TRIDENT

Taking Remote and In-situ Data to Explore Neptune and Triton

Outer Planets Assessment Group
January 14, 2014

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Mentors: Charles Bundy and Karl Mitchell

What is the JPL PSSS?

Each year NASA/JPL selects a group of scientist and engineering graduate students/post-docs to complete a week-long mission concept study.

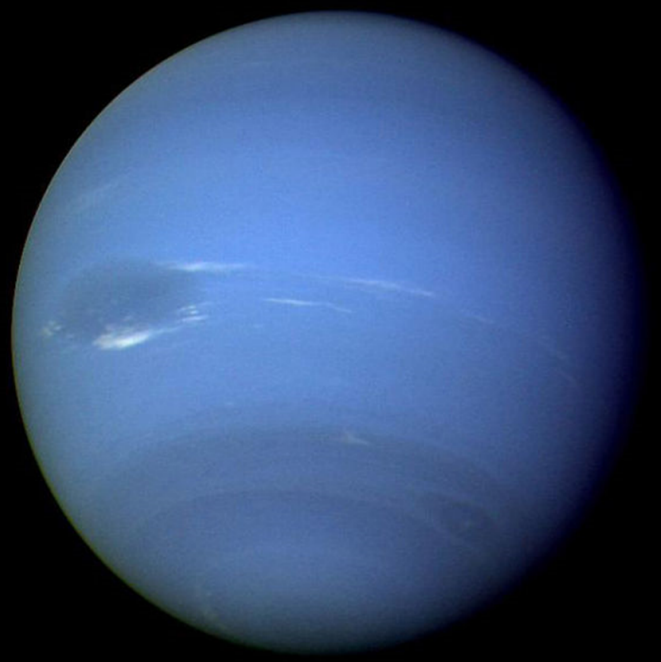
Follow NASA Science Mission Directorate Announcement of Opportunity
New Frontiers 2009 (< FY2015 $1.5B)

Team X
JPL's Advanced Projects Design Team

Present Results
Propose mission concept to authorization review to receive feedback

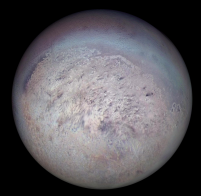
Apply today! (deadline: April 1)
https://pscischool.jpl.nasa.gov/index.cfm

Neptune – Triton system



Neptune

- Fastest winds in the Solar System
- Dynamic storms
- Offset tilted dipole – 16 hour sweep
- Represents class of least explored planets



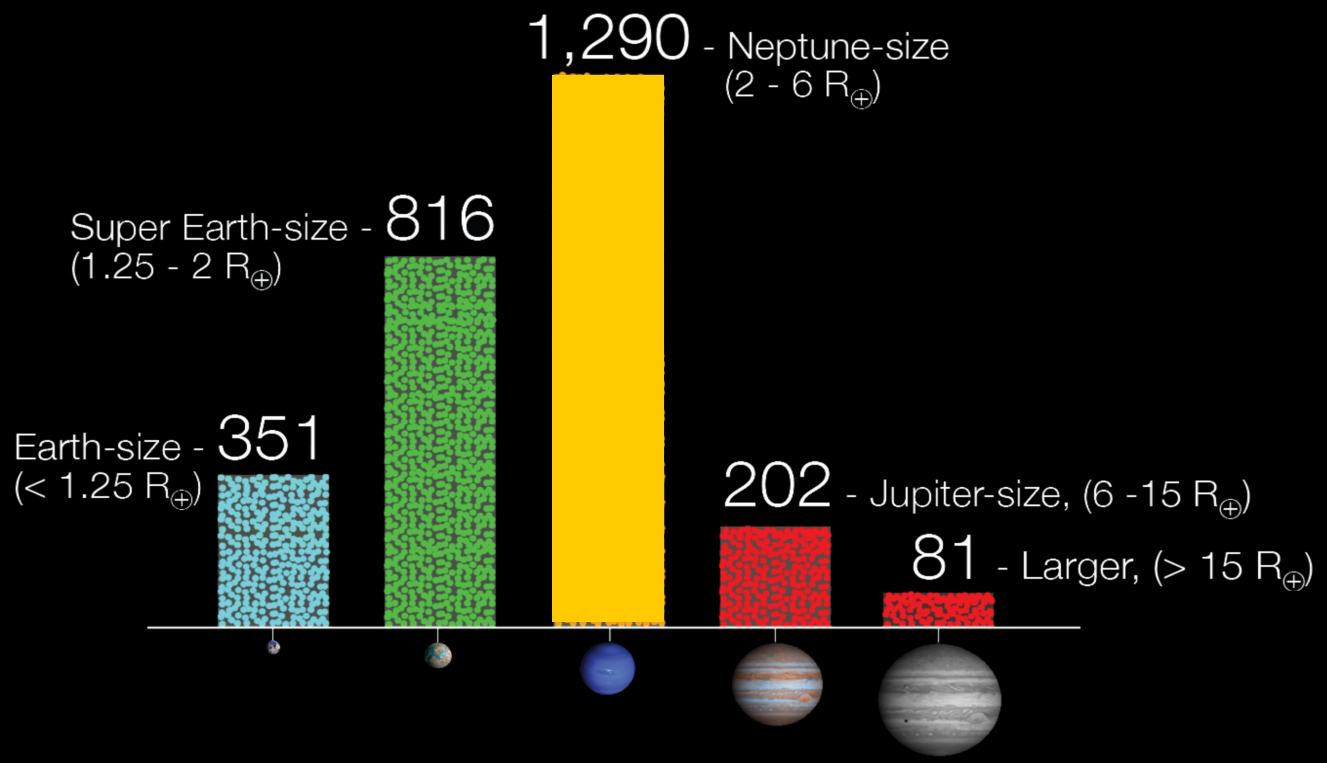
Triton

- Captured KBO
- Active plumes – little tidal heating
- Potential subsurface ocean

Neptune as our local exoplanet

Exoplanet discoveries have grown exponentially since Voyager 2 encounter at Neptune

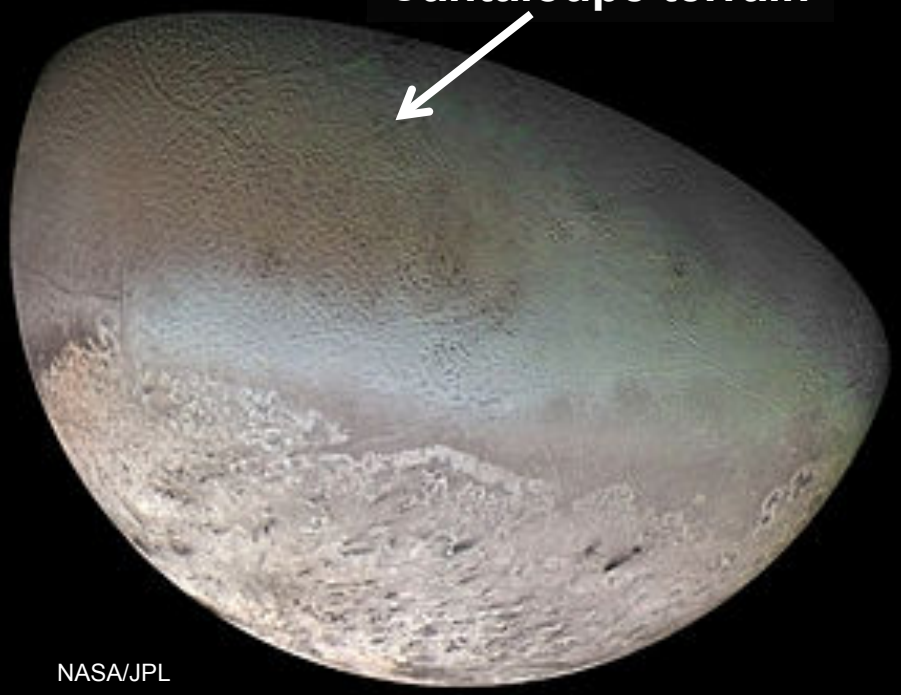
Neptune-size bodies most common exoplanet class



