LUNARIS: Technical Whitepaper

A Science-Backed Lunar Metaverse with Proof-of-Existence Economics

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Abstract

LUNARIS is a decentralized lunar metaverse platform that synthesizes verifiable astronomical data, non-fungible token (NFT) asset ownership, and a multi-token economic system to create a sustainable digital ecosystem tied to real lunar phenomena. This whitepaper presents the technical architecture, economic modeling, cryptographic proof mechanisms, and governance structures underlying the LUNARIS protocol.

Key Innovations:

- NFT metadata anchored to USGS Unified Geologic Map coordinates
- Moon phase-driven dynamic rarity distribution algorithms
- Triple-token deflationary/inflationary balance mechanism
- DAO governance with quadratic voting adjustments
- Proof-of-existence timestamping via Bitcoin-anchored attestation

Target Deployment: Polygon PoS mainnet (Contract addresses to be announced post-audit)

1. Introduction

1.1 Motivation

Since the Apollo program (1969-1972), human engagement with lunar exploration has been primarily observational. The LUNARIS protocol reimagines this relationship by creating verifiable digital ownership of lunar territory representations, backed by peer-reviewed scientific datasets and governed through decentralized consensus mechanisms.

Problem Statement:

- Existing NFT projects lack scientific grounding
- Token economies exhibit unsustainable inflation/deflation cycles
- Educational platforms fail to integrate earning mechanisms
- Space exploration remains inaccessible to general population

Solution:
LUNARIS bridges these gaps through a technically rigorous framework that ensures:

1. Geographic authenticity (USGS map correspondence)
2. Economic sustainability (mathematical modeling of token flows)
3. Educational value (real astronomical event integration)
4. Democratic governance (DAO-controlled parameters)

1.2 Scientific Foundation

All lunar geographic data in LUNARIS derives from:

- **USGS Unified Geologic Map of the Moon** (Fortezzo et al., 2020) - 1:5,000,000 scale
- **LRO (Lunar Reconnaissance Orbiter)** datasets (2009-present)
- **LCROSS impact analysis** (Colaprete et al., 2010) - South Pole water ice confirmation
- **Clementine multispectral imaging** (Lucey et al., 2000) - Titanium abundance mapping

All astronomical calculations use International Astronomical Union (IAU) standards and NASA JPL Horizon System ephemeris data.

2. Lunar Geographic System

2.1 Coordinate Mapping

Each LUNARIS Plot NFT maps to a $100\ \mathrm{m} \times 100\ \mathrm{m}$ area defined by:

$$\mathrm{Plot}_i = (lat_i, lon_i, \Delta_{lat}, \Delta_{lon})$$

Where:

- lat_i, lon_i = center coordinates (selenographic latitude/longitude)
- $\Delta_{lat} = \Delta_{lon} = 0.0009^\circ$ (approximately 100m at lunar equator)

Total addressable lunar surface:

$$N_{total} = \frac{A_{moon}}{A_{plot}} = \frac{38 \times 10^6\ \mathrm{km}^2}{10^4\ \mathrm{m}^2} \approx 3.8 \times 10^9\ \mathrm{plots}$$

MVP deployment: 10,000 plots (Genesis phase)

Full deployment: 187,000,000 plots across 18 designated Lunar States

2.2 Regional Classification

Regions classified by USGS geological units:

Region	Area (km²)	Dominant Geology	Resource Weight
Mare Tranquillitatis	421,000	High-Ti basalt	Ti: 1.0, Ice: 0.1, KREEP: 0.2

Region	Area (km²)	Dominant Geology	Resource Weight
South Polar Region	52,000	Permanently Shadowed Regions (PSRs)	Ice: 1.0, Ti: 0.1, KREEP: 0.3
Oceanus Procellarum	2,568,000	KREEP-rich basalt	KREEP: 1.0, Ti: 0.6, Ice: 0.1

Resource weights determine NFT utility multipliers (Section 5).

2.3 Proof of Geographic Authenticity

Each Plot NFT includes cryptographic hash of:

1. USGS map tile (256×256 px at 1:5M scale)
2. Coordinate metadata (lat/lon/region)
3. Timestamp of mint transaction

Hash stored in NFT metadata and verifiable against USGS public datasets.

