Overview of the Space Environment Test Facilities at NASA GRC's Plum Brook Station

2019 IEEE WiSEE/PWST
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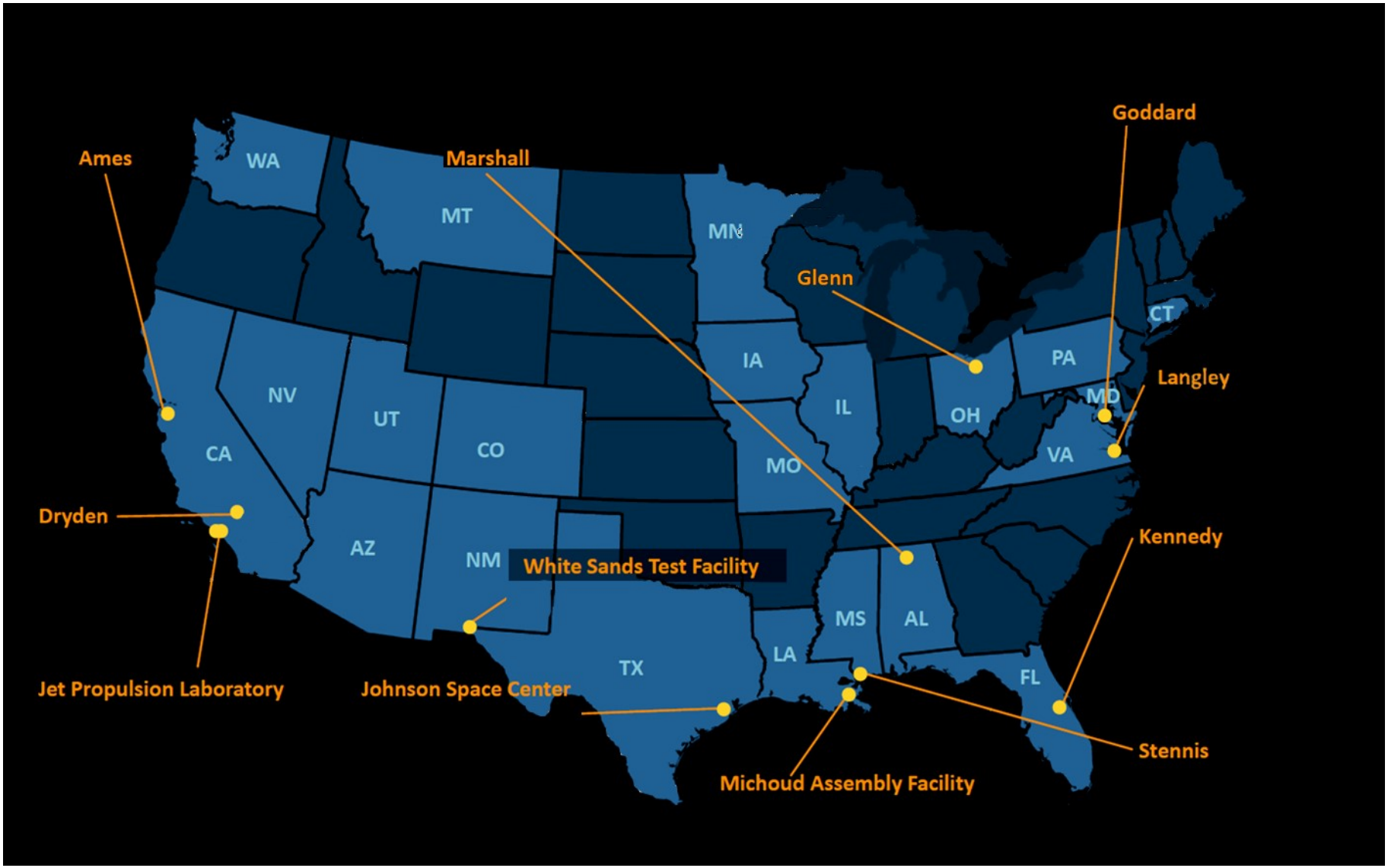
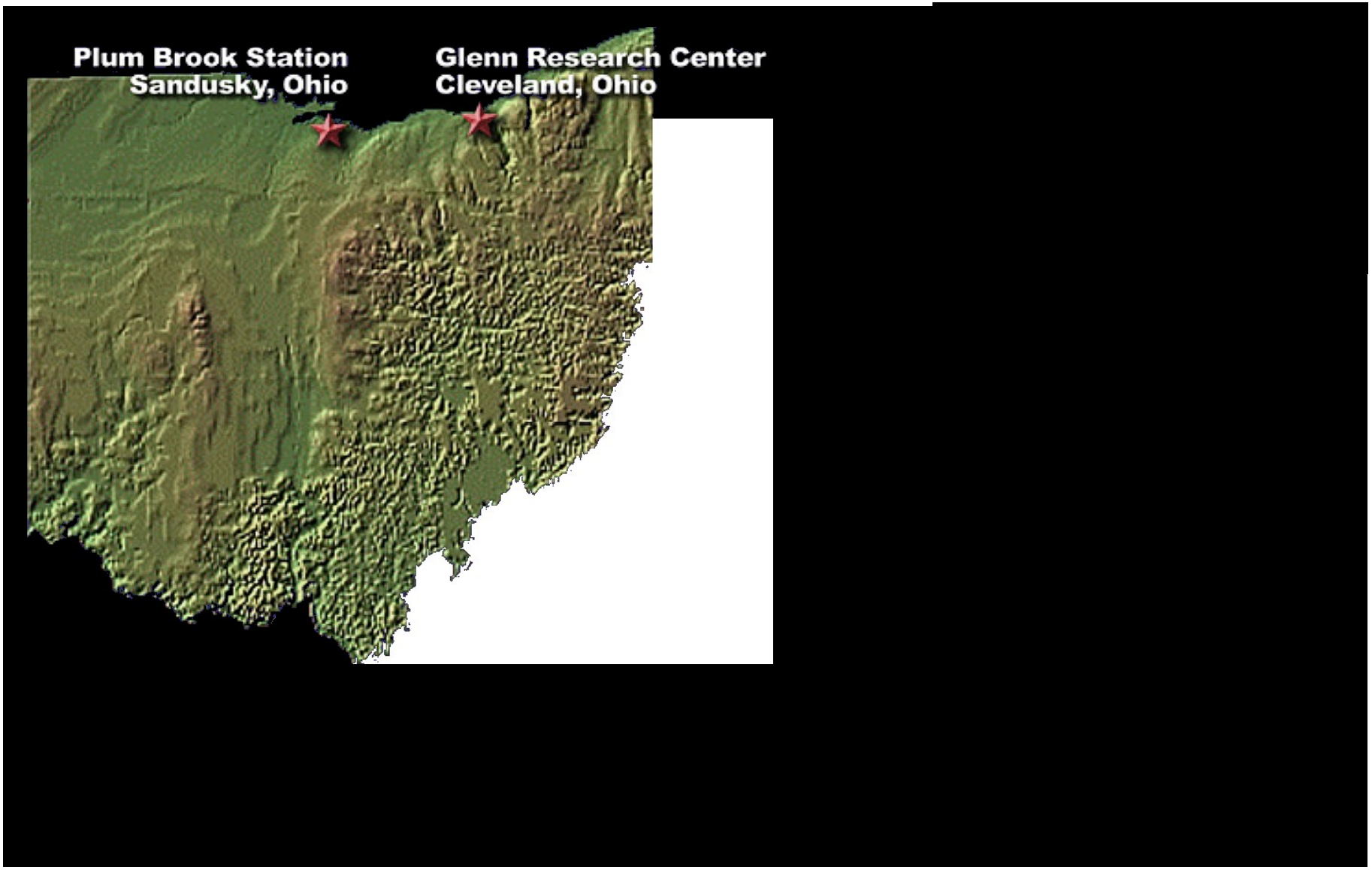
Richard K. Evans
(NASA GRC)

NASA Field Centers



NASA in Ohio


Plum Brook Station
Sandusky, Ohio
Glenn Research Center
Cleveland, Ohio

NASA's Plum Brook Station in Sandusky, Ohio

Satellite campus of NASA GRC used for large-scale space environment testing

NASA's Plum Brook Station in Sandusky, Ohio

What makes Plum Brook Station Unique?

- 10 square miles (25.9 km^2) / 6400 acres / 5400 acres fenced
  - Secure site with securable data and facilities
- Staffed and equipped for
  - Large scale cryogenic tests in harsh conditions
  - Extreme temperatures, pressures, noises and vibrations
  - Explosives and hazardous materials storage
- 100 megawatt power grid
  - Affordable power (vs commercial rates) on day shift
  - High MW tests on site don't affect local users
- Large scale availability of gas and water
- 41/50 miles (66/80 km) from large airports (MFD/CLE)
- 7 miles (11.2 km) from deep water Lake Erie port of Huron, OH
- Multiple unique, world-class, space environment test facilities

