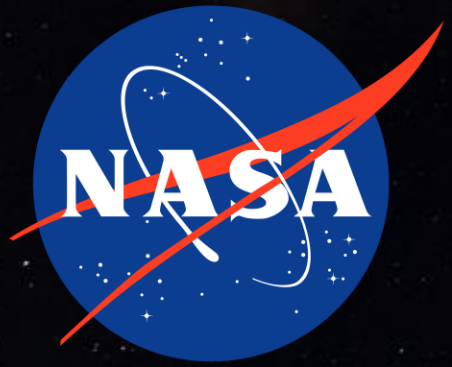


Georgia Tech Space Systems Design Laboratory

LUNAR FLASHLIGHT

Student Operations for Interplanetary Spacecraft: Benefits and Challenges

Presenters: Alan Yeung and Mollie Johnson
Co-Authors: Graham Jordan, Mason Starr, Dr. Glenn Lightsey

LUNAR FLASHLIGHT

6U CubeSat

Developed by NASA JPL, MSFC, Goddard, and Georgia Tech

Lunar Mission

From Earth to the Lunar South Pole

TECHNOLOGY DEMONSTRATION

Green Propellant

First CubeSat to use "green" ASCENT monopropellant

IRIS Comms

Substantially modified IRIS DSN Transponder previously flown on MarCO

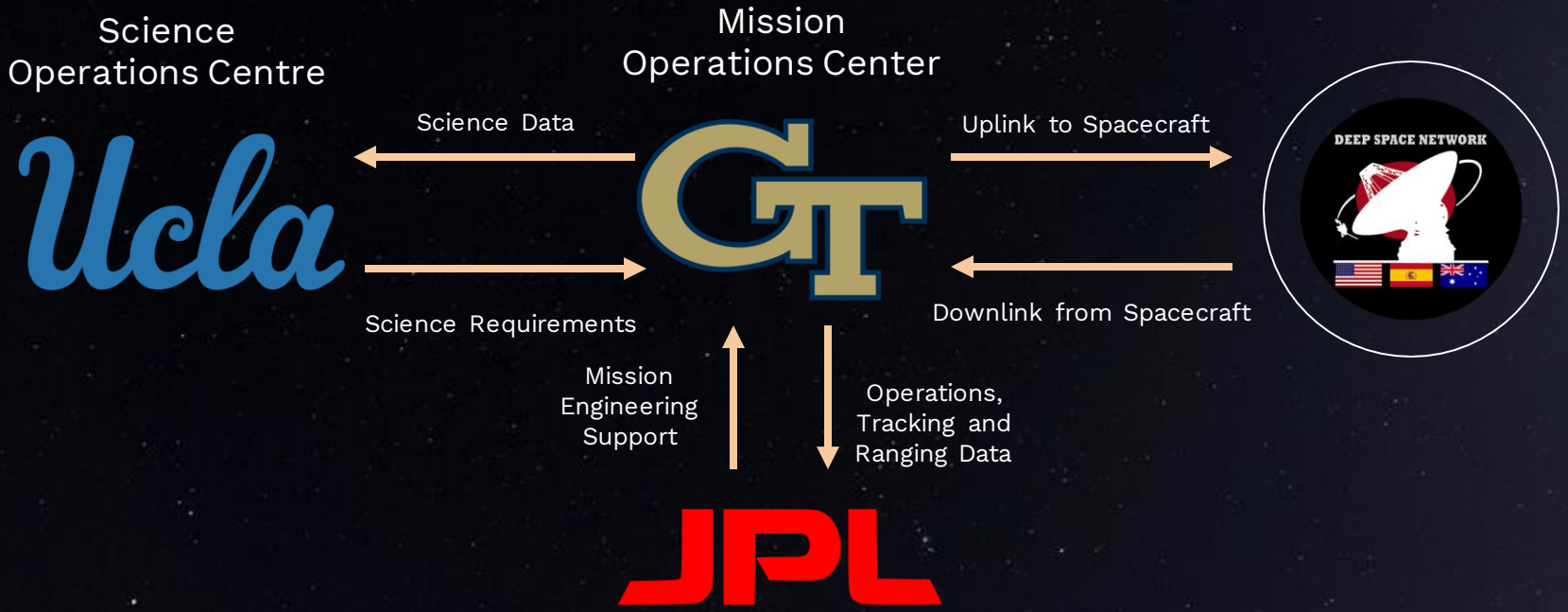
Near-Infrared Spectrometer

Map concentrations of water ice located at the lunar south pole for future Artemis missions

