The search for Near Earth Objects — how CFHT is helping

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Near Earth Objects

- Defined as objects that have perihelion less than 1.3 Astronomical Units
- May be asteroids or comets
- Largest risk is from asteroids (but impacts can be predicted well in advance
- Comets on elliptical orbits will have higher impact velocities, and there would be less warning time

Near Earth Objects

- Earth impact from an asteroid (or comet) is the only natural disaster that can be prevented
  - Pan-STARRS (on Haleakala, Maui) is helping to find dangerous asteroids and comets that may hit Earth in the future
  - MegaCam on CFHT is being used to get rapid additional observations of these objects to characterize their orbits and size

NASA funding

- NASA now funds Near Earth Object discovery and characterization
  - $50 million per year
  - The Chelyabinsk meteorite helped increase funding
  - Operation of Pan-STARRS is funded by the NASA Near Earth Object Observation program
  - NASA has also provided funds to help finish Pan-STARRS2

NASA funding

- Nearly all discovery and confirmation of Near Earth Objects comes from US-operated telescopes
  - The major discovery telescopes were all built for other purposes
  - All NEO discovery telescopes are threatened by light pollution
  - There is much poorer coverage of the southern hemisphere

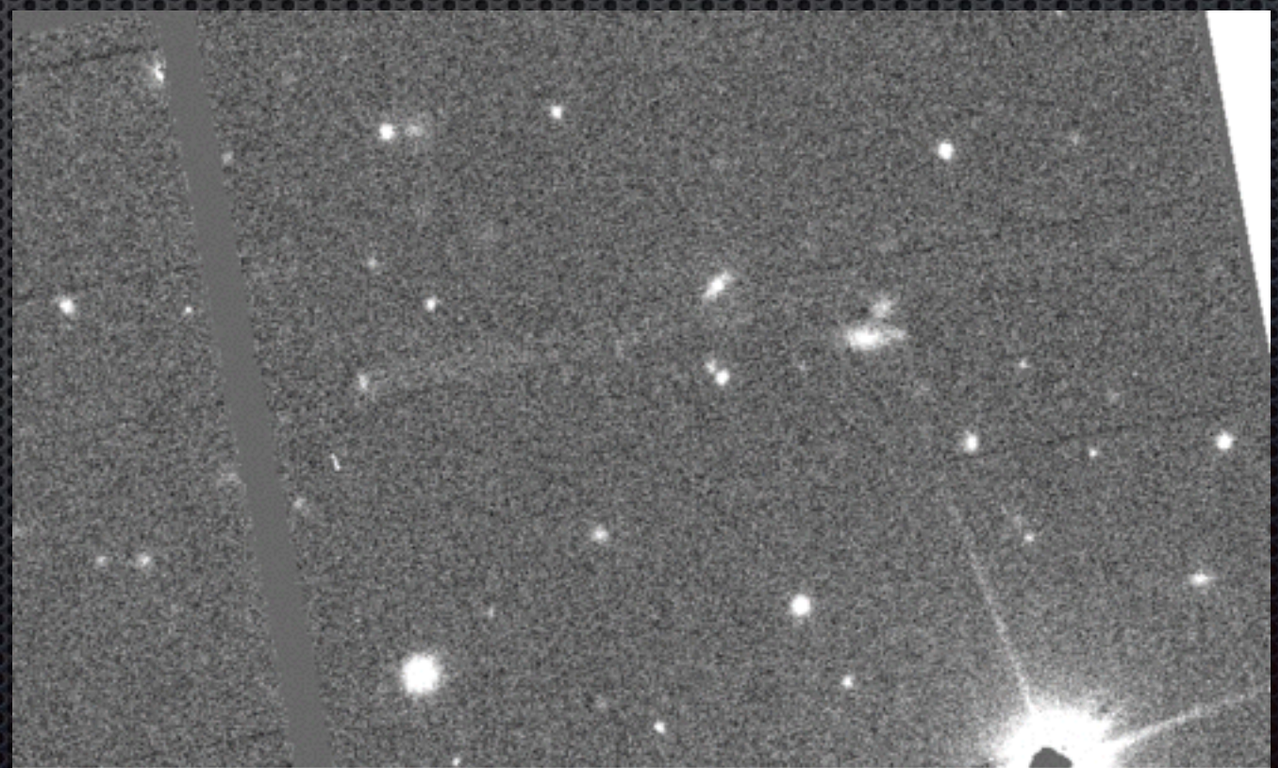
February 15, 2013

Chelyabinsk meteorite

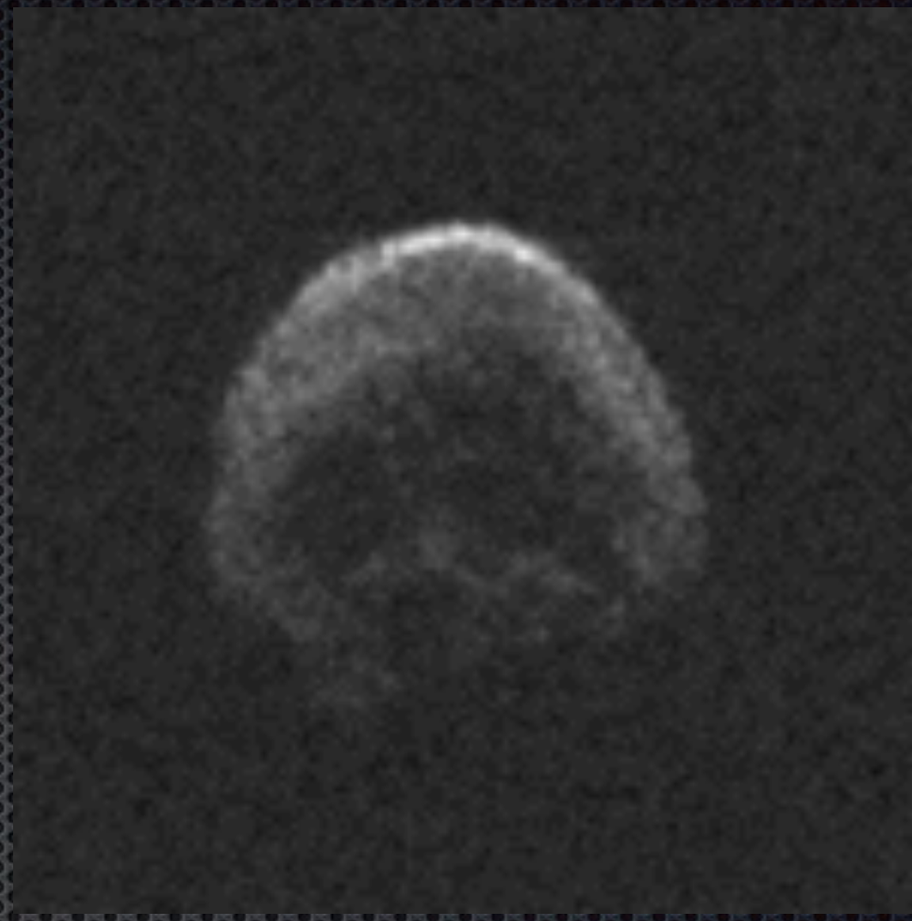
- Approximately 18 meters in diameter
- Approximately 9,100 tonnes
- 19 km/s impact velocity
- Exploded at an altitude of 23 km
  - Glancing trajectory resulted in a high altitude explosion; steeper trajectory would have had more serious consequences
- 500 kilotons of TNT

2015 TB145

- The “Halloween Asteroid”
- Discovered by Pan-STARRS1 on October 10, at a distance from Earth of 0.44 AU; confirmation observations were obtained with CFHT on October 12
- Its motion when discovered was not particularly unusual — scoring only 84 — most Near Earth Objects score 100

