Comet Surface Sample Return

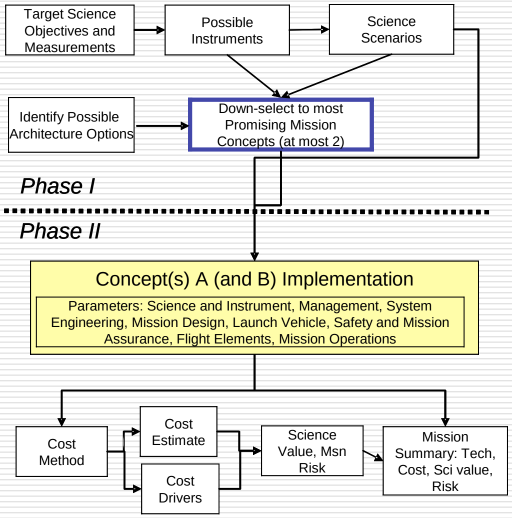
Mission Study Objectives

Science Leads: Hal Weaver (JHU/APL), Mike A’Hearn (UMD)
Program Manager: Glen Fountain (JHU/APL)
Technical Lead: James Leary (JHU/APL)
NASA Lead: Curt Niebur (NASA HQ)

CSSR Mission Study Objectives

- ☐ Prove, or Disprove, the Existence Theorem:
  - A CSSR Mission that returns a macroscopic sample from the surface of a comet is scientifically compelling, technically feasible, can be launched by 2016 ± 1 yr, and can be achieved within a cost cap of $820M (FY07)
  - Report is expected to impact NASA decision-making for next New Frontiers AO
- ☐ Define CSSR Science Objectives (SDT)
- ☐ Define CSSR Measurement Objectives (SDT + Technical Team)
- ☐ Produce a Mission Design that accomplishes the Science & Measurement Objectives (All)

CSSR Study Flow



Target Science Objectives and Measurements
Possible Instruments
Science Scenarios
Identify Possible Architecture Options
Down-select to most Promising Mission Concepts (at most 2)
Phase I
Phase II
Concept(s) A (and B) Implementation
Parameters: Science and Instrument, Management, System Engineering, Mission Design, Launch Vehicle, Safety and Mission Assurance, Flight Elements, Mission Operations
Cost Method
Cost Estimate
Cost Drivers
Science Value, Msn Risk
Mission Summary: Tech, Cost, Sci value, Risk

- ☐ Conservative new technology approach
- ☐ Launch date of 2016+/- 1 year
- ☐ DSN
  - Ka band available
  - 70 M replaced with equivalent capability
- ☐ No international contribution

CSSR Study Schedule Milestones

- ☐ Draft Report due January 2008
- ☐ Peer Review during February 2008
- ☐ Final Report due March 15, 2008
  - Final Presentation to NASA
  - Public Release of report

Science Definition Team Members

- ☐ Mike A'Hearn (UMD) : Co-Chair
- ☐ Hal Weaver (JHU/APL) : Co-Chair
- ☐ Mike Combi (University of Michigan)
- ☐ Yan Fernández (University of Central Florida)
- ☐ Will Grundy (Lowell Observatory)
- ☐ Martha Hanner (University of Massachusetts)
- ☐ Casey Lisse (JHU/APL)
- ☐ Karen Meech (University of Hawaii)
- ☐ Joe Veverka (Cornell University)
- ☐ Paul Weissman (JPL)
- ☐ Mike Zolensky (NASA/JSC)

- ☐ 11 Members Total

CSSR Engineering Team

- ☐ Systems Engineering – JC Leary; PA Hill
- ☐ Mechanical Systems – CT Apland
- ☐ Communications – JR Bruzzi
- ☐ Propulsion – SS Bushman
- ☐ Payload – EH Darlington
- ☐ Mission Design – DW Dunham; JJ Guzman
- ☐ Advanced Technologies – RE Gold
- ☐ Landing Systems – JT Kaidy
- ☐ Sampling Systems – WJ Lees
- ☐ Software – VA Mallder
- ☐ Mechanical Design – DH Napolillo
- ☐ Avionics – JK Ottman
- ☐ Structures – DF Persons
- ☐ Guidance & Control – JC Ray
- ☐ Power – LM Roufberg
- ☐ Operations & Ground Systems – EP Theus
- ☐ Thermal – MJ Wirzburger
- ☐ Costing – LS Wolfarth

