Planetary Defense Coordination Office

NASA--LSST Near--Earth Object Collaboration

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Planetary Defense Coordination Office

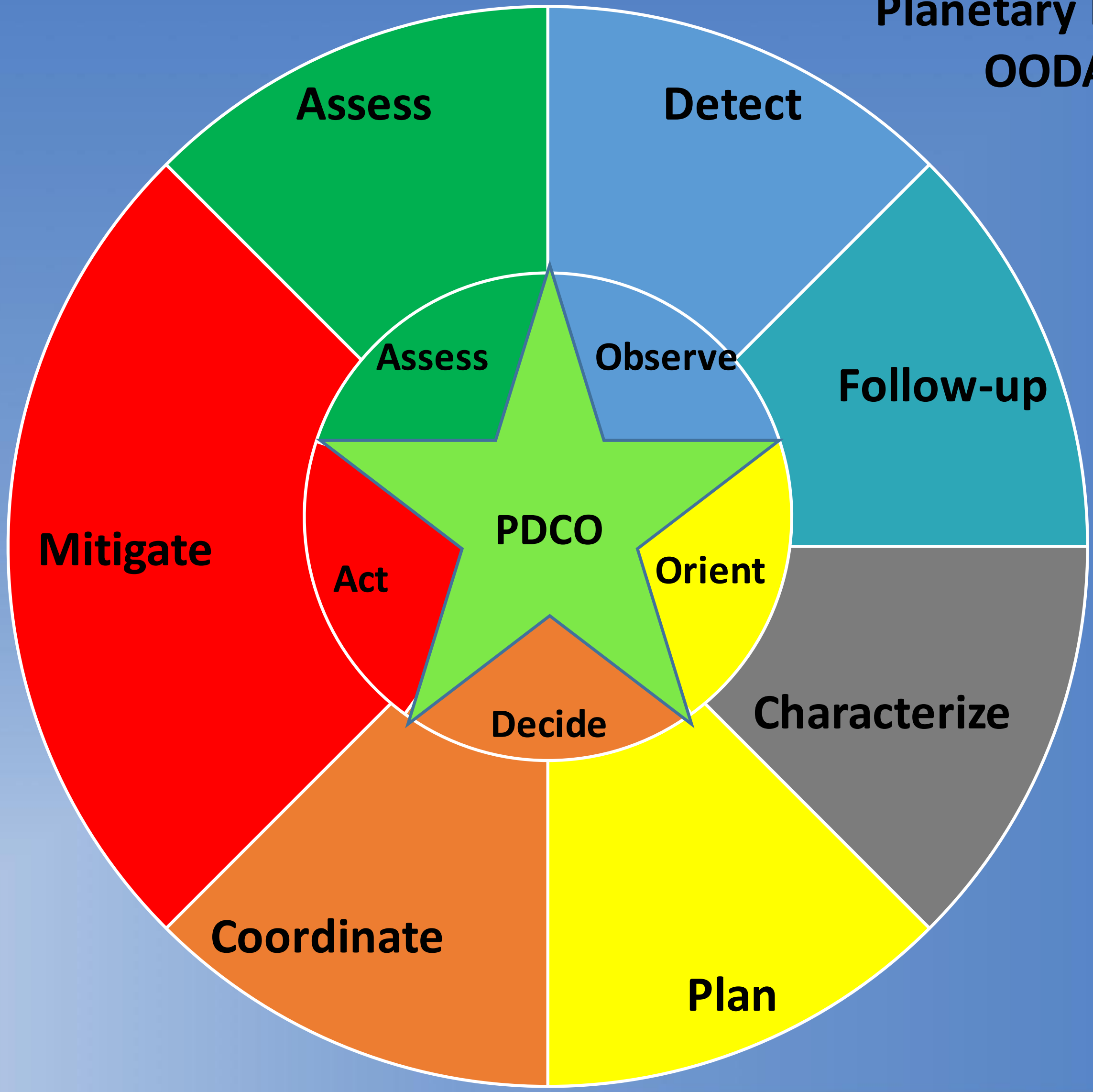
This office was established in January 2016 at NASA HQ to oversee planetary defense related activities across NASA, and coordinate both US interagency and international efforts and projects to address and plan response to the asteroid impact hazard.

Mission Statement:

Lead national and international efforts to:

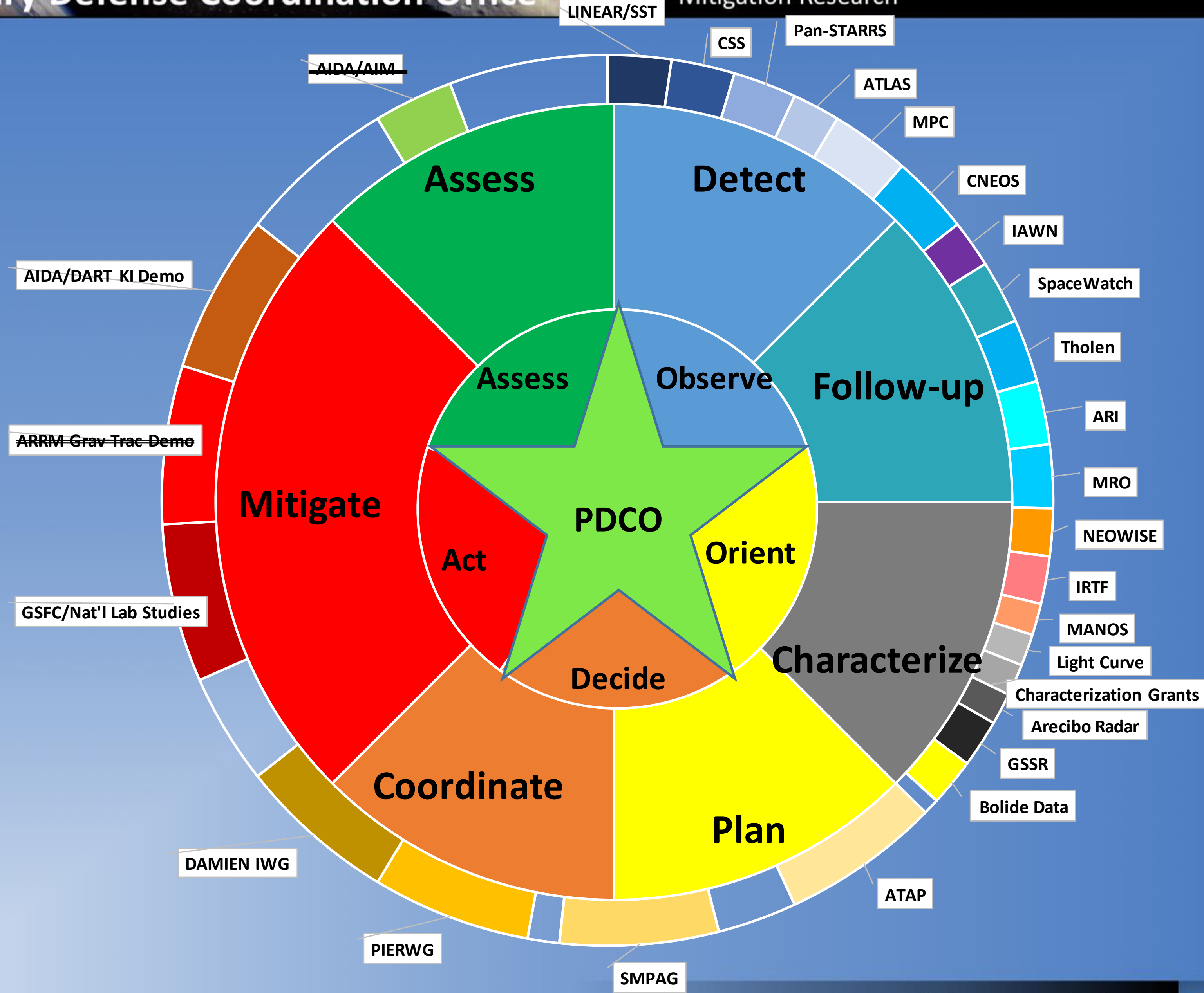
- Detect any potential for significant impact of planet Earth by natural objects
- Appraise the range of potential effects by any possible impact
- Develop strategies to mitigate impact effects on human welfare