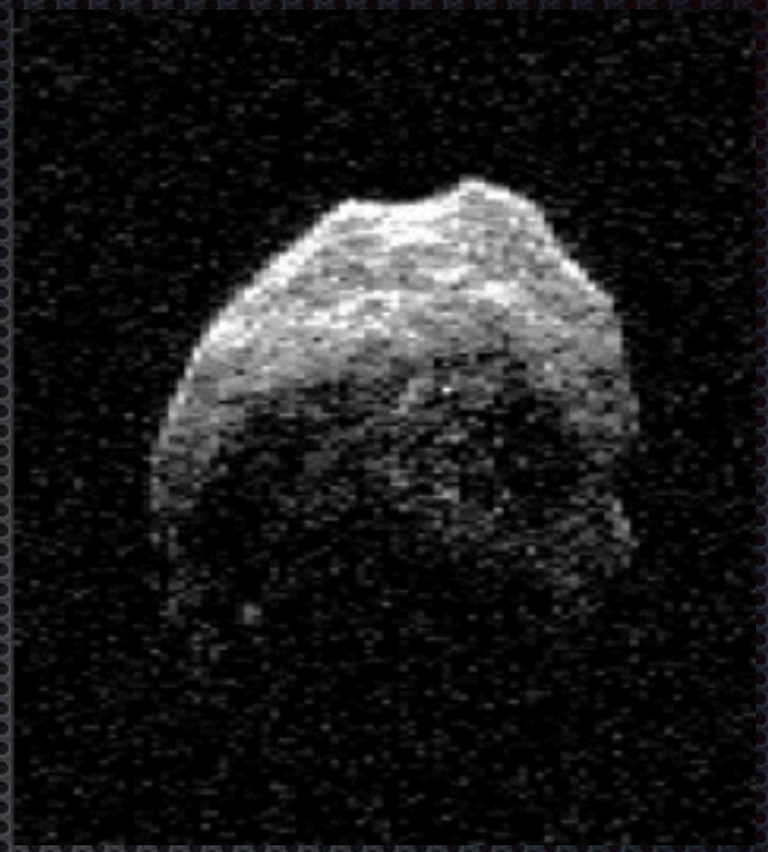


2015 TB145



- Radar observations showed that is roughly spherical with a diameter of 600 meters
- It has an inclined and highly elliptical orbit, making its velocity relative to Earth high — 35 km/s

2015 TB145



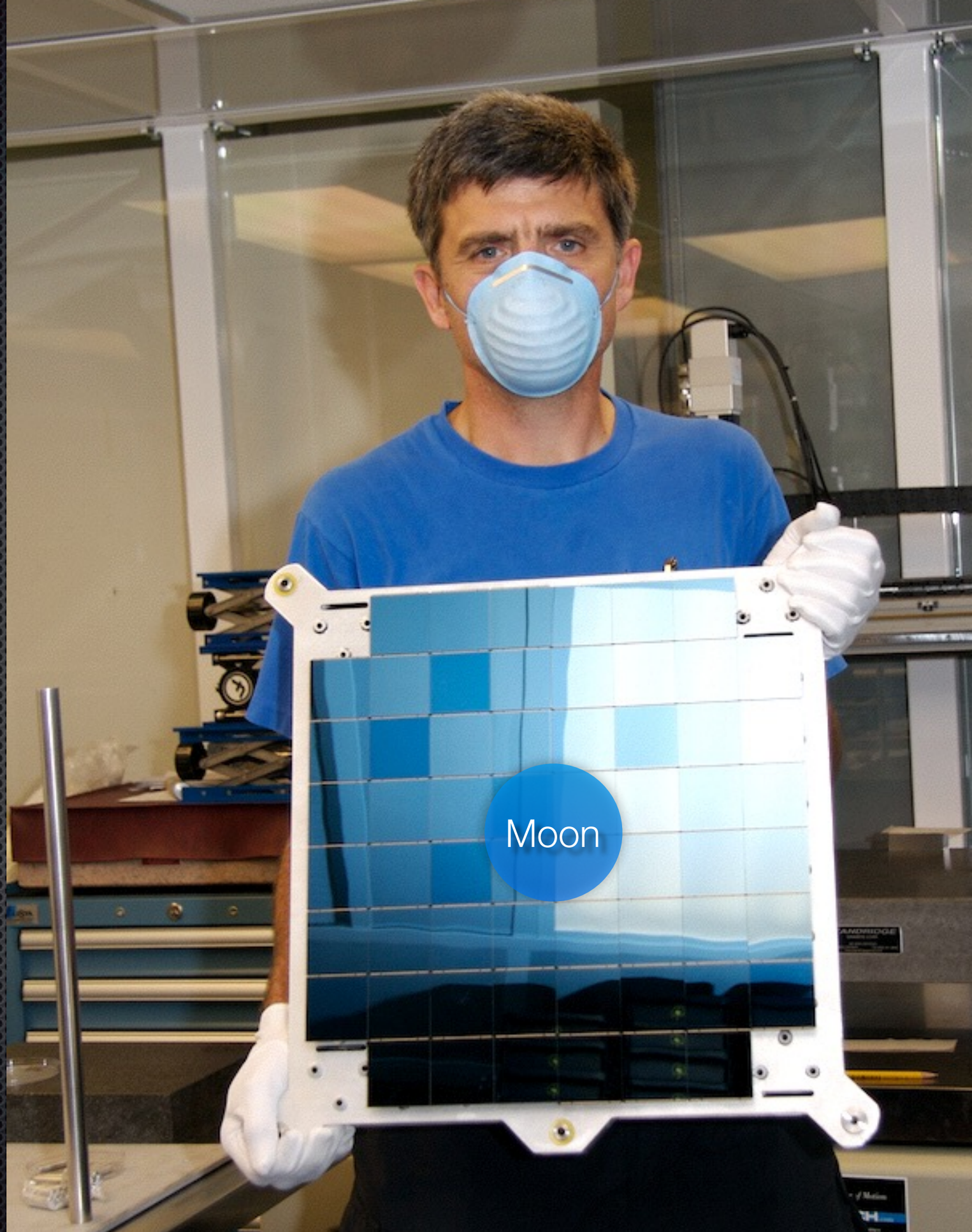
- Energy compared to Chelyabinsk is $(30)^3 * (35/19)^2 =$ 90,000 times as much, or about 40 Gigatons of TNT
- An impact with this energy would be expected to cause about 1,000,000 deaths

The Pan-STARRS telescopes

- Two 1.8-meter diameter telescopes at Haleakala observatory in Maui
- First telescope operational in 2009, second telescope being finished now
- Largest digital cameras in the world
- They will take pictures of the sky up to 4 times per month when both telescopes are operating
- They can survey the sky from +90° to –50° declination

Gigapixel camera

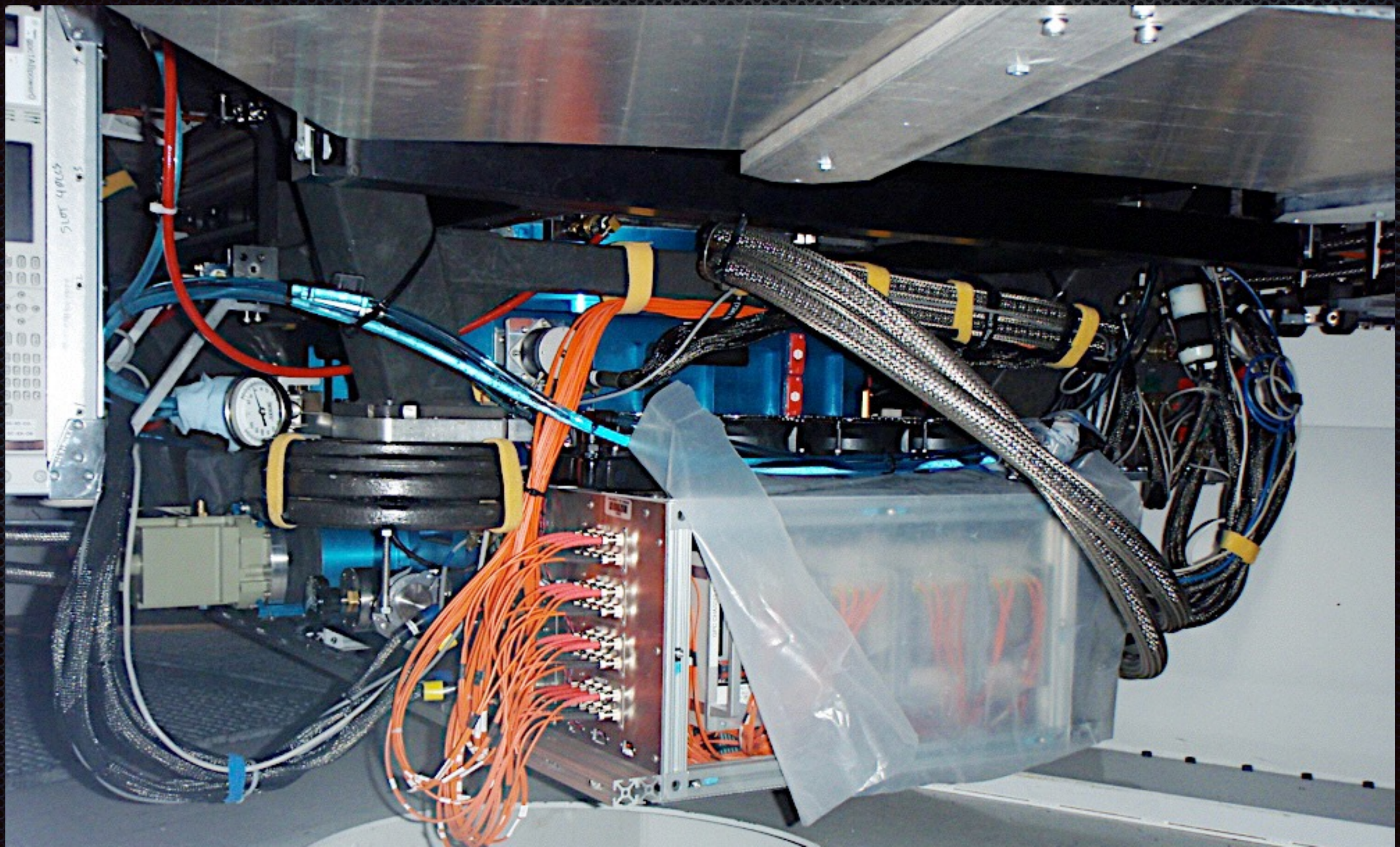
- 1,382,400,000 pixels
- 7 square degree field-of-view



