In Remembrance of Giovanni Lapenta
29 October 1965 - 28 May 2024

J. U. Brackbill

April 28, 2025

Happier Times: Bruges, Belgium, 5 September 2009

Outline of Talk

1. Early years at Los Alamos
2. Research in Space Physics
3. Massively Parallel Computing
4. My Favorites

Table of Contents

1. Early years at Los Alamos
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3. Massively Parallel Computing
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A surprising development

- I received a polite letter from Gianni Coppa, Ravetto and a third professor from Torino
- could they meet with me to discuss a collaboration
- they explained the Italian government ended nuclear energy research, and they were re-organizing as the Dipartimento di Energetica
- they had decided the best way forward was to send students to Los Alamos
- Gianni was the first
- he spent 6 months at MIT, loved Boston, liked Bruno Coppi
- he didn't want to come to Los Alamos
- he stayed in Los Alamos for about 15 years

A Few Facts

- PhD Dipartimento di Energetica, Polytecnico di Torino, 1993
- 1991-2008: Graduate Research Assistant, Director's Funded Post Doc, Staff Member; Los Alamos National Laboratory
- 2008-2024, Professor Space Weather, Mathematics Department. K. U. Leuven

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- adaptive zoning to minimize error
  - Gianni familiar with adaptive zoning from plasma processing
  - found measure of local error in literature of moving finite elements
  - demonstrated reduction of error

Plasma Processing

The modules considered here include
- a *fluid module* to simulate the gas flow through the system;
- a *plasma module*;
- an *object module* that uses particles to simulate all the important details of the geometry of the system;
- a *dust module* to simulate the behavior of contaminants and locate the regions where they tend to accumulate. A dust particle is a heavy plasma species with variable charge to mass ratio.

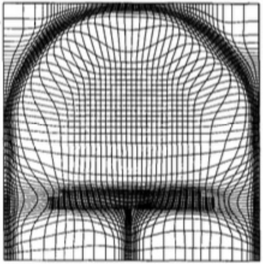

Fig. 10. Example of a realistic 2D geometry. Particles are used to build the main components of the device: the bell jar, the conducting walls, the chuck, and the wafer. A nonuniform grid is used.

- he returned to the method in 2011

[1] [2]

[1] Giovanni Lapenta, Fujio Iinoya, J. U. Brackbill, Particle-in-Cell Simulation of Glow Discharges in Complex Geometries, IEEE Trans. Plasma Science **23** (1995) 769.

[2] G. Lapenta, DEMOCRITUS: An adaptive particle-in-cell (PIC) code for object plasma interactions, J. Comput. Phys. **230** (2011) 4679.

Circular groove traps particles and carries them away

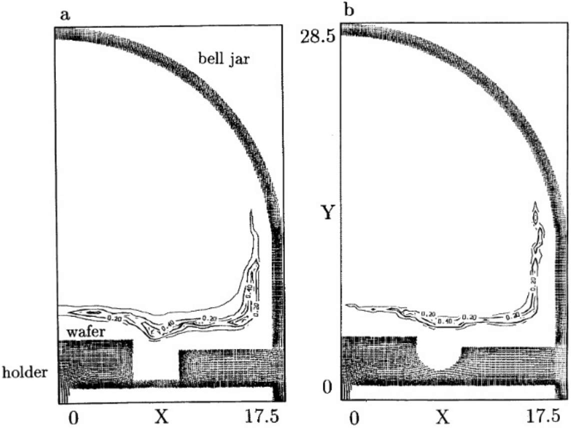

Figure 11. Discharge in a realistic geometry. Isolines of equal density for a square groove (a) and for a circular groove (b). The bell-shaped jar, the electrode, and the wafer are represented by the dotted areas. Distances are in millimetres. [3]

[3] G. Lapenta and J. U. Brackbill, Simulation of dust particle dynamics for electrode design in plasma discharges, Plasma Sources Sci. Technol. **6** (1997) 61-69.

local truncation error

- use adaptive grid to reduce error in solution of Poisson's equation
- with 600 cells and adaptivity (solid line, bottom) same accuracy as uniform grid with 10000 cells (dotted line, top)

[4] [5]

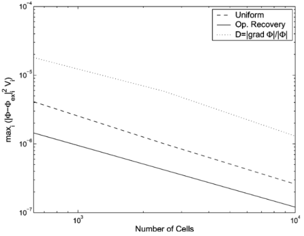

Fig. 4. Poisson equation. CASE 1: Convergence on a uniform (dashed), and two types of adaptive grids: one uses the operator recovery error detector (solid line) and the other uses a variational grid adaptation method based on the heuristic weight $|\nabla\Phi|/\Phi$ (dotted). All grids are squared with equal number of subdivisions in x and y.

