Intercomparison of Global Models and Measurements of the Martian Plasma Environment

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Abstract

At least eight different modeling groups are presently active in simulating the global Martian plasma environment. The models are used for a variety of purposes, including estimate of the present and past rates of escape of the Martian atmosphere. However, they are seldom compared to observations in the same manner, or to each other. We propose to rectify this situation by undertaking a model challenge activity. The goals of the activity are to:

- ***Advance our understanding*** of the basic processes governing the interaction of solar wind plasma with the Martian atmosphere through a combination of modeling and comparison to observations.
- ***Intercompare the many different models*** of the global plasma interaction at Mars using (for the first time) identical input conditions. This will help place published data comparisons and science conclusions drawn from the different model results on a common footing.

Six simulation groups with models ranging from MHD to hybrid have committed to participate in this activity at ISSI. Several additional experts will assist with determining the input conditions for the models, and with comparing the models to spacecraft observations. We will meet at ISSI two times, allowing us to refine the activity and run additional input conditions based on the results of the first iteration. Results of this activity will be presented at meetings such as EGU, EPSC, AGU, and DPS, and are expected to stimulate publication of several manuscripts by the entire group and individual members. Finally, our group will establish a list of desired model runs and data comparisons for future activities in the field.

Scientific Rationale, Goals, and Timeliness

The first simulation of the global Martian solar wind interaction was published by Spreiter et al. in 1970. Since this initial gasdynamic model, the last 35 years (and especially the last decade) have seen continued advances in the number, variety, and sophistication of global models of the Martian plasma environment. Simulations today can be classified according to the physical assumptions they employ: MHD, Hall MHD, multi-fluid, hybrid, and test particle. Within these classifications models can be distinguished by whether they are 2D or 3D, the number of species they follow, their implementation, and the assumptions employed at the model boundaries. *We count at least eight different modeling groups that have been actively simulating the Martian interaction in the past several years*, with one or two additional groups coming on line now. These are: MHD (Ma/Nagy, Terada); Hall MHD (Ma/Nagy); multi-fluid (Harnett/Winglee); hybrid (Brecht/Ledvina, Modolo/Chanteur, Boesswetter/Motschmann, Kallio/Liu, Terada/Shinagawa); test particle (Liemohn/Fang).

These models have been used for a variety of purposes. They have been used to study atmospheric escape rates [e.g. *Ma et al.,* 2002; 2004; *Modolo et al.,* 2005; *Boesswetter et al.,* 2006; *Brecht and Ledvina*, 2007; *Kaneda et al*., 2007; *Harnett and Winglee*, 2006] the structure and topology of magnetic fields in the Martian system [e.g. *Brecht*, 1997; *Harnett and Winglee*, 2005, 2007; *Kallio et al.*, 2008], the influence of the solar wind on the ionosphere [e.g. *Ma et al.*, 2002, 2004] the global shapes of plasma boundaries [e.g. *Liu et al.*, 1999, 2001; *Brecht et al.*, 1991, 1993; *Boesswetter et al.*, 2004], and particle transport near Mars [e.g. *Liemohn et al.*, 2006]. They can be used to simulate the interaction considering conditions that may have existed in the past to trace the evolution of the system over history [e.g. *Barabash et al.*, 2007]. In short, models are powerful tools that can be used to study the effects of different drivers on the Martian system (i.e. variability), reveal the physical processes important in the interaction, and place existing observations in context.

A number of challenges face simulationists as recent spacecraft results are analyzed and digested. *Foremost among these is to identify the source of discrepancies between similar models*. For example, several groups run 3D multi-species simulations. Yet the predicted atmospheric escape fluxes differ by at least an order of magnitude for similar input conditions. The reasons for this difference lie in the different computational schemes and model resolution, and differences in the methods for addressing the ionospheric lower boundary. *Secondly, the models must be compared more rigorously to spacecraft observations* in order to determine where the model assumptions are valid. This includes comparisons to individual orbits of spacecraft data for a variety of different conditions and geometries, and comparison to statistical results derived from many orbits of observation. *These issues must be resolved before the simulations can reliably and believably be applied to the problems mentioned above.*

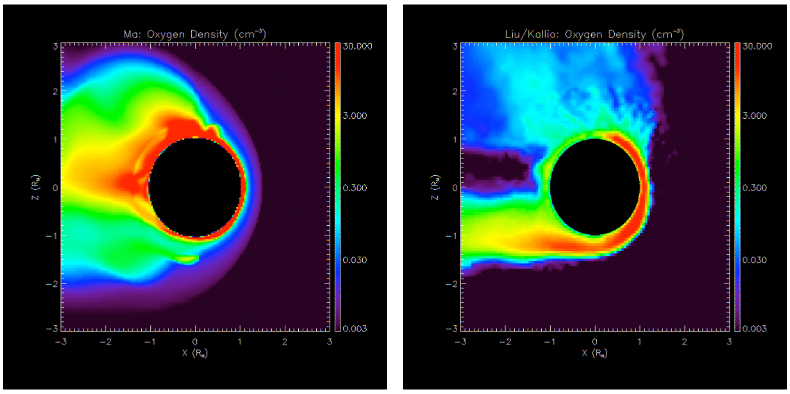
An effective way to address the issues above is for the community to undertake *a model challenge activity where different groups run their models for identical input conditions and compare the results*. "Model challenge" activities are common in other disciplines [e.g Birn et al., 2001], and provide valuable opportunity to both find errors in the models and probe the physics responsible for differences between the models. *We propose to undertake such an activity at ISSI,* with involvement from the modeling community (including representatives at ISSI from six different groups), the data community (including representatives from ion, electron, and magnetic field instruments on Mars Express and Mars Global Surveyor), and experts in the Martian upper atmosphere and plasma environment.

The two main goals of this activity, stated in the abstract, are to advance our understanding of the physical processes governing different regions of the Martian plasma interaction and to intercompare the different models for identical input conditions. *These goals will be accomplished by having several different Mars global plasma models run identical test cases, comparing the results to each other and to spacecraft data.* Table 1 identifies candidate test cases to run, and a minimum set of comparisons to be made. Note that each comparison addresses specific science questions pertaining to the goals of our activity. With these comparisons in hand, we will identify common features of the different simulation results, and key differences. We will use this information to contrast the influence of model assumptions on structure and plasma flows in the interaction region in order to identify the physical processes governing different parts of the interaction. We will further compare the results from the different sets of input conditions to identify their influence (e.g. of solar activity) on the plasma environment, comparing also to observations.

