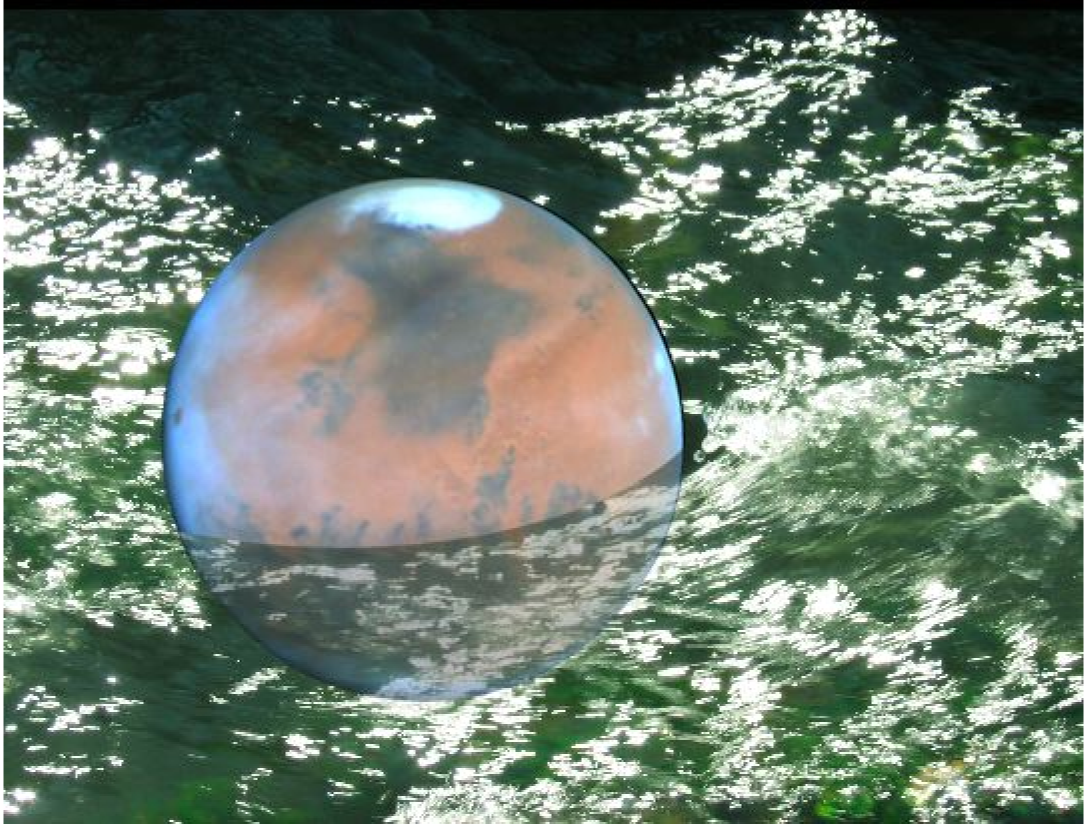
SWIM
Chapman Conference on the Solar Wind Interaction with Mars



22-25 January 2008
Bahia Resort Hotel
San Diego, CA USA

Chapman Conference on the Solar Wind Interaction with Mars

Bahia Resort Hotel ● San Diego, California
22-25 January 2008

CONVENERS

- **David Brain**, University of California, Berkeley (United States)
- **Dana Crider**, Catholic University of America (United States)
- **Rickard Lundin**, Institutet för rymdfysik (Sweden)

PROGRAM COMMITTEE

- **Mario Acuña**, NASA Goddard Space Flight Center (United States)
- **Stanislav Barabash**, Swedish Institute of Space Physics (Sweden)
- **César Bertucci**, Imperial College London (United Kingdom)
- **Eduard Dubinin**, Max-Planck Institute for Solar System Research (Germany)
- **Jane Fox**, Wright State University (United States)
- **Alexander Krymskii**, Southern Federal University (Russia)
- **Helmut Lammer**, Austrian Academy of Sciences (Austria)
- **Janet Luhmann**, University of California, Berkeley (United States)
- **Andrew Nagy**, University of Michigan (United States)
- **Hiroyuki Shinagawa**, National Institute of Information and Communications Technology (Japan)

COSPONSORS

- NASA Mars Program Office
- NASA Mars Fundamental Research

Cover Image: Mars Near Opposition 1995-2005: 1995
Credit: NASA, ESA, and The Hubble Heritage Team (STScI/AURA)
and photograph of stream by David Brain

MEETING AT A GLANCE

Tuesday, January 22, 2008

7:00 a.m. – 8:00 p.m.	Registration/Information Desk
8:30 a.m. – 8:45 a.m.	Conference Welcome
8:45 a.m. – 10:35 a.m.	Oral Sessions
10:35 a.m. – 11:05 a.m.	Refreshment Break
11:05 a.m. – 12:30 p.m.	Oral Sessions
12:30 p.m. – 4:00 p.m.	Lunch/Afternoon Break
4:00 p.m. – 4:35 p.m.	Poster Summaries
4:35 p.m. – 5:45 p.m.	Oral Sessions
5:45 p.m. – 6:15 p.m.	Refreshment Break
6:15 p.m. – 8:00 p.m.	Oral Sessions

Wednesday, January 23, 2008

7:30 a.m. – 5:00 p.m.	Registration/Information Desk
7:30 a.m. – 8:30 a.m.	Poster Set-Up
8:30 a.m. – 10:00 a.m.	Oral Sessions
10:00 a.m. – 10:30 a.m.	Refreshment Break
10:30 a.m. – 12:30 p.m.	Oral Sessions
12:30 p.m. – 2:30 p.m.	Lunch Break
2:30 p.m. – 4:15 p.m.	Oral Sessions
4:15 p.m. – 4:45 p.m.	Poster Summaries
4:45 p.m. – 5:15 p.m.	Afternoon Break/Poster Set-Up
5:15 p.m. – 7:15 p.m.	Poster Viewing/Reception

Thursday, January 24, 2008

8:00 a.m. – 12:30 p.m.	Registration/Information Desk
8:30 a.m. – 10:20 a.m.	Oral Sessions
10:20 a.m. – 10:50 a.m.	Refreshment Break
10:50 a.m. – 12:25 p.m.	Oral Sessions
12:25 p.m. – 6:30 p.m.	Lunch/Afternoon Break
6:30 p.m. – 9:30 p.m.	Conference Banquet and Presentation

Friday, January 25, 2008

8:30 a.m. – 2:00 p.m.	Registration/Information Desk
8:30 a.m. – 10:30 a.m.	Oral Sessions
10:30 a.m. – 11:00 a.m.	Refreshment Break
11:00 a.m. – 12:25 p.m.	Oral Sessions
12:25 p.m. – 1:25 p.m.	Lunch Break
1:25 p.m. – 3:25 p.m.	Oral Sessions
3:25 p.m. – 3:30 p.m.	Conference Closing

PROGRAM OVERVIEW

All oral sessions will be held in Mission Bay Ballroom E, unless otherwise noted. Refreshment Breaks and the Registration/Information Desk will be in the Mission Bay Ballroom E Foyer.

An asterisk after an author's name denotes the author is a student.

Tuesday, January 22

8:30 a.m. – 8:45 a.m. ♦ **Conference Welcome**
Conference Chairs: D. Crider, D. Brain and R. Lundin

Structure and Processes of the Martian Plasma Environment

Session Chairs: C. Bertucci and E. Dubinin

8:45 a.m. - 9:10 a.m. **O. Vaisberg** *(Invited), History of Studies of the Solar Wind Interaction with Mars*

9:10 a.m. - 9:35 a.m. **C. Mazelle** *(Invited), Physics, Structure and Variability of the MPB*

9:35 a.m. - 9:55 a.m. **M. Fraenz,** *The Plasma Environment of Mars as Mapped by the ASPERA-3 Experiment*

9:55 a.m. - 10:15 a.m. **N. Edberg*,** *Global Disturbance of the Location of the Magnetic Pileup Boundary and Bow Shock Caused by the Crustal Magnetic Fields of Mars*

10:15 a.m. - 10:35 a.m. **K. Sauer,** *The Physics of the Ion Composition Boundary at Mars*

10:35 a.m. – 11:05 a.m. ♦ **Refreshment Break**

11:05 a.m. - 11:30 a.m. **A. Fedorov** *(Invited), Mars: Solar Wind Wake and Induced Magnetotail*

11:30 a.m. - 11:50 a.m. **J. S. Halekas,** *The Induced Magnetotail Current Sheet at Mars*

11:50 a.m. - 12:10 p.m. **Y. Futaana,** *ENA Imaging in the Vicinity of Mars: A Review of Mars Express/NPD Observations*

12:10 p.m. - 12:30 p.m. **F. Akalin,** *Investigation on the Magnetic Field Draping Near Mars from MARSIS Observations and Hybrid Simulations*

12:30 p.m. – 4:00 p.m. ♦ **Lunch/Afternoon Break**
Individuals are on their own to explore and enjoy San Diego.

4:00 p.m. – 4:35 p.m. ♦ **Poster Summaries: Structure and Process/Comparative Planetology**
Session Chair: J. R. Espley
Presenters in both the *Structure and Processes of the Martian Plasma Environment* and *Comparative Planetology* sessions will offer one-minute summaries of their posters. A list of those presentations can be found on page 8.

4:35 p.m. - 4:55 p.m. **J. D. Winningham,** *Pitch Angle Sampling in the Martian Magnetosphere*

4:55 p.m. - 5:15 p.m. **R. J. Lillis,** *Electrostatic Potentials in the Near-Mars Environment between 180 km and 400 km Detected by Electron Reflectometry*

5:15 p.m. - 5:45 p.m. ♦ **Session Summary**
Session Chairs: C. Bertucci and E. Dubinin

5:45 p.m. – 6:15 p.m. ♦ **Refreshment Break**

Comparative Planetology

Session Chairs: S. Barabash and J. Luhmann

6:15 p.m. - 6:40 p.m. **T. E. Cravens** *(Invited), Physics of Solar Wind - Atmosphere Interface*

6:40 p.m. - 7:00 p.m. **C. Bertucci,** *The Plasma Environments of Mars and Titan*

7:00 p.m. - 7:20 p.m. **T. L. Zhang,** *Solar Wind Interaction with Venus at Solar Minimum: Venus Express Magnetic Field Observations*

7:20 p.m. - 7:40 p.m. **C. Ferrier*,** *Scale Comparison Between the Magnetosheath and Tail Interface of Mars and Venus*

7:40 p.m. - 8:00 p.m. **P. C. Brandt,** *Energetic Neutral Atom Analysis of the Solar Wind Interaction with Mars and Venus Observed by ASPERA-3 and ASPERA-4*

Wednesday, January 23

8:30 a.m. - 8:55 a.m. **S. Barabash** *(Invited), Non-thermal Escape in the Solar System*

8:55 a.m. - 9:15 a.m. **A. J. Coates,** *Ionospheric Photoelectrons and Their Role in Plasma Escape at Titan: Comparison to Mars*

9:15 a.m. - 9:35 a.m. **J. G. Luhmann,** *Solar Wind Interaction-Related Atmosphere Escape: Further Lessons from Venus*

9:35 a.m. - 10:00 a.m. **J. M. Grebowsky** *(Invited), The Martian Ionosphere: Lessons From Pioneer Venus Orbiter*

10:00 a.m. – 10:30 a.m. ♦ **Refreshment Break**

10:30 a.m. - 10:50 a.m. **H. Y. Wei*,** *Comparison Study of the Flux-rope Structures in the Ionospheres of Mars, Venus and Titan*

10:50 a.m. - 11:15 a.m. **C. T. Russell** *(Invited), Role of Waves in Solar Wind Interactions*

11:15 a.m. - 11:35 a.m. **M. Delva,** *Upstream Waves at Venus and Comparison to Mars*

11:35 a.m. - 12:00 p.m. **G. Marklund** *(Invited), Auroral Processes in the Solar System*

12:00 p.m. - 12:30 p.m. ♦ **Session Summary**
Session Chairs: S. Barabash and J. Luhmann

12:30 p.m. – 2:30 p.m. ♦ **Lunch Break**
Individuals are on their own.

Influence of and on the Atmosphere

Session Chairs: E. Chassefiere and H. Lammer

2:30 p.m. - 2:55 p.m. **H. Lichtenegger** *(Invited), Atmospheric Evolution and Escape Throughout Martian History*

2:55 p.m. – 3:15 p.m. **R. Lundin,** *Solar Forcing and The Cometary Like Escape of Ionospheric Plasma From Mars*

3:15 p.m. – 3:35 p.m. **R. E. Ergun,** *The Role of Plasma Waves in Mars' Atmospheric Loss*

3:35 p.m. - 3:55 p.m. **L. Andersson,** *The Effects of Wave Heating Near the Exobase on the Ion Outflow*

3:55 p.m. – 4:15 p.m. **K. P. Lawrence*,** *Possible Shielding of the Martian Atmosphere from the Early Solar Wind by a Crustal Magnetic Field*

4:15 p.m. – 4:45 p.m. ♦ **Poster Summaries: Atmosphere/Modeling the Interaction**
Session Chair: J. R. Espley
Presenters in both the *Influence of and on the Atmosphere* and *Modeling the Interaction* sessions will offer one-minute summaries of their posters. A list of those presentations can be found on page 9.

4:45 p.m. – 5:15 p.m. ♦ **Afternoon Break/Poster Set-Up**

5:15 p.m. – 7:15 p.m. ♦ **Poster Viewing and Reception** ♦ Bayside Pavilion
Session Chair: J. R. Espley

Thursday, January 24

8:30 a.m. - 8:55 a.m. **S. W. Bougher** *(Invited), Thermosphere and Ionosphere Modeling for Mars*

8:55 a.m. - 9:15 a.m. **M. Paetzold,** *The Structure of the Ionosphere of Mars as Observed with the Mars Express Radio Science Experiment*

9:15 a.m. - 9:35 a.m. **F. Duru,** *Investigation of the Electron Densities and the Boundary Between the Ionosphere and the Solar Wind at Mars from Local Electron Plasma Oscillations*

9:35 a.m. – 9:55 a.m. **D. D. Morgan,** *Variability of Martian Ionospheric Parameters with Solar Wind Dynamic Pressure from MARSIS Active Ionospheric Sounding*

9:55 a.m. - 10:20 a.m. **F. Leblanc** *(Invited), Multi-Instrument Observations of an Aurora-Type Event by Mars Express*

10:20 a.m. – 10:50 a.m. ♦ **Refreshment Break**

10:50 a.m. - 11:10 a.m. **M. O. Fillingim,** *Horizontal Gradients in the Nighttime Ionosphere of Mars and Their Electromagnetic Consequences*

11:10 a.m. - 11:35 a.m. **R. E. Johnson** *(Invited), Martian Exospheric Structure and Influences*

11:35 a.m. - 11:55 a.m. **V. I. Shematovich,** *Hot Neutral Corona at Mars*

11:55 a.m. - 12:25 p.m. ♦ **Sesion Summary**
Session Chairs: E. Chassefiere and H. Lammer

12:25 p.m. – 6:30 p.m. ♦ **Lunch/Afternoon Break**
Individuals are on their own to explore and enjoy San Diego.

6:30 p.m. – 9:30 p.m. ♦ **Conference Banquet and Presentation** ♦ Del Mar Room
J. L. Green *(Invited),* The 1859 Superstorm: How Large Was It?

Friday, January 25

Modeling the Interaction

Session Chairs: A. Nagy and H. Shinagawa

8:30 a.m. - 8:55 a.m. **D. A. Brain** *(Invited), The SWIM Model Challenge*

8:55 a.m. - 9:20 a.m. **J. E. P. Connerney** *(Invited), Mars Crustal Magnetism: Modeling and Interpretation*

9:20 a.m. - 9:40 a.m. **J. R. Espley,** *The Effect of Martian Crustal Magnetic Fields on Solar Energetic Particles*

9:40 a.m. - 10:05 a.m. **E. Kallio** *(Invited), Current State of Hybrid Modeling: Strengths, Weaknesses and Future Plans*

10:05 a.m. - 10:30 a.m. **Y. Ma** *(Invited), Current State of MHD Modeling: Strengths, Weaknesses and Future Plans*

10:30 a.m. – 11:00 a.m. ♦ **Refreshment Break**

11:00 a.m. - 11:25 a.m. **M. Holmstrom,** *Why Should We Compare Models?*

11:25 a.m. - 11:45 a.m. **A. Boesswetter*,** *3D Hybrid Simulations: A Global Picture of the Martian Plasma Environment*

11:45 a.m. - 12:05 p.m. **S. H. Brecht,** *Hybrid Simulations of Mars: Results from Data Specific Simulations for SWIM*

12:05 p.m. - 12:25 p.m. **N. Terada,** *A Three-Dimensional MHD Model of the Solar Wind Interaction with the Ionosphere of Mars: Coupling with a Time-Dependent Exosphere Model*

12:25 p.m. – 1:25 p.m. ♦ **Lunch Break**
Individuals are on their own.

