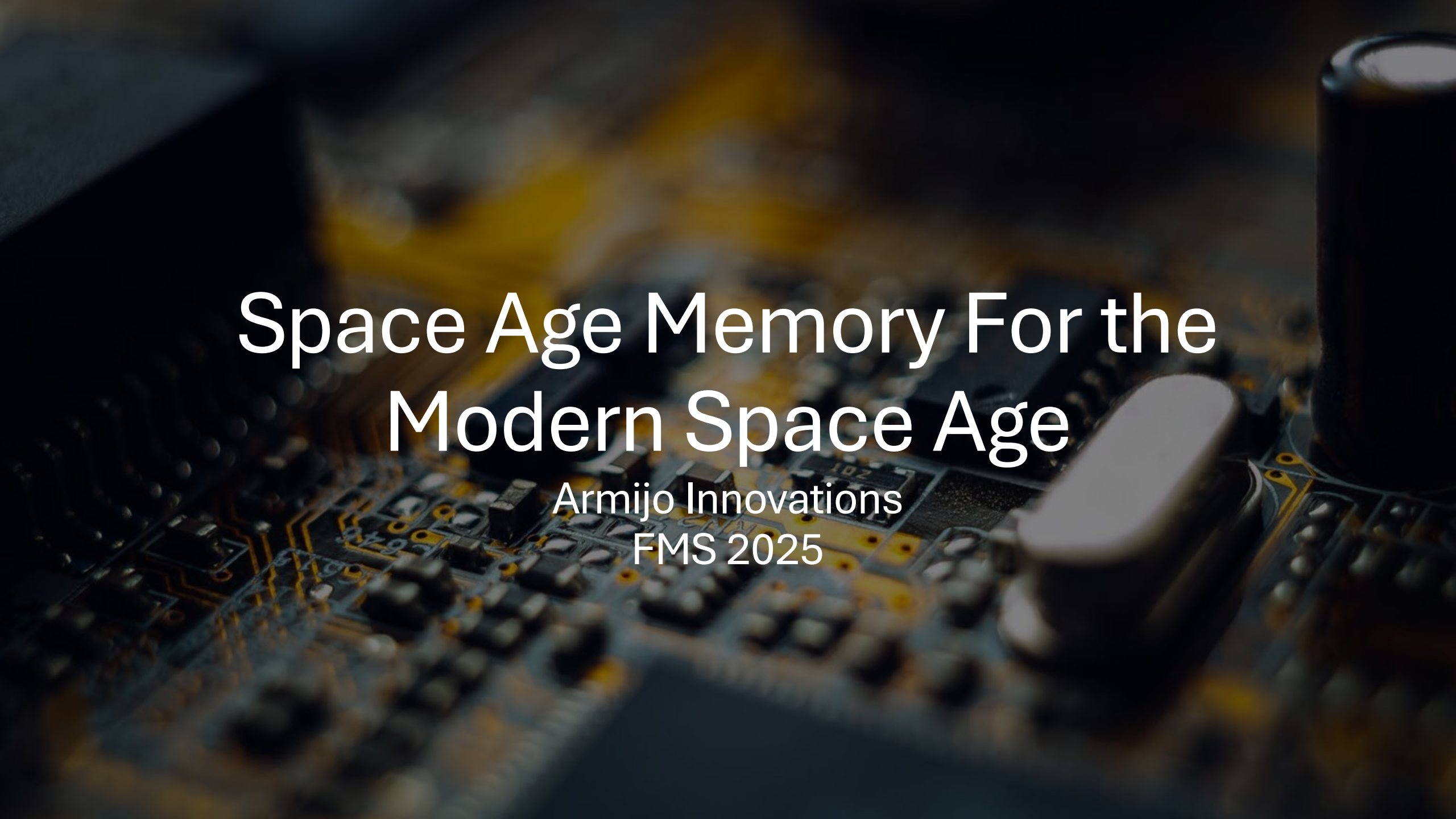


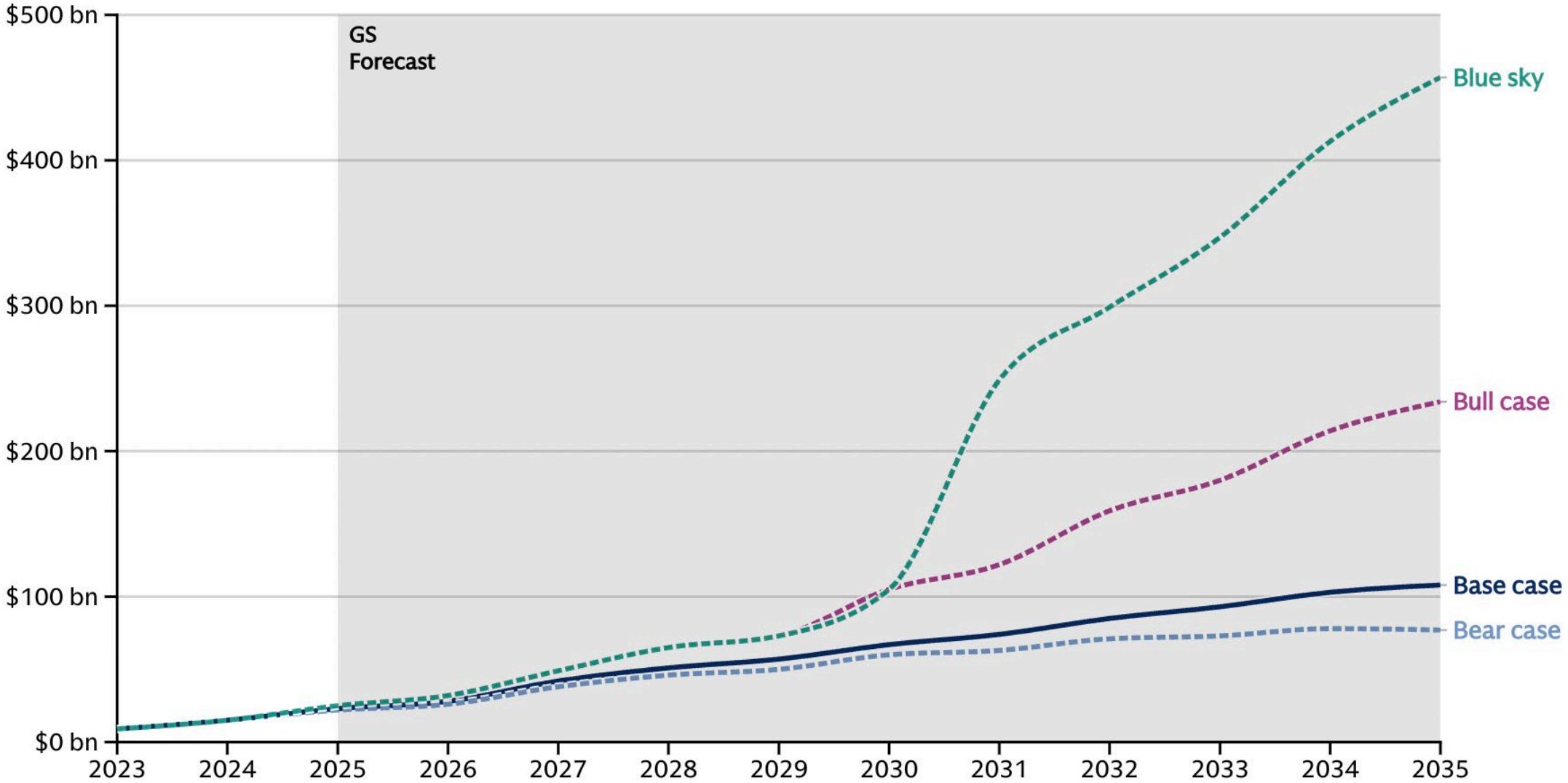
Space Age Memory For the Modern Space Age

Armijo Innovations

FMS 2025

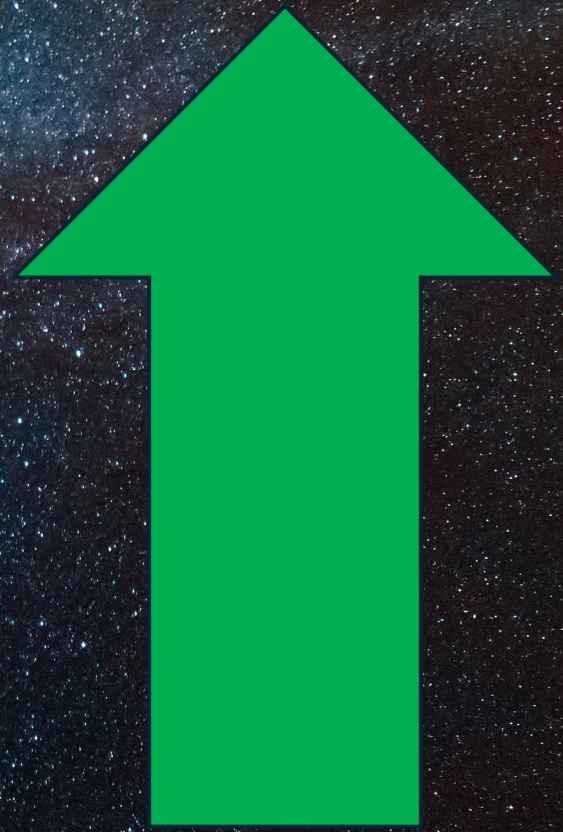
Why Do We Care?

Market projections for low earth orbit satellites



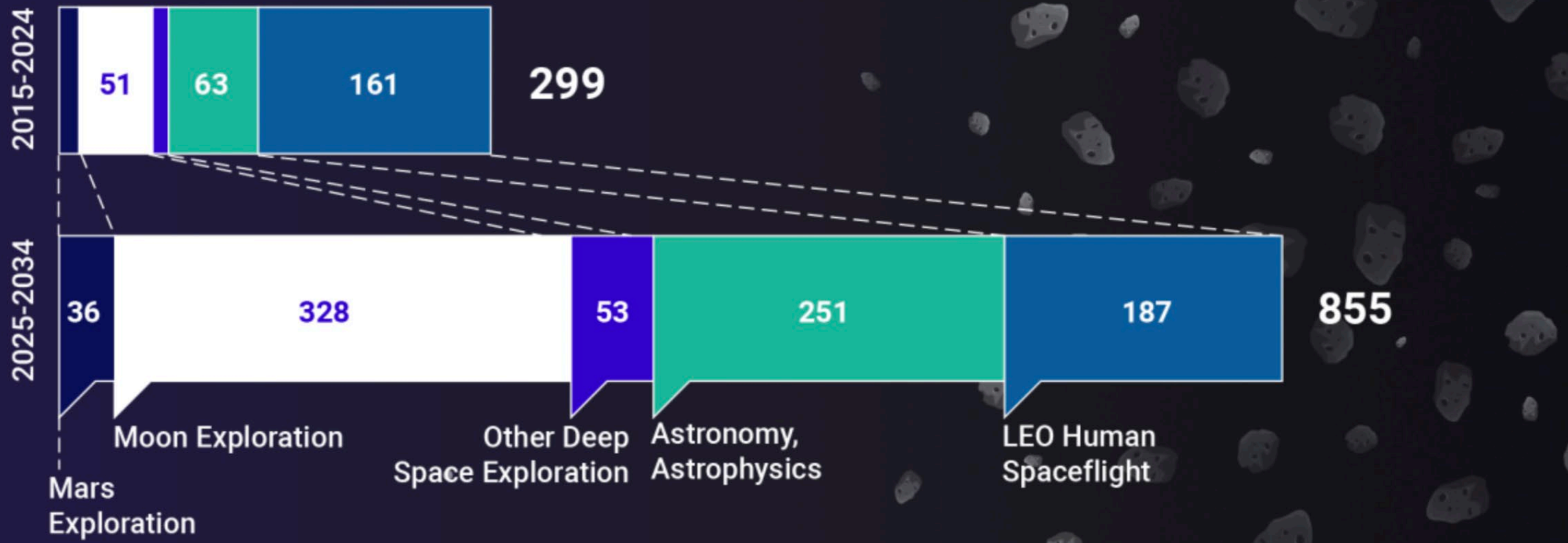
Golman Sachs, 2025

Low Earth Orbit Satellites
Deep Satellites
Space Telescopes
Moon Landers
Mars Rovers and Drones
Interplanetary Vehicles



Number of Space Exploration Missions Launched and to be Launched by Application

(government and commercial combined)



