Socio-economic benefits from ESA's Science Core Technology Programme

A report for esa

CASE STUDY: Charged Particle Diverter

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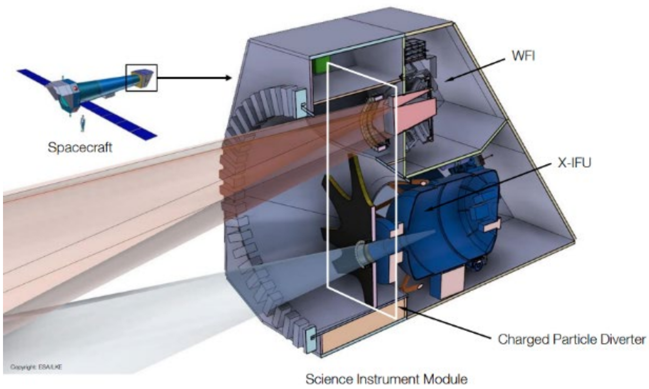
Ensuring optimal performance of ATHENA instruments …

The spacecraft of ESA's ATHENA (Advanced Telescope for High Energy Astrophysics) will be exposed to a considerable flux of charged particles due to the mission's large Halo orbit in L1. Indeed, the protons in solar winds are in the energy range of X-rays, which is the spectrum of focus for the telescope. These protons are thus expected to cause background interference with the scientific measurements from state-of-the-art instruments on board, which is problematic given ATHENA has very strict requirements in terms of quality and lifespan.

ESA identified the need to **minimise this type of background interference** as a critical factor in the ATHENA design, leading to technology development activities progressing in parallel to the initial phases of the mission.

… requires a Charged Particle Diverter, developed in the Czech Republic …

One of the key projects funded under the Science Core Technology Programme (CTP) to mitigate these interferences is the **development of a set of charged particle diverters**. They aim to reduce the background interference generated by soft-protons, which become focused by the Silicon Pore Optics (SPO) mirror modules towards the instrument detectors. The project departed from a set of requirements driven by scientific considerations and evolved towards a detailed design[1] that was then manufactured and tested to the harsh conditions of space. One of the key requirements being the minimisation of system mass while maintaining the required magnetic and structural performance. Electron diverters have been used in space before, but **this would be a first for proton diverters**.



ESA/LKE

This technology development demonstration project has been undertaken by a **Czech industry-academia consortium**. It is led by Frentech Aerospace, an industrial equipment supplier, who acts as the manufacturer. It also includes Brno University of Technology (BUT), one of the Czech Republic's leading research institutions, which is in charge of the magnetic design of the diverter, and L.K. Engineering (LKE), which specialises in technical calculations for mechanical engineering, and is tasked with the mechanical and structural design of the diverter. Frentech and LKE build on their vast experience working on institutional and commercial space projects, while this kind of space design activities are relatively new for BUT.

Frentech Aerospace, BUT & LKE

Through their work on ATHENA's charged particle diverter, this Czech consortium secured a prominent role in an ESA L-class Science mission. This project was identified as an opportunity

[1] Ferreira, et al., 2018. *Design of the charged particle diverter for the ATHENA mission. Space Telescopes and Instrumentation 2018: Ultraviolet to Gamma Ray*. Vol. 10699. International Society for Optics and Photonics, 2018.

to build capabilities and competitiveness for the Czech Republic, and increase industry-academia collaboration.

… with potential for significant socio-economic benefits

Whilst the charged particle diverter demonstrator is reaching its final review point and the industrial phase is ahead, many benefits have already been identified, with the potential of further impacts to come for the Frentech-LKE-BUT consortium, Czech industry, and the broader European landscape.

Building key competencies within a Czech-based consortium of industry and academic actors

New skills and capabilities

A key benefit for the consortium members involved in the project has been the development of new skills and capabilities needed to address the implementation of a technologically-complex solution.

There were several major challenges for this project, not least because it is the first time a proton diverter has been designed for space. Furthermore, there was a **difficult trade-off between magnetic performance and structural performance**. One of the mechanical issues stemmed from the fragility of the permanent magnets when considering how to design them to survive difficult environments (e.g. launch), as well as the consideration that the magnetic field had to be very low for X-ray detectors, but high inside the diverter, or else it could affect the function of the instruments.

