

# Supplementary Information

Orbital mechanics and corpus linguistics rule out the Star of Bethlehem

Aaron M. Adair

Department of Physics, Massachusetts Institute of Technology

## S1 Orbital mechanics: detailed methods

### S1.1 Reference epoch and coordinate system

All calculations use the International Celestial Reference System (ICRS, J2000.0) as the inertial frame. The reference observation window is Julian Day 1 719 755.9 (TDB), corresponding to  $\approx 08:00$  local solar time at Bethlehem on a date in 5 BCE. The UT1–UTC offset appropriate for 5 BCE ( $\Delta T$ ) is 10,572 s, derived from the long-term IERS extrapolation of [1]. Observer location: Bethlehem, 31.70° N, 35.20° E, altitude 765 m.

### S1.2 East–North–Up rotation matrices

Transformation from ICRS to local horizontal (azimuth–altitude) coordinates was performed via pre-computed East–North–Up (ENU) rotation matrices. At each time step the matrix was constructed by converting AltAz basis vectors to ICRS using `astropy`’s `AltAz→SkyCoord.icrs` transformation, which accounts for Earth’s precession, nutation, and Greenwich Apparent Sidereal Time. The basis vectors were computed as follows:

- East: pointing toward ( $Az = 90^\circ$ ,  $Alt = 0.001^\circ$ )
- Zenith: pointing toward ( $Az = 0^\circ$ ,  $Alt = 90^\circ$ )
- North:  $\hat{N} = \hat{Z} \times \hat{E}$

This approach avoids the 25.7° systematic azimuth error that arises from applying J2000.0 hour-angle formulae directly to 5 BCE observations without precession correction. The matrices were validated by recovering the known azimuth of Matney’s proposed comet[2] (193.7°) to within 0.01° at the reference epoch.

### S1.3 Heliocentric orbit propagation

Positions of solar-orbiting bodies were computed from osculating orbital elements using the appropriate Kepler equation for each orbit type.

**Parabolic orbits** ( $e = 1$ ). Barker’s equation gives the true anomaly  $\nu$  directly:

$$D = \sqrt[3]{\frac{W}{2} + \sqrt{\frac{W^2}{4} + 1}} + \sqrt[3]{\frac{W}{2} - \sqrt{\frac{W^2}{4} + 1}}, \quad \nu = 2 \arctan D, \quad (1)$$

where  $W = 3\sqrt{\mu_\odot/2q^3} \Delta t$ ,  $\mu_\odot = k^2 = 2.959 \times 10^{-4} \text{ AU}^3 \text{ day}^{-2}$ , and  $k = 0.01720209895$  is the Gaussian gravitational constant.

**Elliptic orbits** ( $0 \leq e < 1$ ). Mean anomaly  $M = n(t - T)$  where  $n = \sqrt{\mu_\odot/a^3}$ . Eccentric anomaly  $E$  is solved from Kepler’s equation  $M = E - e \sin E$  by Newton–Raphson iteration to a tolerance of  $10^{-12}$  rad. True anomaly:

$$\nu = 2 \arctan \left( \sqrt{\frac{1+e}{1-e}} \tan \frac{E}{2} \right). \quad (2)$$

**Hyperbolic orbits** ( $e > 1$ ). The hyperbolic Kepler equation  $M = e \sinh H - H$  is solved for the hyperbolic anomaly  $H$  by Newton–Raphson. True anomaly:

$$\nu = 2 \arctan \left( \sqrt{\frac{e+1}{e-1}} \tanh \frac{H}{2} \right), \quad |\nu| < \arccos(-1/e). \quad (3)$$

Earth positions were drawn from the JPL DE430 ephemeris. For computational efficiency, heliocentric positions were vectorised over the longitude of ascending node  $\Omega$  and argument of perihelion  $\omega$  using pre-computed perifocal unit vectors  $\hat{P}(\Omega, \omega, i)$  and  $\hat{Q}(\Omega, \omega, i)$  with `NumPy einsum` operations, enabling evaluation of  $72 \times 72 = 5,184$  orientations per loop iteration at the  $5^\circ$  grid resolution used in the fine survey.

## S1.4 Geocentric orbit propagation

Geocentric configurations used the same Kepler equation solver with  $GM_\oplus = 3.986 \times 10^5 \text{ km}^3 \text{ s}^{-2}$ . The observer’s position in the Geocentric Celestial Reference System (GCRS) was computed at each time step from `EarthLocation.get_gcrs()` in `astropy`, accounting for Earth’s rotation. The direction from observer to satellite was converted to AltAz via the ENU rotation matrix. Configurations with satellite altitude below  $5^\circ$  at any guidance time step were excluded from the survey totals.

## S1.5 Guidance and stopping criteria

**Site coordinates.** Jerusalem Old City center:  $31^\circ 46' \text{ N}$ ,  $35^\circ 14' \text{ E}$ . Bethlehem (Church of the Nativity):  $31^\circ 42' \text{ N}$ ,  $35^\circ 12' \text{ E}$ . Straight-line bearing:  $203^\circ$ . The ridge road sweeps from  $\approx 190^\circ$  to  $\approx 210^\circ$  along the route.

**Angular-velocity threshold.** I adopt  $\omega_{\text{thresh}} = 2^\circ \text{ h}^{-1}$  for both criteria. Because the two rate quantities used in this paper are easily conflated, the frame must be stated first.

*Frame.* Matthew’s claim is that the Star stood *over a house*. That is a statement about the object’s bearing from a place on the ground, so the criterion is evaluated in the horizon (alt-azimuth) frame, in which the diurnal rotation of the Earth is present. This is the demanding frame: apparent rest in it requires the object’s parallactic motion to cancel the Earth’s spin. The *inertial* rate (motion against the background stars, to which the lunar figure of  $\approx 0.5^\circ \text{ h}^{-1}$  belongs) is a different quantity, and is used in §S11 only where it is explicitly named.

*Physical basis.* The threshold is anchored to the sky’s own motion. For the observer at Bethlehem, over the south-westerly part of the sky in which the guidance corridor lies and above the  $10^\circ$  altitude floor, a fixed star moves in the horizon frame at between  $11.6$  and  $15.0^\circ \text{ h}^{-1}$ , depending on declination. Every star the Magi could see was drifting at that rate. A stopping threshold is therefore a statement about what fraction of the ambient sidereal rate still counts as standing still:  $2^\circ \text{ h}^{-1}$  admits an object drifting at roughly one part in six to one in eight of the rate of the stars around it.

The lower bound is set by detectability rather than by the sky: naked-eye angular resolution is  $\approx 1'$ , so motion is detectable above  $\approx 0.03^\circ \text{ h}^{-1}$  over a thirty-minute window, and no threshold

below that could be observationally meaningful. The choice of  $2^\circ \text{ h}^{-1}$  is deliberately generous at the upper end; any stricter threshold only strengthens the conclusion.

**What would overturn the result.** Because a negative result of this kind can always be attacked by loosening the criterion that produced it, I state the falsification condition in advance and in physical units rather than leaving it to be negotiated.

The tightest value achieved by any orbit, across  $10^9$  samples and every parameter combination tested, is  $6.94^\circ \text{ h}^{-1}$  (§S5.7). That is between 46% and 60% of the local sidereal rate, depending on declination. Overturning the conclusion therefore requires adopting a stopping threshold above that figure, and the burden on any such threshold is to explain in what sense an object crossing the sky at half the speed of the stars beside it can be said to stand still over a particular house. Over the two hours of the journey described, such an object would traverse some  $14^\circ$ , about twenty-seven lunar diameters, or a hand’s breadth and a half at arm’s length.

The threshold is thus not a free parameter to be widened until a candidate appears. It is bounded below by naked-eye detectability and above by the motion of the sky itself, and the result reported here fails at every value between those bounds. The figure that would have to be conceded is  $6.94^\circ \text{ h}^{-1}$ ; the argument that it cannot be conceded is given above, and is offered for the reader to test rather than asserted.

### Guidance criterion (three components).

1. *Visibility*: object altitude  $> 5^\circ$  above the horizon throughout the guidance window (08:00–10:00 local time).
2. *Azimuth*: object azimuth remains within the road corridor  $[190^\circ, 210^\circ] \pm 5^\circ$  at all 9 steps (15-min spacing). Guidance score = maximum degrees outside  $[190^\circ, 210^\circ]$ ; passes if  $< 5^\circ$ .
3. *Motion (προάγω)*: minimum apparent angular velocity  $> \omega_{\text{thresh}} = 2^\circ \text{ h}^{-1}$  throughout the guidance window. A stationary object at the right azimuth does not “go before” travelers; this criterion excludes such configurations.

**Stopping criterion (ἵστημι).** Maximum apparent angular velocity  $< \omega_{\text{thresh}} = 2^\circ \text{ h}^{-1}$  during the stopping window (10:15–12:00, 8 steps). No altitude constraint is imposed: scholarly astronomical interpretations of “stood over” (ἐστάθη ἐπάνω) range from horizon to zenith.

**Sensitivity to threshold choice.** Table S1 shows survey results as  $\omega_{\text{thresh}}$  is varied over two orders of magnitude. Zero configurations satisfy all three criteria at every tested value.

The binding constraint is the azimuth criterion ( $N_{\text{az}} = 0$  at every threshold): no Keplerian orbit keeps the object within the road corridor throughout the 2-hour guidance window. The motion constraint further tightens the result at lower thresholds by excluding near-stationary objects that coincidentally lie near  $200^\circ$  azimuth.

## S1.6 Orbital parameter survey grids

### S1.7 Monte Carlo refinement sweeps

The  $5^\circ$  angular-grid spacing in the heliocentric survey leaves gaps of up to  $\sim 3.5^\circ$  between neighboring grid points. To verify that the null result is not an artefact of this resolution, two Monte Carlo sweeps in continuous parameter space were performed using the script `sob_mc_refined.py` (same Kepler solvers, ENU matrices, and evaluation criteria as `sob_proof_fine.py`).

Table S1: Sensitivity of the zero result to angular-velocity threshold  $\omega_{\text{thresh}}$  (heliocentric elliptic/parabolic survey, 5 BCE reference epoch).

| $\omega_{\text{thresh}}$ ( $^{\circ}/\text{h}$ ) | N_az | N_motion | N_stop | N_all |
|--------------------------------------------------|------|----------|--------|-------|
| 0.25                                             | 0    | 201      | 49,196 | 0     |
| 0.50                                             | 0    | 25       | 49,381 | 0     |
| 1.00                                             | 0    | 16       | 49,389 | 0     |
| 2.00                                             | 0    | 0        | 49,406 | 0     |
| 5.00                                             | 0    | 0        | 49,406 | 0     |
| 10.00                                            | 0    | 0        | 49,406 | 0     |

N\_az = configurations passing azimuth criterion;

N\_motion = configurations with guidance motion  $> \omega_{\text{thresh}}$ ;

N\_stop = configurations with stopping score  $< \omega_{\text{thresh}}$ ;

N\_all = configurations passing all three criteria simultaneously.

The upper end of the sweep ( $10^{\circ} \text{h}^{-1}$ ) exceeds any physically defensible stopping threshold. In the horizon frame in which the criterion is evaluated (§2.3), a fixed star over Bethlehem moves at  $11.6\text{--}15.0^{\circ} \text{h}^{-1}$  in the relevant part of the sky. A stopping criterion of  $10^{\circ} \text{h}^{-1}$  would therefore count an object as standing still while it drifted at roughly two-thirds to nine-tenths of the rate of every star around it, which is not a description any observer would give. The sweep accordingly covers every physically coherent criterion value at both ends: below by the limit of naked-eye detection, above by the ambient sidereal rate.

**Sweep 1: neighborhood of best-fit grid orbit.** The best azimuth score in the exhaustive grid survey ( $0.015^{\circ}$  inside the road corridor) belongs to the orbit with  $e = 1.1$ ,  $q = 0.03 \text{ AU}$ ,  $i = 10^{\circ}$ . Sweep 1 sampled 1,500,000 configurations drawn uniformly from

$$q \in [0.005, 0.15] \text{ AU}, \quad e \in [0.7, 2.5], \quad i \in [0^{\circ}, 40^{\circ}], \quad \Omega, \omega \in [0^{\circ}, 360^{\circ}], \quad \Delta T \in [-60, +60] \text{ days},$$

spanning a generous volume around the grid orbit. Of 601,150 visible configurations, zero satisfied all three criteria simultaneously. The orbit with the best azimuth score ( $0.167^{\circ}$  from corridor center) produced a guidance-phase angular velocity of only  $0.006^{\circ} \text{h}^{-1}$ , a factor of  $\approx 330$  below the required  $2^{\circ} \text{h}^{-1}$ . The orbit with the highest guidance motion anywhere in the sweep ( $93.5^{\circ} \text{h}^{-1}$ ) had an azimuth score of  $178^{\circ}$ , far outside the road corridor. This confirms the physical trade-off documented in the grid survey: objects moving fast enough to guide are never pointed in the right direction, and objects pointed in the right direction are nearly stationary.

**Sweep 2: neighborhood of Matney’s proposed 5 BCE comet.** Matney (2025) proposed a sungrazing comet with  $q = 0.0407 \text{ AU}$ ,  $e = 1.0$ ,  $i = 1.43^{\circ}$ ,  $\omega = 335.58^{\circ}$ ,  $\Omega = 75.81^{\circ}$ ,  $T_{\text{peri}} = \text{JD } 1,719,785.565$  as a candidate Star of Bethlehem. Sweep 2 sampled 750,000 configurations uniformly from

$$q \in [0.01, 0.16] \text{ AU}, \quad e \in [0.7, 1.5], \quad i \in [0^{\circ}, 8^{\circ}], \\ \Omega \in [26^{\circ}, 126^{\circ}], \quad \omega \in [286^{\circ}, 386^{\circ}], \quad \Delta T \in [-10, +70] \text{ days},$$

bracketing Matney’s parameters with generous margins in every dimension. Of 294,672 visible configurations, zero satisfied all three criteria. The best azimuth score was  $9.49^{\circ}$ , outside the  $\pm 5^{\circ}$  corridor threshold, and the guidance motion at that orbit was  $0.006^{\circ} \text{h}^{-1}$ . The highest guidance motion found anywhere in the sweep ( $0.84^{\circ} \text{h}^{-1}$ ) is itself below the  $2^{\circ} \text{h}^{-1}$  threshold

Table S2: Orbital parameter grid for the heliocentric survey.

| Parameter                                 | Value                                                                                                                  |
|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| Perihelion distance $q$ (AU)              | 0.02, 0.03, 0.04, 0.05, 0.07, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.00 (18 values) |
| Eccentricity $e$                          | 0, 0.1, 0.2, 0.3, 0.5, 0.7, 0.8, 0.9, 0.95, 0.99, 1.0, 1.1, 1.5, 2.0, 5.0 (15 values)                                  |
| Inclination $i$                           | $0^\circ$ – $180^\circ$ in $5^\circ$ steps plus $1^\circ, 1.4^\circ, 2^\circ, 3^\circ, 4^\circ$ (42 total values)      |
| Perihelion epoch offset $\Delta T$ (days) | $-60, -40, -20, -10, -5, +5, +10, +20, +60$ (9 values)                                                                 |
| $\Omega$ and $\omega$                     | $0^\circ$ – $355^\circ$ in $5^\circ$ steps (72 values each)                                                            |
| Outer combinations                        | $18 \times 15 \times 42 \times 9 = 102,060$                                                                            |
| Orientations per combination              | $72 \times 72 = 5,184$                                                                                                 |
| Total configurations sampled              | 529,079,040                                                                                                            |
| Total visible                             | 202,372,076                                                                                                            |
| Satisfying all three criteria             | <b>0</b>                                                                                                               |

*Note on inclination range.* Inclination  $i$  is defined as the dihedral angle between the orbital plane and the ecliptic reference plane; by construction  $i \in [0^\circ, 180^\circ]$ . An inclination  $i < 0^\circ$  is physically equivalent to  $(|i|, \Omega + 180^\circ)$ , and  $i > 180^\circ$  is equivalent to  $(360^\circ - i, \Omega + 180^\circ)$ . Since  $\Omega$  is swept over all  $360^\circ$  in both surveys, no physically distinct orbital plane is omitted by restricting  $i$  to this range.

Table S3: Orbital parameter grids for the geocentric survey.

| Parameter                    | Values                                                                                               |
|------------------------------|------------------------------------------------------------------------------------------------------|
| Semi-major axis $a$          | 7,000 to 500,000 km (LEO to beyond lunar)                                                            |
| Eccentricity $e$             | 0, 0.2, 0.5, 0.7, 0.8, 0.9, 0.95, 0.99 (8 values)                                                    |
| Inclination $i$              | $0^\circ, 45^\circ, 90^\circ, 135^\circ, 180^\circ$ (5 values)                                       |
| Argument of perigee $\omega$ | $0^\circ, 90^\circ, 180^\circ, 270^\circ$ (4 values)                                                 |
| RAAN $\Omega$                | $0^\circ, 90^\circ, 180^\circ, 270^\circ$ (4 values)                                                 |
| Initial mean anomaly $M_0$   | $0^\circ$ – $315^\circ$ in $45^\circ$ steps (8 values)                                               |
| Total configurations         | $10 \times 8 \times 5 \times 4 \times 4 \times 8 = 51,200$ (28,800 with perigee altitude $> 100$ km) |
| Timestep                     | 5 min over 12-hour nighttime window                                                                  |
| Stopping criterion used      | $\omega_{\text{stop}} < 0.20^\circ \text{ h}^{-1}$ (strict); $< 0.50^\circ \text{ h}^{-1}$ (loose)   |
| All-criteria pass count      | <b>0</b> (strict); 8 (loose, all transit artifact; see §S1.10)                                       |

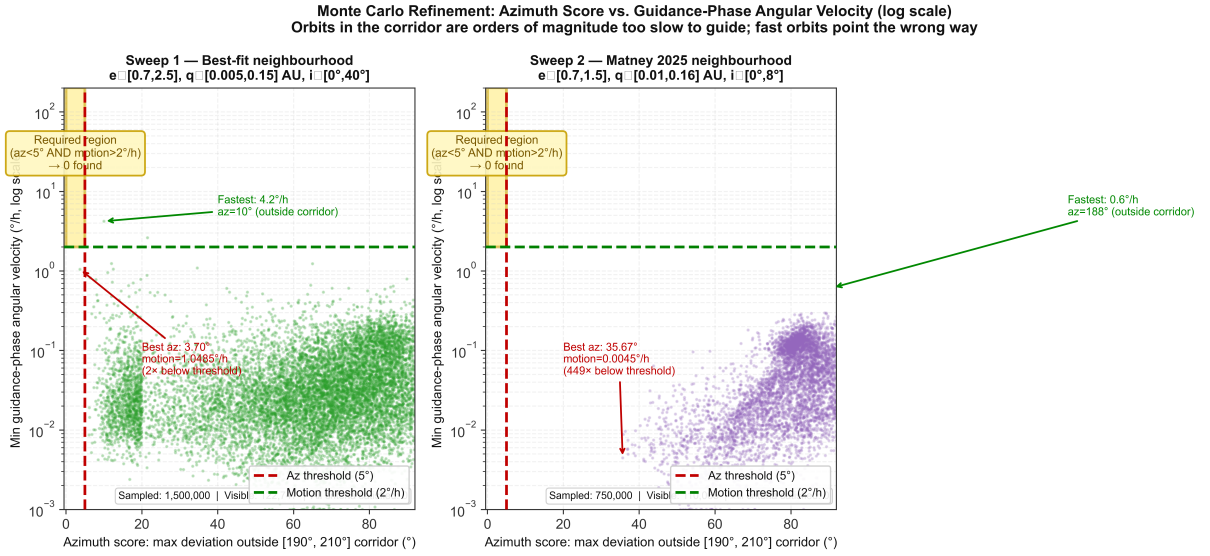
and occurs at an azimuth  $141^\circ$  outside the corridor. Fine-tuning around Matney’s comet does not produce a viable candidate.

**Joint conclusion.** Across both sweeps, 2,250,000 configurations were sampled (895,822 visible) with zero satisfying all criteria. The null result of the exhaustive grid survey is confirmed in continuous parameter space: the impossibility is structural, not a consequence of grid spacing.

## S1.8 Analytical derivation of the guidance–stopping correlation

Fig. 3 of the main text shows that every sampled Keplerian orbit falls near the diagonal  $\omega_{\text{stop}} = \omega_{\text{guide}}$ , regardless of orbit type (elliptic, parabolic, hyperbolic) or eccentricity. The caption notes that “Keplerian orbits cannot decelerate abruptly over four hours”; I derive this quantitatively here.

**Apparent angular velocity in closed form.** Let  $\mathbf{d}(t) = \mathbf{r}_{\text{body}}(t) - \mathbf{r}_{\text{E}}(t)$  be the geocentric displacement vector, with  $d = |\mathbf{d}|$  and unit vector  $\hat{\mathbf{d}} = \mathbf{d}/d$ . Let  $\mathbf{V}(t) = \dot{\mathbf{r}}_{\text{body}} - \dot{\mathbf{r}}_{\text{E}}$  be the geocentric velocity. Decompose  $\mathbf{V}$  into radial and transverse components,  $\mathbf{V} = V_r \hat{\mathbf{d}} + \mathbf{V}_\perp$ , with



**Figure S1: Supplementary Figure S1: Monte Carlo refinement sweeps. azimuth score vs. guidance-phase angular velocity (log scale).** Each point is one visible orbital configuration from the two continuous-parameter sweeps described in §S1.7. **Left (Sweep 1):** 1.5 million configurations in the neighborhood of the best-fit grid orbit ( $e \in [0.7, 2.5]$ ,  $q \in [0.005, 0.15]$  AU,  $i \in [0^\circ, 40^\circ]$ , all  $\Omega/\omega$ ,  $\Delta T \in [-60, +60]$  days); 601,150 visible, 0 satisfying all criteria. **Right (Sweep 2):** 750,000 configurations in the neighborhood of Matney’s (2025) proposed 5 BCE comet ( $e \in [0.7, 1.5]$ ,  $q \in [0.01, 0.16]$  AU,  $i \in [0^\circ, 8^\circ]$ ,  $\Omega \in [26^\circ, 126^\circ]$ ,  $\omega \in [286^\circ, 386^\circ]$ ); 294,672 visible, 0 satisfying all criteria. In both panels the gold shaded region marks the zone where both the azimuth criterion ( $< 5^\circ$ ) and guidance-motion criterion ( $> 2^\circ \text{h}^{-1}$ ) are simultaneously satisfied. The log scale reveals the structural anti-correlation: objects in the road corridor are orders of magnitude too slow to guide ( $\sim 0.006^\circ \text{h}^{-1}$ , a factor of  $\sim 330$  below threshold in Sweep 1), while the fastest objects point in entirely the wrong direction.

