Ground-based Searches for Near-Earth Objects

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Jet Propulsion Laboratory
California Institute of Technology

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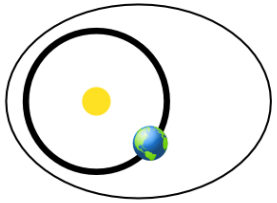
What is a Near-Earth Object?

Amors

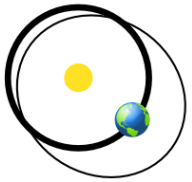
Earth-approaching NEAs with orbits exterior to Earth's but interior to Mars' (named after asteroid (1221) Amor)



$$a > 1.0 \text{ AU}$$
$$1.017 \text{ AU} < q < 1.3 \text{ AU}$$

Apollos

Earth-crossing NEAs with semi-major axes larger than Earth's (named after asteroid (1862) Apollo)



$$a > 1.0 \text{ AU}$$
$$q < 1.017 \text{ AU}$$

Atens

Earth-crossing NEAs with semi-major axes smaller than Earth's (named after asteroid (2062) Aten)

$$a < 1.0 \text{ AU}$$
$$Q > 0.983 \text{ AU}$$

Atiras

NEAs whose orbits are contained entirely within the orbit of the Earth (named after asteroid (163693) Atira)

$$a < 1.0 \text{ AU}$$
$$Q < 0.983 \text{ AU}$$

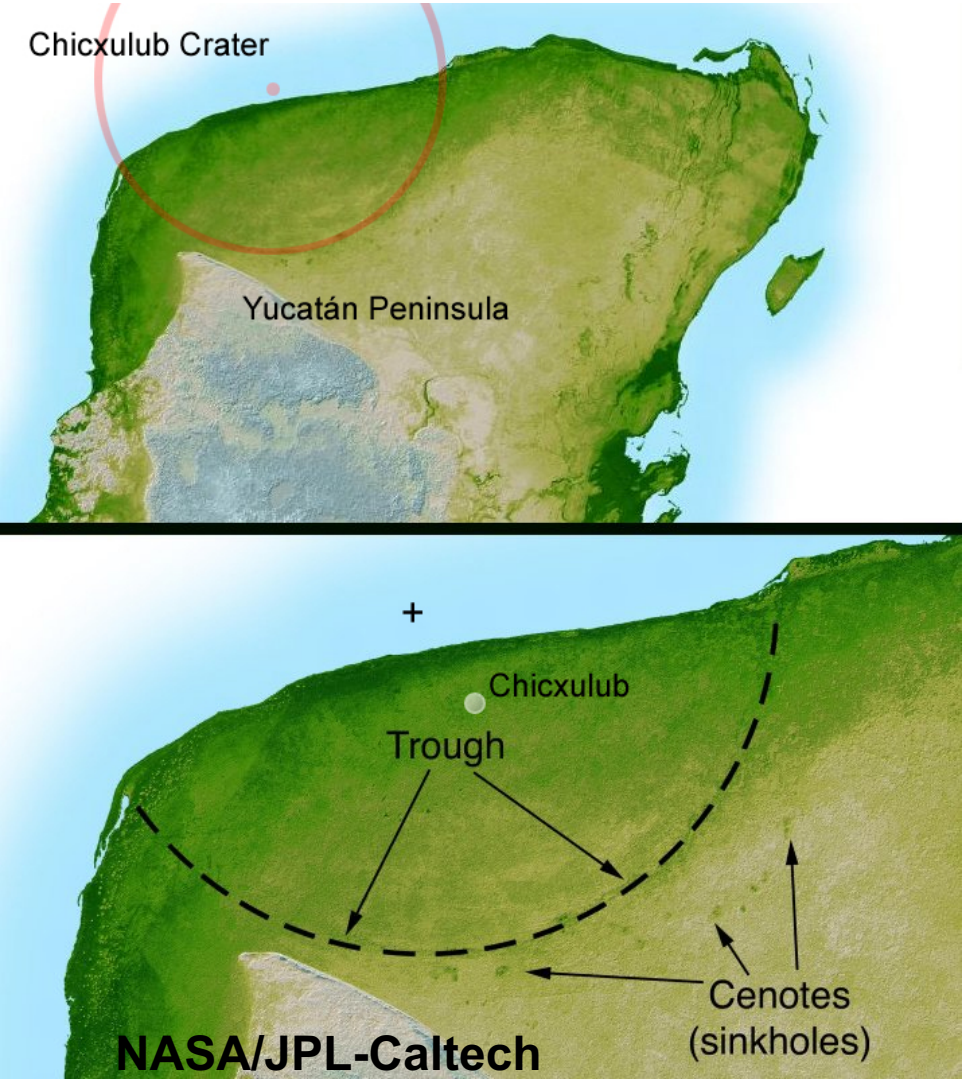
$(q = \text{perihelion distance}, Q = \text{aphelion distance}, a = \text{semi-major axis})$

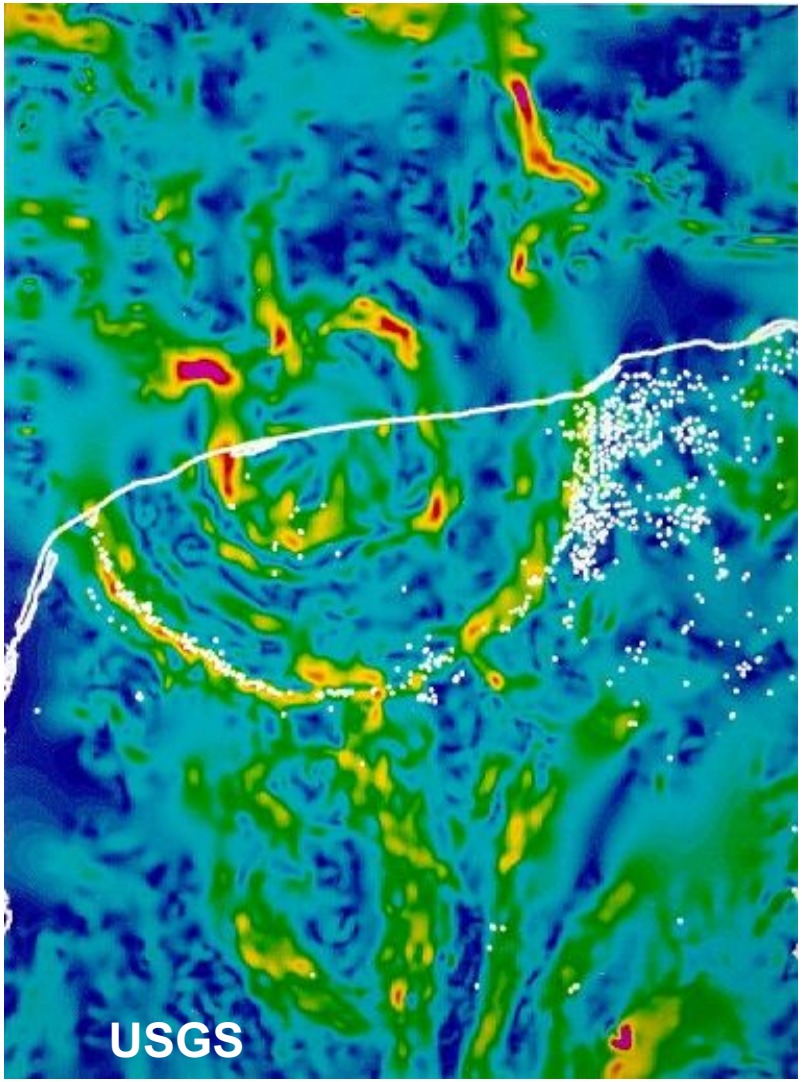
JPL/Caltech/Center for Near Earth Object Studies

What is a Near-Earth Object?

- Asteroid or comet

Why study near earth objects?

