Investigation of the binary asteroid (65803) Didymos which satellite was subjected to an experimental collision with the DART spacecraft

© *S.N. Petrova, A.V. Devyatkin, D.L. Gorshanov, V.N. L'vov, S.A. Rusov*

Pulkovo Astronomical Observatory, Russian Academy of Sciences,
196140 St. Petersburg, Russia
e-mail: stalkered@yandex.ru

Received May 12, 2023
Revised July 23, 2023
Accepted October, 30, 2023

Observations of the binary asteroid (65803) Didymos after experimental collision of its satellite with the DART spacecraft (NASA) were carried out using MTM-500M telescope of the Pulkovo observatory. Computer simulation of orbit evolution of the asteroid in question was modelled using EPOS software systems. Results of the astrometric and photometric studies using the data obtained are presented in this article.

Keywords: Asteroids, Didymos, Dimorphos, astrometry.

DOI: 10.61011/TP.2023.12.57737.f233-23

The threat of collision with small bodies of the Solar System has been relevant for the Earth throughout the history of its existence. The development of technology over the past half century has made it possible to discover and observe more and more asteroids approaching the Earth every year. As part of the Spacewatch Project at the Kitt Peak Observatory (USA) on April 11, 1996 the asteroid (65803) Didymos was discovered, belonging to the Apollo group and ranked by the Minor Planet Center (MPC) as a potentially hazardous asteroid [1]. Its diameter is about 780 m [2]. In 2003, a moon with a diameter of about 170 m [2] was discovered in its possession, it was subsequently named Dimorphos and was chosen as the target for the first-ever experiment to change the trajectory of an asteroid by physical impact [3]. On September 27, 2022 (on September 26 at 23 h 14 min UTC) NASA's DART spacecraft, launched in November 2021, collided with the asteroid Dimorphos [4].

Using the MTM-500M telescope, installed at the Mountain Astronomical Station of the Pulkovo Observatory (MAS CAO RAS, Kislovodsk) [5], observations of the binary asteroid Didymos were carried out in the period October 1–December 27, 2022. More than 1300 CCD frames were obtained. Astrometric and photometric processing of observational data was carried out with the help of EPOS [6] and APEX-II [7] software packages using the numerical ephemeris DE441 [8]. The GAIA DR2 catalog was used as the reference star catalog [9]. The evolution of the orbit of the binary asteroid Didymos was studied on the time interval $t = 1800-2200$ yr, Fig. 1 shows the result.

In this time interval, the asteroid approaches at a distance of no more than $7.4799 \cdot 10^9$ m (0.05 AU) only with the Earth (2003, 2062, 2123 yr) and Mars (1901, 1967, 2144, 2166 yr). No extra-close approaches have been recorded, so changes in the size and shape of the orbit during this period are insignificant. But they do exist: the orbit is gradually „collapsing" into the inner Solar System. Despite the absence of extra-close approaches to planets, the orbit of the asteroid cannot be considered completely regular. Fig. 2 shows graphs of changes in the orbital parameters of the asteroid Didymos over four centuries. There are signs of chaotic motion and small „jumps" of magnitudes, which in the future can lead to significant changes in the orbit.

Elements of the asteroid's orbit from the MPCORB [10] catalog dated September 5, 2022, obtained from 2880 world observations and assigned to epoch JD2459800.5, were taken as initial ones. In order to assess the quality of observations obtained at the MAS CAO RAS, an attempt was made to improve the orbit, assuming that only the results of Pulkovo observations were available. The improvement was based on a sample of 779 observations made by the MTM-500M telescope for the period October 1–December 27,