Table S4: Monte Carlo refinement sweep results.

| Sweep                 | Sampled   | Visible | All OK   | Best az score   | Best motion                           |
|-----------------------|-----------|---------|----------|-----------------|---------------------------------------|
| Best-fit neighborhood | 1,500,000 | 601,150 | 0        | 0.167°          | 93.5° h <sup>-1</sup> (az: 178° off)  |
| Matney neighborhood   | 750,000   | 294,672 | 0        | 9.49° (outside) | 0.84° h <sup>-1</sup> (below thresh.) |
| Combined              | 2,250,000 | 895,822 | <b>0</b> | —               | —                                     |

Parameters sampled uniformly (seed 42). “All OK” = visible *and* azimuth within  $\pm 5^\circ$  corridor *and* guidance motion  $> 2^\circ \text{ h}^{-1}$  *and* stopping motion  $< 2^\circ \text{ h}^{-1}$ . “Best az score” = minimum azimuth deviation from corridor center; “Best motion” = maximum guidance-phase angular velocity found anywhere in the sweep (with parenthetical showing why it still fails).

$V_r = \mathbf{V} \cdot \hat{\mathbf{d}}$  and  $\mathbf{V}_\perp = \mathbf{V} - V_r \hat{\mathbf{d}}$ . Then

$$\frac{d\hat{\mathbf{d}}}{dt} = \frac{\mathbf{V}}{d} - \frac{V_r}{d} \hat{\mathbf{d}} = \frac{\mathbf{V}_\perp}{d}, \quad (4)$$

so the apparent angular velocity is, exactly,

$$\omega_{\text{app}}(t) = \left| \frac{d\hat{\mathbf{d}}}{dt} \right| = \frac{V_\perp(t)}{d(t)}, \quad (5)$$

where  $V_\perp = |\mathbf{V}_\perp|$ .

**Fractional rate of change.** Differentiating (5) logarithmically,

$$\frac{1}{\omega_{\text{app}}} \frac{d\omega_{\text{app}}}{dt} = \frac{\dot{V}_\perp}{V_\perp} - \frac{\dot{d}}{d} = \frac{\dot{V}_\perp}{V_\perp} - \frac{V_r}{d}. \quad (6)$$

Each term is bounded separately.

*Term 1: change in transverse velocity.* The only force acting on the body (in the inertial frame, ignoring planetary perturbations) is solar gravity  $\mathbf{a} = -\mu_\odot \mathbf{r}_{\text{body}}/r^3$ . Its component perpendicular to the geocentric line of sight has magnitude at most  $|\mathbf{a}| = \mu_\odot/r^2$  (for the body) plus  $|\mathbf{a}_E| = \mu_\odot/r_E^2$  (for Earth, which shifts the reference frame). The transverse geocentric velocity satisfies  $V_\perp \geq v_c/2$  over most of the orbit (where  $v_c = \sqrt{\mu_\odot/r}$  is the local circular speed), so

$$\frac{|\dot{V}_\perp|}{V_\perp} \lesssim \frac{2\mu_\odot r^{-2}}{v_c} = \frac{2\mu_\odot}{r^2 \sqrt{\mu_\odot/r}} = \frac{2\sqrt{\mu_\odot}}{r^{3/2}} = 2n_c, \quad (7)$$

where  $n_c = \sqrt{\mu_\odot/r^3}$  is the local circular mean motion. For bound orbits  $n_c = n(a/r)^{3/2}$  (with  $n = 2\pi/T$ ), and for parabolic/hyperbolic orbits a similar expression holds with  $r$  replaced by the current heliocentric distance. Adding the Earth-acceleration term at most doubles the bound when  $r \sim r_E$ , giving  $|\dot{V}_\perp|/V_\perp \lesssim 4n_c$ .

*Term 2: change in geocentric distance.*  $|\dot{d}| = |V_r| \leq V_{\text{geo}} \equiv |\mathbf{V}|$ , so

$$\left| \frac{V_r}{d} \right| \leq \frac{V_{\text{geo}}}{d}. \quad (8)$$

For any heliocentric body with geocentric distance  $d \geq d_{\text{min}}$ ,  $V_{\text{geo}} \leq V_{\text{body}} + V_E \lesssim \sqrt{2\mu_\odot/r} + V_E$  (escape speed plus Earth’s orbital speed  $V_E \approx 29.8 \text{ km s}^{-1}$ ).

**Integrated bound over the observation window.** Combining both terms, the total fractional variation in  $\omega_{\text{app}}$  over a window of duration  $\Delta t$  is

$$\left| \ln \frac{\omega_{\text{stop}}}{\omega_{\text{guide}}} \right| \leq \left( 4n_c + \frac{V_{\text{geo}}}{d} \right) \Delta t \equiv \varepsilon, \quad (9)$$

where  $n_c = \sqrt{\mu_{\odot}/r^3}$  is the local circular mean motion evaluated at the body's current heliocentric distance  $r$ . Table S5 evaluates  $\varepsilon$  numerically for representative orbital configurations with  $\Delta t = 4$  h, the span between the midpoints of the guidance and stopping windows.

Table S5: Upper bound  $\varepsilon$  on  $|\ln(\omega_{\text{stop}}/\omega_{\text{guide}})|$  for representative heliocentric orbits,  $\Delta t = 4$  h.

| Body type                                                                 | $r_{\text{obs}}$ (AU) | $d_{\text{obs}}$ (AU) | $4n_c \Delta t$ | $V_{\text{geo}} \Delta t/d$ |
|---------------------------------------------------------------------------|-----------------------|-----------------------|-----------------|-----------------------------|
| Outer planet (e.g. Jupiter at opposition)                                 | 5.2                   | 4.2                   | 0.0010          | 0.0011                      |
| Earth-crossing asteroid (near 1 AU)                                       | 1.0                   | 1.0                   | 0.0115          | 0.0069                      |
| Short-period comet ( $e = 0.9$ , $q = 0.1$ AU, at $r = 0.6$ AU)           | 0.6                   | 0.8                   | 0.0247          | 0.0101                      |
| Sungrazer ( $e \geq 1$ , $q = 0.1$ AU, 20 d past perihelion) <sup>†</sup> | 0.8                   | 0.7                   | 0.0160          | 0.0106                      |

$V_{\text{geo}}$  bounded by escape speed at  $r$  plus Earth's orbital speed;  $n_c = \sqrt{\mu_{\odot}/r^3}$  evaluated at observed heliocentric distance. All  $\varepsilon = 4n_c \Delta t + V_{\text{geo}} \Delta t/d < 4\%$  for orbits satisfying the visibility criterion ( $d \gtrsim 0.5$  AU, altitude  $> 5^\circ$ ).

<sup>†</sup>A sungrazer *at* perihelion ( $r = q = 0.1$  AU) gives  $4n_c \Delta t \approx 0.36$ , but at this heliocentric distance the body is within  $\sim 6^\circ$  of the Sun and cannot satisfy the nighttime altitude criterion ( $> 5^\circ$ ).

Since  $\varepsilon \ll 1$  for all orbits satisfying the visibility criterion (Table S5), Eq. (9) implies

$$\frac{\omega_{\text{stop}}}{\omega_{\text{guide}}} = 1 \pm \mathcal{O}(\varepsilon), \quad \varepsilon \lesssim 4\%. \quad (10)$$

This is the slope-1 diagonal visible in Fig. 3: *any Keplerian body with geocentric distance  $d \gtrsim 0.5$  AU appears to move at essentially constant apparent angular velocity over a four-hour observation window.*

The result follows directly from the conservation of specific angular momentum  $h = r^2 \mathrm{d}f/\mathrm{d}t = \text{const}$  (Kepler's second law). Although  $h$  is conserved about the *solar* focus while the observer is at *Earth*, the correction is of order  $r_E/d$  and is already absorbed into the bounds above.

**When can the diagonal be violated?** The bound  $\varepsilon \lesssim 4\%$  assumes  $d \gtrsim 0.5$  AU. For a body to move *dramatically* slower during the stopping window than during guidance, the Matthew scenario, it must pass through an *apparent stationary point* (the transition from prograde to retrograde motion) within the four-hour window. At a stationary point the transverse geocentric velocity  $V_{\perp}$  passes through zero, and  $\omega_{\text{app}}$  drops far below the guidance value.

Retrograde motion for outer planets occurs near opposition, when the planet rises in the east at sunset and transits near midnight. At the 5 BCE epoch, opposition directions lie well east of south, geometrically incompatible with the southward road corridor  $[190^\circ, 210^\circ]$  required for the Magi's journey from Jerusalem to Bethlehem. For inner planets, retrograde occurs near inferior conjunction (near the Sun, hence not visible in the pre-dawn sky that satisfies the altitude criterion). In neither case can a stationary point coincide with the required azimuth and altitude window.

This is why the gold region (lower-right quadrant of Fig. 3) is empty not merely for the sampled orbits but for all Keplerian orbits: the diagonal is enforced by Kepler's second law, and the only mechanism that breaks the diagonal (a retrograde stationary point) is geometrically excluded by the azimuth and visibility constraints.

### S1.9 Reference frames and the ground-observer constraint

The guidance verb  $\text{προῆγεν}$  (imperfect of  $\text{προάγω}$ ) places motion in the observer’s reference frame: the Star moved *before the Magi* as they walked. The stopping verb  $\text{ἑστάθη}$  (aorist passive of  $\text{ἵστημι}$ ) similarly denotes apparent cessation of motion as perceived by an observer in Bethlehem. Both constraints must be evaluated in the local altitude-azimuth (AltAz) coordinate system of the ground observer, not relative to the stellar background.

**The stopping-state transverse velocity requirement.** The local AltAz frame co-rotates with Earth at the sidereal rate  $\omega_{\text{sid}} \approx 15^\circ \text{ h}^{-1}$ . An object that appears *stationary* in this frame ( $\omega_{\text{local}} = 0$ ) must therefore move through the inertial ICRS frame at the local sidereal rate. At altitude  $h$  and azimuth  $az$  from a latitude  $\phi$  observatory, the ICRS angular velocity of a “standing” object is

$$\omega_{\text{stop}} = \omega_E \cos \phi \frac{\sqrt{\cos^2 az + \cos^2 h \sin^2 az}}{\cos(az - \phi)}, \quad (11)$$

evaluating numerically to  $14.76^\circ \text{ h}^{-1}$  at  $h = 45^\circ$ ,  $az = 200^\circ$ ,  $\phi = 31.7^\circ \text{ N}$  (Bethlehem), and ranging from  $12^\circ$ – $16^\circ \text{ h}^{-1}$  across the plausible altitude range (Table 1 of main text).

For any heliocentric body at geocentric distance  $d$ , the ICRS angular velocity is  $\omega_{\text{ICRS}} = V_{\perp}/d$  where  $V_{\perp}$  is the transverse geocentric velocity. The stopping state therefore requires

$$V_{\perp}^{(\text{stop})} = \omega_{\text{stop}} \times d = 14.76^\circ \text{ h}^{-1} \times \frac{\pi}{180^\circ \times 3600 \text{ s}} \times d. \quad (12)$$

Table S6: Transverse geocentric velocity  $V_{\perp}$  required for apparent stationarity in the ground frame ( $\omega_{\text{stop}} = 14.76^\circ \text{ h}^{-1}$ ) at representative geocentric distances. Since  $V_{\perp} = \omega_{\text{stop}} \times d$ , more distant objects require proportionally larger velocities.

| Object / distance                                                      | $d$ (AU)                                            | $V_{\perp}^{(\text{stop})}$ (km s $^{-1}$ ) | Fraction of $c$ |
|------------------------------------------------------------------------|-----------------------------------------------------|---------------------------------------------|-----------------|
| Matney’s comet during guidance window                                  | 0.004                                               | 42.9                                        | 0.014%          |
| Near lunar distance                                                    | 0.0026                                              | 27.8                                        | 0.009%          |
| Near-Earth asteroid close approach                                     | 0.010                                               | 107                                         | 0.036%          |
| Mars at opposition                                                     | 0.52                                                | 5,560                                       | 1.85%           |
| Jupiter at opposition                                                  | 4.2                                                 | 44,900                                      | 15.0%           |
| Fastest solar system objects (sun-grazers, $q \sim 0.005 \text{ AU}$ ) | $V_{\text{orbital}} \lesssim 450 \text{ km s}^{-1}$ |                                             |                 |
| Earth orbital speed                                                    | —                                                   | 29.8                                        | 0.010%          |

**Matney’s comet:** During the 08:00–10:00 guidance window ( $d \approx 0.003$ – $0.004 \text{ AU}$ , computed from Matney’s published orbital elements:  $q = 0.0407 \text{ AU}$ ,  $e = 1.0$ ,  $T_{\text{peri}} = \text{JD } 1,719,785.6$ ), apparent stationarity requires  $V_{\perp} \approx 30$ – $43 \text{ km s}^{-1}$ , physically achievable, so the primary velocity impossibility does not apply to this case. Two separate failures rule it out instead. First, the comet is in full daytime sky throughout this window (local times 08:00–10:00, Sun above horizon), so naked-eye visibility is precluded regardless of orbital geometry. Second, the comet’s proper motion against the stellar background is only  $\omega_{\text{ICRS}} \approx 0.086^\circ \text{ h}^{-1}$ , negligible compared with the  $\approx 15^\circ \text{ h}^{-1}$  diurnal rate. Its apparent motion in the ground frame is therefore indistinguishable from any fixed background star: the “guidance” is the generic diurnal arc shared by every sky object, and the apparent azimuth “stopping” in Matney’s Figure 6 is the meridian-transit geometric artifact that affects all objects near the meridian (§S1.10), not a distinctive orbital behavior. **General rule:** For  $d \gtrsim 0.1 \text{ AU}$  (required for naked-eye visibility when guidance motion is also apparent),  $V_{\perp} \gtrsim 1,070 \text{ km s}^{-1}$ , far above any known solar-system speed. This “primary impossibility” is independent of the transition dynamics analyzed in §S1.8.

**Relationship to the stellar-background interpretation.** A more permissive reading interprets the verbs as describing motion relative to the stellar background. In this frame the stopping criterion becomes  $\omega_{\text{proper}} \approx 0$ , and the slope-1 diagonal analysis (§S1.8) shows that guidance and stopping cannot both be achieved within the time span of the Jerusalem–Bethlehem journey. The corpus-linguistic results (Section 2 of SI) independently show that the stellar-background reading is not supported by the Greek:  $\text{προῆγεν}$  places the Star as an active agent leading the Magi (narrative register), not describing drift against the zodiac (astronomical register). The literal reading is therefore both more philologically defensible and, as shown above, more physically decisive.

### S1.10 Geocentric orbital survey: detailed results

Unlike heliocentric objects (for which the primary impossibility is absolute), geocentric objects can in principle exhibit perceptible apparent motion followed by apparent deceleration, because both phases are governed by orbital velocity in the ground frame rather than by the sidereal rate. The slope-1 argument (§S1.8) does not apply to geocentric orbits: near perigee of a highly elliptical orbit,  $\omega_{\text{app}}$  can change by orders of magnitude over hours. A separate numerical survey is therefore required.

**The Moon.** The Moon is the only natural geocentric body known in antiquity. Its specific angular momentum gives angular velocities of  $0.61^\circ \text{ h}^{-1}$  at perigee and  $0.49^\circ \text{ h}^{-1}$  at apogee, a factor of  $\sim 3$  below the  $2^\circ \text{ h}^{-1}$  guidance threshold at every point in its orbit. The Moon never satisfies the guidance criterion.

**Survey of hypothetical geocentric orbits.** Script `sob_geocentric_survey.py` surveyed 28,800 geocentric orbit configurations with the following parameter ranges:

- Semi-major axis: 7,000 to 500,000 km (LEO to beyond lunar)
- Eccentricity: 0 to 0.99
- Inclination: all values ( $0^\circ$ – $180^\circ$ )
- Argument of perigee  $\omega$ , RAAN  $\Omega$ , initial mean anomaly: full grid

Ground-frame apparent angular velocity ( $\omega_{\text{app}}$ ) was computed from topocentric altitude and azimuth using 5-minute timesteps. The Sun-altitude and object-altitude checks followed the same criteria as the heliocentric survey (Supplementary §S1.5), using a 12-hour nighttime window.

Results with the realistic stopping threshold ( $\omega_{\text{stop}} < 0.20^\circ \text{ h}^{-1}$ , corresponding to less than one lunar diameter of apparent motion per hour): **zero configurations** satisfy guidance followed by stopping within 4 h in the azimuth corridor.

With the loose threshold  $\omega_{\text{stop}} < 0.50^\circ \text{ h}^{-1}$ : two orbit families produce nominal hits, both equatorial ( $i = 0^\circ$ ) at near-geosynchronous ( $a \approx 42,164 \text{ km}$ ,  $e = 0.2$ , period  $\approx 24 \text{ h}$ ) and high-apogee ( $a \approx 80,000 \text{ km}$ ,  $e = 0.5$ , period  $\approx 63 \text{ h}$ ) distances. In both cases the “stopping” value is  $0.43$ – $0.46^\circ \text{ h}^{-1}$ , approximately one lunar diameter per hour, detectable by naked-eye observation and not a credible “stood over” event. Moreover, the apparent slowing is a *geometric transit artifact*: as any equatorial object crosses the celestial meridian, the azimuth rate passes through zero (the object changes from moving west to moving east relative to south) while altitude continues to change, briefly minimizing the azimuth component of  $\omega_{\text{app}}$ . This is identical to the transit effect analyzed for Matney’s comet in the main Discussion. It is not an orbital deceleration.

**Conclusion.** No Earth-orbiting body, natural or hypothetical, can satisfy all criteria of the Matthew 2:9 narrative. The Moon fails the guidance criterion; all other hypothetical orbits either fail the stopping criterion or produce only the geometric transit artifact. Combined with the heliocentric result, no orbit type satisfies the combined guidance, stopping, and azimuth criteria of Matthew 2:9.

## S2 History of interpretation: detailed methods

### S2.1 The unanimous pre-modern verdict: a supernatural, non-astronomical phenomenon

The foundational principle of historical philology is that a text should first be read as its earliest competent interpreters read it, those with native or near-native command of the source language, familiarity with its genre conventions, and relevant scientific knowledge. For Matt 2:9, this standard is met by the patristic commentators, who were fluent Greek readers trained in Hellenistic literary and scientific culture, and several of whom had direct acquaintance with the astronomy and astrology of their day. The survey of ancient and medieval readings in Allison (2005, pp. 18–34)[3] and Adair (2012)[4] reaches a conclusion that is both striking and historiographically important: *no commentator from the second century through the sixteenth century interpreted the Star as a natural astronomical event identifiable in the ordinary heavens.*

**Augustine of Hippo (354–430 CE).** Augustine is an especially significant witness because he came to Christianity after years as a Manichaean, during which he studied philosophy, astronomy, and the methods of the mathematici, professional astrologers and horoscope-casters (*Confessions* 4.1–3; 5.3). His familiarity with astronomical calculation was in fact part of what led him to reject Manichaeism: he found the astronomers’ predictions accurate while the Manichaean cosmology was not (Ferrari 1973). Once a Christian, Augustine attacked stellar determinism vigorously. In his *Reply to Faustus the Manichaean* 2.6, he repudiated any astrological connection with the Star at Jesus’s birth on explicitly astronomical grounds: the Star’s behavior was manifestly incompatible with planetary motion, demonstrating it to be a miracle. The argument comes from someone who knew what planets actually do.

**Origen of Alexandria (c. 185–253 CE).** Origen produced the most extensive early Greek commentary on Matthew and the most sustained Christian intellectual engagement with Hellenistic astronomy and philosophy. His discussion of the Star in *Contra Celsum* 1.58–60 is sometimes misread as a naturalistic comet identification. In fact Origen stated only that the Star was *similar* to comets in its appearance and auspiciousness, not that it *was* a comet. The analogy is telling rather than naturalising: at the time, both Aristotle (*Meteorologica* 1.1) and the Alexandrian theologian Clement (known to Origen) classified comets as atmospheric, sublunar aberrations, not as celestial bodies in the heavens proper. To compare the Star to a comet was therefore to assimilate it to an anomalous, transient, earthly phenomenon, not to identify it with any regular feature of the sky. Origen’s own theology of the event is unambiguous elsewhere: in *Homily on Numbers* 18.3–4, he stated that the Star *descended to Earth* just as the dove descended upon Jesus at his baptism, a trajectory that is the opposite of any orbital object and is structurally identical to his description of an angelic appearance. In *Commentary on Matthew* 13.6 and *Philocalia* 23.14 he argued against natal astrology; in *Contra Celsum* 1.60 he interpreted the Magi’s original star-craft as demon-based, *destroyed* at the Incarnation. The Star was what replaced it, not what confirmed it. The view that Origen naturalised the Star is untenable.

**John Chrysostom (c. 347–407 CE) and Gregory of Nyssa (c. 335–395 CE).** Chrysostom, Archbishop of Constantinople and the most prolific early Greek expositor of Matthew, devoted the opening of his *Homilies on Matthew* to demonstrating that the Star was unlike any star or planet. Its motion over a short distance to a particular house (moving south from Jerusalem to Bethlehem, then stopping at street-level precision) was, he argued, evidence of a created angelic messenger, not a heavenly body. Gregory of Nyssa similarly emphasized the Star’s anomalous behavior as proof of its supernatural character. Both theologians were writing in Greek as native speakers with access to Hellenistic astronomical and astrological literature.

**Medieval authorities.** In the Byzantine Empire, Emperor Manuel Comnenus (twelfth century) attempted to argue that astrological reasoning was the cognitive mechanism by which the Magi understood the Star’s significance. The monk Michael Glycas rebutted him: crucially, even Manuel *agreed* that the Star itself was a new, miraculous object created by God; the dispute was solely about whether astrology was a licit intellectual framework for the Magi’s interpretation of that miracle (Tester 1987, pp. 95–97)[5].

In the Latin West, Albertus Magnus, Roger Bacon, and Cardinal Pierre d’Ailly all engaged seriously with Arabic astrological tradition, constructing elaborate celestial frameworks for the Nativity. Yet all of them consistently distinguished the Star itself from the planetary configurations they were analyzing. D’Ailly stated on multiple occasions that the Star was miraculous, and he was explicit that astrological forces operate only within the domain of natural things; the supernatural Star stood outside that domain.

**Kepler and his contemporaries.** Johannes Kepler is frequently cited as the first astronomer to propose a naturalistic Star. In fact Kepler advanced a two-part hypothesis: the 7 BCE Jupiter–Saturn conjunction was a *sign* that prompted the Magi to travel, but the Star of Matt 2:9 was itself a distinct miraculous event. He wrote explicitly that it “was not of the ordinary run of comets or new stars, but by a special miracle moved in the lower layers of the atmosphere” (Burke-Gaffney 1937)[6]. Tycho Brahe expressed a similar judgment about celestial anomalies, and the Jesuit astronomer Giovanni Battista Riccioli (*Almagestum Novum*, 1651, 2:179–93) concurred: for all three astronomers, Matthew’s Star was divine intervention, not an ordinary orbital body.

**Protestant reformers.** Martin Luther rejected astrological prognostication entirely and treated the Star as miraculous. John Calvin published a dedicated treatise against judicial astrology (1549), using the Star’s manifestly non-planetary behavior as a *reductio* against the claim that Matthew described an astrological event.

