Destination Dwarf Planets: A Panel Discussion

OPAG, August 2019

Convened: Orkan Umurhan (SETI/NASA-ARC)
Co-Panelists:
Walt Harris (LPL, UA)
Kathleen Mandt (JHUAPL)
Alan Stern (SWRI)

Dwarf Planets/KBO: a rogues gallery

Unifying Story for these bodies awaits

Name	Diameter (km)	Perihelion/ Aphelion /Current Distance (AU)	Surface characteristics	Other observations/ hypotheses	Moons
Eris	~2326	P=38 A=98 C=96	Appears almost white, albedo of 0.96, higher than any other large Solar System body except Enceledus. Methane ice appears to be quite evenly spread over the surface	Largest KBO by mass second by size. Models of internal radioactive decay indicate that a subsurface water ocean may be stable	Dysnomia
Haumea	~1600	P=35 A=51 C=51	Displays a white surface with an albedo of 0.6-0.8 , and a large, dark red area . Surface shows the presence of crystalline water ice (66%-80%) , but no methane, and may have undergone resurfacing in the last 10 Myr. Hydrogen cyanide, phyllosilicate clays, and inorganic cyanide salts may be present , but organics are no more than 8%	Is a triaxial ellipsoid, with its major axis twice as long as the minor. Rapid rotation (~4 hrs), high density, and high albedo may be the result of a giant collision. Has the only ring system known for a TNO.	Hi'iaka and Namaka
2007 OR_{10}	~1535	P=33 A=101 C=87	Amongst the reddest objects known, perhaps due to the abundant presence of methane frosts (tholins?) across the surface.Surface also show the presence of water ice.	May retain a thin methane atmosphere	S/(225088) 1
Makemake	~1427	P=39 A=53 C=52	Methane, ethane, tholins, and possibly nitrogen present on the surface. Smaller amounts of ethylene, acetylene, and high-mass alkanes (like propane) may be present. Appears red in the visible spectrum. Some nitrogen present, but much less than on Pluto or Triton.	May have an atmosphere up to 4-12 nanobar at surface. May have N_2 convecting layer.	MK 2

(Taken from OPAG Goals Document 09.2018)

Name	Diameter (km)	Perihelion/ Aphelion /Current Distance (AU)	Surface characteristics	Other observations/ hypotheses	Moons
Quaoar	~1092	P=42 A=45 C=42	Surface is moderately red, and albedo may be as low as 0.1, maybe indicating that fresh ice has disappeared from its surface. Crystalline water ice exists at the surface. Small presence (5%) of methane and ethane ice	Crystalline water ice indicates that temperature rose to at least -110°K sometime in the last 10 Ma, possible cryovolcanism spurred by internal radioactive decay	Weywot
Sedna	~1030	P=76 A=936 C=86	Has an albedo of 0.32, a homogeneous surface in color and spectrum, and one of the reddest surfaces in the Solar System, perhaps caused by a surface coating of tholins. Surface composition upper limits are 60% for methane and 70% for water ice. 24% Triton-type tholins, 7% amorphous carbon, 10% nitrogen, 26% methanol, and 33% methane have been suggested for the surface composition.	One of the most distant- known objects in the Solar System, with a highly eccentric orbit, leading to speculation that it may be a member of the inner Oort cloud, in addition to extra- solar origin hypotheses. Models of internal radioactive decay indicate that a subsurface ocean may be stable.	None detected
Orcus	917	P=31 A=48 C=48	Has an albedo of 0.3, is gray in color, and is rich in crystalline water ice, mixed with tholins . Methane and ammonia may be present. Water and methane ices can cover no more than 50% and 30% of the surface respectively.,.	A plutino in a 2:3 resonance with Neptune. Crystalline water ice, and possible ammonia ice, may indicate surface renewal by cryovolcanism. Models of internal radioactive decay indicate that a subsurface ocean may be stable.	Vanth

(Taken from OPAG Goals Document 09.2018)

V&V Crosscutting Science Themes and Priority Questions, and candidate missions relevant to OPAG

Crosscutting Science Themes	*Priority Questions*	*Candidate future missions to outer planets*
Building New Worlds (ORIGINS)	1. What were the initial stages, conditions, and processes of solar system formation and the nature of incorporated interstellar matter?	**Ice Giants mission, KBO mission, Saturn Probe**
	2. How did the giant planets and their satellite systems accrete, and is there evidence that they migrated to new orbital positions?	**Ice Giants mission, Saturn Probe, Io Observer, multiple Ocean Worlds missions**
	3. What governed the accretion, supply of water, chemistry, and internal differentiation of the inner planets and the evolution of their atmospheres, and what roles did bombardment by large projectiles play?	**Ice Giants mission, KBO mission, Io Observer, Titan mission (see Section 8.0) Planetary habitats**

V&V Crosscutting Science Themes and Priority Questions, and candidate missions relevant to OPAG

Crosscutting Science Themes	*Priority Questions*	*Candidate future missions to outer planets*
Planetary Habitats	4. What were the primordial sources of organic matter, and where does organic synthesis continue today?	**Ice Giants mission, multiple Ocean Worlds missions, KBO mission**
	5. Did Mars or Venus host ancient aqueous environments conducive to early life, and is there evidence that life emerged?	***N/A***
	6. Beyond Earth, are there contemporary habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life, and do organisms live there now?	**Multiple Ocean Worlds missions, Ice Giants mission**

V&V Crosscutting Science Themes and Priority Questions, and candidate missions relevant to OPAG

