air-LUSI

Measuring Lunar Spectral Irradiance from a High-Altitude Aircraft

Presented by
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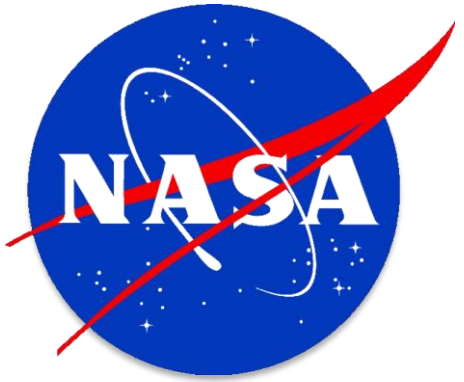
air-LUSI Team



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air-LUSI Objectives

- **Fly SI-traceable instrument** above 90% of the Earth's atmosphere on a high altitude aircraft to measure lunar spectral irradiance [ultimately to an unprecedented level of accuracy (<0.3% k=1 uncertainty)].

- **Build capacity** for acquisition of highly accurate, SI-traceable, exo-atmospheric lunar spectral irradiance.

- **Understand and improve uncertainty** of current knowledge of lunar spectral irradiance to benefit calibration sensitive Earth observations, e.g., ocean colour.

Why measure from an aircraft in the upper atmosphere?

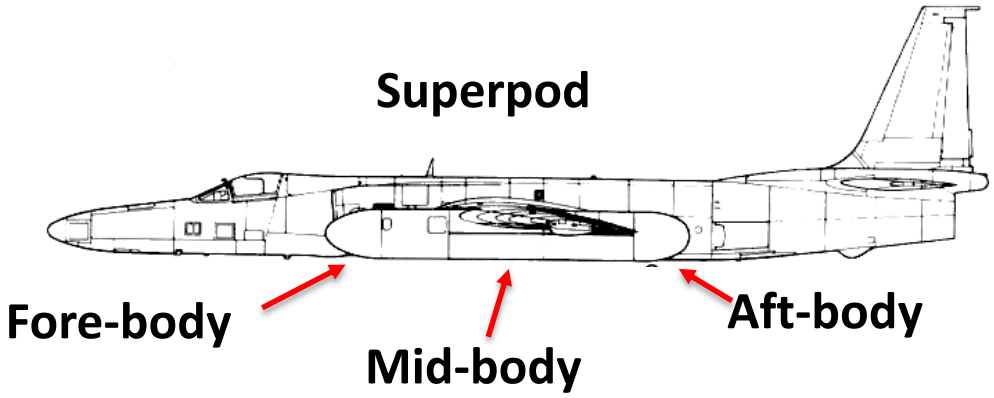
- Much closer to direct exo-atmospheric lunar spectral irradiance measurements than mountain-top measurements; reduces uncertainty.
- Unlike a spaceborne sensor, problems can be more easily resolved on the ground.
- Calibration can be done before and after each flight, and monitored in flight.
- Apparent motion of the Moon across the sky can be greatly reduced by flying east to west.

air-LUSI Subsystems

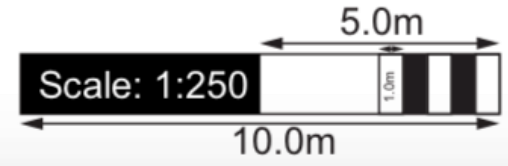
ARTEMIS – Autonomous, Robotic TElescope Mount Instrument Subsystem keeps telescope fixed on the Moon to within 0.1°.

