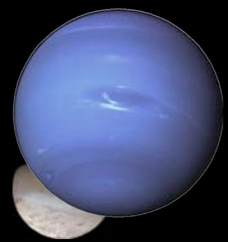
Argo

Voyage Through the Outer Solar System



Candice Hansen (JPL)

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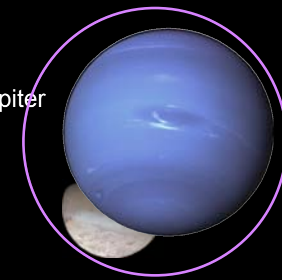
Neptune: the gateway to the Kuiper Belt

Innovative Mission Concept for New Frontiers 04

- Fly by a Trojan (no Jupiter GA) or Jupiter
- Gravity assist from Saturn
- Fly by Neptune/Triton system
- Fly by a scientifically-selected Kuiper Belt Object



Key Characteristics

- Focused science mission
- Simple mission profile
- Current instrument technology *(NH)*
- Current spacecraft technology *(NH)*
- Capable payload
- Radioisotope power

Argo and Decadal Priorities

NOSSE Report: "Opening New Frontiers in Space: Choices for the Next New Frontiers Announcement of Opportunity"

In order for the New Frontiers Program to remain healthy over the long run, it must maintain an influx of new ideas and grow the applicant pool for new missions.

Selected
A. Kuiper Belt – Pluto Explorer ✓
B. Jupiter Polar Orbiter with Probes

Three Remaining
1. South Pole-Aitkin Basin Sample Return
2. Venus In Situ Explorer
3. Comet Surface Sample Return

Five Additional
4. Mars Network Science
5. Trojan/Centaur Reconnaissance ✓
6. Asteroid Rover/Sample Return
7. Io Observer
8. Ganymede Observer

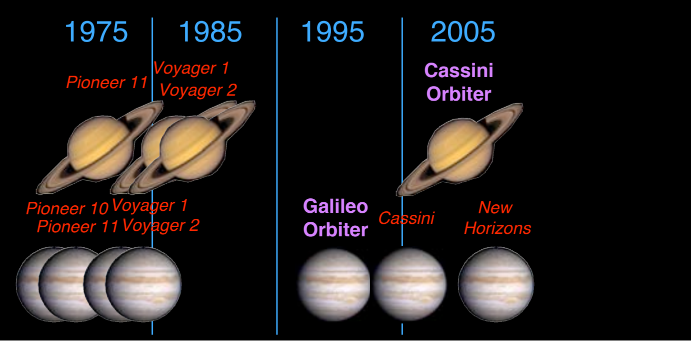
New
Innovative Mission Concepts

- *mission options outside the 3 remaining and 5 additional medium-sized decadal missions* ✓
- *spurred by major scientific and technological developments made since the decadal survey* ✓
- *offer potential to dramatically advance fundamental scientific goals of the decadal survey* ✓
- *accomplish scientific investigations well beyond the scope of the Discovery program* ✓

✓ = Argo

Argo and Decadal Priorities

- Planetary Decadal Survey also explicitly mentions Neptune/Triton in multiple chapters
  - Giant Planets, Large Satellites, Primitive Bodies
- Neptune in far future because Flagship-class orbiter assumed



Argo Neptune Flyby is Crucial

The Neptune flyby enables the opportunity to:

visit a Trojan

swing past Saturn

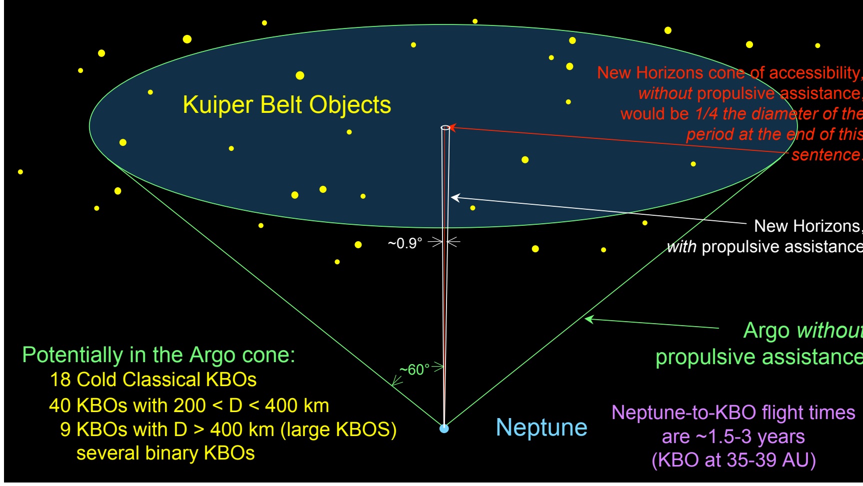
fly by Neptune/Triton

AND continue on to a KBO

The Neptune flyby also permits selection of the KBO with highest scientific interest

