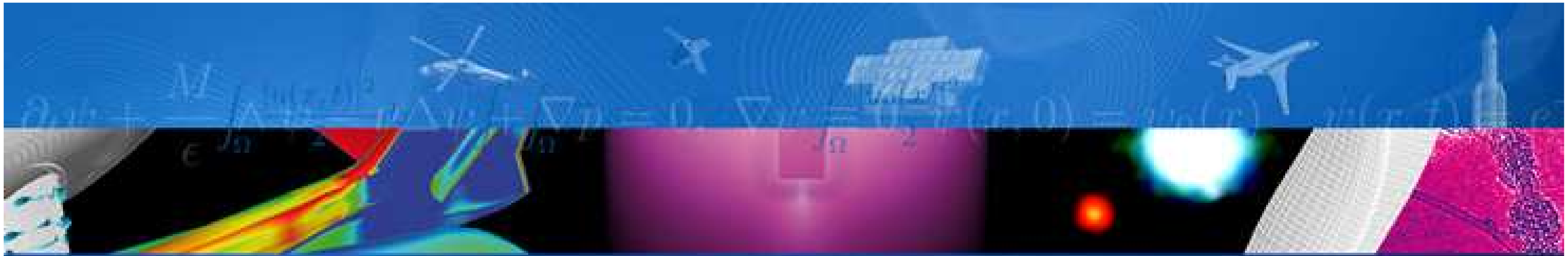

Focus on SPIS limitations for cosmic vision missions

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ONERA : P. Sarrailh, J.-C. Matéo-Vélez, J.-F. Roussel

ARTENUM : J. Forest, B. Thiébault, J. Turbet

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retour sur innovation

Outline

- Introduction
- Focus on the main limitations of SPIS 4.3 (including Demeter simulation with SPIS)
- Performances

Objectives

- Focus on limitations to achieve SPIS simulation concerning:
  - scientific missions (future missions from cosmic vision and past missions)
  - low energy plasma measurements
- Limitations related to:
  - User interface (SPIS-UI) and Numerical solvers (SPIS-NUM)
  - Concerning: inputs, outputs, solvers, thirdparts, the software in general
- Initial list coming from:
  - Initial user requirement list for cosmic vision mission from ESA:
    - List with the SPINE Agenda
    - From the SPINE meeting presentation in 2008
  - Past experience from ONERA/Artenum/IRF/IRAT on SPIS running simulation:
    - Demeter case for example
    - Simulations in other context

Initial user requirements list

- wire boom interaction with plasma (including secondary emission and particle collection);
- solar arrays plasma interaction (including interconnectors current collections);
- energy spectrum of secondary particles (including photo-electron);
- input energy spectrum from the sun in UV-X range;
- detailed characteristics of particle beams emitted by active devices such as ion emitters (when relevant);
- low potential variation due to radar systems;
- exposed high voltage systems;
- magnetic field effect on charged particle collection and emission;
- wake effects;
- shading;
- magnetically induced electric field;
- detailed characteristics of ground based testing environment;
- detailed characteristics of ambient charged particle environment;
- deep dielectric charging effect on surface potential;
- transient effects due to dust impacts;
- rotating spacecraft;
- pitch angle dependency of ambient particles;
- partially transparent grids, e.g., as part of sensors;
- non inter-acting detectors;
- photo-ionisations of neutrals;
- neutral interaction with surfaces (reflection, adsorption and evaporation)..

Software requirement

- The list of effects shall be updated and converted into software requirements taking into account:
  - The accuracy requirement for the physical parameters used as input or output of the simulation shall be defined.
  - The performance of the software

- Initial list of software requirements:
  - varying number of particles according to local mesh size and/or density
  - as high as possible length and time scale ratio
  - expand material property parameters such as the ones describing secondary particle yield curves
  - efficient memory utilization
  - fast run speed