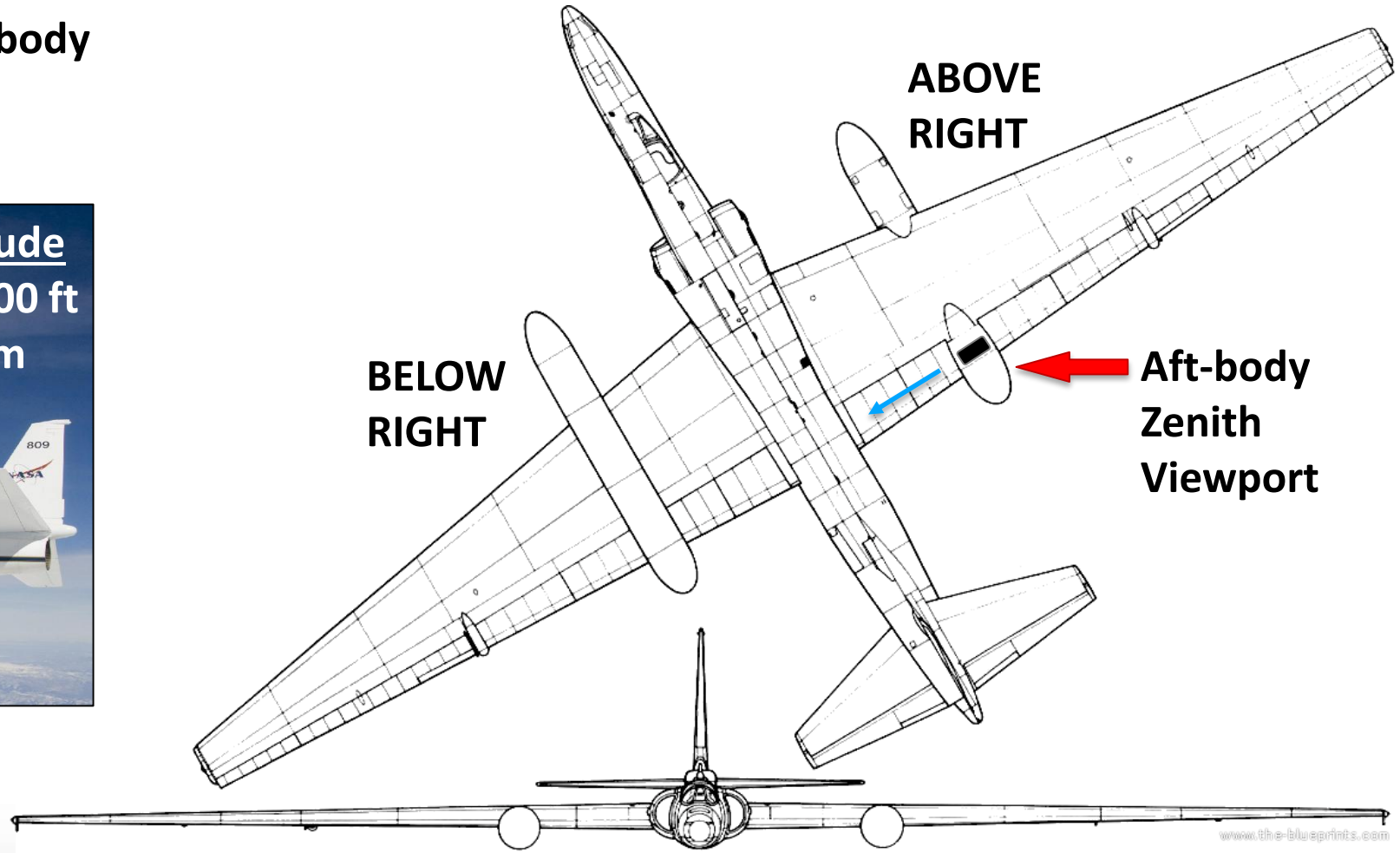
IRIS – IRradiance Instrument Subsystem

- A non-imaging telescope (integrating sphere at focal point).
- Light fed via a fiber optic cable to a spectrograph.
- On-board LED validation source.
- Instrument enclosure keeps the spectrograph and validation source at surface-level P & T during flight.