Nova Space, 2025

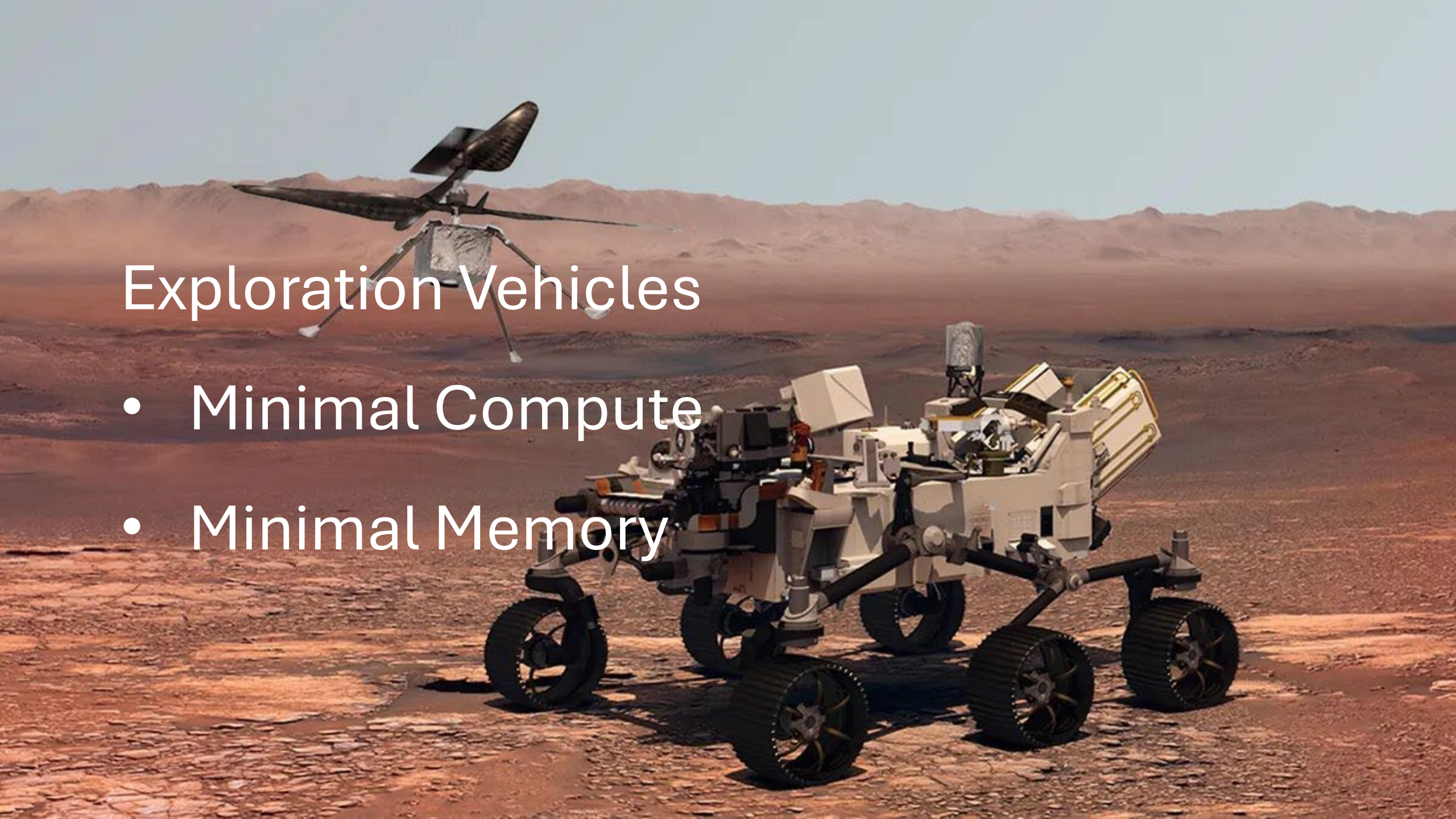
Current Space Tech

Satellites

- Have Little Compute Power
- Have Limited Memory

Satellites

- Have Little Compute Power
- Have Limited Memory
- ***Are Just Data Relays***



Exploration Vehicles

- Minimal Compute
- Minimal Memory

Exploration Vehicles

- Minimal Compute
- Minimal Memory
- ***Are Just Remote Controlled Vehicles***



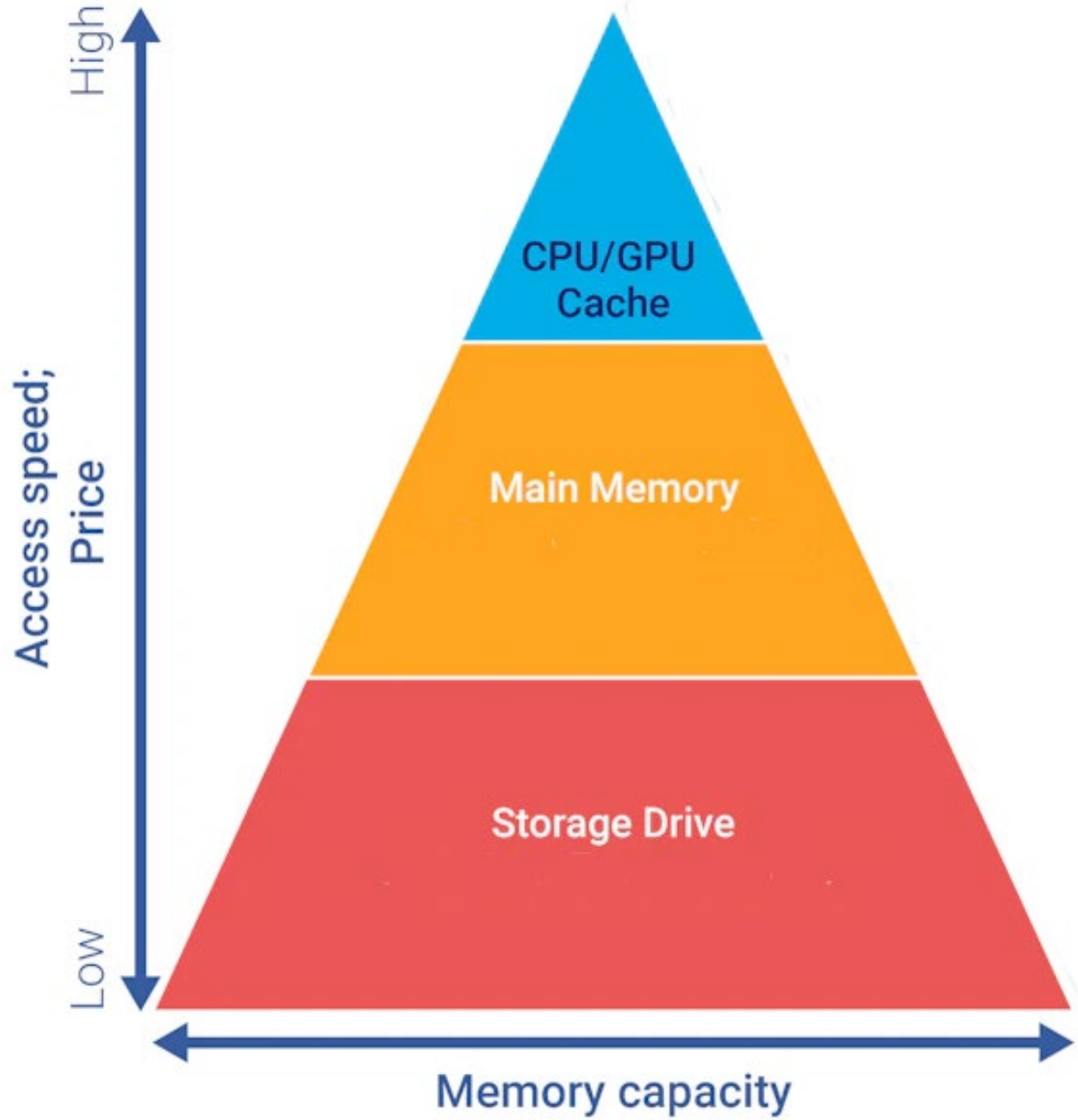
- Satellites Need To Analyze Data Where It’s Collected
- Exploration Vehicles Need More Autonomy

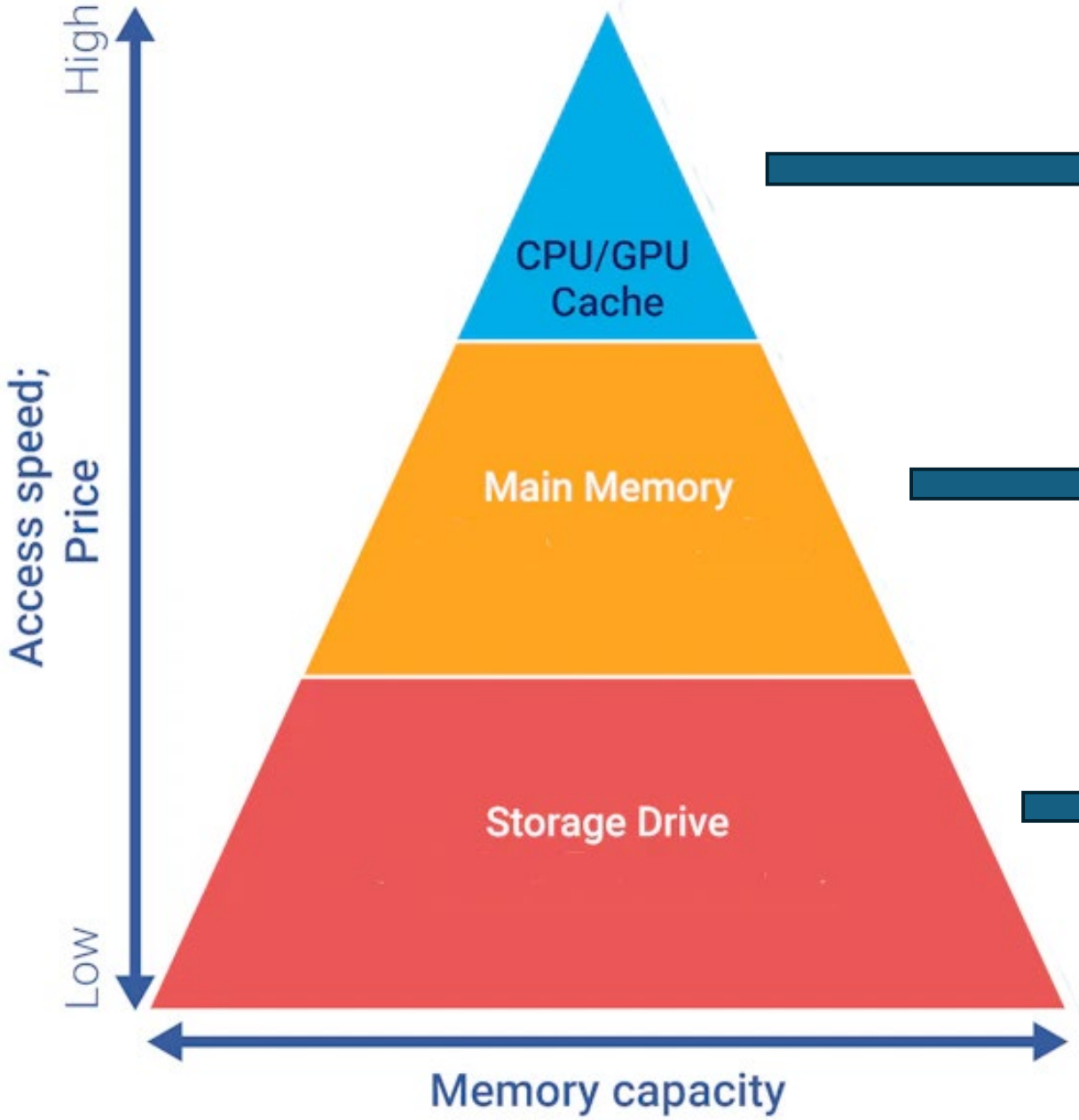


- Satellites Need To Analyze Data Where It’s Collected
- Exploration Vehicles Need More Autonomy
- *Now: Need More Compute, Memory, Storage*
- *Future: Data Centers In Space!*

Why Not COTS?

Let’s Talk About Memory… Starting On The Earth

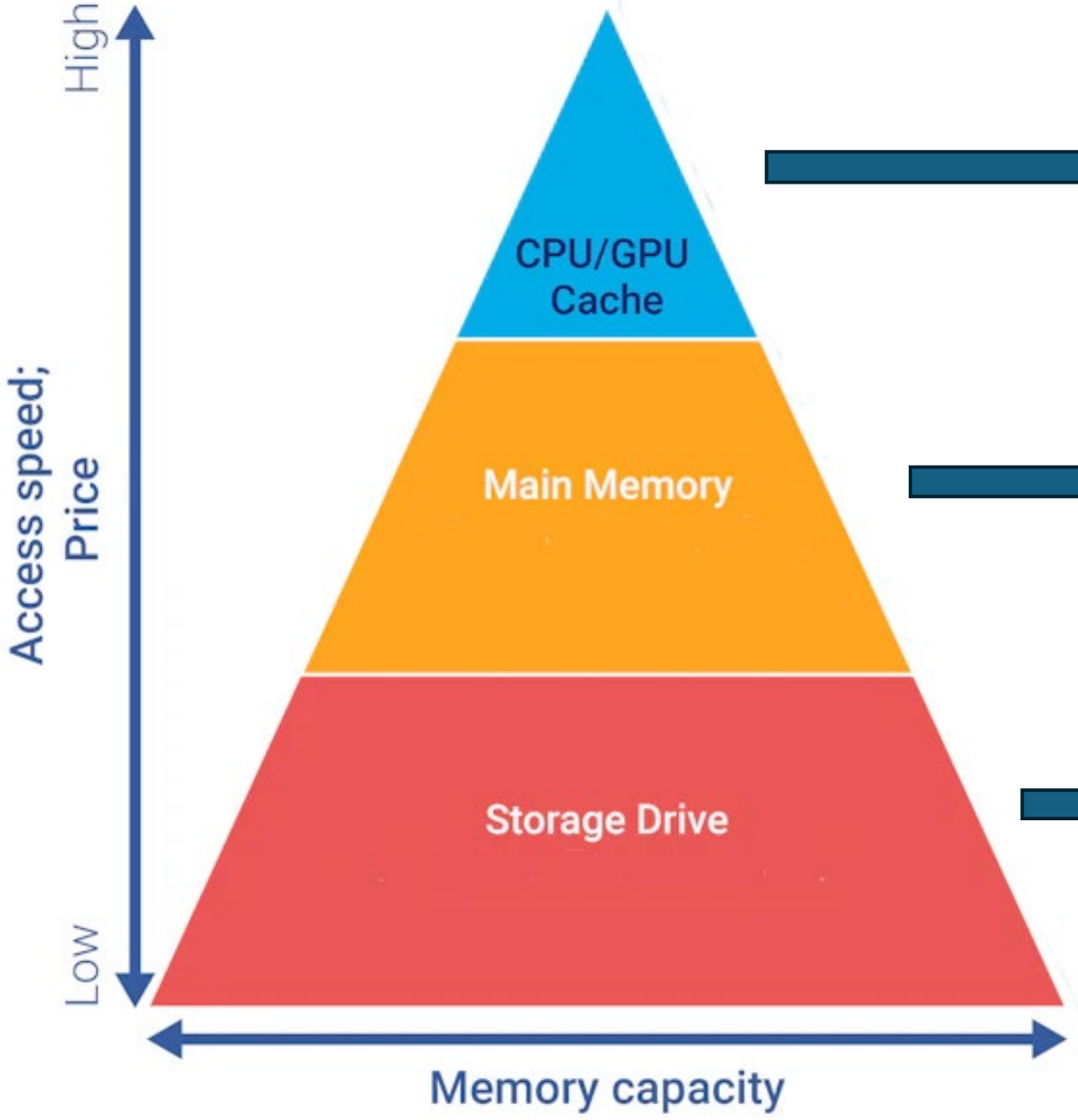

High
Access speed;
Price
Low
CPU/GPU
Cache
Main Memory
Storage Drive
Memory capacity



