Artificial Intelligence Solution Architecting for the Solar Gravity Lens Mission

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Mission Architecture

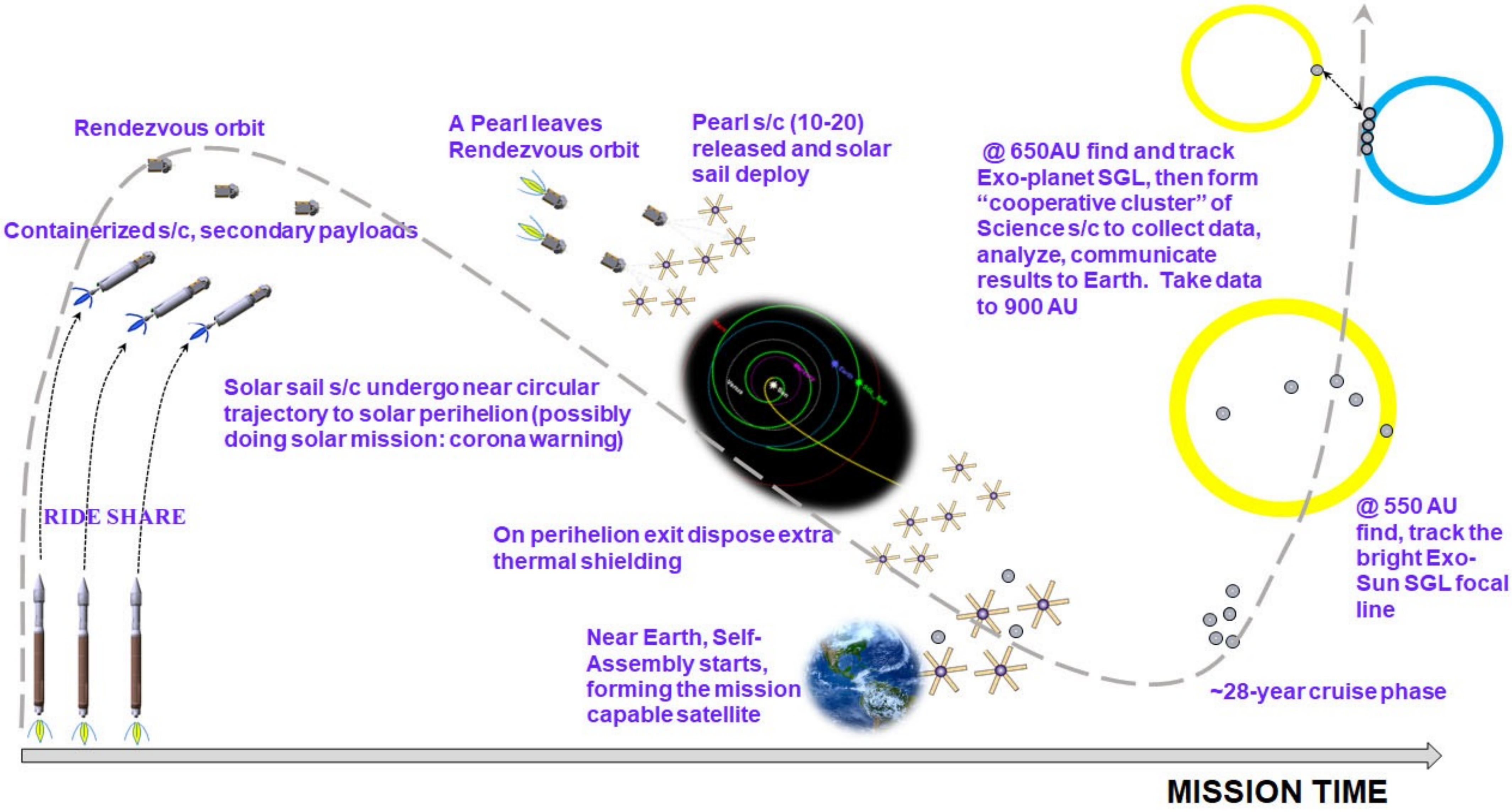

Image Earth-like exoplanets with high resolution using an optical telescope more than 550 Astronomical Units (AU) from the Sun.

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AI/Autonomy Solution Architecting Process

Repeatable iterative process helps multiple customers design projects

Refine CONOPS

- Mission phases
- Goals
- Constraints
- Use cases

Assess Considerations:
Mission requirements, data types and quantity, communications latency, uncertainties, domain expert opinions, etc.