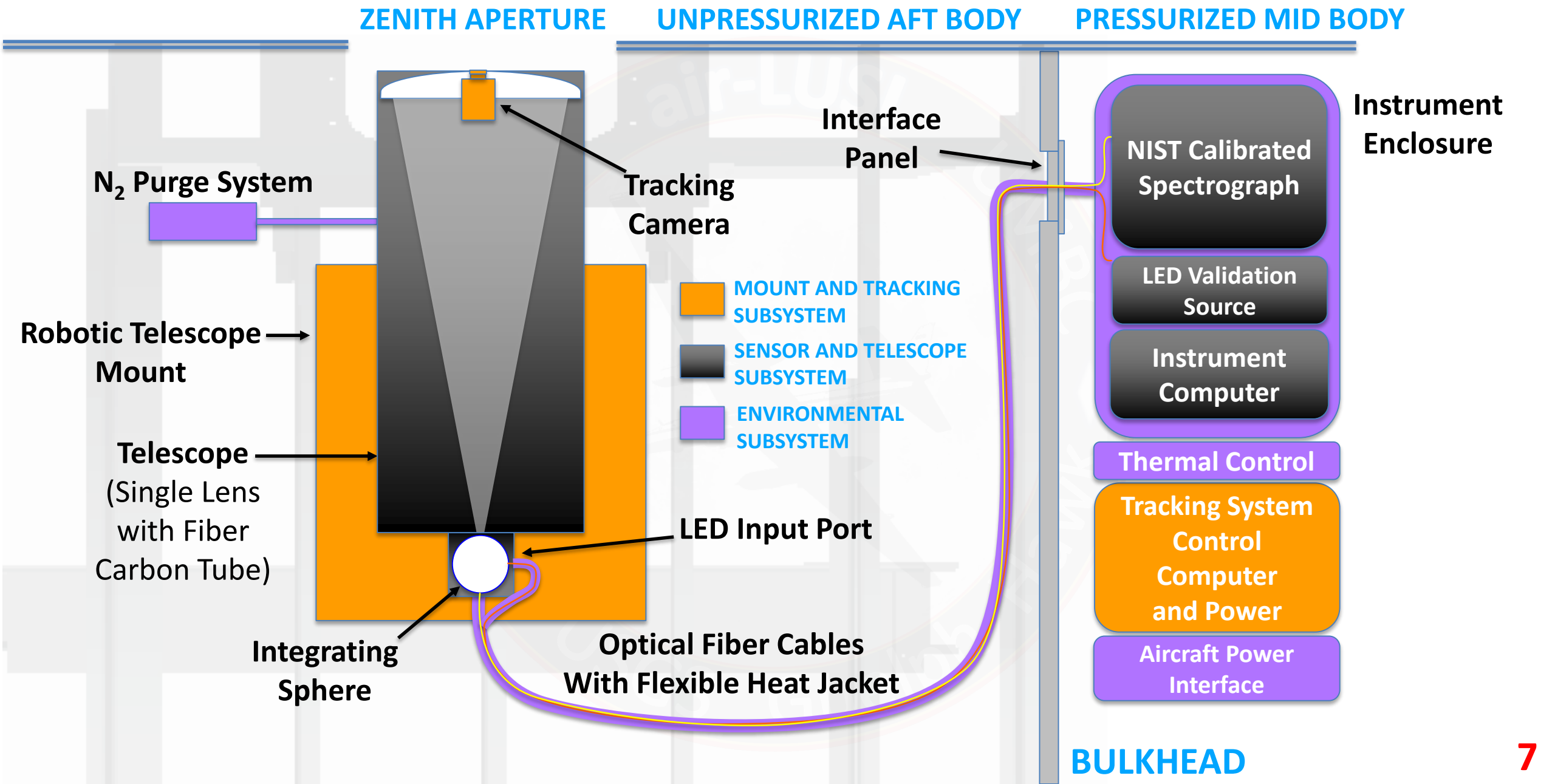
- The telescope and robotic mount are in Superpod Aft-body.
- The sensor enclosure and control computer are in Mid-body.
- IRIS telescope views to port through Aft-body Zenith Viewport.





SUBSYSTEM DIAGRAM

air-LUSI



Hangar calibration configuration (pre & post flight)