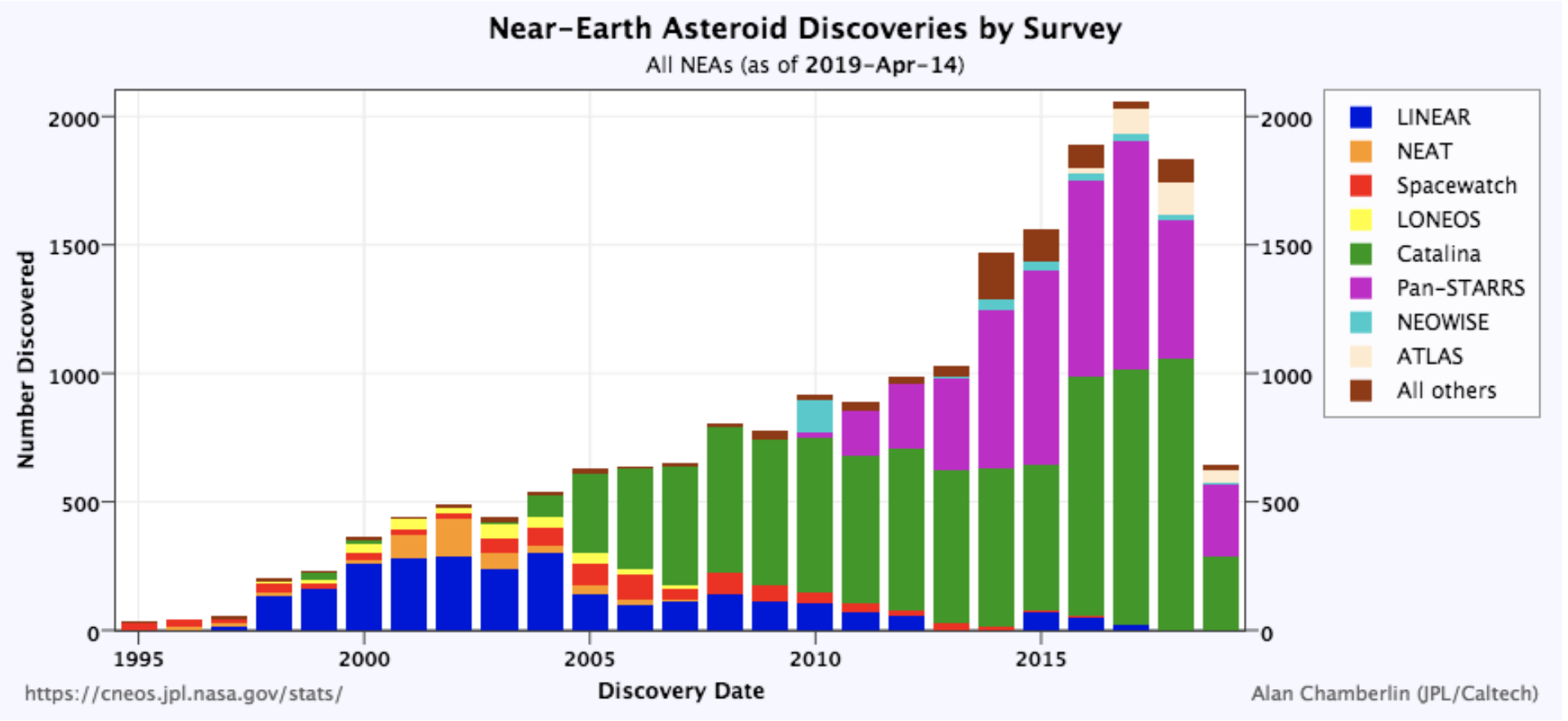




Why study near earth objects?

Why study near earth objects?

How useful are ground-based surveys?



Why not just do it all from space?

- Cost!
  - Time: surveys are time-intensive
  - Money: spacecraft are expensive

The need for a variety of capabilities

- Wide field/shallow
  - Find bright objects quickly
- Narrow/deep
  - Allows fainter objects to be found
- Cadence
  - Fast vs slow moving objects

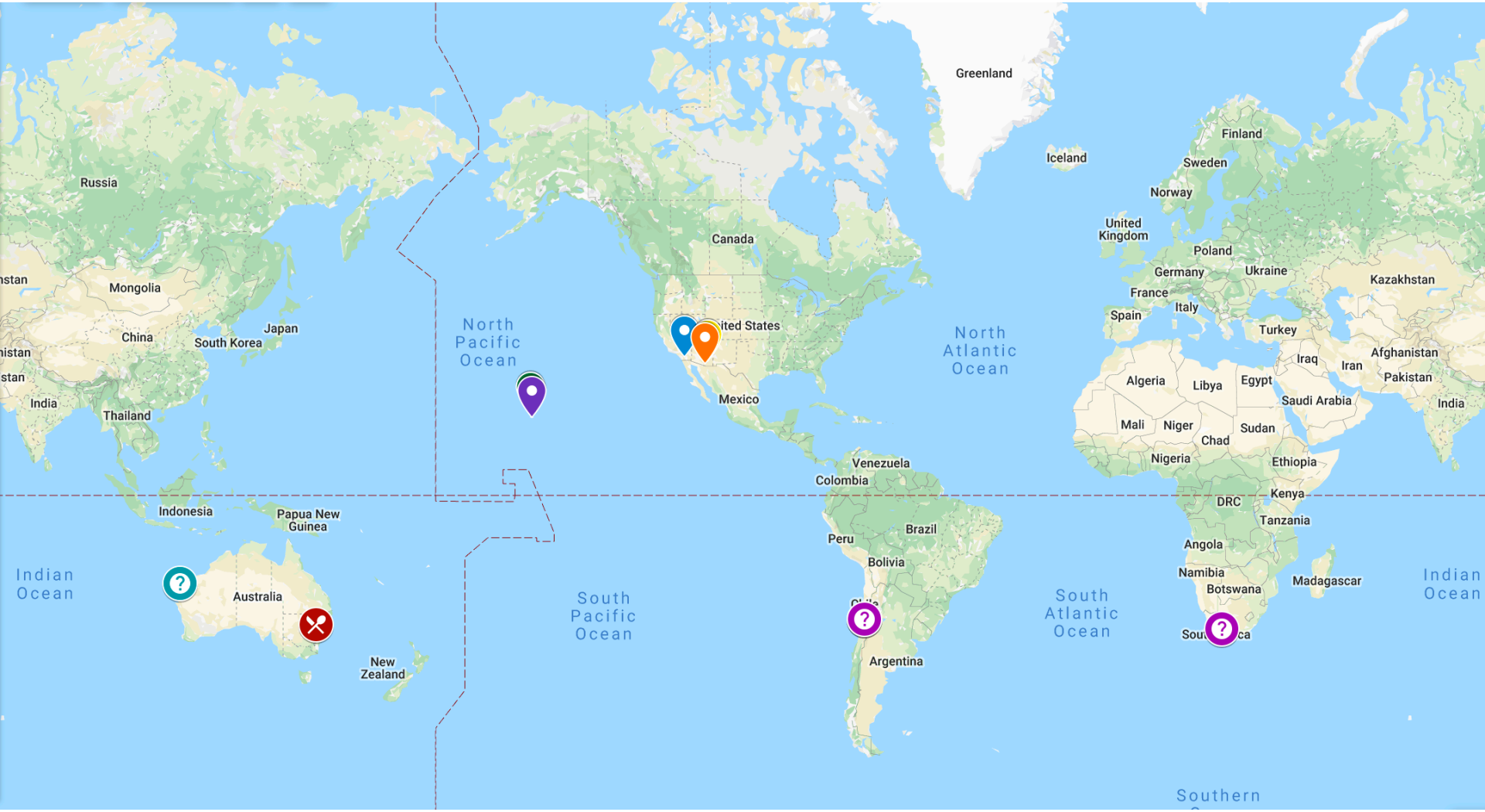
The need for a variety of observing locations