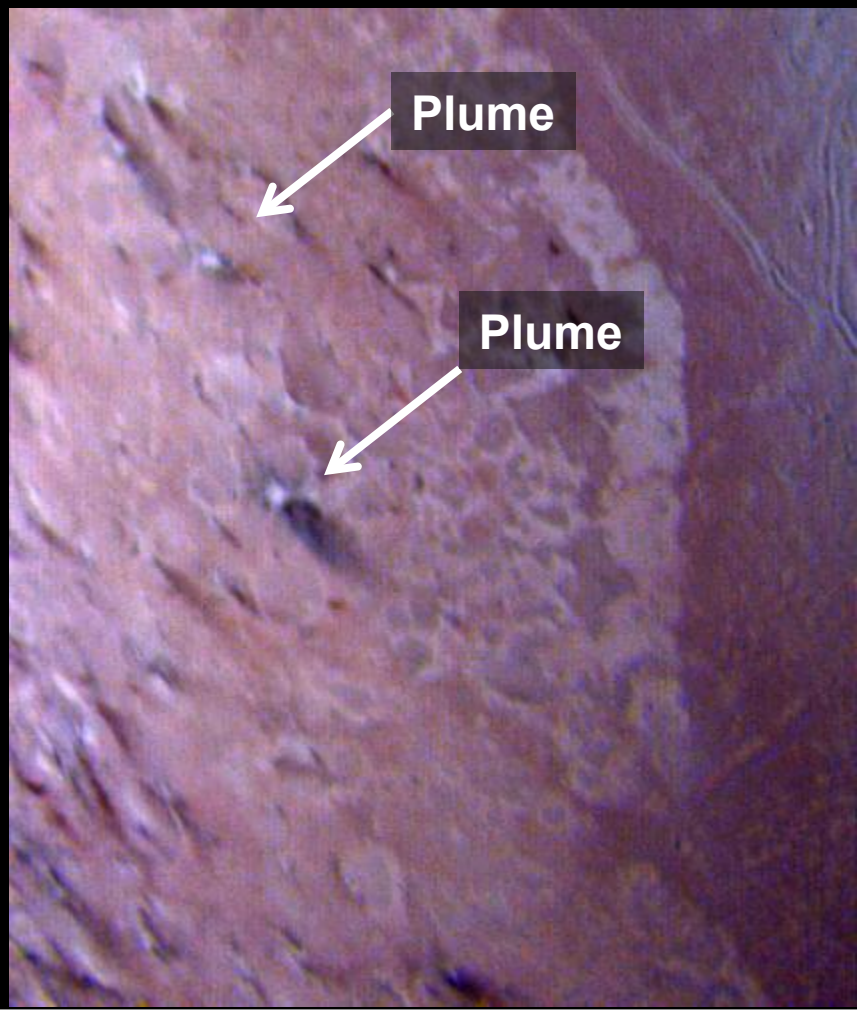
NASA

Triton: Neptune's KBO

Active geology in the far reaches of the Solar System



NASA/JPL



Science we will deliver - 1

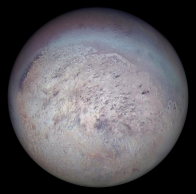
Orbital mission examined, flyby mission achievable

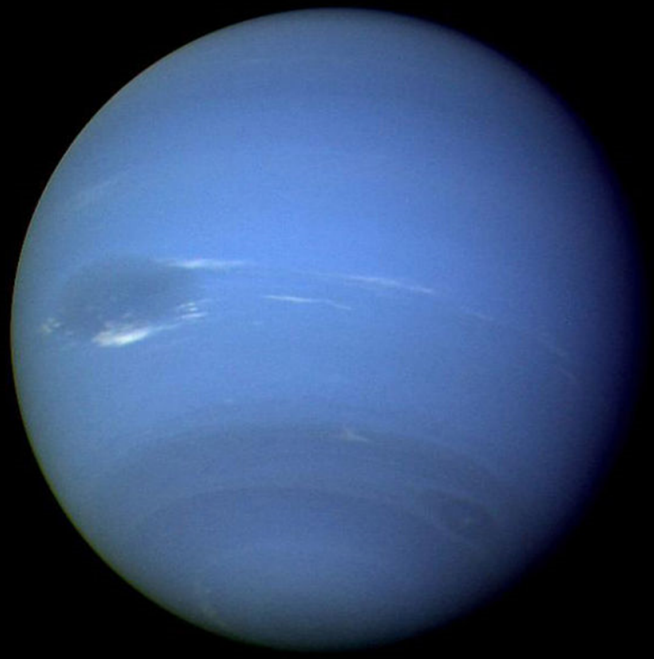
How did Neptune form and evolve?

- What is the composition and structure of Neptune's atmosphere?
- How has Neptune's atmosphere and magnetosphere changed over 53 years?

How did Triton evolve?

- Does Triton have a subsurface ocean?
- How do Triton's plumes work?
- Are the plumes still active 53 years later?
- What is Triton's origin and evolution?





Science we will deliver - 2

How does the interior structure couple with the atmosphere?

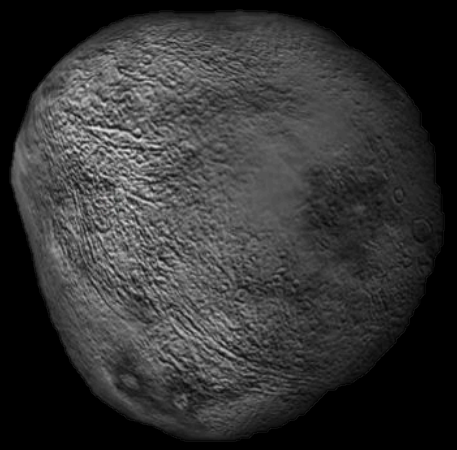
- What is the structure of Neptune's interior?
- What is the vertical extent of the stratospheric oscillations?

What drives Neptune's upper atmospheric dynamics?

- How are hydrocarbons formed in Neptune's upper atmosphere?

What role do small bodies play in the Neptune system?

- What is the composition of Neptune's rings?
- What is the composition of Neptune's small satellites?
- How do Neptune's satellites and rings interact?