1:25 p.m. - 1:45 p.m. **E. Harnett,** *Multi-Fluid Simulations of Flux Ropes in the Martian Magnetotail*

1:45 p.m. - 2:05 p.m. **M. W. Liemohn,** *Velocity-Space Distributions of O+ Pickup Ions Around Mars*

2:05 p.m. - 2:25 p.m. **X. Fang,** *Spatial Distribution of Pickup Oxygen Ion Losses at Mars*

2:25 p.m. – 2:55 p.m. ♦ **Session Summary**
Session Chairs: A. Nagy and H. Shinagawa

2:55 p.m. – 3:25 p.m. ♦ **Meeting Summary of the Effects of Crustal Fields**
Session Chairs: M. Acuña and A. Krymskii

3:25 – 3:30 ♦ **Conference Closing**

Poster Sessions

In addition to the first author and abstract title, each listing begins with the poster number used during the poster viewing session on Wednesday evening.

Poster Session Chair: J. R. Espley

Structure and Processes of the Martian Plasma Environment

S-01 • D. A . Brain, *Observation of a Strong Flux Rope Near Mars*

S-02 • D. H. Crider, *Space Environment Parameters Derived from MGS MAG/ER for You to Use*

S-03 • D. A. Gurnett, *Large Amplitude Density Fluctuations at High Altitudes in the Martian Ionosphere and Their Possible Relationship to Atmospheric Loss Processes*

S-04 • J. P. Eastwood, *Evidence for Collisionless Magnetic Reconnection at Mars*

S-05 • E. Friedrich, *Energetic Neutral Atom Production due to Charge Exchange at Mars*

S-06 • V.G. Mordovskaya, *The Dependence of Magnetic Field in the Perturbed Mars Wake on the Solar Wind Parameters and the Solar Activity*

S-07 • H. Nilsson, *Ion Beam Events Observed by Mars Express Aspera-3*

S-08 • H. Pérez-de-Tejada, *Solar Wind Erosion of the Polar Regions of the Mars Ionosphere*

S-09 • K. Sauer, *Nonlinear Waves in the Plasma Environment of Mars*

S-10 • D. Ulusen, *Transient Events in the Solar Wind Interaction of Mars due to the Strong Crustal Fields*

S-11 • S. Vennerstrom, *Mars Surface Magnetic Observatory: A Geophysical and Environment (GEP) Experiment for ExoMars*

S-12 • P. Wurz, *Investigating the Solar Wind - Mars Atmosphere Interaction with Energetic Neutral Atoms*

S-13 • C. Wang, *Introduction to YH-1, the First Chinese Mars Orbiter*

S-14 • M. Kanao*, *Dependence of Ion Density and Velocity Distributions on the Motional Electric Field*

Comparative Planetology

P-01 • P. P. Hick, *Tomographic Reconstructions of the Solar Wind from Heliospheric Remote Sensing Observations: Density and Velocity Predictions at Mars*

P-02 • A. A. Mardon*, *Noctilucent Clouds as Multiplanetary Phenomena and Interaction With Solar Wind*

P-03 • V. G. Mordovskaya, *The Specific Signatures of the Solar Wind-Phobos Interaction as the Evidence of the Phobos Magnetic Field*

P-04 • V. G. Mordovskaya, *The Possible Reasons of the Secular Acceleration of Phobos*

P-05 • V. G. Mordovskaya, *The Specific Signatures of the Solar Wind-Phobos Interaction and Conditions of their Observation from "Phobos 2 " **Mission****

P-06 • M. Oieroset, *Search for Gas/Dust Escape From Phobos and Deimos Using in Situ Observations From Mars Global Surveyor MAG/ER*

P-07 • N. C. Richmond, *Lunar Mini-Magnetospheres and the Association with Surface Albedo*

P-08 • S. Vennerstrom, *Magnetic Storms at Mars and their Interplanetary Causes*

P-09 • H. Y. Wei*, *Ion Cyclotron Waves at Mars and Venus*

Influence of and on the Atmosphere

A-01 • E. Chassefiere, *The Combined Effects of Escape and Outgassing on Mars Volatile History*

A-02 • J. L. Fox, *The Morphology of the Dayside Ionospheres of Venus and Mars: Evidence for Ion Outflows*

A-03 • R. A. Frahm, *Atmospheric Photoelectron Peaks Observed in the Martian Ionosphere and Magnetosphere*

A-04 • D. L. Kirchner, *Martian Ionospheric Response to the Solar Activity of December 2006*

A-05 • A. J. Kopf*, *A Study of an Upper Layer in the Topside Ionosphere of Mars Using MARSIS*

A-06 • H. Lammer, *Coupled 3-D Hot Particle and Exosphere Modelling of Mars*

A-07 • T. L. McDunn*, *Model Validation Over the 80-140km Region on Mars: A Comparison Between MGCM-MTGCM Simulations and SPICAM Observations*

A-08 • D. L. Mitchell, *The Photoelectron Boundary at Mars*

A-09 • J. I. Nuñez*, *The Mars Ionizing Radiation Characterization Experiment (MIRCE)*

A-10 • C. D. Parkinson, *Hydrogen and Oxygen Hot Ion Precipitation in the Martian Ionosphere*

A-11 • A. Valeille*, *Evolution of Exospheric Suprathermal Oxygen Over Martian History*

A-12 • J. T. Clarke, *HST/STIS Observations of the D/H Ratio and Airglow Emissions in the Extended Martian Upper Atmosphere*

Modeling the Interaction

M-01 • S. H. Brecht, *Hybrid Simulations: Assorted Topics and Future Plans*

M-02 • X. Fang, *The Impact of a Limited Satellite Field of View on the Pickup Ion Measurements Around Mars*

M-03 • M. Holmstrom, *A Self-Consistent Mars-Solar Wind Interaction Model*

M-04 • K. Kaneda*, *Time Variation of the Nonthermal Escape of Oxygen from Mars: A Two-Stream Model Coupled with an MHD Ionosphere Model*

M-05 • S. A. Ledvina, *The Role of Chemistry and Associated Assumptions in Determining the Ionosphere and the Resulting Affects on Effects on the Martian Solar Wind Interaction*

M-06 • M. W. Liemohn, *A Detailed Analysis of Mars O+ Pickup Ion Velocity Space Distributions*

M-07 • J. Schoendorf, *The Plasma Environment Near Martian Crustal Magnetic Fields*

Abstracts

Oral Presentations

22 January 2007

<u>Structure and Processes of the Martian Plasma Environment</u>

History of Studies of the Solar Wind Interaction with Mars

<u>O. Vaisberg</u> (Space Research Institute (IKI), 84/32 Profsoyuznaya Str, Moscow, Russia 117997, ph. +7(495) 333-34-56; fax +7(495) 913-30-40; e-mail: olegv@iki.rssi.ru)

Solar wind interaction with Mars have been studied on Mariner-4, Mars-2, -3, and –5, Phobos, Mars Global Surveyor and Mars Express spacecraft. Plasma and magnetic observations on Mariner-4, Mars-2, -3 showed existence of the bow shock and suggested larger dimensions of an obstacle than ionosphere can support. Evidence of cometary type interaction were found in Mars-2, -3, and –5 observations that led to controversy between magnetospheric and cometary types of the solar wind-Mars interaction. These measurements were used to suggest that the solar wind induced atmospheric losses can play significant role in the evolution of Martian atmosphere. Mars Global Surveyor finding of magnetic anomalies in southern hemisphere of Mars was important in understanding of the magnetic fields in the solar wind-Mars interaction. Mars Express plasma observations showed much smaller loss rate than estimated from earlier observations and suggested that the role of the solar wind induced escape is insignificant. Review of the earlier missions, and the evolution of our understanding of the interaction including the nature of interaction regions are given.

Physics, Structure and Variability of the MPB

<u>C. Mazelle</u> (Centre d'Etude Spatiale des Rayonnements, 9, Avenue du Colonel Roche, 31400, Toulouse, France; ph. 33561557775; fax 33 561556701; e-mail: mazelle@cesr.fr)

This presentation will review the 'state of the art' on the understanding of the physics of the Magnetic Pileup Boundary (MPB). This plasma boundary appears as a characteristic of the interaction of a fast-flowing magnetized plasma (such as the solar wind) with the more or less extended neutral environment of a non-magnetized (or weakly-magnetized) object and has also been referred as the external boundary of the 'induced' magnetosphere around such objects. For Mars, clarification about its characteristic features has been made after Mars
Global Surveyor observations and comparison with previous results from Phobos-2. A huge progress has been achieved more recently from Mars-Express unless the absence of magnetometer of this spacecraft contrary to the formers. However, recent Venus Express results from simultaneous plasma particles and magnetic field data on a very similar object has definitively confirmed the relevance of the physics of this plasma boundary on the issue of atmospheric escape. Moreover, observations of a similar boundary around other objects of either similar or very different nature and different physical parameters such as Titan or comets is also of great relevance for a better understanding of the nature of the boundary despite their specificity and differences. Since observations from a single spacecraft has obvious limitations, the help of simulation is mandatory. A large effort has been made on simulations using mainly a kinetic approach (hybrid) but also multi-fluid methods which cannot take into account all the ion physics such as finite Larmor radius effects (e.g. for Mars or Titan) but can be useful for global studies on a much larger scale. However even the hybrid simulations do not fully investigate

up to now the inner structure of the boundary due to limitations in spatial resolution. There is also a lack of theoretical frame to fully describe the nature of the boundary from an analytical model. Moreover, many issues remain open that will be discussed in this review.

The Plasma Environment of Mars as Mapped by the ASPERA-3 Experiment

M. Fraenz (MPI fuer Sonnensystemforschung, 37191 Katlenburg-Lindau, Germany); E. Dubinin (MPI fuer Sonnensystemforschung, 37191 Katlenburg-Lindau, Germany; ph. +495556979441; e-mail: fraenz@mps.mpg.de); J Kleimann(MPI fuer Sonnensystemforschung, 37191 Katlenburg-Lindau, Germany); C. Martinecz(MPI fuer Sonnensystemforschung, 37191 Katlenburg-Lindau, Germany); E. Roussos(MPI fuer Sonnensystemforschung, 37191 Katlenburg-Lindau, Germany); J. Woch (MPI fuer Sonnensystemforschung, 37191 Katlenburg-Lindau, Germany); S. Barabash(Institutet foer rymdfysik, SE-981 28 Kiruna, Sweden); R. Lundin(Institutet foer rymdfysik, SE-981 28 Kiruna, Sweden); R. A. Frahm(Southwest Research Institute, San Antonio, TX 7228-0510, USA); J. D. Winningham(Southwest Research Institute, San Antonio, TX 7228-0510, USA)

The ASPERA-3 experiment onboard the European Mars Express spacecraft has been measuring the flow of electrons and ions around Mars for more than 3 years. We report on the general characteristics of the interaction of the solar wind with the planetary atmosphere. Specifically we discuss the location of the primary plasma boundaries, the plasma moments observed in the different regions of the magnetosphere, the influence of crustal fields and the escape of heavy ions from the planet. We observe that the magnetic pile-up boundary is a very efficient screen for solar wind electrons and protons. Thus momentum is transferred to planetary ions by the magnetic field induced by the solar wind. Planetary ions escape in plasma clouds along the magnetospheric tail. The escaping clouds can be observed in electron flux enhancements. The escape mechanism is influenced by the orientation of the interplanetary field and the crustal magnetizations in the southern polar hemisphere.

Global Disturbance of the Location of the Magnetic Pileup Boundary and Bow Shock Caused by the Crustal Magnetic Fields of Mars

N. Edberg (Department of Physics and Astronomy, University of Leicester , Leicester , UK ; ph. + 46 18 471 5926; fax +46 18 471 5905 ; e-mail: ne27@ion.le.ac.uk); M. Lester (Department of Physics and Astronomy, University of Leicester , Leicester , UK ; ph. +44 116 2523580; fax +44 116 2523555; e-mail: mle@ion.le.ac.uk)

We present results that show how the magnetic pileup boundary (MPB) of Mars and possibly even the bow shock (BS) is pushed outward by the underlying crustal magnetic fields. We have used the entire premapping data set from the Magnetometer and Electron Reflectometer (MAG/ER) instrument on board Mars Global Surveyor (MGS) in search of crossings of the MPB and BS. We find 913 and 616 such crossings, respectively, and use them to obtain the normal shape and location of the two boundaries. This is in agreement with previous studies but with some small differences in standoff distance as well as in tail radius. The field strength within the MPB is also studied in order to see how it varies with solar zenith angle and altitude. We also confirm previous studies which show that the quasi-perpendicular bow shock is on average located further away than the quasi-parallel shock by about 3%. To compare individual crossings with each other we extrapolate each crossing to the terminator plane in order to remove the solar zenith angle dependence. We then compare the planetocentric coordinates of all crossings with a map of the crustal field of Mars. The results show that the MPB is on average located further away from the planet when the crossing is observed over regions with strong crustal fields. The crustal fields appear to provide extra magnetic pressure which pushes the boundary outward. The same study is done for the bow shock with the same result. This is perhaps more surprising since the BS is located further away from the planet and the strength of the crustal fields decreases rapidly with altitude and hence would be expected to have a smaller effect on the location of the BS.

The Physics of the Ion Composition Boundary at Mars

K. Sauer (Department of Physics, University of Alberta, Edmonton Alberta, Canada; Eduard Dubinin· Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany)

Among others, a contentious problem in the field of Mars plasma research is to clarify the physics of the plasma boundary which is located inside the bow shock and is different from the ionopause. It is characterized by a jump in the magnetic field intensity (Magnetic Pile-up Boundary=MPB) and a change in the ion composition (Ion Composition Boundary=ICB). The main difficulty arises from the fact that classical one-fluid MHD models fail to explain the MPB/ICB. In this respect the two-ion fluid approach in which the dynamics of protons and planetary ions are coupled by electromagnetic forces has been recognized as a major step to understand fundamental processes going on in the Martian multi-ion plasma. As a general statement one can note that the presence of a second ion population modifies the plasma properties significantly: New types of nonlinear waves and structures (solitons, oscillitons and boundaries) may arise. The MPB/ICB is obviously an example. It offers the limits of one-fluid MHD in cases, where the momentum coupling between two ore more ion populations plays a dominant role in the overall plasma dynamics. Results of different approaches starting from simple two-ion models up to hybrid simulations are discussed.

Mars: Solar Wind Wake and Induced Magnetotail

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As well as any non-magnetized object having an atmosphere and interacting with the fast magnetized solar wind flow, Mars creates a disturbed wake in the down-wind part of the interaction region. The central part of such a wake represents a solar wind void filled by draped magnetic field and accelerated ions of the planetary origin, i.e induced magnetotail. There are two important aspects of exploration of the Martian wake: 1) the composition of the planetary ions and the escape rate of different species is the paleontological aspect of the problem; 2) the processes of creation of the solar wind void and ion acceleration in the wake relate to plasma physics. The present paper which is trying to provide a comprehensive view on the Martian wake, discusses partially the first problem, but mainly focuses on the physical processes creating observed structure. The review is based on previous publications, known numerical models, and presumably on the last observations by mass analyzer from the ASPERA-3 package onboard of Mars Express. The essential Martian tail related topics are as follows: 1) The spatial properties and origin of plasma sheet, which is a thin layer of an intense flow of planetary ions accelerated up to 1 keV. It seems that JXB tension acting near the planet is the main source of such acceleration. 2) Contents, origin, and acceleration mechanism of planetary ions observed in the boundary layer between the plasma sheet and magnetosheath. Here the ions are accelerated by pickup in the ionizing exosphere and by polarization electric field. 3) What tail region is the main source of escaping ions. It seems that plasma sheet and boundary layer give the comparable contribution to the planetary ion loss. 4) Modification of electron distribution function associated with ion acceleration and the role of magnetic anomalies. The paper discusses several different approaches to this problem. Each topic is supported by comparison with Venus Express observations to clarify the acting mechanism.

