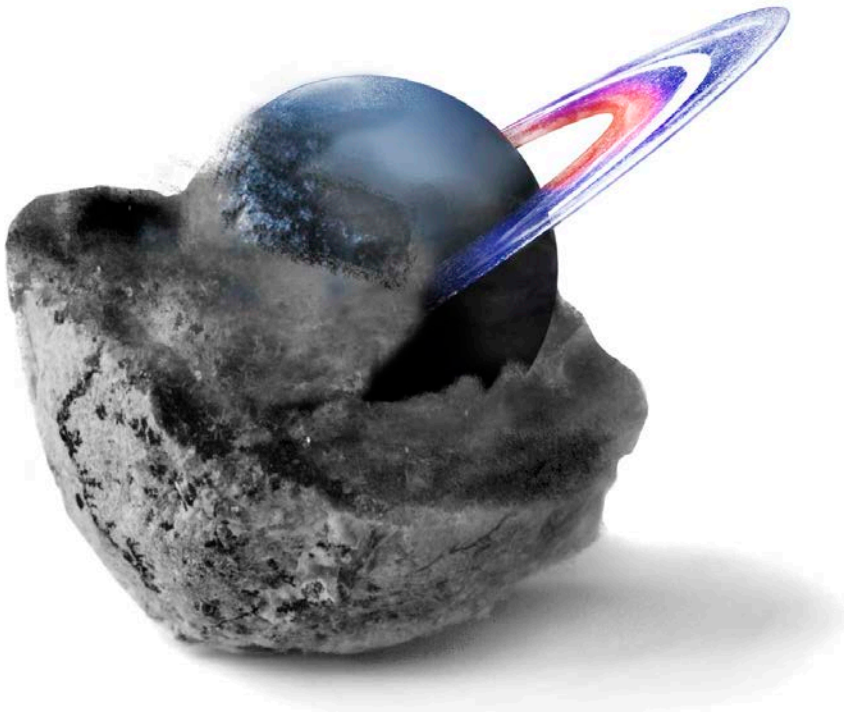

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A NASA PROGRAM BASED ON THIS INITIATIVE

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The Program Approach

- Within the NASA "way-of-doing-business," *Programs* provide a contextual framework under which long-term exploratory activities can be conducted
  - Provide stability, continuity, political defensibility, budgetary resilience, technology rationale
  - Have some possibility of spanning a multiplicity of HQ sponsors (SMD, HEOMD, STMD)
  - Provide a logical POC for international coordination
- Notable examples
  - Mars Program (JPL)
  - Living with a Star Program (GSFC)
  - Others . . .
- NASA's recently-announced *Asteroid Initiative* is well-suited to a program structure
  - It has diverse elements (Observation; Redirection; Deflection; Capture; Crew; Engagement) which are a mix of project and level-of-effort activities.
  - The Grand Challenge element (Planetary Defense) is naturally long-term, requiring a sequence of missions and time-phased activities
- But NASA does not (yet) have a program office

Current NASA Programs

- ARMD
  - Aeronautics Test; Airspace Systems; Aviation Safety; Fundamental Aeronautics; Integrated Systems Research
- HEOMD
  - ISS; Space Comm & Nav; Launch Services; Commercial Spaceflight Development; Exploration Systems Development; Advanced Exploration Systems; Space Life & Physical Sciences
- SMD
  - Astrophysics Explorers; Cosmic Origins; Discovery; Earth Systematic Missions; Earth System Science Pathfinder; Exoplanet Exploration; Explorers; GOES/POES; Heliophysics Explorers; Living with a Star; Mars Exploration; Near-Earth Object Observation (NEOO); New Frontiers; Physics of the Cosmos
- STMD
  - Flight Opportunities; Game Changing Development; NIAC; SBIR/STTR; Small Spacecraft Technology; Space Technology Research Grants; Technology Demonstration Missions

Note: Evidently, there is no current *overarching* NASA Program targeted specifically at small bodies. The NEOO Program is as close as it comes.

