# NEOFIXER

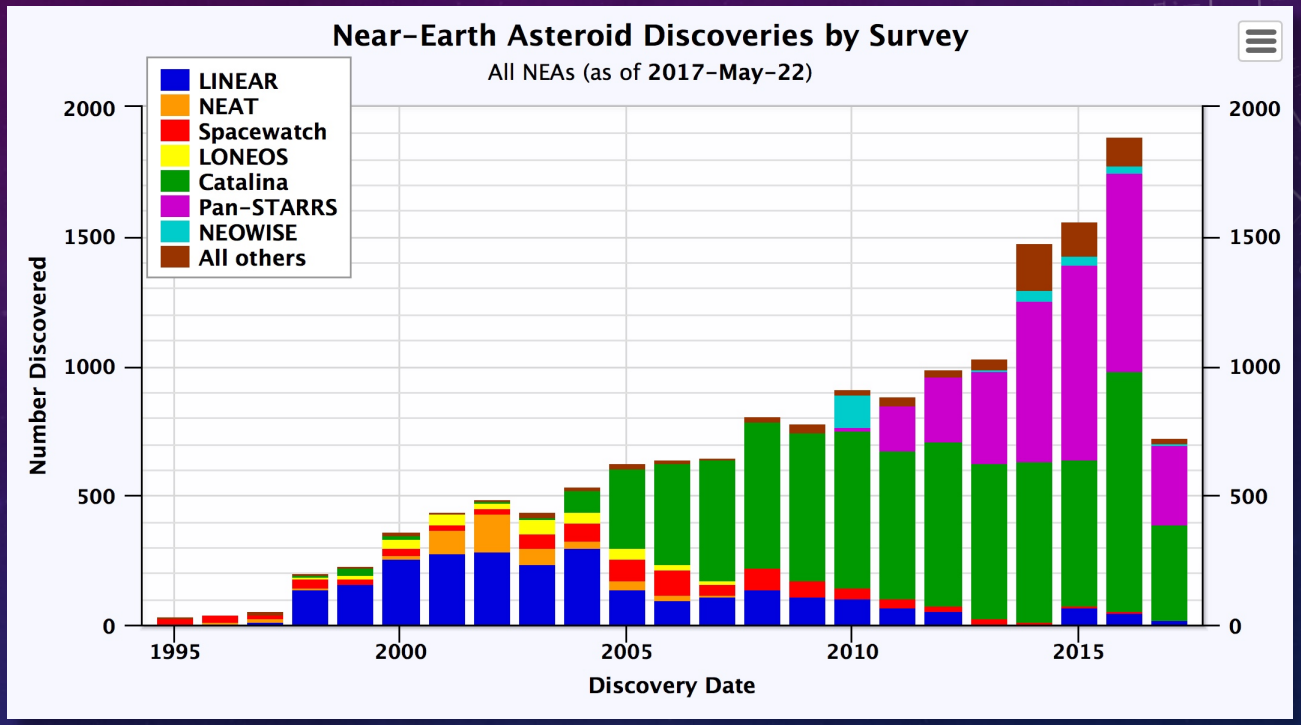
## A BROKER FOR NEAR EARTH ASTEROID FOLLOW-UP

ROB SEAMAN & ERIC CHRISTENSEN

CATALINA SKY SURVEY

*Building the Infrastructure for Time-Domain Alert Science in the LSST Era • May 22-25, 2017 • Tucson*

