Delivering the Solar System: Development of Rubin's Asteroid Discovery Capability

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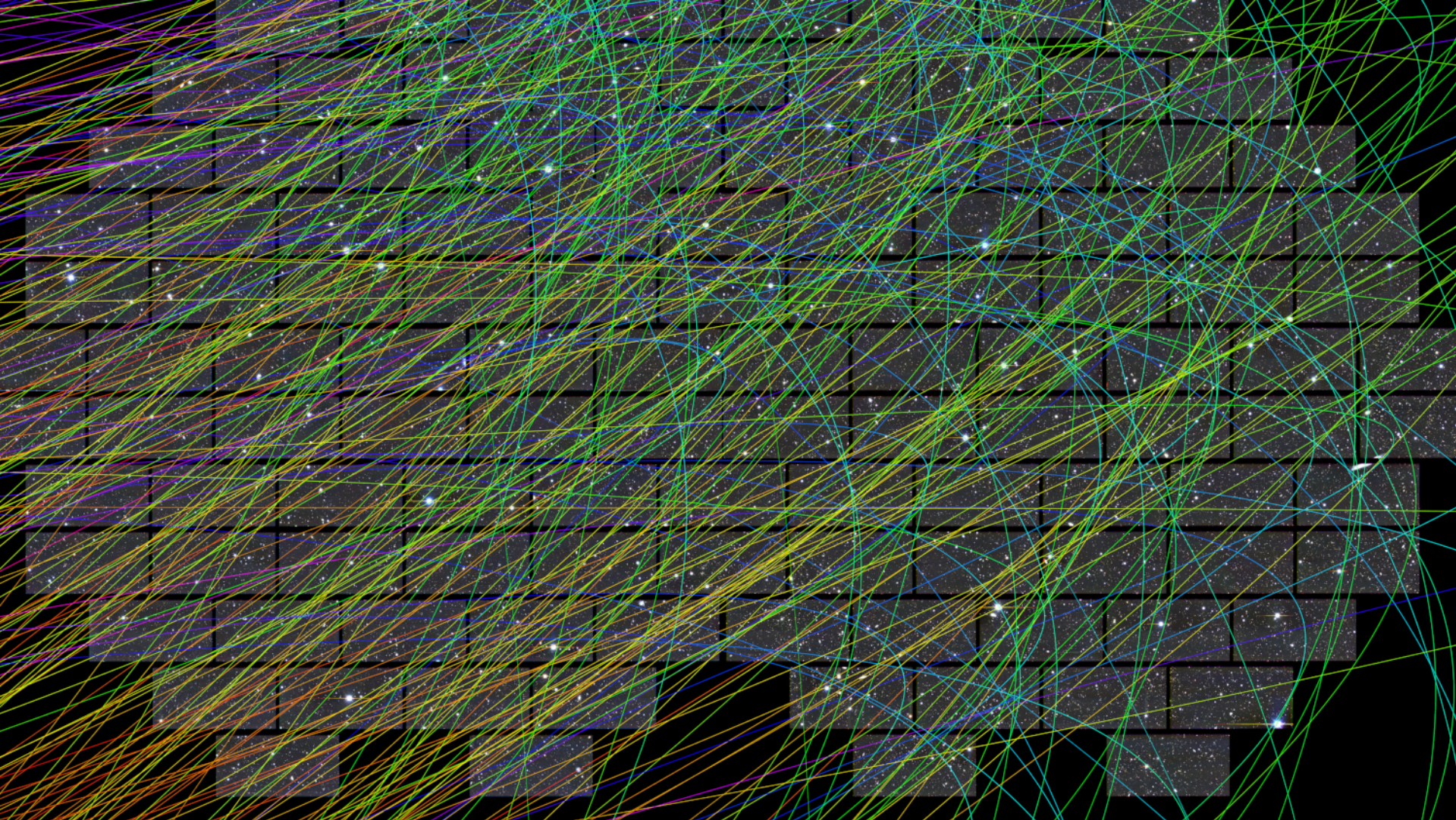
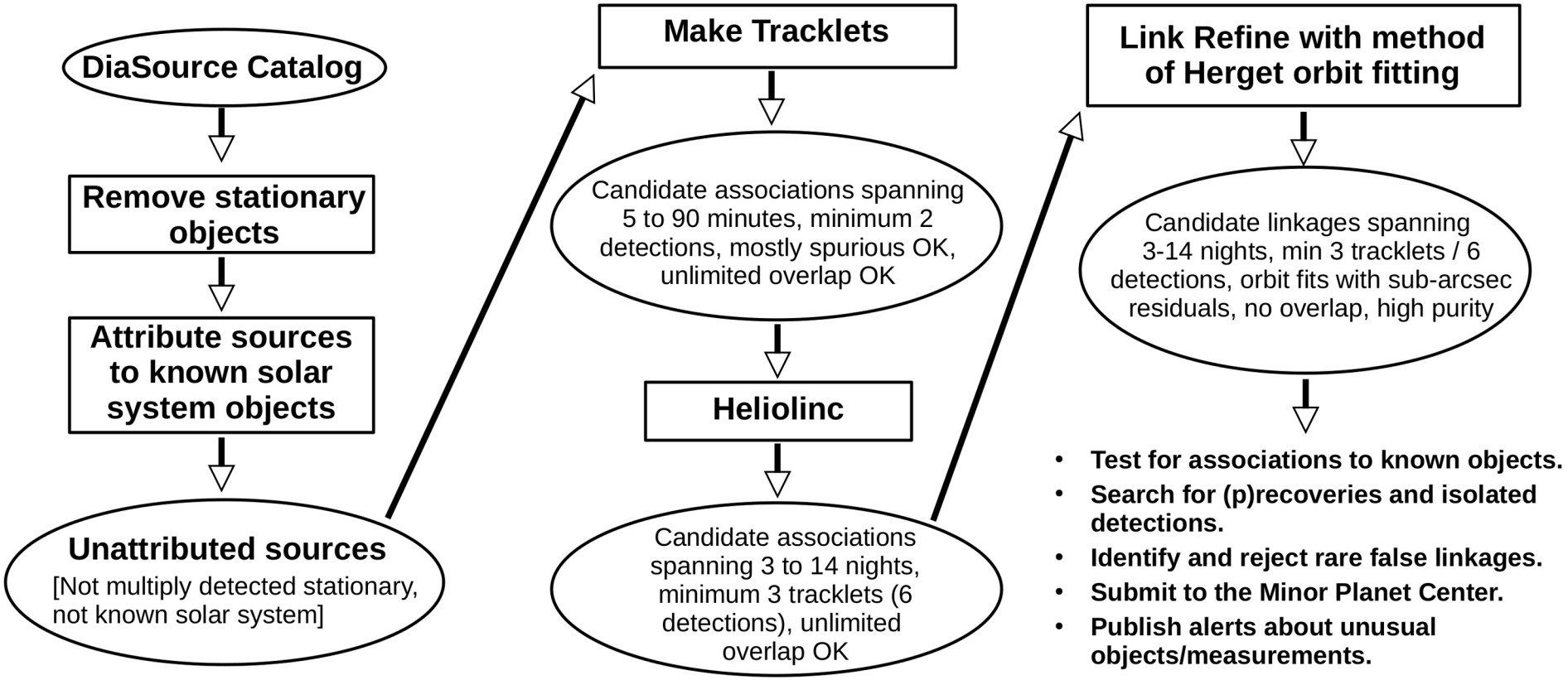


Link this.

