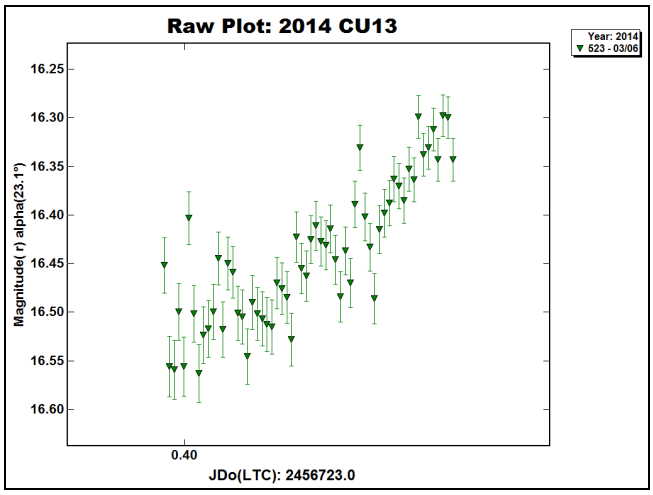

Figure 15. The raw lightcurve of the Apollo-PHA object 2014 CU13. The data are insufficient to constrain a rotational period.

TARGET ASTEROIDS! OBSERVING TARGETS FOR OCTOBER THROUGH DECEMBER 2014

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Asteroids to be observed by the *Target Asteroids!* program during the period of October to December 2014 are presented. In addition to asteroids on the original *Target Asteroids!* list of easily accessible spacecraft targets, an effort has been made to identify other asteroids that are 1) brighter and easier to observe for small telescope users and 2) analogous to (101955) Bennu, the target asteroid of the OSIRIS-REx sample return mission.

Introduction

The *Target Asteroids!* program strives to engage telescope users of all skill levels and telescope apertures to observe asteroids that are viable targets for robotic sample return. The program also focuses on the study of asteroids that are analogous to (101955) Bennu, the target asteroid of the NASA OSIRIS-REx sample return mission. Most target asteroids are near-Earth asteroids (NEA) though observations of relevant Main Belt asteroids may also be requested.

Even though many of the observable objects in this program are faint, acquiring a large number of low S/N observations allows many important parameters to be determined. For example, an asteroid's phase function can be measured by obtaining photometry taken over a wide range of phase angles. The albedo can be constrained from the phase angle observations, as there is a direct correlation between phase function and albedo (Belskaya and Shevchenko (2010). The absolute magnitude can be estimated by extrapolating the phase function to a phase angle of 0°. By combining the albedo and absolute magnitude, the size of the object can be estimated.

An overview of the *Target Asteroids!* program can be found at Hergenrother and Hill (2013).

Quarterly Targets

Target Asteroids! objects brighter than V = 20.0 are presented in detail. A short summary of our knowledge of each asteroid and 10-day (shorter intervals for objects that warrant it) ephemerides are presented. The ephemerides include rough RA and Dec positions, distance from the Sun in AU (r), distance from Earth in AU (Δ), V magnitude, phase angle in degrees (PH) and elongation from the Sun in degrees (Elong).

We ask observers with access to large telescopes to attempt observations of asteroids that are between V magnitude ~20.0 and ~22.0 during the quarter (contained in the table below).

Asteroid Number	Name	Peak V Mag	Time of Peak Brightness
(68278)	2001 FC7	21.9	late Dec
(89136)	2001 US16	21.1	late Dec
(141018)	2001 WC47	19.8	early Oct
(163000)	2001 SW169	21.8	late Dec
(173664)	2001 JU2	21.7	mid Oct
(190491)	2000 FJ10	20.7	early Oct/late Dec
	1996 FO3	19.9	early Nov
	2002 TD60	20.9	late Dec
	2006 YF	22.0	early Nov
	2008 DG5	21.4	late Dec
	2014 MK55	20.2	late Dec

The V < 20 selected targets are split up into four sections: 1) Carbonaceous *Target Asteroids!* List objects, 2) *Target Asteroids!* List objects of unknown type, 3) Non-carbonaceous *Target Asteroids!* List objects, and 4) Other asteroids analogous to the OSIRIS-REx target Bennu or provide an opportunity to fill some of the gaps in our knowledge of Bennu (examples include very low and high phase angle observations, phase functions in different filters and color changes with phase angle).

