The Regolith Biters

A Divide-And-Conquer Architecture for Sample-Return Missions

J. Arrieta J. Smith B. Kennedy

Jet Propulsion Laboratory, California Institute of Technology

2013 NIAC Spring Symposium
March 12–14, 2013
Chicago, Illinois

Copyright 2013 California Institute of Technology
Government Sponsorship Acknowledged

A challenge

— Return up to several kilograms of samples from multiple sites on the nucleus, with stratigraphy and all ices intact, and no cross contamination of collected samples

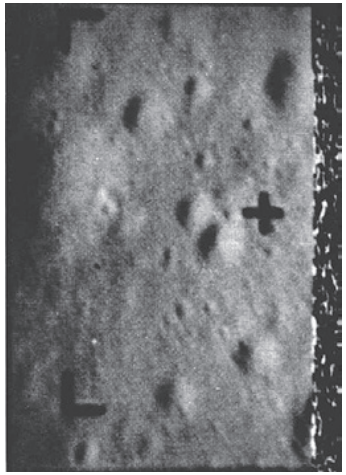
TA04–27

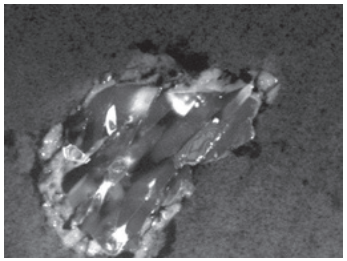
Why sample small bodies?

Science origin and evolution of the Solar System

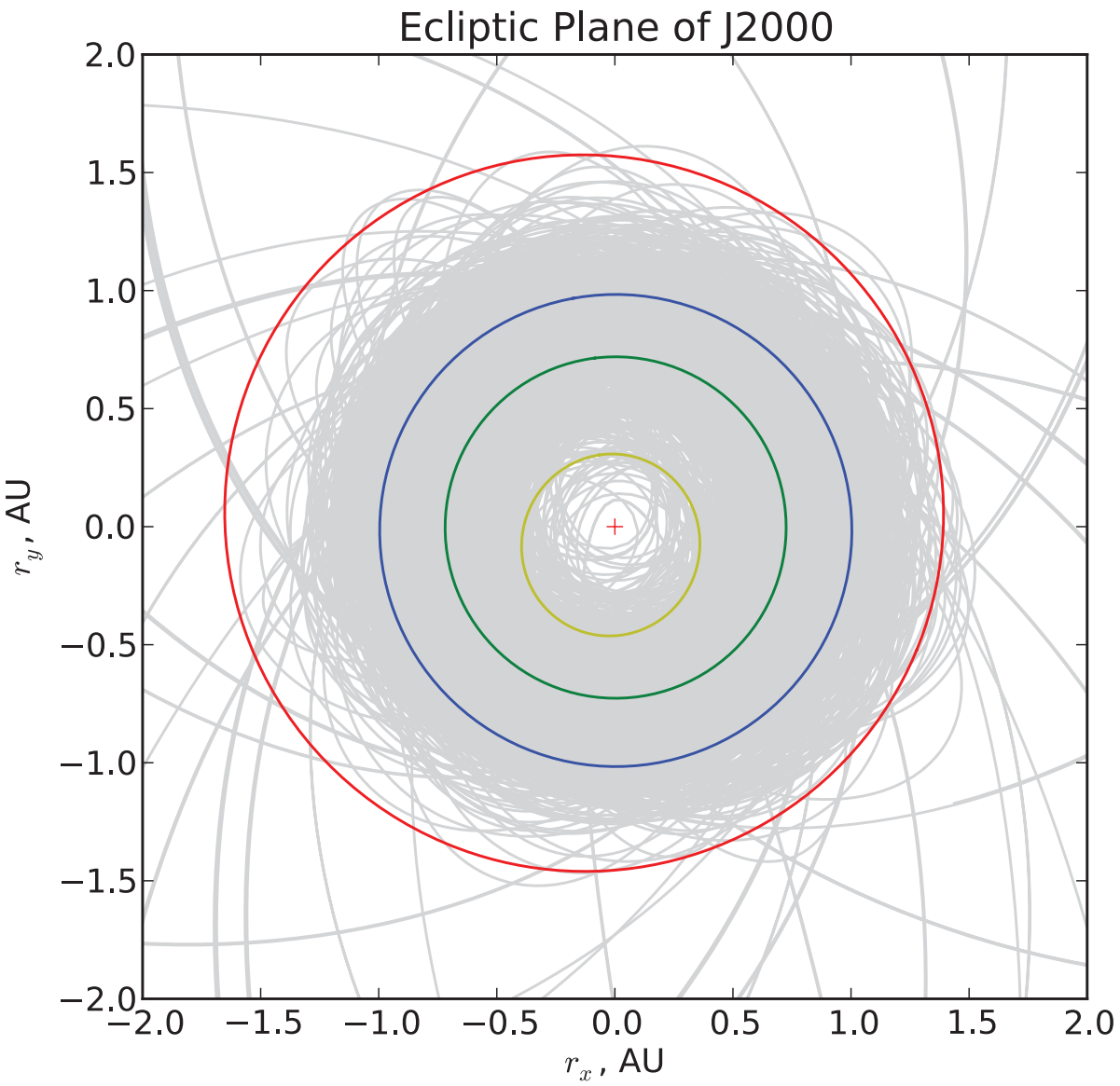
Engineering structure and composition of exploration targets

