Cosmic rays modulation in heliosphere models on GPU

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Introduction

- Parker's transport equation stochastic differential equation (SDE) solution [1] [2] can be demanding on resources. This especially applies to cases in which we want to use simulations withlow-time steps.
- Dunzlaff et. al. [3] accelerated their Parker's transport equation SDE solution using GPU as a computing unit. Compared to the CPU solution, execution time was decreased by 10-60xdepending on the input parameters.

Test no.	K_0[cm²/s]	V[km/s]	dt[s]
I.	5 x 10^{22}	400	5.0
II.	1 x 10^{22}	300	5.0
III.	1 x 10^{22}	700	5.0
IV.	1 x 10^{23}	300	5.0
V.	1 x 10^{23}	700	5.0

Proposed input parameters for accuracy tests

Implementation

- In implementation of F-p model we were able to reach 75% usage of GPU on Pascal architecture.
- In implementation of B-p model we were able to reach 100% usage of GPU on Pascal, Turing and Ampere architecture.
- Increasing number of blocks from 8192 to 32768 resulted in 10% decrease of execution time.
- Using unified memory became bottleneck and we replaced it with manual managed memory. With this approach we were able to decrease execution time by 35.61% and transfer time between RAM and CPU by 54.13%

Acceleration

- F-p method was accelerated by 7.71x against reference CPU system, acceleration in this case was very similar in various combination of input parameters
- B-p method was accelerated by 86.87 to 183.47 against reference CPU system. Acceleration was more significant with lower values of diffusion coefficient K_0.

Accuracy

- The overall accuracy of the 1D F-p model is acceptable. In the majority of evaluated cases, the maximal deviation was 10% for energies greater than 1 GeV. For each test case except test I., we simulated 500 billion quasiparticle trajectories. For the test I. statistics was increased to 1trillion simulations.
- In the upper right figure is shown ratio between GPU implementation of F-p model and spectrum from CN. Accuracy over 1 GeV is acceptable, with maximum deviation of 10%. Under 1GeV we can observe deviations up to 24% at 0.3 GeV.
- For verification of our GPU implementation of F-p model we compared multiple version of GPU implementations with different accuracy against CPU implementation of F-p model in double precision. Energy spectra for single and double precision are nearly identical with maximal deviation of 13% at low energy.
- We were able to compare the ratio between both implementations of B-p model and CN model. The maximum deviation between the ratio of GPU and CPU implementation of B-p method was at the level of 1%. Comparing B-p to CN model, the deviation reached 1% in the case of test II. and III. In test IV. and V. deviation over 1 GeV is less than 5% comparing to CN model. But under 1 GeV we observe a very similar shape, reaching a maximum deviation of 11% in the case of test IV. and 23% in the case of test V..

Conclusion

- Acceleration on GPU can provide needed computing power, especially for backward-in-time implementation.
- GPU implementation of the forward-in-time model proved useful, even with lesser acceleration than the backward-in-time model. Issues with accuracy with time step less than 2.0 s can be considered as edge case because it is not common to use too low time step. We are assuming that from fact that multiple authors did not use time step lower than 5.0 s in [2][3][4][5].

References

[1] Space Science Reviews 212.1 (2017): 151-192.
[2] J. Geophys. Res. Space Physics, 121,doi:10.1002/2015JA022237.
[3] Computer Physics Communications 192 (2015):156-165.
[4] International Conference on Parallel Processing and Applied Mathematics. Springer,Cham, 2017
[5] Computer Physics Communications 207 (2016): 386-399.

