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Measurements of absolute, SI-traceable lunar irradiance with the airborne LUnar Spectral Irradiance (air-LUSI) Instrument

John T. Woodward, Steven W. Brown, Steven E. Grantham, Thomas C. Larason, Stephen E. Maxwell, NIST, Gaithersburg, MD

Kevin R. Turpie (PI), U of Maryland Baltimore County, Baltimore County, MD

S. Andrew Gadsden, Andrew Newton, University of Guelph, Guelph, Ontario, CA

Thomas C. Stone, US Geological Survey, Flagstaff, AZ

Contact: K.R. Turpie <kturpie@umbc.edu>



What did we do?

- Mounted an optical instrument – a spectrograph fiber-coupled to a telescope – in the wing pod of a NASA ER-2 aircraft and flew it at altitudes above 20 km.
- Made hyperspectral measurements of the lunar spectral irradiance in the VNIR spectral region above more than 90 % of the atmosphere.

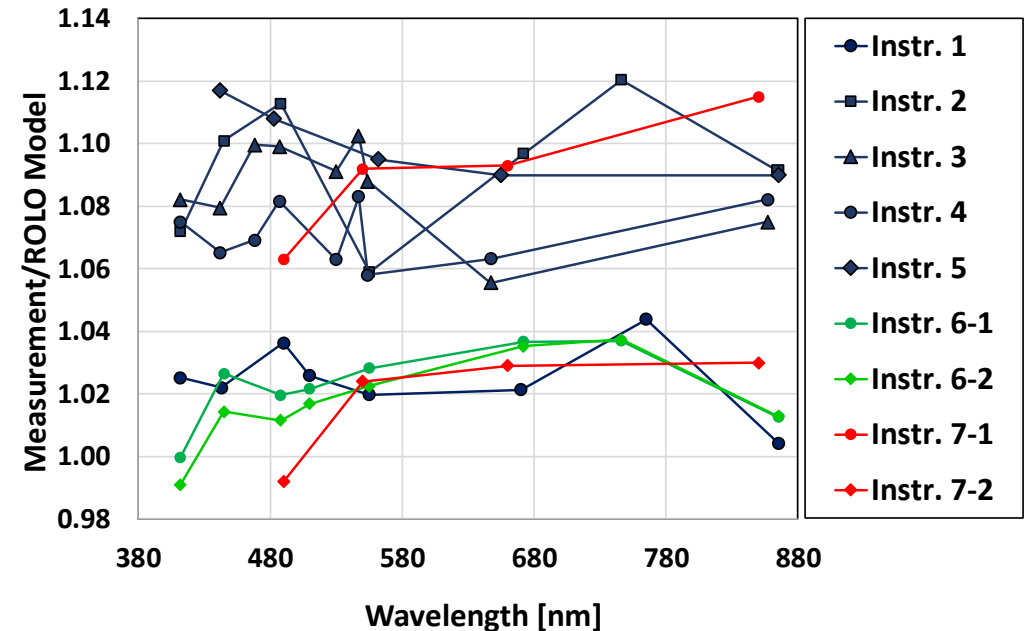


NASA's Armstrong Flight Research Center

Why did we do it?

Limitations in current lunar models that restrict some applications

- The lunar reflectance is exceptionally stable. The moon is a celestial target and there is no atmosphere to contend with.
 - But it is strongly dependent on phase and libration angles and a model is used to predict the reflectance that an instrument measures at a particular viewing geometry.
- Consider the USGS Lunar Model (ROLO Model)
- The RH figure shows measurements by 7 instruments ratioed to the ROLO model.



- The ratio falls into 2 groups, one with a mean ratio of 1.02 and the second with a mean ratio of 1.09.
- The origin of the groupings is unknown: could lie with the measurements or the model or it could wash out with additional comparisons. A low uncertainty calibration could help disentangle sensor biases from model biases.

Constrain the uncertainties in models of lunar irradiance

Provide benchmark measurements at defined lunar phase and libration angles



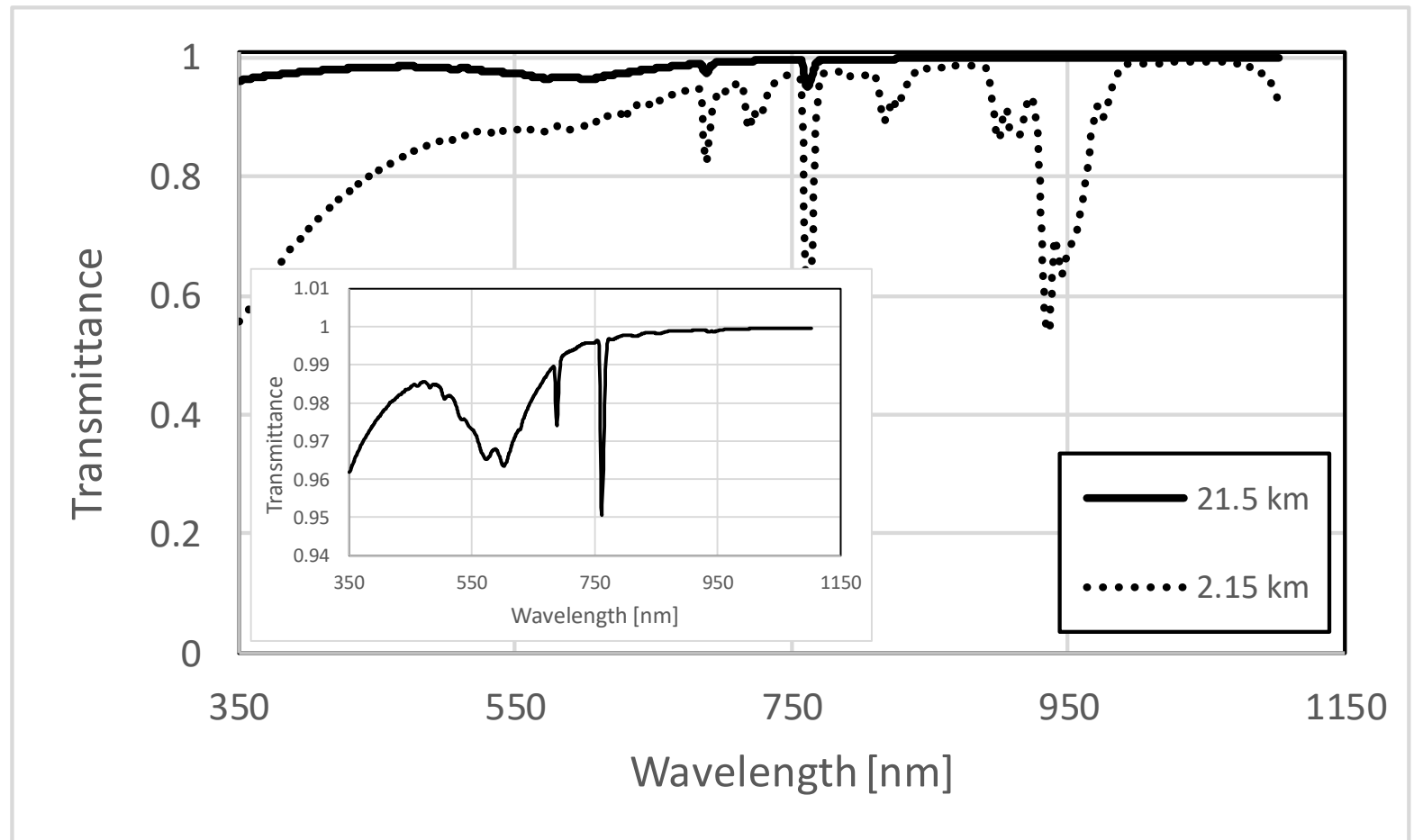
Why did we fly so high (> 20 km altitude)?

