Don't Send the Astronauts to the Asteroid

Bring the Asteroids to the Astronauts

A radical proposal for the planned 2025 asteroid visit

Missions that Create Industry

Asteroid Mining Group

Al Globus, Chris Cassell, Stephen Covey, Jim Luebke, Mark Sonter, Bryan Versteeg, and James Wolff

ISDC 2012, Washington, DC

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Astronauts to Asteroid

- NASA goal: send astronauts to an asteroid in 2025
  - Candidate list neo.jpl.nasa.gov/cgi-bin/nhats
- Issues
  - At least six months travel time
    - Radiation exposure
  - Only a few days or weeks at asteroid
  - No rapid return abort capability for most of the mission
  - No possibility of resupply during the mission
  - Requires very capable vehicle
    - SLS/Orion > $2 billion/year for many years
  - Can only visit one asteroid per mission
  - Mission has no major direct commercial or industrial goal

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Asteroids to Astronauts

- Bring many small asteroids into High Lunar Orbit (HLO) where astronauts set up mining equipment on them to create an industry
  - A few days travel time
  - Indefinite stay times
  - Return/resupply in a few days
  - Falcon Heavy/Dragon probably sufficient
  - Many asteroids per human mission
  - Repeat visits easy
  - Supply multiple markets
  - Significant planetary protection (detection and deflection)
  - Multiple independent components

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Asteroid Return History

- "lunar flyby to remove hyperbolic delta-v: this will naturally insert the returning craft into HEEO" as a capture mechanism in Mark Sonter's 1997 MS thesis, page 69.
- "AsterAnts: A Concept for Large-Scale Meteoroid Return and Processing Using the International Space Station," Al Globus, Bryan Biegel, and Steve Traugott, NAS technical report NAS-99-006.
- "is it economically more advantageous to mine a few large NEOs, return large numbers of small NEOs whole, or something in between?" 2010 International Space University summer project from Al Globus, proposed in 2008.
- Stephen Covey presented a proposal to return Apophis to Earth orbit using lunar gravity assist at ISDC 2011 (May).
- "Asteroid Return Mission Feasibility Study," Brophy, J. R., Gershman R., Landau, D., Yeomans, D., Polk, J., Porter, C., Williams, W., Allen, C., and Asphaug, E., AIAA-2011-5665, 47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, San Diego, California, July 31-Aug 3, 2011.
- Extended abstract of this submitted to AIAA Space 2012 in January 2012.
- The Keck workshop was in September 2011, final report public in April 2012.

Keck Workshop at JPL

- Damon Landau analyzed low-thrust lunar assist to High Lunar Orbit (HLO) for 1991VG, 2006RH120, 2007UN12, 2008 HU4, and 2009BD
  - Assumed 2-3 km/sec from lunar assist, may be optimistic
  - A number of asteroids with return $\Delta v < 2$km/sec exist
- 500 ton asteroid to HLO
  - Assuming a density of 3 tons/m^3 ~ 5-6 m diameter
  - 40 kw Hall Effect solar electric propulsion (SEP)
    - 30,000 m/sec propellant velocity
  - 15.5 ton tug with 12 tons Xenon propellant

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What Do We Need

- Telescopes to find and characterize candidates
- Solar electric propulsion (SEP) vehicle (tug)
  - Capture, despin and return asteroid
    - A thrust program Δv under a few hundred m/s, to enable lunar gravity assists to bring asteroid into HLO
- Human transportation to/from HLO
- Living facilities (Bigelow, ISS)
- Mining hardware, software and procedures
- Markets for materials

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How Many Suitable Asteroids?

