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The Classical and Large-a Solar SYstem (CLASSY) Survey



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PRESENTED AT:



ABSTRACT

Here we introduce CLASSY: the Classical and Large-A Solar SYstem survey. This survey is a large program on the Canada-France-Hawaii Telescope that will use 56 nights in 2022B through 2024A inclusive. Using shift'n'stack techniques, CLASSY will survey 12.2 square degrees of the invariable plane to an anticipated depth of $r=26.6$ in search of Kuiper Belt Objects and extreme trans-Neptunian objects (eTNOs), the vast majority of which will be tracked to a second opposition. This survey has two primary goals: to provide observational tests of the cutting-edge planet formation models; and to test cosmogonic models of orbital emplacement. We will carefully measure the size-frequency distribution of classical TNOs for diameters $30 \leq D \leq 250$ km (assuming 16% albedos). This size range is critical for determining properties of the streaming instability and cloud collapse mechanisms that formed TNOs because it spans between the size of the central bodies that formed from the streaming instability, and the detritus ejected during cloud collapse. Importantly, CLASSY is the first survey designed explicitly to avoid longitudinal discovery biases that may be present in the known eTNOs sample. In this presentation we will summarize key properties of CLASSY and its operations, as well as present the first results from discovery observations in the August and September 2022 dark runs.

THE SURVEY AND DATA REDUCTIONS

CLASSY is a large program on the Canada-France-Hawaii Telescope, ranked as "must do". The Megacam mosaic imager is utilized to provide deep imaging sensitive to moving objects at distances as great as hundreds of au. Shift and stack (shift'n'stack) techniques will be utilized to provide the maximum achievable search depth.

Ecliptic uniformity of pointings is one of the key factors governing the CLASSY survey design. This was followed as closely as possible while also considering the Megacam schedule, RA pressure, and galactic plane avoidance. In particular, we will prioritize the pointings at 22:18:00 RA and 08:10:00 RA where known ETNOs come to and do not come to perihelion.

Each field will receive tracking at 1 year after discovery to provide initial orbital characterization. Distant objects and candidate ETNOs will receive additional follow-up to secure their orbits.

We summarize some parameters of the survey below.

Key Survey Parameters

- 12.1 square degree total coverage
- 6 pointings consisting of 2 side-by-side Megacam Fields
- roughly uniform ecliptic longitude spacing
- a "visit" consists of 32 298s exposures (3 hour sequence)
- anticipated limiting magnitude $r=26.5$

