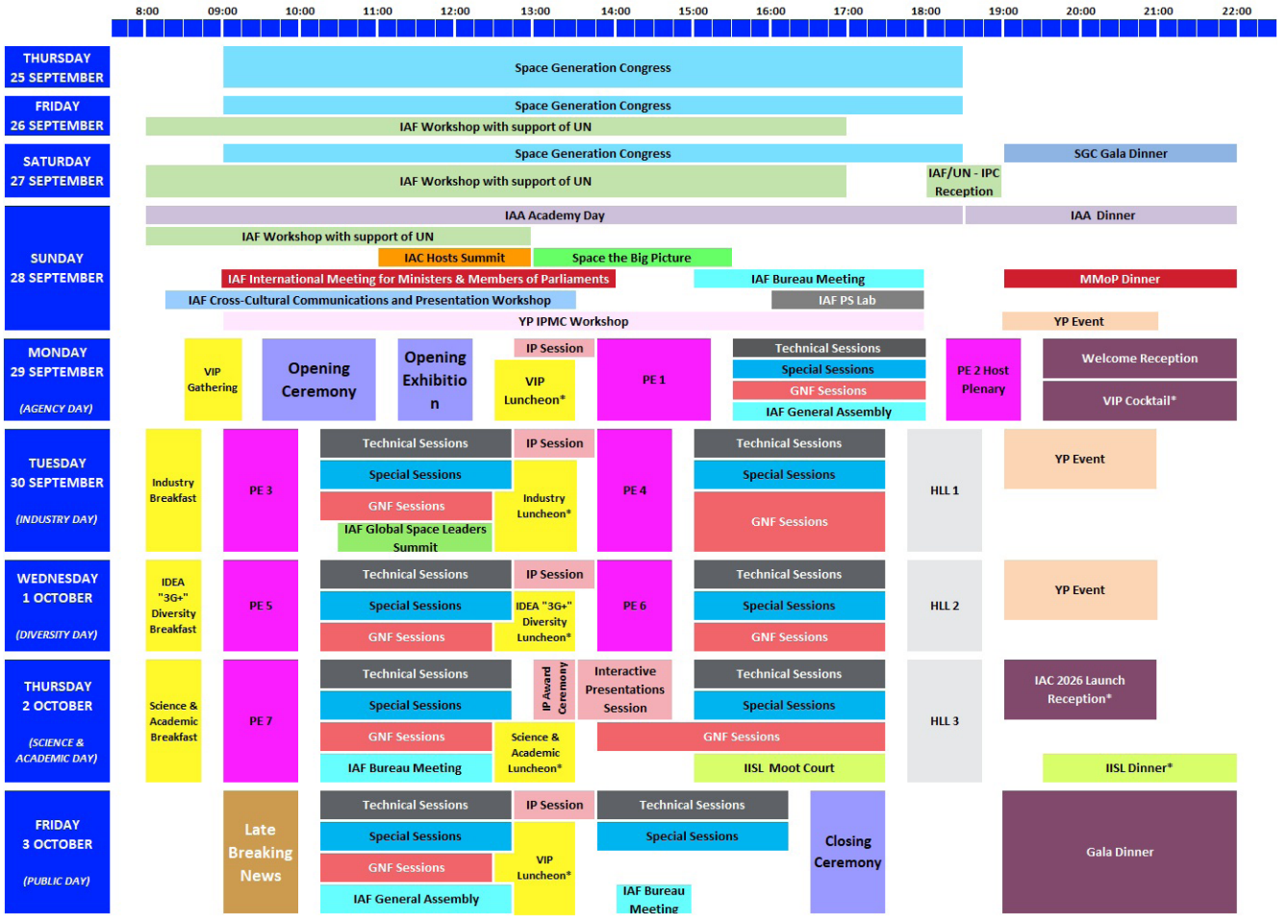
International Astronautical Congress IAC25

Sydney 29 September – 3 October

Announced Interstellar Presentations

Edited by John I Davies



Please Note: *By invitation only; Pre-Congress events as well as the IISL Moot Court are dedicated to the respective participants

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Introduction

This article aims to list all papers announced for IAC25 with relevance to interstellar studies. All information is from programme.
Contact John Davies (john.davies@i4is.org) if you spot any I have missed.
We will report on the papers as delivered in our November and February issues, P51 and P52.
Papers are listed in order of IAC reference.
Each entry is headed –

IAC25 ref	title	author	institution	country

– and is followed by the abstract.

SETI 1: SETI Science and Technology

A4,1,1,x98468	Enhancing the Breakthrough Listen Technosignature Search with Advances in Anomaly Detection	Dr Steve Croft	University California Berkeley	USA

Breakthrough Listen, the planet's most comprehensive search for technosignatures, continues to acquire vast amounts of data from telescopes around the world and in space. Classical techniques have been applied to look for candidate technosignatures, but the enormous data volumes make this challenging, and existing approaches may miss certain types of interesting signals. The Listen program has also employed a variety of anomaly detection techniques that are complementary to existing algorithms. Some of these involve machine learning, whereas others employ novel statistical techniques to find signals missed by the standard pipelines. In other cases we can use new algorithms to vet signals found using classical approaches. I will discuss the use of these algorithms on current and future datasets at optical and radio wave-lengths, how they are being used to constrain the occurrence rate of technosignatures, and synergies with anomaly detection techniques being used in other areas of astronomical observations and engineering.

A4,1,2,x98893	Technosignature Searches with Very Long Baseline Interferometry (Vlbi)	Dr Dong-Jin Kim	CSIRO Astronomy & Space Science	Australia

Recent advances in radio telescope technology, combined with a surge in exoplanet discoveries, have significantly refined the search for extraterrestrial intelligence (SETI). Researchers now integrate machine learning techniques, sophisticated data pipelines, and dedicated observing programs to accelerate radio SETI investigations. In particular, future instruments such as the Square Kilometre Array (SKA) and the next-generation Very Large Array (ngVLA) are expected to further enhance detection capabilities and broaden the scope of these studies. However, SETI faces challenges from numerous human-made radio frequency interference (RFI) signals. To tackle this, Very Long Baseline Interferometry (VLBI) is employed, providing a powerful method to distinguish nearby artificial signals from potential extraterrestrial sources. Specifically, VLBI can filter RFI by analyzing signals across multiple baselines, enabling precise localization and trajectory determination of detected signals. This approach was demonstrated using the Long Baseline Array (LBA). Our project includes characterizing planetary satellite signals, conducting wide-band VLBI surveys of exoplanets in habitable zones, and performing follow-up VLBI observations of promising SETI candidates initially identified by Breakthrough Listen surveys. A notable example is the VLBI observation of signals from multiple satellites at X-band. The fluctuating phase and delay rates, driven by the satellites' motion, show how VLBI can effectively rule out RFI sources within a few hundred astronomical units of Earth. To support these efforts, we have developed specialized data reduction and analysis pipelines tailored for VLBI-based SETI observations. These pipelines are expected to play a key role in future high-sensitivity surveys, advancing the search for extraterrestrial intelligence with unprecedented precision and reliability.