Flowchart for solar system object discovery



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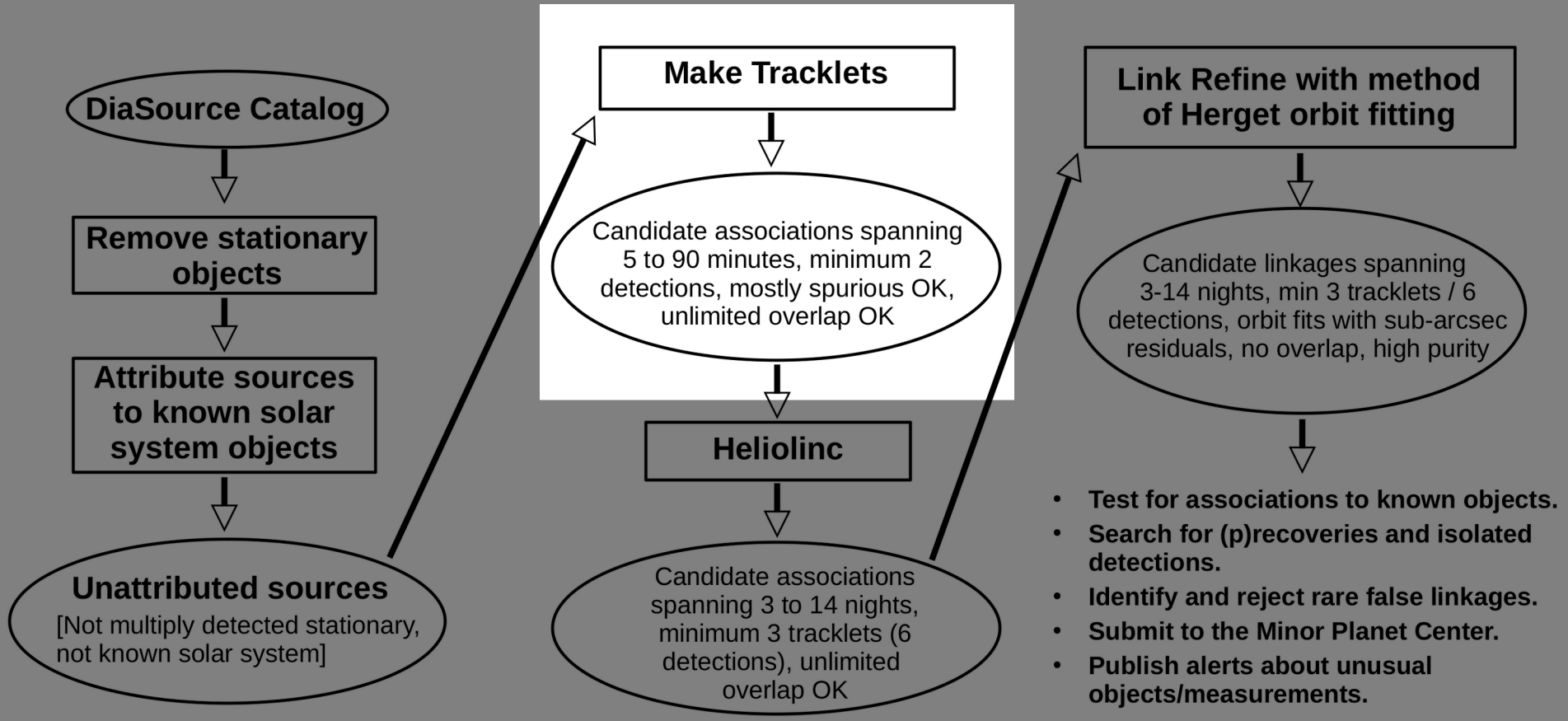
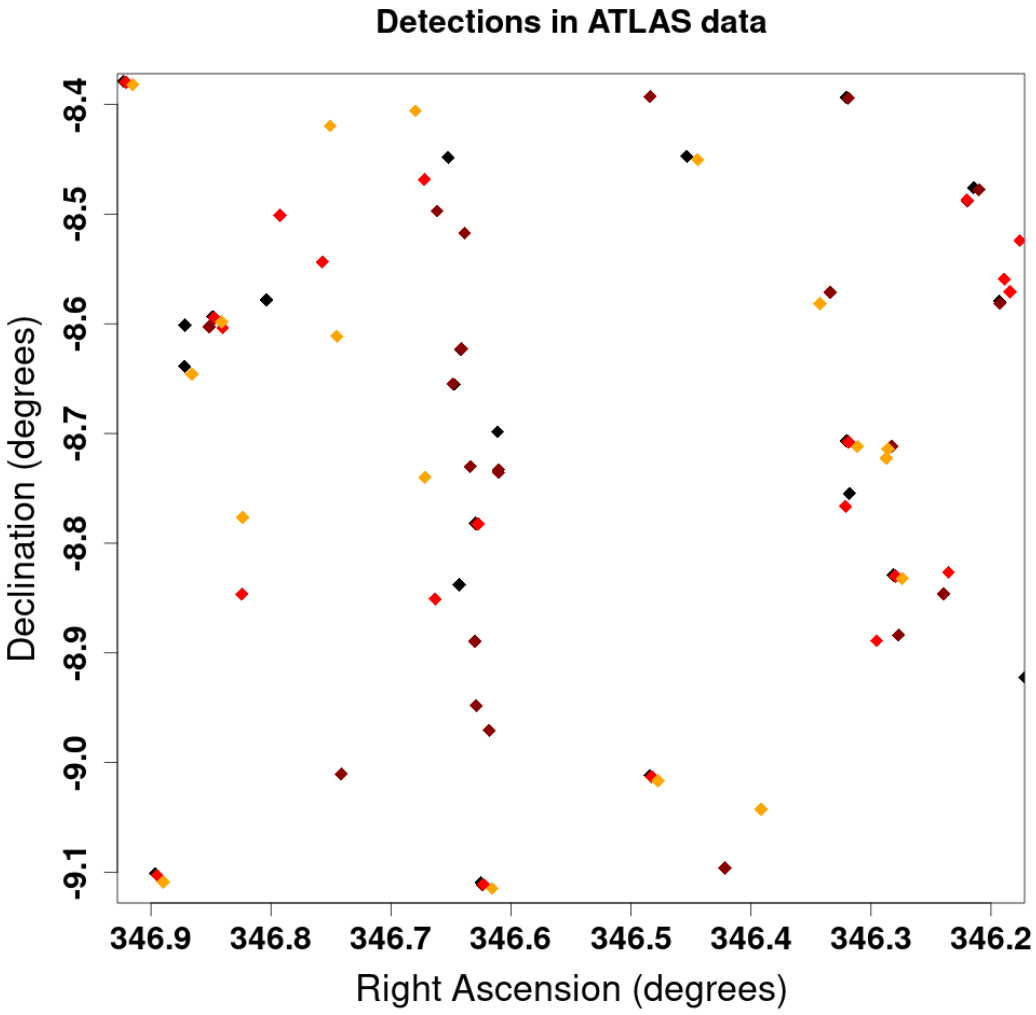
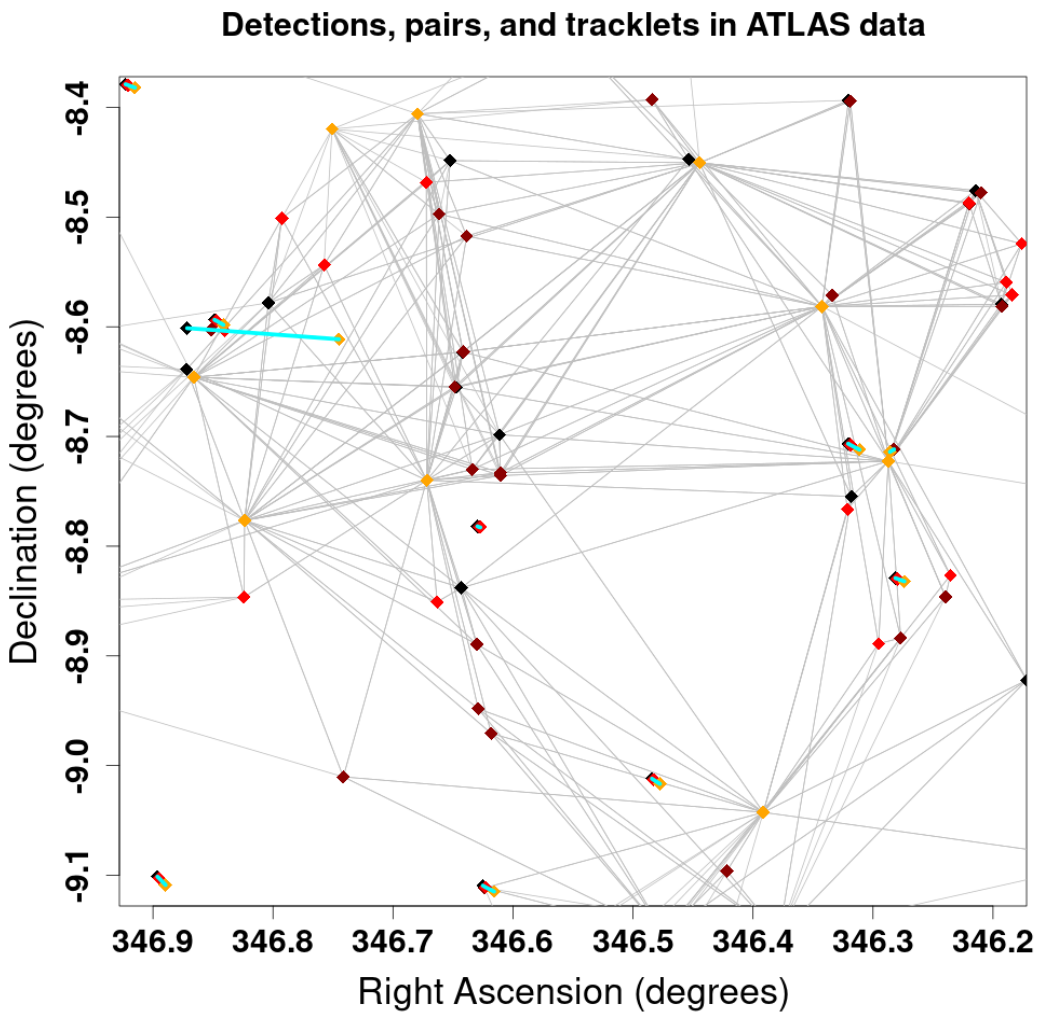
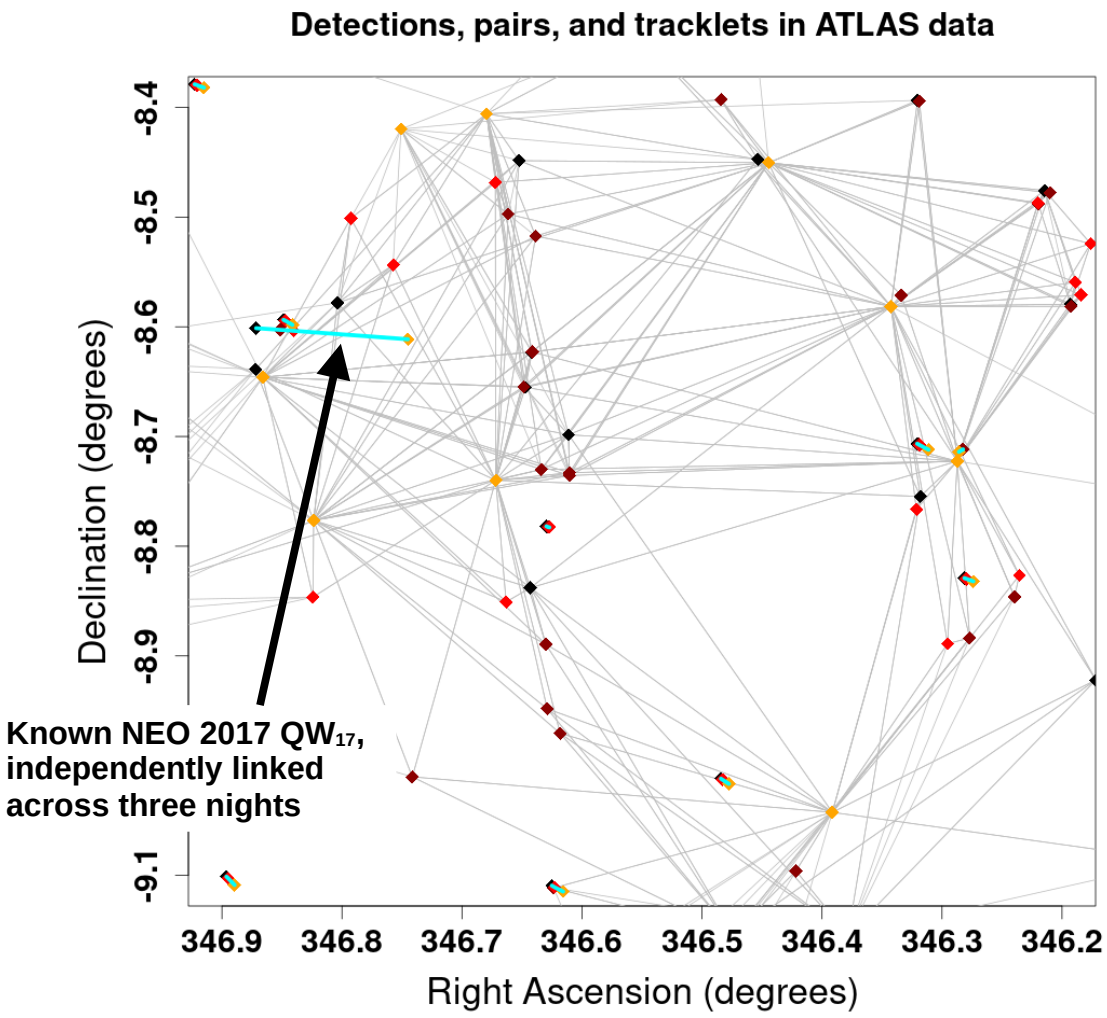




