Rotationally-Resolved Characterization of the Near-Earth Didymos-Dimorphos Binary System After the NASA/DART Impact

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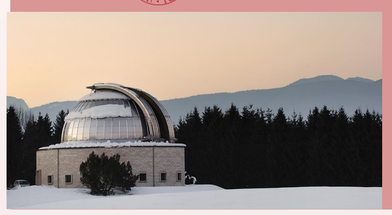

Abstract: Didymos-Dimorphos system is a Potentially Hazardous Asteroid (PHA), the target of the NASA/DART [8] and ESA/HERA space missions as part of an international planetary defense program (Asteroid Impact & Deflection Assessment - AIDA). The NASA Double Asteroid Redirection Test (DART) actively impacted the small moon Dimorphos of the Didymos-Dimorphos binary system on 26th September 2022 causing a variation in its orbital period around Didymos of about 33 minutes. Despite Didymos-Dimorphos binary system has been observed in the last few apparitions (2003, 2019, and 2021), its physical characterization is still somewhat puzzling [1][2][3][4]. In this work we combined all available geometric information with spectral appearance to search for possible surface heterogeneities, or secondary body influence on the spectral slope. We believe that the observed spectral variation could be related to the presence of a dense cloud of dust around the system which is partially and unevenly obscuring the surface.

OBSERVATIONS

We obtained several sets of spectra in the visible range using two telescopes located in Asiago (VI), Italy, on 19th and 20th October 2022, less than one month after the impact, on the night of 18th November 2022, and on the nights of 26th and 27th December 2022. Asiago telescopes have diameters of 1.22 and 1.80 cm and are equipped with spectrometers in the ranges from 500 to 750 nm and from 500 to 950 nm, respectively. We covered the full rotational period of Didymos (2.26h) during two of the observed nights (see Tab.1 for the observational details). The asteroid was bright (from 15.4 to 16.4 visual magnitude) so we obtained good S/N data during almost all the observed nights despite the high airmasses in October and November observations and the vicinity to the galactic plane which made some observations more challenging. The data have been reduced using IRAF astronomical package following standard reduction procedures. We obtained a total of 29 spectra between 5000 and 9000 A with the 1.80m telescope and two spectra on 19 October between 5000 and 7000 A (with the 1.22m telescope).

SPECTRAL APPEARANCE

With the spectra of Dydimos obtained we tried to investigate possible variations with observations from mid October till the end of December 2022, covering also the complete rotational period of 2.26h during more than one night. As we can see from Fig.1 the spectra obtained in October show large variations in slope showing from red to flat appearance across the same night. October flattest spectra are compatible with pre-impact spectra and average S-type. The spectra obtained in November show somewhat smaller variations in slope, while the spectra obtained in December, even though cover most of the rotational phase of Didymos, show almost no variations in slope and a very good match with pre-impact spectra and typical S-type asteroids. Spectral slopes for each observation are reported in Tab. 1. Mid October corresponds to nearly three weeks from the impact and the presence of the dust emitted by Dimorphos was very high and probably not uniformly distributed around the binary system. In fact, during the same night, eg 19th October, we find both a spectrum with a very high slope, confirmed also by spectra obtained with the 1.22 m telescope, and also a flatter one.

Image	Date	Epoch (UT)	Exp time(s)	Spectral Slope [%/1000A]
1.22m telescope				
IMA108103	19 Oct	01:44:44.1	1800	29.6
IMA108106	19 Oct	03:05:47.7	1200	20.0
1.80m telescope				
AF785030	19 Oct	01:36:41.0	720	33.3
AF785105[a]	20 Oct	02:15:35.7	720	19.7
AF785106[a]	20 Oct	02:29:27.0	720	30.0
AF785108	20 Oct	02:59:01.2	720	21.4
AF785109	20 Oct	03:12:59.9	900	15.7
AF785110	20 Oct	03:32:04.0	900	17.9
AF785111	20 Oct	03:49:30.4	720	13.2
AF792179	18 Nov	23:58:30.7	1200	11.7
AF792180	19 Nov	00:22:10.3	1200	8.4
AF792181	19 Nov	00:45:49.5	1200	16.7
AF792183	19 Nov	01:32:22.7	1200	9.7
AF800130	20 Dec	22:38:11.7	1080	12.7
AF800131	20 Dec	23:26:21.6	1080	20.1
AF800132	21 Dec	01:08:36.2	1800	13.3
AF800545	26 Dec	22:09:36.0	1200	13.3
AF800546	26 Dec	22:33:36.6	1500	11.1
AF800547	26 Dec	23:03:28.2	1800	14.1
AF800548	26 Dec	23:36:27.2	1800	12.6
AF800549	27 Dec	00:10:14.7	1800	14.8
AF800550	27 Dec	00:50:16.5	1800	13.5
AF800551[b]	27 Dec	01:23:27.7	1800	12.3
AF800552	27 Dec	01:56:24.7	1800	13.8
AF800553	27 Dec	02:30:01.4	1800	12.2
AF800554	27 Dec	03:02:53.4	1800	19.0
AF800555	27 Dec	03:35:58.2	1800	14.6
AF800625	27 Dec	21:39:48.6	1800	11.3
AF800626	27 Dec	22:11:41.3	1800	13.3
AF800627	27 Dec	22:44:10.0	1800	9.5

