Utilizing Power System Digital Twins and Hardware-in-the-loop Test Approaches to Reduce Risk in Agile Space Applications

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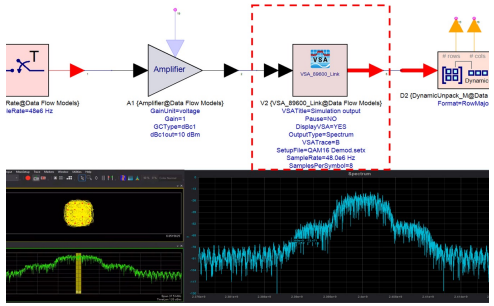
Consistent Measurement Science

Correlation from design to operation



System Concept and Design

Digital models and data

Prototype Testing and Debug

Hybrid digital models and observed physics from hardware

Payload Test Systems

Specific test and validation data

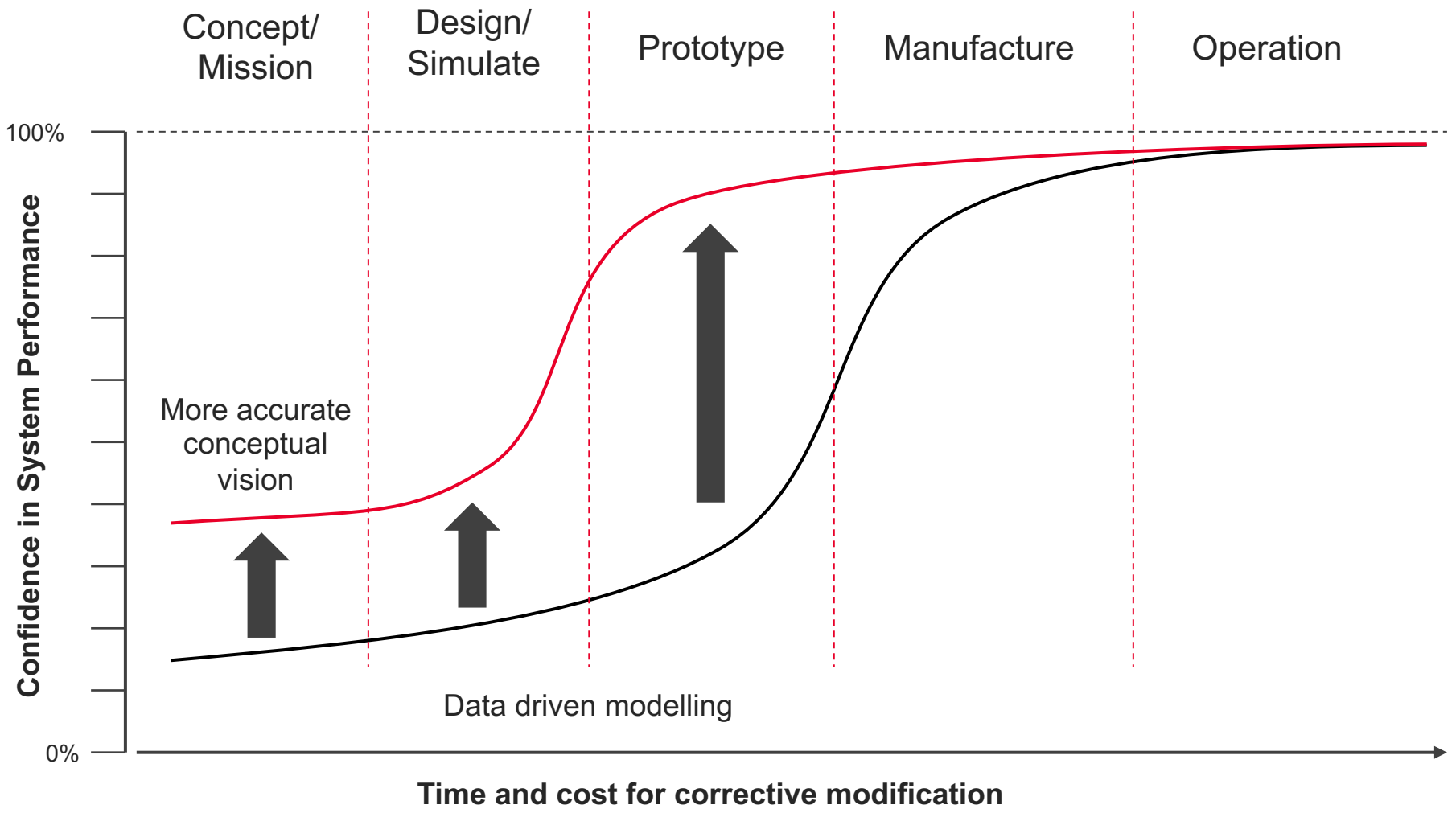
Field Test Equipment

Operational data from observed system

KEYSIGHT TECHNOLOGIES SEDARO

What does data-driven engineering give us?

Earlier confidence in system performance



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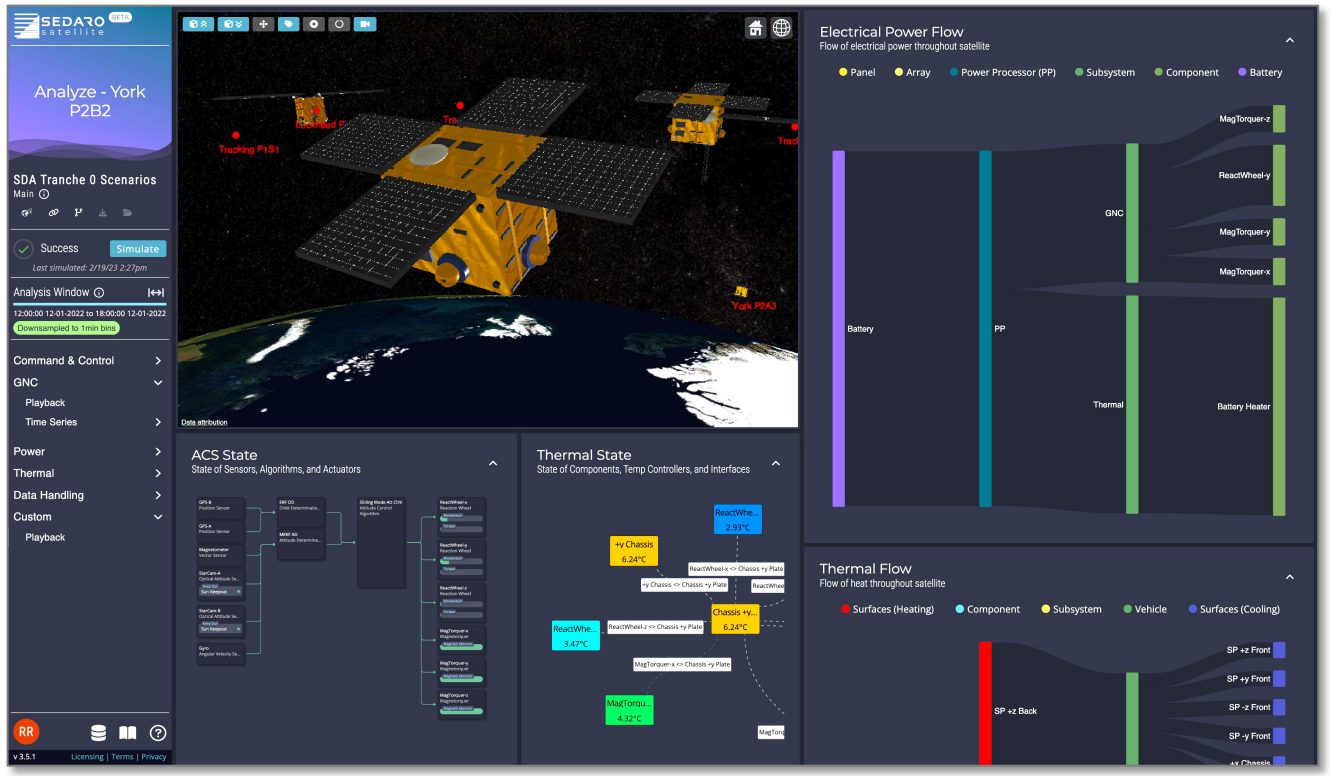
(source: Dr. Kolonay – Air Force Research Laboratory)