Market mining of precious minerals





NEO Population



Concept Origin

Observation spacecraft navigation $\neq$ sample collection

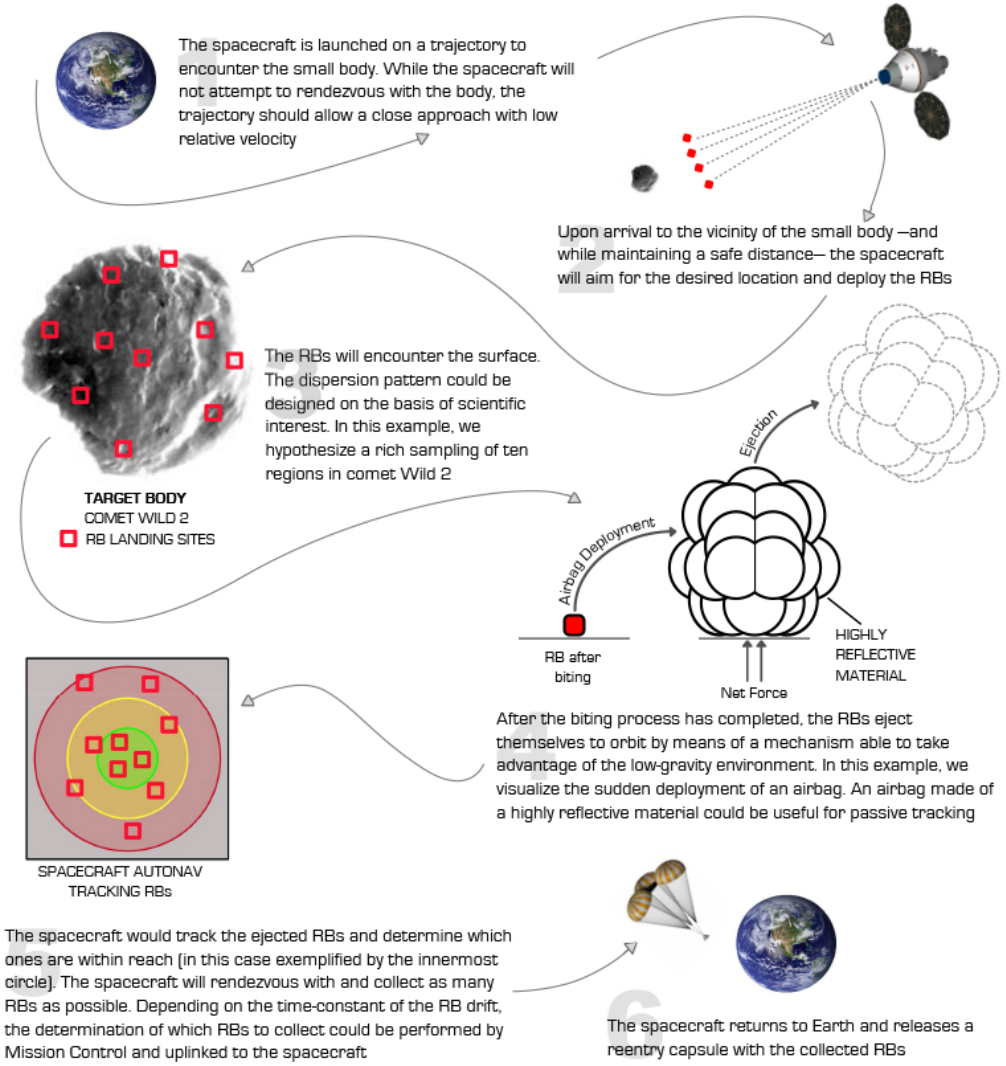
Hypothesis $C(sn) + C(sc) < C(sn + sc)$

Postulate $\uparrow C(sn)$ (*agile spacecraft*), $\downarrow C(sc)$ (*multiple agents*)

— *Prefer complex interactions over complex systems*

— *Favor stochastic over deterministic*

Architecture Diagram



Alignment with NASA's Space Technology Roadmap

— Develop the capability for highly reliable, autonomous rendezvous, proximity operations, and capture/attachment to (cooperative and non-cooperative) free-flying space objects

— Enable robotic systems to maneuver in a wide range of NASA-relevant environmental, gravitational, and surface and subsurface conditions

— Develop subsurface sampling and analysis exploration technologies to support in situ and sample return science missions

Conceivable Strengths

Sampling of bodies with fast rotation currently out of scope for touch-and-go architectures

Sampling of very active comets where coma would endanger the spacecraft upon approach

Sampling of binary systems could reveal the collisional processes in the early Solar System

Distributed, in situ characterization by furnishing the RB encasings with sensing devices

Catalyst for new exploration paradigms *simple systems can cooperate to attain complex goals*

Architecture Stages

Transfer spacecraft from Earth to small body

Deploy the RBs or delivery stage towards the small body

Encounter the surface of the small body; bite it

Eject from the surface to a heliocentric orbit

Rendezvous subset of RBs with mother spacecraft

Return to Earth with collected samples

— Assess astrodynamic feasibility and architectural advantage over conventional sample-return concepts

Transfer and Return

— **Find Earth-SB-Earth Trajectories**

Findings

— *Abundance of feasible trajectories*
— *Robustness to variability in encounter/departure time*
— *Latitude in selection of arrival* Δv

Central Challenges

— *Mixing low- and high-thrust propulsion systems*