There was also a requirement from ESA that a key priority and specification of the diverter was to maintain a low mass, and a large effort had to go into ensuring the final design was lightweight and suitable for assembly. Overall, everything about the design had to be developed to meet precise specifications, where even the magnets could not be 'off the shelf' components due to the mission requirements.

For both LK Engineering and Frentech, **new capabilities and skills were developed by the team by going through the design process** from its initial stages and learning much about technologies they had not worked with before, such as the handling and assembly of magnetic structures.

New partnerships and collaboration

Overall, this project brought together academia and industry in a new way for the Czech space industry, deepening cooperation between the Brno University of Technology and broader national space industry actors, and **displaying the high quality technological and mechanical capabilities within the country**.

LKE

From an industry perspective, the work with BUT expanded a key scientific relationship for companies such as LK Engineering, whilst for Frentech it was the first space project where they had needed such close cooperation with a university.

Involvement in the project from Phase A to flight model means that in a forwards-looking capacity, the consortium is also opening dialogue with potential European prime contractors for the development model, qualification model and flight model.

Knowledge transfer

Thanks to the participation of the consortium members from the very first stages of the charged particle diverter development, as well as the new skills and capabilities formed through their involvement, there has been **knowledge transfer to other areas of the business** for the industry actors within the consortium.

For example, LK Engineering outlined how they created internals tools for the project, which they have now applied to other domains of the company in order to make their work more efficient. In general, the processes they had to set up and implement for carrying out such a complicated project involving technical challenges, consortium partners and a long development period are now being applied to current and future projects, especially from a design perspective, which is applicable to all the work the company undertakes.

Importantly, this knowledge transfer of workflows and methods of analysis can be applied to other space and non-space areas of LK Engineering and Frentech's solutions, and can therefore help **increase commercial competitiveness** by its contribution to **increased work efficiency and results**.

Fulfilling the Czech Republic's goals for space by strengthening and stimulating the supply chain

Securing Czech involvement in a high-profile space science mission

The participation of Czech organisations in the consortium developing a charged particle diverter for ATHENA was an opportunity for the country to be involved in a high profile, boundary-pushing flagship ESA Science mission from phase A to flight model.

This extensive level of engagement in ATHENA, a high profile science mission, is **relatively new for the Czech Republic** and provides many benefits for the country's stakeholders. Chief among them is the opportunity for (sub-) contractors to develop expertise in their field by working to find innovative technological solutions that are meeting some of the most stringent requirements in space missions. Having Czech entities responsible for the development of a high-tech component of ATHENA is particularly **beneficial in increasing the value-added to the national economy from its space domain.**

Czech participation in ATHENA from its early phases is also an opportunity to **optimise the involvement of wider national supply chain actors**, which itself leads to the development of skills and capabilities, such as those outlined in the previous sections for consortium members. Working on this ESA mission also boosts reputation, as it indicates that the organisations involved were successful in being awarded ESA contracts, following the Agency's robust processes, and delivering outputs. This can be seen as an '**ESA stamp of approval**' for the Czech Republic, its industry and scientific community, enhancing credibility, which may help secure new ESA contracts and further collaborations with European primes.

With involvement in this high-profile mission through most of its development (over a decade), ATHENA is a flagship example of Czech capabilities and embeddedness in the heart of European science space activities. Demonstrating that **the Czech Republic *can* and *does* participate in exciting, boundaries-pushing science missions** is critical to attract talent (back) into the country, and inspire a new generation to pursue STEM curricula[2] and space careers. Ensuring a robust talent base is critical in the continuous growth of the Czech space industry.

Strengthening the Czech supply chain

As highlighted earlier, this CTP technology development project was led by a Czech consortium that was composed of an academic institution, BUT, and two industry actors, Frentech and LKE. While the work on ATHENA's charged particle diverter was not the first collaboration between these actors, it was **notable in its scale**. Indeed, such an extensive industry-academia partnership was new for the Czech Republic in space.

This type and level of cooperation is beneficial, as it helps stakeholders identify 'who does what' in the Czech Republic. For example, the consortium members explained that this project helped establish a reliable supply chain of critical system elements, notably with companies supplying carbon-fibre-reinforced polymers (CFRP) structural components. This is especially valuable for potential updated models of the Czech diverter.

