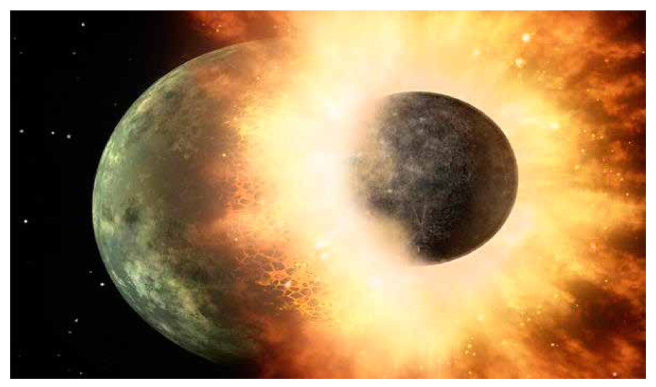
Lunar-forming Giant Impact Model Utilizing GPUs

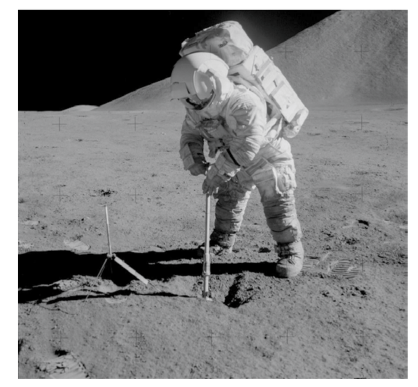
Tarleton State University Particle Modeling Group
Justin Eiland, Travis Salzillo, Brett Hokr, Justin Highland, Will Mayfield and Bryant Wyatt

Introduction



Smithsonian.com
http://blogs.smithsonianmag.com/aroundthemall/files/2009/08/planet-impact.jpg
Retrieved 2013-07-25

