



Candidate Main-belt Asteroids for Surface Heterogeneity

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Abstract

Large terrestrial bodies in our solar system like the Earth, Mars, Mercury, and the Moon exhibit geologically complex surfaces with compositional heterogeneity. From past studies using large telescopes and spacecraft, it was shown that asteroids with diameters larger than 100 km also show surface heterogeneity at hemispheric scales, while on smaller objects, such features remain to be detected. Here, we investigate candidates for surface heterogeneity in a sample of 130 main-belt asteroids using multiepoch spectroscopic data from the MIT–Hawaii Near-Earth Object Spectroscopic Survey, which has been observing asteroids for about 20 yr using a self-consistent observation technique. Twelve conservative candidates with spectra more than 3σ apart from each other at $2.4\ \mu\text{m}$ and 52 optimistic candidates for surface heterogeneity are detected. These candidates include eight objects already reported as being heterogeneous. Our study suggests that the size boundary between small homogeneous asteroids and larger heterogeneous objects, if it exists, is lower than 100 km. A-type asteroids have a higher proportion of heterogeneous candidates than other asteroids. This may be because olivine, which is the main surface constituent of these objects, reacts more efficiently to space weathering with respect to pyroxene, such that a similar range of surface ages will translate into a wider range of optical-to-near-infrared spectral slopes in the case of A-type bodies.

Unified Astronomy Thesaurus concepts: [Small Solar System bodies \(1469\)](#); [Asteroids \(72\)](#); [Main belt asteroids \(2036\)](#); [Asteroid surfaces \(2209\)](#)

1. Introduction

Seen from space, the Earth exhibits a rich variety of albedos and colors attributed to clouds, oceans, and land. Even when focusing only on the land, there are abundant variations, which can be roughly divided into green areas caused by vegetation; brown, vegetation-free areas; and white regions covered by snow and ice. Albedo and color variations further span across vegetation-free lands due to topography, such as mountain ranges and deserts, and different types of rock, such as sedimentary, igneous (rocks formed during terrestrial differentiation processes), and metamorphic.

It is a well-known fact that the surface of Mars, a terrestrial planet with an atmosphere, also has albedo and color variations caused by a variety of mineral types (e.g., Adams & McCord 1969; Bandfield 2002). Similarly, the Moon, the natural satellite of the Earth, has long been known to exhibit surface albedo and color variations, from lunar highlands to maria. This variability has been attributed due to various types of minerals

(e.g., Smith 1974; Smith & Steele 1976). Mercury, a terrestrial planet without an atmosphere, is also known for albedo and color variations (Denevi et al. 2009). On all these terrestrial bodies, albedo and color variations are attributed to planetary differentiation, which led to the formation of a variety of minerals.

Since asteroids are generally observed as point sources, albedo and color variations on the surface of these objects have mostly been achieved through multiepoch observations, in order to investigate color and polarization changes as these objects rotate and as their latitudinal orientation seen from the Earth changes over time (e.g., Groeneveld & Kuiper 1954; Degewij et al. 1979; McChesney et al. 1985; Broglia & Manara 1994). Compared to spatially resolved observations, detecting surface heterogeneities on point-source objects is challenging, unless large variations in the integrated light curve of the rotating object can be measured. Such large variations can be due to global heterogeneities on the object's surface (e.g., bright front side and dark back side) or high-albedo spots on darker surfaces.

As mentioned before, the surface evolution caused by the differentiation of planets and natural satellites larger than 1500 km in size is well understood, but what about small bodies under 1500 km in size? Identifying and characterizing compositionally heterogeneous small bodies can teach us about the early



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accretion history and subsequent thermal evolution of these bodies. In particular, the level of differentiation in these bodies is directly dependent on their formation time in the early solar system. Indeed, this formation time defined the abundance of short-lived radionuclides that was originally accreted by these bodies, which constituted their main source of internal heat.

In recent years, the technological improvement of space telescopes and large ground-based telescopes, as well as the in situ exploration of asteroids with spacecraft, have enabled disk-resolved observations of asteroids, allowing one to investigate their surface heterogeneity (e.g., Fujiwara et al. 2006; Russell et al. 2015; Vernazza et al. 2021). Main-belt asteroids (MBAs) with diameters greater than 100 km for which spatially disk-resolved observations have been conducted show albedo and color variations at hemispheric scales (1 Ceres: Ciarniello et al. 2017, de Sanctis et al. 2018; 2 Pallas: Schmidt et al. 2009, Marsset et al. 2020; 3 Juno: Baliunas et al. 2003; 4 Vesta: Binzel et al. 1997, De Sanctis et al. 2013; 10 Hygiea: Vernazza et al. 2020; 16 Psyche: Ferrais et al. 2020, Cambioni et al. 2022; 21 Lutetia: Sierks et al. 2011). Some of these objects are known to be at least partially differentiated thanks to spectroscopic observations, gravity measurements, and shape measurements (1 Ceres: Castillo-Rogez et al. 2018, Nathues et al. 2020; 2 Pallas: Schmidt et al. 2009, Marsset et al. 2020; 4 Vesta: Russell et al. 2012; 16 Psyche: Cambioni et al. 2022; 21 Lutetia: Weiss et al. 2012).

On the other hand, spacecraft rendezvous observations of four near-Earth asteroids (NEAs) with diameters significantly below 100 km have revealed surface homogeneity at hemispheric scales (433 Eros: Izenberg et al. 2003; 25143 Itokawa: Saito et al. 2006; 101955 Bennu: Barucci et al. 2020; 162173 Ryugu: Tatsumi et al. 2020). Moreover, flyby observations of four MBAs with diameters smaller than 100 km revealed surface homogeneity across the region of their surface observed by the spacecraft (243 Ida: Belton et al. 1996; 253 Mathilde: Veverka et al. 1999; 951 Gaspra: Veverka et al. 1994; 2867 Steins: Leyrat et al. 2010).

Taken together, these past observations indicate that asteroids larger than 100 km in size tend to be compositionally heterogeneous, while smaller bodies are homogeneous at the hemispheric scale. However, this may simply be due to the current low number of available observations. As of 2024, observations of spatially resolved MBAs are limited to those larger than about 100 km in diameter, which were mostly observed with the SPHERE/ZIMPOL instrument on the 8.2 m Very Large Telescope (e.g., Vernazza et al. 2021). Therefore, it is difficult to investigate whether there is a clear size boundary between homogeneous and heterogeneous asteroidal surfaces as of today and if this limit is composition-dependent. Meanwhile, various theoretical studies have been conducted in the past on the thermal evolution of differentiated bodies that produce heterogeneity in the surface layer of these objects (e.g., McSween et al. 2002). However, it is difficult to determine the size boundary between differentiated and nondifferentiated bodies because it depends on various parameters, such as formation time and initial composition.

In the future, 30–40 m class telescopes, such as the 39.3 m Extremely Large Telescope¹³ (ELT), the 30.0 m Thirty Meter Telescope¹⁴ (TMT), and the 25.4 m Giant Magellan Telescope¹⁵ (GMT), will provide the spatial resolution needed to

resolve asteroids as small as ~ 20 km, thereby enabling characterizing their surfaces and measuring the minimum diameter at which surface heterogeneity can be found. However, observation time on these telescopes will be highly competitive. It is necessary to identify candidates for surface heterogeneity beforehand so as not to conduct a blind search.

The MIT–Hawaii Near-Earth Object Spectroscopic Survey (MITHNEOS) provides an interesting data set to investigate asteroid surface heterogeneity. This survey has been conducted since 2000 September to study NEAs using the SpeX spectrograph (Rayner et al. 2003) on board the Infrared Telescope Facility (IRTF) at the summit of Maunakea, Hawaii (DeMeo & Binzel 2008; DeMeo et al. 2014, 2023; Binzel et al. 2019; Marsset et al. 2022). The survey also includes observations of MBAs, and several studies have been conducted using these data (DeMeo et al. 2009, 2019, 2022; Moskovitz et al. 2010; Vernazza et al. 2012, 2014, 2016, 2020; Polishook et al. 2014; Carry et al. 2015; Marsset et al. 2016, 2019; Leith et al. 2017; Pajuelo et al. 2018; Hasegawa et al. 2021b, 2022a, 2022b; Sergeev et al. 2023; Marsset et al. 2024). The survey data are available online and widely used by non-team members (e.g., Hasegawa et al. 2017, 2021a; Kuroda et al. 2021).

A special feature of MITHNEOS is that the observing methodology has remained essentially unchanged over the past 20 yr. It uses the optimal slit width, slit alignment settings for successful spectral acquisition, optimal air-mass range to acquire the target and solar analogs, and 11 fixed solar analogs. Marsset et al. (2020b) showed that an observational uncertainty of the MITHNEOS for the past 20 yr is $4.2\% \mu\text{m}^{-1}$ on slope measurements over $0.8\text{--}2.4 \mu\text{m}$. That is, if the observation is performed using the same method as MITHNEOS, the spectral slope accuracy of the spectrum obtained is expected to be similar to that of that survey.

As mentioned above, when observing an asteroid as a point source, the longitudinal heterogeneity of the asteroid surface can be detected by measuring the spectral change associated with the object’s rotation. However, the heterogeneity may be difficult to detect depending on the orientation of the rotation vector of the asteroid being observed (if the rotation axis of the asteroid is pole-on during the observation, it is impossible to detect any color variation) and the length of the rotation period (if the exposure time is comparable to the period, it is difficult to detect a color change). If the asteroid surface is heterogeneous in the latitudinal direction, it is difficult to detect it with a one-night observation, as the latitude of the subobserver point remains virtually unchanged. Repeating observations at different asteroid seasons allows detection of surface heterogeneity in the latitudinal direction. A serious problem, however, arises from the accuracy of the spectra due to cross-day observations. Nevertheless, if the observations are made using the same method as the MITHNEOS, the accuracy of the measured spectrum should be similar to that reported by Marsset et al. (2020b), assuming proper centering of the asteroid and standard stars within the spectroscopic slit.

On the other hand, MITHNEOS aims at characterizing as “many” objects as feasible during a given night. Conditions change during every night, and the solar standard stars utilized for any given asteroid reduction may or may not be particularly well matched in time, air mass, seeing, and transparency. These can lead to “minor” fluctuations in the output spectrum, rarely enough for taxonomic misclassification but undoubtedly

¹³ <https://elt.eso.org/>

¹⁴ <https://www.tmt.org/>

¹⁵ <https://giantmagellan.org/>

Table 1
Sub-Earth Point Coordinates of Asteroids during Near-IR Observations Based on the DAMIT Database

No.	Obs. Run ^a	Start Time	End Time	α^a (deg)	P^a (hr)	Pole ₁ ^a		SEP ₁ ^a		Pole ₂ ^a		SEP ₂ ^a		Heterogeneity Candidate ^b
						λ_1 (deg)	ϕ_1 (deg)	λ_1 (deg)	ϕ_1 (deg)	λ_2 (deg)	ϕ_2 (deg)	λ_2 (deg)	ϕ_2 (deg)	
1	sp06	2001-06-22T12:15:16	12:22:40	6.5	9.07417	350	81	223	2					Y
1	sp41 ^c	2005-05-19T07:35:18	12:07:19	5.6	9.07417	350	81	261, 159, 85 ^c	-3					Y
1	dm04	2011-12-01T05:45:59	05:50:45	19.3	9.07417	350	81	353	2					Y
2	sp05	2001-03-29T15:27:52	15:37:12	19.0	7.81322	42	-15	331	52					
2	sp89	2010-03-17T14:24:02	14:28:00	19.1	7.81322	42	-15	48	70					
3	sp13	2002-05-08T05:59:03	06:25:07	22.3	7.20953	105	21	79	-49					Y
3	sp21	2003-03-17T14:12:47	14:23:50	14.3	7.20953	105	21	108	27					Y
3	sp96	2011-01-06T14:18:45	14:22:37	21.2	7.20953	105	21	32	-14					Y
4	sp02	2000-10-09T05:15:41	05:36:50	25.9	5.34212	337	56	112	-20					
4	sp86	2009-11-18T15:48:34	15:54:40	23.5	5.34212	337	56	40	31					
6	sp67	2008-01-15T12:04:26	12:09:15	10.7	7.27447	342	51	22	39					
6	sp68	2008-03-10T06:33:43	06:44:17	13.8	7.27447	342	51	117	31					
7	sp16	2002-08-17T10:47:54	10:57:07	7.3	7.13884	20	9	207	-47					
7	sp28	2004-02-20T13:23:07	13:43:02	9.8	7.13884	20	9	345	67					
10	sp08	2001-08-24T10:34:37	10:49:42	3.2	13.82559	307	-29	63	-44					YY
10	sp28	2004-02-19T05:24:27	05:56:47	13.2	13.82559	307	-29	131	51					YY
10	sp111	2012-08-28T10:00:32	10:02:14	2.8	13.82559	307	-29	155	-51					YY
14	sp18	2002-09-28T10:05:55	10:28:45	6.0	15.02987	91	-15	15	5					Y
14	sp25	2003-10-01T15:21:48	15:29:24	20.9	15.02987	91	-15	331	-78					Y
15	sp16	2002-08-17T11:44:10	11:53:23	14.8	6.08275	356	-70	6	-5					Y
15	sp28	2004-02-19T09:21:54	09:25:26	4.8	6.08275	356	-70	4	7					Y
16	sp02	2000-10-09T13:59:50	14:12:01	20.3	4.19595	36	-10	145	-45					Y
16	sp58	2007-01-21T14:05:51	14:26:30	13.2	4.19595	36	-10	140	42					Y
17	sp07	2001-08-15T14:35:41	14:56:09	22.6	12.26603	236	19	93	71					
17	sp96	2011-01-06T13:56:13	14:14:19	17.7	12.26603	236	19	191	-13					
18	sp06	2001-06-22T07:19:53	07:42:05	20.1	11.57031	12	19	149	56					
18	V06	2011-01-10T15:22:00	15:31:50	20.8	11.57031	12	19	168	67					
19	sp48	2005-11-22T08:32:01	08:34:14	10.3	7.44322	103	60	287	-12					
19	sp49	2006-01-29T05:59:32	06:17:37	27.6	7.44322	103	60	321	-14					
20	sp06	2001-06-22T13:13:00	13:37:26	14.0	8.09902	179	39	70	31	360	40	248	-32	YY
20	sp96	2011-01-06T14:24:47	14:28:40	25.7	8.09902	179	39	198	-50	360	40	16	51	YY
21	sp31	2004-09-22T13:35:39	13:47:26	20.0	8.16827	52	-6	68	-85					YY
21	sp61	2007-07-20T05:32:41	06:13:08	22.0	8.16827	52	-6	9	78					YY
21	sp76	2008-12-03T11:30:50	11:37:54	1.6	8.16827	52	-6	292	-75					YY

Table 1
(Continued)

No.	Obs. Run ^a	Start Time	End Time	α^a (deg)	P^a (hr)	Pole ₁ ^a		SEP ₁ ^a		Pole ₂ ^a		SEP ₂ ^a		Heterogeneity Candidate ^b
						λ_1 (deg)	ϕ_1 (deg)	λ_1 (deg)	ϕ_1 (deg)	λ_2 (deg)	ϕ_2 (deg)	λ_2 (deg)	ϕ_2 (deg)	
23	sp96	2011-01-06T11:06:31	11:07:36	11.5	12.31241	158	-46	61	-23	343	-74	248	27	
23	V06	2011-01-10T13:17:21	13:20:45	10.0	12.31241	158	-46	70	-22	343	-74	257	27	
25	sp03	2001-01-30T11:22:43	11:37:45	10.8	9.9354	347	10	32	64					Y
25	V03	2010-09-04T13:53:19	13:58:19	26.3	9.9354	347	10	251	-22					Y
25	sp94	2010-10-13T15:20:04	15:27:34	14.0	9.9354	347	10	114	-22					Y
26	sp08	2001-08-24T07:59:21	08:28:00	4.4	13.10977	88	-52	243	17					
26	sp92	2010-07-11T14:53:32	15:02:48	21.5	13.10977	88	-52	43	-7					
27	sp14	2002-06-01T05:57:29	06:25:05	25.1	10.40828	258	-42	309	1					
27	sp31	2004-09-22T13:51:18	13:53:50	21.8	10.40828	258	-42	116	39					
28	sp09	2002-01-13T14:33:57	14:49:17	17.4	15.70785	98	-10	123	-28					Y
28	V03	2010-09-04T15:27:06	15:34:05	21.3	15.70785	98	-10	166	-88					Y
29	sp03	2001-01-29T15:29:22	15:41:57	21.0	5.39012	323	-29	188	24					
29	sp92	2010-07-12T10:11:53	10:17:37	5.3	5.39012	323	-29	188	-45					
30	sp02 ^d	2000-10-08T08:10:00	15:00:00	10.9	13.68717	106	19	84-265 ^d	-22					
30	sp92	2010-07-12T06:44:03	06:51:19	15.7	13.68717	106	19	190	48					
31	V05	2010-11-01T05:37:57	05:47:48	16.9	5.52959	92	68	241	39					
31	V07	2011-10-20T12:26:57	12:32:14	6.6	5.52959	92	68	178	-19					
32	sp3	2001-01-30T05:50:06	06:14:44	19.5	9.44767	267	58	85	36					Y
32	sp76	2008-12-03T07:00:58	07:21:01	11.8	9.44767	267	58	204	23					Y
33	sp10	2002-03-06T11:40:05	12:07:52	5.0	18.6092	187	-53	148	-26	9	-52	332	28	Y
33	V03	2010-09-04T15:14:30	15:24:03	17.9	18.6092	187	-53	53	-4	9	-52	237	6	Y
36	V05	2010-11-01T06:15:15	06:18:08	14.9	9.92692	190	-55	230	52	45	-49	87	-18	
36	sp97	2011-02-07T05:04:37	05:41:45	29.7	9.92692	190	-55	239	48	45	-49	125	-23	
37	sp07	2001-08-15T13:26:51	13:49:12	15.8	7.33253	270	19	118	5					
37	V03	2010-09-04T14:01:57	14:05:41	26.6	7.33253	270	19	100	58					
37	sp94	2010-10-13T15:30:44	15:38:14	20.8	7.33253	270	19	161	61					
38	sp23	2003-07-05T10:23:38	10:39:09	4.6	12.83612	161	-15	142	44	345	-4	335	-42	
38	sp100	2011-06-07T05:52:03	06:03:49	16.3	12.83612	161	-15	295	-47	345	-4	131	49	
39	sp07	2001-08-14T14:48:16	15:06:03	21.8	5.13824	323	33	42	-19					
39	sp92	2010-07-11T14:42:02	14:50:38	22.2	5.13824	323	33	285	-45					
41	sp70	2008-05-10T09:08:53	09:15:12	17.7	5.98798	200	-32	288	-42					
41	sp84	2009-09-20T09:53:09	10:00:39	2.3	5.98798	200	-32	115	49					
44	sp06	2001-06-21T12:41:37	13:17:53	12.8	6.42142	101	51	292	33					Y
44	sp71	2008-06-11T10:25:12	10:40:19	5.3	6.42142	101	51	215	27					Y

Table 1
(Continued)

No.	Obs. Run ^a	Start Time	End Time	α^a (deg)	P^a (hr)	Pole ₁ ^a		SEP ₁ ^a		Pole ₂ ^a		SEP ₂ ^a		Heterogeneity Candidate ^b
						λ_1 (deg)	ϕ_1 (deg)	λ_1 (deg)	ϕ_1 (deg)	λ_2 (deg)	ϕ_2 (deg)	λ_2 (deg)	ϕ_2 (deg)	
45	sp79	2009-03-30T10:40:23	10:52:08	7.1	5.69915	127	-35	338	-32					Y
45	V02	2010-05-10T15:04:55	15:20:53	22.4	5.69915	127	-35	39	61					Y
49	sp24	2003-08-02T08:17:27	08:35:28	8.9	20.70834	324	-57	269	-24					
49	V06	2011-01-10T10:44:58	11:41:31	2.9	20.70834	324	-57	9	29					
50	sp23	2003-07-05T09:00:20	09:43:05	12.1	14.3108	281	26	276	-52	103	12	72	52	
50	sp265	2020-05-27T09:04:59	09:29:41	4.9	14.3108	281	26	202	-38	103	12	27	37	
54	sp19	2002-10-27T15:18:43	15:37:06	17.1	7.02264	154	17	252	-37					Y
54	sp27	2004-02-18T12:22:13	12:49:05	3.8	7.02264	154	17	114	-66					Y
54	V05	2010-11-01T06:05:09	06:10:23	16.3	7.02264	154	17	284	51					Y
54	sp259	2019-10-26T05:58:55	06:31:36	10.9	7.02264	154	17	333	42					Y
55	sp48	2005-11-29T07:06:13	07:16:35	9.3	4.80404	223	18	180	64					
55	sp49	2006-01-29T05:43:52	05:54:02	23.0	4.80404	223	18	27	65					
57	sp14	2002-06-01T06:30:35	07:00:06	16.4										
57	sp92	2010-07-11T14:05:45	14:15:00	17.8										
58	sp24	2003-08-02T09:48:14	10:06:27	6.6	9.89807	207	6.2	148	-5	141	15	176	55	
58	sp265	2020-05-27T06:59:18	07:46:58	14.7	9.89807	207	6.2	21	-89	141	15	228	-26	
61	sp02 ^d	2000-10-08T10:50:00	15:00:00	19.3										
61	V03	2010-09-04T11:32:07	11:35:48	20.9										
61	sp94	2010-10-14T12:26:42	12:32:02	11.7										
64	sp02	2000-10-08T15:09:13	15:20:49	23.9	8.75032	317	17	106	49	138	14	279	-50	Y
64	sp03	2001-01-29T08:43:31	09:00:47	14.4	8.75032	317	17	24	43	138	14	199	-44	Y
66	sp46	2005-10-30T08:44:58	09:06:57	17.5	9.7357	49	-70	27	-11	225	-68	203	14	
66	sp48	2005-11-22T06:23:32	06:32:19	23.6	9.7357	49	-70	226	-11	225	-68	43	15	
67	sp29	2004-06-15T05:28:43	05:46:41	22.6	15.8504	117	42	138	-4	286	50	321	-9	Y
67	sp111	2012-08-28T07:24:46	07:31:37	20.3	15.8504	117	42	29	38	286	50	225	-50	Y
69	sp40	2005-05-11T05:26:43	05:40:14	22.0	5.65534	250	17	337	10	71	-2	156	-11	
69	sp111	2012-08-28T06:58:01	07:05:39	11.4	5.65534	250	17	96	-47	71	-2	268	47	
70	sp18	2002-09-29T14:17:15	14:49:19	20.6	15.8041	40	26	344	-43	233	24	146	50	Y
70	V05	2010-11-01T07:55:50	08:00:30	4.5	15.8041	40	26	241	-57	233	24	28	60	Y
74	V05	2010-11-01T05:20:38	05:32:44	26.6	17.2675	289	14	304	-71	109	1	143	74	Y
74	V07	2011-10-20T13:42:53	14:07:33	23.6	17.2675	289	14	37	80	109	1	227	-84	Y
82	sp08	2001-08-24T13:06:57	13:25:07	8.3	13.00079	164	-28	143	57	349	-33	332	-58	
82	sp92	2010-07-11T14:29:46	14:40:06	15.5	13.00079	164	-28	227	59	349	-33	56	-60	
92	sp02	2000-10-08T14:58:49	15:02:55	18.1										

Table 1
(Continued)

No.	Obs. Run ^a	Start Time	End Time	α^a (deg)	P^a (hr)	Pole ₁ ^a		SEP ₁ ^a		Pole ₂ ^a		SEP ₂ ^a		Heterogeneity Candidate ^b
						λ_1 (deg)	ϕ_1 (deg)	λ_1 (deg)	ϕ_1 (deg)	λ_2 (deg)	ϕ_2 (deg)	λ_2 (deg)	ϕ_2 (deg)	
92	V05	2010-11-01T05:53:02	05:59:10	19.6										
93	sp22	2003-04-27T08:31:05	08:57:37	9.5	5.98177	19	21	324	71					YY
93	V06	2011-01-10T07:39:03	07:46:28	4.9	5.98177	19	21	217	-13					YY
103	sp07	2001-08-14T11:14:30	11:32:25	2.8	23.74265	85	24	130	25	270	40	298	-23	Y
103	sp92	2010-07-11T14:17:49	14:27:05	20.5	23.74265	85	24	1	7	270	40	173	-8	Y
105	sp24	2003-08-02T12:16:50	12:34:12	16.0	37.118	47	24	323	-27					
105	sp25	2003-09-30T07:20:45	07:26:53	17.8	37.118	47	24	324	-12					
105	V05	2010-11-01T05:04:18	05:16:29	25.8	37.118	47	24	327	17					
106	sp24	2003-08-02T11:08:52	11:26:13	4.6	16.2133	237	1	208	-6	57	12	40	7	Y
106	V06	2011-01-10T07:49:41	07:54:04	1.8	16.2133	237	1	333	39	57	12	156	-40	Y
108	sp10	2002-03-06T13:55:33	14:23:17	12.2	14.25662	181	42	182	-40	353	39	16	42	Y
108	sp14	2002-05-31T07:57:29	08:25:31	15.6	14.25662	181	42	39	-43	353	39	235	49	Y
108	sp92	2010-07-12T14:34:40	14:53:01	16.9	14.25662	181	42	160	48	353	39	353	-49	Y
110	sp03	2001-01-29T15:06:42	15:24:01	16.7	10.9258	149	-55	208	-20	331	-61	27	29	
110	sp64	2007-10-02T07:53:33	08:19:03	13.6	10.9258	149	-55	226	26	331	-61	48	-38	
115	sp10	2002-03-06T13:19:53	13:49:35	14.9	7.23996	35	33	252	71					
115	V03	2010-09-04T05:43:57	06:01:15	22.7	7.23996	35	33	157	45					
118	V03	2010-09-03T05:33:29	05:50:18	20.6	7.8065	346	34	207	-2	176	59	10	6	Y
118	sp102	2011-09-25T15:21:39	15:29:20	12.9	7.8065	346	34	326	-31	176	59	132	31	Y
119	sp06	2001-06-21T08:37:05	08:39:30	11.9	11.46514	339	-67	129	10	181	-61	333	-10	Y
119	sp92	2010-07-11T13:53:22	14:02:37	16.5	11.46514	339	-67	32	-15	181	-61	240	33	Y
120	sp27	2004-02-18T13:32:39	13:56:46	10.4	46.5508	256	39	194	-11	82	55	9	7	
120	V07	2011-10-21T06:53:57	07:16:06	18.1	46.5508	256	39	164	-28	82	55	334	26	
121	sp99	2011-04-30T07:23:00	07:37:20	15.4	5.55088	359	8	231	44	3	15	235	38	
121	V09	2012-01-24T15:14:28	15:24:03	14.1	5.55088	359	8	185	65	3	15	169	62	
128	sp23	2003-07-05T09:53:09	10:15:09	7.1										Y
128	sp24	2003-08-02T07:21:18	07:45:38	16.2										Y
128	sp263	2020-01-27T14:04:26	14:17:20	14.4										Y
130	sp05	2001-03-29T14:54:05	15:17:06	11.5	5.22466	64	-90	164	28					Y
130	V09	2012-01-24T15:29:11	15:32:43	14.9	5.22466	64	-90	331	20					Y
133	sp06	2001-06-22T10:27:15	10:49:13	4.2	12.7087	348	-52	135	-19	155	-59	293	9	Y
133	V06	2011-01-10T14:46:21	15:17:57	19.9	12.7087	348	-52	129	28	155	-59	294	-27	Y
144	sp27	2004-02-18T14:03:28	14:31:21	15.0	13.82517	251	63	10	-24					Y
144	V06	2011-01-10T04:58:32	05:07:22	22.9	13.82517	251	63	31	25					Y

Table 1
(Continued)

No.	Obs. Run ^a	Start Time	End Time	α^a (deg)	P^a (hr)	Pole ₁ ^a		SEP ₁ ^a		Pole ₂ ^a		SEP ₂ ^a		Heterogeneity Candidate ^b
						λ_1 (deg)	ϕ_1 (deg)	λ_1 (deg)	ϕ_1 (deg)	λ_2 (deg)	ϕ_2 (deg)	λ_2 (deg)	ϕ_2 (deg)	
145	V01	2010-02-22T15:05:04	15:18:03	21.4										Y
145	sp89	2010-03-17T13:27:34	13:43:05	16.8										Y
156	V07	2011-10-21T14:07:08	14:23:54	17.6	22.1157	197	9	296	8	22	15	106	-11	
156	V09	2012-01-21T07:44:22	08:01:10	11.0	22.1157	197	9	99	21	22	15	259	-22	
158	sp21	2003-03-16T09:49:41	10:19:35	2.3	14.20569	30	-64	24	18					
158	sp94	2010-10-14T08:14:05	08:29:53	10.3	14.20569	30	-64	200	-19					
160	sp23	2003-07-05T06:05:13	06:19:23	17.4	11.03318	125	-33	85	5	308	-41	272	-7	
160	sp99	2011-04-30T07:00:59	07:19:20	21.7	11.03318	125	-33	309	-54	308	-41	134	51	
180	sp18	2002-09-28T12:53:43	13:21:25	8.7	23.8592	41	-64	148	-24	196	-64	300	26	Y
180	sp92	2010-07-12T11:10:34	11:28:55	7.3	23.8592	41	-64	330	-1	196	-64	127	12	Y
216	sp15	2002-06-17T06:54:22	07:21:17	11.6	5.38528	74	20	167	50					
216	sp127	2013-12-07T07:49:01	09:07:19	12.1	5.38528	74	20	50	-52					
233	sp18	2002-09-29T14:57:28	15:18:52	22.6	19.698	318	61	49	23					Y
233	V09	2012-01-24T09:34:31	09:49:38	4.4	19.698	318	61	21	38					Y
237	sp12	2002-04-15T05:52:28	06:29:38	19.9	29.1753	230	30	133	20	42	14	337	-21	Y
237	V04	2010-09-11T14:47:54	15:04:57	18.8	29.1753	230	30	295	36	42	14	128	-33	Y
237	sp95	2010-10-27T14:56:19	15:25:20	18.7	29.1753	230	30	353	28	42	14	186	-25	Y
244	sp05	2001-03-29T06:41:46	07:14:08	21.1	129.716	41	-80	222	-4	218	-74	41	-4	
244	sp69	2008-04-13T10:59:51	11:18:03	1.9	129.716	41	-80	180	10	218	-74	357	-16	
244	sp70	2008-05-10T08:18:51	08:48:11	11.2	129.716	41	-80	196	10	218	-74	13	-15	
258	sp08	2001-08-24T06:23:12	06:50:04	16.3	10.04008	224	-4	149	-11	40	-9	282	12	Y
258	V03	2010-09-04T14:44:45	14:49:25	27.0	10.04008	224	-4	282	80	40	-9	10	-74	Y
266	sp44	2005-09-05T06:22:15	07:04:42	18.5										YY
266	V06	2011-01-10T05:14:44	05:26:48	20.9										YY
269	sp18	2002-09-28T14:30:16	14:57:59	18.4	33.129	71	-79	242	-17	251	-69	62	15	
269	sp40	2005-05-11T14:54:13	15:12:31	18.6	33.129	71	-79	196	20	251	-69	17	-10	
288	sp18	2002-09-29T11:25:30	11:52:53	5.1										Y
288	sp92	2010-07-12T10:47:06	11:04:16	0.6										Y
289	sp01	2000-09-04T14:46:35	15:26:35	23.4	6.916	134	-79	61	-4	294	-73	221	13	Y
289	sp03	2001-01-29T05:16:54	05:41:23	23.6	6.916	134	-79	167	-6	294	-73	325	-1	Y
301	sp89	2010-03-17T15:03:56	15:24:41	21.9	12.2409	226	70	20	-24	46	61	200	20	Y
301	V02	2010-05-10T10:58:26	11:29:12	9.2	12.2409	226	70	182	-25	46	61	0	18	Y
308	sp18	2002-09-28T09:07:04	09:28:06	3.4										
308	sp39	2005-04-18T09:36:58	09:56:14	8.6										

Table 1
(Continued)

No.	Obs. Run ^a	Start Time	End Time	α^a (deg)	P^a (hr)	Pole ₁ ^a		SEP ₁ ^a		Pole ₂ ^a		SEP ₂ ^a		Heterogeneity Candidate ^b
						λ_1 (deg)	ϕ_1 (deg)	λ_1 (deg)	ϕ_1 (deg)	λ_2 (deg)	ϕ_2 (deg)	λ_2 (deg)	ϕ_2 (deg)	
322	sp18	2002-09-29T08:39:13	09:07:13	13.5	17.5726	77	12	102	4	253	23	310	-8	YY
322	V02	2010-05-11T08:37:27	08:58:42	7.3	17.5726	77	12	237	40	253	23	84	-36	YY
346	sp14	2002-05-31T06:07:17	06:40:00	17.3										Y
346	V06	2011-01-10T13:30:59	13:45:09	17.0										Y
354	sp12	2002-04-15T15:00:38	15:22:39	19.9	4.27718	154	51	170	9					YY
354	dm02	2011-08-08T06:10:13	06:26:21	19.9	4.27718	154	51	93	-17					YY
359	sp03	2001-01-30T13:20:18	13:43:48	10.3										YY
359	V02	2010-05-10T05:17:28	05:54:07	18.3										YY
360	V07	2011-10-21T15:15:03	15:29:33	23.3	6.18959	355	55	359	23					Y
360	spBus	2019-03-04T15:28:45	15:44:36	16.3	6.18959	355	55	32	-2					Y
364	sp61	2007-07-20T14:53:54	15:21:58	27.7	9.15753	67	59	288	-11	283	44	69	3	Y
364	sp64	2007-10-02T11:36:45	11:46:06	6.0	9.15753	67	59	83	-5	283	44	218	5	Y
371	sp07	2001-08-14T07:05:32	07:34:05	13.8	10.73965	93	49	60	37	256	43	265	-43	Y
371	sp18	2002-09-29T12:47:50	13:17:13	12.6	10.73965	93	49	163	-33	256	43	10	29	Y
371	sp92	2010-07-12T10:35:21	10:42:52	0.7	10.73965	93	49	45	38	256	43	249	-39	Y
387	sp21	2003-03-16T09:04:30	09:25:32	8.4	24.14011	123	46	336	-49					
387	sp22	2003-04-27T07:05:09	07:28:56	18.9	24.14011	123	46	88	-52					
389	sp08	2001-08-24T11:40:38	11:59:23	7.7	8.4952	291	-29	268	-21	98	-38	64	21	
389	V03	2010-09-04T14:53:08	15:00:08	19.6	8.4952	291	-29	13	29	98	-38	163	-24	
389	sp94	2010-10-14T12:34:22	12:38:14	9.6	8.4952	291	-29	111	27	98	-38	259	-21	
403	sp22	2003-04-27T09:06:30	09:33:15	6.0	12.26999	230	33	233	-41	65	35	35	44	
403	sp93	2010-09-06T14:56:23	15:14:43	18.4	12.26999	230	33	52	50	65	35	203	-58	
444	sp07	2001-08-15T06:02:25	06:37:36	21.8	6.21516	58	15	296	65	234	38	126	-62	
444	V08	2011-10-25T06:35:49	06:47:34	23.0	6.21516	58	15	199	-1	234	38	32	-1	
485	sp10	2002-03-06T12:52:43	13:14:45	13.0	17.6191	322	-50	299	17					
485	V06	2011-01-10T13:49:48	14:09:00	23.6	17.6191	322	-50	120	20					
512	sp32	2004-10-16T12:30:35	12:53:10	30.0	5.58203	324	45	227	32					Y
512	sp32	2004-10-16T13:24:48	14:06:55	29.9	5.58203	324	45	159	32					Y
512	V04	2010-09-11T06:21:59	06:30:34	32.3	5.58203	324	45	202	-26					Y
532	sp06	2001-06-21T07:02:02	07:17:06	22.7	9.40494	103	11	329	9					
532	sp16	2002-08-17T10:05:47	10:24:22	4.7	9.40494	103	11	61	55					
532	sp76	2008-12-03T10:22:51	10:28:11	7.7	9.40494	103	11	345	-35					
600	V04	2010-09-11T05:32:32	05:54:07	23.4	5.88638	208	-46	63	-24	360	-74	217	12	Y
600	sp101	2011-08-22T13:57:42	14:13:40	15.1	5.88638	208	-46	285	33	360	-74	73	-25	Y

Table 1
(Continued)

No.	Obs. Run ^a	Start Time	End Time	α^a (deg)	P^a (hr)	Pole ₁ ^a		SEP ₁ ^a		Pole ₂ ^a		SEP ₂ ^a		Heterogeneity Candidate ^b
						λ_1 (deg)	ϕ_1 (deg)	λ_1 (deg)	ϕ_1 (deg)	λ_2 (deg)	ϕ_2 (deg)	λ_2 (deg)	ϕ_2 (deg)	
631	sp18	2002-09-29T10:16:44	10:46:08	5.9	5.9022	183	-2	78	74					Y
631	V04	2010-09-11T06:02:58	06:14:56	20.0	5.9022	183	-2	91	-20					Y
631	sp101	2011-08-22T10:17:25	10:35:46	9.4	5.9022	183	-2	267	59					Y
675	sp12	2002-04-15T05:22:43	05:46:38	22.6	7.71549	49	74	15	3	196	49	233	-1	
675	V04	2010-09-11T14:36:18	14:43:34	27.0	7.71549	49	74	13	-18	196	49	226	11	
679	sp04	2001-02-19T14:02:06	14:25:08	11.6	8.45602	42	-5	197	45	220	32	336	-57	
679	sp89	2010-03-17T14:03:13	14:21:36	14.2	8.45602	42	-5	259	64	220	32	147	-85	
688	sp18	2002-09-28T08:32:08	08:59:52	14.2										
688	V08	2011-10-25T07:39:20	08:10:02	16.5										
706	sp48	2005-11-29T07:24:14	08:03:47	9.9	22.016	92	66	203	-43	244	54	61	12	
706	sp49	2006-01-30T05:22:45	05:59:30	21.8	22.016	92	66	26	-35	244	54	241	19	
720	sp02 ^d	2000-10-09T11:10:00	15:00:00	18.4	8.91861	239	40	108-314 ^d	44	33	52	312-158 ^d	-25	
720	sp97	2011-02-07T06:00:16	06:23:29	15.9	8.91861	239	40	257	41	33	52	102	-25	
793	sp18	2002-09-28T11:58:14	12:25:55	7.9	7.3985	0	89	139	8					Y
793	sp92	2010-07-12T06:15:23	06:33:44	20.0	7.3985	0	89	22	6					Y
808	sp07	2001-08-14T12:31:05	13:03:39	13.2	30.6297	26	54	97	-34	192	57	295	31	Y
808	sp92	2010-07-12T14:12:29	14:30:50	18.3	30.6297	26	54	184	-32	192	57	22	28	Y
863	sp09	2002-01-14T06:46:20	07:14:56	15.0										YY
863	sp76	2008-12-03T14:54:26	15:12:46	18.1										YY
925	sp18	2002-09-28T07:58:34	08:22:31	12.3	7.87754	294	41	227	-52					
925	sp102	2011-09-25T06:56:54	07:08:39	9.8	7.87754	294	41	238	-44					
965	V07	2011-10-21T11:41:50	11:58:26	5.1										Y
965	V08	2011-10-25T08:18:42	08:32:26	3.3										Y
984	sp17	2002-09-16T08:57:40	09:19:00	11.9	5.77803	245	52	87	14					Y
984	sp18	2002-09-29T10:52:27	11:18:51	7.3	5.77803	245	52	324	12					Y
984	sp92	2010-07-12T05:50:32	06:09:47	18.3	5.77803	245	52	171	-22					Y
1128	V03	2010-09-04T10:45:02	11:01:50	12.6	10.234	214	-38	234	48	39	-43	60	-44	
1128	V05	2010-11-01T06:50:03	07:11:35	10.8	10.234	214	-38	19	44	39	-43	203	-39	
1139	sp29	2004-06-15T06:58:10	07:55:52	20.9	27.4735	270	-29	108	-29					
1139	sp44	2005-09-05T11:43:22	12:25:19	25.2	27.4735	270	-29	79	16					
1228	sp09	2002-01-13T09:31:23	10:04:26	8.8	22.6973	122	-86	4	-1					
1228	sp21	2003-03-16T12:21:48	12:59:13	10.9	22.6973	122	-86	18	-5					
1300	sp55	2006-10-25T07:39:23	08:39:09	7.9										
1300	sp56	2006-11-21T07:56:14	08:33:03	15.9										

Table 1
(Continued)

No.	Obs. Run ^a	Start Time	End Time	α^a (deg)	P^a (hr)	Pole ₁ ^a		SEP ₁ ^a		Pole ₂ ^a		SEP ₂ ^a		Heterogeneity Candidate ^b
						λ_1 (deg)	ϕ_1 (deg)	λ_1 (deg)	ϕ_1 (deg)	λ_2 (deg)	ϕ_2 (deg)	λ_2 (deg)	ϕ_2 (deg)	
2234	dm05	2012-01-12T14:22:00	15:01:00	21.0	15.8126	49	9	57	54	212	-37	147	-45	Y
2234	dm07	2012-03-20T10:16:08	10:32:30	5.3	15.8126	49	9	63	54	212	-37	173	-51	Y
2335	sp45	2005-10-08T13:20:31	13:59:32	23.7										
2335	sp46	2005-10-30T09:15:14	09:44:13	23.8										
2867	sp57	2006-12-22T13:14:29	14:06:09	7.5										Y
2867	sp58	2007-01-21T09:18:52	09:55:19	8.4										Y
2977	sp16	2002-08-17T14:07:00	14:44:15	21.4	6.25758	178	-70	260	16					
2977	sp18	2002-09-28T11:07:28	11:55:24	5.7	6.25758	178	-70	39	13					
3573	dm10	2012-08-14T07:21:00	07:40:00	3.1	6.54245	142	50	208	36	318	52	32	-42	Y
3573	dm11	2012-09-16T06:28:00	06:30:00	17.2	6.54245	142	50	238	35	318	52	62	-41	Y
3613	sp91	2010-05-09T13:11:02	14:29:33	18.7	308.9	311	67	89	-18	80	69	323	21	Y
3613	sp92	2010-07-12T07:37:41	08:05:56	9.4	308.9	311	67	95	-12	80	69	327	26	Y
3819	sp84	2009-09-20T12:11:38	12:48:45	11.3										Y
3819	sp85	2009-10-25T09:35:42	10:03:41	7.0										Y
3844	sp09	2002-01-12T13:07:32	13:47:40	8.0	13.3314	274	47	212	31	274	47	37	-26	Y
3844	sp22	2003-04-27T09:56:38	10:55:29	23.0	13.3314	274	47	19	14	274	47	210	-19	Y
3873	sp19	2002-10-28T08:28:29	09:05:18	13.2										Y
3873	sp32	2004-10-16T06:40:17	07:41:55	27.8										Y
4455	sp85	2009-10-25T12:48:19	13:27:42	15.8	4.30829	197	-50	304	13	6	-30	110	-10	YY
4455	sp87	2010-01-17T10:37:39	11:14:16	14.0	4.30829	197	-50	163	17	6	-30	320	-23	YY
5401	sp09	2002-01-12T05:09:27	06:05:51	21.8										Y
5401	sp21	2003-03-16T11:39:50	12:17:01	4.1										Y
5641	sp25	2003-09-30T08:43:03	09:50:37	13.3										YY
5641	sp38	2005-04-12T14:27:19	15:15:50	31.0										YY
5641	sp42	2005-06-10T06:48:41	07:51:46	31.0										YY
6478	sp253	2019-03-31T08:47:07	10:22:42	15.9										Y
6478	sp254	2019-04-08T06:36:14	07:31:40	18.9										Y
8838	dm04	2011-12-01T04:38:00	05:22:00	14.1	42.6145	0	51	192	-36	164	35	55	44	
8838	dm13	2013-01-16T08:04:57	08:43:12	7.1	42.6145	0	51	216	17	164	35	82	-10	
20786	sp25	2003-10-01T12:42:48	13:41:33	16.5										Y
20786	sp80	2009-04-27T14:29:24	15:26:09	15.6										Y
20786	sp81	2009-06-21T07:40:47	08:08:51	19.9										Y
29731	dm04	2011-12-01T09:04:00	10:03:00	16.7										Low S/N
29731	dm14	2013-03-01T14:22:00	15:00:00	19.1										Low S/N

Table 1
(Continued)

No.	Obs. Run ^a	Start Time	End Time	α^a (deg)	P^a (hr)	Pole ₁ ^a		SEP ₁ ^a		Pole ₂ ^a		SEP ₂ ^a		Heterogeneity Candidate ^b
						λ_1 (deg)	ϕ_1 (deg)	λ_1 (deg)	ϕ_1 (deg)	λ_2 (deg)	ϕ_2 (deg)	λ_2 (deg)	ϕ_2 (deg)	
34931	sp121	2013-06-13T08:10:30	08:38:13	9.7										Low S/N
34931	dm16	2013-07-18T07:17:26	07:53:02	17.0										Low S/N
35925	dm02	2011-08-08T11:03:48	11:49:39	4.1										YY
35925	dm12	2012-12-12T06:56:01	07:40:28	12.3										YY
40573	dm05	2012-01-23T13:22:00	13:58:00	12.7										Low S/N
40573	dm06	2012-03-04T11:00:00	11:55:00	3.9										Low S/N
42946	sp117	2013-01-17T06:40:37	07:15:40	14.9										Low S/N
42946	dm20	2015-09-11T08:35:59	08:54:12	8.1										Low S/N
45876	dm09	2012-07-22T13:44:00	14:22:00	24.0										Low S/N
45876	dm11	2012-09-16T09:07:14	09:33:03	3.6										Low S/N
271073	sp271	2020-08-30T14:25:15	15:02:10	22.8										Low S/N
271073	sp274	2020-09-28T10:18:04	10:54:58	11.5										Low S/N

Notes.

