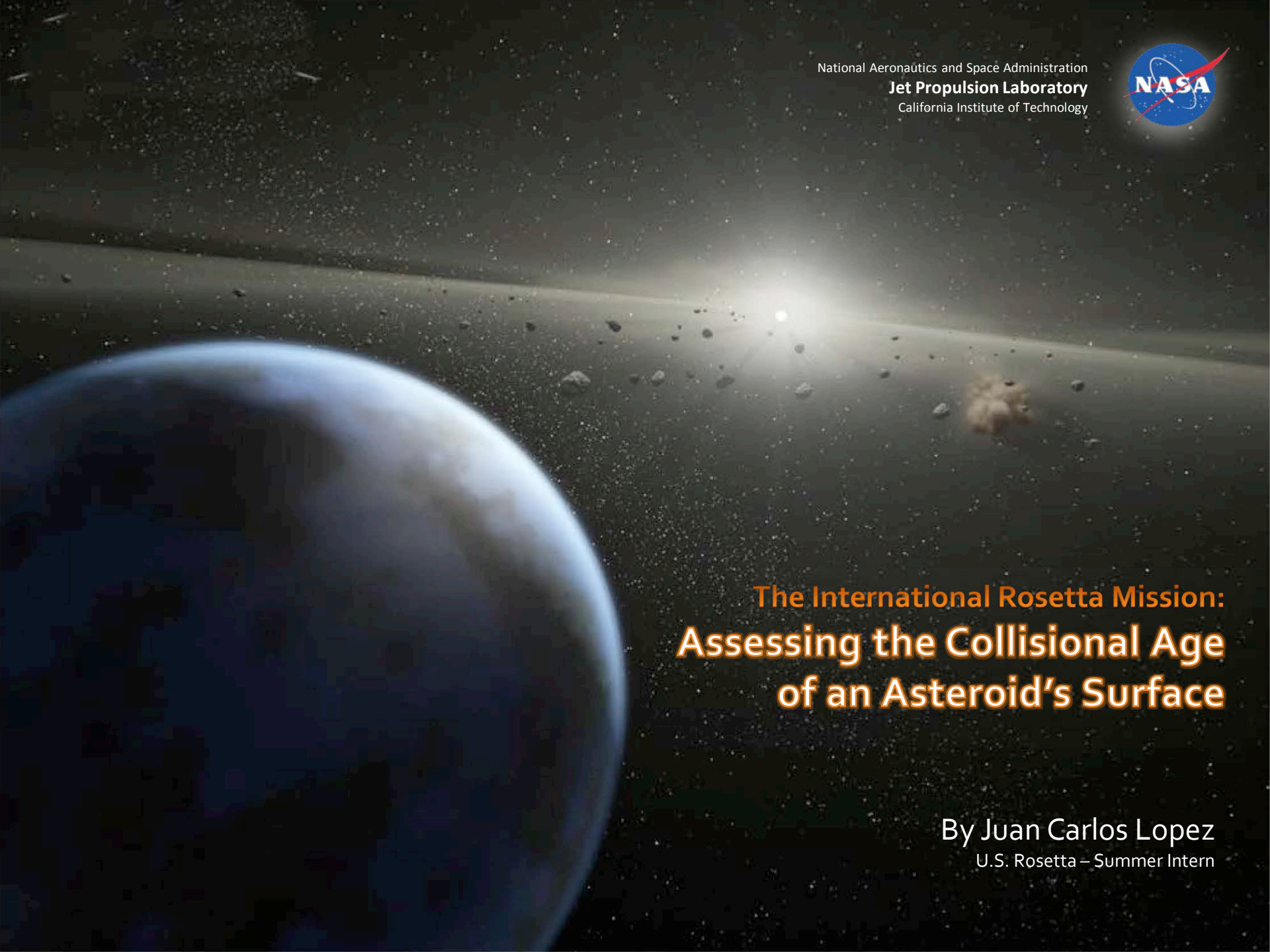
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology



The International Rosetta Mission:

Assessing the Collisional Age of an Asteroid's Surface

By Juan Carlos Lopez
U.S. Rosetta – Summer Intern

Outline

- Personal Background
- Rosetta Overview
- Introductory Concepts
  - Physical Characteristics
    - Shape, size, volume and mass
- Projects:
  - Determining the Age
  - Asteroids Through Time!
- Skills Acquired
- Contributions
- Future Goals
- Acknowledgements

About me

- Born in Garden Grove, CA and raised in Delicias, Chihuahua, Mexico
- UTEP Mechanical Engineering – Expected graduation: 2012
- **Extracurricular Activities:**
  - President of Alpha Lambda Delta Honor Society
  - VP for the American Society of Mechanical Engineers
  - Society of Hispanic Professional Engineers
  - Society of Mexican American Engineers and Scientists
  - Student Government Association
  - UTEP Honors Program
- **Work Experience:**
  - Summer Intern at the NASA Johnson Space Center for the Summer of 2010
  - Teacher Assistant for the UTEP Department of Physics
  - Peer Leader for the UTEP Entering Student Program
  - Tutor for the Academic Center for Engineers and Scientists
- **Honors and Awards:**
  - NASA Student Ambassador
  - Miner Hero Award - Leadership
  - Great Minds in STEM Scholar – SAIC and NASA JSC
  - ALD Leadership Award – Most Valuable Officer
  - Houston Endowment Scholar
  - ExxonMobil Scholar

NASA MUST Project

Motivating Undergraduates in Science and Technology

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The NASA MUST Project supports 100 STEM students with:

- The opportunity to participate in a 10-week NASA summer internship at one of ten NASA field centers
- A one year competitive scholarship
- The MUST Professional and Academic Support System (PASS), which provides tutoring, mentoring, and access to various professional development activities.

Summer 2010: NASA JSC

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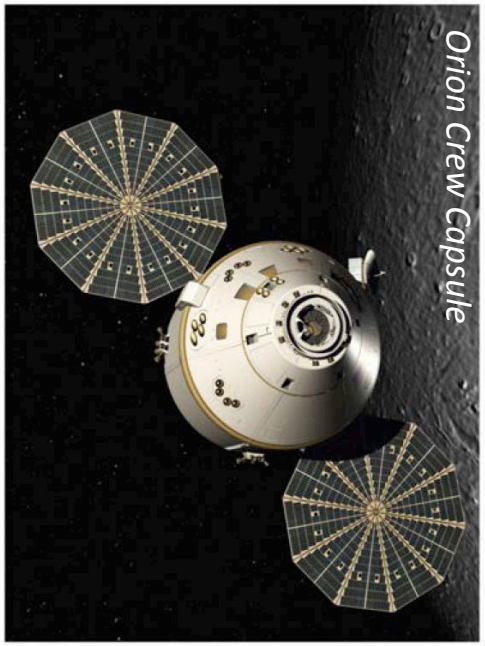
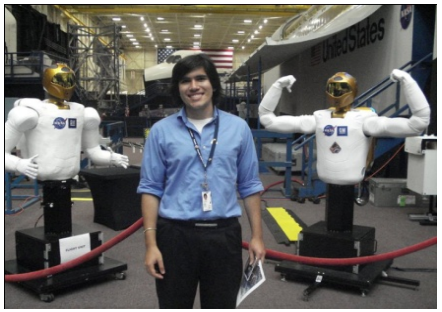
Apollo Night with Gene Kranz



Orion Crew Capsule

NASA MUST Symposium – Cleveland, OH

JSC Tours



ROSETTA

Mission Overview

- Rosetta is an international mission led by the European Space Agency (ESA) with key support and instrumentation from the National Aeronautics and Space Administration (NASA).
- Rosetta is currently on a ten-year mission to catch comet 67P/Churyumov-Gerasimenko (C-G).
  - Flybys of two main belt asteroids: Steins and Lutetia
- Rosetta will be the first spacecraft to orbit a comet's nucleus and to fly alongside a comet as it heads towards the inner Solar System.