- Total 97 detections on 4 different images within a 0.5 square degree area
- Image sequence: black, dark red, red, orange
- Main-belt asteroids, spurious detections, and one NEO are all represented

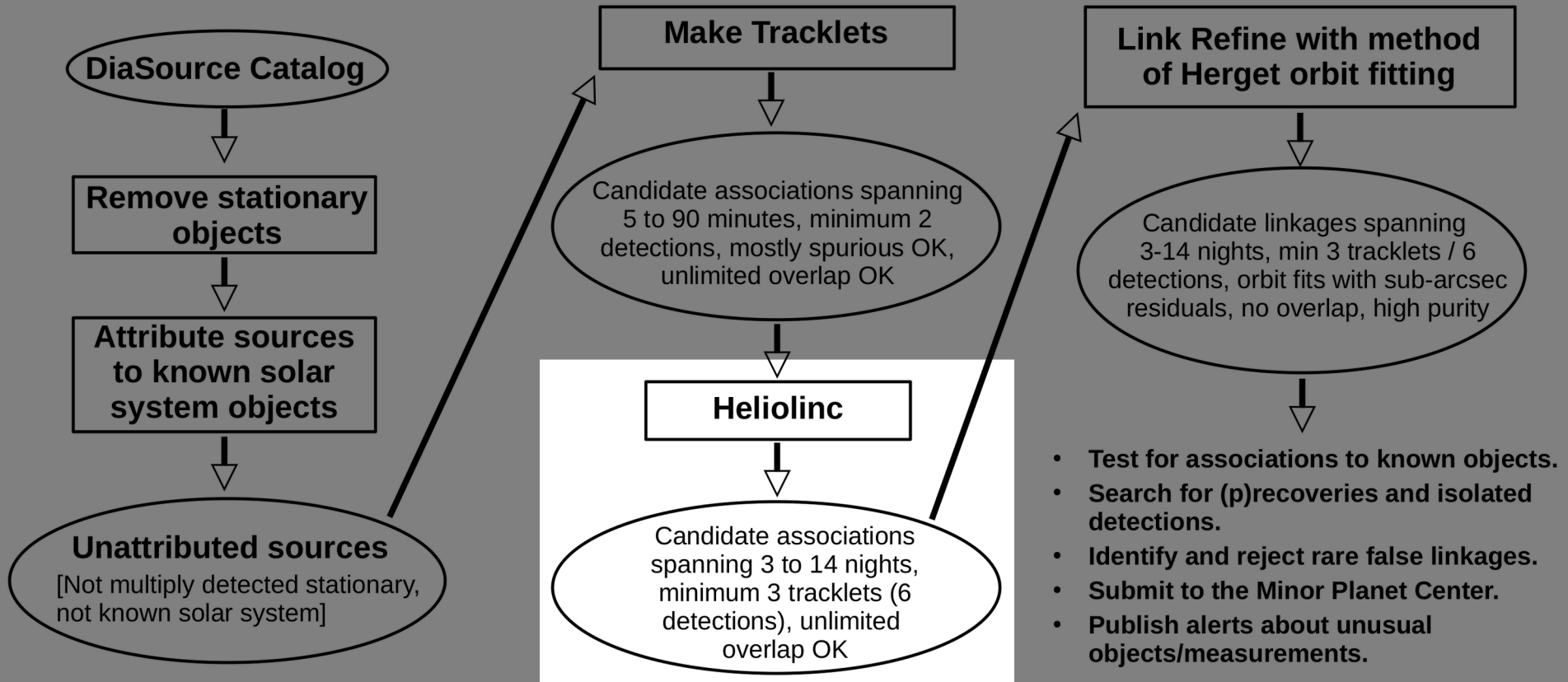


- Gray = pairs
- Cyan = tracklets with 3 or more points
- Angular velocity limit is 10 deg/day
- 97 detections lead to 619 pairs or tracklets



- Gray = pairs
- Cyan = tracklets with 3 or more points
- Angular velocity limit is 10 deg/day
- 97 detections lead to 619 pairs or tracklets
- **HelioLinc3D can sort through this mess!**

Flowchart for solar system object discovery

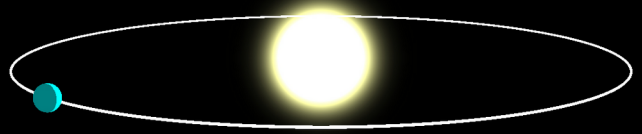


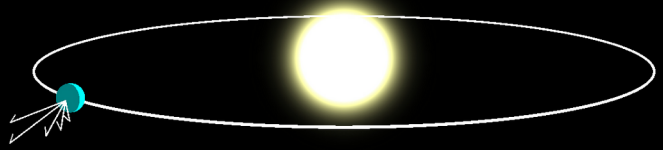
HelioLinc3D

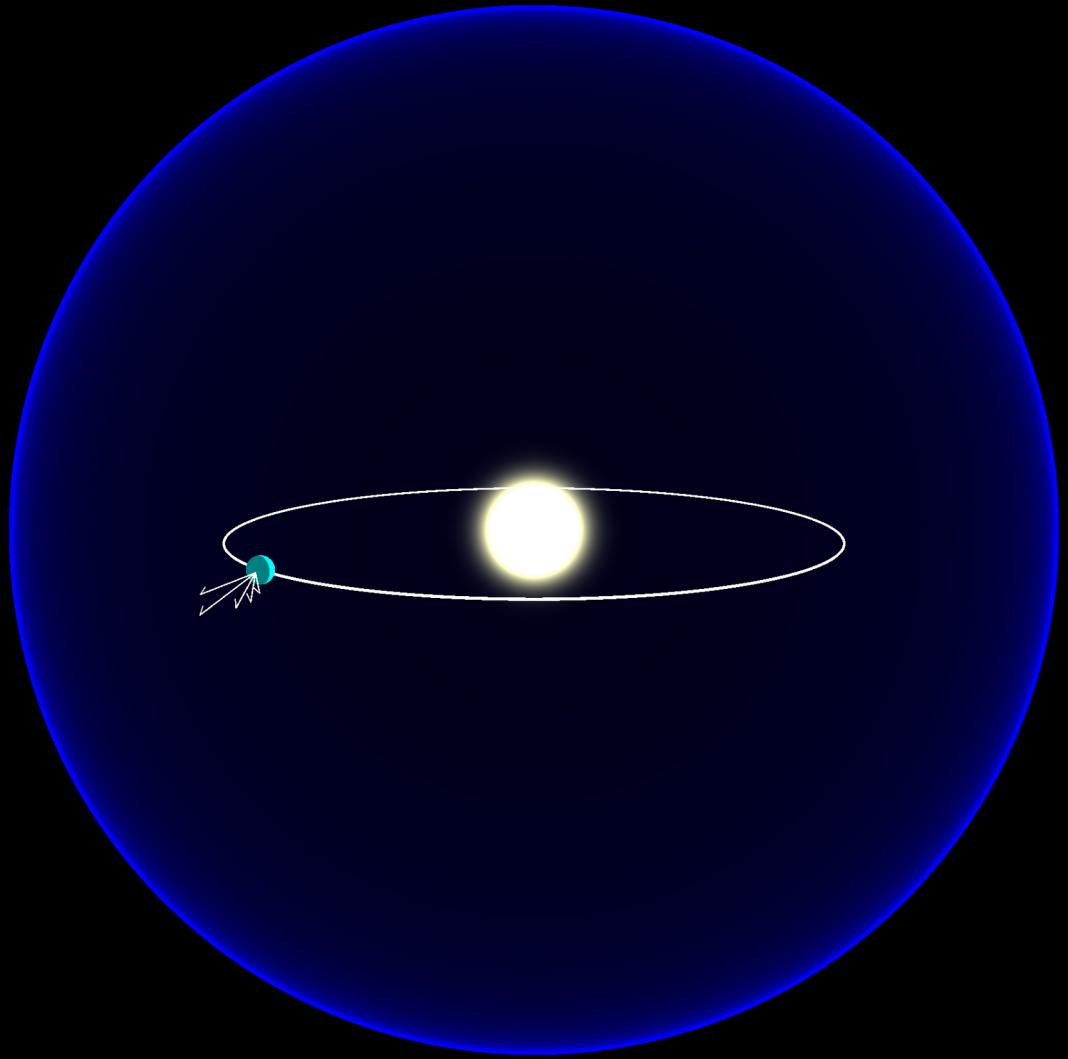
- Closely based on Matt Holman's 2018 paper
- Also built on the work of Siegfried Eggl
- 6D state vectors: does not collapse to sky plane
- Uses full Keplerian orbit-propagation
- Uses 3-parameter form for heliocentric hypotheses

