The Didymos System Characterization Campaign in Support of the Double Asteroid Redirection Test

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Characterization Observations for DART

The Double Asteroid Redirection Test (DART) is NASA's first planetary defense test mission. Launched in November 2021, it intentionally collided with Dimorphos, the satellite of the asteroid Didymos, in September 2022 in an experiment to change the binary orbit period of Dimorphos as a test of the kinetic impactor deflection technique. Because the DART spacecraft was destroyed upon impact, telescopic measurements of the Didymos system are critical to the success of DART.

Characterization measurements of the Didymos system have allowed the compositional and physical properties of Didymos and Dimorphos to be measured or inferred, which in turn enable better model inputs and interpretations to be made.

Pre-Arrival Characterization

The DART project chose Didymos as a target due to its well-characterized nature (Rivkin et al. 2021). Characterization of Didymos done during its bright 2003 apparition included 0.5--2.5-µm spectroscopy (de León et al. 2006), which showed Didymos to have a composition consistent with L or LL-chondrites (Dunn et al. 2013), and radar measurements (Naidu et al. 2020), which provided a size and shape for Didymos and constraints on size for Dimorphos (then unnamed). Photometric measurements combined with the radar measurements allowed an albedo to be estimated for Didymos, and the depth of mutual events provided a more precise measure of the relative sizes of Didymos and Dimorphos.

Post-launch, pre-arrival characterization measurements focused on understanding the baseline state of the Didymos system, including the presence of any rotational variation (Ieva et al. 2022).

Compositional studies

Spectroscopic measurements continued into fall 2022, both to study the possible effects of DART's impact into Dimorphos and to take advantage of Didymos' excellent apparition and close approach. All four of the apertures at the VLT were used to observe Didymos across the visible (Opitom et al. 2023), near-infrared (de León et al. 2022), and mid-IR ranges, as well as to perform spectropolarimetry (Bagnulo et al. 2023). Didymos was also observed with the newly-commissioned JWST, providing data in wavelengths unavailable from the ground (Rivkin et al. 2022). Additional measurements in the visible/near-infrared wavelength range were obtained by DART team members, including observations at Asiago, and the NASA IRTF, among other observatories. IRTF observations taken in the absence and presence of abundant ejecta were used to show that the compositions of Dimorphos and Didymos are consistent with one another (Polishook et al. in prep). JWST NIRSpec observations showed a lack of hydrated minerals on Didymos, consistent with expectations, though hydroxyl created from solar wind implantation cannot be ruled out. JWST MIRI observations show qualitative consistency with ordinary chondrites and other S-class asteroids, with detailed analysis still underway.

Physical properties

In addition to compositional studies, several important physical properties of Didymos can be extracted from the characterization measurements. Multiple approaches point to a thermal inertia of 350-400 J m^{-2} K^{-1} $s^{-1/2}$ using the JWST NIRSpec data. The JWST MIRI data is not yet fully calibrated, but applying the Harris and Drube (2020) approach to the current data points to a thermal inertia ~250 J m^{-2} K^{-1} $s^{-1/2}$. It is not yet clear whether the difference represents different portions of Didymos' surface being probed or observational and analytical uncertainties. The MIRI spectra also appear to be much better matches to small size fractions (<125 µm) of L/LL chondrites vs. larger sizes or chips, suggesting that Didymos' surface likely has abundant sub-mm particles.

Post-impact measurements by Opitom et al. (2023) found no emission lines in the 0.5—0.9 µm region 4 hours after impact, interpreted as a lack of [OI], Xe, NH_2, or H_2O^+ in the system. They also found some color differences within the ejecta cloud at different times, interpreted as different particle sizes dominating the ejecta at different times. Bagnulo et al. (2023) saw a change in polarization level at the time of impact, but no wavelength-dependent change or change in the slope of polarization vs. phase angle, suggesting that "the way in which polarization varies with wavelength depends on the composition of the scattering material, rather than on its structure, be this a surface or a debris cloud".

