ASTEROID EROSION DUE TO ION PLUME

LSAMP URP Scientific Report

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Aug 9, 2024

Abstract

The purpose of this research project is to examine the effects of ion plumes onto asteroids. This simulates a proposed method of asteroid deterioration to prevent collisions with earth. When looking at different asteroid types and compositions, many of the compounds contain different sputtering yields against different plasma. The project aims to observe which gasses (argon, xenon or krypton) works best at eroding asteroid material, and predict deterioration based on material composition of its surface. Currently, only the composition SiO_2 against Argon, Xenon and Krypton has been tested. It is also important to note that it's currently not known which effects will cause asteroids to change orbits; the sputter effects on the surface of the asteroids which transfer momentum, or the change in mass. We are assuming that asteroids are planar, because the topology of asteroids varies which changes the effects of bombardment. To account for this, tests of materials at different angles could provide a good way to simulate the bombardment on the surface of asteroids.

Physical laws that are at the central focus of our research are the laws of universal gravitation, which states that the force of gravity between an object is disproportionate to the distance and proportional to the masses of the two objects in view. The second law of physics that is significant to this research is the law of momentum, or more specifically, the law of the conservation of momentum. This states that the momentum of a system is conserved at all times, which is important because it involves mass which is a variable that we are changing in this simulation. The law of momentum is tied to the orbital motion of a celestial body through its mass. A key idea that must be considered is that if an celestial object's mass is changed, it's orbit in space about another body can be altered as well. This is where the concept of sputtering plays in the scientific architecture of the project.

Currently, we are in the process of acquiring the correct samples to utilize and test, although I have aided in testing materials for other projects, such as ITO. The next steps are to test the remaining materials we have listed, which consists of several different compounds due to the several different types of asteroids, and place the sputtering yield data to plug into a simulation. This simulation will pave the way for the latter part of the project which is projected to begin a few years from now, where we begin to construct the satellite to conduct the asteroid deflection mission against the asteroid Apophis.

Introduction

In the year 2029, the asteroid Apophis is expected to swing past the earth in a near-collision. Apophis is a 27 billion kg asteroid with an average diameter of 1100 feet (NASA, 2024), so a collision with an asteroid of that magnitude will give the human race a first hand experience of what the dinosaurs went through, destroying most civilizations and populations. In the case in the future where an asteroid is guaranteed to hit the earth, there must be ways to combat it and protect the planet. Many methodologies have been conceptualized, such as sending nukes towards the asteroid or using a spacecraft to carry the asteroid away from the planet. The solution that this project is focusing on is utilizing plasma to erode the asteroid. If an asteroid becomes eroded, its mass will change and thus its orbit will change as well, which can prove to be a helpful way to prevent a collision with the earth.

This leads us to the question that we are trying to answer; How much sputter will be yielded when we place gasses against an asteroid? Depending on the gas, the sputter yield may change, but obtaining the right amount of sputter will allow for a more optimal asteroid deflection. Not enough sputter will result in inefficiency to alter an asteroid's course which could be devastating. This will come in handy for planetary defense against celestial bodies, which makes this research quite significant. This idea of using sputtering to deflect asteroids was first conceptualized by Dr. Barbee and Dr. Young, both aerospace engineers teaching at the University of Maryland College Park.

The application of this project, that is the sputtering effect of gasses on asteroids, may not be of urgent importance with the asteroid Apophis, but may prove to be of significance when it is determined that an asteroid is set to collide with earth at any point in the given future. A collision with the earth can spell a death sentence for mankind, so finding ways to divert it is of necessity. This solution can prove to be an effective and cost-efficient way of diverting asteroids and planetary defense.

General Background

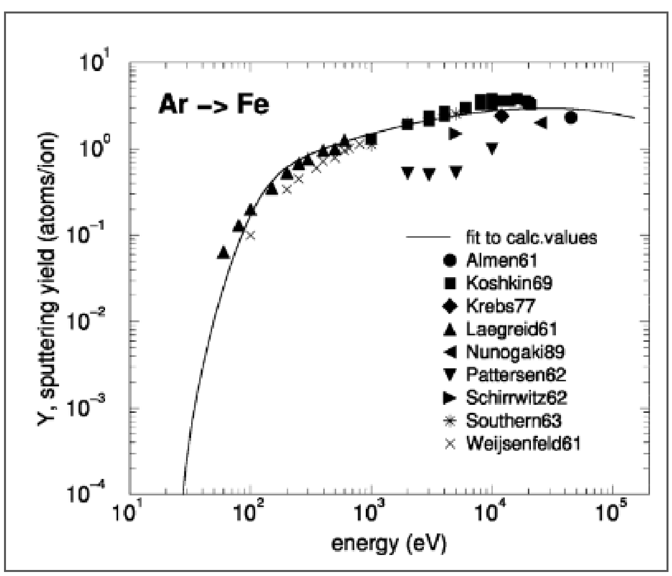
Asteroids come in silicon, carbon and magnesium types (S, C and M types), and have more subsets within these categories. It's often ionic compounds with certain metals being bonded to oxygen (i.e $SiO2$, MgO). There are pyroxenes, olivines and phyllosilicates which are subsets of these asteroid compounds that share common properties. The majority of this project revolves around pyroxenes and olivines which are typically SiO_4 and Si_2O_6 based compounds with different transitional metals attached.