The ephemerides listed below are just for planning purposes. In order to produce ephemerides for your observing location, date and time, please use the Minor Planet Center's Minor Planet and Comet Ephemeris Service:

http://www.minorplanetcenter.net/iau/MPEph/MPEph.html

or the *Target Asteroids!* specific site created by Tomas Vorobjov and Sergio Foglia of the International Astronomical Search Collaboration (IASC) at

http://iasc.scibuff.com/osiris-rex.php .

Carbonaceous Target Asteroids! List objects

None this quarter.

Target Asteroids! List objects of unknown type

(136635) 1994 VA1 (a=1.57 AU, e=0.17, i=7.6°, H = 18.9)
Little is known about this object's physical characteristics. It reaches a peak brightness of V ~ 18.5 in late January 2015. Unfortunately, its phase angle does not cover a very large range. Hopefully large aperture telescopes can obtain lightcurve and color photometry.

DATE	RA	DEC	Δ	r	V	PH	Elong
10/21	07 15.3	+18 41	1.14	1.63	21.7	37	100
10/31	07 31.9	+16 54	1.03	1.61	21.5	37	105
11/10	07 46.2	+14 51	0.93	1.59	21.2	36	111
11/20	07 57.9	+12 35	0.83	1.56	20.9	34	118
11/30	08 06.2	+10 07	0.74	1.54	20.5	32	125
12/10	08 10.6	+07 31	0.66	1.51	20.1	28	133
12/20	08 10.2	+04 53	0.59	1.49	19.7	23	142
12/30	08 04.8	+02 24	0.53	1.46	19.3	20	150

(303450) 2005 BY2 (a=1.27 AU, e=0.33, i=7.3°, H = 20.4)
2005 BY2 is similar to 1994 VA1. We have no information on its physical characteristics, it will peak at V ~ 18.5 (in early January 2015) and it covers a small range of phase angles when bright enough for observation. Again, it is hoped that large aperture facilities will be able to obtain lightcurve and color photometry.

DATE	RA	DEC	Δ	r	V	PH	Elong
11/10	07 07.1	+21 26	0.68	1.47	21.8	35	122
11/20	07 16.9	+22 34	0.58	1.43	21.3	32	130
11/30	07 22.9	+24 23	0.48	1.39	20.8	28	139
12/10	07 23.8	+27 10	0.40	1.34	20.1	23	149
12/20	07 17.4	+31 19	0.32	1.29	19.4	16	159
12/30	07 00.2	+37 06	0.27	1.24	18.7	12	165

Non-carbonaceous Target Asteroids! List objects

(137799) 1999 YB (a=1.32 AU, e=0.07, i=6.8°, H = 18.5)
This ~0.6 km near-Earth asteroid has a low relative delta-V. Spectroscopy has identified it as an Sq-type object. No lightcurve photometry has been published for it. Its phase angle ranges from 7° in early October to 44° at the end of the year.

DATE	RA	DEC	Δ	r	V	PH	Elong
10/01	00 49.8	-04 43	0.40	1.40	17.8	7	171
10/11	00 29.9	-04 11	0.42	1.41	18.0	10	166
10/21	00 13.4	-03 13	0.45	1.41	18.4	18	154
10/31	00 02.8	-01 52	0.49	1.41	18.9	25	143
11/10	23 58.7	-00 13	0.55	1.42	19.3	31	118
11/20	00 00.4	+01 38	0.61	1.42	19.6	36	125
11/30	00 07.0	+03 41	0.68	1.42	20.0	39	134
12/10	00 17.5	+05 51	0.76	1.42	20.3	41	146
12/20	00 31.2	+08 07	0.83	1.42	20.5	43	158
12/30	00 47.4	+10 26	0.91	1.42	20.7	44	169

(138911) 2001 AE2 (a=1.35 AU, e=0.08, i=1.7°, H = 19.1)
2001 AE2 is a ~0.35 km diameter object with a high albedo of 0.34. There is some uncertainty in its taxonomy. Both an S-type and T-type taxonomy has been found for it. The high albedo suggests the S-type taxonomy may be closer to the truth. AE2 reaches a minimum phase angle of 3° and magnitude of V ~ 18.6 in mid-November.