- Total number of NEOs estimated based on WISE data
  - 20,500 > 100 m diameter (25% found)
  - millions > 10 m
  - billions > 2 m
- Properties required
  - < 5 m diameter
  - Low energy relative to Earth
    - Inclination < 2.6 degrees
    - Eccentricity < 0.05 (Earth 0.0167)
    - Semi-major axis between 0.92 and 1.15 AU
- Fraction within parameters based on Gehrels
  - 0.000765 or 756,000 out of a population of 1 billion
- Note: on average there is one small asteroid in Earth/Moon temporary orbit naturally
  - Baoyin: 410 m/sec to stable Earth orbit.

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Candidate Detection

- Money is well spent here
  - The smaller the detectable asteroid the cheaper it is to return and the more candidates there are.
  - As the detectable diameter shrinks, the light reflected goes down as the square, but the mass goes down as the cube.
  - Need to detect absolute magnitude in the high 20s, low 30s
- Keck study
  - Current and planned Earth telescopes can find around five candidates per year.
    - Includes radar for accurate size and orbit determination
  - Since found on Earth approach, return to Earth vicinity in approximately 10 years.
  - 2008 HU4 closest approach in 2016 and 2026
    - 170 m/s delta-v required to bring into Earth-Moon system

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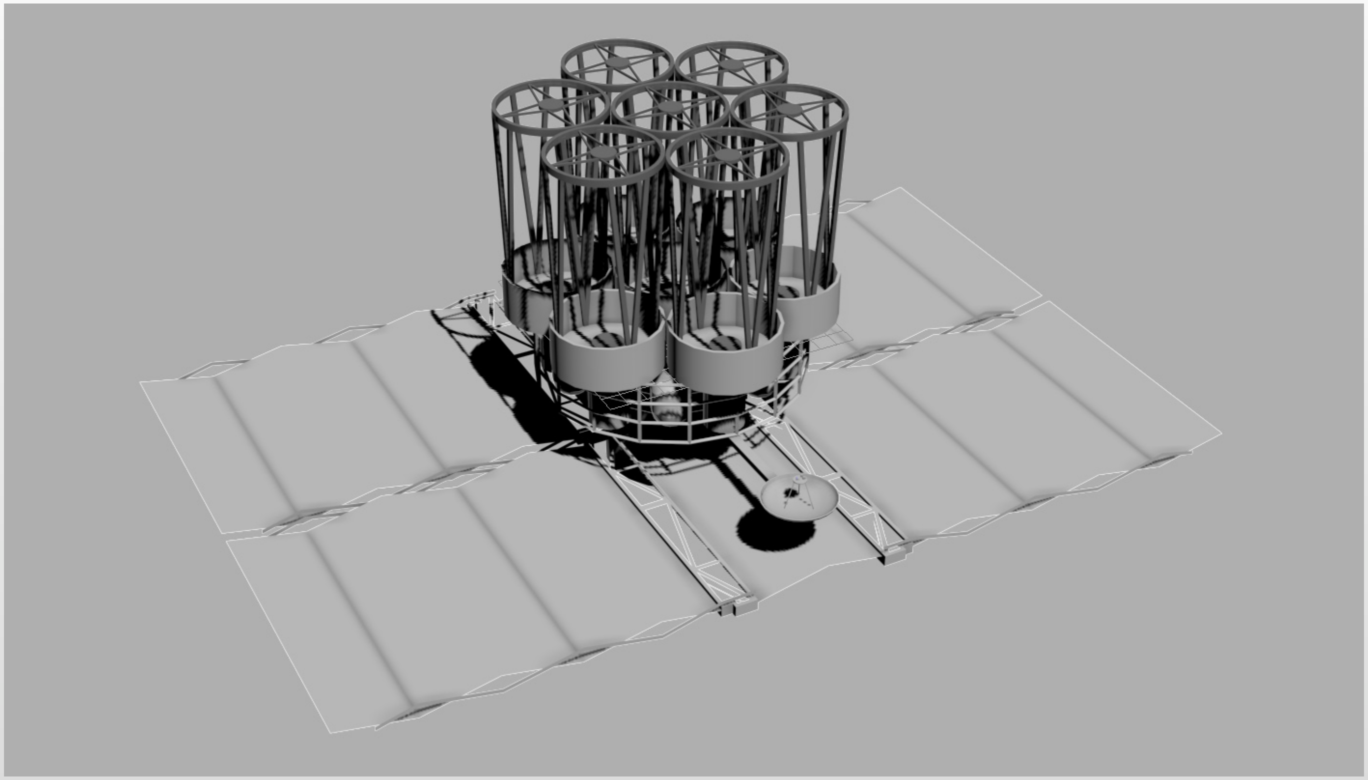
Planetary Resources, Inc.

