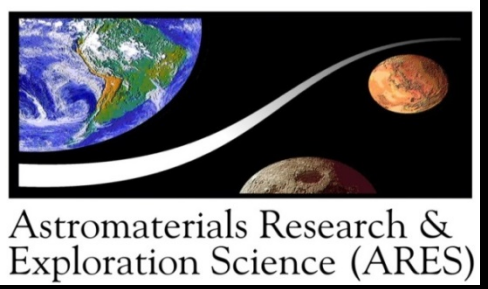
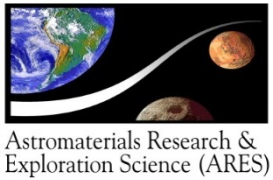


Asteroids, Dwarf Planets, and Two Weeks in a Box

Kristen John, Ph.D.

Postdoctoral Research Fellow
NASA Johnson Space Center

July 1st, 2015



Kristen's SSGF Experience

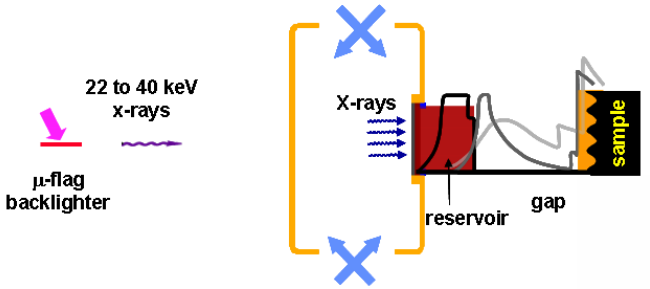
- 2009-2013
- Properties of Materials Under Extreme Conditions
- Practicum: LLNL (2011)
  - Bruce Remington & Hye-Sook Park
  - Omega Laser (LLE)
  - Strength of Ta, Fe

Astromaterials Research & Exploration Science (ARES)

Grad School

- Aerospace Engineering
- Ph.D. Caltech, 2014
  M.S. Caltech, 2010
  B.S. UT-Austin, 2008
- Advisor: G. “Ravi” Ravichandran

Astromaterials Research & Exploration Science (ARES)



NASA

Goal: Strength of tantalum at high pressures

Experiments ⟷ **Simulations**

Validation

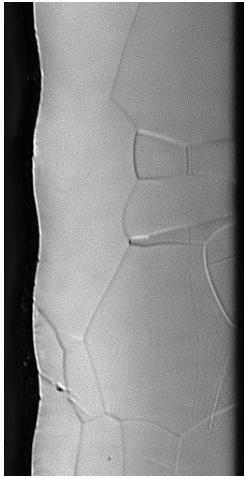
Omega Laser Experiments

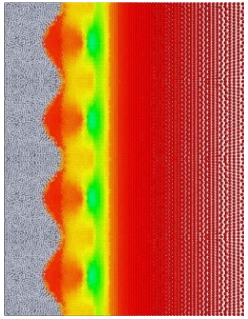
- Measure of strength at high pressures for Ta

Eureka Code with Ta Material Model

- Validate experiments & model
- Run simulations to aid in design of experiments
- Predict material behavior

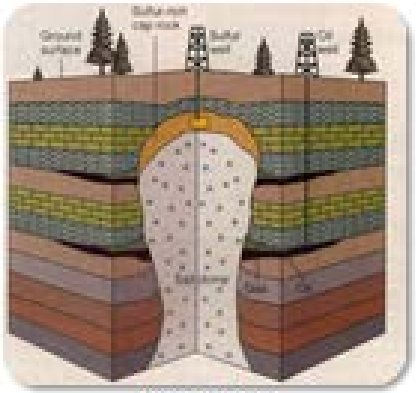
Observational Parameter: Richtmyer-Meshkov (RM) instability





Astromaterials Research & Exploration Science (ARES)

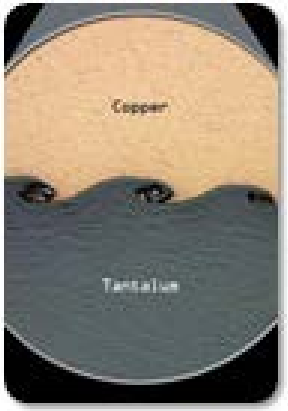
Hypervelocity impacts
space shielding, ballistics



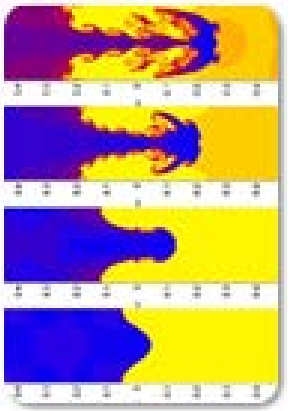
Geology
seismology, salt domes

Astrophysics
planetary impacts, bodies

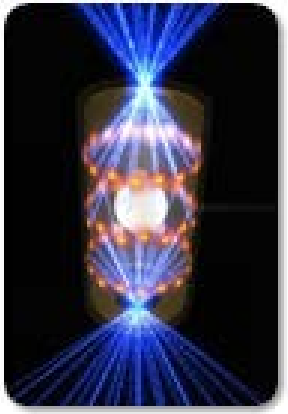
Military
explosives, ballistics, nuclear technology



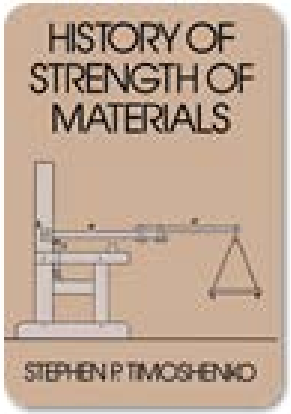
Instabilities



Fusion Energy



Strength
new measurement, high pressures



Astromaterials Research & Exploration Science (ARES)

A Year in the Life of a Post-doc

NASA

NASA
POSTDOCTORAL PROGRAM
Administered by Oak Ridge Associated Universities

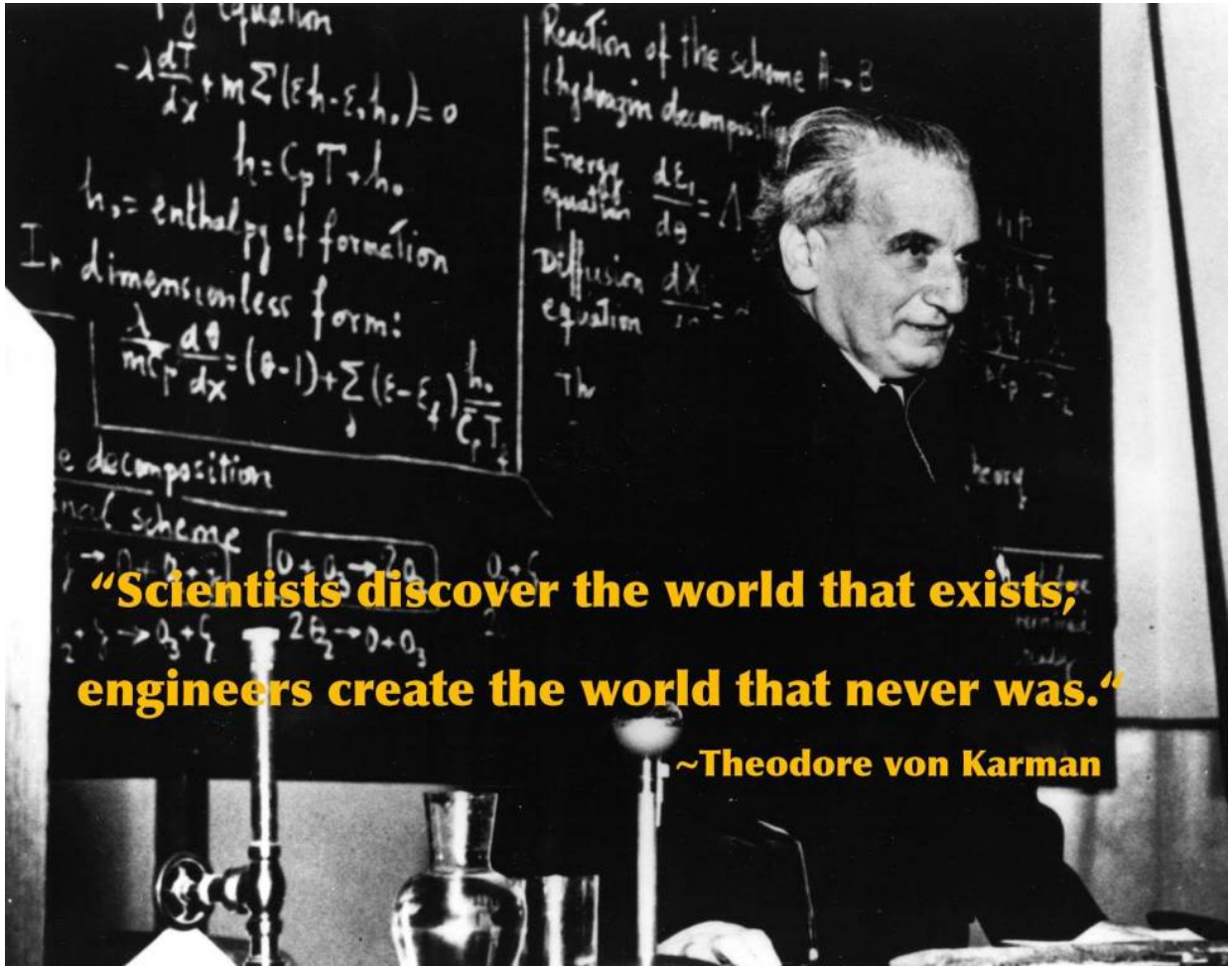
- The Path to NPP
- A Day in the Life of a Post-doc?

Astromaterials Research & Exploration Science (ARES)

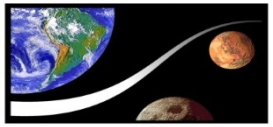
An Engineer Among Scientists

(in a science group among engineers)

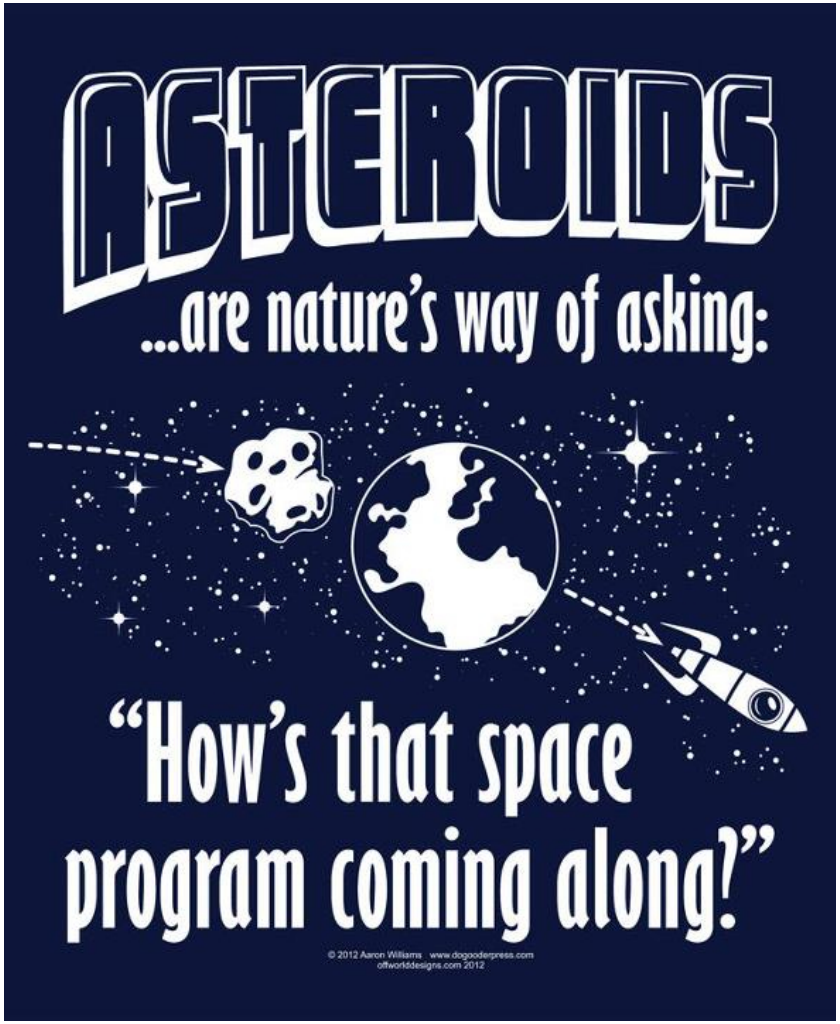
Astromaterials Research & Exploration Science (ARES)



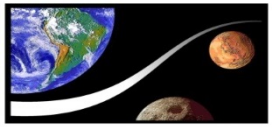
NPP JSC Advisors: Paul Abell & Lee Graham



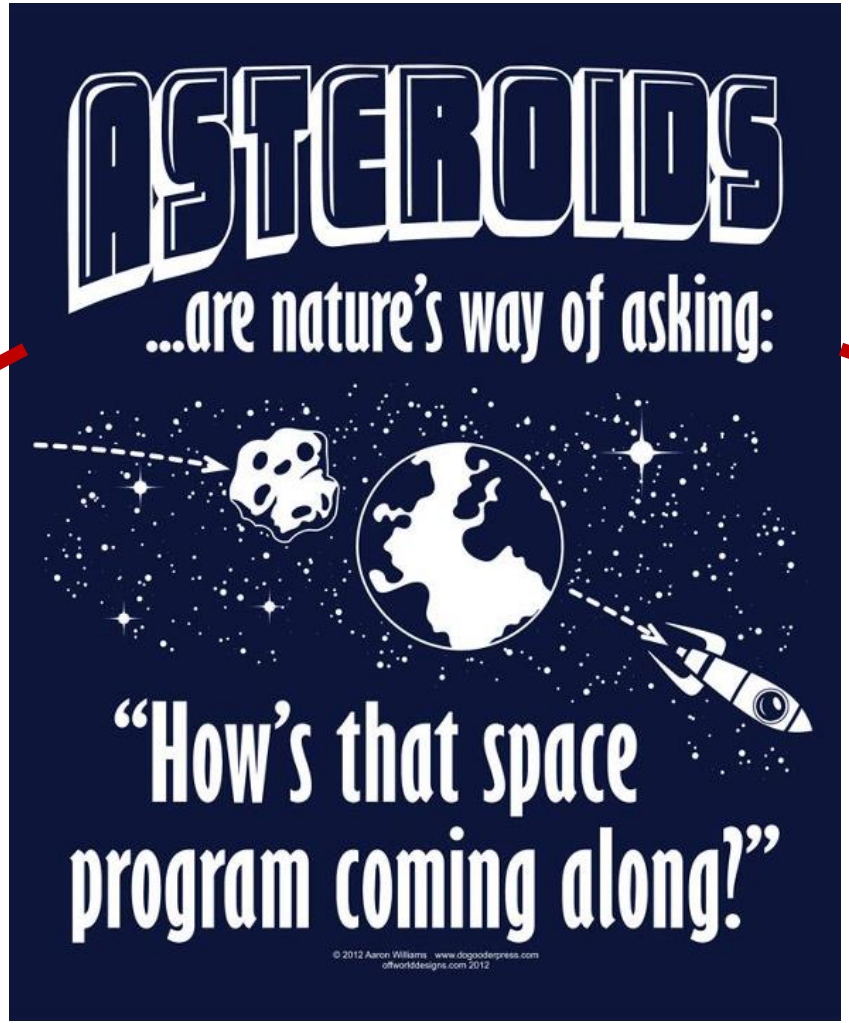
Astromaterials Research &
Exploration Science (ARES)



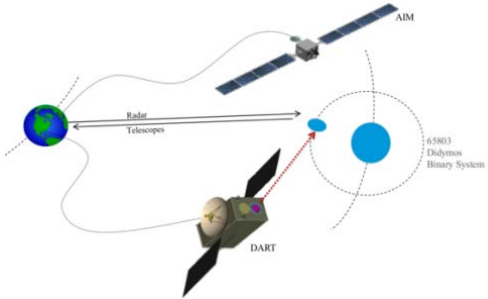
NASA



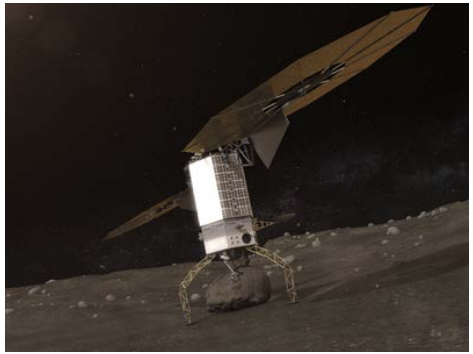
Astromaterials Research &
Exploration Science (ARES)



AIDA



ARM



surface properties,
proximity operations

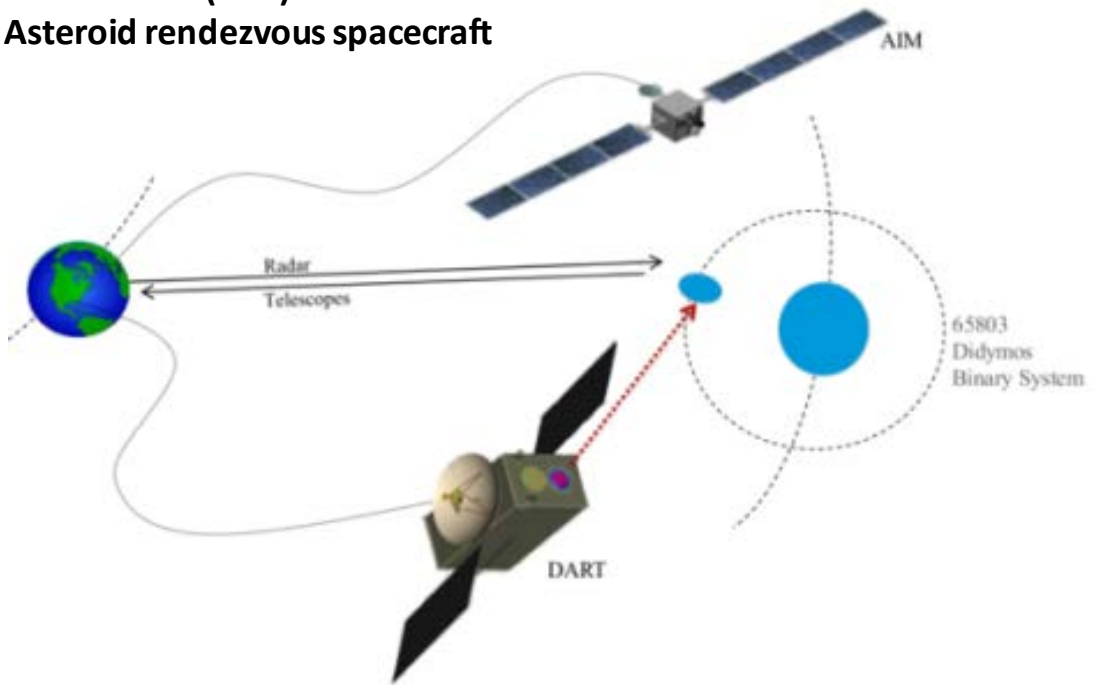
Astromaterials Research & Exploration Science (ARES)

