Metamaterials in Space: Exploring the UK Landscape, Challenges, Opportunities, and Perspectives

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THE UK SPACE AGENCY

Established in 2010, the UK Space Agency's core value proposition is to:

- **Catalyse Investment**, by deploying funding and resources to multiply the value of non-Government contracts and private capital secured by UK space organisations to maximise the space sector's long-term growth
- **Deliver Missions and Capabilities**, independently and with others, that use space science, technology and applications to meet national needs and help humanity to understand our universe.
- **Champion Space**, encouraging other sectors to use space to deliver better services, tackle the climate emergency, inspire STEM education and lifelong learning, and advocate for sustainable space activities.

- An executive delivery agency of Department for Science, Innovation and Technology (DSIT). The UKSA delivers programmes on behalf of the Secretary for State
- ~350 staff across 3 locations
- UK wide business support network
- Industrial and science focus
- Engaged with government departments and partner countries

THE UKSA CORPORATE PLAN (2022-2025)

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Priorities

Launch
Deliver the first small satellite launch from the UK in 2022, and a sustainable commercial UK launch market by 2030.

Innovation
Deliver a step change in the UK's share of the fastest growing or highest-potential commercial space markets, by managing a portfolio of investments in high risk, high reward technologies and applications, supported by future-focused regulation.

Earth observation
Deliver a portfolio of activities that ensures long-term value for money access to the data we need.

Discovery
Manage frequent national and international space missions, short and long term, that strengthen UK capability in space science and engineering, and that offer opportunities for the UK to lead global discovery.

LEO Capabilities
Use the UK's low Earth orbit assets to deliver transformative new capabilities, including in broadband, position, navigation and timing, and Earth observation.

Levelling-up
Increase and spread space investment and jobs, by accelerating the growth of a connected network of local space clusters.

Sustainability
Deliver capabilities to track objects in orbit and to reduce and remove debris; lead global regulation and standard-setting to make space activities more sustainable.

Inspiration
Deliver a programme that inspires young people to pursue STEM education, attracts talent to the UK space sector, and demonstrates the benefits of space science, technology, and applications.

Enabling Activities

Transformation
Transform the Agency into a delivery-focused organisation that puts its people first, is aligned to our Value Proposition and needs of our stakeholders, and is 'match fit' to achieve our priorities.

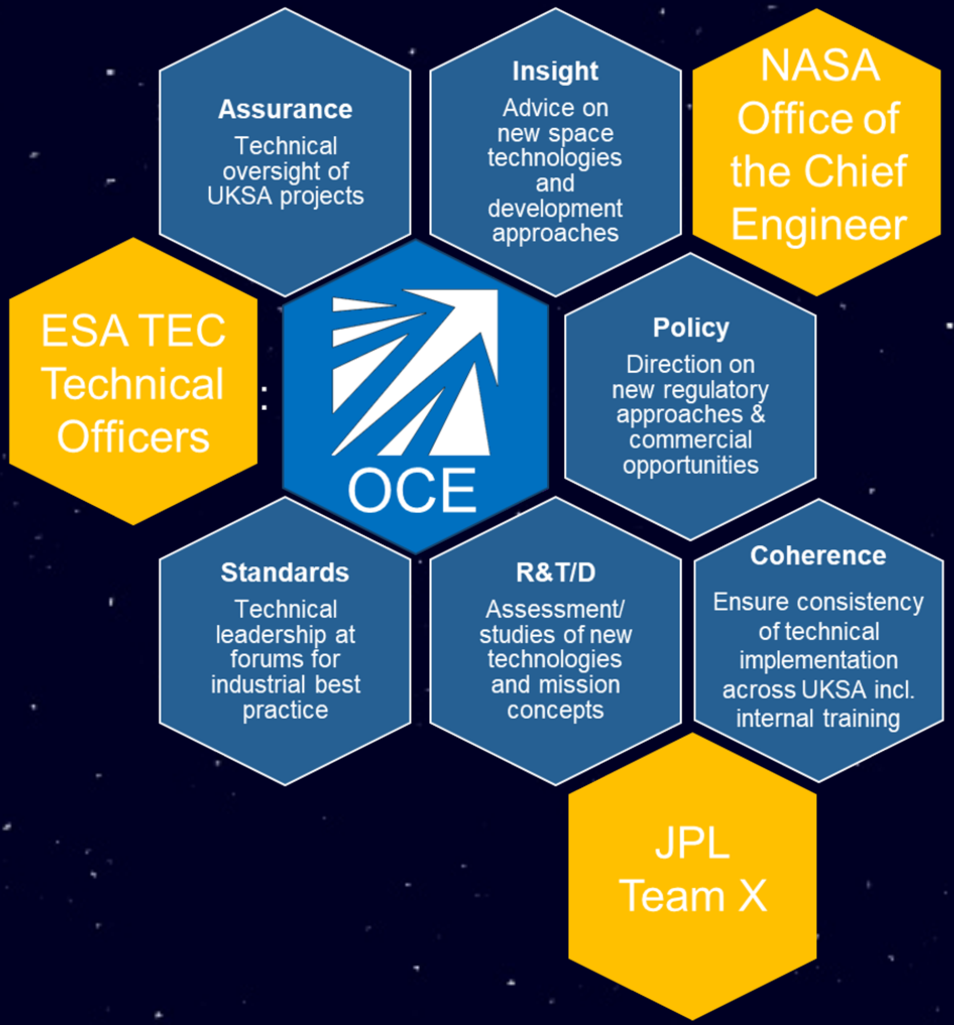
Relationships
Build and manage strong relationships with key space investors, suppliers and customers, that deepen our mutual insight and confidence, and help us to together deliver the National Space Strategy.