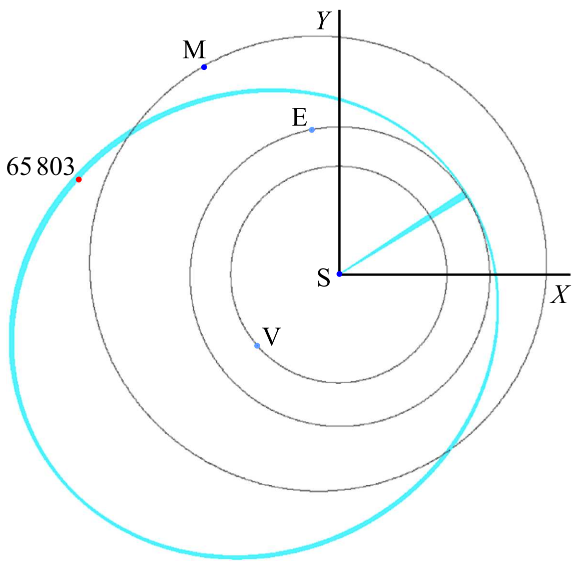

Figure 1. Evolution of the orbit of asteroid (65803) Didymos (together with the line of apsides) with respect to the Sun (S), Venus (V), Earth (E), Mars (M) at the interval $t = 1800-2200$ yr.

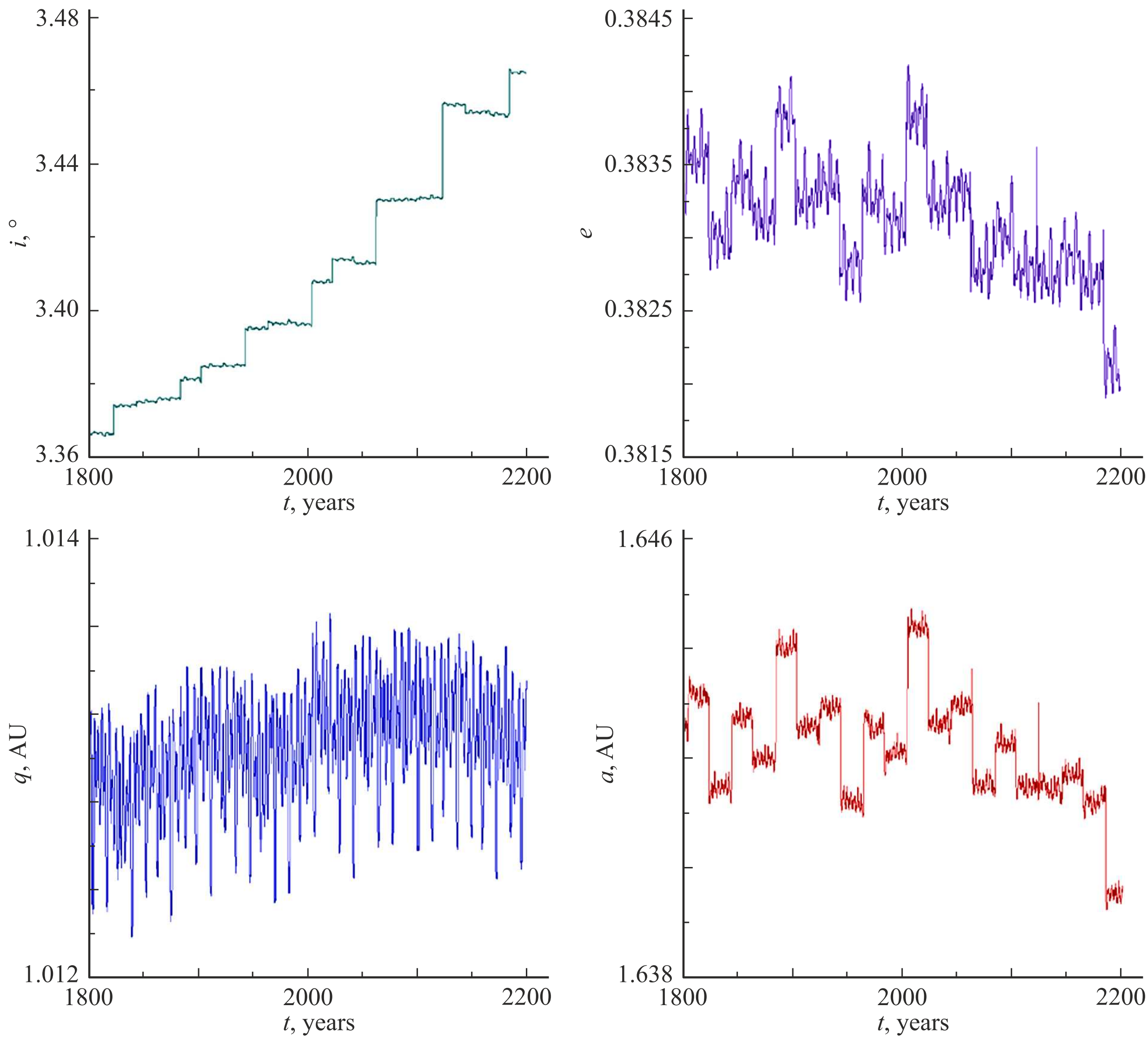

Figure 2. Changes in inclination (i), eccentricity (e), perihelion distance (q), semi-major axis (a) of the orbit of the asteroid Didymos for the period $t = 1800-2200$ yr.