The Induced Magnetotail Current Sheet at Mars

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The Martian induced magnetotail, unlike the terrestrial geotail, forms as magnetic field lines drape around the conducting ionosphere. However, like at Earth, the Martian tail consists of two lobes of oppositely directed magnetic field with a current sheet between them. The Martian magnetotail current sheet was first observed at altitudes of thousands of km by the PHOBOS-2 spacecraft. Recent MGS observations have demonstrated that, even at the low Mars Global Surveyor (MGS) mapping altitude of ~400 km, the spacecraft can still encounter the magnetotail current sheet. The current sheet thickness is on the order of ~100 km at these low altitudes, implying a very highly draped magnetic field configuration.

At Earth, a rich array of fundamental plasma physics processes occur in or near the magnetotail current sheet, notably including reconnection. Recent analyses of MGS data show both direct and indirect evidence of reconnection in the Martian tail, demonstrating that similar physical processes likely operate at Mars.

We will discuss the structure of the Martian magnetotail current sheet, and its response to external drivers and local crustal fields. As part of this work, we will characterize electron distributions in the current sheet. Finally, we will discuss evidence of reconnection and waves in the Martian tail, and investigate how these processes respond to external drivers.

ENA Imaging in the Vicinity of Mars: A Review of Mars Express/NPD Observations

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The energetic neutral atoms (ENAs) imaging techniques have developed rapidly during the last decade. ENA imaging has become a powerful means to remotely investigate the plasma environment and the neutral exosphere of planets. The ASPERA-3 instrument onboard ESA Mars Express mission comprises four instruments; two ENA sensors and an electron and an ion spectrometer. We report observations obtained by the Neutral Particle Detector (NPD). NPD provides measurements of the ENA flux in the energy range 0.1 - 10 keV resolving velocity and mass (H and O) with a coarse angular resolution of 5x30 [degs]. We mainly focus on two observations; hydrogen atoms backscattered from the Martian upper atmosphere and hydrogen atom streams emitted from the subsolar region. The NPD sensors detected intensive fluxes of hydrogen atoms at an energy of 1 keV from the nadir direction around pericenter (~ 270 km). The atoms originated from the solar wind protons precipitate onto the upper atmosphere. They deliver mass, energy, and momentum to atmospheric atoms and mapping of these ENAs provides the global maps of mass, momentum and energy deposition of solar wind protons to the atmosphere. The NPD also observed intensive streams of hydrogen atoms of a solar wind energy emitted from the subsolar region. Since the solar wind can penetrate deeply in the atmosphere, the charge exchange is expected to occur more frequently than other places. The streams exhibit very sharp boundaries, called ENA jet, that can be associated with the charge-exchange with small scale height. In addition, the jet have also been revealed to be influenced by an IMF structure very quickly. These ENAs are thought to be common features for typical non-magnetized bodies because the generation mechanisms are also common for them.

Investigation on the Magnetic Field Draping Near Mars from MARSIS Observations and Hybrid Simulations

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Electron cyclotron echoes detected by the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) instrument onboard Mars Express can be used to measure the local magnetic field strength. These echoes are believed to be caused by the periodic return to the antenna of electrons that are accelerated during the sounder pulse by strong electric fields near the antenna. From the period of the echo, the magnetic field strength in the vicinity of the spacecraft can be computed. These scalar measurements are highly complementary to those obtained by the Mars Global Surveyor Magnetic Field Experiment (MAG/ER). The local magnetic field measured by MARSIS corresponds to the total magnetic field which includes the contribution of crustal magnetic fields and the magnetic field induced by the draping of the interplanetary magnetic field (IMF) lines. By using the model by Cain et al. (2003) for the crustal magnetic field and assuming a steady IMF during a time interval comparable to the time required to pass through a region of strong crustal fields (typically a few minutes), the magnetic field vector induced by the draping can be estimated. Investigations on the magnetic field morphology and the influence of crustal field on the draping are discussed in this study. These results are also compared with three-dimensional hybrid simulation results which provide a global description of the Martian plasma environment.

Pitch Angle Sampling in the Martian Magnetosphere

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The Analyzer of Space Plasmas and Energetic Atoms (ASPERA-3) experiment on board the Mars Express spacecraft conducts measurements of electrons by the Electron Spectrometer (ELS), ions by the Ion Mass Analyzer (IMA), and neutral particles by the Neutral Particle Imager (NPI) and the Neutral Particle Detector (NPD). The Mars Express spacecraft is a 3-axis stabilized platform. The ELS, NPI, and NPD are mounted on the ASPERA-3 scanner, used to generate three-dimensional measurements of the local environment; however, the scanner is infrequently used for scanning (mostly used for pointing). Thus, ELS effectively produces two-dimensional electron flux distributions. Examination of the two-dimensional angular distribution shows directionality differences which can not be successfully untangled since the Mars Express spacecraft does not contain a magnetometer to measure the local Martian magnetic field. At low altitudes, particularly near the terminator, remanent crustal magnetic fields can dominate particle motion. Not knowing the local magnetic field direction can lead to confusing interpretations. The closed loop crustal magnetic fields can straddle the terminator and exist adjacent to field lines which are open to the solar wind within a small area, making it difficult to distinguish between regions which lose plasma to the nightside atmosphere and regions which lose plasma to the solar wind. Thus, the picture of the three-dimensional plasma flow can produce a distorted description of the plasma which is an incorrect description of plasma in various regions. Data from the ASPERA-3 ELS will be presented showing rapidly changing flux distributions as evidence for this small-spatial scale variability in the magnetic topology. Future missions would best benefit from these experiences by using a spinning spacecraft with a magnetometer as a measurement platform.

Electrostatic Potentials in the Near-Mars Environment between 180 km and 400 km Detected by Electron Reflectometry

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In the near-Mars environment between ~180 km and ~400 km altitude, 'open' magnetic topologies are often observed (i.e. magnetic field lines connected both to the interplanetary magnetic field (IMF) and the collisional Martian atmosphere below ~180 km). Depending on their initial pitch angles, solar wind electrons traveling downward on such field lines can magnetically reflect back upwards or collide with neutrals, resulting in a pitch angle-dependent attenuation of upward-traveling electron flux, known as a loss cone. The Mars Global Surveyor (MGS) Magnetometer/Electron Reflectometer (MAG/ER) experiment has measured many millions of loss cones at the MGS mapping altitude of ~400 km.

Electrostatic potentials can accelerate/decelerate these incident electrons parallel to the magnetic field lines, thereby shifting, in an energy dependent way, the range of pitch angles over which the loss cone is formed. To estimate these potentials, we least-squares fit loss cone pitch angle distributions from three adjacent energy channels (~116 eV, 191 eV, 313 eV) to a kinetic model of electron transport. The potentials are typically found to be small (- 10 V to 10 V) but, particularly near the boundaries of crustal magnetic cusps, they can reach magnitudes of ~50 V. We present results of a preliminary survey, examining how observed potentials in different geographic locations vary with solar zenith angle, solar wind pressure and IMF direction. Possible explanations are discussed, including ambipolar electric fields forming near cusps between ions and 'trapped' and 'free' electron populations.

Comparative Planetology

Physics of Solar Wind - Atmosphere Interface

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External plasma (i.e., the solar wind for Venus, Mars, or comets, and magnetospheric plasma for Titan) directly interacts with the upper atmospheres and ionospheres of planets or bodies that lack a strong intrinsic magnetic field. This presentation will explore the similarities and differences between various solar system interaction cases. The atmosphere and ionosphere of a non-magnetic body act an obstacle to an external flow. Comets and Venus represent extreme cases of how this can happen. The nucleus of a comet is very small but produces a large water vapor atmosphere. Cometary neutrals are ionized by solar EUV radiation and the newly created ions are "picked-up" by the solar wind in a very extensive region resulting in mass-loading of the solar wind. The solar wind interaction with the ionosphere of Venus takes place relatively near the planet and mass-loading plays a minor role. The solar wind interaction with Mars is similar in many ways to the solar wind interaction with Venus, although mass-loading is somewhat more important. In addition, the solar wind locally interacts with strong, localized magnetic fields associated with crustal anomalies, particularly in the Martian southern hemisphere. Titan mainly interacts with the flowing plasma in Saturn¹s outer magnetosphere and this incident flow appears to be subsonic and submagnetosonic, yet superAlfvénic, which distinguishes this interaction from other examples of plasma interactions with non-magnetic bodies. Titan is also subject to energy deposition from the precipitation of energetic charged particles in the magnetosphere.

The Plasma Environments of Mars and Titan

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The measurements obtained by the Cassini magnetometer and plasma instruments over more than 30 flybys of Titan have provided invaluable information on its interaction with Saturn's magnetosphere. On the one hand, the virtual absence of a significant global magnetic field and the presence of a dense atmosphere make Titan's interaction very similar to the solar wind interaction with Mars, Venus and comets with a magnetic barrier above Titan's ionosphere and a magnetic tail generated from the draping of Saturn's magnetic field. On the other hand, the diversity of the upstream conditions as Titan orbits its parent planet makes it one of the most outstanding laboratories to study the variability of the plasma structures generated by this interaction.

Previous and current studies on the solar wind interaction with Mars, Venus and comets reveal the occurrence a plasma boundary marking the entry into the magnetic barrier and tail lobes: the Magnetic Pileup Boundary (MPB). At these objects, the MPB has been identified from a series of very clear observational signatures including: an increase in the magnetic field magnitude, the enhancement of the magnetic field draping, and strong changes in the local electron distribution and in the dominant ion population, which are attributed to the increasing influence of the body's exosphere. Based in the mentioned signatures, we present evidence in favour of a magnetic pileup boundary at Titan as implied by Cassini observations. In addition, we study the structure of this boundary with the intention of providing new elements for the interpretation of the observations by MGS, Phobos-2, Mars Express and Rosetta at the Martian MPB.

Solar Wind Interaction with Venus at Solar Minimum: Venus Express Magnetic Field Observations

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The launch of Venus Express provides a new opportunity to study the solar wind interaction with Venus. Although a wealth of knowledge about the interaction of Venus and the solar wind has been obtained from earlier missions, notably the long lasting PVO mission, Venus Express will greatly improve our view of the Venus plasma environment due to many unique characteristics of the mission such as the improved capability of the onboard instrumentation, the unique orbital trajectory and the solar minimum observations at a low altitude compared with PVO. It is the purpose of this paper to illustrate some of the new science obtained by the Venus Express.

Scale Comparison Between the Magnetosheath and Tail Interface of Mars and Venus

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Planetary bodies without intrinsic magnetic fields, but with substantial atmospheres are known to possess cometlike "induced" magnetotails as a result of the mass loading and subsequent "draping" of passing flux tubes. The properties of theses magnetotails depend on the characteristics of both the incident flow of magnetized plasma and the planetary ionosphere. The Venus and Mars wakes can be expected to be very similar because of their induced origin.
In the present work, we are comparing the fine structure of the magnetosheath-induced magnetosphere interface of the both planets. We performed such comparison in two key regions of the planetary wake : 1) plane containing interplanetary magnetic field (IMF) and solar wind velocity (Equator), 2) plane of convection electric field (Polar regions). Both investigations were made on the data of mass analyser IMA, the part of plasma package ASPERA-3/4 onboard of Mars Express and Venus Express correspondingly. For the Venus study, the MAG magnetometer data was used, but for Mars we derived IMF direction from MGS data. The profiles of magnetosheath protons and planetary ions as a function of distance from sun-planet axis were investigated in the different scales. We have shown that, at least, in the polar region, the ion gyroradius defines the structure and size of the transition region.

Energetic Neutral Atom Analysis of the Solar Wind Interaction with Mars and Venus Observed by ASPERA-3 and ASPERA-4

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The solar wind interaction with the upper atmosphere of Mars and Venus produces energetic neutral atoms (ENA). Their detection is a new and innovative tool to globally investigate the nature of the solar wind interaction. We have used data from the Neutral Particle Imager (NPI) of the ASPERA-3 experiment on board Mars Express to search for ENAs produced in the solar wind interaction. NPI measures the integral ENA flux (in the energy range 0.1-60 keV) without mass and energy resolution, but with good angular resolution, 4.5x11.25 deg. We have concentrated the search to two possible sources of ENAs: (1) solar wind protons charge exchanging with the exosphere extending into the solar wind upstream of the bowshock (so-called solar wind ENAs); (2) pick-up ions charge exchanging with the upper atmosphere (so-called planetary ENAs).

One way to distuingish between solar wind and planetary ENAs is through the relation with the interplanetary magnetic field (IMF) clock angle. Since planetary ENAs originate from pick up ions a strong IMF clock angle dependence is expected, while solar wind ENAs should show no dependence. Approximate IMF clock angle was determined from MGS magnetometer observations in the dayside sheath [Brain et al., 2006], and are considered accurate to only to +-90 degrees (since the correspondence between the clock angle in the sheath field, and in the IMF, is only approximate). The eclipse condition for this analysis was that MEX be at least 0.15 RM within the umbra to avoid any possible UV contamination. We find no dependence on IMF clock angle but detect some structure of the intensities around the limbs of Mars. This is indicative of possible detection of solar wind ENAs.

We also discuss some observations by the Neutral Particle Detector (NPD) of the ASPERA-3 and ASPERA-4 experiment on Mars and Venus Express. NPD detects ENAs in the 100 eV - 1 keV with the ability to distuingish between hydrogen and oxygen. We present and discuss NPD observations of the planetary and solar wind ENA components, their species and energy spectra in trying to separate the two. In addition, a neutral particle signature around 600 eV (assuming hydrogen) is observed which clearly does not originate from Mars or Venus. We discuss its possible origin and interpretation.

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Non-thermal Escape in the Solar System

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Particles in the atmospheres of celestial bodies can gain energy exceeding the escape energy and be lost in space. Collisions due to thermal motion below the exobase causes thermal (Jeans) escape and, in some case, hydrodynamic escape. We consider non-thermal processes resulting in the energy gain. Those are photochemical processes, ion-neutral reactions and processes involving acceleration by electric fields such as ion pick-up, atmospheric sputtering, bulk plasma escape, polar wind. Over the solar system the non-thermal escape dominates for heavier materials. In some case, for example Venus, the Jeans escape is negligible even for hydrogen. Therefore non-thermal processes are the key for understanding the present state and evolution of planetary atmospheres. We summarize the current knowledge of the non-thermal escape processes at Mars and place this planet in the context of the other relevant bodies, namely, Venus, Earth, Titan, and comets. We discuss how the escape depends on external conditions and also address the issue how to propagate the currently measured escape rates backwards in time to evaluate the planetological significance of the escape processes. Finally we sum up the problems and the present status of measurement techniques to study escape and outline the frontiers and ideas in this field for new missions to Mars.

Ionospheric Photoelectrons and Their Role in Plasma Escape at Titan: Comparison to Mars

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Titan and Mars are objects with no significant dipole moment, although Mars has crustal magnetic fields. Mars is immersed in the solar wind, while Titan is normally immersed within Saturn’s hot magnetosphere. Electron spectrometers from the CAPS (Cassini Plasma Spectrometer) and ASPERA-3 (Analyzer of Space Plasmas and Energetic Atoms) investigations observe ionospheric photoelectrons at Titan and Mars respectively. Remarkably, photoelectrons are also observed in the tails of both Titan and of Mars. The interaction between Titan with Saturn's magnetosphere has similarities to the interaction between (a) the unmagnetized parts of Mars, and (b) Venus, with the solar wind. The Titan results therefore suggest that plasma escape is most likely also occurring with a similar mechanism at parts of Mars and at Venus as well. Here, we compare measurements of ionospheric photoelectrons at Titan and Mars. We will discuss the implications of this, the use of photoelectrons as a tracer of planetary plasma, and the possible role of photoelectrons in setting up an electric field to enhance ion escape.

