NASA

UNIDENTIFIED ANOMALOUS PHENOMENA

Independent Study Team Report

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Front and back cover photos: views of the earth as photographed from the Earth-orbital Apollo 4 unmanned space mission.

All photos are from NASA unless otherwise indicated.

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Group Photo: Members of the NASA Unidentified Anomalous Phenomena Independent Study Team.

This is a type of lightning known as a red sprite — a phenomenon that has rarely been photographed in this amount of detail. Some thunderstorms produce sprites, but most do not. Photo credit: Stephane Vetter (TWAN)

EXECUTIVE SUMMARY

NASA is in an excellent position to contribute to UAP studies within the broader whole-of-government framework.

The study of Unidentified Anomalous Phenomena (UAP) presents a unique scientific opportunity that demands a rigorous, evidence-based approach. Addressing this challenge will require new and robust data acquisition methods, advanced analysis techniques, a systematic reporting framework and reducing reporting stigma. NASA – with its extensive expertise in these domains and global reputation for scientific openness – is in an excellent position to contribute to UAP studies within the broader whole-of-government framework led by the All-domain Anomaly Resolution Office (AARO).

NASA has a variety of existing and planned Earth- and space-observing assets, together with an extensive archive of historic and current data sets, which should be directly leveraged to understand UAP. Although NASA's fleet of Earth-observing satellites typically lack the spatial resolution to detect relatively small objects such as UAP, their state-of-the-art sensors can be directly utilized to probe the state of the local earth, oceanic, and atmospheric conditions that are spatially and temporally coincident with UAPs initially detected via other methods. Thus, NASA's assets can play a vital role by directly determining whether specific environmental factors are associated with certain reported UAP behaviors or occurrences.

Next, the U.S. commercial remote-sensing industry offers a potent mix of Earth-observing satellites that offer imagery at sub- to several-meter spatial resolution, which is well-matched to the typical spatial scales of known UAP. Although every point on Earth does not have constant high-resolution coverage, the panel finds nonetheless that such commercial constellations could offer a powerful complement to the detection and study of UAP when coincident collection occurs.

At present, analysis of UAP data is hampered by poor sensor calibration, the lack of multiple measurements, the lack of sensor metadata, and the lack of baseline data. Making a concerted effort to improve all aspects is vital, and NASA's expertise should be comprehensively leveraged as part of a robust and systematic data acquisition strategy within the whole-of-government framework.

Moving forward, NASA should contribute to a comprehensive, government-wide approach to collecting future data. The importance of detecting UAP with multiple, well-calibrated sensors is paramount, and NASA could potentially leverage its considerable expertise in this domain to utilize multispectral or hyperspectral data as part of a rigorous data acquisition campaign.

The panel finds that artificial intelligence (AI) and machine learning (ML) are essential tools for identifying rare occurrences, potentially including UAP, within vast datasets. However, these powerful techniques will only work on well-characterized data gathered with respect to strong standards. NASA's extensive experience in the application of state-of-the-art computational and data-analysis techniques should therefore be leveraged to provide critical assistance. Once again, appropriate data collection, curation, and distribution are paramount; NASA, with its world-leading experience in these aspects is well-positioned to play a leading role.

Engaging the public is also a critical aspect of understanding UAP. The panel sees several advantages to augmenting data collection efforts using modern crowdsourcing techniques, including open-source smartphone-based apps that simultaneously gather imaging data and other smartphone sensor metadata from multiple citizen observers worldwide. NASA should therefore explore the viability of developing or acquiring such a crowdsourcing system as part of its strategy. In turn, the panel finds that there is currently no standardized system for making civilian UAP reports, resulting in sparse and incomplete data devoid of curation or vetting protocols. NASA should play a vital role by assisting AARO in its development of this Federal system.

The negative perception surrounding the reporting of UAP poses an obstacle to collecting data on these phenomena. NASA's very involvement in UAP will play a vital role in reducing stigma associated with UAP reporting, which almost certainly leads to data attrition at present. NASA's long-standing public trust, which is essential for communicating findings about these phenomena to citizens, is crucial for destigmatizing UAP reporting. The scientific processes used by NASA encourage critical thinking; NASA can model for the public how to best approach the study of UAP, by utilizing transparent reporting, rigorous analysis, and public engagement.

Finally, the threat to U.S. airspace safety posed by UAP is self-evident. The panel finds that a particularly promising avenue for deeper integration within a systematic, evidenced-based framework for UAP is the Aviation Safety Reporting System (ASRS), which NASA administers for the FAA. This confidential and voluntary reporting system for pilots, air traffic controllers, and other professional aviation staff, receives approximately 100,000 reports per year. Although not initially designed for UAP collection, better harnessing it for commercial pilot UAP reporting would provide a critical database that would be valuable for the whole-of-government effort to understand UAP. In turn, NASA's long history of partnership with the FAA should be leveraged to investigate how advanced, real-time analysis techniques could be applied to future generations of air traffic management (ATM) systems.

FRAMEWORK OF RECOMMENDATIONS

Although AARO leads the whole-of-government response to UAP, the panel recommends that NASA play an essential role within that framework. NASA should leverage its core capabilities and expertise to determine whether it should take a leading or supporting role in implementing a given recommendation.

ORGANIZATION OF THIS REPORT

This report is organized as follows. We present a systematic response to the eight charge elements that formed the Terms of Reference that NASA provided to the Independent Study Team, followed by a detailed set of conclusions and recommendations. These responses stemmed from a series of sub-panel reports that the entire team deliberated in full at the public meeting held on May 31, 2023, all of which are included as work products toward the end of this report for full public transparency.

An orbital sunrise photographed by an Expedition 40 crew member on the International Space Station.

The spectacular aurora borealis, or the "northern lights," over Canada is sighted from the space station near the highest point of its orbital path.

FOREWORD

Unidentified Anomalous Phenomena (UAP) are one of our planet's greatest mysteries. Observations of objects in our skies that cannot be identified as balloons, aircraft, or natural known phenomena have been spotted worldwide, yet there are limited high-quality observations. The nature of science is to explore the unknown, and data is the language scientists use to discover our universe's secrets. Despite numerous accounts and visuals, the absence of consistent, detailed, and curated observations means we do not presently have the body of data needed to make definitive, scientific conclusions about UAP.

At NASA, we use data and the tools of science to explore the unknown in the atmosphere and space. In June 2022, NASA established an external independent study team to find a way we can use our open-source data and resources to help shed light on the nature of future UAP. Much like a team of peer reviewers, NASA commissions independent study teams as a formal part of NASA's scientific process, and such teams provide the agency external counsel and an increased network of perspectives from esteemed scientific experts.

NASA's UAP Independent Study Team is made up of 16 experts from diverse backgrounds in science, technology, data, artificial intelligence, space exploration, aerospace safety, media and commercial innovation. They were assigned to pinpoint the data available around UAP and produce a report that outlines a roadmap for how NASA can use its tools of science to obtain usable data to evaluate and categorize the nature of UAP going forward. This is not a review of previous UAP incidents.

We thank the UAP Independent Study Team members for their service on the study and for their contributions towards the advancement of our nation's understanding of UAP. While we are still evaluating the report and assessing the team's findings and recommendations, NASA's Science Mission Directorate and the Agency are committed to keeping a clear and open pipeline for communication and resources with the Department of Defense's All-Domain Anomaly Resolution Office (AARO) to support its whole-of-government approach towards understanding and resolving UAP cases. NASA is appointing a Director of UAP Research to centralize communications and leverage NASA's extensive resources and expertise to actively engage in the whole-of-government UAP initiative. This individual will also ensure that the agency's vast analytical capabilities, including its proficiency in data management, machine learning and artificial intelligence, are contributed to the government's unified UAP effort.

At NASA, we are committed to openness, transparency, and scientific integrity and they are a central part of our operations. By setting up this independent study team, NASA gained important external perspectives from leading experts in our nation for how we can use our resources to advance the study of UAP data and explore the unknown in air and space for the benefit of all.

Dr. Nicola Fox, Associate Administrator, Science Mission Directorate

A meteor streaks across the sky during the annual Perseid meteor shower.

INTRODUCTION

Recently, many credible witnesses, often military aviators, have reported seeing objects they did not recognize over U.S. airspace. Most of these events have since been explained, but a small handful cannot be immediately identified as known human-made or natural phenomena. These events are now collectively referred to as Unidentified Anomalous Phenomena, or UAP[1].

A vital part of NASA's mission is exploring the unknown using the rigorous process of the scientific method. This means scrutinizing our assumptions and intuition; transparently and diligently collecting data; reproducing results; seeking independent evaluation; and finally, reaching a scientific consensus about the nature of an occurrence. The scientific method challenges us to solve problems by impartially evaluating our own ideas, by being willing to be wrong, and by following the data.