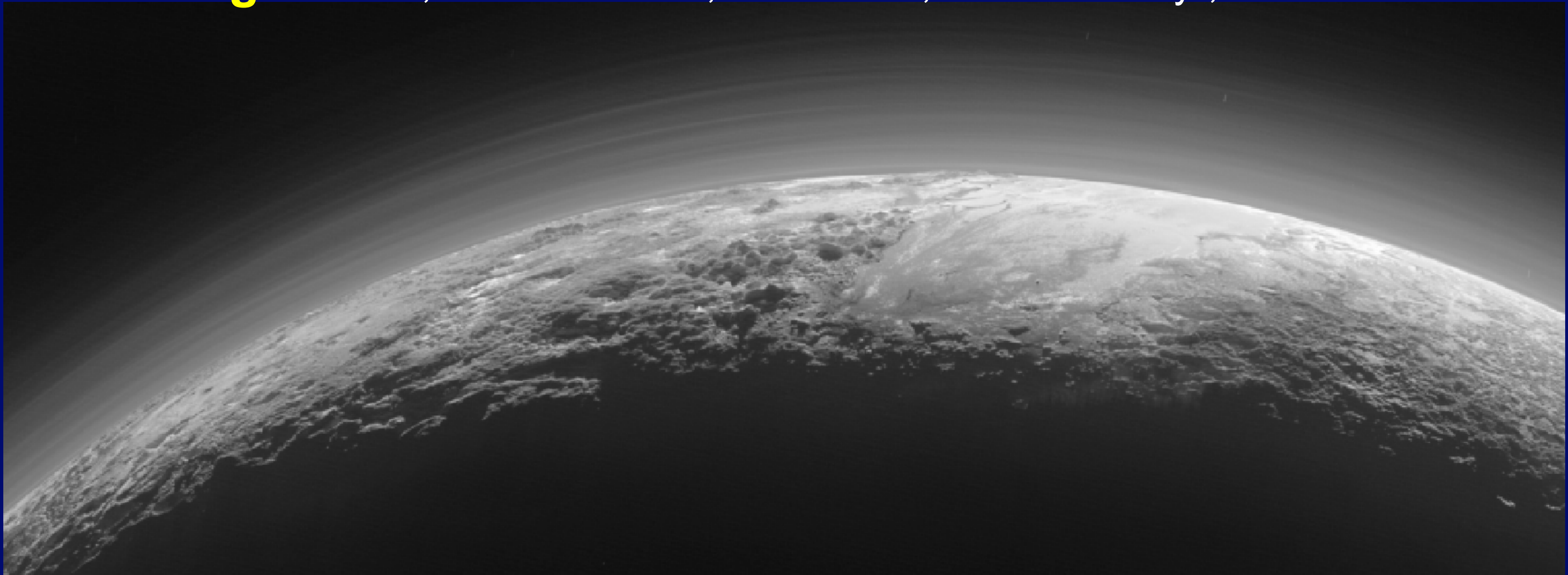
Crosscutting Science Themes	*Priority Questions*	*Candidate future missions to outer planets*
WORKINGS OF SOLAR SYSTEM	7. How do the giant planets serve as laboratories to understand Earth, the solar system, and extrasolar planetary systems?	Ice Giants mission, Saturn probe, multiple Ocean Worlds missions, Io Observer
	8. What solar system bodies endanger Earth's biosphere, and what mechanisms shield it?	N/A
	9. Can understanding the roles of physics, chemistry, geology, and dynamics in driving planetary atmospheres and climates lead to a better understanding of climate change on Earth?	Ice Giants mission, Saturn Probe, Titan mission, Io Observer, KBO mission
	10. How have the myriad chemical and physical processes that shaped the solar system operated, interacted, and evolved over time?	All missions

On the Value of a Pluto-Charon System Orbiter

O.M. Umurhan

with prime assistance from:

Jason Hofgartner[1], Bonnie Buratti[1], Marc Buie[2], Veronica Bray[3], Emmanuel Lellouch[4]



1. Jet Propulsion Laboratory, California Institute of Technology; 2. Southwest Research Institute; 3. University of Arizona; 4. Observatoire de Paris, Meudon;

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"…because it has a little bit of all the KBO Dwarf Planets, that's why"

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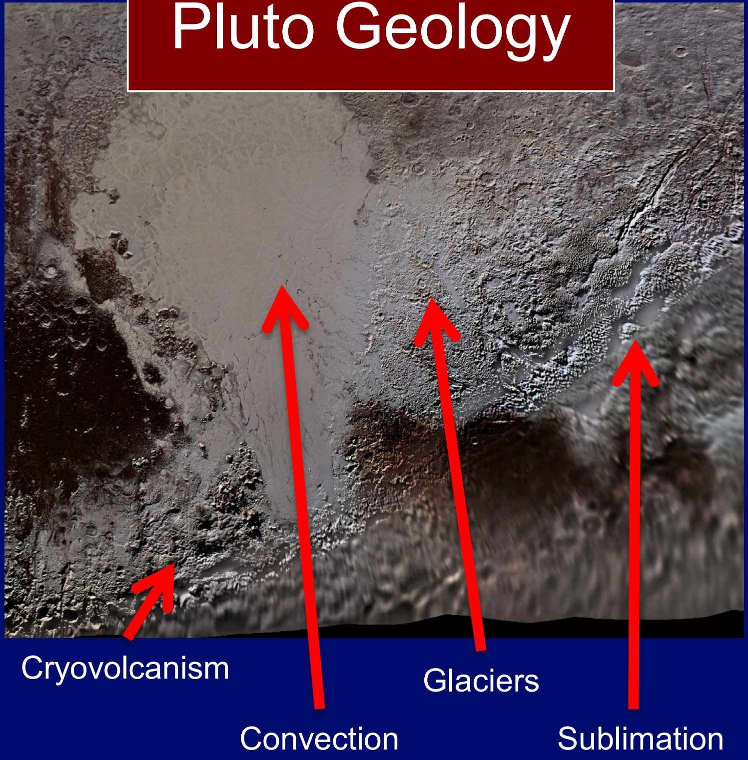
Pluto Geology



Diverse, Unique, **Ongoing**, Endogenic and Exogenic , Liquids?, Stratigraphy: Crust? Glaciers and volatile caps?

