Overview of US/NASA NEO Programs

12 June 2014

Space Mission Planning Advisory Group Mtg #2

Lindley Johnson
NASA Headquarters, Science Mission Directorate
Planetary Science Division, NEO Observation Program

NASA's NEO Search Program
(Current Systems)

Minor Planet Center (MPC)
- IAU sanctioned
- Int'l observation database
- Initial orbit determination

http://www.cfa.harvard.edu/iau/mpc.html

NEO Program Office @ JPL
- Program coordination
- Precision orbit determination
- Automated SENTRY

http://neo.jpl.nasa.gov/

Operations:
Jan 2010 – Feb 2011

Re-activated:
Sept 2013 (discovered 14 new NEOs)

Radar Observations

Goldstone 70 m

These facilities have complementary capabilities and currently observe ~70-80 NEOs/year.

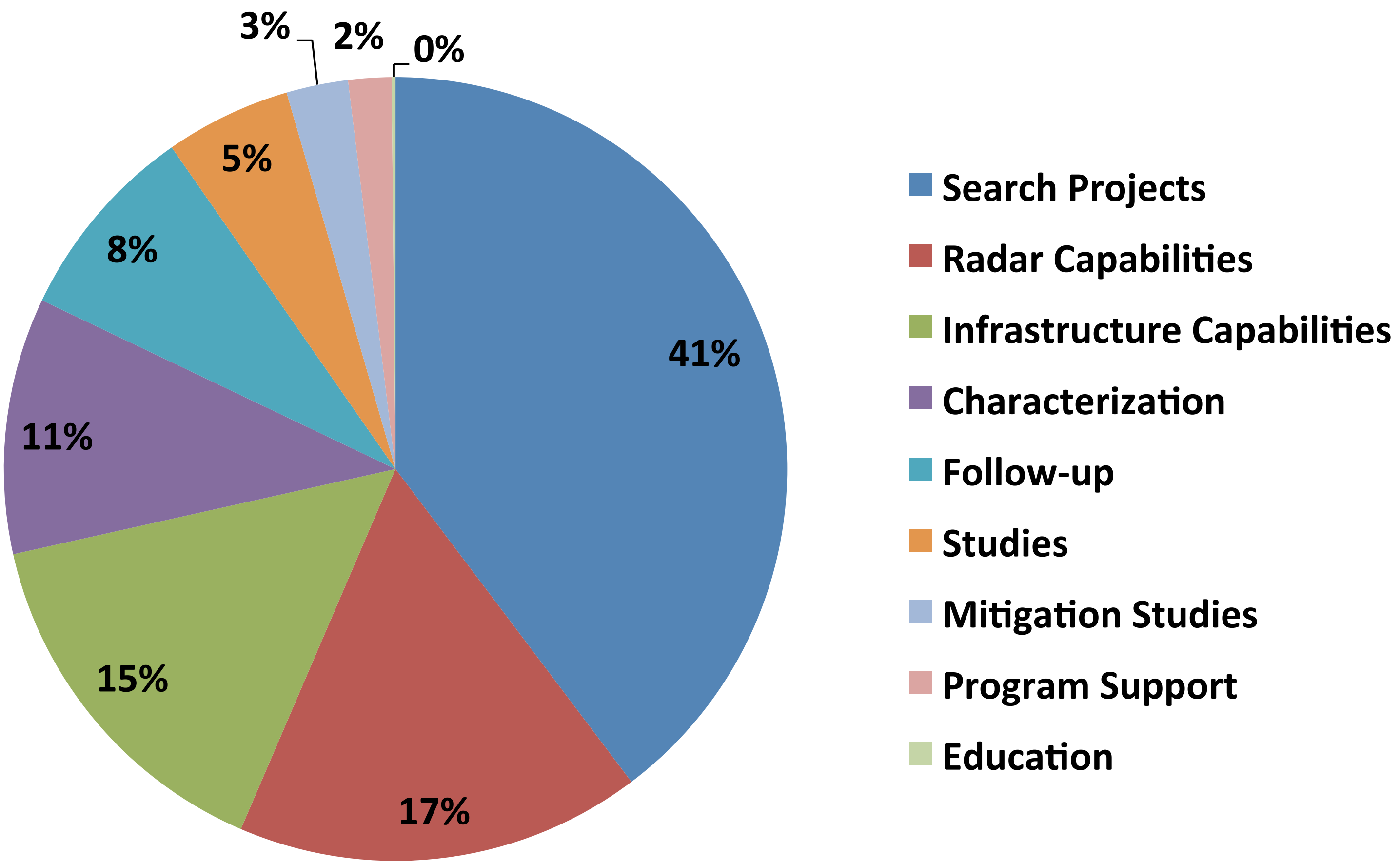
Radar observations can provide:

- **Size and shape to within ~few meters**
- **High precision range/Doppler orbit data**
- **Spin rate, surface density and roughness**

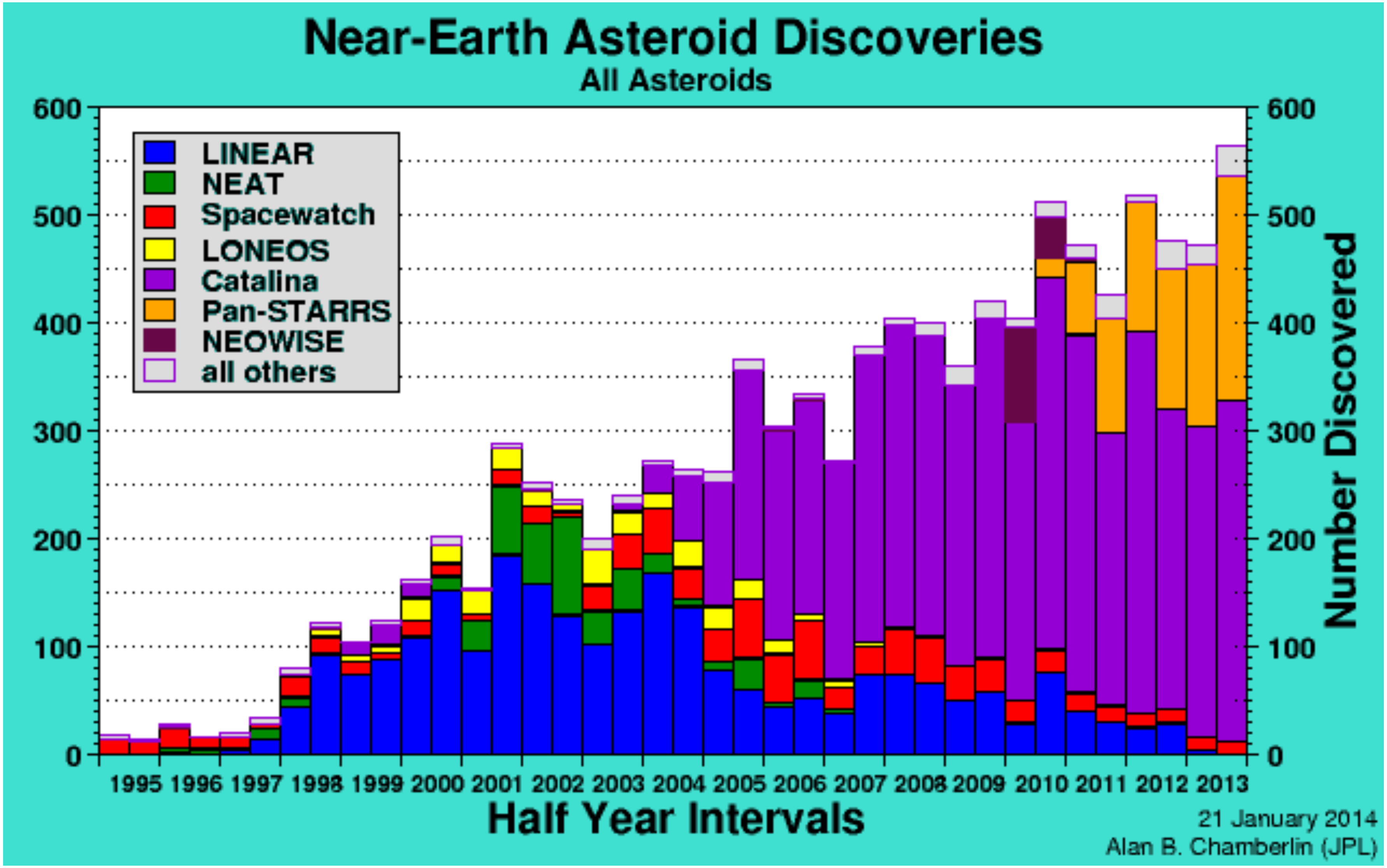
GSSR image of (4179) Toutatis taken on 12 Dec 2012.

Large NEO (~4.5 x 2.4 x 1.9 km). Image resolution is ~3.75 m)