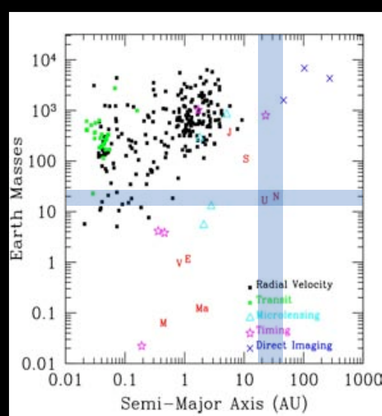
Access to Kuiper Belt Objects

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



Compelling Neptune science

- 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
  - No currently planned mission to Neptune until an orbiter >2045
    Argo will set the stage for a future orbiter



Adapted from the ExoPlanet Task Force Presentation to the AAS, Austin, TX (Jan 2008)

Argo Science Opportunities

Fundamental New Science

- Comparative planetology of multiple KBOs: Pluto (large *in situ*), NH's KBO, Argo's Triton (captured), Argo's KBO (scientifically-selected)
- First surface geology of a Trojan
- First detailed images of Neptune's atmosphere in a new season
- First detailed images of Triton's atmosphere after significant change
- First measurement of stability of an offset/tilted magnetic field
- First detailed images of Neptune's ring system in new dynamical state

Incremental Science

- Ice giant interior measurements
- Small satellite science

Engages a significant fraction of the planetary community

Significant small icy body science as per decadal objectives
Progress on decadal Neptune science objectives
Sets the stage for a future Neptune System Flagship Orbiter
Achievable within New Frontiers resources

Why New Frontiers 04?

- Launch options between 2017 and 2020
  - Such windows occur every 12 years due to giant-planet gravity assist
- Neptune flagship orbiter precludes a KBO flyby (and likely no Trojan)
- Fills in the >50-year observational gap of a dynamic system
  - Will enable linking of future flagship to past flyby
  - The season has already changed on Neptune (solstice was 2005)
  - Loss of expertise from Voyager-era scientists from the 1989 Neptune flyby
- Exoplanetary Neptunes are now known to exist
  - Knowledge of local ice giants is substantially less than gas giants

Argo Launch Windows for Fast Flights

- Preliminary
- Searched 2013-2027
- Two criteria

V_∞ <17 km/sec at Neptune arrival

Time of Flight <10 yrs

Both criteria met

Criteria not met

FF launch window ~2 yrs long
The next window opens in 2027

Mission	Trip Time	V_∞ (km/sec)
Argo w/ JGA	8-10 yrs	12 - 16
Voyager	12 yrs	17
New Horizons	9.5 yrs	14