3. Advanced Minting Mechanics

3.1 Moon Phase-Dependent Rarity Algorithm

Astronomical Input:
Moon phase $\phi(t)$ calculated via:

$$\phi(t) = \frac{(t - t_0) \mod T_{syn}}{T_{syn}}$$

Where:

- t = Unix timestamp (seconds since epoch)
- t_0 = Reference new moon (e.g., Jan 1, 2025, 00:00 UTC)
- $T_{syn} = 29.530588 \text{ days} = 2551442.9792 \text{ seconds}$ (synodic month)

Phase Categories:

$$\text{Phase}(\phi) = \begin{cases} \text{New Moon} & amp; \text{if } \phi \in [0, 0.0625) \\ \text{Waxing Crescent} & amp; \text{if } \phi \in [0.0625, 0.25) \\ \text{First Quarter} & amp; \text{if } \phi \in [0.25, 0.3125) \\ \text{Waxing Gibbous} & amp; \text{if } \phi \in [0.3125, 0.5) \\ \text{Full Moon} & amp; \text{if } \phi \in [0.5, 0.5625) \\ \text{Waning Gibbous} & amp; \text{if } \phi \in [0.5625, 0.75) \\ \text{Last Quarter} & amp; \text{if } \phi \in [0.75, 0.8125) \\ \text{Waning Crescent} & amp; \text{if } \phi \in [0.8125, 1.0) \end{cases}$$

Rarity Distribution Function:

For each phase p, rarity $r \in \{\text{Common}, \text{Uncommon}, \text{Rare}, \text{Epic}, \text{Legendary}\}$ assigned via weighted random sampling:

$$P(r|p) = \frac{w_{p,r}}{\sum_{r'} w_{p,r'}}$$

Weight Matrix W:

Phase	Common	Uncommon	Rare	Epic	Legendary
New Moon	0.80	0.20	0	0	0
First Quarter	0.60	0.30	0.10	0	0
Full Moon	0.40	0.40	0.15	0.04	0.01

(Epic/Legendary only available during Full Moon ± 12 hours)

On-Chain Implementation:
Smart contract queries Chainlink oracle for verified timestamp → calculates $\phi(t)$ → applies $P(r|p)$ via Chainlink VRF (verifiable random function) for provably fair rarity assignment.

3.2 Multi-Stage Minting State Machine

State Transition Diagram:

$$\text{IDLE} \xrightarrow{\text{User initiates mint}} \text{PENDING} \xrightarrow{\text{Phase check}} \text{PHASE\textbackslash\_VERIFIED}$$

$$\xrightarrow{\text{VRF request}} \text{RANDOMNESS\textbackslash\_REQUESTED} \xrightarrow{\text{VRF callback}} \text{RARITY\textbackslash\_ASSIGNED}$$

$$\xrightarrow{\text{Payment verified}} \text{NFT\textbackslash\_MINTED} \xrightarrow{\text{Metadata pinned}} \text{COMPLETE}$$

Each state enforces:

- Phase verification: Timestamp within allowed window (±2 hours buffer for gas price optimization)
- Supply cap: Max 500 mints per Full Moon event
- Anti-whale: Max 3 mints per wallet per phase window
- Payment validation: Exact USDC amount (dynamic pricing via oracle)

3.3 Dynamic Pricing Model

Base price P_0 adjusted by:

$$P(t, r, s) = P_0 \cdot M_r \cdot \left(1 + \frac{s}{S_{cap}}\right)^{0.5}$$

Where:

- M_r = Rarity multiplier (Common: 1.0, Rare: 2.5, Legendary: 10.0)
- s = Current supply minted
- S_{cap} = Phase supply cap
- Exponent 0.5 creates diminishing price increase (Dutch auction in reverse)

Example:

- Full Moon event, $P_0 = 50$ USDC
- Legendary mint ($M_r = 10$)
- 200/500 already minted
- $P = 50 \cdot 10 \cdot (1 + 0.4)^{0.5} = 593.3$ USDC

Price discovery via bonding curve prevents early mint dumping.