Improvement of orbital elements for epoch JD2459800.5

Elements	Initial (MPC)	Improved	Δ	RMS
M, (°)	325.51990	325.51996	+0.00006	0.000001
ω, (°)	319.31887	319.31900	+0.00013	0.000011
Ω, (°)	73.19329	73.19325	−0.00004	0.000008
i, (°)	3.40788	3.40789	+0.00001	0.000001
e	0.3839233	0.3839242	+0.0000009	0.00000001
a, (AU)	1.64432410	1.64432672	+0.00000262	0.000000030
q, (AU)	1.01302977	1.01302987	+0.00000010	0.000001

2022. The RMS (root mean square), which characterizes the representation of observations by the current set of orbital elements, changed from the initial RMS $= 0.331''$ to the end RMS $= 0.147''$. The results of the improvement with an assessment of the accuracy of the obtained values are given in the table, where M — is the mean anomaly, ω — the argument of perihelion, Ω — the longitude of the ascending node, i — the inclination, e — the eccentricity, a — the semimajor axis, q — the perihelion distance, Δ — the correction.

The paper published in „Nature“ [11], which used numerous observations from various ground-based telescopes,

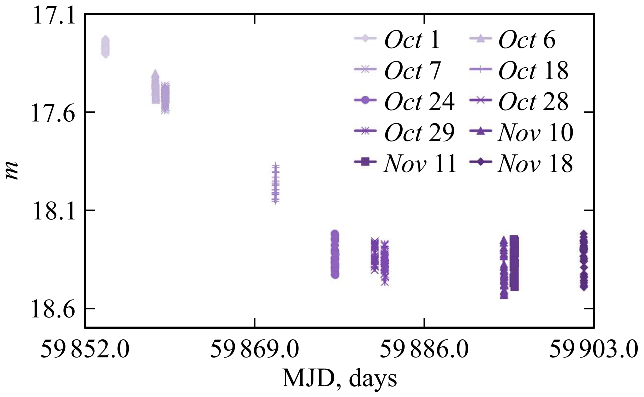

Figure 3. Absolute magnitude dip of the binary asteroid (65803) Didymos.

notes that immediately after the collision, the brightness of the binary asteroid increased by 2.3 magnitude and returned to its original value after about 24 days. The results of photometric processing of the observations obtained by the MTM-500M telescope in the integral band are quite consistent with these conclusions (Fig. 3).

The results of NASA's experiment with the asteroid Dimorphos [12] showed that if one tries to change the orbits of asteroids by kinetic impact, then even such small changes in orbit can prevent possible collisions of asteroids with the Earth.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] Electronic media. Available at: https://www.minorplanetcenter.net/db_search/show_object?object_id=65803

[2] S.P. Naidu, L.A.M. Benner, M. Brozovic, M.C. Nolan, S.J. Ostro, J.L. Margot, J.D. Giorgini, T. Hirabayashi, D.J. Scheeres, P. Pravec, P. Scheirich, C. Magri, J.S. Jao. Icarus, **348**, 113777 (2020). DOI: 10.1016/j.icarus.2020.113777

[3] P. Pravec, C.A. Thomas, A.S. Rivkin, P. Scheirich, N. Moskovitz, M.M. Knight, C. Snodgrass, J. de León, J. Licandro, M. Popescu, A. Thirouin, D. Föhring, C.O. Chandler, W.J. Oldroyd, C.A. Trujillo, E.S. Howell, S.F. Green, J. Thomas-Osip, S.S. Sheppard, T.L. Farnham, E. Mazzotta Epifani, E. Dotto, S. Ieva, M. Dall'Ora, R. Kokotanekova, B. Carry, D. Souami. Planet. Sci. J., **3**, 175 (2022). DOI: 10.3847/PSJ/ac7be1

[4] Electronic media. Available at: https://www.nasa.gov/press-release/nasa-confirms-dart-mission-impact-changed-asteroid-s-motion-in-space

[5] A.P. Kulish, A.V. Devyatkin, V.B. Rafalsky, F.M. Ibragimov, V.V. Kupriyanov, I.A. Vereshchagina, A.V. Schumacher. Izv. GAO, **219** (1), 192 (2009).

