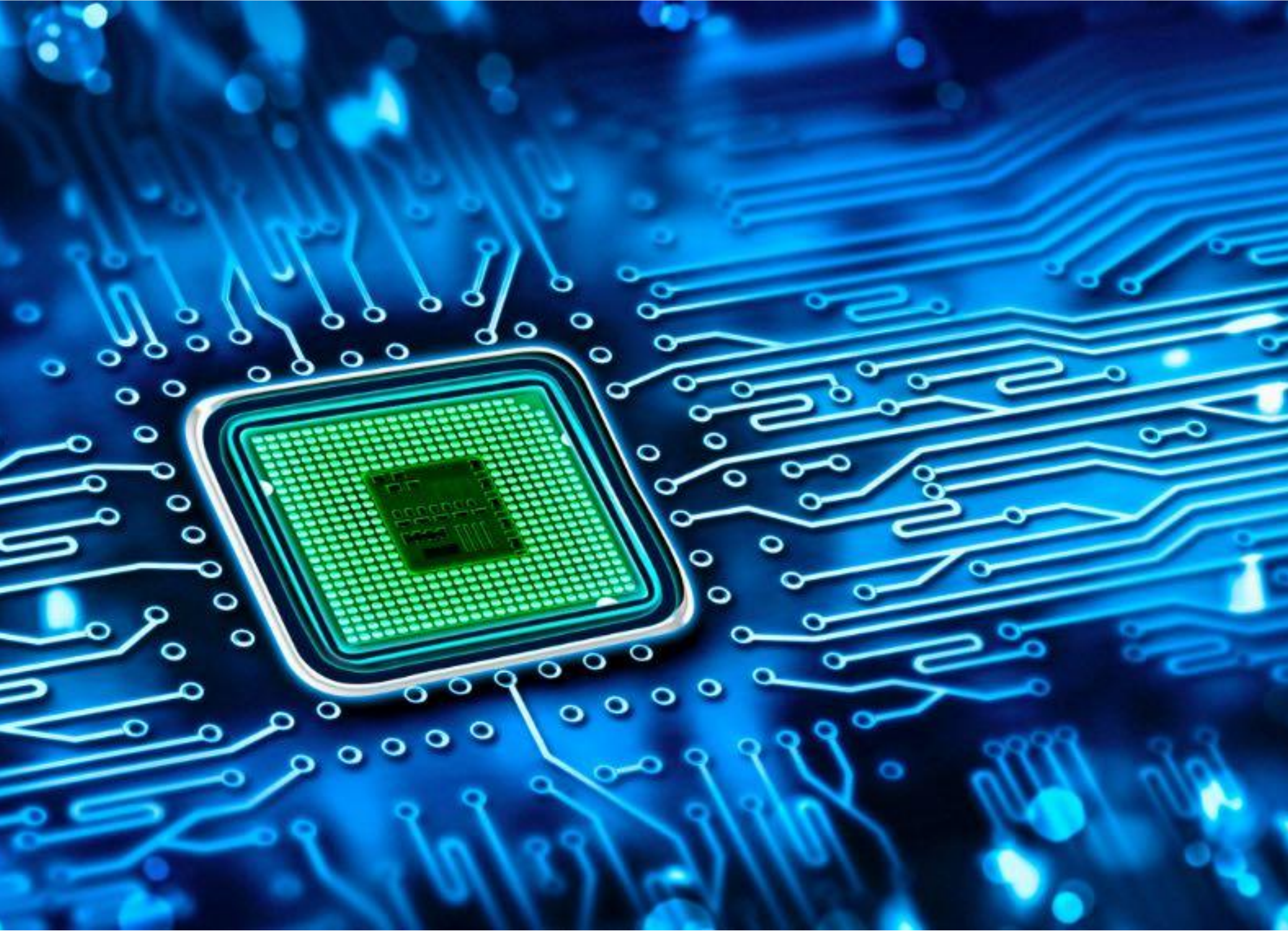


IMPACT ASSESSMENT OF ESA EARLY R&D ACTIVITIES

Big Re-programmable Array for Versatile Environments (BRAVE)

know.space

March 2025

FPGAs enhance the flexibility and miniaturisation of space electronics...