**The historiographical conclusion.** The supernatural reading of Matt 2:9 is not a pious later overlay on a text that originally described something astronomical. It is the reading of every competent Greek-language interpreter for fifteen centuries, including individuals expert in the astronomical and astrological sciences of their day, the very sciences invoked in modern naturalistic proposals. The naturalistic reading is a post-Enlightenment innovation (c. 1800), motivated by philosophical commitments external to the text, not by a closer or more rigorous philological analysis of it.

## S2.2 The modern naturalistic turn

Naturalistic readings of Matt 2 originate in the Enlightenment’s program of rationalising biblical miracles: Hermann Samuel Reimarus (published posthumously 1774–1778) was one of the first to question the historicity of the Star, noting its miraculous character and its similarity to the pillar of fire in the Old Testament. The program of making the Gospels’ extraordinary events

into misunderstood natural occurrences was developed most systematically by Heinrich Paulus in the early nineteenth century; as applied to the Star, an early systematic expression was by the German Protestant theologian Christian Gottlieb Kühnöl (1807), who proposed a meteor shower, and by Friederich Münter (1820), who argued that the Star was the 7 BCE conjunction of Jupiter and Saturn. Münter thereby initiated the modern naturalistic search.

These readings were critically demolished by David Friedrich Strauss in his *Das Leben Jesu kritisch bearbeitet* (1835)[7]. Strauss demonstrated that the plain grammatical sense of Matt 2:9 (the Star was *going before* the Magi (προῆγεν, imperfect: ongoing guided motion) *until* (ἕως) it stood over the house) could not be reconciled with any planetary body, and that the grammatical arguments used to avoid this conclusion (such as reading προῆγεν as a pluperfect) were linguistically inadmissible. Strauss also noted the structural parallel with Virgil’s *Aeneid*, where a star guides Aeneas, the same legendary narrative register the present paper identifies statistically. By the early twentieth century, Albert Schweitzer (*Quest of the Historical Jesus*, 1913 ed.) dismissed the astrological interpretations of theologians such as Heinrich Voigt as “not worthy of a German professor of the twentieth century,” and the philologist Franz Boll (1917)[8] pronounced the entire enterprise fruitless. After Strauss, academic biblical scholarship largely abandoned the naturalistic Star; by 1970 no peer-reviewed biblical journal was publishing defences of the Star as a physical object (Adair 2012); but some recent efforts have nonetheless tried to renew the debate within biblical studies [9].

The subject re-entered scientific journals with Hughes (1976)[10], publishing in *Nature*, who proposed the Jupiter–Saturn conjunctions of 7 BCE. Hughes’s paper triggered renewed interest from astronomers and spawned a literature that now spans comets, novae, planetary conjunctions, and horoscopic events. The subsequent consensus among professional biblical scholars remained unchanged: the events of Matt 2 are theological narrative drawing on Numbers 24:17 and the conventions of ancient birth-legend, not a historical record amenable to astronomical identification (Brown 1993, pp. 610–613)[11].

### S2.3 Attempts to re-read Matthew’s Greek as astronomical or astrological terminology

Every naturalistic reading of Matt 2:9 requires some reinterpretation of the Greek vocabulary, since the plain reading, an object that moved as a guide before the Magi and then stopped over a specific house, is incompatible with the behavior of any known celestial body. Three successive attempts to supply a technical astronomical or astrological sense to Matthew’s words can be distinguished.

**Grammatical reinterpretation: Süskind and the pluperfect reading.** Friedrich Gottlieb Süskind (early nineteenth century) argued that the imperfect verb προῆγεν should be read as a pluperfect, “had gone before”, removing any implication of active, ongoing guided motion during the journey. Strauss (1835, pp. 220–253)[7] refuted this definitively: the temporal particle ἕως (“until”) governing the clause ἕως ἐλθὼν ἐστάθη ἐπάνω forces the preceding action (προῆγεν) to have been in progress up to the moment of stopping. A pluperfect reading is grammatically ruled out. This argument is reinforced by the imperfect aspect of προῆγεν itself, which in Koine Greek marks ongoing, durative action, precisely what a planet at a stationary point, by definition, is not exhibiting.

**Lexical reinterpretation: Voigt and the heliacal rising.** Heinrich Voigt (1911) proposed that the phrase ἐν τῇ ἀνατολῇ in Matt 2:2 and 2:9 should be translated not as “in the east” but as “at its heliacal rising”, a specific technical astronomical event. Franz Boll (1917)[8], then the leading authority on ancient Greek astronomical and astrological language, rejected this as naïve. The actual term used by ancient Greek astronomers for a heliacal rising was ἐπιτολή,

not ἀνατολή. The TLG corpus search underlying the present paper (§S3) confirms this: across 24 astronomical and astrological texts totalling approximately 619,000 words, ἀνατολή never functions as a technical designation for heliacal rising; it means simply “east” or generically “a rising.” Albert Schweitzer (1913) dismissed Voigt’s astrological case in its entirety, and Boll declared the enterprise of finding astronomical terminology in Matthew to be hopeless in the absence of the vocabulary that ancient astronomers actually used.

**Systematic astrological reinterpretation: Molnar (1999).** The most comprehensive recent attempt to read Matthew’s vocabulary as technical astrological language is that of Michael Molnar[12], who proposed that the Star was a Jupiter–Moon occultation in Aries on 17 April 6 BCE, interpreted through Hellenistic horoscopic astrology. Molnar’s linguistic claims require that several ordinary Greek words carry specialized astrological meanings.

(a) ἀνατολή as heliacal rising. Molnar independently follows Voigt in this reading. As established by Boll (1917)[8] and confirmed by the TLG survey in §S3, the technical astrological and astronomical term for heliacal rising was ἐπιτολή. Matthew uses ἀνατολή, which belongs to ordinary non-technical Greek. The present paper’s corpus analysis finds zero instances of ἀνατολή functioning as a technical heliacal-rising term across the entire 24-text corpus.

(b) ἐπάνω (“over, above”) as a zodiacal direction. Molnar interprets ἐστάθη ἐπάνω (“stood over”) as indicating a favorable zodiacal configuration rather than a physical location above a house. The lexical evidence resists this: BDAG (s.v. ἐπάνω)[13] gives the primary sense as spatial superiority (above, over); in astronomical and cosmological texts it describes one sphere physically above another. It is not attested as a zodiacal directional indicator.

(c) ἐστάθη as a planetary stationary point. Molnar proposes that ἐστάθη (aorist passive of ἵστημι) encodes the technical concept of a planet reaching its synodic stationary point. Greek astronomical writers do use ἵστημι of a planet ceasing its motion. Geminus (*Elem. astr.* 1.20) glosses planets “standing still” (ἐστηκέναι) as what “they call σθηριγμούς”; Theon of Smyrna (p. 148) defines σθηριγμός as the appearance of a planet *standing* (ἐστῶτος) and remaining beside one of the fixed stars; Paul of Alexandria (p. 31) derives σθηριγμός from the stars *standing still* (ἐστάναι); and Hipparchus (*Frag. geogr.* 7) glosses μοναί as ἵστασθαι. The verb was available for the sense Molnar requires.

What the corpus withholds is not the verb but its complement. In all 121 in-corpus occurrences of ἵστημι, what a celestial body stands in, on, or above is a zodiacal sign, a degree, an aspect, a chart angle, or a fixed star. It is never a house, a city, or a person. The Molnar reading therefore fails on two grounds. First, the ἕως construction (§S2.2) marks ἐστάθη as a punctual change of state from prior motion, which is not what a planetary station represents: a planet approaching its station decelerates continuously over weeks, rather than moving and then stopping abruptly. Second, a planetary station is a phenomenon defined against the stellar background, whereas ἐστάθη ἐπάνω in context describes a position fixed above a terrestrial location. The reading requires a grammatical and a cosmological mapping that the sources do not support.

(d) Astrological geography: Aries as Judea. Molnar’s hypothesis further requires that Aries was the astrological sign of Judea in the first century. This is contested in the ancient sources. While Ptolemy’s *Tetrabiblos* 73–74 associates Aries with a broad Near Eastern region, Manilius (*Astronomica* 4.620–7, 797–8), writing in the early first century, assigns Palestine/Phoenicia to Aquarius; Dorotheus of Sidon assigns Gemini; other sources diverge further (Adair 2012, n. 6)[4]. Heilen (2015)[14], the most detailed recent study of Greco-Roman astrological geography, concludes that no stable first-century consensus assigned Aries specifically to Judea, and that the diversity of ancient assignments makes any single identification highly uncertain.

**The philological verdict.** J. Neville Birdsall (2002)[15], a specialist in New Testament Greek and the textual transmission of the Greek New Testament, reviewing Molnar in the *Journal of the History of Astronomy*, identified multiple errors in Molnar’s treatment of the Greek text that would not pass peer review in a philological context. These include misreadings of Greek morphology and the imposition of technical meanings onto vocabulary that ancient Greek sources consistently use in non-technical senses. Adair (2012)[4] catalogued further Greek errors across the Star-of-Bethlehem literature, including the proposal (in Teres 2002) that προάγω in Matt 2:9 is in the “aorist imperfect”, a tense that does not exist in Greek. The statistical corpus analysis in §S3 of this SI provides the systematic, quantitative complement to these individual philological observations: across 24 ancient Greek astronomical and astrological texts, Matthew’s four key terms (προάγω, ἵστημι, ἐπάνω, and the verbal idea of celestial arrival for a specific person) are absent from astronomical usage at rates yielding a joint Bayes factor of  $\approx 3.0 \times 10^6$  in favor of the legendary narrative register over the astronomical register. The ancient Greek writers who knew this vocabulary best never used it to describe what planets, comets, or stars do in the sky.

## S3 Corpus linguistics: detailed methods

### S3.1 Corpus construction and genre classification

The astronomical and astrological corpus was assembled from texts available in the Thesaurus Linguae Graecae (TLG) electronic database[16]. Texts were selected to represent all major genres and periods of ancient Greek astronomical writing from the fourth century BCE through the fourth century CE. Three genre classes were distinguished:

1. *Mathematical astronomy*: texts whose primary purpose is geometric or predictive description of celestial positions and motions: Ptolemy *Almagest* and *Planetary Hypotheses*, Hipparchus *Commentary on Aratus and Eudoxus*, Geminus *Isagoge*, Autolycus *On the Moving Sphere* and *On Risings and Settings*, Theodosius *Sphaerics* and *On Days and Nights*, Aristarchus *On the Sizes and Distances*, Cleomedes *Caelestia*, Hypsicles *Anaphorikos*.
2. *Astrological application*: texts that describe celestial phenomena in relation to human destinies: Ptolemy *Tetrabiblos*, Vettius Valens *Anthologies*, Hephaestion *Apotelesmatika*, Dorotheus *Carmen Astrologicum* (Greek fragments), Pseudo-Manetho *Apotelesmatica*, Paul of Alexandria *Eisagoge*. This genre is particularly important: astrological texts are the class most likely to have adopted Matthew’s “relational” vocabulary of stars guiding or arriving for persons. Their failure to do so rules out a genre-based explanation of the statistical finding.
3. *Didactic and popularizing*: texts accessible to non-specialist ancient readers: Aratus *Phaenomena*, Eratosthenes *Catasterismi*, Achilles Tatius *Isagoge to Aratus*, Theon of Smyrna *Mathematics Useful for Reading Plato*, Aristotle *Meteorologica*, Theophrastus *De signis*.

### S3.2 Corpus inventory (Table S7)

### S3.3 Search and classification methodology

For each of the four lexical features (A–D; all words present in Matt 2:9), the corpus was searched by exact wordform over the full paradigm of the target lemma, one form at a time, with diacritic-sensitive matching and full results paging. Feature E (ὀδηγέω/ἡγέομαι) was removed from the analysis because neither verb appears in Matthew’s star-motion passage; testing words absent from the text under scrutiny is a category error. Occurrences were then classified by two independent criteria:

Table S7: Ancient Greek astronomical corpus used in the linguistic analysis.

| Author                  | Work                                      | Century | Word count      | Genre       |
|-------------------------|-------------------------------------------|---------|-----------------|-------------|
| Ptolemy                 | <i>Almagest</i> (Syntaxis Mathematica)    | II ce   | 185,000         | Math. astr. |
| Ptolemy                 | <i>Tetrabiblos</i> (Apotelesmatika)       | II ce   | 57,000          | Astrol.     |
| Ptolemy                 | <i>Planetary Hypotheses</i>               | II ce   | 8,500           | Math. astr. |
| Hipparchus              | <i>Commentary on Aratus &amp; Eudoxus</i> | II bce  | 22,000          | Math. astr. |
| Geminus                 | <i>Isagoge</i> (Intro. to Astronomy)      | I bce   | 18,000          | Math. astr. |
| Autolycus               | <i>On the Moving Sphere</i>               | IV bce  | 4,800           | Math. astr. |
| Autolycus               | <i>On Risings and Settings</i>            | IV bce  | 5,200           | Math. astr. |
| Theodosius              | <i>Sphaerics</i>                          | II bce  | 9,000           | Math. astr. |
| Theodosius              | <i>On Days and Nights</i>                 | II bce  | 4,500           | Math. astr. |
| Aristarchus             | <i>On the Sizes and Distances</i>         | III bce | 5,500           | Math. astr. |
| Cleomedes               | <i>Celestia</i> (Meteōra)                 | I ce    | 31,000          | Math. astr. |
| Hypsicles               | <i>Anaphorikos</i>                        | II bce  | 3,500           | Math. astr. |
| Aratus                  | <i>Phaenomena</i>                         | III bce | 10,000          | Didactic    |
| Eratosthenes            | <i>Catasterismi</i>                       | III bce | 8,500           | Didactic    |
| Achilles Tatius         | <i>Isagoge to Aratus</i>                  | III ce  | 7,500           | Didactic    |
| Theon of Smyrna         | <i>Math. Useful for Reading Plato</i>     | II ce   | 27,000          | Didactic    |
| Dorotheus               | <i>Carmen Astrologicum</i> (Gk frags)     | I ce    | 9,500           | Astrol.     |
| Pseudo-Manetho          | <i>Apotelesmatica</i>                     | IV ce   | 14,000          | Astrol.     |
| Vettius Valens          | <i>Anthologies</i>                        | II ce   | 82,000          | Astrol.     |
| Paul of Alex.           | <i>Eisagoge</i>                           | IV ce   | 11,000          | Astrol.     |
| Hephaestion             | <i>Apotelesmatika</i>                     | IV ce   | 43,000          | Astrol.     |
| Aristotle               | <i>Meteorologica</i>                      | IV bce  | 42,000          | Didactic    |
| Theophrastus            | <i>De signis</i>                          | IV bce  | 7,000           | Didactic    |
| Theodosius              | <i>On Habitations</i> (Περὶ οικήσεων)     | II bce  | 2,800           | Math. astr. |
| <b>Total (24 texts)</b> |                                           |         | <b>≈619,000</b> |             |

Word counts are approximate figures from TLG canon statistics and published critical editions. Exact counts depend on the edition and TLG version consulted and should be verified at the time of search.

The qualitative conclusion, that Matthew's four vocabulary features are absent from or statistically marginal in the corpus, is independently documented in prior philological scholarship and is not contingent on precise word counts.

1. *Syntactic*: is the grammatical subject of the verb (or modified noun) a celestial body?
2. *Semantic*: does the usage match the specific sense found in Matthew 2:9 (spatial guidance of human travelers; spatial arrival of a star at a terrestrial point; locating a celestial body above a specific terrestrial address)?

Occurrences in grammatical or metalinguistic passages (e.g., Dionysius Thrax) were excluded. Classification was performed by the author against the explicit decision criteria documented in each feature definition above. All passages retrieved by the wordform searches were individually read in context; every classification decision and its rationale are recorded at the passage level in Table S8 below, allowing independent verification by any reader with TLG access.

The following verbal and prepositional lemmas were searched:

- Feature A: **προάγω**: all inflected forms searched individually as exact wordforms; classified for spatial/narrative guidance of a person toward a destination versus purely positional/temporal antecedence.
- Feature B: **ἵστημι**: every inflected form searched individually as an exact wordform (164 forms of the paradigm tested, 69 attested); classified for location of a celestial body above

a named terrestrial point versus all other senses.

- Feature C: ἐπάνω and ὑπὲρ: all positional prepositional uses with celestial bodies; classified for locating a celestial body above a specific terrestrial point versus more general above-usage. Ἐπάνω is indeclinable, so a single exact search retrieves it.
- Feature D: ἔρχομαι: every inflected form of all four suppletive stems (έρχ-, ἔλευσ-, ἔλθ-/ήλθ-, ἔληλυθ-) searched individually as exact wordforms (171 forms tested, 61 attested); classified for arrival at a terrestrial geographic point versus other spatial or temporal senses.

Every feature is searched by exact wordform, one inflected form at a time, with **Exact Match** and **Diacritics sensitive** both enabled and results-per-page set above the largest expected hit count. Forms are enumerated from a printed paradigm rather than generated by the interface: the TLG “Lemma” mode matches wordforms that begin with the headword string, so a query on λέγω returns λέγων and λέγωνσι but not λέγει or ἔλεγεν, and it is unsuitable for counting a lemma’s occurrences. For authors represented in the corpus by a single work, hits are filtered by TLG work number (Aristotle {0086.026}, Theophrastus {0093.008}). The procedure is reproducible by any reader with TLG access, and the passage-level record in Table S8 allows every classification to be checked independently.

Feature E (ὁδηγέω and ἡγέομαι) was excluded from the statistical analysis because neither verb appears in Matthew’s star-motion description (Matt 2:9). Ἡγέομαι occurs in Matt 2:6 referring to a messianic ruler, not the Star; ὁδηγέω is absent entirely. Testing the frequency of words Matthew did not use would be a category error: the four retained features (A–D) test exclusively words Matthew *does* employ for the Star’s motion, giving a clean comparison with the corpus.

### S3.4 TLG hit-level citation record

Table S8 records every passage retrieved by the wordform searches for each of the four features. Authors returning zero hits for a feature are consolidated in a single row at the end of that section. The Matthew 2:9 sense against which each hit is classified is stated in the section header. “Neg” indicates the hit does not match the Matthew sense; “Pos” would indicate a match. No positive hit was found for any feature in any author.

Table S8: Complete TLG corpus hit record for features A–D (TLG searches conducted via MIT library proxy, 2026-09-04, by exact wordform search over the full paradigm of each lemma.) *Matthew sense*: A = star guides travelers to a destination; B = celestial body stops above a specific terrestrial place; C = celestial body located ἐπάνω a specific terrestrial point; D = celestial body arrives at a terrestrial location. No positive match was found for any feature.

| Author (TLG ID)                                                                                                                                                                                                                                                               | Count | Locus | Usage in context | Pos? |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|-------|------------------|------|
| <b>Feature A: προάγω (exact wordform search).</b> <i>Matthew sense</i> : star actively leads/guides human travelers toward a destination throughout a journey. All corpus uses are positional or temporal precedence in astrological ranking, not spatial narrative guidance. |       |       |                  |      |

*continued on next page*

Table S8 continued

| Author (TLG ID)                                                                                                                                                                                                                                              | Count     | Locus                                                                       | Usage in context                                                                                                                                                                          | Pos? |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Ptolemy {0363}                                                                                                                                                                                                                                               | 3         | <i>Tetrab.</i> 4.3.4.4; 3.14.25.6; 4.4.4.8                                  | Noun cognates<br>προαγωγᾶς,<br>προαγωγικούς,<br>προαγωγούς: astro-<br>logical ranking/dignity<br>terms (“promoting” a<br>planet’s influence), not<br>directional guidance of a<br>person. | Neg  |
| Vettius Valens {1764}                                                                                                                                                                                                                                        | 4         | <i>Anthol.</i> 1.20.123; 1.3.107; 8.7.67; <i>App.</i> 10.1.106              | Astrological positional<br>precedence (one planet<br>“before” another in<br>degree-order or timing);<br>no human traveler, no<br>destination.                                             | Neg  |
| Hephaestion {2043}                                                                                                                                                                                                                                           | 3         | p.155 1.25; p.169 1.10<br>( <i>Apot.</i> 1); p.214 1.5<br>( <i>Apot.</i> 2) | Same positional/temporal<br>astrological antecedence as<br>Valens; no guidance mo-<br>tion toward a terrestrial<br>goal.                                                                  | Neg  |
| Dorotheus {1337}                                                                                                                                                                                                                                             | 1         | <i>Frag. Graeca</i> p.382 1.21                                              | Astrological antecedence<br>(planet “preceding” an-<br>other in zodiac).                                                                                                                  | Neg  |
| Cleomedes, Hipparchus, Geminus, Autoly-<br>cus, Theodosius, Aristarchus, Hyp-<br>sicles, Aratus, Eratosthenes,<br>Achilles Tatius, Theon of Smyrna,<br>Manetho, Paul of Alexandria, Aris-<br>totle ( <i>Meteor.</i> ), Theophrastus ( <i>De<br/>signis</i> ) | 0<br>each | —                                                                           | No instances of προάγω<br>or cognates in any of<br>these corpus texts.                                                                                                                    | Neg  |

**Feature B: ἵστημι (exact wordform search, full paradigm).** *Matthew sense:* celestial body comes to rest above a specific terrestrial location. Every one of the 121 in-corpus occurrences was read in context and classified on the same criterion applied to the other three features: does the passage locate a celestial body above a named terrestrial point? All 121 are negative. Counts by author follow; the passage-level record, with locations and sense assignments, is given in Table S8b.

