Addressing Challenges to the Design & Test of Operational Lighting Environments for the International Space Station

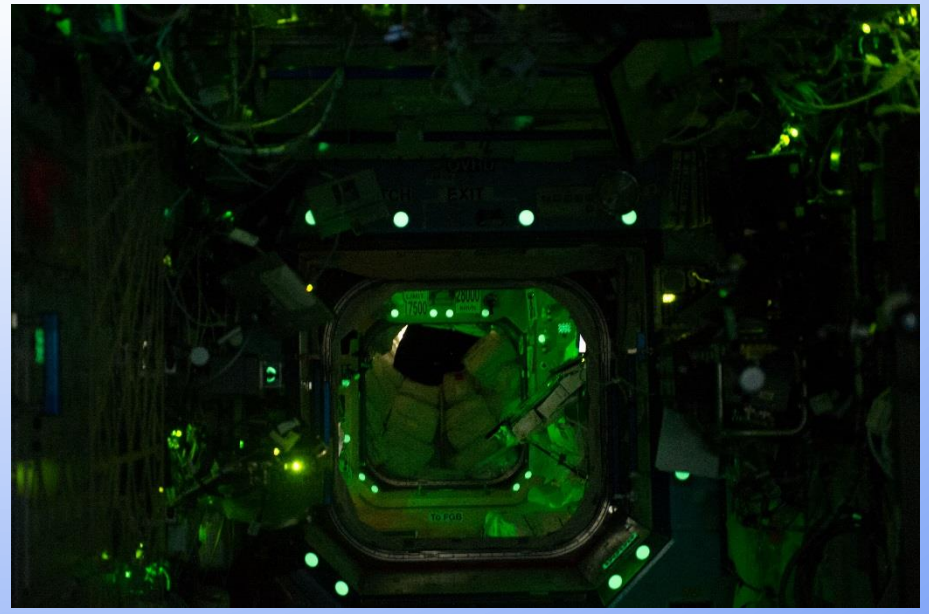


Image Credit: NASA

Toni A. Clark, P.E., Lockheed Martin®

NASA Johnson Space Center Habitability & Human Factors

Lighting Environment Test Facility

…Where the Lighting Environment is not Trivial

- The International Space Station (ISS) is an orbiting laboratory located 250 miles above the Earth's surface.
- Sunrise and sunset occur every 90 minutes.
- There are 15 pressurized habitat modules where astronauts live, work, exercise, and sleep.
- The ISS has multiple external robotic systems.
- Multiple camera systems are available to the crew to monitor robotic and spacecraft approach activities.
- Spacecraft regularly dock to various docking hatches on the station.
- Science experiments are run inside and outside the station's livable habitat.
- Astronauts may be expected to perform external vehicular operations (EVAs) to perform maintenance and repair outside the space station.

…Where Light Fixtures are Custom and Expensive to Replace

- Light sources on the ISS need to be able to operate under extreme environmental conditions.
- Zero gravity creates a condition where heat can only be removed through conduction or forced air cooling, creating challenging thermal control problems for electronics.
- Forced air cooling only works in pressurized environment and creates unwanted noise.
- Electronics and lighting controls on the ISS need to be able to withstand radiation effects.
- Light sources are often custom, specified and designed years ahead of a launch.
- Replacement costs include the cost of the lamps, the cost of launching, and the cost of valuable crew time.

…Where Innovations in Lighting are Needed

- The ISS was designed in the 1970's and 80's.
- High intensity discharge lighting and halogen lighting are currently used for external lighting operations.
- Electro-Magnetic Interference shielded fluorescent lamps, with a corrected color temperature of 4500K are currently used for interior lighting.
- The original design for average illumination levels for task lighting reflects power conservation requirements and not industry architectural human task lighting standards.
- New research on the human response to light spectrum indicates that the astronauts would benefit from an interior lighting system that has the capability of adjusting lighting intensity and corrected color temperature.