Gigapixel camera

- 3 Gigabytes per image
- 1 image every 40 seconds
- 3 Terabytes per night

Gigapixel camera



Pan-Starrs telescope on Haleakala

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383e- sky or bg

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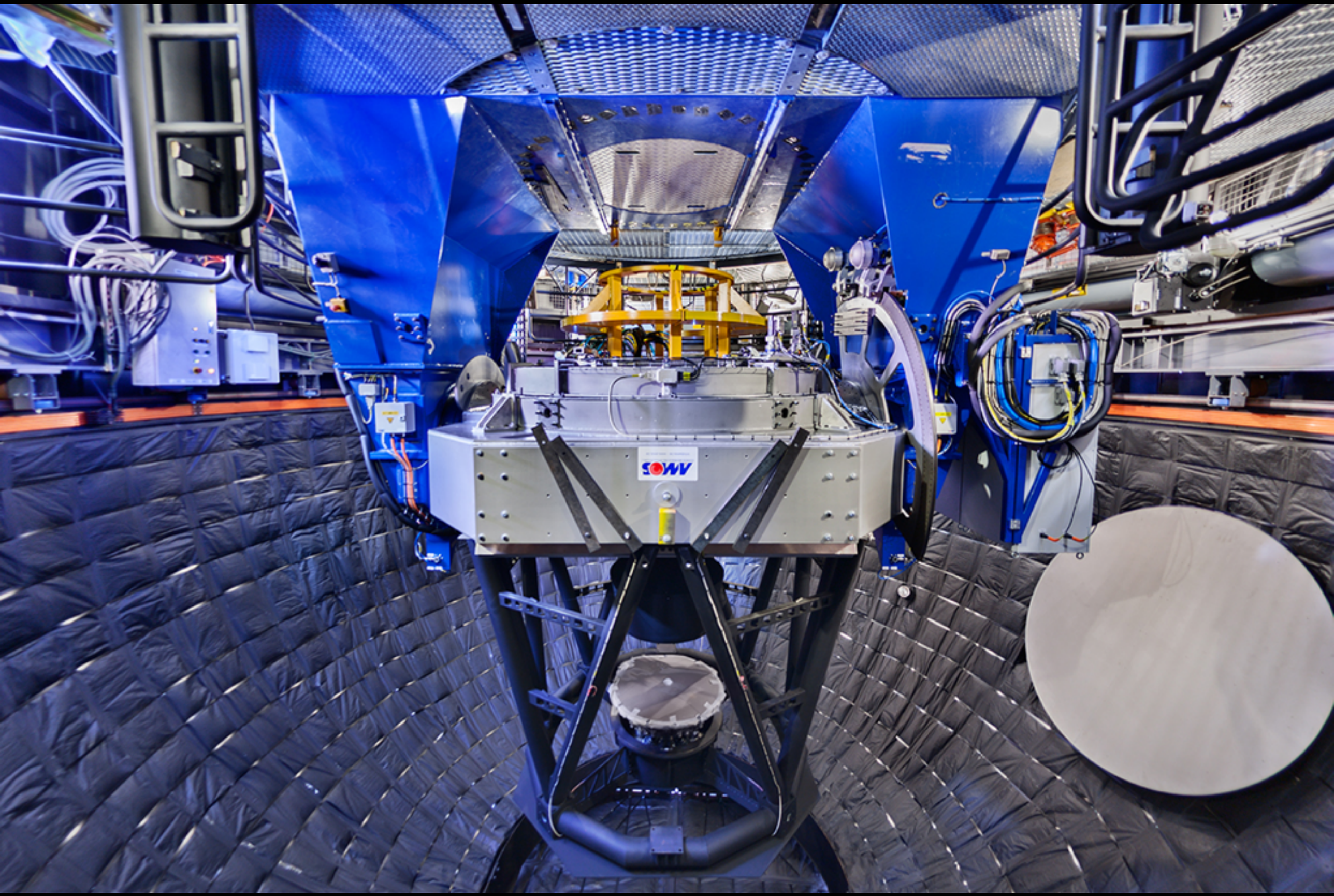
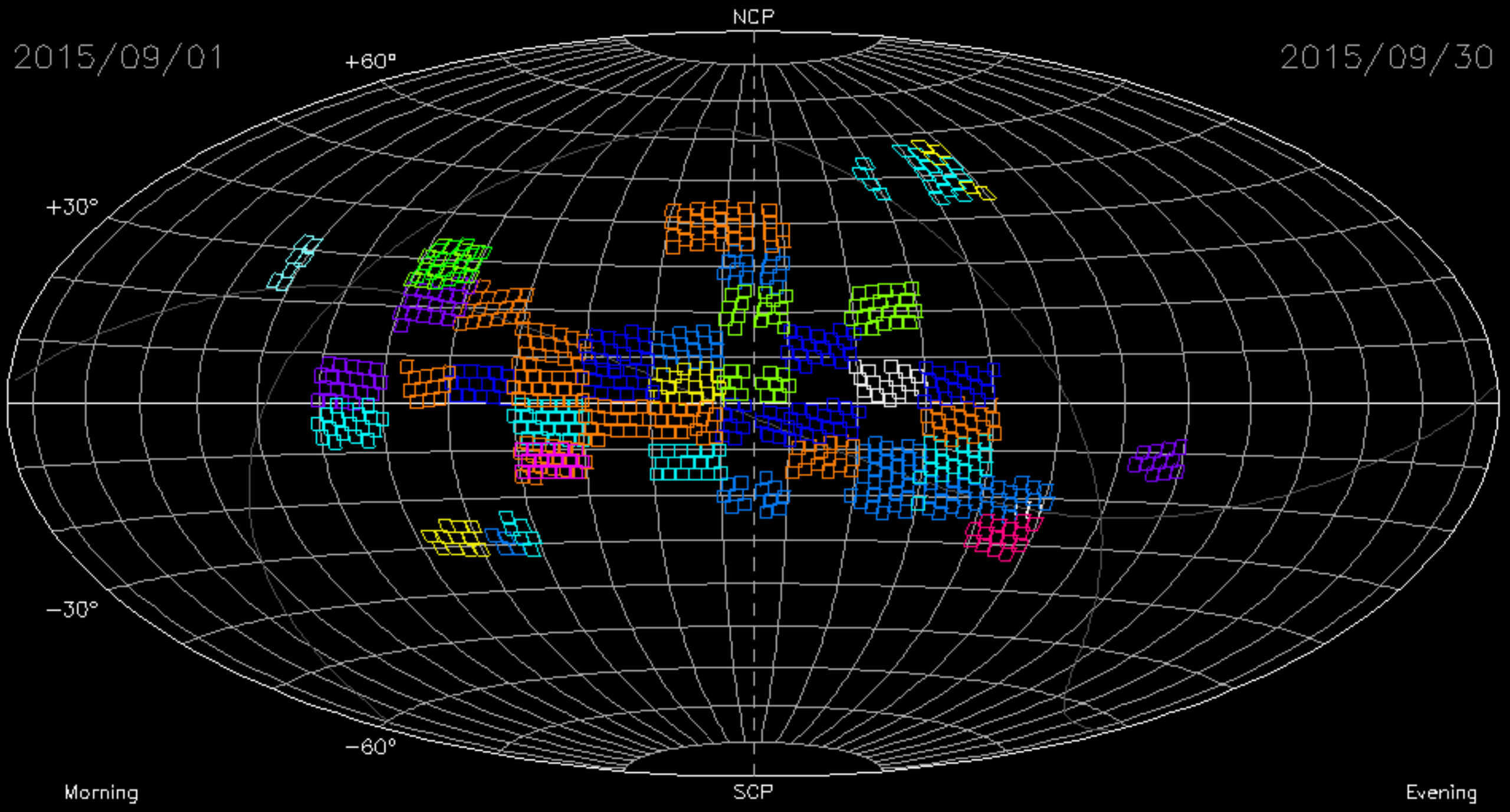
Pan-STARRS2

