Workshop on memristive systems for space applications

João Cunha*, Leopold Summerer
ESA Advanced Concepts Team
April 30th 2015

* organiser

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ESA FACTS AND FIGURES

- Over 50 years of experience
- 20 Member States
- Eight sites/facilities in Europe, about 2200 staff
- 4.4 billion Euro budget (2015)
- Over 80 satellites designed, tested and operated in flight
- Over 20 scientific satellites in operation
- Six types of launcher developed
- 200th launch of Ariane celebrated in February 2011

PURPOSE OF ESA

"To provide for and promote, for exclusively peaceful purposes, cooperation among European states in **space research** and **technology** and their **space applications.**"

Article 2 of ESA Convention

20 MEMBER STATES AND GROWING

ESA has 20 Member States: 18 states of the EU (AT, BE, CZ, DE, DK, ES, FI, FR, IT, GR, IE, LU, NL, PT, PL, RO, SE, UK) plus Norway and Switzerland. Estonia and Hungary will soon be part of ESA (2015)

Seven other EU states have Cooperation Agreements with ESA: Bulgaria, Cyprus, Latvia, Lithuania, Malta, Slovakia and Slovenia. Discussions are ongoing with Croatia.

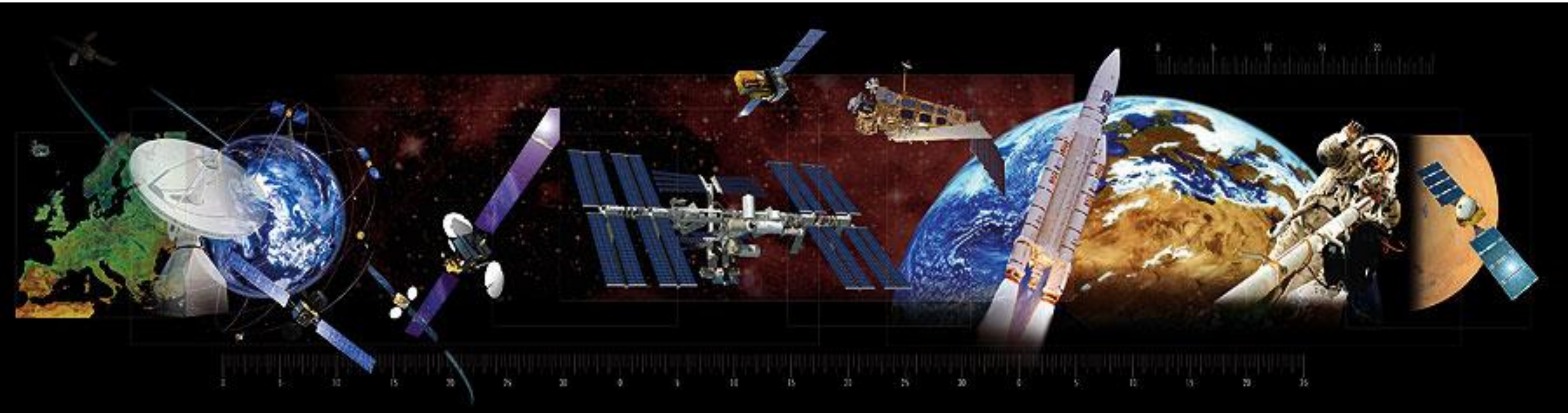
Canada takes part in some programmes under a long-standing Cooperation Agreement.

ACTIVITIES

ESA is one of the few space agencies in the world to combine responsibility in nearly all areas of space activity.

- **Space science**
- **Human spaceflight**
- **Exploration**
- **Earth observation**
- **Launchers**
- **Navigation**
- **Telecommunications**
- **Technology**
- **Operations**

* Space science is a **Mandatory programme**, all Member States contribute to it according to GNP. All other programmes are **Optional,** funded 'a la carte' by Participating States.