Rosetta Spacecraft

OSIRIS

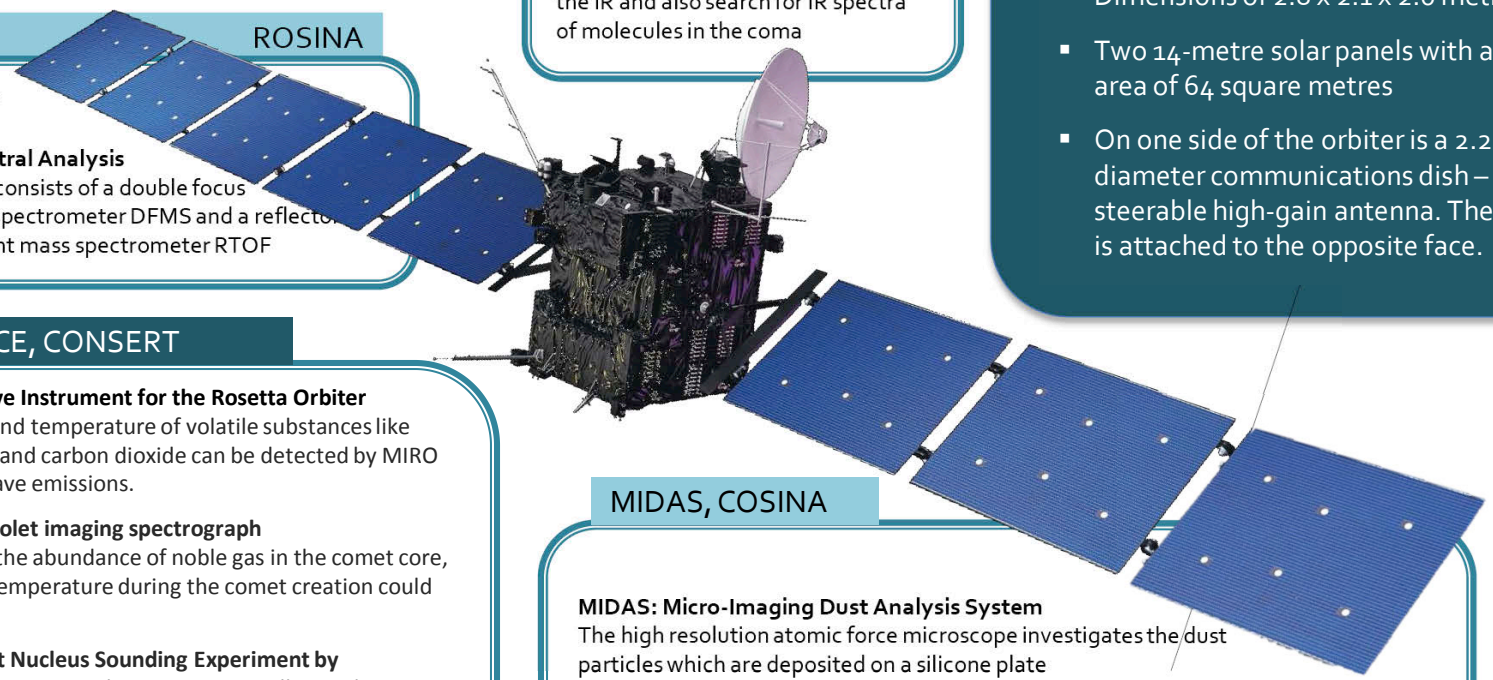
Optical, Spectroscopic, and Infrared Remote Imaging System
The camera system has a narrow and a wide angle lens.

VIRTIS

Visible and Infrared Thermal Imaging Spectrometer
Able to make pictures of the core in the IR and also search for IR spectra of molecules in the coma

ROSINA

Rosetta Orbiter Spectrometer for Ion and Neutral Analysis
The instrument consists of a double focus magnetic mass spectrometer DFMS and a reflectron type time of flight mass spectrometer RTOF



General characteristics:

- Dimensions of 2.8 x 2.1 x 2.0 metres
- Two 14-metre solar panels with a total area of 64 square metres
- On one side of the orbiter is a 2.2-metre diameter communications dish – the steerable high-gain antenna. The lander is attached to the opposite face.

MIRO, ALICE, CONSERT

MIRO: Microwave Instrument for the Rosetta Orbiter
The abundance and temperature of volatile substances like water, ammonia and carbon dioxide can be detected by MIRO via their microwave emissions.

ALICE: An ultraviolet imaging spectrograph
It will search for the abundance of noble gas in the comet core, from which the temperature during the comet creation could be estimated.

CONSERT: Comet Nucleus Sounding Experiment by Radiowave Transmission. This experiment will provide information about the deep interior of the comet. The CONSERT radar will perform tomography of the nucleus by measuring electromagnetic wave propagation between the lander and the orbiter through the comet nucleus

MIDAS, COSINA

MIDAS: Micro-Imaging Dust Analysis System
The high resolution atomic force microscope investigates the dust particles which are deposited on a silicone plate

COSIMA: Comentary Secondary Ion Mass Analyzer
It analyses the composition of dust particles by secondary ion mass spectrometry after the surface is cleaned by indium ion. It can analyze ions up to a mass of 4000 amu.