Launch	Launch Vinf	Launch C3	Arrival Date	Arrival Vinf	TOF (yrs)
8-Oct-2013	11.0	121.0	12-Feb-2030	11.0	16.4
26-Dec-2017	10.5	110.3	26-Apr-2031	10.1	13.3
26-Dec-2017	11.0	121.0	2-Jul-2027	16.3	9.5
26-Dec-2017	11.0	121.0	1-Jan-2030	11.8	12.0
26-Dec-2017	11.0	121.0	29-Dec-2030	10.5	13.0
5-Jan-2018	9.5	90.3	23-Mar-2029	13.0	11.2
5-Jan-2018	10.0	100.0	1-Sep-2027	15.9	9.7
5-Jan-2018	10.5	110.3	7-Nov-2026	17.8	8.8
5-Jan-2018	11.0	121.0	17-Apr-2026	19.4	8.3
15-Jan-2018	9.5	90.3	6-Feb-2028	15.0	10.1
15-Jan-2018	10.0	100.0	14-Dec-2026	17.6	8.9
15-Jan-2018	10.5	110.3	7-Apr-2026	19.5	8.2
15-Jan-2018	11.0	121.0	9-Oct-2025	21.0	7.7
25-Jan-2018	9.5	90.3	26-Mar-2030	11.5	12.2
25-Jan-2018	10.0	100.0	5-Jul-2027	16.3	9.4
25-Jan-2018	10.5	110.3	3-Jun-2026	19.0	8.4
25-Jan-2018	11.0	121.0	8-Oct-2025	21.0	7.7
4-Feb-2018	10.5	110.3	21-May-2030	11.3	12.3
4-Feb-2018	11.0	121.0	26-Apr-2027	16.7	9.2
30-Jan-2019	11.0	121.0	18-Nov-2028	14.1	9.8
9-Feb-2019	10.0	100.0	29-Oct-2029	12.5	10.7
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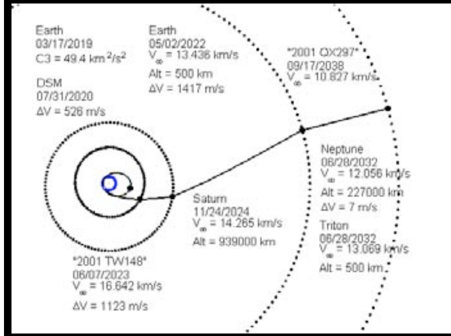
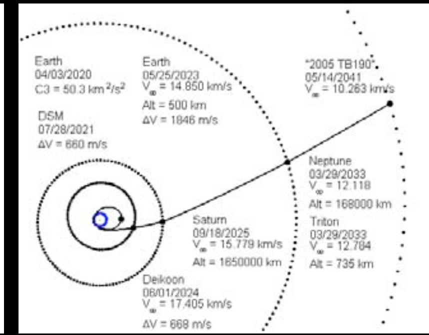
1-Mar-2019	10.0	100.0	15-Oct-2032	8.8	13.6
1-Mar-2019	10.5	110.3	17-Feb-2028	15.8	9.0
1-Mar-2019	11.0	121.0	2-Nov-2026	19.3	7.7
24-Nov-2027	11.0	121.0	26-Mar-2043	10.9	15.3

