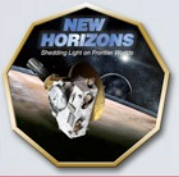


New Horizons HST KBO Search Results: Status Report

Marc Buie for

John Spencer, Alan Stern,
and the KBO Search Team

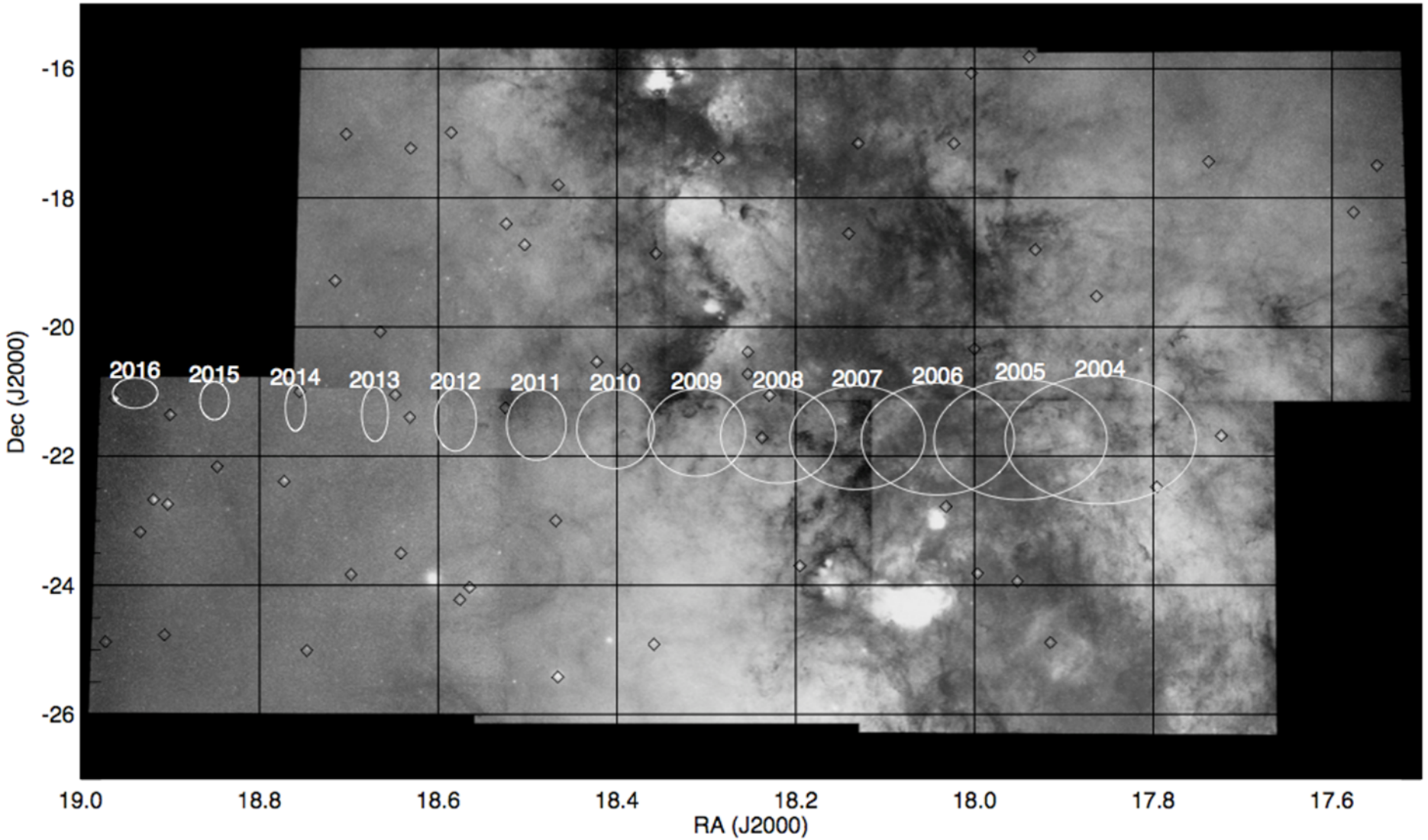
Presentation to STUC

October 15th 2014

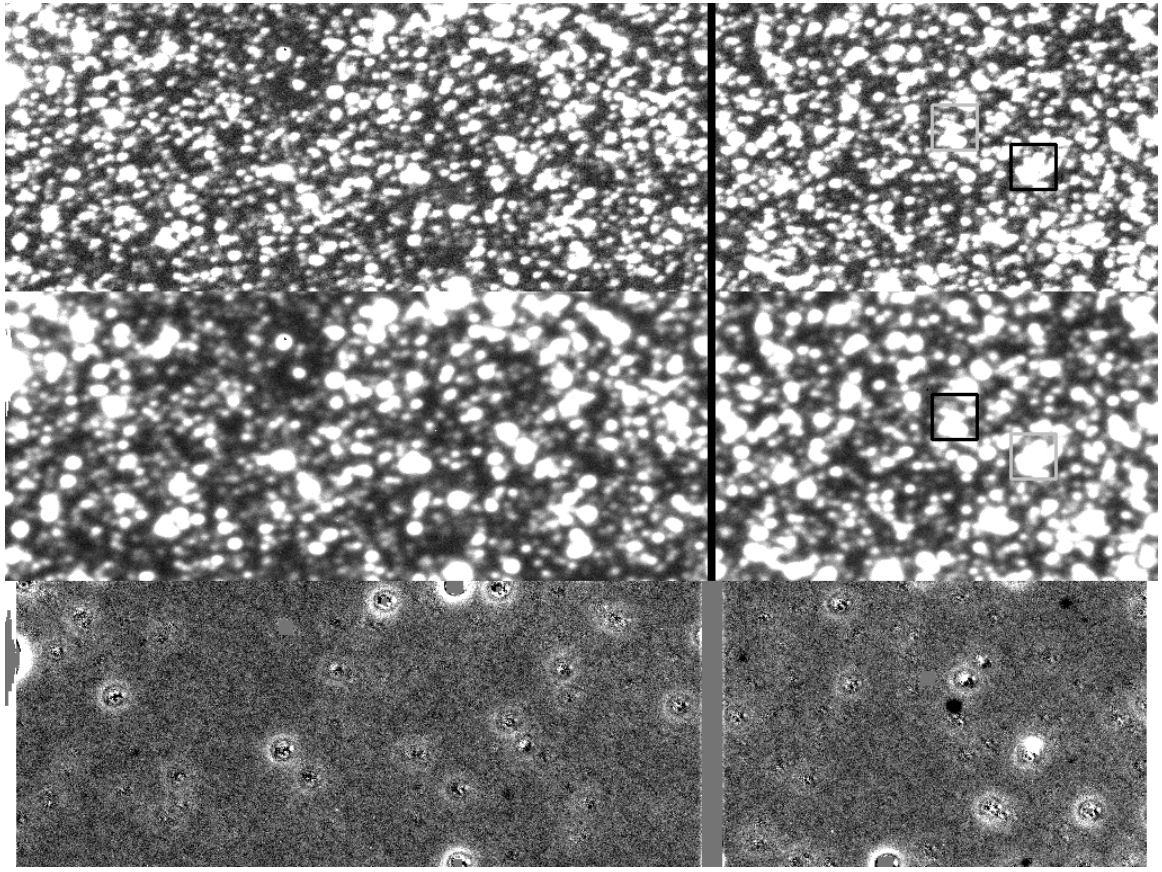
Executive Summary

- The HST KBO Search for New Horizons Has Succeeded
- One Firmly Targetable KBO Has Been Found
- Two More Good Candidates Are Being Tracked
- The Results Above Have Been Multiply Confirmed
- Further Orbit Refinement Is Needed to Make Both Target Selection and an Accurate Targeting Burn
- Announcement of the Basic Results Released Publicly on 2014 Oct 14

