AFRL

Overview of AFRL Radiation Hardening Technologies

Dr. Jesse Mee, ST

DAF Senior Scientist for Radiation Hardening Technologies

Air Force Research Laboratory
One Lab, Two Services

AFRL

Space technologies
Space experimentation

Space Vehicles **RV**

Space Domain Awareness
Laser & high power microwave effects

Directed Energy **RD**

Space access
In-space propulsion
Space logistics

Aerospace Propulsion **RQ**

Super computing resources
Digital transformation

Compute Resources **RC**

Materials & manufacturing
Laser hardening
Additive manufacturing

Materials **RX**

One AFRL – works across vast technological areas, finding synergies that allow us to move faster to field critical space programs

AFWERX **RG/SB**

Classified Programs

SDPE **RS**

Innovation
Tech and industrial base expansion

Inform S&T Vector
Experimentation
Operational assessment
MS&A and Studies

Information RI

Networks & comms
Cyber
Multi-domain C2

Human Effects **RH**

Operator performance
Autonomous systems
Operator training

Munitions **RW**

Small platform PNT, sensors, and components

Sensors **RY**

Sensor & data exploitation
Cognitive EW
Position, Nav, & Timing

Basic Science **OSR**

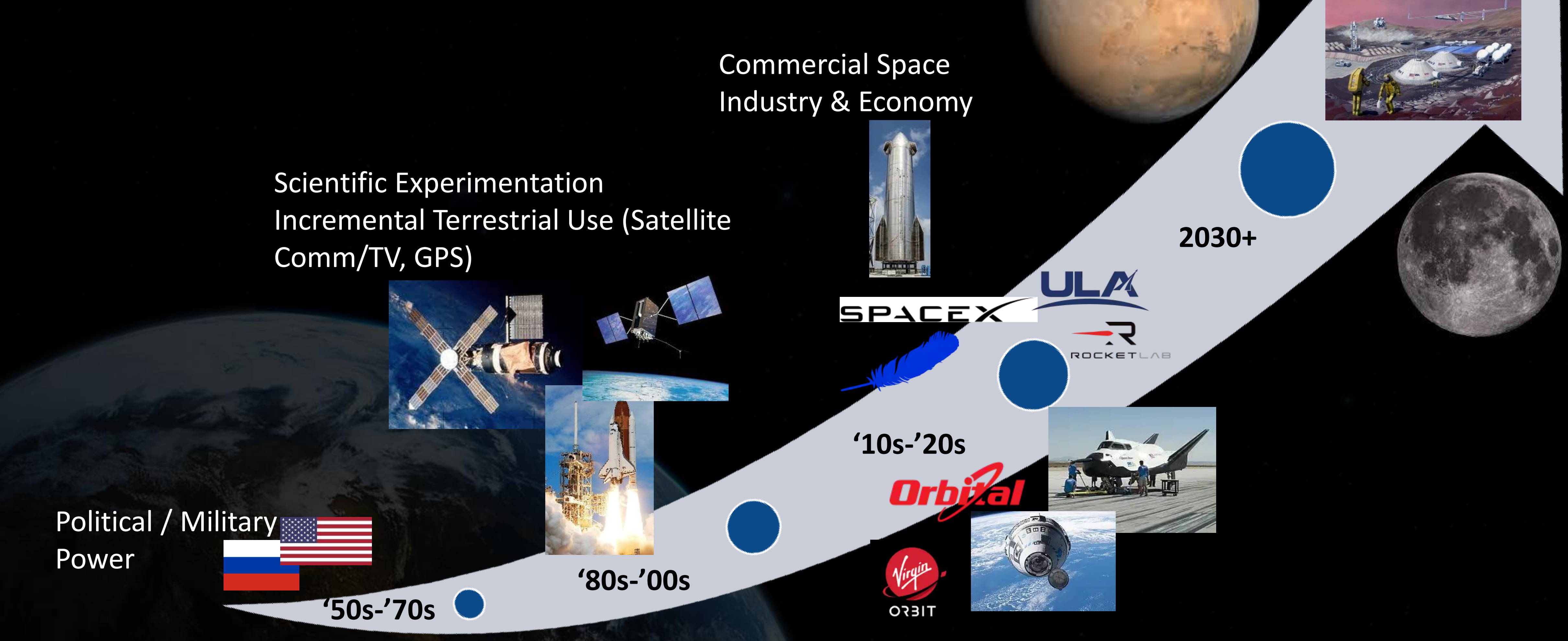
Basic science – materials, quantum, power, etc
International research

AFRL

Evolving Space Ecosystem

Diverse Space Activities …

Changing At An Increasing Pace



Trends for Communications

AFRL

Yesterday
Stove-Piped Missions Areas
(past)

Attributes

- Stove-Piped acquisition and ops
- Strategic requirements focused
- Lengthy requirements process
- Large, costly programs
- Incremental technology
- Limited resiliency

<u>Today</u>
Hybrid Architecture
(today – ~15 years)

Attributes

- Mixture of strategic and tactical
- Orbital regime diversification
- Platform size variation
- International, commercial and DoD coordination and integration
- Multi-path communication

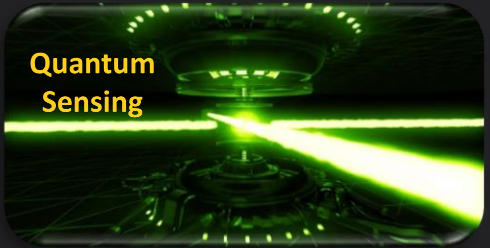
<u>Next</u>
Heterogeneous Architecture
+15 years and beyond

