OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Jan–Jul **Proposal type:** short-term

Short-term Variability of Ultra-wide Trans-Neptunian Binaries

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Abstract of Scientific Justification

The study of binary/multiple minor planet systems supplies a vast set of information including mass, density, albedo, and sizes for each component in a given system. Binary Trans-Neptunian Objects (TNOs) are essentially the only objects in the Kuiper Belt region for which one can determine their masses and, by measuring thermal radiance or assuming an albedo, their densities which is a crucial parameter to understand the formation and evolution of TNOs. By studying the rotational properties of binary systems one can constrain internal structure, cohesion, shape and other physical properties.

We plan to study the short-term variability of at least two ultra-wide Binary TNOs using MMT and Magellan 1. We focus on such systems because both components will be spatially resolved with a 6m-class telescope and thus we will be able to study both components individually, in order to constrain their physical properties.

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	MMT	f/11	MMT Cam			1	dark	March	Feb-Apr	no	no
2	MAG1	f/11	IMACS			2	dark	May	May-June	no	no

Scheduling constraints and unusable dates *(up to 4 lines)*: Targets selected are optimally observable in March, however, February and April are also acceptable for the MMT. Targets selected are optimally observable in May, however, June is also acceptable for the Magellan. As we are observing moving targets, only a relatively short window for observations is possible.

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a ∗ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	2005 EO304 (MMT)	13 34 02.4	-06 17 27	V-mag: 22.8/24.2 (Primary/Sec.), Separation: 2.2″
2	2006 CH69 (MMT)	09 51 17.4	+14 53 05	V-mag: 23/23.4, Separation: 0.8″
3	2000 CF105 (MMT)	09 32 01.4	+15 11 17	V-mag: 23.2/23.9, Separation: 1.1″
4	2001 QW322 (MAG1)	21 47 39.1	-14 53 59	V-mag: 24.5/24.8, Separation: 3″
5	2006 JZ81 (MAG1)	14 57 08.6	-17 31 40	V-mag: 22.8/23.8, Separation: 1″
6	2005 EO304 (MAG1)	13 29 59.0	-05 52 39	V-mag: 22.7/24.2, Separation: 2.2″

Approval for Instrument Use from PI: ____________________________

*(have instrument PI signature appear on, or attach PI e-mail to, **all** copies)*

Graduate students *(provide the following information for **each** student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on **all** submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis

Scientific Justification

Trans-Neptunian Objects (TNOs) are known to be well-preserved fossil remnants from the formation of our Solar System (SS). Therefore, they provide important pieces of information regarding the early stages of the SS. To date, more than 1,500 objects are known, unfortunately, we only have access to a small fraction of the total population (the brightest objects) and our knowledge of the Kuiper Belt (KB) is still very limited. Our approach to study the physical properties of TNOs is based on the short-term variability (i.e. rotational lightcurves of typically a few hours) that allows us to derive some properties like surface, albedo variability, shape and a lower limit of the density. During the past years, we have increased the number of TNOs whose short-term variability has been studied and have tried to debias the sample of studied objects (Thirouin et al. (2010, 2012)). Recently, we focused our study on Binary TNOs (TNBs). In Thirouin et al. (2014), we have shown that rotational and physical properties of the binary population and of the non-binary sample are clearly different (the binary population has a higher mean rotational period and higher shape deformation). Unfortunately, the sample of TNBs with a secure rotational period is still very limited (Figure 1, left). So, our main purpose is to increase this sample to determine whether binaries follow the expected Maxwellian distribution and in particular to focus on a specific kind of TNBs whose short-term variability has never been studied yet. Our goal is to obtain the rotational period as well as the lightcurve amplitude, to derive the size, the albedo and density for all the system components, and study the evolution of these systems. It is also important to point out that to date, except Charon, there is no satellite with a secure rotational periodicity. So, the study of satellite rotation is new and also vital to our understanding of the binarity in the KB.