Search Region Over Time



New Horizons Fields from the Ground



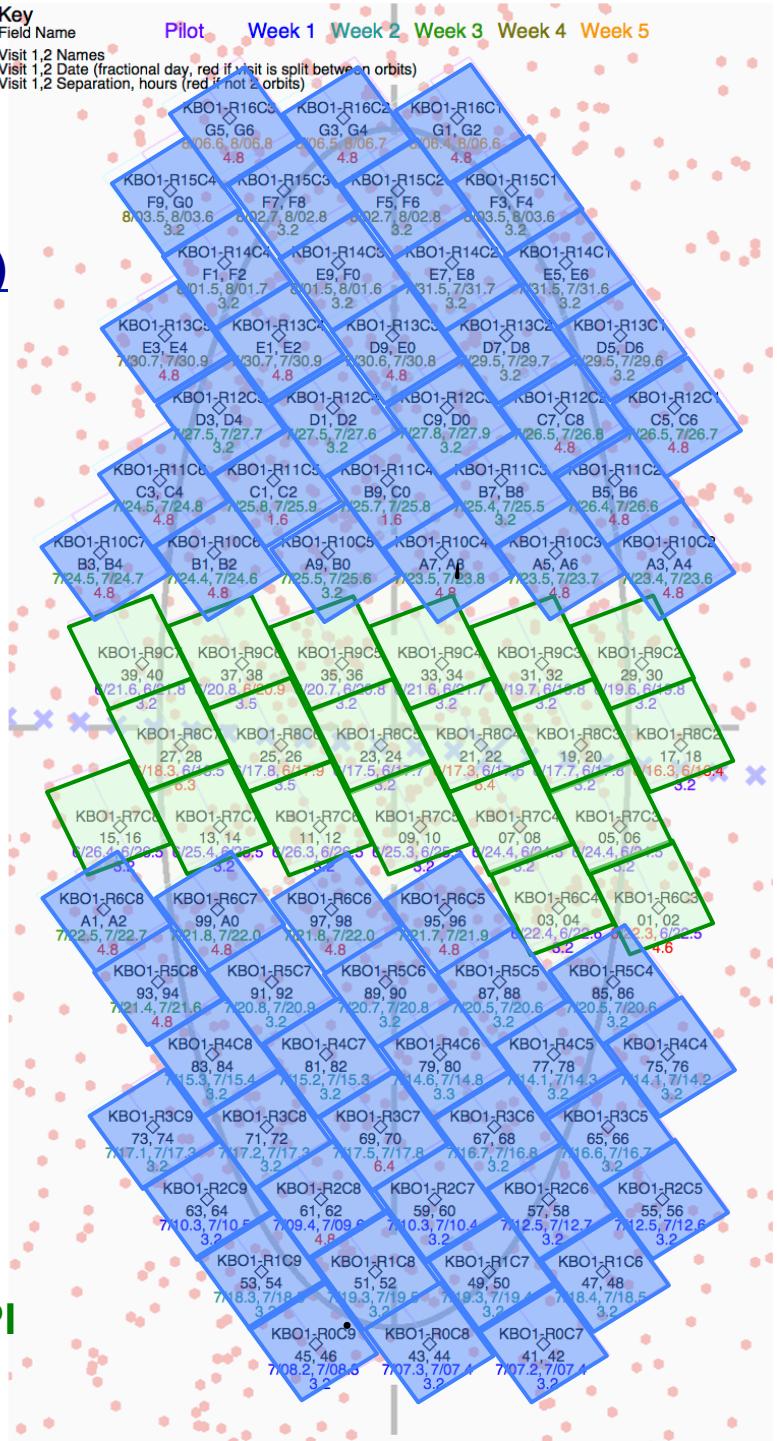
HST KBO Search Background

- A key goal of the New Horizons mission has always been an extended mission to one or more Kuiper Belt Objects (KBOs) after the Pluto.
- No known KBOs are reachable with our available 130 m/sec ΔV, so a dedicated search was required.
- Ground-based searches, ongoing since 2004, have not been successful.
- Granted time for an HST search in 2014.
  - HST's higher angular resolution can find fainter, more numerous KBOs, especially in the crowded Milky Way star fields where this search must be done.

HST Search Strategy

83-field search area, 2 orbits/field (typ 3 hrs apart)

- June 16th – June 25th 2014
  - 40-Orbit pilot search of central region (green), using DD orbit allocation
  - Required discovery of 2 objects to proceed to full search
- July 7nd – August 6th
  - 126-orbit full search (blue), covering the remainder of the search area.
- August 2nd – September 2nd
  - 20-orbit initial follow-up on interesting targets for orbit and targetability refinement
- Mid-Sep to Mid-Oct: Stationary Point
- Late October
  - Planned final 2014 follow-up of remaining interesting objects
  - Uses our 14 remaining allocated orbits, including orbits from separate ToO proposals (PI Benecchi)



