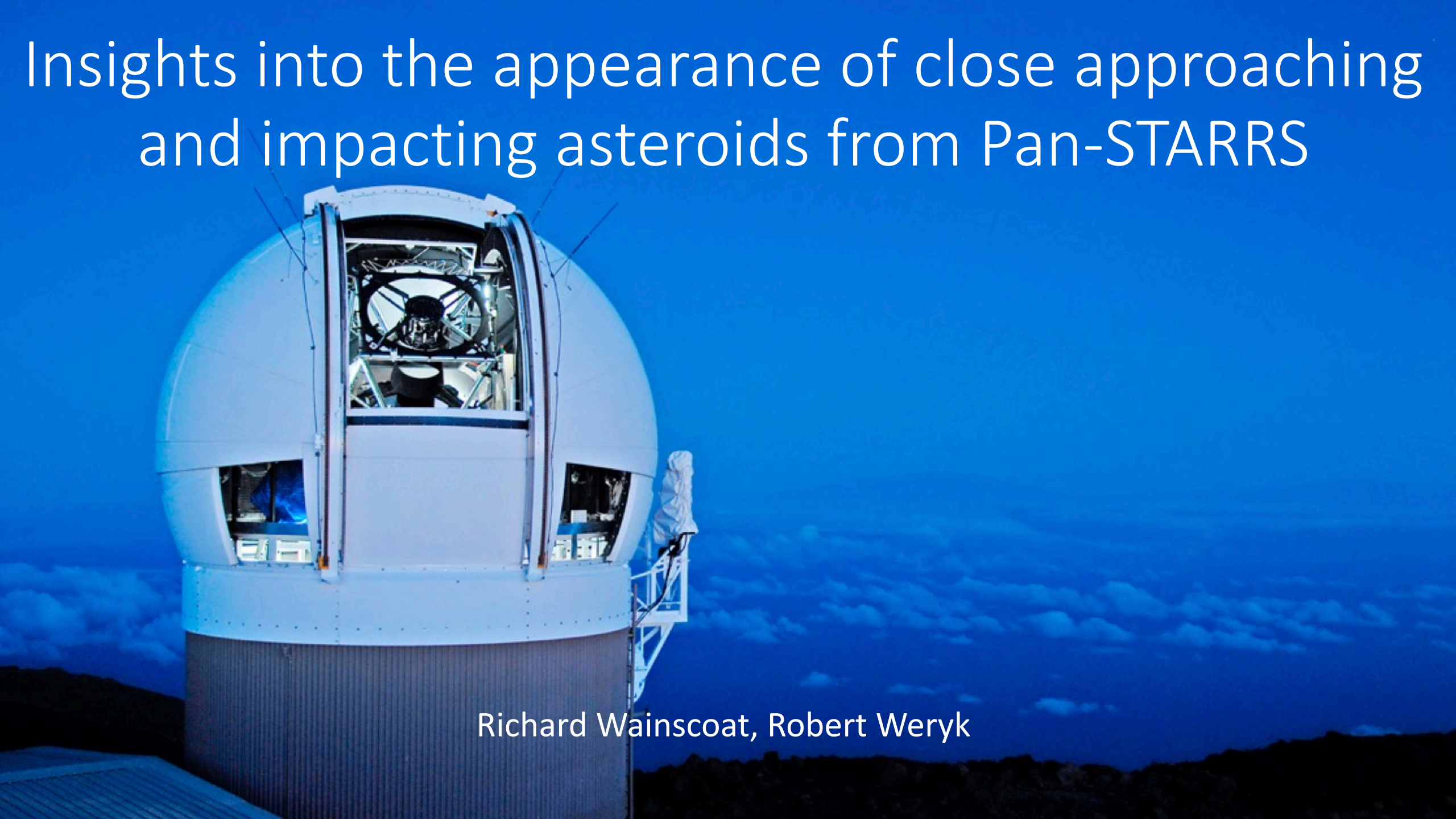
Insights into the appearance of close approaching and impacting asteroids from Pan-STARRS