SPHINX C&DH

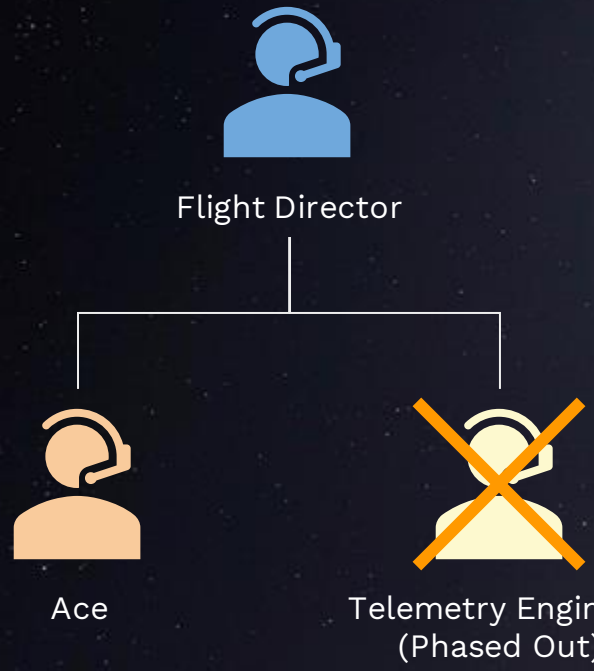
Radiation tolerant Sphinx Command and Data Handling system

MISSION CHAIN



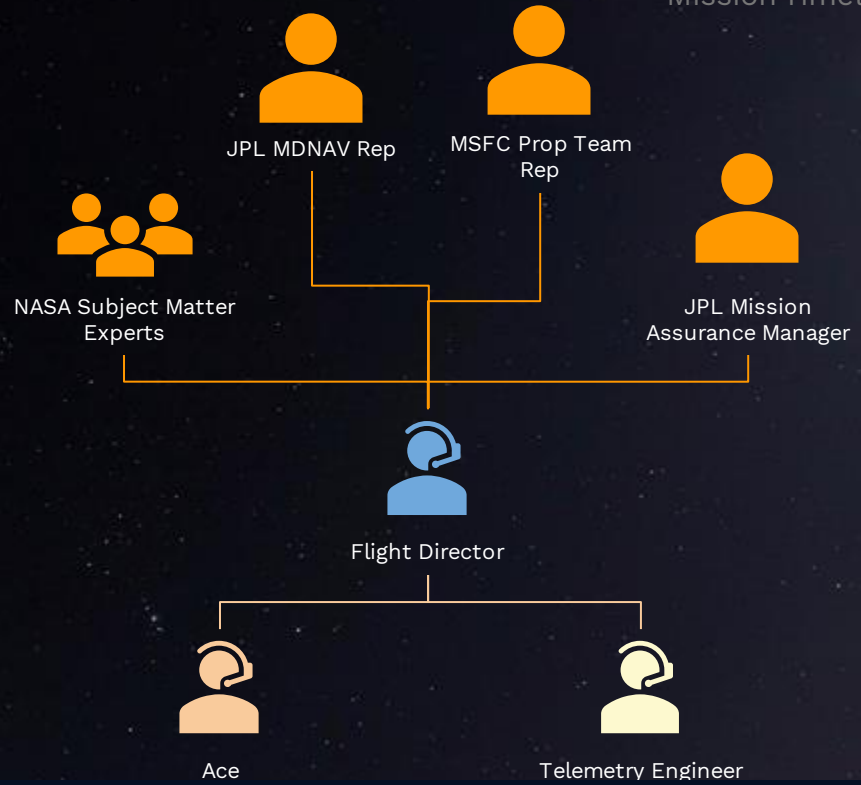
OPERATOR ROLES

- **Flight Director** (Graduate): highest authority in the MOC, handles communications between JPL, the operators, and the DSN
- **Ace** (Undergraduate): directly commands the spacecraft
- **Telemetry Engineer** (Undergraduate): monitors incoming telemetry, performs manual health checkouts of the spacecraft
  Phase out after staff developed expertise working with the spacecraft
- 30 students from pre-launch to extended mission