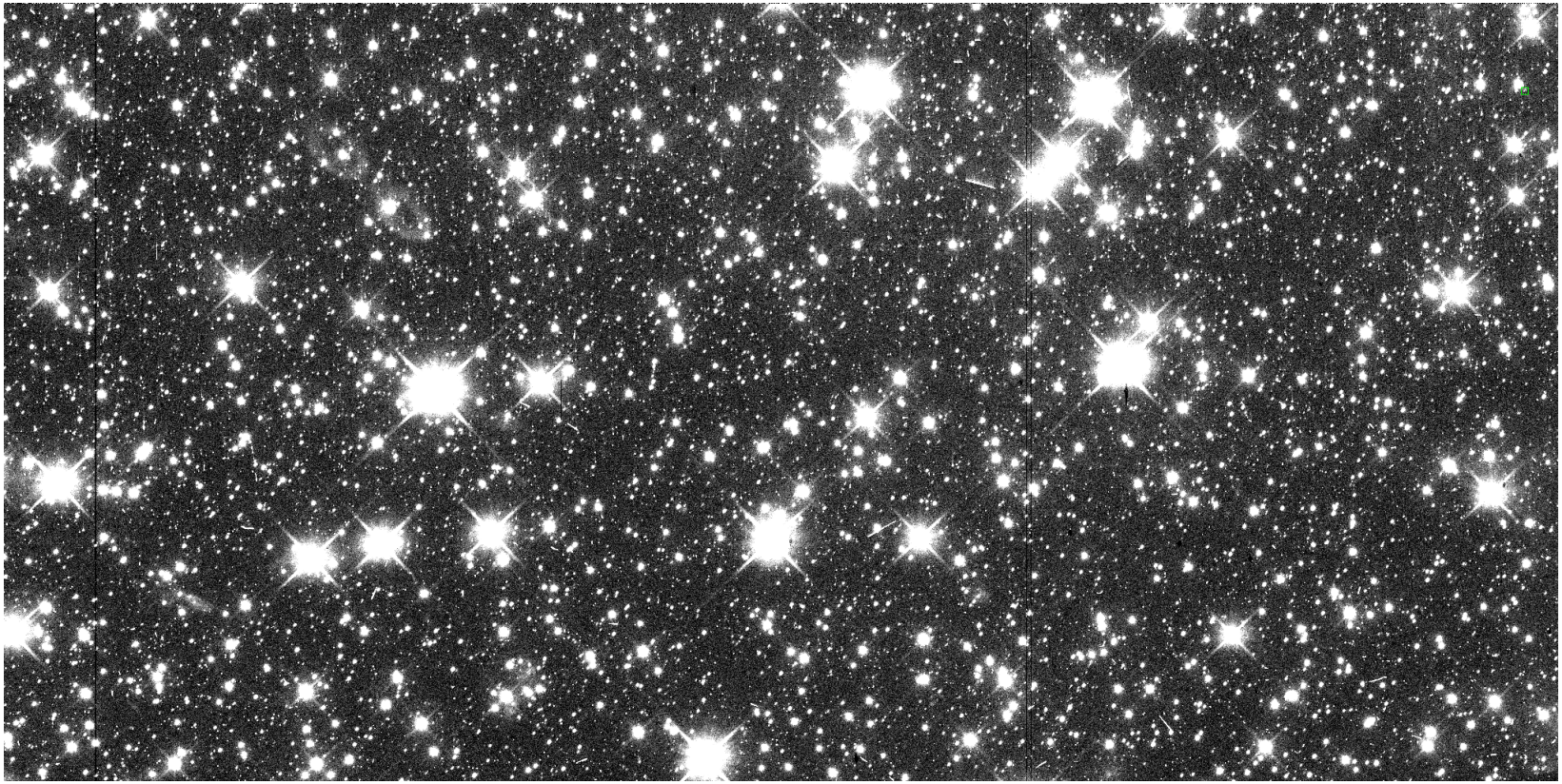
Methodology

- For each field, 2 orbits, 5 370-sec exposures per orbit, F350LP filter, UVIS1+2
- Tracking mean of candidate cloud (non-sidereal and parallax). Smear within cloud < 0.5 pixel per exposure.
- 0.75'' spacing N-S 5-point dither

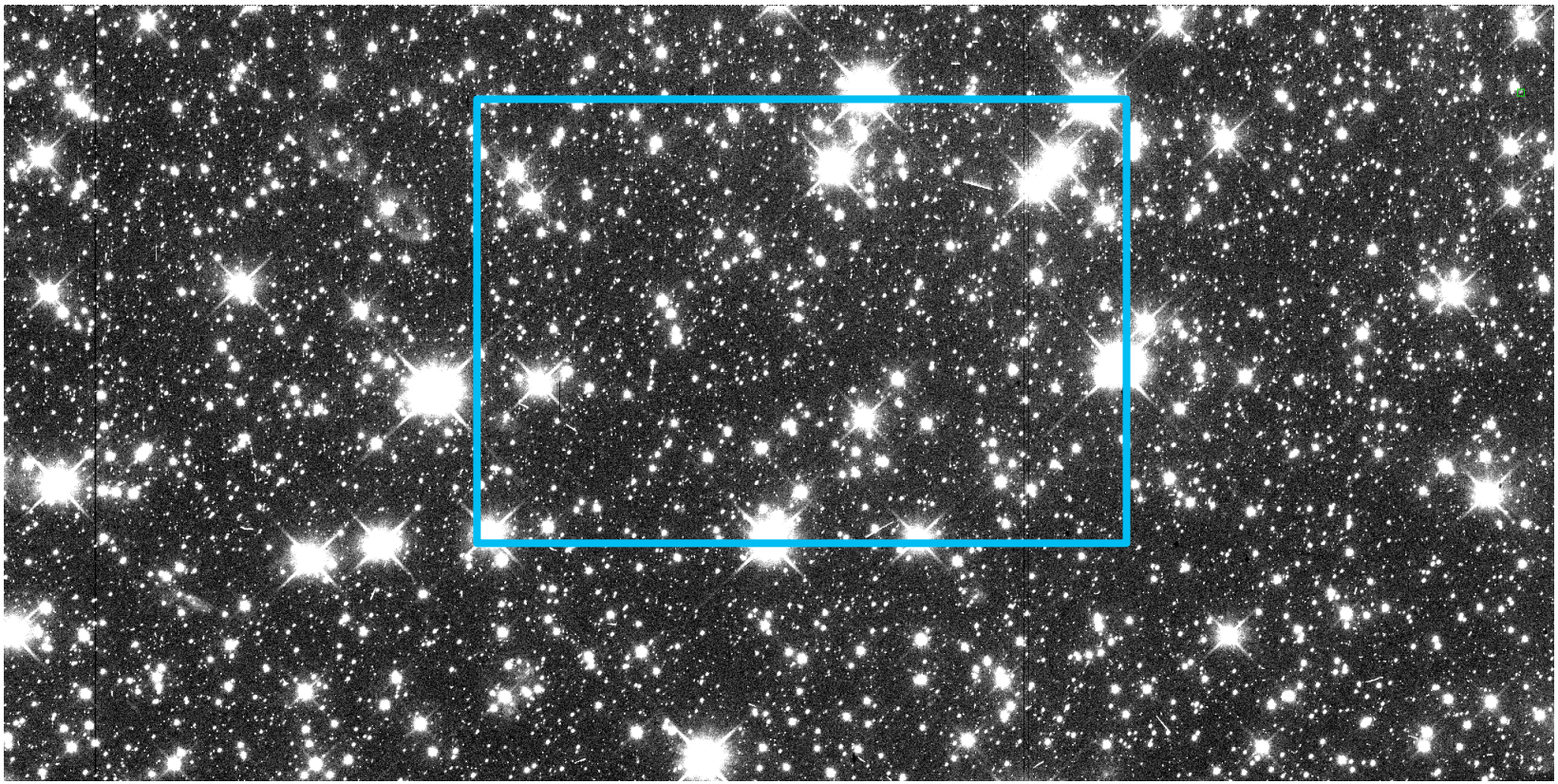
Image Processing Sequence

- Unit set of data is 5 images from one visit (two visits are used to find moving objects)
- Build a reference star image (TNOs and CRS gone)
- Subtract star template
- Rectify images to common grid with 2x sampling for each shift velocity and distance (20-80 shift points)
- Stack rectified images
- Scan stacks for sources
- Scan sources to find coincidence between two orbits consistent with the shift point
- Generate vetting graphics for each candidate
- Visual examination of all candidates