Additionally, BUT highlighted that this CTP-funded project increased its awareness of the true number of companies and organisations involved in the space supply chain in the Czech Republic, and that it was exploring how best to pool the diverse capabilities in the country for existing and new projects. Moreover, working on this ESA CTP project has fostered trust between consortium partners, with Frentech and LKE already working together on other projects, and both envisaging further collaboration with BUT in the future. Therefore, the sizeable and high-profile industry-academia work on ATHENA's charged particle diverter is expected to **catalyse new collaboration in the Czech Republic**.

This is particularly important, as bringing together the existing strengths and capabilities of the Czech supply chain will result in knowledge and technology transfers, boosting innovation across the board. This type of **exchange and synergy strengthens the Czech supply chain**, making it more capable, dynamic, and attractive. This is not only beneficial for the country's space sector, but it also impacts related fields, such as electronics, and mechanical and physical engineering.

Learning and training for young professionals

Working on ATHENA's charged particle diverter provides **critical early-career exposure to young professionals**, which equips them with key expertise and project management skills. This can be applied throughout their careers, ensuring skills sustainability in the Czech space supply chain.

Frentech, LKE and BUT's work on ATHENA's charged particle diverter was beneficial in the development of skills and capabilities, as highlighted in previous sections. This is particularly important for young professionals and PhD candidates, who were offered the opportunity to acquire real flight experience by working on this ambitious flagship ESA mission. Not only were they able to learn from their colleagues within the Czech consortium, increasing their expertise, they also had exposure to industry-leading scientists and engineers at ESA and in the wider ATHENA consortium, expanding their knowledge of the mission.

Additionally, working on this CTP project offered young professionals and PhD students early experience in industry-academia collaboration, which builds critical soft skills in communication and project management. It also exposed them to ESA's robust processes, which demonstrate how

[2] Currently, 18% of bachelor graduates, 26% of master graduates and 45% of doctoral graduates hold a diploma in a STEM subject, with national ambitions to grow these figures: OECD, 2019. *Distribution of graduates and new entrants by field*. Available at: https://stats.oecd.org/Index.aspx?datasetcode=EAG_GRAD_ENTR_FIELD; Government of the Czech Republic, 2020. National Space Plan 2020-2025, available at: https://www.czechspaceportal.cz/wp-content/uploads/2020/08/NSP2020-2025_EN.pdf

complex and demanding projects ought to be developed and implemented to ensure quality, reliability and success.

On top of these hard skills, this early-career exposure helps these young professionals and PhD candidates build key project management soft skills, all of which can be applied later in their careers. This represents a key benefit for the Czech Republic, as it contributes to ensuring that there is a new generation equipped with the necessary expertise and know-how to continue and build on the work of past generations of Czech space scientists and engineers when they retire. Working towards the **sustainability and strengthening of skills and capabilities is central to growing the Czech space sector**.

National space policy support

The work undertaken by the consortium on ATHENA's charged particle diverter and the benefits outlined throughout the report **contribute to achieving the Czech Republic's National Space Plan**[3]. Key national strategic objectives include:

- To have an international image of industrial and scientific excellence;
- To be a high value-added economy;
- To be competitive and innovative;
- To be capable of absorbing and retaining the intellectual capital created; and
- To be an example of an excellent complementarity and cooperation between industrial and academic tissues.

The work undertaken in this CTP-funded project fits very well with these goals, notably by increasing Czech involvement in high-profile European space activities, strengthening and stimulating the supply chain, building skills and capabilities, and fostering knowledge and technology transfer through industry-academia partnerships. **This supports an increase in the country's innovativeness, competitiveness and leadership in space**.

Ensuring the delivery of key scientific observations from space missions

Enabling complex space science missions

The charged particle diverter enables the demanding observations of missions such as ATHENA, by addressing the challenge of proton interference.

ATHENA is an X-ray telescope that is being developed under ESA's Cosmic Vision science theme of 'The Hot and Energetic Universe'. Due to launch in 2035, it seeks to map and study large-scale gas structures and determine their physical properties, survey supermassive black holes, and explore high-energy astrophysical events such as supernova explosions and energetic stellar flares.[4]

One of the challenges faced by the mission is the environment in which it will be operating, and how that interacts with the extremely sensitive instrumentation on board. Positioned in an L1 orbit, the first Lagrange point of the Sun-Earth system that allows for good observations, ATHENA will experience solar wind, which is a stream of charged particles released from the upper atmosphere of the Sun. Within this solar wind are low-energy "soft" protons, tiny particles found in the nucleus