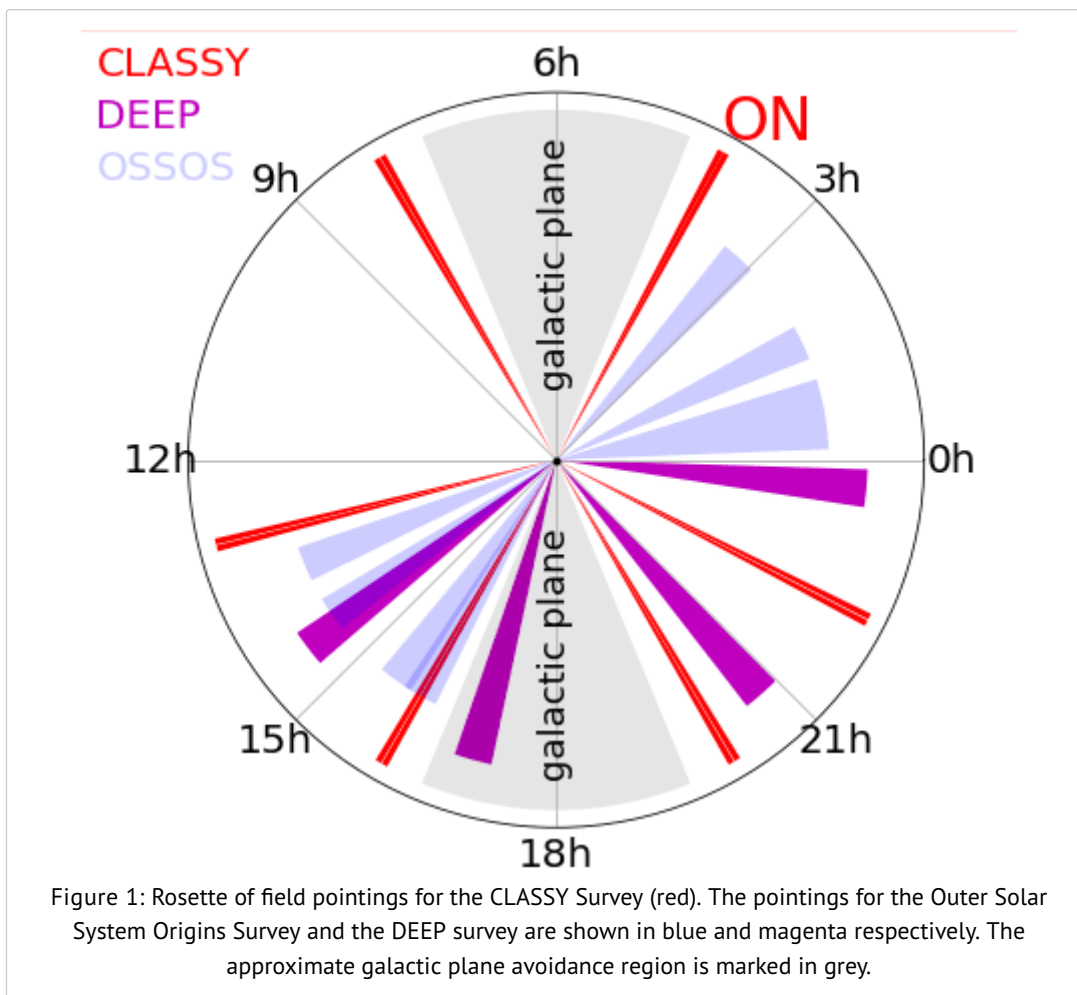


Figure 1: Rosette of field pointings for the CLASSY Survey (red). The pointings for the Outer Solar System Origins Survey and the DEEP survey are shown in blue and magenta respectively. The approximate galactic plane avoidance region is marked in grey.

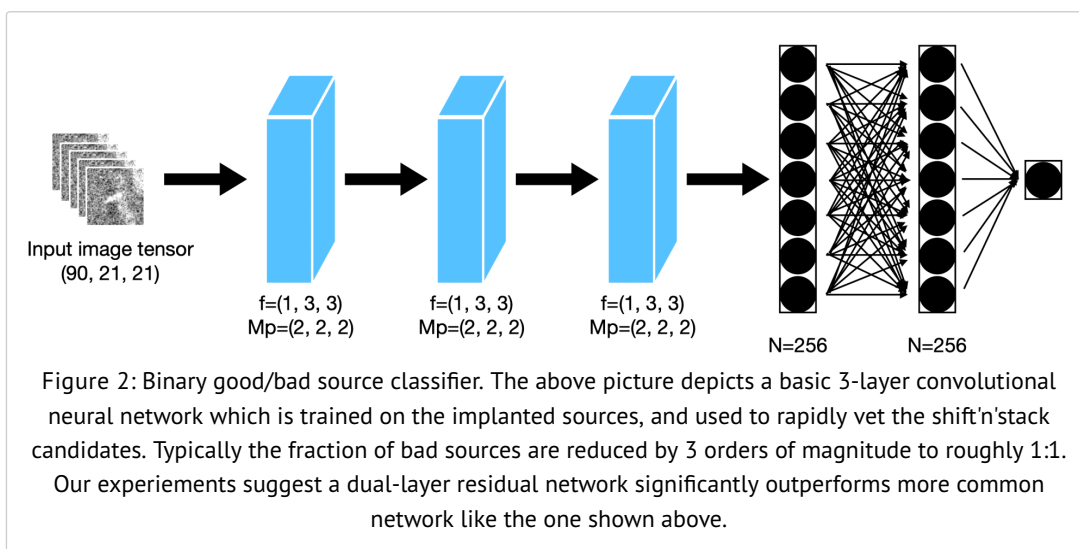
Visit Pattern

- 6 visits to each field
- discovery "triplet" consists of three visits, one per night, near opposition
 - r-band
 - nightly sequence duration ~4.5 hours
- precovery visit ~1 month before discovery
- recovery visit ~1 month after discovery
- follow-up visit at opposition one year away from discovery
 - gri-filter
 - 3 hour sequence duration