[6] V.N. L'vov, S.D. Tsekmeister. Sol. Syst. Res., **46** (2), 177 (2012). DOI: 10.1134/S0038094612020074

[7] A.V. Devyatkin, D.L. Gorshanov, V.V. Kouprianov, I.A. Verestchagina. Sol. Syst. Res., **44** (1), 68 (2010). DOI: 10.1134/S0038094610010090

[8] R.S. Park, W.M. Folkner, J.G. Williams, D.H. Boggs. Astronom. J., **161**, 105 (2021). DOI: 10.3847/1538-3881/abd414

[9] A.G.A. Brown, A. Vallenari, T. Prusti, J.H.J. de Bruijne, C. Babusiaux, C.A.L. Bailer-Jones, M. Biermann, D.W. Evans, L. Eyer, F. Jansen, C. Jordi, S.A. Klioner, U. Lammers, L. Lindegren, X. Luri, F. Mignard, C. Panem, D. Pourbaix, S. Randich, P. Sartoretti, H.I. Siddiqui, C. Soubiran, F. van Leeuwen, N.A. Walton, F. Arenou, U. Bastian, M. Cropper, M.G. Lattanzi, J. Bakker, C. Cacciari, J. Castañeda, L.Chaoul, N. Cheek, F. De Angeli, C. Fabricius, R. Guerra, B. Holl, E. Masana, R. Messineo, N. Mowlavi, K. Nienartowicz, P. Panuzzo, J. Portell, M. Riello, G.M. Seabroke, P. Tanga, F. Thévenin, G. Gracia-Abril, G. Comoretto, M. Garcia-Reinaldos,D. Teyssier, M. Altmann, R. Andrae, M. Audard, I. Bellas-Velidis, K. Benson, J. Berthier, R. Blomme, P. Burgess, G. Busso, B. Carry, A. Cellino, G. Clementini, M. Clotet, O. Creevey, M. Davidson, J. De Ridder, L. Delchambre, A. Dell'Oro, C. Ducourant, J. Fernández-Hernández, M. Fouesneau6, Y. Frémat, L. Galluccio, M. García-Torres, J. González-Núñez, J.J. González-Vidal, E. Gosset, L.P. Guy, J.-L. Halbwachs, N.C. Hambly, D.L. Harrison, J. Hernández, D. Hestroffer, S.T. Hodgkin, A. Hutton, G. Jasniewicz, A. Jean-Antoine-Piccolo, S. Jordan, A.J. Korn, A. Krone-Martins, A.C. Lanzafame, T. Lebzelter, W. Löffler, M. Manteiga, P.M. Marrese, J.M. Martín-Fleitas, A. Moitinho, A. Mora, K. Muinonen, J. Osinde, E. Pancino, T. Pauwels, J.-M. Petit, A. Recio-Blanco, P.J. Richards, L. Rimoldini, A.C. Robin, L.M. Sarro, C. Siopis, M. Smith, A. Sozzetti, M. Süveges, J. Torra, W. van Reeven, U. Abbas, A. Abreu Aramburu, S. Accart, C. Aerts, G. Altavilla, M.A. Álvarez, R. Alvarez, J. Alves,R.I. Anderson, A.H. Andrei, E. Anglada Varela, E. Antiche, T. Antoja, B. Arcay, T.L. Astraatmadja, N. Bach, S.G. Baker, L. Balaguer-Núñez, P. Balm, C. Barache, C. Barata, D. Barbato, F. Barblan, P.S. Barklem, D. Barrado, M. Barros, M.A. Barstow, S. Bartholomé Muñoz, J.-L. Bassilana, U. Becciani, M. Bellazzini, A. Berihuete, S. Bertone, L. Bianchi, O. Bienaymé, S. Blanco-Cuaresma,21,73, T. Boch, C. Boeche, A. Bombrun, R. Borrachero, D. Bossini, S. Bouquillon, G. Bourda, A. Bragaglia, L. Bramante, M.A. Breddels, A. Bressan, N. Brouillet, T. Brüsemeister, E. Brugaletta, B. Bucciarelli, A. Burlacu, D. Busonero, A.G. Butkevich, R. Buzzi, E. Caffau, R. Cancelliere, G. Cannizzaro, T. Cantat-Gaudin, R. Carballo, T. Carlucci, J.M. Carrasco, L. Casamiquela, M. Castellani, A. Castro-Ginard, P. Charlot, L. Chemin, A. Chiavassa, G. Cocozza, G. Costigan, S. Cowell, F. Crifo, M. Crosta, C. Crowley, J. Cuypers, C. Dafonte, Y. Damerdji, A. Dapergolas, P. David, M. David, P. de Laverny, F. De Luise, R. De March, D. de Martino, R. de Souza, A. de Torres, J. Debosscher, E. del Pozo, M. Delbo, A. Delgado, H.E. Delgado, P. Di Matteo, S. Diakite, C. Diener, E. Distefano, C. Dolding, P. Drazinos, J. Durán, B. Edvardsson, H. Enke, K. Eriksson, P. Esquej, G. Eynard Bontemps, C. Fabre, M. Fabrizio, S. Faigler, A.J. Falcão, M. Farrás Casas, L. Federici, G. Fedorets, P. Fernique, F. Figueras, F. Filippi, K. Findeisen, A. Fonti, E. Fraile, M. Fraser, B. Frézouls, M. Gai, S. Galleti, D. Garabato, F. García-Sedano, A. Garofalo, N. Garralda, A. Gavel, P. Gavras, J. Gerssen, R. Geyer, P. Giacobbe, G. Gilmore, S. Girona, G. Giuffrida, F. Glass, M. Gomes, M. Granvik,