[3] Government of the Czech Republic, 2020. *National Space Plan 2020-2025*. Available at: https://www.czechspaceportal.cz/wp-content/uploads/2020/08/NSP2020-2025_EN.pdf
[4] European Space Agency, 2022. *ATHENA: Mission Summary.* Available at: https://sci.esa.int/web/athena/-/59896-mission-summary

of an atom, that can pose a severe threat to the collection of scientific data. Lessons learned from previous X-ray telescopes such as Chandra and XMM-Newton have shown that these protons enter the mirror, becoming concentrated towards the focal plane instruments where their energy can interfere with the detectors, reducing the available exposure times by up to 50% and introducing a "poorly reproducible background component".[5] For example, when XMM-Newton datasets were first produced, soft proton flares increased the background level by several orders of magnitude, causing almost half of the scientific data to be discarded.[6]

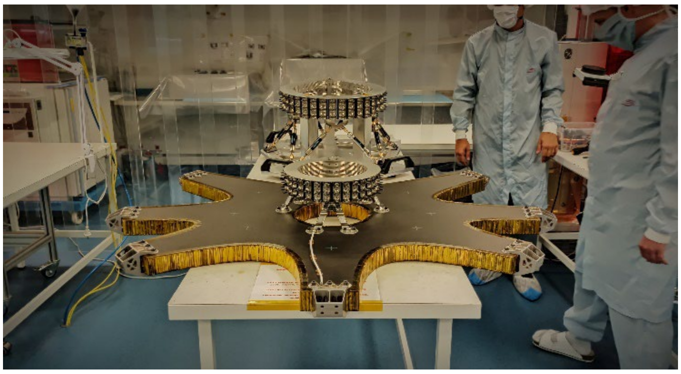
Due to the higher collecting areas of the mirrors for ATHENA, the proton's contribution to residual background will likely be even higher for this mission, hence the need to divert these protons to avoid excess background loading on the Wide Field Imager (WFI) and X-ray Integral Field Unit (X-IFU) instruments.

With scientific goals that include performing X-ray surveys of the high-z sky, populated by faint point sources, and mapping the faint thermal emission in clusters of galaxies, it is crucial for ATHENA to have a low instrumental background in order to achieve success in reaching these objectives.[7] A study simulating the impact of proton scattering on ATHENA's WFI without anything to divert these protons showed that the residual background level would be orders of magnitude above the mission requirements, concluding that a **proton diverter would be vital to the fulfilment of the mission's science objectives**.[8]

Therefore, the development of the charged particle diverter by the consortium is acting as a key enabling technology for the success of the ATHENA mission.

Increased European leadership

The necessity to divert electrons (negatively charged subatomic particles) is not a new requirement in space science missions, with X-ray telescopes on board Chandra, XMM-Newton and Swift already being equipped with diverters that deflect the electrons that are found within radiation belts. However, the challenge facing ATHENA is that of protons, which are ~2,000 times higher in mass than electrons. Because of this, a proton diverter creates the need for a trade-off between the required magnetic field to tackle this issue, the mass budget and the impact on the surrounding instruments.



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The charged particle diverter being developed by this consortium is therefore ensuring it uses the lowest mass possible, for easier integration onto the spacecraft. More significantly, **it is the only space proton diverter being developed globally**, due to the cutting-edge technological demands from ATHENA, differentiating itself from the electron-focused diverters already designed and developed previously.

This positions Europe as a leader in terms of expertise and knowledge in this unique technology, both in its design and implementation. Furthermore, **the technology is not export restricted**,

[5] Lotti, S., Mineo, T., Jacquey, C. et al. *Soft proton flux on ATHENA focal plane and its impact on the magnetic diverter design.* Exp Astron 45, 411–428 (2018).
[6] Ibid
[7] Fioretti, V., et al., 2018. *Magnetic Shielding of Soft Protons in Future X-Ray Telescopes: The Case of the ATHENA Wide Field Imager.* ApJ 867 9
[8] Ibid

having been developed in Europe. Overall, this has **increased Europe's competitiveness** within the sector, being the only provider of this technology in space.