Static RAM

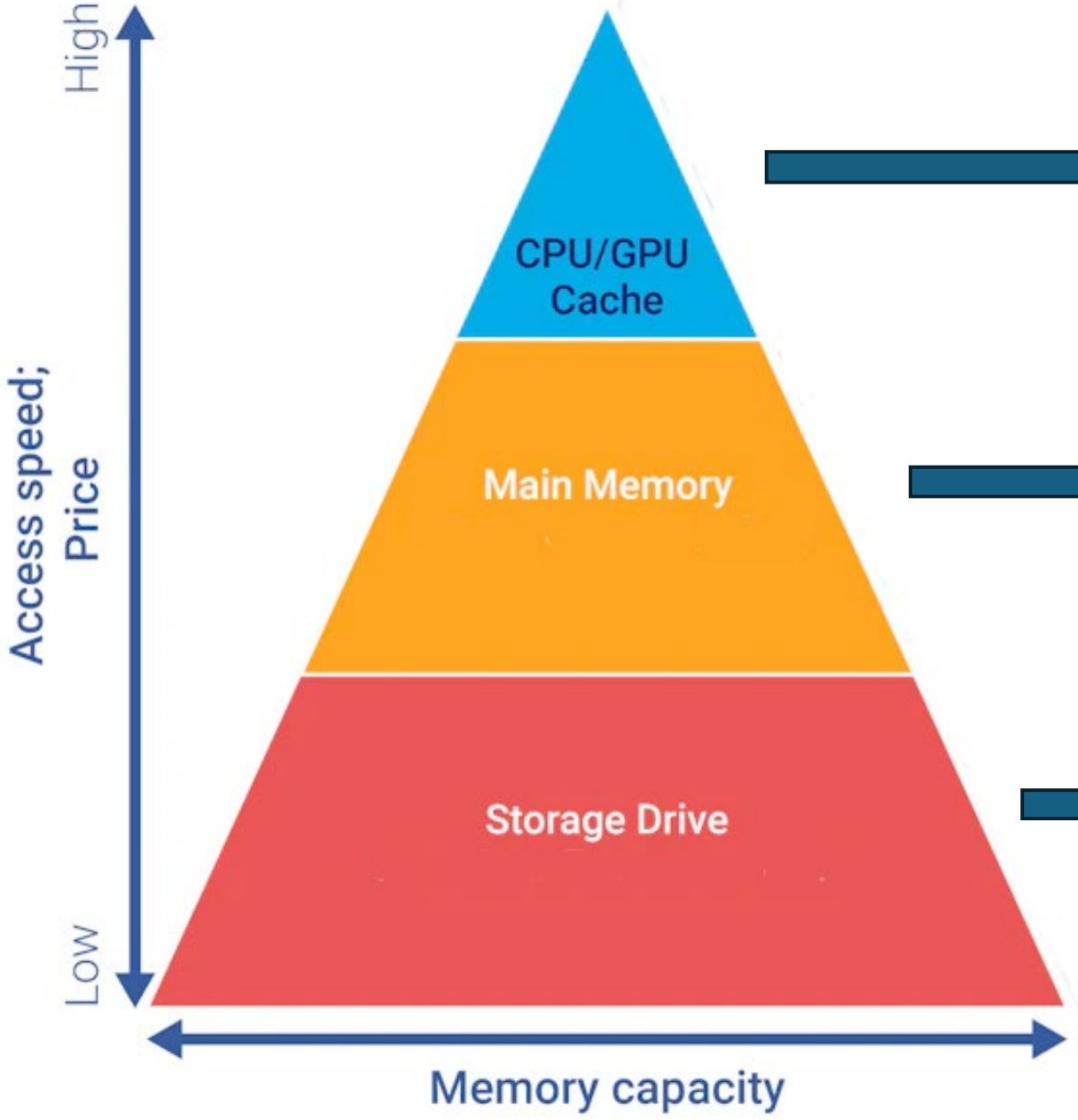
DDR RAM

NAND Flash



On Earth

Static RAM	MOSFET	3nm
DDR RAM	MOSFET	10nm
NAND Flash	MOSFET	14nm



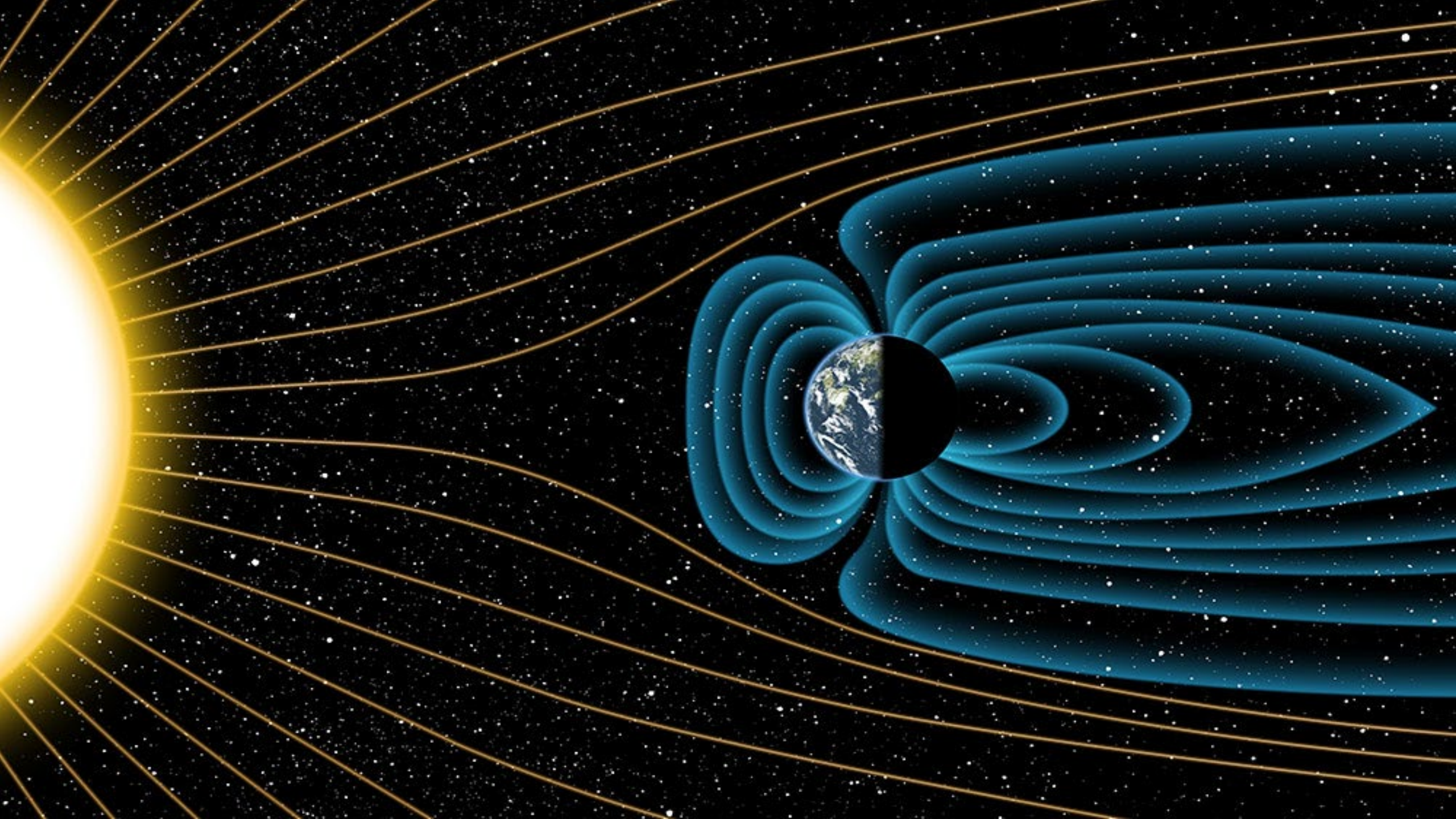
On Earth

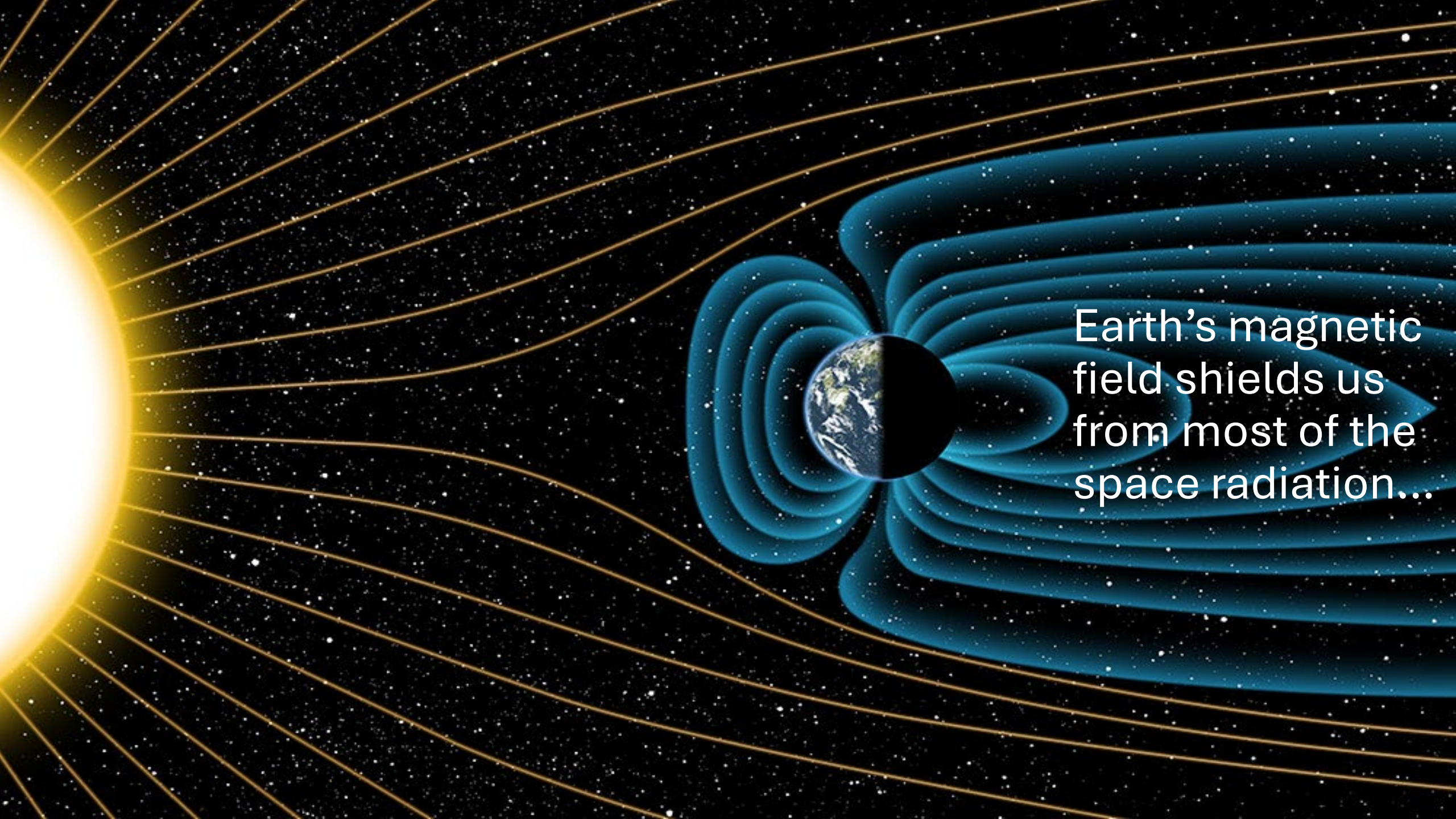
Static RAM	MOSFET	3nm
DDR RAM	MOSFET	10nm
NAND Flash	MOSFET	14nm