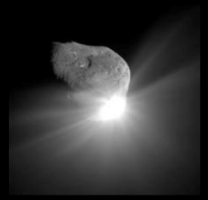
Rosetta

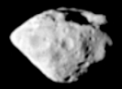
Mission Overview

Juan Carlos Lopez EXIT PRESENTATION

June 2011
Rosetta coasts through areas in the outer solar system where the sun is almost a billion km away. At that distance, Rosetta's solar panels will not be able to gather much energy from the Sun, so the spacecraft will shut down most electrical activities and hibernate until catching comet C-G

July 2005
Rosetta analyzed the collision between Deep Impact and comet Tempel-1

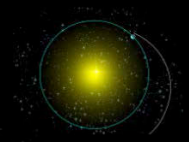




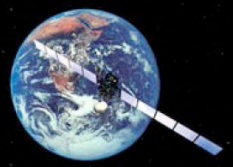
May 2014

July 2010

Sept. 2008



March 2005



Rosetta caught up with Earth and executed the first of its four gravity assists

Rosetta passed within 1700 km of asteroid Steins, enabling its instruments to closely observe the flying rock

Rosetta passed within 3000 km of asteroid Lutetia, and again used its instruments to observe at close range this asteroid, which is about 10 times bigger than Steins

Rosetta will meet comet C-G as it comes hurtling by. Rosetta will release the lander for a controlled soft landing on the comet. After escorting comet C-G past its perihelion, Rosetta will terminate its mission

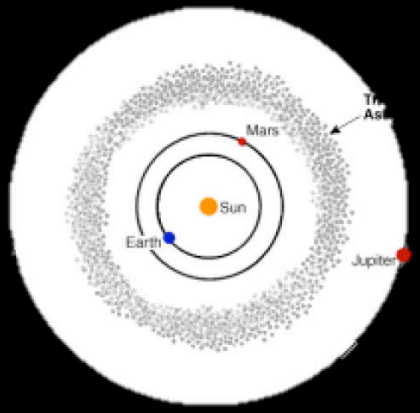
March 2004

Rosetta was launched into space from Europe's Spaceport

February 2007
Rosetta executed a close flyby of Mars, providing gravity assist to the spacecraft to loop back toward Earth

What is an Asteroid?

- Asteroids are metallic, rocky bodies without atmospheres that orbit the Sun
- Most asteroids are found in the main asteroid belt
- Near-Earth Objects (NEO) Program sponsored by NASA
- It is estimated that the total mass of all asteroids would comprise a body approximately 930 miles in diameter (less the half the size of the moon)



Source: National Space Science Data Center. http://nssdc.gsfc.nasa.gov/planetary/text/asteroids.txt

Categorizing Asteroids

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(253) Mathilde

C-type (carbonaceous) : Includes more than 75 percent of known asteroids. Very dark with an albedo of 0.04-0.09. Composition is thought to be similar to the Sun, depleted in hydrogen, helium, and other volatiles. C-type asteroids inhabit the main belt's outer regions.

S-type (silicaceous):
Accounts for about 17% of known asteroids. Relatively bright with an albedo of 0.10-0.22. Composition is metallic iron mixed with iron – and magnesium-silicates. S-type asteroids dominate the inner asteroid belt.

(433) Eros

(21) Lutetia

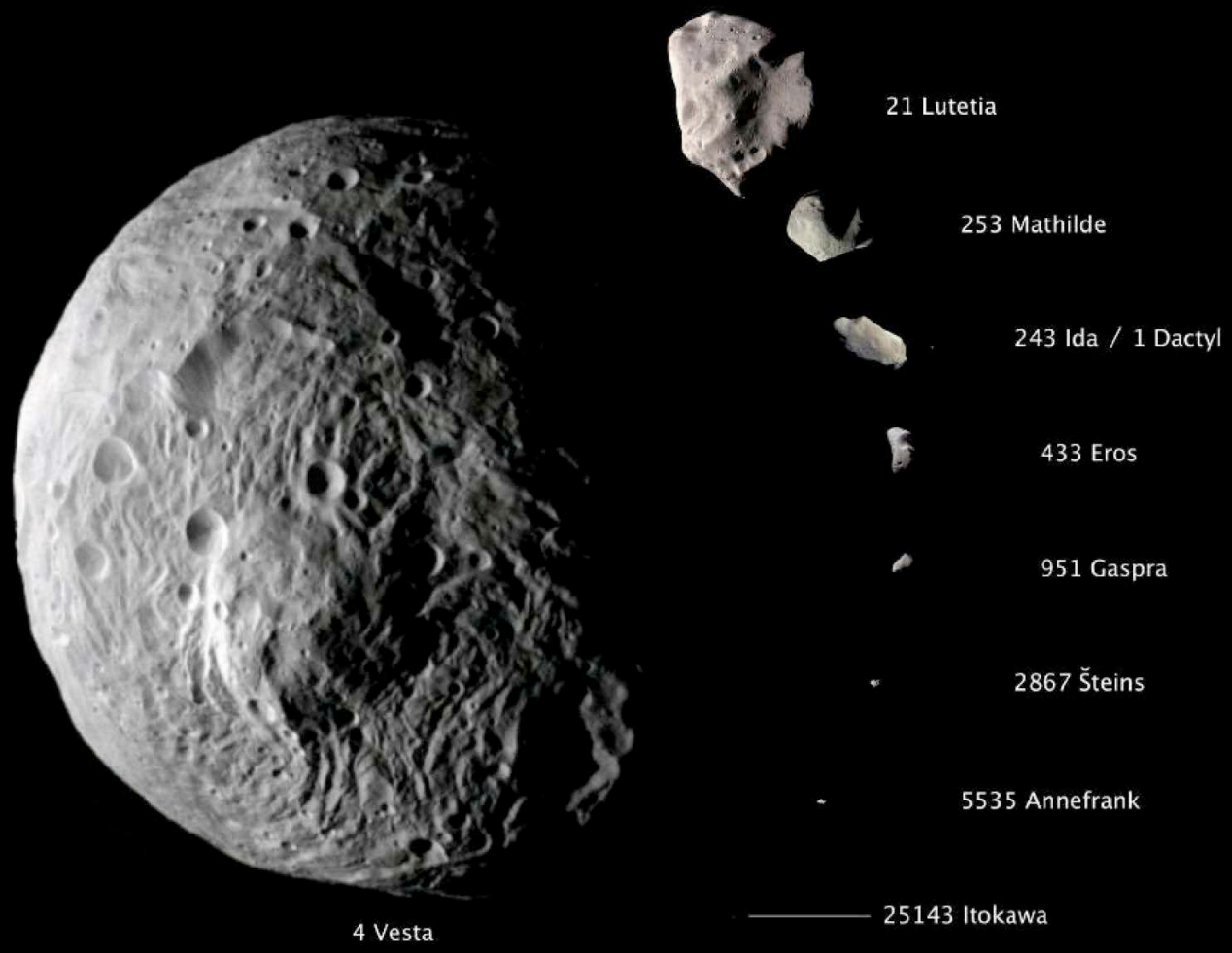
M-type (metallic) : Includes many of the rest of the known asteroids. Relatively bright with an albedo of 0.10-0.18. Composition is apparently dominated by metallic iron. M-type asteroids inhabit the main belt's middle region.

E-type (Enstatite Achondrite):
They are thought to have originated from the highly reduced mantle of a differentiated asteroid. They have a high albedo (0.3 or better), which distinguishes them from the more common M-types. Their spectrum is featureless flat to reddish. Probably because they originated from the edge of a larger parent body rather than a core, E-types are all small.