Attributes

- Resembles more of the modern day internet – IoT of Space
- Ubiquitous communication
- Integrated autonomy and ML/AI
- Truly integrated multi-domain
- Ubiquitous information exploitation and decision making

AFRL/RV Mission Areas

Satellite Communication and PNT



- Robust and resilient PNT
- Wide- and narrowband comm
- Agile Space Capabilities Aligned with User Equipment

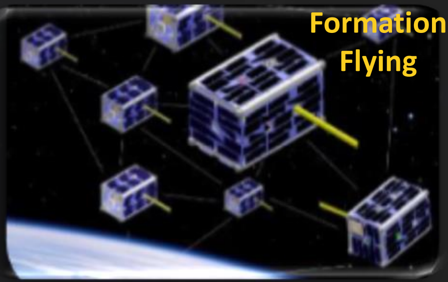
Missile Warning & Tactical ISR

- Novel IR focal planes
- Resilient sensor tech
- Infrared Radiation Effects Lab

Space Environment

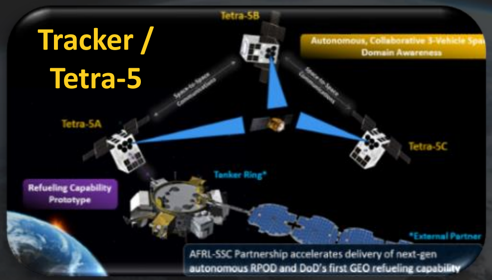
- Sensor design and deployment
- Monitor, forecast, and mitigate
- Dominate the EM Ops Envir.

Pervasive Technologies



- Power, structures, electronics
- Space logistics and maneuver
- Size, weight, power and cost

Advanced Space Operations

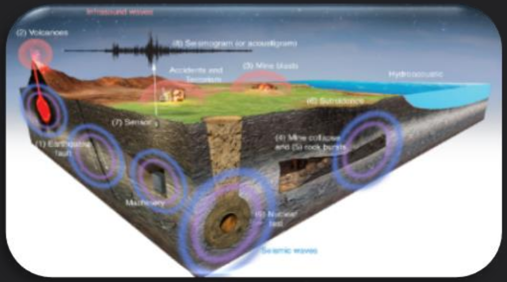


- Cislunar Situational Awareness
- Cyber protection, hardening
- Prompt decision making

Small Satellite Portfolio

- Rapid prototyping & proof of concept
- Cost efficient tech experiments

Nuclear Deterrence Operations

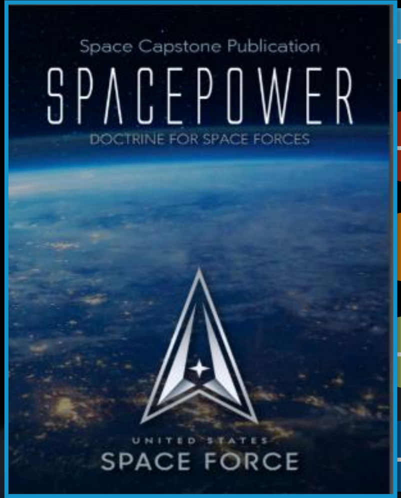


- Inertial navigation systems
- Nuclear Explosion Monitoring
- Hypersonic modelling & sim

Agile Software Operations

- Software factory, SecDevOps
- Unified Data Library market
- User interfaces, decision aids

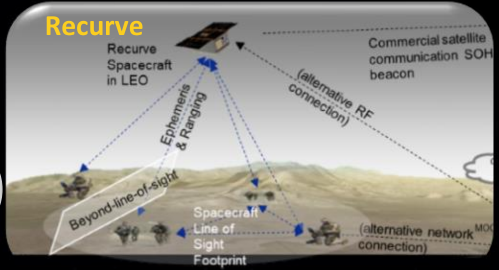
S&T Aligned to DAF Missions



Combat Power Projection

Enabling multi-domain decision making

Information Mobility

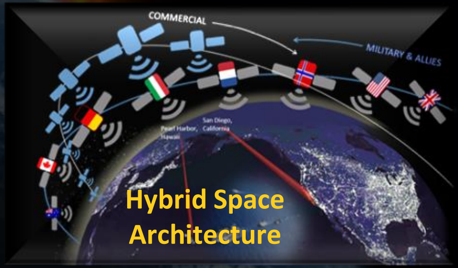


Multi-domain mesh networking

Space Mobility & Logistics

Maneuver without regret enabled by space logistics

Space Security



Multinational system leveraging Gov/Commercial Assets

Space Domain Awareness

Pushing situational awareness into cislunar space

Radiation Hardening Activities Across the Lab

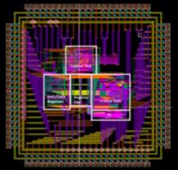
AFRL

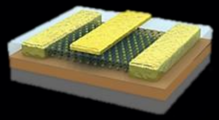
Space Electronics Technology (SET) Overview

Conceive and develop resilient space electronics that enable next-gen warfighting capabilities

Space Electronics Innovations

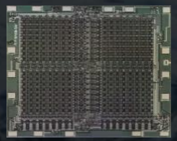
Reversible Computing





2D Materials

Heterogeneous Processing

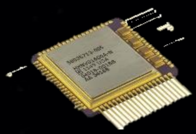


Graphene Memory

Resilient High-Performance Space Electronics

Multi E-Beam Lithography

Rad-Hard M4 Microprocessor

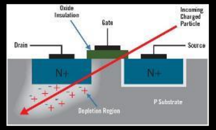


Strategic RH STT MRAM

Strategic RH Microprocessor

Payload Electronics Performance and Resilience

Rad-Tol Single Board computer



Fault Tolerant Computing

Rad Testing of COTS Technologies

Flight Experiment

Explore revolutionary processing architectures & device concepts to provide leap-ahead space capabilities	Innovate high-performance, resilient space electronics, essential for future defense space & missile systems	Assess & Validate that electronics performance and rad susceptibility satisfy mission requirements