[4] G. Lapenta, Variational grid adaptation based on minimization of local trucation error: time-independent problems, J. Comput. Phys. **193** (2003) 159-179.

[5] L.Chacon, G. Lapenta, A fully implicit nonlinear adaptive grid strategy, J. Comput. Phys. **212** (2006) 703.

Gianni's ambition

"I am going to become the Prime Minister of Italy", Gianni Lapenta (private communication at Los Alamos)

Table of Contents

1. Early years at Los Alamos
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3. Massively Parallel Computing
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A brief conversation

Gianni: "Do you mind if I take out the toroidal grid and grid adaptivity to make **CELESTE** run faster?"
Me: "I guess not."

Prof. Lapenta of the Politecnico di Torino in absentia

- students who spent time in Los Alamos
    - Paolo Ricci
    - Stefano Markidis
    - Gianluca Delzanno
    - Gianluca Zuccaro
    - Enrico Camporeale
    - Laura Abradi
    - Cesare Tronci
    - Alberto Marocchino
    - Maria Elena Innocenti

magnetic reconnection studies

- 3D reconnection in a dipole field [6]
- GEM reconnection challenge [7]
- guide field [8]
- nonlinear lower hybrid drift instability (LHDI) [9]
- unexpected role of LHDI in reconnection [10]
- LHDI and the onset of reconnection [11]
- structure of the magnetotail current [12]

[6] G. Lapenta, J.U. Brackbill. Nonlinear Processes in Geophys. **7** (2000) 151.

[7] P.Ricci, G. Lapenta, J.U.Brackbill, Geophys. Res. Lett. **29** (2002) 10:1029/2002/GL015314.

[8] P. Ricci, J.U.Brackbill, W. Daughton, G. Lapenta,, Phys. Plasmas **11** (2004) 4102.

[9] W..Daughton, G. Lapenta, P. Ricci, Phys. Rev. Lett. **93**(2004) 105004-1.

[10] G. Lapenta, J.U.Brackbill, W.S.Daughton, Phys. Plasma **10** (2003)4488.

[11] P. Ricci, J. U.Brackbill, W.Daughton,G.Lapenta, Phys. Plasmas **11** (2004) 4488.

[12] P. Ricci, G. Lapenta, J.U.Brackbill, Geophys. Res. Lett. **31** (2004) L06801.

LHDI again

- linear stability analysis shows the LHDI generates the off-diagonal pressure needed for reconnection [13]

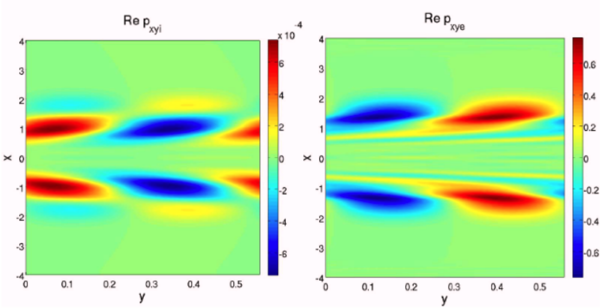

FIG. 13. (Color online) Lower hybrid drift instability: components of the pressure tensor for ions (left) and electrons (right). The top panel is component xx, the middle panel is component yy, and the lower panel is component xy. Pressures are normalized with respect to the maximum value of Re p_{xxe}.

[13] E. Camporeale, G.L.Delzanno, G. Lapenta, W. Daughton, New approach for the study of linear Vlasov stability of inhomogeneous systems, Phys. Plasmas **13** (2006) 092110-1.

Astrophysical Jets

- field lines trace inner current and outer return current
- reverse field Z-pinch MHD stable
- Stirling Colgate was legendary!

