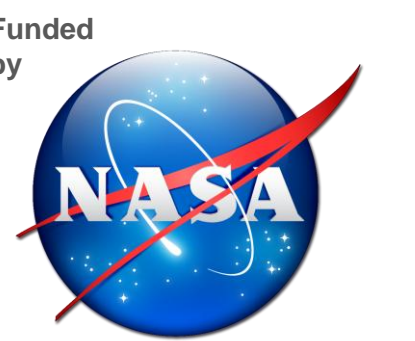


The potentially hazardous binary asteroid (285263) 1998 QE2

F.C.F. Venditti¹, A. Deleon², M. Mota³, S. Marshall¹, A. Safwan⁴, A. Prado⁴

¹University of Central Florida, Orlando, FL, USA (venditti@ucf.edu), ²Southwest Research Institute, San Antonio, TX, USA, ³Federal Institute of Sao Paulo, IFSP, Hortolandia, SP, Brazil, ⁴National Institute for Space Research, Sao Jose dos Campos, SP, Brazil.



During decades of operations, nearly a thousand individual near-Earth asteroids (NEAs) were observed at the Arecibo Observatory, at least half classified as potentially hazardous asteroids (PHAs) as seen in Fig.1. In total, 58 binary or triple NEAs have been observed with Arecibo's radar (Fig 2). Table 1 shows the distribution of NEAs with satellites observed at Arecibo.

In this work, the derived shape model and the orbital elements information for the components of 1998 QE2 are used to study the dynamical environment of the system by applying a methodology that is computationally efficient while preserving the accuracy of the model. Multiple asteroid systems can help to understand the formation mechanism and evolution of small bodies in the solar system. Understanding the dynamical environment around these systems could provide clues to the origin and evolution of these bodies and support future space missions.