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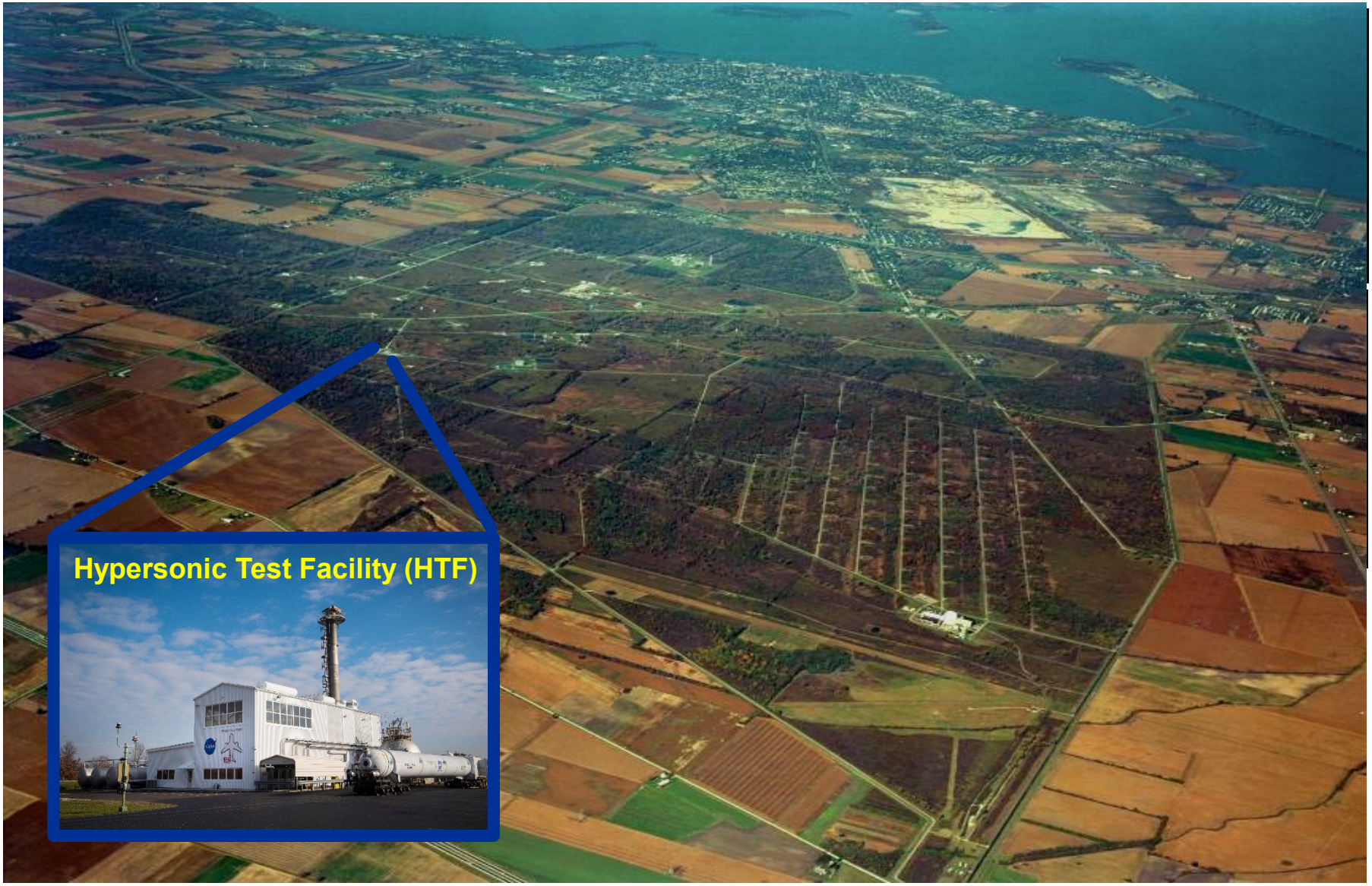
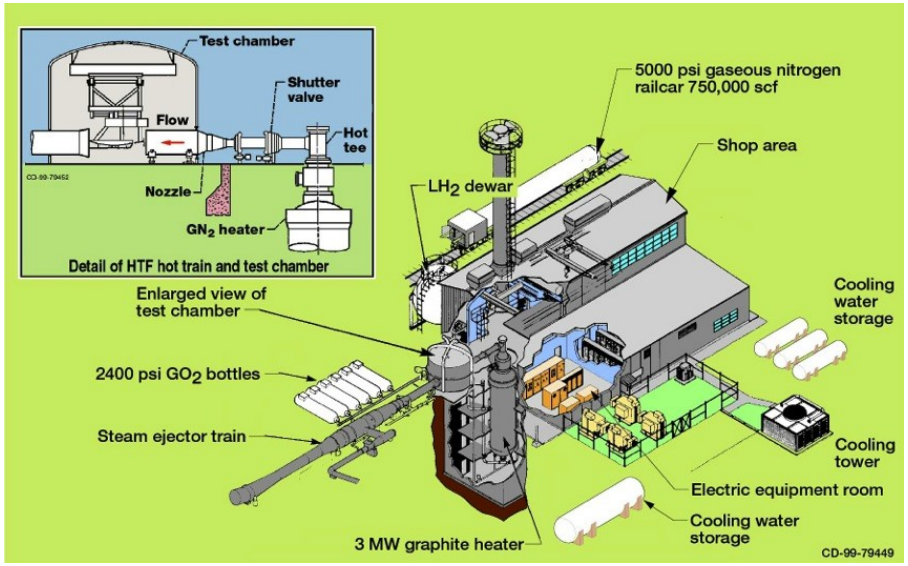
"Where Space Comes Down to Earth"

NASA's Plum Brook Station in Sandusky, Ohio



Hypersonic Test Facility (HTF)

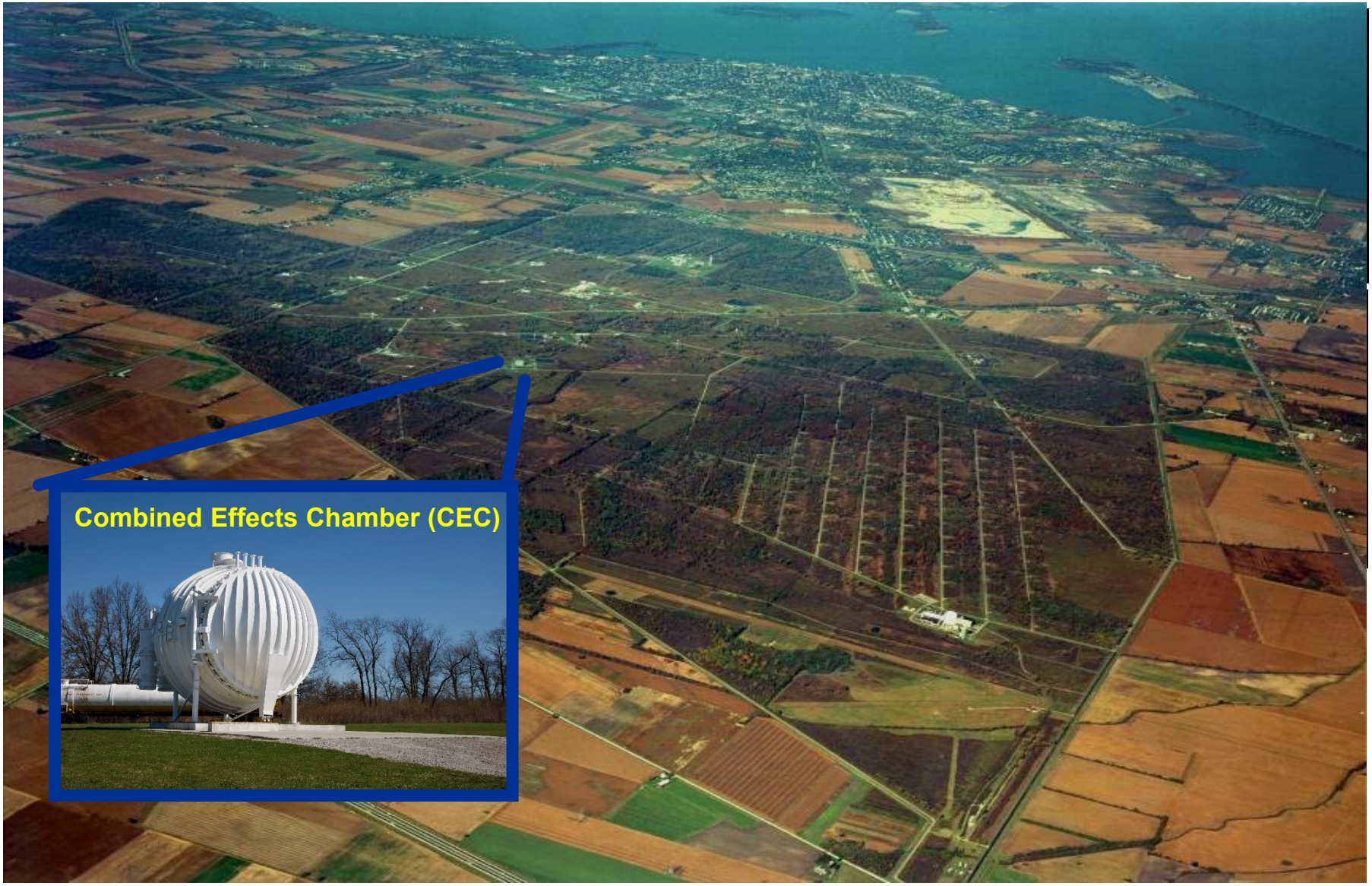


- **HTF is the United States' only large scale, non-vitiated (clean air) hypersonic test facility**
  - **42" test section**
  - **Run times up to 5 minutes**
  - **Capable of Mach 5, 6, 7 flows in either free-jet or direct connect modes**

- **This facility provides basic hot-flow test capabilities**
  - **Large scale hot-gas rocket nozzle testing (ambient or altitude up to 120k ft / 36km)**
  - **Materials testing**
  - **Communications through ionized flows for Entry, Descent, Landing**
  - **Hybrid gas electric propulsion for aviation**
  - **Hypersonic sensors, propulsion, airframe/engine integration**

https://www1.grc.nasa.gov/facilities/htf/

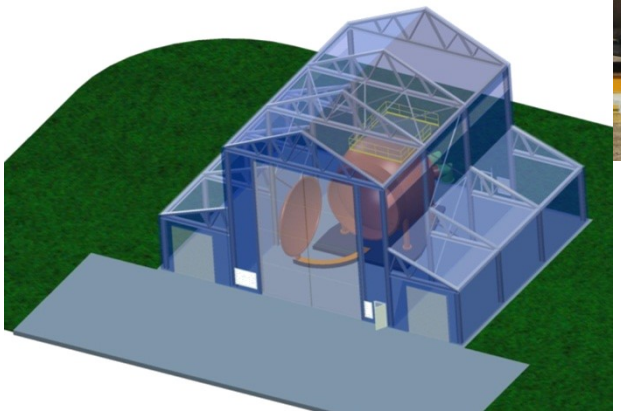
NASA's Plum Brook Station in Sandusky, Ohio



Combined Effects Chamber (CEC)

Planet/Planetoid Space Simulation

CEC helps rule out problems in space surface environments (solid as well as liquid) and qualify cryogenically cooled sensors for aeronautic use



KEY FEATURES

- Large size (25' dia. Spherical chamber)
- Pressure (35 psi) and
- vacuum capability (10-8 torr)
- Liquid hydrogen cold wall (40K temps)
- It can accommodate regolith simulant in the chamber, including stratification for drilling & excavation demonstrations
- Built-in shaker system that can be used for settling and stratification
- Simple design makes chamber inexpensive to maintain and operate

SYSTEMS AND COMPONENT TESTING FOR:

