OBSERVING REQUEST
University of Arizona Observatories

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

Outer Disk Material in the Inner Solar System: a Debiased Survey of Small Hilda Asteroid Compositions

P.I.: Erin Ryan (University of MD & NASA Goddard; *erin.l.ryan@nasa.gov*; 434-409-0401)

CoI(s): Chick Woodward (University of Minnesota), Keith Noll (NASA Goddard)

Abstract of Scientific Justification

Numerous dynamical models published in the last decade have proposed a migration of the gas giant planets in the solar system. These migrational models (e.g. the Nice Model) show that delivery of small bodies from distinct outer solar system reservoirs is possible into the inner solar system regions, the Trojan and Hilda asteroid populations are likely examples. Previous Hilda group asteroid optical studies suggest a common compositional link to the Trojan asteroid population; however, inadequate spectrophotometric data is available of the Hilda asteroids for comparison to the Trojans. We propose a program to obtain spectrophotometric data of the Hilda population between 5 and 50 km for comparison to the Trojan and Kuiper Belt populations and to test the Nice Model of giant planet migration. **This proposal is a U. Minnesota GTO telescope allocation request.**

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	90”	PF	90Prime			5	grey	Feb–Apr	Feb-Apr	no	no

Scheduling constraints and unusable dates *(up to 4 lines)*: None

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	(1746) Brouwer	12:31:26.75	−11:38:34.0	V=16.61
2	(25800) Glukhovsky	06:18:11.66	+25:54:19.4	V= 19.38
3	(2760) Kacha	08:50:54.69	+27:25:19.9	V= 15.72
4	(4757) Liselotte	05:50:55.03	+23:28:27.9	V=18.76
5	(15376) Martak	12:43:05.63	−08:11:29.11	V=19.38
6	(23405) Nisyros	06:00:18.72	+21:55:45.6	V=19.9
7	(15671) Suzannedebarbat	07:21:09.92	+14:43:54.9	V=18.54
8	(73475) 2002 PV1	12:46:32.07	−05:27:53.7	V=19.91
9	(77895) 2001 SH324	13:26:08.64	+04:27:05.7	V=19.10
10	(51930) 2001 QW127	13:42:46.03	−13:53:25.4	V=19.41
11	(51874) 2001 PZ28	13:19:37.33	+00:13:47.7	V=19.10
12	(46302) 2001 OG13	13:06:06.03	−07:31:30.7	V=18.49
13	(88253) 2001 FV69	04:50:21.01	+28:41:25.3	V= 19.63
14	(23301) 2001 AO16	03:46:05.30	+35:19:17	V=18.50
15	(92287) 2000 EX14	05:36:11.67	+31:19:06.8	V=19.77
16	(118520) 2000 EU11	05:43:16.05	+31:44:46.5	V=19.44
17	(103537) 2000 BO17	05:12:45.96	+24:09:56.4	V=19.86
18	(91304) 1999 FU44	12:08:26.03	−07:32:48.8	V=18.11
19	(11410) 1999FU34	14:33:37.4	−13:49:30	V=17.40
20	(15783) 1993 PZ2	14:45:11.1	−16:39:27.1	V=18.74
21	(13504) 1988 RV12	06:09:58.25	+06:06:53.6	V=17.77
22	(7284) 1989 VW	08:58:16.37	+25:35:58.6	V=17.18
23	(85163) 1988 SQ2	12:08:35.79	−00:02:54.3	V=19.34
24	(85162) 1988 SL2	11:24:27.3	+04:34:08.2	V=18.74
25	(90704) 1988 RO12	08:11:21.5	+20:23:16.1	V=19.57
26	(10610) 1996 XR1	12:53:58.07	+00:22:21.9	V=18.9

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

Several lines of evidence suggest that giant planet migration took place in the early solar system. *To properly test the various models, comparison between several distinct small body populations in the outer solar system is needed. In particular the smallest objects may reveal the most unaltered compositions as their surfaces may be less weathered than the large objects which look universally red.*

Three distinct small body populations that display similar colors are the Kuiper Belt, the Trojans and the Hilda asteroid group. The colors of objects (Figure 1a) in these regions range from neutral reflectance slopes, classified as C- and X- types in the Hildas and Trojans, to red, or D-type, reflectance slopes (Doressoundriam et al. 2008; Emery et al. 2011; Dahlgren et al. 1997; Gil-Hutton & Brunini 2008). Varying giant planet migration models such as the Nice Model (Tsiganis et al. 2005; Morbidelli et al. 2005; Gomes et al. 2005) and the Grand Tack (Walsh et al. 2011) utilize dynamics to suggest that Hildas, Trojans, and the Kuiper belt share a common origin.

