Planetary Defense Coordination Office

Lindley Johnson

Planetary Defense Officer

Planetary Defense Coordination Office

NASA HQ

February 22, 2018

Planetary Defense Coordination Office

This new office was established in January 2016 at NASA HQ to oversee planetary defense related activities across NASA, and coordinate both US interagency and international efforts and projects to address and plan response to the asteroid impact hazard.

Mission Statement:

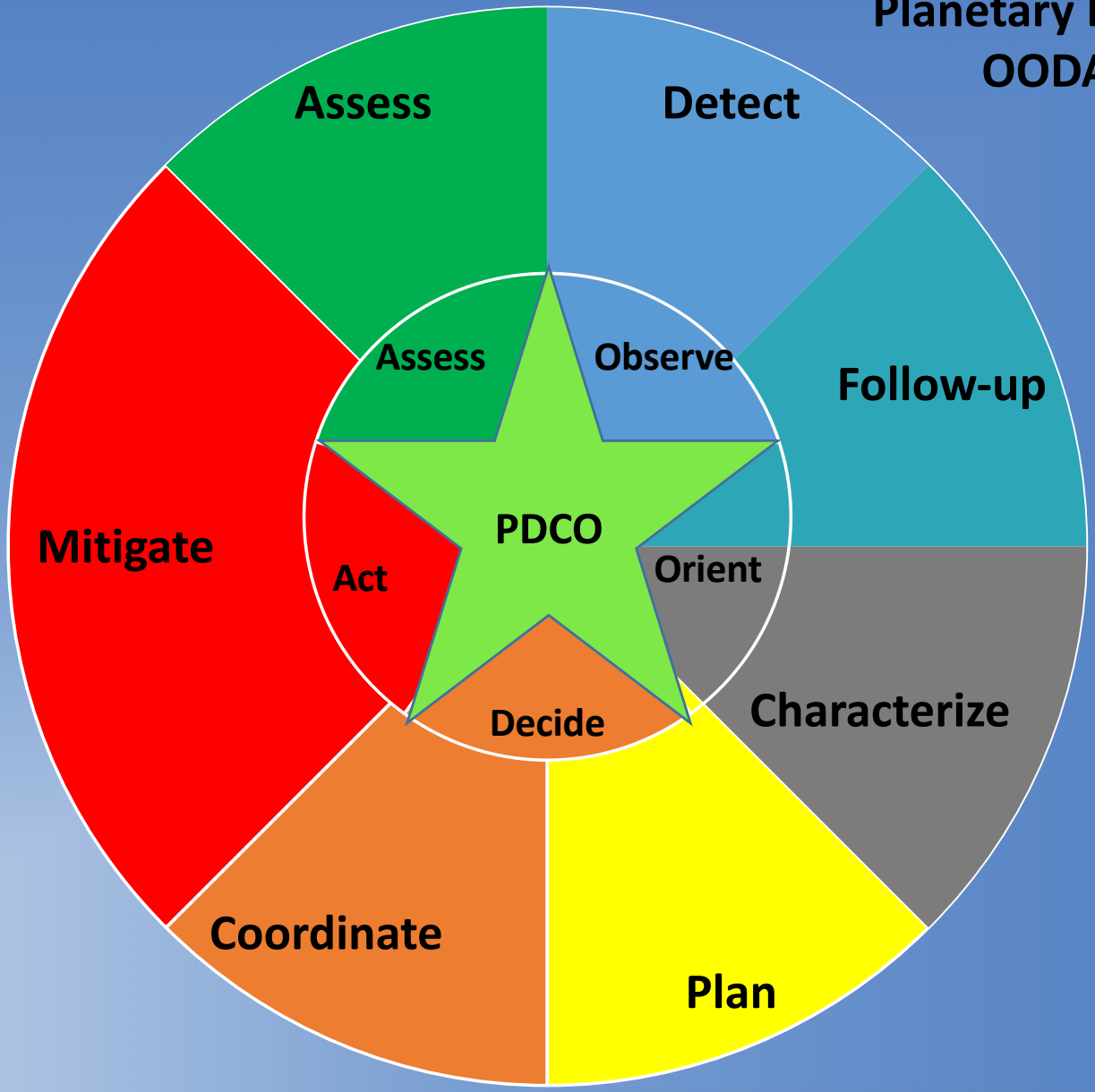
Lead national and international efforts to:

- 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 Coordination Office

- Near-Earth Object Observations Program
- Interagency and International Partnerships
- Mitigation Research

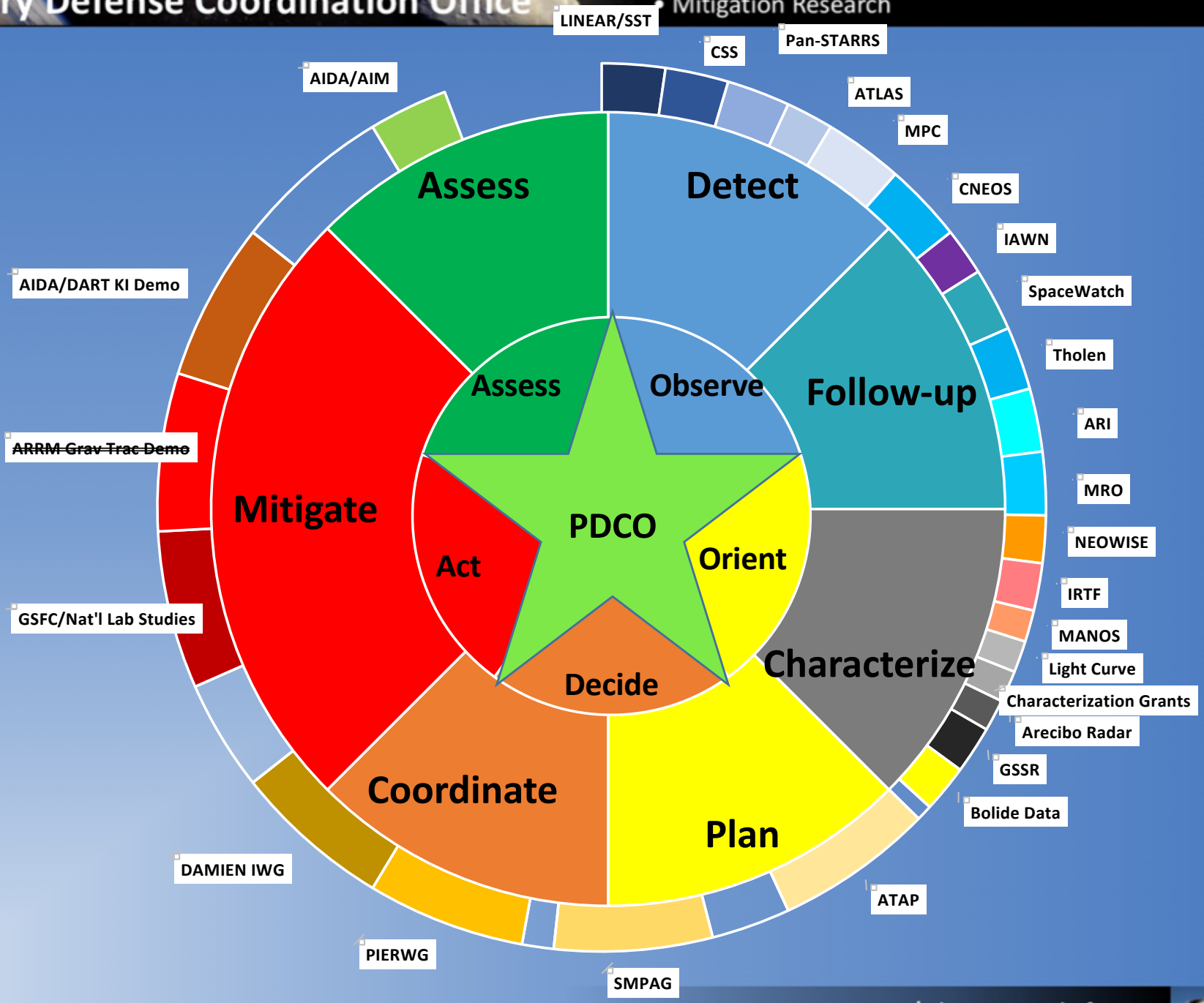
Planetary Defense OODAA Loop



www.nasa.gov/planetarydefense

Planetary Defense Coordination Office

- Near-Earth Object Observations Program
- Interagency and International Partnerships
- Mitigation Research