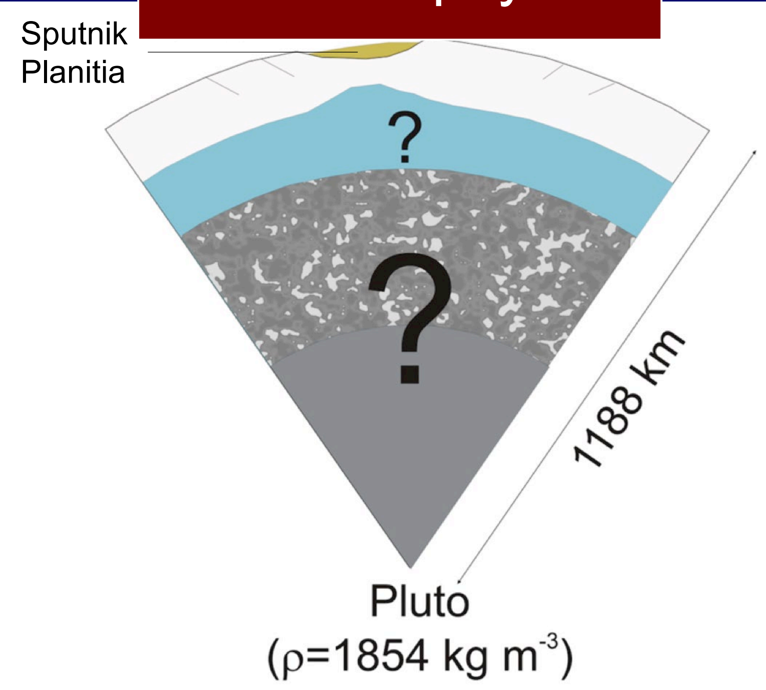
Polar night unknown, non-encounter side needs resolution. Global Map, most desirable.

Instruments: Color cameras (narrow and wide angle), Altimeter, IR spectral imager, *Polar night imaging*: Radar, Laser, Lyman-α imager?

Priority Science Question(s) Addressed

10. How have the myriad chemical and physical processes that shaped the solar system operated, interacted, and evolved over time?

Pluto Geophysics



Spencer et al., 2019

Interior: Ocean? (likely) If so depth, thickness, composition?
Sputnik Planitia: Mascon and Polar wander? Basin origin & age? Depth? Southern Sputnik? Tidal evolution.

Answers to most of these questions needs an orbiter

Instruments: Gravity, Magnetometry, Sounding Radar, Thermal IR/Sub-mm

Priority Science Question(s) Addressed

1. What were the initial stages, conditions, and processes of solar system formation and the nature of incorporated interstellar matter ?

6. Beyond Earth, are there contemporary habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life, and do organisms live there now?

9. Can understanding the roles of physics, chemistry, geology, and dynamics in driving planetary atmospheres and climates lead to a better understanding of climate change on Earth?

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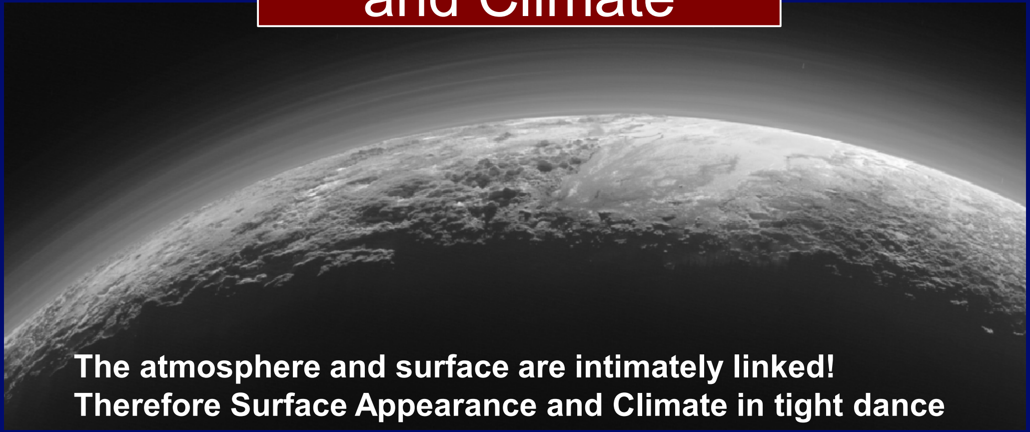
Pluto Atmosphere and Climate



Hazes: Origin? Composition & structure? Properties of Atmospheric Gravity/Wave Propagation? Layering? Cthulhu? Climate: Seasonal Changes? Extremes? Escape: Why is the exosphere so cold?

Answers to most of these questions needs an orbiter as most of these processes vary on the timescales of days-weeks to decades!!!

Instruments: mass spec, sub-mm, UV spectroscopy/occultations, radio occultations, color cameras, plasma spectrometer and waves

Priority Science Question(s) Addressed

4. What were the primordial sources of organic matter, and where does organic synthesis continue today?

9. Can understanding the roles of physics, chemistry, geology, and dynamics in driving planetary atmospheres and climates lead to a better understanding of climate change on Earth?

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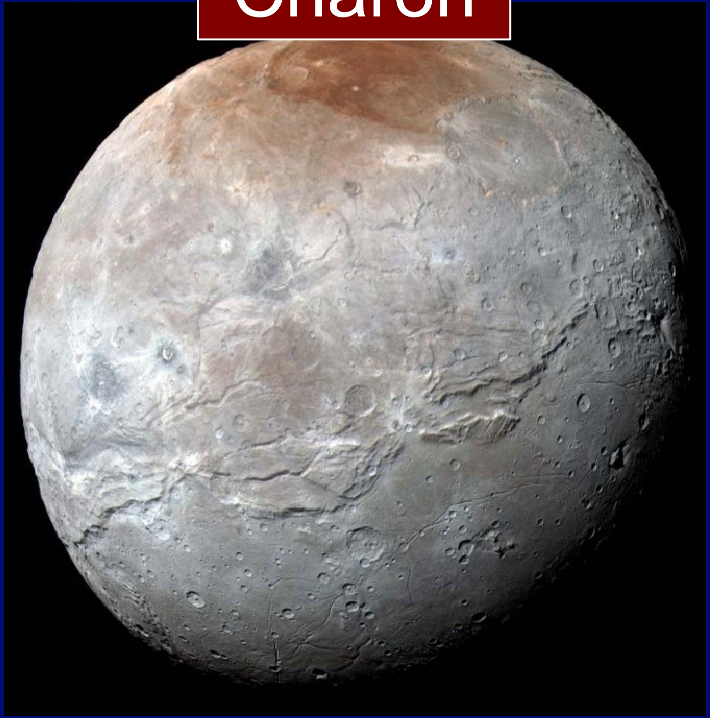
Charon



Hemispherical Dichotomy: Why? Global? Ocean & cyrovolcanism?, Topography: Relief > 20 km? Largest mountains & valleys?, Ammonia: Source and processes? Lifetime? Distribution?, Mordor: Source and Pluto's role? Composition & Depth? Southern MM?