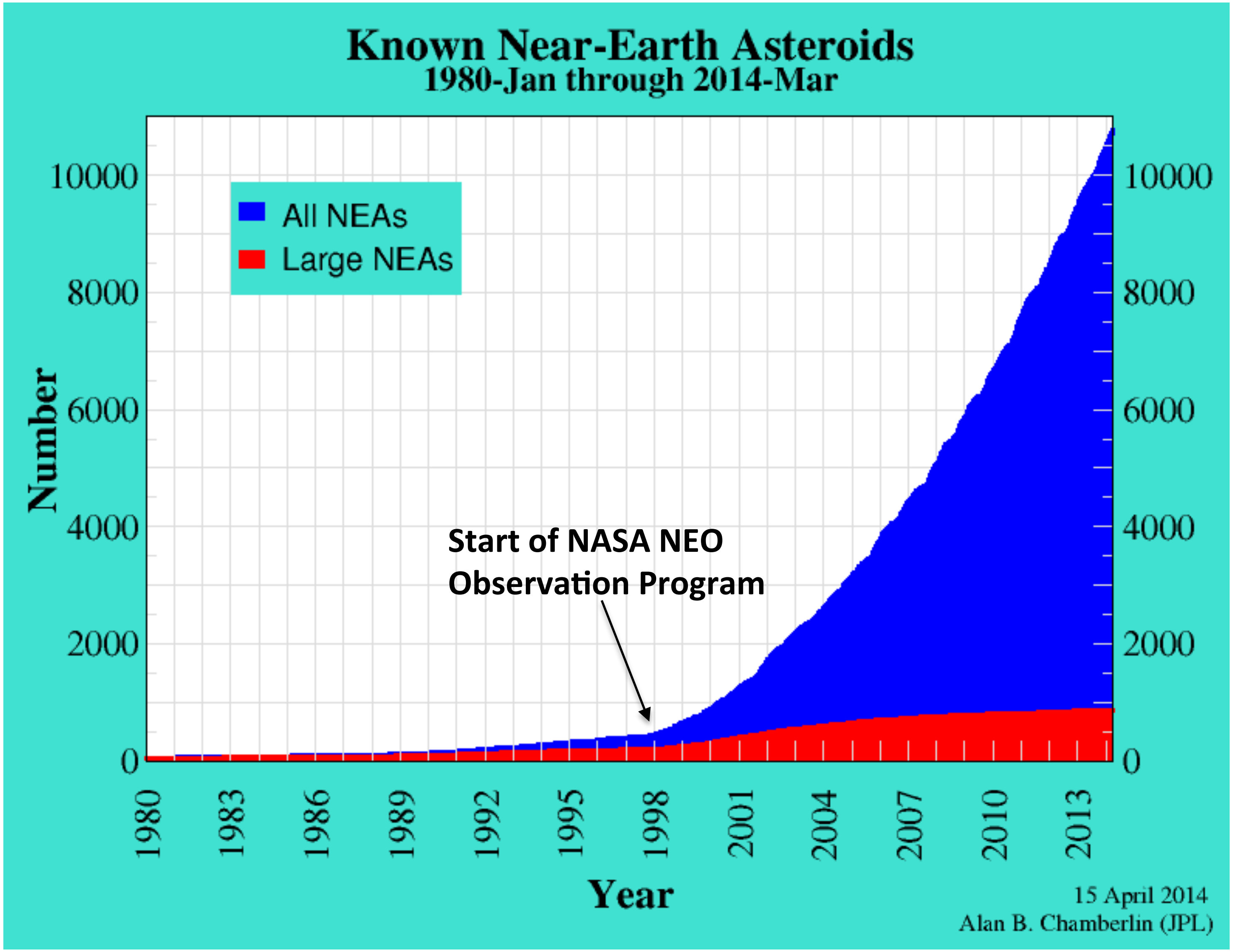
NASA NEO Funding



Global NEA Discoveries



Known NEA Population



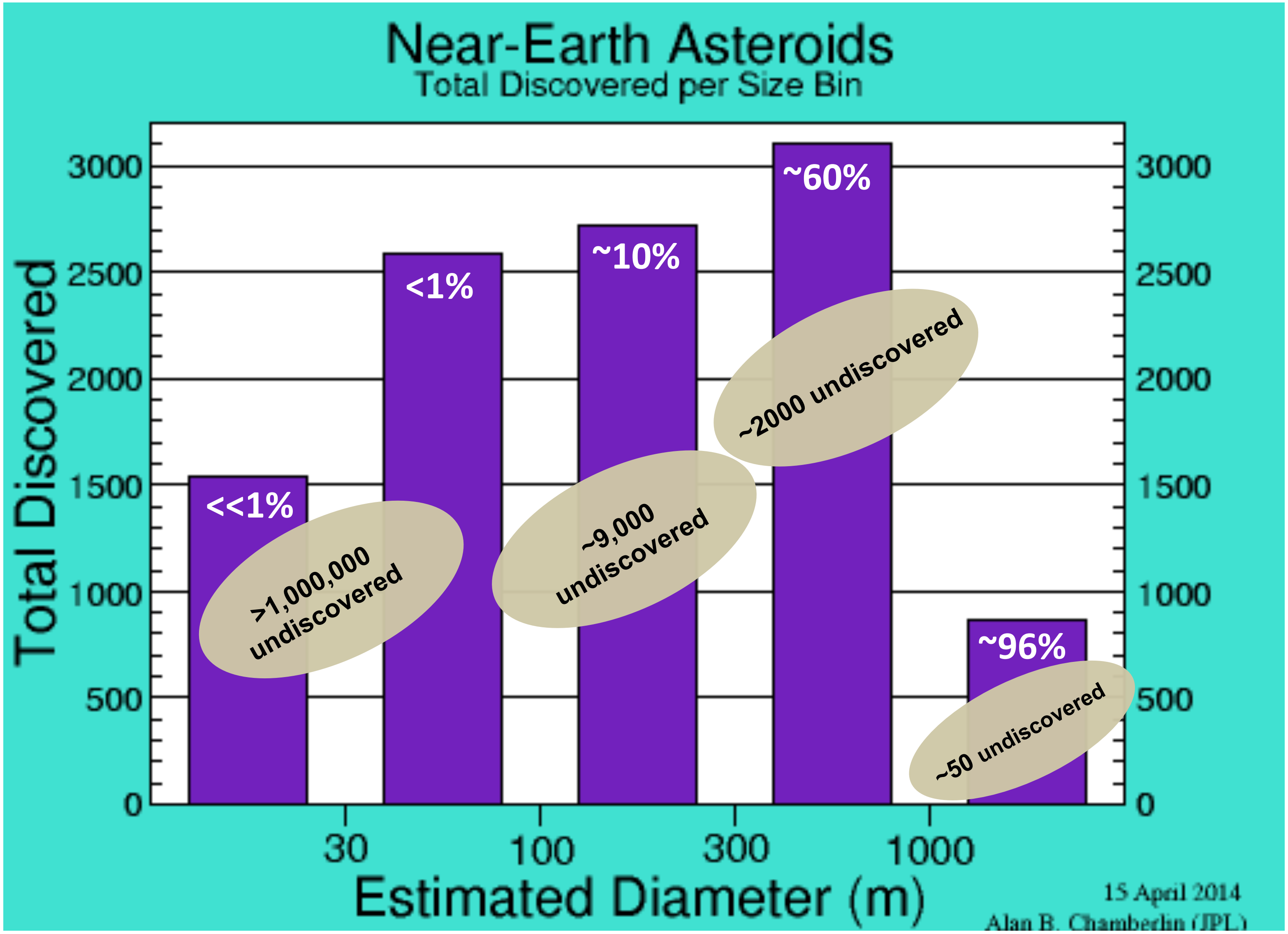
As of 6/11/14

Totals 11,138

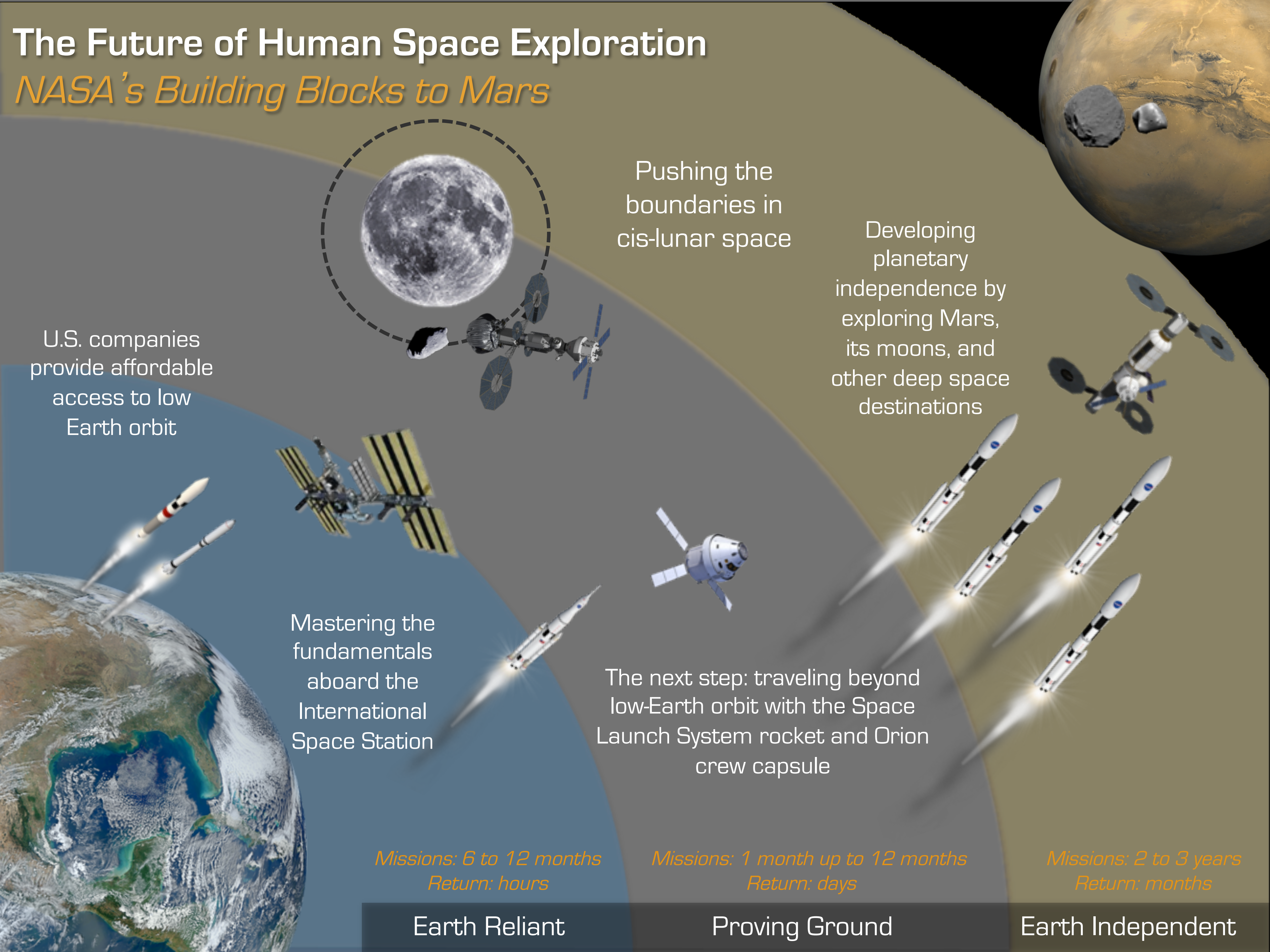
includes:

94 comets
863 'large' NEAs
1484 PHOs

Known NEA Population

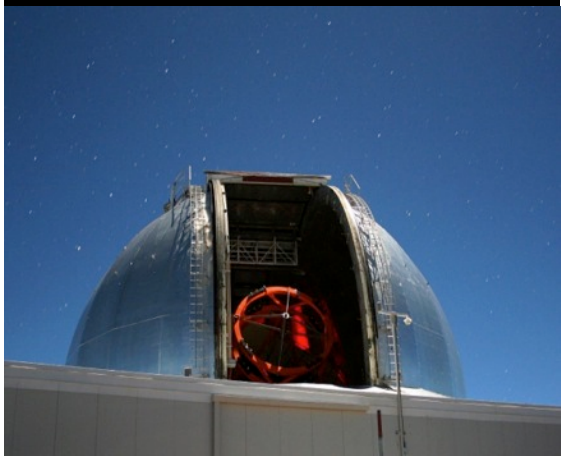
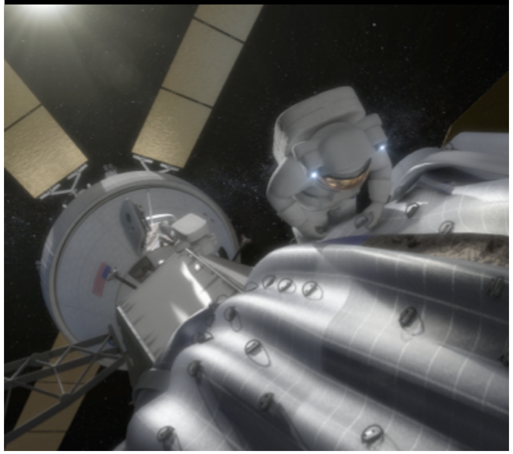


Asteroid Redirect Mission



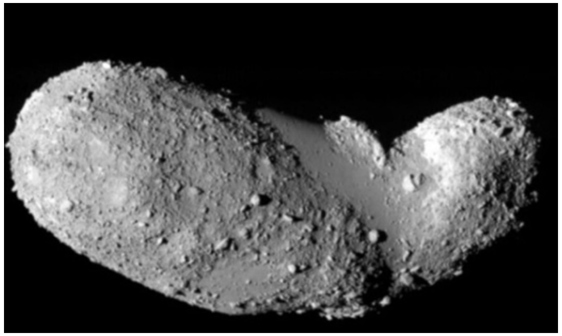
The Future of Human Space Exploration
NASA's Building Blocks to Mars
Pushing the boundaries in cis-lunar space
Developing planetary independence by exploring Mars, its moons, and other deep space destinations
U.S. companies provide affordable access to low Earth orbit
Mastering the fundamentals aboard the International Space Station
The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion crew capsule
Missions: 6 to 12 months
Return: hours
Missions: 1 month up to 12 months
Return: days
Missions: 2 to 3 years
Return: months
Earth Reliant
Proving Ground
Earth Independent

Asteroid Redirect Mission

Identify	Redirect	Explore
		
Asteroid Identification: Ground and space based near Earth asteroid (NEA) target detection, characterization and selection	**Asteroid Redirect Robotic Mission:** High power solar electric propulsion (SEP) based robotic asteroid redirect to lunar distant retrograde orbit	**Asteroid Redirect Crewed Mission:** Orion and Space Launch System based crewed rendezvous and sampling mission to the relocated asteroid

NASA Asteroid Redirect Mission Internal Studies Completed

Robotic Mission Concept (Option A)
- To redirect a small near Earth asteroid and potentially demonstrate asteroid deflection
- Study led by the Jet Propulsion Laboratory



Robotic Mission Concept (now Option B)
- To redirect a boulder from a larger asteroid and potentially demonstrate asteroid deflection
- Study led by the Langley Research Center

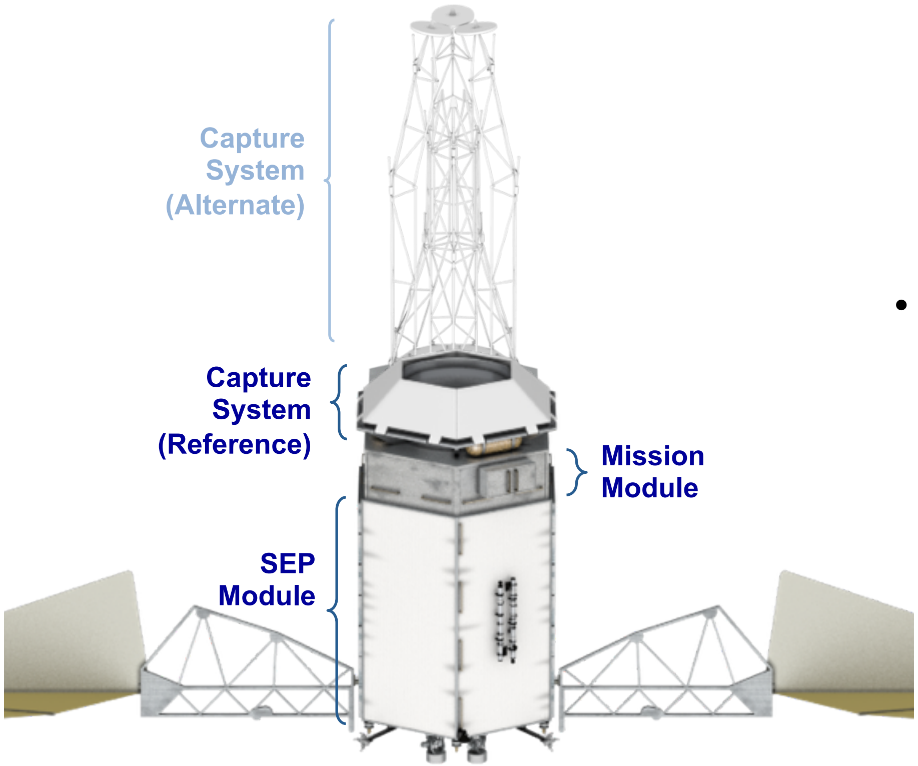
Crewed Mission
- Crew rendezvous and sampling for either concept
- Led by the Johnson Space Center

Robotic Concept Integration Team comparative assessment

Revised Objectives of the Asteroid Redirect Mission

- Conduct a human exploration mission to an asteroid in the mid-2020's, providing systems and operational experience required for human exploration of Mars.
- Demonstrate an advanced solar electric propulsion system, enabling future deep-space human and robotic exploration with applicability to the nation's public and private sector space needs.
- **Enhance the detection, tracking and characterization of Near Earth Asteroids, enabling an overall strategy to defend our home planet.**
- **Demonstrate basic planetary defense techniques that will inform impact threat mitigation strategies required to defend our home planet.**
- Pursue a target of opportunity that benefits scientific and partnership interests, expanding our knowledge of small celestial bodies and enabling the mining of asteroidal resources for commercial and exploration needs.

Asteroid Redirect Robotic Mission Development Strategy



- **Capture System**
  – Reference concept utilized inflatable bag approach.
  – Alternate concept used robotic manipulators.
  – Multiple other candidates identified at Workshop
  – Implemented Broad Agency Announcement and continued internal option risk reduction

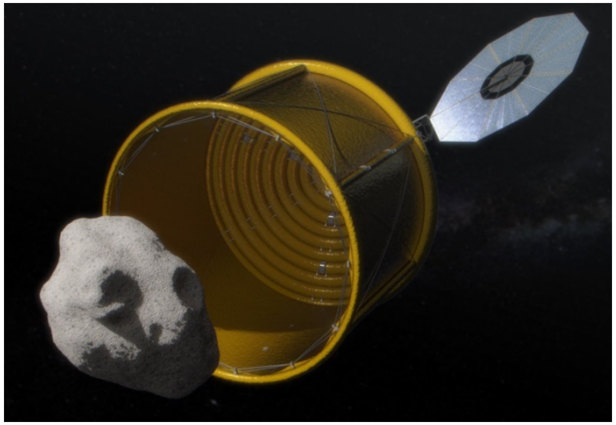
- **Mission Module**
  – Avionics leveraged from SMAP & Mars 2020 avionics.
  – Same core architecture for both capture concepts.
  – Single sensor suite development for crewed mission and both robotic mission concepts.
  – Sensor/algorithm development is a long lead development; mission module is not on critical path.

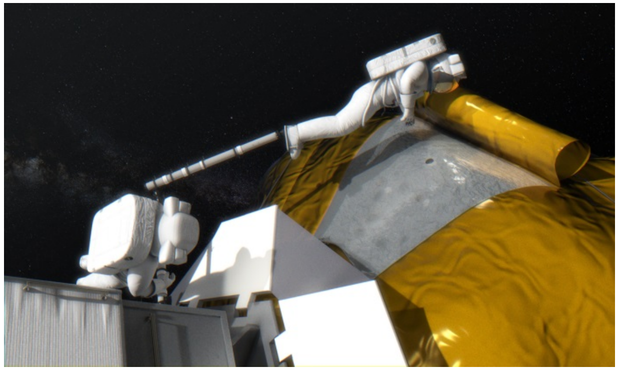
Solar Electric Propulsion (SEP) Module
  – Utilize advanced solar electric propulsion technology development.
  – Expanded from original NASA tech demo plans.
  – Nearly common module for both capture concepts; common technology items (thrusters, arrays, power processing units (PPUs)).

➢ **NASA-led Mission Design & Integration**

Asteroid Redirect Robotic Mission
Whole Small Near-Earth Asteroid Concept (Option A)

- **Rendezvous with small less than 10 meter mean diameter Near Earth Asteroid (NEA)**
  - **Capture <1000 metric ton rotating NEA**
  - **Demonstrate planetary defense techniques**
  - **Maneuver to stable, crew accessible lunar Distant Retrograde Orbit (DRO)**
- **Mission design reference is 2009 BD**
  - **5 meter mean diameter and < 145 metric tons**
  - **Launch mid-2019*; Crew accessible after 3/2024**
- **With recent Spitzer observations, another likely valid candidate: 2011 MD**
  - **Crew accessible after 8/2025**
- **Additional candidate targets expected to be discovered and characterized at the rate of several per year**

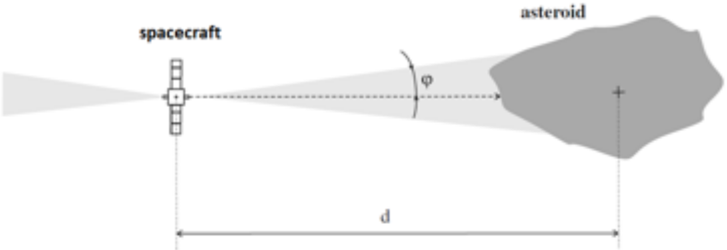




Planetary Defense (PD) Demonstration

- **ARRM could demonstrate the gradual, precise PD approaches of Ion Beam Deflection (IBD) or Gravity Tractor (GT) on a small asteroid**
- **For Reference Mission, a PD demo could be done with minimal impact to the mission design and operations**
  - No design changes, fits in existing timeline
  - IBD operations approach is independent of the size of the asteroid
- **IBD/GT relative performance on a small NEA**
  - IBD, <500 t (like 2009 BD) could impart: 1 mm/s in < 1 hour
  - GT, <500 t (like 2009 BD) could impart: 1 mm/s in < 30 hours