Big Changes are on the Way…

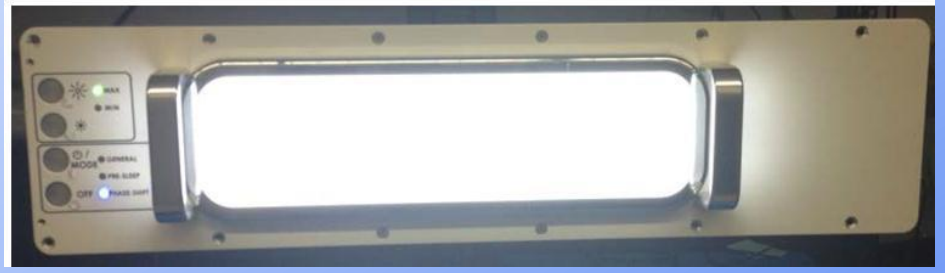
- In 2016, the interior lighting system of the ISS will be upgraded from fluorescent lamp to multi-spectral Light Emitting Diode (LED) lamp technology.
- Nearly half a decade in engineering and human behavioral research supports the change.
- The new lamp, called the Solid State Lighting Assembly, will nearly double the average illumination level, allow the astronauts to control the intensity of the lighting, and allow the crew to change the color temperature to three different color temperature modes.

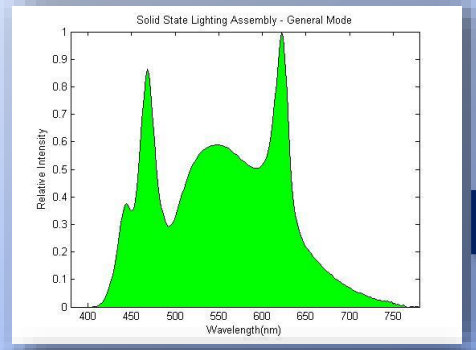
Solid State Lighting Assembly (SSLA) Facts

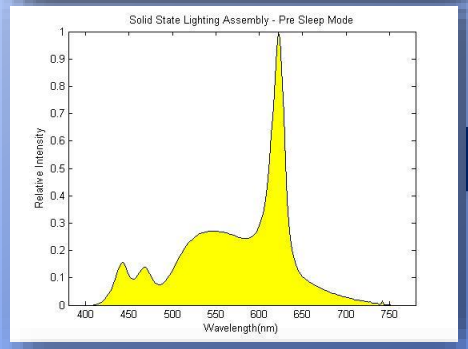
General Illumination: ANSI Color Temperature 4500K

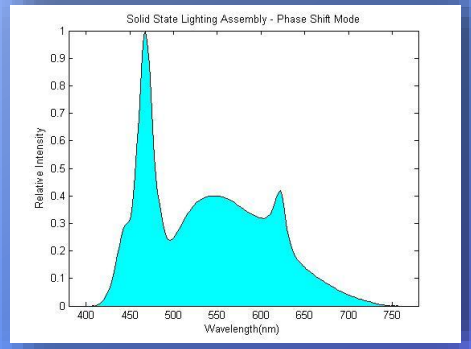
Pre-Sleep: ANSI Color Temperature 2700K

Phase-Shift: ANSI Color Temperature 6500K









Colors represent the 99 colors of the IES-TM-30 Color Accuracy Test.