- *A corporate plan refresh is ongoing*

- *https://www.gov.uk/government/publications/uk-space-agency-corporate-plan-2022-25*

UKSA OFFICE OF THE CHIEF ENGINEER (OCE)

The Office of the Chief Engineer (OCE) provides **deep technical expertise** to support the **design and delivery** of the UKSA project portfolio in order to maintain **UK technical leadership** in civil space activities



OCE Capability Map and Analogue Teams

METAMATERIALS IN SPACE TECHNOLOGY

UK SPACE AGENCY

The Role of Metamaterials in Space

Metamaterials can possess unique properties that make them essential in space technology. As examples, their ability to manipulate electromagnetic waves allows for advanced communication systems, while their structural attributes provide lightweight and robust solutions for space systems.

Examples of Current Applications

Satellite Communication: Metamaterial-based antennas provide high performance, lightweight, and small size attributes, making them ideal for satellite communications.

Thermal Management: Metamaterials offer novel ways to manage heat on spacecraft, significantly enhancing their longevity and reliability.

METAMATERIALS IN THE SPACE ENVIRONMENT

The Space Environment

Space presents a unique and harsh environment with challenges including microgravity, vacuum, wide temperature extremes, and high levels of radiation.

Challenges for Materials in Space

Traditional materials can degrade, perform poorly or fail under these conditions, limiting the functionality and lifespan of space technology.

The Metamaterial Advantage

Metamaterials can be engineered with specific properties to withstand the harsh space environment, leading to increased durability and effectiveness of space technology.

For example, their structural properties can be exploited to handle extreme temperatures and radiation levels, while their ability to manipulate electromagnetic waves can improve communication in the vacuum of space.

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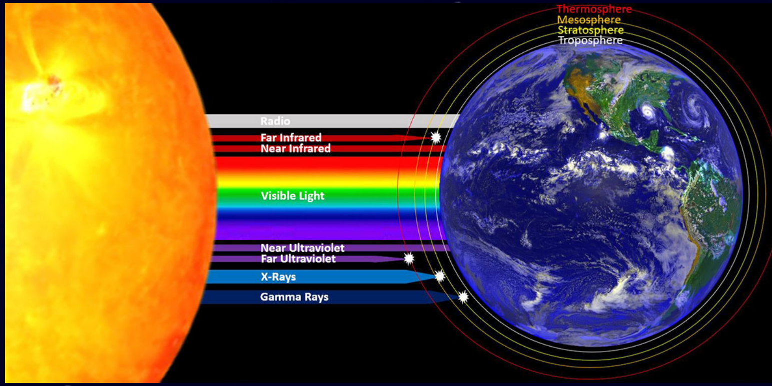
THE SPACE ENVIRONMENT

Radiation

Exposure to cosmic radiation which can damage materials and electronics over time. Metamaterials can be designed to withstand and even manipulate these high energy particles.



