**MINIMAL ATMOSPHERIC LOSS DURING VALLEY NETWORK FORMATION DESPITE LACK OF A GLOBAL MAGNETIC FIELD ON MARS.** K. P. Lawrence[1], S. H. Brecht[2], S. A. Ledvina[3], C. Paty[4], C. L. Johnson[5,6], [1]Stanford University (450 Serra Mall, Stanford, California 94305, klawrence@stanford.edu), [2]Bay Area Research Corp. (55 Loma Vista Dr., Orinda, CA 94563), [3]University of California, Berkeley (Space Sciences Lab., 7 Gauss Way Berkeley, CA 94720), [4]Georgia Institute of Technology (311 Ferst Drive Atlanta, GA 30332), [5]University of British Columbia (6339 Stores Road, Vancouver, BC, Canada, V6T 1Z4). [6]Planetary Science Institute (1700 East Fort Lowell, Suite 106, Tucson, AZ, 85719-2395)

**Introduction:** There are many indications that the environment of present day Mars differs significantly from that of ancient Mars. The existence of mid/late Noachian valley networks [1,2] and extensive erosion in the late Noachian [e.g. 3] require at least intermittent periods during which martian climatic conditions were more clement than present. The apparent delay between the cessation of a global magnetic field, evidenced by the the lack of observable remanent magnetic anomalies over large impact basins such as Hellas and Argyre [4], and the time period showing evidence for surface water, motivates further study of early Mars' atmospheric loss rates. Using global hybrid particle simulations [5] of the solar wind interaction with an early Martian atmosphere, we investigate rates of atmospheric loss of a $CO_2$-dominant atmosphere under standard pressure and temperature conditions. We consider 1, 3, 10, and 50 times nominal EUV conditions, intended to simulate solar wind conditions at present, 2.5, 3.8, and 4.1 Ga, respectively. We compare integrated loss rates with temporal uncertainties in the Martian hydrologic history to determine whether a coeval dynamo is required to maintain conditions amenable to surface water during the late Noachian.

**Early Martian Timeline:** Here we briefly discuss temporal relationships among, and absolute age contraints on, key geological and geophysical processes during early martian evolution. These relationships are shown schematically in Figure 1.

*Geodynamo.* Mars does not currently exhibit a global dynamo-driven magnetic field, but the existence of strong crustal magnetic anomalies indicates that a global field existed in the past. It has been argued that the existence of this magnetic field may have played an important role in arresting the loss of the early Mars atmosphere by solar wind sputtering [e.g. 6], demonstrating the need to constrain the cessation of a global magnetic field. Based on crustal magnetic signatures of major impact basins such as Chryse (magnetized), Utopia (demagnetized), and Hellas (demagnetized), and detailed crater count records, [4] argue for a dynamo shut-off at 4.1 ± 0.03 Ga.

*Fluvial Activity.* Valley networks with characteristics such as high-order dendritic tributaries provide morphological evidence for fluvial activity, erosion and sedimentary transport indicative of a hydrological cycle with sustained precipitation and surface runoff [1]. Using stratigraphic and crater retention ages of drainage basins, several studies have estimated the period of valley network formation to be between 3.9 and 3.6 Ga [e.g 2,7]. It is apparent that valley network formation terminated by the Early Hesperian and that the last large impact basins (Hellas, Argyre, and Isidis) precede the end of valley network formation by several hundred million years.

*Tharsis.* Crustal magnetic field data indicate that much of Tharsis lacks magnetism, suggesting cessation of the dynamo prior to or contemporaneous with its formation [8]. Investigations of thermal demagnetization by intruded magmas suggest that the lack of magnetic remanence associated with the Tharsis province is a result of several episodes of long-lived, magma-driven tectonic activity [9] in the absence of an external magnetic field. Volcanic volumes and associated absolute ages via crater counts imply Tharsis may have contributed nearly 0.8 bars of atmospheric gases from the Late Noachian to the Amazonian [10].

**Model:** Given the constraints provided by the magnetic field observations, fluvial activity and volcanism, it is apparent that the conditions at the surface of Mars supported liquid water from 4.1 to 3.6 Ga. To examine Martian atmospheric evolution during this time period, we model non-thermal escape mechanisms for oxygen ions and neutral $CO_2$ molecules of a hypothetical atmosphere of 100% $CO_2$. Assumptions we make about the initial atmosphere include: 1) subsequent impact related addition or subtraction of atmosphere is negligible, 2) subsequent volatile contributions from Tharsis are not included 3) surface conditions are equivalent to 1 bar and 273K at the time of dynamo shut-down (4.1 Ga).