a Dimorphos in front of Didymos
b Dimorphos behind Didymos

TABLE1: Observational details of Dydimos-Dimorphos

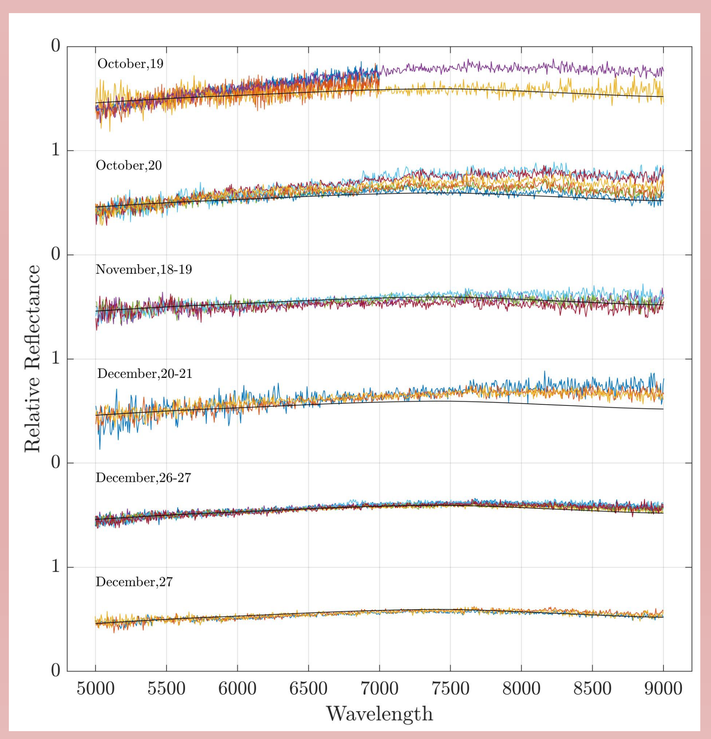

FIGURE 1 Spectra obtained during the 6 observing nights shifted for clarity. The average S-type taxonomic class spectrum is overplotted (solid black line) for each date for comparison.

GEOMETRIC ANALYSIS

To investigate for possible Didymos surface heterogeneities or for a possible influence of a Dimorphos different composition on the spectral appearance, as suggested by Ieva et al. 2022 [5], we computed the geometry of the binary system for each spectral observation using the latest NASA/DART Spice Kernel (JPL orbit solution 516). Using the NASA ancillary system SPICE and its tools (Acton, 1996; Acton et al., 2017) we determined the possible occurrence of mutual events at the epochs of our observations. We found that in 2 cases Dimorphos is in front of Didymos (20 Oct: AF785105, AF78106) and in one case Dimorphos is beyond Didymos (27 Dec: AF800551) as reported in Tab. 1. In all other cases the two bodies are visually separated, thus in principle they both fall within our FOV.

We also computed the phase angle of both bodies, the sub-Earth latitude (aspect angle) and the sub-solar point on both Didymos and Dimorphos surfaces for each observing epoch. Therefore, we estimated the illuminated and visible surface of both bodies, assumed to be ellipsoids, for each epoch, thus determining the surface coverage of each single spectrum. Two examples of surface coverage maps for both bodies are reported in Fig. 2. The aspect angle changes significantly from negative values during the observations in October, to positive values for the observations performed in December. This occurrence, together with the sub-solar latitudes, indicates that mostly the southern hemispheres and the south poles of both bodies are visible and illuminated throughout October observations (see the upper panel in Fig. 2), while in December the observations mostly cover the northern hemispheres including the north poles of both bodies (see lower panel in Fig. 2).

