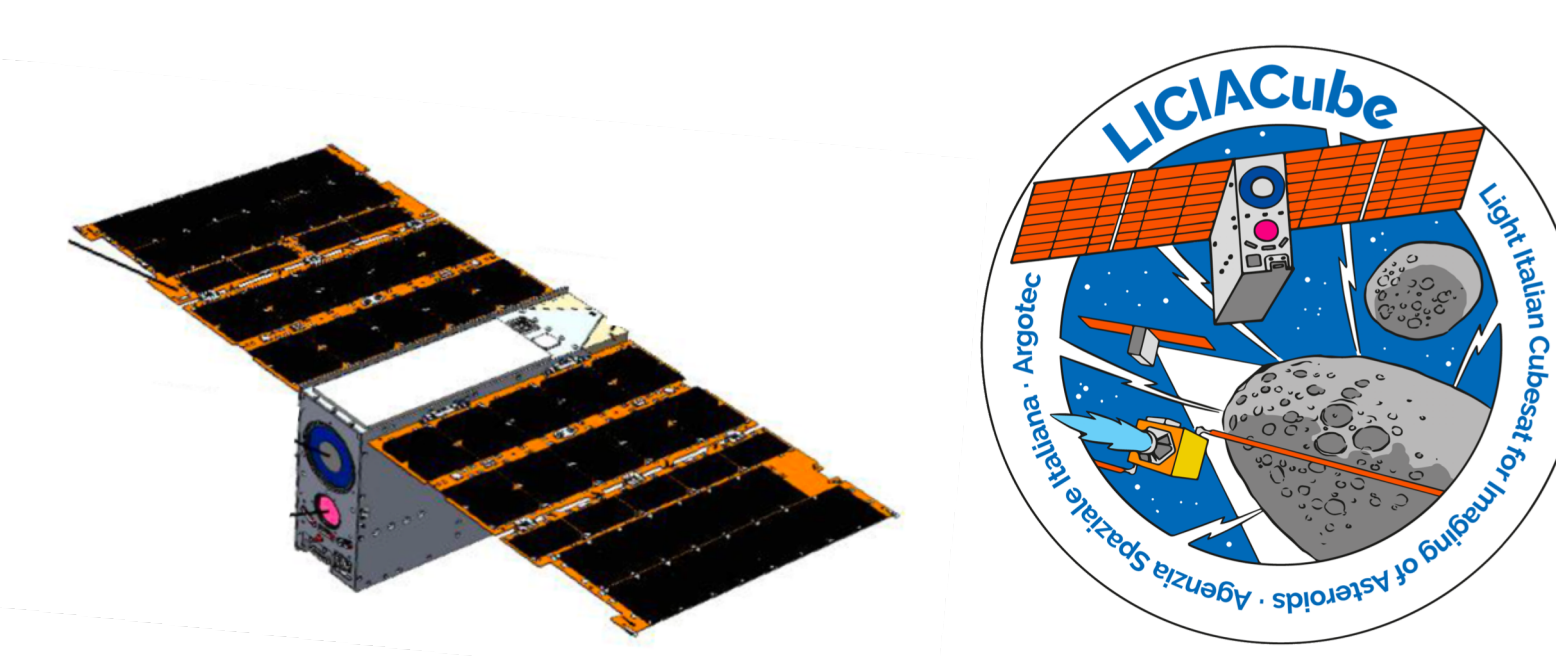


The Dimorphos boulder size-frequency distribution derived from DART/DRACO images: Preliminary results



M. Pajola¹, F. Tusberty¹, A. Lucchetti¹, O. Barnouin², C.M. Ernst², E. Dotto³, R.T. Daly², G. Poggiali^{4,5}, M. Hirabayashi³, E. Mazzotta Epifani³, N. Chabot², V. Della Corte⁶, H. Agrusa⁷, R.-L. Ballouz², N. Murdoch⁸, A. Campo-Bagatin⁹, L. Parro⁹, P. Benavidez⁹, J.B. Vincent¹⁰, A. Rossi¹¹, F. Ferrari¹², J.M. Trigo-Rodriguez¹³, S. Ieva³, S.R. Schwartz¹⁴, S. Ivanovski¹⁵, J. Sunshine⁷, T. Farnham⁷, E. Asphaug¹⁶, A. Rivkin², J.D.P. Deshapriya³, P.H.A. Hasselmann³, J.R. Brucato⁴, A. Zinzi^{17,18}, M. Amoroso¹⁷, S. Pirrotta¹⁷, P. Michel¹⁹, A. Cheng² and the DART & LICIAcube Team.