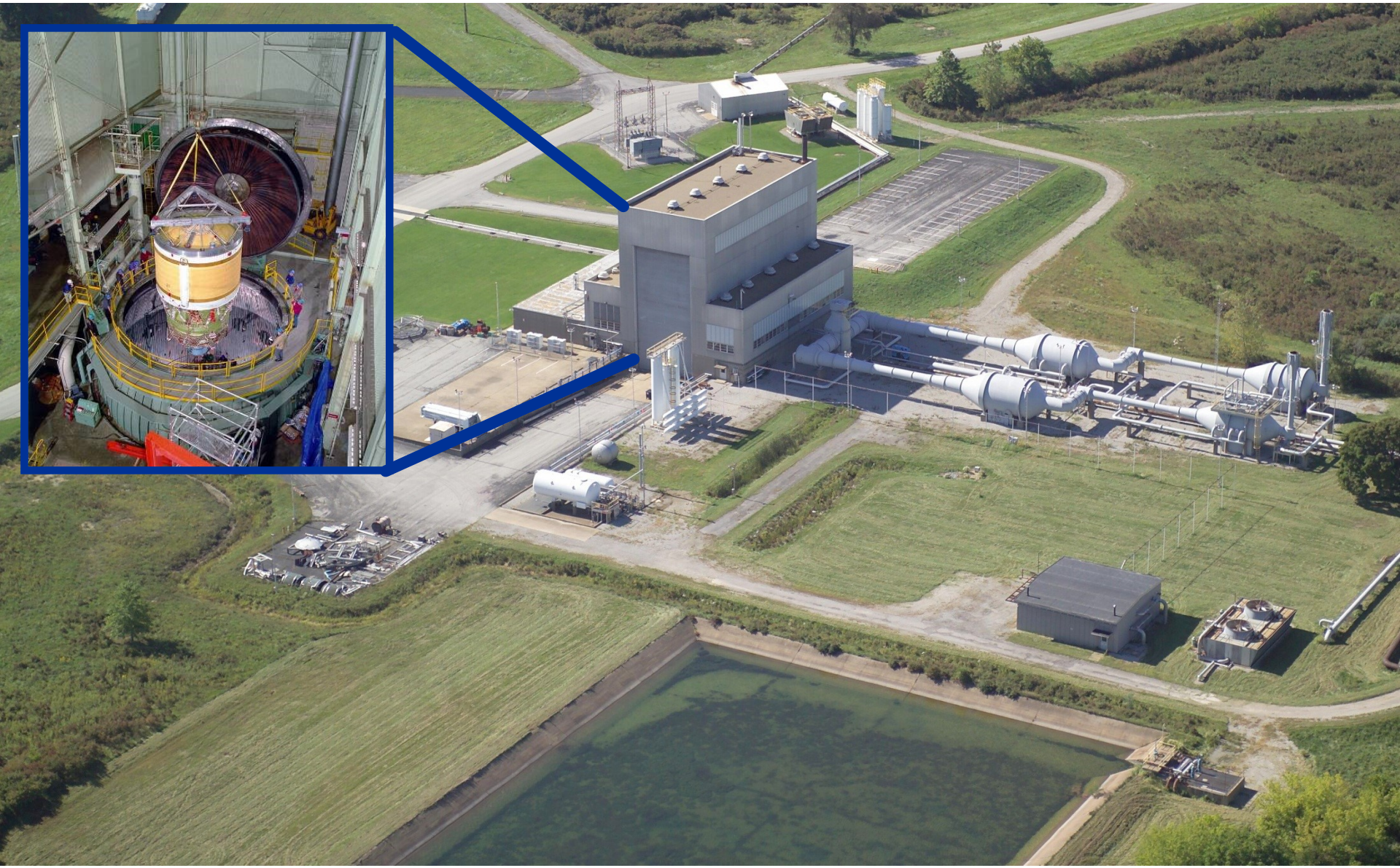
- Landers (robotic and human)
- Rovers (robotic and human)
- In-situ Resource Utilization (ISRU) systems
- Surface power systems
- Heat radiators and deployment systems
- Surface habitats
- EVA systems
- And much more

NASA's Plum Brook Station in Sandusky, Ohio

NASA Glenn Research Center
In-Space Propulsion (ISP) Facility

https://www1.grc.nasa.gov/facilities/isp/

NASA Glenn Research Center
In-Space Propulsion (ISP) Facility



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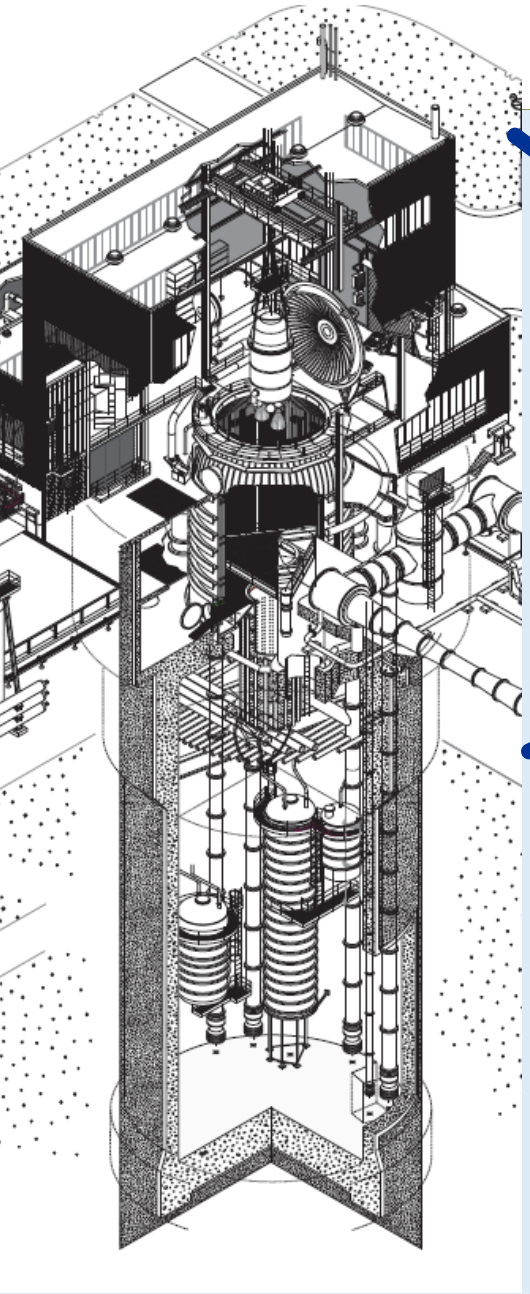

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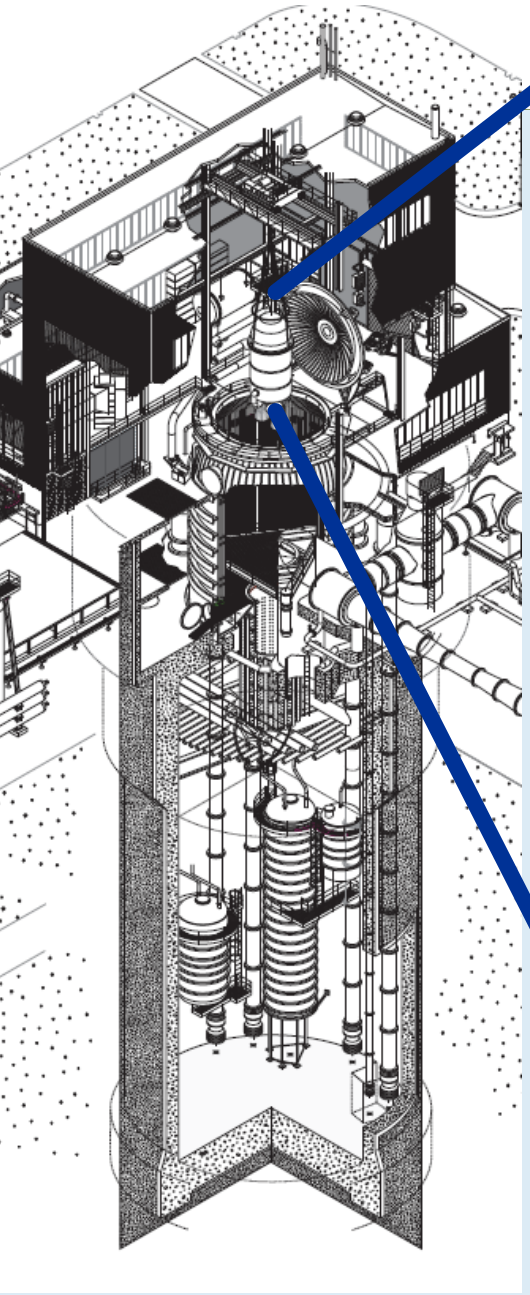


SpaceX
@SpaceX

Follow

Crew Dragon is at @NASA's Plum Brook Station testing facility in Ohio, home to the largest thermal vacuum chamber in the world, to demonstrate its capability to withstand the extreme temperatures and vacuum of space.
instagram.com/p/BkQ8w0mFoxa

4:33 PM - 20 Jun 2018

2,668 Retweets **16,933** Likes

312 2.7K 17K

https://www1.grc.nasa.gov/facilities/isp/

ISP Facility Capability Summary

(all values are approximate and for reference only)

Rocket Test Capability with Vacuum Start

(assumes LH2/LO2 props*)

10K lb Thrust Engine for 380 sec Test Duration

100K lb Thrust Engine for 270 sec Test Duration

300K lb Thrust Engine for 20 sec Test Duration

500K lb Thrust Engine for 5 sec Test Duration

* Other propellant combinations are possible

Space Simulation

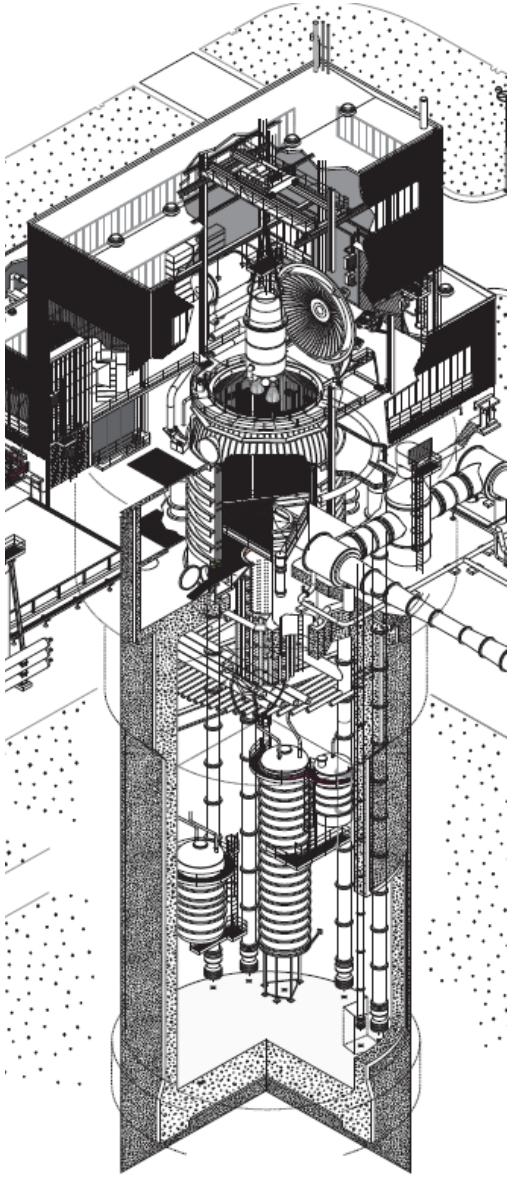
Test chamber is capable of vacuum space soak at $5x10^{-8}$ torr with -320°F (-195 °C) cold wall and 130w/ft^2 radiant heating. Uses mechanical and oil diffusion pumps to achieve vacuum conditions. Facility LN2 capacity is 200gal/min (cold wall uses 100gal/min).