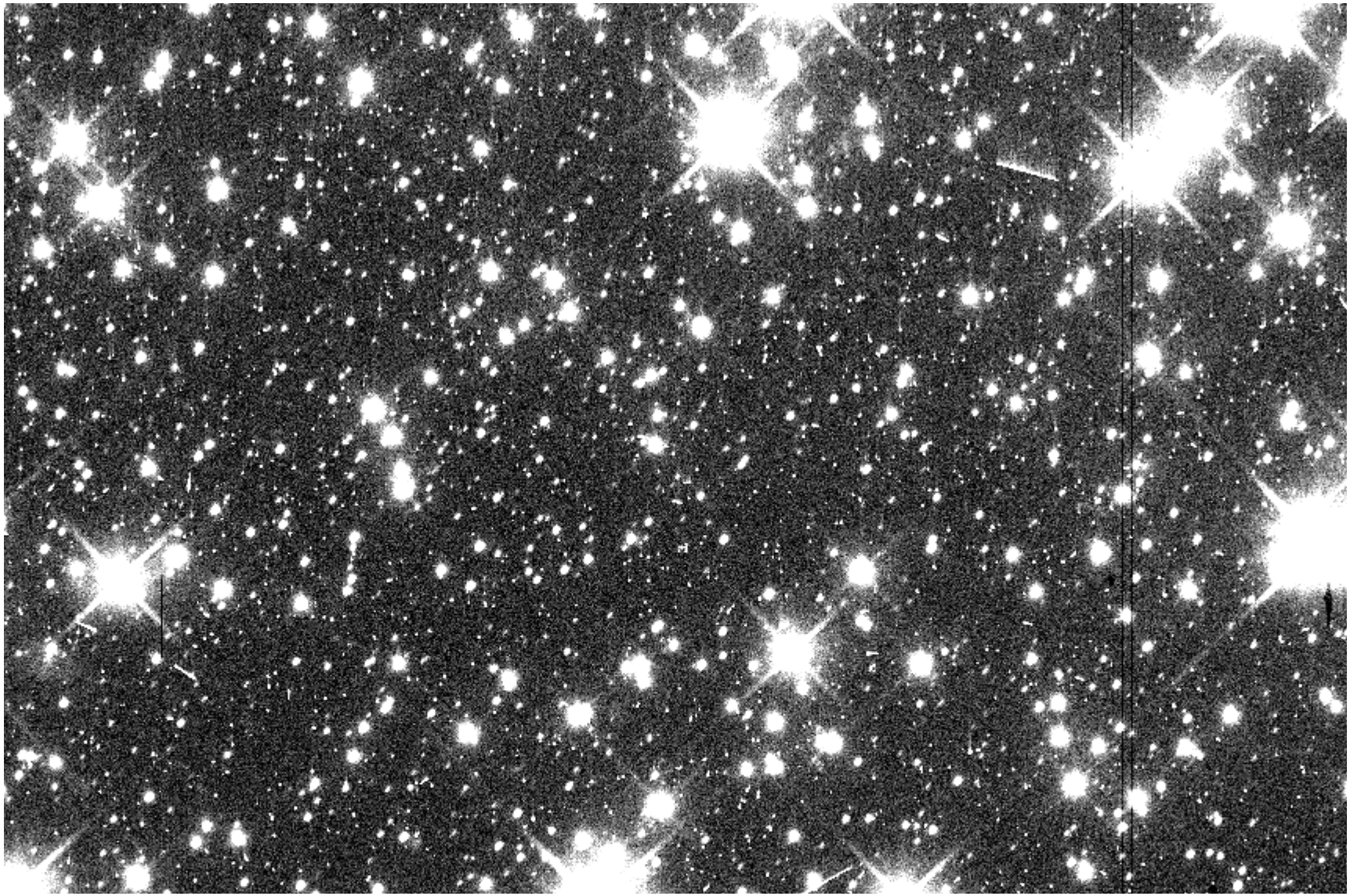
One search image, UVIS1 only



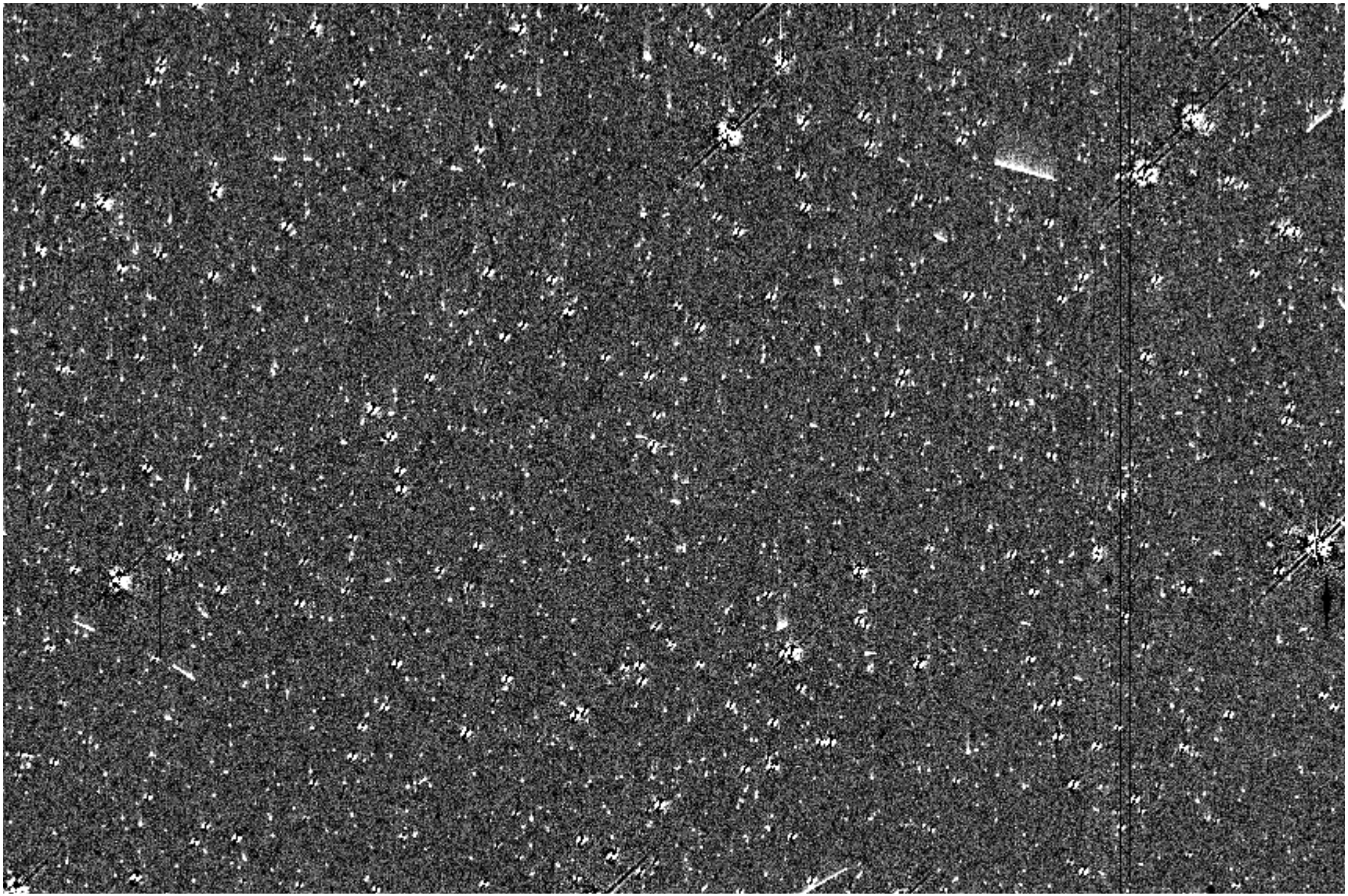
One search image, UVIS1 only



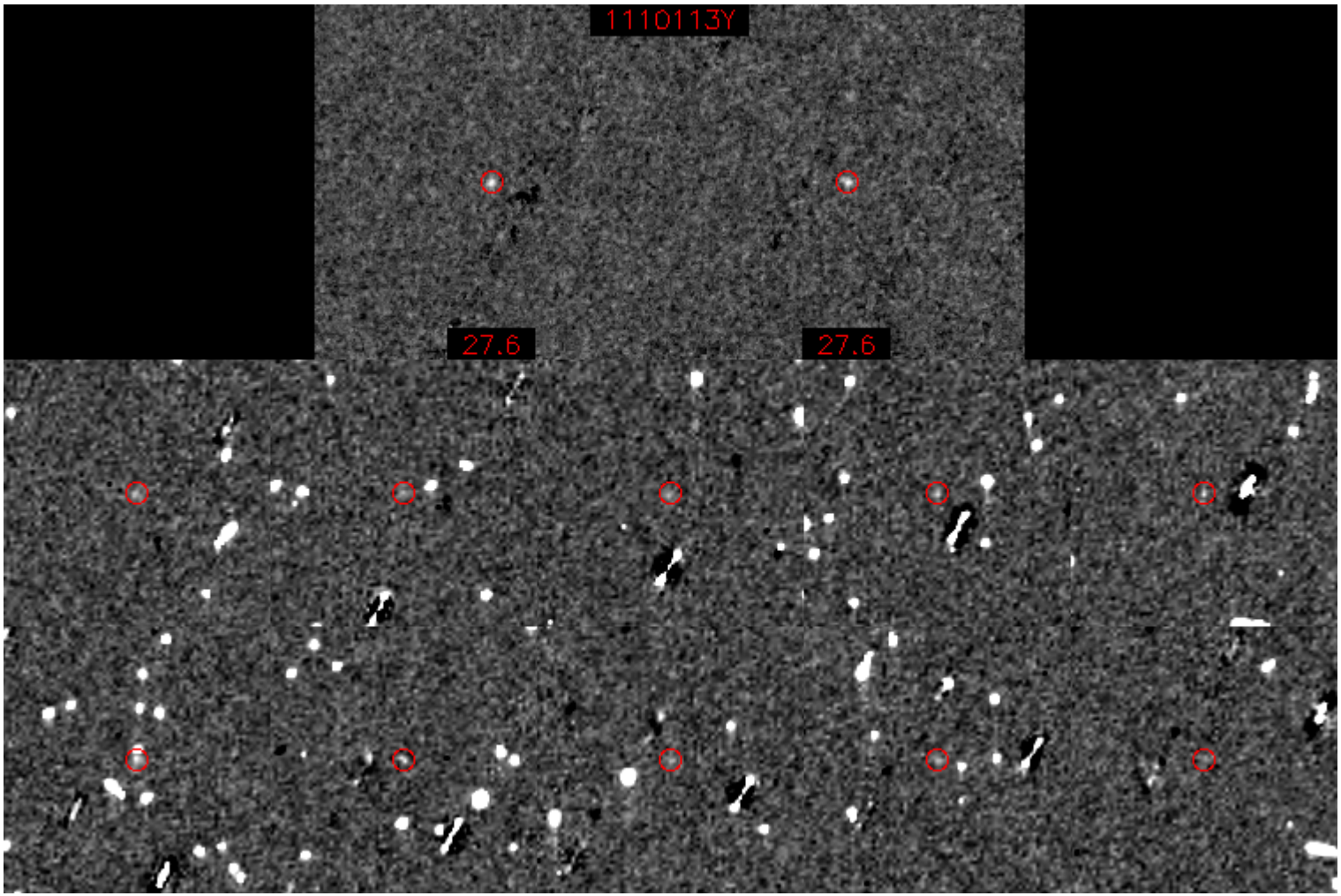
One search image, zoom 2x

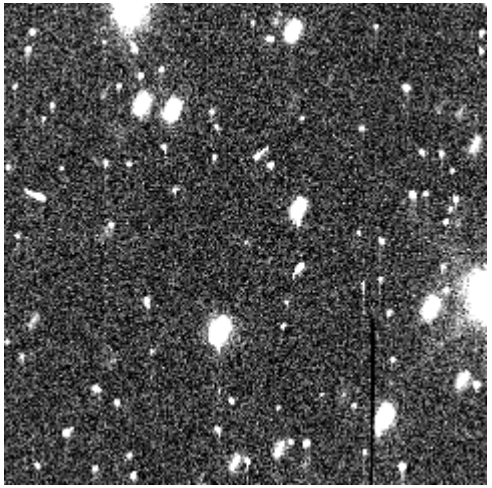


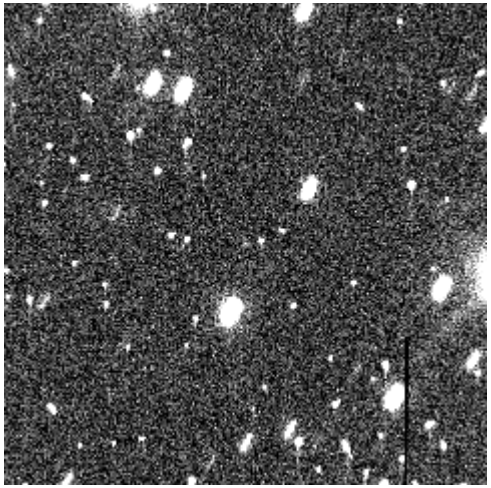
One search image, zoom 2x

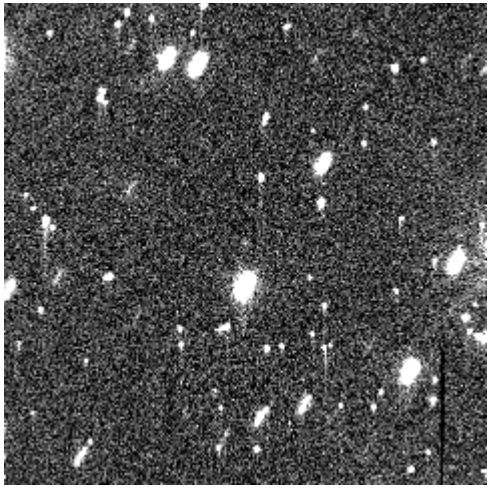


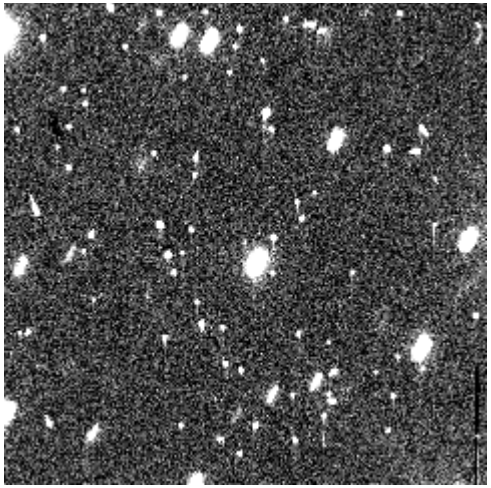
Putting it all together

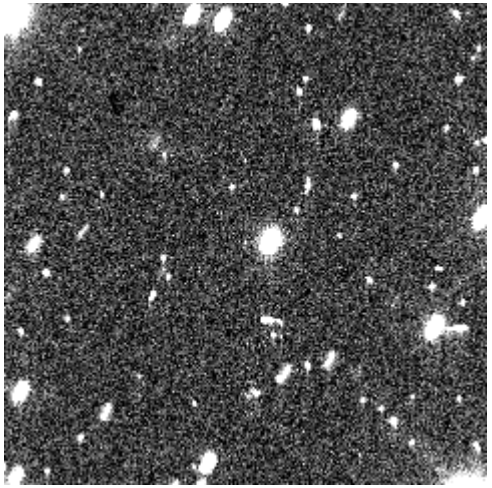




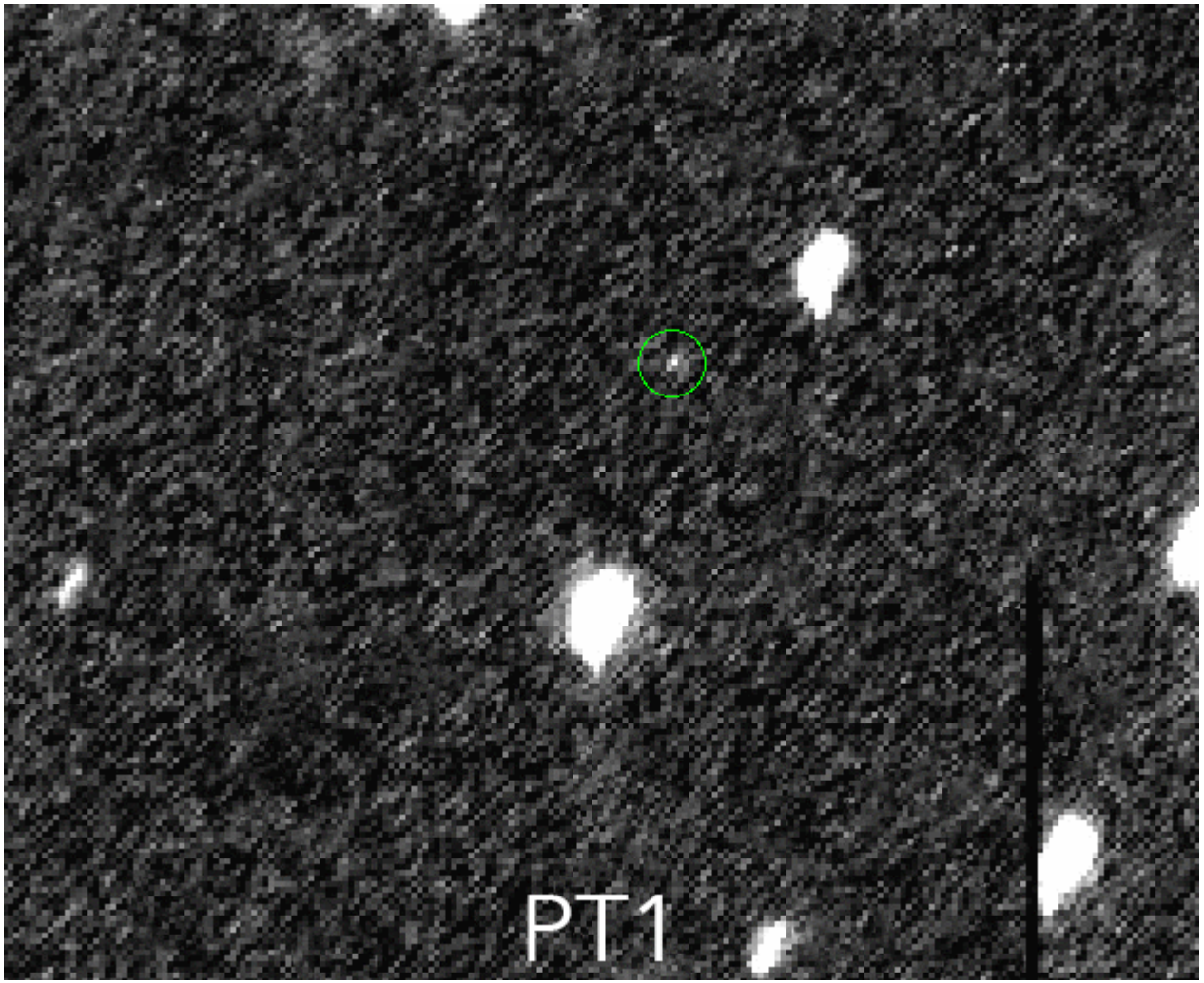








Closeup of PT1 / 1110113Y



Timeline

- Friday, June 13, TAC approval
- Monday, June 16, first data, processing begins