What decisions must the system make?

Identify Type(s) of AI, Autonomy, ML with TRLs

Is autonomy, AI, ML needed?

Or would automation suffice?

Develop & Size Software & Hardware Architectures

Develop & Test Prototypes using Digital Engineering

Increasing Fidelity

Demonstrate to Customer; Iterate as needed

All stages within the process inform and refine each other

CONOPS: Concept of Operations
TRL: Technology Readiness Level

Working definitions

- *Automation (AN): machine takes action where there is no uncertainty*
- *Autonomy (AY): machine makes decisions and takes action to manage uncertainty*
- *Machine Learning (ML): in a learning system, performance improves with experience*
- *Artificial Intelligence (AI): machine does what a human normally would do*
- *Expert System (ES): AI using rules-based reasoning that captures human expert decision processes*

Diagram courtesy of Amy O'Brien, The Aerospace Corporation.

Assess types/levels of AI/autonomy needed up front; design accordingly

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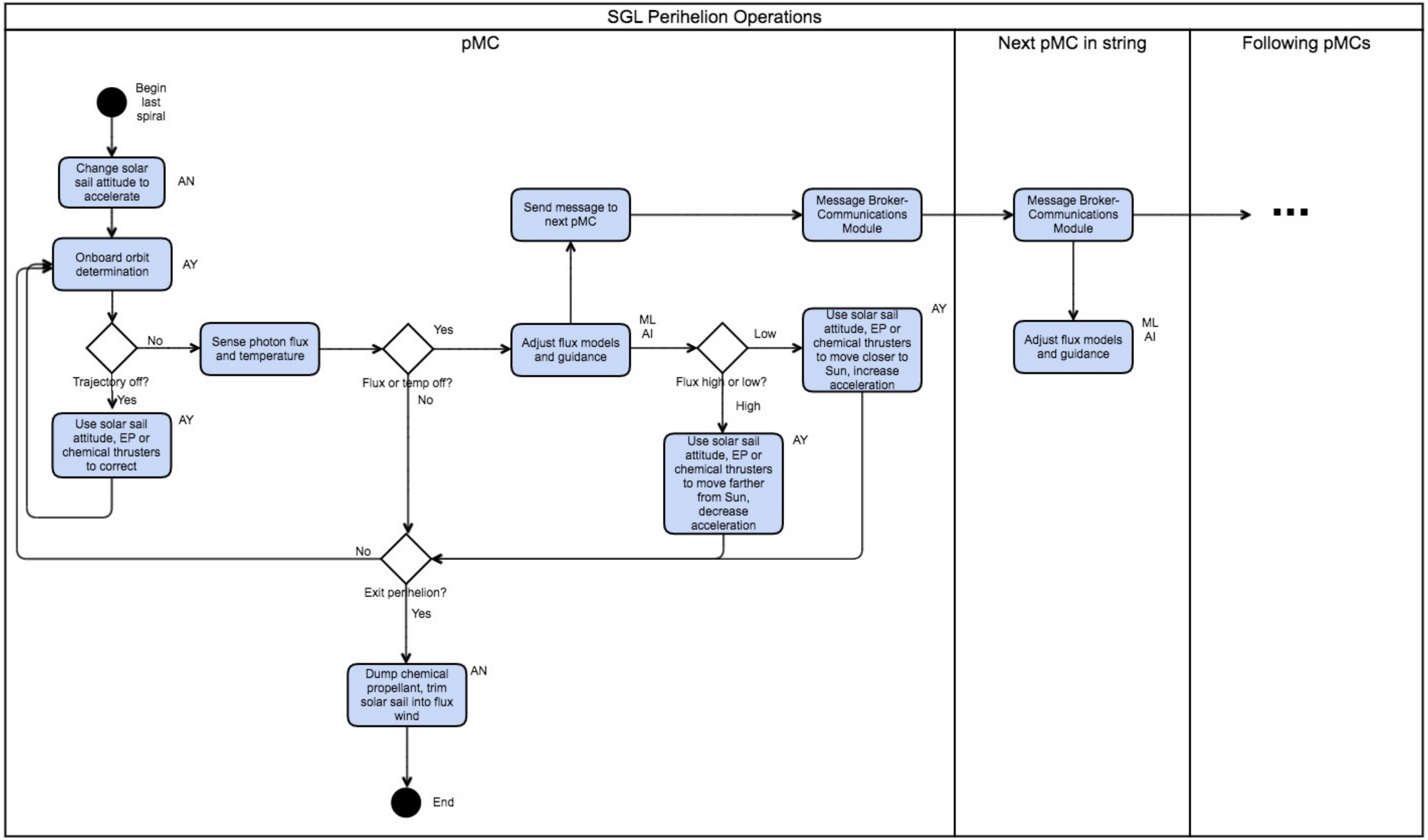
Perihelion Operations Use Case

