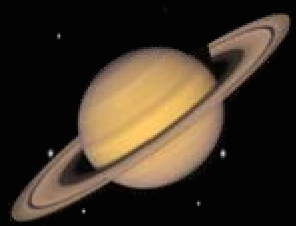
Argo



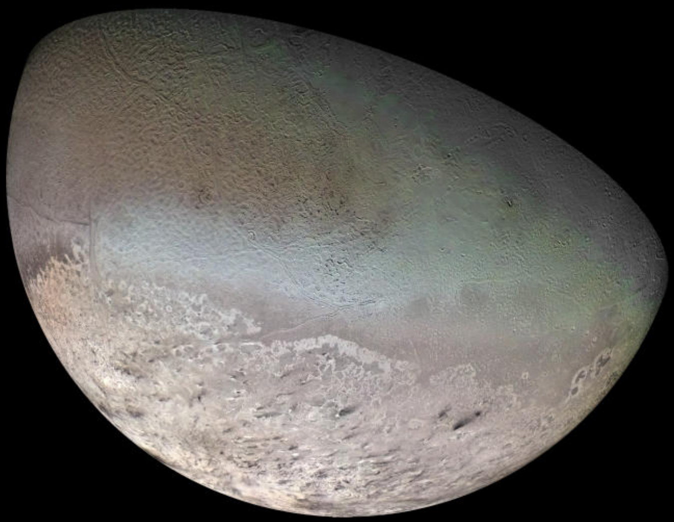
A Voyage Through the Outer Solar System

Candice Hansen (JPL), Don Banfield (Cornell), E. Bierhaus (LMA), Mike Brown (CIT), Josh Colwell (UCF), M. Dougherty (IC), Amanda Hendrix (JPL), Krishan Khurana (UCLA), Alfred McEwen (UAz), Dave Paige (UCLA), Chris Paranicas (APL), Britney Schmidt (UCLA), Mark Showalter (ARC), Linda Spilker (JPL), Tom Spilker (JPL), John Stansberry (UAz), Nathan Strange (JPL), Matt Tiscareno (Cornell)

Argo: a New Frontiers 4 Mission Concept

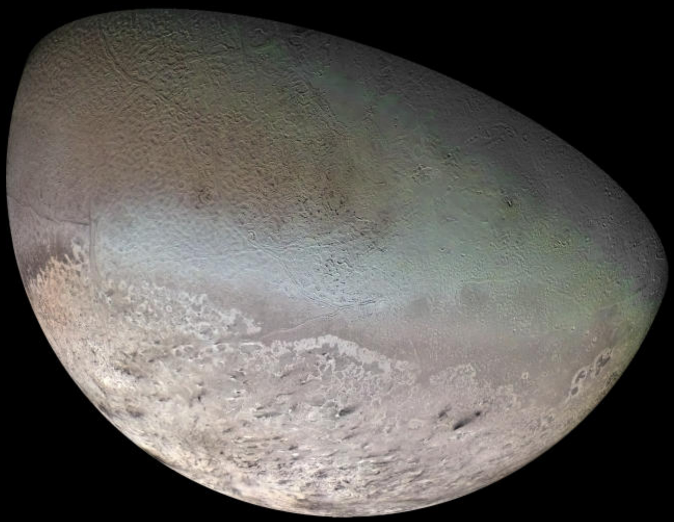
A *small body explorer* doing *exceptional ice giant science*

- Flyby Neptune
- Close flyby of Triton
- Flyby of a *scientifically-selected* Kuiper Belt Object
- Gravity assist from Jupiter and Saturn



A Neptune flyby + KBO mission is

a Pragmatic approach
… with rich science results

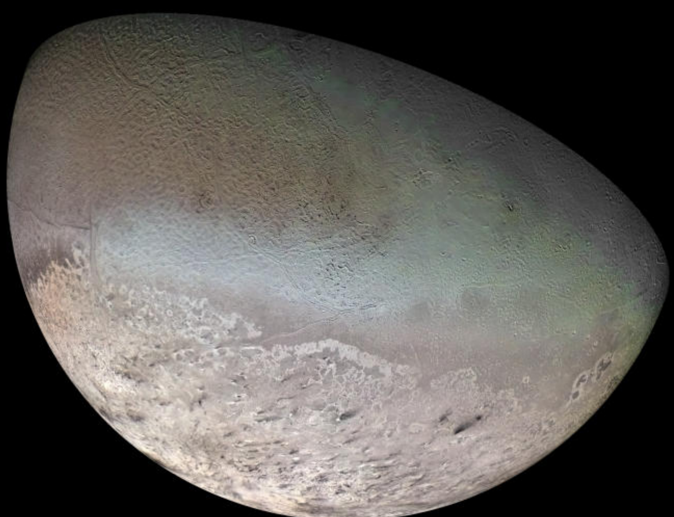


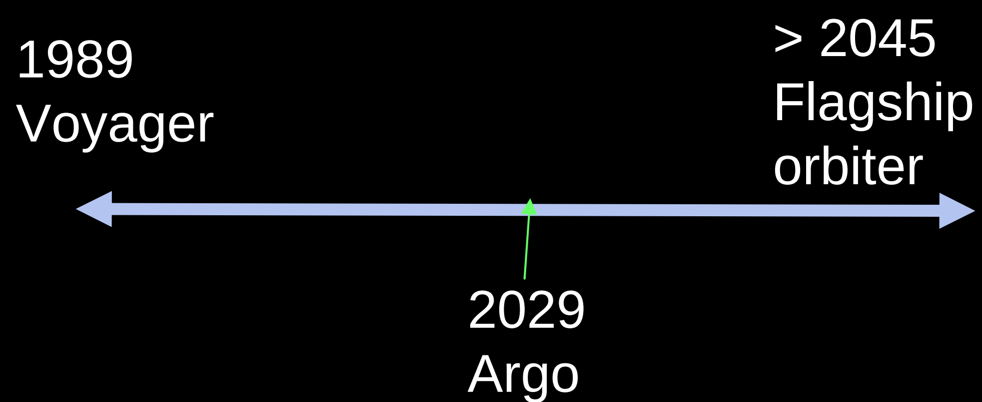
Key Characteristics:

- Focused science mission
- Simple mission profile
- Current instrument technology
- Current spacecraft technology
- Capable payload
- Nuclear power

A Neptune flyby mission is **not** in competition with a flagship orbiter

Rather, it plugs a ~50 year gap in our study of Neptune and Triton



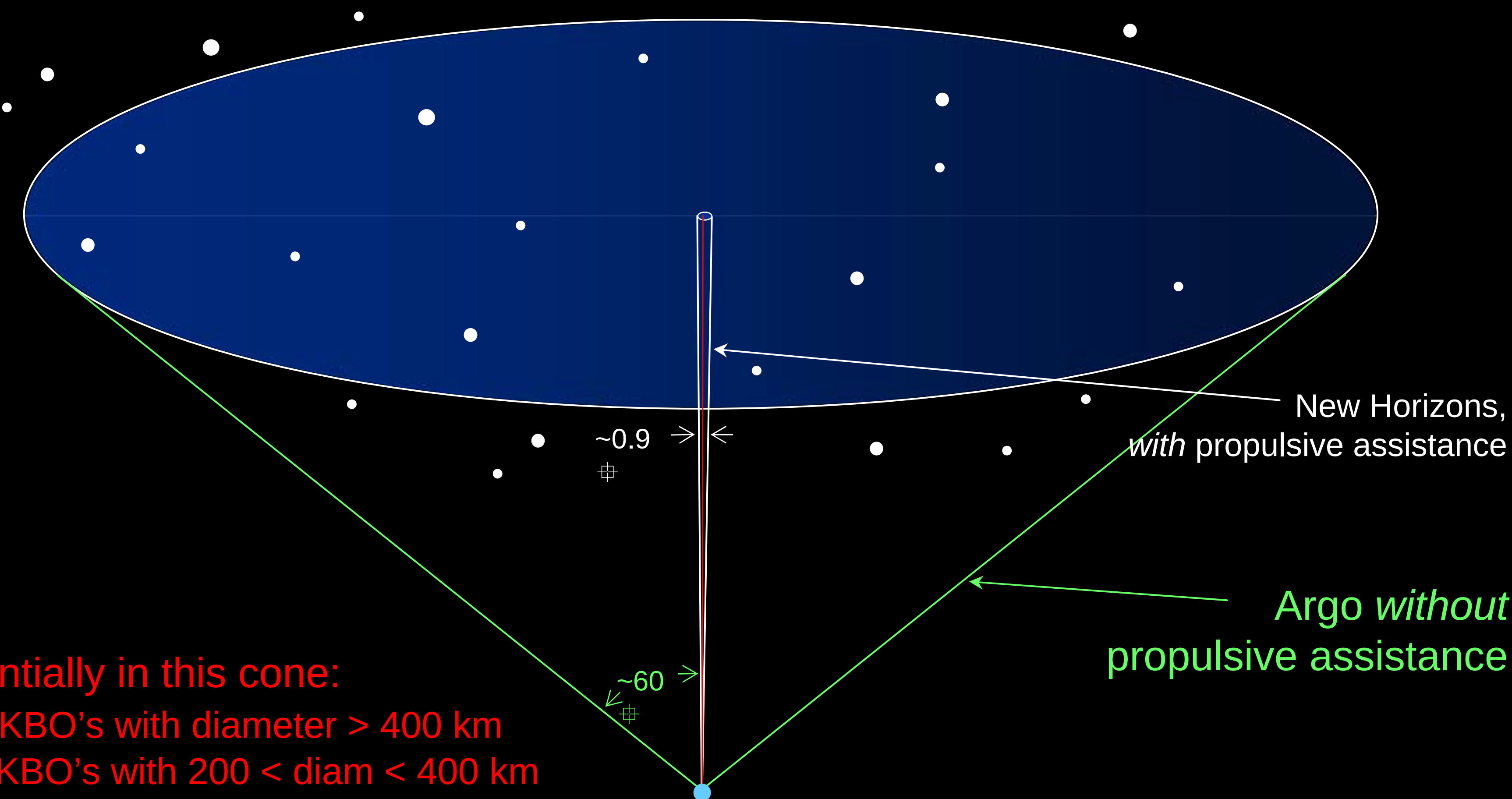


And goes on to a scientifically-selected KBO

Neptune’s Gravity provides Access to KBOs

Argo’s accessible volume is ~4000x that of New Horizons

Flight time to KBO is just ~1.5 - 3 years (KBO at 35-39 AU)



Potentially in this cone:

12 KBO’s with diameter > 400 km

40 KBO’s with 200 < diam < 400 km

18 cold classical KBO’s

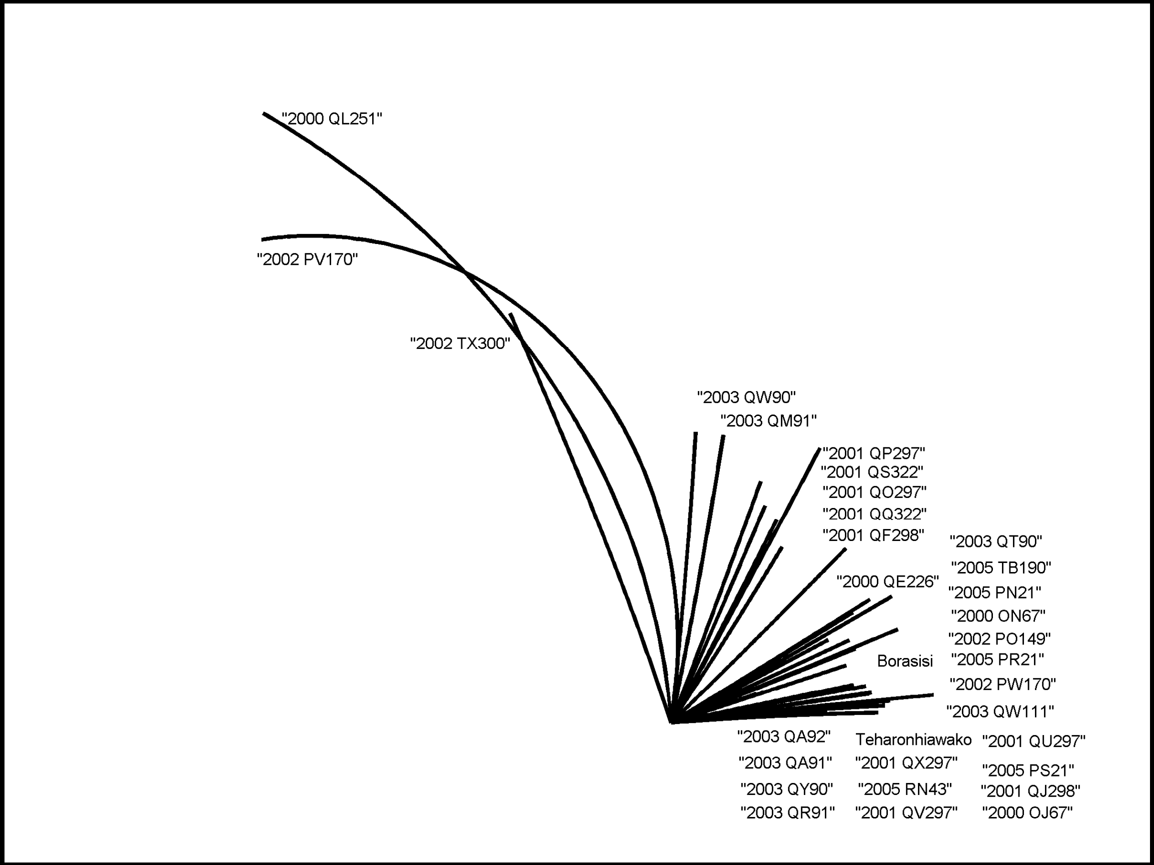
KBOs with a Triton Flyby

Opportunity to compare a ~pristine KBO to a captured and processed KBO (Triton)

Same payload means direct comparisons can be made - no calibration challenges

KBO scientifically selected - choice of:

- cold classical
- scattered
- binary
- size



Origin is at Neptune

32 choices

Neptune flyby enables KBO science

Opportunity to continue on to a KBO!

32 potential KBO targets with Triton flybys
  - Over 200 km diameter
  - Flyby is < 5 years after Neptune

- Eris is reachable in 2044

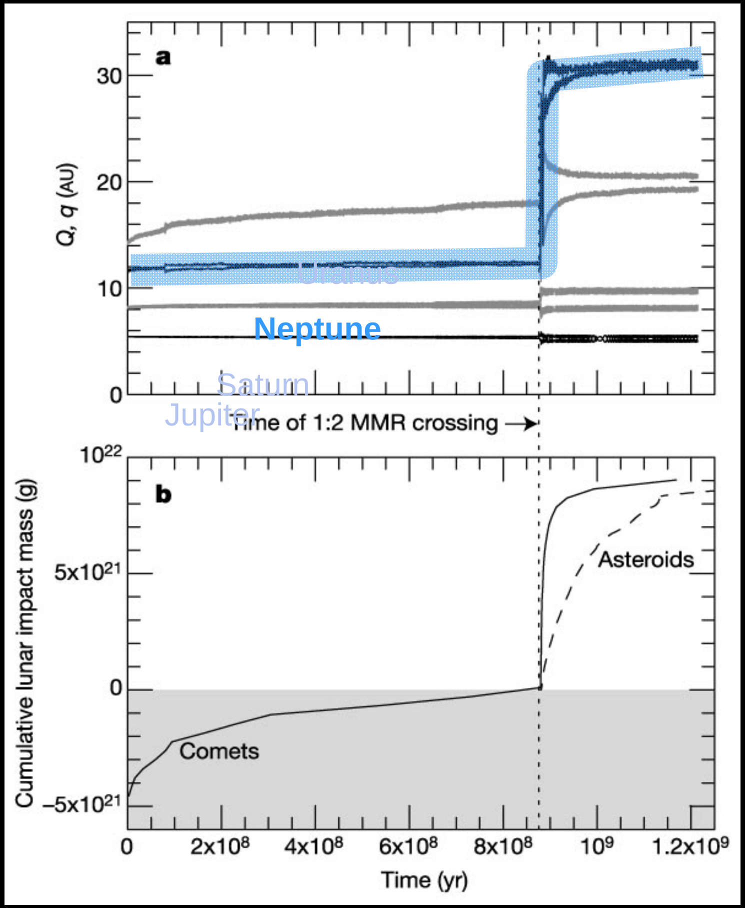
Designation	a (AU)	D (km)	Orbit	Binary?	Number	Name
2002 TX300	43.28	709	SCATNEAR			
2005 RN43	41.7	704	SCATNEAR		145452	
2003 QW90	43.75	508	Hot Classical			
2001 QF298	39.4	503	3:2E			
2005 TB190	76.19	487	SCATEXTD		145480	
2003 QM91	50.13	432				
2001 QS322	44.09	353	Cold Classical			
2003 QA91	44.18	351	Cold Classical	Y		
2001 QT297	44.21	337	Cold Classical	Y	88611	Teharonhiawako
2005 PR21	44.04	310	Cold Classical			
2001 QO297	43.1	303	Cold Classical			
1999 RZ253	43.98	280	Cold Classical	Y	66652	Borasisi
2000 ON67	43.12	278	Cold Classical			
2000 OJ67	43.02	268	Cold Classical	Y	134860	
2000 QE226	44.15	265	Cold Classical			
2001 QU297	52.87	264				
2001 QQ322	44.04	262	Cold Classical			
2001 QJ298	44.18	255	Cold Classical			
2003 QR91	46.36	249	Cold Classical	Y		
2005 PS21	44.3	244	Cold Classical			
2003 QA92	38.04	235	Cold Classical			
2003 QT90	49.36	234				
2001 QV297	44.78	233				
2003 QW111	43.9	231	7:4EEE	Y		
2001 QX297	44.23	230	Cold Classical			
2002 PW170	44.72	229	Cold Classical			
2005 PN21	46.49	229				
2000 QL251	48.03	226	2:1E	Y		
2003 QY90	42.78	224	Cold Classical	Y		
2002 PV170	42.5	222	Cold Classical			
2001 QP297	45.24	221	Cold Classical			
2002 PO149	44.23	211	Cold Classical			

Presentation Outline

- Introduction
- Science Objectives
  - Triton
  - Phoebe
- Mission, Payload, Spacecraft
- Summary

Our Picture of Solar System Evolution has changed fundamentally

- What happened in that dramatic period of solar system history, that so profoundly affected the structure of our solar system?
- What can close-up study of a KBO tell us about that evolution?



From "Origin of the cataclysmic Late Heavy Bombardment period of the terrestrial planets," R. Gomes, H. F. Levison, K. Tsiganis and A. Morbidelli 2005. *Nature* **435**, 466-469.

KBO Reconnaissance

- Investigate a primitive solar system body that is member of a much larger population
  - KBO's are classified as "classical", "resonant", "scattered" or "detached" by their orbital characteristics: semimajor axis, eccentricity and inclination
- Determine comparative properties of captured KBO Triton and a KBO *in situ*
- Expand the diversity of volatile-rich small bodies explored in the outer solar system
  - Between Argo and New Horizons (shown here) we will double the number of explored KBOs
    - Pluto
    - New Horizons *in situ* KBO
    - Triton
    - Argo *in situ* KBO

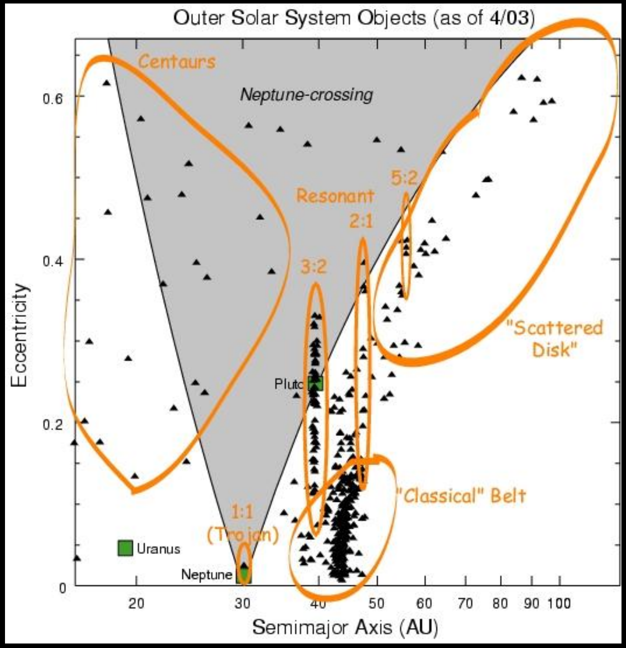


Figure courtesy of the LSST Project (www.lsst.org/Science/fs_oss.shtml)

KBO Level 1 Science Objectives
Bulk Properties

Determine the KBO's *bulk properties:*
mass, volume, composition

Measure size and overall shape
Shape is diagnostic of internal strength

Measure mass, calculate density
- Density -> composition
- Bulk composition -> physical and chemical conditions
extant at time of formation

If we choose a binary KBO we get to do this twice!