Asteroid Impact & Deflection Assessment (AIDA)

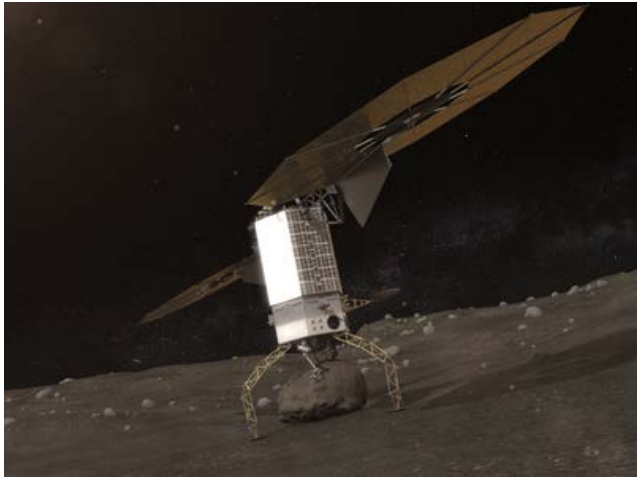
AIDA = AIM & DART

Asteroid Impact Mission (ESA)
Asteroid rendezvous spacecraft

Double Asteroid Redirection Test (NASA/APL)
An asteroid impactor

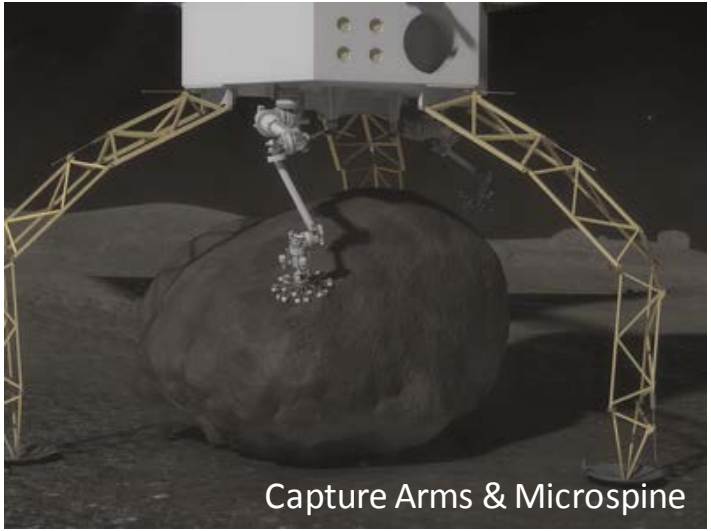


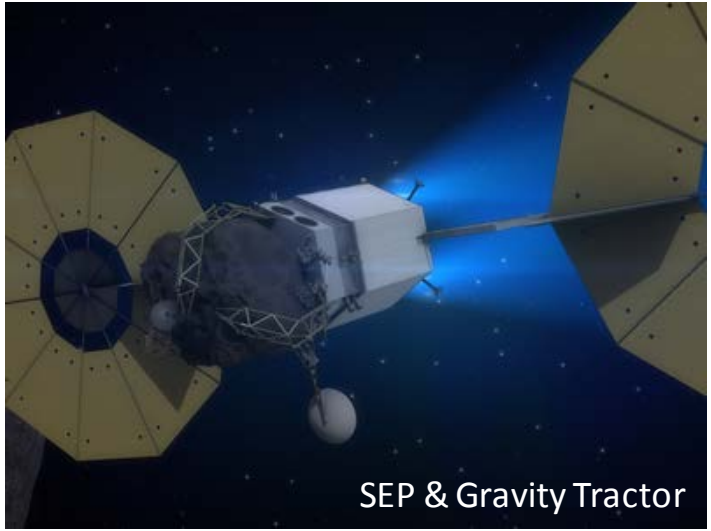
- Test ability to perform a spacecraft impact on a potentially hazardous near-Earth asteroid
- Measure and characterize the deflection caused by the impact



Asteroid Redirect Mission (ARM)

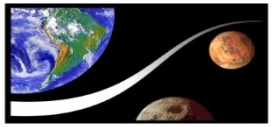
1. Visit an asteroid 2. Redirect its trajectory
3. Bring boulder off the surface back to lunar orbit





“Gravity Tractor" planetary defense technique on a hazardous-size asteroid

Leverages the mass of the spacecraft to impart a gravitational force on the asteroid, slowly altering the asteroid’s trajectory

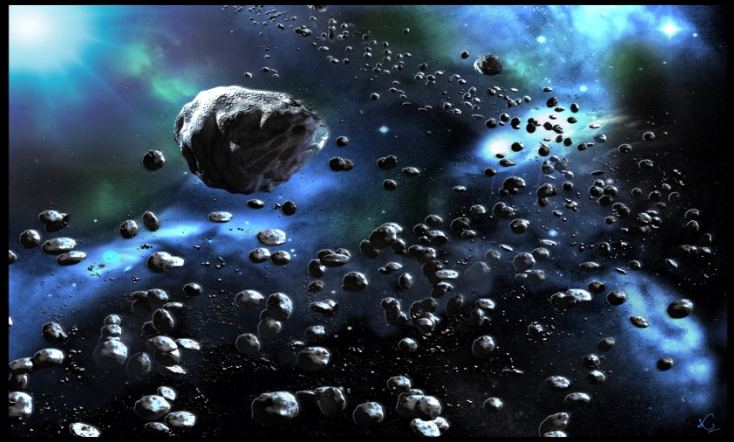


Astromaterials Research &
Exploration Science (ARES)

Investigating Ceres

Astromaterials Research & Exploration Science (ARES)

What are asteroids?



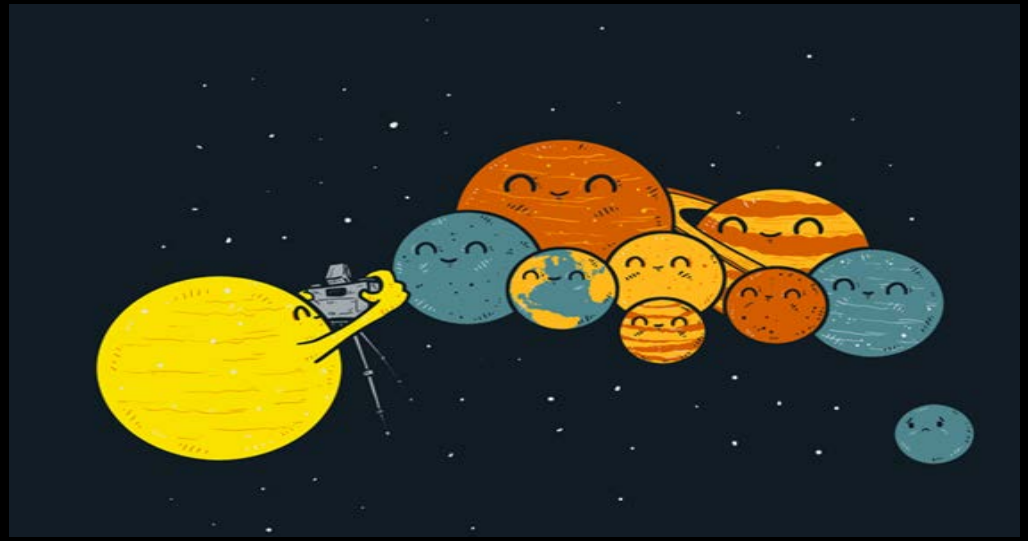
rocky, airless, small, irregular bodies

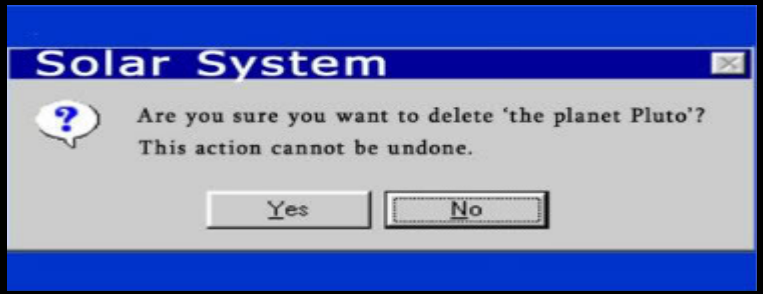
Where are asteroids?

Near-Earth,
Main Belt,
Trojans, KBO's

Astromaterials Research & Exploration Science (ARES)

NASA



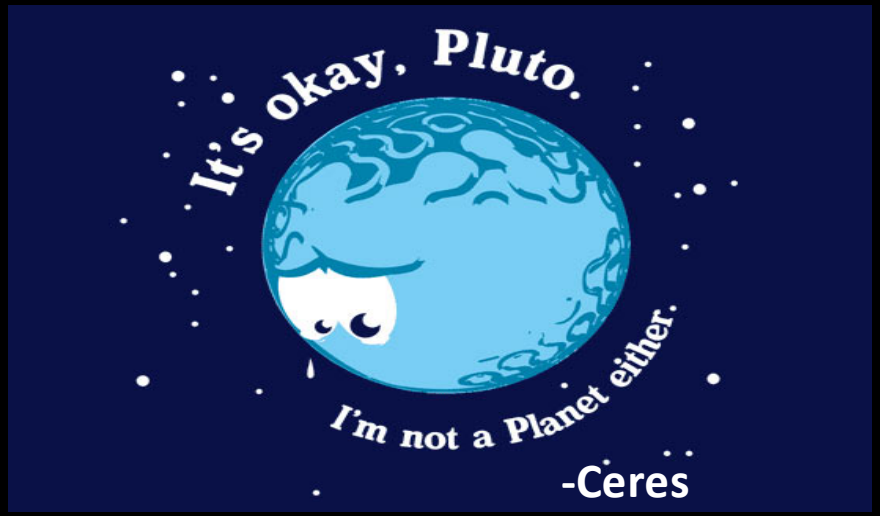


Astromaterials Research & Exploration Science (ARES)

Dwarf Planet Requirements

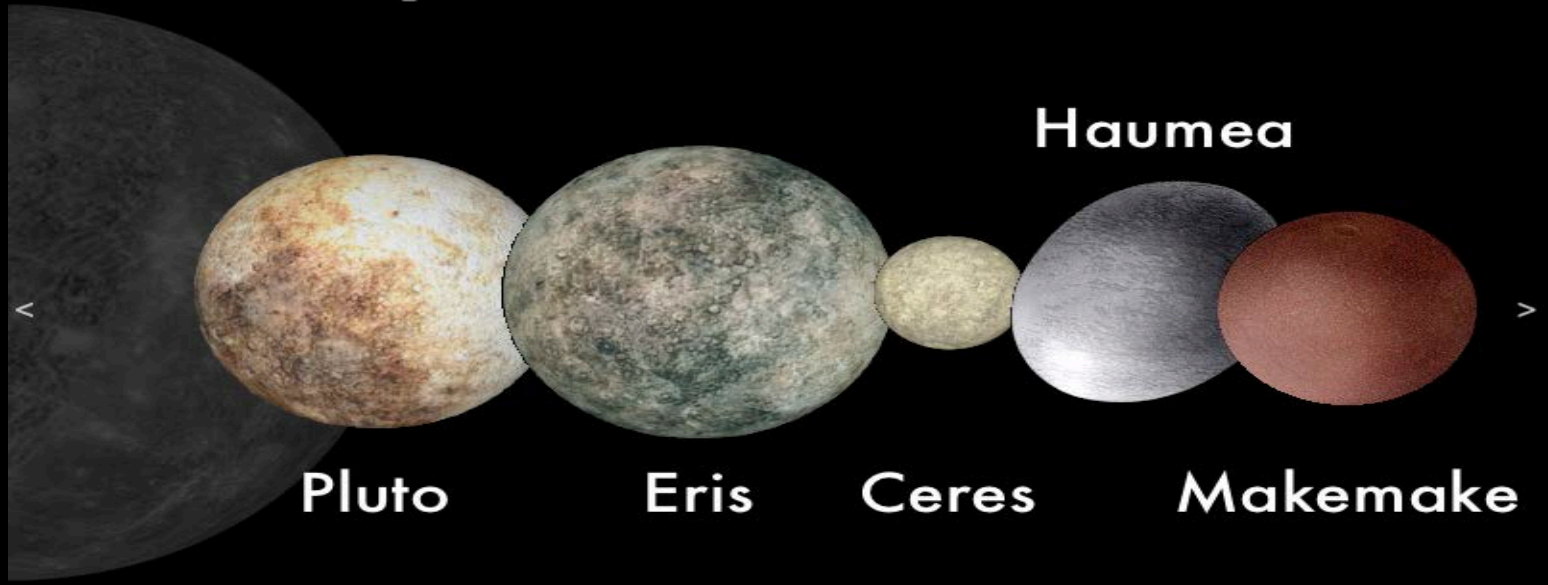
NASA

1. Orbits the sun.
2. Has enough mass to assume a nearly round shape.
3. Has not cleared the neighborhood around its orbit.
4. Is not a moon.



Astromaterials Research & Exploration Science (ARES)

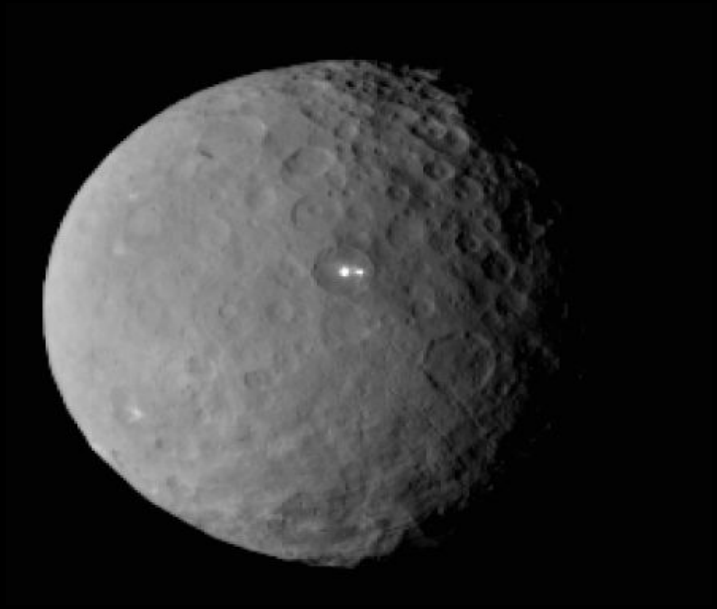
Dwarf planets



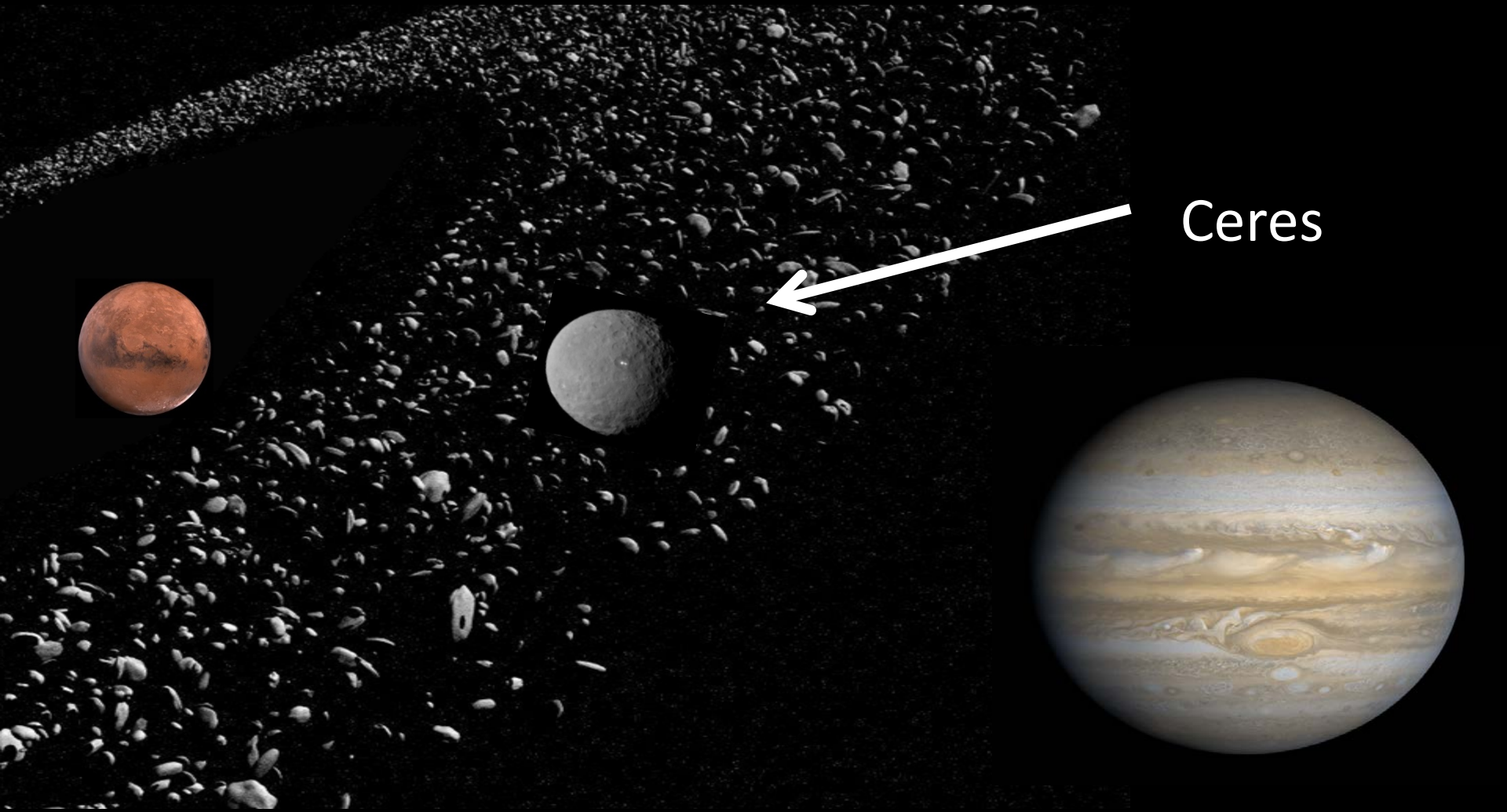
(Sources: http://sos.noaa.gov/datasets/solar_system/mercury.html, http://hubblesite.org/newscenter/archive/releases/2006/16/image/d%5D, http://arcadiastreet.com/cgvistas/ceres_107a.htm)

Astromaterials Research & Exploration Science (ARES)

- 1801: Planet? Asteroid.
- 2006: Dwarf Planet!