Activity diagram



pMC: proto-Mission Capable spacecraft
EP: Electric Propulsion

Autonomy needs are similar to traditional closed-loop guidance, navigation and control (GNC) systems.

- Differences in environment, sensors, actuators.

With no faults, autonomy needs are minimal. Technology Readiness Level (TRL) is low but could be advanced quickly.

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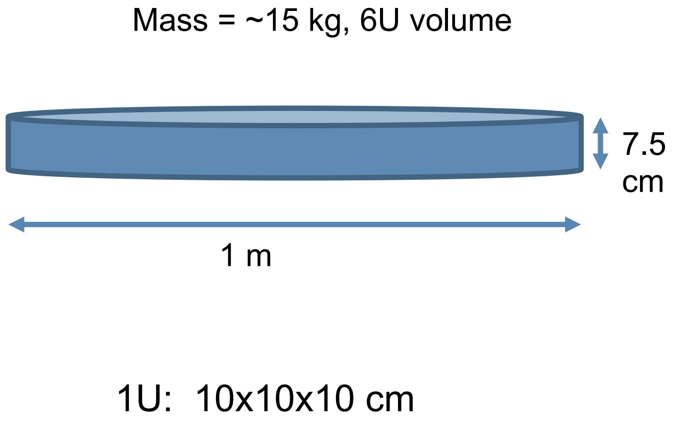
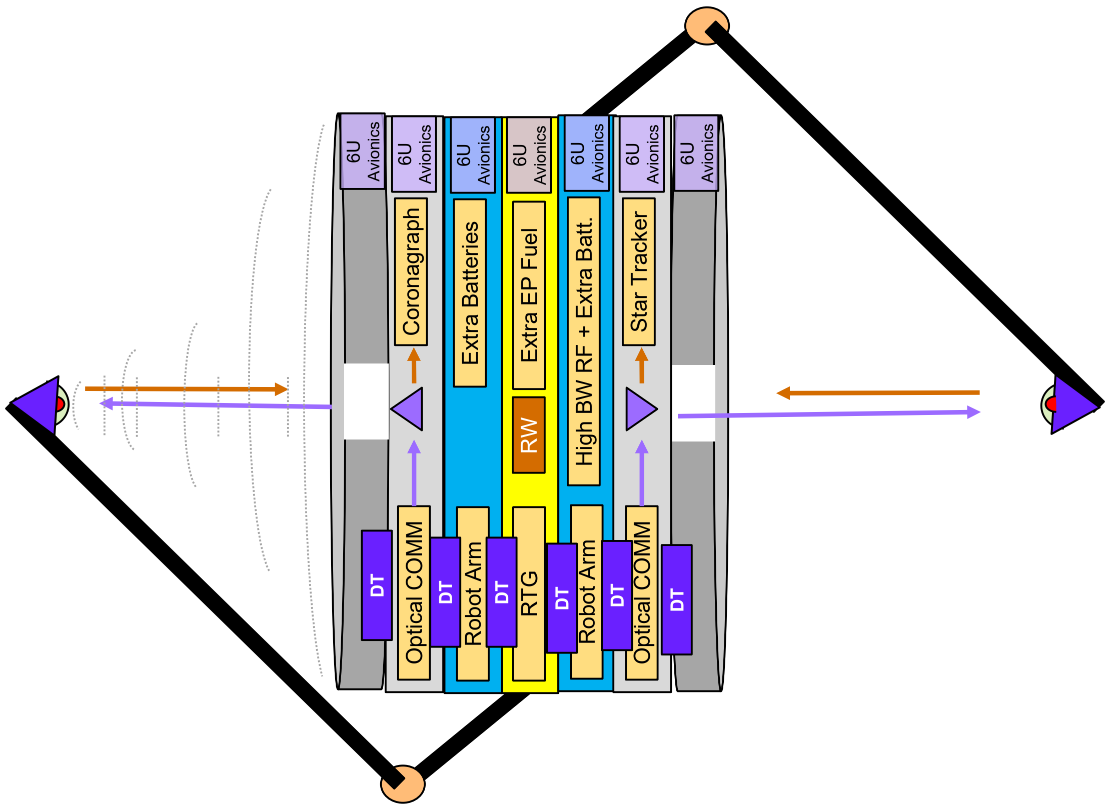
Self-Assembly Use Case



