The YAOKI Lunar Rover

Shinichiro Nakajima, Alejandro Sela, Louis Burtz

Webinar I Lunar Ledger I First Dataset Release

Launching to space:

SpaceX Falcon 9

Leaving Earth:

Intuitive Machines
IM2 Mission

Leaving Earth:

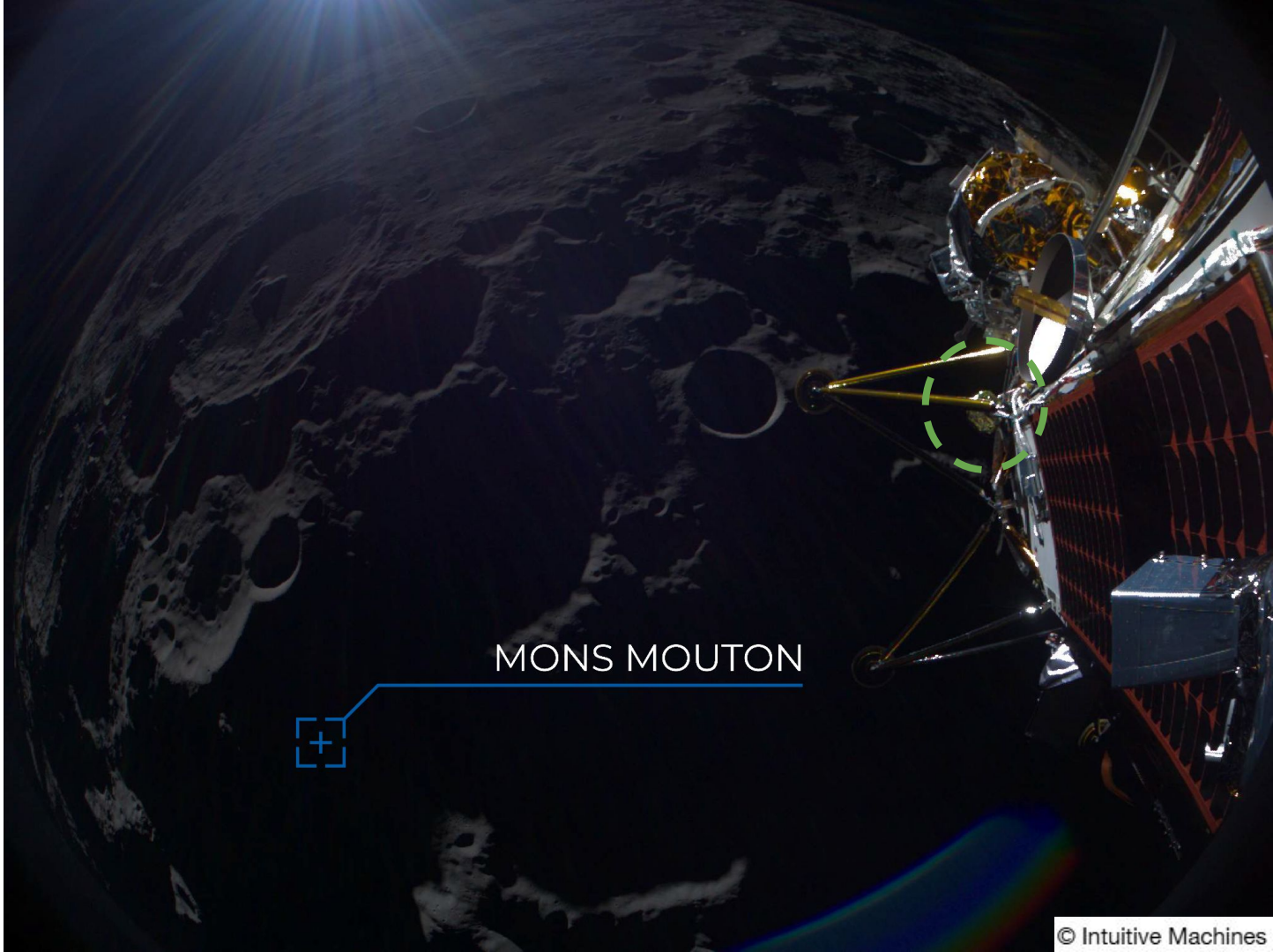
Intuitive Machines
IM2 Mission

Arriving at the Moon:

Intuitive Machines IM2 Mission

Landing on the Moon:

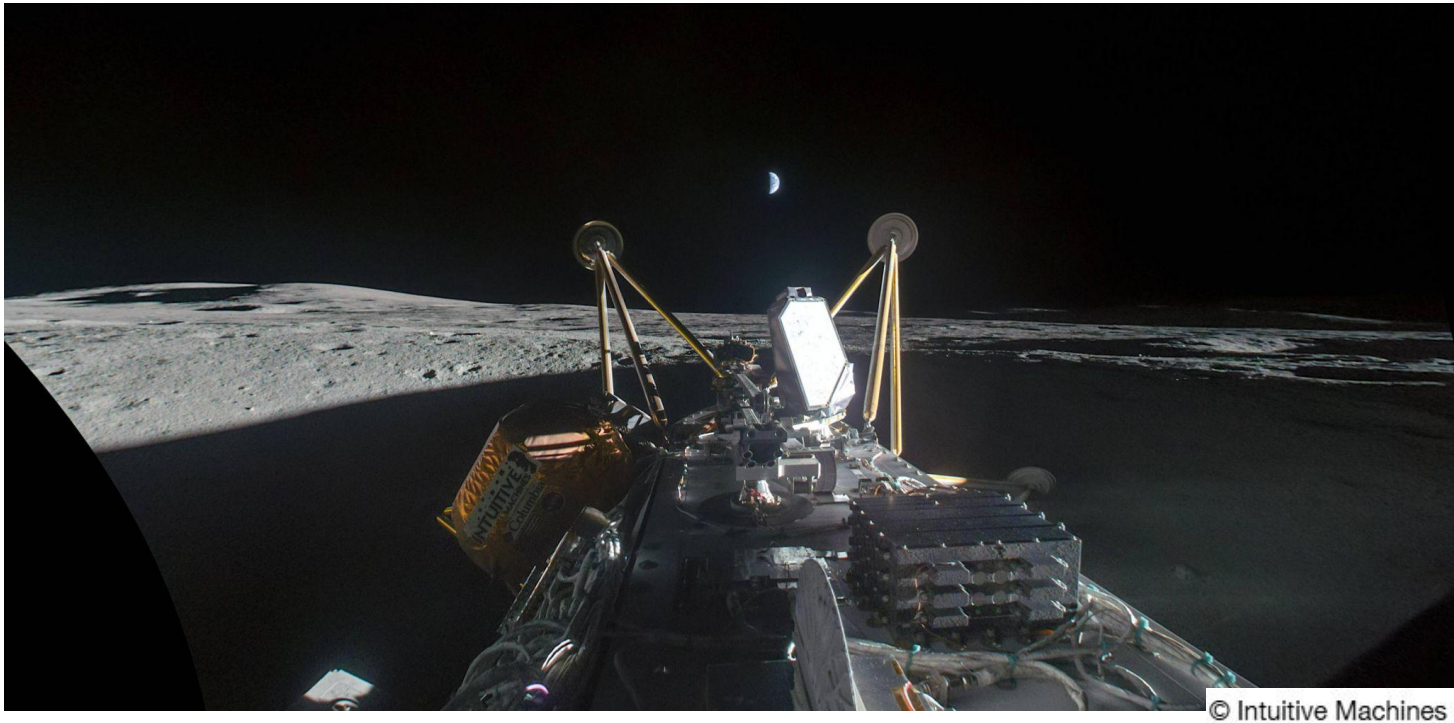
Intuitive Machines IM2 Mission



Landing on the Moon:

Intuitive Machines IM2 Mission

LANDED
ON
THE
MOON
!!!