Reduced atmospheric effects

Atmospheric transmittance increased an order of magnitude between 2.15 km and 21.5 km.

MODTRAN used to simulate atmospheric transmittance

- for the flight geometries,
- with only normal gases,
- zero water vapor, and
- nominal ozone.



Who did it?

air-LUSI Team (Left to Right) – Steven Grantham, Andrew Newton, Kevin Turpie, John Woodward, Tom Larason, Stephen Maxwell



Hawk Institute for Space Sciences
Marc Mogavero, Ron Bettini, ...

In-Flight Operations Center



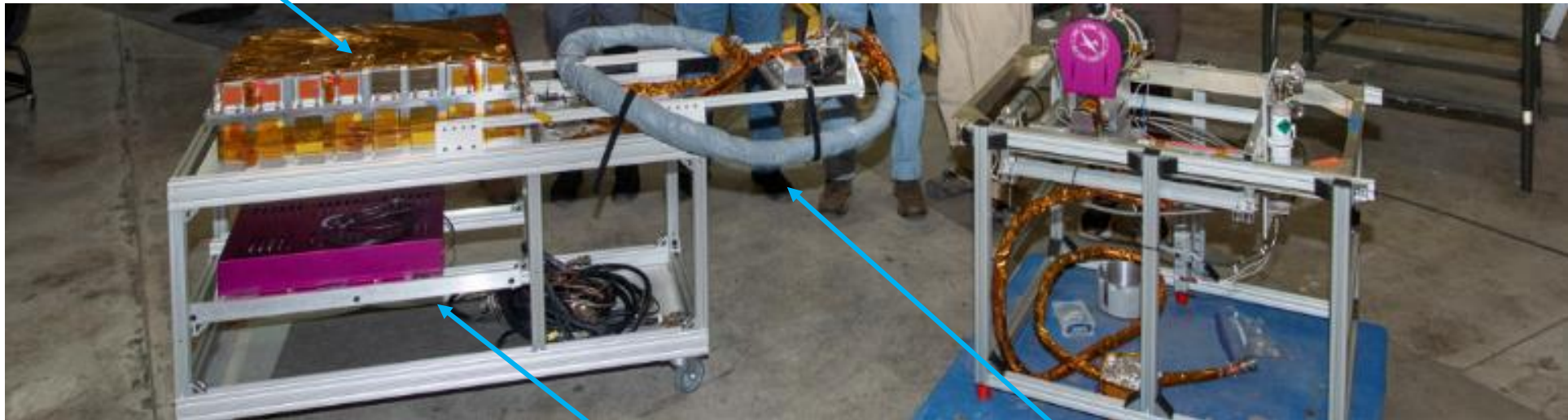
Staff at NASA's Armstrong Flight Research Facility
Brian Hobbs, Tyler Latsha, Fran Becker, Carl Sorenson, ...

Instrument

Clamshell housing:
Spectrograph, LED validation
source, data loggers

Bulkhead Interface Plate

Telescope Assembly:
Actuators, purge gas assembly, IMU
sensor, tracking camera



Spectrograph

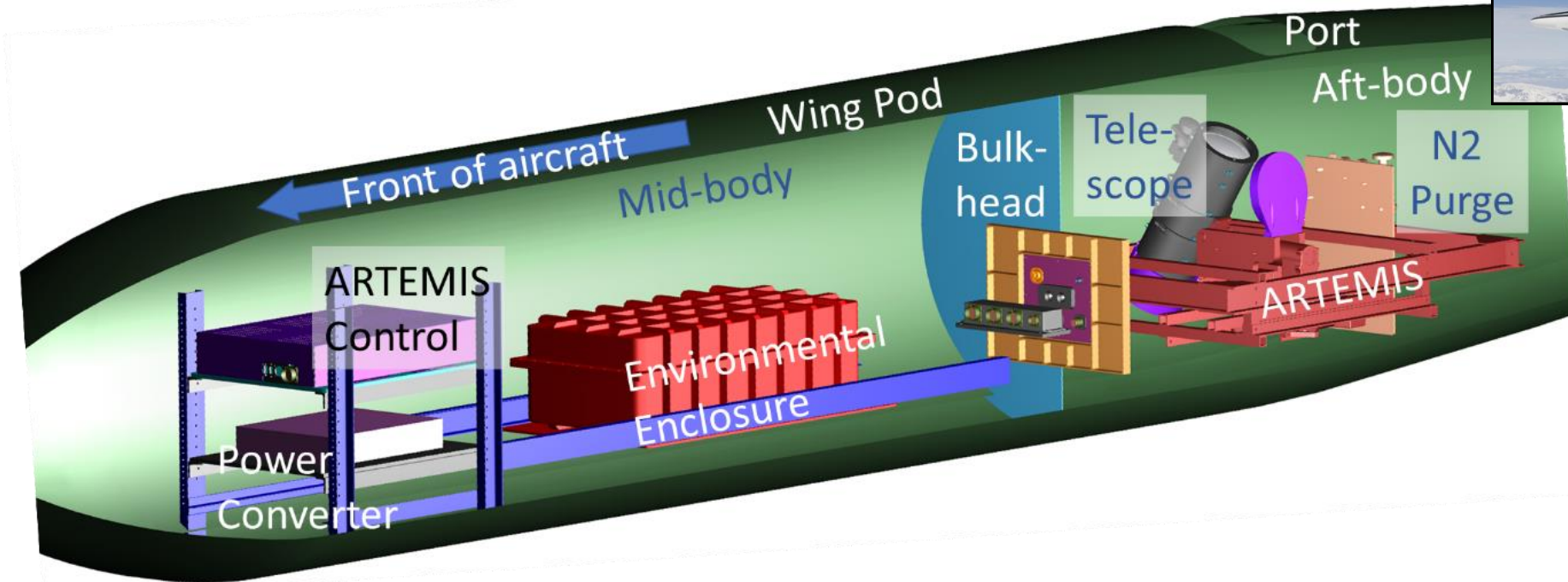
300 nm to 1100 nm
3.7 nm bandpass
0.8 nm pixel-to-pixel