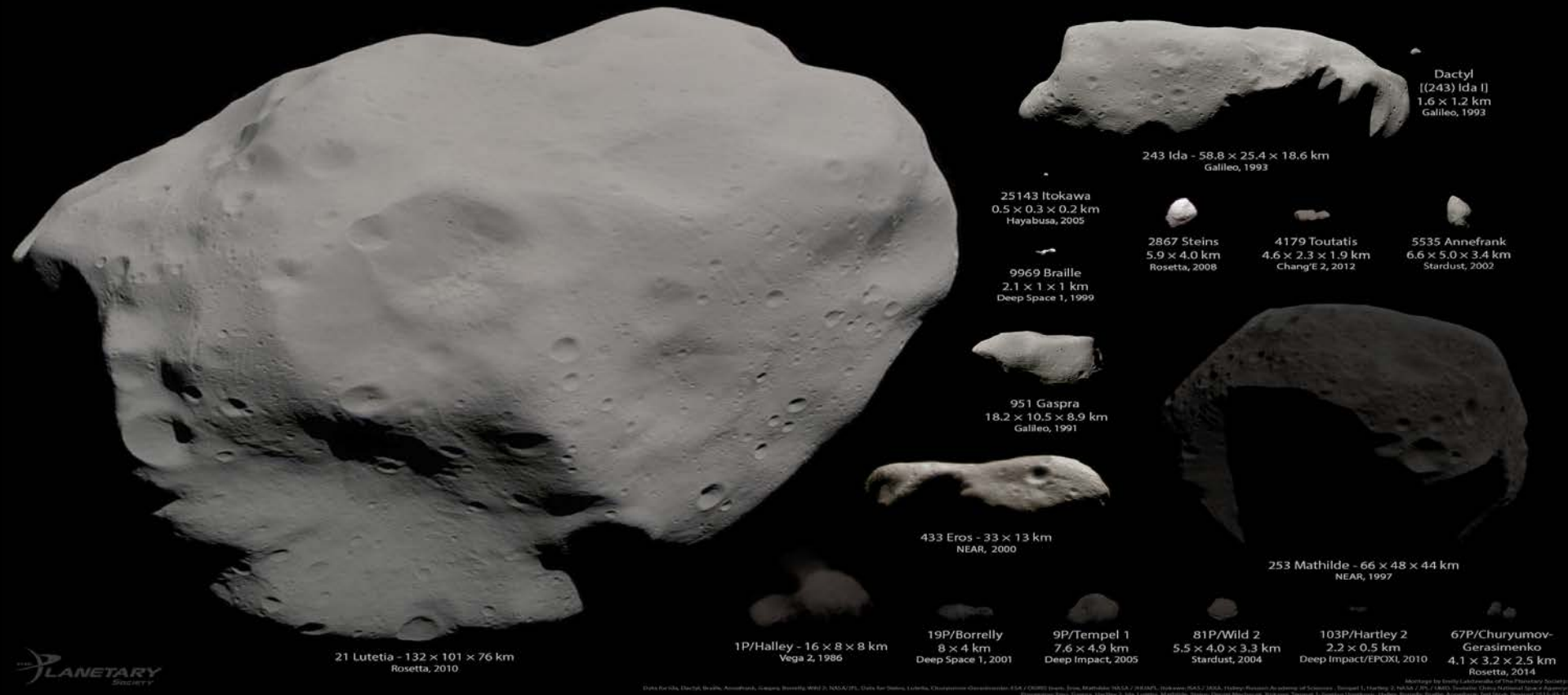


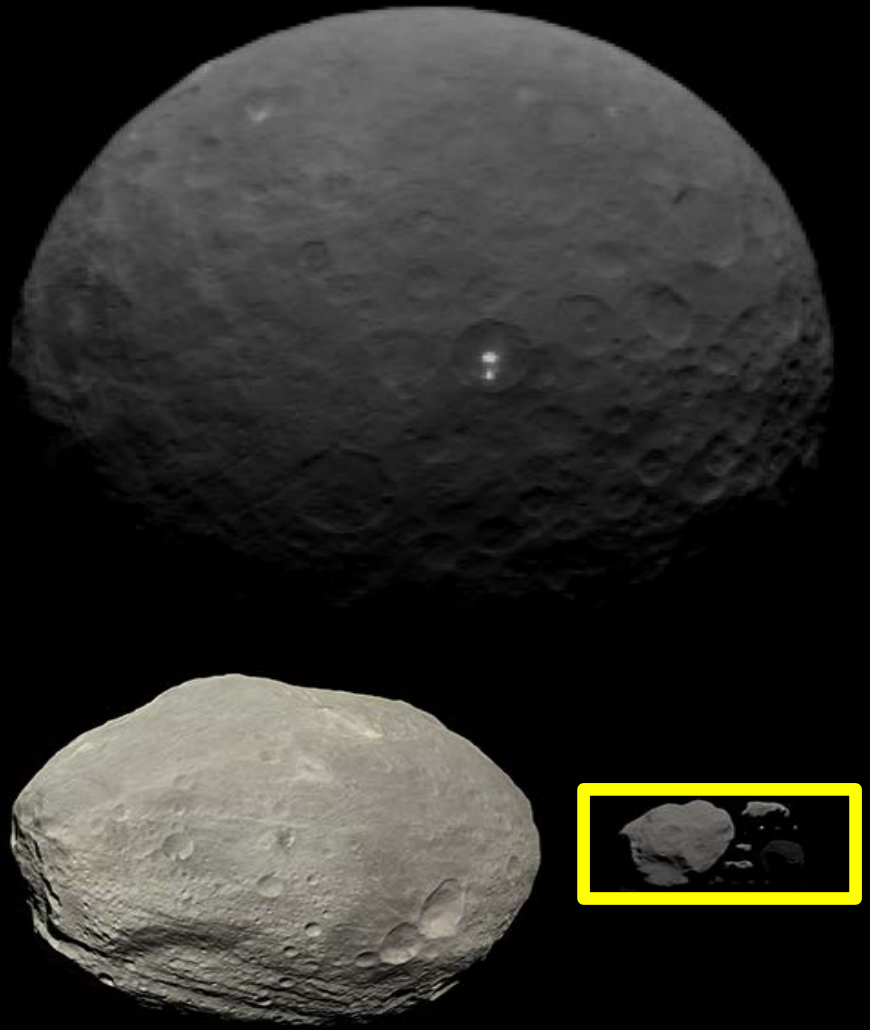
1 Ceres


Ceres


Ceres

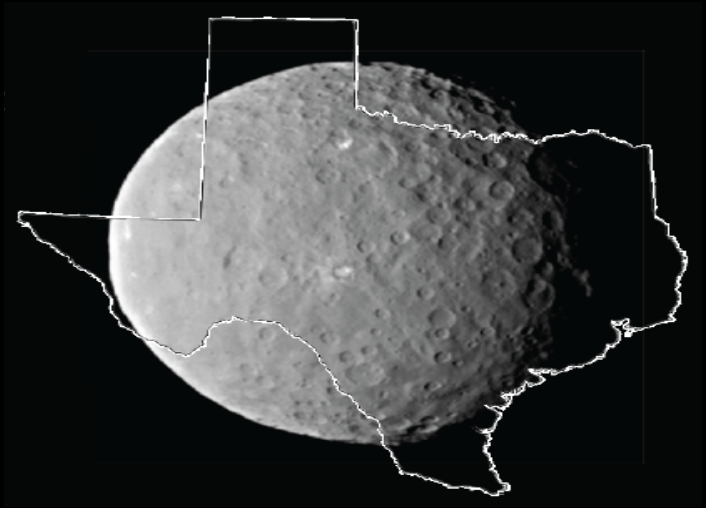
Asteroids By Comparison

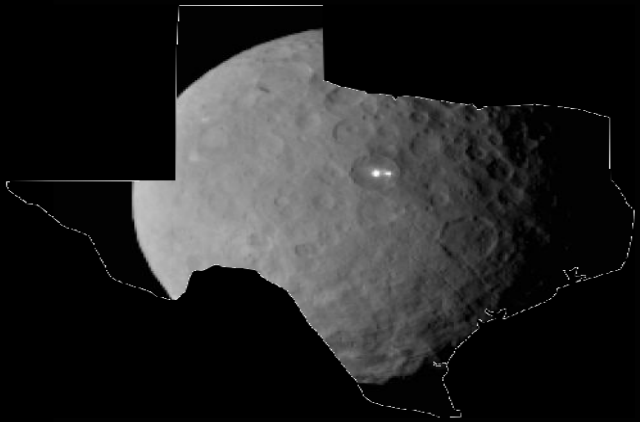




Astromaterials Research & Exploration Science (ARES)

How Big is Ceres?

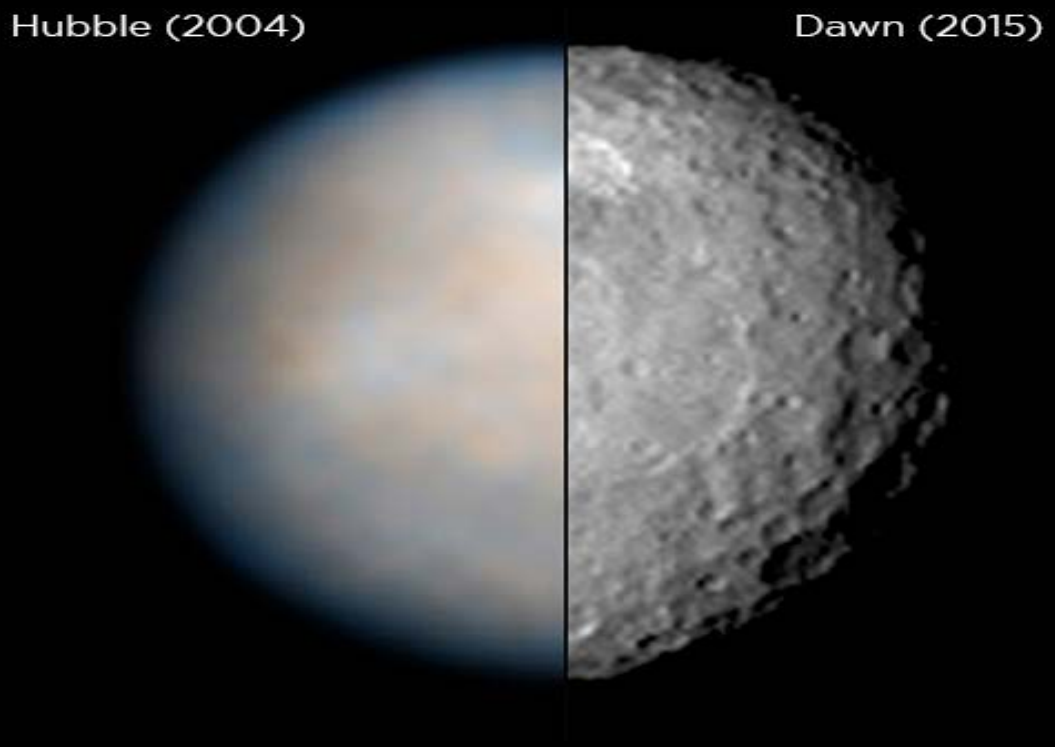




- Diameter of Ceres = 950 km (590 miles)
- Texas = 1244 km wide (773 miles)

Astromaterials Research & Exploration Science (ARES)

Ceres Resolution



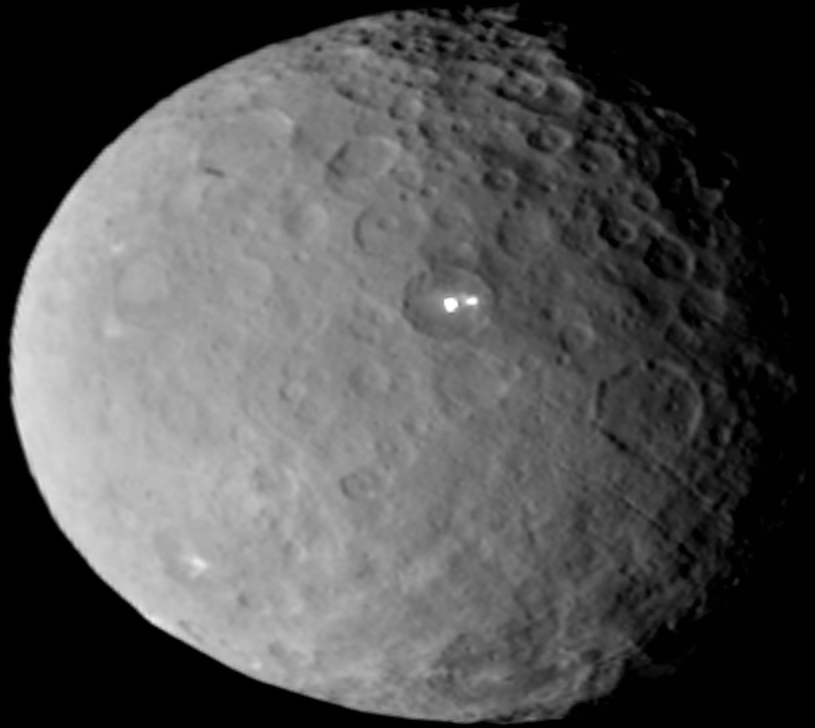
1 Cererian Day = 9 Hours

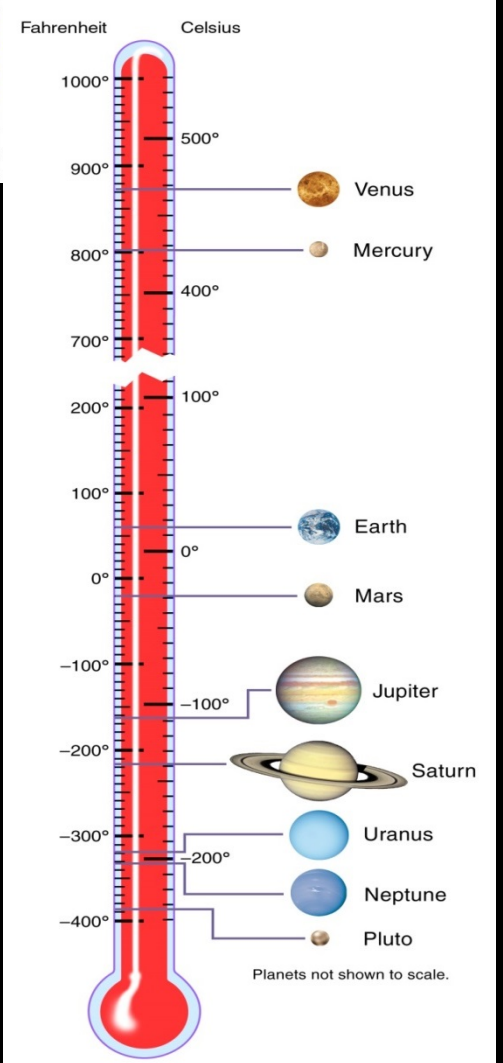
1 Cererian Year = 4.6 Earth Years

Only Dwarf Planet in Inner Solar System

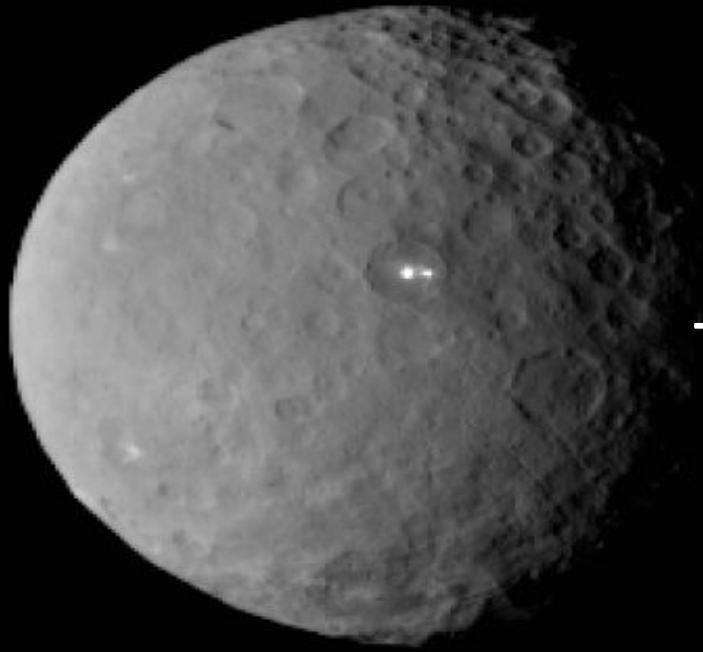
Biggest body in the main belt


CAP'N CRUNCH
C3PO's
DONKEY KONG JUNIOR
G.I. JOE
Super Sugar Crisp
SUGAR SMACKS
DONKEY KONG
MR. T
INDIANA JONES
PUNCH CRUNCH
PAC-MAN
Lucky Charms
OJ's
GHOST BUSTERS
NERDS
SMURF-BERRY CRUNCH
Lucky Charms
S'MORES CRUNCH
CRUNCH BERRIES
SIR Grapefellow
TEENAGE MUTANT NINJA TURTLES CEREAL
Mr. Wonderful's SURPRIZE
CIRCUS FUN
FRUIT BRUTE
Vanilla Wafer
COOKIE CRISP
CORN POPS
E.T. CEREAL
Franken Berry
PEANUT BUTTER
APPLE JACKS
Cracker Jack Cereal
Ice Cream Cones
COUNT CHOCULA
HONEY COMB
Freakies
GREMLINS
Boo Berry
COCOA KRISPIES





How cold is Ceres?