A. Gueguen, A. Guerrier, J. Guiraud, R. Gutiérrez-Sánchez, R. Haigron, D. Hatzidimitriou, M. Hauser, M. Haywood, U. Heiter, A. Helmi, J. Heu, T. Hilger, D. Hobbs, W. Hofmann, G. Holland, H.E. Huckle, A. Hypki, V. Icardi, K. Janßen, G. Jevardat de Fombelle, P.G. Jonker, Á.L. Juhász, F. Julbe, A. Karampelas, A. Kewley, J. Klar, A. Kochoska, R. Kohley, K. Kolenberg, M. Kontizas, E. Kontizas, S.E. Koposov, G. Kordopatis, Z. Kostrzewa-Rutkowska, P. Koubsky, S. Lambert, A.F. Lanza, Y. Lasne, J.-B. Lavigne, Y. Le Fustec, C. Le Poncin-Lafitte, Y. Lebreton, S. Leccia, N. Leclerc, I. Lecoeur-Taibi, H. Lenhardt, F. Leroux, S. Liao, E. Licata, H.E.P. Lindstrøm, T.A. Lister, E. Livanou, A. Lobel, M. López, S. Managau, R.G. Mann, G. Mantelet, O. Marchal, J.M. Marchant, M. Marconi, S. Marinoni, G. Marschalkó, D.J. Marshall, M. Martino, G. Marton, N. Mary, D. Massari, G. Matijevič, T. Mazeh, P.J. McMillan, S. Messina, D. Michalik, N.R. Millar8, D. Molina11, R. Molinaro, L. Molnár, P. Montegriffo, R. Mor, R. Morbidelli, T. Morel, D. Morris, A.F. Mulone, T. Muraveva, I. Musella, G. Nelemans, L. Nicastro, L. Nova, W. O'Mullane, C. Ordénovic, D. Ordóñez-Blanco, P. Osborne, C. Pagani, I. Pagano, F. Pailler, H. Palacin, L. Palaversa, A. Panahi, M. Pawlak, A.M. Piersimoni, F.-X. Pineau, E. Plachy, G. Plum4, E. Poggio, E. Poujoulet, A. Prša, L. Pulone, E. Racero, S. Ragaini, N. Rambaux, M. Ramos-Lerate, S. Regibo, C. Reylé, F. Riclet, V. Ripepi, A. Riva, A. Rivard, G. Rixon, T. Roegiers, M. Roelens, M. Romero-Gómez, N. Rowell, F. Royer, L. Ruiz-Dern, G. Sadowski, T. Sagristá Sellés, J. Sahlmann, J. Salgado, E. Salguero, N. Sanna, T. Santana-Ros, M. Sarasso, H. Savietto, M. Schultheis, E. Sciacca, M. Segol, J.C. Segovia, D. Ségransan, I-C. Shih, L. Siltala, A.F. Silva, R.L. Smart, K.W. Smith, E. Solano, F. Solitro, R. Sordo, S. Soria Nieto, J. Souchay, A. Spagna, F. Spoto, U. Stampa, I.A. Steele, H. Steidelmüller, C.A. Stephenson, H. Stoev, F.F. Suess, J. Surdej, L. Szabados, E. Szegedi-Elek, D. Tapiador, F. Taris, G. Tauran, M.B. Taylor, R. Teixeira, D. Terrett, P. Teyssandier, W. Thuillot, A. Titarenko, F. Torra Clotet, C. Turon, A. Ulla, E. Utrilla, S. Uzzi, M. Vaillant, G. Valentini, V. Valette, A. van Elteren, E. Van Hemelryck, M. van Leeuwen, M. Vaschetto, A. Vecchiato, J. Veljanoski, Y. Viala, D. Vicente, S. Vogt, C. von Essen, H. Voss, V. Votruba, S. Voutsinas, G. Walmsley, M. Weiler, O. Wertz, T. Wevers, Ł. Wyrzykowski, A. Yoldas, M. Žerjal, H. Ziaeepour, J. Zorec, S. Zschocke, S. Zucker, C. Zurbach, T. Zwitter. A & A, **616**, A1 (2018). DOI: 10.1051/0004-6361/201833051