Digital Twin Software



SEDARO

Cloud multi-physics simulation software

- Collaborative
- Full Life-Cycle
- Cloud Scalable
- Natively Interoperable

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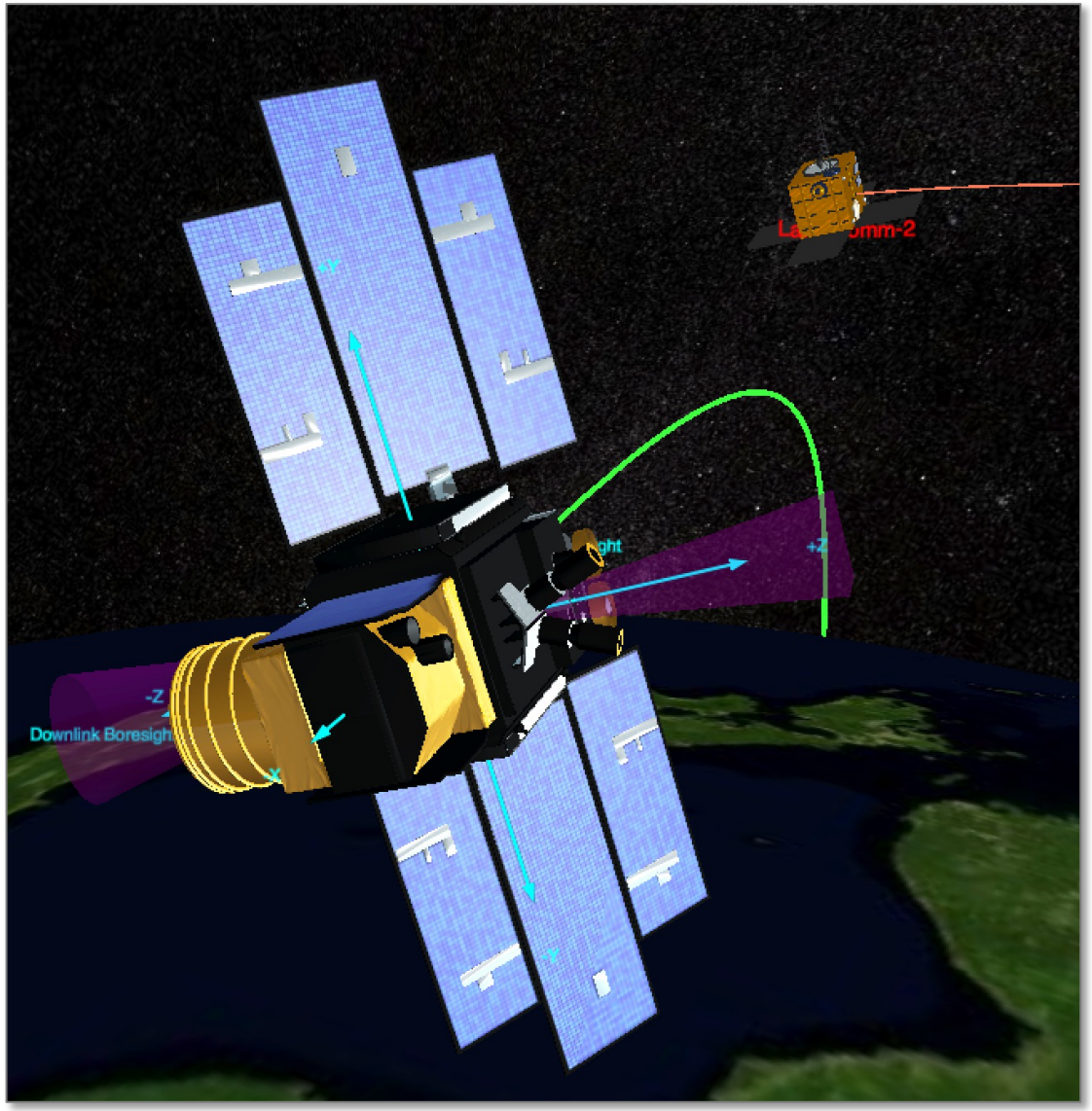
Power Testing for Dynamic Space Vehicles