# 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 ~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

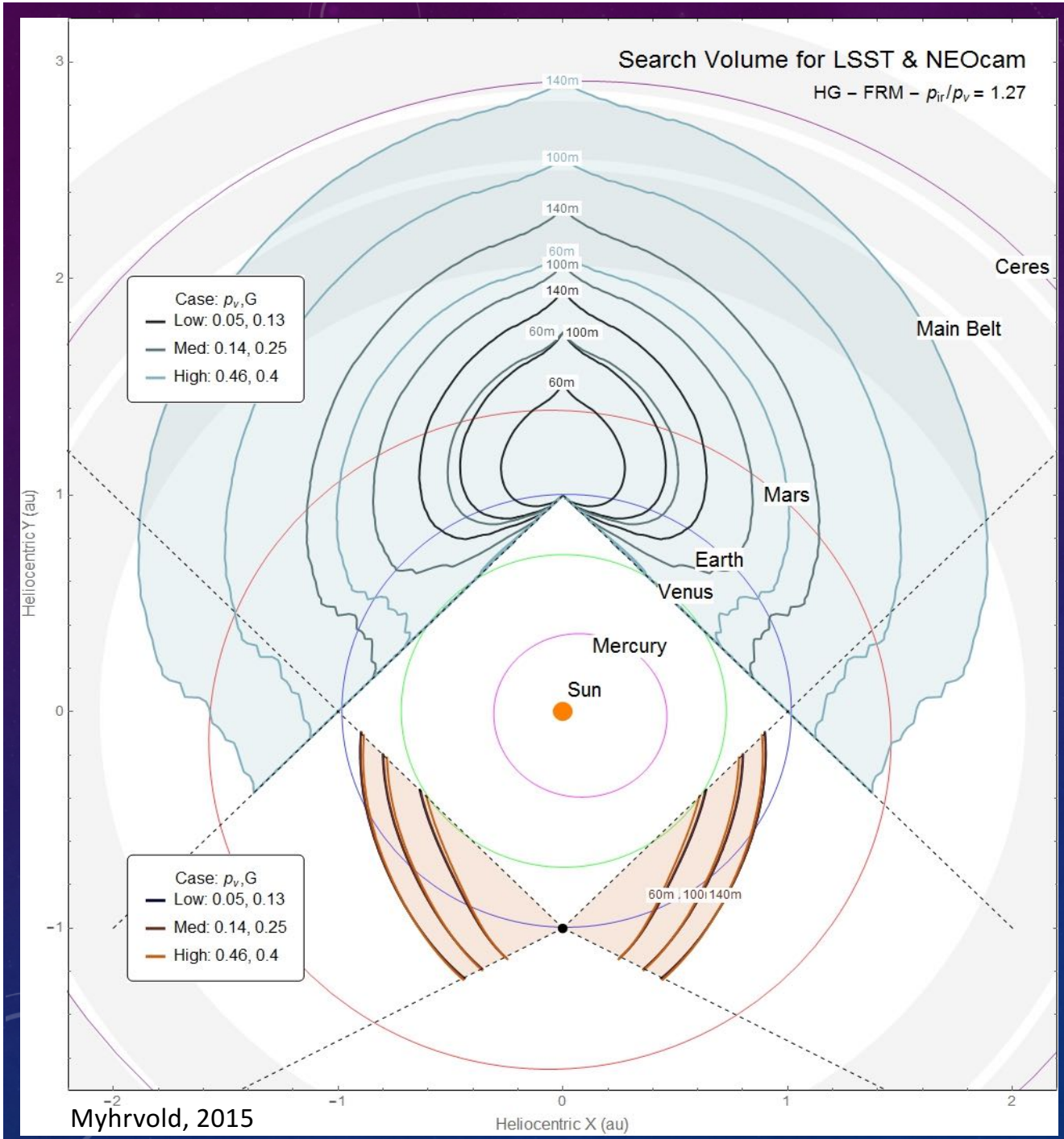
- Before numbers, asteroids get provisional desig.
- For NEOs this generally results in an MPEC
- Recovery – extending an orbital arc to subsequent oppositions – can result from
  - Explicit follow-up (predicted motion with relatively large uncertainty in position)
  - Linking designations from different 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 precovery engine



