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LONDON INSTITUTE OF SPACE POLICY AND LAW

IMPERIAL COLLEGE LONDON – LONDON INSTITUTE OF SPACE POLICY AND LAW

SPACE SAFETY POLICY PROJECT

ISPL REPORT

CONTRIBUTION OF EVIDENCE BASED INFORMATION BY IMPERIAL COLLEGE LONDON INFORMING UK SPACE SAFETY POLICY

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BY

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Table of Contents

Abbreviations

CME	Coronal Mass Ejection
CNI	Critical National Infrastructure
ESA	European Space Agency
EU	European Union
EUSST	EU Space Surveillance and Tracking
GNOSIS	The Global Network on Sustainability in Space
IADC	Inter-Agency Space Debris Coordination Committee
IAWN	International Asteroid Warning Network
ICL	Imperial College London
ISO	International Organization for Standardization
ISPL	London Institute of Space Policy and Law
ITU	International Telecommunication Union
LCA	Life Cycle Assessment
LTS Guidelines	Guidelines for the Long-term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space
MOSWOC	Met Office Space Weather Operations Centre
NASA	National Aeronautics and Space Administration
NEOs	Near-Earth Objects
NSP	National Space Policy
NSSP	National Space Security Policy
OSA	Outer Space Act 1986
S2P	Space Safety Programme
SIA	Space Industry Act 2018
SMPAG	Space Mission Planning Advisory Group
SSA	Space Situational Awareness
STM	Space Traffic Management
SWIMMR	Space Weather Instrumentation, Measurement, Modelling and Risk
SWPS2.1	Space Weather Preparedness Strategy. Version 2.1
UK	United Kingdom
UKRI	UK Research and Innovation
UKSA	UK Space Agency
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
US	United States

Executive Summary

This Final Report presents the potential for Imperial College London (ICL) to contribute to the development of Space Safety Policy of the United Kingdom (UK) government.

Although Space Safety is an area of growing international importance and fundamental to the UK's aspirations in space generally, there is no dedicated reference to Space Safety in current UK Space Policy (including Strategy) documents. However, the UK has been active in different degrees in the following five Space Safety subject areas:

- Terrestrial Environmental Impacts of Space Activities;
- Space Debris;
- Planetary Defence;
- Space Weather; and
- Space Traffic Management (STM).

From such engagement it is possible to infer certain policy directions and related basic strategic approaches. In relation to the subject area of Terrestrial Environmental Impacts of Space Activities, this Study concludes that the UK has the policy direction of preventing adverse changes to the environment on Earth through space activities. Concerning the Space Debris subject area, the UK has policy directions focusing on improving UK's available capabilities and capacities to address space debris and associated hazards challenging UK space based and terrestrial infrastructure and services, with particular emphasis on national security and socioeconomic development and welfare. Regarding the Planetary Defence subject area, the UK concentrates on improving UK's available capabilities and capacities to address Near-Earth Objects and associated hazards. UK Space Weather policy directions aim to improve UK's available capabilities and capacities to address space weather and its associated hazards challenging UK's terrestrial and space based infrastructure and services, also with particular emphasis on national security and socioeconomic development and welfare. Finally, although there is much discussion and consideration by government and non-governmental actors in the UK concerning STM, there is as yet no identifiable policy direction.

Sound Space Safety Policy (including Strategy) development relies on evidence based information. This Study concludes that ICL, a world-renowned academic institution for natural sciences, engineering, medicine and business, has the technical capabilities and expertise in different departments in the various Space Safety subject areas, as well as a fitting Academic Strategy, to produce the necessary reliable evidence. ICL further has excellent structural capabilities and capacities through its first-rate facilities and organisational frameworks to support related engagement. In particular, Space Lab, a network of excellence, is well placed to facilitate coordination of ICL efforts in producing evidence based information and exchanges with government. This therefore provides an excellent opportunity for ICL to more vigorously integrate its technical expertise into the policy-making sphere, in an area that is of increasing international importance and also highly aligned to its Academic Strategy.

1 Report outline

The structure of this Final Report evaluating Imperial College London (ICL)'s potential to contribute evidence based information to the development of UK Space Safety Policy is as follows: Section 2 outlines the research objective and approach, including deliberation of the terms 'Space Safety' and 'Policy'. Section 3 discusses the current state of United Kingdom (UK) Space Safety Policy in general. Section 4 presents the potential for ICL to contribute to UK Space Safety Policy development, including a more detailed examination of the current state of and ICL's potential to contribute to Policy development in the five identified specific Space Safety subject areas. Section 5 offers an overall conclusion, including extra suggestions for further action.

2 Research objective and approach

This Study by the London Institute of Space Policy and Law (ISPL)[1] explores where ICL may contribute evidence based information to Space Safety Policy of the UK government.

The methodological approach has three steps, conducted throughout three interlinked reports:

- the assessment of the state of UK Space Safety Policy as of early March 2020, involving identifying the UK government's policy directions, its related basic strategic approach and notable areas of further action;[2]
- the examination of ICL Space Safety capabilities and expertise, including the determination of the alignment of the various Space Safety subject areas with ICL's Academic Strategy 2020-2025;[3] and,
- based on the findings of the previous points and the present Report, the evaluation of ICL's potential to contribute evidence based information to the development of UK Space Safety Policy.

The research encompassed interviews with selected ICL academic staff, UK policymakers and interested others, as well as the analysis of a wide range of material, including documents made publicly available by the UK government, the European Space Agency (ESA) and the European Union (EU), news articles, and secondary literature.

2.1 Space Safety

According to some experts, "[s]pace safety includes the protection of human life, the safeguard of critical and/or high-value space systems and infrastructures, as well as the protection of Earth, orbital, and planetary environments. [… It] covers many diverse areas [displayed in Fig.1 and ...] can be defined as freedom

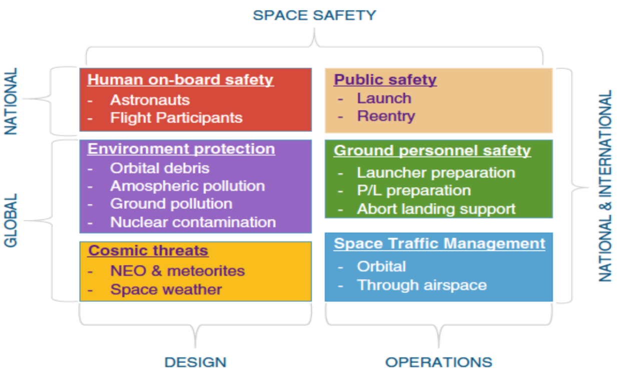

Fig. 1 Space safety fields – Credit: IAASS (International Association for the Advancement of Space Safety)

1 'London Institute of Space Policy and Law' (*ISPL*) <https://www.space-institute.org/> accessed 31 March 2020.
2 See this Study's Report on State of UK Space Safety Policy.
3 See this Study's Report on Imperial College London Space Safety Capabilities and Expertise.

from or mitigation of human or natural harmful conditions. These conditions can cause death, injury, illness, damage to or loss of systems, facilities, equipment or property, or damage to the environment.” Regarding the difference of the often linked terms ‘Safety’ and ‘Security’, they expound that, in general, ““safety” refers to threats that are non[-]voluntary in nature (design errors, malfunctions, human errors, natural hazards, etc.), while “security” refers to threats which are voluntary (i.e., of aggressive nature such as use of anti-satellite weapons).”[4]

However, despite such expert deliberations and the fact that many actors in the space sector invoke the term, no authoritative legal or political definition of ‘Space Safety’ has so far emerged in the UK or at the international level. In view of the above and its research objective, this Study adopts and slightly expands on the Space Safety delineation in ESA’s Space Safety Programme (S2P), ultimately arriving at the following five Space Safety subject areas:

- Terrestrial Environmental Impacts of Space Activities;
- Space Debris;
- Planetary Defence;
- Space Weather; and
- Space Traffic Management (STM).

In general, S2P shall “contribute to the protection of Earth, humanity and assets from hazards originating in space”, with a view to “establishing overall complementarity and maximising synergies among space safety initiatives in Europe”. In particular, S2P shall “provide ESA and its Member States with the necessary tools to conduct effective risk management, addressing hazards originating in space through the identification of their different types, the analysis of their status, severity and magnitude, the prevention of such hazards materialising in the form of genuine threats of damage being caused to Earth or ESA’s space infrastructure by activating mitigation measures and providing appropriate information to support Member State activities aimed at ensuring efficient crisis management, thus giving Europe a lead role in the field”.[5] S2P is divided into three main topic areas: ‘Space Weather’, ‘Planetary Defence’, and ‘Space Debris and Clean Space’. The latter topic area, often referred to as ‘Clean Space initiative’ in its implementation,[6] is directed towards addressing space debris issues, as well as space activities’ terrestrial environmental impact.[7] Additionally, and as explained in more detail in Section 4.5, the on-going international discussion of STM, with varying interpretations of the best scope among governments and non-governmental actors, has an operational safety orientation and links to aforementioned S2P topic areas.

4 Joe Pelton, Tommaso Sgobba and Maite Trujillo, ‘Space Safety’ in Kai-Uwe Schrogl and others (eds), *Handbook of Space Security. Policies Applications and Programs* (Springer 2019) 2–3.

5 S2P superseded ESA’s SSA Programme. It falls under the ‘Space Safety and Security’ pillar: ESA Council ‘Subscription to optional programmes at Space19+ Council meeting at ministerial level’ (2 December 2019) ESA Doc ESA/C-M(2019)100, rev.6 9; ESA Council ‘Resolution on ESA programmes: addressing the challenges ahead’ (28 November 2019) ESA Doc ESA/C-M/CCLXXXVI/Res.3 (Final) 4; regarding the SSA Programme, see e.g.: ‘SSA Programme overview’ (*ESA*) <https://www.esa.int/Safety_Security/SSA_Programme_overview> accessed 30 March 2020. Citation in second document on p.4.

6 ‘The Challenge’ (*ESA*) <https://www.esa.int/Safety_Security/Clean_Space/The_Challenge> accessed 30 March 2020.

7 ESA, ‘Space Safety. Space19+’ (Flyer, ESA) 2-3[unpaginated] <https://esamultimedia.esa.int/docs/corporate/Space19+flyers_SSA_LR.pdf> accessed 21 March 2020; ‘Space Safety’ (Presentation, ESA) 4-5[unpaginated] <https://www.cosmos.esa.int/documents/336356/1803543/ESA-SSA-NEO-HO-0368_1_0_ESAs_new_space_safety_programme_2018-10-16.pdf> accessed 22 March 2020.

