



Artemis I Flight Instrumentation Data Quality Assessment and Processing

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Introduction

- **Artemis I Launch Nov 16th, 2022**
- **Spacecraft travelled further than any during Apollo program**
 - Lunar orbit reached 380,000 miles from the Moon
 - This view of Moon and Earth not seen since the final Apollo mission in 1972
- **Extensive instrumentation**
 - Artemis I collected data from thousands of sensors
 - Assessments of these data validated environments and vehicle performance for *human-rating*



Imagery Sources: NASA

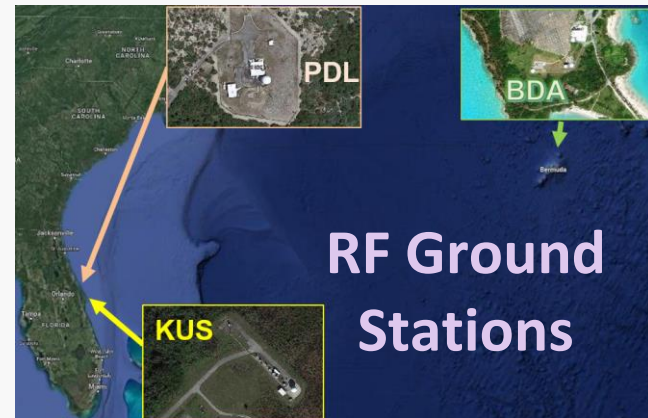
Outline



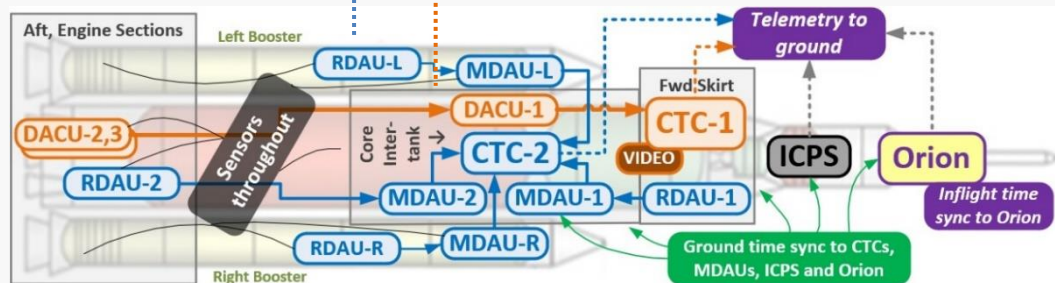
- **SLS Instrumentation Architecture**
- **High Frequency Instrumentation**
- **Testing**
 - Characterization Tests in the Lab
 - Integrated Time Synchronization Test
 - An Unexpected Validation
- **Handling RF Dropouts**
- **The Final Product**

SLS Instrumentation Architecture

- SLS is an integration project
 - Heritage and COTS / MOTS subsystems (enhanced)
 - DFI is a separate, removable system
 - Different clocks, different sync mechanisms
- Instrumentation systems consist of:
 - Operational Flight Instrumentation (OFI)
 - Engineering Flight Instrumentation (EFI)
 - Developmental Flight Instrumentation (DFI)
 - EFI and DFI are relatively high frequency
 - DFI is temporary
- All data are telemetered to 3 ground stations when in range
 - And over hardline, prelaunch
- The focus of the problem is high frequency EFI and DFI