- Group of billionaire angel investors
- Asteroid mining focus
- Initial activity: multiple dedicated 9" 30-50 kg telescopes in LEO for candidate detection

* Image credit: Planetary Resources, Inc.

Space IR/LIDAR Telescope



- Placed near Earth-Sun L4/5
- Looks for candidates with very long synodic period that approach Earth very slowly at low energies
  - Requires quick mission to divert.

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Tug

- Fly to asteroid
- Rendezvous
- Match rotation/tumble and capture
- Despin
- Apply thrust to hit lunar gravity assist into HLO
- Apply thrust to move to stable orbit

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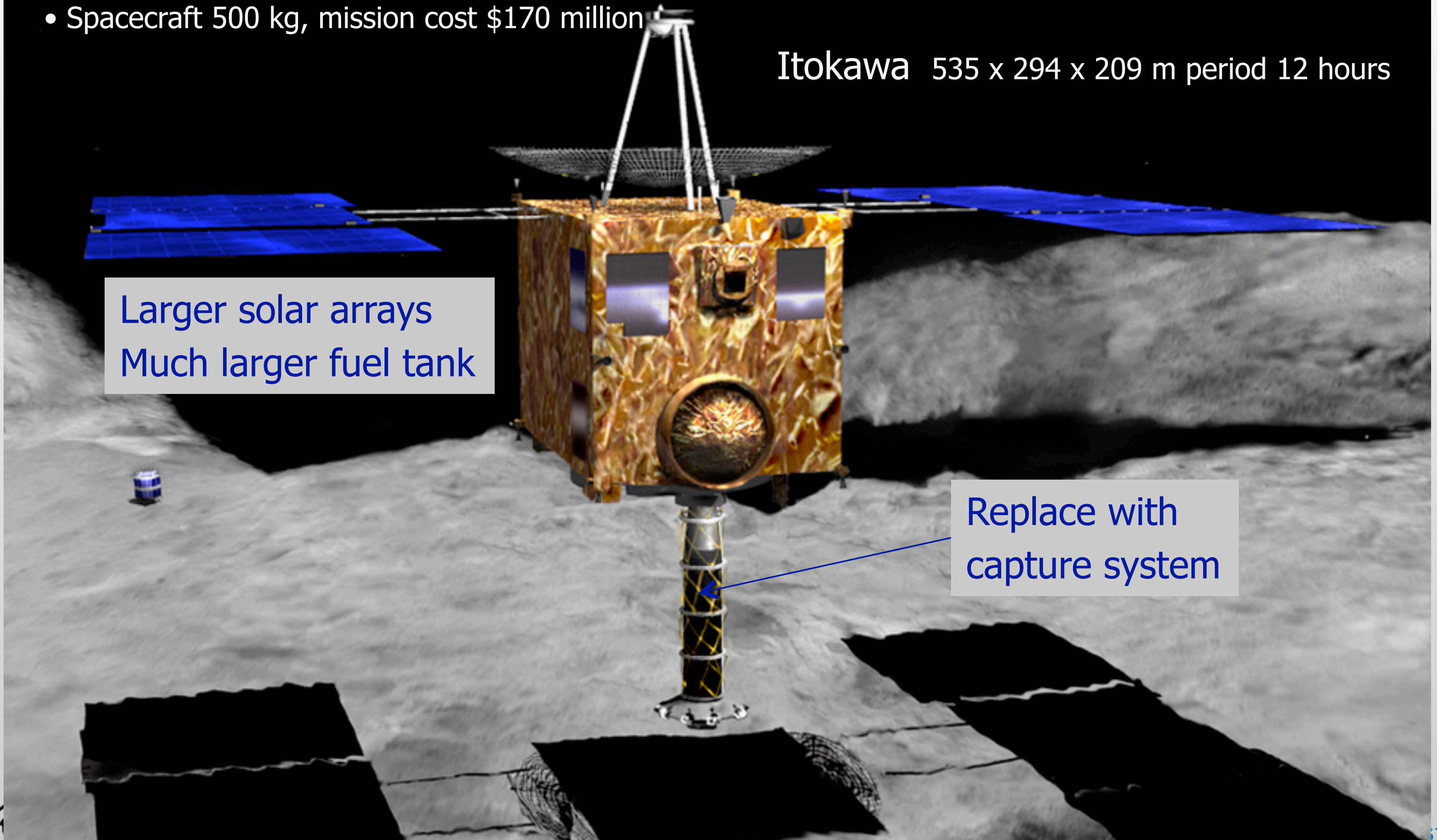
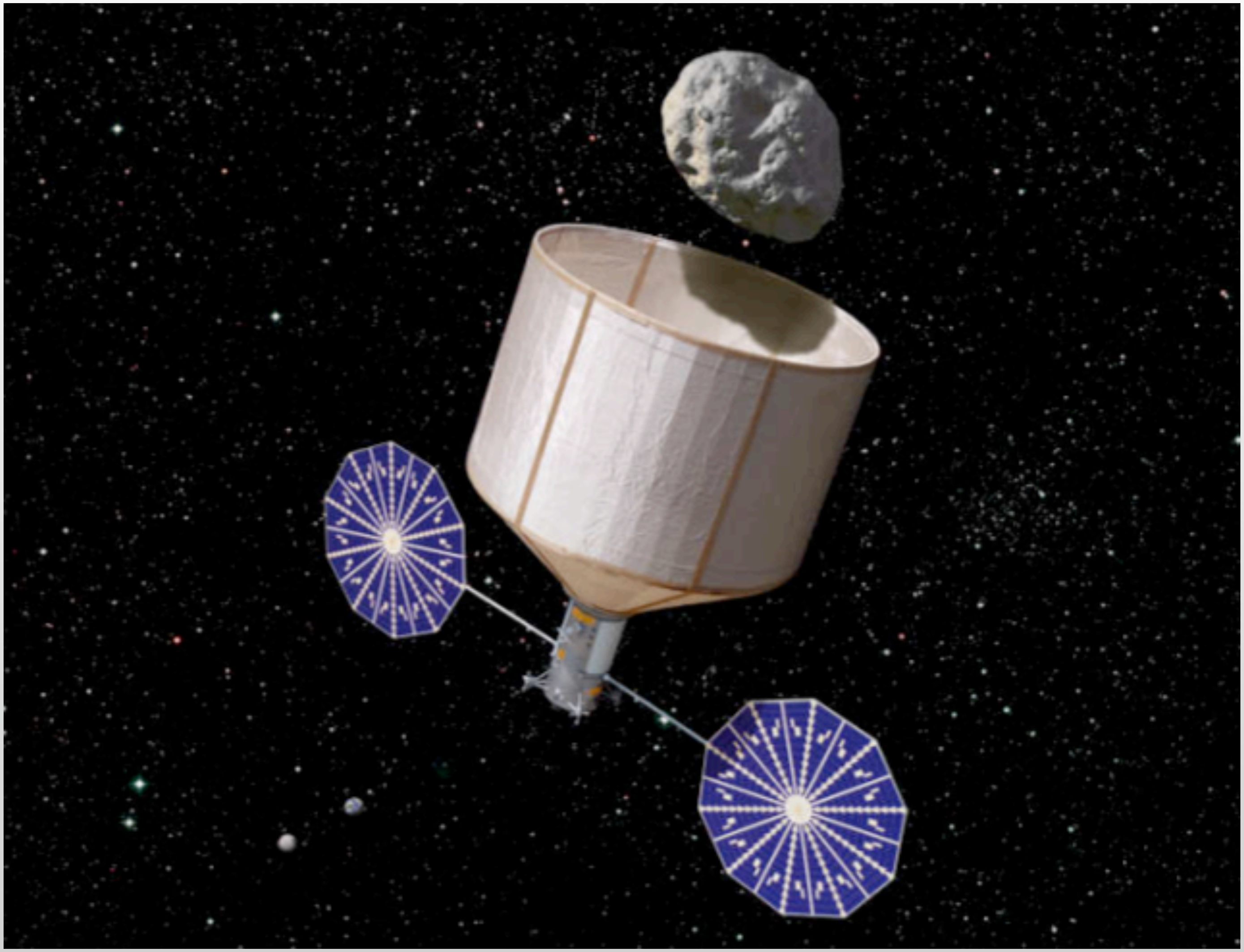
Hayabusa

