Lunar Night Survival & Energy Regulation

ASTRA 2025 Hackathon: Round 1 Submission

Project L.E.A.P.

Lunar Energy Autonomous Platform

A Predictive Energy & Thermal Management System for Sustained Lunar Operations

Event: ASTRA 2025 Hackathon – Where Curiosity Meets Cosmic

Team: The Night Watchers

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The Challenge: The Unforgiving Lunar Night

The primary barrier to a sustainable lunar presence is surviving the ~14.75 Earth days of darkness and extreme cold. This is not just a power problem; it's a battle against physics.

Thermal Extremes

Temperatures plummet from +120°C (250°F) in direct sun to below -173°C (-280°F) at the equator. In **Permanently Shadowed Regions (PSRs)**—key targets for ice discovery—temperatures can reach -250°C (-418°F), nearing absolute zero.

Component Failure

Cryogenic temperatures cause **solder joint embrittlement**, battery electrolyte freezing, and catastrophic failure of sensitive electronics. Thermal cycling induces stress and fatigue, drastically reducing hardware lifespan.

Energy Deficit

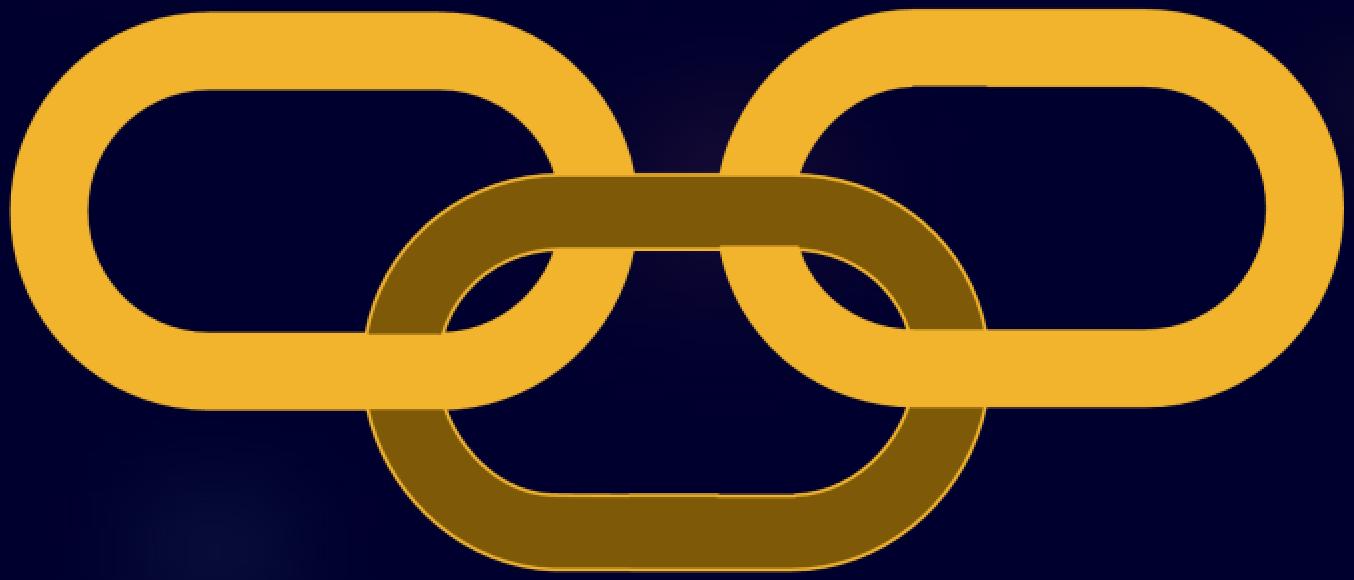
Without sunlight, solar-dependent assets become inert. The energy required to simply stay warm can exceed the total stored energy from the lunar day.

Command Latency

The ~2.56-second round-trip light delay makes real-time manual intervention from Earth impossible. Full autonomy is not a feature; it's a requirement.

Our Solution: Project L.E.A.P. - An Intelligent Ecosystem

Project L.E.A.P. is an integrated, intelligent system that transforms a lunar asset from a passive survivor into a proactive, self-regulating entity. We optimize the intricate balance between power consumption, heat distribution, and operational imperatives.