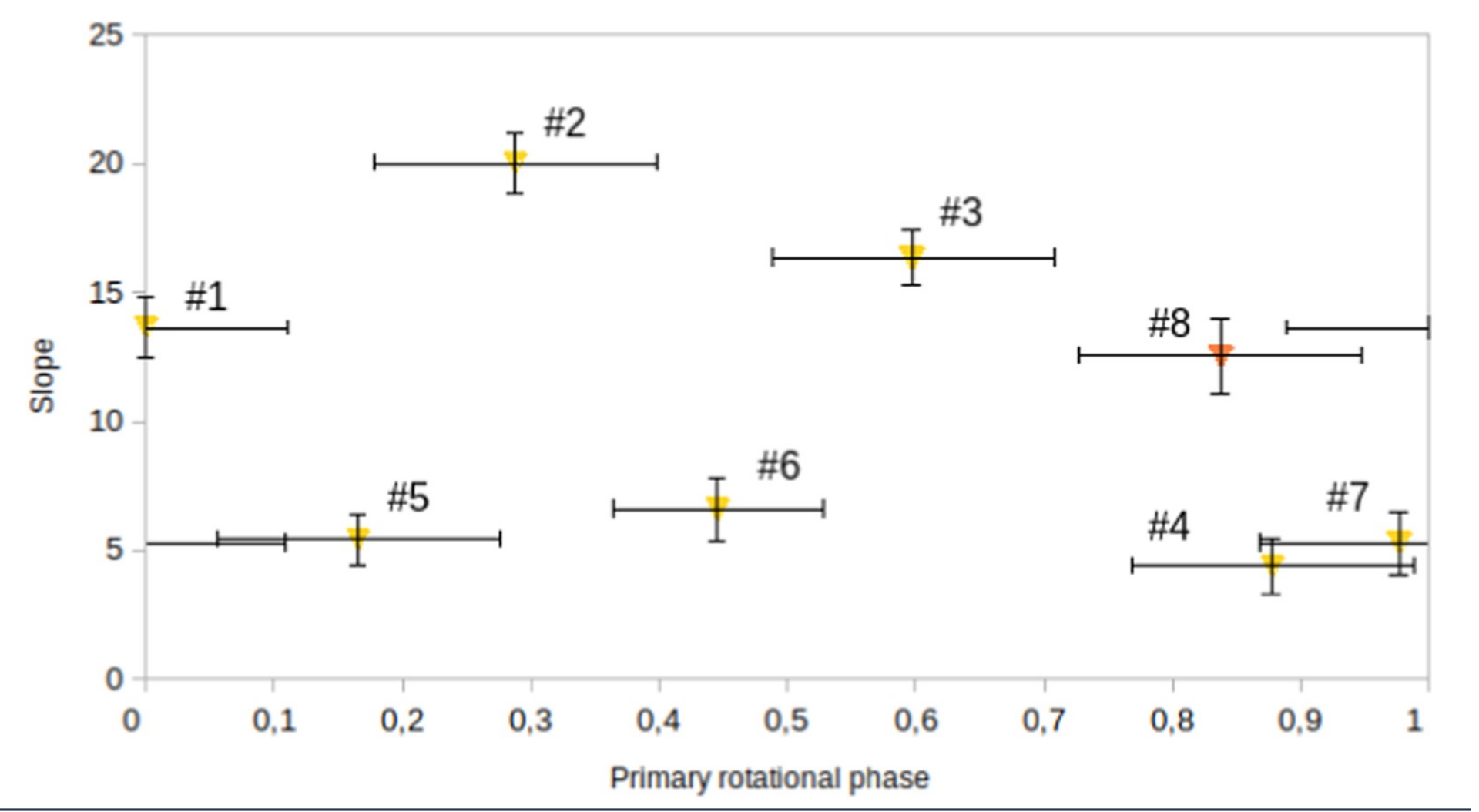

Figure 1: 0.5—0.7-µm spectral slopes vs. the fractional rotational phase, assigned based on the primary lightcurve. For simplicity, 0 is assigned to the first spectrum available (#1). Spectra acquired during the nights of February 15 and February 23 are represented in yellow and orange, respectively. From Ieva et al. (2022)