Uncertainty budget for IRIS Responsivity

Calibration source used to determine IRIS Responsivity

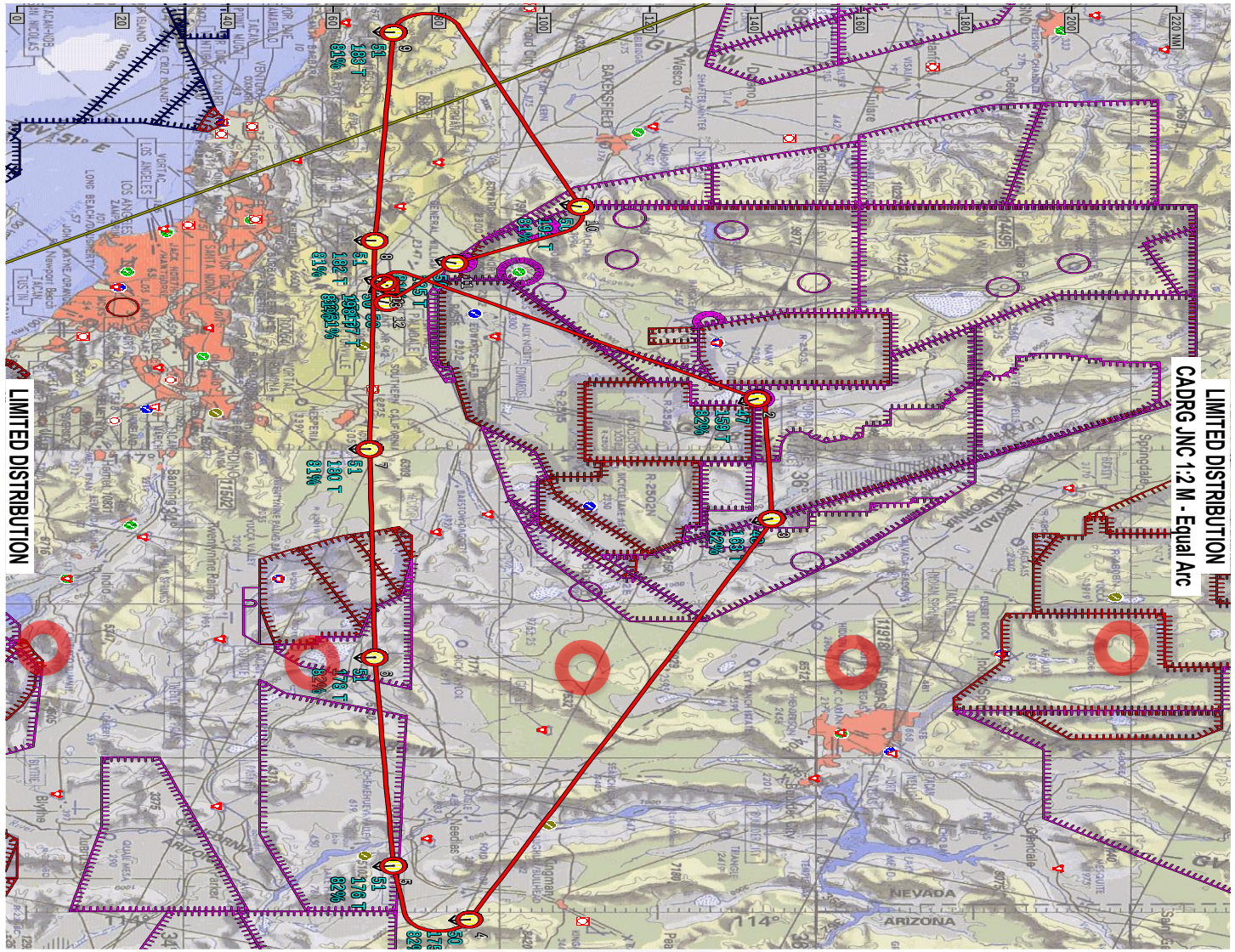
Source of Uncertainty	450 nm	655 nm	900 nm
Transfer Spectrograph (TS) Calibration to FEL	0.51	0.36	0.30
Distance, D1, TS to Source	0.16	0.16	0.16
Distance, D2, IRIS to Source	0.12	0.12	0.12
Alignment, TS to Source	0.02	0.02	0.02
Alignment, IRIS to Source	0.02	0.02	0.02
TS linearity	0.10	0.10	0.10
IRIS linearity	0.10	0.10	0.10
Wavelength	0.10	0.10	0.10
TS measurement	0.06	0.05	0.05
IRIS measurement	0.10	0.10	0.10
Total k=1 % uncertainty IRIS Responsivity (Lab)	**0.58**	**0.45**	**0.41**

Lunar Irradiance Uncertainty Budget

Source of Uncertainty	450 nm	655 nm	900 nm
IRIS Responsivity	0.58	0.45	0.41
Lunar Measurement	0.25	0.1	0.1
Radiometric Stability	0.2	0.2	0.2
Pointing Stability	0.02	0.02	0.02
Temperature	0.2	0.2	0.2
Atmospheric Correction (predicted)	0.2	0.2	0.2
Combined Uncertainty [% k=1]	0.72	0.58	0.55