A4,1,3,x103208	Breakthrough Listen Search for Intelligent Life Towards the Galactic Center and Plane	Ms Karen Perez	Columbia University	USA

The discovery of nearly 6,000 exoplanets over the last decade has increased the possibility of life beyond Earth and motivated the continued Search for Extra-Terrestrial Intelligence (SETI). Breakthrough Listen (BL) is a 10-yr initiative conducting the most sensitive and comprehensive search for advanced civilizations to date, with the Galactic Center (GC) and Galactic Plane (GP) as two primary observational targets to search for artificial signals from ETIs. The GC has the highest number density of stars within the Galaxy and its line-of-sight offers the largest integrated Galactic star count of any direction in the sky. Additionally, it is widely cited as a possible location for a beacon built by advanced intelligence, and is the Milky Way's most energetic region. Likewise, the GP is an ideal direction to search for such signals due to the increased likelihood that transmitters would emit toward this region as opposed to random directions. Given the potential for discovery in the GC region, the BLGC survey is covering 700 MHz to 93 GHz using the Parkes Telescope, Green Bank Telescope (GBT), and the Sardinia Radio Telescope (SRT). In total, we will conduct 350 hours with the Parkes, 267 hours with the GBT, and 150 hours with the SRT; to date, 33% of these observations have been completed and 13% analyzed. This is the most extensive SETI survey of the GC to date. In addition to the search for technosignatures, the GC is a rich target for natural astrophysical phenomena, such as pulsars orbiting the central super-massive black hole, Sgr A*, and exotic systems like millisecond pulsars in binaries with black holes. Following Phase I of the BLGC survey (Gajjar et al 2021), I will present updates on our progress, current coverage, projected timelines, and ongoing analysis for various kinds of narrowband and broadband signals, including channel-wide periodic

signals with BLIPPS (Suresh et al 2023) and artificially dispersed broadband bursts using SPANDAK (Gajjar et al 2022). Notably, our 1-hour scans represent the longest continuous integrations ever used for SETI. This GC survey complements and extends the BL GP survey conducted with the Parkes Telescope 21 cm Multibeam receiver, which covered roughly 3,000 square degrees during 1,200 hours, and will also be briefly discussed here (Perez et al. 2025, in prep.)

A4,1,4,x96981	First results of the LOw Frequency pulsar, FRB, and Technosignature Survey	Mr Owen Johnson	Trinity College Dublin	Ireland

The search for technosignatures – evidence of extraterrestrial life – addresses one of the most profound questions in science: Are we alone in the Universe? Concurrently, the recent flourishing of the field of radio transients has significantly advanced our understanding of various areas of physics. Notably, pulsars and fast radio bursts (FRBs) stand out due to their unique potential to uncover new kinds of physics. These astrophysical phenomena provide valuable insights into gravitational waves, cosmology, and plasma physics, among other fields. All of the above provides the basis for conducting a LOw Frequency pulsar and Technosignature Survey (LOFTS), which aims to search for a range of technosignatures and other transients at 110-190 MHz. Completed through weekly zenith observations using two international LOFAR stations. Here, the first results from the LOFTS survey will be presented, utilizing Breakthrough Listen pipelines to place limits on the prevalence of intelligent life in the Galaxy by searching for narrowband, periodically modulated, and non-naturally dispersed signals.

A4,1,5,x98357	SETI Search with SerendipVI at Medicina (I) radio telescope.	Dr Pierpaolo Pari	INAF – IRA	Italy

At the Medicina radio telescope, the SerendipVI system collects and elaborates SETI signals in the 32 m dish antenna, together with the Nebula tools to process them. The system is up and running and we will present the results from the data analysis on observations of cluster galaxies we have listened to with the 32 m parabolic dish

A4,1,6,x95796	The VLA and High-Frequency SETI: Expanding the Search for Life	Mr Talon Myburgh	-	South Africa

COSMIC (Tremblay et al, 2024, AJ) searches for exoplanetary technologies (“technosignatures”) using the Very Large Array (VLA), by searching for narrow-band signals that drift in frequency over time due to Doppler motions. The first study for high frequency (25-50 GHz) SETI (Search for Extraterrestrial Intelligence) on the VLA was conducted from October 2023 through February 2024. Within the field of view of the VLA, COSMIC forms beams on exoplanetary sources. Gaia’s nearest stars are selected from the DRII catalogue (Czech et al, 2021, PASP), and the recorded results are examined for technosignatures. Using a Taylor tree de-dispersion (TTDD) algorithm within a real-time pipeline, each recorded beam (coherent and incoherent) is searched for drift-rate magnitudes up to ±50Hz/s. All detections are stored as “hits” with the relevant snippet of data stored for posterity. As part of the study conducted on data collected between October 2023 and February 2024, these hits were subjected to several computationally intensive discrimination filters to reject false positives caused by radio frequency interference (RFI), and 12 candidates were identified that required further investigation to determine their origins. The results of this study bound the uncertainty surrounding the prevalence of extraterrestrial life in the Universe and provided insight into the RFI environment at the VLA and the TTDD limitations. This work extends the study from February 2024 to the present and examines the impact of additional filters applied to the hits collection. As a final stage of the pipeline, through beam-forming and imaging, we aim to study these resultant technosignature candidates spatially and in full Stokes. The observable parameter space is therefore significantly expanded beyond that of the conventional SETI.

A4,1,7,x95497	High-frequency targeted SETI with the new MeerKAT band 5 receivers	Dr Andrea Melis	INAF - Istituto Nazionale di AstroFisica	Italy

MeerKAT is an array composed of 64 13.5 m dishes and represents the main precursor of the SKA-mid radio telescope to which will be incorporated to form the final 197 antennas array envisaged for SKA Mid. MeerKAT is fully involved in the SETI project, specifically it is part of the large Breakthrough Listen telescopes network. So far, SETI searches have been mostly carried out at low/medium frequencies, current SETI trend is to widen the search at higher spectral frequency windows and the available instrumentation at the MeerKAT facility does not allow us to go beyond the S-Band (1.75 - 3.5 GHz). In addition, searches are carried out in commensal/piggyback mode only, ie no specific time is reserved for SETI studies to cover sky regions that might supposedly host life. The band 5 project, with which we will install new high-frequency receivers in the 8.3 - 15.4 GHz band, will overcome this limitation. INAF achieved a large funding in the framework of an European program and decided to devote part of the money to enhance the MeerKAT telescope. In the context of this improvement and the time needed to

commission both technically (digitizers, receivers, compressors, software etc) and scientifically the whole instrument, SETI targeted time will also be allocated to conduct techno-signature studies at nearby stars with exoplanetary systems that could potentially be interesting to host (also) intelligence life. In this work, we will present the current status of the project as well as all of the effort to maximize the scientific return from SETI targeted time at high-frequency with the new band 5 MeerKAT receivers.

A4,1,8,x95702	Research into Unidentified Anomalous Phenomena (UAP) as an official academic research topic at a university	Prof Hakan Kayal	Julius Maximilians Universität Würzburg	Germany

The Interdisciplinary Research Center for Extraterrestrial Studies (IFEX) represents a unique academic research topic at the Julius-Maximilians-University in Würzburg, combining research fields from the areas of space technology and research, Search for Extra Extraterrestrial Intelligence (SETI) and research into Unidentified Anomalous Phenomena (UAP). The centre has pioneered various space technologies and investigations, including AI applications in space, such as the nanosatellite SONATE-2 (launched in 2024), AI-supported SSA observatory or sensor technologies for Mars exploration. The presentation introduces the specific activities of IFEX in the areas of small satellite missions, space situational awareness (SSA), UAP research and SETI, and discusses the similarities and synergies between these areas, which can open up new perspectives and applications. It also shows how UAP research can be funded and successfully integrated into academic work at a university, giving the example of IFEX in Germany.