(2867) Steins

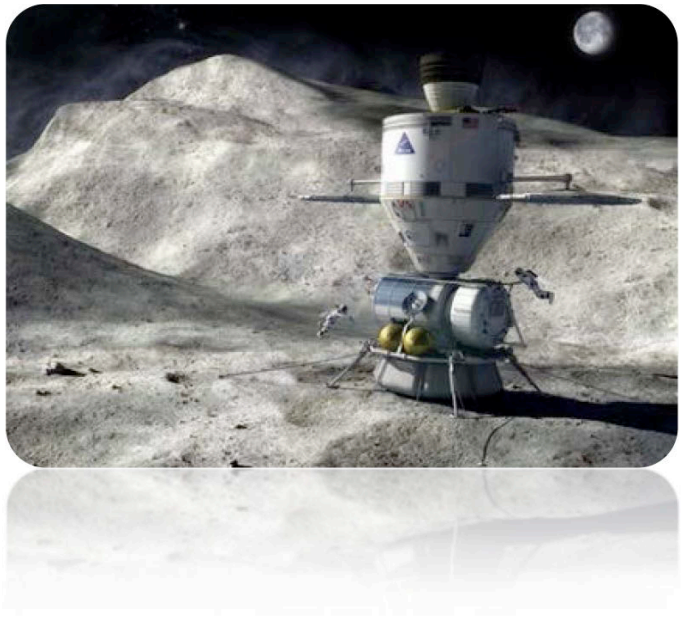
Source: National Space Science Data Center. http://nssdc.gsfc.nasa.gov/planetary/text/asteroids.txt

What is an Asteroid?



Why Study Asteroids?

- Evidence of the solar system formation process
- Constant interaction with Earth – asteroids have modified Earth's biosphere in the past
- Human exploration missions to asteroids have been proposed
- Rich supply of minerals and other sources of energy

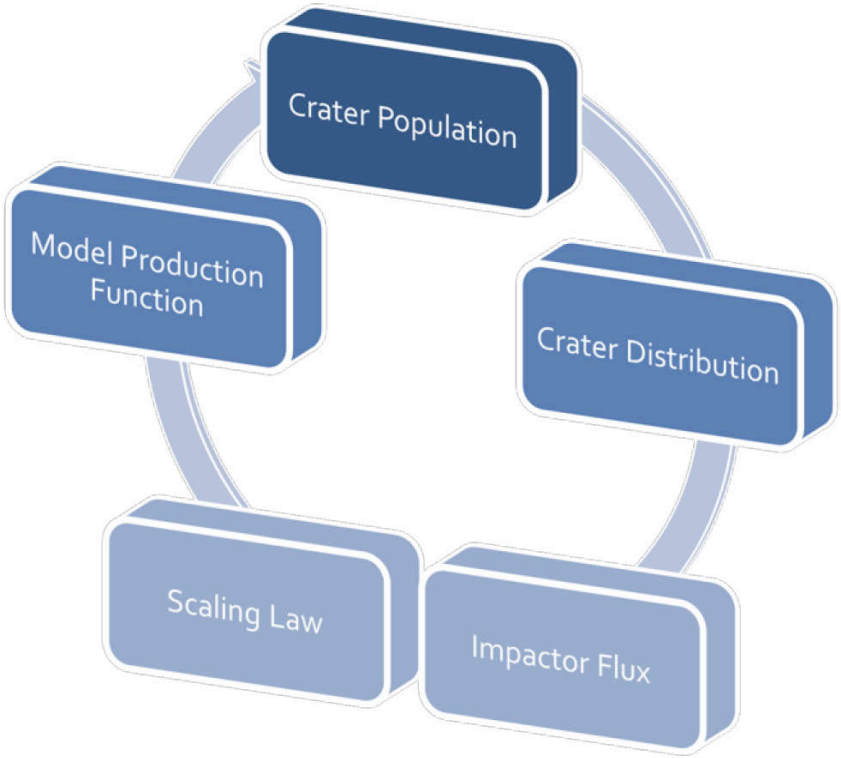


Objectives

- To interpret and document the scientific methods currently utilized in the characterization of asteroid (21) Lutetia in order to render these processes and methods accessible to the public
- Examples include a standardized technique for assessing the age of an asteroid surface, complete with clickable reference maps, methodology of grouping surface characteristics together, and a standardized power law equation for the age
- Results of the study will aid in the development of pedagogical material on asteroids for public use

Activity 1:
Assessing the Age of an Asteroid's Surface

- This activity strives to assess the age of an asteroid's surface by visual and scientific analysis
- To facilitate the process we have divided it in 5 steps:
  1. Crater Population
  2. Crater Distribution
  3. Impactor Flux
  4. Scaling Law
  5. Modeling Production Function



Age of Asteroids

Steins:
18 bona-fide craters and 71 crater-like features
---
89 possible crater

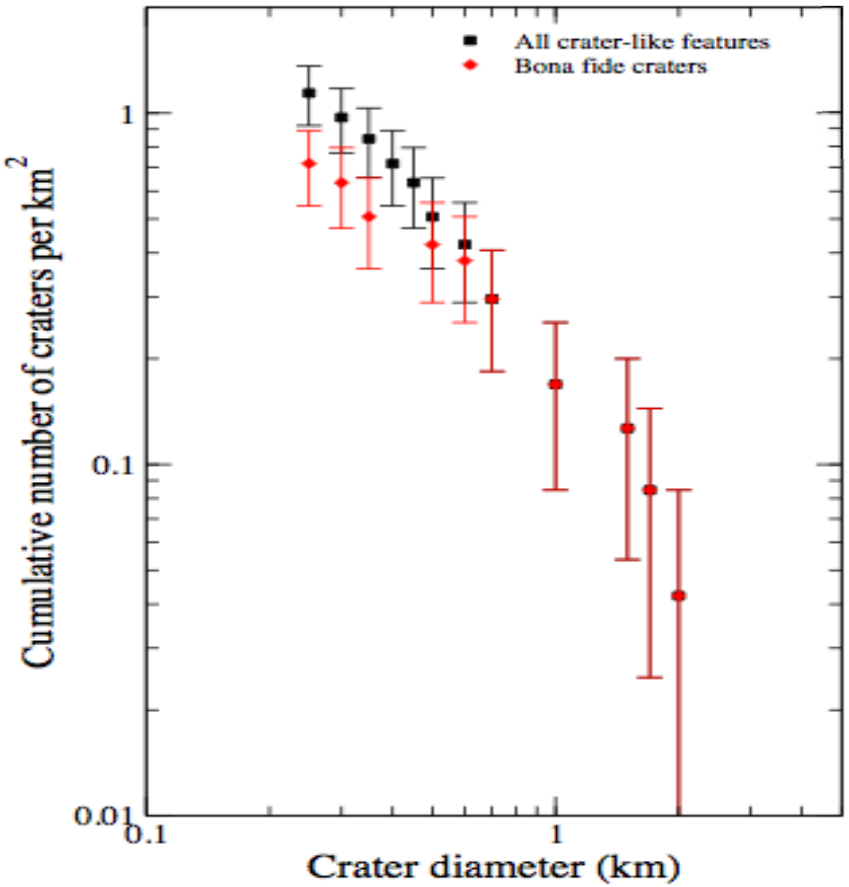
80 craters total

1

- First step is to do a visual inspection of the asteroid's pictures
- Craters will be categorized into "bona fide craters" and "crater-like features"
- Analysis of crater-like features will determine whether or not they will be considered bona-fide craters

