Planetary Defense Program

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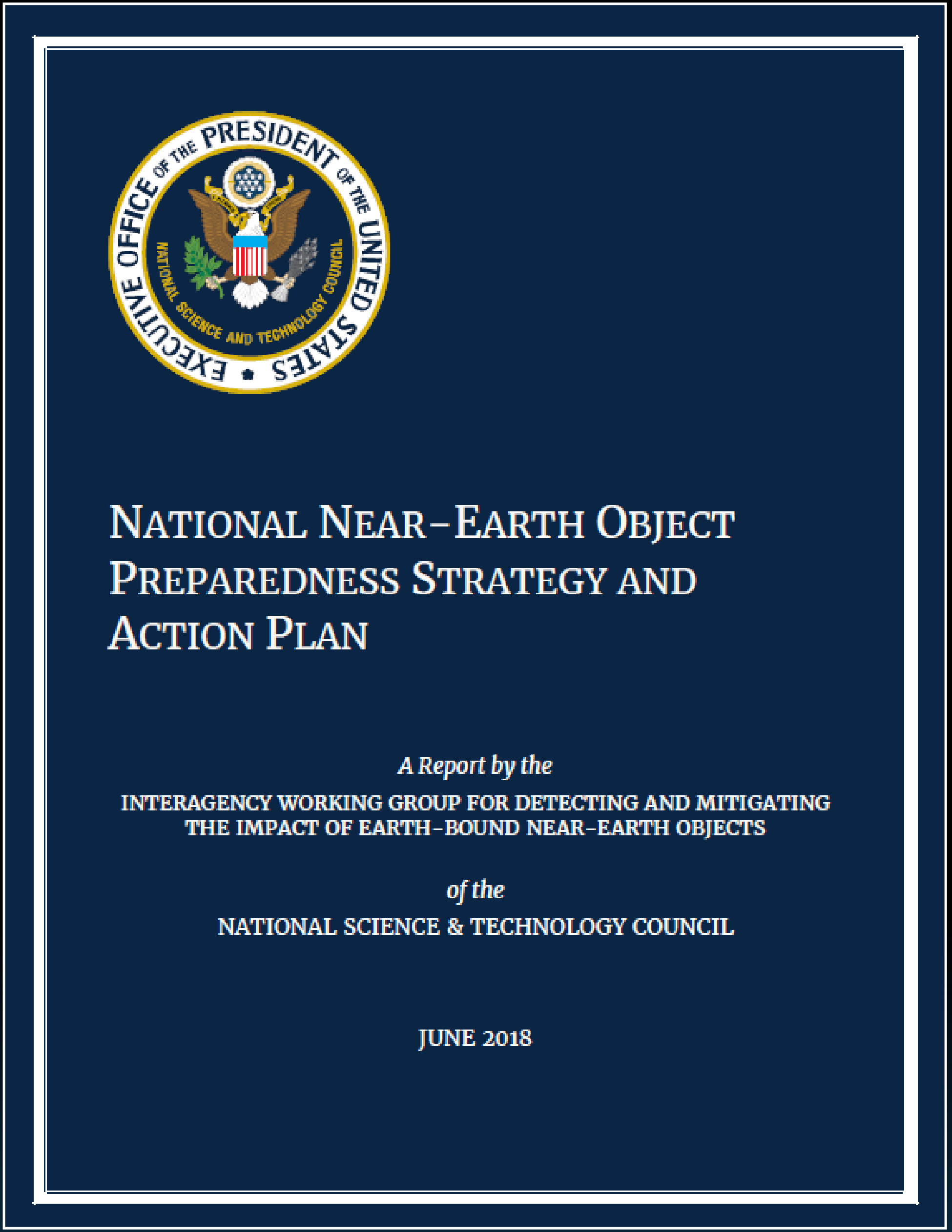
Planetary Science Division
NASA Headquarters
Washington, DC

2 November 2020

PLANETARY DEFENSE
COORDINATION OFFICE

New White House Guidance released on 20 June 2018

https://www.whitehouse.gov/wp-content/uploads/2018/06/National-Near-Earth-Object-Preparedness-Strategy-and-Action-Plan-23-pages-1MB.pdf



NATIONAL NEAR–EARTH OBJECT PREPAREDNESS STRATEGY AND ACTION PLAN

A Report by the

INTERAGENCY WORKING GROUP FOR DETECTING AND MITIGATING THE IMPACT OF EARTH–BOUND NEAR–EARTH OBJECTS

of the

NATIONAL SCIENCE & TECHNOLOGY COUNCIL

JUNE 2018

National NEO Preparedness Strategy and Action Plan

Goals in the New Action Plan

- Enhance NEO detection, characterization, and tracking capabilities
- Improve modeling, predictions, and information integration
- Develop technologies for NEO deflection and disruption
- Increase international cooperation on NEO preparation
- Establish NEO impact emergency procedures and action protocols

Planetary Defense Coordination Office

The Planetary Defense Coordination Office (PDCO) was established in January 2016 at NASA HQ to manage planetary defense related activities across NASA, and coordinate with both U.S. interagency and international efforts to study and plan response to the asteroid impact hazard.

Mission Statement

Lead national and international efforts to:

- Detect any potential for significant impact of planet Earth by natural objects
- Appraise the range of potential effects by any possible impact
- Develop strategies to mitigate impact effects on human welfare


PLANETARY
DEFENSE
ASSESS
[CENTER FOR NEAR EARTH OBJECT STUDIES]
IAU
Minor Planet Center
SEARCH, DETECT & TRACK
[GROUND-BASED & SPACE-BASED OBSERVATIONS, IAWN]
MITIGATE
[DART, FEMA EXERCISES]
CHARACTERIZE
[NEOWISE, GOLDSTONE, ARECIBO, IRTF]
PLAN & COORDINATE
[SMPAG, PIERWG, DAMIEN IWG]

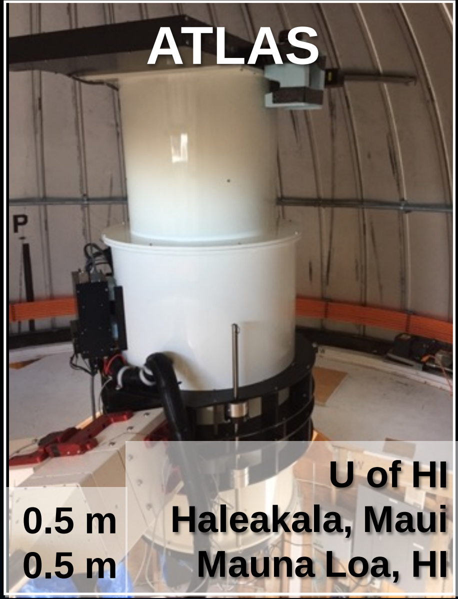
NEO Observations Program (est. 1998)

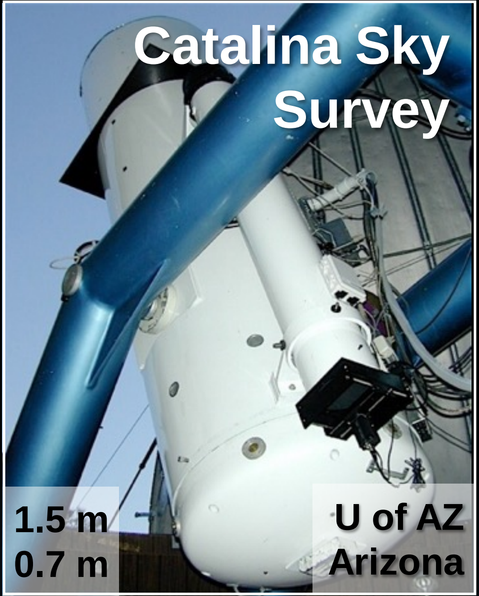
NASA Authorization Act of 2005 set the current priority and objective:

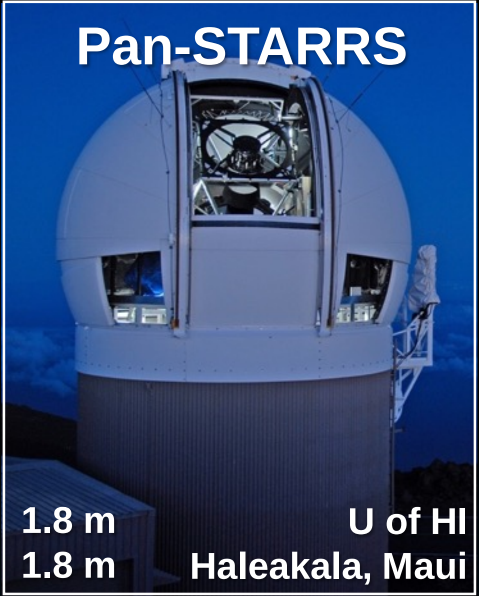
- Amended National Aeronautics and Space Act of 1958 to made NEO detection, tracking and research 1 of 7 explicitly stated purposes of NASA
- Directed NASA to find and catalogue 90 percent of NEOs greater than 140 meters size within 15 years [by 2020]
- “George E. Brown, Jr. Near-Earth Object Survey Act”

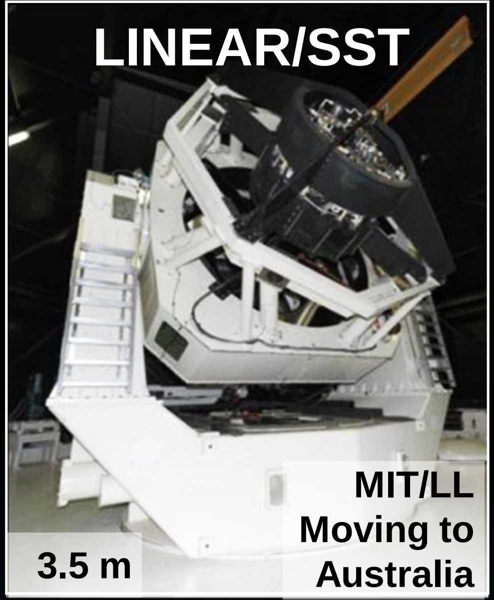
NASA's NEO Search Program

(Current Survey Systems)





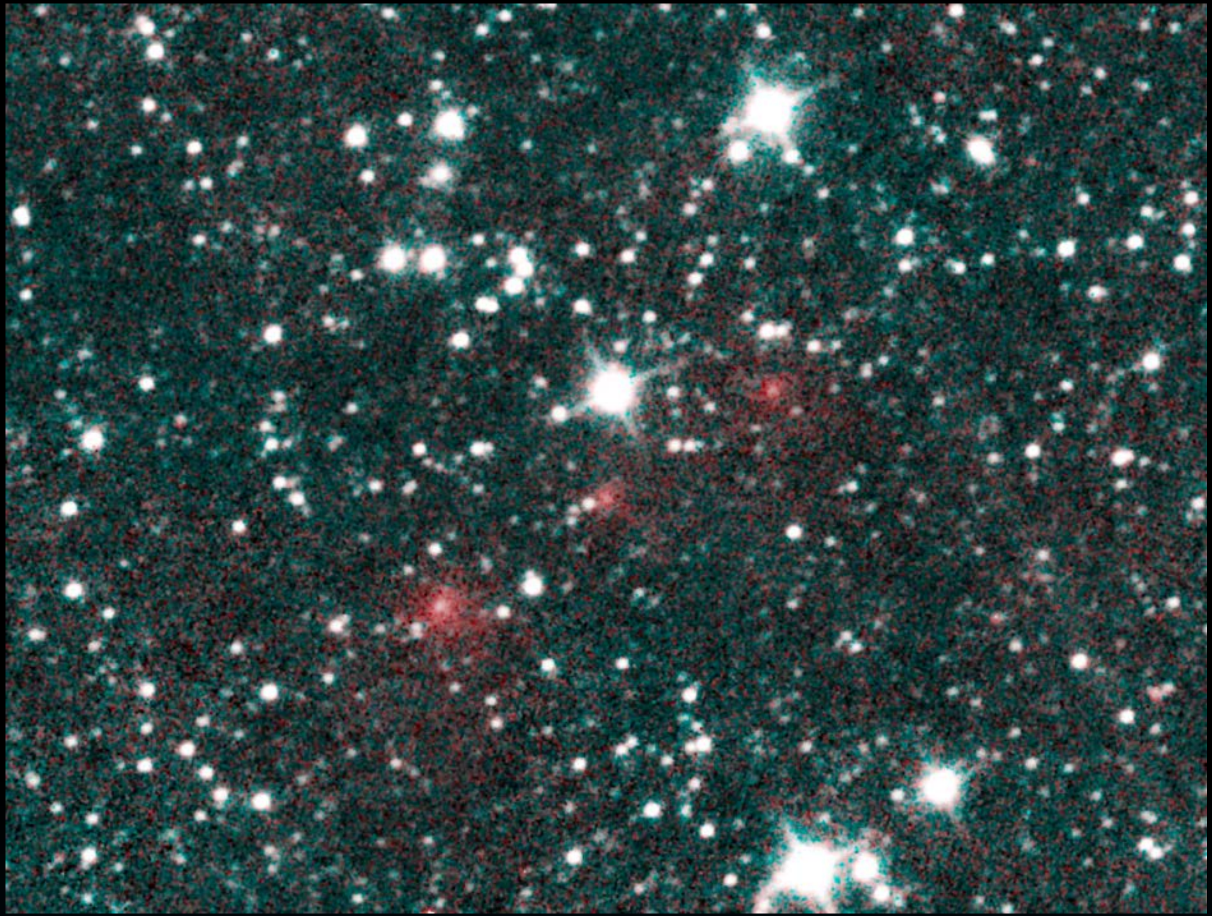




Sites in Chile and South Africa to be commissioned in 2021

Also processing of data for NEO detections from Caltech's Zwicky Transient Facility

Comet C/2020 F3 NEOWISE



Discovery image sequence by the NEOWISE mission, March 27, 2020 (red dots)