Solar Wind Interaction-Related Atmosphere Escape: Further Lessons from Venus

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Although Venus represents a larger and more atmosphere-rich obstacle to the solar wind, it has been an important source of information for the interpretation of observations of the Mars solar wind interaction and the related atmosphere escape. We describe results of some recent efforts to understand the details of solar wind convection electric field effects around Venus that have some bearing on the Mars environment. In particular we use Ion Mass Analyzer and magnetometer observations on Venus Express, combined with models of the solar wind interaction and the pickup ion process to investigate the spatial morphology of the escaping ion population, which is important for making global loss estimates from in-situ measurements along the spacecraft orbit.

The Martian Ionosphere: Lessons From Pioneer Venus Orbiter

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Since the fiery end of the Pioneer Venus Orbiter (PVO) mission in October 1992, after 14 years in orbit, studies of the Venus plasma environment gradually faded away. Interest had switched to Mars with the advent of Mars Global Survey and the subsequent Mars Express. Now interest in Venus is increasing because of Venus Express measurements. The PVO published findings and recent ongoing studies using its data however provide an invaluable complement to the on going analysis of Mars data and to the Venus Express measurements, particularly in regard to how the nightside ionospheres of both planets couple to the neutral atmosphere and magnetic field at low altitudes. The archived PVO data provide the only set of in situ observations available at low altitudes for a planet lacking an intrinsic magnetic field, in the interesting region where a collisionally dominated ionosphere transitions with altitude into a plasma whose dynamics are closely coupled to the IMF induced magnetic field and as a result can be accelerated and lost to interplanetary space. These detailed in situ measurements at Venus can be usefully compared to observations of the remnant field-free ionosphere regions on Mars. Further, the in situ measurements at the boundaries of nightside Venus ionospheric holes, where the locally enhanced magnetic fields could act as magnetic barriers to the ionosphere, complement understanding of the interactions between the Martian ionosphere and its remnant magnetic fields. The PVO data encompasses nightside ionospheric conditions ranging from full-up ionospheres (seen during solar minimum when solar wind dynamic pressure is low) to severely depleted (i.e., so-called disappearing ionospheres) conditions. The latter, seen all the time near solar minimum or during periods of intense solar wind dynamic pressure during solar maximum, are closely analogous to the nightside depleted ionosphere conditions at Mars. The detailed PVO database is thus used to delineate the most prominent nightside low altitude Venus ionosphere/magnetic field features in order to infer what may be happening at Mars, where data is lacking. The analysis of the dependence of the Venus ionosphere topology on changing solar wind dynamic pressure and solar cycle phase also provides context for Venus Express' current solar minimum measurements and for its future observations as solar activity increases.

Comparison Study of the Flux-rope Structures in the Ionospheres of Mars, Venus and Titan

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Magnetic flux ropes, which have the structure of twisted flux tubes, are created in the ionospheres of Mars and Venus by their interactions with the solar wind. They are detected at Mars by Mars Global Surveyor, and at Venus by Pioneer Venus Obiter during solar maximum and Venus Express during solar minimum. The flux ropes have very similar helical characteristics and other statistical properties in the field-free region of Mars and Venus ionospheres. While the flux ropes detected by Venus Express near the lower boundary of ionopause are much less twisted than those in the lower field-free ionosphere and appear to be ropes during the early stage of formation. The interaction of Titan with the flowing magnetized plasma corotating with Saturn is similar to the solar wind interaction with Mars and Venus, and twisted fields are observed in the ionosphere by Cassini. These twisted field line structures resemble the flux ropes near Venus ionopause which are during formation. Comparison study of the flux rope structures in the three ionospheres can improve our understanding of how flux ropes form and how the properties of the ionosphere affect their formation.

Role of Waves in Solar Wind Interactions

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Waves in magnetized plasma usually arise to convert some source of free energy such as provided by a velocity space anisotropy or spatial gradient into heating of the plasma. They often provide important diagnostic information on the processes occurring within the plasma. The strongest and most non-linear wave found in the solar-wind interaction with all the planets is the shock wave that arises to enable the supersonic solar wind to be deflected around a planetary obstacle. Shock waves themselves create strong anisotropies in the plasma that lead to a hierarchy of waves. Beams of particles, some parallel to the interplanetary magnetic field and others transverse called ring beams, can generate waves that reduce the anisotropies. Most of these waves eventually damp in the plasma but mirror-mode waves that grow in ring beams convert velocity space instabilities into spatial inhomogeneities that persist a long time. The flowing solar wind plasma can interact directly with the neutral planetary exosphere, if it extends beyond the magnetic barrier to the solar wind flow, the generalized magnetopause. Charge-exchange, photo- ionization and impact ionization can produce pickup ions that drift in the solar-wind electric field and gyrate about the interplanetary magnetic field. This free energy can then decay into ion-cyclotron waves that appear in the planetary (exosphere) frame close to, but below, the ion gyro frequency. The appearance of this wave is a certain indication of atmospheric loss to the solar wind. Ion-cyclotron waves due to ion pickup are found at Venus, Earth, Mars, Jupiter and Saturn.

Upstream Waves at Venus and Comparison to Mars

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The magnetometer data from the Venus Express mission are investigated for different types of upstream waves. For the classical foreshock waves, generated at the bow shock itself or by particles back streaming from the bow shock, a detailed study of their properties and occurrence in space is presented. As a new feature at Venus, proton cyclotron waves (PCW) were detected in the upstream region till relatively large distances from the planet; they are a direct indication of pick up of planetary protons from the exosphere of Venus. An overview of the observations is presented and the question why they were not observed by PVO is addressed. A comparison of both wave types at Venus and Mars is made, with special emphasis on the different nature of the PCW occurrence between the planets.

Auroral Processes in the Solar System

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Aurora is a universal phenomenon taking place on a majority of the planets in our solar system, all planets having an atmosphere and an internal magnetic field. Aurora is the optical manifestation of the interaction between magnetized plasmas of different properties. Outside Earth, aurora appears on Jupiter, Saturn, Uranus, and Neptune. Even on Mars, with its very thin atmosphere and weak irregular magnetic field, processes characteristic of the aurora take place, as shown by observations of accelerated electron beams interacting with the thin Martian atmosphere. The aurora and the way it is driven differ in many respects between the various planets but a common feature is the electromagnetic emissions generated as electron beams are accelerated towards the planetary atmospheres. This review highlights major differences and similarities of aurora on the different planets particularly focusing on a key issue in auroral research, particle acceleration, by means of quasi-static magnetic field-aligned electric fields or waves, and associated field-aligned currents, plasma heating and electromagnetic radiation.

Influence of and on the Atmosphere

Atmospheric Evolution and Escape Throughout Martian History

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The evolution of the Martian atmosphere with regard to its CO2 and H2O inventory is expected to be strongly affected by thermal and non-thermal atmospheric loss processes of the lightest neutral and ionized constituents into space as well as by chemical weathering of the planetary surface material. The escape processes depend on the intensity of the solar X-ray and EUV (XUV) radiation and on the solar wind density during the Solar system history. In order to investigate the evolution of the of the CO2-rich Martian atmosphere, a diffusive-gravitational equilibrium and thermal balance model is used which allows to study the heating of the thermosphere by photodissociation and ionization processes due to exothermic chemical reactions and cooling by CO2 IR emission in the 15 *m band for different solar radiation exposures. For reconstructing the Sun's radiation and particle fluxes from present time to 4.6 Gyr ago, data from the observation of solar proxies with different ages have been employed. Based on global 3-D magnetohydrodynamic (MHD) and test particle simulation models of the solar wind interaction with the upper atmosphere of Mars, the loss rate of ions over the planet's history is estimated. It is further shown how high XUV radiation fluxes result in a hot and expanded thermosphere, indicating that the high temperature of the early Martian thermosphere could have led to "blow-off" conditions for neutral hydrogen atoms even for high CO2 atmospheric mixing ratios. Finally, the impact of an early planetary dynamo on the erosion of the Martian atmosphere.

Solar Forcing and The Cometary Like Escape of Ionospheric Plasma From Mars

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Solar XUV/EUV and solar wind forcing provides heating-, ionization, energization, and loss of Martian atmospheric atoms and molecules. Various physical processes governing atmospheric erosion is being discussed, but few measurements exists that can distinguish the individual contributions of each process to the total loss rate. The highly variable solar XUV/EUV and solar wind output is an efficiency indicator of the non-thermal loss mechanism leading to escape of ionospheric ions. In the case of the Earth we know that solar forcing variability corresponds to a variability of the ionospheric O+ outflow by up to three orders of magnitude. In this report we compare the variability of planetary ion escape from Mars measured by ASPERA-3 data on Mars Express (MEX) with the measured and inferred variability of solar forcing.

An updated analysis of ASPERA-3 ion data, using data from a new operational mode, suggests that the escape of ionospheric plasma from Mars is very cometary-like, the Martian ionospheric escape dominated by low-velocity (‰10 km/s) tailward streaming plasma. The ions subsequently pick up speed in the deep tail and in the flanks/sheath of the induced magnetosphere of Mars. In addition, the magnetic field above Martian magnetic anomalies governs acceleration process characteristic of highly magnetized plasmas, in the Earth's magnetosphere known as the "Auroral acceleration process".

The variability of the low-energy planetary ion outflow with respect to solar forcing conditions is determined from a statistical study using data from Dec. 2004 to Aug. 2007. Assuming that the the XUV/EUV flux and the solar wind dynamic pressure are the main drivers in solar forcing we find that solar forcing variability leads to outflow rates varying by up to three orders of magnitude. The outflow varies substantially from orbit to orbit, even during stable solar wind conditions. This suggests that solar XUV/EUV may be the most important solar forcing term.

The Role of Plasma Waves in Mars' Atmospheric Loss

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An analysis of recent observations of plasma waves in Mars' ionosphere indicates that plasma processes resulting in ion heating may have had a considerable impact on Mars' atmospheric loss. Plasma waves are generated by the solar wind interaction with Mars. As these waves propagate into the ionosphere they damp through cyclotron resonance with the O+ and O2+ populations in the upper ionosphere leading to substantial ion heating and subsequent O+ and O2+ escape. A combined atmospheric and photochemistry code is used to investigate the loss process. The code demonstrates that this mechanism can support the ~10^24 atoms/s-m^2 O+ outflow suggested by ion observations. Interestingly, the present-day O+ and O2+ loss is primarily constrained by production; there is ample solar wind-driven Poynting flux entering the ionosphere. Therefore intermittent or loss processes without global coverage cannot supply the present-day loss if production limitations are taken into account. We compare ion heating with competing loss processes with consideration of production limitations.

The Effects of Wave Heating Near the Exobase on the Ion outflow

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The processes that control the atmospheric loss to space at Mars remain a subject of intense debate. It has been shown that once a particle reaches the ionopause/magnetic pileup boundary,the solar wind will remove the ions through induced electric fields and pick up processes, hence one can consider these particles lost. Therefore, the main focus is how particles reach the ionopause/magnetic pileup boundary and in which state (neutral or charge). In this paper we focus on how cold ions created at the exobase (<0.1 eV) gain energy (~ 300 K at 300 km) to reach the ionosphere and discuss if the loss of ions are limited to the amount of energy that is transferred to them or if the ion loss is limited by the ion production. This work is based on the code Combined Atmospheric Photochemistry and Ion Tracing code (CAPIT). CAPIT is a two-dimensional code which includes photochemical reactions, Lorentz force, gravity force and wave heating. The CAPIT code can reproduce the Viking Lander temperature and density profiles. Our results indicate that for O + the ion loss at Mars is production limited and that there appears to be abundant energy for wave heating.

Possible Shielding of the Martian Atmosphere from the Early Solar Wind by a Crustal Magnetic Field

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The presence of a core dynamo field during the end of heavy bombardment is difficult to reconcile with the lack of observable remanent magnetic anomalies over large impact basins such as Hellas and Argyre. However, the existence of mid/late Noachian valley networks and extensive erosion in the late Noachian require at least intermittent periods during which climatic conditions were more clement than at present, with surface pressures and temperatures close to, or above, the melting point of H2O. This study investigates the extent to which a remanent crustal magnetic field could have shielded the Martian atmosphere from solar wind stripping, after the cessation of the core dynamo.

We consider the rate of atmospheric loss due to sputtering under several test case scenarios with increasing complexity: 1) no magnetic field, 2) dipole magnetic fields of varying strengths, 3) the modern Martian crustal field, 4) a time varying model including dipole cessation and crustal field evolution. Using the scale height, the density and the pressure as a function of altitude, the number of molecules for a CO2 atmosphere can be calculated for any height and compared to the height of a magnetopause under a variety of early solar conditions (Lammer et al., 2003; Wood et al., 2002). We assume 1-D atmospheric models, but spatial variations in the remanent crustal field are allowed. From these rates of atmospheric loss we determine that a strong crustal magnetic field can partially shield an atmosphere from sputtering. Specifically, the modern Martian crustal magnetic field is sufficiently strong in regions to retard sputtering for an atmosphere as thick as 250-400 km and surface temperature of 273K, assuming ancient solar wind conditions. A strong crustal field may help explain how an atmosphere capable of sustaining surface flow could have survived throughout the Noachian, even after cessation of an internal dynamo.

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Thermosphere and Ionosphere Modeling for Mars

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All the current volatile escape mechanisms for the Mars upper atmosphere are ultimately linked to the structure of the neutral upper atmosphere and ionosphere. Temporal (e.g. solar cycle, season) and spatial (e.g. latitude, longitude, local time or SZA) variations of the Mars thermosphere and ionosphere will result in corresponding variations in escape rates of volatile species impacting the Mars climate history. Upper atmosphere and ionosphere models constitute the first step in a suite of models required to simulate the individual volatile escape processes and rates. These separate models (i.e. MHD, hybrid, exosphere, sputtering and airglow) all require outputs from thermosphere and ionosphere codes to proceed with their simulations. Individual model outputs can be sequentially iterated enabling the individual escape processes to be quantified.

The Michigan Mars Thermosphere General Circulation Model (MTGCM) is being used to supply neutral upper atmosphere and ionosphere fields for the SWIM Model Challenge. The MTGCM itself is a finite difference primitive equation model that self-consistently solves for time-dependent neutral temperatures, neutral-ion densities, and three component neutral winds over the globe [e.g. Bougher et al., 1999; 2000; 2002; 2004; 2006]. Prognostic equations for the major neutral species (CO2, CO, N2, and O), selected minor neutral species (Ar, He, O2, NO, N(4S), and several photochemical ions (e.g., O2+, CO2+, O+, and NO+ below 180 km) are included. These fields are simulated on 33-pressure levels (above 1.32 microbar), corresponding to ~70-300 km (solar maximum conditions), with a 5 degree latitude and longitude resolution. The vertical coordinate is log-pressure, with a vertical spacing of 0.5 scale heights. Key adjustable parameters which can be varied for individual MTGCM cases include the F10.7 or E10.7 index (solar EUV/FUV flux variation), heliocentric distance (orbital variation), and solar declination (seasonal variation). At present, a simple photochemical ionosphere is formulated within the MTGCM [Bougher et al., 2004], based upon the key ion-neutral reactions and rates of /Fox and Sung /[2002], and making use of empirical electron and ion temperatures that are adopted from the Viking mission. Recently completed upgrades for the MTGCM code include a fast NLTE 15-micron cooling scheme, along with the corresponding near-IR heating rates [e.g. Lopez-Valverde et al., 2003].

The Structure of the Ionosphere of Mars as observed with the Mars Express Radio Science Experiment

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The Mars Express Radio Science Experiment MaRS sounds the ionosphere of Mars at microwavelengths and covers altitudes from the base of the ionosphere at 80 km to the ionopause at altitudes between 300 km and 800 km. So far, more than 400 electron density profiles have been observed, mainly at northern latitudes, covering all day- and nighttimes and the polar nights of both northern and southern winter poles. The Mars ionosphere consists of a lower secondary layer M1 at about 110 km, and the main layer M2 at about 135 km altitude, both formed by solar radiation at X-ray and EUV, respectively. The precise and detailed observations of the Mars Express radio science experiment indicates the presence of another layer M3 in the topside above the main layer M2 with a shape of a Chapman function as the transition region between the photochemically induced and Chapman-like M1 and M2 layers and the transport dominated highly dynamical topside region above 200 km altitude. A region of enhanced ionisation below the M1 layer can be observed sporadically and at certain recurrent solar longitude values which is caused by the infall of meteor showers in the atmosphere.