- Weather
- “Always in the dark”
- N/S hemisphere

Observatory Locations: Current

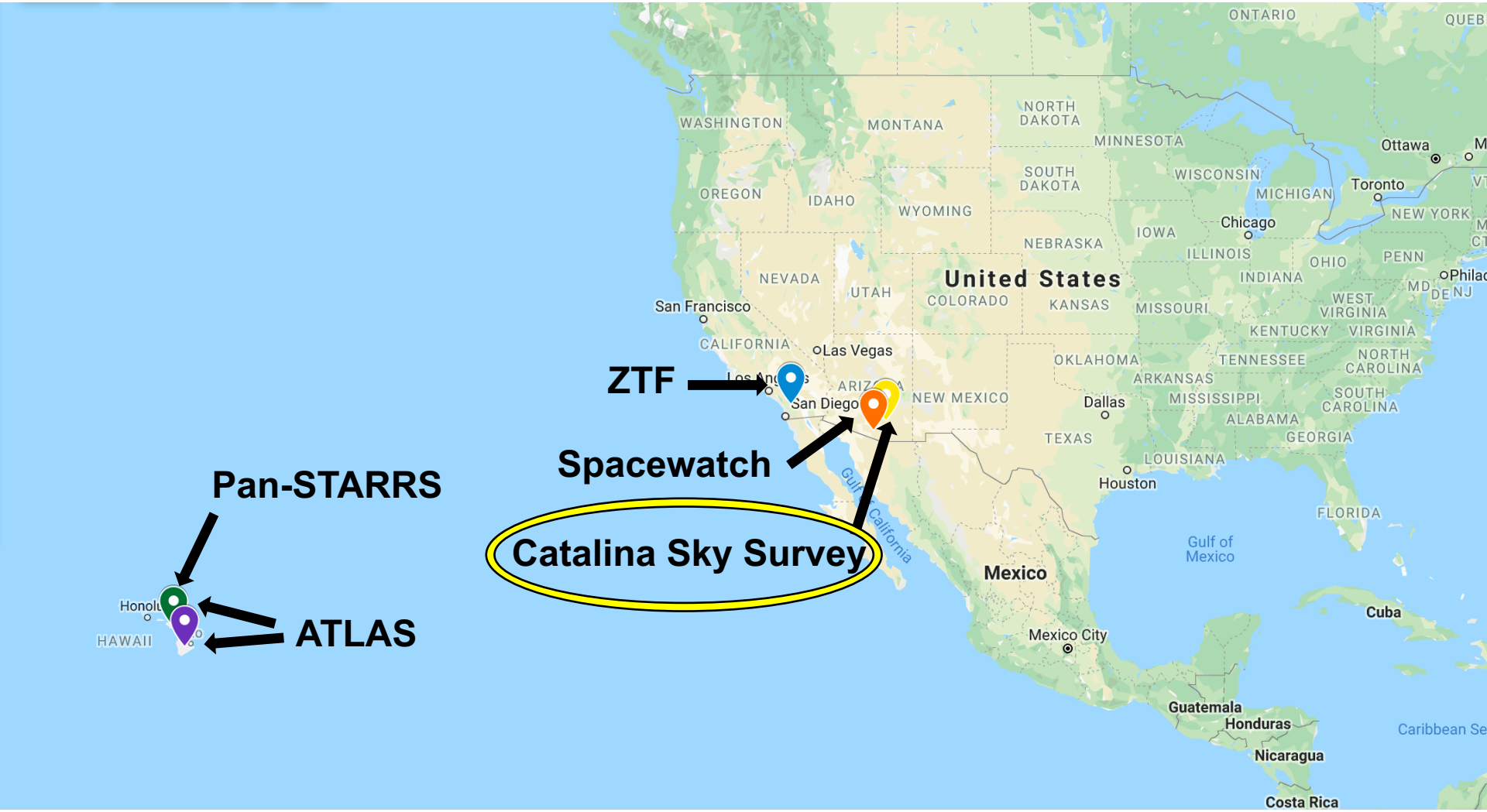
Observatory Locations: Current + Past

Observatory Locations: Current and Future



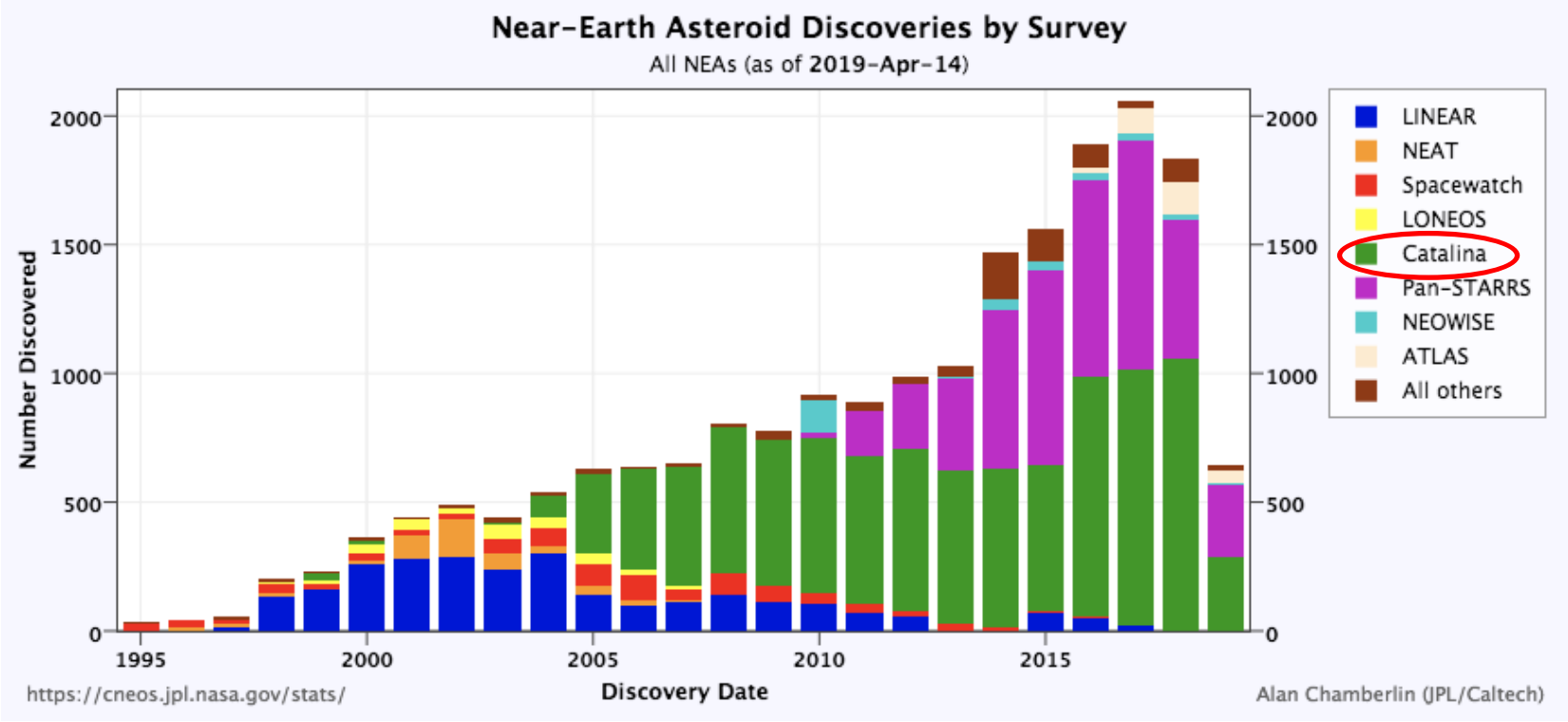
Observatory Locations

Observatory Locations



Catalina Sky Survey (CSS)

- Run by the University of Arizona
- Three parts: CSS, Mt. Lemmon, Siding Spring
- One of the most prolific discoverers of NEOs



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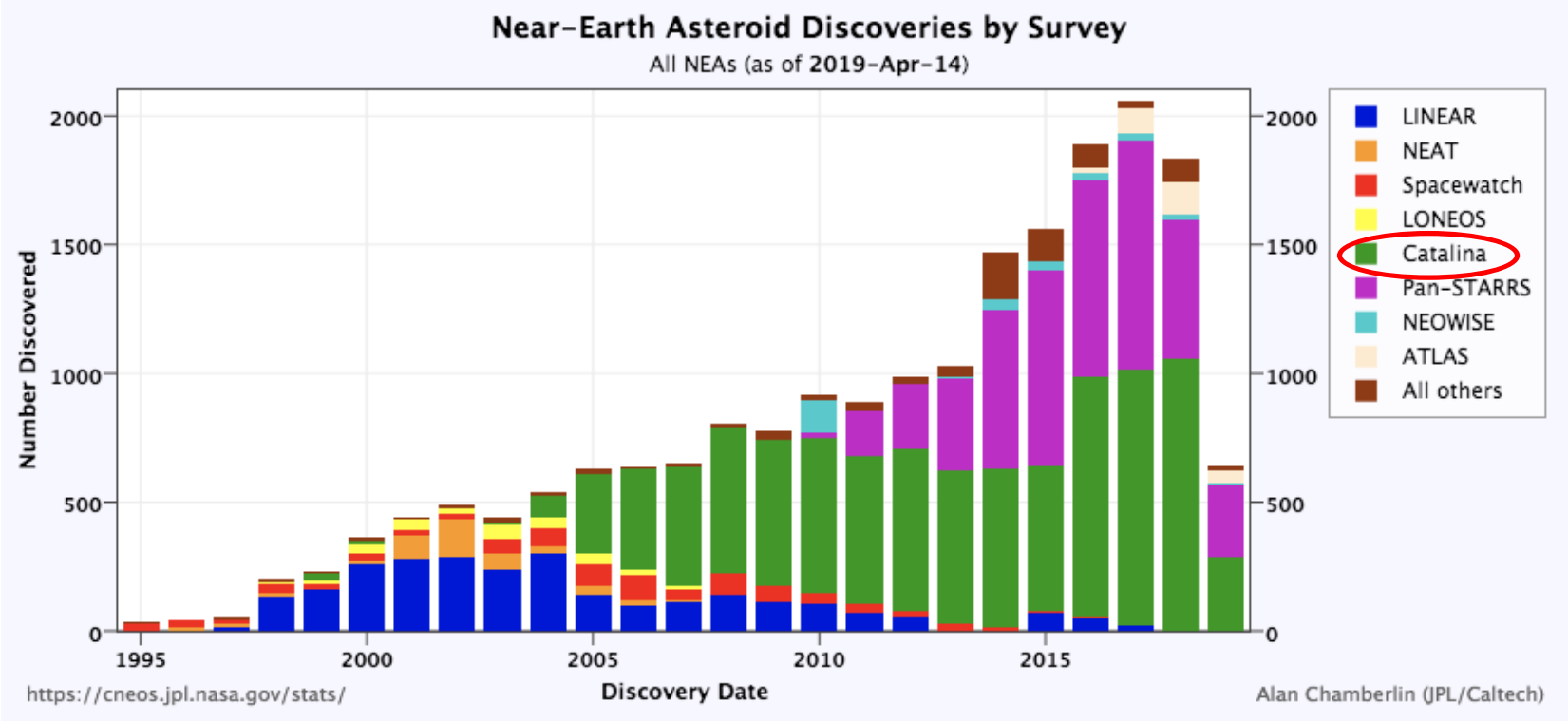
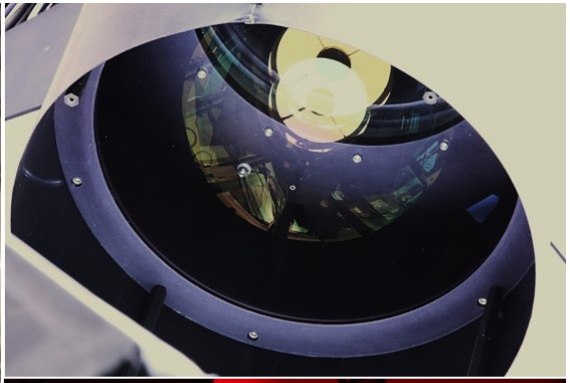
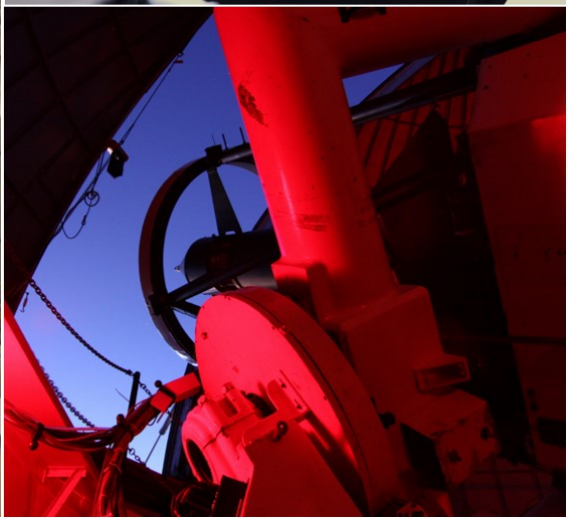