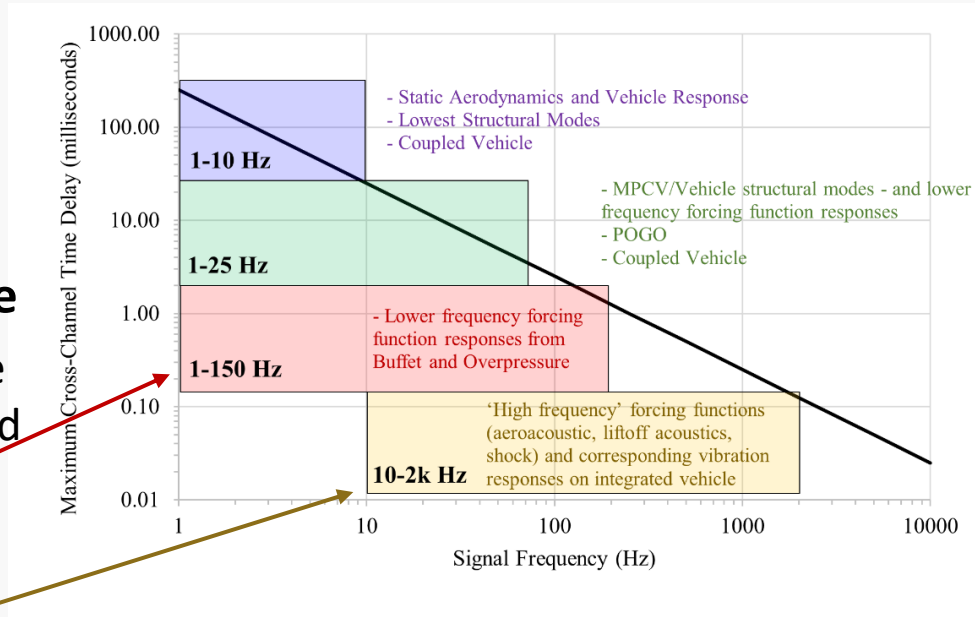


Satellite Images: 2023 TerraMetrics, Airbus, Maxar Technologies, U.S. Geological Survey;
Map Data: 2023 Google, INEGI



Timing Requirements for Different Datatypes

- Level of accuracy needed differs with frequency, which is related to various physical phenomena of interest
- Some are challenging to characterize
 - Unsteady *aerodynamic pressures* due to transonic and supersonic flow need Sampling Rates (SR) of ~150 Hz to resolve
 - *Aeroacoustic measurements* require ~1-10k Hz SR
- Measurements need to be tightly synced across various acquisition systems
 - Mobile Launcher - Boosters - Core Stage – ICPS - Orion



High Frequency Instrumentation



- Each DAU (MDAU, RDAU, DACU) collects thousands of samples from its sensors
 - According to a fixed cycle and sample schedule
 - Data of various frequencies are multiplexed and packed into a large data package, with one reference timestamp
 - Many instances of the same measurement occur in a packet and package

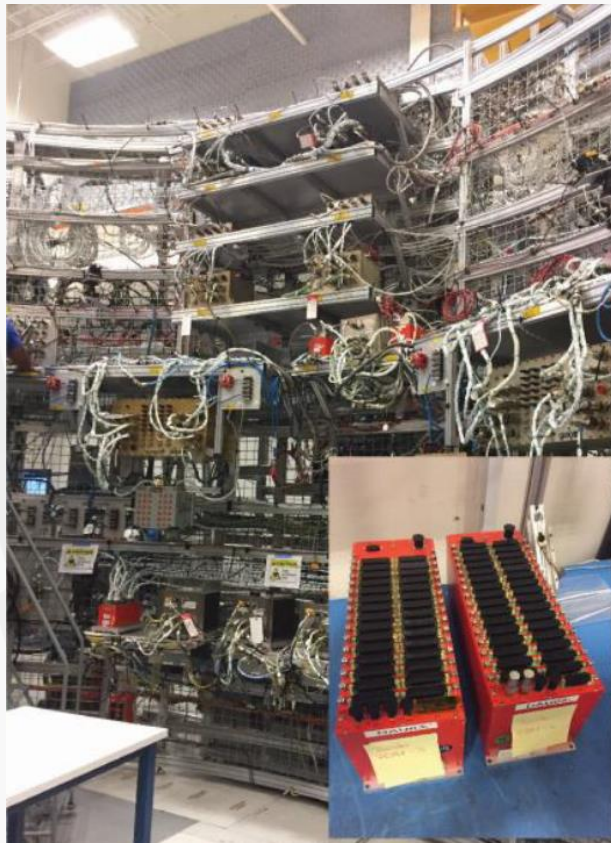


Timestamp

	SLOT 1	SLOT 2	SLOT 3	SLOT 4	SLOT 5	SLOT 6	...
PACKET 1	Packet ID	Meas A	Meas C	Meas D	Meas Y	Meas C	
PACKET 2	Packet ID	Meas B	Meas C	Meas E		Meas C	
PACKET 3	Packet ID	Meas A	Meas C	Meas F	Meas Y	Meas C	
PACKET 4	Packet ID	Meas B	Meas C	Meas G	Meas Y	Meas C	
PACKET 5	Packet ID	Meas A	Meas C	Meas H	Meas Y	Meas C	
PACKET 6	Packet ID	Meas B	Meas C	Meas J		Meas C	
PACKET 7	Packet ID	Meas A	Meas C	Meas K	Meas Y	Meas C	
...							