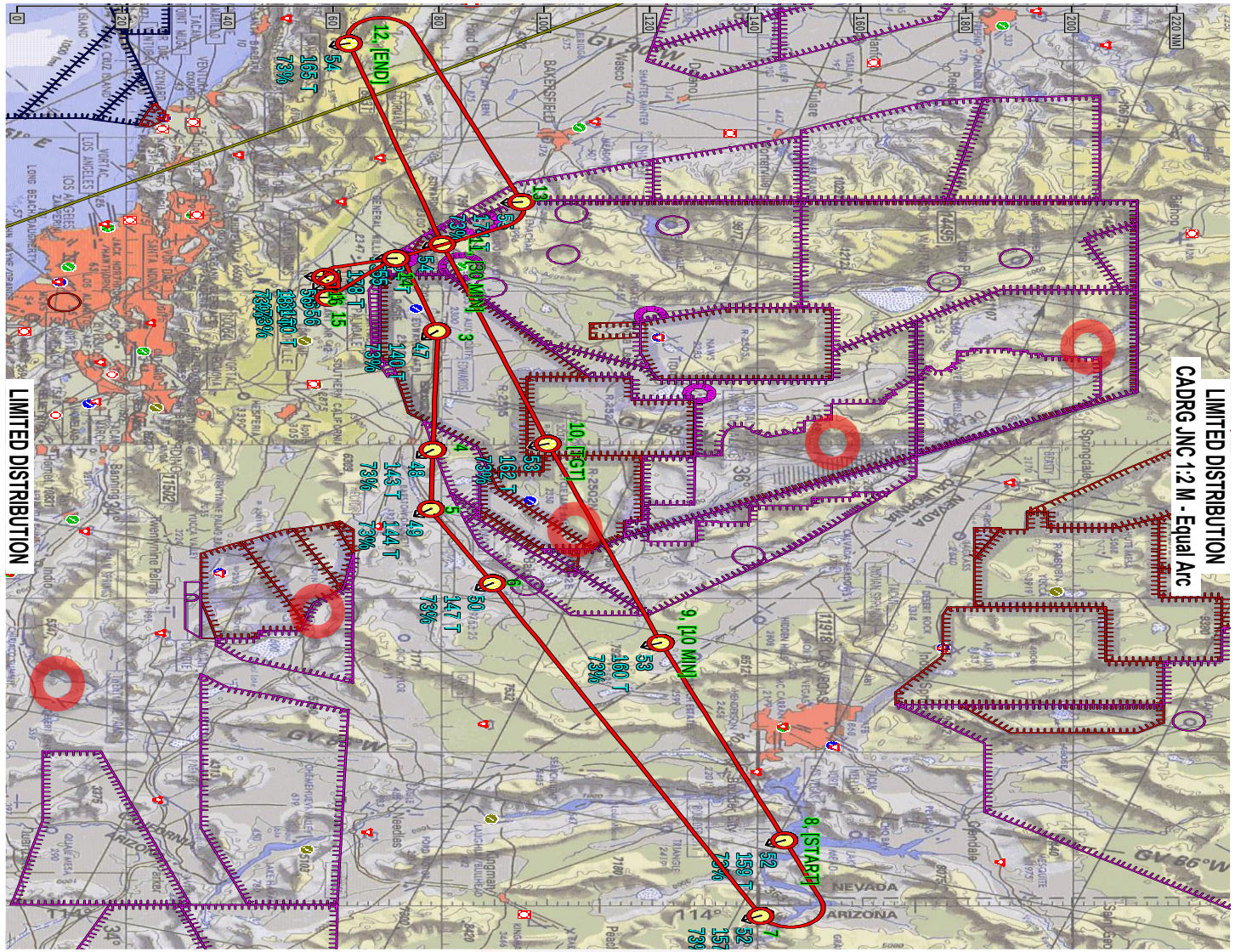
FLIGHT PLAN

1 Aug 2018



FLIGHT PLAN

2 Aug 2018

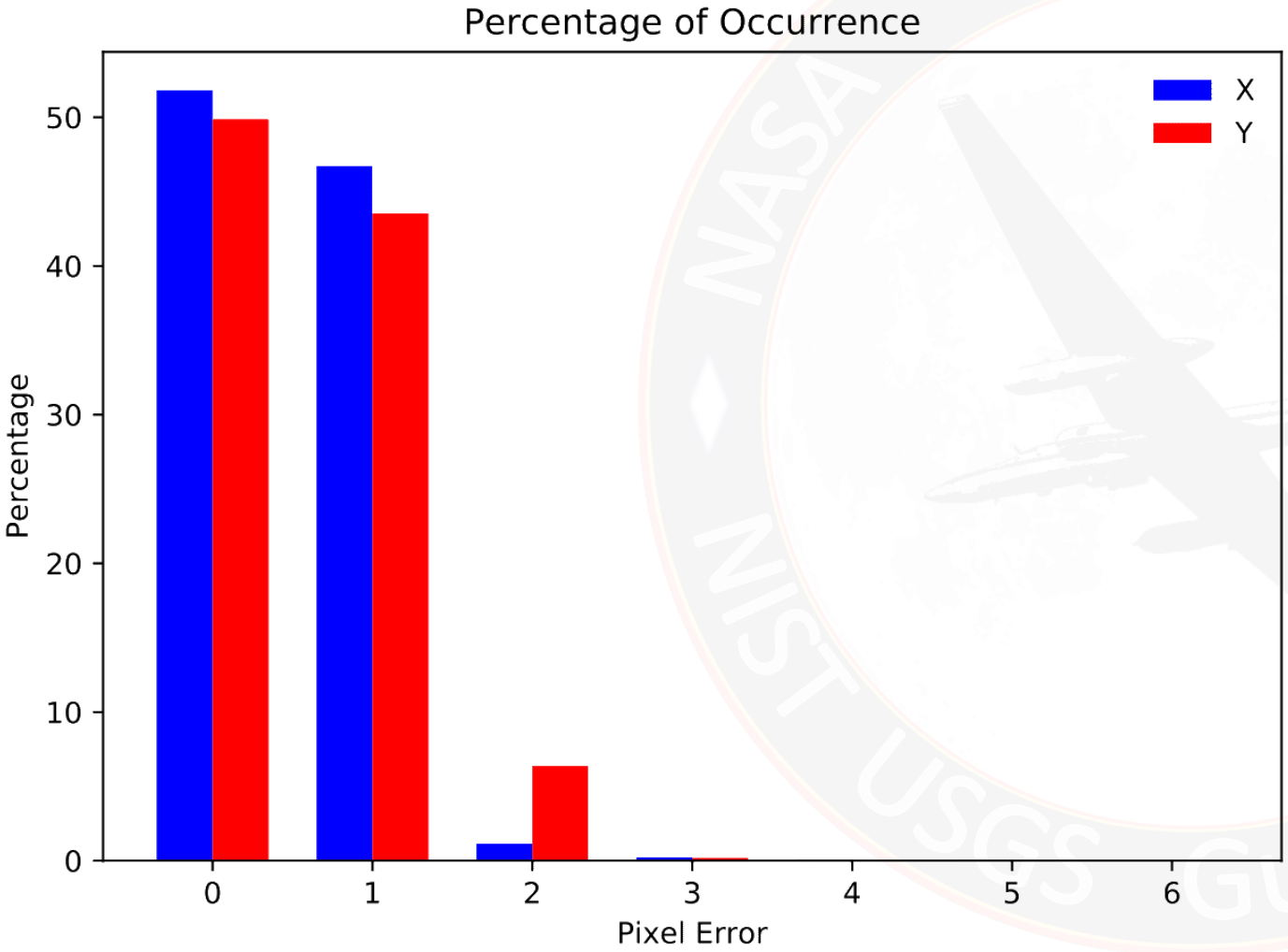


The air-LUSI situation room.

LESSONS LEARNED FROM ENGINEERING FLIGHTS

- Must address issues regarding hangar calibration (alignment, temperature, stray light) that affected pre- and post-flight calibration stability.
- May refine insulation for fiber optics to minimize possible small temperature effects.
- Must add correction for atmospheric effects during calibration, in addition to observing the Moon.
- Issues with the on-board validation source were addressed and will be tested.
- On-board thermal couples were reconfigured.
- In-flight recovery procedures were developed during engineering flight campaign.
- Creating a cover for telescope while stowed to reduce the risk of dust on lens.
- We plan reconfigure the mounting plates and cabling to reduce risk during upload and download of the instrument.