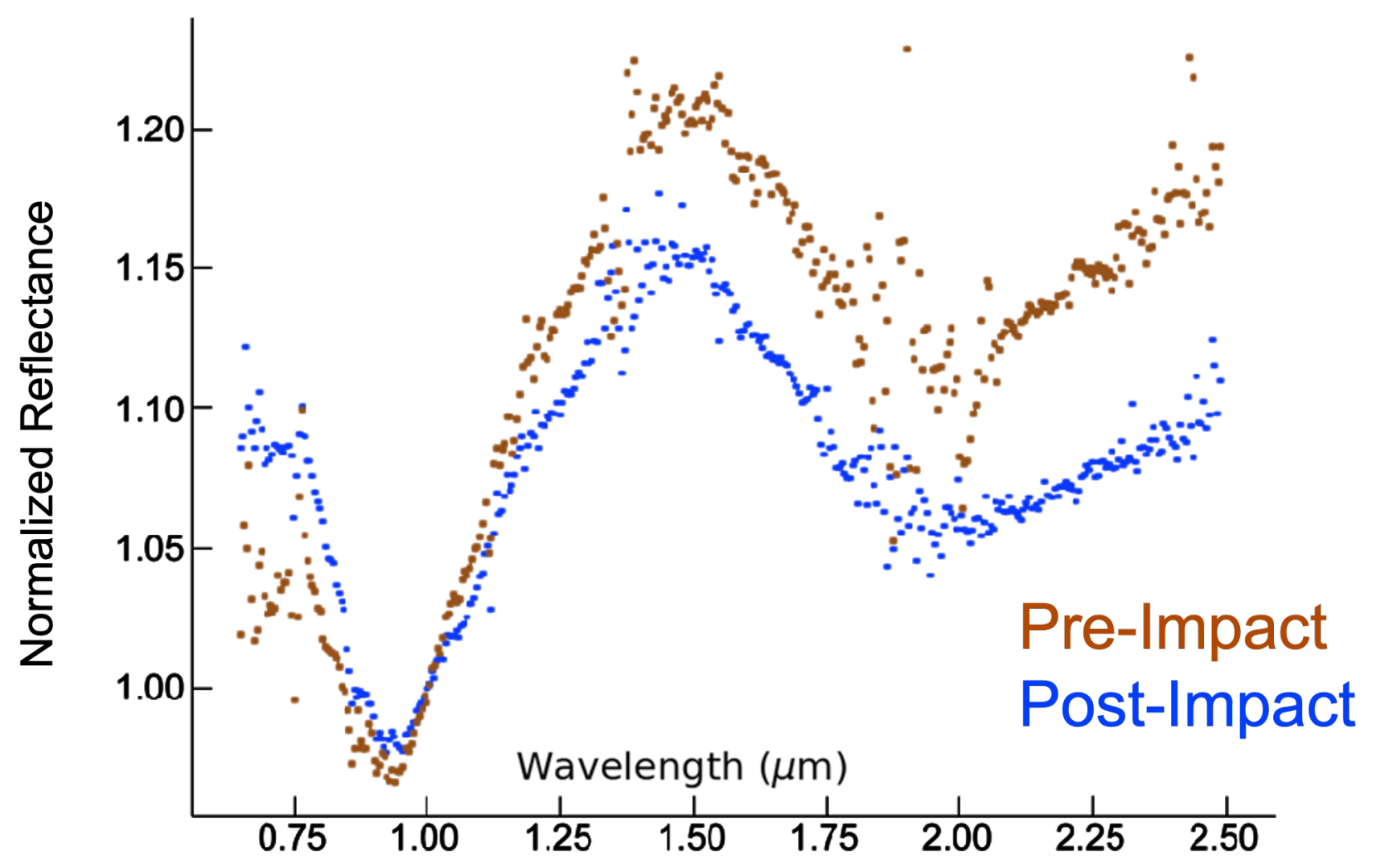

Figure 2: System spectra from IRTF. The pre-impact spectrum (10h before impact) is dominated by Didymos (~96% of the total brightness). Due to the large amount of ejected material, the post-impact spectrum (14h after impact) contains ~2/3 of its flux from Dimorphos material. Both spectra show similar characteristics, suggesting similar compositions for Didymos and Dimorphos. From Polishook et al. (in prep). Credit: NASA Infrared Telescope Facility/Weizmann Institute of Science/Massachusetts Institute of Technology