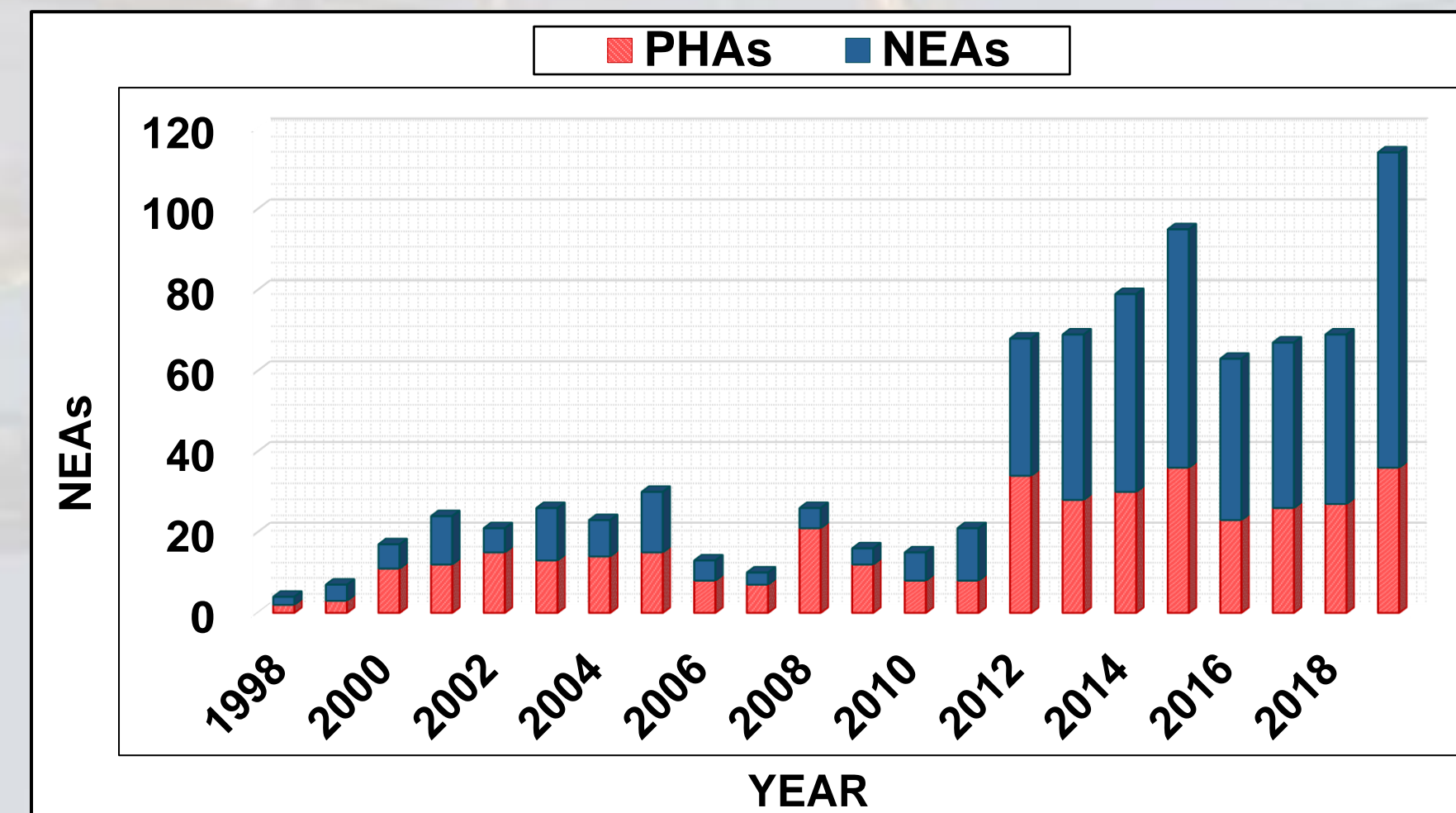


Fig. 1: Detection history of Near-Earth asteroid (NEA) at Arecibo.