Microgravity

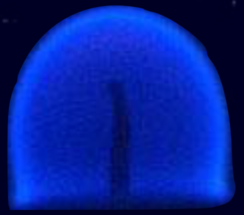
The microgravity environment can impact material behaviour, including thermal and structural properties. Metamaterials can be engineered to perform optimally in these conditions.

Vacuum

Space is a near perfect vacuum, which can lead to outgassing of certain materials and potentially impact structural integrity. Metamaterials can be designed to mitigate these effects.

Extreme Temperatures

Extreme temperature fluctuations, from intense heat from the sun to extreme cold in shadow. Metamaterials can offer enhanced thermal properties, which can be used to manage these temperature extremes effectively.



OPPORTUNITIES

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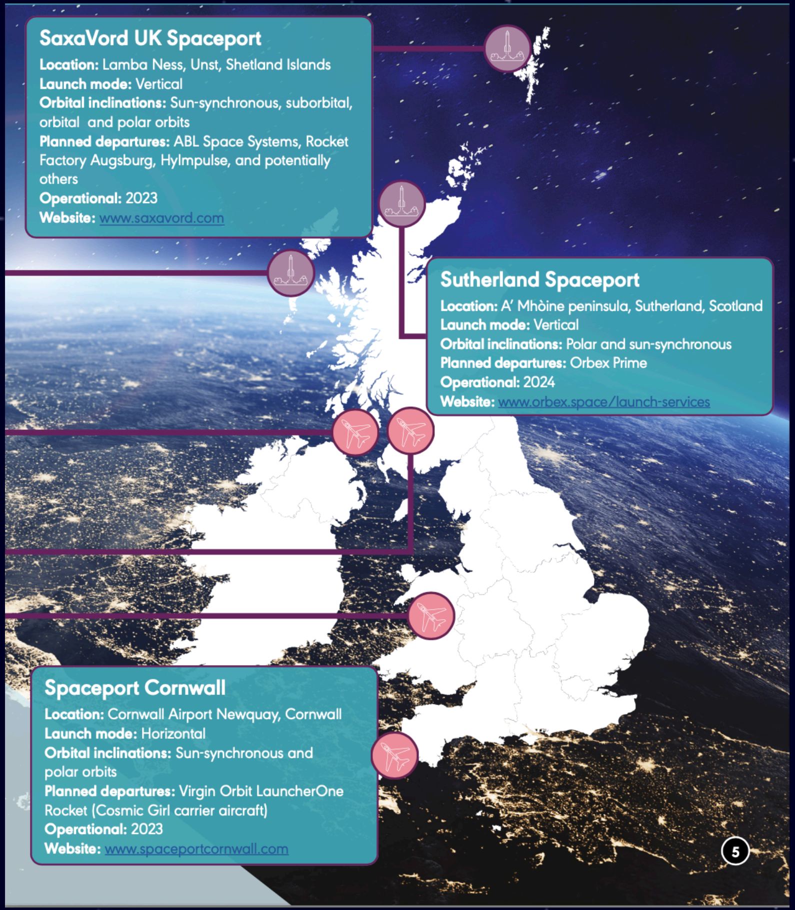
SATELLITES LAUNCH

- The Space Industry Act of 2018 was enacted to establish a flexible, high-level regulatory framework, thereby enabling launches from the UK.
- The government's vision is for the UK to become the leading European provider of small satellite launches by 2030 – offering world-leading capabilities, attracting new markets, and inspiring the next generation of British space professionals.
- A network of Spaceports is being created as part of this initiative.
- The UKSA adopts a two-pronged approach to funding, providing national grants and supporting through the European Space Agency (ESA) for Commercial Space Transportation Services. One stream of the national interventions is a launch technology development programme.
- For metamaterials, there are direct opportunities to add value to launch systems and the associated supply chain. They can also indirectly benefit from the expected strong growth of the national small satellite market.