www.nasa.gov/planetarydefense

Near-Earth Object Observations Program

Kelly Fast

NEOO Program Manager

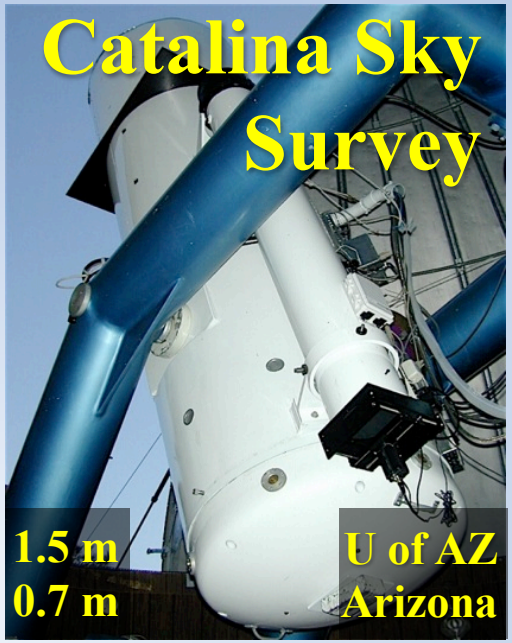
Planetary Defense Coordination Office

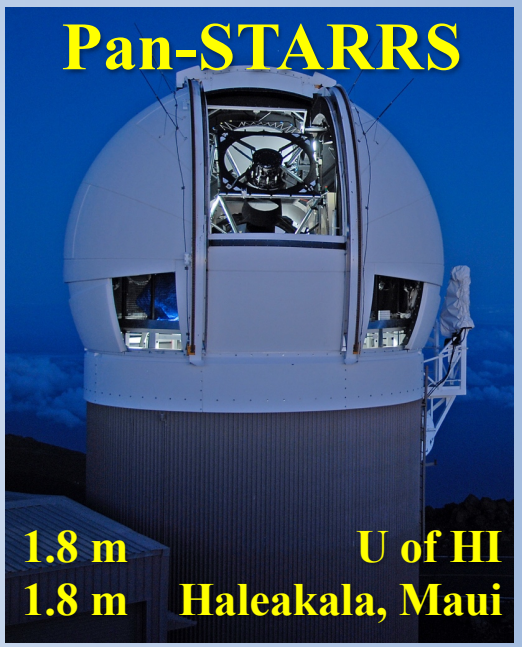
NASA HQ

February 22, 2018

NASA's NEO Search Program

(Current Survey Systems)





The International Astronomical Union Minor Planet Center

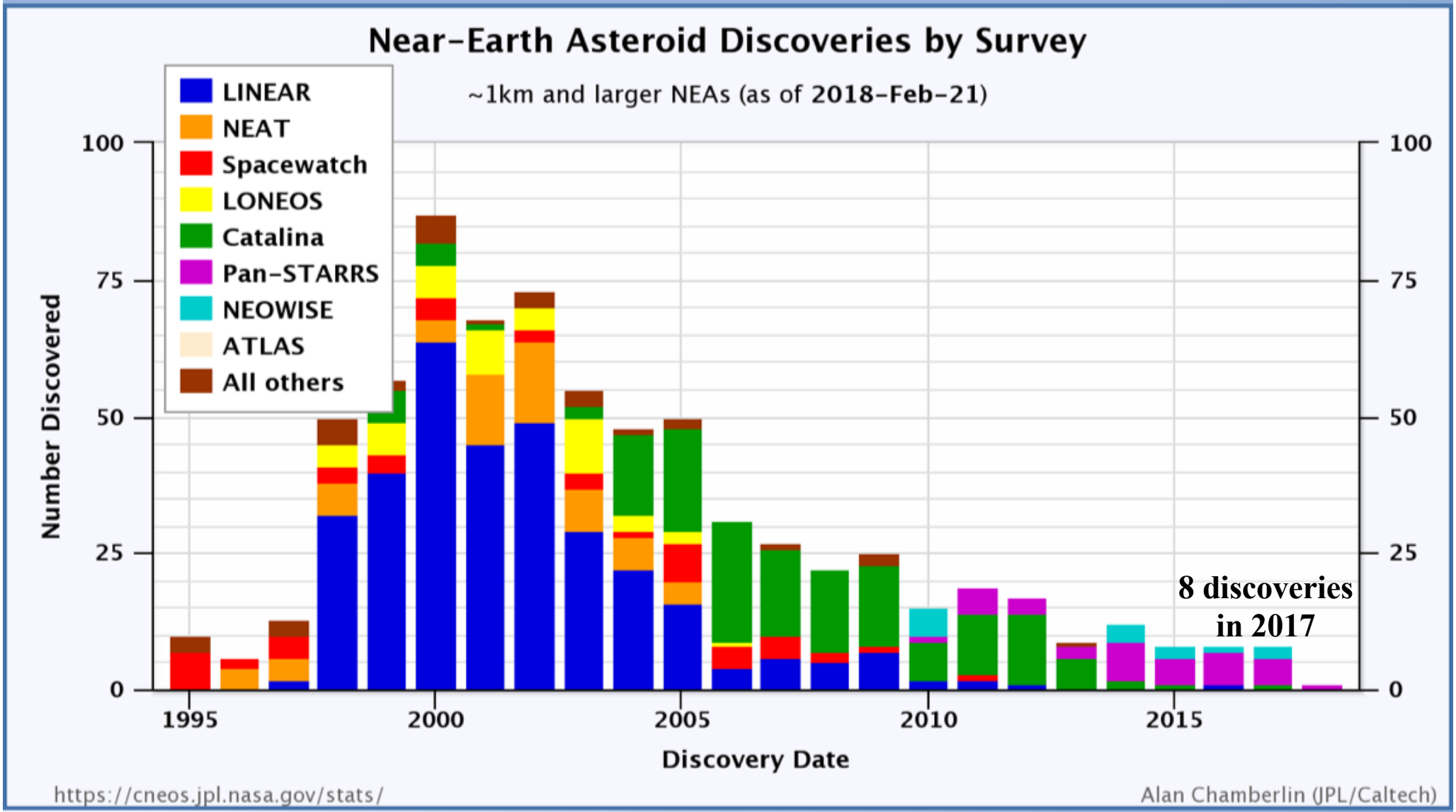
http://minorplanetcenter.net/

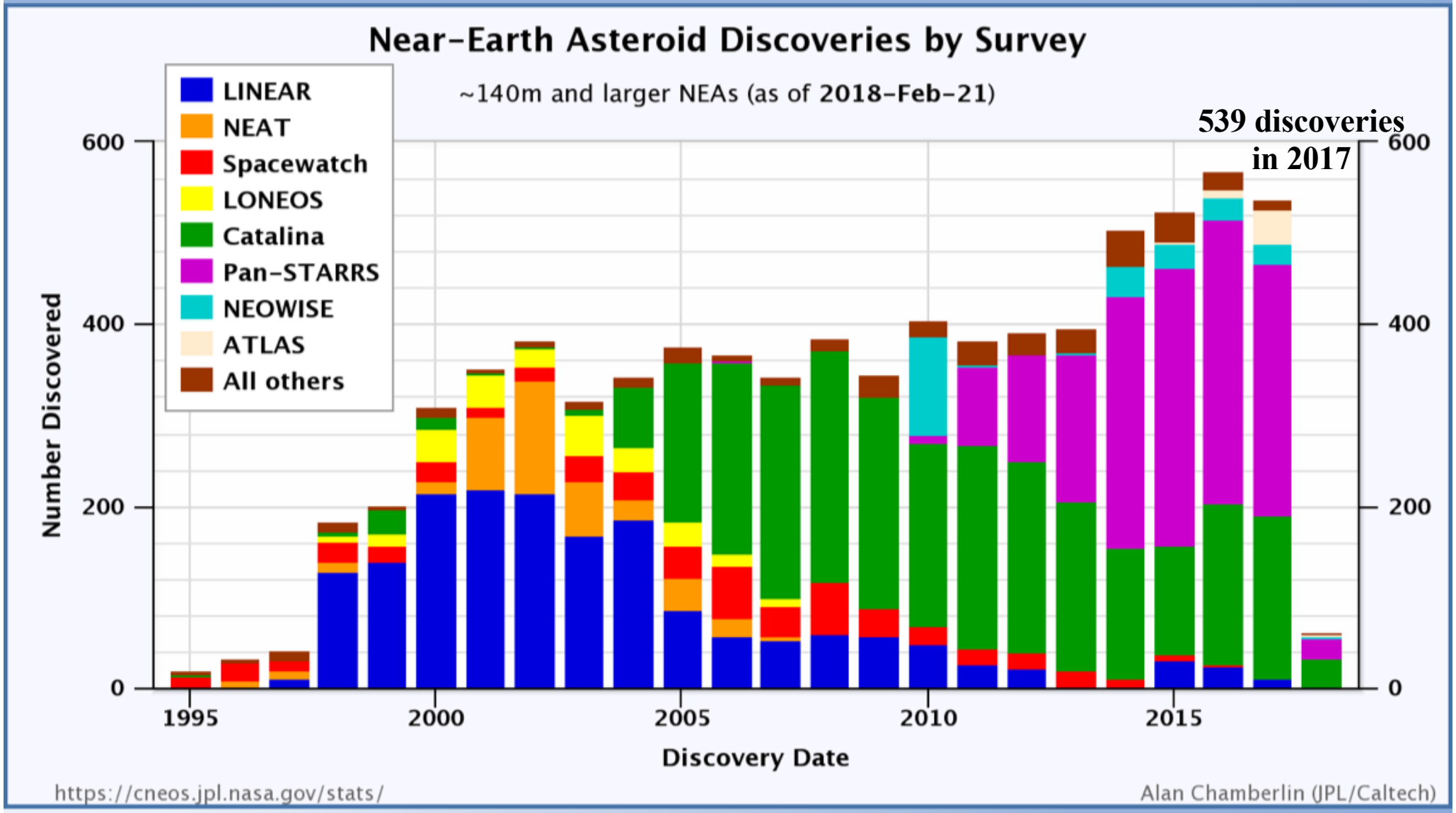
- Receives positional measurement of small bodies from observations made all over the world (and beyond)
- Responsible for identification, designation and initial orbit computation
- Now operating under the **Planetary Data System's Small Bodies Node**

