10 Use Cases of LLMs IN SPACE EXPLORATION

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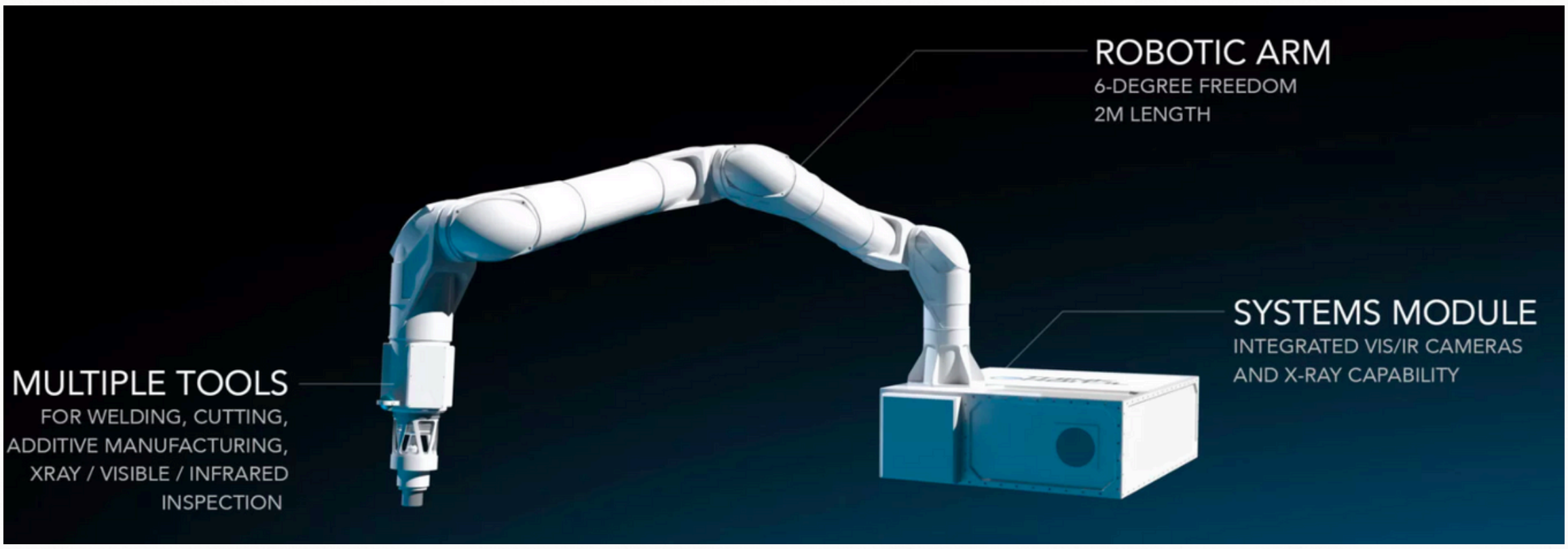
1. In-Orbit Manufacturing

ThinkOrbital is developing **autonomous welding and assembly systems** for space manufacturing. Their GenAI-powered robotic arms can self-correct during welding, ensuring precise construction of space structures.

AI-driven predictive analysis helps detect anomalies and enables self-guided repairs, reducing astronaut intervention. Integrated with **Space Situational Awareness (SSA)** data, LLMs assist in **debris avoidance** by generating automated movement strategies.

These advancements aim to make in-orbit manufacturing fully autonomous, supporting future space infrastructure.