Sample Trojan-Triton-KBO trajectories

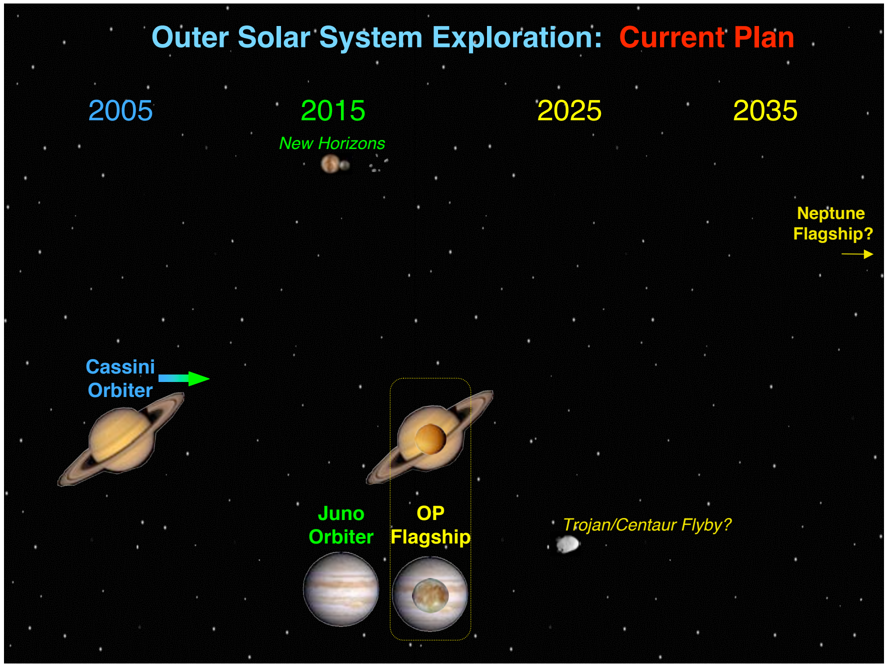


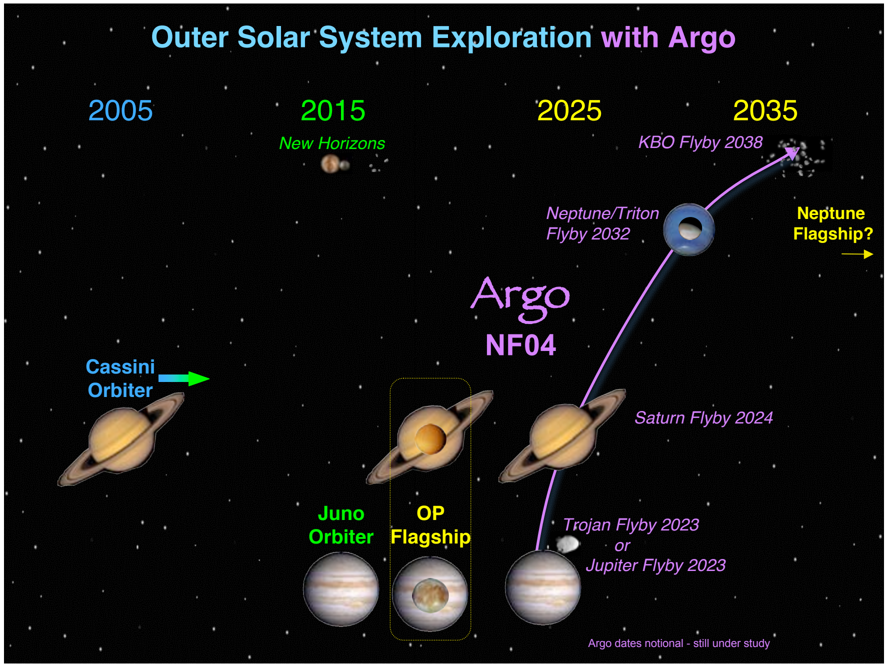
A531/Bi-prop = 755 kg (delivered mass at KBO)
Trojan: 2001 TW148, D ~ 20 km
Triton: flyby alt 500 km at V_∞ = 13 km/s
KBO: 2001 QX297, D ~ 150–350 km
Cold Classical



A531/Bi-prop = 720 kg (delivered mass at KBO)
Trojan: Deikoon, D ~ 50 km
Triton: flyby alt 735 km at V_∞ = 13 km/s
KBO: 2005 TB190, D ~ 250–600 km
Large KBO

Trojan trajectories increase flight time, e.g., from 10 yrs to 13+ yrs





BACK UP CHARTS

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."

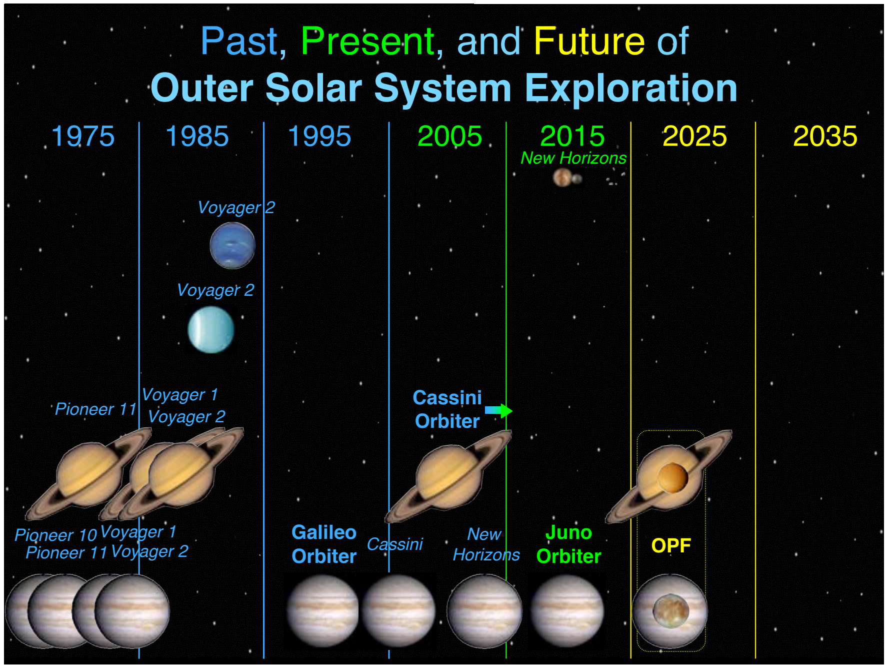
HOWEVER Pg 2-4: "[The Enceladus flyby's] design (and therefore cost) was uniquely derived using actual cost data from the NH mission."