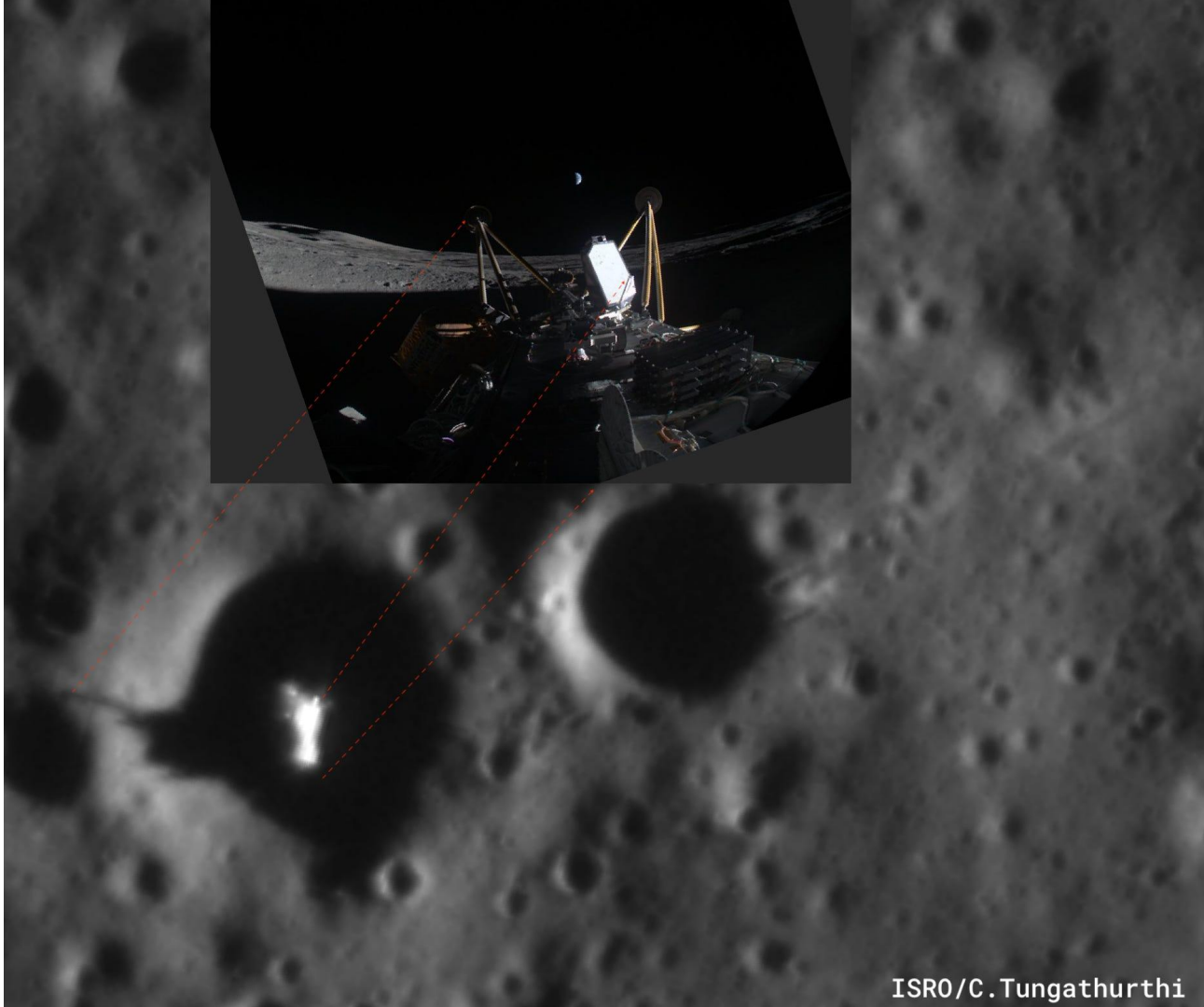
© Intuitive Machines

Landing Site

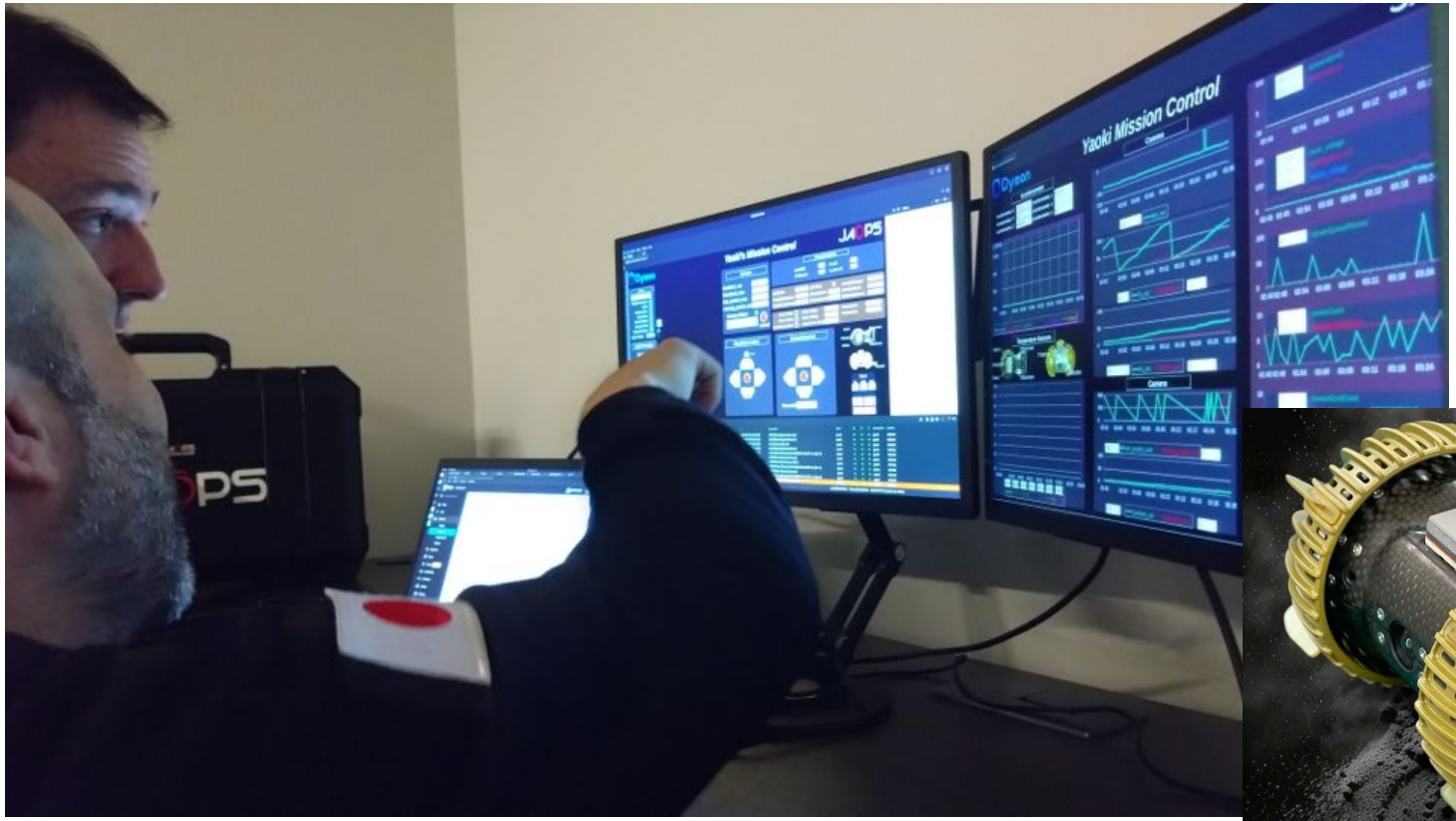
84.8 °S, 29.1°E

Distance from the South Pole:
~160 km

Crater Temperature :
~ -100 °C

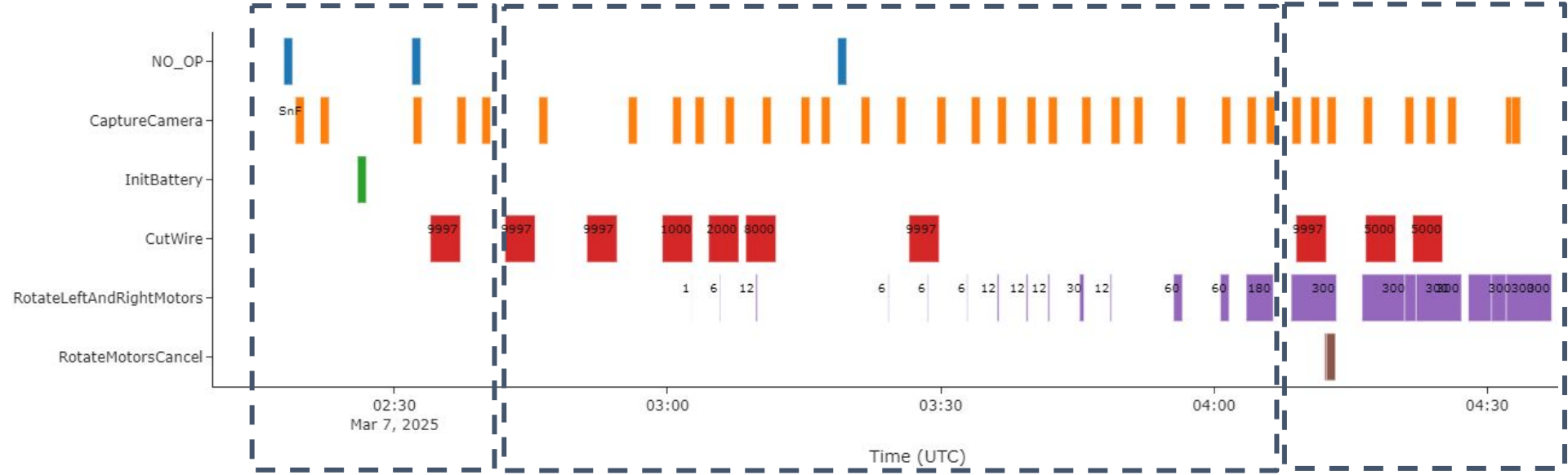


Mission Operations



Mission Operations

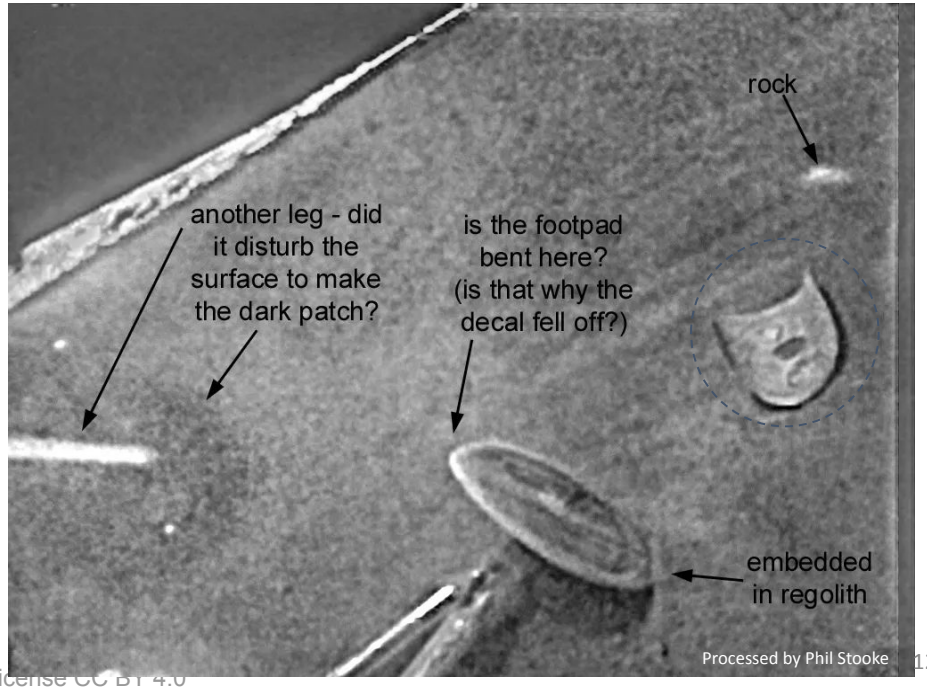