2.2 Policy

'Policy' is an elusive term. It has no authoritative definition. This Study, focused on UK Space Safety Policy, primarily considers the main objectives that drive the UK government's engagement ('policy objectives'; or if less focused 'policy direction') in the various Space Safety subject areas, its related basic strategic approach and notable areas of further action. Typically, an actor's Policy can be considered to articulate the main objectives that drive its engagement in a given subject area, including provision of some information on the general reasoning and policy-making process behind them. A Policy might also introduce strategic milestones in the pursuit of such objectives. Linked to but ranking below a Policy, an actor's Strategy generally outlines the related basic strategic approach, including the strategy-making process behind it, in detail. Under a Strategy, an actor might additionally put forward a Plan supporting the implementation of a particular strategic measure. In practice, it is rarely as clear-cut. For example, official Policy or Strategy documents might not clearly differ between policy objectives and the basic strategic approach. They might be incomplete. Sometimes, a Policy document might even be titled Strategy or Plan.

3 State of UK Space Safety Policy

Ultimately, this Study finds that there is no dedicated reference to Space Safety in the available current UK Space Policy (including Strategy) documents. However, the accessible documents, other material and government actions indicate some present set of UK government policy directions and related basic strategic approach in each of the Space Safety subject areas, save STM.[8]

With the exact scope depending on the final UK-EU framework agreement, this Study further deems it a reasonable assumption that, following the UK's withdrawal from the EU, UK entities will have no or at most limited access to future EU funded Space Safety projects. Yet, this does not mean that there is no potential for UK-EU collaboration, e.g., concerning space weather and Near-Earth Objects (NEOs) that have an inherent impartial character and can be hazardous regionally or globally. Also, the potential creation and maintenance of a mature global STM system will require international – including UK-EU – effort. Regarding ESA, there is no strong indication that such withdrawal will severely hamper the UK potential to promote and participate in (non-EU funded) ESA Space Safety endeavours. However, with a view to the Terrestrial Environmental Impacts of Space Activities subject area, UK entities have to take into account that they might have to abide by (newly created) EU environmental regulations, in whose development the UK government has no further hand, through certain ESA activities. Such regulations might have a spillover effect into ESA.[9]

8 See this Report's Section 4 and this Study's Report on State of UK Space Safety Policy.
9 See this Study's Report on State of UK Space Safety Policy.

4 Potential for ICL contribution to UK Space Safety Policy

This Study considers ICL capabilities and expertise in the various Space Safety subject areas as represented through pertinent technical capabilities and expertise, demonstrated by research interests and activities and outreach actions, through expedient structural capabilities and capacities, demonstrated by ICL facilities and organisational frameworks, and through the alignment of subject area engagement with the ICL Academic Strategy 2020-2025.[10]

While it has had no significant role in the development of – the not yet particularly fixated –[11] UK Space Safety Policy so far, this Study ultimately concludes that ICL, a world-renowned academic institution for natural sciences, engineering, medicine and business, can produce reliable evidence to relevant government personnel and entities that is essential for the clear development of UK Space Safety Policy, especially concerning policy objectives, the related basic strategic approach and the underlying narrative.

For one, ICL has a very strong technical base and existing research interests and activities in the different Space Safety subject areas.[12]

Moreover, Space Safety engagement fits with its Academic Strategy that articulates the arguably ICL-unique feature of desiring to build a focus on research that has a tangible impact on everyday life. The Strategy for 2015-2020[13] declared ICL's mission as "to achieve enduring excellence in research and education in science, engineering, medicine and business for the benefit of society."[14] The new and currently active Academic Strategy for 2020-2025 identifies four connected interdisciplinary themes where "the College will seek to accelerate discovery and impact to society":[15]

- ❖ Sustainable Society
- ❖ Healthy Society
- ❖ Resilient Society
- ❖ Smart Society

Although space research is relevant to all four of these themes, Space Safety engagement is of direct importance to the 'Sustainable Society' and 'Resilient Society' themes, as well as potentially the 'Smart Society' theme.[16] This importance is only likely to grow as space technologies and infrastructure become more than ever integrated into everyday life.

In the context of Space Safety and the current Academic Strategy, it is further notable that the latter puts forward four College-wide embedded capabilities – Engaged; Entrepreneurial; Quantitative; Transdisciplinary – supporting activities within aforementioned four themes. The Space Safety area fundamentally requires transdisciplinary effort. Also, effective involvement in Space Safety Policy development draws on ICL's 'Enabled' capability to "collaborate with

10 For a copy of the Strategy document (Version 1.0 as of March 2020), see: ICL, 'Academic Strategy 2020–2025: V1.0' (ICL) <https://www.imperial.ac.uk/media/imperial-college/about/leadership-and-strategy/provost/public/19-11-Academic-Strategy_FULL_TP.pdf> accessed 16 March 2020.
11 See this Study's Report on State of UK Space Safety Policy.
12 See this Report's Sections 4.1-5 and this Study's Report on Imperial College London Space Safety Capabilities and Expertise.
13 For a copy of the Strategy document, see: ICL, 'Strategy 2015-2020' (ICL) <https://www.imperial.ac.uk/media/imperial-college/about/leadership-and-strategy/public/Strategy2015-2020.pdf> accessed 31 March 2020.
14 ibid 2.
15 ICL (n 10) 5.
16 See this Report's Sections 4.1-5 and this Study's Report on Imperial College London Space Safety Capabilities and Expertise.

communities, stakeholders, governments and industry locally, nationally and internationally to ensure that our work is relevant, timely, and accessible."[17]

Finally, ICL has, thus far, had limited success in impacting UK Space Safety Policy development due to a lack of an across-the-board capacity for Space Policy analysis to complement its technical authority. However, ICL has excellent structural capabilities and capacities through first-rate facilities and organisational frameworks, including labour, tools and resources, enabling the establishment and maintenance of affiliations with government and other non-governmental actors, domestic and international subject matter networks, and effective internal and external communications and outreach. In particular, Space Lab, a network of excellence,[18] is well placed to facilitate coordination of ICL Space Safety efforts in producing evidence based information and exchanges with government. It has even already commenced collaborating with ISPL,[19] a specialised UK based think tank in the Space Policy and Law field with a faculty of leading academics, professionals and others active in the space sector.[20]

4.1 Terrestrial Environmental Impacts of Space Activities

4.1.1 Current state[21]

In relation to the Space Safety subject area of Terrestrial Environmental Impacts of Space Activities, a UK policy direction can be inferred from Outer Space Act 1986[22] (OSA) and Space Industry Act 2018[23] (SIA) licensing guidances, as well as the government's intention to take practical steps to implement the Guidelines for the Long-term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space[24] (LTS Guidelines), adopted by the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) in 2019.[25] In short, this Study concludes that the UK government has the policy direction of preventing adverse changes to the environment on Earth through space activities.[26]

17 ICL (n 10) 5,9. Citation on p.9.
18 'Space Lab' (*ICL*) <https://www.imperial.ac.uk/a-z-research/space-lab/> accessed 30 March 2020.
19 'London Institute of Space Policy and Law' (n 1).
20 See this Study's Report on Imperial College London Space Safety Capabilities and Expertise.
21 For more information, see this Study's Report on State of UK Space Safety Policy.
22 For an up-to-date copy of OSA, visit: 'Outer Space Act 1986' (*legislation.gov.uk*) <https://www.legislation.gov.uk/ukpga/1986/38/contents> accessed 30 March 2020.
23 For an up-to-date copy of SIA, visit: 'Space Industry Act 2018' (*legislation.gov.uk*) <https://www.legislation.gov.uk/ukpga/2018/5/contents> accessed 30 March 2020.
24 For a copy of these Guidelines, see Annex II in: UNGA 'Report of the Committee on the Peaceful Uses of Outer Space. Sixty-second session (12-21 June 2019)' (2019) UN Doc A/74/20 50–69.
25 Concerning this intention, see e.g.: 'UK General Statement, Scientific and Technical Sub-Committee of COPUOS' (*GOV.UK*, 3 February 2020) <https://www.gov.uk/government/speeches/uk-general-statement-scientific-and-technical-sub-committee-of-copuos> accessed 22 February 2020.
26 Derived from information presented in the following material. Policy-wise, Guideline D.1 of the LTS Guidelines notably reads that '[i]n their conduct of space activities [...], States [...] should take into account[...] the social, economic and environmental dimensions of sustainable development on Earth.' UNGA 'Report of the Committee on the Peaceful Uses of Outer Space. Sixty-second session (12-21 June 2019)' (2019) UN Doc A/74/20 68; 'Guidance. Licence to operate a space object: how to apply' (*GOV.UK*, 3 September 2019) <https://www.gov.uk/guidance/apply-for-a-license-under-the-outer-space-act-1986> accessed 30 March 2020; 'Guidance. Applying for a future licence under the Space Industry Act' (*GOV.UK*, 8 February 2019) <https://www.gov.uk/guidance/applying-for-a-future-licence-under-the-space-industry-act> accessed 30 March 2020; 'Guidance for Licence Applicants. Outer Space Act 1986' (August 2018) 3–4 <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/851094/GUIDANCE_FOR_APPLICANTS_Revised_08-08-2018_sw1_UPDATED__3___1_.pdf> accessed 27 February 2020.

This Study further holds that the following points can be considered to indicate the UK's basic strategic approach concerning this policy direction, bearing in mind that domestic space sector licencing is deliberately designed to allow for a flexible application:

- UK licensees of space objects being obliged to take into account the appropriate disposal of the licensed space object at the end of the licensed activity;[27]
- UK Space Agency (UKSA) determining in its current licensing process for launch-only activities whether "there [is] a risk assessment and mitigation plan addressing the hazards to persons and property, including third parties, and the environment (including contamination) under nominal and failure conditions for the following phases – preparation for launch (including storage and handling of toxic propellants), ignition/initial ascent, trajectory down range to attainment of orbital status, and impact/disposal/recovery of launch related objects at the Earth's surface?";[28] and
- requiring applications for future SIA licences to submit an Assessment of Environmental Effects presumably to address aspects like air quality, biodiversity, emissions targets, environmental effects of launch failure, marine impacts, noise pollution, soil health, and water quality;[29]
- the UK government promoting domestic, ESA based and other cooperative technological development that minimises the environmental impact of manufacturing space assets and space launches, as well as maximises the use of renewable resources and space assets' reusability or repurposing as stipulated under Guideline D.1 of the LTS Guidelines.[30] Officially highlighted measures in this regard are national investments into the development of innovative green propulsion systems, and UK led ESA based studies into equipment that enhances the ability for a spacecraft to demise.[31] Notably, within ESA there is the S2P Clean Space initiative. The latter focuses on its terrestrial side on "EcoDesign" fostering the "use [of] new materials and manufacturing processes and design which will have a lower environmental impact on Earth – and […] be compliant with European environmental legislations". As a tool to inform EcoDesign, and improve assessments of space activities' terrestrial environmental impacts in general, ESA developed "an environmental LCA (life-cycle assessment) method applicable to space missions and a guideline for its use."[32] Yet, without many governmental references to this initiative, it is hard to

27 'Guidance. Licence to operate a space object: how to apply' (n 26); 'Guidance for Licence Applicants. Outer Space Act 1986' (n 26) 3.

28 'Guidance for Licence Applicants. Outer Space Act 1986' (n 26) 13.