Comet NEOWISE on July 9, 2020
Dr. Vishnu Reddy, Tuscon, AZ

Planetary Data System's Small Bodies Node

NEO position measurements from observatories

The International Astronomical Union Minor Planet Center

http://minorplanetcenter.net/

- Identification
- Designation
- Initial orbit computation
- Maintain catalog

NASA Jet Propulsion Laboratory California Institute of Technology

cneos Center for Near Earth Object Studies

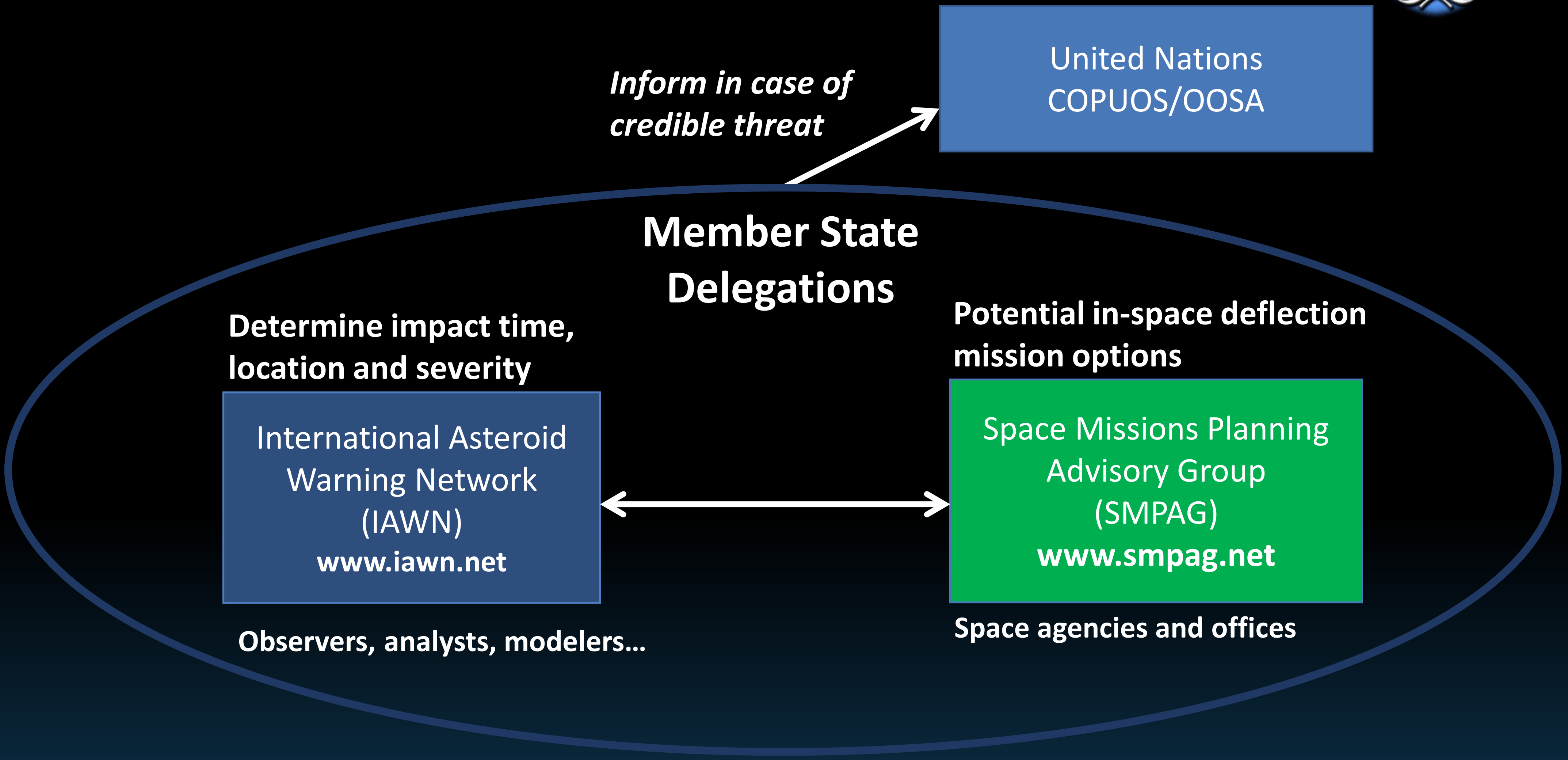
https://cneos.jpl.nasa.gov/

High precision NEO orbits

- Short-term: new discoveries
- Long-term: future orbits of hazardous asteroids
- Predict close approachers

Time, location and geometry in the event of a predicted impact

UN Committee on Peaceful Uses of Outer Space (COPUOS)
UN Office of Outer Space Affairs (OOSA)
Overview for NEO Threat Response



Signatories to the International Asteroid Warning Network (IAWN)

iawn.net

National Institute of Astrophysics, Optics & Electronics (México)

Korean Astronomy Space Science Institute (KASI)

외계행성 탐색시스템 KMTNet
Korea Microlensing Telescope Network

Institute of Astronomy, Russian Academy of Sciences (ИНАСАН)

INASAN

Israel Space Agency

Peter Birtwhistle (UK)
David Balam (Canada)
Patrick Wiggins (USA)
Gennady Borisov (MARGO Observatory)
Jordi Camarasa (Observatori Paus B49)

European Southern Observatory

China National Space Administration

CNSA

Northolt Branch Observatories (UK)

Zwicky Transient Facility (US)

Višnjan Observatory (Croatia)

Instituto de Astrofisica de Canarias (Spain)

University of Nariño Colombia

Crimean Astrophysical Observatory (Russian Academy of Sciences)

esa

European Space Agency

Inst. of Solar-Terrestrial Physics (Siberian Branch, Russian Academy of Sciences)

Sormano Astronomical Observatory (Italy)

National Aeronautics and Space Administration

SONEAR Observatory (Brazil)

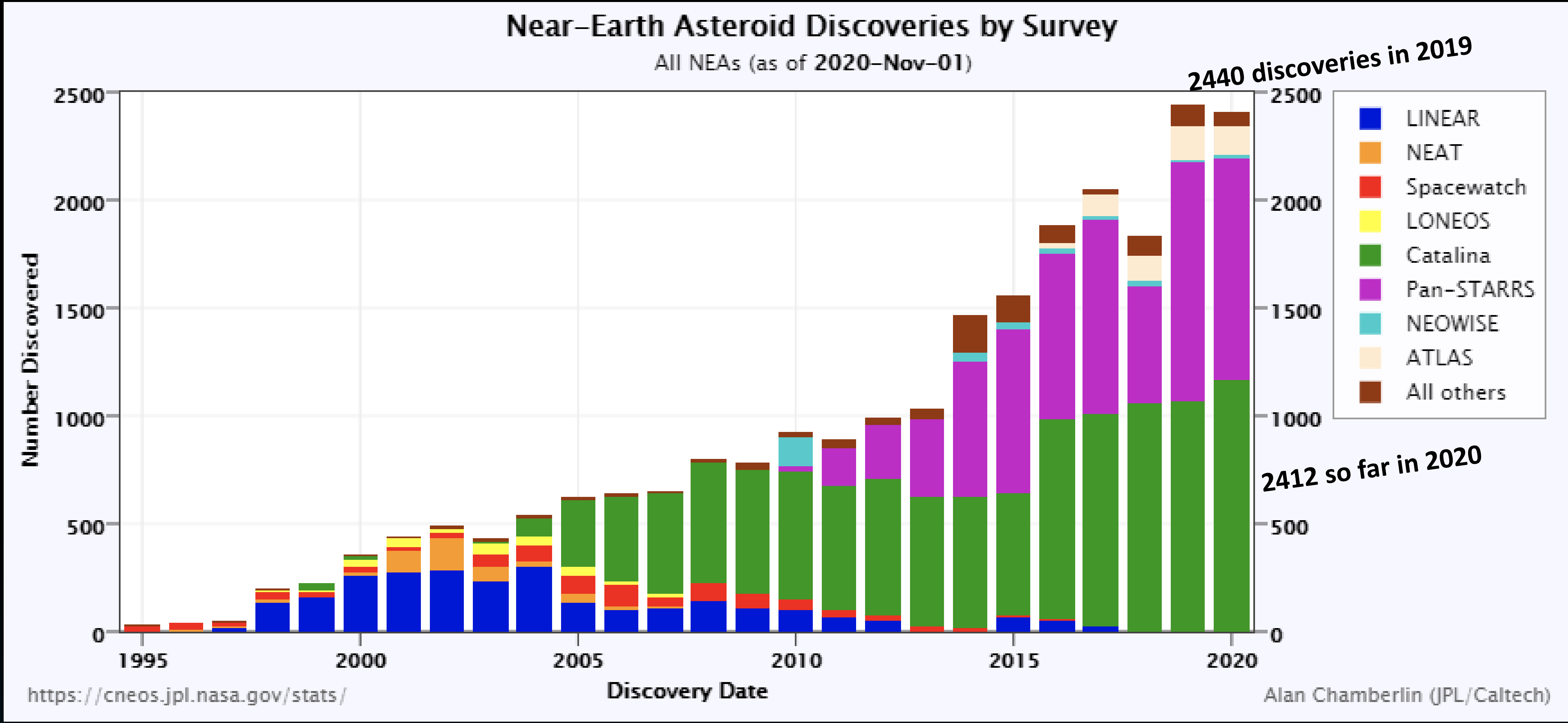
Special Astrophysical Observatory (Russian Academy of Sciences)

Kourovka Astronomical Observatory (UrFU)

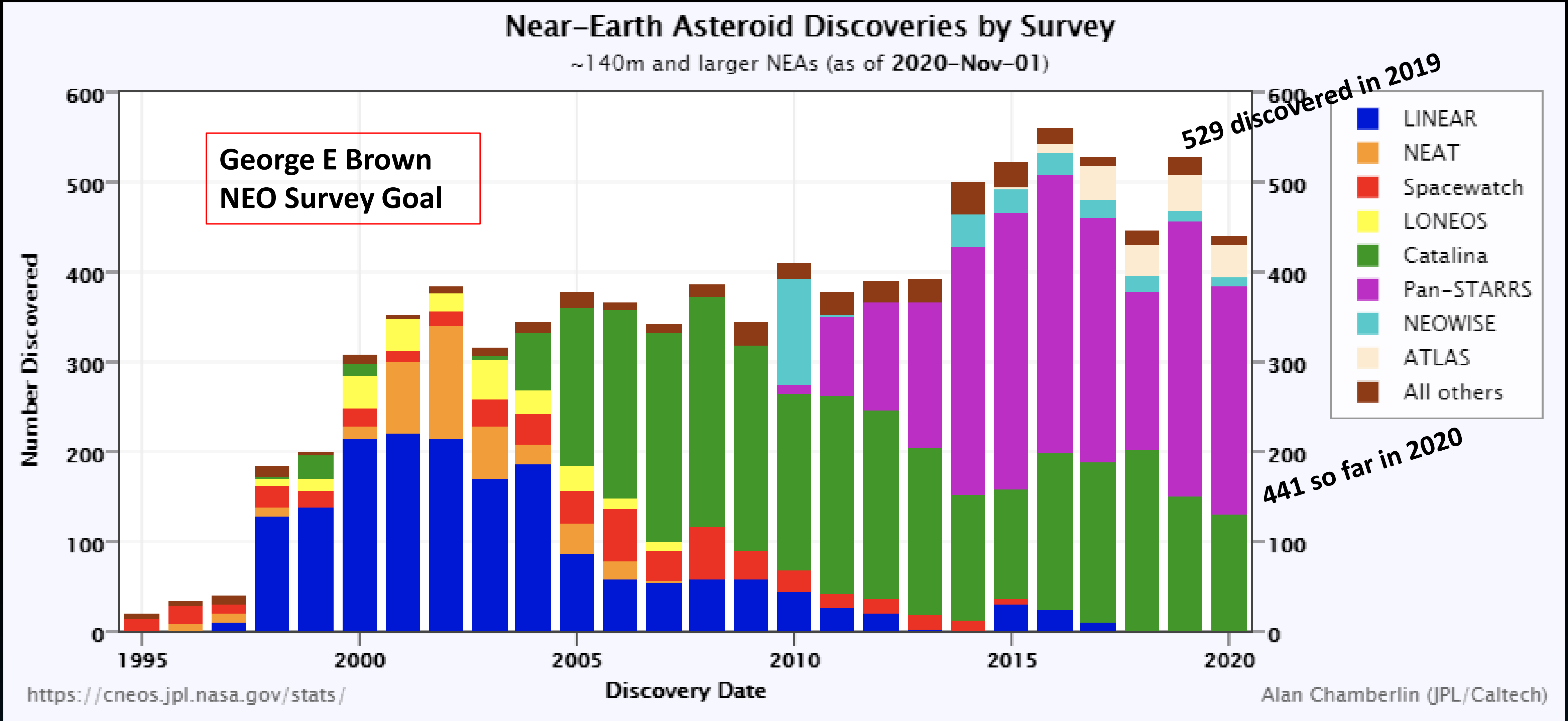
Fondazione GAL Hassin (Italy)