Field Programmable Gate Arrays (FPGAs) are a type of integrated circuit that can be programmed after the manufacturing stage for specific user needs. This makes them vital for space assets, as they consolidate board-level logic and functions into a single chip, being able to perform custom sets of functions while reducing the size, weight, and complexity of circuit boards. For instance, in spacecraft instruments, they can enable real-time data acquisition and onboard processing for sensors, spectrometers and imaging systems. Furthermore, they can support power management and communication systems in spacecraft components, and facilitate precise engine control and telemetry processing in propulsion systems, thereby improving efficiency and responsiveness in manoeuvring and station-keeping operations.

For these reasons, FPGAs have been used in space for over 30 years. For example, they were employed in cameras and wireless communication equipment for NASA and ESA Mars exploration missions, and on board DLR's dual-spectrum infrared detection (BIRD) satellites to enable functions such as satellite payload data processing, memory management and sensor control of infrared cameras.[i]

Traditionally, this technology was anti-fuse based, meaning they are programmable only once. The development of reprogrammable FPGAs overcame this limitation, allowing users to reprogram them multiple times. This enhanced adaptability is particularly valuable for space, as it enables in-orbit updates and reconfiguration, extending hardware lifespans and reducing the need for costly replacements. This capability ensures that space systems can adapt to dynamic mission needs and integrate emerging technologies, particularly as satellite lifetimes continue to increase.[1]

...and NanoXplore emerged as a leader through ESA support...

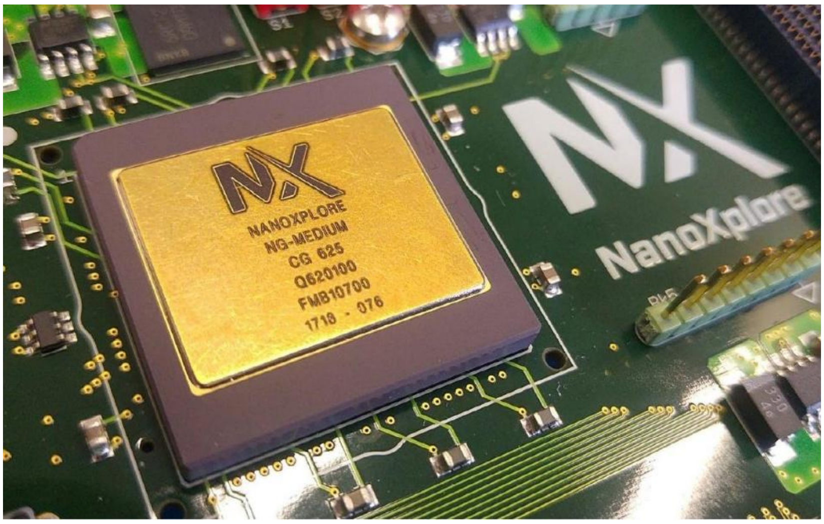
NanoXplore are a French company specialised in the design and development of advanced electronics for space. In 2014, ESA awarded NanoXplore their first Technology Development

[1] Today, the majority of FPGAs are reprogrammable. Therefore, throughout this assessment 'FPGA' refers specifically to reprogrammable FPGAs.

Element (TDE)[2] contract (€1.6m) for the Big Re-programmable Array for Versatile Environments (BRAVE) project, which aimed at developing high performance, radiation-hardened European FPGAs. Under the contract, along with a follow-on TDE contract and support from the Centre National d'Etudes Spatiales (CNES), NanoXplore developed the NG-Medium FPGA. This technology was released to market in 2017 and became the first space-qualified European FPGA, after undergoing ESA's qualification process and receiving certification for ESA mission use in August 2022.[ii]

Since then, NanoXplore have been awarded several follow-on contracts, including three through the TDE programme, three through GSTP, one through ARTES, and one ESA-Horizon 2020 contract, with a combined value of nearly €15m. The BRAVE project progressed thanks to these contracts, with NanoXplore developing new generations of radiation-hardened reprogrammable FPGAs. This includes NG-LARGE, a 65nm technology with enhanced performance; NG-ULTRA, a 28nm technology; and ULTRA300, a 28nm technology with improved data connections and digital-analogue signal converters.

Figure 1: NanoXplore NG-MEDIUM



Source: CNES-Mathieu Albinet[iii]

The objective of these multiple contracts was to develop European-made, increasingly miniaturised, radiation-hardened FPGAs suitable for space use. The FPGAs developed by NanoXplore are characteristically radiation-hardened with various hardware mitigation techniques to offer a lower risk of technological failure.