- Pan-STARRS2 has been constructed adjacent to PS1
- Adding the second telescope enables us to survey a large fraction of the sky multiple times each lunation



SKY COVERAGE

Plot prepared 2015/11/09.150 by the Minor Planet Center

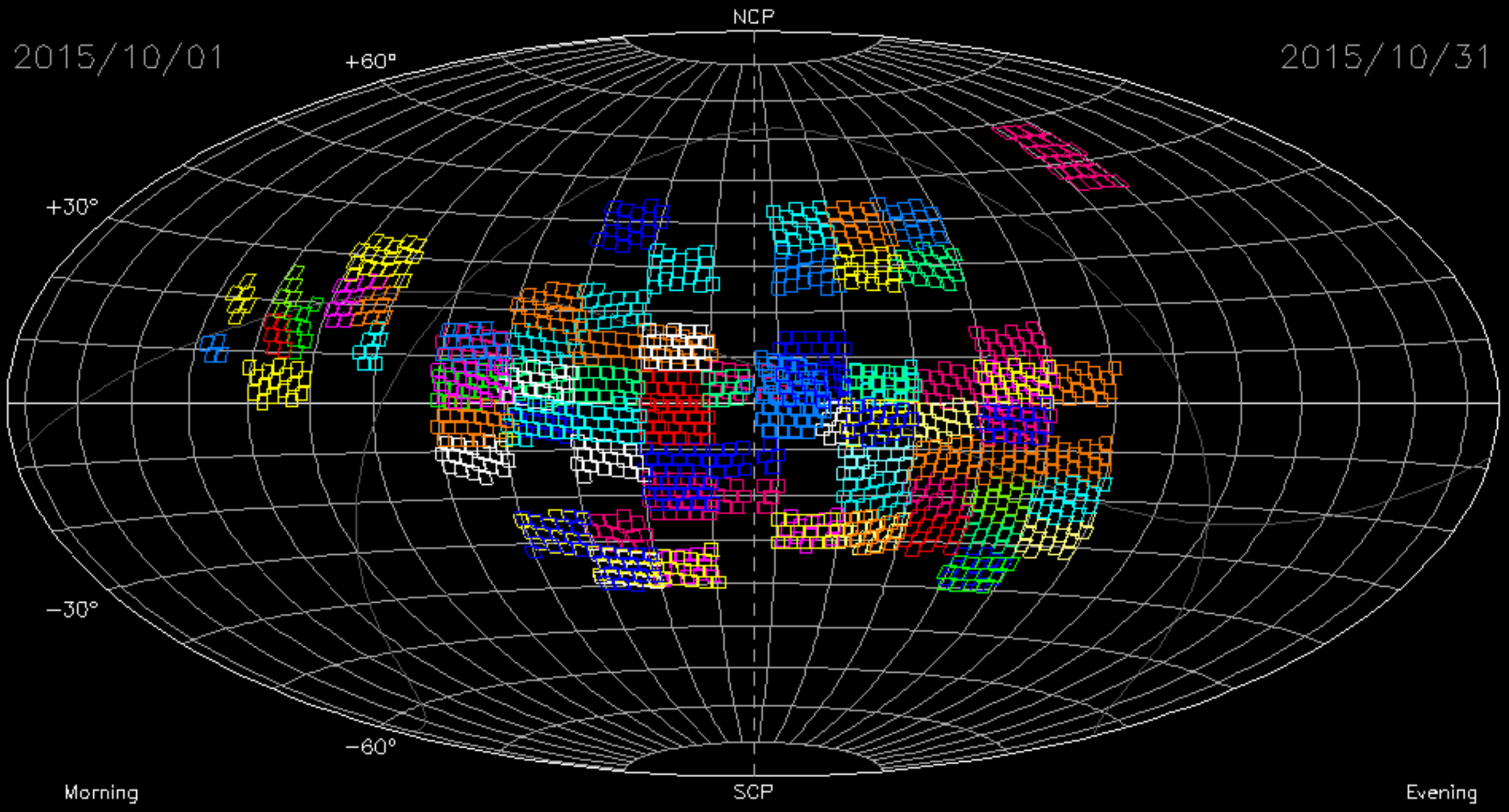


Opposition Point = 23 31.1,−03 08. Fields reaching fainter than V = 18.0.

2015/09/30 (2015 273)	2015/09/29 (2015 272)	2015/09/28 (2015 271)	2015/09/27 (2015 270)	2015/09/26 (2015 269)
2015/09/25 (2015 268)	2015/09/24 (2015 267)	2015/09/23 (2015 266)	2015/09/22 (2015 265)	2015/09/21 (2015 264)
2015/09/20 (2015 263)	2015/09/19 (2015 262)	2015/09/18 (2015 261)	2015/09/17 (2015 260)	2015/09/16 (2015 259)
2015/09/15 (2015 258)	2015/09/14 (2015 257)	2015/09/13 (2015 256)	2015/09/12 (2015 255)	2015/09/11 (2015 254)
2015/09/10 (2015 253)	2015/09/09 (2015 252)	2015/09/08 (2015 251)	2015/09/07 (2015 250)	2015/09/06 (2015 249)
2015/09/05 (2015 248)	2015/09/04 (2015 247)	2015/09/03 (2015 246)	2015/09/02 (2015 245)	2015/09/01 (2015 244)

SKY COVERAGE

Plot prepared 2015/11/09.150 by the Minor Planet Center



Opposition Point = 01 21.7,+08 36. Fields reaching fainter than V = 18.0.