Single proto-Mission Capable (pMC) spacecraft before assembly



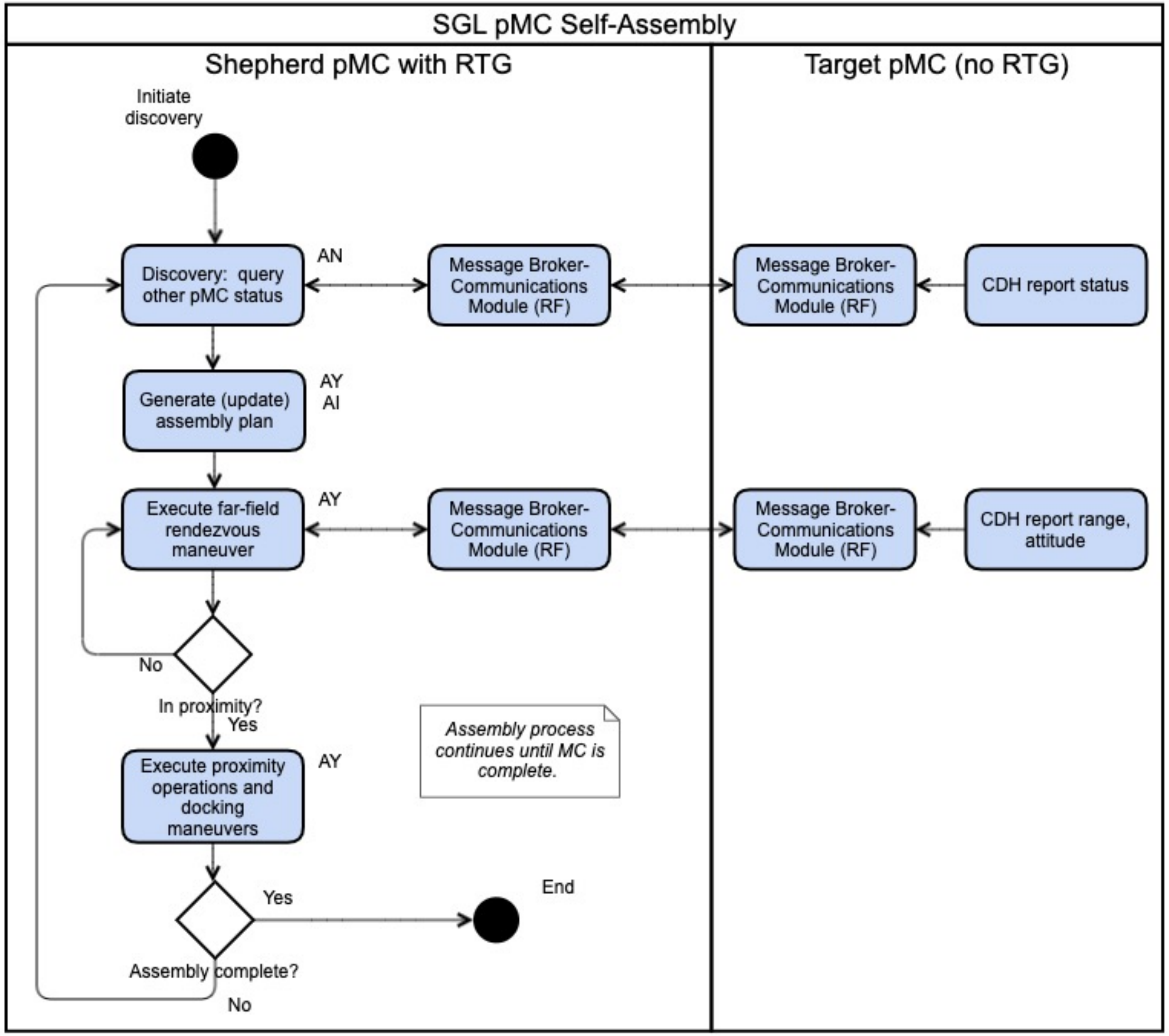
Seven pMCs assembled into a single Mission Capable (MC) spacecraft

This use case is similar to Orbital Express (launch 2008) and CubeSat Proximity Operations Demonstration (CPOD) missions (launch TBD).