¹INAF-Astronomical Observatory of Padova, Vic. Osservatorio 5, 35122 Padova, Italy (maurizio.pajola@inaf.it); ²Johns Hopkins University Applied Physics Laboratory, Laurel, MD-USA; ³INAF-Osservatorio Astronomico di Roma, Monte Porzio Catone, Roma, Italy; ⁴INAF-Osservatorio Astrofisico di Arcetri, Firenze, Italy; ⁵LESIA-Observatoire de Paris PSL, Paris, France; ⁶Auburn University, AL-USA; ⁷INAF-Istituto di Astrofisica e Planetologia Spaziali, Roma, Italy; ⁸University of Maryland, Department of Astronomy, MD-USA; ⁹Institut Supérieur de l'Aéronautique et de l'Espace (ISAE-SUPAERO), Université de Toulouse, France; ¹⁰Universidad de Alicante, Spain; ¹¹DLR Berlin, Germany; ¹²IFAC-CNR, Sesto Fiorentino, Firenze, Italy; ¹³Politecnico di Milano - Bovisa Campus, Dipartimento di Scienze e Tecnologie Aerospaziali, Milano, Italy; ¹⁴Institute of Space Sciences (ICE, CSIC) and Institut d'Estudis Espacials de Catalunya (IEEC), Spain; ¹⁵Planetary Science Institute; University of Arizona, AZ-USA; ¹⁶INAF-Osservatorio Astronomico di Trieste, Trieste, Italy; ¹⁷University of Arizona, AZ-USA; ¹⁸Agenzia Spaziale Italiana, Roma, Italy; ¹⁹Space Science Data Center - ASI, Roma Italy; ²⁰Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France;

Context: On 26 September 2022, the Double Asteroid Redirection Test (DART) spacecraft impacted the surface of Dimorphos, the ~160 m size satellite of the near-Earth binary asteroid (NEA) (65803) Didymos (780 m-size [1], Fig. 1). Numerical models of asteroid disruption, the analyses of asteroids' shapes, and in situ observations, support the interpretation that **small asteroids (0.2-10 km size range)** are reaccumulated remnants from disrupted parent bodies, also called **rubble-piles** (e.g. [2, 3]). **Surface boulders**, therefore, represent directly, the **fragments of those parent-body disruptions** followed by some **evolutionary process**. These processes include cratering and thermal breakdown, followed by the size-sorting and migration of granular materials when an asteroid's regolith is mobilized. Hence, the observed **size-frequency distribution (SFD) of boulders** on the surface of a NEA and the corresponding **fitting indices** is a **powerful tool for understanding the initial formation of boulders and their subsequent evolution**. The boulder SFD is also important in understanding the conditions of the surface for any kinetic deflection experiment such as DART.