Physical Dimensions

Test Chamber Clear Space	33ft (10m) dia
	55ft (16.7m) height
Top Entrance	27ft (8.2m) dia
Diffuser	11ft dia x 37ft long
Spray Chamber	67ft dia x 120ft (36.5m) deep

Exhaust System

Maximum capacity of 120 lbs/sec Dry Air Equivalent (DAE) at 1psia using a three stage intercondensing steam ejector consuming 348 lb/sec of steam. Produces ~0.14 psia in spray chamber with 40ºF water.



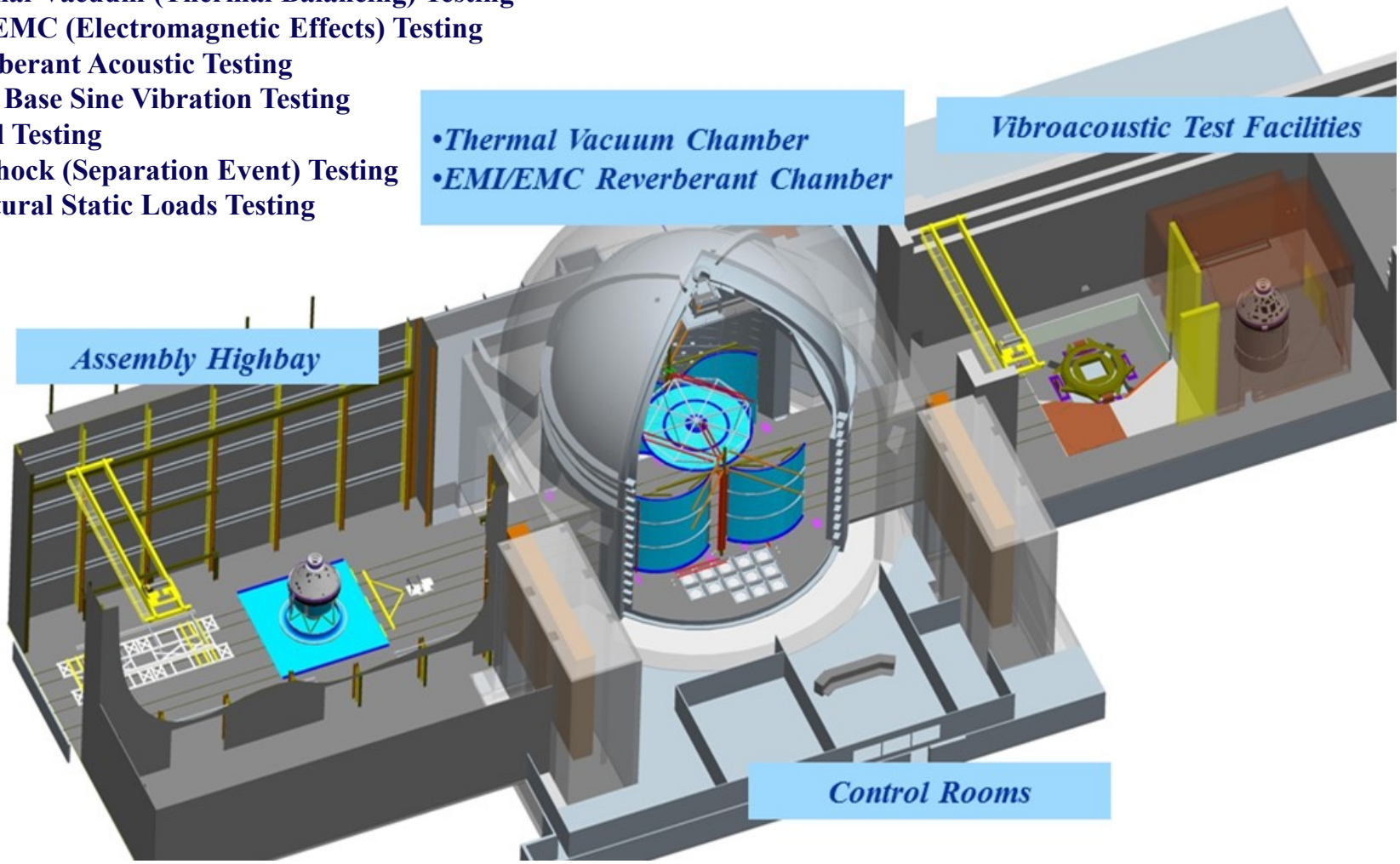
NASA's Plum Brook Station in Sandusky, Ohio

Space Environments Complex (SEC)

Space Environments Complex (SEC)

Space Environment Testing under "one roof"

- Upper Stage (Payload) fairing separation Testing
- Thermal-Vacuum (Thermal Balancing) Testing
- EMI/EMC (Electromagnetic Effects) Testing
- Reverberant Acoustic Testing
- 3-axis Base Sine Vibration Testing
- Modal Testing
- Pyroshock (Separation Event) Testing
- Structural Static Loads Testing



Space Environments Complex (SEC)

One-of-a-kind environmental testing capability at ONE location:

Assembly/Staging Area (High-bay)

Thermal-Vacuum /EMI Chamber

Mechanical Vibration

Reverberant Acoustic

https://www.nasa.gov/specials/sec360/#

Space Environments Complex (SEC)

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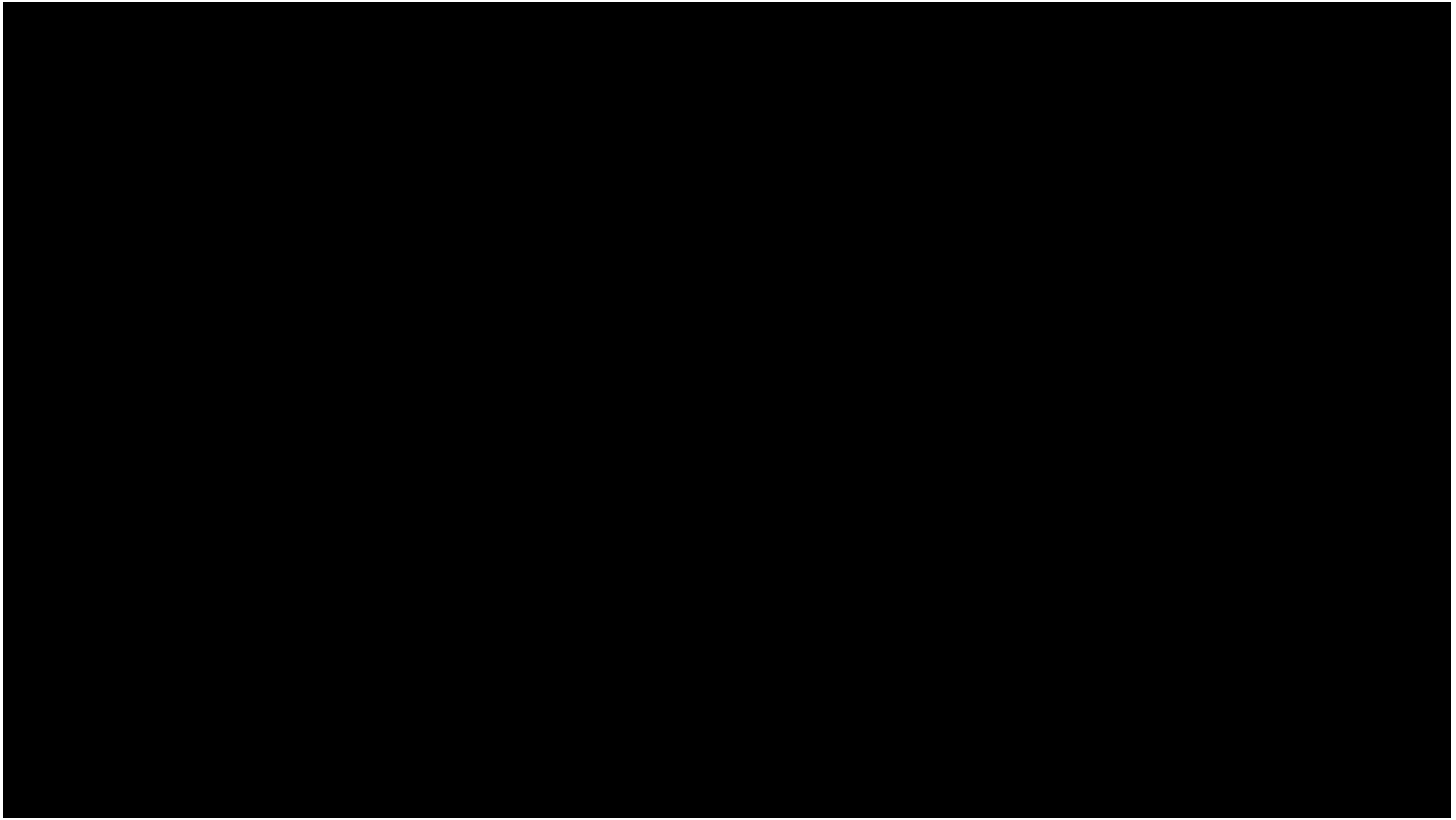

