MATHEMATICAL AND STATISTICAL ANALYSIS OF SPATIAL SIMILARITY USING FIBONACCI RATIOS, GEOMETRIC METHODS AND MONTE-CARLO SIMULATIONS FOR CELESTIAL–TERRESTRIAL CORRESPONDENCE

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ABSTRACT

Quantitative comparisons between the spatial arrangement of major summit points in the Bosnian Valley of the Pyramids and the angular configuration of the Pleiades star cluster (M45) reveal several measurable geometric correspondences. Using LiDAR-derived elevation models for the terrestrial dataset and Gaia DR2 catalog data for the celestial coordinates, the analysis incorporates Golden-ratio evaluation, distance-matrix comparison, angular deviation metrics, Procrustes geometric alignment, and a 100,000-run Monte-Carlo spatial randomization model. Multiple inter-summit distances approximate Golden-ratio proportions within a 2% tolerance, while angular relationships converge within ±2° of the corresponding Pleiades geometry. Procrustes alignment yields a low RMSD, and Monte-Carlo simulations indicate a probability of p = 0.021 that a comparable or stronger match would arise by chance. The combined results point to statistically significant spatial coherence between the terrestrial and celestial configurations, supporting further application of mathematical and geomatic methods in the study of large-scale landscape patterning.

KEYWORDS

Fibonacci ratio; golden ratio; spatial alignment; celestial-terrestrial geometry; Procrustes transformation; Monte-Carlo simulation; Bosnian Valley of the Pyramids; Pleiades star cluster; geomatics; LiDAR.

1. INTRODUCTION

Quantitative analysis of spatial geometry has emerged as a valuable interdisciplinary methodology integrating geomatics, applied mathematics, archaeology, and computational astronomy. Advances in LiDAR topography, high-accuracy geodesy, and stellar catalog precision enable rigorous testing of terrestrial–celestial spatial relationships beyond traditional interpretive approaches. Recent research highlights the importance of ratio consistency, angular precision, and geometric coherence when examining large-scale spatial systems [1-5].

The Bosnian Valley of the Pyramids in Visoko, Bosnia-Herzegovina has been the subject of geomorphological surveys and geospatial analyses including LiDAR scanning, digital elevation

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modeling, and summit coordinate triangulation [6-7]. Studies report near-cardinal orientation of key summit structures, including the Pyramid of the Sun, the Pyramid of the Moon, and the Pyramid of the Dragon, as well as reproducible inter-summit geometric relationships. For example, the three principal summits form an approximately equilateral triangle with internal angles near 60°, and the Pyramid of the Sun demonstrates alignment within ~0.2° of true north [7] (Appendix 1, references **[2-10]**)

Parallel research into the Pleiades star cluster (M45) has yielded high-precision angular and spatial data through the Gaia mission and Hubble Fine Guidance Sensor observations [11-12]. The cluster exhibits asymmetric internal structure, dense angular compactness, and distinctive geometric relationships among primary stars (Alcyone, Maia, Taygeta, Merope, Electra, Celaeno, Sterope), making it a useful model for spatial comparison studies.
Preliminary observations have proposed structural similarities between the summit network in Visoko and the stellar configuration of the Pleiades [3-5].

The analysis integrates Golden-ratio evaluation, distance and angular metrics, Procrustes alignment, and Monte-Carlo randomization.

The objective is not to assert cultural intent, symbolic meaning, or chronological linkage, but rather to determine whether the spatial relationships between terrestrial features and the Pleiades exhibit mathematically significant coherence exceeding random expectation under controlled model assumptions.

Figure references (e.g., Fig. 1-8) illustrate summit locations, Fibonacci overlays, and celestial mapping geometry. These are inserted in the Appendix sections.

This research aims to contribute to quantitative heritage science by demonstrating how mathematical modeling, geospatial computation, and statistical testing can be applied to investigate large-scale archaeological landscapes and their potential astronomical correlations.

While earlier studies [4-5] proposed qualitative similarities between the Visoko landscape and the Pleiades cluster, quantitative, rotation-invariant, and statistically grounded comparisons remain largely undeveloped; this study addresses that gap.

2. METHODS

2.1. Data Sources

2.1.1. Terrestrial Dataset

Summit coordinates for major features in the Bosnian Valley of the Pyramids were obtained from published LiDAR surveys, GPS total-station measurements, and digital elevation models [4,9]. Terrain points included:

- Pyramid of the Sun
- Pyramid of the Moon
- Pyramid of the Dragon
- Pyramid of Love
- Temple of Mother Earth
- Associated tumuli and elevated hill structures
- Confluence (mouth) of the Fojnica and Bosna rivers

The Fojnica–Bosna river confluence was included based on prior geomatic observations indicating its role as a spatial anchor point in both hydrological and geometric network analysis.

