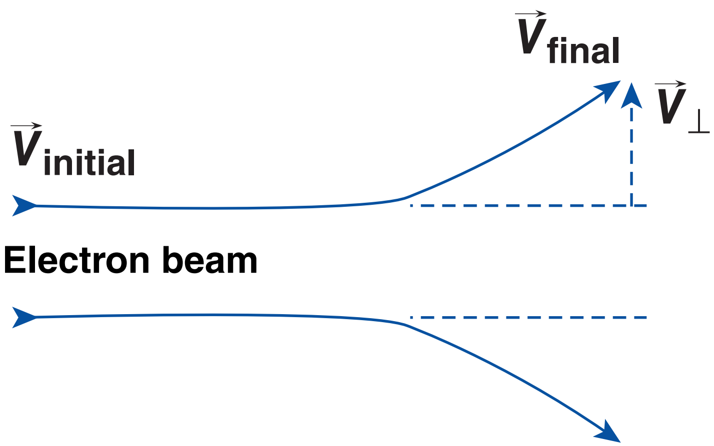
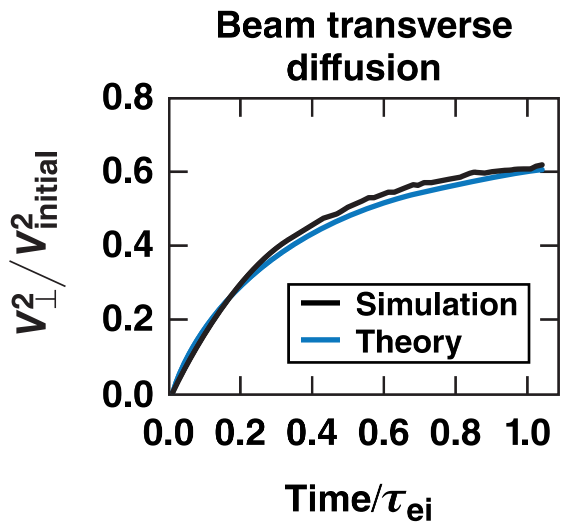
Adapting a Collision Package in Particle-in-Cell Simulations for Graphic Processing Units





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Collision physics can be incorporated accurately and efficiently into particle-in-cell (PIC) codes using parallel graphics processors (GPU's)*

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- The simulation results of beam plasma scattering and electron plasma wave damping tests show that the collision frequencies are consistent with theory
- The collision package, if called every 100 time steps, amounts to only 1.4% of the overall simulation time

*X. Kong *et al*., J. Comput. Phys. 230, 1676 (2011).

Collaborators

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GPU's have both higher computation speeds and memory bandwidths than CPU's

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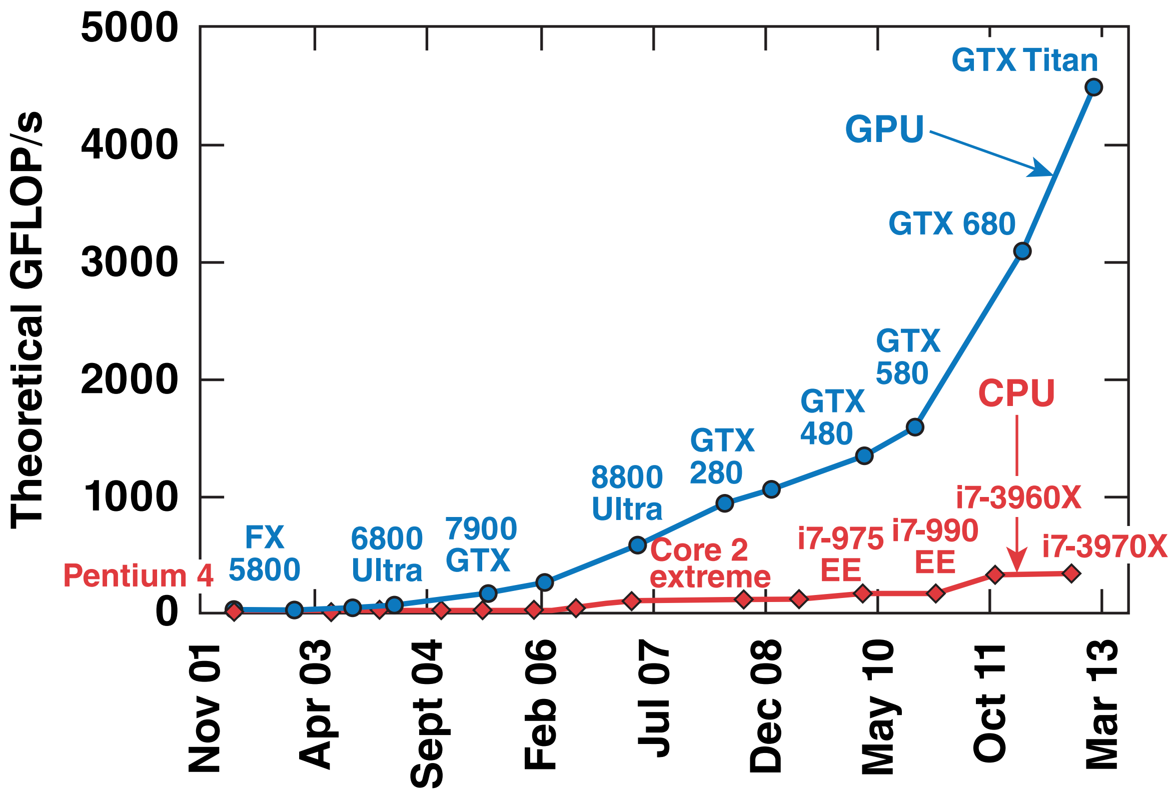

