

Accurate absolute magnitudes for Kuiper belt objects and Centaurs

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Abstract

Accurate absolute optical magnitude values (H_V and H_R) for Kuiper belt objects (KBOs) and Centaurs are becoming increasingly important as observations in other wavelengths, particularly SIRTf thermal infrared measurements, become available for large samples of objects. We present accurate H_V and H_R values for 90 KBOs and Centaurs, based on our published optical photometry. We find that our H_V values are in good agreement with those available from the European photometric survey of minor bodies in the outer Solar System. Comparison with H_V values from the JPL Horizons database and the Minor Planet Center database shows that these sources are systematically brighter than ours by about 0.3 mag.

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1. Introduction

There are now about 1000 cataloged minor outer Solar System bodies, with about 500 having been observed at more than one opposition. For the vast majority, nothing is known of their intrinsic physical properties. In 1995, we began a large and systematic program to obtain optical (BVR) colors and magnitudes for a sample of these objects. Our program has been aimed at obtaining accurate optical colors and searching for correlations of color with various orbital parameters (see, e.g., Tegler et al., 2003). In addition to optical colors, we have also obtained some information on light curves of individual objects (Romanishin and Tegler, 1999; Romanishin et al., 2001).

For all objects in our sample, we have measured accurate V band magnitudes and V–R colors from at least one epoch. These data can, of course, be used to derive an estimate of the absolute visual magnitudes (H_V) of the objects. The H_V

magnitude is one of the most basic observable quantities of a minor Solar System body.

Several groups are using infrared measurements of KBOs and Centaurs, these being obtained with SIRTf, to measure the thermal emission properties of a subset of the population. These observations should yield important new information on the sizes of these objects. Comparison of the infrared and optical fluxes can yield the optical albedo.

To obtain an accurate optical albedo from comparison of optical and infrared observations, an accurate optical absolute magnitude or flux value is required. Because of the increasing importance of accurate values of optical parameters, we present here such information for the objects for which we have published optical photometry. We also compare our derived H_V values with those available from several large databases of properties of minor Solar System bodies.

2. Absolute magnitudes

We use the H, G formalism (Bowell et al., 1989) to derive the absolute visual magnitude (H_V), which is the magnitude that would be observed in the V passband by an observer at

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a distance of 1 AU from an object that is 1 AU from the Sun, at a phase angle of 0° .

We derive H_V from the observed V magnitude, distances, and phase angle:

$$H_V = V - 5 \log(r\Delta) + 2.5 \log[(1 - G)\Phi_1(\alpha) + G\Phi_2(\alpha)], \quad (1)$$

where V is the measured magnitude of the object in V band, r is the heliocentric distance (in AU) at the time of observation, Δ is the geocentric distance (in AU) at the time of observation, α is the phase angle (Sun–target–observer angle) at time of observation and

$$\Phi_i(\alpha) = \exp\left[-A_i \left(\tan \frac{1}{2}\alpha\right)^{B_i}\right], \quad (2)$$

where $i = 1, 2$, $A_1 = 3.33$, $B_1 = 0.63$, $A_2 = 1.87$, $B_2 = 1.22$.

We assume a G value of 0.15, which is the value most often adopted for this class of objects. Using observations over a range of α , [Buie and Bus \(1992\)](#) derive $G = 0.16$ for (5145) Pholus. Unfortunately, almost all of our observations of individual objects are made at a single epoch, so we cannot constrain G values.

Observed V magnitudes and observation dates were taken from our published papers ([Tegler and Romanishin, 1998, 2000, 2003](#); [Romanishin and Tegler, 1999](#); [Tegler et al., 2003](#)). Distances (r and Δ) were derived from the JPL Horizons online database ([Giorgini et al., 1996](#); http://ssd.jpl.nasa.gov/horizons_doc.html). For objects with H_V listed in [Romanishin and Tegler \(1999\)](#), new H_V values were derived for consistency and also to use distances from orbits with any improvements made since that paper. The new H_V values for these objects agree to within 0.01 mag with our previously published values.