Investigation of the Electron Densities and the Boundary Between the Ionosphere and the Solar Wind at Mars from Local Electron Plasma Oscillations

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In addition to the remote sounding of the ionosphere, the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) instrument on the Mars Express spacecraft, also excites local electron plasma oscillations. This study summarizes the investigation of the local electron density using measurements of the locally excited electron plasma oscillation frequency and shows the evidence of the boundary between the solar wind and the ionosphere of Mars. One of the advantages of this method is that the electron densities can be measured at very high altitudes, where remote ionospheric echoes cannot be detected. Measurements from 503 orbits over the period from August 4, 2005 to July 31, 2007 show that the average electron densities at a given solar zenith angle (SZA) decrease exponentially with increasing altitude. There is considerable variability at a given altitude due to the fact that the data at a specific altitude are obtained from different orbits. On the dayside of Mars, this exponential behavior continues up to altitudes of around 750 km. The scale height, in this altitude region, ranges between 130 km and 190 km. The average electron density is almost constant throughout the dayside in a given altitude range, but decreases rapidly as the spacecraft goes into the nightside.

Plasma oscillations are not observed when the spacecraft is inside the solar wind. The fact that the plasma oscillations do not occur in the solar wind, allows us to determine the boundary between the ionospheric plasma and the shocked solar wind plasma (i.e., the ionopause). The ionopause boundary found using this technique has been verified by composition measurements from the ASPERA ELS instrument on Mars Express. The altitude of the boundary between the solar wind and the ionosphere increases with increasing solar zenith angle (SZA). On the dayside, up to 50o of SZA, most of the points are between 400 and 600 km. As SZA approaches the terminator, the altitude increases to very high values, as much as 1200 km.

Variability of Martian Ionospheric Parameters with Solar Wind Dynamic Pressure from MARSIS Active Ionospheric Sounding

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The MARS Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) is a dual-mode radar sounder on board the ESA Mars Express spacecraft, in orbit around Mars since 25 December 2003. The two modes of the instrument are the Subsurface and the Active Ionospheric Sounding (AIS) modes. The AIS mode was deployed in June 2005 and commissioned by early July 2005. Between 5 July 2005 and 9 February 2006, Earth and Mars were within 45 degrees of azimuth of each other. Using data from 84 orbits during this period, we have inverted about 7000 ionospheric traces, yielding values for three ionospheric parameters: the peak ionospheric plasma density, the altitude of that peak above the surface of Mars, and the plasma scale height. We correlate these data with the solar wind dynamic pressure computed with data from the Solar Wind Electron, Proton, and Alpha Monitor (SWEPAM) instrument aboard the Advanced Composition Explorer (ACE) spacecraft and from the Mars Global Surveyor Magnetometer. These analyses yield no correlation of the solar wind dynamic pressure with peak electron density or with peak electron density altitude; however, there is a small but significant correlation of solar wind dynamic pressure with plasma scale height.

Multi-Instrument Observations of an Aurora-Type Event by Mars Express

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We present a new set of observations of Martian aurora obtained by SPICAM UV spectrometer on board Mars Express (MEX). Several auroral emissions are identified on the Martian night side near crustal magnetic fields. During several orbits consecutive events separated by several tens of seconds are observed, highlighting the role of closed and open field line structures in shaping spatially these events. For most of these events coordinated observations with MARSIS and ASPERA-3 on board Mars Express were possible. ASPERA-3 is composed of an ion mass analyzer (IMA), of two neutral particle imager (NPI and NPD) and of one electron spectrometer (ELS). For these particular events, data from the electron spectrometer were available so that a simultaneous measurement of the precipitating electron flux was possible. MARSIS is a multifrequency synthetic aperture orbital sounding radar which monitors in particular the Total Electron Content (TEC) and which was operating for some of these events. At the end, SPICAM UVS is a UV spectrograph covering the spectral range between 110 and 300 nm and which measures the atmospheric glow. It is this latter instrument which clearly provides the spectral evidence of the occurrence of an auroral-event. In order to avoid any ambiguity on the positions of the simultaneous measurements, we used orbits of MEX during which SPICAM UVS field of view was nadir oriented. This new set of observations shows quite strong coincidences between the occurrence of energetic precipitating electrons into the Martian atmosphere, the increase of the TEC, the presence of crustal magnetic field anomalies and auroral-type glow. Following the definition of Brain et al. (2007) of open / closed magnetic field lines, we observe that the aurora detected by SPICAM UVS occur on open field lines. This conclusion therefore suggests a significant relation between aurora events at Mars and the presence of cusp like magnetic field line structures.

Horizontal Gradients in the Nighttime Ionosphere of Mars and Their Electromagnetic Consequences

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Mars lacks a global magnetic field, but it does have intense and localized crustal fields yielding a complex magnetic topology. Where the crustal field has a nearly radial orientation, there is a tendency for the field lines to connect with the IMF, forming cusps that provide a conduit for ionospheric plasma to escape and for solar wind plasma to precipitate into the atmosphere. On the nightside one expects ionization due to solar wind electron precipitation in regions of open (radial) field lines at cusps and an absence of ionization in closed (horizontal) field regions. Recently observed accelerated electrons, which appear to be associated with cusps surrounding the strongest custal fields, will also create very localized regions of enhanced ionization.

Using an electron transport model, we calculate the electron density of the nighttime ionosphere of Mars and its spatial structure. As input we use Mars Global Surveyor electron measurements including an interval when accelerated electrons were observed. Precipitating accelerated electrons increase the maximum ionospheric number density by a factor of 3 over that produced by typical tail electrons. These regions of enhanced ionization are localized and occur near magnetic cusps. Horizontal gradients in the ionospheric electron density on the night side of Mars can reach ~4000 per cc over 200 km or ~20 per cc per km. Even sharper gradients occur near plasma voids; the electron density can go from effectively 0 per cc to ~5000 per cc over a few km.

Such strong gradients in the plasma density have several important consequences. These large pressure gradients will lead to localized plasma transport perpendicular to the ambient magnetic field and will generate horizontal currents and electric fields which will in turn lead to localized Joule heating. Additionally, transport of ionospheric plasma by neutral winds, which vary in strength and direction as a funcion of local time, can generate horizontal currents where the ions are collisionally coupled to the neutral atmosphere while electrons are not. Closure of the horizontal currents and electric fields may require the presence of vertical, field-aligned currents and fields which may play a role in high altitude acceleration processes.

Martian Exospheric Structure and Influences

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Following the collapse of its permanent magnetic field, the Martian atmospheric corona and thermosphere were exposed to solar wind ions and locally produced pick-up ions. This bombardment can cause significant heating of the corona and the loss of atmosphere, a process often referred to as atmospheric sputtering. This occurs along with heating and escape due to photo-processes. Estimates of the effect of atmospheric sputtering on the Martian corona have varied considerably since they depend critically on out knowledge of the feedback processes and of the history the solar EUV flux and the solar wind plasma pressure. In this talk we will review the calculations of these effects and compare them to the photo-induced processes.

Hot Neutral Corona at Mars

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The flow of solar wind and local pick-up ions onto the extended neutral corona of Mars can affect the long-term evolution of its atmosphere through the formation of hot coronas and nonthermal loss to space. Such corona, in turn, alters the incoming solar plasma by mass loading the solar wind with newly created ions and by charge exchange collisions.

The role of the exothermic photochemistry in determining the production and loss to space of the suprathermal (hot) hydrogen, carbon, nitrogen, and oxygen atoms in the upper atmosphere of Mars will be discussed. The energy spectra of hot atoms formed in the direct photo- and electron impact dissociation of atmospheric molecules, exothermic ion-molecular chemistry, and, in particular, in the dissociative recombination of molecular ions were calculated for different solar activity conditions. Detailed calculations of the kinetics and transport of hot neutral atoms in the transition region (from thermosphere to exosphere) of the upper atmosphere of Mars are presented. These calculations were conducted with 1D DSMC numerical model allowing: (i) to obtain the kinetic energy distribution functions of hot neutral atoms in the corona, and (ii) to estimate the energy exchange between the ambient neutral atmosphere and suprathermal neutrals near the exobase. Comparison with the previous models shows that the current model is characterized by higher escape fluxes and higher abundances in the outer regions of the neutral corona at Mars (Krestyanikova and Shematovich 2006).

The current models of hot oxygen distributions and the escaping fluxes in the coronas of terrestrial planets (Krestyanikova and Shematovich 2006; Shematovich et al., 2006) will be compared and discussed, and their manifestation as energetic neutral atoms (ENAs) detected in the recent space missions will be also considered.

The 1859 Superstorm: How Large Was It?

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A starting point in understanding the history of extreme solar wind events and how it might affect other planets is to study the history of Earth's geomagnetic superstorms. Geomagnetic storms, from about the mid-1800's to the present, can be ranked ordered in terms of their magnetic crochet amplitude, SEP fluence, Sun-Earth disturbance transit time, storm intensity, and low-latitude auroral extent. The top-ranking events in each of these disturbance categories comprise a set of benchmarks for extreme space weather. While the 1859 event has close rivals in each of the categories it is only superstorm that is near the top on all of these lists. A closer look at the 1859 storm should provide some measure of the upper bounds of extreme space weather events in the solar system. In addition to scientific measurements such as ground-based magnetometers, newspapers of that era provided an untapped wealth of first hand observations giving time and location along with reports of the auroral forms and colors. The evolution of the aurora over the great storm period will be shown and is accomplished by combining the observations from many available sources in 30-minute intervals. The results of this study show a truly remarkable event occurred that is nothing like anything anyone alive has seen. The great geomagnetic storm of 1859 extended over a period from August 28 through to September 3. The extent of the aurora was so great that it was reported by sailors on ships in the Gulf of Panama. At its height, the aurora was described as blood red and was so bright that one could read a newspaper by its light on the moonless night. A significant portion of the world's 140,000 miles of telegraph lines were unusable for a number of hours due to the extensive ionospheric currents. From these results we can deduce that two massive coronal mass ejections occurred on the sun within about 24 hours with the second one moving at about 2500 km/s which is an order of magnetic greater than the average solar wind speed.

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Modeling the Interaction

The SWIM Model Challenge

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In the past decade the number, variety, and complexity of models of the Martian solar wind interaction have increased greatly. At least ten different modeling groups have simulated the Martian interaction in the past several years using physical assumptions ranging from simple MHD to hybrid. Other "value-added" models have employed some combination of a basic simulation and an added process such as electron transport or ion trajectory tracing. Increases in computational resources have allowed substantial improvements in the physics that can be investigated; for example some models now have spatial resolution comparable to ionospheric scale heights.

These simulations have been applied to investigate a variety of processes and features of the Martian system, including the global shapes of plasma boundaries, magnetic field structure and topology, ionospheric structure, the effects of different drivers, and particle transport. They have also been used to estimate atmospheric escape rates in the present epoch and over Martian history. It is becoming increasingly important that these simulations be compared rigorously to each other and to spacecraft observations to determine where and under what conditions the different model assumptions are
appropriate.

We present the results of a community-wide invitation to simulate the Martian solar wind interaction for a common set of input conditions using many different models. We will discuss the input conditions, as well as the model assumptions used for each participating model, which include one or more representatives of MHD, Hall MHD, hybrid, and value-added modeling groups. We will show detailed comparisons of the model results to each other, including 1-D cuts, 2-D cuts, and escape rates of planetary O+. We will summarize the lessons learned from the model challenge and the prospects for future model comparisons.

Mars Crustal Magnetism: Modeling and Interpretation

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Mars Global Surveyor's (MGS) magnetometer/electron reflectometer (MAG/ER) observed regions of strongly magnetized crust on Mars [1]. The strongest crustal fields were observed in a series of linear bands in the ancient southern highlands [2] but significant fields were observed over most of the planet. The most accurate magnetic field maps were compiled using data acquired during MGS mapping orbit at approximately 400 km altitude, owing to the large number of observations and nearly complete global coverage. Connerney et al. [3] compiled a high-resolution map (mapping orbit altitude) using (only) nightside data and along-track differencing to maximize signal fidelity. Interpretation of this map yields valuable insight regarding crustal evolution on Mars, the role of plate tectonics, and a history of resurfacing by massive lava flows. However, one often desires knowledge of the field elsewhere – particularly nearer to the surface, directly sampled during pre-mapping (between 90 and 200 km) and using the ER technique for remote mapping of field magnitudes. The challenge is to find an appropriate technique for extrapolation of the vector magnetic field to lower altitudes (e.g., 200 km) to aid interpretation of other observations (e.g., ER samples, Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) echoes, auroral emissions). Methods used to infer magnetic fields include direct inversion (e.g., ref. [2]), Fourier techniques for downward continuation [4,5] as applied to survey data and spherical harmonic modeling (e.g., Cain et al) applied to global observations. We will discuss the pros and cons of each in application to Mars research.

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The Effect of Martian Crustal Magnetic Fields on Solar Energetic Particles

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The strong crustal magnetic fields at Mars should affect the distribution of energetic charged particles (e.g., solar energetic particles and galactic cosmic rays) in the Martian atmosphere and across the Martian surface. We present preliminary results from our attempts to model these interactions. We discuss the computational framework used (based on the GEANT4 software toolkit) and the different model components necessary to track the propagation of the particles from interplanetary space down to below the Martian surface. We explore the impact of several significant parameters such as the distribution of the crustal magnetization (i.e., depth, thickness, coherence scale, magnetization strength and direction, including both strong and weak crustal field regions), the atmospheric conditions, and the solar activity level. Within this large parameter space, we present preliminary results and discuss the implications for robotic and human exploration of Mars.

Current State of Hybrid Modeling: Strengths, Weaknesses and Future Plans

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Quasi-neutral hybrid (QNH) model is a self-consistent modeling approach that includes positively charged particles and an electron fluid. The approach has received an increasing interest in space plasma physic research because it makes it possible to study several plasma physical processes that are difficult or impossible to model by self-consistent fluid models, such as effects associated with ions' finite gyroradius, the velocity difference between different ion species, or the non-Maxwellian velocity distribution function. By now three dimensional QNH models have been used to study the solar wind interaction with both non-magnetized (Mars, Venus, Titan, asteroids, the Moon and comets) and magnetized (Mercury and asteroids) Solar System bodies. In this paper we summarize strengths and weaknesses of QNH model approach, and discuss about possible future model developments to deepen our understanding of the Mars - solar wind interaction by hybrid models.

Current State of MHD Modeling: Strengths, Weaknesses and Future Plans

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The Martian ionosphere interacts directly with the solar wind. It is important to include a realistic and self-consistent Martian ionosphere in a Mars global model in order to describe the interaction process adequately. The localized remanent magnetic field and the relatively small scale of Martian ionosphere impose further challenges to the numerical modeling of the global interaction. Kinetic processes such as ion pick-up are also important and could create features beyond the fluid models due to the large gyroradii of the heavy pick-up ions. In this presentation, we present current state of MHD modeling, including strengths, weaknesses and future plans.

Why Should We Compare Models?

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Computer models are increasing in complexity along with the increase in the availability of computational resources. The increased complexity is seen both in the models where more physical processes are included, and in the hardware with the increasing use of parallel computers. This allows for models that are more accurate descriptions of natural systems. On the other hand, the effort and expertise needed to correctly construct and implement numerical models has increased. This increasing complexity also increases the risk of errors in the results. Errors can occur at different stages of a numerical model - in the construction of the mathematical model, in the construction of the numerical algorithm, or in the implementation of the numerical algorithm. A fundamental requirement of the scientific method is reproducibility. Current practices in numerical modeling makes reproduction of scientific results difficult, due to insufficient descriptions of the models and the fact that each researcher chooses slightly different models, parameters and conditions. The outcome is that the final results for different numerical models (investigating the same physical process) will be different, and the reasons will be unknown. In view of the fact that errors are inevitable in any numerical model, this poses a problem. Current practice include testing of the numerical models by each individual research group, and that is necessary, but not sufficient to overcome this problem. Often only global validation is performed, looking at fundamental properties such as consistency with conservation laws, e.g., that mass and energy are conserved. Also, the complexity of the modeled processes is often such that there are no simple analytical solutions or approximations available to compare the numerical results with. Finally, the peer review system does not, and is not suited for, handling testing of the numerical model that supports a scientific conclusion.

Another important issue in numerical modeling is that of standardization. both standardization of data formats for the simulation outputs, and standardization of software interfaces, services, and libraries. The former allows scientists not directly involved in modeling easy access to the modeling results. The latter allows software reuse, internally, and externally between research groups. Current lack of standardization leads to difficulties in analyzing simulation outputs, and duplication of software development efforts.

