The Caltech Wide Area Sky Survey

Beyond (50000) Quaoar

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Abstract. The first phase of the Caltech Wide Area Sky Survey occurred from late November 2001 through mid-April 2003. We present preliminary results from this survey which has detected 28 bright Kuiper Belt Objects (KBOs) and 4 Centaurs, 19 of which were discovered in our survey including Quaoar, the largest KBO, as well as 6 of the 10 intrinsically brightest KBOs. We have surveyed 5108 square degrees of the sky nearest the invariable plane to a limiting red magnitude of 20.7. Correcting for the overabundance of objects near the invariable plane, this represents 27% completeness in terms of KBO numbers. Thus, approximately 100 KBOs and Centaurs brighter than $m_R = 20.7$ exist, about 3/4 of which remain undiscovered. The bright KBOs are consistent with the canonical $q = 4$ size distribution, suggesting that about ten 1000 km diameter KBOs and about one 2000 km diameter KBO exist. Additionally, we observe only 3 KBOs with low inclination ($i < 7$ degrees) with 67% of the sky available to these objects surveyed. This is in sharp contrast with the known KBOs, of which about 60% of the ~ 800 observed objects (as of May 2003) have $i < 7$ degrees. Although we observe at systematically higher invariable plane latitudes than many deeper KBO surveys, such systematic biases cannot fully explain the lack of low inclination objects, a measurement which is significant at the $> 3\sigma$ level. This suggests that the bright KBOs have a fundamentally different maximum size than the fainter KBOs. A better characterization of the survey limiting magnitude and a more thorough modeling of observational bias effects of different classes of KBOs will be made in a future work.

1. Introduction

The brightest Kuiper belt objects (KBOs, also trans-Neptunian objects and Edgeworth-Kuiper belt objects) are of fundamental scientific interest for several reasons: (1) on average, the brightest KBOs are the largest KBOs; (2) the number of very large KBOs are a fundamental constraint for planet growth simulations (Kenyon and Luu, 1999); (3) large KBOs are more likely to have observable occultations; (4) only the brightest KBOs can be studied by near infrared reflectance spectroscopy, i.e. wavelengths where simple organic surface ices can be identified; (5) the thermal emission of the largest KBOs can be detected from the ground, the most often used technique for measuring KBO sizes; and (6) the disks of the largest KBOs can be directly resolved with the Hubble Space Telescope (Brown and Trujillo, 2003).

Despite the myriad of scientific interest in the large KBOs, there have been very few surveys sensitive to these large objects. The largest KBOs are quite rare in the sky, and only surveys dedicated to wide-field time-resolved imaging can be used to find these objects. To date, only three refereed, published surveys of >100 square degrees have detected KBOs: Spacewatch covered ~ 500 square degrees to V magnitude $m_V = 20.0$ and detected 16 KBOs and Centaurs (Larsen et al., 2001); (Trujillo et al., 2001b) surveyed 164 square degrees to limiting red magnitude $m_R = 21.1$, finding 4 objects; and (Tombaugh, 1961), who surveyed $\sim 20,000$ square degrees to $m_V \sim 15.5$, finding Pluto. Elsewhere in this volume, two wide-field surveys appear: (Millis et al., 2002), who published ~ 75 square degrees to $m_R \sim 24$, but now present more recent results including >100 square degrees (Buie et al., 2003); and Moody et al. (2003), who present initial results of >1000 square degrees to $m_R \sim 19.5$. In this work, we present initial results of the Caltech Wide Area Sky Survey, where we have surveyed 5108 square degrees to $m_R = 20.7$ — the most prolific survey to date in terms of finding bright KBOs.

2. Instrumentation and Observations

For this experiment, we have used the Palomar Oschin Telescope, a 1.22 m (48 inch) diameter Schmidt telescope — the same telescope used for the Palomar Sky Survey (Abell, 1959). This telescope has recently been renovated by the Near Earth Asteroid Tracking (NEAT) program at the Jet Propulsion Laboratory (JPL) to operate robotically, where observations are specified nightly and automated control software is responsible for execution of the observations. Although the telescope operates fully autonomously and has weather sensors allowing for dome closures in adverse conditions, operations are typically performed only with the consent of a human operator at the Palomar Hale 5.08 m (200 inch) Telescope, who has emergency override privileges. Data acquired during nightly operations are automatically transferred to JPL and Caltech for daytime processing.

