OBSERVATIONS OF THE DART IMPACT FROM KENYA AND CHILE Colin Snodgrass[1], Cyrielle Opitom[1], Agata Rożek[1], Samuel L. Jackson[1,2], Brian Murphy[1], Petr Pravec[3], James E. Robinson[1], Abbie Donaldson[1], Léa Ferellec[1], Daniel Gardener[1], Woto Huka[4], Calvince Juma[5], Willice Obonyo[5], Vincent Okoth[5], Rashid Shisia[5], Acacia Leakey[4,6], Paul Baki[5,6], Richard Vaughan[6], Martyn Wells[7,6], Susan Murabana[8,6], Chu Owen[8], Peter Kušnirák[3], Kamil Hornoch[3], Julia de Leon[9], Alessandra Migliorini[10], Stefano Bagnulo[11], Zuri Gray[11], Mikael Granvik[12], Alberto Cellino[13], Simon F. Green[2], Benjamin Rozitis[2], Thomas Mueller[14], and the MiNDSTEp and NEOROCKS teams, [1]University of Edinburgh, Royal Observatory, Blackford Hill, Edinburgh, EH9 3HJ, U.K.; csn@roe.ac.uk; [2]The Open University, Milton Keynes, UK; [3]Astronomical Inst. of the Czech Academy of Sciences, Ondřejov, Czech Republic; [4]Turkana Basin Institute, Ileret, Kenya; [5]Technical University of Kenya, Nairobi, Kenya; [6]Kenya Optical Telescope Initiative; [7]UK Astronomy Technology Centre, Edinburgh, UK; [8]Travelling Telescope, Nairobi, Kenya; [9]Instituto de Astrofísica de Canarias, La Palma, Spain; [10]INAF - Istituto di Astrofísica e Planetologia Spaziali, Rome, Italy; [11]Armagh Observatory & Planetarium, Armagh, UK; [12]University of Helsinki, Finland & Lulea University of Technology, Sweden; [13]INAF – Osservatorio Astrofisico di Torino, Italy; [14]Max-Planck-Institut für Extraterrestrische Physik, Garching, Germany

Keywords: *DART mission, ground-based observations*

Introduction:

We report on our observations of the Didymos-Dimorphos asteroid system before, during, and after the impact of the NASA DART spacecraft in September 2022. We combine data from established observatories in Chile, which have highly capable facilities but could not observe the moment of impact, with images collected at a brand new observatory in northern Kenya that was at the right longitude to see the impact 'live'.

Kenyan Observations:

The Kenyan observatory was set up at the Ileret research facility of the Turkana Basin Institute (TBI), in the arid north of the country. This area has long been suggested as an excellent site for astronomical observations due to its very dark skies and unusually (for an equatorial site) dry climate, with the advantage of the infrastructure provided by TBI's camp, which primarily supports archaeological and anthropological research in the area. The University of Edinburgh and TBI, working with the Technical University of Kenya (TUK), set up a 40cm telescope with a research-grade high-speed cooled CMOS camera, which is currently the largest optical telescope in the country, to take advantage of the unique opportunity for African observatories to observe the moment of the DART impact. The telescope is a 'Skywatcher' dobsonian, and the camera a QHY 174GPS, both of which are available for purchase commercially, and maximise collecting area and sensitivity for a reasonable price. The same combination has been widely used by the occultation community to have a portable telescope with a high speed camera, with GPS enabled absolute timing on images [1].

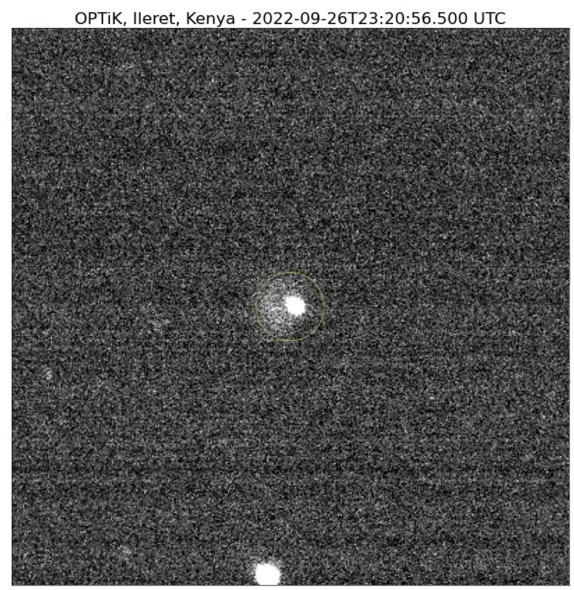

Figure 1: Plume of material visible in images of the Didymos system taken from TBI's Ileret camp 6.5 minutes after the DART impact. Image is approximately 4 arcminutes across, or 13,200 km at Didymos.