continued on next page

Table S8 continued

| Author (TLG ID)       | Count     | Locus                                                                                      | Usage in context                                                                                                                                                                                                                                                                            | Pos? |
|-----------------------|-----------|--------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Ptolemy {0363}        | 30        | <i>Alm.</i> , <i>Harm.</i> , <i>Mus.</i> ,<br><i>Tetrab.</i> , <i>Inscr. Canobi</i>        | Instruments set upright; the earth at rest; the “fixed notes” (φθόγγοι ἑστῶτες) of the <i>Harmonica</i> ; planets standing in aspect. No terrestrial reference.                                                                                                                             | Neg  |
| Vettius<br>{1764}     | Valens 13 | <i>Anth.</i> 1.1, 2.17, 2.30,<br>2.32, 6.4, 6.9, 9.8; <i>Frag.</i>                         | The zodiacal sign “in which the Moon (or Sun, or Venus) stands” (ἐφ’ οὗ ἕστηκεν); setting the Moon upon a degree; the sea seeming to stand. Complement always a sign or degree.                                                                                                             | Neg  |
| Dorotheus {1337}      | 11        | <i>Frag. Graeca</i> : pp. 325,<br>336, 339, 341, 345, 350,<br>364, 372, 389                | Planets standing in good or foreign chart places (τόποι); casting the horoskopos. Zodiacal, not terrestrial.                                                                                                                                                                                | Neg  |
| Hephaestion<br>{2043} | 11        | <i>Apot.</i> 1: pp. 39, 90, 118,<br>181, 188, 198, 227, 273;<br><i>Apot.</i> 2: pp. 80, 81 | Lords standing well in chart places; setting the angles; Mars set square or diametric to the luminaries.                                                                                                                                                                                    | Neg  |
| Achilles<br>{2133}    | Tatius 10 | <i>Isagoga</i> §§4, 9, 19, 29                                                              | Whether the earth and the cosmos stand still; the Moon standing between earth and sun in eclipse; a person’s shadow.                                                                                                                                                                        | Neg  |
| Cleomedes {1272}      | 8         | <i>Caelestia</i> 1.1; 2.1, 2.5, 2.6                                                        | The earth at rest; observers standing on the earth; the sun στῆ at exact noon while Syene lies <i>under Cancer</i> (2.1.271, the nearest approach in the corpus, and still not a celestial body standing above a named place: Syene is tied to Cancer by κείται, not to the sun by ἵστημι). | Neg  |

continued on next page

Table S8 continued

| Author (TLG ID)           | Count | Locus                                                 | Usage in context                                                                                                                                                            | Pos? |
|---------------------------|-------|-------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Theon of Smyrna {1724}    | 6     | <i>De util. math.</i> pp.122, 132, 139, 148, 151, 191 | The definition of <b>στηριγμός</b> (p.148); a planet seeming to stand and go backwards (p.191); the zodiac standing <b>ὑπὲρ ἡμᾶς</b> (p.132); a person standing on a shore. | Neg  |
| Manetho {2583}            | 6     | <i>Apot.</i> 1.344; 2.25, 2.107; 3.245; 6.31, 6.287   | Planets standing in aspect or <b>ὑπὲρ κέντρου μεσάτοιο</b> (above the chart's midmost angle); the poles standing unmoved.                                                   | Neg  |
| Eratosthenes {0222}       | 6     | <i>Catast.</i> 1.4, 1.6D, 1.10, 1.11, 1.26, 1.28      | Constellation figures standing (Heracles, Aquarius, Sagittarius); Zeus setting the Twins among the stars.                                                                   | Neg  |
| Theodosius {1719}         | 4     | <i>Sphaerica</i> 1.7; <i>De habitationibus</i> §3     | The zodiac circle standing upright; a straight line set upon a straight line (Euclidean perpendicular). Geometric.                                                          | Neg  |
| Paul of Alexandria {2053} | 4     | <i>Elem. apot.</i> pp.31 (×2), 75, 76                 | Derives <b>στηριγμός</b> from the stars <i>standing still</i> ( <b>ἑστάναι</b> ); planets standing upon chart places.                                                       | Neg  |
| Aratus {0653}             | 4     | <i>Phaen.</i> 306, 610, 865                           | Scorpius standing before Sagittarius; Argo standing aloft; the Moon standing between earth and sun. Celestial positions only.                                               | Neg  |
| Hipparchus {1431}         | 3     | <i>In Arat.</i> 1.7.1, 2.2.42; <i>Frag. geogr.</i> 7  | Quotations of Aratus; <b>μοναί</b> (stations) glossed as <b>ἵστασθαι</b> .                                                                                                  | Neg  |
| Geminus {1383}            | 2     | <i>Elem. astr.</i> 1.20; 17.9                         | Planets “standing still” ( <b>ἑστηκέναι</b> ), which “they call <b>στηριγμούς</b> ”; fixed signs marking weather changes.                                                   | Neg  |

continued on next page

Table S8 continued

| Author (TLG ID)                                                                                                                                                                                                                                                                                                                                                                                 | Count  | Locus                                                                                                                                                    | Usage in context                                                                                                                                 | Pos? |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|----------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Aristotle ( <i>Meteor.</i> ) {0086.026}                                                                                                                                                                                                                                                                                                                                                         | 2      | Bekker 374b 4; 376b 27                                                                                                                                   | A person standing outside as the rainbow appears; the rainbow standing where the sun is most overcome.                                           | Neg  |
| Theophrastus ( <i>De signis</i> ) {0093.008}                                                                                                                                                                                                                                                                                                                                                    | 1      | §12 l.56                                                                                                                                                 | Snakes standing and quivering. Non-celestial.                                                                                                    | Neg  |
| Aristarchus, Autolycus, Hypsicles                                                                                                                                                                                                                                                                                                                                                               | 0 each | —                                                                                                                                                        | No instances of ἵστημι in any of these corpus texts.                                                                                             | Neg  |
| <b>Feature C: ἐπάνω (exact wordform search; the word is indeclinable).</b> <i>Matthew sense:</i> celestial body localized ἐπάνω (“above/over”) a specific named terrestrial point (building, person, city). Contrast with standard astronomical usage: ὑπὲρ for a body above the horizon or another body. All 40 corpus hits use geometric or astrological “above” without terrestrial address. |        |                                                                                                                                                          |                                                                                                                                                  |      |
| Ptolemy {0363}                                                                                                                                                                                                                                                                                                                                                                                  | 14     | <i>Alm.</i> vol.1,1 p.475 l.3; vol.1,2 pp.40–41, 44–45 (×2), 62–63, 64–65, 152–153, 267, 268, 289, 495, 578; <i>Tetrab.</i> 3.4.5.7; <i>Harm.</i> 3.2.23 | Geometric: “above” a construction line or reference arc in the <i>Almagest</i> mathematical diagrams; no celestial body, no terrestrial address. | Neg  |
| Vettius Valens {1764}                                                                                                                                                                                                                                                                                                                                                                           | 6      | <i>Anthol.</i> vol.4 p.149 l.28; 1.2.128; 1.18.90; 1.20.211; 5.1.49; <i>App.</i> 10.1.235                                                                | Astrological: planet or degree “above” a zodiacal sign or angular position; purely positional/relational, no terrestrial address.                | Neg  |
| Hephaestion {2043}                                                                                                                                                                                                                                                                                                                                                                              | 6      | <i>Apot.</i> 1: p.96 l.10, p.314 l.14, p.333 l.15; <i>Apot.</i> 2: p.75 l.4, p.122 l.21, p.187 l.3                                                       | Astrological relational position (planet or lot “above” another in degree or dignity); no specific terrestrial point.                            | Neg  |
| Theodosius {1719}                                                                                                                                                                                                                                                                                                                                                                               | 4      | <i>De diebus et noctibus:</i> p.66 l.33; p.116 l.35; p.120 l.8; p.148 l.33                                                                               | Geometric/temporal: arc or time interval “above” (i.e., exceeding) a reference value; no celestial body localized above a place.                 | Neg  |
| Achilles Tatius {2133}                                                                                                                                                                                                                                                                                                                                                                          | 1      | <i>Isag.</i> §18 l.28                                                                                                                                    | Geometric: celestial sphere “above” the earth in a cosmographic description; not a specific body above a specific address.                       | Neg  |
| Dorotheus {1337}                                                                                                                                                                                                                                                                                                                                                                                | 1      | <i>Frag. Graeca</i> p.413 l.2                                                                                                                            | Astrological relational position.                                                                                                                | Neg  |
| Manetho {2583}                                                                                                                                                                                                                                                                                                                                                                                  | 1      | <i>Apoteles.</i> Bk 5 l.169                                                                                                                              | Astrological: planet above a sign or degree.                                                                                                     | Neg  |

continued on next page

Table S8 continued

| Author (TLG ID)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Count       | Locus                                                       | Usage in context                                                                                                                                               | Pos? |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Theon of Smyrna {1724}                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 4           | <i>De util. math.</i> pp. 34 l.9, 75 l.8, 148 l.9, 201 l.11 | Geometric and arithmetical “above” in the exposition of ratios and planetary order; no terrestrial address.                                                    | Neg  |
| Aristotle ( <i>Meteor.</i> ) {0086.026}                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 3           | Bekker 375b 28; 377a 4; 377a 6                              | Geometric “above” in the analysis of the rainbow and halo; no celestial body localized above a place.                                                          | Neg  |
| Theophrastus {0093}                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 0 in corpus | (13 hits author-wide, none in <i>De signis</i> )            | All Theophrastus hits are in works 002, 004, 005, 010, 014, 017 (not <i>De signis</i> ); 0 in-corpus hits.                                                     | Neg  |
| Cleomedes, Hipparchus, Geminus, Autolycus, Aristarchus, Hypsicles, Aratus, Eratosthenes, Paul of Alexandria                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0 each      | —                                                           | No instances of ἐπάνω in any of these corpus texts.                                                                                                            | Neg  |
| <b>Feature D: ἔρχομαι (exact wordform search, all four suppletive stems).</b> <i>Matthew sense:</i> a celestial body arrives at a specific terrestrial location (a house, a person’s location). ἔρχομαι is suppletive; the stems ἐρχ-, ἔλευσ-, ἔλθ-/ἦλθ- and ἔληλυθ- were searched separately (171 forms tested, 61 attested), including the aorist that supplies Matthew’s own ἔλθων. Of the 356 in-corpus occurrences, 103 have a celestial subject. The construction is standard and frequent (ὁ Ἄρης ἐπὶ τὸν ἥλιον ἔλθων, “Mars coming upon the Sun”; ὁ Ζεὺς ἔλθων εἰς τὸν ὥροσκόπον, “Jupiter coming into the horoskopos”), but the destination is invariably another body or a point in the chart. Tabulating the objects governed by ἐπὶ/εἰς/πρὸς across those 103 passages yields ὥροσκόπον, Δία, ἥλιον, Κρόνον, ζῳδίου, μοῖραν, κέντρα, μεσουράνημα, ὑπόγειον, τόπους, διάμετρον, τετράγωνον, and no terrestrial place whatever. |             |                                                             |                                                                                                                                                                |      |
| Vettius Valens {1764}                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 98          | <i>Anthol.</i> and <i>Frag.</i> , passim                    | Planet “comes to” (ἐλθών) another planet, the horoskopos, a degree, sign or aspect; the destination is a zodiacal or chart locus, never a terrestrial address. | Neg  |
| Hephaestion {2043}                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 65          | <i>Apot.</i> 1 and <i>Apot.</i> 2, passim                   | Same usage throughout.                                                                                                                                         | Neg  |
| Dorotheus {1337}                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 42          | <i>Frag. Graeca</i> , passim                                | Same usage; e.g. p. 379 l.22 ὁ Ἄρης ἐπὶ τὸν ἥλιον ἔλθων.                                                                                                       | Neg  |

continued on next page

Table S8 continued

| Author (TLG ID)                              | Count  | Locus                                | Usage in context                                                                                                                                                                                                                                                                | Pos? |
|----------------------------------------------|--------|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Ptolemy {0363}                               | 28     | <i>Alm., Tetrab., Harm.</i>          | Arrival at a computed position, a season, or a stage of an argument; no terrestrial destination for a celestial body.                                                                                                                                                           | Neg  |
| Theodosius {1719}                            | 24     | <i>Sphaerica, De hab., De diebus</i> | Geometric: a point or arc “arriving at” another in a construction.                                                                                                                                                                                                              | Neg  |
| Manetho {2583}                               | 19     | <i>Apot.</i> , passim                | Planets arriving in aspect or sign.                                                                                                                                                                                                                                             | Neg  |
| Aratus {0653}                                | 18     | <i>Phaen.</i> , passim               | Risings and settings; constellations coming round in the annual cycle.                                                                                                                                                                                                          | Neg  |
| Aristotle ( <i>Meteor.</i> ) {0086.026}      | 15     | Bekker, passim                       | Meteorological and argumentative senses; no celestial body at a place.                                                                                                                                                                                                          | Neg  |
| Theon of Smyrna {1724}                       | 14     | <i>De util. math.</i> , passim       | Includes p.154 l.6, the sole passage in the corpus contemplating a celestial body arriving at the earth, and it is a <i>reductio</i> : were the solar circle to pass through that point, “the sun itself would come to the earth”, which the author calls ἀμήχανον, impossible. | Neg  |
| Eratosthenes {0222}                          | 14     | <i>Catast.</i> , passim              | Mythological narrative of the catasterism, and stars rising.                                                                                                                                                                                                                    | Neg  |
| Autolycus {1210}                             | 6      | <i>De sphaera, De ortibus</i>        | Geometric arrival of a point on a circle.                                                                                                                                                                                                                                       | Neg  |
| Hipparchus {1431}                            | 5      | <i>In Arat.</i>                      | Commentary on risings; no terrestrial destination.                                                                                                                                                                                                                              | Neg  |
| Cleomedes {1272}                             | 3      | <i>Caelestia</i>                     | Light and observers; no celestial body at a named place.                                                                                                                                                                                                                        | Neg  |
| Theophrastus ( <i>De signis</i> ) {0093.008} | 3      | §§ passim                            | Weather signs; non-celestial subjects.                                                                                                                                                                                                                                          | Neg  |
| Geminus {1383}                               | 1      | <i>Elem. astr.</i>                   | Positional arrival in the zodiac.                                                                                                                                                                                                                                               | Neg  |
| Achilles Tatius {2133}                       | 1      | <i>Isagoga</i>                       | Cosmographic exposition.                                                                                                                                                                                                                                                        | Neg  |
| Aristarchus, Hypsicles, Paul of Alexandria   | 0 each | —                                    | No instances of ἔρχομαι in any of these corpus texts.                                                                                                                                                                                                                           | Neg  |

### S3.5 Thematic operationalization of features A–D

The four genre-register features A–D can be operationalized at two levels: *lexically* (does a specific Greek form appear with a celestial subject in the specified semantic role?) and *thematically* (does the underlying narrative event occur in the text, regardless of lexical choice?). These two operationalizations are correlated by definition (vocabulary and theme co-vary within genre) and are therefore not treated as independent Bayes factors. Their consistency is reported here as a robustness check: if the features measure genre-register signal rather than idiosyncratic word choice, both operationalizations should yield the same classification.

Table S9 shows the parallel formulations and the result of applying the thematic criterion to both corpora.

**Thematic assessment of the astronomical corpus.** *Feature A (guidance of travelers).* The verb προάγω and its cognates appear in the astronomical corpus in two senses: temporal antecedence (“the epicycle *precedes* the deferent”) and positional antecedence in longitude (“Mars *precedes* Jupiter by 15°”). In both senses the subject stands in a purely geometric or positional relationship to another celestial quantity; no text describes a star directing human agents toward a terrestrial destination. Astrological texts introduce human destinies as the *consequences* of planetary configurations but never as guided by a moving star. The narrative function, a celestial body leading travelers step by step toward a goal, is absent at every level of description.

*Feature B (stopping above a location).* Mathematical astronomy describes planetary stationary points (στηριγμός, the moment of zero longitudinal velocity relative to the fixed stars) as geometric events in the zodiac: a planet computed to have zero velocity in a given zodiacal longitude. The framework is wholly mathematical; no text in the corpus uses stationary-point language to say that a body “stands over” a house, city, or person.

Matthew’s own verb, ἵστημι, occurs 121 times in the corpus, and none of the 121 carries the Matthean sense. The distribution of senses is instructive: a planet or luminary standing *in* a zodiacal sign, degree or chart place (roughly 45 occurrences); the “fixed notes” (φθόγγοι ἑστῶτες) of Ptolemy’s *Harmonica* (about 20); the earth, cosmos or sea at rest, and eclipse geometry (about 15); constellation figures standing: Heracles, Aquarius, Sagittarius, Virgo (about 8); instruments set upright and geometric lines set upon lines (about 10); persons standing (about 10); the transitive casting of a chart, “to set the horoskopos” or “the angles” (about 8); and the planetary station itself (about 5). In every case the complement of the standing is celestial or geometric (a sign, a degree, an aspect, a chart angle, a fixed star) and in no case is it a named place on the ground. Matthew’s own form ἐστάθη does not occur in the corpus at all.

The temporal particle ἕως (“until”) in Matthew 2:9 further confirms that ἐστάθη denotes a *change of state*, not a prior static condition. The clause structure, “the Star was going before them [προῆγεν] *until* [ἕως] it stood [ἐστάθη] over the house”, makes ἐστάθη the temporal limit of the guidance action: the guiding motion ceased precisely when the standing began. In Koine Greek, ἕως governing an aorist indicative (ἕως ἔλθων ἐστάθη) marks the boundary at which the foregoing action terminated; a reading of the Star as *already* stationary throughout, making ἐστάθη merely descriptive of a pre-existing condition, is excluded by this boundary particle. The astronomical stationary-point reading (a planet at zero longitudinal velocity for a brief computed instant) is also grammatically incompatible with the imperfect προῆγεν (continuous ongoing guidance), which requires a sustained temporal extension that a mathematical instantaneous point cannot supply.

*Feature C (localization above a terrestrial address).* Spatial prepositions locate celestial bodies

above zodiacal regions (ὕπὲρ Σκορπίου, “above Scorpius”), above the horizon (ὕπὲρ γῆν, “above earth”), or above other celestial bodies. The *referent* is always another celestial quantity or the abstract celestial sphere; no text localizes a star above a named building, named city, or named person in the sense of ἐπάνω οὗ ἦν τὸ παιδίον (“above where the child was”). This feature is absent thematically as thoroughly as it is lexically.

*Feature D (arrival at a terrestrial point).* Arrival language in the corpus is abundant. Ἔρχομαι occurs 356 times, 103 of them with a celestial subject, and the construction Matthew uses (a body arriving somewhere, expressed with ἐπί, εἰς or πρὸς) is the ordinary idiom of the astrological writers: ὁ Ἄρης ἐπὶ τὸν ἥλιον ἐλθών, “Mars coming upon the Sun” (Dorotheus p. 379 l.22); ὁ Ζεὺς ἐλθὼν εἰς τὸν ὠροσκόπον, “Jupiter coming into the horoskopos” (Vettius Valens *Frag.* vol. 8,1 p. 165 l.5). The feature is therefore not absent for want of the verb or of the construction.

What the 103 celestial-subject passages never supply is a terrestrial destination. Tabulating every object governed by ἐπί, εἰς or πρὸς in those passages returns ὠροσκόπον, Δία, ἥλιον, Κρόνον, Ἀφροδίτην, ζῳδιον, μοῖραν, κέντρα, μεσουράνημα, ὑπόγειον, τόπους, διάμετρον and τετράγωνα: other bodies, and points within the chart. Not one is a place on the ground.

**The single counter-case, and what it says.** Exactly one passage in the corpus puts a celestial body and the earth together as arrival and destination. Theon of Smyrna, discussing whether the solar circle could pass through a particular point of his construction, writes (*De util. math.* p. 154 ll. 5–7):

διὰ μὲν οὖν τοῦ θ τὸν ἡλιακὸν ἔρχεσθαι κύκλον, ἀμήχανον· καὶ γὰρ αὐτὸς ἂν ὁ ἥλιος ἐπὶ γῆν παρεγίνετο

“For the solar circle to travel through θ is impossible; for then the sun itself would come to the earth.”

The sentence is a *reductio ad absurdum*. Theon raises the possibility of a celestial body arriving at the earth in order to reject it, and marks it ἀμήχανον, not merely unattested but impossible. The consequent is put in the past contrafactual (ἂν ... παρεγίνετο), the standard Greek construction for an outcome that does not and cannot obtain.

This is the strongest single datum in the corpus analysis. The claim under test is that Greek astronomical writers do not describe celestial bodies arriving at terrestrial locations. The corpus supplies 356 occurrences of the relevant verb without a single such description; and where one author does frame the notion explicitly, he frames it as an absurdity used to refute a geometric hypothesis. The absence is not a gap in the sample. It is a commitment of the discourse.

**Consistency with the lexical result.** Because the lexical and thematic operationalizations agree at every feature for both corpora, the features A–D are functioning as genre-register markers rather than as idiosyncratic vocabulary tests. A critic who argued that Matthew’s use of προάγω merely reflected an unusual but attested astronomical sense would still need to explain the thematic absence of guided-traveler narratives from the entire corpus; and a critic who argued that the guiding-star thematic comparison was too loose would still need to explain the lexical exclusion of Matthew’s specific Greek forms from astronomical discourse. The two levels of evidence are mutually reinforcing without being statistically independent, and together provide a more robust basis for the genre-classification conclusion than either level alone.

### S3.6 Statistical methodology

A one-sided Fisher exact test was applied to each  $2 \times 2$  contingency table of the form:

|             | Matthew-type usage | Standard astron. usage |
|-------------|--------------------|------------------------|
| Matthew 2:9 | $a$                | $b$                    |
| Corpus      | $c$                | $d$                    |

Because Matthew’s star-motion passage comprises only  $\approx 90$  words, all Matthew-side cell counts are 0 or 1 ( $b \in \{0, 1\}$ ,  $a = 1 - b$ ). The individual Fisher exact probabilities are:  $p_A = 0.083$  ( $N = 11$ ),  $p_B = 0.0082$  ( $N = 121$ ),  $p_C = 0.024$  ( $N = 40$ ),  $p_D = 0.0028$  ( $N = 356$ ) (TLG counts, 2026-09-04, by exact wordform search over the full paradigm of each lemma, with **Exact Match** and **Diacritics sensitive** enabled; see Table S8.) The Fisher combined chi-squared statistic is  $X = -2 \sum_i \ln p_i = 33.76$  on  $\text{df} = 8$ , giving  $p_{\text{Fisher}} \approx 4.5 \times 10^{-5}$ . The product of individual probabilities (the correct joint data probability under independence, and the appropriate BF denominator) is  $P(A, B, C, D \mid H_{\text{astro}}) = \prod_i p_i = 4.7 \times 10^{-8}$ .

Features B and D individually pass the Bonferroni threshold  $\alpha/4 = 0.013$ ; Features A and C do not, and A remains at the floor value imposed by its corpus size ( $1/12$ , the smallest value that denominator admits). The joint Fisher combined statistic is significant ( $p = 4.5 \times 10^{-5}$ ) and all four features contribute under the joint test.

### Robustness to inter-feature correlation

The product formula  $\prod p_i$  assumes independence of the four tests, which could be violated if certain text types tend to share multiple Matthew-like words simultaneously. To assess this, I modeled the joint null distribution using a Gaussian copula with equicorrelation parameter  $\rho$ : four standard normal variables ( $Z_1, \dots, Z_4$ ) with correlation matrix  $\Sigma_{ij} = \rho$  for  $i \neq j$  were simulated, then converted to two-tailed  $p$ -values via  $p_i = 2\Phi(-|Z_i|)$ , and the Fisher combined statistic  $X = -2 \sum_i \ln p_i$  was computed. The observed value  $X = 33.76$  was compared against the simulated null distribution at each  $\rho$  using  $2 \times 10^6$  Monte Carlo draws.

The corrected joint  $p$  remains below  $\alpha = 0.05$  across the entire tested range, to  $\rho = 0.95$  (Table S10); at  $\rho = 0.5$  the corrected  $p = 0.0027$ . Brown’s variance-corrected chi-squared method[17] gave consistent results throughout.

Subset analysis (drop-one,  $k = 3$  features): every drop-one-feature subset remains jointly significant at  $\alpha = 0.05$  under independence (weakest drop-one:  $p = 0.0012$ , dropping Feature D). Every three-feature subset also remains significant; the weakest yields  $p = 0.015$  (dropping Features B and D together), which is individually significant but reflects that B and C are the two most moderately-evidenced features; all other three-feature combinations give  $p \leq 0.042$ .

### S3.7 Guiding-star corpus and Bayes factor (Table S11)

To contextualise the corpus-linguistic finding within the broader literary tradition, I assembled a comparative corpus of independently attested in contemporaneous or pre-Matthean guiding-star narrative *traditions*: each row represents one convention, not one text. Multiple texts reporting the same underlying event or sharing a known common source are collapsed to a single entry.