Implementation

Priority	Science Objectives	Probe	Narrow Angle Camera	Magnetometer	Plasma Spectrometer	UV Spectrometer	NIR Spectrometer	Doppler Imager
1	Neptune atmosphere composition	T					B	
2	Neptune atmosphere vertical structure	T				T		
3	Neptune global and zonal wind speeds	T						
4	Neptune cloud evolution		T					
5	Magnetosphere stability over time			T	T			
6	Magnetosphere sheilding from solar particles			T	T			
7	Triton subsurface ocean		T	T				
8	Triton surface geology		T				B	
9	Neptune interior differentiation							B
10	Triton plume chemistry and origin		B			B		
11	Ring and small satellite properties		B			B		

First Ice Giant probe

Government Furnished Equipment

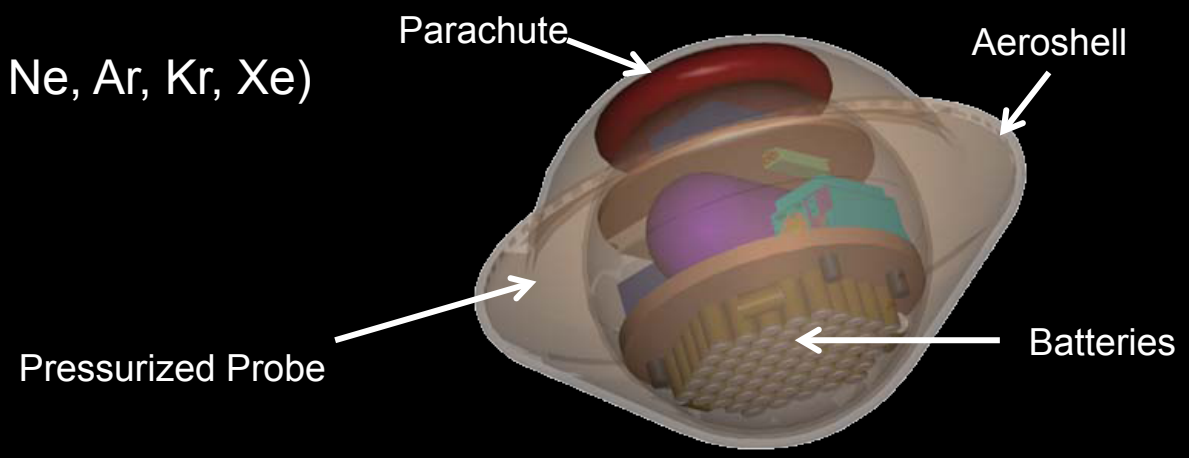
Science:

First-ever Neptune in-situ science
Neptune atmospheric composition
Neptune atmosphere vertical structure

Data Products:

Penetrates to 5-10 bars
Noble gas abundances (He, Ne, Ar, Kr, Xe)
Isotope ratios (N, O, C, S)

Threshold Instrument	
Mass Spectrometer	10 H_20/ 1 Kr & Xe
Atmospheric Structure Instrument & USO	2 temp, 3 pressure, 4 accelerometers
Nephelometer	1 backscatter & 2 radiometer channels
Communication Band	S-band
Size	0.85 m diameter
Lifetime	70-90 min
Mass & Power	150 kg & Primary Battery



Narrow Angle Camera: Clouds, Cracks, and Coverage

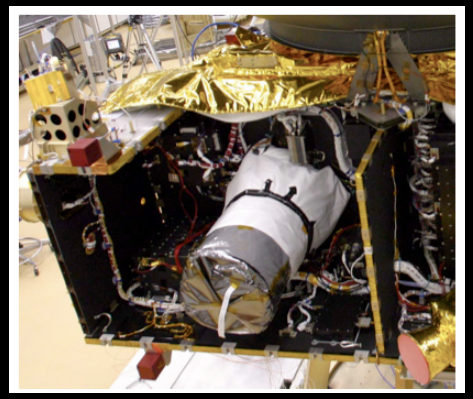
Science:

- Neptune cloud evolution
- Neptune wind speeds
- Triton surface age and morphology
- Triton plumes
- Rings and small moons

Threshold Instrument	
Wavelength range	400-975 nm
IFOV	5 micro rad
FOV	0.29° x 0.29°
Aperture	30 cm
Filters	Clear, Blue, 550 nm, Red, NIR, CH_4
Mass & Power	10 kg & 4 W

Data Products:

- Probe context images
- Global map of Triton
- High resolution plume coverage
- Clear filter images of Triton and Neptune
- Filtered images from 400-910 nm of Neptune and Triton
- Variable spatial resolution throughout flyby
- Resolution 172 km/px to 25 m/px



Derived from New Horizons instrument LORRI

Magnetometer: Filling in the Blanks

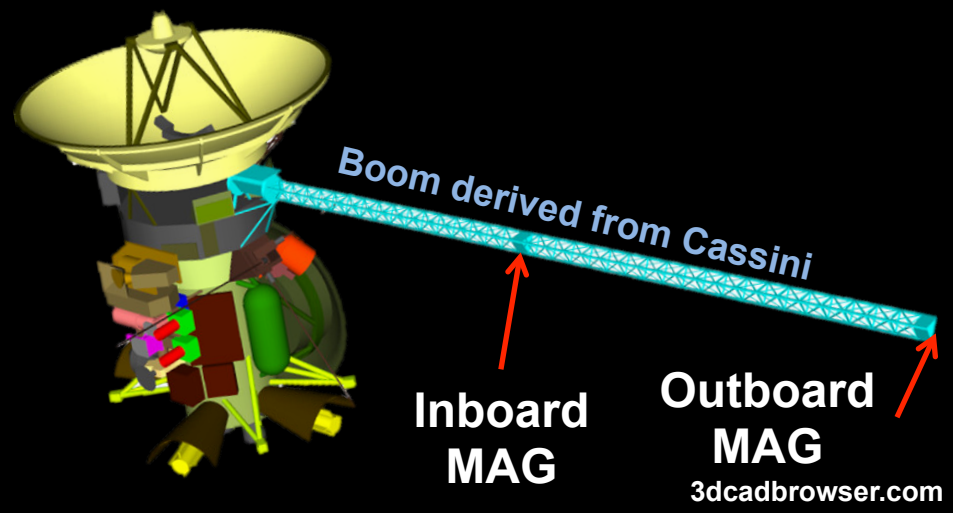
Science:

Ice giant magnetosphere stability
Triton subsurface ocean

Data Products:

3-D magnetic field measurements
1 vector/sec for each MAG

Threshold Instrument	
Fluxgate Magnetometers	2
Boom	10 m
Inboard MAG (@ 5m)	10-500 nT
Outboard MAG (@ 10m)	500-2000 nT
Resolution	< 0.1nT
Mass & Power	1 kg & 2 W



Derived from Messenger

Plasma Spectrometer: Measuring Magnetospheric Stability

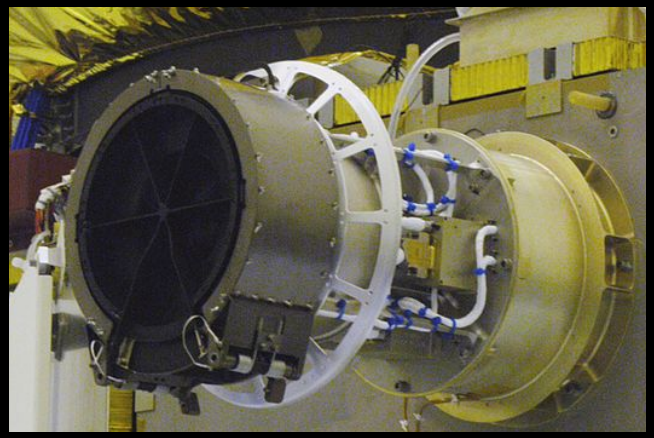
Science:

Planetary shielding from solar particles
Ice Giant magnetosphere variation and stability

Data Products:

Ion and electron energy spectra
Ion pitch angle distribution
Calculated moments: ion density, velocity, pressure, electron density, temperature

Threshold Instrument	
Low Energy Range	10 eV–10 keV
High Energy Range	10 keV–10 MeV
FOV	200° x 10° 160° x 12°
Species	H+, N+, e^-
Energy Res.	10%
TOF | TOF Res.	1-320 ns | 5 ns
Angular Res.	10° (low) 25° (high)
Mass & Power	5 kg & 6 W