This phase of the program uses a wide-field camera with 3 x 4080 x 4080 pixel charge-coupled devices (CCDs), commissioned by the NEAT program. The camera has 15 μm pixels, yielding a 1 arc-second/pixel plate scale, or 3.85 square degrees per exposure. Due to overlap regions between the chips and cosmetic problems in one of the chip quadrants, we average 2.75 square degrees of sky coverage per exposure in sky regions fully tessellated by the camera. Our survey has been granted most of Caltech's 20% share of the Oschin Telescope time, with the remaining 80% used by the NEAT program. We typically observe for 2 hours per night for 20 nights each month, from late November 2001 through mid-April 2003, with our observations and NEAT observations interspersed by the telescope queue control software. On each clear night, we observe 12 fields three times each, with about 1.5 hours between exposures. The median seeing in our dataset is 3.1" full width at half-maximum (FWHM), allowing us to detect objects as slow as 1"/hr over each three hour triplet interval. All observations are processed using a modified version of the extensively used Moving Object Detection Software (MODS, Trujillo and Jewitt, 1998; Jewitt et al., 1998; Jewitt et al., 2000; Trujillo et al., 2001a; Trujillo et al., 2001b). All candidates identified by MODS are verified by eye before follow-up. Typically, this is a trivial matter for the observer as most false positives are due to scattered light near bright stars, faint background sources near the flux threshold, extended sources such as galaxies, superpositions of cosmic rays and pairs of asteroids whose tracks cross or pass near faint sources. Each of these false positives is clearly identifiable because the candidate does not have a point spread function (PSF) consistent with a stellar source, is not moving exactly linearly, or varies in flux. Currently, it takes about 2 hours for each good night of observing (33 square degrees of sky) to check the MODS output by eye. In future versions of this survey, we expect to upgrade the software to automatically reject many of the false positive cases. For this survey, we have selected objects by apparent sky velocity, 1"/hr $< \dot{\theta} <$ 10"/hr, corresponding to heliocentric distances of 11.4 AU $< R <$ 136 AU, since all our fields were taken within 1.5 hours of opposition (Luu and Jewitt, 1988). The sky fraction imaged in this survey appears in Figure 1, representing 5108 square degrees of sky, preferentially imaging the invariable plane. We have achieved 76% sky area completion less than 3 degrees from the invariable plane.

3. Detections and Recovery

The discovery circumstances of KBOs and Centaurs detected in our survey appear in Table I, with the discovery source listed for each object. Of the 32 objects detected, 19 were first discovered in our survey, suggesting that the sky coverage of the invariable plane to date has been about 40%, by a variety of surveys. Of the 13 known objects serendipitously detected in our survey, 6 were discovered by the Spacewatch survey (Larsen et al., 2001), 3 by the Deep Ecliptic Survey (DES, Millis et al., 2002) and each of 4 discovered by other