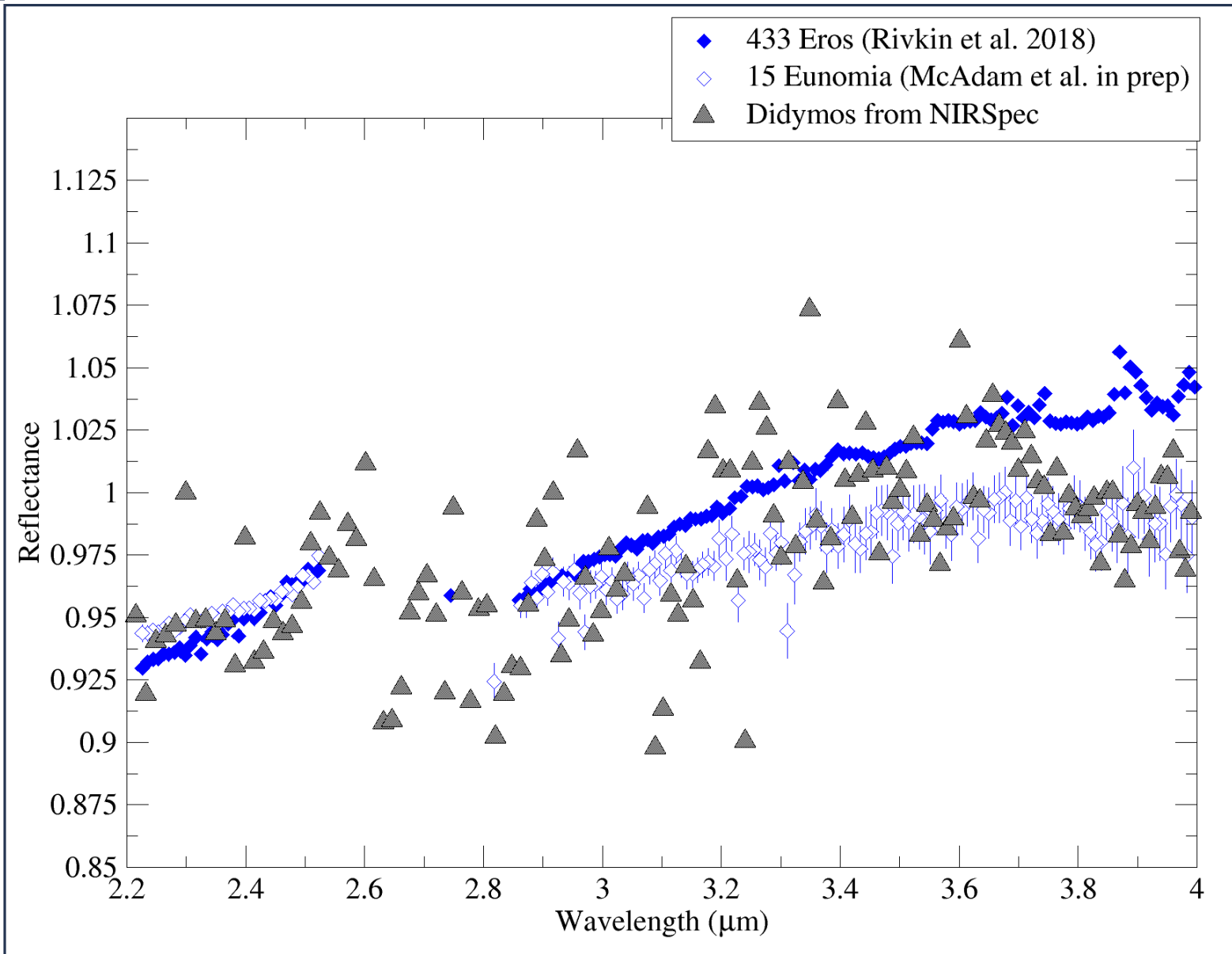

Figure 3: 2.2—4.0-µm spectrum from NIRSpec on JWST. Didymos is seen to have a spectrum consistent with other S-class asteroids in this wavelength region. The 2.5—2.8 µm region is not accessible from the ground, leading to the gap in the Eros and Eunomia spectra. The lack of a resolvable absorption in those wavelengths rules out abundant hydrated minerals on Didymos.