Ion Beam Deflector

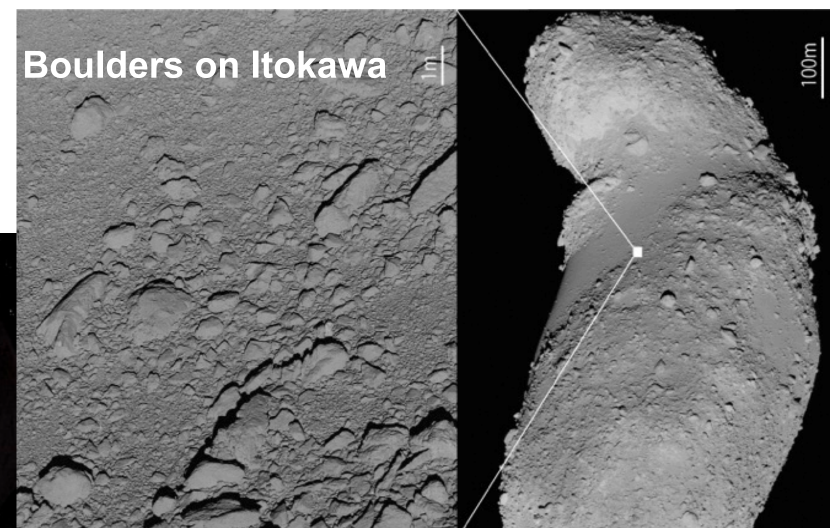


Asteroid size-independent planetary defense demo

Larger Asteroid Mission Concept (Option B)

- Rendezvous with a larger (~100+meter diameter) NEA
  - Collect ~2-4 meter diameter boulder (~10-70 metric tons)
  - Perform deflection demonstration(s) and track to determine effect
  - Return boulder to same lunar orbit
- Mission design reference is Itokawa
  - 2-3 meter, 18 ton boulder crew accessible in 2025 (2019 robotic mission launch)*
- Other targets to be characterized by in situ observation and crew accessible in DRO in 2025
  - Bennu by OSIRIS-Rex
  - 1999 JU3 by Hayabusa
  - 2008 EV5 by radar

    or other means



Planetary Defense Demonstration at a Larger NEA

Planetary Defense Options	Capable?
Kinetic Impactor	✓
Enhanced Gravity Tractor (EGT)	✓
Gravity Tractor	✓
Ion Beam Deflection (IBD)	✓

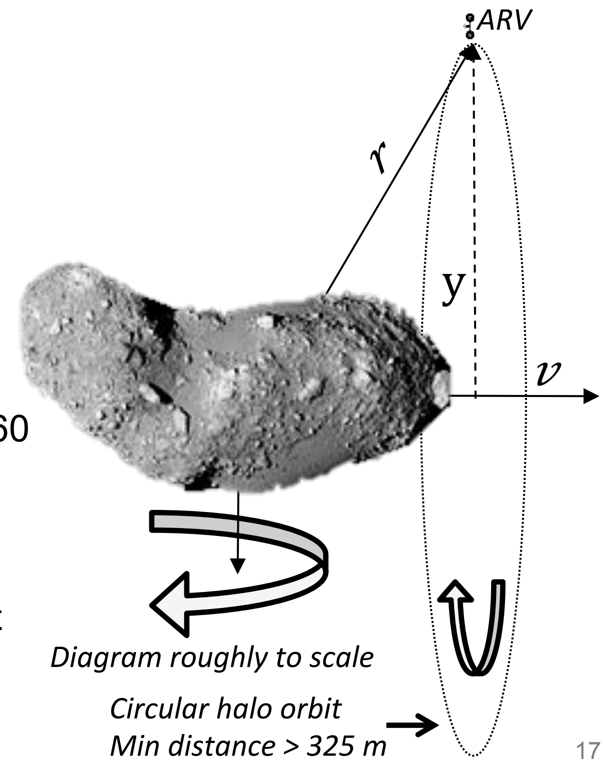
Selected Enhanced Gravity Tractor for Itokawa Case Study

- Relevant to potentially-hazardous-size NEAs: efficiency increases as boulder and NEA masses increase.
- Leverages collected boulder mass.
- Allows spacecraft to maintain safe, constant distance from NEA.
- Demonstrates sustained operations in asteroid proximity.

Focus is on demonstrating the applicability of Enhanced Gravity Tractor on potentially-hazardous-size NEA.

Enhanced Gravity Tractor Concept of Operations for Itokawa

- Phase 1: Fly in close formation with the asteroid with collected boulder (60 days required for measurable deflection with 120 days of reserve performance).
- Phase 2: Wait for orbital alignment to become favorable to allow measurement of deflection beyond 3-σ uncertainty (~8 months from start of Phase 1).



Current and Possible Future Currently Known Candidate Target Asteroids for ARM

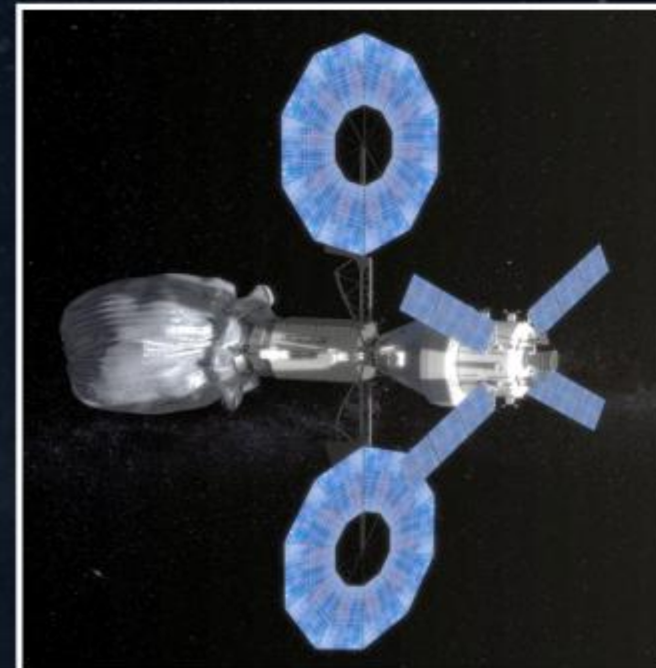
- **Small Asteroids:**
  - Currently, 7 potential candidates
  - 1 validated candidate: **2009 BD**; **crew accessible after 3/2024.**
  - With recent Spitzer observations, another likely valid candidate: **2011 MD; crew accessible after 8/2025.**
  - Possibly another valid candidate in 2016: **2008 HU4**.
  - Potentially future valid candidates, at a rate of a few per year.

- **Larger Asteroids:**
  - Currently, 6 potential candidates
  - Currently, 1 validated candidate: **Itokawa; 2-3 meter boulder crew accessible in 2025.**
  - 2 more valid candidates expected in 2018 (after characterization by other missions): **Bennu** and **1999 JU3**.
  - 1 possibly valid candidate with inferred boulders: **2008 EV5**.
  - Potentially future valid candidates with inferred boulders, at a rate of ~1 per year.

Asteroid Redirect Crewed Mission Overview

Deliver crew on SLS/Orion

Orion Docks to Robotic Spacecraft



EVA from Orion to retrieve asteroid samples

Return crew safely to Earth with asteroid samples in Orion

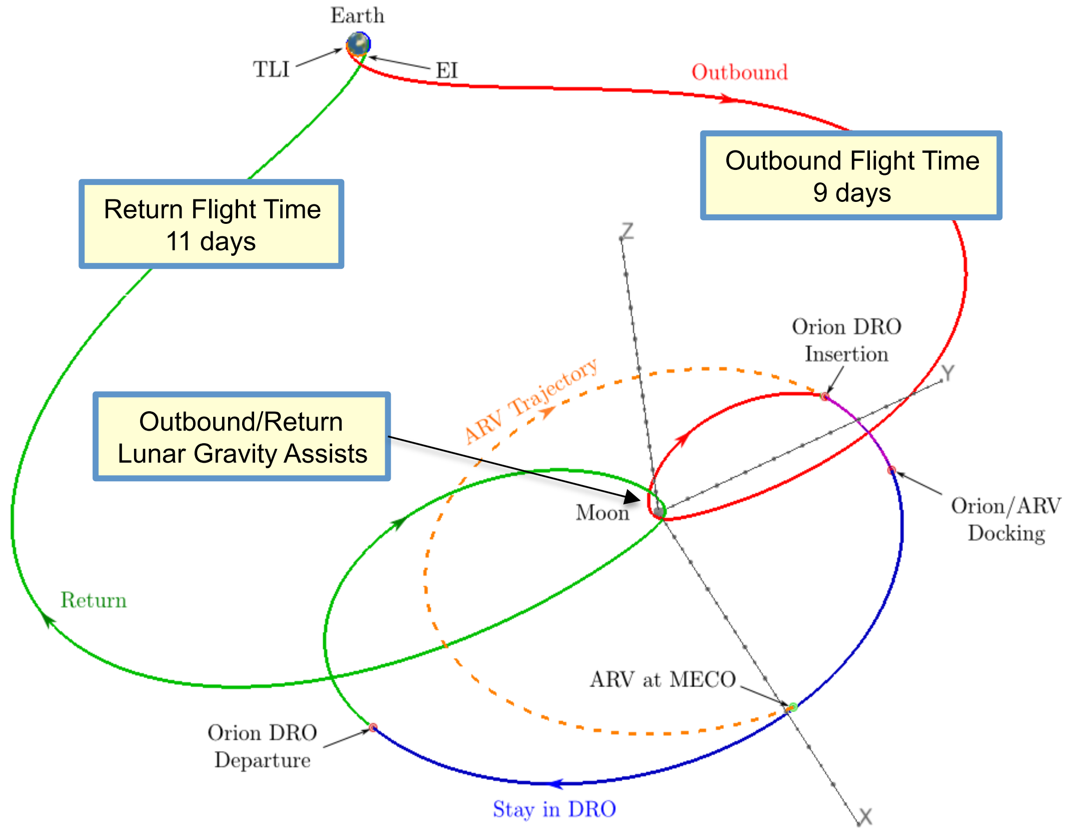
Crewed Mission Trajectory: Earliest Mission for 2009BD