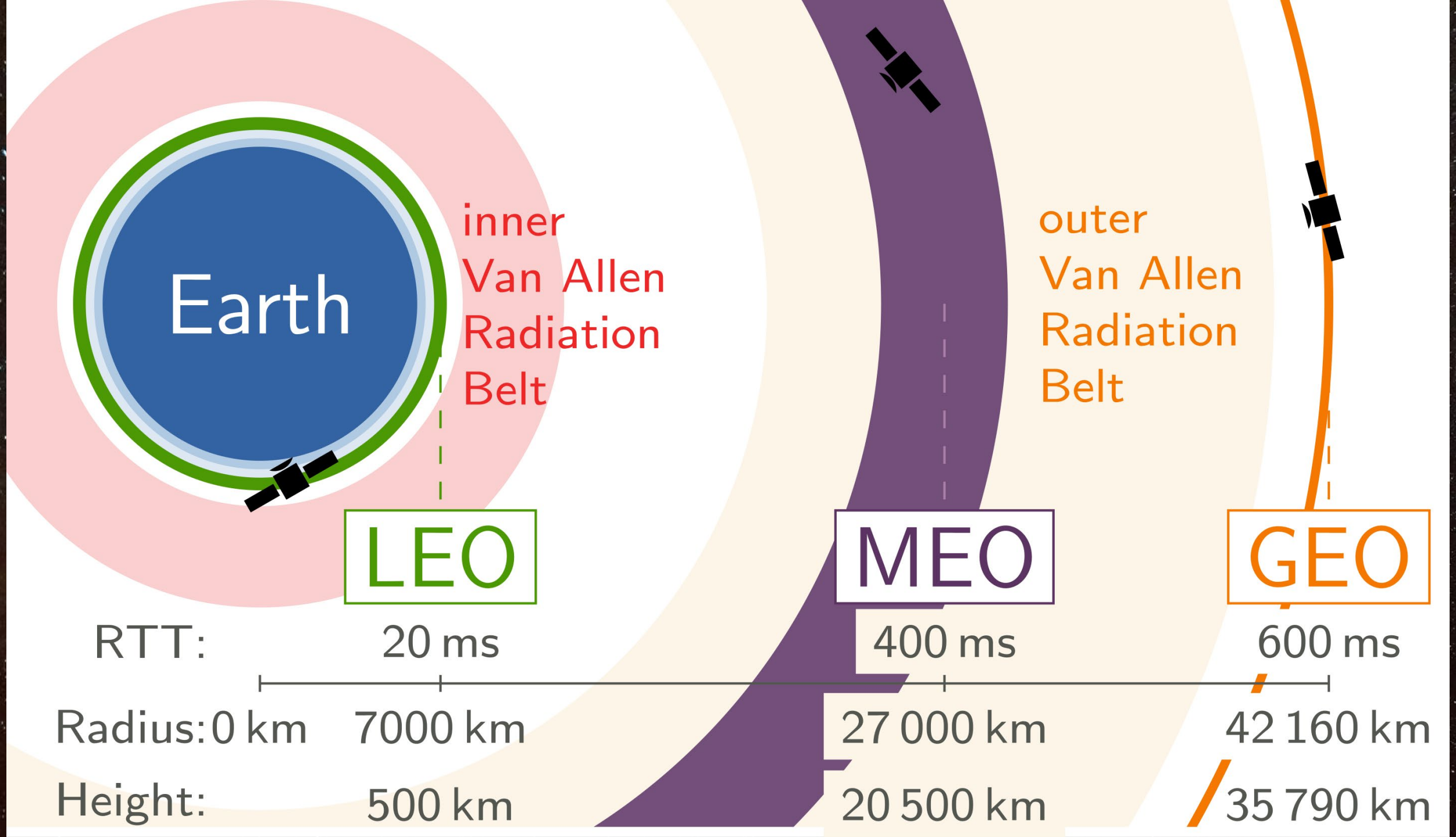
Recipe, Topology, and Density Are Key Aspects of Radiation Sensitivity

Let’s Talk About Radiation…Misconceptions

Misconceptions #1: Radiation Protection Comes From The Atmosphere

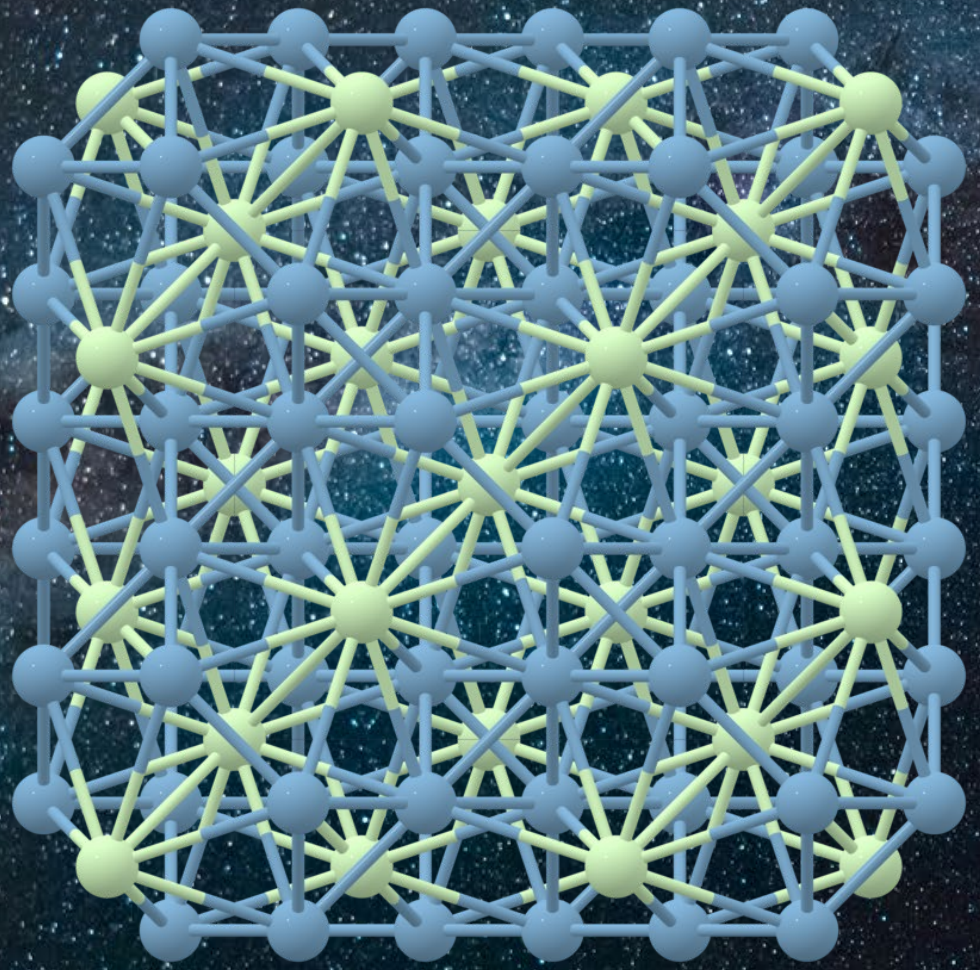



Earth’s magnetic field shields us from most of the space radiation…

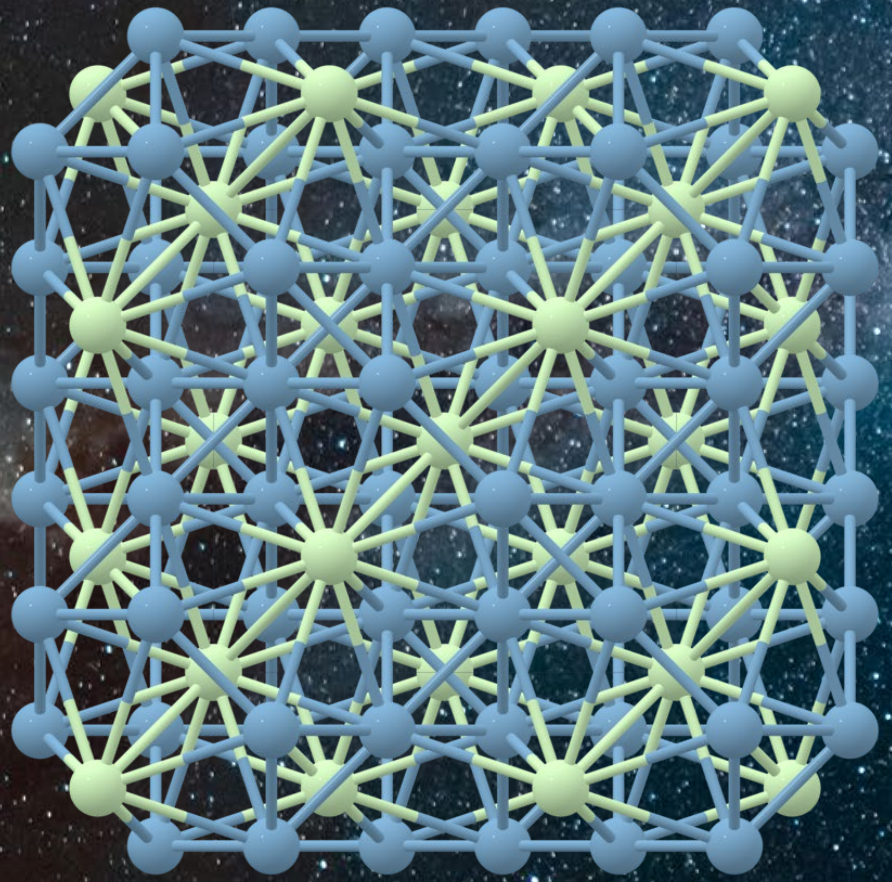

Earth
inner
Van Allen
Radiation
Belt
outer
Van Allen
Radiation
Belt
LEO
MEO
GEO
RTT:
20 ms
400 ms
600 ms
Radius:
0 km
7000 km
27 000 km
42 160 km
Height:
500 km
20 500 km
35 790 km

Misconceptions #2: Shielding Is the Best Protection Against Radiation

The “Too Simplistic” Lattice View of Materials

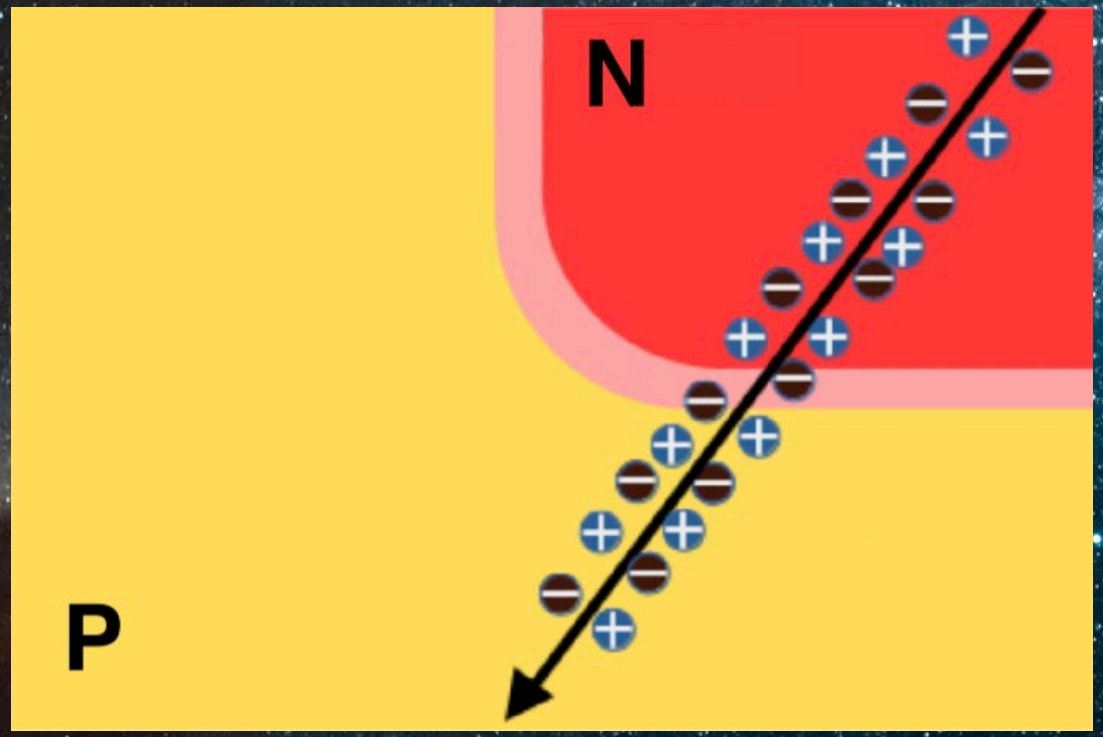


The “Too Simplistic” Lattice View of Materials



- Actually, 99.99999999% of volume is empty space!
- Required shield thickness adds too much weight

