The Pan-STARRS Data Archive
An invaluable resource of faint Near-Earth Object detections

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The Pan-STARRS NEO Survey

- Pan-STARRS is funded by the NASA Near-Earth Object Observations program, and has become one of the most successful surveys for Near-Earth Objects

- The first 3.5 years of Pan-STARRS surveying was a multi-purpose survey not optimized for NEO discovery

- Since April 2014, 90% of the observations with Pan-STARRS have been optimized for NEO discovery

- Pan-STARRS2 is almost fully operational
  - A baffle needs to be installed to reduce stray light
Pan-STARRS cameras

- Pan-STARRS1 has 60 CCDs
- Pan-STARRS2 has 64 CCDs
- The CCDs are orthogonal transfer CCDs
  - The idea was to move charge around to improve image quality by removing coordinated motion such as wind shake
  - Each CCD has 8x8 cells with 600x600 pixels
  - The design led to higher noise and poorer cosmetics than conventional CCDs
The Pan-STARRS NEO Survey

• Pan-STARRS1 has amassed over 1 million science images, comprising over 2.5 Petabytes of data

• Pan-STARRS1 surveys much of the sky north of -50° declination each lunation

  • The Galactic plane is avoided

  • A wide “w-band” filter (400–820 nm) is used when the moon is down or faint

  • The i-band filter is used with a bright moon
Near-Earth Object discovery

- A sequence of four images spaced over a period of approximately 1 hour is used to identify moving objects
- Difference images are formed, and transient (moving) sources identified
  - We form “tracklets” from these sources
  - We require at least 3 detections to form a tracklet
- Objects with high digest scores (likely to be Near-Earth Objects) are posted to the “Near Earth Object Confirmation Page” at the Minor Planet Center for worldwide followup
Why are some moving objects missed?

- There are many reasons why the Pan-STARRS automated processing can miss moving objects:
  - Objects might be faint
  - Objects may move across cell-gaps
  - There may be too many detections for the tracklet formation, requiring triage
    - There are many false detections coming from the CCDs
  - Objects might move in front of background objects
  - Objects might move into cosmetically poor regions of the camera
  - Slow moving objects may be self-subtracted
Object moving across a cell gap (2013 JV17; 5.7 deg/day, H=27.7):

Why are some moving objects missed?
• Very faint object (2018 EQ1) with G magnitude 23.0:
• Found in archival data, but too faint for automated processing

Newly discovered NEOs
Archival searches are made for newly discovered NEOs

These are limited to manageable uncertainty regions (i.e., relatively close in time)

The arc is extended and the orbit improved, making it easier to identify in the future

In some cases, if the arc at the discovery opposition is long enough, the NEO can be found at a previous opposition

Older NEOs
Many of the just over 20,000 NEOs discovered to date have relatively poor orbits

This means that if we tried to look for them now, we would not be able to easily find them

Many of these orbits could be improved using searches in archival data

The most important orbits to improve are the NEOs that have a non-zero impact probability with Earth

Significant followup resources are often spent “rediscovering” previously discovered, NEOs that have poor orbits

Older NEOs
• The Center for Near-Earth Object Studies at JPL maintains the “Sentry” list of all NEOs with non-zero Earth impact probability in the next 100 years

• These impact probabilities are very small, but are not zero

• The list currently contains 906 objects

• Archival data can improve orbits for many of these objects

  • Most likely, the archival data will change the impact probability in the next 100 years to zero

  • Any impact that became more likely would warrant attention

Older NEOs
• We searched the Pan-STARRS archive for objects on the Sentry list for very easy to find (close in time) observations

• We found 55 objects and submitted new astrometry

• 10 of these objects were removed from the Sentry list

Searching for older NEOs
• Searching for older NEOs is not easy, because the uncertainty region can be very large.

• The uncertainty region is often a line in the sky, that can be very narrow (for example, only a few arc seconds wide), but many degrees long.

• It is called the line of variation.

• Another way of thinking about this, is we know that the NEO passed through each position along that line, but that we don’t know when.

1997 GC32 in 2017
Searching for older NEOs
• Searches over such large areas are very difficult, and will require new
development.

• They are also labor intensive.

• NEOs have very distinctive motion.

• Once found, we can be very confident of a recovery.

What if we find an object that is likely to hit Earth?
If a larger object is discovered that has a high likelihood of Earth impact, it is likely that it can be found in the archive near a previous perihelion passage.

- Objects with H=22 (approximately 140 meters in diameter) at opposition will be
  - V=20.8 at a distance of 0.4 AU
  - V=21.9 at a distance of 0.6 AU
  - and will be fainter away from opposition

What if we find an object that is likely to hit Earth?

- Pan-STARRS can easily see a V=22 object in dark conditions, and archival
recoveries fainter than $V=23$ are routinely made

- The magnitude limit is about 1 magnitude brighter for brighter moon conditions

- For most Apollo type orbits of larger objects, it is likely that the object will have been imaged by Pan-STARRS during a past perihelion passage, and archival recovery likely is possible (but might be difficult)

- Exceptions would be objects that are near the Galactic plane during best visibility

What if we find an object that is likely to hit Earth?
• A long extension to the orbit of an impactor would produce strong constraints on the orbit, and allow much longer lead time for possible impact preparations and possible deflection missions.

• Archival data from Catalina and other wide-field telescopes such as CFHT and Subaru may also provide arc extension for impactors.

2019 PDC exercise
Although the orbit for 2019 PDC had been crafted to make precovery unlikely, 2019 PDC would have been in images obtained by Pan-STARRS1 on:

- 5 separate nights in 2011 with magnitude $V < 23$
- 3 of those nights having magnitude $V = 22.1$, making precovery likely provided that the seeing was average or better

How can Pan-STARRS be improved?
• Pan-STARRS could be improved dramatically by developing new cameras

• Newer larger CCDs would be used
  
  • Lower noise (less false detections, allowing fainter NEO discovery)
  
  • High quantum efficiency (fainter NEO discovery)
  
  • Less gaps

A new camera for Pan-STARRS
- The most suitable commercially available CCD at present is manufactured by e2V
- 18 CCDs are needed
- 9216 x 9232 10 micron pixels
- 1.53 Gigapixels
- Slightly larger field-of-view