[10] Electronic media. Available at: https://minorplanetcenter.net/iau/MPCORB.html

[11] A. Graykowski, R.A. Lambert, F. Marchis, D. Cazeneuve1, P.A. Dalba, Th.M. Esposito, D. O'Conner Peluso, L.A. Sgro, G. Blaclard, A. Borot, A. Malvache, L. Marfisi, T.M. Powell, P. Huet, M. Limagne, B. Payet, C. Clarke, S. Murabana, D. Chu Owen, R. Wasilwa, K. Fukui, T. Goto, B. Guillet, P. Huth, S. Ishiyama, R. Kukita, M. Mitchell, M. Primm, J. Randolph, D.A. Rivett, M. Ryno, M. Shimizu, J.-P. Toullec, S. Will, W.-Ch. Yue, M. Camilleri, K. Graykowski, R. Janetzke, D. Janke, S. Kardel, M. Loose, J.W. Pickering, B.A. Smith, I.M. Transom. Nature, **616**, 461 (2023). DOI: 10.1038/s41586-023-05852-9

[12] C.A. Thomas, Sh.P. Naidu, P. Scheirich, N.A. Moskovitz, P. Pravec, S.R. Chesley, A.S. Rivkin, D.J. Osip, T.A. Lister, L.A.M. Benner, M. Brozović, C. Contreras, N. Morrell, A. Rożek, P. Kušnirák, K. Hornoch, D. Mages, P.A. Taylor, A.D. Seymour, C. Snodgrass, U.G. Jørgensen, M. Dominik, B. Skiff, T. Polakis, M.M. Knight, T.L. Farnham, J.D. Giorgini, B. Rush, J. Bellerose, P. Salas, W.P. Armentrout, G. Watts, M.W. Busch, J. Chatelain, E. Gomez, S. Greenstreet, L. Phillips, M. Bonavita, M.J. Burgdorf, E. Khalouei, P. Longa-Peña, M. Rabus, S. Sajadian, N.L. Chabot, A.F. Cheng, W.H. Ryan, E.V. Ryan, C.E. Holt, H.F. Agrusa. Nature, **616**, 448 (2023). DOI: 10.1038/s41586-023-05805-2

Translated by 123