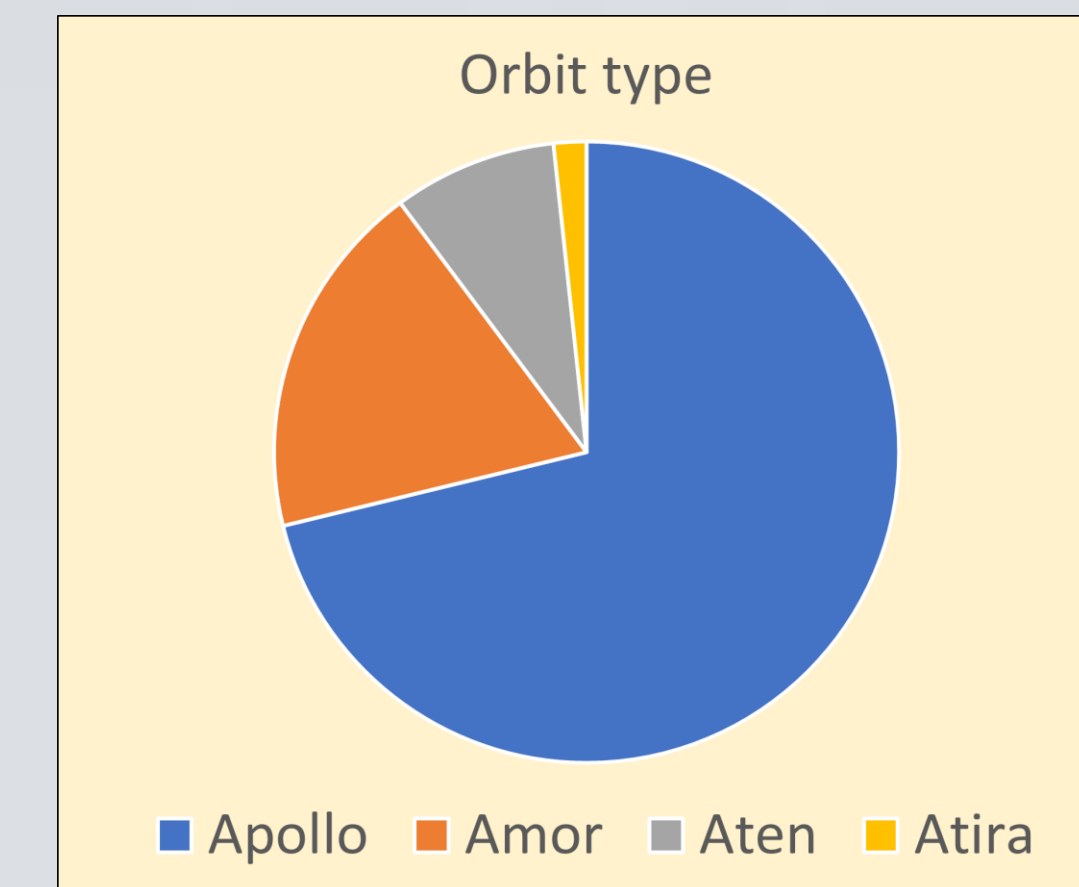


Fig. 2: Orbit type of binary and triple NEAs observed at the Arecibo Observatory.

Table 1: Population of binary/triple NEAs observed at the Arecibo Observatory.

Total AO	58
Binary/Triple	54
Total AO Binary	54
Total AO Triple	4
Total Equal mass	4
PHA	42

Radar observations, physical and dynamical characterization

The binary asteroid (285263)1998 QE2 is one of the largest PHAs known, measuring 3.2km with a 800m satellite, with the last known closest approach to Earth of 0.039 au (~15 lunar distances) on May 31st, 2013. During the 2013 approach, high-resolution radar data was collected at the Arecibo Observatory and Goldstone helping with physical and dynamical characterization of the system.. Fig. 3 shows the Doppler only and Fig.4 the delay-Doppler image of the system.

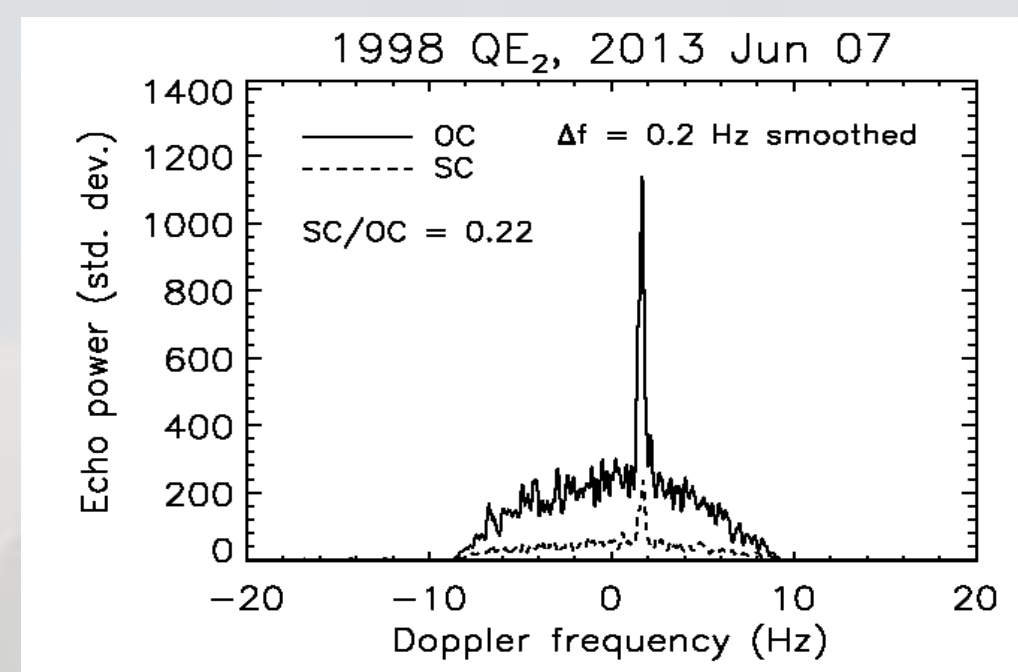


Fig. 3: Echo power spectrum obtained at the Arecibo Observatory on June 8th, 2013.