Planetary Defense OODAA Loop



Planetary Defense Coordination Office

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



Terminology

- "Near Earth Objects (NEOs)"- any small body (comet or asteroid) passing within 1.3 astronomical unit (au) of the Sun
  - 1 au is the distance from Earth to Sun = ~ 93 million miles
  - NEOs are predicted to pass within ~ 30 million miles of Earth's orbit
  - e.g. any small body passing between orbits of Venus to Mars
  - Population of:
    - Near Earth Asteroids (NEAs)
    - Near Earth Comets (NECs) – also called Earth Approaching Comets (EACs)
      - 107 currently known
- "Potentially Hazardous Objects (PHOs)" – any small body that has potential to impact Earth at some point in the future
  - NEOs passing within 0.05 au of Earth's orbit
    - ~ 5 million miles = 20 times the distance to the Moon
  - Appears to be about 10% of all NEOs discovered

NEO Observations Program

Detection and tracking of natural objects – asteroids and comets – that approach within 28 million miles of Earth's orbit

US component to International Asteroid Warning Network

Has provided 98% of new detections of NEOs since 1998

Began with NASA commitment to House Committee on Science in May 1998 to find at least 90% of 1 km and larger NEOs

- That goal reached by end of 2010

NASA Authorization Act of 2005 increased scope of objectives:

- Amended National Aeronautics and Space Act of 1958 ("NASA Charter") to add:

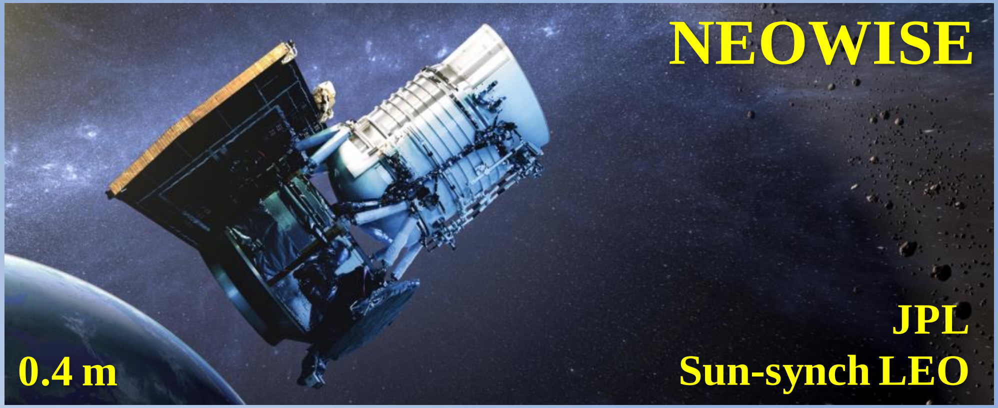
  ''The Congress declares that the general welfare and security of the United States require that the unique competence of the National Aeronautics and Space Administration be directed to detecting, tracking, cataloguing, and characterizing near-Earth asteroids and comets in order to provide warning and mitigation of the potential hazard of such near-Earth objects to the Earth.''

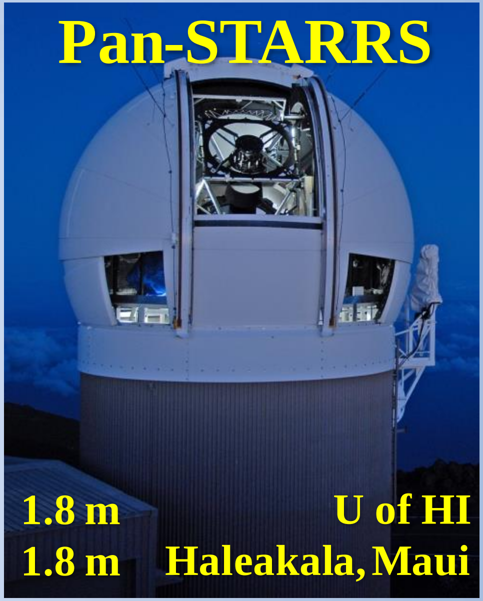
- Made NEO detection, tracking and research 1 of 7 explicitly stated purposes of NASA!
- Provided additional direction:

  "…plan, develop, and implement a Near-Earth Object Survey program to detect, track, catalogue, and characterize the physical characteristics of near-Earth objects equal to or greater than 140 meters in diameter in order to assess the threat of such near-Earth objects to the Earth. It shall be the goal of the Survey program to achieve 90 percent completion of its near-Earth object catalogue within 15 years [by 2020]"