The CSS telescopes

- 1.5-m survey telescope
- 1000 deg^2 per night, limiting mag V~21.5, FoV 5 deg^2
- Primarily used for discovery



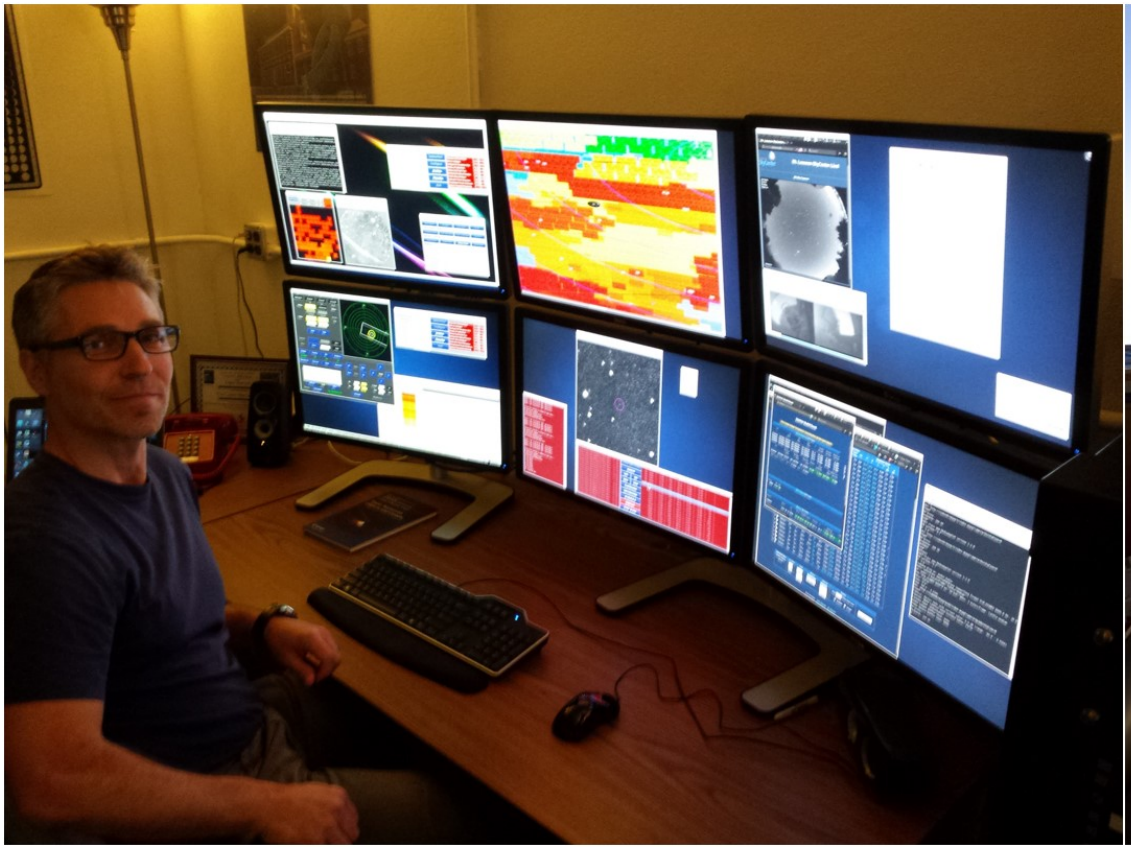


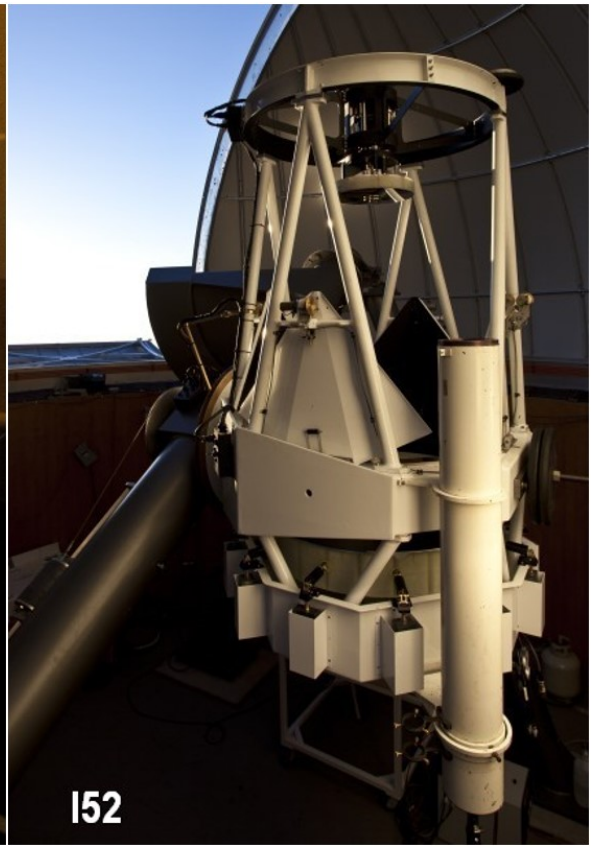
The CSS Telescopes

- 0.7-m survey telescope
- 4000 deg^2 per night, limiting mag V~19.5, FoV 19.4 deg^2
- Wide/shallow

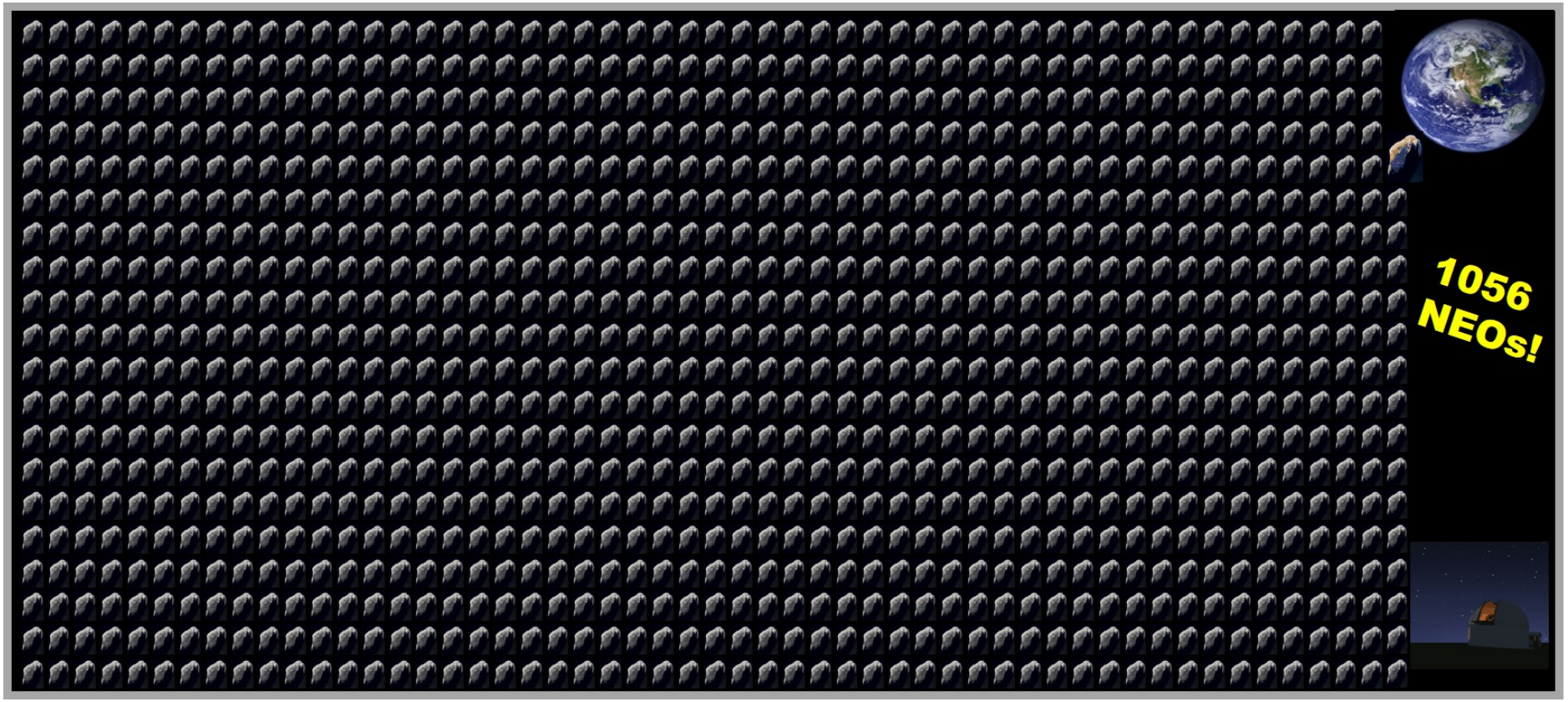
The CSS telescopes

- 1.0-m follow-up telescope
- Limiting mag V~22, FoV 0.3 deg^2, variable exposure length
- Typically recovers 40-80 NEOs per night