Our proposed strategy to tackle the problem of reproducibility and standardization of numerical models in planetary science is to initiate model intercomparison activities. The benefits of model intercomparison activities are many, among them (1) Ensures that the science is reproducible (2) Model errors will be found (3) Standardized data formats for the simulation outputs, making simulation results easier available to data analysts that are not directly involved in simulations. This will also stimulate the comparison between observations and the results of numerical models. (4) Standardized software interfaces, services, and libraries. This will enable software reuse, e.g., of visualization tools and data I/O libraries. It will also simplify the coupling of models, e.g., magnetosphere, exosphere, or thermosphere models. (5) Collaboration between different research groups, using different codes, will increase and provide new research groups in the field with a starting point and reference solutions, and (6) New diagnostics will be found, i.e. new ways of looking at model results.

3D Hybrid Simulations: A Global Picture of the Martian Plasma Environment

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A three dimensional hybrid code for simulation of the solar wind interaction with the ionosphere of planet Mars using curvilinear coordinate systems was developed. Finally, a parallized version of the code was optimized for a MPI
cluster. In this code the ions are represented by macroparticles, whereas the electrons act as a massless, charge neutralizing fluid. The spatial discretization of the Maxwellian equations in curvilinear coordinates was adopted from similar full particle codes, whereas for the time integration the cyclic leapfrog method with a modified current advancement method including magnetic field subcycling is used. The code was successfully applied to the interaction of the solar wind with weak comets, Mars and Titan. For simulation of Mars the neutral oxygen profile was calculated by a thermospheric model
which is self-consistent with respect to the neutral gas temperature and several other heating processes. We have modeled a three dimensional oxygen ionosphere by a Chapman layer model. The 3d hybrid model allows an analysis of the Martian plasma environment as well as non-thermal loss rates of oxygen. The three main loss processes by ion pick-up, plasma-clouds and momentum transfer are automatically included. Different boundaries emerge from the interaction of the solar wind with the continuously produced
heavy-ion plasma of the ionosphere, which could be identified as a bow shock, ion composition boundary and magnetic pile up boundary. The simulation results regarding the shape and position of these boundaries are in good agreement with the measurements made by Phobos-2, MGS and Mars-Express spacecraft. Further consequences are rays of planetary plasma in the tail and heavy ion plasma clouds, which are stripped off from the dayside ICB region by some instability.

Hybrid Simulations of Mars: Results from Data Specific Simulations for SWIM

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We began 3-D hybrid simulations of Mars in 1991 and have continued to this day. The basic scheme used is a scheme that is energy conserving and has been tested continuously since the 1980's. Through this time the computers have improved in size and speed. The data from Mars missions has increased enormously, as the instruments have continued to improve. Finally, the complexity of the simulation models within the hybrid code HALFSHEL, as continued to increase. The simulations are now to the level that significant effort should be expended to compare to the data.

In this paper the results of hybrid simulations of the Mars test problem will be presented coupled with comparisons of this simulation with other Mars simulations we have undertaken. The talk will cover the models within the hybrid code, the assumptions that have been examined, and numerical issues. As the comparison formats are refined, the results will also be presented in this format and compared to data sets as they are provided.

A Three-Dimensional MHD Model of the Solar Wind Interaction with the Ionosphere of Mars: Coupling with a Time-Dependent Exosphere Model

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The solar wind interaction with the ionosphere of Mars is modeled in the framework of three-dimensional multispecies magnetohydrodynamics (MHD). The finite-volume total variation diminishing (TVD) scheme on an unstructured grid system is used to solve the problem. In our model fourteen ion species (O+, O2+, CO2+, NO+, CO+, N2+, N+, C+, He+, H2+, H+, Ar+, Ne+, and Na+) and related chemical reactions and collision processes in the ionosphere are considered. The entire interaction region (from 100 km altitude to 9 planetary radii) is included with a sufficiently fine grid spacing (3.5 km in the lower ionosphere) to simultaneously solve the fine-scale structures and dynamics of the Martian ionosphere and the large-scale solar wind interaction. In this study we have coupled the MHD model with a time-dependent exosphere model by Kaneda et al. [2007], so that we can address dynamical variations of nonthermal escapes of neutrals and ions (including minor ion species) in response to variations in solar wind conditions. The numerical schemes used in our model are quite robust.

We have confirmed that they work stable with solar (stellar) wind parameters ranging from N=1 to 100000 /cc and V=300 to 2000 km/s. Our model is applicable not only to Mars, but also to Venus, Mercury, Earth, and extra-solar planets under extreme stellar wind conditions.

Multi-Fluid Simulations of Flux Ropes in the Martian Magnetotail

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Flux ropes are frequently observed at both the terrestrial magnetopause and in the terrestrial magnetotail. 3D multi-fluid simulations of the solar wind interaction with Mars indicate that flux ropes are also present in the Martian magnetotail. The flux ropes can form and transit through the tail on time scales of minutes and have sizes on the order of 500-1000 km. For the cases studied, flux ropes preferentially form when the strongest magnetic anomalies are located near midnight. The simulation results indicate that passage through a flux rope by a spacecraft would lead to an interved-V type ion spectrum with peak ion energies on the order of a few keV.

Velocity-Space Distributions of O+ Pickup Ions Around Mars

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We report a newly-created highly-parallelized global test particle model for resolving the pickup oxygen ion velocity and spatial distribution around Mars. The background magnetic and convection electric fields are calculated using a three-dimensional multi-species MHD model. Pickup ion generation is obtained through photo-ionization, charge exchange collisions, and solar wind electron impact ionization. The most novel feature of our model is that more than one billion test particles are launched in the simulation domain in total, enabling examination of the pickup ion flux distribution in velocity space. Model results can be used as a tool to investigate the Mars-solar wind interaction in a unique way because the velocity space distribution carries important information about the planetary atmospheric escape. Trajectory tracing in a reverse direction is capable of locating the source regions of particles passing through any spatial point. Given the fact that the particle transport is strongly affected by the electromagnetic environment, the velocity space distribution can thus be used as a unique tool to probe the Mars-solar wind interaction.

Spatial Distribution of Pickup Oxygen Ion Losses at Mars

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The Mars-solar wind interaction is investigated through a combination of two global models: a multi-species MHD model and a newly-created highly parallelized test particle model. The test particle model is the major research tool in this study to monitor the production and loss of pickup oxygen ions. The MHD model supplies the Martian electromagnetic fields, in which the motions of individual test particles are traced. The ion kinetic effects, which are particularly important at Mars due to its weakly magnetized environment, therefore can be addressed more appropriately. In this study, the spatial distribution of pickup oxygen ion losses at Mars is simulated through the combination of the two models. It is found that the polar region is a very important pickup ion loss channel in addition to the tail region, while the Martian tail is traditionally considered as the only major ion loss channel. This finding will have a profound impact on our current understanding of the long-term planetary atmosphere evolution. In addition, results for the SWIM modeling challenge from the test particle model will be highlighted and discussed.

Poster Presentations

Structure and Processes of the Martian Plasma Environment

Observation of a Strong Flux Rope Near Mars

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Flux ropes have previously been reported in two general locations near Mars. Ionospheric flux ropes analogous to those extensively studied near Venus have been observed in the Martian dayside ionosphere (Cloutier et al., 1999; Vignes et al., 2004). Flux ropes indicative of magnetic reconnection have also been observed near nightside current sheets (Eastwood et al., 2007). All previously reported flux ropes have relatively low magnetic field strengths at their peak (no greater than 30 nT and typically closer to 5-10 nT).

Here we report the observation of a very strong (~180 nT) flux rope near the Martian terminator observed by the Mars Global Surveyor (MGS) magnetometer and electron reflectometer (MAG/ER). To our knowledge this is the strongest flux rope reported at Venus or Mars, and may be the strongest sampled anywhere in the solar system. The flux rope was observed downstream from regions of strong crustal magnetic field, at a time of moderately high solar wind pressure shortly after a change in the direction of the draped IMF. Minimum variance analysis of the rope shows that it is nearly force-free. We will present the results of simple model fits to the flux rope, and analysis of the electron energy and pitch angle distributions during the event. The rope clearly formed through interaction of the draped IMF and crustal magnetic anomalies, possibly as a consequence of magnetic reconnection.

Space Environment Parameters Derived from MGS MAG/ER for You to Use

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The Mars Global Surveyor (MGS) Magnetometer/Electron Reflectometer (MAG/ER) package returned data from near Mars for more than 9 years. Besides providing the in situ measure of the vector magnetic field and electron flux, the MAG/ER team has devised other useful measures of the Mars space environment from the MAG/ER data. This poster describes those quantities, how they were derived, and where you can access them for use in your own research. 1) From the magnetic field strength in the pileup region, a proxy for upstream solar wind dynamic pressure is established on an orbit-by-orbit basis. 2) The draping direction of the interplanetary magnetic field (IMF) is determined by looking at the field orientation on the dayside in a small latitude range where crustal fields appear to have minimal effects. 3) From the instrument background on the ER, the MAG/ER team has identified solar energetic particle (SEP) events at Mars. These derived values may be useful since no upstream monitor may be available for these values. Alternatively, they provide an additional data point for studies of solar wind propagation.

Large Amplitude Density Fluctuations at High Altitudes in the Martian Ionosphere and Their Possible Relationship to Atmospheric Loss Processes

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Very accurate high time resolution measurements of the electron density in the Martian ionosphere can be obtained from the excitation of local electron plasma oscillations by the MARSIS (Mars Advanced Radar for Subsurface and Ionospheric Sounding) radar transmitter on the Mars Express spacecraft. At high altitudes, above about 400 km, these electron densities almost always show large amplitude (plus or minus 50%, or more) highly irregular fluctuations on time scales of tens of seconds to minutes. The exception is when the spacecraft is in the solar wind, where the plasma oscillations are typically not observed. The spectrum of the density fluctuations typically follows a power law that decreases rapidly toward higher frequencies, with a power law index of about -1.6 ± 0.2, very close to the Kolmogorov spectrum for isotropic turbulence. Our initial interpretation is that these fluctuations are driven by a velocity-shear interaction (i.e., the Kelvin Helmholtz instability) between the solar wind and the ionosphere, although other possibilities such as a response to fluctuations in the upstream solar wind may play a role. If the fluctuations are driven by the Kelvin-Helmholtz instability, these fluctuations may be the direct signature of the mechanism by which ionosphere plasma and thereby the atmosphere is stripped away from Mars by the interaction with the solar wind.

Evidence for Collisionless Magnetic Reconnection at Mars

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Magnetic reconnection is a fundamental plasma process that enables the rapid conversion of magnetic to particle energy and is important in astrophysics as well as solar, space and planetary physics. Using data from the Mars Global Surveyor (MGS) spacecraft in combination with simulations of reconnection, we present the first direct evidence of collisionless magnetic reconnection at Mars. The evidence indicates that the spacecraft passed through the diffusion region where reconnection is initiated and observed the magnetic field signatures of differential electron and ion motion that uniquely indicate the reconnection process. These are the first such in-situ reconnection observations at an astronomical body other than the Earth. Reconnection may be the source of Mars' recently discovered auroral activity and the changing boundaries of the closed regions of crustal magnetic field.

Energetic Neutral Atom Production due to Charge Exchange at Mars

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An energetic neutral atom (ENA) is formed in a charge exchange process where an energetic ion picks up an electron from a neutral particle. Mars, having no notable global intrinsic magnetic field, cannot shield the neutral particles in its atmosphere from the flow of energetic solar wind protons. Consequently, an extensive production of energetic hydrogen atoms (H-ENAs) occurs. In this study a 3D hybrid (kinetic ions, fluid electrons) quasi-neutral particle-in-cell (PIC) plasma simulation was developed to investigate the production of H-ENAs due to collisions with atomic oxygen (O) and neutral nitrogen molecules (N2) in the transition region of the Martian near-space environment.

In order to better study the interaction between Mars' exosphere and ionosphere, multi-species reactions such as ionization by photons, electron recombination and charge exchange are self-consistently included in the simulation model. The major ions included are exospheric solar wind protons and the planetary O2+, CO2+, O+, and N2+ ions. The motion of the precipitating particles in the atmosphere is followed, and collisions with atmospheric ions and neutrals (O, CO2, N2) are governed by a Monte Carlo algorithm. The fluxes of escaping H-ENAs due to charge exchange collisions with O and N2 are presented.

The Dependence of Magnetic Field in the Perturbed Mars Wake on the Solar Wind Parameters and the Solar Activity

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Using the Phobos~2 data obtained on circular orbits at the 2 radiuses of Mars we studied how the magnitude of the perturbed magnetic field in the Mars wake depends on the solar wind parameters and solar activity. It was established that the value of the perturbed magnetic field in the Mars wake varies from several nT up to tens nT and depends on the density of the ambient solar wind. The dependence is linear. This is the more the density, the higher the value of the perturbed magnetic field in the Mars wake. It is necessary to point out that the same dependence from the velocity is absent. Besides, there is a relation between the width of the disturbed field of the Mars wake and the solar wind density. The width enlarges with increasing of the density.

Since 1960, the most solar activity was on March 6-19, 1989. We examined the longest uniform set of data obtained on circular orbits from March 1 until March 26, 1989 to establish the relation between the solar activity and the signatures of the Mars wake.

Ion Beam Events Observed by Mars Express Aspera-3

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The occurrence of heavy ion beam events in the near Mars space has been investigated. The most extensively studied ion beams have energies of a few hundred eV, and are observed inside the induced magnetosphere boundary. Previously it has been found that the ion beams are correlated with the clock angle of the interplanetary magnetic field. No correlation of the ion beam events with the presence of crustal magnetic fields has been observed. We present updated studies of the relation between ion beam events and solar wind clock angle, the presence of magnetic anomalies, F10.7 cm fluxes measured at Earth and the subsolar magnetic pressure. We furthermore include also the low energy ion fluxes, and an analysis of the direction and temperature of the ion beams.

Solar Wind Erosion of the Polar Regions of the Mars Ionosphere

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Measurements conducted with the ASPERA-3 instrument of the Mars Express spacecraft provide data of plasma fluxes that stream away from the polar regions of the Mars ionosphere with energy spectra whose peak value increases with distance from the planetary surface. The observed energy distribution reveals a velocity boundary layer with ionospheric plasma that is eroded from the polar regions of the Mars ionosphere and that extends in the downstream direction within a geometry similar to that present along the polar flanks of the Venus ionosheath. The direction of motion of the ionospheric particles in those fluxes is close to that of the solar wind velocity and is not mainly oriented in a transverse direction as would have been expected if they were solely accelerated by the convective electric field of the solar wind. The ionospheric plasma eroded and deviated by the solar wind within the boundary layer forms a region whose shape is compatible with that of the asymmetric Mars plasma halo that was inferred from the X-ray emission measured with the reflecting grating spectrometer (RGS) of the XMM-Newton telescope. The latter emission is interpreted as resulting from thermal dissipative processes associated with the transport of solar wind momentum to the polar upper ionosphere where both plasma populations interact with each other. Different conditions are applicable throughout most of the dayside hemisphere where the enhanced interplanetary magnetic field intensities that are observed within the ionosphere should make less efficient the interaction of the oncoming solar wind plasma with the ionospheric material.

Nonlinear Waves in the Plasma Environment of Mars

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The Martian magnetosphere is basically formed by the interaction of the solar wind with the exosphere/ionosphere of Mars and is filled with plasma of different ion species. Differential velocities among them in the process of mass loading lead to the generation of a variety of waves in a broad range of frequencies which have been measured by spacecraft instruments aboard of Phobos-2, Mars Global Surveyor and MarsExpress. Thus, the plasma environment represents a huge laboratory for the study of different aspects of multi-ion waves. Especially, the observation of large-amplitude LF waves has stimulated the investigation of nonlinear waves. It is shown that a new type of

nonlinear stationary structures occurs as result of mode splitting which is caused by the minor ion population near the cross-over frequency creating a point in the omega-k space where phase and group velocity coincide. The so-called oscillitons are characterized by an oscillating spatial structure superimposed on the spatial growth or decay associated with the single-ion soliton. By solving the full nonlinear Hall-MHD equations describing stationary multi-ion flows, solitons and oscillton profiles are obtained in different parameter regimes. Oscillitons may also exist in plasmas which are linearly unstable. As an example, oscillitons are considered in an ion-beam plasma which is relevant for the planetary foreshock region. Additionally, results of non-stationary models are discussed.