X. Kong, Ph.D. thesis, University of Rochester, 2013.

We have adapted *OSIRIS** for the CPU/GPU heterogeneous architecture**

- Retain the *OSIRIS* parallel structure and boundary conditions (90% of the code) and ship the computation-intensive parts (90% of the computing load) to the GPU, using *CUDA*
- Mostly particle-based threading
- A branch-free, charge-conserving current deposition
- Efficient shared-memory usage
- Highly parallel sorting scheme
- Collision package
- We are now developing a GPU-suitable higher-order current deposition
- Our GPU *OSIRIS* (*OSIRIS*_G) has a performance of ~5 ns/particle-step in 2-D on a GTX 680 card, more than 70× faster than the performance of ~350 ns/particle step for non-SSE† *OSIRIS* on an AMD MagnyCours

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*R. A. Fonseca *et al*. Lect. Notes Comput. Sci. 2331, 342 (2002).
**X. Kong *et al*., J. Com. Phys, 230, 1676 (2011); X. Kong, Ph.D. thesis, University of Rochester, 2013.
† Streaming single instruction multiple data extensions

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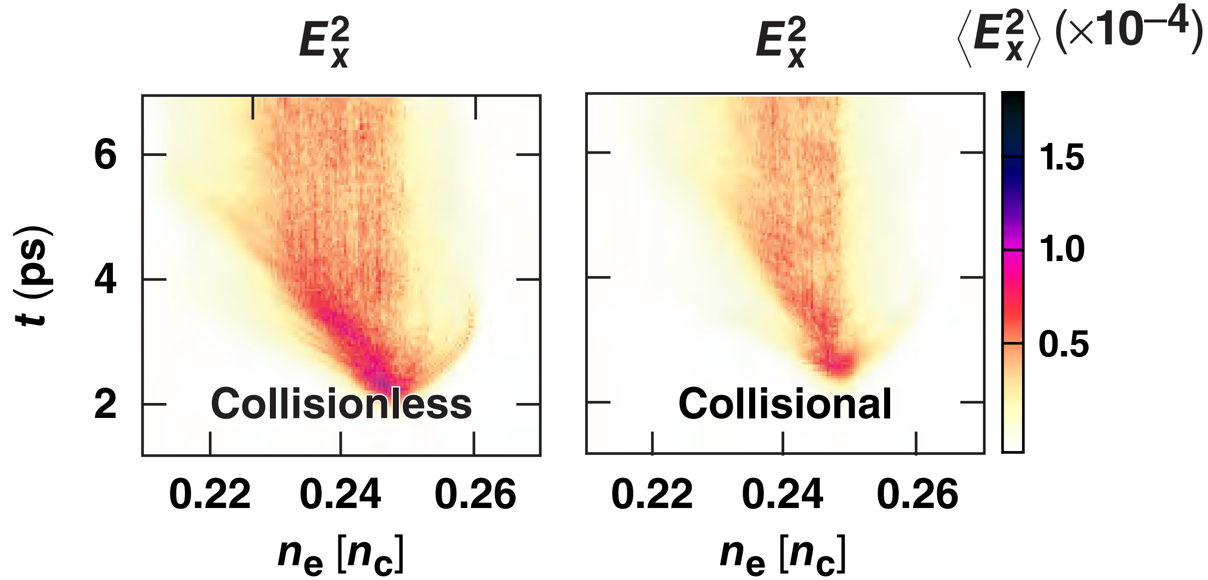
Collisional effect is important in our recent study in laser–plasma interaction (LPI) simulations*

$I = 6 \times 10^{14}$ W/cm^2
$L_n = 150\ \mu$m
$T_e = 3$ keV



- The electron plasma waves excited in the parametric instability are damped by the collision
- The hot-electron energy is reduced to ~5% of the laser energy in the collisional simulation compared to ~16% in the collisionless simulation

*R. Yan *et al*., Phys. Rev. Lett. 108, 175002 (2012).

