CTX

SPECIAL ISSUE

Unidentified Anomalous Phenomena: Science and Analysis



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CTX

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Letter from the Guest Editors

Unidentified Anomalous Phenomena (UAP) is the modern term used for what was traditionally known as Unidentified Flying Objects (UFOs). The term UAP first appeared in the late 1960s and, in recent decades, has gradually replaced UFO in US official and scientific contexts.[1] This shift reflects an effort to move away from the culturally loaded, stigmatized, and often limiting connotations of UFO toward a more inclusive and precise definition. Unlike the earlier term, UAP encompasses reported anomalous detections across multiple domains, rather than being confined to aerial observations alone.

For decades, both trained observers and members of the public have reported objects exhibiting unusual and often unexplained characteristics. These observations have captured widespread attention. For some, national security concerns, safety, and scientific inquiry drive interest; for others, fascination centers on the possibility of unknown technologies or even extraterrestrial origins, reflecting a more speculative and curious approach to what may exist beyond our current understanding. Regardless of motivation, the undeniable reality is that UAP represent a phenomenon of growing significance and interest, making it essential to approach the topic with rigor, without stigma, and guided by evidence-based inquiry.

Growing institutional legitimacy has repositioned UAP from a marginal topic to a subject of serious inquiry. Organizations such as the US Department of Defense, the US Department of Homeland Security, NASA, and leading academic institutions (both within the United States and equivalent organizations internationally) have dedicated significant resources and personnel to studying these phenomena and addressing critical knowledge and analysis gaps. Sustained public interest and congressional hearings have reinforced transparency and accountability, helping normalize the study of UAP as a credible area for scientific and policy inquiry and encouraging more rigorous, open reporting and investigation. Recognizing the importance of this complex subject area, the US Naval Postgraduate School (NPS), in close partnership with the All-domain Anomaly Resolution Office (AARO), presents this inaugural special issue, which centers on integrating scientific methodologies into the study of UAP. Its goal is to highlight the importance of UAP through a focused, systematic, evidence-based approach; encourage stigma-free reporting and dialogue; examine current gaps and challenges; and promote collaborative strategies for the United States, its allies, and partner nations to advance rigorous study and best practices in addressing these phenomena.

The issue opens with a Foreword by Dr. Michael Hesse, who offers valuable insights into the challenges of UAP, the NPS-AARO umbrella initiative, and effective strategies to address them.

In our *CTX* Interview, AARO Director Dr. Jon Kosloski provides a firsthand perspective on the organization's mission, priorities, and strategic direction in advancing UAP-related efforts.

Dr. Randy Bostick discusses the importance of data vetting and accessibility in the study of UAP, emphasizing the need for high-quality datasets, rigorous standards, and well-validated methodologies.

Next, Kaylin Hagopian and Dr. Joshua Shank examine event-based sensing as an emerging technology for detecting, tracking, and characterizing UAP, highlighting its potential as a promising addition to the monitoring toolkit near military ranges, sensitive facilities, high-traffic air spaces, and other areas of critical infrastructure.

In the following essay, Drs. Artem Bilyk and Kyrylo Nikolaiev share lessons learned and best practices for addressing UAP-related challenges during the ongoing Russo-Ukrainian War. They underscore that studying UAP in the modern era is not only a matter of national security and defense but also a complex challenge for contemporary science.

Finally, J. Kevin Ryan provides a practical guide for everyday observers on capturing UAP events at night, emphasizing the critical role of citizen scientists in reporting and documenting them.

Our next call for papers is right around the corner. If you are interested in UAP-related topics and have valuable insights to share, we encourage you to visit the website for more information: https://nps.edu/web/ccht/forthcoming-call-for-papers

We express our sincere appreciation to all special issue contributors, including the editorial board, the *CTX* team, and our dedicated readers.

Tahmina Karimova and Lawrence Walzer
Center on Combating Hybrid Threats
Energy Academic Group
US Naval Postgraduate School

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NOTES

1 Merriam-Webster, "The Words of the Week (Feb. 10)," Merriam-Webster Wordplay, accessed March 24, 2026, https://www.merriam-webster.com/wordplay/the-words-of-the-week-feb-10

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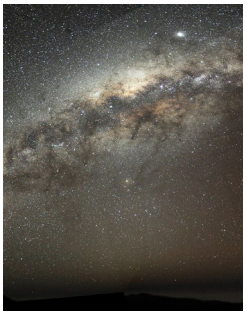
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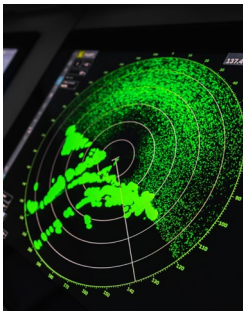
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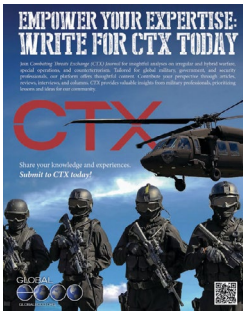
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About the Contributors

Dr. Artem Bilyk is a Ukrainian scientist, engineer, and defense specialist. He is an associate professor at the Defense Intelligence Research Institute in Kyiv, Ukraine. Dr. Bilyk holds a PhD in engineering (Candidate of Technical Sciences) from Kyiv National University of Construction and Architecture.

Dr. Randy Bostick served for more than 20 years in the US Air Force, specializing in image processing and remote sensing, developing advanced methods for extracting actionable intelligence from Department of Defense and Intelligence Community sensor systems. As Science Advisor to the All-domain Anomaly Resolution Office, Dr. Bostick helped advance the US government's approach to Unidentified Anomalous Phenomena studies. His work emphasized the application of rigorous analytic techniques, the effective use of existing government-owned sensor systems, and the design of dedicated sensors and collection strategies to improve data quality and scientific rigor. Now, as an independent consultant, Dr. Bostick remains committed to strengthening scientific methodologies and fostering collaboration across civilian, academic, industry, and government communities. He received his PhD in physics, with a concentration in electro-optical engineering, from the Air Force Institute of Technology.

Kaylin Hagopian works at Sandia National Laboratories and served as project lead for an effort that developed low-power event-based sensing algorithms for wide-area search-relevant applications. She is the primary author of the Wide Area Tracking and Characterization via Event-based sensing Reconnaissance pipeline and currently supports various efforts at Sandia that advance event-based sensing/neuromorphic capabilities, largely for nuclear nonproliferation applications, along with efforts that advance confidence calibration for automatic target recognition. She holds an MS in computer science from the Georgia Institute of Technology.

Dr. Michael Hesse serves as Vice Provost for Research and Innovation at the US Naval Postgraduate School (NPS), where he provides strategic leadership for the university's research enterprise. In this role, he oversees the development and execution of research priorities that advance the US Navy, US Marine Corps, and Department of Defense. Prior to coming to NPS, Dr. Hesse was the Director of the Science Directorate at NASA's Ames Research Center, a position in the Senior Executive Service. Before joining Ames, Dr. Hesse spent three years at the University of Bergen in Norway, where he held a professorship in physics. Dr. Hesse received his diploma and doctoral degree in theoretical physics from the Ruhr-Universität in Bochum, Germany.

Tahmina Karimova joined the US Naval Postgraduate School (NPS) in 2010. She serves as a faculty associate with the Energy Academic Group and as the deputy director for the Center on Combating Hybrid Threats. She holds a master's degree in public administration from the Middlebury Institute of International Studies and an MA in Security Studies from NPS.

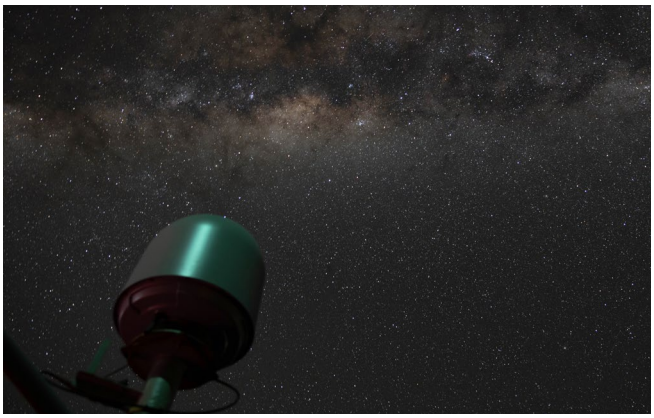
Dr. Jon T. Kosloski serves as the Director of the All-domain Anomaly Resolution Office. Prior to that, Dr. Kosloski held technical and leadership positions within the Research Directorate of the National Security Agency. In that capacity, he led advanced mission-oriented research in the fields of networking and computing and served as a subject matter expert in Free Space Optics, advising various Department of Defense (DoD) agencies. In addition to his optics and crypto-mathematics research, Dr. Kosloski invented an advanced language-agnostic search engine and served at the DoD Special Communications Enterprise Office. He received his PhD in electrical engineering from Johns Hopkins University.

Dr. Kyrylo Nikolaiev is an associate professor at the Defense Intelligence Research Institute in Kyiv, Ukraine. His research focuses on ecological security, sustainable development, and advanced monitoring technologies for studying Unidentified Anomalous Phenomena. Dr. Nikolaiev holds a Doctor of Sciences in public administration (state security) from Ukrainian Interregional Academy of Personnel Management.

J. Kevin Ryan is a retired federal special agent with more than 37 years of combined military and civilian service with the US Air Force Office of Special Investigations (OSI). Special agent Ryan served in more than 15 assignments with OSI including as Director of Counterintelligence for the Department of the US Air Force and US Space Force and concluded his federal career as Chief of Operations for the All-domain Anomaly Resolution Office. A lifelong amateur photographer, he brings both investigative rigor and a passion for the night sky to the study of unidentified anomalous phenomena. Mr. Ryan received an MA in criminal justice from Oklahoma State University and an MA in national security affairs, with a concentration in Western European studies, from the US Naval Postgraduate School.

Dr. Joshua Shank leads the event-based sensing working group at Sandia National Laboratories and leads several projects related to nuclear nonproliferation remote sensing, ranging across novel semiconductor devices, assembly and characterization of remote sensing systems, and algorithm development for data exploitation. Dr. Shank holds a PhD in electrical engineering from the Georgia Institute of Technology.

Lawrence Walzer is a retired US Marine Corps officer and a graduate of the US Naval Postgraduate School (NPS), where he earned a master's degree in national security affairs. He has been a faculty member at NPS for eight years and currently serves as the Director of the Center on Combating Hybrid Threats.



COVER IMAGE

The night sky seen during Exercise Black Jack 25 off the coast of Queensland, Australia, 17 July 2025. Black Jack is a biannual reconnaissance exchange that strengthens relationships and enhances the capabilities and interoperability between the US and Australian reconnaissance forces. (US Marine Corps photo by Lance Cpl. Sawyer Carleton)

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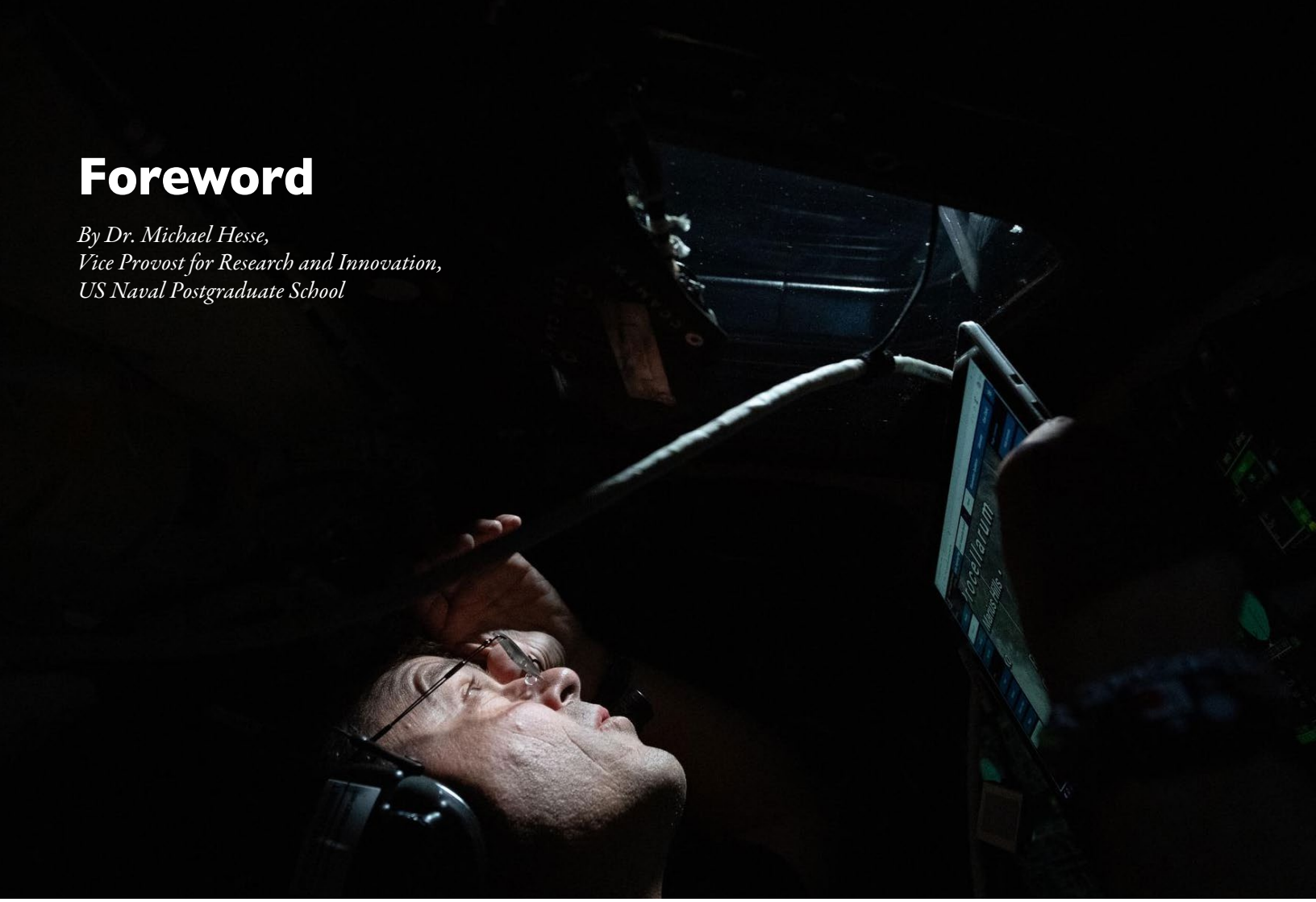
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Foreword

By Dr. Michael Hesse,
Vice Provost for Research and Innovation,
US Naval Postgraduate School



NPS alumnus and Artemis II mission commander, retired US Navy Capt. Reid Wiseman, peers out the window of the *Orion* spacecraft to capture images and video of the Moon and record observations.

Unidentified Anomalous Phenomena (UAP) represent a real and impactful domain-awareness challenge. They sit at the intersection of operational safety, emerging technology assessment, intelligence analysis, and scientific inquiry. Observations span air, maritime, space, and other operational environments. Some can be resolved through conventional explanations. Others remain unresolved—not because they defy physics, but because the information is incomplete, ambiguous, or insufficiently instrumented.

Reducing uncertainty in this domain requires a systematic approach. It requires calibrated sensors, standardized data architectures, rigorous analytic processes, and a culture that prioritizes evidence. Above all, it requires the systematic application of proper scientific methodology.

Recent years have seen significant progress in reporting structures and institutional coordination. Yet, the following persistent gaps remain: inconsistent metadata standards, limited sensor fidelity, uneven analytic frameworks, and cultural hesitancy in reporting. These are solvable problems. They demand dedicated investment in sensing technologies, cross-domain data fusion, reproducible analysis pipelines, and related research grounded in physics, engineering, statistics, and operational analysis.

This special issue of *Combating Threats Exchange (CTX)* is dedicated to strengthening that foundation. The objective is straightforward: bring scientific rigor to a problem set that has too often been characterized by fragmentation or speculation. Scientific inquiry—falsifiable hypotheses, calibrated measurement, uncertainty quantification, reproducibility—is the essential tool for further progress.

At the US Naval Postgraduate School (NPS), through the Center on Combating Hybrid Threats and in close partnership with the All-domain Anomaly Resolution Office, we are building an interdisciplinary framework to integrate operational data with scientific analysis. This effort includes collaborative research agreements, advanced modeling and sensing studies, classified analytic work where required, targeted experimentation, specialized publication, and tailored academic offerings. We are also

expanding communities of interest across service components, fleet commands, allied institutions, and research partners.

NPS is uniquely positioned to contribute. As the Department of Defense's graduate education and applied research institution, we operate at the nexus of theory and operational practice. Our faculty and students bring expertise in plasma physics, signal processing, aerospace engineering, data science, human systems integration, intelligence analysis, and policy. This cross-disciplinary environment is precisely what a multi-domain problem requires.

For the US Navy in particular, persistent global presence across all domains makes domain awareness essential. Unresolved anomalies—if not properly characterized—can obscure sensor limitations, mask emerging technologies, or introduce operational risk. While most cases are likely attributable to conventional sources—natural phenomena, sensor artifacts, commercial systems, or foreign technologies—we cannot assume adequacy of explanation without rigorous analysis. Strategic surprise often exploits ambiguity. Only a systematic approach can reduce it.

Equally important is the human dimension. Although progress has been made in normalizing UAP reporting, cultural reticence still exists. High-quality data begin with professional, stigma-free reporting channels supported by sound analytic feedback loops. Organizational behavior, cognitive bias, and decision science therefore matter as much as hardware and algorithms.

This is not solely a government challenge. Observations may occur near critical infrastructure, maritime corridors, industrial sites, or populated areas. A credible framework requires collaboration across governmental agencies, academia, industry, and allied partners. Shared data standards, interoperable metadata architectures, joint analytic methodologies, and coordinated research efforts will accelerate learning and strengthen attribution capabilities.

From my perspective as a physicist and former NASA research leader, the way forward is clear. Complex phenomena demand measurement. Measurement demands instrumentation. Instrumentation demands calibration. And analysis demands rigor. We must integrate operational awareness with the scientific method, close data gaps, quantify uncertainty, and progressively constrain the space of plausible explanations.

UAP-related challenges are global. Our allies face similar observational ambiguities. Strengthened international cooperation—focused on shared sensing strategies, analytic standards, and coordinated research—will enhance collective domain awareness and strategic stability.

This *CTX* special issue reflects a commitment to move the conversation from conjecture to disciplined inquiry. By embedding scientific methodology within operational frameworks, we strengthen safety, enhance attribution, and reinforce national and allied security in an increasingly complex technological environment.

ABOUT THE AUTHOR

Dr. Michael Hesse is Vice Provost for Research and Innovation at the US Naval Postgraduate School.

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THE *CTX* INTERVIEW

Dr. Jon T. Kosloski, Director, All-domain Anomaly Resolution Office (AARO)



Interviewed by Lawrence Walzer, Director, Center on Combating Hybrid Threats, US Naval Postgraduate School

On 4 December 2025, Lawrence Walzer facilitated an interview with Dr. Jon T. Kosloski. The interview questions were tailored to address key issues surrounding Unidentified Anomalous Phenomena (UAP) for this special journal issue, offering valuable insights into AARO's mission, priorities, and challenges. The discussion provided an important opportunity to hear directly from AARO leadership and explore ways to strengthen interagency collaboration and advance efforts related to UAP problem sets.

Walzer: To begin, could you explain the primary mission of AARO and how it fits within the broader national security and defense framework?

Kosloski: Certainly. AARO's mission is to synchronize efforts across the Department of Defense and other federal agencies to better detect, identify, and attribute objects of interest, with a focus on national security sites and critical infrastructure. Unknown objects in any domain—whether in the air, sea, or space—pose potential threats to national security and warrant the attention of the US government.

AARO is the first whole-of-government effort to advance the idea of "multi-domain awareness" for anomaly resolution as a core security objective. As we have all seen from conflicts around the globe, warfare is changing rapidly. We help the Department stay ahead of developments to ensure our warfighters have the knowledge and tools to mitigate risks and maintain our technological edge in any environment or operational context.

Walzer: That's remarkable. What really stands out to me in AARO's mission is the emphasis on whole-of-government efforts and the pursuit of multi-domain awareness. Those approaches highlight that your work spans all domains—such as land, sea, air, and space—while applying scientific methods to understand potential national security issues. I also appreciate how central collaboration is to your mission, as well as your commitment to reporting findings to Congress and the public.