Think Orbital's Robotic Arm for In-orbital servicing powered by AI

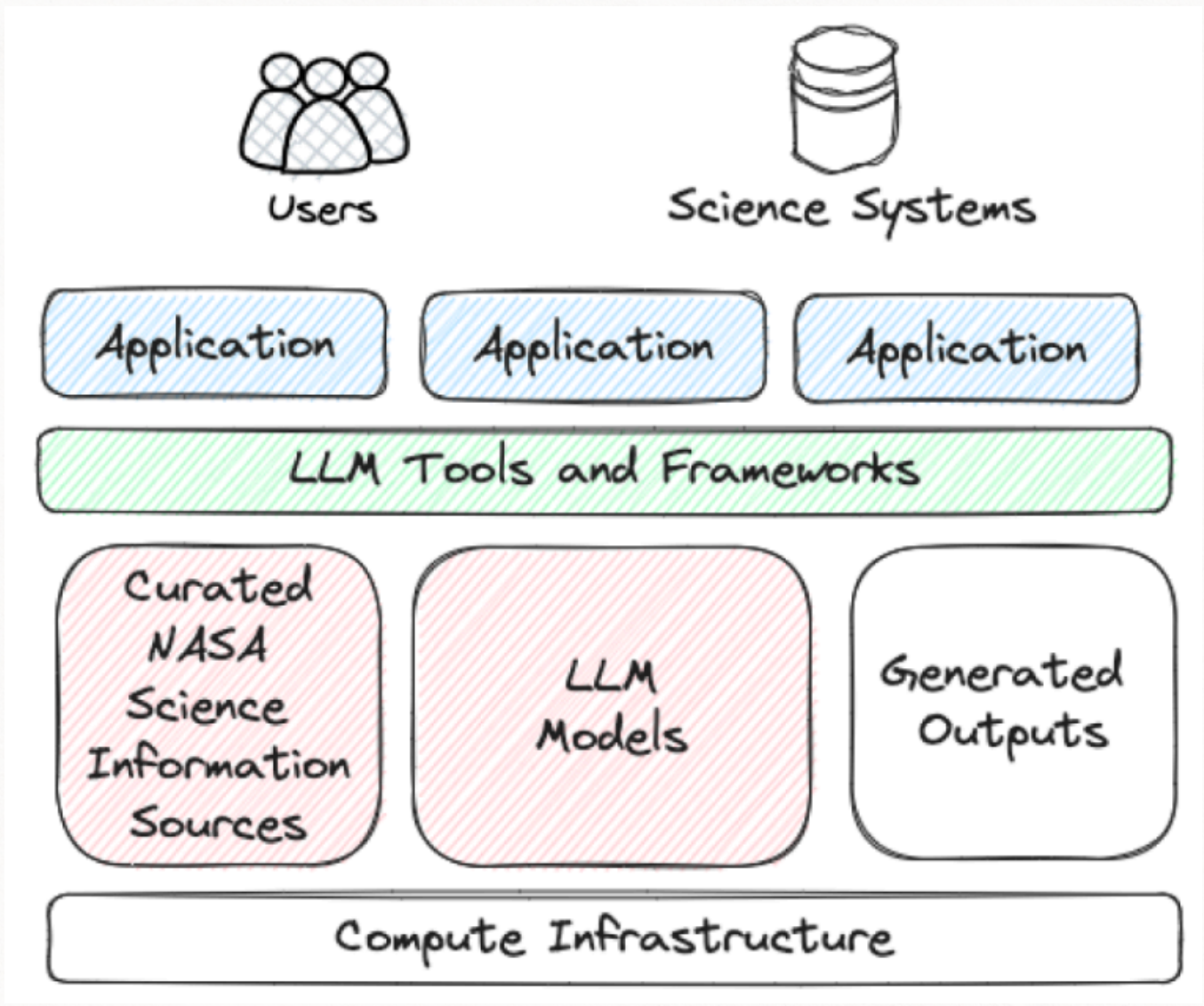
source: thinkorbital

2. SIMULATION TRAINING

LLMs enhance space mission simulations and training by generating realistic scenarios, predicting system failures, and assisting astronauts in problem-solving.

- **ThinkOrbital** uses AI to simulate in-orbit welding processes, helping refine autonomous robotic assembly.
- **NASA** integrates LLMs into training modules, allowing astronauts to interact with AI-driven virtual assistants for real-time troubleshooting.
- **Satellite operators** leverage AI for predictive modeling, simulating space weather effects and orbital adjustments.

These applications improve mission preparedness and operational efficiency in complex space environments.



LLMs in Open Science by NASA

source: nasa

3. AI-driven Assistants

Axiom Space, in collaboration with **AWS**, is developing AI-driven assistants to enhance human-machine interaction in space. During Axiom Mission 3 (Ax-3), Amazon's Alexa was tested aboard the ISS to evaluate its usability in microgravity environments.

By integrating **voice-enabled AI**, Axiom aims to improve **crew support**, **mission planning**, and **real-time data analysis**. These assistants will be deployed on Axiom Station, the first commercial space station, and could influence future Artemis missions.