A4,1,9,x102728	Quantifying Stellar Activity Effects on Narrowband ETI Signals	Dr Vishal Gajjar	SETI Institute	USA

Spectral broadening caused by plasma density fluctuations in the interplanetary medium of exoplanetary systems (Exo-IPM) poses a significant but largely unexplored barrier for detecting narrowband extraterrestrial technosignatures. Signals traversing these turbulent media experience frequency broadening, complicating their detection with conventional narrowband search techniques. Particularly at lower frequencies (below 500 MHz), this effect can be pronounced, broadening signals by more than 1,000 Hz, leading to substantial reductions in search sensitivity. With the recently acquired funding support, we have conducted a detailed theoretical study quantifying spectral broadening limits across different turbulence models, orbital inclinations, and stellar spectral types. In this talk, we will present our key findings and their implications for technosignature searches, highlighting how spectral broadening significantly influences detection strategies. We will also discuss how these insights can specifically inform future observational approaches, particularly for next-generation telescopes like the Square Kilometer Array-Low (SKA-Low) being built in Western Australia. Our results emphasize the importance of designing appropriate narrowband signal search strategies informed by intrinsic spectral broadening caused by Exo-IPM, ultimately optimizing the sensitivity of future radio technosignature surveys

A4,1,10,x103232	Gravitational Wave Communications: The Future of Interstellar Messaging?	Ms Samiksha Raviraja	Airbus Defence and Space	UK

Traditional interstellar communication relies on electromagnetic waves, which are limited by interference, signal degradation, and speed-of-light constraints. Gravitational waves are ripples in spacetime caused by massive cosmic events. This could offer a potential breakthrough in a new form of deep-space communication. By potentially enabling information transfer across large cosmic distances with minimal loss of data or information. This paper will look into seeing the feasibility of recreating this phenomenon or utilising detected gravitational waves to see if information can be sent through them. Be it to keep communications going with a very far away space craft, or to look for ET life, the applications are many and will be explored in this paper. The paper will start off with studying theoretical models of encoding information within artificially generated gravitational waves, as well as potential transmission methods, such as controlled mass displacements or high energy laser induced spacetime oscillations. Then the paper will discuss the several technological challenges of detecting and decoding such signals, considering advancements in gravitational wave observatories like LIGO, Virgo, and LISA. Beyond human applications, the paper will investigate whether advanced ET civilizations could already be utilizing gravitational waves for interstellar communication. If so, SETI (Search for Extraterrestrial Intelligence) efforts may need to shift their focus from the electromagnetic spectrum to gravitational wave detections. This could be valuable information for future SETI work. The paper will define the technological, theoretical, and observational challenges, and how they can be addressed. This research hopes to provide a roadmap for developing gravitational wave-based communication and its potential to revolutionize our understanding of deep-space communication.

A4,1,11,x96711	Moon race, farside protection, United Nations.	Prof Claudio Maccone	International Academy of Astronautics (IAA)	Italy

The Moon Race is in full swing as of 2025. The most important space-faring countries want to set foot on the Moon for a variety of purposes: national prestige, technological superiority and capitalist returns. But the exploitation of the Moon to increase Humanity's Scientific Knowledge has hardly any official place in this Moon Race. Five areas of the Sciences would greatly benefit if pursued on the Moon: 1) COSMOLOGY: only the radio silence still existing on the Moon Farside would enable us to check General Relativity predictions about the early stages of the Universe, like Dark Ages and the like. 2) ASTROBIOLOGY: Prebiotic interstellar molecules detected by their radio emissions could be found much better from the radio-quiet Moon Farside than from the overcrowded Earth Sky. 3) SETI & TECHNOSIGNATURES: since 1959 the largest radio telescopes existing on Earth have been occasionally used to search for "messages" or "hints" that Alien Civilizations exist. None was found, but the part of explored Milky Way is ridiculously small. SETI from Moon Farside is better. 4) PLANETARY DEFENSE: every asteroid and comet in the Solar System must flyby the Sun. Thus, the six orbital parameters of all asteroids and comets could be determined to a higher precision by optical telescopes set on both Nearside & Farside for the Moon. In turn, that would lead to a better estimate of the LEAD TIME, the time Humanity has to prepare for DEFLECTING SPACE MISSIONS. 5) WATER AT THE SOUTH POLE and other Moon venues shielded from the Sun Radiation. 6) LAVA TUBES as shelters from space radiation would be ideal for Human Settlements on the Moon.

A4,1,12,x94251	Machine Learning Applications in the Search for Extraterrestrial Signals	Mr Abbos Madmurotov	-	Uzbekistan

The Search for Extraterrestrial Intelligence (SETI) has long been a cornerstone of scientific exploration, aiming to detect artificial signals from extraterrestrial civilizations. However, the increasing volume of data from modern radio telescopes poses significant challenges in traditional signal detection and analysis. This study explores the application of machine learning (ML) technologies to enhance SETI's signal identification capabilities. Objective: The primary objective of this research is to leverage machine learning algorithms to improve the detection and classification of potential technosignatures within large datasets. By identifying patterns and anomalies beyond the capabilities of traditional Fourier transform techniques, this approach seeks to maximize the efficiency of SETI data processing. Methodology: Our approach integrates supervised and unsupervised learning models to process spectrogram data obtained from global radio telescope networks. A convolutional neural network (CNN) is utilized to classify narrowband signals while isolating interference and noise. Additionally, we implemented an autoencoder-based anomaly detection system to examine previously unexplored signal types. The training dataset combines simulated extraterrestrial signals and real-world astronomical observations, ensuring a diverse input set. Results: Initial testing demonstrates a significant improvement in the detection of narrowband tecnosignatures, with a reduction in false-positive rates by 25%. The anomaly detection system identifies potential unknown signal types that do not fit conventional classifications, offering new avenues for SETI investigations. Furthermore, the integration of ML models reduces the computational time required for processing large-scale datasets by 40%, paving the way for near-real-time analysis. Conclusion: The results indicate that machine learning provides a transformative approach to SETI research, enabling the detection of weaker, more complex signals that might otherwise be overlooked. By integrating advanced ML techniques into SETI data pipelines, this work contributes to improving both the scalability and reliability of signal detection systems. Future efforts will focus on incorporating additional observational datasets and expanding the anomaly detection framework to enhance the search for extraterrestrial intelligence. This study demonstrates the potential of machine learning technologies to address the increasing complexity and scale of SETI research, offering a promising direction for future advancements in the field.

SETI 2: SETI and Society

A4,2,1,x99676	The case of the EQ Peg hoax 25 years ago: Would a replay in today's media landscape have the same result?	Dr Carol Oliver	University of New South Wales	Australia

Potential media reactions to a SETI post-detection event remain the subject of debate. The EQ Peg event, which mimicked media reaction to a potential detection a quarter of a century ago, presents an interesting case if seen in the light of media reaction today. While the event proved to be a hoax, the story reverberated around the world for more than a week – a much shorter timescale than it would take for a potential detection to be confirmed. The event resulted in two back-to-back papers by the authors of this paper. One paper looked at the response of the media and SETI scientists to the claim, and the other proposed an immediate reaction plan, highlighting the need for such plans in the face of potential future events. What have we learned from the event over the past 25 years? Today, fake news, polarisation, and alternative realities spread rapidly across social media. Divisions have deepened across whole societies, and conspiracy theories abound. More recently, generative artificial intelligence, with its ability to create and disseminate content, has unleashed new challenges in communicating the SETI endeavour among public audiences and created opportunities to help direct conversations, particularly in a post-detection event. Understanding and utilising these considerable media changes is not just a matter of interest, but a crucial aspect in the event of a putative signal detection that could hold the answer to one of our most profound questions: Are we alone in the universe?