TC10910

Cumulative collision theory* allows for particle collisions to be calculated at large regular intervals

- The distribution of the scattering angle χ_N can be calculated from the length of the interval
- The scattering angle χ_N is then sampled from this distribution
- The post-collision velocity of each particle is calculated with the sampled scattering angle
- PIC codes do not need to apply collision operations in every time step

$$\coth A - A^{-1} = e^{-\Delta t/\tau_{ei}}$$

$$f(\chi_N) = \frac{A}{4\pi \sinh A} \exp\left(A \cos \chi_N\right)$$

*K. Nanbu, Phys. Rev. E 55, 4642 (1997).

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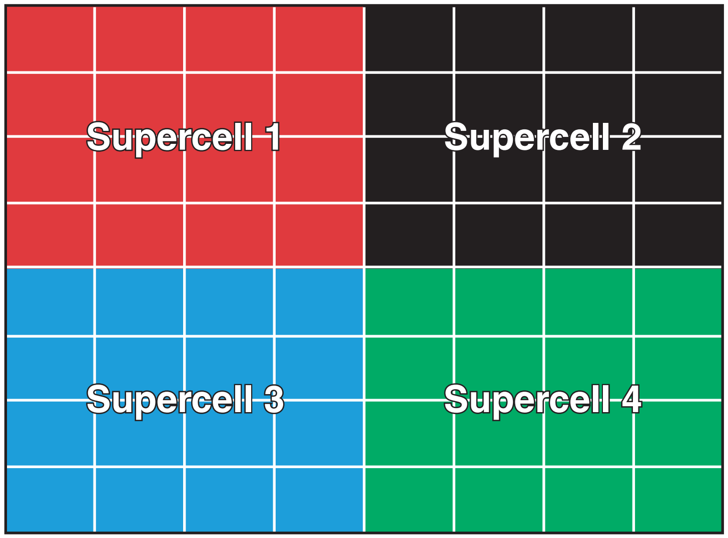
In *OSIRIS*-G, cells and particles are grouped into supercells, each handled by a GPU thread block*



- The supercell size is determined by the shared-memory size of stream-multiprocessors (SM's)
- Each supercell is handled by one SM
  - particles are sorted according to their residing supercell
- The particles in the same (collision) cell are randomly paired and the collision of each pair is handled by a GPU thread

*X. Kong *et al.*, J. Com. Phys. 230, 1676 (2011).

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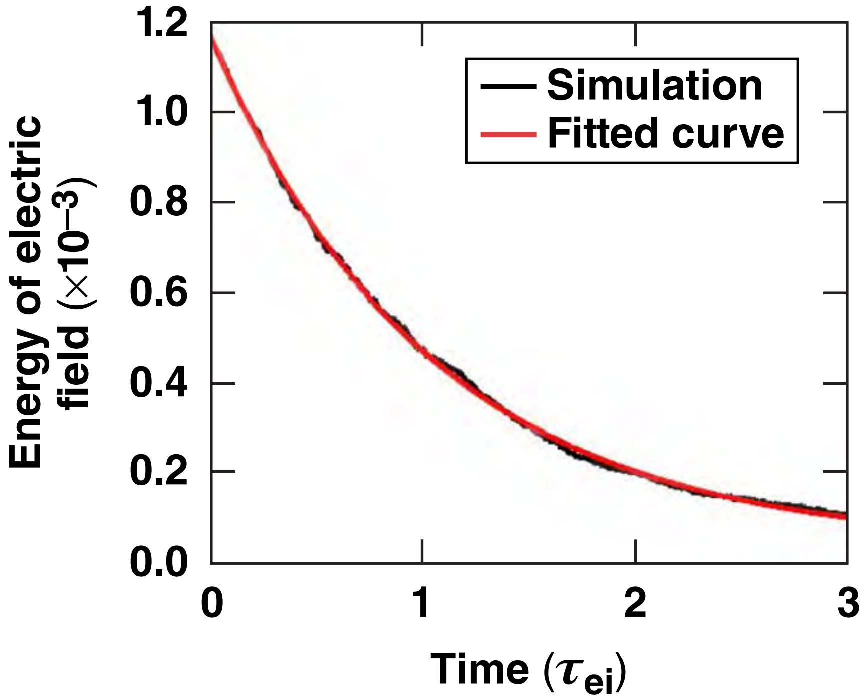
The collision frequencies calculated from the GPU simulation are consistent with theory in the electron plasma wave damping test