NASA Lighting Standards & Requirements

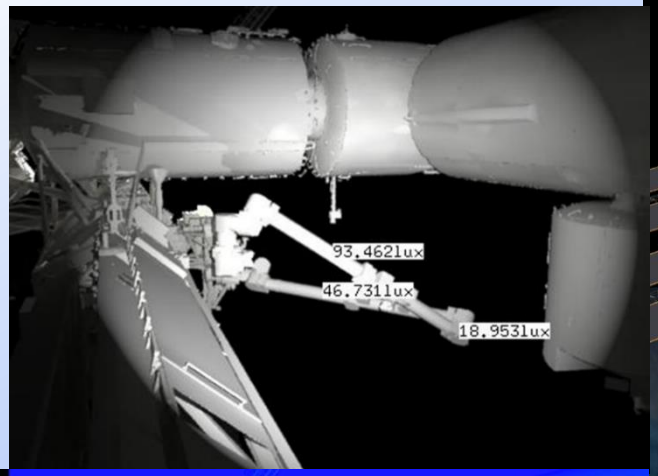
- NASA lighting standards are often a compromise between industry recommendations and the power, weight, and thermal constraints of the spacecraft.
- Like any industry technical standard, changes to NASA lighting standards also can take a while. The commercial lighting industry's rapid changes in the verification and testing of solid state lighting technologies and human performance requirements makes updating NASA standards challenging.
- Depending on the latest revision of a standard or requirement, expect to see references to Color Rendering Index, Color Quality Scale, Illumination Engineering Society task lighting levels, ANSI, Military, and customized lighting requirements.

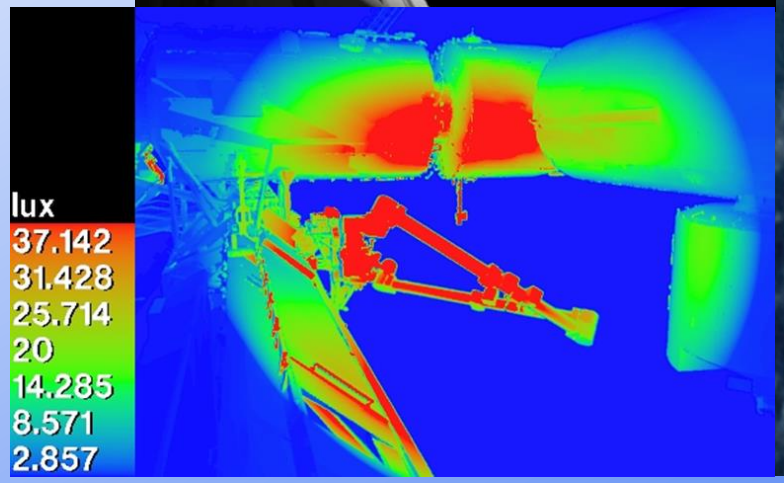
Multiple Jobs, Multiple Tools

- NASA's role in lighting test & analysis requires answers a wide array of questions.
- Lighting requirements need to address both human task performance needs and spacecraft camera and automation needs.
- We operate a controlled lighting test facility to measure light source beam distribution, spectrum, uniformity, flicker, and spectral reflectance. Our test facility also serves camera and sensor design customers that need to address lighting issues.
- We maintain a suite of software analysis tools such as Radiance©, Zemax®, Jack®, and Matlab® to visualize lighting conditions that can't be easily duplicated on the ground.
- The next few slides showcase some the problems we are called to answer.