Look for satellites

KBO Level 1 Science Objectives
Global Map

Determine the KBO's *global surface and photometric properties:*

- color
- variety of terrains
- polar caps

Range of phase angles will address surface texture

Thermal images determine conductivity and heat capacity

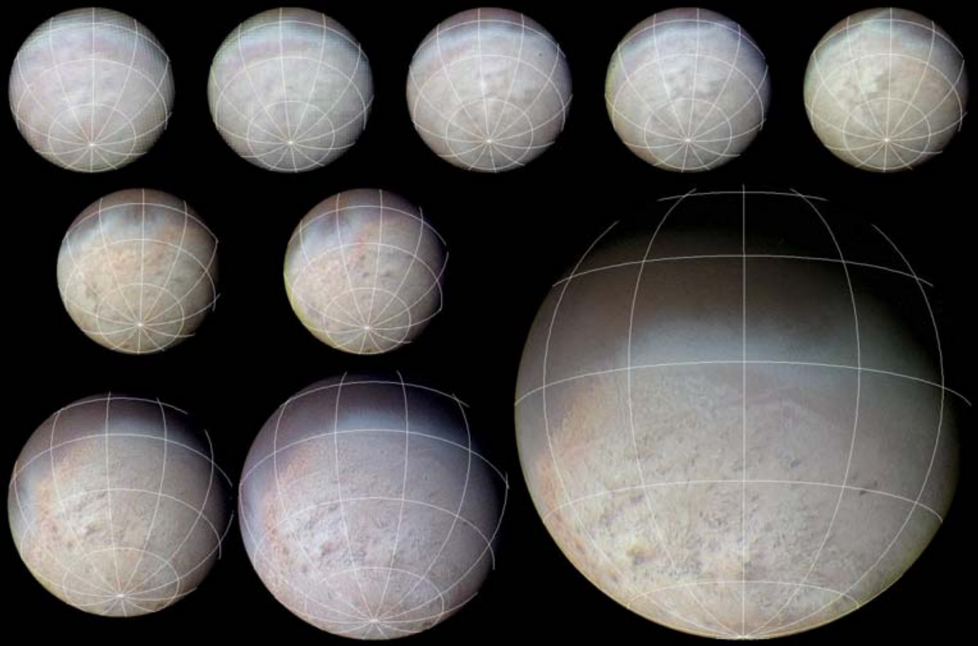
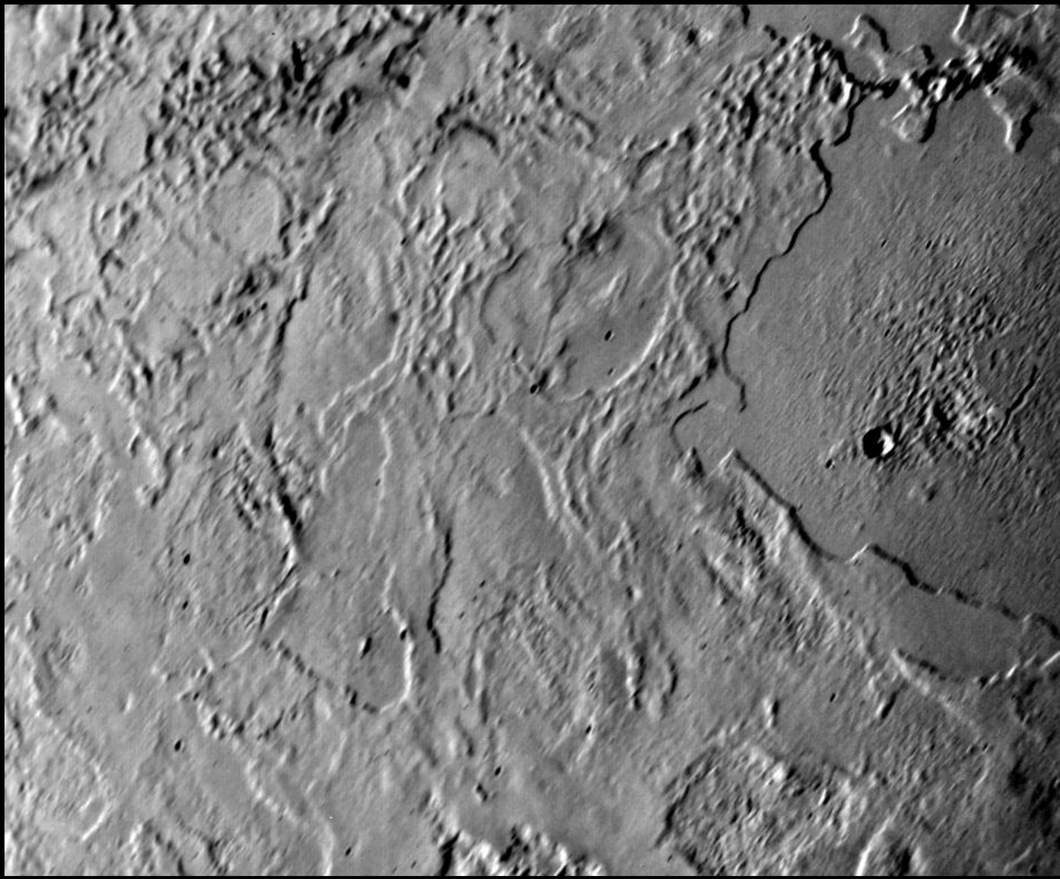


Image KBO at all wavelengths, starting multiple (3) days from closest approach, continuing to high phase angles

KBO Level 1 Science Objectives
Surface History

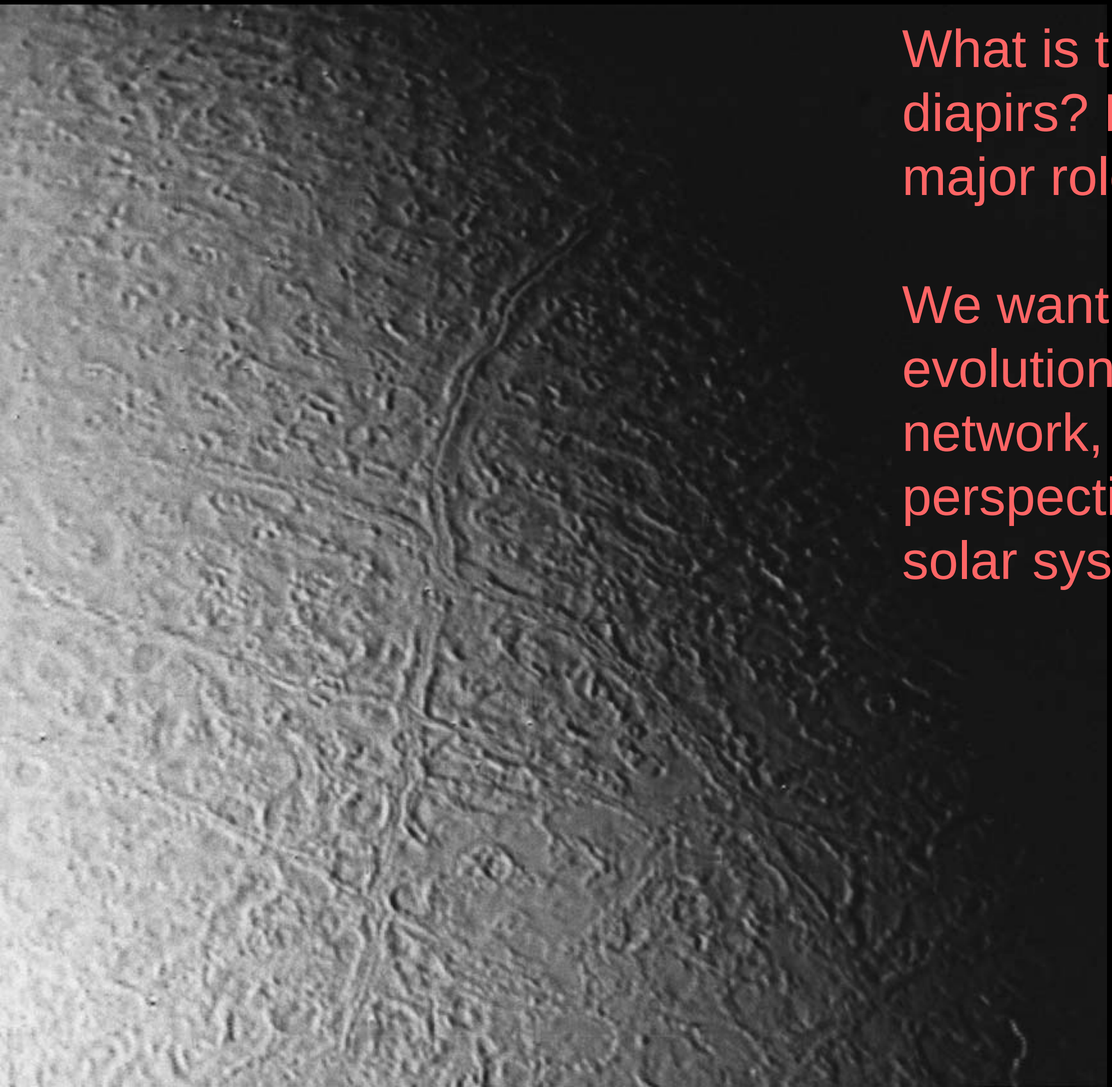
Determine Kuiper Belt collisional history, which in turn will help us to understand cratering chronology throughout the Solar System

Establish relative ages of surface units



High resolution images, to understand the collisional history

KBO Level 1 Science Objectives
Surface History



What is the tectonic history? Are there diapirs? Has cryovolcanism played a major role in renewing the surface?

We want to determine the surface evolution chronology, study the tectonic network, and interpret new data with the perspective of what this tells us about solar system evolution.

High resolution images, to understand the KBO surface evolution

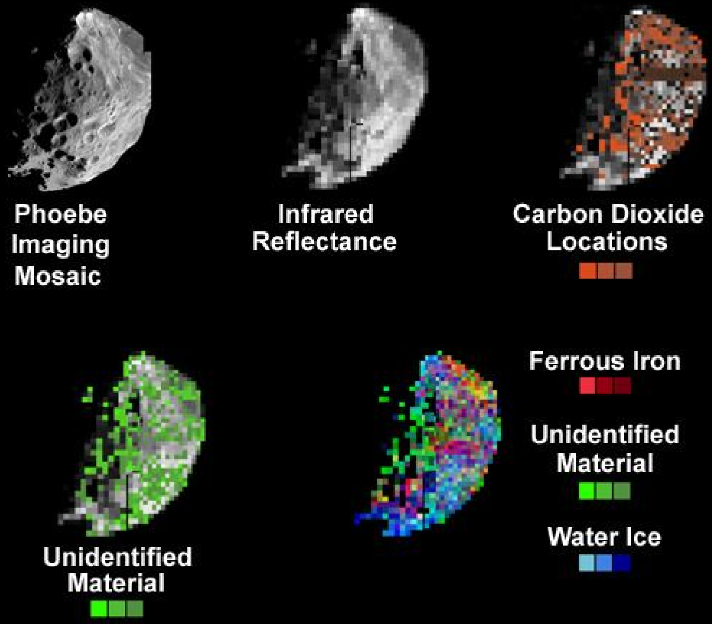
KBO Level 1 Science Objectives
Surface Composition

What is the surface composition?

What does this tell us about the KBO's "color" family?

Extrapolation to other members

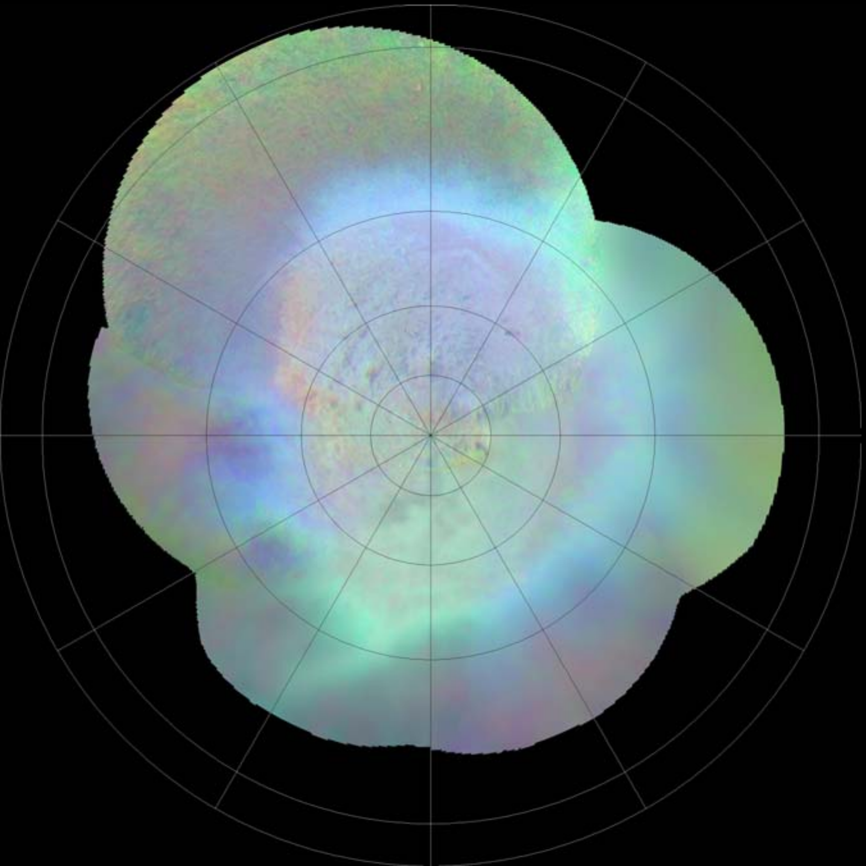
Where did the KBO originate, before solar system restructuring?