Fitted damping rate: $\nu_{fit} = 1.56\ ps^{-1}$

- An electron plasma wave is initialized in a plasma with $T_e = 3$ keV, $T_i = 1.5$ keV, $n_e = n_c/4$, $Z_{eff} = 5.3$
- The fitted damping rate is 96% of the theoretical value of 1.61 ps^{-1}
- The test simulations show that the collisional package needs to be called only every 100 steps (300× per collision time) to produce a satisfactory damping rate

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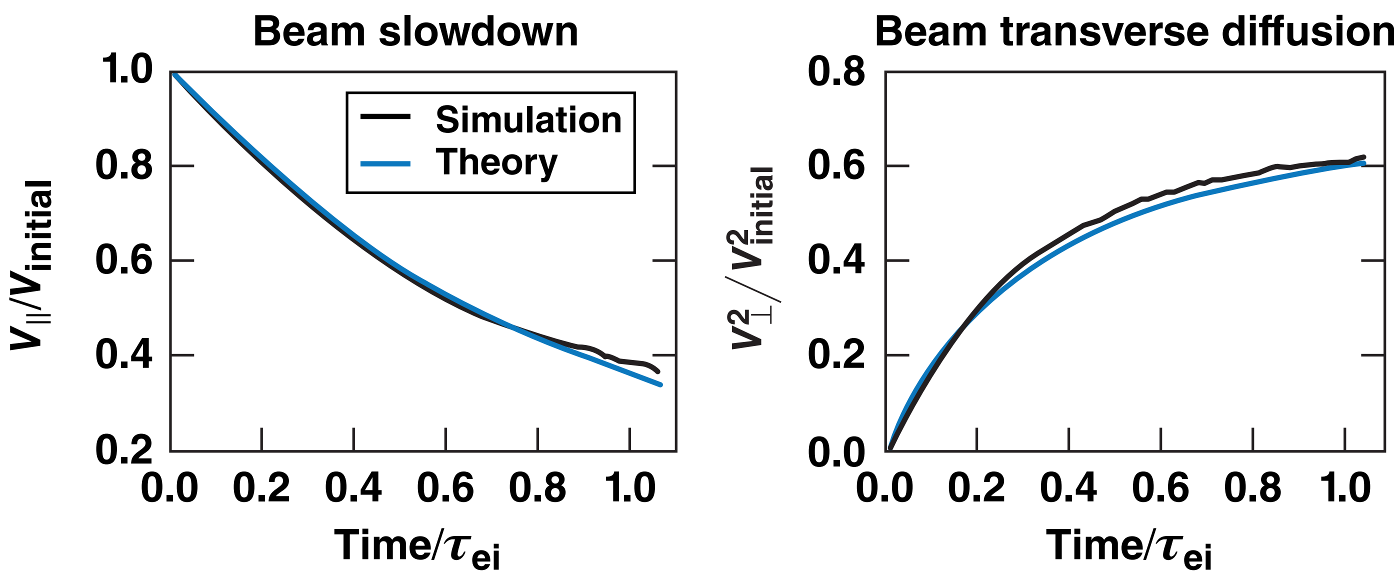
The collision package also generates the correct collision rate in the beam plasma-scattering test



- $V_{\text{beam}} = 0.01c$, $n_{\text{beam}} = 1 \times 10^{18}$ cm^{-3}, $T_i \sim 5$ eV, $n_i = 1 \times 10^{23}$ cm^{-3}
- Both the slowing-down frequency and transverse-diffusion frequency are consistent with theory
- Calling the collision package every 100 steps (90× per collision time) works for this example

Using the collision package does not significantly increase the overall simulation time

- **When the collision package is called every 100 steps, the effective time per step increases by only 1.4%**

A comparison of *OSIRIS* performance on CPU and GPU

	AMD MagnyCours 2.1 GHz CPU (ns)	Nvidia GTX 680 GPU (ns)
Time/particle/step without collision	326	5.36
Time/particle on one collision operation	1032	7.69
Time/particle/step (1 collision/100 steps)	337	5.44

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Summary/Conclusions

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