- Materials returned to Earth!
- Rendezvous and (two) hovers automated (closed loop using camera data)
- Spacecraft 500 kg, mission cost $170 million

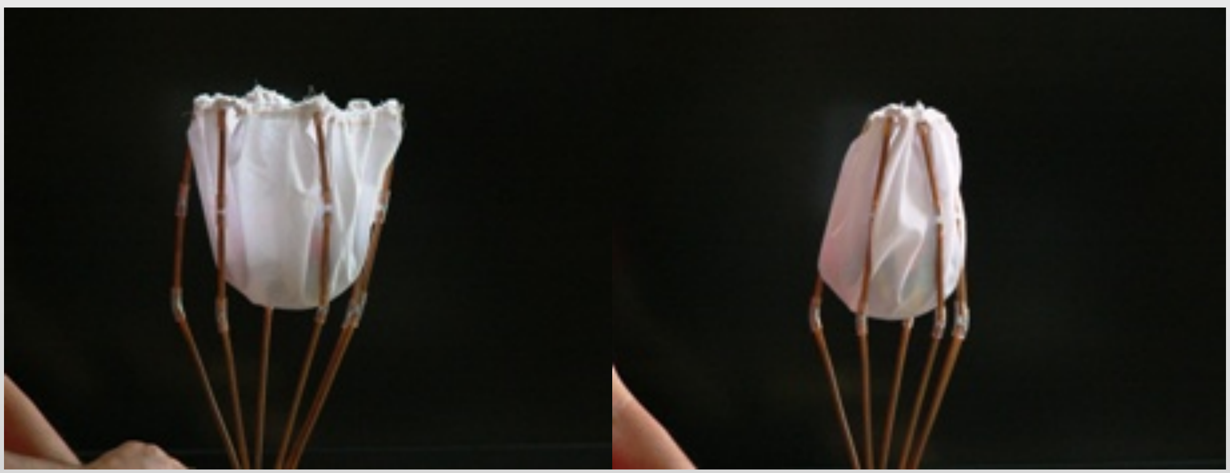


Keck Study Vehicle



From Brophy, et al. “Asteroid Retrieval Feasibility Study”