Hybrid Power Core (The Heart)

- **Baseline Power:** A **Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)** provides a constant ~110W electrical and ~2000W thermal power, independent of sunlight.
- **Operational Power:** High specific energy **Lithium-Sulfur (Li-S) batteries** (~400 Wh/kg) are used for high-demand tasks, offering significant weight advantage.

Adaptive Thermal Loop (The Circulatory System)

- **Heat Distribution: Variable Conductance Heat Pipes (VCHPs)** actively transport waste heat, maintaining thermal stability without electrical power.
- **Localized Heating:** Low-power **Radioisotope Heater Units (RHUs)** (~1W thermal each) are placed directly on sensitive components.

Predictive AI Controller - "The Watcher" (The Brain)

- **Core Technology:** A **Long Short-Term Memory (LSTM) neural network** for time-series forecasting.
- **Function:** Predicts future thermal states and energy needs hours in advance, enabling proactive, optimized decisions.

Technical Methodology: From Prediction to Action

Our methodology is a closed-loop system that continuously learns and optimizes.

System State & Energy Flow

- **Lunar Day:** Triple-junction **Gallium Arsenide (GaAs) solar panels** power operations and charge Li-S batteries. MMRTG waste heat is radiated.
- **Lunar Night:** MMRTG provides baseline 110W for AI, sensors, and VCHP. Li-S battery is in "deep standby" for scheduled, high-power tasks as determined by the AI.

The "Watcher" AI Protocol in Action

The LSTM model is trained on simulated mission data to understand thermal inertia and power consumption patterns.

01

Ingest Data

Continuously ingests time-series data: battery state-of-charge (SoC), temperatures, operational schedule.

02

Predict Future State

Generates a predictive curve for the next 6-12 hours, forecasting temperature drops and energy shortfalls.

03

Generate Action Plan

Creates an optimized schedule of actions, e.g., redirecting 500W thermal energy or deferring non-critical sensor readings to conserve 20Wh.

04

Execute & Learn

Executes the plan and logs results, feeding them back to refine predictions for the next cycle.

Prototyping: Architecture & Simulation Environment

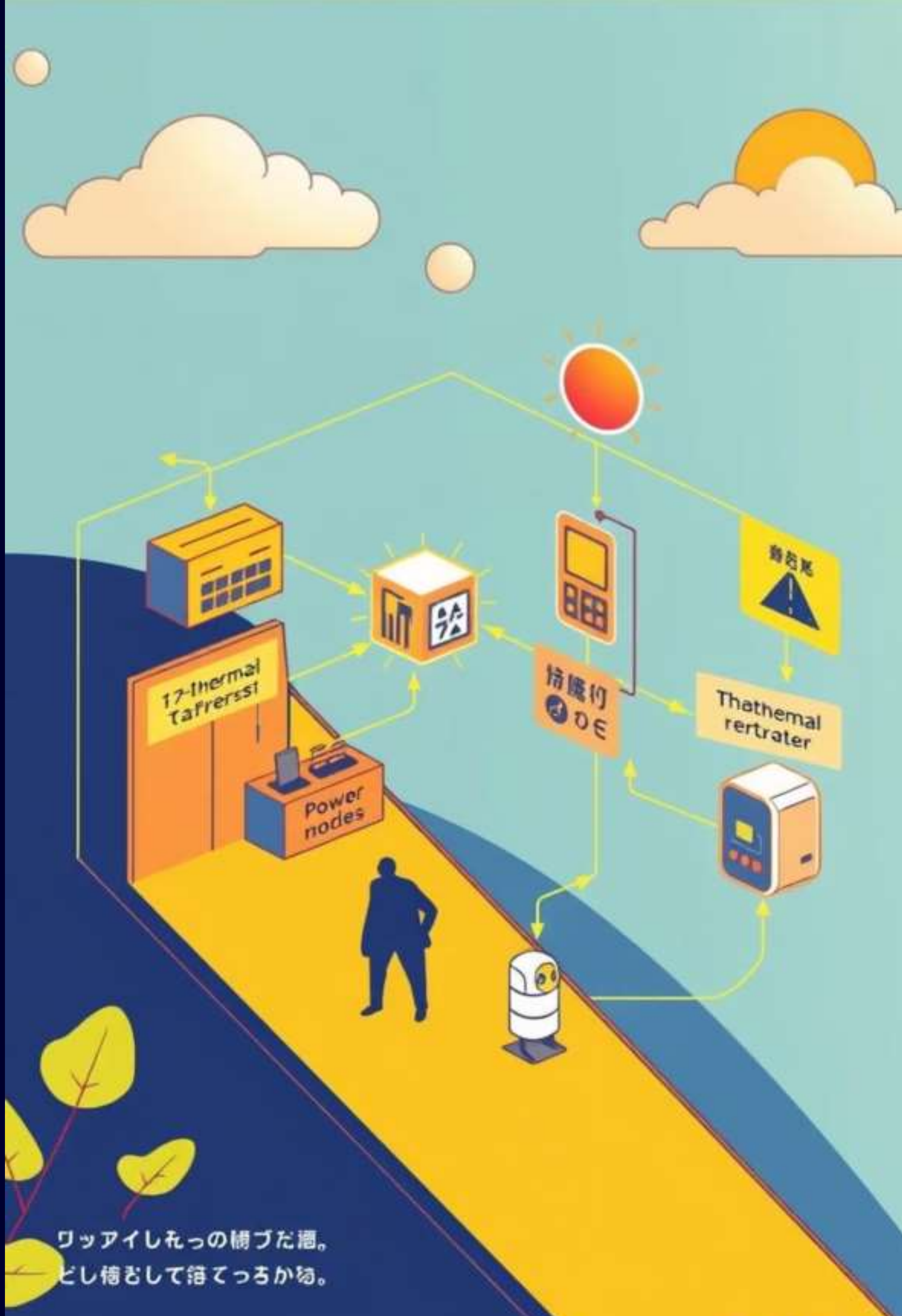
Our hackathon prototype will be a high-fidelity digital twin that validates the L.E.A.P. concept.