Considering your multi-domain work, I am wondering what are the biggest challenges your office faces when investigating UAP?

Kosloski: Far and away, AARO's biggest challenge is a lack of high-quality data. US military sensors, both the technology and the human operators, are second-to-none at doing their specific mission, but they aren't general purpose scientific instruments. So, when one of these highly specialized sensors detects something potentially anomalous, the data captured is often not well-suited for rigorous scientific investigations.

This mismatch can lead to incorrect initial assessments of an object's size, speed, or appearance. AARO sees this play out in its findings: the overwhelming majority of UAP reports we've resolved turn out to be misattributions of ordinary, prosaic (or everyday) objects. Importantly, we do not have a conclusion in mind before we start an investigation. AARO will follow the data wherever it leads, but we need good data to follow.

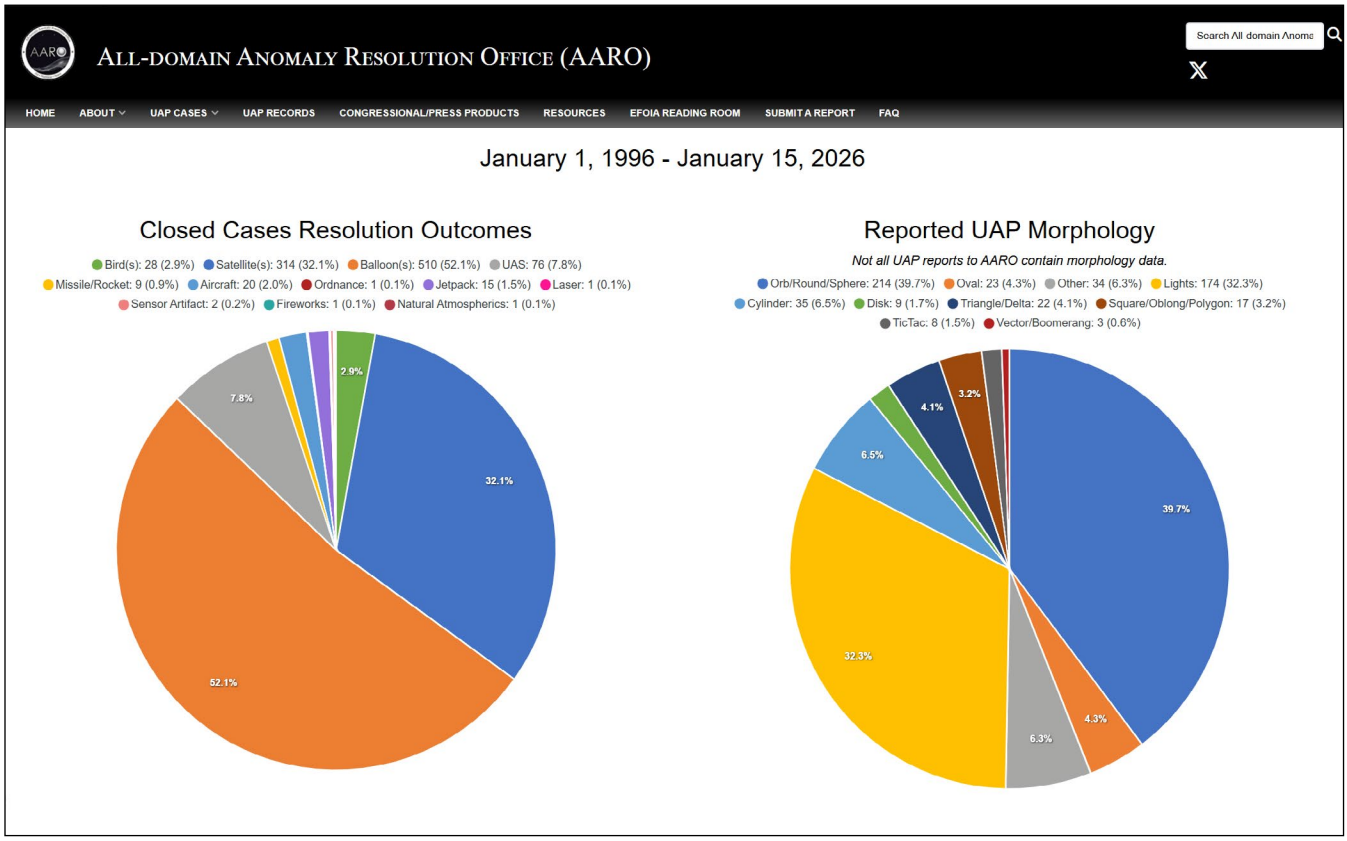
Walzer: How does AARO handle public interest and skepticism/stigma around UAP reports?

Kosloski: This is a crucial point. The US government takes UAP seriously, and there should be no stigma associated with making a UAP report. Detailed reports of UAP observations are essential to AARO's work, and withholding a report could potentially endanger US national security. When a UAP is reported, our team seeks detailed information about its physical characteristics, performance, and behavior. We are also interested in information about the observer and the environment to support a full analysis and, when possible, resolution. AARO focuses its efforts on the national security concerns associated with domain awareness gaps; the stigmatization of UAP reporting actively hinders our mission. We appreciate public interest in UAP and examine each case with an open mind. We always start from a position of curiosity and, from there, we simply follow the data.

> **The US government takes UAP seriously,** and there should be no stigma associated with making a UAP report.

Walzer: Are there specific innovations or tools that you believe will significantly enhance AARO's capabilities?

Kosloski: Above all, we need more high-quality sensor data, and we need better-trained observers. We need the ability to access the many existing sensor systems operated by the US government (USG) while building new, bespoke sensors as needed. As for better-trained observers, we find that a big part of our work focuses on education and awareness. AARO publishes educational materials to help familiarize USG personnel and the public with the common sources of UAP misattributions—things like parallax, satellite flaring, or even in-camera artifacts. Our objective is to improve the quality of the incoming reports so we can focus our resources on the UAP events that may demonstrate truly anomalous characteristics.



AARO UAP case outcomes and morphology distribution (1996–2026)

AARO is also looking into bringing new analytic capabilities online using artificial intelligence-enabled algorithms to filter vast data sets for potential anomalies.

Walzer: What is your approach to interagency information sharing and fostering cooperation internationally?

Kosloski: Interagency cooperation is essential to our work. AARO works closely with partners across the federal government, who bring their own unique expertise to bear in the effort to better understand and respond to UAP sightings. We have also participated in several international engagements with US security partners to share insights and best practices for UAP analysis. Meanwhile, we work with groups outside of government, especially in the scientific and academic communities, which we rely on to provide feedback on our assessments, conduct scientific research, and ensure our approach remains grounded in a peer-reviewed process. We try to share as much information as possible at the unclassified level, recognizing that significant expertise resides outside of government.

Walzer: I could second that. Recognizing how essential interagency cooperation is to your work, our center is eager to join forces with NPS faculty and students (as well as international partners) and help drive collaboration across multiple lines of effort—academic research, education, experimentation, peer-reviewed publications, CRADAs [Cooperative Research and Development Agreements], and more.

Beyond partnerships with academia, interagency teams, and non-governmental organizations, how can the Services—particularly the US Navy—better support your mission?

Kosloski: The best way the Services can support AARO is by continuing to promptly report UAP incidents and retain any technical data in accordance with the February 2025 Joint Staff GENADMIN [General Administration] guidance on UAP reporting and materiel disposition. That guidance lays out the best way to preserve and convey all the important information AARO needs to begin an investigation. There should be no stigma associated with reporting UAP; reporting is in the national security interest.

Walzer: What are the priority research focus areas that may best lead to increased capability and capacity to detect, identify, and attribute UAP?

Kosloski: This is an area where our scientific and academic partners are key. AARO's top priority is facilitating the integration of the nation's diverse, multi-domain sensing capabilities into a single, unified architecture. We need the ability to access all the existing civilian and military



NASA's UAP Independent Study Team

systems we have, making sure all of our systems can talk to each other.

We also need to develop novel detection and filtering algorithms. We are dealing with vast data sets, so we need to find better ways to discriminate potential anomalies from all that noise, particularly when we're dealing with multi-sensor fusion and differing data types. This is important because sensors of different kinds may have observed the same incident from a different perspective, and integrating those perspectives could help AARO in its analysis.

Walzer: What are your long-term goals for the office, and how do you measure success?

Kosloski: Our long-term goal is to ensure that the Department of Defense, the intelligence community, and all the relevant civilian agencies are equipped to efficiently detect, track, analyze, and manage anomalous phenomena. We want them to be using standardized tools and tradecraft, so everyone has a shared awareness using shared language.

Measuring success can be challenging. This isn't a project with a finish line; it's an ongoing mission. However, AARO has already shown success in applying industry-standard intelligence and scientific techniques to reduce the amount of time between receiving a report and rendering a finalized assessment. That improvement in efficiency shows that our value to national security only continues to grow as we hone our tradecraft. Each time we enable a partner to make sense of an observation or improve their domain awareness, that keeps them better informed and safer. We consider that a success.

Walzer: Of course, I have to ask you this next question: in all of AARO's investigations to date, have you found any evidence, data, or credible information that would suggest any UAP are extraterrestrial in origin?

Kosloski: That's the most common question I get, and I am glad to answer it directly. To date, AARO has found no verifiable evidence suggesting any UAP incident we have investigated is extraterrestrial in origin or represents extraterrestrial technology. AARO will not assert a conclusion without evidence to support it, and we will not speculate about a phenomenon's nature or origin based on inconclusive data. As the saying goes, "Extraordinary claims require extraordinary evidence." From what I've seen as director, the data we've analyzed to date simply does not point to that conclusion. We do have many unresolved UAP cases, and we will continue to follow the data wherever it leads.

Walzer: You've stated most resolved cases are "prosaic objects." Of the unresolved cases, what is your working assessment? Are we primarily talking about sensor anomalies, or is there a genuine concern that these represent advanced and unknown technological capabilities from adversaries?

Kosloski: This is precisely the question AARO was established to answer. Many of our cases result from sensor anomalies and other mundane explanations, but there is also the potential for strategic surprise from an adversary, perhaps using a new technology we are not familiar with, or an old technology used in a new way. We simply cannot have "unknowns" operating in our airspace, or any domain for that matter.

> **We simply cannot have "unknowns"** operating in our airspace, or any domain for that matter.

Walzer: Given the sensitivity of your work, I understand that certain data must be handled within specific classification boundaries. How do you balance public interest in UAP with the need to protect classified information? Can you explain what prevents AARO from releasing clearer data or video, and how you are working to declassify information so the public and scientific community can analyze it?

Kosloski: AARO is constantly balancing its commitment to transparency with the need to protect national security information. We understand that public interest in UAP is high. We launched our public website, www.aaro.mil, to share UAP imagery, trends, reports, and educational material at the unclassified level.

However, much of AARO's data comes from highly sensitive military and intelligence systems. Importantly, AARO doesn't directly own these systems, so we work closely with the reporting service to declassify as much as we can while protecting our national security. Releasing unredacted video or military platform data could inadvertently reveal sensitive US information. That's a compromise we simply cannot make. It would be handing a playbook to our adversaries. So, our job is to be as transparent as possible by sharing our conclusions and declassifying imagery only when we are certain it won't damage national security.

When we release data or video, we do so at the media's operational resolution without adulteration, with the only modifications being precise redactions to protect military or intelligence capabilities and vulnerabilities. Many of the systems from which AARO obtains data are not designed to produce high-resolution imagery. The videos that we post on our website are, unfortunately, as good as these reports get. It's part of the reason we continually emphasize the need for more and higher-quality data associated with UAP reports.

Walzer: The government has a history of seeking to address this topic, often with inconclusive or dismissive results. What makes AARO fundamentally different from past efforts, and why should the public trust this time will be different—more transparent, definitive?

Kosloski: AARO is the first whole-of-government effort, established in law by Congress, with the authority to synchronize this work across the Department of Defense, the intelligence community, and other federal agencies. We are an integrated part of the national security framework and report directly to the Deputy Secretary of Defense and the Principal Deputy Director of National Intelligence. We are the first UAP effort to have the full suite of investigative resources required to execute this authority, and unfettered access to programs across the federal government, ensuring that we can be confident in our conclusions.

Our methodology also sets us apart. We have built upon our predecessors' work, and continue to develop a rigorous, data-driven framework with credentialed scientists, investigators, and intelligence analysts. We are systematically applying serious, proven scientific and intelligence tradecraft to a large volume of data to make robustly informed assessments. It is this combination of broad authority, unprecedented access, robust resourcing, and a rigorous analytical process that makes AARO's efforts different from anything that has come before.

Walzer: Recognizing the importance of minimizing technical and intelligence surprises, I'm curious about surprises at a more personal level. After reviewing all these data—reports from pilots, sensor readings, and videos—what, if anything, has personally surprised you the most about the UAP phenomenon?

Kosloski: I have found it surprising that, in this age of ubiquitous sensor coverage, it is still so difficult to get high-quality, actionable data suitable for resolving, or even just advancing our understanding of some of the more intriguing cases. That said, I have also found that many of these initially baffling reports are fully explainable once you apply a rigorous, scientific process. It is easy to look at a strange video and jump to a conclusion. But time and time again, when our team of analysts and scientists dig in, we find the answer. It has been a powerful reminder of how important it is to stick to the data and not let assumptions get ahead of the evidence, regardless of how compelling a good mystery can be. In spite of all the noise, I always try to stay focused on the cases that may demonstrate true anomalies.

> **It is easy to look at a strange video** and jump to a conclusion. But time and time again, when our team of analysts and scientists dig in, we find the answer.

Walzer: Absolutely. The public fascination with UAPs makes it even more important to remain grounded in the data. It's a reminder that, no matter how compelling or mysterious a phenomenon may seem, rigorous scientific methods and evidence-based reasoning must guide our conclusions. Any final thoughts?

Kosloski: At its core, AARO's work is about resolving ambiguity in the name of national security. AARO is committed to a rigorous, data-driven approach as it tackles this complex challenge. We follow the evidence wherever it leads, without speculation or bias. We are here to ensure that operators, service members, and decisionmakers have the clearest possible understanding of their strategic and operational environments.

Walzer: I sincerely appreciate your time and the valuable insights you've provided. Your mission is incredibly important, and I wish you—and your Office—much success. Thank you!

ABOUT THE INTERVIEWER

Lawrence Walzer is Director of the Center on Combating Hybrid Threats at the US Naval Postgraduate School.

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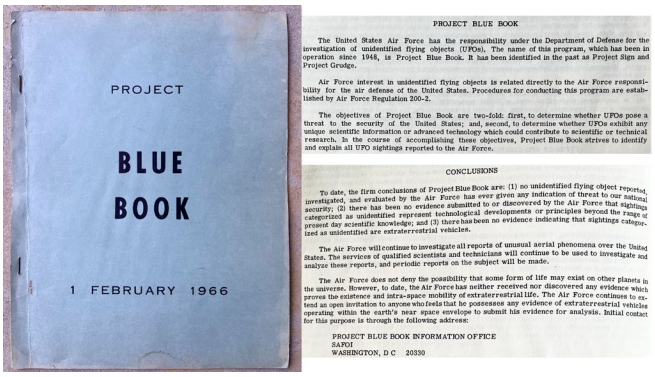


Satellite flaring is an optical phenomenon which can be misinterpreted as unidentified anomalous phenomena (UAP). AARO, 23 January 2025

Data Vetting and Accessibility for the Study of Unidentified Anomalous Phenomena

By Dr. Randy Bostick,
Former Science Advisor,
All-domain Anomaly Resolution Office

In the middle of the twentieth century, the US Air Force established several projects—Project Saucer, Project Sign, Project Blue Book[2]—to investigate the origins and potential threats posed by unidentified flying objects, or UFOs. Most of the evidence available to support investigation came from single-source observers who were not well prepared to report strange or unidentified events. They described these UFOs using familiar references such as "cigars," "wheels," and, famously, "saucers." Except for a few cases, the conclusions they provided were without supporting metrics or reasoning. Although technical collection with advanced (for the time) instruments such as radar began in the 1940s and 1950s, these technologies were not without shortcomings. The initial shortcomings of these new technologies, including system anomalies in the earliest hardware, undoubtedly contributed to detections being interpreted as fantastic and unexplainable objects. The inability to save raw data from these instruments prevented further analysis by systems experts. UFO reporting became a social phenomenon which in turn led to a proliferation of science fiction writing and movies (which fed back into the reporting frenzy).[3] Any real, consequential evidence to support scientific analysis was likely lost in volumes of summary reports.


PROJECT

BLUE BOOK

1 FEBRUARY 1966

PROJECT BLUE BOOK

The United States Air Force has the responsibility under the Department of Defense for the investigation of unidentified flying objects (UFOs). The name of this program, which has been in operation since 1948, is Project Blue Book. It has been identified in the past as Project Sign and Project Grudge.

Air Force interest in unidentified flying objects is related directly to the Air Force responsibility for the air defense of the United States. Procedures for conducting this program are established by Air Force Regulation 200-2.

The objectives of Project Blue Book are two-fold: first, to determine whether UFOs pose a threat to the security of the United States; and, second, to determine whether UFOs exhibit any unique scientific information or advanced technology which could contribute to scientific or technical research. In the course of accomplishing these objectives, Project Blue Book strives to identify and explain all UFO sightings reported to the Air Force.

CONCLUSIONS

To date, the firm conclusions of Project Blue Book are: (1) no unidentified flying object reported, investigated, and evaluated by the Air Force has ever given any indication of threat to our national security; (2) there has been no evidence submitted to or discovered by the Air Force that sightings categorized as unidentified represent technological developments or principles beyond the range of present day scientific knowledge; and (3) there has been no evidence indicating that sightings categorized as unidentified are extraterrestrial vehicles.

The Air Force will continue to investigate all reports of unusual aerial phenomena over the United States. The services of qualified scientists and technicians will continue to be used to investigate and analyze these reports, and periodic reports on the subject will be made.