- MECO Epoch: 2024-May-16 14:36:08 TDB
- Entry velocity: 10.99 km/s

- Total iCPS Δv: 2820 m/s (All iCPS capacity)
- Total Orion Δv: 1010 m/s
- Total Mission Duration: 25.65 days

- Outbound
  - Flight Day 1 – Launch/TLI
  - Flight Day 1-7 – Outbound Trans-Lunar Cruise
  - Flight Day 7 – Lunar Gravity Assist
  - Flight Day 7-9 – Lunar to DRO Cruise
- Joint Operations
  - Flight Day 9-10 – Rendezvous
  - Flight Day 11 – EVA #1
  - Flight Day 12 – Suit Refurbishment, EVA #2 Prep
  - Flight Day 13 – EVA #2
  - Flight Day 14 – Contingency/Departure Prep
  - Flight Day 15 – Departure
- Inbound
  - Flight Day 15 – 20 – DRO to Lunar Cruise
  - Flight Day 20 – Lunar Gravity Assist
  - Flight Day 20-26 – Inbound Trans-Lunar Cruise
  - Flight Day 26 – Earth Entry and Recovery

Mission Duration and timing of specific events will vary slightly based on launch date and trajectory strategy



Outbound Flight Time: 8 days, 9 hrs
Return Flight Time: 11 days, 6 hrs
Rendezvous Time: 1 day
DRO Stay Time: 5 days

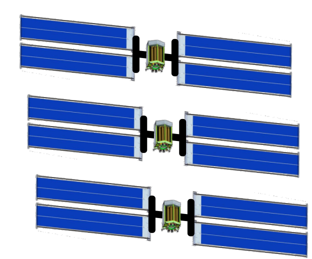
Future Use of ARM Robotic Spacecraft and Solar Electric Propulsion

- **Previous assessments have shown that human Mars missions utilizing a single round-trip monolithic habitat + Orion requires very high power SEP**
  - Approaches 1 MW total power
  - An engineering and operational challenge

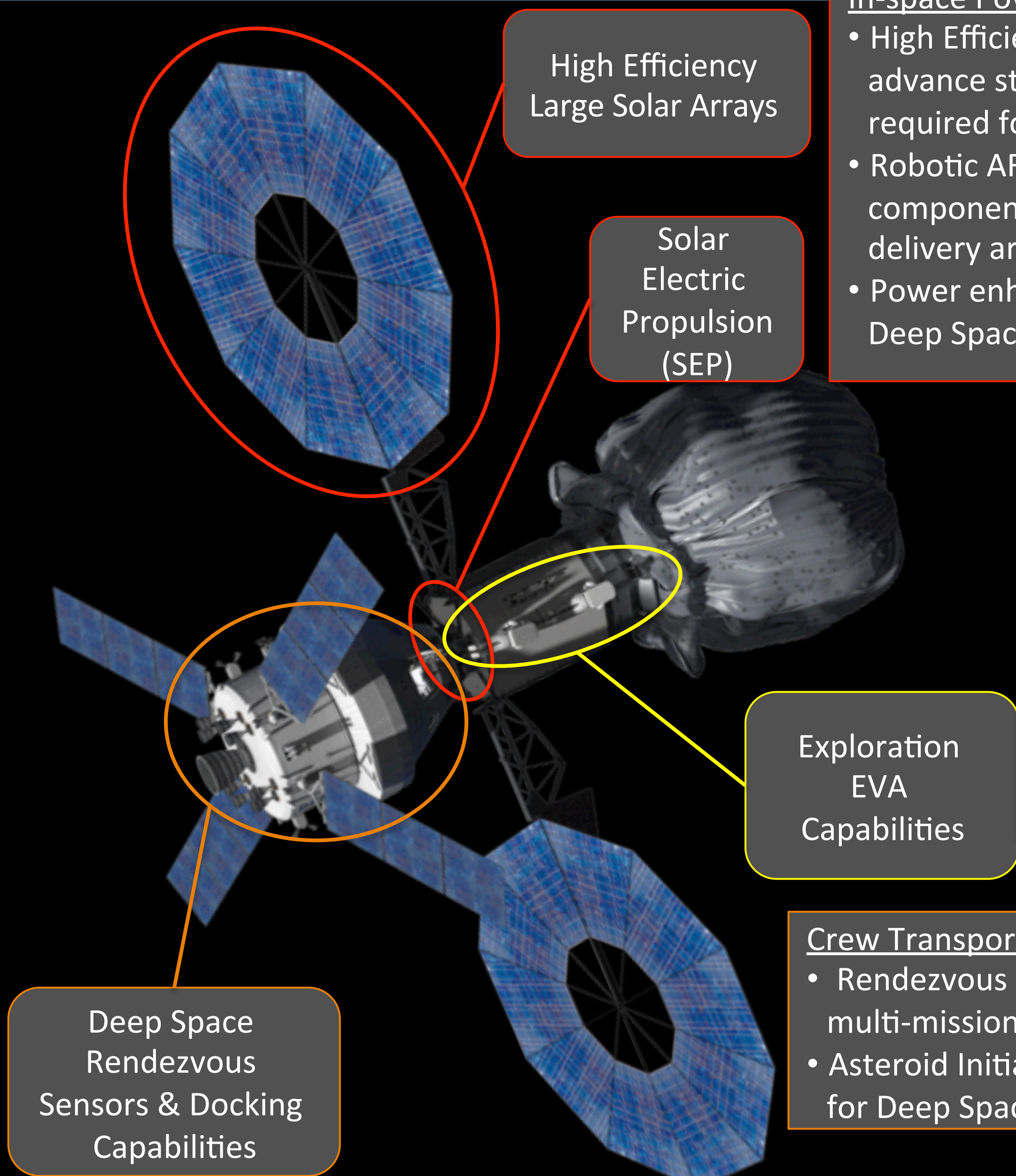
- **Alternate architecture concepts enable ARM derived SEP to be used. As an example:**
  - Pre-deploy crew mission assets to Mars utilizing high efficient SEP, such as
    - Orbit habitats: Supports crew while at Mars
    - Return Propulsion Stages or return habitats
    - Exploration equipment: Unique systems required for exploration at Mars.
  - High thrust chemical propulsion for crew
    - Low-thrust SEP too slow for crew missions
    - Crew travels on faster-transit, minimum energy missions: 1000-day class round-trip (all zero-g)

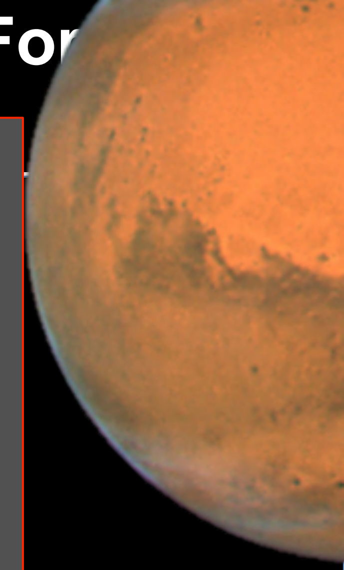
One Very Large SEP

Multiple ARM-derived SEPs



Asteroid Redirect Mission Provides Capabilities For Deep Space/Mars Missions





<u>In-space Power and Propulsion</u> :

- High Efficiency Solar Arrays and SEP advance state of art toward capability required for Mars
- Robotic ARM mission 40kW vehicle components prepare for Mars cargo delivery architectures
- Power enhancements feed forward to Deep Space Habitats and Transit Vehicles

<u>EVA</u>:

- Build capability for future exploration through Primary Life Support System Design which accommodates Mars
- Test sample collection and containment techniques including planetary protection
- Follow-on missions in DRO can provide more capable exploration suit and tools

<u>Crew Transportation and Operations:</u>

- Rendezvous Sensors and Docking Systems provide a multi-mission capability needed for Deep Space and Mars
- Asteroid Initiative in cis-lunar space is a proving ground for Deep Space operations, trajectory, and navigation.

AIDA Concept Overview

US Principal Investigator: Andrew Cheng
andrew.cheng@jhuapl.edu
240-228-5415

US Project Manager: Cheryl Reed
cheryl.reed@jhuapl.edu

Chelyabinsk Meteor on 15 February 2013

May 12, 2014

Asteroid Impact & Deflection Assessment (AIDA) Background

- AIDA is an international cooperation to learn how to mitigate an asteroid impact threat
- AIDA is a low cost demonstration of the kinetic impactor technique to divert a potentially hazardous asteroid
  - Use a spacecraft impact to push an asteroid off its dangerous path
- AIDA is currently in parallel, pre-Phase A studies in the US and in ESA
  - AIM study of rendezvous monitoring spacecraft at ESA
  - DART study of kinetic impactor spacecraft at APL

→ **AIDA = AIM+DART**

AIDA

Asteroid Impact & Deflection Assessment (AIDA)

AIDA

- The Asteroid Impact & Deflection Assessment (AIDA) is a mission concept to demonstrate asteroid impact hazard mitigation with a kinetic impact spacecraft to deflect an asteroid
- AIDA would be a joint US and European mission:
  - European rendezvous spacecraft, the Asteroid Impact Monitor (AIM) mission
  - US kinetic impactor, the Double Asteroid Redirection Test (DART) mission
- The DART mission will intercept the secondary member of the binary Near-Earth Asteroid Didymos in October, 2022

→ AIDA = AIM+DART

AIDA = AIM+DART

- AIM rendezvous spacecraft
  - Autonomous navigation experiment
  - Asteroid proximity operations
  - Orbiter science payload to monitor DART impact and results
  - Surface interaction experiment and landed seismic experiment package
- DART interceptor
  - Return high resolution images of target prior to impact
  - Autonomous guidance with proportional navigation to hit center of 150 meter target body
  - Leverage space-based missile intercept technology