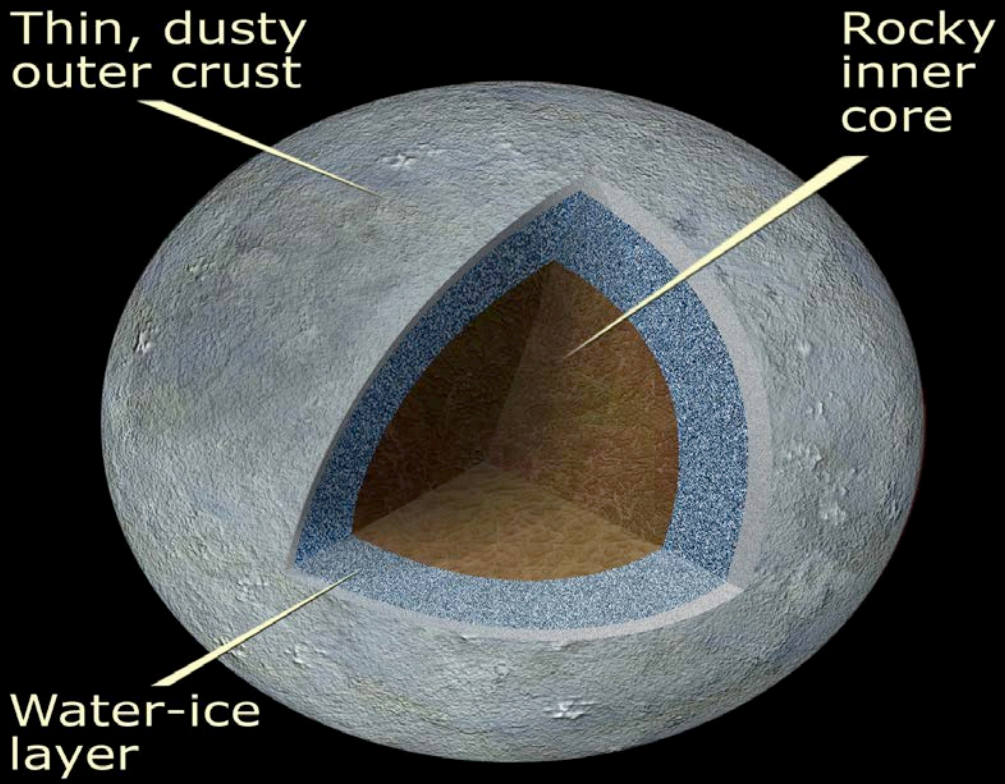


-135 °F

-225 °F

Astromaterials Research & Exploration Science (ARES)

What's it made of?



- Reflectance Spectral Class C
- Carbonaceous content (probably)
- icy crust?
- clays, iron oxides, carbonaceous solids
- high salt content?
- 17-27% Water
- Density = 2.1 g/cc

Image credit: NASA JPL

Astromaterials Research & Exploration Science (ARES)

Water Plumes

- liquid source underground?
- exposed water ice?

Artist's Depiction

Herschel Space Telescope

The White Spots!

Ice volcano?

Ice-filled craters?

Sublimation?

Salt deposits?

Vent or crack?

Exposed water ice?

~~Alien solar array?~~

Reflective minerals?

Water plumes?

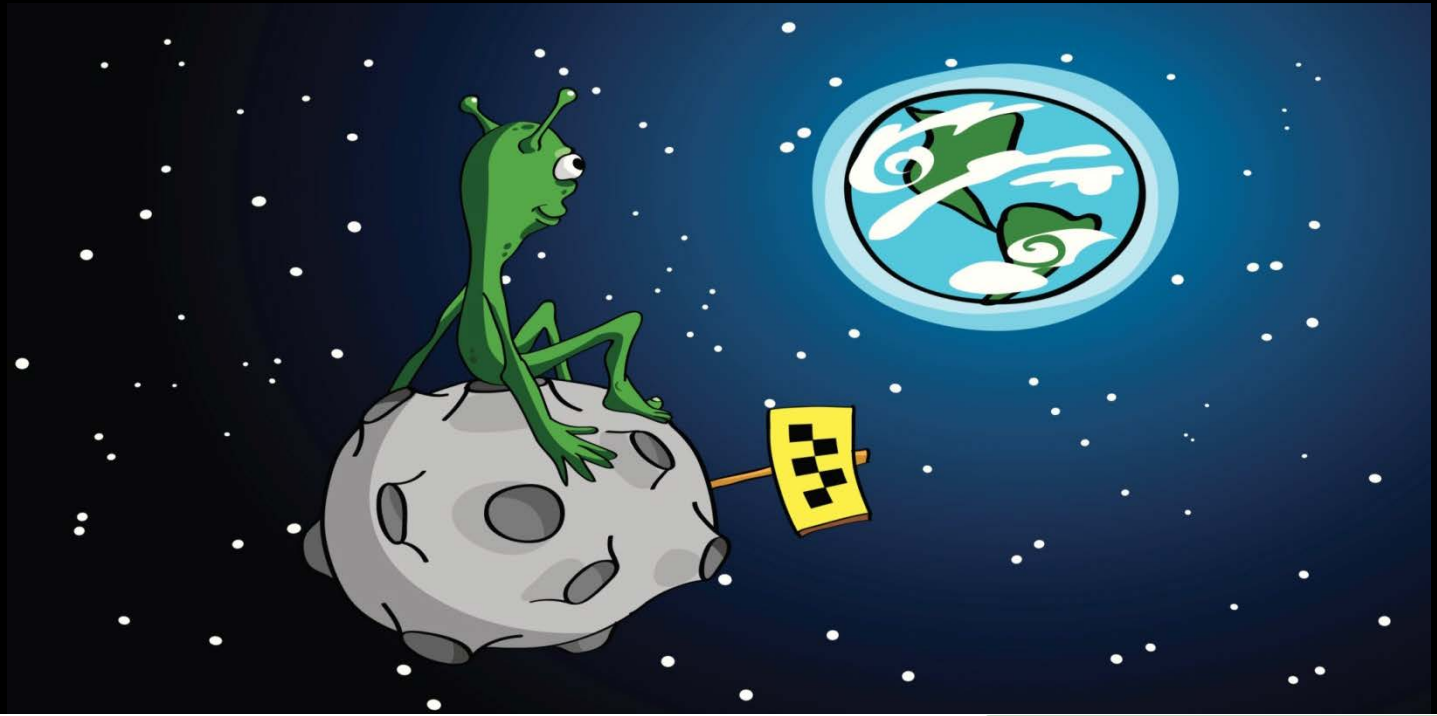
Cryovolcanism?

Ice plumes?

“Until Dawn gets a closer look over the next few months, it’s anyone’s guess what those spots could be.” – Dawn Mission Team

Astromaterials Research & Exploration Science (ARES)

Is Ceres Habitable?



Habitability is: "…extended regions of liquid water, conditions favorable for the assembly of complex organic molecules, and energy sources to sustain metabolism."

– NASA Astrobiology Roadmap, 2008

Why Ceres?

Is it normal?

Poorly understood

Carbonaceous?

Primordial Water

Meteorites?

Transport organics?

Icy World Nearby

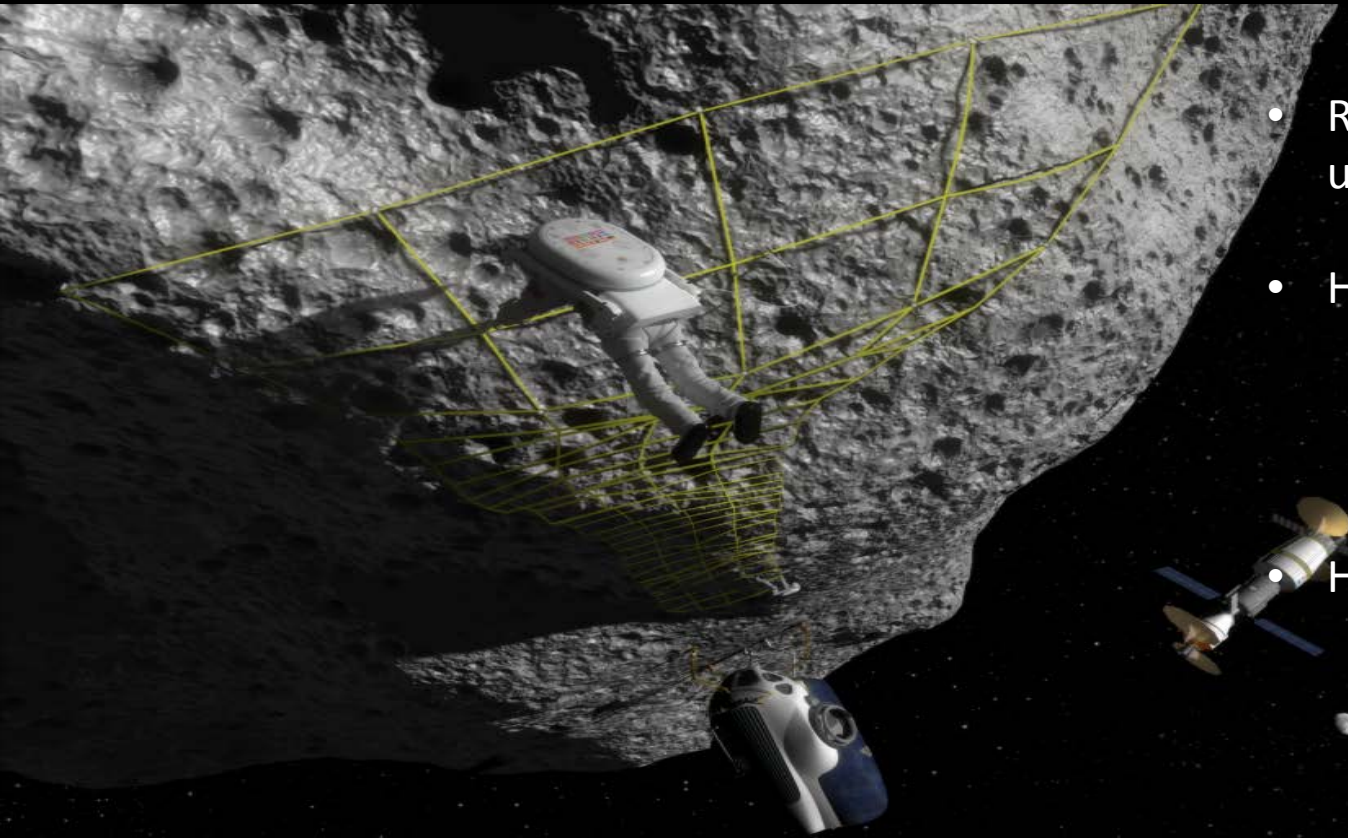
Structure?

Composition?

Low Escape Velocity

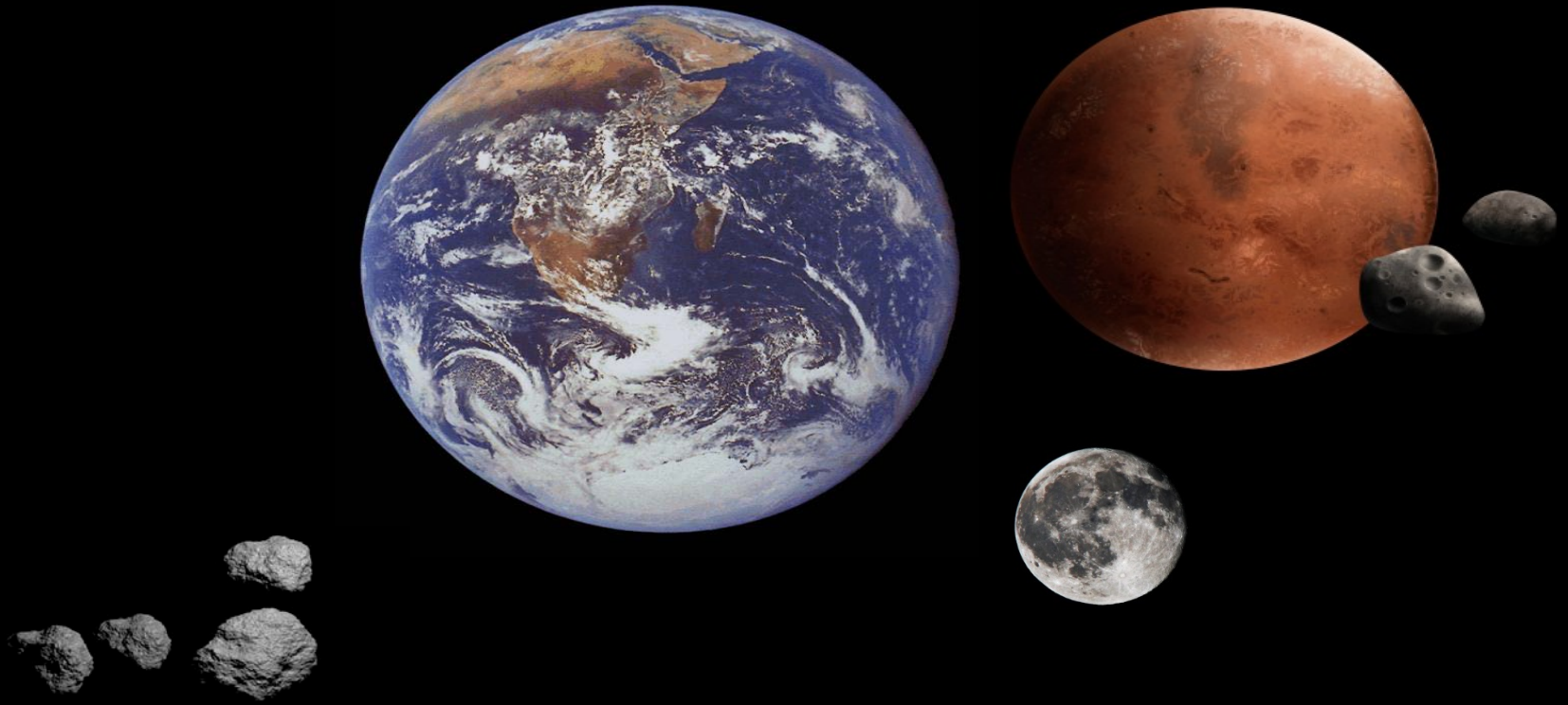
Astromaterials Research & Exploration Science (ARES)

Potential Mission to Ceres

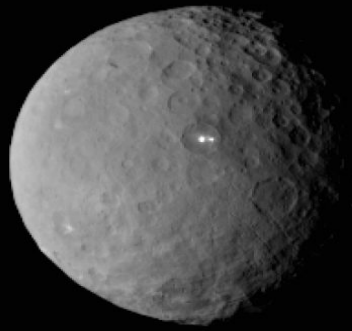


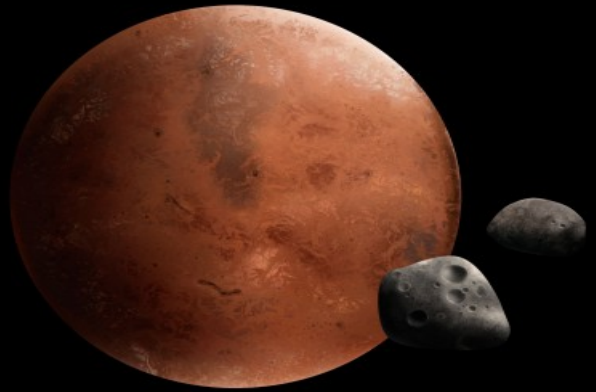
- Rover, lander, manned or unmanned, sample return
- Human Exploration Target
  - Exobiology
  - History
  - Resources
- Human/Spacecraft Friendly
  - 9 Hour Rotation
  - Not too hot!
  - Not too cold!
  - Surface Ops
  - Distance from Sun

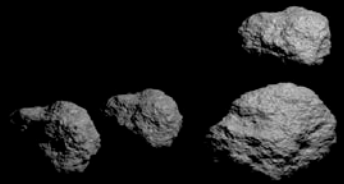
Potential Human Targets



Add Ceres to the List!
Not to Scale!

