtering from the neutral coma may produce detectable hot CO_2 corona.

- The energy deposition with cometary source rates of 10^{28} s^{-1} can reach 10^4 eV cm^{-3} s^{-1}, which is larger than those from pickup O^+ from Mars corona under normal SW conditions.