Table 1: Possible test cases and comparisons for the model challenge

Sample Test Cases	**Sample Comparisons** / *Science Questions Addressed*
• Solar maximum (equinox) • Solar moderate (equinox) • Solar minimum (equinox) • Solar minimum (aphelion) • Solar maximum (perihelion)	• **1D cuts of pressure (dynamic, thermal, magnetic)** *How and where is pressure converted in the interaction region?* • **2D cuts of solar wind and planetary particle density** *What are the pathways for particle escape / penetration?* • **Particle fluxes along a spacecraft orbit trajectory** *Can spatial and temporal effects be separated in observations?* • **Total atmospheric escape flux** *What are the error bars on model predictions of escape?*

A model challenge activity is (in our opinion) long overdue for the Mars plasma community. With the recent spacecraft datasets from Mars Express, it has become increasingly possible to apply a combination of observations and models toward a broad understanding of the physics of solar wind interactions with unmagnetized planets. And with the recent proliferation of published model results for Mars it has become increasingly important that standard methods of comparison be established for the models. A precursor model challenge activity was undertaken for the recent AGU Chapman Conference of the Solar Wind Interaction with Mars (SWIM), involving four of the same simulation groups participating in this proposal. This activity was very well received at the meeting, with the understanding that it was just the start of this important effort that will now be pursued in a more concentrated and organized manner. *Initiation of an ISSI activity now, while there is still momentum and enthusiasm for this effort in the community, is in our opinion very important.*



2D cuts in the noon-midnight plane of escaping oxygen fluxes from Mars, simulated for similar input conditions by an MHD model (left – Y. Ma, 2008) and hybrid model (right – E. Kallio and K. Liu, 2008). The color table ranges from .003-30 cm^{-3}. What are the reasons (physics and/or implementation) for the striking differences?

Finally, *we anticipate that this activity will have benefits beyond the stated goals*. First, it will provide seed ideas for future comparisons and future problems for the individual modelers to tackle. Second, it will prompt scientists affiliated with spacecraft instruments to think about the different data products (in some cases requiring combinations of instrument data sets) that would be most useful for global modelers. Third, this activity will establish a set of baseline input conditions and data products for comparison with any new model of Mars. Finally, our exercise will benefit communities simulating plasma interactions at other unmagnetized bodies such as Venus, Titan, or comets. This includes both adoption of standard comparison data products and investigation of the physics governing the Martian interaction as applied to other bodies.

Expected Output

The main output of the proposed activity will be a series of scientific manuscripts submitted for publication to reputable journals in planetary science or space physics (candidate journals include Planetary and Space Science, Icarus, JGR, Annales Geophysicae, and Space Science Reviews) and presentations at scientific meetings such as AGU, EGU, DPS and EPSC. We anticipate two publications authored by our entire group outlining the model challenge and the main results. Additionally, it is expected that the modeling and data analysis will lead to separate publications and presentations from individual team members or modeling groups.

A final outcome of meeting two will be an itemized list of major results of our study, and a prioritized list of data comparisons and model runs should the activity be continued in the future. This information will be maintained on the Team website at ISSI.

Value Provided by ISSI

A precursor model challenge activity was initiated at the recent Chapman Conference on the Solar Wind Interaction with Mars (SWIM), and included participation from six modeling groups. Remote coordination of the activity was challenging and inefficient, requiring many email exchanges in order to establish input conditions and perform the model comparisons. In the end, identical input conditions were not run for every model. In addition, there was no time for discussion of the activity among all the participants, so that little insight was gained about the underlying physics responsible for model differences.

It became very clear at the SWIM meeting that the goals of this activity are best accomplished when all participants are in the same location at the same time for a period of at least several days, and have no outside interruptions. An ISSI Team meeting provides these conditions. The two meetings will allow the group to have detailed discussion of the model assumptions and implementation, discuss the similarities and differences in the data comparisons as a group, and probe the results and perform new comparisons in "real time". These benefits are simply not possible at larger meetings.

Team Membership

Table 2: Mars Plasma Environment Model Challenge Team

Team Member	Institution	Nationality	Role
Dave Brain	UC Berkeley SSL	USA	Co-leader
Mats Holmstrom	IRF Kiruna	Sweden	Co-leader
Andrew Nagy	U. Michigan	USA	Senior advisor
Yingjuan Ma *	UCLA	USA	MHD modeling
Alex Boesswetter *	ITP Braunschweig	Germany	Hybrid modeling
Steve Brecht	Bay Area Research	USA	Hybrid modeling
Esa Kallio	Finnish Meteorological Inst.	Finland	Hybrid modeling
Ronan Modolo*	IRF Uppsala	Sweden	Hybrid modeling
Mike Liemohn	U. Michigan	USA	MHD + test particles
Steve Bougher	U. Michigan	USA	Atmospheric input
Eduard Dubinin †	Max Planck	Germany	Data comparison
Andrei Fedorov	CESR	France	Data comparison
Markus Fraenz †	Max Planck	Germany	Data comparison
Hans Nilsson	IRF Kiruna	Sweden	Data comparison

* - young scientist (postdoc or recent PhD)
† - may not require ISSI funding

The team has three basic sub-groups. A <u>leadership team</u> consisting of Dave Brain, Mats Holmstrom, and Andy Nagy will coordinate the model inputs and comparisons, data comparisons, and group discussion while at ISSI. A <u>modeling team</u> consists of representatives from six different modeling groups (Boesswetter, Brecht, Kallio, Liemohn, Ma, and Modolo) who will be responsible for running the simulations and extracting relevant information from the model results. A <u>support team</u> consisting of Bougher, Dubinin, Fedorov, Fraenz, and Nilsson (with assistance from Brain and Holmstrom) will provide atmospheric and ionospheric input conditions for the activity, extract spacecraft observations for comparison to model results, and compare the different model results using common display methods.

