NEOFIXER

A BROKER FOR NEAR EARTH ASTEROID FOLLOW-UP

ROB SEAMAN & ERIC CHRISTENSEN

CATALINA SKY SURVEY
• LPL runs 2 NEO projects, CSS and Spacewatch
• Talk to Eric or me about CSS, Bob McMillan for SW
• CSS demo at 3:30 pm
CONGRESSIONAL MANDATE

• Spaceguard goal: 1 km Near Earth Objects ✔

• George E Brown Act to find > 140m (H < 22) NEOs
  • 90% complete by 2020 ✗ (2017: ~ 30%)

• ROSES 2017 language is > 100m

• Chelyabinsk was ~20m (H ~ 25.8) or ~400 kiloton (few per century likelihood)
SUMMARY

• Near Earth Asteroid inventory is “retail Big Data”
• NEOfixer will be NEO-optimized targeting broker
  • No one broker will address all use cases
• Will benefit LSST as well as current surveys
  • LSST not tasked to study NEOs, but rather the Solar System (slower objects and farther away)
• What is the most valuable NEO observation a particular telescope can make at a particular time?
CHESLEY & VERES (1705.06209)

- 55 ± 5.0% for LSST baseline operating alone
- But 42% of NEOs with H < 22 will be discovered before 2022
- And without LSST, current surveys would discover 61% of the catalog by 2032
- Completion $C_{H<22}$ will be 77% combined

*LSST will add 16% to $C_{H<22}$
*Can targeted follow-up increase this?
CHESLEY & VERES *(CAVEATS)*

- Lots of details worth reading
- $C_{H<22}$ degrades by $\sim 1.8\%$ for every $0.1$ mag loss in sensitivity
- Issues of linking efficiency including:
  - Efficiency down to $H < 25$ is lower
  - 4% false MBA-MBA links
ASTROMETRIC FOLLOW-UP

• Not all follow-up is the same
  • Astrometry ≠ photometry ≠ spectroscopy

• To study an object need to know where it is
  • To predict future location, must link past tracklets

• Linking allows solving the orbit
  • but an orbit is needed for linking

• Orbits evolve and orbits have uncertainties
ORBIT CATALOG MAINTENANCE

• Asteroids are assigned a number when orbital uncertainty is about an arcsecond / decade
  • Takes 3-4 oppositions for numbering
  • ~5 years for MBAs, can be decades for NEOS

• Orbit improvement is responsive to
  1. arc length
  2. geometric parallax
  3. astrometric precision / accurate timekeeping

*Need for additional astrometry never ends*
TOPOCENTRIC OBSERVATIONS

• Parallax matters for solar system objects, especially NEOs

• No matter how good LSST observations are, they are restricted to a single site

• All LSST-derived orbits can be improved by complementary follow-up from other sites
NEO DISCOVERY WORKFLOW

1. Surveys publish NEO candidates
2. Follow-up telescopes “subscribe to streams”
3. via MPC’s NEO Confirmation Page (NEOCP)

*NEOs are poster child for Time Domain Brokers
ADES (IAU 2015) ~ VOEvent*
LSST MOPS COMBINES STEPS

- Initial detection
- Real/bogus discrimination
- Follow-up observations
- Initial orbit determination (3-5 day arc)
- Arc extension (out to 12-20 days)

If 3rd tracklet is not identified, no aspect of the potential discovery is preserved – no such thing as a 2-tracklet orbit since most tracklets are false
NEO RECOVERY WORKFLOW

• Before numbers, asteroids get provisional desig.
• For NEOs this generally results in an MPEC
• Recovery – extending an orbital arc to subsequent oppositions – can result from
  • Explicit follow-up (predicted motion with relatively large uncertainty in position)
  • Linking designations from different epochs
• All LSST self-recovery will be the latter?
  • Non-sidereal targeted follow-up (track & stack)
MINOR PLANET CENTER

• MPC web services layered on DB (and flat files)
  • CSS maintains mirrored copy
• MPEC reflects human vetting of candidate NEOs
  • (or other classes of high-value asteroids, TNOs?)
  • Orbit catalog is updated after MPEC
• Community follow-up will confirm LSST discoveries
  • LSST submits observations
  • LSST retrieves MPC orbits
• MPC will remain arbiter (at least for NEOs)
OBSERVABILITY OF NEOS

- Asteroids generally most visible at opposition
- Narrow windows for discovery
- Many NEOs will continue to be discovered by current surveys before LSST workflow has a chance to finish for candidate tracklets
- LSST will be a preccovery engine
Fig. 14. Search volumes as in Fig. 12 for LSST (blue region) and NEOCam (brown region).