Electronics Interface Box
Telescope Controller

Heated umbilical:
Fiber optics and electrical
cables between the telescope
and the spectrograph



Mounting in the aircraft



ARTEMIS control box



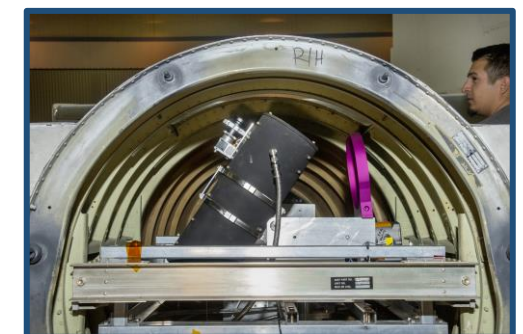
Upload



Umbilical cables

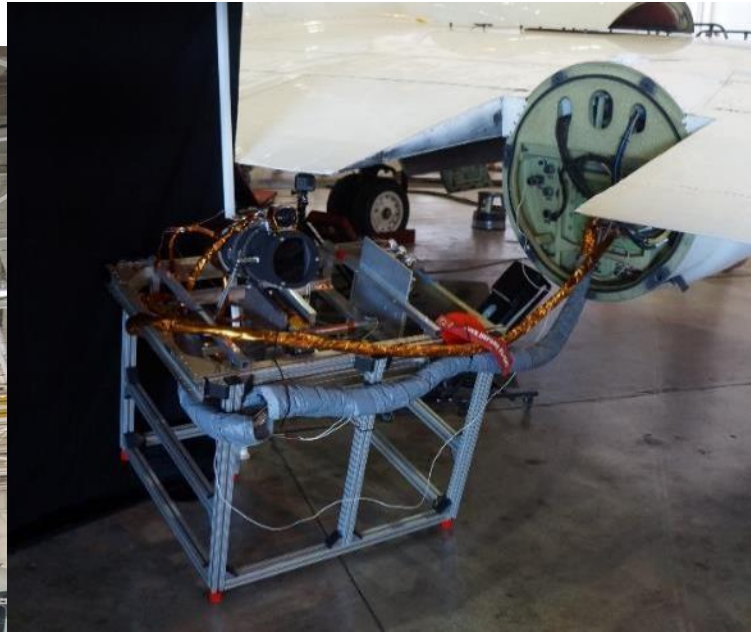
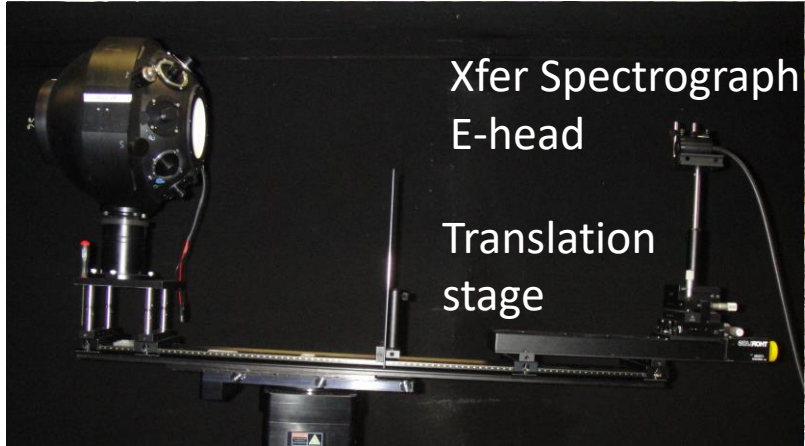


Aftbody



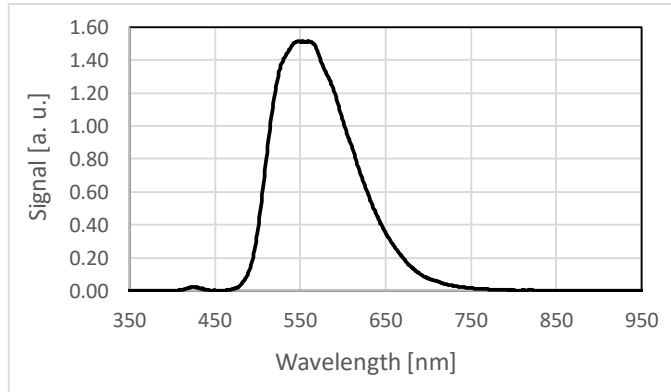
Hanger Calibration Setup during Flight Ops