Timeline of Telecommands Sent



Initial Procedure | Deployment Troubleshooting | Maximizing

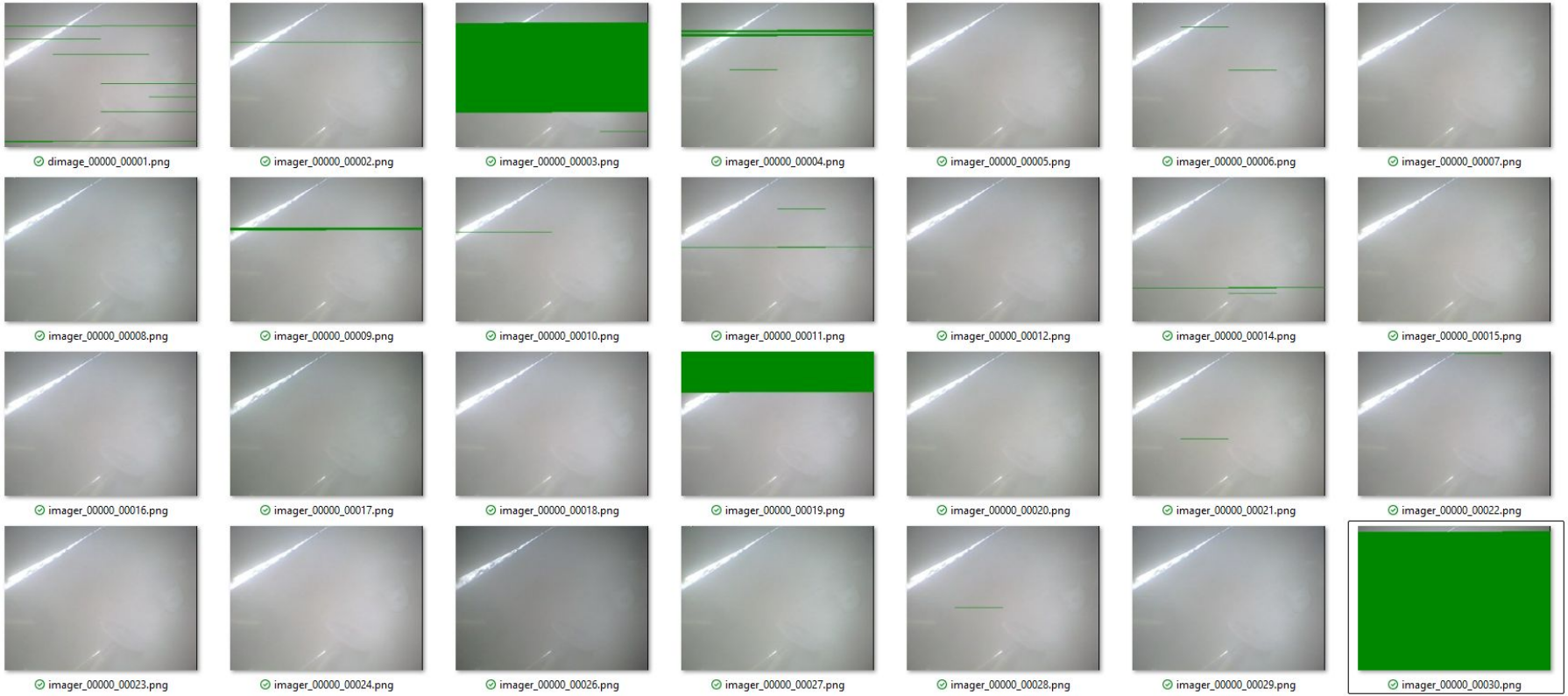
Mission Operations

Images taken from the crater near the lunar South Pole

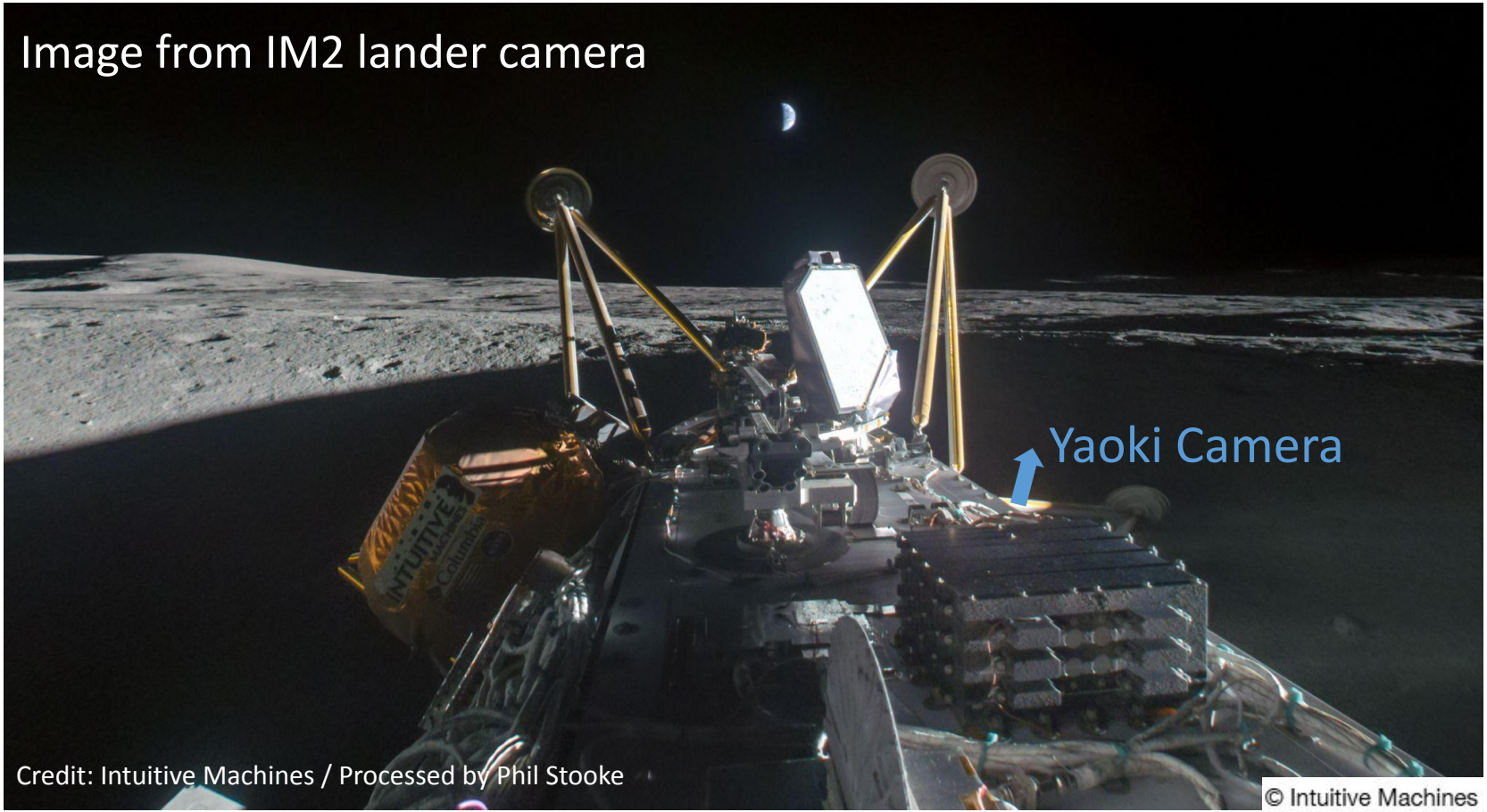


Mission Operations

All 28 YAOKI Images:



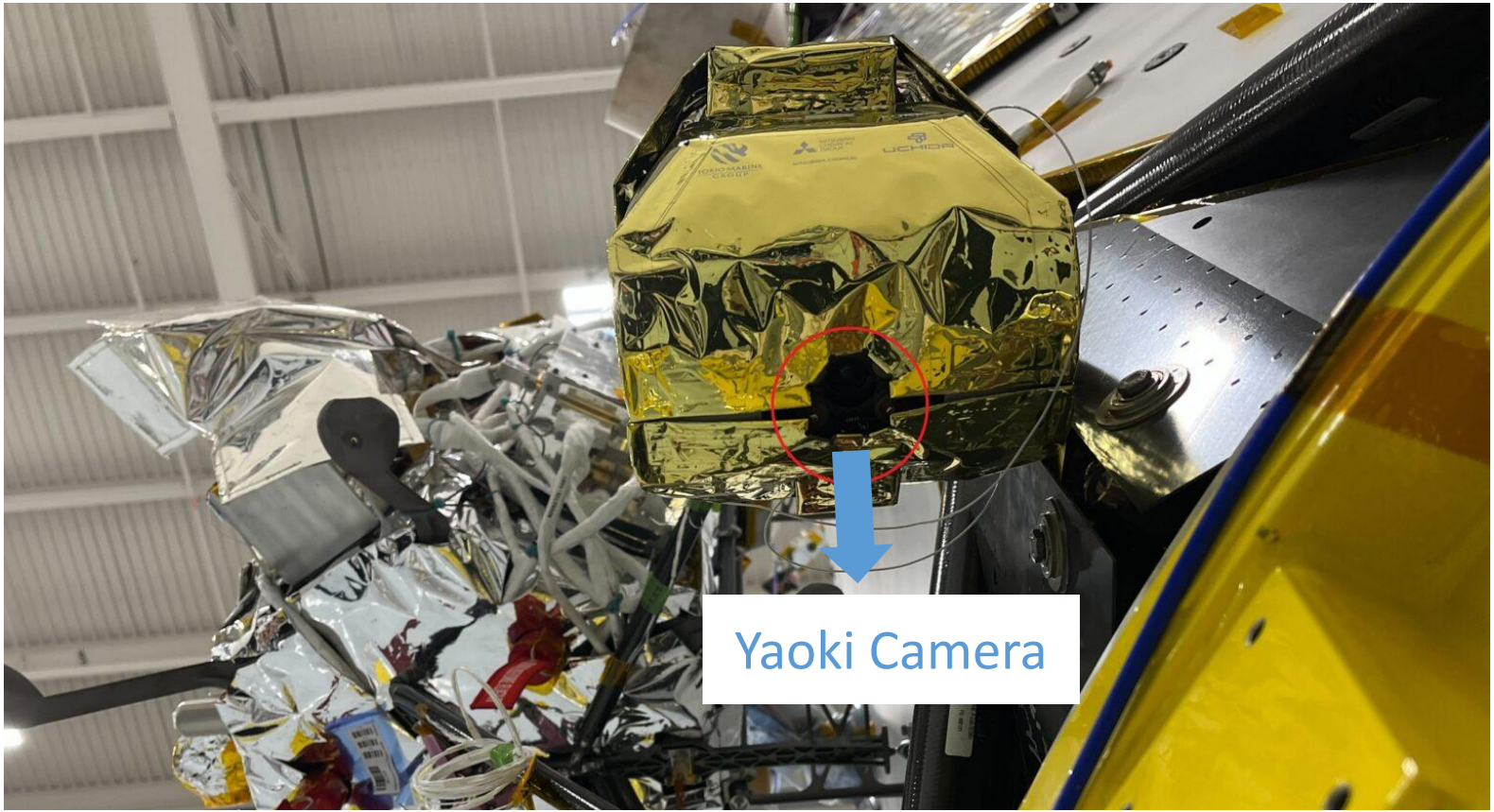
Mission Operations



Mission Operations

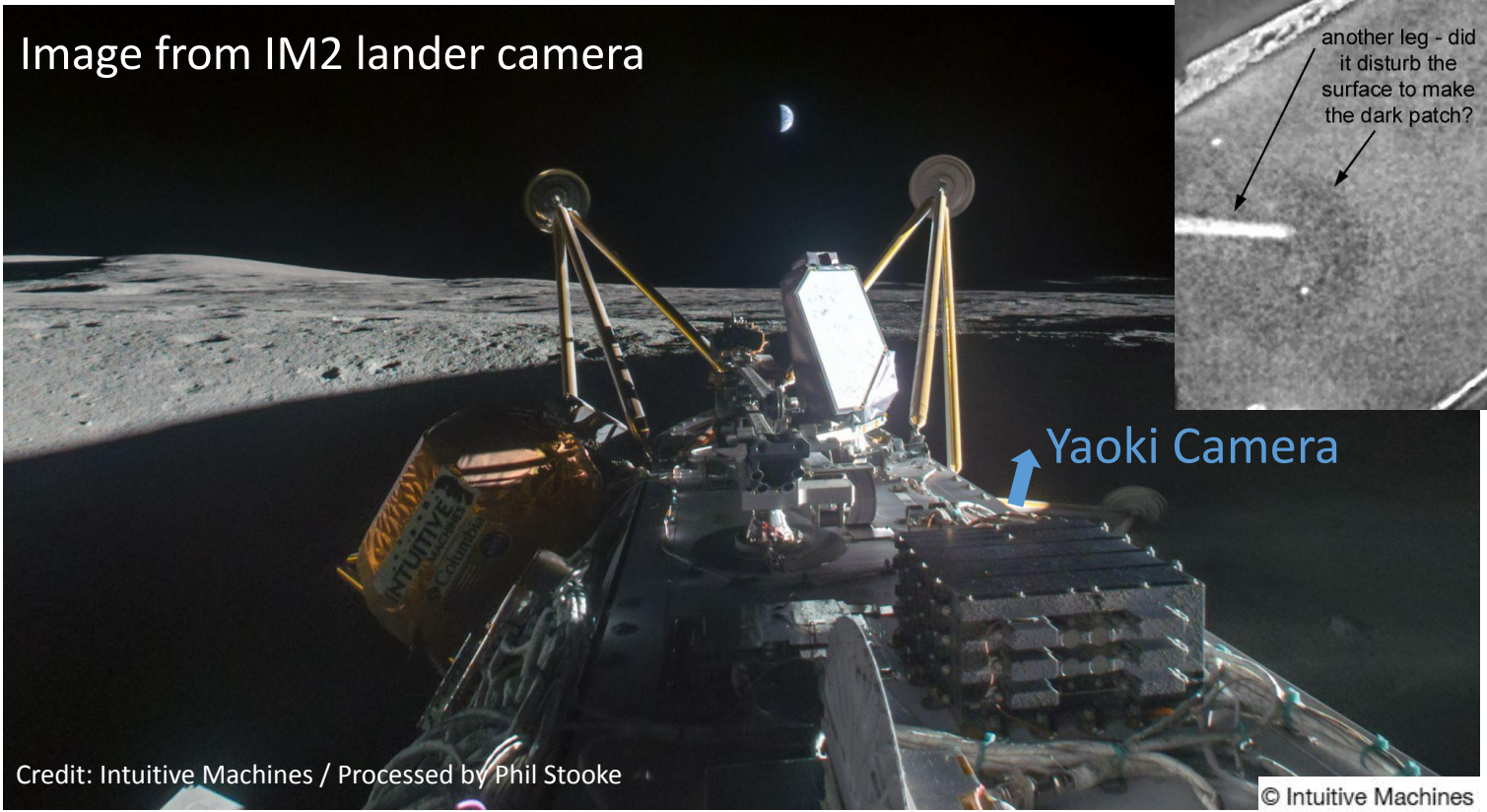
YAOKI Rover before launch

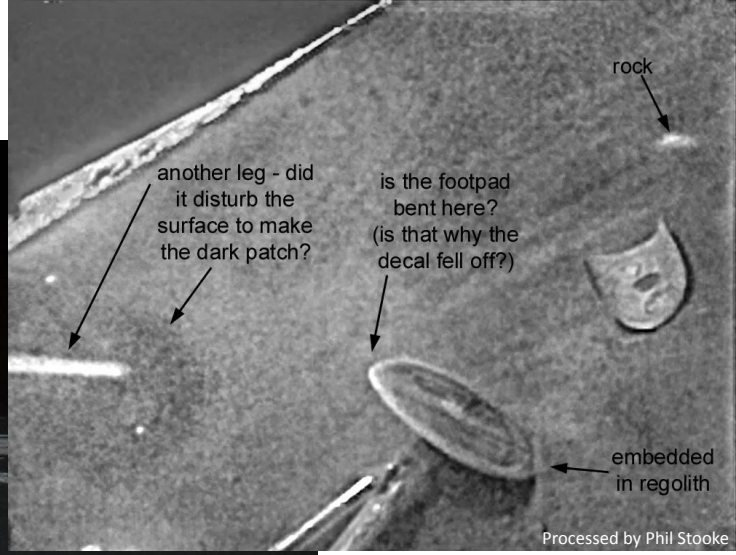
Red Circle = YAOKI camera view port



Dymon

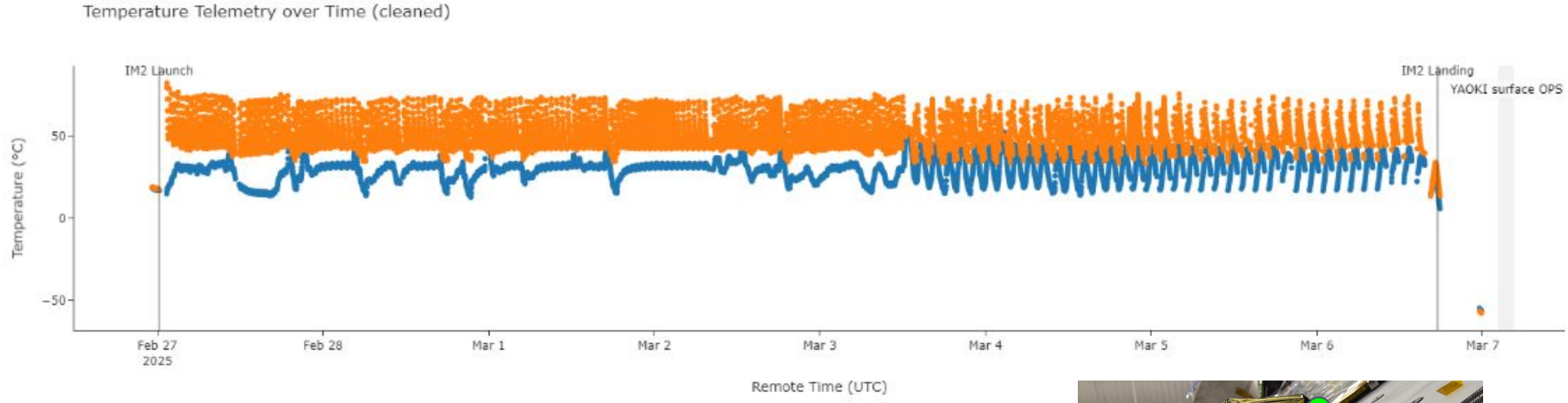
Image from IM2 lander camera





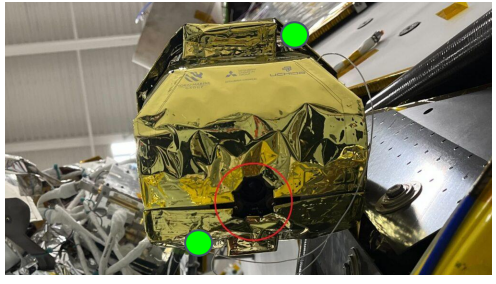
Mission Operations

External Temperature Sensors (x2)



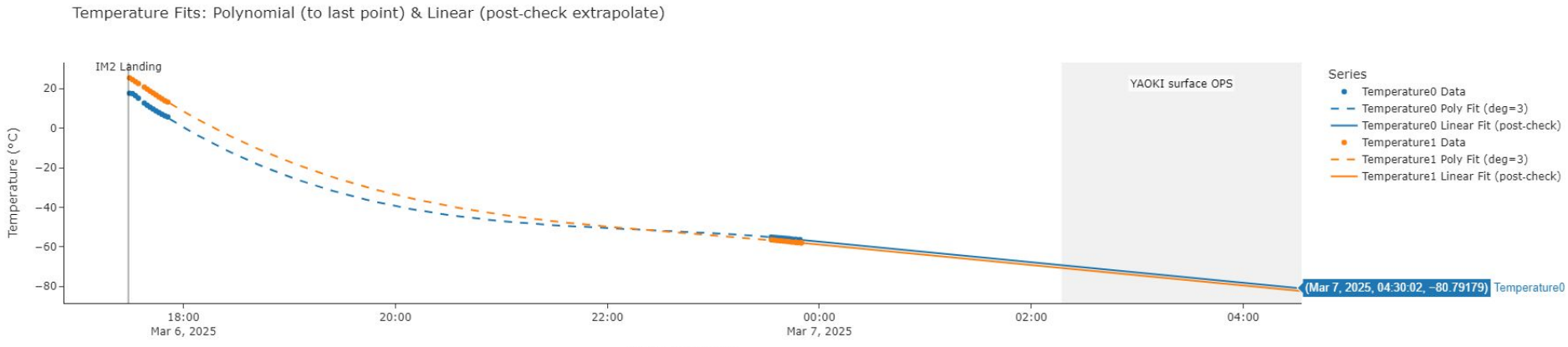
Green dots =

External temperature sensors



Mission Operations

External Temperature Sensors (x2)



Landing

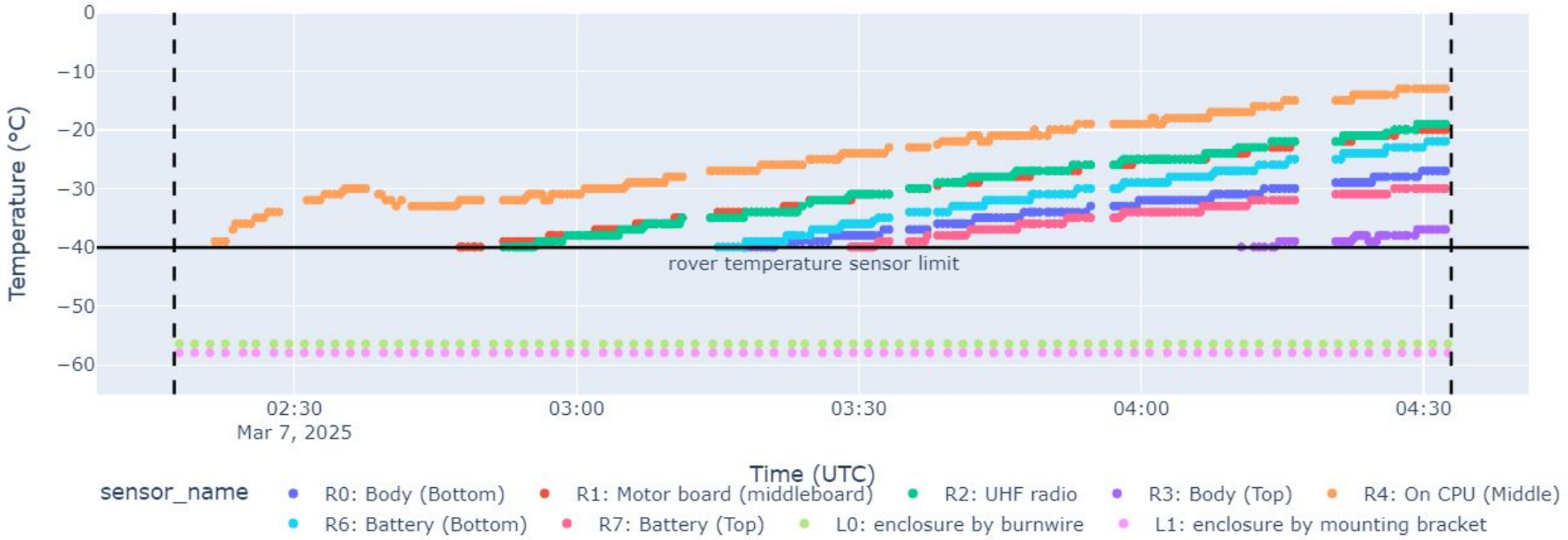
Lander Thermal System Turned OFF

Turned ON briefly

Turned OFF permanently

Mission Operations

Internal Temperature Sensors (x7)



Overview of the Dataset

- All telecommands sent
- All telemetry received
- All images received

Open Data on AWS

jaops-space / im2-yaoki-yamcs-public

- Raw format and processed format
- Tools and tutorials of how to access and analyze the data
- Description of each data item

- Configuration of the Yamcs Mission Control System
  - Mission Database
  - Data Archive
  - You can replay the data like it was received during the mission

Lessons Learned

Rover Name	Country (Entity)	Mission Name	Year
Lunokhod 1 and 2	Soviet Union	Luna 17, 21	1970, 1973
Apollo Lunar Rovers	USA (NASA)	Apollo 15, 16, 17	1971–72
Yutu and Yutu 2	China (CNSA)	Chang'e 3, 4, 6	2013, 2019, 2024
Pragyan	India (ISRO)	Chandrayaan-3	2023
SORA-Q (LEV-2)	Japan (JAXA)	SLIM	2024
MAPP	USA (Lunar Outpost)	Lunar Voyage 1 on IM-2	2025
YAOKI	**Japan (Dymon)**	**YAOKI on IM-2**	**2025**

Operated by JAOPS

Only 10 successful rovers

First Japanese private-sector rover on the Moon
First images of dark crater near South Pole

First lunar rover with open-source mission operations software

First dataset on the Lunar Ledger!