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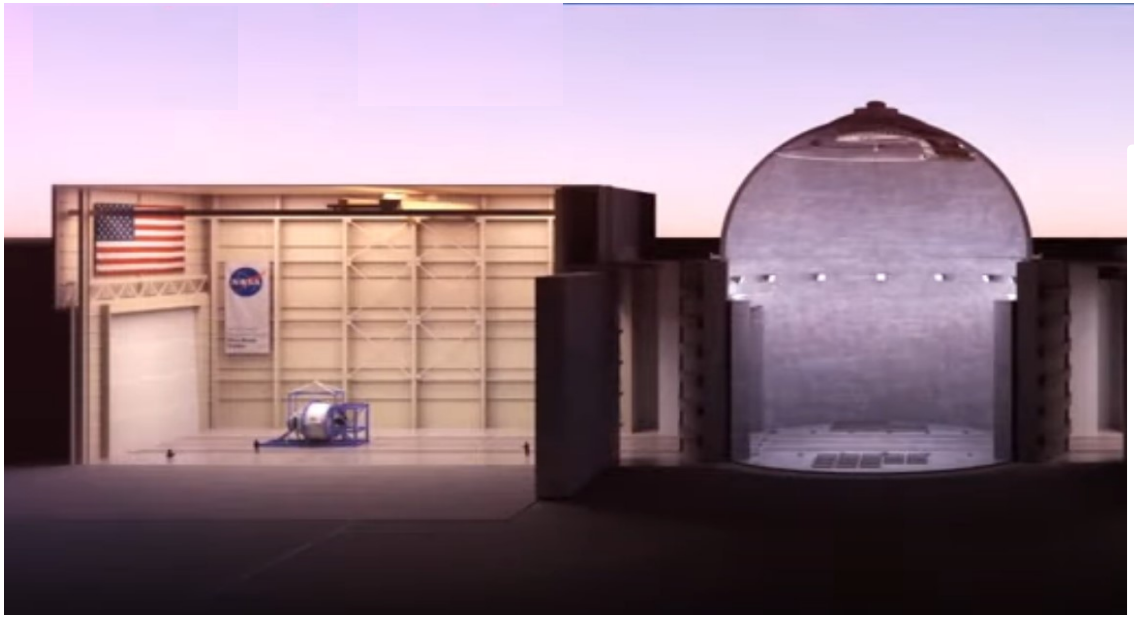
One-of-a-kind environmental testing capability at ONE location:



Thermal-Vacuum / EMI Chamber

… the largest space simulation chamber in the world

- ✓ 800,000 ft^3 volume, 100ft (30m) diameter, 122ft (37m) high
- ✓ Ambient to 10^{-6} Torr vacuum capability
- ✓ Features variable geometry cryogenic shrouds
- ✓ 7 MW power available for solar simulation
- ✓ Reverberant-mode EMI/EMC capability (45MHz–40 GHz)

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One-of-a-kind environmental testing capability at ONE location:

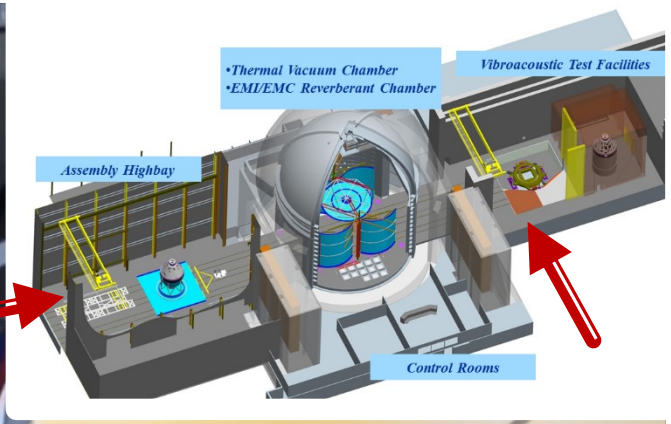
Thermal-Vacuum / EMI Chamber

… the largest space simulation chamber in the world

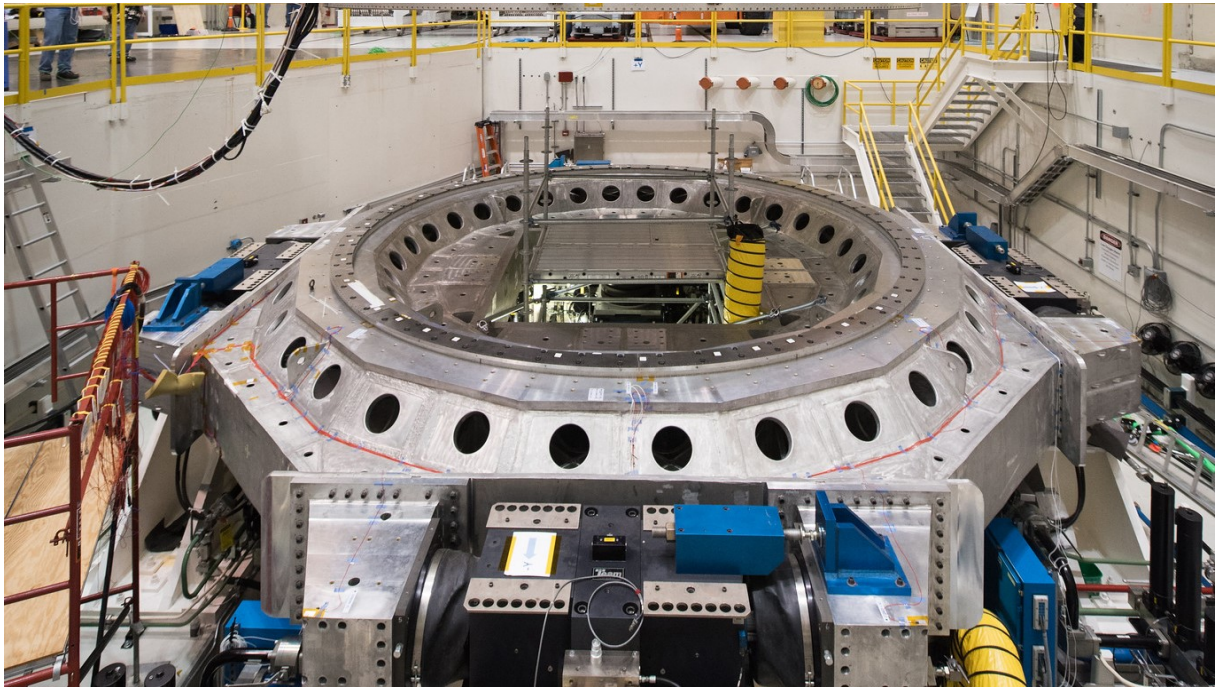
- ✓ 800,000 ft^3 volume, 100ft (30m) diameter, 122ft (37m) high
- ✓ Ambient to 10^{-6} Torr vacuum capability (-200 to 150 °C)
- ✓ Features variable geometry cryogenic shrouds
- ✓ 7 MW power available for solar simulation
- ✓ Reverberant-mode EMI/EMC capability (45MHz–40 GHz)

Space Environments Complex (SEC)

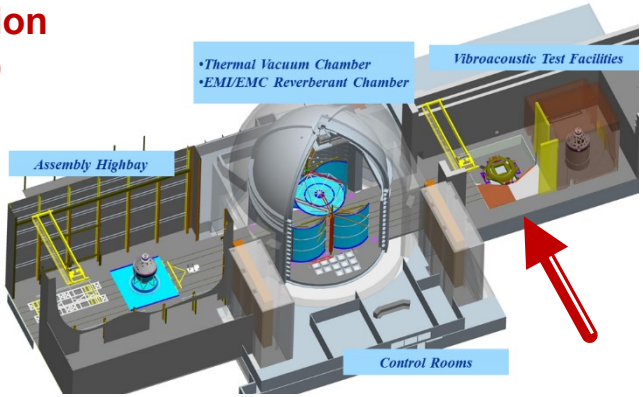
High-Bay Test Areas
(Shock, Modal, Deploy)



Space Environments Complex (SEC)



Mechanical Vibration Test Facility (MVF)

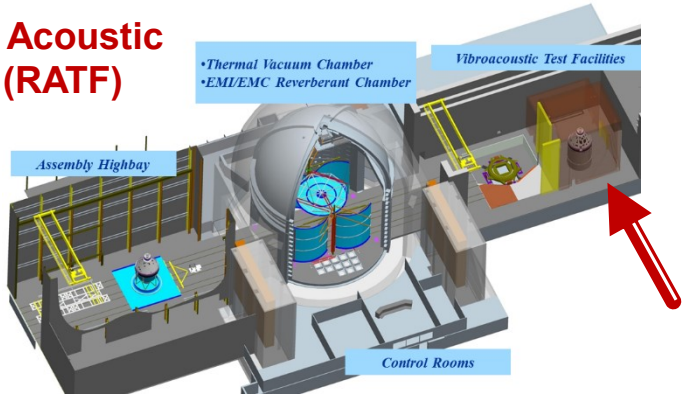


… the highest capacity shaker system in the world

- ✓ 18ft (5.4m) diameter shaker table
- ✓ 75,000 lb (34,000 kg) test article (1.25 g's vertical, 1.0 g's horizontal)
- ✓ Frequency range: 5 - 150 Hertz
- ✓ Sinusoidal testing in 3-axis

Space Environments Complex (SEC) - RATF

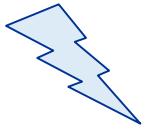
Reverberant Acoustic Test Facility (RATF)



… the most powerful reverberant chamber in the world

- ✓ Capable of an overall sound pressure level of 163 dB
- ✓ 101,000 ft^3 volume, 37.5 ft x 47.5 ft x 57 ft high (2,860 m^3 volume, 11.5m x 14.5m x 17.5m high)
- ✓ 36 acoustic modulators and horns for highly-tailored spectrum-shaping