Strengthening Czech-ESA partnership

Involvement of a Czech-based consortium for a flagship ESA Science mission is strengthening the key ongoing Czech-ESA partnership

The Czech Republic has a long history working with ESA, beginning cooperation in 1996 with a Framework Cooperation Agreement, all the way through to its accession to the Agency in November 2008. The country has had successful ongoing participation with key ESA programmes since becoming a Member State, with Czech contributions to ESA have steadily increased over time, recognizing that **participation in ESA activities is a key tool for developing Czech space activities**, both through mandatory and optional ESA programmes.[9]

One of the key pillars of ESA is the idea that the investment provided by a Member State through their membership fee should be returned through equivalently valued high-tech space contracts as a way of stimulating national space capabilities and industry growth. This results in increased European competitiveness and strengthening of capacity across European industry, and fosters the participation of SMEs in ESA procurement.

An area where this should be encouraged is within the mandatory Science Programme at ESA, where participation can be a challenge for certain Member States who have a small or newly-developing space sector, as opposed to larger space nations with historical expertise, due to the technological complexities of missions that are seeking cutting-edge scientific answers. Therefore, the engagement of Czech-based consortium has provided a way to **increase involvement within the space science domain for the Czech Republic** and build expertise for highly technological solutions, whilst for ESA, the consortium of industry and academic partners for the successful delivery of the charged particle diverter exemplifies the benefits and opportunities that European collaboration and ESA membership can bring to a national industry. Overall, the Czech-ESA partnership helps increase the reputation and capabilities of both the Czech and European industrial landscapes.

Promoting European non-dependence

A key objective of the European Commission, the European Space Agency and the European Defence Agency is to ensure European 'non-dependence' for critical space technologies – defined by the possibility of Europe to have "free, unrestricted access to any required space technology".[10] This is in comparison to 'independence' (that all needed space technologies must be developed in Europe).

As outlined previously, the charged particle diverter is a critical enabling technology for the ATHENA mission, ensuring that the scientific observations can be carried out at the required specifications. Therefore, it was important for Europe to develop its own capabilities in this area, especially when there are no other diverters available that can divert protons, and no reliable global source of a solution to this issue. By ensuring European-based development of this technology rather than sourcing it out to the wider space industry, **ESA also ensured this highly specialised knowledge and skillset was built and retained within Europe**.

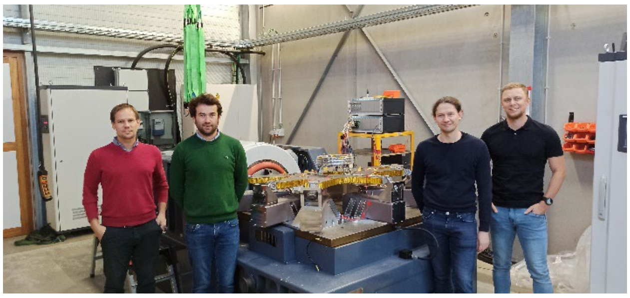
[9] the Czech Republic Ministry of Transport, 2021. the Czech Republic Successful in ESA: Catalogue Vol. 2021. Available at: https://www.czechspaceportal.cz/wp-content/uploads/2020/12/cz_successful_in_esa_2021_web.pdf
[10] European Commission, 2021. *Space Technologies for European Non-Dependence and Competitiveness.* Available at: https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/guidance/guidance-document_horizon-cl4-2021-space-01-81_horizon-cl4-2022-space-01-81_en.pdf

Would these benefits have been realised without ESA?

The benefits outlined from this CTP development work would not have occurred without ESA's support and demand for a charged particle diverter for the ATHENA mission. Science missions of this scale and flying in L1 are infrequent, and thus this development work was bespoke and built-to-spec.

ESA

The stakeholders involved also emphasised the central role ESA played in involving them, and the Czech Republic, from the very beginning of this high-profile mission. This early and continued participation was described as particularly beneficial in terms of learning opportunities for Czech industry and academia, compared to sporadic involvement at a later stage.



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"Without ESA, our involvement from the beginning would have not happened".

- *Martin Závodník (Frentech), Jakub Zlamal (BUT), Richard Hynek (LKE)*

… plus further development and benefits to come

The consortium's charged particle diverter demonstrator has **successfully passed all testing required at this stage**. Working towards ATHENA's 2035 launch, the Czech consortium hopes to collaborate with the prime to finalise the diverter and make it flight-ready during the industrial phase (which is set to begin in the coming months). Frentech, LKE and BUT have already started discussions and co-engineering with companies such as Thales Alenia Space and Airbus Defence and Space ahead of this industrial phase.

The continued involvement of the consortium in these activities are anticipated to **further the wide-ranging benefits** outlined in previous sections, and potentially lead to **unexpected benefits** (e.g. spillovers to the Czech supply chain and economy).