The Air Force does not deny the possibility that some form of life may exist on other planets in the universe. However, to date, the Air Force has neither received nor discovered any evidence which proves the existence and intra-space mobility of extraterrestrial life. The Air Force continues to extend an open invitation to anyone who feels that he possesses any evidence of extraterrestrial vehicles operating within the earth's near space envelope to submit his evidence for analysis. Initial contact for this purpose is through the following address:

PROJECT BLUE BOOK INFORMATION OFFICE
SAFOI
WASHINGTON, D C 20330

US Air Force Project Blue Book report, 1 February 1966

In the twenty-first century, sensing technologies have become ubiquitous, and their capabilities greatly improved. However, the reporting of UFOs, now referred to as unidentified anomalous phenomena (UAP), has not likewise improved. Despite the quantity and quality of data and the general public's exposure to and familiarity with new air- and spacecraft, an era of quality reporting and data for scientific analysis has yet to fully emerge. In reality, the nature of the unknown and anomalous has evolved with advancements in technology, as there will always be objects observed that are outside of a particular sensor's ability to make a quality measurement. Ring doorbells, for example, may detect insects in the near field that appear as far-off blurry points of light moving in strange patterns. The proliferation of sensors and the massive increase in airborne

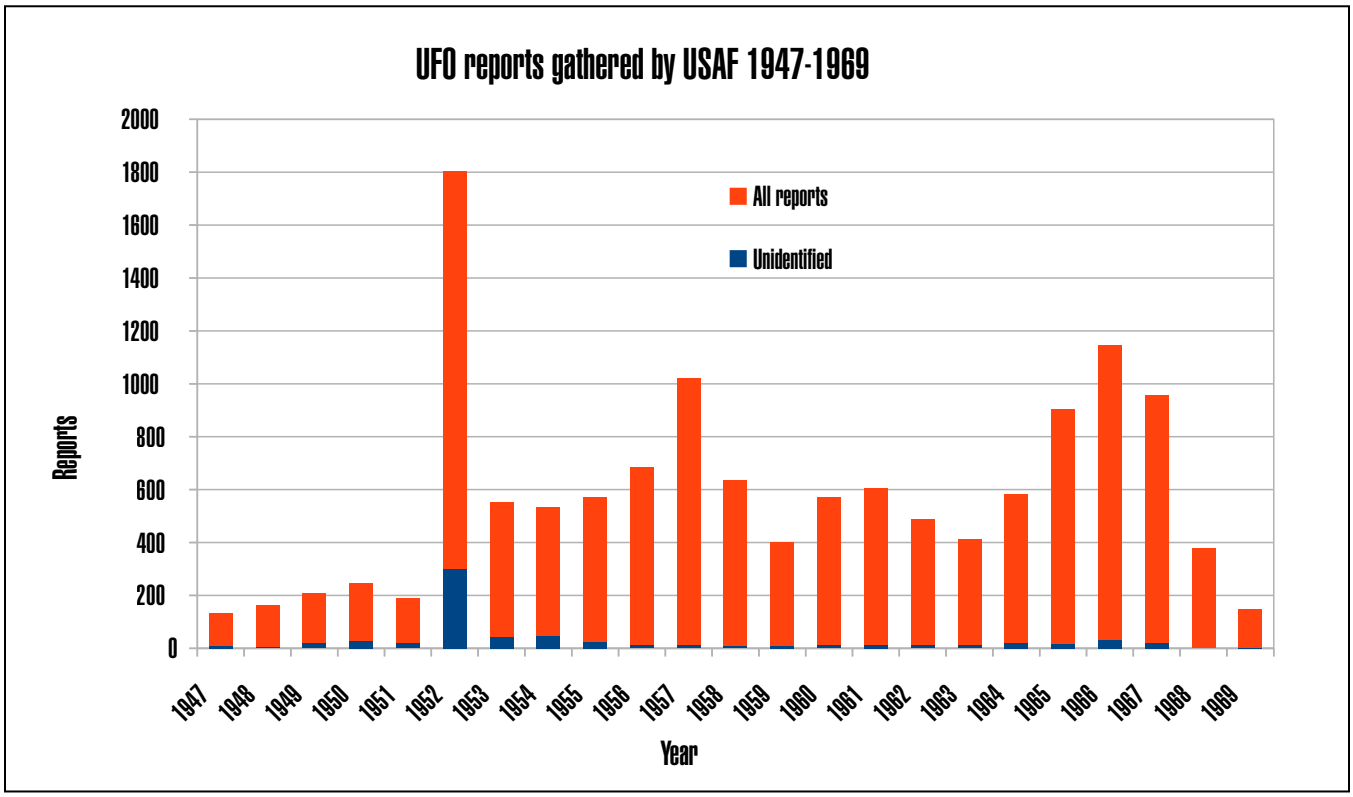
objects provide more ways to observe more phenomena in some peculiar manner.[4] Though the data are there, they are still not always understood, and the quality of the recorded products, along with the rush to analysis and conclusions based on misunderstood data, threatens to become a barrier to scientific analysis and acceptance of UAP research by the broader scientific community.

Nevertheless, scientific study of UAP is in a better position today than it was in the days of Project Blue Book. The shift from a lack of objective sensor data to having too much data is at least a step in the right direction. There is promise in this wealth of sensor data, but a vetting process is needed to separate useful from useless data along with supplemental information on collection and quality. Dedicated collection with calibrated sensors is necessary to advance scientific analysis. The All-domain Anomaly Resolution Office (AARO), as the government lead for UAP reporting and data collection, is in a position to collaborate with the UAP community to ensure quality control and consistency of UAP data products and to promote guidelines for data collection. These are basic functions to enable scientific analysis, results, and conclusions on the nature of UAP. This article proposes a common approach to UAP reporting by offering a definition of analyzable data and associated quality that can support any derived results and conclusions in the study of UAP.

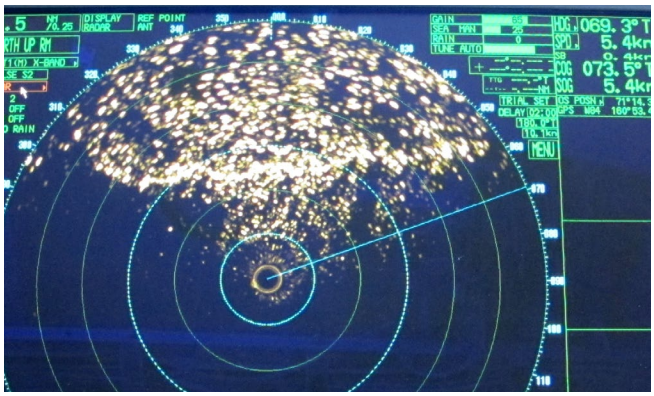
The Definition of Data

The need for quality data and consistent definitions of "quality" has been asserted by AARO and widely recognized by others who study UAP.[5] However, less discussion has been afforded to the meaning of "data," a term that is often abused. While implying numerical or other quantifiable information, "data" in the context of UAP has come to be conflated with any general reporting that may be received, including deductions, explanations, and conclusions made while observing an event, monitoring an instrument, or describing sensor output. Determinations such as "It had a plasma field," "It was very hot," or "It exhibited an advanced form of propulsion" are not data—they are interpretations of what one has observed, often with no objective, sensor-collected information. When presented as such, even unintentionally, rejection by the scientific community follows, as well as an overall unwillingness to engage on the topic of UAP. Data must be objectively collected and presented, with no predetermined conclusions stemming from attempts to better understand UAP.

Many features or characteristics of an object can be learned by collection with remote measurement devices. Most of these are calculated or derived through analysis, not directly measured by the instrument. That which is directly measured is what should be the basic definition of "data."



US Air Force UFO reports, 1947–1969; compiled 24 June 2021



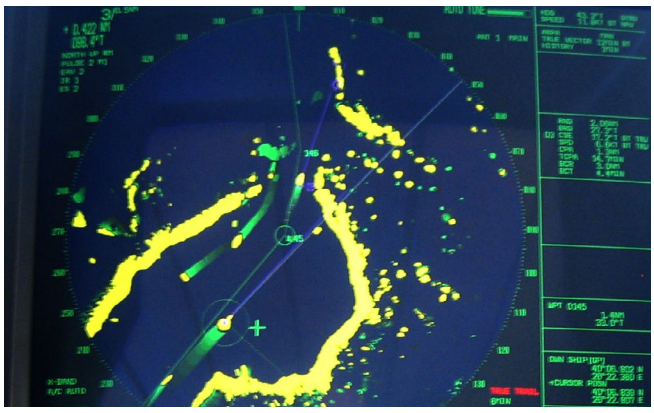
Radar display of pack ice about 100 nautical miles west of Point Barrow, near Utqiagvik, Alaska, 9 August 2012

For example, a simple electro-optical (EO) system such as the WESCAM MX™-20 can measure the following:[6]

- Irradiance: the amount of power or energy incident per unit area on a detector or pixel array.
- Time: the time at which a measurement of irradiance is made on the array.
- Position: the location in the optical system image plane of an irradiance measurement.

A simple radar system can directly measure values such as the following:

- Pulse transmission and arrival time: the time that an electronic signal is sent from the transmitter and collected at the receiver after bouncing off an object.
- Frequency shift: in a Doppler radar, the shift in the frequency of the transmitted pulse due to reflection from a moving object.
- Direction: the angular direction of the object from the radar receiver.
- Received power: the strength of the signal received by the receiver.



Display and control unit of a common maritime navigation and search radar, 29 January 2006

Absolute position in space, size, speed, heading, pulse delay, and acceleration are characteristics and features that can be calculated from the above direct measurements. With assumptions about the object's material composition, analysts can estimate characteristics such as temperature, emissivity, reflectivity, and radar cross-section. Calculating most of these derived quantities requires supporting data specific to the detection sensor or instrument, called metadata. Metadata may include sensor settings, platform location and motion, and other ancillary values. Providing metadata with measurements enables others to repeat and independently verify calculated values. These measurements and the resulting data and metadata are specific to the sensor and do not require new definitions for UAP collection. The science behind the data definitions and calculated values is well known and does not need to be reinvented just because the focus of study is UAP.

Sensor type is a key factor in UAP collection and interpretation, as the calculations that can be derived, and the types of errors that can occur, will vary dramatically between, for example, a passive optical sensor and one that is in motion. For example, the public is likely most familiar with the optical sensors in digital or cellphone cameras, and the images these sensors capture are commonly provided as evidence of UAP. However, most calculations or estimations from passive optical sensor measurements require knowledge of the distance to the target. The range to the target is usually impossible to calculate from a static, monocular collection device. Inaccurate range assumptions lead to poor calculations of UAP speed, acceleration, and size. For moving sensors, such as aircraft, further error is introduced by the effect of parallax (measurement inaccuracy introduced by shifting angles or positions).[7]

For those interested in using optical sensors for UAP collection, deploying two (or more) sensors is highly recommended. Range can be estimated from triangulating lines of sight from multiple sensors separated by a baseline distance.[8] Also, employing two sensors reduces the likelihood of reporting sensor anomalies or other near-field objects as UAP. For example, small bugs flying in front of a camera create pinpoints of light that are often mistaken for distant, erratically moving craft. If these lights appear on only one sensor, we can conclude that they are likely caused by bugs. If the lights appear on two sensors, we can conclude that they are worthy of further analysis.

As a final point, many of the videos provided to AARO (the "Go Fast" and "Mt. Etna" cases in particular[9]) or posted on the internet as "data" have undergone image processing. The FLIR (forward-looking infrared) sensors

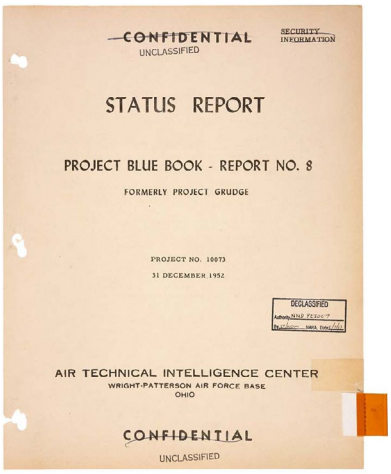


Alleged UFO photograph taken by Paul Trent. Suspected of being a hoax by skeptics, 11 May 1950

on fighter aircraft, used to create infrared images, and the multi-spectral targeting systems on remotely piloted aircraft used for intelligence, surveillance, and reconnaissance missions, almost always have some contrast enhancement or edge detection applied to benefit the sensor's primary mission, which is threat detection, not UAP detection. While the data from such systems provide important information, it is nearly impossible to estimate target brightness or even size for smaller objects.[10] Care must be taken to distinguish the properties of the object being collected from the result of image processing.

The Need for Quality Data

Any substantive UAP claims must be founded upon vetted, sharable data with a known and described quality. The requirement is not necessarily for high-quality data—only that the quality be known in order to determine the confidence in any results derived from it. The term "vetted" refers to data that has not been intentionally altered or artificially created to support a desired conclusion. "Quality" is usually expressed through figures of merit such as spatial resolution and radiometric accuracy, along with associated systematic errors. However, a quantity of lower-quality collections can yield a greater aggregate quality when there are many collections on the same object or phenomenon—rarely the case with UAP instrumented collections. This article focuses on data from instruments and sensors. However, vetted oral reporting can yield a quantity of data that may reveal some quality of patterns of activity, common descriptions, or other trends. Many documented studies related to Project Blue Book written accounts have been conducted in this way, as well as analyses of more recent reports.[11] The point here is that if only one or very few sensors collect data, then it is important that the data be of high quality. However, if many lower-quality sensors collect data, quality can be made up for with quantity.


CONFIDENTIAL
UNCLASSIFIED

SECURITY INFORMATION

STATUS REPORT

PROJECT BLUE BOOK - REPORT NO. 8

FORMERLY PROJECT GRUDGE

PROJECT NO. 10073

31 DECEMBER 1952

DECLASSIFIED

AIR TECHNICAL INTELLIGENCE CENTER

WRIGHT-PATTERSON AIR FORCE BASE

OHIO

CONFIDENTIAL

UNCLASSIFIED

Project Blue Book, status report No. 8, 31 December 1952

> **Any substantive UAP claims** must be founded upon vetted and sharable data with a known and described quality.

AARO has received many videos of purported UAP with descriptors such as "spherical," "circular," "triangular," and "plasmoid" (a ball of light without sharp edges) that were "moving at great speeds." While these descriptions may not be inaccurate or disprovable, they often cannot be verified given the quality of the source data. The shape may be the result of camera defocus, odd surface reflections, and apparent speeds from misjudging distance or camera motion and other effects not associated with the object of interest.



Figure 1: The quality of the image on the left cannot support any conclusion about the subject's identity. The clear image in the middle allows identification as a male human. The image on the right depicts a clearly anomalous human.

Consider the pictures in Figure 1 as a simple example. On the left is an image that cannot be immediately identified as a known entity but might be identified as a gelatinous creature of unearthly origin. We must know the quality of the data to understand whether the image correctly represents the subject or is due to an out-of-focus camera, poor optics, or perhaps image processing (in this case, the author has applied a filter to the image, which is shown in original form in the center of Figure 1). The center image

is from higher-quality data, which allows for characterization of the entity with high confidence as a male human (not anomalous). This male human may still be unidentified, but not because of poor data. His face and features are clear; the image supports further scientific analysis to determine identity. On the right is a clear picture, but now the human has a third eye. This entity would be considered unidentified and anomalous as the third eye is not due to data issues and likewise would demand further study.

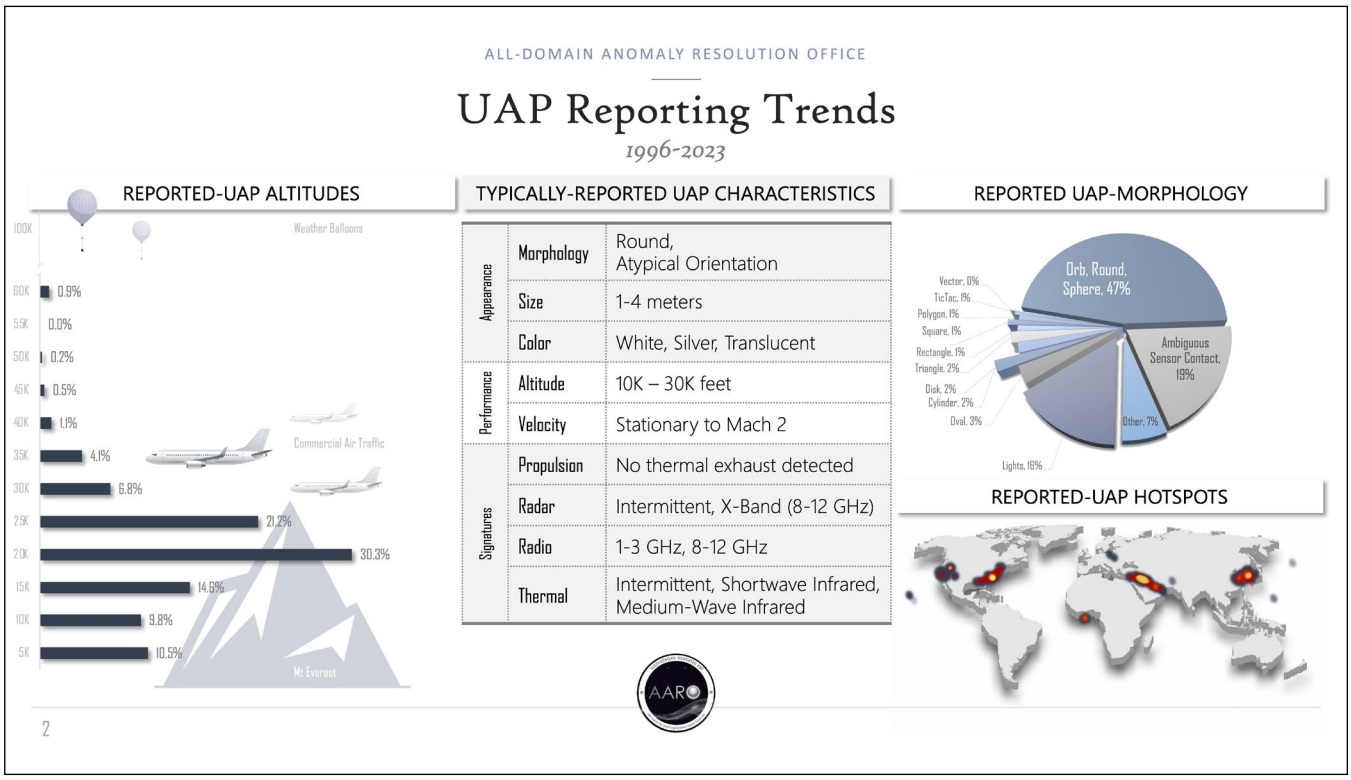
The definition of "sufficient quality" and requirements for sensors dedicated to UAP collection must be discussed and agreed upon by the scientific community and be highly dependent on assumptions about the UAP. However "sufficient quality" is defined, data products with metadata and other sensor phenomenologies must be provided to substantiate analysis. The void of no data or poor data cannot continue to be filled by conjecture, assumption, and imagination. The scientific community will not entertain results or claims with greater assurance than the evidence warrants.[12]

The Influence of Analysis and Results on Data Collection

Data from sensor collections provide the basis for analysis that leads to conclusions. Too often, results are presented without supporting data, with poor or undocumented analysis, or with conclusions the data cannot possibly support. The effect of such presentations is twofold: 1) the reporting stigma related to UAP continues due to continued false claims, and 2) the conclusions become more prominent and energizing than the source data such that, over time, "facts" evolve to support conclusions. Separating data from lore becomes an afterthought, or even impossible, after time has passed. This second effect exemplifies the need for more rigorous approaches to UAP study.

However, the first effect may be more damaging as it, along with the conflation of the terms UAP and UFO, leads to suppression of reporting and recovery of data from legitimate sources. The term "unidentified anomalous phenomena" was introduced to describe an event that an observer could not readily identify. The intent behind establishing this new term was to allow pilots, military personnel, law enforcement officers, and others in sensitive positions to communicate relevant information prior to analysis in a noncontroversial way to inform objective assessments. The UAP designation should not be considered the resolution or the event itself and should not lead to quick conclusions and dismissal of data, as has happened with UFO reports. All UAP reports with supporting data must be taken seriously; serious analysis will lead to determination.

Finally, UAP reporters (and anyone interested in or pursuing UAP research) should not feel obligated or allow



Slide 2 of 7 from Sean Kirkpatrick's presentation to the NASA Independent Study Team on UAPs, 31 May 2023



Crew monitor Aegis large-screen radar displays aboard USS Vincennes (CG-49), 1 January 1988

themselves to be coerced into providing an immediate analysis of what they saw or what their instruments detected. For example, the assessment of a hot, fast-moving object should be left to validated analysis and not an initial description. The self-assessment by an observer that something is "weird" or exotic threatens to lead to the UFO supposition and a reluctance to report and the much-discussed reporting stigma.[13] The focus should be on reporting the observable characteristics that led the observer to deem the object as hot or fast moving and on providing any associated oral, written, or instrumented data. This information provides the basis for scientific investigation; the reporter should be required only to report, not to provide the assessment.

An approach to reducing the stigma of reporting is to use the term UAP in its proper context as an object that is literally unidentified and/or is behaving anomalously with no assumption of origin based on the initial sighting. To alleviate the implied association of UAPs with UFOs, the initial UAP report may be designated a "potential UAP," indicating that data and information have been provided, but that further analysis is needed before concluding that it is truly unidentifiable or anomalous and why. This suggestion is analogous to a citizen reporting suspicious activity to law enforcement and letting those professionals investigate whether a crime is actually being committed and by whom. Perhaps the potential UAP ends up being identified as a balloon, drone, or something incredible, but that should not concern the observer making a report.

The Scientific Study of UAP

There is a need for leadership in organizing and developing data standards to enable the scientific study of UAP. Well-understood data are the foundation of such an effort, whether that data is unintentionally or intentionally collected. The analysis of the data must be documented and repeatable by independent scientists. Any results and conclusions must be traced back to the data through the analysis and cannot assert anything more.

It is not a question of how to make the study of UAP scientifically valid and acceptable; it is a question of applying scientifically valid and acceptable methodologies to the study of UAP. The approach is the same as that for any other domain awareness problem such as countering unpiloted air vehicles or achieving space domain awareness. It is only after scientific analysis indicates that the collected object is not identifiable or is technologically anomalous that the disciplines diverge. Presenting UAP study as a wholly separate field gives the impression of a presumed or necessary outcome, which precludes scientific legitimacy.

> **The critical point** is that the properties of UAP are not *assumed* to exist, but are *proven* to exist.