*Launch systems are critical, requiring **exceptional performance** (structural, thermal, mass). **Metamaterials can enhance these performances**. At the same time, these systems need to be competitive in the global market, and the technology used must enable a sustainable market presence.*



TECHNOLOGY DEVELOPMENT

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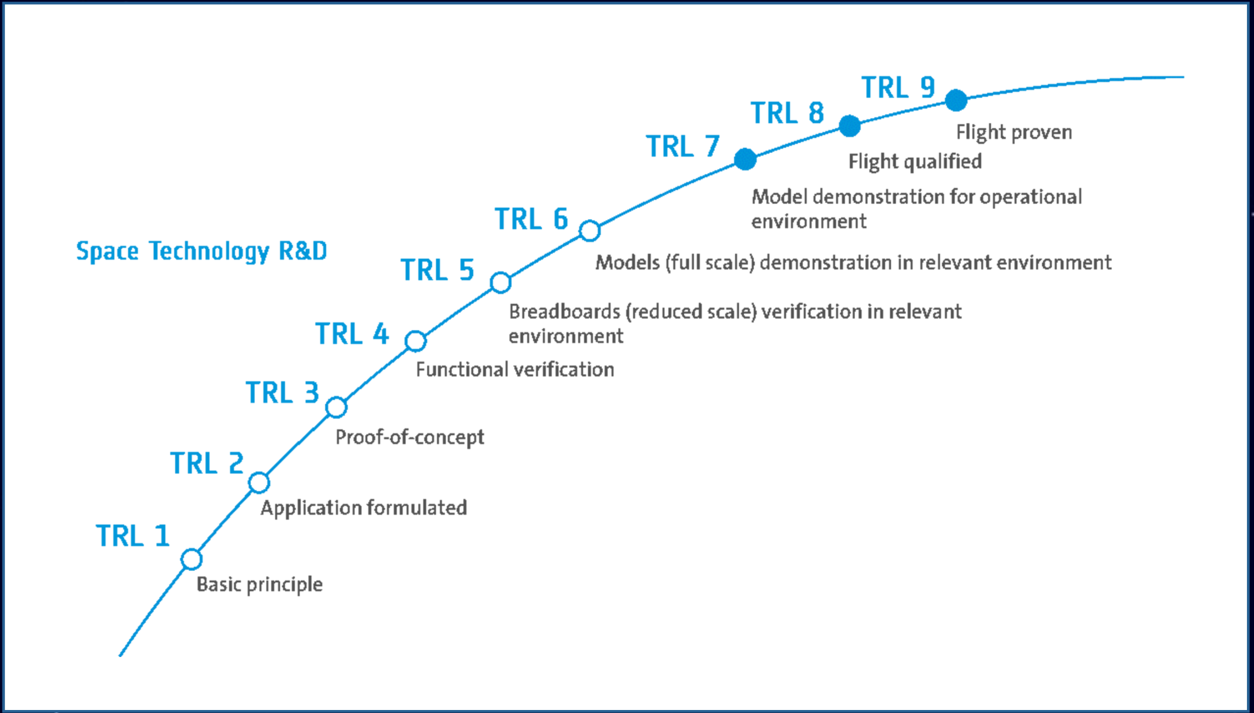
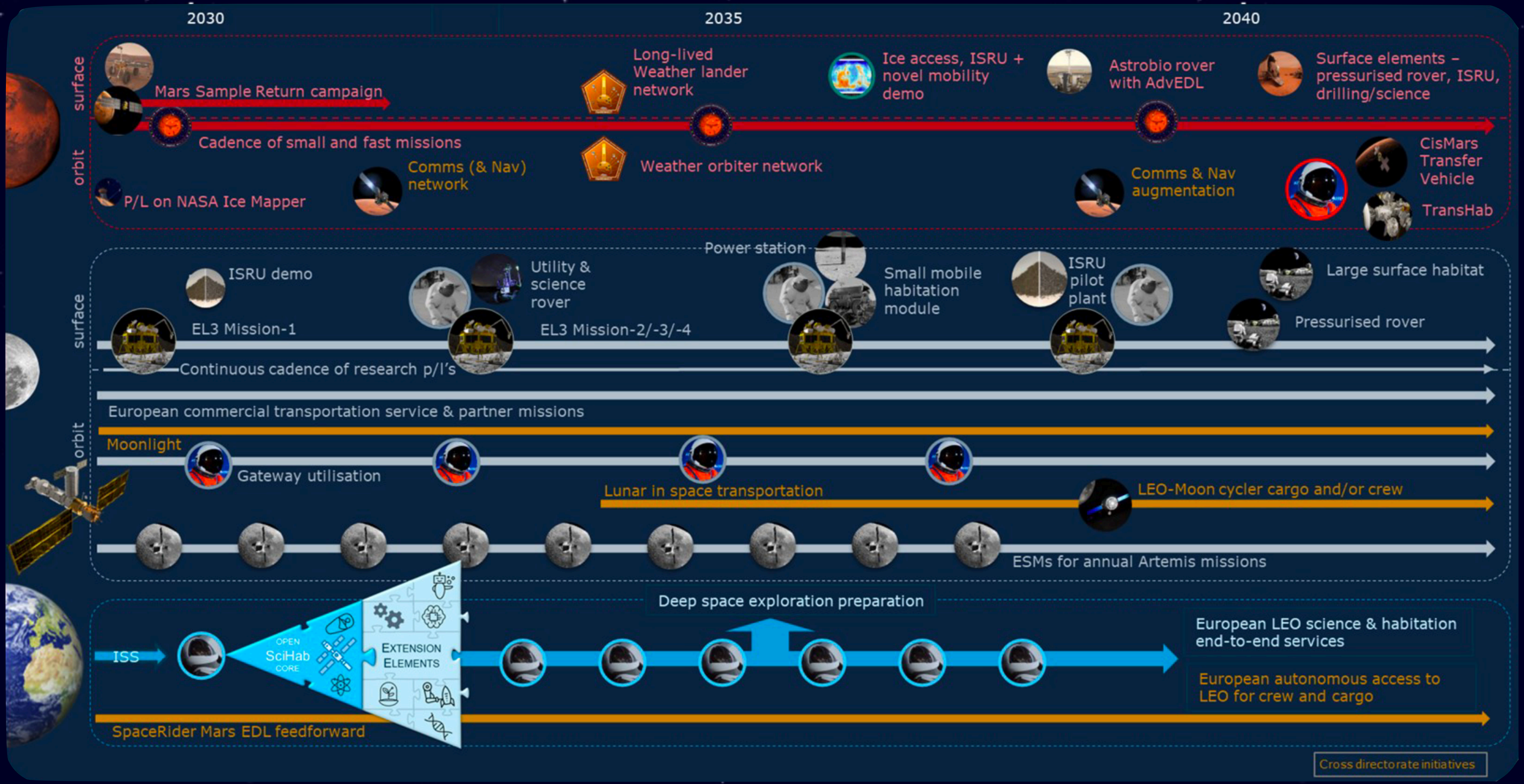
- Technology Readiness Level (TRL) raising programmes to enable technology readiness for operational applications
- The UKSA adopts a two-pronged approach to funding, providing national grants and supporting through the European Space Agency (ESA) for the General Support Technology Programme (GSTP).
- The target of this programme is to promote development of technology for future operational applications on a broad spectrum.
- As an example we are working on a reconfigurable metasurface antenna based on liquid crystal (LC) technology with TWI and Queen's University Belfast (QUB)



SPACE EXPLORATION

ESA TERRAE NOVAE PROGRAMME



Low Earth Orbit

- Human Spaceflight, Microgravity and the International Space Station (ISS)
- Post-ISS scenarios

