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ASPERA.

Where did the water on Mars go?

Today, there is no, or very little, water in the atmosphere of Mars. However, it seems that there once was a lot of water on Mars. For example, studies of surface features suggest that there existed the equivalent of a several hundred meter deep water layer.

The water might be frozen and buried under the surface of the planet, but some of the water might have disappeared from the planet. One way that water can be lost from Mars is through the interaction of Mars' atmosphere with the solar wind. Water molecules in Mars' upper atmosphere can, due to solar radiation, break apart into hydrogen and oxygen, that in turn can be ionized and carried away by the solar wind. It has been estimated that up to 30% of the water may have been lost in this way.

The solar wind is a plasma consisting mostly of protons and electrons that are ejected from the Sun's corona, and streams radially outward through the solar system at speeds of several hundred kilometers per second. Embedded into the solar wind is also the interplanetary magneticfield. Earth has an internal dipole field, generated by currents in a liquid iron core. The solar wind plasma, and magnetic field, deforms this dipole field into a drop shaped magnetosphere, creating a cavity around earth that protects Earth's atmosphere from direct contact with the solar wind. At planets that lack any significant internal magnetic field, such as Venus and Mars, the picture is different. Here the solar wind can come into direct contact with the upper parts of the planets' atmospheres. For Mars, there are several consequences of this interaction:

- Ionospheric current systems are set up that, partially, deflect the solar wind plasma, and magnetic field, around Mars.
- Ions, produced by photoionization or electron impact ionization of neutral atmospheric atoms, are picked up by the solar wind. This slows down the solar wind (mass loading), and results in a loss of atmospheric mass.
- Energetic solar wind protons collide with neutrals in the atmosphere (such as H, H$_2$, O, and O$_2$) and charge-exchange. In effect, the proton gets an electron from the neutral and an energetic neutral atom (ENA) is produced. Also, ionized atmospheric neutrals, can be accelerated by the electric fields, and then charge-exchange with neutrals, producing for example oxygen and hydrogen ENAs. An energetic particle in this context means that the neutral or ion has much larger energy than the thermal energy of the surrounding neutral gas.

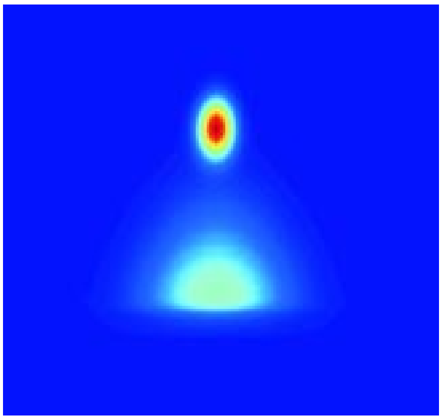

Figure 1. An example of a simulated ENA image. The different colors correspondto the amount of incoming ENAs from that direction. Red means a lot of ENAs and dark blue little. The red dot is in the direction of the sun since a lot of ENAs are generated in the solar wind. The horizontal feature is the limb of Mars. It is straight, not curved, since the image is in polar coordinates. The light blue region corresponds to ENAs generated inside Mars' bow shock.

Mats Holmström, is a scientist at the Swedish Institute of Space Physics (IRF) in Kiruna, doing research in space physics computer simulations related to the instruments constructed at the institute. He also works with science operation planning for the ASPERA-3 instrument. In 1997 he received a PhD in Numerical Analysis from Uppsala University. In 1993, he received a MSc in Mechanical Engineering from University of Houston and a MSc in Engineering Physics from Uppsala University.

To study these interaction processes near Mars in detail, we would ideally like to know the density and velocity distribution of all ions and neutral species, at all locations. Traditionally, a spacecraft make local observations of the environment. Thus, we only get information about one point in space at any moment. To get a global picture, we have to collect statistics on measurements over a long time, loosing temporal resolution, and still we only get measurements along the orbit of the spacecraft, that spans different regions due to orbit plane rotation. These in-place measurements also makes it difficult to separate spatial and temporal effects, e.g., is a measured change in a parameter a spatial change that we passed through, or is it a global change of the parameter with time?

