

Is the Dark Comet 1998 KY₂₆ the Spacecraft Phobos 1?

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ABSTRACT

Since the discovery of new kinds of celestial bodies known as *dark comets*, scientists have speculated about their ontology. A curious hybrid of comet and asteroid, these objects show significant non-gravitational accelerations (NGAs) yet exhibit absolutely no signs of cometary outgassing in the form of a coma or tail. The planned rendezvous of the Hayabusa2 spacecraft with 1998 KY₂₆ in July 2031 elevates the question of this so-called dark comet's nature beyond a purely research exercise, as the true nature of the object may have practical implications for the scientific return of the mission. This study examines the hypothesis that 1998 KY₂₆ may be of technogenic origin, in fact a relic of a historical Russian mission to Mars, the Phobos 1 probe, which suffered a failure 2 months after the launch in July 1988, due to upload of a faulty command. We find that two propulsive ΔV s combined at 1.9 km s^{-1} , the first just after loss of mission and the second in May 1996, allow the orbits and phases of the two bodies to align, with an arbitrarily low *Mahalanobis distance* using the covariance of the dark comet in 6D phase space. There is also evidence that 1.9 km s^{-1} was within the performance envelope of Phobos 1, which had a powerful nitric acid and amine-based autonomous thruster for Mars Orbital Insertion (MOI).

1. INTRODUCTION

Ever since D. Z. Seligman et al. (2023) identified the existence of celestial bodies with orbits perturbed by significant non-gravitational accelerations (NGAs) - (A_1 , A_2 , A_3), radial, transverse and perpendicular to the orbital plane respectively (B. G. Marsden et al. 1973), yet exhibiting no signs of outgassing; the existence and nature of these objects have been the subject of hot debate. Several further such objects were quickly discovered and presented in D. Z. Seligman et al. (2024) which helpfully delineated them into two distinct populations, the *Outer Population* (those with Jupiter Family Comet (JFC) orbits, and the *Inner Population* (with lower semi-major axes and eccentricities).

So what IS the source of these anomalous NGAs? In an attempt to narrow the limits on dust ejection, the Japanese Aerospace Exploration Agency (JAXA) will be conducting an analysis into one dark comet, 1998 KY₂₆ by sending their *Hayabusa2* spacecraft to rendezvous (M. Hirabayashi et al. 2021) with it in 2031. The instrumentation should hopefully be able to detect low levels of dust particle generation possibly sufficient to ascertain whether the rocket effect can indeed be the cause of the non-gravitational acceleration, but more importantly we will finally know what the object actually looks like.

Dark comet 1998 KY₂₆ has been studied extensively in the scientific literature (S. J. Ostro et al. 1999; T. Santana-Ros et al. 2025a; B. T. Bolin et al. 2025; J. Beniyama et al. 2025; S. Ostro et al. 1998; P. Pravec & L. Sarounova 1998; D. Tholen 2003; M. Hicks et al. 1998; D. Farnocchia et al. 2025). In summary, it is a small ($\sim 11 \text{ m}$), extremely rapidly rotating (rotation period $\sim 5.3 \text{ min}$) object with an unusually high albedo (~ 0.52).

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Ongoing investigations and previous research by authors of this paper (e.g. [A. Loeb & R. Cloete \(2025\)](#)), suggest that dark comets could actually be derelict spacecraft missions, and the NGAs could be the result of solar radiation pressure.

The report herein addresses the possible nature of 1998 KY₂₆ and proposes a technogenic (man-made) origin for this object, specifically the Russian Phobos 1 failed mission to Mars, launched 07/07/1988 ([Astronautix.com 2026](#)). For a description and history of these probes, the most massive interplanetary spacecraft ever launched, go to [R. Sagdeev & A. Zakharov \(1990\)](#).

2. SUPPORTING EVIDENCE

A comprehensive computation of all interplanetary missions since the start of the space age was conducted by repeatedly executing Optimum Interplanetary Trajectory Software - OITS ([A. Hibberd 2017](#); [A. Hibberd 2022](#); [A. Hibberd et al. 2021](#)) - with different mission-specific input parameters. Developed by Adam Hibberd, OITS has been exploited for research into missions to interstellar objects, but also to celestial bodies belonging to our own Solar System ([A. M. Hein et al. 2019, 2022](#); [A. Hibberd et al. 2020](#); [A. Hibberd & A. M. Hein 2021](#); [A. Hibberd 2023a,b](#)). Thus an accurate determination of the trajectory profile for each historical mission could be established. The trajectory of 1998 KY₂₆ could then be compared in various ways with each of these missions in turn to establish any similarities.

2.1. Comparison of Orbital Elements

The osculating orbital elements of 1998 KY₂₆ as of 01/01/2001 are shown in Table 1 - refer to row 8.

Observe that the perihelion, $q = 0.984$ au is close to Earth's orbit and the aphelion $Q = 1.482$ au, is around the orbit of Mars. Furthermore the orbital plane is close to the ecliptic with an inclination of 1.48° , slightly less than that of the orbit of Mars ($\sim 1.9^\circ$). This has similarities to a trajectory a mission planner might design to reach Mars, thus clearly it would be most pertinent to compare its orbit with previous Mars missions.

Since there are 5 orbital parameters needed to specify an orbit's shape, size and orientation, we must find a way of comparing one orbit with another in order to determine the 'net orbital difference'.