It is increasingly clear that the majority of UAP observations can be attributed to known phenomena or occurences. When it comes to studying such phenomena, our overarching challenge is that the data needed to explain these anomalous sightings often do not exist; this includes eyewitness reports, which on their own can be interesting and compelling, but are not reproducible and usually lack the information needed to make any definitive conclusions about a UAP's provenance. Thus, to understand UAP, a rigorous, evidence-based, data-driven scientific framework is essential.

This report offers a vision of how NASA could contribute to understanding the phenomena and how the agency's approach will complement the whole-of-government effort to understand UAP.

1 At the time that this study was initiated, Congress defined UAP as Unidentified Aerial Phenomena. After this study began, the term UAP was redefined as Unidentified Anomalous Phenomena.

A weather balloon sails into the sky after release from the Cape Canaveral weather station in Florida.

RESPONSES TO STATEMENT OF TASK

1 What types of scientific data currently collected and archived by NASA or other civilian government entities should be synthesized and analyzed to potentially shed light on the nature and origins of Unidentified Anomalous Phenomena (UAP)?

FINDING

NASA'S fleet of earth-observing satellites should play a powerful supporting role to determine the environmental conditions that coincide with UAP.

NASA has a variety of existing and planned Earth- and space-observing assets, together with an extensive archive of historic and current data sets, which should be used to address the challenges of detecting and/or understanding UAP. NASA's fleet of Earth-observing satellites collect the most data within the Earth system, yet they typically lack the spatial resolution to detect relatively small objects such as UAP. However, they still should play a powerful supporting role to determine the environmental conditions that coincide with UAP. For example, the advanced sensors on the Terra and Aqua missions should be directly utilized to retroactively probe the state of the local earth, ocean, and atmospheric conditions that are spatially and temporally coincident with UAP initially detected via other methods. Thus, NASA can help determine whether specific environmental factors are associated with reported UAP properties or occurrences.

FINDING

It is essential to note the pivotal role that structured data curation plays in a rigorous and evidence-based framework to better understand UAP.

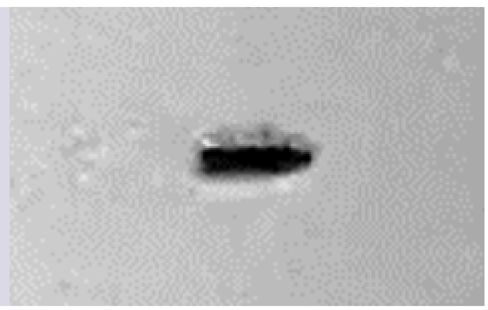
There are other promising civilian capabilities that can be employed to scrutinize UAP. Assets such as the NEXRAD Doppler radar network (160 weather radars jointly operated by the FAA, U.S. Air Force, and National Weather Service) or the Geostationary Operational Environmental Satellites will be essential for distinguishing interesting objects from airborne clutter. Furthermore, forthcoming large-sky surveys enabled by ground-based telescopes such as the Vera C. Rubin Observatory will offer powerful complements in the search for anomalous objects beyond the Earth's atmosphere.

NASA also has substantial experience in Synthetic Aperture Radar (SAR), which can provide much higher angular resolution images of Earth, as well as confirm surface motion and change. The panel sees particular promise in future SAR-based Earth-observing satellites such as NISAR (NASA-ISRO Synthetic Aperture Radar) mission, a partnership with the Indian Space Research Organization. The excellent resolution of NISAR will provide valuable radar data that will potentially be critical for examining UAP directly, in addition to their environmental context. SAR systems will also provide critical validation of any truly anomalous properties, such as rapid acceleration or high-G maneuvers through the Doppler signatures they produce.

Irrespective of the source of the observation, it is essential to note the pivotal role that structured data curation plays in a rigorous and evidence-based framework to better understand UAP. To date, UAP data often consist of observations initially acquired for other purposes, which often lack adequate metadata and are not optimized for systematic scientific analysis. Here, NASA – with its world-leading expertise in curation, archiving, and distribution of large volumes of data – can play a key role. NASA's adherence to FAIR (Findability, Accessibility, Interoperability and Reusability) data principles when generating curated data repositories enables both scientists and citizen scientists to conduct data-mining and meaningful analysis. In addition, due to the absence of a comprehensive system for gathering civilian UAP reports, there are inconsistencies in how data is collected, processed, and curated. The application of NASA's rigor to UAP data protocols will ultimately be essential for a detailed understanding of these phenomena.

South Asian Object (Image 1)
Footage taken by an MQ-9 of an unidentified object in South Asia with an apparent atmospheric wake or cavitation, later assessed as a likely commercial aircraft by the All-domain Anomaly Resolution Office. The cavitation is likely a sensor artifact resulting from video compression.

The appearance of U.S. Department of Defense (DoD) visual information does not imply or constitute DoD endorsement.



2 What types of scientific data currently collected and held by non-profits and companies should be synthesized and analyzed to potentially shed light on the nature and origins of UAP?

FINDING
The U.S. commercial remote-sensing industry offers a potent mix of Earth-observing sensors that have the collective potential to directly resolve UAP events.

The U.S. commercial remote-sensing industry offers a potent mix of Earth-observing sensors that have the collective potential to directly resolve UAP events. For instance, commercial satellite constellations provide imagery at sub- to several-meter spatial resolution, which is well-matched to the typical spatial scales of known UAP. In addition, the high temporal cadence offered by commercial remote-sensing networks can substantially increase the likelihood of providing retroactive coverage of UAP events that are initially observed via other means. The limitation on this data is that at any given time most of the Earth's surface is not covered by commercial satellites at high resolution — for a particular UAP event, we will need to be fortunate to obtain high-resolution observations from space.

Beyond this, the panel applauds the efforts undertaken in the private sector and U.S. academic community to employ one or more inexpensive ground-based sensors that are capable of surveying large areas of the sky. Such sensors, which could potentially be rapidly deployed to areas of known UAP activity may play a key role in establishing so-called "pattern-of-activity" trends, as well as potentially the physical characteristics of UAP themselves.

FINDING

The standardization of collected information via well-crafted calibration will make it possible to carry out a rigorous scientific investigation into UAP. NASA's experience in this area will be vital.

Once more, however, robust data calibration is vital, and here NASA again can play an important advisory role. The calibration process ensures that information gathered from sensors and instruments is precise, dependable and devoid of any systematic errors or biases. In the case of UAP studies, where data often originates from instruments not specifically designed for detecting such objects, proper calibration becomes even more crucial. In turn, metadata, which provides contextual information such as sensor type, manufacturer details, noise characteristics and time of acquisition, must simultaneously be present for an accurate characterization of both a potential UAP as well as the sensor itself. Indeed, several apparent UAP have been demonstrated to be sensor artifacts once appropriate calibration and metadata scrutiny were applied. Although a substantial investment, the standardization of collected information via well-crafted calibration will make it possible to carry out a rigorous scientific investigation into UAP. NASA's experience in this area will be essential.

3 What other types of scientific data should be collected by NASA to enhance the potential for developing an understanding of the nature and origins of UAP?

FINDING

NASA should leverage its considerable expertise in this domain to potentially utilize multispectral or hyperspectral data as part of a rigorous campaign.

To improve our understanding of UAP, NASA should contribute to a comprehensive approach to collecting data within the broader whole-of-government framework to understand UAP. The importance of detecting UAP with multiple, well-calibrated sensors is paramount, and NASA should leverage its considerable expertise in this domain to potentially utilize multispectral or hyperspectral data as part of a rigorous campaign to acquire additional data on future UAP. In addition, forthcoming large-sky surveys enabled by Federal ground-based assets including the Vera C. Rubin Observatory will collect vast quantities of data, which can be directly used to search for anomalous objects beyond the Earth's atmosphere.

Data signatures are vast, and theories that predict novel signatures help guide our searches. It is imperative to set clear evidence thresholds to avoid errors, especially with automated methods. Furthermore, purpose-built future sensors for UAP detection should be designed to adjust on millisecond timescales to aid better detection. In lockstep, alert systems should detect and share transient information quickly and uniformly.

The panel notes that, at present, gathering data on UAP is hampered by sensor calibration challenges and a lack of sensor metadata. In short, calibration ensures that future data gathered are reliable and accurate, while gathering metadata – such as the time, location, and sensor observing modes – ensures that the contextual and environmental factors of a recorded UAP event are well known. Both, in turn, allow for systematic analyses of UAP events, and critically will enable the elimination of false positives due to sensor artifacts. Making a concerted effort to improve both aspects will be vital when gathering future data, and here NASA's expertise should be comprehensively leveraged as part of a robust and systematic data strategy within the whole-of-government framework.