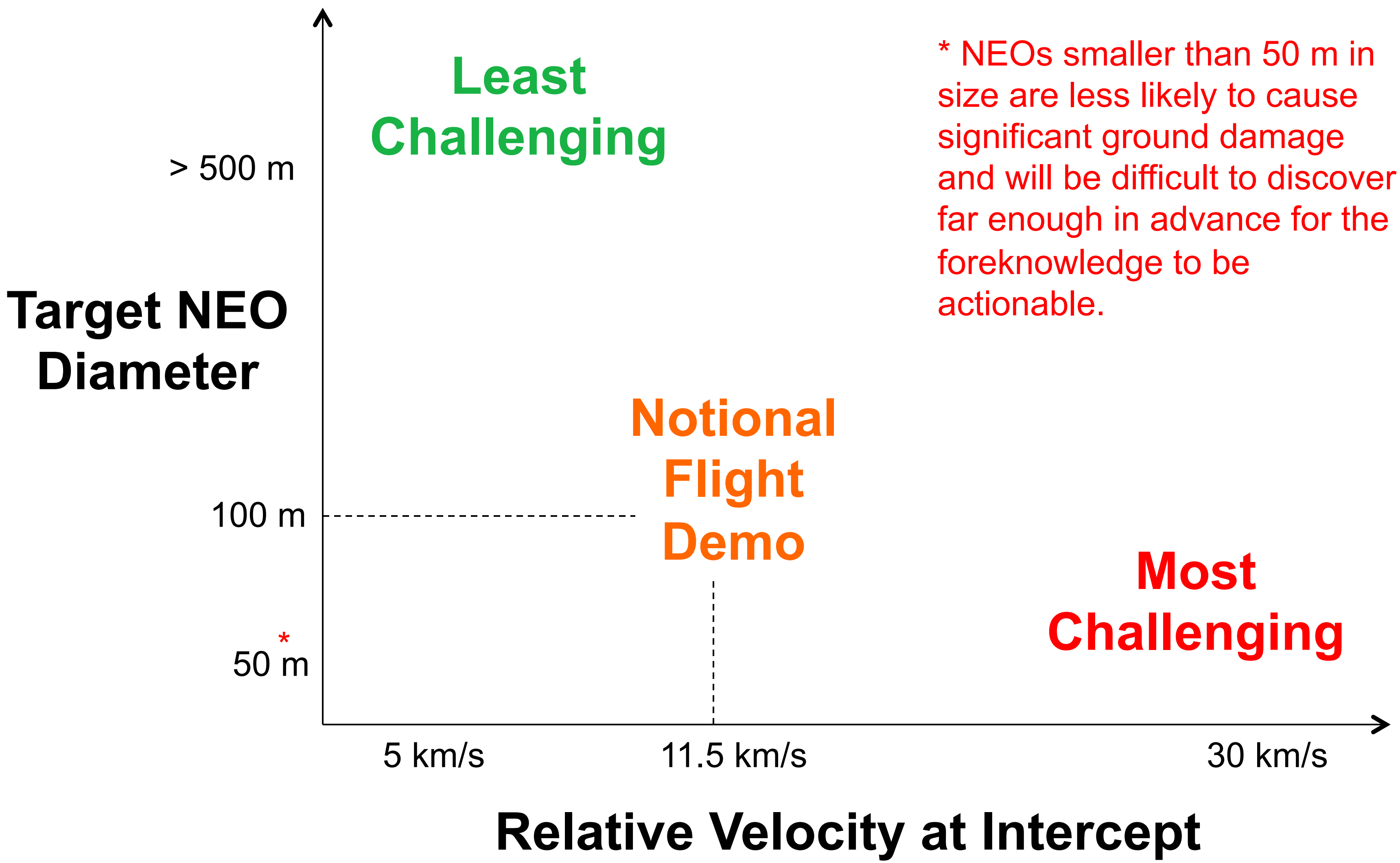
NASA Innovative Advanced Concepts (NIAC) Program

Asteroid Deflection Project

NIAC Research Project

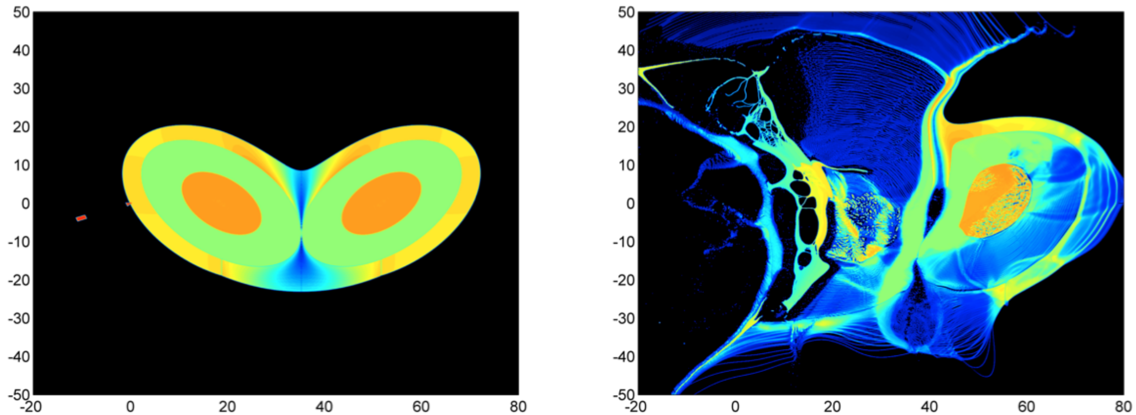
- The NASA Innovative Advanced Concepts (NIAC) Program seeks innovative, technically credible advanced concepts that could one day "Change the Possible" in aerospace.
- NIAC is a component of the Space Technology Mission Directorate (STMD) at NASA Headquarters.
- Our NIAC Phase 2 research project is entitled "*An Innovative Solution to NASA's NEO Impact Threat Mitigation Grand Challenge and Flight Validation Mission Architecture Development*"
- Our NIAC Phase 2 team consists of PI Dr. Bong Wie (Asteroid Deflection Research Center (ADRC), Iowa State University), Co-I B. W. Barbee (NASA/GSFC), and Dr. Wie's graduate students.
- The Phase 1 NIAC project (9 months) was performed by Dr. Wie and his graduate students.
- The Phase 2 NIAC project takes place during FY13 & FY14.
- Mid-Term Review of Phase 2 project was held w/ NIAC Program Office and Subject Matter Experts on Dec 3, 2013; we received very favorable review feedback.

Notional Target Selection Rationale



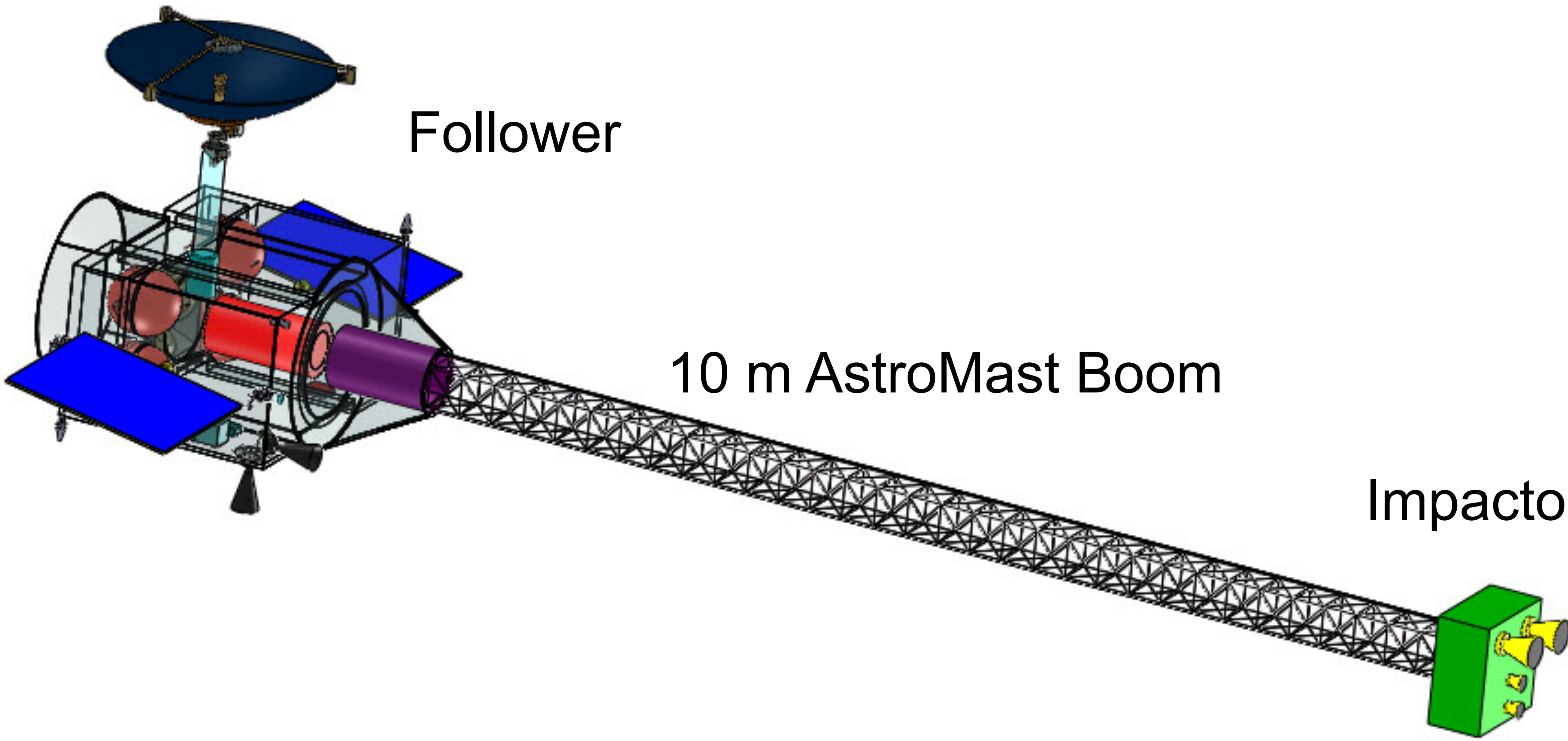
HAIV Concept Background

- The Hypervelocity Asteroid intercept Vehicle (HAIV) combines a kinetic impactor with a Nuclear Explosive Device (NED) delivery system.
  - The leading kinetic impactor portion of the HAIV creates a shallow crater.
  - The following NED carrier portion of the HAIV flies into the crater and detonates.
- Subsurface detonation may be ~20 times more effective at NEO disruption.
- Enhanced effectiveness reduces required NED yield (mass).
- Hypervelocity intercept & reduced NED mass enable short warning time response.
- The HIAV can be deployed without a NED as a pure kinetic impactor.
- First Phase 2 task was a HAIV design study in GSFC's Mission Design Lab (MDL).



Simplified 2-D simulation of a penetrated, 70 kiloton nuclear explosion for a 70 m asymmetric reference target.