29 SIA 2018, s 11 and: 'Guidance. Applying for a future licence under the Space Industry Act' (n 26); some notable documents that might inform the UK Strategy on terrestrial environmental impacts of UK spaceports and launch vehicles are: Ron Macbeth, 'Spaceports: keeping people safe' (Report, PE06415/8, HSE (HSL), 28 September 2018) <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/780509/Spaceports_keeping_people_safe.pdf> accessed 23 March 2020; RPC, 'Space Industry Bill - Spaceflight. Impact Assessment' (RPC-3515(1)-DfT, RPC, 30 September 2016) 28-34,41 <https://www.legislation.gov.uk/ukpga/2018/5/pdfs/ukpgaod_20180005_en_001.pdf> accessed 23 March 2020; Andrew Badham and others, 'UK Government Review of commercial spaceplane certification and operations' (Technical Report, CAP 1189, CAA, July 2014) 234–254 <https://publicapps.caa.co.uk/docs/33/CAP1189_UK_Government_Review_of_commercial_spaceplane_certification_and_operations_technical_report.pdf> accessed 2 March 2020.

30 UNGA 'Report of the Committee on the Peaceful Uses of Outer Space. Sixty-second session (12-21 June 2019)' (2019) UN Doc A/74/20 68–69.

31 UNCOPUOS (STSC) 'Voluntary Implementation of the Guidelines for the Long-term Sustainability of Outer Space Activities and Proposed Reporting Approach by the United Kingdom' (07 February 2020) UN Doc A/AC.105/C.1/2020/CRP.15 6[unpaginated].

32 '2020 Clean Space Industrial Days' (*ESA*) <https://indico.esa.int/event/321/> accessed 2 March 2020; concerning EcoDesign and the LCA, see also: ESA, 'clean space. Safeguarding Earth and Space' (Brochure, BR-330, ESA 2016) 2-4[unpaginated] <https://esamultimedia.esa.int/multimedia/publications/Clean_Space/offline/download.pdf> accessed 14 January 2020; 'Life cycle assessment' (*ESA*, 13 September 2012) <https://www.esa.int/ESA_Multimedia/Images/2012/09/Life_cycle_assessment> accessed 30 March 2020; 'ecodesign' (*ESA*) <https://www.esa.int/Safety_Security/Clean_Space/ecodesign> accessed 30 March 2020. Citations in first link.

gauge the UK's interest and involvement in this initiative's EcoDesign branch.[33] The available material even draws no direct link between this initiative and aforementioned UK led ESA based spacecraft demise oriented studies.

4.1.2 Potential for ICL contribution

ICL has technical capabilities and expertise that, if brought together systematically under a transparent organisational framework, provide a foundation to expand its contribution of reliable evidence based information to UK Space Safety Policy (including Strategy) development in the Terrestrial Environmental Impact of Space Activities subject area. ICL technical capabilities and expertise in this subject area are demonstrated by the awareness of the toxicity of traditional propellants like hydrazine and the understanding of environmental issues related to the development and operation of spacecraft and spaceports by members within the Department of Aeronautics and the Centre for Environmental Policy. Additionally, this Study has come across ICL members, including in the said Department and Centre, with interest and competence in alternative propulsion methods and knowledge of LCAs.[34] This is evidenced by a Department of Aeronautics' UKRI (UK Research and Innovation) funded studentship to study the use of water electrolysis allowing highly efficient propellants to be stored and utilised in a non-hazardous manner.[35] Also, there was an ICL event on "green propellants for small satellite chemical propulsion" in 2018.[36] Furthermore, technical capabilities and expertise pointed out under the various research themes of the following ICL departments might have some potential to generate evidence based information relevant to this subject area:[37]

• Centre for Environmental Policy	• Department of Electrical and Electronic Engineering
• Department of Aeronautics	• Department of Materials
• Department of Chemical Engineering	• Department of Mechanical Engineering
• Department of Chemistry	• Dyson School of Design Engineering
• Department of Civil and Environmental Engineering	• Imperial College Business School
• Department of Earth Science and Engineering	

Engagement in this subject area aligns with elements of the ICL Academic Strategy 2020-2025 themes of 'Sustainable Society' and 'Resilient Society'.[38]

Altogether, evidence based information derived from these technical capabilities and expertise could, for example, assist in formulating UK policy objectives and their narrative in this subject area in an easily comprehensible manner.

33 UKSA reportedly organised and participated in a Clean Space information event in 2013: 'ESA's Clean Space initiative to be presented to UK space sector' (*ESA*, 3 October 2013) <https://www.esa.int/Safety_Security/Clean_Space/ESA_s_Clean_Space_initiative_to_be_presented_to_UK_space_sector> accessed 30 March 2020.

34 Based on interviews with ICL academic staff in February and March 2020 and an ICL meeting attended in March 2020.

35 'Catalytic Combustion of Hydrogen and Oxygen for an Electrolysis Micro Rocket Thruster' (*UKRI*) <https://gtr.ukri.org/projects?ref=studentship-2092770> accessed 16 March 2020.

36 'Green propellants for small satellite chemical propulsion; the future?' (*ICL*) <https://www.imperial.ac.uk/events/98054/green-propellants-for-small-satellite-chemical-propulsion-the-future/> accessed 30 March 2020.

37 For more information, see this Study's Report on Imperial College London Space Safety Capabilities and Expertise.

38 ICL (n 10) 6–7. For more information, see this Study's Report on Imperial College London Space Safety Capabilities and Expertise.

Strategy-wise, it can help refine the UK's aforementioned strategic promotion of domestic, ESA based and other cooperative technological development that minimises the environmental impact of manufacturing space assets and space launches, as well as maximises the use of renewable resources and space assets' reusability or repurposing. Additionally, such information can aid UK licensing authorities in creating reasonable guidelines for licensees of space objects and spaceports who have to address certain environmental considerations, as mentioned in Section 4.1.1.

Finally, such information can deliver valuable input concerning the following – interlinked – areas of further action that could potentially benefit the evolution of the UK's distinct basic strategic approach in this subject area:[39]

- the development of comprehensive domestic licensing guidelines for the identification, quantification and approval of the terrestrial environmental impacts of the many stages and parts of the various current and planned UK space activities, including with a view to any potential integration of ESA's LCA regime and non-governmental actors striving for certainty in their subject area related engagements;
- the advancement of reliable and reasonable domestic and international environmental regulations, taking into account the need to avoid domestic regulations getting too burdensome so as to drive potential space activities elsewhere (flag of convenience approach)[40];
- the clarification of the UK's preferred future role in the EcoDesign branch of ESA's Clean Space initiative; and
- the increased raising of awareness about space activities' terrestrial environmental impacts,[41] including by conducting further studies, and the active discouragement of identified or presumed environmentally problematic space activities, which have special relevance in the context of projects using or contemplating the use of extremely hazardous material like nuclear power sources,[42] the growing number of parties joining the space sector and the creation of new mission concepts. Concerning the latter, one concept deserving attention is small satellite mega-constellations. Their deployment might lead to large numbers of space launches and satellite burn-ups that might result in the contamination of and adverse changes to the composition of the atmosphere.[43]

39 The following points are a selection and emerge from information presented in this Study's Report on State of UK Space Safety Policy, in interviews with policymakers/stakeholders and ICL academic staff in February and March 2020, as well as in the further referenced material. This Study does not claim completeness. Much more thoughts and ideas are promoted in the literature. For some further reading, see the said Report's Section 8.

40 Justin Fisch, 'Green for Liftoff: Structural Changes for Environmental and Economic Sustainability in Space Launching' (2015) 40 Journal of Space Law 57, 58–59.

41 'Raising awareness and winning the argument: Kai-Uwe Schrogl interview' (*ESA*, 14 May 2014) <https://www.esa.int/Safety_Security/Clean_Space/Raising_awareness_and_winning_the_argument_Kai-Uwe_Schrogl_interview> accessed 3 March 2020.

42 Lotta Viikari, *The Environmental Element in Space Law. Assessing the Present and Charting the Future* (Martinus Nijhoff Publishers 2008) 45–48.

43 Martin Ross and James Vedda, 'Op-ed | Time to clear the air about launch pollution' (*SpaceNews*, 3 July 2018) <https://spacenews.com/op-ed-time-to-clear-the-air-about-launch-pollution/> accessed 30 March 2020; Qizhi He, 'Environmental Impact of Space Activities and Measures for International Protection' (1988) 16 Journal of Space Law 117, 118–119.

4.2 Space Debris

4.2.1 Current state[44]

In relation to the Space Safety subject area of Space Debris, the UK government's policy directions can be inferred from a few limited references to space debris in the UK Space Policy documents, namely the National Space Policy[45] (NSP) and the National Space Security Policy[46] (NSSP), as well as the LTS Guidelines, regarding which the UK government intends to take practical steps for implementation,[47] and other information presented below. In short, the UK government has the policy directions of:

a) improving the UK's available space surveillance capabilities and capacities to detect, track, identify, analyse, catalogue and predict space debris and associated hazards[48] with the potential to disrupt, degrade or damage the UK's space based and terrestrial infrastructure and services, especially those significant to national security and socioeconomic development and welfare; and

b) building national resilience capabilities and capacities to such hazards.[49]

The following points can be considered to form part of the UK's basic strategic approach to these policy directions:

- promoting the development and application of space debris surveillance, mitigation and removal capabilities and capacities available to the UK;
- promoting the involvement of and government engagement with industry, academia and defence personnel in building capability and capacity;
- supporting work addressing regulatory challenges and adoption of predictable and proportionate regulations;
- protecting relevant orbital slot and spectrum assignments; and
- bolstering and entering into coordinated international collaborations as much as reasonable, while acting purely nationally when required, e.g. to protect certain national security interests.[50]

Adding some notable details to the first and last bullet point, the UK's current domestic space object licensing guidelines require licensees to take into account space debris related aspects such as the prevention of the contamination of space, non-interference with others' activities, as well as the appropriate disposal of the licensed space object at the

44 For more information, see this Study's Report on State of UK Space Safety Policy.

45 For a copy of this document, see: HM Government, 'National Space Policy' (HM Government, December 2015) <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/484865/NSP_-_Final.pdf> accessed 15 January 2020.

46 For a copy of this document, see: HM Government, 'National Space Security Policy' (UKSA/13/1292, HM Government, April 2014) <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/307648/National_Space_Security_Policy.pdf> accessed 17 January 2020.

47 'UK General Statement, Scientific and Technical Sub-Committee of COPUOS' (n 25).

48 This Study's research suggests that the UK government generally understands 'hazards' as to be non-malicious. The government usually employs the term 'threat' to point towards malicious intent. Some indicators are the references to hazards and threats in: HM Government (n 45) 9; also, according to a POSTbrief by Stock and Wentworth, a hazard 'generally refers to any "natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources"': Michael Stock and Jonathan Wentworth, 'Evaluating UK natural hazards: the national risk assessment' (POSTbrief 31, POST, April 2019) 3 <https://researchbriefings.files.parliament.uk/documents/POST-PB-0031/POST-PB-0031.pdf> accessed 14 February 2020.