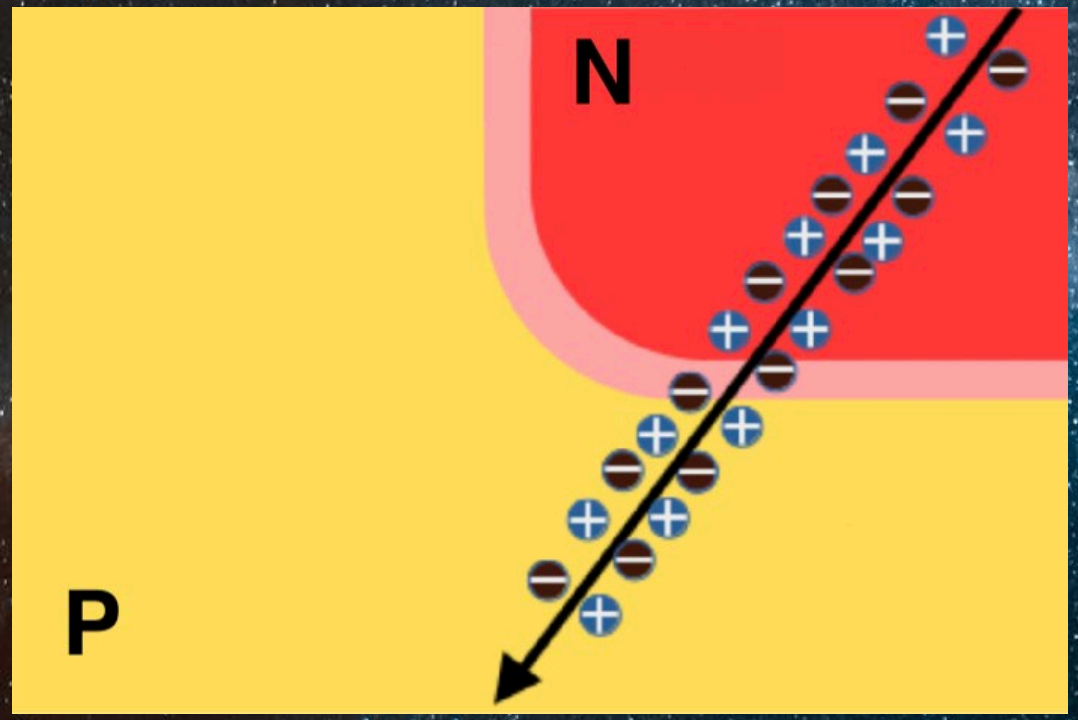
The “Too Simplistic” Lattice View of Materials



A radiation particle will most likely disturb the electron cloud between nuclei…

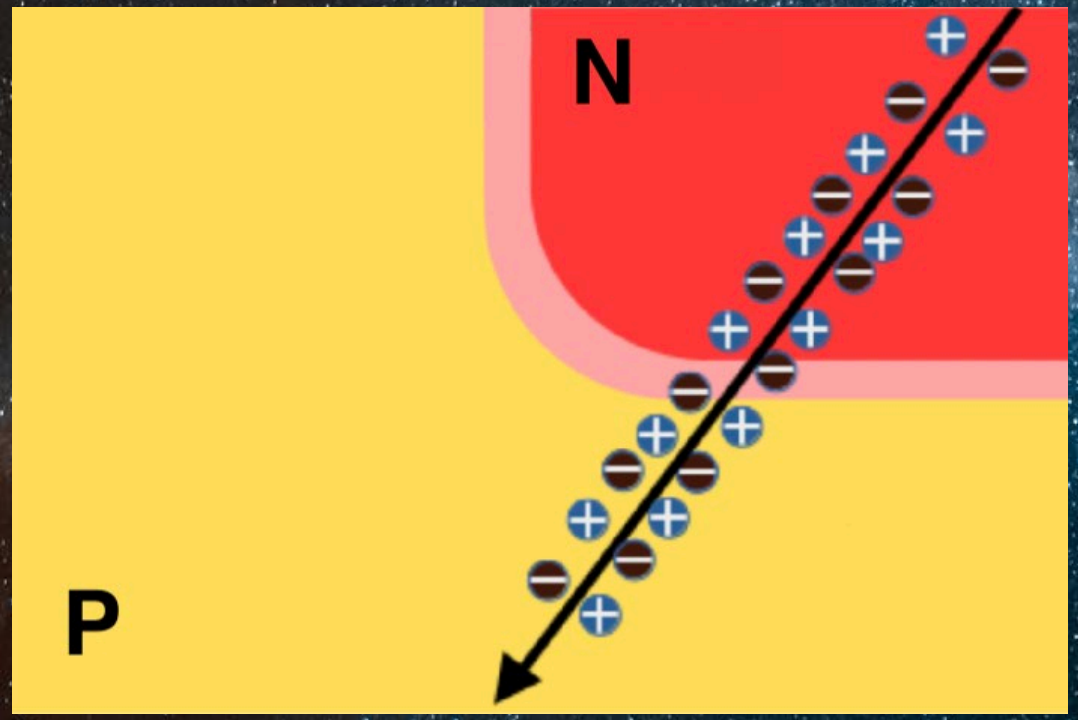
Misconceptions #3: Radiation Always Destroys Electronics

Single Event Effects (SEE) On DRAM/SRAM



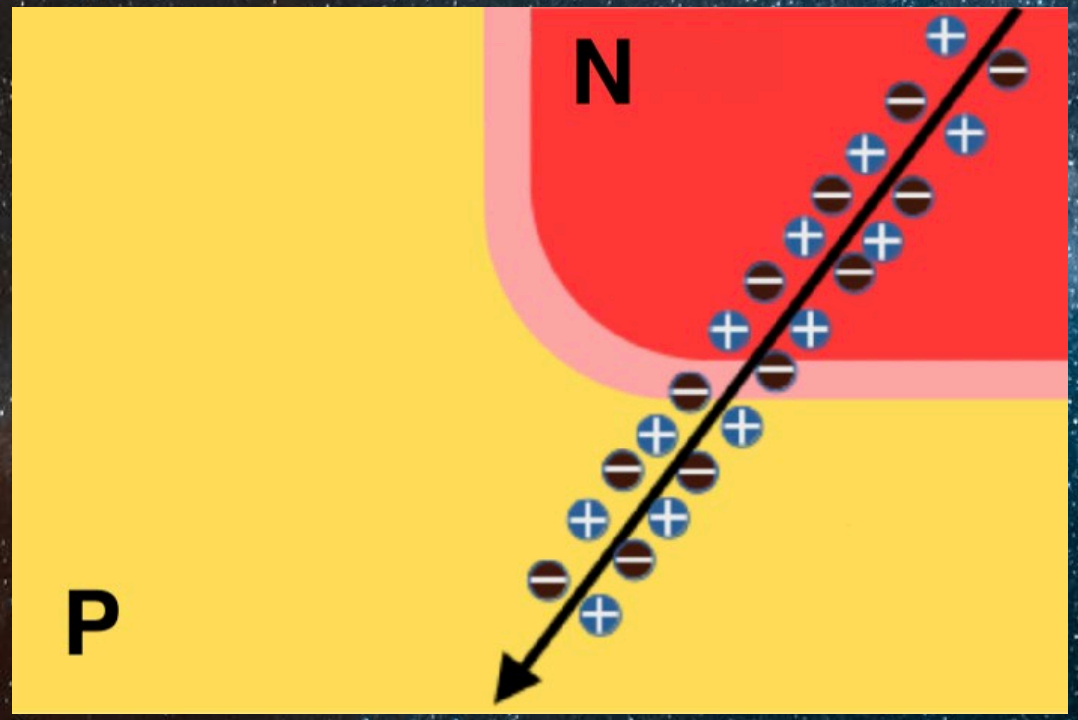
Effect	Remedy
Isolated Bit-Flip	ECC, Detect and Reset

Single Event Effects (SEE) On DRAM/SRAM



Effect	Remedy
Isolated Bit-Flip	ECC, Detect and Reset
Corrupted Ranges	App Fault & Reset, Scrub Memory

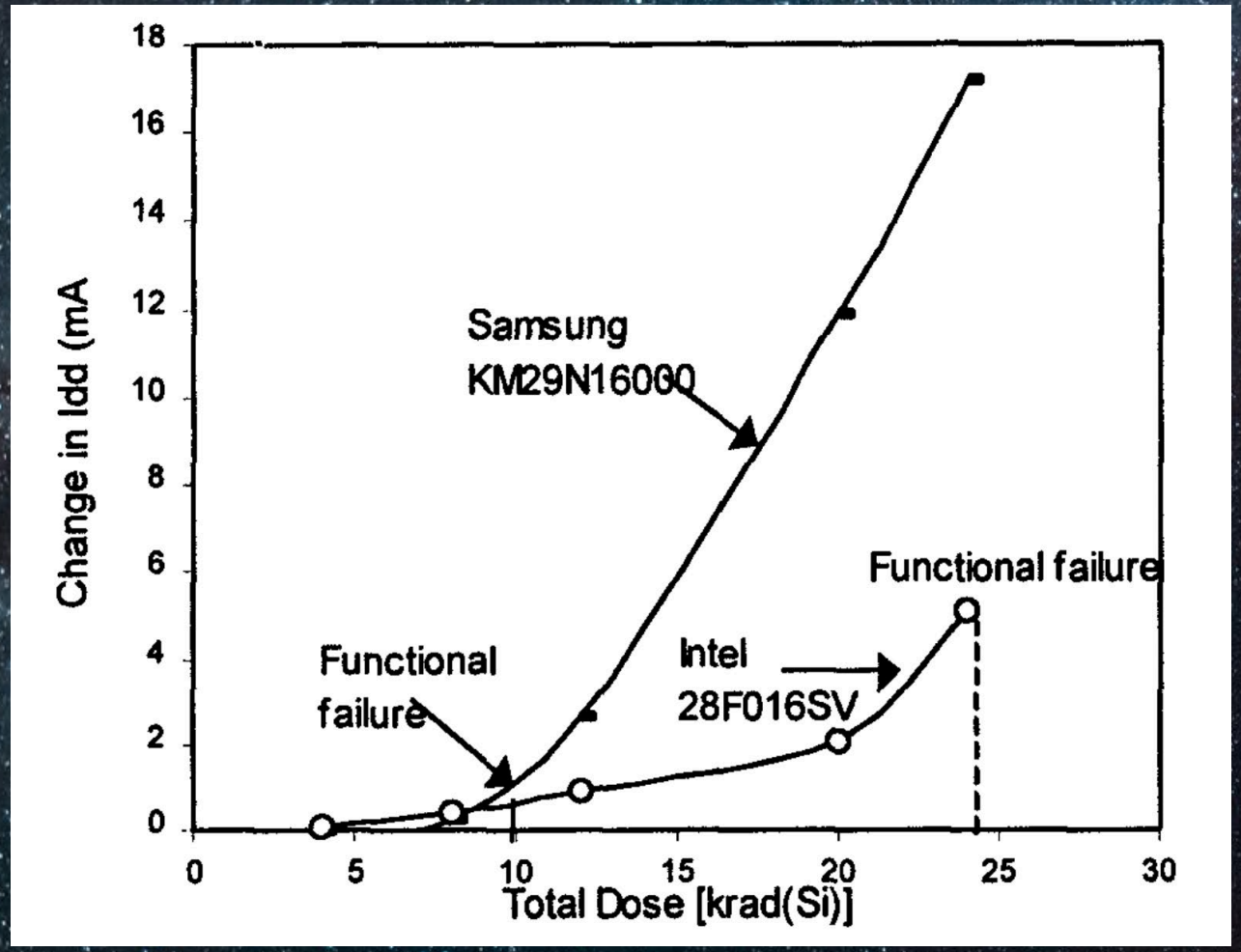
Single Event Effects (SEE) On DRAM/SRAM



Effect	Remedy
Isolated Bit-Flip	ECC, Detect and Reset
Corrupted Ranges	App Fault & Reset, Scrub Memory
Short-Circuit	Detect & Reset ASAP