Data Reductions

- Megapipe astrometric and photometric calibrations
- PSF and artificial source implants with TRIPPY
- Two difference pipelines
 - ISIS image subtraction package (v2.2)
 - LSST pipeline (v19)
- shift'n'stack search with KBmod
- source vetting with custom RESNET good/bad classification
- final confirmation from team of humans

The initial vetting is performed with a convolutional neural network. The basic network architecture is an ensemble of 3 separate networks of the form shown in Figure 2, where the output probability of each network is averaged. Each network is individually trained on a random subset of the training data - same good sources, different set of bad sources, so as to better encompass the range of bad sources that occur in the shift'n'stack stage.



Megacam on the Canada-France-Hawaii Telescope

Megacam is a mosaic CCD imager at the prime focus of the CFHT, providing 1.01 degree areal coverage, and a 0.187" pixel scale.

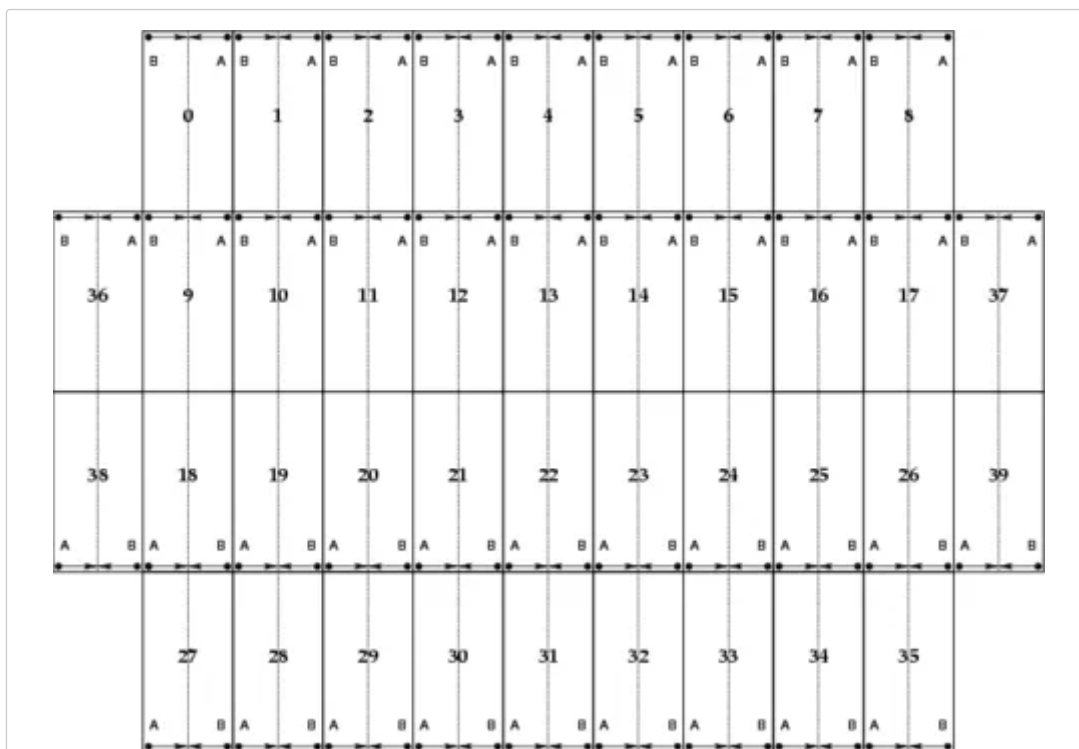
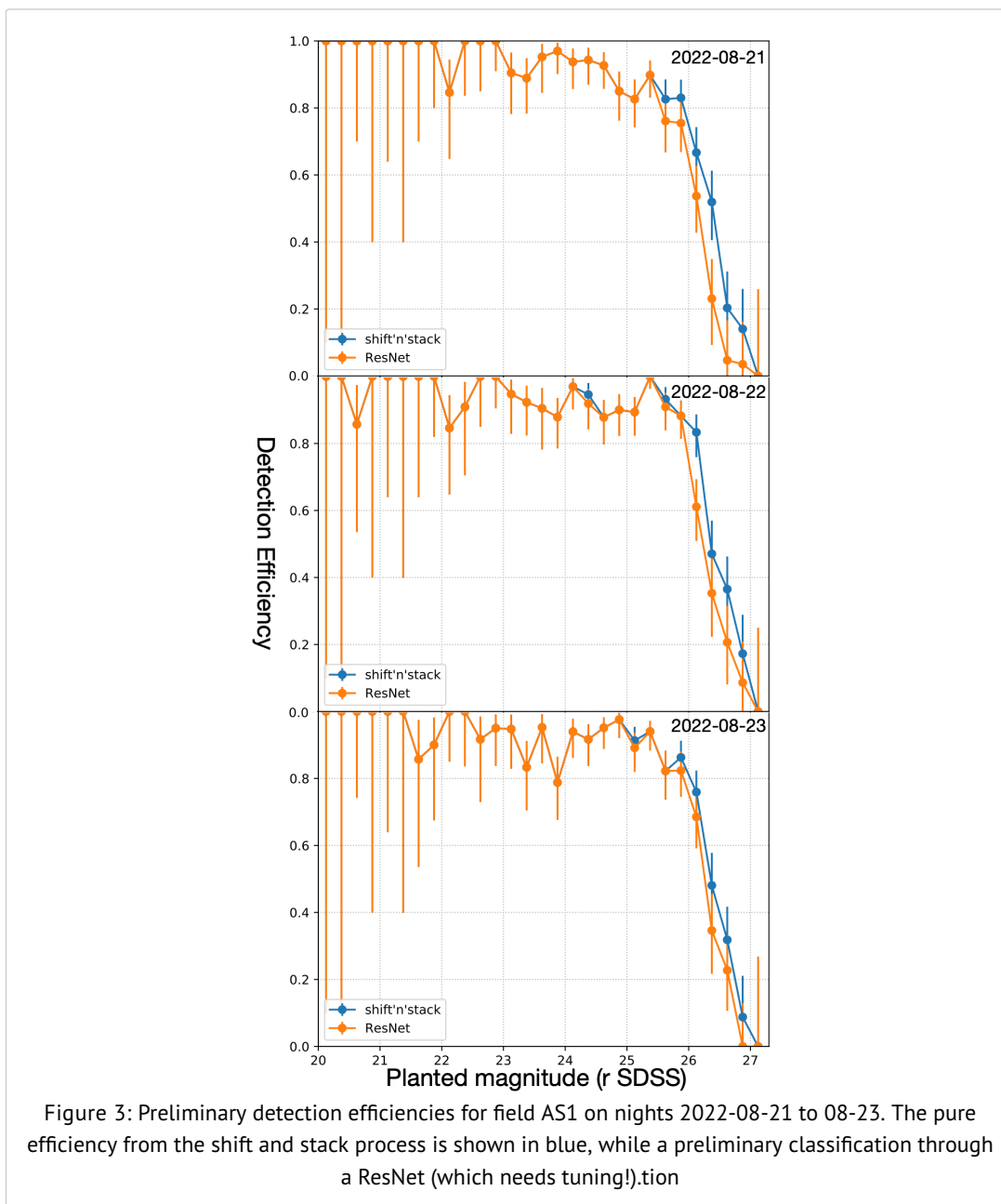


Figure 3: The Megacam chip layout. An example image acquired as part of the CLASSY program is shown in the background of this poster.