49 Policy-wise, the 'Background' Chapter of the LTS Guidelines reads, among others, that "[t]he proliferation of space debris[...] and the increased risks of collision and interference with the operation of space objects may affect the long-term sustainability of space activities. Addressing these developments and risks requires international cooperation by States [...] to avoid harm to the space environment and the safety of space operations." UNGA 'Report of the Committee on the Peaceful Uses of Outer Space. Sixty-second session (12-21 June 2019)' (2019) UN Doc A/74/20 50; HM Government (n 45) 7-9,11; HM Government (n 46) 3-4,7,10-11,13,17.

50 UNGA 'Report of the Committee on the Peaceful Uses of Outer Space. Sixty-second session (12-21 June 2019)' (2019) UN Doc A/74/20 54-55,60,64,68-69; HM Government (n 45) 7-9,11-15; HM Government (n 46) 2-7,10-11,13-19.

end of the licenced activity. Licence applicants have to "demonstrate compliance/conformance with existing norms/best practices in relation to measures such as the IADC [(Inter-Agency Space Debris Coordination Committee)] Space Debris Mitigation Guidelines,[51] [the] Space Debris Mitigation Guidelines of [… UNCOPUOS,[52] the ITU (International Telecommunication Union) Recommendation ITU-R S.1003],[53] and the growing body of international standards relating to debris[like ISO (International Organization for Standardization) Standard 24113 (Space Systems – Space Debris Mitigation Requirements)][54]."[55] The future domestic licensing process for UK spaceport and launch vehicle operators will presumably also address space debris.[56] Further relating to these two bullet points, Guideline D.2 of the LTS Guidelines stipulates, among others, that "new measures [to address the evolution of and manage the space debris population in the long term], together with existing ones, should be envisaged so as not to impose undue costs on the space programmes of emerging spacefaring nations. […] Investigation of new measures could include, inter alia, methods for the extension of operational lifetime, novel techniques to prevent collision with and among debris and objects with no means of changing their trajectory, advanced measures for spacecraft passivation and post-mission disposal and designs to enhance the disintegration of space systems during uncontrolled atmospheric re-entry."[57]

A range of notable on-going UK government promoted domestic and international measures falling under this basic strategic approach are its engagement with Astroscale,[58] the space debris surveillance capabilities and capacities of RAF (Royal Air Force) Fylingdales and the latter's contribution to the United States (US) Space Surveillance Network,[59] UK Ministry of Defence participation in the US led Operation Olympic Defender,[60] investment into ESA's S2P related ADRIOS[61] (Active Debris Removal/ In-Orbit Servicing) and CREAM[62] (Collision Risk Estimation and Automated Mitigation) missions and UK led ESA based studies into equipment to advance the ability for a spacecraft to demise,[63]

51 For a copy of these Guidelines and the most relevant supporting documents, visit: '4 Main IADC Products' (*IADC*, 20 August 2019) <https://www.iadc-home.org/documents_public/view/id/82#u> accessed 2 March 2020.

52 UNOOSA, 'Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space' (UNOOSA, January 2010) <https://www.unoosa.org/res/oosadoc/data/documents/2010/stspace/stspace49_0_html/st_space_49E.pdf> accessed 2 March 2020.

53 For a copy of this Recommendation, see: 'Environmental Protection of the Geostationary-Satellite Orbit' (Rec ITU-R S1003, ITU 1993) <https://www.itu.int/dms_pubrec/itu-r/rec/s/R-REC-S.1003-0-199304-S!!PDF-E.pdf> accessed 2 March 2020.

54 For a copy of this Standard, visit: 'ISO 24113:2019. Space systems — Space debris mitigation requirements' (*ISO*, July 2019) <https://www.iso.org/cms/render/live/en/sites/isoorg/contents/data/standard/07/23/72383.html> accessed 2 March 2020.

55 'Guidance. Licence to operate a space object: how to apply' (n 26); 'Compendium. Space Debris Mitigation Standards Adopted by States and International Organizations' (UNOOSA, 25 February 2019) 56–57 <https://www.unoosa.org/documents/pdf/spacelaw/sd/Space_Debris_Compendium_COPUOS_25_Feb_2019p.pdf> accessed 24 February 2020; 'Guidance for Licence Applicants. Outer Space Act 1986' (n 26). Citation in second document on p.57.

56 'Guidance. Applying for a future licence under the Space Industry Act' (n 26).

57 UNGA 'Report of the Committee on the Peaceful Uses of Outer Space. Sixty-second session (12-21 June 2019)' (2019) UN Doc A/74/20 69.

58 See e.g.: 'National In-Orbit Servicing Control Facility to be built in UK to help remove space debris' (*Astroscale*, 24 July 2018) <https://astroscale.com/national-inorbit-servicing-control-facility/> accessed 28 February 2020.

59 'RAF Fylingdales' (*GlobalSecurity.org*) <https://www.globalsecurity.org/space/facility/fylingdales.htm> accessed 27 March 2020.

60 'Defence Secretary keynote speech at the Air and Space Power Conference 2019' (*GOV.UK*, 18 July 2019) <https://www.gov.uk/government/speeches/defence-secretary-keynote-speech-at-the-air-and-space-power-conference-2019> accessed 22 February 2020.

61 'ESA commissions world's first space debris removal' (*ESA*, 9 December 2019) <https://www.esa.int/Safety_Security/Clean_Space/ESA_commissions_world_s_first_space_debris_removal> accessed 27 March 2020; 'in-orbit servicing/active debris removal' <https://www.esa.int/Safety_Security/Clean_Space/in-orbit_servicing_active_debris_removal> accessed 27 March 2020.

62 Benjamin Bastida Virgili and others, 'CREAM - ESA's Proposal for Collision Risk Estimation and Automated Mitigation' (Conference Paper, 1st International Orbital Debris Conference, Sugar Land, Texas, USA, 9-12 December 2019) <https://www.hou.usra.edu/meetings/orbitaldebris2019/orbital2019paper/pdf/6031.pdf> accessed 27 March 2020.

63 UNCOPUOS (STSC) 'Voluntary Implementation of the Guidelines for the Long-term Sustainability of Outer Space Activities and Proposed Reporting Approach by the United Kingdom' (07 February 2020) UN Doc A/AC.105/C.1/2020/CRP.15 6[unpaginated]; ESA Council 'Subscription to optional programmes at Space19+ Council meeting at ministerial level' (2 December 2019) ESA Doc ESA/C-M(2019)100, rev.6 9.

as well as UKSA involvement in the EU Space Surveillance and Tracking (EUSST) programme.[64] As it stands the UK loses its eligibility to take part in the EUSST programme from 1 January 2021.[65]

4.2.2 Potential for ICL contribution

ICL has technical capabilities and expertise that, if brought together systematically under a transparent organisational framework, provide a foundation to expand its contribution of reliable evidence based information to UK Space Safety Policy (including Strategy) development in the Space Debris subject area. ICL technical capabilities and expertise in this subject area are demonstrated by several ICL members and a PhD student having already engaged in some related work,[66] as well as an Imperial College Aeronautical Society organised Hackathon that addressed, among others, space debris.[67] Also, UKRI has funded a space debris related Department of Aeronautics' studentship and Department of Materials' research project.[68] Moreover, there have been some events[69] and other outreach activities[70] addressing space debris directly and indirectly. Furthermore, technical capabilities and expertise pointed out under the various research themes of the following ICL departments might have some potential to generate evidence based information relevant to this subject area:[71]

• Department of Aeronautics	• Department of Mathematics
• Department of Computing	• Department of Physics
• Department of Electrical and Electronic Engineering	• Dyson School of Design Engineering
• Department of Materials	• Imperial College Business School
• Department of Mechanical Engineering	

64 'What is EUSST?' (*EUSST*, October 2019) <https://www.eusst.eu/> accessed 2 March 2020; 'Satellites and space programmes if there's no Brexit deal' (*GOV.UK*, 27 March 2019) <https://www.gov.uk/government/publications/satellites-and-space-programmes-if-theres-no-brexit-deal/satellites-and-space-programmes-if-theres-no-brexit-deal> accessed 2 March 2020.

65 'Guidance. Satellites and space programmes from 1 January 2021' (*GOV.UK*, 9 August 2019) <https://www.gov.uk/guidance/satellites-and-space-programmes-from-1-january-2021> accessed 2 March 2020.

66 Hugh G Lewis and Timothy Horbury, 'Implications of Prolonged Solar Minimum Conditions for the Space Debris Population', *Proc. '6th European Conference on Space Debris'* (ESA SP-723, ESA, August 2013) <https://conference.sdo.esoc.esa.int/proceedings/sdc6/paper/164/SDC6-paper164.pdf> accessed 16 March 2020; 'Prof. Deeph Chana' (*ICL*) <https://www.imperial.ac.uk/people/d.chana> accessed 16 March 2020; 'Dr Richard Chater' (*ICL*) <https://www.imperial.ac.uk/people/r.chater> accessed 16 March 2020; 'Dr Ravindra T. Desai' (*ICL*) <https://www.imperial.ac.uk/people/ravindra.desai> accessed 16 March 2020; 'Shock Propagation in Complex Laminate Systems' (*ICL*) <https://www.imperial.ac.uk/a-z-research/shock-physics/research/phd-projects/shock-propagation/> accessed 16 March 2020.

67 Tom Creese, 'AeroSoc Hold First Ever Hackathon Event: SpaceHack' (*ICL*, 22 November 2019) <https://www.imperial.ac.uk/news/194086/aerosoc-hold-first-ever-hackathon-event/> accessed 16 March 2020.

68 'Catalytic Combustion of Hydrogen and Oxygen for an Electrolysis Micro Rocket Thruster' (n 35); 'Silicon doped boron carbide a lightweight impact resistant material' (*UKRI*) <https://gtr.ukri.org/projects?ref=EP%2FK028707%2F1> accessed 30 March 2020.

69 'Bio-Inspired Dynamic Surface Grasping' (*ICL*) <https://www.imperial.ac.uk/events/104259/bio-inspired-dynamic-surface-grasping/> accessed 16 March 2020; 'Science, space and security' (*ICL*) <https://www.imperial.ac.uk/events/103959/science-space-and-security/> accessed 16 March 2020; 'Understanding Space Debris – Known and Unknown Knowns' (*ICL*) <https://www.imperial.ac.uk/events/106241/understanding-space-debris-known-and-unknown-knowns/> accessed 16 March 2020.

70 'What is Space Junk? | Space Explained' (*Youtube*, 26 April 2016) <https://www.youtube.com/watch?v=_QbEcDwBJ88> accessed 16 March 2020; aforementioned video involves Dr Simon Foster: 'Foster, Dr Simon S' (*ICL*) <https://www.imperial.ac.uk/collegedirectory/index.asp?PeopleID=606308> accessed 31 March 2020; Michael Jones, 'Imperial takes science to the streets of South Kensington' (*ICL*, 14 October 2013) <https://www.imperial.ac.uk/news/132427/imperial-takes-science-streets-south-kensington/> accessed 16 March 2020.