Moon

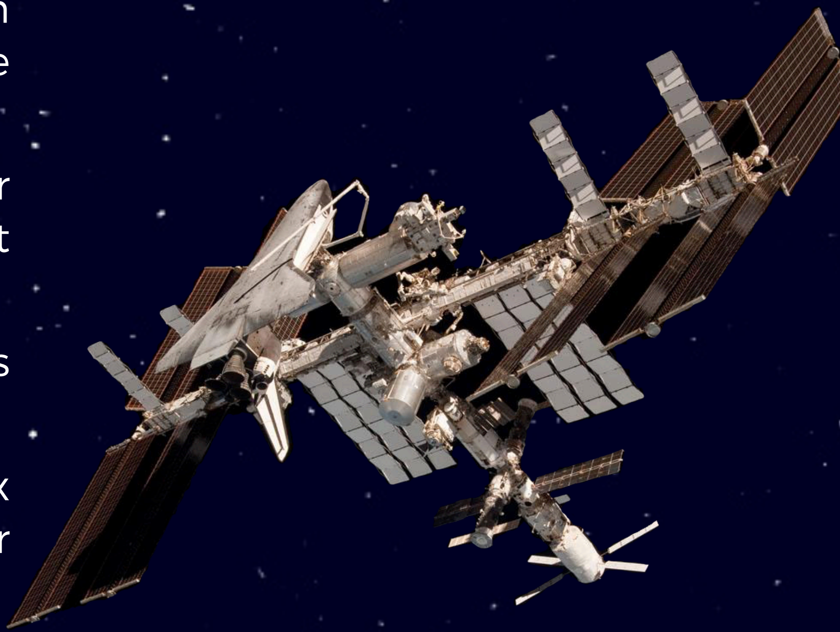
- Robotic Exploration
- Human Exploration
  - Lunar Gateway, Orion, Argonaut...

Mars

- Robotic Exploration
- Human Exploration

SPACE EXPLORATION (LEO)

- The International Space Station (ISS) is the world's largest microgravity laboratory. It facilitates long-duration microgravity experiments in diverse fields such as Physical Sciences, Life Sciences, and Technology Demonstrations.
- Incorporating a "man in the loop" approach, the ISS allows for experimentation in a microgravity, pressurised environment, as well as full exposure to the space environment.
- The UK contributes to the ISS through the development of payloads and/or scientific experiments, and also by providing astronauts to the ESA's astronaut corps.
- Both on the ISS and through commercial initiatives, in-orbit manufacturing is developing. This could potentially open up opportunities for metamaterials.
- The post-ISS scenarios are various and not yet defined, it will probably be a mix of commercial and institutional and will have great opportunities for metamaterials development.



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SPACE EXPLORATION (MOON/MARS)