- Friday, June 20, first pipeline version complete, searching starts but false positive rate is excessive
- Saturday, June 21, first implanted objects
- Sunday, June 22, star templates completed
- Thursday, June 26, second pipeline version complete
- Friday, June 27, first object detected
- Saturday, June 28, second object detected
- Sunday, June 29, pilot data processing completed
- Monday, June 30, approval given for full search

Timeline

- Monday, July 7, data collection resumes
- July 9, 3rd object found
- Jul 22, 4th object found (2 week, 25 field dry spell), object was very weak and not confirmed
- Jul 31, 5th object found (PT2)
- Aug 2, first recovery PT1, interesting; other object not
- Aug 21-23, second recovery PT1, targetable, first recovery PT2, interesting
- Aug 6, survey observations completed
- Aug 7, 6th object found (PT3), processing complete
- Aug 25, PT3 recovery, interesting

HST Search Results

- 5 fields not useful due to guide star failures or moonlight (red outlines)
- All data reduced using 3 independent data reduction pipelines
  - Pipeline depths checked by recovery of implanted objects
  - Pipelines agree on all definite objects
  - Additional manual field inspection search
- Initial Discoveries:
  - 5 definite objects (✕), and 4 additional marginal objects (+) identified
  - Follow-up observations made on all plausibly-real objects with significant (>~10%) initial estimated targetability