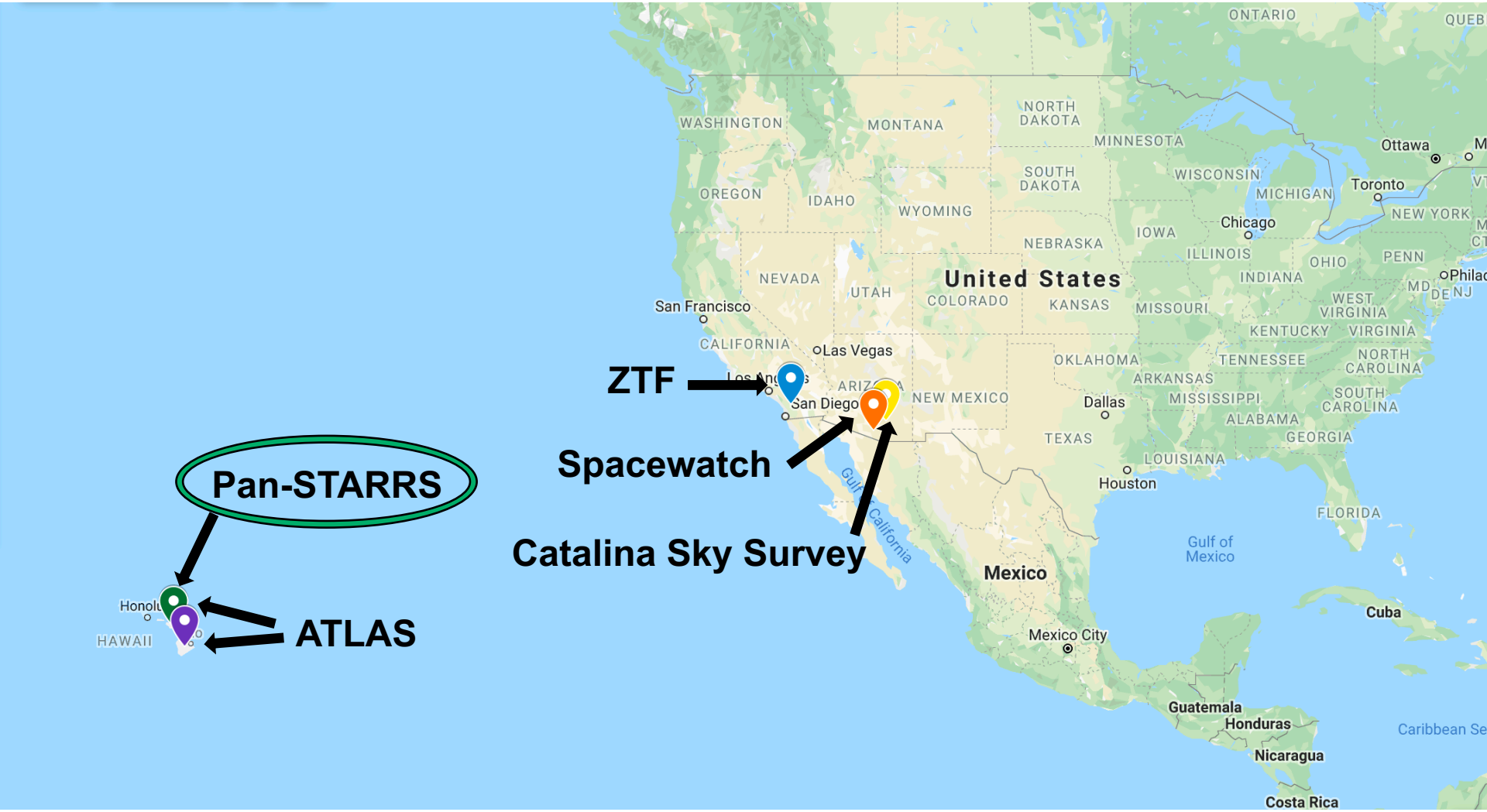


CSS Discovered over 1000 NEOs in 2018!



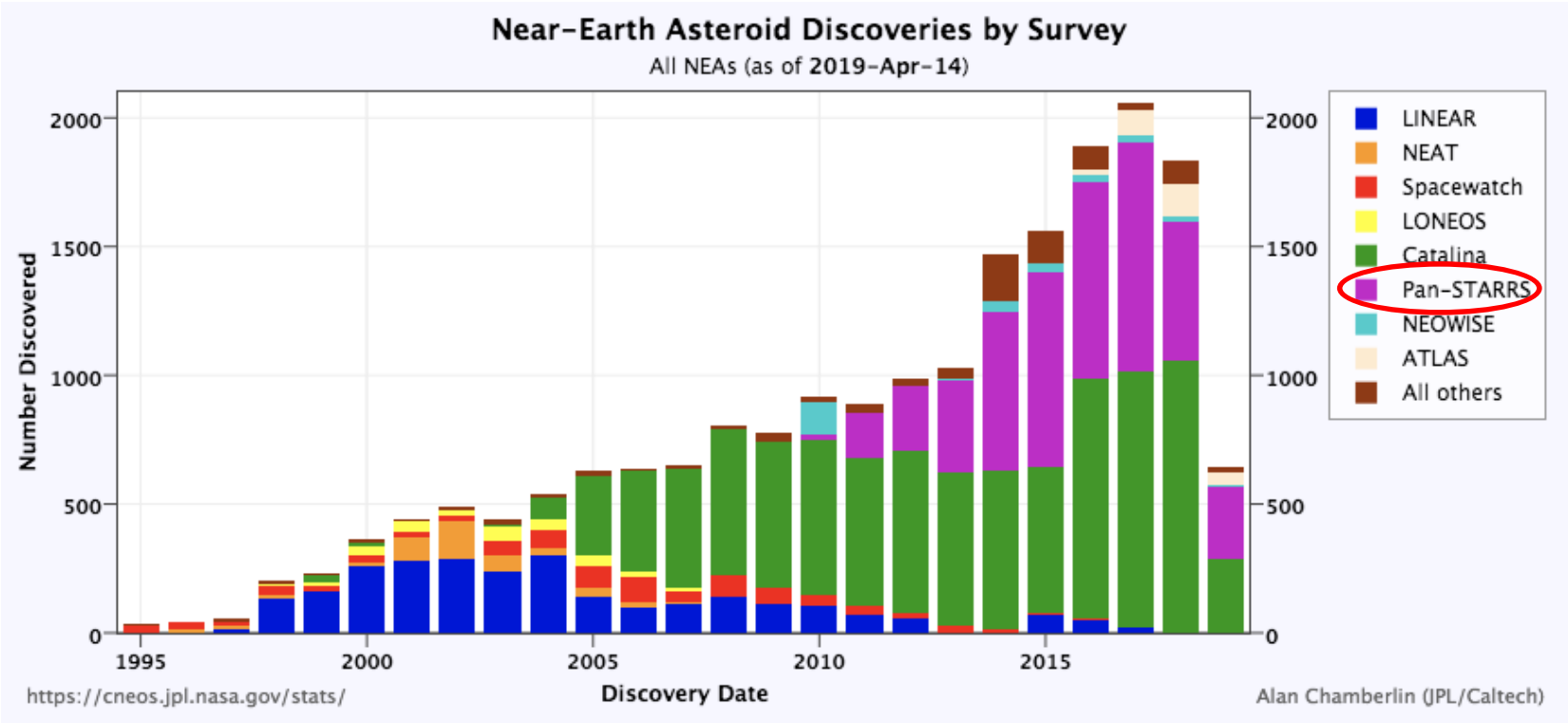
https://catalina.lpl.arizona.edu/news/record-setting-year-catalina-sky-survey-discovers-over-1000-near-earth-asteroid-2018

Observatory Locations



Pan-STARRS

- Panoramic Survey Telescope and Rapid Response System
- Run by the University of Hawaii
- PS1 began in 2010, PS2 began in 2017



The Pan-STARRS telescopes

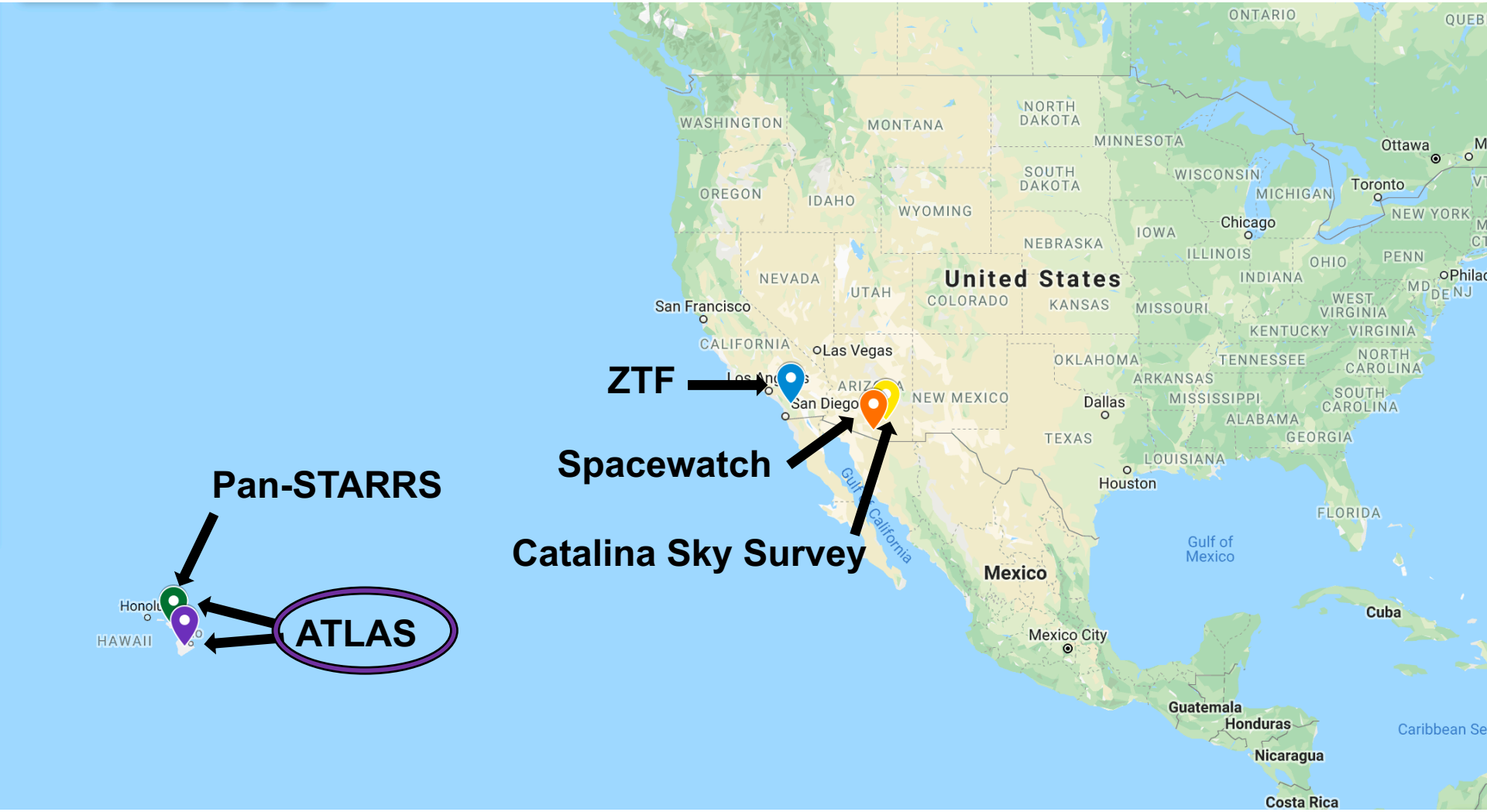
- Two 1.8-m survey telescopes
- ~1000 deg^2 per night per telescope
- FoV = 7 deg^2, limiting magnitude ~22