- ☐ SRV – NASA LaRC (WC Engelund)
- ☐ Navigation & Mission Design – JPL (J Sims)

CSSR SDT Process

- ☐ Kick-off meeting on Aug 21-22, 2007 at JHU/APL
  - ■ Discuss goals of CSSR Mission Study
  - ■ SDT's primary role is to define CSSR Science Requirements, which drives the technical effort, and write the Science portion of the Final Report
  - ■ SDT consults with Technical Team when questions are raised (e.g., clarification of requirements) and trade-off decisions are made
- ☐ Biweekly telecons to discuss requirements and current status
- ☐ SDT solicits advice from "outside" science experts
  - ■ Meeting on Oct 6, 2007 in Orlando, FL with contributions from Akiva Bar-Nun, Dina Prialnik, Uwe Keller, Scott Sandford, Hajime Yano, and Ben Clark
  - ■ Telecon presentation to CAPTEM (Oct 11, 2007)
- ☐ Town Hall forum during DPS Annual Meeting (Oct 11, 2007) to solicit feedback from the community (~30 non-SDT attendees)
- ☐ SDT meeting on Oct 12, 2007 in Orlando, FL to hone Requirements
- ☐ Town Hall forum planned for fall AGU meeting (Dec 10-14, 2007)
- ☐ Next SDT meeting scheduled on December 11, 2007

Science Rationale for CSSR Mission

- ☐ Key questions identified by Decadal Survey and NASA Roadmap for CSSR mission remain valid
  - ■ What processes marked the initial stages of planet and satellite formation?
  - ■ What is the inventory of volatile compounds, especially water, across the solar system?
  - ■ What is the nature of organic material in the solar system, and how has this matter evolved?
  - ■ How do the processes that shape the contemporary character of planetary bodies operate and interact?

Why Sampling Comets is Important

- Most pristine material in the solar system
  - Best record of conditions in the outer solar system during its formation and evolution
  - Best link to interstellar cloud from which solar nebula formed
- Chock full of water and organics, the seeds of life
  - What role did comets play in delivering water and organics to Earth?
- Building blocks of cores of the outer planets
- Critical role in formation and evolution of planetary atmospheres
  - Impacts of comets throughout the solar system
- Comets bring material from the outer solar system to the inner solar system for easy sampling

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General Guidelines for CSSR Mission

- A viable CSSR New Frontiers mission must provide a major scientific advancement over what Discovery missions have done (Stardust, Deep Impact) or could do
  - Stardust samples collected from ***hypervelocity*** (~6 km/s) impacts of coma grains into aerogel
    - Destruction/Alteration of large fraction of impacting material
    - Generally unable to preserve original chemical and mineralogical properties
    - Stardust provided *huge* scientific advances, but ***the science return from CSSR vs Stardust should be even greater than the Stardust advance over previous knowledge***
- As part of New Frontiers, CSSR is a PI-led mission with a single, focused goal - ***Return a Surface Sample***
- Like all mission proposals, descopes must be identified from a baseline mission to a floor

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CSSR Mission Objective

Obtain a Macroscopic Sample of the Surface of a Comet Nucleus and Return It to Earth for Laboratory Analysis

Triage Science Requirements into 3 Groups (aka “Levels”):

Group 1: Must Do, Scientific Floor
-Mission is a ***Failure*** if these objectives are not accomplished
Group 2: Baseline Mission
-Selected mission scoped to achieve both Group 1 and Group 2
-Group 2 considered “highly desirable”
Group 3: Nice to Have
-Scientifically important, but of clearly lower priority than Group 1 & Group 2