Asteroid Search Space

Entering this Volume Does not equal Discovery

Myhrvold, 2015
2017 JF3, discovered by 703 on 2017-05-14
H=21.8 Aten PHA

What if LSST were on Mt. Bigelow?

Lowell observability tool (asteroid.lowell.edu)
2017 JD3, discovered by G96 on 2017-05-14
H=21.8 Apollo PHA

Discovery epoch
2017 GP6, discovered by F51 on 2017-04-05
H=21.1 Apollo PHA

Likely too narrow for LSST to link
NEO DISCOVERY WORKFLOW

1. Surveys publish NEO candidates
2. Follow-up telescopes subscribe to stream(s)
3. via MPC’s NEO Confirmation Page (NEOCP)

*MPC does not assign explicit targets*
4. Other brokers such as JPL’s Scout hazard assessment add value to particular streams (PHAs, NHATS, etc)

5. NEOfixer will recommend targets to
   - ensure highest priority don’t receive all the follow-up
   - lower priority / unlucky targets aren’t ignored
   - solve the “second-grade soccer problem”
   - goal is efficient astrometry, not characterization (to start)
6. LSST will be both:
   • a survey contributing astrometry and initial orbits, and
   • a follow-up engine layered on the MPC orbit database, thus

   *LSST targets will automatically receive follow-up*
   and

   *LSST is also a potential customer for NEOfixer*
NEO Surveys

1. 

NEOfixer

2. 

CSS NEOfixer targeting broker

3. 

MPC (NEOCP)

4. 

MPC DB Mirror

5. 

NEOfixer

6. 

NEO Follow-up

- PS1, etc.
- 60"
- Schmidt
- 61"
- LSST
- 40"
- 61"
- 90"
- 40"

R. Seaman, 9 Apr 2017
NEOFIXER GOALS

• Ensure all NEO candidates receive sufficient follow-up
  • In 1st 4 months 2017, 250 NEOCP objects fell off page
  • Up to one-third can be expected to be NEOs
• For CSS, offload follow-up duties from survey scopes
  • Recover about 25% time for surveying
• Also seek to add faint follow-up capacity
NEOFIXER ARCHITECTURE

• Client-server
• Publish-subscribe
• Scriptable interface (TCL to start)
  • CSS internal workflow (see demo)
• Web form layered on top
  • for amateur community and ad hoc ToO
  • Register with preferences, select streams
NEOFIXER PROTOCOL (SCRIPTING)

- REQUEST_TARGET(S)
  - return TARGET_ID and metadata
- TARGET_SCHEDULED <TARGET ID>
- CONFIRM_TARGET <TARGET ID>
  - return new coordinates / observing time or “no longer needed”
- TARGET_CANCELED <TARGET ID>
  - Support a small number of exceptions
- TARGET_OBSERVED <TARGET ID>
- TARGET_SUCCESS <TARGET ID>
  - Send astrometry to MPC
- TARGET_FAILURE <TARGET ID>
  - Perhaps reschedule for a larger aperture telescope
- SITE_STATUS <metadata>
COMMUNITY WILL BENEFIT

• LSST astrometry submitted to MPC will receive prioritized astrometric follow-up

• LSST co-observing schedule will provide advisory notice of likely LSST self-follow-up

• LSST discoveries will benefit from community confirmation
LSST WILL BENEFIT

• No need for LSST to *only* do self follow-up
  • LSST will import MPC orbit catalog updates

• But NEO candidates from other surveys are not in the catalog until confirmed
  • NEOfixer can provide LSST the same service

• LSST will be a precovery engine like Pan-STARRS
POLICIES

• Will focus on NEOCP to start
  • Goal that all NEO candidates be followed-up

• Partition targets by aperture
  • Basic observability per site
  • May assign to multiple stations
  • Observe before / after constraints
SUMMARY

• NEOfixer will be NEO-optimized targeting broker
• Will benefit LSST as well as current surveys
• MPC will retain current role as orbit arbiter
• For NEOs, relatively small survey and follow-up apertures can be competitive (track to recover trailing losses)

What is the most valuable NEO observation a particular telescope can make at a particular time?
Alex Gibbs will demo CSS target management at 3:30 pm
COMMUNITY VENUES

• Will begin building SPIE Observatory Operations program in the next few months

• Diverse working groups:
  - AAS WGTDA
  - IAU TDA WG
  - AAS WGAS
  - IAU Comm-B2

• Hot-wiring the Transient Universe VI, <WhereWhen>?

• IAU S339 – Southern Horizons in TDA, Nov 2017