INTelligent-automation through Revolutionary Edge Processing for IC and Defense applications (INTREPID)

Space Vehicles
RV

Need for Compute-in-Memory processing

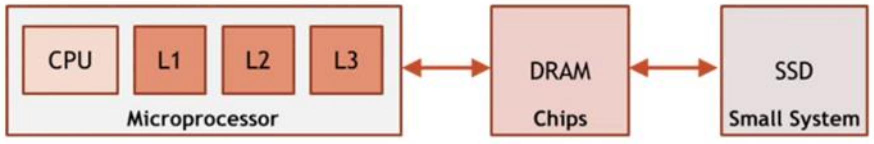
- Many future terrestrial and space systems require copious amounts of AI-based edge processing to support autonomous operations and/or to manage large amounts of image data
- These Artificial Intelligence(AI)/Machine Learning (ML) and image processing applications require frequent memory operations – **power hungry and slow!**
- Most AI or image processing is **matrix-vector multiplication** of large matrices
- The traditional von Neumann CPU architecture memory access hierarchy has a problem – **it requires moving lots of data to/from memory!**
- GPUS – use lots power, typically 100's of watts

Need new strategies to reduce this memory traffic

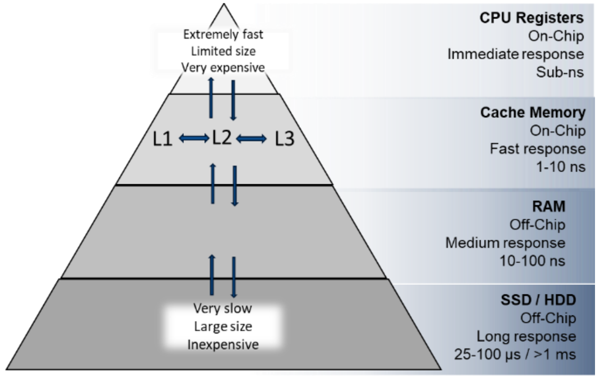
- For digital logic, embed processors in memory and store weights in that memory, reducing the distance between processors and memory, shortening the hierarchy
- Hold weights in resistive memory, then **compute in analog** using Kirchoff's current law

Goal

- Develop prototype radiation-tolerant co-processor/accelerator chip that achieves 10X or better improvement in processing speed and power utilization

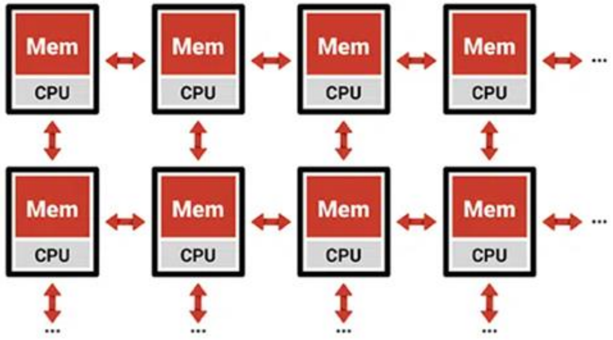


A Standard Computing Architecture

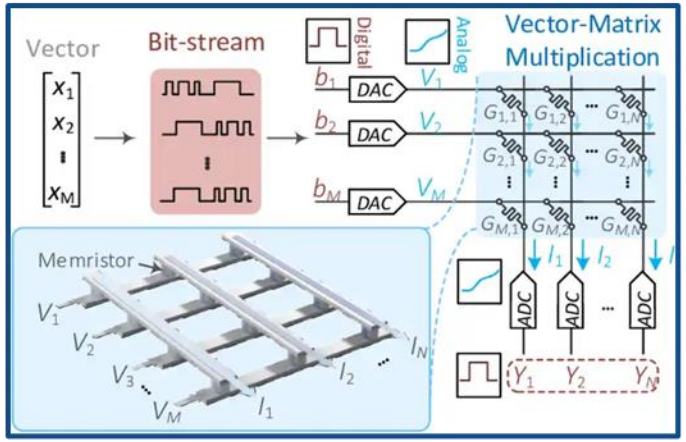


Bottlenecks in traditional Von Neumann CPU Memory Hierarchy

The hierarchy is much slower the further away you are from the processor!



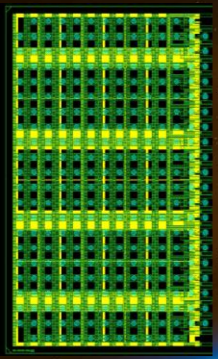
Compute-in-Memory IC



Radiation Hardened Memory Development efforts

Space Vehicles
RV

BAE
12nm DDR3 SDRAM

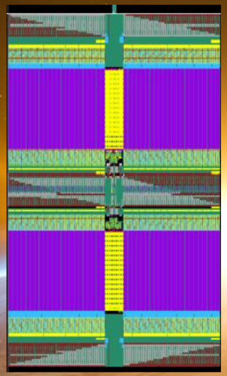


Research and develop a RH Volatile memory technology leveraging advanced 12nm GlobalFoundries FinFET technologies

Reach minimum densities of 1Gbit/device using MCM while maintaining DDR3 compatibility in a synchronous SRAM chip that emulates the functionality of a SDRAM chip