Nominally similar to Quaoar, Sedna and Orcus in terms of color size and observation of crystalline H_2O. Might serve as proxy for them.

Instruments: Same as Pluto Geology and Geophysics

Priority Science Question(s) Addressed

Same as Pluto Geology and Geophysics: 1. 4, 6, 9, 10.

Challenges

- ***Distance:*** Baseline Power: RTG, Long cruise. Data rate: Autonomous processing
- ***Seasons:*** Investigate unilluminated regions, Longevity
- ***Complex tour***?

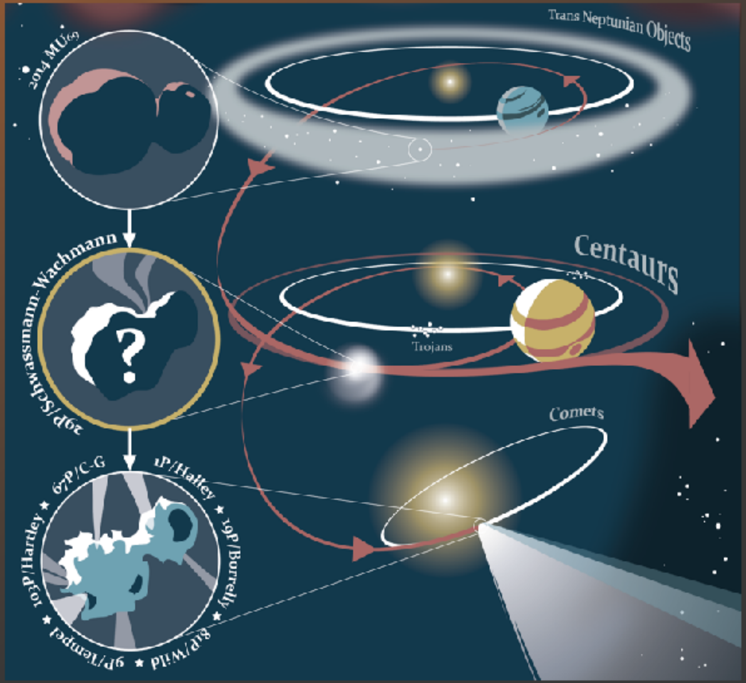
Perhaps not in this next decadal survey -- but you never know!

Wider Appeal

- Pluto is an active low temperature laboratory -- physicists working on low temperature physics will benefit from long-baseline observations and data acquisition.

- Because Pluto-Charon System is arguably representative of conditions and phenomena found across the wider KBO system. Thoroughly studying it will help us understand the processes that govern those systems and their evolution (before we go to visit those places) -- except perhaps for Haumea -- and may lead to the emergence of a unified picture of the lives of these object.

CHIMERA: A JOURNEY TO THE INTERSECTION OF ORIGINS AND EVOLUTION IN THE OUTER SOLAR SYSTEM:



Walt Harris,
LPL,
University of Arizona

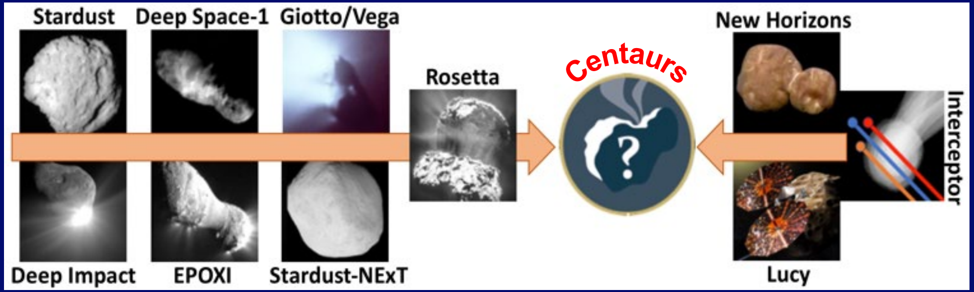
Centaurs as the Next Frontier for Icy Bodies:

Physical Significance

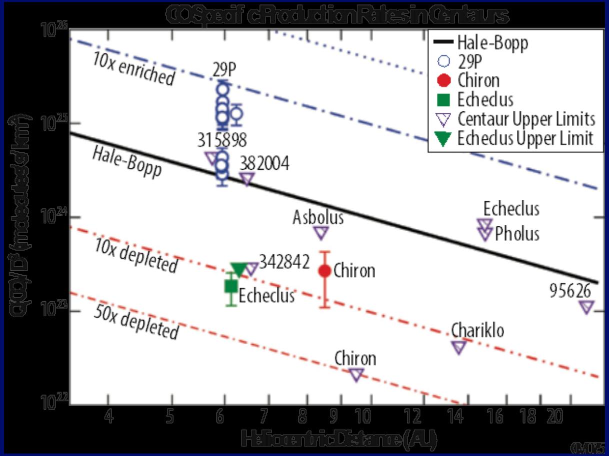
- Occupy an evolutionary intersection.
- Kuiper Belt Source ➔ Jupiter Family Comet (JFC) Destination.
- Least evolved objects inside Neptune.
- Activity distinct from JFCs, similar to LPCs.
- Bridges between ***multiple mission targets***.

Exploration Caveats

- Composition is key, but ***sporadic activity*** limits sampling.
- Chaos in orbits ***obscures dynamical age***.
- Debris rings are a ***potential hazard***.
- Transfer orbit opportunities are widely ***(~100 yr)*** spaced.