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[2] ESA's Technology Development Element (TDE) programme, formerly the Basic Technology Research Programme (TRP), supports early-stage technology developments for a range of application areas including Earth observation, space science, exploration, telecommunications, and navigation.

Figure 2: BRAVE consortium

Source: ESA

Across these contracts, subcontractors STMicroelectronics (FR), Thales Alenia Space (TAS FR) and Airbus (FR, DE, ES) have supported NanoXplore's activities. STMicroelectronics complements NanoXplore's FPGA expertise by providing the manufacturing and assembly of components, while Airbus and TAS contribute to evaluation activities such as radiation testing.

Alongside ESA's support, the development of these FPGAs have been supported by parallel contracts from CNES and the European Commission. This success story exemplifies the impact of coordinated funding from multiple organisations catalysed through ESA funding, with the aim of enhancing European non-dependence and specialised space sector expertise.

...driving Europe's competitiveness with radiation-hardened microelectronics...

The use of FPGAs in space applications is experiencing rapid growth, driven by their flexibility, reprogrammable nature, and ability to address the unique demands of space missions. This adaptability allows for on-the-fly system modifications, a critical capability for space exploration. The global FPGA market for space applications is valued at €1.26 billion in 2024 and is projected to grow to around €1.9 billion by 2030, with Europe representing the second largest market (€320 million in 2023), behind North America.[iv]

This trend is further supported by increasing demand for miniaturised components that optimise size, weight, power, and cost. Miniaturisation is essential for enabling smaller, more affordable satellites while meeting the needs of the modern communication, aerospace, and defence sectors.

However, most commercial FPGA technologies are not inherently designed to endure the extreme conditions of space. This is because the SRAM base of reprogrammable FPGAs is vulnerable to single event upsets caused by radiation. Whilst US competitors have historically focused on adapting terrestrial commercial components for space, NanoXplore develops radiation-hardened technologies specifically designed to withstand the harsh space environment.

This approach not only de-risks technological developments by providing enhanced redundancy to mitigate radiation impacts, but also significantly reduces the burden on satellite system designers – the main customers of these components – who would otherwise need to incorporate these redundancies themselves. The result is a lower cost, risk and time burden for customers, ensuring reliable, space-ready solutions. By pursuing these objectives, NanoXplore aims to position itself as a leader in radiation-hardened electronics, supporting the growing demand for customisable, high-performance solutions in the global space sector.

The project's continuous improvement of reprogrammable FPGAs suitable for space supports the industry's push towards miniaturisation and the development of compact, high-functionality systems. Their inherent flexibility allows designers to modify and optimise circuits even after production, enabling quicker design iterations and shorter development cycles – an essential feature for space missions with evolving requirements.

...while advancing socio-economic benefits and skills development

ESA's funding for the BRAVE project has been instrumental in enabling NanoXplore to become a leading supplier of FPGAs for space, while unlocking a range of socio-economic benefits, such as spinning-in an organisation to the space sector, knowledge and technology transfers, workforce upskilling, new commercial products and revenue, and strengthening Europe's non-dependence in the space sector.

Progressing technological maturity

> Through ESA's support, NanoXplore developed Europe's first radiation-hardened FPGA, advancing the technology from early stages to TRL 9 and operational use in space.

NanoXplore advanced the maturity of radiation-hardened FPGAs, addressing the unique challenges of FPGAs in space's high-radiation environment. As highlighted earlier, the volatile memory base, which enables a reprogrammable configuration, is particularly sensitive to single event upsets, where radiation can flip an individual bit in the memory cells. This can alter the FPGA's configuration, potentially causing data corruption or system malfunctions. To address this challenge, NanoXplore used specific mitigation and redundancy techniques to design their FPGA to reach radiation immunity in space. The development of Europe's first fully radiation-hardened FPGA represents a significant achievement, as it fills an important gap for the European space sector.

A key feature of NanoXplore's FPGAs is their unique approach to redundancy. While standard FPGAs typically rely on a minimum of six transistors to maintain functionality, NanoXplore's products incorporate 12 transistors, offering enhanced protection against radiation impacts. This redundancy not only reduces the risk of technological failure but also minimises the work required by end-users to implement their own redundancy measures, ultimately lowering the overall cost of space systems.

When NanoXplore first embarked on this project, it was a micro-enterprise with no space-specific expertise. The initial investment by ESA and CNES played a critical role in de-risking the company's technological development, giving it the resources and support needed to progress. Over the course of the activity, NanoXplore achieved a substantial advancement in TRL, moving from an early-stage concept to TRL 9 (actual system proven in operational environment). This means that the technology is now fully operational and integrated into space missions, demonstrating its reliability and effectiveness in orbit.