Derived from New Horizons instruments PEPPSI and SWAP, (McComas, 2007; McNutt, 2008)

UV Spectrometer: covering all the bases

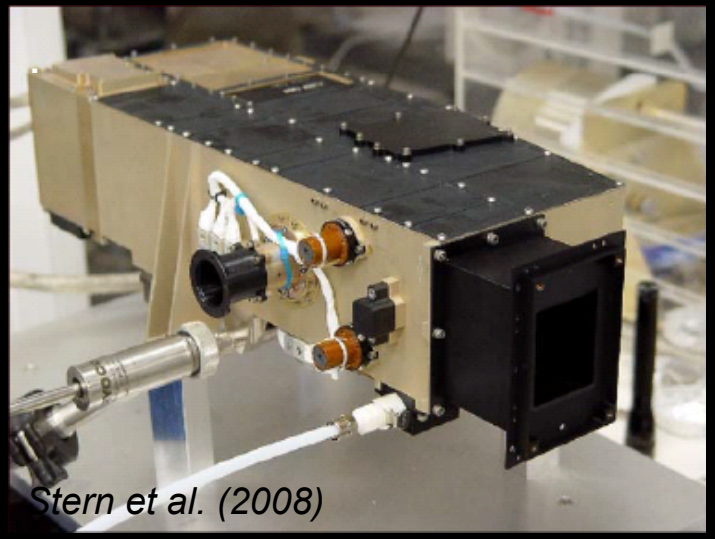
Science:

Structure of Neptune's atmosphere
Composition of Triton's atmosphere/surface
Ring particles sizes

Data Products:

Neptune UV spectra atmosphere
Triton UV spectra atmosphere

Threshold Instrument	
Wavelength	465 – 1880 A
Slot FOV	4° x 0.1°
Box FOV	2° x 2°
IFOV	5 mrad/pixel
Spectral Res.	1.8 A
Data Rate	160 bps
Mass & Power	4.5 kg & 5 W


Stern et al. (2008)

Derived from Alice on New Horizons

NIR spectrometer: key to composition

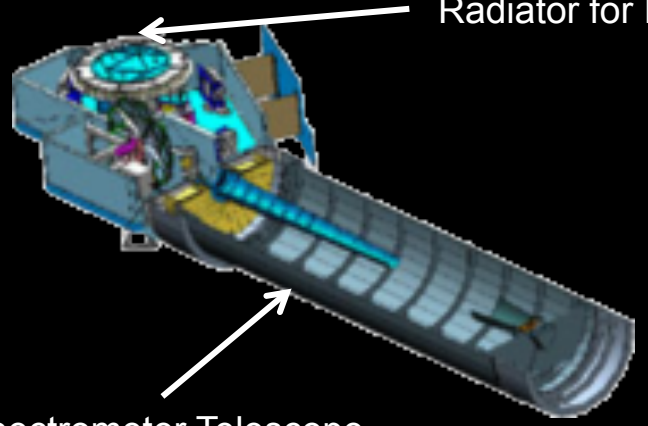
Science:

Neptune's atmosphere composition
Composition of Triton's surface

Data Products:

Terrain IR mapping H_2O, CH_4, CO, and CO_2

Baseline Instrument	
Wavelength	1.05 – 4.8 µm
IFOV	10 µrad
FOV	2.05 mrad
Spectral Res.	~12.5 nm
Mass & Power	28 kg & 21 W



Derived from HRI onboard Deep Impact

Doppler Imager: Unveiling Neptune's Interior

Science:

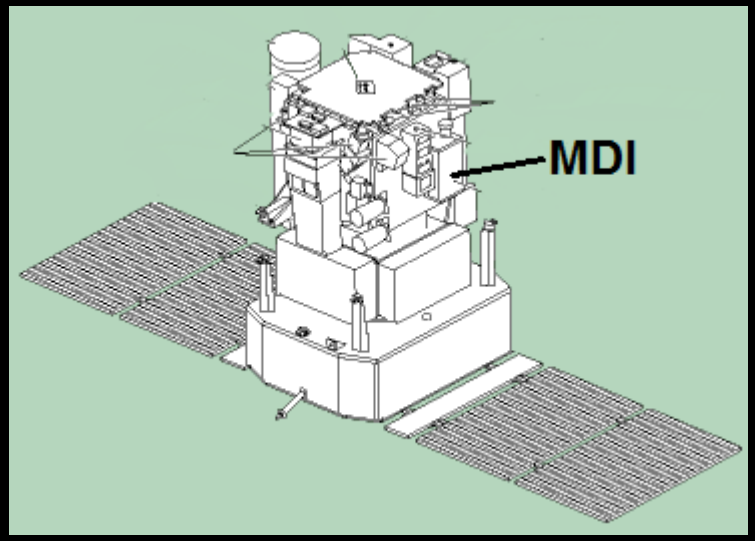
Neptune internal structure

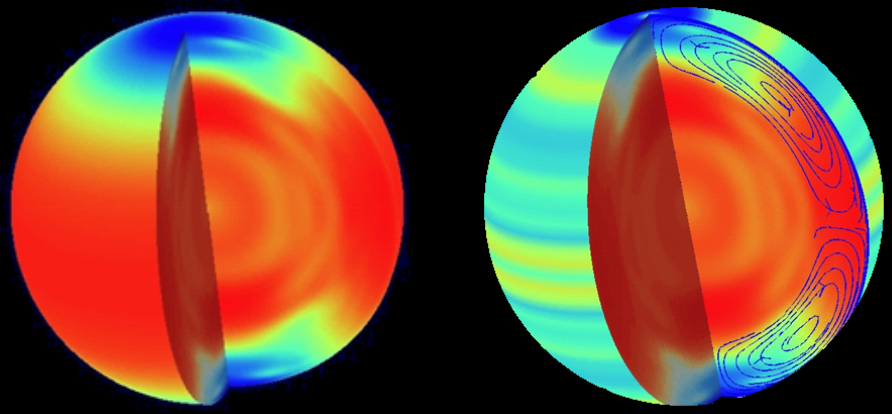
Data Products:

Revolutionary technique never used on outer planets

Harmonics and oscillation measurements to J10 equivalent and beyond

Baseline Instrument	
Aperture	50 cm
Wavelength	770 nm blue-shifted to 13 km/s
IFOV	5 µrad
FOV	2 mrad
Mass & Power	28.5 kg & 40 W





MDI flew on board SOHO and produced these Solar interiors

Mission Design Trades: Too good to be true?

Spacecraft lifetime limitation is 14 years.

EEJN gravity assist trajectory maximizes mass for <15 year TOF

Launch Options	Interplanetary Trajectory	Neptune Trajectory
EELV (Atlas V 551)	Chem Prop Solar EP	Neptune Flyby Triton/Neptune Flyby Chem NOI

Jupiter flybys to Neptune are effective every 12 years and are available between 2016-2018 and 2028-2030.