Figure 2. The main unit (to the right) and IMA with all four sensors, and digital processing units (DPUs) marked.

On the other hand, ENA measurements can provide remote information about the environment since ENAs travel in straight lines from the point where they were generated. So, an ENA image can provide a global, instantaneous, picture. Now, if one is interested in the density and velocity distribution of ions and neutral atoms, an ENA image does not provide direct information about this. We have to do some post processing and modeling to infer these quantities from a measured image. The count rate for each pixel of an ENA image measures the amount of ENAs that were produced along the direction corresponding to that pixel, and emitted toward the sensor. We do not know where along this line the ENAs were produced. Also, the ENA production depends on the distribution of neutrals and ions at each point along the line, something that we are trying to deduce. One approach is to use a parametric model of the ENA production near Mars. This model has parameters for, among other things, the neutral and ion distributions near the planet. Given an observed ENA image we can then compute the set of parameters that most likely produced the image. From these parameters we can then estimate things like the outflow of oxygen ions from Mars, in turn providing an estimate of the amount of water that Mars loses to the solar wind.

That this type of modeling approach is feasible has been shown for Earth’s magnetosphere by the ENA imagers on-board NASA’s IMAGE mission. They have for example been able to provide a lot of new information about the magnetospheric ring currents, especially their global behavior over short time scales, since ENA images provides snapshots of large parts of the magnetosphere. Exactly what, and how much, information about the interaction between Mars and the solar wind ENA images can provide we will only know once an instrument is there, but it will be the first ENA measurements in the low energy range (typical solar wind energies) from another planet. A computer simulated ENA image of Mars is shown in Figure 1.

The ASPERA-3 Experiment

ASPERA-3 is an instrument on-board ESA’s Mars Express mission that will be launched by a Soyuz-Fregat rocket in the beginning of June 2003 from Baikonur in Kazakhstan. It will arrive at Mars around Christmas 2003, and will start to send back data from a polar orbit around Mars early 2004. The Swedish Institute of Space Physics (IRF - Institutet för rymdfysik) in Kiruna is responsible (principal investigator) for the instrument, but the project is highly international, involving 15 research groups from Europe, USA, and Japan. ASPERA-3 is the most complex instrument ever built by IRF. The ASPERA acronym derives from Analyzer of Space Plasmas and Energetic Atoms. The first ASPERA instrument was on-board the Russian Phobos mission to Mars, where it made measurements of ions and electrons in 1989. The second ASPERA (ASPERA-C) was on-board theRussian Mars-96 mission, but due to a kick-off motor failure, it never got on its way to Mars.

The ASPERA-3 experiment consists of four sensors, two ENA sensors, an electron spectrometer, and an ionmass analyzer.

The two instruments that detect ENAs, the **NeutralParticle Imager (NPI)** and the the **Neutral Particle Detector (NPD).** These are cameras, but instead of detecting light (photons) as anordinary camera, they detect ENAs. The NPI has high spatialresolution, but no energy or mass resolution. This corresponds to a camerathat takes sharp pictures, but only in black and white. The NPD haslower spatial resolution, but also energy resolution. This corresponds to a camera that takes grainy pictures, but in color. Both ENA imagers are based on the same principles. When particles enter the instrument, first of all, ions are deflected by an electric field. The neutral atoms are unaffected by the electric field and hit a surface, where the impact generates electrons, and the electrons and time of the event is registered. Thus, the flux of incoming ENAs is detected. For the NPD, the ENA then continues until it hits another surface, again producing electrons that are registered. The time between the surface impacts gives the ENAs velocity. Because of the very large difference in mass between hydrogen (1 atomic mass unit) and oxygen (16 atomic mass units), the most energetic oxygen ENAs the instrument can measure, still move slower than the least energetic hydrogen ENAs. Therefore, by only examining the travel time between the surfaces, we can separate oxygen and hydrogen ENAs. The principle of the NPD is illustrated in Figure 2. The NPI is based on a sensor successfully flown on the Swedish micro-satellite Astrid, launched in 1995. It was also an-board the Mars-96 mission. The NPD is a completely new design.