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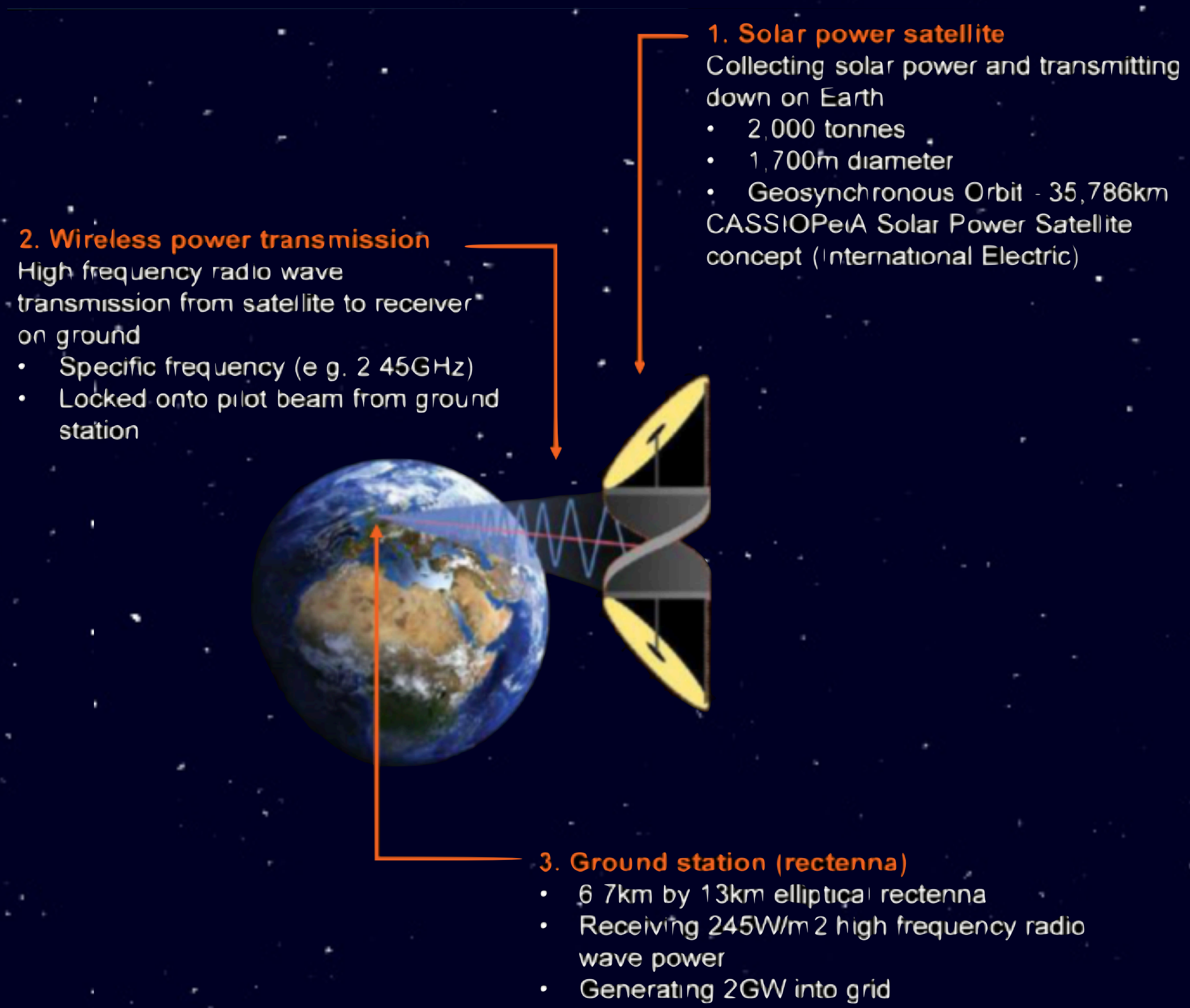
- The UK is promoting and developing the use of nuclear systems to provide long-term energy for exploration missions. A new GSTP (General Support Technology Programme) Component, termed **ENDURE** (EuropeaN Devices Using Radioisotope Energy), aims to deliver a comprehensive European capability for radioisotope heat and power systems by the end of this decade.

- In addition to this, the UK is developing space nuclear reactors and propulsion systems. Nuclear systems, particularly those for space exploration applications, can benefit from the use of metamaterials for nuclear/radiation shielding and neutron moderation and diffusion.

- Advanced systems for exploration and in-situ resources can also leverage metamaterials properties to allow for more effective developments

SPACE-BASED SOLAR POWER

- Emerging discussions are underway around the development of Space-Based Solar Power (SBSP) systems.
- These systems would require gigantic satellites in geostationary orbit (GEO) equipped with large energy storage capabilities, high-power microwave antennas, and lightweight, rigid, thermally-stable structures.
- Metamaterials would be key elements in making the development of such systems feasible.



CONCLUSIONS

- Metamaterials, while relatively novel, have not yet reached mainstream applications in space activities. They occupy a niche in the higher-end performance of communication and thermal control systems.
- Among the UK Space Agency's priorities within the timeframe of the corporate plan, there are considerable opportunities for incorporating metamaterials, particularly for launch systems, technology development, and space exploration. If pursued on a larger scale, this could also apply to Space-based solar power systems.
- A systemic assessment of the potential contributions that the discipline of metamaterials can bring to more effective space activities should be carried out.

THANK YOU FOR YOUR ATTENTION !

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