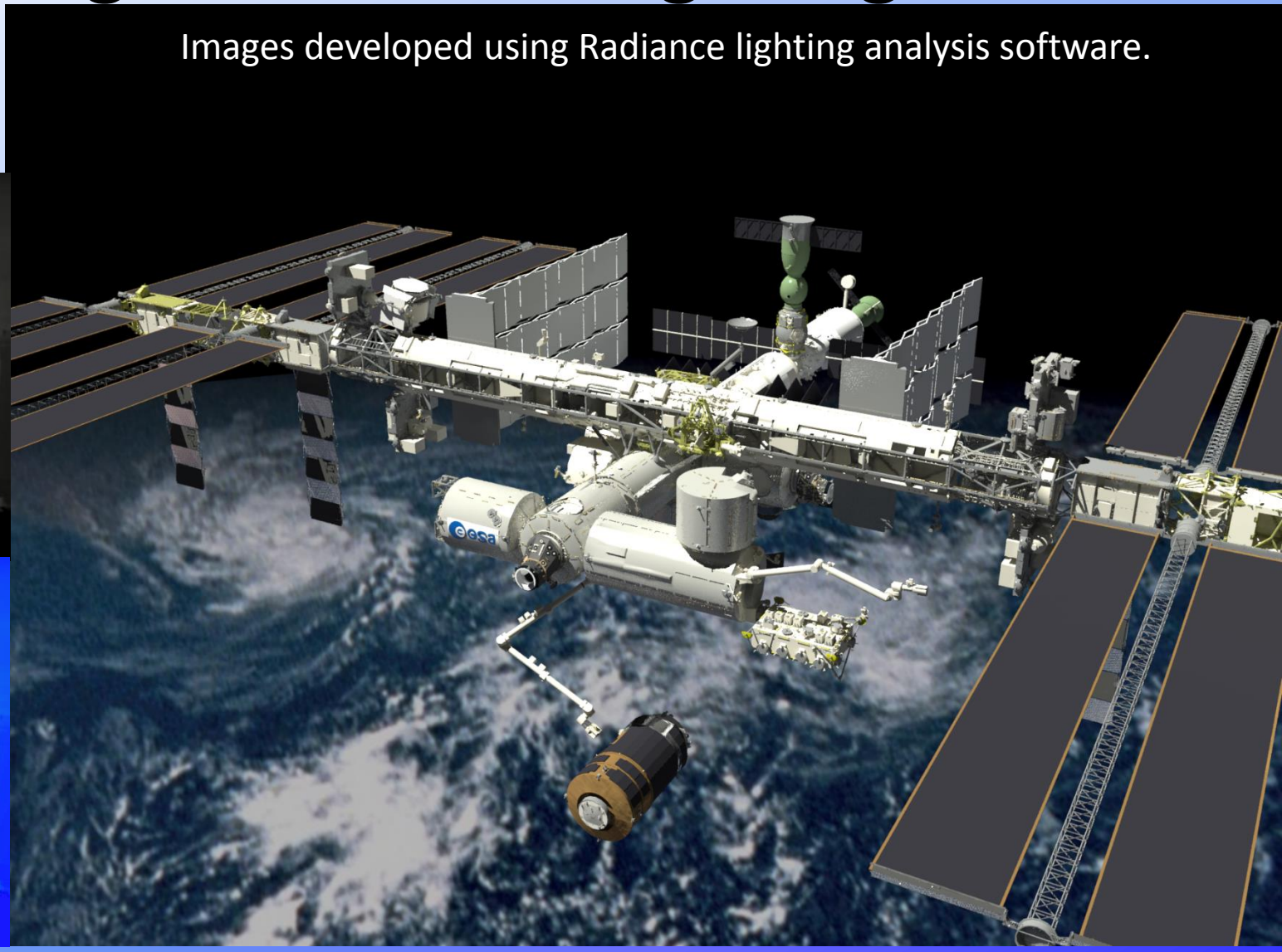
Computer Modeling of External Lighting Environments

Visualizations are used to show astronauts and mission planners how the environment may look and what to expect for light level specific tasks.