Current: TRL 3, Final: TRL 6 (Oct '24)
Deliverable: 512Mb & 2Gbit Die

Honeywell
Strategic RH 90nm MRAM

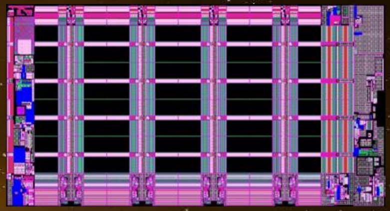


Develop a SRH Non-Volatile 90nm memory technology leveraging Honeywell S90 hardened foundry technology

Demonstrate a 64 to128Mbit/device SRH Spin Transfer Torque (STT) MRAM memory capable of reaching greater density

Current: TRL 3, Final: TRL 6 (Aug '24)
Deliverable: 64Mb Die

Micro-RDC / Infineon
40nm SONOS NOR FLASH

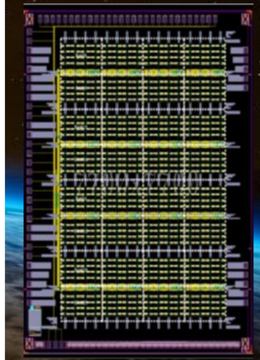


Research and develop a RH memory technology leveraging advanced Infineon SONOS (Silicon Oxide Nitride Oxide Silicon) foundry technology

Demonstrate a 512Mb RH Flash memory technology capable of stacking to greater density

Current: TRL 3, Final: TRL 8 (Jul '25)
Deliverable: 512Mb Die

Western Digital
Strategic RH 90nm MRAM



Research and develop a SRH Non-Vol 90nm memory technology leveraging advanced CMOS trusted technology and Western Digital foundry technologies

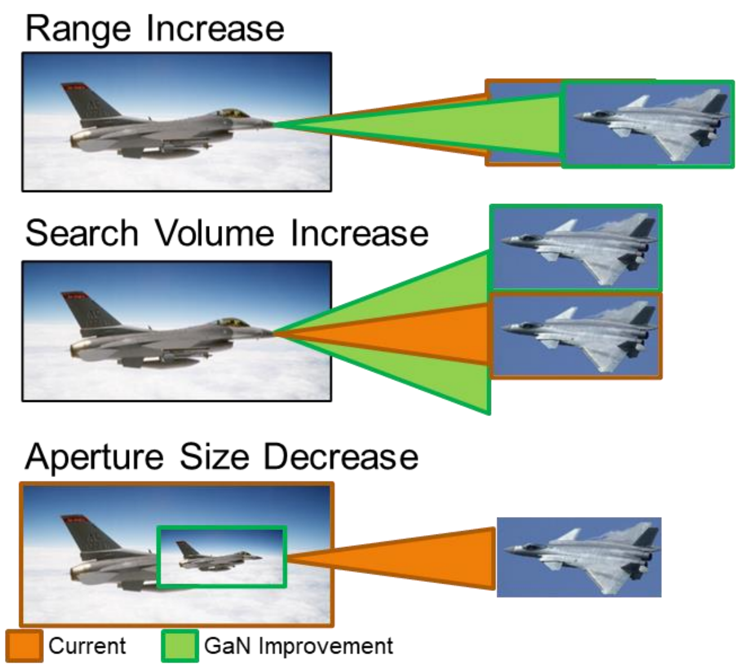
Demonstrate a min density of 4Gbit/device SRH Spin Transfer Torque (STT) MRAM memory capable of reaching MCM density approaching 32Gbit