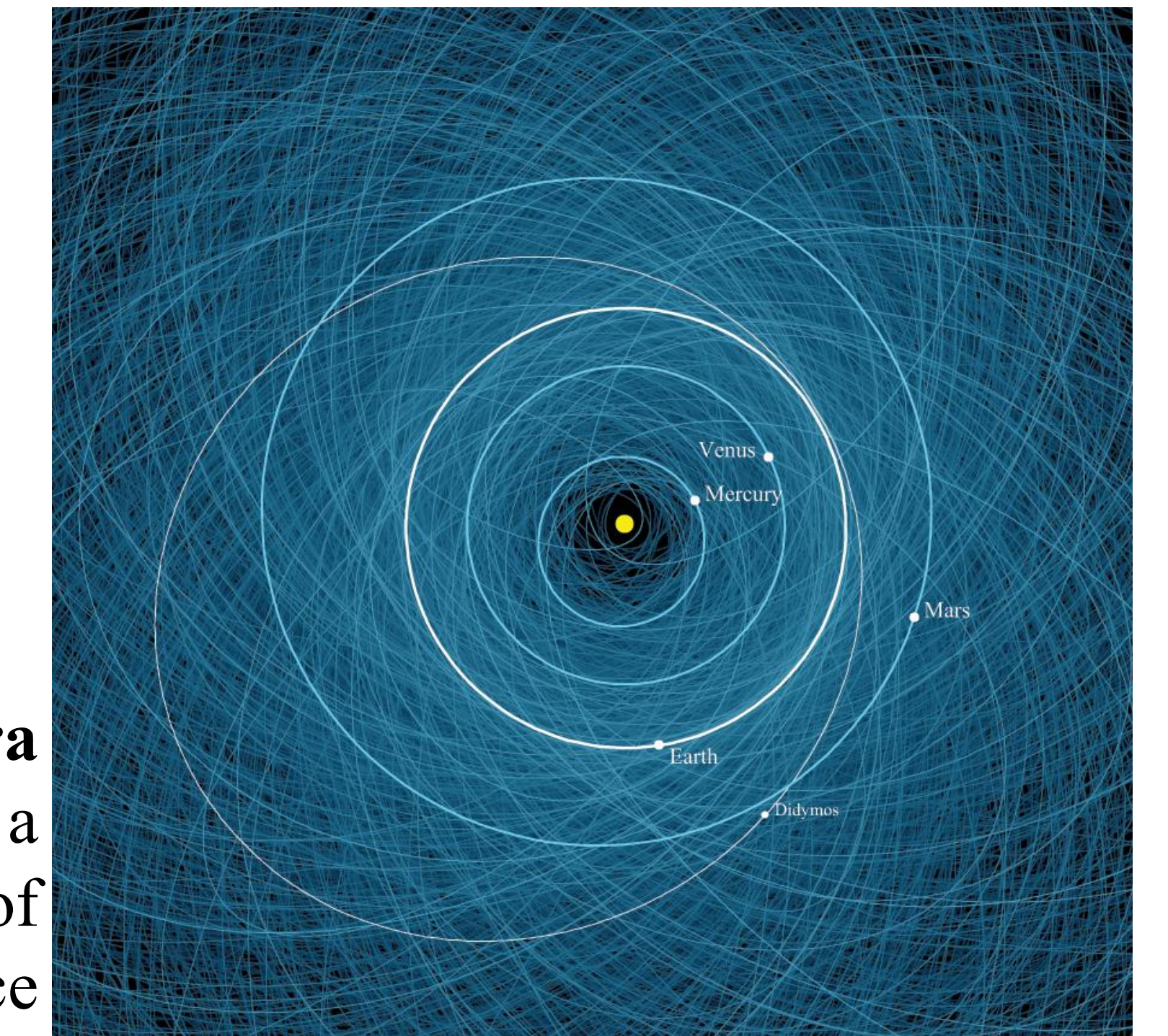


Figure 1. The orbit of NEA (65803) Didymos.