In addition to these team members, two other simulation groups have expressed interest in being involved in this activity without attending the meetings at ISSI. These are Naoki Terada (MHD model) and Erika Harnett (multi-fluid model). There may be other simulation groups that opt to participate in this manner as well. We do not rely on their participation to make this activity successful, but will welcome additional input from their models if they are able to supply it by the time of each meeting, with the philosophy that the more active models that can be intercompared using identical input conditions the better it is for the community as a whole.

Project Schedule

Our project has five phases centered around two meetings at ISSI. **Prior to Meeting 1** the entire team will participate in choosing appropriate input conditions for the models to run (2-3 cases). The modeling team will run the simulations and extract information for comparisons, while the support team will choose relevant spacecraft results for comparison. The leadership team will gather the results and perform the comparisons.

Meeting 1 will last four days at ISSI, preferably in Spring 2009. During this meeting the support team will first present the chosen model inputs and relevant spacecraft observations. The modeling team will present basic information about each model (assumptions, limitations, and implementation choices) and results of the model runs. The leadership team will present the results of the intercomparison between models and spacecraft data. The entire team will then discuss the results and underlying physics revealed for different regions, perform new data comparisons in response, and choose 2-3 new input conditions to be run for the next meeting.

Between meetings the support team will choose relevant spacecraft observations for the new input conditions, and the modeling team will run the new simulations and extract the results for comparison. The leadership team will gather the results and perform comparisons.

During **Meeting 2** (Fall 2009 or Spring 2010 preferred) the leadership team will review the results and outcome of Meeting 1 and the different teams will present the outcomes of the tasks undertaken between meetings (support team: input conditions and spacecraft observations; modeling team: model results; leadership team: model comparisons). Then the entire group will discuss the results and the underlying physics revealed by the comparisons, perform new comparisons as necessary, and create a list of accomplishments and priorities for the future.

After **Meeting 2** the entire team will refine the comparisons if necessary, submit a summary group manuscript for publication, and interested parties will submit supporting publications.

We have included an expert in modeling of the plasma interaction at Mars as part of our team (Andrew Nagy). However, we welcome addition of other experts at ISSI's discretion. Candidates include Janet Luhmann, Stas Barabash, or Chris Russell for the Martian interaction and Nojan Omidi, Antonius Otto, or Merav Opher for modeling.

Required Facilities

Our group requires a room that can seat all participants, a computer, projector, and screen so that the results can be presented and discussed, and internet access (preferably wireless) for all participants. Other facilities that are not strictly required (but are preferred) include: a white board, easel with paper, or second computer projector and screen; and a telephone with conference capability (videoconferencing options may also be desirable).

Financial Support

We request financial support to cover per diem and accommodation for 14 participants to attend two week-long meetings at ISSI (28 man-weeks). Additionally, we request travel costs to and from the meetings for the team co-leaders – Mats Holmstrom and Dave Brain.

Appendix 1: References

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Appendix 2: Short Curriculum Vitae for Team Members

Alexander Boesswetter

Education:
1997 Abitur (High School Diploma)

1997-2004 Student at the Technical University of Braunschweig Subjects: Physics, Geophysics and Computer Science

2004 Diploma Degree and Diploma Thesis at the Institute for Theoretical Physics, in cooperation with the Institute for Geophysics and Extraterrestrial Physics.
Supervisors: Prof. Dr. U. Motschmann and Prof. Dr. K.-H. Glassmeier
Thesis: Plasma boundaries at Mars: A 3D simulation study (in German)

2004-2008 PhD Student at the Institute for Theoretical Physics, TU Braunschweig
Member of the 'International Max Planck Research School on Physical Processes in the Solar System and Beyond' at the Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany
Supervisors: Prof. Dr. U. Motschmann and Prof. Dr. K.-H. Glassmeier

2008/05 estimated submission of PhD thesis

Expertise:
Global numerical 3D hybrid modeling of the solar wind interaction with Mars and Venus; Data analysis of magnetometers and plasma instruments of ASPERA/Phobos-2, ASPERA-3/MEX, ASPERA-4/VEX

Publications (as first author):
Boesswetter, A., Bagdonat, T., Motschmann, U., Sauer, K. (2004): Plasma boundaries at Mars: a 3-D simulation study; Ann. Geophys. 22, pp. 4363-4379.
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Professional Preparation

Undergraduate:	Northwestern University (Physics)	B.A. 1977
Graduate:	University of Colorado (Astrogeophysics)	M.S. 1980
	University of Michigan (Aeronomy)	Ph.D. 1985
Postdoctoral:	National Center for Atmospheric Research	1985-1987
	University of Arizona (Planetary Aeronomy)	1987-1990

Recent Professional Appointments

2003-present	NCAR Affiliate Scientist. High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colorado.
2002-present	Senior Research Scientist, later Research Professor. Space Physics Research Laboratory, University of Michigan, Ann Arbor.

NASA Mars Mission Participation

1. Selected MRO Accelerometer Facility Team Member (2005-2008)
2. Mars Aerobraking Team Member and Atmospheric Advisory Group (AAG) Participation.
   - Mars Global Surveyor (1997-1999)
   - Mars Odyssey (2001-2002)
   - Mars Reconnaissance Orbiter (2006).

Mars Research: Key NASA R&A Programs

- Mars Data Analysis Program (1999-2010). Characterize the Mars upper atmosphere structure and dynamics using available datasets (e.g. MGS, Odyssey, MRO Accelerometer) and Mars Thermospheric General Circulation Model (MTGCM) simulations. Ongoing research program.
- Mars Critical Data Products Program (2003-2004). Provide MTGCM simulated data files for the MARSGRAM-2005 empirical model; used for all recent Mars spacecraft aerobraking operations.

Recent Mars Publications:

Bougher, S. W., S. Engel, R. G. Roble, and B. Foster, Comparative Terrestrial Planet Thermospheres : 3. Solar Cycle Variation of Global Structure and Winds at Solstices, **JGR., 105**, 17669-17689, (2000).