Technology Stack

- **Core:** Python 3.9+
- **Physics & Data:** NumPy, Pandas, **SciPy**
- **AI/ML: TensorFlow/Keras** for LSTM model
- **Visualization:** Plotly, Streamlit for interactive dashboard

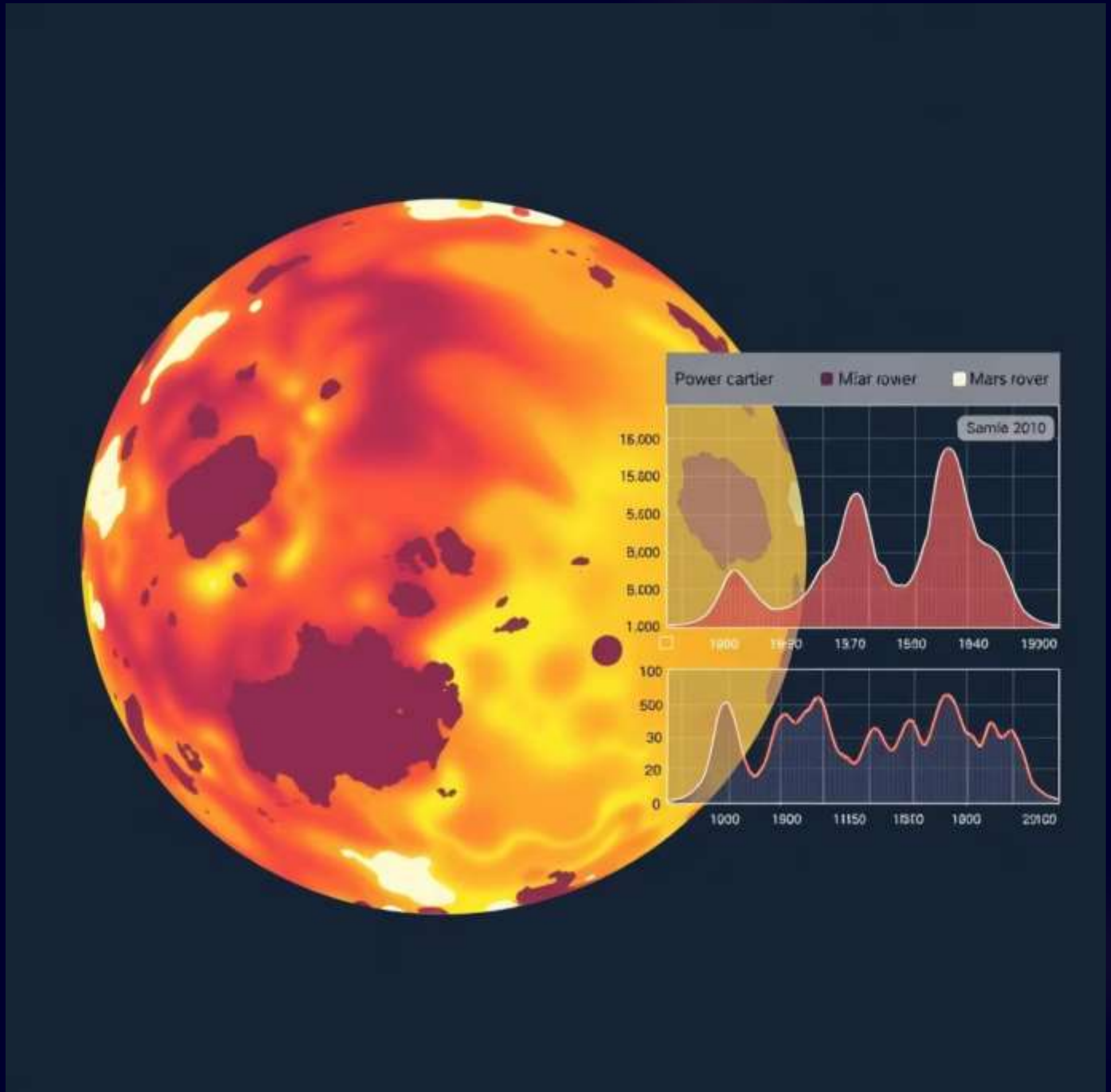
Simulation Architecture

- **Physics-Based Environment:**
  - **Thermal Model:** Lumped-element model using **Stefan-Boltzmann Law ($P=\epsilon\sigma AT4$)**.
  - **Power Model:** Tracks energy flow from sources (solar, MMRTG) to storage (battery SoC) and loads.
- **AI Controller (watcher.py):** Trained LSTM model interfaces with simulation.
- **Mission Scheduler:** Predefined script for operational goals; AI ensures achievement without compromising survival.



Datasets & Ground Truth

Our model's accuracy depends on realistic training data. We will construct a synthetic dataset grounded in real-world information.



Environmental Data from NASA LRO

Time-series temperature data from the **Lunar Reconnaissance Orbiter's Diviner Radiometer** for sites like **Shackleton crater**.

Engineering Data from Existing Missions

Public data from missions like **MSL (Curiosity)** and **Mars 2020 (Perseverance)** for power consumption profiles.

Simulated Mission Scenarios

A master "mission timeline" defines operational tasks, generating thermal and power data for LSTM training.

Expected Outcomes & Quantitative Validation

Our deliverables will provide clear, data-driven proof of our solution's effectiveness.

Interactive Dashboard (Live Demo)

A Streamlit application visualizing the digital twin's real-time performance.

Key Demonstrable Metric

Side-by-side simulation of a **Control Case** (reactive thermostat) vs. **L.E.A.P. Case** (predictive AI).

Proof of Success

- >25% higher reserve battery power at lunar night end.
- >50% reduction in thermal cycling stress.
- 100% completion of mission-critical tasks.

Full Code Repository & Video

Documented codebase and a concise 2-minute video explaining results.

Mission Impact & Scalability

Project L.E.A.P. is not a theoretical exercise; it is a key enabling technology for the next era of space exploration.

Direct Relevance to Artemis

Essential for NASA's goal of a **"sustainable lunar presence,**

Enhancing CLPS Missions

Provides a software-based intelligence layer to maximize lifespan and scientific return for commercial lunar landers.

Scalability

- **Up:** AI logic scales to multi-module lunar bases.
- **Down:** "L.E.A.P. Lite" for smaller CubeSat landers.
- **Beyond:** Adaptable to Mars and deep-space probes.

The future of exploration isn't just about going further; it's about staying longer.

Project L.E.A.P. is our contribution to that future.

Team: The Night Watchers

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