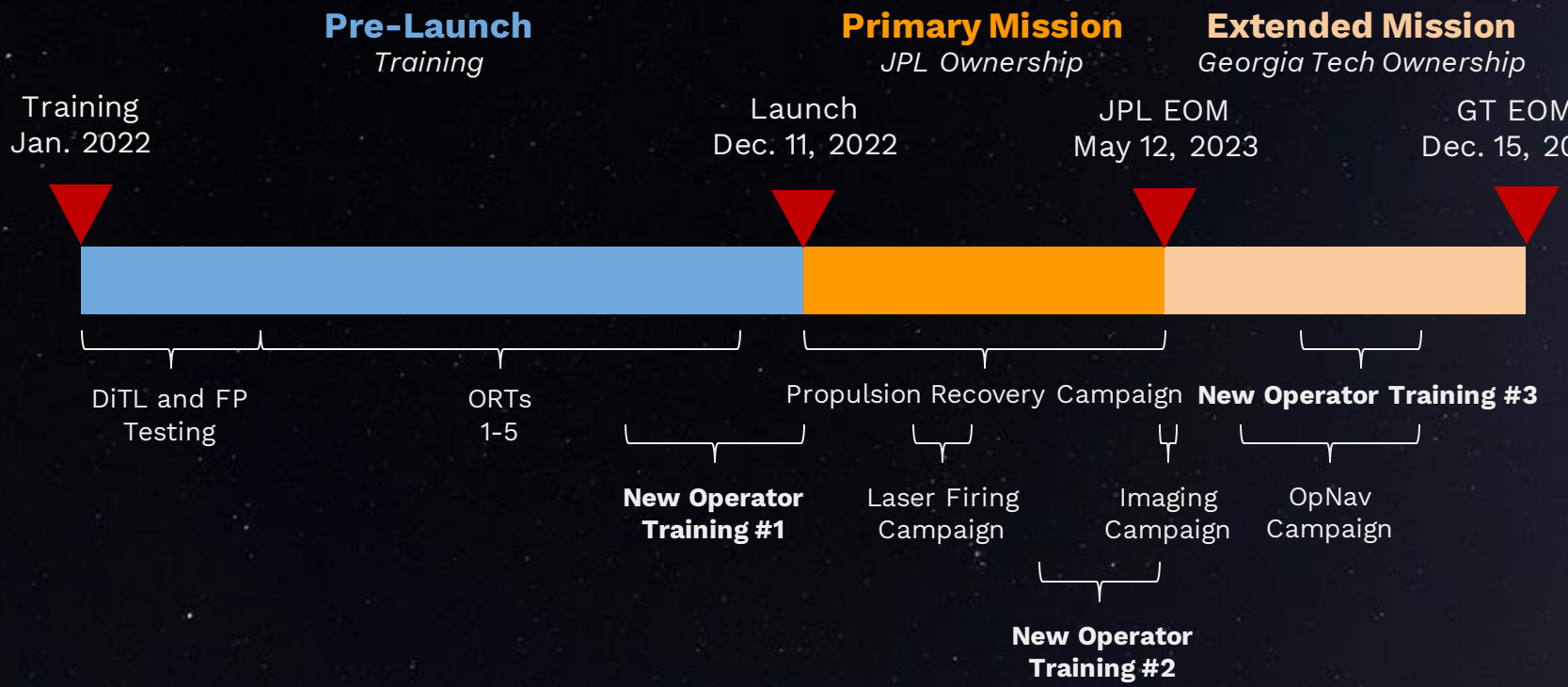


JPL & MSFC SUPPORT

- **Subject Matter Experts**: Experienced NASA engineers for every subsystem
- **Experts on the Line**: NASA engineers who watch the contacts as they happen virtually



MISSION TIMELINE



BENEFITS and CHALLENGES

Challenge 1: Training students to be operators

Students began with **no operations experience**

Graduate students and undergraduate students have **varying degrees of applicable knowledge**

First group of students to conduct operations of an interplanetary spacecraft

Challenge 1: Training students to be operators

Students began with **no operations experience**	JPL experts trained first round of students and conducted **Operational Readiness Reviews and Tests** (ORRs and ORTs)
Graduate students and undergraduate students have **varying degrees of applicable knowledge**	Experienced students trained inexperienced students through **shadowing and reverse-shadowing practices**
First group of students to conduct operations of an interplanetary spacecraft	**NASA SMEs were available** to provide assistance and answer questions

OPERATIONS SUCCESSES

Propulsion Recovery

- **Anomalous operations for 6 months**
  - Propulsion characterization
  - **Rotating TCMs**
  - 2-week planning time became 12-hr for activity turnaround
- Identified probable cause: *FOD in propulsion fuel lines*
- Problem ultimately unrecoverable