ARTEMIS In-flight performance

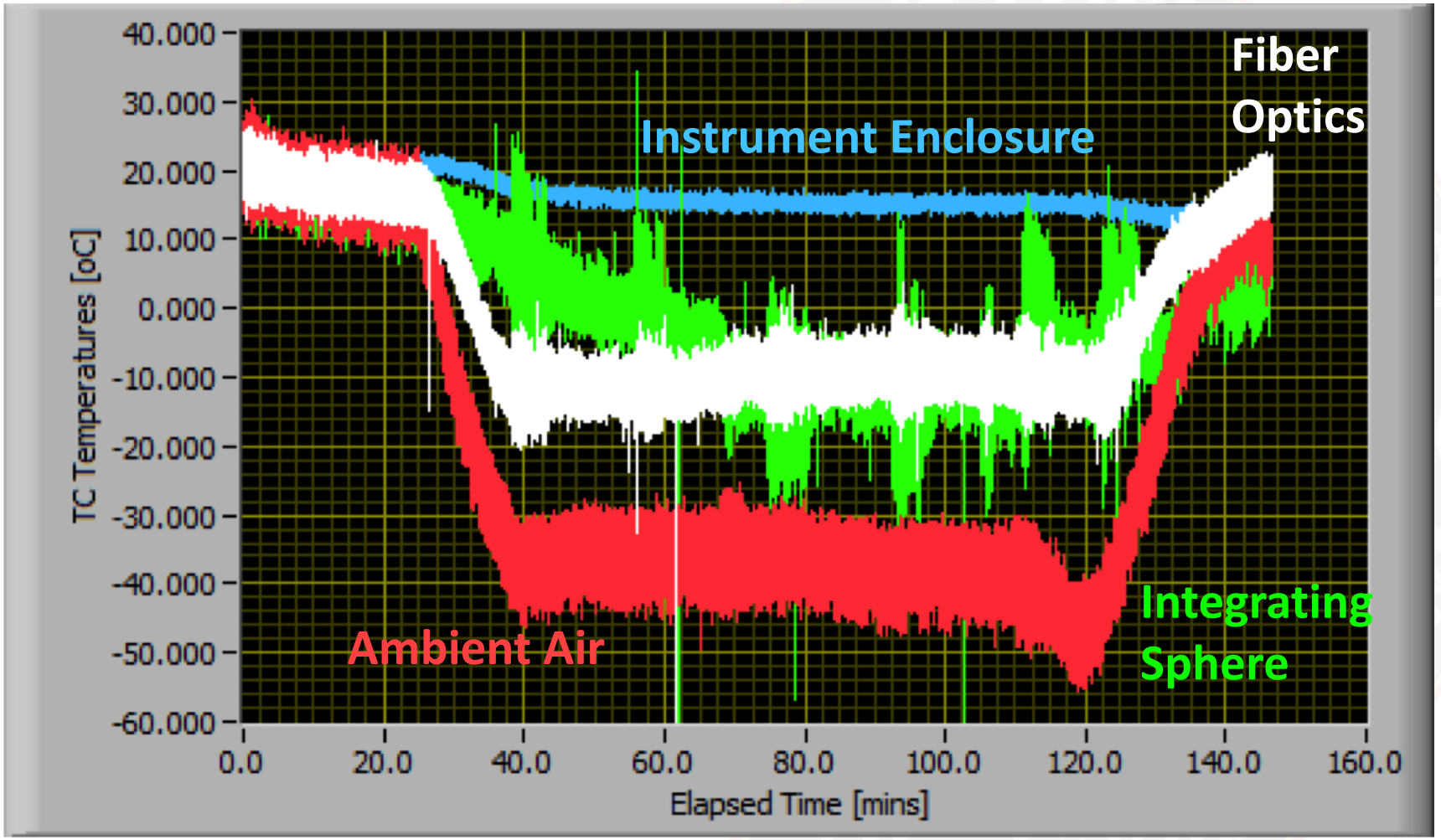


Statistic	X (px)	Y (px)	Radial Offset (px)	Offset In Degrees
Average	-0.43	0.32	0.91	0.048
RMSE	0.74	0.84	1.12	0.059
Median	0.00	0.00	1.00	0.053
Min	-5.00	-5.00	7.07	0.37
Max	6.00	4.00	7.21	0.38

1 px = 0.053 deg

ARTEMIS generally tracked within ~0.05°.