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**

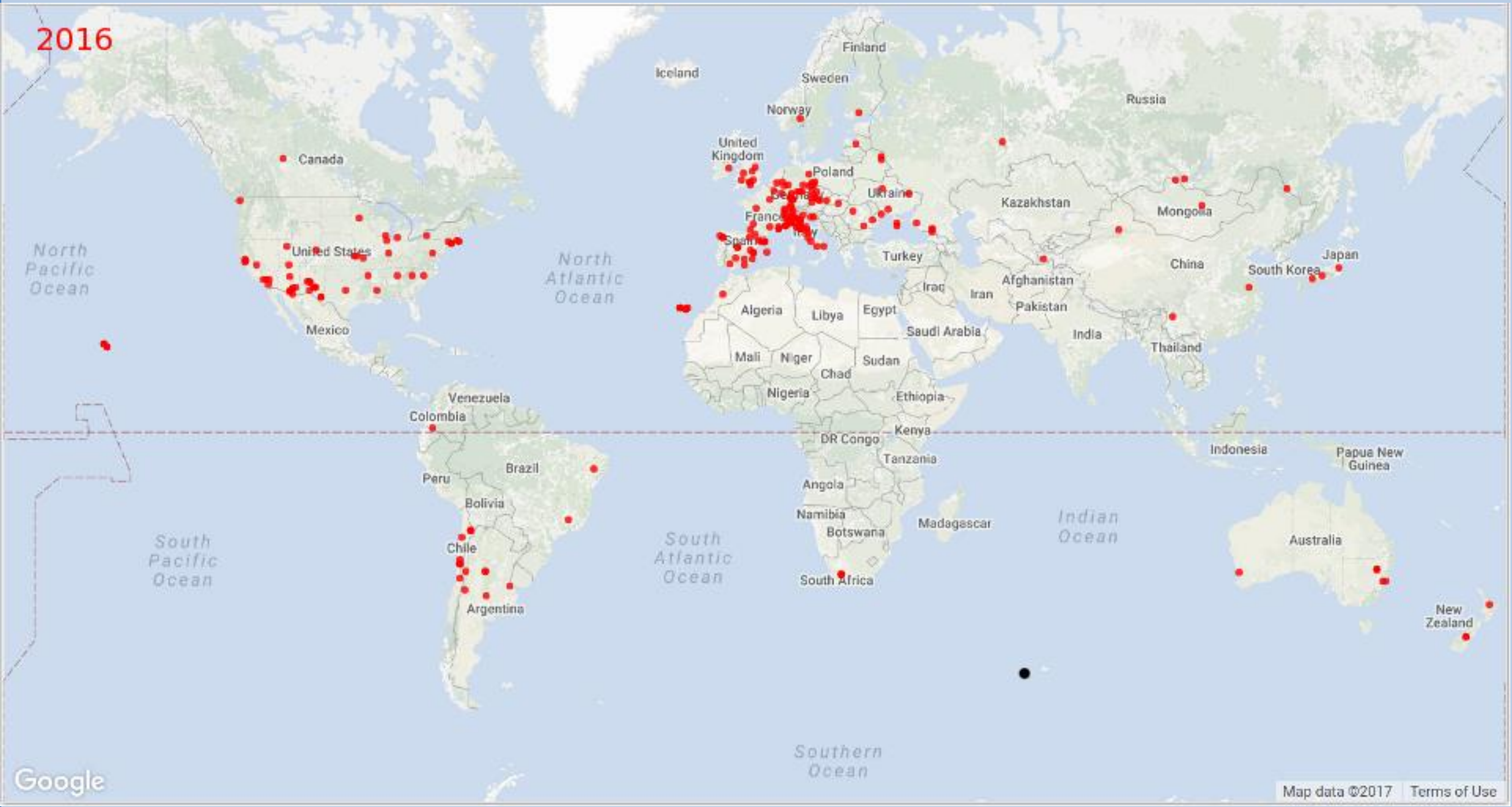
Jet Propulsion Laboratory
California Institute of Technology

cneos
Center for Near Earth Object Studies
https://cneos.jpl.nasa.gov/

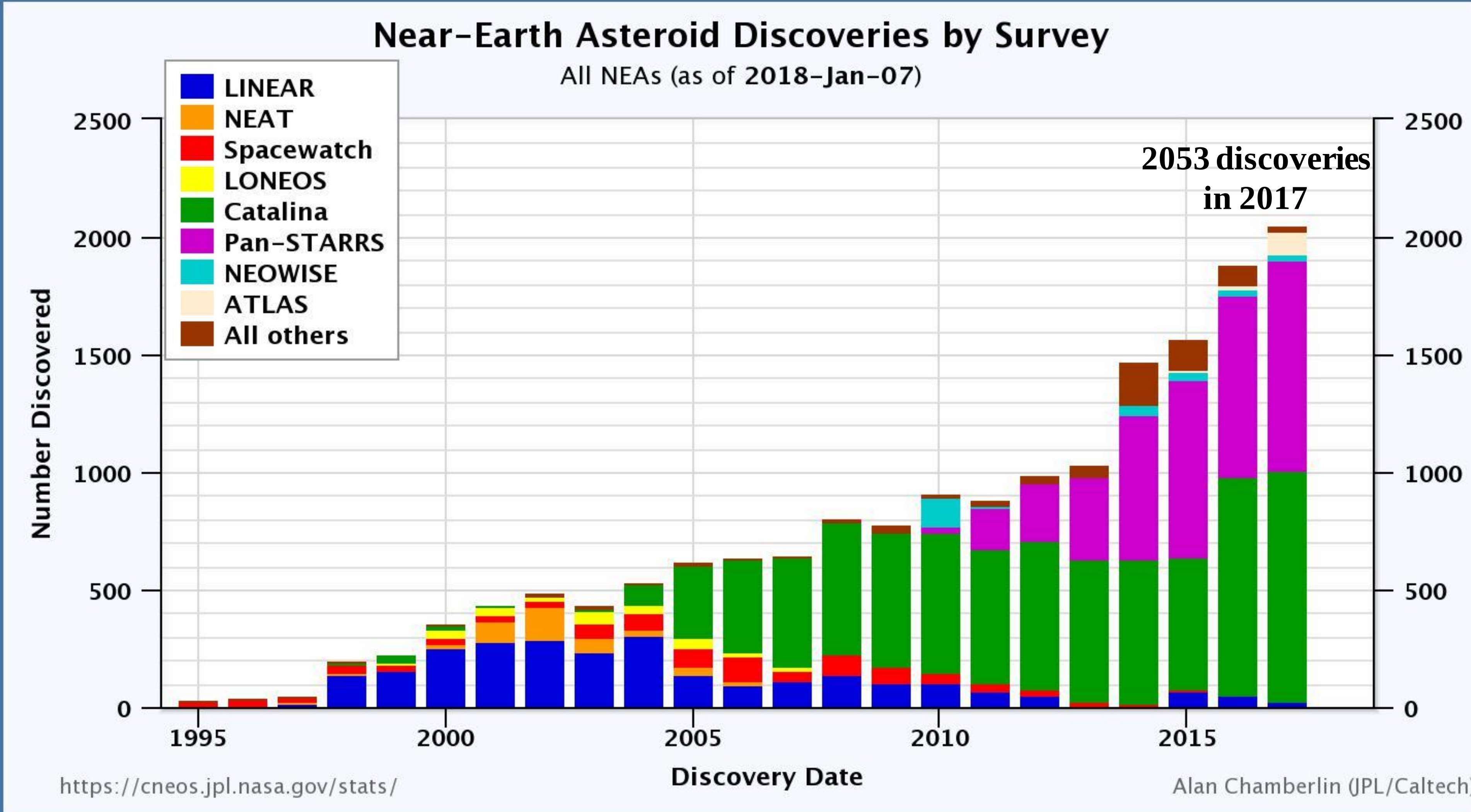
- Computes high-precision orbits of near-Earth objects
- Performs long-term analyses of possible future orbits of hazardous asteroids (Sentry) and computes orbits for new potential asteroid discoveries to determine any impact hazard (Scout)
- Predicts the impact time, location and geometry of any predicted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