To round out the application of the scientific method, a hypothesis is necessary. Historical investigations such as Project Blue Book and the Condon Report sought to disprove the idea that there is an aspect of the natural world not yet explored by science.[14] The inferred hypothesis, and one commonly followed, is that if the UAP described in a report do exist, they must be of extraterrestrial intelligence and not of this world. This hypothesis, which requires only existence to be "true," cannot be proven or disproven, as it requires no explanation of origin. Moreover, UAP, by definition, are not specific, definable entities.[15] Rather, the term "UAP" describes phenomena that cannot be immediately explained, although they may eventually be explained—perhaps as birds, balloons, or other prosaic objects. A testable hypothesis is that the phenomena described in reports and collected in sensor data exist, and that they have physical, energetic, or other properties that current technology cannot explain (or the null hypothesis that these objects *can* be explained by existing technologies—a hypothesis easier to test because it lends itself to requirements for collection). The properties that UAP may display that are not presently explainable must be determined by the scientific community. The critical point is that the properties of UAP are not *assumed* to exist, but are *proven* to exist.

The Way Ahead

Anecdotal reports and unverified claims are insufficient to meet the rigorous standards of empirical science and lead to skepticism and limited academic engagement. AARO is in position to take the lead in a field of research that struggles to gain acceptance within the broader scientific community. This leadership can be accomplished, as in other scientific, defense, or intelligence communities, by establishing data standards to ensure interoperability, discovery, assessment, and exploitation. Application schemas and metadata should also be standardized and documented.

Likewise, study and analysis should be aligned with the standards common to scientific methods and intelligence reporting. The guidelines for the study of UAP data collected by sensors (analytic approaches to verbal and written witness accounts are a separate area of study) should include the following:

- Objective and independent observation: A phenomenon, which should initially be referred to as a "potential" or "possible" UAP, must be recorded by a sensor-based detection system (e.g., radar, infrared sensors, visual recordings). The data from these recordings should be provided without subjective bias, preprocessing, or sensor error. While it is desirable that sensors be calibrated as well as possible, it is more important that the degree of calibration be known. Any preprocessing sensor error that cannot be avoided must be documented. Ideally, this documentation would include corroborative multi-sensor data from diverse detection methods (e.g., visual, electromagnetic, acoustic), ensuring that the phenomenon is not an artifact of a single type of sensor.
- Documented and transparent analysis: All data analysis methods must be well-documented and made available for scrutiny by the scientific community to ensure transparency and to eliminate errors. The analysis should be repeatable by independent entities.
- Analysis of alternatives: To maintain consideration as a "UAP," the event must be thoroughly analyzed to exclude all known natural phenomena, human-made objects, and sensor anomalies as potential explanations. This analysis includes levels of confidence in ability to make a conclusion based on error analysis and quality of provided data.
- Conclusions and results: Results must be presented in a fashion that characterizes the observed phenomena in terms of physical, radiometric, or other quantitative means. The conclusions on identification and origin are then put forward to the scientific community to propose the employment of known or advanced technologies given the state of the art, potential function, and intended purpose.

AARO, in collaboration with defense, intelligence, academic, and industry partners, should consider these guidelines and agree upon vetted methodology for UAP study.

ABOUT THE AUTHOR

Dr. Randy Bostick is the former Science Advisor for the All-domain Anomaly Resolution Office.

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NOTES

1 The views represented in this paper are presented for the purpose of scientific discussion and do not represent All-domain Anomaly Resolution Office advocacy or activities.

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US Air Force pilot observes suspected Chinese surveillance balloon over central United States

Event-Based Sensing for Unidentified Anomalous Phenomena Detection, Tracking, and Characterization

By Kaylin Hagopian and Dr. Joshua Shank, Sandia National Laboratories

The term unidentified anomalous phenomena (UAP) refers to unknown aerial targets present in an airspace of concern. They can span a wide spectrum of target types, including birds, stars, planes, satellites, and drones. UAP have presented an increased concern in the last several years due to their presence near military ranges, sensitive facilities, and other high-traffic air spaces. While some phenomena have been identified as benign objects such as balloons or birds, some remain unidentified and may represent intentionally deployed technology. No matter their origin, these objects pose a threat to air safety, and in the case of intentional technology must be positively identified as such and distinguished from the benign objects. Many UAP are difficult to detect, display a wide range of characteristics, and operate at unpredictable times. Developing a highly capable sensing system to detect, track, and characterize UAP is one of the primary challenges for next-generation airspace monitoring sensors.

Maintaining custody of an airspace to ensure detection of UAP with many possible characteristics operating at unpredictable times requires persistent remote sensing. This persistent sensing layer must cover a large geographic area and be able to detect and track objects with a high probability of accurate identification. These sensors must have the following characteristics:

- Fast response times to detect and continuously track the motions of individual objects
- Low data bandwidth, producing sparse data that include only signals of interest to decrease processing and decision response times
- High dynamic range to enable detection of bright and dark objects in challenging environments that include multiple objects approaching the sun's position in the field of view and in deep shadows in the same scene
- Data capture sufficient for accurate discrimination between real targets, false positives (e.g., birds), and a cluttered background
- Low power for situations requiring off-grid operation for extended periods
- Small and lightweight design

Conventional sensors, such as high-speed radars or traditional imaging cameras, typically possess a subset of these desirable characteristics. For example, high-speed radars tend to quickly detect and track multiple targets, but they can produce large volumes of data, require considerable power to actively illuminate the airspace, and struggle with cluttered backgrounds. Traditional imaging cameras typically are low power, but they also have slow response times, limited dynamic range, and require complex image processing to mitigate cluttered backgrounds. As such, remote sensing for UAP detection and tracking often requires operational tradeoffs among these desirable characteristics and accompanying drawbacks.

Event-based sensing is a novel technology that achieves all of these features simultaneously. Event-based sensors (EBSs) are becoming recognized as a promising technology for UAP detection and tracking because they are able to provide a persistent wide-area search capability for initial target detection and cue higher-value, nonpersistent remote-sensing assets for characterization and identification.

This article discusses the potential for using EBSs for UAP detection, focusing on the technology's characteristics relevant to this application space. We then present a series of visual EBS signatures from various target types and discuss potential paths for detection, identification, and characterization of UAP.

Event-based Sensors for UAP Detection

EBSs are a novel camera technology whereby each pixel acts as an independent, asynchronous optical change detector. In conventional camera technology, all pixels act in concert to record a scene and output related data; in event-based sensing, only pixels that detect a sufficient change in optical intensity report an "event," while pixels that do not detect a change remain "silent." This architecture consumes minimal power and data bandwidth, enabling EBSs to possess all the desirable characteristics listed above for UAP detection: fast response times, low data bandwidth, high dynamic range, sufficient data capture capability, and low power in a small and lightweight design.

Fast Response Times

The sparse change detection schema enables EBSs to allocate data bandwidth only to dynamically changing areas of a scene, typically achieving 100-microsecond response times. The asynchronicity of EBS event reporting enables each pixel to respond at the local speed of the scene without the latency introduced by synchronizing all pixels. This architecture allows EBSs to dynamically react at the speed of the scene rather than at an *a priori* rate, simultaneously detecting and tracking very high- and low-speed objects. In addition, EBS data can be used to support initial object discrimination and characterization.

EBS response speed is fundamentally faster than traditional cameras because its asynchronous operation enables pixels to respond on an "as needed" basis as a scene evolves, whereas traditional cameras must synchronize all pixels to produce dense data frames at set intervals, independent of the scene's actual dynamics. Additionally, conventional cameras require *a priori* knowledge of expected targets and dynamics for the configuring of parameters like frame rate, gain, and integration time. For example, to consistently detect a visible 10 Hz signal, the frame rate must be at least 20 Hz. This response often requires either biasing camera systems towards faster frame rates and higher data volumes or sacrificing detection performance by missing higher-speed dynamics.

Figure 1 shows the nearly instantaneous response time of EBSs in an extreme case. The data were recorded during a counter-unmanned aerial systems (CUAS) collect when a lightning strike occurred in the background. Pixels exposed to the lightning's changing intensity responded so rapidly that they captured the successive stages of the strike: leader formation, primary channel formation, and return stroke. During this dazzling, split-second event, the sensor still detected the target UAS at its own response speed while largely suppressing the background that a traditional camera would transmit.

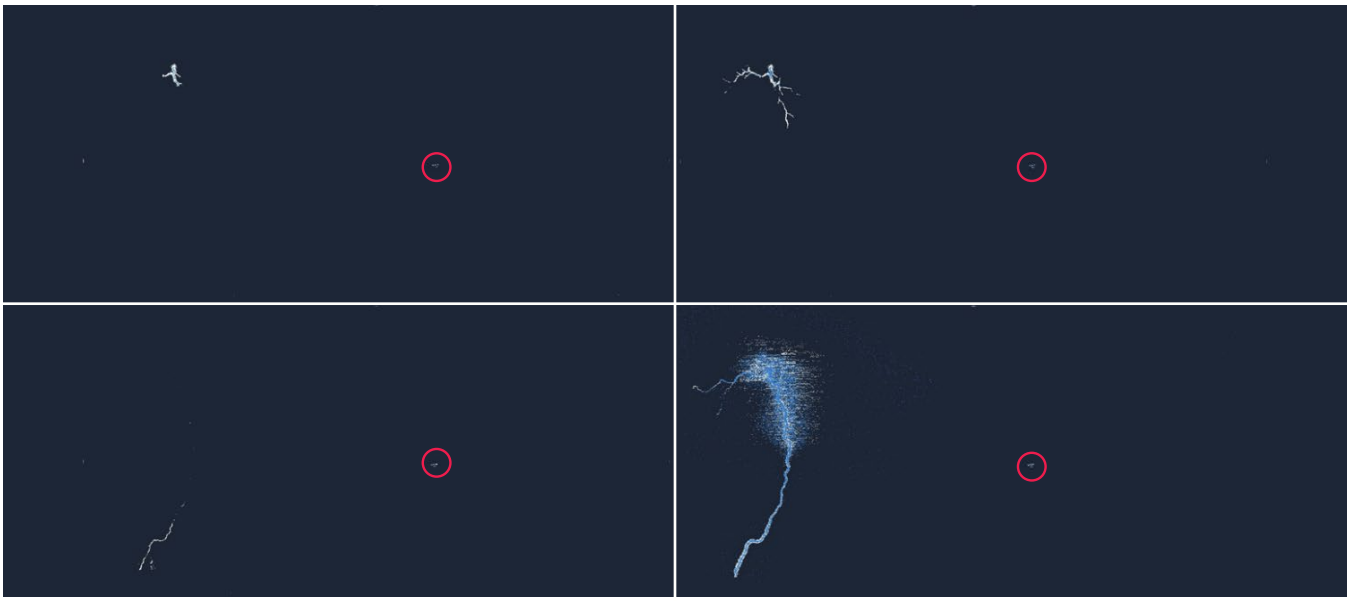


Figure 1: Screenshots from an event-based sensing CUAS collect (drone enclosed in red circles) during which lightning struck in the background (to the left in all four screenshots). While the full dataset contains substantially more temporal information than appears here, pixels allocated the response bandwidth to capture each phase of the strike, including leader formation (top left photo), channel formation (top right and bottom left photos), and return stroke (bottom right photo).

Low Data Bandwidth

As EBSs report only data related to change, they require much smaller data bandwidth than traditional imaging cameras as they do not record redundant information associated with a scene's static areas. Traditional imaging cameras output full frame information, which is generally greater than 1 million pixels at greater than 10 Hz. This rate produces tens to hundreds of megabytes of data per second, which must be continuously processed or transmitted to a remote location. Much of these data are related to unnecessary background information such as the sky, clouds, and buildings. Sandia National Laboratories has found that, for real-world scenes, EBSs typically produce 1–5 percent of the data volume a traditional framing camera produces.

For example, Figure 2 shows a swarm of Group 2 drones (enclosed in red circles) recorded by an EBS (top) and by a conventional framing camera (bottom). While the conventional camera reports the full scene, including static background features such as empty sky and mountain peaks, EBSs report only the data related to change (black values correspond to "silent" pixels that reported no events). Thus, since EBSs output sparse data compared to the conventional camera's image frames, the sensor data are naturally more prominent. (Background features such as mountain peaks may still be visible due to air scintillation or camera motion.)

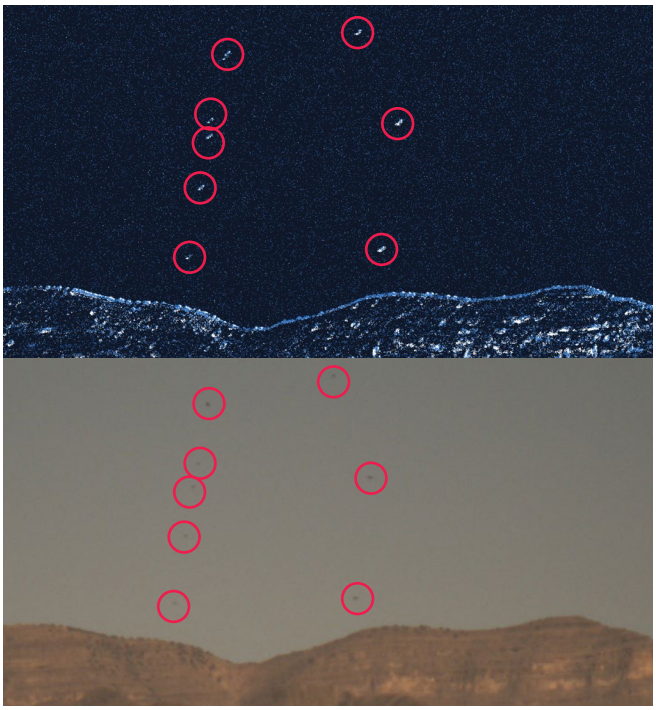


Figure 2: Data collected from an EBS (top) and a conventional framing camera (bottom). Both show the same scene at roughly the same time. The drones (enclosed in red circles) show more prominently in the EBS output due to the suppression of data related to static or background elements. Event data were accumulated into a frame for visualization. White and blue represent events of increasing and decreasing polarity (luminance), respectively; black corresponds to "no data."

Image prominence to the human eye is not equivalent to detectability by an algorithm. As this example shows, event-based sensors concentrate information around change, providing a higher proportion of information relevant to detection and tracking algorithms than traditional cameras.

High Dynamic Range

While the core architecture of EBSs does not intrinsically impact dynamic range (the ratio between the brightest and darkest parts of an image), the major commercial off-the-shelf (COTS) EBSs use log-amplifiers in their pixel circuitry, which yield a dynamic range of greater than 120 decibels (dB). This capability supports operation across a wide range of conditions, from nighttime low-light illumination to direct sunlight in the field of view.

In Figure 3, an event-based sensor was set up with the sun deliberately in the field of view. A ball was then thrown such that its arc approached the sun's position in the field of view. As Figure 3 shows, the event-based sensor data enabled clear detection and tracking of the ball throughout its trajectory.



Figure 3: Event snapshot showing the sun and a thrown ball. The ball is clearly visible due to its motion. Note that the static background did not generate data. White and blue represent events of increasing and decreasing polarity (luminance), respectively; black corresponds to "no data."

Data Capture Capability

The high temporal responsivity of EBSs, coupled with their potentially high-definition (720 x 1280) resolution, enables them to capture signature information that supports discrimination among different types of targets. This combination allows EBSs to produce clear target signatures even when targets are moving or changing (e.g., blinking) rapidly—as opposed to conventional framing cameras, where motion blur may prevent the capability to distinguish among different target types. The section "Event-based Sensing Signatures," later in the article, presents multiple examples of EBS signatures.

Low Power

While traditional passive imaging cameras are typically not high power, they produce dense image frames that require high-power processing to convert raw data into usable information. Scenes consist largely of redundant background information that must be removed to reveal targets of interest. Image processing of redundant information can be a key reason for high system power usage and reporting latency.

An initial layer of background subtraction is built directly into the pixel architecture of EBSs; pixels that do not detect change do not consume power by reporting static background information. This architecture saves power both through the sensor's non-response and through the reduced quantity of data that systems must process.

Small and Lightweight Design

COTS EBSs are small and lightweight—on the order of tens of millimeters in height, width, and depth, and weighing only tens of grams. Depending on use, the optics attached to the sensor are often a larger factor than the camera itself for determining the size and weight of the overall sensing system.

Processing EBS Data

Although using EBSs for UAP applications is a promising and steadily growing field, their novel data format poses a key challenge. EBS output includes the pixel coordinates (x,y) related to physical location in the sensor's field of view, the microsecond precision time (t) at which a change was observed, and the increase or decrease in polarity (p) associated with the change (brightening or dimming). These data are represented as a sparse list of asynchronous $<x,y,t,p>$ tuples, requiring novel algorithms to perform detection and identification. EBS algorithms are still immature compared to algorithms for conventional framing systems.

One approach to processing EBS data commonly found in the literature involves converting EBS data to more conventional "frames" and leveraging existing framing algorithms on the data. Although this approach can produce results with little development effort, it sacrifices the full advantage of the fine-grained temporal information EBSs provide. As previously mentioned, temporal information enables the production of distinct signatures for different target types, which supports target recognition; this benefit diminishes when producing frames, which collapse the temporal information. Streaming algorithms that can operate on the data in sparse $<x,y,t>$ or $<x,y,t,p>$ event space must be developed.

Although EBS data presented in framed format by accumulating events over a time window is easier for humans to interpret, this representation is misleading and, as noted, diminishes the richness of information the sensors provide. An alternate way to visualize EBS data is through a 3-D scatterplot (spatiotemporal volume), which emphasizes the data's sparse nature and the true "shape" of the signature, but is less easily interpreted by humans. Figure 4 provides an example of EBS data presented as a framed image (top), where brighter pixels mean more events triggered at those locations, and as a scatterplot (bottom), where each dot corresponds to an event in $<x,y,t>$ space and each dot's color corresponds to polarity $<p>$.

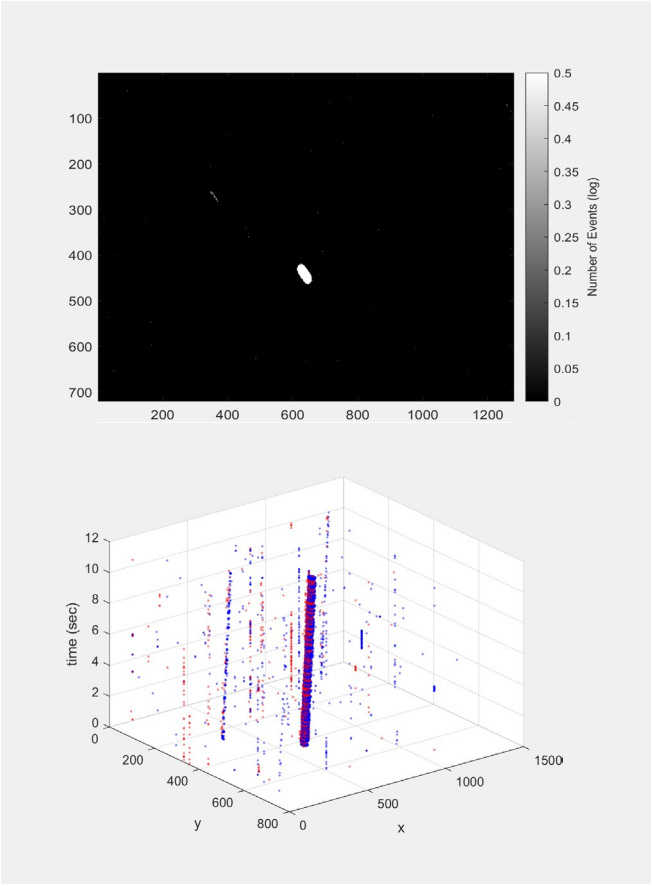


Figure 4: Example representations of EBS data for a couple of stars: (top) framed visualization in which brighter pixels correspond to more event-prolific locations; (bottom) scatterplot visualization (spatiotemporal volume) showing the data in $<x,y,t,p>$ space—each dot corresponds to an event, and colors correspond to polarity. It is apparent from this visualization (but hidden in the framed visualization) that the stars were slowly moving down and to the right in the sensor's field of view.

In the following EBS signature subsections, we present both visualizations. The frame image is more human-friendly, but the scatterplot conveys a more complete target signature.