Richard Wainscoat, Robert Weryk

2019 OK

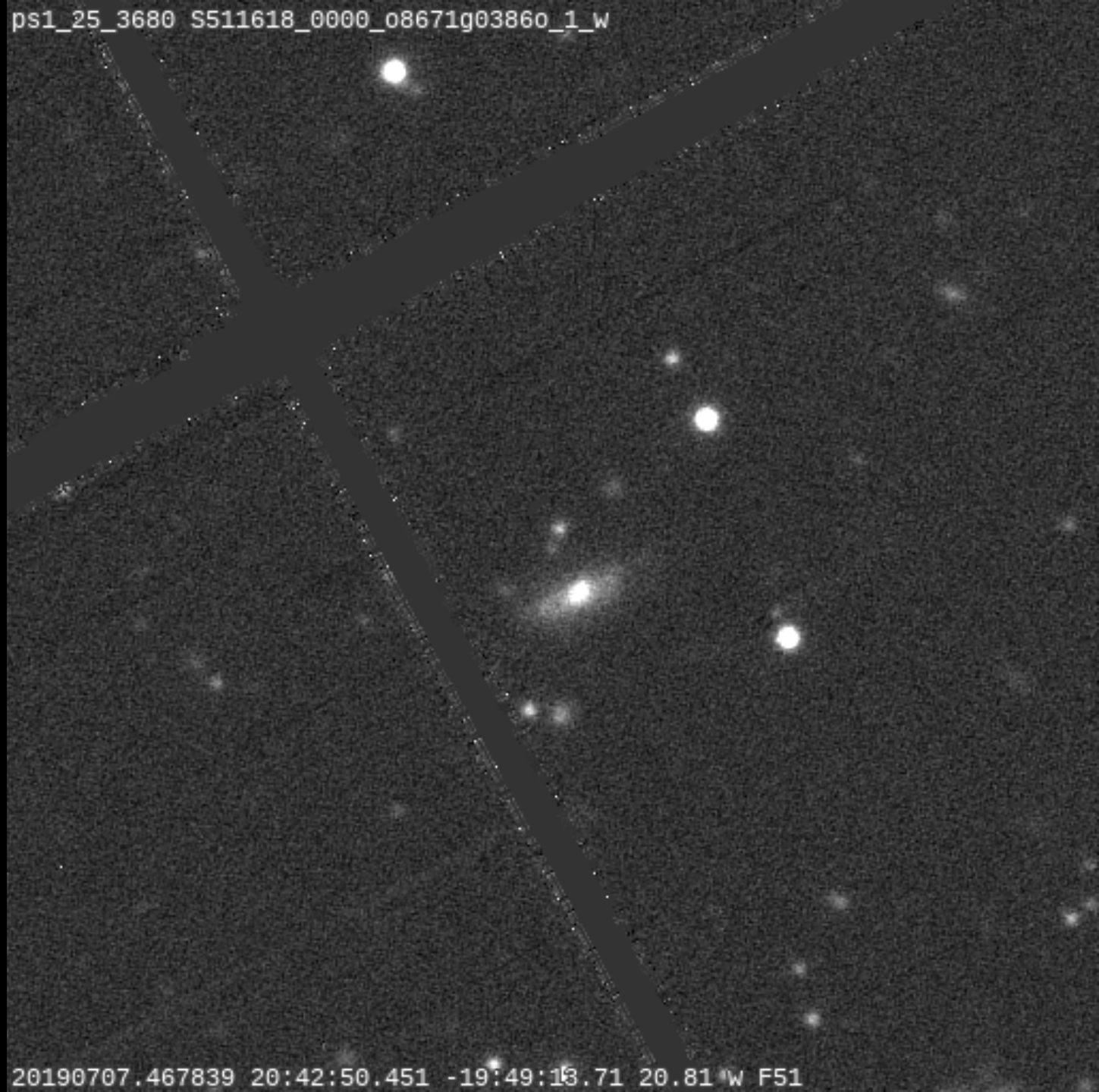
- 100-meter asteroid that passed within 71,000 km of Earth on July 25, 2019
  - It was discovered on July 24, one day before close approach