Data were collected without any filter to maximise throughput.

Additional observations were collected from a second site in Kenya, Laikipia, by the Travelling Telescope educational charity, who provide education and observing opportunities with small telescopes to schools across the region. Data were collected with 20 and 30 cm diameter telescopes equipped with CCD cameras.

The observing teams in Kenya reported immediate brightening of the Didymos system at impact time, and that the asteroid quickly took on

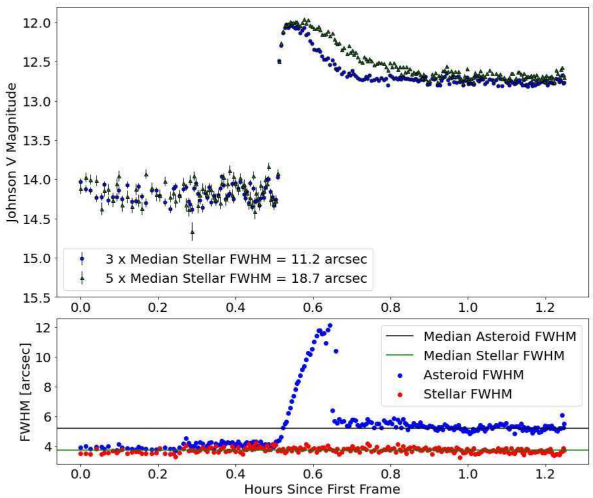

Figure 2: Evolution of the brightness and profile width of the Didymos system seen from Kenya (TBI Ileret).

a ‘fuzzy’ appearance, which became a resolved semi-circular cloud that rapidly expanded before fading from view over the hours following the impact (fig. 1). At the peak the system was around two magnitudes brighter than it was pre-impact – this short peak dropped to a constant level around 1.5 magnitudes brighter than pre-impact within an hour (fig. 2). The projected expansion speed of the cloud was measured to be around 1.6 km/s.

Chilean Observations:

In Chile we made use of telescopes at the La Silla and Paranal sites of the European Southern Observatory (ESO). As part of the NEOROCKS and MiNDSTEp projects, we used the 1.54m Danish telescope at La Silla to obtain high precision photometry before and after the impact to contribute to measurements of the change in orbital period of Dimorphos [2], and to characterise the evolving ejecta morphology over the days and weeks post-impact. We also took advantage of a rare simultaneous allocation of time on all four of the 8m telescopes that comprise the ESO Very Large Telescope (VLT) at Paranal to perform unique observations of the Didymos system: characterising the early ejecta evolution with an adaptive-optics equipped integral-field spectrograph; studying the polarisation of the scattered light from the system; obtaining before- and after-impact thermal infrared measurements; and measuring the visible and near-infrared spectrum of the system with high precision and high resolution.

Observations with the MUSE integral field spectrometer revealed both the distribution of ejecta from the DART impact (fig. 3) and the spectral behaviour of this ejecta. Differences in colour between the initial ejecta and the tail show evidence for changing size distribution as finer dust is blown away by solar radiation pressure [3]. The data also allowed us to search for any evidence for emission lines from an expanding gas cloud, potentially from left over fuel in the DART spacecraft that was released on impact – hypothesised to be the source of the rapidly expanding early ejecta seen from Kenya – but none were detected [3].

Polarimetric observations with the FORS instrument revealed a sharp change in polarisation of the light reflected by the Didymos system after the DART impact [4]. This is attributed to the differences between dominant particles in the ejecta cloud and on the asteroid surface.

Analysis is still ongoing of thermal infrared observations, and of high-resolution spectroscopy, of Didymos before and after the impact. These will place constraints on the total mass of material ejected, and its composition.