To this end, we adopt the so-called non-singular orbital parameters defined as follows:

$$e1 = a, \quad e2 = e \cos(\Omega + \omega), \quad e3 = e \cos(\Omega + \omega), \quad e4 = e \sin(\Omega + \omega), \quad e5 = \sin\left(\frac{i}{2}\right) \cos(\Omega), \quad e6 = \sin\left(\frac{i}{2}\right) \sin(\Omega) \quad (1)$$

where the usual symbols are employed for the Keplerian orbital parameters. Thus for each comparison between 1998 KY₂₆ and a mission, the net orbital difference can be taken as the norm (or 'root sum square') of the difference in the 6 non-singular components, $e1, e2, e3, e4, e5, e6$.

Figure 1 represents the results of this analysis.

We find the smallest discrepancy to be the Russian Mars mission 'Phobos 2', with the 'Phobos 1' mission following on close behind. Since Phobos 2 made it successfully to a Mars rendezvous, that would rule out this probe, whereas Phobos 1 was lost on an interplanetary trajectory after a faulty command was uploaded to it on 02/09/1988.

Note that in order to properly ascertain the orbit of Phobos 1 (launched 07/07/1988), we need a reasonable notion of its planned arrival date, and there is some uncertainty over this. An arrival date of 24/01/1989 is adopted here, a few days before its twin and immediate successor Phobos 2 is known to have reached Mars. Refer Figure 2 which goes into further analysis of this.

Number	Designation	Discovery	H (mag)	a (au)	q (au)	e	i (deg)	Ω (deg)	ω (deg)
1	2001 ME₁	25/05/2001	16.53	2.648	0.353	0.867	5.811	86.212	300.523
2	2005 UY₆	29/10/2005	18.14	2.257	0.294	0.870	12.153	343.600	180.776
3	1998 FR₁₁	24/03/1998	16.42	2.812	0.827	0.706	6.660	129.909	158.522
4	2012 UR₁₅₈	22/10/2012	20.7	2.239	0.324	0.855	3.220	287.738	238.091
5	2003 RM	02/09/2003	19.8	2.921	1.165	0.601	10.854	336.702	324.518
6	2005 VL ₁	04/11/2005	26.45	0.892	0.691	0.225	0.247	39.812	226.461
7	2010 RF ₁₂	01/09/2010	28.42	1.061	0.861	0.188	0.883	163.838	267.583
8	1998 KY ₂₆	28/05/1998	25.6	1.233	0.984	0.202	1.481	84.365	209.372
9	2016 NJ ₃₃	28/05/2016	25.49	1.312	1.038	0.208	6.640	279.682	24.070
10	2010 VL ₆₅	04/11/2010	29.22	1.069	0.915	0.144	4.713	223.635	252.126
11	2013 BA ₇₄	31/01/2013	25.4	1.759	0.976	0.445	5.302	310.753	202.871
12	2006 RH ₁₂₀	14/09/2006	29.5	0.996	0.960	0.036	0.283	49.644	121.622
13	2016 GW ₂₂₁	14/04/2016	24.76	0.827	0.605	0.268	3.652	33.877	8.224
14	2013 XY ₂₀	26/11/2013	25.65	1.131	1.010	0.106	2.863	78.634	18.187

Table 1. The dark comets as listed in [D. Z. Seligman et al. \(2024\)](#), with magnitudes (extracted from therein) and osculating orbital elements as of 01/01/2001 taken from NASA JPL Horizons. The dark comets above the double horizontal bar and in bold are outer population and below are inner population