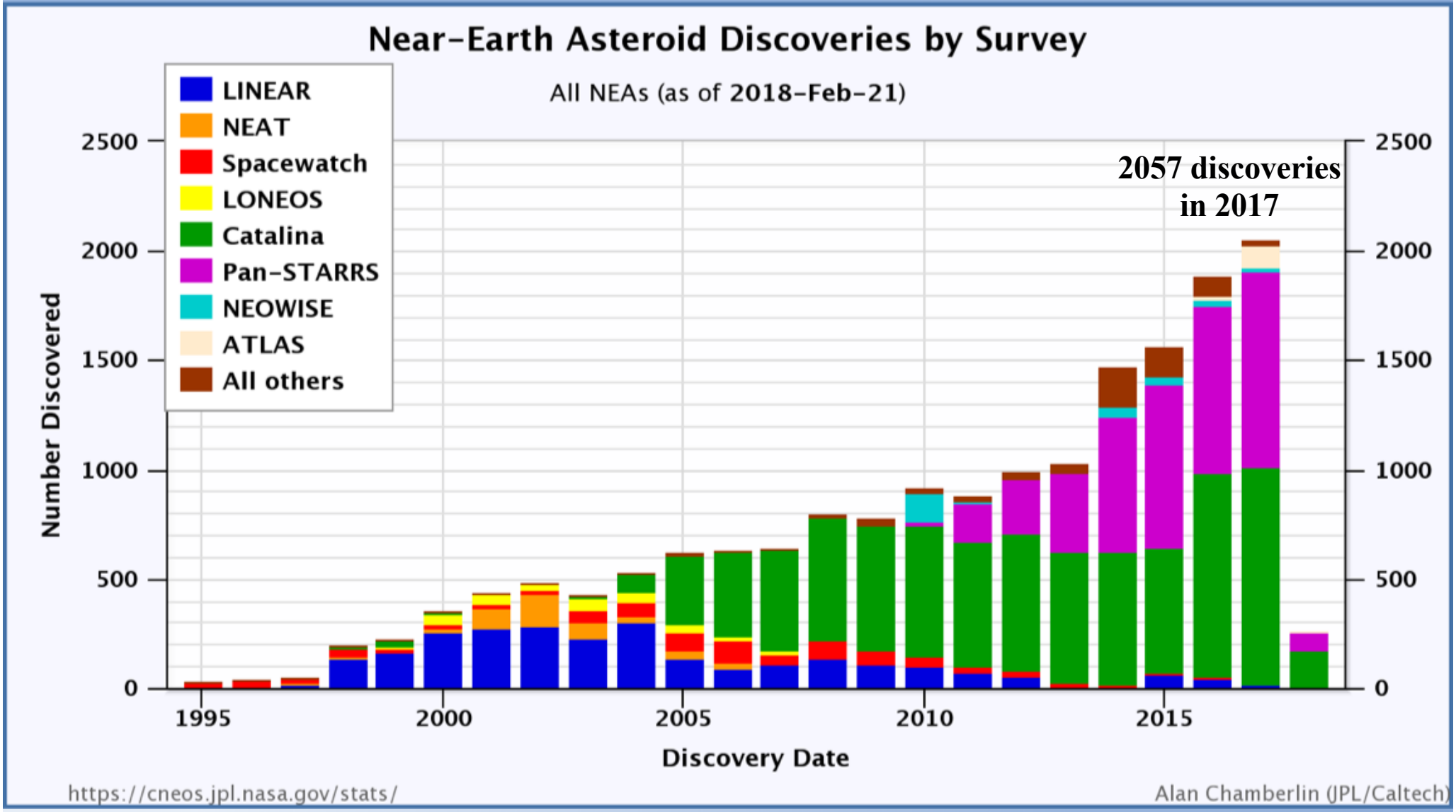
Jet Propulsion Laboratory, California Institute of Technology — CNEOS Center for Near Earth Object Studies

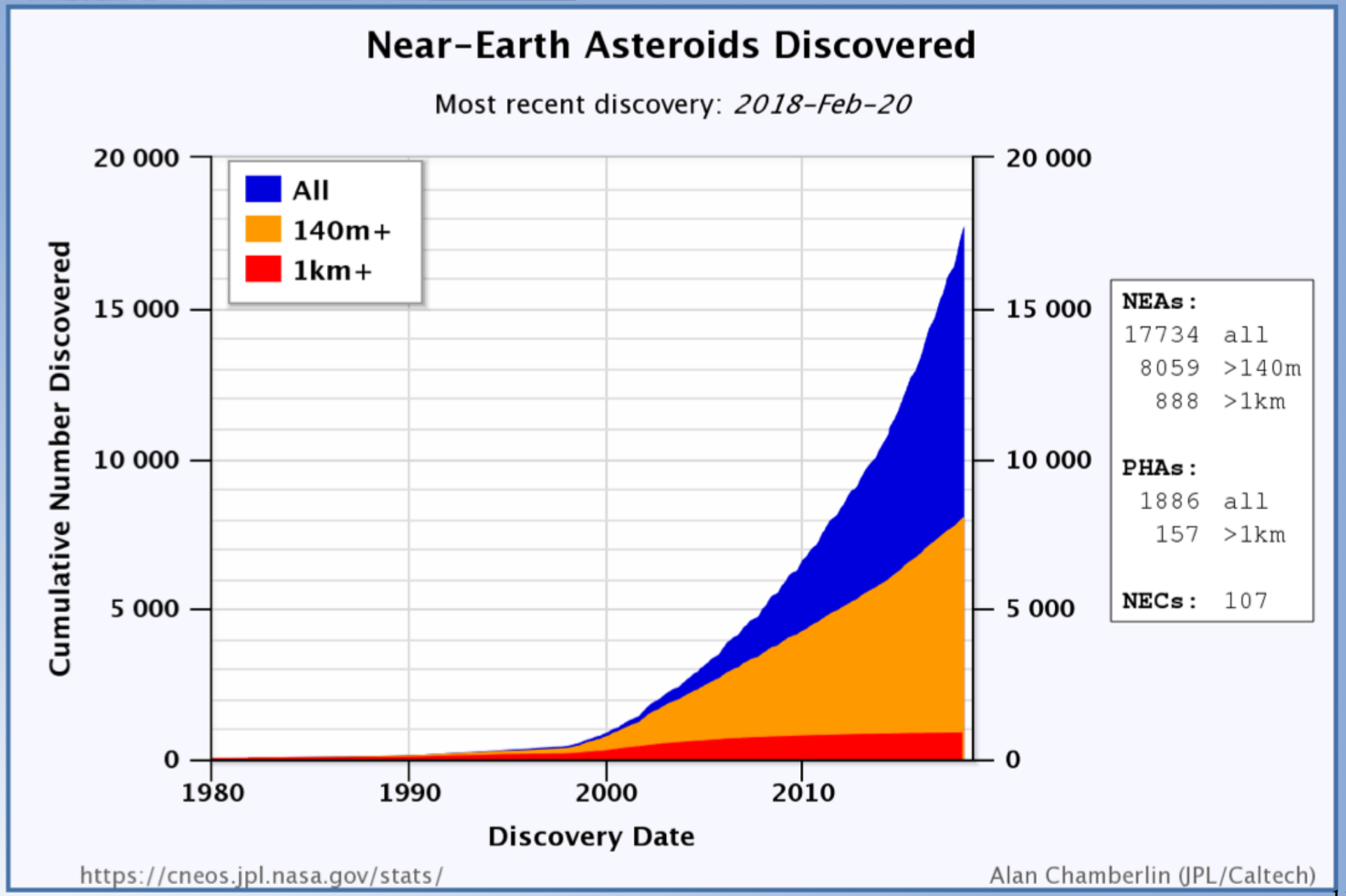
https://cneos.jpl.nasa.gov/

- Computes high-precision orbits of near-Earth objects
- Performs long-term analyses of possible future orbits of hazardous asteroids (Sentry) and computes orbits for new potential asteroid discoveries to determine any impact hazard (Scout)
- Predicts the impact time, location and geometry in the event of a predicted impact