NIST



Flight Protocol

LED Spectrum



Before Take-off

Spectrograph & LED
are turned on

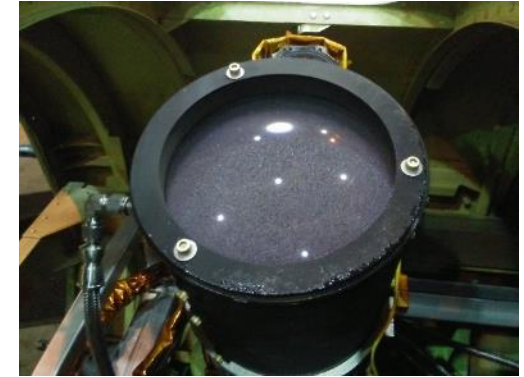
30 min

At altitude

Telescope unstowed,
tracking turned on, LED is
shuttered, lunar
measurements acquired

45 min

Ice on the telescope lens



After landing

System is shut down

During ascent

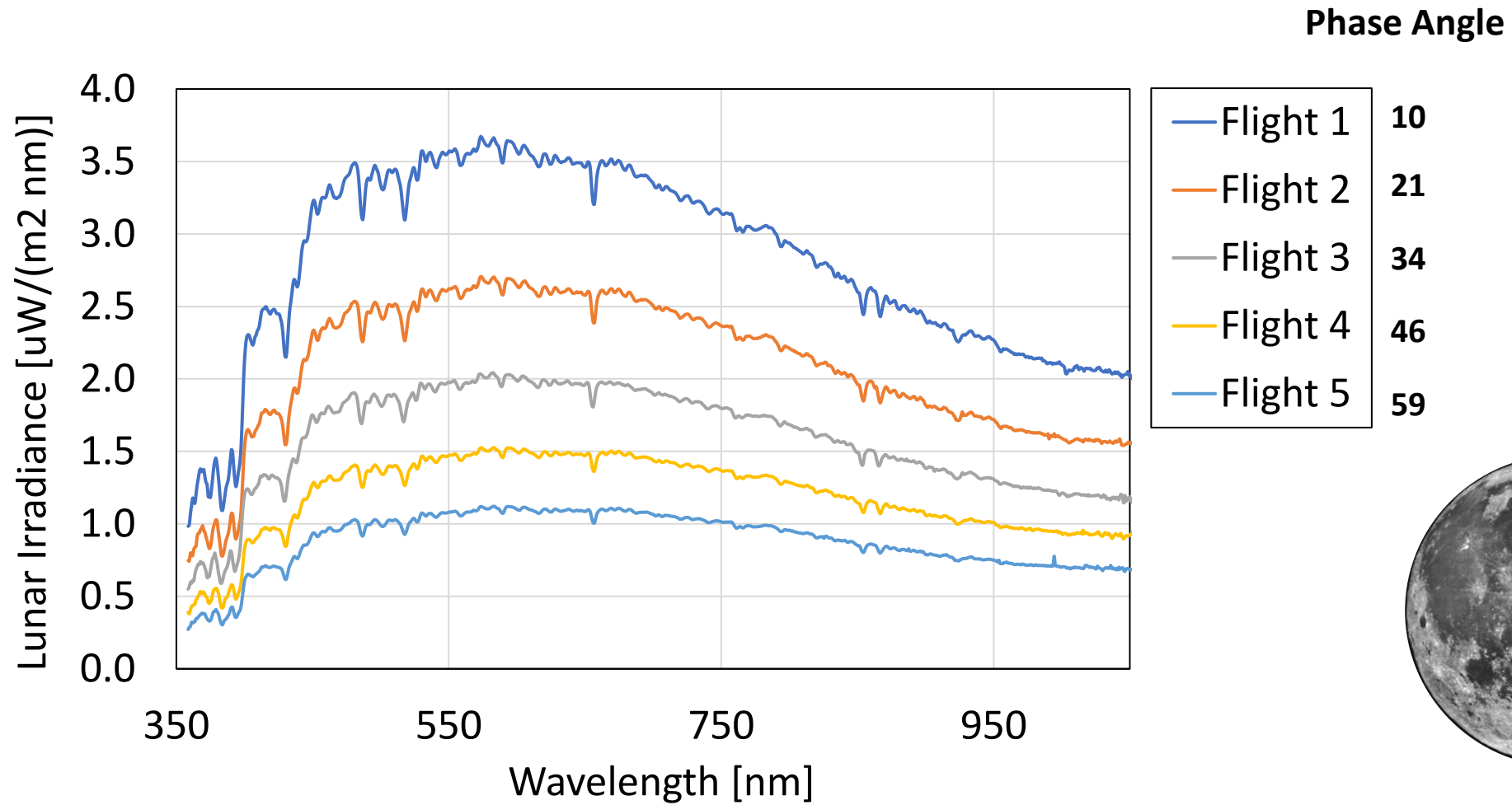
Heaters are turned on;
Data logging starts