"Wired" Measurement Topology



Sensors & Transducers

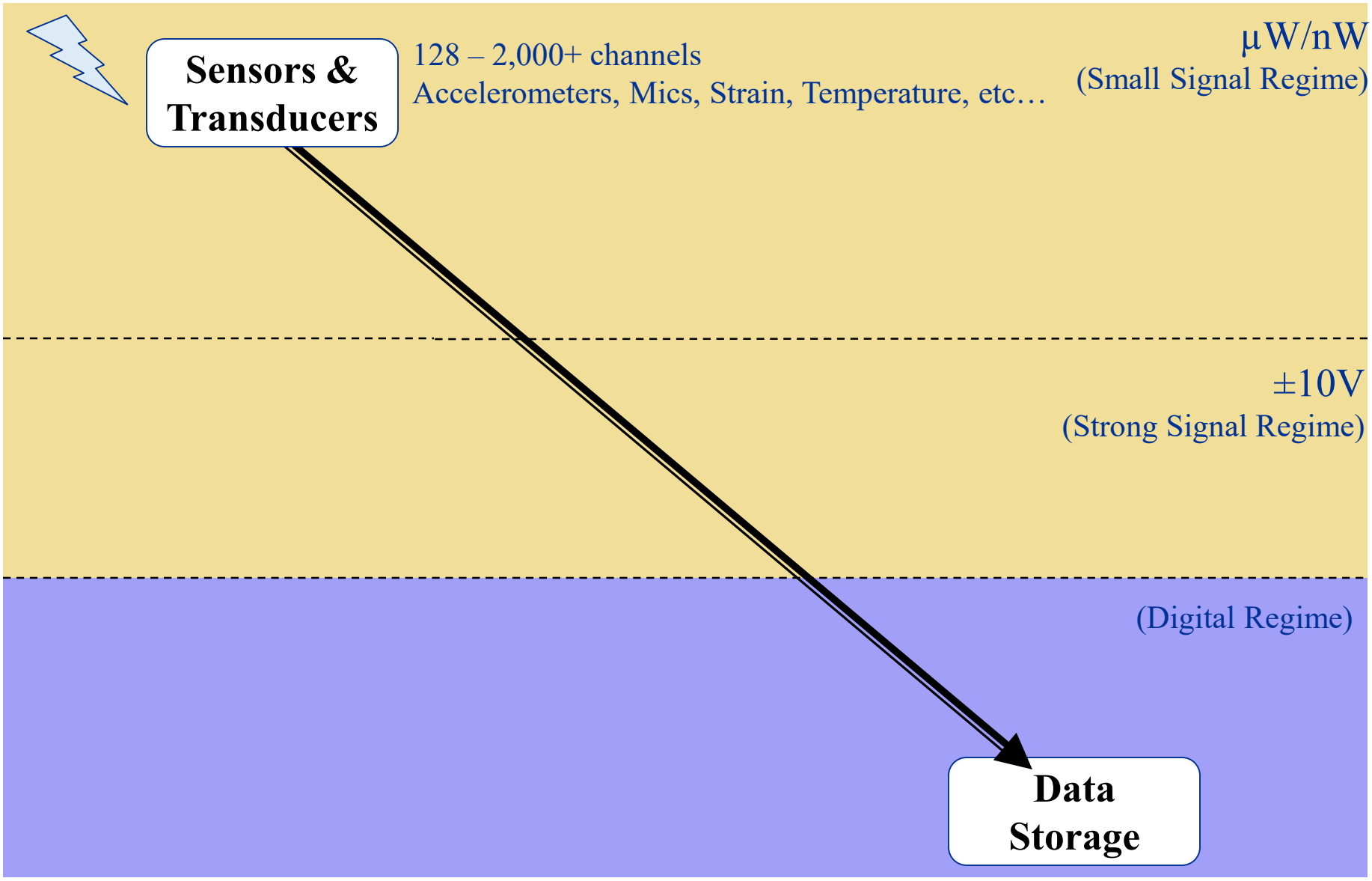
128 – 2,000+ channels
Accelerometers, Mics, Strain, Temperature, etc…

µW/nW
(Small Signal Regime)

(Digital Regime)

Data Storage

"Wired" Measurement Topology



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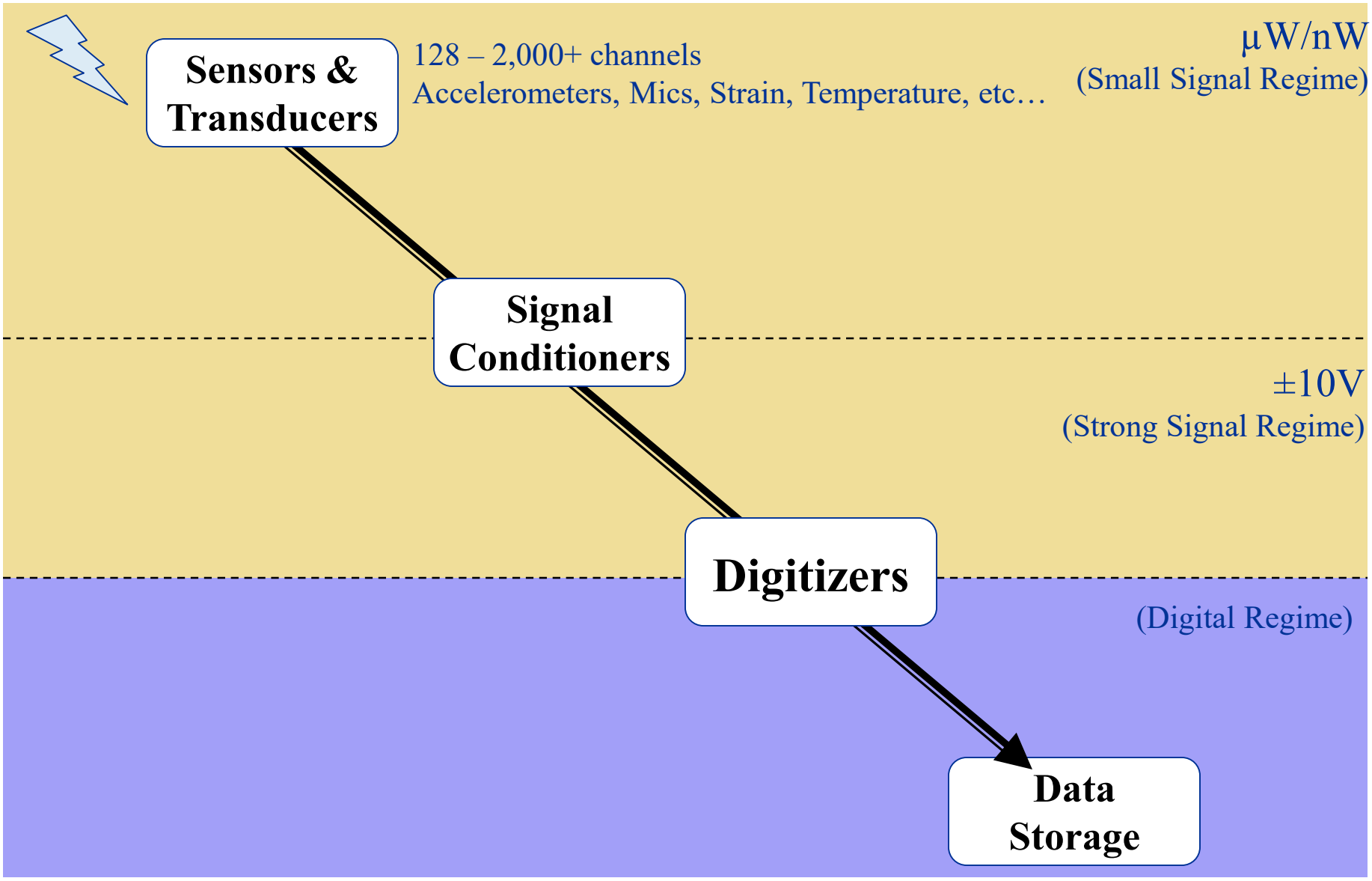

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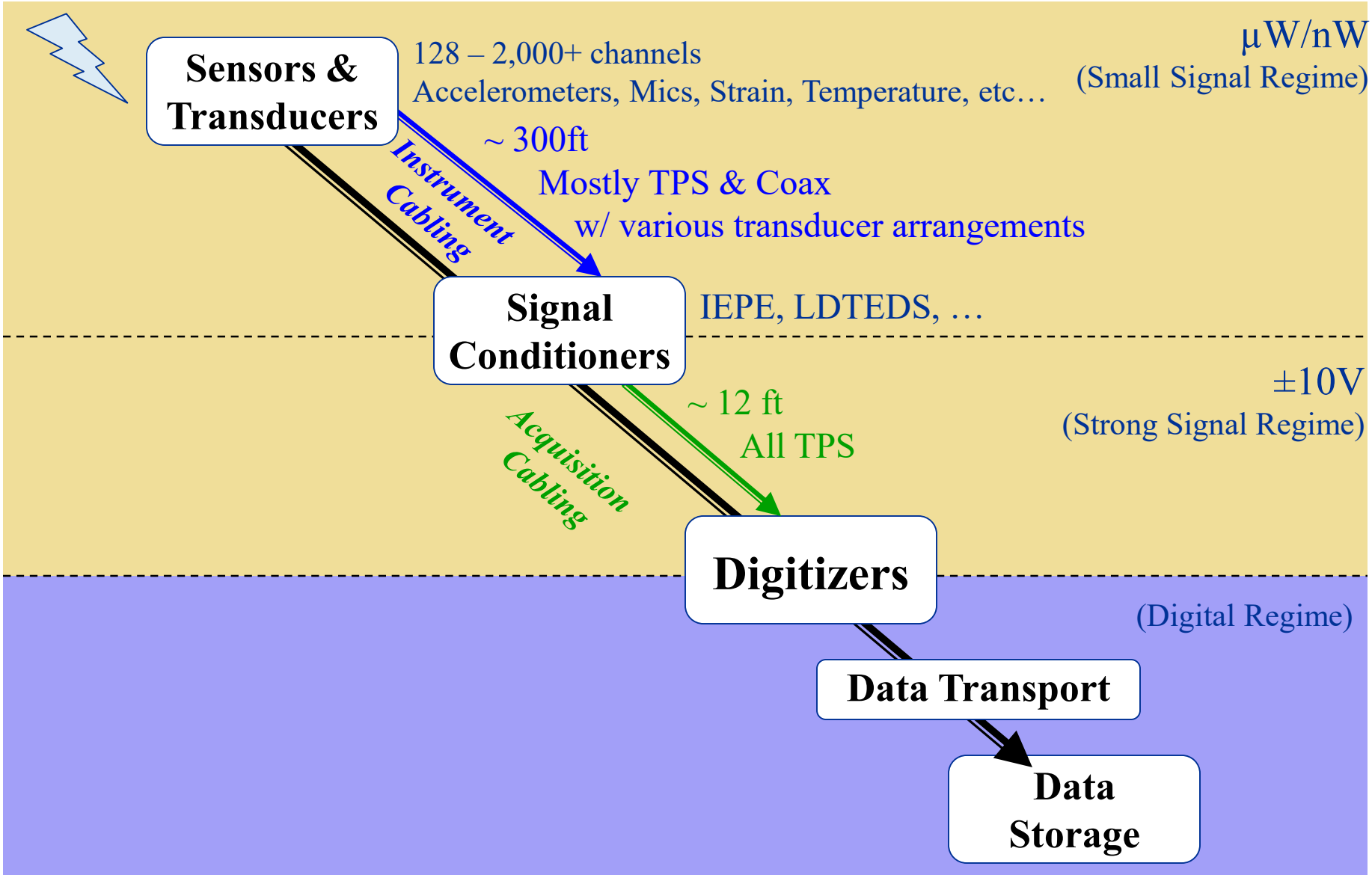