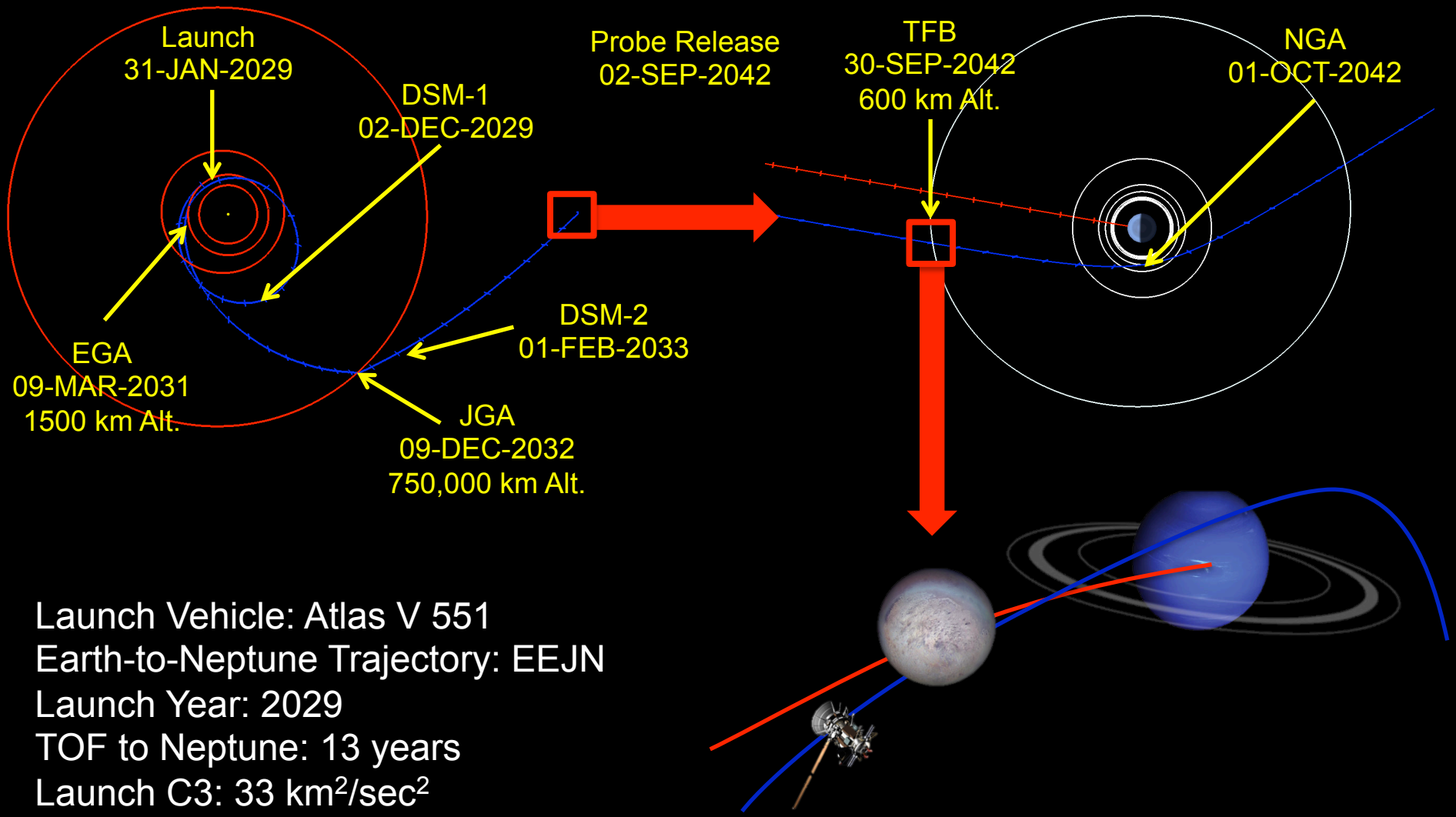
Net mass delivered to Neptune orbit increases as TOF increases.

Chemical Propulsion orbiter was evaluated not feasible.

SEP orbiter was evaluated not feasible.

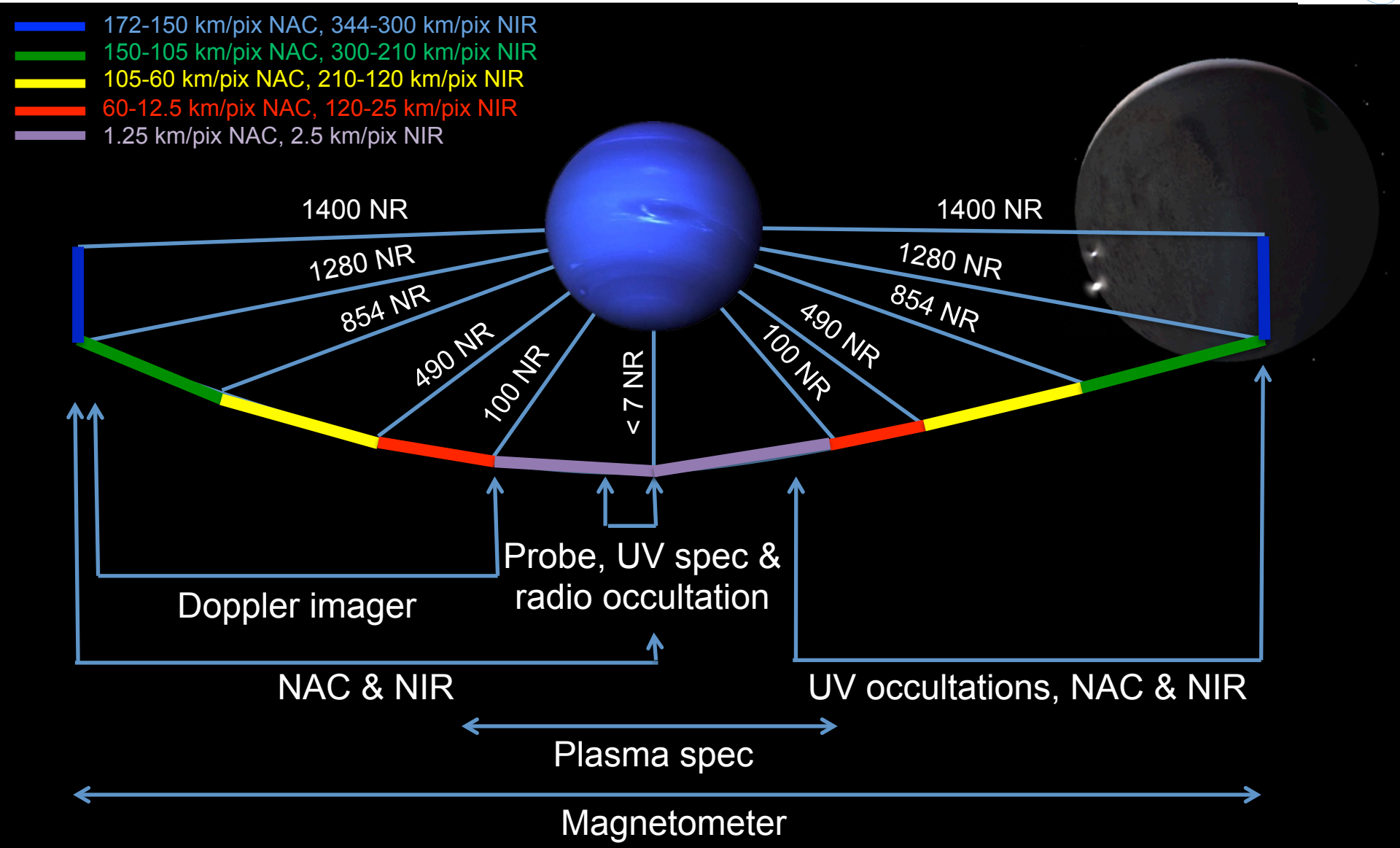
Only Flyby trajectory feasible given launch vehicle constraints.

Mission Design: How fast can we go?