^a The observational run (Obs. Run), phase angle (α), rotational period (P), ecliptic longitude and latitude of pole solution (Pole), and ecliptic longitude and latitude of sub-Earth point at the time of observations (SEP).

^b Y: “optimistic” candidates. YY: “conservative” candidates.

^c Spectra of 1 Ceres in sp41 combined all three separate observations into one. It shows a practically average Ceres spectrum.

^d Records of observed times for asteroids have been lost. Observation time was assumed to be below air mass 2 and before dawn.

creating systematic variations with enough frequency to misinterpret independent nights that do not precisely match. This implies that one should be very careful when claiming heterogeneity when using this data set. Here, we prefer to talk about “candidates for heterogeneity” that remain to be corroborated by future observations.

Therefore, in this work, we search for asteroid candidates for surface heterogeneity using MITHNEOS and additional spectroscopic surveys that use the same observational and reduction method as MITHNEOS in preparation for future observations for heterogeneity detection using extremely large telescopes.

2. Observation Method and Data Reduction

MITHNEOS conducts spectroscopic observations of asteroids with the 3.2 m NASA IRTF located on Maunakea, Hawaii. The survey makes use of the SpeX near-IR spectrograph (Rayner et al. 2003) combined with a $0''.8 \times 15''$ slit in the low-resolution prism mode to acquire the asteroid spectra over the 0.7–2.5 μm wavelength range. The observations consist of a series of spectral images with 120 s exposure time (and sometimes shorter in the case of very bright targets) using an ABBA beam pattern to efficiently remove the sky background by subtracting pairs of AB images. Typically, three calibration stars known to be very close spectral analogs to the Sun are observed each night for removal of the solar colors from the asteroid spectra. These solar analogs, which are G2V–G5V stars, include Hyades 64, 93–101, 98–978, 102–1081, 105–56, 107–684, 107–998, 110–361, 112–1333, 113–276, and 115–271 (Marsset et al. 2020b).

Data reduction and spectral extraction of the MITHNEOS data are performed with IRAF, as well as homemade recipes written in IDL and Python. The AutospeX software tool is also used to automatically write sets of command files (Rivkin et al. 2005). Reduction steps include trimming the images, creating a bad-pixel map, flat-fielding the images, sky-subtracting between AB image pairs, tracing the spectra in both the wavelength and spatial dimensions, coadding the spectral images, extracting the spectra, performing wavelength calibration, and correcting for air-mass differences between the asteroids and their corresponding solar analogs. We use an atmospheric transmission (ATRAN) model by Lord (1992) to determine a coefficient for each object (each asteroid and each star) that minimizes atmospheric water absorption effects. Next, the resulting asteroid spectra are divided by each of the stellar spectra obtained during the same night in order to remove the solar gradient. Finally, an average reflectance spectrum is produced for each asteroid by combining the spectra obtained by use of the different solar analogs.

This reduction method is also described in Binzel et al. (2019) and Marsset et al. (2022) in detail.

3. Observation Data Sets

This study used the following two data sets: MITHNEOS from 2000 September 4 to 2022 June 5 (principal investigator from the fall of 2000 to the fall of 2014: Richard P. Binzel; principal investigator from the spring of 2015 to the spring of 2022: Francesca E. DeMeo) and data for which the principal investigator is Pierre Vernazza, which were obtained following the same observation method as MITHNEOS from 2010 February 22 to 2012 January 24. The MITHNEOS data set consists of both NEAs and MBAs. The MITHNEOS data for

NEAs were published in Binzel et al. (2019) and Marsset et al. (2022). Most of the MBA data were published in DeMeo et al. (2009) or are published here in this work for the first time (see Appendix A for a full reference list for the data). The Vernazza data consist of only MBAs. Circumstances for MBAs of MITHNEOS (MITHMBAs) and Vernazza’s observations (MBAs only) are shown in Tables A1 and A2, respectively. Spectra of asteroids with only one observation that have not been previously published are also shown in Appendix B.

The two data sets consist of both NEAs and MBAs, but this study is restricted to MBAs. The reasons for this are as follows.

The first reason relates to the signal-to-noise ratio (S/N) of the available spectra. Since the main purpose of MITHNEOS is to study NEAs, a very large number of spectra of NEAs have been obtained. However, because NEAs are generally faint and exhibit a large sky motion, the data often have a worse S/N than the accuracy of Marsset et al. (2020b).

The second reason stems from the existing dependency of asteroid spectral slopes with phase angle. The spectral slope of an asteroid is known to vary depending on the phase angle at which it is observed (e.g., Sanchez et al. 2012; Thomas et al. 2014; Binzel et al. 2019; Fornasier et al. 2020) in visible and near-infrared wavelengths. Spectral phase reddening of asteroids has also been observed at visible wavelengths (e.g., Fornasier et al. 2015; Perna et al. 2018; Tatsumi et al. 2020). Including NEAs, which are often observed at large and varying phase angles (e.g., Perna et al. 2018), in our study may lead to incorrect conclusions regarding the surface spectral heterogeneity of these objects. Spectral slope variation of the near-infrared spectra with respect to the phase angle at the time of observation is larger for D-type asteroids, whose spectra have steep slopes in visible and near-infrared wavelengths, than for C-complex asteroids, whose spectra have flat slopes (Lantz et al. 2018). Hasegawa et al. (2022b) showed that spectral slope variations of D-type asteroids due to variations of the phase angle are smaller than the slope uncertainty of MITHNEOS if the phase angle varies by less than 20° . For S-type asteroids, it is smaller than this uncertainty within a 35° variation of the phase angle. NEAs observed by MITHNEOS may have had a difference greater than this phase angle requirement during the observations. The observed phase angle differences between the asteroids used in this study do not exceed 20° (see Table 1).

The third reason is that the rotational state properties are available for only a handful of NEAs (16 NEAs) in our data set (see Section 4). Furthermore, one quarter of these NEAs have been identified as having a YORP effect. The observed geometry of most NEAs cannot be thus estimated.

For these three reasons, only spectra of MBAs are considered in this study. A total of 130 asteroids with more than two spectroscopic measurements are compiled.

4. Observing Geometry

To check possible surface heterogeneity, we need to know which side of the asteroid was facing the Earth during the observation—the sub-Earth point. We determined the ecliptic latitude and longitude of the sub-Earth point of the asteroids at the time their spectra were obtained using the online sky projection tool on the Database of Asteroid Models from Inversion Techniques web page (DAMIT¹⁶; Āurech et al. 2010). DAMIT contains $\sim 16,000$ models for almost 11,000

¹⁶ <https://astro.troja.mff.cuni.cz/projects/damit/>

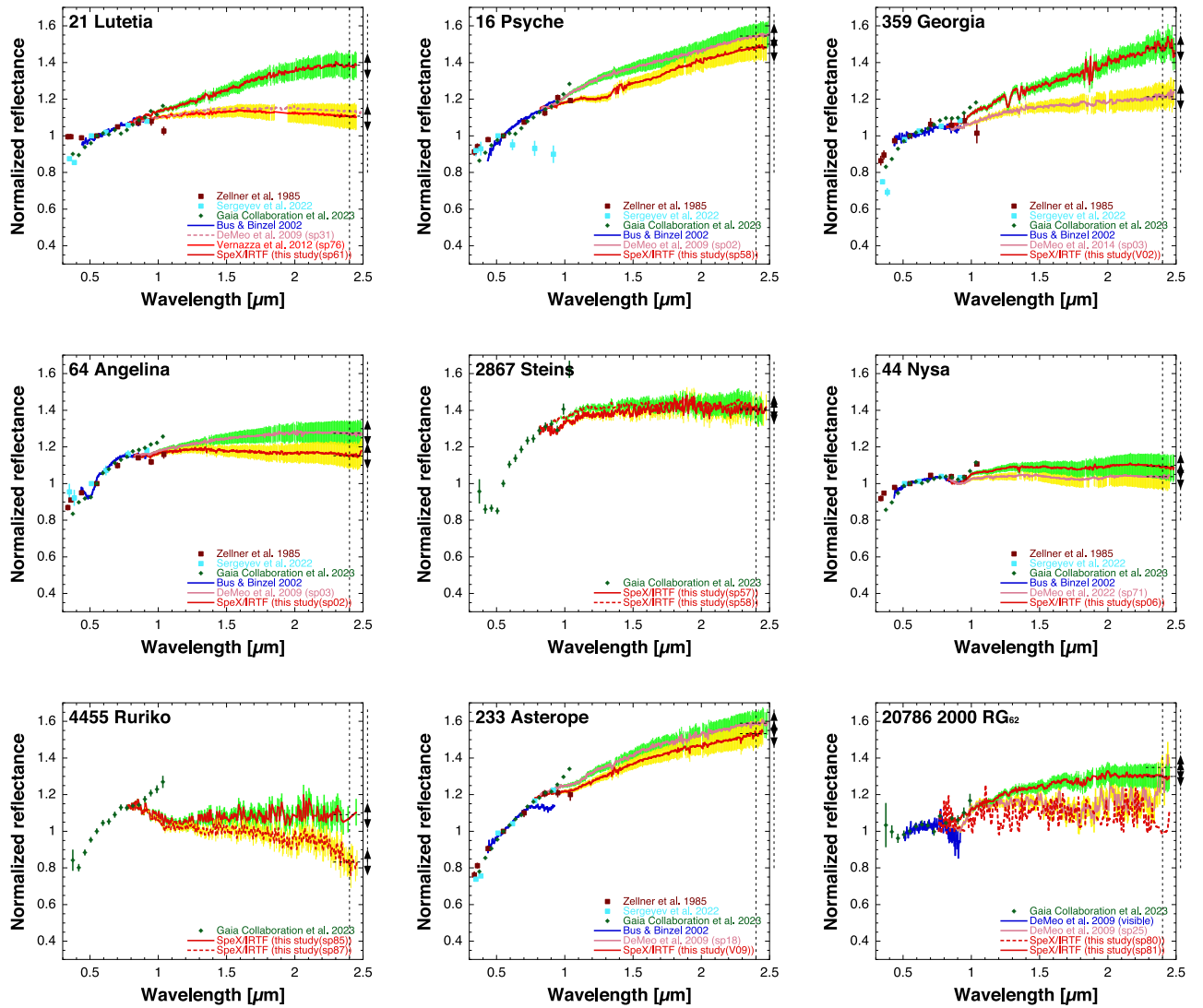


Figure 1. Reflectance spectra of X-complex asteroids selected as heterogeneous candidates in this study. Visible spectrophotometric and spectroscopic data were taken from Zellner et al. (1985), Bus & Binzel (2002), Sergeev et al. (2022), and Gaia Collaboration et al. (2023). Data of Sergeev & Carry (2021) were also used in the case of few visible spectral data. The green and yellow error bars represent the observational uncertainty of Marsset et al. (2020b). They are shown for the two most extreme spectra (Section 5). Different colors are used only for better readability. The black arrows show the slope uncertainty centered at the reflectance value of the spectra at $2.40 \mu\text{m}$, as marked by the black dashed lines.

asteroids (2023 August). Three-dimensional convex shapes, pole orientations, and sidereal rotation periods of asteroids in DAMIT are calculated using the photometry inversion technique of Kaasalainen & Torppa (2001) and Kaasalainen et al. (2001).

Table 1 shows the phase angle and the ecliptic latitude and longitude of the sub-Earth point at the exposure midtime of observation for asteroids with multiple near-infrared spectra. Shape models are available for 103 objects. For the remaining 21 asteroids (excluding the low-S/N cases), their shape models have not been derived yet. We keep these objects in our sample, but the question of their geometric orientation during our spectroscopic observations remains open for now.

5. Method for the Identification of Candidates for Surface Heterogeneity

To select candidates for surface heterogeneity, we conduct the following steps. First, we reject spectra with low S/N that prevented measuring the spectral slope with a better accuracy

than the slope uncertainty of Marsset et al. (2020b). Next, the uncertainty of Marsset et al. (2020b) is plotted on each near-infrared spectrum normalized to unity at $0.8 \mu\text{m}$. Since we focus solely on near-infrared spectra rather than visible spectra in our search for surface heterogeneity, the coupling of visible and near-infrared spectra does not come into play. If there are more than two spectra, the spectra farthest in reflectance from each other are compared. If the uncertainty ranges of the compared spectra do not overlap with each other, then the asteroid is judged to have a heterogeneous surface. To be more accurate, the selection conditions of heterogeneity candidates are the existence of a nonoverlapping region of more than $0.1 \mu\text{m}$ wavelength range for the reasons that follow. Figures 1–5: The likelihood of a given spectrum to fall within the green or yellow error bars of the other spectrum (which correspond to the 1σ range) is 68.3%. Therefore, there is a 31.7% chance that the spectrum falls outside of that range due to the statistical uncertainty and half that probability on one side or the other (above or below).

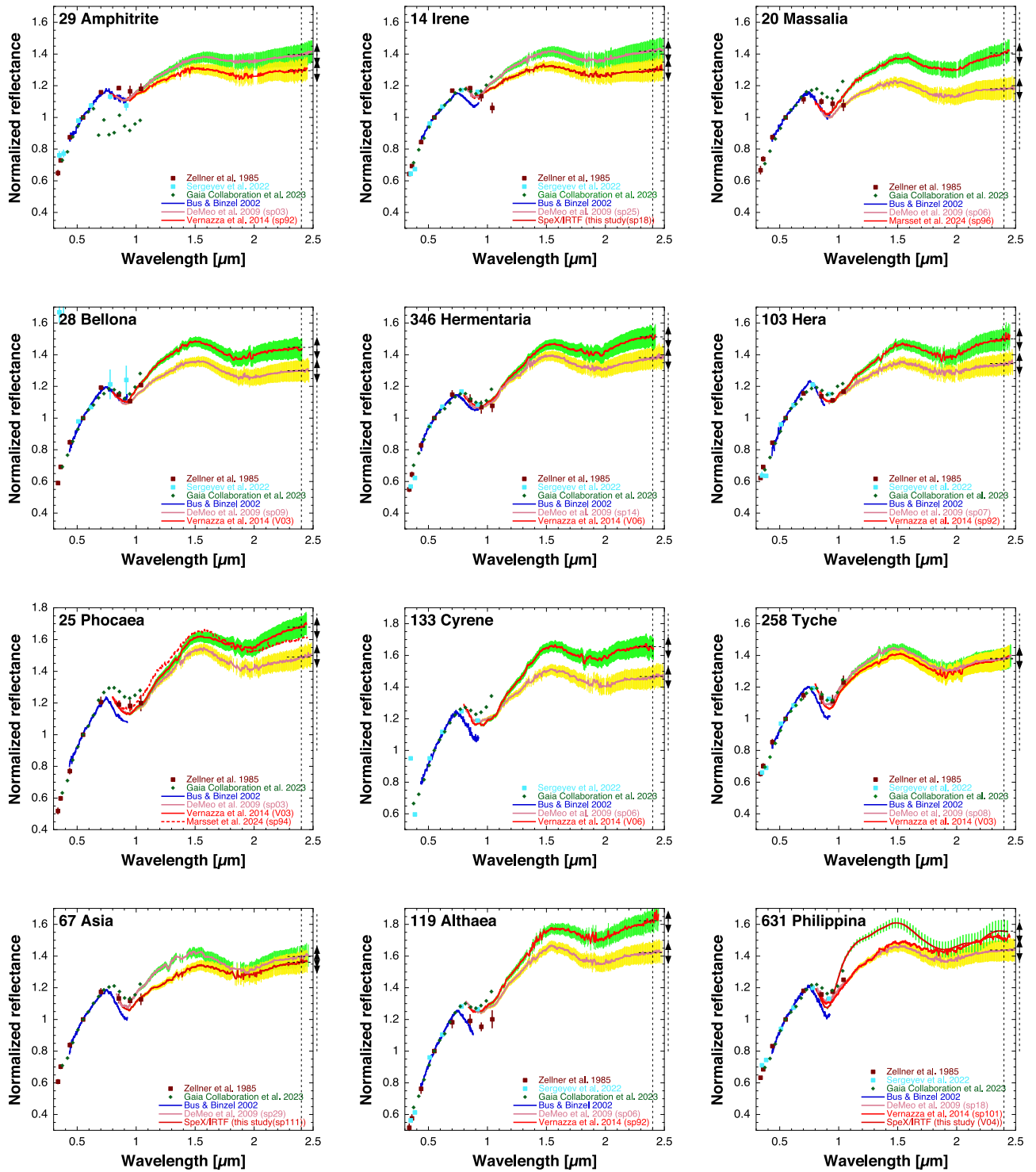


Figure 2. Reflectance spectra of S-complex V-, R-, and K-type asteroids identified as candidates for surface heterogeneity.

The probability that one spectrum is half out of the 1σ range is 15.9%, assuming a Gaussian distribution. Since the statistical uncertainty can move both spectra up and down, the probability of overlap is the square of that value. Under the uncertainty of Marsset et al. (2020b), the probability of two spectra not meeting the overlapping criteria is 2.52% for a homogeneous asteroid. Moreover, to increase the accuracy to a level below 1% ($2.75\sigma \sim 0.6\%$), more than 18 data points would be required. Given that the wavelength increment of the spectrum is $0.005 \mu\text{m}$, this corresponds to $0.1 \mu\text{m}$ of consecutive

nonoverlapping. This comparison was made over the range $0.8\text{--}2.45 \mu\text{m}$.

However, it is possible that these statistics are flawed by looking for differences over a short wavelength range. Therefore, candidates searched using the above method are considered as “optimistic,” while we define asteroids exhibiting a slope variation of more than 3σ between epochs as “conservative” candidates (that is, more likely to be truly heterogeneous). We look for spectral slope heterogeneity and do not perform any analysis of absorption-band parameters.

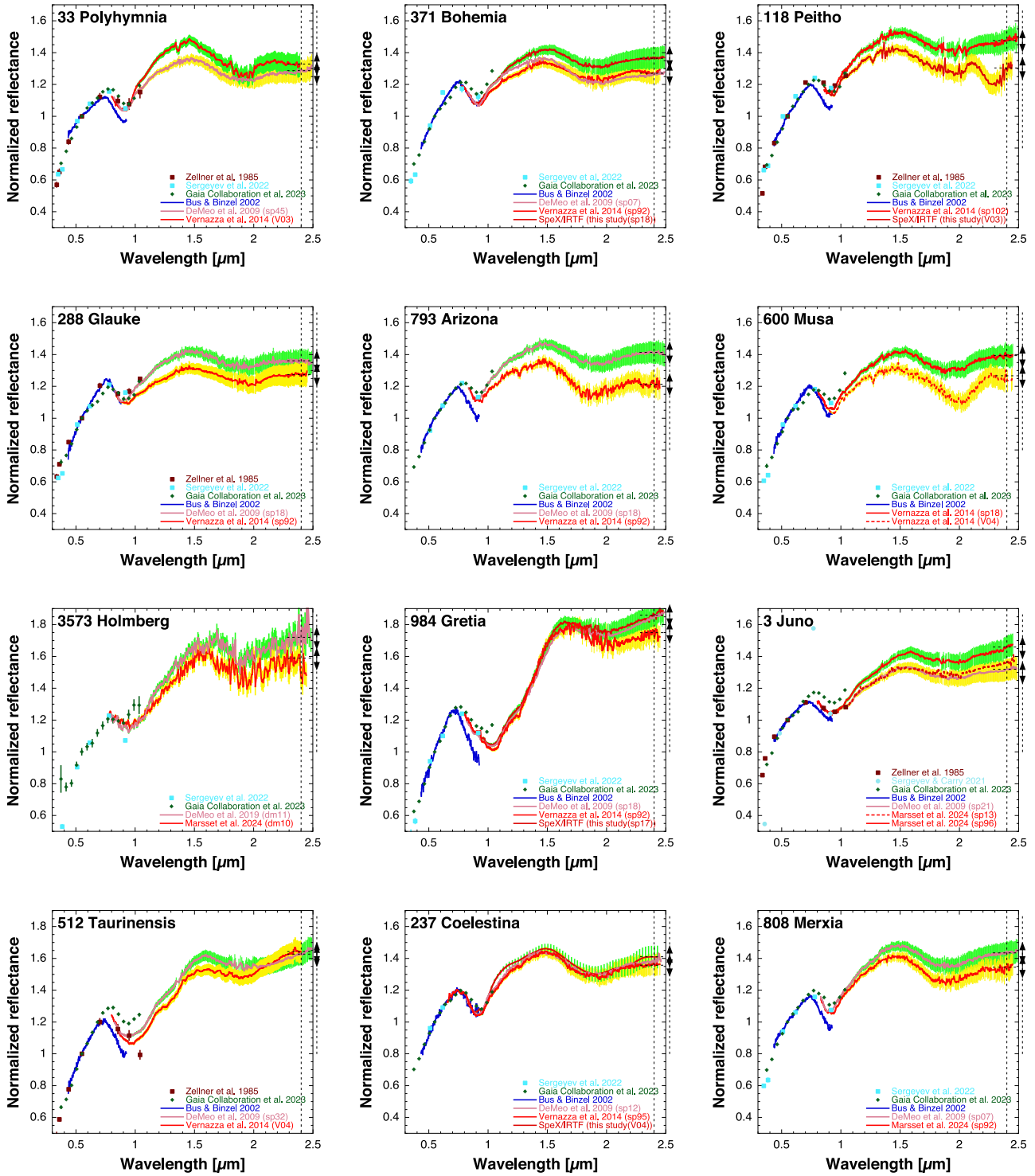


Figure 2. (Continued.)

6. Results

Figures 1–5 show spectra of 64 candidates for surface heterogeneity. Each figure is dedicated to asteroids belonging to a similar spectral type. Similar figures for the remaining 66 asteroids not determined to be heterogeneous candidates are shown in Appendix B. Figure 6 shows the histogram of spectral slope variability in our sample, given by the number of sigma variation of the normalized spectra measured at $2.4 \mu\text{m}$. There

are 52 optimistic heterogeneous candidates and 12 conservative heterogeneous candidates.

1 Ceres, 3 Juno, 10 Hygiea, 16 Psyche, and 21 Lutetia were observed with high spatial resolution and confirmed to exhibit albedo and color variations at hemispheric scales in previous studies (Baliunas et al. 2003; Weiss et al. 2012; de Sanctis et al. 2018; Ferrais et al. 2020; Vernazza et al. 2020). Using our selection criteria (Section 5), we identify 1 Ceres, 3 Juno, and 16 Psyche as optimistic heterogeneous candidates and 10

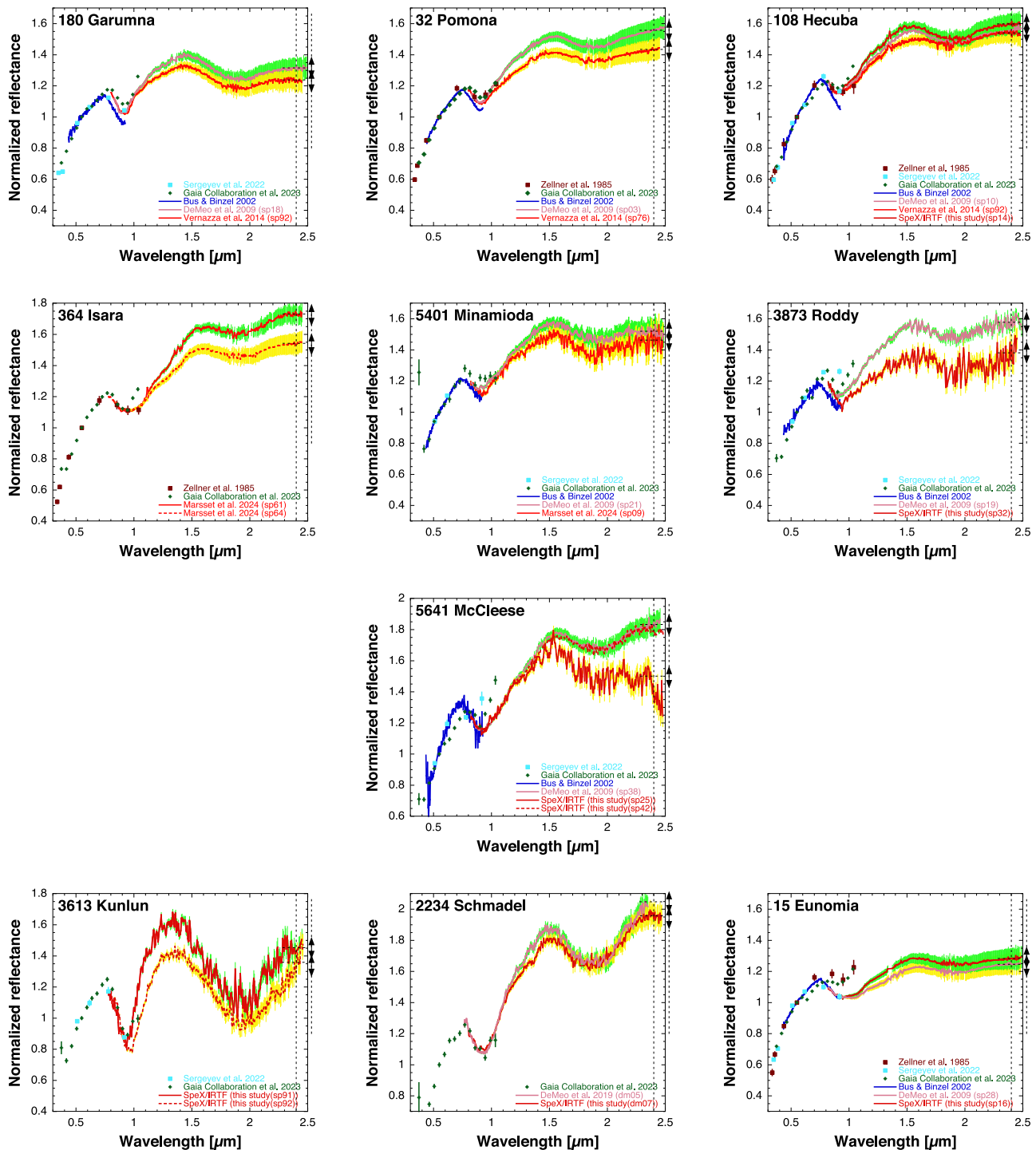


Figure 2. (Continued.)

Hygiea and 21 Lutetia as conservative heterogeneous candidates.

The spectra of 1 Ceres from observing runs dm04 and sp41 (see Table 1) are consistent with the average spectrum obtained by the Dawn spacecraft (de Sanctis et al. 2018; left panel of Figure 7). However, the spectrum from sp06 deviates from that average.

The area observed during sp06 is centered at longitude 223° , latitude $+2^\circ$. This region includes region A (longitude 231° , latitude $+23^\circ$), which is one of the areas where the water

absorption line was detected by the Herschel Space Observatory (Küppers et al. 2014). In region A, the Occator crater with a diameter of ~ 90 km (longitude 239° , latitude $+19^\circ$), which is a geologically young crater comprising two very bright areas, is present (De Sanctis et al. 2016). Some spectra of the Cerealia Facula, a very bright spot at the center of the crater and predominantly composed of sodium carbonate (De Sanctis et al. 2016), are in agreement with that of sp06 within the observing uncertainty (Figure 7). In addition, the area observed during the sp06 observation includes four exposed water-rich

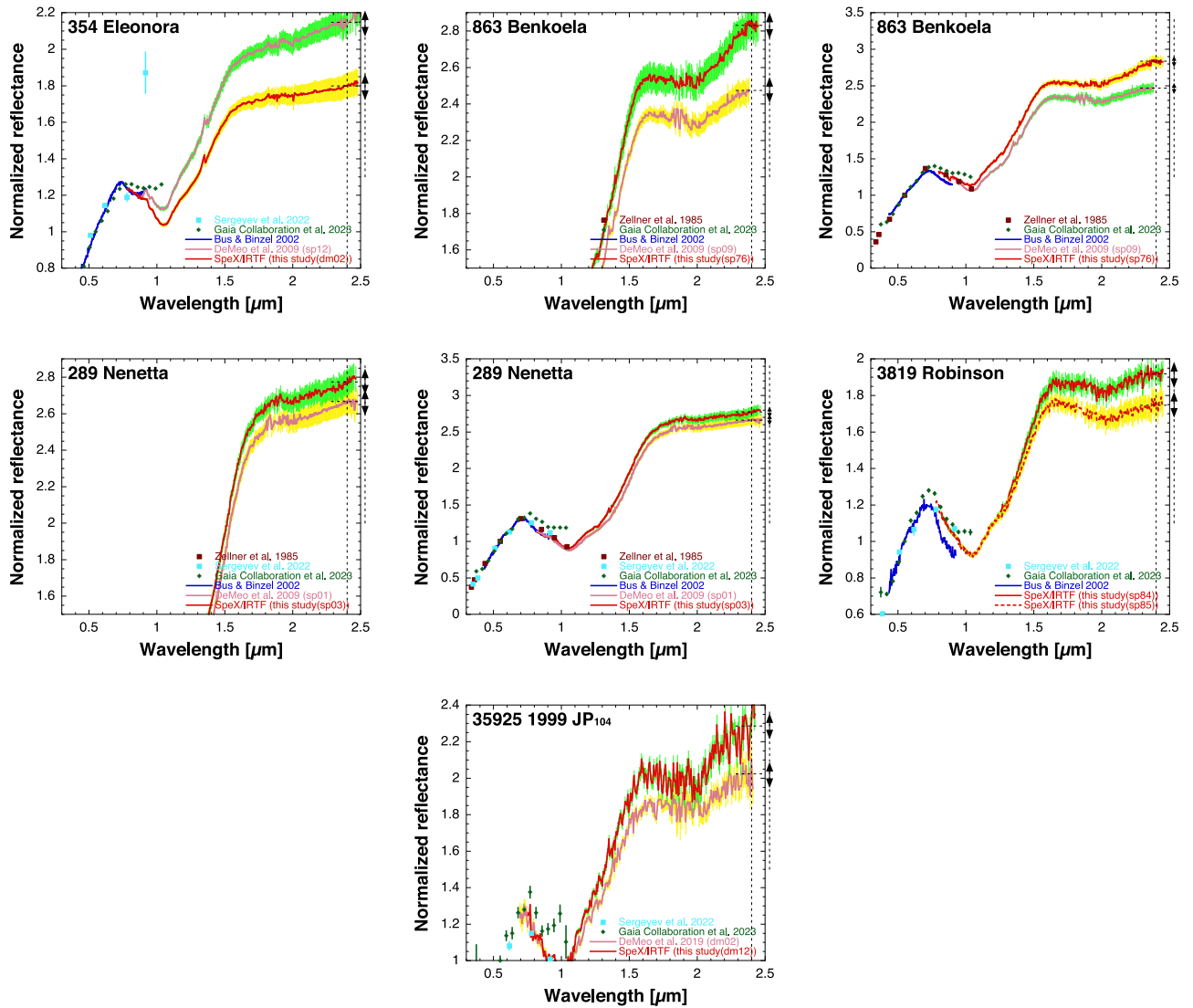


Figure 3. Reflectance spectra of A-type asteroids identified as candidates for surface heterogeneity. There are two types of graphs for 863 and 289: one where the scale of the vertical axis is similar to other graphs and one where the entire spectrum is shown.

areas: B area (longitude 115° , latitude $+70^\circ$); D area, Juling Crater (longitude 170° , latitude -35°); G area, Ezinu Crater (longitude 200° , latitude $+42^\circ$); and I area, Baltay Catena (longitude 265° , latitude -48°) (Combe et al. 2019). The averaged spectra of these four water-rich areas agree very well with the sp06 spectrum (Figure 7). Combe et al. (2019) stated that exposed water ice on region A was detected by the Dawn spacecraft. Ciarniello et al. (2017) showed a map of the albedo difference at 2 and $0.55 \mu\text{m}$ and a three-color map of 2.2, 1.8, and $1.2 \mu\text{m}$ of 1 Ceres. Inside the region observed during the sp06 observation, there are regions with a blue spectrum (in Figures 14 and 17 in Ciarniello et al. 2017). The total of these areas accounts for approximately 50% of the area observed at the time of the sp06 observation. To summarize, Dawn observations show that about 50% of the surface visible during sp06 correspond to areas with a bluer (and brighter) spectrum than the average Ceres surface, which is consistent with having a bluer ground-based spectrum in sp06 compared to other epochs.

It was reported that 1 Ceres episodically emits water vapor (A’Hearn & Feldman 1992; Küppers et al. 2014). Perna et al. (2015) also reported changes in the visible slope of 1 Ceres and

attributed this to an extended surfacing process occurring from 2012 October to 2013 January. On the other hand, no such phenomenon was confirmed in 2001 when sp06 was conducted. In addition, all detections of water vapor on 1 Ceres corresponded to heliocentric distances of less than 2.72 au (Küppers et al. 2014), while the heliocentric distance of 1 Ceres was 2.89 au during sp06. This suggests that water vapor was not being produced during these observations. However, it cannot be completely ruled out that the emitting water vapor did not occur immediately before the sp06 observation. The released water gas would have adhered to the surface layer and become very thin ice before the time of the sp06 observation. Then, the infrared spectrum would have become a negative slope in slope, which is typical for water ice (e.g., Combe et al. 2016). This may be another factor explaining the blue spectrum in sp06.

Meanwhile, for 2 Pallas and 4 Vesta, surface heterogeneity was not detected in our study. The reasons for nondetection in the case of 4 Vesta are as follows. The two spectra of 4 Vesta are consistent with one another within the uncertainty range of Marsset et al. (2020b). Comparing the band II depth, which is a pyroxene absorption band at $1.95 \mu\text{m}$, reveals that the

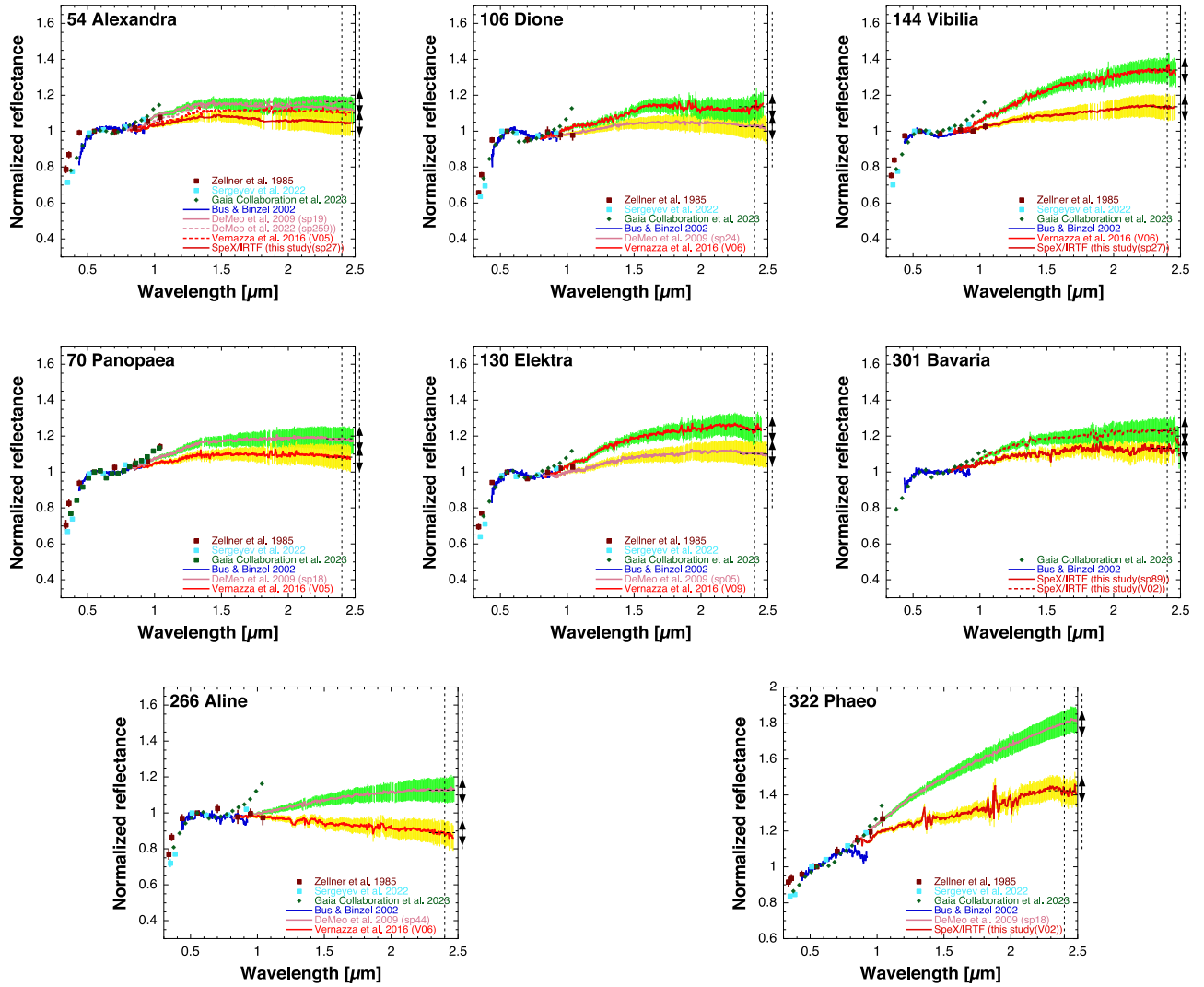


Figure 4. Reflectance spectra of Ch/Cgh- and D-type asteroids identified as candidates for surface heterogeneity.

measurement from sp02 (0.25) is deeper than that from sp86 (0.22). Looking at the Dawn spacecraft, it can be seen that the band II depth in the geological area corresponding to sp02 (0.2–0.35) was observed, on average, deeper than that of sp86 (0.15–0.3; De Sanctis et al. 2012), thereby providing additional validity to the spectra used in this study in the case of a good S/N. In addition, the spectral variability from the equatorial to southern regions of Vesta measured by De Sanctis et al. (2013) is smaller than the observational uncertainty of Marsset et al. (2020b). Therefore, it is not surprising that the spectroscopic measurements from sp02 and sp86, which were obtained close to the equatorial and southern regions, agree within the observational uncertainty.