The panel also sees several advantages to augmenting potential data collection efforts using modern crowdsourcing techniques, including open-source smartphone-based apps that simultaneously gather imaging data and other smartphone sensor data from multiple citizen observers. NASA should therefore explore the viability of developing or acquiring such a crowdsourcing system as part of a future data strategy.

FINDING

NASA's expertise should be comprehensively leveraged as part of a robust and systematic data strategy within the whole-of-government framework.

As stated above, NASA's fleet of Earth-observing satellites must also play a key role in collecting future data on environmental conditions coinciding with UAP sightings. Despite the mismatch in spatial resolution between the present generation of satellites and typical UAP events, by gathering and analyzing future satellite data, we will undoubtedly gain insights into the typical environmental factors associated with UAP. Future missions, such as the NOAA/NASA Geostationary Extended Observations (GeoXO) satellite system, will provide even more robust data that will prove important in UAP analysis. NASA should also leverage sensors that expand its observational reach, such as penetrating deeper into the ocean or at the air/sea interfaces.

Next, collection efforts from radio and optical astronomy that are designed for technosignature searches should be expanded from the Earth's atmosphere to the whole solar system. Additionally, near-Earth objects (NEO) programs also have significant data collections about phenomena close to Earth's atmosphere, which constitutes an untapped repository of data both for characterizing natural phenomena and anomalies. NASA should consider integrating these elements as part of a robust future-data strategy.

Finally, NASA's very involvement in gathering future data will play an important role in reducing stigma associated with UAP reporting, which very likely leads to data attrition at present. NASA's long-standing public trust, which is essential for communicating findings about these phenomena to citizens, is crucial for destigmatizing UAP reporting and scientific research. The scientific processes used by NASA encourage critical thinking; NASA can model for the public how to approach a topic, such as UAP, by applying transparent reporting and rigorous analyses when acquiring future data.

Middle East Object

Footage taken by an MQ-9 of an apparent silver, orb-like object in the Middle East. Due to limited data, the object remains unidentified.

The appearance of U.S. Department of Defense (DoD) visual information does not imply or constitute DoD endorsement.

4 Which scientific analysis techniques currently in production could be employed to assess the nature and origins of UAP? Which types of analysis techniques should be developed?

FINDING

AI and ML, combined with NASA's extensive expertise, should be utilized to investigate the nature and origins of UAP.

Artificial intelligence (AI) and machine learning (ML) have proven to be essential tools for identifying rare occurrences within vast datasets. These methodologies, combined with NASA's extensive experience and expertise, should be utilized to investigate the nature and origins of UAP by examining data from sources such as satellites and radar systems. However, the effectiveness of AI and ML in studying UAP depends critically upon the quality of the data used to train the AI and in subsequent analysis. At present, UAP analysis is more limited by the quality of data than by the availability of techniques. As a consequence, it is a higher priority to obtain better quality data than it is to develop new analysis techniques.

Once AARO and other agencies, including NASA, accumulate an extensive and well-curated catalog of baseline data, these can be used to train neural networks so that they can characterize deviations from normal. The panel finds that standard techniques that are routinely applied in astronomy, particle physics, and other areas of science can be adapted for these analyses.

When it comes to detecting anomalies – such as UAP – within datasets, there are two approaches. The first approach involves constructing a model that represents the expected signal characteristics then searching for any matches against this model. The second approach involves using a model of the background properties and searching for anything that deviates from that model. The panel notes that the first approach is difficult as we do not possess a consistent description of the physical characteristics of UAP. The second approach, on the other hand, requires an understanding of what is considered normal and known in a given search area, which can then be distinguished from what is unusual and unknown. AARO has already begun this task by studying what "normal" phenomena such as solar glint or balloons look like to military sensors. The program of systematically calibrating observations of "normal" is an essential step before starting to search for the abnormal.

A third potential avenue for scientific analysis is to cross-correlate NASA's extensive databases with the locations and times of reported UAP events. Once an extensive list of UAP reports is made available, the panel regards this as a promising method for future analysis. Again, NASA's expertise in AI and ML will allow it to make a prominent contribution.

FINDING

NASA, with its expertise in data calibration, management, and advanced analysis is well-positioned to take a central role in these efforts.

For any scientific analysis purposes, including UAP analysis, it is essential that the data used for AI and ML are collected according to rigorous standards. The data must be collected using calibrated instruments tailored to their respective use cases accompanied by metadata to facilitate calibration and contextual comprehension. Proper curation and integration of data are also critical for enabling scientific analysis. To establish a baseline understanding, an examination of known events with precisely calibrated instruments is also necessary. NASA, with its expertise in data calibration, management, and advanced analysis is well-positioned to take a central role in these efforts within the whole-of-government framework to assess UAP.

5 In considering the factors above, what basic physical constraints can be placed on the nature and origins of UAP?

Observations of UAP to date are inconsistent and do not adhere to similar characteristics. As a consequence, it is difficult to put physical constraints on them at present, which provides a strong motivation for the rigorous, evidence-based framework articulated in this report. The strongest physical constraints are not on the anomalous events but on the conventional events: we know the range of velocities and accelerations that can be achieved by state-of-the art platforms, drones, balloons and planes. Deviations from this behavior, such as any well-characterized observation of velocities and accelerations outside of that range, are scientifically interesting for UAP assessment and analysis. The panel emphasizes that clearly determining distances is key to understanding and corroborating any claimed anomalous high-velocity and high-acceleration events, a fact borne out by AARO's findings that the vast majority of UAP have prosaic explanations.

FINDING
The panel regards placing physical constraints on UAP, together with the suite of plausible natures and origins, as being within reach.

If the whole-of-government framework to understanding UAP – with NASA playing a crucial role – were to implement the preponderance of steps prescribed above, then the panel regards placing physical constraints on UAP, together with the suite of plausible natures and origins, as being within reach. If all unidentified events move at conventional speeds and accelerations, this likely points towards a conventional explanation for these events. Convincing evidence of verified anomalous accelerations and velocity would point towards potentially novel explanations for UAP.

6 What civilian airspace data related to UAPs have been collected by government agencies and are available for analysis to a) inform efforts to better understand the nature and origins of UAPs, and b) determine the risk of UAPs to the National Air Space (NAS)?

FINDING
With its world-leading expertise in data curation and organization, NASA is well-positioned to advise on the best methodologies for establishing repositories of civilian airspace data.

Government agencies, including the FAA, gather civilian airspace data that can be analyzed to probe for UAP. These data include information obtained from air traffic control towers and radar systems. However it is essential to note that such data are not always optimized or suitable for rigorous scientific analysis of UAP. The observations almost always happen incidentally using instruments not specifically designed for detecting objects; furthermore, crucial contextual information in the form of metadata is often missing. Although civilian airspace data has been used by AARO to assist with the analysis of isolated UAP cases, the broad corpus of such data is unlikely to yield a global understanding of the size, movement, or nature of UAP.

Furthermore, at present, there is no standardized Federal system for making civilian UAP reports. While AARO is establishing a systematic mechanism for military and intelligence community UAP reports, current FAA guidelines instruct citizens wanting to report UAP to contact local law enforcement or one or more non-governmental organizations. As a result, the collection of data is sparse, unsystematic, and lacks any curation or vetting protocols.

Here, once more, NASA can provide important assistance to the whole-of-government effort to understand UAP. With its world-leading expertise in data curation and organization, NASA is well-positioned to advise on the best methodologies for establishing repositories of civilian airspace data.

7 What current reporting protocols and air traffic management (ATM) data acquisition systems can be modified to acquire additional data on past and future UAPs?

FINDING

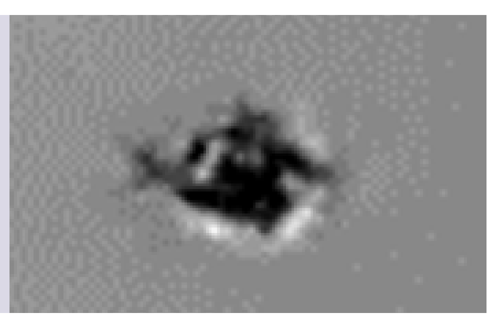
Leveraging the Aviation Safety Reporting System for commercial pilot UAP reporting would provide a critical database.

It is clear to the panel that establishing a more robust and systematic framework and data repository for UAP reporting is essential. This particularly applies to civilian reporting of UAP: current FAA guidelines suggest that citizens wanting to report UAP contact their local law enforcement or one or more non-governmental organizations, which is inadequate for drawing scientific inferences. Although such eyewitness reports are often interesting and compelling, they are insufficient on their own for making definitive conclusions about UAP. Thus, their effective corroboration within a robust reporting and follow-up framework based on systematically gathered data (including the ATM system) can provide a useful tool for understanding UAP.