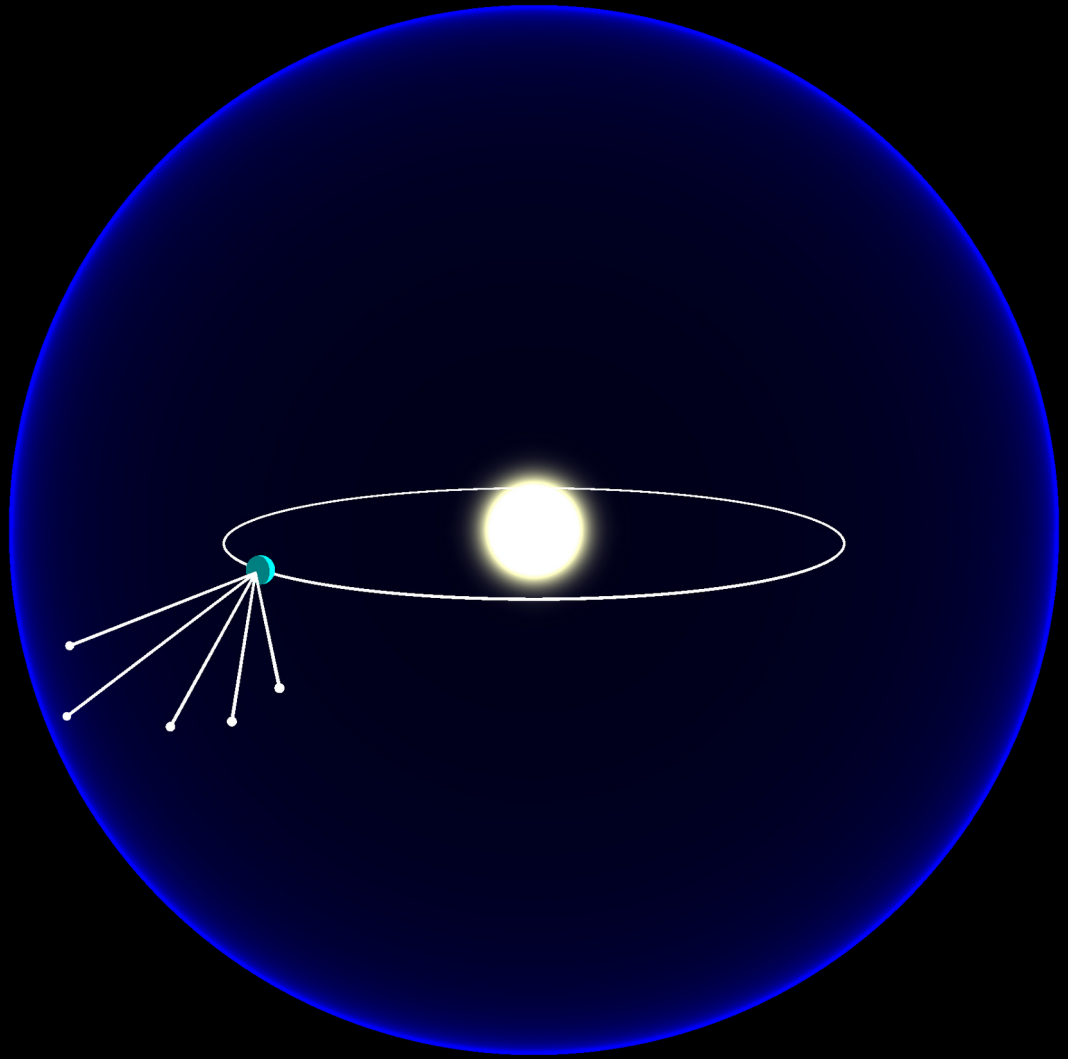
>97% completeness on main-belt asteroids and NEOs in all-sky LSST simulations