Crater Population

Age of Asteroids



2

- A table with the diameter size and cumulative number of craters must be generated
- Once the table is completed and all the craters counted, the user must plot a "Crater Diameter vs. Cumulative Number of Craters per km^2" graph

Crater Distribution

Total surface area of Steins: 23.7km^2 (25% of total surface)

Age of Asteroids

3

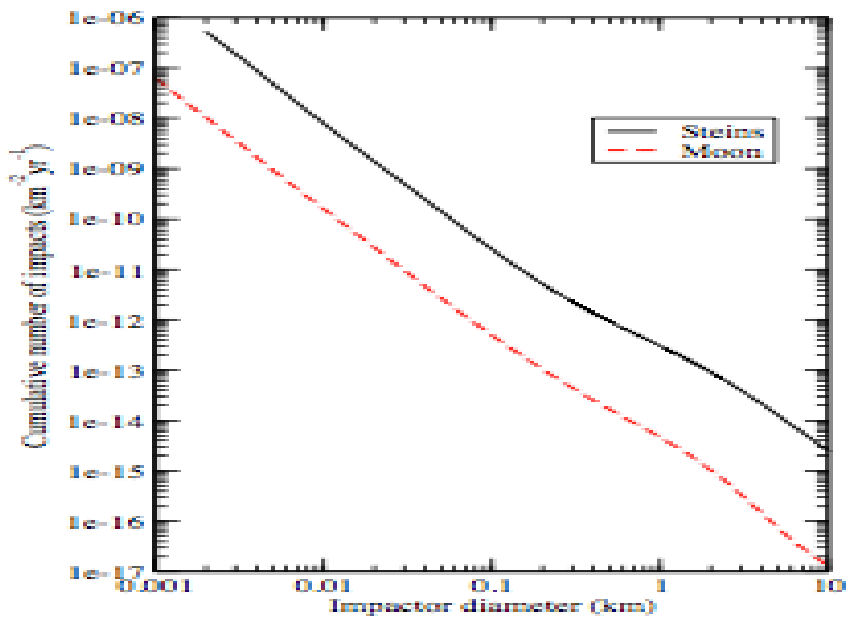
Impactor Flux

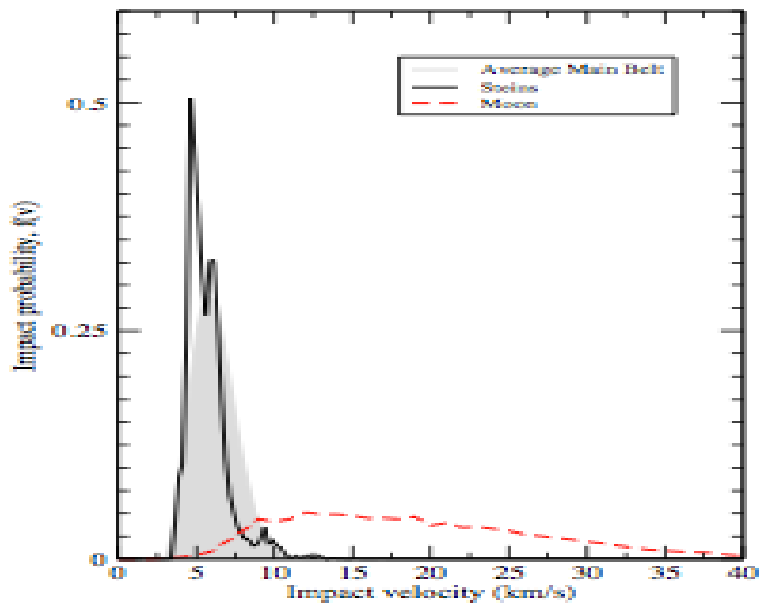
- Next we must calculate the impactor flux, which is expressed in terms of a differential distribution, which represents the number of incoming bodies per unit of impactor size (d), impact velocity (v) and per unit time.

$$\phi(d,v)=h(d)f(v)$$

where

h(d) = the impactor differential size distribution, and
f(v) = the distribution of impact velocity normalized to $fvdv=1$.





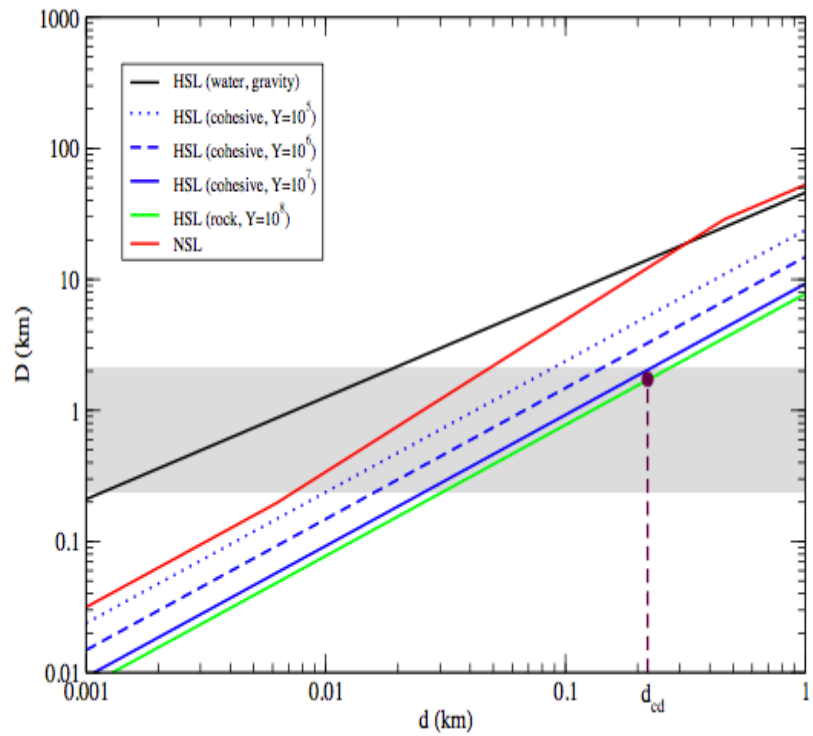
Age of Asteroids

4

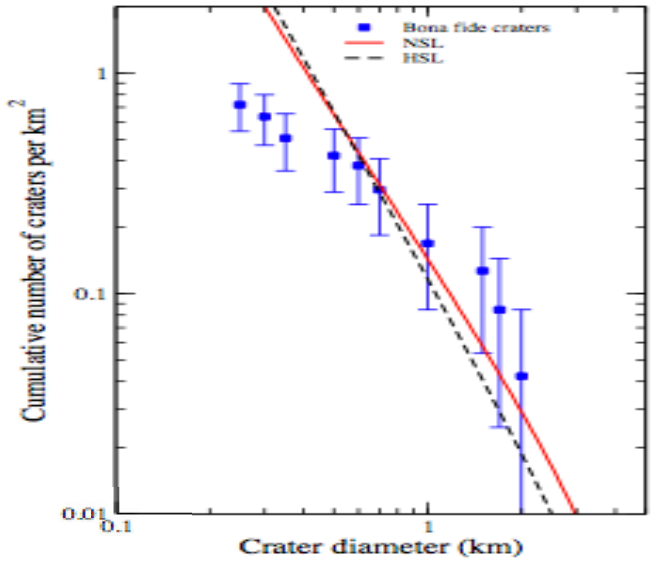
- The impactor flux is then converted into a cumulative crater distribution of model production function, MPF, using a scaling law (SL)
- The SL utilized will depend on the physical characteristics of the asteroid
- The purpose of the Scaling Law is to find a relationship between the crater diameter (D) and the impactor diameter (d) in order to transpose the impactor flux, that is:

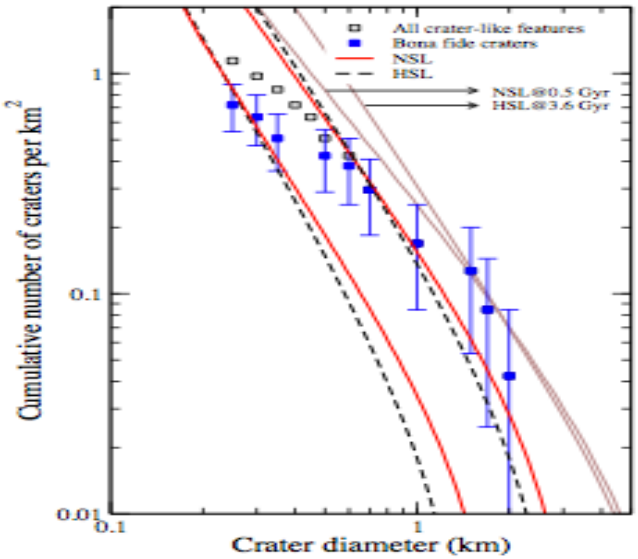
$$\phi(d,v) \rightarrow \phi(D)$$

Scaling Law



Age of Asteroids





5

$$MPF(D,t) = \int_{D}^{\infty} \phi(\tilde{D},t)\,\varepsilon(\tilde{D},t)\,d\tilde{D}$$

The model production function (MPF) is the differential distribution $\phi(D)$ of the number of craters with respect to their diameters expressed per unit time and surface area. The obtained MPF will be used to analyze the data obtained in step 2 and from there approximate the age of the surface (best fitting).

Steins collisional age: 50 to 150 million years ago

Model Production Function

Age of Asteroids

Juan Carlos Lopez EXIT PRESENTATION

NASA MUST Project

My Summer Internship at the NASA Jet Propulsion Laboratory:
Procedures for the Analysis of Asteroids with Data from the International Rosetta Mission

Juan Carlos Lopez[1]
The University of Texas at El Paso

Mentor: Claudia Alexander[2]
Jet Propulsion Laboratory

August 13th, 2011

Abstract:

Rosetta is an international mission led by the European Space Agency (ESA) with key support and instrumentation from the National Aeronautics and Space Administration (NASA). Rosetta is currently on a ten-year mission to catch comet 67P/Churyumov-Gerasimenko (C-G); throughout its voyage, the spacecraft has performed flybys of two main belt asteroids (MBA) including asteroid (21) Lutetia. Data on the physical, chemical, and geological properties of Lutetia are currently being processed and analyzed. Accurate interpretation of such data is fundamental in the success of Rosetta's mission and overall objectives. Post-flyby data analyses strive to correlate the size, shape, volume, and rotational rate of Lutetia, in addition to interpreting its multi-color imagining, albedo, and spectral mapping. Although advancements in science have contributed to the examination of celestial bodies, methods to analyze asteroids remain largely empirical, not semi-empirical, nor *ab initio*. This study aims to interpret and document the scientific methods currently utilized in the characterization of asteroid (21) Lutetia in order to render these processes and methods accessible to the public. Examples include a standardized technique for assessing the age of an asteroid surface, complete with clickable reference maps, methodology of grouping surface characteristics together, and a standardized power law equation for the age. Other examples include determining the density of an object. Context for what both density and age mean is a bi-product of this study. Results of the study will aid in the development of pedagogical material on asteroids for public use, and in creation of an academic database for selected targets that might be used as a reference.

1 Summer Intern, U.S. Rosetta, NASA-JPL, The University of Texas at El Paso.
2 Project Scientist, U.S. Rosetta, NASA-JPL, Mail Stop – 321-569

NASA MUST Project

explained utilizing data from the Rosetta spacecraft of asteroid (2867) Steins, in addition to elaborating on the projects and activities developed as a result of such research.

Figure 1. Asteroid (2867) Steins taken by the Rosetta Spacecraft. Image credit: European Space Agency.

2. Determining the Age of Surface

Executive Summary:

Objective of this procedure is to create the Production Function (MPF) from which the collisional age of an asteroid can directly be estimated. To do it we must (a) characterize the size, and distribution of craters in the (b) the impactor flux must be derived, and to a functional form in a single variable scaling law (SL). (c) this function is then over all crater sizes, after accounting for material properties of each target. (d) will then be fitted into the crater in (a) in order to predict the age.

The first step to assess the age of an asteroid's surface is done by visual inspection. Craters are identified and counted, and its diameters are measured. To do this, the images must be divided into sub-sections of one square kilometer (km^2) in surface area, this will also facilitate the process of data. Craters will be categorized as *bona fide craters* or *crater-like features*. Bona fide craters are those with well-defined edges, which are remarkably visible to the naked eye.

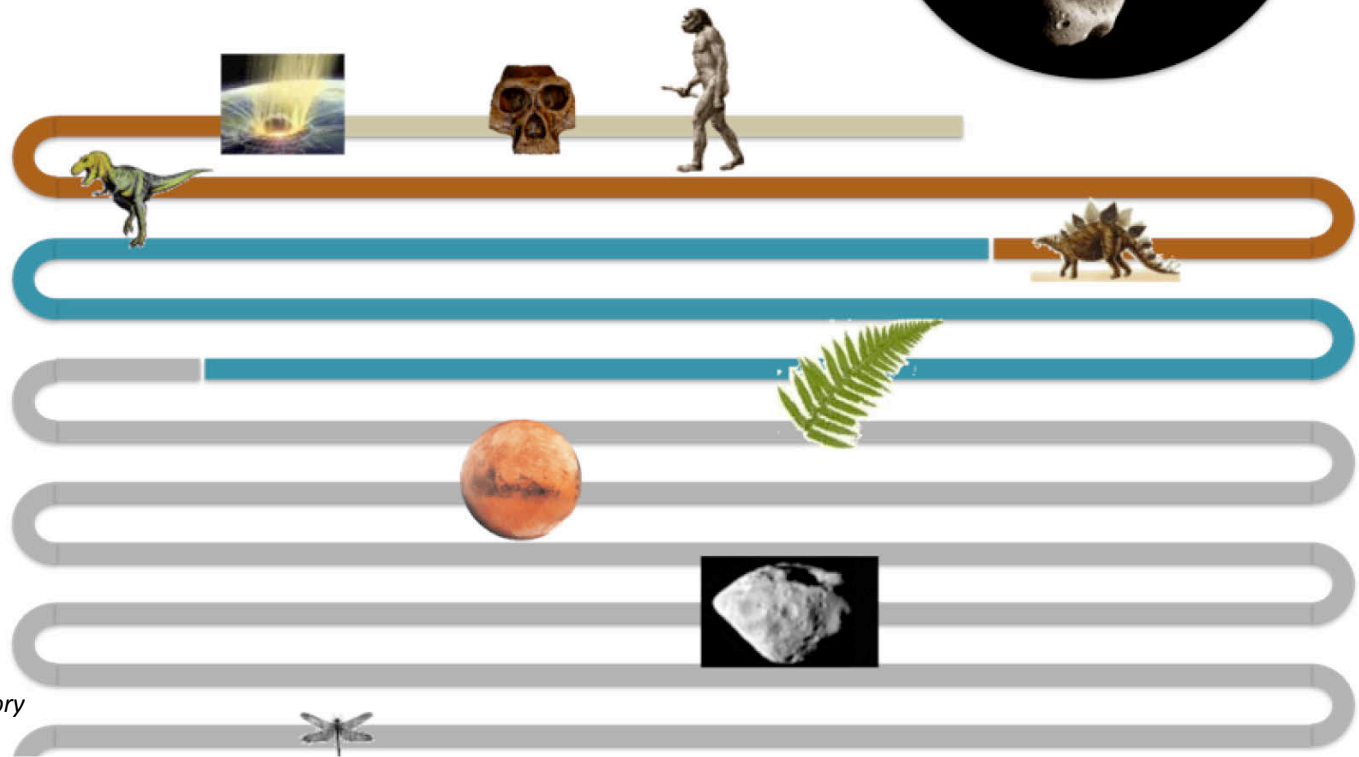
The result of visual inspect will be a table containing the number of craters, category, and diameter. Once the table is competed, the user