Why study the Hildas?

The Hilda asteroid group is unique within these three populations. In a instantaneous top down view of the solar system, the positions of Hildas trace a triangle with apexes near the Jovian L3, L4, and L5 Lagrange points, which can only be replicated by an inward migration of Jupiter (Franklin et al. 2004). Additional models of giant planet migration by Broz & Vokroulicky (2008) show that the Hilda asteroid population is non-native as a native population of planetesimals would have been completely disrupted by Jupiter and Saturn crossing a 2:1 resonance. This suggests that the Hilda population has been completely repopulated from other regions.

Unlike Kuiper Belt objects (KBOs) and Trojans, the Hildas are not well studied in the optical. This is the problem we address in this proposal. Compositional studies within the Hilda asteroid group before the Sloan Digital Sky Survey (SDSS) were limited to the largest 50 asteroids, which revealed a number of D-type asteroids (Dahlgren et al. 1997), similar to the Trojans. This study noted a change from a red slope towards a neutral slope as a function of decreasing size. Subsequent study of Hilda asteroid detections by SDSS of Gil-Hutton & Brunini (2008), found only 100 Hildas which were distributed in three compositional classes of D-, C- and X- types whose reflectances are given in Figure 1a. The result from SDSS did not suggest a continued flattening of the reflectance spectra as a function of decreasing size for small Hildas (diameters $<$ 50 km), instead the SDSS Hildas displayed a greater color diversity than the large objects from Dahlgren et al. (1997). This is consistent with the color results for the Trojans as well which show greater spectra diversity at small sizes (Emery et al. 2011). *Even with the addition of SDSS colors to the database of optical color data for Hildas, the number of Hildas with known colors is a factor of 10 less than the number of Trojans with colors making discrimination between varying dynamical models difficult.*

The disagreement in size dependent properties also extended to the study of Hilda asteroid group albedos. Spitzer results from $\sim$60 Hilda asteroids by Ryan & Woodward (2011) find an inverse relation with asteroid diameter and albedo similar to that seen within the Trojan population by Fernandez et al. (2009). Results from the WISE survey (Grav et al. 2012) do not agree with albedo-diameter relation from the Spitzer results, however they find a broadening of Hilda asteroid albedos at diameters $<$ 20 km (Figure 1b). This result is consistent however with the optical colors wherein the large asteroids are of a single compositional type, but the compositions vary at smaller sizes. With a larger optical color sample of Hildas with diameters $<$ 20 km, we expect to confirm this broader range of optical colors which would parallel the KBO and Trojan populations where color diversity increases with decreasing size.

Is it possible to discriminate between dynamical models?

Dynamically the combination of the Grand Tack and Nice Models are preferred at the current time as they replicate observed dynamical parameters, such as the presence of scattered disk objects in the Kuiper Belt and objects trapped in Neptunian resonances. The exact compositional predictions from these two models have come under question, specifically in the case of the Grand Tack, as this model assumes all carbon rich asteroids originated at heliocentric distances larger than the Saturn natal distance without and compositional evidence from meteorites to support this assumption. The Nice Model is not the only proposed dynamical model which could account for the presence of the Hilda group asteroids. Models of the migration of Jupiter by Franklin et al. (2004) suggest the possibility that the Hilda asteroids are objects from the main belt trapped by an inward migration of Jupiter by 0.45 AU. An inward migration of Jupiter can drive the eccentricities of asteroids originally in near circular orbits ($e < 0.05$) to a distribution that closely matches the Hilda asteroid population mean eccentricity of $e \sim 0.19$. Trapping of field asteroids via migration preferentially traps the highest eccentricity objects at the greatest semimajor axis. If a remnant local population was present to be trapped, it too could have a compositional gradient along the lines suggested by Gradie et al. (1989) to explain the transition from silicate rich asteroids in the inner main belt to carbon rich asteroids in the outer main belt. To test this model, additional Hilda asteroids with known colors are also required. *To test both the Nice Model and a simple inward migration model for Jupiter utilizing the Hilda asteroid population, we propose to increase the sample of Hilda asteroids with colors to a statistically robust 500 objects.*