PRELIMINARY RESULTS

We have assembled a preliminary pipeline that includes artificial source implantation, calibration, differencing, and shift'n'stack search. We present here initial results from a search of the AS1 field (22:18:33.79, -12:17:00.2) discovery triplet. The AS1 discovery triplet was observed on three consecutive nights, August 21-23, 2022.

In Figure 3 we show the preliminary detection efficiency of the search demonstrating that in normal conditions we can reach our desired limiting magnitude of $r=26.5$ (50% threshold).



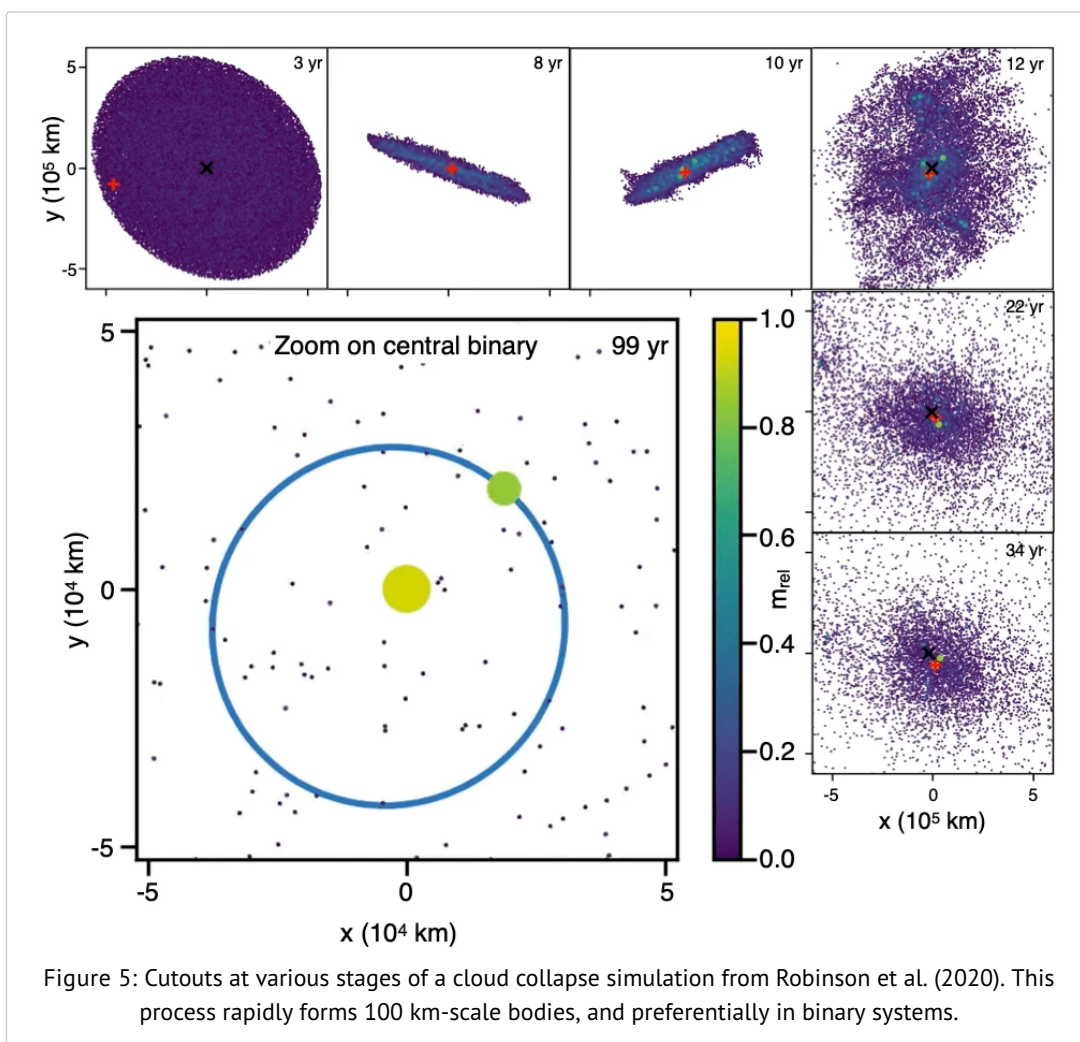
In Figure 4 we show the first detection from the preliminary search.