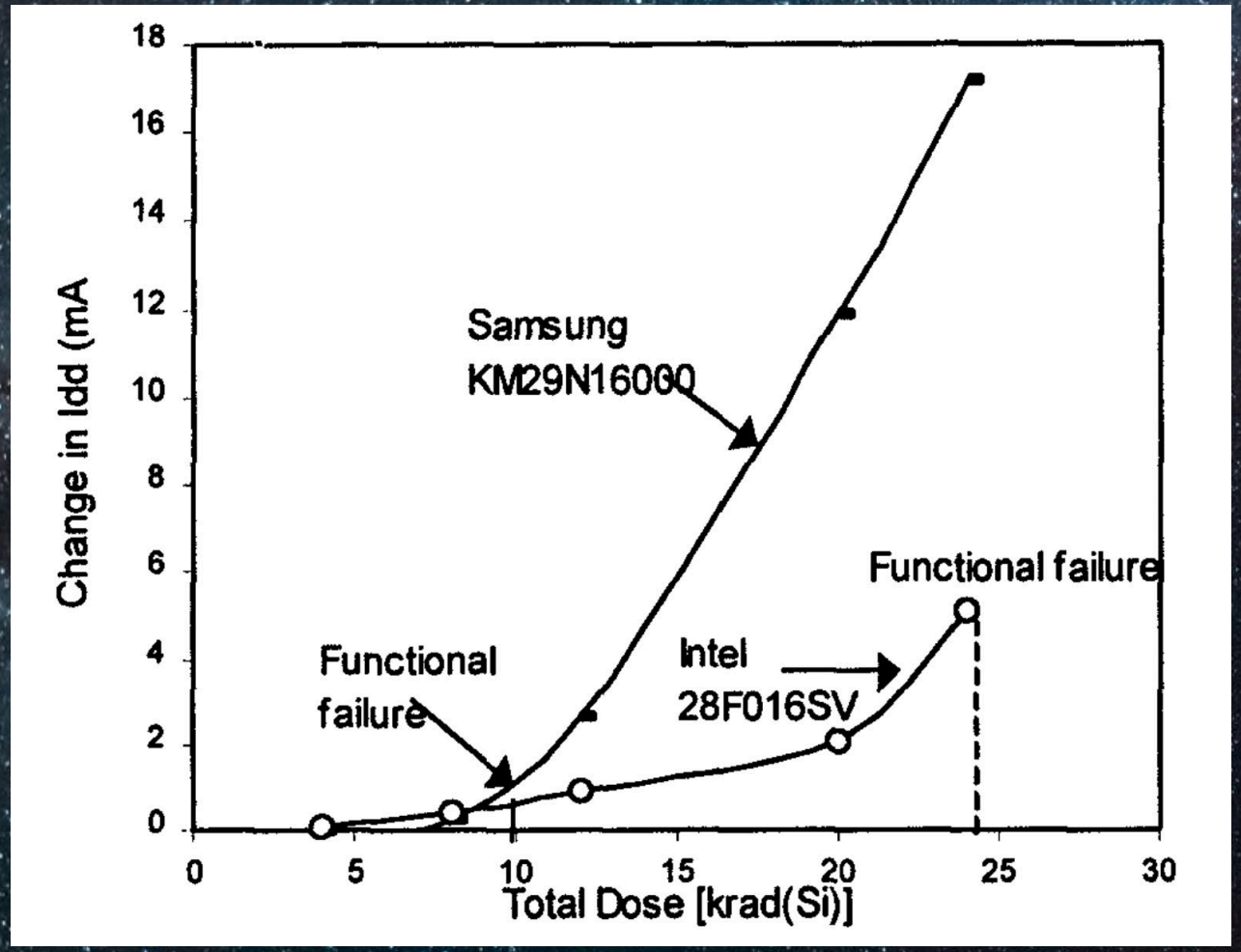
Misconceptions #4: Just “Turn It Off And Turn It On Again”

Total Ionizing Dose (TID) in NAND Flash



Total Ionizing Dose on Flash Memories , NASA

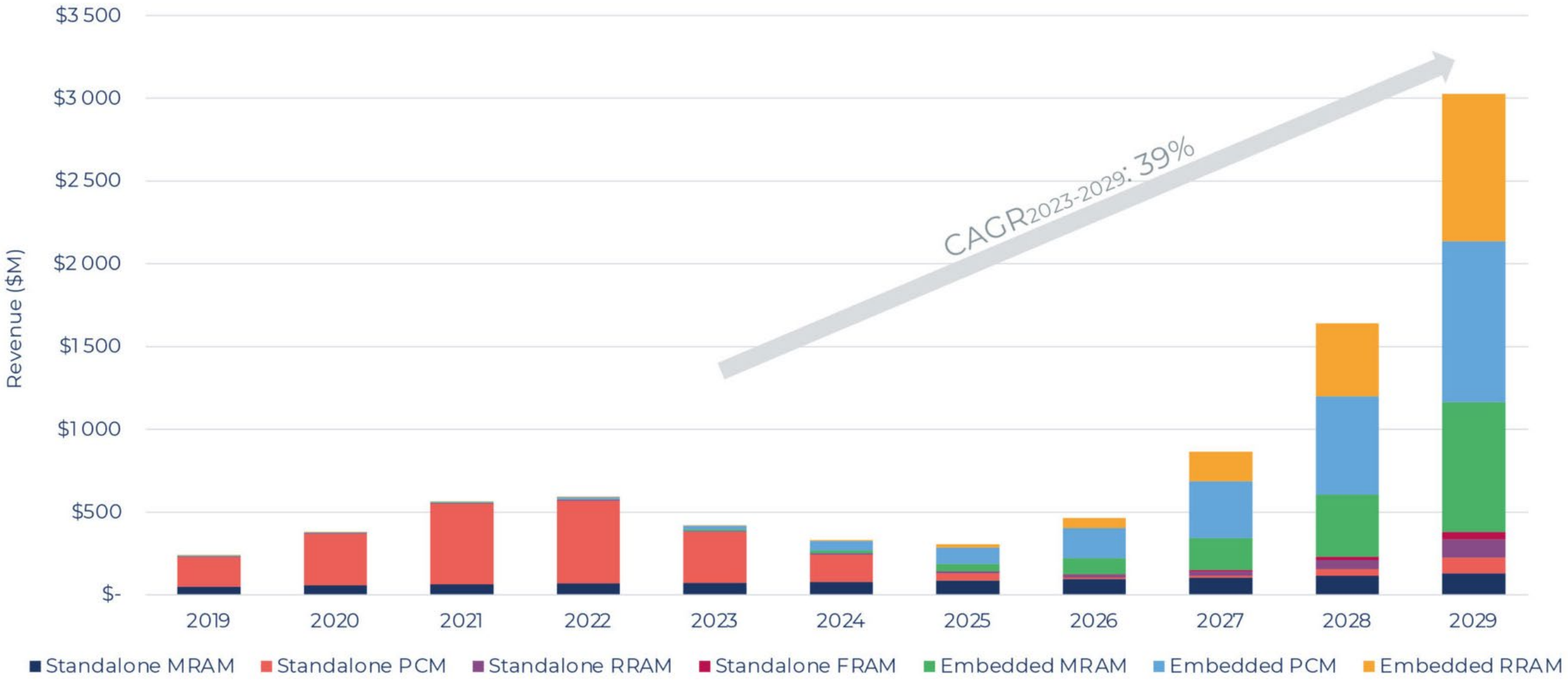
Total Ionizing Dose (TID) in NAND Flash



Total Ionizing Dose on Flash Memories , NASA

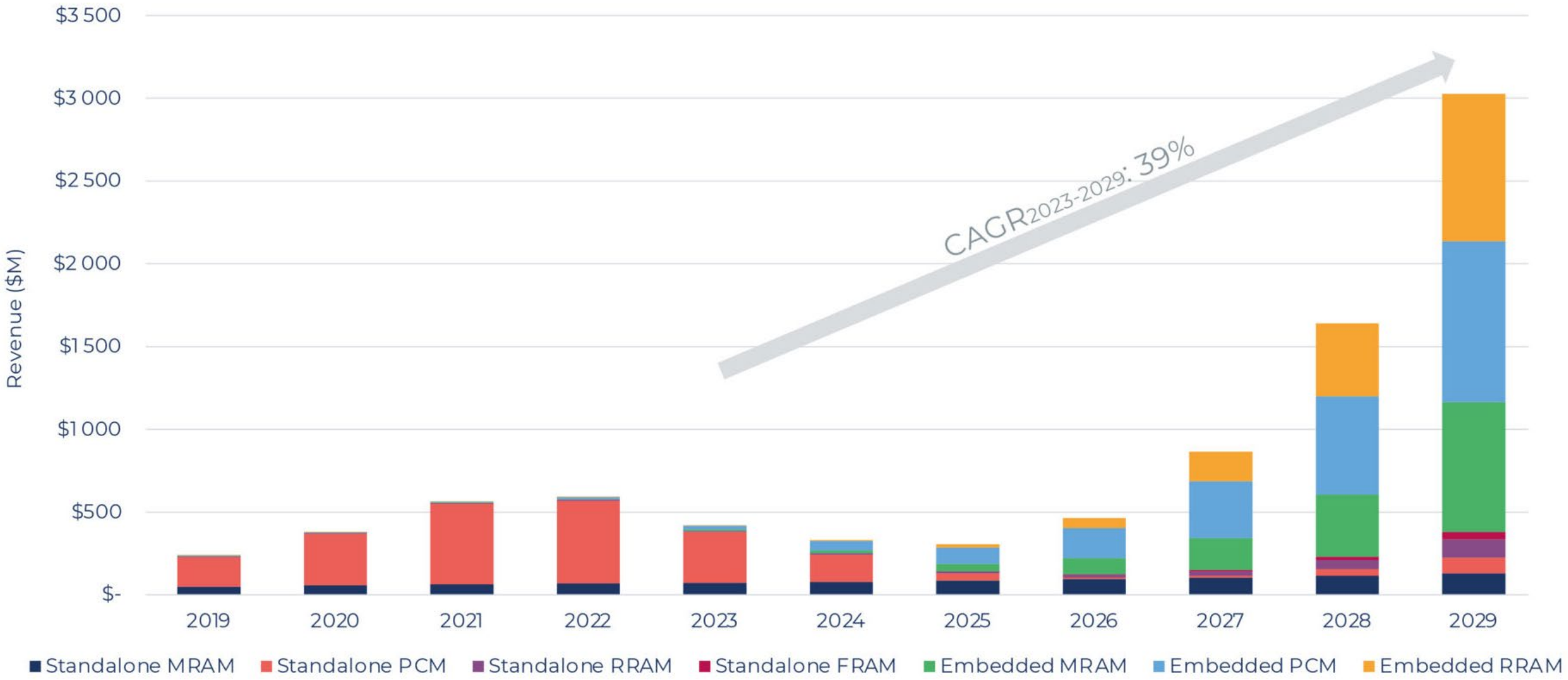
But Advanced Micro-Electronics Is Too Expensive, Right?

Emerging NVM Market



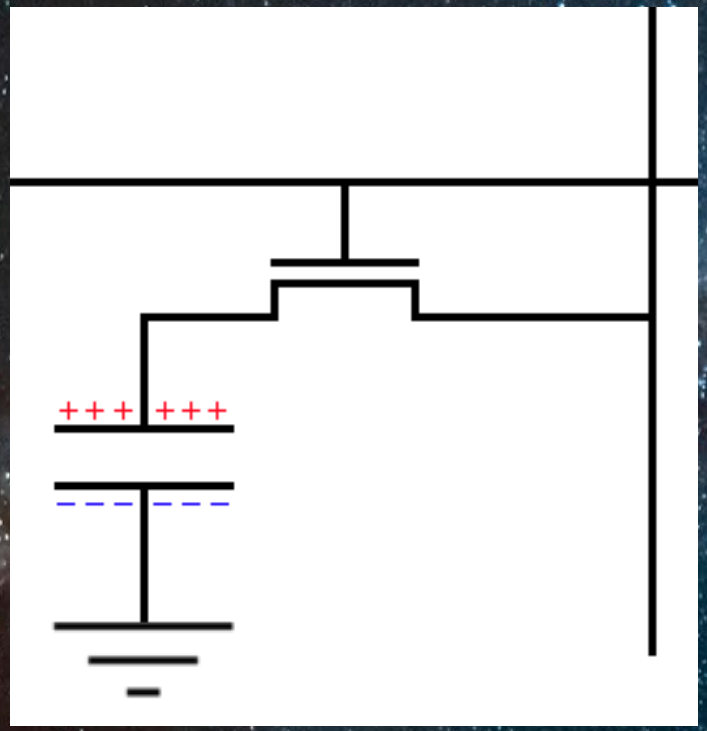
Yole Group, 2025

Emerging NVM Market



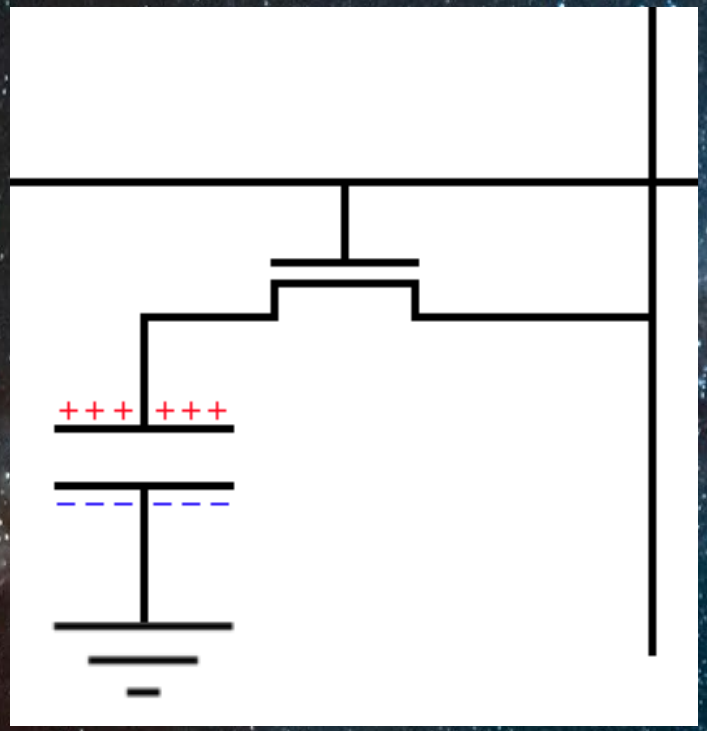
Yole Group, 2025

Magneto-Resistive RAM (MRAM)