71 For more information, see this Study's Report on Imperial College London Space Safety Capabilities and Expertise.

Engagement in this subject area fits elements of the ICL Academic Strategy 2020-2025 themes of ‘Sustainable Society’, ‘Resilient Society’ and ‘Smart Society’.[72]

Altogether, evidence based information derived from these technical capabilities and expertise could, for example, assist in formulating UK policy objectives and their narrative in this subject area in an easily comprehensible manner. Strategy-wise, it can help promote aforementioned development of space debris surveillance, mitigation and removal capabilities and capacities available to the UK. Such information can also aid UK licensing authorities in creating reasonable guidelines for licensees of space objects and spaceports who have to comply and conform with certain norms and best practices, as put forward under Section 4.2.1.

Lastly, such information can deliver valuable input concerning the following – interlinked – areas of further action that could potentially benefit the evolution of the UK’s distinct basic strategic approach in this subject area:[73]

- the continuous development of domestic guidelines addressing space debris issues, especially in light of the increasing number of space debris related international norms and best practices, liability issues, defence sector involvement, non-governmental actors striving for certainty in their subject area related engagements and the development of an increasing number of removal and mitigation technologies that might have dual-use potential;[74]
- the advancement and streamlining of reliable and reasonable domestic and international space debris regulations, taking into account the need to avoid domestic requirements getting too burdensome so as to drive potential space activities elsewhere (flag of convenience approach)[75] and the “need for differentiated degrees of responsibility in the clearing of space debris, in line with the space activities of each Member State”;[76]
- the clarification of the UK’s preferred future role in the space environment branches of ESA’s Clean Space initiative;
- the determination and implementation of further domestic and international surveillance and data exchange mechanisms, especially as the UK loses access to EUSST, and due to its dependence on the US and the defence sector involvement;
- the determination and implementation of a sound domestic and international mechanism for the development of and the provision of access to removal and mitigation technologies; and

72 ICL (n 10) 6–7; regarding the Smart Society theme, artificial intelligence and machine learning might be able to assist in activities such as active debris removal: Jessica, ‘Artificial intelligence challenged to help catch derelict satellites’ (*ESA*, 15 May 2019) <https://blogs.esa.int/cleanspace/2019/05/15/artificial-intelligence-challenged-to-help-catch-derelict-satellites/> accessed 16 March 2020. For more information, see this Study’s Report on Imperial College London Space Safety Capabilities and Expertise.

73 The following points are a selection and emerge from information presented in this Study’s Report on State of UK Space Safety Policy, in interviews with policymakers/stakeholders and ICL academic staff in February and March 2020, as well as in the further referenced material. This Study does not claim completeness. Much more thoughts and ideas are promoted in the literature. For some further reading, see the said Report’s Section 8.

74 Concerning such technologies, see e.g.: Jason L Forshaw and others, ‘The active space debris removal mission RemoveDebris. Part 1: From concept to launch’ (2020) 168 Acta Astronautica 293, 294; James Alver, Andrew Garza and Christopher May, ‘An Analysis of the Potential Misuse of Active Debris Removal, On-Orbit Servicing, and Rendezvous & Proximity Operations Technologies’ (Capstone Project for the conferral of Master of Arts, Int’l Science and Technology Policy (Space Policy), The George Washington University and SWF, 06 May 2019) <https://swfound.org/media/206800/misuse_commercial_adr_oos_jul2019.pdf> accessed 30 March 2020; C Priyant Mark and Surekha Kamath, ‘Review of Active Space Debris Removal Methods’ (2019) 47 Space Policy 194; Zachary Keck, ‘Space Is Truly the Final Frontier (For the Next Great War)’ (*The National Interest*, 17 June 2018) <https://nationalinterest.org/blog/the-buzz/space-truly-the-final-frontier-the-next-great-war-26284> accessed 30 March 2020.

75 Fisch (n 40) 58–59.

76 Citation in: UNGA ‘Report of the Committee on the Peaceful Uses of Outer Space. Sixty-second session (12-21 June 2019)’ (2019) UN Doc A/74/20 18.

- the increased raising of awareness about space debris issues, including by conducting further studies, and the active discouragement of identified or presumed related problematic space activities,[77] as they gain special relevance with increasing number of new parties joining the space sector and new mission concepts potentially involving a high collision risk are created, such as automated on-orbit servicing and the deployment of small satellite mega-constellations.[78]

4.3 Planetary Defence[79]

4.3.1 Current state[80]

In relation to the Space Safety subject area of Planetary Defence, the available material allows inferring that the UK has the policy directions of:

a) improving the UK's available space surveillance capabilities and capacities to detect, track, identify, analyse, catalogue and predict NEOs and associated hazards; and

b) developing capabilities and capacities to solve or at least mitigate such hazards.

The following points can be considered to form part of the UK's related basic strategic approach:

- promoting international engagement to establish the relevant capabilities and capacities.[81] For example, UKSA is a member of the Space Mission Planning Advisory Group[82] (SMPAG). Such membership also indicates a link between UKSA and the International Asteroid Warning Network[83] (IAWN), an ex officio member of SMPAG.[84] Moreover, some UK entities have a reported involvement in ESA's S2P Planetary Deference topic area related Hera mission[85]

77 ibid.

78 Concerning the space debris challenges in the context of mega-constellations, see e.g.: Jonathan O'Callaghan, 'The Risky Rush for Mega Constellations' (*Scientific American*, 31 October 2019) <https://www.scientificamerican.com/article/the-risky-rush-for-mega-constellations/> accessed 27 March 2020.

79 Future researchers concerning this subject area might benefit from a look at this link: Karel A van der Hucht, 'Near Earth Asteroids (NEAs). A Chronology of Milestones 1800 - 2200' (*ESA*, 2 February 2020) <http://neo.ssa.esa.int/neo-chronology> accessed 24 February 2020.

80 For more information, see this Study's Report on State of UK Space Safety Policy.

81 Conclusion based on an interview with a policymaker/stakeholder in February 2020, the examples listed in the next few lines, as well as the following comment by a UKSA spokesperson in 2013: 'The European Space Agency does address NEOs on behalf on its Member States...as it recognises they are a global hazard, not unique to any country and that they require an international response.' Sarah Griffiths, 'A one-man mission to save the WORLD: Retired Welshman monitors Armageddon asteroids from his DIY observatory' (*Mail Online*, 31 October 2013) <https://www.dailymail.co.uk/sciencetech/article-2480862/A-man-mission-save-WORLD-Retired-Welshman-monitors-Armageddon-asteroids-DIY-observatory.html> accessed 12 March 2020.

82 'Space Mission Planning Advisory Group' (*ESA*) <https://www.cosmos.esa.int/web/smpag> accessed 25 February 2020.

83 'International Asteroid Warning Network' (*IAWN*) <http://iawn.net/> accessed 25 February 2020.

84 Drawing on information presented in: Romana Kofler and others, 'International coordination on planetary defence: The work of the IAWN and the SMPAG' (2019) 156 Acta Astronautica 409; SMPAG, 'Space Mission Planning Advisory Group Work Plan' (SMPAG—PL-001/13, SMPAG, October 2017) <https://www.cosmos.esa.int/documents/336356/336472/SMPAG-PL-001_1_3_Workplan_11_October_2017.pdf> accessed 25 February 2020.

85 Massimiliano Vasile, 'Task 5.2 and UK Activities' (Presentation, SMPAG Meeting #14, 57th UNCOPUOS STSC, Vienna, Austria, 6 February 2020) 5-6[unpaginated] <https://www.cosmos.esa.int/documents/336356/336472/UK_Task+5_-_Vasile_2020-02-06.pdf> accessed 25 February 2020.

and Comet Interceptor mission.[86] Furthermore, some current EU funded Planetary Defence related projects such as Stardust-R,[87] NEOROCKS[88] and NEOShield-2[89] include UK participants;

- promoting the involvement of and government engagement with industry, academia and defence personnel in building capability and capacity; and
- supporting work addressing regulatory challenges and adoption of predictable and proportionate regulations.[90]

4.3.2 Potential for ICL contribution

ICL has technical capabilities and expertise that, if brought together systematically under a transparent organisational framework, provide a foundation to expand its contribution of reliable evidence based information to UK Space Safety Policy (including Strategy) development in the Planetary Defence subject area. ICL technical capabilities and expertise in this subject area are demonstrated by some involvement in ESA's Hera mission and the National Aeronautics and Space Administration (NASA)'s DART (Double-Asteroid Redirection Test) mission, both linked to the NASA funded AIDA (Asteroid Impact and Deflection Assessment) mission aimed to demonstrate the deflection of an asteroid.[91] ICL will also contribute to ESA's recently selected Comet Interceptor mission.[92] ICL and the University of Glasgow further collaborate on the UK Fireball Network designed to track meteorites before they land on UK soil, as well as to subsequently recover them.[93] UKRI has funded some NEO impact related research projects by the Department of Earth Science and Engineering.[94] Additionally, ICL has at least one staff member who was part of the government funded UK Near Earth Object Information Centre, operational from 2002 to 2012[95].[96] Withal, ICL has expertise on cosmic dust that

86 Detlef Koschny, 'How the European Space Agency Does Planetary Defense' (*The Planetary Society*, 27 September 2019) <https://www.planetary.org/blogs/guest-blogs/2019/planetary-defense-in-esa.html> accessed 24 February 2020; Andrew Youngson, Caroline Brogan and Hayley Dunning, 'Comet chasing and Animal AI: News from the College' (*ICL*, 5 July 2019) <https://www.imperial.ac.uk/news/191889/comet-chasing-animal-ai-news-from/> accessed 28 March 2020; Emily Lakdawalla, 'ESA to Launch Comet Interceptor Mission in 2028' (*ESA*, 21 June 2019) <https://www.planetary.org/blogs/emily-lakdawalla/2019/esa-to-launch-comet-interceptor.html> accessed 24 February 2020.

87 'A European research project to explore and exploit asteroids and make the use of space sustainable.' 'Stardust-R. The H2020 Space Debris and Asteroid research network' (*Stardust Network*) <http://www.stardust-network.eu/> accessed 25 February 2020.

88 Vasile (n 85) 5.

89 'Funding by the European Commission (EU)' (*neoshield.eu*) <https://www.neoshield.eu/science-technology-asteroid-impact/research-funding-eu/> accessed 30 March 2020; 'The Team' (*neoshield.eu*) <https://www.neoshield.eu/science-technology-asteroid-impact/dlr-airbus-paris-surrey-aerospace/> accessed 24 February 2020.

90 The last two bullet points build on NSP and NSSP derivable strategic elements directed towards SSA or the space sector in general. Such elements were already indicated in the context of the basic strategic approach concerning the Space Debris subject area.

