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Comment on angeo-2021-64

Anonymous Referee #2

Referee comment on "*Menura*: a code for simulating the interaction between a turbulent solar wind and solar system bodies" by Etienne Behar et al., Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2021-64-RC2, 2022

The manuscript introduces a new parallel hybrid-PIC plasma code for combined turbulence and comet—solar wind interaction studies. The manuscript draws from two adjacent fields of plasma simulations: those of global planetary plasma environments and those of fundamental plasma phenomena (namely turbulence), and bridges these into a novel package with plenty of foreseeable applications and is of scientific significance. As more of a technical paper describing the simulation, its scientific conclusions are meager, but promising, with most of the substance in describing and validating the code results – a necessary step before proceeding further to the actual science. Having a simple side-by-side comparison for the comet driven by laminar versus turbulent solar wind, or a simple overlay of a contour of the laminar simulation on top of the turbulent simulation (e.g. an estimated bow-wave position) would help to flesh out the results a lot, but is not strictly necessary for publication.

There are, however, some issues left to be addressed before I can recommend acceptance: inclusion of some additional diagnostics and some clarifications on the cometary environments. The presentation of the paper varies from good to missing captions, and additional editing and proofing will help quite a bit to polish the manuscript. There are editing suggestions listed below my specific comments (top-level and line-by-line), but I recommend the authors also double-check the captions and figure labels itself for consistency and completeness against the Annales guidelines.

Top-level:

Section 2: The divergence of magnetic field is not discussed with respect to the solver. Since *Menura* uses node-centered values (line 75), and not e.g. a Yee-type mesh that guarantees conservation of initial div(B), it should be shown that div(B) is a) somehow controlled for or, at the least, b) that it remains small enough for the specific applications. Notably, also the referred Matthews+1994 discretized the electric field at cell centers for the handling of curl(E) – the choice of and grounds for deviating from this should be written out.

Section 4: The omni-directional power spectra are not normalized, which is fine by itself, but it does raise the question on the energy budget in the simulation – is total energy conserved during the simulation, approximately? As this manuscript is the technical paper for *Menura*, it would be good to note with the above div(B) concern.

Section 5.1, Lines 236-244: It is understandable to describe a comet without a solid body, etc. from the modelling standpoint, but comets should still be introduced as the actual physical object we are familiar with (finite size, weak gravity), and then concisely justify the assumptions embedded to the model (e.g. nucleus size << grid scale).

Another, entirely reasonable simplification for this manuscript is the use of photo-ionization only for the source of cometary ions, while particle processes, such as charge exchange and electron impact ionization can have similar production rates to photoionization. These are especially interesting in the context of solar wind turbulence, since the particle processes are coupled to solar wind particle distributions, which I see as a great additional motivation for this line of inquiry.

Section 7: Beyond CIR and CME inclusions, could Menura also handle sector boundary crossings? A consistent thorn with time-varying input solar wind for object-frame simulations is the inability to touch the normal component of B at the front wall, but this is possible for the moving-box simulation, correct?

Line-by-line comments:

Line 1: "between planetary science and fundamental plasma physics", perhaps, to more specifically refer to turbulence studies as a part of fundamental plasma physics? I would argue plasma physics and planetary science have been bridging for quite a while with e.g. studies of Mars' ion escape driven by solar wind.

Line 63: "running its solver exclusively on GPUs" – to state this already at this point: on multiple GPUs in parallel

Lines 72-75: Esp. considering the large macroparticle counts required for the turbulence simulation, the authors should note the hybrid-Vlasov methods and briefly discuss the choice of PIC over Vlasov.

Line 75: "evaluated at the nodes", esp. footnote: Depending on the context, values evaluated at "cell" locations may refer to values averaged over the volume of the cell, instead of point-wise values at the nodes (which is less ambiguous, as nodes usually refer to geometric points, in this context), so "equivalently used by other authors" is not true,

in general. This is also not relevant for the manuscript, so I would drop the footnote.

Figure 1: E* does not appear to be used for J_n+1 as stated in the text.

Lines 185-188: wavenumber and inertial length dimensions are incompatible – is this a formatting error with a missing slash? I am confused by the statement "inertial range" – is this referring to the ion inertial length (in which case I'd expect k ~ di) or Inertial Alfvén Waves?

Line 179: Adding to particle velocities before the particle distributions are introduced as Maxwellian is slightly out of order.

Lines 200-205: Do the authors mean to introduce a Fourier transform in (x,y) instead of (\perpendicular,\parallel) plane? It would not make much sense to do a Fourier transform in the B\parallel direction, if the guide field is out-of-plane. Then "chosen bins of k_\perp" would make sense in the (k_x, k_y) plane. The k_\perp binning is said to be arbitrarily chosen – is this an logarithmic binning with an arbitrary number of bins, or a truly arbitrary function in k\perp? This should be specified more exactly.

Line 216: initial bulk velocity perturbation spectrum is not shown after all?

Line 231: "The first and foremost interest… is it size" is not well-qualified: The size of the plasma environment might be of foremost interest to plasma scientists, while e.g. the size of the nucleus for others (and this is hardly distinguishable from water ion gyroradii).

General Editing:

Citations are not well formatted in the text (\cite vs \citep?), making the text hard to parse.

Line-by-line editing

Line 3: overlapping field*s*

Lines 14-15: a bit repetitive with 3x “communities”

Line 16: eventful instead of event-full

Lin 27: “planet*ary* magnetospheres”

Line 36: “shedding new light”

Line 46: “magnetosphere”

Line 101: “copied to”?

Line 105: “field values”

Line 115: “one gets”

Line 116: “three types of variables”, perhaps, since there are a lot of particles, even at single cell-level.

Line 142 "normalized equations of the solver are given in *Appendix* A"

Table 1 Caption missing.

Line 150: Introduce panel labels for Fig.2, with the B-parallel Fourier transform as panel a) and perpendicular as panel b) and use these in the text.

Line 153: format k.d_i with \cdot or other more suitable operator

Figure 2: Missing subscripts for k (parallel, perpendicular); missing panel labels

Line 162: “not captured”

Line 164: “both growth rates”, perhaps

Figure 3, left: should the WHAMP solution label be |E| for compatibility?

Line 171: “the amount of particles per node”

Line 181: remove “while”

Line 186: k_inj,min/max formatting missing commas? For wave vector amplitude, maybe use wave vector length instead, to contrast with perturbation amplitude.

Figure 4 requires legend and colormap for left panel, right panel could also include slopes for high-k analytic lines

Line 213: “associated with”

Figure 5: missing units

Line 256: ”Small scale oscillations are current”?

Line 262: “macroparticles”

Line 295: “Message Passing Interface”

Line 307: Perhaps “injector data structure”, rather than “variable”

Line 309: “NVIDIA”

Table 3: u0 is given twice, "Physical parameters of the model comet", since an actual comet is more than the model includes

Line 331: “one full turbulence domain injection period: 1500…” or so? Current form implies 1500 iterations being more than one full period.

Line 350: “this lack” - “this deficiency”?

Line 353: “reset” is a strange word here. “Processed”, perhaps?

Line 358: “phenomena”