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.

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 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.
estimate of the solar wind ion velocity and all other
data at the moment in time when the real
image was taken. We say that we have extracted pa-
rameters 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 pa-
rameter values. This means that the parameter extrac-
tion can take hours or even days. This is not accept-
able, as
we would like to know the parameters as soon as possi-
ble 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 extrac-
tion. First of all, we can minimize the number of sim-
ulated 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 prob-
lem on a parallel computer. Fortunately, the structure
of the problem is well suited for parallel execution.

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 generat-
ed 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 com-
puter model of Mars’ environment. This model in-
cludes how the ions flow around Mars, the composi-
tion 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. Fig-
ure 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 so-
lar wind and the thickness of Mars atmosphere. A sim-
ulated 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 infor-
mation. 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 sim-
ulation parameters that generated this matching im-
gage are close to the real parameters, so we now have an

Further Readings

http://www.iris.se

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