Nasa
http://apod.nasa.gov/apod/image/1103/Moonrise2DdiC.jpg
Retrieved 2013-07-30

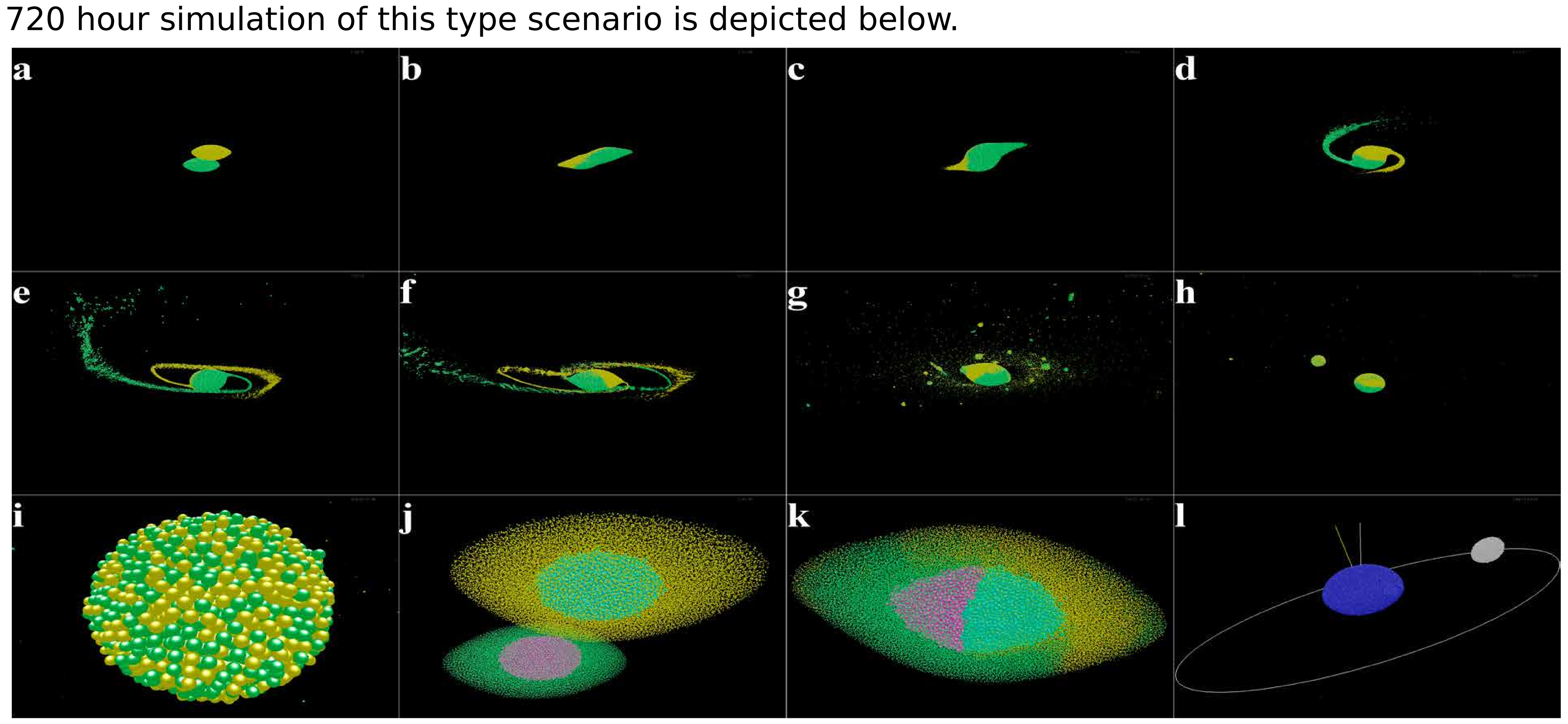


Nasa
http://www.hq.nasa.gov/office/pao/History/alsj/a15/AS15-92-12424.jpg
Retrieved 2013-07-25

Recent giant impact models focus on producing a circumplanetary disk of the proper composition around Earth and defer to earlier works for the accretion of this disk into the Moon. The discontinuity between creating the circumplanetary disk and accretion of the Moon is unnatural and lacks simplicity. In addition, current giant impact theories are being questioned due to their inability to find conditions that will produce a system with both the proper angular momentum, and a resultant Moon that is isotopically similar to Earth. Here we return to first principles and produce a continuous model that can be used to rapidly search the vast impact parameter space to identify plausible initial conditions. This is accomplished by focusing on the three major components of planetary collisions: constant gravitational attraction, short range repulsion, and energy transfer. The structure of this model makes it easily parallelizable and well-suited to harness the power of modern graphics processing units (GPUs). The model makes clear the physically relevant processes and allows a physical picture to naturally develop. We demonstrate here how the model readily produces a stable Earth-Moon system from a single, continuous simulation. The resultant system possesses many desired characteristics such as an iron-deficient, heterogeneously mixed Moon and accurate axial tilt of the Earth.

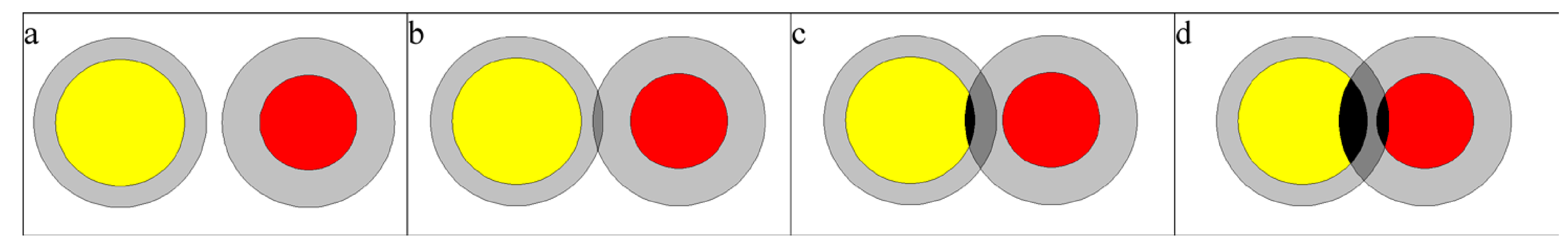
Simulation

The planets in the solar system orbit the Sun in the same direction in the ecliptic plane. With the exception of Venus and Uranus, planets in our solar system all spin on their axes of rotation in the same direction. Hence a natural scenario for a young planetary collision would be one between two fast spinning planets both orbiting and spinning in the same direction, parallel to the ecliptic plane. A 720 hour simulation of this type scenario is depicted below.