For 2 Pallas, it is possible that this is the same case as 4 Vesta. However, the absence of heterogeneity detection does not necessarily imply that an object’s surface is homogeneous.

6 Hebe (Gehrels & Taylor 1977), 25 Phocaea (Groeneveld & Kuiper 1954), and 44 Nysa (Tupieva 2003) were predominantly detected as exhibiting color changes with rotation period in multicolor light-curve observations. Here, using our data set, we identify 25 Phocaea and 44 Nysa as optimistic candidates. Nysa was reported to have small spectral slope variations (Fornasier et al. 2008). In Gaffey et al. (2015), spectral changes

associated with rotation were identified in the case of 354 Eleonora, and this asteroid is also selected as a conservative heterogeneous candidate. Several rotationally resolved spectral observations reported that 21 Lutetia has a heterogeneous surface (Nedelcu et al. 2007; Lazzarin et al. 2010; Perna et al. 2010). Furthermore, Barucci et al. (2012) concluded that the surface of 21 Lutetia is not uniform, based on the results obtained by Rosetta and ground-based observations.

We note two cases—that of 4455 Ruriko (Figure 1) and 5641 McClesse (Figure 2)—where the asteroid spectra acquired at two different epochs exhibit similar shapes up to $\sim 1.4 \mu\text{m}$, and then one of the spectra drops steeply with respect to the other. This effect is especially obvious at wavelengths longer than $2 \mu\text{m}$. It is possible that slit misalignment is the cause of this spectral discrepancy. However, if the spectrum were normalized to $0.8 \mu\text{m}$ in Figure 9 in Marsset et al. (2020b), the shorter wavelengths would tend to shift more. The reflectance that does not match only less than $2 \mu\text{m}$ can be explained by slit misalignment. This suggests that slit misalignment is not the cause of this discrepancy. On the other hand, there are known examples of asteroids showing a similar behavior in the literature, such as 2015 TC₂₅ (Reddy et al. 2016), 6478 Gault, 511684 2015 BN₅₀₉, and 2001 YM₂

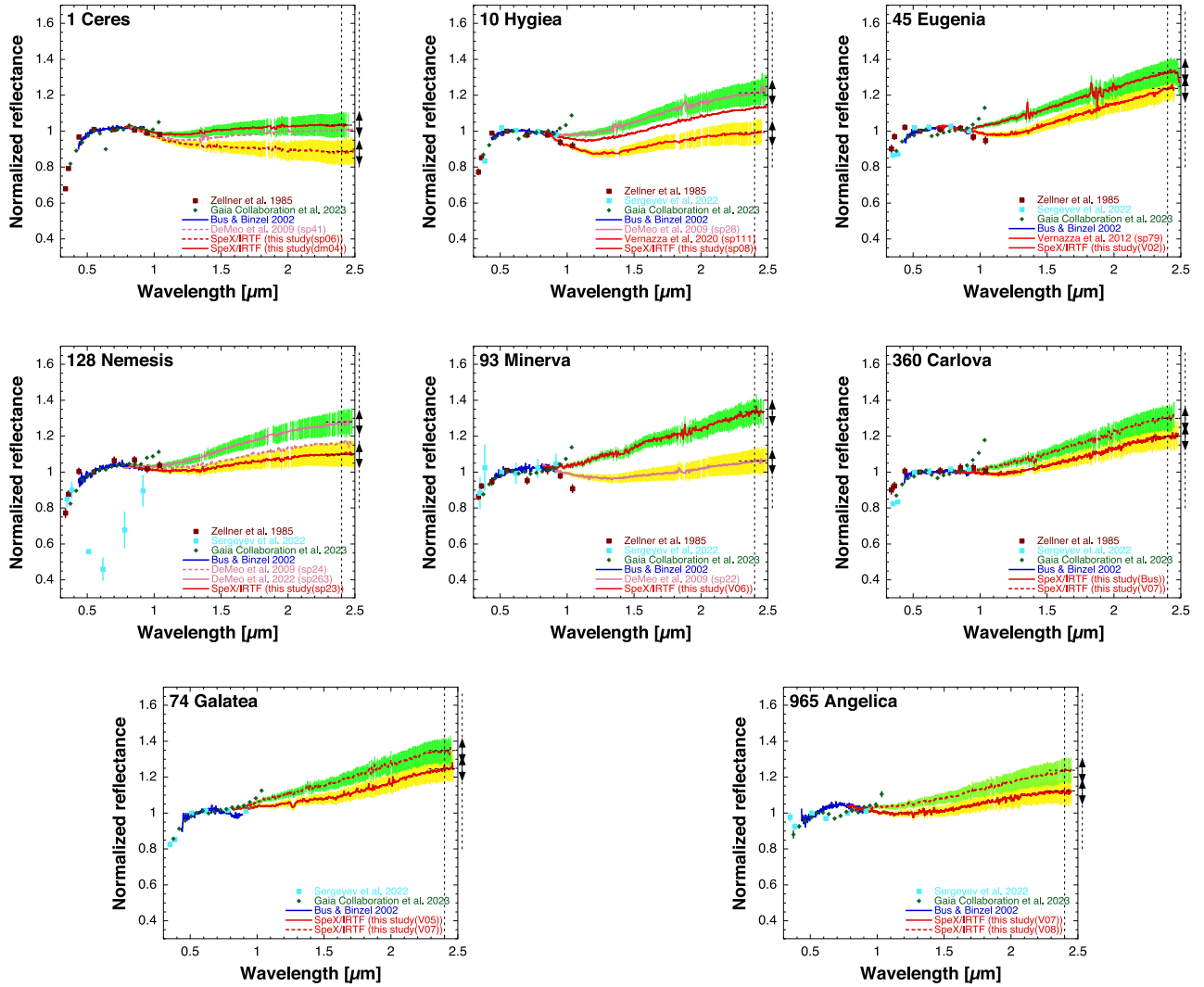


Figure 5. Reflectance spectra of B/C-type asteroids identified as candidates for surface heterogeneity.

(Marsset et al. 2019). It was suggested that these asteroids exhibited a region of their surface lacking fine-grained regolith during the observations. Another example comes from laboratory measurements of the H4 chondrite Ochansk, which also shows a drop in reflectance beyond $1.4 \mu\text{m}$ as particle size increases (see Hasegawa et al. 2019). These results suggest that 4455 Ruriko and 5641 McCleese are only partially covered with fine regolith. However, as for the rest of our data set, these two objects should be considered only as candidates for surface heterogeneity. This remains to be confirmed by other methods (see Section 7).

Most asteroids with reported surface heterogeneity in previous studies are confirmed to be heterogeneous candidates in our study. Specifically, of the 11 asteroids that were reported to have a heterogeneous surface in the past, three (10 Hygiea, 21 Lutetia, and 354 Eleonora), five (1 Ceres, 3 Juno, 16 Psyche, 25 Phocaea, and 44 Nysa), and three objects (2 Pallas, 4 Vesta, and 6 Hebe) are considered conservative, optimistic heterogeneous candidates, and noncandidates, respectively. This provides confidence that the candidates identified in this study are truly heterogeneous.

In previous studies, surface heterogeneity was detected only in the case of asteroids larger than 100 km in diameter for

which rotationally resolved multicolor data were obtained (see Section 1). In the present study, the optimistic+conservative and conservative candidate's detection rates are 45% and 11%, respectively, for these objects (Figure 8). Meanwhile, tentative heterogeneity detection is also found for objects smaller than 100 km for the first time. In the case of these objects, the optimistic+conservative and conservative candidate rates of heterogeneity of those are 52% and 8%, respectively (Figure 8). Our study therefore suggests that objects smaller than 100 km can be heterogeneous at hemispheric scales, with the smaller candidate for heterogeneity in our sample having a diameter of ~ 5 km.

Table 2 shows the heterogeneity detection for each asteroidal spectral type. As mentioned earlier, a nondetection does not imply intrinsic homogeneity. Thus, the fractions provided in Figure 8 are lower limits only.

It can be seen that the fraction of optimistic and conservative heterogeneous candidates within A-type asteroids is higher than that of other spectral types.

7. Discussion

In this study, surface heterogeneous candidates were identified for asteroids with diameters both larger and smaller

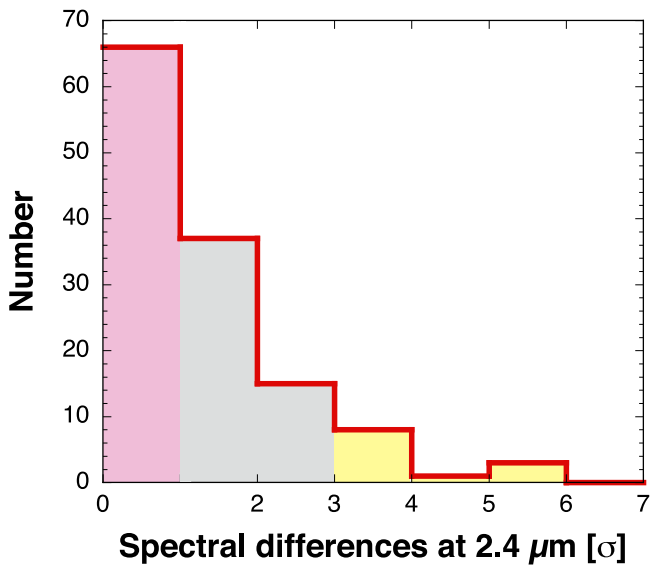


Figure 6. Distribution of spectral slope variation at $2.4 \mu\text{m}$ in our data set. Pink: nondetection for surface heterogeneity (66 objects). Gray: optimistic candidates (52 objects). Yellow: conservative candidates (12 objects). Since optimistic candidates and noncandidates for surface heterogeneity are not determined using reflectance differences at $2.4 \mu\text{m}$, the value of 1 on the abscissa is intentionally left out.

than 100 km. Since the MITHNEOS spectroscopic data were not optimized for the detection of surface heterogeneity on asteroids, our candidates remain to be confirmed in the future by spectroscopic observations spanning several nights (to sample the whole rotation phase) and epochs (to sample different geometries, e.g., sub-Earth points). Specifically, the observing scheme should consist of repeated observations of (i) the target asteroid, (ii) a nearby solar reference star, and (iii) a second nearby solar “check star” of similar S/N to the asteroids, for which division by the solar reference star should reveal a nearly constant “flat line” for each and every measurement. Ideally, we should also repeat observing the same geometry for confirmation. After such stringent observations (e.g., Nedelcu et al. 2007; Lazzarin et al. 2010; Perna et al. 2010), the surface heterogeneity on asteroids can be securely confirmed.

Another method for detecting surface heterogeneity through point-source observations is to perform polarization observations sampling the whole rotation phase (Degewij et al. 1979). Degewij et al. (1979) showed that 4 Vesta exhibits rotational variation of its polarimetric curve; 20 yr later, spatially resolved Hubble Space Telescope imaging of 4 Vesta confirmed surface heterogeneity (Binzel et al. 1997). Similarly, for 16 Psyche, surface heterogeneity was confirmed by polarizational observations (Castro-Chacón et al. 2022) and spatially disk-resolved observations (Ferrais et al. 2020; Cambioni et al. 2022). Ideally, combining the two independent methods, polarimetry and spectroscopy, would provide a higher level of confidence of detecting surface heterogeneity.

However, it is difficult to detect surface heterogeneity in the latitude direction with only a few rotation periods when an asteroid is observed as a point source. Therefore, to confirm heterogeneity detection, the most reliable method is to spatially decompose the asteroid and measure differences in albedo and color across its surface, e.g., by means of integral-field spectrographs.

A-type asteroids—As mentioned in Section 6, A-type asteroids have a high abundance of optimistic and conservative heterogeneous candidates compared to other spectral types. Possible reasons are discussed hereafter.

A-type asteroids are considered olivine-dominated asteroids and originated from the mantle of differentiated bodies (e.g., Cruikshank & Hartmann 1984; Sunshine et al. 2007). Most A-type asteroids have very red spectra (e.g., DeMeo et al. 2009, 2019), but olivine-dominated asteroids with an unweathered surface (flatter spectra) have been found among NEAs (Reddy et al. 2011; Hasegawa et al. 2018).

We do not observe any predominant change in absorption-band positions in the spectra of A-type asteroids with spectral heterogeneity (Figure 3). In Sunshine et al. (2007), a method for determining the compositional ratios of fayalite/forsterite from observed spectra is presented; they are derived from the band position and band intensity after subtraction of the spectral continuum. Combining Sunshine et al.’s method with this study indicates that there are no compositional differences in the constituent minerals forming the surface layers of A-type asteroids with observed spectral variability (see Appendix C). Yamada et al. (1999) performed space-weathering simulation experiments and showed that the position of absorption bands in peridotite does not change with the degrees of space weathering, but the spectral continuum does. Combining results from these space-weathering experiments with our study indicates that the spectra of A-type asteroids with detected heterogeneity can be explained by the degree of the space-weathering process.

Experiments of Yamada et al. (1999), Sasaki et al. (2001, 2003), Matsuoka et al. (2015, 2020), and Hasegawa et al. (2019) simulating space weathering were conducted on the same experimental and measurement instruments, allowing for direct comparison. The laser irradiation energy and the reflectance at $2.4 \mu\text{m}$ of the spectrum normalized by $0.55 \mu\text{m}$ for the olivine (A-type asteroid), ordinary chondrite (S-complex asteroid), and carbonaceous meteorites (Ch/Cgh-type asteroid) derived from these studies are shown in Figure 9. Assuming that laser irradiation energy correlates linearly with the time during which an object was exposed to space weathering, if the two ages of the two spectra of a given asteroid are the same, then the difference in reflectance change at $2.4 \mu\text{m}$ must be greater for the A-type asteroid than for the S-complex asteroids. In other words, an A-type asteroid spectrally reddens faster than an S-complex asteroid. Therefore, the higher heterogeneity detection rate of A-type asteroids with respect to S-complex may be due to the tendency of these bodies to redden more quickly. Along these lines, Vernazza et al. (2009) showed that olivine-rich asteroids/meteorites are more sensitive to space weathering.

Asteroid surfaces are covered with craters of different sizes and ages. The oldest surfaces of bodies within the 10–100 km size range are known to be a few Gyr old (Table 6 in Bottke et al. 2020). However, in the case of Ch/Cgh-type asteroids, the spectral changes due to space weathering are matured in $10^{3.5}$ – $10^{4.5}$ yr (see next subsection), meaning that no significant spectral change occurs after such a timescale. It is possible that the spectral change in A-type asteroids progressively reaches maturation after $\sim 10^{6.5}$ yr compared to the S-complex asteroids ($\sim 10^{5.5}$ yr; see next subsection). In other words, A-type asteroids would continue to undergo spectral changes relative to space weathering over a longer period of time than asteroids

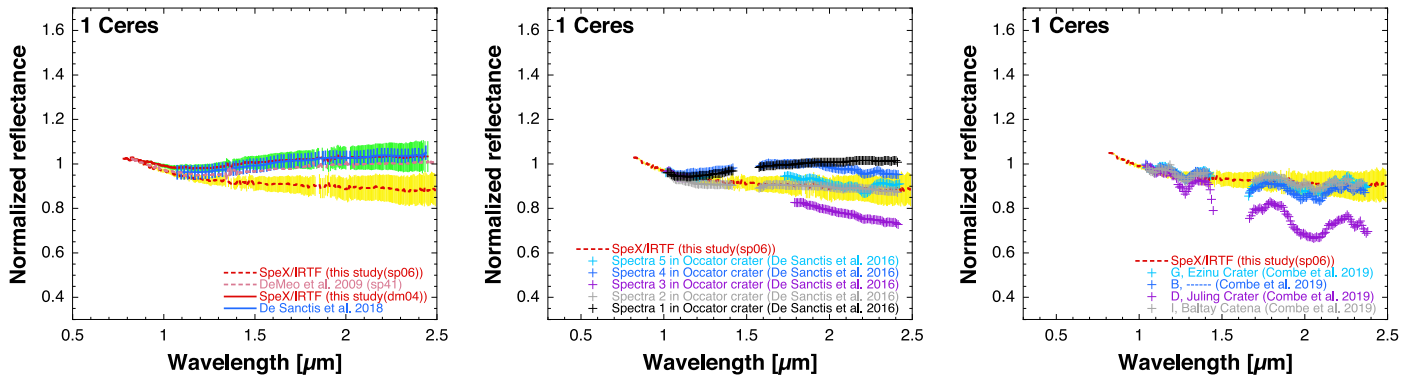


Figure 7. Left panel: comparison between the spectra of 1 Ceres obtained in this study and the average spectrum from the DAWN spacecraft (de Sanctis et al. 2018). Middle panel: comparison between the sp06 spectrum of 1 Ceres obtained in this study and spectra of the Occator crater (De Sanctis et al. 2016). Five regions are located in the ~ 90 km Occator crater on 1 Ceres. Spectra 5 and 1 correspond to the brightest area and dark floor in Occator, respectively. As the numbers in the spectrum become smaller, their reflectances are decreasing (e.g., absolute reflectance values of craters 5, 4, 3, 2, and 1 at $1.0 \mu\text{m}$ are 0.25, 0.13, 0.10, 0.05, and 0.03, respectively). Right panel: comparison between the sp06 spectrum of 1 Ceres obtained in this study and spectra of exposed water-rich areas (Combe et al. 2019).

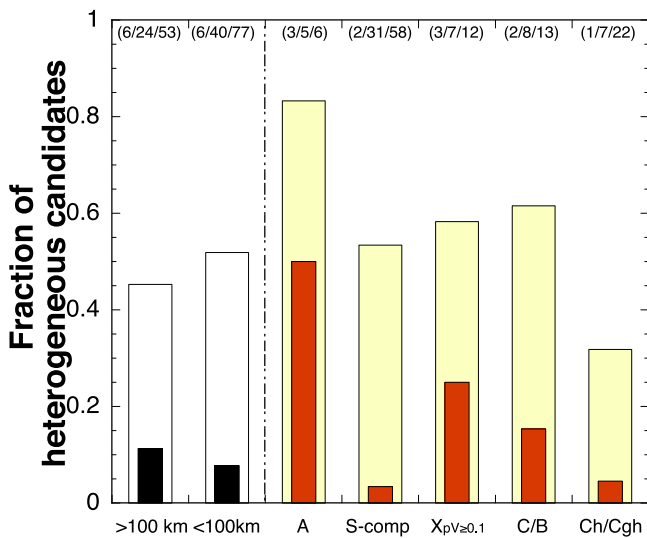


Figure 8. Fraction of heterogeneous candidates for each asteroid size and taxonomic type. We emphasize that nondetection does not necessarily imply intrinsic surface homogeneity. Hence, this fraction of heterogeneity candidates is a lower limit. The numbers in the parentheses above the graph indicate conservative heterogeneous candidates/optimistic+conservative heterogeneous candidates/total number.

of other spectral types. On the other hand, the intensity of spectral change for A-type asteroids in response to space weathering may be more than 3 times more variable than for Ch/Cgh-type and S-complex asteroids (see Figure 9). In other words, compared to other spectral type asteroids, A-type asteroids may show a more pronounced change in spectral slope for a similar range of surface ages.

In summary, there are two factors that can cause differences in the spectral slope of asteroids due to space weathering. The first factor is the saturation time of spectral change due to space weathering relative to the difference in surface age. The longer the saturation time due to space weathering, the easier it is to detect the surface heterogeneity. The second factor is the large amount of spectral variation in response to space weathering. Both factors might act in favor of A-type asteroids. This may be due to the fact that olivine, the major mineral in the surface layer of A-type asteroids, reacts more efficiently to space weathering and has a longer saturation timescale with respect to other minerals.

Age of space weathering—As mentioned earlier, the space-weathering simulation experiments of Yamada et al. (1999), Sasaki et al. (2001, 2003), Matsuoka et al. (2015, 2020), and Hasegawa et al. (2019) were conducted using a consistent experimental setup and instrument, allowing for direct comparison between measurements obtained for a wide range of materials. Using results from these experiments, space-weathering ages for each asteroid can be estimated.

The space-weathering age of 25143 Itokawa is assumed to be 10^3 – 10^4 yr based on previous studies (Noguchi et al. 2014; Matsumoto et al. 2018; Jin & Ishiguro 2022). This estimation does not take into account changes in spectra due to differences in particle size. Both solar wind and micrometeoroid impacts vary by roughly 1 order of magnitude between the near-Earth region and the main asteroid belt (Divine 1993; Jehn 2000). Taking this into account, and assuming one or both of these phenomena are the main cause for spectral changes, the space-weathering age of an S-complex asteroid in the main belt with a reflectivity of $2.4 \mu\text{m}$ equivalent to that of 25143 Itokawa would be roughly 10^4 – 10^5 yr. Based on the range of spectral changes observed among heterogeneous S-complex asteroid candidates (lime area in Figure 9), the lower limit of the space-weathering age is approximately $10^{3.5}$, and the upper limit of the space-weathering age is more than $10^{5.5}$. This range of values overlaps with the obtained space-weathering age range of $10^{5.5}$ – $10^{9.5}$ yr for families of S-complex asteroids in the main belt (Vernazza et al. 2009; Marchi et al. 2012).

Other factors from space-weathering exposure age may explain the spectral slope variability of A-type asteroids. In the case of an A-type asteroid with a high metal content, the olivine content would be relatively low, in which case the spectral reddening due to space weathering would be less. Cloutis et al. (2015) showed the metal content of some A-type asteroids (289 Nenetta: 15%; 354 Eleonora: 20%; 863 Benkoela: 5%; 3819 Robinson: 5%). 354 Eleonora may have a low degree of reddening due to low olivine content. In contrast, the lower degree of reddening in the case of 3819 Robinson, which has the same olivine content as 863 Benkoela, may be due to the fact that the surface is younger than that of 3819 Robinson.

Surface layers of Ch/Cgh-type asteroids in the main belt are roughly $10^{3.5}$ – $10^{4.5}$ yr old when space weathering is mature. This indicates that the surfaces of most of the existing Ch/Cgh-type asteroids have undergone space weathering and that their spectra have reached maturation.

Table 2
Candidates of Heterogeneous Surface of Each Type of Asteroid

No.	Diameter ^a (km)	Geometric Albedo ^a	Number of Times Observed	BD Tax. ^b	Heterogeneity Candidate ^c	Remark
354	151.3	0.202	2	A	YY	
863	32.4	0.443	2	A	YY	
289	32.3	0.267	2	A	Y	
3819	11.1	0.219	2	A	Y	
35925	4.4	0.176	2	A	YY	
8838	14.3	0.237	2	A		A: 3/5/6
4	495.0	0.382	2	V		
3613			2	V	Y	V: 0/1/2
2234	9.5	0.284	2	R	Y	R: 0/1/1
29	202.9	0.197	2	S	Y	
14	142.4	0.263	2	S	Y	
20	138.5	0.234	2	S	YY	
28	109.2	0.225	2	S	Y	
346	95.3	0.282	2	S	Y	
103	86.1	0.207	2	S	Y	
25	79.2	0.210	3	S	Y	
133	69.9	0.233	2	S	Y	
258	64.6	0.170	2	S	Y	
67	58.7	0.252	2	S	Y	
119	58.5	0.222	2	S	Y	
631	54.8	0.197	3	S	Y	
33	54.0	0.232	2	S	Y	
371	51.1	0.234	3	S	Y	
118	40.2	0.217	3	S	Y	
288	31.2	0.226	2	S	Y	
793	27.5	0.186	2	S	Y	
600	24.8	0.243	2	S	Y	
3573			2	S	Y	
7	227.0	0.228	2	S		
532	202.3	0.213	3	S		
6	192.7	0.249	2	S		
18	140.0	0.225	2	S		
57	113.8	0.211	2	S		
27	111.9	0.225	2	S		
23	106.9	0.257	2	S		
37	105.8	0.193	3	S		
30	94.0	0.192	2	S		
26	88.4	0.229	2	S		
61	83.8	0.214	3	S		
17	83.2	0.205	2	S		
389	79.3	0.200	3	S		
115	71.9	0.400	2	S		
82	60.9	0.210	2	S		
485	59.3	0.246	2	S		
925	58.1	0.247	2	S		
403	46.6	0.191	2	S		
158	36.3	0.263	2	S		
2977	9.1	0.179	2	S		
984	32.9	0.402	3	Sa	Y	
3	232.5	0.242	3	Sq	Y	
720	34.0	0.201	2	Sq		
512	22.0	0.201	3	Sqw	Y	
39	160.2	0.265	2	Sqw		
237	40.3	0.220	3	Sr	Y	
808	32.4	0.213	2	Sr	Y	
180	24.9	0.220	2	Sr	Y	
1228	16.2	0.170	2	Sr		
32	82.0	0.250	2	Sw	Y	
108	70.0	0.201	3	Sw	Y	
364	28.0	0.252	2	Sw	Y	
5401	9.6	0.368	2	Sw	Y	

Table 2
(Continued)

No.	Diameter ^a (km)	Geometric Albedo ^a	Number of Times Observed	BD Tax. ^b	Heterogeneity Candidate ^c	Remark
3873	7.5	0.512	2	Sw	Y	
5641	5.7	0.455	3	Sw	YY	
675	67.7	0.267	2	Sw		
244	11.2	0.194	3	Sw		
1139			2	Sw		S-comp: 2/31/58
6478			2	Q/S		Cometary-like activity
15	247.8	0.223	2	K	Y	
3844			2	L		
387	102.8	0.182	2	L		
679	58.4	0.135	2	L		K/L: 0/1/4
21	102.1	0.201	3	Xc (X)	YY	
16	230.2	0.151	2	Xk	Y	
359	47.3	0.230	2	Xk	YY	
69	135.4	0.149	2	Xk		
216	125.3	0.138	2	Xk		
92	123.7	0.263	2	Xk		
110	85.8	0.183	2	Xk		
55	65.0	0.319	2	Xk		
64	58.2	0.466	2	Xe	Y	
2867	5.2	0.300	2	Xe	Y	
44	73.2	0.512	2	Xn	Y	
4455	13.8	0.337	2	Xn	YY	X _{albedo} ≥0.1: 3/7/12
233	98.5	0.096	2	Xk	Y	
160	79.5	0.066	2	Xc		X _{albedo} <0.1: 0/1/2
20786			3	Xk/Xn	Y	X _{albedo} unknown: 0/1/1
2	505.3	0.154	2	B		
1	973.9	0.087	3	C	Y	
10	417.8	0.069	3	C	YY	
45	200.2	0.047	2	C	Y	
128	176.2	0.059	3	C	Y	
93	144.3	0.071	2	C	YY	
360	122.1	0.049	2	C	Y	
74	115.9	0.046	2	C	Y	
965	59.5	0.061	2	C	Y	
31	264.1	0.051	2	C		
120	162.9	0.053	2	C		
444	162.8	0.049	2	C		
688	43.1	0.058	2	C		C/B: 2/8/13
54	154.8	0.057	4	Cgh	Y	
106	150.0	0.087	2	Cgh	Y	
144	142.3	0.060	2	Cgh	Y	
70	130.5	0.060	2	Cgh	Y	
38	107.5	0.076	2	Cgh		
1128	39.5	0.061	2	Cgh		
1300	29.8	0.088	2	Cgh		
706	29.3	0.056 ^d	2	Cgh		
130	182.0	0.079	2	Ch	Y	
301	53.1	0.057	2	Ch	Y	
19	198.0	0.064	2	Ch		
121	189.8	0.061	2	Ch		
41	176.8	0.080	3	Ch		
49	148.9	0.060	2	Ch		
145	139.0	0.052	2	Ch		
156	120.0	0.043	2	Ch		
105	118.3	0.035	3	Ch		
36	110.5	0.054	2	Ch		
58	92.2	0.060	2	Ch		
50	89.4	0.045	2	Ch		

Table 2
(Continued)

No.	Diameter ^a (km)	Geometric Albedo ^a	Number of Times Observed	BD Tax. ^b	Heterogeneity Candidate ^c	Remark
66	71.8	0.062	2	Ch		
266	106.9	0.052	2	Ch (B)	YY	Ch/Cgh: 1/7/22
269	54.4	0.098	2	D		
322	70.9	0.084	2	D (X)	YY	
308	134.8	0.053	2	T		D/T: 1/1/3
596	114.6	0.037	3	T (D)		Cometary-like activity

Notes.

^a Mean diameters and geometric albedos obtained from IRAS (Tedesco et al. 2002), AKARI (Usui et al. 2011), and Wide-field Infrared Survey Explorer (Masiero et al. 2011).

^b The Bus–DeMeo taxonomy for this study.

^c Y: “optimistic” candidates. YY: “conservative” candidates.

^d An albedo value of 706 was obtained using the new absolute magnitude of 11.4 instead of the old absolute magnitude of 10.5.

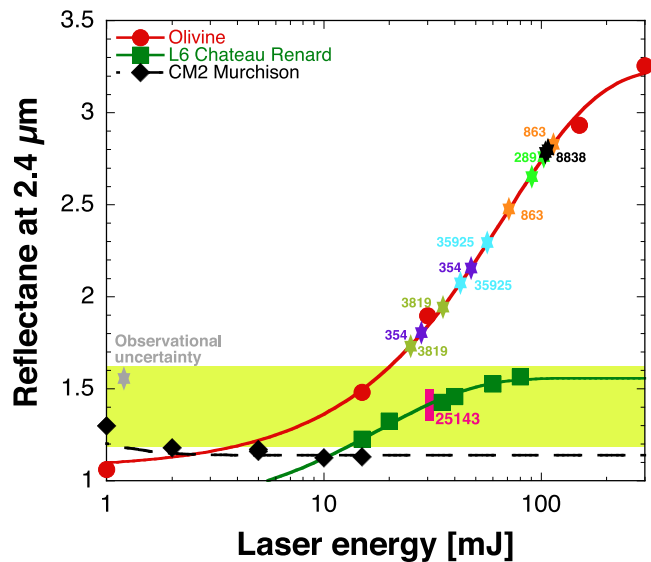


Figure 9. This figure shows the spectral reddening of meteorite samples in response to laser bombardment as a function of the laser energy level. The vertical axis indicates the reflectance value of the bombarded sample at $2.4 \mu\text{m}$ after normalization of the spectrum to a value of 1 at $0.55 \mu\text{m}$. The horizontal axis corresponds to the laser energy. Data for the olivine, L6 Chateau Renard meteorite, and CM2 Murchison meteorite were taken from Sasaki et al. (2001, 2003), Matsuoka et al. (2015, 2020), and Hasegawa et al. (2019). The olivine spectrum is on the verge of maturation after 150–300 mJ of laser irradiation. As an archetype of ordinary chondrites, we show the L6 Chateau Renard meteorite because there are a large number of data available for that meteorite. In the case of that meteorite, maturation is reached at an irradiation of 60–80 mJ. A multiplication factor was applied to the results obtained for the chip sample in order to match the results obtained for pellet samples. Data from the CM2 Murchison meteorite were used as carbonaceous chondrites. The spectrum of the Murchison meteorite is in a mature state after 5–10 mJ laser irradiation. The lime area indicates the distribution range of S-complex asteroids with confirmed heterogeneity. The observation uncertainty (gray star) is taken from Marsset et al. (2020b).

Spectral slope variability can be caused not only by space weathering (e.g., Yamada et al. 1999; Lantz et al. 2018) but also by particle size (e.g., Johnson & Fanale 1973; Hasegawa et al. 2019). Note that the ages listed here do not take into account additional spectral variability due to variations in surface grain size, so the ages are only indicative values.

8. Conclusions

Terrestrial planets such as the Earth, Mars, Mercury, and the Moon have albedo and spectral changes across their surfaces, coming from heterogeneous surface composition. The three largest asteroids, 1 Ceres, 2 Pallas, and 4 Vesta, and asteroids with diameters greater than 100 km, 3 Juno, 10 Hygiea, 16 Psyche, and 21 Lutetia, are also known to display surface heterogeneity at hemispheric scales (see Section 1). Meanwhile, the surface layers of 433 Eros, 101955 Bennu, and 162173 Ryugu, which are less than 20 km in diameter, have been found to be homogeneous at hemispheric scales through spacecraft observations (see Section 1). These results appeared to show that the boundary between homogeneous and heterogeneous asteroid surfaces is located around 100 km, but the possibility of observational bias is very high. To confirm this, it would be necessary to observe MBAs using giant telescopes such as ELT, TMT, and GMT, which are currently under construction and capable of spatially resolving 20–30 km diameter MBAs. In the meantime, we present here a candidate selection of MBAs exhibiting signs of surface heterogeneity using the MITHNEOS database, where observations were made using a self-consistent method over a 20 yr period. Twelve asteroids—10 Hygiea (C), 20 Massalia (S), 21 Lutetia ($X_{pv} \geq 0.1$), 93 Minerva (C), 266 Aline (Ch), 322 Phaeo (D), 354 Eleonora (A), 359 Georgia ($X_{pv} \geq 0.1$), 863 Benkoela, 4455 Ruriko ($X_{pv} \geq 0.1$), 5641 McCleese (Sw), and 35925 1999 JP₁₀₄ (A)—are identified as conservative heterogeneity candidates. Another 52 asteroids fulfill our less stringent criteria, and we consider those as optimistic candidates. The fraction of optimistic+conservative and conservative candidates for MBAs larger than 100 km in diameter are 45% and 11%, respectively. The percentage of optimistic+conservative and conservative heterogeneous candidates for MBAs smaller than 100 km in diameter are 52% and 8%, respectively. Our study implies that there is no size boundary between heterogeneous/homogeneous asteroid surfaces near 100 km. Note that the candidate rate in this study is a lower limit, and it is possible that many more objects actually have surface heterogeneity.

The derived fractions of optimistic+conservative and conservative candidates for A-type, S-complex, $X_{pv} \geq 0.1$ -complex, C/B-type, and Ch/Cgh-type asteroids with heterogeneous surface layers are found to be 83%, 53%, 58%, 62%,

and 32% and 50%, 3%, 25%, 15%, and 5%, respectively. The difference between the heterogeneity candidate rate of A-type and S-complex asteroids suggests that space weathering is the main cause of spectral heterogeneity in these classes of objects.

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Facility: IRTF:3.2mIRTF.

Software: IRAF (Tody 1993), IDL.

Appendix A Observational Circumstances

Observation logs of MBAs obtained by MITHNEOS and Vernazza's studies are shown in Tables A1 and A2.