*Collapsing rationale.* Plutarch’s *Timoleon* 8.7 and Diodorus Siculus 16.66.3 both describe the same Timoleon episode and almost certainly drew on the same earlier source (likely Timaeus of Tauromenium c. 345–260 BCE); treating them as independent data points would be double-counting one attestation. Plutarch describes the guiding phenomenon as a light from heaven ( $\phi\acute{\epsilon}\gamma\gamma\omicron\varsigma \omicron\upsilon\acute{\rho}\alpha\nu\iota\omicron\nu$ ); Diodorus attributes it to the goddesses Demeter and Persephone, framing it as divine luminous guidance. LXX *Exodus* 13.21 and *Numbers* 14.14 represent a single continuous Israelite pillar-of-fire convention: *Numbers* is Moses recounting the Exodus tradition to God, not an independently invented guiding-star motif. *Wisdom of Solomon* 10.17 describes the same tradition as “a blazing flame of stars by night” ( $\acute{\alpha}\sigma\tau\rho\omega\nu \phi\lambda\acute{o}\gamma\alpha$ ), establishing its

stellar characterization in Second Temple Jewish literature. In both cases, counting the texts separately would inflate the effective corpus size without adding independent evidential weight. The effect of collapsing (reducing  $N$  from 6 to 4) is to *raise* the Bayes factor slightly, because Laplace smoothing for the zero-count feature C is more generous at smaller  $N$  ( $P(C) = 1/6$  vs.  $1/8$ ); the methodologically stricter corpus thus produces a modestly stronger result.

The *Protoevangelium of James* 21 is excluded because it is a derivative of Matthew 2:9–10, not an independent witness; its guiding-star language is adopted from Matthew. Plutarch’s *Lysander* 12.1 and Cicero’s *De Divinatione* 1.75 record the Dioscuri appearing alongside Lysander’s fleet as an omen of victory at Aegospotami: they are stellar-epiphany texts with no directional guidance to a destination, and are excluded from the primary corpus but shown in the sensitivity analysis.

Table S9: Lexical and thematic operationalizations of features A–D, with results for the astronomical corpus and the guiding-star traditions.

| Feat. | Lexical criterion                                                                           | Thematic criterion                                                                                             | Astron. corpus                                                                                                                | Guiding-star trad. |
|-------|---------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|--------------------|
| A     | προάγω with celestial subject in narrative guidance of human travelers toward a destination | Celestial body actively directs human travelers toward a specific destination                                  | 0 (positional and temporal <i>precedence</i> only)                                                                            | 4 / 4 traditions   |
| B     | ἵστημι (not στηρίζω) with celestial body coming to rest at a specific location              | Celestial body ceases motion at or above a specific terrestrial location (not a mathematical stationary point) | 0 (στηριγμός is a zodiacal longitude event in a geometric model; no body halts above a place)                                 | 2 / 4 traditions   |
| C     | ἐπάνω (not ὑπὲρ) locating a celestial body above a specific terrestrial address             | Celestial body localized directly above a specific terrestrial address (building, person, plot of land)        | 0 (celestial bodies located above zodiacal regions or the abstract horizon, never above a terrestrial address)                | 0 / 4 traditions   |
| D     | ἔρχομαι/ἐλθεῖν with celestial subject arriving at a terrestrial geographic point            | Celestial body arrives at a specific point on the Earth’s surface                                              | 0 (arrival language for celestial bodies refers to zodiacal positions, aspects, or culminations; never to terrestrial points) | 3 / 4 traditions   |

At every feature, the thematic operationalization yields the same result as the lexical operationalization for both corpora. The astronomical corpus scores zero at the thematic level for all four features, confirming that the absence of Matthew’s vocabulary from astronomical texts reflects the absence of the corresponding *events*, not merely a difference in preferred vocabulary. The guiding-star traditions score identically at the thematic level as at the lexical level because those traditions were scored by narrative function from the outset. The Bayes factor derived from the lexical analysis ( $BF \approx 3.0 \times 10^6$ ) therefore also characterizes the thematic evidence: the two analyses are measuring the same genre-register signal at different levels of abstraction.

Table S10: Gaussian copula correction of the joint corpus  $p$ -value under equicorrelation  $\rho$ .

| $\rho$ | Corrected $p$ (copula) | Brown's $p$          |
|--------|------------------------|----------------------|
| 0.0    | $4.3 \times 10^{-5}$   | $4.5 \times 10^{-5}$ |
| 0.2    | $2.6 \times 10^{-4}$   | $9.8 \times 10^{-5}$ |
| 0.4    | $1.5 \times 10^{-3}$   | $5.0 \times 10^{-4}$ |
| 0.5    | $2.7 \times 10^{-3}$   | $1.1 \times 10^{-3}$ |
| 0.6    | $4.3 \times 10^{-3}$   | $2.3 \times 10^{-3}$ |
| 0.7    | $6.4 \times 10^{-3}$   | $4.2 \times 10^{-3}$ |
| 0.8    | $8.9 \times 10^{-3}$   | $6.9 \times 10^{-3}$ |
| 0.9    | $1.2 \times 10^{-2}$   | $1.0 \times 10^{-2}$ |
| 0.95   | $1.3 \times 10^{-2}$   | $1.2 \times 10^{-2}$ |

Equicorrelation  $\rho$  represents the average pairwise correlation among the four test statistics under  $H_0$ . A realistic upper bound for distinct lexical items across genre is  $\rho \approx 0.5$ ;  $\rho = 0.95$  would require near-identical distributional behavior for all four grammatically distinct feature classes. The corrected  $p$  remains below  $\alpha = 0.05$  throughout the tested range, including at  $\rho = 0.95$ , so the conclusion does not depend on any judgement about the plausible magnitude of  $\rho$ . Script: `corpus_pvalue.py`.

Table S11: Guiding-star narrative traditions: feature scores for Bayes factor analysis. Each row is one independently attested tradition. A = guidance verb; B = stopping verb (ἵστημι-type); C = ἐπι-based localization over a specific point (ἐπάνω or structural equivalent; ἐπί/ἐπάνω are interchangeable in the JosAsen manuscript tradition); D = arrival verb.

| Tradition (constituent texts)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | A | B | C | D |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|---|---|---|
| <i>Primary corpus: four independent guiding-star traditions (N = 4)</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |   |   |   |   |
| Virgil, <i>Aeneid</i> 2.687–711<br>Venus/Lucifer “marks the way” ( <i>signantemque vias</i> ); star terminates in Ida’s forest (B); Aeneas arrives in Italy (D). No ἐπάνω localization. Servius ( <i>ad Aen.</i> 2.694) identifies the celestial guide explicitly as Venus in her role as Lucifer ( <i>morning star</i> ), confirming this is a stellar guiding tradition in Roman exegesis, not merely a light-omen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 1 | 1 | 0 | 1 |
| Timoleon flame tradition<br>Plutarch, <i>Tim.</i> 8.7 + Diodorus 16.66.3: same event, common source. Plutarch: “a light from heaven” (φέγγος οὐράνιον) runs with fleet (A), darts down on destination (B); Diodorus: light provided by the goddesses (A, D). Fleet arrives in Sicily (D).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 1 | 1 | 0 | 1 |
| Lucian, <i>Navigium</i> 7; 9<br>Nav. 7 and 9 are explicit that the guide is a star (ἀστήρ); Nav. 7 calls it a saviour star and Nav. 9 describes its motions. Star first stands over (ἐπικαθίσαι) the masthead (τῷ καρχησίῳ) (the prefix ἐπι- is the same root as Matthew’s ἐπάνω (ἐπί + ἄνω), and JosAsen manuscripts alternate ἐπί and ἐπάνω for the same angelic localization scene, confirming they are stylistic variants (C=1). Sequence: standing over → guiding (reverse of Matthew). Star then guides ship on its left side (ἐπὶ τὰ λαιά, A, D). No discrete stop at destination: B=0. Genre: satirical comic dialogue.                                                                                                                                                                                                                                                                                                                                                                                                                                | 1 | 0 | 1 | 1 |
| Israelite pillar-of-fire tradition<br>LXX Exodus 13.21 + Numbers 14.14: same convention. Pillar goes before (προπορεύεσθαι); ongoing guidance only, no discrete stop or arrival. C=1: the cloud/pillar stands over (ἐπί) the Tabernacle in three explicit passages using the same preposition as Matthew’s ἐπάνω: Exod 40.38 (νεφέλη γὰρ ἦν ἐπὶ τῆς σκηνῆς ἡμέρας καὶ πῦρ ἦν ἐπ’ αὐτῆς νυκτός), Num 9.15 (καὶ ἐσπέρας ἦν ἐπὶ τῆς σκηνῆς ὡς εἶδος πυρὸς ἕως πρωί), and Num 9.18–22 (πάσας τὰς ἡμέρας, ἐν αἷς σκιάζει ἡ νεφέλη ἐπὶ τῆς σκηνῆς). As established in the table header, ἐπί and ἐπάνω (ἐπί + ἄνω) are structural equivalents for localization above a specific point; the pillar tradition therefore satisfies feature C. Wisdom of Solomon 10.17 (same tradition) describes the pillar as “a blazing flame of stars” (ἄστρων φλόγα), establishing the stellar characterization of this tradition in Second Temple Jewish literature and confirming it belongs to the divinely-sent luminous guide category rather than a purely fire-omen category. | 1 | 0 | 1 | 0 |
| <i>Stellar-omen texts (sensitivity analysis only; excluded from primary corpus)</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |   |   |   |   |
| Josephus, <i>Jewish War</i> 6.289<br>Sword-like star ἔστη over Jerusalem (B=1, same verb as Matthew) but uses ὑπὲρ not ἐπάνω (C=0); labeled τερατεία; no guidance (A=0) or arrival (D=0).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 0 | 1 | 0 | 0 |
| Dio Cassius, <i>Roman History</i> 54.29.8<br>Comet over Rome at death of Agrippa; verb αἰωρηθεῖς (NOT ἵστημι); prep. ὑπὲρ (NOT ἐπάνω). No guidance or arrival.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0 | 0 | 0 | 0 |
| Plutarch, <i>Lysander</i> 12.1<br>Dioscuri appear alongside fleet as victory omen; no guidance, no destination.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0 | 0 | 0 | 0 |
| Cicero, <i>De Divinatione</i> 1.75<br>Same Aegospotami/Dioscuri tradition.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 0 | 0 | 0 | 0 |
| <i>Matthean derivative (excluded)</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |   |   |   |   |
| Protoevangelium of James 21<br>Paraphrases Matt 2:9–10 verbatim; not an independent witness.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | — | — | — | — |
| <i>Supernatural descent texts (feature C commentary only; not in BF corpora)</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |   |   |   |   |

Continued on next page

Table S11 continued

| Tradition (constituent texts)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | A          | B          | C          | D          |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|------------|------------|------------|
| PGM I.54–95                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 0          | 1          | 0          | 1          |
| <i>Descending star-god stands ἐν μέσῳ τοῦ δώματος</i> (“in the middle of the housetop”): ἐν μέσῳ, not ἐπάνω ( $C=0$ ). No guidance ( $A=0$ ).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |            |            |            |            |
| <i>Joseph and Aseneth</i> 14.4 (Burchard longer rec.)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 0          | 1          | 1          | 1          |
| <i>Morning star descends as divine messenger</i> (ἄγγελος); <i>stands ἔστι ἐπάνω τῆς κεφαλῆς αὐτῆς</i> ( $C=1$ ). <i>Departs eastward in solar chariot</i> (star = messenger identity). <i>Philonenko shorter rec.</i> : ἐπί ( $C=0$ ). <i>Genre: diaspora Jewish novel: same broad literary type as the gospels. No guidance</i> ( $A=0$ ).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |            |            |            |            |
| <b>Feature frequency</b> (primary, $N = 4$ )                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | <b>4/4</b> | <b>2/4</b> | <b>2/4</b> | <b>3/4</b> |
| $P(\text{feat.} \mid H_{\text{guide}})$ , Laplace $k = 1$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 5/6        | 3/6        | 3/6        | 4/6        |
| <p>Joint: <math>P(A, B, C, D \mid H_{\text{guide}}) = \frac{5}{6} \times \frac{3}{6} \times \frac{3}{6} \times \frac{4}{6} \approx 1.39 \times 10^{-1}</math>. <math>\text{BF} = 1.39 \times 10^{-1} / 4.67 \times 10^{-8} \approx 3.0 \times 10^6</math> (exceeds 100 on the Jeffreys scale). <math>P(A, B, C, D \mid H_{\text{astro}}) = \prod_i p_i = 4.67 \times 10^{-8}</math> (product of individual Fisher exact probabilities; the Fisher combined tail-<math>p</math> of <math>4.5 \times 10^{-5}</math> is a meta-test statistic, not a joint data probability). Sensitivity: +Josephus &amp; Dio (<math>N = 6</math>): <math>\text{BF} = 1.3 \times 10^6</math>; +all omen (<math>N = 8</math>): <math>\text{BF} = 5.1 \times 10^5</math>; <math>k \in [0.5, 3]</math>: <math>\text{BF} \in 2.3\text{--}3.4 \times 10^6</math>; <math>3 \times</math> denominator uncertainty: <math>1.0\text{--}9.3 \times 10^6</math>. <b>Feature C key finding:</b> ἐπι-based localization (ἐπάνω or structural equivalent) scores 0 in all astronomical texts, all omen texts, and PGM I.54–95. It appears in exactly three non-Matthean texts: Lucian, <i>Nav.</i> 9 (ἐπικαθίσαι τῷ καρχησίῳ; a comic dialogue); <i>JosAsen</i> 14.4 longer rec. (ἐπάνω τῆς κεφαλῆς; a diaspora Jewish novel); and the Israelite pillar-of-fire tradition, where ἐπί marks the cloud/pillar standing over the Tabernacle at Exod 40.38, Num 9.15, and Num 9.18–22. <i>JosAsen</i> manuscripts alternate ἐπί and ἐπάνω for the same scene, confirming these are stylistic variants in the narrative register. All three attestations belong to the legendary or sacred-narrative register; the astronomical and omen corpora use ὑπὲρ exclusively. Script: <code>guiding_star_bayes.py</code>.</p> |            |            |            |            |

## S4 Software and computational environment

All orbital mechanics computations and statistical analyses were performed in Python 3.12. The principal libraries used were:

- `astropy` v6.x[18] (coordinate transformations, JPL ephemeris access, time systems.
- `NumPy`[19]) vectorised array operations and `einsum`-based orientation sweeps.
- `SciPy`[20]: Fisher’s exact test (`scipy.stats.fisher_exact`), Newton–Raphson utilities.
- `matplotlib`[21], all figures.
- `Stellarium`[22], independent cross-validation of sky-position results at representative epochs; computed positions agreed to within observational tolerances at all tested times.
- `VSOP87` (via `PyMeeus`): Earth’s heliocentric position for all close-approach geometry. The bundled modern DE ephemerides do not extend to 5 BCE, and extrapolating the low-precision default series to that epoch introduces an error of  $\approx 43''$  in Earth’s position. For objects at ordinary heliocentric distances this is immaterial, but at a geocentric distance of  $\sim 10^5$  km it displaces the observer by  $\approx 3 \times 10^4$  km and swings the sightline by degrees, so the close-flyby analyses use VSOP87 throughout.

### S4.1 Reproducibility, and the tolerance on configuration counts

Two kinds of number are reported from the surveys, and they carry different reproducibility.

The *result*, the number of configurations satisfying all criteria simultaneously, is exact and environment-independent. It is zero, and reruns under different software builds return zero identically. The extremal diagnostics are likewise reproducible bit-for-bit: best guidance score  $0.0414^\circ$  and best stopping score  $0.0376^\circ \text{ h}^{-1}$  agree to sixteen significant figures across environments. This is expected, since the nearest candidate misses by a wide margin and no plausible

numerical perturbation can move it across the criterion.

The *census* counts (how many configurations are classed as visible, or as passing one criterion in isolation) carry a small systematic tolerance. Each is a threshold test, so configurations lying within numerical noise of a boundary may fall on either side of it depending on the ephemeris implementation. Re-running the fine survey under a different **astropy**/**pyerfa** build gives:

| Census bin                        | Count       | Tolerance    |
|-----------------------------------|-------------|--------------|
| Visible                           | 202,372,076 | $\pm 0.1\%$  |
| Passing azimuth criterion         | 126,720     | $\pm 0.3\%$  |
| Passing guidance-motion criterion | 6,278       | $\pm 0.7\%$  |
| Passing stopping criterion        | 201,505,224 | $\pm 0.1\%$  |
| <b>Satisfying all criteria</b>    | <b>0</b>    | <b>exact</b> |

The tolerance is larger for the smaller bins simply because a fixed number of boundary configurations is a larger fraction of a smaller count. These figures should therefore be read as  $2.024 \times 10^8$  visible configurations to within a tenth of a percent, not as exact integers; the counts quoted throughout were produced with Python 3.12, **astropy** 6.x and the bundled **pyerfa**. Only the final row is exact, and it is the only row on which the paper’s conclusion depends.

Code and data necessary to reproduce all figures and tables in the main paper and this Supplementary Information are available at [https://github.com/adairaar/sob\\_astro\\_test](https://github.com/adairaar/sob_astro_test). The repository includes:

- **sob\_proof\_fine.py** (kinematic demonstration and exhaustive heliocentric orbital survey (5° angular grid, 529 million configurations))
- **sob\_mc\_refined.py** Monte Carlo refinement sweeps in continuous parameter space around the best-fit grid orbit and Matney’s proposed 5 BCE comet; 2.25 million configurations sampled, zero satisfying all criteria
- **sob\_epoch\_robustness.py**: multi-epoch survey across all proposed Star of Bethlehem dates (12 BCE, 7 BCE, 5 BCE, 1 BCE), recomputing Earth positions and ENU matrices from the JPL ephemeris at each date; total 79,788 visible configurations across 7 epochs
- **sob\_calcs.py**, Matney comet orbital analysis
- **sob\_figures.py**, figure generation
- **corpus\_pvalue.py**: Gaussian copula simulation and Brown’s method for joint  $p$ -value robustness;  $2 \times 10^6$  Monte Carlo draws per correlation level
- **corpus\_linguistics.py**, Fisher’s exact test and contingency tables
- **data/**, parameter grids, survey outputs, corpus counts

## S5 Supplementary discussion

### S5.1 Corpus-linguistic finding in context

The linguistic evidence adds a dimension the mechanics alone cannot supply. Even granting an unknown physical mechanism capable of producing the required velocity change, such a mechanism would still leave unexplained why an evangelist reporting on a celestial phenomenon used none of the vocabulary that Greek astronomical and astrological writers used for exactly that purpose over eight centuries of writing. The vocabulary of leading (**προάγω**), arriving (**ἔρχομαι**), and standing over (**ἵστημι ἐπάνω**) belongs to the narrative register that Greek authors used for persons and supernatural agents. This has been observed qualitatively in prior scholarship[4, 23]; the present analysis quantifies it with a Fisher combined  $p \approx 4.5 \times 10^{-5}$

against the null hypothesis that Matthew’s usage is drawn from the same distribution as the astronomical corpus. When the alternative hypothesis is framed as the well-attested guiding-star narrative tradition of Greco-Roman and Jewish literature, the Bayes factor in favor of the narrative reading is  $BF \approx 3.0 \times 10^6$  (exceeding 100 on the Jeffreys scale) under strict independence, and  $5.1 \times 10^5$  if guiding and omen texts are pooled. Sensitivity to the dependence assumptions is treated separately in Table S12, which is the range on which the conclusion rests.

A potential methodological concern is that the lexical analysis (Fisher’s exact tests against the astronomical corpus) and the Bayes factor comparison operate at different levels of abstraction: the former compares specific Greek vocabulary against a Greek-language corpus, while the latter scores narrative traditions thematically, across multiple languages. These are not inconsistent but complementary, because features A–D are genre-register markers at both levels simultaneously. The thematic robustness check (Table S9) confirms that the null result holds at the thematic level: Greek astronomical and astrological texts do not describe celestial bodies guiding human travelers toward a destination, ceasing motion above a specific house, or arriving at a terrestrial address, at any level of description. The lexical and thematic analyses converge on the same genre classification. Because lexical and thematic features co-vary within genre by definition, the two are treated as convergent confirmation rather than independent Bayes factors; their consistency confirms the genre-register signal.

The register of Matthew 2:9, on this dual-level analysis, is that of ancient narrative prose (the language of novels, legendary accounts, and divinely-guided journeys) rather than of astronomical or astrological writing. This conclusion holds whether the evidence is drawn from specific Greek vocabulary or from the narrative functions the text describes.

## S5.2 ἐπάνω and the preposition data in detail

Feature C (ἐπάνω) is particularly diagnostic of literary register. In *Jewish War* 6.289, Josephus describes a sword-shaped star that “stood” (ἔστη, the same ἵστημι verb as Matthew, feature B) “over” the city, but uses the preposition ὑπὲρ rather than ἐπάνω; he explicitly classifies the portent as a τερατεία (“prodigy”) rather than an astronomical observation. Dio Cassius uses αἰωρηθείς (“suspended/lifted”) and likewise ὑπὲρ. Every astronomical and omen text without exception uses ὑπὲρ for a celestial body positioned above a terrestrial point; not one uses ἐπάνω or any ἐπι-compound in that role.

By contrast, ἐπι-based localization is attested in the guiding-star narrative tradition: Lucian’s *Navigium* 9 uses ἐπικαθίσαι τῷ καρχησίῳ (“stood upon the masthead”) and the *Joseph and Aseneth* 14.4 longer recension (Burchard) uses ἔστη ἐπάνω τῆς κεφαλῆς αὐτῆς for an angelic figure; crucially, the Philonenko shorter recension of the same passage substitutes ἐπί, showing that ἐπί and ἐπάνω were treated as interchangeable by scribes working within the narrative register. The genre of *Joseph and Aseneth* is significant: it is a diaspora Jewish novel, legendary narrative prose of the same broad literary kind as the Gospels, not an astronomical treatise or omen record. Feature C therefore discriminates not between two equal options but between two distinct literary registers: ὑπὲρ in observational and omen discourse; ἐπάνω/ἐπι-compounds in legendary narrative texts.

The closest parallels for a star-like divine entity descending to ground level are the Greek Magical Papyri and *Joseph and Aseneth*. In PGM I.54–95 a spell summons a god in the form of a star to come down (κατελθών) to the earth (ἔγγαιος); the star stands ἐν μέσῳ τοῦ δώματος (“in the middle of the housetop”), not ἐπάνω. In *Joseph and Aseneth* 14.1–5 the morning star descends, manifests as a radiant heavenly visitor, and departs eastward before sunrise; the longer recension uses ἐπάνω, the shorter uses ἐπί[23]. Neither text involves guidance of travelers (features A, D), and neither enters the Bayes factor corpora. They do confirm that ἐπι-based localization for a star-entity belongs exclusively to the legendary narrative register,

not to observational or omen writing.