Legacy:

In addition to supporting the DART mission, the TBI telescope has been used to train Kenyan students in astronomical observation, and to demonstrate the quality of the site for astronomical observations, with a goal of establishing a larger, permanent, and remotely operable research observatory in the area. This capacity building and site testing is also of great importance in supporting Kenya’s goal of contributing to planetary defence through observations of asteroids as part of the International Asteroid Warning Network (IAWN). Representatives of the recently formed Kenyan Space Agency (KSA) joined the observing team at Ileret to witness the DART impact – development of telescopes in Kenya specifically to contribute to the IAWN is one of the ambitions of the KSA.

In coming years the Ileret telescope will be used for student training field schools as part of the Development in Africa with Radio Astronomy (DARA) programme. DARA is coordinated by the University of Leeds in the UK, and includes partners across Africa to increase science capital in the region through training in astronomy, and is connected to the upcoming Square-Kilometre Array, a major radio telescope that will be sited in Africa and Australia. Use of the TBI telescope will expand the training available through this scheme to include visible wavelength observations as well as radio astronomy, again taking advantage of the facilities at the TBI Ileret camp, which regularly hosts field

Figure 3: Evolution of the ejecta over approximately a month after the DART impact, seen by the MUSE instrument at the ESO VLT (ESO, [3]). Each image is 1 arcminute, or approx 3,000 km, across.

schools for students studying early human evolution in this unique part of Africa.

In the longer term there has long been interest in setting up a permanent observatory in Kenya, to take advantage of its equatorial location (able to see both Northern and Southern constellations), very dark skies, and relatively arid climate. The Kenya Optical Telescope Initiative has commissioned satellite-based surveys of meteorological conditions in various locations in the country, and hosted meetings in Edinburgh, Nairobi and Cape Town to drive the development of astronomy in the country. TUK students took observations over an extended period (around two months) on either side of the DART impact to enable further testing of Ileret as an astronomical site, and future work will test nearby mountain-top locations. The visibility of the DART impact from Kenya gave this project fresh impetus in 2022; development of astronomy and a permanent research observatory in Kenya will be a significant 'bonus' legacy from the DART project.

Acknowledgments:

This project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreements No 871149 (Europlanet 2024 RI – Kenya observations) and No 870403 (NEOROCKS – Danish 1.54m observations).

The MiNDSTEp consortium: F. Amadio, M. Andersen, M. Bonavita, V. Bozza, M.J. Burgdorf, B. Campos Estrada, D. Crake, M. Dominik, A. Donaldson, J. Fynbo, D. Gardener, T.C. Hinse, M. Hundertmark, U.G. Jørgensen, E. Khalouei, M. Kretlow, P. Longa-Peña, N. Peixinho, M. Rabus, S. Rahvar, P. Rota, S. Sajadian, J. Skottfelt, C. Snodgrass, J. Southworth, J. Tregloan-Reed

The NEOROCKS team: E. Dotto, M. Banaszkiewicz, S. Banchi, M.A. Barucci, F. Bernardi, M. Birlan, A. Cellino, J. De Leon, M. Lazzarin, E. Mazzotta Epifani, A. Mediavilla, D. Perna, E. Perozzi, P. Pravec, C. Snodgrass, C. Teodorescu, S. Anghel, A. Bertolucci, F. Calderini, F. Colas, A. Del Vigna, A. Dell'Oro, A. Di Cecco, L. Dimare, I. Di Pietro, P. Fatka, S. Fornasier, E. Frattin, P. Frosini, M. Fulchignoni, R. Gabryszewski, M. Giardino, A. Giunta, T. Hromakina, J. Huntingford, S. Ieva, J.P. Kotlarz, F. La Forgia, J. Licandro, H. Medeiros, F. Merlin, J. Nomen Torres, V. Petropoulou, F. Pina, G. Polenta, M. Popescu, A. Rożek, P. Scheirich, A. Sonka, G.B. Valsecchi, P. Wajer, A. Zinzi.

References:

[1] A. M. Zangari, et al. (2017) in *AAS/Division for Planetary Sciences Meeting Abstracts #49* vol. 49 of *AAS/Division for Planetary Sciences Meeting Abstracts* 504.03. [2] C. A. Thomas, et al. (2023) *Nature* in press:arXiv:2303.02077 doi. arXiv:2303.02077. [3] C. Opitom, et al. (2023) *A&A* 671:L11 doi. [4] S. Bagnulo, et al. (2023) *ApJL* 945(2):L38 doi.