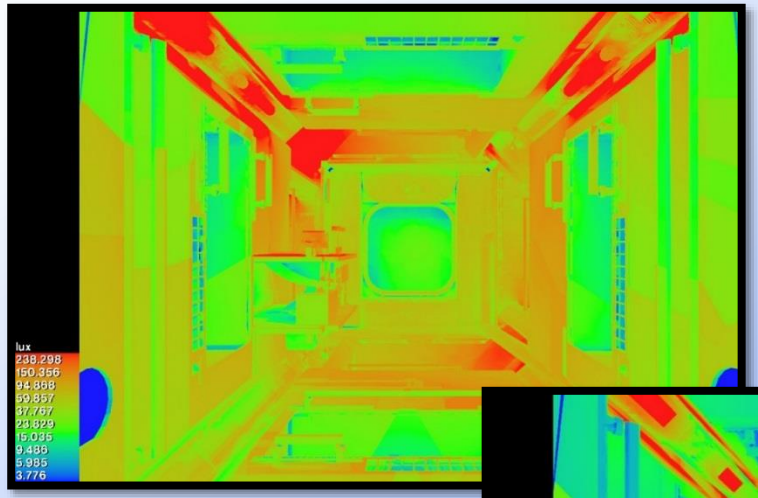




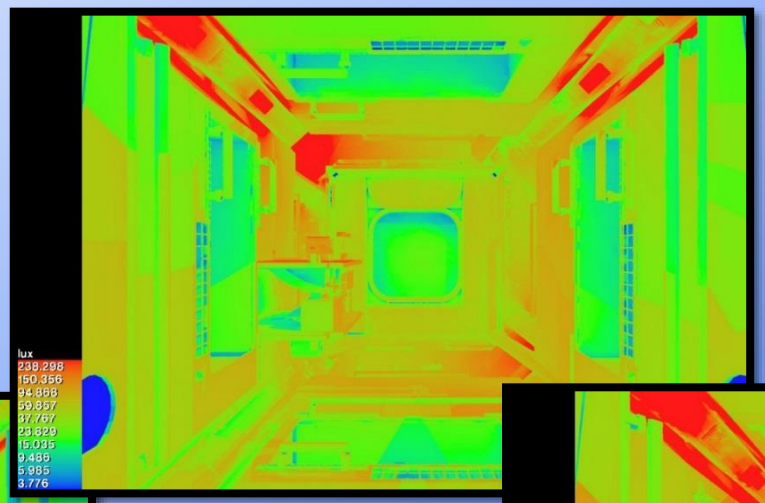
Images developed using Radiance lighting analysis software.