Our derived H_V values are listed in [Table 1](#). For the majority of the objects, we have observations taken only during one night, or perhaps a few nights during one observing run. The information in this table is available online at <http://observatory.ou.edu/kbos.html>. Our color survey is continuing, and we will update the online information as we derive final magnitudes and colors for newly observed objects. For convenience we also list H_R values in [Table 1](#), derived from the H_V values and published V–R colors.

3. Comparison with other sources

Another large photometric survey of minor outer Solar System bodies is available from a collaboration of a number of observers using European Southern Observatory (ESO) telescopes. They present H_V values ([Doressoundiram et al., 2002](#)) or H_R values ([Peixinho et al., 2004](#)), which we converted to H_V values by adding their V–R color for each object. Ignoring a few objects in these lists with large (greater than 0.1) errors in H_V , we find 30 objects in common with

Table 1
 H_V and H_R magnitudes

Number	Name	Prov.	Des.	H_V	H_R
		2003	CO1	9.29	8.80
		2001	XZ255	11.24	10.49
		2001	SQ73	9.24	8.78
		2001	QX322	6.70	6.10
		2001	KG77	8.62	8.18
		2001	KC77	7.23	6.67
		2001	FM194	7.91	7.47
		2000	KK4	6.46	5.82
		2000	FZ53	11.72	11.16
		2000	FS53	7.88	7.17
		2000	CR105	6.60	6.08
		2000	CQ105	6.29	5.85
		2000	CF105	7.59	6.89
		1999	TR11	8.63	7.88
		1999	HV11	7.47	6.88
		1999	HS11	6.88	6.16
		1999	CF119	7.42	6.81
		1998	WX24	6.79	6.09
		1998	WV24	7.43	6.93
		1998	KS65	7.63	6.99
		1998	FS144	7.17	6.60
		1997	SZ10	8.75	8.10
		1997	QH4	7.44	6.77
		1997	CV29	7.71	7.06
		1997	CT29	7.19	6.44
		1996	TS66	6.50	5.74
		1996	TQ66	7.69	6.99
		1996	TK66	6.75	6.12
		1996	RR20	7.20	6.49
		1996	RQ20	7.00	6.56
		1995	HM5	8.29	7.88
		1994	TA	12.05	11.37
		1993	RO	8.92	8.41
		1993	FW	7.09	6.46
95626		2002	GZ32	7.24	6.82
88269		2001	KF77	10.52	9.79
87269		2000	OO67	9.82	9.10
86047		1999	OY3	6.46	6.09
85633		1998	KR65	7.10	6.43
83982		2002	GO9	9.17	8.41
82158		2001	FP185	6.38	5.80
82155		2001	FZ173	6.23	5.68
82075		2000	YW134	4.74	4.19
79360		1997	CS29	5.52	4.91
73480		2002	PN34	8.66	8.14
65489		2003	FX128	6.60	6.04
63252		2001	BL41	11.46	10.95
60621		2000	FE8	6.83	6.35
60608		2000	EE173	8.49	8.00
60458		2000	CM114	7.36	6.86
55636		2002	TX300	3.47	3.11
54598	Bienor	2000	QC243	7.69	7.19
52975	Cyllarus	1998	TF35	8.99	8.24
52872	Okyrhoe	1998	SG35	11.23	10.75
52747		1998	HM151	8.02	7.40
50000	Quaoar	2002	LM60	2.74	2.10
49036	Pelion	1998	QM107	10.54	10.02
47171		1999	TC36	5.33	4.64
44594		1999	OX3	7.85	7.16
42355		2002	CR46	7.65	7.13

(continued on next page)

Table 1 (continued)