Challenges

Dynamic solar panel illumination and temperatures

- Coupling to thermal and GNC

Dynamic loading

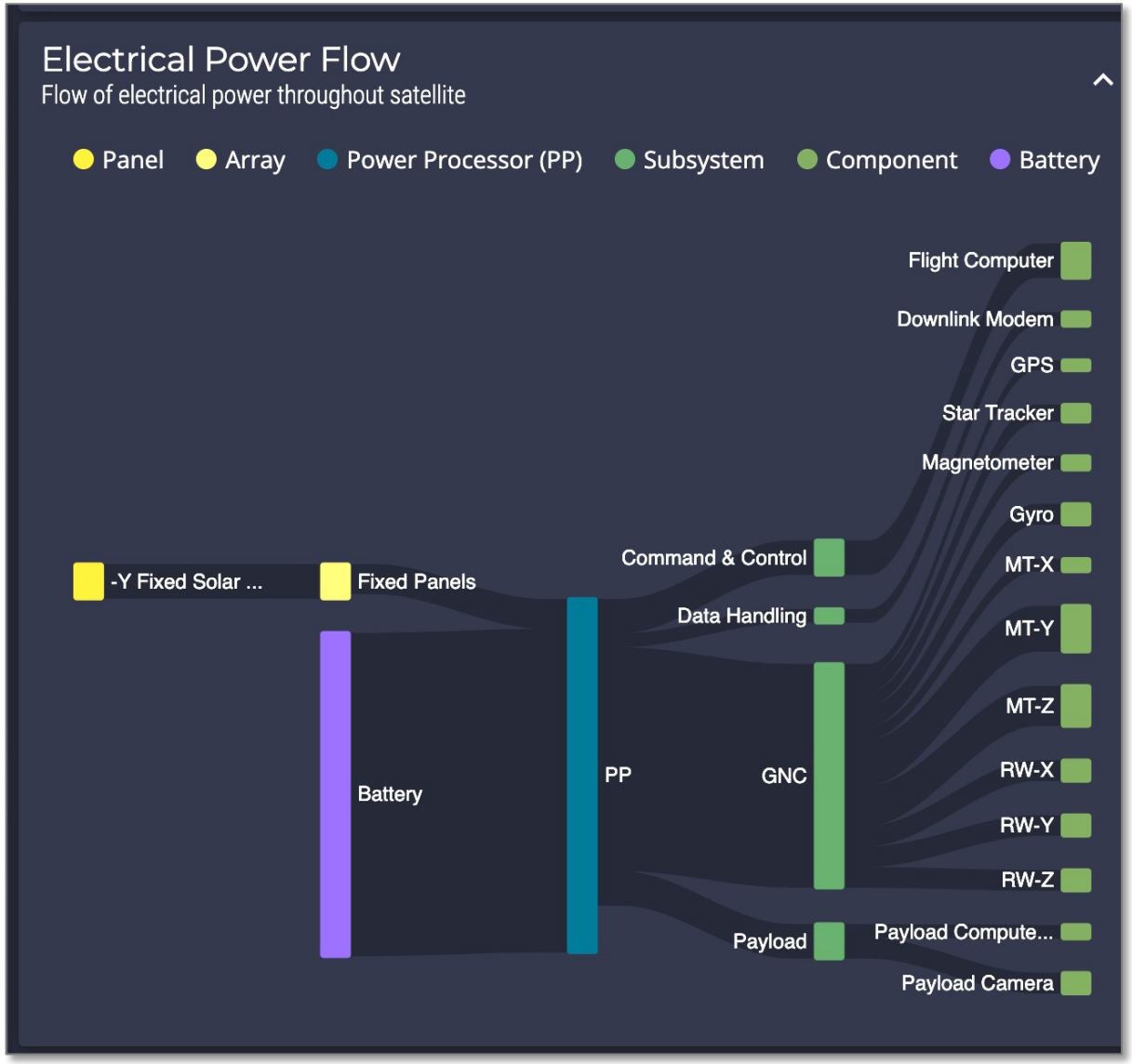
- Coupling to all subsystem dynamics

  Actuators, heaters, coolers, TX/RX, payload processing

- Coupling to inter-agent dynamics

  ISAM/RPOD and P-LEO satcom

Power Testing for Dynamic Space Vehicles



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Digital Twin HIL Test Configuration