Amazon Echo used in International Space Station

source: axiom

4. SPACE TRAFFIC MANAGEMENT

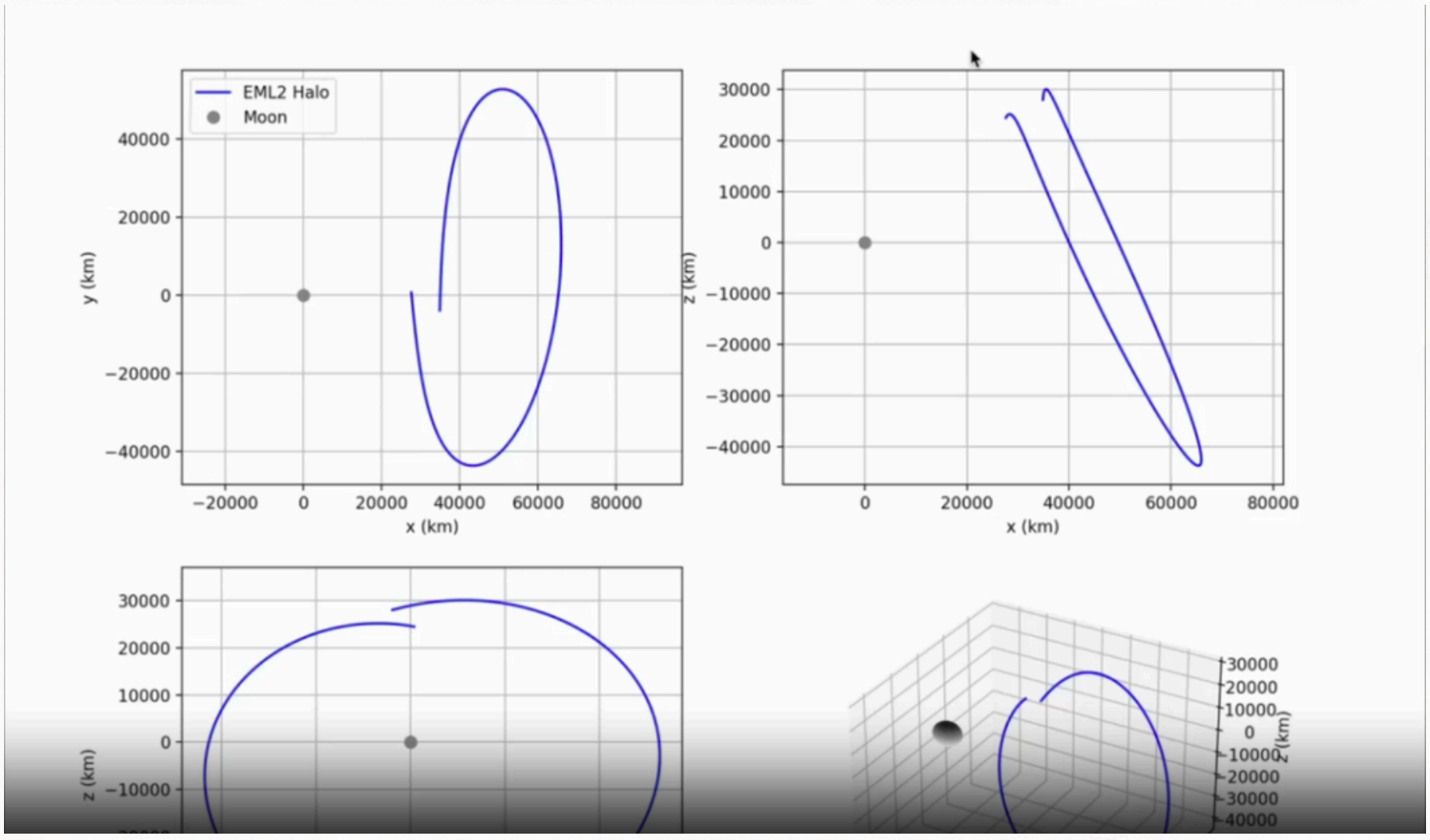
Kayhan Space is exploring **GenAI** for space traffic management, focusing on areas where AI adds real value. While physics-based models handle object dynamics, AI excels at solving complex, large-scale problems.

🔹 Where AI Makes an Impact

- **Maneuver planning** for satellite constellations under strict constraints.
- **Identifying uncorrelated objects** in massive datasets.
- Detecting unexpected movements of non-cooperative satellites.

🔹 Broader Industry Applications

- Smarter satellite mission planning for resource efficiency.
- AI-powered simulators for better testing.
- Enhanced Earth observation with image processing and security features.