[VIDEO] https://res.cloudinary.com/amuze-interactive/image/upload/f_auto,q_auto/v1664580849/aas/f6-7c-4a-05-9c-2b-d7-db-d7-ab-7a-e7-a6-aa-05-59/image/ds9_2_wfcgwh.mp4

Figure 4: The first detection from the preliminary search. This object has been detected across all three nights of the AS1 triplet observations. The animation displays the difference images of all three nights aligned in pixel coordinates. The object appears to fall in nearly the same place each night because we reposition to account for the average keplerian sheer. It has a brightness $m_r \sim 23$ and is moving at a rate of motion of $3.0''/\text{hr}$, consistent with a heliocentric distance $r=42$ and $H=6.8$. The frames with green circles mark the starting frame of each nightly sequence.

SIZE FREQUENCY DISTRIBUTION OF THE COLD CLASSICAL KBOS

One of the primary goals of CLASSY is to measure the size frequency distribution (SFD) of the cold classical Kuiper Belt Objects (CCKBOs). The high binary fraction and SFD of the CCKBOs provide the strongest evidence for a planetesimal population having formed through pebble cloud collapse, likely initiated by the streaming instability (see Figure 5).



CLASSY will detect and track ~ 400 CCKBOs with diameters as small as ~ 30 km (assuming 16% albedos). Unlike larger bodies that are certainly the primary direct collapse products, the smaller sizes that CLASSY are sensitive to may largely be the ejected detritus of cloud collapse (see Figure 4). Importantly, CLASSY will also provide detections with brightnesses that overlap with the ultra-faint sample expected of a forthcoming JWST survey (GO-1568, PIs Stansberry, Trilling, Fraser).

