Solar wind interactions with the Earth, planets and comets: is the solar wind turbulent?

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We aim to understand whether and how the turbulent nature of the solar wind affects the structure and dynamics of the solar wind interaction with the Earth and other solar system bodies. We focus here more specifically on the interaction between a turbulent solar wind and different kinds of objects : (i) a comet and (ii) a magnetised planet. We aim in this way at shedding light on the macroscopic effect of the upstream solar wind turbulence on (i) the structure and dynamics of the induced magnetosphere of a comet, as well as (ii) the dynamics of the bow shock, the magnetosheath and the magnetopause of an intrinsic magnetosphere.

For this purpose, we use the newly developed kinetic hybrid code Menura. Menura is built around a hybrid Particle-In-Cell solver, treating electrons as a massless charge-neutralising fluid, and ions as massive charged particles. It solves iteratively the particles' dynamics, gathers particle moments at the nodes of a grid, at which the magnetic field is also computed, and then solves Maxwell's equations. The solver uses the popular Current Advance Method (CAM) in the solar wind reference frame. Menura simulates the global interaction between a fully turbulent solar wind and various bodies of the solar system using a two-step approach. First, a fully developed turbulent hybrid simulation is used to "prepare" a periodic turbulent solar wind. Second, a solar system object (e.g. planet, comet) is injected onto this self-consistent turbulent plasma. Using this numerical model, we perform direct comparisons using both turbulent and laminar solar wind inputs. We show and discuss how the turbulent nature of the solar wind controls the dynamics of various frontiers, modifies the magnetosheath dynamics (in an intrinsic magnetosphere), and affects the inner plasma dynamics and plasma escape (in an induced magnetosphere).

Quick answer : **YES** ➔ *So let it be turbulent!*

Methodology

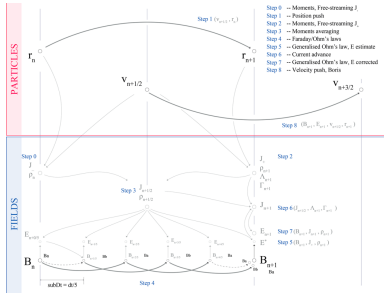
Hybrid PIC code **Menura**, written in C++ in conjunction with the CUDA programming model and the Message Passing Interface (MPI) standard.

Code source available on GitLab:
https://gitlab.com/etienne_behar/menura
Code documentation: https://menura.readthedocs.io/

Step 1: "Prepare" a turbulent magnetised plasma (➔ solar wind).

Step 2: Make this turbulent solar wind impact an object (e.g. comet, planet).

Possibility to inject a laminar solar wind (instead of turbulent)
Possibility to inject another kind of magnetized plasma perturbation



Algorithm of Menura's solver, with its main operations numbered from 0 to 8, as organised in the main file of the code. r and v are the position and velocity vectors of the macroparticles. Together with the magnetic field B, they are the only variables necessary for the time advancement. The electric field E, the current J, and the charge density , as well as the CAM pseudo-moments 3 and 0, are obtained from r, v and B.

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***Menura*: a code for simulating the interaction between a turbulent solar wind and solar system bodies**

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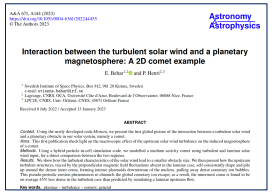
Example 1: Solar wind interaction with comets (*induced* magnetosphere)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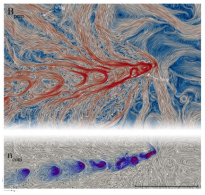
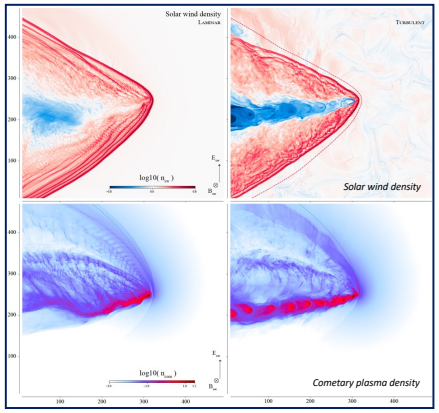
Interaction between the turbulent solar wind and a planetary magnetosphere: A 2D comet example





Magnetic field (line and amplitude)

Solar wind and cometary plasma densities

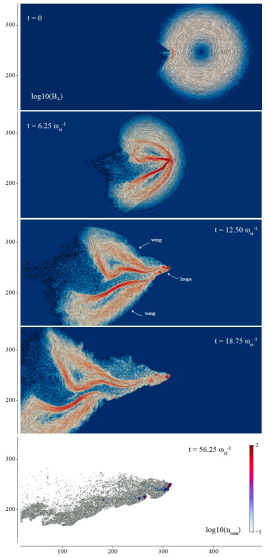
Main results :

Bow shock compression.

High dynamics within the induced magnetosphere directly inherited from solar wind dynamics.

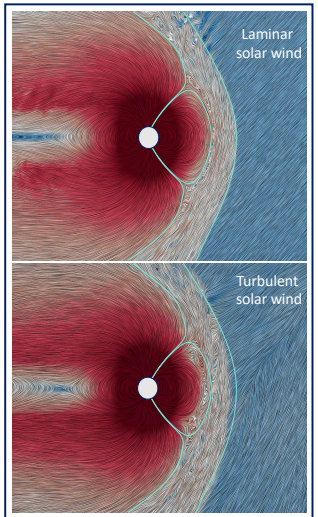
Plasma loss strongly modified by turbulent nature of the solar wind.

➔ What about Venus and Mars?

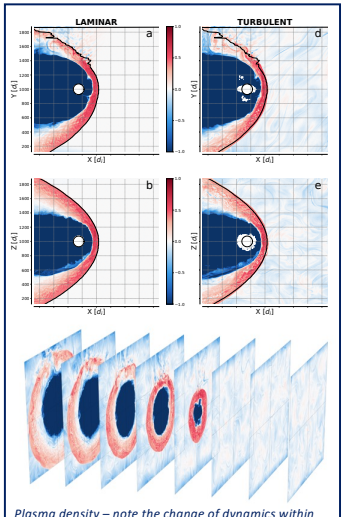


Numerical experiment that aims at isolating the basic mechanism at play.

Example 2: Solar wind interaction with a magnetized planet (*intrinsic* magnetosphere)

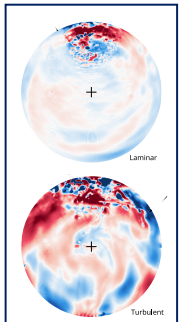


Magnetic field lines and amplitude. Note the change of position of both the bow shock and the magnetopause.



Plasma density – note the change of dynamics within the magnetosheath. Which part of the magnetosheath turbulence is inherited from the solar wind, which part is reset by the shock?

On-going work: Earth-like or Mercury-like magnetosphere and its interaction with a turbulent solar wind



Dynamics of bow shock surface position, forced by the solar wind dynamics