Laser Firing Campaign

- **Validated infrared spectrometer** laser payload in-flight
  - Technology demonstration
  - 10s, 30s, 90s firing
- Laser firing attempt at Earth during Earth flyby perigee
  - *Cancelled due to inclement weather*

Imaging Campaign

- **Took images in space** with star tracker camera

Moon and Earth

Partially shadowed Earth

LESSONS LEARNED

- **Onboard operators with DSN training**
  - *Avoid “black box” approaches and miscommunication with the DSN*
- **Have a larger team to prevent information siloing**
  - *Disseminate information among operators as evenly as possible to reduce workload and avoid burnout*
- **NASA SMEs were critical** for problem solving and expertise where operators fell short
  - *In anomalous cases, consider sending an experienced operator(s) to assist in-person*

Challenge 2: Fully student operations without JPL

Grad students no longer assigned to the project

Loss of critical skillsets needed for further development

Completely **new operating parameters** for **heliocentric orbit**

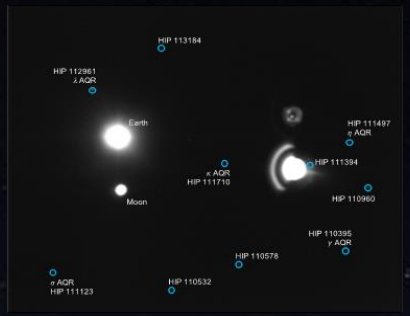
Challenge 2: Fully student operations without JPL

Grad students no longer assigned to the project	**Promoted experienced undergraduates** to flight directors
Loss of critical skillsets needed for further development	**Recruited non-aerospace majors** to replace key skillsets such as software
Completely **new operating parameters** for **heliocentric orbit**	**Inexperienced operators** worked with **experienced operators**

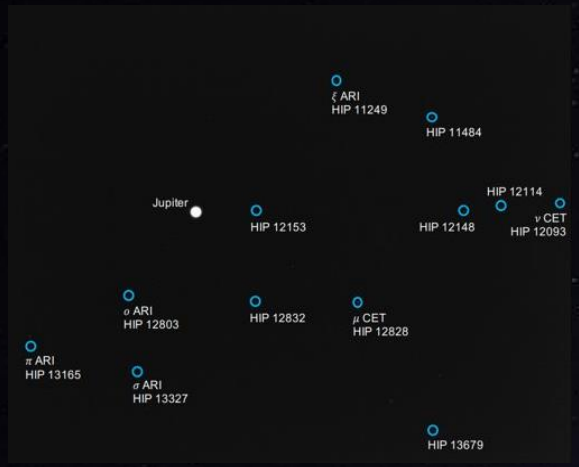
OPERATIONS SUCCESSES

LONEStar OpNav Experiment

- **Star-Tracker Images Taken of Various Celestial Objects**
  - Used in experiment to determine effectiveness of LF localization



Long exposure of Earth-Moon System and starfield



Jupiter and Defined Stars

6 Months of Extended Operations

- **Maintained communications** with LF 11M km from Earth
  - Developed Earth slewing downlink passes
- **Deployed** undeployed solar panel
- Performed **comm data rate** and **payload systems experiments**

LESSONS LEARNED

- **Maintaining concise written records** of system interactions
  - *Summarize solutions to solved problems in easy to understand procedures*

- **Having operators with diversified skillset** is useful for sustainable operations
  - *Personnel with dedicated skills is important to take the lead on activities and mentor other operators to gain those skills*

- **Designing software tools** and other systems **with varying staff experience levels** in mind
  - *Account for varied experiences in different skills and develop a structured training plan*

Challenge 3: Balancing student responsibilities

High turnover rate due to **graduation**

Classes, extracurriculars, and other **academic responsibilities**

Limited working hours and **academic breaks**

Graduate: 20 hr/week
Undergraduate: < 10 hr/week

Challenge 3: Balancing student responsibilities

High turnover rate due to **graduation**	**Train replacement operators** several months before graduation
Classes, extracurriculars, and other **academic responsibilities**	Assemble large teams of operators to **rotate shifts**, **use shared calendar** for time management
Limited working hours and **academic breaks** Graduate: 20 hr/week Undergraduate: < 10 hr/week	**Develop autonomous capabilities** early on for no-activity contacts

OPERATIONS SUCCESSES

1-Year Anniversary

- Anomalous operations for 6 months
- **Technology Demonstration**: use of ASCENT propellant and laser spectrometer payload