Through these achievements, NanoXplore has demonstrated how targeted support and investment can enable a small company to overcome technological development challenges, including the high costs to develop space-qualified hardware. Producing a chip for space can cost around €8m, and therefore entering this sector requires high levels of investment, bringing the risk of high commercial losses. ESA's continued investment was essential in mitigating these risks, enabling faster time to market – an essential factor in the highly competitive space industry.

Furthermore, continuous support from ESA, CNES and the European Commission helped the project overcome the 'innovation valley of death' – a period between early-stage R&D and later stage demonstration where funding and support is often lacking, hindering developments. ESA has thus been pivotal in progressing NanoXplore's radiation-hardened FPGAs from concept to operational success in space.

Enhancing European non-dependence

ESA funding is contributing to advancing European non-dependence in the supply of FPGAs, which are an enabling technology.

Ensuring non-dependence for essential technologies is a central strategic objective for Europe, strengthening the resilience of its space-based activities and infrastructure. ESA, along with other European institutions (e.g., European Commission and European Defence Agency), identified FPGAs as a critical technology, where Europe needs to build capability to avoid restrictive trade regulations often imposed on space-grade electronics.[v]

Historically, the FPGA market has been dominated by US-based companies, which has left Europe dependent on external suppliers and export restrictions (e.g., ITAR). The ESA-funded BRAVE project enabled Europe to establish a competitive alternative to the US solutions, strengthening strategic autonomy in space technology and thus the resilience of European space activities.

NanoXplore has also focused on supply chain consolidation to enhance Europe's resilience. All chip components are manufactured within Europe, ensuring local control of production processes. This is largely made possible through the partnership established with STMicroelectronics, who collaborate closely with NanoXplore to manufacture the technology platforms for the FPGAs developed under BRAVE.

Increasing technological leadership, competitiveness and reputation

The development of radiation-hardened FPGAs, which are inherently tailored for the space environment, lower costs for customers, enabling Europe to not only provide an alternative solution to US technology, but also to compete commercially. NanoXplore benefited reputationally from these activities, becoming a European leader in radiation-hardened FPGAs.

A key differentiator of NanoXplore's products compared to foreign alternatives is their dedicated focus on radiation hardening. Unlike American competitors, whose business models often involve minimal adaptation of commercial components for space applications, NanoXplore has developed its FPGAs specifically for space use, requiring little to no modifications at the design stage. This represents a cost saving for end-users, minimising the need for them to implement their own redundancy measures. This has given the company a competitive niche in the market.

While NanoXplore's radiation-hardened FPGAs are cost competitive, their performance is still slightly behind that of US solutions, though the European company expects to achieve comparable performance levels within the next three years, ensuring its position as a leader in the market for space-qualified FPGAs.

European leadership in this technology is already starting to be reflected in international missions. For example, China's Chang'e 6 mission, which successfully landed on the far side of the Moon in May 2024, carried CNES' DORN (Detection of Outgassing RadoN) instrument, within which NanoXplore's NG-MEDIUM chip was integrated.

Through this development of radiation-hardened FPGAs, improvements in performance, and involvement in missions, Europe and NanoXplore have taken a leadership position in the domain. This progress supports European competitiveness and enhances the company's reputation, providing a unique advantage in the global space technology market.

Supporting a commercial spin-in into the space sector

ESA's support enabled a non-space company – NanoXplore – to successfully adapt its FPGA expertise for space, de-risking its entry into the sector. It has also led to the creation of fruitful partnerships, which could be leveraged in the future.

NanoXplore was founded in 2010 by three experts from the semiconductor industry. Continued support from ESA, CNES and the European Commission was instrumental in enabling the company to adapt its terrestrial FPGA experience for space use.

The successive activities played a critical role in de-risking this transition by providing financial backing and technical space expertise. For example, NanoXplore benefited from specialised space qualification training and insights into radiation testing, which are essential for ensuring the reliability of electronics in space environments. CNES also assisted NanoXplore on radiation testing and mitigation techniques, enabling the company to meet the rigorous standards of the space sector. Additionally, the company was able to build new valuable partnerships, with ESA and its subcontractors (i.e., STMicroelectronics, Airbus and TAS), which can be leveraged for new opportunities in the future.