Currently 25+ signatories

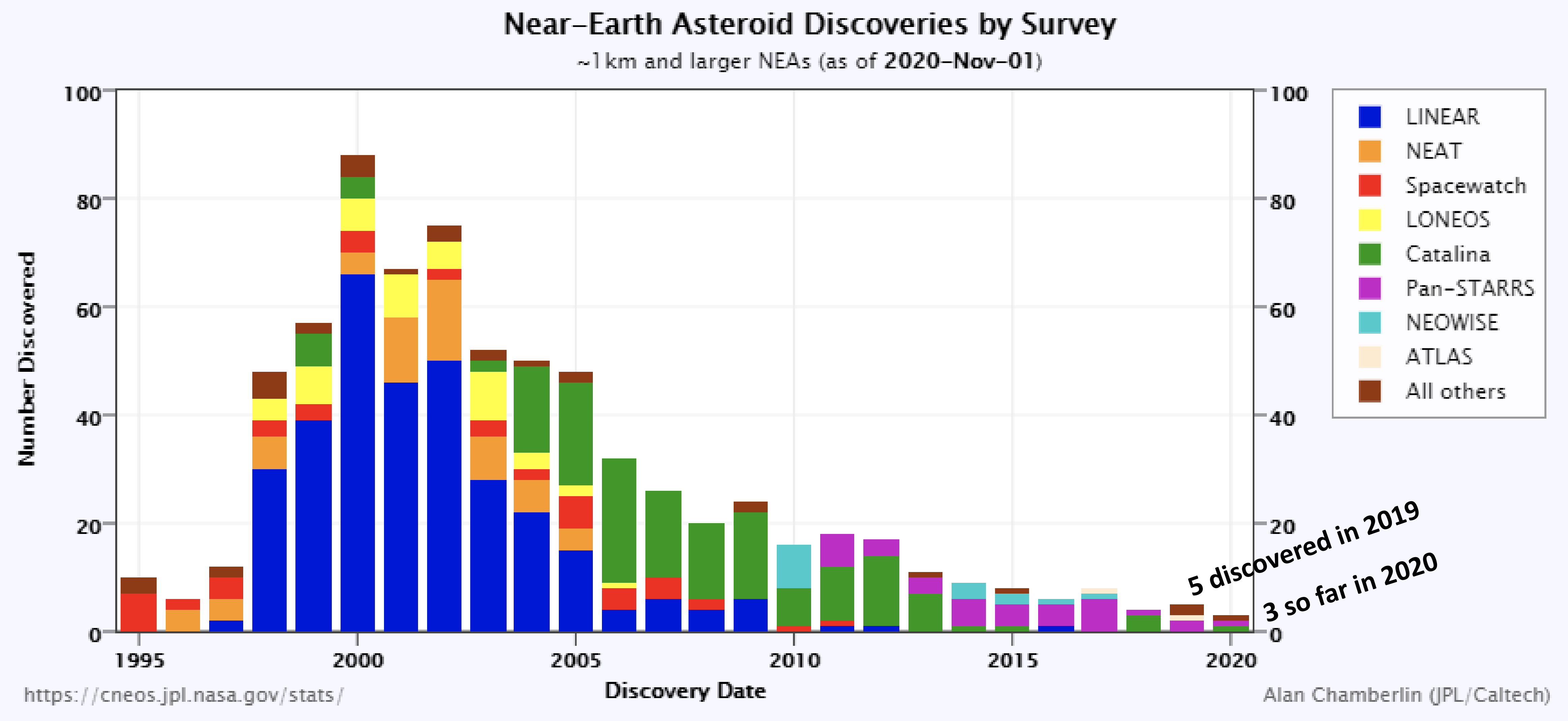
All Near-Earth Asteroids (NEAs)

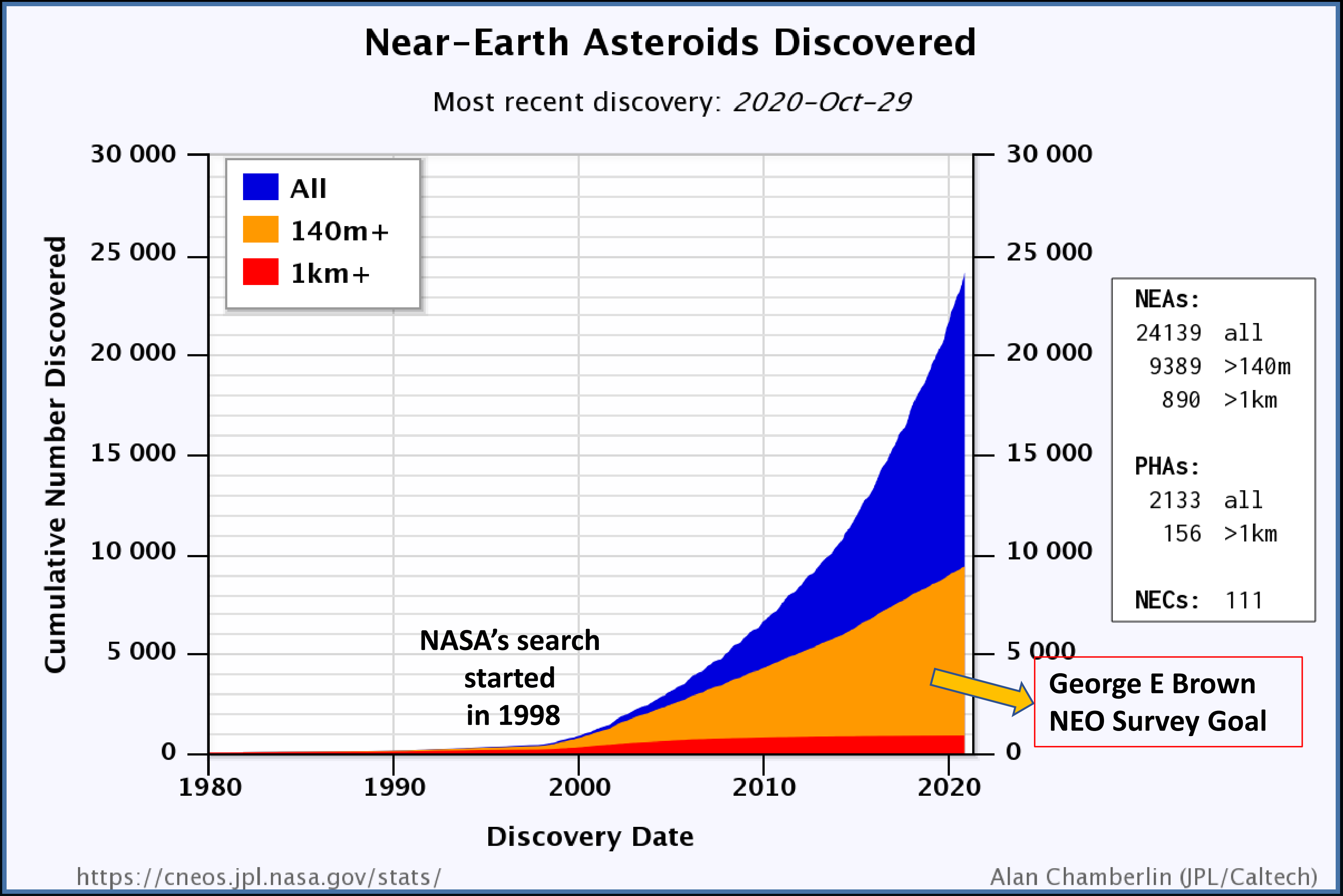


NEAs 140 Meters and Larger



NEAs 1 Kilometer and Larger



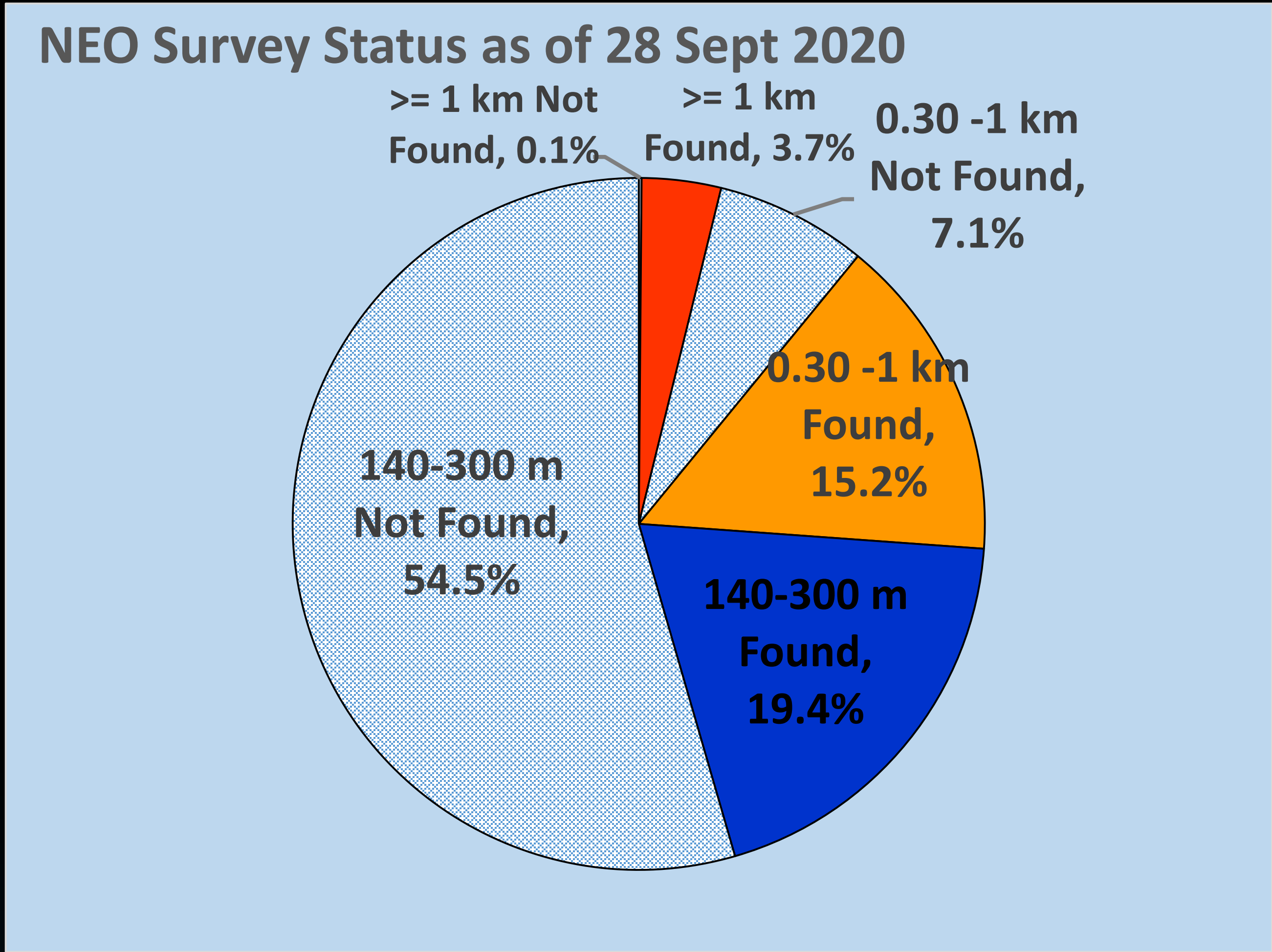


**Potentially Hazardous Asteroids come within 7.5 million km of Earth orbit*

Progress: 140 Meters and Larger

Total Population estimated to be ~25,000

George E Brown
NEO Survey Goal

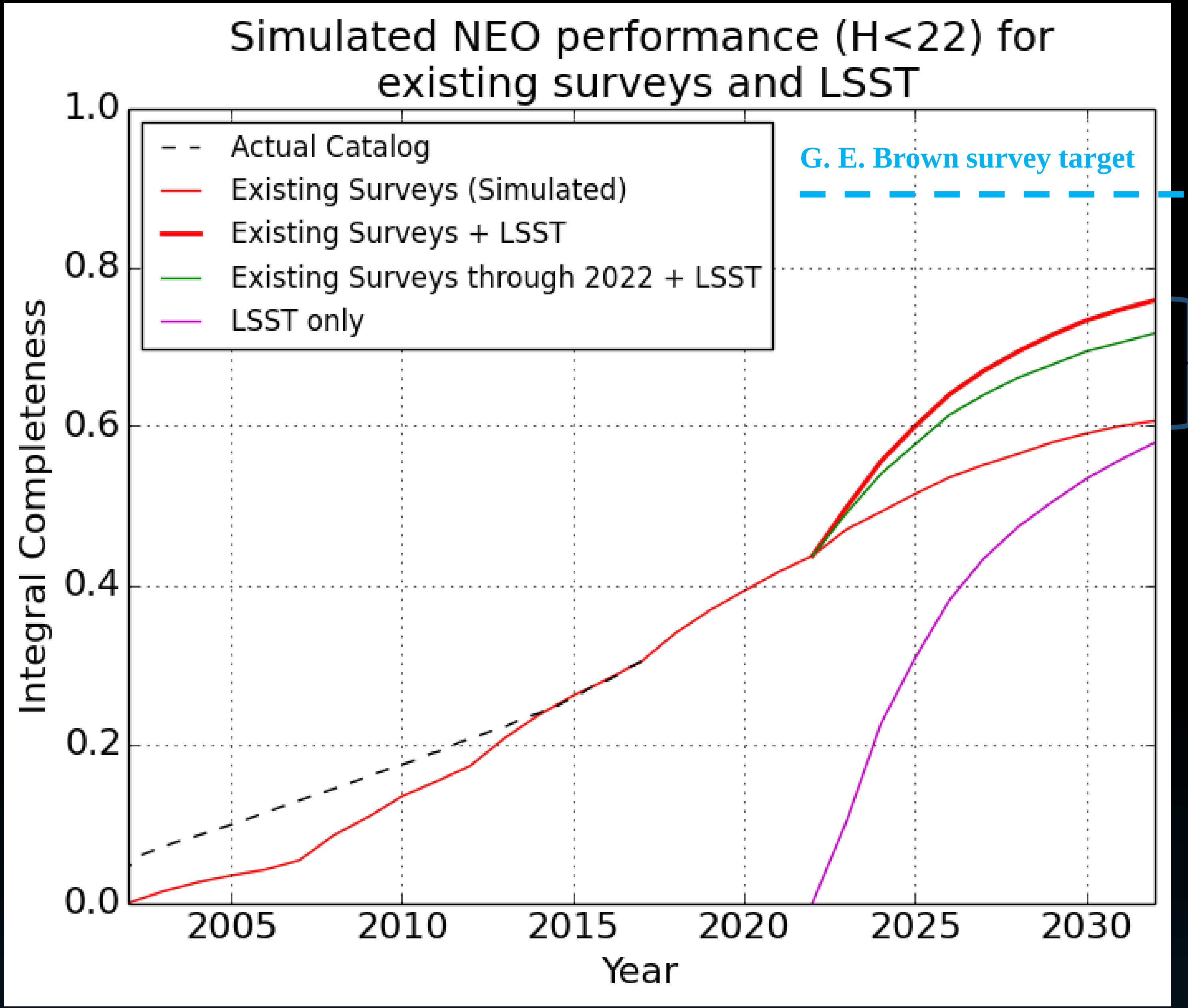


At current discovery rate, it will take more than 30 years to complete the survey.