Self-Assembly Use Case

Activity diagram

RTG: Radioisotope Thermoelectric Generator
RF: Radio Frequency
CDH: Command and Data Handling



This use case requires autonomous rendezvous and docking; and onboard planning and scheduling. Both are TRL 7 for other missions; probably need to be adapted for SGL.

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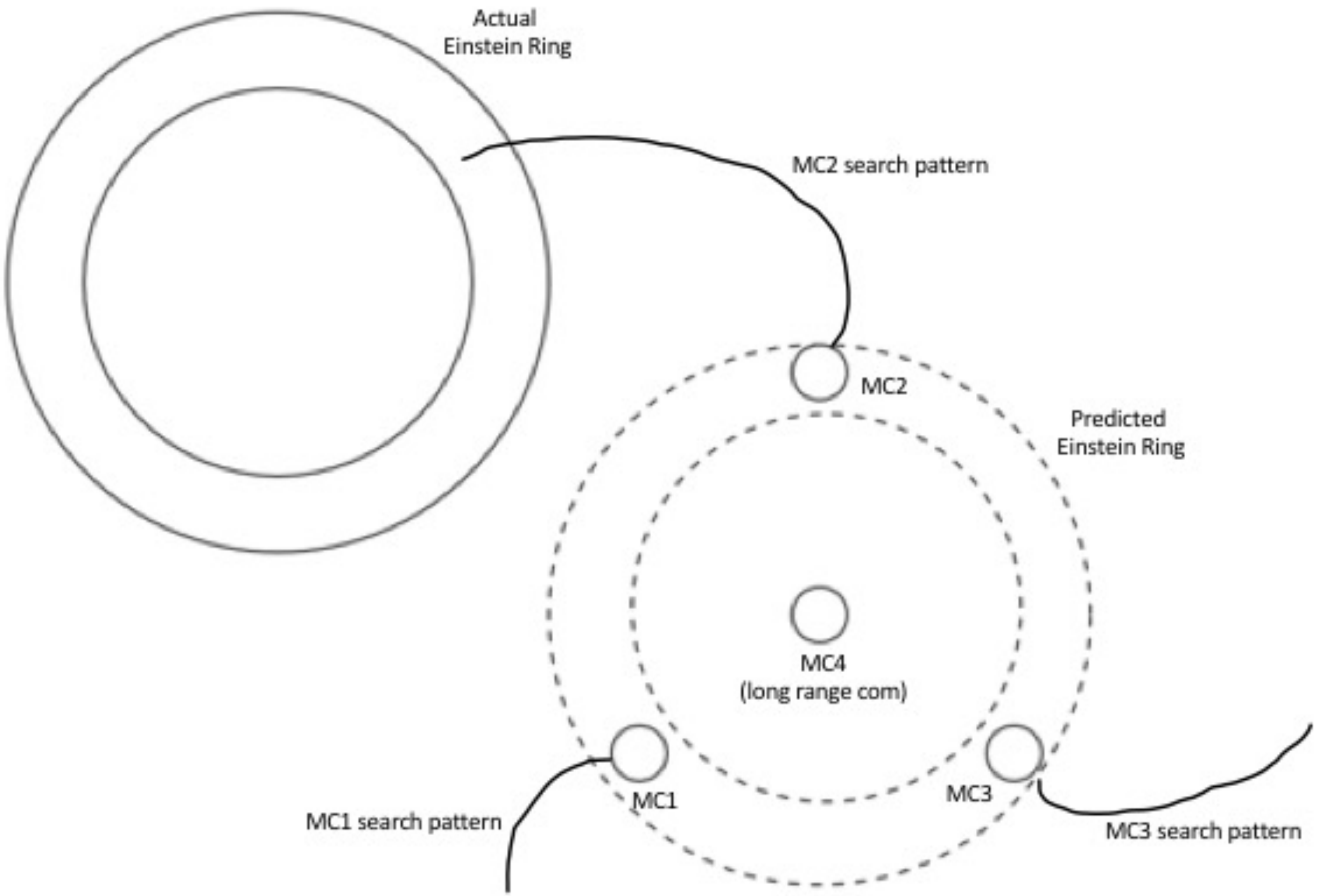
Exo-Sun Acquisition Use Case

Search pattern



Actual Einstein ring location may be different from predicted location.