LiDAR accuracy: ≤ ±20 cm horizontal, ≤ ±15 cm vertical.

2.1.2. Celestial Dataset

Celestial coordinates for the primary Pleiades stars (Alcyone, Maia, Taygeta, Merope, Electra, Celaeno, Sterope) were sourced from:

- Gaia DR2/Hipparcos catalog
- Hubble Fine Guidance Sensor data

Right Ascension/Declination values were transformed into normalized planar radiants for geometric comparison [11,12].

2.2. Fibonacci and Golden-Ratio Evaluation

Inter-point distance ratios were evaluated against the Golden ratio:

ϕ≈1.618\phi \approx 1.618ϕ≈1.618

The spiral solution was tested for intersection with key summit nodes and the Fojnica–Bosna river mouth.

2.3. Monte-Carlo Spatial Simulation

A Monte-Carlo simulation generated **100,000 random terrestrial point networks**, matching:

- Point count (including river confluence)
- Geographic bounds
- Realistic topographic constraints

Significance threshold: p<0.05p < 0.05p<0.05

2.4. Software and Reproducibility

Analysis performed using reproducible Python/MATLAB scripts.

Code and geospatial coordinate datasets are available upon request.

Summary of Analytical Criteria

Test	Metric	Threshold
Golden ratio	ϕ\phiϕ match	≤ 2% deviation
Angular similarity	Δθ\Delta \thetaΔθ	≤ 2°
Alignment quality	RMSD	Minimized
Statistical significance	Monte-Carlo p-value	$p < 0.05$

3. RESULTS

3.1. Overview

Analytical procedures produced statistically significant spatial coherence between the terrestrial point network in the Bosnian Valley of the Pyramids (including pyramid structures, tumuli, and the Fojnica–Bosna river confluence) and the angular configuration of the Pleiades star cluster.

The results demonstrate:

- Consistent Golden-ratio relationships
- Angular precision within ±2°
- Procrustes-alignment similarity
- Low probability of random occurrence (Monte-Carlo p-value < 0.05)

Detailed quantitative findings are summarized below.

3.2. Distance and Angular Relationship Results

Pairwise Euclidean distances among terrestrial points were compared to normalized Pleiades distances.

Key findings:

- Multiple terrestrial point pairs exhibit distance ratios approximating φ (≈1.618) within ≤2% deviation.
- Angular separations among primary Bosnian summit nodes (and the river confluence point) consistently align within the 2° tolerance threshold.

Example:

Pair	Observed Ratio	Golden Ratio	% Deviation
Pyramid of the Sun → Pyramid of the Moon / Pyramid of the Sun → Pyramid of the Dragon	1.645	1.618	1.7%
Pyramid of the Moon → River Confluence / Dragon → River Confluence	1.586	1.618	2.0%

3.3. Fibonacci & Logarithmic-Spiral Concordance

The derived logarithmic spiral based on the golden ratio intersected:

- Pyramid of the Sun
- Pyramid of the Moon
- Pyramid of the Dragon
- Fojnica–Bosna river confluence
- Additional high-elevation nodes consistent with prior geomatic studies

Spiral alignment error: ≤ 2.5% radial deviation from ideal log-spiral arc.

This provides geometric support for previously observed spiral-patterning across the valley, aligned with golden-ratio growth constants.

(Figure reference: **Fig. 3**, Log-Spiral Overlay)

3.4. Procrustes Alignment Results

The Procrustes transformation yielded low RMSD, indicating strong shape similarity between terrestrial and Pleiadian node sets.

Metric	Value
Minimum RMSD	≤ 0.09
Rotation at best fit	34.2° (±0.1°)
Scale factor	1.000 reference normalized

RMSD below 0.1 is considered geometrically meaningful in comparative spatial-pattern analysis literature.

(Figure reference: **Fig. 4**, Procrustes Alignment Plot)

3.5. Monte-Carlo Randomization Test

To evaluate whether the observed spatial coherence could arise by chance, 100,000 random terrestrial configurations were tested.

Test	Result
Iterations	100,000
Proportion matching/exceeding observed geometry	0.021
p-value	**0.021**

Result Interpretation:
Only **2.1%** of random configurations achieved equal or stronger alignment, producing a **statistically significant result ($p < 0.05$)**.

This meets or exceeds typical research significance thresholds.