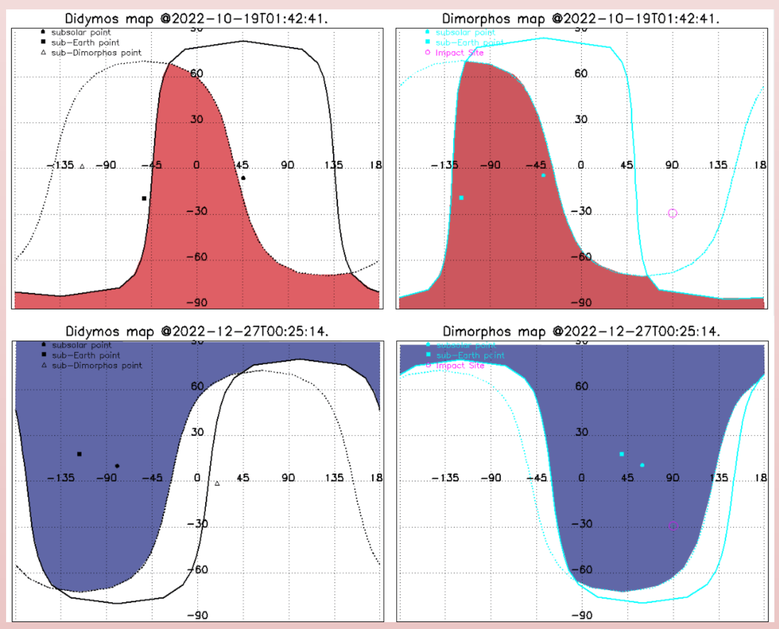

FIGURE 2 Examples of geometric observing conditions for one of the reddest spectra (AF785030) acquired on 19 October (upper panel) and one of the flat spectra (AF800549) acquired on 26 December. Left panels show with filled colors Didymos surface coverage (observable and illuminated), while the right panels show, Dimorphos surface coverage. The magenta open circle in the right panels shows the impact site location on the surface of Dimorphos.

Due to the fast rotation of the primary body (2.26h period), significant variations occur, both in October and in December, in the illuminated and visible surface longitudinal regions, corresponding to Didymos rotational phases. The impact site is located on the unilluminated and not visible surface portion of Dimorphos during all October observations, while it becomes observable in most of November and December observations.

CONCLUSIONS

We observe significant variations in slope among the spectra acquired both on 19 and 20 October, about 25 days after DART impact on Dimorphos.

Since the observations in October were quite challenging due to the large airmasses of Didymos especially at the beginning of the night, we checked for a possible correlation between the spectral slope and the airmasses, but no correlation was found for observations under 2.0 airmasses. We investigated if the observed spectral variability could be correlated with Didymos surface heterogeneities, or with the effect of Dimorphos on the observed spectral slope.

We determined the observing geometry of the binary system at each epoch and found that we mostly see the two bodies separately, and for the few cases of mutual events occurring (see Tab. 1) we do not find any evident correlation between the spectral slope and the mutual event. We could therefore exclude that mutual events influence the appearance of the observed spectra.

We believe that the spectral variation could be related to the presence of a dense cloud of dust around the system which is partially and unevenly obscuring the surface. The very red spectra observed in October would be then explainable due to the presence of mm-cm size range dust particles as reported by Li et al. 2023 [10]. The observed variations could be correlated with the presence of anisotropic dust structures that cross the observable line of sigh at different epochs during the rotation of the system.

The gradual decrease in the variations observed from October to November and then to December seems to indicate that the dust cloud is becoming gradually thinner and is revealing the true surface of Didymos, without significant composition variations. The increased similarity between the observed spectra and a typical S-type spectra (see Fig. 1) observed in December is also supporting this hypothesis.

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Acknowledgements. Acknowledgments: This work was supported by the Italian Space Agency (ASI) within the HERA project (ASI-UNIBO agreement n. 2022-8-HH.0).