Use of Rubin Telescope

From 2017 NASA/NSF study report

https://cneos.jpl.nasa.gov/doc/LSST_report_2017.html



LSST reduces the distance to the goal in 2032 roughly by half, compared to where we would be with currently operating surveys alone.

"NEO-optimized" LSST cadences tested so far increase completeness by only a few %.

NEO Surveillance Mission

Approach identified in multiple studies, most recently in:

- 2019 National Academies Study: Finding Hazardous Asteroids Using Infrared and Visible Wavelength Telescopes
- 2017 NEO Science Definition Team Report: Update to Determine the Feasibility of Enhancing the Search and Characterization of NEOs

Current development is built upon:

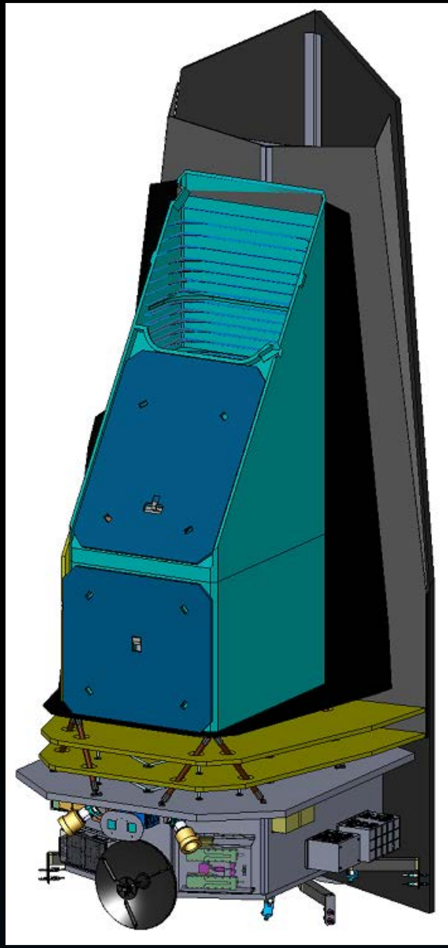
- NEOCam concept matured in proposals to Discovery Program
- Support of technology development – passively cooled thermal IR detectors
- NEOCam extended Phase A development
- NEO Surveillance Mission formulation

NEO Surveillance Mission

Objectives:

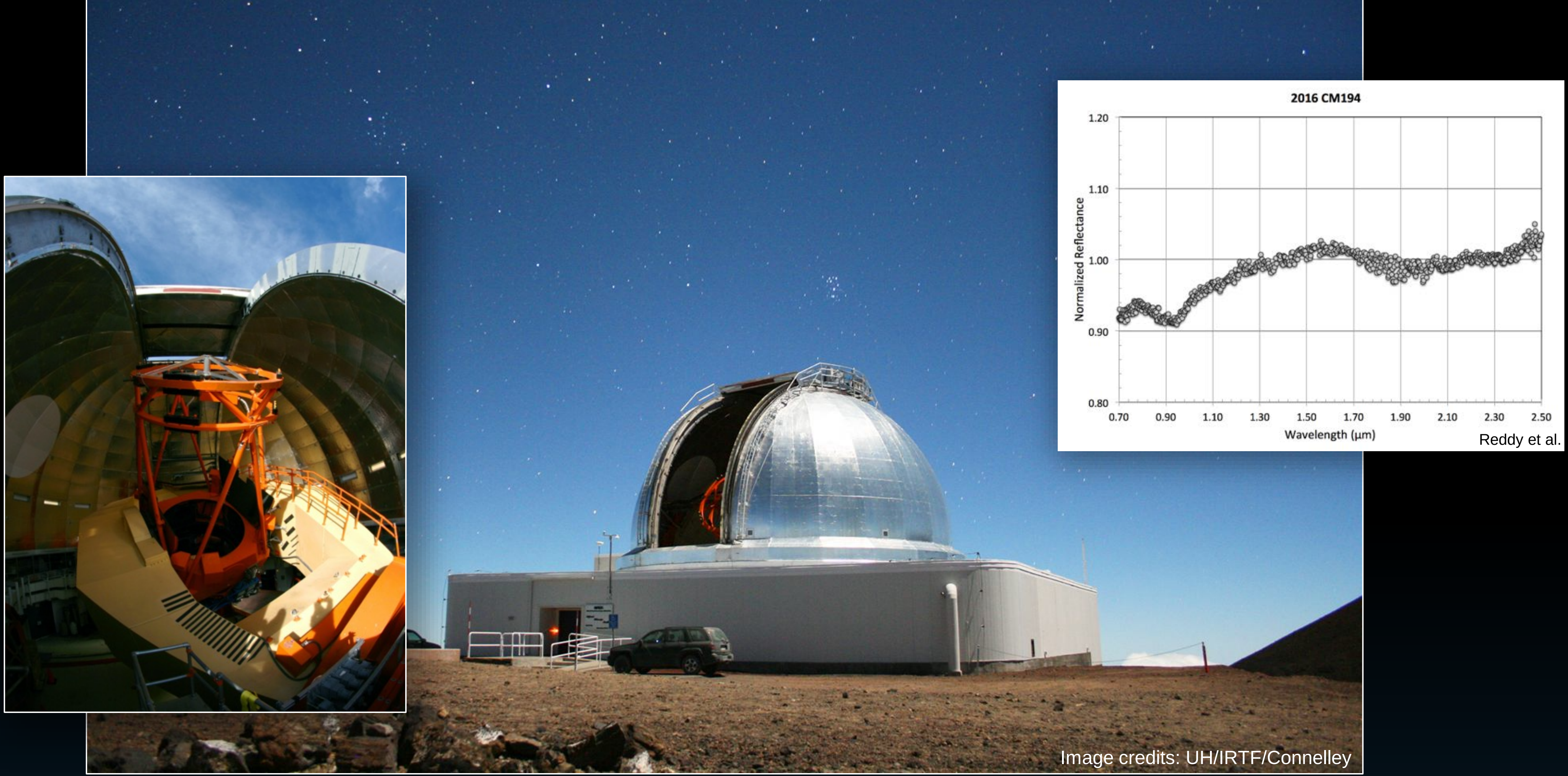
- Find 65% of undiscovered Potentially Hazardous Asteroids (PHAs) >140 m in 5 years (goal: 90% in 10 years)
- Estimate sizes directly from IR signatures
- Compute cumulative chance of impact over next century for PHAs >50 m and comets
- Deliver new tracklet data daily to the Minor Planet Center

NEO Surveyor Space-based IR Observatory



NASA’s Primary NEO Characterization Assets

NASA’s Infrared Telescope Facility



Reddy et al.

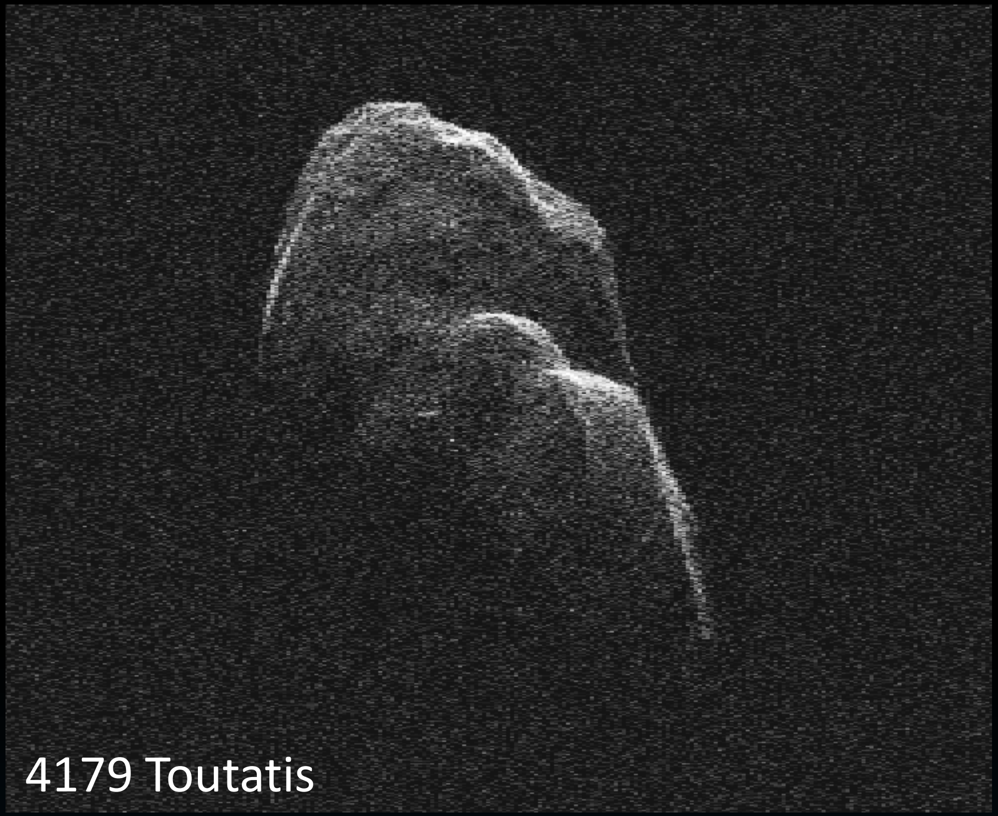
Image credits: UH/IRTF/Connelley

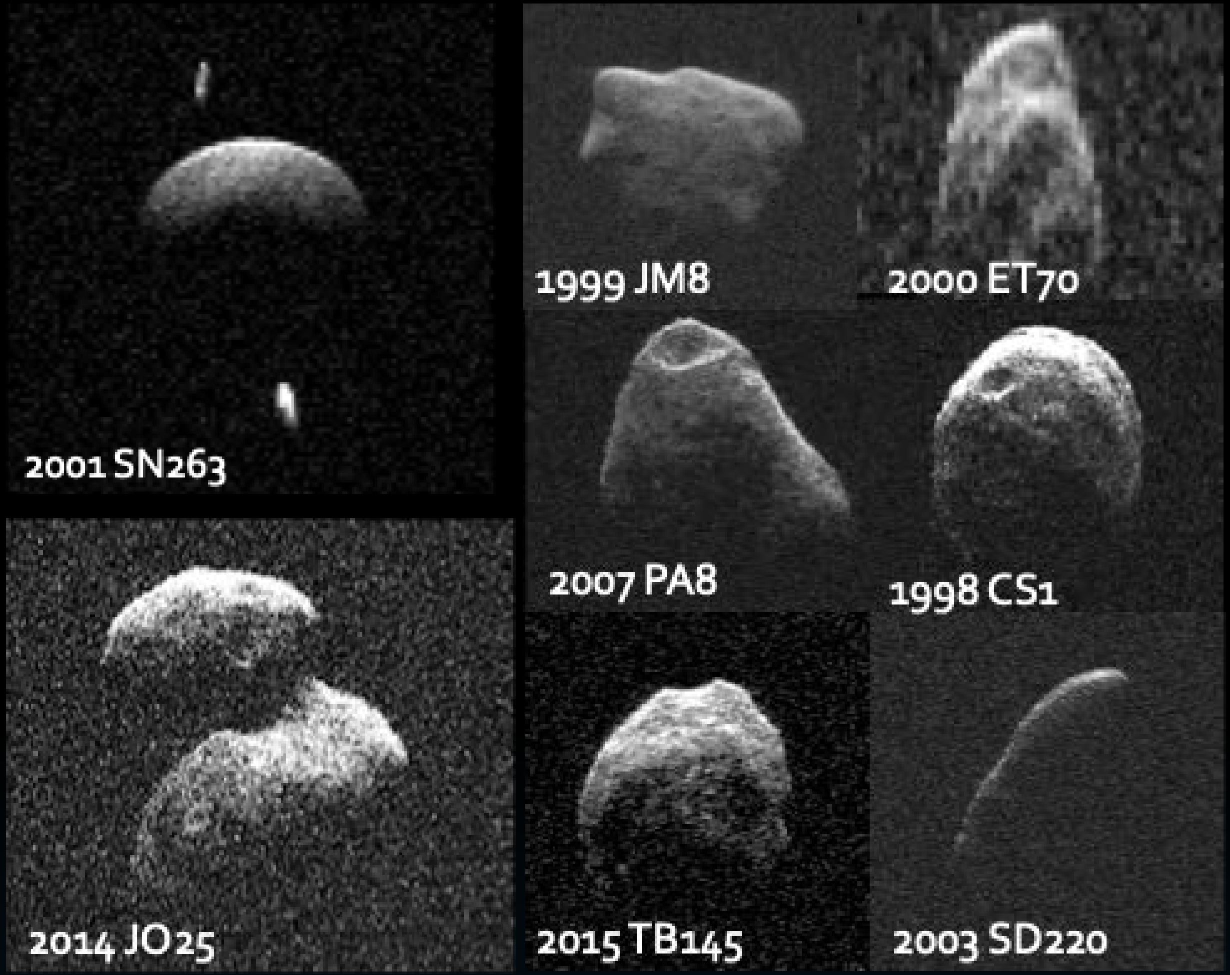
NASA's Primary NEO Characterization Assets

Goldstone Planetary Radar

Arecibo Planetary Radar

Planetary Radar: Shape and Size





Nex-Gen Planetary Radar First Step: KaBOOM

(Ka-Band Objects Observation and Monitoring)

Demonstrated coherent uplink arraying with real time atmospheric twinkling compensation at Ka band, operationally demonstrating a
<u>low life cycle cost, self calibrating, stand alone system</u>.