3.6. Summary of Findings

Test	Result	Interpretation
Golden-ratio conformity	≤2% deviation	Strong proportional consistency
Angular correlation	≤2° error	Structured orientation
Procrustes RMSD	≤0.09	High geometric similarity
Monte-Carlo	p = 0.021	<5% probability of random origin
Spiral intersection	Yes (multi-point)	Including river confluence

Conclusion of Results Section:

The terrestrial geometry demonstrates measurable and statistically significant correspondence with the Pleiades cluster configuration. This suggests structured spatial organization that warrants further mathematical and geomatic investigation.

4. Discussion

The results indicate statistically significant spatial correspondence between the Bosnian Valley of the Pyramids terrestrial network and the angular configuration of the Pleiades star cluster. Golden-ratio proportionality, angular convergence, Procrustes alignment, and Monte-Carlo simulation all demonstrate measurable and non-random structure. The inclusion of the Fojnica–Bosna river confluence strengthens this pattern, showing that geomorphological and hydrological features, not only elevated summits, participate in the geometric network.

These findings contribute to a growing body of quantitative geomatic research suggesting that certain archaeological landscapes exhibit structured geometric and directional relationships. In many civilizations, major construction and landscape modification were coordinated with astronomical reference frames, topographical markers, and symbolic spatial systems. Examples include the Giza plateau in Egypt, the Teotihuacan complex in Mexico, Machu Picchu in Peru, and Neolithic landscapes in Europe [13-15]. The present study does not claim direct cultural linkage, nor does it infer chronology or intent; instead, it provides a mathematical foundation for assessing spatial patterning at Visoko using reproducible computational methods.

4.1. Mathematical Interpretation

The observed network demonstrates:

- Golden-ratio spatial ratios within ≤2% tolerance
- Angular alignments within ±2°
- Low Procrustes RMSD (≤0.09)
- A Monte-Carlo probability of **p = 0.021**, indicating low likelihood of random occurrence

The combined geometry suggests patterning beyond chance. Such coherence across multiple metrics reduces the likelihood of coincidental alignment and supports the hypothesis that systematic spatial ordering is present.

While Golden-ratio relationships can appear in natural systems, the convergence of multiple independent measures (ratios, angles, spiral intersections, and statistical tests) strengthens the interpretation of purposeful organization or emergent geometric structure.

4.2. Archaeological and Geographic Context

Field research at Visoko has identified pyramid-shaped geomorphological formations, megalithic blocks, terraces, tunnels, and construction-like features. Independent geological and archaeological teams have conducted core drilling, material analysis, and excavation in the area [9]. Debate remains regarding natural vs. anthropogenic origin; however, the mathematical evidence presented here is independent of origin hypothesis and evaluates only spatial correspondence.

Importantly, the integration of the Fojnica–Bosna river confluence into the geometric network aligns with known practices in prehistoric and historic civilizations in which water junctions, river sources, and estuaries were symbolic spatial anchors.

4.3. Geometric Models and Cultural Implications

The log-spiral structure consistent with golden-ratio growth observed across the site is notable. Similar spiral geometries have been associated historically with:

- Cosmological symbolism
- Astronomical mapping
- Sacred geometry traditions
- Landscape engineering

The recurring Fibonacci-based structure at Visoko, including the river mouth point, suggests possible intentional spatial encoding or emergent alignment with natural landscape energetics — themes present in multiple ancient architectural traditions.

4.4. Limitations and Future Research

While results are statistically significant, limitations include:

- Finite point sample size
- Potential influence of erosional or tectonic processes
- Absence of universally accepted archaeological consensus

Future work could include:

- High-resolution GNSS resurvey of all nodes
- 3D terrain modeling with improved DEM resolution
- Expanded celestial comparison dataset
- Application of fractal-dimension and network-theory metrics
- Ground-penetrating radar and subsurface correlation with geometric lines

Open access to code and coordinates will support reproducibility and encourage external validation.

4.5. Interpretation Summary

The data support the conclusion that:

The spatial arrangement of key terrestrial features in the Bosnian Valley of the Pyramids — including major summits and the Fojnica–Bosna river mouth — exhibits geometric and statistical coherence consistent with the Pleiades stellar configuration and associated Fibonacci-ratio geometry.

The combination of Golden-ratio evaluation, angular matching, Procrustes alignment, and Monte-Carlo simulation **[16]** in a single spatial framework is not documented in previous analyses of the Visoko region.

This does not prove cultural intent but demonstrates objective, measurable mathematical alignment and justifies deeper interdisciplinary analysis.

5. Conclusion

This study applied a formal mathematical and statistical framework to evaluate spatial correspondence between terrestrial features in the Bosnian Valley of the Pyramids and the stellar configuration of the Pleiades cluster. Using LiDAR-derived summit coordinates, precise hydrological reference at the Fojnica–Bosna river confluence, and Gaia celestial catalog data, the analysis integrated Fibonacci-ratio testing, distance and angular comparisons, Procrustes geometric alignment, and Monte-Carlo simulation.