During descent

Tracking stopped,
Telescope stowed,
Purge turned on,
LED data acquired



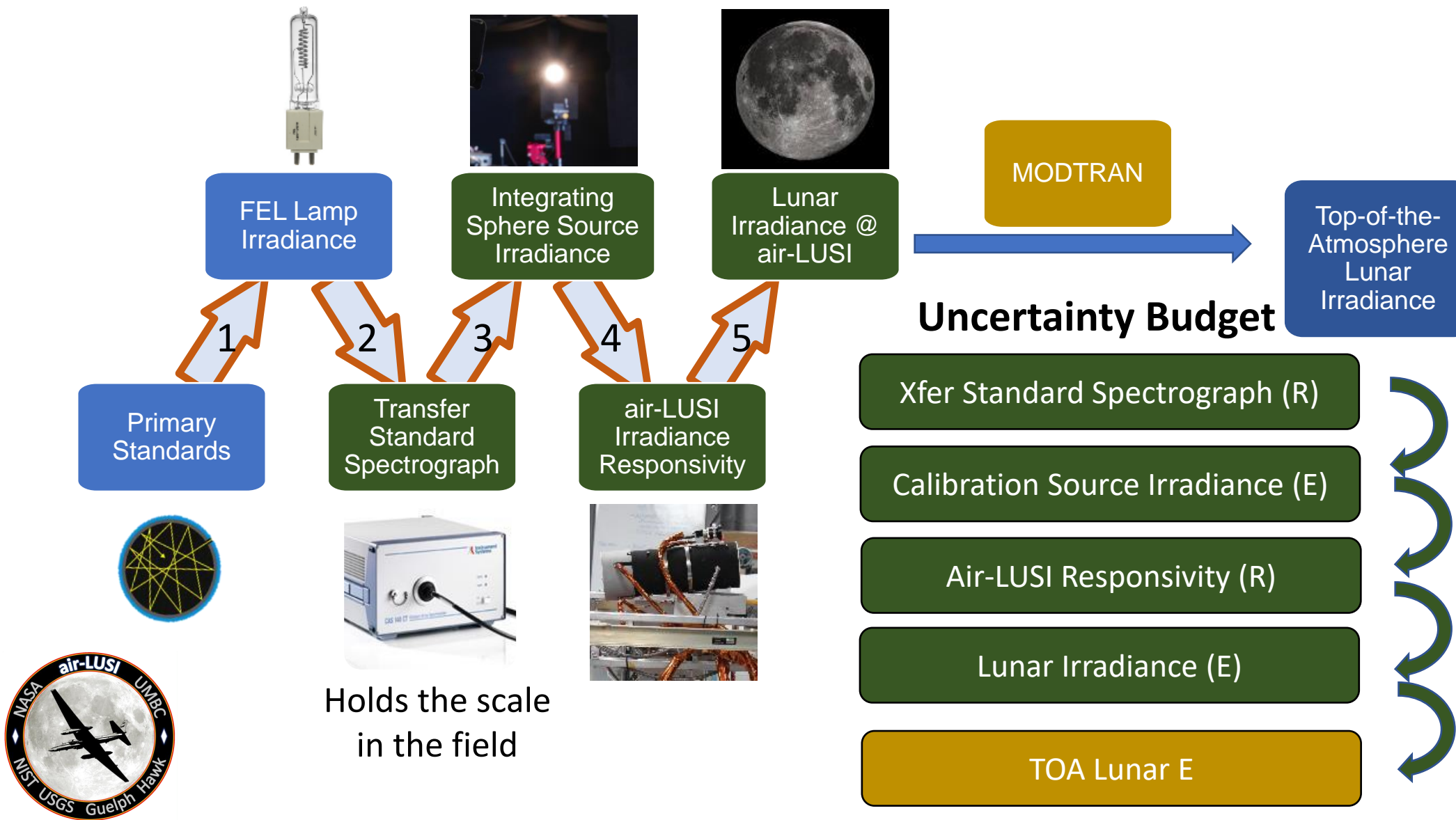
Lunar Irradiances



Tracking the Moon during Flight
Requirement within 0.5° ; our average RMSE across all [science/demo] flights was 0.1°

How well did we do?