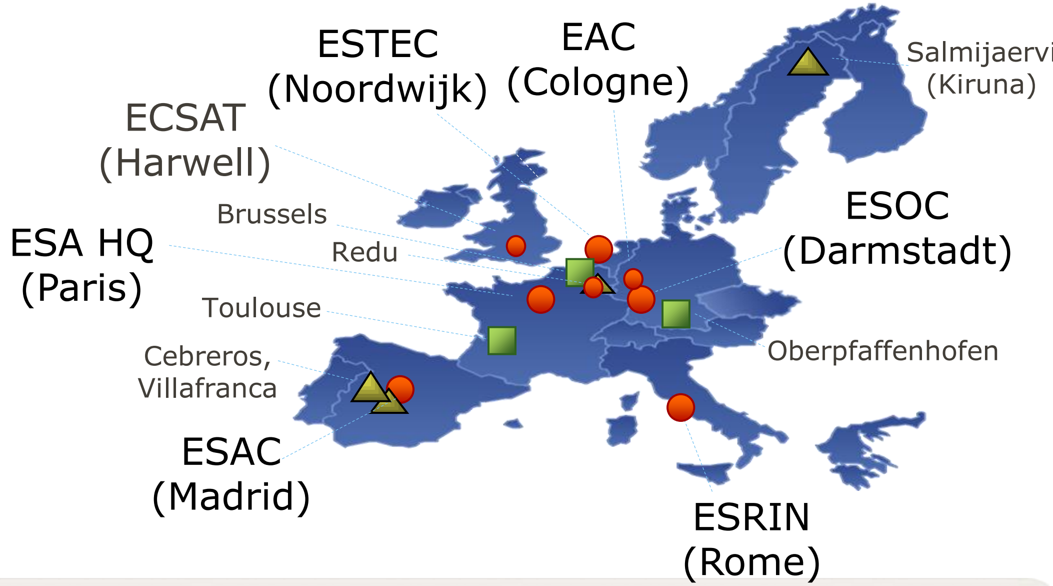


ESA'S LOCATIONS

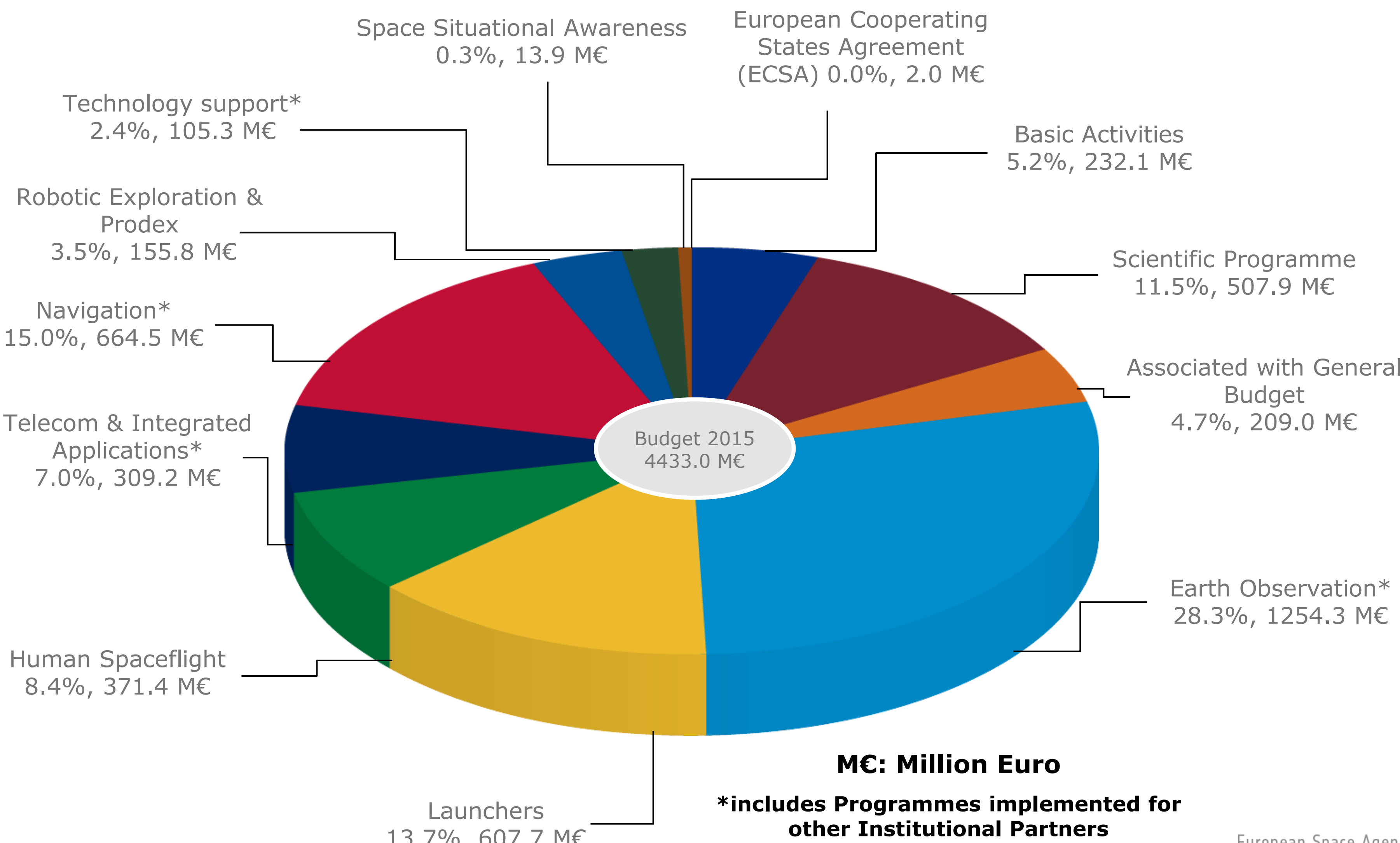
ESA sites/facilities

Offices

ESA ground stations



ESA 2015 BUDGET BY DOMAIN



M€: Million Euro

***includes Programmes implemented for other Institutional Partners**

ESA DIRECTORS

Director General
Jean-Jacques Dordain

Science & Robotic Exploration
Alvaro Giménez Cañete

Launchers
Gaele Winters

Human Spaceflight & Operations
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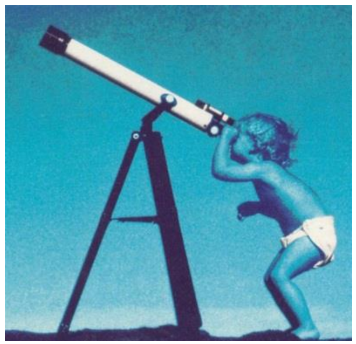
Giuseppe Morsillo

Future Preparation and Strategic Studies Office (TEC-SF)



General Studies Programme

- Strategic, missions and interdisciplinary studies in preparation of ESA's future
- System studies

