

**THE DYNAMO MICRO-ORBITER PROJECT: INVESTIGATION OF MARS GRAVITY/MAGNETIC FIELDS AND ATMOSPHERIC INTERACTIONS.** E. Chassefiere, F. Forget, S. Smrekar, H. Reme, C. Mazelle, M. Acuna, J. Connerney, M. Purucker, R. Lin, J. Luhmann, M. Parrot, J. J. Berthelier, M. Menvielle, P. Touboul, E. Quemerais, J. L. Bertaux, J. Clarke, A. Nagy, J. P. Barriot, M. Blanc, H. Waite, M. Moncuquet, J. L. Bougeret, G. Hulot, O. Grasset, C. Sotin, S. Bougher, B. Jakosky, D. Breuer, and M. Parmentier.

Dynamo is a small Mars orbiter planned to be launched as an auxiliary passenger on the European Ariane V launcher. It is aimed at improving gravity and magnetic field resolution, in order to better understand the magnetic, geologic and thermal history of Mars, and characterizing current atmospheric escape, which is still poorly constrained. These objectives are achieved by using a low periapsis orbit, similar to the one used by the Mars Global Surveyor spacecraft during the aerobraking phase. The proposed periapsis altitude for Dynamo of 120-130 km, coupled with the global distribution of periapses to be obtained during one Martian year of operation, through about 5000 low passes, will produce a magnetic field data set with approximately five times the spatial resolution of MGS. Although some gravity data were acquired at low altitude in the northern hemisphere, most of the gravity field data will be obtained from much higher altitudes (360-400 km) during the nominal observing phase of MGS. Low periapsis provides a unique opportunity to investigate the chemical and dynamical properties of the deep ionosphere, thermosphere, and the interaction between the atmosphere and the solar wind, which is supposed to give rise to significant atmospheric escape, in the absence of an intrinsic magnetic field withholding the solar wind from upper atmospheric layers.

There is much room for debate on the importance of current atmosphere escape processes in the evolution of the Martian atmosphere, as early "exotic" processes including hydrodynamic escape and impact erosion are traditionally invoked to explain the apparent sparse inventory of present-day volatiles. Yet, the combination of low surface gravity and the absence of a substantial internally generated magnetic field have undeniable effects on what we observe today. In addition to the current losses in the forms of Jeans and photochemical escape of neutrals, there are solar wind interaction-related erosion mechanisms because the upper atmosphere is directly exposed to the solar wind. The solar wind related loss rates, while now comparable to those of a modest comet, nonetheless occur continuously, with the intriguing possibility of important cumulative and/or enhanced effects over the several billion years of the solar system's life. If the detailed history of the Martian internal field could be traced back, and the current escape processes could be understood well enough to model the expected stronger losses under early Sun conditions, one could go a long way toward constraining this part of the mysterious history of Mars' atmosphere. Note that MGS measurements of crustal mag-

netization suggest that the cessation of the internal magnetic dynamo occurred during the few first hundred million years of Mars' history, but such a preliminary result needs further confirmation and refinement.

Dynamo will provide a detailed mapping of gravity and magnetic anomalies, from Doppler tracking using an X-band transponder and in-situ magnetometry, respectively. Remote sensing of the magnetic field by electron reflectometry could be used synergistically with magnetometry. The increased coverage and resolution will allow for better definition of the crustal magnetic anomaly sources and elastic lithospheric thicknesses for smaller geologic features. These data will extend the reconnaissance-oriented analyses of MGS data and enable systematic process-oriented studies to be undertaken. In addition to enhanced resolution of the magnetic anomalies, comparison of Dynamo data with spatially coincident MGS data will allow an assessment of noise in the magnetic data due to spacecraft fields and time-varying external (ionospheric) fields of Mars. The increase in resolution will allow identification of discrete sources at a scale of hundreds of km, providing information on the three-dimensional distribution of sources. This will be very useful for placing the sources in a stratigraphic context and understanding the origin of the magnetic remanence. Magnetic anomalies of particular features should be well-resolved, allowing an assessment of the presence of linear, age-progressive anomalies such as might be expected had rifting occurred during reversals of the magnetic field. Magnetic lineations evidenced by MGS in ancient cratered highlands are the most striking example of such structures. Assuming that a relative age relationship between possible magnetic reversals can be determined, regional studies can be placed into a global context to understand the magnetic field history, and thus by inference, the thermal evolution of the planet.

