Simulation of Gravitational Potential of the Milky Way on its Satellite Galaxy

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Objective

Professor Chiueh and his team at the NTU array lab have been involved in research of a wave-like solution for the non-relativistic universal dark matter. Our project aimed to simulate the time-dependent dynamics of the components of a satellite galaxy due to the gravitational force field of the Milky Way and test the ability of wave dark matter model to explain galactic dynamics.

Methods Involved

We started by simulating the translational motion of a single massive free particle A under the force field of a heavy point mass object B which is in circular motion. Particle A is at rest at the centre on the circular trajectory that particle B is moving on. Particle A is then set in motion under the Gravitational force field generated by particle B. The trajectory traversed by paritcle A during one complete orbit of particle B can be seen in the first image to the right.

As our next step. We simulate the gravitational potential due to the circular motion on the heavy point mass B (equivalent to milky way galaxy). The central dot is particle A. The change of potential accross a 512×512 pixel square box can be seen in the animation to the right.

Challenges

Our initial approach was to analyze the components of the satellite galaxy from the Milky way's frame of reference. This approach, however, resulted in high computational complexity since we had to account for the translational motion of the satellite galaxy's components. Hence, I attempted to analyze the components of our galaxy from the non-inertial frame of reference of satellite galaxy by including a fictitious force. This highly simplified the computations and received much appreciation from Professor Chiueh.

Another challenge was to maximize the precision of the N-body simulation within the computational limits. We searched for a balance between the requirements of a high-resolution N-body simulation and the consequent computational complexity by writing a comprehensive script using C++ and CUDA.

Conclusion

We generated the simulation of translation of a paticle A in the gravitational field of another heavy point mass B which moves in a circular trajectory centered at the initial position of particle A. This system can be considered as an approximation of the (Milky Way + Satellite Galaxy) system if we center ourselves to the frame of reference of the satellite galaxy. In that case, the milky way can be considered as a heavy point mass revolving around the satellite galaxy.

We also build a model which calculates the gravitational potential due to the Milky Way on a $512 \times 512 \times 512$ pixel box centered at the centre of satellite galaxy. This model gives the value of gravitational potential on each pixel of the box. Thus, it can be used to guide the dynamics of an N-body simulation for the stellar and Dark Matter components of our satellite galaxy.