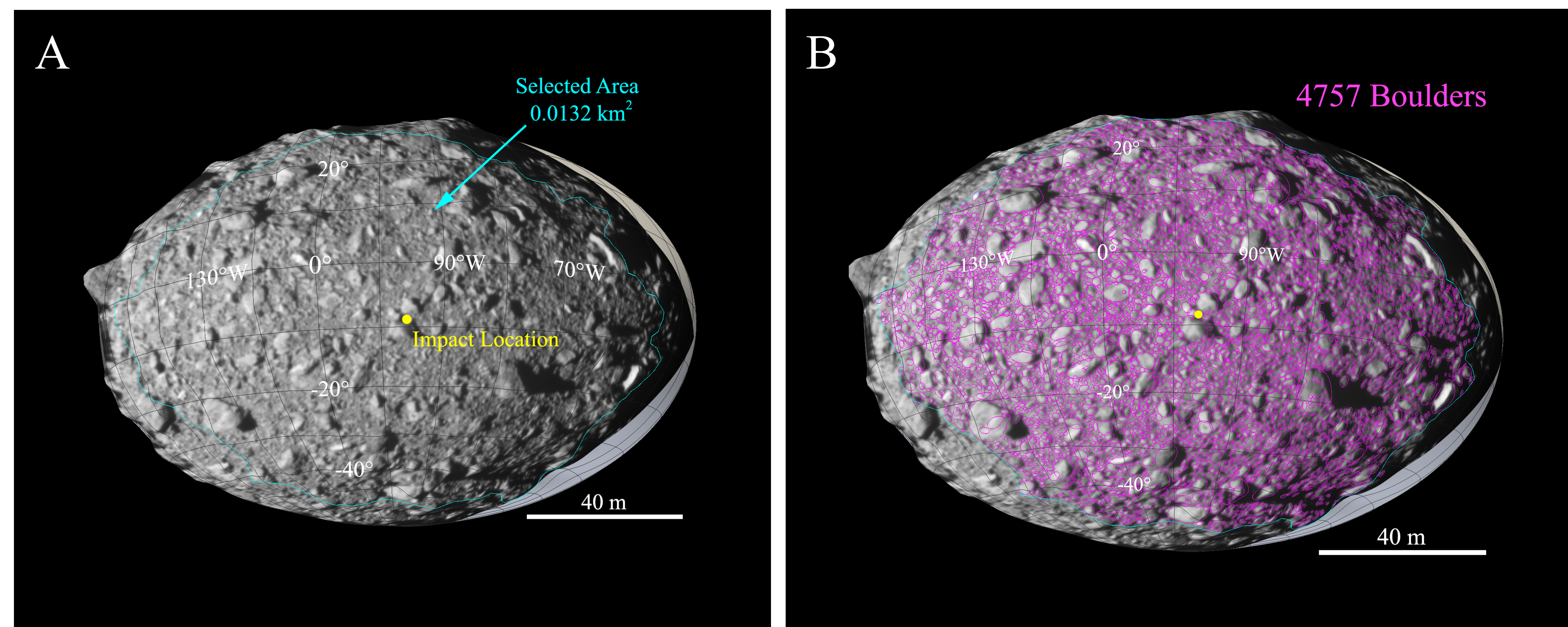


Figure 2. Left-hand panel: The DRACO images projected onto the Dimorphos shape model. The study area is highlighted with a light-blue polyline. The DART impact location is indicated with a yellow dot. Right-hand panel: The 4757 boulders identified on the surface of Dimorphos.

Imagery Dataset: During the last minutes of the DART mission, the **DRACO scientific camera** [4] imaged the surface of Dimorphos at different spatial scales, ranging from few meters to a maximum resolution of 5.5 cm. We decided to use **two DRACO images** with a phase angle of 59.4°, taken from a target distance of 52.56 km and 40.73 km. The resulting illuminated surface has a **spatial scale of 0.26 m and 0.20 m**, hence all features larger than 0.6-0.8 m in size can be identified (Fig. 2).

By using the Small Body Mapping Tool (SBMT, [5]) we directly projected the DRACO images onto the Dimorphos shape model [6] and then identify and manually count boulders as ellipses (Fig. 2) from **an area that is 0.0132 km² wide**. The value of an ellipse's major axis is then used as the maximum diameter of the boulder.

The total number of boulders identified is 4757, with a maximum size of 16 m (Fig. 3)