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Education

2002	Ph.D., *Astrophysical and Planetary Sciences*	University of Colorado
1997	M.S., *Astrophysical and Planetary Sciences*	University of Colorado
1995	B.A., *Physics* and *Math*	Rice University

Experience

2005 – present	Assistant Research Physicist, University of California, Berkeley
2003 – 2005	Postdoc, University of California, Berkeley
2002 – 2003	Postdoc, University of Colorado at Boulder
Fall, 2002	Instructor, University of Colorado at Boulder
1995 – 2002	Research Assistant, University of Colorado at Boulder

Professional Organizations

American Geophysical Union; Division for Planetary Sciences

Research

Dr. Brain studies the plasma interaction at non-magnetized planets, and is especially interested in the implications of the plasma interactions for atmospheric loss processes and upper atmospheric structure. Dr. Brain's recent research has focused primarily on analysis of observations of magnetic fields and charged particles near Mars, including studies on the effect of crustal magnetic fields on the Martian plasma interaction, magnetic topology and plasma boundaries near Mars, Martian aurorae, and the magnetic field draping around the Martian ionosphere. He also has ongoing investigations into analysis of Venus Express electron data as well as the effects of large space weather events on the upper atmospheres of Venus, Mars, and extra-solar planets.

Selected Publications

Brain, D.A., J.S. Halekas, and J.P. Eastwood, *Observation of a Large Core Field Flux Rope near Mars*, **Geophys. Res. Lett., in preparation**, 2008.

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Indiana University	M.S., Physics, 1968
The Citadel	B.S., Physics, 1967

Dr. Brecht founded Bay Area Research Corp. in 1995 to continue his research into nonlinear behavior of plasma and fluid systems. One of his present research programs involves the simulations of Mars and Titan with 3-D hybrid particle codes. In addition, he has developed and continues to improve a shock acceleration model for trapped relativistic electrons. He has also worked on the study of the dynamics of the Jovian radiation belts following the Shoemaker-Levy 9 comet impacts. The research into the physics of collisionless shocks where mulitple species of ions is presently his main areas of research.

Dr. Brecht joined Berkeley Research Associates as senior scientist in 1982, He devoted his attention to studying nonlinear plasma behavior. This research embodied analytic as well as large scale particle simulations of beam plasma instabilities, their nonlinear effects, cross field transport and collisionless shocks. In addition Dr. Brecht continued his research into the plasma dynamics of large scale systems such as planetary magnetospheres and solar flares.

Prior to joining BRA Dr. Brecht worked for SAIC under contract to the Naval Research Laboratory. While there he performed research into basis plasma processes such as ion-ion instabilities and their nonlinear consequences. The emphasis of this research was cross-field transport of plasma by Rayleigh-Taylor instability, explanation of data, and models for system codes. During this period, Dr. Brecht began developing 3-D MHD codes for magnetospheric simulations. This effort resulted in large scale 3-D MHD simulations for the Earth's magnetosphere.

Dr. Brecht has served on a variety of national committees including the National Academy of Science committee, CODMAC, the NASA Space Sciences Theory working group, and chaired the NASA subcommittee on supercomputing. He has been principal investigator on 30 research programs in the last 13 years.

Dr. Brecht is a member of the American Physical Society, American Geophysical Union, AAAS, IEEE, and SPIE. He has published over 100 articles and technical reports and presented over 100 technical papers to learned societies.

Eduard Dubinin

Max-Planck-Institut für Sonnensystemforschung
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Germany
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Education

1974	Ph.D., Space Physics	Moscow Physics and Technology Institute

Experience

Dr. Eduard Dubinin received his PhD in Space Physics from the Moscow Physics and Technology Institute in 1974. He was staff member of the Space Research Institute (IKI) as senior scientist. In 1996 he was visiting scientist at the Max-Planck Institute for Extraterrestrial Physics (Berlin). From 1997 to 1999 he was visiting scientist at the Max-Planck Institute for Aeronomy (Lindau). In 2000 E. Dubinin was visiting scientist at the University of Michigan. From 2001 to 2003 he was guest scientist at the Max-Planck Institute of Aeronomy (Lindau). E. Dubinin was CoI of plasma experiments on Prognoz-7, 8, Interball-1, 2, Phobos-2, Mars-96. He was actively involved to the international program of Mars investigation. From 2004-2007 E. Dubinin was DFG-funded scientist at MPS.

E. Dubinin was CoI of the ASPERA experiment on Phobos-2 which was the 'forerunner' of the ion mass spectrometers IMI and IMA onboard Nozomi and Mars Express missions. He was leading investigator (LI) of the ASPERA-C experiment for Mars-96 which became the prototype of ASPERA-3 and ASPERA-4. Dubinin has closely collaborated with other experiment teams of the Phobos-2 mission in multi-instrumental studies of the Mars and Venus plasma environment. Dr. Dubinin is the author and co-author of ~170 papers and more than 60 papers concerning Mars and Venus space physics.

Selected Recent Publications

E. Dubinin, K. Sauer, M. Delva, R. Grard, S. Livi, R. Lundin, A. Skalsky, K. Schwingenschuh, K. Szegö, and J.-G. Trotignon, Multi-instrument study of the upstream region near Mars: Phobos-2 observations, *J. Geophys. Res.*, 105, 7557–7571, 2000.

E. Dubinin, K. Sauer, M. Delva, S. Livi, R. Lundin, A. Skalsky, and K. Szego, Deceleration of the solar wind upstream of the Martian bow schock. Mass-loading or foreshock features?, *Adv. Space Res.*, **26**, 1627–1631, 2000.

E. Dubinin, M. Fraenz, J. Woch, S. Barabash, R. Lundin, and M. Yamauchi, Hydrogen exosphere at Mars: Pickup protons and their acceleration at the bow shock, *Geophys. Res. Lett.*, **33**(22), L22103, doi:10.1029/2006GL027799, 2006.

E. Dubinin, M. Fränz, J. Woch, E. Roussos, S. Barabash, R. Lundin, J. D. Winningham, R. A. Frahm, and M. Acuña, Plasma Morphology at Mars. Aspera-3 Observations, *Space Sci. Rev.*, **126**, 209–238, doi:10.1007/s11214-006-9039-4, 2006.