— *Cryogenic containment of collected samples*

Deployment and Encounter

- **Assess option of single agents vs delivery stage**
- **Characterize encounter kinetic conditions***

Findings

- *Comfortable separation between spacecraft and target*
- *Control over encounter Δv and dispersion pattern*
- *Resistance to impact is of secondary importance**
- *Surface diversity demands different RB designs*

Central Challenges

- *Autonav capabilities for target acquisition and homing*
- *Develop RB prototype for field testing*

Ejection and Rendezvous

- **Characterize RB post-ejection orbital band***
- **Estimate marginal rendezvous cost***

Findings

- *Rotation rate is main contributor to variance*
- *Rendezvousing with several RBs is Δv-feasible*
- *Upper bound in time-to-capture is about two days*

n	1	2	3	4	5	6
Δv (m/s)	100	200	350	500	800	1,100
$M\Delta v$	100		150		300	

Central Challenges

- *Tracking of multiple RBs; autonomous rendezvous*
- *RB/sampling site correlation*

Going forward

— Architecture is feasible from an astrodynamic perspective; it suggests advantages over status quo

Guidance I	Extend Deep Impact terminal guidance algorithm
Tracking	Laboratory testing of passive tracking technologies
Guidance II	Develop proof-of-concept for autonomous rendezvous
Sensing	Develop preliminary distributed sensing options
Systems	Size and cost vehicle and subsystems
Prototype	Develop and print RB subject for field testing
Integration	Assemble representative end-to-end mission
Outreach	Collaborate with asteroid mining industry
NIACization	Bring in other NIAC concepts into the architecture

NRC Prioritization of TA04 Level 3 Technologies

- *Guidance Algorithms*
- *Docking and Capture Mechanisms/Interfaces*
- *Vehicle System Management & FDIR*
- *Dexterous Manipulators (including robot hands)*
- *Supervisory Control (including time delay supervision)*
- *Extreme Terrain Mobility*
- *Robotic Drilling and Sample Handling*
- *Small Body / Microgravity Mobility*

- *Relative Navigation Sensors*
- *Multi-Agent Coordination*

TA04–33