Target Selection

- Any comet is fair game, as long as the mission design demonstrates that the Group 1 objectives can be achieved within the cost cap
  - Allow proposers to be innovative and creative in choice of comet
  - Comets that are already well-characterized may lower mission risk, but monitoring of nucleus during rendezvous phase mitigates this risk
  - Comets already well-characterized could require shorter rendezvous phase, thereby decreasing risk
  - Choosing comet already visited by spacecraft permits synergism between CSSR and previous results
  - Owing to accessibility issues, a Jupiter Family Comet (JFC) willl be the likely CSSR mission target

Target Selection (2)

- SDT identified 9 comets to serve as potential case studies for the CSSR mission
  - 9P/Tempel 1 (Deep Impact target)
  - 19P/Borrelly (DS1 target)
  - 81P/Wild 2 (Stardust target)
  - 67P/Cheryumov-Gerasimenko (Rosetta target)
  - 21P/Giacobini-Zinner (ICE target)
  - 22P/Kopff (CRAF target)
  - 6P/d'Arrest (CONTOUR target)
  - 43P/Wolf-Harrington (recent change in q from 2.5 to 1.5 AU)
  - 46P/Wirtanen (Original Rosetta target)

Group 1 Objectives

- Return substantial (≥ 500 cc) sample of comet surface for Earth laboratory investigation
  - Maintain the elemental, molecular, and mineralogical integrity of all sampled material that is stable at -10 C at 1 bar
    - Must prevent aqueous alteration of sample
  - Sample volume can be reduced to ≥ 250 cc in exchange for substantially lower temperatures that are justified for preservation of the sample
  - Determine the geomorphological context of sampled region
    - Global visible mapping of nucleus to ≤ 1 m resolution
    - Visible characterization of sampled region to ≤ 1 cm resolution
  - Laboratory curation facilities must have the capability to maintain the samples without degradation for ≥ 5 yr

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Group 2 Objectives

- Maintain the elemental and molecular integrity of volatile species that may evolve from the sample (e.g., species that sublimate at -10 C and 1 bar)
  - Capture evolved species (e.g., in flasks)
- Return material from a depth ≥ 10 cm (~3 diurnal thermal skin depths), if the sampled region has a shear strength ≤ 50 kPa
- Determine whether sample is from an active region of the nucleus
  - Monitor nucleus for ≥ 20 rotation periods while the comet's activity is within a factor of ~10 of its peak value during its orbit around the Sun
- Sample multiple locations
  - Active and Inactive regions
  - Regions with different geomorphologies
- Choose sample locations to accuracy of ≤ 50 m

Group 3 Objectives

- Sample to depth ≥ 50 cm
- Preserve stratigraphy of sampled region
  - Even gross (3 cm scale) information is valuable
- Perform remote compositional observations of nucleus surface, including sampled area
- Perform remote compositional observations of coma, including near sampled area
- Perform thermal mapping of entire nucleus
  - Identification of icy terrain
- Measure dust flux in coma
  - Simple counter is sufficient

Discussion of Science Priorities

- SDT has had major discussions on two issues
  - Priority of sample depth requirement
    - 2 of 11 SDT members insist that sample ***must*** be collected at least 3 diurnal skin depths below the surface, and would make this is a Group 1 requirement
    - 9 SDT members say that macroscopic sample collected anywhere and at any depth justifies CSSR mission
    - Everyone feels that collection to a depth ≥10 cm is feasible (easy?), but the requirement will be difficult, if not impossible, to verify in-flight
    - Sampling ***surface only*** of an ***active area*** is considered sufficient by everyone, but verifying that sampled region is active is problematic
  - Priority of volatile capture requirement
    - 1 SDT member feels that capture of sublimated volatiles must be a Group 1 requirement

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Measurement Objectives & Payload

- Characterize surface of nucleus in visible light (panchromatic): global resolution ≤1 m, locally near sample to a resolution ≤1 cm
  - Capable (~5 μrad/pixel) Narrow Angle Camera (NAC)