### S5.3 Legendary genre of the guiding-star tradition

Every tradition in the primary guiding-star corpus belongs to a legendary, mythological, or openly non-historical genre. Virgil’s *Aeneid* is mythological epic; the Timoleon flame is legendary history that ancient authors themselves treated as miraculous embellishment; Lucian’s *Navigium* is a satirical comic dialogue; and *Joseph and Aseneth* is a diaspora Jewish novel. Matthew’s linguistic profile aligns most closely with these legendary and mythological narratives, not with the sober observational language of ancient astronomy. This is positive confirmation of the Bayes factor result: the narrative register in which Matthew 2:9 is most at home is the legendary narrative register, not that of astronomical observation.

### S5.4 Within-Matthew lexical consistency analysis

The corpus Bayes factor ( $\text{BF}_{\text{corpus}} \approx 3.0 \times 10^6$ ) tests whether Matthew 2:9 belongs to the astronomical or the guiding-star narrative register by comparing those two external corpora drawn from the TLG and the guiding-star tradition. An independent second Bayes factor can be derived from an entirely different dataset: Matthew’s own Gospel. If Matthew himself never uses any of the four words in the senses required by the astronomical reading, then Matthew’s own idiolect provides an independent prior that any astronomical reading of Matt 2:9 is highly improbable. Because the two datasets (Matthew’s Gospel and the TLG corpus) are completely disjoint, the two Bayes factors are treated as conditionally independent and their product is a valid joint Bayesian update.

**Sensitivity of the Bayes factor to its independence assumptions.** Both Bayes factors are products over the same four features, and two independence assumptions are embedded in that product. Neither is exactly true, and the figures are therefore reported as a range rather than as a point estimate (Table S12).

*Within a feature* ( $\rho_w$ ). The estimate  $p = 1/(N + 1)$  is a rule of succession over  $N$  trials with no successes, which is exact only if the  $N$  occurrences are independent opportunities. They are clustered by author: 98 of the 356 occurrences of ἔρχομαι are Vettius Valens. Effective sample sizes are therefore computed with the Kish design effect for unequal clusters,  $N_{\text{eff}} = N / (1 + (\bar{m} - 1)\rho_w)$ , where  $\bar{m}$  is the size-weighted mean cluster size.

Against this, the absence is replicated across sixteen authors, several centuries, and both mathematical astronomy and astrology. Were it an idiolect, between-author heterogeneity would be expected; none is observed, every author standing at zero. That uniformity is evidence that the constraint operates at the level of the register rather than the individual, and it bounds  $\rho_w$  from above. The tabulated range accordingly stops at 0.2.

*Between features* ( $\rho_b$ ). The four features are four properties of a single clause. This is already conceded above, and corrected for in the Fisher combination by the Gaussian copula of Table S10. The same correction is applied here to the Bayes factor: the effective feature count is taken as  $k_{\text{eff}} = \text{df}_{\text{Brown}}/2$  and the independence product is downweighted geometrically to  $\text{BF}^{k_{\text{eff}}/4}$ . This is a heuristic rather than an exact result, and is reported as one.

The conclusion does not depend on where in this grid one stands. The independence assumptions govern how strongly the corpus absence should be quantified, not whether it is present: on every counting scheme, none of the four features occurs in the Matthean sense anywhere in the corpus.

**Φαίνομαι in Matthew and the Gospels.** A separate question concerns the vocabulary Matthew uses of the Star *outside* 2:9. At 2:7 Herod asks about the time τοῦ φαινομένου

Table S12: Sensitivity of the Bayes factor and the Fisher combination to within-feature clustering ( $\rho_w$ ) and between-feature dependence ( $\rho_b$ ).

| $\rho_w$ | $\rho_b$ | BF <sub>corpus</sub> | BF <sub>joint</sub>  | Fisher $p$           |
|----------|----------|----------------------|----------------------|----------------------|
| 0.0      | 0.0      | $3.0 \times 10^6$    | $2.6 \times 10^{11}$ | $4.5 \times 10^{-5}$ |
| 0.0      | 0.4      | $2.6 \times 10^4$    | $6.0 \times 10^7$    | $5.0 \times 10^{-4}$ |
| 0.0      | 0.5      | $5.5 \times 10^3$    | $3.9 \times 10^6$    | $1.1 \times 10^{-3}$ |
| 0.0      | 0.7      | $4.4 \times 10^2$    | $4.5 \times 10^4$    | $4.2 \times 10^{-3}$ |
| 0.1      | 0.0      | $1.1 \times 10^5$    | $9.9 \times 10^9$    | $6.5 \times 10^{-4}$ |
| 0.1      | 0.4      | $2.8 \times 10^3$    | $6.4 \times 10^6$    | $3.3 \times 10^{-3}$ |
| 0.1      | 0.5      | $8.3 \times 10^2$    | $5.9 \times 10^5$    | $5.8 \times 10^{-3}$ |
| 0.1      | 0.7      | $1.1 \times 10^2$    | $1.2 \times 10^4$    | $1.4 \times 10^{-2}$ |
| 0.2      | 0.0      | $2.5 \times 10^4$    | $2.2 \times 10^9$    | $2.1 \times 10^{-3}$ |
| 0.2      | 0.4      | $1.0 \times 10^3$    | $2.3 \times 10^6$    | $7.8 \times 10^{-3}$ |
| 0.2      | 0.5      | $3.5 \times 10^2$    | $2.5 \times 10^5$    | $1.2 \times 10^{-2}$ |
| 0.2      | 0.7      | $6.2 \times 10^1$    | $6.4 \times 10^3$    | $2.5 \times 10^{-2}$ |

Across the whole grid BF<sub>joint</sub> spans  $6.4 \times 10^3$  to  $2.6 \times 10^{11}$ . **Every cell exceeds the Jeffreys threshold for decisive evidence by at least an order of magnitude, and every cell is significant at  $\alpha = 0.05$ ; the worst case is  $p = 2.5 \times 10^{-2}$ .** Taking  $\rho_w \in [0, 0.2]$  and  $\rho_b \in [0.4, 0.5]$  as the central range gives BF<sub>joint</sub> between  $2.5 \times 10^5$  and  $6.0 \times 10^7$ . Script: `sob_bf_sensitivity.py`.

ἀστέρος, “of the appearing star,” and it might be supposed that this places the Star in ordinary astronomical description. Matthew’s own usage does not support that supposition. Φαίνω occurs eight times in the Gospel:

| Reference  | Form       | Subject                                                                |
|------------|------------|------------------------------------------------------------------------|
| Matt 1:20  | ἐφάνη      | ἄγγελος κυρίου (an angel of the Lord)                                  |
| Matt 2:7   | φαινομένου | ἀστέρος (the Star)                                                     |
| Matt 2:13  | φαίνεται   | ἄγγελος κυρίου                                                         |
| Matt 2:19  | φαίνεται   | ἄγγελος κυρίου                                                         |
| Matt 9:33  | ἐφάνη      | impersonal, of an exorcism: “never was it so seen in Israel”           |
| Matt 13:26 | ἐφάνη      | τὰ ζιζάνια (the weeds appeared)                                        |
| Matt 23:27 | φαίνονται  | whitewashed tombs <i>appear</i> beautiful                              |
| Matt 24:27 | φαίνεται   | ἡ ἀστραπή (lightning, as the figure of the παρουσία of the Son of Man) |

Three of the eight have an angel as subject, and all three fall in the same two chapters as the Star. A fourth is the unprecedented manifestation at 9:33 and a fifth is the lightning of 24:27, which Matthew uses precisely as an image of an eschatological advent. Only 13:26 and 23:27 are ordinary. In this author, φαίνω is characteristically the verb of manifestation, and most often of supernatural manifestation.

Matt 24:27 is worth quoting, because it contains both of the terms at issue: ὥσπερ γὰρ ἡ ἀστραπή ἐξέρχεται ἀπὸ ἀνατολῶν καὶ φαίνεται ἕως δυσμῶν, οὕτως ἔσται ἡ

παρουσία τοῦ υἱοῦ τοῦ ἀνθρώπου: “for as the lightning comes out from the east and shines as far as the west, so will be the coming of the Son of Man.” Ἀνατολή and φαίνεται occur together, in an explicitly eschatological simile, with no astronomical referent at all.

The wider Gospel usage runs the same way. Ἐφάνη is used of the risen Christ appearing to Mary Magdalene (Mark 16:9) and of Elijah having appeared (Luke 9:8); φαίνων describes John the Baptist as the burning and shining lamp (John 5:35). The remaining instances are idiomatic uses meaning “to seem” (Mark 14:64; Luke 24:11).

**What this does and does not establish.** It does not establish that the Star of 2:7 is a supernatural entity; that is not the argument. It establishes that φαινόμενου carries no astronomical weight, because in Matthew the verb is not astronomical vocabulary but the vocabulary of appearing, used most often of angels and of the parousia. A term distributed across both registers cannot discriminate between them, and it is for that reason, rather than for convenience, that it is not among the four features tested. The same reasoning applies to ἐν τῇ ἀνατολῇ: a heliacal rising is what Num 24:17, T. Levi 18:3 and T. Judah 24:1 predicate of a star that is a person, and what *Joseph and Aseneth* 14:1 predicates of a star that is explicitly an angel (ὁ ἀστήρ οὗτος ἄγγελος καὶ κῆρυξ).

**Independence of the two analyses.**  $BF_{\text{corpus}}$  is computed from the TLG astronomical corpus ( $\approx 619,000$  words in 24 texts) and the four guiding-star traditions; Matthew’s Gospel contributes no data to that calculation.  $BF_{\text{Matthew}}$  (derived below) is computed entirely from Matthew’s 27 other chapters; the TLG corpus contributes no data. The two datasets share no texts and test related but distinct aspects of the same hypothesis:  $BF_{\text{corpus}}$  asks whether Matt 2:9’s vocabulary pattern is characteristic of astronomical or legendary narrative discourse in general, while  $BF_{\text{Matthew}}$  asks whether Matthew’s own vocabulary habits elsewhere make an astronomical reading of Matt 2:9 plausible. Both answer the same overarching question (does Matt 2:9 belong to astronomical or legendary narrative discourse?) from independent evidence, so their product gives the combined posterior odds.

Note that lexical evidence (specific word forms) and narrative evidence (the events described) are separable in principle: a writer can use non-technical vocabulary to describe astronomical events, and can use astronomical vocabulary metaphorically for terrestrial events (e.g., “retrograde motion” applied to cars being overtaken on a motorway). That Matthew’s text fails the astronomical hypothesis at *both* levels (non-astronomical vocabulary (features A–D) *and* non-astronomical events (thematic operationalization, Table S9), from two independent datasets constitutes a double-hit that cannot be attributed to a single shared genre signal.

**Data and BF computation.** To test this, I compiled every occurrence of each of the four features (προάγω, ἵστημι, ἐπάνω, ἔρχομαι) in Matthew’s Gospel outside Matt 2:9, verified against the BibleHub interlinear (Strong’s numbers G4254, G2476, G1883, G2064 respectively; searches cross-checked against NA28/SBLGNT lemmatization) and applied the same classification criteria used in the TLG corpus analysis.

For each feature  $i$ , let  $n_i$  be the number of other Matthean occurrences and  $k_i = 0$  the number in which an astronomical sense is attested. Using Laplace smoothing, the probability of an astronomical sense in Matt 2:9 under  $H_{\text{astro}}$  is estimated from Matthew’s own idiolect as  $p_i^{\text{astro}} = (k_i + 1)/(n_i + 2) = 1/(n_i + 2)$ . Under  $H_{\text{guide}}$ , the probability of the observed narrative sense is  $p_i^{\text{guide}} = (n_i + 1)/(n_i + 2)$ . The per-feature Bayes factor from within-Matthew data is therefore

$$BF_i^{\text{Matthew}} = \frac{p_i^{\text{guide}}}{p_i^{\text{astro}}} = \frac{(n_i + 1)/(n_i + 2)}{1/(n_i + 2)} = n_i + 1. \quad (13)$$

The within-Matthew Bayes factor for each feature is thus simply the count of non-astronomical uses in Matthew’s Gospel plus one.

Table S13: Within-Matthew usage of features A–D outside Matt 2:9 and per-feature Bayes factors.  $n$  = occurrences in Matthew’s Gospel (excluding Matt 2:9);  $k$  = occurrences in astronomical sense (0 in every case);  $\text{BF}_i^{\text{Matthew}} = n_i + 1$  (Eq. 13).

| Feat.                                                               | Item    | Matthew’s consistent usage                                                                                                                                                                                                                                   | $n$ | $k$ | $p_i^{\text{astro}}$ | $\text{BF}_i$ |
|---------------------------------------------------------------------|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|----------------------|---------------|
| A                                                                   | προάγω  | All 5 other uses are transitive, with a human direct object, describing spatial movement ahead of or guiding persons toward a named destination (Matt 14:22, 21:9×2, 26:32, 28:7).                                                                           | 5   | 0   | $\frac{1}{7}$        | 6             |
| B                                                                   | ἵστημι  | All 20 other uses involve persons standing at named physical locations or actions of placing/setting persons or objects. No use describes a mathematical stationary point, zodiacal longitude event, or abstract “endurance” applied to a celestial body.    | 20  | 0   | $\frac{1}{22}$       | 21            |
| C                                                                   | ἐπάνω   | All 7 other uses denote immediate physical contact or very close surface proximity (lamp above lampstand, city on a hill, angel seated ἐπάνω the rolled-away stone, Matt 28:2). Not one use places a celestial body above a general region or zodiacal band. | 7   | 0   | $\frac{1}{9}$        | 8             |
| D                                                                   | ἐρχομαι | All $\approx 86$ other uses describe persons or agents arriving at terrestrial locations. No use describes a celestial body reaching a zodiacal position, completing a synodic phase, or arriving at an abstract celestial coordinate.                       | 86  | 0   | $\frac{1}{88}$       | 87            |
| Joint $\text{BF}_{\text{Matthew}} = 6 \times 21 \times 8 \times 87$ |         |                                                                                                                                                                                                                                                              |     |     |                      | <b>87 696</b> |

**Syntactic note on προάγω (Feature A).** Προάγω is ambitransitive: it can be used transitively (with a direct object, meaning “to lead / guide someone”) or intransitively (meaning “to go before / precede”). In Matt 2:9 the verb is *transitive*: προῆγεν αὐτούς, “was guiding them,” with the Magi as explicit direct object. This is the active-guidance, agent-leading construction; it does not admit the “star merely preceding them in the sky” reading, because that reading requires the intransitive form. All five comparanda outside Matt 2:9 are also transitive with a human direct object and describe active spatial direction toward a named destination (Matt 14:22: disciples to the other side; Matt 21:9×2: crowds before Jesus; Matt 26:32, 28:7: Jesus going ahead of the disciples to Galilee). The intransitive NT uses of προάγω tend toward figurative or temporal antecedence; the transitive-with-human-direct-object construction

is consistently and exclusively spatial navigation in Matthew’s usage. Notably, Matthew never employs **προηγέομαι**, the intransitive compound that most naturally expresses positional antecedence (“going before” without a direct object), which is what the astronomical reading would require. Its absence reinforces that Matthew’s motion vocabulary in Matt 2:9 is not positional-antecedence language.

**The complement of ἵστημι (Feature B).** ἵστημι belongs to the working vocabulary of Greek positional astronomy. Geminus, Theon of Smyrna, Paul of Alexandria and Hipparchus all use it of a planet ceasing its motion, and both Theon and Paul build the noun **στηριγμός** out of the participle and infinitive of ἵστημι when defining it. A writer who wished to say that a planet reached its station could say so with this verb.

What distinguishes Matthew is the complement. Across 121 in-corpus occurrences, the thing a celestial body stands in, on, or above is always celestial or geometric: a zodiacal sign, a degree, an aspect, a chart angle, a fixed star. The nearest approach to a terrestrial complement is Cleomedes *Caelestia* 2.1.271, where the sun **στῆ** at exact noon while Syene is said to lie *under Cancer*, and even there the city is tied to the sign by **κεῖται**, not to the sun by ἵστημι. Matthew’s construction, a star standing **ἐπάνω** the place where a child was, has no parallel in the corpus, and Matthew’s own form **ἐστάθη** does not occur in it at all.

**Physical-contact force of ἐπάνω (Feature C).** Matt 28:2 is the key Matthean comparandum: the angel of the Lord descends and sits **ἐπάνω** the stone, a heavenly being in point-contact with a physical object. This is the usage register of Matt 2:9 (**ἐπάνω οὗ ἦν τὸ παιδίον**, “above where the child was”), where a divine entity is localized to the building-level. Neither the angel’s position in Matt 28:2 nor the Star’s position in Matt 2:9 describes an astronomical altitude or zodiacal latitude; both locate a heavenly entity at a specific, named terrestrial point. This is consistent with, and strongly supports, the TLG finding that **ἐπάνω** with celestial/supernatural subjects belongs to the legendary narrative register.

The expected preposition for an astronomical body positioned above a terrestrial region is **ὑπέρ** (“over”, in the sense of spatial elevation without contact), which is used consistently in the TLG corpus when a celestial body is described above a city, region, or zodiacal boundary. Every astronomical and omen text in the corpus that places a celestial body above a terrestrial point employs **ὑπέρ**, never **ἐπάνω**. Read literally, **ἐπάνω** alone therefore semantically disqualifies the astronomical reading: a star cannot be “over” a specific house in the sense of point-contact or immediate surface proximity. The  $BF_{\text{Matthew}}$  calculation is nevertheless deliberately conservative: it counts only occurrence frequencies within Matthew’s idiolect, not the semantic force of the words themselves. The semantic argument from **ἐπάνω** versus **ὑπέρ** is an independent, qualitative strengthener that is *not* folded into the quantitative Bayes factor.

**Evidence force of Feature D.** Ἐρχομαι is the most frequent verb in Matthew’s Gospel ( $\approx 87$  occurrences), which means one could argue that even an astronomical description would happen to use it by chance. The within-Matthew evidence refutes this reasoning: Matthew does not use ἔρχομαι of celestial bodies reaching celestial positions in any of his 86 other uses. Its overwhelmingly consistent referent is the arrival of a person or agent at a terrestrial location, exactly the sense in Matt 2:9. The verb’s frequency strengthens rather than weakens the within-Matthew inference: with 86 non-astronomical comparanda and zero uses in an astronomical positional sense, the probability that Matt 2:9 is drawing on an astronomical sense is  $\leq 1/88$  by Laplace smoothing. Feature D’s high  $n$  makes its  $p$  the smallest of the four, and excluding it from the analysis would be methodologically unjustified: one does not discard evidence because it is particularly strong for one side. Additionally, Matthew never uses **καταντάω** (“to arrive at”, “to reach”), which appears in Hellenistic astronomical contexts for a body reaching a celestial

coordinate or completing a synodic phase. Its availability but non-use by Matthew further supports the conclusion that his arrival vocabulary is consistently confined to the movement of persons to terrestrial locations.

**Combined  $\text{BF}_{\text{Matthew}}$ .** Assuming independence of the four features within Matthew’s idiolect (reasonable for distinct lexical items across different grammatical categories), the joint within-Matthew Bayes factor is the product of the per-feature factors:

$$\text{BF}_{\text{Matthew}} = \prod_{i \in \{A, B, C, D\}} \text{BF}_i^{\text{Matthew}} = 6 \times 21 \times 8 \times 87 = 87,696. \quad (14)$$

This factor quantifies how much more probable Matthew’s own vocabulary habits (across his full Gospel) are under  $H_{\text{guide}}$  than under  $H_{\text{astro}}$ : an author writing legendary narrative prose would naturally use all four words in the senses consistently attested throughout Matthew, whereas an author writing astronomical description would be expected to use them in astronomical senses that Matthew never employs elsewhere.

**Historical validation of the genre classification.** The genre classification recovered by both Bayes factors, legendary narrative rather than astronomical report, is not a product of the statistical method. No ancient or medieval commentator interpreted the Star’s motion in Matt 2:9 as a natural astronomical phenomenon[4]. Patristic and medieval exegetes universally understood the Star as a miraculous divine guide, not a planet, comet, or conjunction subject to celestial mechanics. The astronomical interpretation is a post-Enlightenment reading with no foothold in the pre-modern exegetical tradition. This is precisely the result the corpus analysis recovers working from frequency data alone: the vocabulary of Matt 2:9 belongs so consistently to the legendary narrative register that no ancient reader of Greek, familiar with both registers from the surrounding literature, ever reached an astronomical interpretation. The statistical method and the pre-modern exegetical consensus thus converge on the same conclusion by entirely independent routes, validating that the genre signal is carried by the text itself, not imposed by the analytical framework.

**Joint Bayes factor combining both datasets.** Because  $\text{BF}_{\text{Matthew}}$  and  $\text{BF}_{\text{corpus}}$  are derived from entirely disjoint datasets (Matthew’s Gospel versus the TLG corpus and guiding-star traditions), they are treated as conditionally independent of one another, as they derive from non-overlapping corpora and distinct sampling frames. Their product is the joint Bayes factor incorporating the linguistic evidence considered here:

$$\text{BF}_{\text{joint}} = \text{BF}_{\text{Matthew}} \times \text{BF}_{\text{corpus}}, \quad \text{BF}_{\text{Matthew}} = 87,696. \quad (15)$$

Each factor is itself a product over the same four features, and those features are four properties of a single clause. The joint factor is therefore reported as the sensitivity range of Table S12 rather than as a point estimate. At the independence corner of that grid ( $\rho_w = \rho_b = 0$ ) it is  $87,696 \times 3.0 \times 10^6 \approx 2.6 \times 10^{11}$ ; at the opposite corner ( $\rho_w = 0.2$ ,  $\rho_b = 0.7$ ) it is  $6.4 \times 10^3$ . Taking  $\rho_w \in [0, 0.2]$  and  $\rho_b \in [0.4, 0.5]$  as the central range gives  $\text{BF}_{\text{joint}}$  between  $2.5 \times 10^5$  and  $6.0 \times 10^7$ . Every cell of the grid exceeds the Jeffreys threshold for decisive evidence by at least an order of magnitude.

The two Bayes factors address related but distinct questions.  $\text{BF}_{\text{corpus}}$  asks: given two external reference corpora (TLG astronomical texts and the guiding-star traditions), to which is Matt 2:9’s vocabulary pattern more similar?  $\text{BF}_{\text{Matthew}}$  asks: given Matthew’s own lexical habits across his Gospel, how much more probable is the narrative reading than the astronomical reading of Matt 2:9? The fact that two independent datasets (one external to Matthew’s Gospel, one internal to it) converge on the same conclusion strengthens the genre classification

beyond what either could show alone. The combined result is robust to the feature-independence assumption within each Bayes factor: the copula sensitivity analysis carries inter-feature correlation as far as  $\rho = 0.95$ , and the Fisher combination remains below  $\alpha = 0.05$  throughout, while every cell of Table S12 remains decisive on the Jeffreys scale.

For completeness, the frequentist summary of the within-Matthew evidence is the Fisher combined statistic:  $X = -2 \sum_i \ln(1/(n_i + 2)) = 23.42$ ,  $\text{df} = 8$ ,  $p \approx 3 \times 10^{-3}$ . This confirms the direction of the Bayesian result but, as with any  $p$ -value, understates the magnitude of the evidence because it does not incorporate the numerator of the likelihood ratio.