Stakeholders

- Science
  - A diverse community whose interests span main-belt asteroids, near-Earth asteroids, comets
    - NASA SMD; NASA Centers; universities; other institutions; SBAG
  - Includes discovery and characterization activities (Earth or space-based) as well as missions to selected targets.
- Human Space Flight
  - NASA's stated plan of record (i.e., the Flexible Path) posits asteroids first, later followed by Mars, as target destinations.
- Space Resources
  - Today, primarily the domain of commercial entities, e.g., Planetary Resources, Deep Space Industries)
  - But, over the years, NASA has signaled its own interest in space-based resources
- Protect the Earth
  - Congressional directives; NRC reports
  - Private activities, e.g., B612 Foundation

Program (RFI Response)

	Advanced Studies	Technology Developmen t	Robotic Missions	Ground-Based Observations	Crewed Operations	Commercial ization	Education & Public Outreach
Asteroid Observations	X	X	X	X			X
Asteroid Redirection Systems	X	X	X				
Asteroid Deflection Demonstration	X	X	X				
Asteroid Capture Systems	X	X	X				
Crew Systems for Asteroid Exploration	X	X			X	X	X
Partnerships and Participatory Engagement			X	X		X	X

Note: A typical element typical of most NASA programs, but missing here, is Science Research and Analysis. The Asteroid Initiative RFI acknowledged the importance of science, but did not explicitly solicit science ideas. Such an element could easily be added.

Program Objectives (Nominal)

1. Significantly increase the opportunities for human space exploration beyond Earth orbit, possibly as a path to crewed exploration of Mars.
2. Protect Earth from future asteroid impacts.
3. Foster a new commercial space business utilizing asteroid resources, with US industry leading the way.
4. Advance key space technologies essential for the future.

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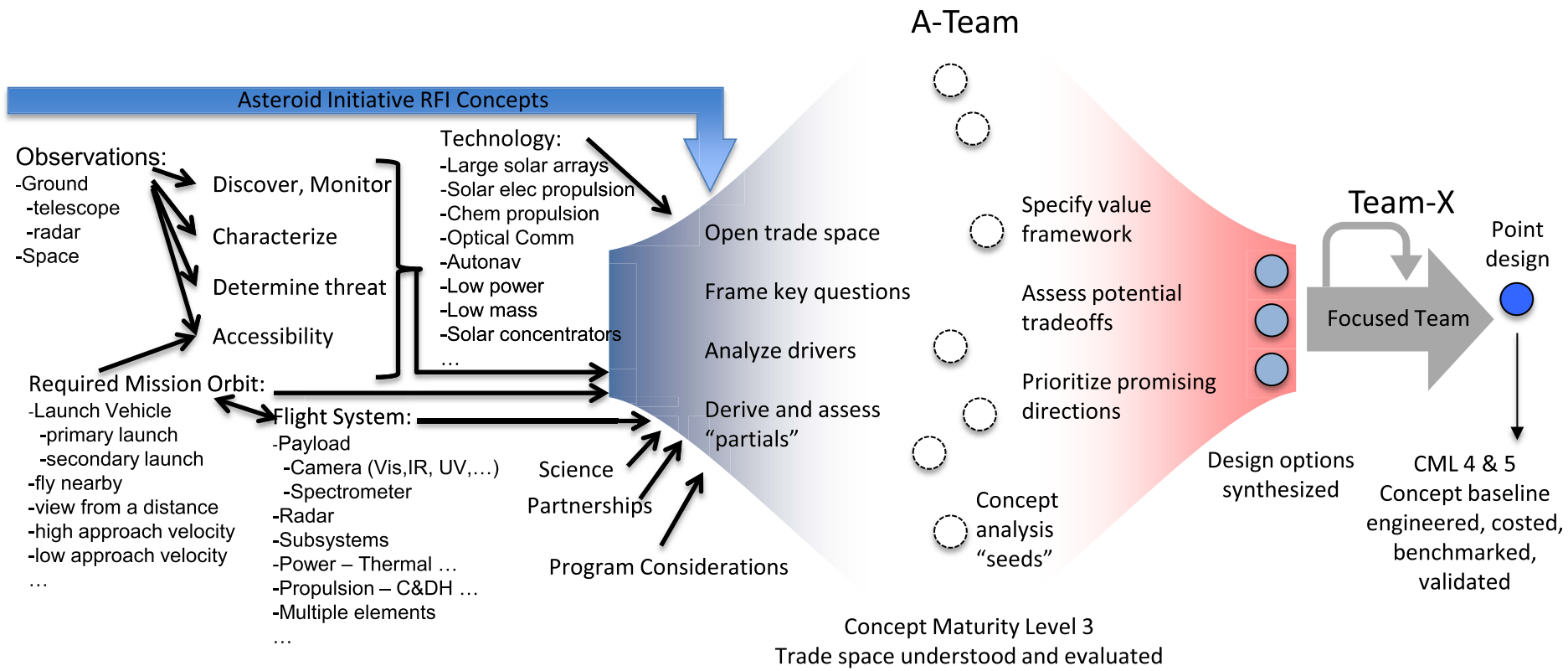
Advanced Studies