Animations

Link for the animation of Figure 1: Trajectory of point object A

Link for animation of Figure 2: heatmap of gravitational potential due to B

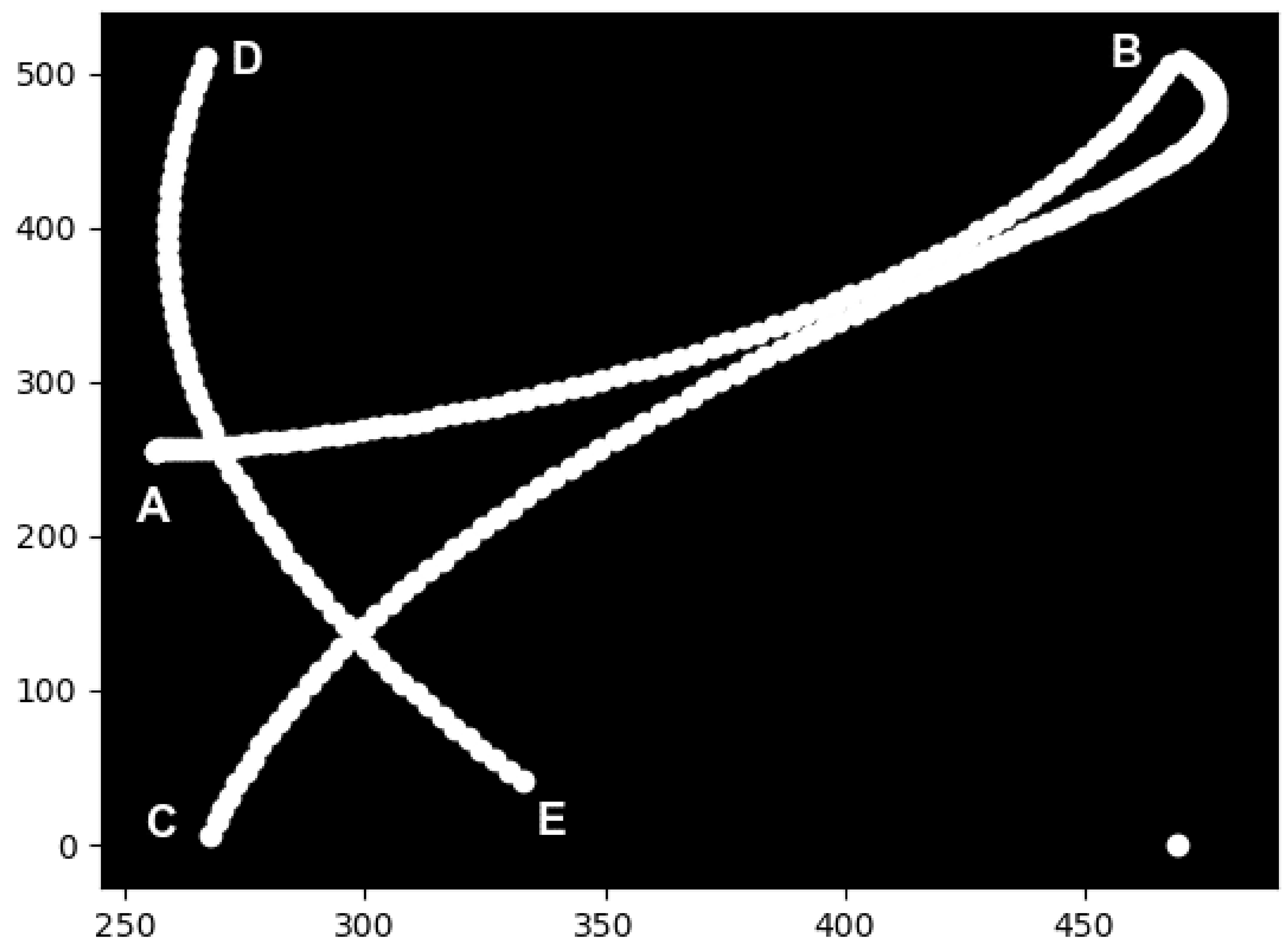

Figure 1:Trajectory of Particle A under the influence of gravitational force field of particle B revolving at a radius of 512 pixels. Particle A starts at point A (256,256)and reaches to point B and then point C. The trajectory arc DE is the continuation of particle A's path after C. Due to the use of periodic boundary conditions, if the particle crosses the simulation box boundaries, the continuing trajectory starts from the opposite sides

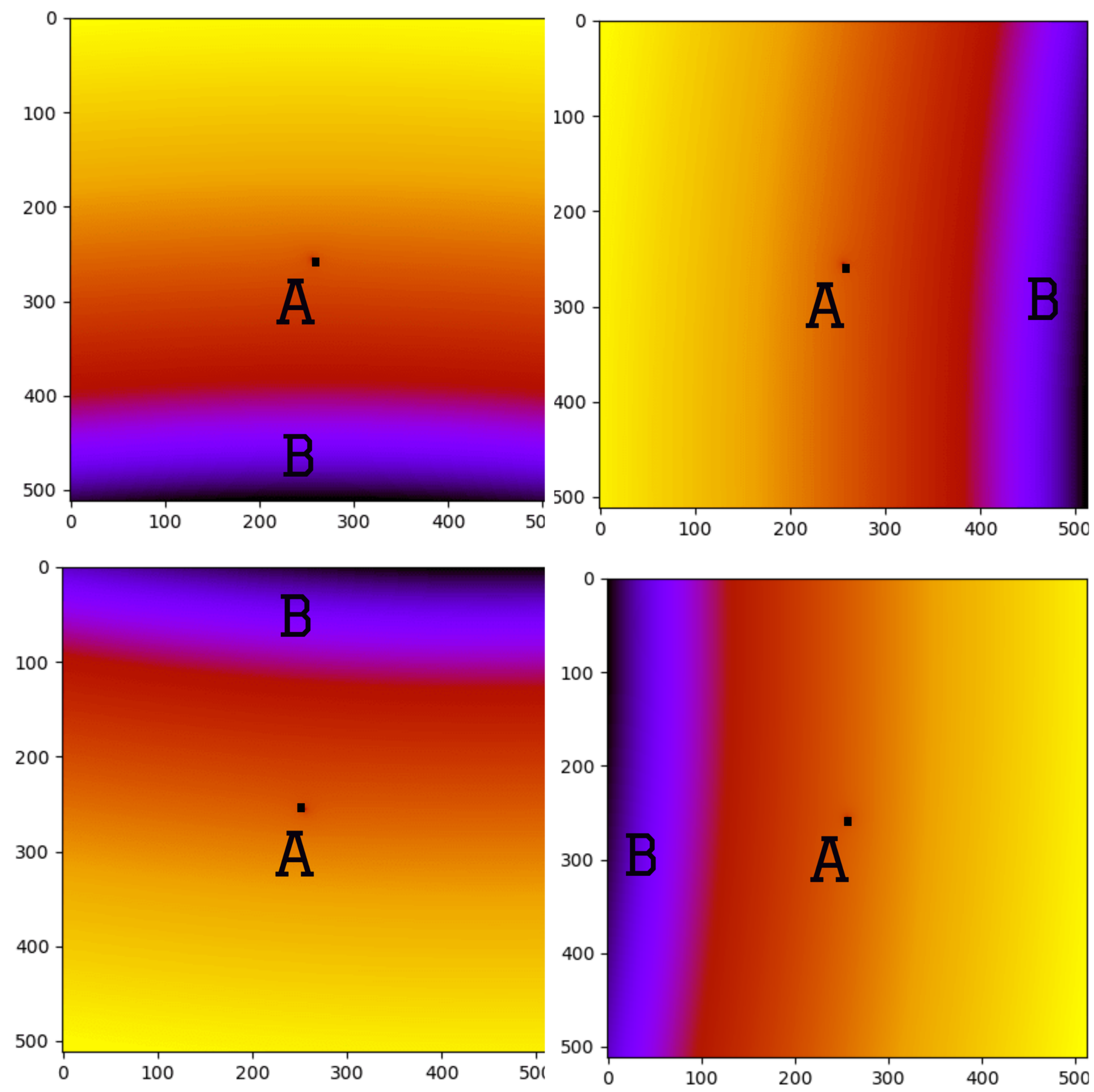

Figure 2:Heatmap representation of Gravitational Potential due to the circular motion of Point Mass B. Note that B is mobing on a circular trajectory with $radius = 512$ pixels from the center of the box. The top-left panel is the Gravitational potential heatmap for $t = 0$. Top-right is for $t = 25$ units. Bottom-left is for $t = 50$ units and Bottom-right for $t = 75$ units. Here violet denotes higher potential.