June 28, 2019

- 27 days before close approach
- 0.07 degrees per day
- V=22.7
- Digest2 score was 87
- Too faint for automatic detection

July 7, 2019

- 18 days before close approach
- 0.01 degrees per day
- V=21.2
- Digest2 score 99
  - Motion was to the east
- Motion was too slow for automatic detection



2019 OK

- This object highlights some of the problems discovering possible impactors
  - Motion was very slow
  - Around July 17, the Full Moon crossed right in front of the object
    - Surveys didn’t look near the object between July 16 and July 20 because of the Moon
  - The Milky Way was about 30 degrees to the west
    - Pan-STARRS and Catalina avoid the Milky Way
  - As impactors get closer, for several days, their motion mimics that of main-belt asteroids (so they are likely to be ignored)
    - Their motion will likely show curvature due to proximity

2019 OK

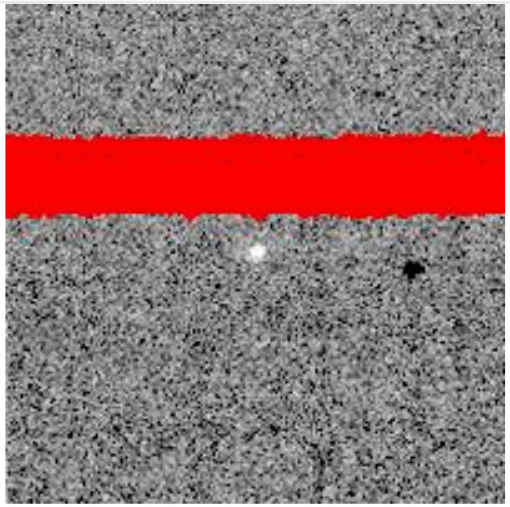
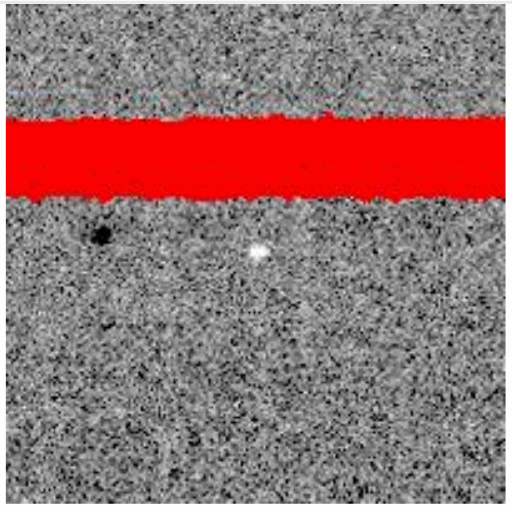
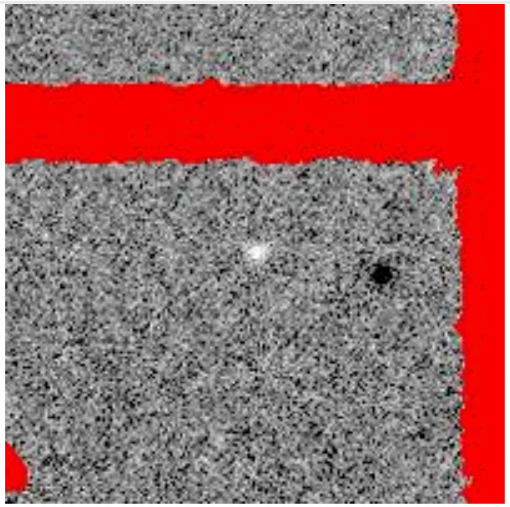
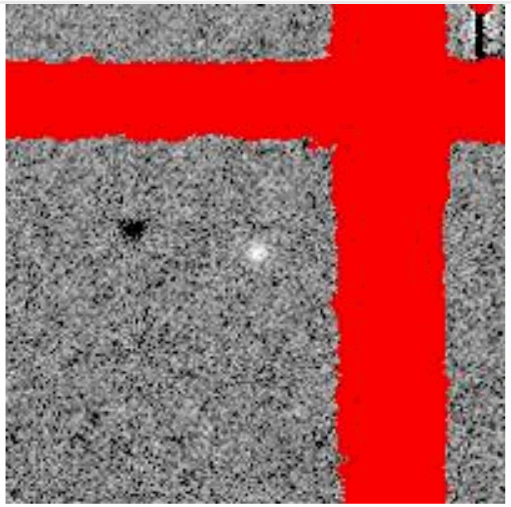
- The motion of a nearby object depends on what time of night it is observed
- Most observatories are at desert (low) latitudes, so the topocentric motion due to rotation of the observer around Earth's axis is significant, and changes depending on the time of night and aspect of the observation
- Pan-STARRS and other surveys usually try to observe near the meridian to get good image quality, and reduced sky brightness and extinction
  - If Pan-STARRS had observed 2019 OK earlier or later on July 7, 2019, the motion would have been faster, and perhaps it would have been discovered