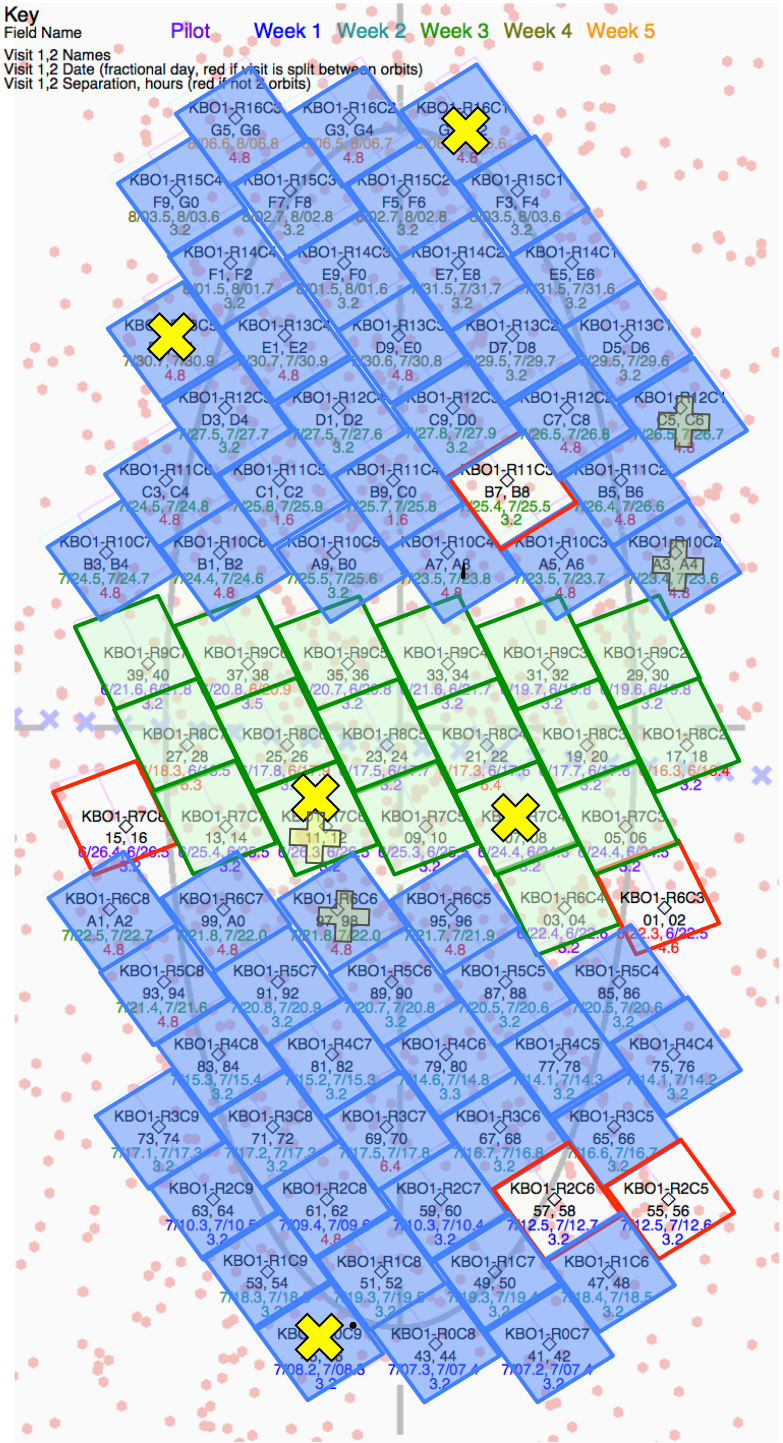


Table of Discoveries After Follow Up

List of Potential Targets													
Name	Nick-name	Mag-nitude	Estimated Diameter Albedo = 0.15	Estimated Diameter Albedo = 0.04	Current Targetability Probability	Current Mean Delta-V, m/sec	Number of Orbits	First Seen	Most Recent Follow-up	Arc Length, Days	Next Planned Follow-up	Encounter Date	Encounter Helio-centric Distance, AU	Notes
1110113Y	11/PT1	26.8	25 km	45 km	1.00	25	8	Jun 26	Aug 23	58	Late Oct	Jan 2019	43.4	100% targetable with multiple models and assumptions
E31007AI	E3/PT2	26.3	30 km	55 km	0.07	160	6	July 30	Aug 23	24	Late Oct	2018-9	43-44	Still of interest- more follow-up planned
G12000JZ	G1/PT3	26.4	30 km	55 km	0.97	115 - 175	6	Aug 6	Aug 25	19	Late Oct	Jun 2019	44.0	Targetability depends on assumed priors - least unusual orbits are most targetable
4510067S	45	26.9			0.00		2	July 8		< 1				Inaccessible based on discovery images- no follow-up requested
0720090F	7	27.4			0.05		4	Jun 24	Aug 3	40				Unlikely to be targetable based on first follow-up - no further follow-up requested
a31006AP061	A3	27.4			0.20		2	July 23		< 1				Marginal: attempted recovery failed.
11102065	11b	27.5					2	June 26		< 1				Marginal: Probably not real
c520022H	C5	27.5			Small		2	July 26		< 1				Marginal: low targetability if real
9720067D	97	27.6			0.00		2	July 21		< 1				Marginal: Not targetable even if real

Conclusion:

We have identified 1 KBO that is definitely targetable, and 2 more potentially targetable KBOs.

Checking Targetability: Further Details

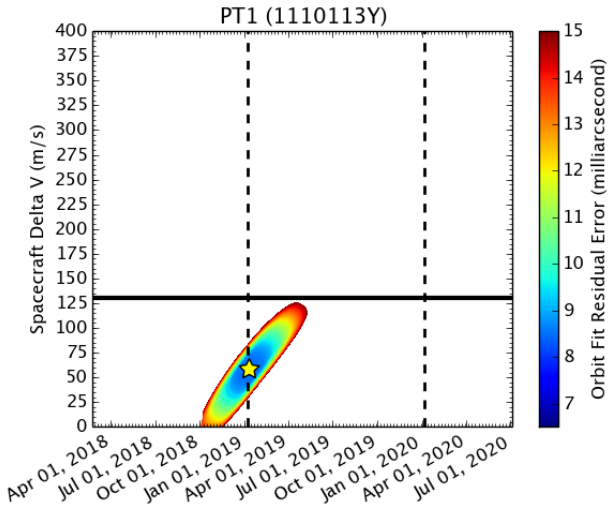
Three steps to determine targetability:

1. **Astrometry**
   - Depends on quality of astrometric star catalog employed
   - Astrometry supported by a custom catalog tied to UCAC4 catalog
     - Custom catalog is needed to go deep enough to match the stars in the HST images
     - Based on CFHT data, which is known for very high astrometric precision
   - Very high confidence in the catalog and derived astrometry, based on:
     - Excellent consistency relative to the HST images (milliarcsec level)
     - Low orbit-fit residuals (milliarcsec level)
     - Consultation with catalog's author (Stephen Gwyn, Hertzberg Institute for Astrophysics)