At NASA Kennedy Space Center

- Real time atmospheric twinkling compensation at Ka-band.
- A phased array of widely separated (by 60m) 12 meter COTS dish antennas
- Leading to a high power, high resolution radar system

- **KaBOOM builds on previous successfully demonstrated concepts, technologies and methods to prove the final steps towards an operational coherent array radar capability.**
- **KaBOOM validated the ability to achieve coherent power combining from widely separated antennas *(CW/Comm mode capability available today)***

Why a Long Baseline Phased Dish Array Architecture?

- **Greater Capability**
  - More power on target from lower cost transmitters
    - N^2 effect
      - Power α N (antennas) x N (transmitters)
  - Beam “Forms” above the atmosphere (no need for spectrum / safety coordination)
  - Lower operating costs (“wall power”)
- O&M / Sustainment Model
  - Graceful degradation to failure of single elements
    - Do not need additional redundancy / reliability
    - Architecture itself is resilient to failure
  - Antenna is the functional “LRU”
  - COTS and additive manufacturing leverages “scale”

Challenges

- Correct for atmospheric phase fluctuations [twinkling] in real time
- Self-calibrating, stand-alone system
- Extend architecture to larger scale, multi mission capability

- Approach leverages decades of radio telescope experience in the design, integration, operation and sustainment of high performance receive arrays.
- Applying this expertise to the “reverse problem” of transmitting coherent power through the atmosphere.

O&M: Operations & Maintenance
LRU: Line Replaceable Unit

What is CLEAR

- The Cis Lunar Environment Array Radar (CLEAR) project is a small scale implementation and the next step in the development cycle of the Space Object Array Radar (SOAR) program leading to a true deep space radar system capable of detecting and characterizing objects in cis-lunar space and leading to capability for Near Earth Objects (NEO) out to 0.5 AU (46 million miles)

- The CLEAR radar system will have immediate capabilities upon completion to detect, track, and characterize objects in cis-lunar orbit which is a risk mitigation for the Gateway platform, the astronauts, missions in low lunar orbit, and lunar surface operations, as well as cis-lunar space domain awareness

- CLEAR would be an adaption of a NASA prototyping activity called KARNAC (Kaband Array Radar for Near-earth-objects Accurate Characterization) and would be best executed under the Planetary Defense Coordination Office as a partnered activity with other NASA directorates and **other USG entities.**

77 Detected Close Approaches <1 Lunar Distance in 2019

Up to 24 larger than 20m. Up to 2 larger than 100m.

PLANETARY DEFENSE COORDINATION OFFICE

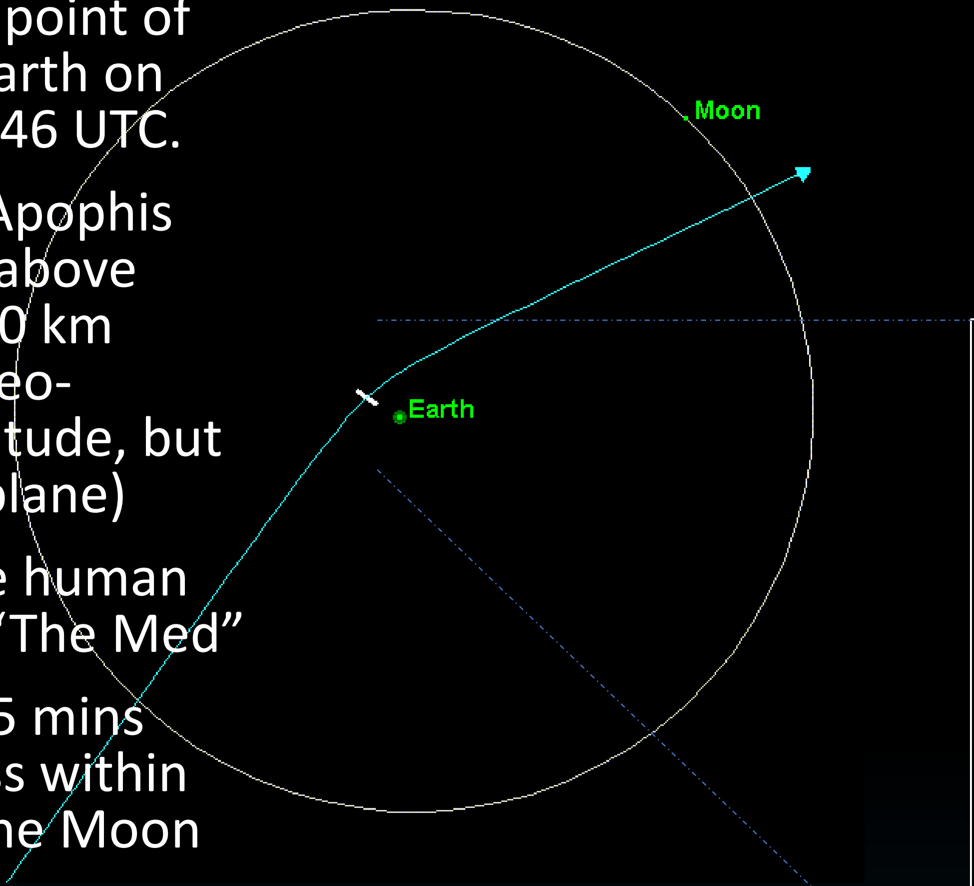
NASA

Object	Close-Approach (CA) Date	CA Distance Nominal (LD | au)	Estimated Diameter
(2019 AS5)	2019-Jan-08 00:37 ± < 00:01	0.04 | 0.00010	0.92 m - 2.1 m
(2019 AE9)	**2019-Jan-12 11:09 ± < 00:01**	**0.26 | 0.00067**	**9.9 m - 22 m**
(2019 BO)	2019-Jan-16 01:13 ± < 00:01	0.18 | 0.00046	6.3 m - 14 m
(2019 BV1)	2019-Jan-24 20:53 ± < 00:01	0.35 | 0.00090	4.9 m - 11 m
(2019 BZ3)	2019-Jan-27 23:29 ± < 00:01	0.13 | 0.00032	4.8 m - 11 m
(2019 CN5)	2019-Feb-11 07:23 ± 00:03	0.31 | 0.00079	7.3 m - 16 m
(2019 DG2)	2019-Feb-26 07:39 ± 00:24	0.61 | 0.00158	5.4 m - 12 m
(2019 DF)	2019-Feb-26 21:11 ± 00:09	0.45 | 0.00116	2.9 m - 6.5 m
(2019 EH1)	2019-Mar-01 17:38 ± < 00:01	0.06 | 0.00016	2.5 m - 5.7 m
(2019 EN2)	2019-Mar-13 23:38 ± < 00:01	0.86 | 0.00221	8.0 m - 18 m
(2019 FA)	2019-Mar-16 01:14 ± < 00:01	0.60 | 0.00154	4.8 m - 11 m
(2019 EA2)	**2019-Mar-22 01:53 ± < 00:01**	**0.80 | 0.00205**	**18 m - 41 m**
(2019 FQ)	**2019-Mar-23 18:17 ± < 00:01**	**0.86 | 0.00220**	**10 m - 23 m**
(2019 FC1)	**2019-Mar-28 05:46 ± < 00:01**	**0.27 | 0.00069**	**20 m - 45 m**
(2019 FV1)	2019-Mar-31 05:27 ± < 00:01	0.87 | 0.00223	4.6 m - 10 m
(2019 GP21)	2019-Mar-31 19:00 ± 07:46	0.93 | 0.00238	3.0 m - 6.6 m
(2019 GN20)	**2019-Apr-12 07:06 ± < 00:01**	**0.98 | 0.00253**	**14 m - 31 m**
(2019 GC6)	**2019-Apr-18 06:41 ± < 00:01**	**0.57 | 0.00146**	**13 m - 30 m**
(2019 HE)	**2019-Apr-20 21:12 ± < 00:01**	**0.58 | 0.00150**	**12 m - 28 m**
(2019 JK)	2019-Apr-30 08:12 ± < 00:01	0.69 | 0.00178	6.7 m - 15 m
(2019 JX1)	2019-May-02 12:39 ± < 00:01	0.47 | 0.00120	4.0 m - 8.9 m
(2019 JY2)	2019-May-05 17:12 ± < 00:01	0.38 | 0.00098	3.2 m - 7.2 m
(2019 JH7)	2019-May-16 00:06 ± < 00:01	0.19 | 0.00048	3.1 m - 7.0 m
(2019 KT)	**2019-May-28 03:48 ± < 00:01**	**0.85 | 0.00217**	**13 m - 29 m**
(2019 LY4)	2019-Jun-06 01:30 ± < 00:01	0.22 | 0.00056	7.3 m - 16 m
(2019 LW4)	**2019-Jun-08 17:04 ± < 00:01**	**0.65 | 0.00166**	**9.3 m - 21 m**
(2019 NK1)	2019-Jul-02 09:49 ± < 00:01	0.69 | 0.00177	2.6 m - 5.7 m
(2019 MB4)	**2019-Jul-09 07:20 ± < 00:01**	**0.82 | 0.00211**	**16 m - 35 m**
(2019 NF7)	2019-Jul-09 12:07 ± < 00:01	0.98 | 0.00253	6.4 m - 14 m
(2019 NN3)	**2019-Jul-10 16:29 ± < 00:01**	**0.83 | 0.00214**	**29 m - 66 m**
(2019 OD)	**2019-Jul-24 13:31 ± < 00:01**	**0.93 | 0.00239**	**54 m - 120 m**
(2019 OK)	**2019-Jul-25 01:22 ± < 00:01**	**0.19 | 0.00048**	**59 m - 130 m**
(2019 OD3)	**2019-Jul-28 02:56 ± < 00:01**	**0.49 | 0.00126**	**11 m - 25 m**
(2019 ON3)	2019-Jul-29 01:19 ± 00:14	0.56 | 0.00143	7.4 m - 16 m
(2019 QB1)	**2019-Aug-20 11:54 ± 00:01**	**0.32 | 0.00083**	**8.7 m - 20 m**
(2019 QH2)	2019-Aug-20 18:12 ± 00:08	0.13 | 0.00033	2.2 m - 5.0 m
(2019 QD)	2019-Aug-22 01:28 ± < 00:01	0.78 | 0.00200	4.7 m - 11 m

Object	Close-Approach (CA) Date	CA Distance Nominal (LD | au)	Estimated Diameter
(2019 QR8)	2019-Aug-26 08:51 ± 01:08	0.80 | 0.00207	6.6 m - 15 m
(2019 QQ3)	2019-Aug-26 15:14 ± 00:01	0.25 | 0.00064	3.7 m - 8.2 m
(2019 RQ)	2019-Sep-02 16:45 ± < 00:01	0.29 | 0.00074	2.1 m - 4.6 m
(2019 RP1)	2019-Sep-05 22:04 ± < 00:01	0.10 | 0.00025	7.3 m - 16 m
(2019 RC1)	2019-Sep-07 10:48 ± < 00:01	0.48 | 0.00123	4.6 m - 10 m
(2019 SJ)	2019-Sep-16 18:56 ± < 00:01	0.64 | 0.00163	8.3 m - 19 m
(2019 SU2)	2019-Sep-21 02:48 ± 00:01	0.19 | 0.00048	2.6 m - 5.8 m
(2019 SD1)	2019-Sep-21 06:46 ± < 00:01	0.73 | 0.00187	5.5 m - 12 m
(2019 SS2)	2019-Sep-21 07:12 ± 00:02	0.30 | 0.00077	2.0 m - 4.4 m
(2019 SS3)	**2019-Sep-22 22:48 ± 00:21**	**0.73 | 0.00188**	**15 m - 34 m**
(2019 SX8)	2019-Sep-28 07:50 ± < 00:01	0.99 | 0.00255	4.3 m - 9.7 m
(2019 TE)	2019-Sep-28 20:31 ± 01:31	0.93 | 0.00238	6.8 m - 15 m
(2019 TD)	2019-Sep-29 18:49 ± 00:01	0.34 | 0.00087	3.9 m - 8.7 m
(2019 SM8)	2019-Oct-01 13:56 ± < 00:01	0.41 | 0.00106	3.8 m - 8.6 m
(2019 SP3)	**2019-Oct-03 06:33 ± < 00:01**	**0.97 | 0.00249**	**14 m - 31 m**
(2019 TN5)	2019-Oct-05 22:38 ± < 00:01	0.32 | 0.00083	5.5 m - 12 m
(2019 UU1)	2019-Oct-18 06:23 ± < 00:01	0.59 | 0.00151	2.2 m - 5.0 m
(2019 UG)	2019-Oct-18 09:23 ± < 00:01	0.84 | 0.00215	6.3 m - 14 m
(2019 UL3)	2019-Oct-19 22:22 ± < 00:01	0.77 | 0.00199	5.9 m - 13 m
(2019 UN8)	2019-Oct-23 16:41 ± 00:17	0.93 | 0.00240	3.1 m - 6.9 m
(2019 UO8)	2019-Oct-25 13:30 ± < 00:01	0.41 | 0.00105	3.7 m - 8.3 m
(2019 UX12)	2019-Oct-26 03:07 ± 00:01	0.99 | 0.00255	4.8 m - 11 m
(2019 UD10)	2019-Oct-27 10:08 ± 00:02	0.44 | 0.00112	6.3 m - 14 m
(2019 UB8)	2019-Oct-29 06:30 ± < 00:01	0.50 | 0.00127	4.3 m - 9.7 m
(2019 UN13)	2019-Oct-31 14:45 ± < 00:01	0.03 | 8.43e-5	1.0 m - 2.2 m
(2019 UG11)	**2019-Nov-01 20:42 ± < 00:01**	**0.55 | 0.00140**	**12 m - 28 m**
(2019 VA)	2019-Nov-02 17:28 ± < 00:01	0.28 | 0.00071	5.8 m - 13 m
(2019 VD)	**2019-Nov-04 09:56 ± < 00:01**	**0.45 | 0.00117**	**8.7 m - 20 m**
(2019 VR)	2019-Nov-04 10:30 ± < 00:01	0.35 | 0.00091	6.4 m - 14 m
(2019 VS4)	**2019-Nov-06 16:28 ± < 00:01**	**0.36 | 0.00093**	**9.2 m - 21 m**
(2019 VB5)	2019-Nov-09 17:29 ± < 00:01	0.38 | 0.00097	1.2 m - 2.7 m
(2019 VF5)	2019-Nov-09 23:16 ± < 00:01	0.49 | 0.00127	8.1 m - 18 m
(2019 WH)	**2019-Nov-19 08:01 ± < 00:01**	**0.22 | 0.00057**	**15 m - 35 m**
(2019 WV1)	2019-Nov-19 23:51 ± 00:09	0.72 | 0.00185	6.2 m - 14 m
(2019 WG2)	**2019-Nov-23 08:44 ± < 00:01**	**0.47 | 0.00121**	**27 m - 60 m**
(2019 WJ4)	2019-Nov-30 20:05 ± < 00:01	0.85 | 0.00219	5.5 m - 12 m
(2019 YB)	2019-Dec-18 00:12 ± 00:03	0.44 | 0.00113	3.1 m - 7.0 m
(2019 YS)	2019-Dec-18 15:12 ± < 00:01	0.17 | 0.00044	1.3 m - 3.0 m
(2019 YU2)	**2019-Dec-23 19:28 ± < 00:01**	**0.26 | 0.00066**	**8.9 m - 20 m**
(2019 YV4)	**2019-Dec-25 21:41 ± 11:01**	**0.98 | 0.00251**	**9.3 m - 21 m**