2019 OK

- Wainscoat et al. (Icarus, 2021) show that some asteroids approaching Earth from a little east of opposition undergo a period of very slow apparent motion which will make them very difficult to discover by a survey that is searching for moving objects
  - It occurs because induce topocentric westward motion cancels natural eastward motion of the object as it approaches Earth
  - It does not occur for objects approaching Earth from west of opposition — these objects move to the west
    - However, objects approaching from the west may have motions that mimic main-belt asteroids resulting in them being ignored

2020 SO

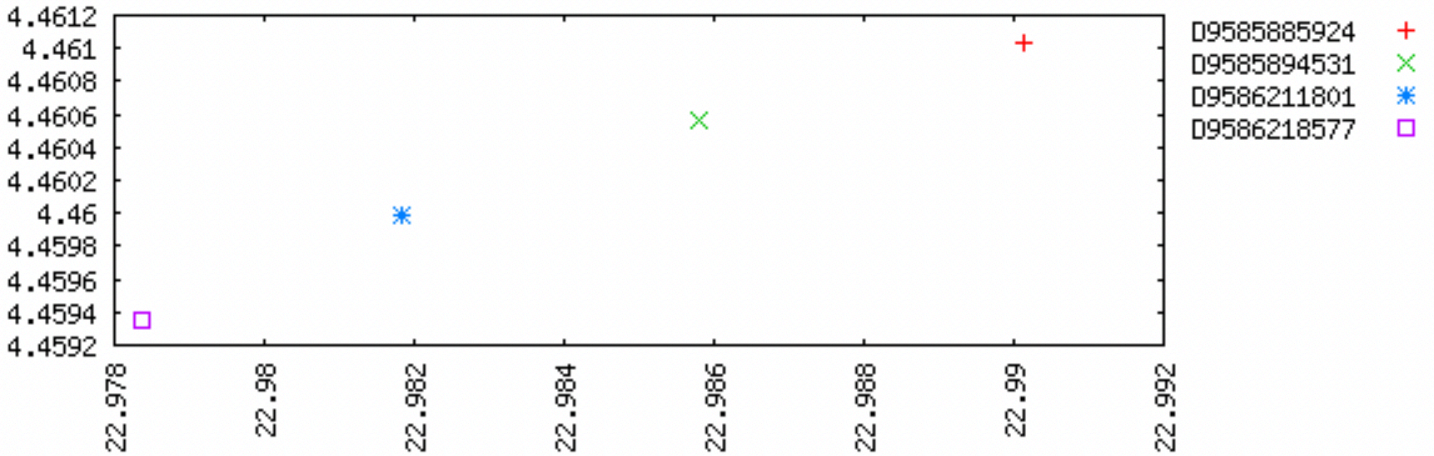
- Although this object turned out to be a the Surveyor 2 Centaur rocket booster body, the discovery provides valuable insight
- It was seen by Pan-STARRS as a faint object that had main-belt type motion
  - However, it was not moving in a straight line — its motion had curvature
  - Curvature is a signature of a nearby object since it must be caused by topocentric motion of the observer
- The object was forced onto the NEO Confirmation Page