- Two-year set of trade space definition and exploration studies with full assessment
- Experts from diverse areas produce a set of trade space evaluation criteria and feasible concepts
- Feasible concepts evaluated across the trade space to produce the best combinations
- Highest ranked architectures along with the combinations of feasible concepts
- Second year consists of mission concept maturation and roadmap evaluation

Technology Development

- High power solar electric propulsion
  - Very propellant-efficient for redirecting large masses
- Large solar arrays for propulsion and power
  - May be enabled by solar concentrators
- Chemical propulsion where short trip times are needed
- Optical communications for high-bandwidth
- Robotics and autonomous systems
  - Navigation
  - Entry, Descent and Landing
  - Proximity operations
- Scientific Instruments and sensors
- Low power systems for precursor and support activities
- Low mass structures and materials for precursor and support activities
- Others …

Robotic Missions

(Black for USA; RED for International)

- ESA: Giotto (*Halley*); Rosetta (*Churyumov–Gerasimenko*; *Steins*; *Lutetia*)
- ISAS / JAXA: Sakigake (*Halley*); Hayabusa (*Itokawa*); Hayabusa-2 (*1999 JU_3*)
- NASA/APL: NEAR (*Eros*); CONTOUR (Failed)
- NASA/GSFC: ICE (*Giacobini-Zinner*); Osiris-Rex (*Bennu*)
- NASA/JPL: Galileo (*Gaspra*; *Ida*; *Dactyl*); Cassini (*Masursky*); Stardust (*Annefrank*; *Wild-2*; *Tempel-1*); Deep Space-1 (*Braille*; *Borrelly*); Deep Impact (*Tempel-1*); EPOXI (*Hartley-2*); Dawn (*Vesta*; *Ceres*); NEOWISE (IR Search)
- USSR / Russia: VEGA (*Halley*)
- CNSA / China: Chang'e-2 (*Toutatis*)

Ground-Based Observations

(Black for USA; RED for International)

1. NASA/JPL: Goldstone Solar System Radar (GSSR) NEA observations
2. NAIC: Arecibo Radio Observatory (ARO) NEA observations
3. ESA: NEO Coordination Center, Frascati, Italy
4. European Union (27 nations): Asteroid defense technologies
5. DLR: NEO Shield Project
6. University of Hawaii: 8 small asteroid detection telescopes (2015)
7. Korea: Microlensing Telescope Network
8. ESA: Optical Space Telescope (Canary Is.) used 4x/month for asteroids
9. Russia: Academy of Sciences 1.6m telescope for NEO assessments
10. USAF: Space Surveillance Network
11. Chile, NSF, DOE, B. Gates, C. Simonyi: Large Synoptic Survey Telescope (LSST) (Cerro Pachon, Chile)
12. US SAO: Minor Planet Center has a de facto clearinghouse role

Items 1 & 2: GSSR and ARO typically work as partners for NEA radar activities, including cooperative bi-static observations. Together, they form a unique capability.

Items 3 - 12: This info taken from Space News, June 3, 2013, p. 5.