- An instructions manual to assess the age of asteroids has been written. The manual uses data and information from Steins in order to illustrate the procedure
- Same procedure can be applied to other asteroids, thus can be useful to support future activities and other outreach efforts

Activity 2: Asteroids Through Time

Juan Carlos Lopez EXIT PRESENTATION

Purpose: This activity strives to develop a historical perspective of asteroids by identifying their "birth" through events occurring in the formation of the Solar System.



Asteroids Through Time

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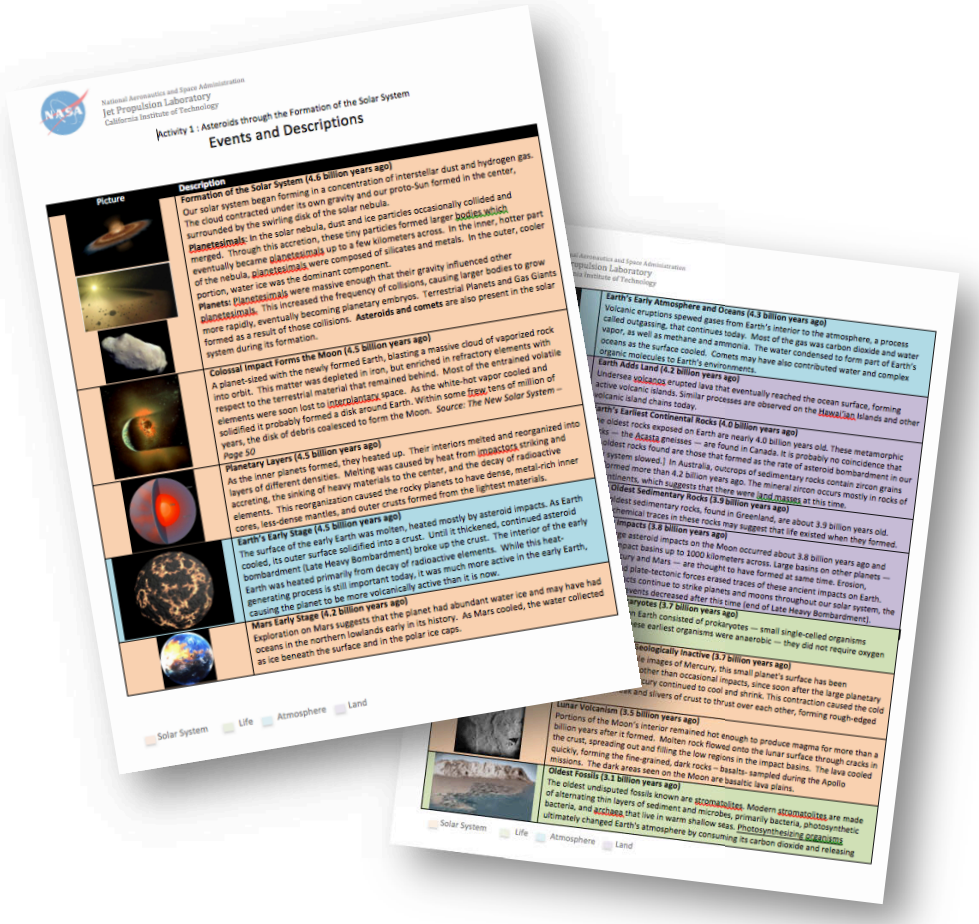

National Aeronautics and Space Administration
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Activity 1 : Asteroids through the Formation of the Solar System

Events and Descriptions

Picture	Description
	Formation of the Solar System (4.6 billion years ago) Our solar system began forming in a concentration of interstellar dust and hydrogen gas. The cloud contracted under its own gravity and our proto-Sun formed in the center, surrounded by the swirling disk of the solar nebula. **Planetesimals:** In the solar nebula, dust and ice particles occasionally collided and merged. Through this accretion, these tiny particles formed larger bodies which eventually became planetesimals up to a few kilometers across. In the inner, hotter part of the nebula, planetesimals were composed of silicates and metals. In the outer, cooler portion, water ice was the dominant component. **Planets:** Planetesimals were massive enough that their gravity influenced other planetesimals. This increased the frequency of collisions, causing larger bodies to grow more rapidly, eventually becoming planetary embryos. Terrestrial Planets and Gas Giants formed as a result of those collisions. **Asteroids and comets** are also present in the solar system during its formation.
	Colossal Impact Forms the Moon (4.5 billion years ago) A planet-sized with the newly formed Earth, blasting a massive cloud of vaporized rock into orbit. This matter was depleted in iron, but enriched in refractory elements with respect to the terrestrial material that remained behind. Most of the entrained volatile elements were soon lost to interplanetary space. As the white-hot vapor cooled and solidified it probably formed a disk around Earth. Within some few tens of million of years, the disk of debris coalesced to form the Moon. *Source: The New Solar System – Page 50*
	Planetary Layers (4.5 billion years ago) As the inner planets formed, they heated up. Their interiors melted and reorganized into layers of different densities. Melting was caused by heat from impactors striking and accreting, the sinking of heavy materials to the center, and the decay of radioactive elements. This reorganization caused the rocky planets to have dense, metal-rich inner cores, less-dense mantles, and outer crusts formed from the lightest materials.
	Earth's Early Stage (4.5 billion years ago) The surface of the early Earth was molten, heated mostly by asteroid impacts. As Earth cooled, its outer surface solidified into a crust. Until it thickened, continued asteroid bombardment (Late Heavy Bombardment) broke up the crust. The interior of the early Earth was heated primarily from decay of radioactive elements. While this heat-generating process is still important today, it was much more active in the early Earth, causing the planet to be more volcanically active than it is now.
	Mars Early Stage (4.2 billion years ago) Exploration on Mars suggests that the planet had abundant water ice and may have had oceans in the northern lowlands early in its history. As Mars cooled, the water collected as ice beneath the surface and in the polar ice caps.