2015/10/31 (2015 304)
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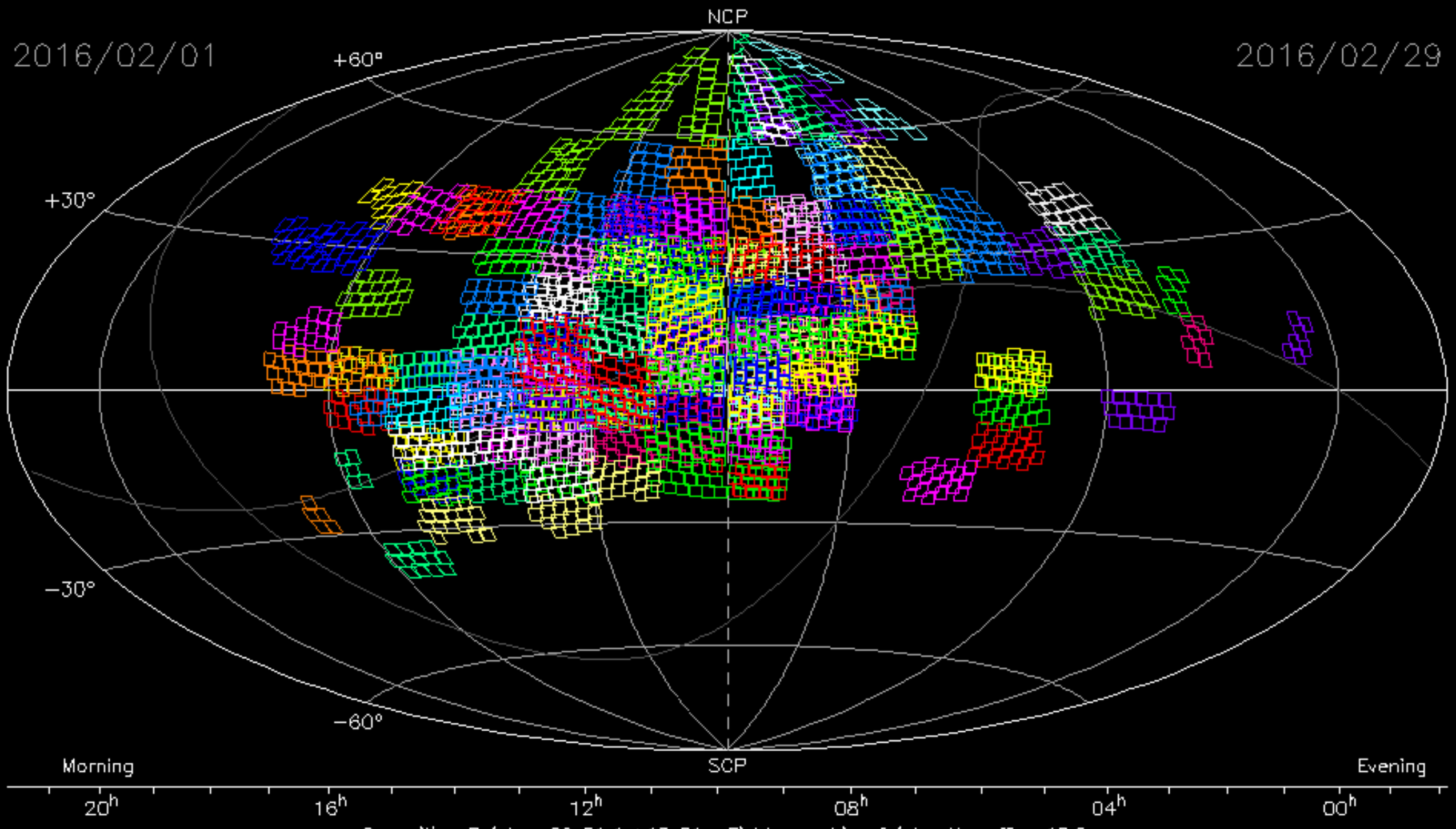
2015/10/02 (2015 275)

SKY COVERAGE

Plot prepared 2016/03/10.656 by the Minor Planet Center



Opposition Point = 09 51.1,+13 01. Fields reaching fainter than V = 18.0.

2016/02/29 (2016 060)
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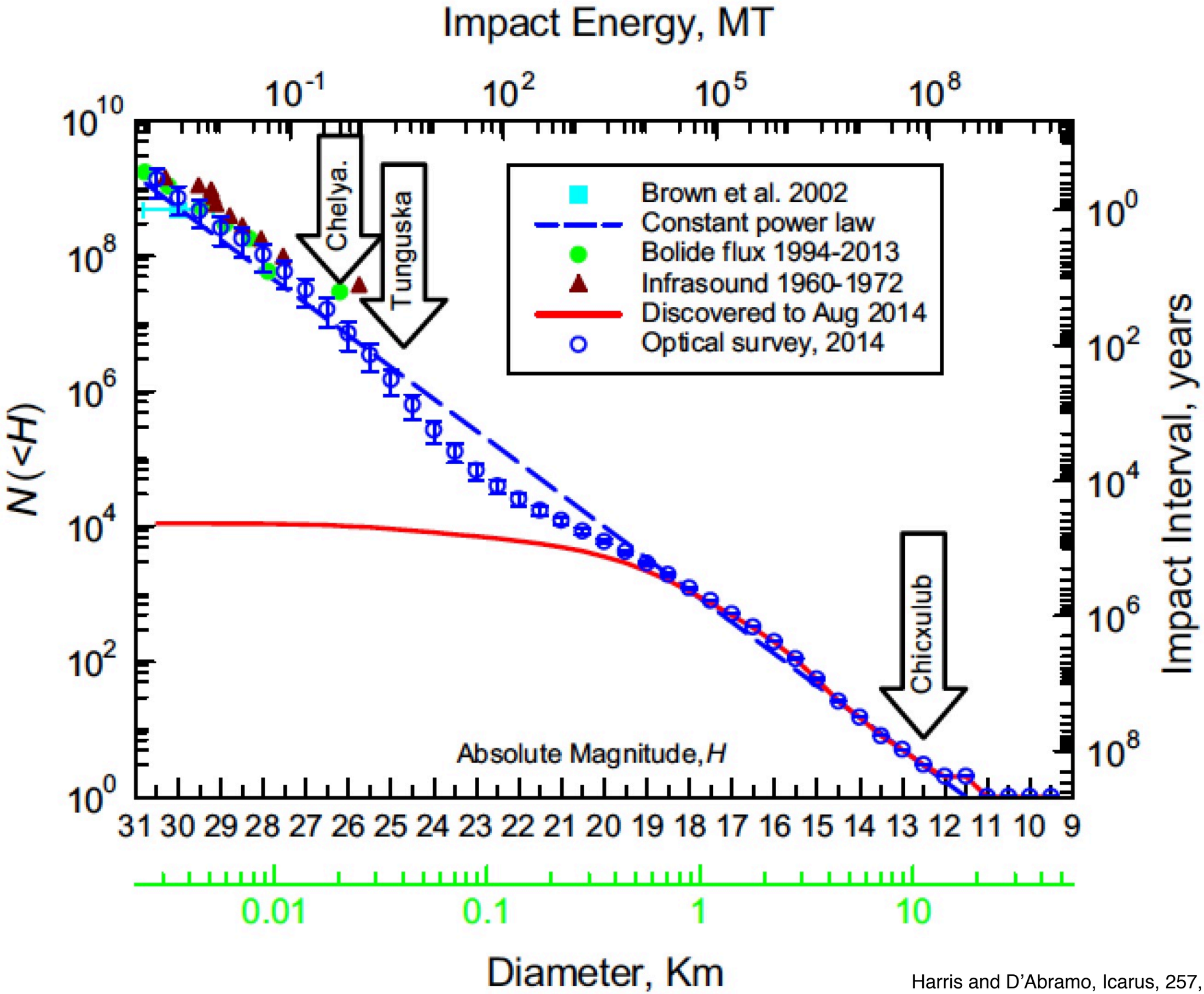
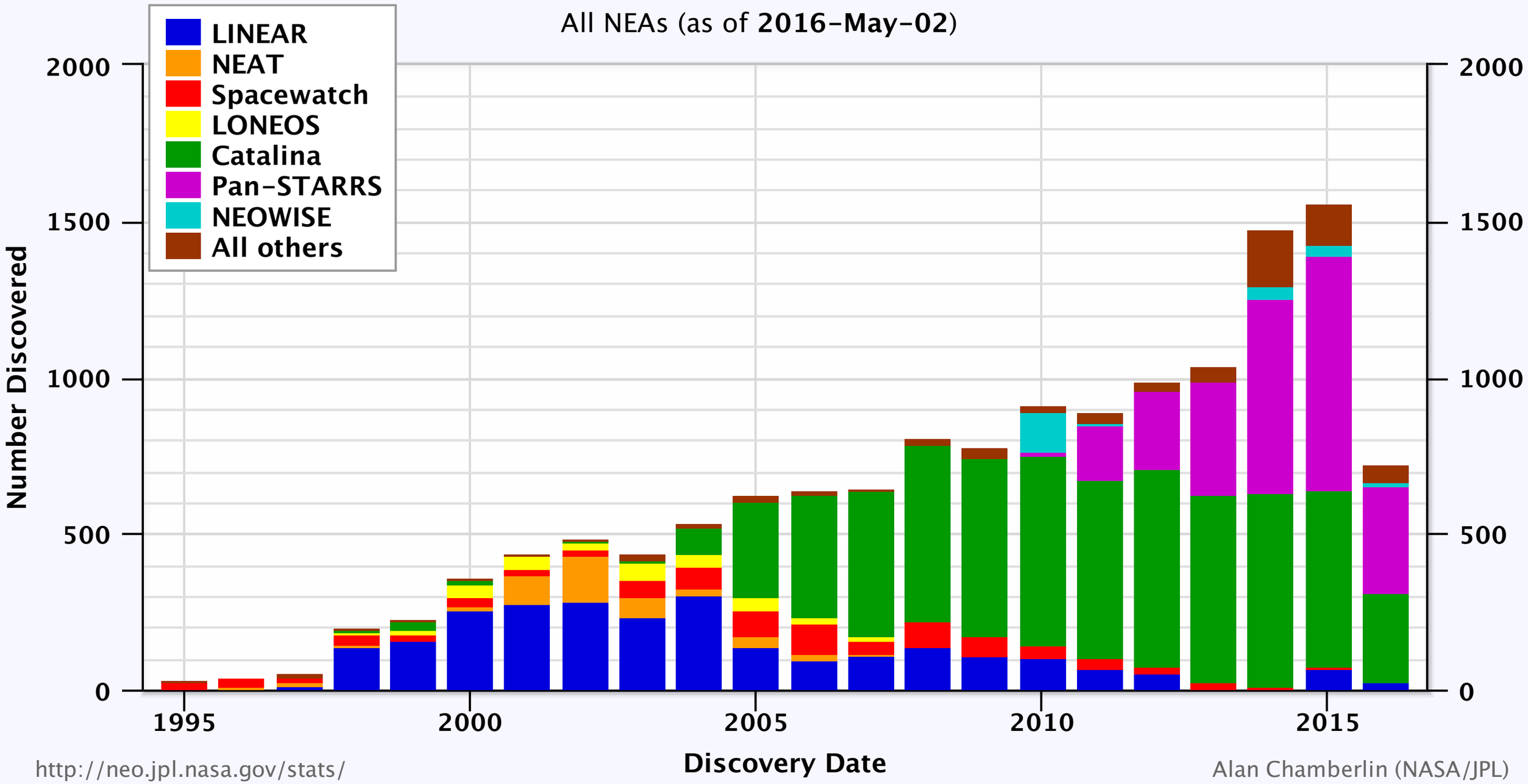