Acknowledgment

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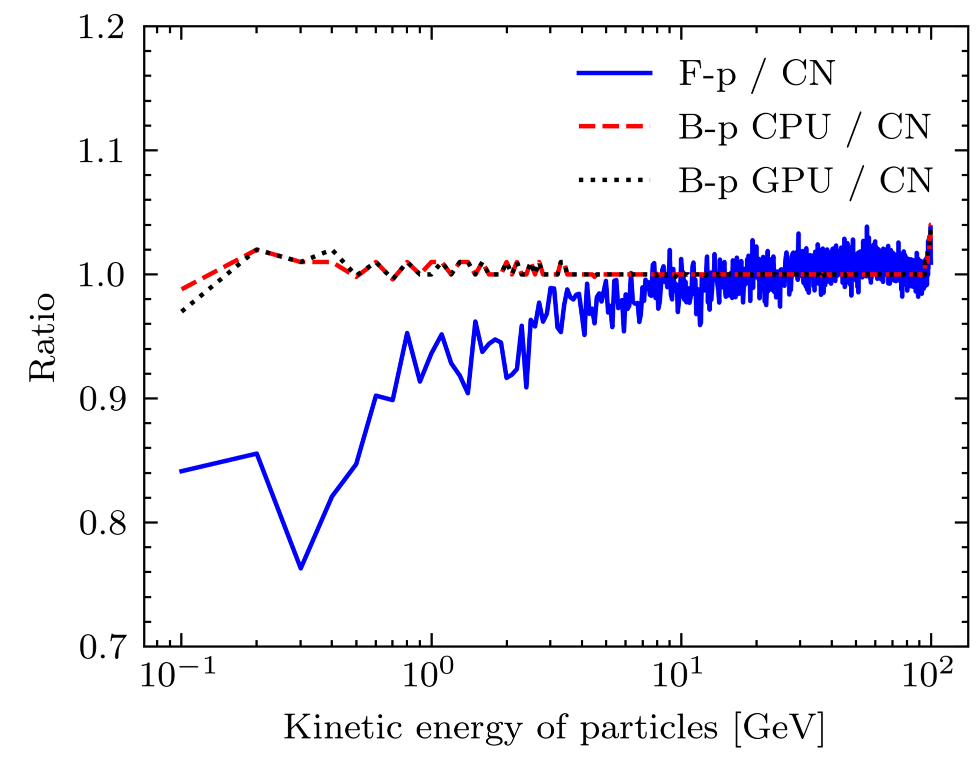
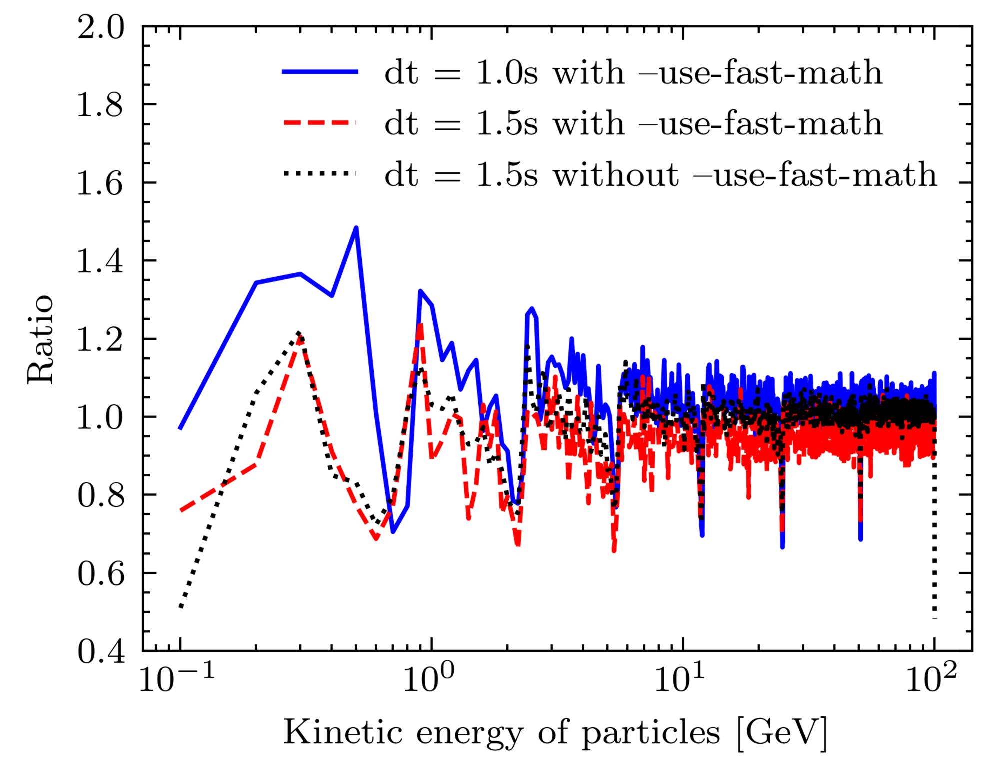
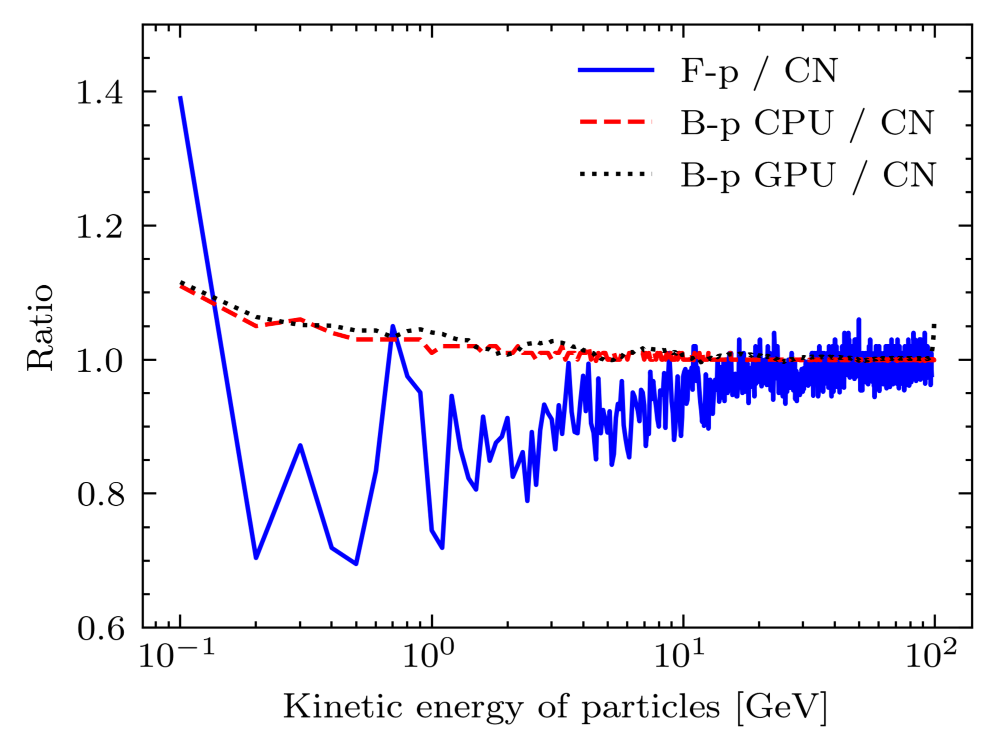