Topology "studies the spatial relationships between objects or features on the earth's surface. It is concerned with understanding how these objects or features are connected and how they relate to one another in space." (O'donohue, 2022). In other words, topology is the study of the surface of an object as it relates to its depth, texture and similar qualities. This is key to know because it is the reason why we test samples at various angles, to simulate the topology of an asteroid.

All elements and compounds have something called a sputter yield, which is just how many atoms are rubbed off when an ion of a certain plasma is shot at it. A plasma is a state of matter that a gas reaches when the ions are separated from each other. These sputter yields can also vary from element to element, as it also depends on the type of gas being emitted and the angle at which it contacts. Now, asteroids dwell at a certain orbit when around a celestial body, and when this asteroid is approaching a celestial body, you can change the direction it's going by altering its momentum. This is thanks to the universal law of gravitation and the law of momentum, both being products of the mass of the object. This is where sputtering and asteroid orbits tie together. As mentioned earlier, when you shoot a plasma at an asteroid sputtering occurs at its surface which can change the trajectory of the asteroid and protect a planetary body (in this case, Earth). This sputtering can change the asteroid's mass, and due to the above mentioned physical laws, the orbit of the asteroid will be changed, which can be helpful in planetary defense.

In the overarching view of this project, we plan to send a satellite to the asteroid apophis and test whether or not this application of sputtering yields would be effective in diverting the asteroid. The satellite will consist of an ion engine, which will spew out the gas directly onto the asteroid, with a collinear and opposite propulsion system in the opposite direction to maintain it's position relative to the asteroid. This allows for a constant emission of plasma onto the asteroid to administer sputter. In terms of how the plasma will be emitted, we are thinking of using a conventional ion sputter gun and focusing the beam using magnets.

Corporations such as NASA typically utilize xenon gas for ion thrusters. The only con about this is that xenon is a decently expensive element that would be difficult for us to consistently buy especially with our budget. Due to this, experiments utilizing krypton and argon are the focus of our research right now, because these gasses are cheaper and more available for us to purchase and obtain. However, even though krypton and argon are cheaper, they fundamentally are lighter gasses, as they have lower atomic masses compared to xenon (less protons, neutrons and electrons). Due to this gas being lighter, the sputtering yield against materials may be lower, meaning it'll be harder to change the mass of an asteroid using these plasmas. In the case that we use these cases instead of xenon, we would utilize either a higher energy of electron volts (eV) or more atoms being emitted at once, in order to foster an effective sputter yield effect.



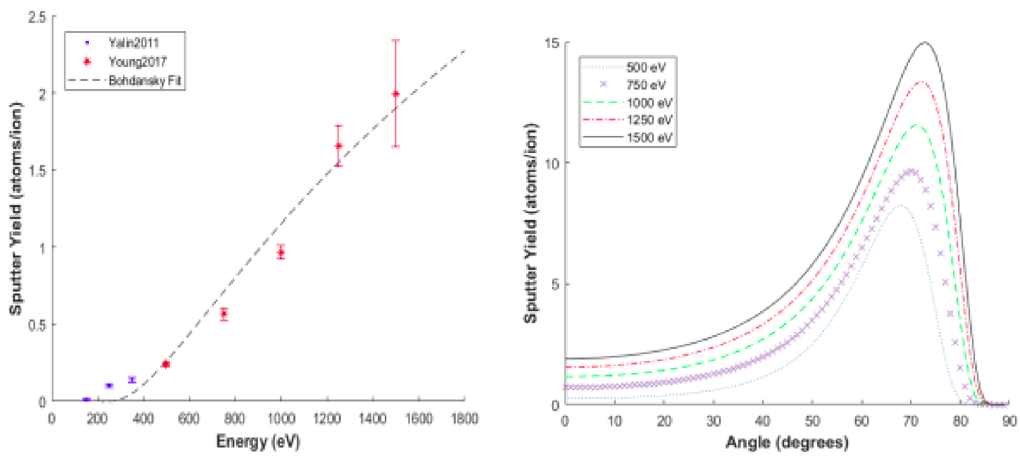
Eckstein, W. "Sputtering yields." *Vacuum*, vol. 82, no. 9, May 2008, pp. 930–934

Methodology

Necessary materials to conduct the project are a vacuum chamber, plasma sputter gun, gas, asteroid samples or compound materials and a profilometer. Within these materials, high serial analytical equipment is needed for more extensive analysis, and various machinery such as a coolant or air pump would be needed. The budget of this project can vary depending on the type of equipment, but expect at least $3k for all equipment. The Labview application will be needed to display and record energy data as it pertains to the plasma, and Matlab may also be used to simulate asteroid encounters with plasma as it corresponds to sputtering yield data and logistics.