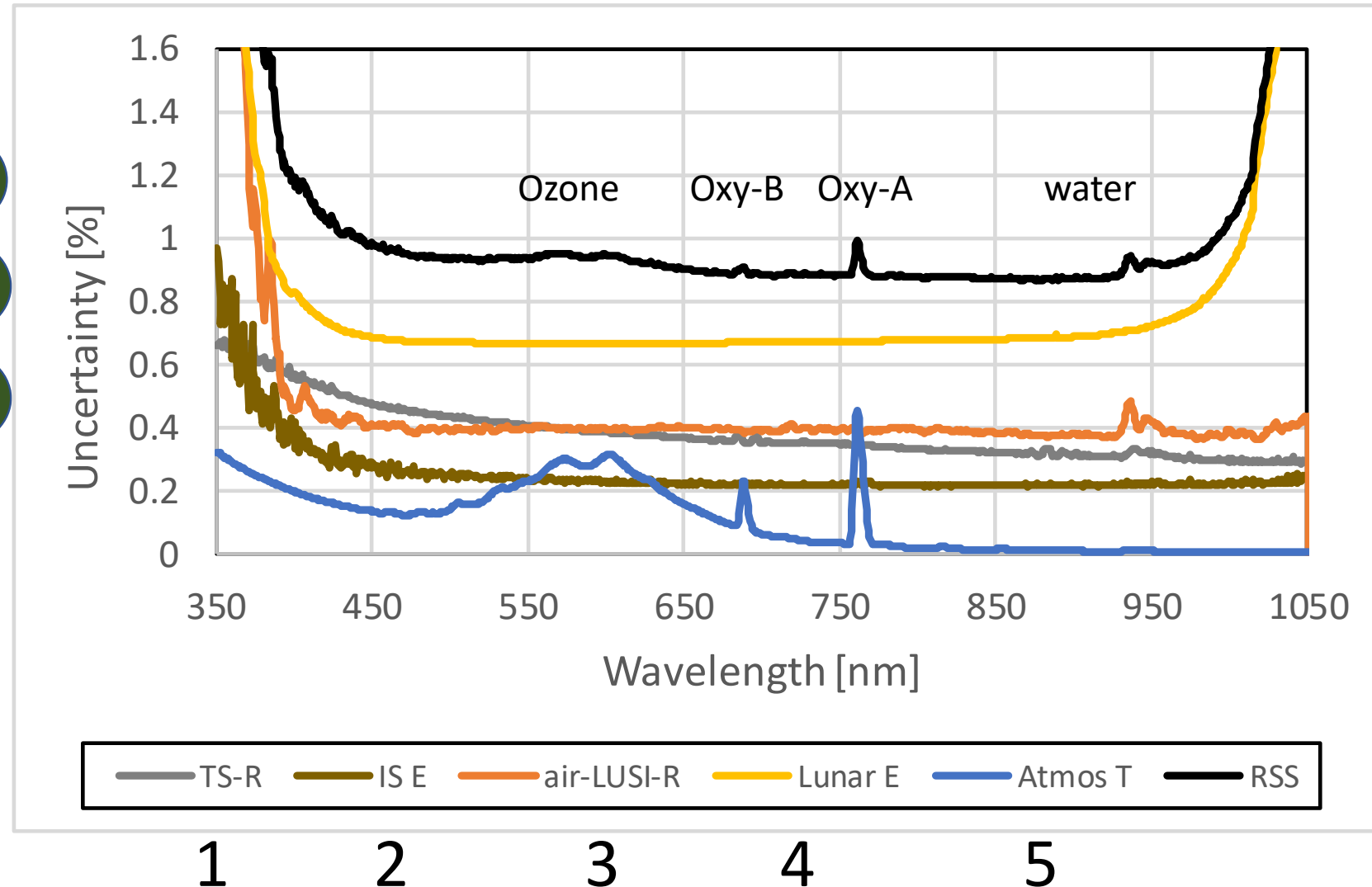
Measurement Chain & Uncertainty Budget



Uncertainty budget by Component

Steps in the Measurement Chain

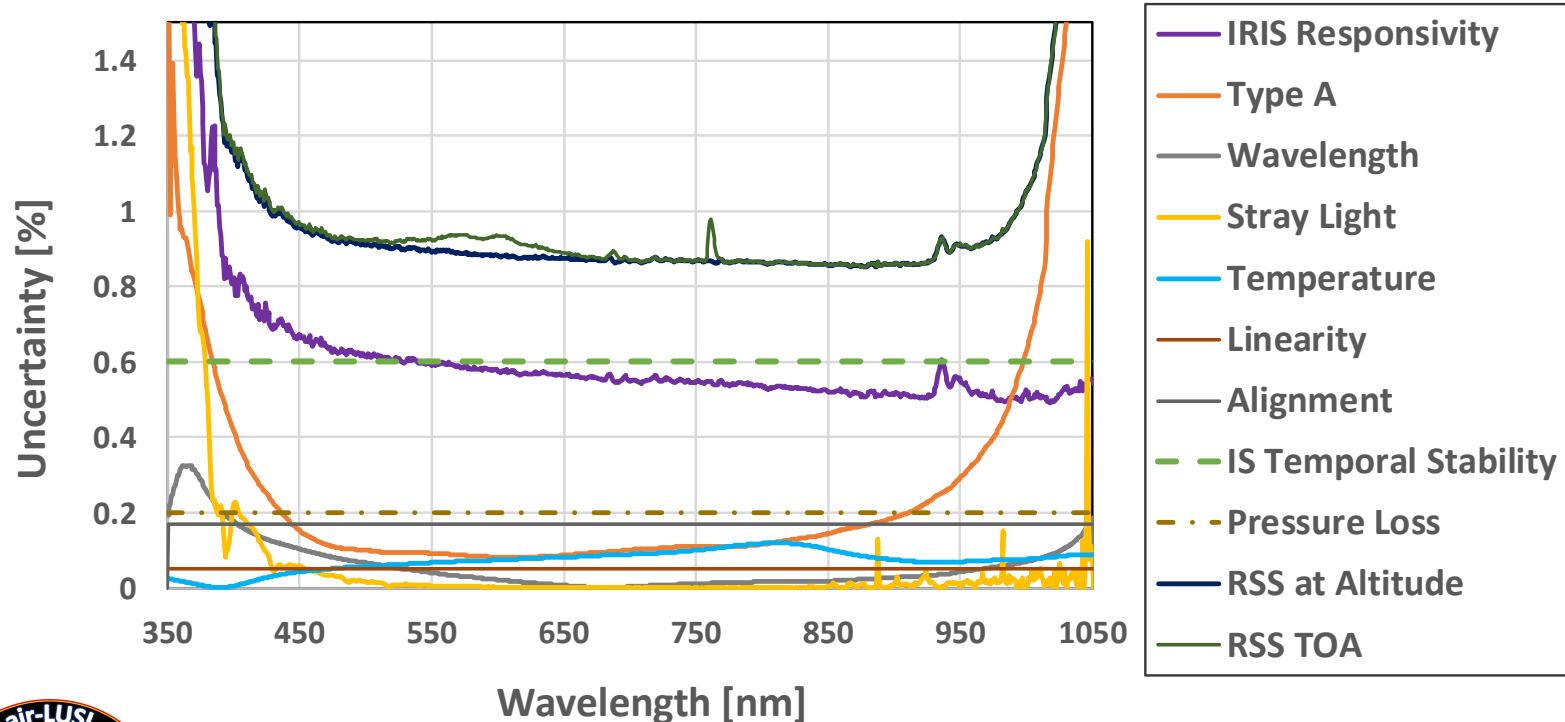
- 1 Xfer Standard Spectrograph (R)
- 2 Calibration Source Irradiance (E)
- 3 Air-LUSI Responsivity (R)
- 4 Lunar Irradiance (E)
- 5 MODTRAN



TOA Lunar Irradiance Uncertainty Budget

Elements that make up the uncertainty budget

Dominant components: Responsivity & IS Temporal Stability



Dashed lines correspond to estimated uncertainties from in-flight anomalies.