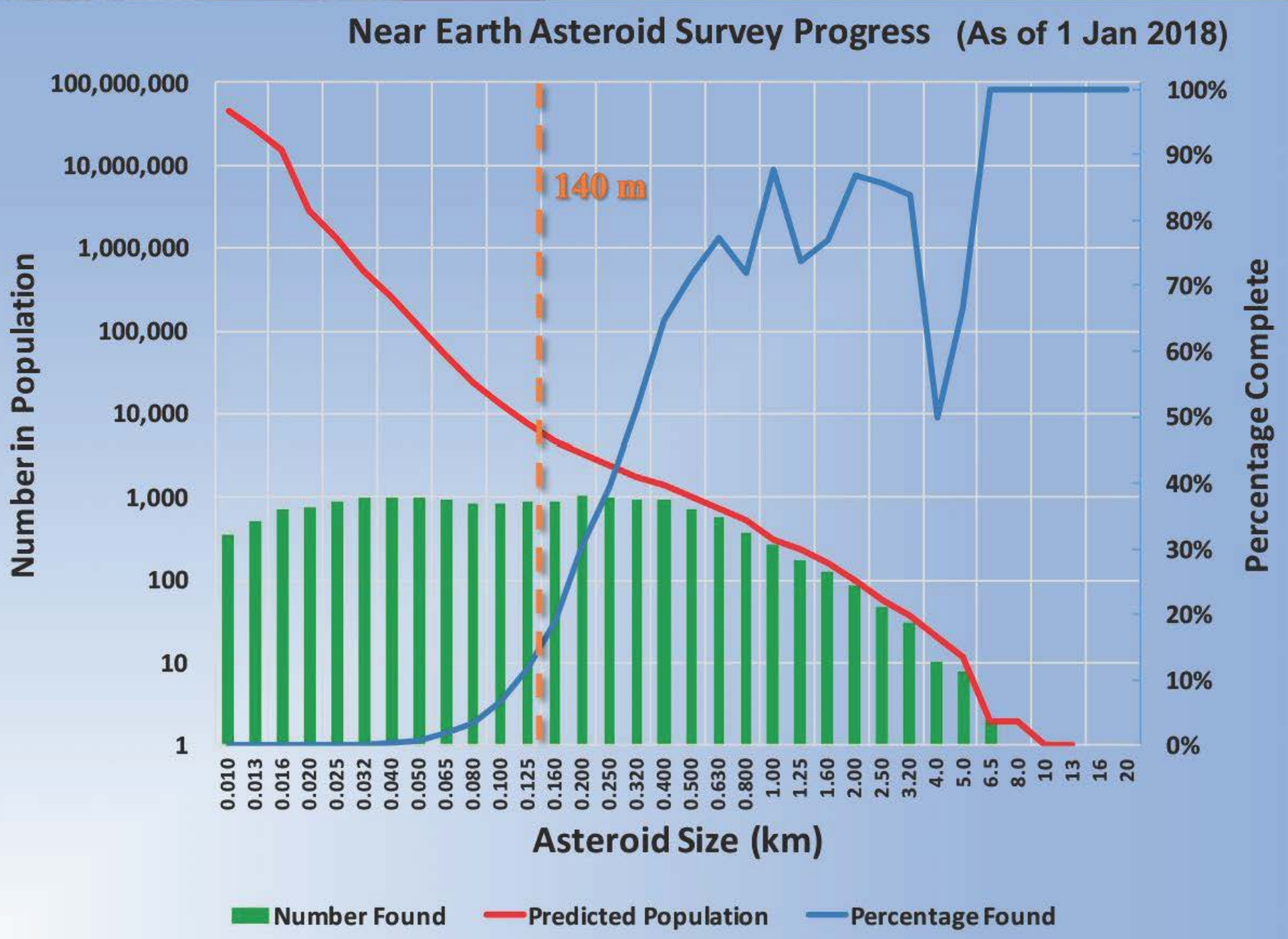

Near-Earth Asteroid Discoveries by Survey
~1km and larger NEAs (as of 2018-Feb-21)
LINEAR
NEAT
Spacewatch
LONEOS
Catalina
Pan-STARRS
NEOWISE
ATLAS
All others
Number Discovered
100
75
50
25
0
1995
2000
2005
2010
2015
Discovery Date
8 discoveries in 2017
https://cneos.jpl.nasa.gov/stats/
Alan Chamberlin (JPL/Caltech)


Near-Earth Asteroid Discoveries by Survey
~140m and larger NEAs (as of 2018-Feb-21)
539 discoveries in 2017
LINEAR
NEAT
Spacewatch
LONEOS
Catalina
Pan-STARRS
NEOWISE
ATLAS
All others
Number Discovered
0
200
400
600
1995
2000
2005
2010
2015
Discovery Date
https://cneos.jpl.nasa.gov/stats/
Alan Chamberlin (JPL/Caltech)


Near-Earth Asteroid Discoveries by Survey
All NEAs (as of 2018-Feb-21)
LINEAR
NEAT
Spacewatch
LONEOS
Catalina
Pan-STARRS
NEOWISE
ATLAS
All others
2057 discoveries in 2017
Number Discovered
0
500
1000
1500
2000
2500
1995
2000
2005
2010
2015
Discovery Date
https://cneos.jpl.nasa.gov/stats/
Alan Chamberlin (JPL/Caltech)