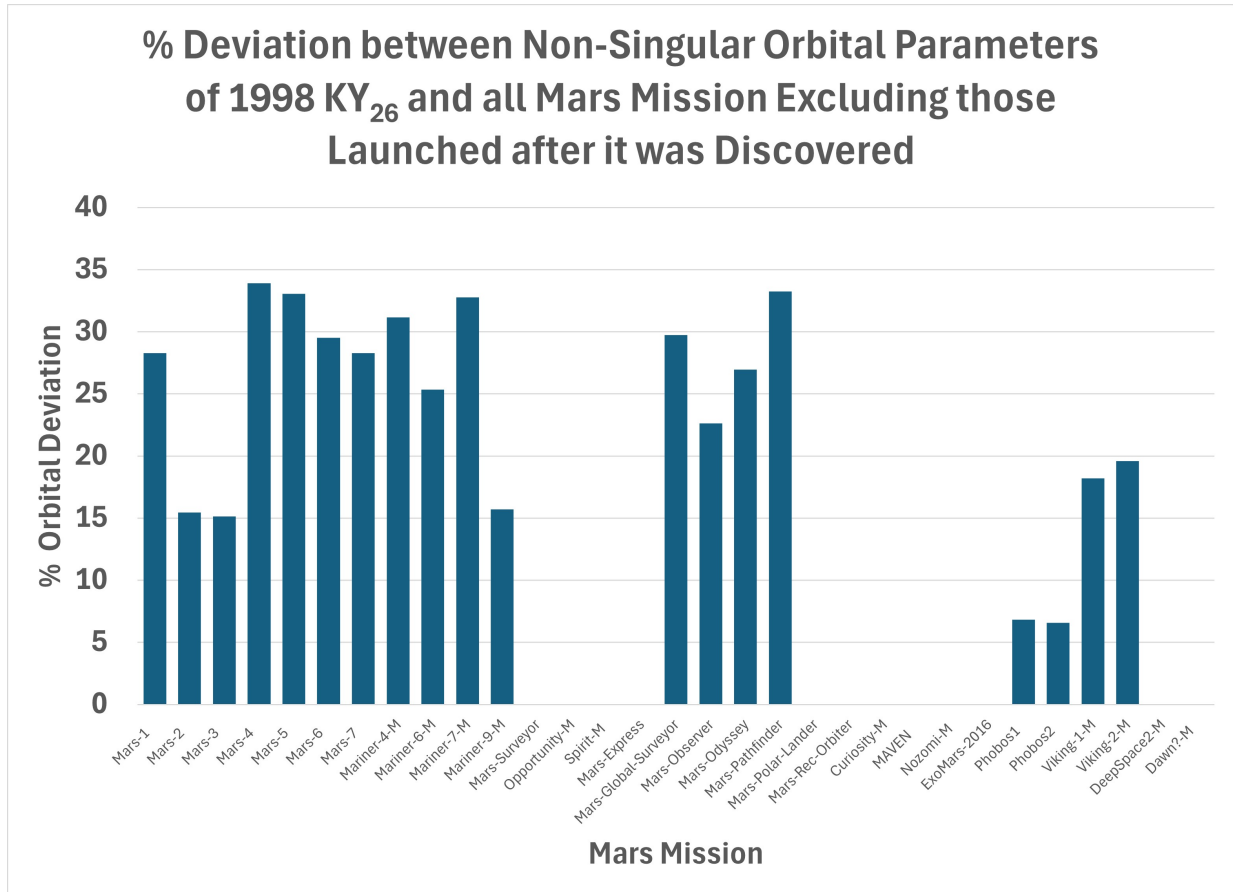


Figure 1. Magnitude vector difference in non-singular orbital parameters between 1998 KY₂₆ and 31 historical Mars missions.

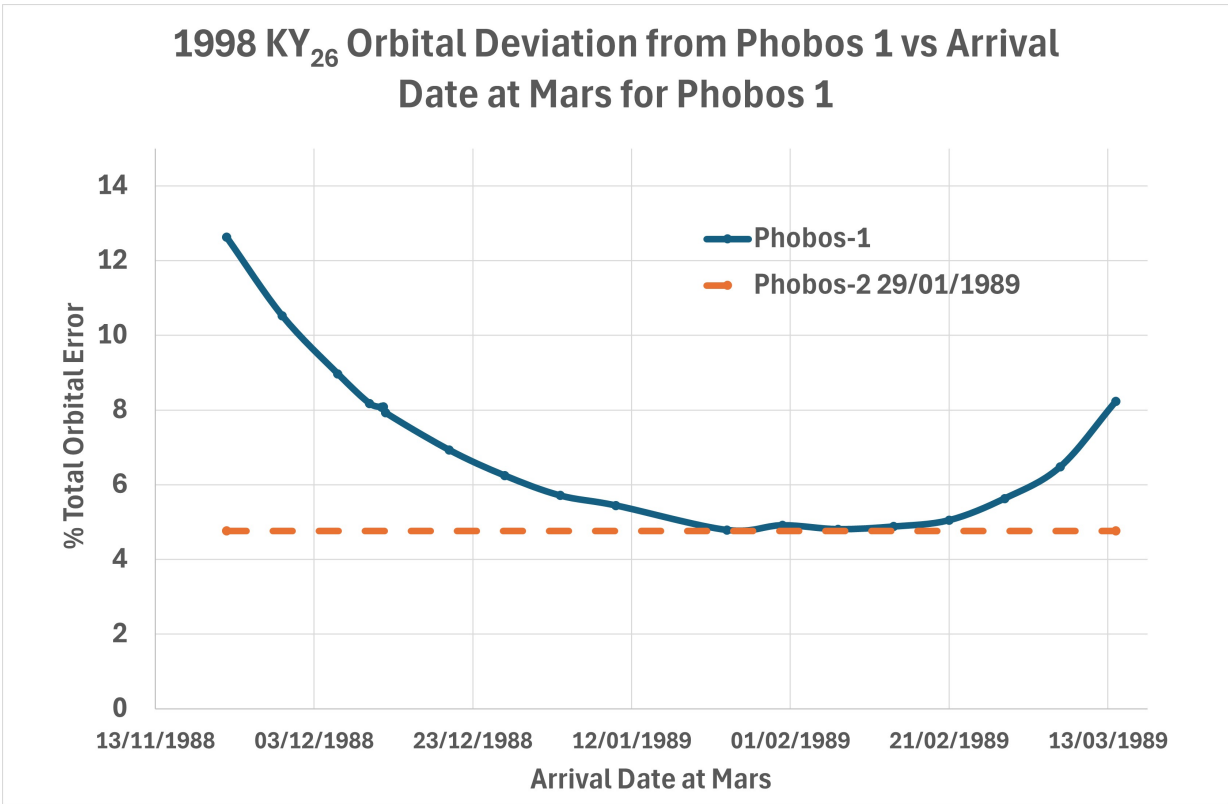


Figure 2. Comparison of the orbital discrepancy between 1998 KY₂₆ and Phobos 1 as a dependency on possible arrival date at Mars, showing a minimum over a long period of arrival dates with the date adopted here 24/01/1988 a plausible assumption.