HAIV with Boom Extended



EXERCISE

FEMA Exercise

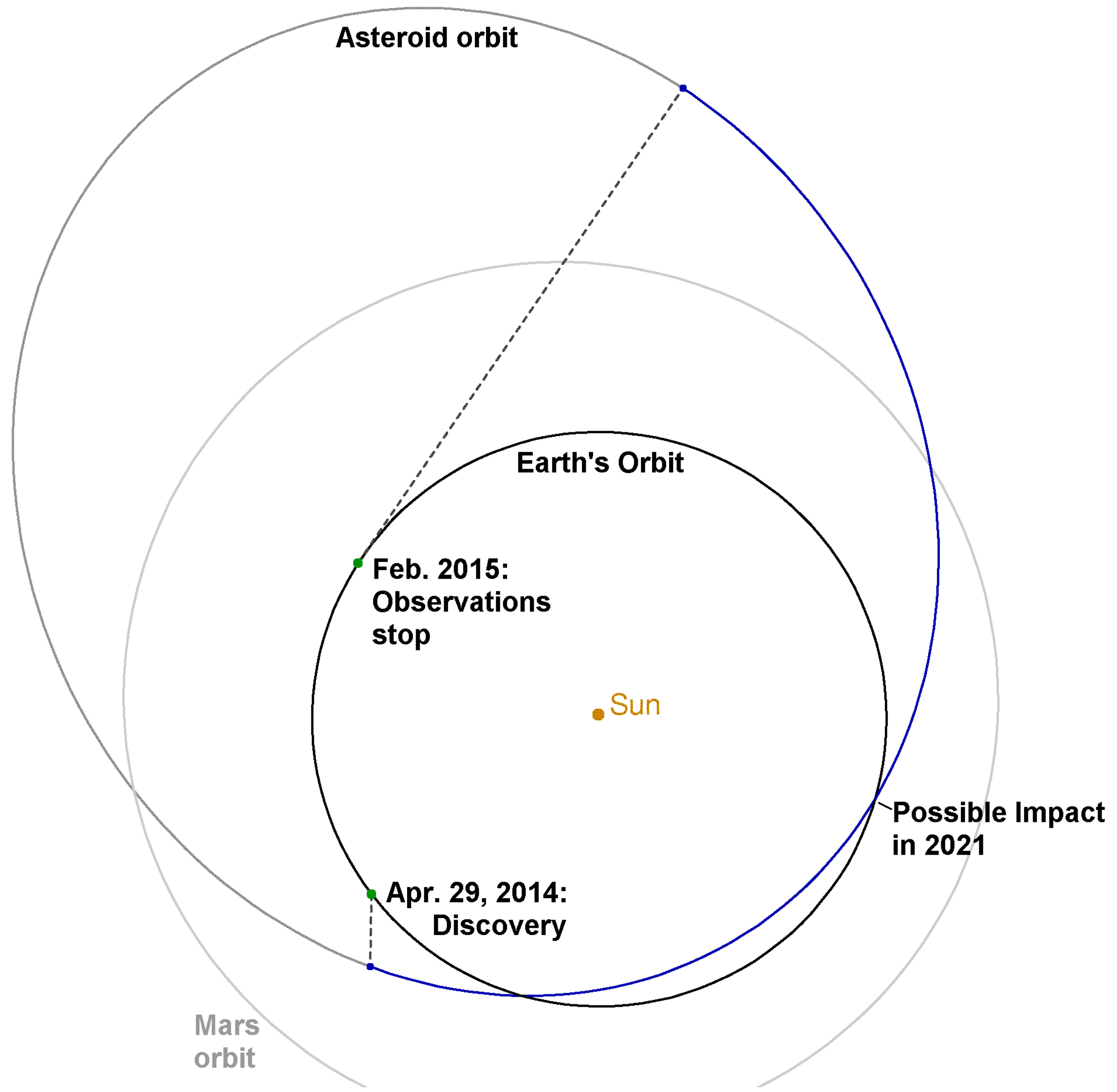
20 May 2014

Impact Predicts

Lindley Johnson
NASA Headquarters, Science Mission Directorate
Planetary Science Division, NEO Observation Program

EXERCISE

Orbit of Asteroid 2014 TTX



Initial Notification of 2014 TTX

EXERCISE

May 10, 2014

Asteroid 2014 TTX was discovered by the NASA funded Catalina Sky Survey in the early morning of 29 April while it made a relatively distant approach to Earth, only coming within about 16 million miles (25 million kilometers). The asteroid is 350 to 900 feet (120 -300 meters) in size and its orbit carries it as far out as about halfway the distance to Jupiter's orbit and as close to the sun as just inside the Earth's orbit. As of May 1st, asteroid 2014 TTX is one of 11,008 Near-Earth objects that have been discovered.

Although its orbit is still quite uncertain, this asteroid could again be in the Earth's neighborhood in 2021 and the Near-Earth Object Program Office states the probability this asteroid could impact Earth is only 1 in 3,000. The object should be easily observable in the coming months and once additional observations are provided to the Minor Planet Center in Cambridge, Massachusetts, the initial orbit calculations will be improved and the most likely result will be a dramatic reduction, or complete elimination, of any risk of Earth impact.

NASA detects, tracks and characterizes asteroids and comets passing close to Earth using both ground- and space-based telescopes. The Near-Earth Object Observations Program, commonly called "Spaceguard," discovers these objects, characterizes a subset of them, and determines their orbits to determine if any could be potentially hazardous to our planet.

JPL manages the Near-Earth Object Program Office for NASA's Science Mission Directorate in Washington. JPL is a division of the California Institute of Technology in Pasadena.

More information about asteroids and near-Earth objects is at: http://www.jpl.nasa.gov/asteroidwatch .

EXERCISE

Inject #1 Current Situation – 6 Aug 2021
30 days to Impact

EXERCISE

The **space mission to deflect** Near Earth Asteroid 2014 TTX **was not completely successful.** Although the majority of the mass of the approximately 200 meter (600 feet) in size asteroid has been moved away from an Earth impact trajectory, **a fragment of the body estimated to be from 40 to 60 meters (120-180 feet) in size remains** on a course which **will impact the Earth on 5 September**. Numerous calculations of this object's orbit by NASA's NEO Program Office at the Jet Propulsion Laboratory on the "Sentry" potential impact monitoring system, using observations provided from astronomical observatories around the world, indicate the fragment **will impact on 5 September, 2021, shortly after noon local time (CDT)**. Impact will occur somewhere along or within approximately 30 kilometers (20 miles) either side of a line starting from about 200 kilometers (125 miles) south of New Orleans, LA, in the Gulf of Mexico, and extending to the northwest about 1000 kilometers (625 miles) across Houston, TX, to about 300 kilometers (190 miles) to the northwest of Austin, TX. Since the object will approach from the direction of the Sun, optical observations will not be possible in the three weeks prior to impact. However, NASA's interplanetary radar should be able to pick up the object approximately one week prior to impact and provide more precise measurements of its final trajectory, which should significantly narrow the impact risk corridor in the days prior to impact. Any further action to attempt to disrupt the object and mitigate the impact or its effects must wait for these radar observations.

EXERCISE

Potential Impact Footprint

EXERCISE

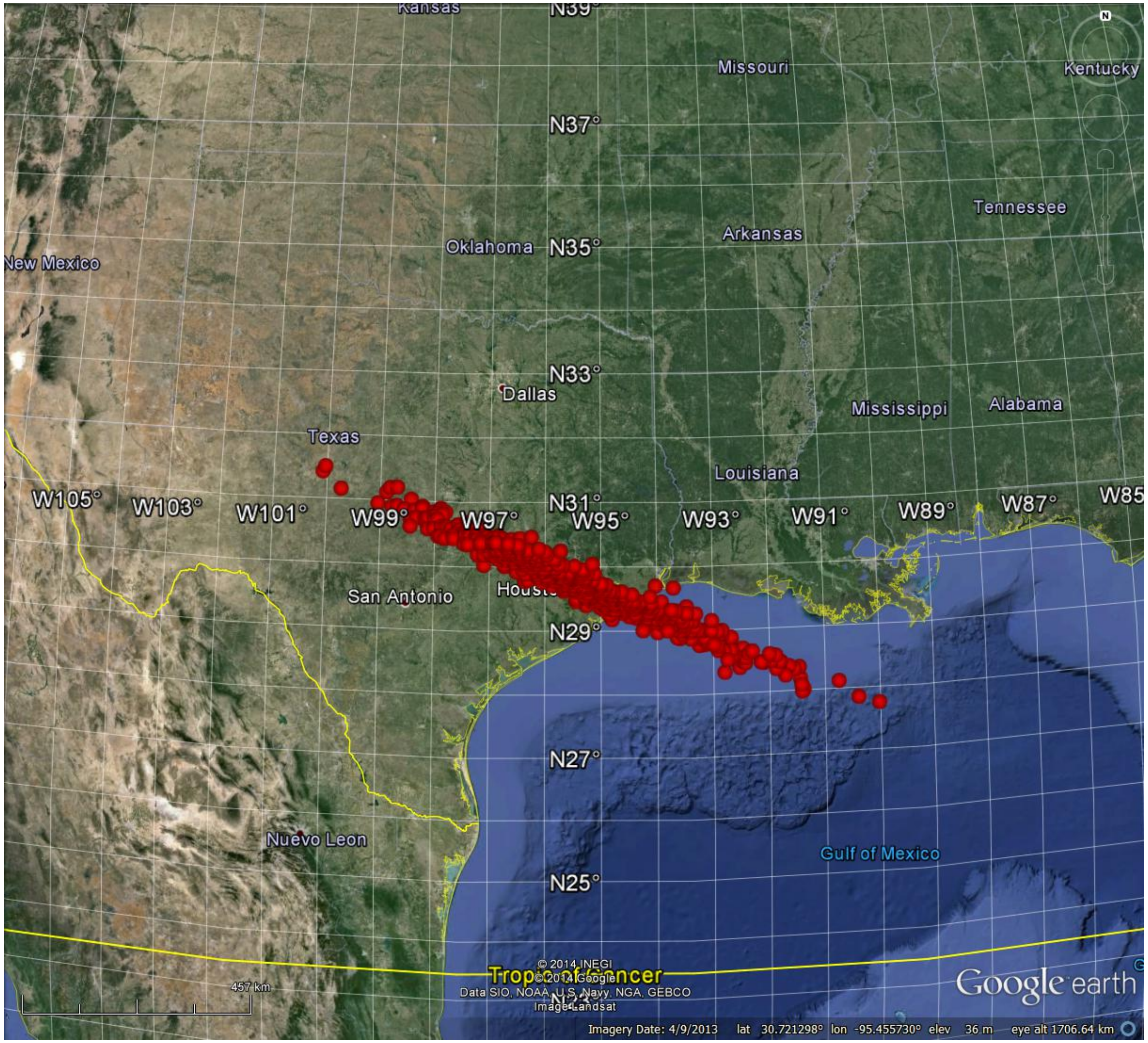
30 Days prior to Impact

Probability 100%

Date/Time (UTC)
2021 Sep 5 17:02

Center Point
Latitude
29.7
Longitude
-95.3

Footprint size
1000 x 50 km
Major-axis azimuth (deg)
130



EXERCISE

Inject #2: 28 Aug 2021 - Impact in 8 days

EXERCISE

NASA's Goldstone radar successfully collected observations of the asteroid 2014 TTX fragment during the last few hours. Using these initial radar observations the NASA NEO Program's Sentry impact monitoring system indicates **the fragment will still impact on 5 September, 2021, about 2 minutes after noon local time (CDT), but the risk area has been greatly reduced**. Precise orbit calculations place the **impact point somewhere within a 90 by 40 kilometer (60 by 25 mile) oval centered approximately 12 miles to the southeast of downtown Houston, TX,** with the longer axis of the oval running from the southeast to the northwest of that point. More radar observations will be collected in the next few days to further isolate the potential impact point and better determine the size of the object.