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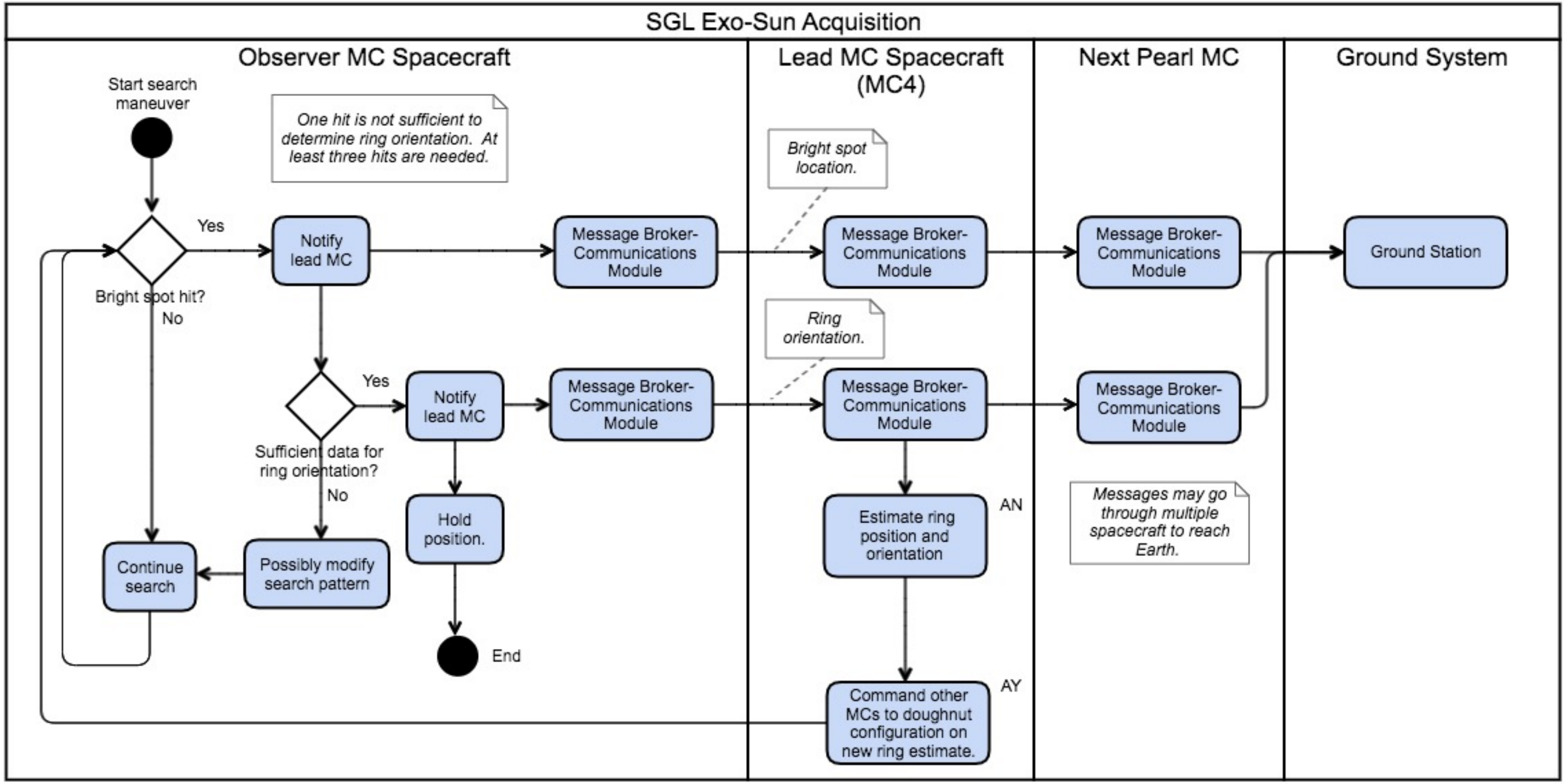
Exo-Sun Acquisition Use Case

Activity diagram



Assuming no spacecraft failures, autonomy needs are minimal for this use case. Estimate TRL 2, but could be advanced quickly with simulation.