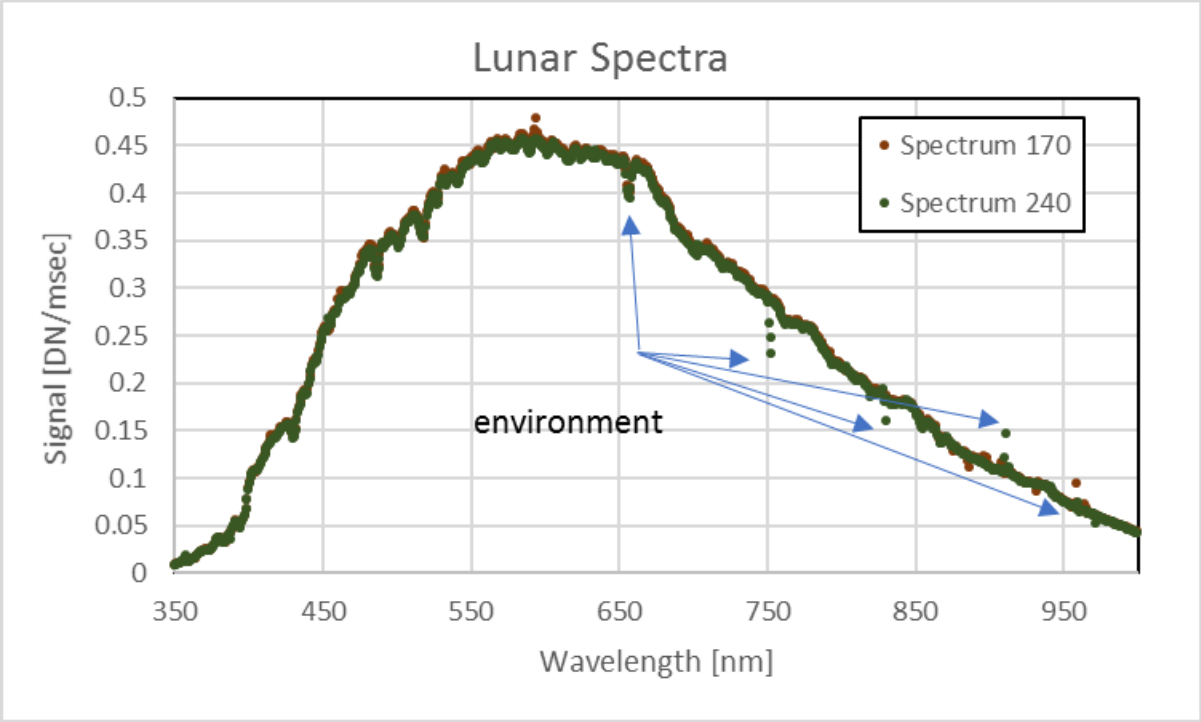
Thermal Control Performance

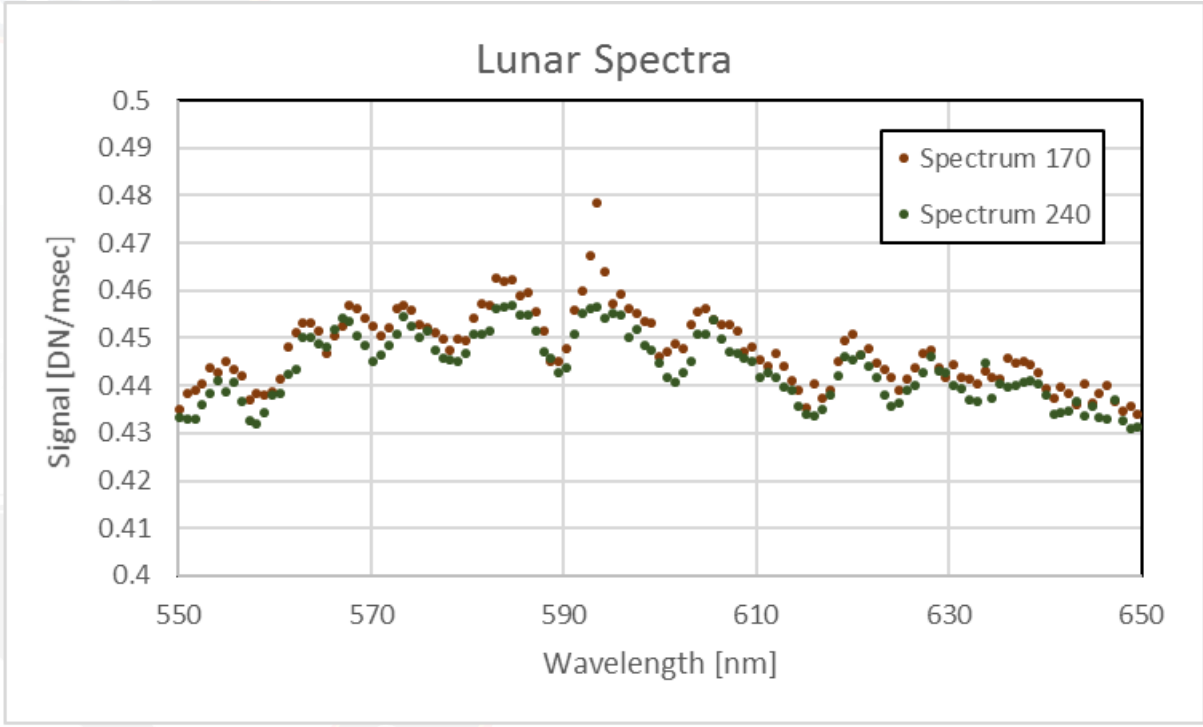


Instrument enclosure successfully maintain internal temperature (ΔT <2°) (and pressure) and during observations.

(NOTE: Thermal couplers were not properly calibrated for test flights, so the scale here is not accurate)

IRIS Engineering Test Flight Results





Occasional spike observed and attributed to cosmic rays.
Overall signal is very stable and strong (at 62° phase).

CONCLUDING REMARKS

- air-LUSI functioned beyond expectations during engineering flights (given several months of development, small budget).
- Systems functioned autonomously to a few pilot switches (inc. N_2 purge system).
- Robotic telescope mount moved telescope to viewport, locked onto the Moon keeping it steady to within 0.05°, and return to stow position for descent.
- Instrument enclosure maintained stable environment for spectrometer and validation source ($\Delta T<2°$ and stable pressure).
- Measurements appear to have good SNR and precision.
- Demonstration flight campaigns for Sept and Oct have been scheduled.
- We would like to have a mini-shop for Satellite Lunar Calibration (TBD) to discuss early results.

THANK YOU