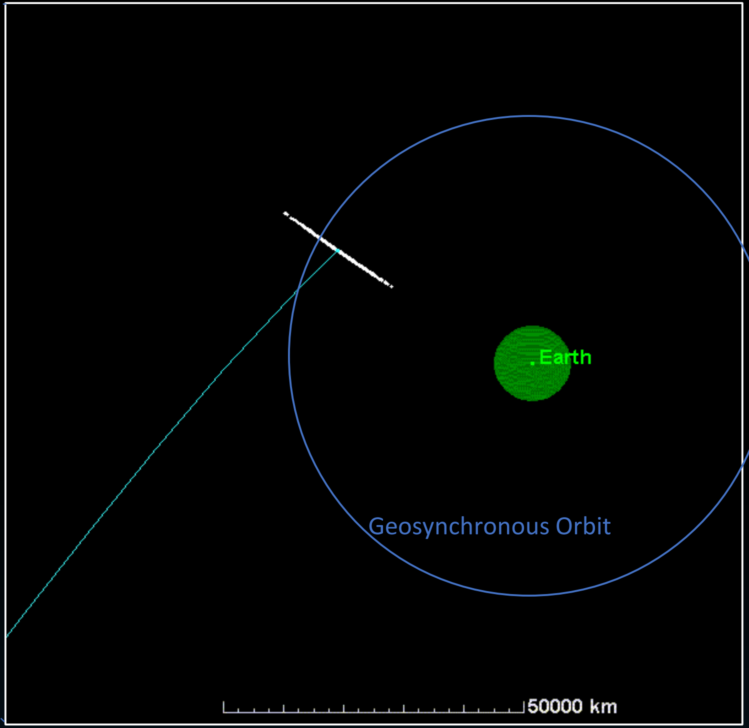
Apophis Close Approach

- Apophis will reach its point of closest approach to Earth on April 13th, 2029, at 2146 UTC.
- At closest approach, Apophis will pass ~31,000 km above Earth's surface (~4,500 km closer to Earth than geo-synchronous orbit altitude, but well above the orbit plane)
- It will be visible to the human eye. Best view from "The Med"
- About about 16 hrs 45 mins later, Apophis will pass within about 96,000 km of the Moon



Predicted Close Approach of
2004 MN4 "Apophis"
(an ~340m Object)
on April 13, 2029

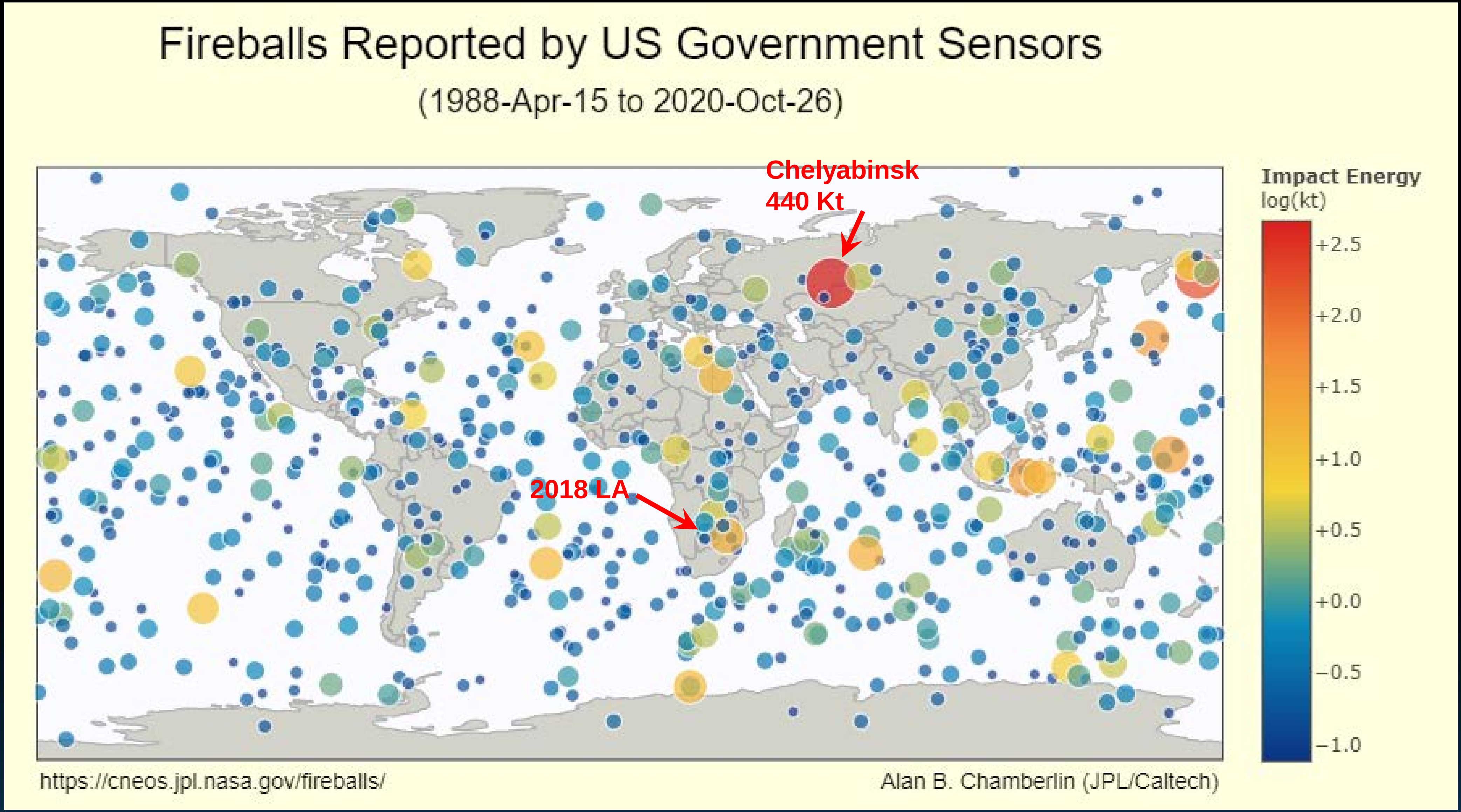
CLOSE-UP VIEW



https://publish.twitter.com/?query=https%3A%2F%2Ftwitter.com%2FJimBridenstine%2Fstatus%2F1257669052085960705&widget=Tweet

Other **known** PHOs of significant size will pass within lunar orbit this decade, eg 2001 WN5

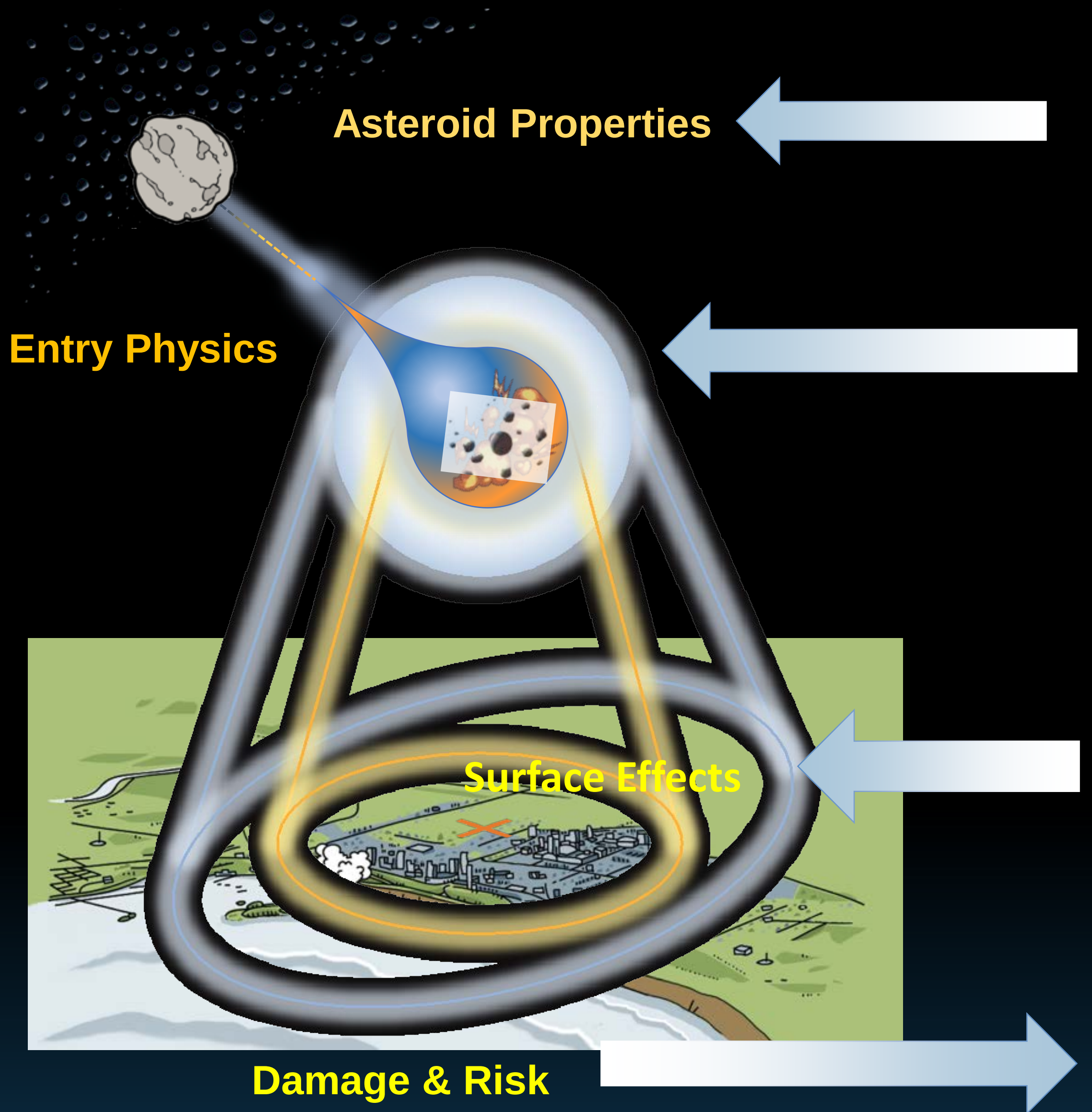
Bolide Reports and Data



PLANETARY DEFENSE COORDINATION OFFICE

Botswana Meteorite

Asteroid Threat Assessment



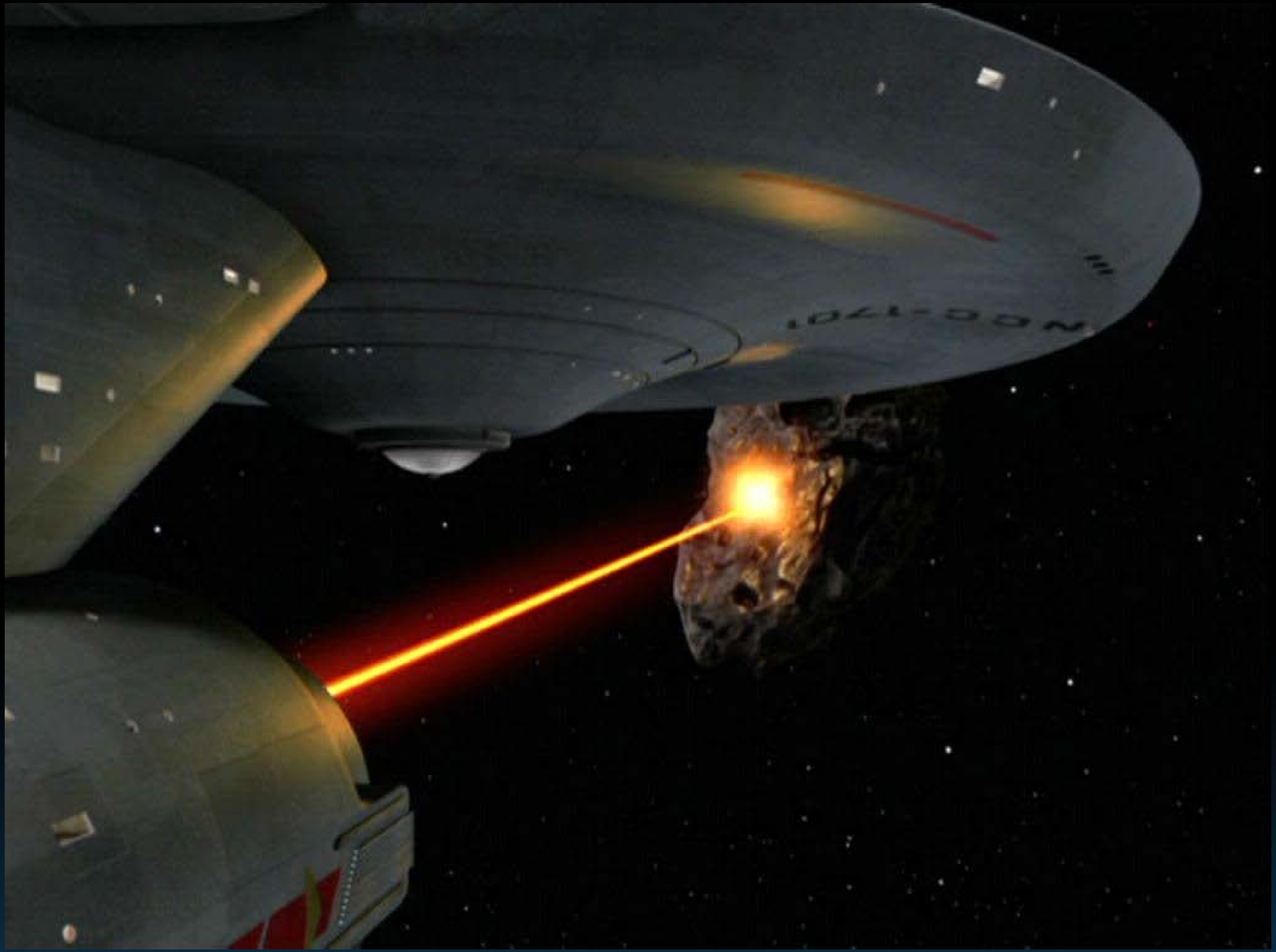
Characterization
- Measurements
- Inference
- Data aggregation
- Property database website