Table A1
Observational Circumstances of MITHMBAs

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V ^a (mag)	R _h ^a (au)	Δ ^a (au)	α ^a (deg)	BD Tax. ^a	References
1	Ceres		sp06	2001-06-22T12:15:16	12:22:40	7.6	2.892	1.911	6.5	()	
1	Ceres		sp41 ^b	2005-05-19T07:35:18	07:41:34	7.1	2.697	1.707	5.6	C	DeMeo et al. (2009)
1	Ceres		sp41 ^b	2005-05-19T10:09:44	10:16:01	7.1	2.697	1.708	5.6	C	DeMeo et al. (2009)
1	Ceres		sp41 ^b	2005-05-19T12:00:59	12:07:19	7.1	2.697	1.708	5.7	C	DeMeo et al. (2009)
1	Ceres		dm04	2011-12-01T05:45:59	05:50:45	8.8	2.940	2.614	19.3	()	
2	Pallas		sp05	2001-03-29T15:27:52	15:37:12	9.4	2.911	2.443	19.0	B	DeMeo et al. (2009)
2	Pallas		sp89	2010-03-17T14:24:02	14:28:00	8.9	2.684	2.066	19.1	()	
3	Juno		sp13	2002-05-08T05:59:03	06:25:07	10.2	2.657	2.409	22.3	()	Marsset et al. (2024)
3	Juno		sp21	2003-03-17T14:12:47	14:23:50	10.6	3.278	2.599	14.3	Sq	DeMeo et al. (2009)
3	Juno		sp96	2011-01-06T14:18:45	14:22:37	9.9	2.605	2.145	21.2	()	Marsset et al. (2024)
4	Vesta		sp02	2000-10-09T05:15:41	05:36:50	7.3	2.262	1.898	22.2	V	DeMeo et al. (2009)
4	Vesta		sp86	2009-11-18T15:48:34	15:54:40	7.9	2.477	2.330	23.5	()	
5	Astraea		sp28	2004-02-19T15:23:03	15:30:29	10.9	2.244	1.721	24.6	S	DeMeo et al. (2009)
6	Hebe		sp67	2008-01-15T12:04:26	12:09:15	9.4	2.534	1.627	10.7	S	Vernazza et al. (2014)
6	Hebe		sp68	2008-03-10T06:33:43	06:44:17	9.8	2.642	1.799	13.8	()	
7	Iris		sp16	2002-08-17T10:47:54	10:57:07	8.0	2.128	1.135	7.3	()	
7	Iris		sp28	2004-02-20T13:23:07	13:43:02	9.3	2.571	1.648	9.9	S	DeMeo et al. (2009)
8	Flora		sp13	2002-05-08T06:30:11	07:09:12	10.9	2.430	2.005	23.9	S	DeMeo et al. (2009)
9	Metis		sp75	2008-10-31T09:53:25	09:58:07	8.5	2.135	1.147	3.4	K	
10	Hygiea		sp08	2001-08-24T10:34:37	10:49:42	9.9	3.155	2.155	3.2	()	
10	Hygiea		sp28	2004-02-19T05:24:27	05:56:47	10.9	3.314	2.588	13.2	C	DeMeo et al. (2009)
10	Hygiea		sp111	2012-08-28T10:00:32	10:02:14	9.8	3.120	2.118	2.8	()	Vernazza et al. (2020)
11	Parthenope		sp47	2005-11-13T12:16:39	12:24:10	10.3	2.513	1.619	12.1	Sq	DeMeo et al. (2009)
13	Egeria		sp41	2005-05-19T05:54:53	06:05:56	11.3	2.459	1.990	23.4	Ch	DeMeo et al. (2009)
14	Irene		sp18	2002-09-28T10:05:55	10:28:45	10.7	3.016	2.049	6.0	()	
14	Irene		sp25	2003-10-01T15:21:48	15:29:24	11.4	2.737	2.331	20.9	S	DeMeo et al. (2009)
15	Eunomia		sp16	2002-08-17T11:44:10	11:53:23	8.5	2.269	1.364	14.8	()	
15	Eunomia		sp28	2004-02-19T09:21:54	09:25:26	9.1	2.757	1.787	4.8	K	DeMeo et al. (2009)
16	Psyche		sp02	2000-10-09T13:59:50	14:12:01	6.3	2.594	2.000	20.3	Xk	DeMeo et al. (2009)
16	Psyche		sp58	2007-01-21T14:05:51	14:26:30	11.1	3.191	2.446	13.2	()	
17	Thetis		sp07	2001-08-15T14:35:41	14:56:09	12.6	2.588	2.196	22.6	S	DeMeo et al. (2009)
17	Thetis		sp96	2011-01-06T13:56:13	14:14:19	12.1	2.598	1.891	17.7	()	Vernazza et al. (2014)
18	Melpomene		sp06	2001-06-22T07:19:53	07:42:05	11.2	2.712	2.141	20.1	S	DeMeo et al. (2009)
19	Fortuna		sp48	2005-11-22T08:32:01	08:34:14	9.6	2.062	1.113	10.2	()	
19	Fortuna		sp49	2006-01-29T05:59:32	06:17:37	11.3	2.117	1.781	27.6	Ch	DeMeo et al. (2009)
20	Massalia		sp06	2001-06-22T13:13:00	13:37:26	10.8	2.736	1.885	14.1	S	DeMeo et al. (2009)
20	Massalia		sp96	2011-01-06T14:24:47	14:28:40	10.3	2.163	1.659	25.8	()	Marsset et al. (2024)
21	Lutetia		sp31	2004-09-22T13:35:39	13:47:26	10.8	2.173	1.369	20.1	Xc	DeMeo et al. (2009)
21	Lutetia		sp61	2007-07-20T05:32:41	06:13:08	11.1	2.229	1.485	22.0	()	

Table A1
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V ^a (mag)	R _n ^a (au)	Δ ^a (au)	α ^a (deg)	BD Tax. ^a	References
21	Lutetia		sp76	2008-12-03T11:30:50	11:37:54	10.3	2.428	1.444	1.6	()	Vernazza et al. (2012)
22	Kalliope		sp55	2006-10-25T13:43:42	13:55:16	11.0	2.616	1.998	19.6	X	DeMeo et al. (2009)
23	Thalia		sp96	2011-01-06T11:06:31	11:07:36	9.3	2.018	1.080	11.5	S	Vernazza et al. (2014)
24	Themis		sp45	2005-10-08T05:28:30	05:42:41	12.8	3.533	2.832	12.9	C	DeMeo et al. (2009)
25	Phocaea		sp03	2001-01-30T11:22:43	11:37:45	12.6	2.972	2.106	10.8	S	DeMeo et al. (2009)
25	Phocaea		sp94	2010-10-13T15:20:04	15:27:34	11.2	2.302	1.406	14.0	()	Marsset et al. (2024)
26	Proserpina		sp08	2001-08-24T07:59:21	08:28:00	10.9	2.617	1.618	4.4	S	DeMeo et al. (2009)
26	Proserpina		sp92	2010-07-11T14:53:32	15:02:48	12.4	2.692	2.257	21.5	()	
27	Euterpe		sp14	2002-06-01T05:57:29	06:25:05	11.5	2.365	1.998	25.1	()	
27	Euterpe		sp31	2004-09-22T13:51:18	13:53:50	10.3	2.109	1.330	21.8	S	DeMeo et al. (2009)
28	Bellona		sp09	2002-01-13T14:33:57	14:49:17	10.9	2.374	1.584	17.4	S	DeMeo et al. (2009)
29	Amphitrite		sp03	2001-01-29T15:29:22	15:41:57	10.7	2.649	2.210	21.0	S	DeMeo et al. (2009)
29	Amphitrite		sp92	2010-07-12T10:11:53	10:17:37	9.5	2.682	1.685	5.3	()	
30	Urania		sp02	2000-10-08T???:???:?c	???:???:?c	10.1	2.067	1.110	10.8	S	DeMeo et al. (2009)
30	Urania		sp92	2010-07-12T06:44:03	06:51:19	11.6	2.543	1.701	15.7	()	Vernazza et al. (2014)
32	Pomona		sp03	2001-01-30T05:50:06	06:14:44	12.4	2.659	2.080	19.5	Sw	DeMeo et al. (2009)
32	Pomona		sp76	2008-12-03T07:00:58	07:21:01	11.9	2.771	1.905	11.8	()	Vernazza et al. (2014)
33	Polyhymnia		sp10	2002-03-06T11:40:05	12:07:52	14.0	3.762	2.811	5.0	S	DeMeo et al. (2009)
34	Circe		sp28	2004-02-20T07:37:05	07:51:11	12.7	2.456	1.781	19.9	Ch	DeMeo et al. (2009)
36	Atalante		sp97	2011-02-07T05:04:37	05:41:45	12.6	1.952	1.885	29.7	Ch	
37	Fides		sp07	2001-08-15T13:26:51	13:49:12	11.1	2.494	1.650	15.9	S	DeMeo et al. (2009)
37	Fides		sp94	2010-10-13T15:30:44	15:38:14	10.7	2.201	1.439	20.8	()	Vernazza et al. (2014)
38	Leda		sp23	2003-07-05T10:23:38	10:39:09	12.9	3.152	2.157	4.6	Cgh	DeMeo et al. (2009)
38	Leda		sp100	2011-06-07T05:52:03	06:03:49	13.1	2.862	2.125	16.3	()	
39	Laetitia		sp07	2001-08-14T14:48:16	15:06:03	10.3	2.460	1.848	21.8	Sqw	DeMeo et al. (2009)
39	Laetitia		sp92	2010-07-11T14:42:02	14:50:38	10.5	2.489	1.916	22.2	()	Vernazza et al. (2014)
40	Harmonia		sp32	2004-10-16T12:15:32	12:23:08	9.4	2.165	1.174	3.8	S	DeMeo et al. (2009)
41	Daphne		sp70	2008-05-10T09:08:53	09:15:12	9.9	2.021	1.124	17.7	Ch	DeMeo et al. (2009)
41	Daphne		sp84	2009-09-20T09:53:09	10:00:39	11.4	3.081	2.082	2.2	()	
42	Isis		sp06	2001-06-21T09:38:52	09:53:58	9.9	2.079	1.084	7.9	K	DeMeo et al. (2009)
43	Ariadne		sp48	2005-11-22T08:21:09	08:28:24	11.4	2.327	1.448	14.1	Sq	DeMeo et al. (2009)
44	Nysa		sp06	2001-06-21T12:41:37	13:17:53	11.1	2.783	1.907	12.8	()	
44	Nysa		sp71	2008-06-11T10:25:12	10:40:19	10.6	2.666	1.670	5.3	Xn	DeMeo et al. (2022)
45	Eugenia		sp79	2009-03-30T10:40:23	10:52:08	11.1	2.581	1.614	7.0	C	Vernazza et al. (2012)
47	Aglaja		sp98	2011-04-05T05:06:44	05:21:07	13.6	3.265	2.863	17.2	C	
48	Doris		sp45	2005-10-08T05:14:26	05:24:35	12.4	3.184	2.593	16.1	Ch	DeMeo et al. (2009)
49	Pales		sp24	2003-08-02T08:17:27	08:35:28	12.6	3.124	2.195	8.9	Ch	DeMeo et al. (2009)
50	Virginia		sp23	2003-07-05T09:00:20	09:43:05	13.5	2.738	1.838	12.1	Ch	DeMeo et al. (2009)
50	Virginia		sp265	2020-05-27T09:04:59	09:29:41	13.8	3.077	2.087	4.9	()	
51	Nemausa		sp29	2004-06-14T09:16:11	09:19:29	10.9	2.308	1.360	11.8	Cgh	DeMeo et al. (2009)
52	Europa		sp52	2006-06-28T06:30:36	06:53:19	11.8	3.234	2.604	15.8	C	DeMeo et al. (2009)
54	Alexandra		sp19	2002-10-27T15:18:43	15:37:06	13.1	3.096	2.558	17.1	Cgh	DeMeo et al. (2009)
54	Alexandra		sp27	2004-02-18T12:22:13	12:49:05	12.1	3.090	2.116	3.9	()	
54	Alexandra		sp259	2019-10-26T05:58:55	06:31:36	11.5	2.520	1.602	10.9	()	DeMeo et al. (2022)
55	Pandora		sp48	2005-11-29T07:06:13	07:16:35	11.1	2.429	1.492	9.3	()	
55	Pandora		sp49	2006-01-29T05:43:52	05:54:02	12.5	2.497	2.162	23.0	Xk	DeMeo et al. (2009)
56	Melete		sp31	2004-09-22T13:56:49	14:04:21	12.6	2.550	1.849	19.0	Xc	DeMeo et al. (2009)
57	Mnemosyne		sp14	2002-06-01T06:30:35	07:00:06	13.0	3.422	2.980	16.4	S	DeMeo et al. (2009)
57	Mnemosyne		sp92	2010-07-11T14:05:45	14:15:00	12.3	3.026	2.458	17.8	()	Vernazza et al. (2014)
58	Concordia		sp24	2003-08-02T09:48:14	10:06:27	12.7	2.723	1.739	6.6	Ch	DeMeo et al. (2009)
58	Concordia		sp265	2020-05-27T06:59:18	07:46:58	13.2	2.597	1.743	14.7	()	
60	Echo		sp259	2019-10-26T06:41:06	07:13:50	13.2	2.563	2.098	21.8	S	DeMeo et al. (2022)
61	Danae		sp02	2000-10-08T???:???:?c	???:???:?c	12.5	2.753	2.183	19.3	S	DeMeo et al. (2009)
61	Danae		sp94	2010-10-14T12:26:42	12:32:02	11.6	2.604	1.704	11.7	()	
62	Erato		sp84	2009-09-20T10:13:18	10:25:05	12.5	2.641	1.669	6.9	C	Marsset et al. (2016)
63	Ausonia		sp25	2003-09-30T08:35:12	08:38:43	10.5	2.314	1.348	8.6	Sw	DeMeo et al. (2009)
64	Angelina		sp02	2000-10-08T15:09:13	15:20:49	12.0	2.455	2.146	23.9	()	
64	Angelina		sp03	2001-01-29T08:43:31	09:00:47	10.9	2.368	1.502	14.3	Xe	DeMeo et al. (2009)
65	Cybele		sp25	2003-09-30T10:06:12	10:09:44	11.5	3.509	2.509	1.2	Cb	DeMeo et al. (2009)
66	Maja		sp46	2005-10-30T08:44:58	09:06:57	12.8	2.266	1.438	17.5	()	
66	Maja		sp48	2005-11-22T06:23:32	06:32:19	13.3	2.241	1.640	23.6	Ch	DeMeo et al. (2009)
67	Asia		sp29	2004-06-15T05:28:43	05:46:41	12.1	2.274	1.580	22.6	S	DeMeo et al. (2009)

Table A1
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V ^a (mag)	R _n ^a (au)	Δ ^a (au)	α ^a (deg)	BD Tax. ^a	References
67	Asia		sp111	2012-08-28T07:24:46	07:31:37	11.0	1.977	1.112	20.3	()	
69	Hesperia		sp40	2005-05-11T05:26:43	05:40:14	12.0	2.659	2.297	22.0	Xk	DeMeo et al. (2009)
69	Hesperia		sp111	2012-08-28T06:58:01	07:05:39	12.5	3.472	2.660	11.4	()	
70	Panopaea		sp18	2002-09-29T14:17:15	14:49:19	13.2	2.777	2.372	20.6	Cgh	DeMeo et al. (2009)
72	Feronia		sp259	2019-10-26T07:27:17	07:51:21	11.7	2.154	1.184	7.7	D	DeMeo et al. (2022)
73	Klytia		sp26	2003-10-16T09:21:22	09:34:51	12.8	2.595	1.653	9.0	S	DeMeo et al. (2009)
76	Freia		sp44	2005-09-05T07:10:56	07:52:13	13.9	3.855	3.039	9.9	C	DeMeo et al. (2009)
77	Frigga		sp55	2006-10-25T08:46:07	09:27:35	11.5	2.370	1.384	4.2	Xe	DeMeo et al. (2009)
78	Diana		sp46	2005-10-31T05:14:18	05:24:28	13.0	2.857	2.182	16.8	Ch	DeMeo et al. (2009)
79	Eurynome		sp75	2008-10-31T05:07:26	05:45:21	11.6	2.122	1.586	26.3	S	Vernazza et al. (2014)
81	Terpsichore		sp98	2011-04-05T09:42:28	10:00:30	13.2	3.124	2.177	7.1	C	
82	Alkmene		sp08	2001-08-24T13:06:57	13:25:07	13.2	3.218	2.287	8.3	S	DeMeo et al. (2009)
82	Alkmene		sp92	2010-07-11T14:29:46	14:40:06	13.9	3.329	2.721	15.6	()	Vernazza et al. (2014)
84	Klio		sp24	2003-08-02T12:40:27	12:53:08	11.1	1.822	0.857	14.5	Ch	DeMeo et al. (2009)
85	Io		sp24	2003-08-02T10:12:31	10:24:46	10.3	2.151	1.176	10.1	C	DeMeo et al. (2009)
86	Semele		sp17	2002-09-15T11:06:40	11:25:45	12.3	2.505	1.603	12.7	Ch	
87	Sylvia		sp44	2005-09-04T15:15:31	15:27:18	12.9	3.351	3.010	17.2	X	DeMeo et al. (2009)
88	Thisbe		sp263	2020-01-27T06:18:43	06:34:07	12.4	2.968	2.444	17.8	C	
90	Antiope		sp44	2005-09-05T06:05:00	06:16:34	12.9	2.671	2.032	19.3	C	DeMeo et al. (2009)
92	Undina		sp02	2000-10-08T14:58:49	15:02:55	12.4	3.184	2.889	18.1	Xk	DeMeo et al. (2009)
93	Minerva		sp22	2003-04-27T08:31:05	08:57:37	11.8	2.629	1.684	9.5	C	DeMeo et al. (2009)
96	Aegle		sp49	2006-01-28T07:43:31	07:53:57	12.7	2.950	2.314	16.5	T	DeMeo et al. (2009)
97	Klotho		sp45	2005-10-08T04:55:38	05:09:48	12.9	2.806	2.497	20.7	Xc	DeMeo et al. (2009)
99	Dike		sp47	2005-11-13T12:45:06	13:23:49	14.4	3.136	2.311	11.7	Xc	DeMeo et al. (2009)
101	Helena		sp57	2006-12-22T14:12:33	14:24:19	12.5	2.817	1.914	9.6	S	DeMeo et al. (2009)
103	Hera		sp07	2001-08-14T11:14:30	11:32:25	10.8	2.485	1.477	2.8	S	DeMeo et al. (2009)
103	Hera		sp92	2010-07-11T14:17:49	14:27:05	11.9	2.484	1.799	20.5	()	Vernazza et al. (2014)
105	Artemis		sp24	2003-08-02T12:16:50	12:34:12	11.8	2.215	1.319	16.0	Ch	DeMeo et al. (2009)
105	Artemis		sp25	2003-09-30T07:20:45	07:26:53	12.3	2.332	1.515	17.8	Ch	
106	Dione		sp24	2003-08-02T11:08:52	11:26:13	11.6	2.936	1.939	4.6	Cgh	DeMeo et al. (2009)
108	Hecuba		sp10	2002-03-06T13:55:33	14:23:17	13.0	3.074	2.256	12.2	Sw	DeMeo et al. (2009)
108	Hecuba		sp14	2002-05-31T07:57:29	08:25:31	13.3	3.090	2.393	15.5	Sw	
108	Hecuba		sp92	2010-07-12T14:34:40	14:53:01	14.1	3.410	3.032	16.9	()	Vernazza et al. (2014)
110	Lydia		sp03	2001-01-29T15:06:42	15:24:01	12.8	2.946	2.316	16.7	Xk	DeMeo et al. (2009)
110	Lydia		sp64	2007-10-02T07:53:33	08:19:03	11.6	2.521	1.644	13.6	()	
111	Ate		sp31	2004-09-22T08:05:36	08:19:07	11.8	2.707	1.724	5.3	Ch	DeMeo et al. (2009)
113	Amalthea		sp87	2010-01-17T13:30:19	13:46:35	11.9	2.269	1.396	14.6	Sqw	
114	Kassandra		sp52	2006-06-28T07:18:37	09:38:14	12.3	2.705	1.761	9.9	K	DeMeo et al. (2009)
115	Thyra		sp10	2002-03-06T13:19:53	13:49:35	12.0	2.746	1.955	14.9	S	DeMeo et al. (2009)
117	Lomia		sp285	2021-09-09T08:50:07	09:08:05	12.2	2.942	1.941	2.8	C	
118	Peitho		sp102	2011-09-25T15:21:39	15:29:20	12.2	2.208	1.279	12.9	S	Vernazza et al. (2014)
119	Althaea		sp06	2001-06-21T08:37:05	08:39:30	12.6	2.687	1.777	11.9	S	DeMeo et al. (2009)
119	Althaea		sp92	2010-07-11T13:53:22	14:02:37	12.3	2.461	1.621	16.5	()	Vernazza et al. (2014)
120	Lachesis		sp27	2004-02-18T13:32:39	13:56:46	12.4	2.972	2.093	10.4	C	
121	Hermione		sp99	2011-04-30T07:23:00	07:37:20	13.8	3.777	3.529	15.4	Ch	
128	Nemesis		sp23	2003-07-05T09:53:09	10:15:09	11.6	2.821	1.844	7.1	()	
128	Nemesis		sp24	2003-08-02T07:21:18	07:45:38	12.1	2.786	2.022	16.2	C	DeMeo et al. (2009)
128	Nemesis		sp263	2020-01-27T14:04:26	14:17:20	12.7	3.004	2.269	14.4	()	DeMeo et al. (2022)
130	Elektra		sp05	2001-03-29T14:54:05	15:17:06	13.1	3.724	2.983	11.5	Ch	DeMeo et al. (2009)
131	Vala		sp53	2006-07-20T09:11:53	09:26:03	13.0	2.355	1.356	5.9	K	DeMeo et al. (2009)
133	Cyrene		sp06	2001-06-22T10:27:15	10:49:13	11.6	2.659	1.654	4.2	S	DeMeo et al. (2009)
140	Siwa		sp27	2004-02-18T14:57:00	15:25:09	13.3	2.675	2.316	21.3	Xc	
141	Lumen		sp91	2010-05-09T05:21:13	05:39:35	14.1	3.130	2.788	18.5	Ch	Vernazza et al. (2016)
142	Polana		sp86	2009-11-18T13:18:26	14:16:58	14.3	2.687	1.774	10.0	C	
144	Vibilia		sp27	2004-02-18T14:03:28	14:31:21	13.4	3.277	2.657	15.0	Cgh	
145	Adeona		sp89	2010-03-17T13:27:34	13:43:05	12.4	2.580	1.813	16.8	Ch	
147	Protogeneia		sp24	2003-08-02T11:32:34	11:52:22	13.0	3.052	2.052	3.9	C	DeMeo et al. (2009)
150	Nuwa		sp24	2003-08-02T09:18:06	09:42:40	12.3	2.771	1.812	8.4	C	DeMeo et al. (2009)
151	Abundantia		sp47	2005-11-13T14:27:05	14:41:26	13.9	2.559	2.118	21.9	Sw	DeMeo et al. (2009)
153	Hilda		sp40	2005-05-10T05:23:51	05:42:13	14.4	4.162	4.032	14.0	X	DeMeo et al. (2009)
158	Koronis		sp21	2003-03-16T09:49:41	10:19:35	13.3	2.908	1.918	2.3	S	DeMeo et al. (2009)
158	Koronis		sp94	2010-10-14T08:14:05	08:29:53	13.5	2.784	1.874	10.3	()	Marsset et al. (2024)

Table A1
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V ^a (mag)	R _n ^a (au)	Δ ^a (au)	α ^a (deg)	BD Tax. ^a	References
160	Una		sp23	2003-07-05T06:05:13	06:19:23	14.1	2.911	2.255	17.4	Xc	DeMeo et al. (2009)
160	Una		sp99	2011-04-30T07:00:59	07:19:20	14.3	2.727	2.487	21.6	Xc	
164	Eva		sp281	2021-05-17T11:49:15	11:59:56	13.2	3.007	2.030	6.0	Xc	
168	Sibylla		sp279	2021-01-11T08:56:46	09:20:59	13.0	3.299	2.356	5.7	Ch	
170	Maria		sp06	2001-06-22T11:49:05	12:12:08	13.6	2.711	1.821	12.7	S	DeMeo et al. (2009)
173	Ino		sp260	2019-11-03T14:47:35	14:59:05	13.3	2.717	2.671	21.2	Xc	DeMeo et al. (2022)
175	Andromache		sp47	2005-11-13T13:49:18	14:03:39	13.5	3.176	2.425	13.3	Cg	DeMeo et al. (2009)
176	Iduna		sp292	2022-04-04T10:34:18	10:52:36	13.6	3.713	2.717	1.5	Ch	
180	Garumna		sp18	2002-09-28T12:53:43	13:21:25	14.5	2.781	1.841	8.8	Sr	DeMeo et al. (2009)
180	Garumna		sp92	2010-07-12T11:10:34	11:28:55	15.1	3.177	2.219	7.3	()	Vernazza et al. (2014)
181	Eucharis		sp25	2003-10-01T10:23:15	10:36:27	12.5	3.140	2.187	6.7	L	DeMeo et al. (2009)
187	Lamberta		sp27	2004-02-18T10:55:04	11:21:55	11.6	2.464	1.523	9.0	Ch	
188	Menippe		sp12	2002-04-15T14:01:49	14:31:02	13.4	2.528	1.780	18.1	S	DeMeo et al. (2009)
191	Kolga		sp38	2005-04-12T15:20:18	15:40:13	14.3	3.104	2.415	15.3	Cb	DeMeo et al. (2009)
192	Nausikaa		sp50	2006-04-30T07:33:06	07:44:53	12.0	2.995	2.122	11.4	Sw	DeMeo et al. (2009)
196	Philomela		sp278	2020-12-10T14:14:38	14:32:36	11.8	3.162	2.375	12.4	Sq	
199	Byblis		sp21	2003-03-17T14:29:22	14:58:47	13.3	2.844	2.110	15.8	D	DeMeo et al. (2009)
200	Dynamene		sp27	2004-02-18T12:57:17	13:21:30	12.5	2.847	1.916	8.2	Ch	
201	Penelope		sp28	2004-02-19T08:26:14	08:36:52	13.1	3.070	2.191	10.0	Xk	DeMeo et al. (2009)
203	Pompeja		sp279	2021-01-14T08:51:39	09:14:35	12.9	2.617	1.753	12.6	RR	Hasegawa et al. (2021b)
205	Martha		sp24	2003-08-02T08:46:17	09:04:25	13.5	2.775	1.853	10.7	Ch	DeMeo et al. (2009)
208	Lacrimosa		sp101	2011-08-22T08:49:50	09:17:48	13.1	2.934	1.938	4.3	S	Marsset et al. (2024)
209	Dido		sp290	2022-01-28T14:55:51	15:09:31	13.8	3.056	2.721	18.5	C	
210	Isabella		sp47	2005-11-13T12:03:29	12:13:52	12.8	2.400	1.478	10.9	Cb	DeMeo et al. (2009)
212	Medea		dm08	2012-06-06T06:05:18	06:23:41	14.3	3.292	3.177	17.9	X	Hasegawa et al. (2022b)
213	Lilaea		sp258	2019-09-26T12:27:08	12:37:25	13.4	2.799	1.959	13.4	C	DeMeo et al. (2022)
214	Aschera		sp33	2004-10-24T04:56:10	05:31:51	13.8	2.647	1.948	17.9	Xn	DeMeo et al. (2009)
216	Kleopatra		sp15	2002-06-17T06:54:22	07:21:17	12.6	3.424	2.607	11.6	Xe	DeMeo et al. (2009)
216	Kleopatra		sp127	2013-12-07T07:49:01	09:07:19	9.8	1.219	2.144	12.1	()	
221	Eos		sp02	2000-10-08T???:???:?°	???:???:?°	12.4	2.864	2.050	13.7	K	DeMeo et al. (2009)
226	Weringia		sp10	2002-03-06T14:26:36	15:03:45	14.3	2.575	1.872	18.3	S	DeMeo et al. (2009)
233	Asterope		sp18	2002-09-29T14:57:28	15:18:52	13.2	2.598	2.321	22.6	Xk	DeMeo et al. (2009)
234	Barbara		sp57	2006-12-22T14:38:13	14:57:30	14.3	2.943	2.481	18.5	L	DeMeo et al. (2009)
236	Honorina		sp50	2006-05-01T09:26:17	10:02:17	12.8	3.200	2.205	3.4	L	DeMeo et al. (2009)
237	Coelestina		sp12	2002-04-15T05:52:28	06:29:38	14.8	2.939	2.818	19.9	Sr	DeMeo et al. (2009)
237	Coelestina		sp95	2010-10-27T14:56:19	15:25:20	14.5	2.955	2.504	18.7	()	Vernazza et al. (2014)
243	Ida		sp21	2003-03-17T13:08:20	13:36:13	14.6	2.943	2.106	12.4	Sw	DeMeo et al. (2009)
244	Sita		sp05	2001-03-29T06:41:46	07:14:08	15.9	2.368	1.689	21.1	Sw	DeMeo et al. (2009)
244	Sita		sp69	2008-04-13T10:59:51	11:18:03	14.9	2.466	1.465	1.9	()	Vernazza et al. (2014)
244	Sita		sp70	2008-05-10T08:18:51	08:48:11	15.5	2.455	1.518	11.2	()	
245	Vera		sp75	2008-10-31T05:59:06	06:35:47	12.6	2.607	2.118	21.2	S	Vernazza et al. (2014)
246	Asporina		sp37	2005-03-09T14:48:54	15:30:43	13.1	2.466	1.949	22.3	A	DeMeo et al. (2009)
247	Eukrate		sp278	2020-12-10T15:41:27	15:55:46	13.4	2.568	2.401	22.5	C	
250	Bettina		sp26	2003-10-16T13:35:26	13:44:47	12.0	2.903	1.991	9.6	Xk	DeMeo et al. (2009)
258	Tyche		sp08	2001-08-24T06:23:12	06:50:04	11.6	2.209	1.322	16.3	S	DeMeo et al. (2009)
261	Prymno		sp64	2007-10-02T11:50:59	12:05:20	12.8	2.491	1.521	7.3	Xk	
264	Libussa		sp41	2005-05-19T05:20:36	05:39:53	14.2	2.999	3.005	19.4	S	DeMeo et al. (2009)
266	Aline		sp44	2005-09-05T06:22:15	07:04:42	13.4	2.668	1.984	18.5	Ch	DeMeo et al. (2009)
267	Tirza		sp24	2003-08-02T10:46:27	11:04:32	13.5	2.551	1.545	3.9	D	DeMeo et al. (2009)
268	Adorea		sp84	2009-09-20T13:14:06	13:32:26	13.9	3.471	2.710	12.3	X	Marsset et al. (2016)
269	Justitia		sp18	2002-09-28T14:30:16	14:57:59	15.0	2.986	2.494	18.4	D	Hasegawa et al. (2021b)
269	Justitia		sp40	2005-05-11T14:54:13	15:12:31	12.7	2.094	1.226	18.6	D	DeMeo et al. (2009)
278	Paulina		sp14	2002-05-31T06:46:29	07:14:19	13.4	2.398	1.679	20.5	S	DeMeo et al. (2009)
279	Thule		sp35	2005-01-08T07:08:24	07:36:46	15.2	4.275	3.586	10.3	D	DeMeo et al. (2009)
286	Iclea		spBus	2019-03-04T14:46:07	15:01:58	14.7	3.271	2.756	16.2	Ch	
288	Glauke		sp18	2002-09-29T11:25:30	11:52:53	14.7	3.329	2.358	5.1	S	DeMeo et al. (2009)
288	Glauke		sp92	2010-07-12T10:47:06	11:04:16	13.0	2.602	1.585	0.6	()	Vernazza et al. (2014)
289	Netteta		sp01	2000-09-04T14:46:35	15:26:35	13.6	2.292	1.672	23.4	A	DeMeo et al. (2009)
289	Netteta		sp03	2001-01-29T05:16:54	05:41:23	14.3	2.459	2.193	23.6	()	
295	Theresia		sp18	2002-09-28T05:57:44	06:25:25	14.9	2.785	2.101	17.4	Sw	DeMeo et al. (2009)
298	Baptistina		sp97	2011-02-07T08:36:55	08:55:15	13.5	2.051	1.083	7.2	Xe	
301	Bavaria		sp89	2010-03-17T15:03:56	15:24:41	15.1	2.578	2.142	21.9	Ch	

Table A1
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V ^a (mag)	R _n ^a (au)	Δ ^a (au)	α ^a (deg)	BD Tax. ^a	References
302	Clarissa		sp233	2017-07-26T14:57:08	15:30:43	15.3	2.256	1.907	26.6	C	
308	Polyxo		sp18	2002-09-28T09:07:04	09:28:06	11.8	2.703	1.709	3.4	T	DeMeo et al. (2009)
308	Polyxo		sp39	2005-04-18T09:36:58	09:56:14	12.2	2.764	1.818	8.6	()	
316	Goberta		sp93	2010-09-07T12:35:25	12:57:15	14.7	2.998	2.085	9.8	C	Marsset et al. (2016)
322	Phaeo		sp18	2002-09-29T08:39:13	09:07:13	11.8	2.114	1.183	13.4	D	DeMeo et al. (2009)
324	Bamberga		sp263	2020-01-27T14:20:39	14:33:37	12.9	3.533	2.998	14.6	C	
334	Chicago		sp107	2012-04-21T05:23:18	05:28:09	13.6	3.900	3.025	8.2	Xc	
337	Devosa		sp18	2002-09-28T07:01:56	07:31:38	12.7	2.504	1.707	16.9	Xk	DeMeo et al. (2009)
339	Dorothea		sp89	2010-03-17T11:55:00	12:18:08	14.0	3.291	2.309	3.4	L	
344	Desiderata		sp28	2004-02-19T15:32:30	15:41:51	12.3	2.278	1.838	25.0	Ch	
345	Tercidina		sp45	2005-10-08T05:59:09	06:09:19	12.5	2.330	1.525	18.1	Ch	DeMeo et al. (2009)
346	Hermentaria		sp14	2002-05-31T06:07:17	06:40:00	12.5	3.083	2.513	17.3	S	DeMeo et al. (2009)
349	Dembowska		sp06	2001-06-22T14:39:18	14:54:24	10.5	2.814	2.128	17.6	R	DeMeo et al. (2009)
352	Gisela		sp06	2001-06-22T06:03:48	06:36:41	14.4	2.505	1.896	21.5	Sw	DeMeo et al. (2009)
354	Eleonora		sp12	2002-04-15T15:00:38	15:22:39	11.5	2.906	2.557	19.9	A	DeMeo et al. (2009)
354	Eleonora		dm02	2011-08-08T06:10:13	06:26:21	11.5	2.888	2.474	19.9	()	
359	Georgia		sp03	2001-01-30T13:20:18	13:43:48	14.3	3.147	2.288	10.3	Xk	DeMeo et al. (2009)
360	Carlova		spBus	2019-03-04T15:28:45	15:44:36	14.7	3.530	3.331	16.3	C	
364	Isara		sp61	2007-07-20T14:53:54	15:21:58	13.6	2.094	1.561	27.7	()	Marsset et al. (2024)
364	Isara		sp64	2007-10-02T11:36:45	11:46:06	11.7	1.980	0.990	6.0	Sw	Marsset et al. (2024)
365	Corduba		sp285	2021-09-12T05:16:24	05:30:43	14.6	2.890	2.524	20.0	Ch	
371	Bohemia		sp07	2001-08-14T07:05:32	07:34:05	12.7	2.580	1.701	13.8	S	DeMeo et al. (2009)
371	Bohemia		sp18	2002-09-29T12:47:50	13:17:13	13.2	2.818	1.960	12.6	()	
371	Bohemia		sp92	2010-07-12T10:35:21	10:42:52	11.9	2.573	1.557	0.6	()	Vernazza et al. (2014)
377	Campania		sp91	2010-05-09T05:43:05	05:57:25	13.9	2.817	2.303	19.6	Ch	Vernazza et al. (2016)
378	Holmia		sp12	2002-04-14T11:23:01	11:50:48	14.3	3.138	2.145	3.1	S	DeMeo et al. (2009)
387	Aquitania		sp21	2003-03-16T09:04:30	09:25:32	11.9	2.976	2.048	8.4	()	
387	Aquitania		sp22	2003-04-27T07:05:09	07:28:56	12.5	2.884	2.350	18.9	L	DeMeo et al. (2009)
389	Industria		sp08	2001-08-24T11:40:38	11:59:23	11.9	2.764	1.798	7.7	S	DeMeo et al. (2009)
389	Industria		sp94	2010-10-14T12:34:22	12:38:14	12.0	2.757	1.833	9.6	()	Vernazza et al. (2014)
402	Chloe		sp04	2001-02-19T09:18:44	09:40:40	12.4	2.285	1.422	15.4	L	DeMeo et al. (2009)
403	Cyane		sp22	2003-04-27T09:06:30	09:33:15	12.7	2.698	1.717	5.9	S	DeMeo et al. (2009)
403	Cyane		sp93	2010-09-06T14:56:23	15:14:43	13.9	2.880	2.295	18.4	()	Vernazza et al. (2014)
412	Elisabetha		sp282	2021-06-11T06:07:33	06:25:50	13.7	2.655	1.972	18.9	C	
416	Vaticana		sp93	2010-09-07T14:58:56	15:19:58	14.1	3.397	3.485	16.8	Sw	Vernazza et al. (2014)
426	Hippo		sp277	2020-11-19T07:19:13	07:32:51	14.1	3.171	2.619	16.4	C	
434	Hungaria		sp08	2001-08-23T12:19:08	12:45:33	13.1	1.835	0.888	15.9	Xe	DeMeo et al. (2009)
438	Zeuxo		sp252	2019-03-18T13:44:30	14:12:06	14.0	2.436	1.689	18.7	C	
444	Gyptis		sp07	2001-08-15T06:02:25	06:37:36	13.0	2.725	2.522	21.8	C	DeMeo et al. (2009)
446	Aeternitas		sp07	2001-08-14T11:44:24	12:06:00	12.3	2.441	1.475	9.2	A	DeMeo et al. (2009)
453	Tea		sp07	2001-08-15T11:47:22	12:22:31	13.3	2.208	1.236	9.9	Sw	DeMeo et al. (2009)
455	Bruchsalia		sp283	2021-07-05T05:53:58	06:04:38	14.2	2.878	2.450	20.0	Xc	
456	Abnoba		sp15	2002-06-17T06:08:50	06:38:44	13.4	2.300	1.755	24.6	S	DeMeo et al. (2009)
460	Scania		sp15	2002-06-17T08:00:14	08:28:11	14.7	2.775	1.774	4.5	L	DeMeo et al. (2009)
485	Genua		sp10	2002-03-06T12:52:43	13:14:45	12.3	2.595	1.727	13.0	S	DeMeo et al. (2009)
512	Taurinensis		sp32	2004-10-16T12:30:35	12:53:10	13.7	1.840	1.209	30.0	Sqw	DeMeo et al. (2009)
512	Taurinensis		sp32	2004-10-16T13:24:48	14:06:55	13.7	1.840	1.208	30.0	()	
513	Centesima		sp05	2001-03-29T13:21:17	13:53:39	15.1	3.258	2.510	13.3	K	DeMeo et al. (2009)
532	Herculina		sp06	2001-06-21T07:02:02	07:17:06	9.9	2.382	1.763	22.7	S	DeMeo et al. (2009)
532	Herculina		sp16	2002-08-17T10:05:47	10:24:22	10.2	3.085	2.094	4.7	()	
532	Herculina		sp76	2008-12-03T10:22:51	10:28:11	10.2	2.987	2.059	7.7	()	Vernazza et al. (2014)
534	Nassovia		sp97	2011-02-07T08:59:03	09:17:23	13.5	2.818	1.834	1.6	S	Marsset et al. (2024)
538	Friederike		sp248	2018-12-02T13:05:47	13:18:42	14.2	3.019	2.154	10.6	X	Vernazza et al. (2020)
566	Stereoskopia		sp279	2021-01-11T10:55:25	11:13:24	12.8	3.316	2.337	1.9	C	
570	Kythera		sp28	2004-02-19T11:50:37	12:46:29	14.4	3.760	2.817	5.2	D	DeMeo et al. (2009)
579	Sidonia		sp04	2001-02-20T08:53:14	09:17:43	12.9	3.255	2.384	9.6	K	DeMeo et al. (2009)
584	Semiramis		sp65	2007-11-12T10:37:22	10:44:53	10.6	1.929	0.963	9.1	Sw	Vernazza et al. (2014)
596	Scheila		sp14	2002-06-01T09:36:36	09:49:55	11.7	2.446	1.432	0.4	T	DeMeo et al. (2009)
596	Scheila		sp97	2011-02-07T09:21:44	09:40:04	13.4	3.021	2.075	6.4	D	Hasegawa et al. (2022a)
596	Scheila		sp292	2022-04-04T14:23:51	14:34:31	13.2	2.463	1.789	20.3	D	Hasegawa et al. (2022b)
599	Luisa		sp04	2001-02-19T08:30:42	08:55:11	14.1	3.211	2.538	14.6	L	DeMeo et al. (2009)
600	Musa		sp101	2011-08-22T13:57:42	14:13:40	14.5	2.693	1.873	15.1	S	Vernazza et al. (2014)

Table A1
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V ^a (mag)	R _n ^a (au)	Δ ^a (au)	α ^a (deg)	BD Tax. ^a	References
606	Brangane		sp18	2002-09-29T13:23:52	13:51:15	13.9	2.073	1.460	26.3	L	DeMeo et al. (2009)
617	Patroclus		sp40	2005-05-11T05:52:21	06:31:52	16.5	5.827	5.872	9.9	X	Vernazza et al. (2012)
625	Xenia		sp04	2001-02-20T07:32:53	08:00:35	15.2	3.050	2.408	15.9	Sw	DeMeo et al. (2009)
631	Philippina		sp18	2002-09-29T10:16:44	10:46:08	13.0	2.959	1.990	5.9	S	DeMeo et al. (2009)
631	Philippina		sp101	2011-08-22T10:17:25	10:35:46	13.3	3.019	2.094	9.4	()	Vernazza et al. (2014)
636	Erika		dm08	2012-06-06T06:33:24	07:01:12	15.3	3.207	2.788	17.8	X	
653	Berenike		sp21	2003-03-17T06:55:34	07:23:12	14.1	2.907	2.163	15.1	K	DeMeo et al. (2009)
661	Cloelia		sp21	2003-03-16T13:20:31	13:48:13	14.5	2.965	2.232	15.0	K	DeMeo et al. (2009)
670	Ottegebe		sp18	2002-09-29T09:14:21	09:40:45	12.1	2.270	1.277	4.6	S	DeMeo et al. (2009)
673	Edda		sp06	2001-06-21T07:39:47	08:12:25	15.0	2.825	2.127	17.3	L	DeMeo et al. (2009)
675	Ludmilla		sp12	2002-04-15T05:22:43	05:46:38	12.9	2.609	2.360	22.6	Sw	DeMeo et al. (2009)
679	Pax		sp04	2001-02-19T14:02:06	14:25:08	14.2	3.263	2.455	11.6	L	DeMeo et al. (2009)
679	Pax		sp89	2010-03-17T14:03:13	14:21:36	14.6	3.359	2.700	14.2	()	
688	Melanie		sp18	2002-09-28T08:32:08	08:59:52	14.1	2.373	1.485	14.2	C	DeMeo et al. (2009)
694	Ekard		sp293	2022-05-01T14:10:00	14:48:00	16.4	3.148	2.197	5.5	Ch	
699	Hela		sp35	2005-01-08T09:30:07	09:59:43	16.4	3.148	2.197	5.5	S	DeMeo et al. (2009)
706	Hirundo		sp48	2005-11-29T07:24:14	08:03:47	14.5	2.431	1.501	9.9	()	
706	Hirundo		sp49	2006-01-30T05:22:45	05:59:30	15.7	2.555	2.108	21.8	Cgh	DeMeo et al. (2009)
716	Berkeley		sp08	2001-08-24T14:13:07	15:10:04	15.5	3.024	2.113	10.0	S	DeMeo et al. (2009)
720	Bohlinia		sp02	2000-10-09T???:???:?c	???:???:?c	14.7	2.876	2.313	18.4	Sq	DeMeo et al. (2009)
720	Bohlinia		sp97	2011-02-07T06:00:16	06:23:29	14.4	2.858	2.149	15.9	()	Marsset et al. (2024)
729	Watsonia		sp07	2001-08-14T13:13:09	13:45:46	14.1	2.945	2.114	13.3	L	DeMeo et al. (2009)
733	Mocia		sp290	2022-01-28T14:25:45	14:44:03	14.9	3.210	2.810	17.2	C	
739	Mandeville		sp18	2002-09-28T15:01:07	15:28:48	13.8	2.863	2.546	20.3	Xc	DeMeo et al. (2009)
742	Edisona		sp21	2003-03-16T13:52:39	14:20:21	14.8	3.295	2.482	11.5	K	DeMeo et al. (2009)
747	Winchester		sp290	2022-01-28T13:46:30	13:58:02	13.0	3.126	2.381	13.6	C	
762	Pulcova		sp85	2009-10-25T12:14:04	12:32:24	13.0	3.160	2.211	6.4	C	
773	Irmintraud		sp31	2004-09-22T09:37:05	09:56:21	13.0	2.735	1.756	5.7	T	DeMeo et al. (2009)
776	Berbericia		sp38	2005-04-12T10:56:03	11:15:09	12.8	3.353	2.499	10.4	Cgh	DeMeo et al. (2009)
782	Montefiore		sp06	2001-06-22T06:41:42	07:14:22	15.1	2.142	1.566	26.4	Sw	DeMeo et al. (2009)
785	Zwetana		sp41	2005-05-19T06:19:59	06:29:17	12.2	2.044	1.139	17.0	Cb	DeMeo et al. (2009)
789	Lena		sp16	2002-08-17T06:53:50	07:26:25	15.4	2.292	1.690	23.9	Xk	DeMeo et al. (2009)
793	Arizona		sp18	2002-09-28T11:58:14	12:25:55	13.7	2.490	1.525	7.9	S	DeMeo et al. (2009)
793	Arizona		sp92	2010-07-12T06:15:23	06:33:44	15.5	2.885	2.474	20.0	()	Vernazza et al. (2014)
808	Merxia		sp07	2001-08-14T12:31:05	13:03:39	14.3	2.812	1.954	13.2	Sr	DeMeo et al. (2009)
808	Merxia		sp92	2010-07-12T14:12:29	14:30:50	14.8	2.889	2.282	18.3	()	Marsset et al. (2024)
810	Atossa		sp263	2020-01-28T14:17:54	14:45:26	16.6	2.555	1.735	14.9	Sw	
824	Anastasia		sp07	2001-08-14T07:46:48	08:30:56	14.1	2.431	1.529	13.8	L	DeMeo et al. (2009)
845	Naema		sp89	2010-03-17T14:32:31	15:00:16	15.5	2.998	2.489	18.0	Cgh	
847	Agnia		sp04	2001-02-19T09:45:16	10:09:45	14.3	2.820	1.846	4.3	S	DeMeo et al. (2009)
854	Prostia		sp99	2011-04-30T13:10:22	13:28:42	14.4	2.032	1.082	13.0	V	
863	Benkoela		sp09	2002-01-14T06:46:20	07:14:56	14.6	3.299	2.697	15.0	A	DeMeo et al. (2009)
863	Benkoela		sp76	2008-12-03T14:54:26	15:12:46	14.8	3.160	2.926	18.1	()	
908	Buda		sp53	2006-07-20T07:01:02	07:39:46	15.2	2.808	1.968	14.0	D	DeMeo et al. (2009)
913	Otila		sp07	2001-08-15T13:57:19	14:29:54	15.2	2.022	1.282	24.8	Sw	DeMeo et al. (2009)
925	Alphonsina		sp18	2002-09-28T07:58:34	08:22:31	12.9	2.897	2.041	12.3	S	DeMeo et al. (2009)
925	Alphonsina		sp102	2011-09-25T06:56:54	07:08:39	12.7	2.877	1.960	9.8	()	Vernazza et al. (2014)
929	Algunde		sp06	2001-06-21T10:10:35	10:35:41	13.5	1.993	0.979	3.1	S	DeMeo et al. (2009)
939	Isberga		sp101	2011-08-22T13:32:36	13:50:57	15.2	1.887	1.194	28.4	Sq	Carry et al. (2015)
944	Hidalgo		sp31	2004-09-22T12:25:28	13:21:19	14.3	2.283	1.455	17.9	D	DeMeo et al. (2009)
984	Gretia		sp17	2002-09-16T08:57:40	09:19:00	12.1	2.257	1.318	11.9	()	
984	Gretia		sp18	2002-09-29T10:52:27	11:18:51	11.9	2.258	1.280	7.3	Sa	DeMeo et al. (2009)
984	Gretia		sp92	2010-07-12T05:50:32	06:09:47	14.7	3.172	2.797	18.3	()	Vernazza et al. (2014)
985	Rosina		sp40	2005-05-11T10:36:41	11:15:50	16.3	2.546	1.553	5.5	S	DeMeo et al. (2009)
1015	Christa		sp290	2022-01-28T14:02:28	14:20:44	14.7	3.341	2.679	14.0	C	
1020	Arcadia		sp21	2003-03-17T08:22:58	08:59:44	16.4	2.737	1.865	12.2	Sr	DeMeo et al. (2009)
1021	Flammario		sp89	2010-03-17T12:22:44	12:37:06	13.5	2.994	2.060	7.9	C	
1065	Amundsenia	1926 PD	sp37	2005-03-08T12:08:36	13:04:10	16.2	2.840	1.878	6.0	S	DeMeo et al. (2009)
1076	Viola	1926 TE	sp91	2010-05-09T09:49:28	10:21:49	16.1	2.654	1.691	8.2	C	
1094	Siberia	1926 CB	sp21	2003-03-16T05:42:33	06:22:27	15.9	2.225	1.781	25.8	Xk	DeMeo et al. (2009)
1126	Otero	1929 AC	sp04	2001-02-20T08:21:49	08:49:31	14.6	1.941	1.111	21.1	Sw	DeMeo et al. (2009)
1139	Atami	1929 XE	sp29	2004-06-15T06:58:10	07:55:52	16.7	2.425	1.733	20.9	()	