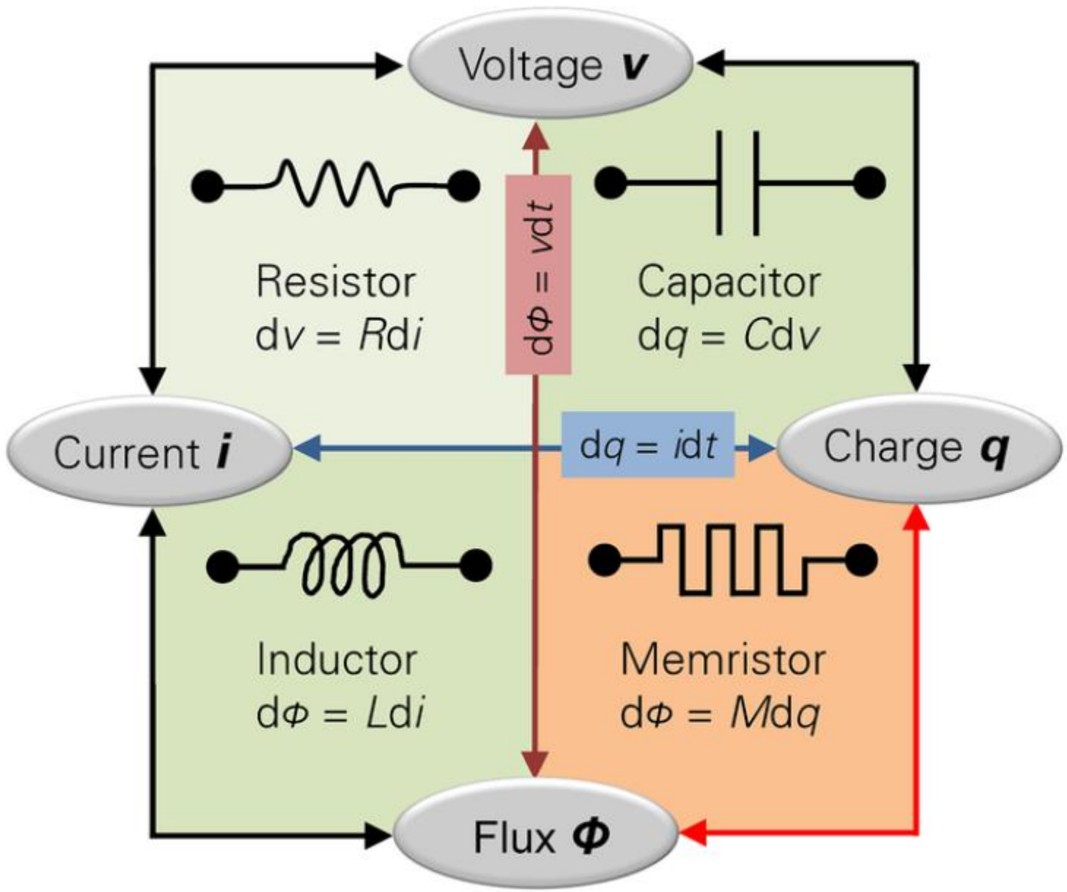
Advanced Concepts Team

- Internal research think-tank
- Objective to monitor, perform and foster research on advanced space systems, innovative concepts and working methods

Workshop Overview

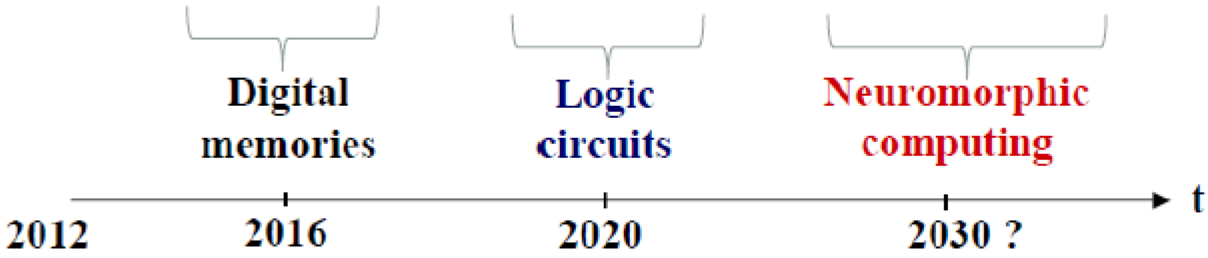
Time	Speaker	Title
10:00	LS+JC, ESA TEC-SF	Welcome and Introduction
Memristors: the basics		
10:30	Dirk Wouters, RWTH-Aachen	Fundamentals of memristors
Memristor applications: memories		
11:00	Dirk Wouters	Resistive memories (RRAM) - principles and technology
11:30	Said Hamdioui, TU Delft	Memritor-based Computing: beyond CMOS and beyond von-Neumann
12:00	Andrea Fantini, IMEC	Radiation hardness of memristive systems
Electronics in space applications		