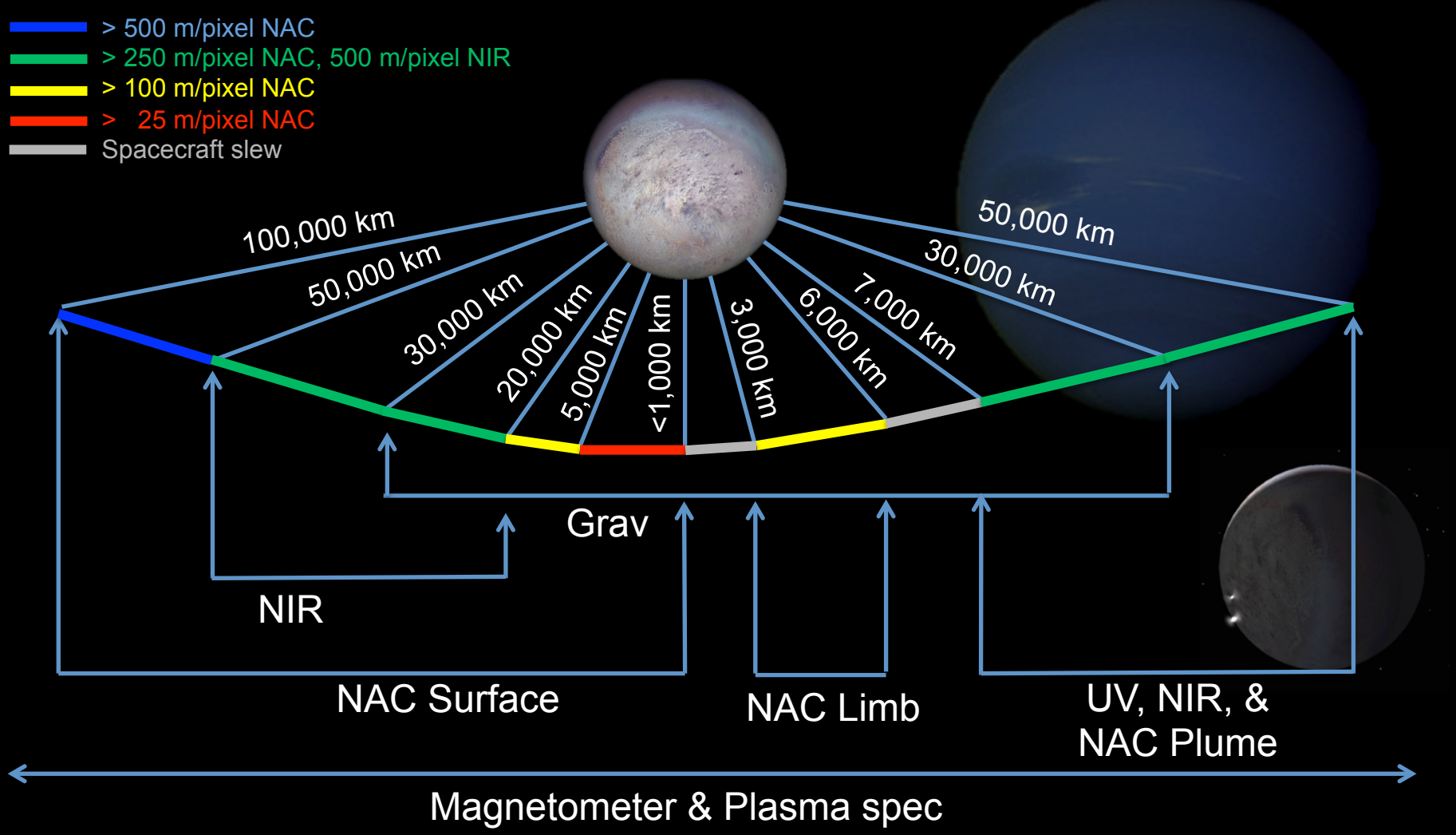
Launch Vehicle: Atlas V 551
Earth-to-Neptune Trajectory: EEJN
Launch Year: 2029
TOF to Neptune: 13 years
Launch C3: 33 km^2/sec^2
EME2000 DLA: -7.407 deg