4. Triple-Token Economic Architecture

4.1 MOONX (Utility Token)

Supply Dynamics:

$$\frac{dS_{MOONX}}{dt} = E(t) - B(t)$$

Where:

- $E(t)$ = Emission rate (minting/staking/mining rewards)
- $B(t)$ = Burn rate (marketplace fees/crafting/upgrades)

Emission Function:

$$E(t) = \sum_{i=1}^{N_users} \min(E_i(t), C_i)$$

Where:

- $E_i(t)$ = Individual user's potential earnings
- C_i = User's tier-based daily cap
- $C_i \in \{100, 300, 800, 2000, 5000\}$ MOONX for Tiers 1-5

Individual Earning Rate:

$$E_i(t) = R_{base} \cdot M_{NFT} \cdot M_{phase}(\phi(t)) \cdot M_{region}$$

- $R_{base} = 20$ MOONX/hour (baseline)
- M_{NFT} = NFT efficiency multiplier (Rover: 1.0-2.5×, Plot rarity: 1.0-3.5×)
- $M_{phase}(\phi)$ = Phase multiplier (New Moon: 0.8, Full Moon: 2.0)
- M_{region} = Regional bonus (South Pole Ice missions: 1.5×)

Burn Mechanisms:

$$B(t) = B_{market}(t) + B_{craft}(t) + B_{upgrade}(t) + B_{storage}(t)$$

$$B_{market}(t) = 0.5 \cdot 0.02 \cdot V_{market}(t)$$

(50% of 2% marketplace fee burned)

$$B_{craft}(t) = \sum_{j} Q_j \cdot C_j$$

(Q_j = quantity crafted, C_j = crafting cost in MOONX)

Equilibrium Analysis:

Target steady state: $E(t) \approx 1.1 \cdot B(t)$ (10% net inflation)

If : DAO activates buyback protocol (Section 4.4)

If : Emission caps increased by governance vote

4.2 LUNAR (Governance Token)

Fixed Supply: $S_{LUNAR} = 100,000,000$ (immutable)

Distribution Schedule:

Allocation	Amount	Vesting
Community Rewards	40M	Linear 4 years
DAO Treasury	20M	No vesting (controlled by governance)
Team	20M	1-year cliff, 4-year linear
Presale (if conducted)	15M	6-month cliff, 2-year linear
Liquidity Provision	5M	No vesting (locked in pools)

Voting Power:

$$V_i = L_i \cdot (1 + 0.5 \cdot \mathbb{1}_{T_i \geq 4})$$

Where:

- L_i = LUNAR holdings of voter i
- $\mathbb{1}_{T_i \geq 4}$ = Indicator (1 if user in Tier 4-5, else 0)
- Tier multiplier prevents whale dominance (capped at +50%)

Quadratic Voting Option:

For critical proposals (tokenomics changes, treasury allocation >10%), voting power:

$$V_i^{quad} = \sqrt{L_i}$$

Reduces large holder influence, enacted via governance meta-vote.

Staking Rewards:

$$R_{stake} = L_{staked} \cdot \left(0.12 + 0.03 \cdot \frac{L_{staked}}{S_{LUNAR}}\right)$$

- Base APY: 12%
- Bonus APY: Up to +3% if staking >1% of total supply
- Paid from DAO treasury (20M allocation)

4.3 MOON-3 (Premium Token)

Supply: $S_{MOON3} = 10,000,000$ (fixed)

Emission:

Exclusively via:

1. Advanced mining (Tier 4-5 only): 0.1-1% drop rate per session
2. Eclipse events: 500 MOON-3 distributed (proportional to active playtime during event)
3. Legendary NFT staking: 0.5 MOON-3/day
4. DAO special missions: Variable (50-500 MOON-3)

Deflationary Use Cases:

- Fusion crafting: Burns 100 MOON-3 per Fusion-grade NFT
- Tier skip mechanism: Burns 200 MOON-3 for instant Tier 3→4 upgrade
- Exclusive zone access: Requires minimum 50 MOON-3 holdings (not burned, but locked)

Economic Rationale:

With ≈10,000 MOON-3 minted/month (100K users), and 2,000-3,000 burned via fusion/upgrades:

$$\frac{dS_{MOON3}}{dt} \approx -200,000 \text{ per year (deflationary)}$$

Creates long-term scarcity premium.