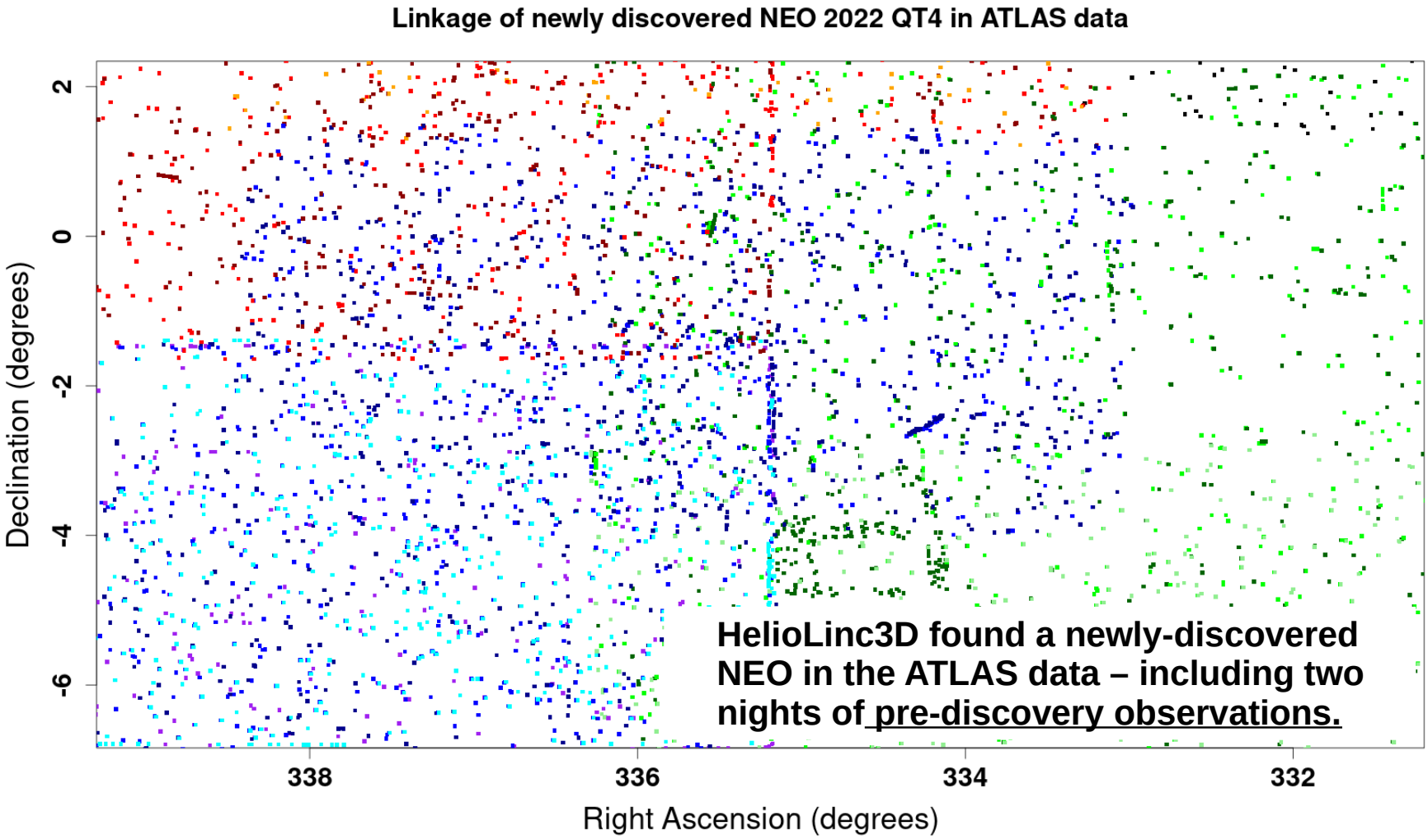
Image credit: Bruno C. Quint

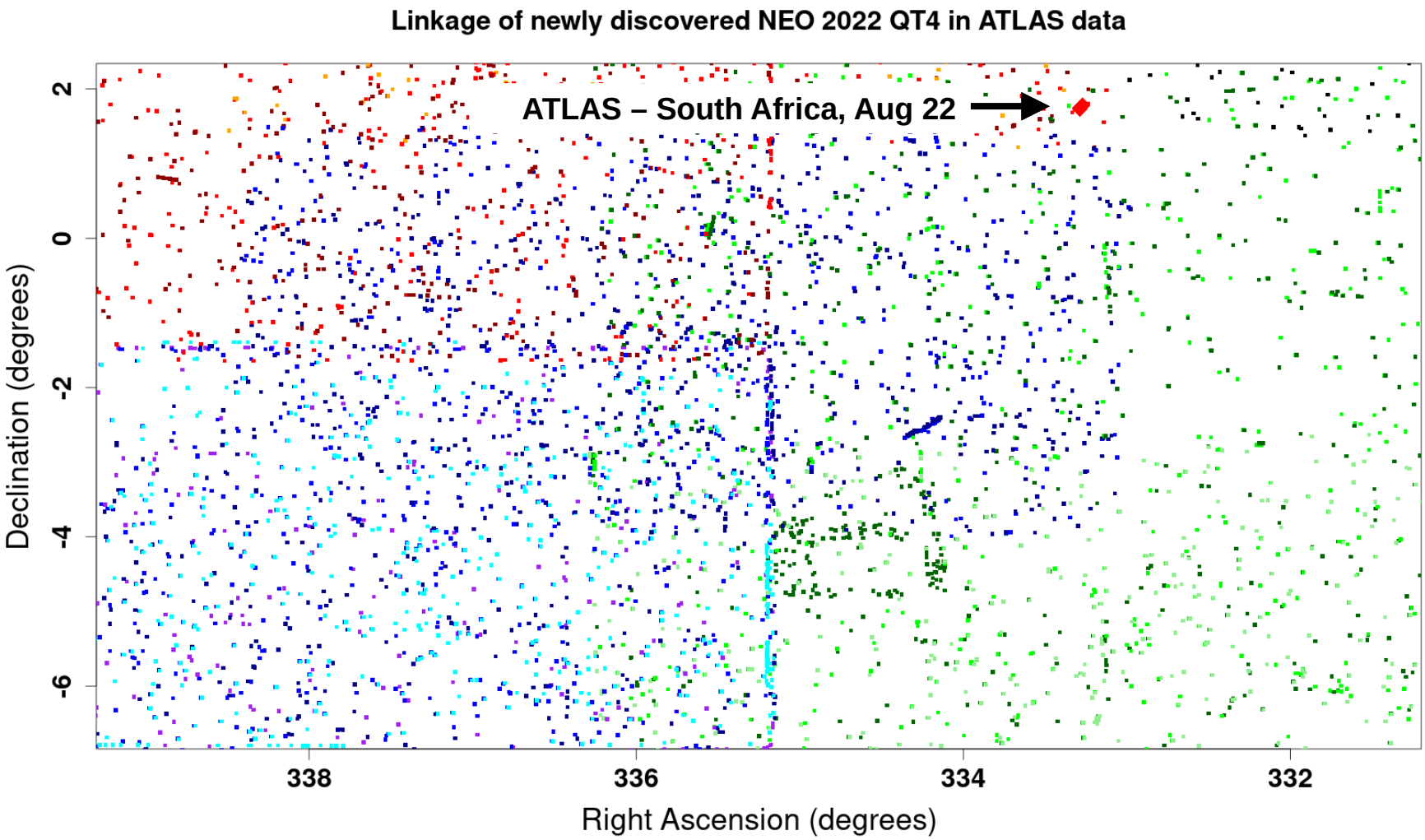


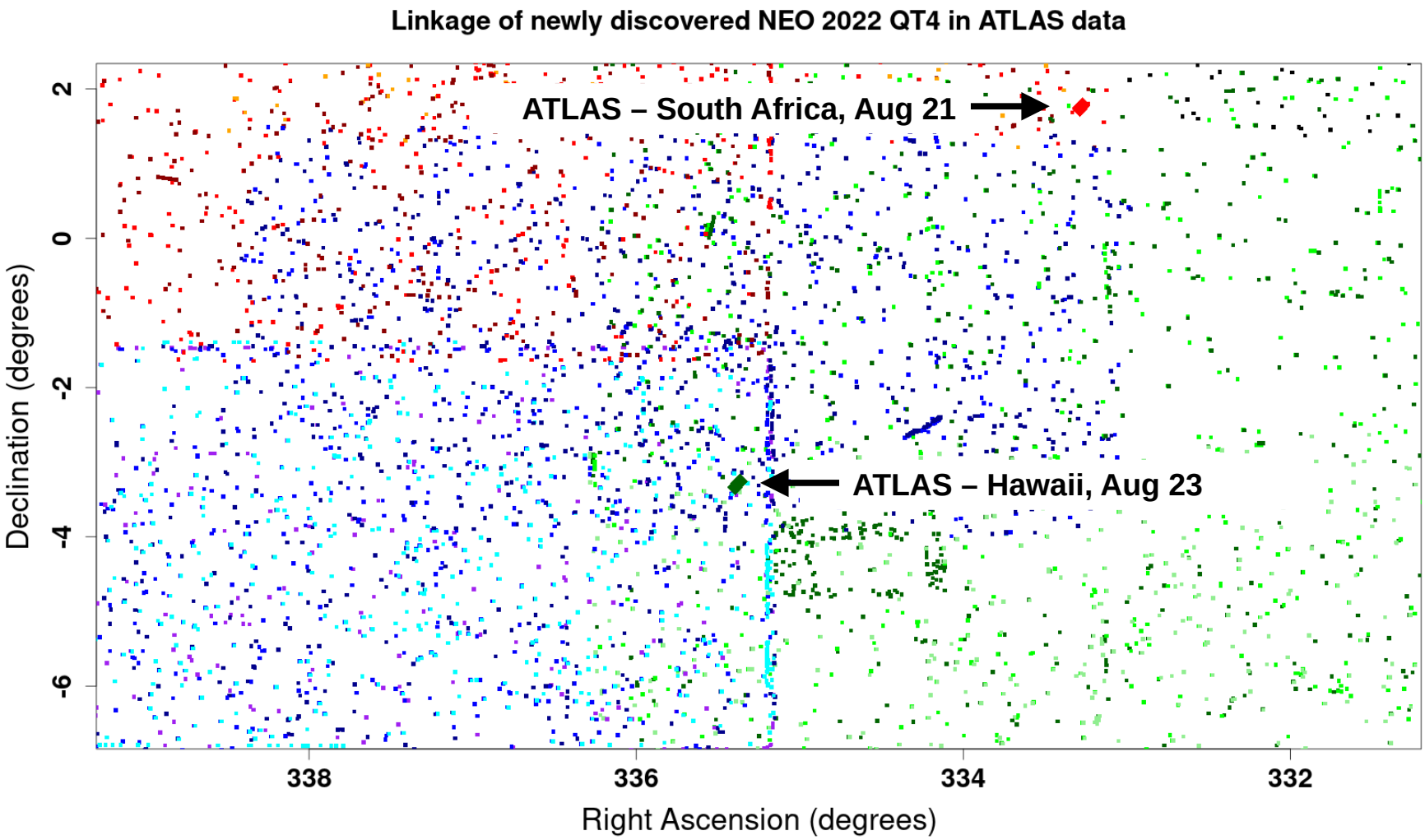


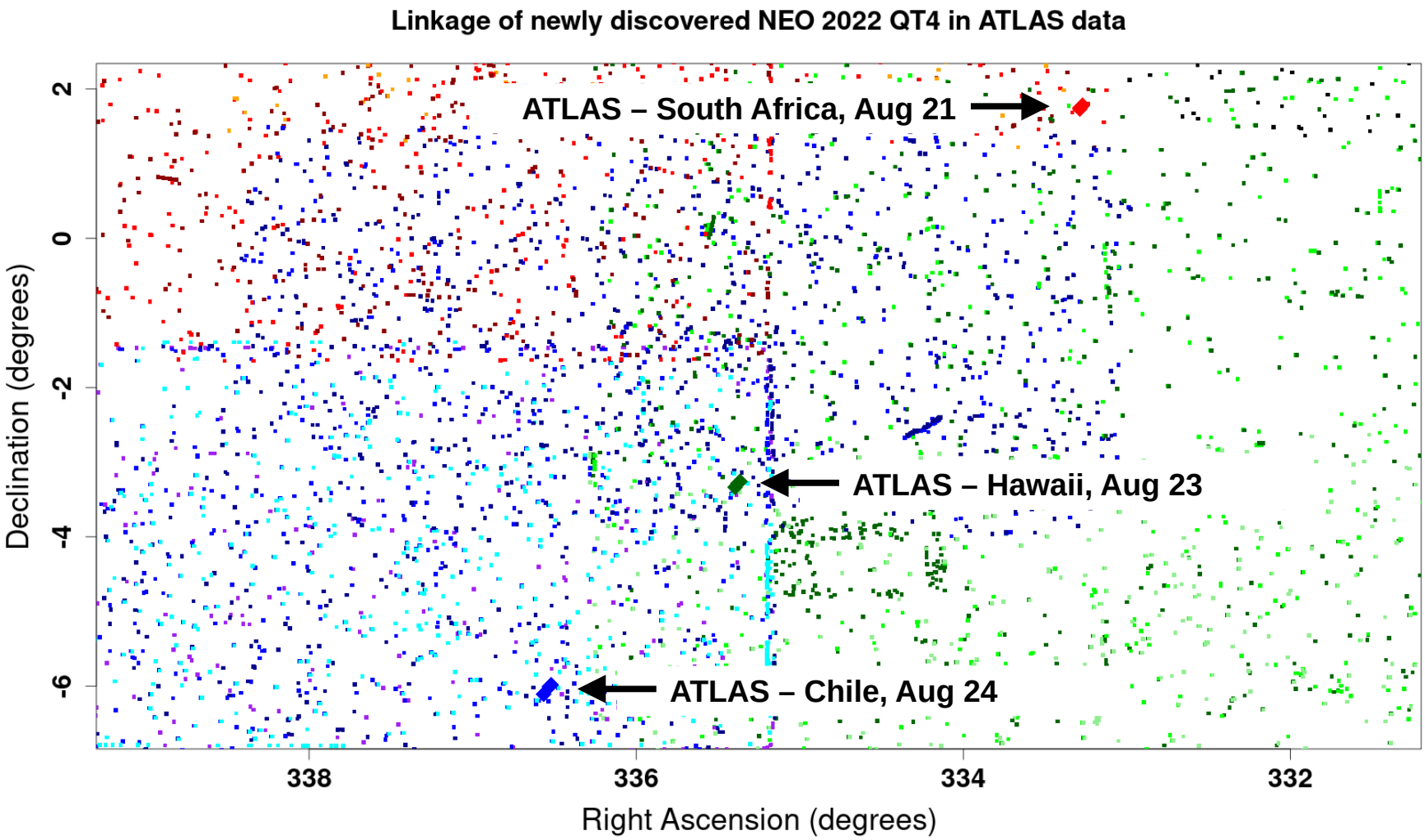


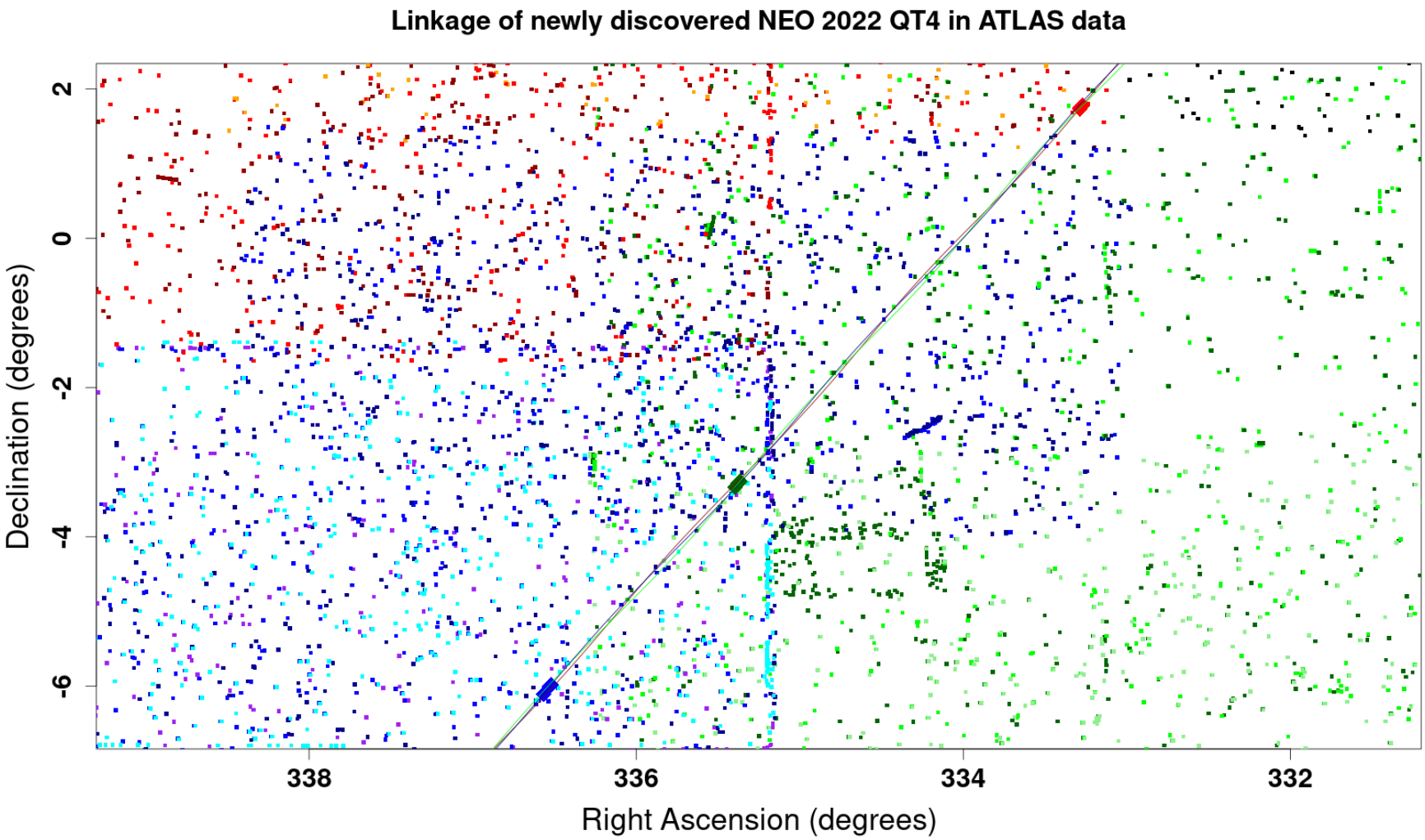



Linkage of newly discovered NEO 2022 QT4 in ATLAS data
Declination (degrees)
2
0
-2
-4
-6
338
336
334
332
Right Ascension (degrees)
HelioLinc3D found a newly-discovered NEO in the ATLAS data – including two nights of pre-discovery observations.


Linkage of newly discovered NEO 2022 QT4 in ATLAS data
ATLAS – South Africa, Aug 22
Declination (degrees)
2
0
-2
-4
-6
338
336
334
332
Right Ascension (degrees)


Linkage of newly discovered NEO 2022 QT4 in ATLAS data