Neptune Observation Plan

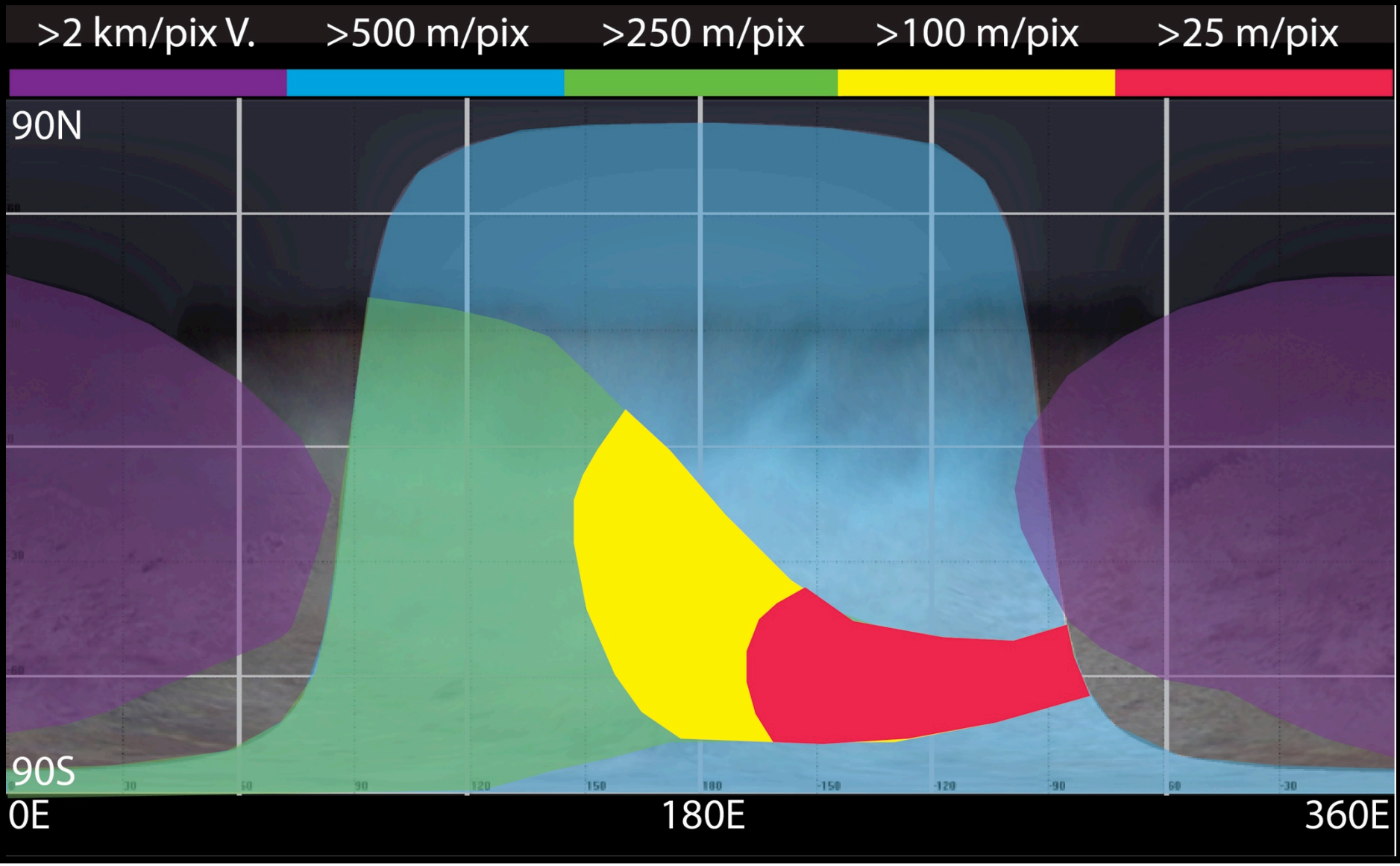


Created by: Jason Leonard, Jennifer Scully, and Alex Patthoff

Triton Observation Plan

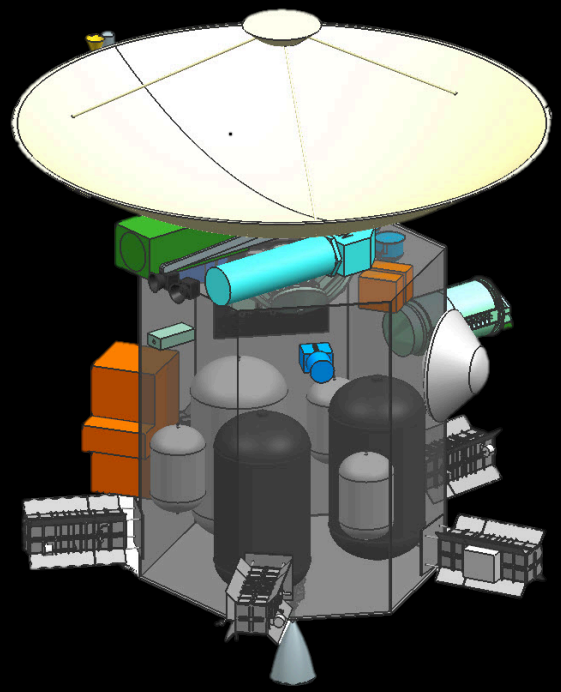


Planned Triton NAC Resolutions



Systems Overview

Functional Requirement	Specification
Lifetime	14 years
Mass	2908 kg Wet 1251 kg Dry
Attitude Control	Rxn-wheels
Propulsion	Bi-prop



Key Features	
Baseline ASRG Powered	Planetary Protection at Provisional Cat. 2
Primary Battery Storage	Significant Redundancy
Dual CDS Redundancy	Technology Development Program

Power

Five Baseline ASRGs
- ~120 W_e at Year 15

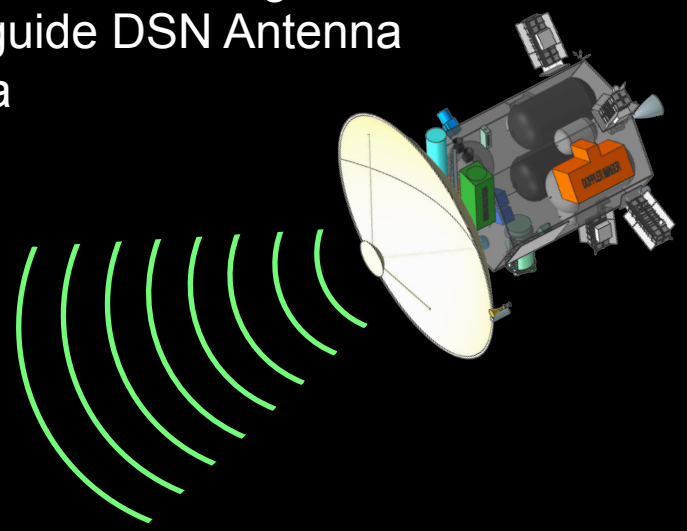
Two lithium ion batteries
- 24 A-h total
- Assumed 5%/yr deg.

Event	Probability of event occurring	Can still do…
Single Failure	< 10%	Baseline Science
Double Failure	< 3%	Threshold Science

Telecom & Ground Operations

Fully Redundant 4-m HGA	
Uplink/Downlink	X / X & Ka
Probe Com	S
TWTA	X and Ka
UST (Transponder)	Dual Band X/X/Ka
Deep Space Network	
34-m BWG	750x 8-hour passes
70-m	21x 8-hour passes

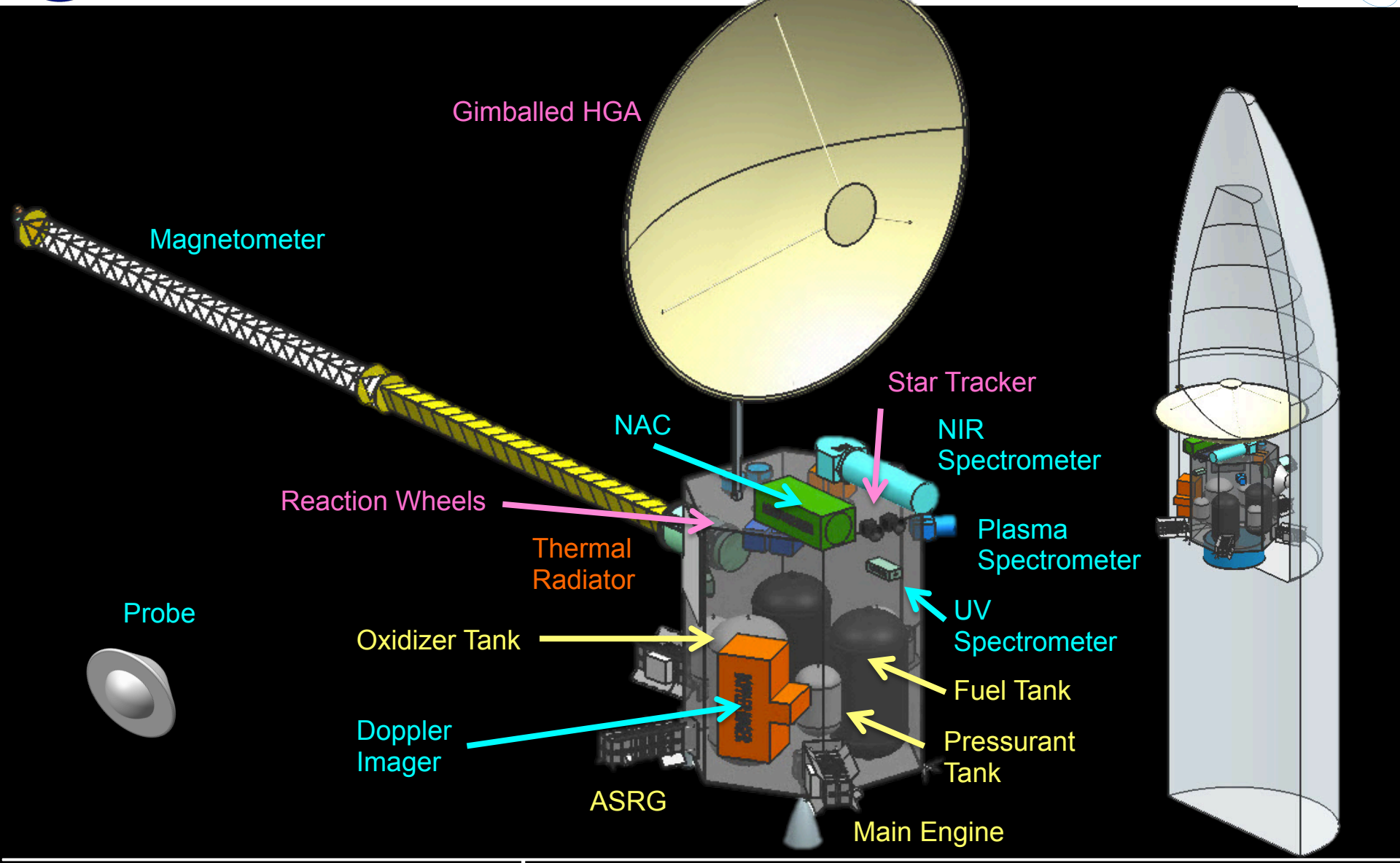
4-m Tri-frequency Gimballed High Gain Antenna
34-m Beam Waveguide DSN Antenna
70-m DSN Antenna