4.4 DAO-Controlled Economic Stabilization

Buyback Protocol:

Trigger condition:

(30% price drop in 7 days)

Response:

$$B_{buy}(t) = \min(0.3 \cdot T_{treasury}, 0.5 \cdot V_{7day})$$

(Use up to 30% of treasury or 50% of 7-day volume, whichever is smaller)

Burn Allocation:

Of buyback amount B_{buy}:

- 50% permanently burned

- 30% redistributed to LUNAR stakers
- 20% held as treasury reserve

5. NFT Utility Framework

5.1 Plot NFT Mechanics

Passive Staking:

$$R_{passive} = R_0 \cdot (1 + 0.5 \cdot r) \cdot (1 + 0.3 \cdot g)$$

- $R_0 = 10$ MOONX/day (base rate)
- $r \in \{0, 0.5, 1.5, 3.0, 5.0\}$ for rarities Common→Legendary
- $g \in \{0, 0.2, 0.5\}$ for region geological weight (Section 2.2)

Example: Rare Plot in South Pole (Ice: 1.0)

$$R = 10 \cdot (1 + 0.5 \cdot 1.5) \cdot (1 + 0.3 \cdot 1.0) = 22.75 \text{ MOONX/day}$$

Active Mining:

Requires Plot + Rover NFT pairing.

$$R_{active} = R_{base} \cdot M_{rover} \cdot M_{phase} \cdot M_{spec} \cdot T_{session}$$

- $R_{base} = 40$ MOONX/hour
- M_{rover} = Rover efficiency (1.0-2.5×)
- M_{phase} = Phase multiplier (0.8-2.0×)
- M_{spec} = Resource specialization bonus (1.0-1.5×)
- $T_{session}$ = Session duration (1-8 hours, user choice)

Example: Uncommon Rover (1.5×) + Rare Plot (Ti specialization 1.3×) during Full Moon:

$$R = 40 \cdot 1.5 \cdot 2.0 \cdot 1.3 \cdot 4 = 624 \text{ MOONX per 4-hour session}$$

5.2 Rover NFT Rental Market

Smart Contract Escrow:

Renter deposits collateral $C = 2 \cdot V_{rover}$ (2× rover floor price)

Rental terms:

- Daily fee F (set by owner)
- Revenue split: Renter keeps 70%, owner receives 30% of mining output
- Duration: 1-30 days

Settlement:

$$P_{owner} = F \cdot D + 0.3 \cdot \sum_{i=1}^{D} R_i$$

$$P_{renter} = 0.7 \cdot \sum_{i=1}^{D} R_i - F \cdot D - C_{gas}$$

Where D = rental days, R_i = daily mining output

If renter fails to return (breach), collateral C transferred to owner.

5.3 Fusion System (Advanced Crafting)

Fusion Formula:

Combine 3 NFTs of same type + rarity → 1 NFT of next rarity tier

Costs:

- 100 MOON-3 (burned)
- 5,000 MOONX (burned)
- 3× input NFTs (burned)

Output:

- 1 NFT of higher rarity
- Attributes averaged + 20% bonus
- Unique "Fusion" trait (visual indicator)

Economic Impact:

Reduces supply of lower rarities → increases floor prices → incentivizes active gameplay over passive holding.

6. Lunar Cycle Integration

6.1 Real-Time Phase Synchronization

On-Chain Oracle:

Chainlink custom external adapter queries NASA JPL Horizon System API:

Request:

```
COMMAND = '301' (Moon)
CENTER = '399@399' (Earth)
QUANTITIES = '20' (Phase angle)
STEP_SIZE = '1h'
```

Response parsed for $\phi(t)$ with ±0.01% precision.

Oracle updates every 6 hours; cached on-chain for gas efficiency.

Verification:

Users can independently verify phase via:

$$\phi_{verify} = \frac{1}{2\pi} \arccos\left(\frac{\mathbf{r}_{sun} \cdot \mathbf{r}_{moon}}{|\mathbf{r}_{sun}| \cdot |\mathbf{r}_{moon}|}\right)$$

Using public ephemeris data.

6.2 Eclipse Event Protocol

Detection:

Eclipse occurs when:

($\epsilon = 5^\circ$ threshold for partial, 1.5° for total)

Triggered by oracle + DAO manual confirmation.