This proposal is a continuation of UMN Guaranteed Time program scheduled for observations in late November 2012- November 2014. Time was also awarded for a version of this proposal at the Kitt Peak 4 meter in fall 2013. This program is approximately 70% complete with a total of 204 asteroids observed for this program via a combination of 90 inch and fall 2013 KPNO 4-m time. Preliminary results from our survey confirm that Hilda group asteroids have a large color diversity in the optical when small asteroids are included (Figure 2). A gradient in asteroid taxonomic type with eccentricity does not appear in our preliminary results, suggesting that a simple inward migration scenario of Jupiter through an asteroid disk with a smooth compositional gradient is incorrect (Figure 3); objects were either resonant trapped in a compositionally mixed outer asteroid belt or delivered from the outer regions of the solar system. Additional analysis on the color-eccentricity relationship is required; the broad ranges of colors associated with taxonomic types may not be the best measure of a compositional gradient, instead an optical color slope-eccentricity relationship should also be investigated.

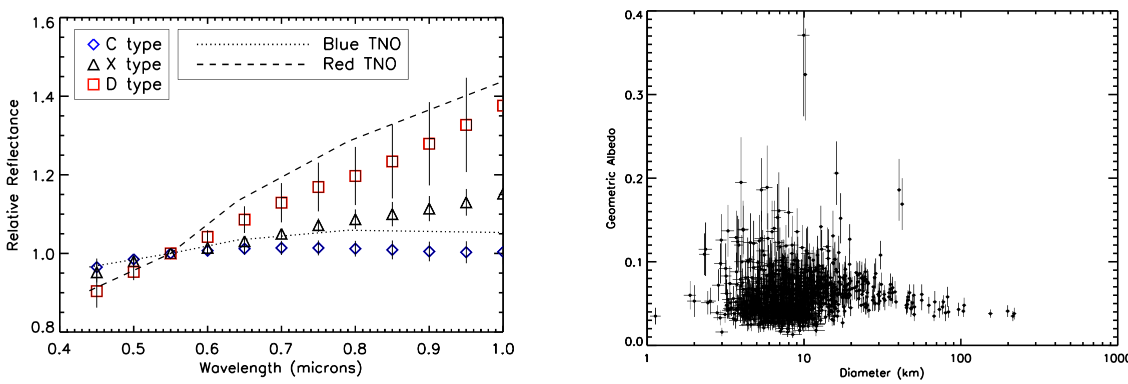

Figure 1: *Left:* Relative reflectances of C-,X- and D-type asteroids as defined in the Bus-DeMeo classification scheme (DeMeo et al. 2009) in colored symbols with the 3σ variance in relative reflectances for each asteroid type. The average relative reflectances of neutral and red Kuiper Belt objects (BB and IR in the Barucci taxonomy; Perna et al. 2010) are also plotted as dotted and dashed lines respectively. The overlap is suggestive of a common origin for Hildas and KBOs (and Trojans) asteroid populations. *Right:* The geometric albedos derived from WISE observations from Grav et al. (2012) show an increased diversity for objects smaller than 20 km.

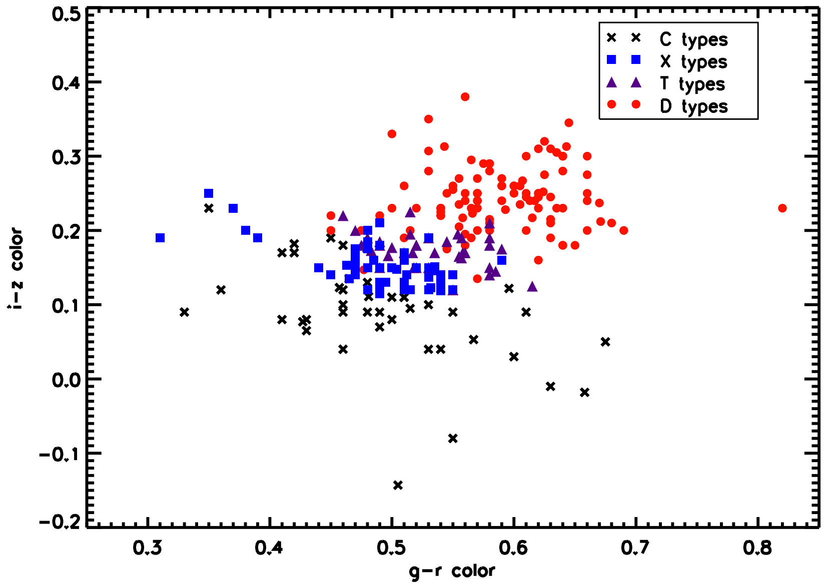

Figure 2: Sloan g-r vs i-z colors for Hildas in our preliminary sample. Black asterisks denote C-type asteroids, blue squares denote X-type asteroids, purple triangles denote T-type asteroids and red circles denote D-type asteroids using SMASS taxonomic definitions. These Hilda group asteroid colors are far broader than those presented in optical surveys of the 1990's and are show a larger blue population at small sizes.