13:30	Véronique Ferlet-Cavrois, TEC-QEC	Electronics in extreme environments - requirements
14:00	Cristiano Calligaro, RedCat Devices	Radiation Hard RRAM (R2RAM project)
Memristor applications: from memory to pattern recognition		
14:30	Andy Thomas, Bielefeld University	Neuromorphic memristive systems
15:00	Lutz Nielen, RWTH-Aachen	Memristive pattern recognition capacitive networks

The fourth fundamental (missing) element



Chua IEEE Trans. Circuit Theory 18 (1971)
Strukov et al. *NATURE* 453.7191 (2008)

Why?
Extremely versatile new component



* From Julie Grollier (UMP CNRS-Thales, U. Paris-Sud)
"Neuromorphic Comuping – Memristors"

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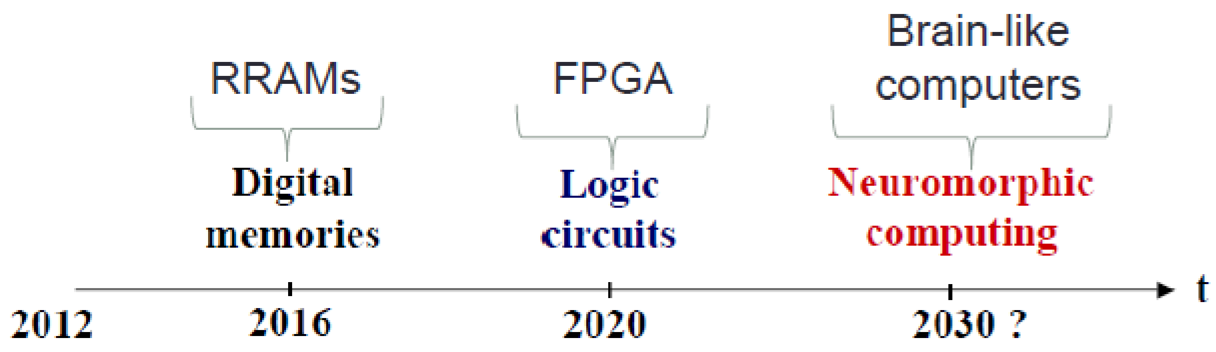