A particularly promising avenue for deeper integration within a systematic, evidenced-based framework for is the NASA's Aviation Safety Reporting System (ASRS), which NASA administers for the FAA. This system is a confidential, voluntary, non-punitive reporting system that receives safety reports from pilots, air traffic controllers, dispatchers, cabin crew, ground operators, maintenance technicians, and UAS operators that provides a unique data source for emerging UAS safety issues. ASRS receives reports describing close-calls, hazards, violations, and safety-related incidents. With 47 years of confidential safety reporting, ASRS has received more than 1,940,000 reports, averaging approximately 100,000 per year. Reports are received from all aspects of aviation operations. Although the system resides at NASA Ames and involves NASA employees, the ASRS program is solely funded by FAA and it is not part of NASA's Aeronautics activity. Although not initially designed for UAP collection, leveraging this system for commercial pilot UAP reporting would provide a critical database that would be valuable for the whole-of-government effort to understand UAP, and here NASA should provide technical assistance.

South Asian Object (Image 2)
Footage taken by an MQ-9 of an unidentified object in South Asia with an apparent atmospheric wake or cavitation, later assessed as a likely commercial aircraft by the All-domain Anomaly Resolution Office. The cavitation is likely a sensor artifact resulting from video compression.

The appearance of U.S. Department of Defense (DoD) visual information does not imply or constitute DoD endorsement.



8 What potential enhancements to future ATM development efforts can be recommended to acquire data concerning future reported UAPs to assist in the effort to better understand the nature and origin of the UAPs?

FINDING

NASA's strong partnership with the FAA will be pivotal to designing future air traffic management systems to acquire UAP data.

NASA's deep experience in researching and developing air traffic management tools, together with its strong partnership with the FAA, will be pivotal to designing future ATM systems to acquire UAP data. At present, surveillance instruments are not designed to detect anomalous objects, and associated metadata are often absent. NASA should begin by developing new concepts and ideas for ATM systems, which enable these systems to assist in the effort to better understand UAP.

NASA should leverage its expertise by reviewing and demonstrating passive sensing techniques. NASA should also consider platforms that include new types of data such as imaging data and even multispectral or hyperspectral data. In turn, NASA could conduct research to see whether machine learning algorithms could be incorporated into future ATM systems to detect and analyze UAP in real-time. This research would represent a complex undertaking whose outcome could allow for substantial and systematic gathering UAP data as well as a robust characterization of the background. Once again, NASA's experience and expertise in these areas would allow it to provide critical assistance in identifying and evaluating new safety systems.

This NASA Space Shuttle STS-100 image captures naturally occuring von Karman vortices forming in clouds near Rishiri-to island in Japan, caused by a stable, low-cloud atmosphere flowing over a tall obstacle.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

We recommend that NASA play a prominent role in the whole-of-government effort to understand UAP by leveraging its extensive expertise to contribute to a comprehensive, evidence-based approach that is rooted in the scientific method. We specifically recommend that NASA utilize its existing and planned Earth-observing assets to probe the local environmental conditions associated with UAP that are initially detected by other means. In so doing, NASA can directly probe whether certain environmental factors are coincident with known UAP. We further recommend that NASA explore enhancing collaborations with the U.S. commercial remote-sensing industry, which offer powerful constellations of high-resolution Earth-observing satellites.

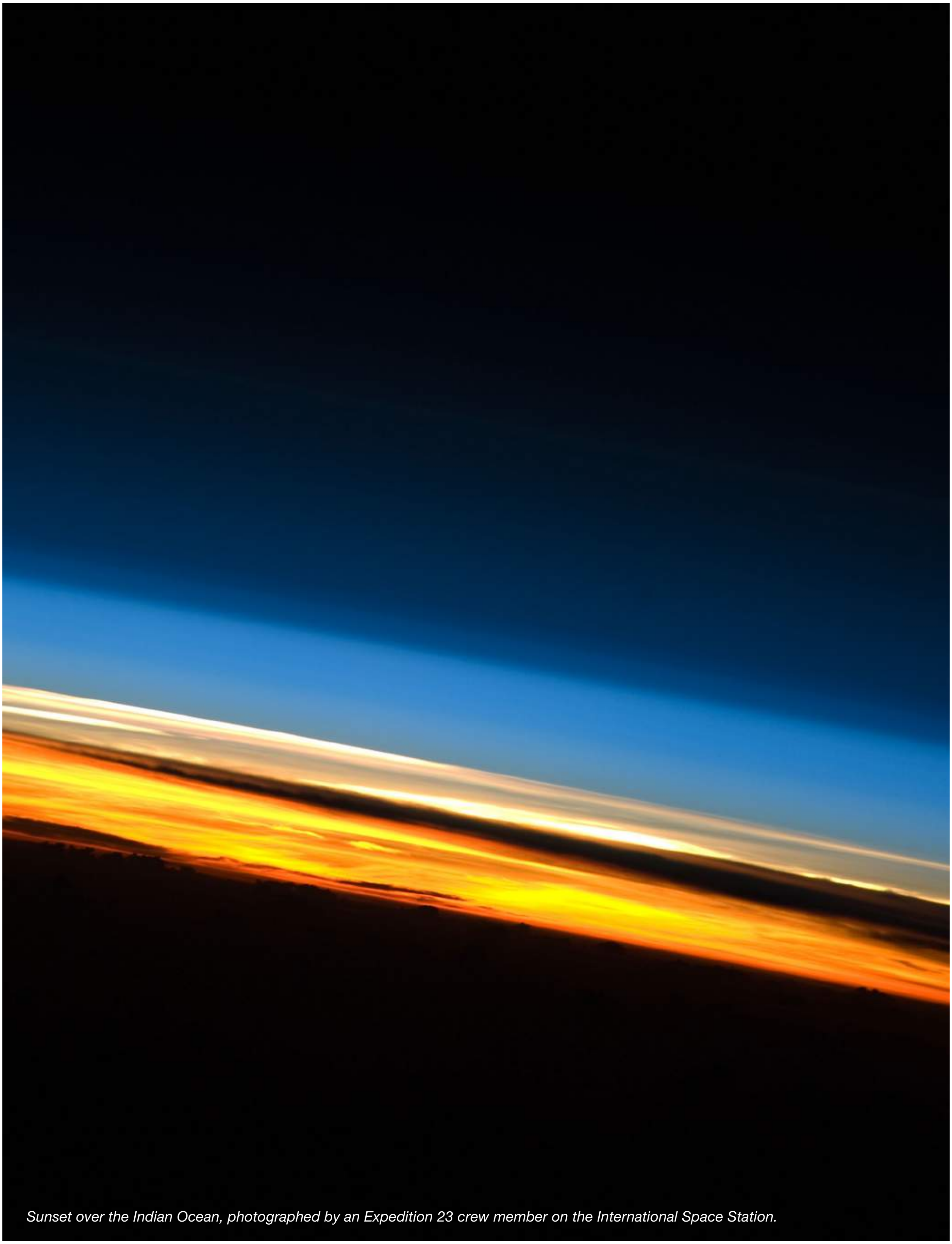
At present, the detection of UAP is often serendipitous, captured by sensors that were not designed or calibrated for this purpose, and which lack comprehensive metadata. Coupled with incomplete data archiving and curation, this means that the origin of numerous UAP remain uncertain. The importance of detecting UAP with multiple, well-calibrated sensors is thus paramount, and accordingly we recommend that NASA leverage its considerable expertise in this domain to potentially utilize multispectral or hyperspectral data as part of a rigorous data acquisition campaign.

In turn, the panel finds that sophisticated data analysis techniques, including artificial intelligence and machine learning, must be used in a comprehensive UAP detection campaign when coupled with systematic data gathering and robust curation. Here, we recommend that NASA's expertise in these key areas be contributed to the whole-of-government UAP effort.

The panel finds that public engagement in the effort to better understand UAP will be vital. NASA, by lending its name to UAP studies, is already helping to reduce stigma associated with reporting. Beyond this, we recommend that NASA explore the viability of developing or acquiring a crowdsourcing system, such as open-source smartphone-based apps, to gather imaging data and other smartphone sensor data from multiple citizen observers as part of a wider effort to more systematically gather public UAP reports.

Lastly, we recommend that the Aviation Safety Reporting System (ASRS) for commercial pilot UAP reporting be better leveraged, providing a critical database for the whole-of-government effort to understand UAP. The agency's long history of partnership with the FAA should also be capitalized to investigate how advanced, real-time analysis techniques could be applied to future generations of air traffic management (ATM) systems.

In conclusion, NASA is uniquely positioned to contribute to a robust and systematic approach to studying UAP, furthering its mission of advancing scientific knowledge, technical expertise, and exploration. When considering the above recommendations, and according to budget priorities, NASA should leverage its core capabilities and expertise to determine whether it should take a leading or supporting role in implementing a given recommendation. The positioning of NASA's role should further be situated within the context of the broader whole-of-government approach to understanding UAP.