Number	Name	Prov.	Des.	H_V	H_R
38628	Huya	2000	EB173	5.03	4.43
38084		1999	HB12	7.04	6.47
33001		1997	CU29	6.68	6.02
32929		1995	QY9	8.06	7.59
32532	Thereus	2001	PT13	9.32	8.85
31824	Elatus	1999	UG5	10.49	9.82
29981		1999	TD10	9.06	8.59
26375		1999	DE9	5.20	4.62
26308		1998	SM165	6.13	5.38
24978		1998	HJ151	7.67	6.96
24835		1995	SM55	4.54	4.15
20108		1995	QZ9	8.58	8.06
20000	Varuna	2000	WR106	3.92	3.36
19521	Chaos	1998	WH24	4.94	4.32
19308		1996	TO66	4.76	4.38
19299		1996	SZ4	8.44	7.92
19255		1994	VK8	7.56	6.89
16684		1994	JQ1	7.14	6.51
15875		1996	TP66	7.39	6.71
15874		1996	TL66	5.39	5.04
15820		1994	TB	8.07	7.39
15810		1994	JR1	7.35	6.99
15789		1993	SC	7.26	6.56
15788		1993	SB	8.15	7.68
15760		1992	QB1	7.61	6.83
10370	Hylonome	1995	DW2	9.53	9.10
10199	Chariklo	1997	CU26	6.76	6.28
8405	Asbolus	1995	GO	9.18	8.71
7066	Nessus	1993	HA2	9.52	8.75
5145	Pholus	1992	AD	7.63	6.85

our sample presented in Table 1. The mean difference between the ESO collaboration H_V values and ours for these 30 objects is -0.01 ($s = 0.13$) mag. A histogram of the differences is presented in Fig. 1. Twenty two out of 30 differences are 0.1 mag or less in absolute value, while the remaining differences trail out a few tenths of a magnitude to both positive and negative sense. This histogram shows that there is reasonable overall agreement between our H_V values and those of the ESO collaboration. Those objects with differences greater than 0.1 mag may be objects that have lightcurves with amplitude of greater than 0.1 mag that were observed at different parts of their lightcurve by different observers.

The combination of our survey and the ESO survey contains photometry for about 160 unique objects, approximately 30% of the currently known population with multiple opposition orbits. Several online databases contain orbital and physical properties of much larger samples of objects: the JPL Horizons system, referenced previously and the MPC (Minor Planet Center) databases (<http://cfa-www.harvard.edu/iau/lists/MPLists.html>). These sites list absolute magnitude values derived mostly using photometry derived from discovery or astrometry observations.

Because these sites give at least some information for every known object, they are important, particularly for statistical studies. To check the accuracy of the absolute magnitudes listed on these sites, we computed the magnitude

differences between the H_V values listed in Table 1 and those obtained from the other databases. The distribution of magnitude differences are shown in Fig. 1. The average difference between JPL and ours (H_V (JPL) $- H_V$ (ours)) is -0.34 ($s = 0.33$). The average difference between MPC and ours (H_V (MPC) $- H_V$ (ours)) is -0.29 ($s = 0.34$). Thus, these H_V magnitudes are significantly brighter than ours.

To find the origin of these systematic offsets in H_V values, one would have to carefully review the input magnitudes into the databases for each object. The vast majority of observed magnitudes for minor bodies in the outer Solar System in these databases presumably come from observations primarily taken for either discovery or astrometry of these objects. Such observations are often taken using non-standard filters (see, e.g., Millis et al., 2002), photometric calibrations are not always made, and less than photometric observing conditions can be utilized. We stress that the magnitudes in the MPC and Horizons databases are from a number of different sources, and that some of these undoubtedly have better magnitude values than others.

For minor Solar System bodies, the combination of optical flux, related to the amount of sunlight reflected from the body, and thermal infrared flux, from the thermal emission of the body, can, of course, yield the size and optical albedo of the body (see, e.g., Harris and Lagerros, 2002, and references therein). How would a mis-estimate of the optical magnitude and hence optical flux affect the results of this technique? Detailed application of this technique requires a thermal model of the body, so a precise answer of this question is not simple. However, because the albedo (A) of these outer Solar System bodies is assumed to be low, it is easy to see the approximate effects. As the infrared emission is related to the amount of sunlight absorbed by the body, which is goes as $1 - A$, even a significant fractional change in A (if A is small compared to 1) will result in only small fractional change in $1 - A$. Thus, a given fractional overestimate in the optical flux will primarily result in the same fractional overestimate in the derived optical albedo.

