Charge-Exchange Processes near Mars

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The Solar System Physics group conducts comparative research on the evolution and dynamics of solar system objects (planets, asteroids, comets, meteoroids), and their interaction with the solar wind. This is accomplished by measurements in space, data analysis and computer simulations.

The development of space instruments is the main activity, and we are involved in several interplanetary missions, for example the European Space Agency's (ESA's) Mars Express mission, the Japanese Nozomi mission to Mars, ESA's Bepi Columbo mission to Mercury, Venus Express, SMART-1 to the Moon and Rosetta to comet Wirtanen. The different instruments developed at IRF detects ions, electrons and neutral atoms, along with their velocity, mass and arrival direction (imaging).

Computer simulations support the instruments at several stages. At the planning stage, simulations are used to predict external fluxes and instrument characteristics. At the data analysis stage, simulations enables the researchers to extract as much information as possible from the data collected.

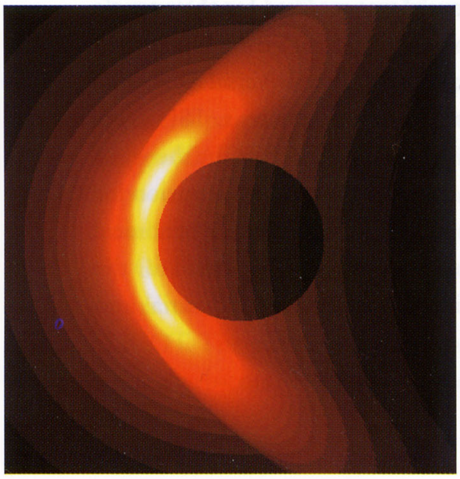

Figure 1: A computer simulated image of Martian X-ray emissions from charge-exchange between solar wind ions and Mars' exosphere. The view direction is perpendicular to the Mars-Sun line, with the Sun to the left. Mars is seen as a dark disc.

An example of predictive simulations is the generation of X-rays from charge-exchange between ions in the solar wind and the atmosphere of Mars. The result of a simulation of the X-ray flux is shown in Figure 1. Such X-rays from Mars have not been detected yet, since no detector that is sensitive enough has examined Mars. When that happens the simulations can be compared with observations.

Another example of simulations is the production of energetic neutral atoms (ENAs) that are produced when a high velocity ion collides with a neutral atom and the ion picks up an electron from the neutral, thus becoming an ENA. Near Mars this occurs when ions from the solar wind collides with atoms in Mars atmosphere. A property of ENAs is that they travel in straight lines since they, as neutrals, are unaffected by magnetic and electric fields.

ASPERA-3 is an experiment developed at IRF for ESA's Mars Express mission, that will be launched in June 2003. On ASPERA-3 there are two instruments that detect ENAs, the Neutral Particle Imager (NPI) and the the Neutral Particle Detector (NPD). These are cameras, but instead of detecting light (photons) as an ordinary camera, they detect ENAs. The NPI has high spatial resolution, but no energy resolution. This corresponds to a camera that takes sharp pictures, but only in black and white. The NPD has lower spatial resolution, but also energy resolution. This corresponds to a camera that takes grainy pictures, but in color.

When Mars Express goes into orbit around Mars in 2003, the NPI and NPD will start to take pictures of Mars and the surrounding region of space. It is difficult to interpret these images directly. The brightness of the images is proportional to the number of incoming ENAs from that direction. The only thing we know is from which direction the ENAs came, not how far away they were produced. Since each produced ENA corresponds to a collision between an ion and an atom in Mars atmosphere, if we knew where the detected ENAs were produced, we would know more about how the ions and the neutral atoms are distributed around Mars.

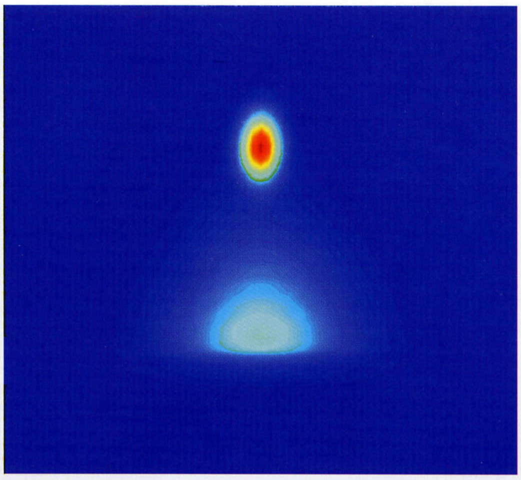

Figure 2: An example of a simulated ENA image. The different colors correspond to the amount of incoming ENAs from that direction. Red means a lot of ENAs and dark blue little. The red dot is in the direction of the sun since a lot of ENAs are generated in the solar wind. The horizontal feature is the 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.

One way to solve this problem is to construct a computer model of Mars' environment. This model includes how the ions flow around Mars, the composition of Mars atmosphere and how ENAs are produced by ion-atom collisions. We can then compute what an ENA image would look like from a certain point. Figure 2 shows an example of such an image, which we call a simulated ENA image.

The computer model contains several parameters, such as the incoming velocity of the ions from the solar wind and the thickness of Mars atmosphere. A simulated ENA image will look different if we change these parameters. Given a picture taken by the NPI or the NPD (a "real" image), we can use this to extract information. We generate simulated images for different parameter values until we find a simulated image that looks like the real image. It is now likely that the simulation parameters that generated this matching image are close to the real parameters, so we now have an estimate of the solar wind ion velocity and all other parameters at the moment in time when the real image was taken. We say that we have extracted parameters from the image.

Generating each simulated ENA image can take a long time. To find a simulated image that matches the real image, we might have to generate thousands of simulated images, corresponding to different parameter values. This means that the parameter extraction can take hours or even days. This is not acceptable, as we would like to know the parameters as soon as possibly after the real image is taken, and we must be able to analyze the incoming data continuously. There are two ways to shorten the time for the parameter extraction. First of all, we can minimize the number of simulated images that we have to generate to find a match to the real image. This can be done by choosing an appropriate optimization algorithm. Secondly, we can generate each simulated image faster. We can do this by using clever algorithms, and by solving the problem on a parallel computer. Fortunately, the structure of the problem is well suited for parallel execution.

Further Readings

http://www.irf.se

http://sci.esa.int/marsexpress/

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