Sunset over the Indian Ocean, photographed by an Expedition 23 crew member on the International Space Station.

ACKNOWLEDGEMENTS

The compilation of this report has been a significant task, made possible only through the collective efforts of a dedicated team of professionals. We would like to take a moment to acknowledge and express our gratitude to those who have been instrumental in this endeavor.

At the forefront, our profound appreciation goes to NASA for their unwavering support and commitment. We are deeply grateful to NASA Administrator Sen. Bill Nelson for his visionary approach, recognizing the importance of NASA's involvement in this initiative. Dr. Daniel Evans, our Designated Federal Official, has provided exceptional leadership and guidance throughout this study. Our gratitude extends to Science Mission Directorate Associate Administrator Dr. Nicky Fox and her predecessor, Dr. Thomas Zurbuchen, for their invaluable advice. Additionally, a special mention must be made of NASA's Earth Science Division for graciously hosting this activity under the Earth Science Advisory Committee.

Handling media inquiries with finesse and professionalism, Katherine Rohloff, NASA's UAP Press Secretary, has been an essential pillar in our communication strategy. Her dedication to ensuring accurate and effective communication of our findings to the public has been commendable.

Our sincere thanks go to Dr. Sean Kirkpatrick, the Director of AARO. His expertise and collaboration have been invaluable, enriching our understanding and providing a solid foundation for our committee's work.

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To all mentioned and the countless others who have contributed behind the scenes, we extend our deepest gratitude. Your commitment, expertise, and passion have been the driving force behind this report, and we are profoundly thankful for your contributions.

WORK PRODUCTS: DISCUSSION

The panel's responses to the eight charge elements in the Terms of Reference, as well as the panel's overall recommendations and conclusions, all stemmed from a series of sub-panel reports that the entire team deliberated in full at the public meeting held on May 31, 2023. The reports are included in this section for full public transparency.

UAP in a Scientific Context

On June 9, 2022, NASA announced an independent study of unidentified anomalous phenomena (UAP), with a focus on identifying how the Agency could address the question scientifically. Recently, many credible witnesses, often military aviators, have reported seeing objects they did not recognize over U.S. airspace. Most of these events have since been explained, but a small handful cannot be immediately identified as known humanmade or natural phenomena. These events are now collectively referred to as UAP. But are these objects real or are they sensor artifacts? Are they a threat to aerospace safety? Are they a threat to U.S. national security? Are they unknown natural phenomena? What else could they be?

This report outlines several approaches NASA could take if the Agency chooses to address the question of UAP.

A vital part of NASA's mission is to explore the unknown. Often, the most exciting aspect of exploration is discovering unexplained phenomena. After discovery, the next step in charting the unknown requires applying rigorous scientific approaches to understand an observation. This means scrutinizing our assumptions and intuition; transparently and diligently collecting data; reproducing results; seeking independent evaluation; and finally, reaching a scientific consensus about the nature of an occurrence. It was Thomas Jefferson who, in an 1808 letter, wrote: "A thousand phenomena present themselves daily which we cannot explain, but where facts are suggested, bearing no analogy with the laws of nature as yet known to us, their verity needs proofs proportioned to their difficulty."

Today, we summarize Jefferson's conclusion as "extraordinary claims require extraordinary evidence." This is especially true when it comes to claims that could profoundly change how we view our place in the cosmos. Over millennia, we've developed ever more powerful instruments to study the universe and each time we've looked at the sky—or our planet—in a different way, we've observed surprising and perplexing phenomena that at first defied explanation.

For example, in 1967, astrophysics graduate student Jocelyn Bell-Burnell discovered a pulsing cosmic radio source. Its pulses were so regular—just like a ticking clock—that it at first seemed artificial in origin. But she eventually discovered that her confoundingly periodic cosmic object was a rapidly rotating neutron star: a pulsar. Today, scientists know of thousands of pulsars, and they can harness their clock-like rotation to probe everything from nuclear physics to gravitational waves produced by colliding supermassive black holes. In the 1960s, satellites also detected mysterious gamma-ray bursts. These initially looked like evidence for covert Cold War-era nuclear tests. Now, astronomers know that these tremendously energetic explosions are caused when massive stars cataclysmically collapse and die, and when stellar corpses violently collide.

Science has also solved mysteries that originated much closer to home, including the mechanisms behind bioluminescence and glittering atmospheric "sprites"—beautiful orange-red flashes of light that were reported for more than a hundred years but only scientifically explained recently. The crucial steps in understanding these events were the systematic collection of data, the rigorous testing of hypotheses, the development of new observational techniques to study unknowns, and an open and transparent scientific discussion.

The scientific method challenges us to solve problems by stringently evaluating our own ideas, by being willing to be wrong, and by following the data into unknown territory—wherever it may lead us. As Carl Sagan wrote in *The Demon-Haunted World*, "science carries us toward an understanding of how the world is, rather than how we would wish it to be."

Science is a process that reveals reality rather than sculpts it—no matter how unsatisfying or confusing that reality might be.

That includes the question of whether UAP have an extraterrestrial origin. There is an intellectual continuum between hypothesizing that faraway extraterrestrial civilizations might produce detectable technologies, and looking for those technologies closer to home. But in the search for life beyond Earth, extraterrestrial life itself must be the hypothesis of last resort—the answer we turn to only after ruling out all other possibilities. As Sherlock Holmes said, "Once you eliminate the impossible, whatever remains, no matter how improbable, must be the truth."

To date, in the peer-reviewed scientific literature, there is no conclusive evidence suggesting an extraterrestrial origin for UAP. When it comes to UAP, the challenge we have is that the data needed to explain these anomalous sightings often do not exist; this includes eyewitness reports, which on their own can be interesting and compelling, but aren't reproducible and usually lack the information needed to make any definitive conclusions about a phenomenon's provenance.

This report offers a vision of how NASA could contribute to understanding the phenomena and how the agency's approach might complement efforts by other federal entities. Congress has made the Department of Defense's All-domain Anomaly Resolution Office (AARO) the lead Federal organization for resolving these anomalies. With its emphasis on open scientific inquiry, NASA can complement AARO's work.

The following sections highlight the information provided to the panel, and our conclusions, over seven months of fact-finding.

What is NASA's Role?

NASA is a science-driven agency committed to exploring and understanding air and space. That mission includes tackling unknown phenomena, whether in the farthest reaches of the universe or closer to home, as well as here on Earth. For more than 60 years, the Agency has focused on astronomy, astrophysics and aeronautics; it also uses space-based assets to study our home world's aquatic, atmospheric, cryospheric, and terrestrial systems.

As a result of NASA's long and storied history of space (and space-based) research, the Agency has amassed a robust and rigorous scientific arsenal for investigating unexplained observations, which will be crucial for studying UAP. The Agency has a variety of existing and planned assets—plus a trove of historic and current data sets—that could be used to address the challenges of detecting and/or understanding UAP. NASA research also employs a wide range of observation and analytical methods, using calibrated sensors, advanced data analysis, modeling, and cutting-edge computational and data visualization tools. As such, NASA's missions, data, and technical expertise in science and engineering could help to investigate and understand reported UAP.

The panel considered how existing and/or planned NASA missions, data, experience, or studies might contribute to the understanding of UAP using global satellite and suborbital observations. Chiefly, NASA's scientific discoveries, results, and databases are public. Already, an extensive data archive from NASA satellites and foreign partner space agencies is openly available, ensuring transparency as well as the opportunity for citizen scientist participation.

In Earth science, NASA's core mission is to understand and protect our home planet. Passive radiometric Earth-observing missions, such as NASA's Terra and Aqua satellites, currently employ a range of sensors that collect information about Earth's land, ocean, atmosphere, and other components. These data sets could help to identify weather, ocean, and other environmental characteristics coincident with UAP observations. New Earth-observing missions, such as NISAR (NASA-ISRO Synthetic Aperture Radar), a partnership with the Indian Space Research Organization, will provide valuable radar data that could be helpful for examining UAP directly, in addition to their environmental context.

These newer observations live within a historical context. For more than 50 years, global time series data gathered by NASA (with partners including the National Oceanic and Atmospheric Administration [NOAA]) have allowed researchers to examine trends within and across components of Earth's systems. Such long-term data sets help scientists better understand the evolving Earth, while also identifying natural and anthropogenic variability in the Earth system. Knowing that baseline allows researchers to detect and examine Earth's environment for anomalies. Examples of naturally occurring anomalies include events such as harmful algal blooms, hurricanes and typhoons, changes in the jet stream, drought and fire conditions, and bioluminescence in the ocean. Understanding the origins of such large-scale phenomena is at the heart of NASA's Earth science mission.

NASA has a long and successful record of partnering with other Federal agencies. In the study of UAP, the establishment of a NASA/AARO liaison will be an important step towards enabling interagency cooperation.