Kayhan's Moon-Earth Rotating Frame

5. LLM for Research

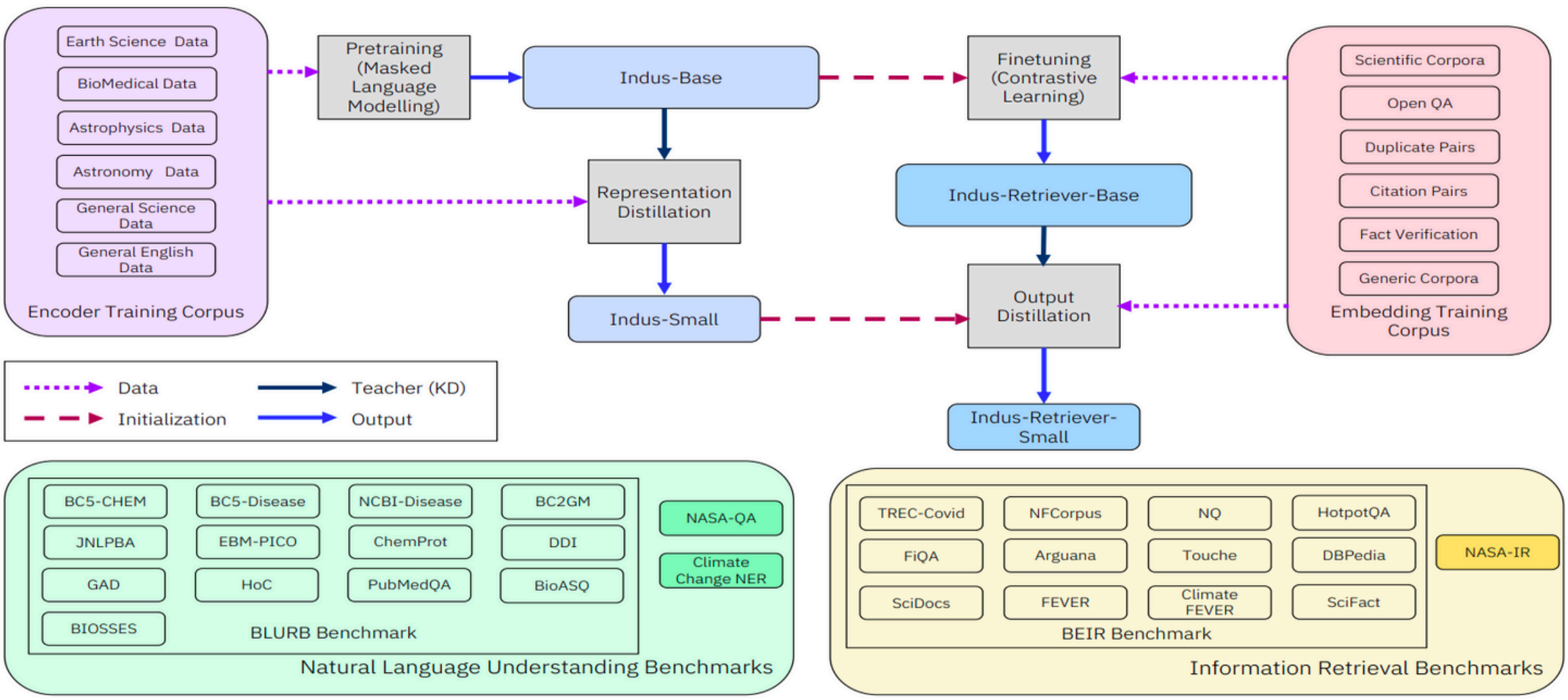
NASA and **IBM** developed **INDUS**, a specialized AI model trained on **60B+** scientific tokens to enhance research in Earth science, astrophysics, and biology.

🔹 Key Features

- Custom tokenizer for scientific terms.
- Encoders & sentence transformers for accurate text processing.
- 268M+ text pairs used for fine-tuning.

🔹 Real-World Use

- Better search & Q&A for NASA's datasets.
- Enhanced publication categorization at GES-DISC.
- Smarter dataset navigation in Open Science.



INDUS architecture

source: https://arxiv.org/pdf/2405.10725

6. Satellite Image Labelling

ARSIC is a novel approach to automatically generating captions for satellite images, addressing the lack of large-scale annotated datasets. It guides LLMs to describe object annotations instead of interpreting images directly, overcoming their limitations in handling visual data.