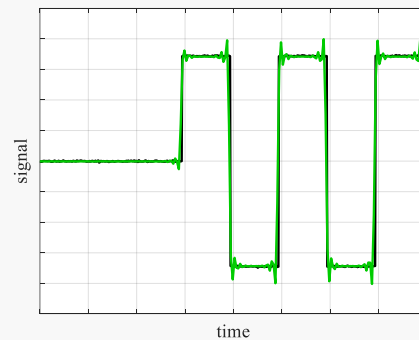
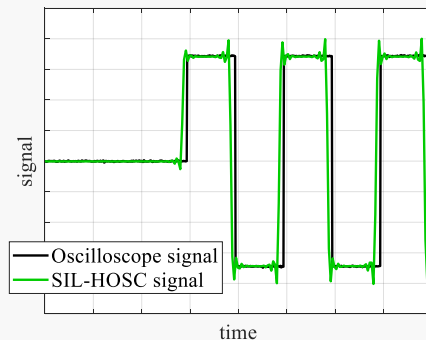
- Keys to accurate timing
 - Clock accuracy
 - Timestamp accuracy
 - Individual sample time offsets within a package (including “filter delays”)

Characterization Tests in the SLS Avionics SIL



Imagery Source: NASA (David Piatak)

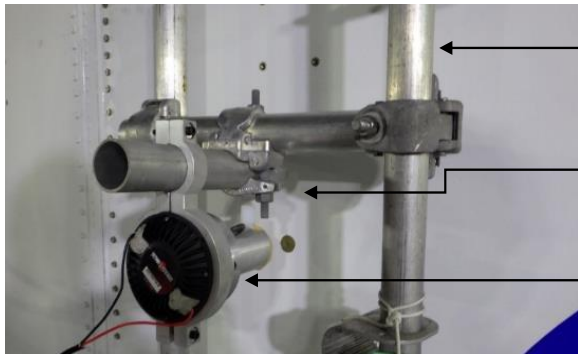
- The SIL has every SLS avionics component throughout Booster and Core Stage
 - (hardware and modeled)
 - ICPS, Orion and Ground are emulated
 - 70 km cables in Core Stage, 12 km in Booster
 - Extensive test infrastructure
- Plots of square wave sync with incorrect time offsets (left) and corrected (right)



Integrated Time Sync Test: Overview

- Stakeholders must integrate data from many different DAU systems
- At the VAB, Elements were merged into a stack, ready for integrated tests
- Test approach:
 - Speakers across the stack produced intermittent chirps
 - Chirps stimulated Artemis sensors, and independent “truth” microphones
 - Resulting signals were processed through instruments / subsystems

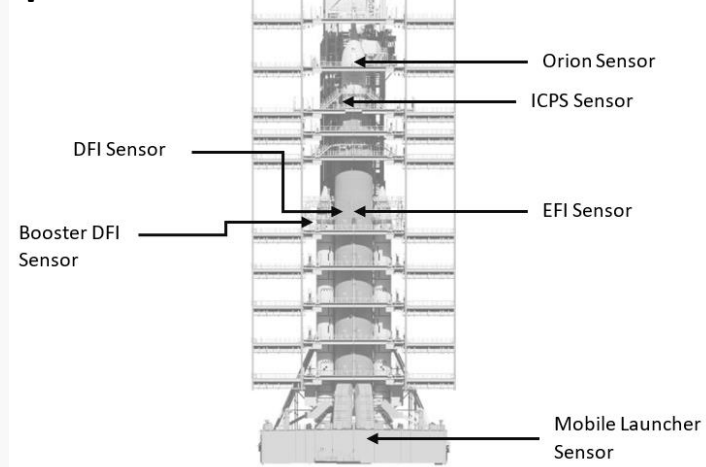
Audio Speaker Assembly near Artemis Sensor