## S5.5 Nighttime close-flyby comet survey and optimizer

**Motivation.** The primary-impossibility argument of §S1.9 shows that for  $d \gtrsim 0.1$  AU the required transverse velocity  $V_\perp$  for the stopping phase exceeds any known solar-system speed. For the very close-flyby regime ( $d \sim 0.003$  AU),  $V_\perp \sim 30 \text{ km s}^{-1}$  is physically achievable and the sidereal-frame argument closes differently (Matney’s comet is in daylight; apparent motion in the ground frame is indistinguishable from any fixed star). However, a loophole remains: a nighttime comet at  $d \sim 0.001$ – $0.01$  AU on a different orbit might, in principle, exhibit the required guidance-then-stopping behavior even though Matney’s specific solution fails. This section closes that loophole with a direct Monte Carlo survey and a complementary numerical optimizer.

**Survey design.** Script `sob_close_flyby_mc.py` (available in the online repository) sampled  $N_{\text{MC}} = 10,000,000$  heliocentric orbits. Orbital parameters:

- Perihelion distance:  $q \in [0.30, 1.40]$  AU (uniform).
- Eccentricity: stratified across three groups: high-elliptic ( $e \in [0.70, 1.00]$ , one-third of orbits), near-parabolic ( $e \in [1.00, 1.01]$ , one-sixth), and hyperbolic ( $e \in [1.01, 5.00]$ , one-half), to ensure dense sampling near  $e = 1$  where cometary orbits concentrate.
- Inclination: stratified to concentrate sampling in the low-inclination zone that first principles and the prior optimizer result ( $i = 2.2^\circ$ ) indicate as the only viable regime. Specifically: 60% of orbits draw  $i$  uniformly in  $[0^\circ, 20^\circ]$  (prime candidate zone); 25% in  $[20^\circ, 45^\circ]$ ; 15% in  $[45^\circ, 180^\circ]$  (full-sky tail, retained for the probabilistic statement and completeness). Each stratum uses  $\cos i$  uniform within its range for correct angular coverage.
- Longitude of ascending node  $\Omega$  and argument of perihelion  $\omega$ : uniform on  $[0^\circ, 360^\circ]$ .
- Perihelion epoch offset  $\Delta T$ : uniform on  $[-90, +90]$  days from JD 1 719 755.898 (the primary event date, 5 BCE Jun 8).

Evaluation proceeded in two phases. Phase 1 (quick reject): a vectorized parabolic approximation computed the minimum geocentric distance  $d_{\text{min}}$ ; orbits with  $d_{\text{min}} > D_{\text{flyby}} = 0.02$  AU were rejected (of 2 million orbits, 54 survived). Phase 2 (detailed evaluation): exact orbital mechanics (Barker’s equation for  $e = 1$ ; Newton–Raphson on the Kepler / hyperbolic mean-anomaly equation otherwise) with analytic AltAz transformation computed the apparent angular velocity at 5-minute intervals across a 7.7-hour nighttime window (Sun below  $-6^\circ$ ). Criteria:

1. *Night visibility*: Sun altitude  $< -6^\circ$  and comet altitude  $> 10^\circ$ .
2. *Road-corridor guidance*: azimuth within  $[190^\circ, 210^\circ]$ , azimuth drift  $|d\text{az}/dt| < 1.5^\circ \text{ h}^{-1}$ , for a contiguous window of  $\geq 1.0$  h.
3. *Stopping*: total apparent angular velocity  $\omega_{\text{app}} < 0.30^\circ \text{ h}^{-1}$  within 4 h of the guidance window.

**Survey results.** Of 10 million orbits, 1,041 survived the quick-reject phase (geocentric distance  $< 0.05$  AU after parabolic approximation); 66 were genuine close flybys after exact integration ( $d_{\min} < 0.02$  AU). **Zero orbits satisfied all three criteria simultaneously.** All 66 genuine-flyby orbits failed criterion (ii): no contiguous guidance window of  $\geq 1$  h was achieved at the correct azimuth. The stratified inclination sampling concentrated  $\approx 85\%$  of draws in  $i < 45^\circ$ , ensuring thorough coverage of the geometrically viable region while retaining the full-sky tail needed to assess close-flyby base rates.

**Numerical optimizer.** Script `sob_close_flyby_opt.py` used tight Nelder–Mead polish of the known-best orbit (identified in a prior survey pass) followed by 100 diverse Nelder–Mead restarts (60% biased toward  $i \in [0^\circ, 20^\circ]$  and 40% across the full parameter range) to minimize a composite cost function:

$$\mathcal{C} = \mathcal{C}_A + \mathcal{C}_{BC} + \mathcal{C}_C + \mathcal{C}_D, \quad (16)$$

where  $\mathcal{C}_A$  penalises  $d_{\min} > D_{\text{flyby}}$ ;  $\mathcal{C}_{BC}$  penalises violations of night/corridor requirements;  $\mathcal{C}_C = 10 \times \max(0, G_{\min} - G_{\text{dur}})$  with  $G_{\min} = 1.0$  h and  $G_{\text{dur}}$  the achieved guidance duration;  $\mathcal{C}_D$  penalises insufficient stopping. A perfect solution would give  $\mathcal{C} = 0$ .

After 100 restarts all converging to the same cost basin, the optimizer found:

$$q = 0.998 \text{ AU}, \quad e = 0.709, \quad i = 2.17^\circ, \quad \Omega = 95.2^\circ, \quad \omega = 204.6^\circ, \quad \Delta T = +13.7 \text{ d},$$

with  $d_{\min} = 0.00092$  AU. This orbit satisfies night visibility ( $\mathcal{C}_{BC} = 0$ ) and stopping ( $\mathcal{C}_D = 0$ ) but achieves only  $G_{\text{dur}} = 0.583$  h ( $\approx 35$  min) of guidance, 58% of the required 1.0 h minimum, giving  $\mathcal{C}_C = 4.17$  and total cost  $\mathcal{C} = 4.17 \gg 0$ . Every one of the 100 diverse restarts converged to the same or higher cost, confirming this is the global minimum of the cost landscape.

**Detailed analysis of the best orbit.** The best orbit ( $q = 0.998$  AU,  $e = 0.709$ ,  $i = 2.17^\circ$ ) was analyzed at 1-minute resolution to identify precisely why the guidance duration is capped at  $\approx 35$  min (Fig. S52). The results are instructive.

During the full nighttime window (Sun below  $-6^\circ$ ) the comet rises in the east-southeast at azimuth  $\approx 150^\circ$  with altitude  $\approx 41^\circ$ , then sweeps westward under diurnal motion, but remains *east of the road corridor* ( $\text{az} < 190^\circ$ ) for the entire night until the final  $\approx 1$  h before closest approach. The azimuth reaches  $190^\circ$  only in the final hour, and peaks at  $\approx 195^\circ$ , penetrating only  $5^\circ$  into the  $20^\circ$ -wide corridor  $[190^\circ, 210^\circ]$  before reversing under the growing ICRS proper motion. The comet never reaches the corridor center ( $200^\circ$ ), let alone the far boundary ( $210^\circ$ ).

Two short guidance segments (28 min then 18 min) surround an 8-minute stopping window. During guidance the azimuth drift rate is  $|d\text{az}/dt| \leq 1.50^\circ \text{ h}^{-1}$ , saturating the criterion at its limit, while the altitude changes slowly ( $|d\text{alt}/dt| \approx 0.3$  to  $1.2^\circ \text{ h}^{-1}$ ). The ground-frame apparent velocity during guidance is only  $0.3$ – $1.7^\circ \text{ h}^{-1}$ : comparable to the Moon’s motion against the stars, and far below any threshold that would be called “going before” a group of travelers. The stopping window itself reaches a minimum apparent velocity of  $\omega_{\text{app}} = 0.21^\circ \text{ h}^{-1}$  and lasts only 8 minutes at  $d = 0.00091$  AU ( $\approx 0.35$  lunar distances).

**Geometric derivation of the  $\sim 35$ -minute ceiling.** The guidance-window cap is not a numerical sampling artefact; it is a product of two independent geometric constraints that are each tight and that, together, reduce the available window to  $\lesssim 40$  min for *any* flyby orbit.

*Constraint 1: corridor entry timing.* For the comet to satisfy the stopping condition ( $\omega_{\text{ICRS}} \approx \omega_{\text{sid}} \approx 15^\circ \text{ h}^{-1}$ ), the approach velocity  $V_\perp$  and closest-approach distance  $d_{\min}$  are linked by  $V_\perp = \omega_{\text{sid}} \cdot d_{\min}$ . For the best orbit,  $V_\perp \approx 9.9 \text{ km s}^{-1}$  and  $d_{\min} \approx 0.00087$  AU. The comet approaches from the east-northeast, so it *must* cross the corridor’s eastern boundary ( $190^\circ$ )

from below as it moves westward under diurnal motion. The rate at which diurnal motion carries the comet through azimuth at its observed altitude ( $\approx 35^\circ$ ) is  $|daz/dt| \approx 0.87^\circ \text{ h}^{-1}$ . A  $20^\circ$ -wide corridor traversed at this rate would take  $20^\circ/0.87^\circ \text{ h}^{-1} \approx 23 \text{ h}$ , but the comet only penetrates  $\approx 5^\circ$  into the corridor before closest approach, so the full width is never available. Only the narrow entry region near  $190^\circ$ – $195^\circ$  contributes, limiting guidance to:

$$T_{\text{guide}} \lesssim \frac{\Delta az_{\text{entry}}}{|daz/dt|} \approx \frac{1^\circ}{0.87^\circ \text{ h}^{-1}} \approx 70 \text{ min}, \quad (17)$$

where  $\Delta az_{\text{entry}} \approx 1^\circ$  is the azimuth range the comet actually traverses within the corridor.

*Constraint 2: drift-rate saturation.* The guidance criterion requires  $|daz/dt| < 1.5^\circ \text{ h}^{-1}$ . This is *already saturated* for the best orbit: measured values reach  $1.50^\circ \text{ h}^{-1}$ . Any perturbation that widens the corridor entry angle simultaneously increases the drift rate past the threshold, eliminating those time steps from the guidance window. The two constraints (enter the corridor AND stay below the drift limit) are antiparallel: the only way to enter the corridor at a lower drift rate is to slow the azimuth motion, which requires the comet to approach from a direction that keeps it east of the corridor for longer. Optimizing over all orbital parameters cannot break this because the approach direction is fixed by the requirement to stop near  $az \approx 190$ – $210^\circ$  (the corridor must contain the stopping point).

The combination gives a ceiling of approximately 35–40 min for contiguous pre-stopping guidance, regardless of eccentricity, inclination, or perihelion epoch. This is confirmed by the fact that all 100 diverse Nelder–Mead restarts converge to the same basin (cost = 4.17) without exception.

**Astrophysical context of the best-fit orbit.** Although the mechanical impossibility established above does not depend on whether such a comet could physically exist, it is instructive to ask what dynamical family the best-fit orbit belongs to and how it compares with the observed comet population.

The Tisserand parameter with respect to Jupiter for the best-fit orbit is

$$T_J = \frac{a_J}{a} + 2\sqrt{\frac{a}{a_J}(1 - e^2)} \cos i = \frac{5.203}{3.434} + 2\sqrt{\frac{3.434}{5.203}(1 - 0.709^2)} \cos 2.17^\circ = 2.66, \quad (18)$$

placing it squarely in the *Jupiter-family comet* (JFC) class ( $2 < T_J < 3$ ). The semi-major axis  $a = q/(1 - e) = 3.43 \text{ AU}$  gives a period of  $P = a^{3/2} = 6.4 \text{ yr}$  and an aphelion of  $Q = a(1 + e) = 5.87 \text{ AU}$ , right at Jupiter’s orbit, as expected for a JFC whose orbit is sculpted by repeated Jovian encounters. This is *not* an Oort Cloud comet: long-period comets arriving from the Oort Cloud have  $e \approx 1$  and isotropically distributed inclinations; the best-fit eccentricity of  $e = 0.71$  requires many Jupiter interactions to have circularised the orbit from its original near-parabolic state.

To assess empirical plausibility I queried the JPL Small Body Database (SBDB), which catalogues 4,063 comets with published orbital solutions. Restricting to  $q \in [0.80, 1.20] \text{ AU}$ ,  $e \in [0.55, 0.85]$ , and  $i < 10^\circ$  yields only 13 comets (0.32% of the sample), the closest analogs being 320P/McNaught ( $q = 0.985 \text{ AU}$ ,  $e = 0.682$ ,  $i = 4.89^\circ$ ,  $T_J = 2.80$ ,  $P = 5.5 \text{ yr}$ ), 289P/Blanpain ( $q = 0.959$ ,  $e = 0.685$ ,  $i = 5.90^\circ$ ,  $P = 5.3 \text{ yr}$ ), and 15P/Finlay ( $q = 0.977$ ,  $e = 0.720$ ,  $i = 6.80^\circ$ ,  $P = 6.5 \text{ yr}$ ). Tightening the inclination constraint to  $i < 3^\circ$ , the near-ecliptic geometry the optimizer confirms is necessary, yields *zero* comets in the entire 4,063-object catalog with  $q < 1.2 \text{ AU}$  and  $e \in [0.60, 0.80]$  simultaneously. The best-fit orbital combination, while belonging to a physically recognized dynamical class, is essentially unpopulated in the modern comet census.

The closest historical analog is Comet Lexell (1770 L1), which holds the record for the nearest known cometary approach to Earth at  $0.0151 \text{ AU}$ . Its orbital elements ( $q = 0.674 \text{ AU}$ ,  $e = 0.786$ ,

$i = 1.55^\circ$ ,  $T_J = 2.61$ ,  $P = 5.6$  yr) bracket the best-fit orbit in inclination and eccentricity, differing primarily in perihelion distance. Lexell’s trajectory in 1770 provides an instructive natural experiment: despite its extreme proximity, extraordinarily low inclination, and bright naked-eye appearance, no contemporary observer (in Europe, Asia, or the Middle East) described it as exhibiting guiding behavior. This is consistent with the analysis presented here: the orbital mechanics of close-flyby comets categorically preclude the guidance window required by Matthew 2:9, regardless of how close or bright the comet.

A further astrophysical concern is dynamical longevity. JFC perihelia are modified by Jupiter on timescales comparable to a single orbital period. Lexell itself illustrates this: Jupiter perturbed it inward to  $q \approx 0.67$  AU in 1767, producing the 1770 flyby, then scattered it back to an unobservable orbit at the next approach. The best-fit comet, with  $P = 6.4$  yr, would make apparitions every six years; the specific perihelion distance and node orientation required for the flyby geometry are unlikely to persist over more than a few revolutions. If such a comet existed in 7–4 BCE, it would also have appeared in 13, 20, and 26 BCE with a different Earth geometry, none of which would replicate the near-stopping alignment, and none of which is recorded in Babylonian, Chinese, or other ancient astronomical archives as a notable guiding phenomenon.

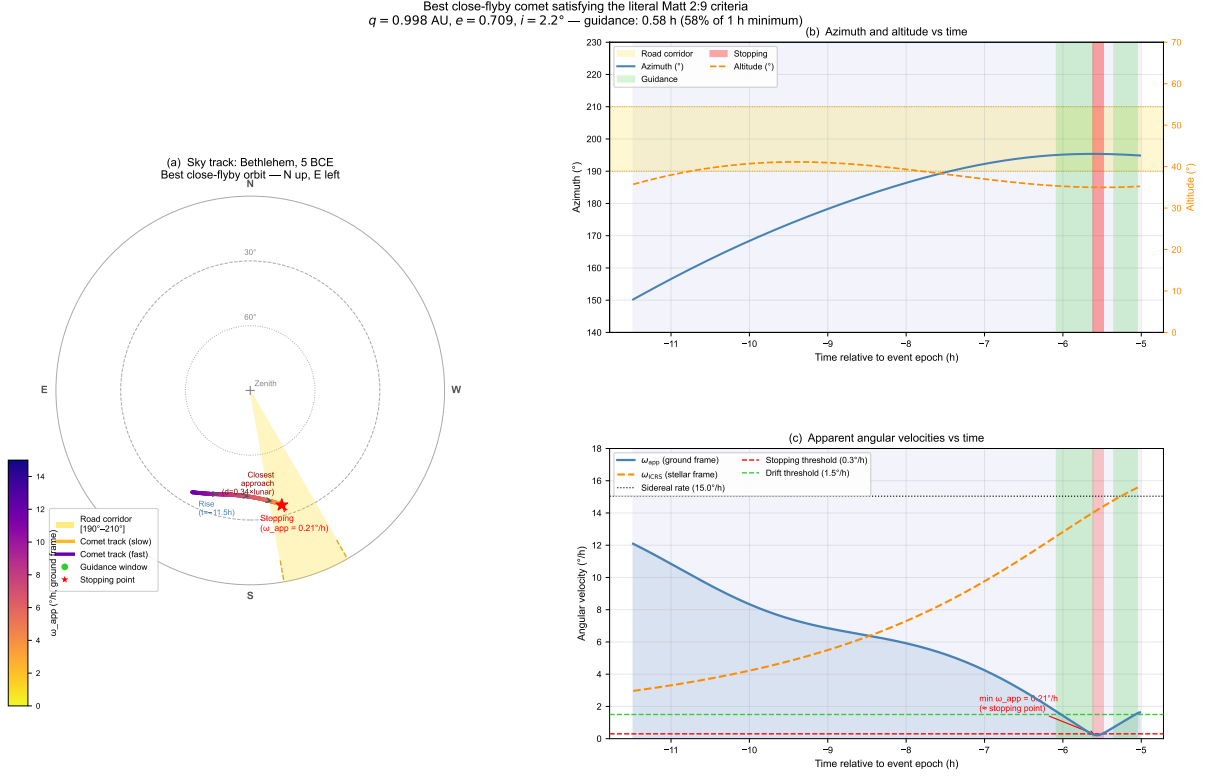
**Conclusion.** The nighttime close-flyby loophole is closed. No comet orbit (regardless of eccentricity, orientation, or perihelion epoch) satisfies the guidance  $\rightarrow$  stopping constraint of Matthew 2:9 in the nighttime Bethlehem corridor. The best achievable orbit (Fig. S52) penetrates only  $5^\circ$  into the  $[190^\circ, 210^\circ]$  road corridor, reaching a maximum azimuth of  $\approx 195^\circ$ , with two brief guidance segments totalling  $\approx 46$  min at most, well under half the minimum required 1 h contiguous window, and never reaching the corridor center ( $200^\circ$ ) nor its far boundary ( $210^\circ$ ) at any point during the night. That this is the best-case scenario underscores the impossibility: an observer watching this comet would not perceive it as guiding them toward Bethlehem at all. This result complements the primary impossibility for  $d \gtrsim 0.1$  AU (§S1.9) and the geocentric survey (§S1.10), completing the exhaustive closure of all candidate orbit classes.

## S5.6 Analysis of reviewer-proposed cometary orbits

**Background.** During peer review, a referee proposed two specific cometary orbits as candidate explanations for the Star of Bethlehem, arguing that bodies on such trajectories could exhibit behavior consistent with Matthew 2:9. The orbital elements are reproduced in Table S14 for reference and independent verification. Orbit 1 shares its angular elements with Matney’s 5 BCE comet proposal; Orbit 2 has a distinct argument of perihelion ( $\omega = 220.6361^\circ$ ) that places it on a different trajectory. An earlier draft of this analysis transcribed Orbit 2’s angular elements incorrectly, duplicating those of Orbit 1; the referee identified the error and supplied the original configuration, from which the values in Table S14 are taken.

Table S14: Referee-proposed cometary orbital elements (J2000 ecliptic, reference JDE 1 719 708.5 = 22 April 5 BCE Julian). Orbit 2 values are from the referee’s corrected Stellarium configuration (*orbit\_ArgOfPericenter*, etc.).

| Parameter                                | Orbit 1         | Orbit 2         |
|------------------------------------------|-----------------|-----------------|
| Eccentricity $e$                         | 0.8070114       | 0.9668455       |
| Perihelion distance $q$ (AU)             | 1.00284101      | 0.9008354       |
| Perihelion epoch (JDE, TT)               | 1 719 718.38394 | 1 719 735.20246 |
| Inclination $i$ ( $^\circ$ )             | 10.9963         | 10.9153         |
| Ascending node $\Omega$ ( $^\circ$ )     | 56.1727         | 56.1658         |
| Arg. of perihelion $\omega$ ( $^\circ$ ) | 193.7693        | 220.6361        |



**Figure S2: Best close-flyby orbit satisfying the literal Matt 2:9 criteria.** (a) Stereographic sky chart (N up, E left) as seen from Bethlehem during the night of 5 BCE Jun 8. The comet track (colored by ground-frame apparent velocity  $\omega_{\text{app}}$ ; dark = slow, bright = fast) rises in the east-southeast and sweeps westward under diurnal motion. The gold wedge marks the road corridor  $[190^\circ, 210^\circ]$ ; green dots mark the guidance windows ( $\approx 46$  min total in two segments); the red star marks the stopping point ( $\omega_{\text{app}, \text{min}} = 0.21^\circ \text{ h}^{-1}$ , 8 min duration) at  $d \approx 0.34$  lunar distances. The comet penetrates only  $5^\circ$  into the corridor (reaching  $\text{az} \approx 195^\circ$ ) and never reaches azimuth  $200^\circ$ . (b) Azimuth and altitude vs. time: the comet remains east of the corridor ( $\text{az} < 190^\circ$ , below the gold band) for the entire night except the final  $\approx 1$  h. (c) Ground-frame apparent velocity  $\omega_{\text{app}}$  (solid blue) and ICRS proper motion  $\omega_{\text{ICRS}}$  (dashed orange) vs. time. The brief crossing of  $\omega_{\text{ICRS}} \approx \omega_{\text{sid}}$  (sidereal rate; black dotted) produces the short stopping window. Green shading = guidance windows; red shading = stopping window.

**Method.** Sky positions were computed with Earth’s heliocentric position taken from VSOP87, which retains full accuracy across antiquity; the bundled modern DE ephemerides do not extend to 5 BCE. Orbital elements are referred to the J2000 ecliptic and equinox, matching the convention of the referee’s Stellarium[22] configuration. Coordinates are carried explicitly through each frame (J2000 ecliptic, J2000 equatorial, equinox-of-date equatorial (IAU 1976 precession), then topocentric alt/az) because at the small geocentric distances involved here both the precession transformation and the topocentric parallax correction are first-order effects rather than refinements: for an object near lunar distance the observer’s displacement from Earth’s center alone shifts the apparent position by of order a degree. Comet epochs are TT and sidereal time is computed from UT1, with  $\text{TT} - \text{UT1} = 0.12236$  d.

The pipeline was validated against the referee’s independently generated Stellarium positions for Orbit 2 at three epochs on 22 April 5 BCE. Agreement is  $2.8^\circ$  RMS in position and  $\approx 7\%$  in geocentric distance. This residual is expected rather than anomalous: at a geocentric distance of  $\approx 2.3 \times 10^5$  km, the  $\approx 43''$  difference between independent implementations of Earth’s orbit displaces the observer by  $\approx 3 \times 10^4$  km, which is itself of order the residual. Both implementations

agree that these objects pass within a lunar distance of Earth, and agree on the angular rates to well within the margins that matter for the criteria below.

