

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

Wesley C Fraser, Samantha Lawler, Edward Ashton, Ying-Tung Chen, Yukun Huang, Brett J Gladman, J. J. Kavelaars, Jean-Marc C. Petit, Stephen D J Gwyn, Lowell Peltier, et al.

▶ To cite this version:

Wesley C Fraser, Samantha Lawler, Edward Ashton, Ying-Tung Chen, Yukun Huang, et al.. The Classical and Large-a Solar SYstem (CLASSY) Survey. DPS 2022: 54TH ANNUAL MEETING OF THE DIVISION FOR PLANETARY SCIENCES, DPS, Oct 2022, London (ON), Canada. hal-04235052

HAL Id: hal-04235052

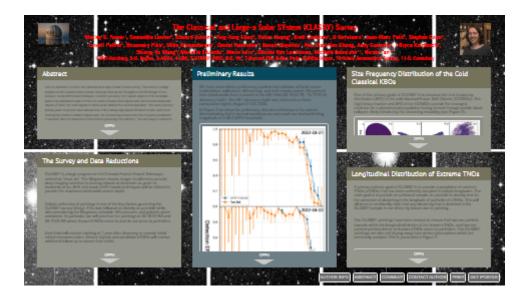
https://hal.science/hal-04235052

Submitted on 10 Oct 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

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



Wesley C. Fraser¹, Samantha Lawler², Edward Ashton³, Ying-Tung Chen³, Yukun Huang⁴, Brett Gladman⁴, JJ Kavelaars¹, Jean-Marc Petit⁵, Stephen Gwyn¹, Lowell Peltier⁶, Rosemary Pike⁷, Mike Alexandersen⁷, Daniel Hestroffer⁶, Benoit Noyelles⁵, Rex Chan-Kao Chang, Andy Connolly⁶, J Bryce Kalmbach⁶, Shiang-Yu Wang³, Marielle Eduardo⁶, Mario Juric⁶, Christa Van Laerhoven, Michele Bannister¹¹, Nicole Tan¹¹

1-NRC-Herzberg, 2-U. Regina, 3-ASIAA, 4-UBC, 5-UTINAM CNRS, 6-U. Vic, 7-Harvard CFA, 8-Obs. Paris, 9-UWashington, 10-Yukon Astronomical Society, 11-U. Canterbury





PRESENTED AT:

54TH ANNUAL MEETING OF THE DIVISION FOR PLANETARY SCIENCES LONDON, ONTARIO & VIRTUALLY ANYWHERE 2-7 OCTOBER 2022

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≲D≲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

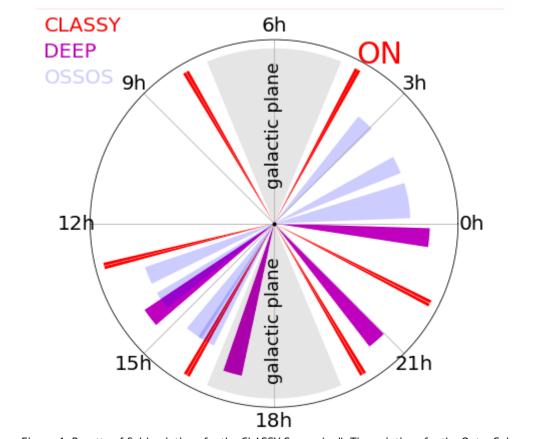


Figure 1: Rosette of field pointings for the CLASSY Survey (red). The pointings for the Outer Solar System Origins Survey and the DEEP survey are shown in blue and magenta respectively. The approximate galactic plane avoidance region is marked in grey.

Visit Pattern

- 6 visits to each field
- $\bullet\,$ discovery "triplet" consists of three visits, one per night, near opposition
 - or-band
 - o 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
 - $\circ \ gri\text{-}filter$
 - o 3 hour sequence duration

Data Reductions

- Megapipe astrometric and photometric calibrations
- PSF and artificial source implants with TRIPPy
- Two difference pipelines
 - o ISIS image subtraciton package (v2.2)
 - o LSST pipeline (v19)
- shift'n'stack search with KBmod
- $\bullet\,$ 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.

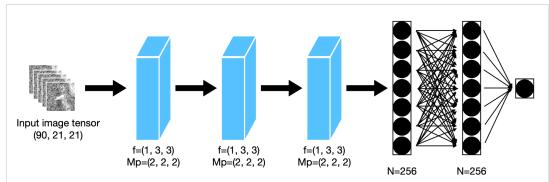


Figure 2: Binary good/bad source classifier. The above picture depicts a basic 3-layer convolutional neural network which is trained on the implanted sources, and used to rapidly vet the shift'n'stack candidates. Typically the fraction of bad sources are reduced by 3 orders of magnitude to roughly 1:1. Our experiements suggest a dual-layer residual network significantly outperforms more common network like the one shown above.

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.

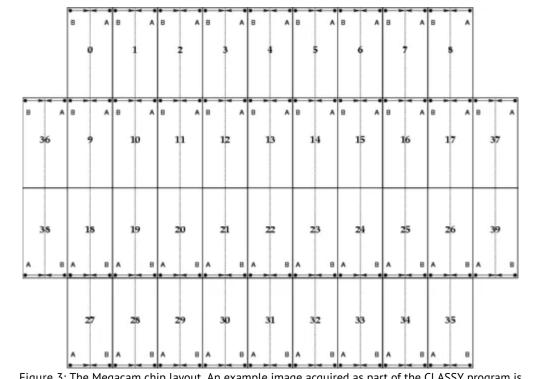


Figure 3: The Megacam chip layout. An example image acquired as part of the CLASSY program is shown in the background of this poster.