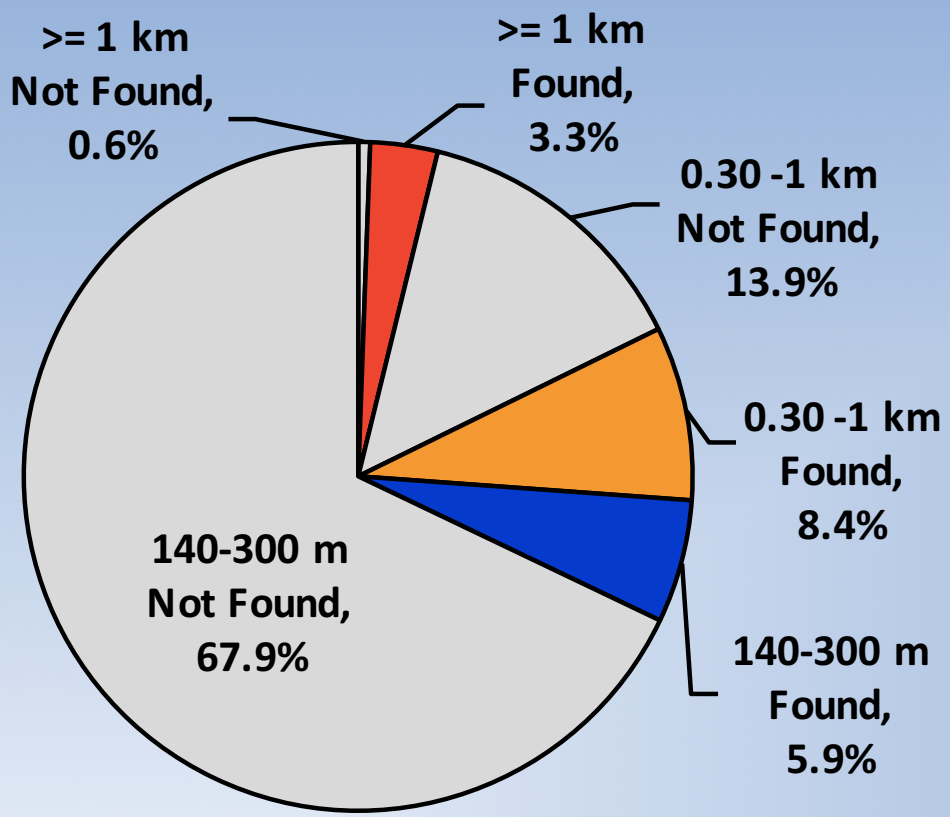


*Potentially Hazardous Asteroids come within 7.5 million km of Earth orbit

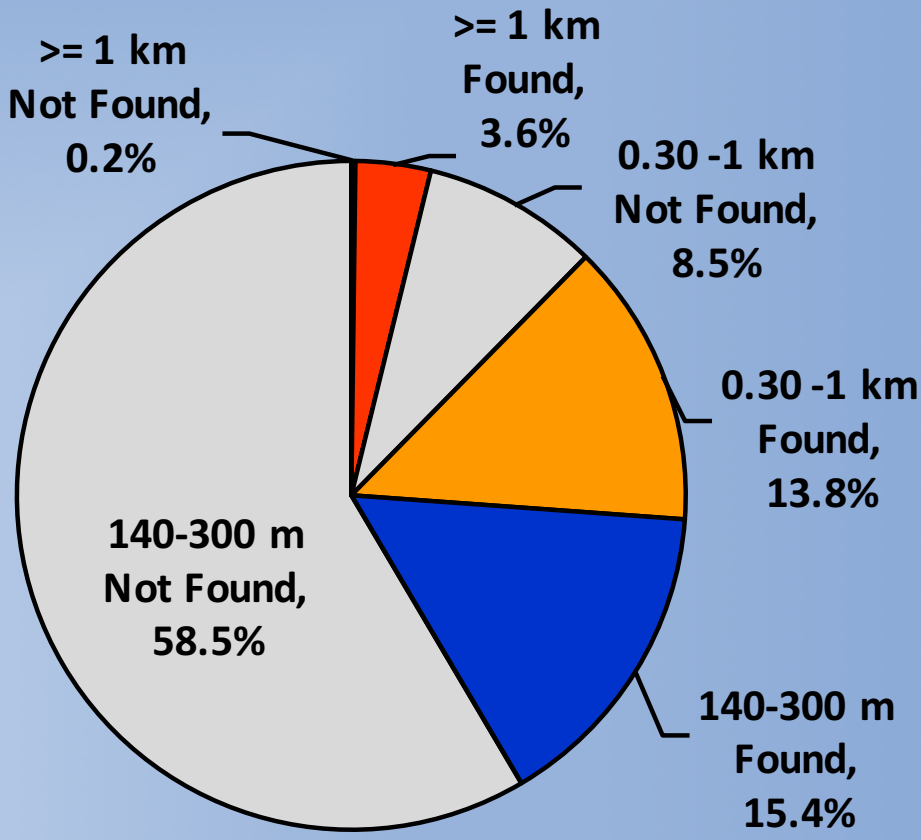

Near Earth Asteroid Survey Progress (As of 1 Jan 2018)
Number in Population
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
Percentage Complete
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
140 m
0.010
0.013
0.016
0.020
0.025
0.032
0.040
0.050
0.065
0.080
0.100
0.125
0.160
0.200
0.250
0.320
0.400
0.500
0.630
0.800
1.00
1.25
1.60
2.00
2.50
3.20
4.0
5.0
6.5
8.0
10
13
16
20
Asteroid Size (km)
Number Found
Predicted Population
Percentage Found

NEO Population - 140 meters and larger

NEO Survey Status Jan 2010



NEO Survey Status Jan 2018



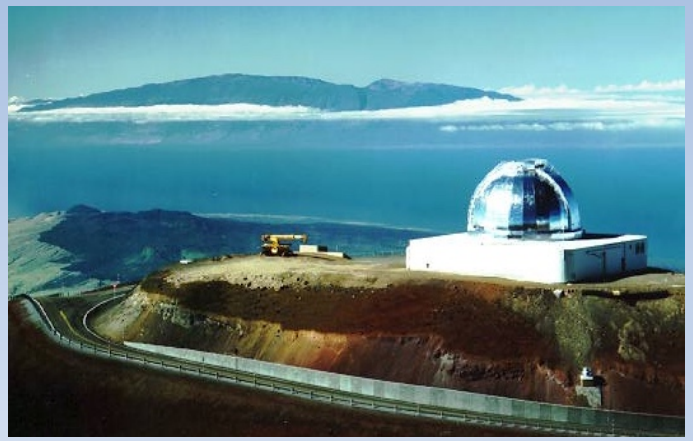
Primary NEO Characterization Assets and Enhancements

Radar (Goldstone and Arecibo)

- Increased time for NEO observations
- Streamlining Rapid Response capabilities
- Increased resolution (~4 meters)
- Improve maintainability


Goldstone Radar


Arecibo Observatory

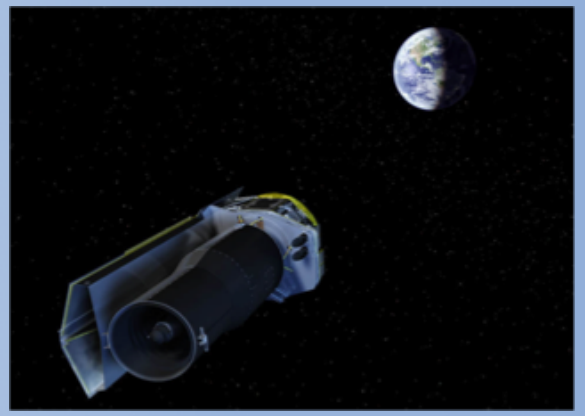


NASA Infrared Telescope Facility (IRTF)

- Increased call-up for Rapid Response
- Improving operability/maintainability
- Improve instrumentation for spectroscopy and thermal signatures

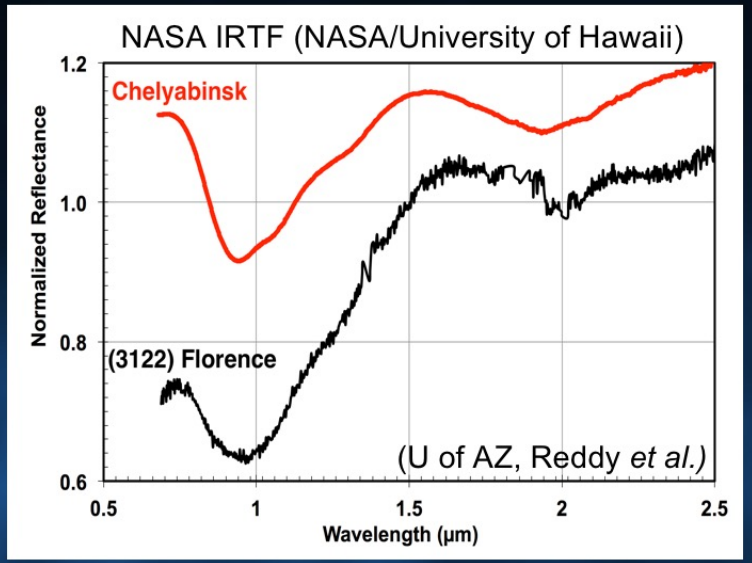
Spitzer Infrared Space Telescope

- Orbit about Sun, ~176 million km trailing Earth
- In extended warm-phase mission
- Characterization of comets and asteroids
- Thermal signatures, albedo/sizes of NEOs
- Longer time needed for scheduling



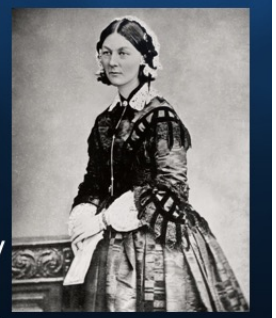
Large Near-Earth Asteroid (3122) Florence Found to be Ordinary Stony Chondrite - With TWO moons!

Radar imagery of Florence, which measures 2.8 miles in diameter, revealed surface features along with two moons orbiting the asteroid and measuring ~300-1000 feet in diameter. Florence is only the third triple asteroid known in the near-Earth population out of more than 16,500 discovered to date.



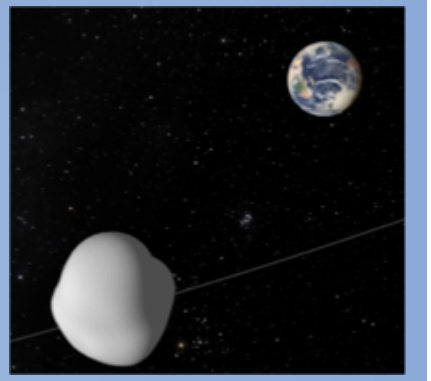
Spectroscopic observations by astronomers operating NASA's Infrared Telescope Facility (IRTF) on Maunakea, Hawaii, indicate that (3122) Florence is an S-type or "stony" asteroid with surface composition similar to ordinary chondrite meteorites, such as the Chelyabinsk meteorite.

Florence passed 4.4 million miles from Earth on September 1, 2017 and was the largest asteroid to make such a close approach since NASA began its Near-Earth Object Observations program in 1998. Florence was discovered in 1981 by astronomer Schelte "Bobby" Bus and named for Florence Nightingale.