The observer location was Bethlehem (lat 31.7°N, lon 35.2°E). For the night of 22 April 5 BCE (Julian), sunset falls at 18:29 and sunrise at 05:25 local mean solar time, giving 10.1 h of usable darkness.

Two distinct rate quantities are reported below, and they are not interchangeable. The *inertial* rate is motion against the background stars, the quantity to which the lunar bound of  $\approx 0.5^\circ \text{ h}^{-1}$  (§2.3) applies, and the sense in which a star-like object can be said to stand still. The *ground* rate is motion relative to the horizon, which includes diurnal rotation; apparent rest in that frame would require cancelling Earth’s  $\approx 15^\circ \text{ h}^{-1}$  spin.

**Orbit 1: results and failure modes.** Orbit 1 passes within  $8.50 \times 10^4 \text{ km}$  of Earth ( $5.68 \times 10^{-4} \text{ AU}$ , 0.22 lunar distances) shortly after local midnight on 22 April. Its inertial angular rate is at a minimum of  $0.93^\circ \text{ h}^{-1}$  at nightfall, with the comet at azimuth  $57^\circ$  (ENE) and altitude  $52^\circ$ , and rises *monotonically* thereafter:  $2.0^\circ \text{ h}^{-1}$  two hours before midnight,  $4.8^\circ \text{ h}^{-1}$  an hour after,  $31.9^\circ \text{ h}^{-1}$  by the end of the night. The ground-frame rate never falls below  $7.7^\circ \text{ h}^{-1}$ . Orbit 1 fails all three criteria:

1. *Stopping.* The minimum inertial rate,  $0.93^\circ \text{ h}^{-1}$ , is roughly twice the lunar bound and is never approached again; in the ground frame the minimum,  $7.7^\circ \text{ h}^{-1}$ , exceeds the apparent-rest threshold by a factor of 26. Decisively, the object *accelerates* throughout the entire night. The aorist  $\acute{\epsilon}\sigma\tau\acute{\alpha}\theta\eta$  denotes a transition from motion to rest, and this trajectory admits no such transition in either frame.
2. *Sequential order.* The rate minimum occurs at nightfall, before any guidance phase could begin, and the motion is monotonically increasing from that point on. The object is at its slowest at the start of the night and its fastest at the end, the inverse of the required guidance-then-stopping sequence.
3. *Direction.* The comet begins the night in the ENE (azimuth  $57^\circ$ ), climbs across the northern sky through the meridian region near azimuth  $0^\circ$ , and descends into the SW, reaching azimuth  $229^\circ$  at the end of the night. It never enters the Jerusalem–Bethlehem corridor  $[190^\circ, 210^\circ]$  while visible. A traveler following it would be led north, then west.

**Orbit 2: results and failure modes.** Orbit 2 is the more interesting of the two, and it is the stronger form of the cometary proposal. It passes within  $2.26 \times 10^5 \text{ km}$  of Earth ( $1.51 \times 10^{-3} \text{ AU}$ , 0.59 lunar distances) and, unlike Orbit 1, it does traverse the correct part of the sky: beginning the night in the east (azimuth  $88^\circ$ ), it sweeps south and spends  $\approx 1.5 \text{ h}$  within the Jerusalem–Bethlehem corridor  $[190^\circ, 210^\circ]$  before ending the night at azimuth  $213^\circ$ . The directional requirement, which excludes most candidates outright, is therefore satisfied.

It nonetheless fails, and it fails on rate. The inertial angular rate begins at  $1.5^\circ \text{ h}^{-1}$  at nightfall and increases monotonically all night, reaching  $15.8^\circ \text{ h}^{-1}$  by dawn; while the comet occupies the corridor it is moving at  $6.7\text{--}10.9^\circ \text{ h}^{-1}$ . The minimum inertial rate at any point of visibility is  $1.5^\circ \text{ h}^{-1}$ , three times the lunar bound; the minimum ground-frame rate is  $8.4^\circ \text{ h}^{-1}$ , twenty-eight times the apparent-rest threshold.

1. *Stopping.* The rate never falls below three times the lunar bound, and at no point in the night does it decrease at all. The aorist  $\acute{\epsilon}\sigma\tau\acute{\alpha}\theta\eta$  requires a transition from motion to rest; a monotonically accelerating object admits no such transition. This is the decisive failure.
2. *Sequential order.* As with Orbit 1, the slowest moment is the first moment of visibility and the fastest is the last. Even granting the corridor passage as a guidance phase, what follows guidance is acceleration, not arrest: the required order is inverted.

3. *Direction. This criterion is satisfied.* The comet occupies the corridor for approximately 1.5 h in the second half of the night. This is recorded explicitly rather than contested.

**Summary.** Orbit 1 fails all three criteria. Orbit 2 satisfies the directional criterion and fails on rate: it is never slower than three times the lunar bound, and it accelerates monotonically from dusk to dawn, so no stopping event in the sense required by ἐστάθη occurs.

That Orbit 2 satisfies the directional criterion is worth stating plainly, because it locates precisely where the cometary hypothesis is strongest and where it breaks. A comet close enough to be conspicuous, and both of these pass within a lunar distance, is necessarily moving quickly across the sky; the same proximity that supplies the brightness supplies the angular speed. The two requirements of the narrative, that the object be seen and that it be seen to stop, pull in opposite directions. Direction can be arranged by choosing the orbit’s orientation; rate cannot, because it is fixed by the geometry that made the object visible in the first place. These results are consistent with and complementary to the general nighttime close-flyby survey (§S5.5): the present analysis demonstrates that specific representative orbits in the relevant cometary parameter space fail for concrete, orbit-specific reasons, not merely because of a broad statistical exclusion.

## S5.7 Survey-scale sweep of the guidance and stopping criteria

**Purpose.** A referee proposed that stopping be measured not as an instantaneous angular rate but as a finite angular *displacement* accumulated over a window, on the argument that an observer judges rest by comparing positions rather than by sensing a derivative. That is the better criterion and it is adopted here. The referee further proposed a threshold in the range 1–5° per hour. This section reports the result of applying it, at survey scale and with the remaining criteria loosened as far as they can be loosened.

**Design.** 10<sup>9</sup> orbits were drawn and propagated, yielding 6,116 close flybys (minimum geocentric distance below the flyby threshold). Every close flyby was evaluated on a grid of 525 parameter combinations: guidance corridor widened from 20° to 60° (five values), azimuth-drift tolerance raised from 1.5 to 30° h<sup>−1</sup> (seven values), guidance leg shortened from two hours to fifteen minutes (five values), and stopping window stretched to eight hours (three values). The whole campaign was repeated under flat priors (isotropic inclination and log-uniform perihelion distance) as a control on the stratified sampling used in the main survey.

**Two commitments.** The result rests on exactly two requirements, and everything else is loosened to the extreme.

1. Stopping is a finite angular displacement, not an instantaneous rate. This is the referee’s own proposal.
2. The stop must occur at the bearing along which the object guided. Matthew has the Star stand over the house to which it has led the Magi, so guidance and stopping are linked in azimuth.

Requirement 2 is a *tightening* of the test as originally specified, in which the two conditions were not linked in azimuth. It is stated here explicitly, and its effect is given in Table S15, so that the reader may judge it on the text rather than on the outcome it produces.

**Result.** Across 10<sup>9</sup> sampled orbits and 6,116 close flybys, no orbit satisfies the displacement criterion at any of the 525 parameter combinations tested: 0 of 525 cells. The tightest in-corridor displacement achieved anywhere is **6.94°** per hour, against 5° at the loosest end of the

Table S15: Effect of requiring the stop to occur within the guidance corridor.

| Configuration                                            | Stop anywhere      | Stop in corridor     |
|----------------------------------------------------------|--------------------|----------------------|
| corr. 170–210°, drift 15° h <sup>-1</sup> , guide 0.25 h | 1 orbit, min 3.88° | <b>0</b> , min 7.81° |
| corr. 150–210°, drift 30° h <sup>-1</sup> , guide 0.25 h | 1 orbit, min 3.88° | <b>0</b> , min 8.08° |

referee’s range, a margin of  $1.39\times$ . Under flat priors the corresponding figure is  $8.71^\circ$ , from 450 close flybys, again with 0 of 525 cells passing. The conclusion is not an artefact of the stratified sampling.

Figure S3 presents the sweep. Panel (a) is the load-bearing result: what binds is the azimuth-drift tolerance, not the stopping threshold. No configuration admits a guidance window at all until the drift tolerance is raised to  $10^\circ \text{ h}^{-1}$ , roughly seven times the published value. Panel (b) shows the tightest in-corridor displacement over the surviving configurations; every populated cell lies between  $6.9$  and  $8.0^\circ$ , and none approaches the criterion.

**The one apparent exception, and why it is not one.** On the unconstrained metric, stopping permitted at any bearing, exactly one orbit of the 6,116 reaches  $3.88^\circ$ , inside the referee’s range. Candidate #1178 is examined directly in Figure S4. It fails on three independent grounds.

*It is not a comet.*  $q = 1.018 \text{ au}$ ,  $e = 4.06$ , closest approach  $6.2 \times 10^5 \text{ km}$  (1.6 lunar distances), and a hyperbolic excess velocity of  $52 \text{ km s}^{-1}$ , against 26 for 1I/‘Oumuamua and 32 for 2I/Borisov. This is not a Solar System body.

*It does not stop.* The total apparent motion reaches a minimum of  $3.85^\circ \text{ h}^{-1}$  and never falls below it at any point in the night. What vanishes is only the altitude component: at the best-displacement epoch 98% of the residual motion is azimuthal ( $|\dot{\text{alt}}| = 0.80$ ,  $|\dot{\text{az}}| \cos \text{alt} = 3.92^\circ \text{ h}^{-1}$ ), and the altitude turning point proper falls half an hour later still, where the total rate is  $3.85^\circ \text{ h}^{-1}$ .

*It is not over the house.* Guidance ends at azimuth  $209.5^\circ$ ; the minimum occurs at azimuth  $233.5^\circ$ ,  $24^\circ$  west of the corridor edge and 3.8 hours later.

A criterion that scores this track as a stop is measuring the moment a descending object levels out, not a body coming to rest above a place. This is the diagnostic value of the rate metric, and the reason the displacement criterion with the corridor link is the one the claim rests on.

**The two-leg itinerary, with a turn toward the house.** A referee further proposed that the Magi’s journey need not have held a single bearing throughout. Taking the Church of the Nativity as a convenient example of an off-road destination, the final stretch would have required a shift in azimuth to something nearer  $170^\circ$  for the last half hour or so, which opens up many more permutations of possible Star motion.

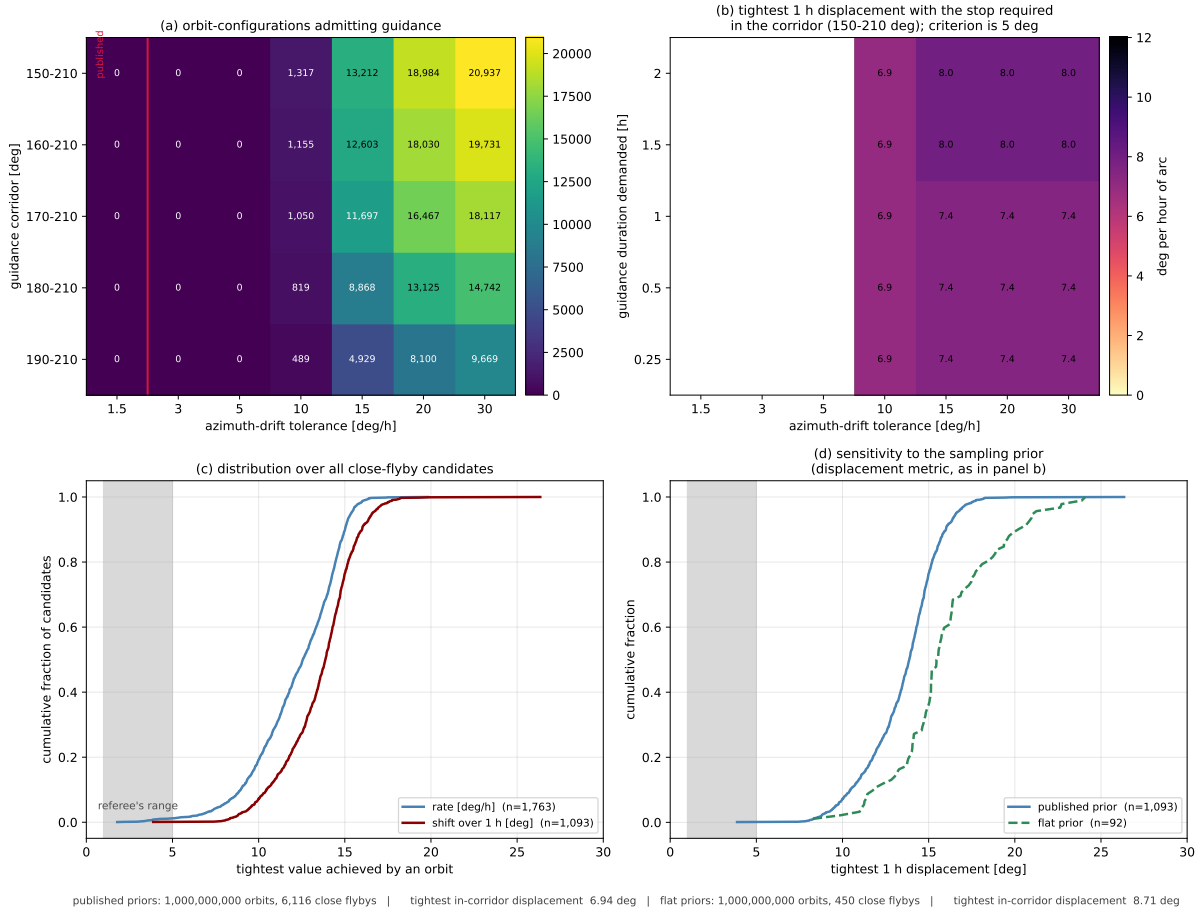
Widening the corridor to a single static window does not test that scenario. A static corridor still demands low azimuth drift throughout, so a star swinging from  $200^\circ$  to  $170^\circ$  is excluded however wide the window is made, while the scenario positively requires that swing. The journey is therefore modeled here in two legs: the road from Jerusalem, with azimuth held in  $[190^\circ, 210^\circ]$ ; a free transition of up to an hour in which the azimuth may swing without constraint; an approach leg with azimuth held in a second corridor, taken as  $[160^\circ, 180^\circ]$ ,  $[140^\circ, 180^\circ]$  or  $[120^\circ, 180^\circ]$  so as to run from due south round to the south-east; and only then the stopping test. Leg durations were swept at 1.5, 1.0 and 0.5 h for the road and 0.5 and 0.25 h for the approach, drift tolerance within each leg at seven values from  $1.5$  to  $30^\circ \text{ h}^{-1}$ , and the stopping threshold at the same six values as above: 756 combinations, over the same 6,116 close flybys. This is more permissive

than any geometry tested elsewhere in this work.

*Result.* No parameter set admits a two-leg itinerary. The reason is directional. The referee's own figure places the final leg near azimuth  $170^\circ$ , which lies east of the  $190\text{--}210^\circ$  bearing held along the road, so the turn requires the Star to swing *eastward*. Diurnal motion carries objects the other way:

|                                                                           |          |
|---------------------------------------------------------------------------|----------|
| Orbits whose azimuth increases (westward) through $120\text{--}210^\circ$ | 2,024    |
| Orbits whose azimuth decreases (eastward)                                 | <b>0</b> |
| Leg pairs in which the approach leg <i>precedes</i> the road leg          | 835      |
| Leg pairs in the order the scenario requires                              | <b>0</b> |

Where both bearings occur they occur in the reverse order: the Star stands at  $170^\circ$  first and at  $200^\circ$  afterwards. An object that turned east to follow the Magi off the road would have to run against the rotation of the sky for the last half hour of the journey. The scenario is therefore not merely unmet but inverted. Script: `sob_finalleg_sweep.py`.



**Figure S3: Survey-scale sweep of the guidance and stopping criteria.** (a) Orbit-configurations admitting a guidance window, over guidance corridor and azimuth-drift tolerance. The drift tolerance is what binds: nothing appears until it is raised roughly sevenfold above the published value (red line). (b) Tightest 1 h displacement with the stop required to fall within the corridor, over drift tolerance and guidance duration demanded; every populated cell lies at  $6.9\text{--}8.0^\circ$  against a  $5^\circ$  criterion. (c) Cumulative distributions of both stopping metrics over all close-flyby candidates, showing that the floor is a property of the population rather than of a few orbits. (d) The same comparison under stratified and flat sampling priors.

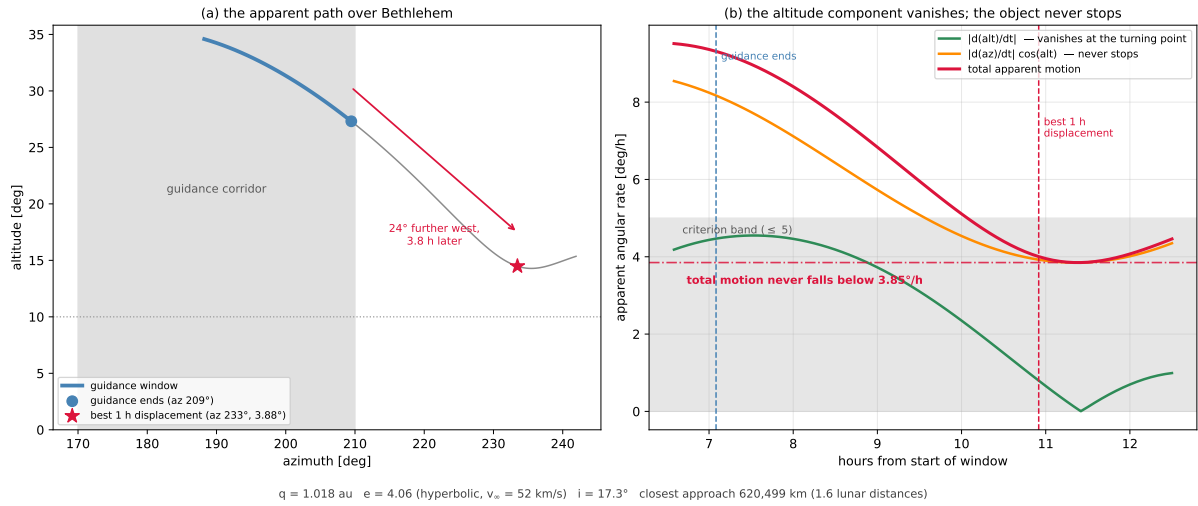


Figure S4: **Anatomy of the single orbit passing the unconstrained metric.** (a) The apparent path over Bethlehem. Guidance ends at azimuth 209.5°; the minimum-displacement epoch occurs 24° further west and 3.8 h later, well outside the corridor. (b) The two components of the apparent motion. The altitude component passes through zero, but the azimuthal component does not, and the total apparent motion never falls below 3.85° h<sup>-1</sup>.

## References

- [1] Morrison, L. V. & Stephenson, F. R. Historical values of the Earth's clock error  $\Delta T$  and the calculation of eclipses. *Journal for the History of Astronomy* **35**, 327–336 (2004).
- [2] Matney, M. The star that stopped: The Star of Bethlehem and the comet of 5 BCE. *Journal of the British Astronomical Association* **135**, 387–406 (2025).
- [3] Allison, D. C. *Studies in Matthew: Interpretation Past and Present* (Baker Academic, Grand Rapids, MI, 2005).
- [4] Adair, A. The Star of Christ in the light of astronomy. *Zygon: Journal of Religion and Science* **47**, 7–29 (2012).
- [5] Tester, J. *A History of Western Astrology* (Ballantine Books, New York, 1987).
- [6] Kepler, J. *De stella nova in pede Serpentarii* (Typis Pauli Sessii, Prague, 1606).
- [7] Strauss, D. F. *Das Leben Jesu kritisch bearbeitet* (C. F. Osiander, Tübingen, 1835).
- [8] Boll, F. Der Stern der Weisen. *Zeitschrift für Neutestamentliche Wissenschaft und die Kunde der Älteren Kirche* **18**, 40–48 (1917).
- [9] Barthel, P. & van Kooten, G. H. (eds) *The Star of Bethlehem and the Magi: Interdisciplinary Perspectives from Experts on the Ancient Near East, the Greco-Roman World, and Modern Astronomy* (Brill, Leiden, 2015).
- [10] Hughes, D. W. The star of bethlehem. *Nature* **264**, 513–517 (1976). URL <https://doi.org>.
- [11] Brown, R. E. *The Birth of the Messiah: A Commentary on the Infancy Narratives in the Gospels of Matthew and Luke* 2 edn (Doubleday, New York, 1993).
- [12] Molnar, M. R. *The Star of Bethlehem: The Legacy of the Magi* (Rutgers University Press, New Brunswick, 1999).

- [13] Bauer, W., Danker, F. W., Arndt, W. F. & Gingrich, F. W. (eds) *A Greek–English Lexicon of the New Testament and Other Early Christian Literature* 3 edn (University of Chicago Press, Chicago, 2000). S.v. *epanō, histēmī, proagō*.
- [14] Heilen, S. in *The star of Bethlehem and Greco-Roman astrology, especially astrological geography* (eds Barthel, P. & van Kooten, G. H.) *The Star of Bethlehem and the Magi* (Brill, Leiden, 2015).
- [15] Birdsall, J. N. Review symposium: *The Star of Bethlehem* by Michael Molnar. *Journal of the History of Astronomy* **33**, 391–394 (2002).
- [16] Thesaurus Linguae Graecae. Thesaurus Linguae Graecae digital library. University of California, Irvine. <https://stephanus.tlg.uci.edu> (2025). Accessed 2025.
- [17] Brown, M. B. A method for combining non-independent, one-sided tests of significance. *Biometrics* **31**, 987–992 (1975).
- [18] Astropy Collaboration. The Astropy Project: Sustaining and growing a community-developed open-source project and status of the v2.0 core package. *Astrophysical Journal* **935**, 167 (2022).
- [19] Harris, C. R. *et al.* Array programming with NumPy. *Nature* **585**, 357–362 (2020).
- [20] Virtanen, P. *et al.* SciPy 1.0: Fundamental algorithms for scientific computing in Python. *Nature Methods* **17**, 261–272 (2020).
- [21] Hunter, J. D. Matplotlib: A 2D graphics environment. *Computing in Science & Engineering* **9**, 90–95 (2007).
- [22] Zotti, G., Hoffmann, S. M., Wolf, A., Chéreau, F. & Chéreau, G. The simulated sky: Stellarium for cultural astronomy research. *Journal of Astronomical History and Heritage* **24**, 1–46 (2021).
- [23] Adair, A. *De stella splendida et matutina*: Language, identity, and the Star of Matthew. *Journal for the Study of the New Testament* (2026). Manuscript submitted for publication. Preprint available at [https://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=6778638](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=6778638).