In addition to the Agency's Earth science research programs, NASA also supports programs in astrobiology. Some of these programs investigate life in extreme environments on Earth—with the hypothesis that such organisms and conditions could be analogs for habitable environments elsewhere in the universe. Other programs investigate the possibility that extraterrestrial life exists.

In astrophysics and space sciences, NASA is focused on understanding the universe. Looking for anomalies in both air and space will likely lead to novel discoveries; some might reveal entirely new physics, while others will be interesting and important even if their explanations lie in conventional physics. In time-domain astrophysics, researchers are increasingly interested in identifying unusual, transient events. At radio wavelengths, this includes the recent discovery of fast radio bursts, which astronomers are still struggling to understand. Recently, most innovation has been accomplished by combining information from multiple observatories that operate at different electromagnetic wavelengths, from radio and optical telescopes on the ground to ultraviolet and gamma-ray telescopes in space, and even with different messengers: neutrinos and gravitational waves. Observatories with extensive sky coverage and dense time coverage are ideal for spotting near-Earth objects with large proper motions and phenomena with anomalous time evolution. For example, the NASA Planetary Defense Coordination program is dedicated to leveraging NASA and partner astrophysical research assets to identify and classify near-Earth objects—such as asteroids—that move rapidly across the sky.

In addition to its extensive Federal and international partnerships, NASA is also uniquely capable of leveraging public and private partnerships—for example, working with commercial partners in Earth-observing satellite data. These collaborations could result in new technologies that may be useful in observing and understanding UAP. Partners, including other Federal agencies such as NOAA and the Federal Aviation Administration (FAA), may collect data that could help to understand UAP. Moreover, NASA has a strong record of international collaboration, which could be beneficial, as the study of these phenomena would benefit from global cooperation and data sharing. Given NASA's experience with long-term scientific projects and missions, the Agency is well equipped to handle the extensive and ongoing study that UAP investigation likely requires.

Many scientists and aviators consider the study of UAP to be "fringe" at best. The panel heard a first-hand account of the type of stigma that may come from reporting UAP, which almost certainly leads to attrition in reporting.

Recently, the DoD began encouraging military aviators to disclose anomalies they encountered, which resulted in a significant increase in UAP reports: Between March 5, 2021, and August 30, 2022, DoD received a total of 247 new UAP reports, according to an analysis published by the Office of the Director of National Intelligence (ODNI) in 2022. In contrast, 263 reports had been filed in the 17 years prior to March 2021. Dr. Sean Kirkpatrick reported at this panel's public meeting that AARO has now collected more than 800 reported events. This includes the addition of data from the FAA. AARO and ODNI assess that the observed increase in the reporting rate is partially due to a better understanding of the possible threats that UAP may represent—either as flight safety hazards or as potential adversary collection platforms. This is partially due to reduced stigma surrounding UAP reporting.

The negative stigma that impacts reporting rates in turn impacts the study of UAP. In testimony before the Senate Commerce, Science and Technology Committee on February 15, 2023, the Acting FAA Administrator was asked about the process for civilian reporting of balloons. The Administrator, who is also a pilot, indicated that the protocols and reporting of balloons may be spotty. Thus, even as such reports are being encouraged, there are still barriers to reporting observations. For example, how or where should someone make a report? Will the reporter be believed or shamed? Will any action be taken to understand the event?

NASA could play an important role in destigmatizing the UAP reporting process. NASA's long-standing public trust, which is essential for communicating findings about these phenomena to the public, is also crucial for destigmatizing UAP reporting. The scientific processes used by NASA encourage critical thinking and skepticism; within this framework, there should be no credulous acceptance of unlikely reports with unlikely explanations. NASA can model for the public how to approach a topic, such as UAP, by applying transparent reporting and rigorous analyses.

Further, the NASA brand is trusted, global, and positive, representing science, curiosity, and technological achievement in the face of adversity. NASA serves as an example of professionalism and leadership in technological advancement. The NASA logo is enough to generate interest and credibility; studies of things that were previously fringe moved into the mainstream when NASA became involved. Prominent examples of NASA's involvement in public life include slogans like "NASA is with you when you fly," which promote aviation safety. In turn, every U.S. commercial aircraft and every U.S. air traffic control tower has NASA-supported technology on board.

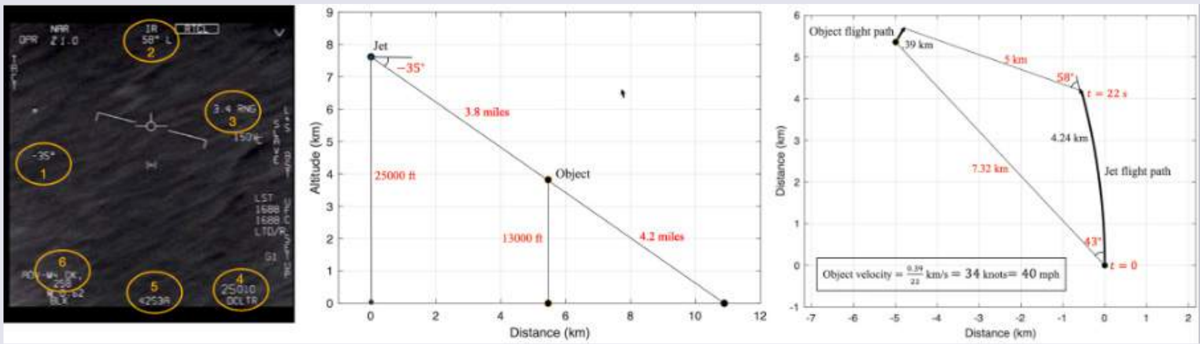
NASA's public announcement of its UAP Independent Study Team membership was met with interest and spurred both positive and negative feedback. At least one scientist serving on the study team reported receiving negative (hate) mail from colleagues due to their membership. Others were ridiculed and criticized on social media. Study Team members also noted firsthand knowledge of colleagues who were warned to stay away from research in areas like extraterrestrial technosignatures, which could damage their scientific credibility and promotion potential. These experiences further confirm the negative stigma associated with studying unusual or unexplained phenomena. Such criticism, either by detractors or by proponents of the extraterrestrial hypothesis, are anathema to the scientific method, which NASA always has and will continue to promote in an objective and open-minded fashion.

As a Federal agency, NASA can make it safer for researchers to explore data within the civilian aerospace domain by starting that work within the Agency itself. NASA can look at how civil data is shared, study how reporting can be incentivized, and help to engage the community. For example, NASA can rally the civil space community through requests for information, by convening conferences, by offering grand challenges, and other activities.

Many Federal, state, local, private, and other domestic and international partners collect data and observations that could be relevant for understanding UAP. As an example, NASA's potential to study the universe is enhanced through partnerships with other agencies, such as the National Science Foundation (NSF) and the Department of Energy (DoE), which are currently building facilities such as the Vera C. Rubin Observatory that will generate data that may be useful for understanding UAP in space. NASA's ability to study Earth is enhanced through partnerships with NSF, which supports Antarctic research. The Antarctic is a superb environment for collecting meteorites. With its low level of human activity, it is a low "clutter" environment for identifying anomalies. Such sparsely occupied airspaces may offer a low background environment for UAP searches; however, it is unclear as to whether or not constraining the search geographically would exclude their presence, or whether environmental phenomena could also be a significant, location-dependent source of noise.

The Federal partnership between AARO and NASA already provides a foundation for a collaborative examination of UAP events. In addition, NASA and AARO should engage other agencies, as appropriate and as needed.

A well-known UAP event is the "GoFast" video, recorded by navy aviators from the USS Theodore Roosevelt. A still frame from this video is shown in the Figure below, where the infrared camera has locked onto a small object in the center. The video gives an impression of an object skimming above the ocean at a great velocity. But analysis of the numerical information on the display reveals a less extraordinary interpretation.



The circled numbers in the image provide the information needed to estimate the object's altitude and velocity. This information includes (1) elevation angle of the camera (negative = downward), (2) azimuth angle of the camera, (3) target range in nautical miles, (4) the aircraft's altitude in feet, (5) time reference in seconds, and (6) indicated air speed in knots. Using items 1, 3, and 4, plus a bit of trigonometry, we calculate that the object is at an altitude of 13,000 feet, and 4.2 miles from the ocean behind it (see middle panel). Given that the aircraft's groundspeed is about 435 mph, we may conclude that the impression of rapid motion is at least partly due to the high velocity of the sensor, coupled with the parallax effect.

We can use other information from the display to place some limits on the true velocity of the object. This analysis is summarized in the right-hand panel, which depicts an overhead view of the encounter during a 22-second interval. The jet was banking left at about 15° during this time, which corresponds to an approximate turning radius of 16 kilometers. We know the range and bearing of the object at the start (t=0s) and end (t=22s) times. Using the calculated true air speed (TAS) and a bit more trigonometry, we find the object moved about 390 meters during this 22-second interval, which corresponds to an average speed of 40 mph. This is a typical wind speed at 13,000 feet.