Table A1
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V ^a (mag)	R _n ^a (au)	Δ ^a (au)	α ^a (deg)	BD Tax. ^a	References
1139	Atami	1929 XE	sp44	2005-09-05T11:43:22	12:25:19	14.2	1.621	0.731	25.2	Sw	DeMeo et al. (2009)
1143	Odysseus	1930 BH	sp42	2005-06-10T10:53:02	11:54:56	15.2	5.712	4.699	0.6	D	DeMeo et al. (2009)
1147	Stavropolis	1929 LF	sp07	2001-08-15T08:33:42	09:05:28	12.9	1.814	0.812	6.9	Sw	DeMeo et al. (2009)
1148	Rarahu	1929 NA	sp05	2001-03-29T10:39:40	11:12:03	14.9	3.268	2.297	4.9	K	DeMeo et al. (2009)
1167	Dubiago	1930 PB	sp44	2005-09-05T05:23:18	06:01:29	15.5	3.148	2.790	18.3	D	
1180	Rita	1931 GE	sp46	2005-10-31T07:17:36	07:35:47	14.9	3.751	2.882	8.4	D	
1228	Scabiosa	1931 TU	sp09	2002-01-13T09:31:23	10:04:26	15.5	2.706	1.782	8.7	()	
1228	Scabiosa	1931 TU	sp21	2003-03-16T12:21:48	12:59:13	15.6	2.686	1.782	10.9	Sr	DeMeo et al. (2009)
1300	Marcelle	1934 CL	sp55	2006-10-25T07:39:23	08:39:09	15.5	2.767	1.822	7.9	Cgh	DeMeo et al. (2009)
1300	Marcelle	1934 CL	sp56	2006-11-21T07:56:14	08:33:03	16.0	2.765	2.024	15.9	()	
1310	Villigera	1932 DB	sp50	2006-05-01T07:09:36	07:48:47	15.2	2.146	1.536	25.5	S	
1329	Eliane	1933 FL	sp16	2002-08-17T13:38:35	14:01:47	14.5	2.302	1.471	18.1	Sqw	DeMeo et al. (2009)
1332	Marconia	1934 AA	sp42	2005-06-10T05:46:48	06:26:42	16.2	3.353	2.671	14.4	L	DeMeo et al. (2009)
1350	Rosselia	1934 TA	sp06	2001-06-21T14:24:05	14:56:41	15.4	2.761	2.032	17.2	S	DeMeo et al. (2009)
1406	Komppa	1936 RF	sp64	2007-10-02T13:38:59	13:53:20	15.1	2.463	1.580	13.7	D	
1412	Lagrula	1937 BA	dm02	2011-08-08T12:38:01	12:56:21	15.5	2.276	1.323	11.4	Sw	DeMeo et al. (2019)
1433	Geramtina	1937 UC	sp16	2002-08-17T11:05:27	11:38:05	15.4	2.624	1.660	8.5	S	DeMeo et al. (2009)
1443	Ruppina	1937 YG	sp221	2016-08-15T11:04:55	11:23:10	14.5	2.756	1.744	0.8	S	
1459	Magnya	1937 VA	sp04	2001-02-20T11:50:29	12:27:43	15.8	3.709	2.781	6.1	Vw	DeMeo et al. (2009)
1471	Tomio	1938 SL ₁	sp45	2005-10-08T06:13:36	06:31:46	15.0	2.526	1.638	12.9	D	DeMeo et al. (2009)
1474	Beira	1935 QY	dm12	2012-12-12T06:10:40	06:22:37	14.4	1.395	0.816	43.8	B	
1494	Savo	1938 SJ	sp55	2006-10-25T06:07:57	06:46:18	15.1	1.911	1.133	24.3	Sqw	DeMeo et al. (2009)
1542	Schalen	1941 QE	sp39	2005-04-18T11:23:59	12:03:25	15.8	3.358	2.463	9.1	D	DeMeo et al. (2009)
1583	Antilochus	1950 SA	sp40	2005-05-11T14:12:53	14:51:16	16.0	5.323	4.501	6.9	D	
1589	Fanatica	1950 RK	sp123	2013-08-08T05:34:23	06:11:29	16.9	2.545	2.316	23.5	Srw	
1642	Hill	1951 RU	sp07	2001-08-15T11:10:48	11:43:37	14.9	2.923	1.926	4.3	S	DeMeo et al. (2009)
1658	Innes	1953 NA	sp03	2001-01-30T11:44:17	12:20:02	15.7	2.906	1.947	5.5	Sw	DeMeo et al. (2009)
1659	Punkaharju	1940 YL	sp11	2002-03-15T09:38:29	10:15:35	14.8	3.299	2.354	6.3	S	DeMeo et al. (2009)
1660	Wood	1953 GA	sp37	2005-03-08T14:34:45	15:28:45	15.4	2.086	1.533	26.7	S	DeMeo et al. (2009)
1662	Hoffmann	A923 RB	sp21	2003-03-17T11:58:56	12:45:08	16.5	3.179	2.259	8.1	Sr	DeMeo et al. (2009)
1667	Pels	1930 SY	sp19	2002-10-28T14:34:05	15:30:06	16.1	2.482	1.761	18.8	Sw	DeMeo et al. (2009)
1701	Okavango	1953 NJ	dm02	2011-08-08T14:19:00	14:56:00	16.6	3.051	3.327	17.6	Sv	
1709	Ukraina	1925 QA	sp97	2011-02-07T06:43:15	06:54:41	17.0	2.550	1.828	17.9	S	DeMeo et al. (2019)
1751	Herget	1955 OC	sp06	2001-06-22T09:31:32	10:06:01	16.1	2.888	1.905	6.4	S	DeMeo et al. (2009)
1768	Appenzella	1965 SA	sp104	2011-10-31T06:13:56	06:48:38	15.6	2.025	1.186	19.7	C	
1807	Slovakia	1971 QA	sp30	2004-09-15T07:44:57	08:23:48	15.6	1.964	1.255	26.2	Sqw	DeMeo et al. (2009)
1839	Ragazza	1971 UF	sp05	2001-03-29T07:18:44	07:51:05	16.9	2.917	2.183	15.4	S	DeMeo et al. (2009)
1848	Delvaux	1933 QD	sp07	2001-08-15T09:49:16	10:21:54	14.5	2.771	1.758	0.2	S	DeMeo et al. (2009)
1857	Parchomenko	1971 QS ₁	sp263	2020-01-27T13:28:43	13:56:29	16.2	2.314	1.601	20.3	Sq	DeMeo et al. (2022)
1858	Lobachevskij	1972 QL	sp12	2002-04-14T10:50:59	11:19:06	15.5	2.640	1.644	3.2	S	DeMeo et al. (2009)
1903	Adzhimushkaj	1972 JL	sp21	2003-03-17T13:40:25	14:07:50	15.5	2.976	2.186	13.6	K	DeMeo et al. (2009)
1904	Massevitch	1972 JM	sp01	2000-09-04T??:??:?? ^c	??:??:?? ^c	15.4	2.617	1.806	15.8	V	DeMeo et al. (2009)
1910	Mikhailov	1972 TZ ₁	sp85	2009-10-25T10:09:50	10:47:04	16.0	3.166	2.181	3.1	C	
1912	Anubis	6534 P-L	sp94	2010-10-14T13:45:31	14:41:15	16.0	2.639	1.833	15.3	S	Marsset et al. (2024)
1929	Kollaa	1939 BS	sp04	2001-02-19T13:32:09	13:59:59	15.8	2.210	1.318	14.3	V	DeMeo et al. (2009)
2035	Stearns	1973 SC	sp19	2002-10-28T13:47:00	14:26:12	16.3	2.107	1.491	25.4	Xe	DeMeo et al. (2009)
2036	Sheragul	1973 SY ₂	sp96	2011-01-06T05:57:06	06:26:23	17.3	2.327	2.043	24.9	S	DeMeo et al. (2019)
2042	Sitarski	4633 P-L	sp08	2001-08-23T12:52:13	13:29:30	16.6	2.681	1.722	8.6	Sr	DeMeo et al. (2009)
2045	Peking	1964 TB1	sp09	2002-01-14T05:50:47	06:37:18	16.5	2.484	1.958	21.7	V	DeMeo et al. (2009)
2085	Henan	1965 YA	sp12	2002-04-14T07:39:56	08:17:02	16.5	2.789	2.057	16.5	L	DeMeo et al. (2009)
2107	Ilmari	1941 VA	sp49	2006-01-29T06:34:19	07:52:48	16.0	2.461	1.995	22.6	Sw	DeMeo et al. (2009)
2157	Ashbrook	A924 EF	sp21	2003-03-16T11:07:32	11:35:22	15.5	2.695	1.701	0.9	S	DeMeo et al. (2009)
2195	Tengstrom	1941 SP ₁	sp35	2005-01-07T07:21:15	08:18:12	16.0	2.009	1.457	27.5	S	
2234	Schmadel	1977 HD	dm05	2012-01-12T14:22:00	15:01:00	17.6	2.730	2.450	21.0	R	DeMeo et al. (2019)
2234	Schmadel	1977 HD	dm07	2012-03-20T10:16:08	10:32:30	15.9	2.586	1.608	5.3	()	
2246	Bowell	1979 XH	sp39	2005-04-17T11:14:13	11:54:07	16.0	3.668	2.709	5.4	D	DeMeo et al. (2009)
2311	El Leoncito	1974 TA ₁	sp40	2005-05-10T07:18:39	08:09:07	16.9	3.820	3.367	14.5	D	
2335	James	1974 UB	sp45	2005-10-08T13:20:31	13:59:32	15.0	1.618	0.724	23.7	()	
2335	James	1974 UB	sp46	2005-10-30T09:15:14	09:44:13	14.5	1.532	0.624	23.8	S	DeMeo et al. (2009)
2353	Alva	1975 UD	sp14	2002-05-31T08:33:22	09:10:38	15.4	2.722	1.723	4.6	S	DeMeo et al. (2009)
2354	Lavrov	1978 PZ ₃	sp21	2003-03-17T07:29:38	08:17:38	16.6	2.932	2.146	14.0	L	DeMeo et al. (2009)
2378	Pannekoek	1935 CY	sp40	2005-05-11T13:11:47	14:08:55	16.2	3.286	2.418	10.5	Cgh	DeMeo et al. (2009)

Table A1
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V ^a (mag)	R _n ^a (au)	Δ ^a (au)	α ^a (deg)	BD Tax. ^a	References
2386	Nikonov	1974 SN ₁	sp15	2002-06-17T13:36:42	14:23:16	15.6	2.386	1.620	19.5	S	DeMeo et al. (2009)
2396	Kochi	1981 CB	sp07	2001-08-15T08:03:25	08:17:07	15.6	2.838	1.845	4.9	S	DeMeo et al. (2009)
2401	Aehlita	1975 VM ₂	sp16	2002-08-17T08:23:20	09:01:07	16.7	2.880	1.897	5.9	S	DeMeo et al. (2009)
2442	Corbett	1980 TO	sp17	2002-09-15T10:27:39	10:52:14	15.5	2.251	1.273	7.8	V	DeMeo et al. (2009)
2448	Sholokhov	1975 BU	sp21	2003-03-16T07:24:13	07:52:28	15.0	2.587	1.777	15.5	L	DeMeo et al. (2009)
2463	Sterpin	1934 FF	sp89	2010-03-16T13:01:12	13:56:28	16.2	2.749	1.929	14.0	Sw	Marsset et al. (2024)
2501	Lohja	1942 GD	sp09	2002-01-12T14:16:01	14:53:22	15.9	2.393	1.619	17.7	A	DeMeo et al. (2009)
2504	Gaviola	1967 JO	sp22	2003-04-27T07:38:27	08:25:47	16.3	2.525	1.898	20.7	Sr	DeMeo et al. (2009)
2521	Heidi	1979 DK	sp09	2002-01-13T12:37:03	13:14:27	15.3	2.606	1.647	6.0	S	DeMeo et al. (2009)
2566	Kirghizia	1979 FR ₂	sp13	2002-05-08T08:06:11	08:43:40	15.8	2.409	1.452	9.8	V	DeMeo et al. (2009)
2579	Spartacus	1977 PA ₂	sp02	2000-10-10T05:33:42	06:14:15	17.1	2.216	1.403	18.9	V	DeMeo et al. (2009)
2616	Lesya	1970 QV	sp263	2020-01-27T14:47:14	15:14:58	16.7	2.327	1.800	23.5	Sw	
2715	Mielikki	1938 US	sp07	2001-08-15T12:46:17	13:18:58	15.0	2.324	1.483	17.5	Sw	DeMeo et al. (2009)
2732	Witt	1926 FG	sp07	2001-08-15T10:25:57	10:58:33	15.4	2.773	1.761	0.9	L	DeMeo et al. (2009)
2823	van der Laan	2010 P-L	sp48	2005-11-22T06:39:52	06:48:55	16.4	2.203	1.340	16.1	V	Moskovitz et al. (2010)
2850	Mozhaiskij	1978 TM ₇	sp48	2005-11-29T08:10:51	08:50:04	15.7	2.343	1.377	6.4	Sw	
2851	Harbin	1978 UQ ₂	sp08	2001-08-24T12:28:15	13:00:56	15.6	2.418	1.448	8.7	V	DeMeo et al. (2009)
2867	Steins	1969 VC	sp57	2006-12-22T13:14:29	14:06:09	16.6	2.669	1.726	7.5	Xe	
2867	Steins	1969 VC	sp58	2007-01-21T09:18:52	09:55:19	17.3	2.686	1.756	8.4	()	
2873	Binzel	1982 FR	sp09	2002-01-13T14:57:48	15:35:04	16.9	2.439	1.627	16.0	Sq	DeMeo et al. (2009)
2875	Lagerkvist	1983 CL	sp11	2002-03-16T11:33:40	12:10:46	15.4	2.542	1.548	1.7	S	DeMeo et al. (2009)
2911	Miahelena	1938 GJ	sp21	2003-03-17T09:47:51	10:24:38	15.7	2.632	1.721	10.8	Sw	DeMeo et al. (2009)
2912	Lapalma	1942 DM	sp04	2001-02-20T11:09:01	11:46:08	15.2	2.141	1.182	8.7	V	DeMeo et al. (2009)
2919	Dali	1981 EX ₁₈	sp56	2006-11-21T09:30:28	10:07:09	16.9	3.460	2.479	2.2	C	
2956	Yeomans	1982 HN ₁	sp65	2007-11-12T12:21:32	13:44:50	16.6	3.014	2.041	4.2	S	Vernazza et al. (2014)
2957	Tatsuo	1934 CB ₁	sp21	2003-03-16T08:20:48	08:57:55	15.5	3.231	2.265	5.0	K	DeMeo et al. (2009)
2965	Surikov	1975 BX	sp40	2005-05-10T14:40:29	15:10:40	15.3	1.945	1.108	22.2	Sv	DeMeo et al. (2009)
2977	Chivilikhin	1974 SP	sp16	2002-08-17T14:07:00	14:44:15	16.4	2.312	1.592	21.4	()	Marsset et al. (2024)
2977	Chivilikhin	1974 SP	sp18	2002-09-28T11:07:28	11:55:24	15.4	2.326	1.340	5.7	S	DeMeo et al. (2009)
2990	Trimberger	1981 EN ₂₇	sp96	2011-01-06T09:24:07	09:59:04	16.4	2.182	1.213	6.0	Ch	
3028	Zhangguoxi	1978 TA ₂	sp13	2002-05-07T09:47:28	10:15:22	14.8	2.950	1.961	4.7	K	DeMeo et al. (2009)
3029	Sanders	1981 EA ₈	sp97	2011-02-07T09:43:55	10:07:01	15.2	2.170	1.189	3.7	S-comp	DeMeo et al. (2019)
3155	Lee	1984 SP ₃	sp06	2001-06-22T08:53:08	9:25:56	16.0	2.557	1.584	8.4	V	DeMeo et al. (2009)
3248	Farinella	1982 FK	sp39	2005-04-18T10:02:30	10:42:04	15.8	3.430	2.441	3.5	D	DeMeo et al. (2009)
3283	Skorina	1979 QA ₁₀	dm09	2012-07-22T11:26:54	11:43:17	15.5	2.235	1.230	5.2	D	DeMeo et al. (2014)
3317	Paris	1984 KF	sp50	2006-05-01T06:04:43	07:04:48	16.2	5.539	5.183	10.1	D	DeMeo et al. (2009)
3363	Bowen	1960 EE	sp12	2002-04-15T11:28:17	12:24:36	15.9	2.696	1.709	4.8	Sr	DeMeo et al. (2009)
3385	Bronnina	1979 SK ₁₁	dm11	2012-09-16T11:02:46	11:09:47	15.6	2.238	1.289	11.2	S	DeMeo et al. (2019)
3395	Jitka	1985 UN	sp04	2001-02-19T10:13:13	10:47:26	15.5	2.662	1.696	5.7	S	DeMeo et al. (2009)
3430	Bradfield	1980 TF ₄	sp15	2002-06-17T08:34:08	09:23:19	16.1	2.619	1.628	6.2	S	DeMeo et al. (2009)
3485	Barucci	1983 NU	sp94	2010-10-14T08:45:53	09:13:38	15.6	2.325	1.330	2.4	C	
3491	Fridolin	1984 SM ₄	sp15	2002-06-17T11:23:53	12:20:26	16.8	2.911	1.999	10.7	S	DeMeo et al. (2009)
3511	Tsvetaeva	1982 TC ₂	sp12	2002-04-15T08:14:09	08:51:40	16.1	2.502	1.647	14.9	Srw	DeMeo et al. (2009)
3573	Holmberg	1982 QO ₁	dm10	2012-08-14T07:21:00	07:40:00	16.0	2.379	1.371	3.1	()	Marsset et al. (2024)
3573	Holmberg	1982 QO ₁	dm11	2012-09-16T06:28:00	06:30:00	16.8	2.369	1.542	17.2	S	DeMeo et al. (2019)
3613	Kunlun	1982 VJ ₁₁	sp91	2010-05-09T13:11:02	14:29:33	16.8	2.414	1.639	18.7	V	
3613	Kunlun	1982 VJ ₁₁	sp92	2010-07-12T07:37:41	08:05:56	16.5	2.463	1.496	9.4	()	
3628	Boznemcova	1979 WD	sp50	2006-04-30T07:51:52	09:11:47	17.4	3.015	2.073	8.2	O	DeMeo et al. (2009)
3635	Kreutz	1981 WO ₁	sp47	2005-11-12T12:59:12	14:01:14	16.1	1.717	0.768	14.0	Srw	DeMeo et al. (2009)
3701	Purkyne	1985 DW	sp07	2001-08-14T10:36:53	11:09:36	16.3	2.811	1.804	2.7	S	DeMeo et al. (2009)
3703	Volkonskaya	1978 PU ₃	sp51	2006-06-03T07:56:29	08:57:45	17.0	2.254	1.283	9.8	Vw	Moskovitz et al. (2010)
3734	Waland	9527 P-L	sp08	2001-08-24T13:30:20	14:08:12	17.2	2.822	1.923	11.4	L	DeMeo et al. (2009)
3749	Balam	1982 BG ₁	sp121	2013-06-13T12:06:27	13:24:03	16.6	2.468	1.482	7.3	Sw	Marsset et al. (2024)
3788	Steyaert	1986 QM ₃	sp21	2003-03-17T09:04:41	09:41:26	16.3	2.754	1.877	11.9	S	DeMeo et al. (2009)
3819	Robinson	1983 AR	sp84	2009-09-20T12:11:38	12:48:45	15.5	2.421	1.488	11.3	A	
3819	Robinson	1983 AR	sp85	2009-10-25T09:35:42	10:03:41	15.2	2.404	1.436	7.0	()	
3844	Lujiaxi	1966 BZ	sp09	2002-01-12T13:07:32	13:47:40	16.1	2.853	1.926	8.0	()	
3844	Lujiaxi	1966 BZ	sp22	2003-04-27T09:56:38	10:55:29	15.9	2.981	1.980	23.0	L	DeMeo et al. (2009)
3873	Roddy	1984 WB	sp19	2002-10-28T08:28:29	09:05:18	15.3	2.019	1.086	13.2	Sw	DeMeo et al. (2009)
3873	Roddy	1984 WB	sp32	2004-10-16T06:40:17	07:41:55	17.1	2.132	1.944	27.8	()	
3903	Kliment Ohridski	1987 SV ₂	sp17	2002-09-16T09:28:24	10:06:18	16.3	2.867	1.894	6.2	S	DeMeo et al. (2009)
3910	Liszt	1988 SF	sp16	2002-08-17T12:55:19	13:29:07	15.9	2.621	1.704	11.6	S	DeMeo et al. (2009)

Table A1
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V ^a (mag)	R _n ^a (au)	Δ ^a (au)	α ^a (deg)	BD Tax. ^a	References
3949	Mach	1985 UL	sp08	2001-08-24T09:09:34	09:49:26	16.0	2.259	1.252	3.1	Sq	DeMeo et al. (2009)
4038	Kristina	1987 QH ₂	sp19	2002-10-28T12:18:34	13:15:50	15.9	2.080	1.125	10.3	Vw	DeMeo et al. (2009)
4067	Mikhel'son	1966 TP	dm17	2014-01-09T06:46:00	06:48:00	16.5	2.150	1.467	23.0	X	
4188	Kitez	1979 HX ₄	sp07	2001-08-14T08:41:44	09:14:22	15.5	2.102	1.132	10.8	Sq	DeMeo et al. (2009)
4264	Karljosephine	1989 TB	dm14	2013-03-01T08:33:00	08:35:00	17.6	2.442	1.665	17.6	Sw	DeMeo et al. (2019)
4352	Kyoto	1989 UW ₁	sp15	2002-06-17T12:29:47	13:25:45	16.5	2.923	2.152	15.2	S	DeMeo et al. (2009)
4402	Tsunemori	1987 DP	sp107	2012-04-21T08:29:44	08:57:29	16.1	2.949	1.956	3.7	Srw	
4407	Taihaku	1988 TF ₁	sp08	2001-08-24T10:56:31	11:34:29	16.0	2.555	1.568	6.2	Sqw	DeMeo et al. (2009)
4417	Lecar	1931 GC	sp08	2001-08-23T10:13:28	10:50:49	15.9	2.846	1.840	2.5	Sw	DeMeo et al. (2009)
4455	Ruriko	1988 XA	sp85	2009-10-25T12:48:19	13:27:42	16.6	2.910	2.202	15.9	Xn	
4455	Ruriko	1988 XA	sp87	2010-01-17T10:37:39	11:14:16	16.6	2.886	2.105	14.0	()	
4570	Runcorn	1985 PR	sp06	2001-06-21T11:58:58	12:36:19	16.1	2.154	1.199	12.4	Sw	DeMeo et al. (2009)
4580	Child	1989 EF	sp89	2010-03-17T09:18:07	10:14:32	16.0	2.406	1.585	16.6	S	Marsset et al. (2024)
4674	Pauling	1989 JC	sp109	2012-05-26T11:53:17	12:28:09	15.6	1.943	0.936	4.7	A	
4713	Steel	1989 QL	sp12	2002-04-14T13:13:28	13:50:32	15.6	1.815	0.977	23.9	Sw	DeMeo et al. (2009)
4737	Kiladze	1985 QO ₆	sp15	2002-06-17T09:41:40	10:46:58	16.1	2.513	1.510	4.7	L	DeMeo et al. (2009)
4744	Rovereto	1988 RF ₅	sp64	2007-10-02T08:33:34	10:05:58	16.9	3.317	2.368	6.5	D	
4905	Hiromi	1991 JM ₁	sp123	2013-08-08T13:33:40	13:52:00	16.2	2.175	1.638	26.3	Sw	Polishook et al. (2014)
4995	Griffin	1984 QR	sp19	2002-10-28T10:02:47	10:58:43	15.2	1.614	0.773	27.4	S	DeMeo et al. (2009)
5013	Suzhousanzhong	1964 VT ₁	sp09	2002-01-14T08:09:38	08:42:58	16.4	2.619	1.663	6.4	Sw	DeMeo et al. (2009)
5026	Martes	1987 QL ₁	sp107	2012-04-21T07:57:39	08:25:24	17.3	2.524	1.537	5.6	Ch	Polishook et al. (2014)
5111	Jacliff	1987 SE ₄	sp44	2005-09-05T10:57:20	11:35:17	15.0	2.057	1.066	7.3	V	DeMeo et al. (2009)
5202	Charleseliot	1983 XX	dm11	2012-09-17T05:10:00	05:28:00	17.4	2.424	1.717	20.2	D	DeMeo et al. (2014)
5209	Oloosson	1989 CW ₁	sp97	2011-02-07T07:10:00	08:08:37	17.3	4.946	4.187	7.9	D	
5292	Mackwell	1991 AJ ₁	sp55	2006-10-24T13:37:05	14:14:14	16.0	2.367	1.661	20.3	S	Vernazza et al. (2014)
5379	Abehiroshi	1991 HG	sp51	2006-06-03T07:08:14	07:48:54	15.9	2.267	1.294	9.6	Sr	DeMeo et al. (2009)
5401	Minamioda	1989 EV	sp09	2002-01-12T05:09:27	06:05:51	16.3	2.375	1.773	21.8	()	Marsset et al. (2024)
5401	Minamioda	1989 EV	sp21	2003-03-16T11:39:50	12:17:01	16.2	2.906	1.926	4.1	Sw	DeMeo et al. (2009)
5577	Priestley	1986 WQ ₂	sp101	2011-08-22T12:46:46	13:19:17	16.4	1.766	0.914	24.8	Sw	
5641	McCleese	1990 DJ	sp25	2003-09-30T08:43:03	09:50:37	16.4	2.010	1.067	13.3	()	
5641	McCleese	1990 DJ	sp38	2005-04-12T14:27:19	15:15:50	15.8	1.592	0.787	31.0	Sw	DeMeo et al. (2009)
5641	McCleese	1990 DJ	sp42	2005-06-10T06:48:41	07:51:46	16.0	1.630	0.827	31.0	()	
5685	Sanenobufukui	1990 XA	sp05	2001-03-29T07:58:51	08:31:12	15.6	2.554	1.676	13.2	S	DeMeo et al. (2009)
5840	Raybrown	1978 ON	sp08	2001-08-24T09:56:25	10:29:57	15.7	2.505	1.498	2.5	L	DeMeo et al. (2009)
6067		1990 QR ₁₁	dm07	2012-03-20T14:48:00	15:09:00	17.5	3.023	3.089	18.7	A	DeMeo et al. (2019)
6249	Jennifer	1991 JF ₁	sp93	2010-09-06T05:44:06	06:23:29	16.4	1.802	1.406	33.9	Xe	
6478	Gault	1988 JC ₁	sp253	2019-03-31T08:47:07	10:22:42	17.8	2.299	1.437	15.9	Q	Marsset et al. (2019)
6478	Gault	1988 JC ₁	sp254	2019-04-08T06:36:14	07:31:40	17.9	2.282	1.483	18.9	S	Marsset et al. (2019)
7057	Al-Farabi	1990 QL ₂	dm04	2011-12-01T13:56:00	14:15:00	17.1	2.137	1.350	20.1	S	DeMeo et al. (2019)
7172	Multatuli	1988 DE ₂	sp110	2012-07-21T10:45:56	11:38:51	17.9	2.753	1.776	7.2	S	DeMeo et al. (2019)
7302		1993 CQ	dm06	2012-03-04T10:07:00	10:25:00	16.7	2.957	1.982	4.3	S	DeMeo et al. (2019)
7343	Ockeghem	1992 GE ₂	sp226	2017-01-03T06:40:48	07:17:40	17.1	1.899	1.259	28.0	Sw	Marsset et al. (2024)
7468	Anfimov	1990 UP ₁₁	sp117	2013-01-17T11:05:16	11:42:21	16.6	3.025	2.058	4.2	A	
7472	Kumakiri	1992 CU	sp93	2010-09-06T11:16:15	12:33:29	17.1	3.328	2.362	5.9	Q	Leith et al. (2017)
7745		1987 DB ₆	sp125	2013-10-04T09:03:15	09:40:39	16.9	2.541	1.557	5.2	C	
7763	Crabeels	1990 UT ₅	sp14	2002-06-01T08:24:13	09:20:04	17.1	2.641	1.744	12.6	L	DeMeo et al. (2009)
8306	Shoko	1995 DY ₁	sp124	2013-09-07T10:14:58	10:33:18	16.2	1.749	0.766	11.0	Sq	Marsset et al. (2024)
8334		1984 CF	sp21	2003-03-17T10:54:32	11:51:28	16.9	2.576	1.649	10.1	S	DeMeo et al. (2009)
8838		1989 UW ₂	dm04	2011-12-01T04:38:00	05:22:00	16.8	3.150	2.438	14.1	A	DeMeo et al. (2019)
8838		1989 UW ₂	dm13	2013-01-16T08:04:57	08:43:12	16.3	3.141	2.213	7.1	()	
9404		1994 UQ ₁₁	dm11	2012-09-17T09:39:00	09:41:00	17.6	2.670	1.730	9.5	S	DeMeo et al. (2019)
9570		1988 RQ ₅	dm11	2012-09-17T05:51:57	06:39:51	17.8	2.744	2.019	17.0	Sw	
9763		1991 RU ₁₇	dm02	2011-08-08T11:57:00	12:17:00	16.2	2.206	1.195	2.7	S-comp	DeMeo et al. (2019)
9898	Yoshiro	1996 DF	dm11	2012-09-16T07:45:00	07:47:00	16.7	2.293	1.315	7.7	S-comp	DeMeo et al. (2019)
9983	Rickfienberg	1995 DA	sp119	2013-04-13T08:26:19	09:30:56	17.8	2.856	1.977	11.7	A	
10195	Nebraska	1996 RS ₅	sp56	2006-11-21T08:47:34	09:24:25	15.7	2.490	1.532	7.1	Sq	Vernazza et al. (2014)
10278	Virkki	1981 EW ₃₀	sp275	2020-10-14T08:54:56	09:22:32	17.1	1.797	0.888	18.7	Sw	Sergeyev et al. (2023)
10327	Batens	1990 WQ ₆	dm02	2011-08-08T13:05:00	13:44:00	17.8	2.042	1.110	15.2	S-comp	DeMeo et al. (2019)
10715	Nagler	1983 RL ₄	dm16	2013-07-19T14:55:00	14:57:00	17.5	1.967	1.614	31.0	A	DeMeo et al. (2019)
10977	Mathlener	3177 T-2	dm07	2012-03-20T08:35:00	08:54:00	17.3	2.186	1.190	1.1	A	DeMeo et al. (2019)
11318		1994 XZ ₄	dm22	2015-11-10T10:30:11	11:07:07	17.2	1.494	0.534	15.9	Sqw	
11406	Ucciocontin	1999 CY14	dm14	2013-03-01T12:48:42	13:33:13	17.8	2.601	1.739	13.2	S-comp	DeMeo et al. (2019)

Table A1
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V ^a (mag)	R _n ^a (au)	Δ ^a (au)	α ^a (deg)	BD Tax. ^a	References
11952		1994 AM ₃	dm11	2012-09-17T07:58:00	08:00:00	17.2	2.409	1.406	1.8	S	DeMeo et al. (2019)
12264		1990 CD	dm17	2014-01-08T10:03:16	10:35:53	17.0	2.434	1.461	4.1	Sw	
13137		1994 UT ₁	dm12	2012-12-12T05:36:00	06:33:00	16.7	2.341	1.410	10.1	S-comp	DeMeo et al. (2019)
13577	Ukawa	1993 HR ₁	dm09	2012-07-22T10:41:00	11:06:00	17.5	2.179	1.182	7.1	S	DeMeo et al. (2019)
13724	Schwehm	1998 QF ₅₅	dm10	2012-08-14T08:56:00	09:52:00	16.6	2.194	1.182	1.7	S	DeMeo et al. (2019)
13791		1998 VC	sp58	2007-01-21T10:05:02	11:05:04	16.8	2.355	1.371	0.7	S	Marsset et al. (2024)
14291	Savereide	1104 T-1	dm11	2012-09-16T07:01:00	07:20:00	17.9	2.360	1.513	16.5	D	DeMeo et al. (2014)
14390		1990 QP ₁₀	sp108	2012-04-29T10:33:36	11:06:03	16.8	3.250	2.246	1.7	V	
15107	Toepperwein	2000 CR ₄₉	sp117	2013-01-17T05:40:37	06:16:03	18.7	2.666	1.833	13.6	S	Polishook et al. (2014)
15112	Arlenewolfe	2000 CY ₉₄	dm12	2012-12-12T07:56:00	08:15:00	18.3	2.592	1.686	10.6	D	DeMeo et al. (2014)
16025		1999 CA ₁₀₄	dm14	2013-03-01T09:09:00	09:27:00	18.3	2.635	1.725	10.5	S	DeMeo et al. (2014)
16520		1990 WO ₃	dm05	2012-01-23T10:42:00	11:21:00	17.1	2.341	1.360	2.6	A	DeMeo et al. (2019)
17107		1999 JJ ₅₁	sp93	2010-09-06T09:45:33	10:58:57	17.0	2.800	1.795	2.1	S	Marsset et al. (2024)
17288		2000 NZ ₁₀	sp119	2013-04-13T09:42:44	10:34:30	17.9	2.651	1.679	6.7	Sw	Polishook et al. (2014)
17716		1997 WW ₄₃	dm16	2013-07-19T09:41:00	09:43:00	17.7	2.155	1.145	4.1	S	DeMeo et al. (2019)
17818		1998 FE ₁₁₈	dm07	2012-03-20T13:25:00	13:56:00	17.4	2.627	1.937	18.3	A	DeMeo et al. (2019)
17889	Liechty	1999 DH ₃	dm13	2013-01-16T06:51:19	07:44:55	17.6	2.489	1.541	7.8	A	DeMeo et al. (2019)
17906		1999 FG ₃₂	dm11	2012-09-16T11:35:00	11:37:00	16.9	2.079	1.237	19.7	D	DeMeo et al. (2014)
18098		2000 LR ₂₀	dm04	2011-12-01T12:09:27	12:55:47	18.2	2.078	2.904	12.6	Sw	DeMeo et al. (2019)
18810		1999 JF ₉₆	dm16	2013-07-18T10:38:49	11:15:56	18.2	3.007	2.006	4.1	Sq	Marsset et al. (2024)
18853		1999 RO ₉₂	dm15	2013-05-17T08:09:00	08:28:00	18.7	3.326	2.390	7.8	A	DeMeo et al. (2019)
19312		1996 VR ₇	dm14	2013-03-01T11:19:00	11:58:00	18.9	2.547	1.629	10.5	S	DeMeo et al. (2019)
19570	Jessedouglas	1999 LH ₆	dm04	2011-12-01T05:56:00	06:36:00	17.2	2.560	1.655	10.9	S	DeMeo et al. (2019)
19652	Saris	1999 RC ₁₁₇	sp108	2012-04-29T11:15:38	12:09:00	17.6	2.717	1.715	2.6	A	DeMeo et al. (2019)
20439		1999 JM ₂₈	sp117	2013-01-17T11:50:22	12:51:03	16.1	2.063	1.080	1.9	S	DeMeo et al. (2014)
20452		1999 KG ₄	dm14	2013-03-01T13:40:00	14:00:00	18.2	2.338	1.632	20.5	K	DeMeo et al. (2014)
20596		1999 RX ₁₈₈	dm17	2014-01-11T04:58:00	05:00:00	19.3	2.418	2.104	23.8	S-comp	DeMeo et al. (2019)
20786		2000 RG ₆₂	sp25	2003-10-01T12:42:48	13:41:33	17.4	2.056	1.157	16.5	Xk/Xn	DeMeo et al. (2009)
20786		2000 RG ₆₂	sp80	2009-04-27T14:29:24	15:26:09	16.8	1.875	0.935	15.6	()	
20786		2000 RG ₆₂	sp81	2009-06-21T07:40:47	08:08:51	16.4	1.745	0.816	19.9	()	
21205		1994 PV ₂₇	dm12	2012-12-12T08:38:01	08:54:37	18.5	2.696	1.759	7.9	Sr	
21238	Panarea	1995 WV ₇	sp53	2006-07-20T09:34:38	10:21:38	17.1	2.803	1.810	5.4	V	
21646	Joshuaturner	1999 NK ₅₃	dm09	2012-07-22T12:12:00	12:31:00	18.5	2.797	1.815	6.6	X	DeMeo et al. (2019)
21809		1999 TG ₁₉	sp112	2012-09-14T09:18:31	09:56:52	17.5	2.676	1.673	2.1	A	DeMeo et al. (2019)
22693		1998 QF ₁₀₂	dm14	2013-03-01T05:11:00	05:59:00	19.2	2.850	2.566	20.2	R	
22959		1999 UY ₁	sp97	2011-02-06T11:04:17	11:55:01	17.5	2.507	1.536	4.9	Sw	
23615		1996 FK ₁₂	dm16	2013-07-19T14:32:14	14:48:37	19.2	2.850	2.566	20.2	A	
24436		2000 ES ₅₆	dm08	2012-06-06T11:20:00	12:32:00	17.3	2.142	1.245	16.7	Xn	
24447		2000 QY ₁	sp225	2016-12-24T09:06:56	10:00:37	17.5	1.358	0.438	26.1	A/D	
24673		1989 SB ₁	dm09	2012-07-22T12:53:00	13:12:00	17.6	2.434	1.471	9.8	S	DeMeo et al. (2019)
27151		1998 YT ₃	dm02	2011-08-08T08:22:00	09:18:00	17.4	2.913	1.915	4.4	S	DeMeo et al. (2019)
27268		1999 YS ₉	sp113	2012-10-12T12:26:54	12:45:14	17.4	2.262	1.353	13.5	Sw	Marsset et al. (2024)
27791	Masaru	1993 DD ₁	dm04	2011-12-01T11:28:00	11:48:00	17.1	2.123	1.241	15.6	S-comp	DeMeo et al. (2019)
28218		1998 YA ₆	dm04	2011-12-01T10:33:00	11:04:00	18.1	2.200	1.264	10.7	S-comp	DeMeo et al. (2019)
29731		1999 BY ₂	dm04	2011-12-01T09:04:00	10:03:00	17.3	2.142	1.245	16.7	S	DeMeo et al. (2019)
29731		1999 BY ₂	dm14	2013-03-01T14:22:00	15:00:00	19.2	2.675	2.063	19.1	()	
30698	Hippokoon	2299 T-3	dm11	2012-09-17T07:01:53	07:46:30	18.8	4.905	3.909	1.8	Xk	
31393		1998 YG ₈	dm05	2012-01-23T11:44:00	12:42:00	17.5	2.220	1.240	2.8	A	DeMeo et al. (2019)
31455		1999 CU ₁₄	dm15	2013-05-17T05:59:00	06:37:00	18.9	2.940	2.160	14.7	Sr	
31735		1999 JJ ₇₂	dm03	2011-09-13T11:12:00	11:49:00	17.4	3.051	2.088	6.6	S-comp	DeMeo et al. (2019)
31881		2000 FL ₁₅	sp254	2019-04-08T07:47:05	08:23:55	17.3	1.619	0.650	14.1	L	
32222	Charlesvest	2000 OD ₂₃	dm04	2011-12-01T13:13:02	13:50:30	17.3	2.625	1.821	15.0	Sr	
33745		1999 NW ₆₁	sp99	2011-04-30T12:31:51	12:45:32	16.8	2.188	1.247	12.5	S-comp	DeMeo et al. (2019)
33917	Kellyoconnor	2000 LK ₁₉	dm14	2013-03-01T10:46:00	10:48:00	18.2	2.421	1.437	3.6	C/X	DeMeo et al. (2014)
33952		2000 ML ₅	dm02	2011-08-08T07:22:00	09:18:00	16.9	2.213	1.283	13.7	S-comp	DeMeo et al. (2019)
34931		6621 P-L	sp121	2013-06-13T08:10:30	08:38:13	17.4	2.287	1.315	9.7	Sw	
34931		6621 P-L	dm16	2013-07-18T07:17:26	07:53:02	18.0	2.287	1.420	17.0	()	
35102		1991 RT	dm11	2012-09-16T09:44:00	09:46:00	17.0	2.020	1.045	9.7	S	DeMeo et al. (2019)
35925		1999 JP ₁₀₄	dm02	2011-08-08T11:03:48	11:49:39	17.2	2.497	1.492	4.1	A	DeMeo et al. (2019)
35925		1999 JP ₁₀₄	dm12	2012-12-12T06:56:01	07:40:28	18.1	2.642	1.774	12.3	()	
36256		1999 XT ₁₇	dm07	2012-03-20T12:36:00	12:53:00	17.4	3.039	2.164	10.6	A	DeMeo et al. (2019)
37479		1130 T-1	sp252	2019-03-21T11:31:39	12:08:27	17.0	1.613	0.619	3.7	Xn	