Harris and D'Abramo, Icarus, 257, 302 (2015)

Near-Earth Asteroid Discoveries by Survey

All NEAs (as of **2016-May-02**)



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

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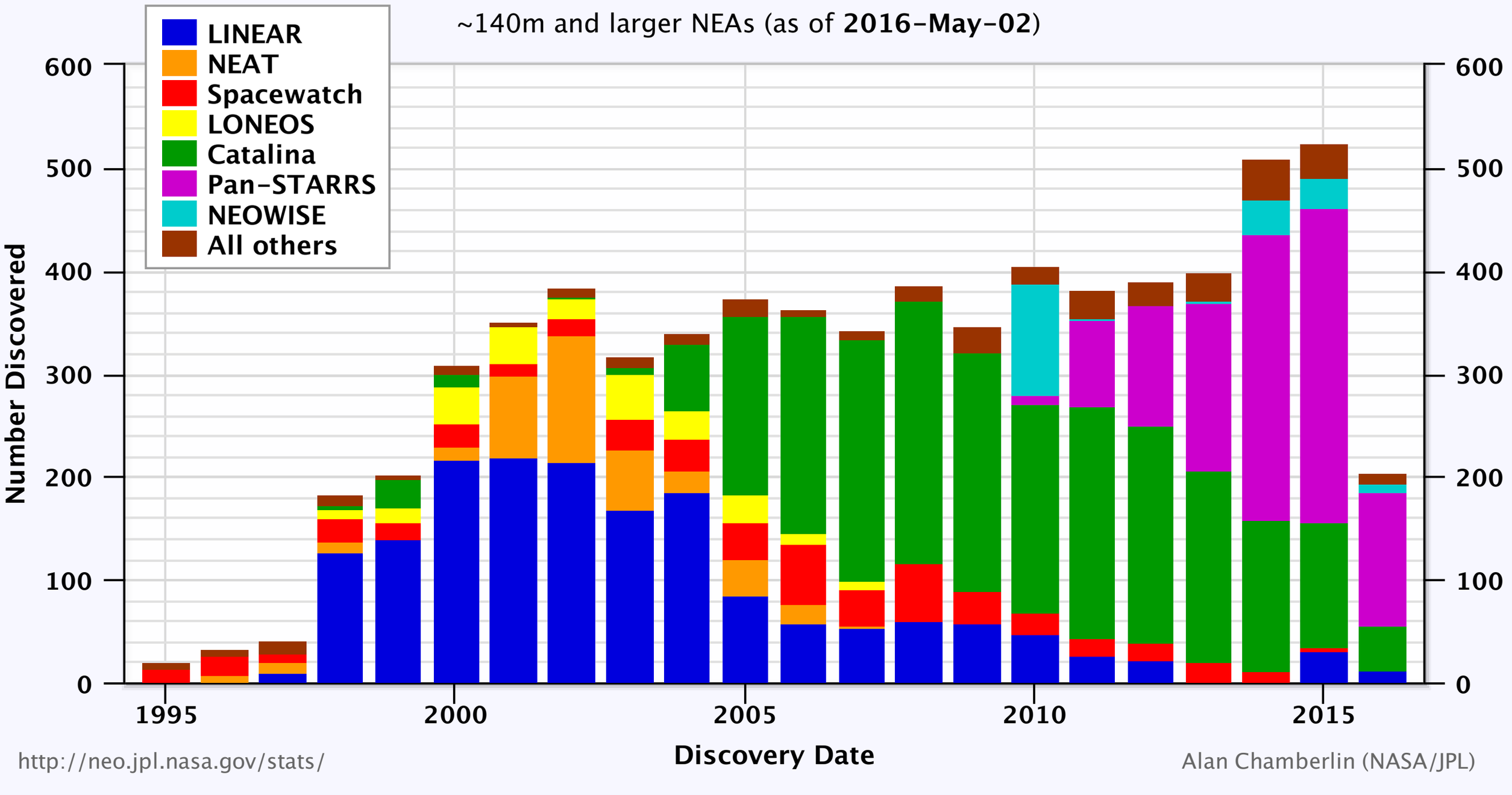
Near-Earth Asteroid Discoveries by Survey

~140m and larger NEAs (as of **2016-May-02**)



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

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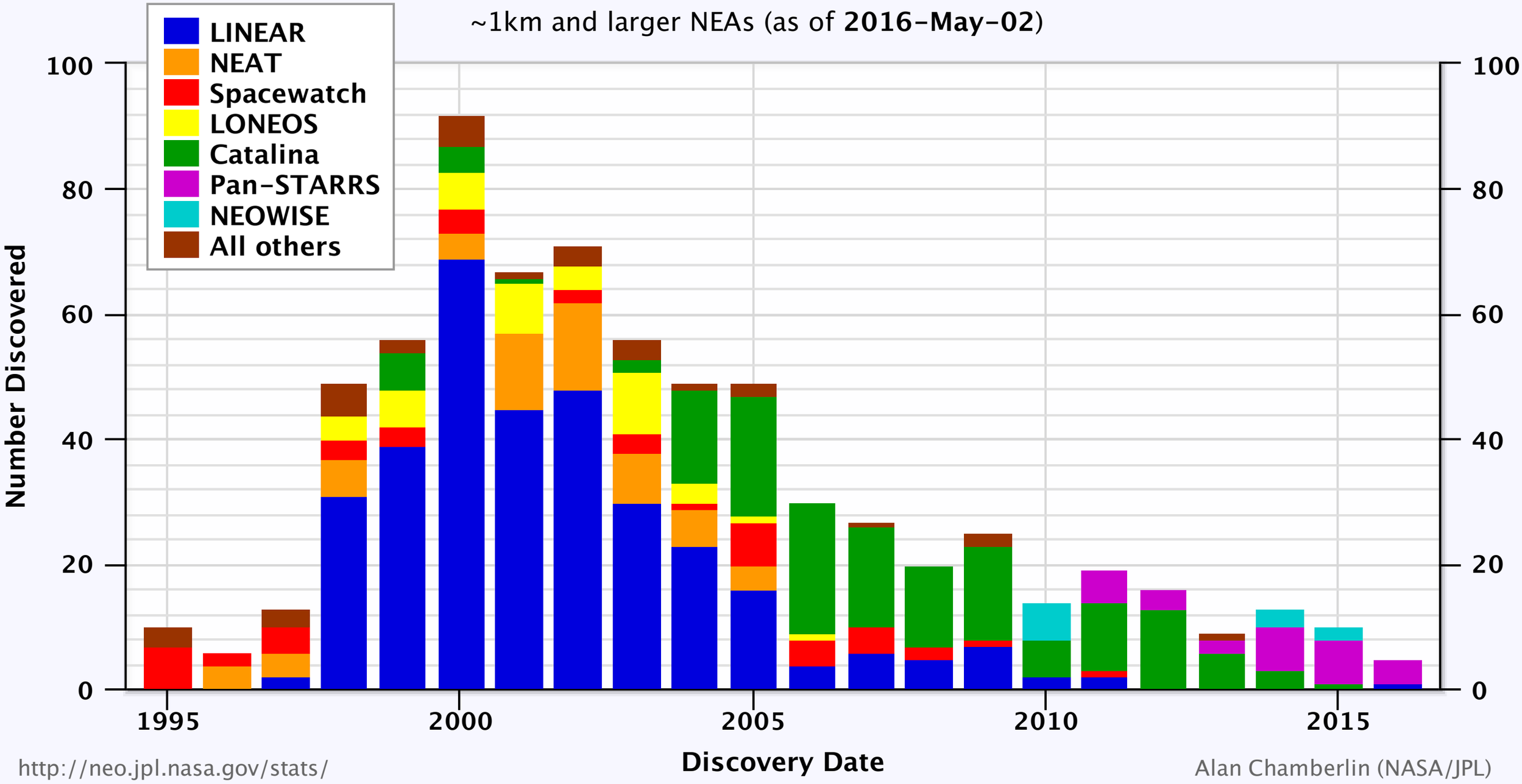
Near-Earth Asteroid Discoveries by Survey