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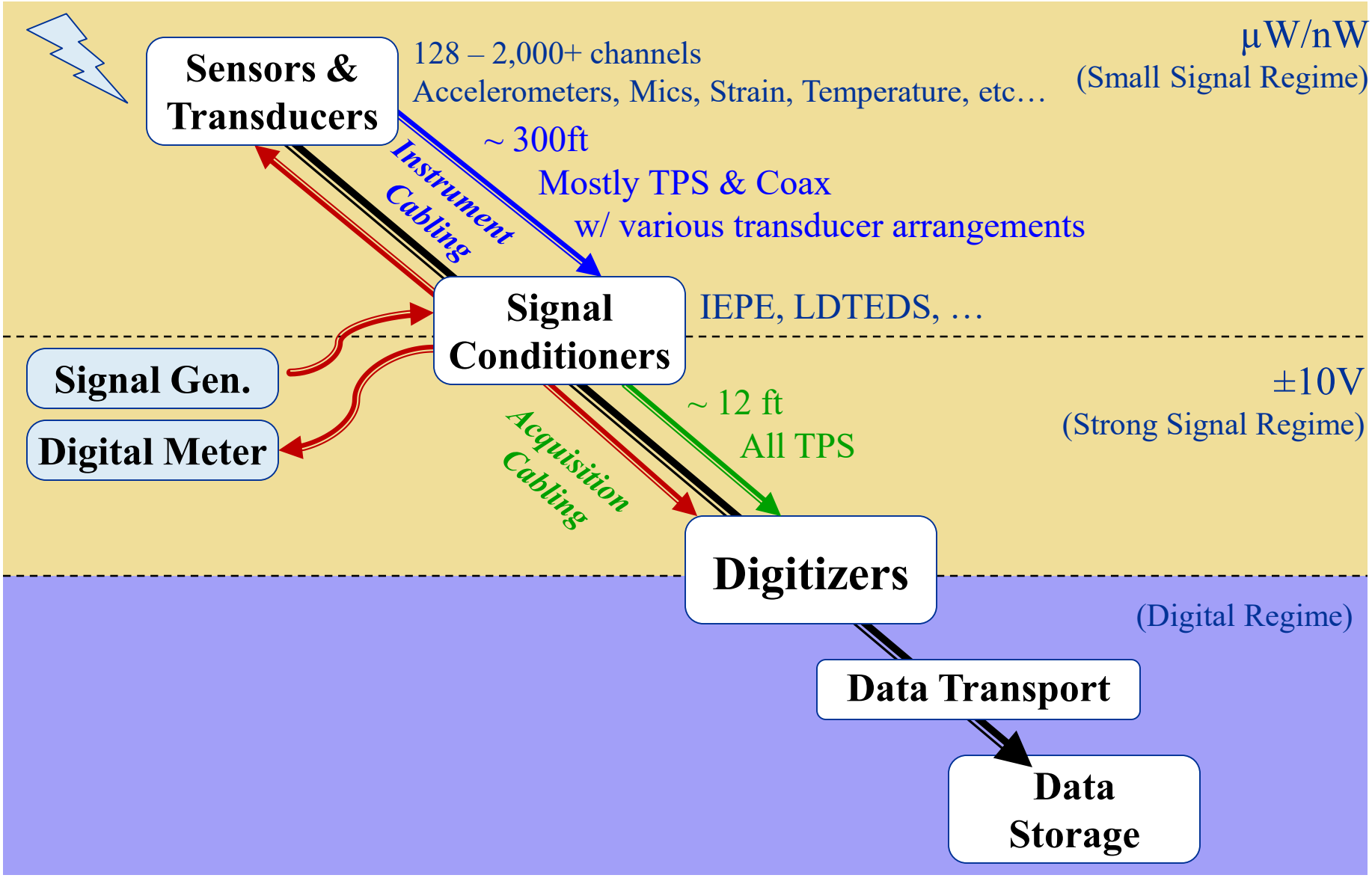

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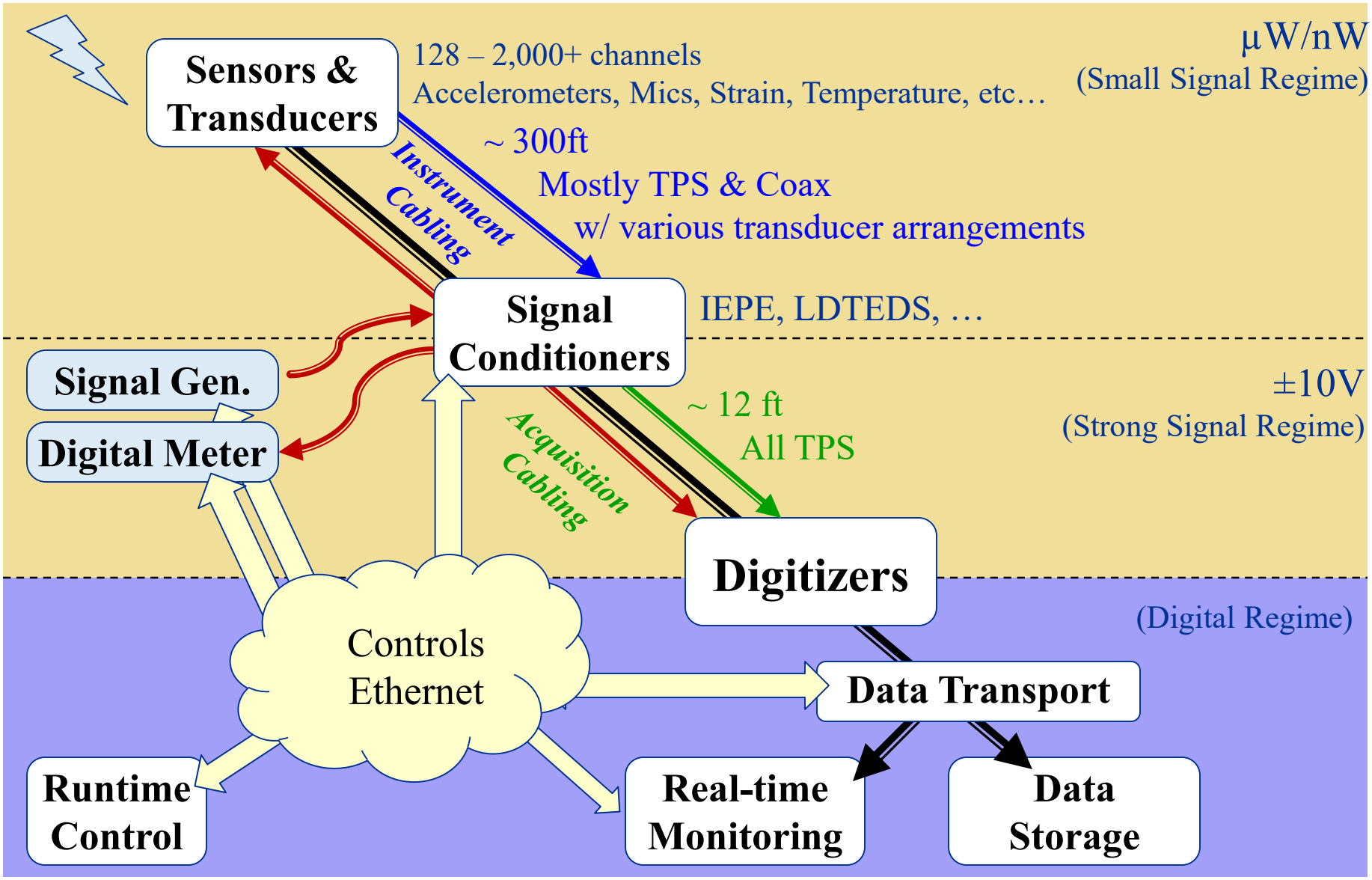
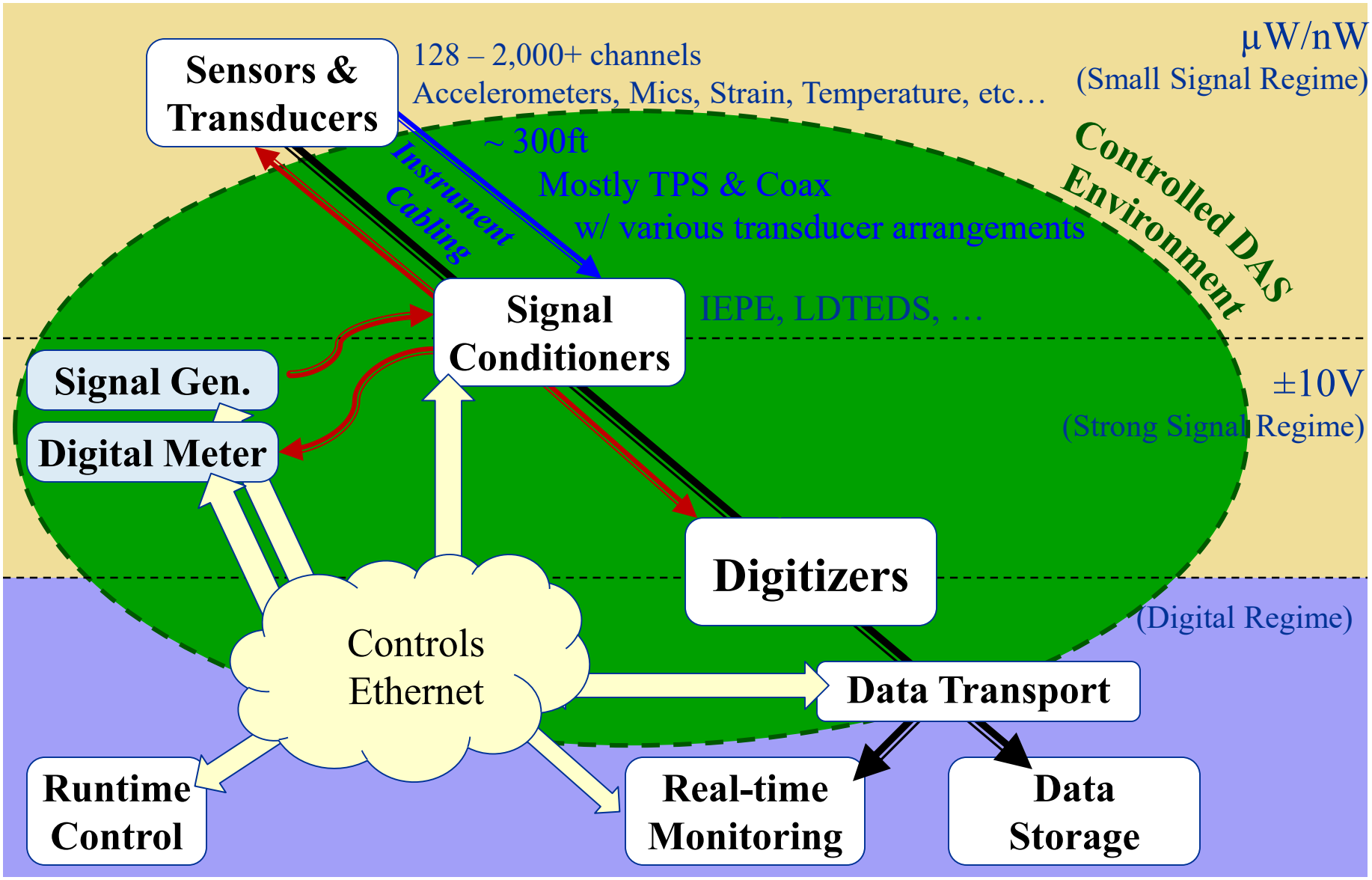
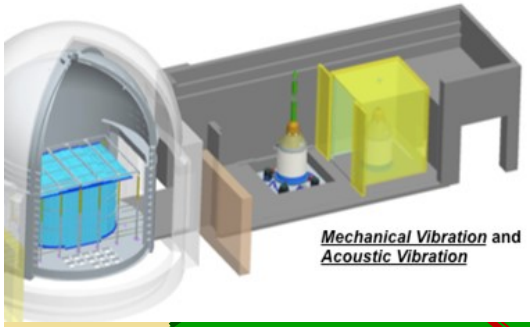


"Wired" Measurement Topology



"Wired" Measurement Topology (HSDAS)



28, 256, 512, 1,024 and ~ 2,000+ channels
ccelerometers, Mics, Strain, Temperature, etc…

µW/nW
(Small Signal Regime)

< 300ft
Mostly TPS & Coax
w/ various transducer arrangements

Controlled DAS Environment

Standardized Signal Conditioning/Ch.