FITS
FITS

Recompute tracklet features with selected detections

eatures



	Digest	Probability	Velocity	Pos. Ang.	GCR	GCD	Curvature	Export
iff)	1.0	N/A	0.203 $^{-0.201/-0.201}_{-0.03}$	-98.2	0.724	0.271	+0.116 | −0.366 | −0.365 | +0.116	80c ADES Java/C

2020 SO

- This object was discovered because it had a lot of curvature and very clean astrometry
- On a good night, Pan-STARRS submits tracklets for thousands of main-belt asteroids
  - Usually, low-digest score objects with high great circle residuals aren’t submitted — usually because of poor astrometry — often, one of the detections is corrupted or touches a cell boundary

Curvature — can we do better?

- Objects with digest score <65 are not normally published to the NEO Confirmation Page
- Digest does not consider curvature — it is based solely on the bulk motion in the tracklet
- Present efforts to find low-digest high-curvature objects with Pan-STARRS are manual, and require diligence from the person reviewing the objects
  - This can be difficult when faced with many thousands of tracklets, nearly all of which are ordinary main-belt objects

The danger of “crying wolf”

- Bad astrometry can mimic curvature, and produce apparent impactors
- We need to be careful when submitting objects that appear to have significant curvature — is the astrometry good?
- Fast-rotating asteroids can be difficult to measure when they have a significant light curve
  - The light curve can produce an inaccurate position which may have the appearance of curvature
  - Sometimes, the only reliable way to measure a position of a fast-rotating asteroid may be completely manual

Recent improvements at Pan-STARRS

- Both telescopes are now working well, with similar efficiency
- We now attempt same-night self-follow up of NEO candidates that post to the NEOCP
  - This is useful because there are few NEO follow up assets immediately to the west of Hawaii
  - The self-follow up extends the arc from about 1 hour to 3–4 hours, which places strong limits on the distance of the NEO candidate
  - This should be very helpful in the event that a possible impactor is discovered by Pan-STARRS

Recent improvements at Pan-STARRS

- Self-follow up is not possible at the end of the night, because the twilight makes the sky too bright
- Self-follow up is also limited by moonrise during the waning gibbous phase of the lunar cycle

Is Pan-STARRS seeing impacting objects and not reporting them?

- Probably
- Pan-STARRS is inefficient at discovering faster moving asteroids
  - Asteroids may move across cell gaps in our detectors
  - Trailed objects are not as easily detected as point sources
- The findtracklets algorithm that Pan-STARRS and others use to find moving objects relies on the objects moving (at least mostly) in a straight line
  - Detections of an object with signifiant curvature may not be linked

Should Pan-STARRS adjust its observing strategy to find imminent impactors?

- Pan-STARRS does very well at discovering larger NEOs, and this is a major focus of our mission
  - We plan to continue our present strategy of using a sequence of four 45-second w-band exposures spaced over approximately 45 minutes
- Pan-STARRS is probably more efficient at detecting impactors that are a few days out than small impactors less than 24 hours before impact
  - Larger impactors are more important than small impactors that will burn up in the atmosphere

How can Pan-STARRS improve its detection of imminent impactors?

- The Pan-STARRS cameras are not ideal for the detection of fast-moving objects, and replacing the cameras could yield a large improvement in detection efficiency
  - New cameras would use larger modern detectors that do not have the cell structure that is in the present Pan-STARRS CCDs
  - New cameras would have higher quantum efficiency, slightly larger area, and less noise; longer exposure times could be used
  - New cameras would likely double the number of NEOs discovered by Pan-STARRS
  - CCDs or CMOS?