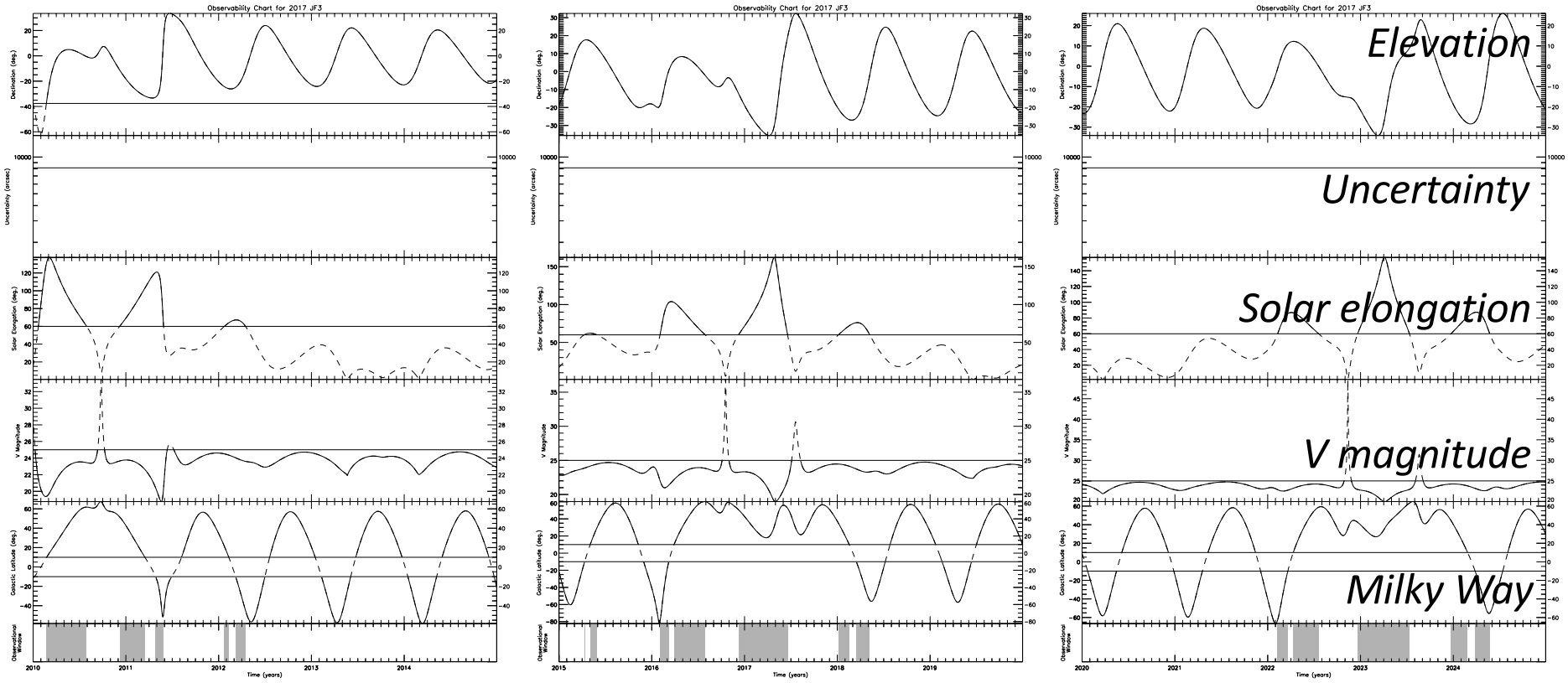

Myhrvold, 2015

# Asteroid Search Space

*Entering this Volume Does not equal Discovery*