http://www.ifa.hawaii.edu/info/press-releases/PS1/PS1.jpg

'Oumuamua: the first known interstellar object

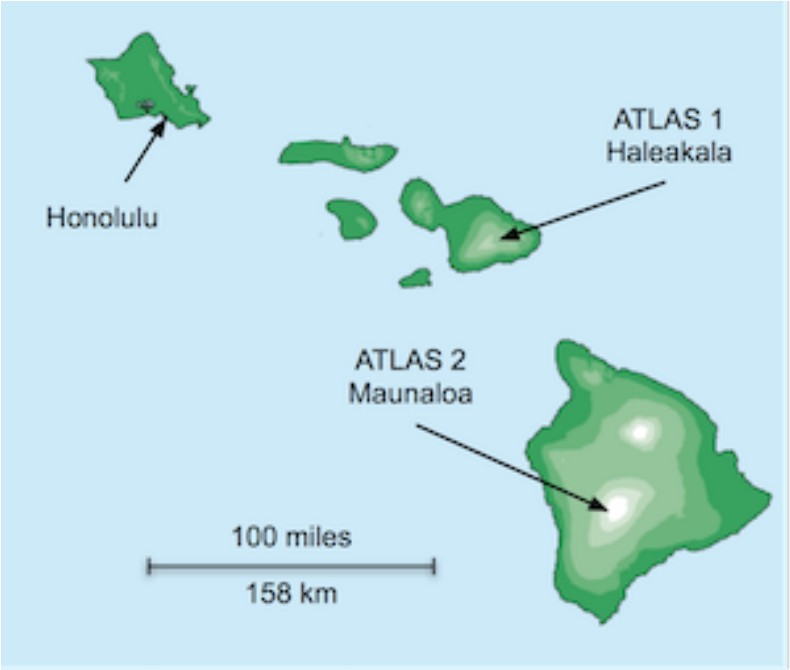
K. Meech et al./ESO

Observatory Locations



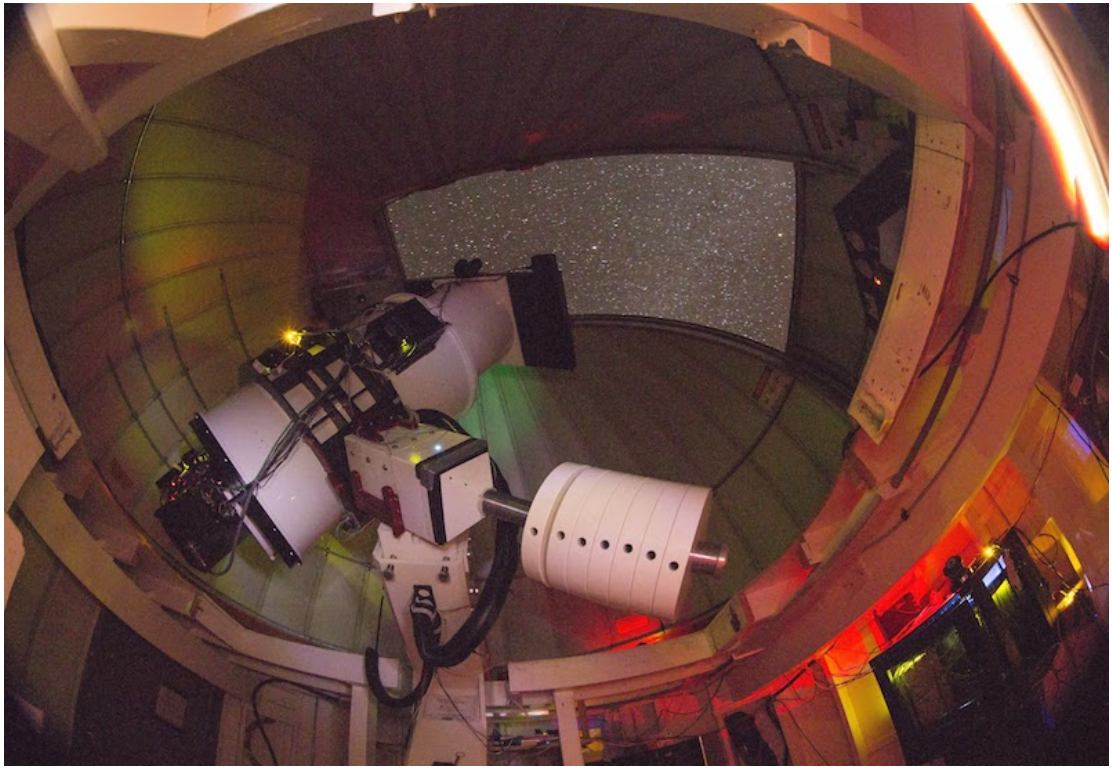
ATLAS

- Asteroid Terrestrial-impact Last Alert System
- Run by the University of Hawaii
- First started in late 2015
- Two identical telescopes



ATLAS

- Two 0.5-m survey telescopes
- Limiting mag ~20, FoV = 7.4 deg^2
- 20,000 deg^2 three times per night: wide and shallow



Photograph by Henry Wieland

ATLAS

- Plan to add two more telescopes by 2020: one in South Africa, and one in Chile

So far, **ATLAS** has discovered

Near-Earth Asteroids	293
Potentially Hazardous Asteroids	33
Comets	19
Supernovae	3187

Observatory Locations

Zwicky Transient Facility (ZTF)

- Run by Caltech and a large international group of collaborators
- *NOT* a dedicated NEO survey telescope, but all data are searched for NEOs
- First light Nov. 1, 2017
- Science survey began March 17, 2018