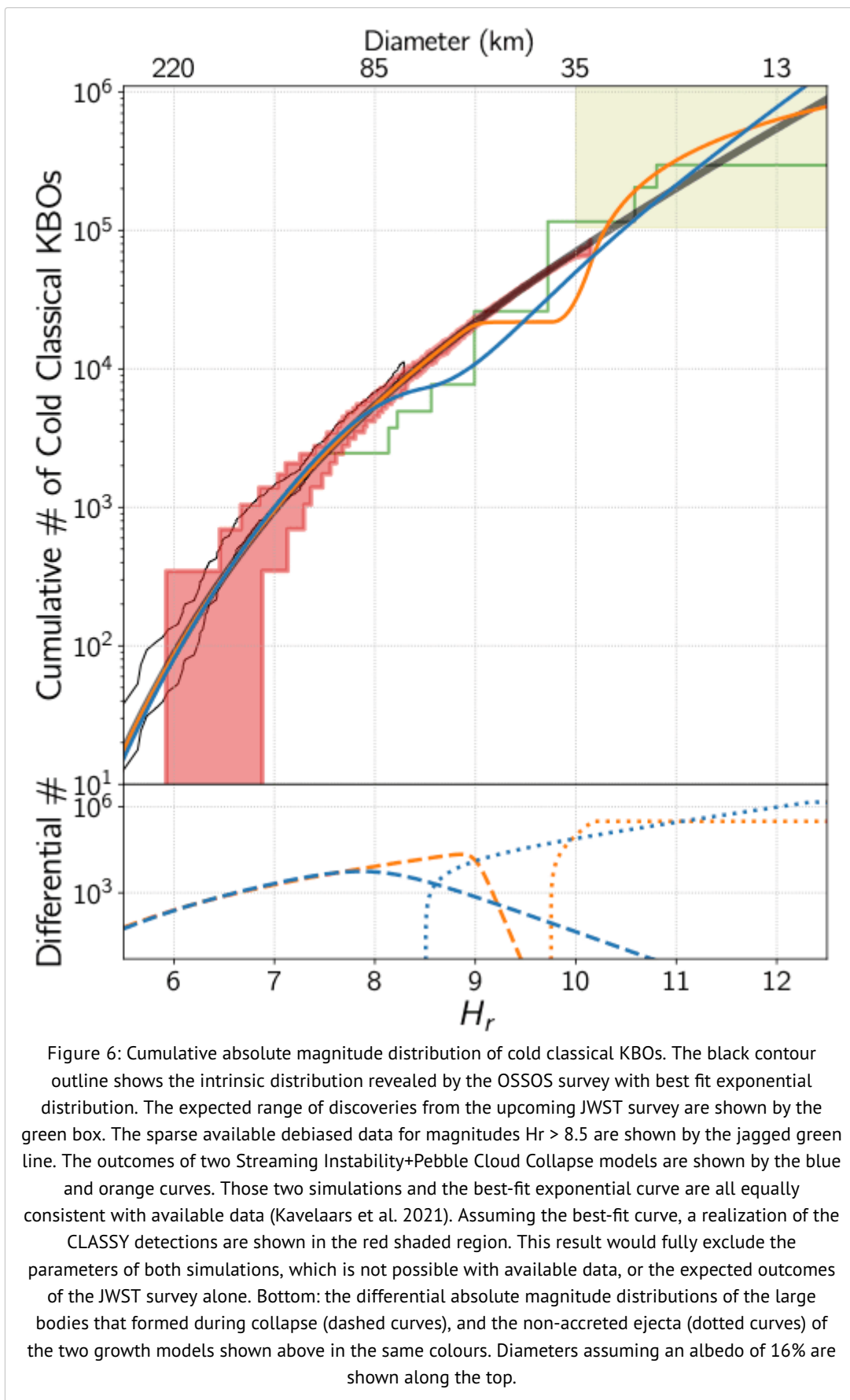
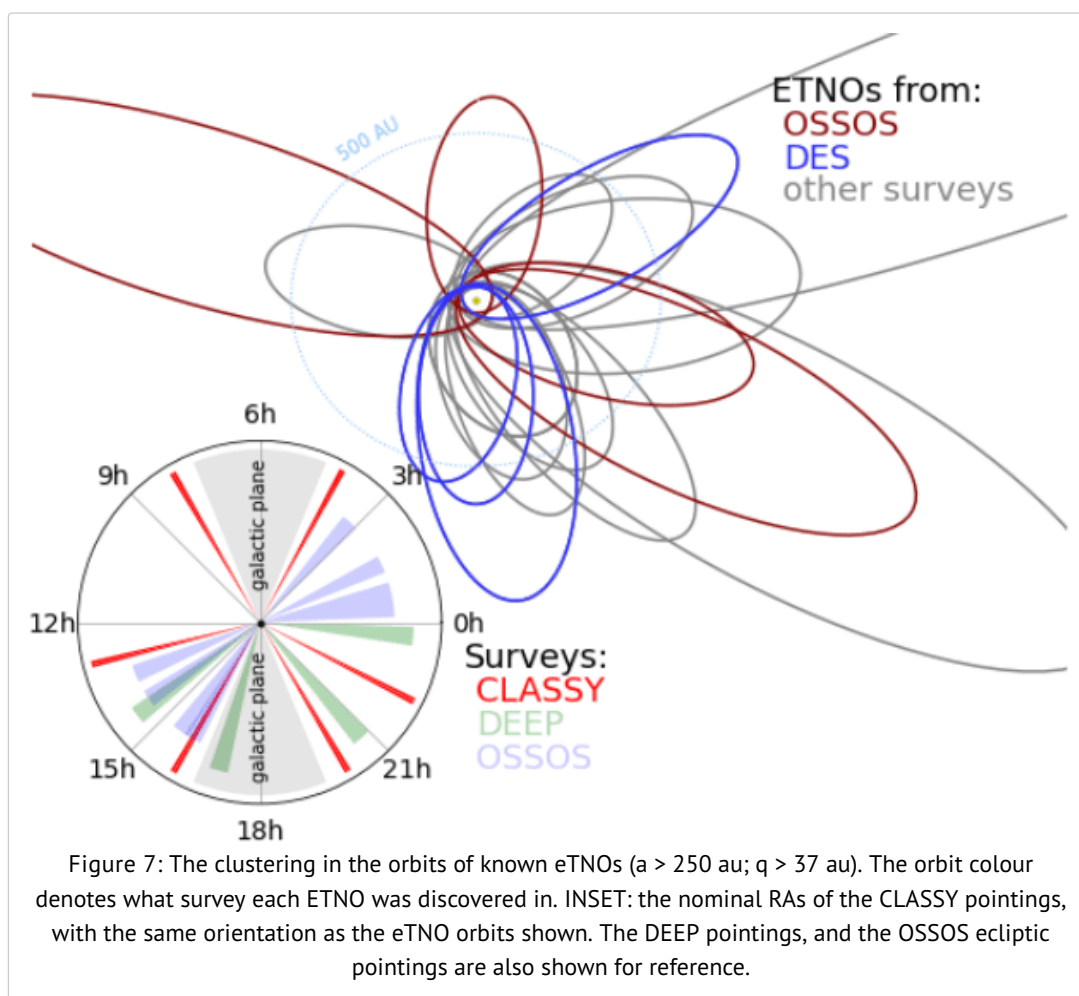