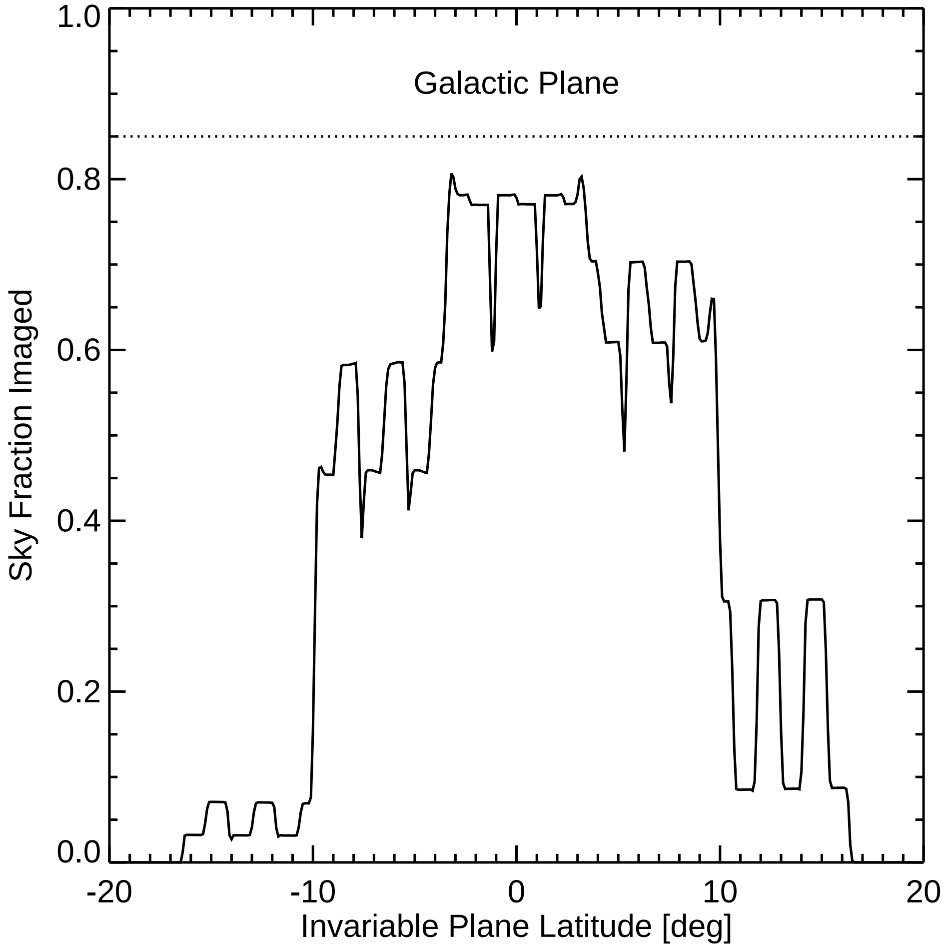

Figure 1. Survey sky fraction imaged as a function of invariable plane latitude is pictured above. Sky fraction averages 76% within 3 degrees of the invariable plane. The departure from 100% is primarily due to galactic plane avoidance (about 15%) with the remainder due to poor weather. Within 10 degrees of the invariable plane, coverage averages 64%. The narrow drops in sky coverage are aliasing effects caused by the fact that the camera is aligned with the celestial pole, not the invariable plane.

surveys (Jewitt et al., 1998; Trujillo et al., 2001b; Delsanti et al., 2000; and Pravdo et al., 1999).

Recovery efforts have been aided by the fact that many of the discovered objects are quite bright. Each object has only a 3 hour arc shortly after discovery. Follow-up observations are made at the Palomar 1.52 m (60 inch) telescope on a monthly basis. Each month, all objects discovered in the previous 3 months are attempted for recovery, and results are reported to the Minor Planet Center (MPC). For new objects, positions are predicted using the method of Bernstein and Khushalani (2000). Since discovered objects are so bright, recovering objects a month after discovery with only a 3 hour arc is not difficult with the ~ 13 arcmin field of view of the Palomar 1.52 m in imaging mode. Additionally, many of the brightest objects have been found in other datasets by the DLR-Archenhold Near Earth Objects Precovery Survey (DANEOPS, Hahn et al., 1999), as well as by the authors of this work and other works. Typically, publicly available digitally archived datasets have been used for these precoveries, such as the NEAT data available through Skymorph (Lawrence et al., 1998) and the Digital Palomar Observatory Sky Survey (DPOSS, Djorgovski et al., 2002). The brightest KBO, (50000) Quaoar was found in several photographic plate archives, including those of Kowal (1989).

4. Very Slow Moving Objects

Although we have the ability to detect objects as slow as 1"/hr over our 3 hour interval, there are an increased number of apparently real false positives at such slow rates, due to our large plate scale (1"/pixel) and the effect of differential refraction and seeing variations on stellar objects. Such very slow moving objects (VSMOs) are very valuable, since they would indicate very large bodies (> 2500 km in diameter assuming 10% albedo) at roughly 100 AU, so the ~ 2 objects per night that appear to be VSMOs are compared to the DPOSS (about the same flux limit as our survey), to determine if they are due to a known background source with apparent velocity caused by atmospheric effects. Occasionally, there is no background source apparent for the detected VSMOs, so we recover such objects in the following month. For each such VSMO, we re-image the "discovery" location using a deep Palomar 1.52 m image. To date, of the ~ 60 such VSMOs detected, all have proved to be false, due to faint background sources not apparent in the DPOSS.

5. Survey Depth, Efficiency and Completeness

We have not yet fully calibrated our survey depth. Since our survey operates during all lunations, all seeing conditions and all photometric weather conditions, magnitude limits can easily change by 0.3 magnitudes or more from night to night. Additionally, since observations are conducted using NEAT's filterless CCD, color corrections for the wide

Table I. Discovery circumstances and Modified Julian Date (MJD) of KBOs and Centaurs detected in our survey are presented below, including the survey of first discovery. Invariable plane latitude of discovery (β), heliocentric and geocentric distances (R and Δ, respectively), phase angle (α) and red magnitude (m_R) are calculated from Minor Planet Center data using HORIZONS.