- Map the surface temperature of the nucleus: global resolution ≤10 m, locally near sample to a resolution ≤1 m
  - Could use near-IR (1-5 μm) spectral imager or thermal-IR imager
- Remote measurements of surface composition: global resolution ≤10 m, locally near sample to a resolution ≤1 m
  - Could use Near-IR (1-5 μm) spectral imager or Near-IR Camera with multiple filters
- Measure the composition of the coma gas
  - Could use Mass Spectrometer or near-IR (1-5 μm) spectral imager
- Measure dust flux
  - Could use nepholometer

Payload Complement

- Instruments baselined (in priority order)
  - Sampler
    - Multiple corers
    - Active system (drill, grinder, scooper) required for risk mitigation
  - NAC
    - Facility instrument required for optical navigation
  - Sample Collection Verification Imager
    - Facility instrument required for risk mitigation
  - Sample Monitoring Suite (P/T)

================Science Floor==================

  - IR/Thermal Imager
  - LIDAR
    - Facility instrument used for long-range proximity operations
  - WAC (with filter wheel)
  - Dust Measurement Instrument
  - Neutral Mass Gas Spectrometer
  - Subsurface Radar
- Other Drivers/Factors
  - Covers
  - Scanning Platform(s)

CSSR Mission Risks

- Programmatic
  - Closure on requirements priority with SDT consensus
  - Planetary protection
  - Development of curation facility
  - Public response to return of cometary material

- Technical
  - Sampler design with unknown comet surface properties
  - Landing complexity
  - SRV design changes for sample handling & thermal control
  - Mechanical accommodation of all payload elements
    - May require instrument descopes
  - Complexity of trajectory

CSSR Mission Risks (cont’d)

- Cost
  - Electric propulsion cost growth with dependencies on:
    - NEXT funding
    - Dawn Performance
  - Oversubscription of payload

Cost Summary

- A Comet Sample Return Mission can be performed for a cost within the $820M cap
  - Resolution (and costing) of remaining trades will add to depth of study
- Careful balancing of science payload required to keep within cap
  - Mission with “minimal” payload is ~$750M
- Work with Headquarters to begin dialogue with those who can have major impact on programmatic risks
  - Planetary protection
  - Curation facility

In Summary

- It’s the sample, stupid!
  - Returning an unaltered piece of a comet nucleus is the paramount objective of the CSSR mission
  - All other objectives are secondary

- CSSR mission is scientifically compelling, even at the floor

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Backup Material

Key Technical Requirements

- The Mission concept cost cap shall be <$820M in FY07$.
- The Mission concept shall assume a 2016 launch date (±1 year).
- The Mission concept shall be limited to using EELV-class launch vehicles.
- The Mission communications shall be via DSN 70-m antennas or an equivalent.
- The Mission shall be capable of returning a surface sample of ≥500 cc from the target comet to Earth (UTTR) for laboratory investigation.
- The Mission shall be capable of preserving the comet sample's organics and volatiles at a temperature ≤-10°C at a pressure of 1 bar.
- The Mission shall maintain the elemental, molecular, and mineralogical integrity of the sampled material.
- The Mission shall monitor the target body for >20 rotations in the period -10 days to +100 days around perihelion passage.
- The Spacecraft's sampling mechanism shall be capable of obtaining a core sample ≥10 cm deep with a goal of 50 cm.
- The Mission shall be capable of detecting the target comet >3 months out.
- The Mission shall be capable of mapping the target comet's surface to ≤1-m resolution.
- The Spacecraft shall be capable of descending to the surface for sample capture at least three times.