This collaborative approach allowed NanoXplore to navigate the demanding requirements for space-grade technologies and build credibility with prospective clients and partners, effectively 'spinning-in' into the space sector from the terrestrial semiconductor industry. This two-way spillover of knowledge has helped the company expand its capabilities and enter a new sector where it can generate additional revenue, while also helping grow the European space sector and foster innovation.

Follow-on funding and contracts

From its initial TDE contract, NanoXplore has secured nearly €15.5m in ESA follow-on funding through various contracts to develop the next generation of radiation-hardened FPGAs for space.

Since NanoXplore's first TDE contract in 2014, the company has been awarded multiple ESA, CNES and EU follow-on contracts to advance radiation-hardened FPGAs. The contracts awarded by ESA include:

- In 2016, ESA awarded a subsequent TDE contract of €600,000 for a quality evaluation of NanoXplore's NG-MEDIUM FPGAs, which led to the commercialisation of this technology.
- Between 2017 and 2020, NanoXplore secured two further TDE contracts (i.e., €1.1m and €270,000 respectively), which helped develop NG-LARGE - a 65nm FPGA with enhanced power and capacity.
- NanoXplore secured additional follow-on funding from ESA to continue BRAVE, resulting in the development of NG-ULTRA. The project team secured almost €7m across three GSTP and one TDE contract to develop and prototype this 28nm FPGA with enhanced performance capacity in a more compact size. NanoXplore is currently undertaking space validation for this product through an ongoing ARTES contract, valued at €3m.
- In 2020, ESA awarded NanoXplore €500,000 through TDE to develop ULTRA300 - a 28nm technology providing unique features such as converters between digital and analogue signals. This was supported by an additional €3m ESA-Horizon 2020 contract.

Looking ahead, NanoXplore is collaborating within a consortium to secure a €20m contract aimed at developing multiple products based on 7nm radiation-hardened FPGAs. If successful, this contract would drive advancements for the next generation of FPGAs for space, furthering Europe's competitiveness in the domain.

ESA offers various funding streams[3] that enable the progression of technology maturity from early R&D to flight demonstration, helping the Agency build long-term technology roadmaps. This ensures that, as Europe pursues ambitious missions, its supply chain has the necessary technological capabilities to promptly and effectively respond to emerging requirements. In

[3] This includes the Discovery & Preparation Programme, Technology Development Element (TDE), General Support Technology Programme (GSTP), Advanced Research in Telecommunications Systems (ARTES), FutureEO, and Navigation Innovation and Support Programme (NAVISP).

this case, the successive support facilitated by ESA programmes enabled several new generations of radiation-hardened FPGAs to be developed, matured, and deployed.

New commercial products and revenue

Enabled by successive ESA contracts, NanoXplore has developed and commercialised radiation-hardened FPGAs, now used in active space missions, addressing growing demand from industry.

As a result of the successive ESA-funded activities highlighted earlier, NanoXplore introduced four distinct radiation-hardened reprogrammable FPGA chips to the market: NG-MEDIUM, NG-LARGE, NG-ULTRA and ULTRA300. With increasing demand from satellite manufacturers, space agencies and defence contractors, these radiation-hardened FPGAs are positioned to serve a growing market that requires high-reliability components for long-duration space missions and other radiation-intensive environments. NanoXplore shared that their sales, currently estimated between €17m-€20m, are projected to grow by nearly 50% in the next year, with much of this success attributed to ESA's support on the BRAVE project.

NanoXplore has secured roles on several space missions to provide radiation-hardened FPGAs. Alongside the Chang'e 6 mission, NG-MEDIUM has been used on the French-Chinese satellite SVOM (Space-based multi-band astronomical Variable Objects Monitor), ESA's HERA mission, and is set to be leveraged on ESA's SMILE mission. Thanks to the close partnership between NanoXplore and Thales Alenia Space established through the project, NG-ULTRA will be integrated into TAS' Space Inspire product line. NG-ULTRA will also be used in Galileo Second Generation (G2) satellites.

ESA funding has been crucial in expanding NanoXplore's commercial product portfolio and broadening its revenue streams, notably helping the company overcome the high entry barriers associated with space (e.g., high upfront costs of R&D, long and costly qualification process for space hardware, and the difficulty of securing early commercial adoption in a risk-averse industry). The long-term investment thus allowed NanoXplore to increase not only its capabilities but also its competitiveness.

