Space RadSim

Binary-Agnostic Fault Injection to Evaluate Cosmic Radiation Impact on Exploit Mitigation Techniques in Space

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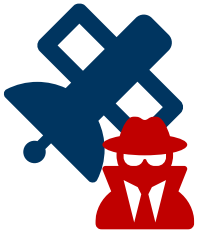
Motivation

Broad application spectrum

2025: ~2600
2023: 2136

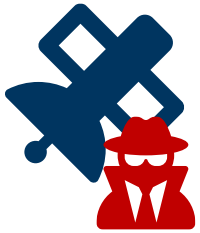
2010: 81

Increasing number of satellites



Interesting to attackers

Previous Research



Small satellites often vulnerable [1]

Lacking access control

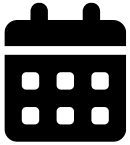
Existing research

No exploit mitigations

No Research

[1] Johannes Willbold, Moritz Schloegel, Manuel Vögele, Maximilian Gerhardt, Thorsten Holz, and Ali Abbasi.
Space Odyssey: An Experimental Software Security Analysis of Satellites. In IEEE Symposium on Security and Privacy (S&P), 2023

Hardware Survey



2020-2023
4 Years

Launch Dates

Only unique designs

Counting Method

Open Source Intelligence (OSINT)

Data Source

Year	Conventional CPUs							Radiation-hardened CPUs				No data
	ARM-C M	ARM-C A	AVR32	ARM9	AVR8	Other	∑	MSP430	LEON3	PicoSkyFT	∑	
2020	10	7	2	4	2	-	25 (51%)	1	-	1	2 (4%)	22 (45%)
2021	8	1	2	3	3	4	21 (42%)	1	-	-	1 (2%)	28 (56%)
2022	18	5	4	1	1	10	39 (30%)	4	4	-	8 (6%)	85 (64%)
2023	21	2	2	1	1	6	33 (22%)	-	-	-	0 (0%)	117 (78%)
∑	**57**	**15**	**10**	**9**	**7**	**20**	**118 (31%)**	**6**	**4**	**1**	**11 (3%)**	**252 (66%)**

Available Exploit Mitigations

Platform	Compiler	Stack Canary	Safe Stack	Shadow Stack	CFI	FSan
ARM Cortex-M	GCC	✓	✗	✗	✗	✗
ARM Cortex-M	LLVM	✓	✗	✗	✓	✓
ARM Cortex-A	GCC	✓	✗	✗	✗	✗
ARM Cortex-A	LLVM	✓	✓	✗	✓	✓
AVR32	GCC	?	✗	✗	✗	✗
AVR32	LLVM	–	–	–	–	–

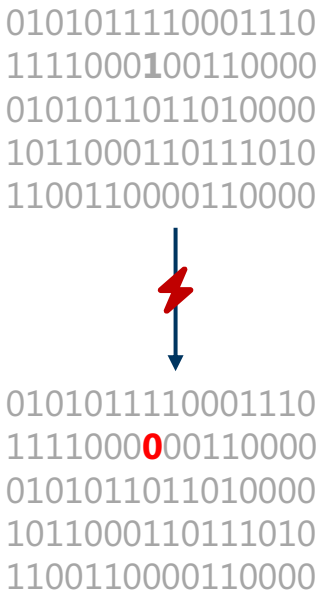
Stack Canaries (all)

Stack Canaries (strong)

Control Flow Integrity (CFI)

Function Sanitization

Single Event Upsets



Code Section Bitflips

```
02 48          LDR    R0, =5
03 49          LDR    R1, =7
00 eb 01 02    ADD    R2, R0, R1
1a 60          STR    R2, [R3]
fe e7          B      endless
```

```
02 48          LDR    R0, =5
03 49          LDR    R1, =7
00 eb 01 02    ADD    R2, R0, R1
1a 61          STR    R2, [R3, 0x10]
fe e7          B      endless
```

Data Section Bitflips

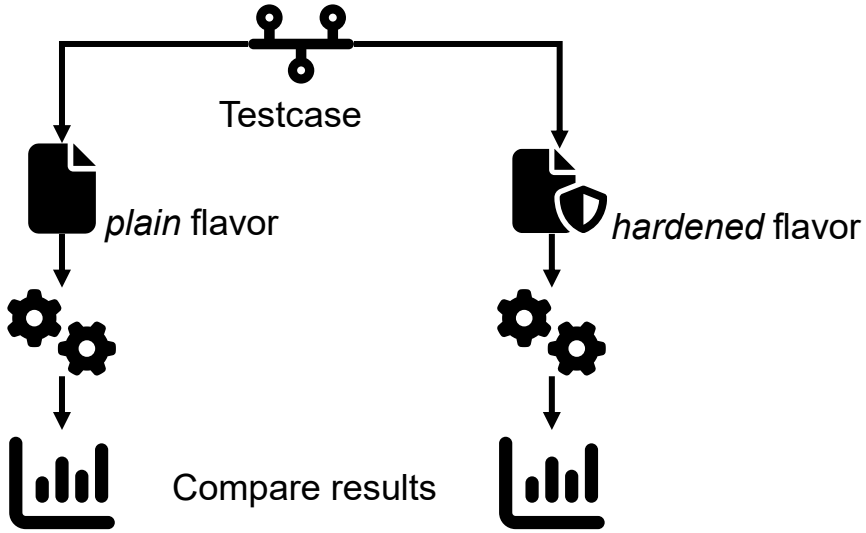
Stack Entry	No Error	Silent Error	Hard Error
Return Address		!	×
Saved Regs.	✓	!	×
Stack Canary			×
Local Vars	✓	!	×