A4,2,2,x99139	The History of the IAA Seti Permanent Committee - 2000 to 2009	Ms Lori Walton	Consultant	Canada

This paper is the fourth in a series detailing the history of the International Academy of Astronautics (IAA) SETI (search for extraterrestrial intelligence) Permanent Committee. The IAA established the SETI Committee in 1974 in response to growing awareness that humanity might one day detect evidence of intelligent extraterrestrial life. The SETI Committee has a wide-ranging mandate to examine all aspects of the search for intelligent extraterrestrial life, including international issues, astrophysical and astronomical observations, biochemistry, exoplanets, complex life and evolution, planetary space missions, SETI search strategies, and the societal, legal, and political ramifications of a confirmed detection. The IAA SETI Committee, now in its 51st year, is the only international entity that meets annually to organize symposia, select papers for publication, address specialized topics in SETI, and collaborate with other organizations. The founding and early activities of the committee, up to 1999, have been described in three previous papers. This paper focuses on the committee's activities throughout the 2000s, a decade that began with a key presentation by IAA SETI Committee members to the United Nations Committee on the Peaceful Uses of Outer Space. The presentation outlined a position paper on potential transmissions from Earth in response to a confirmed detection of extraterrestrial intelligent life. Throughout the 2000s, the SETI Committee worked on updating the 'Declaration of Principles Concerning Activities Following the Detection of Extraterrestrial Intelligence" and grappled with the emerging field of "active SETI." Key search efforts during the decade included the wildly popular SETI@home project, the long-running SERENDIP program, and optical laser searches. In 2007 the Allen Telescope Array became operational, and SETI search programs increasingly focused on examining newly discovered exoplanet systems for evidence of extraterrestrial technology. The decade concluded with the launch of the Kepler Space Telescope in 2009, ushering in a new era of exoplanet discovery.

A4,2,3,x101000	Patterns in Perception of a Simulated Message from Space	Ms Daniela De Paulis	SETI Institute	USA

Between March and June 2024, we conducted a pilot project as a follow up to A Sign in Space. The initial project consisted in receiving a simulated extra-terrestrial message that was transmitted towards Earth, with a community of citizen scientists working on decoding the message. The project generated 6,639 images that represent the chronology of the visual analysis of the message by 137 citizen scientists from 24 May 2023 to 18 June 2024. The overall interpretation process of the message produced 55,006 posts over 120 chats, all collected on one Discord channel. The message image, called the "Star Map" by the citizen scientist community, was widely studied, and there were a total of 285 active interpreters from various cultural and social backgrounds. The rich collection of interpretation data allows us to explore how humans in general and those from various countries responded to the message. What patterns emerged in the responses? What were the salient aspects of the message? We next ask if this is particular to humans or do other species recognize patterns in the message? We wondered how chimpanzees, next of kin to humans, would respond to the message. We conducted a study with five chimpanzees at a

sanctuary (Fauna Foundation) to systematically explore their reaction and potential interpretation of the stimuli. We conducted three separate experiments in a pilot study that established a methodology to collect chimpanzees' interpretations of the message. The chimpanzees directed behaviors toward the stimuli as compared to images with random arrays. The chimpanzees marked on the images with crayons in one experiment. While the study was limited in scope with only five chimpanzees, this methodology can be used for future research. By analyzing pattern recognition around A Sign in Space, our research aims at comparing interpretation results from various animal species, with diverse cognition, perception, anatomy, and ecological adaptations. This could help identify SETI's limits and strengths in interpreting a potential extraterrestrial signal or message. It would also help SETI in making predictions about possible forms of alien communication. By understanding how various species interpret the same message, we might be able to highlight possible pathways to cognition, generalised across various species. This knowledge would in turn help SETI make possible estimates on the cognitive patterns of an extraterrestrial species. The team on this proposal takes an interdisciplinary and humble approach to search for patterns of perception on Earthlings.

A4,2,4,x99704	SETI Post-Detection Protocols: Progress Towards a New Version	Prof Michael Garrett	University of Manchester	UK

The International Academy of Astronautics (IAA) has long provided guiding principles for the response to a potential SETI signal detection. The foundational Declaration of Principles Concerning Activities Following the Detection of Extraterrestrial Intelligence, first formulated in 1989, has been widely recognised by the international scientific community. A supplemental set of draft protocols addressing the possibility of a reply to an extraterrestrial signal was prepared in 1995, with both documents presented in a position paper to the UN Committee on the Peaceful Uses of Outer Space. In keeping with the evolving landscape of SETI research, the IAA SETI Protocols were streamlined and updated in 2010. Recognising the need for continued adaptation, the IAA SETI Committee established a Task Group in 2022 to re-examine the protocols in light of recent advances in search methodologies, the expansion of international participation in SETI, and the increasing complexity of the global information environment. As SETI operates in a rapidly changing world, the protocols are considered a living document, requiring ongoing refinement to remain relevant and effective. A preliminary report was presented at the International Astronautical Congress (IAC) in Baku in 2023, outlining proposed revisions. This effort continued through the IAC 2024 in Milan, where a Draft Revised Declaration of Principles was presented, and initial feedback was received from the community, including members of the IAA SETI Committee. Since then, we have continued to seek broader community input, refining the proposed updates based on further discussions and consultations. At IAC 2025 in Sydney, we wish to present the outcomes and convergence of this process, including the finalised text of the revised protocols.

A4,2,5,x102557	The International Institute of Space Law SETI Working Group: Introduction, Overview, and Findings So Far	Prof Andrea Harrington	Institute of Air and Space Law, McGill University	Canada

In 2024, the International Institute of Space Law (IISL) commenced a Working Group to address legal issues relating to SETI. The group substantially re-evaluated its mandate and recommenced its work from January 2025. The purpose of this paper is to provide an overview of the Working Group's efforts to this point. By presenting our findings at IAC, we hope to be able to engage and receive feedback from the wider SETI community, rather than just those linked with the IISL. The IISL has a long history of hosting subject-specific working groups under the umbrella of space law research, including the most recently completed efforts of the AI Working Group. The SETI Working Group is an interdisciplinary effort, not one simply limited to those who study law, policy, and the social sciences. By integrating participants across disciplines, it endeavors to provide insights that are comprehensive and match with the most current understandings in the field. The Working Group is tackling the issues through a sequential evaluation of five subtopics, preceded by establishment of underlying assumptions and definitions to be utilized by the group as a whole. The first subtopic addresses the legal implications of METI or "messaging extra-terrestrials." These efforts can be conducted by state or non-state actors, but can states be held responsible? Are there disclosure requirements for these activities? Are these activities governed by the existing international space law regime? Subtopics 2-5 address potential alterations to obligations of terrestrial states under international law that may occur. Subtopic 2 addresses the confirmation of extraterrestrial technology or discovery of such an artefact. Here, issues include potential responsibility to share information and the legal and ethical questions addressing whether a response could or should be

made. Subtopic 3 addresses first contact that could occur as an ETI response to human METI activities, direct outreach from the ETI, or human outreach after detection/confirmation. Here, the issues surround the potential human response. Who should respond and how? Is it possible to achieve co-ordination rather than fragmentation of contact? Do states bear responsibility for a response? Subtopic 4 addresses ongoing contact, managing the activity and responsibility for it. Finally, subtopic 5 addresses potential conflict that may arise between humanity and ETI. Is there a possibility for unified action, and if so how? What rules of warfare would apply? It's important to the group that issues of conflict with ETI do not dominate the final report.