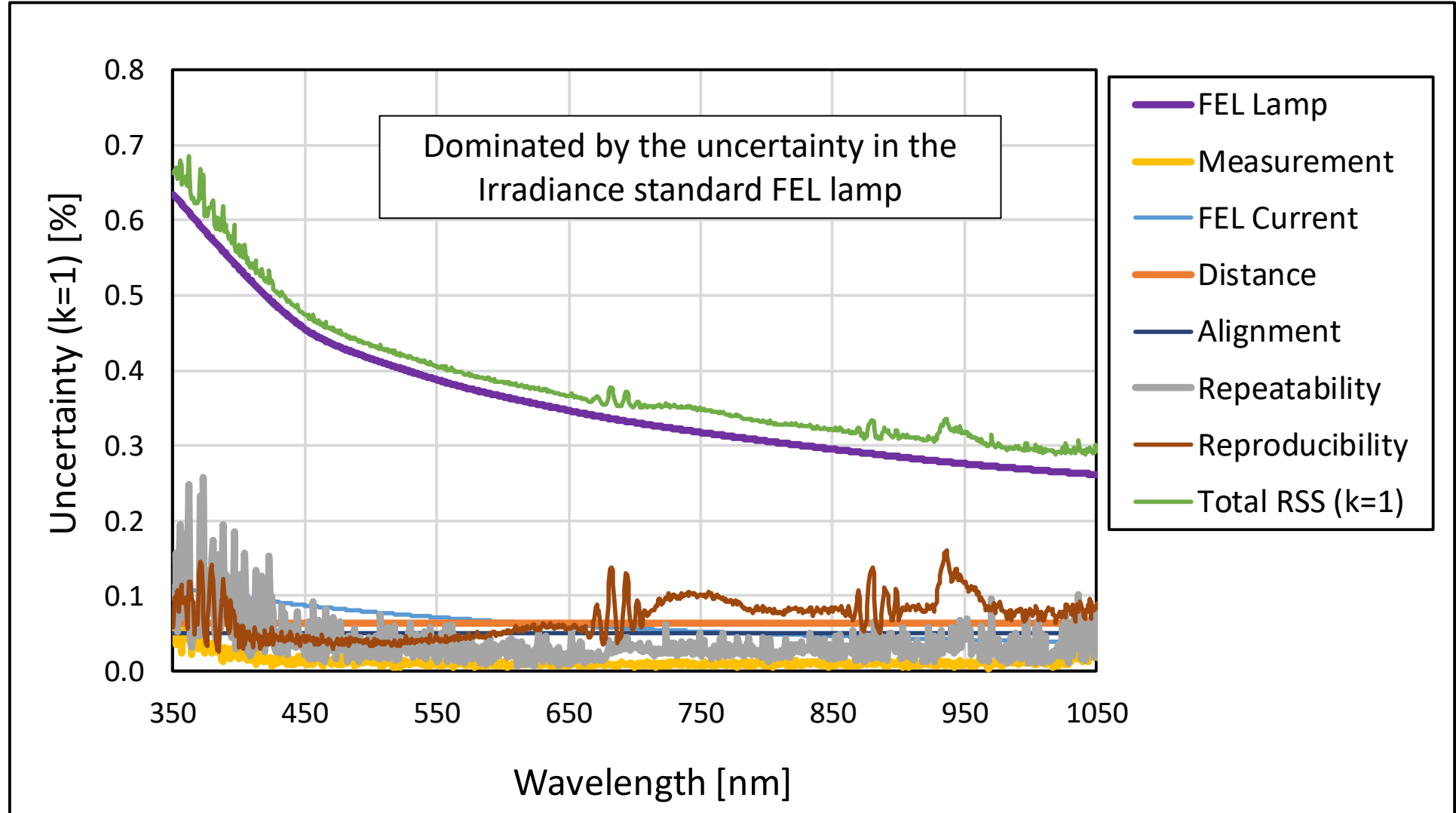
‘Pressure loss’ because electrical feed-throughs were not hermetically sealed.

‘IS Temporal Stability’ refers to the changed in throughput of the telescope receiver, an integrating sphere made of PTFE, determined from measurements of the LED source.

There is a phase transition for PTFE $\sim 19^\circ\text{C}$; our temperature control range was from 15°C to 25°C .



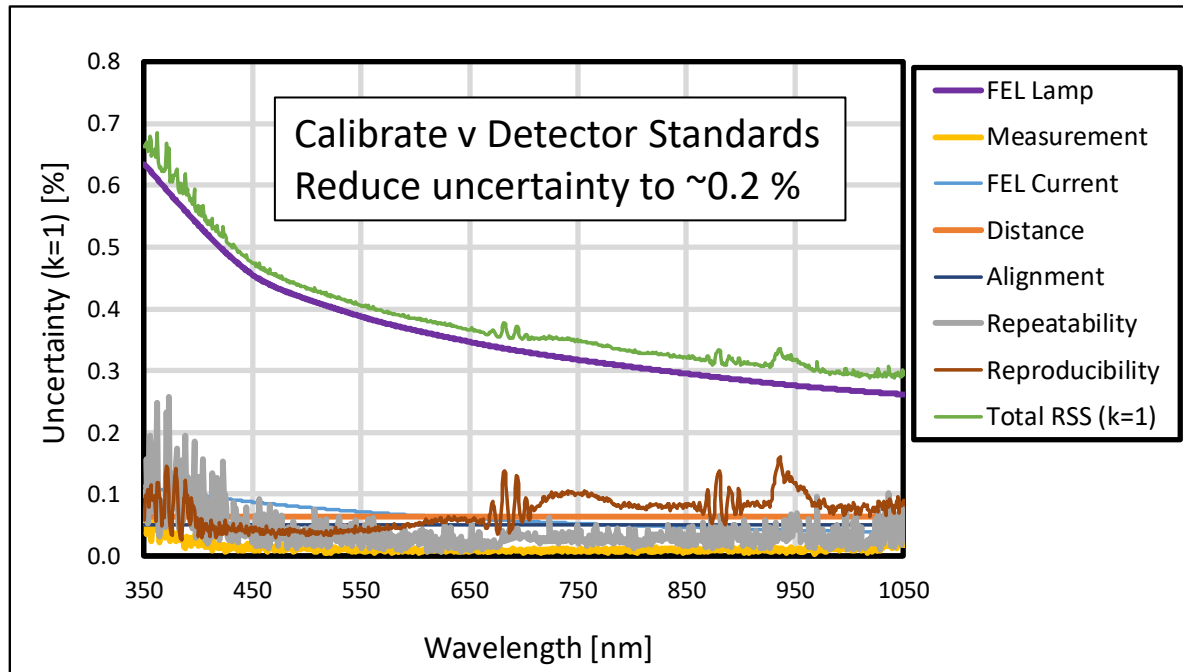
Transfer Spectrograph Uncertainty Budget



Improvements to air-LUSI to reduce the uncertainties TOA Lunar Irradiance (Future Flights)