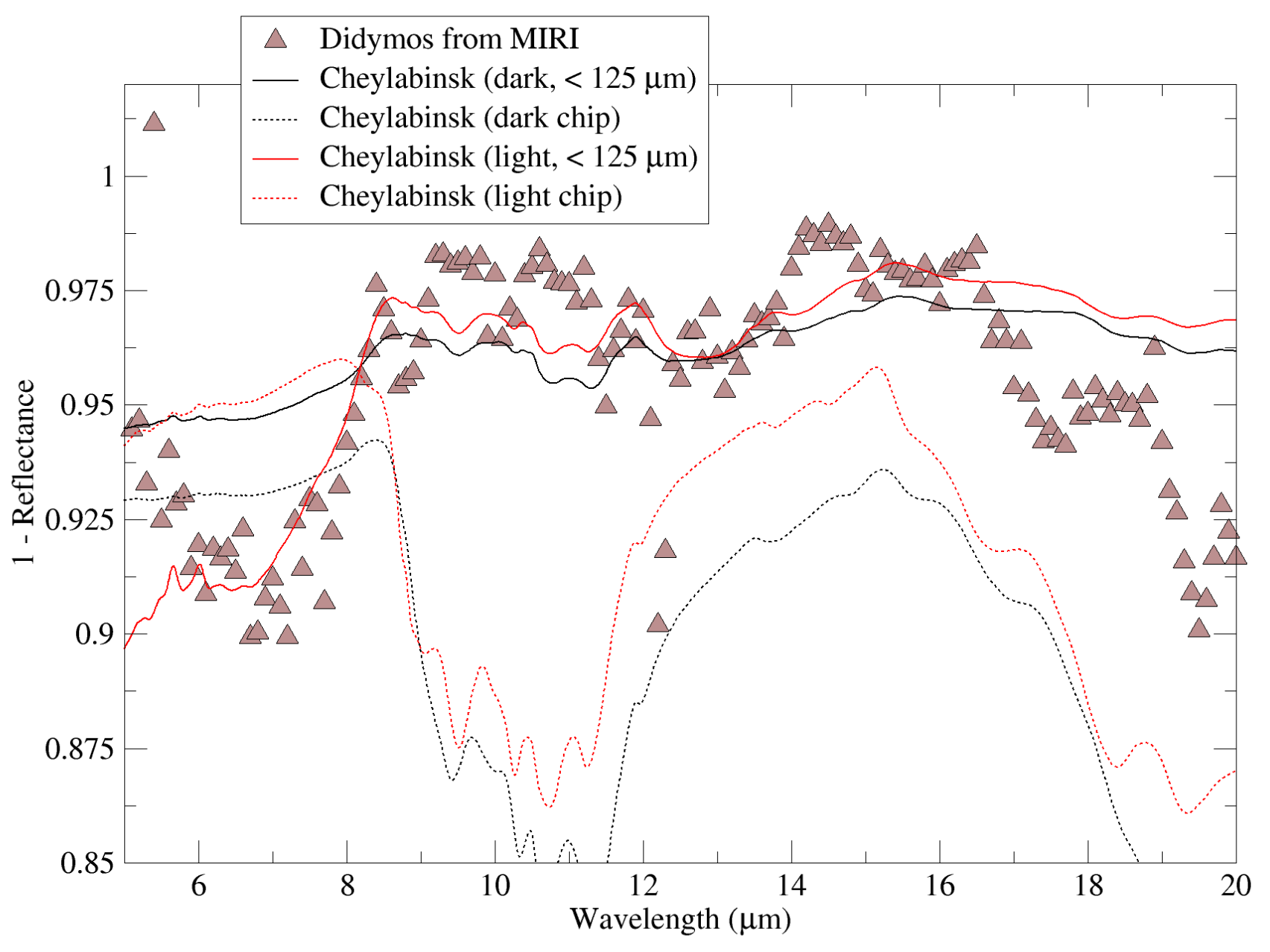

Figure 4: JWST/MIRI spectra of Didymos show similarities to powdered samples of the light lithology of the LL Chelyabinsk meteorite. Detailed spectral analysis is still underway.