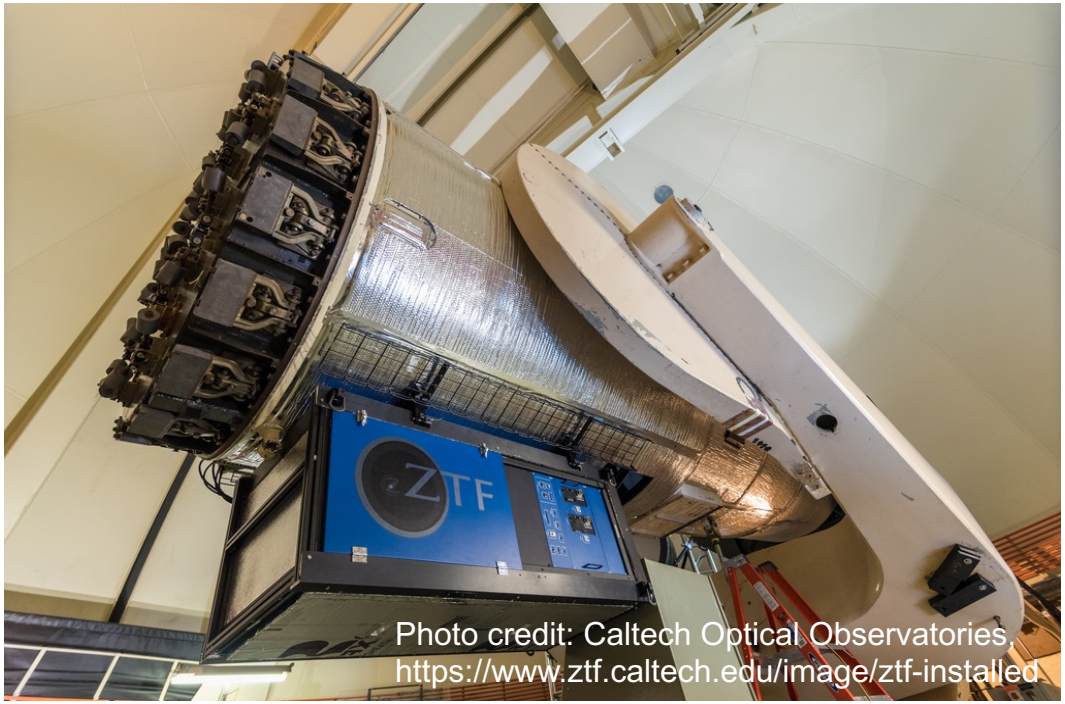
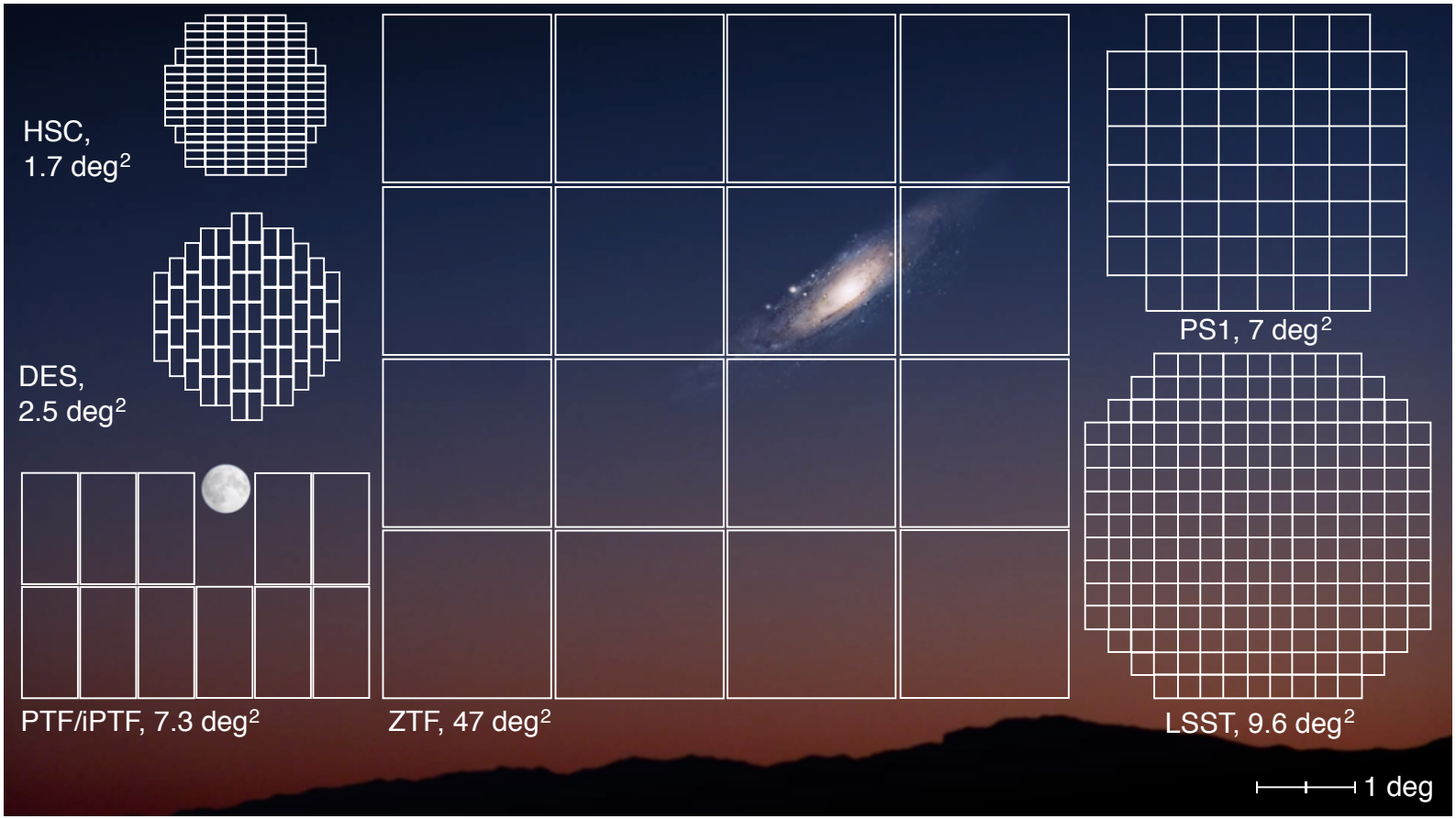


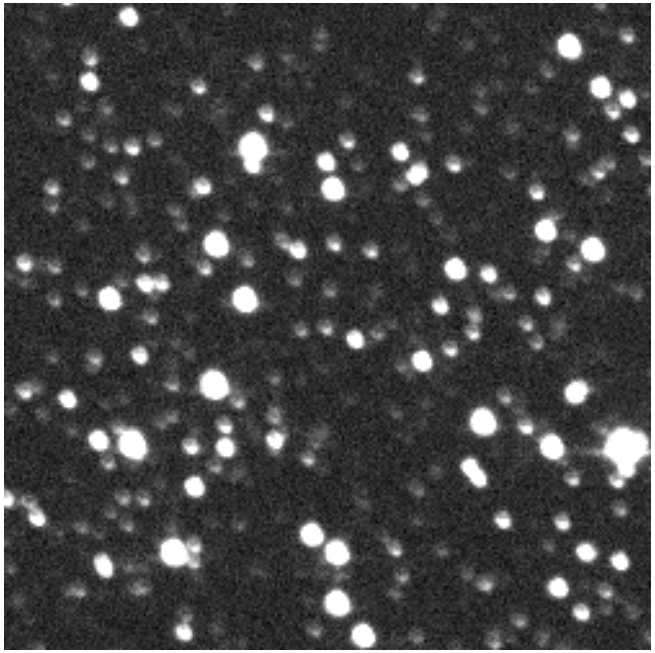
Photo credit: Caltech Optical Observatories, https://www.ztf.caltech.edu/image/ztf-installed

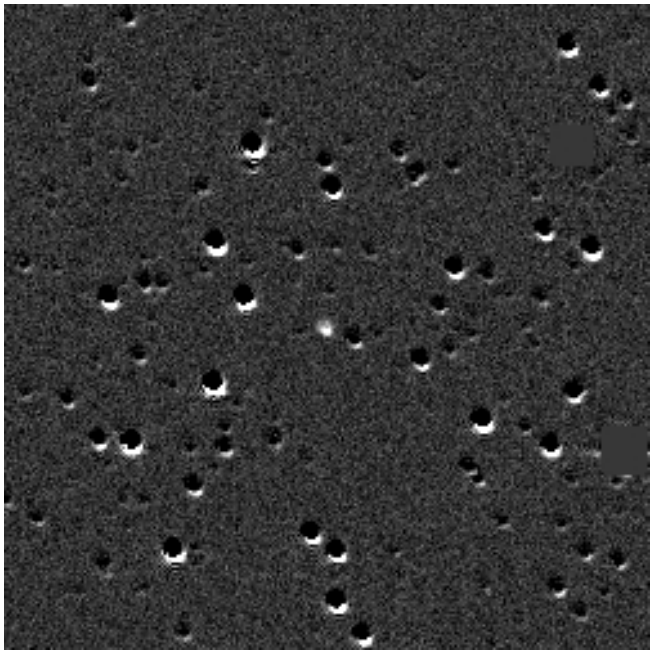
The ZTF telescope

- 48” survey telescope
- Variable sky coverage per night
- Limiting mag ~20.5, FoV = 42.7 deg^2