91 Vasile (n 85) 6[unpaginated]; Detlef Koschny and Ian Carnelli, 'Hera mission. Status update' (Presentation, SMPAG Meeting #14, 57th UNCOPUOS STSC, Vienna, Austria, 6 February 2020) <https://www.cosmos.esa.int/documents/336356/336472/Hera_status_-_Koschny_2020-02-06+(2).pdf> accessed 25 February 2020; Koschny (n 86); 'Spacecraft' (*ESA*) <https://www.esa.int/Safety_Security/Hera/Spacecraft2> accessed 24 February 2020. The first link indicates the ICL involvement.

92 Koschny (n 86); Youngson, Brogan and Dunning (n 86); Lakdawalla (n 86). Information about ICL involvement provided by an ICL academic staff member in March 2020, as well as under the second link.

93 Sarah McMullan, ICL Department of Earth Science and Engineering, is a co-lead researcher: Caroline Brogan, 'Meteorite observation network sets out to catch a falling star' (*ICL*, 4 March 2020) <https://www.imperial.ac.uk/news/195873/meteorite-observation-network-sets-catch-falling/> accessed 16 March 2020.

94 For example: '3D Numerical Modelling of Large, Rapid, Violent Geologic Processes' (*UKRI*) <https://gtr.ukri.org/projects?ref=NE%2FE013589%2F1> accessed 16 March 2020; 'Numerical Modelling of Impact Cratering on Asteroids' (*UKRI*) <https://gtr.ukri.org/projects?ref=studentship-1839044> accessed 16 March 2020; 'Numerical Modelling of Meteoroid Airbursts and Blastwaves' (*UKRI*) <https://gtr.ukri.org/projects?ref=studentship-1841370> accessed 16 March 2020; Professor Collins has had a strong involvement in these projects: 'Professor Gareth Collins' (*ICL*) <https://www.imperial.ac.uk/people/g.collins> accessed 16 March 2020.

95 Griffiths (n 81).

96 Iwan P Williams, 'The UK Near Earth Object Information Centre (NEOIC)', *Proc. of the International Astronomical Union Symposia and Colloquia 236 'Near Earth Objects, our Celestial Neighbors: Opportunity and Risk'* (IAU 2006) 474 <https://www.cambridge.org/core/services/aop-cambridge-core/content/view/S1743921307003602> accessed 26 February 2020; this staff member is: 'Dr Matthew Genge' (*ICL*) <https://www.imperial.ac.uk/people/m.genge> accessed 16 March 2020.

can be a risk factor to satellites and increase in volume around Earth with the passing of a NEO.[97] Besides that, ICL also previously conducted NEO related outreach activities,[98] and a member of ICL Centre for Languages, Culture and Communication published an article on “Negotiating Uncertainty: Asteroids, Risk and the Media”.[99] Furthermore, technical capabilities and expertise pointed out under the various research themes of the following ICL departments might have some potential to generate evidence based information relevant to this subject area:[100]

• Department of Aeronautics	• Department of Mathematics
• Department of Computing	• Dyson School of Design Engineering
• Department of Earth Science and Engineering	• Imperial College Business School

Engagement in this subject area is also consistent with elements of the ICL Academic Strategy 2020-2025 themes of ‘Sustainable Society’ and ‘Resilient Society’.[101]

Altogether, evidence based information derived from these technical capabilities and expertise could, for example, assist in formulating UK policy objectives and their narrative in this subject area in an easily comprehensible manner. Strategy-wise, it can help to advance UK international engagement to establish the relevant Planetary Defence capabilities and capacities, as well as contribute to work towards the creation of appropriate norms and practices, as referred to in Section 4.3.1.

Finally, such information can deliver valuable input concerning the following – interlinked – areas of further action that could potentially benefit the evolution of the UK’s distinct basic strategic approach in this subject area:[102]

- the development of an authoritative definition of NEOs to be tackled under Planetary Defence, also considering cosmic dust;
- the systematic selection of appropriate mitigation or deflection measures, tacking into account the potentially significant resource and preparation time requirements domestically and internationally, including through ESA and with the EU,[103] as well as the dual-use potential of the involved technology;
- the clarification of the UK preferred future role in ESA’s S2P Planetary Defence topic area, SMPAG and IAWN;

97 Based on an interview with an ICL academic staff member in February 2020. Also, see the research activities of Dr Matthew Genge: ‘Dr Matthew Genge’ (n 96); this hazard to satellites is further indicated in: ‘Space dust kills satellites like tiny atom bombs’ (*The Economist*, 17 August 2017) <https://www.economist.com/science-and-technology/2017/08/17/space-dust-kills-satellites-like-tiny-atom-bombs> accessed 16 March 2020.

98 Colin Smith, ‘11 tips for viewing and collecting asteroid fragments’ (*ICL*, 30 June 2017) <https://www.imperial.ac.uk/news/180289/11-tips-viewing-collecting-asteroid-fragments/> accessed 16 March 2020; Colin Smith, ‘Imperial researchers support asteroid awareness day’ (*ICL*, 30 June 2017) <https://www.imperial.ac.uk/news/180291/imperial-researchers-support-asteroid-awareness/> accessed 16 March 2020; involved ICL academic staff members were, e.g.: ‘Dr Clements’ (*ICL*) <https://www.imperial.ac.uk/people/d.clements> accessed 3 March 2020; ‘Dr Wren Montgomery’ (*ICL*) <https://www.imperial.ac.uk/people/w.montgomery> accessed 30 March 2020; ‘Foster, Dr Simon S’ (n 70); ‘Professor Gareth Collins’ (n 94).

99 Felicity Mellor, ‘Negotiating Uncertainty: Asteroids, Risk and the Media’ (2010) 19 Public Understanding of Science 16; ‘Dr Felicity Mellor’ (*ICL*) <https://www.imperial.ac.uk/people/f.mellor> accessed 16 March 2020.

100 For more information, see this Study’s Report on Imperial College London Space Safety Capabilities and Expertise.

101 ICL (n 10) 6–7. For more information, see this Study’s Report on Imperial College London Space Safety Capabilities and Expertise.

102 The following points are a selection and emerge from information presented in this Study’s Report on State of UK Space Safety Policy, in interviews with policymakers/stakeholders and ICL academic staff in February and March 2020, as well as in the further referenced material. This Study does not claim completeness. Much more thoughts and ideas are promoted in the literature. For some further reading, see the said Report’s Section 8.

103 Somewhat indicated in: Kofler and others (n 84).

- the advancement of NEO observation capabilities and related database-building domestically and internationally. After all, "[t]o date, more than 90% of objects with diameters larger than 1 km have been discovered, but this figure drops to only 10% when considering 100 m-sized objects, any one of which would be many times more destructive if they hit Earth than the Tunguska or Chelyabinsk events";[104]
- the increased building of public awareness, including by conducting further studies, to avoid misunderstandings and turmoil in the case of a severe event; and
- the development of a fully-fledged UK severe NEO strike preparedness strategy similar to severe space weather events, despite the low probability of such strikes. Fatalities and environmental and socioeconomic impact might be great.

4.4 Space Weather[105]

4.4.1 Current state[106]

In relation to the Space Safety subject area of Space Weather,[107] the UK government's policy directions can be inferred from a combined reading of NSP, NSSP and the Space Weather Preparedness Strategy in its Version 2.1 (SWPS2.1). In short, this Study concludes that the UK government presently has the policy direction of:

a) improving the UK's available capabilities and capacities to identify, monitor, assess and predict space weather and its associated hazards[108] with the potential to disrupt, degrade or damage the UK's available terrestrial and space based infrastructure and services, with a special focus on those elements with significance to the UK's national security and socioeconomic development and welfare; and
b) building national resilience capabilities and capacities to such hazards.[109]

The following can be considered to form part of the UK's basic strategic approach concerning these policy directions:

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104 Citation in: 'SSA Programme overview' (n 5).

105 Researchers who are new to this topic might benefit particularly from a look at the following ESPI report: Marco Aliberti and Wells Leyton, 'European Space Weather Services: Status and Prospects' (ESPI Report 68, ESPI, February 2019) <https://espi.or.at/publications/espi-public-reports/send/2-public-espi-reports/414-european-weather-services-status-and-prospects> accessed 21 February 2020.

106 For more information, see this Study's Report on State of UK Space Safety Policy.

107 With no authoritative domestic or international legal definition of space weather and its associated hazards, a look at SWPS2.1 suggests that the UK government's presently politically approved delineation of space weather is to consider it as a consequence of solar activity. Hazard-wise, the government recognises three solar activity components as to deserve special attention due to their potential to create considerable negative socioeconomic or national security impacts: Coronal Mass Ejections (CMEs); solar flares; and solar energetic particles. Solar wind is also recognised as another substantial space weather component. However, solar wind "does not impact the Earth by itself and therefore [… SWPS2.1] include[s] this in reference to CMEs." Some examples for negative impacts are electrical power loss, transportation disruption, e.g. in aviation, telecommunication loss, and the disturbance or loss of satellite systems, which might provide, e.g., navigation or communications services. Cabinet Office and BIS, 'Space Weather Preparedness Strategy. Version 2.1' (BIS/15/457, Cabinet Office and BIS, July 2015) 1,5-7,IV(Annex D) <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/449593/BIS-15-457-space-weather-preparedness-strategy.pdf> accessed 17 January 2020. Citation in footnote on p.6; this is supported by information in: 'What is space weather?' (*Met Office*) <https://www.metoffice.gov.uk/weather/learn-about/space-weather/what-is-space-weather> accessed 14 January 2020.

108 This Study's research suggests that the UK government generally understands 'hazards' as to be non-malicious. The government usually employs the term 'threat' to point towards malicious intent. Some indicators are the references to hazards and threats in: HM Government (n 45) 9; also, according to a POSTbrief by Stock and Wentworth, a hazard 'generally refers to any "natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources"': Stock and Wentworth (n 48) 3.

109 HM Government (n 45) 7-9,11-12; HM Government (n 46) 3-4,7,10,13-14,17; various references in SWPS2.1 also support this conclusion: Cabinet Office and BIS (n 107) 5,17-18,I(Annex A).