NASA/JPL

DSN Phase	Start	Months	DSN Hours
Launch and operations	28-Jan-29	1.0	630
Early cruise	28-Feb-29	9.9	396
Quiet cruise rehearsal	28-Dec-29	10.1	396
Pre through EGA1	1-Nov-30	5.9	411
Quiet cruise to JGA	2-May-31	18.0	258
Prep through JGA	2-Nov-32	3.0	181
Quiet cruise/prep for hibernation	1-Feb-33	2.0	45
Hibernation	5-Apr-33	98.9	503
Prep for Neptune encounter	8-Jul-41	12.0	2448
Probe support	10-Jul-42	1.0	735
Neptune science return	9-Aug-42	12.0	2394

The Optimal Configuration



Neptune/Triton Mission with Limited Cost

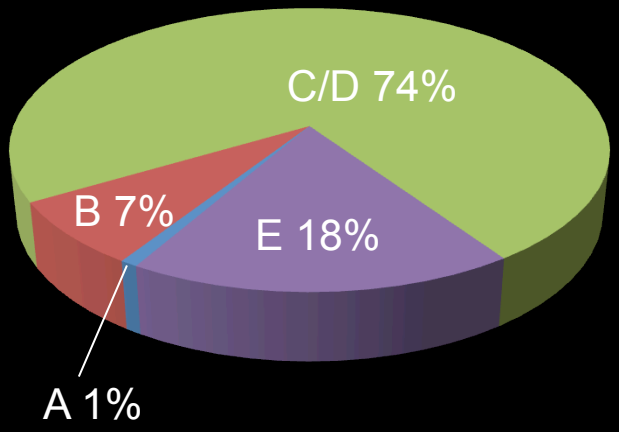
Cost cap: $1.5 B ($FY2015)

NICM (NASA Instrument Cost Model) database and parametric estimates from previously flown instruments + internal JPL labor rates

System cost: JPL grassroots and parametric models

Forward pricing rates used NASA's inflation indices

Mission Cost Summary	Reserve	Total Cost (M $FY2015)
Development (A – D)	30%	1103.1
Phase A	30%	11.0
Phase B	30%	99.3
Phase C/D	30%	992.8
Operations (E)	15%	240.3
Project Cost w/o LV	**27%**	**1343.5**
Launch Vehicle	0%	30.0
Total Project Cost	**26%**	**1373.4**

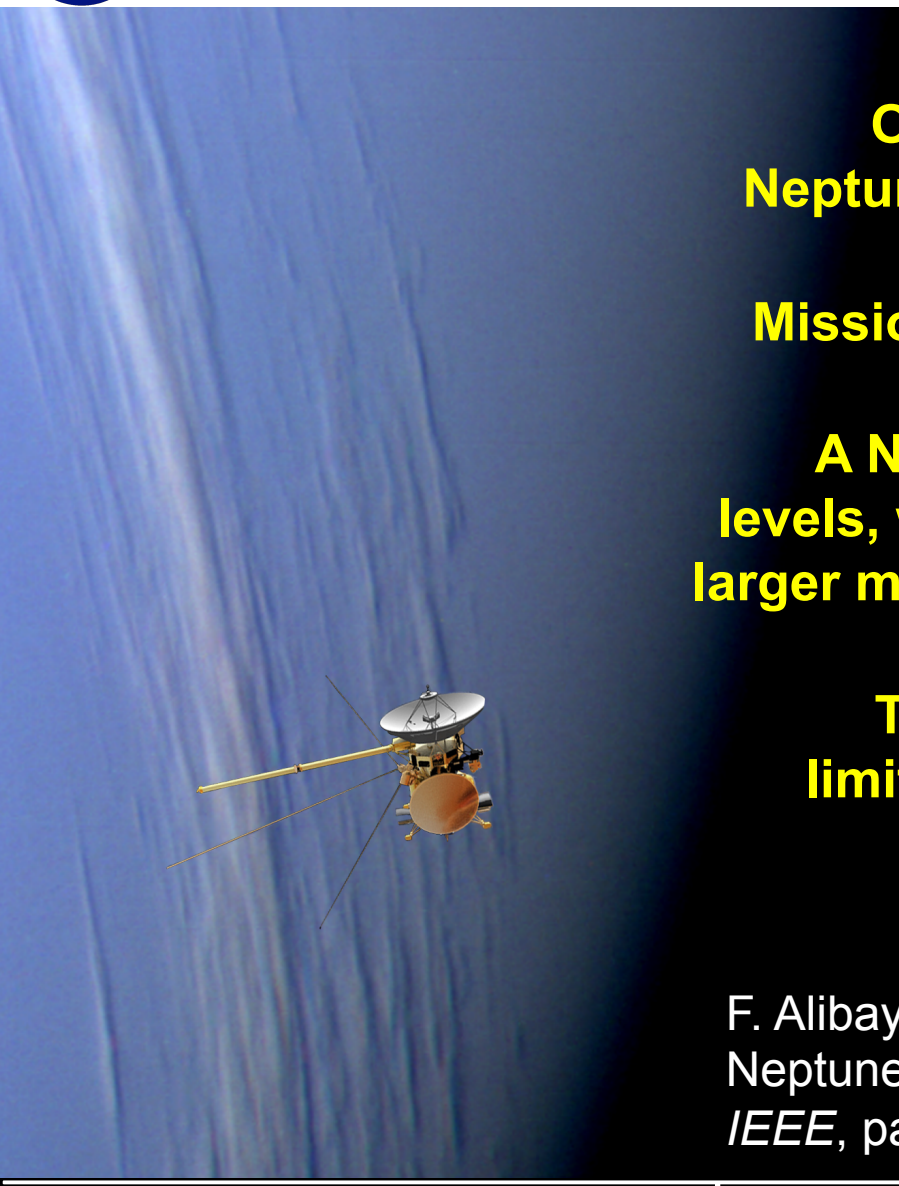


De-scope List

	De-scope option	Criteria	Savings			Decision Point
			$M	kg	W	
1	Doppler Imager	Phase A studies show design to be infeasible	57.5	28.5	40	End of Phase A
2	Doppler Imager	Lack of margin at PDR	52	28.5	40	PDR
3	1 ASRG	Insufficient mass or cost margin	25	35	-	Phase C
4	Reaction Wheels	Insufficient mass or cost margin	6	30	44	Phase C
5	Antenna Gimbal	Insufficient mass or cost margin	10	21.8	-	Phase C
6	Reduce data volume*	Insufficient power	0.5-3.5	2-20	2-10	Phase C
7	NIR	Lack of margin at PDR	25	28	21	PDR

* Data volume can be reduced by using a smaller (3m) antenna, switching to X-band, reducing post-encounter mission duration and/or removing a memory card

TRIDENT Concluding Remarks



Optimal launch date: January 31, 2029
Neptune closest approach: October 1, 2042

Mission lifetime is limited by ASRG lifetime

A Neptune orbiter, at current technology levels, would require a launch vehicle with a larger maximum payload than the Atlas V 551

The use of MMRTG over ASRG further limits the possibility of a Neptune orbiter

F. Alibay, et al. Design of a low cost mission to the Neptune System . In *Aerospace Conference, 2014 IEEE*, pages 1–19, Big Sky, MT, March 2014.

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