System Overview

- Spacecraft design and operation leveraging recent experience
  - NEAR, MESSENGER, STEREO, New Horizons
- Proximity operations and landing strategy
  - NEAR-like proximity operations
  - Internally developed landing strategy using multiple levels of protection (inertially-based navigation similar to NEAR augmented with imaging, multi-path LIDAR, and multi-path radar)
- Sampling strategy
  - Internally developed strategy for coring coupled with drilling/grinding/scooping mechanism to improve chance of bulk sample return
  - Return capsule augmented with sample monitoring (T/P) suite and volatile capture devices

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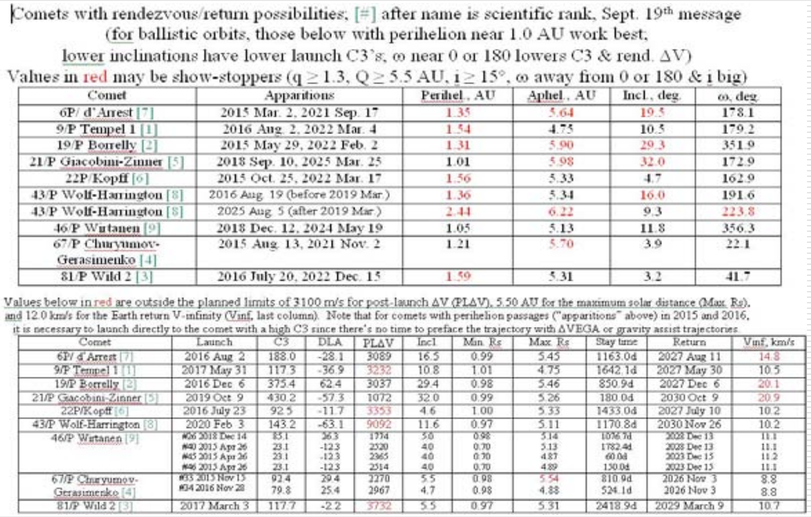
Major Trade Areas

- Mission/Science Trades
  - Trajectory Complexity
  - Payload Complement
  - Sample Acquisition
  - Sample Handling
- Spacecraft Trades
  - Sample Return Vehicle Design (Stardust vs. MSR)
  - Power Subsystem Design (RPS vs. Solar Array)
  - Communications Bandwidth
  - Propulsion Subsystem Design (Electric vs. Conventional)

Trajectory Complexity

- Targets of scientific interest are difficult to rendezvous
  - All past comet missions have been flybys (Rosetta, 67P/C-G TBD)
- ΔV requirement >3 km/s will drive mission to EP (and perhaps beyond cap)
- Duration longer than 10 years may drive reliability requirements
- Rendezvous and return near perihelion to minimize solar distance
  - >3 AU starts to impact the design; >5.5 AU is technically risky
- Launch energy will drive to larger launch vehicle
- Staying at the comet through perihelion would drive mission duration up by ~x2

Target Analysis



Comets with rendezvous/return possibilities; [#] after name is scientific rank, Sept. 19th message
(for ballistic orbits, those below with perihelion near 1.0 AU work best,
lower inclinations have lower launch C3's, ω near 0 or 180 lowers C3 & rend. ΔV)
Values in red may be show-stoppers (q ≥ 1.3, Q ≥ 5.5 AU, i ≥ 15°, ω away from 0 or 180 & i big)

Comet	Apparitions	Perihel., AU	Aphel., AU	Incl., deg.	ω, deg
6P/ d'Arrest [7]	2015 Mar. 2, 2021 Sep. 17	1.35	5.64	19.5	178.1
9/P Tempel 1 [1]	2016 Aug. 2, 2022 Mar. 4	1.54	4.75	10.5	179.2
19/P Borrelly [2]	2015 May 29, 2022 Feb. 2	1.31	5.90	29.3	351.9
21/P Giacobini-Zinner [5]	2018 Sep. 10, 2025 Mar. 25	1.01	5.98	32.0	172.9
22P/Kopff [6]	2015 Oct. 25, 2022 Mar. 17	1.56	5.33	4.7	162.9
43/P Wolf-Harrington [8]	2016 Aug. 19 (before 2019 Mar.)	1.36	5.34	16.0	191.6
43/P Wolf-Harrington [8]	2025 Aug. 5 (after 2019 Mar.)	2.44	6.22	9.3	223.8
46/P Wirtanen [9]	2018 Dec. 12, 2024 May 19	1.05	5.13	11.8	356.3
67/P Churyumov-Gerasimenko [4]	2015 Aug. 13, 2021 Nov. 2	1.21	5.70	3.9	22.1
81/P Wild 2 [3]	2016 July 20, 2022 Dec. 15	1.59	5.31	3.2	41.7

Values below in red are outside the planned limits of 3100 m/s for post-launch ΔV (PLΔV), 5.50 AU for the maximum solar distance (Max. Rs), and 12.0 km/s for the Earth return V-infinity (Vinf, last column). Note that for comets with perihelion passages ("apparitions" above) in 2015 and 2016, it is necessary to launch directly to the comet with a high C3 since there's no time to preface the trajectory with ΔVEGA or gravity assist trajectories.