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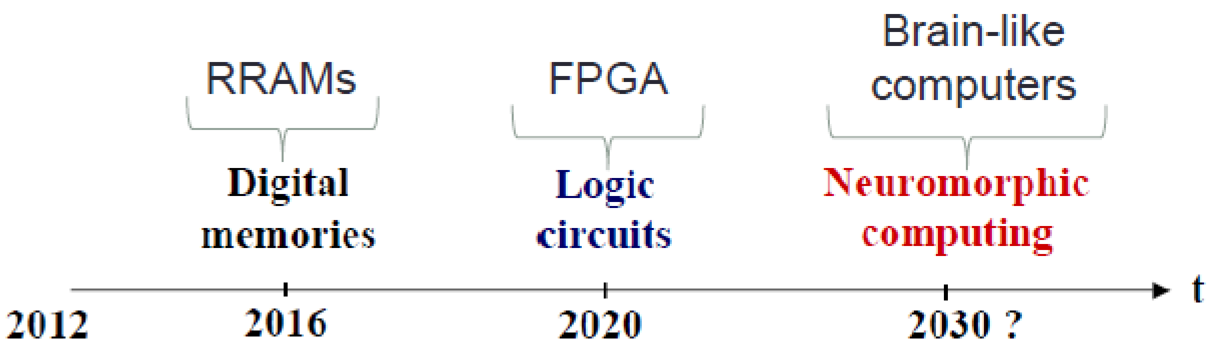

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- First short-term application in memory:
- higher density;
- high switching speeds;
- low power consumption;
- non-volatility;
- rad-hard by construction.

Why?
Memristor for electronic memory

Table 1 | Comparison of memory and storage technologies[119]. Note that circuit-level overheads for the listed performance metrics are in general different among different device technologies and could often dominate individual device performance.*

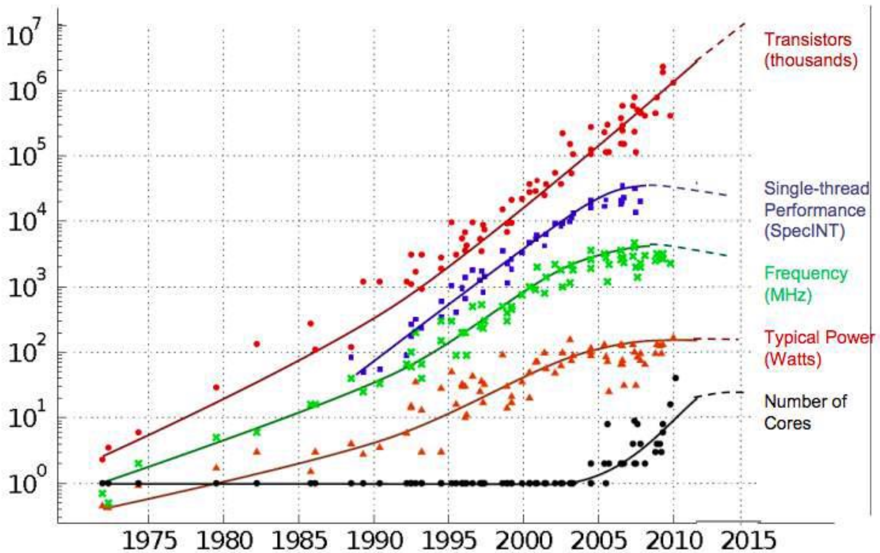
	Memristor	PCM	STTRAM	SRAM	DRAM	Flash (NAND)	HDD
		Prototypes		Commercialized technologies			
Reciprocal density (F^2)	<4	4–16	20–60	140	6–12	1–4†	2/3
Energy per bit (pJ)	0.1–3	2–25	0.1–2.5	0.0005	0.005	0.00002	$1\text{–}10\times10^9$
Read time (ns)	<10	10–50	10–35	0.1–0.3	10	100,000	$5\text{–}8\times10^6$
Write time (ns)	~10	50–500	10–90	0.1–0.3	10	100,000	$5\text{–}8\times10^6$
Retention	years	years	years	As long as voltage applied	<<second	years	years
Endurance (cycles)	10^{12}	10^9	10^{15}	$>10^{16}$	$>10^{16}$	10^4	10^4