E. Dubinin, R. Lundin, M. Fränz, et al., Electric fields within the martian magnetosphere and ion extraction: ASPERA-3 observations, *Icarus*, **182**, 337–342, doi:10.1016/j.icarus.2005.05.022, 2006.

E. Dubinin, D. Winningham, M. Fränz, et al. Solar wind plasma protrusion into the martian magnetosphere: ASPERA-3 observations, *Icarus*, **182**, 343–349, doi:10.1016/j.icarus.2005.05.023, 2006.

E. Dubinin, M. Fraenz, J. Woch, J.D. Winnigham, R. Frahm, R. Lundin and S. Barabash, Suprathermal electron fluxes on the nightside of Mars: ASPERA-3 observations, Planetary Space Sci., (in press) doi:10.1016/j.pss.2007.12.010

E. Dubinin, G. Chanteur, M. Fraenz, R. Modolo, J. Woch, E. Roussos, S. Barabash, R. Lundin and J.D. Winningham, Asymmetry of plasma fluxes at Mars. ASPERA-3 observations and hybrid simulations, Planetary Space Sci., (in press), doi:10.1016/j.pss.2007.12.006

Andrei FEDOROV
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FRANCE
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Related Experience/Education

- 1980 M.S in Physics, in the Moscow Institute of Physics and Technology (MFTI), Moscow
- 2000 Ph.D in Physics and Mathematics, in the Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation (IZMIRAN), Troitsk (Moscow region), Russia.
- Lead Investigator: CORALL/INTERBALL, FONEMA/MARS-96, ASPERA-4/Venus Express
- Co-Investigator: SWEA/STEREO, ASPERA-3/Mars Express, MEA/Bepi Colombo, IDEE/Taranis

Previous Project Participation

- For the ion spectrometer CORALL (INTERBALL)
  - Led the design, fabrication and calibration of the instrument.
  - Led the data processing and data analysis
- For the ion mass spectrometer FONEMA (Mars-96)
  - Led the design of electrostatic part of the sensor
  - Led the the fabrication of the Russian part of the instrument
- For the neutral particle imager NPD of ASPERA-3/Mars Express
  - Led the conceptual design and calibration of the prototype
- For the ion mass spectrometer IMA of ASPERA-3/Mars Express
  - Numerical simulation and calibrations of the sensor
  - Led data processing and data analysis
- For the ion mass spectrometer IMA of ASPERA-4/Venus Express
  - Led design and fabrication of the position-sensitive detector
  - Sensor calibrations
  - Led data processing and data analysis

Relevant Publications:

S.Barabash, A. Fedorov, J.-A.Sauvaud et al, (2007) The loss of ions from Venus through the plasma wake, Nature, v.450, pp.650-653, doi:10.1038

S. Barabash, A.Fedorov, R. Lundin and J.-A.Sauvaud,(2007) Martian atmospherix erosion rates, Science, v.315, pp.501-503

A. Fedorov, C. Ferrier, J.-A. Sauvaud et al, (2007) Comparative analysis of Venus and Mars magnetotails, Planet Space Sci. In press

A. Fedorov, E.Budnik, J.-A. Sauvaud et al, (2005) Structure of the martian wake, Icarus, v. 182, Issue 2, p. 329-336.

A.Fedorov, E.Budnik, H.Stenuit, T. Moreau, and J.-A.Sauvaud,Antiparallel reconnection as a possible source of high- and low-latitude boundary layers, Geophysical Monograph Vol.133, AGU, 2003

A.Fedorov, E.Budnik, and J.-A.Sauvaud\Interconnection of the high-latitude and low-latitude boundary layers when IMF By is dominant, Adv.Space Res., V.30, N12, 2002

Employment

- 1981–2000 Staff scientist and then senior scientist in Space Research Institute (IKI), Moscow
- 2000–present "Ingénieur de recherche" in CESR/CNRS, Toulouse

Markus Fränz

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Education

1983	Vordiplom physics	Universität Würzburg
1989	Mag.rer.nat physics	Universität Wien
1994	PhD Geophysics	Universität Braunschweig

Experience

Dr. Markus Fränz studied theoretical physics at the universities of Würzburg and Vienna. His diploma work was on quantum cosmology. He worked on the simulation of air pollution on parallel computers at the Austrian Federal Institute of Health in 1990. His PhD he did at the university of Braunschweig and the Max-Planck-Institute for Aeronomy (now Sonnensystemforschung) from 1991 to 1994 on energetic particle observations by the Ulysses mission. He took a postdoc position at Queen Mary College, University of London from 1995 to 2001, first preparing analysis procedures for the Cluster mission, then on plasma instabilities in the solar wind observed by Ulysses and other spacecraft. From 2001 he is working as a senior scientist at the Max-Planck-Institut für Sonnensystemforschung, first on the analysis of Cluster observations, since 2004 on the observations of the Mars and Venus Express Aspera experiments. Since 2007 he is defining instrumentation for the BepiColombo mission. His primary field of interest is the interaction of the solar wind with the planets. He also has a solid background in scientific computing.

Selected Recent Publications

M. Fränz and D. Harper, Heliospheric Coordinate Systems, *Planet. Space Sci.*, **50**, 217–233, 2002.

M. Fränz, E. Dubinin, E. Roussos, J. Woch, J. D. Winningham, R. Frahm, A. J. Coates, A. Fedorov, S. Barabash, and R. Lundin, Plasma Moments in the Environment of Mars, *Space Sci. Rev.*, **126**, 165–207, doi:10.1007/s11214-006-9115-9, 2006.

M. Fränz, J. D. Winningham, E. Dubinin, et al., Plasma intrusion above Mars crustal fields—Mars Express ASPERA-3 observations, *Icarus*, **182**, 406–412, doi:10.1016/j.icarus.2005.11.016, 2006.

A. Bößwetter, S. Simon, T. Bagdonat, U. Motschmann, M. Fränz, E. Roussos, N. Krupp, J. Woch, J. Schüle, S. Barabash, and R. Lundin, Comparison of plasma data from ASPERA-3/Mars-Express with a 3-D hybrid simulation, *Ann. Geophys.*, **25**(8), 1851–1864, 2007.