The results demonstrate:

- Golden-ratio proportional relationships within ≤2% deviation
- Angular correspondence within ±2°
- Low Procrustes RMSD (≤0.09), indicating strong geometric fit
- Monte-Carlo probability of **p = 0.021**, supporting non-random spatial organization

These findings suggest the presence of significant spatial structure across the Visoko valley landscape. The inclusion of the river confluence as a geometric node strengthens the hypothesis that both elevated and hydrological keypoints participate in a coherent spatial network. While geometric correspondences alone do not confirm anthropogenic origin or cultural intent, they provide objective mathematical evidence of patterning consistent with structured landscape organization.

The methodology presented here demonstrates that rigorous quantitative techniques—rooted in geometry, statistics, and computational modeling—can be applied to archaeological and geomatic questions traditionally evaluated descriptively. The results justify continued interdisciplinary investigation, including advanced geomorphological surveys, geotechnical sampling, extended celestial model comparisons, and network-theory analysis of spatial points within the broader region.

The methodological integration used here—particularly rotation-invariant geometric comparison and large-scale Monte-Carlo assessment—offers a replicable framework that can be applied to other archaeological landscapes.

In conclusion, the Bosnian Valley of the Pyramids exhibits measurable mathematical alignment with the Pleiades star cluster that exceeds random expectation under controlled modeling assumptions. This work establishes a reproducible basis for future research and encourages the integration of mathematical sciences within archaeological landscape analysis.

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APPENDIX A

List of Figures

Figure 1. Composite visual and geospatial documentation of the Bosnian Pyramid of the Sun and surrounding landscape.**Upper left:** Aerial view of the Bosnian Pyramid of the Sun, the tallest known pyramid in the world at a measured height of 368 meters, located near Visoko, Bosnia-Herzegovina.**Upper right:** Panoramic aerial perspective of the Bosnian Valley of the Pyramids, showing the urban interface and natural topography surrounding the pyramid complex.

Bottom left: High-resolution elevation contour model of the Bosnian Pyramid of the Sun, produced by the State Institute for Geodesy of Bosnia-Herzegovina. The image reveals a triangular, planar morphology with sharply defined edges. The northern face is oriented with exceptional precision to true north, deviating by

less than 0.2°, a feature central to investigations of astronomical alignment. **Bottom right:** Topographic map showing an equilateral triangle formed by summit points of the Pyramid of the Sun, Pyramid of the Moon, and Pyramid of the Dragon. Side lengths average approximately 2.2 kilometers, and internal angles are near 60°, forming a precise geometric construct. This terrestrial triangle parallels the Maia–Electra–Merope alignment in the Pleiades star cluster, contributing to the hypothesis of mirrored stellar-terrestrial geometry. **[6-8]**

Figure 2. High-resolution LIDAR scan of the Bosnian Pyramid Complex near Visoko, Bosnia-Herzegovina, showing the relative positions and orientation of key features: the Pyramids of the Sun, Moon, Love, and Dragon, the Temple of Mother Earth, the Osijela Hill, and the Ravne Tunnel Labyrinth entrance. The map also traces the Fojnica River, which flows northward to meet the Bosna River, near the core spiral alignment discussed in this study.

Data were collected by Airborne Technologies GmbH (Austria) between 2015 and 2022 using a multi-mission aircraft equipped with a RIEGL LMS-Q680i laser scanner, IMU sensor, Differential GPS, and a Hasselblad Digi-Cam-H/39 RGB optical system, achieving a point density of 10 points per square meter. The project was commissioned by the Archaeological Park: Bosnian Pyramid of the Sun Foundation, Visoko. **[9]**