Entry Simulations & Testing
- Coupled aerothermodynamics
- Ablation & radiation modeling
- Arc jet testing

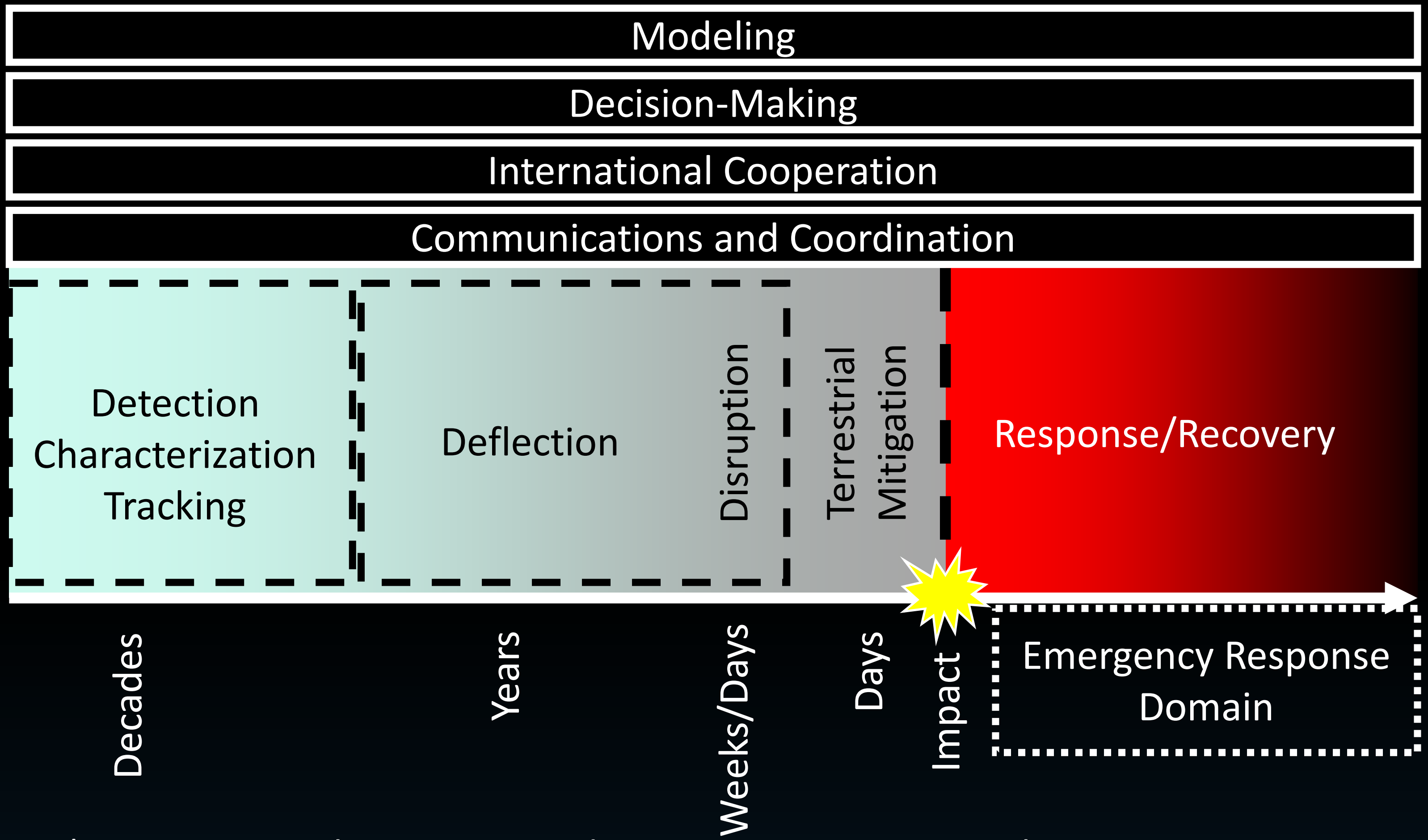
Effect Simulations
- 3D blast simulations
- Impact crater simulations
- Tsunami simulations
- Thermal radiation models
- Global effects

Probabilistic Risk Assessment
- Analytic physics-based entry and damage models
- Probabilistic Monte Carlo simulation using uncertainty distributions

Impact Mitigation Techniques



Planetary Defense Timeline*



* From National NEO Preparedness Strategy, 30 December 2016

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Impact Mitigation Techniques

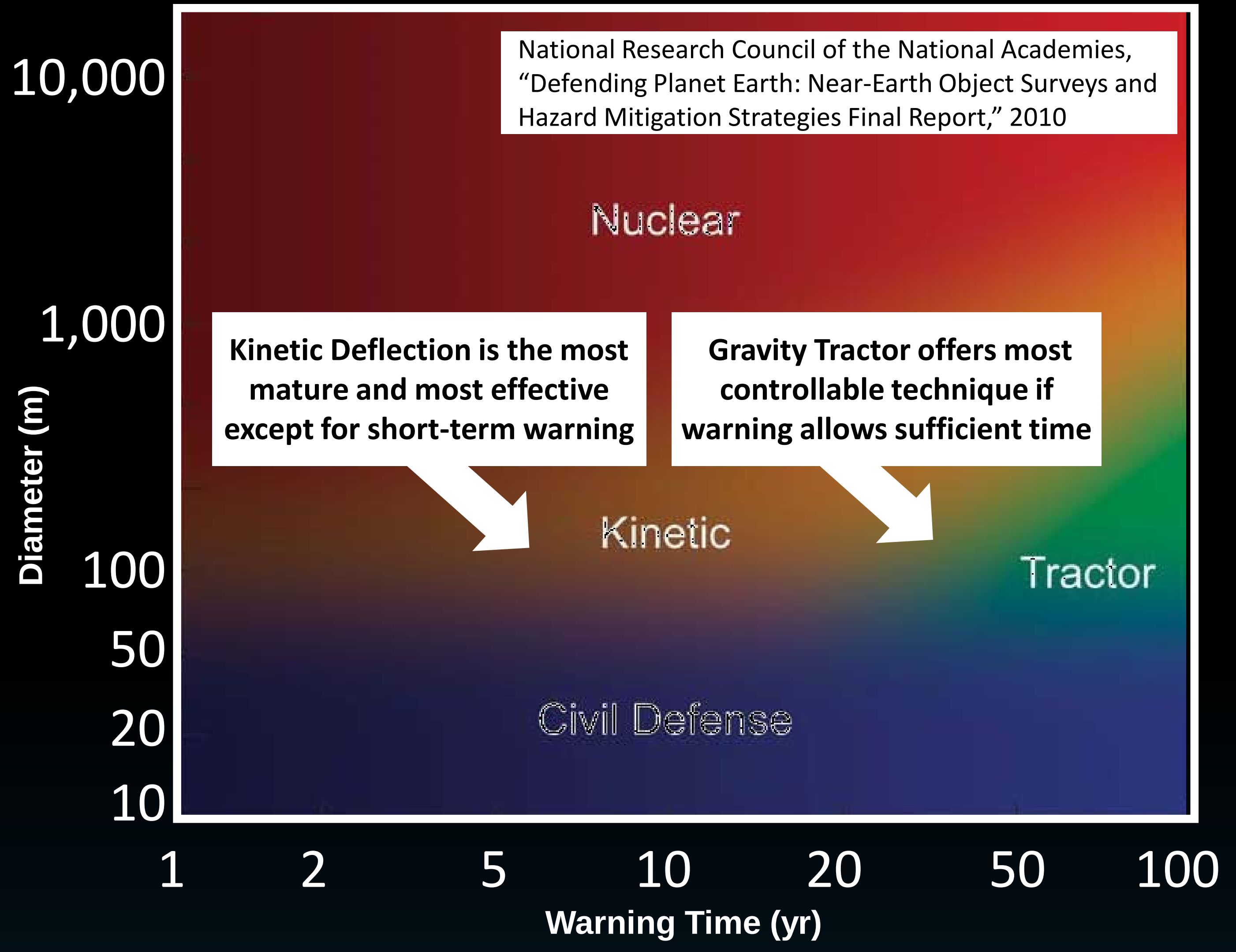
NASA

Most viable techniques:

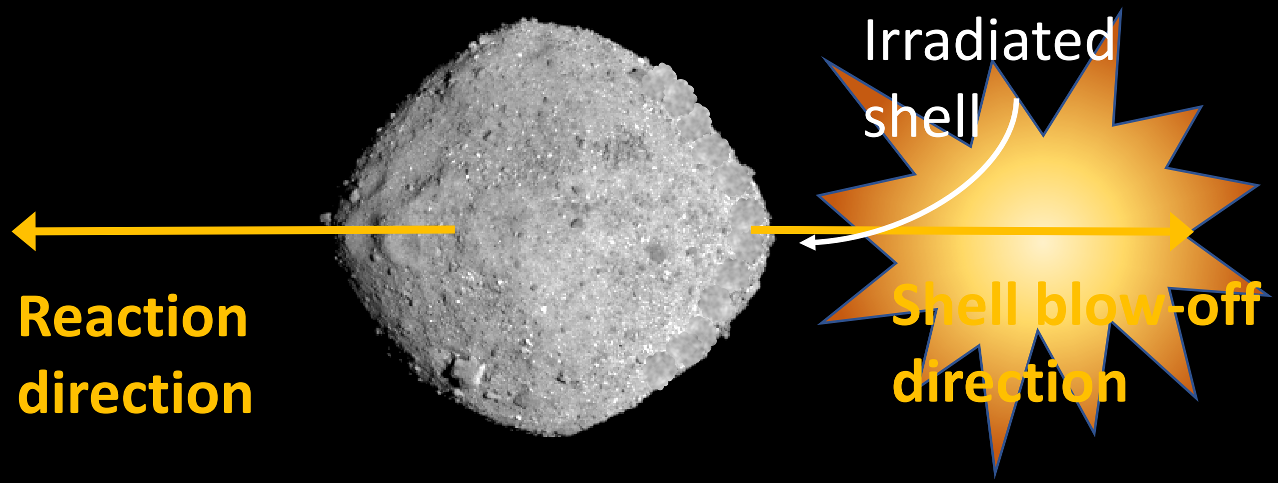
- Kinetic Impactor
- Gravity Tractor
- Nuclear Explosive Device

Technology demonstration and validation needed before implementation in impact mitigation

International participation in any asteroid mitigation / deflection campaign is highly desirable if not essential to overall acceptability

