Swiftest: An N-Body dynamics code incorporating collisional regime determination and fragmentation

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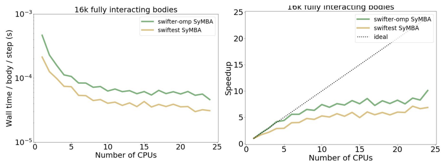
Introduction

In this work we present the algorithm behind the updated version of the N-body dynamics code Swifter-SyMBA [1], which we have dubbed "Swiftest". The development of Swiftest was motivated by recent models of terrestrial planet accretion [2, 3], martian moon accretion from a circumplanetary debris disk [4,5], and collisional regime determination [6, 7]. These models show that perfect accretion does not capture the wide range of collisional outcomes present during accretion. We aim to use Swiftest to present a more realistic model of the accretionary environment.

Performance

Due to the increasing number of particles resulting from fragmentation, computational performance has become a key focus in Swiftest.
We have implemented parallelism and aectorization through OpenMP and SIMD directives, focusing on single node performance. Key features of Swiftest that have been parallelized include checking for close encounters, computing accelerations, and calculating total energy of the system.



Concurrent & Future Work

For preliminary results concerning the use of Swiftest in martian moon accretion and terrestrial planet accretion, see our talk in the Early Planetary Systems session. Currently, we are working to optimize Swiftest in a shared-memory parallel computing environment. In the future, we hope to use Swiftest to analyze the effect of collisional debris on the cratering history of Mars, the cyclical formation of the martian moons from a ring [5], and the accretion timescale of the Solar System.

References

[1] Duncan, M.J., Levison, H.F., & Lee, M.H. (1998) *AJ*, Vol. 116 (2067-2077). **[2]** Clement, M.S., et al. (2019) *Icarus*, Vol. 321 (778-790). **[3]** Chambers, J.E. (2013) *Icarus*, Vol. 224 (43-56). **[4]** Canup, R., & Salmon, J. (2018) *Sci Adv*, Vol. 4 (1-6). **[5]** Hesselbrock, A.J. & Minton, D.A. (2017) *Nat Geo*, Vol. 10, 4 (266-269). **[6]** Genda, H., Kokubo, E., & Ida, S. (2012) *ApJ*, Vol. 744 (1-8). **[7]** Leinhardt, Z.M., & Stewart, S.T. (2012) *ApJ*, Vol. 745 (1-27).

Motivation

Fig. 1

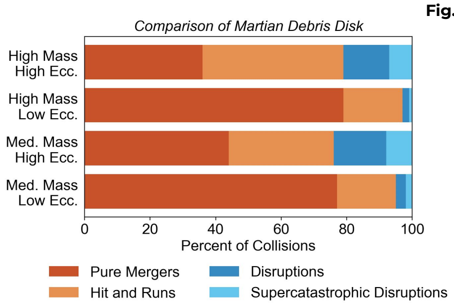
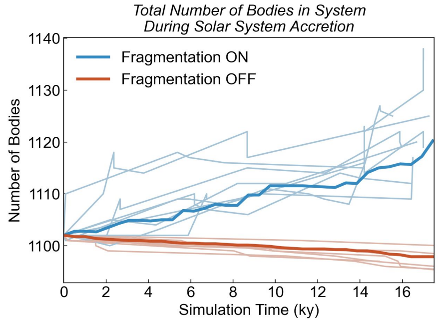


Fig. 2



The Martian System

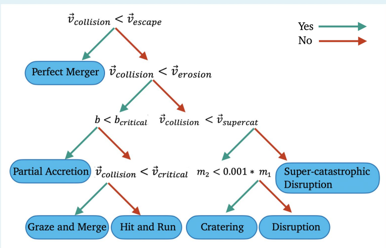
Mars, and its two moons, Phobos and Deimos, represent a challenging environment within which to study moon formation. Our group is exploring the formation of Phobos and Deimos from a debris disk affected by collisional fragmentation. The initial mass and eccentricity of this debris disk has a strong effect on the types of collisional events that occur. Understanding these events will help constrain the initial disk properties, the timeline of accretion, and the mechanism by which the moons formed.

The Solar System

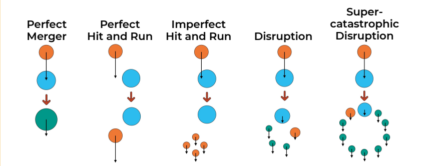
Many recent studies have shown that solar system accretion was an imperfect process resulting in collisional debris that can extend the accretion timeline of the terrestrial planets [2, 3, 6, 7]. Our group is exploring the fate of this debris, and its effect on the cratering history of Mars. The plot above shows that just in the first 20 ky of solar system accretion, simulations with fragmentation begin to accumulate debris. With Swiftest, we plan to run longer accretion simulations to study the entire lifetime of this debris.

Fragmentation

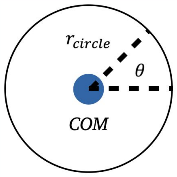
Regime Determination Flowchart



Collisional Regimes



Determine Fragment Position and Velocity



$$\theta = \frac{2\pi}{n_{frag}}$$

$$r_{circle} = \frac{rhill_1 + rhill_2}{2\sin\left(\frac{\pi}{n_{frag}}\right)}$$

Fragments are added in a circle of radius r_{circle} around the center of mass in the plane of the collision. The total number of fragments, n_{frag}, is spaced around the circle in increments of θ.

$$p_{frag} = \left(-r_{circle} * \cos(\theta * n_{frag,i}) * \left(\frac{\vec{v}_{rel}}{|\vec{v}_{rel}|}\right)\right) + \left(-r_{circle} * \sin(\theta * n_{frag,i}) * \left(\frac{((\vec{v}_{rel} \times \vec{x}_{rel}) \times \vec{v}_{rel}}{|(\vec{v}_{rel} \times \vec{x}_{rel}) \times \vec{v}_{rel}|}\right)\right) + p_{com} + p_{offset}$$

$$\vec{v}_{frag} = \left(-\sqrt{\frac{2G(m_1 + m_2)}{r_{circle}}} * \cos(\theta * n_{frag,i}) * \left(\frac{\vec{v}_{rel}}{|\vec{v}_{rel}|}\right)\right) + \left(-\sqrt{\frac{2G(m_1 + m_2)}{r_{circle}}} * \sin(\theta * n_{frag,i}) * \left(\frac{((\vec{v}_{rel} \times \vec{x}_{rel}) \times \vec{v}_{rel}}{|(\vec{v}_{rel} \times \vec{x}_{rel}) \times \vec{v}_{rel}|}\right)\right) + \vec{v}_{com} + \vec{v}_{offset}$$

p_{frag}: *the position of the fragments added in the collision*
p_{com}: *the position of the center of mass of the collision*
p_{offset}: *the offset between the positions of the centers of mass of the colliding bodies and the added fragments*
$\vec{v}_{frag}$: *the velocity of the fragments added in the collision*
$\vec{v}_{com}$: *the velocity of the center of mass of the collision*
$\vec{v}_{offset}$: *the offset between the velocities of the centers of mass of the colliding bodies and the added fragments*