Event-based Sensing Signatures

A UAP ultimately remains a UAP if there is mystery surrounding its identity. Solving that mystery requires the capability to rapidly and robustly distinguish among different types of known targets based on signature. EBS may afford such determinations. The next several subsections present EBS signatures for various UAP-relevant target types to further illustrate the uniqueness of the data generated and the potential of EBS.

EBS Signature: Birds

Birds tend to exhibit fluid and complex trajectories (especially compared to planes or drones). They can change velocity suddenly—which can lead to sporadic decreases and increases in event rate along their dynamic paths. These decreases and increases produce distinct signatures in event space. Figure 5 shows examples of two bird trajectories.

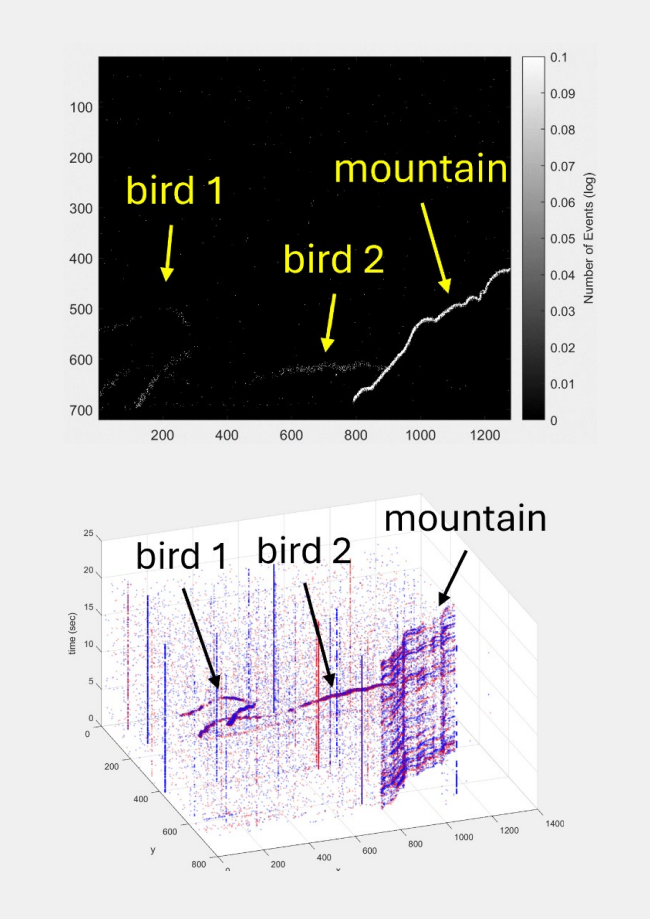


Figure 5: EBS signature for two birds: (top) frame and (bottom) scatterplot

A UAP ultimately remains a UAP if there is mystery surrounding its identity. Solving that mystery requires the capability to rapidly and robustly distinguish among different types of known targets based on signature.

EBS Signature: Bugs

Flying bugs can also have dynamic trajectories—often these are rapid and circular or oscillatory in nature. If the bug is close enough to the sensor, prominent wavelike patterns can be observed in its flight path (potentially associated with wing motion). Figure 6 shows an example of a bug flying close to the sensor.

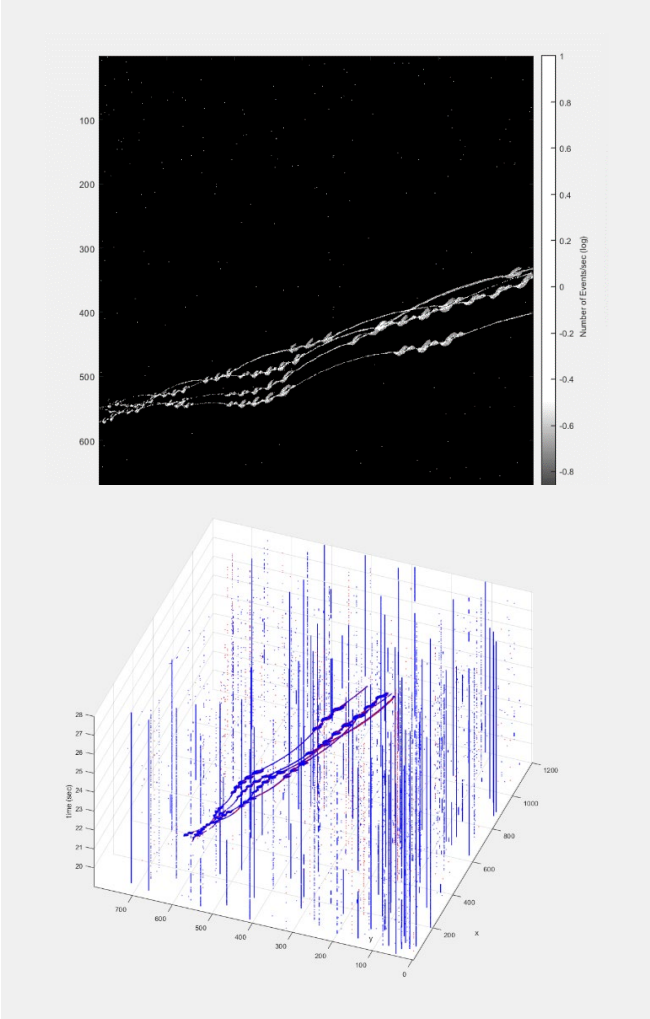


Figure 6: EBS signature for a flying bug: (top) frame and (bottom) scatterplot

EBS Signature: Commercial Planes

Planes flying at night produce a distinct signature, as the Federal Aviation Administration requires commercial aircraft to activate anti-collision lights at night. These lights typically flash in a very periodic on/off illumination pattern and at a frequency of 1-2 Hz—which translates to very clear periodic groups of events. If a beacon's light is occluded from the EBS, the observed frequency may drop below 1 Hz. A plane's trajectory tends to be roughly linear and of constant velocity, which produces a signature distinct from those of birds and bugs (figures 5 and 6, respectively). Figure 7 shows an example of a commercial plane flying with its lights on at night.

EBS Signature: Stars

EBSs can also detect stars due to air scintillation, which causes apparent twinkling. Stars exhibiting less twinkling (i.e., dimmer stars) tend to produce fewer events than those exhibiting more prominent twinkling (i.e., brighter stars). As stars move slowly with respect to the Earth, the EBS signatures for stars, if observed over long enough durations, capture this motion. Figures 8 and 9 show EBS signatures for brighter and dimmer stars, respectively. Note how stars appear as slanted, rather than completely vertical, lines in the spatiotemporal volume image; this pattern reflects their motion through the sky (any purely vertical lines indicate sensor noise).

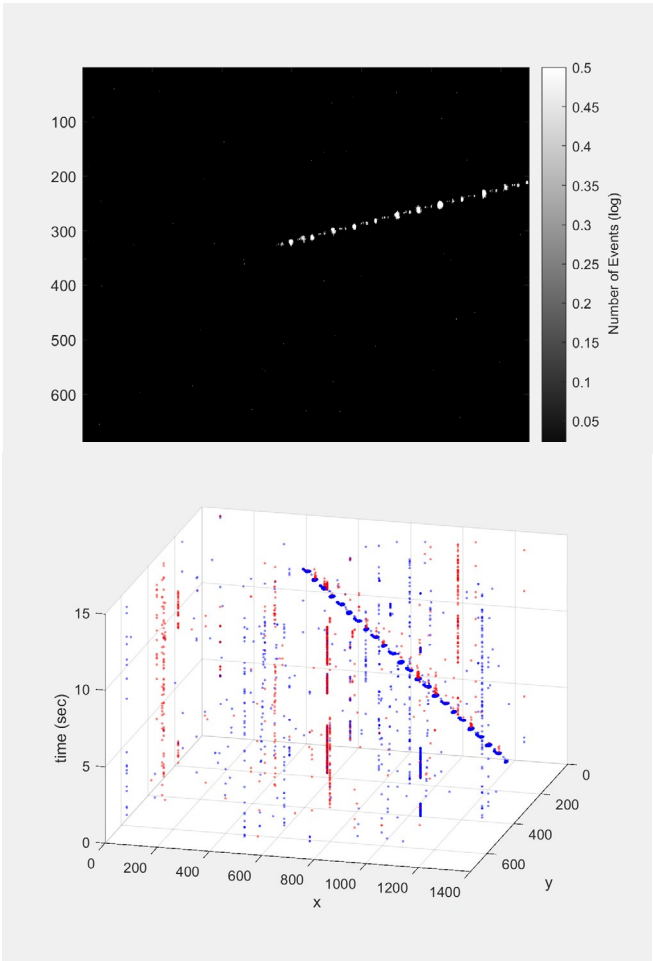


Figure 7: EBS signature for a commercial plane flying with its anti-collision lights on: (top) frame and (bottom) scatterplot

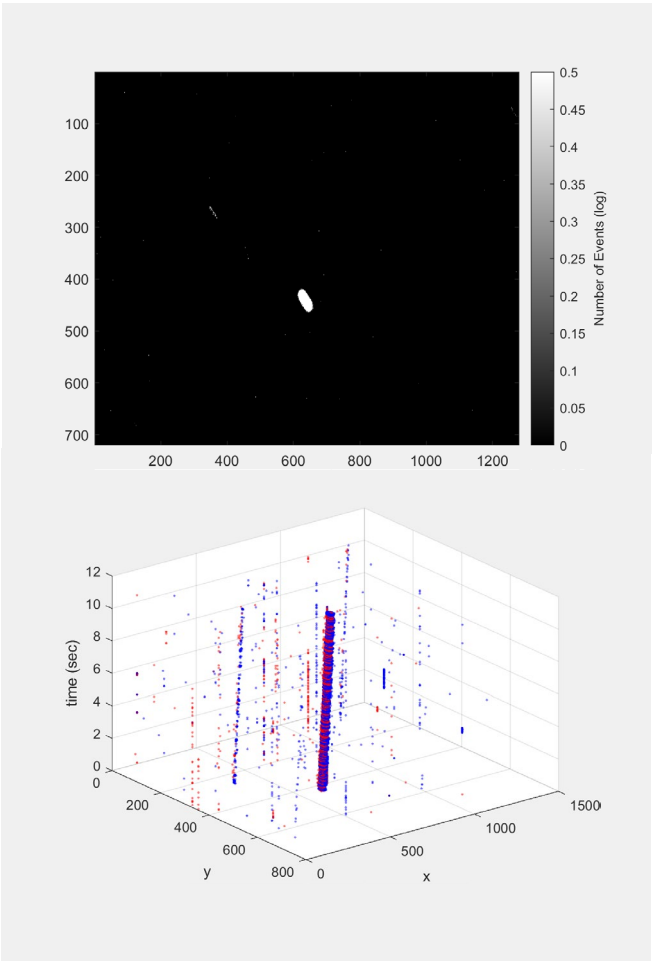


Figure 8: EBS signatures for a bright star: (top) frame and (bottom) scatterplot

Planes flying at night produce a distinct signature, as the Federal Aviation Administration requires commercial aircraft to activate anti-collision lights at night.

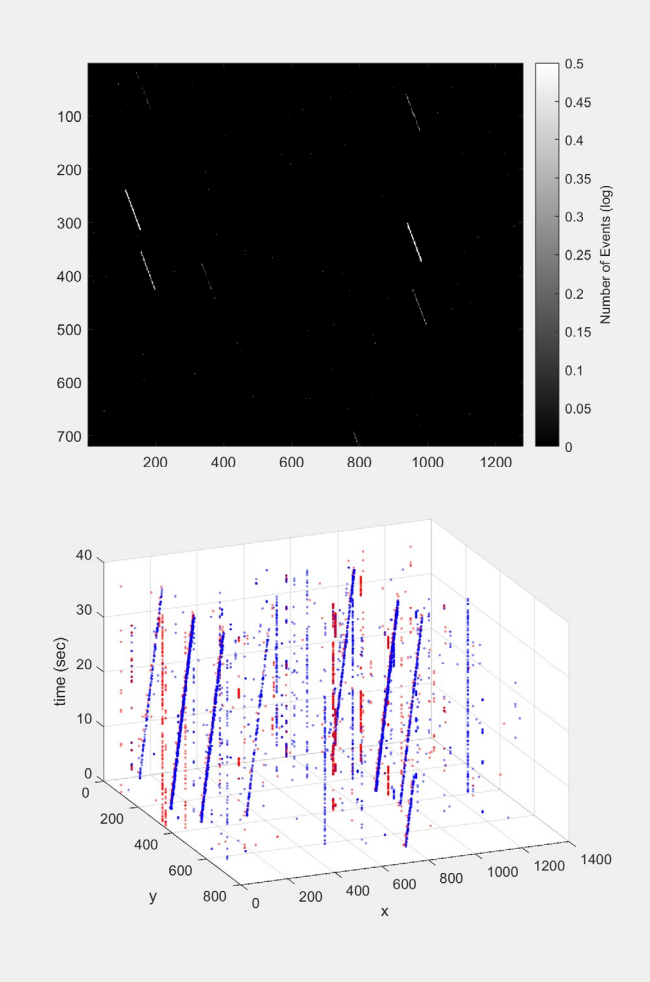


Figure 9: EBS signatures for dim stars: (top) frame and (bottom) scatterplot

Satellite and star signatures are often similar, particularly for satellites and dim stars; however, they can be distinguished by their speeds, as satellites are typically recorded as faster than stars (shooting stars may be an exception).

EBS Signature: Satellites

Satellite signatures resemble those of planes and stars because their trajectories are roughly linear and constant in velocity, so they appear as straight lines in EBS data. However, their signatures deviate from those of planes in direction and strobe frequency: satellites tend to move more vertically, whereas planes tend to travel more horizontally, and satellite illumination is relatively consistent or aperiodic, whereas planes exhibit a periodic on/off illumination pattern at night. Satellite and star signatures are often similar, particularly for satellites and dim stars; however, they can be distinguished by their speeds, as satellites are typically recorded as faster than stars (shooting stars may be an exception, but their paths are much shorter than those of satellites). Figure 10 shows an example of satellite signatures.

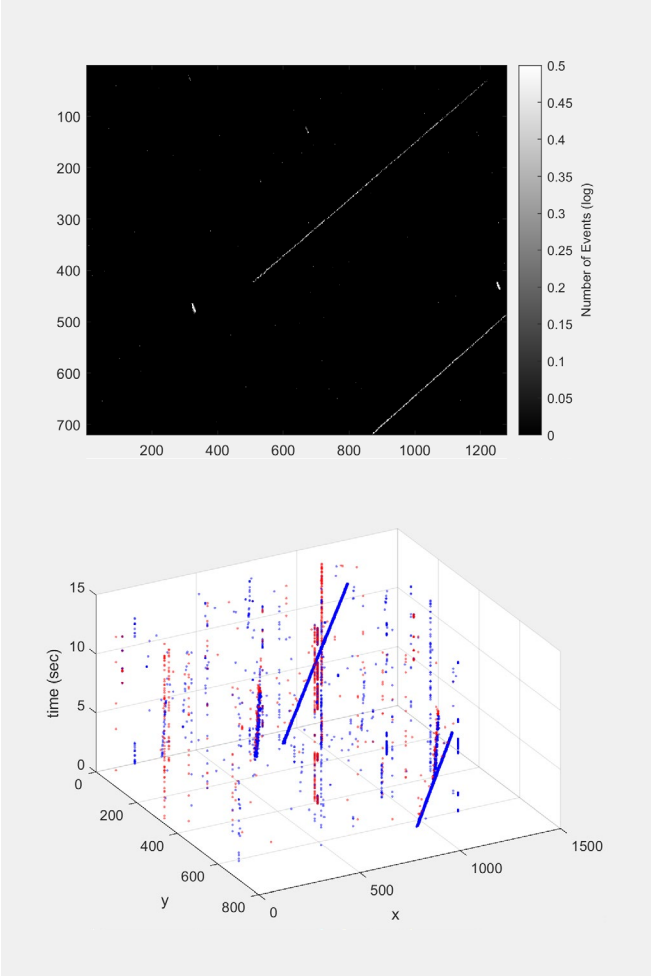


Figure 10: EBS signature for two satellites: (top) frame and (bottom) scatterplot

EBS Signature: Quadcopter Drones

Quadcopter drone signatures are characterized by the drone's ability to hover and maneuver; the signatures display agile, multidirectional flight. Figure 11 shows an example of a quadcopter signature. In this instance, the quadcopter starts by hovering, then shifts to the right (with respect to the x axis/sensor) and hovers for many seconds before once again moving to the right. This inconsistent, sporadic hovering and moving makes this signature distinct from those explored above.

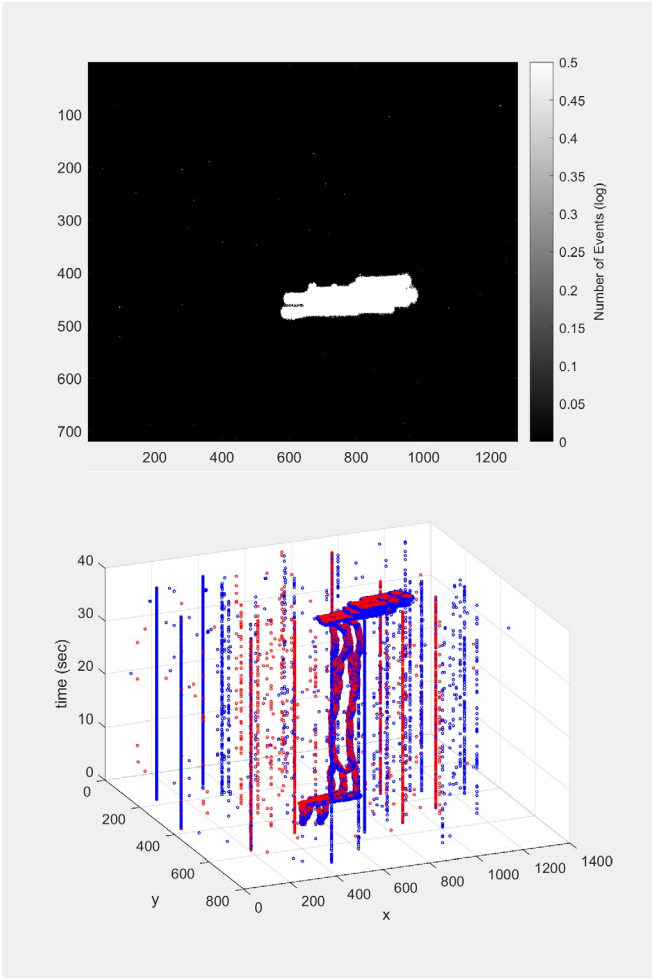


Figure 11: EBS signature for a quadcopter drone: (top) frame and (bottom) scatterplot

Exploiting Event-based Sensing Signatures

As the previous subsections show, multiple types of UAP-relevant targets can appear in EBS data, each with distinct signatures. Drones are an interesting target type for detection and characterization because their signatures are multifaceted, with their rotors producing periodic signals and their bodies producing non-periodic linear motion. This section focuses on detecting and characterizing drones using Sandia National Laboratories' Wide Area Tracking and Characterization via EBS Reconnaissance (WATCHER) Pipeline. We present example algorithm output that demonstrates the ability to use EBS data to simultaneously detect multiple drones in a scene and, separately, characterize a drone's rotor frequency by leveraging the high temporal responsivity of EBSs.

The WATCHER Pipeline

Sandia National Laboratories' WATCHER pipeline is a general-purpose feature-extraction capability able to detect, track, and characterize linear motion and periodic signals in a scene. Researchers have used this pipeline, in part, to investigate the use of EBSs for a variety of CUAS scenarios, ranging from distant point-like targets to closer, spatially resolved vehicles, using both stationary EBS and mobile EBS.

The WATCHER pipeline includes multiple filtering, clustering, characterization, and tracking algorithms. It is regularly stress-tested with new use cases and datasets, existing algorithms are refined, and capabilities are expanded to address multiple applications. As such, the pipeline is continually being improved. The long-term goal is to convert the entire pipeline to a streaming workflow; currently, some of the algorithms are streaming-capable, while others rely on processing batches of events.

To demonstrate the promise of EBSs for automatic UAP detection, tracking, and characterization, WATCHER was applied to two CUAS scenarios—small drone swarms at a distance, and a single large drone—both detected by a stationary EBS. The following sections present the results.