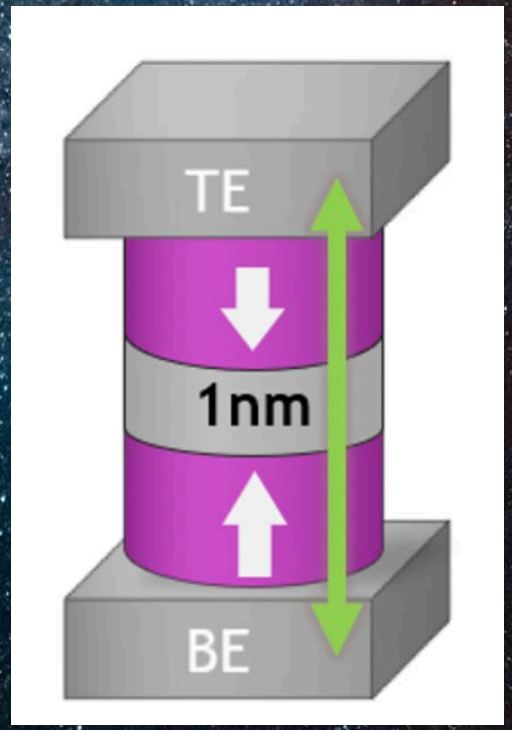


DRAM depends on +/-charge

Magneto-Resistive RAM (MRAM)



Lots of PN Junctions



MgO

DRAM depends on +/-charge

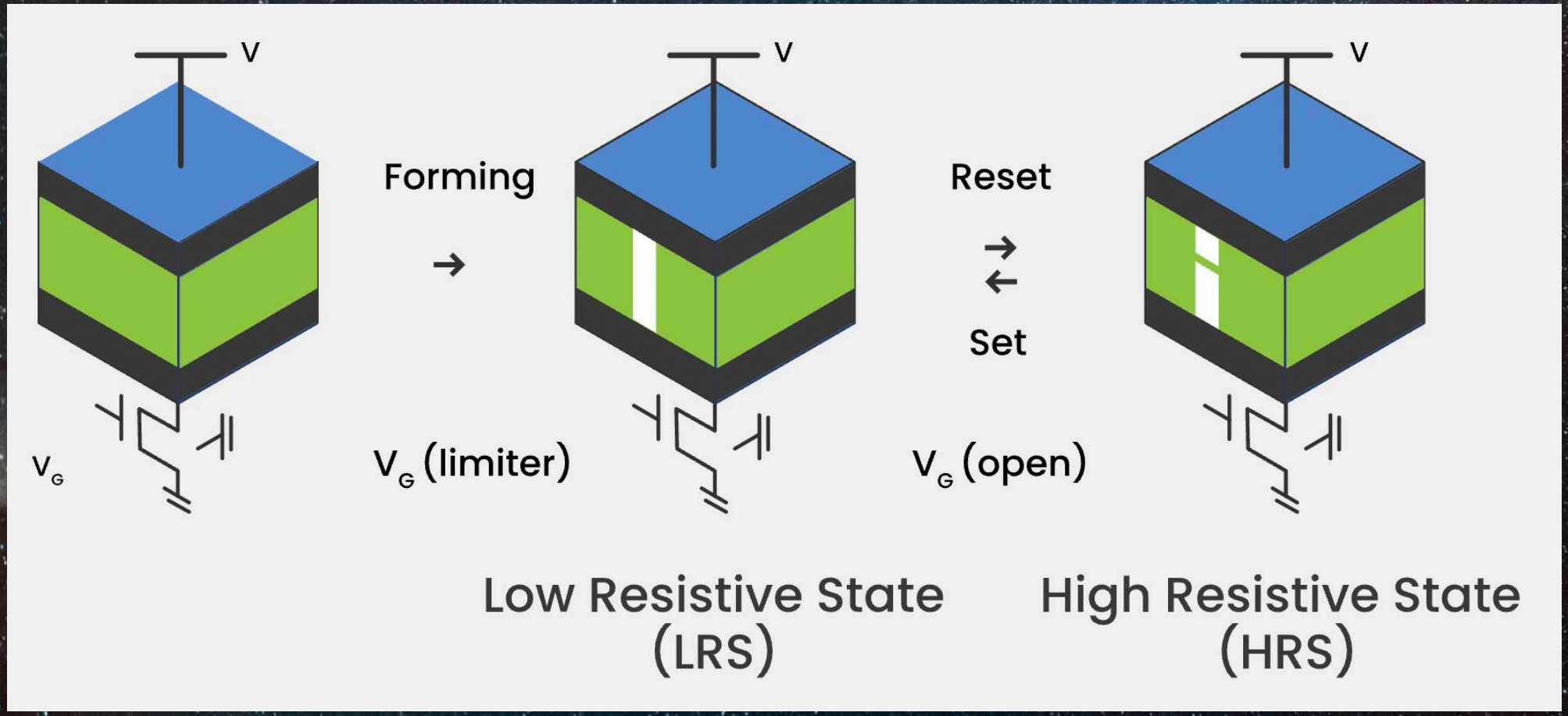
MRAM uses magnetism!

MRAM Radiation Tolerance

	MTJ MRAM	ST-MRAM[1]	NOR Flash	NAND Flash	FRAM	P/CRAM	Units
Density[2]	16 Mb	1000	1,000	128,000	4	512	Mb
Access Time	35	<10	25	20	55	16	ns
Standby Current	<1	<1	<1	<1	<1	<1	mA
Read Current	30	15	20	25	<10	15	mA
Write Current	30	15	50	25	<10	20	mA
Endurance	Infinite	Infinite	100k	0.5-10k	10^{14}	10^{6}	P/E Cycles
Retention	>20	>20	>10	>10	>10	>10	Yrs @ 55°C
Cell Size	10	<4	6	5	10	6	F^2
Cost/Mb	1.5	?	0.01	0.0002	10	0.05	USD
SEU Immune	Yes	Yes	No	No	No	Yes	n/a
SEL Immune	Yes	Yes	No	No	No	Yes	n/a
TID	>1000	>1000	<100	<100	<100	>1000[3]	krad (Si)

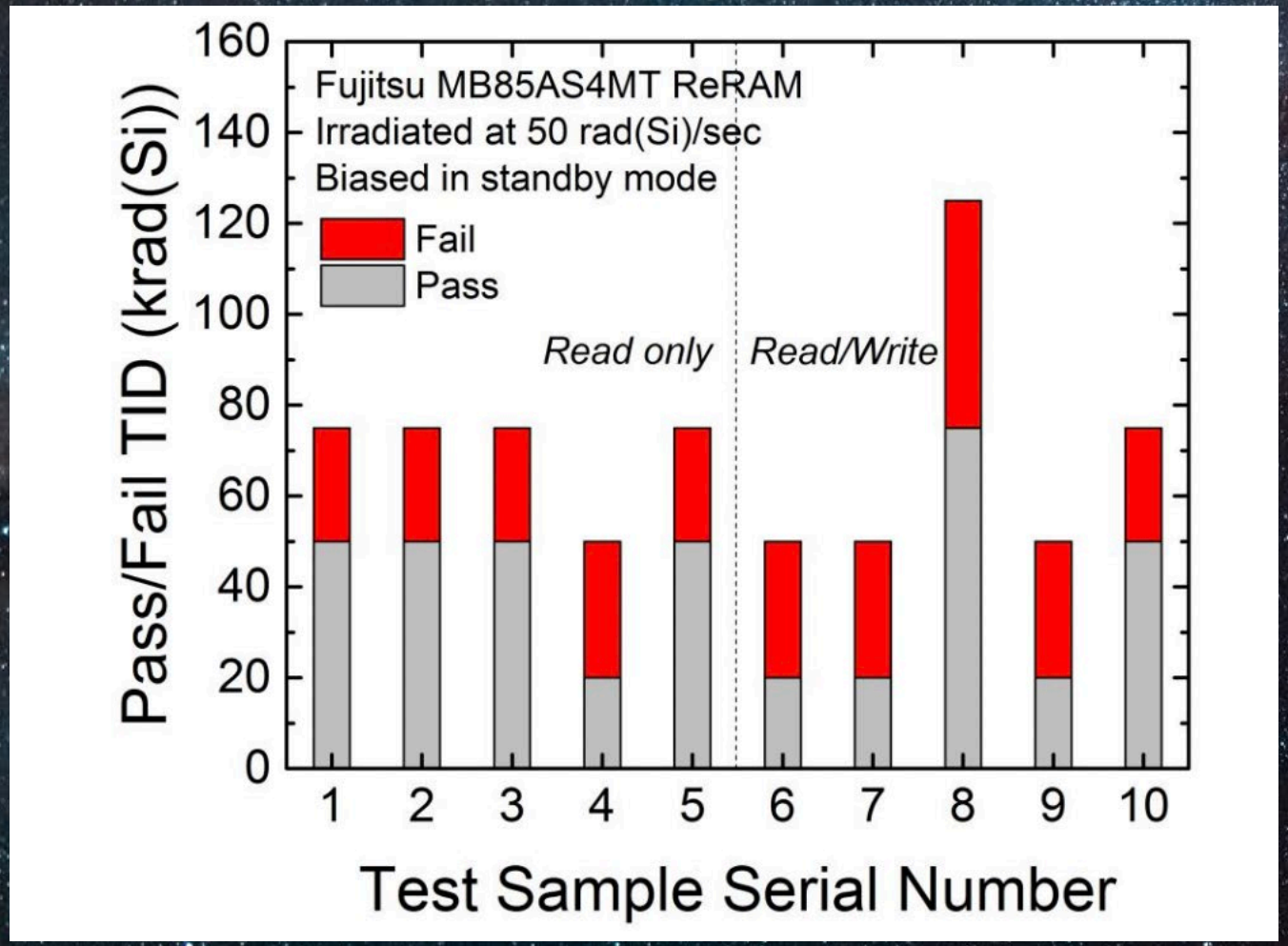
MRAM Technology Status, NASA

Memristor Resistive RAM (ReRAM)



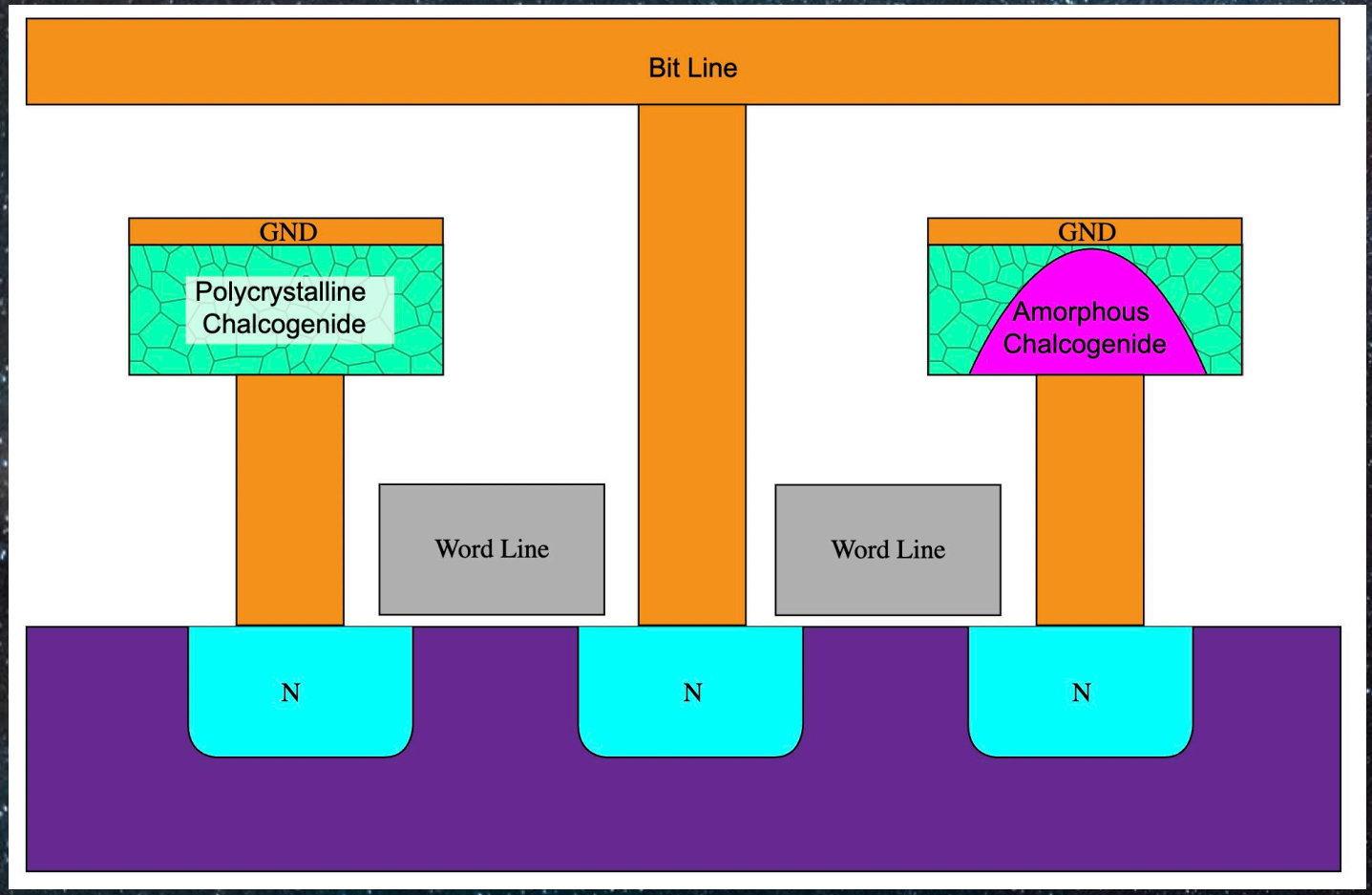
memristor based storage of bit

ReRAM Radiation Tolerances



Total Ionizing Dose Test Report for the MB85AS4MT ReRAM, NASA

Phase Change RAM (PCRAM)



resistive based storage of bit

PCRAM Radiation Tolerance

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Access Time	35	<10	25	20	55	16	ns
Standby Current	<1	<1	<1	<1	<1	<1	mA
Read Current	30	15	20	25	<10	15	mA
Write Current	30	15	50	25	<10	20	mA
Endurance	Infinite	Infinite	100k	0.5-10k	10^{14}	10^{6}	P/E Cycles
Retention	>20	>20	>10	>10	>10	>10	Yrs @ 55°C
Cell Size	10	<4	6	5	10	6	F^2
Cost/Mb	1.5	?	0.01	0.0002	10	0.05	USD
SEU Immune	Yes	Yes	No	No	No	Yes	n/a
SEL Immune	Yes	Yes	No	No	No	Yes	n/a
TID	>1000	>1000	<100	<100	<100	>1000[3]	krad (Si)

MRAM Technology Status, NASA

Novel Memory Is Also Driving Novel Compute

Beyond Von-Neumann...