Supporting
structure
Pressure
sensor
Audio
speaker

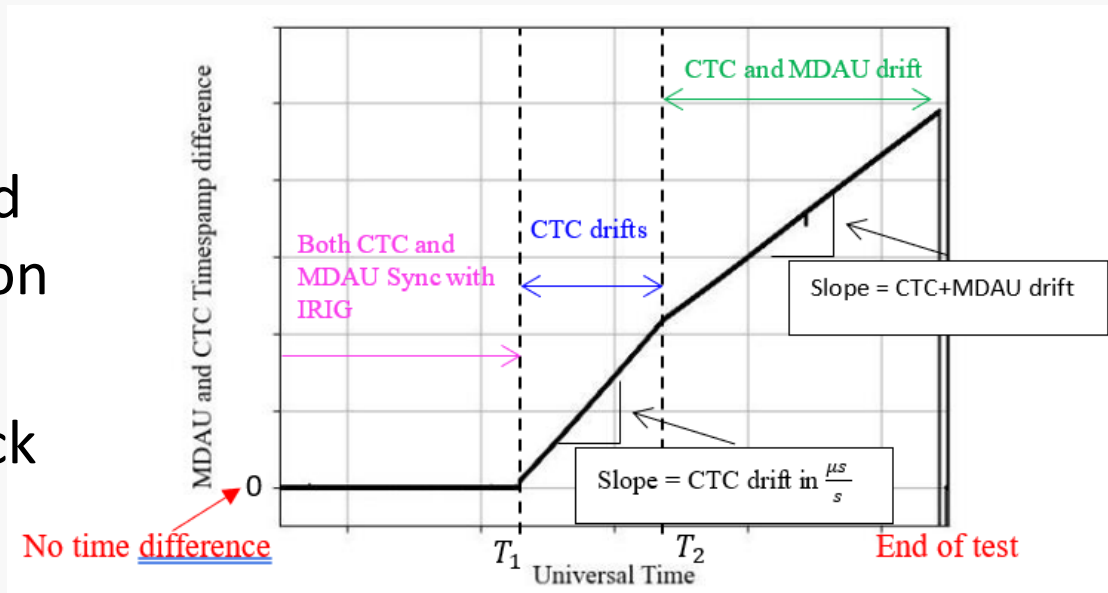
Imagery Source: NASA (Oleg Goushcha)

Speaker Assemblies Across the Stack



Integrated Time Sync Test: Clock Errors

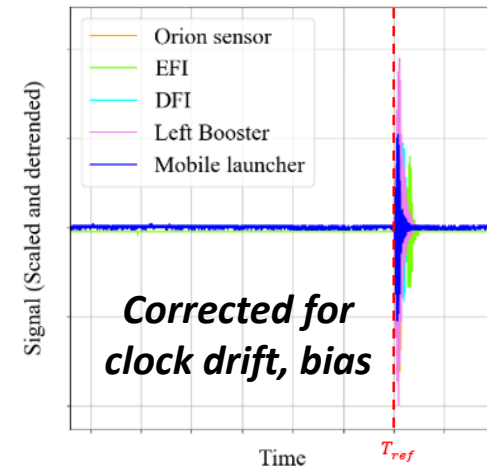
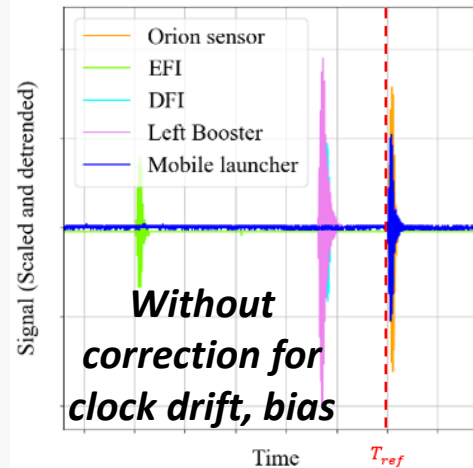
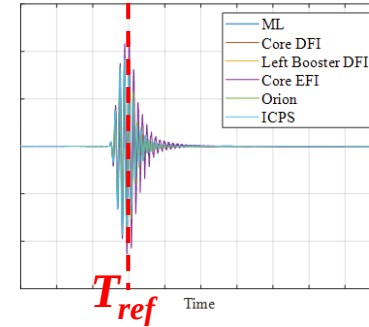
- Stopped time sync to different subsystems at different times
- Measured clock drifts and biases over a long duration
- Derived (and validated) methods to measure clock bias and drift *from SLS telemetry (flight data)*