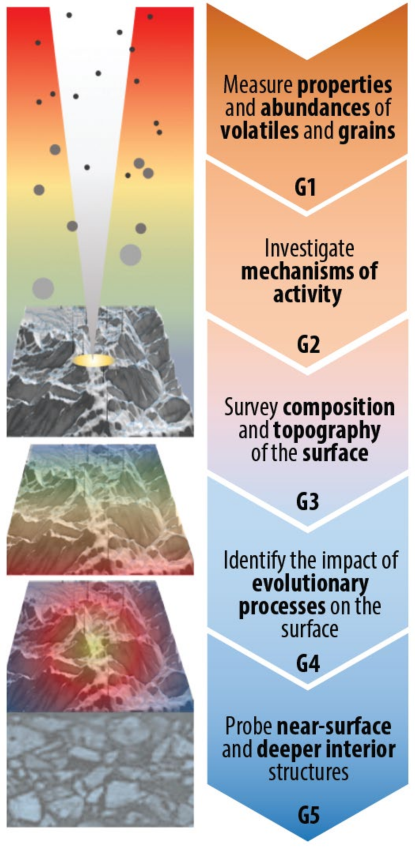
29P/Schwassmann-Wachmann 1(SW1)



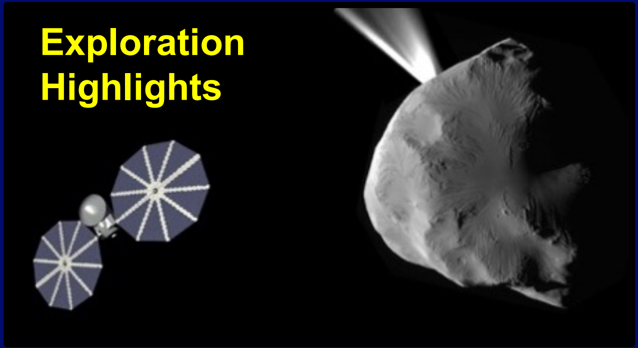
SW1 is ***the essential Centaur*** for the study of evolution and activity of outer solar system small bodies.

- SW1 is the most active Centaur and the one known to be continuously so (for at least 100 yr).
- SW1 is the only icy body to experience frequent (~7/yr) major outbursts.
- Its heliocentric distance is physically significant.
  - ***Local temperatures drive transformations (e.g. amorphous ice)***
  - ***Direct activity comparisons with LPCs***
  - ***Similar conditions to early Trojans***
- SW1's low eccentricity orbit is ***seasonally stable***.
- Recent models (Sarid et al., 2019) show SW1 is in a 'gateway' orbit through which *2/3rds of future JFCs pass just-prior to making the transition*.

Goals, Drivers, and Mission Summary



- The *Chimera* mission targets the ***hybrid features*** of SW1 to explore the physical evolution of small bodies from the coma to deep interior.
- To effectively (and safely!) probe composition, outbursts, and surface changes ***requires extended proximity*** (orbit or slow flyby)
- A once in 50 yr orbital resonance ***temporarily allows <u>orbital</u> exploration in the Discovery class***. The next resonance is in ***2083*** *after* a change in the SW1 orbit.



- 100 day ***slow approach*** to avoid debris
- >2 years of ***low-risk orbital operations***
- High-heritage instruments provide ***surface imaging***, ***spectral and in situ composition***, ***interior structure***, and ***thermal properties***
- Supplemental science from ***Jupiter polar regions*** and a possible ***second JFC flyby***.

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

The Role of KBO exploration in understanding the formation and evolution of the solar system

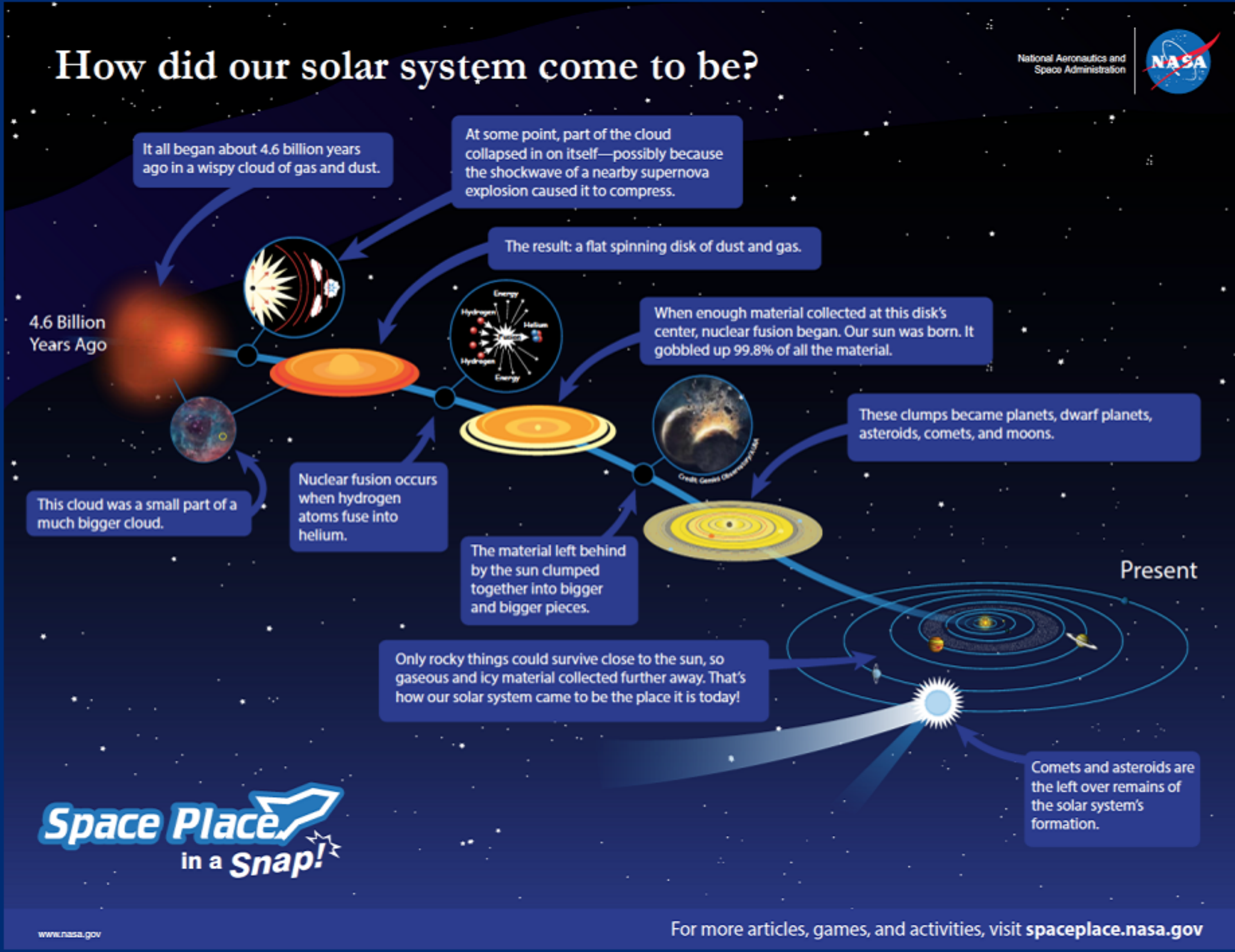
Kathleen Mandt

Johns Hopkins University Applied Physics Laboratory (JHU/APL)