Lessons Learned

Surviving the launch, cruise and surface environments is hard

- The accelerometer failed. But all other electronics worked well!
- Not space-grade / multi-million dollar dedicated development

Sending data from the Moon is hard

- Choose carefully what data to send, how much can be sent, how to send it
- Always send raw data. Calibration only on the ground.
- Software to re-configure data sending parameters

Landing on the Moon is hard

- Record data in space before landing
- Plan for contingency landing scenario together with the lander provider
- Expect anomalies: design robust deployment system and data acquisition

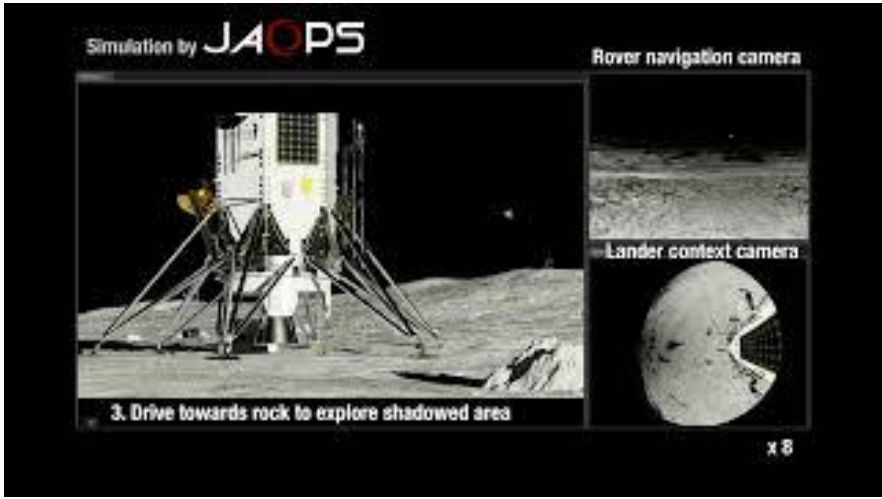
Lessons Learned

Mission Operations are critical from the beginning of development

- Hardware + Software + Mission Operations

Standards and heritage increase reliability and reduce development time

- Yamcs Mission Control System
- CCSDS communication protocols
- Deployment infrastructure



Test early, test often, test fully

- Create (and budget) for several Flight Models
- Leverage simulation from development to mission planning to testing to operator training to collecting scientific data properly
- Expect and prepare for the unexpected

Why Join the Lunar Ledger?

1. Share this unique dataset
2. Share lessons learned
3. Empower others to analyze
4. Set a precedent

Vision of JAOPS:

JAOPS is committed to being a driver of safe, successful, and sustainable space mission operations by promoting best practices for the planning, collection, and delivery of lunar mission data.

Vision of Dymon:
Dymon continues to push the frontier through new missions that will collect valuable data and support humanity's expansion into space.

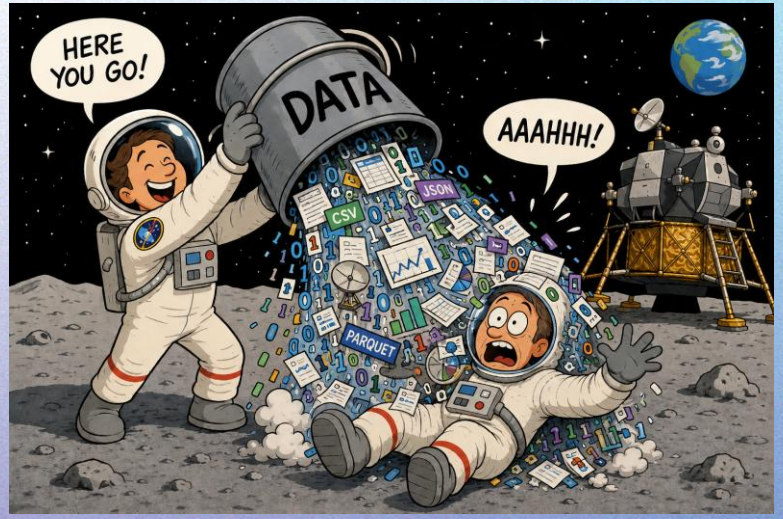
Vision of YAOKI:
Fall 7 times, stand up 8 times!

OPEN LUNAR
FOUNDATION

YAOKI Rover Dataset

Zack Gainsforth, Mehak Sarang | Open Lunar
Shinichiro Nakajima | Dymon
Alejandro Sela, Louis Burtz | JAOPS

July 1, 2026



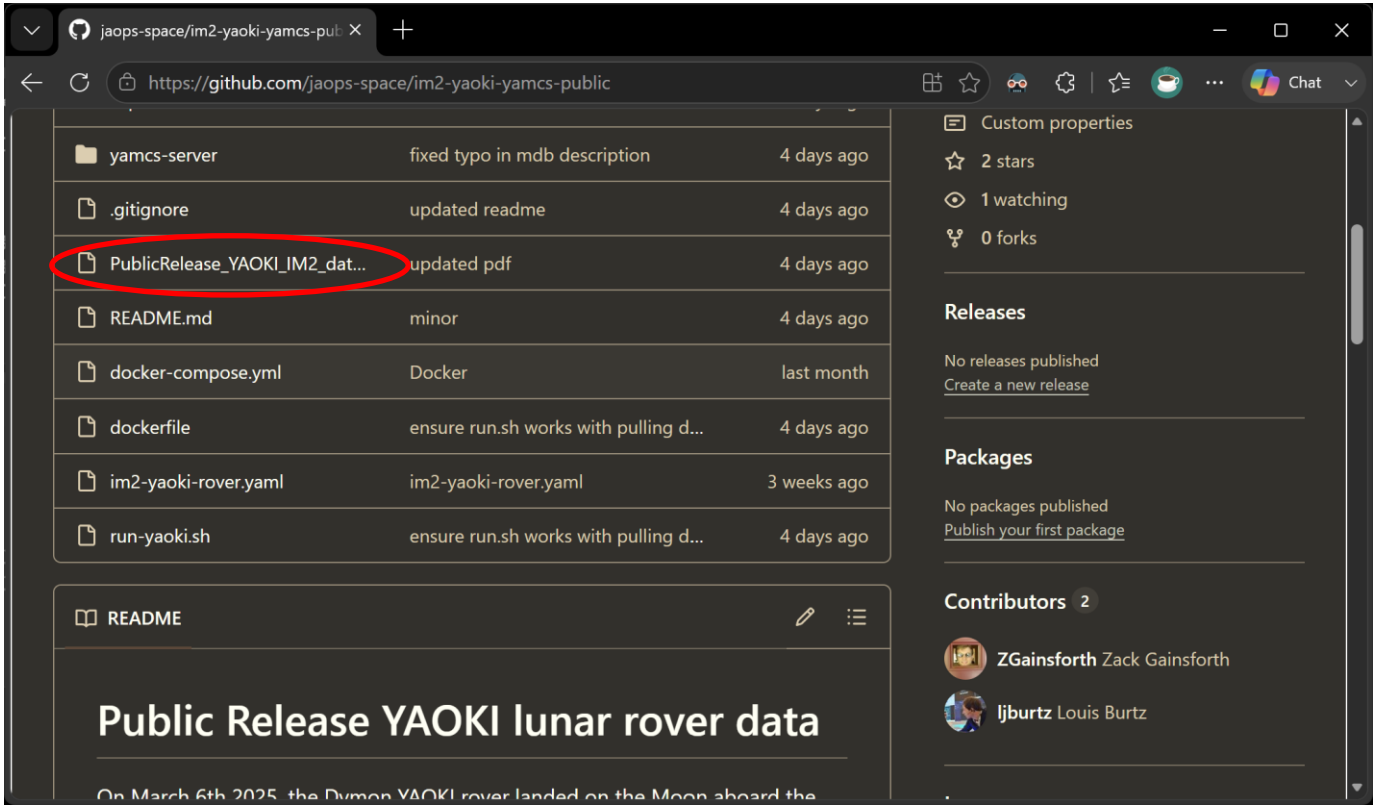
What does a data release look like?

Where to start?

https://github.com/**jaops-space**/im2-yaoki-yamcs-public

The easiest place to start is the Github!

Look for the PDF in the main directory.