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

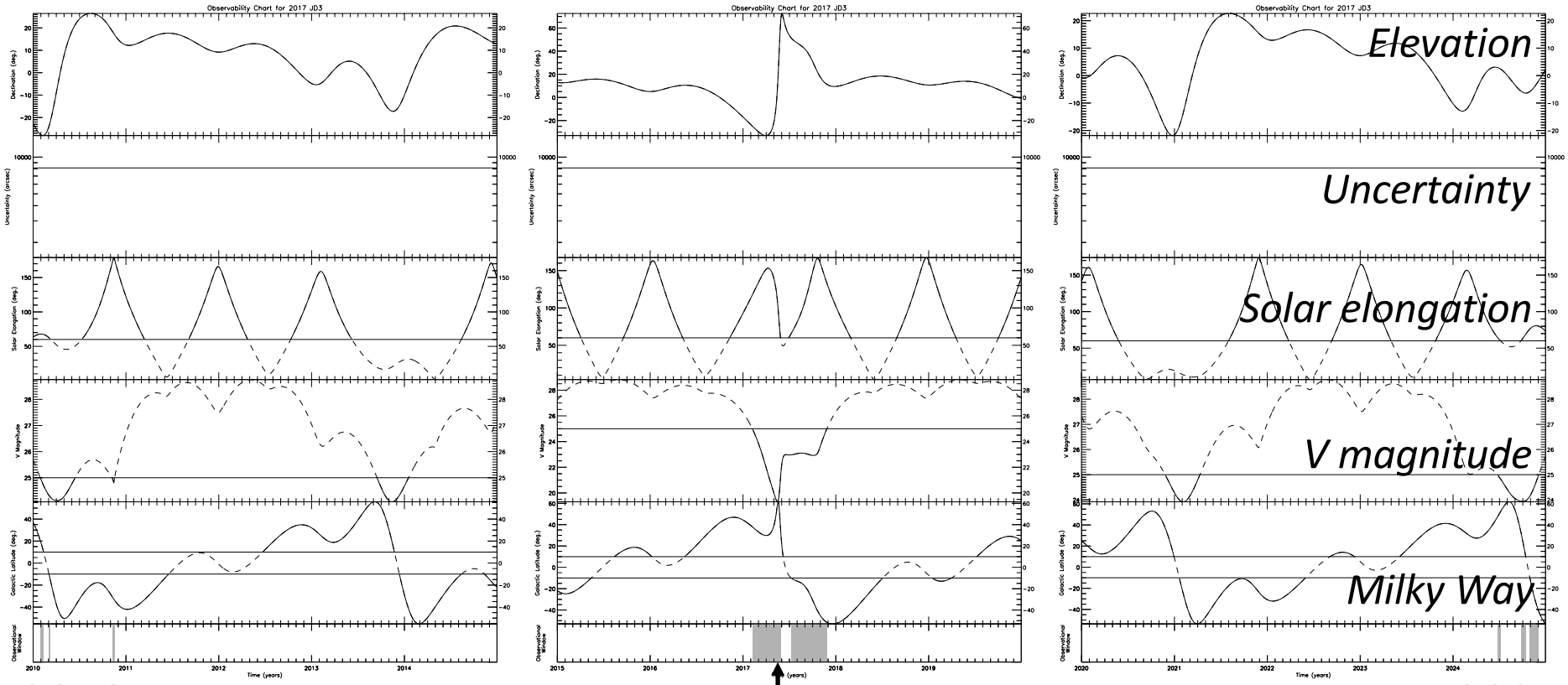
*What if LSST were on Mt. Bigelow?*