Prov. Desig.	MJD	β [deg]	R [AU]	Δ [AU]	α [deg]	m_R [mag]	Discovery Work
1996 TL_{66}	52235.17574	-0.4	35.03	34.09	0.48	20.76	(Jewitt et al., 1998)
2001 YH_{140}	52261.27447	-0.3	36.40	35.48	0.56	21.16	This Work
2001 YJ_{140}	52263.20884	7.0	28.20	27.27	0.63	21.85	This Work
2002 AW_{197}	52284.30125	-7.5	47.39	46.49	0.49	20.06	This Work
1999 DE_9	52321.34928	-3.1	34.18	33.21	0.33	20.05	(Trujillo et al., 2001b)
2001 FP_{185}	52339.28532	-0.2	34.29	33.33	0.47	21.48	(Millis et al., 2002)
2000 EC_{98}	52348.24572	-1.2	14.89	13.90	0.11	21.00	(Larsen et al., 2001)
2000 GN_{171}	52369.27479	-0.8	28.69	27.70	0.19	20.50	(Larsen et al., 2001)
1999 KR_{16}	52373.24833	0.0	37.58	36.60	0.30	21.50	(Delsanti et al., 2000)
1996 GQ_{21}	52373.27193	2.8	39.45	38.48	0.39	21.12	(Larsen et al., 2001)
2002 JR_{146}	52401.21471	-8.3	32.98	31.98	0.31	20.69	This Work
2001 KX_{76}	52406.31013	0.4	43.11	42.14	0.36	19.51	(Millis et al., 2002)
2002 KW_{14}	52411.26060	-0.3	39.71	38.70	0.11	21.67	This Work
2002 KX_{14}	52411.27163	-2.0	39.20	38.19	0.01	20.59	This Work
2002 KY_{14}	52413.32436	1.5	10.97	10.00	1.41	20.29	This Work
2002 LM_{60}	52429.23727	6.1	43.43	42.42	0.18	18.98	This Work
2002 MS_4	52443.26647	12.9	46.99	46.00	0.29	20.85	This Work
2002 PN_{34}	52464.26690	1.5	13.35	12.38	1.34	19.38	(Pravdo et al., 1999)
2002 QX_{47}	52512.17227	6.4	17.98	16.99	0.64	21.14	This Work
1998 SM_{165}	52545.20769	-1.8	35.32	34.34	0.38	21.26	(Larsen et al., 2001)
2001 UR_{163}	52554.14505	2.9	48.99	48.00	0.17	20.67	(Millis et al., 2002)
2002 UX_{25}	52556.17123	2.4	42.69	41.70	0.20	19.91	(Larsen et al., 2001)
2002 TC_{302}	52556.21525	5.7	48.33	47.36	0.28	20.77	This Work
1995 SM_{55}	52557.23500	8.2	39.22	38.26	0.42	20.63	(Larsen et al., 2001)
2002 VR_{128}	52581.11081	5.0	35.68	34.70	0.20	21.42	This Work
2002 VE_{95}	52592.29471	-6.9	27.98	27.01	0.31	19.77	This Work
2002 WC_{19}	52594.26186	-5.3	44.23	43.28	0.32	21.59	This Work
2002 XV_{93}	52618.21134	12.1	40.64	39.68	0.30	21.71	This Work
2002 XW_{93}	52618.24664	8.0	43.54	42.57	0.17	22.19	This Work
2003 AZ_{84}	52652.27563	-8.0	45.89	44.92	0.20	20.63	This Work
2003 FX_{128}	52720.27735	9.7	25.23	24.30	0.82	19.68	This Work
2003 FY_{128}	52724.26595	-6.3	38.29	37.29	0.12	19.62	This Work

Table II. Orbital elements of KBOs and Centaurs detected in our survey are presented below, including classifications of multi-opposition objects (Classical = Cl, Scattered = S, Centaur = Ce, Resonant = 1:2 or 2:3). Data are from the Minor Planet Center: absolute magnitude H, semimajor axis a, eccentricity e, inclination i and oppositions observed (days given in parenthesis for single-opposition arcs). For brevity, orbital epoch, mean anomaly, longitude of perihelion, and longitude of ascending node have been omitted.