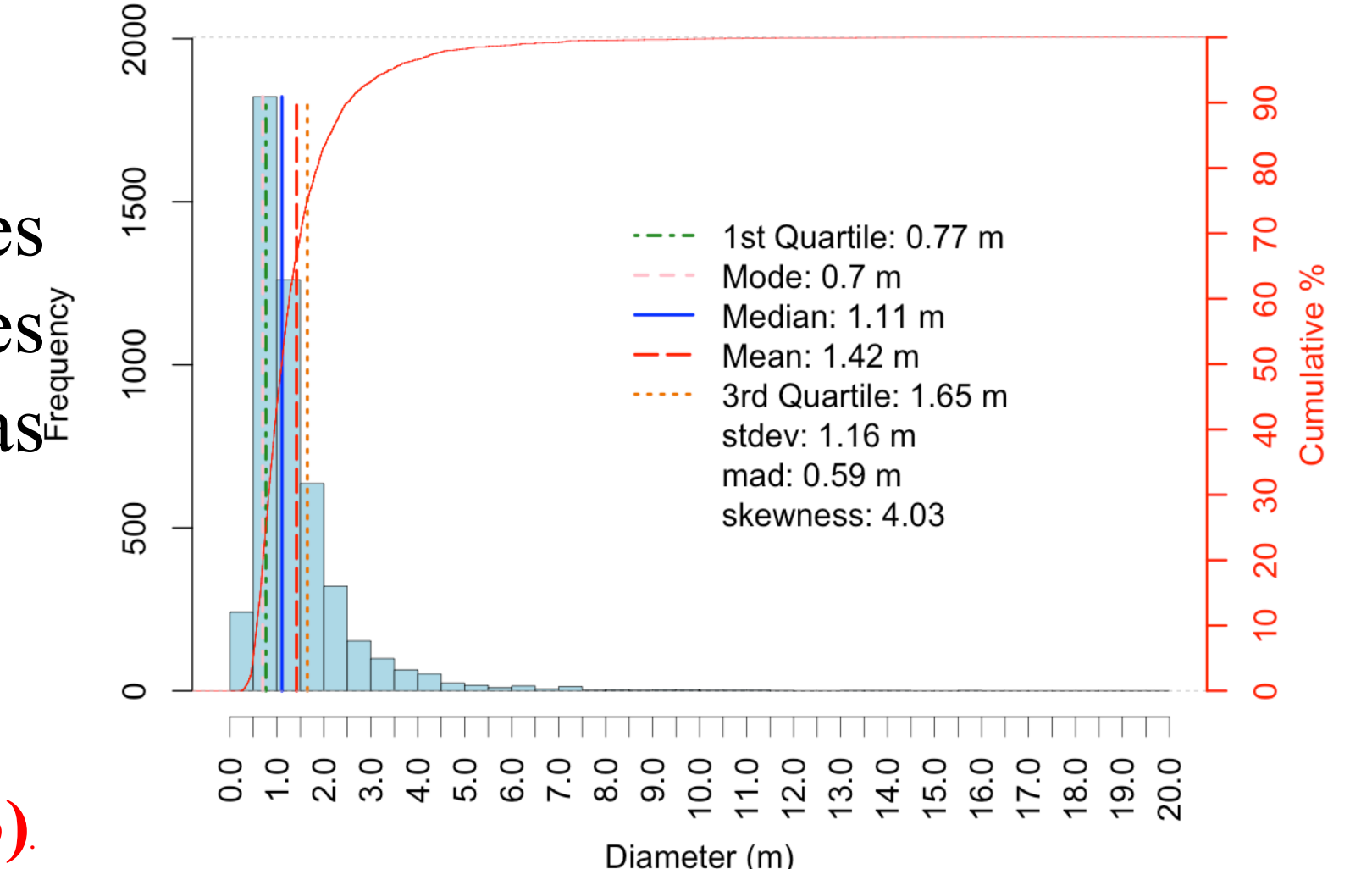


Figure 3. Frequency histogram of the Dimorphos identified boulders.

A power-law SFD fitting curve?

To evaluate if the resulting SFD is fitted by a power-law or not we made use of the **Clauset et al. [7] method** to validate the existence of the power-law fitting model.

Considering the significance level of 0.10, our **p-value** (computed from **2500 Kolmogorov-Smirnoff statistic tests**) is **<0.1** (Fig. 4). This suggests that the boulder SFD does **not** come from a **power law distribution**, but instead, from a different one.