New jobs and upskilling the workforce

Since the initial ESA TDE contract, NanoXplore's workforce has grown from 5 to over 150 employees through the successive investments it secured for the development of radiation-hardened FPGAs. The company continues to expand through partnerships with leading universities, while upskilling its workforce.

Since initial ESA and CNES funding in 2014, NanoXplore has expanded its workforce from 5 full time employees to over 150, thanks to the ongoing investments for the development of radiation-hardened FPGAs. The company is fostering a talent pipeline into the space sector through its internship programme and partnerships with leading universities in Turin, Milan, and Pisa, which is enabling the recruitment and training of highly skilled talent. This headcount growth has not only helped significantly increase the company's R&D and production capacity, but it has also contributed to enhancing Europe's pool of technical expertise in high-end electronics for space.

As highlighted earlier, NanoXplore has significantly benefited from ESA and CNES space expertise to leverage its terrestrial semiconductor expertise into the development of space-grade technology. The successive activities have therefore had a notable upskilling benefit for the company and its workforce, across seniority levels. Knowledge development has been particularly important for the young professionals and students involved in the different activities. NanoXplore implemented a balanced workforce model, pairing seasoned professionals with junior staff to ensure knowledge transfer. This approach has allowed the company to build robust electronic and digital engineering teams, increasing its internal capabilities as well as contributing to the wider development of Europe's high-tech and space workforce.

Spillovers to terrestrial sectors

NanoXplore is leveraging the innovations from the space radiation-hardened FPGAs developed with ESA funding for application in terrestrial markets. Their robustness makes them valuable for defence, avionics, and scientific research, diversifying present and future commercial opportunities.

While the BRAVE project initially leveraged terrestrial technologies for space, the innovations enabled by the past decade of ESA-funded radiation-hardened FPGA developments for space could have promising applications in terrestrial sectors such as defence and scientific research, and the high-volume avionics market. These sectors share similar size, flexibility and redundancy constraints to space technologies and could therefore utilise solutions similar to NanoXplore's radiation-hardened FPGAs.

The company is actively exploring collaborations with organisations outside of the space industry, including in physics (i.e., with CERN) and the defence sector. These partnerships aim to leverage investments in the space technology to create cost-effective, reliable radiation-hardened FPGAs for a wider range of sectors.

Pursuing these terrestrial markets would create new revenue streams for NanoXplore, who aims to generate around €100–200 million in annual sales through the sale of radiation-hardened FPGAs. In order to capture these markets, the company will focus on incorporating the unique security and costing requirements of each market into their FPGAs, which will further diversify the company's product portfolio.

Would these benefits have been realised without ESA?

The success of this project is fundamentally tied to ESA's continuous support. The successive investments from ESA through its TDE, GSTP and ARTES programmes enabled the establishment of a long-term technology roadmap to develop commercially competitive and flight-proven radiation-hardened FPGAs. This has contributed to enhancing Europe's leadership and non-dependence for an enabling technology for space activities. ESA acted as a catalyst, with its initial support helping NanoXplore secure CNES and European Commission funding.

The activities over the past decade have resulted in a range of socio-economic benefits, including the 'spin-in' of a terrestrial company into the space sector, the upskilling and growth of NanoXplore's workforce, and the development of new commercial products and revenue streams (both in space and terrestrially).

"ESA's support was absolutely crucial – everything we have achieved today stems from this activity. Taking a risk with a small team of just five non-space experts was a bold approach, but ESA's involvement was instrumental in de-risking the technology and enabling us to establish ourselves as leaders in a field where Europe previously had limited capabilities". – E. Lepape, NanoXplore

Without ESA funding and technical expertise, NanoXplore would have faced significant challenges in securing sufficient R&D resources and navigating the complexities of the space sector. The company would have also likely struggled to establish the credibility and collaborative networks necessary to achieve the technological breakthroughs that have positioned it as a leader in radiation-hardened FPGA technology. Overall, the benefits outlined in this case study would have been unlikely to materialise.