Key Features of ARSIC

1. **LLM-Guided Captioning** – LLMs like GPT-4 summarize object annotations instead of raw images, improving caption accuracy.
2. **Geospatial Analysis** – Uses external APIs to analyze object relations, clustering, and geographical context for better descriptions.
3. **Fine-Tuned Model** – Adapts a GIT (image2text) model trained on Xview and DOTA datasets to generate captions specific to aerial imagery.

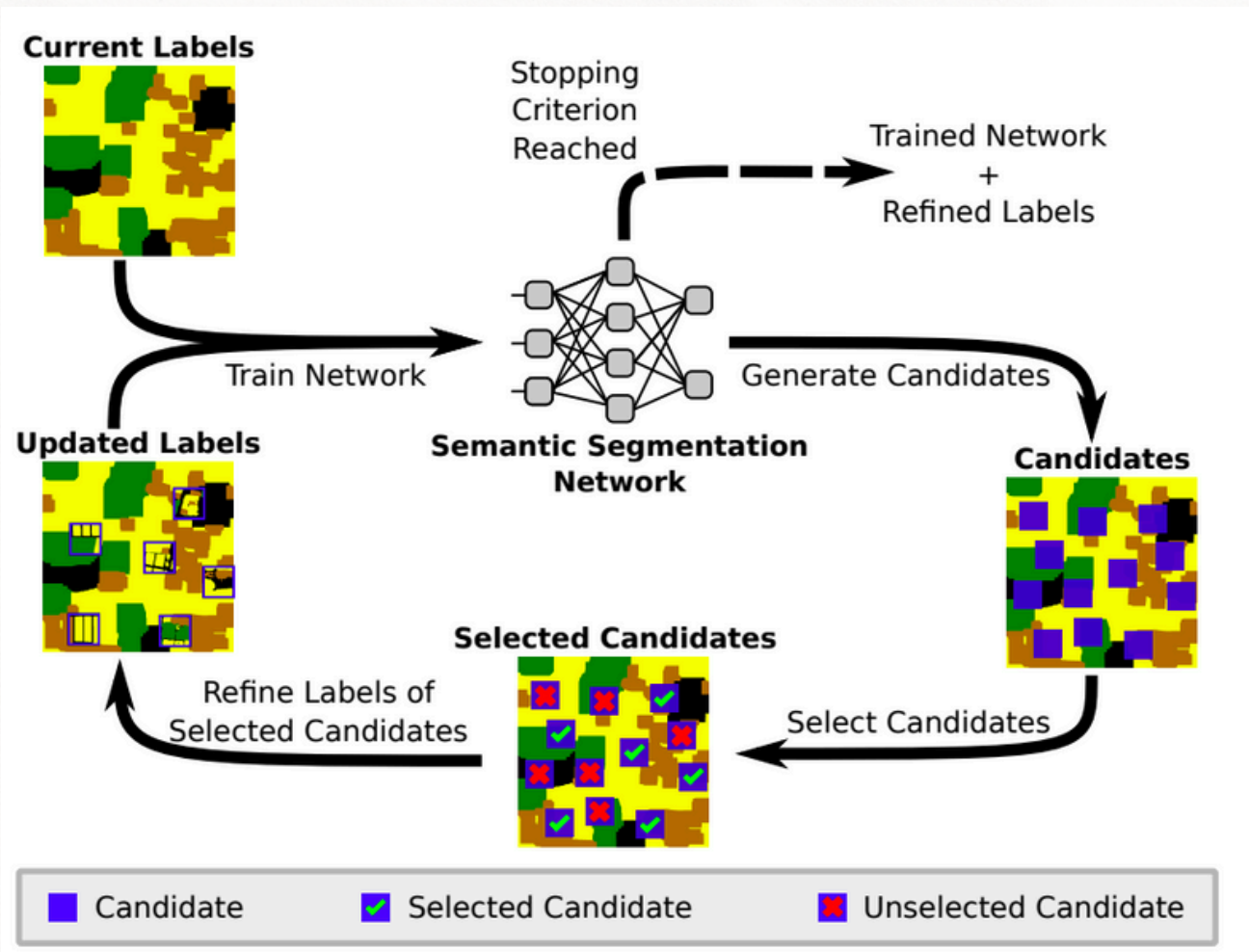


Illustration of Model Learning Cycle

source: https://arxiv.org/pdf/2309.06159

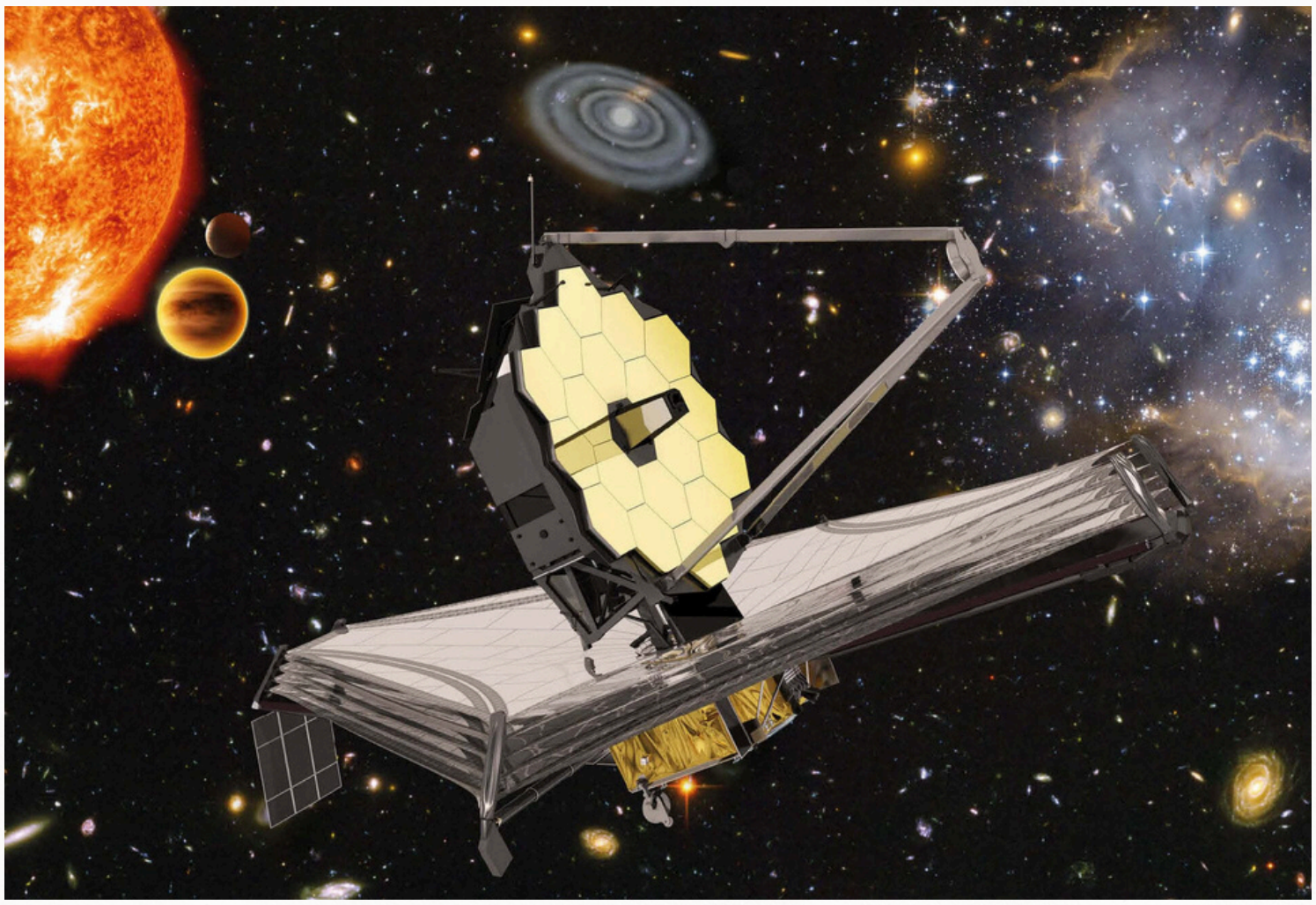
7. First LLM in Space

In 2024, **Booz Allen Hamilton** and **HPE** deployed an LLM on the **ISS**, running on Spaceborne Computer-2 (SBC-2). It helps astronauts:

- **Find information** from manuals, procedures, and experiment data instantly.
- **Troubleshoot issues** by diagnosing problems in equipment and suggesting solutions.
- **Assist** in experiments with step-by-step guidance and automation of **repetitive tasks**.
- **Reduce data transfer delays** by processing queries locally instead of relying on Earth-based mission control.

8. Predictive Maintainence

Spacecraft, satellites, and telescopes operate in harsh environments where equipment failures can be costly and mission-critical. LLMs can enhance predictive maintenance by analyzing logs, sensor data, and historical performance trends to detect potential failures before they happen.