C. Martinecz, M. Fränz, J. Woch, *et al.,*Location of the bow shock and ion composition boundaries at Venus—initial determinations from Venus Express ASPERA-4, *Planetary Space Sci., (in press), doi:/10.1016/j.pss.2007.07.007*

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Degrees

- MS (mechanical engineering) 1993, University of Houston
- MS (engineering physics) 1993, Uppsala University
- PhD (numerical analysis) 1997, Uppsala University
- Docent (space physics) 2004, Umea University

Experience

- University of Houston, Dept. of Mechanical Engineering.
  Research assistant for NASA Lyndon B. Johnson Space Center 1991-93
- Uppsala University, Dept. of Scientific Computing.
  PhD student, 1993-97
  Teaching in C++-programming 1993-97; in parallel computing 1994-96;
  in optimization 1996-97.
- Umea University, Dept. of Space Physics.
  Lektor in Mathematics, 1998-2000
  Teaching in calculus 1998-00; in C-programming 1998-00
- Swedish Institute of Space Physics, Kiruna.
  Post Doc, 2001
- NASA's Goddard Space Flight Center, Greenbelt, Maryland, USA.
  National Research Council (NRC) Associate, 2005
- Swedish Institute of Space Physics, Kiruna.
  Scientist, 2002-
  Deputy Head of the Solar System Physics and Space Technology program.
  Operations Manager for the ASPERA-3 experiment.
  Representative for the High Performance Computer Center North (HPC2N)
  Member of the Swedish National Allocations Committee (SNAC), 2006-2008.

Refereed Publications

In total 69 refereed publications, 13 as first author. Some selected are:

- Energetic neutral atoms as the explanation for the high velocity hydrogen around HD 209458b, M. Holmstrom, A. Ekenback, F. Selsis, T. Penz, H. Lammer, and P. Wurz, *Nature*, 451, 970-972, 2008.
- Asymmetries in Mars' Exosphere: Implications for X-ray and ENA Imaging, M. Holmstrom, *Space Science Reviews*, 126(1-4):435-445, 2006.
- *Planetary ENA imaging: Effects of different interaction models for Mars*, H. Gunell, M. Holmstrom, S. Barabash, E. Kallio, P. Janhunen, A.F. Nagy, and Y. Ma, Planetary and Space Science, 54(2):117-131, 2006.
- *Solar Wind-Induced Atmospheric Erosion at Mars: First Results from ASPERA-3 on Mars Express*, R. Lundin, S. Barabash, H. Andersson, M. Holmstrom et al., Science, 305, 1933-1936, 2004.
- En*ergetic neutral atoms at Mars: I. Imaging of solar wind protons*, M. Holmstrom, S. Barabash and E. Kallio, Journal of Geophysical Research-Space Physics, Vol. 107, No. 10, 2002.
- *X-ray imaging of the solar wind-Mars interaction*, M. Holmstrom, S. Barabash and E. Kallio, Geophysical Research Letters, 7(28):1287-1290, 2001.

NAME: Esa J. Kallio, Dr.
BORN: January 9, 1965

EDUCATION: 1996: PhD, Theoretical physics, University of Helsinki, Finland

EXPERIENCE:

Qualified positions:

- 1990-1996, 1997-2001, 9/2007 – present
  Senior scientist
  Space Science Unit, Finnish Meteorological Institute
- 2001 - 8/2007
  Academy Fellow
  Finnish Academy of Science
- 1996-1997
  PhD student
  Space Science Laboratory, the University of California, Berkeley, USA
- 2003 – present
  Leader of FMI's global hybrid model team

EXPERTISE:

- Global numerical hybrid modeling of the solar wind interaction with the Solar System objects (Mercury, Venus, the Moon, Mars, Saturnian moon Titan, asteroids)
- Data analysis (ASPERA/Phobos-2, ASPERA-3/MEX, ASPERA-4/VEX, magnetometers)
- Participation in experimental space projects:
  [currently flying instruments] Co-investigator: ASPERA-3/MarsExpress, ASPERA-4/VenusExpress and ICA/ROSETTA particle instruments
  [instruments in preparation] Co-investigator: SERENA/BepiColombo, PHEBUS/BepiColombo and MEFISTO/BepiColombo instruments.
- Publications:
  about 80 refereed publications
  (http://www.ava.fmi.fi/~kallio/publications_Esa.html)
- Activity in Scientific Societies:
  2005-2007: ESA's Solar System Working Group (SSWG), member.

MICHAEL W. LIEMOHN
Associate Professor
Atmospheric, Oceanic, and Space Sciences Department
University Of Michigan, Ann Arbor

Education:
1997: Ph.D. in Atmospheric and Space Science, University of Michigan, Ann Arbor
1995: M.S. in Atmospheric and Space Science, University of Michigan, Ann Arbor
1992: B.S. in Physics and Mathematics, Rose-Hulman Institute of Technology, Terre Haute, IN

Professional Activities:

August 2006 - present:	Associate Professor, Atmospheric, Oceanic, and Space Science Dept., University of Michigan, Ann Arbor
February 2003 - August 2006:	Research Associate Professor, AOSS Dept., U-M
August 1998 - February 2003:	Assistant Research Scientist, AOSS Dept., U-M
February 1997 - August 1998:	National Research Council Resident Research Associate, NASA Marshall Space Flight Center, Huntsville, AL

Research Summary:
My current research activities include energetic electron and ion modeling around Mars, with comparisons against the Mars Global Surveyor and Mars Express data sets. I am also involved with modeling of the stormtime inner magnetosphere (electrons, ring current, and plasmasphere) and understanding both the large-scale and small-scale processes of relevance.

Selected Publications (out of 91 peer-reviewed papers in print, press, or submitted):

Liemohn, M. W., Y. Ma, A. F. Nagy, J. U. Kozyra, J. D. Winningham, R. A. Frahm, J. S. Sharber, S. Barabash, and R. Lundin, Numerical modeling of the magnetic topology near Mars auroral observations, *Geophys. Res. Lett.*, in press, doi: 10.1029/2007GL031806, 2008.