ATLAS – South Africa, Aug 21
ATLAS – Hawaii, Aug 23
Declination (degrees)
2
0
-2
-4
-6
338
336
334
332
Right Ascension (degrees)


Linkage of newly discovered NEO 2022 QT4 in ATLAS data
ATLAS – South Africa, Aug 21
ATLAS – Hawaii, Aug 23
ATLAS – Chile, Aug 24
Declination (degrees)
2
0
-2
-4
-6
338
336
334
332
Right Ascension (degrees)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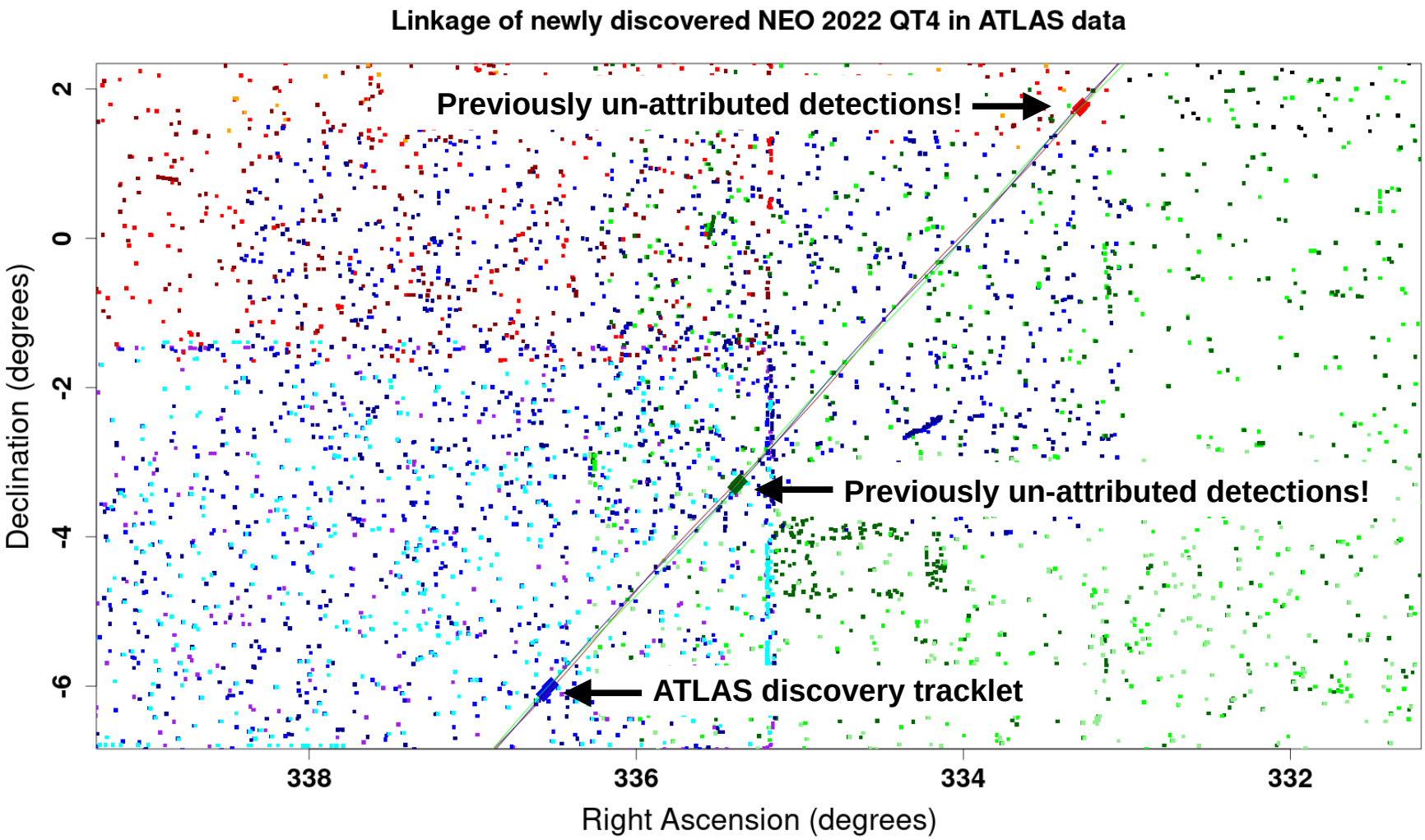

Linkage of newly discovered NEO 2022 QT4 in ATLAS data
Previously un-attributed detections!
Previously un-attributed detections!
ATLAS discovery tracklet
Declination (degrees)
2
0
-2
-4
-6
338
336
334
332
Right Ascension (degrees)