*The energy to operate NAND Flash is typically hundreds of picojoules per bit primarily because accessing the memory cells requires charging word and bit lines to high voltages. †Smaller number represents an effective area for multi-level cells. PCM, phase-change memory; STTRAM, spin torque transfer random access memory; SRAM, static RAM; DRAM, dynamic RAM; HDD, hard disk drive.

Yang, J. Joshua, Dmitri B. Strukov, and Duncan R. Stewart. "Memristive devices for computing." *Nature nanotechnology* 8.1 (2013): 13-24.

Why? (use in memories) General industry and space industry

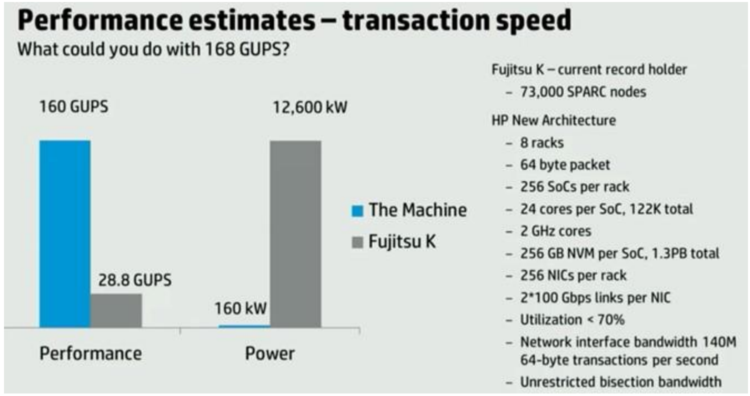
C Moore, *Data Processing in ExaScale-ClassComputer Systems,* Salishan, April 2011



There is a *memory wall*!

HP's The Machine new computer architecture (at 06/2014)

- No cache, only single purpose memories
- No copper buses, integrated photonic fibers
- Targets Big Data applications
- Scheduled release date: 2018



HP June 2014 keynote

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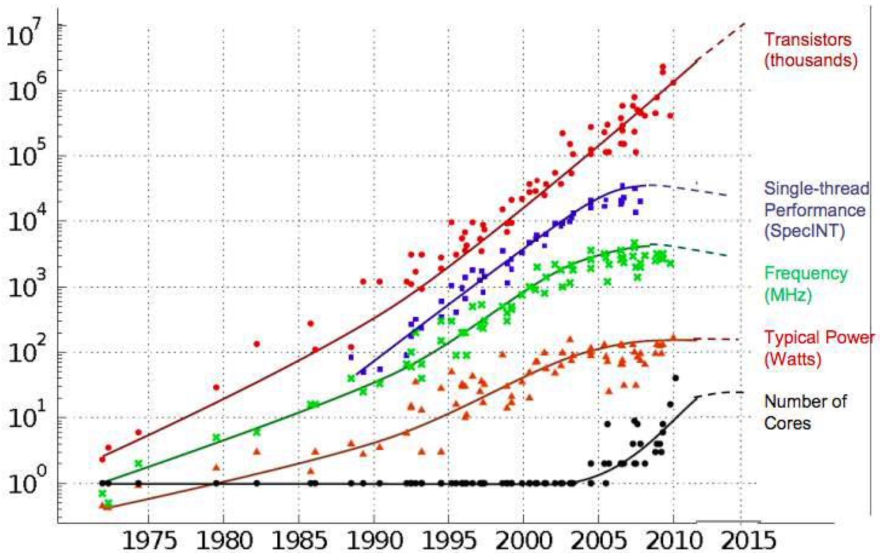