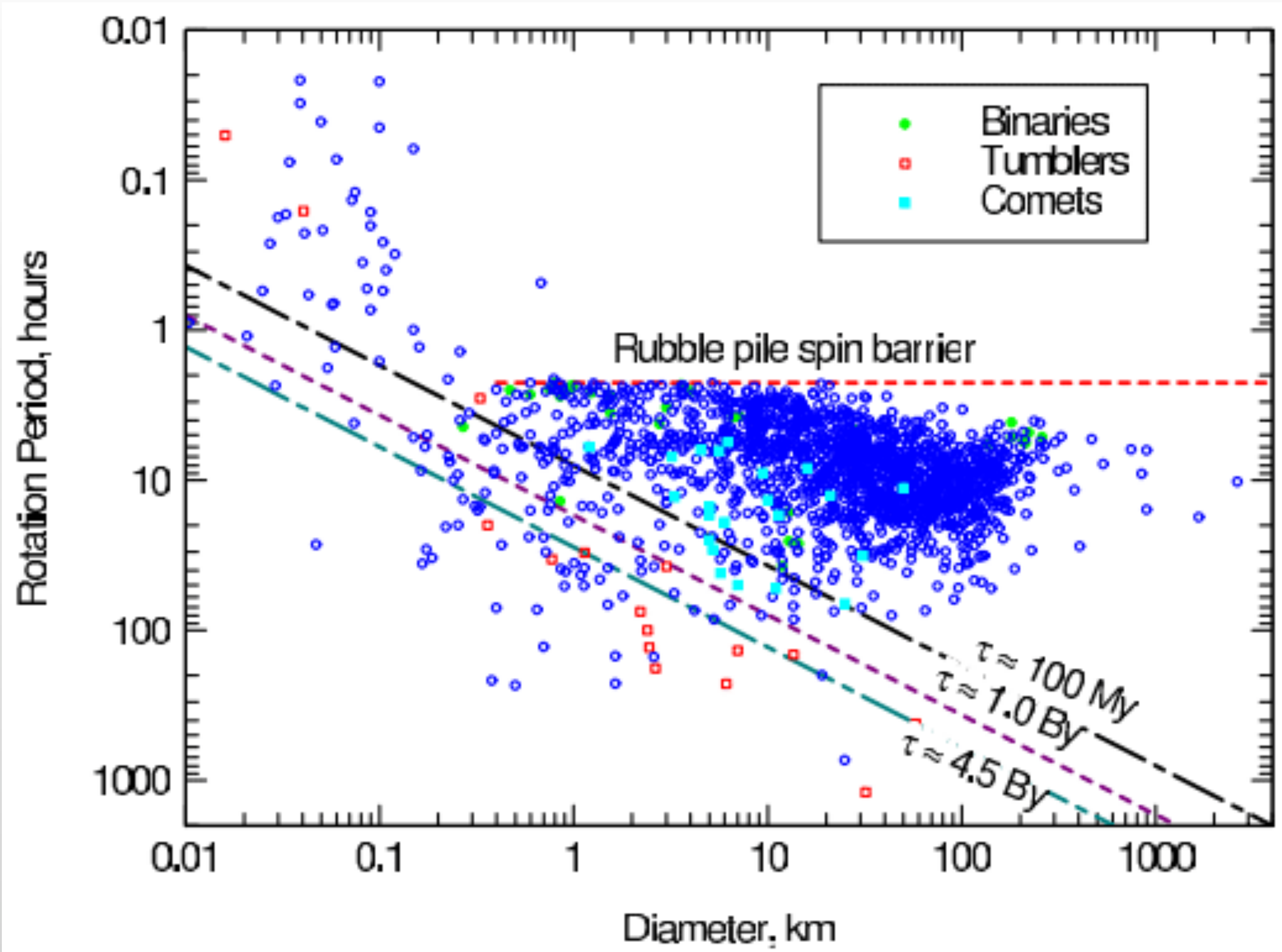
Asteroid Capture Model



- 1/50 scale
- ¼″ copper tubing
- Flexible tubing joints
- Segments: 5 m long

Very little strength needed to handle SEP forces

Rotation Rates



Credit: "Rotational Properties of Asteroids, Comets and TNOs," Harris and Prevec

Tug Mission Cost

- Bus and bag concept
- Well characterized costs
  - Launcher: $80-$100M
  - Bus: ~$150M
    - Includes avionics, power, propulsion
  - Ground station $25M
- Capture system and integration: ~$250M
- Total: ~$500M