Transient Events in the Solar Wind Interaction of Mars due to the Strong Crustal Fields

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The strong crustal magnetic fields on Mars present a variable obstacle to the solar wind, and the interaction of the solar wind with these crustal sources is expected to produce transient events seen in particle densities, distribution, and energies. In this study, we model the character of these local temporal events by perturbing the solar wind interaction with an unmagnetized body. We find that a condition of stable, trapped radiation in the vicinity of the crustal fields is not likely but local trapping of electrons on ?short? time scales is expected over the regions of strong crustal magnetic fields. Interestingly, both daytime and nighttime auroral events are observed in the vicinity of these regions. In addition, the transport along reconnected field lines of ionospheric plasma generated on the day side over the crustal source regions, are hypothesized to account for the electron flux enhancements and magnetic field perturbations observed on the nightside of Mars by Mars Global Surveyor.

Mars Surface Magnetic Observatory: A Geophysical and Environment (GEP) Experiment for ExoMars

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Mars Surface Magnetic Observatory (MSMO), an experiment planned as part of the Geophysical and Environment Package (GEP) on ExoMars, is likely to provide the first magnetic field measurements ever performed at the surface of Mars. It will provide unique information in a wide spectrum of scientific applications in accordance with the ExoMars scientific objectives.

In the solar wind interaction with the Martian atmosphere currents are generated to shield the ionosphere from the piled-up field above. With the MSMO we will investigate the efficiency of the shielding and the morphology of the ionospheric currents. While the interaction has been observed from orbiting spacecraft, the MSMO will provide the first continuous measurements from a low altitude vantage point. If a landing site close to one of the crustal magnetic anomalies is selected we will also be able to study the currents created in the direct interaction between the solar wind and the crustal field .

The magnetometer proposed for the MSMO experiment derives from instruments flown in dedicated geomagnetic missions (Ørsted, CHAMP, SAC-C). The current magnetometer is a miniaturised version of the earlier instruments and is baselined for the ESA PROBA-2 and Swarm missions. In order to determine the orientation of the measured magnetic field vector the MSMO-magnetometer is combined with an attitude sensor consisting of two gravity sensors.

Investigating the Solar Wind - Mars Atmosphere Interaction with Energetic Neutral Atoms

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Mars has no significant intrinsic magnetic field to shield itself from its surrounding plasma environment. The solar wind thus directly interacts with the planetary ionosphere and atmosphere. One of the by-products of this close encounter is the production of energetic neutral atom (ENA) emissions. The ASPERA-3 instrument on the Mars Express mission of ESA is equipped with electron, ion, and neutral particle sensors. During the course of the Mars Express mission ENAs have been observed with ASPERA-3 originating from various places of the Martian particle environment: ENA jets from the sub-solar point, ENA albedo from sun-facing side of Mars, ENAs from the magnetosheath, and ENAs from the tail region. These set of measurements allows for a global picture of the Solar WInd - Mars Interaction. In addition, comparisons with model calculations show agreement at the qualitative level (the images) as well as on the quantitiative level (ENA fluxes).

Introduction to YH-1, the First Chinese Mars Orbiter

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China's first Mars orbiter, namely YH-1, will be launched in October 2009 as part of a joint mission with Russia. YH-1 is supposed to be lifted with Russian Phobos-Grunt mission and inserted into the orbit around Mars, with an apocenter 80000 km, and the percenter height of 800 km. The inclination of the orbit would be ± 5 degree to the Mars' equator. The small Chinese satellite will explore the Martian space environment. The main scientific objectives include: (1) detailed investigation of plasma environment and magnetic field; (2) study of martian ions escaping processes and possible mechanisms; (3)ionosphere occultation measurement between YH-1 and Phobos-Grunt focusing on sub-solar and midnight regions. (4) observation of sand storms. The scientific payload consists of the plasma package, flux-gate magnetometer, optical imager, and occultation receiver. The lifetime of YH-1 is designed to be one year.

Dependence of Ion Density and Velocity Distributions on the Motional Electric Field

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The recent observations by Mars Express (MEX) and Mars Global Surveyor observed successfully the solar wind-Mars interaction region including some boundaries such as the bow shock, the induced magnetosphere boundary (IMB), and the photoelectron boundary [Lundin et al., 2004]. Using the ion density and velocity data observed by Ion Mass Analyzer of ASPERA-3 on MEX from Jun.7 2004 to Mar.13 2006, together with the clock angle of the IMF estimated from the magnetic field data by Mars Global Surveyor, we plotted the distribution of the ion density and veloity on the plane including the motional electric field. Proton velocity vector distribution is asymmetric by the direction of the motional electric field. In this paper, we study the effect of the motional electric field on the plasma around Mars.

Comparative Planetology

Tomographic Reconstructions of the Solar Wind from Heliospheric Remote Sensing Observations: Density and Velocity Predictions at Mars.

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Remote sensing observations of the solar wind over a large range of elongations (angular distances from the Sun) provide a data base for modeling the solar wind in the inner heliosphere, out to and beyond the orbit of Mars. We use interplanetary scintillation (IPS) data from meter-wavelength radio systems (from STELab, Univ. of Nagoya, Japan), and Thomson scattering brightness data (from the Solar Mass Ejection Imager, SMEI) in tomographic reconstructions of the density and radial outflow velocity of the solar wind, both in corotating structures and in transient features such as coronal mass ejections (CMEs). We describe our 3D reconstruction technique that relies on the changing perspective view of solar wind structures from solar rotation and outward flow as observed from Earth. The technique allows reconstruction of solar wind structure of CMEs at a resolution determined by the angular and temporal resolution of the remote sensing data. We obtain estimates of solar wind parameters at specific heliospheric locations (e.g., Earth, Mercury and deep space spacecraft such as Ulysses, and Stereo A and B) as a time series extracted from the 3D density and velocity solutions. Here we discuss the density and velocity obtained at Mars in comparison with the dynamic pressure at Mars as modeled from magnetometer data taken by the Mars Global Surveyor (Crider et al., J. Geophys. Res. 108(A12), 1461, 2003). We emphase variations in dynamic pressure that are related with CMEs observed in the remote sensing observations.

Noctilucent Clouds as Multiplanetary Phenomena and Interaction With Solar Wind

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Noctilucent clouds(NLC's) have been observed on the Earth since the late 19th century and this year their was a report that NLC's have been seen on satelite images from Mars. This phenomena could give models for how NLC's are formed and how or if differences in the distance from the Sun, different flux rates, and potential effects of the Solar wind. NLC phenomena has different theories of cause and this might include solar wind interaction. NLC's are high altitude clouds that appear on a seasonal basis in high latitudes. NLC might be a phenomena that occurs in other solar system bodies aside from just the Earth and Mars. Now baseline data can be expanded to see solar wind interaction.

The Specific Signatures of the Solar Wind-Phobos Interaction as the Evidence of the Phobos Magnetic Field

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The arguments supporting the possibility for Phobos being a magnetized obstacle are examined. It is the data which were acquired during the closest fly-by of the Phobos mission and which are consistent with the manifestations of the magnetic field of Phobos.

The magnetic field enhancements observed during the closest fly-by were correlated with the approaches of the spacecraft to Phobos. The magnetic field signatures depended on the plasma parameters of the solar wind and were different for low and high plasma density. For higher density the pile up was observed that became significant when the ion skin depth was comparable to the actual size of Phobos obstacle that permits rough to estimate the size of Phobos

obstacle. This size is about 150--170 km. Source with equivalent magnetic moment M' = 1015 A m2 in Phobos leads to the development of such obstacle to the solar wind flow.
The another estimation with using the equation of pressure balance for the solar wind and the magnetic field of Phobos at the magnetopause gives the same value of the magnetization of Phobos for the lower density plasma. Phobos rotates around Mars turning to it by the same side. This peculiarity of the rotation of the magnetized Phobos around Mars leads to the observation of the magnetic field signatures which, especially the direction, are phase locked with Phobos rotation rate.

The Possible Reasons of the Secular Acceleration of Phobos

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The observed positions of Phobos are in good agreement with predictions from orbital motion models derived from observations with the notable exception that Phobos is gradually getting ahead of its predicted location and the discrepancy is growing by an amount which averages 0.8 s/yr. The orbit of Phobos is experiencing the secular acceleration. The probable mechanisms responsible for the secular acceleration are examined. The estimates of the orbital acceleration due to a magnetization of Phobos are made.

The Specific Signatures of the Solar Wind-Phobos Interaction and Conditions of their Observation from "Phobos 2 " **Mission***

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Using magnetic field and plasma data acquired during "Phobos-2" mission in regions which have not been explored before, we examine the solar wind interaction with Phobos. Two types of specific signatures of the solar wind - Phobos interaction have been observed depending on the distance of their observation.

There are the signatures in the fly-by data set when the spacecraft was located permanently in a vicinity of Phobos and the distances between them were 180--400 km. Two types of the disturbances are observed due to various parameters of the solar wind. The draping magnetic field of the solar wind around Phobos appears 180--300~km from the Phobos day-side depending on the solar wind density and becomes significant when the proton skin depth is comparable with the actual size of the Phobos obstacle. Enhancement of the magnetic field of another nature at approach to Phobos had been observed when the dynamic pressure of the solar wind was very weak. These magnetic field enhancements in the regular part can be really attributed to the signatures of the solar wind - Phobos interaction because their appearance correlates strong with the S/C approaches to Phobos. They had disappeared when the S/C moved away from Phobos.
Another type of the signatures due to the interaction of Phobos with the solar wind had been observed when the distance between Phobos and S/C was about 5.000 km. These remote signatures of their interaction had wave character. The observation of these effects depends on the geometry of an experiment.

Search for Gas/Dust Escape From Phobos and Deimos Using in Situ Observations From Mars Global Surveyor MAG/ER

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More than 600 elliptical aerobraking and science phasing orbits made by Mars Global Surveyor (MGS) early in the mission provide unprecedented coverage of the solar wind in the vicinity of the Martian moons Phobos and Deimos, as well as their orbits. We have performed a comprehensive survey of electron and magnetic field perturbations in the solar wind to search for possible signatures of solar wind interaction with dust or gas escaping from the moons. We find that the solar wind perturbations are distributed quite equally over the spatial area covered by MGS and there are no clustering of perturbations near Phobos, Deimos, their orbits, or their wakes. We conclude that the density of the gas/dust escaping the moons is too low to induce detectable electron and magnetic field perturbations in the solar wind.

Lunar Mini-Magnetospheres and the Association with Surface Albedo

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In this paper, we use Lunar Prospector magnetometer (LP-MAG) data to investigate more quantitatively the possible existence of mini-magnetospheres at the Moon, and discuss the results in comparison with data on the interaction between Mars and the solar wind. In addition, we discuss the potential role of solar wind deflection in producing swirl-like high-albedo markings on the lunar surface. For this study, we make use of a recently produced global map of the vector lunar magnetic field. This global map was produced using LP-MAG data from quiet external conditions (when the Moon was in the solar wind and the spacecraft in the lunar wake, and data from the geomagnetic tail). However, passes were also identified where external field contamination was relatively low from times when the Moon was in the solar wind and the spacecraft was on the dayside. These data measure the combined crustal and solar wind magnetic fields. In combination with measurements from quiet external conditions, these data can be used to investigate the way in which the crustal anomalies interact with the solar wind. Here, we present a comparison of LP-MAG measurements obtained under different external conditions for isolated anomalies near craters Abel and Airy. These anomalies have been selected because they are both relatively strong, but while a high albedo marking has been mapped at Airy, it is not certain that there is an albedo anomaly at Abel. The results comparing coverage of these anomalies under different external conditions will be used to discuss the possible existence of mini-magnetospheres at those locations. In addition, we will present forward modeling results of anomaly source properties, including source geometry and directions of magnetization, for the Abel and Airy anomalies (using LP-MAG data from quiet external conditions). The model results will be used to discuss more quantitatively whether the sources of isolated anomalies are

collocated with regions of unusual albedo, and whether the direction of magnetization plays a role in the existence of lunar mini-magnetospheres. A comparison of these results with data from studies on the interaction of Mars with the solar wind will be used to contrast the way in which the strong crustal anomalies of Mars interact with the solar wind, compared with the relatively weak lunar anomalies.

Magnetic Storms at Mars and their Interplanetary Causes

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In analogy with magnetic storms at the Earth, periods of significantly enhanced global magnetic activity also exist at Mars. The extensive database of magnetic measurements of the Mars Global Surveyor (MGS), covering almost an entire solar cycle, are used in combination with solar wind measurements near Earth to investigate these events and their interplanetary causes. Based on superposed epochs analysis and examination of individual events the time-development of typical magnetic storms is described. Solar wind parameters measured by ACE is propagated to Mars, and the resulting predicted solar wind variations near Mars are compared and verified using clock-angle estimates based on the MGS-data. Large-scale heliospheric structures can be clearly distinguished, and the analysis shows that many storms are associated with compression regions in front of solar wind high-speed streams. In addition a single event of a passage of a magnetic cloud is analyzed. In this event the Earth is located upstream of Mars, and both the cloud signature and its immediate surroundings is clearly repeated in the clock-angle variations observed first at ACE and then by the MGS.

Ion Cyclotron Waves at Mars and Venus

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Because of the lack of global magnetic fields, both Mars and Venus do not have magnetospheres to shield their high-altitude atmospheric particles from being lost into the solar wind. When their atmospheric hydrogen atoms are ionized and picked up by the solar wind, proton cyclotron waves are created from the free energies of the ring-beam distribution of the pick-up ions. Thus, the magnetic observations of ion cyclotron waves enable us to study the atmospheric loss due to solar wind pick-up process. The Mars Global Surveyor detects proton cyclotron waves which extend from the magnetosheath of Mars to over 12 Mar radii with amplitudes that vary only slowly with distance. By equating the wave energy flux with 1/10 of the particle kinetic energy over the wave-observed area, the hydrogen loss-rate at Mars is estimated to be about 10^24 protons/second. At Venus, proton cyclotron waves are observed by Venus Express up to 7 Venus radii, and proton loss rate are estimated to be about 2*10^24 protons/second.

The Influence of and on the Atmosphere

The Combined Effects of Escape and Outgassing on Mars Volatile History

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Recent observation and missions to Mars have provided us with new insight on the past habitability of Mars and part of its history but in the same time it raised many questions about how the planet evolved to its present state. This work is meant to show that even with the few data we have and by using simple straightforward models, it is possible to have some answers about the evolution of Mars. We extrapolate the past state of the Martian atmosphere from its present state by taking into account the effects of volcanic degassing which constitutes an input of volatiles and atmospheric escape into space. We focus on CO2 as the most likely main gas present in the atmosphere at that time and involved in large scale and long term processes.

The Morphology of the Dayside Ionospheres of Venus and Mars: Evidence for Ion Outflows

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The topside scale heights of the electron density profiles on Mars and Venus may be indicative of the rates of ion outflows. Many models of the low solar activity Martian ionosphere have shown that the RPA profiles from Viking could not be fitted by models without imposing an upward velocity boundary condition of about 1 km/s on the ions.We model here the ionospheres of Mars for low and high solar activities for different upward velocity boundary conditions, and compute the maximum upward fluxes for a given model. We compare the computed profiles to measured profiles and derive the implied fluxes. These upward and nightward flowing ions may escape or flow to the nightside where they converge and flow downward forming a nightside ionosphere. We find that the implied upward velocities are on the order of, but not equal to the maximum values the we derived from our models. We compare the results to those we have recently computed for Venus.

Atmospheric Photoelectron Peaks Observed in the Martian Ionosphere and Magnetosphere

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The Analyzer of Space Plasmas and Energetic Atoms (ASPERA-3) experiment on board the Mars Express spacecraft conducts measurements of electrons by the Electron Spectrometer (ELS), ions by the Ion Mass Analyzer (IMA), and neutral particles by the Neutral Particle Imager (NPI) and the Neutral Particle Detector (NPD). The ELS instrument detects peaks in the photoelectron spectrum at 21-24 eV and 27 eV which come from the interaction of a carbon dioxide molecule or an atomic oxygen atom with a 30.4 nm photon. These peaks are strongest in the dayside ionosphere where they are mainly generated, but are also observed at large distances in the Martian tail. Observations in the tail show the most intense flux at times when the ELS sensor look direction points toward the Sun. At these times, the ELS observes distinct peaks which are narrow in energy. Recently, the instrument detects these nightside fluxes as a single broad photoelectron peak instead of the two distinct peaks as observed in the dayside ionosphere. Modeling of the electrons which create these peaks has shown that away from the source region, the electrons lie within a small pitch angle range. In this paper we examine selected passes of nightside ELS observations in order to better understand the differences in the dayside and nightside photoelectron peak signatures.

