

## OORT CLOUD EXPLORER - DYNAMIC OCCULTATION EXPERIMENT: OCLE-DOCLE.

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### ABSTRACT

A microsatellite telescope tuned to detection of Oort cloud and Kuiper belt objects via serendipitous stellar occultation will enable the first ever probing of the structures of the very distant solar system (Oort cloud) and the smallest members of the Kuiper belt (sub 1 km radius). Studying the Oort cloud's current structure will provide insights to the birth cluster of the solar system, in turn providing constraints on planet and star formation. Studying the smallest members of the Kuiper belt provides a link between the short period comets and their theorized reservoir (the Kuiper belt) as well as probing the processes of collisional erosion in a debris disk system. The contents of the Oort cloud and the small members of the Kuiper belt are currently un-observable and the existence is inferred from the appearance of long and short -period comets. Stellar occultation caused by the passage of random Oort cloud/Kuiper belt members across the line-of-site to a distant star will cause a variation in the observed flux from that star, a variation which can be detected and quantified by a space telescope operating on a micro-satellite platform. Canadian astronomers partnering with canadian space industry and our international colleges are well placed to lead the construction of such a facility and thus blaze a trail towards a new mode of exploring the origins of structure in the universe.

### 1. INTRODUCTION

The Oort cloud is that region of the solar system that extends radial from the zone where gravitational forces from galactic tides and stellar fly-bys of the forming solar system start to dominate the motions of solar system objects (around 2,000 AU from the Sun) to the zone where passing stars and the galactic potential cause objects to fully decouple from solar orbits (around 20,000 AU). The existence of the Oort cloud has been posited for many decades as the required source for 'long period' comets whose semi-major axis appear to cluster around  $\sim 10^4$  AU (Oort 1950). Generally, Oort cloud comets have semi-major axis values of  $\sim 20,000$  AU during their first return passage into the solar system. The Oort cloud is populated by objects that originated in the region where the giant planets form but were scattered to larger aphelia through gravitational encounters with the giant planets. When the aphelia of these scattered objects reach beyond  $\sim 400$  AU their perihelia are lifted out of the planetary region via perturbations from the galactic tides (Duncan et al. 1988). About 5% of the material that is scattered into the 'inner-outer solar system' ( $\sim 400$  AU) finds a pseudo-stable home in the Oort cloud.

The distance to the inner-edge of the Oort cloud (sometimes called the Inner Oort cloud) is dependent on the stellar environment in which the Sun formed. Models form Inner Oort clouds that are more tightly bound to the Sun (inner edge at  $\sim 1,000$  AU from the Sun) than previously predicted because the passing stars in a cluster are able to decouple the scattering objects from the planetary region before the semi-major axis of these objects becomes large (Brasser et al. 2006; Kaib & Quinn 2008).

In-situ observational measurements of the structure of the Oort cloud is exceedingly difficult, owing to the  $D^{-4}$  flux dependence. At this time there is very little, perhaps zero, direct observational measurement of this structure. The object 90377 (Senda) is a candidate for membership, but with a semi-major axis of less than 1000 AU this object is certainly among the closest members of the putative Inner Oort cloud. On the flip side, because of the higher rate of encounters between outer Oort cloud objects and passing stars, we have a biased sampling of the outer members of the population. The knowledge of the intrinsic structure of the Oort cloud (both inner and outer) is crucial if we are to unravel the conditions and processes that lead to the formation of the solar system.

The Kuiper belt is that region of the solar system beyond 30 AU and stretching to the inner edge of the Oort cloud. The Kuiper belt can be thought of as a debris disk, containing the remains of the formation of the outer solar system. This region likely contains the most pristine material from our solar systems formation and is the likely source of the the short period comets (comets with periods of less than 200 years). The smallest members of the Kuiper belt population have yet to be detected (excluding the candidate detection reported in Schlichting et al. (2009)) and so the link between the short period comets and the Kuiper belt remains theoretical. This link makes a strong prediction on the number of objects that must be located in the Kuiper belt to explain the short period comets ( $\sim 10^{11}$  sources smaller than 1 km Duncan & Levison 1997). In addition, measuring the size distribution of the smallest members of the Kuiper belt will lead to strong constraints on the collisional evolution of the belt, informing on the collisional processes of exo- debris disks.