Plasma model

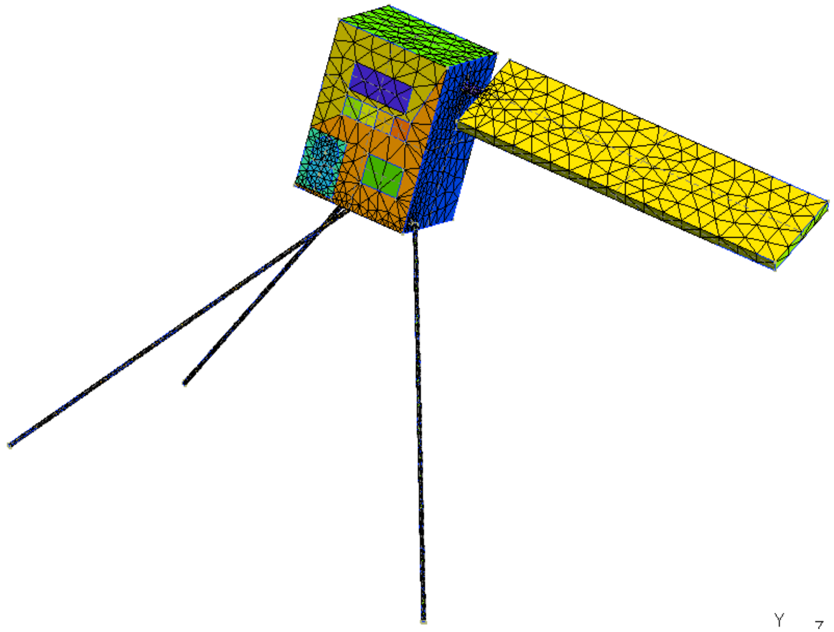
- Full PIC method:
  - Memory consuming: number of cells depends on the Debye length
  - High CPU time cost due to:
    - Large number of particles
    - Necessity to resolve the plasma frequency

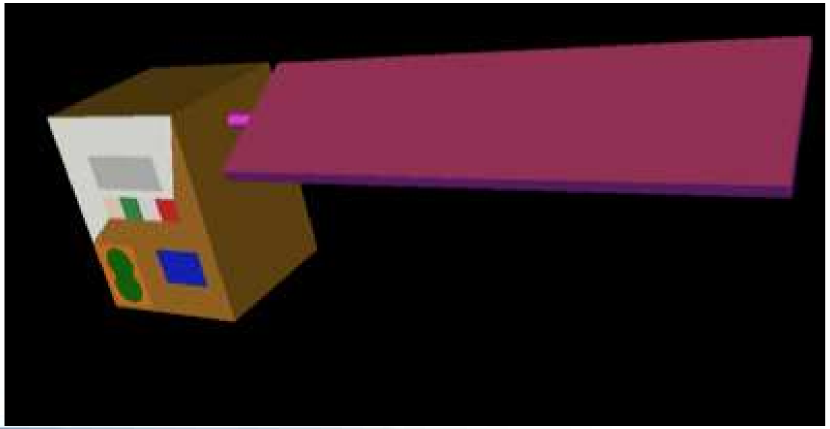
- Best to use other possibility:
  - Hybrid model (Maxwell-Boltzmann relation for electrons) – not valid for positive SC potential or barrier potential > Te
  - Multi-zone (robustness to be verified yet)

- Solutions:
  - Prevent additional cost (software implementation and optimization of simulation parameters)
  - Multi-threading the SPIS-NUM (CPU time gain only)
  - Massive parallelization

Feedbacks from Demeter modelling

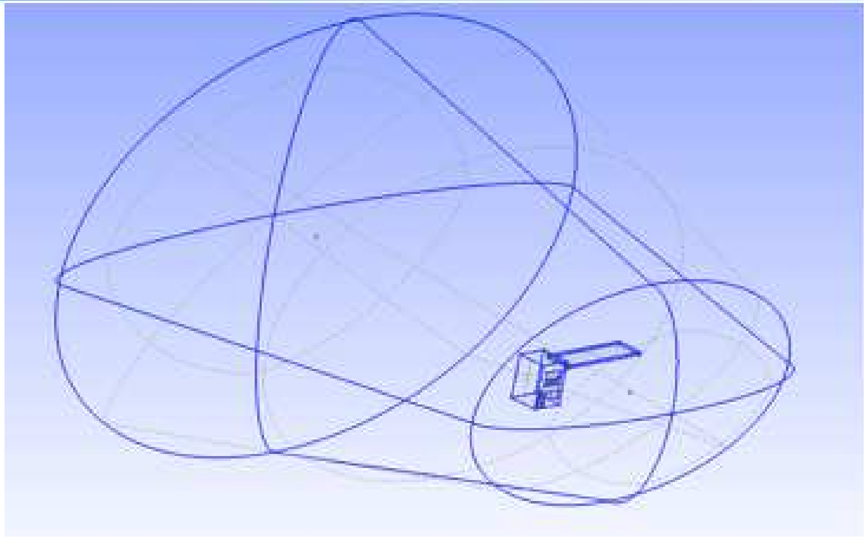
- Study currently done by Artenum under a CETP/LATMOS funding/effort
- Detailed modelling of the Demeter mission, characterised by:
  - Most detailed geometry as possible
  - Detailed modelling of vicinity of scientific instruments (IAAP) and probes
  - Detailed modelling of the wake structure
  - Observation of very thin effects (e.g. variation of potential lower than Te)
- Severe physical and numerical constraints
  - T_e=0.2eV,T_i=0.09eV, v_i=7500m/s, n_e=10^{10} m^{-3}
  - Very low Debye length / SC-size ratio
  - Meso-sonic regime, with a wake structure
  - Need of large computational domain w.r.t. the characteristic sizes and long relaxation times
  - Positive S/C and/or domains leading to the necessity to use full PIC models.