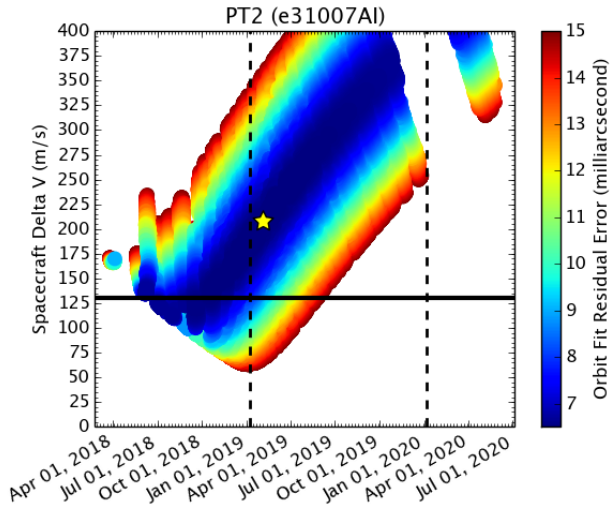
2. **Orbit determination**
   - Three independent orbit fits to the same astrometry for object 11 give consistent ΔVs to within +/- 6 m/sec (5% of our 130 m/sec budget)
   - Note: Object 11 orbit fits have low Delta-V for all reasonable variations in the weighting of the astrometry or the expected orbits

3. **Delta-V calculations**
   - Using the same orbital elements, 2 teams get identical ΔV to within 1 m/sec

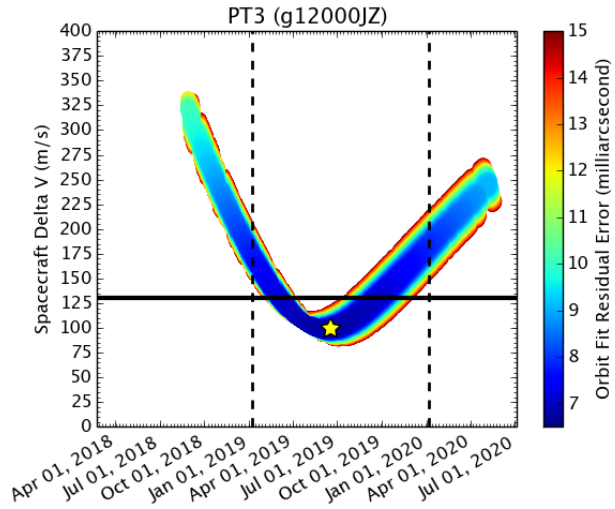
Orbit Estimates and Targetability



a = 43.94 ± 0.08 AU
e = 0.019 ± 0.009
i = 2.4506 ± 0.0004



a=44.4 ± 1.3 AU
e=0.10 ± 0.12
i=3.814 ± 0.016



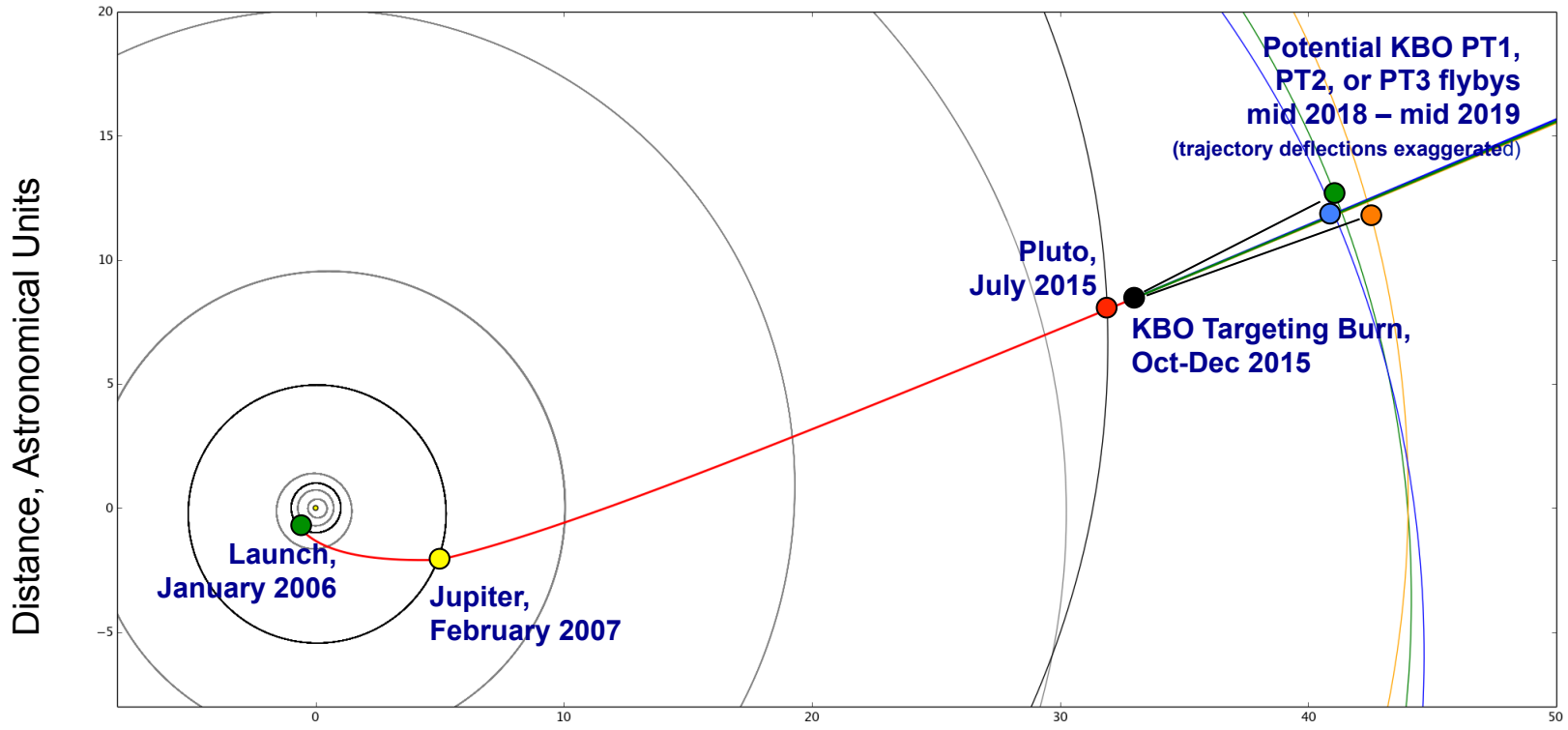
a=44.2 ± 0.6 AU
e=0.10 ± 0.07
i=4.134 ± 0.008

All three of these objects have scheduled observations from Oct. 15-22.

Orbit quality will improve with each new observations but the single biggest improvement will come with first observation next year.

Target Flyby Locations and Timing

- Potential encounters are in late-2018 to mid-2019
- All candidates at in size range recommended by 2003 Planetary Decadal Survey, and will be at 43 – 44 AU, in the "Cold Classical" Kuiper Belt
  - ~1 billion miles beyond Pluto!
  - Most pristine KBO population
- Multiple target flybys are not feasible with available fuel



Summary

- We have extremely high confidence that object “11” is targetable by New Horizons.
- Objects “G1” and “E3” may also be targetable, though still uncertain due to shorter arcs
  - Both cost more fuel, but are still under consideration because they are 50% brighter than “11”
    - Both are probably large: So potentially better science
    - Both are brighter: So easier orbit determination
    - Both are brighter: So easier OpNav on final approach
  - Planned October recoveries will reduce uncertainties, could eliminate one or both
- It’s unlikely that NH can visit more than one of these three objects within our fuel budget.