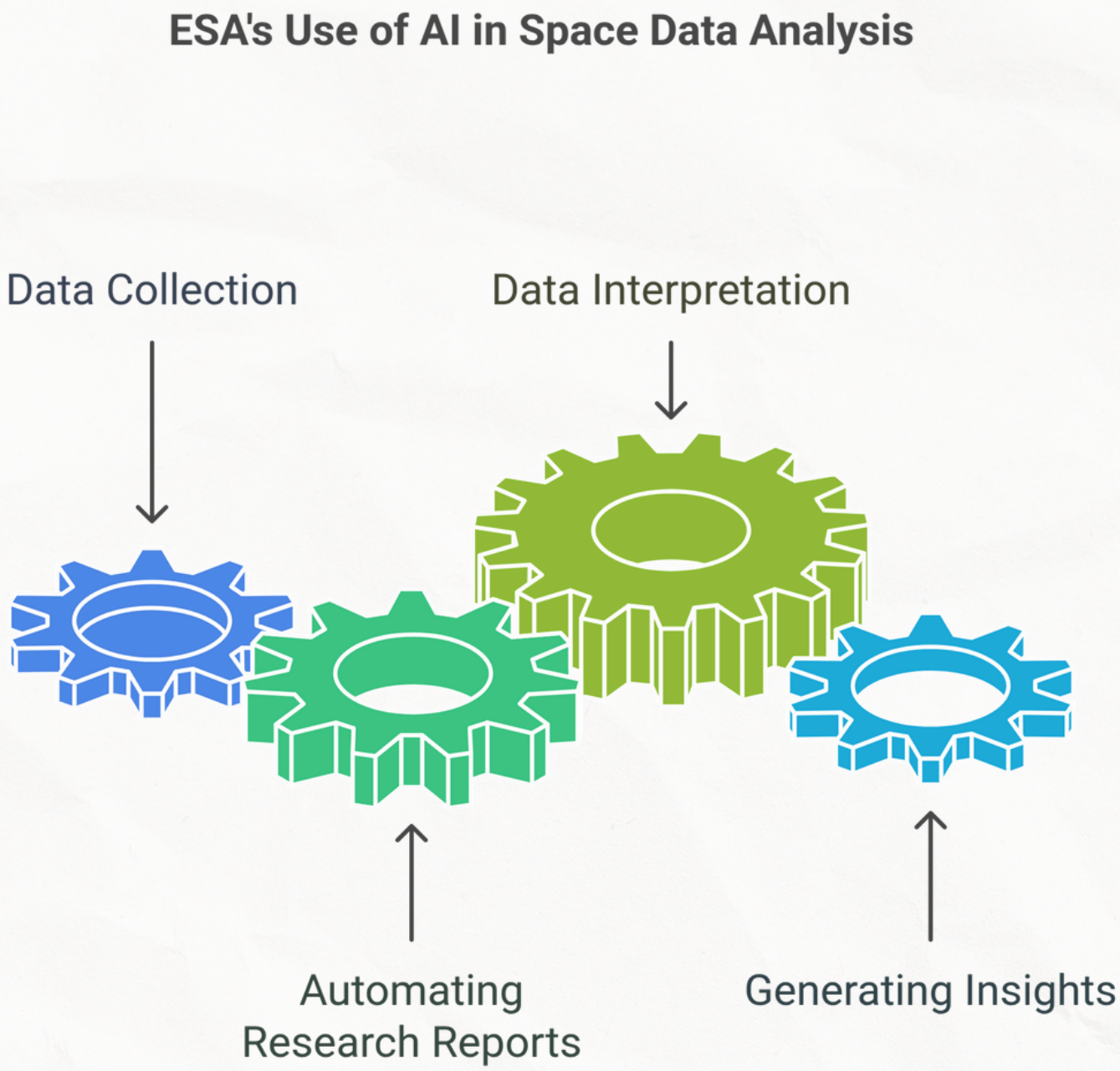


The James Webb Space Telescope (JWST) uses AI to monitor system health by analyzing vast amounts of telemetry data. LLMs can assist in:

- **Anomaly Detection:** Identifying unusual patterns in sensor readings that indicate hardware degradation.
- **Log Analysis:** Parsing mission logs to detect subtle signs of wear or potential failures in instruments like the NIRCam or MIRI.
- **Automated Alerts:** Providing early warnings to engineers, allowing proactive maintenance planning.