Fault Injection (FI) Approach

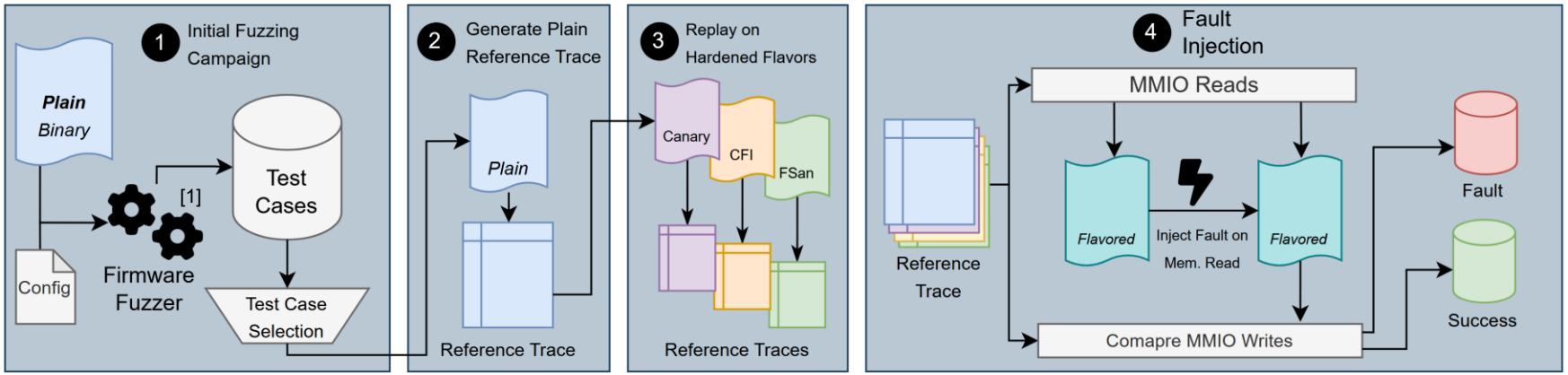
Existing Solutions:

- Pre-defined PC for FI
  - PCs break when hardening
- Probability for FI
  - Introduces randomness

Space RadSim:

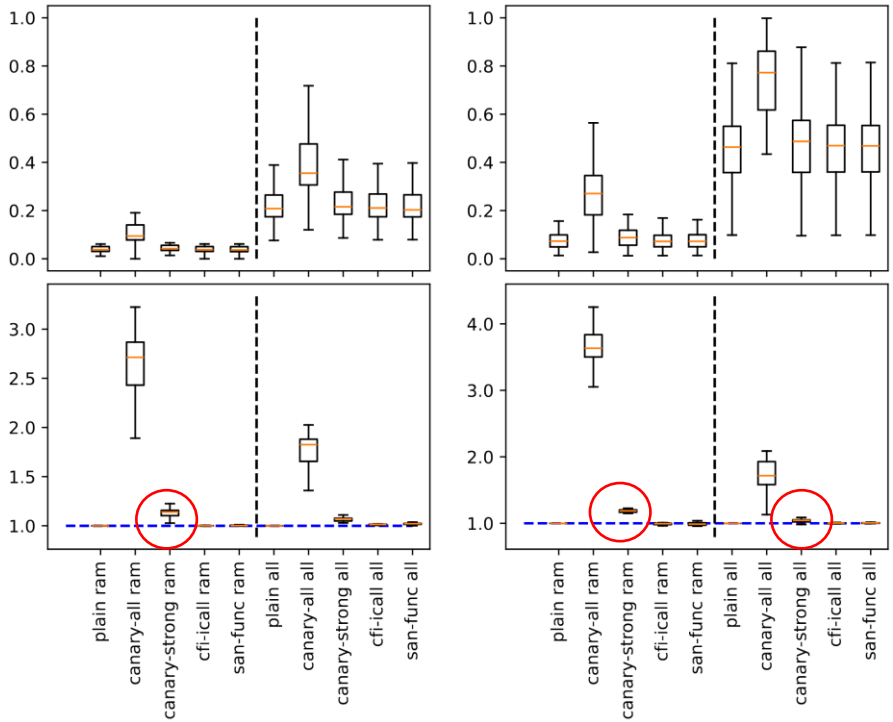


RadSim Design Overview



[1] Tobias Scharnowski, Simon Wörner, Felix Buchmann, Nils Bars, Moritz Schloegel, and Thorsten Holz. Hoedur: Embedded Firmware Fuzzing using Multi-stream Inputs. In USENIX Security Symposium, 2023.

Results



Stack Canaries (all):

- Increase crash prob. by 2.7/3.6x
- 23/44% code size increase
- Only for reference

Stack Canaries (strong):

- Crash prob.: 14/19% increase
- 3/3% code size increase

Conclusion

Survey of Applicable Mitigations:

- Extensive hardware survey
- Surveyed compiler-level support for mitigations

Binary-Agnostic Fault Injection Engine:

- Check every possible bitflip
- Stack canaries degrade failure probability beyond code-size increase

Results:

- Stack canaries degrade failure probability beyond code-size increase

Open Source Code:

CISPA-SysSec/space-radsim

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