Fang, X., M. W. Liemohn, A. F. Nagy, Y. Ma, D. L. De Zeeuw, J. U. Kozyra, and T. Zurbuchen, Pickup oxygen ion distribution around Mars, *J. Geophys. Res.*, in press, doi: 10.1029/2007JA012736, 2008.

Coates, A. J., et al., Ionospheric photoelectrons at Venus: Initial observations by ASPERA-4 ELS, *Planet. Space Sci.,* in press, 2008.

Liemohn, M. W., Y. Ma, R. A. Frahm, X. Fang, J. U. Kozyra, A. F. Nagy, J. D. Winningham, J. R. Sharber, S. Barabash, and R. Lundin, Mars global MHD predictions of magnetic connectivity between the dayside ionosphere and the magnetospheric flanks, *Space Sci. Rev.*, *126*, 63-76, 2007.

Liemohn, M. W., et al., Numerical interpretation of high-altitude photoelectron observations, *Icarus, 182*, 383-395, 2006.

Liemohn, M. W., J. L. Fox, A. F. Nagy, and X. Fang, Hot carbon densities in the exosphere of Venus, *J. Geophys. Res., 109*, A10307, doi: 10.1029/2004JA010643, 2004.

Recent Community Activities:

Various NASA and NSF proposal review panels, including for Planetary Sciences

LWS TR&T Steering Committee, 2007 - present. Help define the NRA solicitation for the TR&T program.

Team Leader (2005-present), NASA LWS TR&T Focused Science Team for Radiation Belt Studies. Plan meetings each year for the 8 PIs of radiation belt grants from the 2004 LWS proposal competition, and be the main liaison for our progress with the NASA discipline scientist for the LWS TR&T program.

Chairman, NASA Geospace Management Operations Working Group, 2005 - 2007. Provide advisory support to the Geospace science program element at NASA.

SEC Roadmap Committee, 2004 - 2005. Help define the mission priorities for accomplishing the NASA Sun-Earth Connection science goals.

Ying-Juan Ma
Assistant Research geophysicist
IGPP, UCLA, Los Angeles

Education:

2006: Ph.D in Atmospheric and Space Sciences, Univ. of Michigan, Ann Arbor, MI

2000: M.S. in Space Sciences, Univ. of Sci. & Tech of China, Hefei, China

1997: B.S. in Space Sciences, Univ. of Sci. & Tech of China, Hefei, China

Professional Activities:

05/2007-present	Assistant Research geophysicist, IGPP, UCLA
01/2006-04/2007	Research fellow, University of Michigan
09/2000-12/2005	Graduate Student Research Assistant, University of Michigan

Recent Honors and Awards

Fred L. Scarf Award Recipient, AGU, 2007
Rackham Predoctoral Fellowship, University of Michigan, 2004-2005,
AGU Outstanding Student Paper Awards, 2003 Fall

Research Interest:

Magnetohydrodynamic (MHD) modeling of solar wind-Mars interaction, specially the effect of the upstream solar wind conditions and the effect of crustal magnetic field on the interaction process. Also I am interested in studying the escape fluxes of Martian ionosphere and evaluating of the importance of various physical processes, such as mass loading, charge exchange and impact ionization. I am also involved in the numerical study of the plasma interactions around Titan and the analysis of Cassini magnetometer data during Titan flybys.

Selected Peer-Reviewed Publications

Ma, YJ and A. F. Nagy, Ion Escape Fluxes from Mars, *Geophys. Res. Let.*, **34**, 8, CiteID L08201, doi: 10.1029/2006GL029208, 2007

M. W. Liemohn, YJ Ma, R. A. Frahm, et al., Mars global MHD predictions of magnetic connectivity between the dayside ionosphere and the magnetospheric flanks, *Space Science Reviews*, **126**, 1-4, 63, doi:10.1007/s11214-006-9116-8, 2006

Ma, YJ, A. F. Nagy, T. Cravens, I. V. Sokolov, K. C. Hansen, J. Wahlund, F. Crary, A. Coates and M. Dougherty, Comparisons between MHD model calculations and observations of Cassini flybys of Titan, *J. Geophys. Res.*, **111**(A5), Cite ID A05207, 2006

Ma, YJ, A. F. Nagy, T. E. Cravens, I. V. Sokolov, J. Clark and K. C. Hansen, 3-D Global MHD model Prediction of the first close flyby of Titan by Cassini, *Geophys. Res. Let. ,* **31**, L22803, 2004

Ma, YJ, A. F. Nagy, I. V. Sokolov, and K. C. Hansen, Three-dimensional, multispecies, high spatial resolution MHD studies of the solar wind interaction with Mars, *J. Geophys. Res.*, **109**, A07211, doi: 10.1029/2003JA010367, 2004

Ma, YJ, A. F. Nagy, K. C. Hansen, D. L. DeZeeuw and T. I. Gombosi, 3D Multi-Species MHD Studies of the Solar Wind Interaction with Mars in the Presence of Crustal Fields, *J. Geophys. Res.,* **107***,* A10, 1282, doi: 10.1029/2002JA009293, 2002

Ronan MODOLO

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Personal information
born the 1976/08/09, Bourges (France)
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Present occupation

2008 Research assistant, Swedish Institute of Space Physics. Research interest:

- Computational research in space plasma physics, ionization processes, coupling charged and neutral species in planetary atmosphere.
- Development of 3D multi-species hybrid simulation models for Mars and Titan.
- Solar wind and kronian plasma interaction with the exosphere/ionosphere of Titan, and solar wind interaction with Mars.
- Data analysis and interpretation of the Langmuir Probe observations of the RPWS experiment onboard Cassini
- Data analysis and interpretation of radar observations (MARSIS) on Mars-Express.