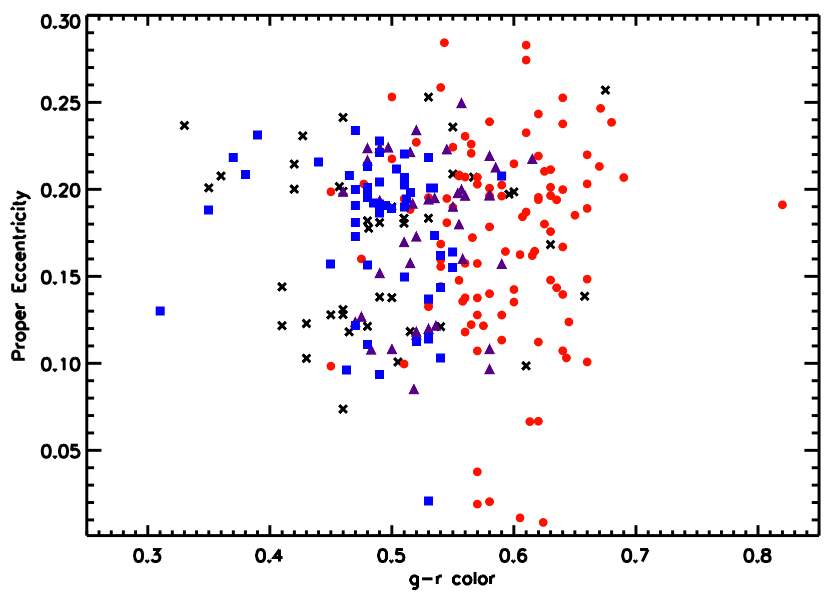

Figure 3: Preliminary results of Hilda group asteroid taxonomic type show no gradient over the range of orbital eccentricities. If the preliminary results matched the Franklin et al. scenario, we'd expect to see D-types (red circles) at the top right of the plot and C-types (black asterisks) at the bottom left of the plot.

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**)*

To increase the number of Hilda asteroids with known colors to 500 we propose to observe objects with a number of optical ground based telescopes. Colors for 150 are available from the literature, however we note that the results from the Sloan Digital Sky Survey may be unintentionally biased towards objects with large diameters and/or geometric albedos. We therefore propose to utilize the WISE Hilda asteroid catalog (Grav et al. 2012) to select targets for optical study and debias our study as a function of diameter. Of the 3313 Hilda group asteroids known, the WISE mission detected 1021 of these objects.

The WISE asteroid survey completeness is primarily related the asteroid flux; assuming the quoted 5σ detection limit of 10 mJy at 22 μm for the WISE survey, the detection limit for a Hilda group asteroid by WISE is 6 km. Due to rotational concerns, we will limit our observations of Hilda asteroids with the Bok Telescope to the 400 objects detected by WISE with diameters $>$ 10 km.

Complications in obtaining Hilda asteroid colors: Studies of asteroid rotational frequencies by Pravec et al. (2002) have found a rapid rotator cutoff at 12 revolutions per day for asteroids with diameters between 1 and 20 km. While few lightcurves are available for the Hilda asteroids, the possible contamination due to rotational effects can be minimized by obtain data over less than half a rotational period (= 1 hr) and utilization of a observing cadence wherein one filter is used as a reference filter between other object exposures. When a one hour total integration time cutoff is imposed for asteroids to be studied at the 2.3-m Bok Telescope, we are limited to only Hilda asteroids with diameters $>$ 10 km (V $\sim$ 20.), limiting our analysis to only $\sim$ 400 total asteroids. The cadence we propose to use is g - i - g - z -g. With this observing cadence, the total observation time required per object in the range of 18. $<$ V $<$ 20. with filter change and readout overhead is 45 minutes, less than the half the period of the fastest rotators. Over 5 nights of observations, we anticipate obtaining data for 50 objects.