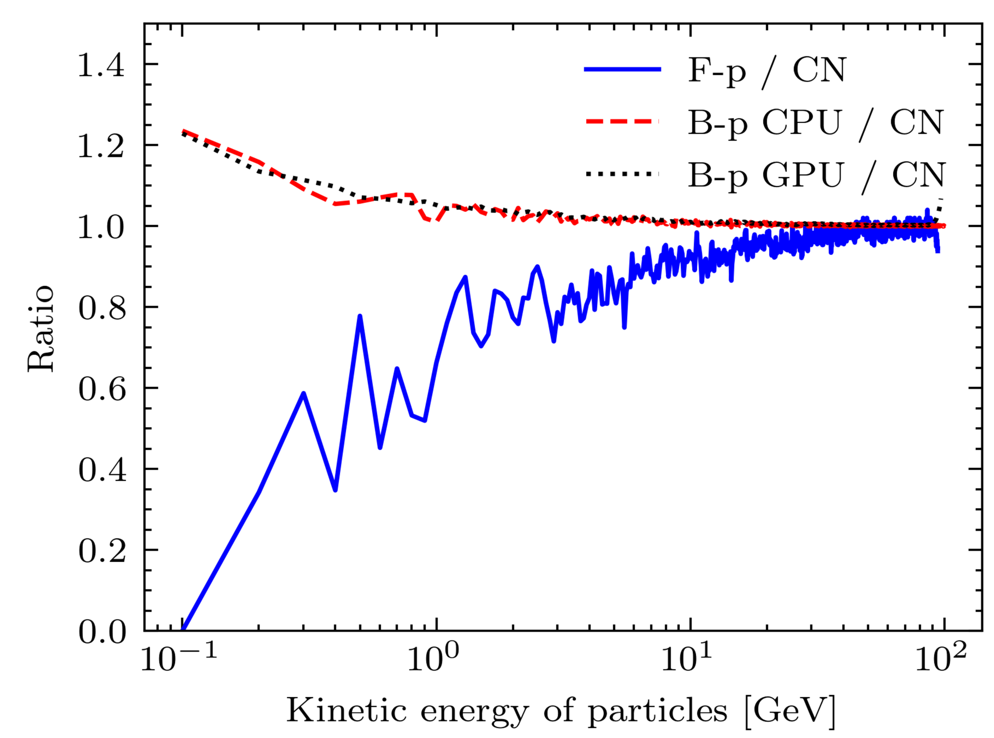
Ratio of energy spectra for solar wind speed V = 400 km/s, difusion coefficient K_0=5 x 10^{22}cm²/s and time step dt = 5.0s