We use a kinetic hybrid particle model (HALFSHEL) [5] to calculate oxygen ion loss. This model retains the full kinetic behavior of multiple ion species, treats the electrons as a massless neutralizing fluid, treats the particles and fields self-consistently, includes both Hall and Pedersen conductivities, includes both ion-neutral drag and gravity, and solves the governing atmospheric chemical equations throughout the simulation. An advantage of tracking the full vector trajectory of each particle, is the ability to track which particles move away from the planet and which reipact the atmosphere with the potential to cause sputtering of neutral molecules. We consider results from these

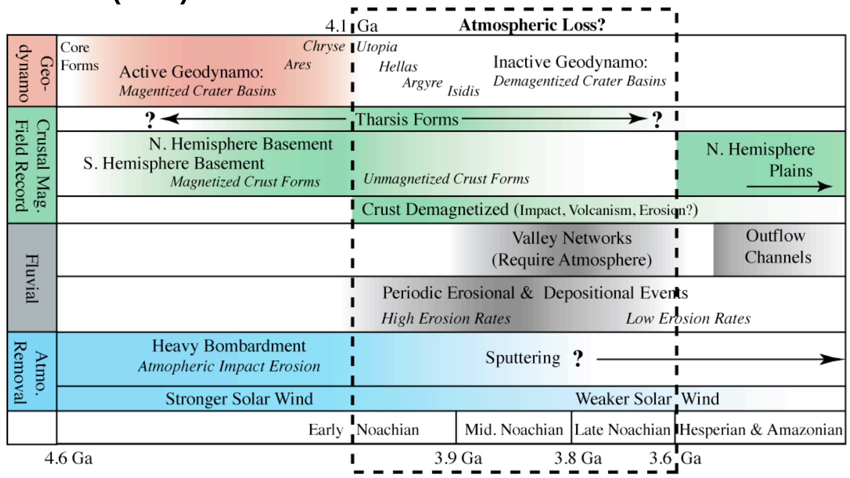


**Figure 1.** Schematic representing the general tim-ing and duration of major geophysical events in early Martian history.

model simulations as instantaneous snapshots in time. The simulation is allowed to run for time scales that account for the ionospheric equilibration time (~10,000 sec).

**Results & Discussion:** Figure 2 presents results of $O^+$ flux loss for our simulations during three Martian epochs (present, 2.5, and 3.8 Ga) displaying a more steady loss rate between the 3EUV and 10EUV cases. Note previous studies [11,12,13] use present day martian surface pressure and temperature conditions as atmospheric parameter constraints even for early solar wind conditions.

Although we model the loss rates for $O^+$ ions – photodissociation and ion outflow are not the only loss mechanism. Sputtering has been proposed as the major loss mechanism for the early martian atmosphere. We calculate sputtering loss of $CO_2$ molecules using, 1) calculated total $O^+$ loss rates and previously-derived sputtering efficiencies [e.g. 11,14] and, 2) tracked particles from each simulation that have trajectories toward the planetary surface and energies above 1 keV, together with the collisional cross-section of $CO_2$ molecules.

Assuming that the sputtering efficiency and $O^+$ loss rates are independent of time, we calculate an atmospheric pressure change due to $CO_2$ loss from 4.1 to 3.6 Ga. Results range from 54 mbar (relatively inconsequential) to 500 mbar of loss, the latter of which is difficult to reconcile with fluvial observations. However, Tharsis volcanics could have released as much as 800 mbar worth of volatiles [10] after the cessation of the dynamo, more than compensating for our highest loss estimate.

It is apparent that the lack of evidence for an active dynamo does not conflict with evidence of stable surface water during the same time period. We suggest that perhaps the lack of evidence for surface water after ~3.6 Ga marks the beginning of the change in Mars global conditions, rather than the end. In addition, our preliminary results indicate that the thicker ionosphere, produced through both increased solar wind activity and a denser early atmosphere, may have provided a sufficiently stable stand-off boundary to prevent solar wind stripping at lower atmospheric altitudes.

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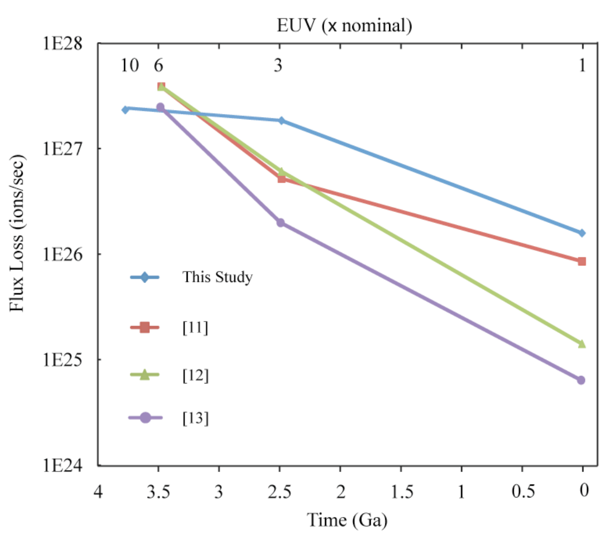


**Figure 2.** $O^+$ flux loss in ions per second versus time in Ga (bottom axis) and equivalent solar EUV flux (top axis) for this study and previous studies [11,12,13].