131,072 elements

Model - Methods



In this work, large aggregates of spheres with common radii, referred to as elements, are grouped together to form bodies, referred to as impactors. The dynamics of the model are solely determined by the sum of all pairwise forces between elements. These pairwise forces are described as follows. When two elements are not in physical contact, they interact solely through the attractive force of gravity. Once in physical contact the elements experience a repulsive force. The contact region of two overlapping spheres is a circle with an area determined by the separation of their centers. Hence the repulsion force is proportional to the separation squared. To simulate an element's resistance to deformation, each is given a shell. If this shell is not penetrated, the repulsive force is elastic. If the shell is penetrated, the force is inelastic to account for energy loss due to internal vibration, as well as deformation of the element. As two elements converge past their shell depths, the repulsion force remains strong, but as they separate, this repulsion force is greatly reduced. Impactors are restricted to being composed of two types of elements: silicate material and iron. Silicate and iron elements are allowed to have different repulsive strengths, different repulsion reductions, and different shell depths.

Element-element separation	Force if separation is decreasing	Force if separation is increasing
$D \le r$ (fig. 1a)	$G \bullet M_{Si} \bullet M_{Fe}/r^2$	Same as decreasing
$D - D \bullet SDP_{Si} \le r < D$ (fig. 1b)	$G \bullet M_{Si} \bullet M_{Fe}/r^2 - 0.5 \bullet (K_{Si}+K_{Fe})(D^2 - r^2)$	Same as decreasing
$D - D \bullet SDP_{Fe} \le r < D - D \bullet SDP_{Si}$ (fig. 1c)	$G \bullet M_{Si} \bullet M_{Fe}/r^2 - 0.5 \bullet (K_{Si}+K_{Fe})(D^2 - r^2)$	$G \bullet M_{Si} \bullet M_{Fe}/r^2 - 0.5 \bullet (K_{Si} \bullet KRP_{Si}+K_{Fe})(D^2 - r^2)$
$\text{epsilon} \le r < D - D \bullet SDP_{Fe}$ (fig. 1d)	$G \bullet M_{Si} \bullet M_{Fe}/r^2 - 0.5 \bullet (K_{Si}+K_{Fe})(D^2 - r^2)$	$G \bullet M_{Si} \bullet M_{Fe}/r^2 - 0.5 \bullet (K_{Si} \bullet KRP_{Si}+K_{Fe} \bullet KRP_{Fe})(D^2 - r^2)$
r < epsilon	Set r equal to epsilon and calculate accordingly	Not applicable

Results and Conclusions

The results of the simulation depict a stable Earth-Moon system with the Moon forming just outside the Roche radius. The Moon is void of iron and is a heterogeneous mix of almost equal material from both impactors as shown in Tile i. Views of the iron cores before and after impact are illustrated in Tiles j and k. The tilt of the resultant Earth's equatorial plane is 21.5 degrees off the ecliptic plane (Tile l).

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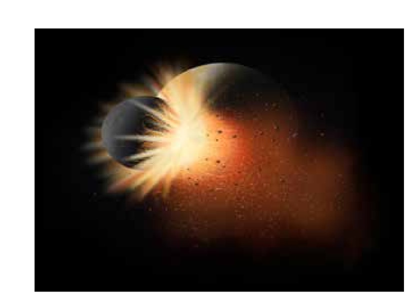
The Giant Impact Theory has come under attack in the last year because of its inability to produce an Earth-Moon system with the proper angular momentum and a Moon that is isotopically similar to Earth. More researchers and new models like the one presented here are needed in the field of computational astrophysics to breathe new life into the Giant Impact Theory. We believe that the affordable power delivered by modern GPUs can accomplish this goal. For example, this project would have been outside the financial scope of our group without the utilization of NVIDIA GPUs.



Impact Theory Gets Whacked
Daniel Clerk
Science
11 October 2013
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