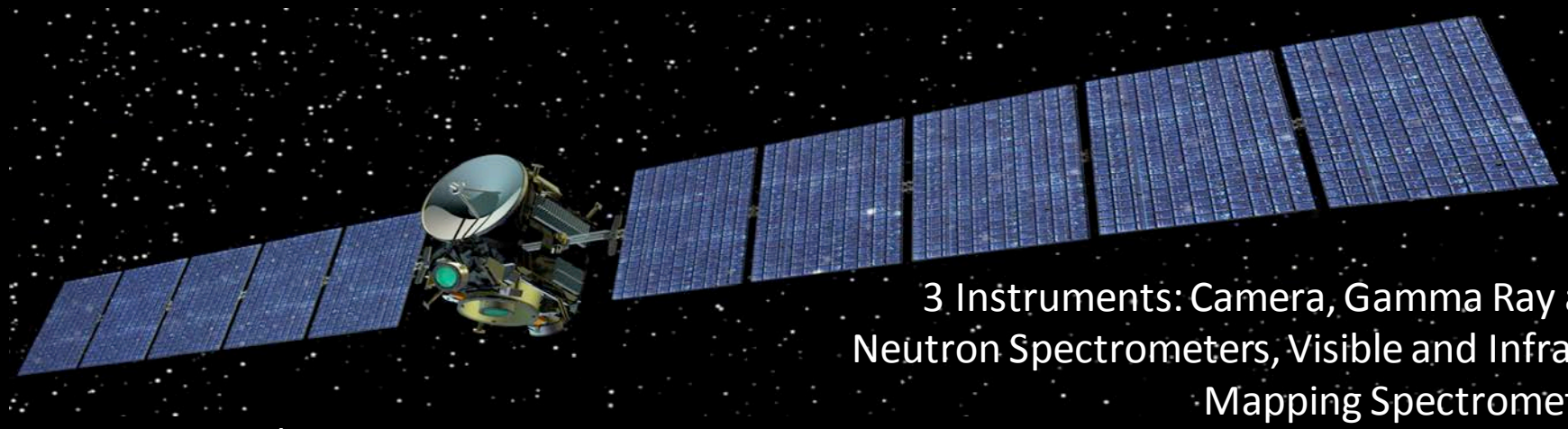






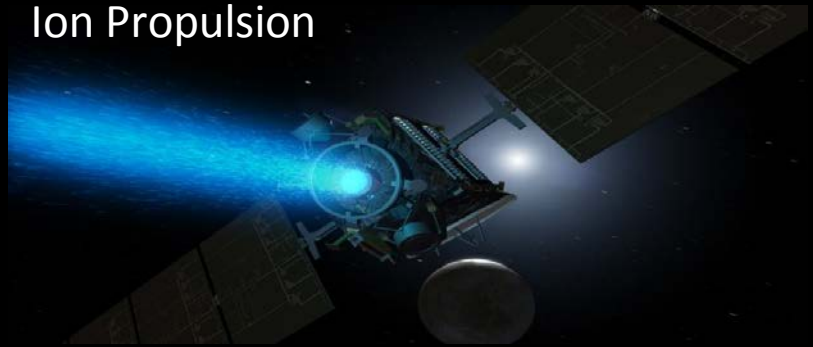
Astromaterials Research & Exploration Science (ARES)

The Dawn Spacecraft



3 Instruments: Camera, Gamma Ray and Neutron Spectrometers, Visible and Infrared Mapping Spectrometers

Ion Propulsion

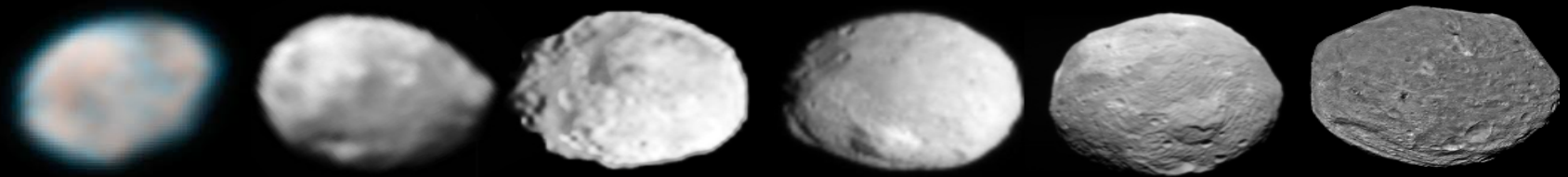


NASA's Largest Interplanetary Spacecraft

Astromaterials Research & Exploration Science (ARES)

NASA

Vesta



414,000,000 km
2007
HST

265,000 Km
June 6, 2011

152,000 Km
June 24, 2011

100,000 Km
July 1, 2011

41,000 Km
July 9, 2011

5,000 Km
July 24, 2011

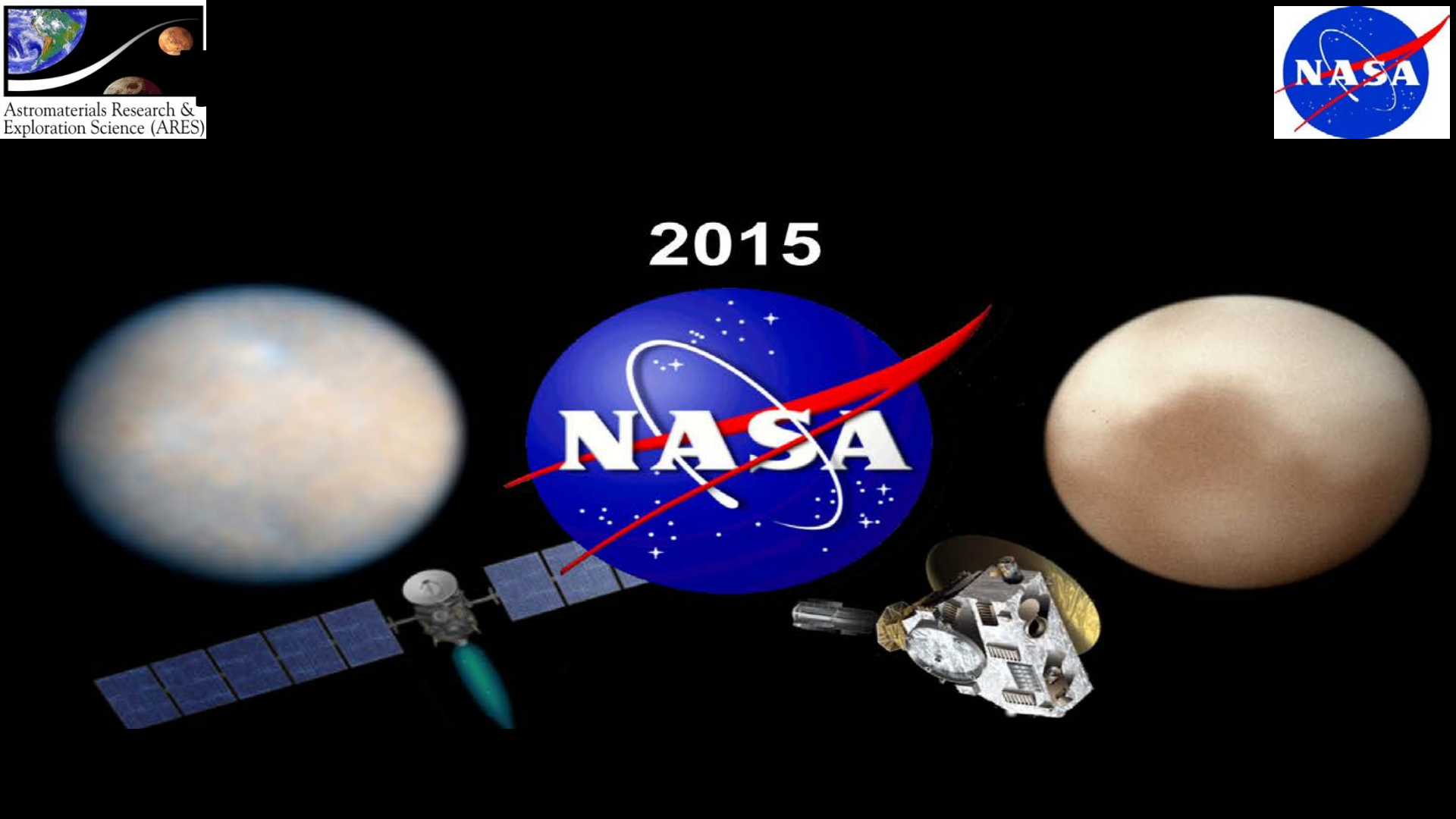
Ceres

414,000,000 Km
January 24, 2004
Hubble Space Telescope

145,000 Km
February 4, 2015

83,000 Km
February 12, 2015

46,000 Km
February 19, 2015


Astromaterials Research &
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NASA
2015
NASA

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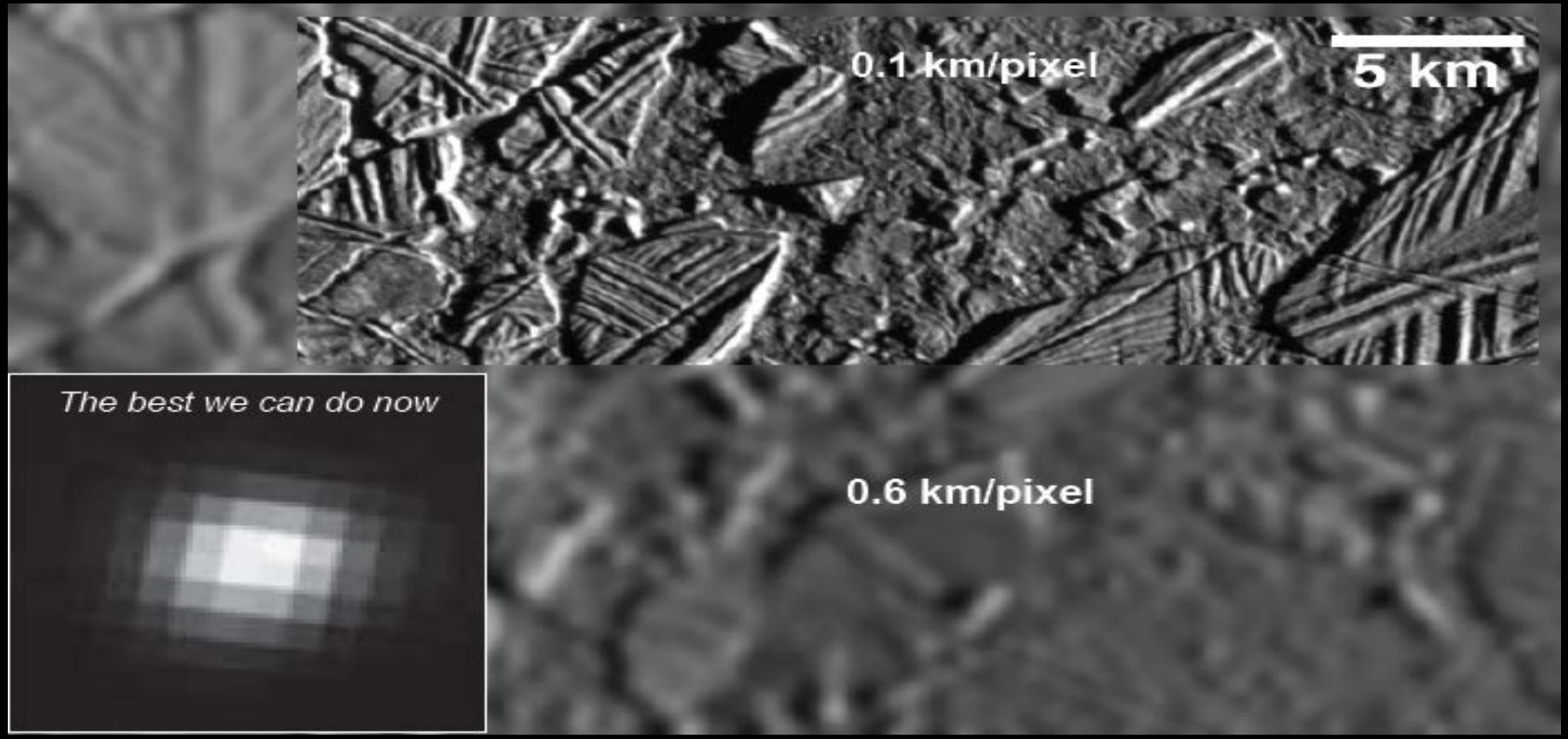
Pluto Resolution



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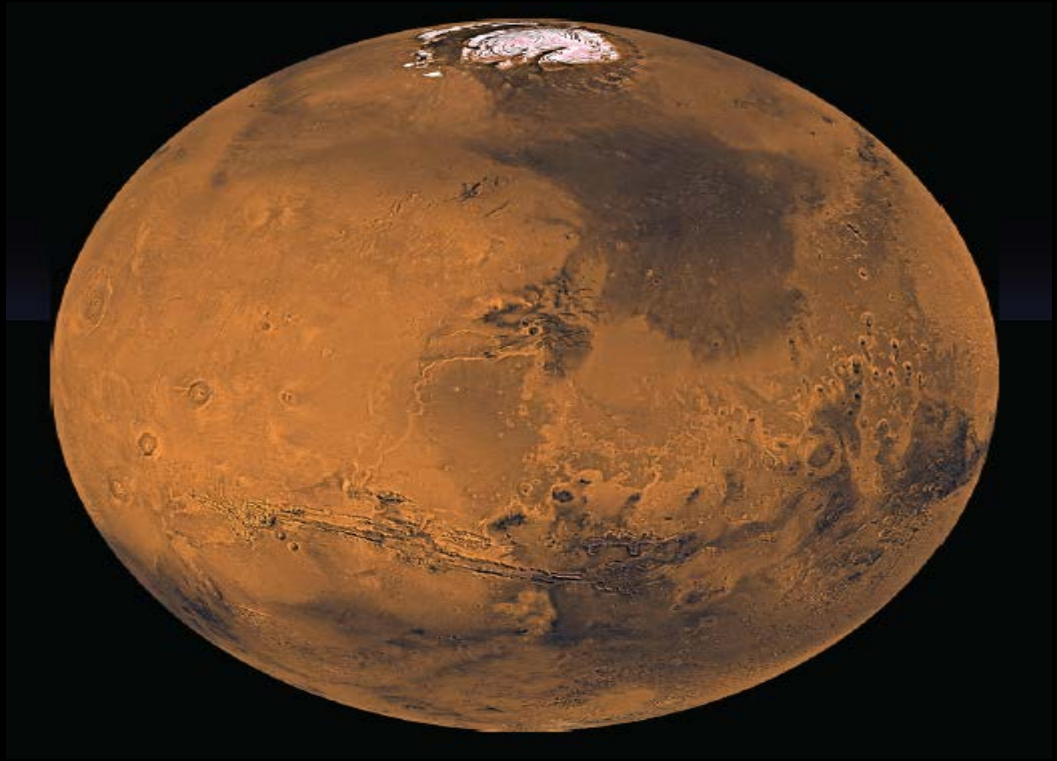

NASA

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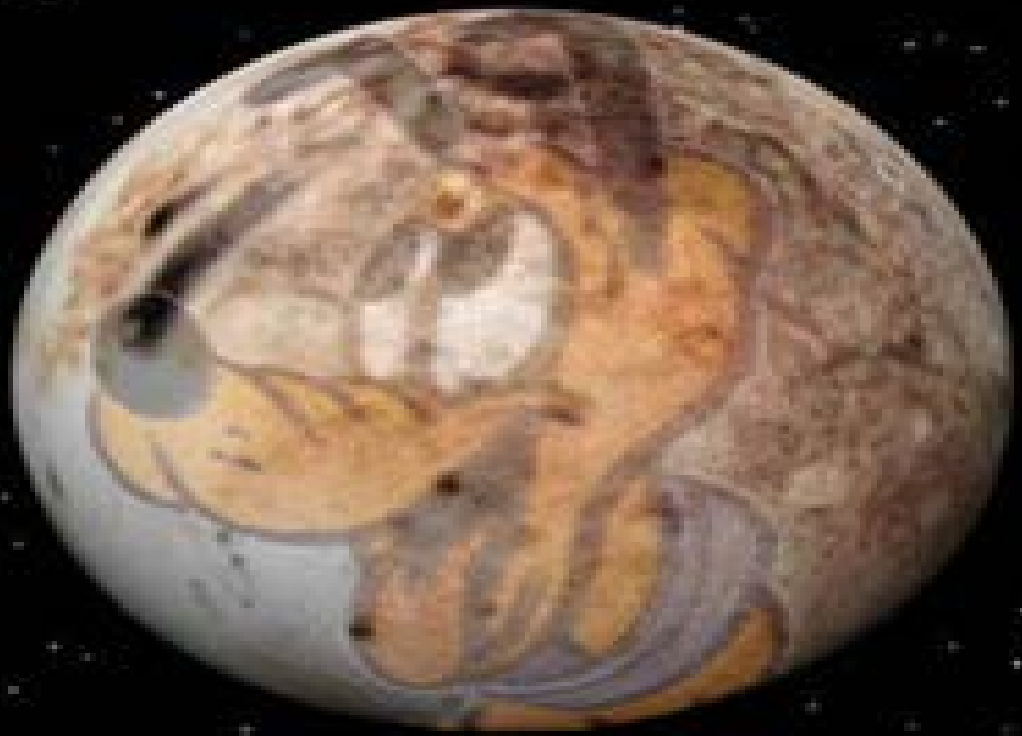
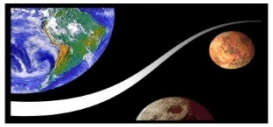


Stay Tuned…July 14th



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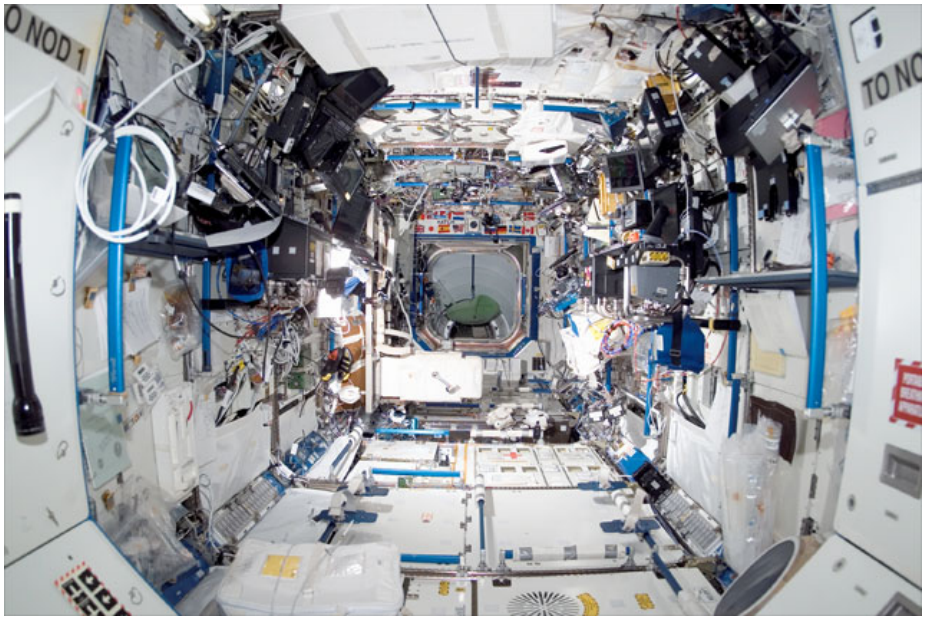
Experiments on the Space Station