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

Argo Mission Concept Team

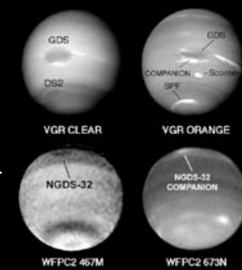
- Principal Investigator (PI): Candice Hansen, Triton science
- Deputy PI: Heidi Hammel, Neptune science
- Project Scientist: Linda Spilker, ring science
- Senior Science Advisor: Ed Stone
- Co-Investigator: John Stansberry, KBO science
- Co-Investigator: Krishan Khurana, magnetospheric science
- Mission Architect: Tom Spilker
- Trajectory Design: Nathan Strange
- Instrument Leads: Alfred McEwen, Don Banfield, Amanda Hendrix



Argo Science Objectives

Nearly all aspects of the Neptune system detectable from Earth have changed significantly since Voyager fly-by in 1989

- Neptune's atmosphere shows fundamental differences in large-scale structure
  - No Vgr GDS, significant atmospheric evolution on <5-yr timescale; evidence for stratospheric heating since Voyager



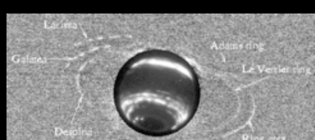
Neptune Measurement Goals

- 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

Argo Science Objectives

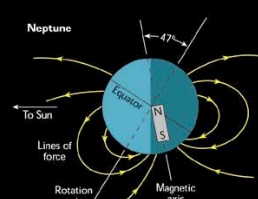
Nearly all aspects of the Neptune system detectable from Earth have changed significantly since Voyager fly-by in 1989

Ring system science objectives (plus small satellites)



- The ring system has changed
  - Arcs evolved within <8 yrs

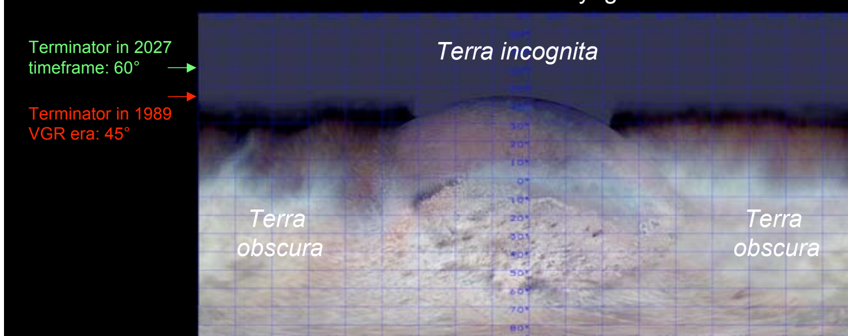
- Neptune's Magnetosphere
  - Very complex and undetectable from Earth



Argo Science Objectives - Triton

Map regions of Triton seen only from a distance by Voyager ("terra obscura") -- as well as more of Triton's northern hemisphere -- in order to extend the post-capture cratering history and reveal surface modification.

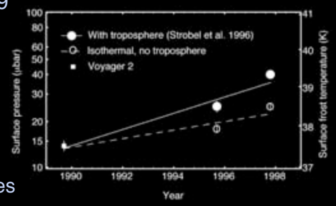
- More of Triton's northern hemisphere will be sunlit
  - Most of it was in seasonal darkness for Voyager



Argo Science Objectives - Triton

Argo will map the distribution of ices on Triton’s surface and measure the atmospheric pressure to capture another point in time for modelling climate change on an icy body

- Triton's atmosphere has changed significantly since the Voyager flyby in 1989
  - *Nitrogen and methane ices move seasonally from hemisphere to hemisphere, causing the pressure of the atmosphere to vary with seasonal*

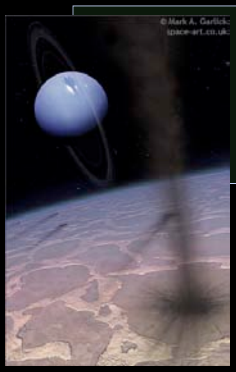


Measurement Objectives

- 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

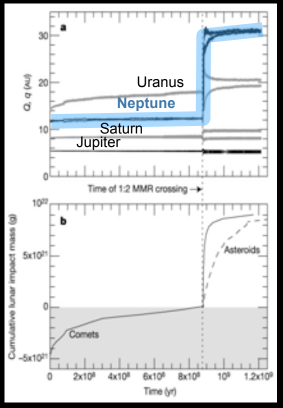
Science Motivation

- Relevance to life and habitability
  - "The giant planet story is the story of the Solar System." *
    - Direct implications for habitability
    - Delivery of volatiles to inner solar system



– Argo can search for organic compounds on Triton's active surface

* From the NAS NRC study: *New Frontiers in the Solar System: An Integrated Exploration Strategy*, often called the "Planetary Decadal Survey"



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.