WBS	Description	DDT&E Total (FY12$M)	Flight HW Total (FY12$M)	DD&FH Total (FY12$M)
06.1.1	Payloads	65.0	28.0	93.0
06.1.2	Command & Data Handling	50.1	18.3	68.5
06.1.3	Communications and Tracking	29.7	13.7	43.4
06.1.4	Guidance, Navigation, and Control (GN&C)	17.2	12.7	29.9
06.1.5	Electrical Power Subsystem	190.3	62.1	252.4
06.1.6	Thermal Control (Non-Propellant)	26.0	13.2	39.3
06.1.7	Structures and Mechanisms	52.1	26.0	78.0
06.1.8	Propulsion System	156.0	67.5	223.5
06.1.9	Propellant	0.0	0.0	0.0
	Subtotal	**586.4**	**241.6**	**828.0**
	IACO	41.6	12.6	54.1
	STO	37.7		37.7
	GSE Hardware	77.0		77.0
	SE&I	109.9	35.6	145.5
	PM	42.5	18.3	60.8
	LOOS	40.6		40.6
	Spacecraft Total (with Integration)	**935.7**	**308.0**	**1243.7**
Prime Contractor Fee (10% less payload)		87.1	28.0	115.1
Spacecraft Total with Fee		**1022.7**	**336.0**	**1358.7**

Figure 16. Cost estimate for the Prime Contractor (including fee) in FY'12 $.