Near-Earth Asteroid 2012 TC4 Campaign

Close approach on Oct. 12, 2017 at <8 Earth radii



Goal - Exercise the Planetary Defense system

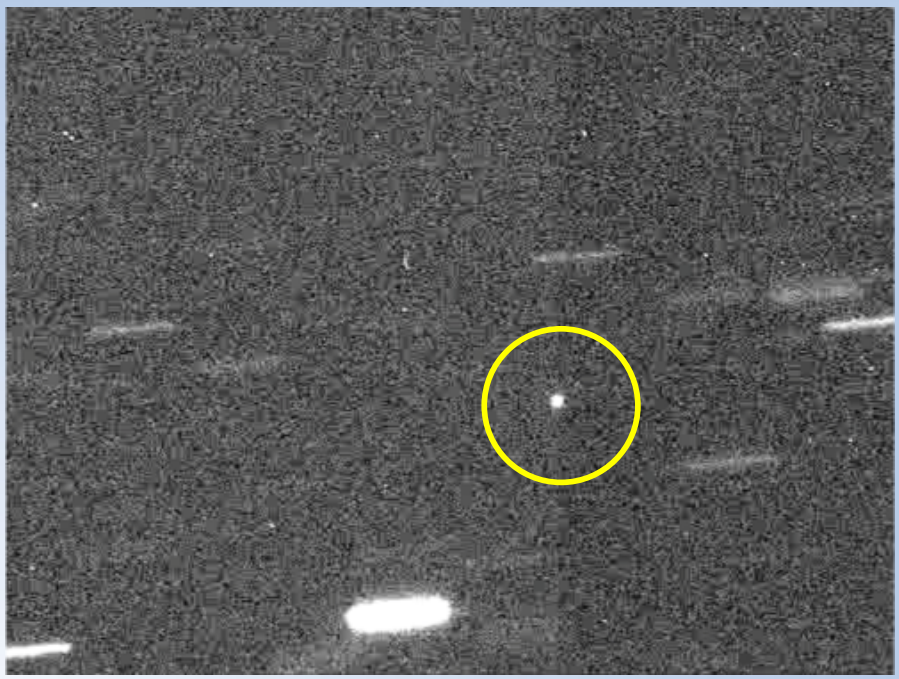
- **Recovery and Follow-up:** Recovery confirmed early August 2017
- **Characterization:** Light curves, photometry, spectroscopy, radar
- **Modeling:** orbit determination, threat assessment and impact modeling exercises
- **Communications:**
  - NASA management, White House, other agencies
  - Within the NEO community and with the public
- **International Asteroid Warning Network (IAWN)** participation

TC4 - Results of Exercise:

- Astronomers from the U.S., Canada, Colombia, Germany, Israel, Italy, Japan, the Netherlands, Russia and South Africa tracked TC4
- Close approach occurred at about 27,200 miles
- Radar observations of 2012 TC4 showed it to be oblong of about 20 x 40 feet (6x12 meters) in size
- Light curve and then radar showed it tumbling with about a 12 minute period
- Precision orbit determination was able to rule out any impact by TC4 for the foreseeable future
- More information: http://2012tc4.astro.umd.edu/

Discovery of the First Interstellar Object

- 1I/2017 U1 (‘Oumuamua)
- Discovered on October, 19 2017 by the Pan-STARRS1 telescope during near-Earth object survey operations
- Speed and trajectory indicate it originated outside of and is not bound to our solar system



- Object is asteroidal in nature (no coma observed)
- Object is highly elongated, with an axis ratio greater than 3:1
- Observations suggest a surface reddened due to irradiation by cosmic rays over its history

3200 Phaethon Close Approach (12/16/17, 26.8 LD)

Arecibo Radar Retweeted

Arecibo Observatory @NAICobservatory · 6 Oct 2017

We are proud to stand strong with our staff and Puerto Rico in the aftermath of Hurricane Maria. #PRSeLevanta

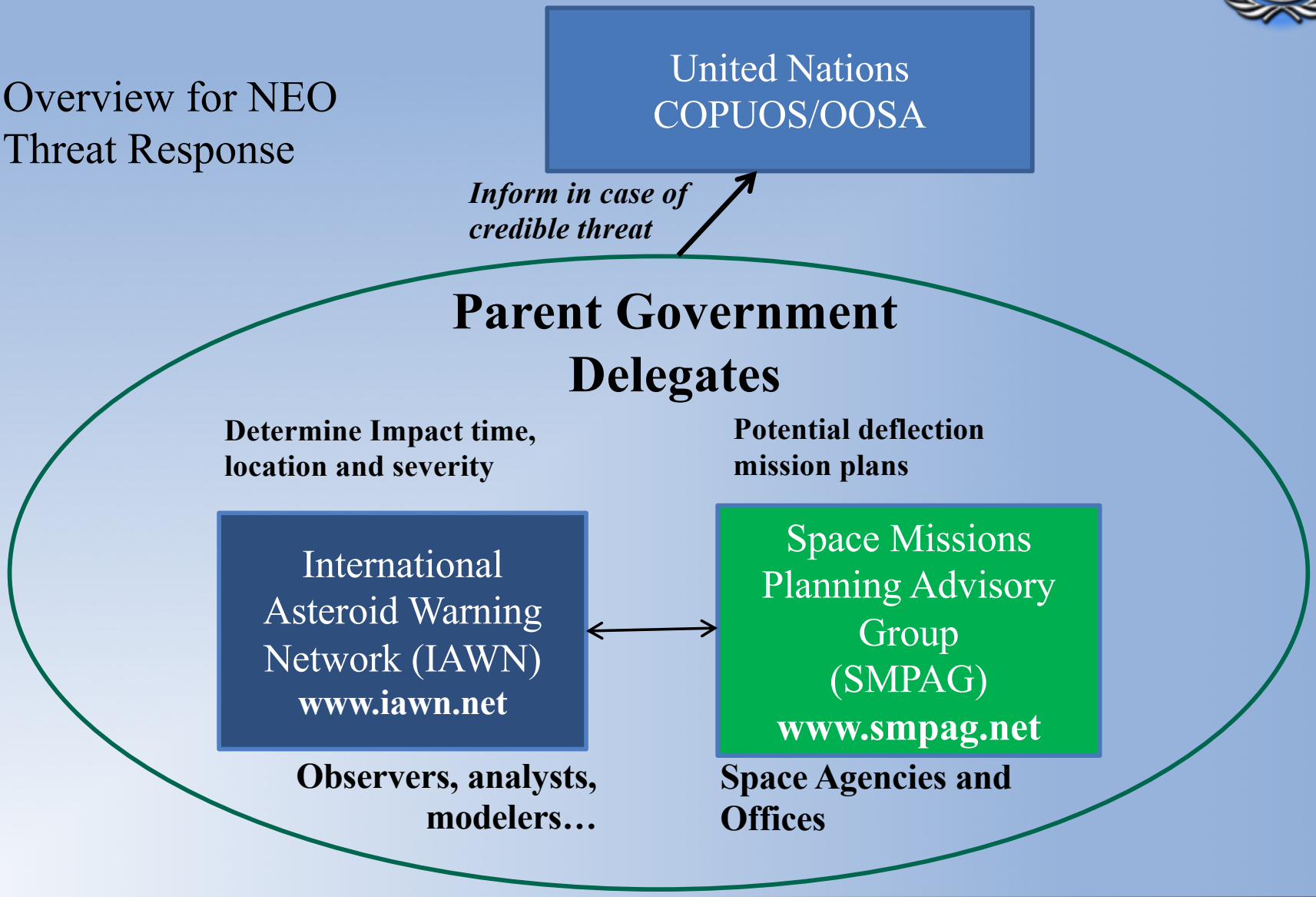
NEO Close Approaches 2017 – 4 < Geosynch