The magnetic transient variations of ionospheric origin induce in the conductive planet an electromagnetic field of internal origin, which is a function of the electric conductivity distribution in the solid planet. The study of the relationship between the external and internal fields, as measured by the magnetometer, would therefore allow to perform electric tomography of Mars at both regional and global scales, down to a few hundreds of kilometers in depth. The electric conductivity is thermally active and depends on the presence of conductive phases like carbon, water rich fluids, partially molten mantellic material. The longer period range, that is periods typically ranging from a few tens of minutes to one martian day, would allow to

## The Dynamo Micro-Orbiter Project: E. Chassefiere et al.

probe the uppermost 400-500 km in the martian mantle, and then to derive information on the structure, thermodynamics and composition of the Mars upper mantle. The shorter period range would allow to probe the Mars uppermost kilometers, thus providing information on the distribution at a regional scale of liquid water in the subsurface.

A three-axis electrostatic accelerometer, coupled with a system of density gauges, is planned to be flown on *Dynamo*, in order to help in separating the gravity signal from atmospheric surface effects. This package, synergistically with a system of density gauges, may be used as well for measuring the density and wind velocity in the thermosphere of Mars. MGS has provided more than 1000 vertical structures of the Mars thermospheric density, but the sensitivity of the MGS accelerometer was not large enough for direct wind measurement. The first phase of MGS aerobraking witnessed the onset, rise, and decay of a regional dust storm event, and the corresponding responses of the lower atmosphere temperatures, dust opacities, and upper atmosphere densities at a given height. This observed global response of a regional dust storm, significantly impacting thermospheric densities over the course of 2-4 days, was extraordinary and unexpected. MGS also confirmed that the Mars lower thermosphere (100-130 km) is a highly variable region on time scales of a day or less. The MGS aerobraking experience monitoring the Mars atmosphere near perihelion and near aphelion suggests that the coupling of the Mars lower and upper atmospheres is composed of: (1) inflation/contraction of the atmosphere, and (2) dynamical forcing (tides, planetary waves, gravity waves) connected to the unexplored middle atmosphere (50-100 km). Models are presently unable to reproduce observed features, pointing to our present lack of understanding regarding dynamical processes connecting the Mars lower and upper atmospheres. *Dynamo* remote/in-situ measurements of the Mars thermosphere will provide global dynamical constraints, enabling a comprehensive characterization of this atmospheric coupling to be obtained.

The evolutionary effect of photochemical escape, pickup of atmospheric ions by the solar wind fields, and sputtering of neutrals from the atmosphere by impacting pickup ions is still poorly characterized. This exercise

requires combining a model for the early solar Extreme UltraViolet emission, a model for the history of the solar wind properties, models of the early Martian upper atmosphere, and an assumed history of the planetary magnetic field. The first of these required elements is satisfied to a degree by astronomical observations of Sun-like stars, while the solar wind history is problematic in that winds of such strength are not generally observable for these stars. Nevertheless, some Lunar implantation studies at least suggest that the early solar wind was stronger by at least a few times in particle flux. Note that a much higher enhancement factor of three to four orders of magnitude is invoked by some solar physicists to explain the present solar lithium depletion. For an upper atmosphere, a reasonable first approximation is to adopt the current atmosphere exposed to the hypothetical early solar EUV fluxes. For the global magnetic field, it is simplest to assume that the present conditions of a negligible field prevailed. With this assumption, and the conservative scenarios described above, calculations indicate that important amounts of atmospheric constituents could have been lost due to the absence of planetary magnetic field protection from the solar wind. It is notable that most of the early solar wind-related losses occur in the first ~1.5 billion years of Mars' history when the solar EUV flux was strongest.

While it can always be argued that some process or processes that we cannot test or prove were responsible for the loss of most of the early Martian atmosphere, we have the possibility of observationally testing a contender that we know continues to operate today. We can exploit the recently discovered Martian remanent magnetic fields by using them to reconstruct the history of the strength of the dynamo generated planetary field. We can also make measurements of the upper atmosphere and solar wind relevant to the escape processes to confirm that they work today in the manner that our models envision. In-situ measurements of thermal ions and neutrals, as well as energetic particles (ions, electrons, neutral atoms) involved in escape processes, will be done by mass spectrometry. These measurements could be completed by EUV spectroscopy of airglow emissions. Solar EUV may be monitored by using a Langmuir probe and/or a devoted subsystem of the EUV spectrometer.