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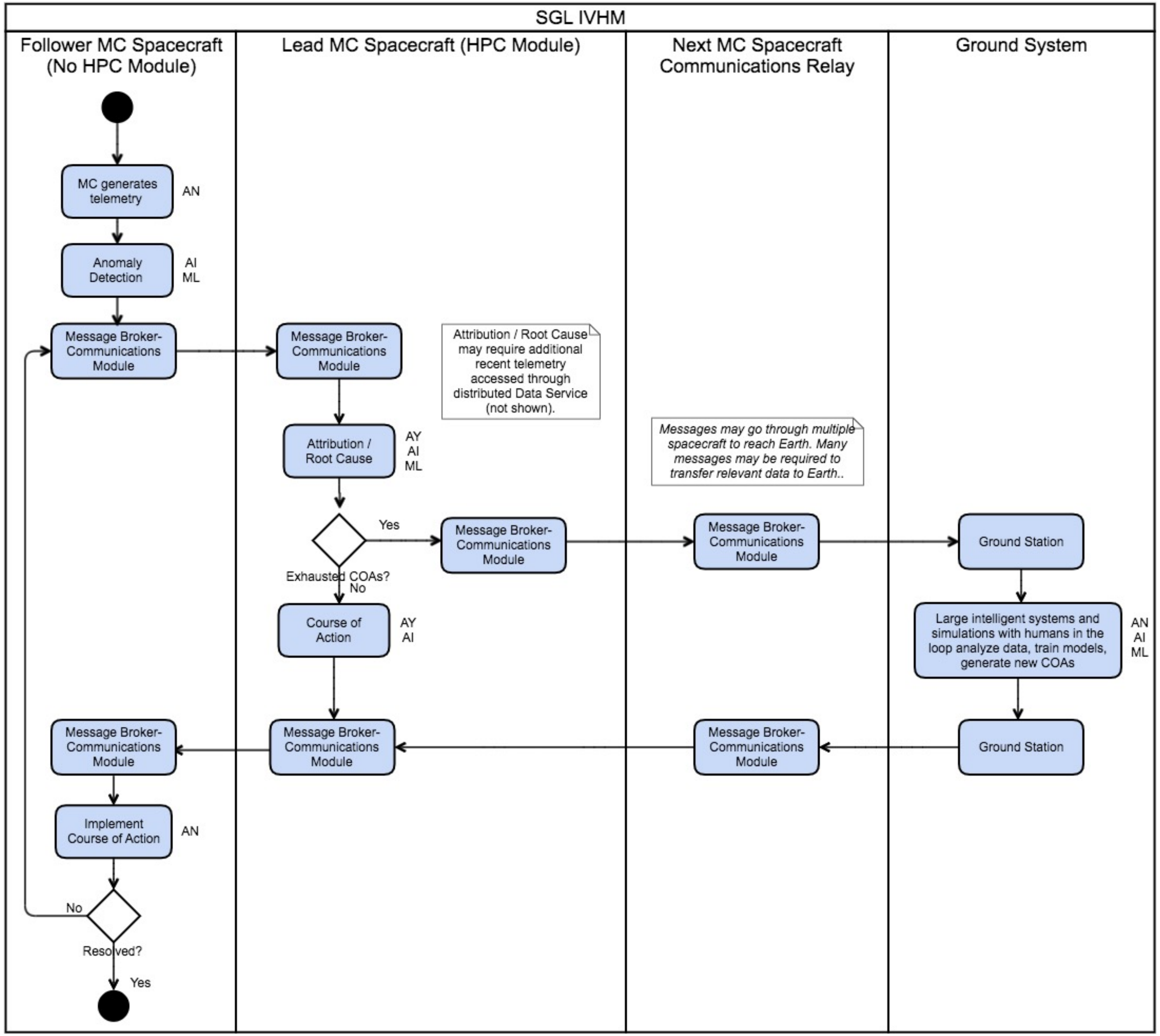
Fault Detection and Correction (FDC) Use Case

Activity diagram

HPC: High Performance Computing
COA: Course of Action

The FDC use case will probably require extensive use of autonomy due to ~1 week round-trip light time and high likelihood of hardware faults and failures over 50 year lifetime in deep space. TRL for this technology is low.

Additional work is needed to define specific time-critical faults.



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Conclusions

- SGL makes it possible to do high-resolution imaging and spectroscopic analysis of a habitable Earth-like exoplanet
- In most use cases, the AI and autonomy requirements can be satisfied with existing technologies.
- Guidance and control algorithms need to be adapted for perihelion passage phase of the mission.
- Fault detection and correction requires new AI/ML technology to ensure reliability over 50+ year mission lifetime.

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