Ultra-Wide Trans-Neptunian Binaries (UWTNBs) are systems with a large separation and near-equal mass between both components. We selected a sample composed of three wide binaries (eight UWTNBs are known but, only three are visible next semester. Binary systems have identically colored components (Benecchi et al. (2009)), which means that binary systems have identically colored components (Figure 1, right). This means that each component formed from similar material in a similar region of a locally homogeneous protoplanetary disk. The formation mechanism of UWTNB is still unknown. Gravitational collapse models (Parker et al. (2011), Nesvorny et al. (2010)) reproduce the current orbital distribution suggesting that such binaries were formed in-situ in the cold classical belt through relatively rapid gravitational collapse. The existence of these weakly bound systems suggests that they never suffered any strong collisional evolution nor close encounter with Neptune, making UWTNBs valuable dynamical tracers of KB evolution. Because UWTNBs are minimally dynamically evolved, their rotation may be primordial. If they have survived undisturbed since their formation, then we might expect very low amplitude lightcurves. But, if they have large amplitude lightcurves then we have to ask if they could have survived the kind of collision needed to produce a non-spherical shape or if it might be evidence of albedo variations as the source of variability. From the lightcurves, we will also be able to derive, for each system components, the albedo, the density and the size (Thirouin et al. (2014)).

Because of the large separation of UWTNB components, we can obtain resolved images of each component separately. So, we can study, at the same time, the short-term variability of the primary and of the secondary. As already mentioned, our main purpose is to study rotational properties of UWTNBs. On the other hand, we are also interested on the color variations between both components. A previous attempt to observe short-term variability (Kern et al.(2006)) for 2003 QY_{90} (separation of $0.3''$) was incompletely resolved, limiting the results (Figure 2). By observing more widely separated TNBs in optimal conditions with a larger telescope, we expect a full resolution of both components.

We propose to observe at least two UWTNBs with the MMTCam and at least two UWTNBs with the IMACS-Magellan to derive the rotational periods of the individual components, from which we can constrain the size, albedo and density for both components.

Our immediate objective is to determine the short-term variability of UWTNBs. For some objects, nearly complete lightcurves will be obtained. For others, follow-up observations may be required to fully determine the lightcurve. For both system components, densities, albedos, and sizes will be derivable from the variability constraints that we will obtain. As there is no infrared data for our targets sample, we will have to derive the object density according to Chandrasekhar (1987) work about equilibrium figures. Because the system masses are known (Parker et al. (2011)) and because we will be able to derive the density and size of each components, the albedo will be derived as in Noll et al. (2008). Based on derived information, we will be able to favor or discard formation models as suggested in Thirouin et al. (2014). For example, by computing the specific angular momentum and the scaled spin rate of the system (parameters depending of the rotational period, density, size, shape), one can favor a rotational fission model if the object falls near the MacLaurin-Jacobi transition.

Note that it is not critical for the success of this program that all sample targets are observed. In case that less than the requested observing time is available, we will observe a smaller number of targets and constrain the physical properties of this subset.

References:
Benecchi et al. (2009), Icarus, Vol.200, 292-303.
Chandrasekhar (1987), New York : Dover.
Kern et al. (2006), Icarus, Vol.183, 179-185.
Nesvorny et al. (2010), AJ, Vol.140, 785-793.
Noll et al. (2008), pp., p.345-363.
Parker et al. (2011), AJ, Vol.743.
Thirouin et al. (2010), A&A, Vol. 522.
Thirouin et al. (2012), MNRAS, Vol.424, 3156.
Thirouin et al. (2014), A&A, Vol., 569, id.A3.