Event Activation:

- All yields multiply by $\times 5$
- MOON-3 drop rate $\times 10$
- Special "Eclipse NFT" snapshot: All active users during 4-hour window receive commemorative badge
- Emergency DAO multisig can extend/cancel if oracle fails

7. DAO Governance Architecture

7.1 Proposal Lifecycle

Stages:

1. **Draft:** Forum discussion (off-chain, 7 days minimum)
2. **Submission:** 10,000 LUNAR deposit (refunded if >20% quorum reached)
3. **Voting:** 7-day on-chain vote
4. **Timelock:** 48-hour execution delay (security buffer)
5. **Execution:** Automated smart contract call or multisig action

Quorum Requirements:

$$Q_{min} = \max(0.2 \cdot S_{LUNAR}^{circulating}, 5,000,000)$$

(20% of circulating supply or 5M LUNAR, whichever is greater)

Passing Threshold:

(60% approval + quorum)

7.2 Emergency Multisig

Composition: 5-of-9 multisig (community-elected signers)

Powers (limited):

- Pause contracts (max 72 hours)
- Oracle override (manual phase/eclipse trigger)
- Treasury spending <1% without full DAO vote

Elected Annually: LUNAR holders vote, top 9 vote-getters become signers

8. Security & Audit Framework

8.1 Smart Contract Security

Development Standards:

- OpenZeppelin v5.0+ contracts (ERC-721, ERC-20, AccessControl)
- Solidity 0.8.20+ (built-in overflow protection)
- ReentrancyGuard on all state-changing functions
- Pausable mechanism (emergency only)

Audit Plan:

- Internal review (completed pre-testnet)
- External audit by recognized firm (scheduled pre-mainnet, firm to be announced)
- Public bug bounty (post-launch, $100K pool)

8.2 Oracle Security

Chainlink VRF v2.5:

- Provably random rarity assignment
- 6-block confirmation delay
- Callback gas limit: 200,000

Price Oracle:

- Chainlink USDC/USD feed (1-hour heartbeat)
- Fallback: Uniswap V3 TWAP (24-hour window)

8.3 Frontend Security

Metadata Storage:

- IPFS pinning via Pinata (redundant)
- Backup on Arweave (permanent)
- JSON schema validation (prevent malformed data)

9. Deployment Specifications

9.1 Blockchain

Network: Polygon PoS mainnet

Rationale:

- Gas fees: ≈ 30 Gwei = $0.01-0.05/tx (vs. Ethereum $5-50)
- Speed: 2-second block time (vs. Ethereum 12 seconds)
- Ecosystem: OpenSea native support, Chainlink oracle coverage
- Security: Plasma bridge to Ethereum (fallback security)

Contract Addresses: To be announced post-audit

9.2 Token Standards

Asset	Standard	Extensions
Plot NFT	ERC-721	ERC-721Enumerable, ERC-721URIStorage
Rover NFT	ERC-721	ERC-721Enumerable, ERC-721URIStorage
MOONX	ERC-20	ERC-20Burnable, ERC-20Permit
LUNAR	ERC-20	ERC-20Votes (on-chain governance), ERC-20Snapshot
MOON-3	ERC-20	ERC-20Burnable, ERC-20Capped

9.3 Gas Optimization

Minting: Batch minting (up to 3 NFTs/tx) reduces gas 40%

Storage: Pack multiple uint8 variables into single uint256 slot

Transfer: ERC-721A-style consecutive token ID optimization

10. Roadmap

Phase 0: Pre-Launch (Current)

- Whitepaper publication
- OpenTimestamps proof submission
- Community building (Discord, social)
- Contract development (testnet)

Phase 1: Genesis Launch (Q4 2025)

- Mainnet contract deployment
- First 1,000 Plot NFTs (Mare Tranquillitatis)
- MOONX token live
- Staking activation
- Marketplace beta (OpenSea)

Phase 2: Expansion (Q1 2026)

- Rover NFTs (5,000 supply)
- Active mining feature
- South Pole region (1,000 plots)
- Artemis II celebration event (Feb-Apr 2026)

Phase 3: DAO Activation (Q2 2026)

- LUNAR token launch
- Governance portal
- First DAO votes (parameter tuning)
- 10,000+ user milestone

Phase 4: Maturity (Q3-Q4 2026)

- MOON-3 token
- Fusion crafting
- 18 Lunar States complete
- Artemis III landing event (late 2026)

Phase 5: Metaverse (2027+)

- 3D lunar environment
- Multi-chain bridge
- Educational partnerships
- Mars expansion exploration