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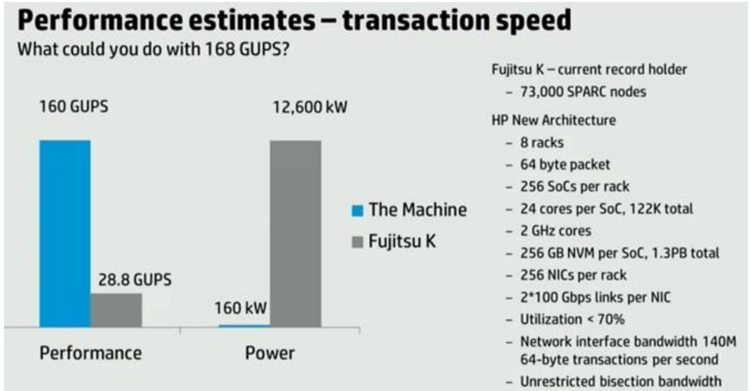
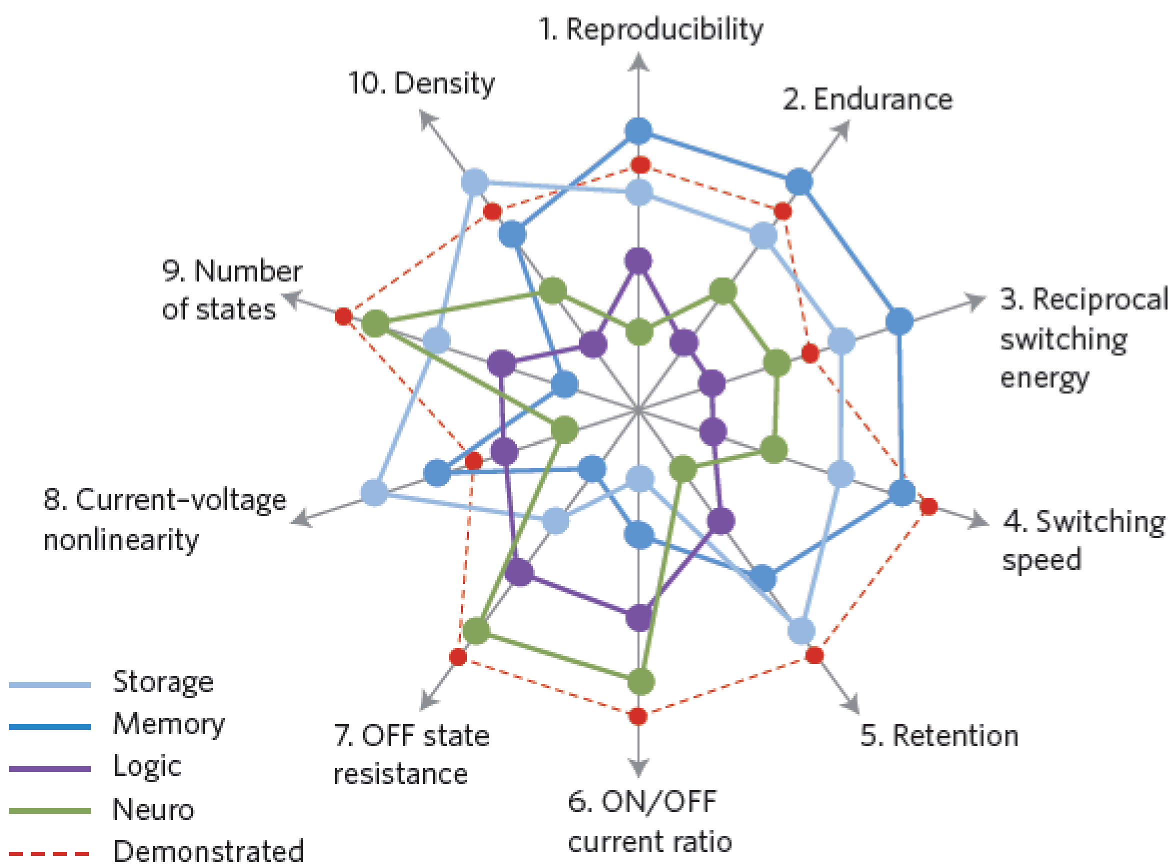


HP June 2014 keynote

Space industry: Special requirements in terms of ***reliability***, ***availability*** and ***radiation hardness***.

Note: innovation in microelectronics technologies made Cubesats technology ready to perform some tasks previously reserved for more bulky structures.

Why?
New possibilities with the same element



Yang, J. Joshua, Dmitri B. Strukov, and Duncan R. Stewart. "Memristive devices for computing." *Nature nanotechnology* 8.1 (2013): 13-24.

Enjoy and thank you!

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