14

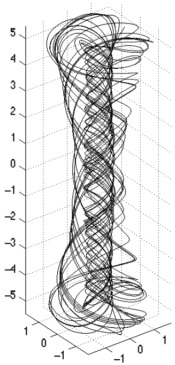

FIG. 7.—Impulsive injection case with $\alpha = 20$. Shown is one magnetic field line at $t = 5$. The field line goes up in a tightly wound central helix and comes back in a loosely wound helix.

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14 H. Li, G. lapenta, J.M.Finn, S. Li, Stirling A. Colgate, Modeling the large-scale structures of astrophysical jets in magnetically dominated limit, Ap J. **643** (2006) 92-100.

Table of Contents

1. Early years at Los Alamos
2. Research in Space Physics
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to do or not to do

Arguments against:

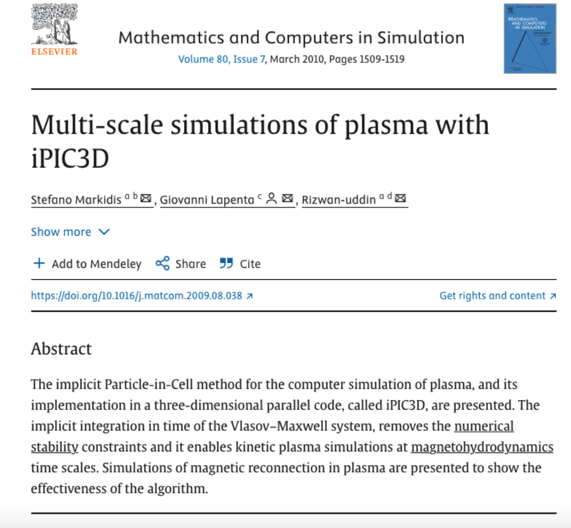
- accessibility of computing resources
- cost of developing and maintaining code
- barriers to innovation in computing
- increased cost of research group

Arguments for:

- solve otherwise impossible problems
- encourages collaboration of larger, more diverse groups
- when it is a question of national priority or prestige, resources available

iPIC3D

Stefano Markidis' development of a parallel version of CELESTE made it possible for Gianni to get support for simulation on a larger scale than before.


ELSEVIER
Mathematics and Computers in Simulation
Volume 80, Issue 7, March 2010, Pages 1509-1519

Multi-scale simulations of plasma with iPIC3D

Stefano Markidis [a b], Giovanni Lapenta [c], Rizwan-uddin [a d]

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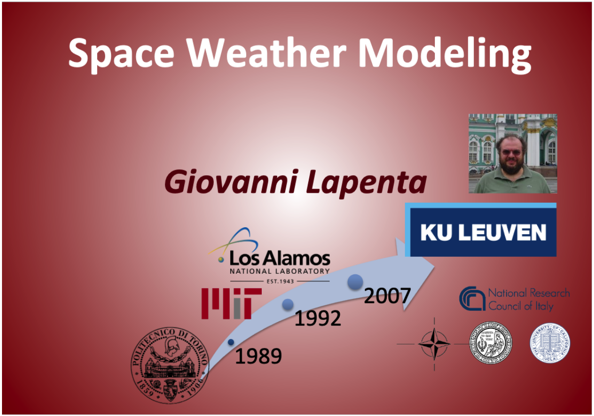
Abstract

The implicit Particle-in-Cell method for the computer simulation of plasma, and its implementation in a three-dimensional parallel code, called iPIC3D, are presented. The implicit integration in time of the Vlasov–Maxwell system, removes the numerical stability constraints and it enables kinetic plasma simulations at magnetohydrodynamics time scales. Simulations of magnetic reconnection in plasma are presented to show the effectiveness of the algorithm.

Gianni's 'Space Weather Talk'



15

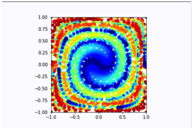
[15] https://indico.nbi.ku.dk/event/817/contributions /5752/attachments/1908/2696/Lapenta.pdf

Table of Contents

1. Early years at Los Alamos
2. Research in Space Physics
3. Massively Parallel Computing
4. My Favorites

Turbulent Magnetogenesis

- Initial Taylor-Green Vortex generates high strain that causes anisotropies to develop in the electron pressure



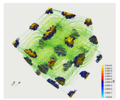


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Figure 2. Rendering of the Taylor–Green turbulent field, with filled contours of the magnetic field $|B|$ (colored patches) and streamlines of ions velocity (green) at $t = 800\omega_{pe}^{-1}$.