KEYSIGHT
Solar Array
E4361A
SAS

Single Conv MPPT
BlueSolar 7515

KEYSIGHT
Bus Load
N6791A
E-Load

KEYSIGHT
Battery
N6781A
Battery Emulator

Imp, Vmp, Isc, Voc

V, I

P

V, I

Voc

V, I

SEDARO

MISSION GNC C&DH

POWER COMMS THERMAL

Digital Twin Simulation

Digital Twin HIL Test Configuration

```
# Measure bus voltage
bus_voltage = keysight.q_float(keysight.ip_pa,
'MEAS:SCAL:VOLT:DC? (@1)')

# Measure battery current
battery_current = -keysight.q_float(keysight.ip_pa,
'MEAS:SCAL:CURR:DC? (@1)')

# Measure solar array voltage and current
current = max(0, keysight.q_float(keysight.ip_saas,
'MEAS:SCAL:CURR:DC? (@1)'))
voltage = max(0, keysight.q_float(keysight.ip_saas,
'MEAS:SCAL:VOLT:DC? (@1)'))

# Set battery open circuit voltage based on simulated
state of charge
keysight.w(keysight.ip_pa, f'VOLT
{battery_voltage(stat_of_charge)}, (@1)')

# Set battery bus load power based on component and
bus converter power draw
keysight.w(keysight.ip_pa, f'POW
{unreg_bus_load_power}, (@2)')

# Set solar array IV curve based on cell, panel, and
array models and illumination
keysight.w(keysight.ip_saas, f'CURR:SAS:IMP {Imp},
(@1);ISC {Isc}, (@1)')
keysight.w(keysight.ip_saas, f'VOLT:SAS:VMP {Vmp},
(@1);VOC {Voc}, (@1)')
```

Eight lines of python for HIL

SEDARO satellite

Analyze - Wildfire

Wildfire Scenarios - HIL

Keysight no-HIL

- Command & Control
  - Playback
  - Time Series
  - Window Statistics
- GNC
  - Playback
  - Time Series
  - Window Statistics
- Power
  - Playback
  - Time Series
    - Power Generation
    - Energy Storage
    - Power Processing
    - Subsystem Loading
    - Dissipation
  - Window Statistics
- Thermal

RA

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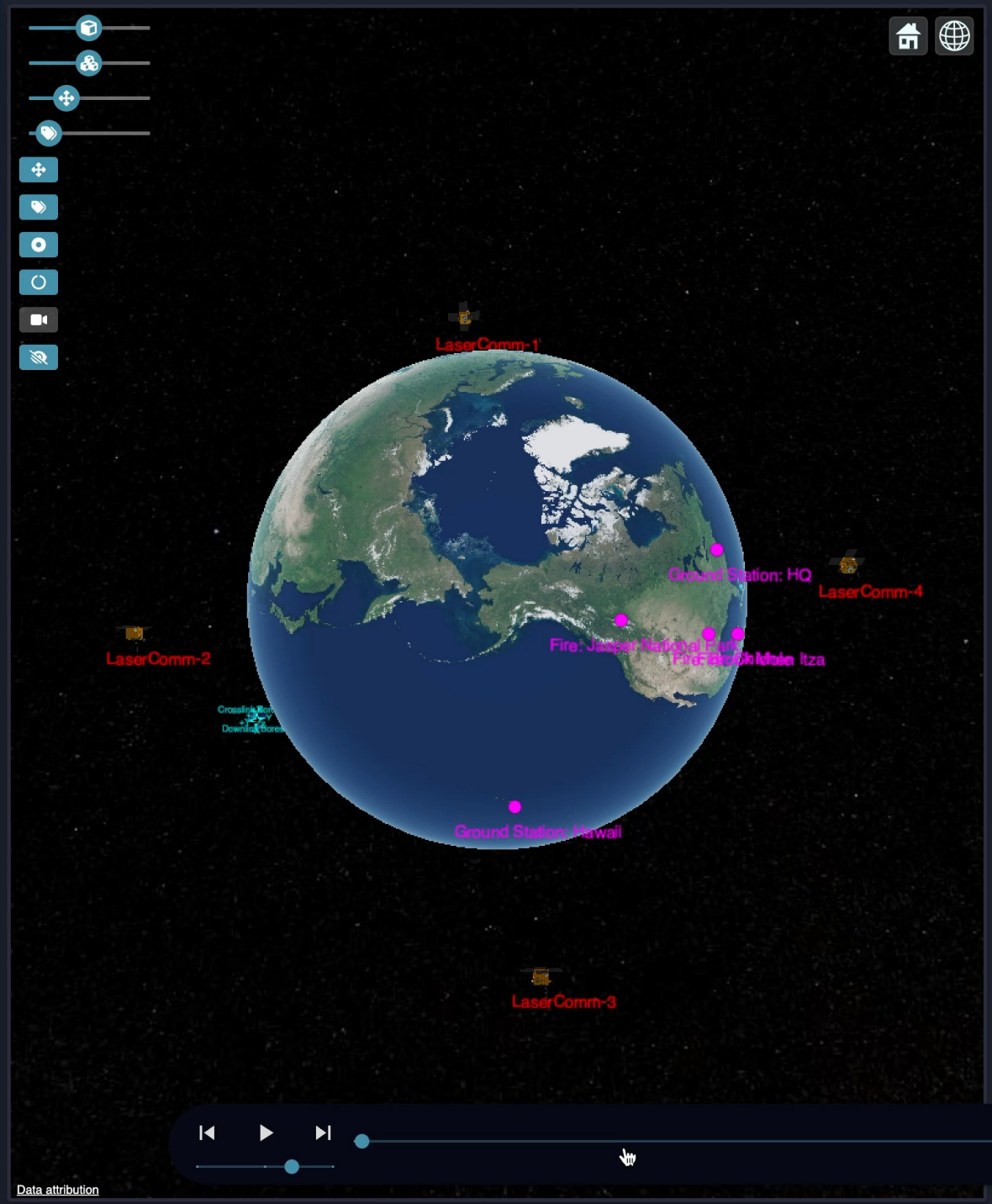