Near IR images, to understand the KBO origin and surface evolution

KBO Level 1 Science Objectives Volatile Ices and Seasonal Processes

How are nitrogen, methane, CO and CO_2 ices distributed across the surface?
Do they move seasonally from hemisphere to hemisphere forming polar caps?



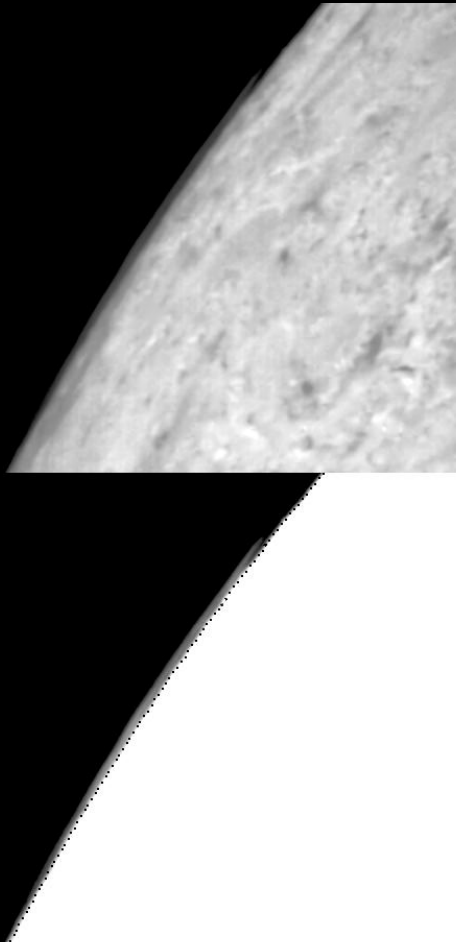
- Voyager had no means (no NIR spectrometer) of mapping surface ices - existing compositional data is earth-based, thus full-disk
- On Triton, ground-based data shows N_2 ice, with trace amounts of CH_4, CO_2 and CO ices

Compare to Pluto, KBOs - volatile inventory in the solar system

KBO Level 1 Science Objectives
Volatile Ices and Seasonal Processes

On a large KBO, is the climate is controlled by a nitrogen atmosphere in vapor equilibrium with surface frost?

- Look for existence of atmosphere (uv stellar and/or solar occultation data)
- *Images to look for limb haze*



Measure atmospheric pressure

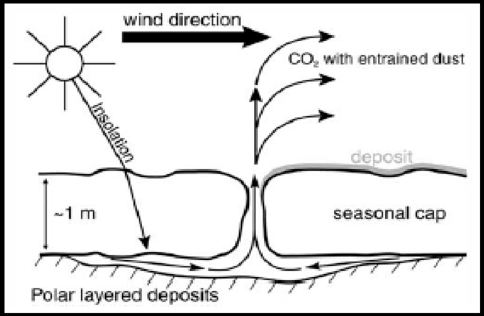
Measure surface temperatures - energy balance models

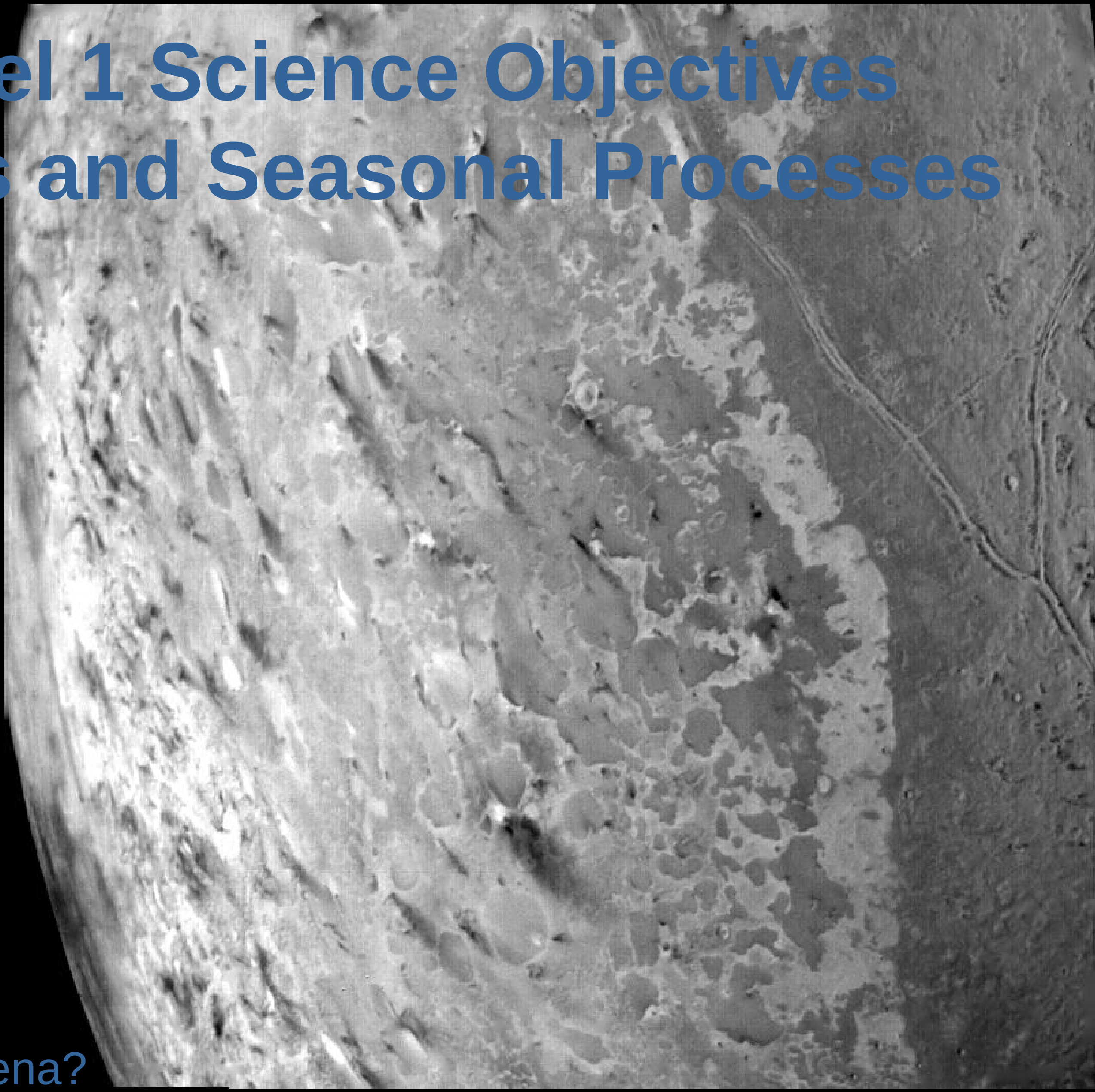
KBO Level 1 Science Objectives
Volatile Ices and Seasonal Processes

Recall Triton's astonishing geysers

What powers these plumes?

Similar to Mars?

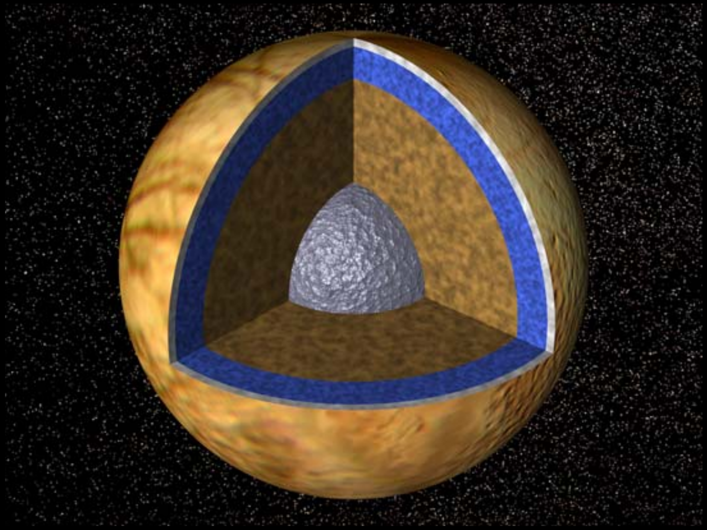




Is this a common phenomena?

If all that is required is translucent ice, plumes may not be unusual

KBO Level 1 Science Objectives Internal Structure



Does the KBO have an internal conducting layer?

This would be strong evidence for a liquid layer

> Measure inductive response of the KBO to the changing interplanetary magnetic field (IMF)
>
> Requires that Argo pass by just as solar wind boundary crosses the KBO
>
> Timing is not guaranteed, however results could be profound…

Derived Requirements

- Interior studies - Close flyby, magnetometer
- Surface geology - long focal length, high snr camera
- Surface Composition - near IR spectrometer
- Surface Properties - thermal mapper
- Atmosphere - ultraviolet spectrometer
- Seasons – near IR & thermal instruments