30 Students

- **10 graduate students**
- **20 undergraduate students**

GDS Tool Development

- **Created several in-house custom software tools**
- Semi-autonomous MTAK momentum management and reactive time script (SMARTs), Downlink Helper, LF SeqGen, etc.
  - For more details, see Starr 2023

LESSONS LEARNED

- **Select operators who will be present before and after launch**
  - *Longstanding presence reduces need for information transfer*
  - *Operators present during pre-launch I&T had a significant knowledge advantage*
- **Schedule "on-call" backup operators in advance**
  - *Reduce the need for finding last-minute replacements in case of emergency*
- **Reduce the number of contacts and make them autonomous** when possible
  - *Also frees up DSN time for other projects*

EMERGENT BENEFITS

Student mission operations for the Lunar Flashlight have revealed 3 emergent benefits:

Reduced operations cost

Strong industry-university partnerships

Hands-on experience for students

EMERGENT BENEFITS

Average salary of a mission operator at JPL: $137,000/year *Glassdoor.com*
- Not including benefits

Total: **$137,000/year**

Equivalent cost of an **undergraduate** student: **free!**
- Undergrads perform research for degree credits

Equivalent cost of a **graduate** student via GT Graduate Research Assistantship:
- $2,400/mo stipend x 12 mo
- Up to $15,323 in tuition and fees x Fall, Spring, and Summer
  - *All values based on Spring and Summer 2023 tuition rates*

Total: **$74,492/year**

45.6% salary cost reduction

**Ideal for high-risk, low-cost Class D missions*

EMERGENT BENEFITS

- Strong GT-JPL **strategic relationship** developed
  - Future collaboration
  - Brand enhancement
  - Talent acquisition
- **6 out of 30** students on the project **worked for JPL** as an intern or full-time
- Applicable between other target institutions

EMERGENT BENEFITS

- Operations engineering is not part of the required aerospace curriculum
- Operations provides students a **hands-on experience**
  - Builds knowledge and understanding
  - Exercises problem-solving skills
  - Bolsters resumes
- **21 out of 30 students** on the project were able to get **internships or jobs** during or immediately after their experience with Lunar Flashlight

SUMMARY

Challenges overcome:
- Training grads and undergrads to be operators
- Operations with only undergraduates
- Balancing student responsibilities

Benefits gained:
- Reduced operations cost
- Stronger industry-university relations
- Students gain applicable experience

REFERENCES

M. Krause et. al., "LONEStar: The Lunar Flashlight Optical Navigation Experiment," ARXIV Computer Vision and Pattern Recognition, 2024. https://doi.org/10.48550/arXiv.2401.12198

M. Starr, M. Hauge and G. Lightsey, "Shining a Light on Student-Led Mission Operations: Lessons Learned from the Lunar Flashlight Project," AIAA 2024-0822. *AIAA SCITECH 2024 Forum.* January 2024.

N. Cheek et. al, “Systems Integration and Test of the Lunar Flashlight Spacecraft,” in Proceedings of the Small Satellite Conference, Beyond LEO, SSC22-II06, 2022. https://digitalcommons.usu.edu/smallsat/2022/all2022/149/

M. Hauge et al., “Operations systems engineering for the lunar flashlight Mission,” in *Small Satellite Conference*.,Utah State University, Logan, UT. SSC23-WVII-02, 2023.

M. Starr, “Development of tactical and strategic operations software for NASA’s Lunar Flashlight Mission,” in *Small Satellite Conference,* Utah State University, Logan, UT. SSC23-XII-05, 2023.

B. Cohen et al., “Lunar Flashlight science ground and flight measurements and operations using a multi-band laser reflectometer,” Icarus, Volume 413, 2024, 116013, SSN 0019-1035, 2024. https://doi.org/10.1016/j.icarus.2024.116013.

Glassdoor. *Total Salary Range for NASA Jet Propulsion Laboratory Mission Operations Engineer* [Online]. Available: https://www.glassdoor.com/Salary/NASA-Jet-Propulsion-Laboratory-Mission-Operations-Engineer-Salaries-E116768_D_KO31,58.htm.

Georgia Tech Office of the Bursar. *View Tuition Costs by Semester* [Online]. Available: https://bursar.gatech.edu/tuition-fees

QUESTIONS?

Corresponding Author: Alan Yeung
Contact: ayeung33@gatech.edu
Co-Presenter: Mollie Johnson
Contact: mojohn23@mit.edu


Georgia Tech
Space Systems Design Laboratory