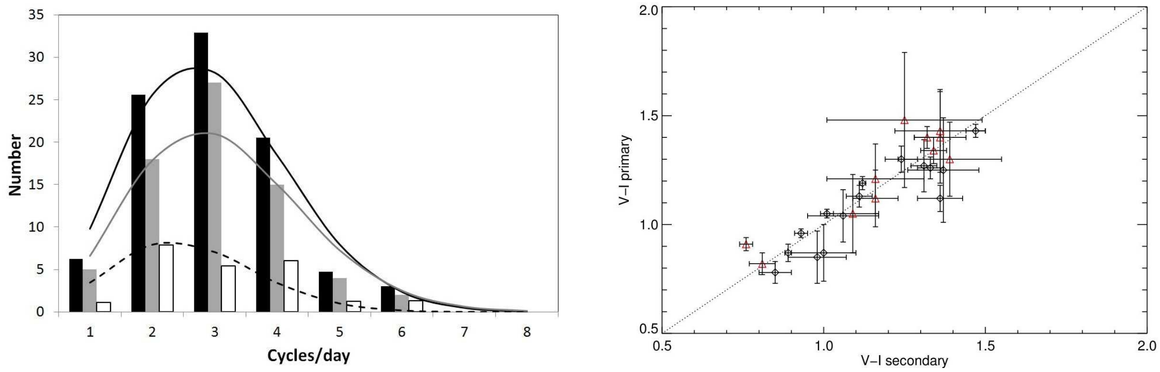

Figure 1: **Left:** Number of objects vs. rotational frequency: Black bars represent the whole sample of TNOs whose short-term variability have been studied, gray bars are for the sample without binary objects, and white bars represent the binary sample. The dash, black and gray lines are Maxwellian fits to the different samples of data. The sample of TNBs is still clearly subject to low-number statistics and requires further exploration. Figure from Thirouin et al. (2014). **Right:** The secondary vs. primary colors for TNBs are plotted. The dashed line indicates components of identical color (Slope=1). Black diamond symbols are for non-ultra wide binaries whereas red triangles are for ultra-wide binaries. Based on this study, it seems that the UWTNBs follow the same tendency as the TNBs. Figure adapted from Benecchi et al. (2009).

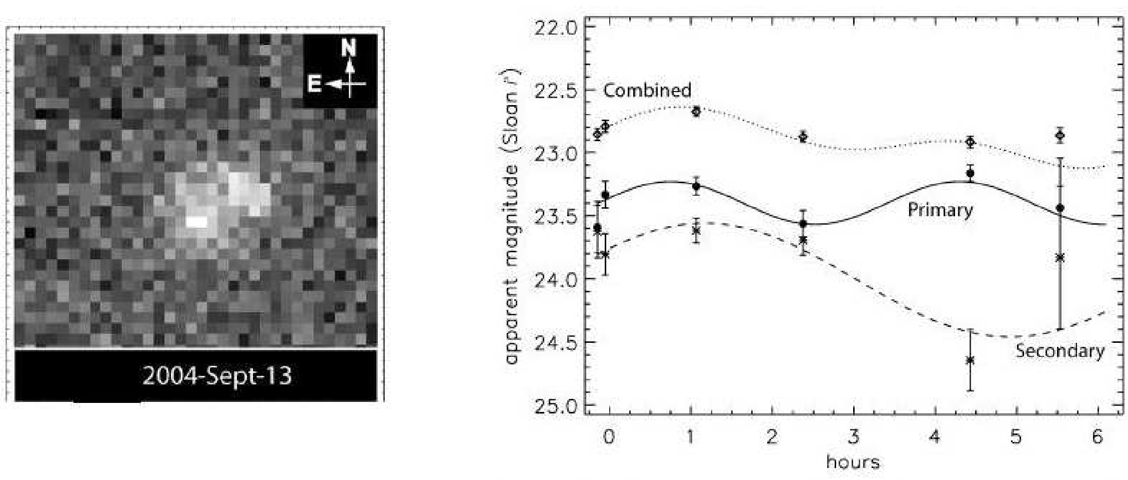

Figure 2: **Left:** Image obtained with the 6m telescope at Las Campanas Observatory. **Right:** Lightcurve observations for 2003QY90 collected on the night of 2004, September 13. The primary lightcurve (closed circles, solid line), the secondary lightcurve (stars, dashed line) and the combined lightcurve (open diamonds, dotted line) are plotted. Figure adapted from Kern et al. (2006).