Prov. Desig.	H	a [AU]	e	i [deg]	Opp	Class
1996 TL_{66}	5.4	83.935	0.583	24.0	4	S
2001 YH_{140}	5.5	42.691	0.147	11.1	2	Cl
2001 YJ_{140}	7.3	39.808	0.301	6.0	2	2:3
2002 AW_{197}	3.3	47.520	0.128	24.3	5	1:2
1999 DE_{9}	4.7	56.140	0.425	7.6	4	S
2001 FP_{185}	6.2	225	0.848	30.8	3	S
2000 EC_{98}	9.5	10.749	0.455	4.3	4	Ce
2000 GN_{171}	6.0	39.520	0.284	10.8	5	2:3
1999 KR_{16}	5.8	48.895	0.304	24.8	4	1:2
1996 GQ_{21}	5.2	94.047	0.594	13.3	7	S
2002 JR_{146}	5.5	53.398	0.382	13.1	(38d)	
2001 KX_{76}	3.2	39.387	0.243	19.7	7	2:3
2002 KW_{14}	5.7	43.835	0.094	10.0	(28d)	
2002 KX_{14}	4.5	38.760	0.042	0.4	3	Cl
2002 KY_{14}	9.9	12.724	0.137	17.0	(26d)	
2002 LM_{60}	2.6	43.249	0.035	8.0	9	Cl
2002 MS_{4}	4.1	44.863	0.047	17.6	(51d)	
2002 PN_{34}	8.1	30.721	0.566	16.7	2	Ce
2002 QX_{47}	8.6	18.916	0.049	7.6	(15d)	
1998 SM_{165}	5.8	47.528	0.368	13.5	8	1:2
2001 UR_{163}	4.2	51.450	0.281	0.8	6	S
2002 UX_{25}	3.6	42.708	0.145	19.4	5	Cl
2002 TC_{302}	3.9	55.548	0.299	35.1	3	S
1995 SM_{55}	4.8	41.863	0.107	27.1	6	Cl
2002 VR_{128}	5.9	37.020	0.227	14.4	(73d)	
2002 VE_{95}	5.3	39.451	0.291	16.3	6	2:3
2002 WC_{19}	5.1	44.239	0.0	9.2	(100d)	
2002 XV_{93}	5.6	40.496	0.238	13.3	(76d)	
2002 XW_{93}	5.8	38.088	0.275	14.4	(104d)	
2003 AZ_{84}	4.0	39.730	0.175	13.5	2	2:3
2003 FX_{128}	5.6	111	0.845	22.8	(34d)	
2003 FY_{128}	3.8	43.808	0.126	12.3	(30d)	

range of KBO colors observed will be neccessary. Thus, characterising the survey will require extensive analysis which will be performed in coming months, including one or more of the following: comparison of all detected stellar images to the USNO-A2.0 sky catalog (Monet et al., 1998), suitable faint stars in the Tycho 2.0 catalog (Høg et al., 2000), the LONEOS photometric standard catalog (Skiff, 2003) and perhaps the USNO-B catalog (Monet et al., 2003); comparison of detected asteroids to asteroids with well-measured magnitudes; and analysis of Landolt standards (Landolt, 1992) which were both targeted and imaged serendipitously. Each of these photometric calibration procedures will be considered until a consistent picture of the limiting magnitude of the survey is developed. A simple estimate of the limiting magnitude can be computed from discovery statistics: since the KBO magnitude distribution is rather steep (a factor 4 increase in objects for each 1 magnitude increase in depth), most objects are found near a survey's limiting magnitude. From Table I, the median detected object magnitude is $m_R = 20.7$, which is a reasonable and conservative first-order estimate of sensitivity of this survey.

The efficiency of MODS at detecting moving objects has been well-analysed in previous works such as Trujillo et al. (2001a). However, since we operate at a much coarser plate scale in the current survey, we expect that overall maximum efficiency (dominated by background star densities) should be lower for this dataset, perhaps around 85%. We plan to further analyse the effects of stellar density on the efficiency of the moving object detection program in a future work. However, for the time being, we have compared our survey field coverage with the known positions of the brightest KBOs, and have not found any cases where known bright KBOs were missed by MODS. In every case, either the brightest KBOs were not imaged at all, or they were imaged during non-photometric conditions which were rejected from the survey fields and are not included in our sky coverage tabulation.

6. The Primordial KBOs

The most striking fact about the KBOs detected in our survey is that only 3 of 28 bright KBOs have been found with low inclination ($i < 7$ degrees). This is very different from the current known sample of 802 KBOs, roughly 60% of which have low inclinations ($i < 7$ degrees). This observation is partly explained by the fact that we survey systematically higher invariable plane latitudes than many of the traditional faint surveys which observe near the invariable plane. But, although we are more sensitive to higher inclination objects, we are not any less sensitive to low inclination objects — we have covered $\sim 67\%$ of the sky within 7 degrees of the invariable plane (Figure 1) and found only 3 low inclination bodies. The simplest interpretation of these observations is that there are very few low inclination, bright KBOs, and the vast majority of very large KBOs have been excited at some point from their presumably low-inclination formation states. This fundamental, observed fact is notable because it is directly due to our survey, where the invariable plane has been well-observed for the first time.