Small UAS Targets: Swarms at a Distance

In the first case, the pipeline processed a dataset containing a swarm of Group 2 drones flying several kilometers away, such that the UAS targets spanned too few pixels across all devices to resolve features. Figure 12 compares output from an EBS (top) and a conventional framing camera (bottom).

As apparent in Figure 12 (and previous figures), event-based data can be noisy, though they still require significantly less bandwidth than framing cameras. This noise can stem from multiple factors including sensor-specific nuances like noisy pixels, selectable sensor settings, ambient light levels, and optics (lens selection, focus). The first portion of the WATCHER pipeline handles noise by running a series of filtering algorithms that leverage spatial, spatiotemporal, and polarity correlation event information. Next, WATCHER identifies clusters associated with periodic and non-periodic

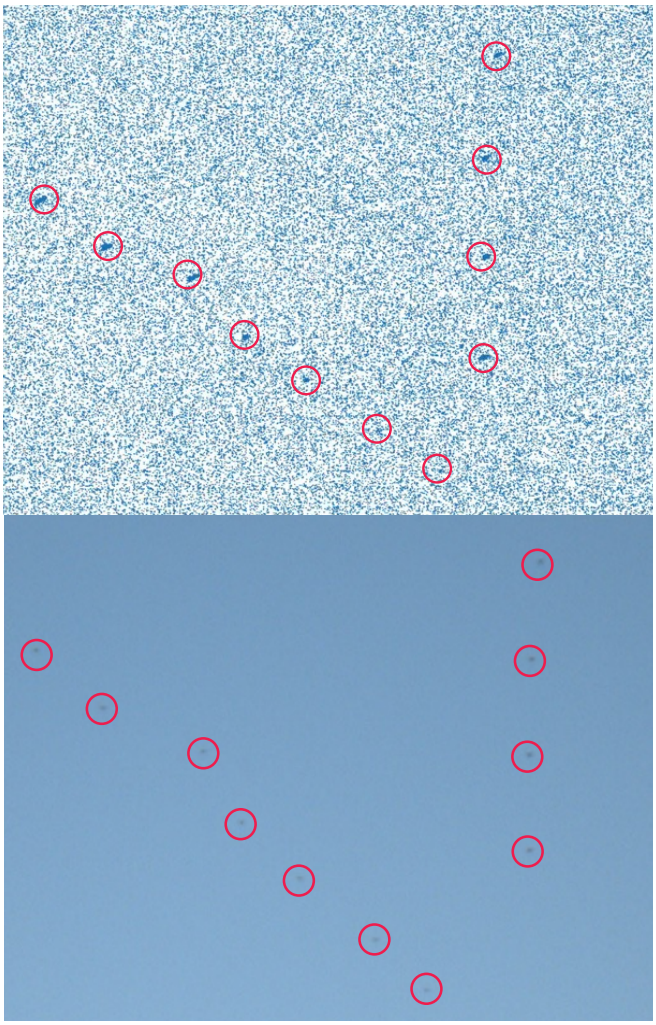


Figure 12: Data collected from an EBS (top) and a conventional framing camera (bottom). Both images show the same scene at roughly the same time. The system accumulated event data into a frame for visualization (blue corresponds to an event; white corresponds to "no data"). Red circles, added manually, mark the locations of the drones.

signals in the event data and characterizes them. This process begins with object clusters initially being unidentified and uncharacterized (i.e., they are UAP). An initial round of characterization separates "periodic" from "non-periodic" clusters, and a second round performs finer-level identification. Events within a cluster can be generated by unresolved targets (those without prominent shape or features) or resolved targets (those with observable shape and features). Unresolved targets are distinguished from noise based on their "bulk" signals (e.g., overall motion type, flashing lights). As targets become more resolved due to higher zoom optics or closer proximity to the sensor, "detail" signals (e.g., shape, periodic rotor signals) are used to support more precise identification.

WATCHER identifies clusters associated with periodic and non-periodic signals in the event data and characterizes them.

Figure 13 illustrates the clusters identified in this drone swarm: the pipeline detected all drones, with only a few false positives. All clusters were identified as not including periodic signals (i.e., clusters were "non-periodic") as the drone rotors were too small to resolve. Figure 14 shows velocity estimates for each cluster.

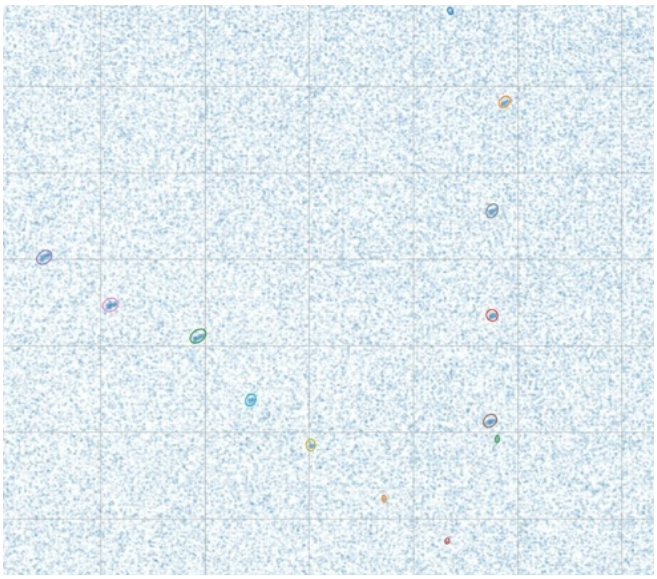


Figure 13: Non-periodic clusters identified by the WATCHER pipeline in event data from a drone swarm. The pipeline automatically detected all drones, with only a few false positives.

These results indicate that the vertical line of drones (right side in both images) were moving rightward and slightly upward at a consistent rate, whereas the diagonal line of drones (left side in both images) were moving at variable speed to merge with the vertical line. In particular, drones in the upper-left portion of the diagonal line were moving to the right more quickly than those in the lower-right portion. Additionally, drones in the upper left of the diagonal line were shifting slightly upward, whereas those at the bottom were moving slightly downward. Taken together, these results suggest that the drones in the diagonal line were maneuvering to perform a "zipper" merge with the drones in the vertical line, which matches the observed behavior.

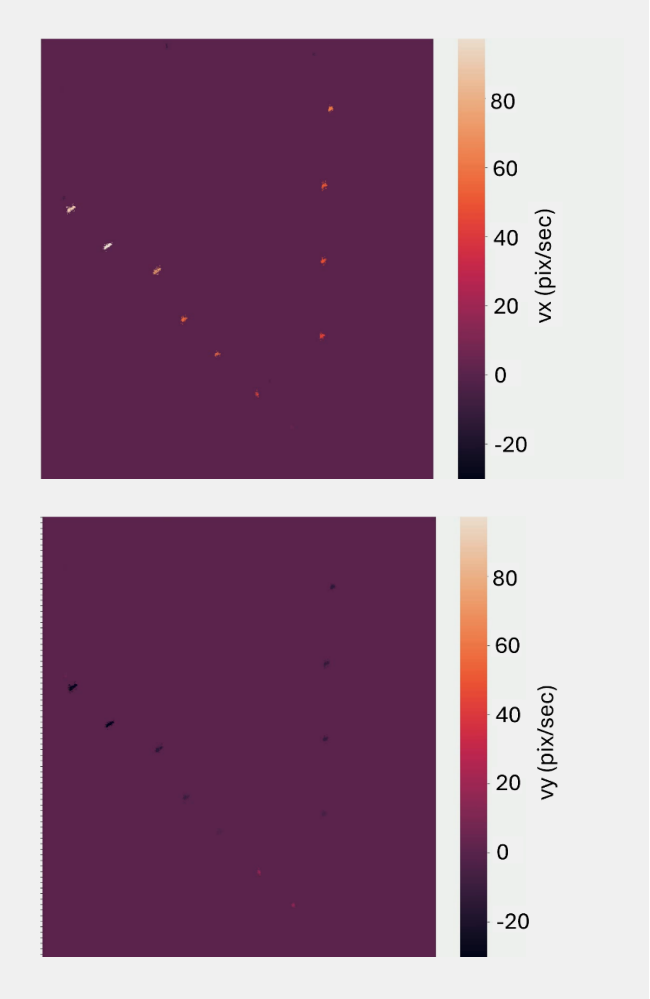


Figure 14: Velocities estimated by the WATCHER pipeline for a swarm of Group 2 drones. (top) X-direction velocities: positive values indicate movement to the right. (bottom) Y-direction velocities: negative values indicate upward movement.

Large UAS Target: Stationary EBS

In the second case, the WATCHER pipeline processed a dataset containing a single drone flying close to the sensor, such that the target's rotors spanned enough pixels to resolve clearly. The EBS remained stationary for these data. Figure 15 shows a framed data visualization.



Figure 15: Framed visualization of EBS data showing the scene composition of the second CUAS case, in which the EBS remained stationary and the drone was large with well-resolved rotors. White corresponds to an event; black corresponds to "no data."

As Figure 16 shows, a well-resolved drone at closer range than in the first CUAS scenario is separable into periodic (rotor) and non-periodic (drone body) components, providing quantitative information for target characterization. Pixels responding to the rotors operate at speeds fast enough to assess both rotor speed and phase, yielding detailed information on the drone's lift capabilities and design. Rotor speed (frequency) changes as the drone maneuvers, and rotor phase establishes that the drone has two blades per rotor that are counter-rotating (i.e., each rotor spins opposite its neighbors).

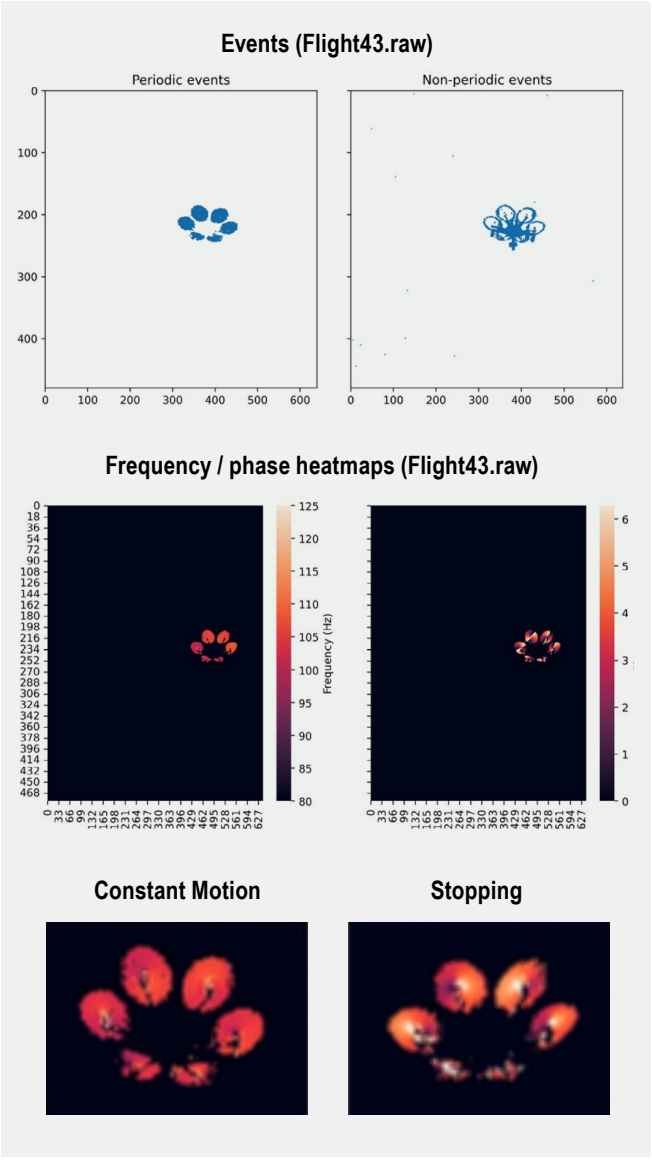


Figure 16: (top) Separation of periodic from non-periodic EBS drone data. (middle) Quantitative assessment of rotor frequency (left) and phase (right), providing characterization information for the periodic clusters. (bottom) Frequency changes corresponding to changes in drone motion.

The two CUAS cases above demonstrate the promise of EBS for detecting and characterizing multifaceted signatures. Future EBS data processing efforts will expand the algorithmic capabilities available, including robust classifiers that explicitly leverage EBS signature differences to distinguish among target types and convert more UAP into known targets.

Conclusion

EBSs are a promising technology for UAP detection, tracking, and characterization. This novel sensing architecture enables faster response times on the order of kHz, with low data bandwidth, high dynamic range, and low power consumption in a physically small (tens of millimeters) and lightweight (tens of grams) design.

Signatures from multiple target types relevant to airspace monitoring appear prominently in event-based sensing data, each with distinct characteristics. These differences may be leveraged to develop new algorithms that rapidly distinguish among UAP types, converting them from unidentified phenomena to identified targets. Sandia National Laboratories' general-purpose feature extraction WATCHER pipeline can be used for wide-area detection, tracking, and characterization of multiple objects in a single scene. Although WATCHER was not developed specifically for UAP application, we have demonstrated that it can detect drones, estimate vehicle velocities for tracking, and, when rotors are sufficiently resolved and in focus, measure rotor frequency for characterization.

We plan to extend the WATCHER pipeline to increase its utility for UAP applications, for example, by incorporating UAP-relevant classifiers, improving the robustness of existing algorithms to reduce noise and recognize confusers (such as reflections), and adding ego-motion removal (which separates camera motion from target motion). We also plan to assess the impact of sensor focus on pipeline performance and investigate techniques for automatic sensor adjustments, such as autofocus.

Overall, early results demonstrate the strong potential of EBSs for low-power, persistent monitoring systems to maintain custody of an airspace against unpredictable and potentially dangerous UAP, expanding the tools we have available to keep the nation, and its people, safe.

Acknowledgements

The authors would like to thank Marlene Dugger for her support in analyzing and generating results illustrating signatures of various target types in EBS space, along with John van der Laan and Jeremy Wright for providing the data used to test the WATCHER pipeline on the rotor analysis UAS case.

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Mobile groups of Ukrainian National Guard hunt for Russian drones.

Ukrainian Military Observations and Analysis of Aerospace Objects and Phenomena during Defense against the Russian Federation

By Drs. Artem Bilyk and Kyrylo Nikolaiev,
Defense Intelligence Research Institute,
Kyiv, Ukraine

Aerospace domain awareness is one of the main challenges for the national security of all countries.[1] The widespread use of aerospace reconnaissance, communications, and navigation requires reliable monitoring, tracking, and analysis of aerospace objects and phenomena (AOP) and their actions in the aerospace domain (ASD). Timely detection and identification of AOP is an important task for improving situational awareness in the ASD to ensure airspace security.

Some AOP, after detailed analysis, are identified as drones, balloons, lanterns, or even clouds. However, some objects and phenomena cannot be immediately identified because they demonstrate characteristics incompatible with available data on known objects: high speeds, instantaneous acceleration, lack of visible signs of propulsion, non-trivial light effects, and so on.[2] Some of these objects, which could be initially referred to as unidentified flying objects (UFOs), are eventually identified, but some are recognized as anomalous based on these factors and are formally categorized as Unidentified Aerial Phenomena (UAP). UAP pose a potential threat because they may collide with aircraft and because of the effects of their light, radiation, and electromagnetic emissions on technical systems, people, and the environment.

According to a US Department of Defense (DoD) report, "unknown drones" have been a growing threat to critical national infrastructure, military bases, and other facilities for the past few years.[3] Undoubtedly, a large share of these reports reflects the wide availability and variety of civilian drones, as well as the smuggling, industrial espionage, and intelligence activities of other countries.[4] Many of these "unknown drones" exhibit the unusual UAP characteristics mentioned above.

Leading countries such as the United States, France, Norway, and Argentina maintain specialized units and organizations responsible for centralized AOP data collection and identification.[5] Identifying AOP is a key issue, as they can pose a threat to national security, especially during wartime. Reports published by US governmental organizations including the All-domain Anomaly Resolution Office (AARO) and the Office of the Director of National Intelligence (ODNI),[6] as well as other organizations studying UAP, state that UAP pose a clear national security threat because their origins, motives, and capabilities are unknown.[7] Therefore, monitoring and studying UAP is important due to the potential danger they pose and their constant presence in controlled and restricted ASD.

Russia's war against Ukraine, which began locally in 2014, has been full-scale since February 2022. One feature of this war is the saturation of the operational environment with reconnaissance systems, the use of unmanned aerial vehicles (UAVs), and a wide variety of existing and newer weapons at an unprecedented scale. These factors have had a major impact on UAP observations. Ukrainian civilians and military personnel now pay far greater attention to objects in the sky because their safety and lives depend on it. A significant

number of types of AOP associated with combat operations have emerged, and false identifications of civil aircraft have decreased because martial law prohibits civil aviation flights. Due to the full-scale aggression of the Russian Federation, hundreds of thousands of monitoring systems and tools operate continuously across various platforms to record events in the ASD, particularly in combat zones, while detecting potentially threatening enemy air attack and reconnaissance assets. As the number of ASD monitoring systems expands and the level of professionalism among personnel increases, both the number and the quality of AOP reports continue to rise.

The purpose of this article is to introduce the Ukrainian methodology for observing, detecting, and identifying AOP; to provide an overview of Ukrainian military UAP video-detection cases during the 2023-2024 full-scale invasion by the Russian Federation; to contribute to ongoing UAP research; and to help other countries improve their ASD security.

AOP Monitoring by the Armed Forces of Ukraine

Figure 1 shows the process of observing, detecting, and identifying AOP by the Armed Forces of Ukraine.[8]

As Figure 1 shows, the primary identification stage provides a basis for a final identification and threat assessment. This article presents an overview of the observation, detection, and primary identification of AOP, as well as part of the final identification stage. While primary identification mainly uses visual data on AOP, final identification requires the preparation of specialized numerical and other data.

Observation and Detection

Observation of the ASD is carried out visually or through technical means. Detection of AOP is the process of establishing their presence through observation using various methods (visual, thermal, acoustic, radar, etc.). Monitoring equipment and devices include individual (micro-level), local (meso-level), and global (macro-level) electronic and mechanical systems that measure and record environmental conditions. Rapidly developing individual electronic and mechanical systems include mobile devices, smartphones, surveillance cameras, mini radars, and portable stations for measuring meteorological conditions and other environmental parameters. Local systems currently include departmental and private devices, aircraft, and other platforms. Global monitoring systems for ASD in Ukraine include satellites, meteorological stations, and radar stations.[9]

Visual monitoring devices and instruments include cameras, night vision devices, telescopes, and binoculars. These devices can be portable, stationary, or mounted on moving vehicles and equipment. Because of the war, thousands of military and civilian cameras have been deployed along the frontline and across Ukraine, recording video and thermal imagery. Radio reconnaissance devices, widely used by the Ukrainian military, can detect AOP radio emissions and help to identify them. Radar detection uses specialized systems that vary in design, range, operational altitude, and frequency bands.

Satellites and spacecraft monitor AOP from hundreds of kilometers above Earth, while space-based imagery is capable of providing highly accurate visual detection, thermography, and electronic reconnaissance. Nearly any type of AOP data-collection equipment can be installed on satellites and spacecraft. Ukraine, lacking its own reconnaissance satellites, relies on foreign partners (the United States, Europe, and others) and commercial satellite imagery for operational information.

Manned and unmanned aerial vehicles are the most common platforms for monitoring systems in the ASD, primarily due to their low cost. The active use of UAVs, especially near the war zone, makes it possible to monitor AOP in close to real time and to analyze threats. Manned vehicles can provide more detailed information and support faster decision-making when crews detect AOP, but they put those crews at risk. The low visibility and maneuverability of UAVs, along with some models' ability to hover for extended periods over a point on the Earth's surface, enable extensive data collection. Their high speed allows them to maneuver closer to AOP for better visibility. Thousands of Ukrainian military

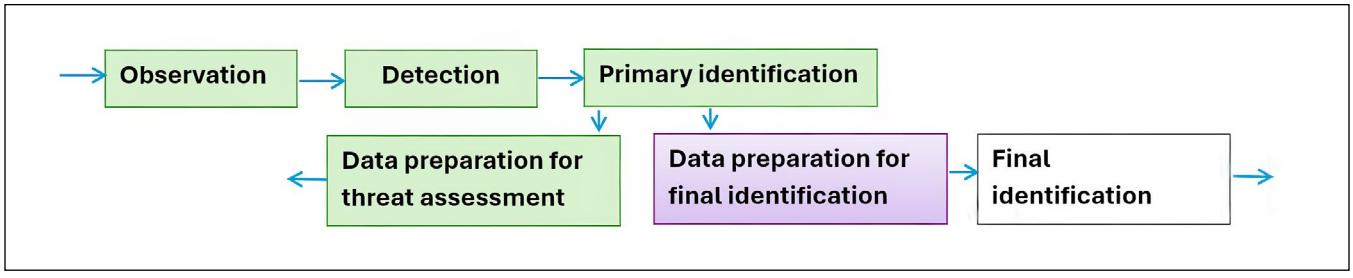


Figure 1. The main stages of AOP observation, detection, and identification by the Armed Forces of Ukraine.