Fig. 4: Delay-Doppler radar image obtained at the Arecibo Observatory on June 9th, 2013.

Complete 3D shape modelling constitutes the highest-level product that radar data can provide and can be used to obtain the gravitational potential of the object [1]. Figure 5 show the shape model for the primary component of 1998 QE2, while Figure 6 shows an approximate shape for the satellite slightly ellipsoidal.

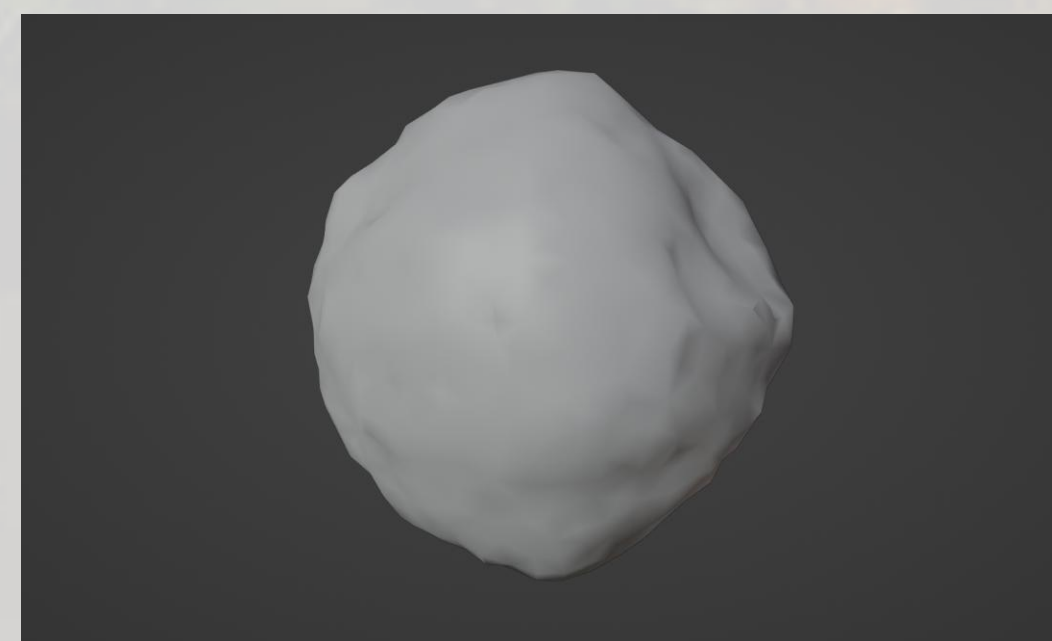


Fig. 5: 3D shape model of primary component of 1998 QE2.

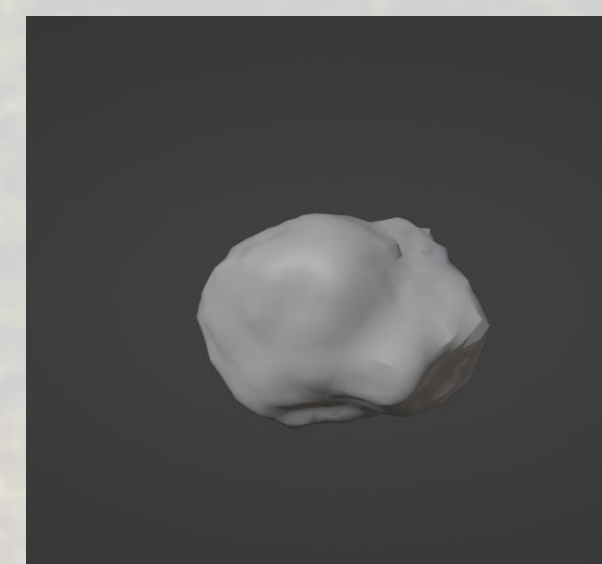


Fig. 6: 3D shape model secondary component of 1998 QE2.