DATE	RA	DEC	Δ	r	V	PH	Elong
10/01	04 07.0	+18 33	0.64	1.46	20.4	35	124
10/11	04 09.4	+18 07	0.58	1.46	20.0	30	134
10/21	04 05.6	+17 22	0.53	1.46	19.6	23	144
10/31	03 55.6	+16 19	0.49	1.46	19.2	16	157
11/10	03 40.3	+15 03	0.47	1.46	18.8	7	170
11/20	03 22.6	+13 43	0.47	1.45	18.7	5	173
11/30	03 06.2	+12 35	0.48	1.45	19.1	14	160
12/10	02 54.3	+11 55	0.51	1.44	19.5	22	147
12/20	02 48.4	+11 47	0.56	1.43	19.9	29	135
12/30	02 48.6	+12 10	0.61	1.43	20.2	34	125

Other Asteroids Analogous to the OSIRIS-REx Target (101955) Bennu

(112) Iphigenia (a=2.43 AU, e=0.13, i=2.6°, H = 9.8)
Iphigenia is a ~70-80 km carbonaceous asteroid located in the inner Main Belt. Its orbit is similar to those of the Polana and Eulalia carbonaceous families and Iphigenia may be related to these families and to the OSIRIS-REx target asteroid (101955) Bennu (Walsh et al. 2013).

Quite a bit is known about Iphigenia. It has a dark 0.039 albedo, a hydrated Ch taxonomy, and a slow rotation period of ~31.4 h. It reached a minimum phase angle of 0.2° on August 11.

DATE	RA	DEC	Δ	r	V	PH	Elong
10/01	20 59.4	-16 14	1.38	2.12	13.3	23	125
10/11	21 03.8	-15 45	1.48	2.12	13.5	25	116
10/21	21 11.1	-15 04	1.59	2.12	13.7	27	108
10/31	21 20.7	-14 14	1.70	2.12	13.8	27	101
11/10	21 32.4	-13 12	1.81	2.12	14.0	28	94
11/20	21 45.7	-12 01	1.93	2.13	14.1	28	87
11/30	22 00.2	-10 40	2.05	2.13	14.3	27	81
12/10	22 15.8	-09 11	2.17	2.13	14.4	27	75
12/20	22 32.1	-07 34	2.28	2.14	14.4	26	69
12/30	22 49.1	-05 49	2.40	2.14	14.5	24	63

(635) Vundtia (a=3.14 AU, e=0.08, i=11.0°, H = 9.0)
As with most large Main Belt asteroids, much is known about Vundtia such as its taxonomy (either a C- or B-type), low albedo (0.045) and diameter (~98 km). It has a long rotation period that is estimated to be around 11.8 h in length with a low 0.15-0.30 magnitude amplitude. Vundtia can be observed from an extreme minimum phase angle of 0.04° on September 26 UT. A peak brightness of V = 13.0 is also reached on that date.

DATE	RA	DEC	Δ	r	V	PH	Elong
10/01	00 06.2	+00 29	1.96	2.96	13.1	2	174
10/11	23 59.9	-00 48	1.99	2.95	13.3	6	162
10/21	23 54.7	-01 56	2.04	2.95	13.5	10	151
10/31	23 51.3	-02 50	2.12	2.94	13.7	13	140
11/10	23 49.9	-03 27	2.22	2.94	13.9	15	129
11/20	23 50.6	-03 47	2.33	2.94	14.1	17	119
11/30	23 53.3	-03 50	2.45	2.93	14.2	19	109
12/10	23 58.1	-03 37	2.58	2.93	14.4	19	101
12/20	00 04.6	-03 11	2.72	2.93	14.5	20	92
12/30	00 12.6	-02 33	2.86	2.92	14.6	20	84

(1862) Hathor (a=0.84 AU, e=0.45, i=5.9°, H = 20.0)
Hathor is an Aten near-Earth asteroid with an SQ-type taxonomy. It has a very high albedo of 0.60 indicating a 0.3-km diameter. The high albedo also calls into the question whether Hathor is actually an SQ-type asteroid.