Computer Modeling of Interior Lighting Environments

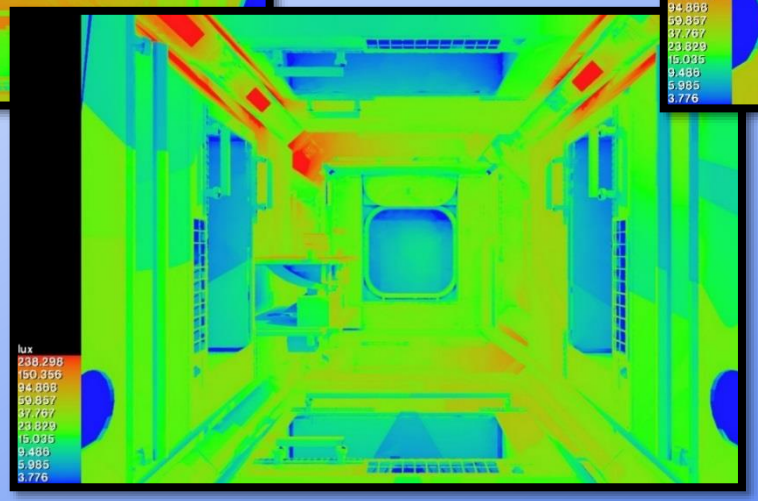


Fluorescent

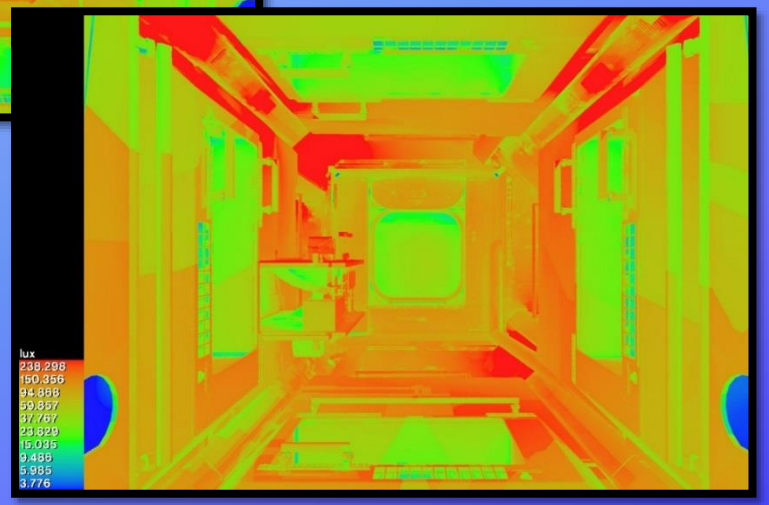


SSLA – General -DEFAULT

ISS Node 2 false color illuminance maps were developed using Radiance lighting analysis software.



SSLA – PreSleep -DEFAULT



SSLA – PhaseShift -DEFAULT

Computer Modeling of Interior Lighting Environments

Fluorescent

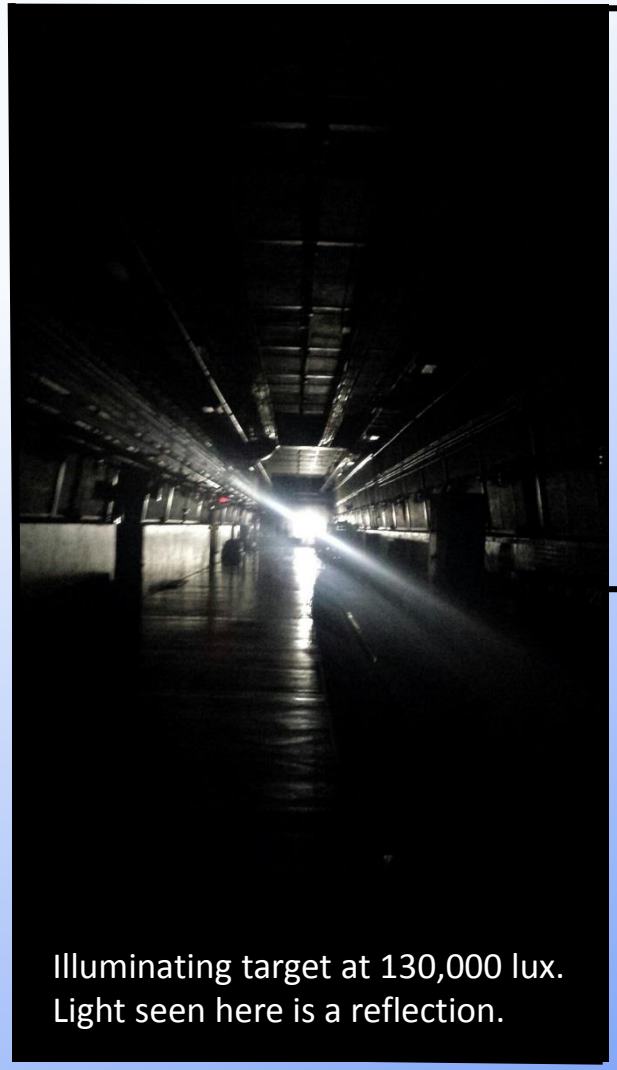
SSLA – General -DEFAULT

ISS Node 2 perceived light intensity images were developed using Radiance lighting analysis software.

SSLA – PreSleep -DEFAULT

SSLA – PhaseShift -DEFAULT

Laboratory Testing of Lighting Systems



Illuminating target at 130,000 lux.
Light seen here is a reflection.

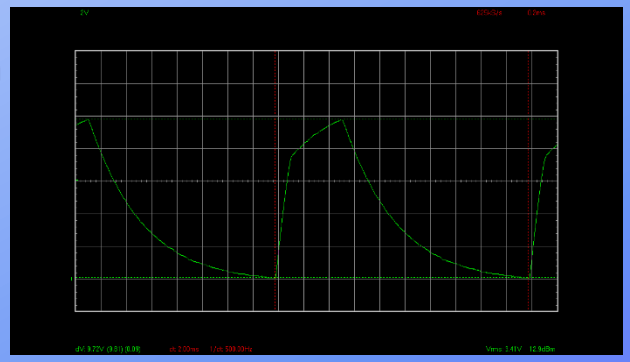
Calibration of Camera/Lighting Systems

Lamp illumination test.