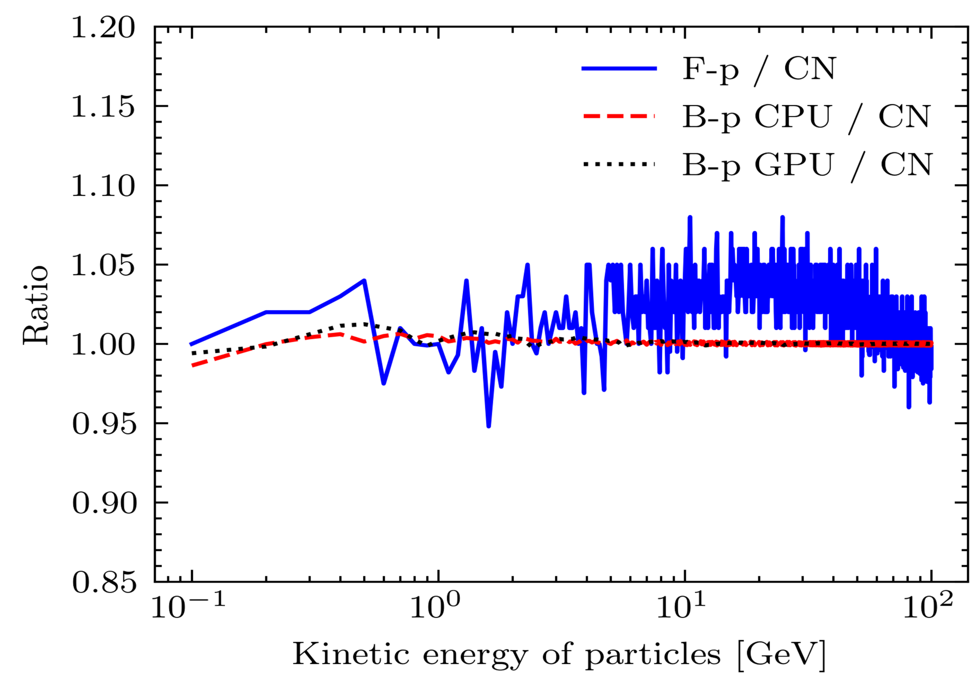
Ratio of energy spectra between GPU and CPU implementations



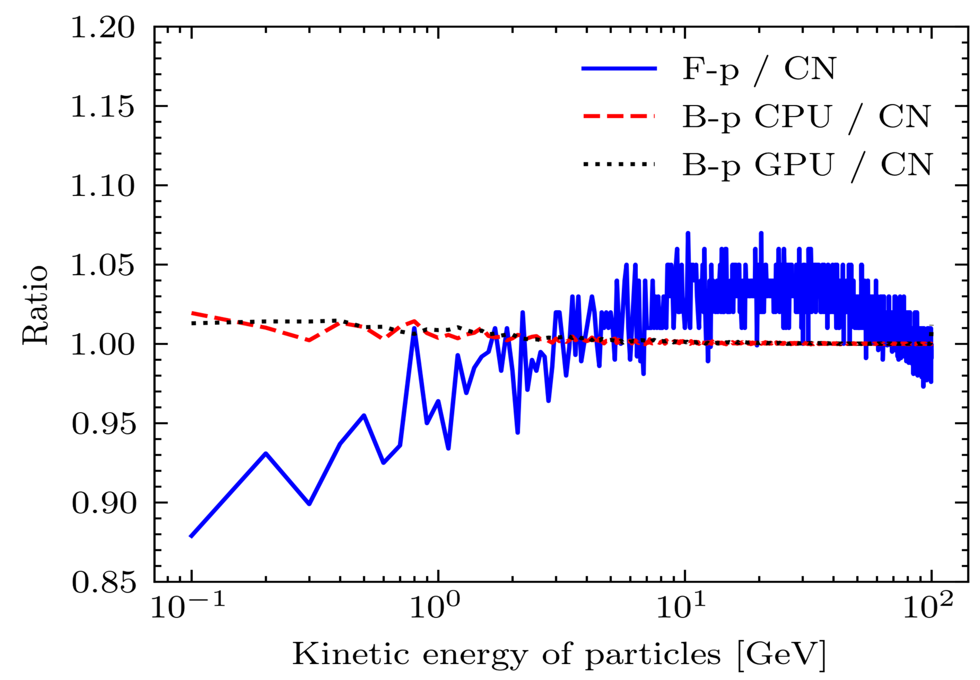
Ratio of energy spectra for solar wind speed V = 300 km/s, difusion coefficient K_0=1 x 10^{22}cm²/s and time step dt = 5.0s



Ratio of energy spectra for solar wind speed V = 700 km/s, difusion coefficient K_0=1 x 10^{22}cm²/s and time step dt = 5.0s



Ratio of energy spectra for solar wind speed V = 300 km/s, difusion coefficient K_0=1 x 10^{23}cm²/s and time step dt = 5.0s



Ratio of energy spectra for solar wind speed V = 700 km/s, difusion coefficient K_0=1 x 10^{23}cm²/s and time step dt = 5.0s