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science.* ***(up to one page)***

The targets selected for this proposal are faint, with a V-band magnitude between 22 and 24. So, the observational run has to be carried out during dark nights (Nights with a Moon illumination between 0% to 30% are acceptable).

Our proposal is focused on the short-term variability of ultra-wide binaries. The main priority of this proposal is to obtain lightcurves (short-term variability study to have rotational period and amplitude) for at least 2 systems. As we want resolved lightcurves (i.e. to separate both components of the system, and so obtain the lightcurve for each component), we need good seeing conditions. In fact, the seeing has to be lower that the separation between both components. This means that the lightcurves of 2005 EO304 and 2001 QW322have to be carried out with a seeing $\leq 1.5''$, whereas lightcurves of 2000 CF105, 2006 CH69, and 2006 JZ81 require a seeing $\leq$0.6-0.8$''$. Such seeing conditions are in agreement with the MMT mean seeing of 0.8$''$. As the mean rotational period for TNOs is around 8h (Duffard et al. 2009), we require a minimum of 8h for each system. Our strategy is to observe at least two systems during the night. We will carry out 5 images of the first target, then switch to the second target and carry out 5 images, and repeat such a process during the entire night. Observations have to be carried out in the r'-band (to avoid fringing effects and maximize the SNR). In case of bad weather conditions, we will observe brighter targets with a preference for binary systems. If no binary systems bright enough are visible, we will observe non-binary TNOs.

We need a minimum signal-to-noise ratio (SNR) between 10-50 for all objects. Assuming a seeing of 0.75$''$, the time exposures in the R-band for a object with a visual magnitude of 23 is 600s to have a SNR around 30 (according to the exposure time calculator). For the faintest objects (magnitude 24), a SNR around 20 will be required and corresponding exposure time is 900s in the r'-band. Exposure time has to be adjusted according to the satellite brightness. In fact, satellites are fainter than the primaries and we required a SNR around 20-50 for the primary and around 10-20 for the satellite. As mentioned, secondaries are fainter than primaries and so exposure times have to be adjusted regarding the SNR of the secondaries. Exposure times have been computed using the MMT exposure time calculator. Similar exposure times will be used for the Magellan observations.

We need a 6m-class telescope because our targets are faint (magnitude in the V-band between 22 to 24). We need an imaging instrument capable of delivering a signal-to-noise ratio around 10-50 for all objects with integration times below 900s (typically), in the r'-band. Also, the integration time has been chosen in order to avoid trailing of the object or trailing of the stars (if differential tracking rates are used). The target choice will depend on the quality night.

Because of the MMT and Magellan sizes and because of the MMTCam and IMACS capabilities, we think that these facilities are the best option to observe such objects.

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

This is the first time we submit this proposal and so, we have no awarded time yet. We request one night at the MMT to observe at least 2 ultra-wide binaries, and 2 nights at the Magellan to observe 3 ultra-wide binaries. The target choice will depend on the weather condition during the observing night. As our main concern is to separate both components of the systems, we are basically seeing-dependent. In case of bad weather, we will observe bright targets, not necessarily binaries.

In this proposal, we select only 5 objects that are visible this semester. However, more ultra-wide TNBs are known, and so more observing time will be requested in the next semester(s) to complete this study. In fact, we want to observe most of these objects in order to propose a reliable study and draw conclusions about this kind of objects. We estimate that 1 more night with good weather conditions are needed to complete our program.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). (**up to one page**)*

PI Mommert has been awarded 2 bright nights of 90"/PISCES in 2014B (December, 8-9, 2014) to obtain NIR photometry of Centaurs and TNOs in support of existing Spitzer photometry. The observations have not yet been conducted. For the same program, Mommert has been awarded 10 hrs (10 hrs requested) of UKIRT/WFCAM in 2014B (u/14b/ua14, PI: Mommert). Similar observations in 2014A (PI: Don McCarthy, u/14a/ua15) had a completion rate of 99%, are mostly reduced and analyzed; observations in 2014B have not yet started due to the unavailability of WFCAM on the telescope. The results of both observing runs will be published together in early 2015.