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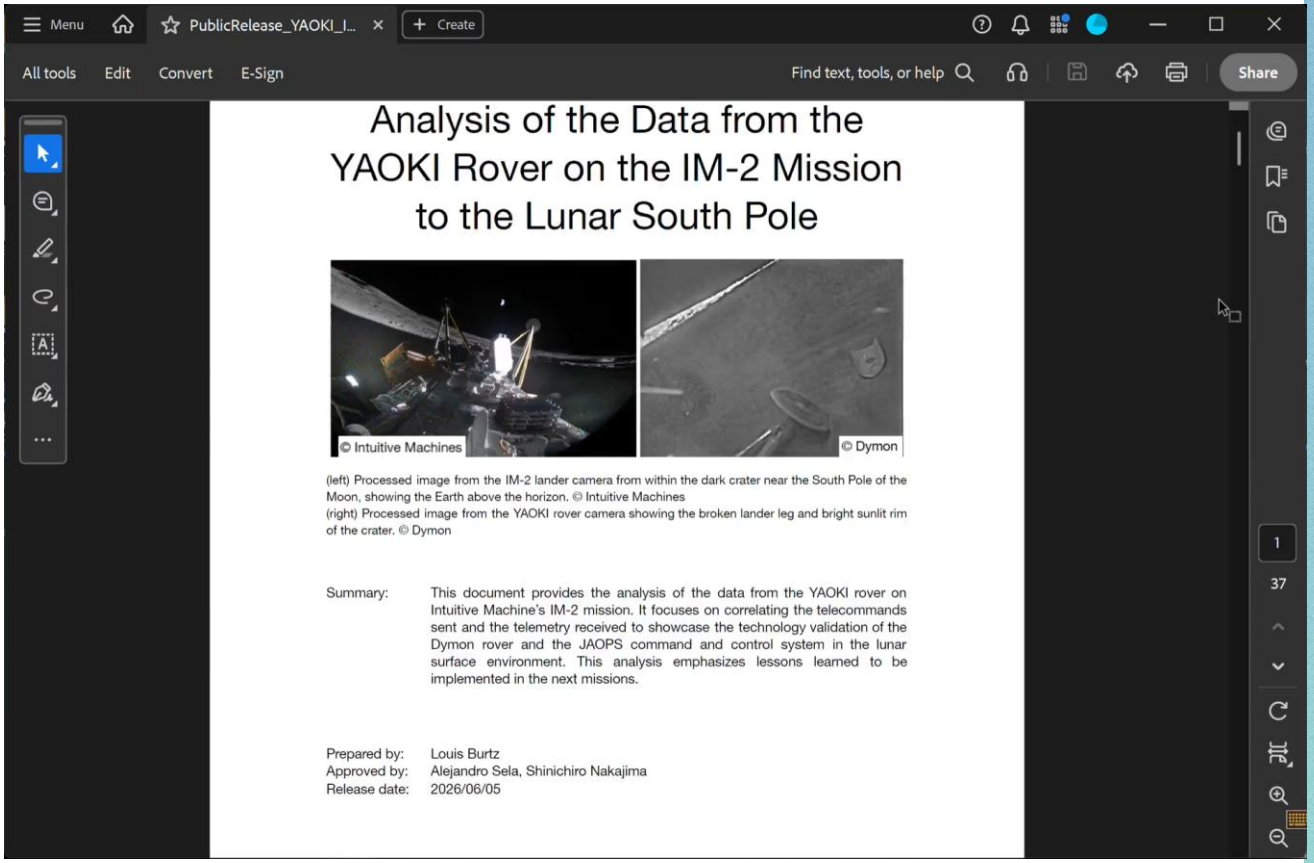
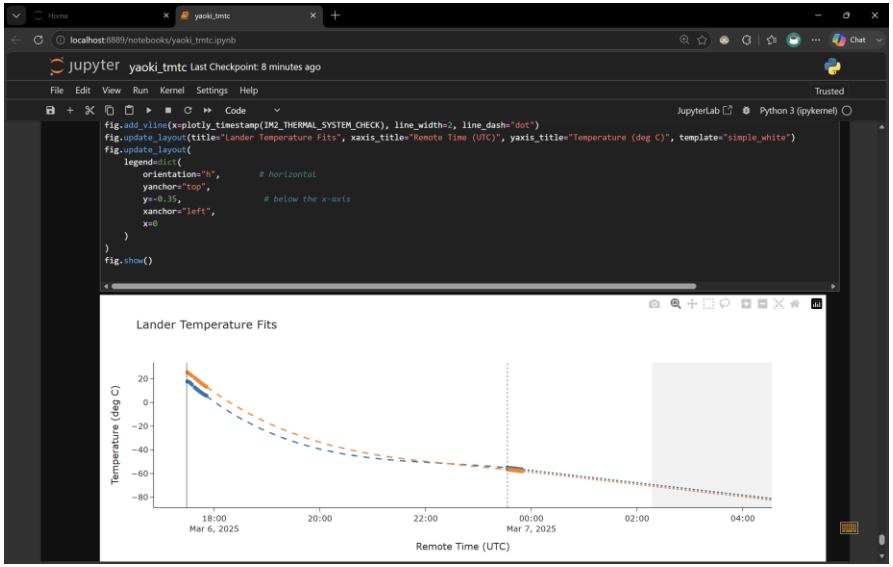
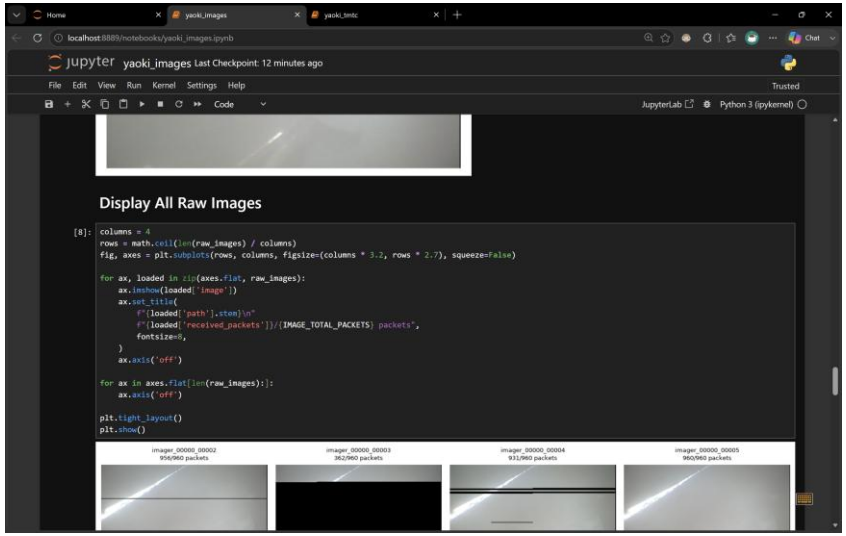


Use Python Jupyter notebooks to play with data

Yaoki_tmtc downloads the Telemetry and Telecommand data. The code shows basic operations.

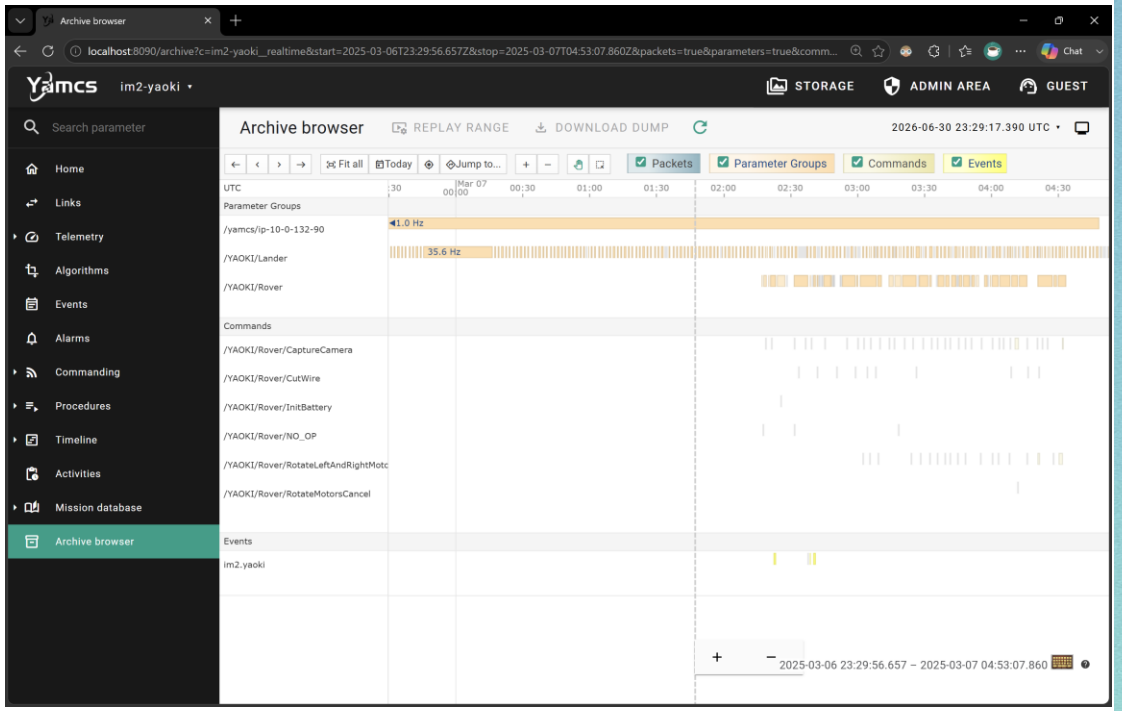




Yaoki_images downloads the camera data. The code shows basic operations.

The Yamcs database is included

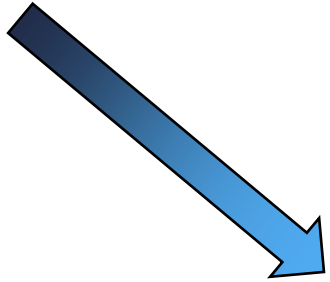
The rover was controlled using the Yamcs mission control software. The database can be used to simulate any portion of the mission in realtime.



Ensure Easy Long-term Access for Everyone

Yamcs MISSION CONTROL

In order to ensure the data is easily accessible using an **industry standard**, **open-source format**, all mission data was additionally converted to Apache Parquet.



Parquet

This code for this conversion exists in the export subdirectory of the github repository.

Ensure Easy Long-term Access for Everyone

YAOKI__Rover__ADC_TEMP4.metadata.yaml

```yaml
kind: telemetry
source_name: /YAOKI/Rover/ADC_TEMP4
description: ''
rows: 399
fields:
  generation_time:
    description: UTC timestamp assigned when this
    telemetry sample was generated.
    dtype: datetime64[us, UTC]
    observed:
      null_count: 0
      non_null_count: 399
      min: '2025-03-07T02:17:15.150000+00:00'
      max: '2025-03-07T04:32:56.331000+00:00'
  acquisition_time:
    description: UTC timestamp when the sample was
```

Each TMTC stream has a text file (yaml) describing the data format.