Integrated Time Sync: Results

- Data showed the simultaneous sonic chirps from speakers
- “Truth” signals were recorded by microphones, and timetagged using a ground time source
- SLS / Orion instruments captured the chirps and processed the measurements through the various subsystems
- After correcting for bias and drifts, signals aligned to within ~10 microseconds

*“Truth” signal,
recorded by
mics*



An Unexpected Validation

- The most powerful lightning strike recorded at KSC occurred during a pad test *with avionics powered on*
- Instruments recorded the strike
- Clocks were independently validated
- The Lightning Protection System was also validated

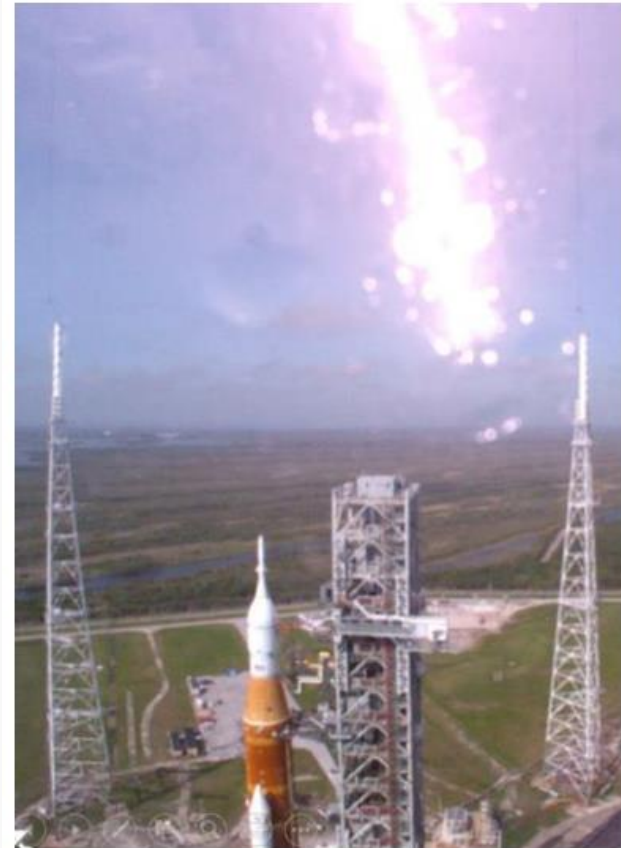
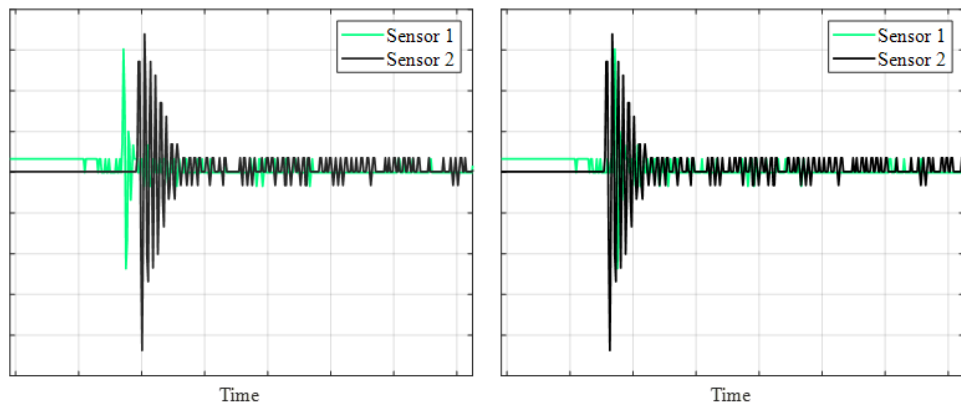
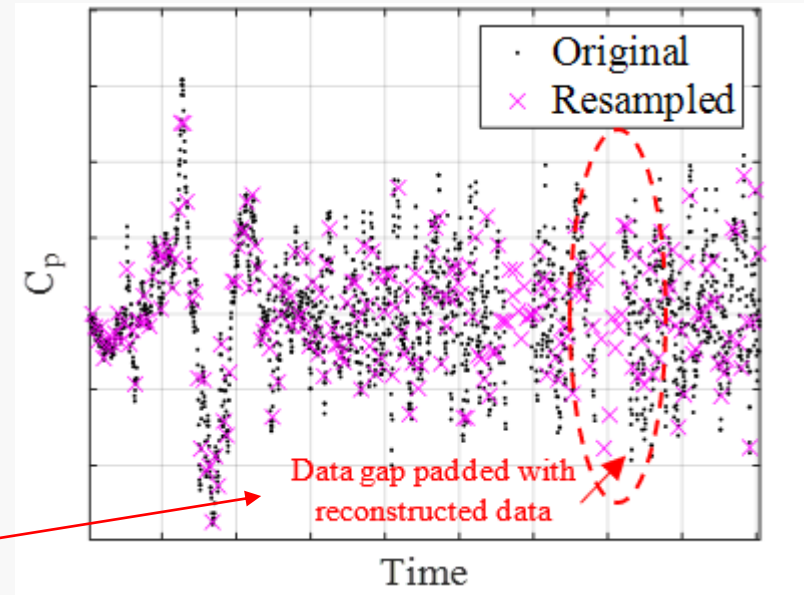