- promoting the development and application of space weather surveillance and forecasting capabilities and capacities available to the UK, as well as creating response plans, protective technical measures, alternatives and fall-back options against space weather hazards, including on the infrastructure and service operator and owner side;
- promoting involvement of and government engagement with industry, academia and defence personnel in building capability and capacity;
- avoiding inadvertently creating new vulnerabilities to space weather;
- improving public awareness to space weather hazards;
- supporting work addressing regulatory challenges and adoption of predictable and proportionate regulations;
- dealing with relevant orbital slot allocation and spectrum management;
- bolstering and entering into international collaborations as much as reasonable, while acting nationally when required, e.g. to protect certain national security interests.[110]

Strategically, SWPS2.1 further reveals that the UK government is especially concerned to prepare for and be able to respond to the demands of a severe space weather event.[111] The government's accepted baseline, or 'reasonable worst case scenario', for a severe space weather event is the Carrington Event[112] of 1859 that encompassed some of the largest space weather phenomena on record. The government is aware that not all strategically considered impacts of such an event are necessarily known, proven, tested or fully understood yet.[113] Resilience oriented strategic measures shall particularly address the Critical National Infrastructure (CNI).[114]

Prominent current government promoted domestic measures are a £20 million investment through the UKRI Strategic Priorities Fund into the Space Weather Instrumentation, Measurement, Modelling and Risk (SWIMMR) programme[115] and the establishment and continuous improvement of the Met Office Space Weather Operations Centre (MOSWOC). MOSWOC provides 24/7 space weather forecasts and warnings.[116] The Met Office also has a strong international engagement.[117] The UK is one of the main contributors to ESA's S2P Space Weather topic area.[118] The most prominent ESA space weather mission with UK involvement in recent years was the Solar Orbiter satellite, launched in February

110 HM Government (n 45) 8,11-15; Cabinet Office and BIS (n 107) 3,5,17-18; HM Government (n 46) 2-6,13-19.
111 Cabinet Office and BIS (n 107) 5.
112 For some more information about the event, see e.g.: Edward W Cliver and William F Dietrich, 'The 1859 space weather event revisited: limits of extreme activity' (2013) 3 Journal of Space Weather and Space Climate 1; Trudy E Bell and Tony Philipps, 'A Super Solar Flare' (*NASA*, 6 May 2008) <https://science.nasa.gov/science-news/science-at-nasa/2008/06may_carringtonflare> accessed 14 February 2020.
113 Based on information in: Cabinet Office and BIS (n 107) 1,9-10; HM Government (n 46) 10; Cabinet Office, 'National Risk Register of Civil Emergencies. 2012 edition' (Cabinet Office, February 2012) 7 <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/211858/CO_NationalRiskRegister_2012_acc.pdf> accessed 12 February 2020.
114 Cabinet Office and BIS (n 107) 17–18; for more information on CNI, see: 'Critical National Infrastructure' (*Centre for the Protection of National Infrastructure*) <https://www.cpni.gov.uk/critical-national-infrastructure-0> accessed 10 March 2020.
115 '£20 million to accelerate British research into forecasting space weather' (*UKRI*, 24 September 2019) <https://www.ukri.org/news/20-million-to-accelerate-british-research-into-forecasting-space-weather/> accessed 21 February 2020; 'Space Weather Instrumentation, Measurement, Modelling and Risk (SWIMMR)' (*UKRI*) <https://nerc.ukri.org/research/funded/programmes/sfp-swimmr/> accessed 28 March 2020.
116 'The Met Office and space weather' (*Met Office*) <https://www.metoffice.gov.uk/weather/learn-about/space-weather/met-office-role> accessed 20 February 2020.
117 See this Study's Report on State of UK Space Safety Policy.
118 Aliberti and Leyton (n 105) 27–33.

2020.[119] Additionally, the UK contributes 70 million €[120] to ESA's Lagrange mission.[121] Here the focus until the next ESA Ministerial Council meeting in three years is reportedly on instrument development.[122]

4.4.2 Potential for ICL contribution

ICL has technical capabilities and expertise that, if brought together systematically under a transparent organisational framework, provide a foundation to expand its contribution of reliable evidence based information to UK Space Safety Policy (including Strategy) development in the Space Weather subject area. ICL technical capabilities and expertise in this subject area are demonstrated by having several researchers with space weather expertise[123] and currently working on space weather simulations.[124] With funding from UKSA, ICL researchers also assessed economic impacts of space weather.[125] Again with UKSA funding, ICL was responsible for the development of one of the scientific instruments, the magnetometer, on-board ESA's recently launched Solar Orbiter and leads the mission's magnetic field investigation.[126] Moreover, at the end of 2018, a South Korean satellite piggybacked an ESA kit called Service Oriented Spacecraft Magnetometer that includes ICL built sensors and serves space weather monitoring.[127] UKRI has funded various ICL space weather related researches over the past years.[128] ICL is involved in the Strategic Advisory Group of the current UKRI Strategic Priorities Fund supported SWIMMR programme.[129] Additionally, ICL is experienced in public outreach on space weather.[130] Furthermore, technical capabilities and expertise pointed out under the various research themes of

119 'Spacecraft launches to explore the Sun' (*GOV.UK*, 10 February 2020) <https://www.gov.uk/government/news/spacecraft-launches-to-explore-the-sun> accessed 21 February 2020.

120 ESA Council 'Subscription to optional programmes at Space19+ Council meeting at ministerial level' (2 December 2019) ESA Doc ESA/C-M(2019)100, rev.6 9.

121 'UK teams complete space weather mission study ahead of selection decision in November' (*GOV.UK*, 10 October 2019) <https://www.gov.uk/government/news/uk-teams-complete-space-weather-mission-study-ahead-of-selection-decision-in-november> accessed 21 February 2020.

122 Jeff Foust, 'ESA declares success at ministerial meeting' (*SpaceNews*, 28 November 2019) <https://spacenews.com/esa-declares-success-at-ministerial-meeting/> accessed 21 February 2020.

123 E.g.: 'Dr Jonathan P. Eastwood' (*ICL*) <https://www.imperial.ac.uk/people/jonathan.eastwood> accessed 17 March 2020; 'Professor Timothy Horbury' (*ICL*) <https://www.imperial.ac.uk/people/t.horbury> accessed 17 March 2020; 'Dr Enrico Biffis' (*ICL*) <https://www.imperial.ac.uk/people/e.biffis> accessed 17 March 2020.

124 'Space Weather Simulation' (*ICL*) <https://www.imperial.ac.uk/space-and-atmospheric-physics/research/areas/space-weather/> accessed 17 March 2020.

125 JP Eastwood and others, 'Quantifying the economic value of space weather forecasting for power grids: an exploratory study' (2018) 16 Space Weather 2052; JP Eastwood and others, 'The Economic Impact of Space Weather: Where Do We Stand?' (2017) 37 Risk Analysis 206.

126 'Spacecraft launches to explore the Sun' (n 119); 'Solar Orbiter' (*ICL*) <https://www.imperial.ac.uk/a-z-research/space-and-atmospheric-physics/research/missions-and-projects/space-missions/solar-orbiter/> accessed 17 March 2020.

127 Hayley Dunning, 'First "piggyback" kit for monitoring space weather launched' (*ICL*, 4 December 2018) <https://www.imperial.ac.uk/news/189372/first-piggyback-monitoring-space-weather-launched/> accessed 17 March 2020.

128 E.g.: 'Imperial College Astrophysics & Space Physics Consolidated Grant April 2013 - March 2016' (*UKRI*) <https://gtr.ukri.org/projects?ref=ST%2FK001051%2F1> accessed 17 March 2020; 'Magnetic Reconnection as a Universal Plasma Process: Investigating Onset, Energy Release and Particle Acceleration' (*UKRI*) <https://gtr.ukri.org/projects?ref=ST%2FG00725X%2F1> accessed 17 March 2020; 'Modelling the acceleration, transport and loss of radiation belt electrons to protect satellites from space weather (Rad-Sat)' (*UKRI*) <https://gtr.ukri.org/projects?ref=NE%2FP017347%2F1> accessed 17 March 2020; 'Space and planetary physics' (*UKRI*) <https://gtr.ukri.org/projects?ref=ST%2FN000692%2F1> accessed 17 March 2020; 'Space and planetary physics 2019-2022' (*UKRI*) <https://gtr.ukri.org/projects?ref=ST%2FS000364%2F1> accessed 17 March 2020; 'Space Weather Impacts on Ground-based Systems (SWIGS)' (*UKRI*) <https://gtr.ukri.org/projects?ref=NE%2FP017142%2F1> accessed 17 March 2020; 'Turbulent Heating of Space Plasmas' (*UKRI*) <https://gtr.ukri.org/projects?ref=ST%2FN003748%2F1> accessed 17 March 2020.

129 Concerning the programme, see: 'Space Weather Instrumentation, Measurement, Modelling and Risk (SWIMMR)' (n 115). The information about the Group membership was provided by an ICL academic staff member in March 2020.

130 E.g.: 'Carrington: The Next Generation Space Weather Mission' (*ICL*) <https://www.imperial.ac.uk/events/104888/carrington-the-next-generation-space-weather-mission/> accessed 17 March 2020; 'Solar Storms and Space Weather' (*ICL*) <https://www.imperial.ac.uk/events/108215/solar-storms-and-space-weather/> accessed 17 March 2020; 'Space Weather: the importance of observations' (*ICL*) <https://www.imperial.ac.uk/events/107405/space-weather-the-importance-of-observations/> accessed 17 March 2020.

the following ICL departments might have some potential to generate evidence based information relevant to this subject area:[131]

• Department of Computing	• Department of Physics
• Department of Electrical and Electronic Engineering	• Dyson School of Design Engineering
• Department of Mathematics	• Imperial College Business School

Engagement in this subject area is also consistent with elements of the ICL Academic Strategy 2020-2025 theme of 'Resilient Society'.[132]

Altogether, evidence based information derived from these technical capabilities and expertise could, for example, assist in formulating UK policy objectives and their narrative in this subject area in an easily comprehensible manner. Strategy-wise, it can contribute to all elements of the UK basic strategic approach introduced in Section 4.4.1.

Finally, such information can deliver valuable input concerning the following – interlinked – areas of further action that could potentially benefit the evolution of the UK's distinct basic strategic approach in this subject area:[133]

- the inclusion of space weather components that are not related to the Sun such as galactic cosmic rays;[134]
- the further evaluation of space weather impacts on existing and emerging UK space assets, including concerning space objects using solar electric propulsion for orbit raising to geostationary that requires passing through the radiation belts, making such space objects much more exposed to space weather effects;
- the systematic selection and promotion of appropriate mitigation measures, with a view to the fact that impacts of events may vary and different assets may be affected differently;
- the development of detailed response plans to space weather events that might be less severe in speed and size than Carrington-style events. Reliable responses should also require domestic mechanisms that are tested regularly and ensure the continued monitoring of impacts of space weather events throughout the full disaster management cycle;
- the clarification of the UK's preferred future role in ESA's S2P Space Weather topic area, as well as other international space weather coordination mechanisms, taking into account the potential for synergies and the avoidance of unnecessary overlaps, as well as the proliferation of mitigation technology to technologically less advanced parties in the space sector, e.g. for the benefit of developing states and to reduce space debris creation through space weather events;
- the further advancement of cross-national data exchange; and

131 For more information, see this Study's Report on Imperial College London Space Safety Capabilities and Expertise.
132 ICL (n 10) 7. For more information, see this Study's Report on Imperial College London Space Safety Capabilities and Expertise.
133 The following points are a selection and emerge from information presented in this Study's Report on State of UK Space Safety Policy, in interviews with policymakers/stakeholders and ICL academic staff in February and March 2020, as well as in the further referenced material. This Study does not claim completeness. Much more thoughts and ideas are promoted in the literature. For some further reading, see the said Report's Section 8.
134 'About space weather' (*ESA*) <http://swe.ssa.esa.int/what-is-space-weather> accessed 14 January 2020.

- the increased building of public awareness, including by conducting further studies,[135] regarding socioeconomic impacts of space weather to enhance UK government and business preparedness to space weather events.