EXERCISE

Potential Impact Footprint

EXERCISE

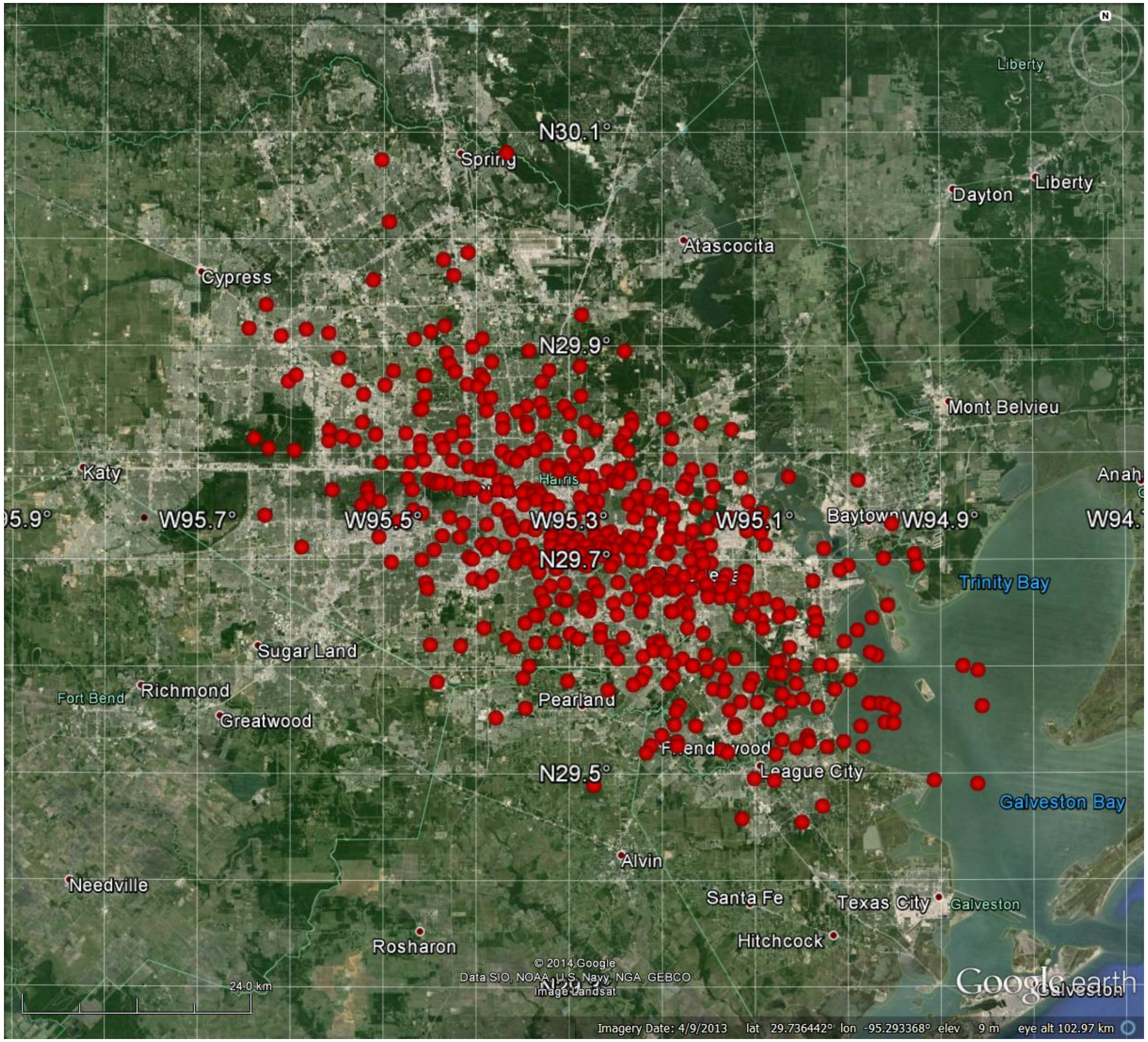
8 Days prior to Impact

Probability 100%

Date/Time (UTC)
2021 Sep 5 17:02:24

Center Point
Latitude
29.728
Longitude
-95.313

Footprint size
90 x 40 km
Major-axis azimuth (deg)
120



EXERCISE

Inject #3: 30 Aug 2021 – Impact in 6 days

EXERCISE

NASA's Goldstone radar has successfully collected additional observations of the asteroid 2014 TTX fragment over the last several days. This has allowed the NASA NEO Program's Sentry impact monitoring system to **significantly narrow the area where the fragment will impact on 5 September, 2021, at just past 2 minutes after noon local time (CDT).** Precise orbit conjunction calculations **place the impact point somewhere within a narrow oval 30 kilometers (20 miles) long by 2 kilometers (1.5 miles) wide that runs almost north to south down the southeast quadrant of Houston, TX.** The center of the oval is placed at latitude 29.710 north and longitude 95.252 west with the long axis of the oval running at 174 degrees azimuth. However, **radar imaging of the object confirms that it is approximately 50 meters (150 feet) in size.** Therefore a significant portion is likely to survive entry of Earth's atmosphere and **devastate an area across the ground that could extend up to 25 kilometers in radius from the impact point**. More radar observations will be collected in the next few days to further isolate the potential impact point and support terminal trajectory object disruption operations.

EXERCISE

Potential Impact Footprint

EXERCISE

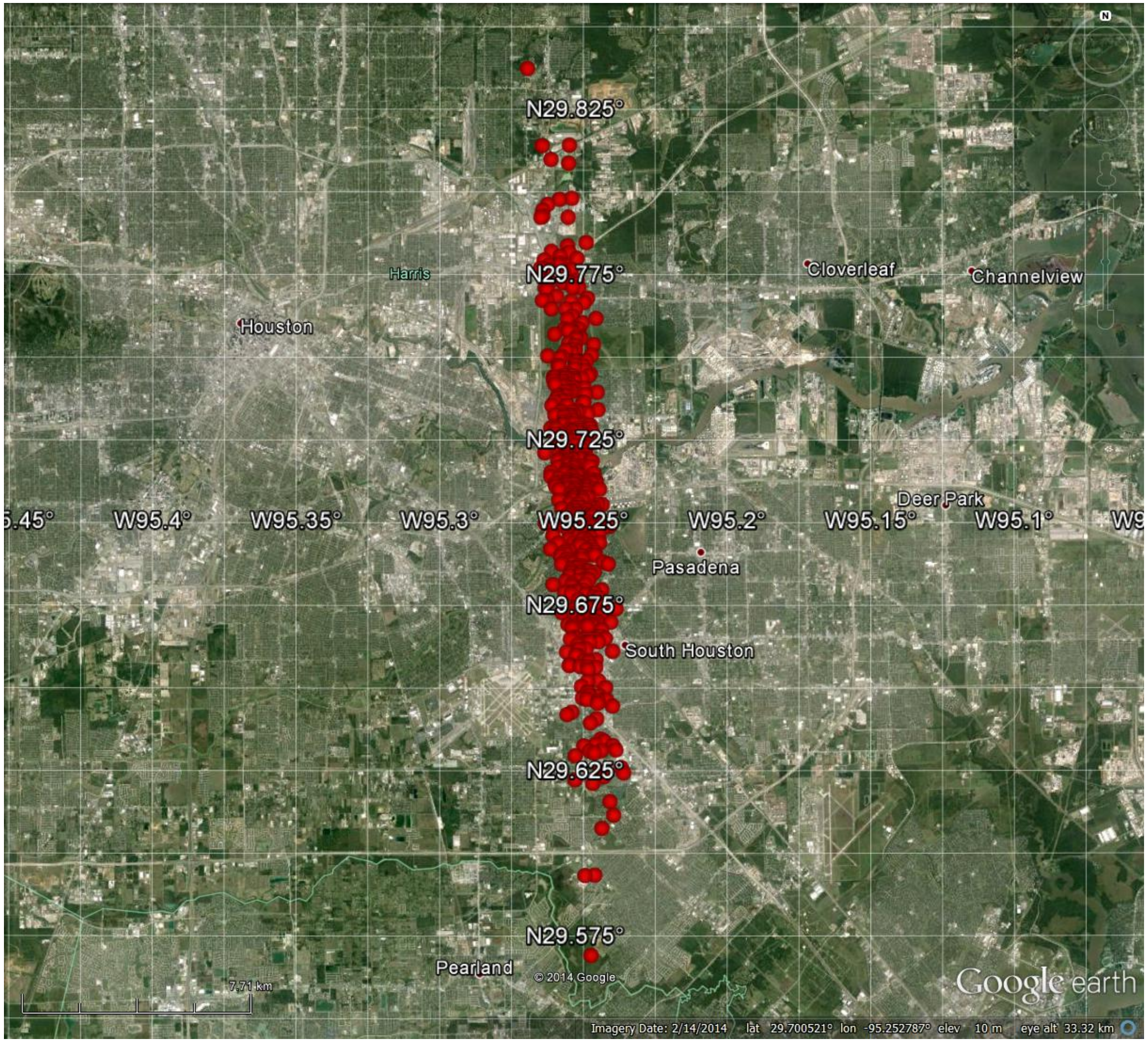
6 Days prior to Impact

Probability 100%

Date/Time (UTC)
2021 Sep 5 17:02:24.01

Center Point
Latitude
29.710
Longitude
-95.252

Footprint size
30 x 2 km
Major-axis azimuth (deg)
175



EXERCISE