Solar System Life Atmosphere Land

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Earth's Early Atmosphere and Oceans (4.3 billion years ago) Volcanic eruptions spewed gases from Earth's interior to the atmosphere, a process called outgassing, that continues today. Most of the gas was carbon dioxide and water vapor, as well as methane and ammonia. The water condensed to form part of Earth's oceans as the surface cooled. Comets may have also contributed water and complex organic molecules to Earth's environments.

Earth Adds Land (4.2 billion years ago) Undersea volcanos erupted lava that eventually reached the ocean surface, forming active volcanic islands. Similar processes are observed on the Hawaiian Islands and other volcanic island chains today.

Earth's Earliest Continental Rocks (4.0 billion years ago) The oldest rocks exposed on Earth are nearly 4.0 billion years old. These metamorphic rocks — the Acasta gneisses — are found in Canada. It is probably no coincidence that oldest rocks found are those that formed as the rate of asteroid bombardment in our system slowed.] In Australia, outcrops of sedimentary rocks contain zircon grains formed more than 4.2 billion years ago. The mineral zircon occurs mostly in rocks of continents, which suggests that there were land masses at this time.

Oldest Sedimentary Rocks (3.9 billion years ago) Oldest sedimentary rocks, found in Greenland, are about 3.9 billion years old. Chemical traces in these rocks may suggest that life existed when they formed.

Impacts (3.8 billion years ago) Large asteroid impacts on the Moon occurred about 3.8 billion years ago and impact basins up to 1000 kilometers across. Large basins on other planets — Mercury and Mars — are thought to have formed at same time. Erosion, and plate-tectonic forces erased traces of these ancient impacts on Earth. Comets continue to strike planets and moons throughout our solar system, the events decreased after this time (end of Late Heavy Bombardment).

Prokaryotes (3.7 billion years ago) Earth consisted of prokaryotes — small single-celled organisms. These earliest organisms were anaerobic — they did not require oxygen

Geologically inactive (3.7 billion years ago) In the images of Mercury, this small planet's surface has been quiet other than occasional impacts, since soon after the large planetary impacts. Mercury continued to cool and shrink. This contraction caused the cold crust and slivers of crust to thrust over each other, forming rough-edged cliffs.

Lunar Volcanism (3.5 billion years ago) Portions of the Moon's interior remained hot enough to produce magma for more than a billion years after it formed. Molten rock flowed onto the lunar surface through cracks in the crust, spreading out and filling the low regions in the impact basins. The lava cooled quickly, forming the fine-grained, dark rocks – basalts- sampled during the Apollo missions. The dark areas seen on the Moon are basaltic lava plains.

Oldest Fossils (3.5 billion years ago) The oldest undisputed fossils known are stromatolites. Modern stromatolites are made of alternating thin layers of sediment and microbes, primarily bacteria, photosynthetic bacteria, and archaea that live in warm shallow seas. Photosynthesizing prokaryotes ultimately changed Earth's atmosphere by consuming its carbon dioxide and releasing

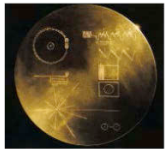
Solar System Life Atmosphere Land

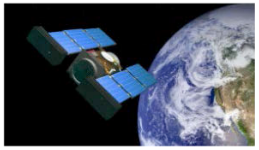
- Timeline includes 50 events since the formation of the solar system
- Six asteroids were selected for this activity: Gaspra, Mathilde, Ida, Eros, and Steins
- Activity has been finished and will soon be implemented

My Summer Experience

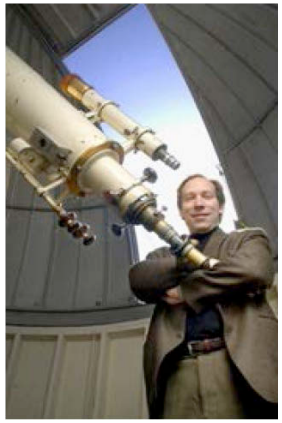
Juan Carlos Lopez EXIT PRESENTATION

STS-135 Pre-Launch Education Unconferece





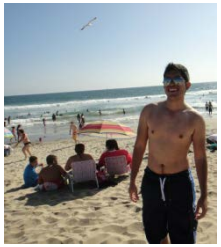
Field trip to Goldstone



My Summer Experience

Juan Carlos Lopez EXIT PRESENTATION

Chalk Festival – Pasadena, CA



Skills Acquired

- Gained a better understanding of asteroids, astrobiology, astrophysics and the scientific process
- Applied and enhance research/reading abilities
- Increased communication skills
- Enhanced my organization and time management skills
- Learned about the importance of teamwork

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My Contributions to NASA

- Contributed to a team of NASA staff on the development of STEM-based activities for outreach efforts
- Supported an international mission through projects to motivate and inspire others
- Served as mentor for high school and college JPL summer interns
- Developed useful manuals for future Rosetta activities

Future Goals

Back to NASA – Fall 2011
Start my tour as a co-op for NASA -JSC in Houston, TX

Make a Difference
Continue doing outreach in my community as well as keep participating in NASA-related events through the NASA Student Ambassador Program

UTEP – Spring 2011
Go back to UTEP and finish my 7th semester of ME

Graduation – Fall 2012
Bachelor's of Science in Mechanical Engineering

Acknowledgements

Dr. Claudia Alexander
Ms. Andrea Angrum
Mr. Art Chmielewski
Ms. Jenny Tieu
Ms. Amy Dickinson
Ms. Suzanne Dodd
Ms. Sun Matsumoto
Mr. Enrique Medina
Mr. Jefferson Hall
Mr. Fernando Peralta

Fellow Interns:
Myers Hawkins
Richard Knowles
David Widen

Thank You!

References

- Marchi,S., Barbieri, C., Kuppers, M., Marzari, F., Davidsson, B., Keller, H.U., Besse, S., Lamy, P., Mottola, S., Massironi, M., Cremonese, G., 2010. The cratering history of asteroid (2867) Steins. Planetary and Space Science 58, 1116-1123.
- Bottke, W., Durba, D., Nesvorny, D., Jedicke, R., Morbidelli, A., Vokrouhlicky, D., Levison, H., 2005. The fossilized size distribution of the main asteroid belt. Icarus 175, 111-140.
- Marchi, S., Morbidelli, A., Cremonese, G., 2005. Flux of meteoroid impacts on Mercury. Astronomy & Astrophysics, 1123-1127.
- U.S. Rosetta Website: http://rosetta.jpl.nasa.gov. July, 2011
- JPL Website: http://jpl.nasa.gov. July, 2011