A4,2,6,x99521	The Societal and Legal Consequences of Detecting Extraterrestrial Intelligence: A Governance Gap	Ms Shrawani Shagun	National Law University, Delhi	India

The search for extraterrestrial intelligence (SETI) has long been a scientific endeavour, but its legal and societal implications remain largely unexplored in governance frameworks. While scientific protocols such as the SETI Post-Detection Framework provide voluntary guidelines for how an extraterrestrial signal should be discovered, no binding international legal framework addresses the political, ethical, and societal consequences of first contact. The Outer Space Treaty (OST) and other space law instruments are silent on governance mechanisms in the event of extraterrestrial detection, leaving a regulatory vacuum that could lead to geopolitical tensions, misinformation, and ethical dilemmas. The core problem is the lack of a structured, multilateral approach to handling the discovery and communication with extraterrestrial intelligence (ETI). If a signal is detected, who has the authority to respond? How should such information be disclosed to the public? What role do international institutions play in mitigating potential risks, including political instability, cultural disruption, and security threats? This paper explores the research question: Does the absence of a legal and institutional framework for extraterrestrial contact create risks for global security, governance, and social stability, such as the potential for geopolitical tensions, misinformation, and ethical dilemmas? This paper assesses existing protocols and their limitations by employing an interdisciplinary approach that draws upon international law, political science, sociology, and risk analysis. This research identifies patterns in governance failures and successes by examining historical instances of major scientific discoveries with global impact — such as nuclear technology and artificial intelligence. Additionally, it evaluates how different political and cultural systems might react to extraterrestrial discovery, highlighting the risks of disinformation, monopolisation of information, and geopolitical exploitation. This interdisciplinary approach ensures a comprehensive analysis of extraterrestrial intelligence detection's legal and societal implications. The paper argues that the current lack of legal and institutional preparedness could result in fragmented national responses, where individual states or private entities act unilaterally, potentially exacerbating global instability. It proposes establishing an international governance mechanism under the United Nations or through a new multilateral treaty to ensure transparency, ethical considerations, and co-operative decision-making. This mechanism would include a legally binding post-detection protocol, an international ETI response council, and mechanisms for managing public disclosure and media narratives. By framing extraterrestrial contact as a global governance issue rather than merely a scientific or speculative question, this research contributes to the emerging discourse on space law, security, and international co-operation

A4,2,7,x103067	Refiguring Communication in SETI: Cybernetics, Analogy, and Improvisation in the Search for Extraterrestrial Life	Ms Kate Genevieve	University of Sussex	New Zealand

The search for extraterrestrial intelligence (SETI) can benefit from a reassessment of how communication is defined and understood. This paper integrates cybernetic, ecological and creative theories of communication, drawing on the ecological cybernetics of Gregory Bateson, to propose a relational and process-oriented approach. Building on this semantic and epistemological emphasis, this paper presents Islands, an interdisciplinary art-science project developed in collaboration with SETI scientists, creative technologists, and performance practitioners. In terms of narrative, the project draws together insights from disaster studies in Oceania to examine how local narratives and adaptive governance models can inform SETI's post-detection frameworks and the challenge of imagining interspecies communication, recognising that any post-detection scenario unfolds within diverse sociopolitical and epistemic contexts. Novel to the SETI discussion, Islands employs digital techniques that leverage projective geometry to create a speculative topological research tool to model complex communication. This mathematical approach responds to and extends models based on projective geometry used to model intersubjectivity and conscious perception in affective Neuroscience and animal communication and explores the value of applying such methods to questions of the more-than-human. The practical implications of mobilising theoretical work on process in a way that brings together projective geometry, complexity science, and

bioacoustics to explore alternative topologies and sensory architectures, is to sketch methods that may support creative and responsive frameworks of communication and search. Proposing interdisciplinary topological methods attempts to leverage emergent possibilities in creative technology for SETI, with potential value for identifying systemic anomalies, adaptive structures, self-organising systems and encoded patterns in astronomical data. This paper argues that SETI can broaden its theoretical foundations with cybernetic methods capable of incorporating research on comparative cognition, non-human communication systems and enactive epistemologies. Aesthetic and technological approaches to communication, and to the context-dependent, metaphoric underpinnings of analogic and abductive thought and meaning-making itself, extend creative computational methods to approach philosophical and semantic questions in ways that suggest fresh approaches to the recognition and detection of non-anthropocentric modes of communication and technology.

A4,2,8,x102108	Space and Interstellar Travel and What We Want to be Remembered For – The Case for Indigenous Knowledges for Communication with Prospective ET's and for Human spaceflight purpose and a Collective Earth Message	Dr Sasha Alexander	Western Sydney University	Australia

This paper presents a study comprising avenues to enhance engagement of space industries sharing of indigenous cultural perspectives in support of the health and wellbeing for human spaceflight and maximising the opportunities to connect with civilisations yet unknown or identified and how we capture earth-based cultural diversities and richness. The future of space exploration is envisioned and motivated to travel as far as possible in the pursuit of new knowledge and to explore new environments possibly inhabited. The prospect to engage has created wonderment and challenges on what to share and what format visual, auditory or other may engage with extraterrestrials optimistically in a non-combative way. In recent decades approaches to sharing cultural knowledge have included the 'Arecibo message' in 1974, space probes Pioneers 10 and 11 from 1972 with small metal plaques, Voyager 1 and 2 with gold-plated copper disk phonographic record with natural sounds, musical selections from different cultural eras initially in 1977, and an orbiting TESLA Roadster electric car one of the latest forays relaying the status of our world today and values of cultural origins. Voyager contents were assembled in part at Cornell University under planetary scientist Dr Carl Sagan including 115 images and a variety of natural sounds, spoken greetings from earth-people in 55 languages and physical recording disk technology was thought the most robust and ET approachable. Therefore, scope to reconsider what Earth and it's peoples could be remembered for is yet to be fully realised for series of cultural affirming actions in captured representations of a sustainable civilization often defined in continuity by recordings, patterns, motifs, totems, designs, architecture, science and advancing technologies. The 76th Annual International Astronautics Congress Sydney, Australia is being held on the lands of 29 clan groups of the Eora Nation which form part of over 600 indigenous nations and 250 languages in Australia and represent the longest continuous culture in the world at more than 65,000 years pre-dating Europe and the Americas. The contributions of this paper will be a series of reflections on past cultural indigenous engagement and cultural representations of space, astronomy, and contributions and opportunities that the space missions of today and tomorrow offer towards further discovery, to reinforce and promote indigenous cultures in space for the health, wellbeing, physical and cultural sustainability supporting Earth's continued future and the space missions that follow a shared and culturally respectful and enriched engagement model.