Table A1
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V ^a (mag)	R _n ^a (au)	Δ ^a (au)	α ^a (deg)	BD Tax. ^a	References
38699		2000 QX ₆₃	dm15	2013-05-17T09:23:00	09:42:00	17.7	2.065	1.054	0.8	L	
38707		2000 QK ₈₉	sp120	2013-05-12T11:11:23	12:07:06	18.1	2.503	1.495	1.7	V	Polishook et al. (2014)
40573		1999 RE ₁₃₀	dm05	2012-01-23T13:22:00	13:58:00	18.1	2.769	1.928	12.7	S	DeMeo et al. (2019)
40573		1999 RE ₁₃₀	dm06	2012-03-04T11:00:00	11:55:00	17.7	2.873	1.894	3.9	()	
41357		2000 AD ₅₂	dm03	2011-09-13T13:53:00	15:10:00	17.2	2.011	1.140	19.1	Sw	
42946		1999 TU ₉₅	sp117	2013-01-17T06:40:37	07:15:40	18.1	2.605	1.798	14.9	Sw	Polishook et al. (2014)
42946		1999 TU ₉₅	dm20	2015-09-11T08:35:59	08:54:12	17.7	2.700	1.740	8.1	()	
44028		1998 BD ₁	dm16	2013-07-18T13:50:00	14:08:00	18.8	2.914	2.389	19.0	S	DeMeo et al. (2019)
45610		2000 DJ ₄₈	sp113	2012-10-13T07:23:55	08:15:30	17.9	2.559	1.566	2.8	Sw	
45876		2000 WD ₂₇	dm09	2012-07-22T13:44:00	14:22:00	18.7	2.233	1.585	24.0	()	Marsset et al. (2024)
45876		2000 WD ₂₇	dm11	2012-09-16T09:07:14	09:33:03	17.6	2.293	1.293	3.6	Sw	Marsset et al. (2024)
46456		4140 P-L	dm16	2013-07-19T11:54:00	12:16:00	18.2	2.249	1.589	23.6	S-comp	DeMeo et al. (2019)
48049		2001 DB ₉₀	sp120	2013-05-12T08:54:09	09:31:20	18.4	2.216	1.275	12.5	X	
52726		1998 GY ₆	dm16	2013-07-18T06:14:55	07:03:19	18.4	2.755	2.026	17.3	A	
53233		1999 CO ₁₁₇	sp58	2007-01-21T11:10:12	12:09:59	17.1	2.458	1.530	9.7	Sq	Vernazza et al. (2014)
53424		1999 SC ₃	sp115	2012-12-14T14:23:59	15:11:38	17.9	1.871	1.073	23.5	S-comp	DeMeo et al. (2014)
54041		2000 GQ ₁₁₃	sp115	2012-12-14T07:23:05	08:20:45	17.8	2.317	1.388	10.4	V	Polishook et al. (2014)
55543	Nemeghaire	2001 XN ₁₆	dm16	2013-07-18T09:21:27	09:38:20	17.2	2.255	1.253	5.7	Sq	Marsset et al. (2024)
56690		2000 LZ ₁₄	dm02	2011-08-08T09:50:00	10:48:00	17.7	2.214	1.200	0.3	S-comp	DeMeo et al. (2019)
59115		1998 XG ₃	dm14	2013-03-01T06:30:00	06:48:00	19.2	2.147	1.678	26.6	S	DeMeo et al. (2019)
60631		2000 FC ₂₆	dm14	2013-03-01T09:53:00	10:12:00	19.0	2.864	1.924	7.6	A	DeMeo et al. (2019)
60716		2000 GD ₆₅	sp111	2012-08-28T08:24:24	09:08:20	19.1	2.515	1.548	8.5	S	Polishook et al. (2016)
74096		1998 QD ₁₅	sp125	2013-10-04T12:46:59	13:24:01	18.5	2.238	1.281	9.8	S/Sq	Polishook et al. (2014)
75810		2000 AX ₂₄₄	dm07	2012-03-20T09:17:00	09:53:00	18.0	2.413	1.429	4.8	A	DeMeo et al. (2019)
76818	Brianenke	2000 RG ₇₉	sp226	2017-01-03T07:20:27	07:57:32	16.2	1.749	1.009	28.2	Xe	Pajuelo et al. (2018)
77578		2001 KC ₁₂	sp120	2013-05-12T10:31:27	11:08:28	18.5	2.429	1.430	4.6	S	
77653		2001 KH ₇₂	dm16	2013-07-18T08:26:00	09:05:00	18.5	2.934	1.953	6.3	S	DeMeo et al. (2019)
81850		2000 KL ₆₀	dm16	2013-07-19T13:03:00	13:23:00	17.6	1.964	1.065	18.9	S	DeMeo et al. (2019)
83463		2001 SP ₆₉	dm16	2013-07-18T09:48:00	10:07:00	17.9	2.275	1.304	9.9	Srw	Marsset et al. (2024)
84480		2002 TM ₂₆₆	sp110	2012-07-21T09:59:00	10:36:08	16.7	1.826	0.862	14.7	D	
85119	Hannieschaft	1972 RD	sp273	2020-09-21T11:54:01	12:26:51	17.7	1.717	0.741	11.8	Xc	
88604		2001 QH ₂₉₃	sp121	2013-06-12T09:21:13	10:07:58	17.4	2.879	1.877	4.0	S/Sq	Polishook et al. (2014)
91450		1999 RV ₂₄	dm11	2012-09-16T10:16:00	10:18:00	17.4	1.743	0.772	13.0	S	DeMeo et al. (2019)
92516		2000 ND ₂₅	dm07	2012-03-20T07:40:00	08:17:00	17.8	2.304	1.319	4.8	A	DeMeo et al. (2019)
95560		2002 EX ₉₈	dm17	2014-01-11T06:26:00	06:28:00	18.9	2.628	1.942	17.9	A	DeMeo et al. (2019)
97335		1999 YF	dm13	2013-01-16T09:21:23	09:56:23	17.9	1.737	0.766	7.9	S	DeMeo et al. (2019)
99278		2001 QA ₆₈	sp217	2016-04-14T07:33:38	08:18:13	18.0	1.588	0.618	15.0	Xk	
101703		1999 CA ₁₅₀	sp125	2013-10-03T09:17:10	10:04:16	18.3	2.380	1.404	6.9	Sw/Q	Polishook et al. (2014)
105840		2000 SK ₁₅₅	dm04	2011-12-01T08:06:00	08:43:00	17.9	2.630	1.653	3.8	A	DeMeo et al. (2019)
109068		2001 QT ₂₁	dm16	2013-07-19T11:01:49	11:39:02	17.0	1.850	0.844	6.7	S	
111114		2001 VR ₈₆	sp120	2013-05-12T07:55:30	08:51:20	19.1	2.660	1.710	9.2	Srw	
111186		2001 WA ₈	dm16	2013-07-19T06:41:00	07:24:00	18.9	2.293	1.396	15.3	C	DeMeo et al. (2019)
125102		2001 UH ₃₅	dm14	2013-03-01T07:34:00	08:01:00	19.4	2.208	1.564	23.4	X/D	DeMeo et al. (2014)
125739		2001 XH ₁₁₆	sp201	2014-09-01T09:33:37	10:10:45	17.1	1.871	0.865	4.0	Sq	
129761		1999 GL ₆	dm16	2013-07-19T06:02:01	06:18:25	17.4	1.775	0.902	25.7	L	
130206		2000 AK ₂₀₁	sp216	2016-03-12T08:13:11	08:47:57	18.0	1.715	0.830	21.8	Xe	
156015		2001 RX ₈₁	dm22	2015-11-10T05:23:43	06:16:58	17.6	1.640	0.727	20.2	B	
165213		2000 SJ ₁₂	sp274	2020-09-28T11:02:15	11:48:25	18.1	1.797	0.810	8.3	X	
175158		2005 EM ₆₆	dm16	2013-07-19T08:40:00	09:17:00	18.4	1.882	0.900	11.5	S	DeMeo et al. (2019)
190541		2000 RO ₇₇	sp224	2016-11-28T06:34:26	07:11:18	17.4	1.546	0.703	28.4	X-comp	
222205		2000 DV ₁₁₇	sp223	2016-10-25T06:44:43	07:40:25	17.3	1.637	0.655	8.5	Xc	
247264		2001 SW ₈	dm11	2012-09-16T08:24:00	08:26:00	18.4	1.924	0.936	8.0	C/X	DeMeo et al. (2014)
271073		2003 KU ₁₃	sp271	2020-08-30T14:25:15	15:02:10	17.8	1.697	0.799	22.8	()	
271073		2003 KU ₁₃	sp274	2020-09-28T10:18:04	10:54:58	17.7	1.772	0.799	11.5	X-comp	
281396		2008 QN ₄₈	dm20	2015-09-12T07:21:10	08:07:23	17.7	1.616	0.653	16.5	Svw	
357208		2002 GJ ₁₀₃	sp26	2003-10-16T10:52:05	11:29:35	17.5	2.183	1.206	7.1	C-comp	
366616		2003 NP ₄	sp271	2020-08-30T13:34:29	13:52:46	18.2	1.575	0.755	31.3	B	
376246		2011 ES ₇₇	sp206	2015-02-06T13:22:49	13:59:55	17.5	1.611	0.642	10.1	S-comp	
377052		2002 TB ₁₄₂	dm22	2015-11-10T07:06:04	07:38:16	18.1	1.670	0.753	19.3	S	
440022		2002 OZ ₁₆	sp211	2015-10-05T07:21:38	07:58:43	18.0	1.550	0.577	14.2	X	
442037		2010 PR ₆₆	sp209	2015-07-20T05:49:12	06:35:39	16.3	1.022	0.064	83.3	S-comp	
443880		2001 UZ ₁₆	sp211	2015-10-05T05:13:15	06:26:48	18.3	1.024	0.169	77.1	L	

Table A1
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V^a (mag)	R_h^a (au)	Δ^a (au)	α^a (deg)	BD Tax. ^a	References
443892		2001 XT ₄	dm22	2015-11-10T08:51:41	09:28:25	17.3	1.464	0.480	7.7	Sq	
516460		2005 LW ₇	sp210	2015-09-22T07:21:54	08:08:38	18.2	1.463	0.465	8.0	B	

Notes.

^a Observational run ID, apparent V-band magnitude (V), heliocentric (R_h) and geocentric distances (Δ), phase angle (α), and Bus–DeMeo taxonomy for MITHMBAs observations.

^b Spectra of 1 Ceres in sp41 combined all three separate observations into one.

^c Records of observed times for asteroids have been lost.

Table A2
Observational Circumstances of Vernazza's Studies

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V^a (mag)	R_h^a (au)	Δ^a (au)	α^a (deg)	BD Tax. ^a	References
12	Victoria		V05	2010-11-01T04:54:37	05:00:23	11.5	1.822	2.206	26.4	L	
18	Melpomene		V06	2011-01-10T15:22:00	15:31:50	11.3	2.666	2.231	20.8	()	Vernazza et al. (2014)
23	Thalia		V06	2011-01-10T13:17:21	13:20:45	9.5	2.016	1.066	10.0	()	Vernazza et al. (2014)
25	Phocaea		V03	2010-09-04T13:53:19	13:58:19	11.9	2.187	1.679	26.3	()	Vernazza et al. (2014)
28	Bellona		V03	2010-09-04T15:27:06	15:34:05	12.5	2.484	2.760	21.3	()	Vernazza et al. (2014)
31	Euphrosyne		V05	2010-11-01T05:37:57	05:47:48	12.9	3.394	3.137	16.9	C	
31	Euphrosyne		V07	2011-10-20T12:26:57	12:32:14	10.6	2.653	1.688	6.6	C	
33	Polyhymnia		V03	2010-09-04T15:14:30	15:24:03	14.0	2.720	3.155	17.9	()	Vernazza et al. (2014)
36	Atalante		V05	2010-11-01T06:15:15	06:18:08	10.9	1.937	1.014	14.9	()	Vernazza et al. (2016)
37	Fides		V03	2010-09-04T14:01:57	14:05:41	11.6	2.232	1.875	26.7	S	Vernazza et al. (2014)
45	Eugenia		V02	2010-05-10T15:04:55	15:20:53	12.5	2.564	2.114	22.4	C	
46	Hestia		V05	2010-11-01T08:30:03	08:33:54	10.9	2.170	1.179	1.5	Xc	
49	Pales		V06	2011-01-10T10:44:58	11:41:31	11.8	2.808	1.831	2.9	()	Vernazza et al. (2016)
54	Alexandra		V05	2010-11-01T06:05:09	06:10:23	11.8	2.469	1.660	16.3	()	Vernazza et al. (2016)
61	Danae		V03	2010-09-04T11:32:07	11:35:48	12.2	2.557	1.956	20.9	()	Vernazza et al. (2014)
70	Panopaea		V05	2010-11-01T07:55:50	08:00:30	11.5	2.516	1.535	4.5	()	Vernazza et al. (2016)
74	Galatea		V05	2010-11-01T05:20:38	05:32:44	13.3	2.209	2.038	26.6	C	
74	Galatea		V07	2011-10-20T13:42:53	14:07:33	13.6	2.473	2.174	23.6	C	
75	Eurydike		V07	2011-10-21T13:37:59	13:52:30	13.6	2.522	2.013	21.9	X	
80	Sappho		V03	2010-09-03T05:14:33	05:22:06	13.0	2.284	2.380	24.9	S	Vernazza et al. (2014)
83	Beatrix		V05	2010-11-01T06:26:46	06:44:21	13.6	2.600	2.150	21.6	Xk	
89	Julia		V06	2011-01-10T12:21:03	12:45:19	11.3	2.871	2.043	12.6	S	Vernazza et al. (2014)
91	Aegina		V07	2011-10-21T04:38:00	05:03:52	14.3	2.753	2.663	21.1	Cgh	Vernazza et al. (2016)
92	Undina		V05	2010-11-01T05:53:02	05:59:10	12.0	2.864	2.441	19.5	()	
93	Minerva		V06	2011-01-10T07:39:03	07:46:28	12.6	3.143	2.186	4.9	C	
95	Arethusa		V07	2011-10-21T06:17:56	06:34:02	13.7	2.982	2.943	19.3	Ch	Vernazza et al. (2016)
100	Hekate		V03	2010-09-04T11:05:59	11:13:33	11.7	2.686	1.741	9.4	S	Vernazza et al. (2014)
102	Miriam		V07	2011-10-20T07:14:56	07:46:55	13.2	2.020	1.576	28.9	Cgh	
105	Artemis		V05	2010-11-01T05:04:18	05:16:29	13.5	2.169	2.259	25.8	()	Vernazza et al. (2016)
106	Dione		V06	2011-01-10T07:49:41	07:54:04	11.7	2.968	1.987	1.8	()	Vernazza et al. (2016)
107	Camilla		V05	2010-11-01T08:08:32	08:22:36	13.6	3.703	3.407	15.3	Xk	Vernazza et al. (2012)
112	Iphigenia		V07	2011-10-20T15:16:07	15:33:07	14.1	2.400	1.838	22.6	Ch	Vernazza et al. (2016)
115	Thyra		V03	2010-09-04T05:43:57	06:01:15	12.8	2.609	2.359	22.7	()	Vernazza et al. (2014)
116	Sirona		V03	2010-09-04T14:08:35	14:18:37	13.3	2.848	2.623	20.7	S	Vernazza et al. (2014)
118	Peitho		V03	2010-09-03T05:33:29	05:50:18	14.0	2.379	2.790	20.6	()	Vernazza et al. (2014)
120	Lachesis		V07	2011-10-21T06:53:57	07:16:06	13.5	3.170	2.857	18.1	()	
121	Hermione		V09	2012-01-24T15:14:28	15:24:03	14.0	3.910	3.538	14.1	()	Vernazza et al. (2016)
123	Brunhild		V03	2010-09-04T14:22:34	14:30:40	13.6	2.406	2.145	24.8	S	Vernazza et al. (2014)
124	Alkeste		V06	2011-01-10T12:49:45	13:03:06	12.0	2.758	1.791	4.7	S	Vernazza et al. (2014)
125	Liberatrix		V01	2010-02-22T06:42:00	07:08:15	14.4	2.951	2.838	19.6	Xc	
127	Johanna		V06	2011-01-10T09:49:51	10:09:36	12.2	2.579	1.619	6.0	Ch	Vernazza et al. (2016)
130	Elektra		V09	2012-01-24T15:29:11	15:32:43	13.9	3.761	3.818	14.9	()	Vernazza et al. (2016)
133	Cyrene		V06	2011-01-10T14:46:21	15:17:57	13.6	2.883	2.657	19.9	()	Vernazza et al. (2014)
137	Meliboea		V01	2010-02-22T07:16:34	07:42:28	14.3	3.773	3.065	11.7	Ch	
143	Adria		V09	2012-01-21T07:16:49	07:38:14	13.9	2.898	2.116	13.8	X	

Table A2
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V ^a (mag)	R _h ^a (au)	Δ ^a (au)	α ^a (deg)	BD Tax. ^a	References
144	Vibilia		V06	2011-01-10T04:58:32	05:07:22	12.0	2.242	1.610	22.9	()	Vernazza et al. (2016)
145	Adeona		V01	2010-02-22T15:05:04	15:18:03	12.8	2.545	2.033	21.4	()	Vernazza et al. (2016)
146	Lucina		V07	2011-10-20T12:38:35	13:09:43	12.9	2.897	2.004	10.5	Cgh	Vernazza et al. (2016)
148	Gallia		V06	2011-01-10T13:06:43	13:14:30	12.1	2.761	1.946	13.7	S	Vernazza et al. (2014)
154	Bertha		V07	2011-10-21T09:31:59	09:46:30	12.7	3.453	2.474	3.5	C	
156	Xanthippe		V07	2011-10-21T14:07:08	14:23:54	14.3	3.116	2.655	17.7	Ch	Vernazza et al. (2016)
156	Xanthippe		V09	2012-01-21T07:44:22	08:01:10	13.4	2.948	2.087	11.0	()	
159	Aemilia		V07	2011-10-20T07:53:28	08:24:45	13.6	3.206	2.418	12.5	Ch	Vernazza et al. (2016)
162	Laurentia		V06	2011-01-10T06:28:15	06:49:48	14.5	3.027	2.664	18.5	Ch	
163	Erigone		V01	2010-02-23T06:26:47	06:39:46	13.7	1.919	1.487	30.6	Ch	Vernazza et al. (2016)
165	Loreley		V07	2011-10-21T14:28:55	14:47:08	14.0	3.387	3.328	17.0	C	
166	Rhodope		V01	2010-02-23T08:10:30	08:36:31	14.1	2.599	1.785	15.0	Xc	
169	Zelia		V03	2010-09-04T11:15:30	11:19:17	12.3	2.080	1.159	15.3	Sw	Vernazza et al. (2014)
170	Maria		V03	2010-09-04T11:38:25	11:44:11	13.7	2.513	1.871	20.7	Sw	
171	Ophelia		V01	2010-02-22T06:19:17	06:36:15	13.9	2.889	2.461	19.3	C	Marsset et al. (2016)
174	Phaedra		V06	2011-01-10T14:13:54	14:41:01	13.4	2.868	2.323	18.3	S	Vernazza et al. (2014)
179	Klytaemnestra		V03	2010-09-04T14:34:55	14:41:59	12.9	2.663	2.063	19.9	S	Vernazza et al. (2014)
185	Eunike		V07	2011-10-21T06:39:13	06:48:46	12.8	2.557	2.458	22.8	C	
194	Prokne		V07	2011-10-21T06:07:11	06:14:58	12.1	2.003	1.916	29.3	Cgh	Vernazza et al. (2016)
206	Hersilia		V07	2011-10-20T13:18:03	13:35:29	13.0	2.650	1.809	14.0	C	
207	Hedda		V06	2011-01-10T06:01:07	06:23:14	14.9	2.350	2.238	24.6	Ch	Vernazza et al. (2016)
211	Isolda		V07	2011-10-21T09:11:47	09:25:13	12.8	2.901	2.131	14.6	Cgh	Vernazza et al. (2016)
223	Rosa		V07	2011-10-20T14:13:19	15:03:41	15.3	2.737	2.663	21.2	D	Marsset et al. (2016)
230	Athamantis		V03	2010-09-03T05:03:07	05:08:53	12.3	2.299	2.424	24.5	L	Vernazza et al. (2014)
233	Asterope		V09	2012-01-24T09:34:31	09:49:38	12.4	2.826	1.858	4.4	()	
237	Coelestina		V04	2010-09-11T14:47:54	15:04:57	15.0	2.943	3.123	18.8	()	Vernazza et al. (2014)
240	Vanadis		V07	2011-10-21T14:51:46	15:10:23	13.6	2.198	2.015	26.9	Cgh	Vernazza et al. (2016)
242	Kriemhild		V09	2012-01-24T14:11:52	14:23:19	13.4	2.539	1.699	14.2	Xk	
258	Tyche		V03	2010-09-04T14:44:45	14:49:25	12.0	2.108	1.560	27.0	()	Vernazza et al. (2014)
266	Aline		V06	2011-01-10T05:14:44	05:26:48	13.9	2.377	2.722	20.9	()	Vernazza et al. (2016)
275	Sapientia		V07	2011-10-20T15:37:34	15:39:57	14.0	2.699	2.315	21.2	Xk	
293	Brasilia		V01	2010-02-23T08:41:40	08:55:59	14.2	2.565	1.721	14.1	Ch	Vernazza et al. (2016)
301	Bavaria		V02	2010-05-10T10:58:26	11:29:12	14.1	2.561	1.605	9.2	()	
322	Phaéo		V02	2010-05-11T08:37:27	08:58:42	14.2	3.360	2.417	7.3	()	
338	Budrosa		V07	2011-10-21T09:51:52	10:07:32	13.4	2.876	2.141	15.6	Xk	
342	Endymion		V07	2011-10-20T08:30:20	09:06:47	14.3	2.565	1.728	14.7	B	Vernazza et al. (2016)
346	Hermentaria		V06	2011-01-10T13:30:59	13:45:09	12.6	2.966	2.373	17.0	()	Vernazza et al. (2014)
359	Georgia		V02	2010-05-10T05:17:28	05:54:07	15.0	3.148	2.774	18.3	()	
360	Carlova		V07	2011-10-21T15:15:03	15:29:33	13.4	2.511	2.232	23.3	()	
375	Ursula		V09	2012-01-24T13:51:33	14:01:44	12.7	3.456	2.543	7.2	C	
379	Huenna		V01	2010-02-22T05:11:59	05:23:59	14.7	3.029	2.863	19.1	C	Marsset et al. (2016)
381	Myrrha		V07	2011-10-25T04:50:32	05:11:36	14.0	3.086	2.715	18.3	C	
383	Janina		V01	2010-02-22T05:39:42	06:10:18	14.7	3.029	2.864	21.6	B	Marsset et al. (2016)
386	Siegena		V06	2011-01-10T07:01:33	07:07:49	12.4	2.444	2.075	23.3	Cgh	
388	Charybdis		V07	2011-10-21T10:43:48	10:55:00	13.0	2.872	1.925	7.5	C	
389	Industria		V03	2010-09-04T14:53:08	15:00:08	12.9	2.769	2.216	19.6	()	Vernazza et al. (2014)
392	Wilhelmina		V08	2011-10-25T05:57:52	06:28:33	14.3	2.546	1.973	20.9	Cgh	Vernazza et al. (2016)
393	Lampetia		V09	2012-01-24T09:56:28	10:18:33	13.9	3.698	2.758	5.3	Cgh	
396	Aeolia		V01	2010-02-22T14:28:49	14:58:53	14.5	2.628	1.873	16.6	Xc	
398	Admete		V08	2011-10-25T06:58:21	07:33:47	15.0	2.600	1.995	20.0	Cg	
405	Thia		V08	2011-10-26T04:32:29	04:59:08	13.9	2.571	2.686	21.7	Ch	Vernazza et al. (2016)
409	Aspasia		V09	2012-01-21T04:47:12	05:02:45	11.9	2.712	1.868	12.9	X	
410	Chloris		V02	2010-05-10T14:48:26	15:00:54	11.4	2.105	1.230	18.0	Ch	Vernazza et al. (2016)
414	Liriope		V08	2011-10-26T05:17:26	05:52:30	15.6	3.506	2.993	15.1	Ch	
417	Suevia		V09	2012-01-21T05:34:49	06:09:51	14.2	2.807	2.032	14.6	X	
423	Diotima		V06	2011-01-10T12:00:56	12:16:45	12.3	3.158	2.293	10.0	C	
432	Pythia		V06	2011-01-10T07:11:49	07:32:50	13.4	2.716	1.923	14.6	S	Vernazza et al. (2014)
441	Bathilde		V09	2012-01-21T05:07:46	05:29:46	12.6	2.585	1.725	13.0	T	
444	Gyptis		V08	2011-10-25T06:35:49	06:47:34	12.0	2.289	1.672	23.0	()	
461	Saskia		V09	2012-01-24T14:56:01	15:07:56	14.7	2.763	1.853	9.6	X	Marsset et al. (2016)
468	Lina		V09	2012-01-21T06:29:12	07:09:14	14.6	3.292	2.327	4.0	X	Marsset et al. (2016)
471	Papagena		V03	2010-09-04T11:26:26	11:28:30	10.0	2.328	1.429	14.4	Sq	Vernazza et al. (2014)
478	Tergeste		V07	2011-10-21T10:58:12	11:07:49	12.6	3.049	2.115	7.8	L	

Table A2
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V ^a (mag)	R _h ^a (au)	Δ ^a (au)	α ^a (deg)	BD Tax. ^a	References
485	Genua		V06	2011-01-10T13:49:48	14:09:00	12.8	2.393	1.970	23.6	()	Vernazza et al. (2014)
490	Veritas		V03	2010-09-04T13:33:18	13:44:26	13.7	2.876	2.334	18.9	Ch	Vernazza et al. (2016)
494	Virtus		V07	2011-10-21T13:06:07	13:32:41	14.5	3.169	2.486	14.9	Ch	Vernazza et al. (2016)
512	Taurinensis		V04	2010-09-11T06:21:59	06:30:34	13.4	1.719	1.042	32.3	()	Vernazza et al. (2014)
521	Brixia		V01	2010-02-22T13:55:49	14:21:37	14.9	3.478	3.102	16.0	Ch	Vernazza et al. (2016)
526	Jena		V08	2011-10-26T05:59:49	06:34:49	15.9	3.455	2.806	13.9	C	Marsset et al. (2016)
543	Charlotte		V07	2011-10-21T10:14:54	10:35:22	13.7	2.677	1.832	13.6	Xk	
545	Messalina		V08	2011-10-25T05:18:28	05:39:52	14.1	2.675	2.600	21.7	C	
547	Praxedis		V09	2012-01-24T14:28:54	14:50:30	14.3	2.867	1.989	10.7	X	
551	Ortrud		V07	2011-10-21T12:08:09	12:25:42	13.4	2.660	1.681	5.0	C	
563	Suleika		V03	2010-09-04T15:03:35	15:10:35	12.7	2.097	1.883	28.7	Sw	Vernazza et al. (2014)
564	Dudu		V07	2011-10-21T12:32:42	12:59:54	14.9	2.938	2.032	9.7	X	
578	Happelia		V09	2012-01-24T10:24:21	10:41:10	14.2	3.251	2.278	3.1	Cg	
586	Thekla		V09	2012-01-21T09:47:01	09:48:53	13.7	2.864	1.912	6.1	Ch	Vernazza et al. (2016)
600	Musa		V04	2010-09-11T05:32:32	05:54:07	15.2	2.527	2.418	23.4	()	Vernazza et al. (2014)
604	Tekmessa		V09	2012-01-24T11:01:22	11:10:01	13.6	2.942	1.961	2.1	Cg	
621	Werdandi		V05	2010-11-01T07:18:08	07:44:29	16.0	3.064	2.258	12.6	B	Marsset et al. (2016)
631	Philippina		V04	2010-09-11T06:02:58	06:14:56	14.3	2.933	2.867	19.9	()	Vernazza et al. (2014)
654	Zelinda		V07	2011-10-21T11:12:07	11:24:10	12.0	2.344	1.427	12.2	Ch	
668	Dora		V02	2010-05-10T06:21:51	07:11:52	16.8	3.013	2.120	10.7	Cgh	Vernazza et al. (2016)
675	Ludmilla		V04	2010-09-11T14:36:18	14:43:34	12.6	2.212	2.048	27.0	()	Vernazza et al. (2014)
688	Melanie		V08	2011-10-25T07:39:20	08:10:02	14.8	2.449	1.637	16.4	()	
695	Bella		V05	2010-11-01T08:36:18	08:43:55	12.0	2.221	1.265	9.1	S	Vernazza et al. (2014)
705	Erminia		V09	2012-01-24T11:17:56	11:25:11	12.8	2.794	1.914	11.0	X	
735	Marghanna		V07	2011-10-21T11:28:53	11:39:28	11.6	1.940	0.952	4.9	Ch	Vernazza et al. (2016)
741	Botolphia		V09	2012-01-24T13:02:13	13:18:50	14.7	2.532	1.993	21.1	X	
767	Bondia		V02	2010-05-11T05:22:34	06:43:35	16.3	3.640	3.034	14.0	B	Marsset et al. (2016)
768	Struveana		V01	2010-02-23T11:26:06	11:51:53	15.1	3.214	2.282	7.1	D	
791	Ani		V01	2010-02-23T05:43:24	06:18:46	15.1	3.156	3.087	18.2	X	
797	Montana		V04	2010-09-11T06:43:08	06:50:24	14.9	2.482	1.894	21.7	Sq	Vernazza et al. (2014)
804	Hispania		V01	2010-02-23T09:03:05	09:14:58	13.0	3.207	2.333	9.7	C	
826	Henrika		V08	2011-10-26T07:45:49	08:11:35	15.9	2.741	1.861	11.8	Xc	
910	Anneliese		V08	2011-10-26T08:17:00	08:42:48	15.4	2.967	2.203	14.3	Cgh	Vernazza et al. (2016)
954	Li		V03	2010-09-04T07:31:44	07:54:37	13.9	2.619	1.643	7.1	Cb	Marsset et al. (2016)
965	Angelica		V07	2011-10-21T11:41:50	11:58:26	13.5	2.481	1.501	5.1	C	
965	Angelica		V08	2011-10-25T08:18:42	08:32:26	13.4	2.472	1.484	3.3	C	
971	Alsatia		V08	2011-10-25T08:35:50	08:49:36	13.3	2.377	1.414	7.7	C	
997	Priska		V02	2010-05-10T11:34:50	12:34:17	15.9	2.330	1.394	12.0	Cgh	Vernazza et al. (2016)
1086	Nata	1927 QL	V07	2011-10-20T06:29:27	06:56:32	15.4	3.306	2.897	16.9	Ch	Vernazza et al. (2016)
1109	Tata	1929 CU	V07	2011-10-20T04:51:24	05:22:40	15.5	3.099	2.564	17.1	X	Vernazza et al. (2020)
1128	Astrid	1929 EB	V03	2010-09-04T10:45:02	11:01:50	15.2	2.736	1.857	12.6	Cgh	
1128	Astrid	1929 EB	V05	2010-11-01T06:50:03	07:11:35	15.2	2.762	1.867	10.8	Cgh	
1369	Ostanina	1935 QB	V01	2010-02-24T13:40:30	14:19:48	15.9	3.583	2.610	3.5	B	
1384	Kniertje	1934 RX	V01	2010-02-23T04:53:27	05:34:24	15.7	2.280	1.705	23.6	Ch	Vernazza et al. (2016)
1403	Idelsonia	1936 QA	V01	2010-02-22T09:17:25	09:57:11	16.5	3.347	2.392	5.2	Cgh	Vernazza et al. (2016)
1599	Giomus	1950 WA	V03	2010-09-05T06:17:39	06:53:35	16.5	3.165	2.543	16.1	Cg	Vernazza et al. (2020)
1726	Hoffmeister	1933 OE	V01	2010-02-22T08:04:30	09:08:35	17.2	2.909	2.164	14.9	B	
1734	Zhongolovich	1928 TJ	V07	2011-10-20T05:37:36	06:13:45	15.5	2.168	1.548	24.5	Ch	Vernazza et al. (2016)
1783	Albitskij	1935 FJ	V03	2010-09-04T06:21:33	07:18:24	16.9	3.008	2.190	13.2	Ch	Vernazza et al. (2016)
1795	Woltjer	4010 P-L	V01	2010-02-23T14:13:00	15:19:16	16.5	2.606	1.888	17.7	B	Vernazza et al. (2016)
1936	Lugano	1973 WD	V02	2010-05-10T09:45:01	10:26:53	15.1	2.467	1.478	6.1	Ch	Vernazza et al. (2016)
1970	Sumeria	1954 ER	V02	2010-05-10T08:24:13	09:23:34	15.9	2.634	1.640	4.9	B	Vernazza et al. (2016)
2040	Chalonge	1974 HA	V03	2010-09-04T12:53:05	13:28:09	16.8	3.200	2.492	14.6	Cgh	
2152	Hannibal	1978 WK	V07	2011-10-21T05:09:54	06:00:15	15.3	2.568	1.906	19.3	Ch	
2169	Taiwan	1964 VP ₁	V03	2010-09-04T10:04:48	10:40:46	16.9	2.730	1.811	10.7	Cgh	
2306	Bauschinger	1939 PM	V02	2010-05-10T07:17:17	08:07:01	16.7	2.827	1.881	8.7	Xk	
2428	Kamenyar	1977 RZ ₆	V07	2011-10-20T09:28:09	09:59:16	15.5	2.896	1.904	2.0	Ch	Vernazza et al. (2016)
2598	Merlin	1980 RY	V01	2010-02-23T10:26:19	11:20:09	17.0	2.736	1.754	3.1	B	Vernazza et al. (2016)
2807	Karl Marx	1969 TH ₆	V07	2011-10-20T11:17:08	12:10:54	16.7	2.790	1.801	3.1	B	Vernazza et al. (2016)
2930	Euripides	6554 P-L	V07	2011-10-21T07:30:44	08:57:36	17.5	2.783	1.901	11.5	C	
2934	Aristophanes	4006 P-L	V03	2010-09-03T06:10:28	06:51:29	14.0	2.790	2.380	20.6	B	Vernazza et al. (2016)
2996	Bowman	1954 RJ	V03	2010-09-04T11:59:58	12:43:01	17.0	2.798	2.118	17.6	C	
3611	Dabu	1981 YY ₁	V01	2010-02-23T06:51:47	07:55:26	17.0	2.378	1.616	18.5	B	Vernazza et al. (2016)

Table A2
(Continued)

No.	Name	Provisional Designation	Obs. Run ^a	Start Time	End Time	V^a (mag)	R_h^a (au)	Δ^a (au)	α^a (deg)	BD Tax. ^a	References
3775	Ellenbeth	1931 TC ₄	V03	2010-09-04T09:02:06	09:28:22	15.4	2.137	1.140	5.5	B	Vernazza et al. (2016)
3885	Bogorodskij	1979 HG ₅	V01	2010-02-23T09:21:43	10:20:26	17.4	2.936	2.015	8.6	B	
3985	Raybatson	1985 CX	V02	2010-05-10T13:23:40	13:54:51	15.5	2.581	1.677	12.4	Xk	
4292	Aoba	1989 VO	V08	2011-10-26T06:46:11	07:39:51	17.3	2.810	2.219	18.4	Xc	
4461	Sayama	1990 EL	V02	2010-05-10T12:47:04	14:43:14	15.4	2.561	1.654	12.4	Xn	
5348	Kennoguchi	1988 BB	V05	2010-11-01T08:56:06	09:36:59	16.5	2.555	1.598	7.5	B	Vernazza et al. (2016)
5416	Estremadoyro	1978 VE ₅	V03	2010-09-04T09:32:57	09:49:44	15.5	2.124	1.136	7.6	B	Vernazza et al. (2016)
5592	Oshima	1990 VB ₄	V02	2010-05-11T09:06:12	09:47:14	17.0	3.248	2.325	8.5	B	Vernazza et al. (2016)
7868	Barker	1984 UX ₂	V03	2010-09-04T08:09:06	08:50:25	15.7	2.149	1.198	12.0	Ch	Vernazza et al. (2016)
8008		1988 TQ ₄	V07	2011-10-20T10:05:05	11:01:18	16.7	2.552	1.563	3.3	B	

Note.

^a Observational run ID, approximate apparent V -band magnitude (V), heliocentric (R_h) and geocentric distances (Δ), phase angle (α), and Bus–DeMeo taxonomy for the Vernazza observations.

Appendix B Complementary Figures

Figures B1, B2, and B3 show spectra of asteroid candidates for which surface heterogeneity was not detected, asteroids observed multiple times with low S/N, and unpublished asteroids observed only once, respectively.