The need for 4 filter observations: Taxonomic studies of small (D $<$ 50 km) Trojan and Hilda asteroids (Gil-Hutton & Brunini 2008; Emery et al. 2011) have revealed that these objects display two basic color groups - one grouping characteristic of C and X type asteroids, and another characteristic of D type asteroids. To reliably discriminate between the relative reflectances of these different types (shown in Figure 1), we must utilize data in at least 3 Sloan filters. Filters selected for this program are g' for an anchoring of relative reflectances and the i' and z' filters at 0.76 and 0.91 microns where the greatest difference in relative reflectance between the C and X taxonomic types is observed. A study of the MPC absolute magnitudes used by the WISE team by Pravec et al. (2012) show significant discrepancies with other observations, thus we will also obtain observations with the r' filter, to determine an asteroid's brightness in Bessel V which will allows us to update the WISE albedo and diameter estimates.

References:

Broz, M. & Vokrouhlicky, D. 2008, MNRAS, 390, 715; Dalhgren, M., et al. 1997, A & Ap, 323, 606; Doressoundriam, A., et al. 2008, Color Properties and Trends of the Transneptunian Objects, in The Solar System Beyond Neptune; Emery, J.P., et al. 2001, Icarus, 141, 25; Fernandez, Y., et al. 2009, AJ, 138, 240; Franklin, F.A., et al. 2004, AJ, 128, 1391; Gil-Hutton, R. & Brunini, A. 2008, Icarus, 193, 567; Gomes, R., et al. 2005, Nature, 435, 466; Grav, T., et al., 2012, AJ, 744, 197; Mainzer, A., et al. 2012, ApJ, 745, 7; Morbidelli, A., et al. 2005, Nature, 435, 462; Pravec, P., et al. 2002, Asteroid Rotations, in Asteroids III; Ryan, E.L. & Woodward, C.E. 2011, AJ, 141, 186; Tsiganis, K., et al. 2005, Nature, 435, 459; Walsh, K, et al. 2011, Nature, 475, 206

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**)*

Time requested:

The 26 objects in the target table are a sample Hilda asteroids detected by the WISE mission which are observable in the spring 2015 semester. As Hilda asteroids are distributed throughout the solar system in an annulus around a heliocentric distance of $\sim$4.2 AU, a number of Hildas are available for observation at any time of the year. 5 nights of observations should allow us to obtain colors for $\sim$50 objects assuming approximately 45 minutes per object and additional standard calibration overheads.

Time is requested in the Feb to Apr timescale of the spring 2014 semester to maximize the number of available targets. In this period, there are 72 objects that are both observable (above 1.5 arimasses for 30 minutes or more) and brighter than 20th magnitude in V, thus allowing us to obtain photometry in less than a half the standard rotation time of objects in this size range.

Previous time awarded:

November 2012: 5 nights awarded. Loss of 2 nights to weather plus a significant loss of time a 3rd night due to diagnosing and fixing issues related to a network switch replacement done on the mountain in the middle of the run. 20 objects observed.

April 2013: 3 nights awarded. 2 nights lost due to high winds. 9 objects observed in the last night.

June 2013: 2 nights were scheduled in conjunction with an additional 3 nights for a UMN program to study potential Deep Impact flyby target 2002 GT. 24 objects completed.

September 2013: 2 nights awarded, but a lingering monsoon season limited the number of targets completed to 10.

October 2013: 3 nights awarded, 34 targets observed

January 2014: 4 nights awarded, 14 targets observed, weather required dome to be closed 2.75 of the 4 nights.

June 2014: 5 nights awarded, 25 targets observed, non photometric conditions resulted in no Hilda observations during 2 of the 5 nights.

October and November 2014: 8 nights total have been awarded to this 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)***

⋆ November 2012: 5 nights awarded. Loss of 2 nights to weather plus a significant loss of time a 3rd night due to diagnosing and fixing issues related to a network switch replacement done on the mountain in the middle of the run. 20 objects observed.

⋆ April 2013: 3 nights awarded. 2 nights lost due to high winds. 9 objects observed in the last night.

⋆ June 2013: 2 nights were scheduled in conjunction with an additional 3 nights for a UMN program to study potential Deep Impact flyby target 2002 GT. 24 objects completed.

⋆ September 2013: 2 nights awarded, but a lingering monsoon season limited the number of targets completed to 10.

⋆ October 2013: 3 nights awarded, 34 targets observed

⋆ January 2014: 4 nights awarded, 14 targets observed, weather required dome to be closed 2.75 of the 4 nights.

⋆ June 2014: 5 nights awarded, 25 targets observed, non photometric conditions resulted in no Hilda observations during 2 of the 5 nights.

⋆ October and November 2014: 8 nights total have been awarded to this program.