16 bit ADCs
1,024 – 1,536 channels
variable SR/Ch.

±10V
(Strong Signal Regime)

Acquisition Cabling

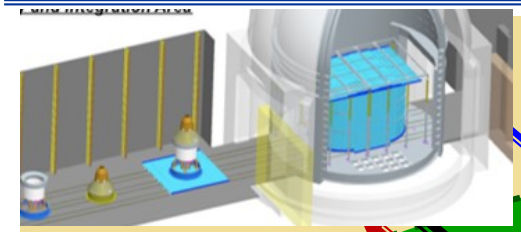
Controls Ethernet

4Gbps/ea.

(Digital Regime)

3TB/ea.

"Wired" Measurement Topology (LSDAS)



128, 256, 512, 1,024 and ~ 2,000+ channels
Accelerometers, Mics, Strain, Temperature, etc…

µW/nW
(Small Signal Regime)

Controlled DAS Environment

< 300ft

Type "T" Thermocouples

280)

Integrated Temperature Measurement System

ADAS Translator Brick/PC

±10V
(Strong Signal Regime)

Ethernet Cabling

Controls Ethernet

4Gbps/ea.

(Digital Regime)

3TB/ea.

In-Space Propulsion (ISP) Test Facility - DAS

Designed for High Altitude Engine Testing

Instrument Cabling to Test Chamber		Quantities
1	Single Pair, Twisted-Pair Shielded	>1,700 Ch. 1PR TPS
2	Four-Wire, Twisted-Pair Shielded	312 Ch. of 4C / Ch.
3	Impedance Matched Coaxial	~64 Ch.
Signal Conditioning Equipment		
4	Constant-Voltage Bridge Conditioners	76 Ch.
5	Constant-Current Bridge Conditioners	32 Ch.
6	ICP/IEPE Conditioners	48 Ch.
7	Charge-Type Amplifiers	
8	Filter/Amplifier Signal Conditioners	160 Ch.
9	Frequency-to-Voltage	28 Ch.
10	Direct Voltage Inputs	600+ (see ADCs)
11	UTR Thermocouple Conditioners	<tbd>
Digitizing Equipment (ADCs)		
12	High-Speed Digitizers (110 kHz MBW/Ch.)	32 Ch. - 256 Ch.
13	Low-Speed Digitizers (1 kHz MBW/Ch.)	576 Ch.
14	Discrete Channel Acquisition	32 Ch.
Data Storage		
15	RAID 1+0 redundant fail-over storage	2.5 – 3 Terabytes
Control, Monitoring and Post-Processing		
16	Dedicated Control Computers	2
17	Dedicated Monitoring Computers	4
18	Dedicated Post-Processing Computer	1
Other Notable System Elements		
19	IRIG-B Distribution	All
20	LTO-3 Tape Archival System	All

Space Environments Complex (SEC) – HSDAS

Designed for Large-Scale Environment Testing

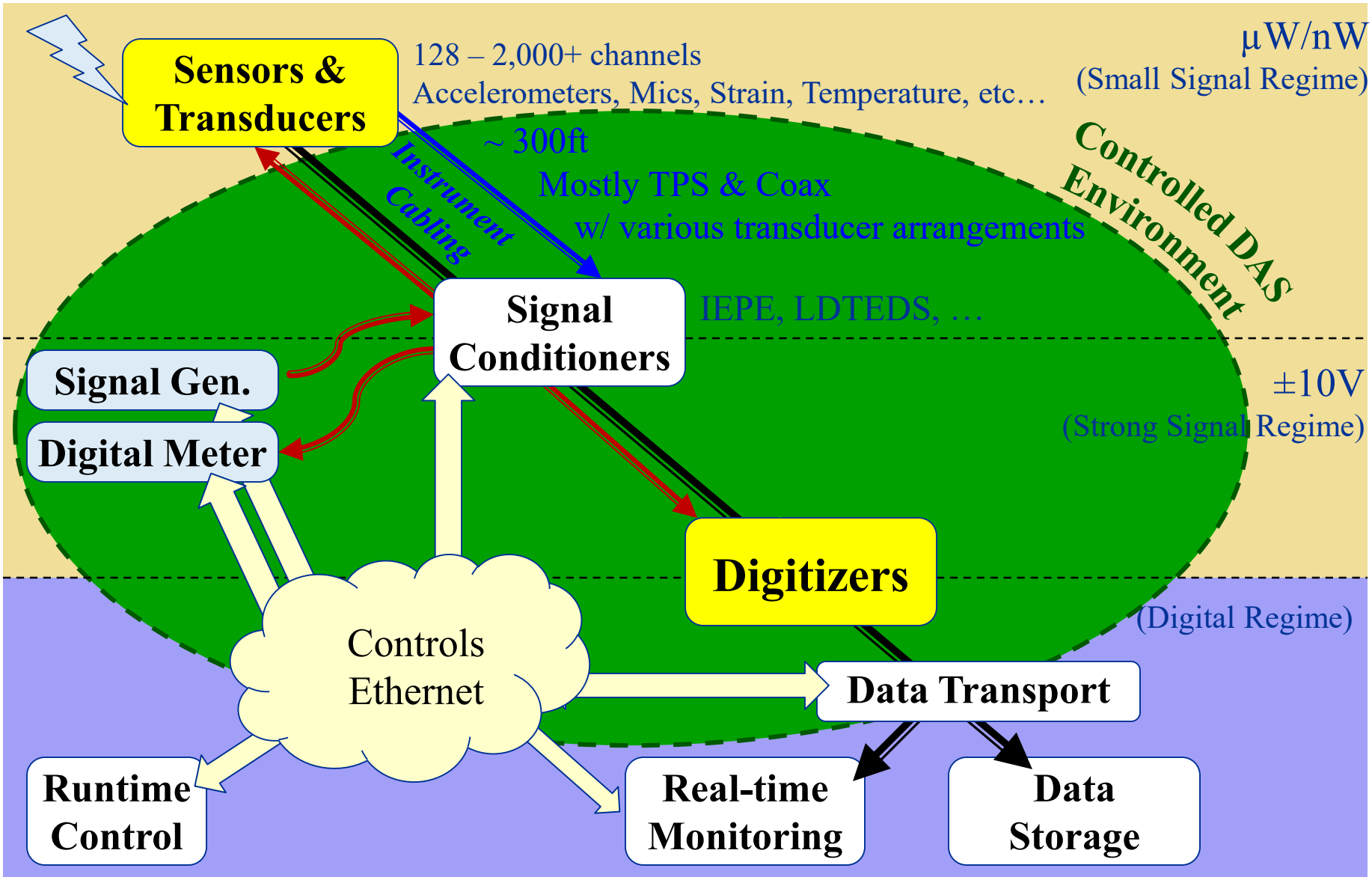
Instrument Cabling to the MVF table and RATF chambers		Num. of Channels
2	Impedance Matched Coaxial to/from ACS	64 Ch.
3	Impedance Matched Coaxial to/from VCS	64 Ch.
Signal Conditioning Equipment		
5	Constant-Voltage Bridge Conditioners	160 Ch.
6	Direct Voltage Inputs from ACS/VCS	64 Ch.
7	Buffered Voltage Outputs to ACS/VCS	64 Ch.
Digitizing Equipment (ADCs)		
Data Storage		
9	RAID 1+0 redundant fail-over storage	3 Terabytes total
Control, Monitoring and Post-Processing		
10	Dedicated Control Computers	1
11	Dedicated Monitoring Computers	3
12	Dedicated Post-Processing Computer	1
Other Notable System Elements		
13	IRIG-B Distribution	All
14	LTO-3 Tape Archive	All

Space Environments Complex (SEC) – LSDAS

Designed for Large-Scale Environment Testing

Instrument Cabling in the Vacuum Chamber Annulus		Num. of Channels
1	Single Pair, Twisted-Pair Shielded	324 Ch. 1PR TPS
2	Four-Wire, Twisted-Pair Shielded	288 Ch. 4C/Ch.
3	Impedance Matched Coaxial	126 Ch. BNC
		- 1,280 Ch.
Signal Conditioning Equipment		
5	ICP/IEPE Conditioners	64 Ch. *
6	Constant-Voltage Bridge Conditioners	48 Ch. †
7	Charge-Type Conditioners	24 Ch. †
8	Direct Voltage Inputs	120 Ch.
9	Buffered Voltage Follower Outputs	As needed†
10	Thermocouple Signal Conditioning	
Digitizing Equipment (ADCs)		
11a	Low-Speed Digitizers/Data-Translators (10Hz SR)	512 Ch. - 1,280 Ch.
Data Storage		
12	RAID 1+0 redundant fail-over storage	3 Terabytes total
Control, Monitoring and Post-Processing		
13	Dedicated Control Computers	1
14	Dedicated Monitoring Computers	4*
15	Dedicated Post-Processing Computer	1*
Other Notable System Elements		
16	IRIG-B Distribution	All
17	LTO-3 Tape Archive	All*

Topology of "Wired" Measurements

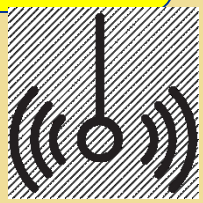


Topology of "Wireless" Measurements

PWST WiSEE Sensors

128 – 2,000+ channels
Accelerometers, Mics, Strain, Temperature, etc…

µW/nW
(Small Signal Regime)



~20 channels pressure form ambient to 10^{-6} Torr vacuum capability
~1,200 channels temperature from -200 to 150 °C
.. Is this possible?

PWST WiSEE Interrogator(s)

(Digital Regime)

Controls Ethernet

Data Transport

Runtime Control

Real-time Monitoring

Data Storage

Thank you.