Figure 6: Cumulative absolute magnitude distribution of cold classical KBOs. The black contour outline shows the intrinsic distribution revealed by the OSSOS survey with best fit exponential distribution. The expected range of discoveries from the upcoming JWST survey are shown by the green box. The sparse available debiased data for magnitudes $H_r > 8.5$ are shown by the jagged green line. The outcomes of two Streaming Instability+Pebble Cloud Collapse models are shown by the blue and orange curves. Those two simulations and the best-fit exponential curve are all equally consistent with available data (Kavelaars et al. 2021). Assuming the best-fit curve, a realization of the CLASSY detections are shown in the red shaded region. This result would fully exclude the parameters of both simulations, which is not possible with available data, or the expected outcomes of the JWST survey alone. Bottom: the differential absolute magnitude distributions of the large bodies that formed during collapse (dashed curves), and the non-accreted ejecta (dotted curves) of the two growth models shown above in the same colours. Diameters assuming an albedo of 16% are shown along the top.

LONGITUDINAL DISTRIBUTION OF EXTREME TNOs

A primary science goal of CLASSY is to provide a population of extreme TNOs (eTNOs) that has been uniformly sampled in ecliptic longitudes. The main goal is to provide an unbiased sample as possible to directly test for the presence of clustering in the longitude of perihelia of eTNOs. This will allow us to confidently state that any clustering that is detected in the CLASSY sample is not driven by biases due to pointing.

The CLASSY pointings have been chosen to ensure that two are pointed towards within the longitudinal cluster of the known eTNOs, and two are pointed where no known eTNOs come to perihelion. The CLASSY pointings are also not shying away from winter observations which are commonly avoided. This is presented in Figure 7.



AUTHOR INFO

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ABSTRACT

Here we introduce CLASSY: the Classical and Large-A Solar SYstem survey. This survey is a large program on the Canada-France-Hawaii Telescope that will use 56 nights in 2022B through 2024A inclusive. Using shift'n'stack techniques, CLASSY will survey 12.2 square degrees of the invariable plane to an anticipated depth of $r=26.6$ in search of Kuiper Belt Objects and extreme trans-Neptunian objects (eTNOs), the vast majority of which will be tracked to a second opposition. This survey has two primary goals: to provide observational tests of the cutting-edge planet formation models; and to test cosmogonic models of orbital emplacement. We will carefully measure the size-frequency distribution of classical TNOs for diameters $30 \lesssim D \lesssim 250$ km (assuming 16% albedos). This size range is critical for determining properties of the streaming instability and cloud collapse mechanisms that formed TNOs because it spans between the size of the central bodies that formed from the streaming instability, and the detritus ejected during cloud collapse. Importantly, CLASSY is the first survey designed explicitly to avoid longitudinal discovery biases that may be present in the known eTNOs sample. In this presentation we will summarize some of the key properties of CLASSY and its operations, as well as present the first results from discovery observations in the August and September 2022 dark runs.