Our calculation has neglected wind effects on the aircraft, and thus there is uncertainty in this result. But the analysis reveals that the object need not be moving at an extraordinary velocity. Note also that the object appears bright against a dark ocean for these display settings. This indicates that the object is colder than the ocean. There is thus no evidence of heat produced by a propulsion system. This further supports the conjecture that the object is most likely drifting with the wind. The availability of additional data would enable a more firm conclusion about the nature of this object.

Original GoFast video, released by the Department of Defense:
https://www.navair.navy.mil/foia/documents

U.S. Federal agencies that could support the effort to understand UAP include the DoD, Department of State, the FAA, the Department of Commerce (DoC) and major agencies within DoC including NOAA, the National Institute of Standards and Technology, and the Bureau of Ocean Energy Management, plus the DoE and NSF.

Data on UAP

Status of Existing Data

NASA collects an enormous amount of data using highly-calibrated, validated equipment from a variety of environments and domains across the entire Earth. Could NASA bring this same approach of rigorous science to UAP?

Before we can apply the scientific method to understanding an unusual phenomenon, the relevant data must first meet standards for data-driven approaches. Many such standards have been codified over time, including the FAIR data principle—an acronym for Findability, Accessibility, Interoperability, and Reusability[2]. We followed these and other similar principles when reviewing the current status of data on UAP, and that analysis led to the findings and recommendations in this report.

UAP data are rarely, if ever, collected in a concerted effort to understand the phenomenon; they are usually coincidental observations. Often, observations of UAP are made using instruments or sensors that have not been designed or calibrated to detect anomalous objects, and to constrain their movement parameters. Metadata (meaning sensor type, manufacturer, noise characteristics, time of acquisition, instrument sensitivity, information about the data storage such as bit-depth, location of the sensor, conditions of the sensor such as temperature, exposure characteristics, and so on) are often absent, making calibration and a thorough understanding of context difficult. So, there is correspondingly limited information associated with many of the unresolved UAP reports—even if several reports are accompanied by photographic or videographic evidence.

As a result, existing observations are neither optimized for studying UAP nor are they suited for a systematic scientific analysis.

In addition, much of the data collected by military sensors or intelligence satellites are classified—often because of what the imagery could reveal about U.S. technical capabilities to our adversaries, and not because of what is actually in the images. While essential for security, these classified observations enhance the sense of mystery and conspiracy surrounding UAP, and they present an obstacle to scientific inquiry.

For many events, the data and metadata did not enable a conclusive characterization of the size, motion, or nature of the UAP. Yet, where it did, such as in the "GoFast" UAP video, the apparent anomalous behavior of the UAP can often be explained by the motion of the sensor platform[3].

In contrast, NASA observations are made using well-calibrated instruments that have been designed for their specific use cases. This is how NASA can scientifically approach the study of Earth- and space-based phenomena.

In science, data need to be reproducible, and hypotheses falsifiable—the scientific method works by systematically analyzing data with the intent to falsify a hypothesis.

As a general principle, the data should support measurement that can rule out specific explanations or interpretations, leaving us with no choice but to embrace its opposite. In the case of UAP, the hypothesis we seek to reject (or "null hypothesis") is that the UAP have phenomenology consistent with known natural or technological causes. Eyewitness reports should be considered along with corroborating sensor data in the study of UAP as reports may reveal patterns (for example, clusters in time or location). Yet, without calibrated sensor data to accompany it, no report can provide conclusive evidence on the nature of UAP or enable a study into the details of what was witnessed. While witnesses may be inherently credible, reports are not repeatable by others, and they do not allow a complete investigation into possible cognitive biases and errors (such as accuracy in perception, or misperception caused by environmental factors, errors in the recording device, judgment or misjudgment of distance or speed, for

2 *https://www.nature.com/articles/sdata201618*
3 Dr. Sean Kirkpatrick's presentation to this committee, May 31, 2023

example). Therefore, the reports do not alone constitute data that can support a repeatable, reproducible analysis, and the hypothesis that what was witnessed was a manifestation of known natural or technological phenomena cannot be falsified.

Collecting New Data

The instrumental characteristics of the equipment that can potentially capture UAP data are important information that should be available for researchers studying the observations. This is essential for a data- driven study of UAP. These characteristics may include lab-measured (rather than field-reported) error rates of sensors that are routinely used by both civilian and military aircraft; modeling of optical "ghosting" in the images due to scattering of solar and lunar glints within the camera system; solar or bright star glints from oceans' surfaces; and noise sources intrinsic to the sensors themselves.

Multisensor platforms are important for providing a complete picture of a UAP event. An object's motion should be recorded, as well as its shape (imaging data), color (multispectra or hyperspectral data) and any sounds and other characteristics. Crowd-sourced observations that are standardized can also offer important metadata information that can be used to filter and classify events.

The panel sees an advantage to augmenting potential data collection efforts using modern crowd-sourcing techniques, including open-source smartphone-based apps. Using open-source software is consistent with NASA's commitment to transparency. From multiple near-simultaneous observations with smartphones, imaging and sound data could be collated, and metadata used to triangulate an object's location and estimate its velocity and size.

Such a database could be developed through a partnership involving AARO, NASA, and commercial partners. The collected data would need to meet the standards described above, so platform developers would need to focus on constructing a data architecture that would support such collection. NASA can use its experience in citizen science projects to help minimize data noise, systematic errors, and cognitive biases related to human observed events (as opposed to sensors).

Once an anomalous signal is identified, new discovery infrastructure may be needed to characterize it in full. Collecting additional data on a rapidly evolving phenomenon of interest has become a common practice in astrophysics, but collection of what in astrophysics is referred to as "follow-up data" requires a high level of automation in the collection, reduction, (real time) analysis of the discovery data, and robotization of follow-up facilities. While NASA has historically paved the way for this mode of observing by developing and supporting the General Coordinates Network (GCN) that enables rapid coordination of observations from ground and space assets, consideration of developing such an infrastructure should follow after careful planning of the discovery data as outlined above as such a plan is significantly resource-intensive. If systematic studies of these events continue to reveal anomalies, then future studies may consider optimizing such a system of follow-up observations.

Data Curation and Integration

There is no standardized Federal system for making civilian UAP reports. While the DoD is establishing a systematic mechanism for military UAP reports, current FAA guidelines instruct persons wanting to report UAP to contact local law enforcement or a non-governmental organization such as the National UFO Reporting Center[4]. This results in inhomogeneously collected, processed, and curated data.

Integrating NASA's open, civilian dataset with DoD's more focused, restricted information would take some effort. Additionally, data integration opportunities exist with NOAA. Assets such as the NEXRAD Doppler radar network (160 weather radars jointly operated by the FAA, U.S. Air Force, and National Weather Service) or the Geostationary Operational Environmental Satellites may be very useful for distinguishing interesting objects from airborne (wind-borne) clutter.

4 https://www.faa.gov/air_traffic/publications/atpubs/atc_html/chap9_section_8.html

Commercial remote sensing systems could be another source of high-quality UAP-relevant data, as high-resolution, high-cadence imagery captured by dense satellite constellations could resolve UAP events. For instance, commercial constellations provide daily (or more frequent) cadence imagery, at sub- to several- meter spatial resolution. However, integrating anomalous events across platforms, including radar data and commercial downward looking satellites, is an expensive exercise.

In addition to integration, data curation is also an important part of the scientific approach. Currently, studying even a single UAP event requires a heavy lift in retrieving data (and metadata, when available), which at the moment is entirely manual. It cannot be automated due to the poor organization and curation of the data. Organized data repositories are needed to facilitate automation in retrieving UAP data—and therefore, to facilitate the systematic, scientific approach to studying UAP. NASA's extensive experience in data calibration, cleaning, curation, management, and distribution, and its practice of making all of its data accessible to the public, could be leveraged to set up curated data repositories for the study of UAP. These repositories could include data from NASA assets that are suitable for the study of UAP, as well as crowd-sourced data from NASA-related platforms.

Curated public repositories of UAP data would facilitate data mining (or knowledge discovery from data) by scientists and citizen scientists. Several platforms built for analyzing scientific data have led to historical scientific discoveries. For example, the *Galaxy Zoo,* a platform that collects astrophysical data and enables citizen-scientist projects, led to the discovery of Boyajian's Star—a star with unique and peculiar fluctuations in brightness that at one point was considered a potential signature of alien technology. Years later, the star's behavior was understood to be the work of a disk of disrupted comets.