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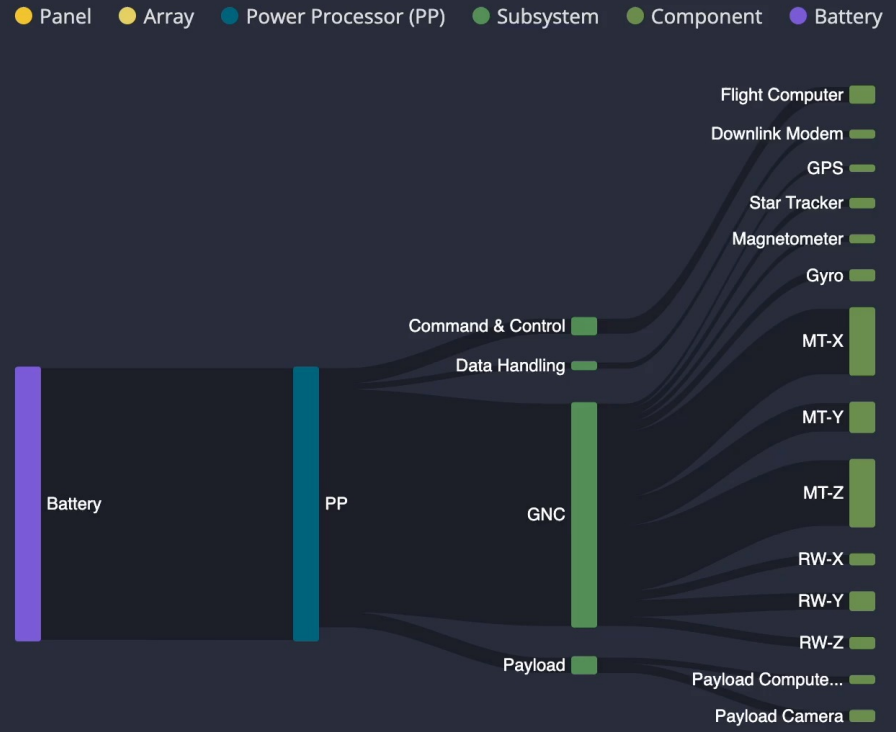
Data attribution