- anisotropy drives Weibel instability which generates magnetic field

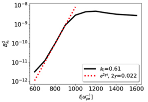

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Figure 6. Growth rate of the Weibel instability for the fastest-growing mode k_0 = 0.61. The red line is the fit to the exponential growth phase.

- simulation with 512^3 grid, 500 particles/cell ... $625X10^8$ particles

16

[16] F. Pucci, M. Viviani, F. Valentini, G. Lapenta, W. H. Mattheus, and S. Servidio, 'Turbulent Magnetogenesis in a Collisionless Plasma, Astrophys. J. Lett. 922:L18 2021

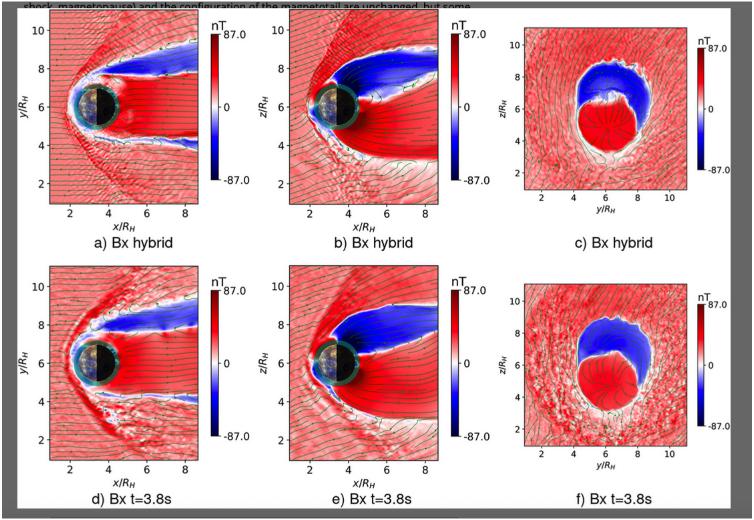
"Do we need to consider electron's kinetic effects to properly model a planetary magnetosphere: The case of Mercury"

- a fully kinetic calculation with initial conditions provided by a hybrid simulation (particle ions/fluid electrons)
- results:
    - the overall global evolution is not significantly affected by the presence of electron kinetic scales
    - main features remain similar
    - localized features are modified
    - increased wave activity

17

[17] G. Lapenta, D. Schriver, R.J.Walker, J. Berchem, N. F.Echterling, M. El Alaoui, P. Travinicek, JGR Space Phys. 10.1029/2021JA030247

Comparison of hybrid and kinetic calculations



Finding reconnection sites with a Lorentz transform

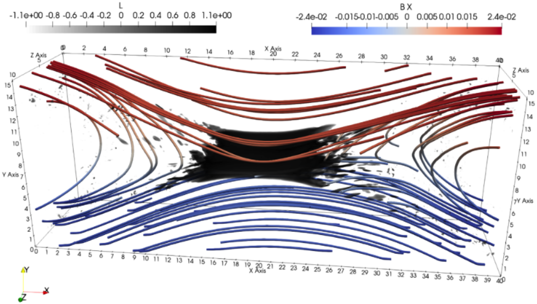


Figure 5. Volume rendering of the Lorentz frame indicator $\mathscr{L}$. A negative value implies subluminal speed for the Lorentz transformation that eliminates the magnetic field in the reconnection plane. A myriad of locations in the outflow and the main central reconnection regions are flagged as locations where the Lorentz transformation can eliminate the magnetic field at subluminal speed.

- reconnection sites are where two components of the magnetic field are zero, and the frame speed is subluminal.
- black indicates reconnection sites

18

[18] G. Lapenta, Ap. J. **922** (2021) 147.

You will miss him.

- Gianni performed a great service to his colleagues. He was a spokesman for Space Science and an effective fund raiser.
- He developed new tools to solve fundamental problems, he chose good problems, and wherever he went his colleagues were eager to work with him.
- He returned to Torino days before he died in the hope that he could spend his last hours in his home in Rubiana.
- Last Christmas was our first without a cheerful call from Gianni. He would tell us about the family celebration on Christmas Eve with his family.