Planet	Date	Arrival Velocity km s ⁻¹	Departure Velocity km s ⁻¹	ΔV at Encounter km s ⁻¹	Cumulative ΔV km s ⁻¹
Earth	1988 JUL 07	0.0000	3.4107	3.4107	3.4107
Mars	1989 JAN 24	2.6349	0.0000	0.9881	4.3987

Table 2. Table of Velocities as Calculated by OITS for the 'Nominal' Phobos 1 Mission

Orbital Parameter	Units	Phobos 1	1998 KY ₂₆
Semi-major Axis, <i>a</i>	au	1.302	1.233
Eccentricity, <i>e</i>		0.219	0.202
Perihelion, <i>q</i>	au	1.0166	0.984
Inclination, <i>i</i>	°	1.36	1.481
LOAN, Ω	°	-74.68	84.365
AOP, ω	°	368.31	209.372

Table 3. Orbital elements of Phobos 1 in Comparison to 1998 KY₂₆

2.2. Visual Comparison of Orbits

The orbits of Phobos 1 and 1998 KY₂₆ as of the launch of the mission are depicted in Figure 3. Observe there is an obvious similarity between these two orbits, albeit the locations of the two objects are separated by a significant difference in ecliptic longitude, and there is a noticeable discrepancy in semi-major axis, *a*.

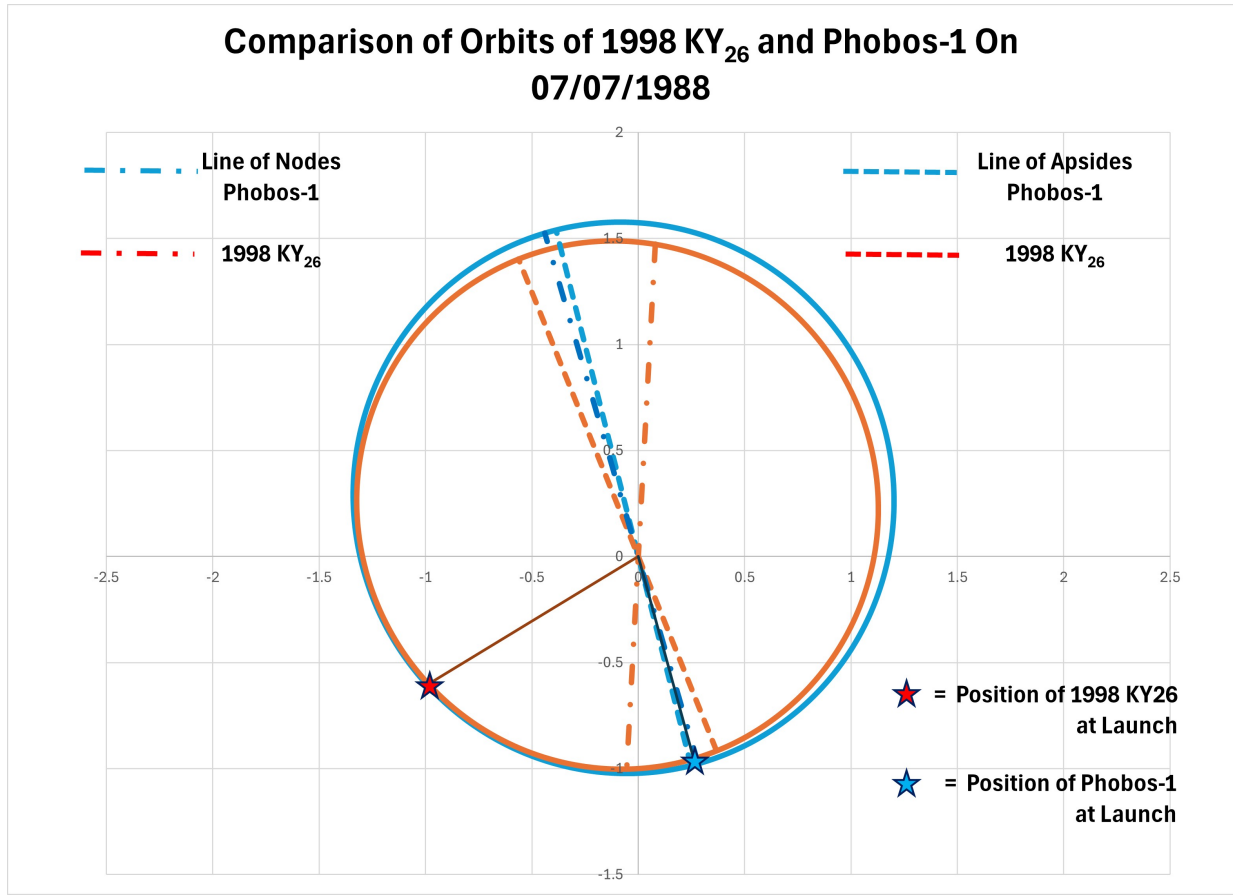


Figure 3. 2D view of the orbits of 1998 KY₂₆ and the Phobos 1 probe at the time of launch, showing a striking similarity between the two orbits.

2.3. Comparison of Diameter

Assuming a span for each solar panel of ~ 5 m, that would give the overall diameter of ~ 10 m. From [T. Santana-Ros et al. \(2025a\)](#), 1998 KY₂₆ has a diameter of 11 ± 2 m.