On October 22 UT, Hathor passes within 0.05 AU of Earth. Observability begins in mid-October when Hathor can be seen at phase angles larger than 100°. Peak brightness is reached on October 27/28 at V ~ 15.0. Minimum phase angle occurs on October 31 at 7°. Radar observations are planned for this apparition. This is one of the few asteroids for which the Yarkovsky Effect has been measured (Farnocchia et al. (2013).

Color and lightcurve photometry are requested in addition to phase function observations.

DATE	RA	DEC	Δ	r	V	PH	Elong
10/11	10 08.8	+23 09	0.09	0.95	19.7	124	52
10/16	08 53.0	+26 56	0.06	0.98	17.7	102	74
10/21	06 25.8	+26 43	0.05	1.01	15.8	66	112
10/26	03 49.9	+15 46	0.06	1.05	15.0	25	153
10/31	02 28.2	+06 15	0.08	1.07	15.2	7	172
11/05	01 49.3	+01 18	0.11	1.10	16.3	17	161
11/10	01 28.8	-01 13	0.15	1.12	17.2	25	151
11/15	01 17.3	-02 33	0.18	1.14	17.9	31	143
11/20	01 11.1	-03 10	0.22	1.16	18.5	36	137
11/25	01 08.1	-03 22	0.26	1.18	19.0	39	131
11/30	01 07.5	-03 17	0.30	1.19	19.4	42	126
12/05	01 08.5	-03 00	0.34	1.20	19.8	44	122

(3200) Phaethon (a=1.27 AU, e=0.89, i=22.2°, H = 14.6)
Phaethon is well known as the parent object of the Geminid meteor shower. Whether the shower was produced by cometary activity or a series of splitting events, the Geminids are now one of the strongest annual showers. Recently Phaethon has been observed to display comet-like activity around perihelion (Jewitt et al. 2013, Li and Jewitt 2013). It is a B-type asteroid similar to Bennu, the OSIRIS-REx target. Though carbonaceous, it is not as dark as many other carbonaceous asteroids (albedo 0.11). A rotation period of 3.60 h and amplitude of up to 0.34 magnitudes have been measured for this 5 km near-Earth asteroid.

Phaethon peaks in brightness at V ~ 16.1 in early December. Its phase angle ranges from a minimum of 9° in late November to over 100° in early March 2015.

DATE	RA	DEC	Δ	r	V	PH	Elong
10/01	05 37.6	+36 32	1.75	2.18	18.7	27	102
10/11	05 37.8	+37 18	1.56	2.14	18.4	26	111
10/21	05 32.9	+38 08	1.38	2.08	18.0	24	122
10/31	05 20.9	+38 56	1.21	2.02	17.6	21	133
11/10	04 59.9	+39 28	1.05	1.95	17.1	17	146
11/20	04 28.3	+39 15	0.92	1.88	16.5	12	158
11/30	03 47.4	+37 36	0.83	1.80	16.1	10	162
12/10	03 03.1	+34 06	0.78	1.71	16.1	16	151
12/20	02 23.5	+29 07	0.76	1.61	16.2	26	134
12/30	01 53.3	+23 42	0.78	1.50	16.4	36	116

(68267) 2001 EA16 (a=1.51 AU, e=0.43, i=38.8°, H = 16.8)
One of the brighter NEAs of the quarter, 2001 EA16 peaks at V ~ 15.7 in mid-October. Surprisingly for such a large, bright NEA, little has been published on its characteristics. Photometry over a range of phase angles from 129° to 42° is possible this quarter. Lightcurve and color photometry are also requested.