9. Research & Documentation

The **European Space Agency (ESA)** utilizes AI to handle vast datasets from missions like **Gaia** (which maps the Milky Way) and **Euclid** (which studies dark matter and dark energy). LLMs assist by:



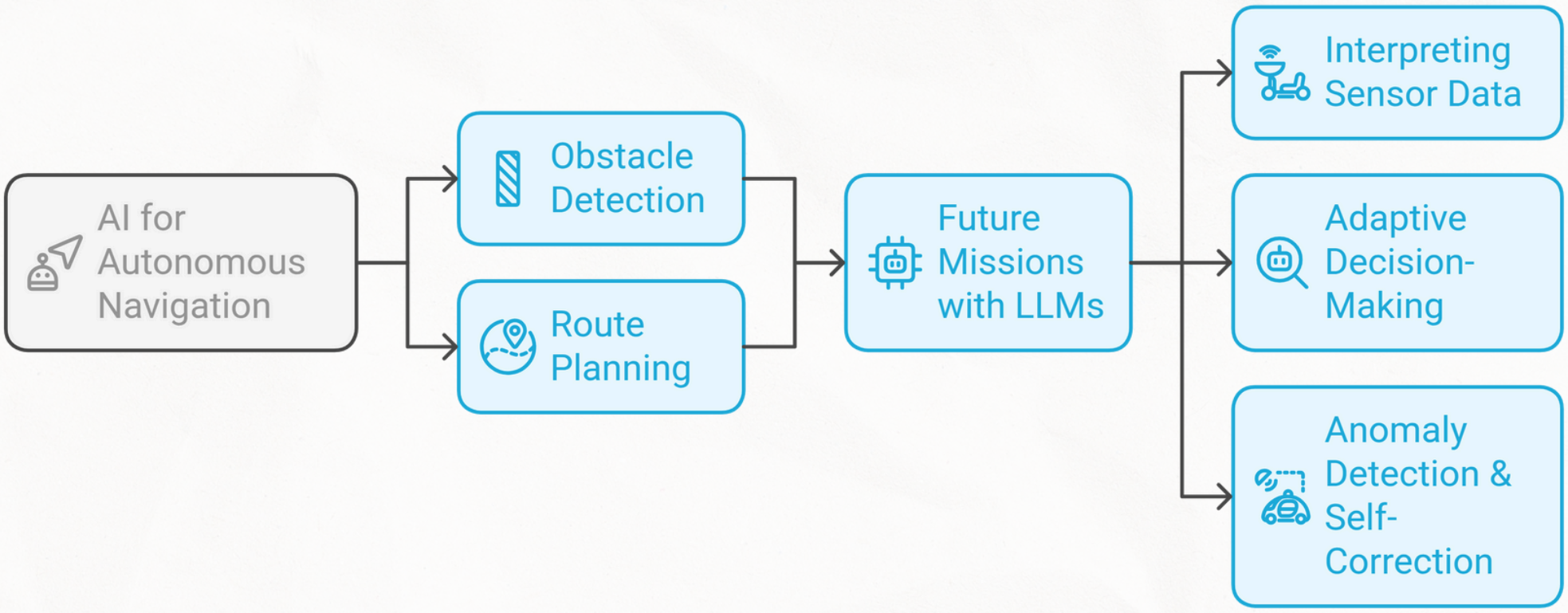
- **Automating Research Reports:** Summarizing observational data from deep-space telescopes into structured reports.
- **Data Interpretation:** Extracting key findings from complex datasets, helping astronomers identify patterns in celestial objects.
- **Generating Insights:** Assisting in hypothesis generation by correlating historical space observations with new discoveries.

10. Autonomous Spacecraft Operations

The Perseverance rover on Mars uses AI for autonomous navigation, allowing it to detect obstacles, plan routes, and adapt to terrain without waiting for Earth-based instructions. Future missions could leverage LLMs for even more autonomy by:

- **Interpreting Sensor Data:** Analyzing environmental conditions (e.g., atmospheric readings, radiation levels) to adjust mission strategies.
- **Adaptive Decision-Making:** Selecting scientific targets, adjusting instrument settings, or modifying experiments based on real-time data.
- **Anomaly Detection & Self-Correction:** Identifying issues in propulsion, power systems, or scientific instruments and applying corrective measures.

Mars Rover Autonomy Enhancement



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