Presentation Outline

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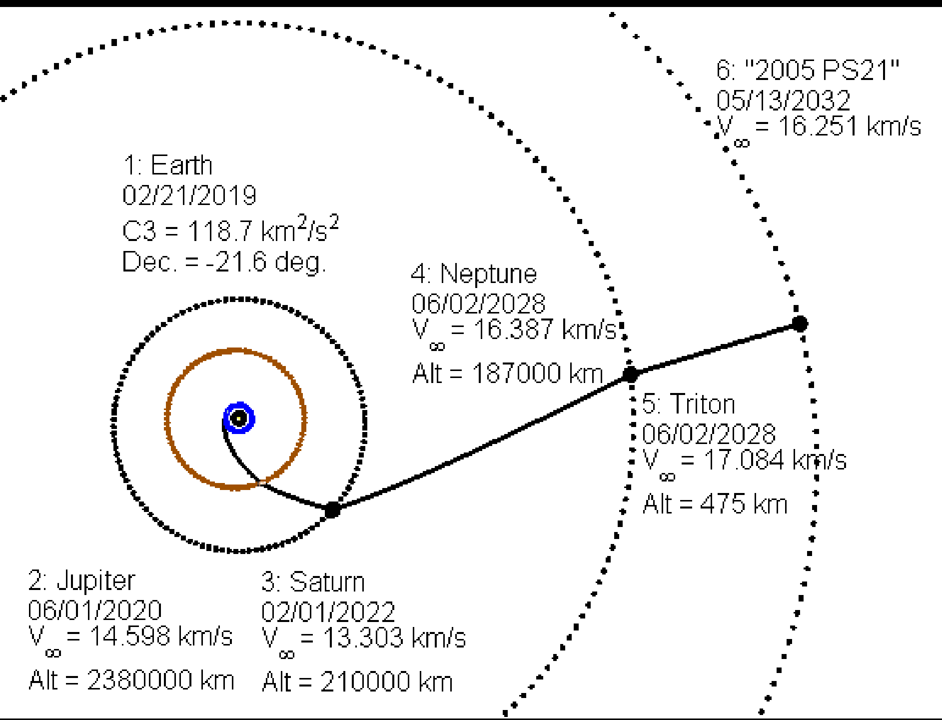
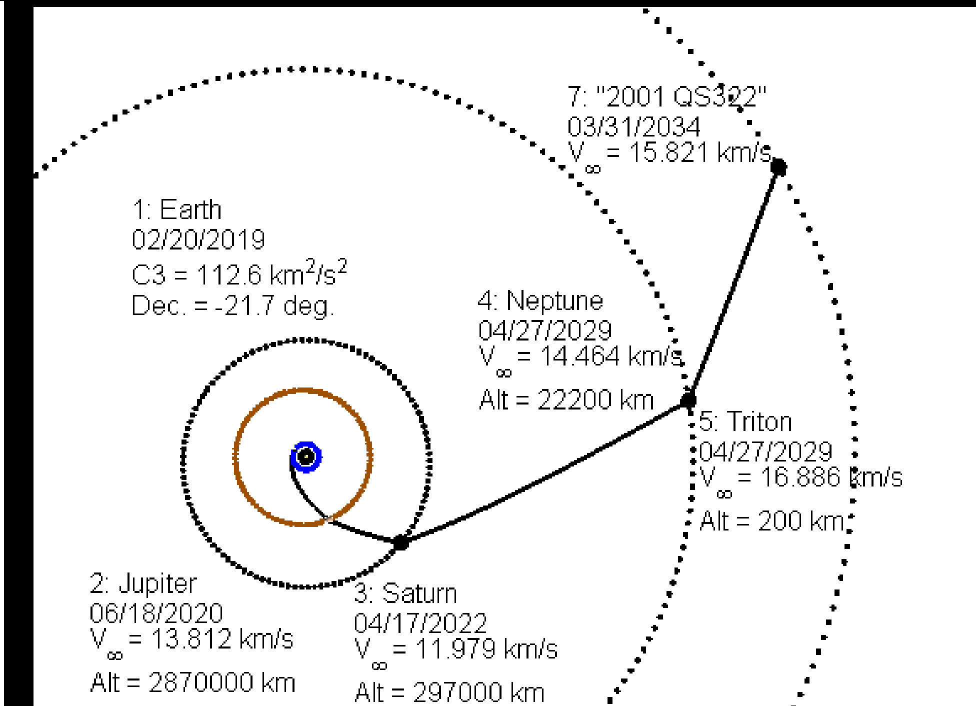
Example 2019 Launch Options

Voyager-like flight times to Jupiter and Saturn; even faster to Neptune



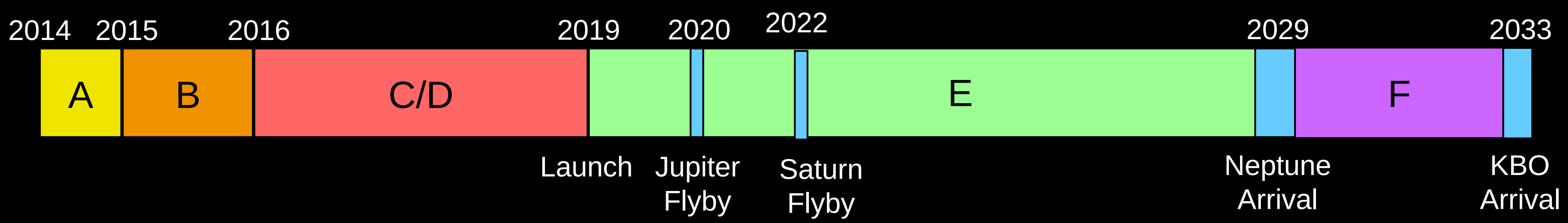


Time of Flight = 9.3 yr
Neptune flyby 2028
38S Neptune periapsis
KBO: 2005 PS21

Time of Flight = 10.2 yr
Neptune flyby 2029
21N Neptune periapsis
KBO: 2001 QS 322

Project Timeline

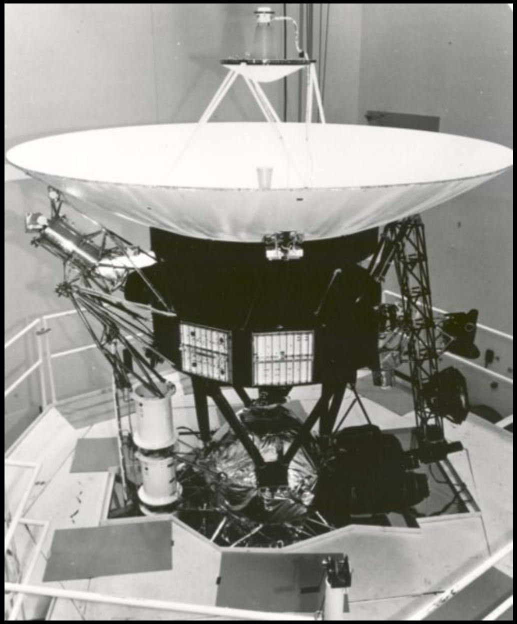
- Phases A, B, C/D, E, F (with science windows)



- Project start in 2014 for 2019 launch, ~9-year flight, 6-month Neptune science phase
- Launch opportunities occur between 2015 and 2019; such windows only occur every 12 years
- KBO arrival date depends on which KBO is selected

Modern Technology

- Voyager *launched* in 1977
- Voyager technology now >35 years old!
- Technology that could fly on Argo today (no technology development needed)



  - Visible camera with a CCD, not a vidicon
  - Near-IR array, not single channel bolometer
  - UV multi-pixel imaging, not single channel
  - Solid-state recorders, not tape recorders
  - Ka band for telecom and radio science

Spacecraft

- Envision a spacecraft similar to New Horizons spacecraft
  - Similar total mass and mass distributions (~400 kg dry mass)
  - Similar power needs (200 W)
- Must use nuclear power
- By maintaining similar scope we expect to remain in the New Frontiers budget envelope
  - Team X session needed to verify cost estimate
  - Costing only done by analogy at this point

Notional Argo Payload

Preliminary suite based on science traceability matrix

- High resolution visible camera - New Horizons (NH) level
- Near-Infrared spectrometer - NH heritage
- UV solar & stellar occ. spectrometer - reduced Cassini heritage
- Far-infrared imaging radiometer - Diviner heritage
- Magnetometer - ST5 (UCLA)
- Charged particle spectrometer – Messenger heritage
- Gimbaled high-gain antenna - heritage radio science instrument

Beyond this: explore trade space for other instrumentation in terms of science, cost, power, and mass

Payload mass example

8.6 kg Lorri

10.5 Ralph

5.0 UV

12.0 Diviner

10.0 Magnetometer w/ boom

3.5 Charged particle spectrometer

1.5 USO

51.1 kg Total

Figure 1. The MCS flight instrument photographed during calibration at JPL. Major elements of the instrument are identified.

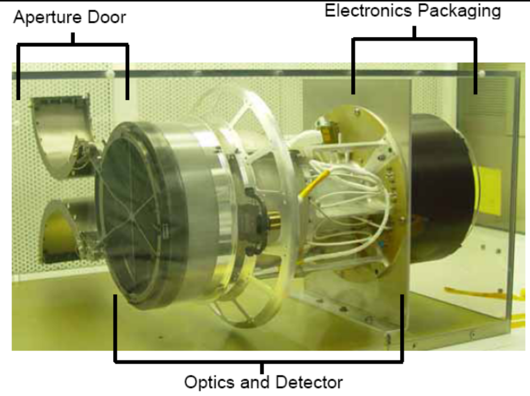


Figure 18. Photograph of SWAP instrument highlighting subassemblies

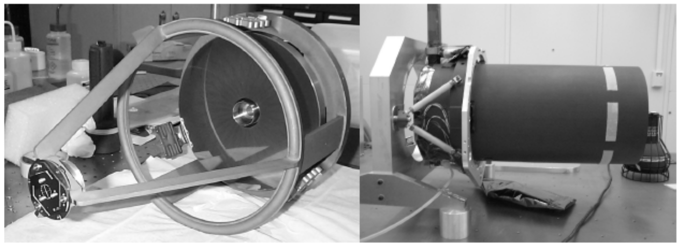


Figure 1 (left) LORRI telescope assembly, showing SiC mirrors and metering structure; (right) LORRI composite baffle and flexure mount on test stand

Telecommunication Options

- Use existing DSN facilities with flight-proven high gain antenna

- X-band downlink to a 70-m DSN station
  - Voyager 2 transmitted 21 kbps from Neptune (with arraying)
  - NH will send 0.7-1.2 kbps from Pluto
- Ka-band downlink
  - 14-16 kbps to a 70-m DSN station; ~4 kbps to 34-m
    - Assuming smaller 2 - 2.5 m HGA

- Design for simultaneous observation and downlink (gimballed high gain antenna)
  - Significantly improves science yield for one-time science opportunities
  - Saves costs in Phase E

Presentation Outline

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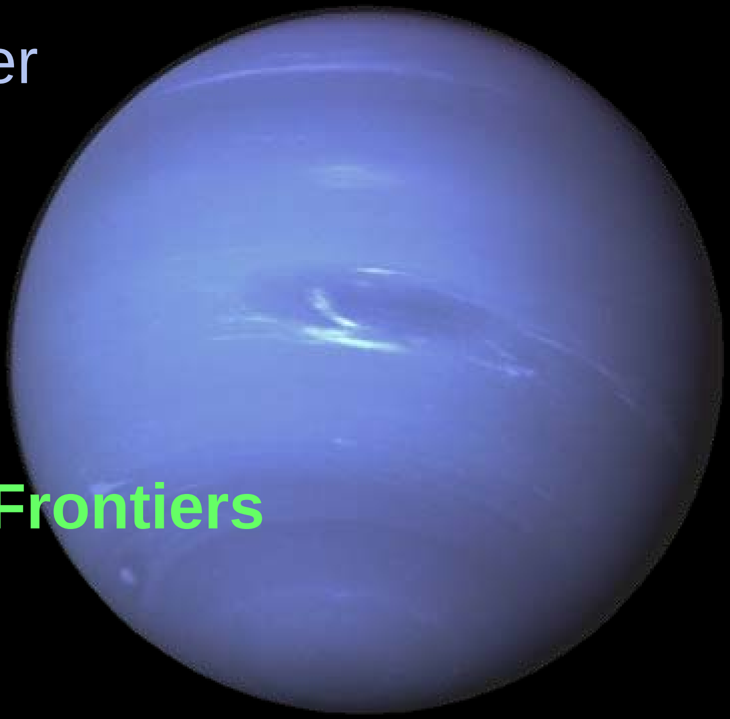
Summary

- **Neptune and Triton are compelling flyby targets**
  - Dynamic worlds, rich opportunities for new science discoveries
  - Trajectories identified with reasonable trip times and approach velocities
- A **KBO encounter** explores another primitive outer solar system body
  - Triton / KBO comparison
  - Pluto / KBO comparison
  - Numerous potential targets



- This **Mission** is **feasible for New Frontiers**
  - Key new science addressed by instrument package based on New Horizons heritage
  - Broad community appeal
  - Mission can be accomplished within New Frontiers cost cap