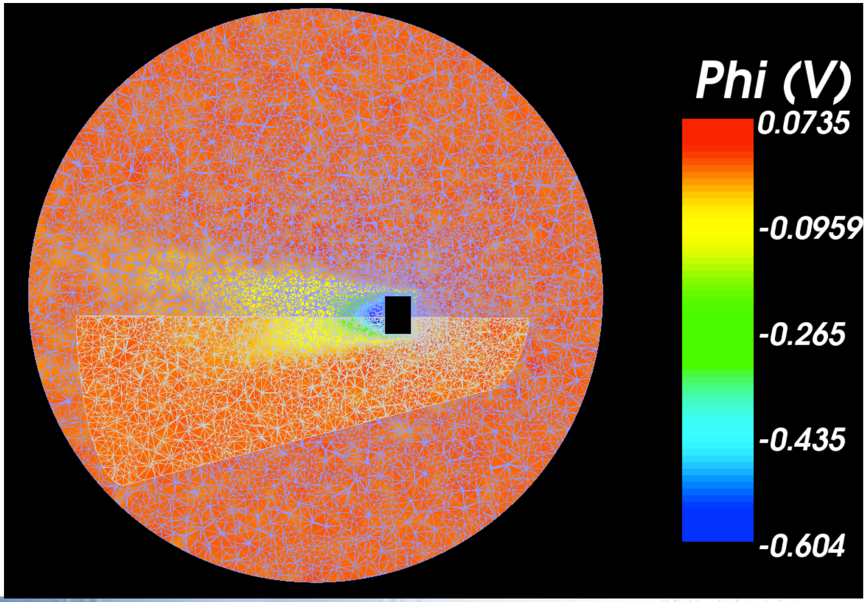




Numerical challenge: pushing back the SPIS limits

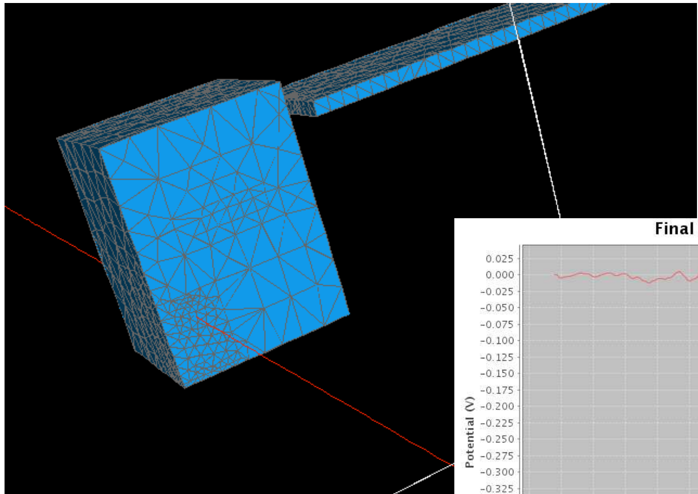
- Large grids
  - In hybrid mode
    - Ext. bound radius: 6m
    - Local resolution: ext. bound 0.3m; S/C surface 0.1m; IAP instrument up-to 0.015m
    - Up-to 7e5 cells
  - In full PIC mode
    - Tronconic shape for a better adaptation to the wake structure
    - Very strong limitation on the global size of the computational domain
- S/C at various potentials
  - Negative: hybrid mode
  - Positive: full PIC
- Study of the impact of the external boundary shape/extension
  - Several shapes of external bound, with cross-comparison