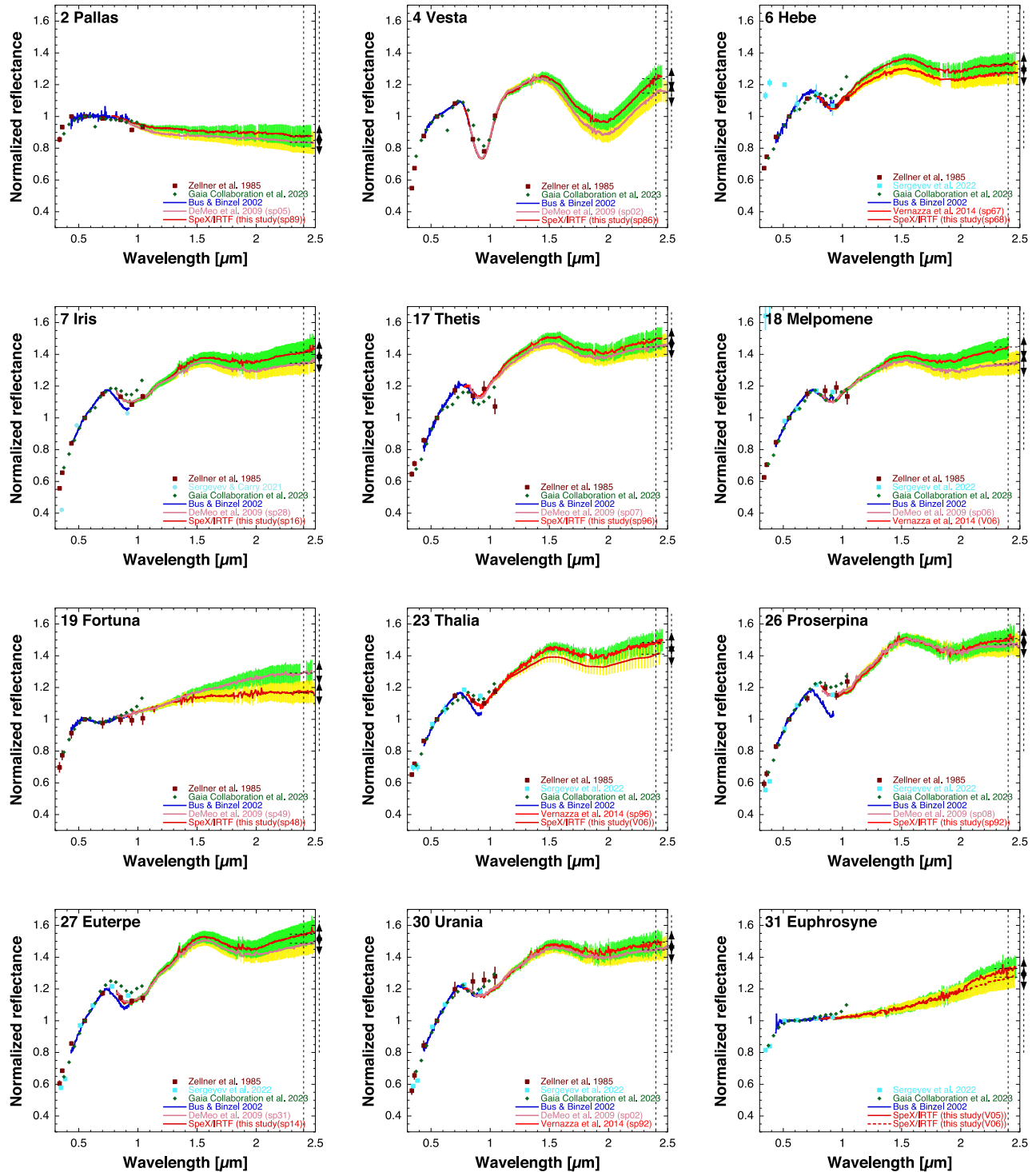


Figure B1. Reflectance spectra of asteroids not identified as candidates for surface heterogeneity.

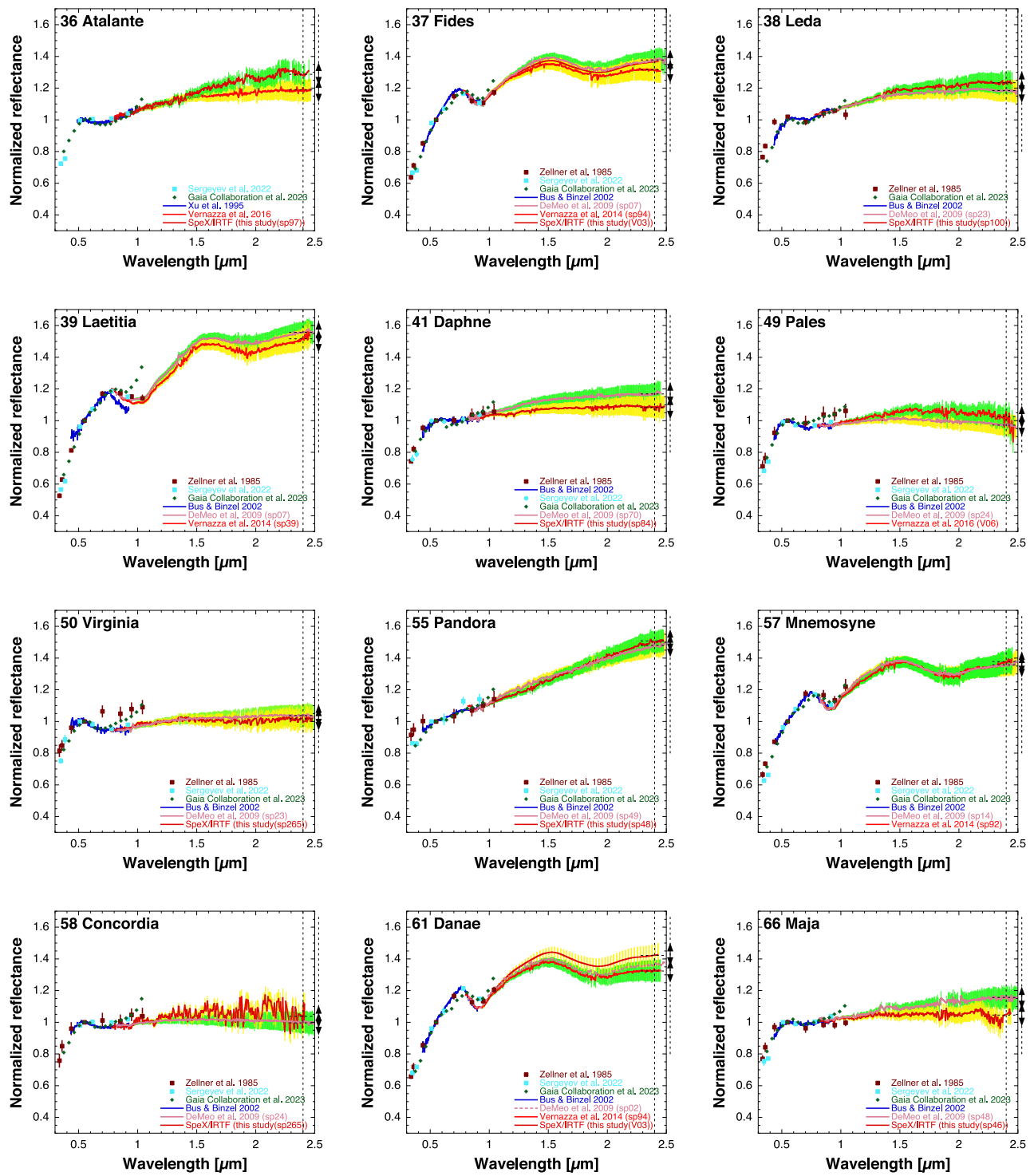


Figure B1. (Continued.)

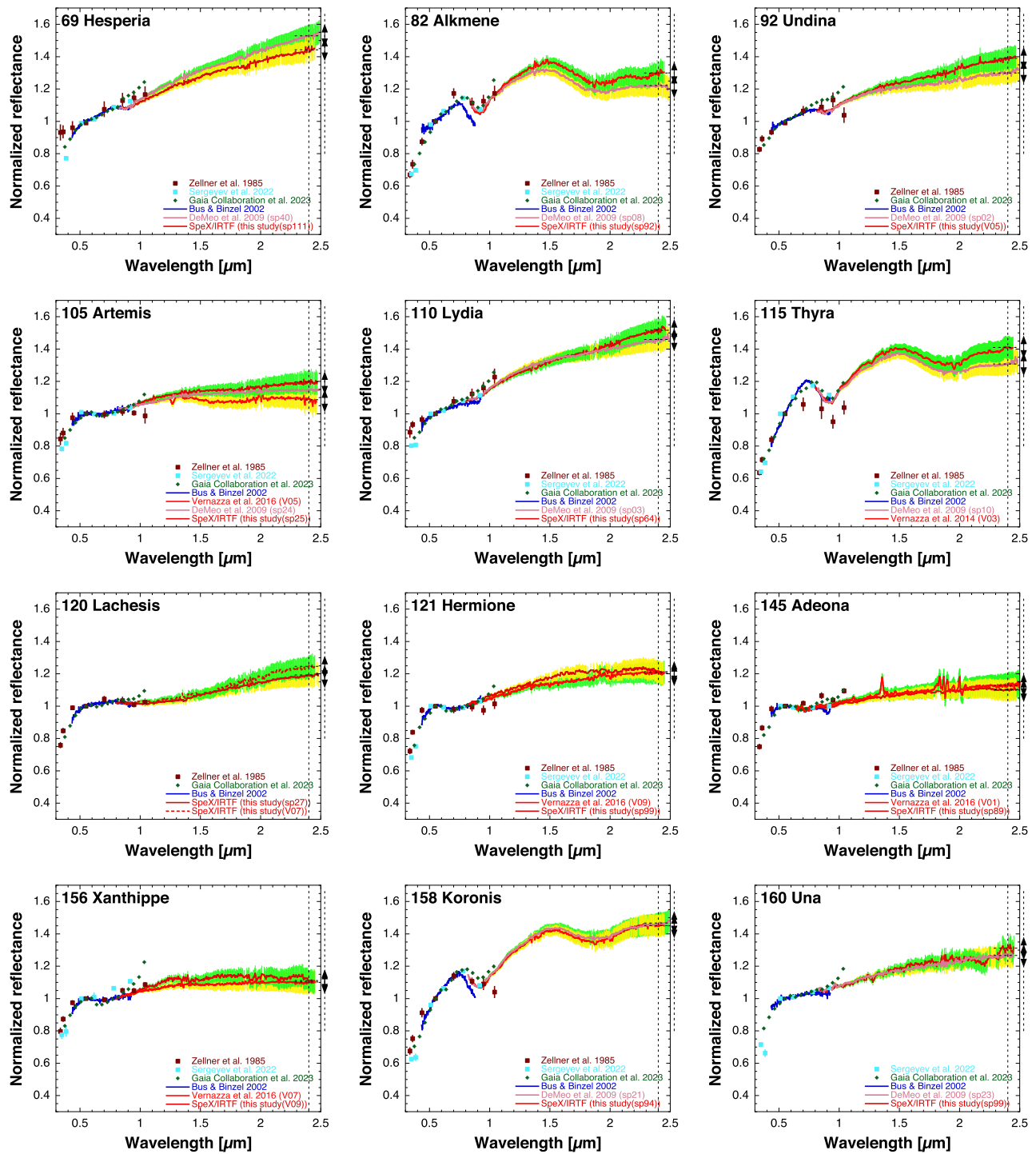


Figure B1. (Continued.)

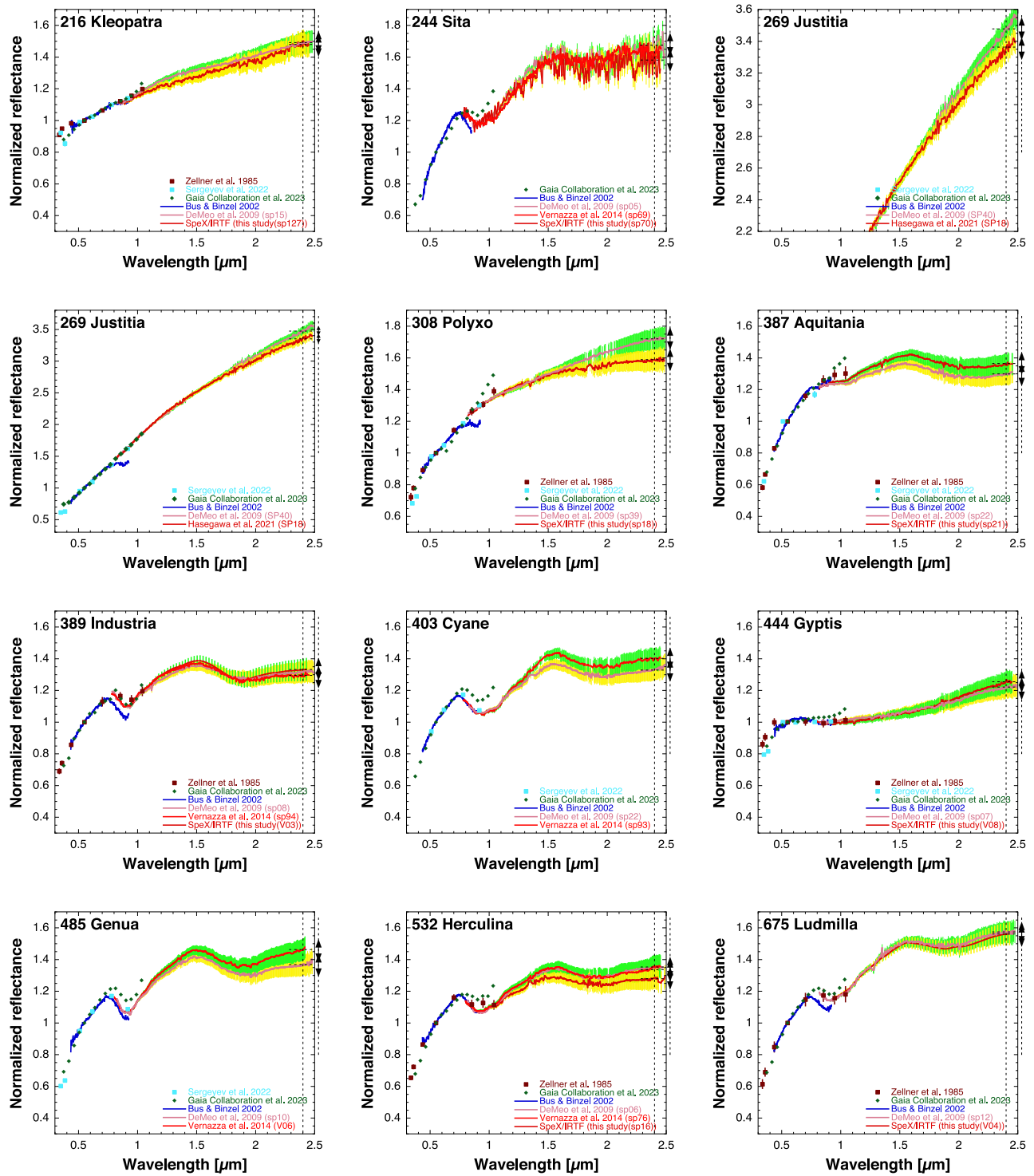


Figure B1. (Continued.)

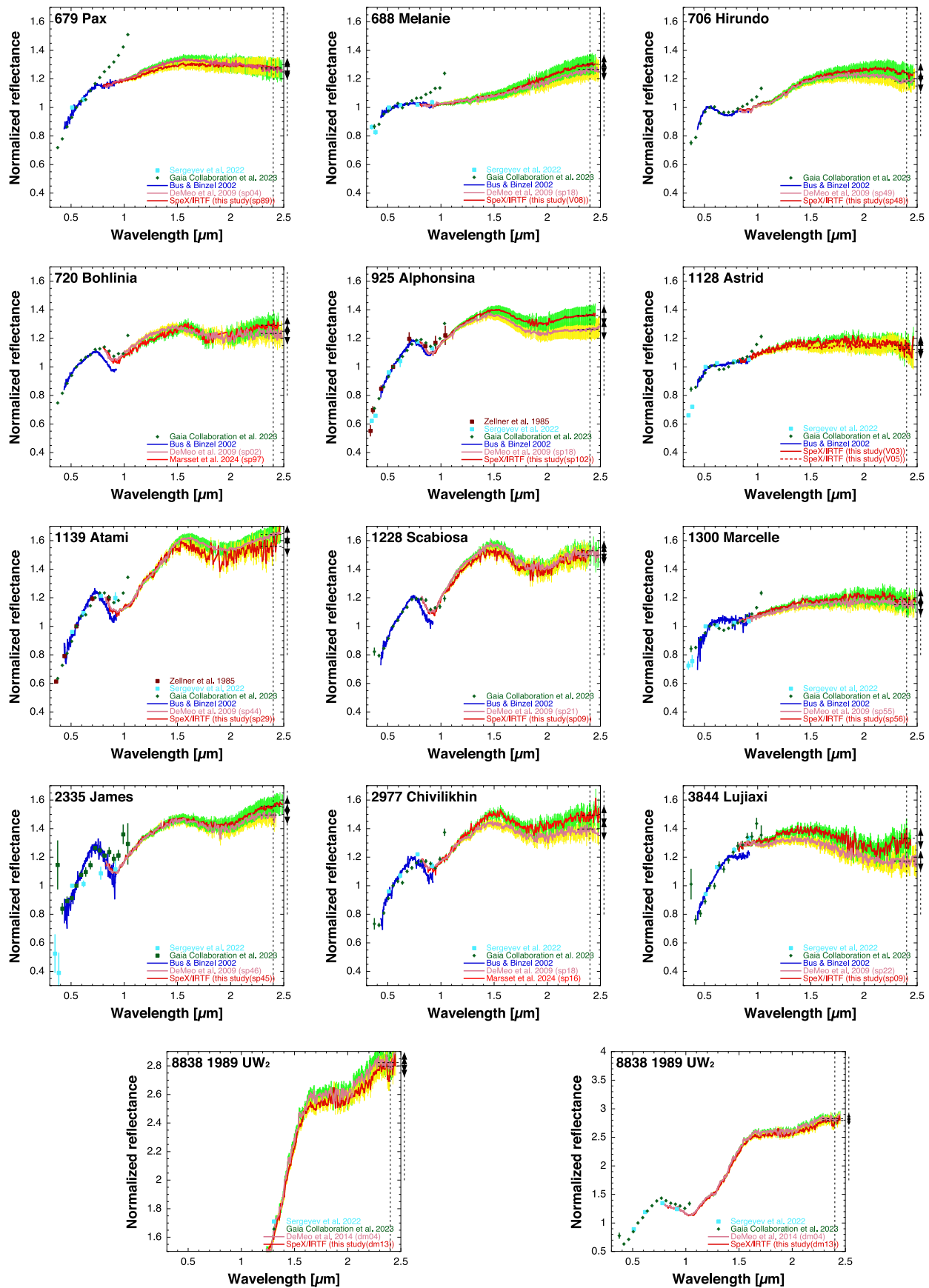


Figure B1. (Continued.)

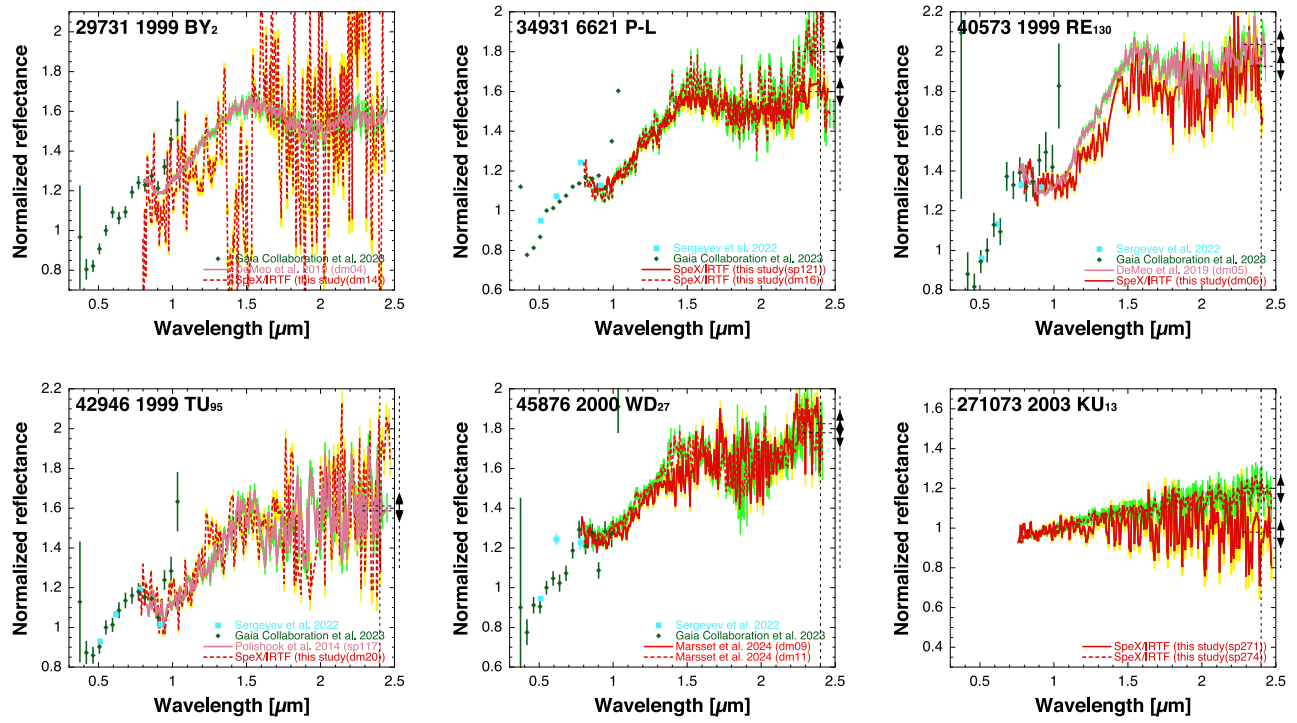


Figure B2. Reflectance spectra of asteroids observed multiple times with low S/N.

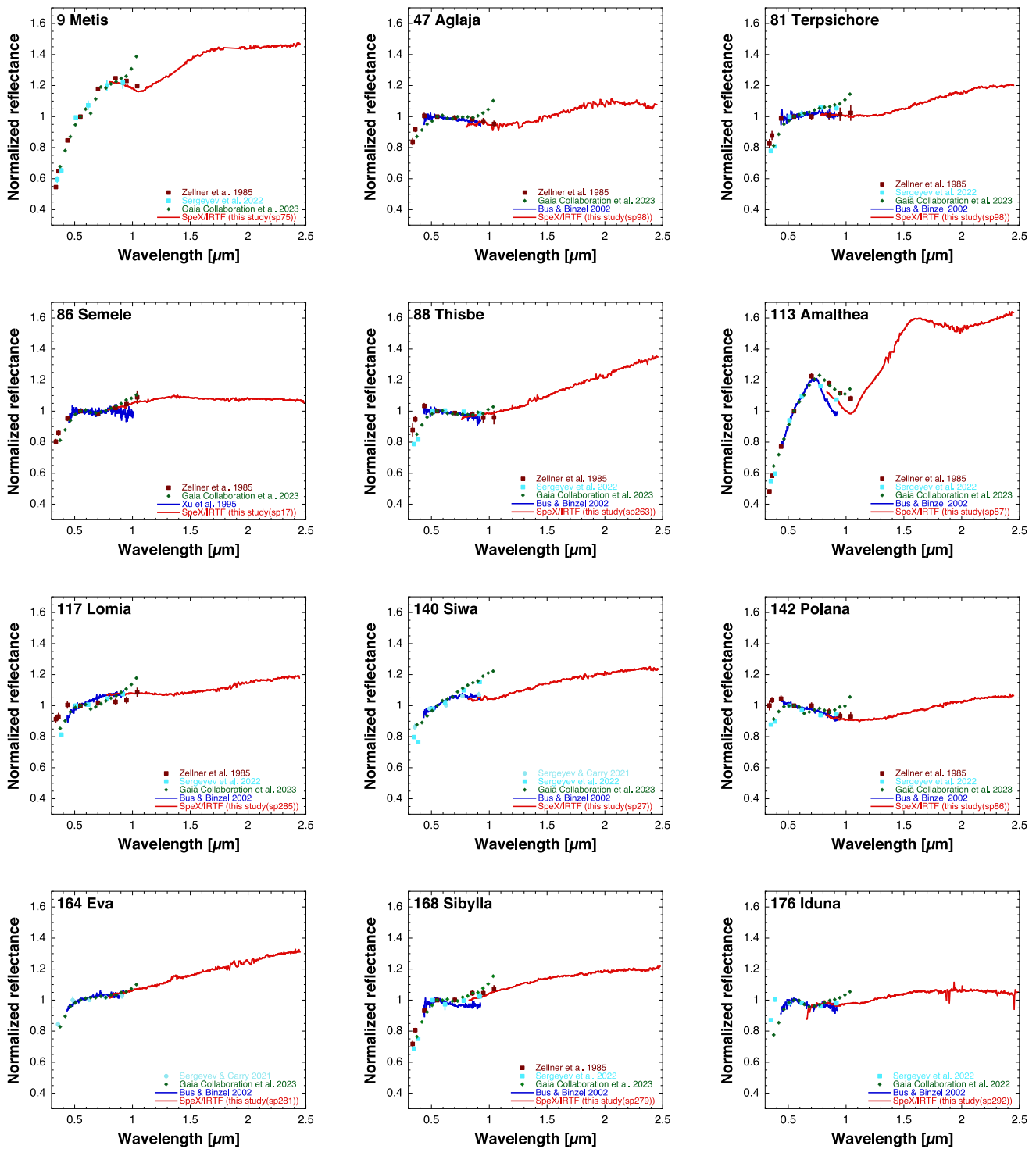


Figure B3. Reflectance spectra of unpublished asteroids in MITHMBAs observations.

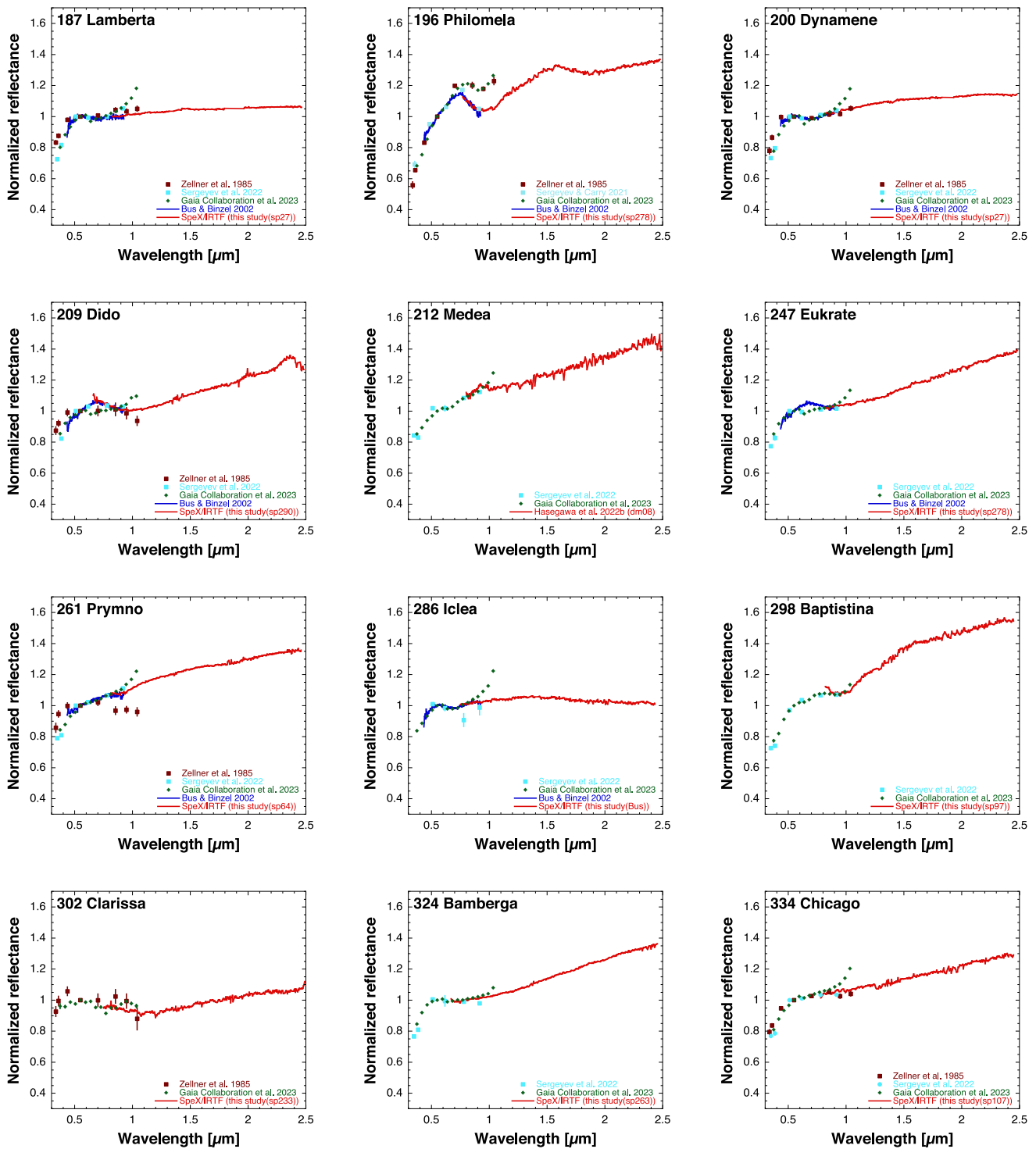


Figure B3. (Continued.)

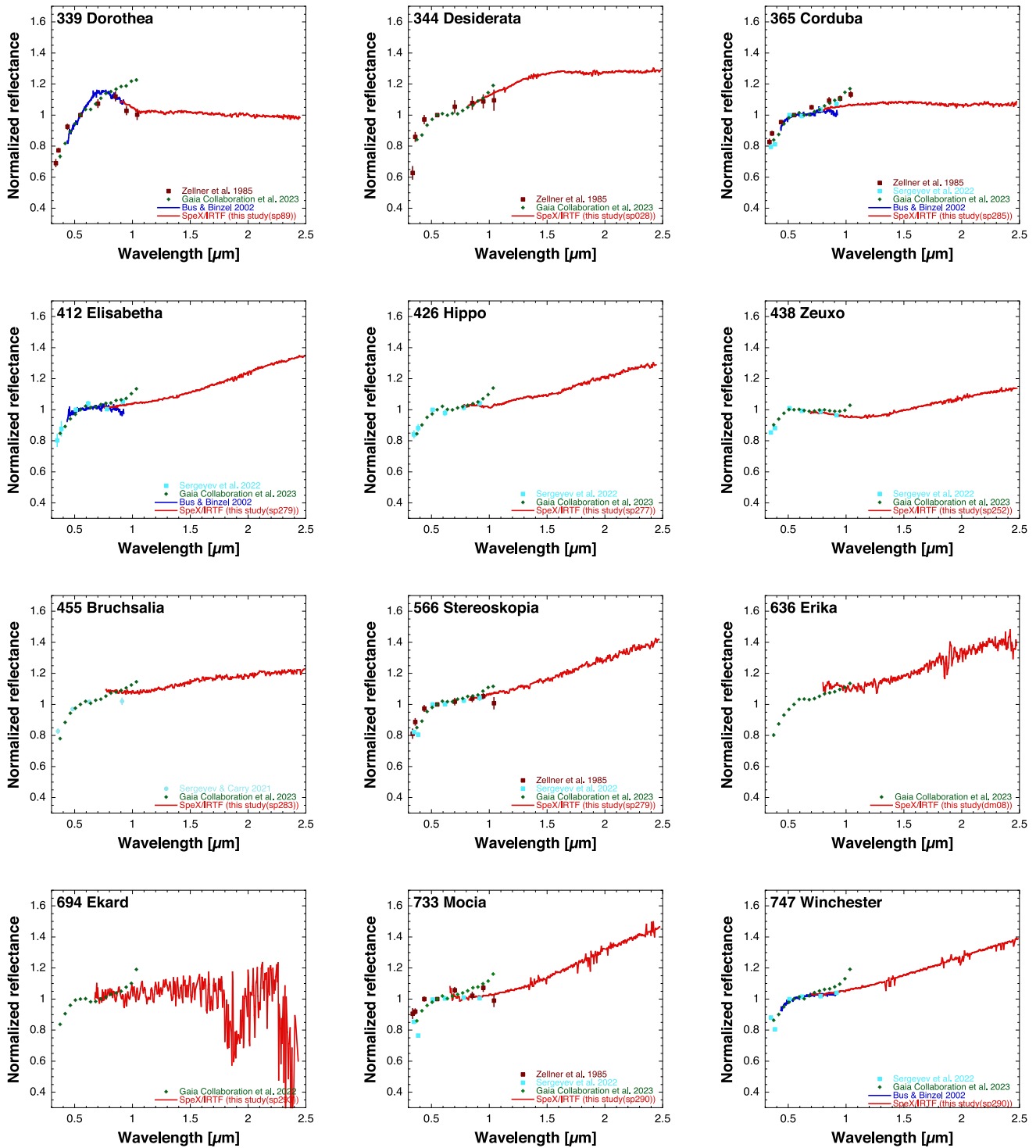


Figure B3. (Continued.)

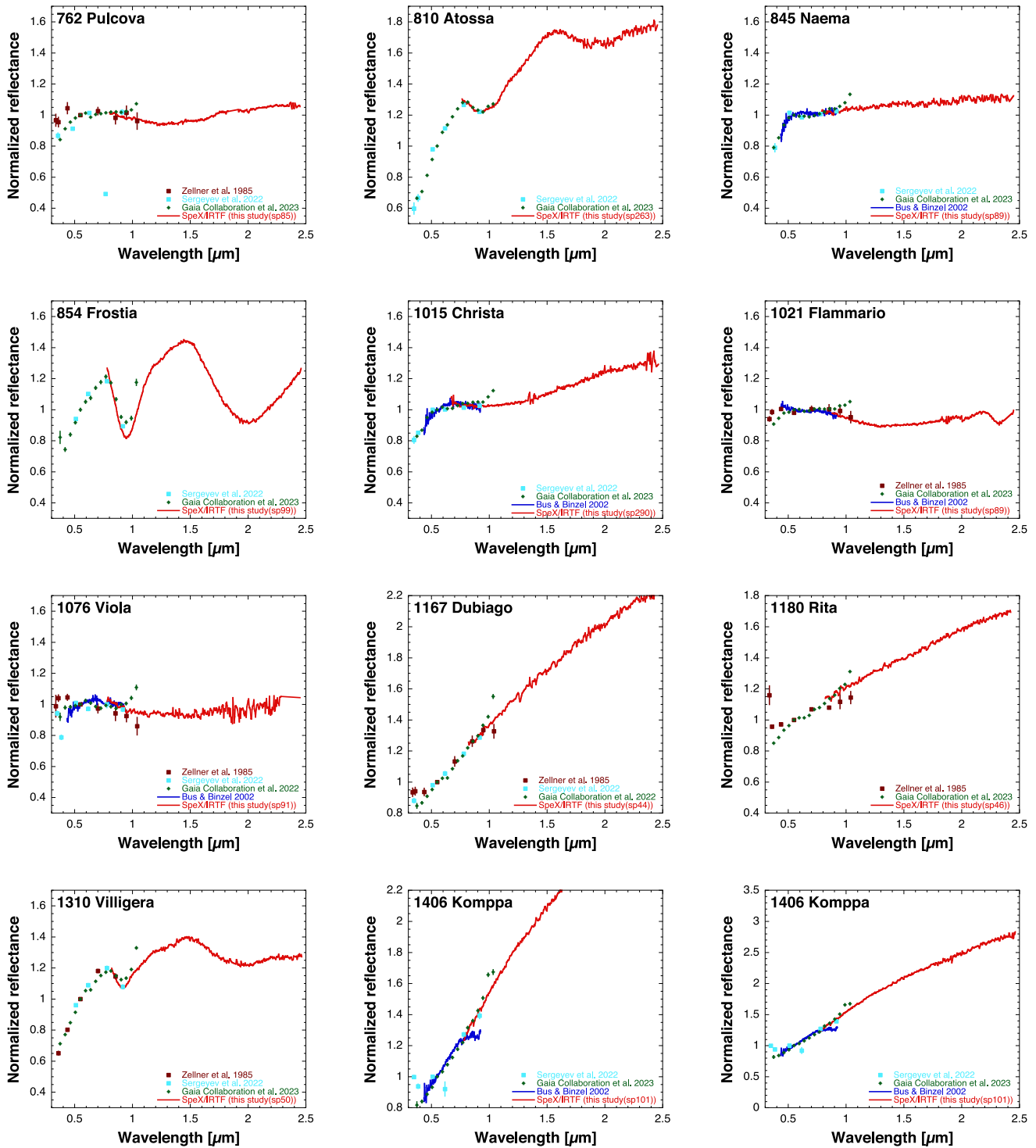


Figure B3. (Continued.)

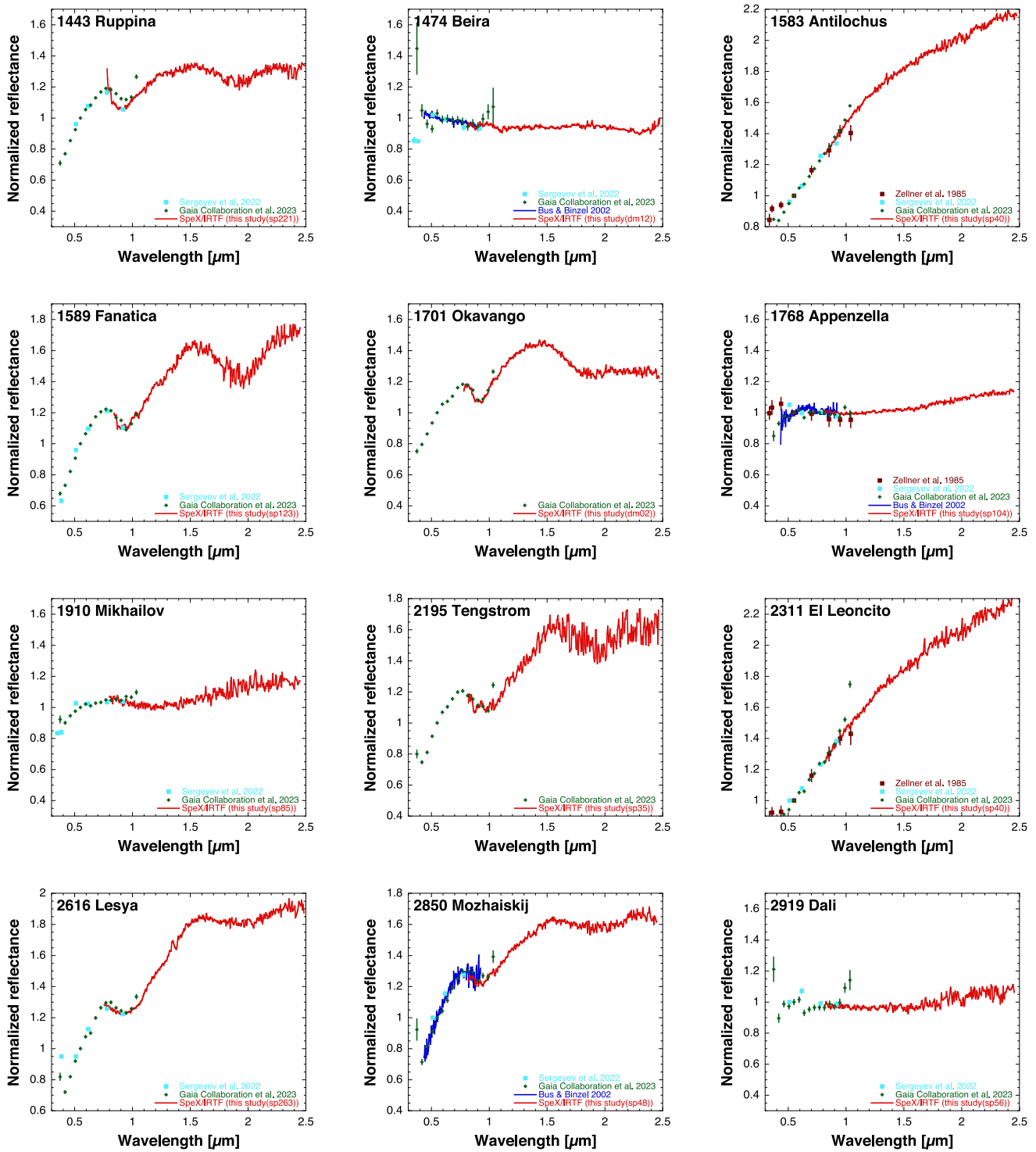


Figure B3. (Continued.)