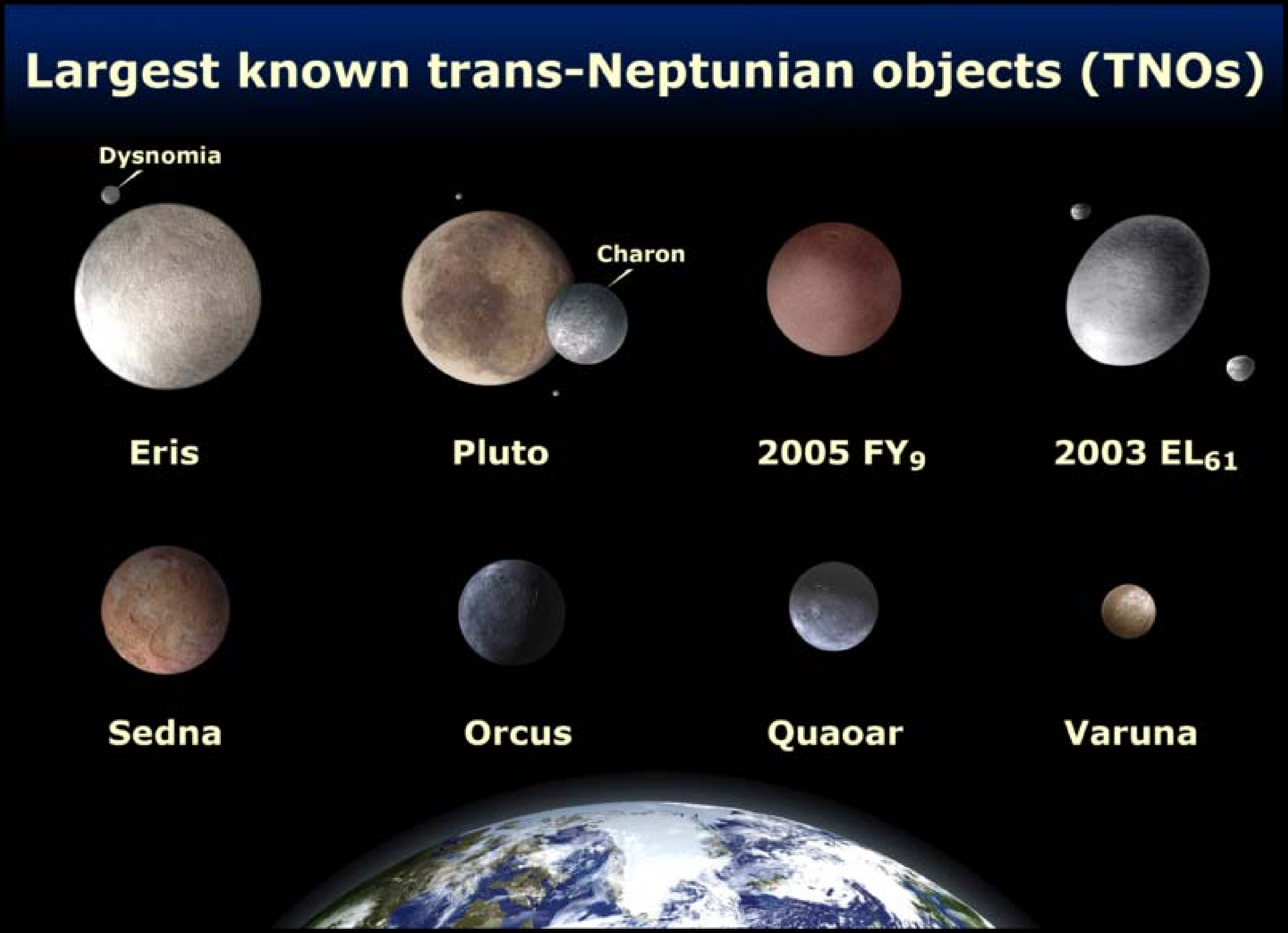
Giant Planets Panel and Outer Planet Satellites Panel have requested an RMA study of Neptune / Triton mission concepts that will fit within a New Frontiers cost cap

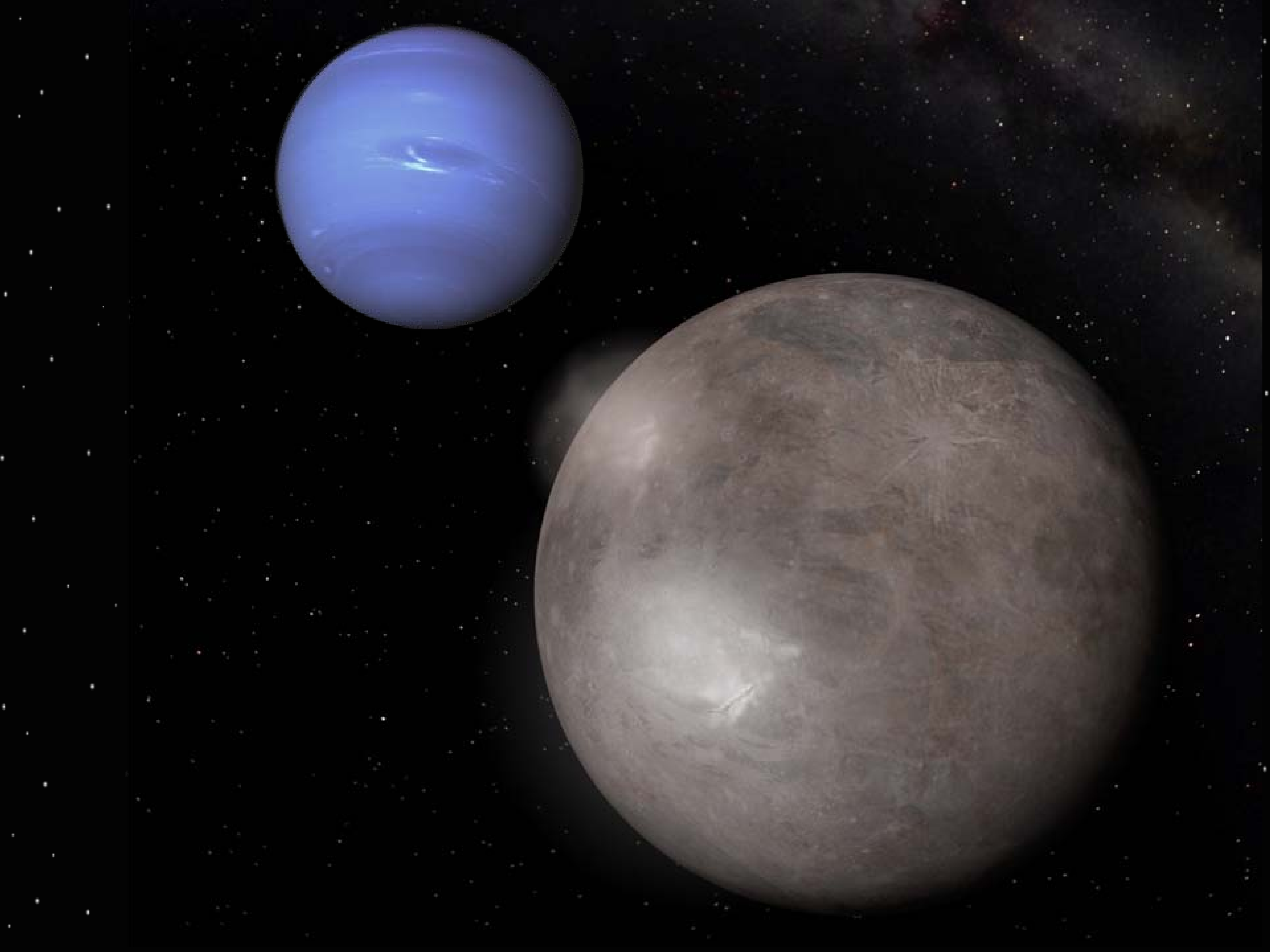
This is an invitation to the Primitive Bodies Panel to get involved

- Reinforce a flyby mission
- Look at Triton / KBO flyby geometry trades

Backup Slides

Neptune flyby enables KBO science





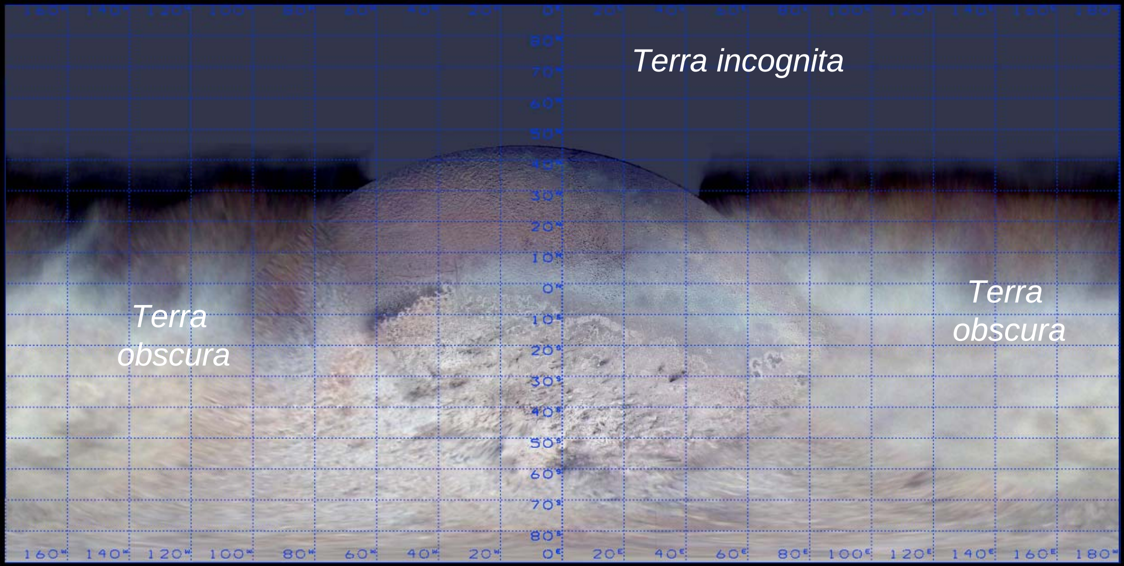
Triton Level 1 Science Objectives
Surface History

One side of Triton was seen only at a distance by Voyager (‘terra obscura”) and more of the northern hemisphere will be illuminated in 2029. Near-global surface coverage will extend the post-capture cratering history and other modification of Triton’s surface.

- More of Triton's northern hemisphere will be sunlit
  - Most of it was in seasonal darkness for Voyager

Terminator in 2027: 60°

Terminator in 1989 for VGR flyby: 45°



Anti-Neptune hemisphere observed only at low resolution (~60 Km) by Voyager. Best resolution ~1 km

Triton Level 1 Science Objectives
Atmospheric Processes

Triton's haze layer - what are the aerosol properties? Have they changed since Voyager? Where do they come from?

Winds distribute fine material across the surface - Have the winds changed direction? What does that imply for the sublimation process?

Image hazes at variety of phase angles and wavelengths to get particle size distribution

Map direction of fan of fines on the surface

What a Neptune flyby can do

- Neptune Measurement Goals
  - new visible and first-ever near-ir mapping of small-scale cloud dynamics and evolution
  - first detailed spatially-resolved spectroscopic mapping of cloud composition
  - first auroral ultraviolet images
  - first detailed infrared map
  - gravitational moments refined for interior models

Argo Mission Statement

Argo is the next step for outer solar system exploration, illuminating the genesis and evolution of the solar system by

- characterizing Kuiper Belt objects with diverse evolutionary paths ranging from captured KBO Triton to an *in situ* KBO, and
- accomplishing ground-breaking science at Neptune by opening a window on the dynamical nature of the atmosphere, rings, and magnetic field, and laying the groundwork for future ice-giant missions.

Why Now?