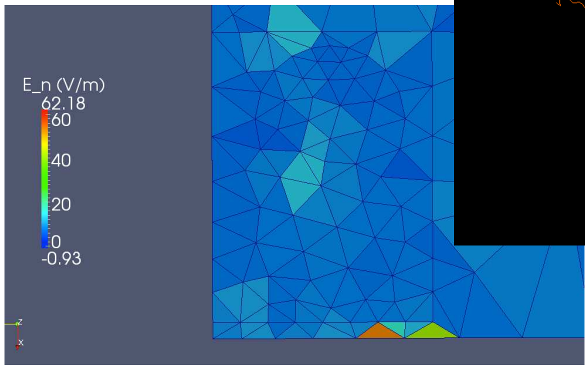


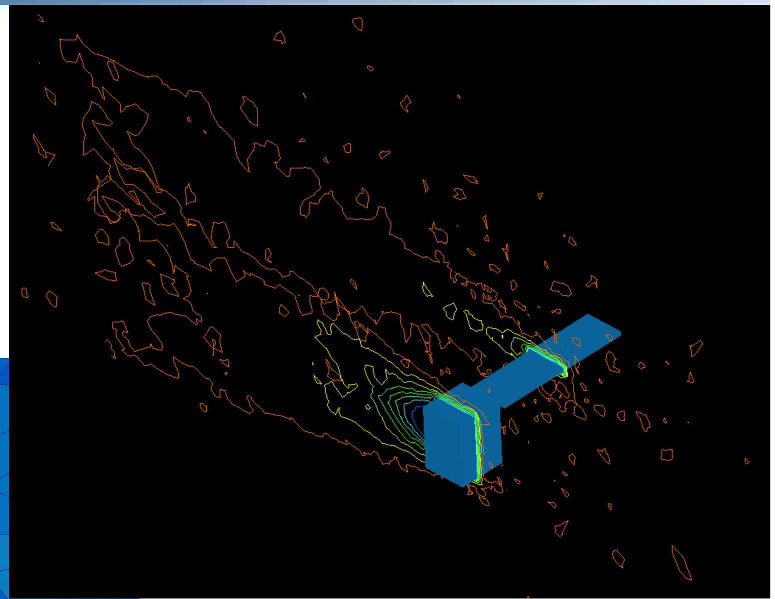


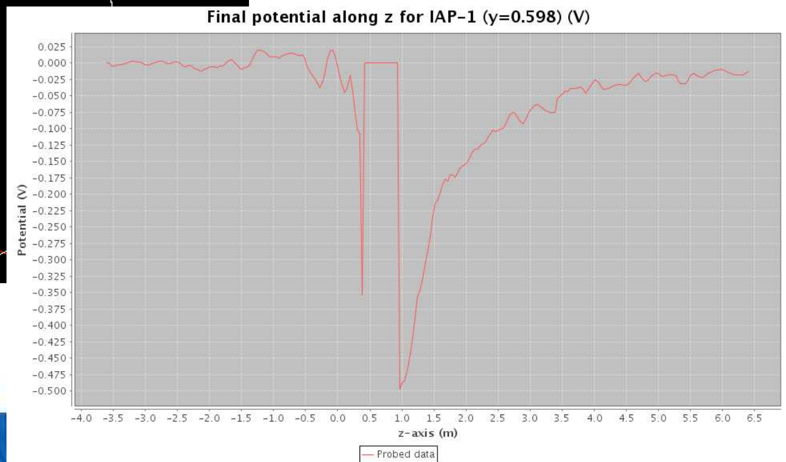
But already detailed and useful results

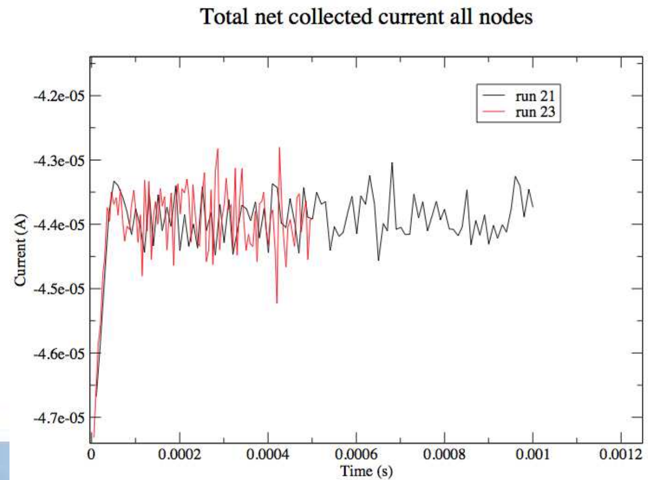
- Possibility to model complex and realistic structure, including
- Realistic and detailed wake structure on a large extension
- Detailed information close to IAP
- Reasonable noise level