https://www.youtube.com/watch?v=53Js-_vo3mo

International Asteroid Warning Network

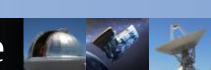


Received ~18.6 million observations (1.7 million on NEOs) from 76 countries in 2016 (and one in space!)


Near-Earth Asteroid Discoveries by Survey
All NEAs (as of 2018-Jan-07)
LINEAR
NEAT
Spacewatch
LONEOS
Catalina
Pan-STARRS
NEOWISE
ATLAS
All others
2053 discoveries in 2017
Number Discovered
Discovery Date
0
500
1000
1500
2000
2500
1995
2000
2005
2010
2015
https://cneos.jpl.nasa.gov/stats/
Alan Chamberlin (JPL/Caltech)

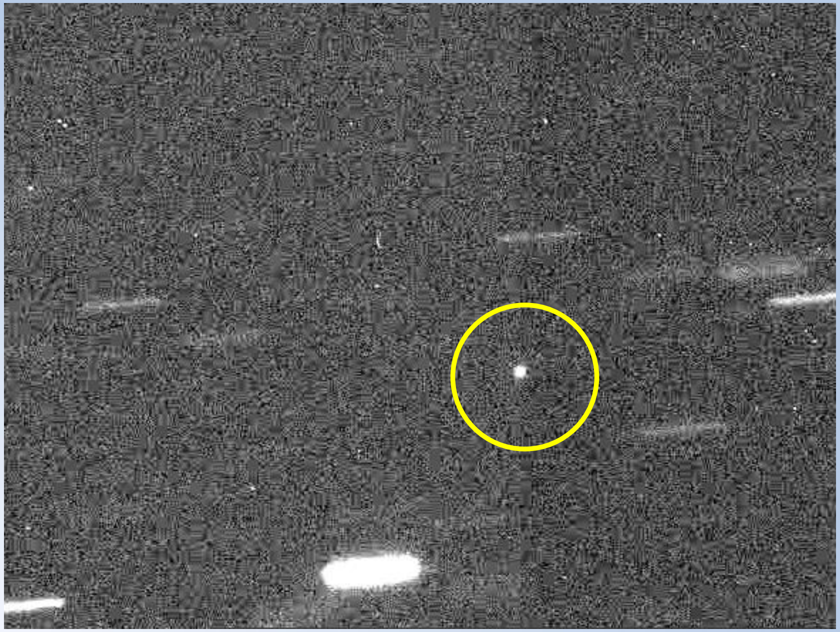
NEO Close Approaches 2017 – 4 < Geosynch

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
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