4.5 Space Traffic Management[136]

4.5.1 Current state[137]

According to the often cited definition by the International Academy of Astronautics, STM "means the set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space and return from outer space to Earth free from physical or radio-frequency interference." Existing provisions that fit under this umbrella but arguably do not constitute a mature system are, among others, Space Situational Awareness (SSA) data-sharing agreements, space debris mitigation guidelines, various industry standards and best practices, space object registration, licensing requirements and ITU radio-frequency regulations. However, as the European Space Policy Institute (ESPI) rightly observes, "[t]here are probably as many definitions of STM as there are organizations and experts addressing the concept. [… Overall], there is no international consensus today on a characterization and delimitation of STM, leaving significant margin to adapt the concept to the various views and needs of different organizations."[138]

Ultimately, this Study concludes that the UK has no identifiable policy directions and related basic strategic approach in the STM subject area.[139] Nonetheless, with varying interpretations of the best scope among them, the UK government and non-governmental actors seem to agree that a mature global STM system will be beneficial to address challenges and increase certainty in the stable use of outer space for all. For one, this is indicated by input from various policymakers and others interested, including from industry and academia, during interviews in the context of this Study.[140] Furthermore, the UK government intends to take practical steps to implement the LTS Guidelines.[141] Moreover, there are some institutions with involvement of UK entities that could serve the development of a mature global STM system, such as the Consultative Committee for Space Data Systems[142] (CCSDS), the Consortium for

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135 Such future studies can build on, e.g.: Eastwood and others, 'Quantifying the economic value of space weather forecasting for power grids: an exploratory study' (n 125); Eastwood and others, 'The Economic Impact of Space Weather: Where Do We Stand?' (n 125).

136 Researchers who are new to this topic might benefit particularly from a look at the following ESPI report: Sebastien Moranta, Tomas Hrozensky and Marek Dvoracek, 'Towards a European Approach to Space Traffic Management' (ESPI Report 71, ESPI, January 2020) <https://espi.or.at/publications/espi-public-reports/send/2-public-espi-reports/494-espi-report-71-stm> accessed 17 March 2020.

137 For more information, see this Study's Report on State of UK Space Safety Policy.

138 Concerning the citations, see: Moranta, Hrozensky and Dvoracek (n 136) 3,6.

139 If treated generously, the closest that it might have come to those is in NSP by stating that "[t]he UK will continue to play a leading role in promoting a sustainable, safe, secure and peaceful space environment, especially working through [… UNCOPUOS]. […] Nations around the world have to share the space environment. […] The Government is committed to further developing Transparency and Confidence Building Measures in Outer Space as outlined in the 2013 report of the United Nations Group of Governmental Experts and promoting norms of responsible behaviour that could contribute to the international legal framework of Space activities. Through its work in international fora such as the United Nations General Assembly, the Conference on Disarmament and the G7 [(Group of Seven)] the UK will continue to promote the rule of law and its application to the Space domain." HM Government (n 45) 11,14-15; NSSP has a similar notion: HM Government (n 46) 16–18.

140 Interviews with policymakers/stakeholders and ICL academic staff in February and March 2020. Also, the British High Commissioner to Singapore recently stated: 'Starlink and OneWeb mega constellation satellites start to be launched in to space; these cause us to take a second look at space traffic management': 'Speech. Enabling the safe, secure and sustainable use of Outer Space' (*GOV.UK*, 15 January 2020) <https://www.gov.uk/government/speeches/enabling-the-safe-secure-and-sustainable-use-of-outer-space> accessed 31 March 2020.

141 'UK General Statement, Scientific and Technical Sub-Committee of COPUOS' (n 25).

142 'The Consultative Committee for Space Data Systems' (*CCSDS*) <https://public.ccsds.org/default.aspx> accessed 30 March 2020.

Execution of Rendezvous and Servicing Operations[143] (CONFERS), the European Cooperation for Space Standardization[144] (ECSS), UKRI funded The Global Network on Sustainability in Space[145] (GNOSIS), IADC,[146] ISO,[147] ITU,[148] the Space Data Association[149] (SDA), the Space Frequency Coordination Group[150] (SFCG) and the Space Safety Coalition[151] (SSC).[152] Also, UK engagement falling under the Space Debris, Planetary Defence and Space Weather subject areas could contribute to such development.[153] Withal, there is an extensive library of material produced by UK and partner states' academics and space sector professionals addressing the various aspects of STM.[154] That being said, domestic and international discussions on STM are on-going and the final outcome cannot be foreseen.[155]

4.5.2 Potential for ICL contribution

ICL has technical capabilities and expertise that, if brought together systematically under a transparent organisational framework, provide a foundation to expand its contribution of reliable evidence based information to UK Space Safety Policy (including Strategy) development in the STM subject area. ICL technical capabilities and expertise in this subject area are demonstrated by various departments understanding safety issues in the design of space technology, as well as conducting work related to operationally important areas like transport, communications, control, robotics, autonomous systems, rocketry, reusability, satellite de-tumbling, mission planning, space debris, space weather and NEOs. Also, they have the expertise to inform the development of, e.g., space related industry standards and best practices. Moreover, there is an awareness that certain new mission concepts like small satellite mega-constellations can interfere with astronomy or be potentially affected by astronomy tools. Notably, this study has come across a Student in the MSc Transport and Business Management programme who is interested in writing an STM related thesis.[156] Overall, expertise pointed out under the various research themes of the following ICL departments could, especially through joint and systematic engagement, have potential to produce evidence based information relevant to this subject area:[157]

• Department of Aeronautics	• Department of Mechanical Engineering
• Department of Civil and Environmental Engineering	• Department of Mathematics
• Department of Computing	• Department of Physics
• Department of Electrical and Electronic Engineering	• Dyson School of Design Engineering

143 'Current Members' (*CONFERS*) <https://www.satelliteconfers.org/members/> accessed 30 March 2020.
144 'ECSS Members' (*ECSS*) <https://ecss.nl/organisation/ecss-members/> accessed 30 March 2020.
145 'The Global Network on Sustainability in Space' (*GNOSIS*) <https://gnosisnetwork.org/> accessed 31 March 2020; 'The Global Network on Sustainability in Space (GNOSIS)' (*UKRI*) <https://gtr.ukri.org/projects?ref=ST%2FS005447%2F1> accessed 30 March 2020.
146 'Inter-Agency Space Debris Coordination Committee' (*IADC*) <https://www.iadc-home.org/> accessed 30 March 2020.
147 Moranta, Hrozensky and Dvoracek (n 136) 71–72.
148 'List of Member States' (*ITU*) <https://www.itu.int/online/mm/scripts/gensel8> accessed 30 March 2020.
149 'Participants' (*SDA*) <https://www.space-data.org/sda/participants/> accessed 30 March 2020.
150 'SFCG Membership' (*SFCG*) <https://www.sfcgonline.org/Members/default.aspx> accessed 30 March 2020.
151 'Endorsees' (*SSC*) <https://spacesafety.org/endorsees/> accessed 30 March 2020.
152 Naturally, this list is not complete. There are many more institutions that could serve STM.
153 For the UK subject area engagement, see the respective sections in this Report and this Study's Report on State of UK Space Safety Policy.
154 For some examples, see Section 8 in this Study's Report on State of UK Space Safety Policy.
155 Findings supported by interviews with policymakers/stakeholders in February and March 2020.
156 Based on interviews with ICL academic staff in February and March 2020. See also this Report's Space Debris, Planetary Defence and Space Weather sections.
157 For more information, see this Study's Report on Imperial College London Space Safety Capabilities and Expertise.

• Department of Materials	• Imperial College Business School

Engagement in this subject area is also consistent with elements of the ICL Academic Strategy 2020-2025 theme of 'Resilient Society'.[158]

Altogether, evidence based information derived from these technical capabilities and expertise can deliver valuable input concerning the following – interlinked – areas of further action that could potentially benefit the evolution of clear UK STM policy objectives, their underlying narrative and a distinct related basic strategic approach:[159]

- the comprehensive deliberation and determination of gaps and priorities, including how much a mature global STM system can and needs to be built on legally binding or non-binding provisions, focus on coordination or control (e.g., akin to Air Traffic Control), require involved parties to have insurance coverage, incorporate a reward and penal system, and include strong organisational oversight and enforcement mechanisms;
- the creation and adoption of consistent domestic and international procedures to discuss, decide on and implement STM, with particular view to shorten timelines to reach consensus, the heavy reliance on the USA in SSA, and the potential involvement of aforementioned institution, e.g. UKRI funded GNOSIS, that could serve the development of a mature global STM system;
- the encouragement of more public engagement and educational activities in developing STM; and
- the further promotion of the development of STM enabling technology and the determination of a mechanism that creates fair access to STM technology and the operational side among all parties in the global space sector.

5 <u>Conclusion</u>

As is clear from this Study's findings as presented in this Final Report, UK Space Safety Policy (including Strategy) is not specifically focused. However, there is varied UK engagement in the various Space Safety subject areas. This provides ICL, through its identified subject area related technical capabilities and expertise, its structural capabilities and capacities as well as its fitting Academic Strategy, with significant opportunities to contribute evidence based information to government for the development of sound UK Space Safety Policy.

Alongside the indicated actions throughout Section 4, ICL also has the standing to rally other actors in the space sector to call upon government to tackle the following systemic desirable areas of further action as they can help interested parties to contribute to UK Space Safety policy (including strategy)-making, including the establishment of clear Space Safety subject area specific policy objectives and the distinct related basic strategic approaches, and its implementation effectively and efficiently:

158 ICL (n 10) 7. For more information, see this Study's Report on Imperial College London Space Safety Capabilities and Expertise.

159 The following points are a selection and emerge from information presented in this Study's Report on State of UK Space Safety Policy and in interviews with policymakers/stakeholders and ICL academic staff in February and March 2020. This Study does not claim completeness. Much more thoughts and ideas are promoted in the literature. For some further reading, see the said Report's Section 8.

- the publication of an official organigram or other official graph outlining UK policy (including strategy)-making regarding each subject area in general, as well as an official procedure that academic actors could follow to contribute proactively to it; and
- the maintenance of an official, continuously updated and easy-to-access government list of its promoted domestic and international strategic measures concerning each subject area, along with information on resource (including funding) allocation.[160]

ICL is well placed to take the next step in playing a more central role to the development of evidence based UK Space Safety Policy. This can be enhanced by coordinated and streamlined efforts that bring relevant ICL departments and researchers together. Organisationally, as indicated in Section 4, ICL already has a framework for that matter through Space Lab and its collaboration with ISPL, presenting a golden opportunity. Thematically, there are multiple options to align ICL Space Safety research engagement. An interesting approach could be coordination around the Grand Challenges,[161] which may appeal to government and provide a route to additional funding.

160 Identified as desirable areas of further action in this Study's Report on State of UK Space Safety Policy.

161 For a starting point, see: 'Policy paper. The Grand Challenges' (*GOV.UK*, 13 September 2019) <https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/industrial-strategy-the-grand-challenges> accessed 31 March 2020.

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