Photo: NASA

Handling RF Dropouts

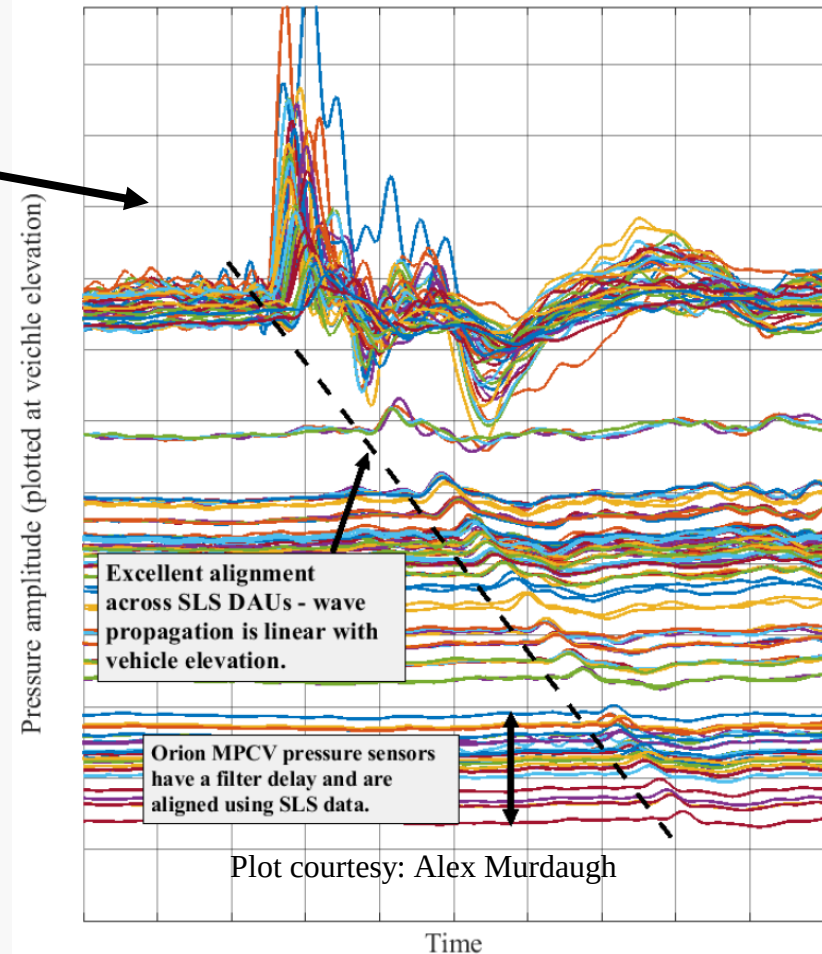
- Flight data suffered from occasional data dropouts due to RF transmission interruptions
- From cross-channel analysis a “clean” dataset was needed
- Missing data may be reconstructed using a **Fourier decomposition approach**



Required Time Accuracy was Achieved in Flight Data



- Pressure wave propagating across vehicle during liftoff
- Pressures are plotted at the **inversed** vehicle elevation
 - Engine section at top
 - Orion at the bottom
- Data from several DAUs across the stack



Conclusions

- **Preflight testing provided**
 - a very good understanding of the sensor data, *prior to flight*
 - validation of time accuracy across DAUs
- **SIL characterization testing is planned for Artemis II to measure time offsets and behavior of other measurements**
- **A strobe signal was added to the AR02 flight configuration to enhance MDAU-DACU alignment**



Photo: NASA

QUESTIONS?

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