Career summary

2007-2008 Research Scholar, University of Iowa, USA, under the supervision of Prof. D. Gurnett

2005-2007 Post-doctoral position, Swedish Institute of Space Physics, Uppsala, Sweden, under the supervision of Dr. J.-E. Wahlund

2004-2005 Teaching and Research Assistant, University of Versailles, France, under the supervision of Dr. G. Chanteur

Education, Academic honours and Awards

2006	« Plasma Award » from the French Society of Physics
2001-2004	PhD in Plasma Physics, « Mention très honorable avec les félicitations du jury » (highest score), University of Versailles, France, under the supervision of Dr. G. Chanteur, "Modélisation de l'interaction du vent solaire, ou du plasma kronien, avec les environnements neuters de Mars et de Titan"
2000-2001	Master in Mathematics, Simulations and Physics Applications, University of Versailles, France, accredited by Ecole Polytechnique, ENSTA and ENS-Cachan

Scientific Responsibilities

2004-2007 Supervisor and co-Supervisor of Master thesis works in France and Sweden
Referee to different international scientific journals

Languages and Computer skills

• **Languages**	French: mother tongue, English: fluent, Spanish and Swedish: beginner
• **Computer skills**	Operating systems: Windows, Unix, Linux Software: Word, Excel, Mozilla-Firefox, Power-Point, PV-Wave, IDL, Matlab Programming languages: Fortran (77/90/95), C, HTML, MPI

Publication list

Selection –

- Modolo et al, Influence of the solar EUV flux on the Martian plasma environment, Ann. Geophys.., 23, p. 433-444, 2005
- Modolo et al, Simulated Solar Wind plasma interaction with the Martian exosphere: influence of the solar EUV flux on the Bow Shock and the Magnetic Pile-up Boundary, Ann. Geophys.,24,p.3403-3410,2006
- Chaufray et al, 2007, Mars Solar Wind interaction : formation of the Martian corona and atmospheric loss to space, Journ. Geophys., Vol. 112, E09009, doi:10.1029/2007JE002915, 2007
- Modolo et al, Plasma environment in the wake of Titan from hybrid simulations - a case study, Geo. Res. Let., Vol. 34, L24S07, doi:10.1029/2007GL03489, 2007
- Modolo and Chanteur , A global hybrid model for Titan's interaction with the Kronian plasma: Application to the Cassini Ta flyby, J. Geophys. Res., 113, A01317, doi: 10.1029/2007JA012453, 2008

Andrew F. Nagy

University of Michigan

Biographical Sketch.

Professor Nagy was born in Budapest, Hungary. He completed his high school education in Sydney, Australia. He received a Diploma in Radio Engineering and an Honors B. E. degree from the University of New South Wales. He completed his graduate education in the U.S., receiving M.S. degrees from the University of Nebraska and the University of Michigan and a Ph. D. from the University of Michigan. He has been on the faculty of the University of Michigan since 1963, having had short term appointments at UCSD, Utah State University and Stanford University.

Scientific Experience.

Professor Nagy has over forty years of experience in both theoretical and experimental studies of the upper atmospheres, ionospheres and magnetospheres of the Earth and planets. He was principal and co-investigator of a variety of instruments flown on OGO, Pioneer Venus, Dynamic Explorer etc. He was Interdisciplinary Scientist for the Dynamic Explorer and Pioneer Venus programs. He has also participated, both as an instrument and science collaborator, on the Soviet VEGA and PHOBOS missions. He is a team member of the Radio Science Investigation on Cassini, and was co-investigator on the Nozomi mission. He has led the development of numerous theoretical models related to planetary atmospheric and ionospheric studies and has been involved in a large variety of data analysis and interpretation studies. He has been the principal or co-author of over 300 papers published in refereed journals; he has also authored/co-authored a number of review papers and encyclopedia chapters and a book on the “Ionospheres”. He is the Editor-in-Chief of the latest ISSI book in preparation on “Comparative Aeronomy”.

Service Activities and Honors.

Professor Nagy has been the chair or member of a large number of Committees and Boards of NASA, NSF, NAS/NRC, AGU, COSPAR, URSI etc. He has also served as Editor of *Geophysical Research Letters* and *Reviews of Geophysics and Space Physics*. He was also the President of the Space Physics and Aeronomy Section of AGU. Professor Nagy is a Fellow of the AGU. He is also a member of the Hungarian Academy of Sciences and the International Academy of Astronautics. He was the Nicolet Lecturer at AGU and was a winner of the NASA Public Service Medal.

Curriculum Vitae

Name: **Hans Nilsson**
Date of birth: 19 January 1968
Position: Research Scientist
Address: Swedish Institute of Space Physics (IRF)
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Email: hans.nilsson@irf.se

Degree:

1991	Master of Science in Applied Physics and Electrical Engineering, Linköping University, Technical Department
1996	PhD in Space Physics, Umeå University, successfully defended 23 February
Thesis title:	Ionospheric plasma studies with the EISCAT and Søndre Strømfjord Radars
Supervisors:	Prof. Bengt Hultqvist and Sheila Kirkwood, Swedish Institute of Space Physics
2006	Docent Umeå University

Employment:

1992-1996:	Research student, Swedish Institute of Space Physics, Kiruna
1996-present:	Permanent Scientific Staff (90 % since 1998) at Swedish Institute of Space Physics, Kiruna
1998-present:	Head of the computer group at the Swedish Institute of Space Physics, Kiruna (10%)

50% paternal leave: October 1995 - August 1996

Relevant experience:

- Member of the Swedish EISCAT committee 1999 – 2002
- Project leader for the Descartes project participating in EU sponsored campaigns such as THESEO-O3-LOSS and SAMMOA 1997-2001
- Co-PI for the Ion Composition Analyzer (ICA) of the ESA Rosetta mission
- Co-I for Miniaturized Ion Particle Analyzer (MIPA) on ESA's Bepi Colombo mission
- Co-I for Solar Wind Ion Monitor (SWIM) on Indian Chandrayan mission
- Participation in SWEDARP 2006/2007 Antarctic expedition

PhD student supervision:

Johan Arvelius, IRF, 2006, Descartes project, supervisor
Lars-Göran Westerberg, Luleå, 2007, Cluster project, assisting supervisor
Martin Waara, IRF, current, Cluster project, supervisor

Collaborating pos-doc's

Dr. Y. Ebihara (1999-2001), currently senior scientist at STELAB, Nagoya, Japan.
Dr. Y. Hobara (2003-2005), currently at University of Sheffield

Publications

49 publications in refereed journals of which 14 first-authored, 2 more first authored currently submitted

Appendix 3: Team Contact Information

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