The Electron Spectrometer (ELS) provides directional information and energy for incoming electrons. It is a very small, low power, electrostatic analyzer, that measure electron energies by the amount that they are deflected by an electric field. It is a reduced version of the MEDUSA instrument flown on the Swedish Astrid-2 and Munin missions in 1998 and 2000.

The Ion Mass Analyzer (IMA) is an improved version of the ion mass spectrographs for the Freja, Mars-96, and Planet-B missions. It is an exact copy of the ICA instrument that will be on-board ESA's delayed Rosetta mission, now to be launched in 2004. An electrostatic analyzer selects ions in an energy band. Then a magnetic field deflects ions according to mass, before they are detected by a micro-channel plate that also registers the incoming direction of the ion.

The NPI, NPD and ELS are housed together in a main unit that is placed on a rotating platform (scanner) so that the sensors can make measurements of incoming particles from all directions. Also, the main unit contains a digital processing unit (DPU) that communicates with all the sensors, and passes on the measured data to the spacecraft for down-linking to Earth. IMA is a separate unit, connected by a cable to the main unit. The total weight of the experiment is 8.2 kg, the power consumption is up to 13.5 W. The size of the main unit is 36 x 39 x 23 cm and IMA is a 25 cm long, and 15 cm wide cylinder. The main unit and IMA are shown in Figure 3.

Venus Next

IRF is constructing ASPERA-4, identical to ASPERA-3, that will be on-board ESA's Venus Express mission, to be launched in November 2005. Having two identical instruments at Venus and Mars will provide us with a unique opportunity to make comparisons between the two planets' environments, helping answer the question why one of the planets now is a dry overheated greenhouse, where even zinc melts, and the other planet is a cold dry desert.

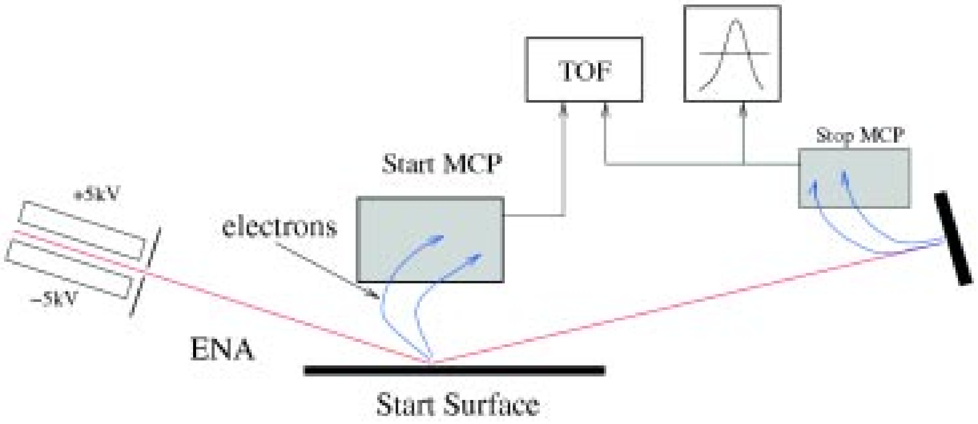

Figure 3. Illustration of the NPD working principle that shows the neutral atoms' trajectories, from left to right, through the deflectors, and hitting the two surfaces where electrons are generated. These electrons are then detected by micro channel plates (MCPs), and the time of flight (TOF) between the two surfaces can be computed.

Further readings.

http://www.irf.se
http://sci.esa.int/marsexpress/

The Analyzer of Space Plasmas and Energetic Atoms (ASPERA-3) for the Mars Express Mission, S. Barabash et al., ESA Special Publication, SP-1240, 2002.