UAVs operate continuously, many of them provided by international partners.

Special stationary and mobile monitoring systems are among the most promising means of monitoring and detecting AOP because they are relatively inexpensive, support the deployment of monitoring networks, are easy to disguise, and can be quickly upgraded. Stationary systems are located on the ground, on towers and masts, on building elements, and in other locations. Mobile monitoring systems are deployed on vehicles, equipment, and specialized unmanned mobile platforms. Modern monitoring systems are typically multispectral, but require specialized hardware, data storage, and transmission systems. For example, since 2023, Ukraine has deployed a nationwide system of acoustic sensors aimed at detecting drones in real time based on the characteristic noise of their engines and to predict their trajectories.

Ukraine produces some technical monitoring systems domestically, but since 2022, it has received many through international technical aid or purchased them from foreign partners, including the United States, Norway, France, Great Britain, and others (see Figure 2).

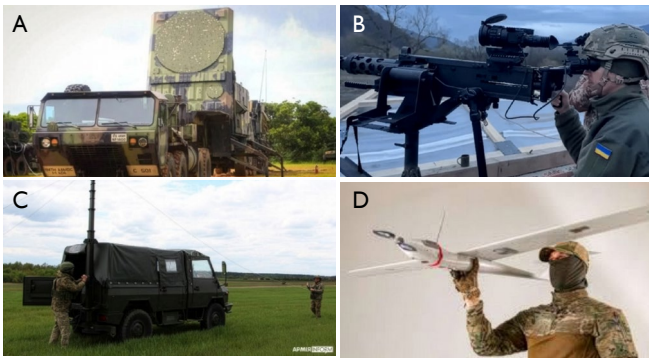


Figure 2. Examples of local and individual technical systems used in Ukraine for ASD monitoring for military purposes: (a) "Patriot" air defense radar; (b) thermal imaging surveillance system; (c) deployment of a UAV monitoring complex; (d) special reconnaissance UAV

Identification

Identification is the process of establishing the identity of AOP based on the parameters and features of known anthropogenic and natural AOP. Two types of identification are distinguished: primary and final.

Primary Identification

Primary identification is carried out directly by personnel involved in monitoring and detecting AOP or is automated using specialized technical systems. It provides the data needed to assess threats and support rapid decisions on how to neutralize them, if necessary. The data for threat assessment is prepared by the personnel involved in monitoring and detecting AOP, or other specialists, who promptly transmit it to the appropriate officials for decision-making. Threat-assessment data include key AOP parameters such as direction of movement, trajectory, speed, and general description. These data should be sufficient to enable decisions on how to neutralize possible threats, which is the top governmental priority. Inability to identify an AOP during primary identification does not prevent the preparation of threat-assessment data or decisions on potential neutralization.

AOP can remain unidentified at the primary stage for many reasons: poor observation conditions; limited capabilities of monitoring instruments; variability in existing and emerging aerial technologies (aircraft, UAVs, missiles) used by both Ukrainian and Russian forces; specialized flight modes (e.g., very low altitudes, no lights or identification marks, loudspeakers, thermite payloads); and the use of fiber-optic–controlled drones by both sides, which can operate inside buildings or lie in ambush on the ground. The enemy is actively using camouflage and deception measures to avoid Ukrainian air defenses. These measures include special UAV coloring; radio-absorbing and thermal-insulating coatings; engine noise reduction; the use of false targets, such as air balloons and reflector-equipped UAVs; missiles with dipole reflectors (strips of foil or pieces of metallized fiberglass) and heat traps; and UAV camouflaged as birds.

Final Identification

Final identification is aimed at conducting further analysis when an AOP remains unidentified after primary identification. In such cases, the primary identification data are sent to other specialists for final identification analysis. Data required for final identification include AOP parameters and features. AOP parameters describe the AOP quantitatively and can be expressed numerically (e.g., speed, size, brightness). AOP features describe AOP qualitatively and cannot be expressed numerically (e.g., color, shape). The parameters and features should comprehensively characterize the AOP to support identification with a high level of confidence; be measured using available tools and instruments; and have known limits of variability for different observation conditions. The final identification of AOP may require specific calculations, the use of specialized software, laboratory tests, field work, and so on. A designated official makes the final AOP identification decision.

Final identification analysis may show that initially unidentified AOP with unusual parameters and features are the latest

developments in enemy aircraft or UAV, effects of weapons use, or other phenomena. Parameters and features that are highly unlikely to match those of known objects and phenomena are classified as anomaly factors.[10] If anomaly factors remain after final identification, the AOP is recognized as anomalous and is categorized as UAP. Table 1 presents examples of anomaly factors considered when identifying military UAP observations in Ukraine.

Table 1. Examples of UAP Anomaly Factors

Characteristics	Anomaly Factors
Appearance	Sudden appearance; gradual appearance in clear skies
Body	Shape uncharacteristic of known objects or phenomena; blurred shape
Details	Lack of details inherent in known objects or phenomena; presence of unusual details
Movement	Sudden acceleration or stopping; ultra-high velocity; turning at high velocity at sharp angles; abnormal trajectory; long hovers in one place; high-speed rotation; inappropriate location; non-trivial trajectory; trans-domain movement
Transformation	Splitting into parts; sudden change of shape, metamorphosis; separation or joining of objects
Effects	Color change, unusual colors; ultra-brightness, flashes, pulsations; high or low temperature; rays with finite length, fragmented rays; different types of radiation; non-trivial, remote influences
Interactions	Landing or take-off in unsuitable locations; environmental, technical, and biological impacts; residual effects; environmental changes
Disappearance	Sudden disappearance; visual invisibility; gradual disappearance in clear sky

Public and Military Study of Anomalous Phenomena

Because of these threats, both the public and military in Ukraine are engaged in the study of anomalous phenomena, which also presents opportunities. In the public sector, the Ukrainian Scientific Research Center for the Analysis of Anomalies ("Zond"), a separate unit of the Aerospace Society of Ukraine, has conducted extensive research on anomalous phenomena since 2004.[11]

In the military sector, the Armed Forces of Ukraine issued a special order in 2023 stating the need to track unidentified objects in the sky.[12] In 2024, the Ukrainian Defense Forces established a special unit—a research laboratory that analyzes AOP reports and collects and investigates UAP cases. This unit has produced two manuals on AOP identification and UAP information analysis. It has also developed a questionnaire to collect detailed information from military eyewitnesses[13] (see Figure 3). To avoid misidentification, the unit accepts only reports that include photos, videos, or other material evidence. It has also developed a scientific UAP identification methodology,[14] and has begun specialized military training to increase ASD awareness and prepare personnel to receive UAP observation reports.



Figure 3. Two manuals, written in 2024 and approved in 2025, for AOP identification and UAP information analysis in the Armed Forces of Ukraine

> **Civilian reports support military identification of AOP**, because of the large number of potential witnesses and their uniform distribution across the territory.

At the same time, a special "ePPO" ("electronic air defense") app supports users in both sectors. Voluntary programmers from the Technari group developed the app, which collects real-time coordinates of observed objects and phenomena in the ASD. A separate "UFO" button allows civilian eyewitnesses to report initially unidentified objects other than those that are clearly of artificial origin (drones, airplanes, helicopters, missiles, quadcopters, aerial explosions) (see Figure 4).

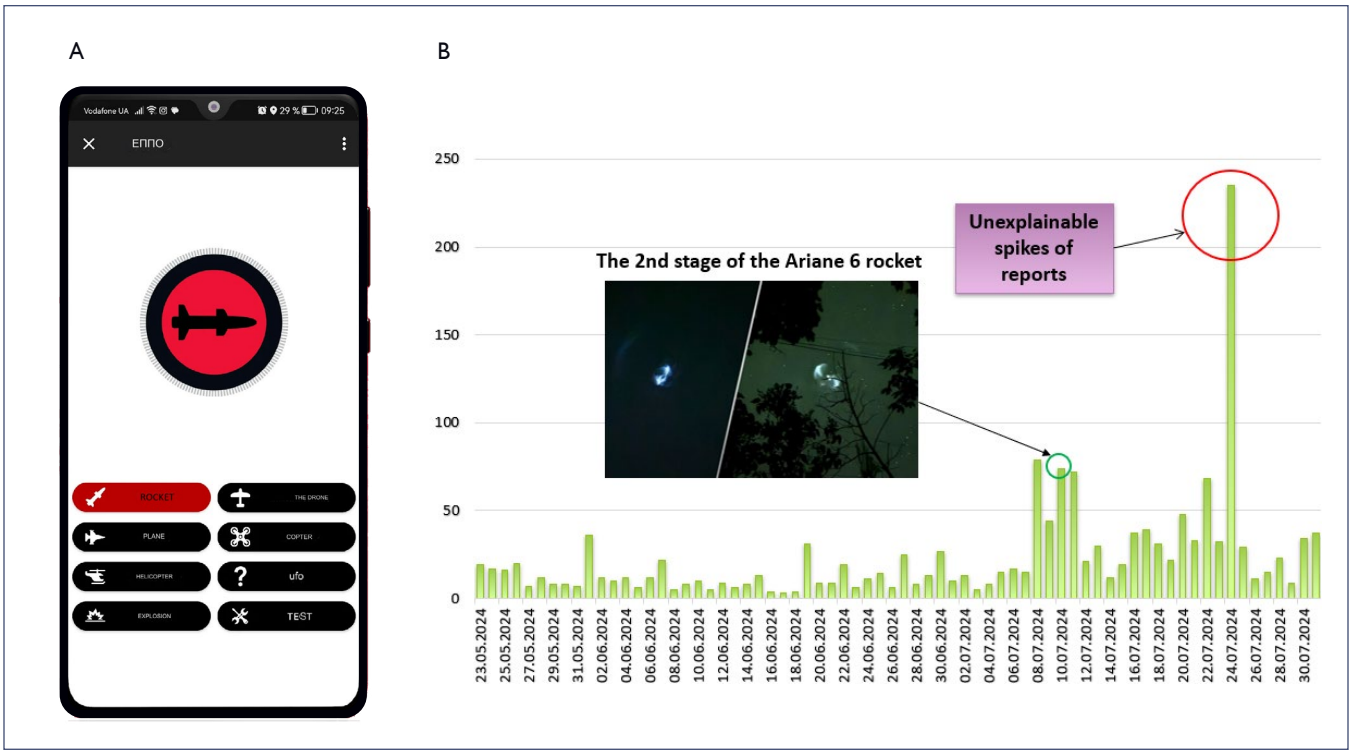


Figure 4. (a) The Ukrainian ePPO application; (b) example UFO statistics from the application (1-31 July 2024). Some spikes were identified as launch effects related to the Ariane 6 space rocket, while others remain unexplained.

This app currently has more than 800,000 users.[15] Civilian reports support military identification of AOP, because of the large number of potential witnesses and their uniform distribution across the territory. Based on these data, ePPO processing is performed by artificial intelligence (AI), which identifies the objects and predicts their location and flight trajectories. If necessary, a shootdown is planned.[16]

AOP with Wartime Origins that May Initially Remain Unidentified

In general, AOP can be classified by origin as natural (e.g., clouds, meteors, auroras) or anthropogenic (e.g., manned and unmanned aircraft, balloons, rocket launch effects). In Ukraine, many AOP may currently result from military operations and their effects: winged UAVs, drones, missiles, explosions, smoke clouds and trails, bombs, parachutes, signal rockets, military planes, and helicopters. Some AOP that appear natural-looking may have anthropogenic causes, such as dust clouds or artificially created clouds. The effects of anthropogenic AOPs can also occur simultaneously with natural AOPs, which distorts their parameters and features and complicates detection and identification. To achieve deception, the enemy may intentionally alter the parameters and features of artificial objects.

Figures 5, 6, and 7 show unusual military-related aerospace effects and objects that may initially be unidentified. Figure 5 illustrates a range of missile and gliding bomb launch, flight, and explosion effects that could lead to AOP being classified as unidentified at the primary identification stage because they often look unusual, especially from a distance.



Figure 5. (a) Air-launched missile; (b) ground-launched missile; (c) gliding bomb; (d) cruise missiles in group flight; (e) ignition charge (Russian); (f) phosphorus charge (Russian); (g) illuminating aerial bombs; (h, i) signal rockets

Figure 6 illustrates a range of objects, balloons, and drones that may lead to AOP being classified as unidentified at the primary identification stage because they can fly at low altitudes and produce a wide range of light effects. Russia may also use "unknown drones" for reconnaissance and to induce panic among civilians, and may mask their drones as natural AOP or UAP and deploy them during or after actual UAP waves to avoid detection and targeting.

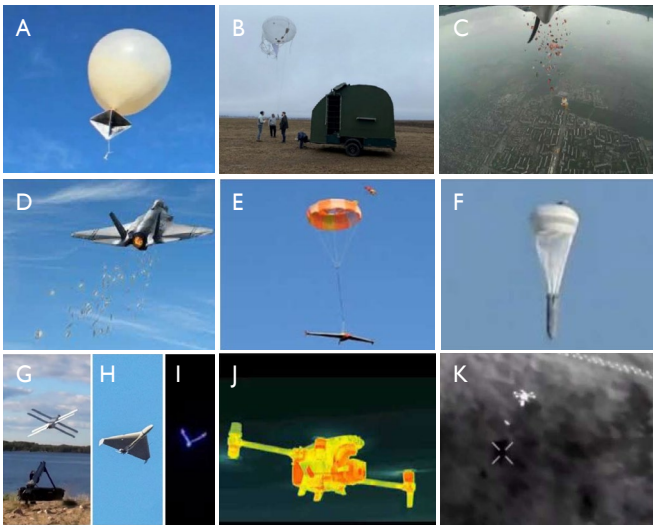


Figure 6. (a) Balloon with reflectors, used as a false target for air defense systems; (b) Ukrainian military tethered reconnaissance balloon; (c) leaflets dropped from a UAV; (d) dipole reflectors dropped from an aircraft to confuse radar; (e) parachute for UAV landing; (f) Russian bomb with parachute; (g) Russian Lancet strike drone; (h) Shahed strike drone; (i) Shahed strike drone with lights at night; (j, k) thermal images of quadcopters

Russia may also use "unknown drones" for reconnaissance and to induce panic among civilians, and may mask their drones as natural AOP or UAP and deploy them during or after actual UAP waves to avoid detection and targeting.

Figure 7 illustrates artificial light, smoke, and explosion effects that may lead to AOP being classified as unidentified at the primary identification stage because they can move rapidly and appear as bright flames or light sources. Aircraft may also fly without lights at very low altitudes to avoid detection.



Figure 7. (a, b) Ukrainian military mobile fire team using searchlight beams to detect UAVs; (c, d) UAV struck with a thermite payload; (e) fireball from an air explosion; (f) smoke charges; (g) downing of a Russian aircraft; (h) multiple explosions of anti-aircraft shells; (i) heat traps (flares that emit intense heat to divert infrared-guided missiles) launched from a Ukrainian helicopter

Separate consideration should be given to cases in which natural or anthropogenic AOP appear unusual due to peculiarities or defects of observation equipment. These include optical glare, aberrations, camera frame defects, problems with matrix illumination (in camera, video systems, and thermal imagers), hardware processing errors, and software errors in AOP detection and identification. Unidentified objects and phenomena observed in the ASD may result from human technical activity, natural processes, or unknown non-human-made objects with abnormal characteristics.[16] Many natural phenomena remain unexplored, often transient and sporadic with unusual characteristics in their phenomenology, physical manifestations, and effects on people and equipment.

Examples of UAP Observed by the Ukrainian Military

This section presents several examples of UAP observed by the Ukrainian military in 2023-2024, along with their parameters and features. These cases exhibit anomaly factors similar to those reported in the United States and other countries, indicating that UAP are a truly global phenomenon. Generalized data on the military UAP cases described in this article are summarized in Table 2.

Figure 8 (a) shows a wedge-shaped formation of five spherical UFOs recorded by a Mavic 3T drone with a thermal imager in a Ukrainian war zone in 2024. The objects followed a straight trajectory and produced no sound. Each object measured about 1 meter (m) in diameter and moved at about

30 meters per second (m/s). Final identification analysis classified the objects as UAPs due to anomaly factors, including small size, unusual shape, group formation, regular group formation, high velocity, straight trajectory, and low altitude.

Figure 8 (b) shows a single hovering, flat or cigar-shaped unidentified object recorded by the thermal imaging camera of a Mavic 3T UAV in the Ukrainian war zone in 2024. No sound was recorded. The object's diameter was about 30 m. Final identification analysis classified the object as UAP due to anomaly factors, including large size, unusual shape, and hovering.



Figure 8. Military UAV thermal imaging video in the Ukrainian war zone: (a) wedge-shaped formation of five spherical UAP; (b) hovering flat or cigar-shaped UAP

Figure 9 (a) shows an in-line formation of four spherical UFOs recorded by a Mavic 3T UAV thermal imaging camera in the Ukrainian war zone in 2024. Each object measured about 2 m in diameter and moved at a speed of about 100 m/s. Final identification analysis classified the objects as UAP due to the anomaly factors, including small size, unusual shape, group formation, high velocity, straight trajectory, and low altitude.

Figure 9 (b) shows a single ultra-fast cigar-shaped vertical unidentified object recorded by the thermal imaging camera of a Bayraktar UAV in central Ukraine in 2023. The object followed a straight trajectory and produced no sound. Its



Figure 9. (a) In-line formation of four spherical UAPs recorded by a military UAV in the Ukrainian war zone; (b) a single ultra-fast, near-vertical cigar-shaped UAP recorded by a Bayraktar UAV in Ukraine in 2023

estimated size was less than 1 m, and its velocity was about 250 m/s. Final identification analysis categorized the object as UAP due to anomaly factors including small size, unusual shape and spatial orientation, ultra-high velocity, straight trajectory, and low altitude.

On 24 December 2024, the Ukrainian military used a Mavic 3T UAV to record a UAP simultaneously with conventional and thermal cameras, as shown in Figure 10 (a). The infrared footage shows a group of five spherical objects (left), while these objects are completely invisible to the conventional camera (right). Final identification analysis classified the objects as UAP due to anomaly factors including small size, unusual shape, group formation, visual invisibility, straight trajectory, and low altitude.

Figure 10 (b) shows a stable formation of four spherical UFOs recorded by a Mavic 3T UAV thermal imaging camera in the Ukrainian war zone on 3 March 2024. Each object measured up to 2.7 m in diameter and moved at a speed of 40 m/s. Final identification analysis classified the objects as UAP due to

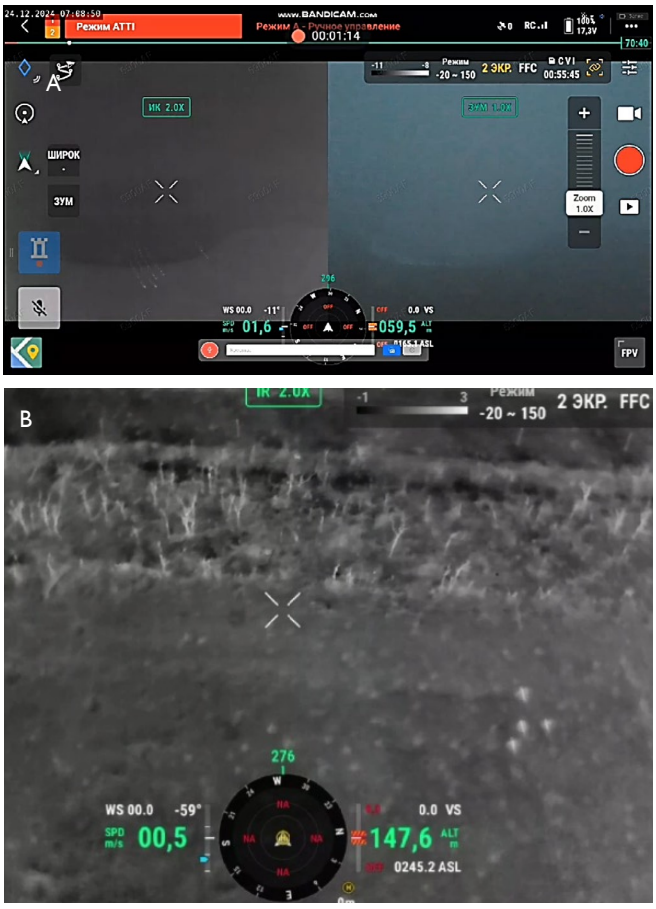


Figure 10. (a) Five spherical UAPs recorded by a military UAV using thermal imaging in the Ukrainian war zone (left); the objects are invisible to the conventional camera (right); (b) another formation of four spherical UAPs recorded by a military UAV in a Ukrainian war zone

anomaly factors, including small size, unusual shape, group formation, high velocity, straight trajectory, and low altitude.