Current: TRL 3, Final: TRL 6 (Oct '28)
Deliverable: 4Gbit Die

Gallium Nitride (GaN) RF Microelectronics Prototyping Capability

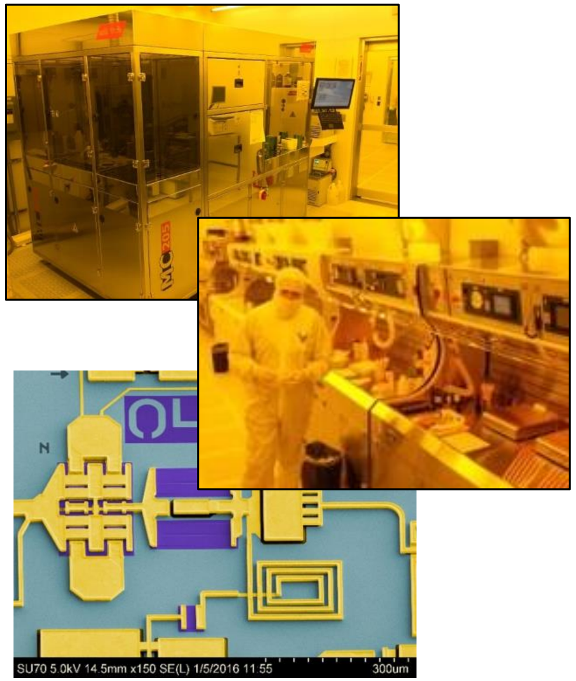
Sensors RY

GaN provides 5-10x RF power per element



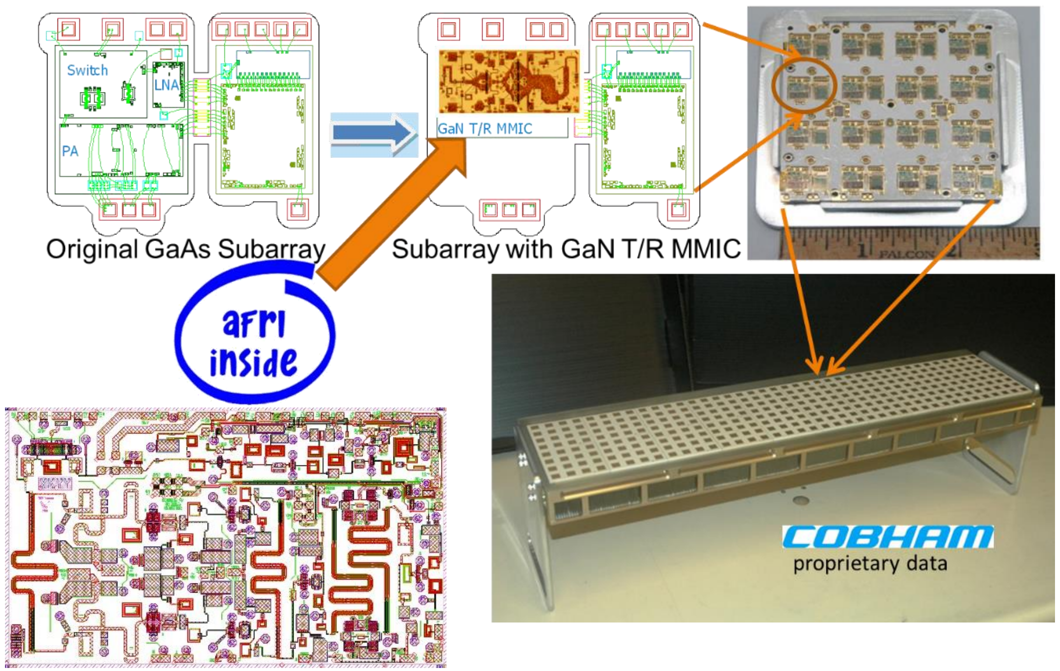
GaN is a critical military technology to sense our adversaries first and win

AFRL/RY State-of-the-Art Cleanroom



AFRL on-site R&D enables SMEs to lead national sensor tech programs

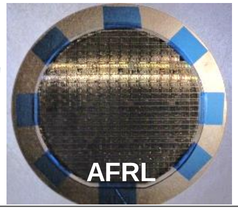
AFRL/RY X-Ka Band GaN RF Electronics Rapid Prototyping



AFRL matured on-site GaN prototyping to produce relevant X-Ka band RF sensors that inform DAF Programs of Records

AFRL successfully transferred its 0.14 micrometer RF GaN technology to multiple defense and commercial industry partners

NORTHROP GRUMMAN
MACOM
qorvo
BAE SYSTEMS



AFRL has led GaN from basic research to transition over a 20+ yr span

"Beyond GaN" → Gallium Oxide Power Microelectronics

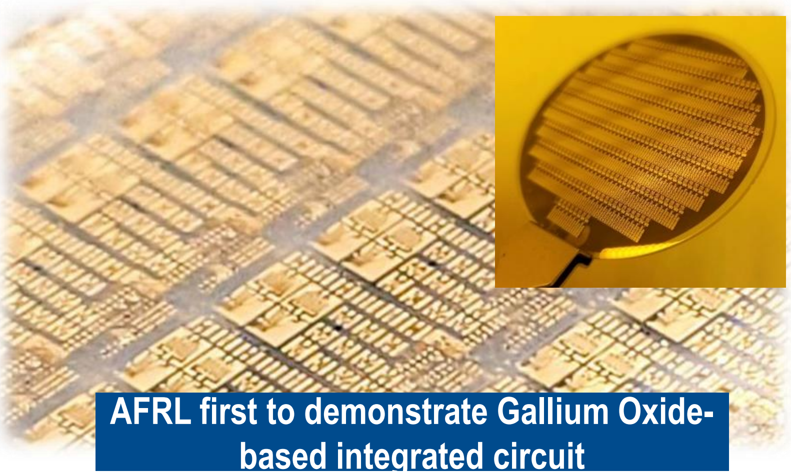
Sensors RY

Gallium Oxide Attributes

- Large substrate availability
- 2-3x voltage over incumbent technology
- Wide range of electrical conductivity

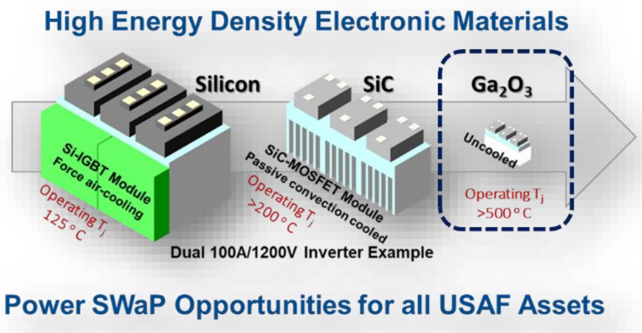
AFRL is the global leader and built large domestic/int'l R&D community of interest

AFRL in-house Gallium Oxide Prototypes



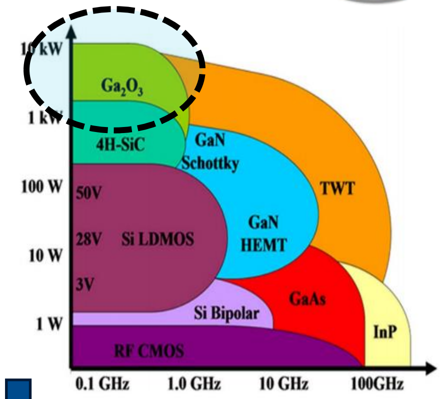
AFRL first to demonstrate Gallium Oxide-based integrated circuit