- Launch opportunity window from 2015 - 2019
  - Such windows occur every 12 years due to Jupiter gravity assist
- Waiting for flagship, or next window, will result in ~50-year gap in observations of a Triton dynamic system
- Neptune / Triton Flyby is complementary to eventual Neptune system orbiter
  - Outstanding ice giant science can also be obtained on the way to the KBO
- Exoplanetary Neptunes are now known to exist
  - Knowledge of local ice giants is substantially less than gas giants
- Current technology far surpasses Voyager-era technology
- Need time to resolve nuclear power issues

NF3 vs. NF4

New Frontiers 3		New Frontiers 4
AO out	2009	
	2010	
	2011	
	2012	
	2013	AO comes out 54 months after NF3 AO, write proposal
	2014	Downselect, Step 2 = Phase A
	2015	Phase B
	2016	Phase C/D
	2017	Phase C/D
	2018	Phase C/D
	2019	Launch in February
	2020	Backup launch in January

The schedule for NF4 is tight but not out of the question

Argo Launch Vehicle Requirements

- Criteria for launch vehicle choice
  - Desired trip time
  - Spacecraft mass
  - Launch trajectory C_3

C_3 (km^2/sec^2) ≡ square of the hyperbolic excess velocity

hyperbolic excess velocity ≡ craft's speed when it "breaks free of Earth's gravity" (*i.e.*, has just climbed out of Earth's gravity well)

- For a given launch vehicle:
  - higher C_3 → faster trip time BUT smaller spacecraft mass that vehicle can launch

Example trajectories aimed at Jupiter gravity assists (to Neptune, for instance)

C_3	Trajectory	Launch Vehicle and Mass	Trip time to Jupiter
25	Delta-VEGA (Propulsive Deep Space Maneuver, single Earth gravity assist)	*Smallest Atlas V can propel >1000 kg to this C_3*	*4-5 years*
80	Direct Earth-to-Jupiter, "just barely getting there"	*Mid-sized Atlas V can propel >500 kg to this C_3*	2-2.5 years
162	New Horizons, high-speed Jupiter gravity assist to Pluto	*Largest Atlas V with an additional Star-48 upper stage to propel 478 kg to this C_3*	13 months

- Currently examining trades among launch mass capacity, C_3, and trip time to Neptune (next slide)

Argo Discovery Opportunities

These measurement objectives are accessible to a flyby, but are impossible from L2, from near-Earth orbit, and from Earth even with a 30-m telescope

- Neptune
  - Small-scale cloud distribution
  - Atmospheric lightning
  - Magnetic field measurements in completely different orientation
  - First detailed compositional/spectral map
  - First detailed infrared map
  - Gravitational moments refined for interior models
- Overall unique viewing geometry
  - High-phase angle observations of atmospheres of Neptune & Triton, rings
- Triton & in situ KBO
  - Geologic mapping (and for Triton: mapping expanded beyond Voyager with improved resolution)
  - Surface evolution & atmospheric structure
  - Magnetic field
  - First compositional/spectral map
  - First detailed infrared map
- Nereid and perhaps other moons
  - First detailed images
- Ring system
  - Detailed structure and evolution

Of $1B Boxes and Bricks

"I heard that a joint NASA study by JPL and APL said NASA couldn't send any mission to the outer Solar System for less than $1B."

This is wrong.

The "Titan and Enceladus $1B Mission Feasibility Study" *actually* said:

Pg 1-1: "no missions to Titan or Enceladus that achieve at least a moderate understanding beyond Cassini-Huygens were found to fit within the cost cap of 1 billion dollars (FY'06)."

Relevance to Neptune: None

"But I also heard that the study said NASA couldn't even send a BRICK (spacecraft with no instruments) to the outer Solar System for less than $800M."

This is only partially correct.

CORRECT Pg 1-11: "Even the lowest cost mission studied [Enceladus flyby], without the cost of science payload, has a minimum expected cost of ~$800M."

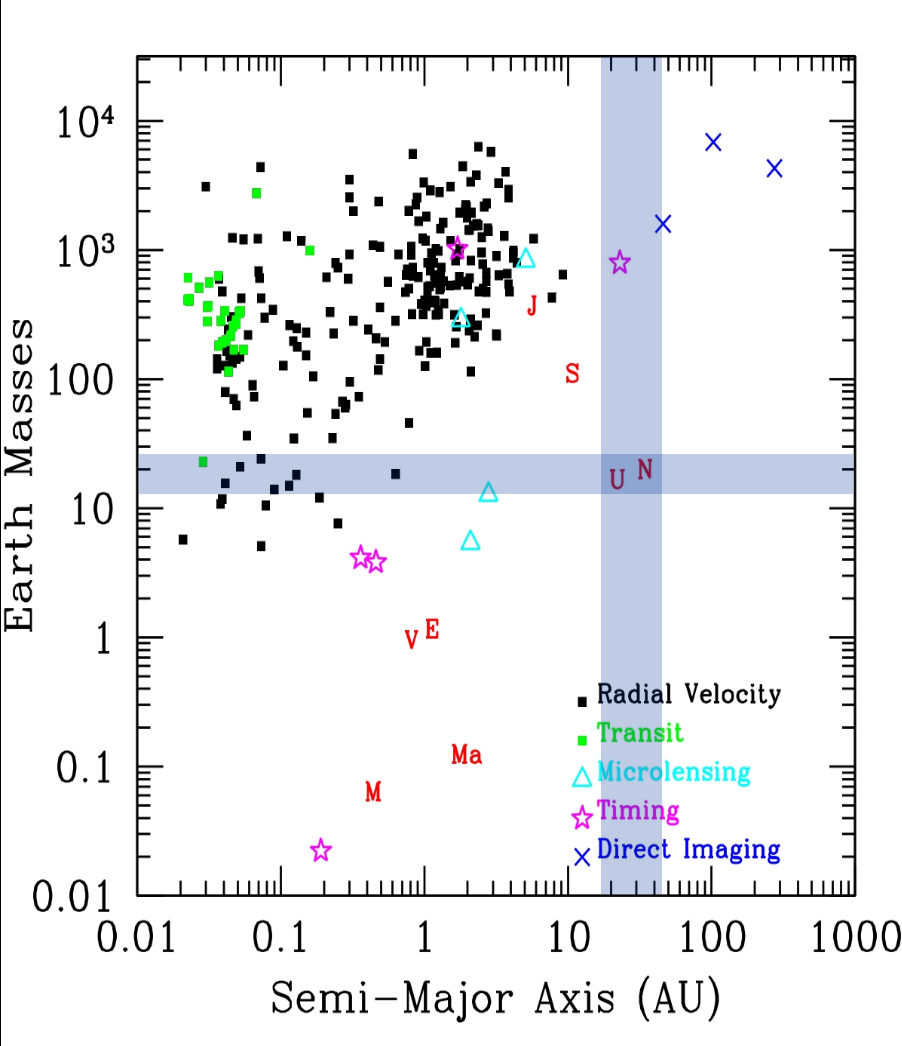
HOWEVER Pg 2-4: "[The Enceladus flyby's] design (and therefore cost) was uniquely derived using actual cost data from the NH mission."

Neptune cost mitigators: Can use an Atlas 541 instead of a 551. Do not require Star-48 upper stage. Other savings under study.

Result: $$ available for Argo science payload within $800M cap

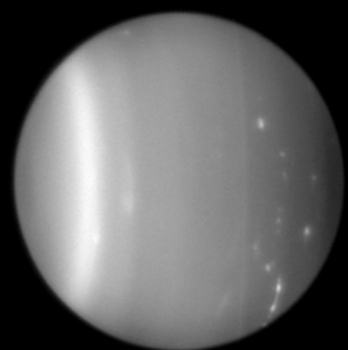
Why study Neptune? Broader Perspective

- Planetary System Architecture
  - Exoplanet population increasing dramatically
    - Growing number of ice-giant-mass objects
    - Pushing towards U/N equivalent distances in near future
      - Microlensing
      - Near-IR radial velocity
  - Knowledge of local ice giants extremely limited
    - Earth-based efforts extraordinarily challenging compared to J & S
      - Ice giants smaller
      - Ice giants much more distant
      - Ice giants colder



Which Ice Giant?

Uranus



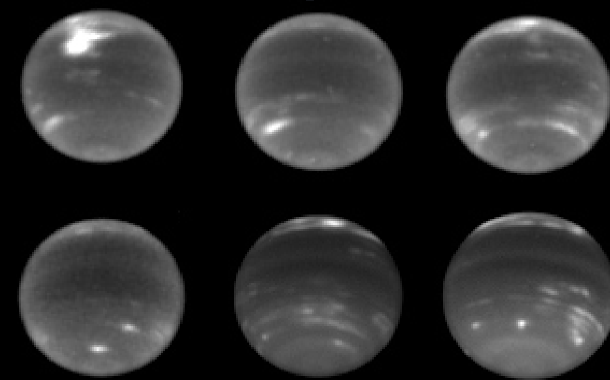
Uranus Pros

- Closer; shorter trip time
- Full retinue of original satellites
- Dynamic ring system
- Interesting magnetic field

Uranus Cons

- ▯💧♒□◆●♎ ♎□ ♦♒♏ ♐ly-by at equinox (2007, 2049) to get active atmosphere (see equinoctial above) and full

Neptune



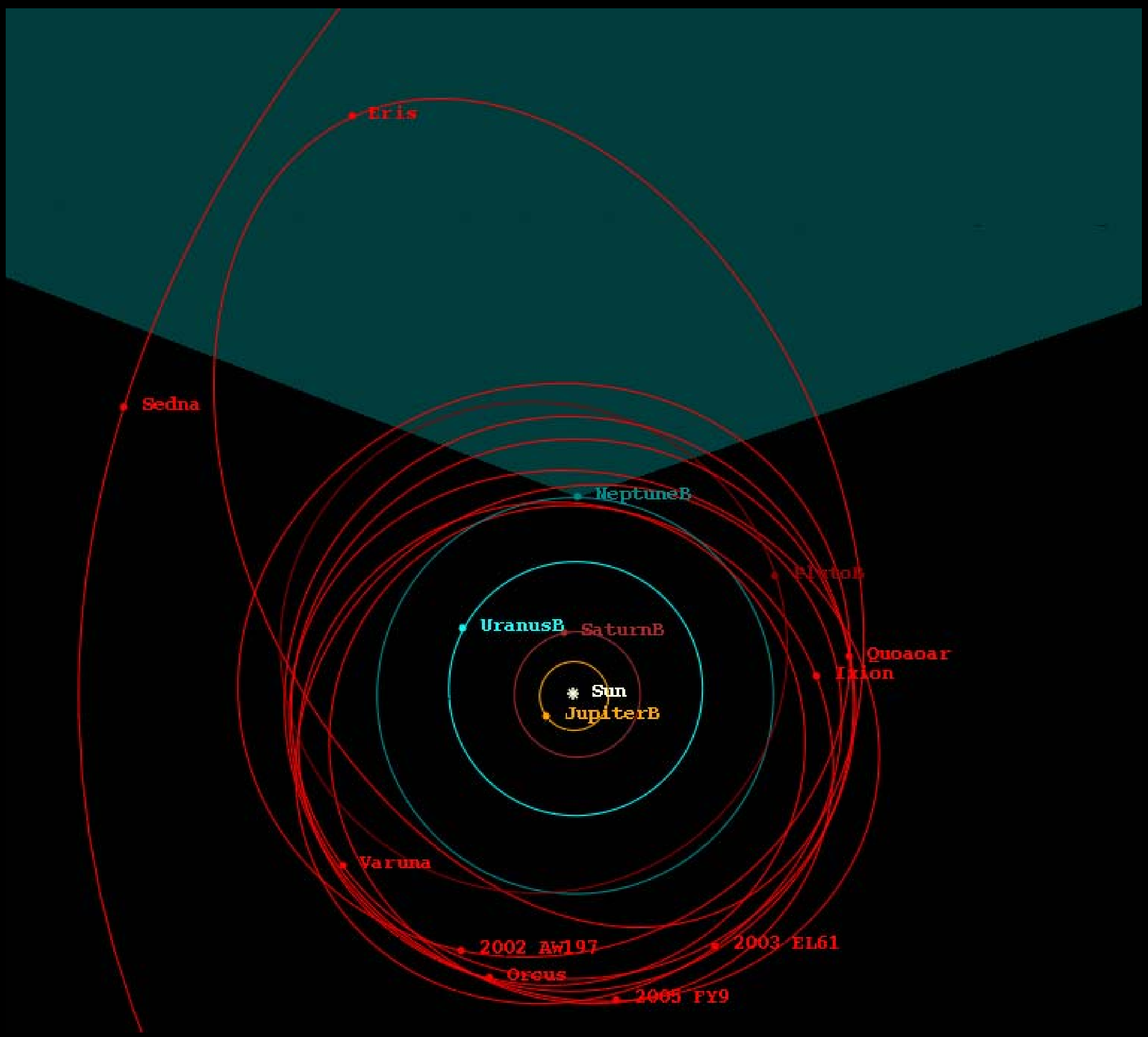
Neptune Pros

- Triton (captured KBO[?], active)
- Atmosphere always active
- Dynamic ring system
- Interesting magnetic field