Object	CA Date	CA Distance LD | au	Est. Diameter
2017 AG13	2017-Jan-09 12:50 :	0.54 | 0.00139	16 m - 36 m
2017 BX	2017-Jan-25 04:54 :	0.69 | 0.00178	6.7 m - 15 m
2017 BH30	2017-Jan-30 04:51 :	0.13 | 0.00035	4.6 m - 10 m
2017 BS32	2017-Feb-02 20:24	0.42 | 0.00109	9.2 m - 21 m
2017 DG16	2017-Feb-23 21:08	0.36 | 0.00092	3.7 m - 8.2 m
2017 DR34	2017-Feb-25 04:52	0.58 | 0.00149	3.8 m - 8.6 m
2017 EA	2017-Mar-02 14:05	0.05 | 0.00014	1.8 m - 4.1 m
2017 DS109	2017-Mar-05 14:29	0.92 | 0.00236	17 m - 38 m
2017 FW158	2017-Mar-17 14:10	0.32 | 0.00082	5.6 m - 13 m
2017 FD3	2017-Mar-17 14:28	0.47 | 0.00120	7.5 m - 17 m
2017 FS	2017-Mar-19 03:33	0.28 | 0.00073	4.2 m - 9.4 m
2017 FX158	2017-Mar-20 02:16	0.71 | 0.00182	4.2 m - 9.5 m
2017 FN1	2017-Mar-20 21:02	0.16 | 0.00042	2.0 m - 4.5 m
2017 FM1	2017-Mar-20 22:38	0.33 | 0.00086	3.3 m - 7.4 m
2017 FJ101	2017-Mar-30 07:51	0.85 | 0.00217	5.4 m - 12 m
2017 FU102	2017-Apr-02 20:18	0.57 | 0.00146	4.9 m - 11 m
2017 GM	2017-Apr-04 10:32	0.04 | 0.00011	2.8 m - 6.3 m
2017 HJ	2017-Apr-16 05:43	0.35 | 0.00091	8.6 m - 19 m
2017 HG49	2017-Apr-21 04:34	0.93 | 0.00238	7.9 m - 18 m
2017 HG4	2017-Apr-22 06:24	0.61 | 0.00156	7.9 m - 18 m
2017 HV2	2017-Apr-23 22:04	0.33 | 0.00084	4.4 m - 9.9 m
2017 JA	2017-May-02 07:24	0.26 | 0.00067	4.4 m - 10.0 m
2017 JQ1	2017-May-04 01:16	0.44 | 0.00114	3.6 m - 8.0 m
2017 JB2	2017-May-04 03:18	0.14 | 0.00037	4.1 m - 9.1 m
2017 OO1	2017-Jul-21 03:32 ±	0.33 | 0.00085	33 m - 74 m
2017 QP1	2017-Aug-14 21:23	0.16 | 0.00042	37 m - 83 m
2017 QN2	2017-Aug-20 21:56	0.56 | 0.00145	7.0 m - 16 m
2017 QB35	2017-Sep-03 08:41	0.93 | 0.00238	3.6 m - 8.0 m

Object	CA Date	CA Distance LD | au	Est. Diameter
2017 SQ2	2017-Sep-14 16:14	0.52 | 0.00133	18 m - 40 m
2017 SM2	2017-Sep-20 07:34	0.81 | 0.00207	9.0 m - 20 m
2017 SZ32	2017-Sep-20 15:49	0.53 | 0.00137	3.8 m - 8.5 m
2017 SR2	2017-Sep-20 20:29	0.24 | 0.00062	5.0 m - 11 m
2017 SU17	2017-Sep-24 08:12	0.72 | 0.00185	6.6 m - 15 m
2017 SS12	2017-Sep-24 15:32	0.67 | 0.00172	9.9 m - 22 m
2017 TQ2	2017-Sep-30 12:16	0.27 | 0.00069	3.5 m - 7.9 m
2017 SX17	2017-Oct-02 10:20	0.23 | 0.00058	6.3 m - 14 m
2017 TF5	2017-Oct-10 07:40	0.73 | 0.00188	31 m - 68 m
2012 TC4	2017-Oct-12 05:42	0.13 | 0.00034	12 m - 27 m
2017 UF	2017-Oct-15 03:23	0.99 | 0.00255	7.1 m - 16 m
2017 TH5	2017-Oct-16 17:16	0.26 | 0.00067	6.1 m - 14 m
2017 UR2	2017-Oct-17 16:32	0.83 | 0.00213	7.5 m - 17 m
2017 TD6	2017-Oct-19 18:53	0.50 | 0.00128	9.8 m - 22 m
2017 UJ2	2017-Oct-20 14:07	0.05 | 0.00012	1.8 m - 4.0 m
2017 UA52	2017-Oct-21 06:25	0.51 | 0.00132	5.3 m - 12 m
2017 UL6	2017-Oct-28 11:24	0.16 | 0.00040	1.0 m - 2.3 m
2017 UK8	2017-Oct-30 05:18	0.59 | 0.00151	5.9 m - 13 m
2017 VE	2017-Nov-04 05:13	0.88 | 0.00227	13 m - 28 m
2017 VL2	2017-Nov-09 09:50	0.31 | 0.00079	16 m - 36 m
2017 VF14	2017-Nov-13 15:30	0.80 | 0.00204	5.4 m - 12 m
2017 WW1	2017-Nov-21 19:18	0.37 | 0.00094	3.0 m - 6.8 m
2017 WA14	2017-Nov-21 19:53	0.25 | 0.00063	8.4 m - 19 m
2017 WE30	2017-Nov-26 17:55	0.08 | 0.00020	1.1 m - 2.5 m
2017 YZ4	2017-Dec-28 15:50	0.58 | 0.00149	6.0 m - 13 m
2017 YE7	2017-Dec-30 17:47	0.80 | 0.00206	5.2 m - 12 m
2018 AH	2018-Jan-02 04:25 :	0.77 | 0.00199	85 m - 190 m

UN Office of Outer Space Affairs
Committee on Peaceful Uses of Outer Space

Overview for NEO Threat Response



Worldwide Observing Network

Received ~22 million observations (~ 201,000 on NEOs) from 47 countries in 2017 (and one in space!)

IAWN Report, Feb 2018

Decision Thresholds: IAWN<->SMPAG

IAWN/SMPAG: Criteria/Thresholds for Impact Response Actions

- IAWN shall warn of predicted **impacts exceeding a probability of 1%** for all objects characterized to be **greater than 10 meters in size**, or roughly equivalent to **absolute magnitude of 28** if only brightness data can be collected.

- Terrestrial preparedness planning should begin when warned of a possible impact:
  - Predicted to be **within 20 years**,
  - Probability of impact is assessed to be **greater than 10%**, and
  - Object is characterized to be **greater than 20 meters in size**, or roughly equivalent to **absolute magnitude of 27** if only brightness data can be collected

- SMPAG should start mission option(s) planning when warned of a possible impact:
  - Predicted to be **within 50 years**,
  - Probability is assessed to be **greater than 1%**, and
  - Object is characterized to be **greater than 50 meters in size**, or roughly equivalent to **absolute magnitude of 26** if only brightness data can be collected.

Planetary Impact Emergency Response Working Group (PIERWG)

Established by the partnership of the Federal Emergency Management Agency (FEMA) and National Aeronautics and Space Administration (NASA) to:

- Develop guidance to prepare for any potential impact of our planet by a large natural object, and
- Coordinate responsibilities and resolve preparedness and operational issues relating to interagency response and recovery activities at the national level.
- ***The PIERWG provides a forum for developing the essential information and recommendations needed by senior leadership to make informed decisions to respond to the unique challenges of an impending near-Earth object impact.***

PIERWG: Goals and Objectives

Primary Objectives are to:

- Promote cohesiveness in planning, organization, equipment, training, exercises, and operations to facilitate interagency response, recovery, and preparedness.
- Identify policy issues affecting the interagency community to elevate to decision-makers in order to ensure a collaborative and coordinated approach.
- Serve as a steering committee for all phases of interagency risk and planning analysis, including informing strategy, procedural courses of action, draft products, and approving completed products.
- Determine how PIERWG recommendations could be integrated into Department/Agency planning initiatives and doctrine.