~1km and larger NEAs (as of **2016-May-02**)



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

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Pan-STARRS asteroid data

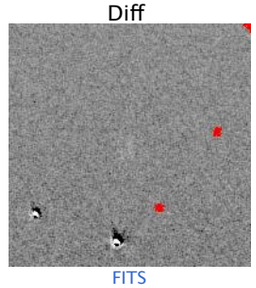
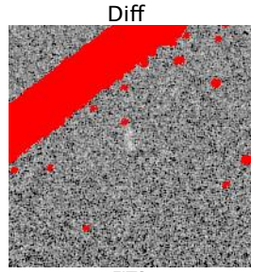
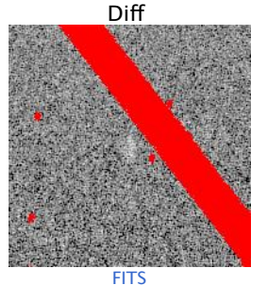
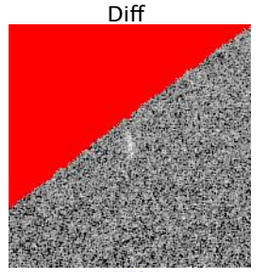
- 7,300,000 tracklets submitted
- 25,000,000 detections submitted
- 645,000 distinct asteroid observed
- 456,000 unnumbered asteroids observed
- 190,000 asteroid discoveries
- 4,630,000 detections in isolated tracklet file

46120482

Show trail-fitted astrometry | Submit suspected comet | MPCheck
Detections MPC | DES
IOD Search

Submitted as **P10oPL4** by **schunova**

UNATTRIBUTED	NONSYNTHETIC	N/A	2.768 RA −0.126 DEC −2.765 Ecliptic λ −1.017 Ecliptic β −2.620	−177.4	NEO 100.0 Prob 0.85	0.94

Field ID	Detection ID	Epoch (MJD)	Δt	RA (deg)	Dec (deg)	S/N	Mag	Filter	V-Mag	Obscode	MOPS Object Name	Flags	Morphology Show Extended Attributes	Stamp Download ZIP Download 1k Chip Stamps (Experimental)	Submit
o7317g0524o (350756) OSSR.R03S2.11.Q.w PA: 307.8° Decider | IQ OTA CELL FLAGS 66 11 N	3526343060	57317.502932 2015-10-22 12:04:13.0 UT	--	51.822949 3h27m17.51s ±0.20"	−10.684080 −10d41'02.69" ±0.20"	4.41	22.05 ±0.25	w	22.21 ±0.25	F51	NS	**0X2204001** PSFMODEL EXT_LIMIT AP_MAGS LINEAR_FIT **0X000080** PASS1_SRC	Moment ratio: 4.32 Major axis: 7.13px Minor axis: 4.25px PA: 173.25° χ^2/DOF: 1.08	Diff  FITS Req 1000x1000 | Comet	☑
o7317g0541o (350757) OSSR.R03S2.11.Q.w PA: 307.8° Decider | IQ OTA CELL FLAGS 66 01 N	3526350847	57317.513965 2015-10-22 12:20:07.0 UT	+15m	51.821464 3h27m17.15s ±0.18"	−10.715231 −10d42'54.83" ±0.18"	5.50	21.84 ±0.20	w	22.00 ±0.20	F51	NS	**0X2200001** PSFMODEL AP_MAGS LINEAR_FIT **0X0000C2** DIFF_WITH_DOUBLE ON_CONVPOOR PASS1_SRC	Moment ratio: 3.84 Major axis: 5.99px Minor axis: 4.51px PA: 11.11° χ^2/DOF: 1.02	Diff  FITS Req 1000x1000 | Comet	☑
o7317g0558o (350774) OSSR.R03S2.11.Q.w PA: 307.8° Decider | IQ OTA CELL FLAGS 66 0-1 N	3526483140	57317.524980 2015-10-22 12:35:58.0 UT	+31m	51.820147 3h27m16.84s ±0.20"	−10.745150 −10d44'42.54" ±0.20"	4.59	21.85 ±0.24	w	22.01 ±0.24	F51	NS	**0X2204001** PSFMODEL EXT_LIMIT AP_MAGS LINEAR_FIT **0X0000C0** ON_CONVPOOR PASS1_SRC	Moment ratio: 5.20 Major axis: 6.98px Minor axis: 5.29px PA: 178.77° χ^2/DOF: 1.06	Diff  FITS Req 1000x1000 | Comet	☑
o7317g0575o (350775) OSSR.R03S2.11.Q.w PA: 307.8° Decider | IQ OTA CELL FLAGS 56 70 N	3526488851	57317.535984 2015-10-22 12:51:49.0 UT	+47m	51.818772 3h27m16.51s ±0.19"	−10.775481 −10d46'31.73" ±0.19"	5.04	21.67 ±0.22	w	21.83 ±0.22	F51	NS	**0X2200001** PSFMODEL AP_MAGS LINEAR_FIT **0X0000C0** ON_CONVPOOR PASS1_SRC	Moment ratio: 4.42 Major axis: 7.04px Minor axis: 4.46px PA: 7.93° χ^2/DOF: 0.95	Diff  FITS Req 1000x1000 | Comet	☑