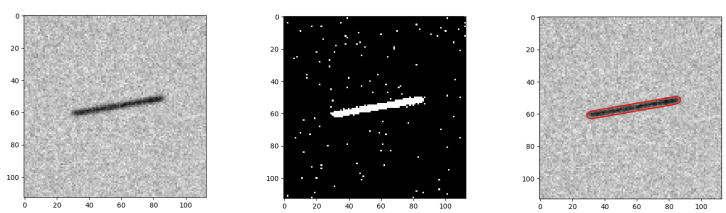


ZMODE = ZTF Moving Object Discovery Engine



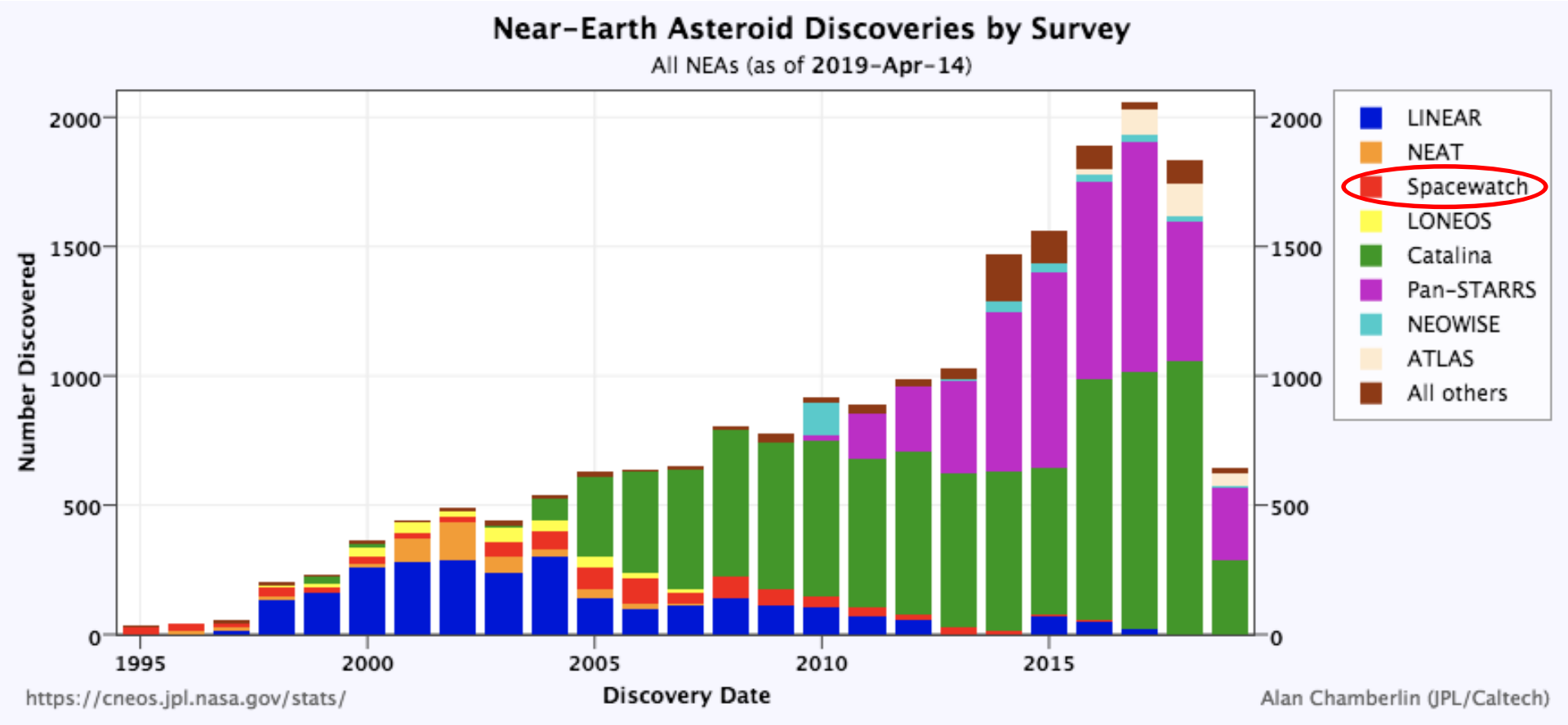


ZStream: fast moving NEO discovery



Observatory Locations

Spacewatch: a long-term workhorse for NEO searches



Spacewatch: a long-term workhorse for NEO searches

- First to use CCD-scanning routinely in astronomy (1984).
- First to use CCDs to survey the sky for comets and asteroids.
- First near-Earth asteroid discovered with a CCD (1989 UP).
- First astronomical group to develop automated, real-time software for moving-object detection.
- First to discover a near-Earth asteroid by software (1990 SS).
- Discovered the NEO 1997 XF11 that caused temporary excitement as a potential impactor.
- Discovered the TNO (20000) Varuna that was temporarily the largest known TNO other than Pluto.

The Spacewatch Telescopes

- 1.8-m follow-up telescope

- 0.9-m follow-up telescope

Spacewatch now: a workhorse for NEO follow-up observations

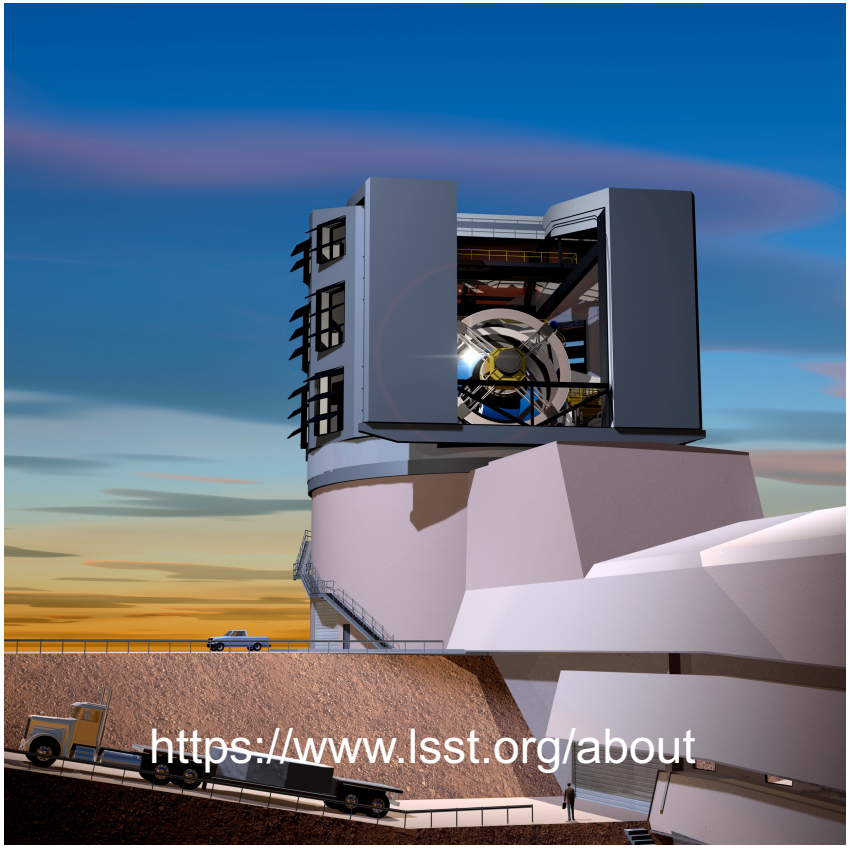
- In 2018, Spacewatch made 77% of all the observations of PHAs world-wide that were fainter than V magnitude 22.5 at the time of observation.

- The Spacewatch 1.8-meter telescope is the largest telescope in the world that is dedicated exclusively to astrometry of asteroids.

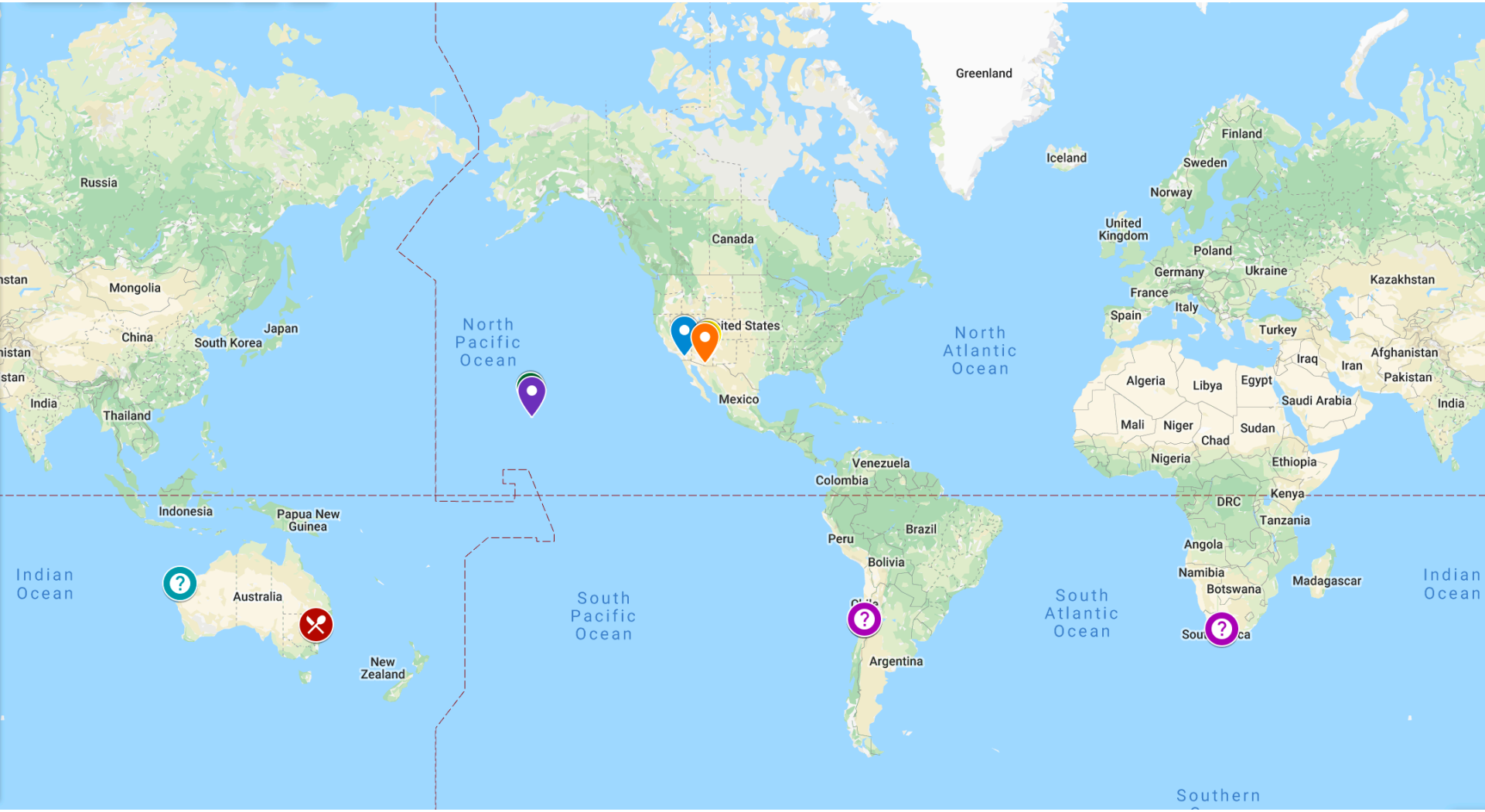
Future of ground-based surveys

- Additional ATLAS telescopes in southern hemisphere

- LSST: Large Synoptic Survey Telescope
  - Cerro Pachon, Chile
  - 8.4-m primary mirror
  - Can observe entire sky every 3 nights
  - Limiting magnitude 24.5
  - Not a dedicated NEO survey



Observatory Locations: Current and Future



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