Crewed Operations
(The Outpost Station)

- NASA could establish an "Outpost Station"
  - Would be the central focus of its activities in trans-lunar space
  - Would co-orbit with the asteroid returned by the Asteroid Redirect Robotic Mission
  - Could become the first stop for explorers, entrepreneurs and pioneers heading out to the new frontier
  - Would enhance NASA's relevance to the American people, private sector U.S. industry, and the world
  - Could fundamentally lead to a space-faring civilization
- The Outpost Station would start as a small facility, occasionally human-tended:
  - Conduct experiments with asteroid material
  - Seek practical methods for producing rocket fuel, breathable atmosphere and engineering structures with minimal terrestrially-supplied feedstock
  - Determine the best way to harness the asteroid as feedstock for robust radiation shielding
    - Once this has been accomplished, it will be possible to affordably create a safe, permanently-inhabited outpost with long durations stays, possibly simulating manned missions to Mars
  - Analyze the asteroid and it's constituents parts either for fundamental science, or as part of characterizing NEA threats
  - Demonstrate technologies using the ARRM asteroid as a test case for protecting the Earth from asteroid impact
- Eventually, outpost activity can be more engineering and production oriented:
  - Full scale production of propellants and atmosphere, possibly by private enterprise
    - NASA, commercial space tourism and/or in-situ resource utilization industries could be customers
  - Construction of larger-scale engineering structures
    - Space hotels
    - Vehicles for manned missions to Mars
  - Maintenance of a large mass of asteroid material, and the propulsion system needed to move that material in deep space, always on alert and ready to be moved to intercept and deflect dangerously large inbound asteroids, if or when they are detected

Commercialization

- NASA's existing Commercial Technology Program:
  - Sponsors a number of organizations around the U.S.
  - Is designed to assist U.S. businesses in accessing, utilizing, and commercializing NASA-funded research and technology.
- Each NASA field center has a Commercial Technology Office
  - The centers promulgate the healthy spin-off of NASA-developed technologies into the commercial world.
- Technology can flow in both directions
  - NASA intentionally seeks to acquire technology from Industry
- Finally, needed technologies can be developed within the context of a NASA-Industry partnership

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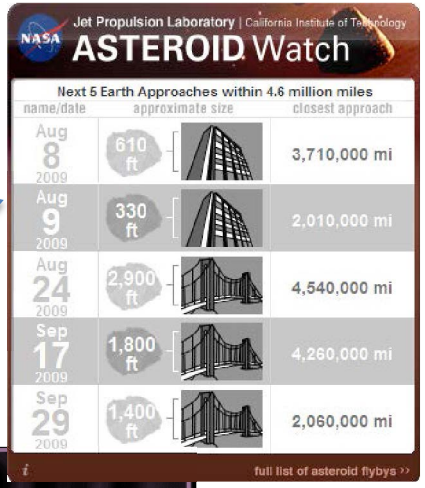
Education and Public Outreach
(and Citizen Science)

- Each time a near-Earth asteroid flies close by the Earth, it is a media event
  - Adventure, danger, the unknown, . . .
- Numerous people have asserted that the two things that get kids interested in science are space and dinosaurs
  - Near-Earth asteroids are relevant to both
  - They are made-to-order PR items
- There is potential for a logical and productive interface with the amateur astronomer community
  - Example: Amateur Observer's Program
  - Example: Comet ISON
  - Example: Halley Watch (c. 1986)



Science Research & Analysis

(Some Examples)

- NASA's ROSES call for 2013 included Appendix C.3, which calls for Laboratory Analysis of Returned Samples, in particular those particulates of asteroid origin returned to Earth by Japan's Hayabusa mission in 2010.
- NASA's Planetary Geology and Geophysics program element (ROSES Appendix C.4) calls for investigations that use existing data to study asteroid surfaces and interiors.
- The Planetary Astronomy program element (ROSES Appendix C.5) calls for "observations over the entire range of wavelengths from the ultraviolet to radio that contribute to the understanding of the general properties and evolution of the Solar System, its planets, their satellites, and asteroids and comets".
- The Outer Planets Research (OPR) program element (ROSES Appendix C.7) supports diverse scientific investigations that "contribute to the understanding of the outer Solar System, including the giant planets, their satellites, and smaller solid bodies including comets, asteroids, and Kuiper Belt Objects."
- The Moon and Mars Analog Missions Activities program element (ROSES Appendix C.14) solicits investigations that address "integrated interdisciplinary field experiments as an integral part of preparation for planned human and robotic missions to asteroids, the Moon, and/or Mars."

<u>Conclusion</u>: These kinds of activities could be consolidated under the auspices of a Small Bodies Program Office, should NASA choose to do so