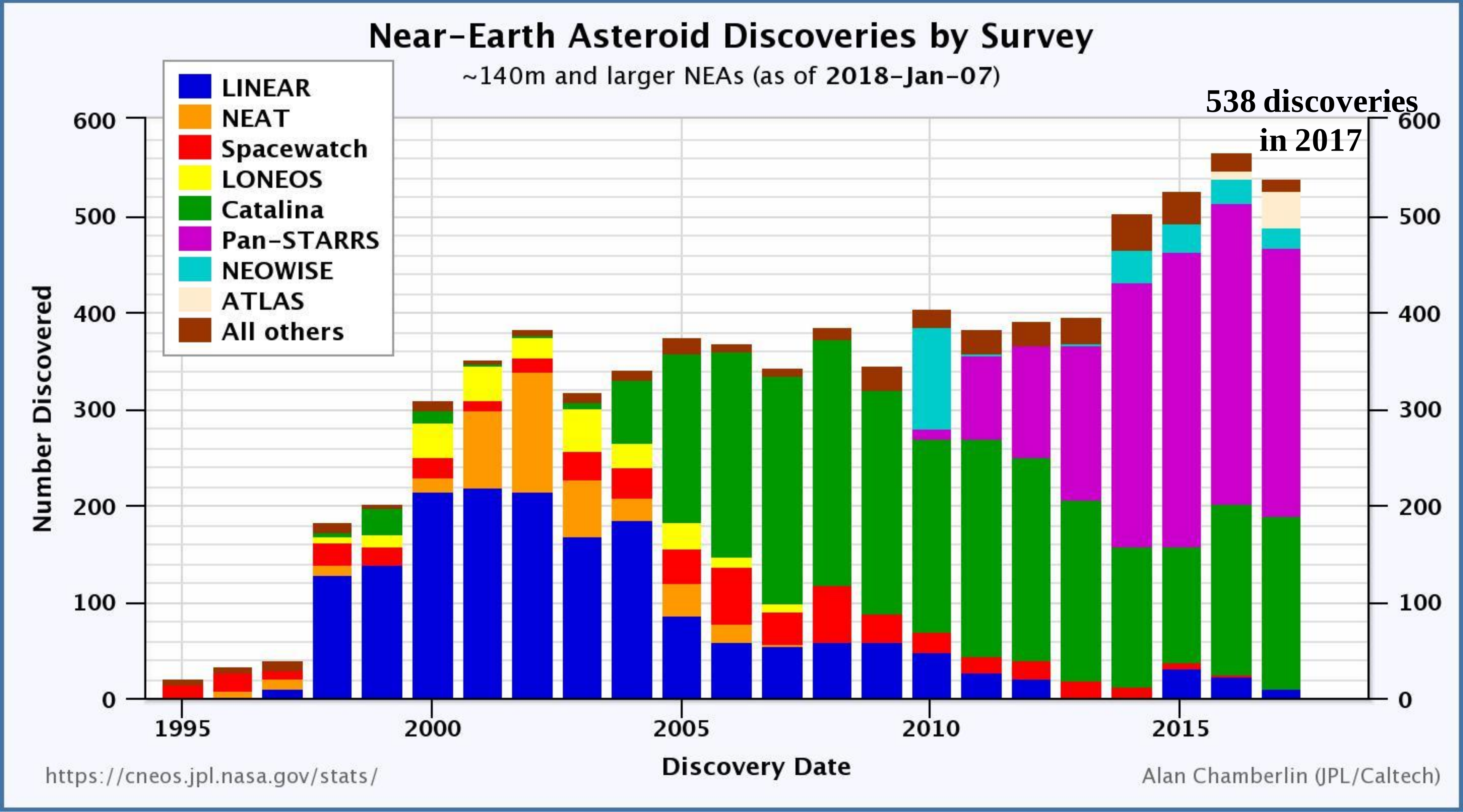


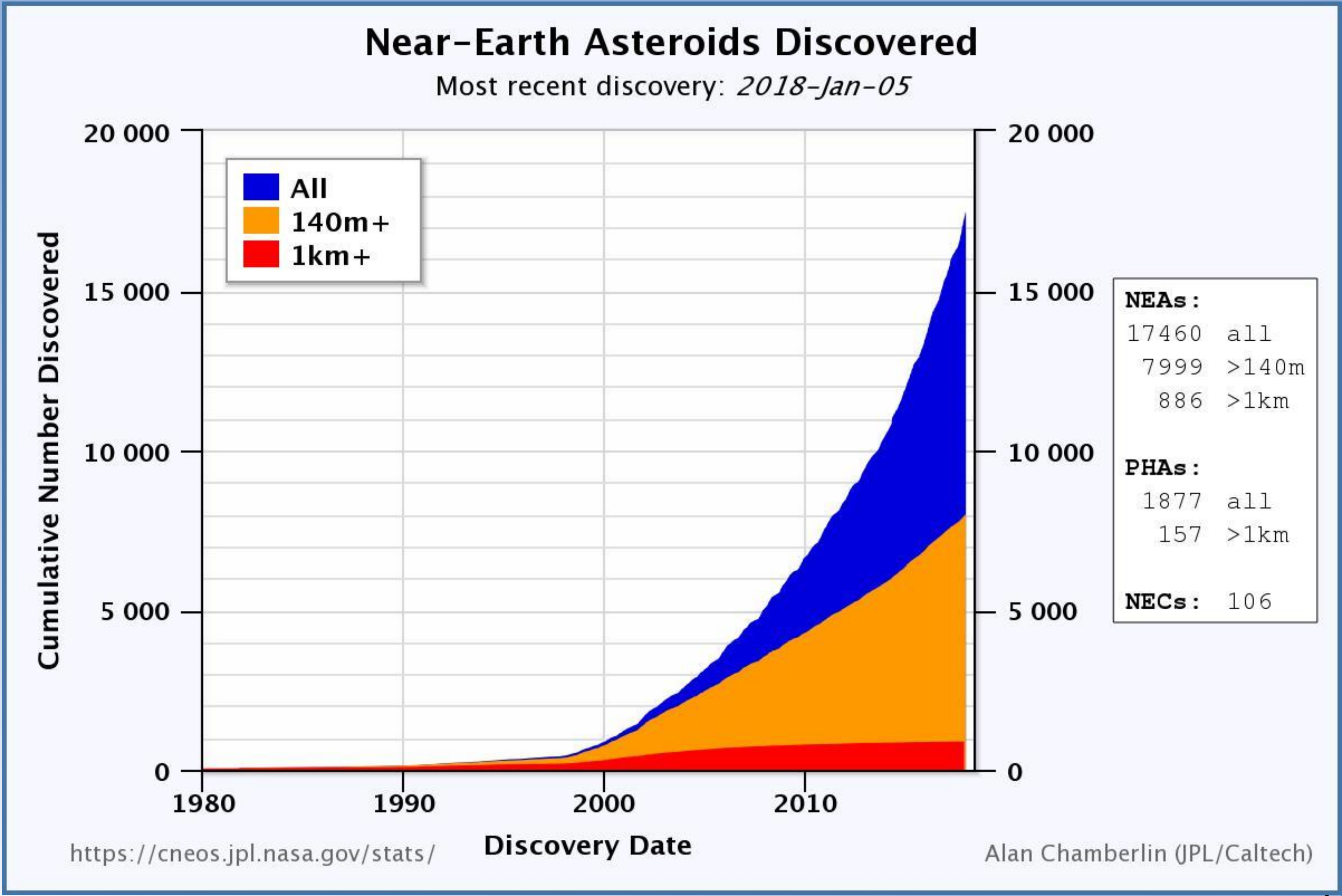
Discovery of the First Interstellar Object