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).

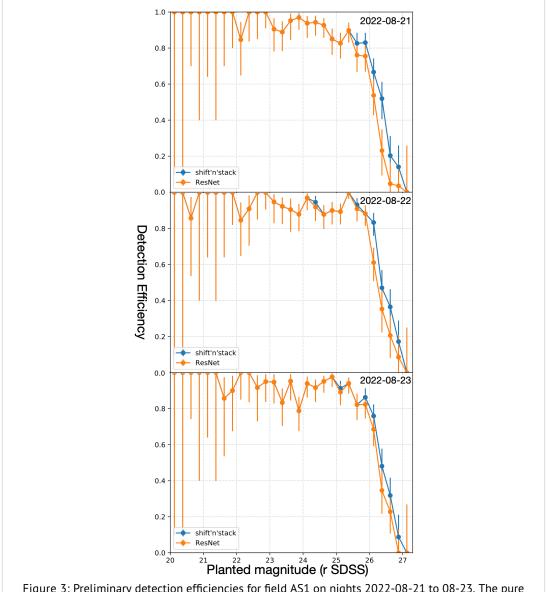


Figure 3: Preliminary detection efficiencies for field AS1 on nights 2022-08-21 to 08-23. The pure efficiency from the shift and stack process is shown in blue, while a preliminary classification through a ResNet (which needs tuning!).tion

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~23 and is moving at a rate of motion of 3.0 "/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).

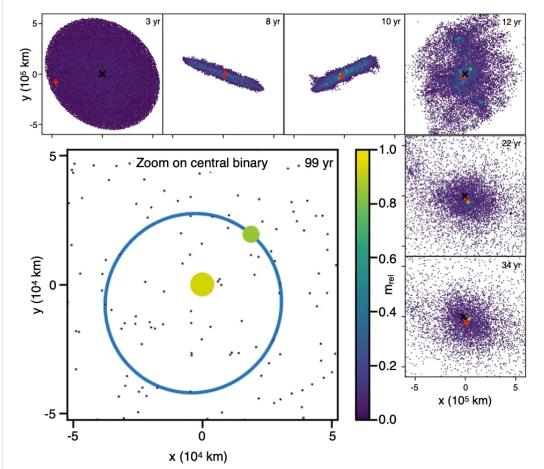


Figure 5: Cutouts at various stages of a cloud collapse simulation from Robinson et al. (2020). This process rapidly forms 100 km-scale bodies, and preferentially in binary systems.

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 sentitive too 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).

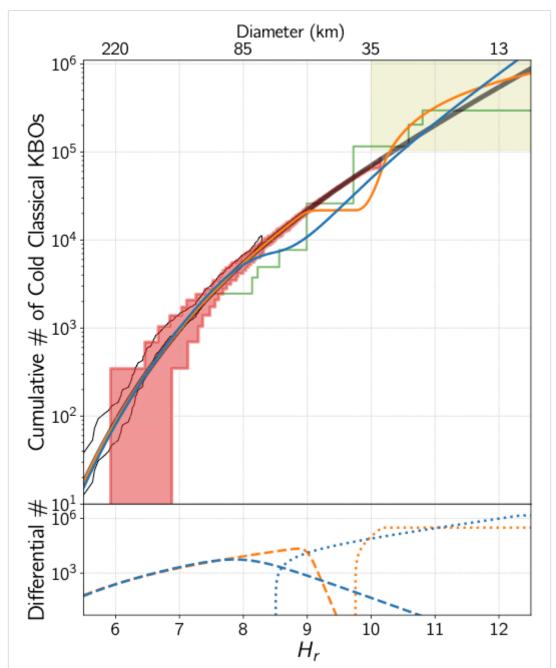


Figure 6: Cumulative absolute magnitude distribution of cold classical KBOs. The black contour outline shows the intrinsic distribution revealed by the OSSOS survey with best fit exponential distribution. The expected range of discoveries from the upcoming JWST survey are shown by the green box. The sparse available debiased data for magnitudes Hr > 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 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.

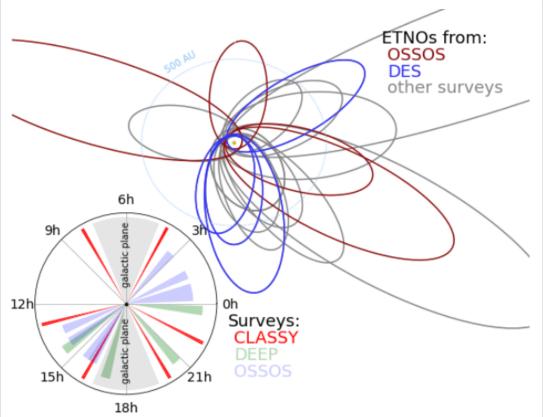


Figure 7: The clustering in the orbits of known eTNOs (a > 250 au; q > 37 au). The orbit colour denotes what survey each ETNO was discovered in. INSET: the nominal RAs of the CLASSY pointings, with the same orientation as the eTNO orbits shown. The DEEP pointings, and the OSSOS ecliptic pointings are also shown for reference.

AUTHOR INFO

 $We sley \ C \ Fraser \ (Herzberg \ Astronomy \ and \ Astrophysics \ Research \ Centre; \ we sley, fraser@nrc-cnrc.gc.ca) \ and \ Samantha \ Lawler \ (University \ of \ Regina; \ Samantha. Lawler@uregina.ca) \ are the principal investigators of the CLASSY program.$

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.