Electric Power System State

State of satellite power generation, storage, and distribution

Electrical Power Flow

Flow of electrical power throughout satellite



Conclusions

Modern LEO space vehicles are more dynamic and reconfigurable

Greater risk of corner cases and unpredictable multi-physics interactions

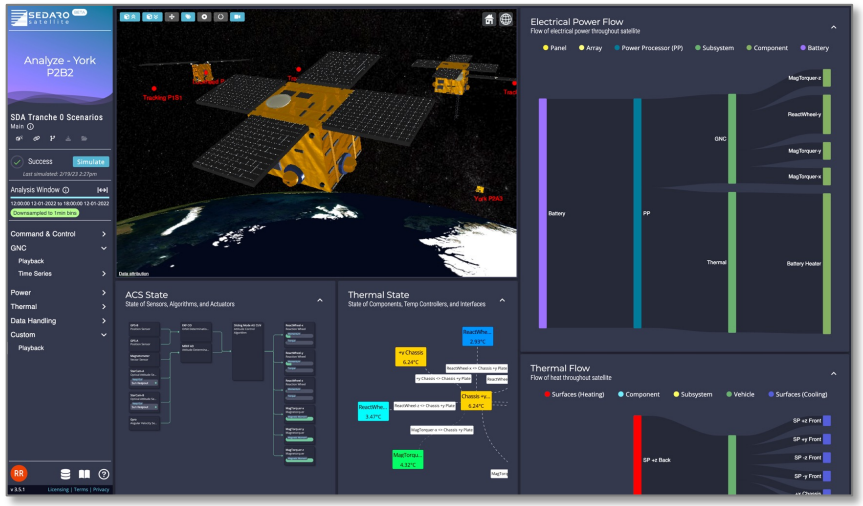
Cloud-native simulations can drive HIL to improve the quality and speed of power testing