- 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

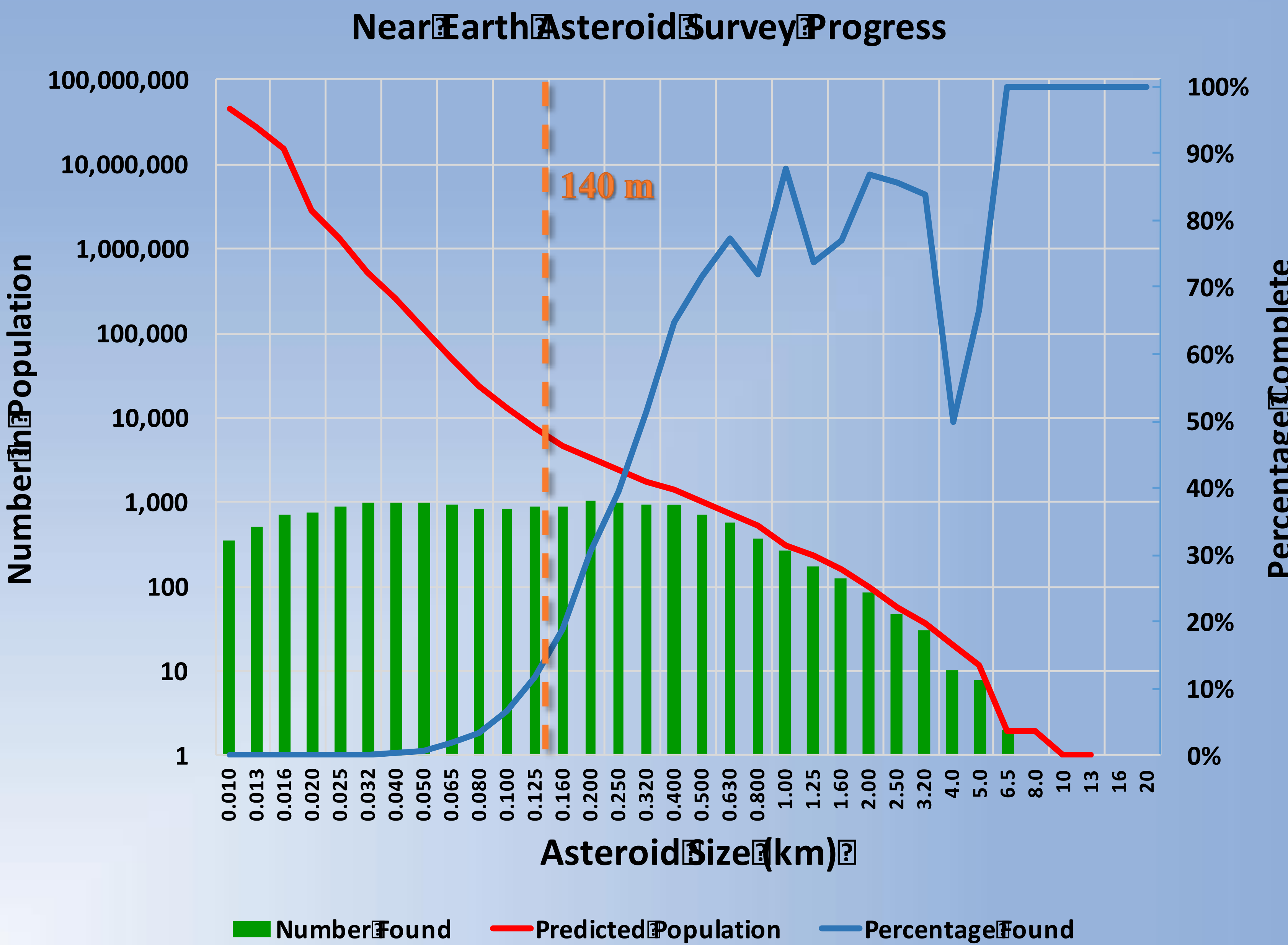


- Object is asteroidal in nature (no coma observed)
- Object is highly elongated, with an axis ratio >3:1 perhaps 10:1
- Observations suggest a surface reddened due to irradiation by cosmic rays over its history


Near-Earth Asteroid Discoveries by Survey
~140m and larger NEAs (as of 2018-Jan-07)
538 discoveries in 2017
LINEAR
NEAT
Spacewatch
LONEOS
Catalina
Pan-STARRS
NEOWISE
ATLAS
All others
Number Discovered
0
100
200
300
400
500
600
1995
2000
2005
2010
2015
Discovery Date
https://cneos.jpl.nasa.gov/stats/
Alan Chamberlin (JPL/Caltech)

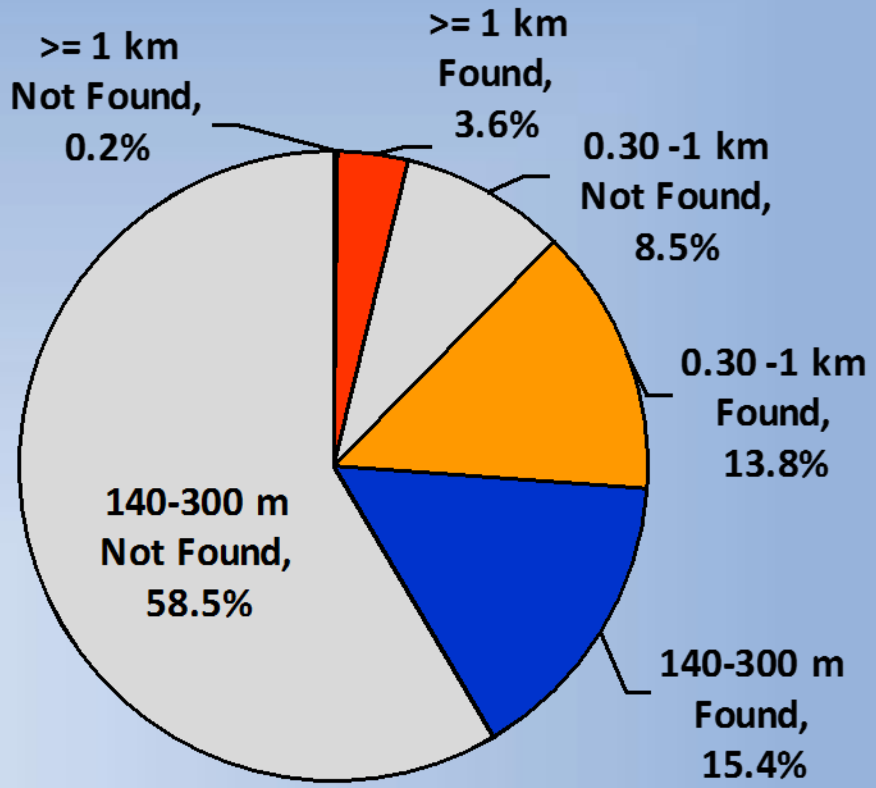


**Potentially Hazardous Asteroids come within 7.5 million km of Earth orbit*


Near Earth Asteroid Survey Progress
140 m
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
Number in Population
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage Complete
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
Population Estimate ~ 25,000 asteroids

NEO Survey Status Jan 2018



Study of LSST's Capabilities for NEO Discovery

Study Structure

- Quasi-independent study carried out in parallel by LSST project "outsiders" (JPL) and "insiders" (U. Washington), agreeing on basic assumptions and parameters.
- Panel of 5 independent reviewers vetted Study Plan and Final Report. (Authors made 1 set of revisions to Plan and Report, based on reviewers' comments.)