2.4. Comparison of Brightness

The absolute magnitude of 1998 KY₂₆ from [Table 1](#) is 25.6 and taken from [D. Z. Seligman et al. \(2024\)](#). Assuming a highly reflective albedo for the Phobos probes of 1, with the diameter adopted in [Section 2.3](#), we get a calculated absolute magnitude of 25.5, which is in close agreement.

2.5. Light Curve

The light curve for the short period after discovery in 1998, is given in [Figure 4](#). Observe there are fluctuations in apparent magnitude of ~ 2.0 . This is a huge amplitude and very suggestive of a rapidly spinning elongated object.

For a projected aspect ratio a/b , this is related to fluctuations in apparent magnitude, ΔM , by:

$$\Delta M = 2.5 \log_{10} \left(\frac{a}{b} \right) \quad (2)$$

This can be rearranged as follows:

$$\left(\frac{a}{b} \right) = 10^{\frac{\Delta M}{2.5}} \quad (3)$$

This leads to an aspect ratio of approximately 6.3:1, representing a very elongated object such as possibly the Phobos 1 probe (which had extended solar panels).

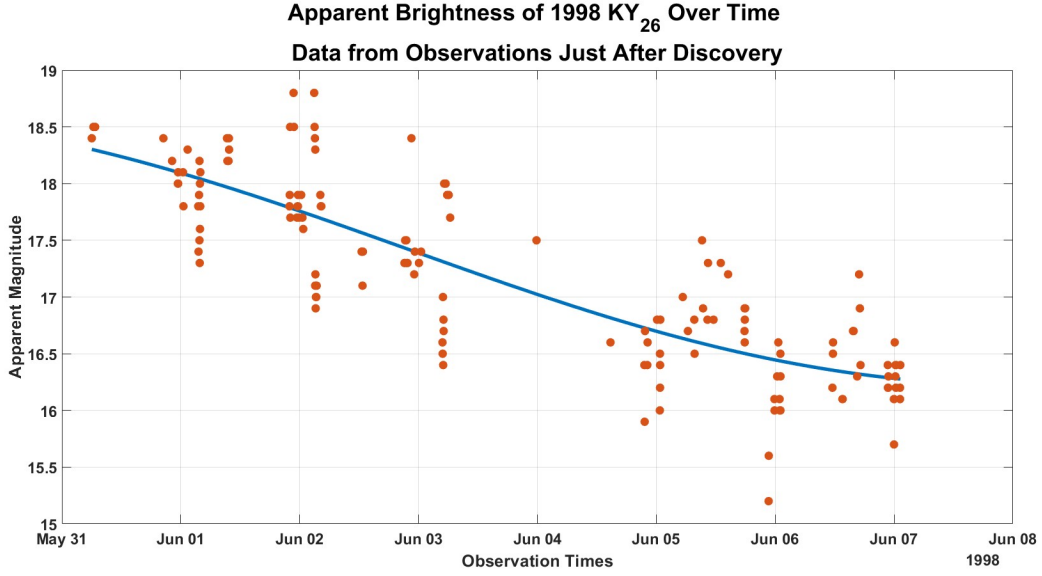


Figure 4. Light Curve of 1998 KY₂₆ just after discovery.

2.6. Implications

The combination of high albedo from [T. Santana-Ros et al. \(2025a\)](#) of 0.52 ± 0.08 , the diameter of 11 ± 2 m, and low spin period of 5.3516 ± 0.0001 mins, all suggest a small, tough, monolithic object, such as the Phobos 1 probe.

3. POSSIBLE SCENARIO

The details of the Phobos 1 mission, as generated by OITS are provided in [Table 2](#), and a comparison of the orbital parameters between Phobos 1 and 1998 KY₂₆, is given in [Table 3](#).

As a historical perspective, following a request from the Moscow 'Space Research Centre', the 'European Southern Observatory' (ESO) attempted to observe the Phobos 1 probe 20 days after mission failure ([ESO 1988](#)). The result was negative in that the probe was not visible at the predicted coordinates, however referring to the article, they suggest this was due to 'a faulty rocket fire after contact was lost?'.

Let us pursue this hypothesis and model the suspected thrust as an impulsive change in velocity (ΔV) some time between loss of mission and the non-observation of the probe by ESO on 22/09/1988, a period encompassing 20 days. This impulsive ΔV would be insufficient to align the orbits of the two bodies since, as is apparent from [Figure 3](#), there was a large discrepancy in heliocentric longitude (or alternatively mean anomaly) between the two objects at launch, and therefore at the time of mission loss. Consequently the next simplest scenario can be applied with the assumption that there is a further, second ΔV , some time before 1998 KY₂₆ was discovered.

To this end some REBOUND ([H. Rein & S. F. Liu 2012](#)) N-body integration software was developed. First, the state vector of the probe while it was en route to Mars (specifically on 02/09/1988, the day of loss of mission), was supplied by examination of OITS trajectory results. The REBOUND simulation was initialized at this point. The state vectors of the Sun, the Moon and all the planets were then extracted at this time by executing the NASA SPICE ([C. H. Acton 1996](#); [C. Acton et al. 2018](#)) command `spkezr_c` with the binary SPICE kernel file `de430.bsp` providing the necessary data. The command line argument to this software included the path of a file containing 8 numbers, as follows:

1. The first ΔV component x in 'ECLIPJ2000', $\Delta V1_x$
2. The first ΔV component y in 'ECLIPJ2000', $\Delta V1_y$
3. The first ΔV component z in 'ECLIPJ2000', $\Delta V1_z$

