Towards a GPU based particle model for streamer discharges

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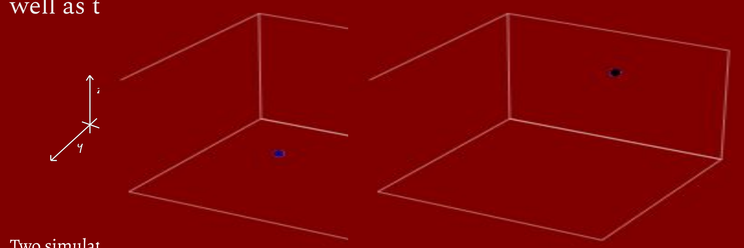
INTRODUCTION

Terrestrial gamma-ray flashes (TGFs) are bursts of X- and gamma-rays emitted thunderstorms[1] and are produced as Bremsstrahlung photons when a relativistic electron scatters off an air nucleus[2]. Such relativistic electrons can be created by the sufficiently strong electric fields which occur in the presence of streamers or leaders.
This project aims to simulate electron avalanches and streamer discharges to improve our understanding of thunderstorm processes as well as t

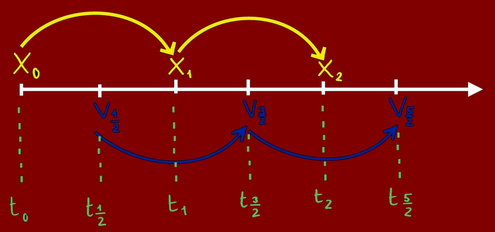


Two simulat e left movement is largely random; on the right all particles move in the negative z-direction due to the high field.

MODEL SETUP

Our Monte Carlo particle code simulates individual electrons and supports parallelism within a processing unit. With our particle code, we simulate electrons and their collisions with ambient gas molecules using a null collision scheme[3].

To update the position and velocity of an electron, we use a leap-frog scheme As a test case, we simulate an electron in vacuum with initial energy ε_0= 1 eV in an ambient field of E_0= -280 V/m in the *z*-direction.

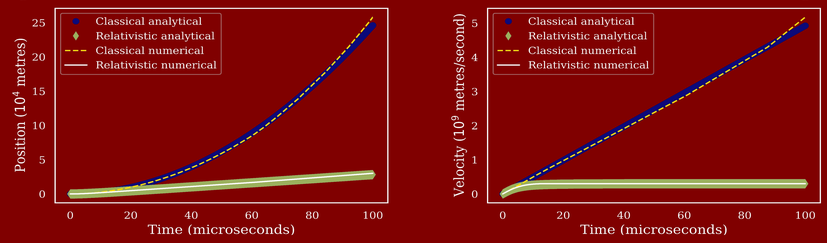


$$\mathbf{v}_{\frac{1}{2}} = \mathbf{v}_{-\frac{1}{2}} + \mathbf{E}\frac{q\Delta t}{m}$$

$$\mathbf{r}_1 = \mathbf{r}_0 + \Delta t \mathbf{v}_{\frac{1}{2}}$$

Schematic of the leapfrog integration along with the leapfrog equations.

Comparison of the analytic and numerical solutions show very good agreement. Note that he classical scheme finds velocity values exceeding *c*.

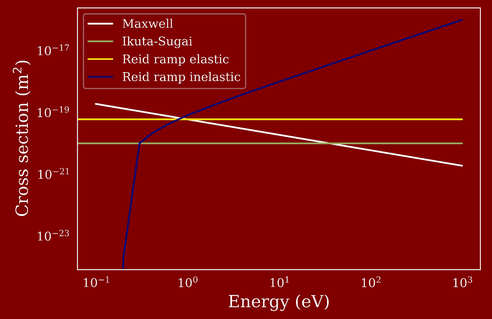


Analytical and numerical solutions for the classical and relativistic leapfrog schemes..

BENCHMARKING

The collision procedure is benchmarked by comparison with known data[4]. The Maxwell and Ikuta-Sugai methods test the elastic collision scheme and the Reid ramp method tests both elastic and excitation collisions. Cross-sections are plotted below.

The Maxwell benchmarking method uses an ambient gas density of n_0 = 10^{23} m^{-3} with an electric field of 1 Td and an assumed ambient temperature of 293 K. The mass ratio is m_e / 4 a.m.u.]

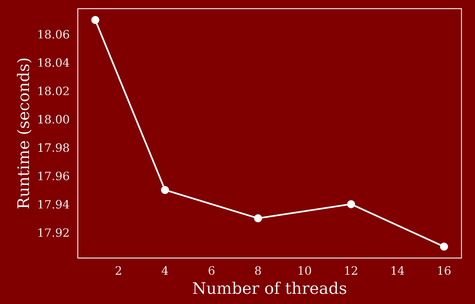


PERFORMANCE EVALUATION

Two performance tests are performed: i) a simple comparison between the serial and parallelised codes, run on the same machine, is performed. These comparisons are run for the Maxwell benchmarking case, and ii) the program's runtime as a function of the number of threads used for the simulations, under the same initial conditions.

RESULTS

Performance evaluation results

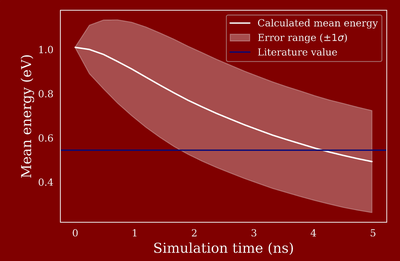


Serial	Parallel
5.02	4.68

Left, Runtimes for varying numbers of threads for the test case simulation time 1 ns.

Top, Runtimes in hours for the serial and parallelised codes with a simulation time of 1 μs.

Benchmarking results



Mean energy <ε> as a function of time for the Maxwell benchmarking. Literature value taken from [3].

CONCLUSIONS

- ➔ We have developed a 3D Monte Carlo particle code
- ➔ First benchmarking results within an errorbar
- ➔ First tests of parallelised code

OUTLOOK

- ➔ Support parallelisation between compute units as well as within
- ➔ Couple with a GPU-based Poisson solver and GPU-based fluid model to produce a 3D hybrid model
- ➔ Use this to study streamers, leaders and TGFs

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