4. Conclusions

We have presented accurate H_V values for a sizable sample of outer Solar System objects. Comparison of our values with those of the European collaboration photometric survey shows good agreement. Comparison of these values with those of several databases of general object properties shows significant systematic differences, with our values predominantly fainter.

Obviously, the ideal situation to compare optical and infrared photometry would be to have truly simultaneous observations at all wavelengths. Such coordination is usually not possible. Our observed magnitudes are carefully calibrated in standard filters. If it is not possible to obtain new calibrated optical photometry, values from our survey, or derived from magnitudes given by the European survey, should

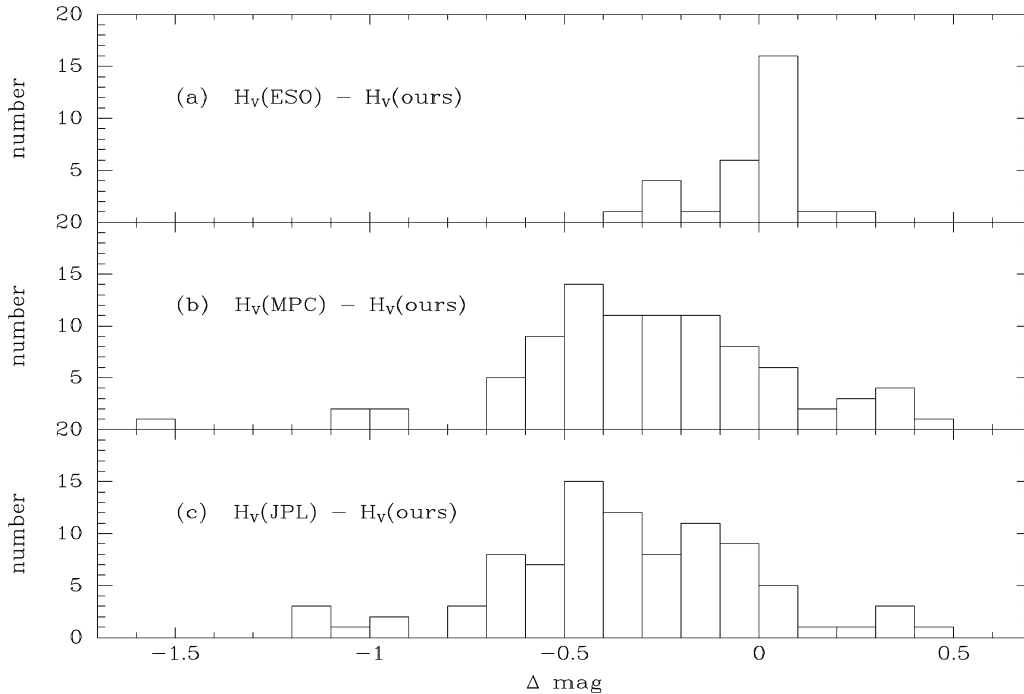


Fig. 1. (a) Histogram of differences between H_V magnitudes from the ESO collaboration and those reported here for 30 objects. (b) Histogram of differences between H_V magnitudes from the JPL Horizons site and those reported here for 90 objects. (c) Histogram of differences between H_V magnitudes from the MPC site and those reported here for 90 objects.

be used if available for the objects of interest. If absolute magnitudes from other databases must be used, the systematic offsets reported here can be used to obtain more accurate H_V values. However, due to the scatter and heterogeneous sources of the magnitudes in these databases, the use of these magnitudes for purposes such as measuring optical albedos is strongly discouraged.

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