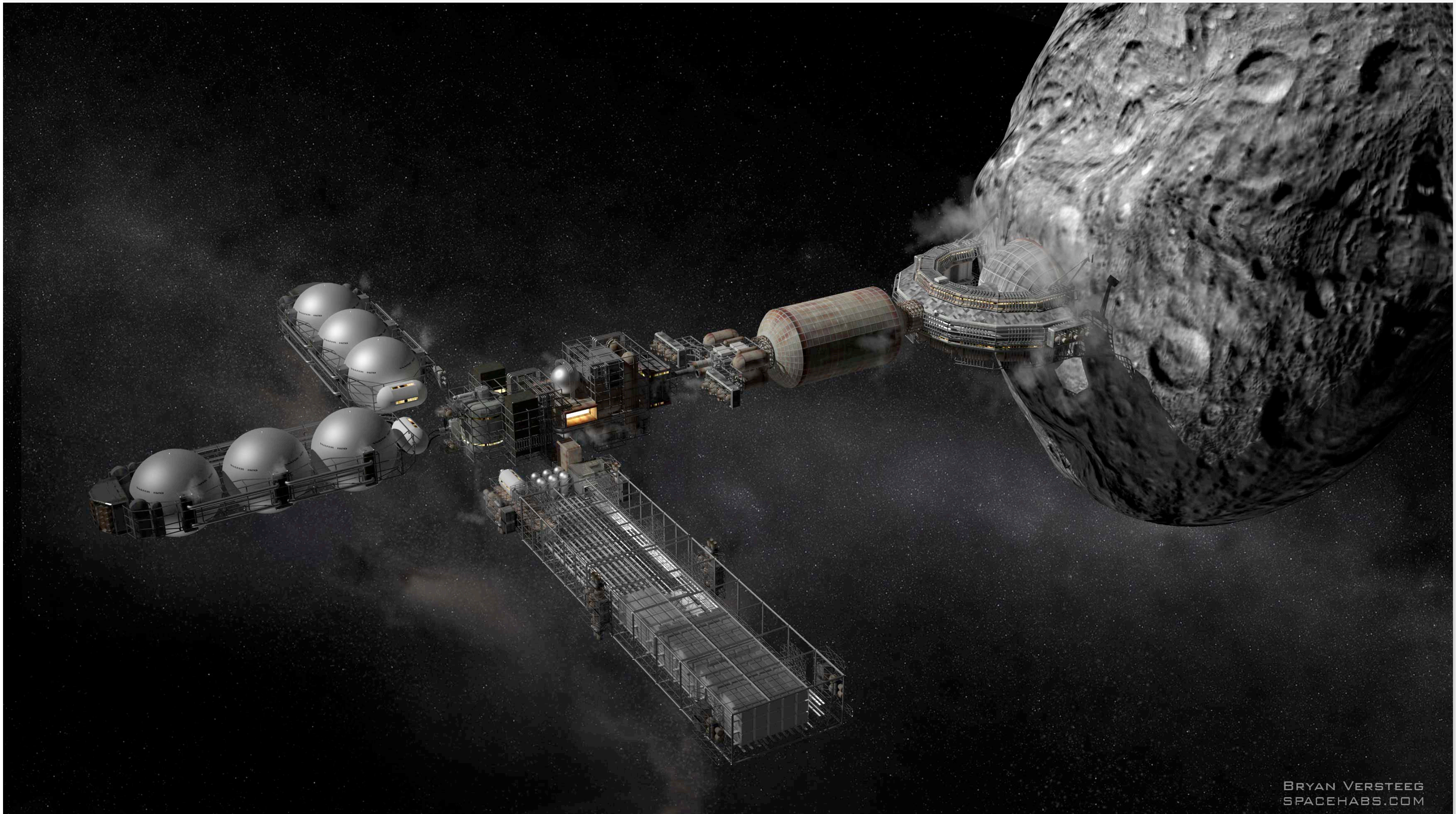
40

	FY12$M	
NASA insight/oversight	204	15% of prime contractor costs
Phase A	68	5% of B/C/D costs
Spacecraft	1359	Prime Contractor B/C/D cost plus fee (10% - less science payload)
Launch Vehicle	288	Atlas 551
Mission Ops/GDS	117	10 year mission plus set-up
Reserves	611	30% reserves
Total	**2647**	

Keck Costs

Credit: Keck Workshop final report

Typical Asteroid Mining Concept



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Small Asteroid Mining

- Asteroids are small enough to place inside processing system, like a wood chipper.
  - Controls dust, rocks
  - Permits opposing forces
  - Can spin for separation
- Astronaut setup and initial debugging, teleoperated thereafter
  - Automating mining is difficult, although progress has been made on Earth. Asteroids are a new environment and will require time to develop knowledge and capabilities

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Markets

- Samples for scientist to study
  - Will pay $100s millions for missions to return asteroid samples
- 1,000 kg/yr of monomethyl hydrazine/oxidizer $270M/yr
- Shielding for habitat (e.g., Bigelow) modules and exploration vehicles outside magnetosphere
- Water for drinking, electrolysis into H/O fuel/oxidizer
  - At 10% water (carbonaceous chondrites at 3.3 tons/m^3)
    - 5 m asteroid provides ~40 tons of water
    - 10 m provides ~330 tons of water
  - O, 89% of H/O mass, also available from other compounds
- Metals and silicon for Space Solar Power satellite structure
- Complex components and molds via 3D printing
- High value metals for Earth

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Comparison

Astronauts to Asteroid	Asteroid to Astronauts
Six months travel time	A few days travel time
No rapid return	Return in a few days
No resupply	Resupply in a few days
Fixed, short stay times	Indefinite stay times
Much larger Δv, new vehicles required	Smaller Δv, Falcon Heavy and Dragon sufficient
One asteroid per mission	Potentially many asteroids per mission
Repeat visits to same asteroid very difficult	Repeat visits easy
Cannot supply asteroid materials markets beyond science	Potentially supply multiple asteroid materials markets
Some contribution to planetary defense	Includes full planetary defense system (detection and deflection)
Single, monolithic system	Many nearly independent components of intrinsic value

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Conclusion

Bring the asteroids to the astronauts!!!