Study Objectives

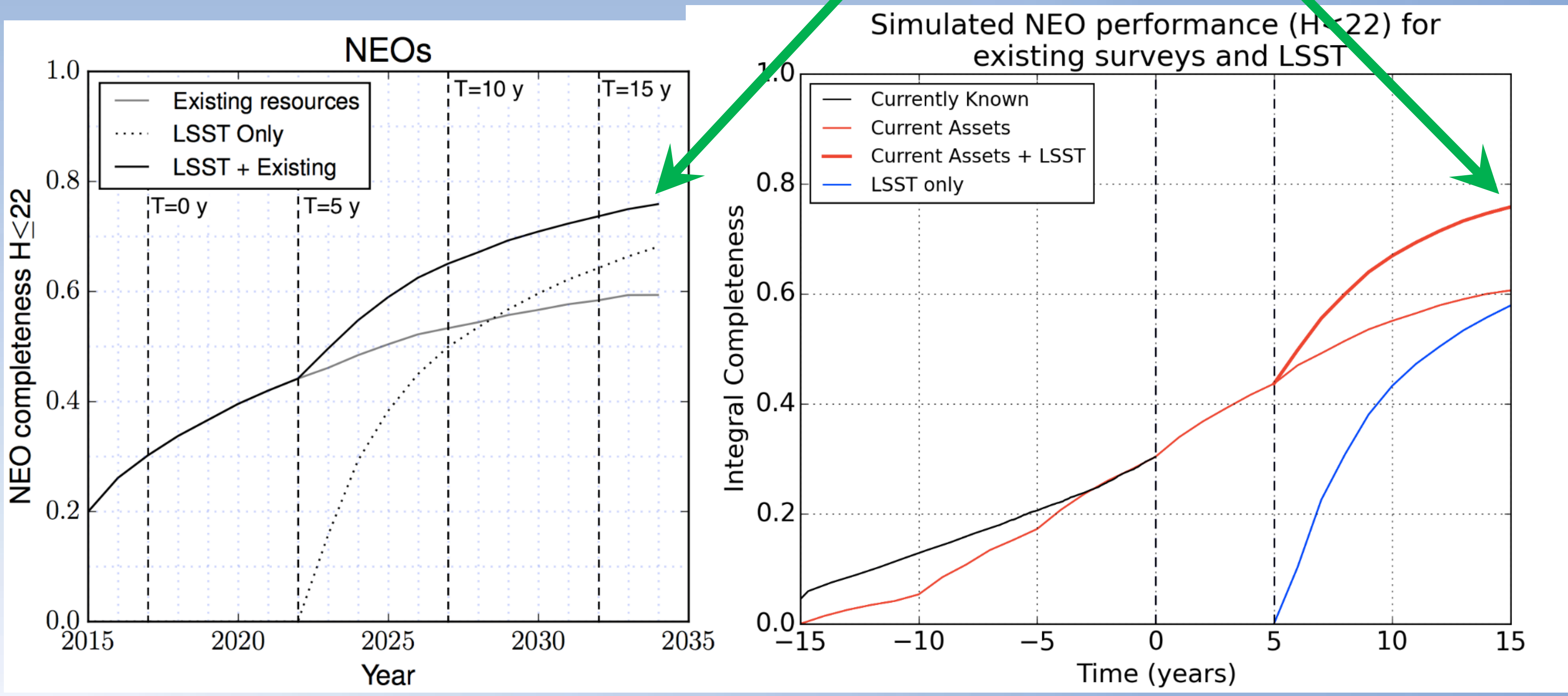
- Determine how many NEOs can be discovered by LSST, under various assumptions regarding system performance, presuming *a priori* that multiple individual detections can be linked to obtain object orbits.
- Determine the efficiency of the linking process and its robustness to the likely numbers of false detections resulting from the optical system and difference-imaging approach.
- Assess whether alternatives to the baseline LSST survey cadence may substantially change NEO discovery performance.

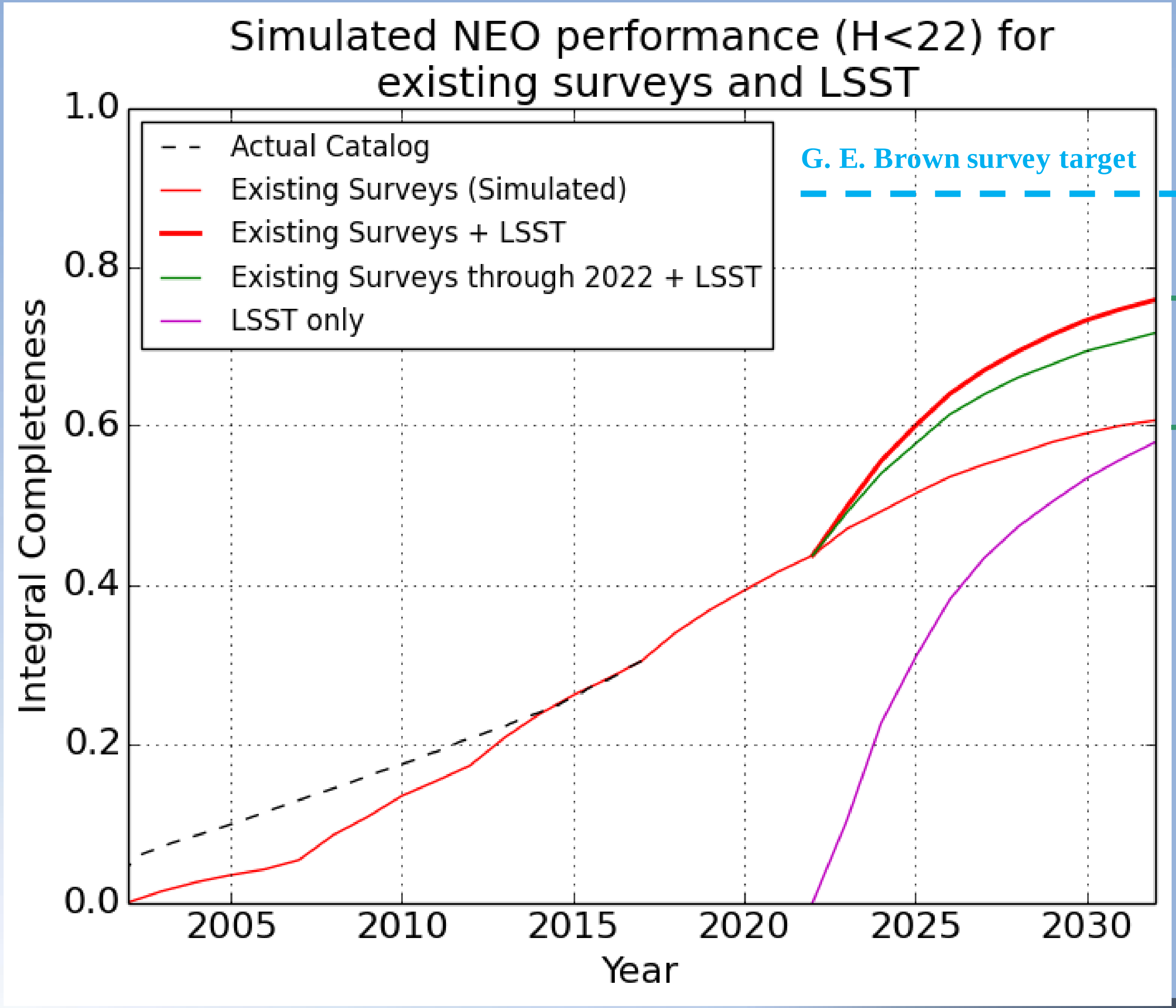
UW and JPL teams agree on the big-picture result

From consensus white paper

UW

JPL





From JPL report

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 %.