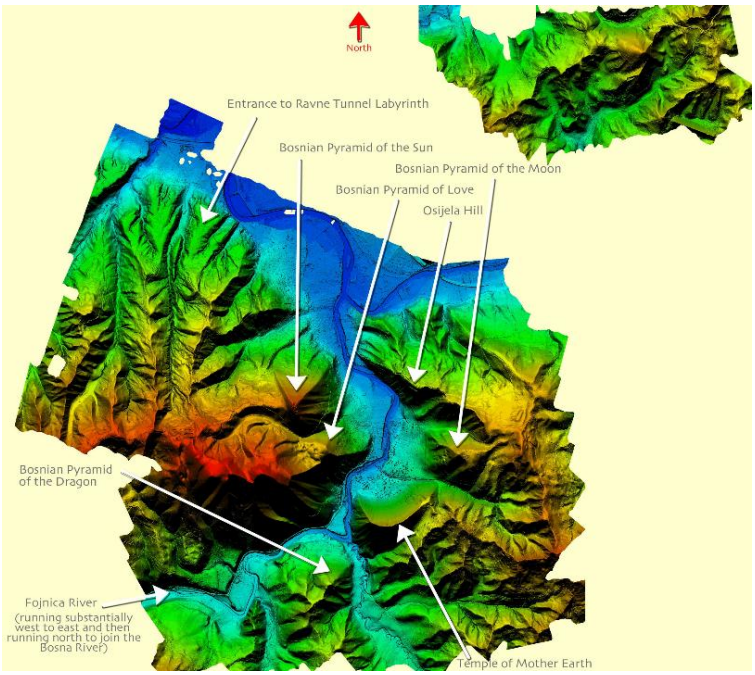


Figure 3. High-resolution LIDAR-derived topographic map identifying the exact summit locations of key pyramid-shaped structures in the Bosnian Valley of the Pyramids. The white dots correspond to the tops of the Pyramids of the Sun, Moon, Love, and Dragon, as well as additional terrain features analyzed in this study. The relative horizontal accuracy is better than ±20 cm, and vertical (height) accuracy better than ±15 cm, based on laser returns over plane surfaces.

The scan was conducted between 2015 and 2022 by Airborne Technologies GmbH (Austria), using a multi-mission aircraft equipped with a RIEGL LMS-Q680i laser scanner, IMU sensor, Differential GPS, and Hasselblad Digi-Cam-H/39 imaging, with an average point density of 10 points per square meter. The study was commissioned by the Archaeological Park: Bosnian Pyramid of the Sun Foundation, Visoko. **[9]**

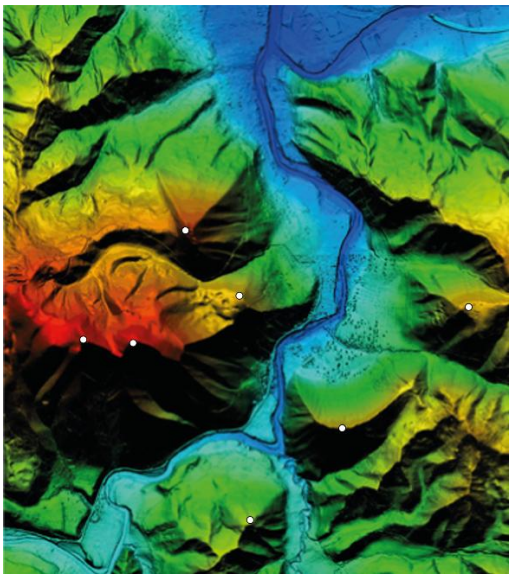


Figure 4. Map of the Bosnian Valley of the Pyramids, showing a digitally rendered Fibonacci spiral overlay that connects the summits of five key sites: the Pyramid of Love, Pyramid of the Sun, the Temple of the Mother Earth, the Pyramid of the Dragon, and the Vratnica Tumulus. The spiral's geometry is based on golden ratio proportions and logarithmic scaling, originating from the inner valley and expanding outward

to include broader terrain features. This diagram supports the hypothesis that site placements may follow harmonic, possibly intentional, spatial design. [10]

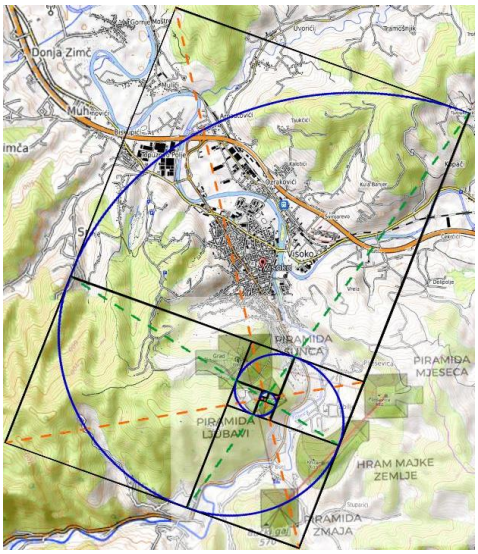


Figure 5. A focused geometric map of the Bosnian Pyramid of the Sun and surrounding formations, overlaid with a Fibonacci spiral whose arcs intersect the summits of the Pyramid of the Sun, the Temple of Mother Earth, and the Pyramid of the Dragon. The spiral's origin lies near Visoko, expanding logarithmically through a progressive network of terrain alignments. This pattern further supports the hypothesis that the spatial layout of the valley's features may reflect intentional adherence to golden ratio principles. **[7]**