### 2. CURRENT ACTIVITIES

Ground based direct imaging surveys using the CFHT and Subaru telescopes have been searching for traces of the inner Oort cloud. The object Sedna (semi-major axis of  $\sim 530$  AU and eccentricity of 0.855) may be the first detected member of the inner edge of the cloud. About 300 square degrees have been surveyed to limits of  $R \sim 23.5$  to search for additional

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Sedna’s without success. These upper limit surveys are not yet in conflict with population scalings based on Sedna’s detection. Surveys with deeper limits covering larger areas will be needed before this population is adequately probed.

Probing the bulk of the Oort cloud will require sensitivities to objects smaller than 500km diameter at +10,000 AU. These objects have a flux of  $R \gtrsim 45$  mag in optical light, indicating that these sources can not be detected via reflected light even in the era of Overwhelmingly Large Optical telescopes. Sources as small as few a tens of kilometres could, however, be detected via the method of serendipitous stellar occultation (SSO) (see Bickerton et al. 2008, 2009, for example). Attempts at SSO have yet to truly succeed, despite a small number of claimed detections. The most compelling reported detection was made using analysis of a decade’s worth of time-series data from the Hubble Space Telescope’s Fine Guidance Sensor. This analysis resulted in the reported detection of one  $2.8\sigma$  event (Schlichting et al. 2009, see Figure 1). Even after a decade of ground-based surveys the number of sub-km objects in the Kuiper belt remains very poorly constrained (see Figure 2). The main limitations of the SSO approach are the long sample durations required to ensure a highly significant event (one expected detection in  $10^8$  samples) and the frequency distribution of noise caused by atmospheric scintillation which tend to mimic the variation in flux caused by the diffraction events being sought.

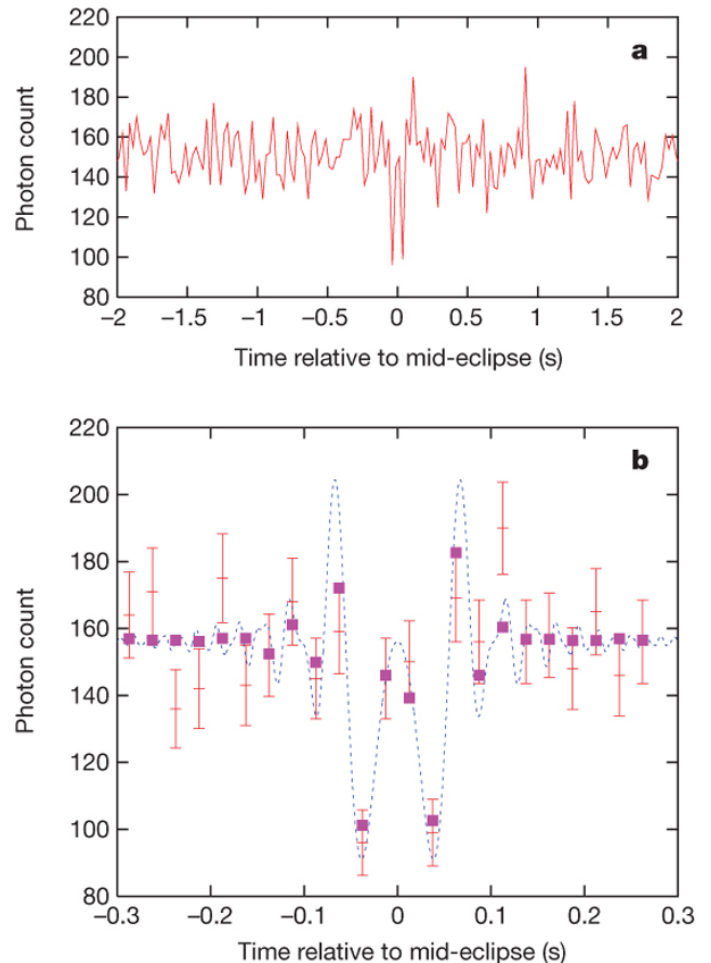
**The joint restrictions of long duration monitoring from a stable platform while avoiding the effects of atmospheric scintillation make space observing the most viable option for an SSO survey.**

### 3. OCLE-DOCLE: A CANADIAN MICRO-SATELLITE

OCLE-DOCLE is a space observatory, compatible with the CSA Multi-Mission Microsatellite Bus (MMMB). The OCLE-DOCLE design resulted from a competitive call for concept studies funded by the CSA. The resulting, rather brilliant design, places a 30cm clear aperture telescope with a  $2\times 0.5$  degree FOV (see Figure 3) onto a MMMB (see Figure 4). The primary science driver for the OCLE-DOCLE concept is the detection and measurement of the solar system’s Kuiper belt and Oort cloud via SSO. Measuring the distribution and number density of these relics from the formation of the solar system will improve the understanding of the processes that formed the planets. The complete results of the OCLE-DOCLE concept study are available from the website [http://www.cfeps.net/OCLE\\_DOCLE/](http://www.cfeps.net/OCLE_DOCLE/).