DATE	RA	DEC	Δ	r	V	PH	Elong
10/01	14 05.2	-43 20	0.13	0.92	17.7	129	46
10/11	17 23.3	+15 56	0.11	0.96	15.8	106	68
10/21	19 01.4	+41 59	0.21	1.02	16.2	78	90
10/31	19 47.3	+48 59	0.34	1.08	17.0	67	95
11/10	20 17.3	+51 13	0.46	1.14	17.5	60	97
11/20	20 42.9	+52 50	0.58	1.21	18.0	54	97
11/30	21 08.2	+54 04	0.69	1.27	18.4	50	97
12/10	21 34.6	+55 12	0.80	1.34	18.7	47	97
12/20	22 03.1	+56 19	0.91	1.40	19.0	44	96
12/30	22 34.1	+57 26	1.01	1.47	19.3	42	95

(85713) 1998 SS49 (a=1.92 AU, e=0.64, i=10.8°, H = 15.6)
No taxonomy has been determined for 1998 SS49. NEOWISE found an albedo of 0.076, which is consistent with a carbonaceous nature. The low albedo also suggests that it is a relatively large object with a diameter on the order of 3.5 km. Due to its bright H value, it is 17th magnitude or brighter for the entire quarter. Phase angle observations over a range from 36° to 113° are possible. Peak brightness is reached in early/mid-November at V ~ 14.6. Lightcurve and color photometry are requested in addition to phase function photometry.

DATE	RA	DEC	Δ	r	V	PH	Elong
10/01	04 28.2	+18 06	0.72	1.49	17.2	36	119
10/11	04 52.1	+20 32	0.57	1.39	16.6	37	123
10/21	05 24.7	+24 03	0.43	1.29	15.9	39	125
10/31	06 17.8	+29 23	0.31	1.19	15.1	44	123
11/10	08 04.7	+35 57	0.22	1.09	14.6	58	111
11/20	11 07.7	+33 12	0.19	0.99	15.0	85	84
11/30	13 22.8	+18 35	0.24	0.89	16.2	107	60
12/10	14 29.2	+07 07	0.34	0.80	17.1	113	49
12/20	15 09.7	-00 39	0.46	0.74	17.3	109	45
12/30	15 42.5	-06 39	0.59	0.70	17.3	99	45

(137032) 1998 UO1 (a=1.60 AU, e=0.76, i=25.5°, H = 16.6)
1998 UO1 is a ~1.1 km Sq-type NEA with an albedo of ~0.18. No lightcurve information has been published. During the October-December quarter, its phase angle ranges from a high of 126° in

early October to 32° in late December. Peak brightness occurs at V ~ 16.5 in mid-October.

DATE	RA	DEC	Δ	r	V	PH	Elong
10/01	14 52.2	-22 36	0.30	0.80	18.8	126	40
10/11	17 56.2	-14 04	0.24	0.95	16.8	94	72
10/21	20 14.5	-00 35	0.34	1.09	16.7	64	98
10/31	21 21.2	+06 14	0.50	1.23	17.4	51	106
11/10	21 59.1	+09 40	0.68	1.35	18.1	45	107
11/20	22 25.5	+11 48	0.87	1.47	18.7	41	104
11/30	22 46.8	+13 22	1.07	1.58	19.3	38	100
12/10	23 05.4	+14 43	1.27	1.68	19.7	36	96
12/20	23 22.7	+15 58	1.47	1.77	20.1	34	90
12/30	23 39.2	+17 12	1.68	1.86	20.4	32	85

(175114) 2004 QQ (a=2.25 AU, e=0.67, i=5.7°, H = 16.7)

The Apollo near-Earth asteroid 2004 QQ is observable over a wide range of phase angles this quarter. Minimum phase is reached on November 28 at 8°. On October 1st, its phase angle is 104° though it is possible even higher phase angles can be observed during the preceding month (~120-130°). QQ is at maximum brightness for much of late-October/early November at V ~ 16.2. Little is known about this object so photometry of all types is encouraged.