International Space Station



Orbit height: 400 km Speed: 7.66 km/s 15.54 orbits/day

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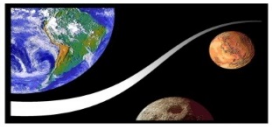
SpaceX

Sunday, June 28th, 2015



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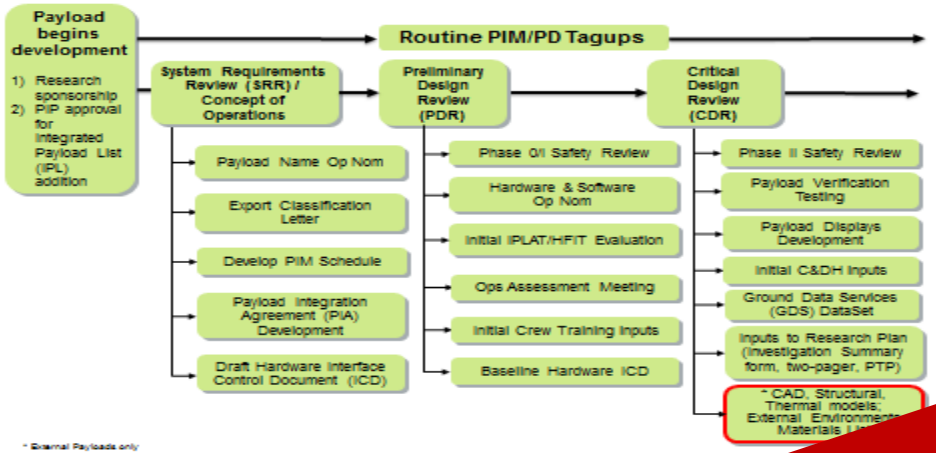
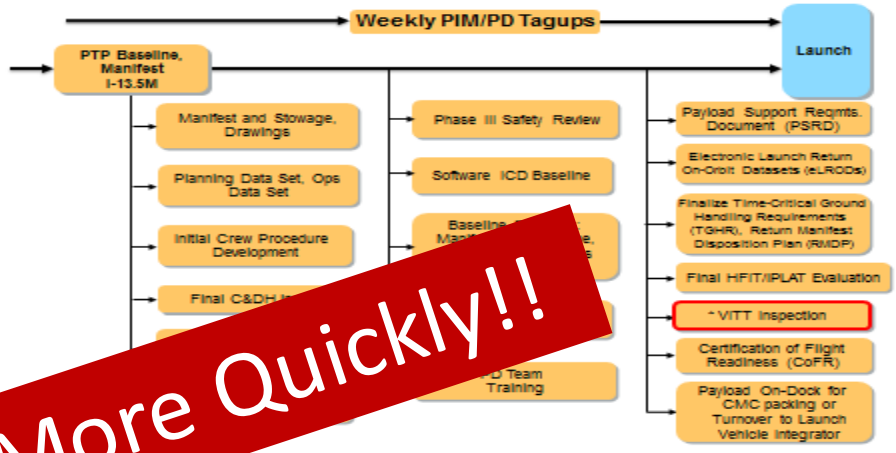
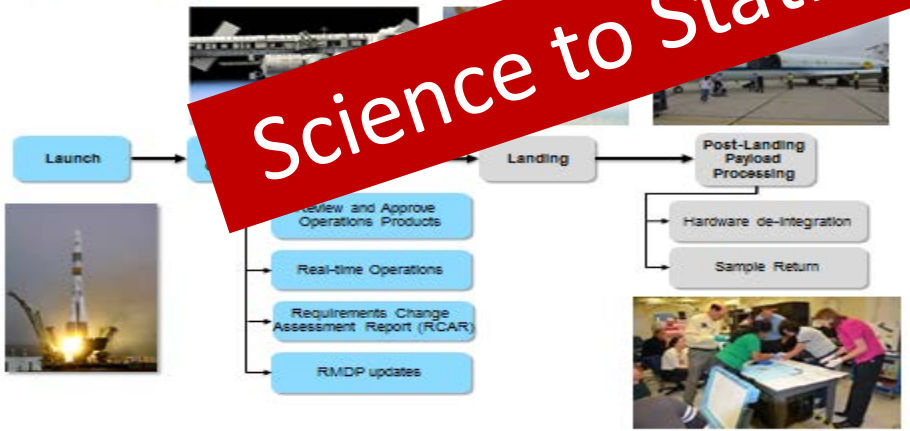
Strategic Timeframe Overview



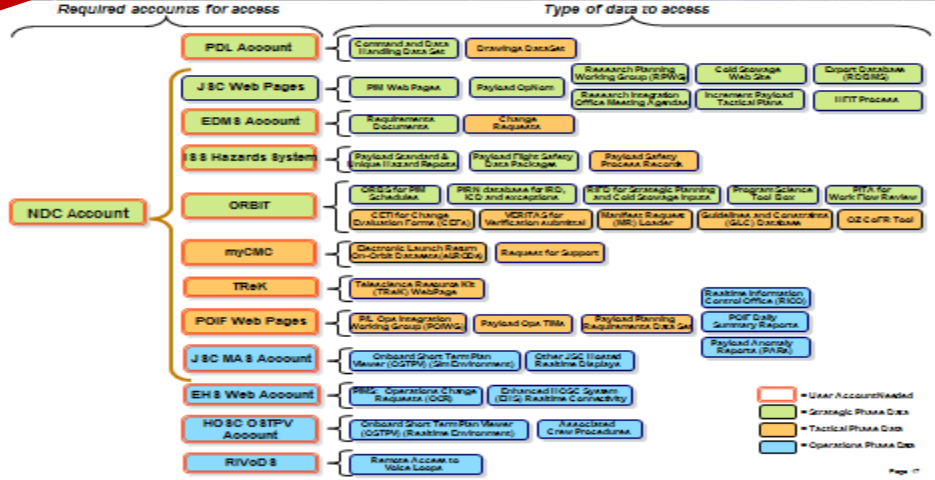
Tactical Timeframe Overview



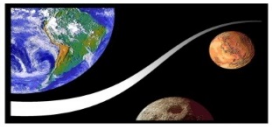
Operations Timeframe



Data Set Tools / Websites



Science to Station More Quickly!!



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DNA Sequencing in Space

Astromaterials Research & Exploration Science (ARES)

DNA Sequencing in Space

- Test a small COTS DNA sequencer in microgravity on the ISS
  - Test the basic functionality by comparing ISS sequencing results of pre-determined samples to ground results
  - Evaluate crew operability and potential for degrees of autonomy

Astromaterials Research & Exploration Science (ARES)

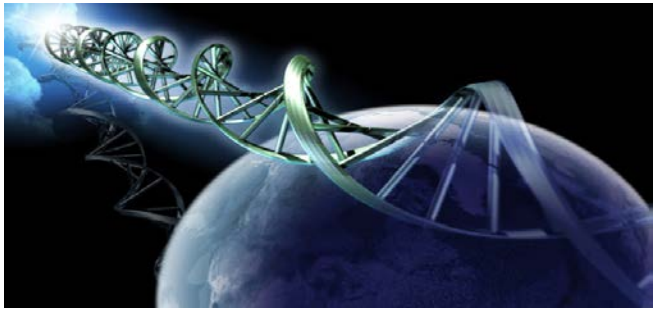
Why Sequence in Space?

- Operational environmental monitoring
- Research
- Med Ops
- Functional testing for integration into robotics for Mars exploration mission
- Microbiology capabilities on ISS

Astromaterials Research & Exploration Science (ARES)

Benefits to In-flight Sequencing

- Sequencing on the ISS can inform real-time decisions (remediation strategies, research, med ops, etc.)
- Unlike other technologies, sequencing is not limited to the detection of specific targets, but rather will provide data on the entirety of a sample
- Reduce down mass (sample return for environmental monitoring, crew health, etc.)
- Real-time analysis can influence medical intervention
- Support astrobiology science investigations
  - Technology superiorly suited to *in situ* nucleic acid-based life detection



Astromaterials Research & Exploration Science (ARES)

What are we flying?

Oxford Nanopore *MinION*

- A miniaturized, portable device for electronic single-molecule sensing
- Capable of DNA, RNA, and protein sequencing
- Will serve as the first device to assess the capability of DNA sequencing in the microgravity environment of space

Oxford NANOPORE Technologies®

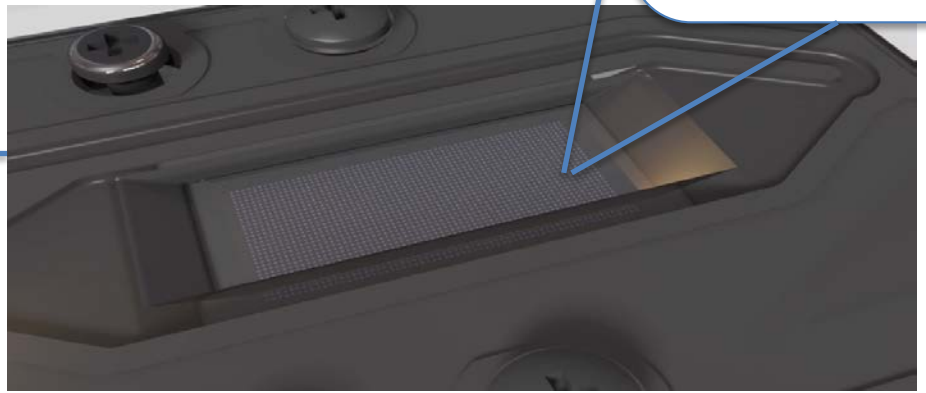
Astromaterials Research & Exploration Science (ARES)

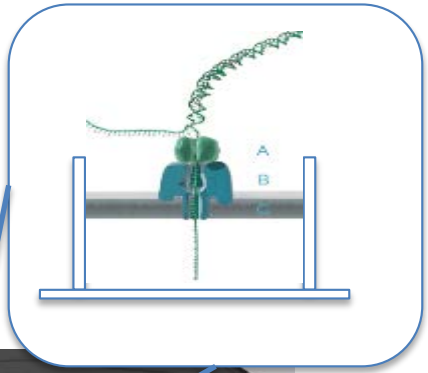
How small is small?

- Mass: 120 grams
- Dimensions: 3 ¾ x 1 ¼ x 5/8 in
- Powered by Microsoft Surface Pro3 Tablet

Nanopore Technology

- A nanopore is a nano-scale hole
- An ionic current passes through the nanopores and measures the changes in current as biological molecules pass through the nanopore
- The information about the change in current can be used to idenitfy that molecule. It can distinguish between the four standard DNA bases (G,A,T,C)





Oxford NANOPORE Technologies®

The First DNA Sequencer in Space

4. Connect MinION to laptop

5. Sample injection

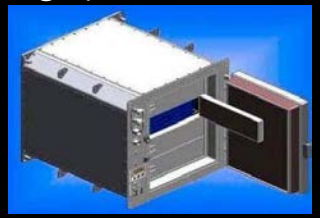
6. Dispose of dispenser

7. Close MinION

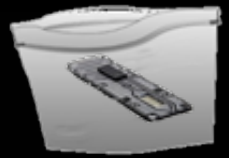
8. Data collection

3. Remove & thaw sample

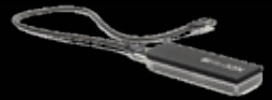
2. Stowage (Ambient, -20°C, 4°C)



9. Stow used flow cell for return

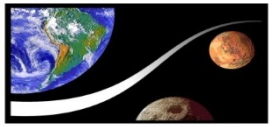


10. Stow MinION & USB cord



1. Launch packaged items

11. Return of payload



Astromaterials Research &
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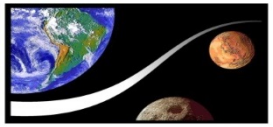
Studying Asteroids on the Space Station

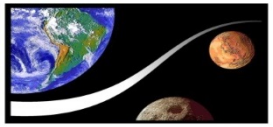


Regolith

Sure, it's a cool name.

But why should we care?

- Regolith is the fine, pulverized material on the surface of airless bodies like the Moon, asteroids, comets, etc.
- It has no biological component, otherwise we'd call it "soil"
- It is dry, with predominantly sharp-edged grains, and held together by microgravity and inter-particle forces
- In many ways, *it is like nothing found on Earth*



Regolith

- Apollo astronauts reported a “gunpowder-like” smell from lunar regolith, arising perhaps from oxidation of regolith on entry into the crew cabin
- Health hazards are uncertain
- Apollo reported degradation of sealing surfaces from regolith, and that it clung to all exposed surfaces and was very difficult to remove

Astromaterials Research & Exploration Science (ARES)

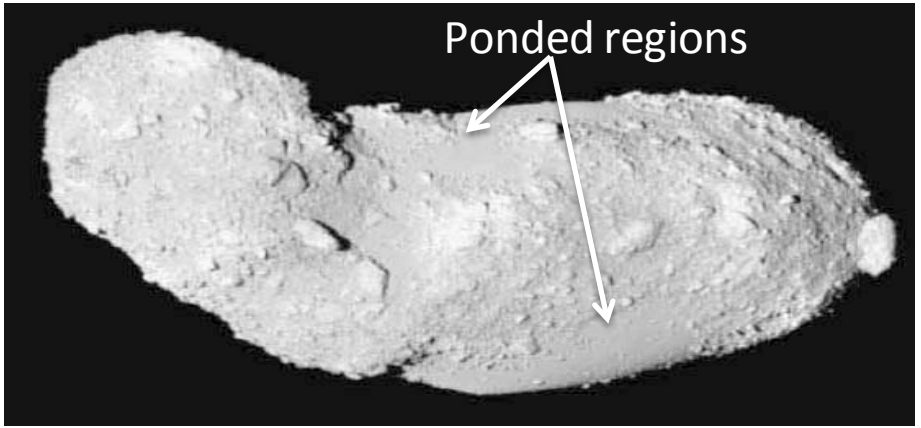
The Good, The Bad, And The Regolith

- As evidenced by the six Apollo missions that landed on the lunar surface, this regolith is anything but harmless
  - "gummed up mechanical joints"
  - "coated the radiators on the lunar rover"
  - "sneaked into oxygen-hose connections"
  - "snagged zippers, clotted Velcro fasteners, and scratched helmet visors and camera lenses"
  - wore away the outer layer of astronauts' spacesuits, and penetrated seals around helmets and gloves, causing oxygen leaks
- For future exploration missions, both robotic and crewed, many subsystems will be vulnerable
  - instruments, spacesuits, airlocks, vehicles, hardware, robotics, and the crew will all be susceptible

Astromaterials Research & Exploration Science (ARES)

Regolith

- We know even less about the mechanical properties and behavior of regolith
  - *How do you set an anchor in regolith?*
  - *Why do some asteroids and comets have "ponded" regions and what are they?*
  - *How does the regolith compare to the bulk asteroid/comet composition?*
  - *What are the hardness, size distribution, and other physical properties of regolith?*



Asteroid Itokawa

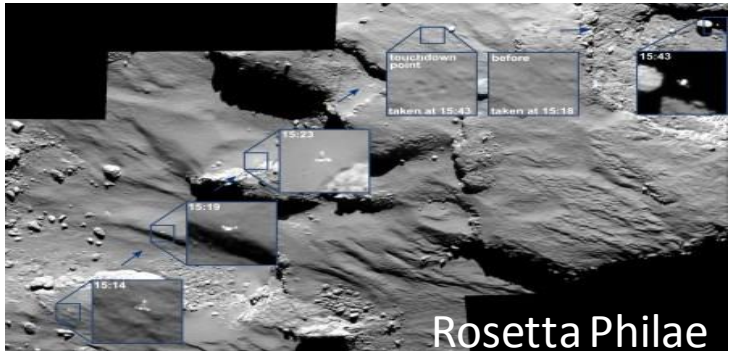
Strata-1: An Experiment

Because You'd Sure Better Understand Regolith Before You Have to Cling to It

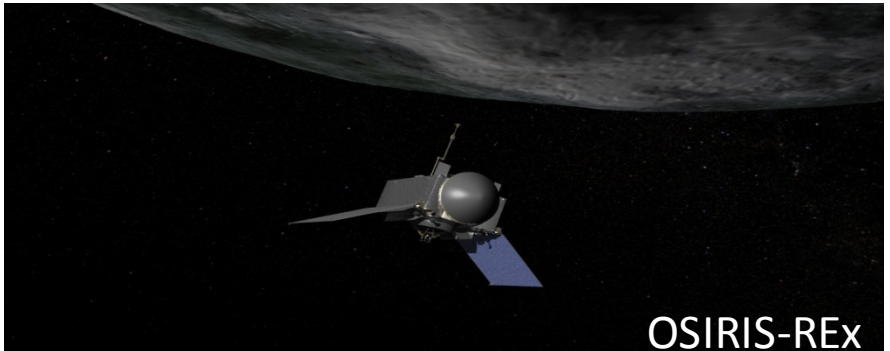
Astromaterials Research & Exploration Science (ARES)

Strata-1
Purpose & Objectives

- Strata-1's mission objective is to develop an initial experimental facility designed to investigate the fundamental properties of regolith on small, airless bodies.
- Strata will provide answers about how regolith behaves in microgravity; provide fundamental data on developing models to determine how easy or difficult it is to anchor a spacecraft in regolith, how it interacts with spacecraft and spacesuit materials, and other important properties.