The technical requirements for OCLE-DOCLE concept were determined using a model of the small object populations of the Kuiper belt and Oort cloud. No members of these populations have ever been detected via reflected light: these models are speculative but grounded in solid published research. None of the ground based upper-limits, nor the HST-FGS2 detection, conflict with the densities predicted by these models. The model solar system was used to simulate the end-to-end performance of the various telescope components that were available in the design and select through the various design choices to optimize the detection rate while staying within the cost and mass envelopes of a microsatellite.

To achieve the primary scientific goal, the OCLE-DOCLE payload is designed to stare at a target star cluster over long periods, reporting high-precision photometry on approximately 1000 stars simultaneously at a continuous rate of 30-40 Hz. The payload will perform gain calibration (if necessary), pixel binning, centroiding of pre-selected bright stars



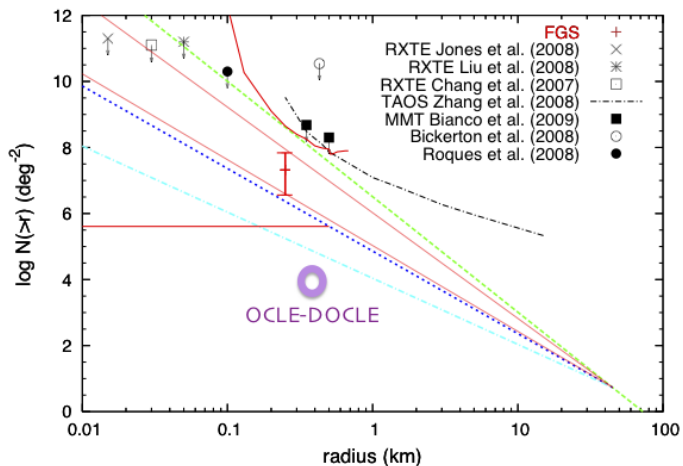
**Figure 1.** Photon counts time-series of a candidate occultation event observed by HST=FGS2 (Schlichting et al. 2009) a) the complete time series; b) binned signal. The duration of the event is  $\sim 0.2$  seconds, simulations indicate an optimal sampling frequency of  $\sim 35$ Hz.

for navigation, and data transmission to the spacecraft memory. Background subtraction will not be implemented, as we are only interested in photometric differences over very short periods, and dark current variations are not expected to be an issue at this high readout rate.

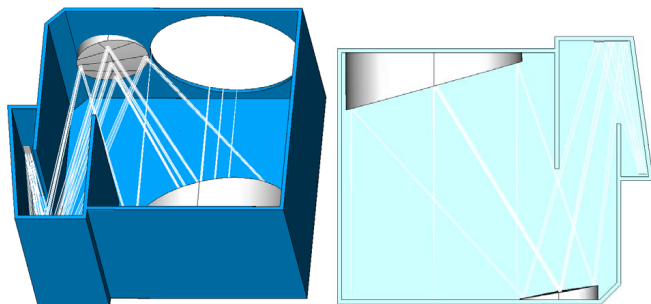
As designed, the OCLE-DOCLE concept provides more than 6 orders of magnitude improvement in detection sensitivity over all existing ground-based surveys aimed at small Kuiper Belt and Oort cloud objects and 2 orders of magnitude more sensitive than the re-analysis of a decades worth of HST observations. OCLE-DOCLE will incorporate the largest aperture telescope feasible within the microsatellite resource envelope (see Figure 4). OCLE-DOCLE has a simple optical design (see Figure 3) involving reflective elements, a single thermal zone, and a deployable combination dust-shield and external earth-exclusion and stray light baffle (not shown in the figure). The mission is similar to the Canadian MOST and NEOSSAT microsatellite space telescopes, depending on this heritage for certain aspects of predicted performance. Total mission cost is estimated to be \$22M.