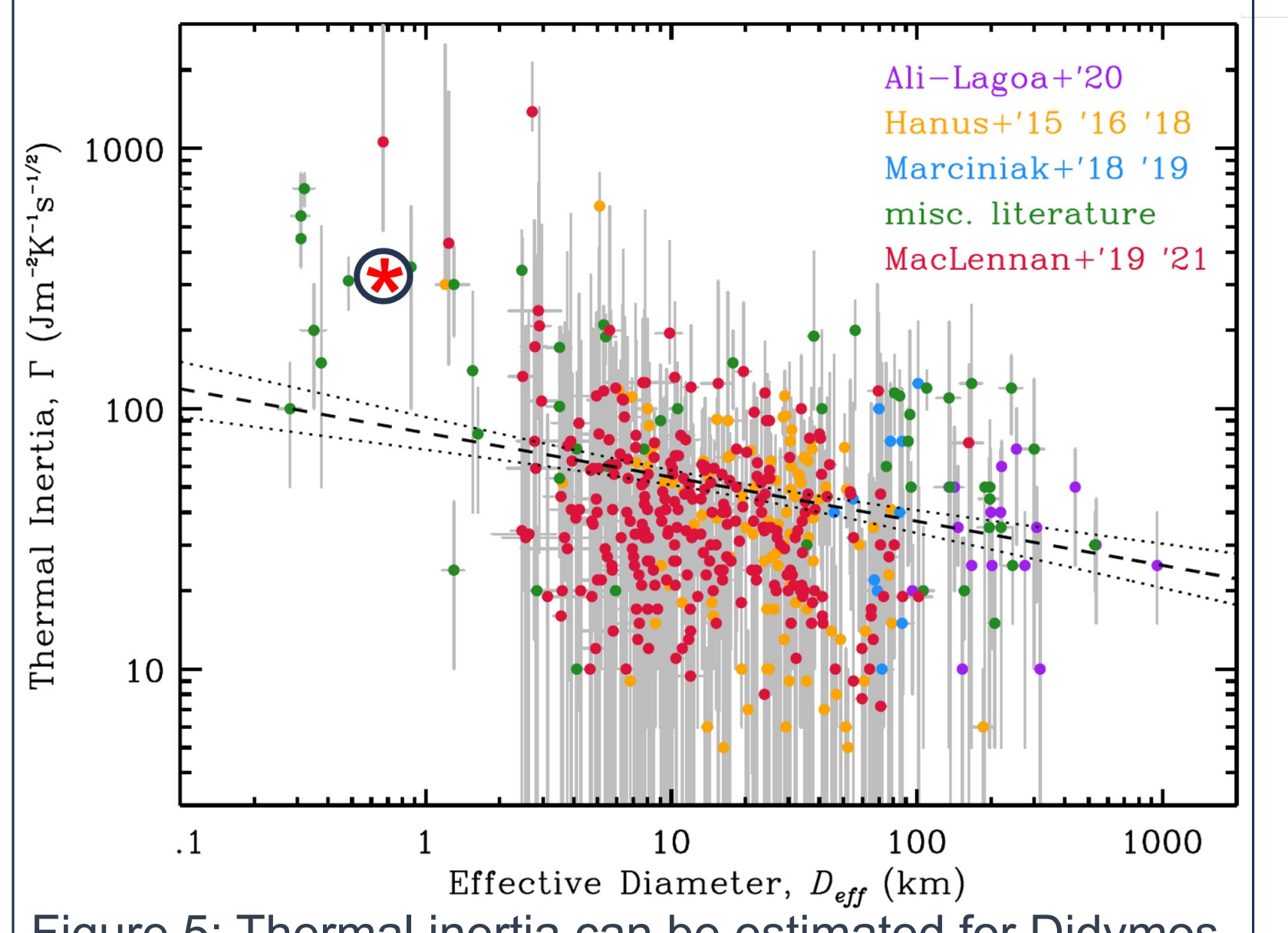

Figure 5: Thermal inertia can be estimated for Didymos from the JWST spectra. The resulting value (circled red asterisk) is consistent with other NEOs of similar sizes. Figure modified from MacLennan and Emery (2020)