Comet	Launch	C3	DLA	PLΔV	Incl	Min. Rs	Max. Rs	Stay time	Return	Vinf, km/s
6P/ d'Arrest [7]	2016 Aug 2	188.0	-28.1	3089	16.5	0.99	5.45	1163.0d	2027 Aug 11	14.8
9/P Tempel 1 [1]	2017 May 31	117.3	-36.9	3232	10.8	1.01	4.75	1642.1d	2027 May 30	10.5
19/P Borrelly [2]	2016 Dec 6	375.4	62.4	3037	29.4	0.98	5.46	850.9d	2027 Dec 6	20.1
21/P Giacobini-Zinner [5]	2019 Oct 9	430.2	-57.3	1072	32.0	0.99	5.26	180.0d	2030 Oct 9	20.9
22P/Kopff [6]	2016 July 23	92.5	-11.7	3353	4.6	1.00	5.33	1433.0d	2027 July 10	10.2
43/P Wolf-Harrington [8]	2020 Feb 3	143.2	-63.1	9092	11.6	0.97	5.11	1170.8d	2030 Nov 26	10.2
46/P Wirtanen [9]	#26 2018 Dec 14 #40 2015 Apr 26 #45 2015 Apr 26 #46 2015 Apr 26	83.1 23.1 23.1 23.1	26.3 -12.3 -12.3 -12.3	1774 2520 2365 2514	5.0 4.0 4.0 4.0	0.98 0.70 0.70 0.70	5.14 5.13 4.87 4.89	1076.7d 1782.4d 60.0d 150.0d	2028 Dec 13 2028 Dec 13 2023 Dec 15 2023 Dec 15	11.1 11.1 11.2 11.1
67/P Churyumov-Gerasimenko [4]	#33 2015 Nov 15 #34 2016 Nov 28	92.4 79.8	29.4 25.4	2270 2967	5.5 4.7	0.98 0.98	5.54 4.88	810.9d 524.1d	2026 Nov 3 2026 Nov 3	8.8 8.8
81/P Wild 2 [3]	2017 March 3	117.7	-2.2	3732	5.5	0.97	5.31	2418.9d	2029 March 9	10.7

Target Selection

- ☐ 67/P (C-G) will be the common target to facilitate architecture comparison (Ballistic and Low-Thrust)
  - Ballistic is very difficult and may require relaxing the launch window requirement
- ☐ 67/P will be well studied by the time the sample return mission gets there
- ☐ Higher science value targets are technically riskier (very difficult to reach and return even with low-thrust trajectories)

Design Decision – Limit mission to Atlas V due to cost and risk (NASA certification already complete).

Sample Acquisition

- ☐ Sample Mechanical Properties
  - Corer will not alter material; pore size is of concern
  - Thruster plumes mitigated prior to sampling
  - Active system will disrupt sample but helps ensure bulk sample
- ☐ "Cryogenic" Acquisition
  - Sample required to be maintained <-10°C at all times [sample acquisition and maintenance <-135°C will be examined for comparison but is thought to be outside scope of study]
  - Surface temperature and properties are of concern

Sample Handling

- ☐ Volatile Management
  - Full cryogenic handling is problematic
    - ☐ Cruise (thermal path from inside SRV)
    - ☐ Return (mitigation for soak back and time on the ground – cooler power?)
    - ☐ Ground (all ground handling/processing must be done cryogenically – cost)
  - Capturing volatiles possible
    - ☐ Mitigating cross-contamination is difficult
- ☐ Stratigraphy
  - Managing detailed stratigraphy through landing is difficult
    - ☐ Parachute system; shock isolation
  - Stratigraphic information can be obtained by multiple cores of different length