Martian Ionospheric Response to the Solar Activity of December 2006

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In early December 2006, an active solar region produced several X-class solar flares. Due to orbital geometry, Venus and Mars were located on the same approximate solar magnetic field line, while Earth was just past solar conjunction with Mars. The Venus-Mars alignment allowed measurement by the ASPERA instruments on the Venus and Mars Express spacecraft of energetic particles produced by the flares. At Mars, observations with the MARSIS instrument reveal significant effects on the Martian ionosphere, including radar wave absorption as described by Morgan et al. (2006), production of a nightside ionosphere with a maximum plasma frequency of up to 2 MHz, and a localized nightside ionization patch with a plasma frequency of 3.8 MHz. This ionization patch was observed by both the ionospheric sounding and subsurface sounding modes of the MARSIS instrument and was persistent over a period of days, suggesting it to be associated with a localized crustal magnetic field.

A Study of an Upper Layer in the Topside Ionosphere of Mars Using MARSIS

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The Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) aboard ESA's Mars Express spacecraft has now provided over two years worth of measurements of the Martian ionosphere. MARSIS operates by transmitting a radar pulse, using its echo to study the topside ionosphere at Mars. Initial analysis, which focused on the main ionospheric layer, revealed a peak electron density for the ionosphere of roughly 105 cm-3 at an altitude of about 130 km, consistent with the results from the Viking landers in the 1970s. However, analysis of the MARSIS data also unexpectedly revealed a vertical density profile at a higher altitude, indicating the presence of another distinct layer higher in the ionosphere. The peak density of this layer is typically around 104 cm-3, and peaks at an altitude near 200 km. The most probable cause for this feature is a peak in the density of O+ ions, which the Viking landers previously found to peak near 225 km. Other possible causes, including solar wind transport, magnetic field effects, and Kelvin-Helmholtz instabilities, have also been considered. This feature has been detected at many locations in the planet's ionosphere at various spacecraft altitudes, and shows no indication of time dependence. Therefore, it is believed to be a normal part of the Martian ionosphere and not due to transient variations in the solar UV flux. However, this feature does exhibit some dependence on solar interaction, as it is most prevalent at lower solar zenith angles. In addition, efforts to explain this feature have been further confounded by the occasional detection of a third density falloff at even lower frequencies, likely corresponding to another layer at even higher altitudes. Any model explaining the feature near 200 km should also allow for this higher feature as well.

Coupled 3-D Hot Particle and Exosphere Modelling of Mars

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We developed a 3-D hot particle Monte Carlo code which can be coupled to a 3-D exosphere test particle model. These coupled codes can be used for studying expected asymmetries related to latitude and longitude as well as day and nightside production rates and distributions of hot particles in planetary exospheres. The newly photochemically generated energetic neutral atoms are traced from their point of origin up to the exobase as a function of longitude, latitude, production process, collision probability with the cool background atmosphere, change of direction (altitude and angles) and energy dependent collision cross sections. For modelling the Martian background atmospheric and temperature profiles from the mesopause to the exobase we apply a diffusive gravitational equilibrium and thermal balance model. The hot particles which arrive above the exobase with energies higher than the corresponding exobase temperature of the background gas are divided into energy bins and used for the calculation of the energy density distributions as a function of latitude and longitude. These calculated energy density distributions of photochemically produced hot atoms at the Martian exobase are used as inputs for 3-D hot particle exosphere simulations. Finally we compare our results with that obtained with two stream models.

Model Validation Over the 80-140km Region on Mars: A Comparison Between MGCM-MTGCM Simulations and SPICAM Observations

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A knowledge of the state of the middle-upper atmosphere is essential for simulating the interaction between the solar wind and the upper atmosphere. Such boundary conditions are provided by thermospheric general circulation models such as the coupled multi-dimensional MGCM-MTGCM. Recent increases in the number of datasets available for the Martian middle atmosphere (~80-140 km) have made model validation for this region feasible. This investigation validates the MGCM-MTGCM at middle altitudes by comparing simulated densities with observed densities from the Mars Express SPectroscopy for the Investigation of the Characteristics of the Atmosphere of Mars (MEX/SPICAM) stellar occultations. Additionally, the SPICAM dataset is used to constrain the model, thereby facilitating exploration of the underlying physical processes controlling the structure of the middle atmosphere. Deeper insight into the physics governing the middle atmosphere will lead to an enhanced representation of the upper atmosphere in the boundary conditions utilized in computer simulations of solar wind-upper atmosphere interactions.

The Photoelectron Boundary at Mars

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With intense but localized crustal magnetic fields and an extended atmosphere, Mars presents a complex obstacle to the solar wind. In the northern hemisphere, where crustal magnetic fields are weak, the solar wind is able to impinge directly on Mars' atmosphere/ionosphere, resulting in an interaction similar to that observed at Venus. In the elliptical pre-mapping orbits, the Electron Reflectometer (ER) onboard Mars Global Surveyor (MGS) observed a persistent boundary at altitudes ~200-800 km, where the electron population changes over a few tens of km from one dominated by solar wind/magnetosheath electrons to one dominated by ionospheric photoelectrons. This boundary generally does not have a magnetic signature (a change in amplitude or direction), and there are no observations of thermal plasma (energies < 1 eV). Consequently, it is unclear if this boundary is associated with the ionopause, so it has been dubbed the "photoelectron boundary", or PEB.

The PEB was identified as a "boundary" because it was observed on every orbit and marked an altitude below which only ionospheric photoelectrons were observed. The purpose of this talk is to describe and interpret PEB crossings in the mapping orbit. All longitudes and latitudes are sampled, but at a 370-430 km altitude range and a 2-pm local time. This is sufficiently low to observe over 1 million PEB crossings. The large data volume allows us to search for trends in the PEB location as a function of longitude, latitude, solar zenith angle, altitude, magnetic field parameters, and external drivers, such as the EUV flux and solar wind dynamic pressure.

This is combined with electron pitch angle data for several representative cases to understand the magnetic topology associated with the PEB. The goal is to understand the nature of the PEB and the low-altitude solar wind interaction with Mars. What is the large-scale magnetic configuration when the spacecraft is below the PEB? What role do crustal fields play? How does the system respond to external drivers? What is the PEB, and is it related to the ionopause?

The Mars Ionizing Radiation Characterization Experiment (MIRCE)

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The Mars Ionizing Radiation Characterization Experiment (MIRCE) is a radiation detector proposed by a transdisciplinary team of graduate and undergraduate students to operate from an aerial platform, such as an airplane or balloon. MIRCE would characterize the radiation environment in the Martian atmosphere, a first in Mars exploration. Little is known about the radiation environment in the Martian atmosphere. Direct measurements of the radiation types and levels in the atmosphere are a necessity to determine the accuracy of radiation models to help assess the potential for astrobiology on the Martian surface and a precursor to human exploration of Mars. The primary science goal of MIRCE is to detect and quantify the ionizing radiation of high energy particles of solar and cosmic origin above the Martian surface. Investigations include 1) measuring the following radiation in the Martian atmosphere: protons, alpha particles, and heavier ions; 2) determining the flux of ionizing radiation above the surface; and 3) determining how the ionizing radiation varies above the surface during flight and possibly descent from cruising altitude. Data measured by MIRCE could subsequently be used to characterize the shielding properties of the Martian atmosphere through interaction with the ionizing radiation, help refine our understanding of the structure of the Martian plasma environment, and determine how the ionizing radiation environment could affect human exploration of Mars and the viability of microorganisms on the surface.

Hydrogen and Oxygen Hot Ion Precipitation in the Martian Ionosphere

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High energy H/H+ ion precipitation into Earth's upper atmosphere has previously been modeled (Fang et al., 2004; 2005). Recently, we have extended this work for the Martian ionosphere using different cross sections for relevant

Martian "background" species. Additionally, we have included O+/O precipitation with the view to keeping track of secondary hot ions/neutrals, which important for sputtering in the Martian upper atmosphere. Atmospheric effects of these precipitating hot ions in the Martian atmosphere are studied and reported on.

Evolution of Exospheric Suprathermal Oxygen Over Martian History

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As a part of a global effort, the dynamics of the flow of energetic particles through the Martian upper atmosphere has been studied. Being the most important reaction, the dissociative recombination (DR) of O2+ is responsible of most of the production of hot atomic oxygen deep in the thermosphere of Mars.

To understand the Martian exosphere, it is then necessary to employ a global kinetic model which can include a self-consistent description of both thermosphere collisional region and exospheric collisionless domain. In this study, we have used our Direct Simulation Monte Carlo (DSMC) model in combination with the 3D Mars Thermosphere General Circulation Model (MTGCM) of Bougher et al. [2006, Geophys. Res. Lett., 33, doi:10.1029/2005GL024059.] to describe self-consistently the region of the upper thermosphere where the exosphere is generated, the entire exosphere, and its feedback into the thermosphere generally.

Along with the effect of ionization, the DSMC method allows us to provide profiles of density and temperature, atmospheric loss rates and return fluxes as functions of the Solar Zenith Angle (SZA) for all cases considered. To present a complete description of this physical problem we examined several of the most limiting cases spanning spatial and temporal domains.

The contribution of the different physical and chemical escape processes was studied and compared for the present but also earlier Mars epochs characterized by different solar inputs (1 EUV, 3 EUV and 6 EUV) for Equinox conditions [Zhang et al., 1993, JGR, 98

HST/STIS Observations of the D/H Ratio and Airglow Emissions in the Extended Martian Upper Atmosphere

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HST observations of Mars near opposition in 2001 and 2003 were performed to address some key questions about the escape of water from the martian atmosphere. In May 2001 long aperture STIS echelle spectra of Mars were obtained to determine accurate values for the D and H columns, and the D/H ratio, in the upper atmosphere of Mars. The present-day D/H ratio gives vital information needed to understand the evolution of Mars' atmosphere, the historic escape of water into space, and potentially the remaining water abundance on Mars. Since this ratio appears to vary with altitude in the martian atmosphere, it is important to determine the value at the top of the atmosphere, from which D and H may escape into space. In August 2003 intensity profiles of H, O, and CO UV emissions were also measured with STIS across the planet and above the limb with 24 km resolution at Mars. These emission profiles can be used to measure the scale heights of thermal and suprathermal populations, which can be compared with models to constrain the escape flux of H and O from the upper atmosphere. This work was supported by grant HST-GO-08658.05-A from the Space Telescope Science Institute to Boston University.

Modeling the Interaction

Hybrid Simulations: Assorted Topics and Future Plans

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In this talk we will discuss a variety of topics concerning the simulation of the Mars environment. These will include issues of using crustal fields and some preliminary results, our merging with MHD codes, and our future efforts with respect to modeling Mars

The Impact of a Limited Satellite Field of View on the Pickup Ion Measurements Around Mars

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The pickup oxygen ion distribution around Mars is investigated using a newly-created highly-parallelized test particle model. A substantial improvement on the number of the test particles in the simulation domain (more than one billion in total) enables an unprecedented examination of the pickup ion flux distribution in velocity space, which is not achievable in previous simulation studies due to the insufficient statistics arising from the limited number of test particles. The capability of simulating the velocity space distribution at any spatial location provides an excellent opportunity to evaluate the impact of a limited satellite field of view (FOV) on the pickup ion measurement in the Martian environment. The comparison between the simulation results for a whole angular FOV and a limited FOV along some pseudo spacecraft orbits is useful to assess the efficiency of pickup ion measurement in the existing and future planned missions at Mars.

A Self-Consistent Mars-Solar Wind Interaction Model

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Hybrid models (ions are represented by particles and electrons by a fluid) of the Mars-Solar wind interaction also need to model Mars' neutral exosphere. Traditionally, exospheric densities and velocity distributions are modeled by spherical symmetric analytical Chamberlain functions, assuming gravity is the only force acting on the neutrals. Planetary exospheres are however not spherical symmetric to any good approximation, as evident from observations, due to non-uniform exobase conditions and effects such as photoionization, radiation pressure, charge exchange, recombination and planetary rotation. Even though neutrals in the exospheres by definition do not collide often, collisions occur. Especially near the exobase the transition is gradual from collision dominated regions at lower heights (with Maxwellian velocity distributions) to essentially collisionless regions at greater heights.

We present hybrid simulations of the Mars-Solar wind interaction that include a collisional exosphere self consistently using the direct simulation Monte Carlo (DSMC) approach. The code is three dimensional, parallel and uses an adaptive grid, allowing many particles to be included in the simulations, leading to accurate results.

Time Variation of the Nonthermal Escape of Oxygen from Mars: A Two-Stream Model Coupled with an MHD Ionosphere Model

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Mars has no significant intrinsic magnetic field, hence no magnetosphere, indicating that the escape mechanism of the Martian atmosphere differs from that at the earth. Escape of neutrals is potentially important for the evolution of the Martian environment. McElroy et al. [1977] suggested that dissociative recombination of O2+, the major ion in the Martian ionosphere, was the major escape mechanism for oxygen. Since then a number of theoretical, quantitative calculations of nonthermal oxygen escape rates have been reported. However, all the calculations were restricted to the case where the ionospheric parameters were assumed to be under steady state condition. We have investigated the escape rates by combining a time-dependent ionosphere model, i.e., a two-stream model has been coupled with a one-dimensional MHD model to simultaneously calculate the variations of the hot oxygen fluxes and the ionospheric parameters.

The solar wind, which is changing all the time, directly interacts with the Martian ionosphere. Time variation of the solar wind parameters is expected to result in a dynamic response of the ionosphere. For example, an enhancement of the solar wind dynamic pressure causes a downward displacement of the ionopause altitude. In such a case, molecular oxygen ions in the upper ionosphere are pushed to lower altitudes, leading to a temporal enhancement of the dissociative recombination rate around the exobase altitude. In this presentation, we will present the result of the calculations for the time variation of the nonthermal escape of oxygen due to the dissociative recombination of O2+ during an ionopause displacement.

The Role of Chemistry and Associated Assumptions in Determining the Ionosphere and the Resulting Affects on Effects on the Martian Solar Wind Interaction

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The interaction of the solar wind with the Martian ionosphere is a long standing problem of interest. The problem is complex. There are many ionospheric processes that play an important role in the interaction. In this paper we present results of global hybrid simulations of the Mars solar wind interaction. We examine the sensitivity of simulation results to key ionospheric processes such as the ion-neutral chemistry and the ionospheric conductivity as well as assumptions about the neutral atmosphere. We show that the assumptions and processes play a significant role in the global topology of the interaction and the ionospheric loss rates.

A Detailed Analysis of Mars O+ Pickup Ion Velocity Space Distributions

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Velocity-space distributions for O+ pickup ions around Mars are systematically examined. It is shown that the velocity-space distribution is highly non-Maxwellian, exhibiting non-gyrotropic and non-symmetric pick angle distribution, including beam-like features. Distributions as a function of energy, look direction, and spatial location are presented and evaluated, particularly with regard to their ability to reveal the underlying physical processes and particle source locations. The two main particle loss locations are directly downstream through the tail/wake region and a polar plume in the direction of the interplanetary motional electric field. The tail/wake velocity-space distributions contain numerous packets of flux in restricted energy-angle regions, each being a cluster of ions from a specific source location flowing along a specific, often complicated trajectory through the Mars space environment. The polar plume is an energetic beam from the subsolar region with a very narrow and spatially dependent energy-angle domain.

The Plasma Environment Near Martian Crustal Magnetic Fields

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We introduce a new model of the Mars ionosphere-solar wind system. The Mars space environment is simulated with a two-fluid (plasma and neutral) MHD model that encompasses a computational grid from approximately 52 km altitude through to the solar wind. Mars simulations can be made with the MHD module alone, or together with neutral hydrodynamics, ion-neutral chemistry, photoionization of neutrals, and the full Ohm's law. Using this model, we investigate the plasma environment in the presence of the crustal magnetic fields, focusing on ionospheric structure and current patterns.