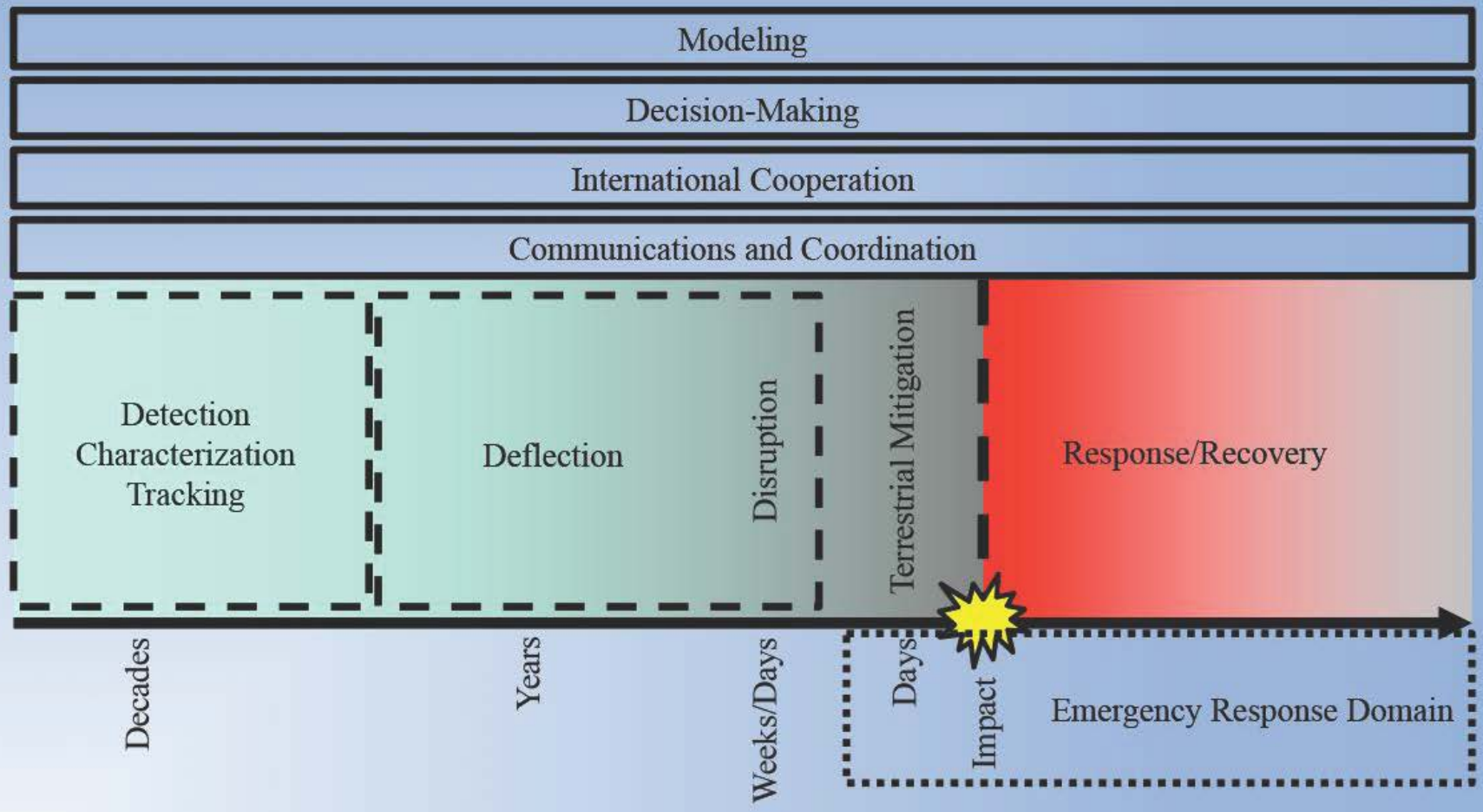
Detecting And Mitigating the Impacts of Earth-bound Near-Earth Objects (DAMIEN) Interagency Working Group (IWG)

- Purpose: to serve as an interagency body to define, coordinate, and oversee goals and programmatic priorities of Federal science and technology activities related to potentially hazardous or Earth-impacting NEOs, including prediction and National Preparedness capabilities.
- Scope: will provide NEO Earth-impact response and recovery input into the National Planning Framework, called for by the Presidential Policy Directive 8 (PPD-8): *National Preparedness* (2011) and National critical infrastructure resilience initiatives outlined in PPD-21: *Critical Infrastructure Security and Resilience* (2013).

DAMIEN IWG: Membership

- Department of Commerce (NOAA)
- Department of Defense (USAF, USSTRATCOM, AFSPC)
- Department of Energy (NNSA)
- Department of Homeland Security (FEMA)
- Department of the Interior (USGS)
- Department of State (OES)
- NASA Planetary Defense Coordination Office (PDCO) (Co-Chair)
- National Science Foundation (AST)
- National Security Council
- Office of the Director of National Intelligence
- Office of Management and Budget
- Office of Science and Technology Policy (Co-chair)

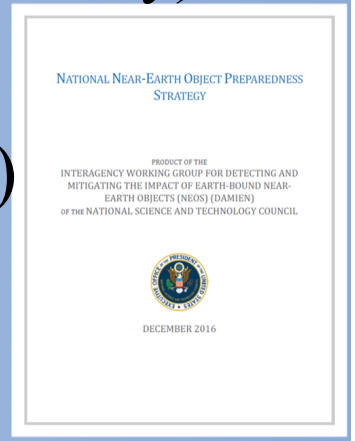
Planetary Defense Timeline*



* From National NEO Preparedness Strategy, 30 December 2016

DAMIEN: Goals

- Develop a National NEO Preparedness Strategy (NNPS)
  - Articulate goals for extending and enhancing prediction (detection, characterization and monitoring) and National Preparedness (protection, mitigation, response and recovery) for potentially hazardous or Earth-impacting NEOs.
- Develop a NEO Preparedness Action Plan (NPAP)
  - Establish actions, timelines, and milestones for the implementation of the NNPS.
- Develop metrics to measure progress of the plan annually, or as needed.


National Near-Earth Object Preparedness Strategy

Product of the
Interagency Working Group for Detecting and Mitigating the Impact of Earth-Bound Near-Earth Objects (NEOs) (DAMIEN)
of the National Science and Technology Council

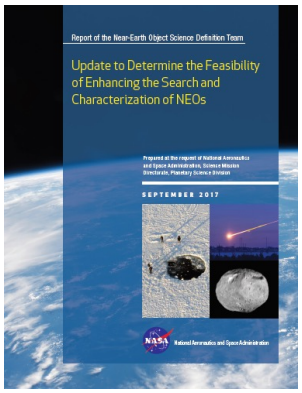
December 2016

The National NEO Preparedness Action Plan

- Statements from the *Strategy* about the *Action Plan*:
  - Foster a collaborative effort in which the Nation can better understand, prevent, and prepare for the effects of a NEO impact
  - Identify goals and activities to enhance the understanding of risk from, and national preparedness for, NEO impacts
  - The Action Plan… details the Federal activities that will be undertaken to implement this Strategy and achieve the seven high-level goals, and includes deliverables, timelines, and metrics to measure progress and success
  - The EOP will coordinate the development and execution of the Action Plan and will reevaluate the Strategy and Action Plan within three years of the date of publication respectively, or as needed
  - The goals and associated objectives "support a collaborative and Federally-coordinated approach to developing effective policies, practices, and procedures for decreasing the Nation's vulnerabilities associated with the NEO impact hazard."

NEO Survey Science Definition Team Report*

Finding 3

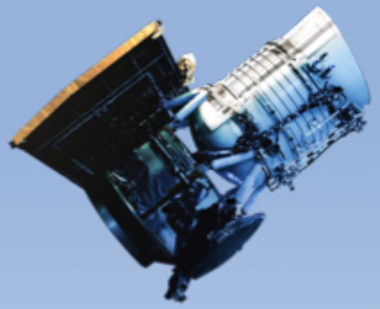


- Satisfaction of the 140 meter cataloguing objective will require space-based search systems
  - IR and/or visible sensors in the 0.5-1.0 meter diameter range are credible, cost benefit favorable, options using available technology
  - Best cost/benefit and lowest risk space system options located at L1*
  - Fastest completion of 140 m objective and best warning provided by large aperture IR or combined visible and IR systems located at L1
  - Search systems located near-Earth have substantial warning benefit
- The addition of a single 4-meter ground-based search system aids completion timeline for any of the space-based options

*** IR systems in GEO (ex 20cm) and LEO not assessed**

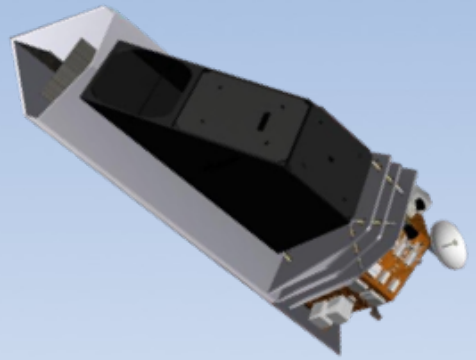
*https://www.nasa.gov/sites/default/files/atoms/files/2017_neo_sdt_final_e-version.pdf

PDCO Flight Mission Projects



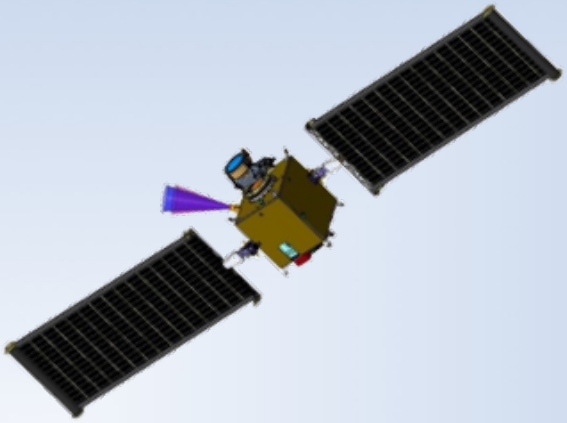
NEOWISE

- Continues in extended NEO survey operations



NEOCam: Near-Earth Object Camera

- Infrared survey telescope optimized for meeting congressional mandate to find and characterize NEOs down to 140 meters in size
- Continues in extended Phase A
- SRR/MDR 27-28 February



DART: Double Asteroid Redirection Test

- Demonstration of kinetic impactor technique
- Target - Moon of 65803 Didymos
- Launch 2020, impact 2022
- Continues in Phase B
- Mission-level PDR 10-12 April