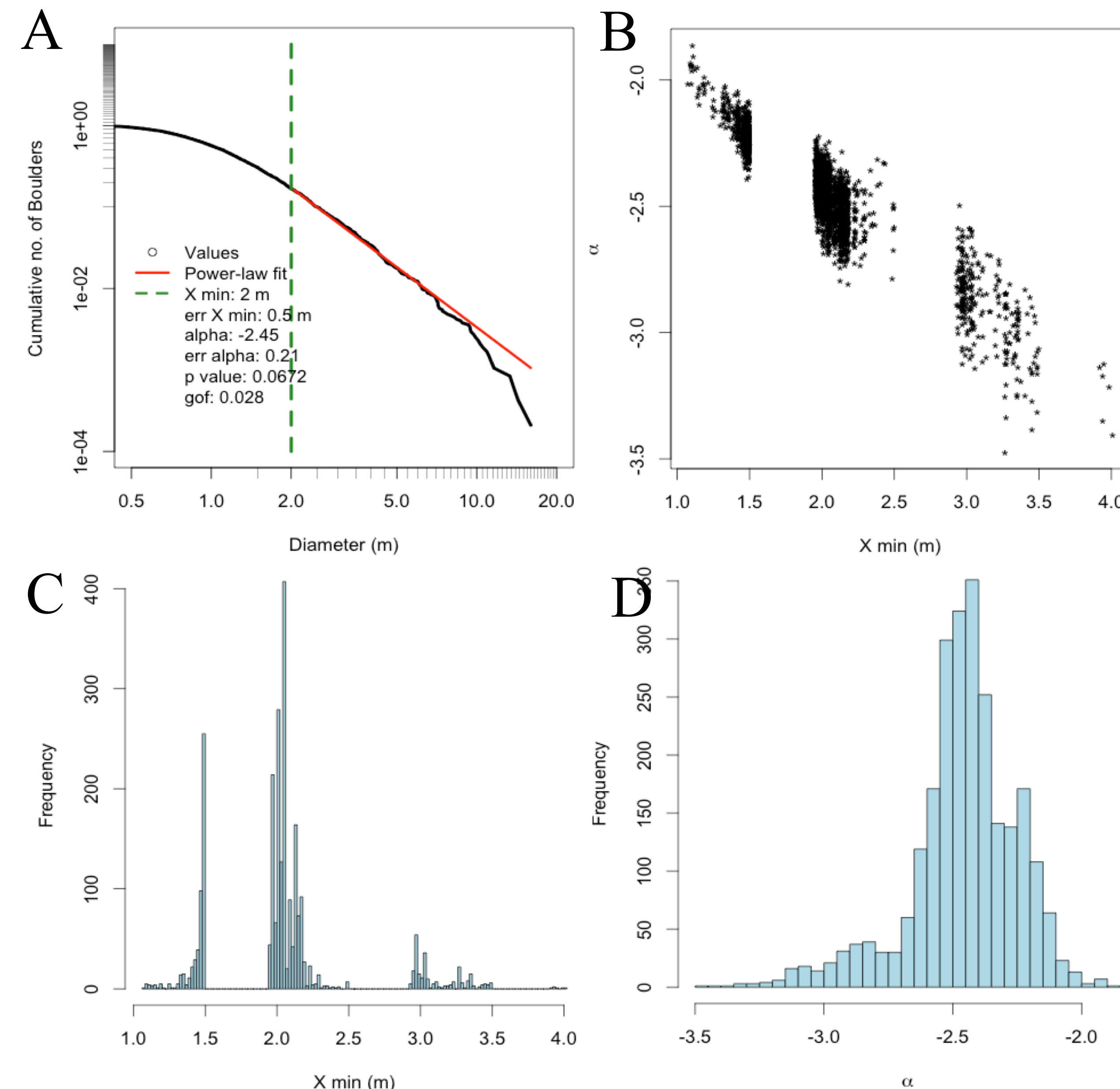


Figure 4. A) Normalized cumulative distribution function showing the obtained sizes, the power-law fitting curve and the xmin limit. (B) Scatter-plot of xmin against alpha resulting from 2500 synthetic datasets. (C) Frequency histogram of xmin. (D) Frequency histogram of the power-law index alpha.

We best-fitted the boulder SFD with an exponential-law curve & a Weibull one.

Considering the 0.20 spatial scale of the images used, all boulders larger than 0.60, i.e. 3 pixels can be positively identified. To be **conservative**, we decided to use a lower limit of **1.0 m** to compute the power-law, **exponential-law and Weibull parameters**. As it is possible to see from Fig. 5, the best fitting curve is definitely the Weibull one, which is in the form (upper cumulative) of: $y = A \exp\left(-\left(\frac{x}{\lambda}\right)^k\right)$. The parameters we are getting for the global counts are: $\lambda = 0.0327$; $k = 0.39589$ and $A = 9995083.23$.