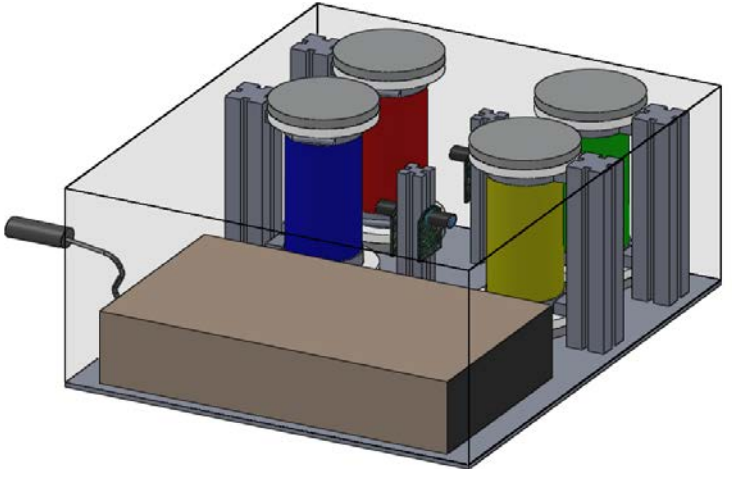
Rosetta Philae

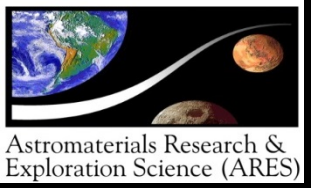

OSIRIS-REx

Astromaterials Research & Exploration Science (ARES)

Strata-1
Purpose & Objectives

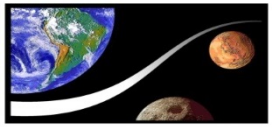
- The Strata-1 facility will feature four transparent tubes that are partially filled with regolith simulants which are exposed to extended microgravity and the ambient vibration environment on ISS.
- Strata-1 will image the movement of the simulants in the tube in a “time-lapse” fashion
- Strata-1 launch and landing will have “restrained” simulants
- Strata-1 is completely passive





Strata-1 Science Questions

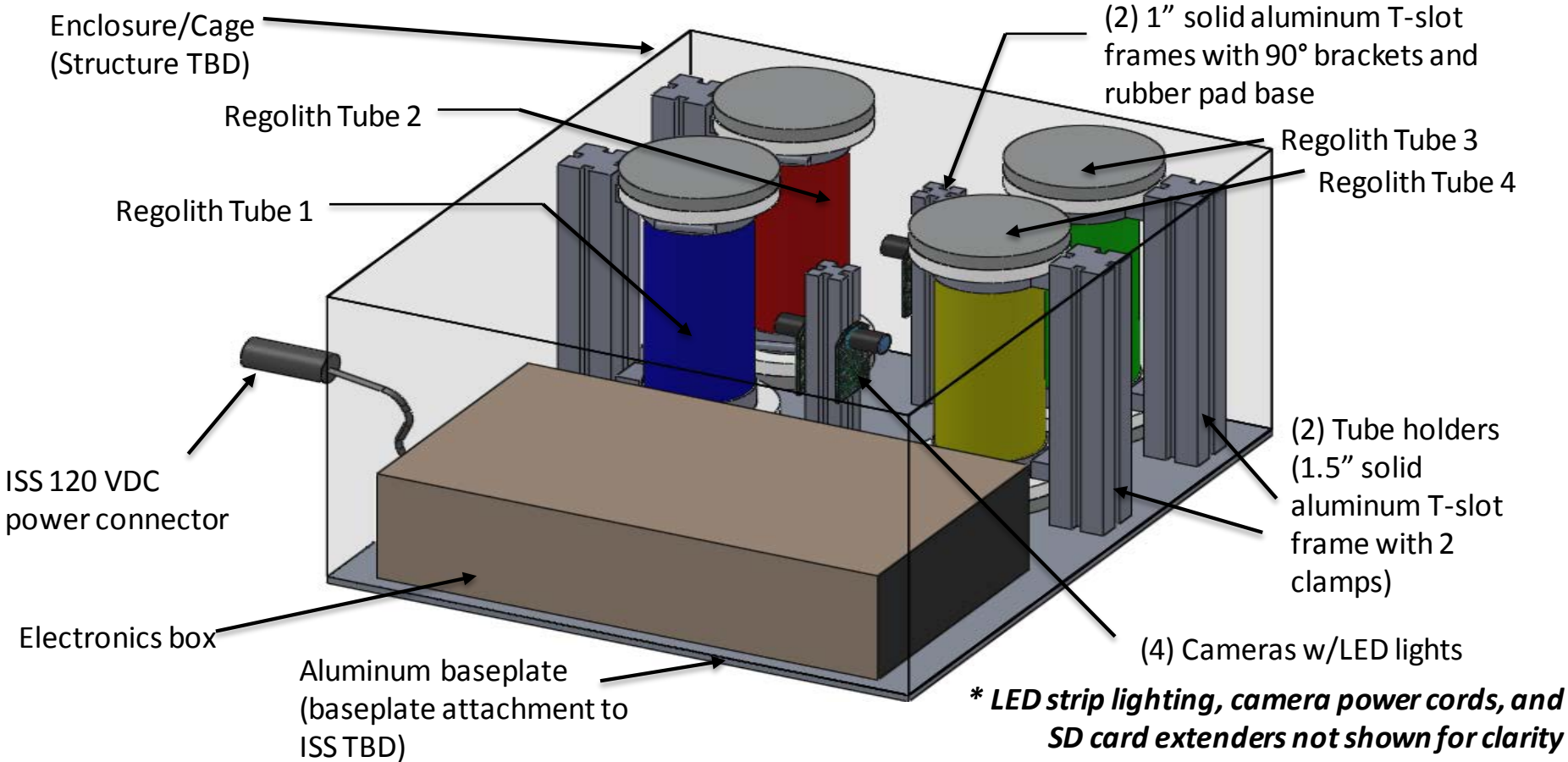
- Science Questions:
  - *How does regolith evolve under extended microgravity and ambient vibration?*
    - *We will use Strata results to refine models of regolith evolution, to record compositional and size gradients in the evolved material, and will apply findings to observations of comets and asteroids NASA has visited and will visit in the future*
  - *What roles do particle density, particle shape, and particle composition play in the evolution of regolith?*
    - *We will use Strata results to refine our understanding of airless body evolution*
    - *We will apply Strata results to interpret sample return mission findings from samples to whole-body composition*



Tube Contents

	Material	Max Quantity	Description	Manufacturer
Material 1: Meteorite	olivine (~40%), pyroxene (~35%), Fe-Ni metal (~15%) , Trolite (FeS) (~5%), Feldspar (~5%)	~4.2 kg	This will be an ordinary L-chondrite meteorite.	The Solar System
Material 2: Regolith Simulant	smectite or serpentine clay (37.7%), kerogen (1.1%), magnetite (24.3%), pyrrhotite (7.2%), and olivine (29.7%)	~4.2 kg	This is a simulant representing a carbonaceous chondrite meteorite.	University of Central Florida - Dan Britt
Material 3: Glass Beads	silica glass beads, rounded (100%)	~2.9 kg		TBD
Material 4: Glass Fragments	silica glass, fragmented (100%)	~2.9 kg		TBD

Volume: 16.25” x 19.25” x 11.00”
Mass: 30 kg

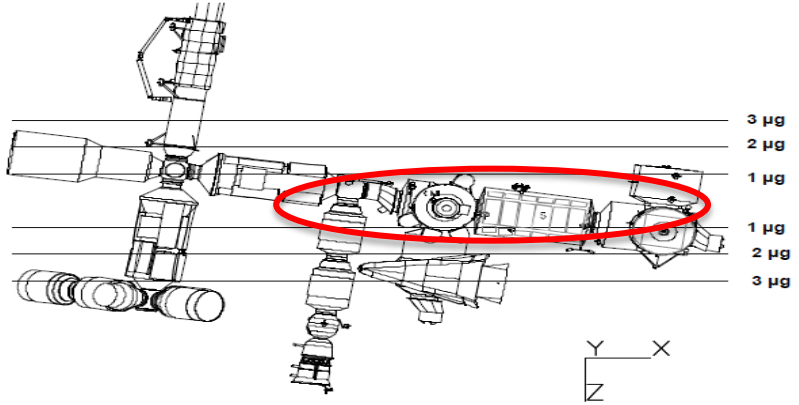


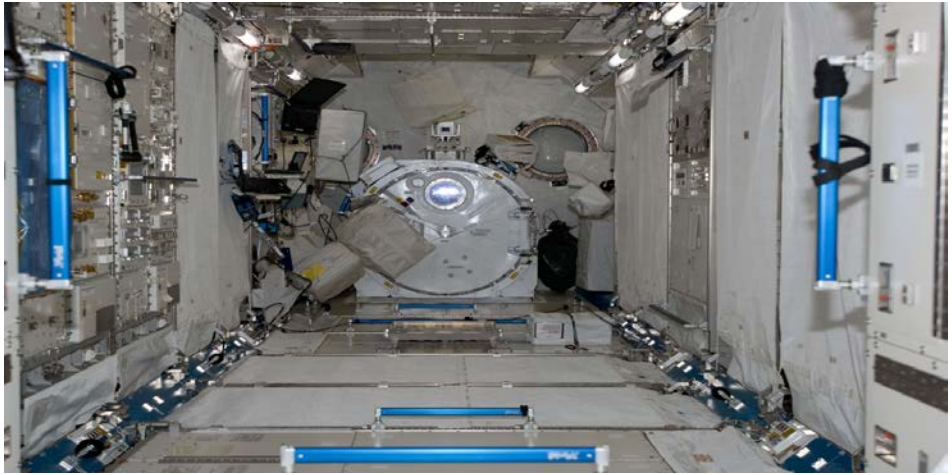
**** LED strip lighting, camera power cords, and SD card extenders not shown for clarity***

Astromaterials Research & Exploration Science (ARES)

“Best” Micro-g environment

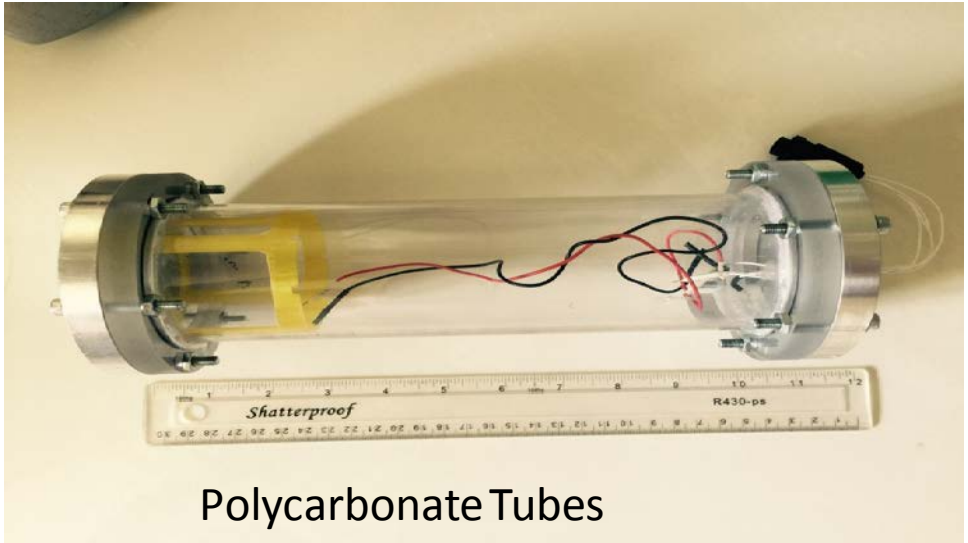
- Location: TBD
- i.e. closest to 1x10E-6 g ellipsoid if at all possible
- Accelerometer package





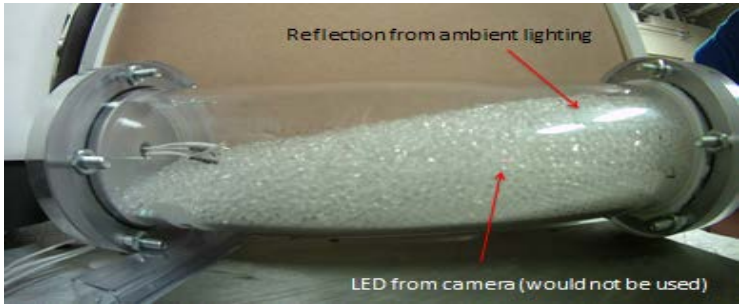
Astromaterials Research & Exploration Science (ARES)

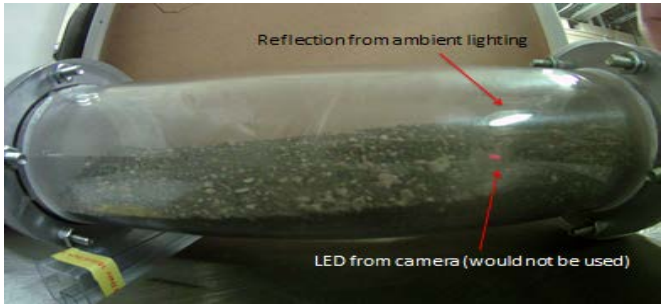
Tubes & Cameras



Polycarbonate Tubes

HackHD 1080p high definition circuit board-mounted cameras

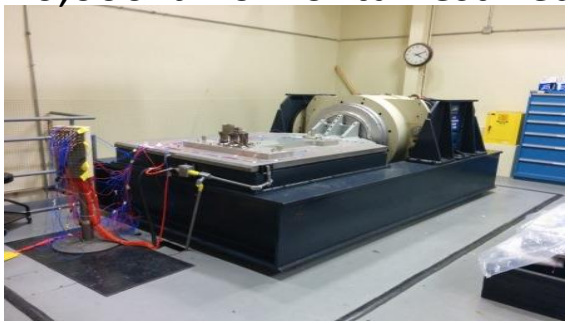




Astromaterials Research & Exploration Science (ARES)

Vibration/Structural Testing

20,000 lb Horizontal Test Bed

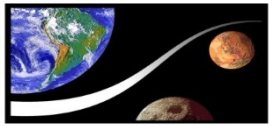


40,000 lb Horizontal Test Bed

- Testing Date: Aug/Sept. (TBD)

40,000 lb Vertical Test Bed

Perform a wide range of vibration tests in all axes to evaluate structural dynamic properties



Potential Future *Strata-X* Science Questions

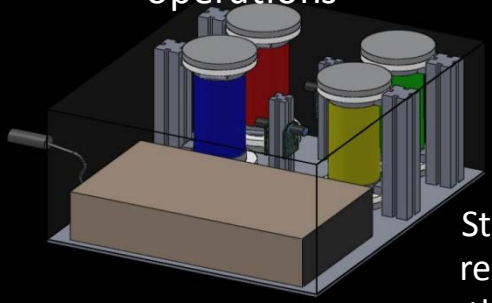
- Tests of anchors
- Tests of space suit and spacecraft materials to regolith exposure
  - quantify adhesion of silicate and carbonaceous regolith to spacesuit and spaceflight hardware
- Dynamical observations of small amounts of free-floating material to understand inter-particle interactions
- Dynamical observations to study evolution of collisions between small particles (i.e. planet formation)
- Cohesion properties of diffuse regolith
- Actively agitated sample tubes to understand regolith evolution after shock events
- Active components in sample tubes (i.e. launch mechanism) to study impacts, collisions
- Tests of sample collection techniques
- Specific examination of the “Brazil nut effect” (BNE) in regolith
  - BNE is the propensity of larger particles to migrate to a regolith surface
- And others, to include refinements based on Strata-1 results

Strata-1

Regolith in Microgravity

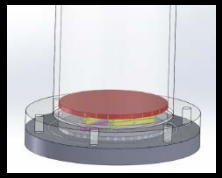
3. Initial crew service

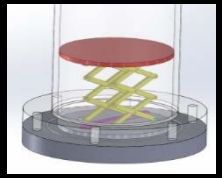
4. Strata-1 autonomous operations



5. Memory card changeout

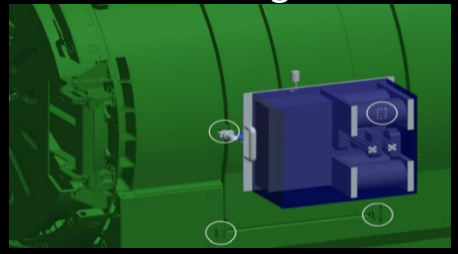
6. Uninstall Strata-1



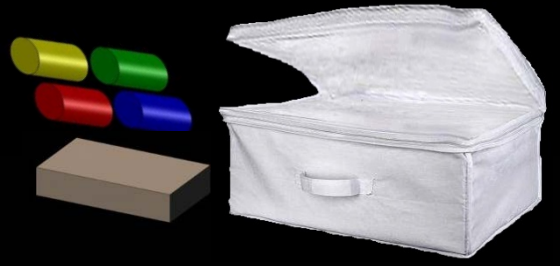


Steps 4 & 5 are repeated every three months.