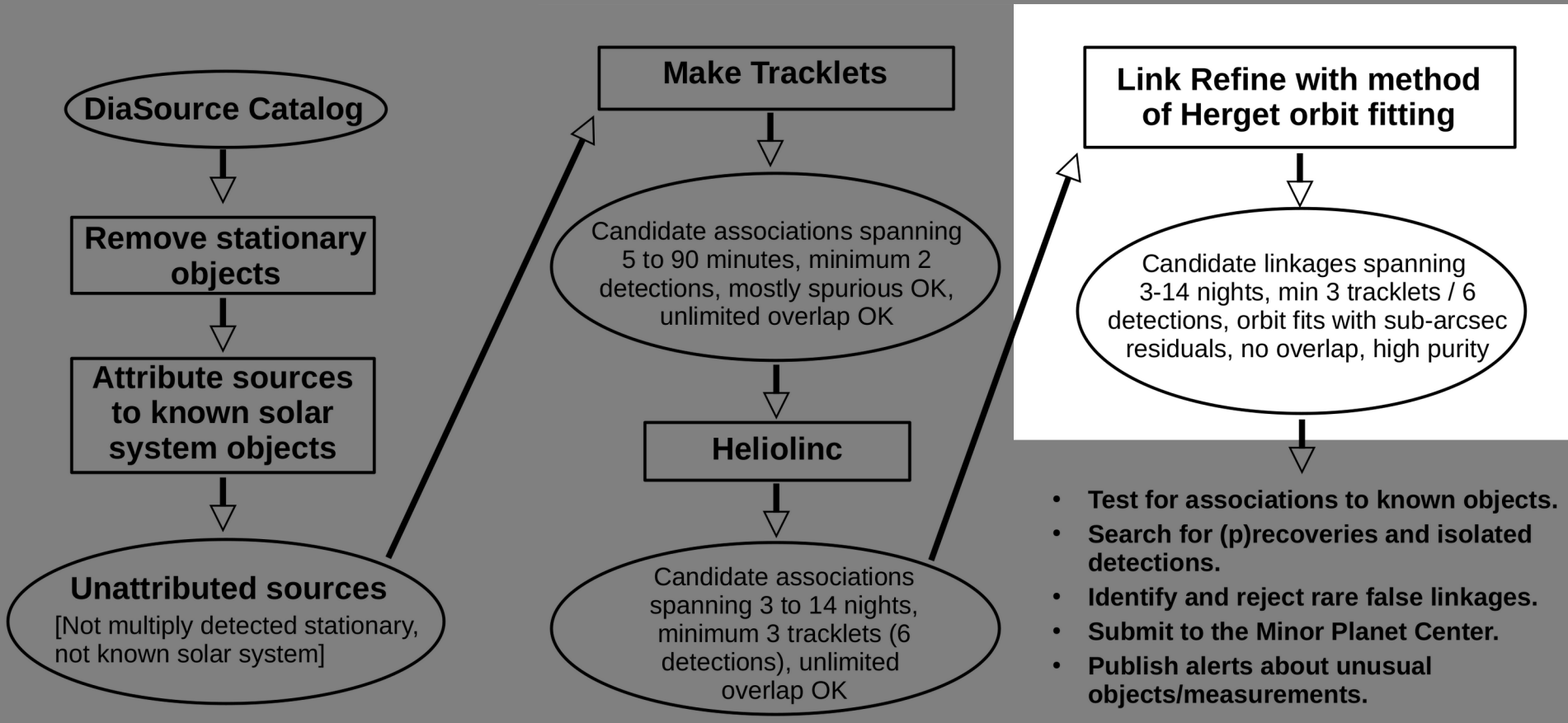
Testing HelioLinc3D

Input data (2 wk)	All detections	Paired detections	Pairs/tracklets
LSST sim	6.084×10^6	5.014×10^6	2.467×10^6
ATLAS (4 sites)	2.177×10^7	1.961×10^7	1.335×10^8

Output data	Hypotheses	Findable objects	Found objects	Completeness
LSST – main belt	3676	200063	197725	98.8%
ATLAS – main belt	3676	Not yet known	>30000	Not yet known
LSST – NEO	43805	449	437	97.3%
ATLAS – NEO	2152	Not yet known	>41	Not yet known

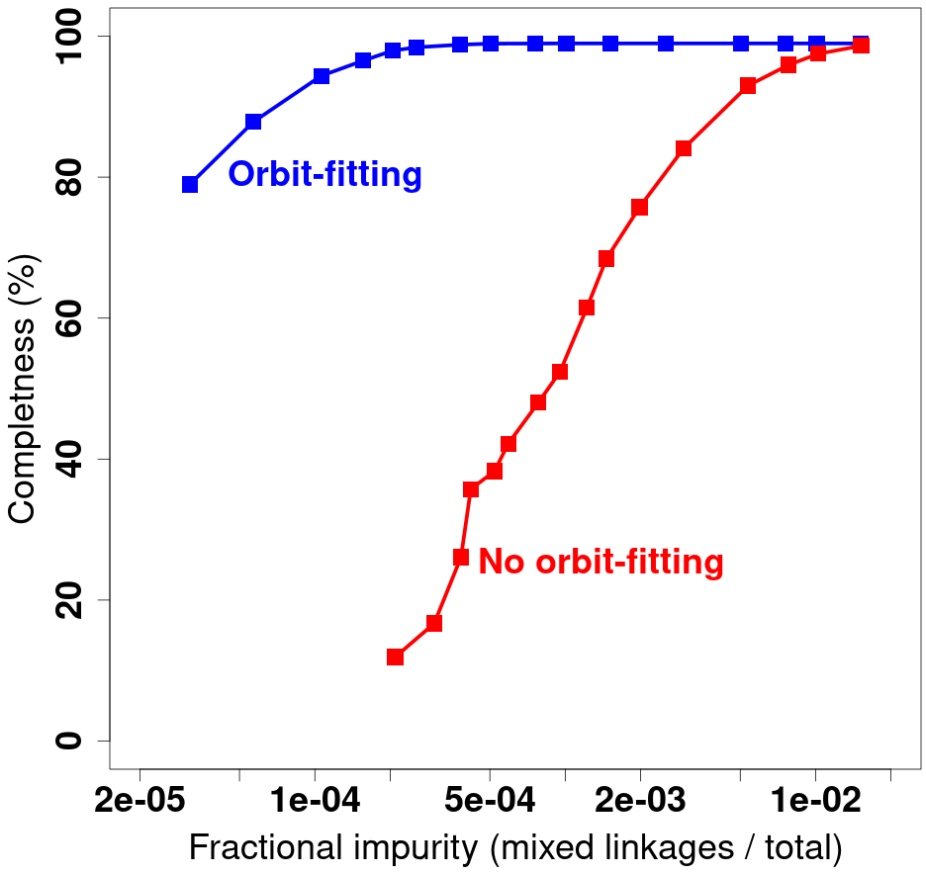
Image credit: Bruno C. Quint

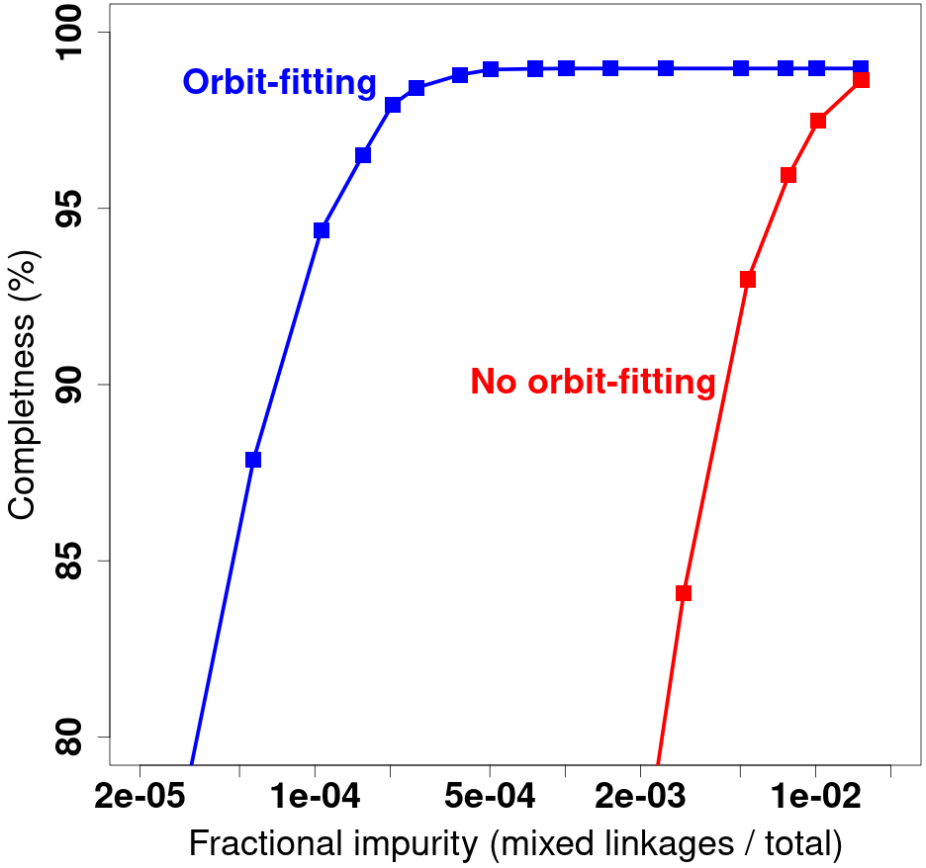
Flowchart for solar system object discovery

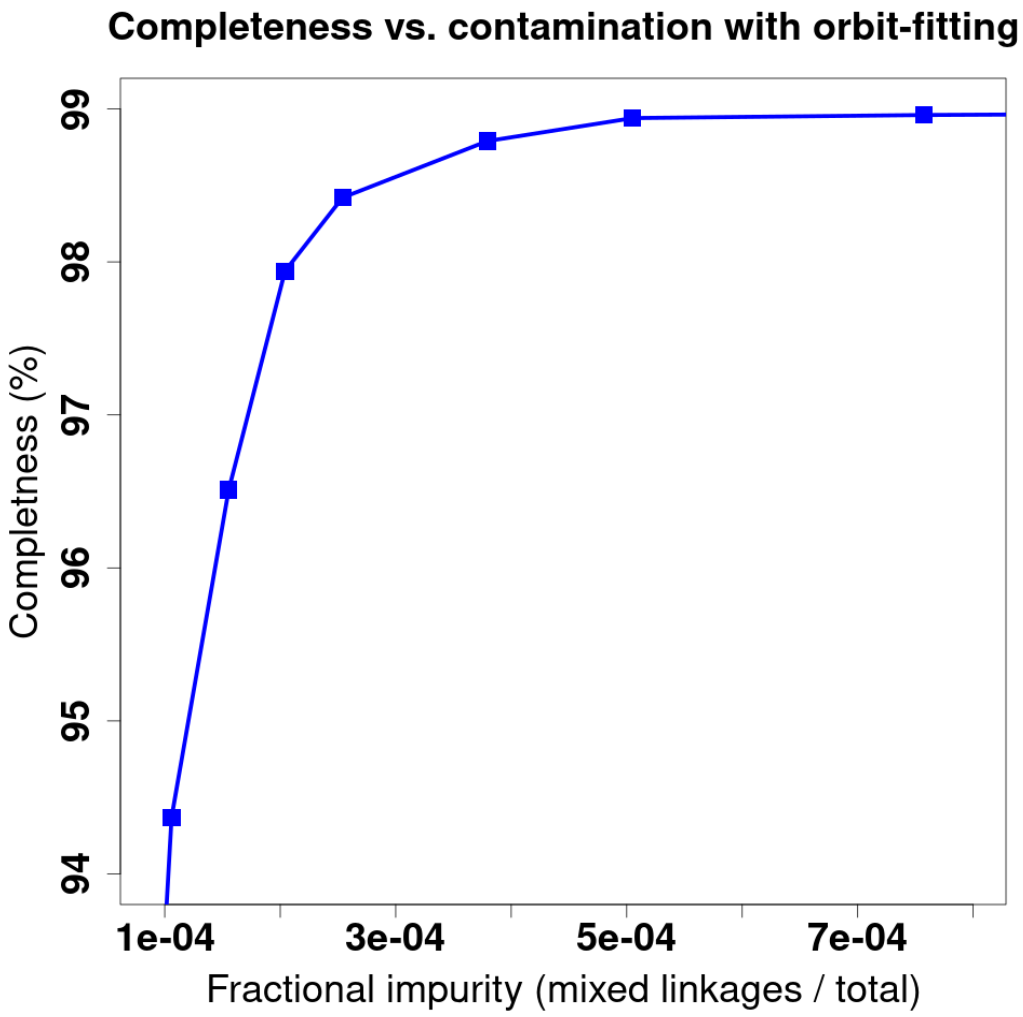


- **Test for associations to known objects.**
- **Search for (p)recoveries and isolated detections.**
- **Identify and reject rare false linkages.**
- **Submit to the Minor Planet Center.**
- **Publish alerts about unusual objects/measurements.**