A4,2,9,x101040	A first contribution to the history of Italian SETI	Dr Paolo Musso	InCosmiCon Research Center	Italy

The first seminal paper about SETI, Searching for Interstellar Communications, published in Nature on 19 September 1959, was written by an American author, Philip Morrison, and another Italian, Giuseppe Cocconi. Nonetheless, from then on, for 30 years Italy has not taken part in the research that arose from that article. But in 1990 two Italian guys, Claudio Maccone and Stelio Montebugnoli, met while participating in the Bioastronomy Meeting held in Val Cenis, and the history of Italian SETI began. From then on, the contributions by Italian investigators to search for extraterrestrial civilizations have constantly increased, both in number and quality, but so far nobody had tried to tell their history. In 2024, on the occasion of the IAC Milano 2024, a first contributions appeared, in a book written by myself (Ascoltando l'infinito silenzio. L'Italia e la ricerca delle civilt`a extraterrestri), but which could count on several contributions from the main protagonists of Italian SETI. In this paper I present the main topics covered in the book and the possible future developments of this work.

A4,2,10,x99230	New Cosmic Perspectives: Indigenous Knowledge and SETI	Dr Alvin D Harvey	MIT	USA

"Is there 'life' in the cosmos?" is a fundamental question that drives a multitude of international scientific and engineering endeavours. From SETI to astrobiology, the fundamental framing of this question from a Western scientific lens has already dictated fundamental assumptions. Such assumptions and resulting answers provide a concreteness to the interdisciplinary effort SETI that may limit its ability to respond to the consequences of detecting an extraterrestrial signal. Such an effort with a potentially globally impactful finding could be supported by additional frameworks of knowledge and science. Namely, Indigenous Knowledge Systems, representing perspectives, experiences, and philosophies of Indigenous People who have held relationships with land and stars across millenia may provide a more holistic understanding and response. In this presentation, this broad and exciting partnership area is investigated from philosophy to promising practices in mutually beneficial partnerships between the space community and Indigenous Peoples. Generational socio-ecological knowledge is diverse across the Indigenous Peoples and Nations around the globe. Respecting the contextual nature of Traditional Ecological Knowledge, while still acknowledging shared principles of Indigenous People, forms a flexible network of life practices that challenges and complements fundamental western scientific frameworks. In particular, the question of what "life" is from a shared Indigenous worldview diverges from Western science - a divergence that is representative in the differing treatment of biotic and abiotic elements of our terrestrial environments. Developed approaches based on Indigenous scientific values that favour respectful, inquisitive, and reciprocal relationships to alternate forms of "life" are also informed by lived experiences of colonization by "explorers" seeking resource extraction and "civilization development." These divergences and others are places of conversation, partnership, and co-creation that can grow the SETI community and further expand its cosmic outlook, communication, and purpose. This presentation will provide a grounded overview of ongoing successes and challenges in such partnerships across the space community that provides guidance on building SETI-Indigenous partnerships. Additionally, this presentation will touch upon the potential alignments and contrasts in scientific philosophies between Indigenous communities and SETI that could provide a basis for novel concepts and language on SETI's work and impact.

A4,2,11,x97016	Sustainability Puzzles and the Extraterrestrial Turn	Dr Chelsea Haramia	University of Bonn	Germany

The goal of sustainability is often used to both critique and justify the accelerated development of humans' technological capabilities, leading to sustainability puzzles and various self-defeating solutions. Sustainability-reasoning also shows up in debates about detection of and contact with extraterrestrial others — for example, the Sustainability Solution to the Fermi Paradox. While it is indeed possible that the technological trajectory of some alien species has run roughly parallel to ours, speculation about the sustainability-practices of extraterrestrial others is at the same time yet another example of the cosmic mirror, wherein our reasoning about the cosmos reflects strongly back onto ourselves. SETI searches and debates regarding extraterrestrial technology can assist us in understanding our own technology and its potential trajectories. Sustainability discourse in technology ethics has taken a decidedly planetary and species-level direction, with theorists positing both a Terrestrial Turn based on Anthropocene concerns and the impact of the human species on geological and ecological systems, as well as a Structural Turn based on AI and digital technologies' embeddedness in humans' socio-technical systems—a turn that speaks to environmental concerns as well as social sustainability. In intersection with these moves, I posit the Extraterrestrial Turn, uncovering notable parallels among the puzzles we encounter in sustainability discussions regarding AI and other technologies on Earth and puzzles regarding outer space use and exploration of the Solar System and beyond. Both the Space Sustainability Paradox and the Sustainability Solution to the Fermi Paradox highlight legitimate fears about social and environmental activities that are not only deeply unsustainable but also deeply unwise. Such fears have led to worthwhile reasoning about the relevance of wisdom and the possibility of an aspirational Sapiezoic Eon in Earth's geologic record. I recognize moral wisdom as an important piece of a Sapiezoic solution to sustainability puzzles. I contend that sustainable technology goals should include contributions from extraterrestrial technology debates, specifically with respect to scope, teleology, and methodological tools. I conclude that both contemporary SETI searches for extraterrestrial technology and the ancient concept of moral wisdom together have an important role to play in sustainability debates regarding humanity's terrestrial and extraterrestrial futures.

A7.2 Science Goals and Drivers for Future Exoplanet, Space Astronomy and Space Physics

A7,2,1,x102212	Interstellar Probe: US Decadal Survey Recommendations and Strategic Next Steps	Dr Pontus Brandt	Johns Hopkins University Applied Physics Laboratory	USA

In 2022, a four-year, NASA-directed concept study on a pragmatic Interstellar Probe was completed by Johns Hopkins APL and submitted to the US Solar Space Physics Decadal Survey. Released late 2024, the Decadal Survey Report recommended for the first time that the "NASA Science Mission Directorate (SMD) should develop a cross-divisional approach for planning, operation, and management of future projects and programs for interdisciplinary science. Specifically,. . . support development of a mission to interstellar space". Interstellar Probe is a mission to escape the solar system to understand how the Sun upholds our protective magnetic bubble – the heliosphere. Targeting more than twice the distance of the Voyager mission, Interstellar Probe would explore completely new territory in the Very Local Interstellar Medium (VLISM) carrying a comprehensive suite of in-situ and remote instrumentation. On its escaping trajectory, flyby observations of unexplored dwarf planets and Kuiper Belt Objects would push our understanding of planetary system formation and evolution. Beyond the zodiacal cloud infrared measurements would uncover the extragalactic background light, providing new knowledge in to stellar and galactic formation. An Interstellar Probe is timely as recent findings indicate that the Sun is currently transitioning between two interstellar clouds. Furthermore, recent studies show that a few million years ago the heliosphere may have been wiped out for hundreds of thousands of years as it passed through a very dense interstellar cloud, pointing to a potentially game-changing role of the heliosphere in the evolution of our home in the galaxy. With Voyager going offline in the next few years, Interstellar Probe is also an urgent mission for NASA, for the US, and for the world as a whole. A trajectory through the forward hemisphere of the heliosphere would be accomplished by a launch in 2036-2042 using conventional chemical propulsion and a launch vehicle, such as the Space Launch System, Falcon Heavy, or Starship. A Jupiter Gravity Assist would propel the 860 kg spacecraft to between 5 and 10 au/year with the first dwarf planet flyby as soon as four years after launch, and arriving in the VLISM after only 12-24 years. The spacecraft is designed to a 50-year nominal lifetime using modern-day technology with two next-generation Radioisotope Thermal Generators ensuring 300 We at end of nominal mission. Here, we present an overview of the mission, discuss the decadal recommendations, the need for cross-divisional approaches and the strategic roadmap toward launching Interstellar Probe in the coming decades.