Analog
Compute-In-Memory

Neuromorphic

Compute-In-SRAM

Promising Low Power Alternatives For Space Computing...

Beyond Von-Neumann...

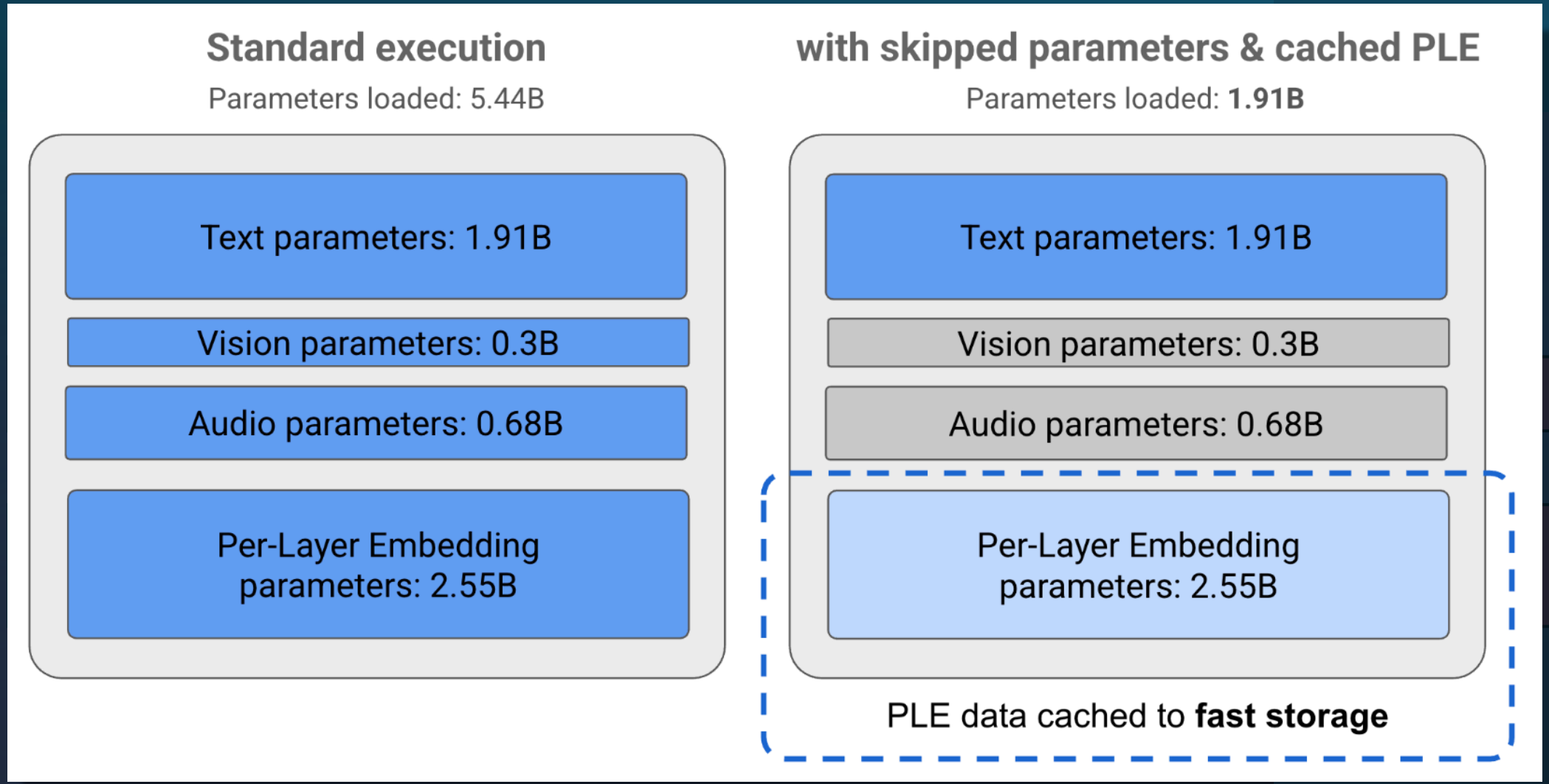
Analog
Compute-In-Memory

Neuromorphic

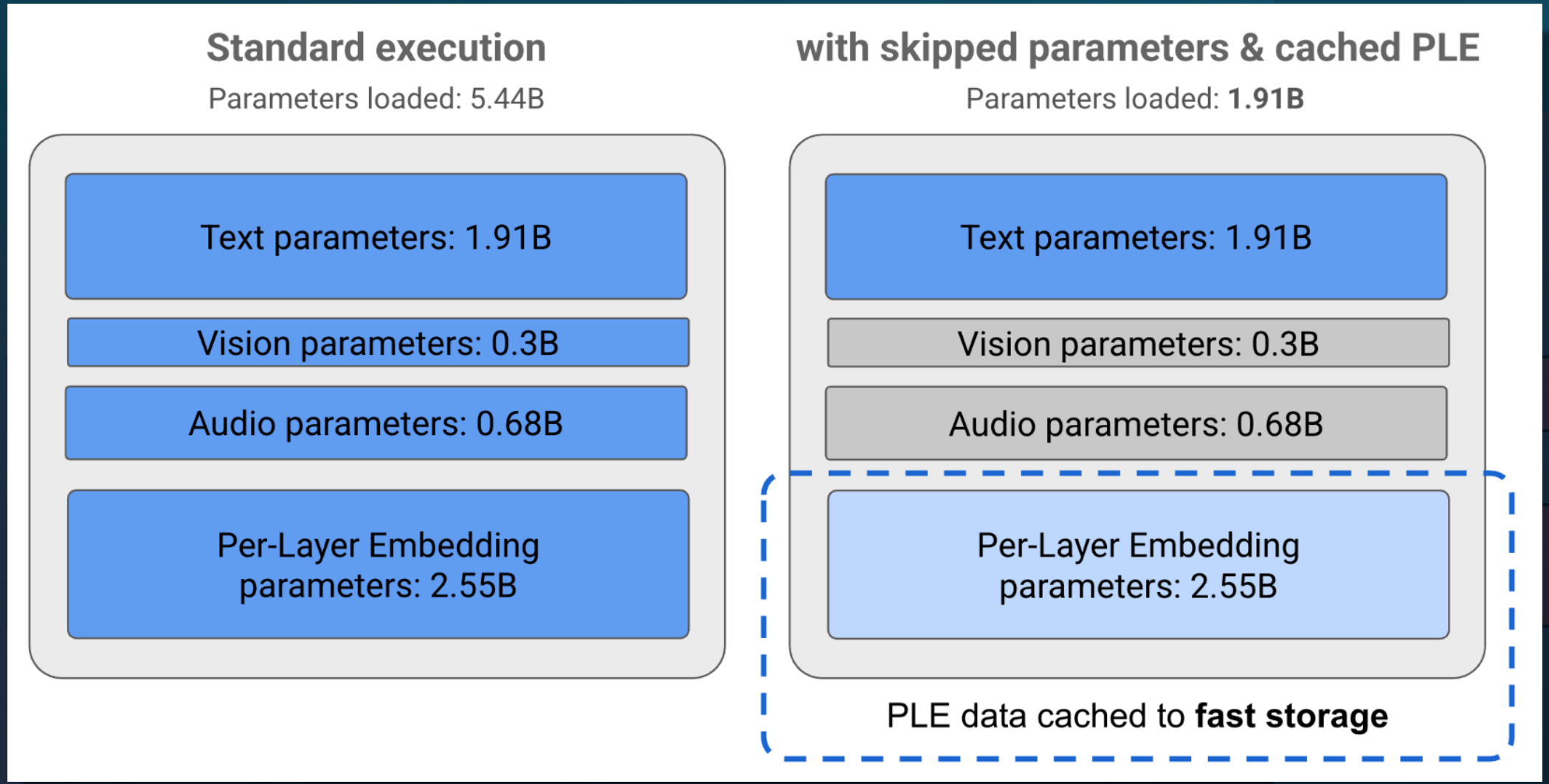
Compute-In-SRAM

Who Will Be Radiation Tolerant First?

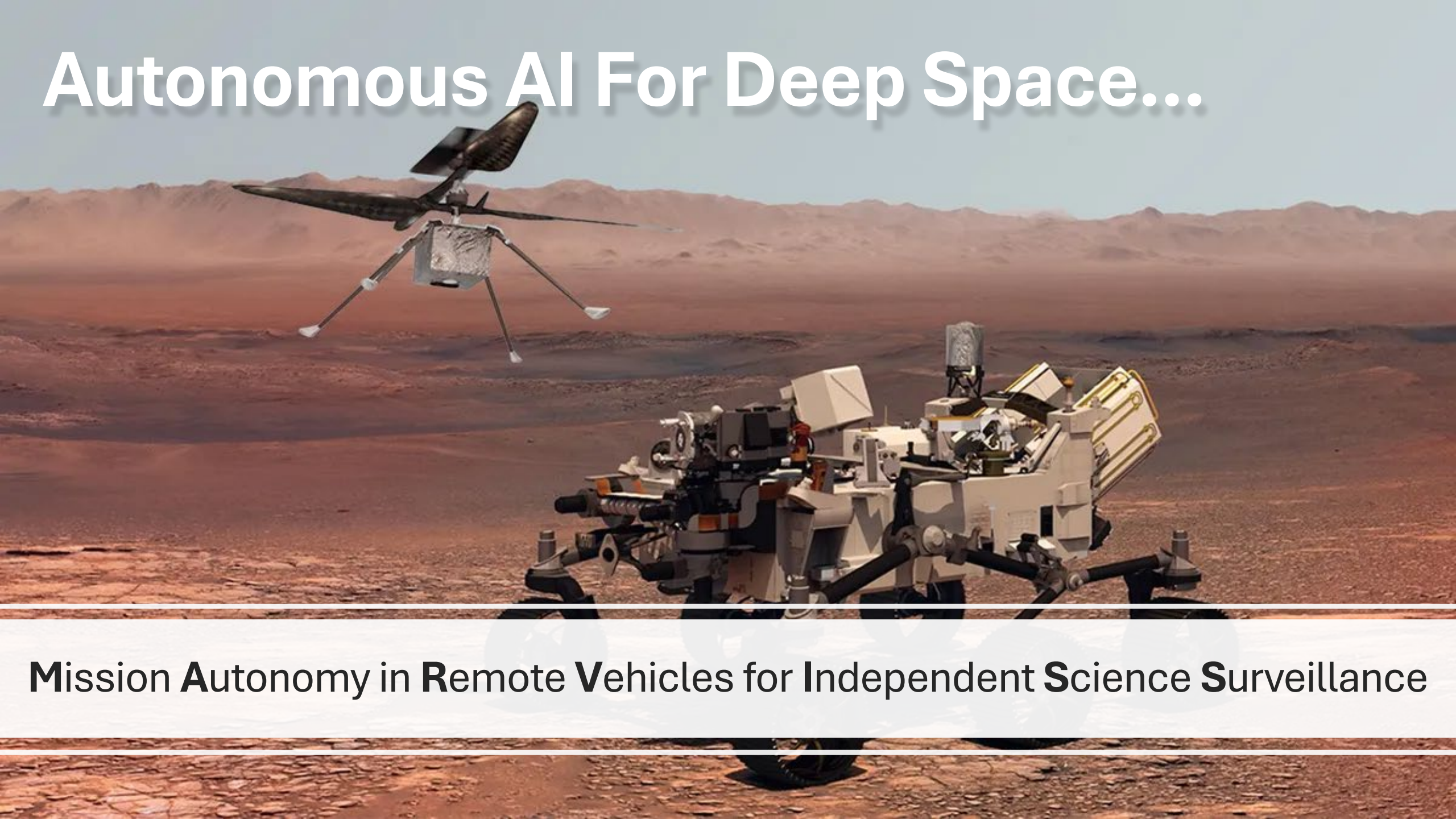
Small Language Models (Gemma3N)



Small Language Models (Gemma3N)



Autonomous AI For Deep Space...



Mission **A**utonomy in **R**emote **V**ehicles for **I**ndependent **S**cience **S**urveillance