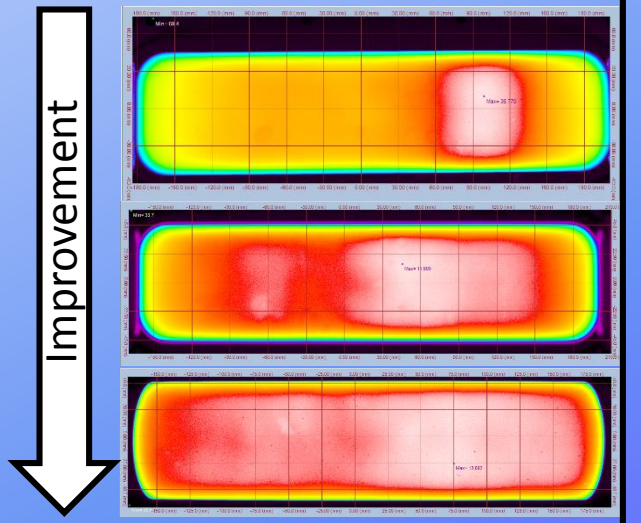
Cameras often don't have the dynamic and adaptive range that humans do for observing a wide range of light levels. These 2 images show different camera evaluations to test how lighting conditions impact camera imagery of an external spacecraft component.

Light Source Flicker Testing

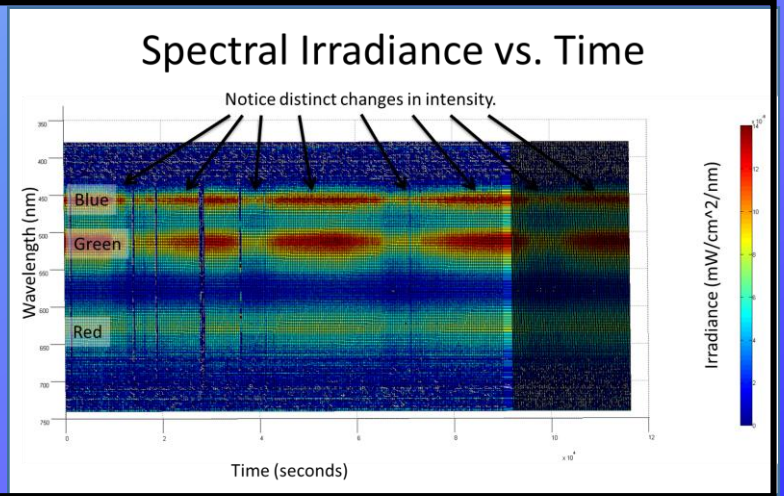
Flicker can create problems for cameras & sensors



Demonstration on how imaging colorimeter was used to improve the uniformity of luminance for a light source



Spectral irradiance testing of light source inside thermal test chamber



Research & Innovation

To stay current with new lighting technologies, methods of verification of lighting systems, and impacts to human factors, the lighting team at Johnson Space Center is also active in research. Current and recently funded research includes:

- Evaluation of color accuracy standards to determine applicability to spaceflight application.
- Research and testing to determine compromise on light source design that addresses spectral requirements for a health countermeasure without impacting color accuracy and camera performance.
- Research on the impact of displays and indicator lamps have on environmental light spectrum within an operational environment.

Final Words & Acknowledgements

Thank you for this opportunity to share my team's experience in developing and evaluating spaceflight lighting systems for NASA and the International Space Station.

The following NASA and contractor teammates shared in the contribution of information and graphics for this presentation.

James Maida

Shawn Armstrong

George Salazar

Rick Boettger

Kim Tran

Andrei Kolomenski