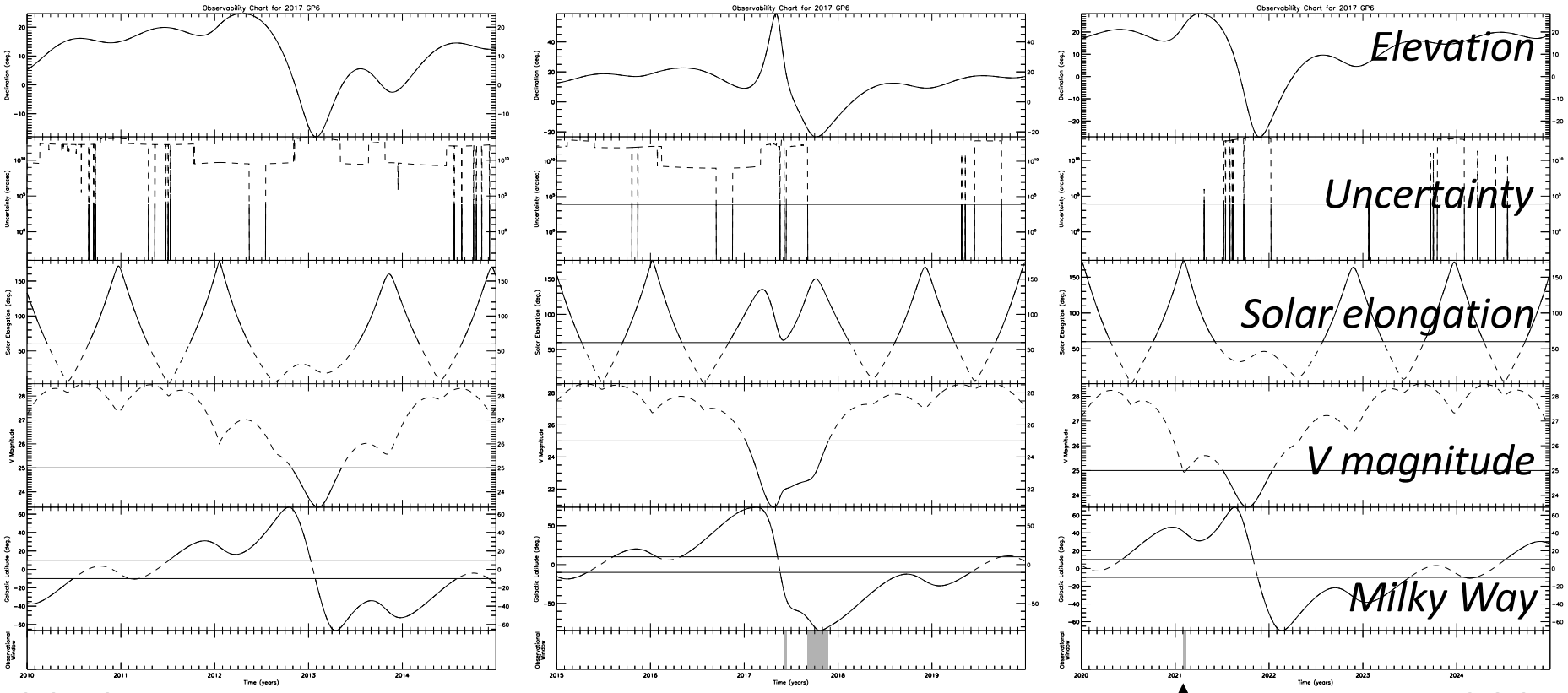

*2010* *2025*

Lowell observability tool (*asteroid.lowell.edu*)