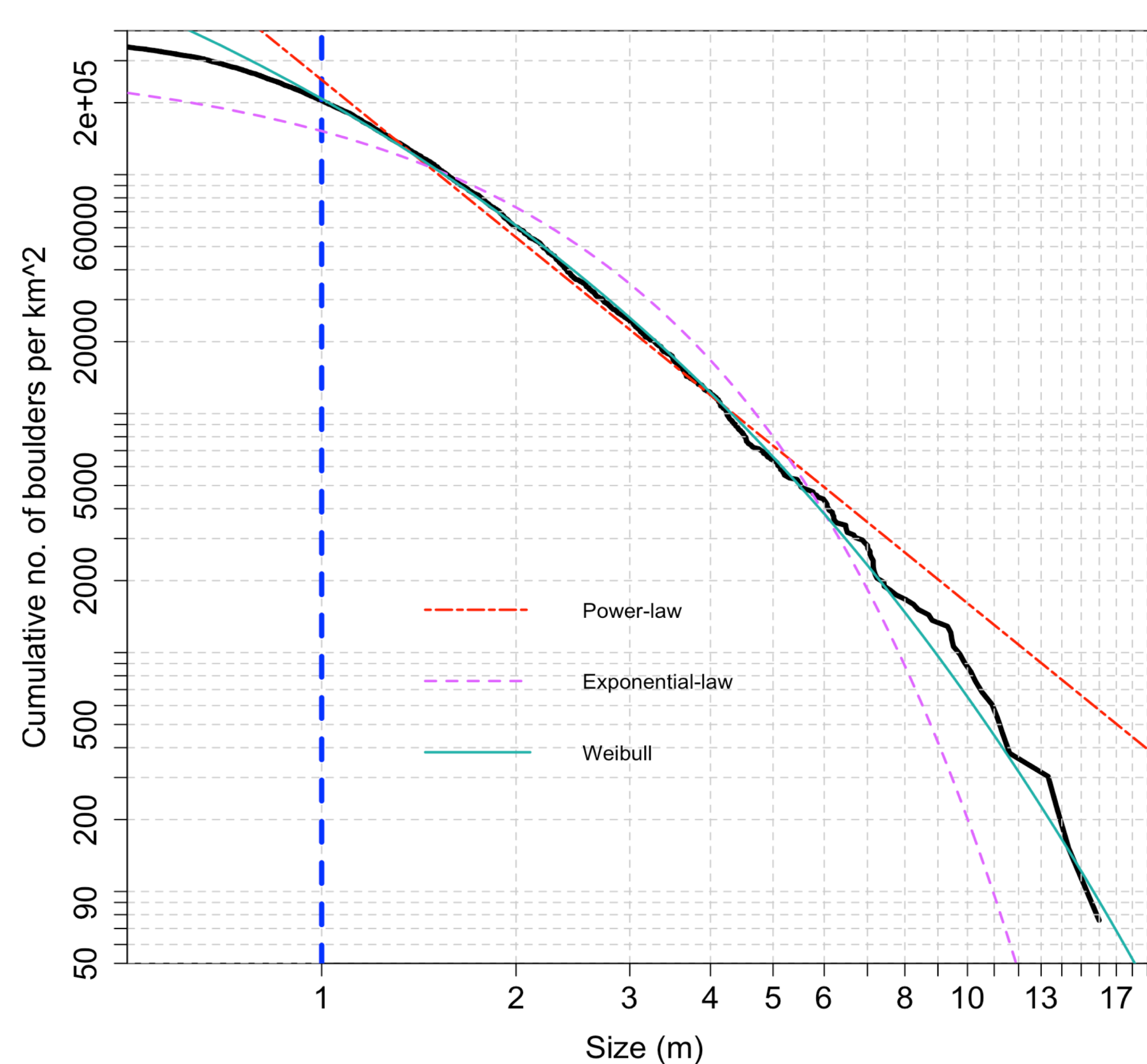


Figure 5. The three best fitting curves computed for Dimorphos boulder SFD. The blue dashed line is the 1.0 m lower completeness limit.