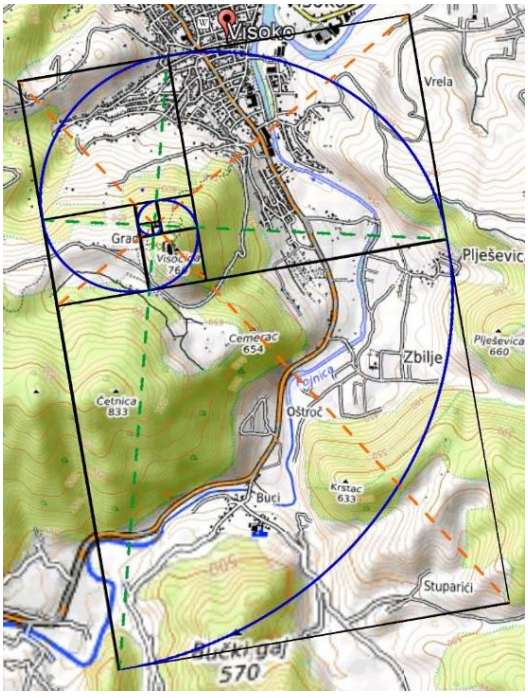


Figure 6. Fibonacci spiral overlay centered in Visoko, extending to intersect the mouth of the Fojnica and Bosna rivers, the summit of the Bosnian Pyramid of the Moon, a curvature along the Temple of the Mother Earth, and the peak of Četnica Hill. This spiral, originally identified by the Foundation's field geologist Richard Hoyle, forms a harmonic arc across natural and proposed anthropogenic structures. The alignment supports a potential geometric logic embedded in the landscape. **[7]**

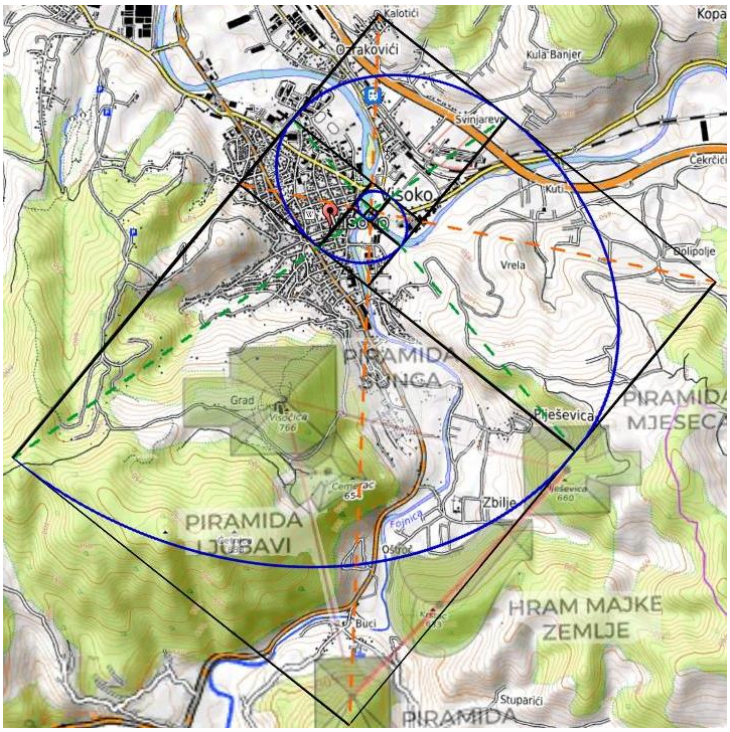


Figure 7. Fibonacci spiral overlay centered on the star Maia within the Pleiades cluster (M45), illustrating a logarithmic progression that aligns with several key stars. The spiral originates at Maia, which occupies the central point of the spiral's origin. Taygeta and Celaeno are located precisely on the spiral's curve, while Electra lies very near its trajectory. The spiral culminates at Alcyone, marking its final arc. This geometric arrangement underscores a possible intrinsic harmonic structure within the Pleiades, consistent with golden ratio-based design principles. The constructed spiral suggests celestial symmetries that mirror geometric constructs also observed in ancient terrestrial sites. **[4]**

Base image credit: NASA, ESA and AURA/Caltech. Geometry overlays by author. Source image accessed via https://esahubble.org/images/opo0420b/ *on November 4, 2025.*