# 2017 JD3, discovered by G96 on 2017-05-14
# H=21.8 Apollo PHA



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




*2010*

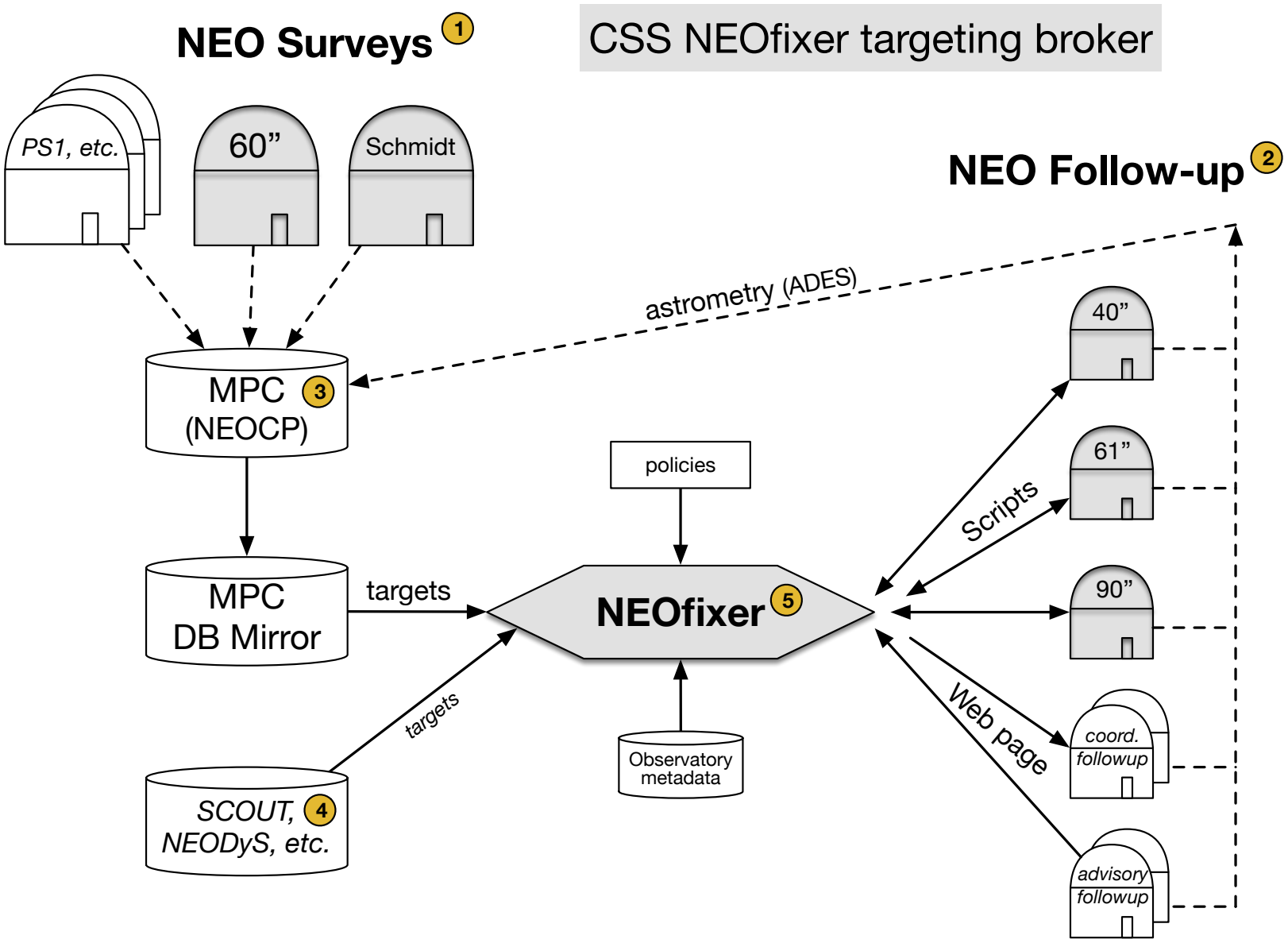
*2025*

*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*


NEO Surveys 1
CSS NEOfixer targeting broker
PS1, etc.
60”
Schmidt
NEO Follow-up 2
astrometry (ADES)
MPC 3
(NEOCP)
40”
61”
90”
policies
Scripts
MPC
DB Mirror
targets
NEOfixer 5
Web page
coord.
followup
advisory
followup
Observatory
metadata
targets
SCOUT, 4
NEODyS, etc.

# NEO DISCOVERY *CONTINUED*

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)