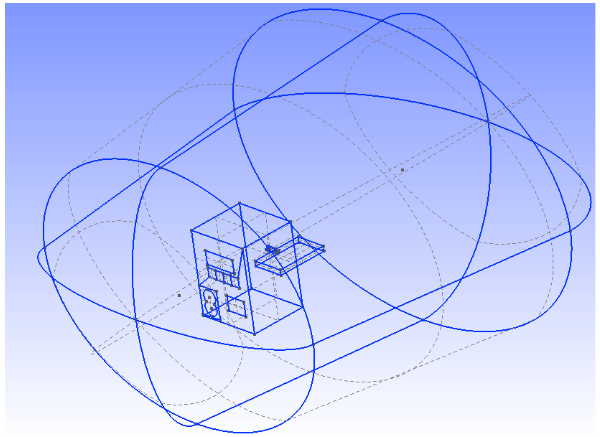






Difficulties, limitation and trouble-shootings

- Large mesh and particles based models naturally very costly in memory, but:
  - Some memory leaks (NUM level):
    - Especially in full PIC models;
    - Impact especially in long simulation runs
    - Partially fixed on the last releases of SPIS.
  - Some memory leaks (UI level):
    - At the data-extraction phase (conversion DF form NUM to UI);
    - At the data saving phase;
    - At the data export/conversion phase (VTK and ASCII).
  - Memory over cost, due to the implementation of current JVMs (e.g. SUN or OpenJDK), leading to strong limits especially in PIC
    - Partially solved by the use of optimised JVM like Oracle JRockit one
    - Limit the grid size to about 1e6 cells
    - Limit number of particles (about 6part/cell for the previous grid)
    - Limit the size of the modelled system



- Strong limits in the persistence scheme (too many data to save, difficult to reload)
- Settings need expertise in function of the studied physic and used models
  - Selection of models
  - Number of particles and ratio ni/ne taking into account the presence of the wake
  - S/C-size/computational domain size ratio

Limits of the Demeter example

- Physics limited to LEO plasma conditions:
  - Debye length very small w.r.p. to the S/C size and the computational domain size
  - Meso-sonic conditions impact the settings of the PIC model
  - Very critical and extreme case
  - Severe demand on the outputs quality and signal/noise level
- “Limits of the software” are also linked to the “limits of the user’s expertise”
  - First runs only, probably with non-optimized settings:
    - Numerical times not applied here yet;
    - Multi-models not used yet for positive areas;
  - Probably too much outputs impacting the whole memory foot print and computational time
    - Need to “select” the outputs in a simpler and finer way
  - Bette knowledge of the limits and application conditions of each numerical model may deeply impact on the effective limits of the software
  - Cross-analysis by parametric studies may be very useful but may be costly in terms of CPU time.
- More advanced tests on larger computers needed for a finer evaluation of limits

Meshing and transport

- Meshing with GMSH (thirdpart tool):
  - Factor of 10^5 in SPIS4.3 between smallest and largest mesh size
  - 2D meshing good
  - 3D meshing not so good, necessitates imbricate boxes for smooth refinement everywhere

- Solutions:
  - Mesh inspector
  - Perhaps better 3D meshing with Netgen

- Particle trajectory calculation:
  - In case of uniform E (and no B)
    - Exact trajectory integration in each tetrahedron
  - In case of non-uniform E (wire elements for example) or with a magnetic field B:
    - Runge-Kutta Cash-Karp adaptive method (4th and 5th order to determine and control the error)
    - Costly in CPU times
  - Possible amelioration for uniform E with B using a quasi-exact method:
    - Integrate exact trajectory in each cell
    - Iterative model to calculate the interception of trajectory with the tetrahedron surfaces (by dichotomy-like method)

Detectors and probe

- Actually, nothing specific in SPIS

- Small detectors (interaction or not with the plasma)
  - The statistics on current collected:
    - Limited with forward tracking
    - Backtracking restricted to ambient populations
    - Solution ? Test particle approach (back/forward tracking on pre-computed potential map)
  - Concerning the outputs:
    - No export of distribution function
    - No trajectory plot from collection to emission site

- Semi-transparent grid are not possible

- Collection and emission by a thin elements:
    - Thin wires = only electric field modelling by now (no collection nor emission)
    - Thin panels = SPIS UI mesh splitting TBDone

Boundary conditions

- Distribution functions
  - Only Maxwellian injected
  - Need for Kappa distribution ?
  - no pitch angle dependency (anisotropy)

- Injection of particles
  - nothing specific in case of simulation box boundary inside the sheath
  - Wake simulation (needs sufficiently big boxes)

Particle in volume

- Control of the number of super particles (noise/accuracy)
  - Today
    - calculated on the external boundary limit
    - no guarantee anywhere else
  - Better if possible to control globally the number of super particles

- Photo-ionization
  - No model for that in SPIS

- Neutral modeling
  - Today: neutral exists in SPIS:
    - Emission from sputtering and sources or ambient
    - Transport and weight deposit in cells
    - Impinging flux
    - Display OK: flux on surfaces, and densities, mean velocity and temperature in volume
  - Need for something else ?