Vacuum chamber, air pump and ionizers

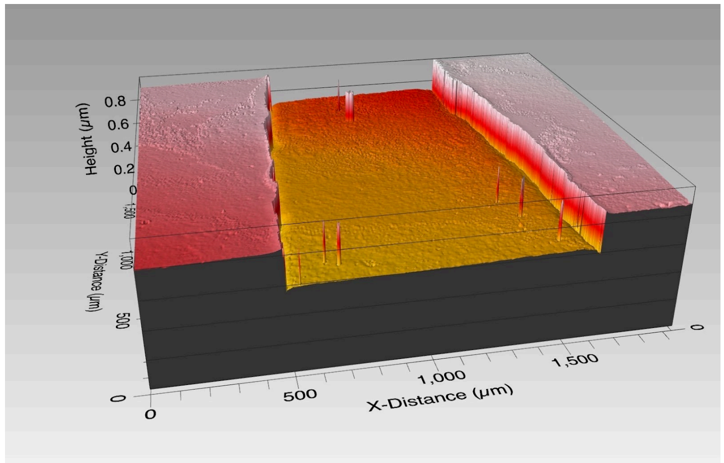
The method of experimentation is as follows: asteroid samples will be collected using the university's FabLab and gas canisters are held in stock. Using a vacuum chamber, samples will be placed directly in front of a sputter gun that releases plasma onto the sample at different energy levels. Using the Labview application, we time how long a sample will be exposed to a plasma and at what energy the plasma is being released. We run the eroded samples through FabLab's profilometry equipment to determine the sputtering yields and total erosion of the sample. This is done 3 times (we're still determining the optimal number of times) to find an accurate depiction of data. Due to the diverse topology of an asteroid, we aim to test the samples at different angles within the vacuum chamber. This means that the plasma will be hitting the asteroid material at different angles, which is a factor in the effectiveness of ion sputtering. Projected increments are 15 degrees with 75 degrees being the maximum angle between the asteroid sample and ion beam.



Sputtering yield of SiO_2 with variable energies and angles

Above are two graphs depicting sputtering yield data of SiO_2 against a plasma gas. As the energy levels of the plasma increases, measured in electron volts (eV), the sputtering yield increases. Also, as the angle between the plasma beam and sample increases, it follows a logarithmic trend with a peak sputtering yield around 70 degrees. This data can be used to predict and analyze the sputtering yield of an asteroid's surface with the utilization of a plasma beam.

It is important to note that the samples cannot be touched with our bare hands, because the natural oil that our hands produce can alter the erosion or scanning of the sample. This is why tweezers or gloves must be used when handling a sample. Once a sample is used, we use the FabLab profilometer to scan the sample and determine the change in surface depth which informs you how much it has eroded. Using this data you can find the sputter yield for that combination of gas and compound at that specific angle and energy level. Repeat this process for the same sample 3 times for an accurate average.



Example scan of a sample, SiO_2

Conclusion

To conclude, asteroid sputtering can prove to be an effective way to deter an asteroid from colliding with a planetary body. The change in mass an asteroid experiences when a plasma shaves off atoms causes the asteroid to alter its orbit and trajectory due to the change in momentum and gravitational pull. Although we have not been able to conclude the effectiveness of most compound sputtering yield data, the idea of utilizing sputtering to erode an object is very much applicable. Our next steps are to continue testing asteroid samples against gasses such as krypton, argon and xenon to determine the overall effectiveness of ion plume erosion. After this data set has been compended, we can then use it to simulate asteroid encounters with these plasma gasses in our Matlab simulation. Furthermore, future applications of this research can be used to construct a satellite or similar celestial object to perform a real life erosion of an asteroid in space.

Acknowledgement

This project was funded by the National Science Foundation in collaboration with the Louis Stokes Alliance for Minority Participation at the University of Maryland NSF Grant #HRD-2207374.

Special thanks to the SPPL team, Dr. Jarred A. Young, Dr. Raymond Sedwick, Christian Anderson, and Dr. Kofi Addo.

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