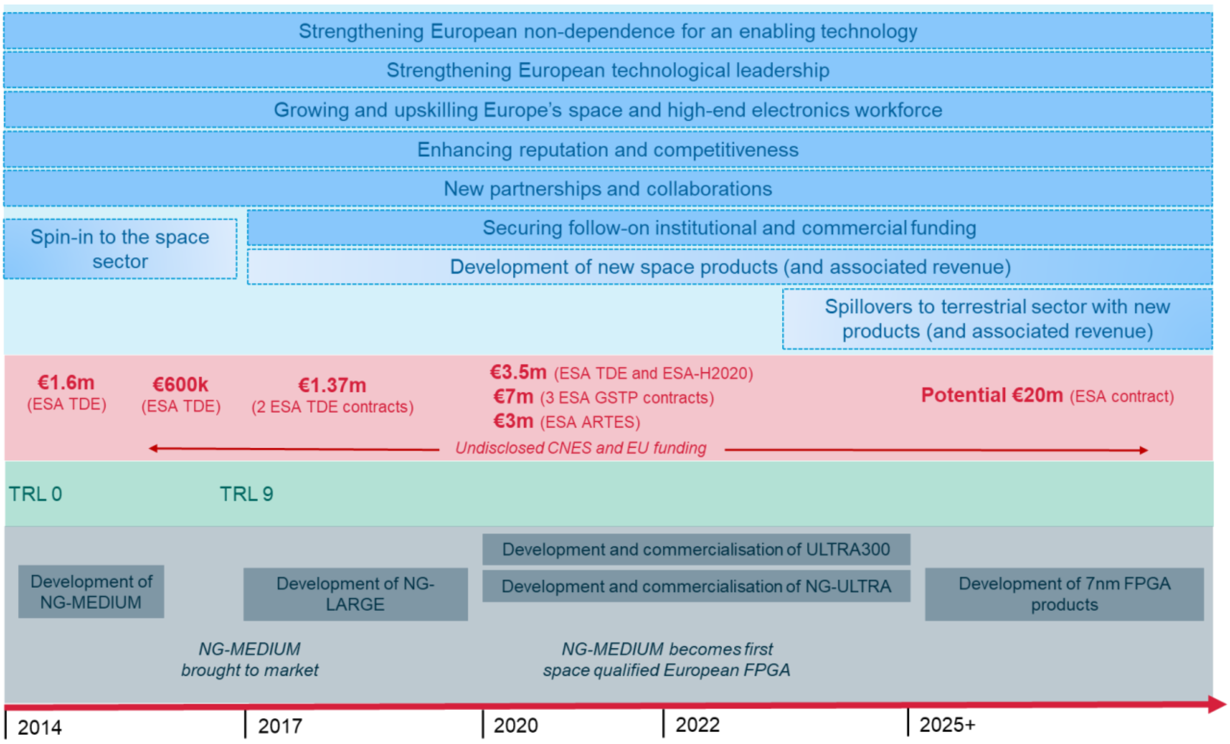
Next steps: Further development, further benefits

Building on its current achievements, NanoXplore is poised to expand its product portfolio with new radiation-hardened FPGA designs that cater to both emerging needs within the space sector and opportunities in terrestrial industries. By strengthening its industrial credibility and offering, NanoXplore aims to establish itself as a trusted supplier in high-volume commercial markets, securing its position as a key player across diverse sectors.

Additionally, the company is committed to addressing the skills gap in Europe's high-tech workforce. Through continued collaboration with leading European universities and industry partners, NanoXplore will further contribute to the development of the next generation of talent. By supporting a highly skilled workforce, the company will participate to enhancing Europe's competitive edge in high-end electronics and space technology.

A preliminary timeline overview of the BRAVE project and associated benefits are provided below.

Figure 3: Overview of the timeline of the BRAVE project and the associated benefits



Source: know.space based on NanoXplore and ESA data

Key priority indicators

Programme	Technology Development Element (TDE), General Support Technology Programme (GSTP), Advanced Research in Telecommunications Systems (ARTES) + CNES and European Commission funding
Country	France, Germany, Spain
Duration	2014 - Ongoing
Lead contractor	NanoXplore (FR)
Sub-contractors	STMicroelectronics (FR), Thales Alenia Space (FR) and Airbus (FR, DE, ES)
TRL progression	From nascent concept to TRL 9
Spin-in into the space sector	1 (NanoXplore)
Jobs supported	150+ (across the different contracts)
New collaboration with ESA	1 (NanoXplore)
Partnerships created	At least 4 (NanoXplore with Airbus, TAS, STMicroelectronics and ESA)
Follow-on funding applied/secured	Secured: • ~€12.5m from ESA across various contracts under the TDE, GSTP and ARTES programmes • €3m ESA-Horizon 2020 contract • Undisclosed CNES funding • Undisclosed EU funding Applied: • €20m from ESA, as part of a consortium.

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