4. The time in days to first ΔV
5. The second ΔV component x in 'ECLIPJ2000', ΔV_{2_x}
6. The second ΔV component y in 'ECLIPJ2000', ΔV_{2_y}
7. The second ΔV component z in 'ECLIPJ2000', ΔV_{2_z}
8. The time in days between first and second ΔV

There were two outputs of this software - first the mean square *Mahalanobis Distance* (P. C. Mahalanobis 1936) between the spacecraft and 1998 KY₂₆ as of the epoch 07/04/2000 08:13:52. The reference state vector and covariance matrix (used to derive the Mahalanobis distance) were taken from *find_orb* (B. Gray 2025) at this epoch time. The second output was the sum of the magnitudes of the two ΔV s with 1.9 km s⁻¹ subtracted. This was to impose a constraint on the total magnitude of ΔV , to align it with a reasonable level expected from the probe.

Two optimization paradigms were utilized, first Global Non-Linear Programming (NLP) software in the form of NOMAD (S. Le Digabel 2011), followed then by Covariance Matrix Adaptation Evolutionary Strategy (CMA-ES) (N. Hansen & A. Ostermeier 2001) as implemented by N. Hansen et al. (2025). For an attempt to explain the logic behind CMA-ES intuitively, go to N. Hansen (2023).

The workflow adopted was to first try and hone the independent variables listed above to around a global minimum (NOMAD), following this up by a more structured evolutionary strategy to find the precise minimum using CMA-ES. This combined effort proved very fruitful.

In the early stages of this workflow, a scaled displacement in 6D phase space was calculated by the software, and output to the optimizers as an objective to minimize, like so:

$$D = \sqrt{\left(\frac{DX}{AU}\right)^2 + \left(\frac{DV}{AU/day/0.017}\right)^2} \quad (4)$$

where in the above, DX and DV are respectively the distance and velocity difference between the probe and 1998 KY₂₆, with the 0.017 figure as a convenient scaling factor. This produced good convergence with a combination of NOMAD followed by CMA-ES.

However, with the Mahalanobis distance, $MD2$, as the objective, this only reduced to an acceptable level when a 9th optimizable parameter, ΔT , was added to the 8 enumerated above. The optimal magnitude of this ΔT was minimal at only ~ 2 hours, and might be attributed to a slight error in phase between the two objects, possibly originating from an error in the time-stamp generated by OITS, or other unknown causes.

The final solution is provided in Table 4. It is interesting to note that, as already indicated, the total ΔV was constrained to 1.9 km s⁻¹, and furthermore no additional optimal solutions with tighter ΔV constraints were forthcoming. It should also be affirmed that, by the nature of global optimization, this is NOT a non-existence proof.

It is now necessary to compare this level of ΔV with the total available to the Phobos 1 probe, since the mission was lost very early on, and nearly all allocated propellant would have been present. From [Astronautix.com \(2026\)](#), the propulsion system exploited for Mars Orbital Insertion (MOI) was a combination of nitric acid and an amine-based propellant. Such a propulsion system has huge momentum change capability. Let us adopt a specific impulse of $I_{sp} \sim 315$ secs, and exploit the famous Tsiolkovsky rocket equation:

$$\frac{M_f}{M_0} = \exp\left(-\frac{\Delta V}{gI_{sp}}\right) \quad (5)$$

This leads to a propellant mass fraction of $1-M_f/M_0 \sim 46\%$.

Parameter	Optimized Parameter	Units	Notes:
ΔV_{1x}	-0.579	km s^{-1}	mag: 0.612096 km/s
ΔV_{1y}	-0.049	km s^{-1}	
ΔV_{1z}	0.191	km s^{-1}	
Time $\Delta V1$	0.826	days	Date: 1988 SEP 02 19:49:43
ΔV_{2x}	0.010	km s^{-1}	mag: 1.279599 km/s
ΔV_{2y}	0.835	km s^{-1}	
ΔV_{2z}	0.970	km s^{-1}	
Time $\Delta V2$	2815.628	days	Date: 1996 MAY 19 10:54:16
ΔT	2.010	hours	

Table 4. Optimal Solution found by NOMAD and then CMA-ES, ultimately attaining an insignificantly small square Mahalanobis distance

From R. Sagdeev & A. Zakharov (1990), the autonomous thruster for MOI was 3600 kg compared to the overall mass of the probe of 6200 kg. This represents a mass fraction of at most $\sim 58\%$, disregarding the structural mass of the autonomous thruster. In conclusion, $\Delta V = 1.9 \text{ km s}^{-1}$ would seem to be within the propulsion envelope of the Phobos 1 probe, adding plausibility to the association with 1998 KY₂₆.

Attention is now drawn to the orbital path followed by the Phobos 1 probe according to the solution summarised in Table 4 - refer Figure 5 for the 3D perspective and the plan view is provided in Figure 6. The displacement between the positions of the two bodies is shown in Figure 7.