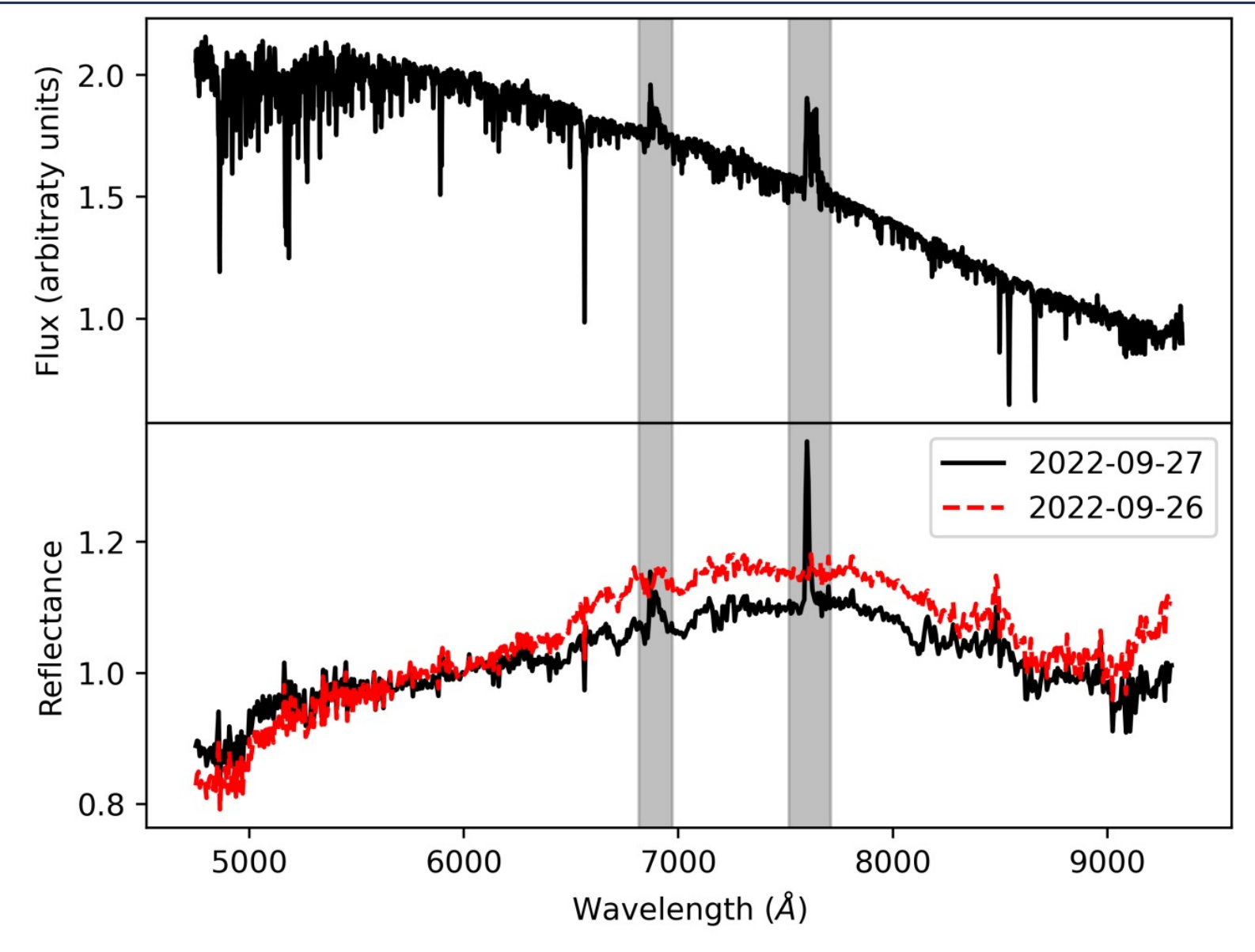

Figure 7: Spectrum of Didymos over the VLT/MUSE wavelength range. Upper: Spectrum of Didymos within a 5" radius aperture on 27 September, illustrating the lack of emission lines 4 hours after the impact. Lower: Pre- and post-impact reflectance spectra of Didymos. Grey areas are strongly affected by telluric absorption. From Opitom et al. (2023)