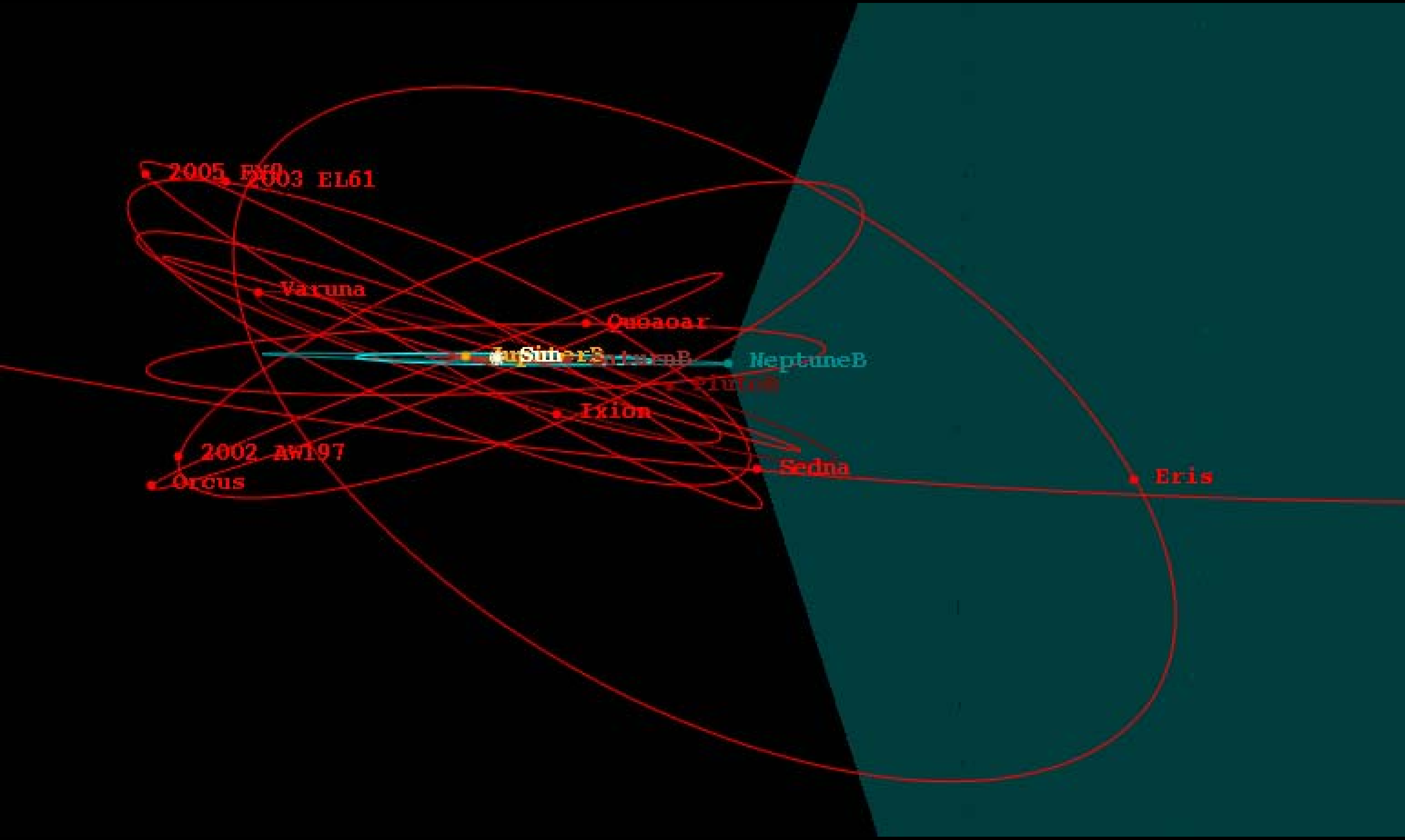
Neptune Cons

- Farther away; longer trip time

KBO Accessibility - top view



KBO Accessibility - side view



Triton Level 1 Science Objectives Interior

Triton has a youthful surface, likely substantially modified when Triton was captured by Neptune.

What does this tell us about the capture process? What level of heating did Triton experience? Did it differentiate?

- Determining the moment of inertia will tell us whether Triton has a differentiated core
- Detection of an intrinsic or induced magnetic field will tell us whether there is an internal conducting layer
  - Voyager closest approach was at an altitude of ~40k km, too far away to measure Triton's gravity field or any intrinsic magnetic field

Science Objective: fly close enough to Triton to measure the moment of inertia and detect the existence of an intrinsic or induced magnetic field, > 0.5 R_T

Decadal Priorities, 1 of 3

Class of Question	Scientific Themes	Earth-Based Orbiting Facilities	Neptune POP	Analysis and Modeling	Lab	ARGO
	Theme 1. ORIGIN AND EVOLUTION					
	Solar-System Giant Planets					
Paradigm altering	How did the giant planets form?	x	xxx	xx	xx	xx
"	What are the orbital evolutionary paths of giant planets?	o	xxx	xxx	o	x
Pivotal	What are the elemental compositions of the giant planets?	x	xxx	xx	x	xx
"	What are the internal structures and dynamics of giant planets?	xx(1)	xxx	xxx	x	xx
	Extrasolar Giant Planets and Brown Dwarfs					
Pivotal	How can we use the giant planets in our solar system to calibrate spectroscopic observations (optical, infrared, radio) of extrasolar giant planets?	xx	xxx	xxx	x	xxx

Decadal Priorities, 2 of 3

Class of Question	Scientific Themes	Earth-Based Orbiting Facilities	Neptune POP	Analysis and Modeling	Lab	ARGO
	Theme 2. INTERIORS AND ATMOSPHERES					
	Interiors					
Pivotal	What is the nature of phase transitions within the giant planets?	xx(1)	xxx	xx	x	xx
"	How is energy transported through the deep atmosphere? Do radiative layers exist?	xx(1)	xxx	xx	x	xx
"	How and where are planetary magnetic fields generated?	x(1)	xxx	xxx	o	xxx
Foundation building	What is the nature of convection in giant planet interiors?	xx(1)	xxx	xxx	o	xx
"	How does the composition vary with depth?	x(1)	xxx	xx	o	xx

Decadal Priorities, 3 of 3

Class of Question	Scientific Themes	Earth-Based Orbiting Facilities	Neptune POP	Analysis and Modeling	Lab	ARGO
	Theme 2. continued: *Atmospheres*					
Pivotal	What energy source maintains the zonal winds, and how do they vary with depth? What role does water and moist convection play?	x	xxx	xx	x	xxx
"	What physical and chemical processes control the atmospheric composition and the formation of clouds and haze layers?	x	xxx	xx	x	xxx
Foundation building	How and why does atmospheric temperature vary with depth, latitude, and longitude?	x	xxx	xx	x	xxx
"	How does the aurora affect the global composition, temperature, and haze formation?	x	x	xx	x	x
"	What produces the intricate vertical structure of giant planet ionospheres?	x	xx	xx	x	xx
"	At what rate does external material enter giant planet atmospheres, and where does this material come from?	x	o	xx	x	o
"	What can organic chemistry in giant planet atmospheres tell us about the atmosphere of early Earth and the origin of life?	x	x	xx	x	x

Power Source Options

	BOL Electric Power (W)	EOL (14 yrs) Electric Power (W)	Unit Mass (kg)	Estimated Unit Cost	# Units Needed
MMRTG	115	103	44	$35M	3 (*or even* 2)
ASRG	140	127	20	$20M	2
GPHS-RTG (unit F-5)	300 *	228	55	?	1

* New Horizons' GPHS-RTG used a mix of old and new Pu; BOL power for that unit was only 240 W

If NF-03 AO excludes nuclear-powered missions,
then *no* outer Solar System missions are possible other than flagship.
If NF-03 AO is broader, missions may be possible (J-N-KBO; J-S-N-KBO).

KBO Level 1 Science Objectives
Surface History

Triton's surface is only lightly peppered with craters

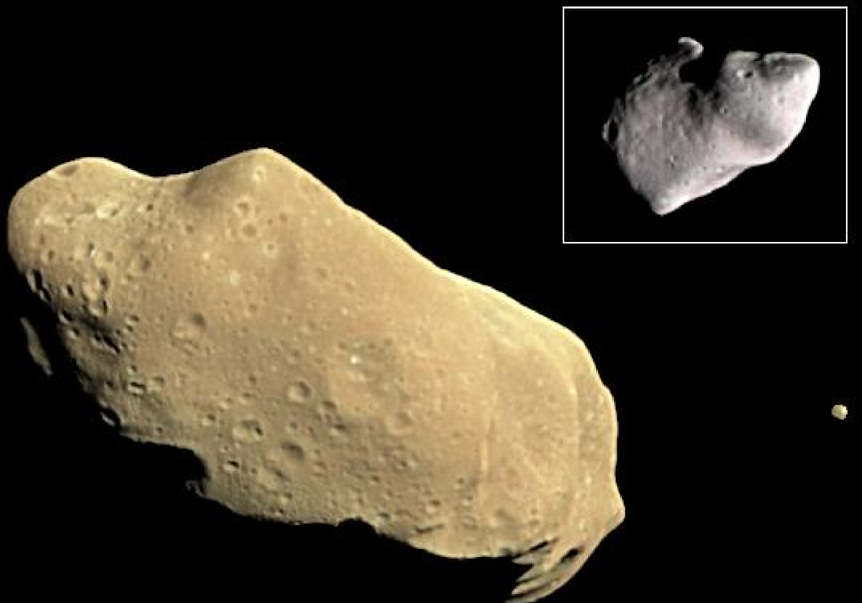
If Triton was captured very early in the history of the Solar System, aided by an extended proto-Neptunian atmosphere, then tidal evolution to a circular orbit and differentiation should have been complete in order 10^8 yrs, followed by billions of years of impact cratering. Yet the surface is lightly cratered. Was it actually captured much more recently?

What is the history of bombardment

Asteroid Belt

Gaspra

- Eros and Mathilde



Ida and its moon, Dactyl