High-Speed Power Switching

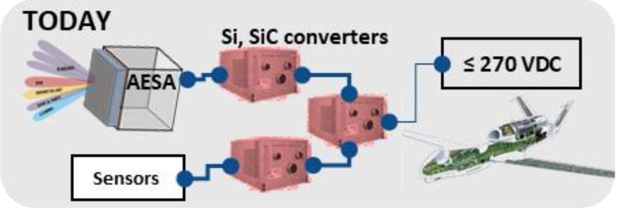


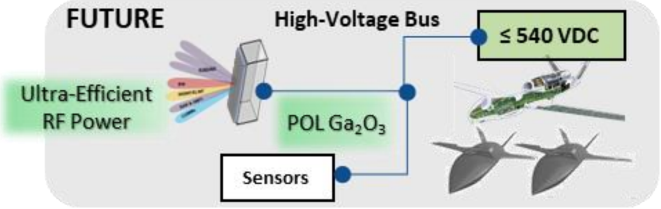
High-Pulsed RF Power

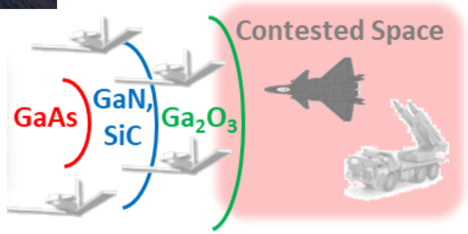
AFRL led Gallium Oxide R&D as an AFOSR 6.1 program in 2016 to a promising 6.2 program at AFRL/RY & RX



RF Sub-Systems Applications





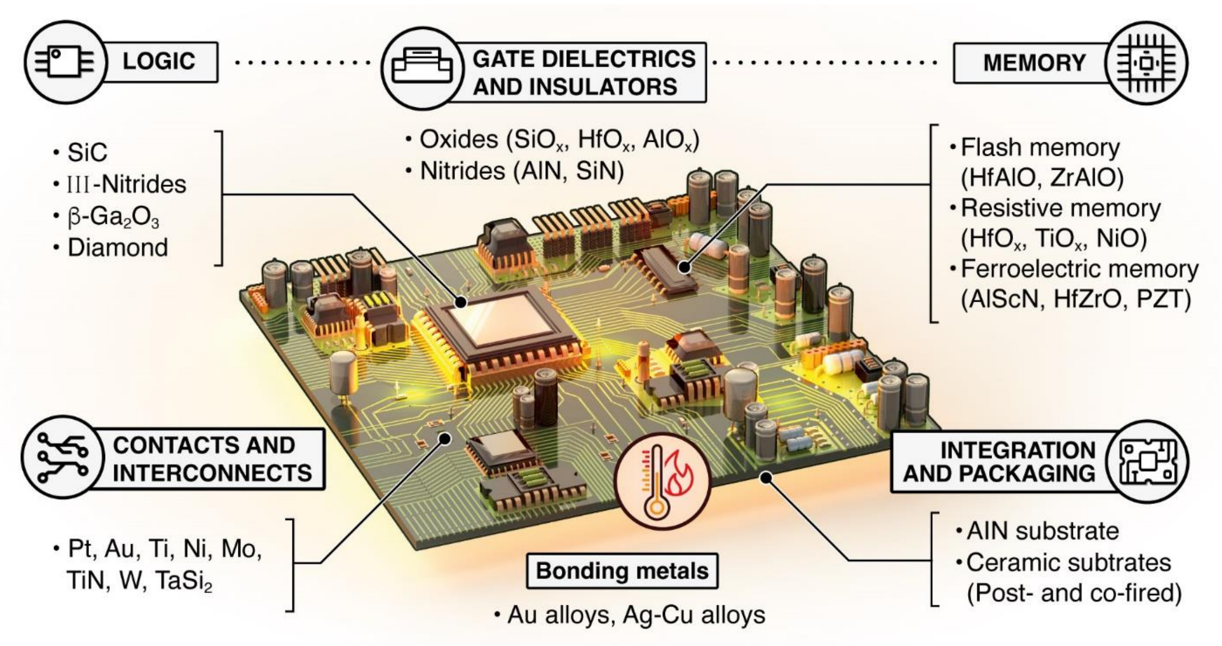


Gallium Oxide reduces size, weight, complexity while supporting future high power density upgrades across all DAF platforms