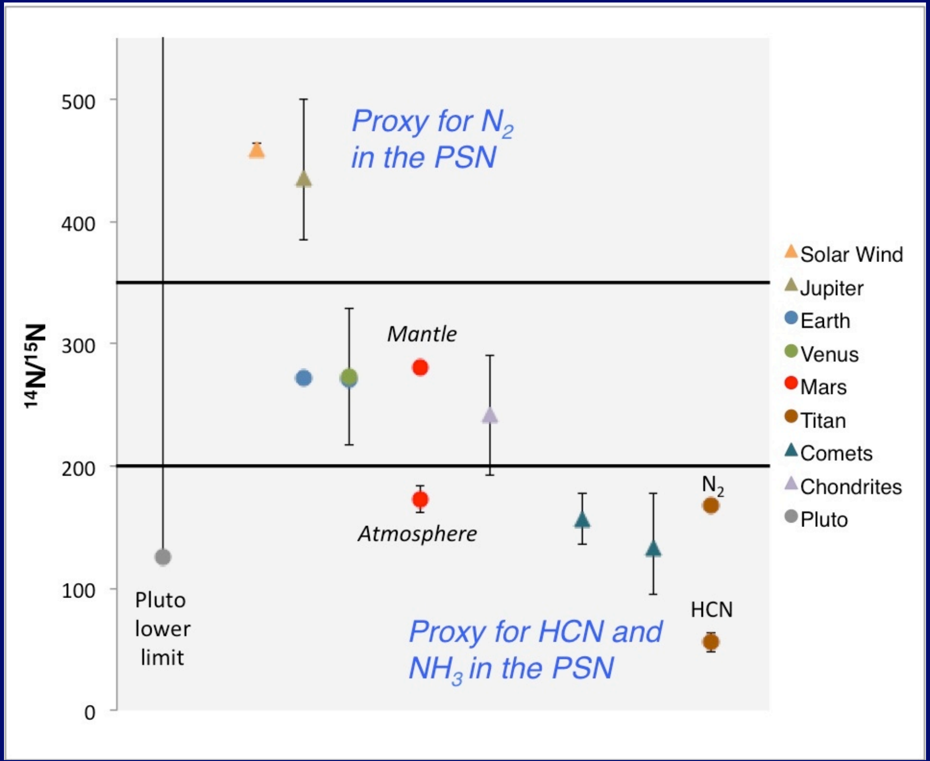
@mommascientist

A mission to Planet-sized KBOs advances NASA Goals:

- Formation
  - How did the solar system form?
  - Giant planets and small bodies are time capsules of formation
- Evolution
  - Atmospheres evolve over time
- Comparative Planetology
  - Small icy bodies are time capsules
  - Larger icy bodies have atmospheres that evolved



Observations from multiple missions are required for studying origin and evolution of the SS

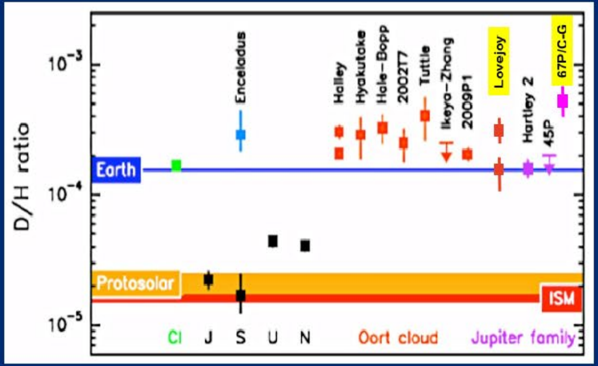


- Primordial (triangles) ratios represent values preserved from the Protosolar Nebula (PSN)
  - Jupiter
  - Solar Wind
  - Comets
  - Meteorites
- Evolved (circles) ratios have changed over time
  - Terrestrial planets and Titan
  - Not measured: Pluto & Triton

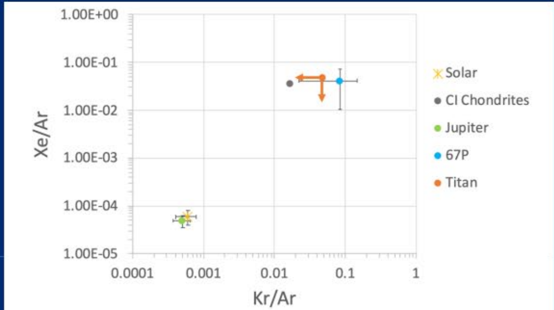
Value of in situ observations of solar system formation ”time capsules” of the Solar System

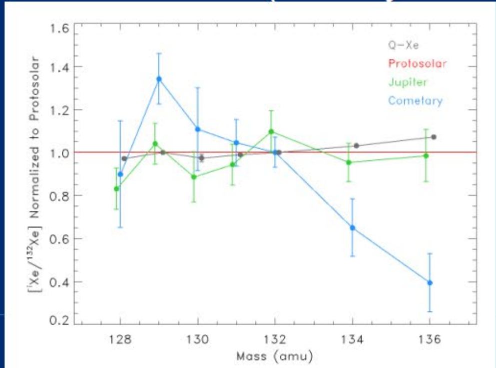
Example from the Rosetta mission

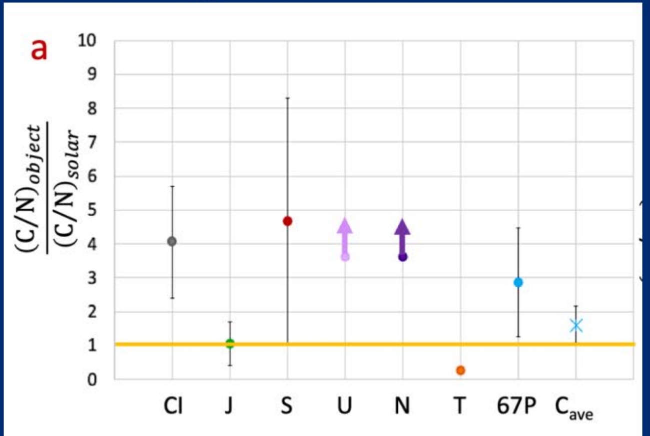
- D/H ratio in water highest yet, but varies by a factor of 2 among measurements (Altwegg et al. 2014, 2017)