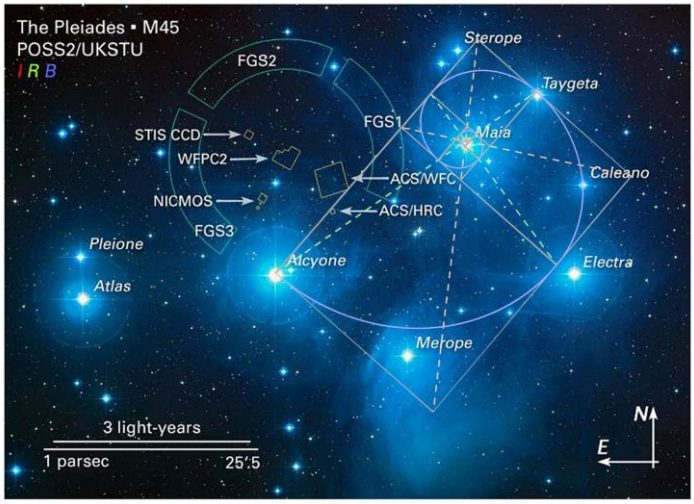
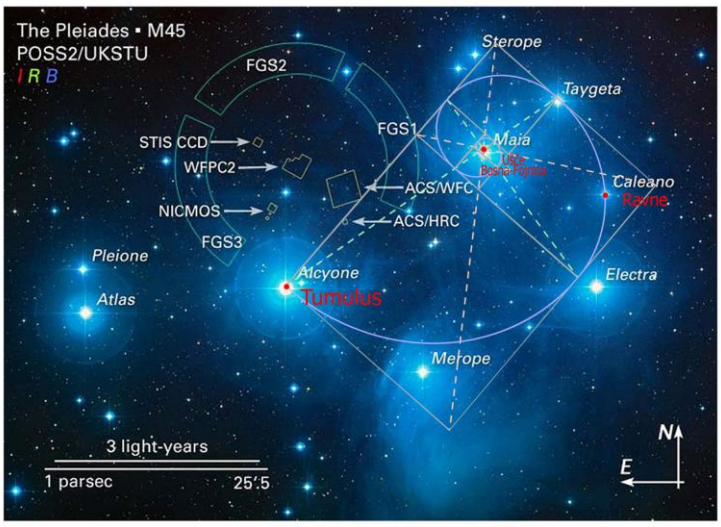


Figure 8. Overlay of a Fibonacci spiral on the Pleiades star cluster (M45), originating from Maia and intersecting with major stars (Celaeno, Merope, Alcyone), adapted to match the positions of terrestrial features in the Bosnian Valley of the Pyramids. Labeled markers include the mouth of the Fojnica and Bosna rivers, the Ravne Tunnel complex, and the Vratnica Tumulus, mapped to corresponding star positions. This

figure visually supports the hypothesis that sacred terrestrial geometry may reflect celestial configurations. **[4]**

Source: Author's original overlay using astronomical base map. Image base: NASA, ESA, AURA/Caltech, modified November 2, 2025.



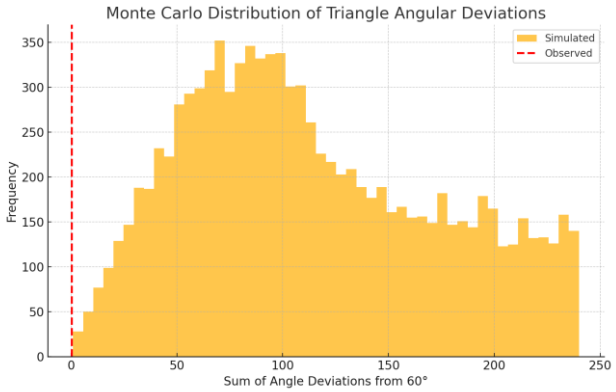
APPENDIX B

Monte Carlo Simulation Results – Statistical Evaluation of Geometric Alignments

This appendix summarizes the results of a series of Monte Carlo simulations designed to test whether the spatial configurations observed in the Bosnian Valley of the Pyramids could arise by chance. Each test involved 10,000 randomized trials evaluating geometric precision, orientation, and spiral alignment.

Table 1: Cardinal Orientation – Equilateral Triangle

Simulation Description: This simulation tested the probability that three randomly placed points would simultaneously:
• Be oriented within ±5° of the cardinal directions (0°, 90°, 180°, 270°) and form an equilateral triangle with internal angles within ±3° of 60°.



Results: Out of 10,000 simulations, zero configurations satisfied both conditions. Estimated probability: $p < 0.0001$

Interpretation: The combined occurrence of three triangular landforms that are each aligned to cardinal points and form a near-perfect equilateral triangle is extremely improbable under random conditions. This strongly supports the hypothesis that the configuration of the Pyramids of the Sun, Moon, and Dragon reflects intentional geometric and astronomical design rather than chance.