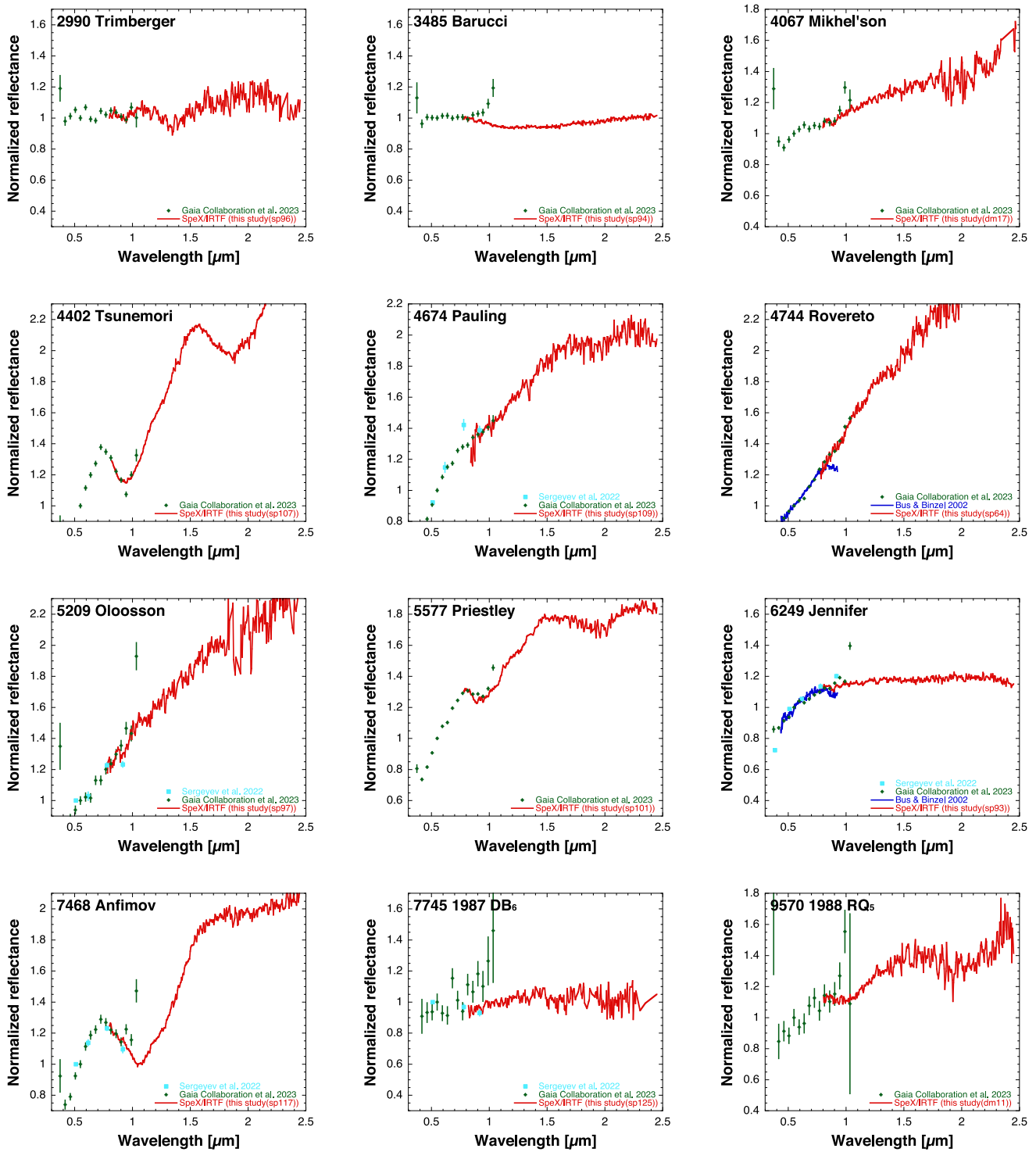


Figure B3. (Continued.)

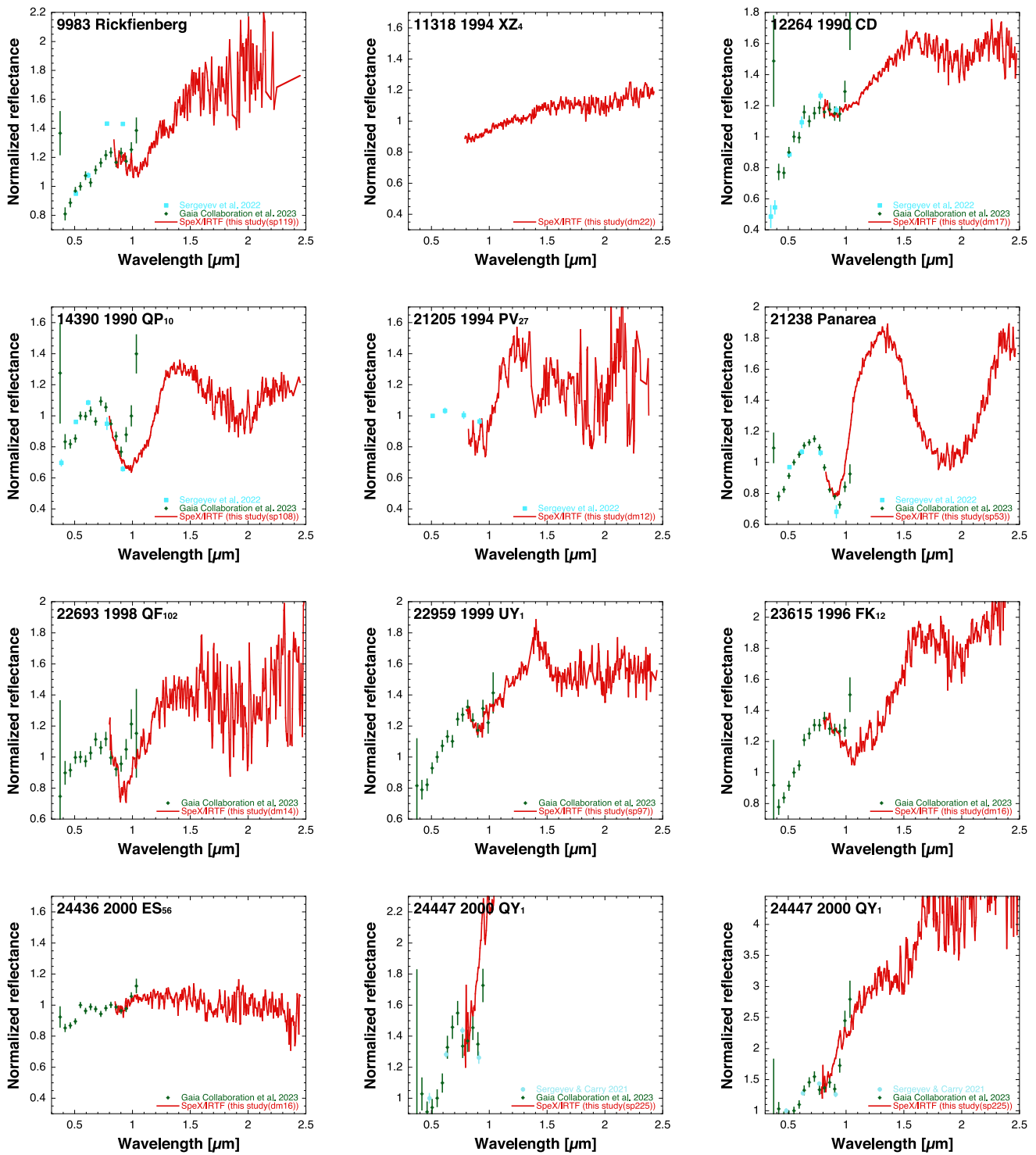


Figure B3. (Continued.)

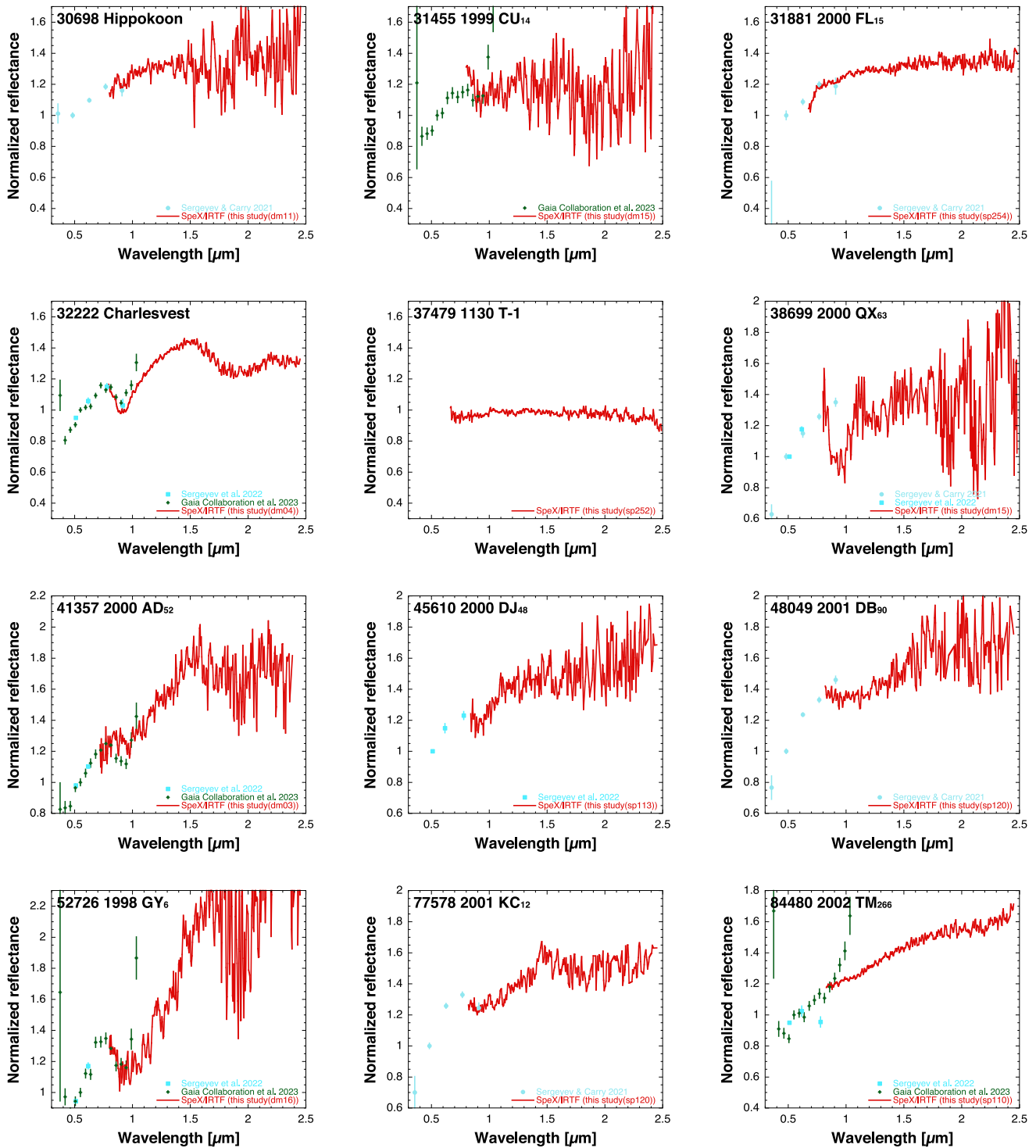


Figure B3. (Continued.)

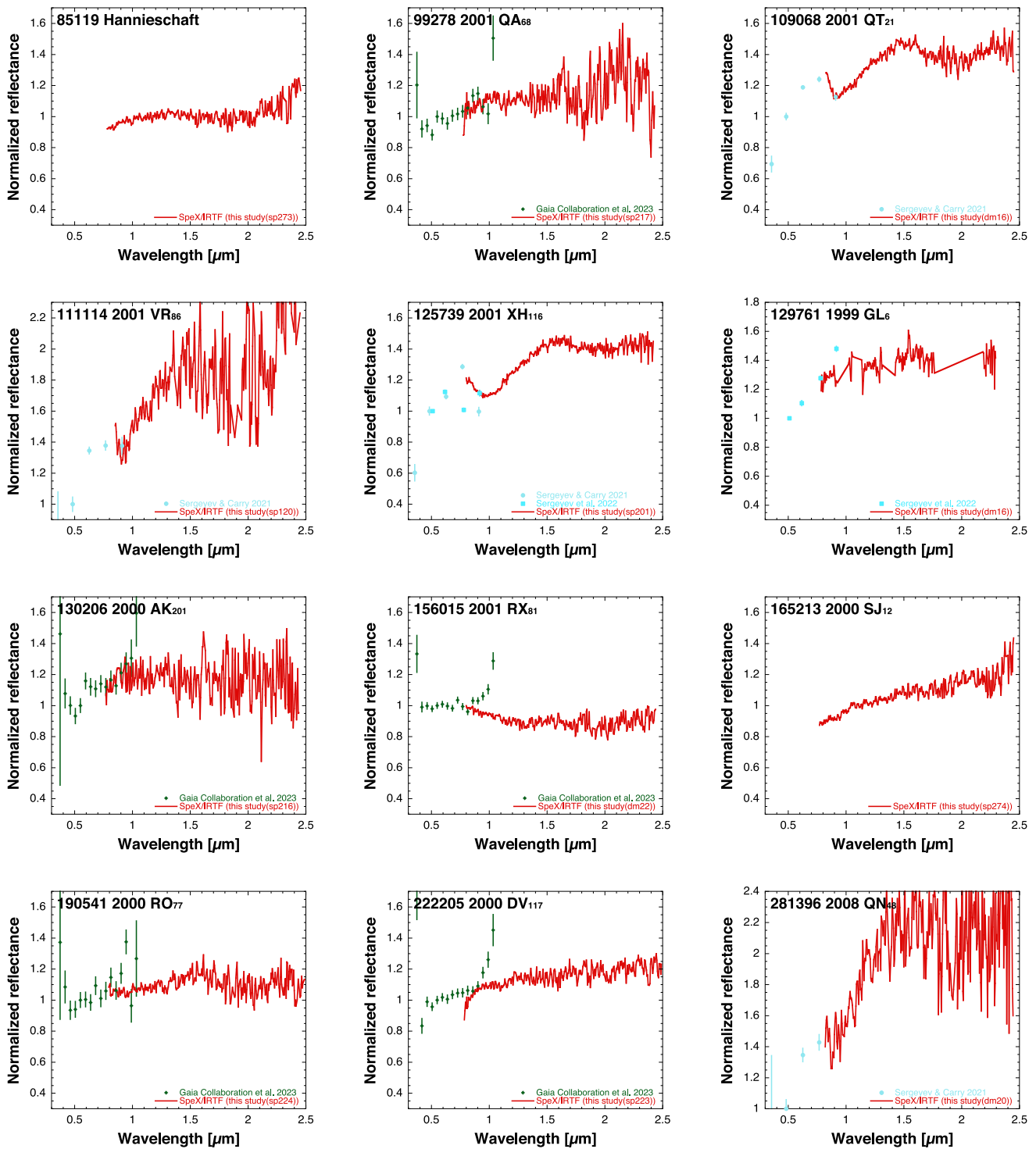


Figure B3. (Continued.)

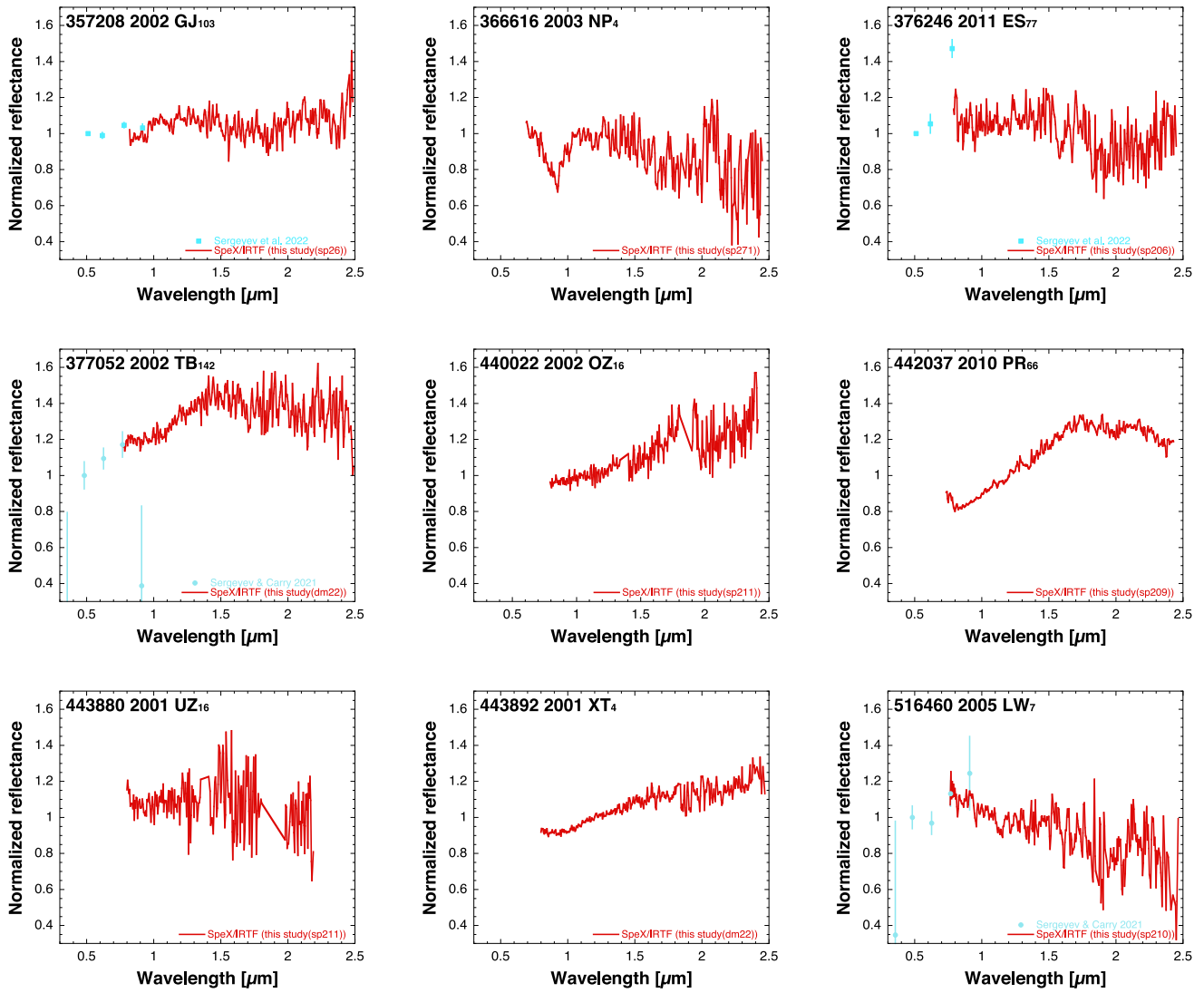


Figure B3. (Continued.)

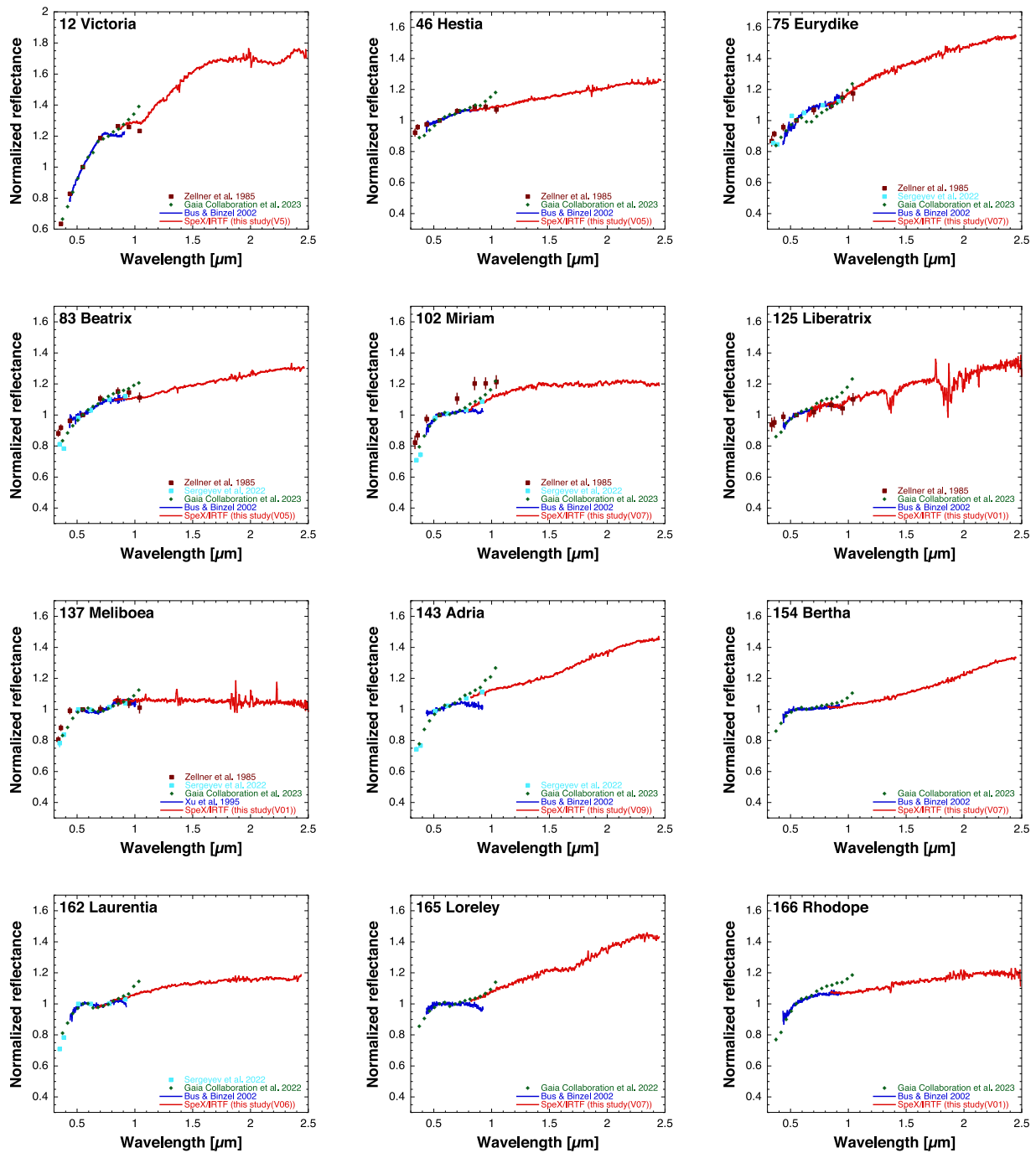


Figure B4. Reflectance spectra of unpublished asteroids in Vernazza's observations.

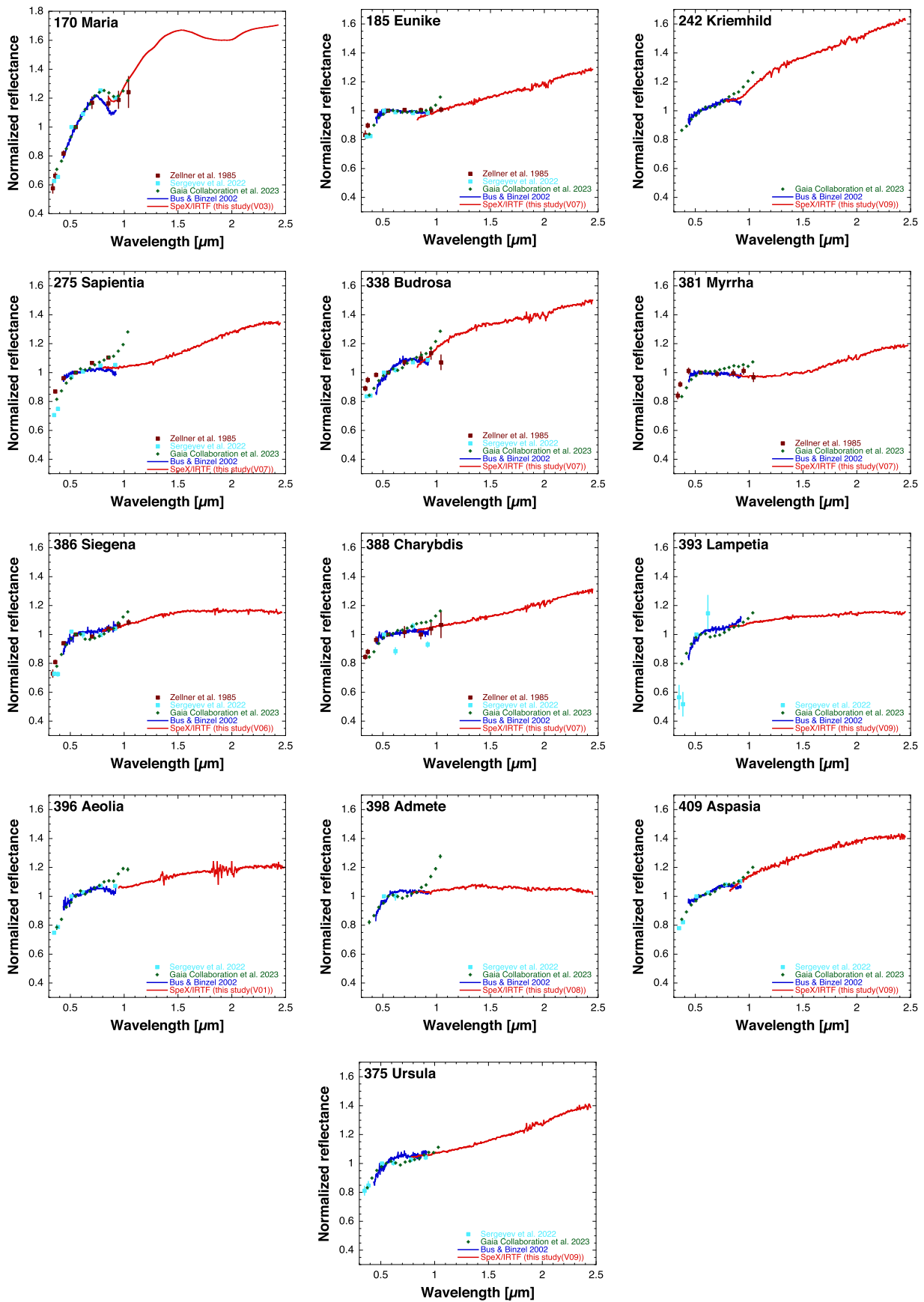


Figure B4. (Continued.)

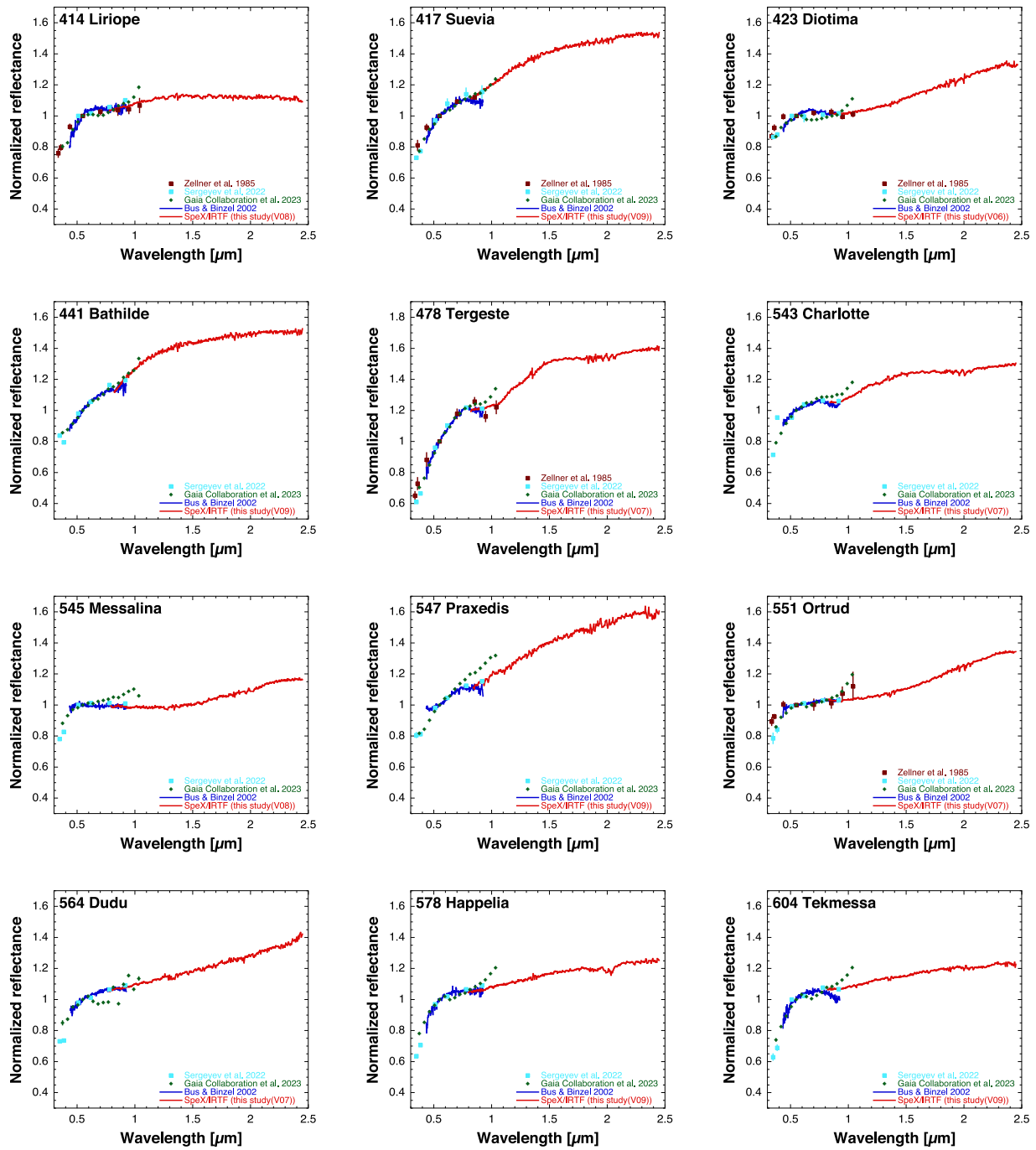


Figure B4. (Continued.)

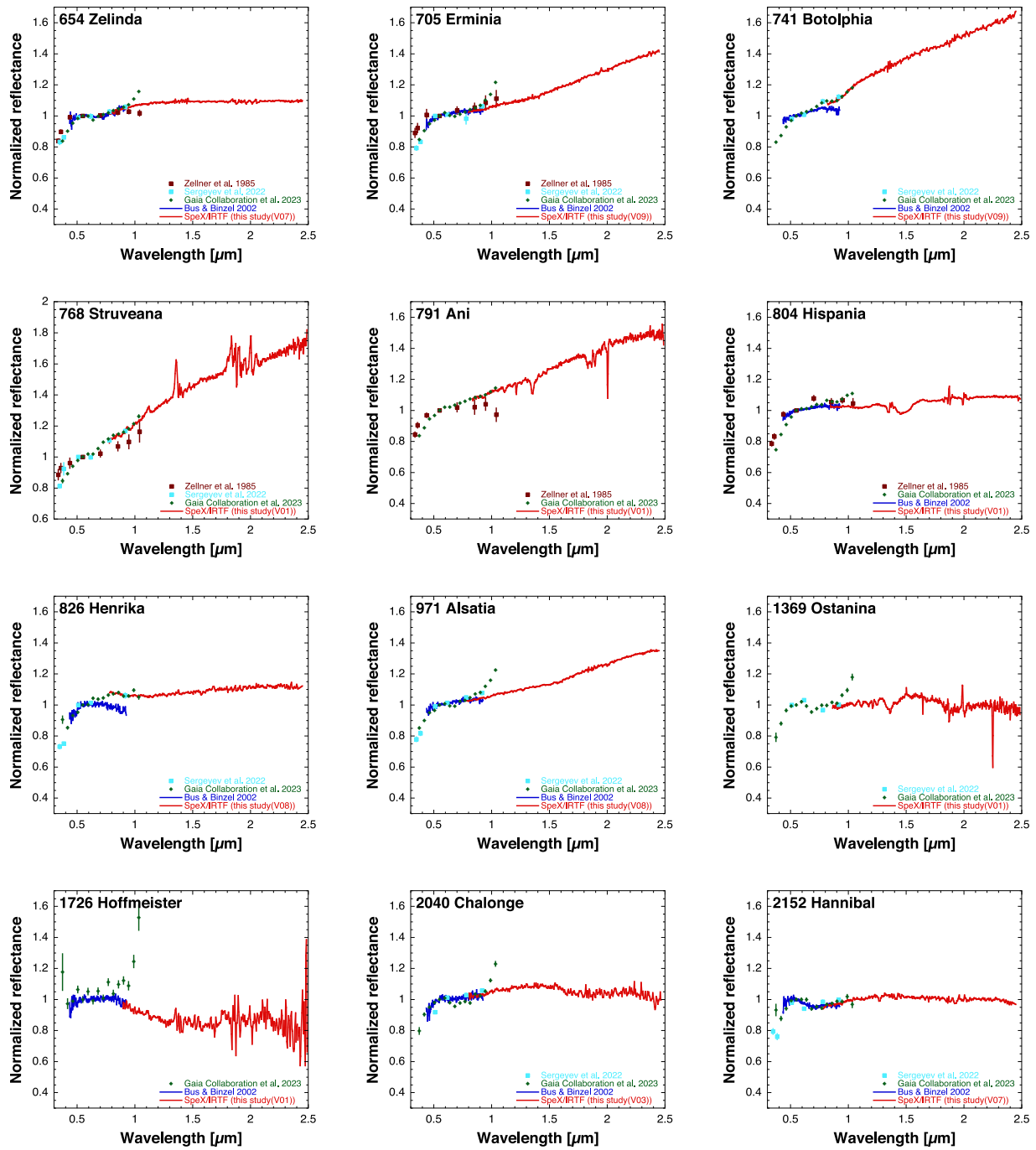


Figure B4. (Continued.)

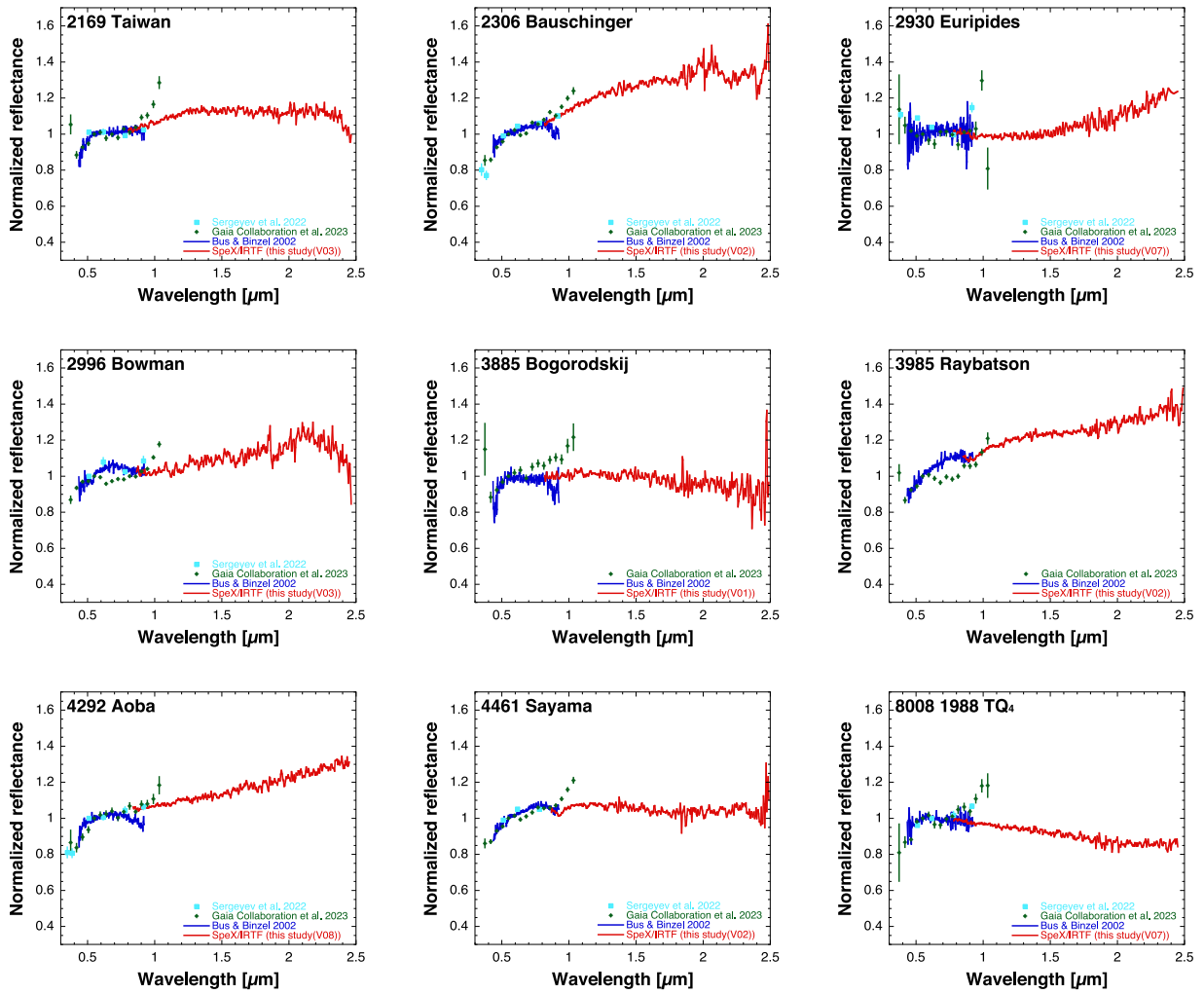


Figure B4. (Continued.)

Appendix C Band Parameters of A-type Asteroids

A-type asteroids identified as candidates for surface heterogeneity may have different surface composition minerals. Here we compare the absorption-band characteristics of A-type asteroids to better understand their surface composition. For the comparison, the slope of one spectrum was corrected to match the slope of the other spectrum. In the region where both spectra overlap (0.8–2.45 μm), the spectrum to be corrected was divided by the reference spectrum to obtain the correction value for each wavelength. The obtained correction values were used to create

a quadratic correction equation as a function of wavelength. The spectrum to be corrected was divided by the obtained correction formula to correct the slope of the spectrum. The spectra of each of the A-type asteroids identified as candidates for surface heterogeneity were consistent within the observational uncertainty of the MITHNEOS (Marsset et al. 2020b; Figure C1). This indicates that the absorption bands characteristics of the two spectra obtained for each A-type asteroid are consistent. Consequently, A-type asteroids in our sample appear to be compositionally homogeneous, and their spectral slope variations are related to space weathering (Section 7).

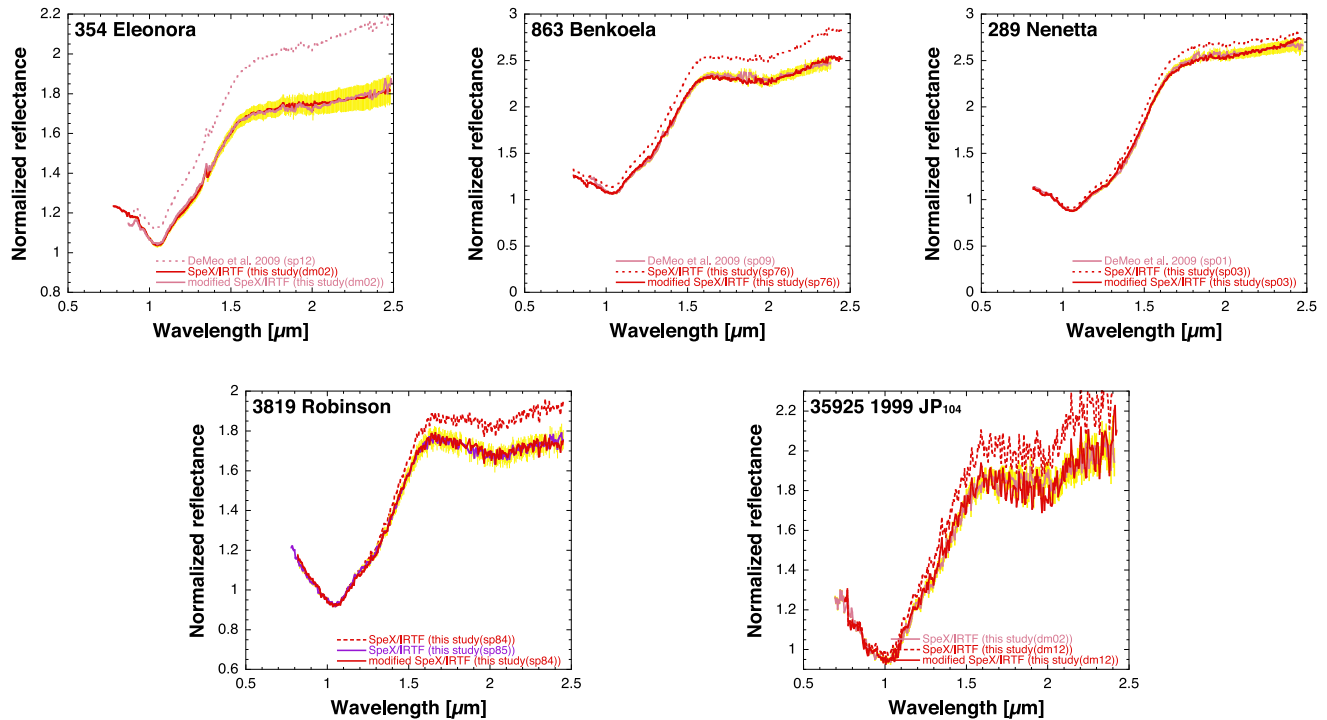















Figure C1. Reflectance spectra of A-type asteroids identified as candidates for surface heterogeneity. The yellow error bars represent the observational uncertainty of Marsset et al. (2020b). To compare each absorption band, corrections were made to match the slope of one spectrum to the slope of the other.

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