A strategy that encourages citizen analysis of UAP data would bring an element of transparency to the field that could help combat biases, preconceived skepticism, and mistrust of authorities. Opening the analysis to a large audience would also improve robustness: Multiple competing but independent teams, working on solving science's biggest questions, provide an additional layer of verification. As an example, the unexpected finding that the universe is expanding at an accelerating rate (because of the mysterious force that we now call "dark energy") is a good example of how that might work. In the 1990s, two independent teams simultaneously found evidence for the accelerating cosmos using data that had been collected and analyzed independently.

Analyzing UAP Data

When searching for a signal in data, scientists often have to separate and extract it from a complex background of signals produced by unrelated phenomena—commonly referred to as simply "background," noise, or clutter. Therefore, when looking for rare and unusual events, a common strategy is to search where there is little background noise. For example, neutrino experiments are often conducted underground (e.g. the Gran Sasso National Laboratory in Italy, IceCUBE in Antarctica); most particles cannot reach those depths because they are absorbed by the Earth. Meteorite hunters are often most successful in Antarctica—any rock found on top of a glacier is an interesting object.

In contrast, the airspace near military sites is a challenging place to search for UAP: human aircrafts, drones, balloons, and other objects, are all significant sources of background.

Geographically, sparsely occupied airspaces—such above the South Pole—may offer a low background environment for UAP searches. But UAP are poorly understood, and it's not clear whether limiting the search geographically would exclude their presence, or whether environmental phenomena could also be a significant, location-dependent source of noise. Another background-limiting strategy would be to examine astronomical plates for satellites prior to 1959, when Sputnik, the first artificial satellite of Earth[5] launched. (Although, if something unusual were to be found in historical astronomical plates, it would be difficult to verify its nature with additional data, as historical records may be incomplete, lost, intractable, not reproducible, and at best laborious to cross-reference.)

5 *https://www.sciencedirect.com/science/article/pii/S0094576522000480*

Fortunately, modern analytical techniques have improved our ability to find extremely rare signals within a sea of clutter, whether that is one Higgs event in 10^{10} collisions with the Large Hadron Collider, or a small number of photons from an exoplanet hiding in a billion stellar background photons. If the background cannot be minimized, it has to be characterized in detail and completely; detailed knowledge of the signatures (morphological, spectroscopic, kinematic) of all known airborne events need to be incorporated to eliminate spurious detections of known phenomena. This requires an extensive study of known events with accurately calibrated instruments.

There are numerous balloons and drones in the air at any moment. Observers may report some of these conventional objects as anomalies. The DoD already has the responsibility of alert response to unexplained aircraft in U.S. airspace. NASA could be a partner in the search for aerospatial events by enabling cross-identification with anomalies in the Earth-space environment. Since NASA data are already public and offered to the world in well-curated repositories accessible programmatically, the Agency's portfolio is set up to enable cross-referencing with NASA data and contribute to this characterization.

A database that supports the characterization of background signals should include information about the launch rate of balloons (weather, scientific, commercial, hobbyist, and military—where allowed by national security considerations); number of aircraft in the sky across the United States and the globe; daily drone launch rate within U.S. airspace; as well as characteristics of the appearance and motion capabilities of these items.

There are two approaches to detecting anomalies in large datasets. If you are looking for a needle in a haystack, one approach is to have a detailed model of the properties of needles and look for anything that looks like a needle. The other approach is to have an accurate model of the properties of hay and look for anything that looks different from hay.

In the first approach, if one knows the signal to expect, a model (or simulations) can be developed to look for that signal in large datasets. While we may be able to anticipate the sorts of signals produced by physical systems that adhere to known laws of physics, we cannot comprehensively envision all possible signals that could explain UAP, or that come from new technology or new physics (were it adversarial, extraterrestrial, or a naturally occurring but as-of-yet unknown phenomena).

The alternative approach to detecting anomalies requires a deep and thorough knowledge of what is normal and known, which can subsequently be separated from what is anomalous and unknown.

Machine learning has emerged as a powerful tool for the search for rare events, such as the creation of a Higgs Boson at an accelerator, the detection of rare cancer types, or the detection of fraudulent credit card charges to intrusions in cyber infrastructure. Machine learning and AI can play a role in the study of UAP, but not until the data both meet the standards described above and enable an extensive characterization of known and anomalous signals.

A recommendation about which methodologies specifically should be applied to this problem cannot be given at this time, as that selection depends on the nature of the data to be analyzed. Thus this question should be asked after (or ideally together with) the questions pertaining to UAP observing platforms and curated repositories for UAP data. Once the nature of the data is established, selecting algorithms for their analysis can be completed.

However, in the broad and lively domain of anomaly detection it is likely that methodologies for studying UAP already exist or can be adapted from analytical methods developed in other fields. Developing entirely new methodologies will likely be unnecessary and even a waste of resources, though adapting existing methods will still require some amount of dedicated effort. NASA could leverage its name, broad reach, and popularity to encourage and support an extensive review of existing methods for anomaly detection in the context of multidisciplinary conferences, workshops, and data challenges with mock datasets.

Observations Beyond Earth's Atmosphere

Even if all of the UAP events have conventional origins, the search for signs of life beyond Earth is a compelling scientific quest. For many years, researchers in astrobiology and SETI, the Search for Extraterrestrial Intelligence, have focused on developing the techniques and methods needed to spot life's signatures in the cosmos. To do that, they must first identify an anomalous signature—perhaps something suggestive of life—and then determine if that signature has an explanation based on known phenomena or if it reveals previously undetected biological or even technological activity.

These NASA-supported scientific communities have relevant experience in first determining and then communicating whether observations that might at first appear extraordinary actually justify making extraordinary claims[6,7].

Many of NASA's science missions are, at least in part, focused on answering the question of whether life exists beyond Earth. Those investigations include missions looking for biosignatures, perhaps on Mars or the icy moons orbiting Jupiter and Saturn—as well as farther afield, in the ratios of molecules present in exoplanet atmospheres.

Searching for signs of alien technology is a natural extension of those investigations. In 2017, Jill Tarter, one of the pioneers in the scientific search for extraterrestrial intelligence, coined the term "technosignatures" to capture the breadth of technologies that might be detectable. Today, we consider technosignatures to be the fingerprints of an advanced civilization in the same way that we consider metabolic byproducts, or ratios of atmospheric gases, to be the fingerprints of biology.

NASA funded short-lived searches for radio technosignatures decades ago. More recently, the agency funded a study of potential atmospheric technosignatures on exoplanets; it also supported a survey for the waste heat generated by Dyson spheres in existing infrared data. Such surveys provide useful astrophysical data even in the absence of a technosignature discovery. In addition, solar system exploration offers multiple possibilities for technosignature searches at modest additional costs. These studies could provide scientifically useful results whether or not they identify technosignatures.

NASA is the lead agency for solar system exploration. It already has an active program of detecting objects in our solar neighborhood using both ground-based and space-based facilities, and it could leverage those capabilities to search for objects in space with anomalous motion or trajectories. For example, we are capable of launching spacecraft that can escape Earth's orbit—and even escape the Sun's gravity. A more advanced civilization could be capable of building crafts that can travel much faster than the 45 km/s escape velocity from Earth's orbit, or even the 600 km/s escape velocity from our Galaxy. Interstellar travel would likely require such speeds and may entail travel at relativistic velocities. Searching for high velocity objects moving through our solar system is an example of a high risk of failure/high value of return study. In addition to looking for anomalous velocities in new or existing datasets, search programs could target objects with unusual light curves, acceleration, spectral signatures, or other relevant anomalies.

Currently planned or existing NASA missions can widen their scope to include searching for extraterrestrial technosignatures in planetary atmospheres, on planetary surfaces, or in near-Earth space. These searches generally wouldn't require changes in hardware or data acquisition, but may simply require new directions in data analysis. For example, high sensitivity studies of the stable Earth-Moon Lagrange points might conceivably find technosignatures but would likely have a high scientific payoff, such as possibly finding remnants of the collision that formed our Moon.

At this point there is no reason to conclude that existing UAP reports have an extraterrestrial source. However, if we acknowledge that as one possibility, then those objects must have traveled through our solar system to get here. Just as the galaxy does not stop at the outskirts of the solar system, the solar system also includes Earth and its environs. Thus, there is an intellectual continuum between extrasolar technosignatures, solar system SETI, and potential unknown alien technology operating in Earth's atmosphere. If we recognize the plausibility of any of these, then we should recognize that all are at least plausible.

6 Community Report From the Biosignatures Standards of Evidence Workshop - *https://arxiv.org/abs/2210.14293*

7 National Academies Independent Review of the Community Report from the Biosignature Standards of Evidence Workshop: Report Series Committee on Astrobiology and Planetary Sciences (2022) - *https://nap.nationalacademies.org/catalog/26621/independent-review-of-the-community-report-from-the-biosignature-standards-of-evidence-workshop*