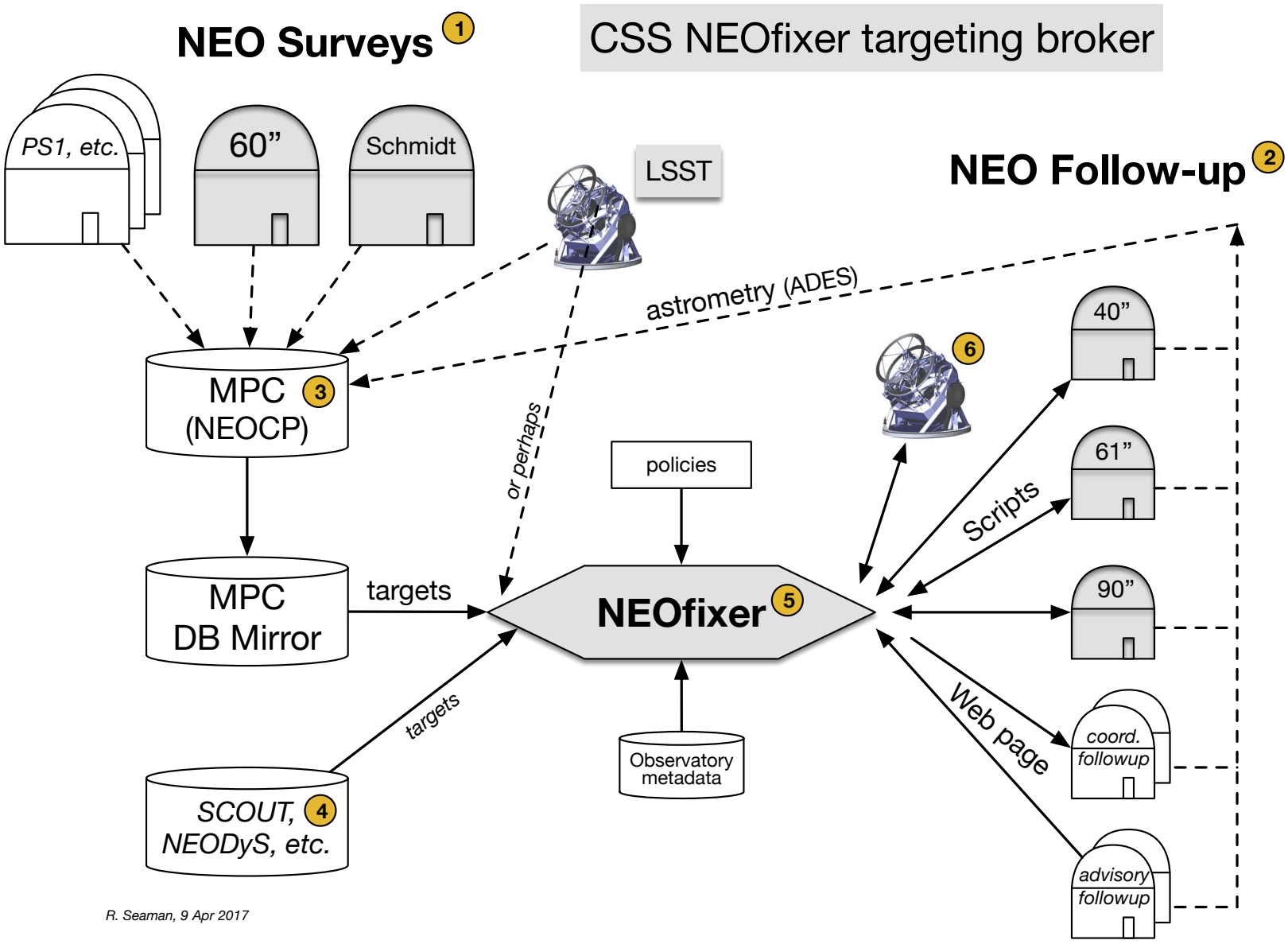
# NEO DISCOVERY *CONTINUED, #2*

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
CSS NEOfixer targeting broker
PS1, etc.
60”
Schmidt
LSST
NEO Follow-up 2
astrometry (ADES)
MPC 3
(NEOCP)
or perhaps
6
40”
61”
90”
policies
Scripts
MPC
DB Mirror
targets
NEOfixer 5
Web page
coord.
followup
Observatory
metadata
targets
SCOUT, 4
NEODyS, etc.
advisory
followup
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?*

# DEMO

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


IAU Symposium 339
NOVEMBER 13-17, 2017 • STELLENBOSCH, SOUTH AFRICA
SOUTHERN HORIZONS
IN TIME-DOMAIN ASTRONOMY
IAU Symposium 339 diverges from tradition by featuring topical workshops that emphasize discussion, seek cross-cutting technical solutions, and foster new research collaborations
HTTP://IAUS339.AST.UCT.AC.ZA
Seneca: Time discovers truth