Orbital properties of 1998 QE2

Table 2 shows information and the heliocentric orbital properties of 1998 QE2 system, while Table 3 shows the orbital elements for the secondary component of the system.

Table 2: Properties and information of the 1998 QE2 system

Number	285263
Provisional Designation	1998 QE2
Type	Amor, NEO, PHA
Absolute Magnitude (H)	17.2
Rotation period	4.749 h
Eccentricity	0.5716
Semi-major axis	2.4238 au
Inclination	12.859 °
Discovery Date	Aug/19/1998
Discovery By	LINEAR

Table 3: Orbital elements for the secondary component of 1998 QE2.

Semi-major axis	6.302730 km
Orbital period	1.32265035 d (31.7436084 hrs)
Longitude of ascending node	208.58°
Inclination	55.11°
Arg pericenter	13.307924°
Time of pericenter	2456449.568048 JD

The gravitational environment of 1998 QE2

The Potential Series Expansion Method (PSEM) was used to obtain the gravitational potential of the asteroid. the asteroid's shape is represented by a polyhedral model where each tetrahedron's gravitational potential is then calculated individually, allowing for a series expansion that captures the asteroid's complex shape summing the gravitational contributions from all tetrahedral elements, we approximate the total gravitational potential of the asteroid (Fig. 7) [2].

we obtained the zero-velocity surfaces and identified the equilibrium points, along with their eigenvalues. We then analysed the stability of these points and present the projection of the zero-velocity surface onto the xy-plane in Figure 8. The equilibrium points around asteroid 1998 QE2 exhibit an asymmetrical distribution and similar potential values, indicating non-uniform gravitational influences.

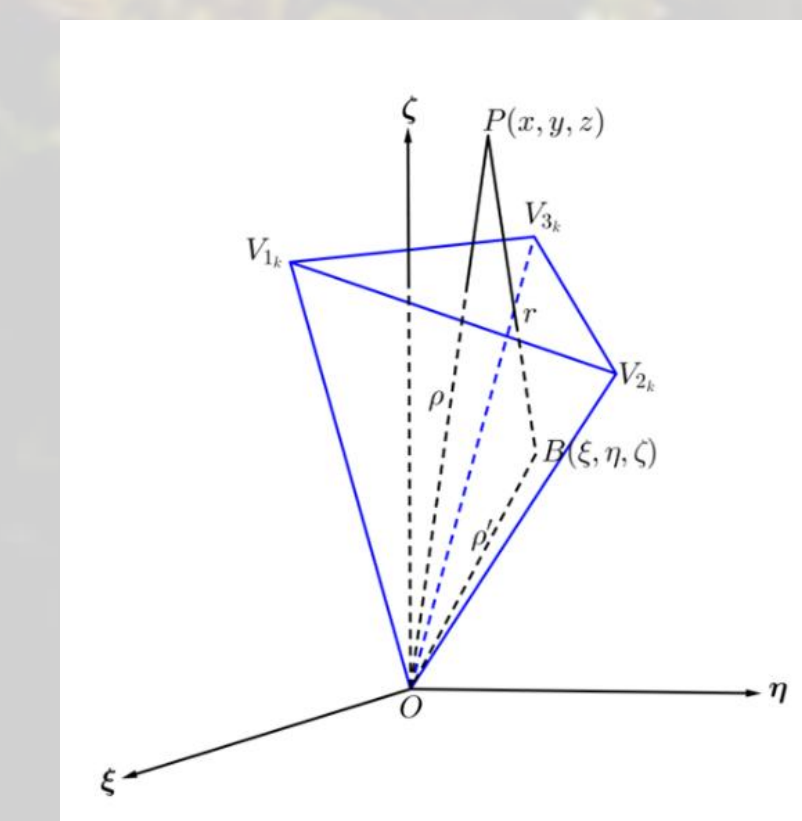


Fig. 7: Tetrahedron QkQ_k, with vertices V1kV1_k, V2kV2_k, V3kV3_k, and OO.