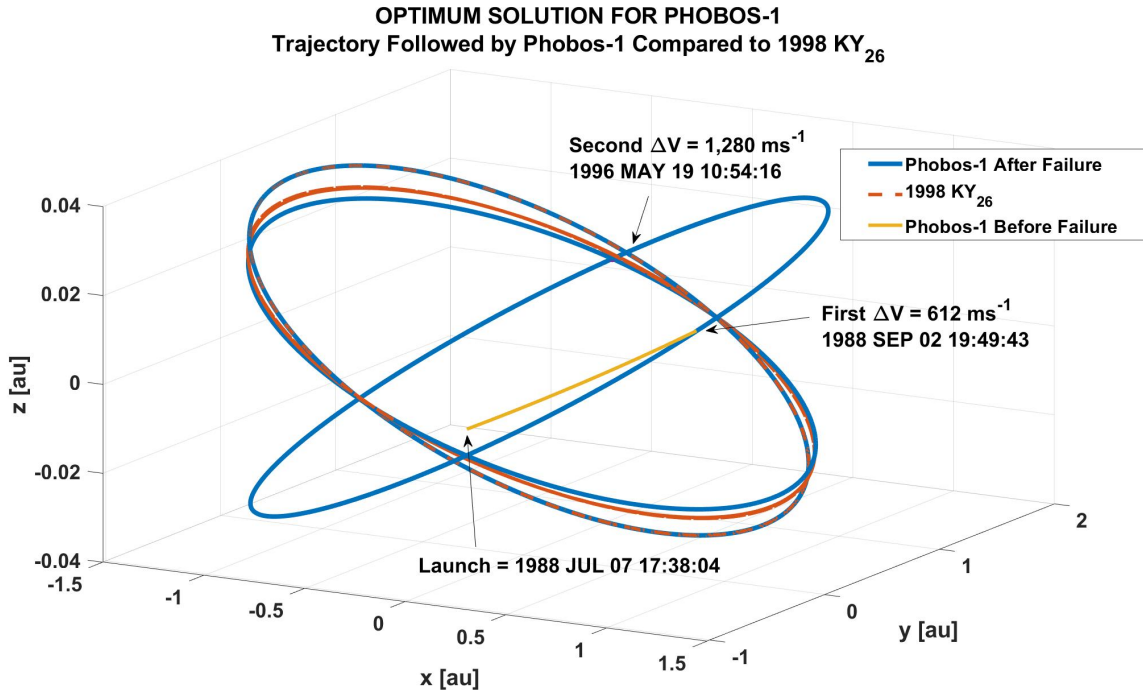


Figure 5. Solution trajectory followed by the Phobos 1 probe (blue line) compared to that of 1998 KY₂₆ retrodicted by NASA Horizons, SPICE (red dashed line)