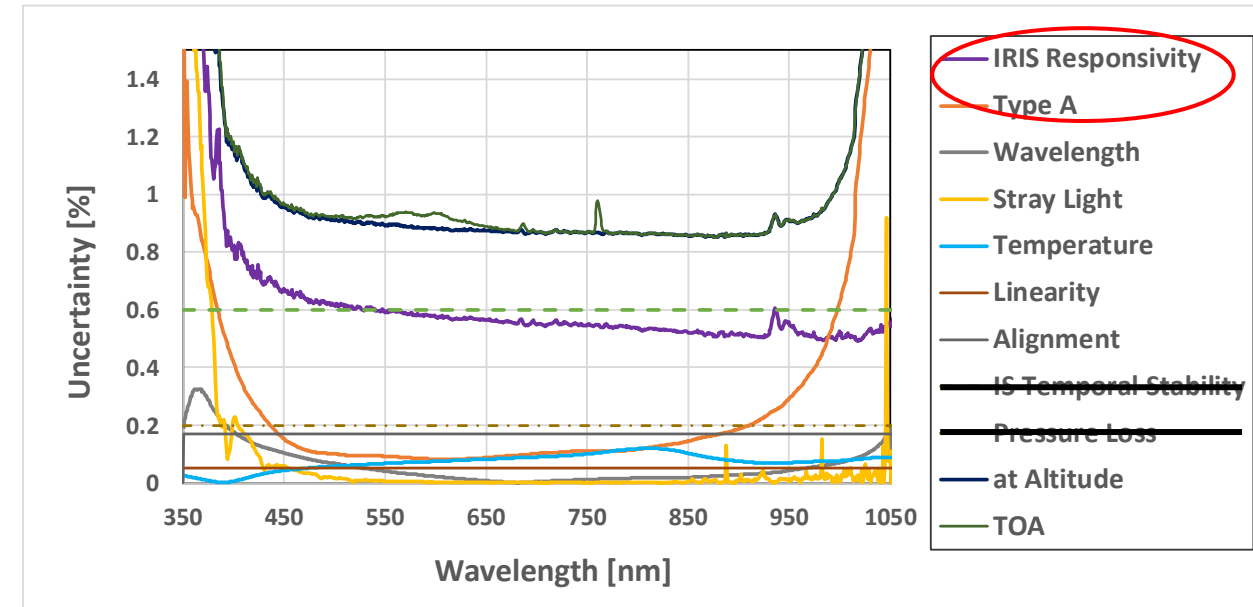
Reduce Calibration Uncertainties



Moving to a detector-based calibration
(e.g. calibrate IRIS on SIRCUS)



Eliminate in-flight surprises

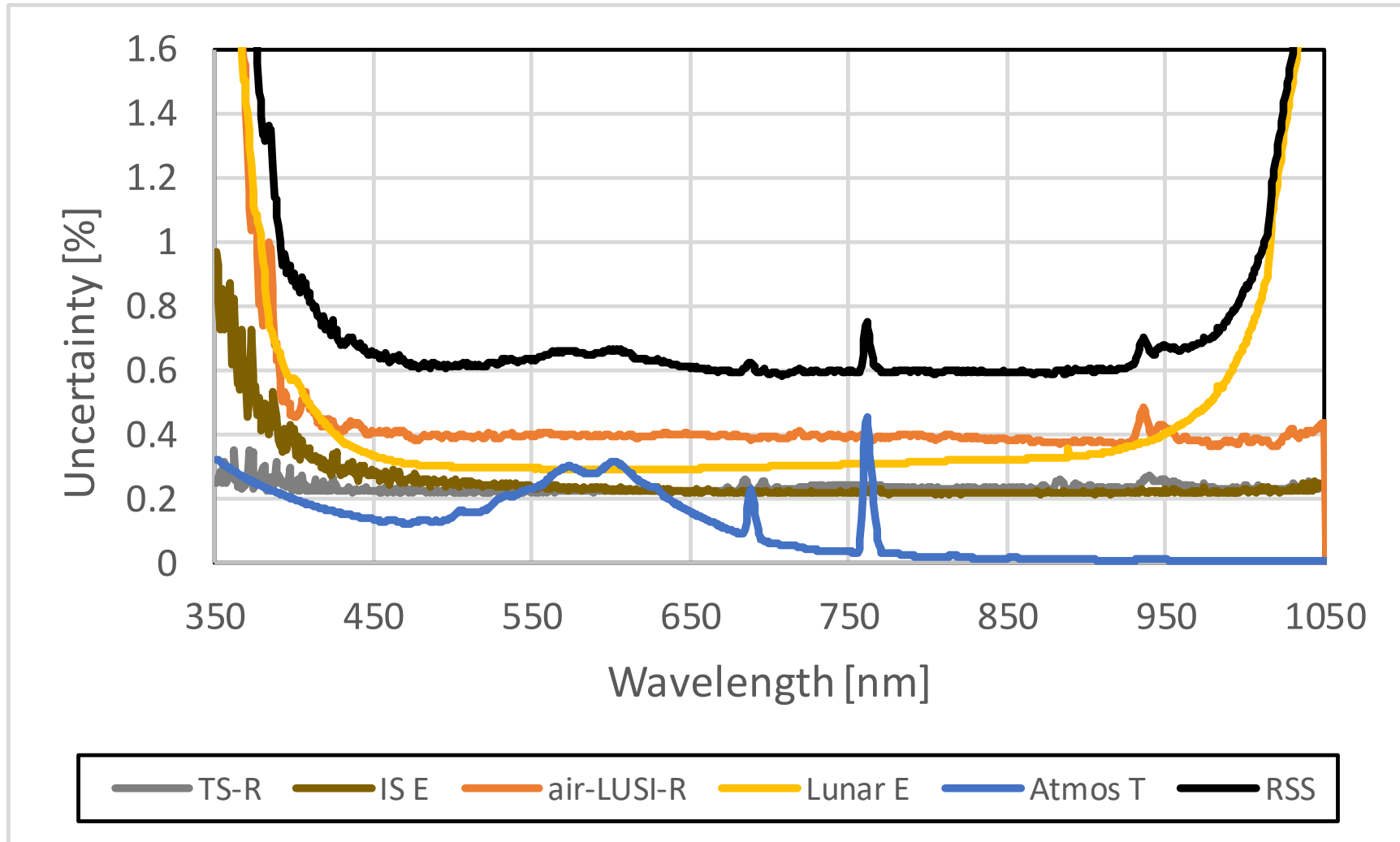


Tighter control over temperature – keep away
from sintered PTFE phase transition
temperature

Fix connector Instrument Enclosure feed-thru's

Potential Uncertainty budget for Future Flights

If all goes well ...



Summary

- 5 flights, covering phase angles over the range from 10° to 60°
- SI-traceable measurements of the lunar irradiance
- Preliminary uncertainty budget developed with uncertainties less than 1 % over the spectral range from 450 nm to 970 nm
- Identified a path forward to potentially achieve uncertainties ~ 0.6 %



Funding for this work was provided by the
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Thank you

NIST

NIST Folks heading home following a Flight



Woodward

Grantham

Larason

Maxwell



UNIVERSITY
of GUELPH

UMBC
AN HONORS UNIVERSITY IN MARYLAND

USGS
science for a changing world

