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The Solar System Origins Legacy Survey: Motivation, Design, and Initial Results

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Abstract

The Solar System Origins Legacy Survey (SSOLS) is a Cycle 26 Hubble Space Telescope (HST) Treasury Program designed to determine the process by which Cold Classical Kuiper Belt binary systems were assembled. 206 HST orbits are devoted to observations of Cold Classical Kuiper Belt Objects (CCKBOs) that were discovered by the CFEPS and OSSOS surveys. This HST KBO sample set is the largest ever drawn from a well-characterized discovery pool, which allows the properties observed by HST to be mapped back to the intrinsic properties of the population.

1. Introduction

Within the Kuiper Belt resides a reservoir of material likely to be the most pristine and primordial known to exist in the Solar System: the radially-narrow, low-inclination Cold Classical Kuiper Belt (Levison & Stern 2001, Parker & Kavelaars 2010, Batygin et al. 2011, Nesvorny 2015). It has been dynamically preserved in close to its original location and state since the reorganization of the gas giants that dispersed the protoplanetesimal disk roughly 4 Gyr ago.

The physical properties of Cold Classical Kuiper Belt Objects are unique, including their exceptionally high binary fraction — with nearly a third of currently-surveyed objects found to be near-equal mass systems (Noll et al. 2008) — an unusually steep size distribution (Bernstein et. al. 2004, Fraser et al. 2014), and almost unanimously optically red surfaces (Tegler & Romanishin 2000) with high albedos (Stansberry et al. 2008, Bruker et al. 2009, Vilenius et al. 2014).

2. SSOLS Target Set

To date, HST observations are responsible for the majority of observational knowledge regarding CCKBO binary systems. However, binarity can bias the discovery probability of a KBO; a binary system has larger surface area than a solitary object of equal mass. Thus, to accurately infer the properties of the binary population and contrast them against the population of apparently solitary objects, a sample must be drawn from a pool with well-characterized discovery circumstances. The Outer Solar System Origins Survey (OSSOS; Bannister et al. 2015) and Canada-France Ecliptic Plane Survey (CFEPS; Petit et al. 2011) samples provide such a pool from which to draw. The SSOLS sample consists of the complete sample of CFEPS and OSSOS $i<6^o$ Cold Classical Kuiper Belt Objects brighter than $m_r \leq 24.5$ and $H_r \leq 8$; a total of 220 targets, 206 of which will be targeted for new observations under the SSOLS program.

3. Observational Goals

SSOLS aims to answer three questions regarding the CCKBO population through its observations:

1) **How similar are the single and binary CCKBO luminosity functions?** This query probes whether CCKBOs formed initially as binary systems through a pebble collapse process (Nesvorny et al. 2010), or formed as initially solitary objects through some other process. If binaries are assembled from initially solitary objects, the location of the break magnitude in the luminosity function should be substantially brighter than the solitary population; however, if the binary objects are formed from the mass distribution of clumps of collapsing pebbles, then the luminosity function shift will be smaller.

2) **What is the intrinsic distribution of binary component colors?** This query further tests the collapse hypothesis; if binary systems form from a locally homogenous, globally heterogenous disk of pebbles, the components should have similar colors while the population as a whole should

match the distribution of solitary colors (Nesvorny et al. 2010).

3) **How similar are the orbit and color distributions of single and binary CCKBOs?** This query addresses the recent hypothesis that a component of the CCKBO binary systems was implanted from a formation location at an initially smaller heliocentric distance. These “blue binary” systems (Fraser et al. 2017) will be distributed in color and orbital space distinct from any in situ CCKBO population.

3.1 Existing Constraints

Existing HST observations indicate that the luminosity function shift lies somewhere between the extremes predicted by ideal assembly of initially-solitary objects (0.75 magnitudes) and initial partition into binary systems (0.25 magnitudes). Figure 1 illustrates current constraints on the luminosity function shift between solitary and binary objects from existing HST observations of CCKBOs; this figure has not been accurately corrected for discovery biases, as existing HST samples were not drawn from characterizable surveys. Also illustrated in Figure 1 are the estimated constraints after SSOLS observations are complete and the bias corrections are fully applied. The SSOLS observations will cleanly distinguish between the two cases.

4. Observation Design and Time Frame

All SSOLS targets will be observed with an identical strategy; fully dithered F606W (WFC3 V-band) and F814W (WFC3 I-Band) will be obtained over a single orbit per target. These observations will permit the highest possible angular resolution to be retrieved while also delivering a high-SNR measurement of the system and component V-I color index. Observations began in May 2019. Results will be posted in real-time to the program website at http://ssols.space.

5. Summary and Conclusions

SSOLS represents the largest solar system GO program yet conducted by HST. It will deliver a well-calibrated sample of binary and color properties for a Treasury Sample of Cold Classical Kuiper Belt Binaries, and provide a basis for testing the origins of binary systems in the Kuiper Belt. This in turn will further refine our understanding of the processes by which the first generations of planetesimals formed in the outskirts of our solar system.

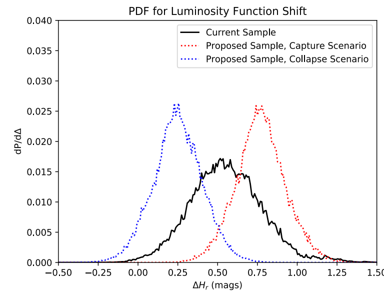

Figure 1: Estimated shift between the location of the break magnitude in binary CCBOs and in solitary CCKBOs using existing HST observations (black histogram). Red and blue histograms illustrate estimated constraints after completion of SSOLS under the case that binaries formed from initially-solitary objects (red) or as primordial binaries (blue).

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