C3.5-C4.10 Joint Session on Nuclear Power and Propulsion Systems, and Propellantless Propulsion Innovative Concepts and Technologies

C3,5-C4.10,4,x103235	Cold Fusion in Space: A Game-Changer for Deep Space Propulsion?	Ms Samiksha Raviraja	Airbus Defence and Space	UK

Long distance and duration space missions are limited by current propulsion and power generation technologies. Chemical rockets require excessive fuel, nuclear fission poses radiation risks, and solar energy is impractical for deep-space travel beyond the heliopause. This paper discusses a possible alternative called Cold fusion. Cold fusion is a theoretical energy source that could potentially provide almost limitless power with minimal radioactive byproducts. This could revolutionize propulsion and space infrastructure if realistically feasible and successfully developed. Recent research, advancements and breakthroughs in low energy nuclear reactions will be studied in this paper, the challenges in achieving sustained fusion reactions, and potential reactor designs optimized for space environments. Its advantages and risks will also be dived into. The possibilities cold fusion offers makes it a worthwhile innovative technology to look into and study the extent of its applications in space. If cold fusion can be harnessed, it could enable lightweight, high-efficiency propulsion systems, dramatically reducing mission costs. Besides just propulsion, cold fusion could potentially power future space colonies, providing a sustainable long term energy source for lunar bases, Martian settlements, and asteroid mining operations and any other mission that is away from accessible resources. However cold fusion is a very new arena and in early stages, and faces a good level of skepticism. The paper will study the current state of research around cold fusion, regulatory considerations, and potential ways to test cold fusion reactors in microgravity environments to understand more about how it reacts. Finally, the paper shall provide a roadmap to future studies, tests and applications specifically for space missions.

C3,5-C4.10,12,x103188	Experimental analysis of a Centrifugal Fuel Element from a Centrifugal Nuclear Thermal Propulsion Engine	Mr Spencer Christian	The Ohio State University College of Engineering	USA

Centrifugal Nuclear Thermal Propulsion (CNTP) is an unproven Nuclear Thermal Propulsion (NTP) design with improved specific impulses than traditional NTP designs. While traditional NTP designs, such as those from the Rover and NERVA programs, have past experimental data on which to base design decisions, the CNTP design has been largely theoretical. Only a few models have been made to predict its operability and practicality. This work details the progress and operation of an experimental test environment at The Ohio State University to investigate the CNTP design. The primary focus of the test environment is the centrifugal fuel element, specifically its functionality and thermos-mechanical behaviour. The experimental data gathered from the test stand is vital to validating the models for the CNTP design. Initial experimentation has included a range of propellant flow properties, propellant outlet pore size, and rotation rates. Further advancements to the test environment are still needed to represent the materials and components from the CNTP design more accurately.

C3,5-C4.10,14,x95943	Mission Burn Characterization Using a Centrifugal Nuclear Thermal Rocket	Mr Mitchell Schroll	Propulsion Research Center, University of Alabama in Huntsville	USA

A Centrifugal Nuclear Thermal Rocket (CNTR) is an advanced propulsion concept that would allow for a near doubling of specific impulse over traditional nuclear propulsion and quadrupling of specific impulse compared to traditional chemical rockets. However, this increased theoretical performance comes at a cost. Studies conducted during the ROVER/NERVA program and models developed for more modern nuclear engines show substantial mass cost to cool down the reactor after each engine firing. Additionally due to the dynamic nature of the liquid core reactor and centrifugal elements a more complex startup process is also required compared to traditional chemical rockets. The purpose of this paper is to investigate the transient operation modes of a CNTR and combine those results with previously conducted studies on steady-state operation to characterize the total system specific impulse. This result is then applied to a mission analysis model to determine the overall benefit of such a system. Using previously developed systems models an expanded transient state systems model was developed in Python utilizing OpenMC, CEA, RefProp and other open-source libraries. The code calculates the optimum operating conditions for the engine geometry provided then performs an analysis of the startup and shutdown conditions for a given burn length. From this data a total propellant mass, fuel burnup, and total impulse can be calculated. These parameters are then fed into a trajectory analysis model to determine the required burn lengths for the prescribed target destination and payload. The mission analysis was performed using a SysML model previously developed and modified to accommodate the CNTR system. The payload configurations were determined using the NASA Mars Reference Design Architecture 5.0 for a manned Mars mission and New Frontiers program requirements for outer planetary scientific missions. The results of the study found for the configurations considered that CNTR is viable for scientific missions to all the outer planets with mission durations closing in 12 years or less. Additionally, it was found that CNTR would be a viable upgrade to a manned Mars mission reducing total mass required by 100 mT and enabling round trip missions to less than 420 days.

D4.4 Strategies for Rapid Implementation of Interstellar Missions: Precursors and Beyond

D4,4,1,x96464	Nuclear Electric Propulsion for Fast Interstellar Precursor Missions: Physical Limits on Performance	Dr Ralph L McNutt, Jr	The Johns Hopkins University Applied Physics Laboratory	USA

Reaching "nearby" interstellar space is challenging due to the long distances and associated long travel times. Of 20 Interstellar Probe studies and concepts articulated from 1960 through 2022, three have been based upon nuclear electric propulsion (NEP), seen as an enabling technology relying on multiple years of continuous thrusting at large distances from the Sun. Promised large solar system escape speeds of 10 to 20 au/year depend upon decadal time scales for continuous thrusting combined with sufficiently large "specific power" for the combined spacecraft-power-propulsion system. The "figure of merit," usually denoted by $\alpha\tau$, with α the power per unit mass (usually expressed as kilowatts/kilogram) and τ the thrust time of the system (typically in years). The former is often also expressed as the reciprocal "specific mass" (kilograms/kilowatt). Electric propulsion has become common for station keeping of near-Earth assets, but its use, in the guise of solar electric propulsion (SEP) relying on solar arrays for electrical energy, for primary propulsion in interplanetary space has been limited to date. The notable examples are Deep Space 1 (DS-1) (2.5 kilowatts, electric (kWe), launched 1998), Dawn (10.3 kWe, 2007), the Double Asteroid Redirection Test (DART) mission (6.6 kWe, 2021), and Psyche (19.2 kWe, 2023). No corresponding NEP systems have ever been built, much less flown: SNAPSHOT was a 500 We reactor 1 Paper ID: 96464 oral aimed to provide power to a small test ion engine (1965, failed after 43 days in orbit) and the Nuclear Electric Space Test Program (NEPSTP) was to have flown a mix of ion engines powered by a Soviet Topaz II (aka Enisey) reactor (35 kW, thermal/6 kWe thermionic, Preliminary Design Review (PDR) 1993 and then cancelled). Since NEP continues to be advocated as a primary solution for near-term interstellar exploration, we have examined the Master Equipment Lists (MELs) for various extremely deep-space missions, as a function of time and technological maturity to look for commonalities in what sort of $\alpha\tau$ parameters and other constraints may be implicitly imposed on notional interstellar missions. Examples include, durability, multi-year autonomous operation, decade-long reactor lifetime, and associated reactor and waste-heat rejection masses, as well as communication and science instrument requirements needed for a viable scientific mission toward the stars.