#### 3.1. An Innovative Microsatellite

The OCLE-DOCLE instrument concept provides a many factors increase in sensitivity over previous and ongoing microsatellite space telescopes (MOST; NEOSSAT). With a



**Figure 2.** Size distributions of Kuiper belt objects (extrapolated from the smallest reflected light detection at 30km) that are consistent with SSO surveys. All previously reported (non-)detections are also shown (see Schlichting et al. 2009, for details). Purple ring indicates the required density to ensure that OCLE-DOCLE will have a very rich detection set if the HST-FGS2 detection is real and a non-detection would be inconsistent with all reasonable extrapolations of the Kuiper belt size distribution.)

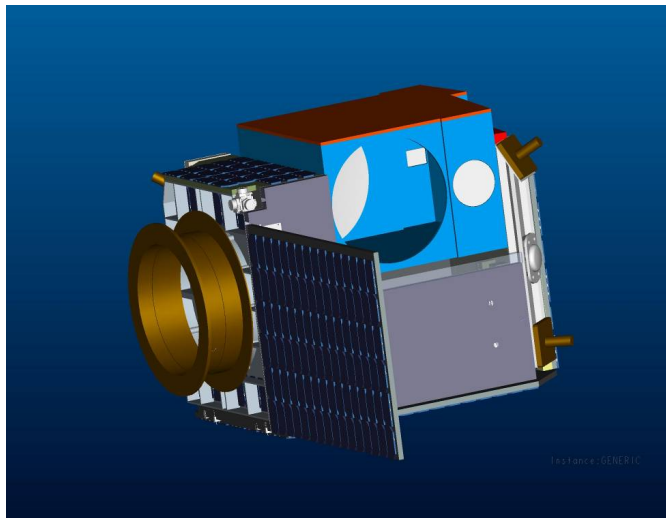


**Figure 3.** The optical layout of the OCLE-DOCLE telescope concept. The entrance pupil of 30cm is imaged, via an off-axis TMA onto a 2x0.7 deg FOV. The 95% encircled energy is less than 1" across the entire FOV.

30cm clear aperture, OCLE-DOCLE provides a factor of 5 increase in sensitivity over these existing missions for similar applications. This optical design is near the limit that can be provided within the mass and volume constraints of a microsatellite secondary launch slot.

The OCLE-DOCLE concept design relies on the availability of a new class of emerging CMOS imaging devices being developed for high-speed scientific applications. These back-illuminated (BI-CMOS) devices can provide higher frame rates at comparable sensitivity with extremely low power dissipation relative to CCDs (~1%) and are inherently radiation tolerant. Coupling these BI-CMOS devices with low-readnoise electronics designed specifically for the OCLE-DOCLE observing strategy enables our strategic advantage.

A recently proposed NASA Discovery Class mission (Whipple) would achieve detection rates similar to OCLE-DOCLE. The Whipple concept consists of a centrally obstructed 77cm aperture imaging onto a 6x6 degree focal plane paved with CMOS devices using readout electronics with substantially higher readnoise than the state-of-the-art detectors used in the OCLE-DOCLE design. The estimated cost of the



**Figure 4.** MMBB configuration of the OCLE-DOCLE design concept showing an optional deployable solar array for improved power performance during large elongation observing. The blue part of the mock-up is the telescope component of the satellite.

Whipple projects is +\$400M.

OCLE-DOCLE's enormous competitive advantage comes from packing the largest possible aperture into the low cost micro-satellite platform while employing state-of-the-art detectors and camera electronics.

Future detection of Oort cloud objects will be made using space based occultation platforms. With a one year operational lifetime the OCLE-DOCLE project (a CSA microsatellite mission concept) lays out the path to a unique window within the observing space that could make great advancements in serendipitous stellar occultation. The design concept as presented will detect one highly significant occultation event per month assuming the HST-FGS2 detection is actually a false candidate and true detection requires two orders of magnitude more sensitivity. If the density implied by the single HST-FGS candidate is correct then OCLE-DOCLE we detect 100s of events per month.

#### 4. RECOMMENDATIONS

At this time, however, there are no clear funding opportunities for further development of OCLE-DOCLE which is estimated to cost \$22 million. A number of international partners have stepped forward with offers to fund and construct specific components of the OCLE-DOCLE facility. Now is the time for action within Canada.

**We urge the LRP Panel to strongly recommend OCLE-DOCLE as micro-satellite to be funded through the Canadian Space Agency in partnership with our international colleges.**

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