To draw further conclusions, we determine the statistical significance of this effect by answering the question, how many bright KBOs do we expect to detect at low inclination? This is neccessarily a function of the latitudes we observe and the intrisic inclination distrubtion of the known KBOs. Scaling from all known KBO detections, Brown (2001) estimates the intrisic inclination distribution of the KBOs assuming circular orbits. Using his model scaled to our $i > 7$ degrees data, our total sky coverage and the discovery statistics of a roughly even fraction of Resonant, Classical and Scattered KBOs, we find that we should expect to observe on average of 10.5 KBOs with inclinations below 7 degrees (Figure 2). The probability that 3 or fewer detections would occur by chance alone when 10.5 detections are expected in a Poissonian distribution is 1 in 540, the equivalent of a 3.1σ event in Gaussian statistics. Thus, there is a statistically significant lack of bright bodies at low inclination when compared to the discovery statistics of fainter bodies. The simplest physical interpretation of this observation is that there is the maximum size of the low-inclination, bright KBOs differs from the maximum size of the high-inclination bright KBOs. This fundamental size difference is compatible with the Levison and Stern (2001) finding that the intrinsically bright KBOs have higher inclinations. The lack of bright low-inclination KBOs is also circumstantially compatible with the supposition that the color-inclination correlations observed in the Kuiper belt are due to two superimposed populations (Trujillo and Brown, 2002), one red and primordial (as in Tegler and Romanishin, 2000) and the other modified and exhibiting a wide range of colors. If such a two-population model were responsible for the color diversity in the Kuiper belt, one would expect fundamental size distribution and compositional differences between the low-inclination and high-inclination populations.

The above analysis assumes that all orbits are circular in nature. Since both Plutinos and Scattered KBOs are typically not circular, there are possible bias effects that are as yet unaccounted for in the above calculation. These will be considered in a later work, where more comprehensive orbital modelling will be considered. The expectation is that this will not have much effect our results, because when considering