High Temperature Cyclable Non-volatile Memory for Extreme Computing

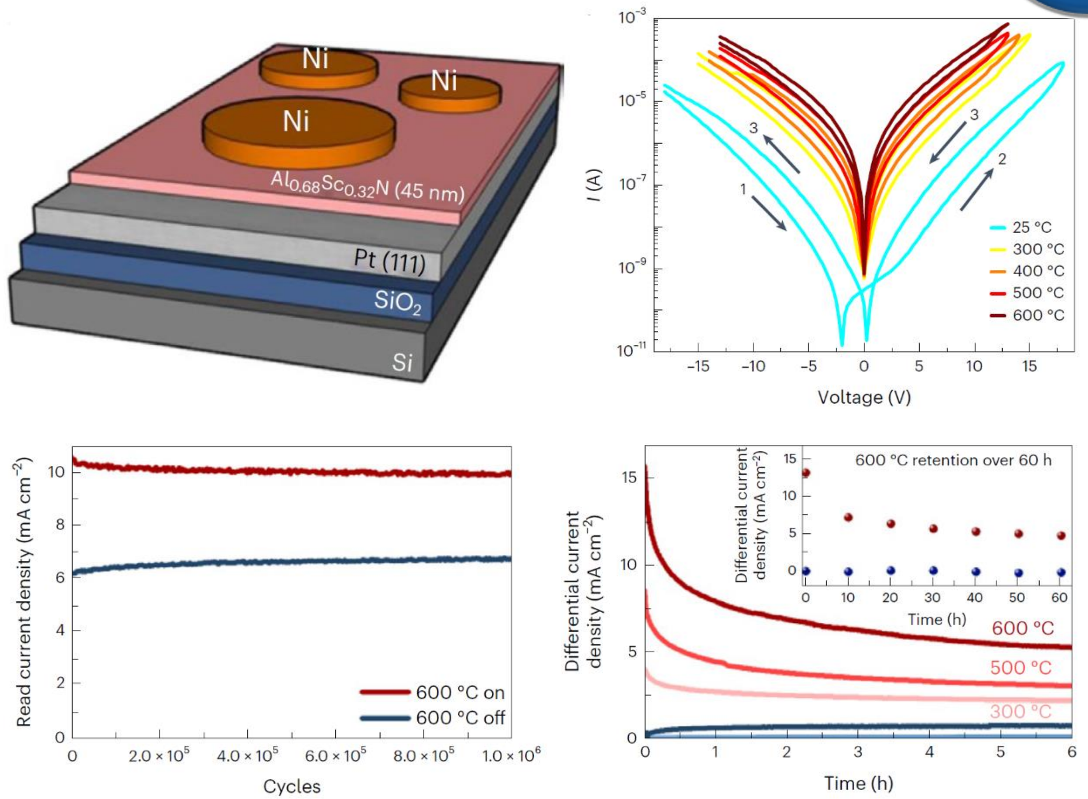
Materials
RX

High temperature operating electronics require new material solutions to push beyond 200°C operation



Of the available suite of new materials for high temperature electronics, non-volatile memory has still yet to be demonstrated in a scalable, reliable device

D. Pradhan, et al. "Materials for High Temperature Digital Electronics", arXiv:2404.03510.

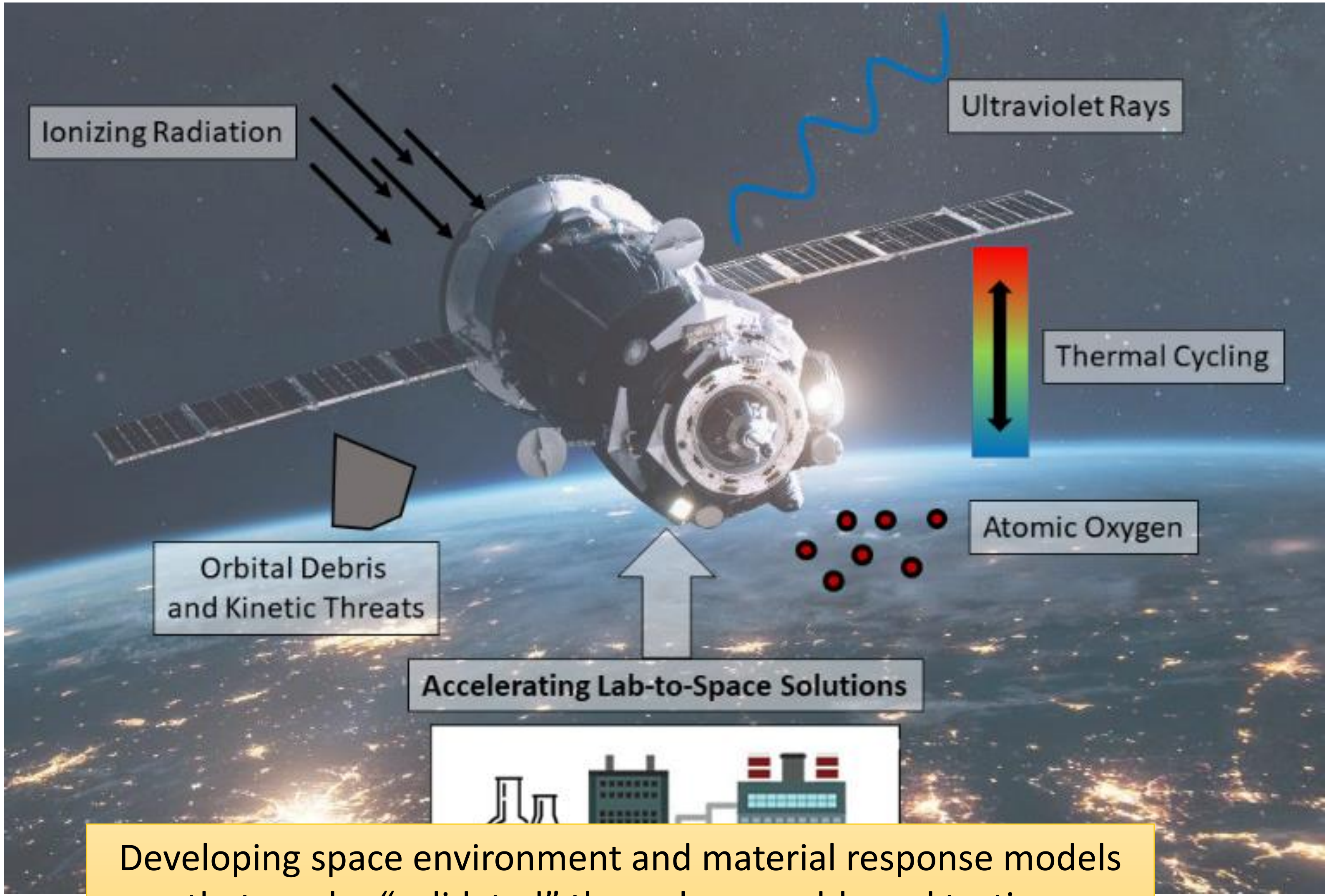


AlScN ferrodiodes developed at University of Pennsylvania and tested at AFRL/RX demonstrate >600°C operation, non-volatile operation and retention over 60h at 600°C