Surface interactions

- Shadowing
  - Self shadowing to be developed in the frame of SPIS-GEO
  - Only source point sun (unique incidence angle)

- Secondary electron under electron impact
  - True
    - Only Maxwellian injection, user defined yield (material parameters)
    - No other model for the dist. function as e.g. as a function of impacting particle energy
  - Backscattered
    - depending on impinging distribution
  - Control of the super particle number is difficult

- Secondary electron under photon
  - Only Maxwellian injection, user defined yield (material parameters)

- Sources
  - Limited to implemented distributions (see SPIS documentation)
  - Only constant over time

Simulation control

- Change of simulation parameters (discrete/continuous)
  - Today, "Scenario" can be implemented in SPIS-NUM
  - Scenario are discrete variation of simulation data with time
  - Two scenario exists in SPIS:
    - Potential sweep scenarios (SPIS 4.3)
    - ESD risk scenario (only in the "ESD Prediction Tool" version of SPIS)
  - But not exist:
    - Spinning S/C
    - Environment change, sources
    - Material properties change
    - etc…

- Convergence
  - Convergence on what parameter ?
  - SC potential, SC current, total energy, total particle number to be developed in SPIS-GEO
  - But is it relevant for scientific simulation ?

Other requirements …

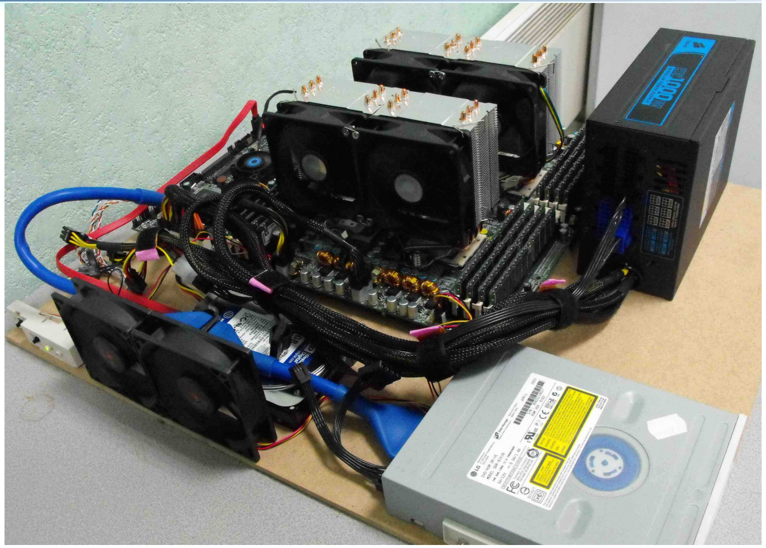
Small sub-systems

- Today: possible local mesh refinement (using imbricate box)
- If a lot of them (e.g. solar arrays interconnects): not possible

- V cross B
  - No model by now in SPIS

- Effect of micro-meteoroid
  - nothing specific
  - what for ?
  - possible: plasma generated by a time-limited source

For fine simulations, we have to pay the price



- SPIS-NUM models are highly optimized but for detailed simulations we have to pay the price.
    - Physics leads to large and refined meshes, costly in memory
    - Fine physics needs higher statistic (nb. particles), costly in CPU-time
- <u>Stop to use old-fashion pocket calculators!</u>
- Present study done on very modest computer (Artenum's "super computer" Belzebuth):
    - Quad AMD Opteron 2Ghz, 22Gb RAM
    - Bought 270€ on… E-Bay…
- For comparison, at the Terratech workshop
    - Fluid mechanics (Code ASTER): mesh about 3e8 cells on EDF supercomputer (92 Tflops).
    - Solid mechanics (Code Saturn): about 5e8 cells
    - Japanese S/C-charging code (MUSCAT) initially designed to be run on the Earth Simulator (40 Tflops, means 12 000 times Artenum's Belzebuth!)