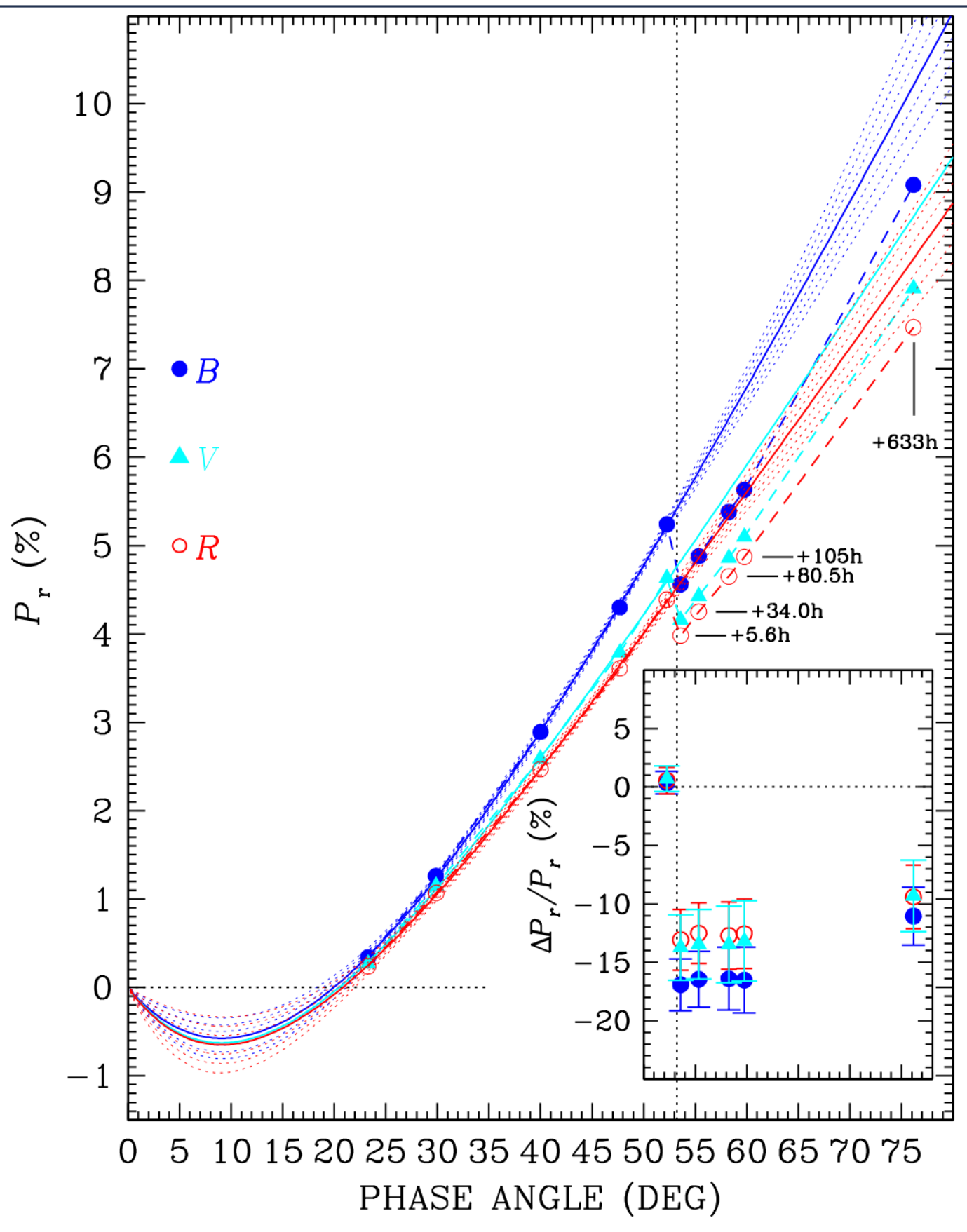

Figure 8: VLT/FORS2 measurements of Didymos' polarization vs. phase angle (symbols with dashed lines) compared to pre-impact fits (solid lines). A dotted vertical line indicates the impact. While polarization curves are vertically offset pre- and post-impact, the trend with phase angle remains the same. From Bagnulo et al. (2023)

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