

# Ion Escape from Mars: Measurements in the Present to Understand the Past

ROBIN RAMSTAD



Swedish Institute of Space Physics

Umeå University

Akademisk avhandling som med vederbörligt tillstånd av Rektor vid Umeå Universitet för avläggande av filosofie doktorsexamen framläggs till offentligt försvar i aulan vid Institutet för rymdfysik, Rymdcampus 1, Kiruna, fredagen den 8 december 2017, kl. 09:00.

Avhandlingen kommer att försvaras på engelska.

Fakultetsopponent: Dr. David Brain, Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, USA.

## **Ion Escape from Mars: Measurements in the Present to Understand the Past**

Robin Ramstad

Institutet för rymdfysik, Kiruna

Institutionen för fysik, Umeå Universitet, Umeå

ISBN: 978-91-982951-3-9, ISSN: 0284-1703

### **Abstract**

Present-day Mars is a cold and dry planet with a thin CO<sub>2</sub>-dominated atmosphere comprising only a few mbar pressure at low altitudes. However, the Martian surface is marked with valley networks, hydrated mineral clays, carbonates and the remains of deltas and meandering rivers, i.e. traces of an active hydrological cycle present early in the planet's geological history. A strong greenhouse effect, and thus a thicker atmosphere, would have been required to sustain a sufficiently warm environment, particularly under the weaker luminosity of the early Sun. The fate of this early atmosphere is currently unknown.

While several mechanisms can remove atmospheric mass over time, a prominent hypothesis suggests that the lack of an intrinsic Earth-like global magnetic dipole has allowed the solar wind to erode the early Martian atmosphere by imparting energy to the planet's ionosphere which subsequently flows out as ion escape, over time depleting the greenhouse gasses and collapsing the ancient hydrological cycle. Previous studies have found insignificant ion escape rates under present-day conditions, however, the young Sun emitted significantly stronger solar wind and photoionizing radiation flux compared to the present. The geological record establishes the time of collapse of the hydrological cycle, estimated to have occurred in the mid-late Hesperian period (~3.3 billion years ago) at latest. To constrain the amount of atmosphere lost through ion escape since, we use the extensive database of ion flux measurements from the Analyzer of Space Plasmas and Energetic Atoms (ASPERA-3) particles package on the Mars Express orbiter (2004-present) to quantify the ion escape rate dependence on upstream solar wind and solar radiation conditions.

The Martian ion escape rate is shown to be insensitive to solar wind parameters with a weak inverse dependence on solar wind dynamic pressure, and linearly dependent on solar ionizing photon flux, indicating efficient screening of the bulk ionosphere by the induced magnetic fields. The impact of an extreme coronal mass ejection is studied and found to have no significant effect on the ion escape rate. Instead, intense solar wind is shown to only increase the escaping energy flux, i.e. total power of escaping ions, without increasing the rate by accelerating already escaping ions. The orientation of the strongest magnetized crustal fields are shown to modulate the ion escape rate, though to have no significant time-averaged effect. We also study the influence of solar wind and solar radiation on the major Martian plasma boundaries and discuss factors that might limit the ion escape rate, including solar wind-ion escape coupling, which is found to be  $\lesssim 1\%$  and decreasing with increased solar wind dynamic pressure. The significant escape rate dependencies found are extrapolated back in time, considering the evolution of solar wind and ionizing radiation, and shown to account for only  $4.8 \pm 1.1$  mbar equivalent surface pressure loss since the time of collapse of the Martian hydrosphere in the Hesperian, with ~6 mbar as an upper estimate. Extended to the late Noachian period (3.9 billion years ago), the found dependencies can only account for  $\lesssim 10$  mbar removed through ion escape, an insignificant amount compared to the  $\gtrsim 1$  bar surface pressure required to sustain a warm climate on early Mars.