2. Install in designated location



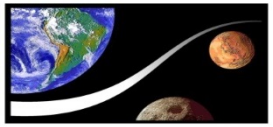
7. Stow hardware for return



1. Launch Strata-1 assembly

8. Dispose of other hardware

9. Return Strata-1 hardware



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Analog Missions

Astromaterials Research & Exploration Science (ARES)

NEEMO-20

- NASA Extreme Environment Mission Operations (NEEMO)
- 14-day underwater mission
  - Evaluate tools and techniques for future spacewalks
  - Variety of surfaces and gravity levels
  - Asteroids, Moons of Mars, Mars
  - Communication time delays
- 4-person international crew
- Habitat is 62 feet below the surface of the Atlantic Ocean (Key Largo, Florida)
- http://www.nasa.gov/neemo

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HERA

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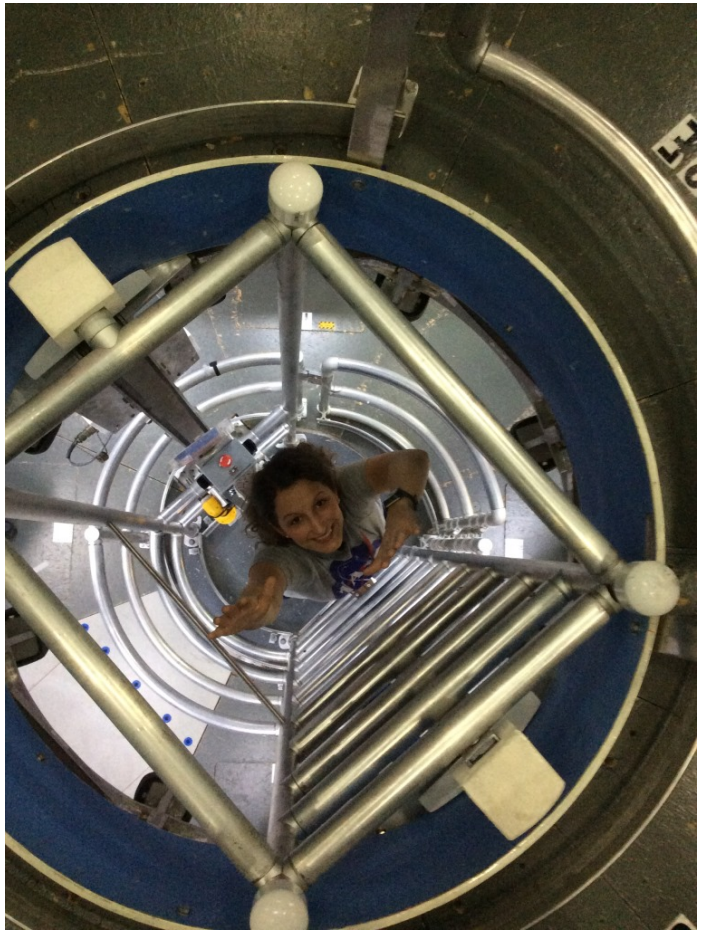
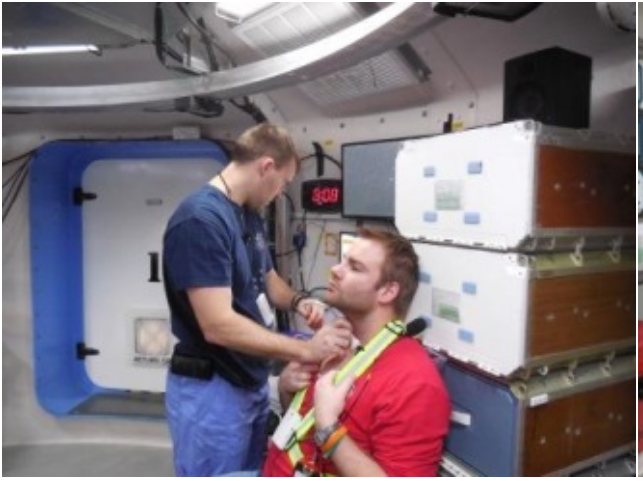
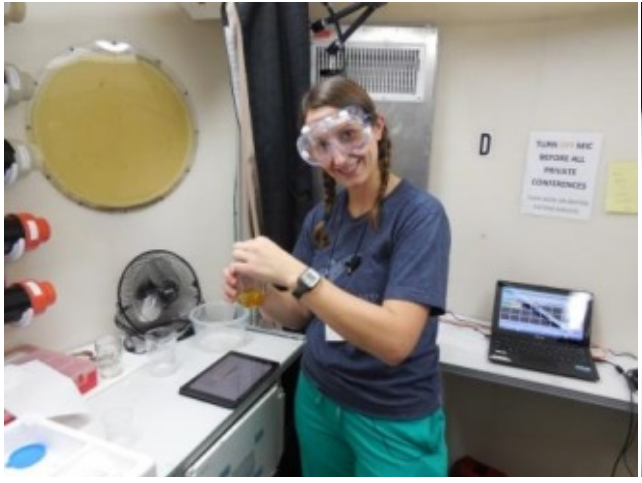





TEXAS
ROCKET
SCIENCE


NASA


D
TURN OFF MIC
BEFORE ALL
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CONFERENCES

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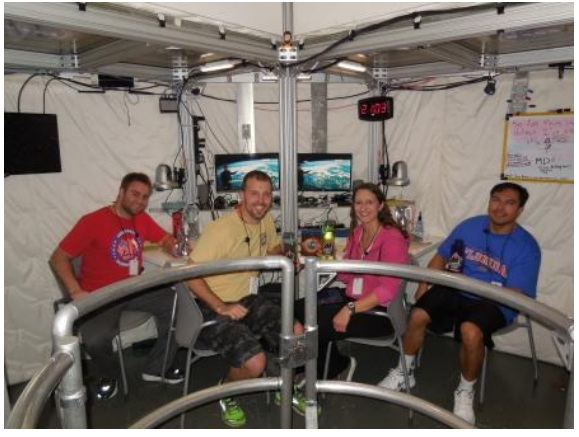
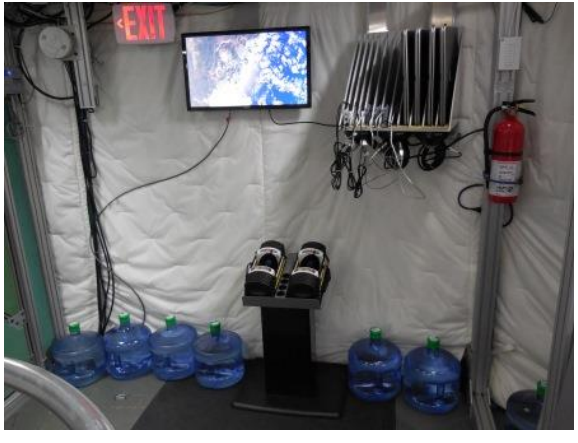
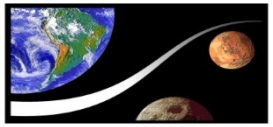
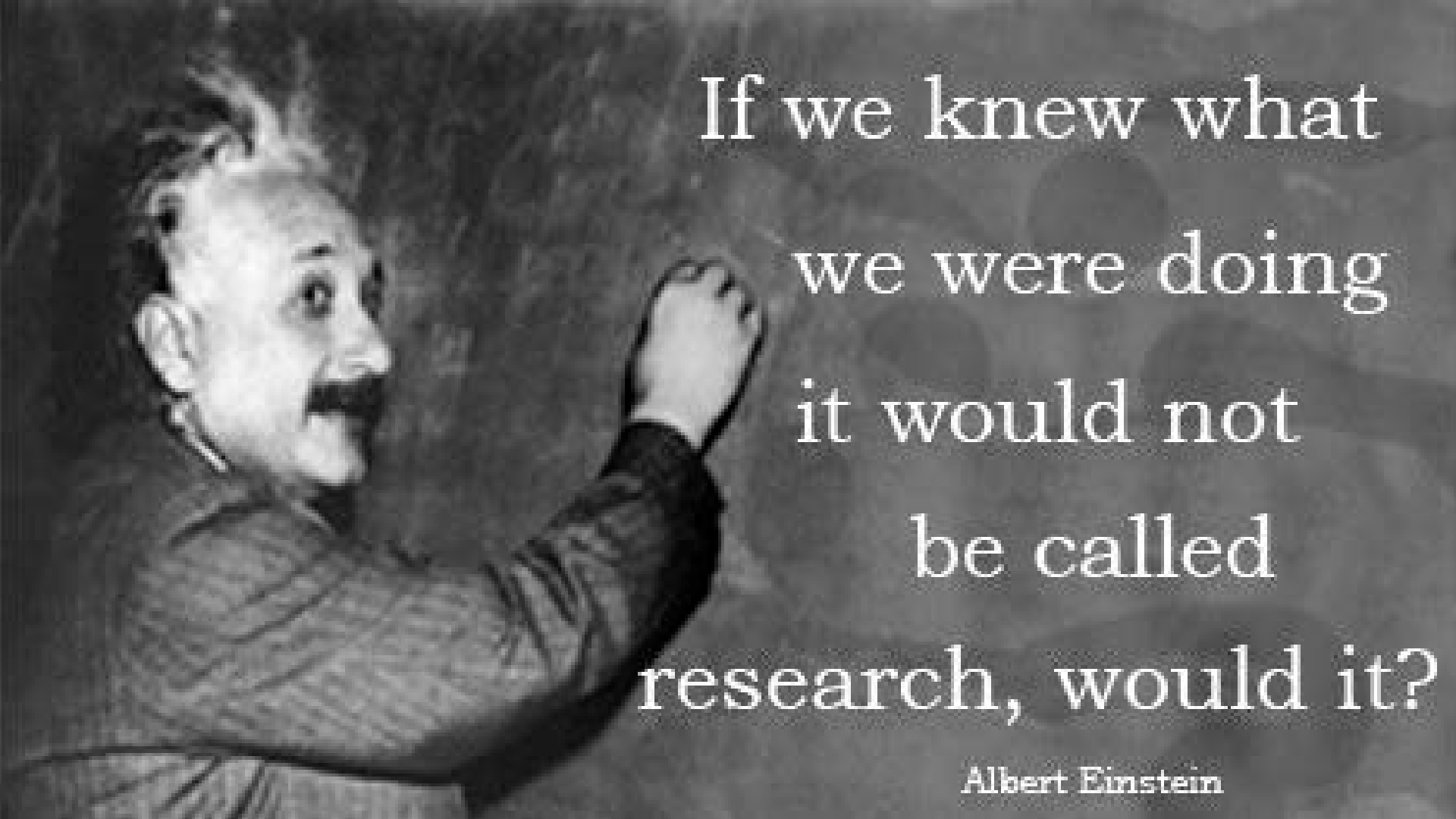






HERA Tour

- Play PAO Video


If we knew what
we were doing
it would not
be called
research, would it?
Albert Einstein

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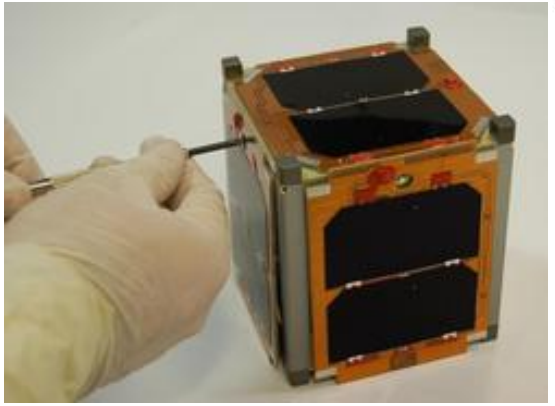
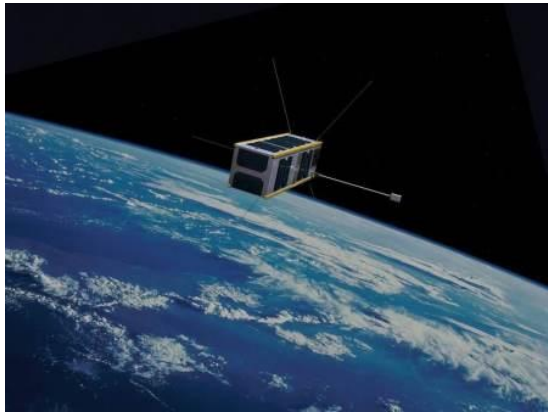
Mission Concept Development

- Brainstorming Meetings
- Exploration Meetings
- CubeSats
- L4/L5 Trojan Search



1U = 10 cm x 10 cm x 10 cm



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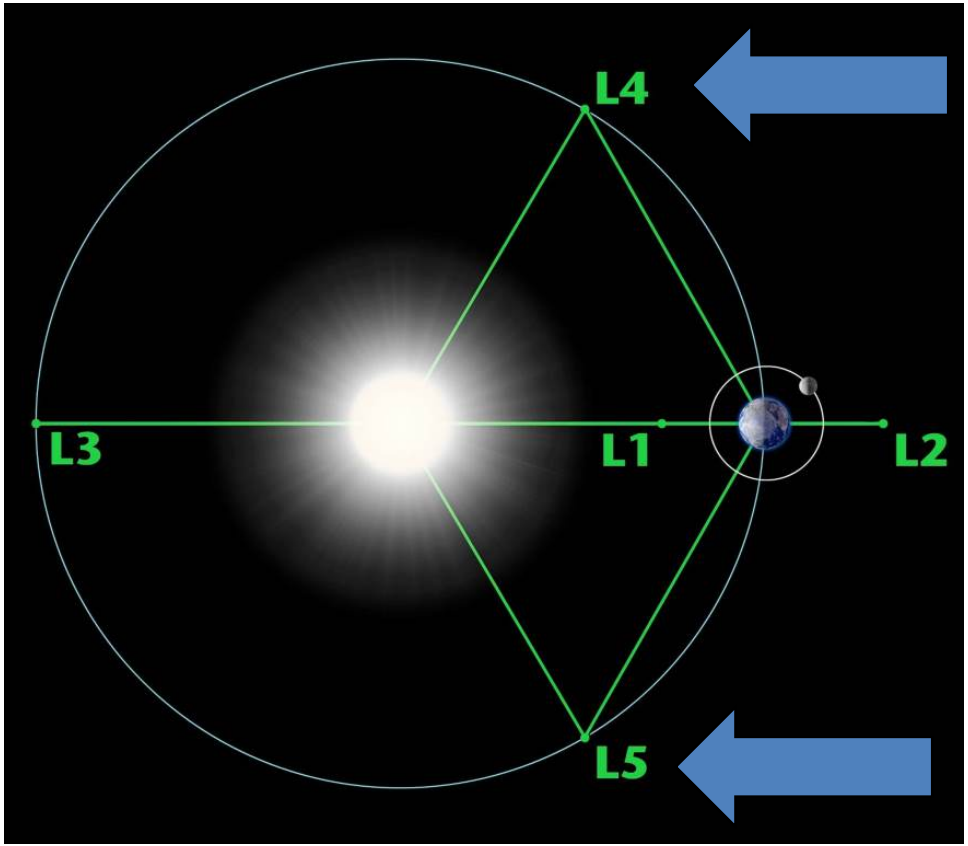
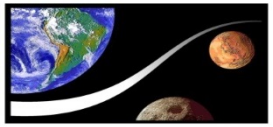
Investigating Trojan Asteroids at the L4/L5 Sun-Earth Lagrange Points

- The presence of objects in the Sun-Earth L4 and L5 Lagrange points has long been suspected, and in 2010 NASA's Wide-field Infrared Survey Explorer (WISE) detected a 300 m object [1]. To investigate these Earth Trojan asteroid objects, it is both essential and feasible to send spacecraft to these regions
- A Trojan asteroid shares an orbit with a planet or large moon, and orbits around one of the two stable Lagrange points.
- Trojan asteroids do not collide with the co-orbiting object because they lie 60° ahead of (L4) or behind (L5) the larger body's orbit.





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Asteroid Science Instruments

Asteroid Science	Associated Instrumentation
Global properties: mass, shape, density, rotation, porosity	Radioscience measurements, LIDAR, imagers, spectrometers
Presence of volatiles	Spectrometers, hyperspectral imagers, micro-GPR (ground penetrating radar)
Local magnetic field detection	Micro-magnetometer
Interior and surface structure	Passive/active seismic measurements, radar
Topography	Imagers, optical cameras, LIDAR, radar
Mineralogical composition	Visible, near-IR, x-ray, gamma-ray spectrometer; hyperspectral imagers
Radiation characterization	Dosimeter
Temperature, thermal inertia	Hyperspectral imager, RFID surface acoustic wave (SAW) sensors, thermal infrared (TIR) detector
Surface roughness	Hyperspectral imager, LIDAR
Dust environment characterization	Imagers, optical camera, Langmuir Probe, active & passive sensors
Surface mobility: granular flow, regolith movement, particle levitation	Imagers, optical camera, RFID SAW sensors
Particle size distribution	Micro-imagers
Particle properties: structure, texture, shape, thickness	Visible imager
Cohesion, friability, surface strength, compaction	Penetrometer, imagers, load cell, physical interaction tool
Mechanical properties of surface: compressive strength, tensile strength, shear strength, toughness, hardness	Penetrometers, gages, specialized tests
Albedo of particles	Imagers, optical camera, IR detector
Subsurface environment characterization: voids, clumps, mass concentrations, temperature, thermal inertia	Penetrometers, micro-GPR, thermocouples

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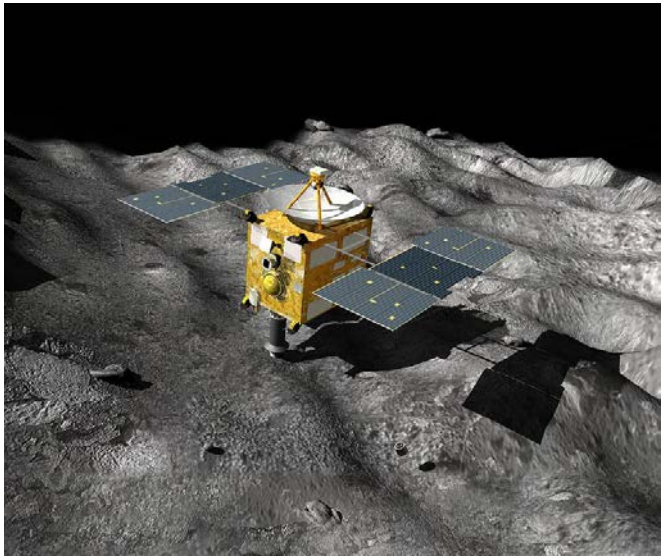
Visiting Asteroids

- Only 2 asteroid missions have visited the surface
- Fly-by missions have observed asteroids remotely:
  - Galileo spacecraft (asteroids Gaspra and Ida)
  - Rosetta (asteroids Steins and Lutetia)
  - NEAR (asteroid Mathilde)
  - Stardust, Chang'e 2, Deep Space 1, Vega 2, Deep Impact
- Ground observations, rendezvouses, and fly-bys
  - rotation rates, asteroid taxonomic class, general composition, shape, and size.
- Surface investigations
  - internal structure, detailed composition, surface topography, collisional history, particle size distribution, particle behavior, mechanical properties of the regolith
- Why Asteroids?
  - Asteroids are of scientific interest largely because of the information they will provide about the origins of the Solar System. Additionally, asteroids provide an exploration interest due to the low delta-V required to visit them and because of their presumed high volatile content that could provide possibilities for in-situ resource utilization



2001	**NEAR**	**Eros**
2005	**Hayabusa**	**Itokawa**
2011-2015	**Dawn**	**Vesta & Ceres**
2014	**Rosetta**	**Comet 67P/CG**
2018	**Hayabusa-2**	**1999 JU3**
2018	**OSIRIS-REx**	**Bennu**

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Strength of Meteorites

- Why?
  - More realistic modeling of impacts involving meteoroids and their parent bodies
  - Improving calculations of meteoroid entry into the atmosphere
  - Understanding the properties of asteroids visited by spacecraft
  - Critical in developing adequate models for understanding the mechanical behavior of meteorites and asteroids
- What?
  - Characterize strength of meteorites over a range of loading conditions that represent various processes in the Solar System
  - Perform compressive and tensile strength tests on an LL5 chondrite
  - Create a platform for expanding the limited data on strength of ordinary and carbonaceous chondrites
  - Quasi-statics tests, then dynamic tests
  - Ordinary chondrites, then carbonaceous chondrites

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Questions?

- Thanks to DOE NNSA SSGF for a wonderful opportunity!