MPC Digest

Full results

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MPC Digest2
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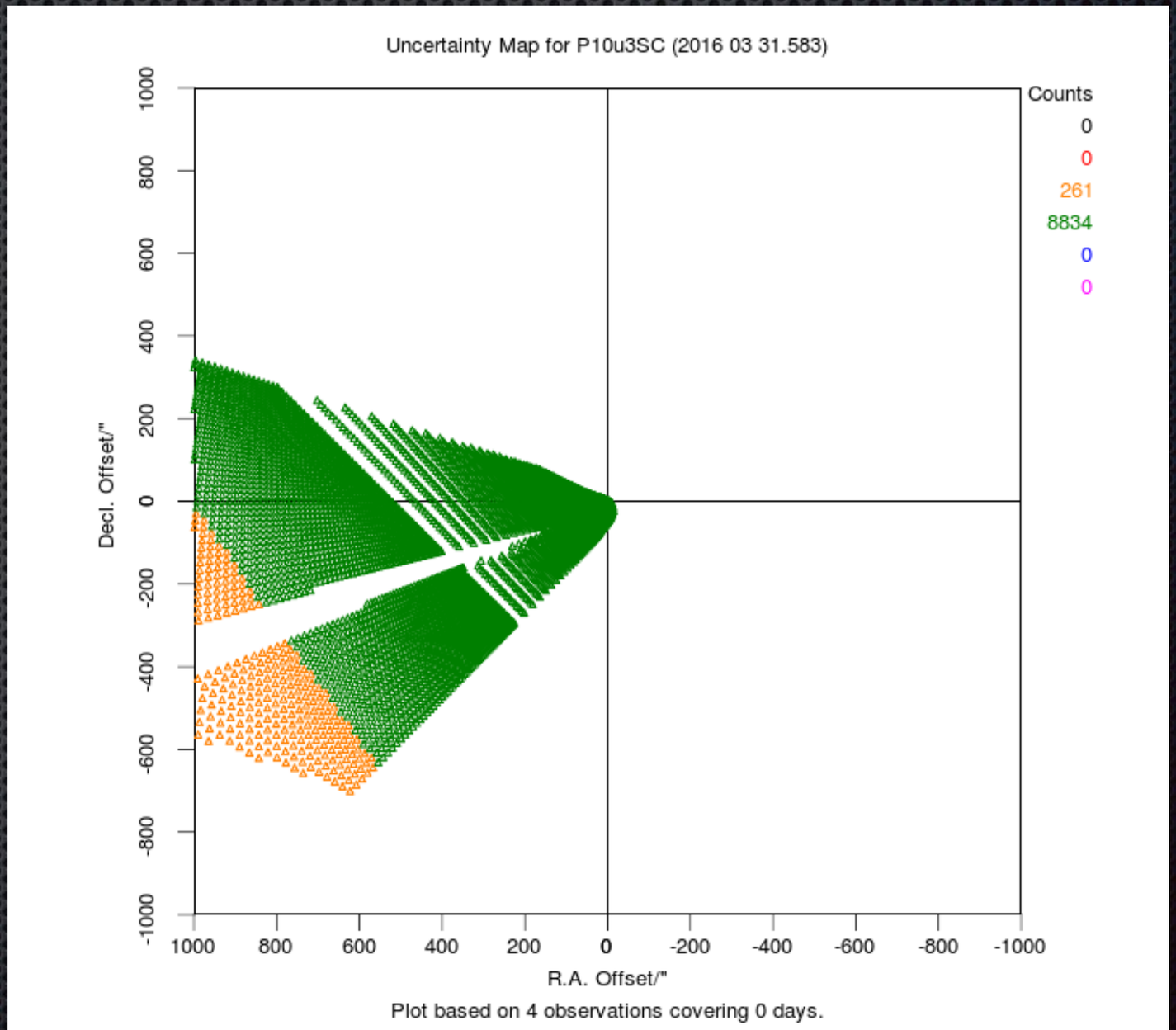
Recovering NEOs with CFHT

- We attempt to recover NEOs with CFHT one night after they are discovered by Pan-STARRS
  - Typical motions range from 0.1 to 10 degrees per day
- The wide field of view of MegaCam is essential

Recovering NEOs with CFHT

- Nearly all uncertainty regions are asymmetric
- Additional offsets — to center in chips 15, 24, and 16, 25 would be very helpful



Explanation of Uncertainty Map

What do possible impactors look like?

- Relatively slow motion in the sky
- Their motion shows curvature
  - This is caused by our own motion as Earth rotates
- The wide field of view of CFHT is very important because predicted positions can have large errors

Comets

- Pan-STARRS discovered more than half of all new comets in 2014, 2015 and to date in 2016
  - CFHT has played a major role in confirming nearly all of these comet discoveries
    - The excellent image quality is essential for confirming cometary nature

Low-activity comets

- Pan-STARRS has discovered what may be a new class of comets that have low activity
  - These may represent asteroidal material that was ejected into the Oort cloud at the same time as icy comets were ejected into the Oort cloud
- CFHT has played a critical role in identifying these objects
- First paper was published in Science Advances on April 29

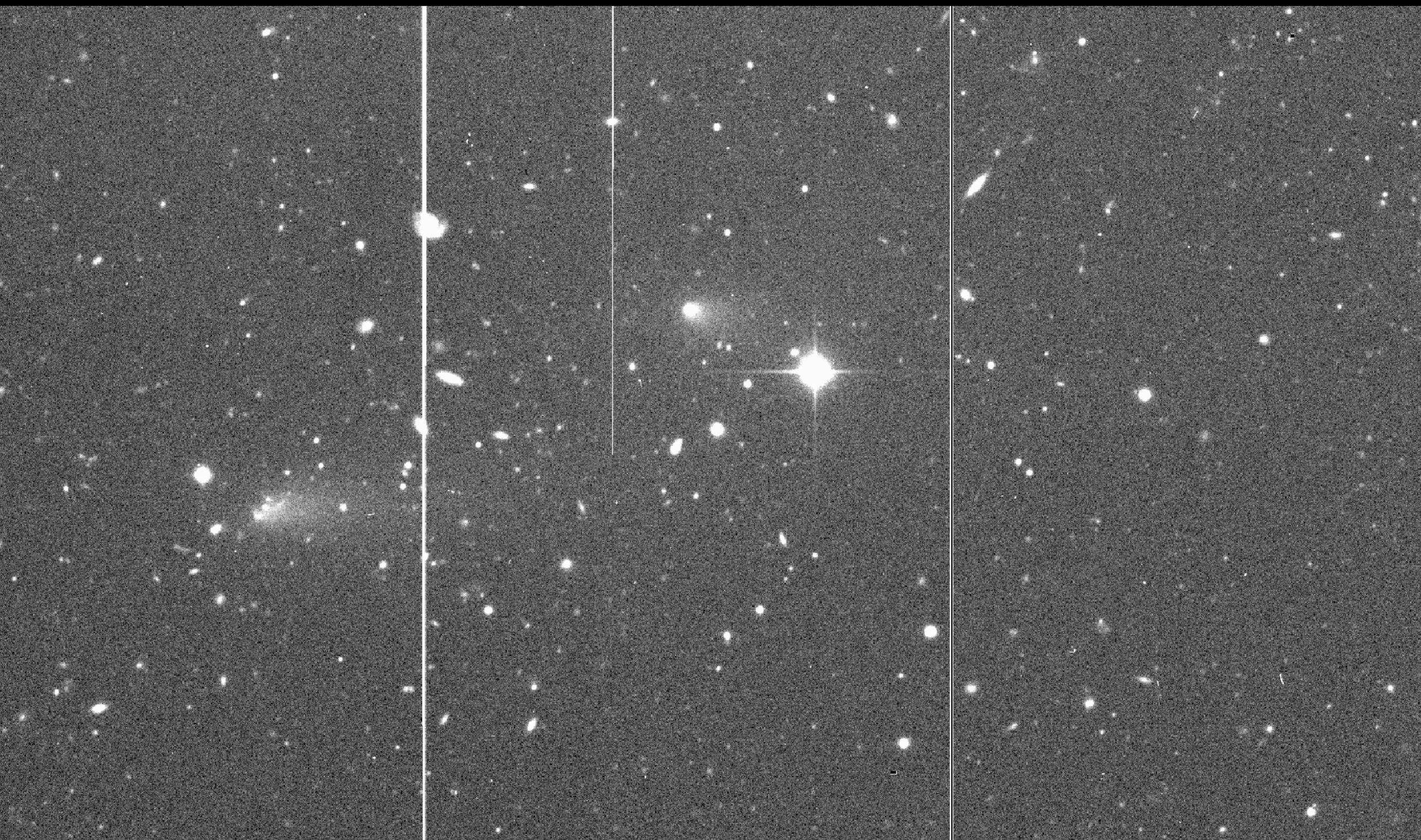
Low-activity comets

- Amateur astronomers had been claiming to see cometary activity on some of these objects, hiding their true nature
- These low activity comets (asteroidal material from the Oort cloud) may represent a new, unaccounted for impact risk to Earth
  - Velocity relative to Earth is high due to elliptical orbits
    - Kinetic energy from impact will be much higher than for a comparably sized asteroid with Earth-like orbit

Split comet

- We have been following Comet P/2010 V1 since January using MegaCam
  - It has been undergoing a spectacular splitting event
    - Pieces of the comet are spread over three chips of MegaCam and undergo rapid changes in brightness
    - We obtained imaging with HST
    - It is now becoming fainter, and there is a a large amount of diffuse emission spread over several chips

P/2010 V1 (center chip)



Future plans

- We plan to continue using MegaCam to characterize unusual solar system objects detected by Pan-STARRS
- Soon, we hope to detect, and characterize a (small) object before impact with Earth
- Pan-STARRS discoveries of comets, combined with CFHT followup is proving to be particularly productive