11. Legal & Disclaimers

11.1 Regulatory Compliance

LUNARIS tokens are **utility tokens** designed for platform functionality, not securities. However:

- Users should consult legal counsel regarding tax obligations
- KYC/AML may be required for large transactions (>$10,000 USD equivalent) depending on jurisdiction
- Team disclaims responsibility for users' regulatory compliance

11.2 Virtual Ownership

LUNARIS NFTs represent **virtual assets** in a digital metaverse. They do NOT confer:

- Legal ownership of physical lunar territory (prohibited under Outer Space Treaty 1967)
- Rights enforceable in terrestrial courts
- Claims against governmental or intergovernmental space agencies

11.3 Investment Risk

Cryptocurrency markets are highly volatile. Users may lose entire investment. This whitepaper is NOT financial advice.

No guarantees regarding:

- Token price appreciation
- Platform longevity
- Earning rate sustainability

DYOR (Do Your Own Research) before participating.

12. References

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13. Appendix A: Mathematical Proofs

A.1 Token Equilibrium Stability

Theorem: Under assumptions $E(t) = E_0 + \epsilon(t)$ and $B(t) = \alpha \cdot E(t)$ where $\alpha \in (0.9, 1.1)$, the system converges to bounded oscillation around $E_0/(1-\alpha)$.

Proof:

Let $S(t)$ = circulating supply. Then:

$$\frac{dS}{dt} = E(t) - B(t) = E(t)(1-\alpha)$$

If $E(t) = E_0 + A\sin(\omega t)$ (periodic emission due to moon cycles):

$$S(t) = S_0 + \int_0^t (E_0 + A\sin(\omega\tau))(1-\alpha)\,d\tau$$

$$= S_0 + E_0(1-\alpha)t - \frac{A(1-\alpha)}{\omega}(\cos(\omega t) - 1)$$

Bounded by $|S(t) - S_0 - E_0(1-\alpha)t| \le \frac{2A(1-\alpha)}{\omega}$. ∎

14. Appendix B: Smart Contract Interfaces (Specifications)

B.1 PlotNFT Contract

```
interface IPlotNFT {
    struct PlotMetadata {
        int32 latitude;      // Scaled by 1e6
        int32 longitude;     // Scaled by 1e6
        uint8 region;        // Enum: 0=Tranq, 1=SouthPole, etc.
        uint8 rarity;        // 0=Common, 1=Uncommon, ..., 4=Legendary
        uint256 moonPhase;   // Phase at mint (0-1000000)
    }

    function mint(uint8 region) external payable returns (uint256 tokenId);
    function getMetadata(uint256 tokenId) external view returns (PlotMetadata memory);
    function stake(uint256 tokenId) external;
```

```
    function unstake(uint256 tokenId) external;
    function getStakeReward(uint256 tokenId) external view returns (uint256);
}
```

B.2 MOONX Token Contract

```
interface IMOONX {
    function mint(address to, uint256 amount) external; // Only minter role
    function burn(uint256 amount) external;
    function getUserDailyCap(address user) external view returns (uint256);
    function getTodayMinted(address user) external view returns (uint256);
}
```

15. Appendix C: Verification Procedures

C.1 OpenTimestamps Verification

To verify this whitepaper's timestamp:

1. Download `LUNARIS_Technical_Whitepaper_v1.0.pdf` and corresponding `.ots` file
2. Visit https://opentimestamps.org
3. Upload both files to "Verify" section
4. Confirm Bitcoin block attestation matches claimed timestamp (October 30, 2025)

Expected output:

```
Success! Bitcoin block XXXXXX attests data existed as of [timestamp]
```

C.2 Geographic Coordinate Verification

To verify Plot coordinates:

1. Access USGS Moon Map: https://astrogeology.usgs.gov/search/map/unified_geologic_map_of_the_moon_1_5m_2020
2. Input Plot's lat/lon from NFT metadata
3. Confirm region classification matches (Mare Tranquillitatis, South Pole, etc.)
4. Cross-reference resource weights with published USGS/LRO data

END OF WHITEPAPER

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This document represents the technical design of LUNARIS as of October 30, 2025. Implementation details may evolve based on security audits, community feedback, and technological advancements. All changes will be versioned and timestamped via OpenTimestamps protocol.

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