Each TMTC stream has a parquet file with the raw data.

YAOKI__Rover__ADC_TEMP4.parquet

YAOKI__Rover__ADC_TEMP4.... (399 rows) | Table | Charts | SQL | Export CSV | Export JSON | Polars | Python

Schema

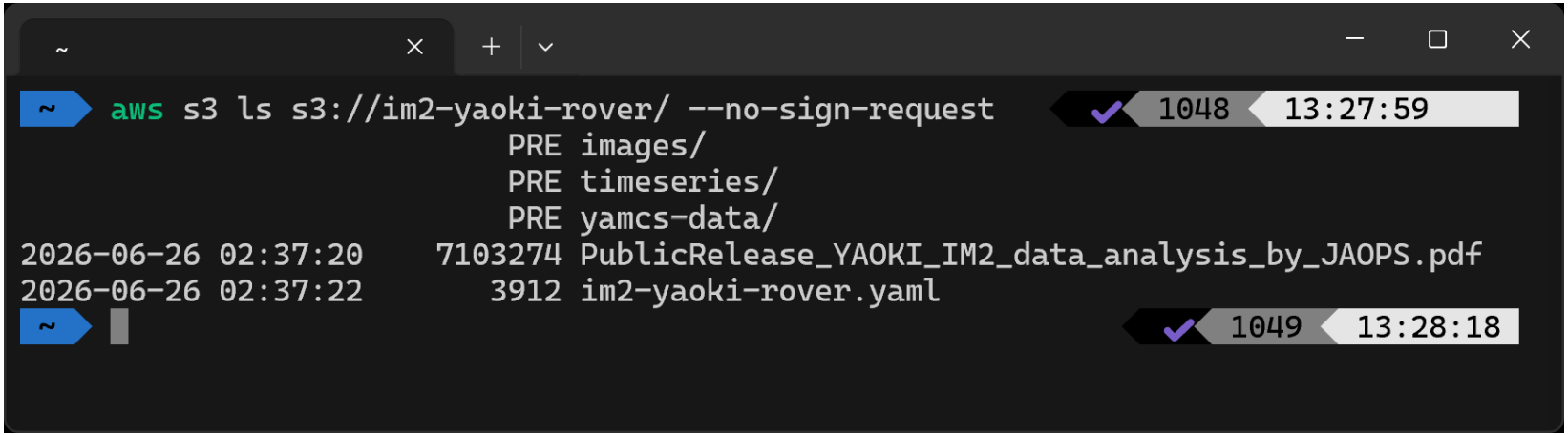
Column	Type
generation_time	TIMESTAMP WIT...
acquisition_time	TIMESTAMP
raw_value	DOUBLE
eng_value	DOUBLE

generation_time	acquisition_time	raw_value	eng_value
filter	filter	filter	filter
1741314214408	null	-37	-37
1741314239147	null	-36	-36
1741314273038	null	-36	-36
1741314299309	null	-36	-36
1741314329405	null	-36	-36
1741314359189	null	-35	-35
1741314389313	null	-35	-35
1741314419329	null	-35	-35
1741314449279	null	-34	-34
1741314479322	null	-34	-34
1741314510344	null	-34	-34
1741314689916	null	-32	-32

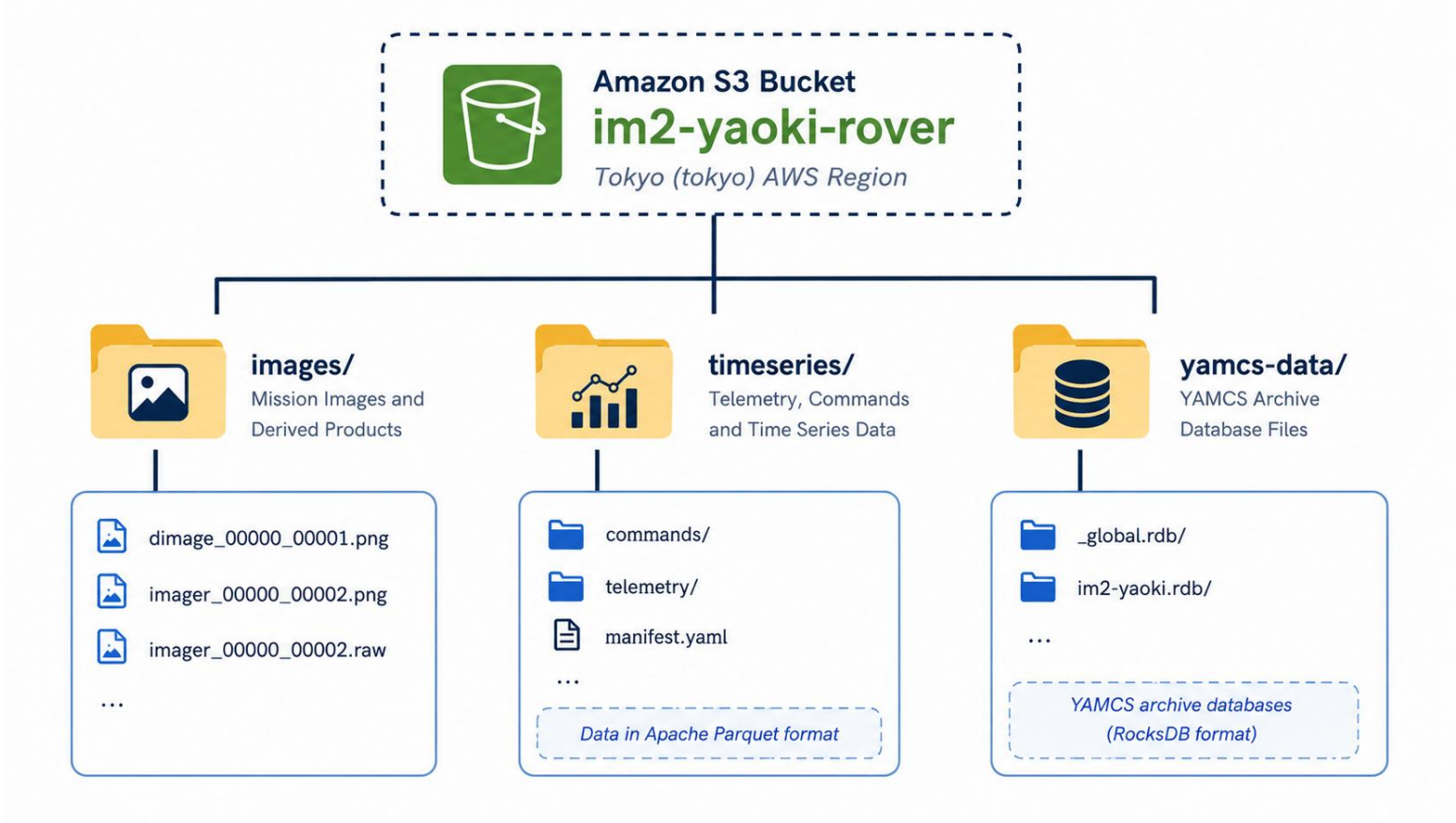
The Raw Data is on Amazon

We are using a publicly accessible Amazon S3 bucket.

It is **accessible world-wide** and **permanent**. You can access it through AWS tools, python or a browser.



Data structure of the Amazon Data



Data Archival - media

High quality hard disk drives are chosen for sedentary robustness, not performance.

Different manufacturing batches and manufacturers.

Also archive hardware for reading the drives!

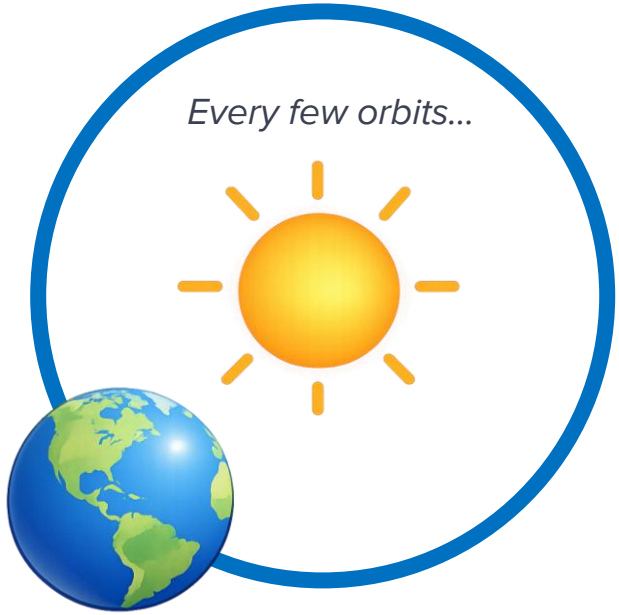
Later evolutions to include additional media types.

Data Archival - Duplication

Each location has multiple backups.

Multiple locations provides high redundancy.

Data Archival – Periodic data verification



Each backup uses parity codes for error correction.

Every few years, an operator checks data integrity and transfers data to new media when appropriate.

We are excited to see what the community does with this data!

Questions?
(Code demo next)

You can also email me:
data@openlunar.org