Sampling Baseline

- "Touch and Go" baseline vs. landing to reduce risk
- Plan is to sample near dawn terminator (within 20°)
- Redundant coring pairs will be carried
  - Different lengths provide stratigraphic information (10-cm and TBD-cm, longest technically feasible)
  - Different diameters mitigate pore size sampling risk (TBD-mm and TBD-mm)
  - Each corer capable of carrying >250 cc of material
- At least one active system will be carried
  - Will ensure a bulk sample is captured from any surface type (capable of >500 cc of material)
- Volatile capture flasks will be provided for individual samples
- Sample temperature will be maintained below -10°C

SRV Design

Stardust/Genesis heritage design (with parachute and helicopter catch) was compared with Mars Sample Return (MSR) ballistic return design

- Heritage design may allow preservation of stratigraphic information
- MSR design would be pathfinder for future work, eliminates parachute complexity (could eliminate electrical interface through to SRV depending on sample monitoring requirements)
- MSR design has higher cost risk

DESIGN TRADE DECISION – Carry both architectures forward for detailed comparison.

Power Subsystem Design

Radioisotope Power Systems were considered versus solar array power

- Positive Aspects
  - RPS removes aphelion trajectory constraint
  - Solar arrays during landing are a concern

- Negative Aspects
  - RPS adds significant cost risk
  - RPS limit system power (MMRTG performance)
  - ASRG TRL is low
  - Cannot target Earth return with RPS onboard (need separable spacecraft)

DESIGN TRADE DECISION – Solar arrays baselined, no RPS solution considered possible within study programmatic constraints.

Communications Subsystem Design

- Articulated Dish HGA
  - Pros
    - Potential for higher Bandwidth
      - Accommodates both X-Band & Ka-Band
      - Easily scalable for higher gain
      - Accommodates use of higher power TWTAs
    - No restriction on S/C attitude
    - Straightforward antenna design
  - Cons
    - Complex/heavy mechanisms
    - Deployable boom required
    - Risk of moving parts
      - gimbals & rotary joints
    - Single-point failure for RF steering support at encounter

- 1-D Phased-Array HGA
  - Pros
    - Covers range of Earth direction w/ restriction on S/C roll only
    - Electronically scanned
    - No mechanisms or deployables
    - Light-weight
    - Graceful degradation with failure
  - Cons
    - Limits maximum bandwidth
      - X-Band only
      - Limit on practical size (gain)
      - Limit on total SSPA power
    - Less efficient power amps
    - More complex antenna design
    - Additional DSN Time/Cost

DESIGN TRADE DECISION – Carry both architectures forward for detailed comparison.

Propulsion Subsystem Design

Ballistic trajectories with conventional propulsion were compared with low-thrust trajectories with solar electric propulsion

- Conventional propulsion
  - Limits target options and drives the need for more complex trajectory (planetary flybys; limited launch opportunities)
  - Requires more propellant mass (2-10x)
  - May require 3rd Stage (like New Horizons)
  - >$25M cheaper (if no 3rd Stage)
- Electric propulsion
  - Allows more scientifically interesting targets to be considered
  - Increases cost risk and operations complexity (may drive the need for larger solar arrays)
  - Monoprop system still required for proximity operations

DESIGN TRADE DECISION – Carry both options forward for detailed comparison.

Conclusion

- Phase II (Detailed Design) will focus on two architectures to determine if one or both fit within study constraints and meet science requirements
  - Ballistic vs. Low-Thrust
    - Common spacecraft bus designs where possible (e.g., avionics and communications)
    - Common proximity operations and sampling scenario for each architecture
    - Common sampling system for each architecture
    - SRV trade (Heritage vs. MSR) will be evaluated and lowest cost solution that satisfies science requirements will be selected
    - Science floor payload (additional instruments added if resources are available)