Argo Science Objectives - KBO

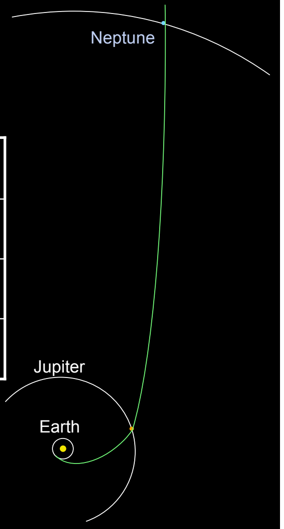
- Determine comparative properties of captured KBO Triton and a KBO *in situ*
- Expand the diversity of volatile-rich small bodies in the outer solar system
  - Between Argo and New Horizons (shown here) we will double the number of explored KBOs
    - Pluto
    - New Horizons *in situ* KBO
    - Triton
    - Argo *in situ* KBO

Getting to Neptune

- Option A - Jupiter-Neptune
  - Trip time of 8-10 years
  - Approach velocity of order 12-16 km/sec

Mission	Trip Time	Approach Velocity (km/sec)
Option A	8-10 yrs	12 - 16
Voyager	12 yrs	17
New Horizons (Pluto)	9.5 yrs	14

- May even have Jupiter-Saturn-Neptune trajectories (under study)
- Exploring trades between trip-time and approach velocities (next slide)



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).

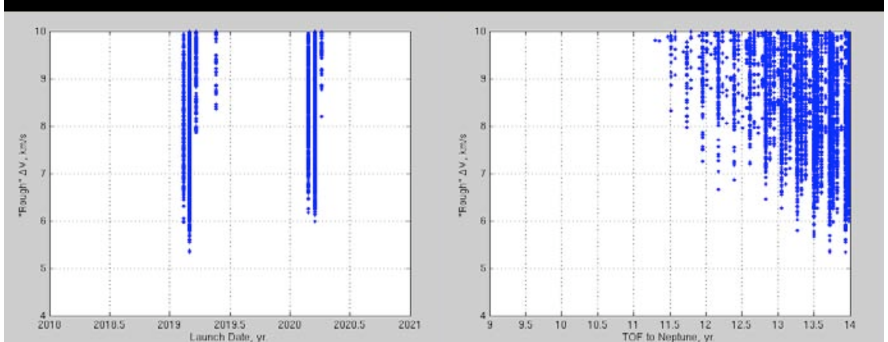
Notional Argo Instrumentation Options

Preliminary suite based on science traceability matrix

- High resolution visible camera - New Horizons (NH) or reduced Cassini heritage - Alfred McEwen
- Near-Infrared spectrometer - NH heritage - Don Banfield
- UV solar & stellar occ. spectrometer - reduced Cassini heritage - Amanda Hendrix
- Far-infrared linear radiometer - Diviner heritage - David Paige
- Magnetometer - replaces NH dust instrument - Krishan Khurana
- Charged particle spectrometer - NH heritage
- Gimballed high-gain antenna - heritage radio science instrument

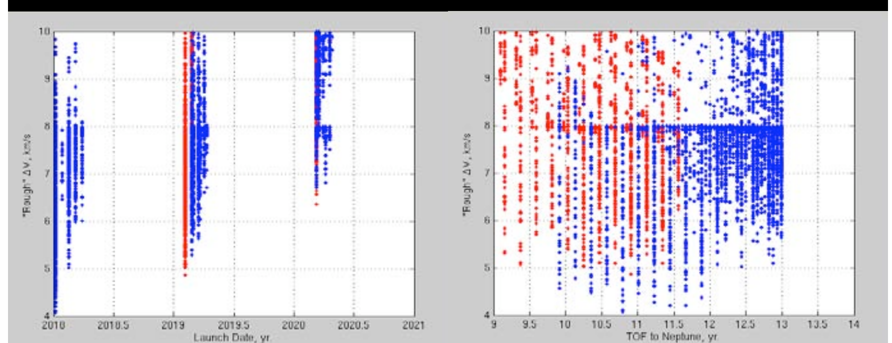
Beyond this: explore trade space for other instrumentation in terms of science, cost, power, and mass

UNCONVERGED TRAJECTORIES Trojan, Triton, and KBO



Trojan D > 10 km, KBO D > 400 km or cold-classical
ΔV optimizes down, TOF not likely to decrease by more than a year.

UNCONVERGED TRAJECTORIES Triton and KBO (no Trojan)



Jupiter still available for 2018 launch
• Red dots require upper stage