1 MHD modeling of the interaction between the solar wind and solar system objects

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Summary

We use a general solver of the magnetohydrodynamic (MHD) equations to perform simulations of the interaction between the solar wind and objects in the solar system. The solver has been adapted so that we can add our own initial values, boundary conditions and source terms. The solar wind-comet interaction is the first problem that we have studied using this solver, and the resulting plasma flow is used together with a production model for energetic neutral atoms (ENAs) to produce ENA images as detected by a virtual instrument. The aim of the project is however broader: To structure the software such that it is as easy as possible to adapt it for different solar system objects. The code can then be used as a tool in the modeling and data analysis for interplanetary missions that the Swedish Institute of Space Physics is involved in, e.g., Mars Express, Venus Express and BepiColombo.

Introduction

In this project we have adapted an open source application – the FLASH code[1] – to make magnetohydrodynamic (MHD) simulations of the interaction between the solar wind and solar system objects. The first object we have studied is a comet of the same type as Halley. Using the resulting plasma flow from the MHD simulations we compute the emissions of energetic neutral atoms (ENAs), formed when solar wind protons charge exchange with cometary neutrals, and the subsequent detection of the ENAs by a virtual instrument.

The FLASH code

The FLASH code[1] is an open source application capable of handling general compressible flow problems. The modularity of the code permits users to solve flow problems using only the appropriate modules. Written mainly in Fortran 90, the FLASH code contains different solvers for flow problems along with a version of the PARAMESH library[2] that handles an adaptive computational grid. FLASH is portable, and uses the Message-Passing Interface (MPI) for inter-processor communication. By using this existing code we benefit from the extensive testing and optimization of the code that has been done. Correctly implementing an efficient parallel fluid solver on an adaptive mesh is a formidable task.

MHD plasma flow simulations

Using the MHD solver of the FLASH code, we have added initial values, boundary conditions and source terms to the MHD equations. We have written a general code that can be adapted to compute the solar wind interaction with different objects, and have used the solar wind-comet interaction as an initial case. The comet MHD model follows Ogino[3] and models the comet nucleus as a source of ions, produced by photoionization of neutrals. This is the simplest possible one-fluid MHD model of a comet, but it is sufficient for the purpose of our study − to investigate the morphology of ENA emissions from comets. The photoions are picked up by the solar wind that is decelerated (mass loaded). Our MHD simulations reproduces Ogino's simulation results as far as we can verify. To the left in Figure 1 we see the resulting density distribution for one simulation run, where we can note the bow shock where the solar wind is decreased to sub-magnetosonic speeds.

Benefiting from the utilities for parallelization and automatic grid refinement implemented in the FLASH code, the simulations scale well with the number of processors as shown to the right in Figure 1. To produce results useful for the generation of low resolution ENA images (see below), a typical simulation will need at least 100 CPU hours provided that a minimum of 50 GB of memory is available. Thus, high performance computing is needed both in terms of computational time and memory since we are interested in generating many ENA images, e.g., for parametric studies.

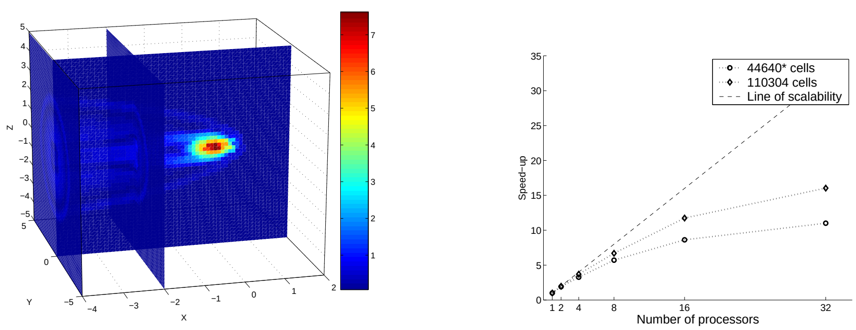

Figure 1: [Left] Log10 of the normalized density of the plasma flow around a comet obtained by our MHD simulations. The solar wind (with density 1.0) is coming from the positive x-direction and the comet nucleus is centered at the origin. Lengths have been normalized by Earth's radius. [Right] The speedup for two different problem sizes as a function of the number of processors.

Energetic neutral atom emissions from a comet

Given the ion flow from our MHD simulations, we then compute the ENA production from charge exchange between solar wind ions and cometary neutrals by line of sight convolutions of the ion flux and neutral density[4].

The production model for ENAs used at present is a rather simplified one, but gives an estimate of the flux and morphology of ENAs produced at comets. An example of a simulated ENA image is shown in Figure 2. These simulated ENA images of the solar wind interaction with a comet can serve as a basis for an investigation of what information can be gained from ENA imaging of comets. In the future, ENA imaging of comets can provide us with global information of their interaction with the solar wind, in the same way that we are now investigation the Mars-solar wind interaction using the ENA sensors on the ASPERA-3 experiment, in orbit around Mars as a part of ESA's Mars Express mission[5].

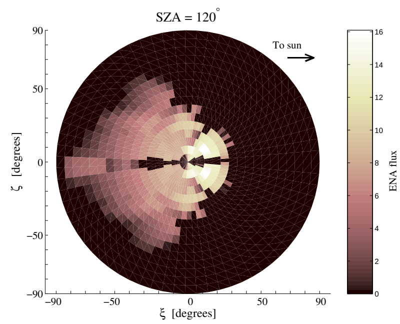

Figure 2: Simulated ENA image as seen from a virtual instrument at a cometocentric distance of 3 Earth radii with a solar zenith angle of 120 degrees. Log10 of the detected ENA flux is shown in units of $\mathrm{sr}^{-1}\mathrm{m}^{-2}\mathrm{s}^{-1}$.

Publications and references

Publications

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