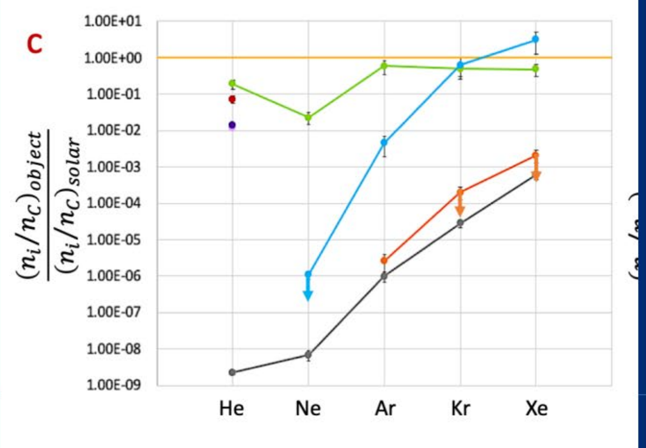


- Two noble gas measurements, with isotopologues (Balsiger et al. 2016; Marty et al. 2017; Rubin et al. 2018; 2019)
- Bulk abundances and isotope ratios of Carbon (Le Roy et al. 2015; Haessig et al. 2017)

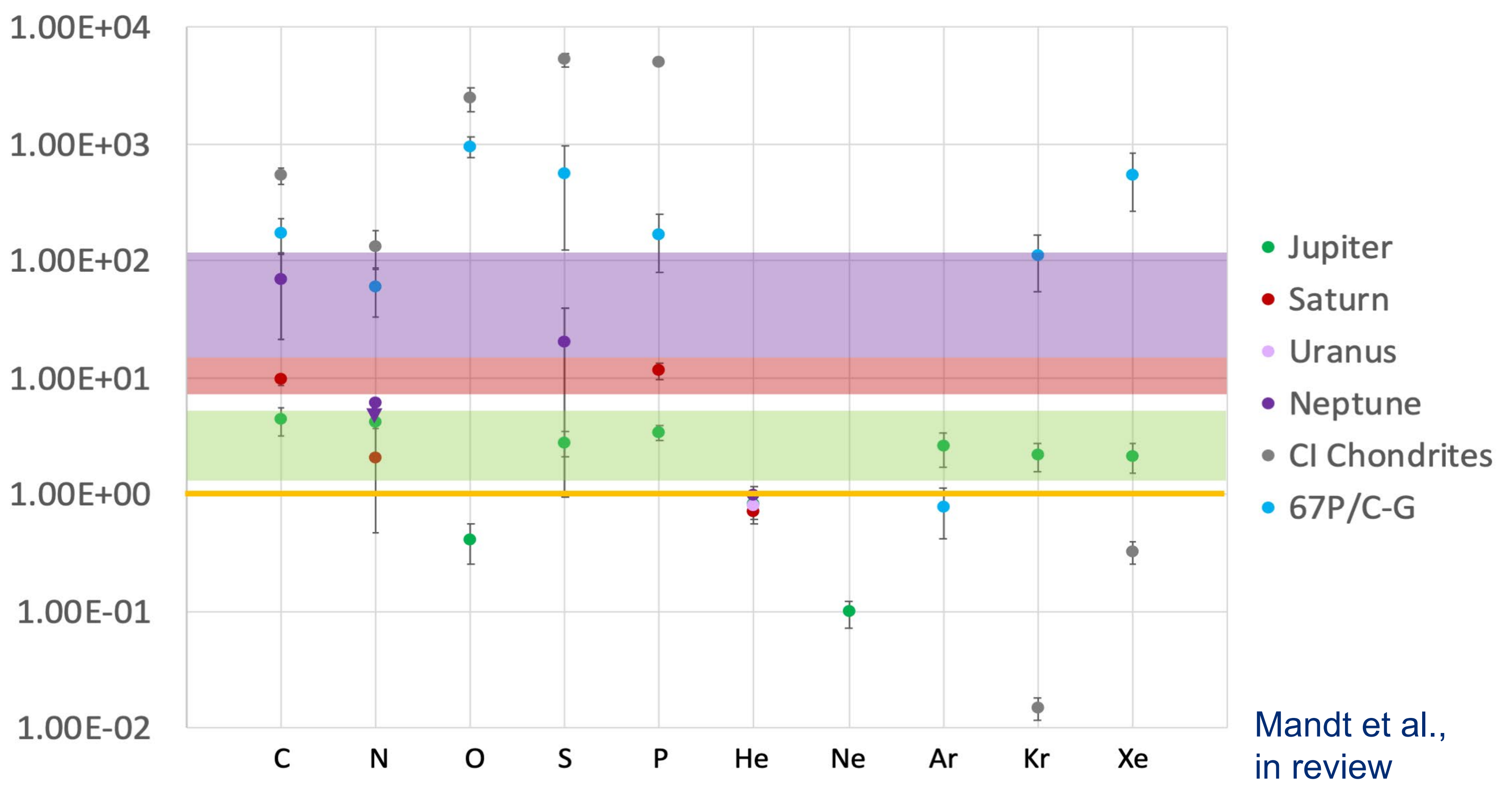








Observations from multiple missions are required for comparative planetology



Mandt et al., in review

What mission(s) will provide the greatest science return?

Orbiter

- Maximum science return for single target
- Highest cost and technical challenge
- Best for in-situ observations of volatiles
- Long-term remote monitoring
- How do you slow down?