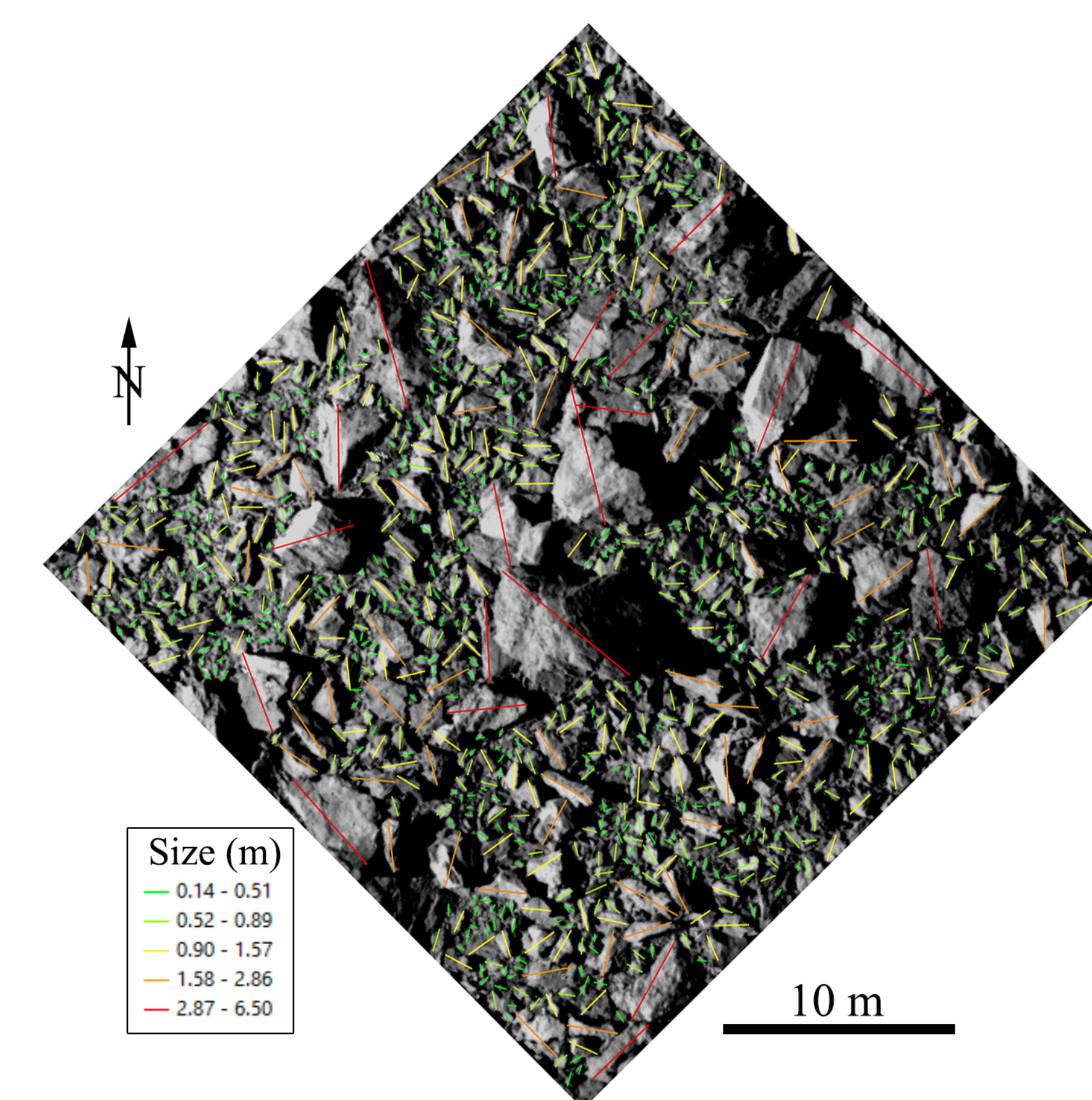


Figure 6. The area where DART impacted Dimorphos surface. The 953 counted boulders are classified based on their sizes.

For what concerns **the DART impact site** we used the last full image obtained from DRACO, which has a spatial scale of 5.5 cm (Fig. 6). Inside the **880 m² area** we identified **953 boulders/pebbles** with a maximum size of 6.5 m.

By using the conservative 5 pixels limit (i.e. we considered only boulders larger than 30 cm) we derived that the best fitting curve is still a **Weibull** one, with parameters that are: $\lambda = 0.0540$; $k = 0.44867$ and $A = 8976340.94$.

Weibull fit explanation: still under discussion!!
<<BUT>> not a single formative or degradation process.

Acknowledgments: This research was supported by the Italian Space Agency (ASI) within the LICIAcube project (ASI-INAF agreement AC n. 2019-31-HH.0) and the DART mission, NASA Contract No. NNN06AA01C to JHU/APL.

References: [1] Rivkin, A.S., et al. 2021. PSJ, 2, 173. [2] Watanabe, S., et al. 2019. Science, 364, 268. [3] Lauretta, D.S., et al. 2019. Nature, 568, 55. [4] Fletcher, Z. J., et al. 2018. Proceedings SPIE 10698. [5] Ernst, C.M. et al. (2018), LPSC #49, 2018, ab. 2083. [6] Daly, R.T., et al. (2022), PSJ, 3:207. [7] Clauset, A., et al., (2009) SIAM Rev. 2009, 51, 661–703.