Hybrid-cloud may be required for high-frequency in-the-loop dependencies

Digital twin software and test equipment make each other better

Power Test > Digital Twin: model tuning and validation

Digital Twin > Power Test: system/subsystem coupling



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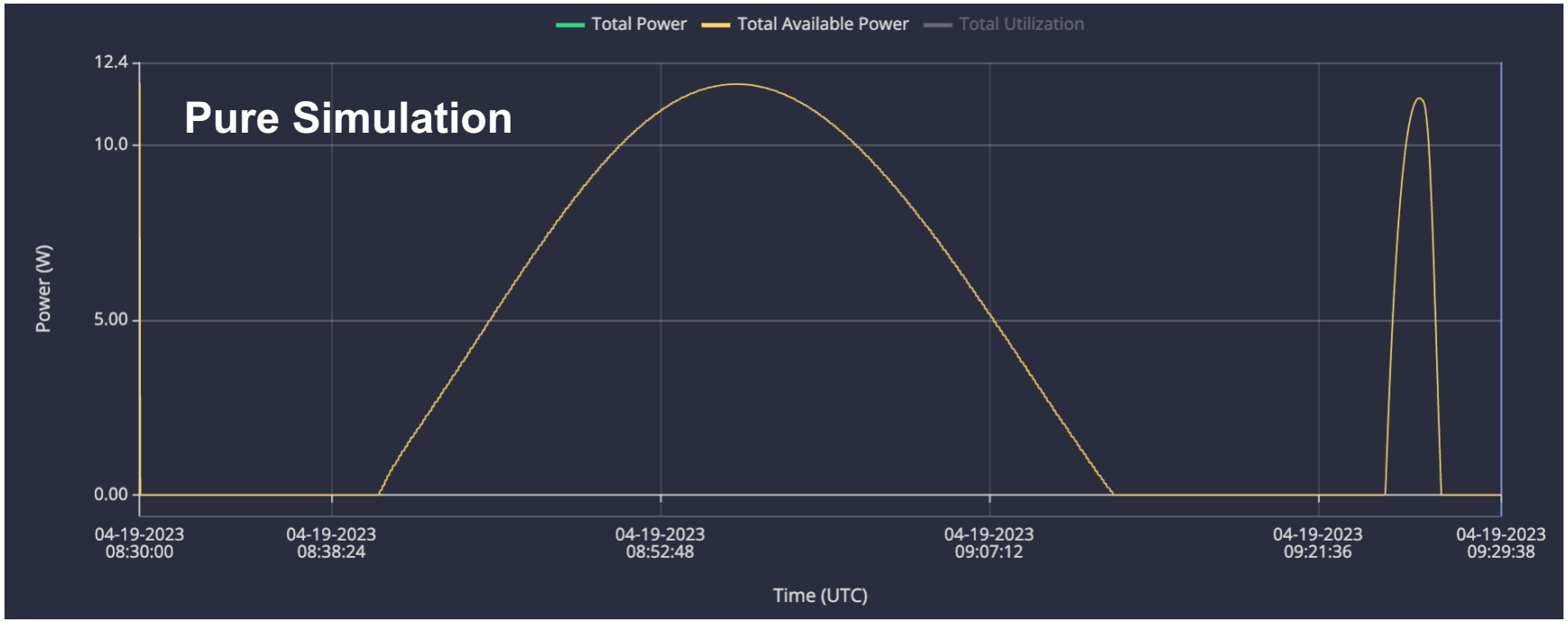
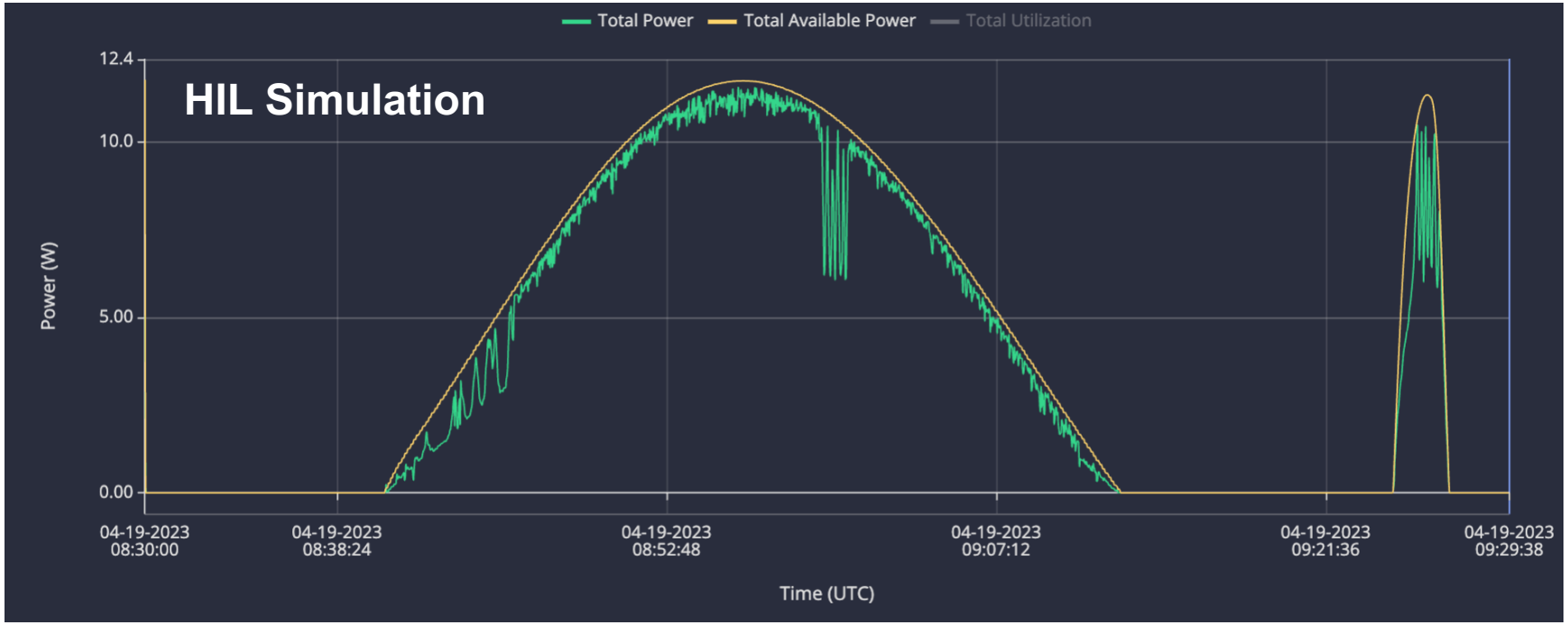
Thank you

Backup: Power Generation Results





Backup: Dissipation Results