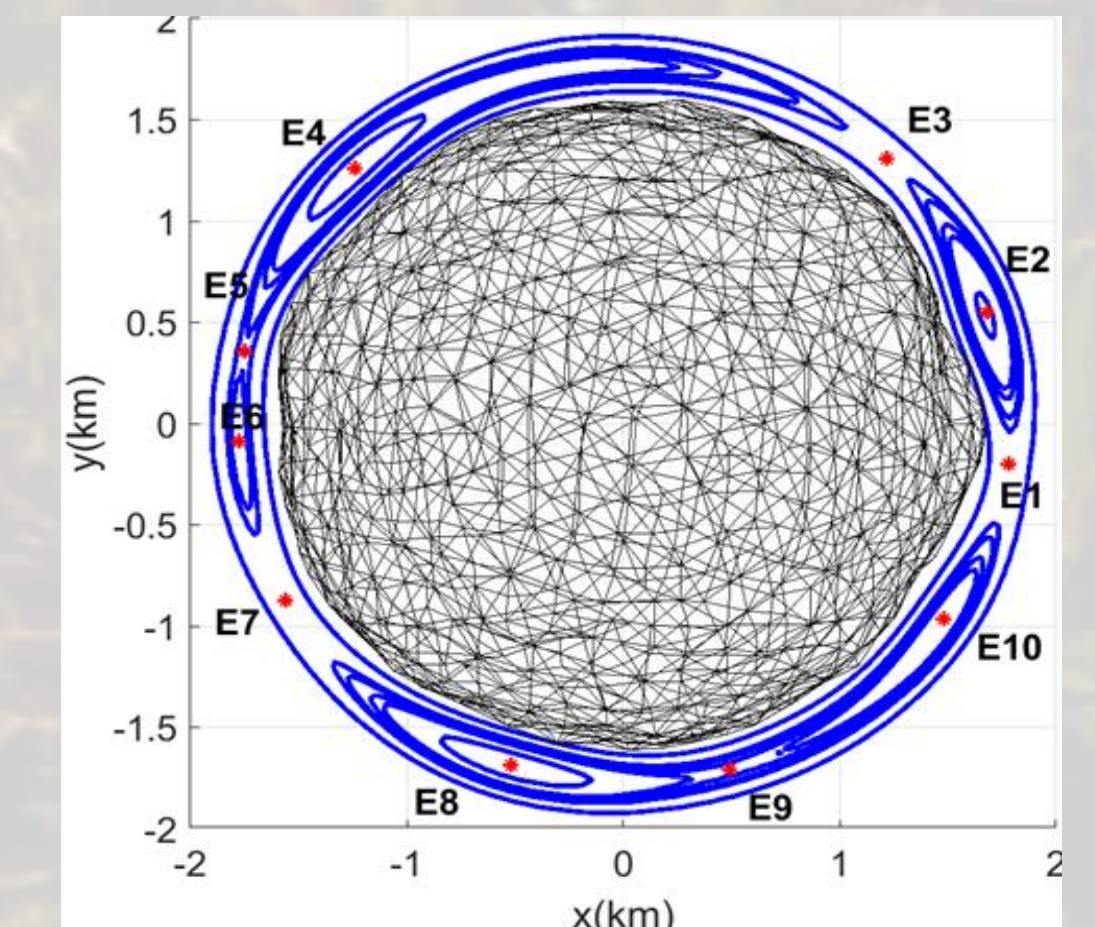


Fig. 8: Zero-velocity curves and equilibrium points.

[1] McGlasson, R.A., et al., 2022. Radar and Lightcurve Observations and a Physical Model of Potentially Hazardous Asteroid 1981 Midas. *The Planetary Science Journal*, 3(2), p.35. Observations and a Physical Model of Potentially Hazardous Asteroid 1981 Midas. *The Planetary Science Journal*, 3(2), p.35.

[2] Mota, M.L., Aljbaae, S., Prado, A.F.B.A.: The potential series expansion method: application to the asteroid (87) Sylvia. *European Physical Journal Special Topics* 232(18-19), 2961–2966 (2023).