D. Pradhan, et al. "A scalable ferroelectric non-volatile memory operating at 600°C", *Nature Electronics*, 2024.

AFOSR CoE: Lab-to-Orbit

Materials
RX



Developing space environment and material response models that can be "validated" through ground-based testing

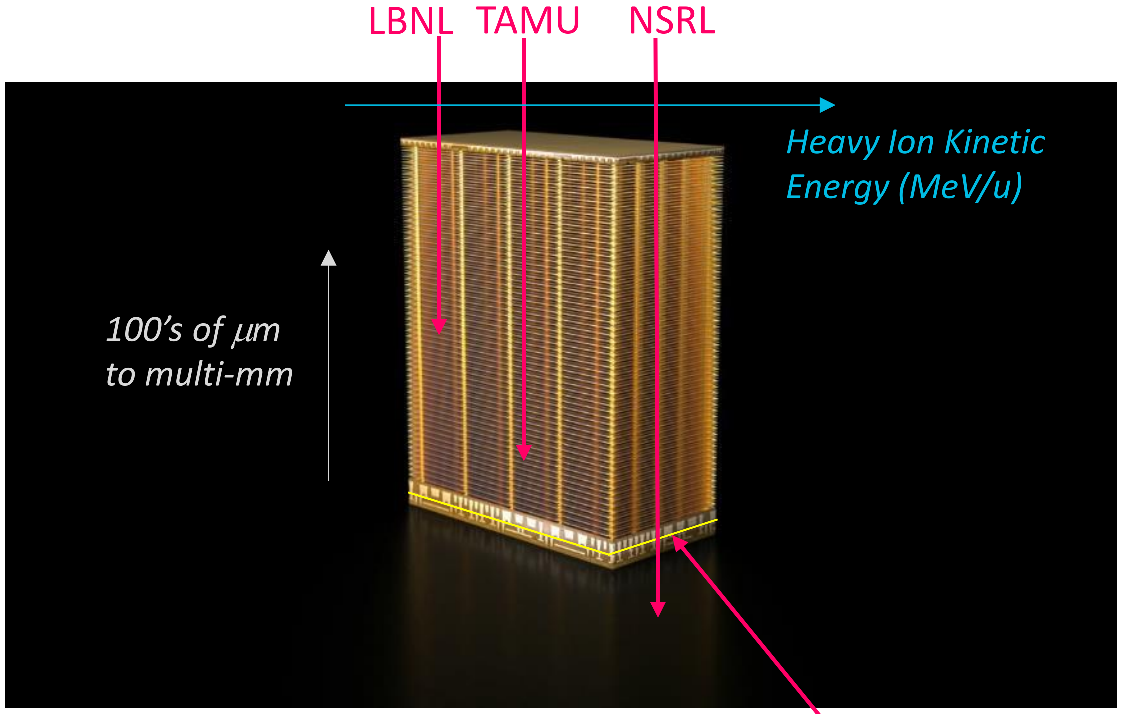
New AFOSR Center of Excellence (mid-FY24 Start)

The overarching goal of this CoE is to develop basic research foundations to address fundamental challenges in the correlation between ground-based experimentation and on-orbit performance in order to accelerate the development cycle of space technologies.

- **New Laboratory Capabilities for Combined Effects**
- **Advanced and In-situ Characterization Tools**
- **New Validation Approaches for Material Response to LEO Environment**

Semiconductor Innovations Driving SEE Testing Challenges

- ***Monolithic/stacked 3D IC (e.g. NAND FLASH)***
- ***Heterogeneous Integration/Advanced Packaging***
- ***Backside Power Delivery (Intel 20A, 18A)***



Advanced 3D NAND FLASH (232 layer – Micron)

Deep Sensitive Volume

- ✗ ***Die Thinning***
- ✗ ***Low Energy HI***
- ✗ ***Laser Testing (?)***
- ✓ ***High Energy HI***

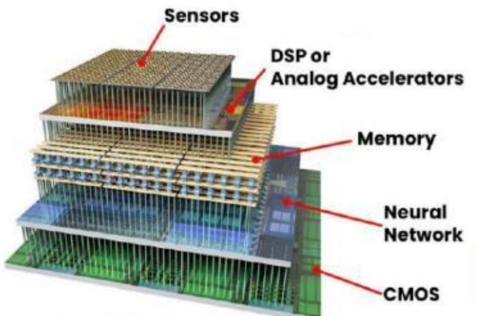


Image credit: ACS Nano 2023

Image Credit: SAMUEL K. MOORE, A Peek at Intel's Future Foundry Tech - IEEE Spectrum, 21 Feb 2024

Backside Power Delivery (Intel 20A, 18A) / 3D Heterogeneous Integration

Final Thoughts

- **Understand the *Transition Path* for your project/program**
  - Answer the “So What” question
- **Workforce Development / Internship Opportunities**
  - SRHEC SCALE Program (https://research.purdue.edu/scale/)
  - AFRL Scholars Program (https://afrlscholars.usra.edu/)
  - NRC Research Associateship Programs (https://www.nationalacademies.org/our-work/rap/for-applicants)
- **Have Fun**