Study of LSST's Capabilities for NEO Discovery

Major Consensus Results

- LSST's nominal strategy of two visits per night per field can be successful in discovering NEOs after 12 days of data collection. False detections are not a serious obstacle, based on a rate demonstrated in Dark Energy Camera data. The conclusion is robust to factors of a few in the false positive rate.
- Assuming that existing NEO surveys continue to operate and incrementally improve, the H < 22 NEO catalog is likely to surpass 75% completeness after LSST's 10-year baseline survey. Continuing the same survey would increase completeness by about 1% per additional year, up to 5 years.
- A completeness level of 90% is likely beyond reach without major system modifications or contributions from another next-generation survey.
- PHA completeness would be about 5 percentage points higher than NEO completeness, owing to PHAs' closer mean proximity to Earth.
- Changing the observing strategy to 3 or 4 visits per night per field would not improve linking efficiency, and therefore would reduce survey completeness due to reduced sky coverage.

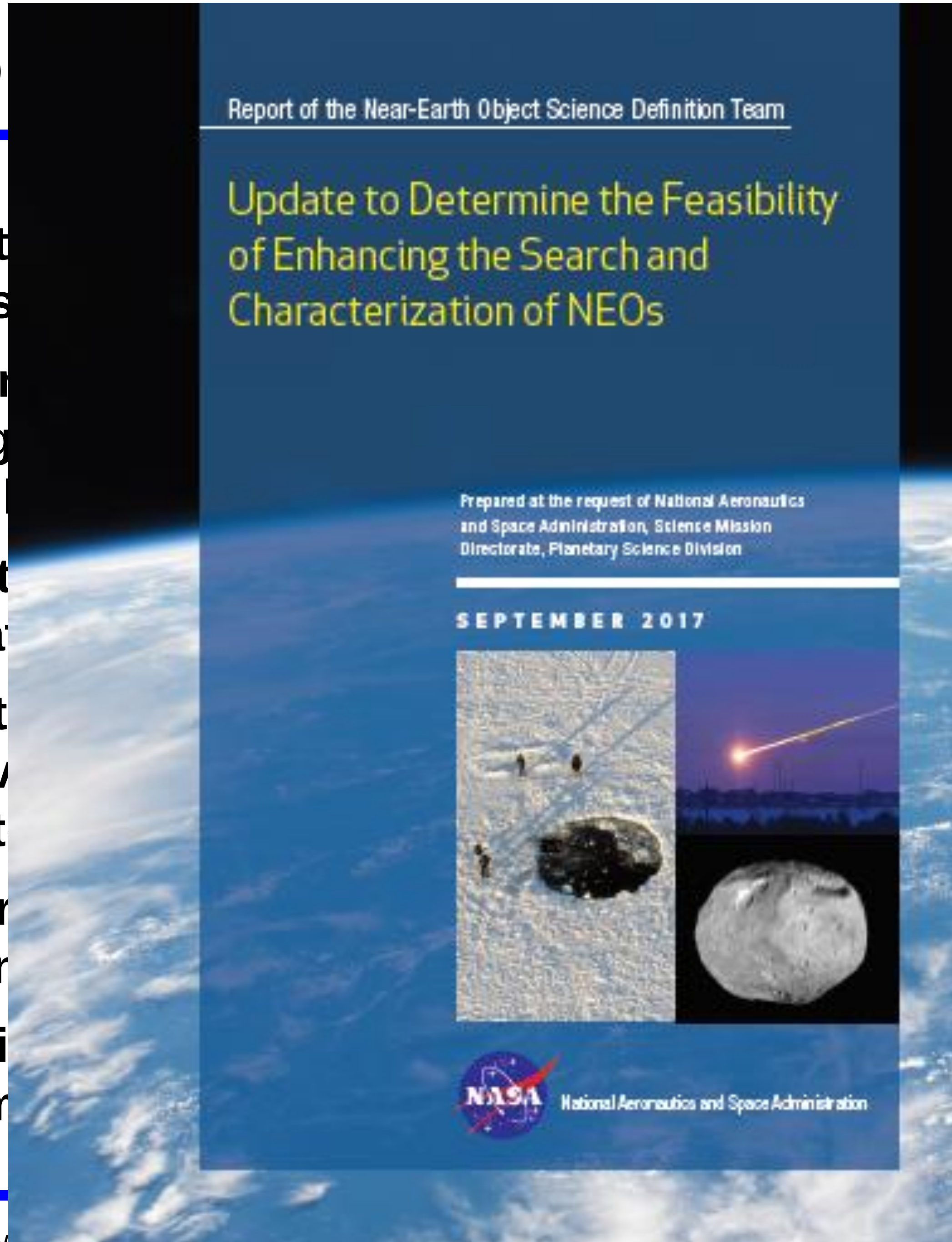
Study of LSST's Capabilities for NEO Discovery

Final Report Delivered to NASA in March 2017, comprised of 3 documents:

- JPL team report, "Projected Near-Earth Object Discovery Performance of the Large Synoptic Survey Telescope"
  - Subsequently published as JPL Publication 16-11, arXiv:1705.06209; and as Veres & Chesley 2017ab, AJ, 154, art. id. 12, 13.
  - https://cneos.jpl.nasa.gov/doc/LSST_report_2017.html
- UW team report, "The Large Synoptic Survey Telescope as a Near-Earth Object Discovery Machine"
  - To be published in Icarus, arXiv:1711.10621.
- Consensus report, "A Joint White Paper Summarizing Results from Independent Simulations of LSST's NEO Discovery Performance"

NEO … eport*

- Satisfact … e will require s…
  - IR ar … diameter rang… ions using avail…
  - Best … m options loca…
  - Fast … st warning prov… sible and IR syst…
  - Sear … stantial warr…
- The addi … arch system aids com … ed options



LEO not assessed

*https://ww … -version.pdf

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 $\geq$4-meter ground-based search system aids completion timeline for any space-based option**

*** 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

Future Direction for LSST Collaboration on NEO Discovery

While certain we will want to take advantage of the considerable survey capabilities that LSST will provide for solar system objects, there is a process to be followed:

- Step 1 - Complete NEO Survey Analysis of Alternatives report
- Step 2 – Learn outcome of FY2019 NASA Science Budget Submittal
- Step 3 – Along with other to be decided Initiatives, begin Discussion with NSF/AST for LSST Collaboration
- Step 4 – Determine best course of action for incorporation of LSST data into NEO Observations Search and Survey pipeline

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