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D4,4,4,x103236	META-STARWISP: An Autophagic Interstellar Probe	Haroon B Oqab	Space Canada Corporation	Canada

As humanity sets its sights beyond the solar system, there is a need for dedicated interstellar precursor missions to explore and characterize the interstellar environment. Before we can send probes — or eventually crewed missions — to other star systems, understanding these conditions is essential for designing future deep-space missions that can withstand the harsh and unknown environment between the stars. In this talk, we introduce a novel concept for an interstellar precursor probe designed to push the boundaries of exploration beyond the heliosphere, into the interstellar medium, and to another star system. Meta-Starwisp, is an autophagic interstellar probe — a self-consuming spacecraft that is accelerated to relativistic speeds by beamed power. This proposed interstellar probe utilizes its own structural components as fuel integrating in-situ resource utilization with advanced propulsion, enabling extended mission lifetimes without reliance on external refueling. By gradually consuming non-essential structural elements, the spacecraft reduces mass while sustaining its journey, optimizing energy efficiency for deep-space exploration. Crucially, this system also allows for a controlled deceleration manoeuver upon arrival at another star system, and maximize the scientific return of the mission. We will explore the key engineering principles behind this self-consuming design, its implications for long-duration interstellar travel, and its potential to pave the way for the humanity's initial missions to another star. This approach redefines long term space sustainability, offering a transformative pathway toward our interstellar future.

D4,4,5,x95149	Interstellar Travel That Uses Cosmological Entanglement, Topological Propulsion, and Mathematics' Riemann Hypothesis	Mr Rodney Bartlett	-	Australia

Cosmological entanglement - not limited to laboratories and temperatures near absolute zero - might be achieved by adaptation of cosmology's holographic principle. The principle says the 3rd dimension results from information in a 2nd dimension. If every particle (even the photon and graviton) has many positive and negative electric charges that potentially cancel, the charges would - as electronics shows - produce binary digits making the 2nd and all dimensions programmable. By reprogramming that 2nd dimension, the 3rd dimension (and thus, distance) is feasibly totally removed between the centres of particles or wave functions, physically quantum-entangling them. Wick rotation's x-axis could describe the four known dimensions of space-time while its y-axis could describe the physical quantum entanglement of particles and waveforms achieved with the holographic principle. Being different from ordinary space-time and incorporating Wick Rotation's imaginary numbers, the holographic entanglement's lack of distances in space and time might produce "imaginary space" and "imaginary time". To understand topological propulsion, we start with a parallelogram. When a parallelogram is visualized in three dimensions, this physical cosmological entanglement can be compared to "collapse" of the 3-dimensional analogue of the parallelogram. The bottom and top would occupy an identical one-line space. This would result in a shape having two dimensions and a single surface viz topology's Mobius strip - along which particles like photons, gravitons, and electrons could travel. Electricity, and its associated magnetism, traversing an array of these single surfaces could produce what might be called "topological propulsion" and photon-graviton interaction could, using Einstein's 1919 paper "Do gravitational fields play an essential role in the structure of elementary particles?", produce any and all particles, forming a 100% emissions-free "topological manufacturing" which is applicable to every factory and powered form of transportation. This collapse is a form of warping of space. The Riemann hypothesis is concerned with "nontrivial zeros" on the "critical line", stating that these zeros lie on the vertical axis of the Complex Plane ie on the y-axis in then undiscovered Wick rotation. We saw how Wick rotation describes imaginary space-time. Since the critical line links Wick rotation to the Riemann hypothesis, spacetime may be describable by Riemann. The critical line pertains to zeros - so the distances in space-time that could be described by the Riemann hypothesis might equal zero, making time travel to both the past and future possible as well as making instant intergalactic travel feasible.

D4,4,6,x103127	Design of a Self-Sufficient generation for Interstellar Travel: Project Hyperion	Mr Saeed Vahdani	Space Generation Advisory Council (SGAC)	Iran

The Hyperion Project's ambition is to design and test the feasibility of a self-sustaining spacecraft for a 250-year journey to a nearby exoplanet. The main focus of the study would be that which concerns interstellar exploration: sociocultural conditions, life support, propulsion, and long-term sustainability. One design challenge involves architectural provisions for artificial gravity within the ship to work against physiological degradation from generation to generation. The habitat is modulated to also contain radiation shielding, micrometeoroid protection, and modular adaptation to improve its resilience capabilities to deep space. A proposed optimal population size of 1,000,500 individuals is to be maintained for genetic diversity, social stability, and continuation of knowledge for maintenance of the ship and eventual settlement of planets. It is a bio-regenerative, closed-loop air, water, and waste recycling system that does not deplete resources. Food production includes hydroponics, cellular agriculture, and microbes. All of these methods maintain a healthy ecology. Industrial subsystems including additive manufacturing and in situ material recycling ensure that production continuities are always there for strategic production of tools, infrastructure, and even medical supplies. A governance model incorporating adaptive decision-making, education, and ethical frameworks would be fundamental for the eldership of societies succeeding each other across generations. A knowledge-preservation strategy would hedge against technological stagnation through the combined use of digital repositories, apprenticeship models,

and education assisted by artificial intelligence. The propulsion basis for this study centres on nuclear-electric propulsion (NEP) and highly efficient energy systems to provide the necessary delta-v for interstellar flight, and all of its needed redundancy and fault tolerance. A communication system with long-distance delayed messaging protocols ensures student research continuity and interaction with Earth. Technical aspects are being incrementally improved by means of computer simulations, integrated socio-cultural models and research from literature reviews, expert consultations, and 3D modeling software). In precision, habitat design maximizes modularity, flexibility in the workplace, and mass minimized. Sociological and psychological models assess the societal impact of multi-generational space travel. The current study details some of the critical trade-offs and engineering constraints, including mass budget, risk mitigation, and redundancy planning. Future work will delve into AI-controlled habitat upkeep, psychological adaptation mechanisms, and new propulsion that reduces travel time.

D4,4,7,x97805	The Cosmic Development Goals	M Tessa Rankin	International Space University (ISU)	France

We propose a set of Cosmic Development Goals (CDGs) – a forward-looking framework to guide and encourage the international community in the responsible, sustainable, and equitable usage of space in order to maintain space as a domain of opportunity, co-operation, and shared prosperity for all. We are witnessing a transformation of the space sector with the involvement of new players including student and commercial enterprises, increased participation from new nation-states, and the expansion of public-private partnerships. As a result, the space environment is becoming increasingly interconnected and competitive and stands to gain from an outline of guiding goals that aim to align and co-ordinate all actors in transparency and accountability of space activities. The CDGs were drafted from modern-day insights related to space law, governance, sustainability, ethics, and industry trends drawing from literature on government policies, academic research, and perspectives of industry leaders, private stakeholders, and key investors in the space sector. From this literature, we synthesized the broad culmination of concerns of the developing sector and aligned the CDGs to encompass these issues and priorities such as environmental stewardship and the protection of space, equitable access to and sustainable use of space resources, the ethical considerations of human exploration and expansion beyond Earth, and the promotion of international collaboration for ethical governance of space. In this paper, we present the CDGs to help shape a future where space exploration and utilization can contribute to scientific innovation, economic growth, and international relations in line with global sustainability goals and the evolving needs of the space sector. By addressing both current challenges and leveraging emerging opportunities, the CDGs present an encouraging and adaptable method of balancing innovation and ambition while maintaining the peaceful and sustainable use of space.