DATE	RA	DEC	Δ	r	V	PH	Elong
10/01	09 08.8	+43 33	0.21	0.93	17.0	104	64
10/11	07 40.8	+46 35	0.24	1.02	16.4	78	89
10/21	06 27.8	+45 51	0.27	1.12	16.2	57	110
10/31	05 28.0	+43 02	0.32	1.22	16.2	38	130
11/10	04 41.2	+39 04	0.37	1.32	16.3	23	149
11/20	04 07.6	+34 53	0.45	1.43	16.4	11	164
11/30	03 45.7	+31 09	0.55	1.53	16.9	8	167
12/10	03 33.3	+28 13	0.67	1.62	17.6	13	158
12/20	03 27.9	+26 06	0.80	1.72	18.3	18	148
12/30	03 27.8	+24 39	0.96	1.81	18.9	22	138

(204131) 2003 YL (a=1.15 AU, e=0.63, i=5.7°, H = 19.8)

Physical characteristics of this asteroid are lacking. It brightens to a peak V of ~16.5 in mid-December when it will be as close as 0.07 AU from Earth. Phase angle will range from higher than 130° in early December to 37° at the end of the year.

DATE	RA	DEC	Δ	r	V	PH	Elong
12/05	17 49.9	+00 38	0.14	0.87	23.2	148	28
12/10	18 54.9	+15 14	0.09	0.93	20.0	130	47
12/15	21 55.6	+39 20	0.07	0.99	17.1	88	88
12/20	01 24.1	+40 07	0.10	1.04	16.8	53	122
12/25	02 43.7	+33 40	0.15	1.10	17.5	41	134
12/30	03 17.8	+29 40	0.22	1.15	18.3	37	136

(214088) 2004 JN13 (a=2.87 AU, e=0.70, i=13.3°, H = 15.0)

2004 JN13 will become one of the brightest near-Earth asteroids of the quarter peaking at V ~ 12.7 in late November. The brightness is a combination of its large size (3km diameter) and close approach to Earth (0.14 AU). Past characterization efforts have identified JN13 as an ordinary chondritic Sq-type asteroid with an albedo of 0.25. No lightcurve information has been published for this asteroid.

This quarter its phase angle spans from a maximum of 108° in late October to a minimum of 8° in mid-December. In late October, it is a far southern object around V ~ 16. It races north and becomes visible for most northern observers during the 2nd half of November.

DATE	RA	DEC	Δ	r	V	PH	Elong
10/01	15 42.7	-49 21	0.42	0.89	16.2	94	62
10/11	15 43.4	-56 23	0.34	0.87	16.1	102	59
10/21	15 26.0	-65 18	0.27	0.88	15.9	107	58
10/31	13 47.1	-76 27	0.20	0.92	15.3	106	63
11/10	07 39.4	-72 08	0.15	0.98	14.1	91	80
11/20	05 53.5	-39 48	0.14	1.05	12.9	60	113
11/30	05 21.8	-08 18	0.17	1.13	12.7	29	147
12/10	05 06.2	+09 46	0.25	1.23	13.1	11	167
12/20	04 58.1	+19 12	0.34	1.32	13.9	10	167
12/30	04 55.4	+24 23	0.46	1.42	14.9	16	157

(275976) 2001 XV10 (a=2.21 AU, e=0.58, i=22.3°, H = 16.0)

There are no published physical characteristics for this asteroid. Throughout the October-December quarter, it is reasonably bright at V ~ 16.8 to 17.6. Its phase angle spans from 92° down to 32° during the same period. A minimum phase angle of 24° is reached in early February 2015 when the asteroid will be around V ~ 18.5. Any photometry (color, phase function lightcurve) will greatly increase our knowledge of this Apollo near-Earth asteroid.

DATE	RA	DEC	Δ	r	V	PH	Elong
10/01	08 03.3	+15 28	0.34	0.93	16.8	92	68
10/11	08 37.8	+27 05	0.38	0.96	16.8	85	73
10/21	09 11.8	+35 29	0.44	1.00	16.9	77	78
10/31	09 43.4	+41 39	0.49	1.06	17.0	69	84
11/10	10 10.7	+46 28	0.53	1.13	17.1	61	91
11/20	10 32.2	+50 37	0.58	1.21	17.2	54	97
11/30	10 46.3	+54 31	0.62	1.29	17.3	48	104
12/10	10 51.1	+58 18	0.66	1.37	17.4	42	111
12/20	10 44.2	+61 53	0.70	1.45	17.5	37	118
12/30	10 23.2	+64 52	0.74	1.53	17.6	32	125

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