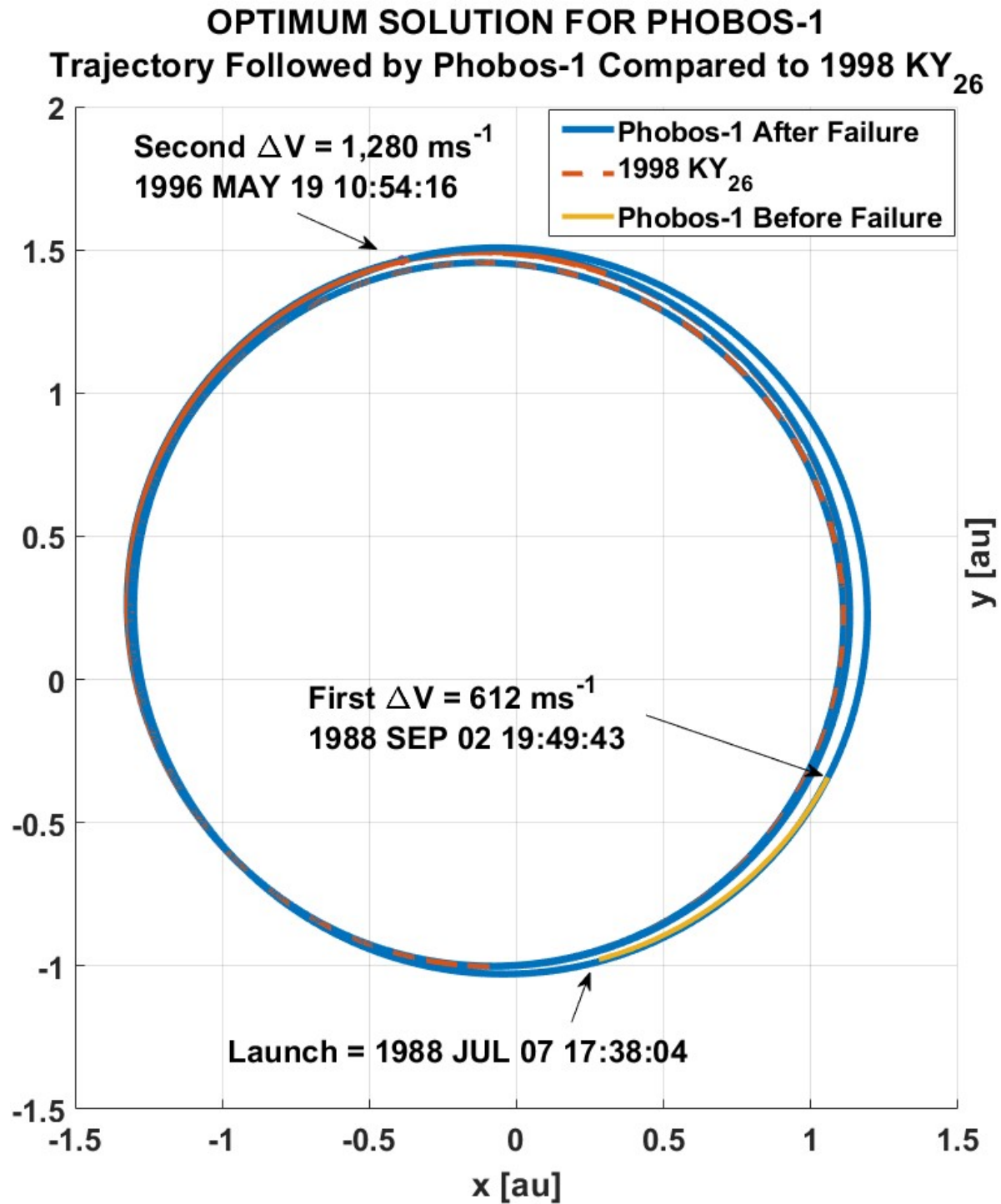


Figure 6. Solution trajectory (plan view) followed by the Phobos 1 probe (blue line) compared to that of 1998 KY₂₆ retrodicted by NASA Horizons, SPICE (red dashed line)

4. DISCUSSION

To be clear, this research cannot unequivocally identify that 1998 KY₂₆ is really the Phobos 1 probe, it analyses the evidence in support of this conclusion, which is quite compelling. We have found:

1. The Phobos 1 and 1998 KY₂₆ orbits are visually similar

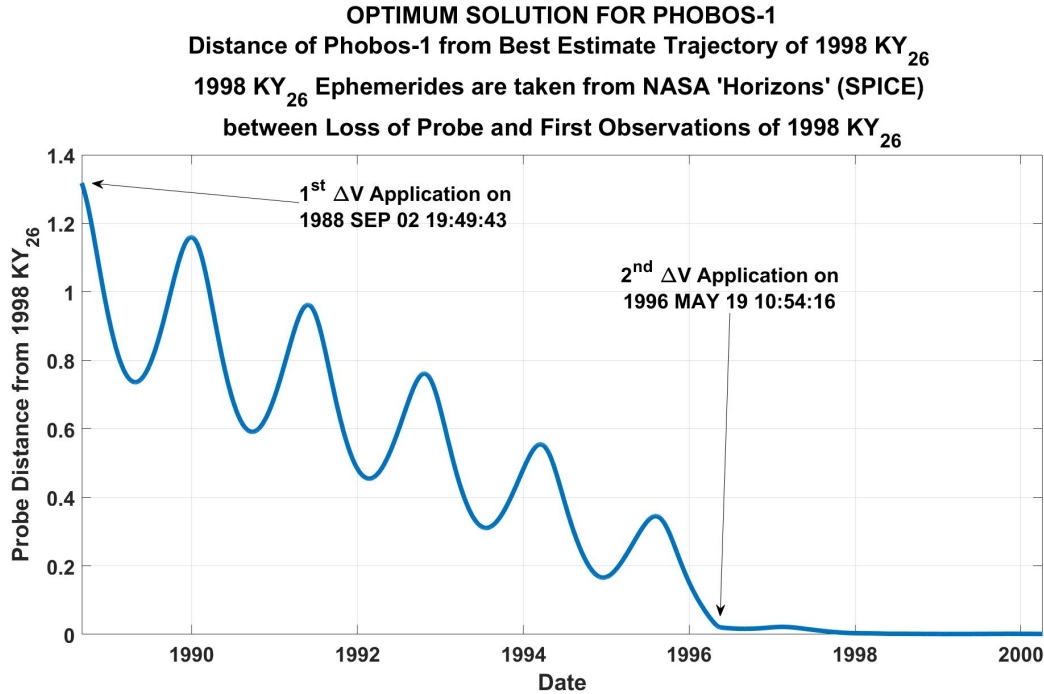


Figure 7. Displacement between the Phobos 1 probe and 1998 KY₂₆

2. The difference between these orbits is compatible energetically with the overall ΔV envelope available to Phobos 1
3. The 2 orbits converge and are statistically compatible, given the uncertainty in the orbit of 1998 KY₂₆, which is tightly constrained due to the existence of over 230 observations of this dark comet
4. There is a historical record in support of the hypothesis that a propulsive ΔV was delivered shortly after loss of mission
5. The Phobos 1 mission was lost early on in the probe's transit to Mars enabling a large ΔV capability
6. There is supportive observational data of the dark comet, i.e. size, albedo and spin
7. The object appears to be quite elongated from changes in its apparent magnitude

This can be compared to the evidence to the contrary:

1. it is generally assumed by the scientific community that this is a natural body
2. there are AI-assisted (SAGE) reconstructions of the object based on optical and RADAR data, which suggest it is an asteroid with a random asteroid-type shape, though with apparent 'concavities' (T. Santana-Ros et al. 2025b)

So to the question: 'is 1998 KY₂₆ the Phobos 1 probe?' there is plenty of supporting evidence, yet the JAXA Hayabusa2 mission to this object in 2031 will effectively 'put the cat amongst the pigeons'.

5. CONCLUSION

This paper identified several independent lines of evidence that motivate further consideration of the possibility that the dark comet 1998 KY₂₆ is in fact technogenic, specifically the Russian Phobos 1 probe to Mars. It suggests a particular historical path through which the trajectories of the probe and the dark comet could evolve to become effectively statistically indistinguishable. In anticipation of the Hayabusa2 observations in 2031, which will be decisive in resolving the origin of this object, we encourage further observational, dynamical, and theoretical studies aimed at more tightly constraining the nature and properties of 1998 KY₂₆.

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