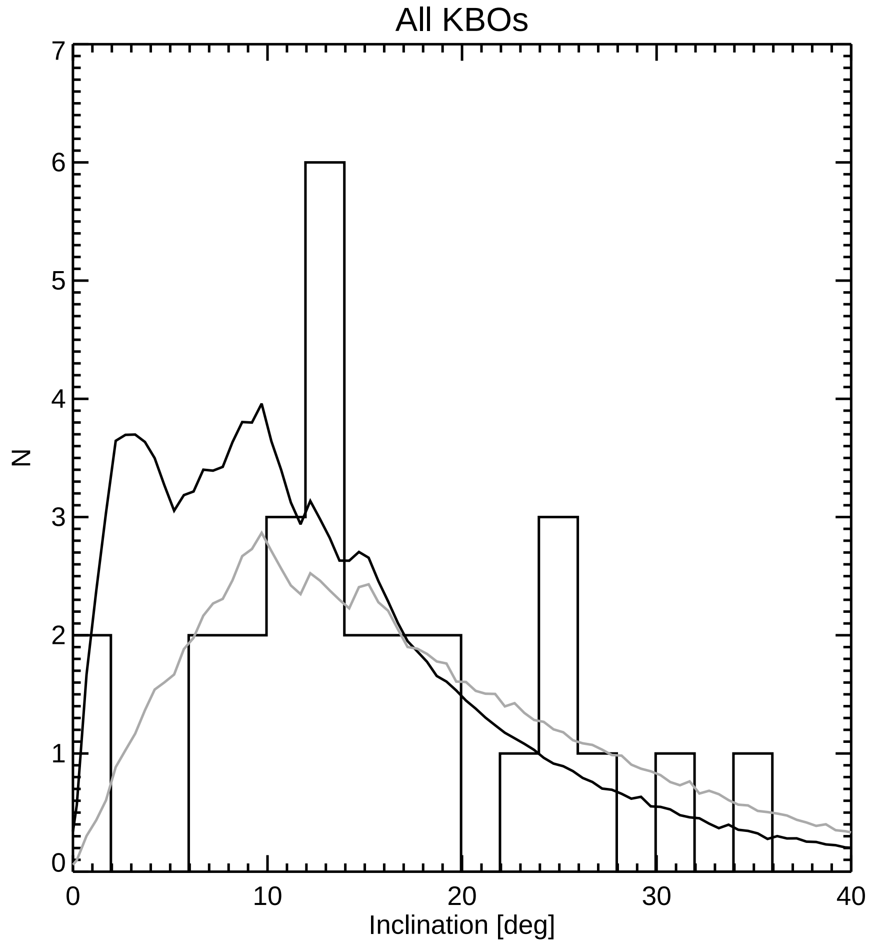

Figure 2. Illustrated are inclinations of detected KBOs (histogram) and a simulation of expected inclinations assuming the Brown (2001a) inclination distribution for all KBOs (black line) and predicting the inclination distribution expected given our sky area observed. Note only 3 low inclination ($i < 7$ degrees) KBOs were found where 10.5 are expected, an effect that is significant at the 3.1σ level. The grey line represents the inclination model used for the total population estimates. The three small peaks in the models between 10 and 18 degrees are due to sky coverage effects.

the Classical KBOs alone, which have low eccentricities, the statistical significance of the observation increases. Using the Brown (2001) Classical KBO model and restricting our analysis to the 11 KBOs that have eccentricities e below 0.2 (corresponding to a median magnitude difference of 0.2 over the course of the orbit — a very small flux bias), we would expect to see 7.9 low inclination KBOs given the 10 high inclination KBOs that we observed (Figure 3). We observed only 1 low

i, low-e KBO; an equal or greater occurance would only happen by chance in 1 of 2600 Poissonian trials, corresponding to a 3.5σ event in Gaussian statistics. Thus, we conclude that the deficiency of low-inclination bright KBOs is real. This observation is consistent with the supposition that the high inclination KBOs are of fundamentally different origin than the low inclination KBOs.

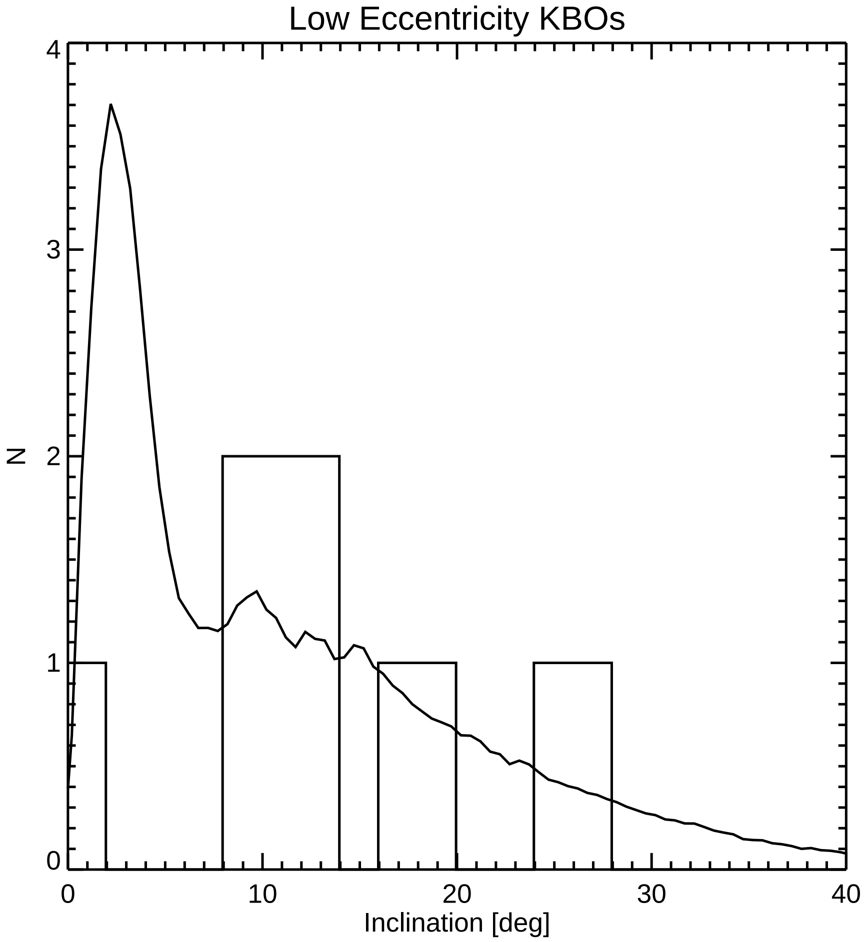

Figure 3. Illustrated are inclinations of detected KBOs with low eccentricities ($e < 0.2$, histogram) and a simulation of expected inclinations assuming the Brown (2001a) inclination distribution for the Classical KBOs (black line) given the sky area coverage of our survey. Note that only 1 low inclination ($i < 7$ degrees) KBO was found where 7.9 are expected, an effect that is significant at the 3.5σ level. The three small peaks in the model between 10 and 18 degrees are due to sky coverage effects.