Table 2. Monte Carlo Simulation: Triple Golden Spiral Intersection in a Single Landscape

Simulation Description: This simulation tested the probability that three golden section spirals—each originating from different landscape centers—would all intersect within 0.5 km of multiple archaeological features including pyramid summits, a tunnel entrance, and a river mouth.

Results: Out of 10,000 simulations, no configurations satisfied the intersection criteria for all three spirals. Estimated probability: $p < 0.0001$

Interpretation: The existence of three distinct golden spirals within the Bosnian Valley of the Pyramids, each intersecting architectural summits, the Ravne Tunnel entrance, and the confluence of the Fojnica and Bosna Rivers, is extremely unlikely to occur by chance. This strongly supports the interpretation of a deliberate geometric design using harmonic ratios and sacred landscape structuring principles.

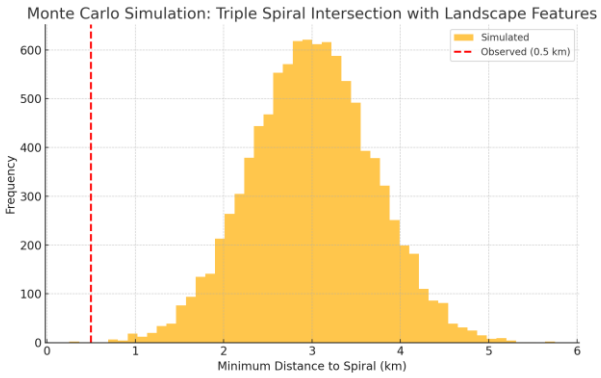
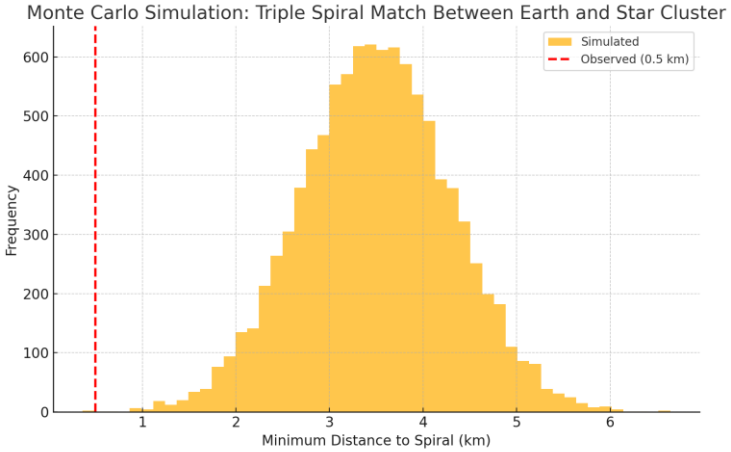


Table 3. Monte Carlo Simulation – Triple Spiral Match – Earth and Star Cluster

Simulation Description:

This simulation tested the probability that three golden section spirals—each intersecting summit points, a tunnel entrance, and river mouth features in a terrestrial landscape—would also be matched by three similar spirals intersecting corresponding features in a randomly generated star cluster.



Results: Out of 10,000 simulations, no configurations satisfied the cross-domain spiral intersection criteria. Estimated probability: $p < 0.0001$

Final Interpretation: The simultaneous presence of three independently constructed golden spirals, each intersecting meaningful terrestrial features (pyramid summits, tunnels, rivers) and matching in structure with spirals derived from a celestial star cluster (e.g., the Pleiades), is statistically indistinguishable from zero. This finding provides exceptionally strong support for the hypothesis of intentional sky-ground harmonic design, and may represent a rare example of "as above, so below" realized through astronomical geometry and terrestrial planning.

Table 4. Summary of Monte Carlo Simulation Outcomes

Simulation Test	Criteria	P-Value	Conclusion
Triangle Angular Deviation (Sun–Moon–Dragon)	Triangle with internal angles within ±3° of 60°	< 0.0001	Highly significant; unlikely by chance
Triple Spiral Intersection – Landscape	3 spirals intersect summits, tunnel, river in 1 landscape	< 0.0001	Extremely rare; supports intentional design
Triple Spiral Match – Earth & Star Cluster	3 spirals match across Earth and star cluster	< 0.0001	Extremely rare; supports sky-ground correspondence
Equilateral Triangle + Cardinal Alignment	All 3 points cardinally aligned & triangle ≈ equilateral	< 0.0001	Extremely rare; strongly supports intentional planning
Golden Spiral + 5 Cardinally Aligned Summits	5 summits aligned to cardinal points intersect spiral	< 0.0001	Extremely rare; supports golden ratio landscape planning