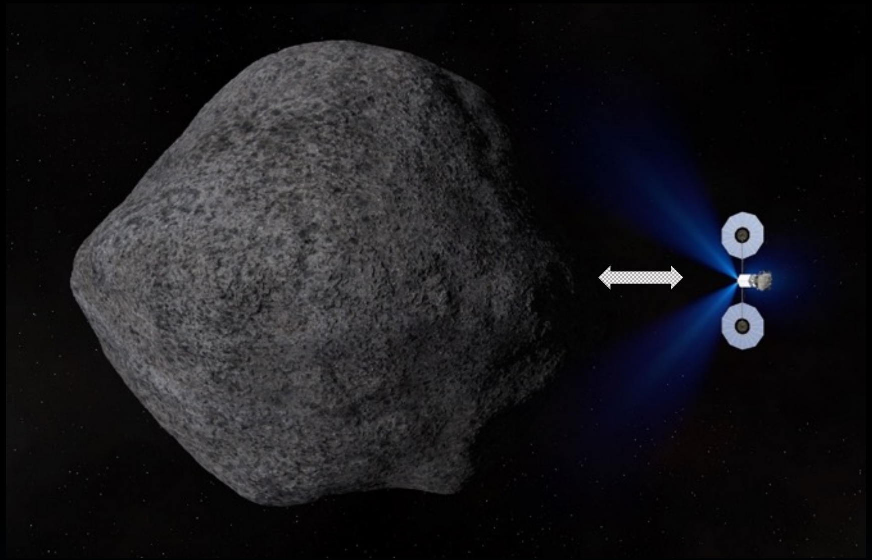


Deflection by Nuclear Explosive Device

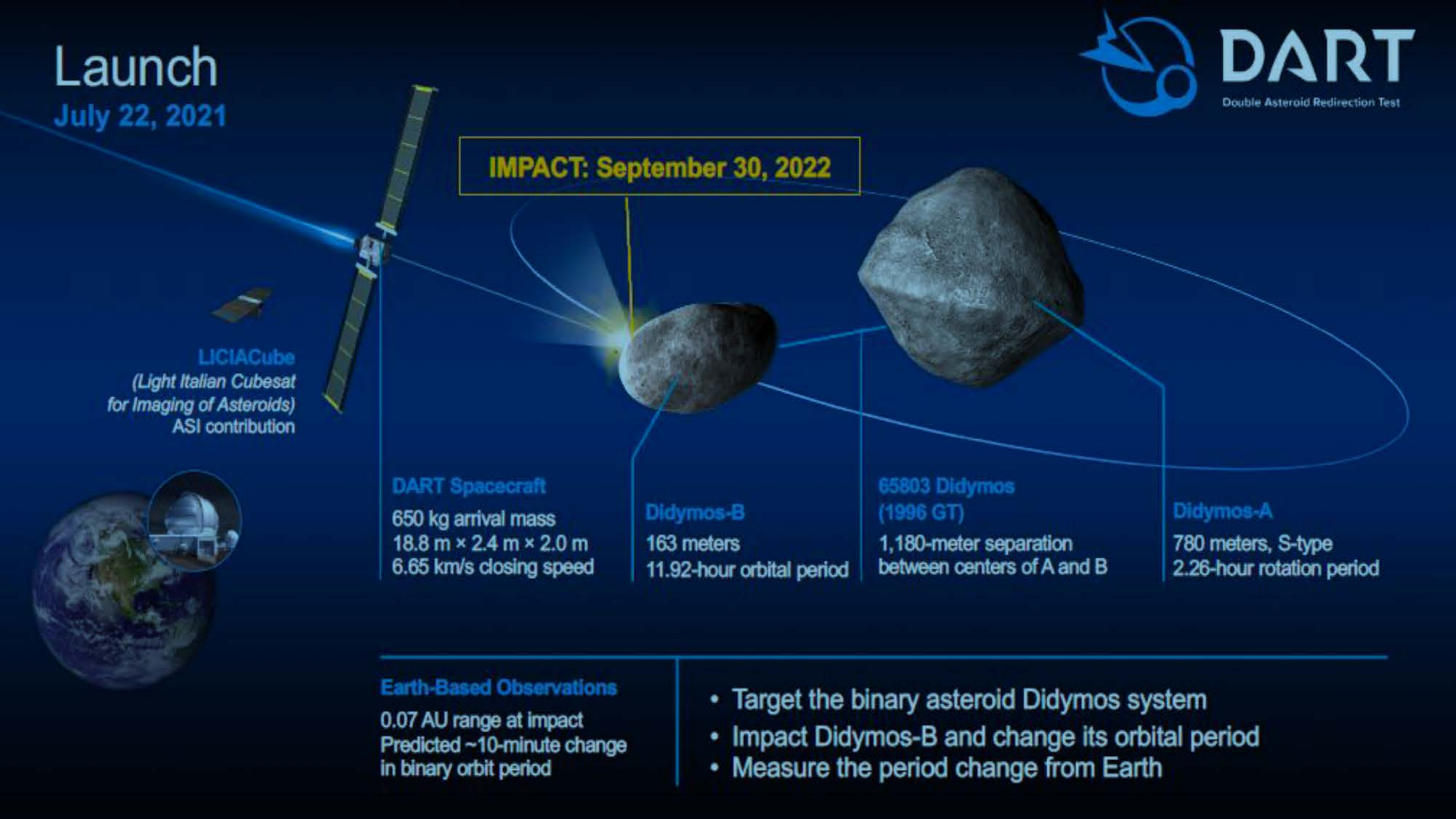


Planetary Defense Demonstration: Enhanced Gravity Tractor (EGT)

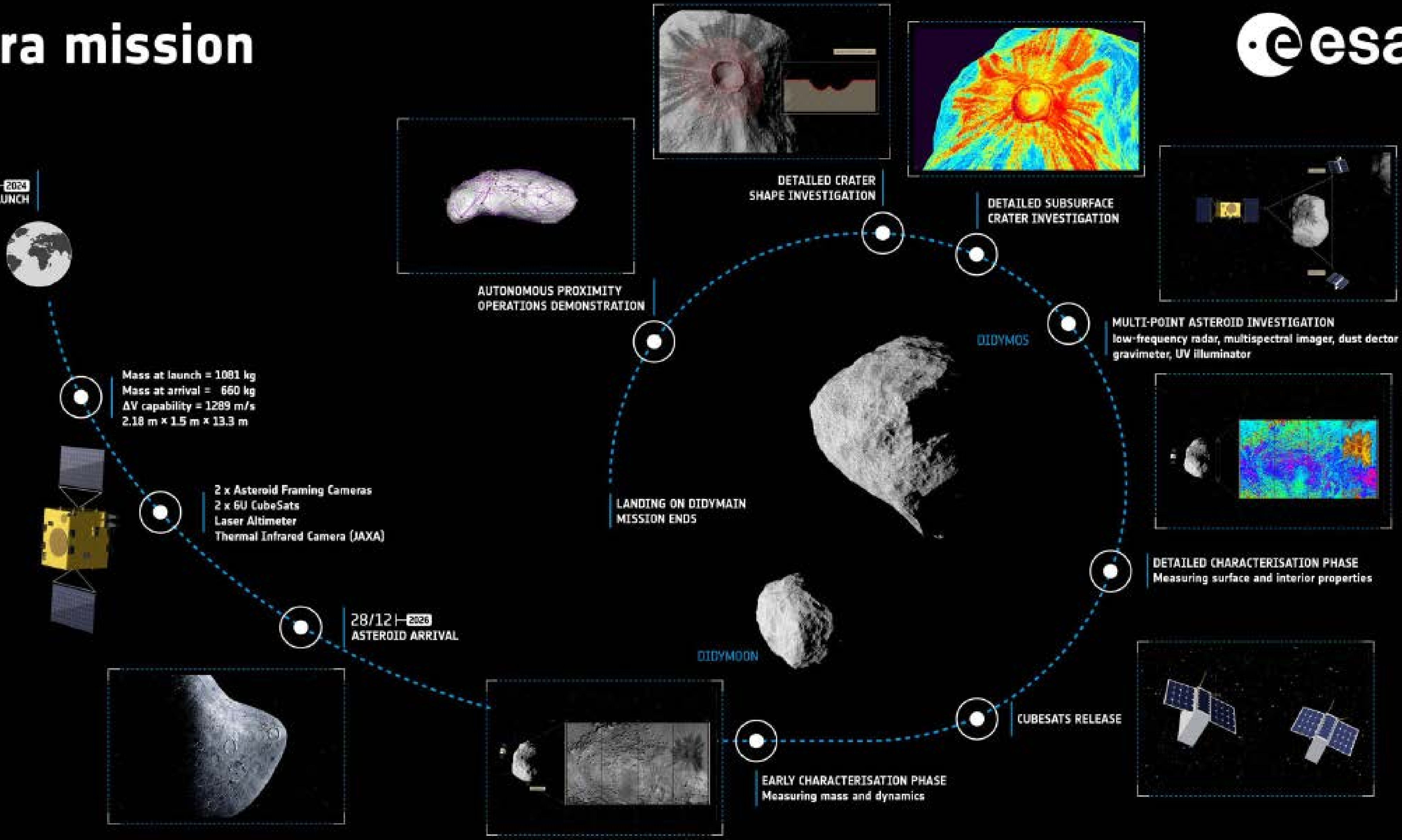
Uses the mass of the collected boulder to augment the mass of the spacecraft and increase the gravitational attraction.

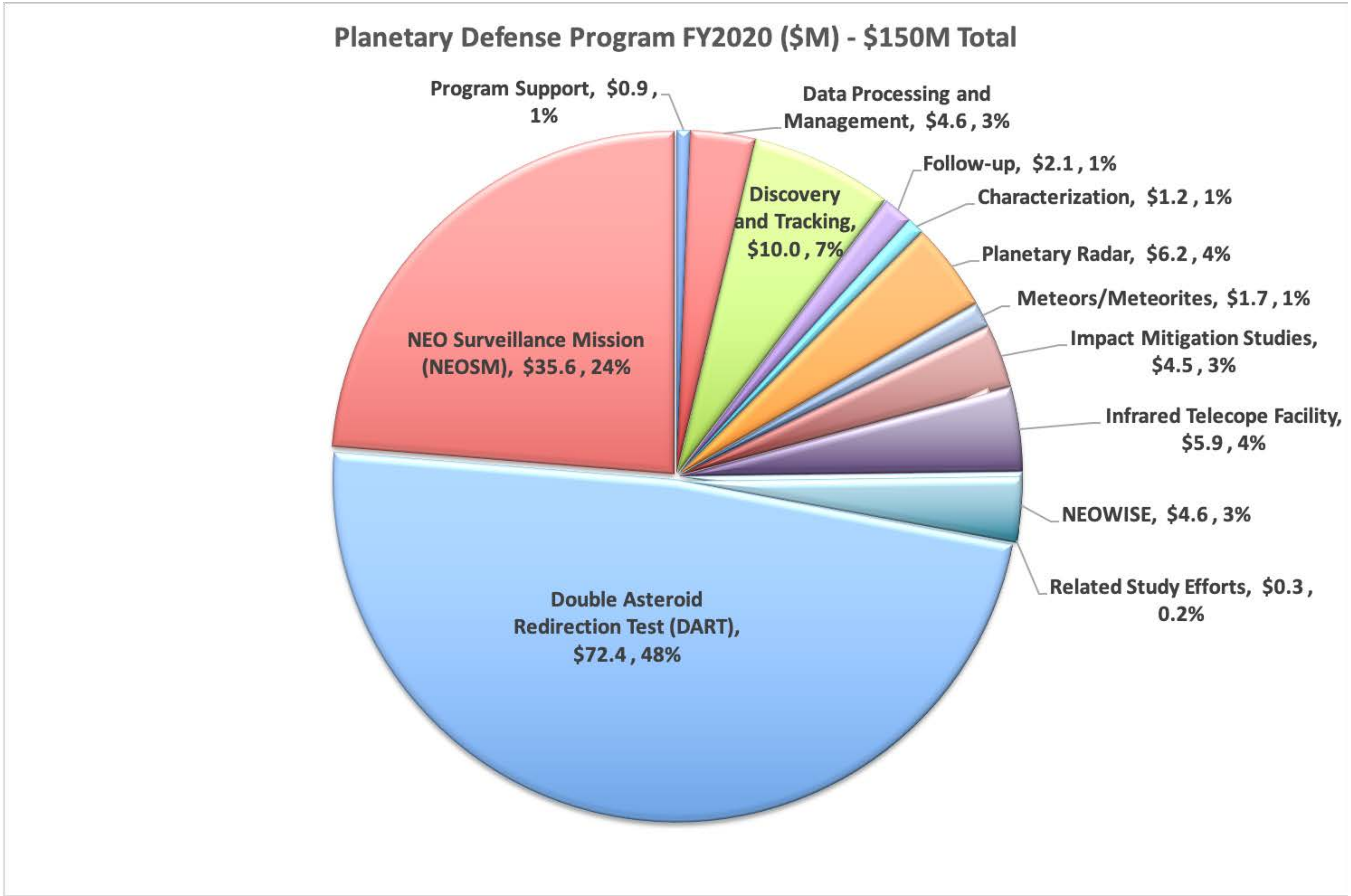


Actual EGT planetary defense mission could adjust the power/propellant load and asteroid mass collected, to increase the effectiveness of this technique.


Launch
July 22, 2021
DART
Double Asteroid Redirection Test
IMPACT: September 30, 2022
LICIACube
(Light Italian Cubesat
for Imaging of Asteroids)
ASI contribution
DART Spacecraft
650 kg arrival mass
18.8 m × 2.4 m × 2.0 m
6.65 km/s closing speed
Didymos-B
163 meters
11.92-hour orbital period
65803 Didymos
(1996 GT)
1,180-meter separation
between centers of A and B
Didymos-A
780 meters, S-type
2.26-hour rotation period
Earth-Based Observations
0.07 AU range at impact
Predicted ~10-minute change
in binary orbit period
• Target the binary asteroid Didymos system
• Impact Didymos-B and change its orbital period
• Measure the period change from Earth

hera mission




Planetary Defense Program FY2020 ($M) - $150M Total
Program Support, $0.9, 1%
Data Processing and Management, $4.6, 3%
Discovery and Tracking, $10.0, 7%
Follow-up, $2.1, 1%
Characterization, $1.2, 1%
Planetary Radar, $6.2, 4%
Meteors/Meteorites, $1.7, 1%
Impact Mitigation Studies, $4.5, 3%
Infrared Telecope Facility, $5.9, 4%
NEOWISE, $4.6, 3%
Related Study Efforts, $0.3, 0.2%
Double Asteroid Redirection Test (DART), $72.4, 48%
NEO Surveillance Mission (NEOSM), $35.6, 24%

Considerations for future Planetary Defense Flight Projects:

1. Although science can also benefit from Planetary Defense flight missions, the flight missions in this line are focused on NEO search and/or characterization, or in-space mitigation technology development. Currently, these are strategic, directed investigations as opposed to competed. As such, the report could identify specific prioritized planetary defense goals for “strategic missions”, even if the anticipated costs are below the current $500M competed mission threshold.
2. The panel should look for opportunities with Planetary Science flight missions where Planetary Defense objectives could be achieved with augmentation by Planetary Defense funding to add capability or enhance operations of otherwise purely Planetary Science missions.
3. Planetary Defense flight investigations believed executable for less than approximately $500 million should be identified and prioritized. They could be either directed to a specific purpose or, if for a more broadly identified objective (e.g. Apophis encounter), proposed by community investigators through an AO process to address the Planetary Defense goals and challenges identified.
4. It is not foreseen the projected budget for Planetary Defense would allow flight projects in excess of $500M development costs. However, if the panel finds specific flight investigations are needed with Life Cycle Costs (LCC) in the approximate range $500 million to $1 billion, the report should provide the candidate objectives to be achieved for each mission and they should be prioritized.

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