Orbit fitting enables increased purity and completeness

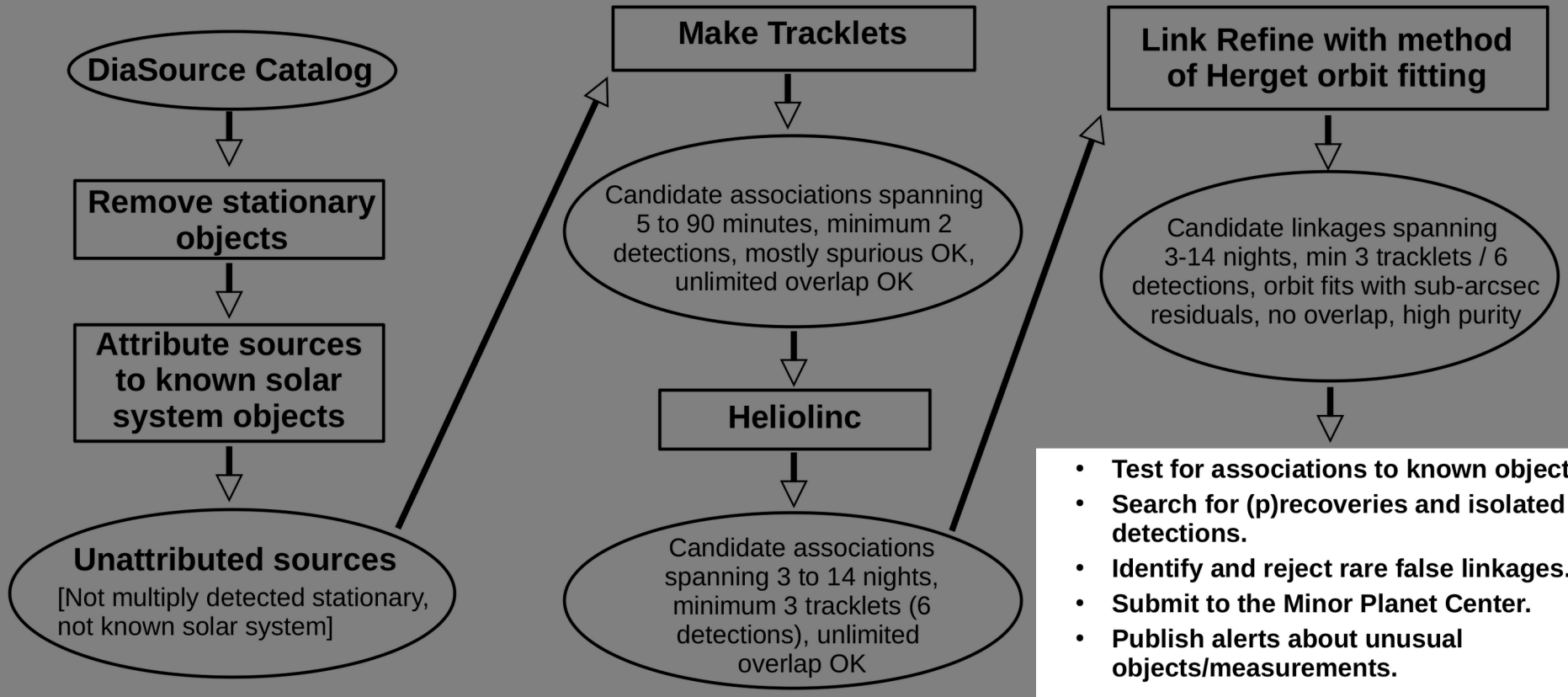






- Can move along the curve by changing the threshold for an acceptable orbit fit (i.e., max RMS astrometric residual).
- Orbit-fit RMS residual thresholds used in this plot range from 0.1 to 0.3 arcseconds.
- A second round of screening using an N-body orbit fitter such as find_orb is feasible, since Link Refine reduces the number of candidate linkages enormously.

Flowchart for solar system object discovery



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When the linking is done:

- **Test for associations to known objects.**
- **Search for (p)recoveries and isolated detections.**
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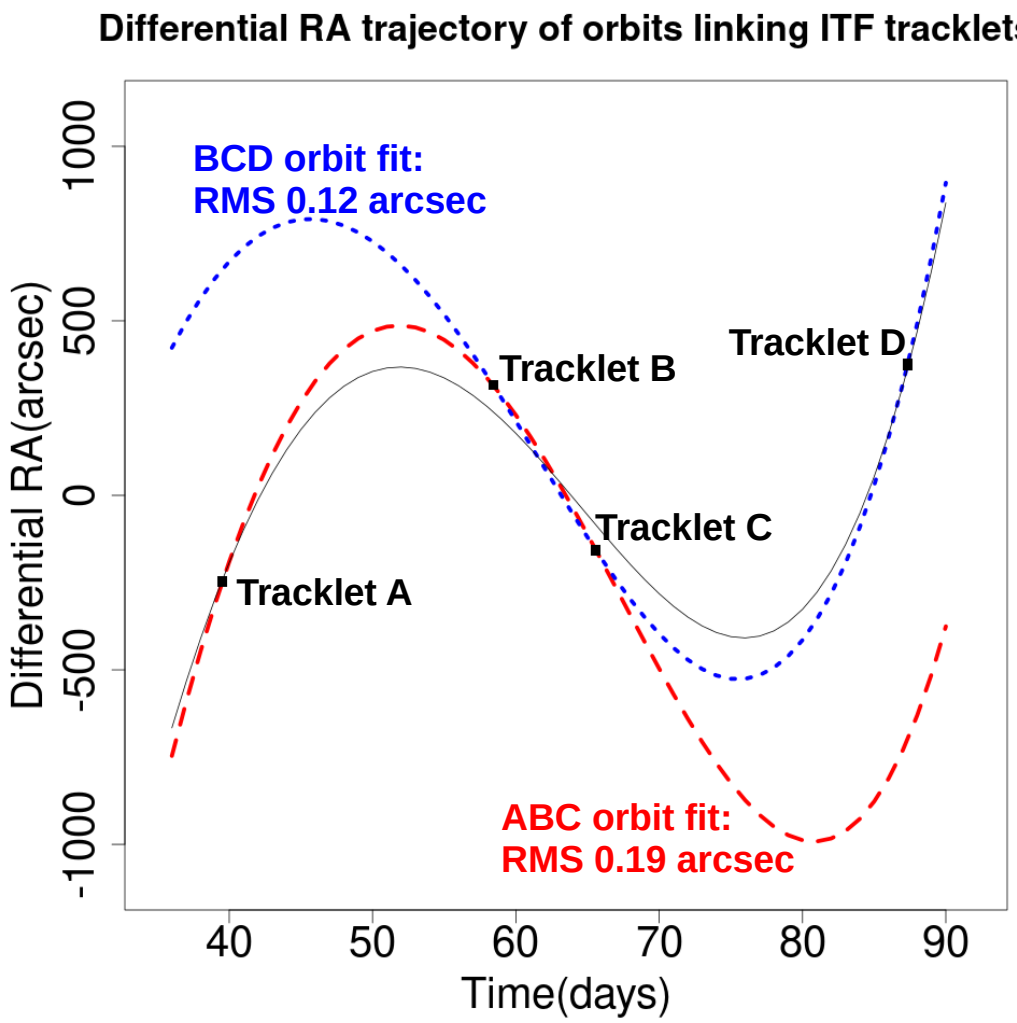
Associations to known objects

- **Optional for LSST, since the MPC will do it**
- **Might be valuable to confirm uncertain linkages, identify more detections**
- **Very different from single-source attribution**
- **Essentially orbit-orbit linking**
- **Can link to short-arc discoveries from previous oppositions**

Precoveries and isolated detections

- **Helpful for confirming uncertain linkages**
- **Isolated detection = the object is detected only once that night**
- **Must fall in the time range spanned by the linkage**
- **Precovery tracklets could be identified going back days to weeks**
- **We'll be running on fresh data: recoveries should be in the original linkage**

Identify and reject false linkages



- All measurements are from Pan-STARRS
- Each orbit (ABC and BCD) looks individually excellent
- The combined orbit fit ABCD has impossibly high RMS astrometric residuals of 36.06 arcsec
- At least one of the linkages ABC and BCD must be incorrect

Why this doesn't mean LSST is doomed: ***TIME***

Identify and reject false linkages

- **Weird orbits require strong confirmation**
- **Could be confirmed through linkage to past discoveries, tracklets, or isolated detections**
- **Question an NEO linkage if contributing tracklets are individually consistent with the main belt**
- **Be suspicious of non-random astrometric residuals, large time-gaps**
- **Possible role for machine learning here**

Publish alerts about unusual objects/measurements

- **Interstellar objects!**
- **Comets**
- **NEOs making close approaches**
- **Known objects that brighten suddenly**
- **Other photometric anomalies?**

What do *you* want to hear about?