7. Future Work

The current work is a preliminary analysis of the recently completed Caltech Wide Area Survey. More analysis will be done before final publication of this work: (1) recovery of the 9 KBOs which have single opposition orbits (all of which currently have 30 day orbits or longer); (2) a more complete discussion of the resonance occupations of the observed KBOs; (3) an analysis of the longitudinal distribution of the KBOs; (4) a more thorough simulation of the efficiency of the discovery algorithm for KBOs; and (5) a photometric calibration of the imaged fields as a function of seeing, airmass and background sky brightness levels.

This survey will be extended with an upgraded camera beginning in the fall of 2003. The new camera will consist of 112 CCDs with 600 x 2400 13 μm pixels, yielding ~ 10 square degrees per exposure, a factor 3 larger than the camera used in this work. We will also consider observations closer to the galactic plane which can be executed using Fourier PSF matching and image differencing techniques. Our goal is to find all the bright KBOs available in the sky. Completeness calculations (Figure 2) show that there are roughly 105 bright KBOs over the whole sky, 28 of which we have already found. To date, we are 27% complete in terms of KBO detections although we are only 12% complete in terms of sky fraction, because the KBOs are preferentially near the invariable plane, which we have already observed. The vast majority (roughly 85%) of these bright KBOs should be detectable at less than 2 airmasses from Palomar during some part of the year. Thus, we expect to find about 60 more KBOs over the next year and a half. We have detected 3 very large (diameter $D \gtrsim 1000$ km) KBOs in our survey: (50000) Quaoar (D = 1260 km, Brown and Trujillo, 2003), (28978) Ixion (D = 1055 km, Altenhoff and Bertoldi, 2002) and 2002 AW_{197} (D = 890 km, Margot et al., 2002). Since we are 27% complete in KBO number, we expect to find ~ 10 very large $D > 1000$ km KBOs in total. To date, our bright KBOs follow the typical KBO size distribution ($q = 4$, Trujillo et al., 2001a) such that for every 16 KBOs found of a given diameter D, 1 should have diameter $2D$. Thus, of these 10 very large ($D > 1000$ km KBOs), ~ 1 should have a diameter approaching that of Pluto, with $D \sim 2000$ km. Since these estimates are based on very low number of found objects, actual results could easily differ by a factor of 3 from these predictions purely due to Poisson detection statistics.

8. Summary

We summarize the preliminary findings of the Caltech Wide Area Survey as follows:

(1) We have surveyed 5108 square degrees of sky to limiting red magnitude of $m_R = 20.7$. This represents 12% of the sky, but 27% of the KBOs, since KBOs are preferentially located near the invarible plane, as are our observations. We have detected 28 KBOs and 4 Centaurs, 19 of which were first discovered in our survey. Six of the 10 intrisically brightest KBOs were first discovered in our survey.

(2) Before the current survey, only $\sim 40\%$ of the invariable plane had been surveyed for bright KBOs, with discoveries reported by a variety of different survey sources. Thus, this survey represents the first $> 50\%$ invariable plane coverage KBO-sensitive survey since Tombaugh (1961).

(3) We have found no very large, very distant objects, although we are sensitive to bodies as distant as 100 AU. A 2500 km diameter body with 10% albedo at 100 AU would be detectable near our magnitude limit, as would a 4000 km diameter body with 4% albedo at 100 AU.

(4) Only 3 of the 28 detected KBOs have low inclinations ($i < 7$ degrees). This deficiency of low inclination bright KBOs, compared to the number expected from observations of the faint KBOs (Brown, 2001) is statistically significant (3.1σ). Considering only the 11 KBOs in near-circular ($e < 0.2$) orbits (i.e. the Classical KBOs), for which there are fewer systematic biases, yields similar results (3.5σ significance) given the Classical KBO inclination distribution of Brown (2001).

(5) With the upcoming second phase of the survey, using a 10 square degree camera, we will survey the entire sky for bright KBOs. We expect to find ~ 7 more KBOs that are 1000 km in diameter and ~ 1 KBO that is 2000 km in diameter, as well as $\sim 85\%$ of the remaining ~ 80 KBOs that are brighter than $m_R < 20.7$.

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