Image source: Princeton Sat. Sys., NASA/JHUAPL/SwRI

Flybys

- Science return for multiple targets
- Can fit under NF and Discovery budget
- Limited in situ potential
- Single remote observation
- Engage all of NASA: e.g. Interstellar Probe

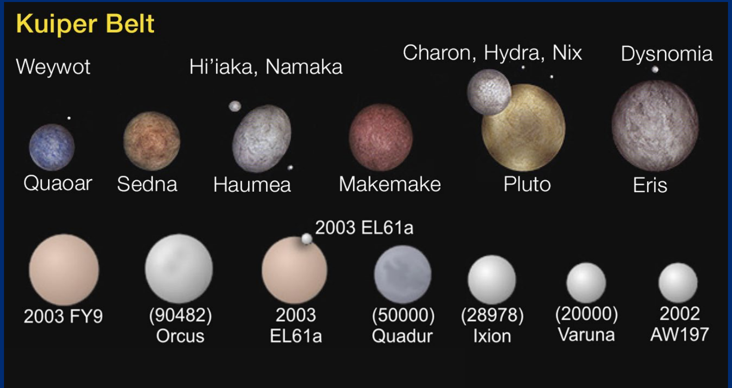
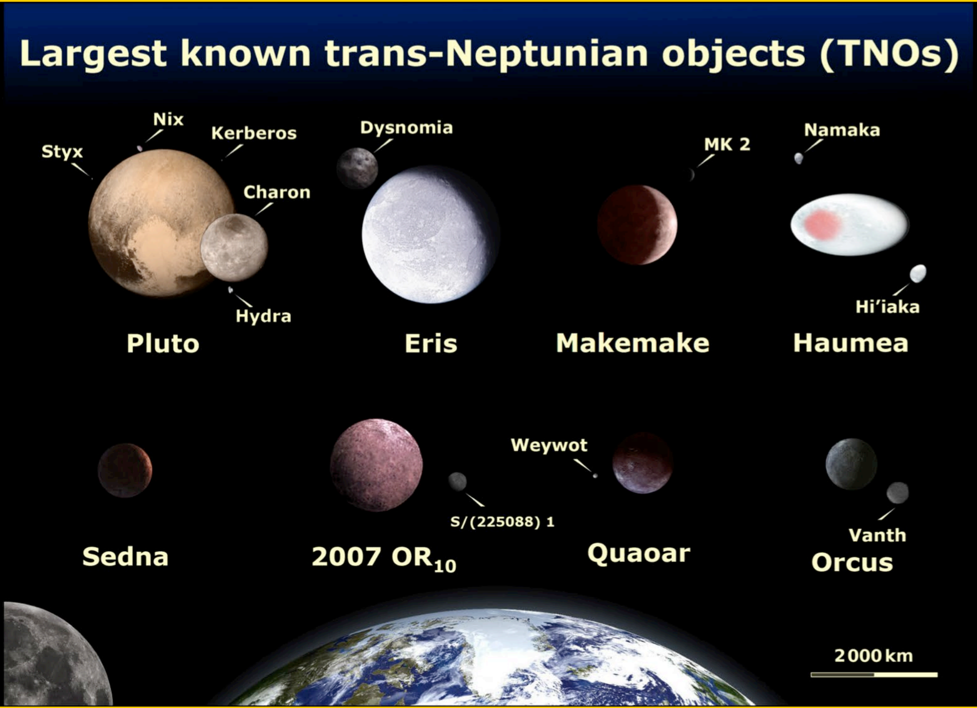


Image source: pluto.jhuapl.edu

There are pros and cons for both orbiters and flybys. Proper exploration of the Kuiper Belt will take advantage of both mission architectures

OPAG Dwarf Planets Panel



Alan Stern (SWRI)

20 August 2019

Some Thoughts

- To compete well in the DS, our community should:

  1. Not over-reach, as in the past, with dual flagship dreams.

  2. And adopt a <u>unified strategy</u> that consolidates missions where feasible to advance multiple OP communities, including:
     - KBOs and Dwarf Planets
     - Ocean Worlds
     - Giant Planets

- And our strategy should consider all major mission categories from Discovery to New Frontiers to Flagships.

A Broad Spectrum of Exciting Options Exist

- **Flagship Neptune Orbiter-Triton Explorer**
- **Flagship Pluto Orbiter with Follow On KBO-DP Exploration**
- **NF Uranus Flyby Continuing to KBOs and DPs**
- **NF Dedicated KBO-DP Reconnaissance Flybys**
- **Discovery Centaur Reconnaissance**

Except for Dual Flagships,
I Believe Any Two of These Should be Achievable.

Unifying Science Themes Proposed by *Destination Dwarf Planets* Panel

Building New Worlds (Origins)

Initial conditions of outer solar system, types of materials incorporated into bodies and where, chemical budget of outer solar system at birth dictates what drifts into inner planet zone (disk transport)

Planetary Habitats

Ocean world systems, synthesis of organics,   evolution of climatary systems

Solar System Workings

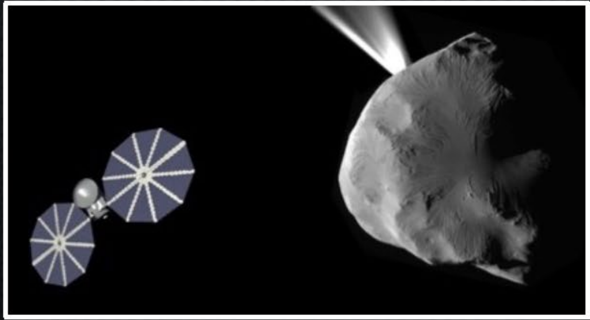
Comparative planetology. Processes driving planetary climates and atmospheres potentially leading to terrestrial/martian insights, complex interplay of chemical/physical surface and surface-atmosphere processes, past and present.

Supplemental Slides

Mission Summary

- The *Chimera* mission targets the hybrid features of SW1 to explore the physical evolution of small bodies.
- To effectively (and safely!) probe composition, outbursts, and surface changes requires extended proximity (orbit or slow flyby)
- A once in 50 yr orbital resonance *temporarily* allows orbital exploration in the discovery class. The next resonance is in 2083 *after* a change in the SW1 orbit.

Exploration Highlights



- 100 day slow approach to avoid debris
- 2 years of low-risk orbital operations
- High-heritage instruments provide surface imaging, spectral and *in situ* composition, interior structure, and thermal characteristics
- Supplemental science from Jupiter and a potential second JFC flyby (31P/SW2)