Analysts performed spatial modeling and corresponding mathematical calculations for all selected observations, which enabled them to determine and systematize anomaly factors. Table 2 summarizes data on these military UAP observations in Ukraine in 2023–2024.

classified as UAP because of their anomalous characteristics. For example, UAP often fly in groups, and may be visible on thermal imagers but invisible to conventional cameras.

Recognition and study of UAP are matters of national security as well as challenges for modern science. Effective cooperation among all components of the national security and civilian sectors is essential to detect, identify, and, if necessary,

Table 2. Summary of Ukrainian UAP Observed by the Military (2023–2024)

Date	Shape	Size (m)	Number	Velocity (m/s)	Altitude (m)	Reference
15 Feb 2023	cigar-shaped vertical	0.3–0.5	1	250	200…300	Figure 9.b
24 Feb 2024	disc/cigar-shaped	26.4–32.4	1	0	105	Figure 8.b
26 Mar 2024	spherical	1.3–2.7	4	20–42	50–100	Figure 10.b
Feb or Mar 2024 (specific date unknown)	spherical	1.2–6	5	7.3–36.5	100–200	Figure 8.a
28 Mar 2024	spherical	2–2.9	4	76.2–110.8	100–150	Figure 9.a
24 Dec 2024	spherical	0.3–0.65	5	7.5–16.6	20–40	Figure 10.a

Observational data from military UAP reports in Ukraine align with US reports—for example, average size (1-4 m) and predominant shape (spherical).[18] Because these UAP parameters were derived from objective analysis of video and other technical materials, the similarity of characteristics, in our opinion, suggests that UAP are globally prevalent and may share a common source of origin.

During World War II, pilots in the eastern and other theaters of operation repeatedly observed UAP that demonstrated behavior far beyond the aviation capabilities of the time. However, the limited technical equipment of the aircraft and ground stations prevented the wide-scale, detailed recording of these phenomena. Today, modern technical capabilities offer the potential to expand knowledge of UAP and help answer questions about their role on Earth.

Conclusion

Due to the war in Ukraine, civilians, military personnel, and thousands of technical systems continuously conduct large-scale observations to detect AOP. This has increased the observation and reporting of unknown objects in the airspace, many of which are determined to be of natural or artificial origin, such as enemy drones and other reconnaissance and attack systems. However, some objects are neutralize potential threats as quickly as possible. Coherent, coordinated ASD monitoring significantly reduces misidentification and related losses.

> **Timely, reliable AOP identification protects** military personnel, prevents fratricide from mistaken shootdowns, conserves scarce air defense ammunition, and enables the collection of UAP characteristics for further scientific study of these potential threats and their technologies.

Timely, reliable AOP identification protects military personnel, prevents fratricide from mistaken shootdowns, conserves scarce air defense ammunition, and enables the collection of UAP characteristics for further scientific study of these potential threats and their technologies.

The saturation of the military operational environment with monitoring systems creates new opportunities to study UAP. Technical systems play a critical role in observation, detection, and identification of UAP because they provide objective data, expand the UAP knowledge base, and support potential reverse engineering. Detailed identification helps distinguish anthropogenic and natural objects and phenomena from those that are truly anomalous. In the future, integrating diverse systems to enhance their capabilities, combined with advanced AI analysis tools, will likely enable real-time multispectral detection of UAP across much of the globe.

The growing number of military UAP observations worldwide, along with the issue of "unknown drones," has brought renewed attention to UAP as potential enemy reconnaissance or strike systems; at the same time, the technologies they demonstrate are of significant engineering interest.[19] Finally, the possibility of a third, potentially "non-human" presence throughout human history presents a profound challenge to our understanding of the world in which we live.

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Capturing Unidentified Anomalous Phenomena Events: A Practical Photography Guide for Everyday Observers

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Recent attention from governmental bodies, including the All-domain Anomaly Resolution Office (AARO), the Department of Defense, and NASA, has underscored the national interest in documenting Unidentified Anomalous Phenomena (UAP). AARO's findings have highlighted a critical shortage of high-quality visual data, particularly from consumer sources, and emphasized the need for validated methods to record these events. Historically, reports of UAP have consisted mainly of anecdotal narratives and vague imagery lacking the rigor required for scientific inquiry. Today, the ubiquity of high-resolution consumer cameras presents a pivotal opportunity—provided those cameras are used correctly.

The challenge is that most cameras are not designed to photograph UAP. Modern imaging systems are optimized for predictable subjects: portraits, landscapes, wildlife, and sports. Their automatic exposure, focus, and stabilization routines assume a known subject at a known distance behaving in a known way. By definition, UAP conform to none of these assumptions. They appear without warning, at unknown range, moving in ways that defeat autofocus and confuse metering systems. In this sense, the most capable UAP imaging platform is not the most *sophisticated* one—it is the most *manual* one, one in which the photographer, not the camera, controls every parameter of image capture.

Woman looking at night sky with amateur astronomical telescope

The scientific study of UAP—objects whose origins and behaviors, often due to insufficient technical data, cannot be readily identified as conventional, human-made, or natural phenomena—requires rigorous, reproducible, and technically sound imaging data. Peer assessments consistently find that most UAP cases remain unsolved because of the chronic absence of high-quality imagery, particularly at night, when sightings are most frequently reported. If a phenomenon has no previously known cause, the evidentiary burden on the image is even greater.[1]

UAP events are unpredictable and rare; most are captured unexpectedly, at distance, under poor conditions, and without ideal focus or framing. Professional sensor arrays cover only select areas for limited periods, so most potentially important imagery will continue to come from consumer devices by amateur photographers. However, careful preparation and disciplined technique can elevate those observations to analytically useful data.

This article aims to make you "camera-ready"—whether your encounter is planned or unplanned—by helping you optimize your equipment and settings, understand why manual control matters, and preserve your imagery in ways that maintain its scientific integrity through evidence-based protocols aligned with peer-reviewed publication standards for anomalous phenomena research.

Technical Requirements for UAP Imaging

High-value UAP imagery differs fundamentally from "viral" footage intended for mass consumption. Organizations such as AARO seek high-resolution, in-focus, high-contrast, and contextual photos and videos. Higher resolution is achieved by getting physically closer to the object, using higher-quality



Night long-exposure setup in Kirchdorf in Tirol, Austria: a Sony a7R IV mounted on a Geekoto tripod

equipment (larger, better lenses), and providing scene context through multiple frames. Scientific value is defined by the potential for the following:

- Photometric analysis: Well-calibrated, unaltered images enable estimates of object brightness, color, and surface properties, which can reveal potential physical characteristics.
- Triangulation: Precise spatial and temporal data enable researchers to reconstruct an object's position and speed using geometry, provided multiple observers or devices record the object.
- Chain of custody: Original images and video must retain intact metadata and be handled so that third parties can verify their provenance, supporting credibility in peer review and official investigations.

The government has emphasized that nearly all historical UAP evidence has been compromised by low resolution, unknown provenance, missing timestamps, or undocumented digital alterations.[2] A UAP image's scientific value depends on whether third parties can verify what was recorded, when and where it was recorded, and how the files were handled. Isolated single frames with incomplete metadata, heavy compression (overly compressed digital images show "artifacts"—blocky, pixelated, or blurry areas, especially in areas with subtle gradients or fine detail), or undocumented edits rarely support firm conclusions. Conversely, original unprocessed image files, accompanied by intact Exchangeable Image File Format (EXIF) metadata, Global Positioning System (GPS) coordinates, and an auditable handling history, allow analysts to integrate them with environmental data (astronomical catalogs, airplane GPS data, Federal Aviation Administration data, and weather radar) to constrain hypotheses.[3]

Data Hierarchy and Chain of Custody

Establishing a credible chain of custody begins with identifying the digital master. Preserve files in their native, unprocessed states (see Table 1) and move them to Write Once, Read Many (WORM) storage or a cloud-based "hashed" repository immediately after capture. Hashing provides a unique fingerprint for a digital photo by running the photo file through a tool that calculates a value (most commonly using the Secure Hash Algorithm or SHA-256). Hashing can also help prevent unintentional overwriting of EXIF metadata and ensure that the version scientists analyze is identical to the version recorded by the camera sensor. When copying files for analysis, it is essential to clearly label the derivatives and keep the originals unmodified.

Table 1: UAP Documentation Formats and Values

Format Type	Examples	Forensic Value	Scientific Rationale
Unprocessed (RAW)	.DNG, .ARW, .CR3, .NEF	Highest	Direct sensor output; contains the highest dynamic range and most complete metadata for astrometric calibration.
High-Bitrate Video	.MOV / .MP4 (ProRes, All-I)	High	Minimal inter-frame compression; preserves motion vectors and luminosity changes with high fidelity.
Standard Video	.MP4 / .MOV	Moderate	Subject to compression artifacts; useful for motion but less reliable for morphology (shapes and structure).
Processed Still	.JPEG, .HEIC	Low	8-bit depth; "baked-in" sharpening and noise reduction destroy low-contrast data and faint signals.
Proprietary Meta	.XMP, .LOG	Auxiliary	Sidecar files (small text-based files that live alongside your raw image) that document every edit made to a RAW file, ensuring the audit trail is intact.



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

Timestamp Accuracy

Synchronizing your devices to global time standards is essential. UAP observers should use devices synchronized via GPS, Network Time Protocol (NTP), or Coordinated Universal Time (UTC). Even a few seconds of timestamp error can confound later triangulation efforts. If multiple observers record the same UAP, synchronized times enable velocity estimation and pattern recognition that would otherwise be impossible. Enable GPS tagging when appropriate; otherwise, log the location precisely using other methods.

Metadata Preservation and Provenance

Metadata ("data about data") is information stored within an image file that describes how, when, and where the camera captured the image. Metadata authenticates the time, place, device, and settings; enables cross-correlation with external datasets; supports photometric and astrometric calibration; and substantially reduces ambiguity in post hoc analysis. Metadata preservation is key to chain-of-custody considerations as well as scientific assessment.

> **Metadata preservation is key to chain-of-custody considerations** as well as scientific assessment.

EXIF is the most common metadata standard, and it is embedded in nearly all cameras and smartphones. Metadata provides a schematic overview of EXIF fields commonly encountered in original, unprocessed image formats and JPEG workflows. Although field names vary by vendor, the core elements—timestamp, coordinates, lens, exposure—are common and should be preserved end to end.

Maintaining an observation log is crucial to establishing provenance. UAP photographers should keep a contemporaneous log (in a paper notebook, voice memo, or digital note-taking app, such as Apple's iOS Notes) that includes the observer's name, date, time (in UTC format; include time zone), precise location and orientation, equipment used, settings, and a narrative of the observation. Figure 1 shows an example of an observation log.

OBSERVATION LOG

Observer Information

Observer(s):_____ Contact:_____

Date (UTC): _____ Local time zone: _____ Start: _____ End: _____

Location (lat/lon/elev): _____

Orientation

Azimuth/bearing/compass heading_____

Tilt/elevation angle/pitch_____

Roll/roll angle_____

Relative orientation to landmarks or frame axes _____

Sensor orientation (portrait/landscape; vertical/horizontal) _____

Equipment and Settings

Equipment (camera/lens/firmware/tripod/remote): _____

Settings (stills):
Aperture _____ Shutter _____ Camera sensitivity setting (ISO)_____

White balance _____Original unprocessed image format: Y/N

Settings (video):
Resolution _____ Frames per second _____ Shutter _____

Camera sensitivity setting (ISO) _____ White balance _____

Observational Details

Environmental notes (clouds, wind, temperature, skyglow): _____

_____

Narrative (behavior, headings, elevation angles, apparent speed/brightness): _____

_____

Other sensors or witnesses (names, devices, recordings): _____

_____

File list (original names, sizes, hashes): _____

_____

Figure 1. Example Observation Log

Equipment Considerations

Capturing high-fidelity UAP imagery poses unique challenges for both non-specialist observers and professional investigators. UAP documentation often occurs under spontaneous, low-light conditions. These conditions push consumer and professional-grade hardware to their limits, demanding a delicate balance among light sensitivity, focal precision, and mechanical stability. The following sections analyze the critical hardware components and configurations



Close-up macro camera lens

needed to mitigate environmental factors and reduce optical artifacts that frequently obscure nighttime UAP recordings.

Camera Systems and Sensor Architectures

The efficacy of UAP documentation largely depends on the sensor's spatial resolution and the amount of light collected during the exposure (driven primarily by lens aperture area and exposure time).[4] Digital cameras used in this context commonly fall into two sensor-format categories: full-frame (36×24 mm) and APS-C (Advanced Photo System type C, a smaller sensor format, approximately 22×15 mm, depending on manufacturer).[5] For a given lens focal length and shooting position, full-frame provides a wider field of view, while APS-C introduces a "crop factor" that yields a narrower field of view equivalent to a longer focal length on full-frame, often advantageous for framing distant targets.[6] For otherwise comparable sensor technology and megapixel counts, full-frame sensors typically have larger photosites, which can improve high-ISO (International Organization for Standardization; a measure of light sensitivity) noise performance (i.e., signal-to-noise ratio) in low-light conditions.[7]

Among interchangeable-lens consumer cameras used for low-light documentation, both digital single-lens reflex (DSLR) and mirrorless systems are common; however, mirrorless bodies can offer workflow advantages because the electronic viewfinder presents a live sensor-based view with exposure preview ("What you see is what you get").[8] Many mirrorless systems also provide manual-focus aids—such as focus magnification ("focus check") and focus peaking—that help the operator achieve precise focus on faint point sources without repeated test exposures.[9]

For scientific-grade evidence collection, the system should support RAW capture (i.e., unprocessed sensor data, preferably uncompressed or lossless-compressed when available) to preserve maximum data for later analysis,[10] and you should understand and document the sensor's ISO-invariance characteristics (i.e., how read-noise and dynamic range behave across ISO) because these characteristics affect how reliably underexposed frames can be brightened in post-processing without materially changing the noise floor.[11]

Lenses

For nighttime UAP observation, you will need to balance light-gathering capacity (aperture) with resolving power. While ultra-fast lenses theoretically maximize photon throughput, they often introduce significant softness and spherical aberration (blurring) that occurs when a lens operates at its widest aperture. Consequently, high-quality or prime lenses often provide a superior balance and are essential for distinguishing between a distant object and optical artifacts.



Camera evolution: retro film and SLR cameras

Wide-angle lenses make it easier to find the target, but distant objects appear very small—sometimes smaller than a single pixel. Conversely, long telephoto lenses provide high detail but significantly complicate manual tracking and amplify the effects of platform vibration. A mid-telephoto range (35–135mm full-frame equivalent) is generally recommended as the standard, balancing field of view (FOV) with sufficient object scale.

Finally, the lens's mechanical design is critical. In low-light environments where autofocus systems often fail, lenses with hard infinity stops or calibrated manual focus scales are indispensable. These mechanical features allow you to achieve reliable focus on the celestial background instantly, ensuring the system is "mission-ready."

Tripods and Stabilization

To ensure the metric integrity of UAP imagery, minimizing mechanical resonance and platform instability through the use of tripods and other stabilization methods is paramount. The primary objective of stabilization is to prevent motion blur. A high-mass tripod equipped with a fluid or precision ball head provides the necessary stability for smooth tracking and extended exposure durations. To further lower the system's center of gravity and increase wind resistance, use the center-column ballast hook to suspend a static weight (e.g., a sandbag). Avoid extending the center column too high, as it can cause a pendulum effect that creates shake.

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Photographers use a tripod to stabilize cameras with heavy telephoto lens attachments to get sharp photographs.

In high-mobility or time-critical scenarios when a traditional tripod is impractical, a monopod or "travel" system offers a compromise between portability and stability. While these platforms do not support the multi-second exposures required for deep-field photometry, they can mitigate hand tremor at moderate shutter speeds; however, they reach a threshold of effectiveness at exposures exceeding one second. For documenting unconventional trajectories, a static, fixed camera on a tripod provides the most reliable way to maintain a consistent spatial reference frame; if the camera moves, analysts must reconstruct the reference frame from the scene (e.g., background stars or landmarks or motion-sensor data), which increases analytic uncertainty.[12]

Intervalometers

An intervalometer is a feature that enables the camera to take pictures automatically, rapidly, and at predetermined intervals. Paired with wired or wireless technology, an intervalometer offers a powerful means of capturing potential UAP. With an intervalometer, you can take multiple photos of the same scene or subject with different exposure settings, a method called bracketing. Bracketing can provide you with a set of images at varying brightness (some underexposed, some overexposed) from which you can choose or combine the best parts. The combination of remote technology and an intervalometer can also enable detailed time-lapse photography—valuable when your attention alternates between visual observation of a scene and framing a specific event with the camera.



Intervalometer for Canon DSLRs

Power and Storage

In UAP documentation, a camera system is only as reliable as its power and storage infrastructure. Because sightings are often transient and unpredictable, the difference between capturing high-fidelity evidence and suffering a total system failure often comes down to the observer's preparedness.

When recording in 4K high-bitrate video or high-speed RAW bursts, the camera generates a massive amount of data that must be written to the memory card instantaneously. Using standard consumer-grade cards can lead to "buffer filling," when the camera freezes while waiting to write data, or worse, frame-dropping, when it skips critical motion data to prevent a system crash.

> **Because sightings are often transient and unpredictable,** the difference between capturing high-fidelity evidence and suffering a total system failure often comes down to the observer's preparedness.

Investigating transient phenomena requires V60 or V90-rated high-endurance cards, which are designed to handle sustained high-speed writes without overheating or corrupting the file structure. In UAP work, a corrupted file means losing primary evidence that can never be replicated. Investing in professional-grade storage ensures that every captured image is safely committed to disk with its metadata intact.

Keep in mind that cold weather can cause unexpected issues for camera systems. Standard lithium-ion batteries are prone to voltage drops and capacity loss in the low-temperature environments common during outdoor or high-altitude night observations. Cold temperatures can effectively halve a camera's expected runtime, often causing it to shut down at the precise moment of data acquisition, when the processor is under maximum load. To mitigate this risk, prioritize external power delivery (USB-C PD) via high-capacity battery packs, when possible, which allow the camera to run for hours rather than minutes. This "always-on" approach ensures you aren't changing batteries while an anomaly is in the frame, a critical failure point in solo field operations.

Optical vs. Digital Magnification

In UAP documentation, a critical distinction must be made between optical zoom and digital magnification. Optical zoom uses the physical displacement of lens elements to increase the focal length, thereby concentrating the target's light across the entire sensor surface. This process preserves the imaging system's native resolution, ensuring that each pixel represents unique spatial data.

Conversely, digital zoom is a software operation that crops a portion of the captured image and then enlarges it to the original frame size using interpolation (estimating new pixel values from neighboring pixels).[13] Because this process does not capture additional optical detail, it primarily makes existing limitations more visible; in low-light UAP imagery, digital zoom can increase noise, blur, and atmospheric softening while adding no new signal. If the capture pipeline also applies lossy compression and/or strong in-camera processing, it can further degrade fine detail, increasing the risk that small luminous targets are rendered as "blob-like" shapes.[14] For forensic-grade work, preserve the original, unaltered image.

Photographs vs. Video

The choice between photographs and video for UAP documentation depends on the phenomenon's dynamics and the observer's objectives. Both formats offer advantages (see Figure 2), but their effectiveness varies in nighttime scenarios.

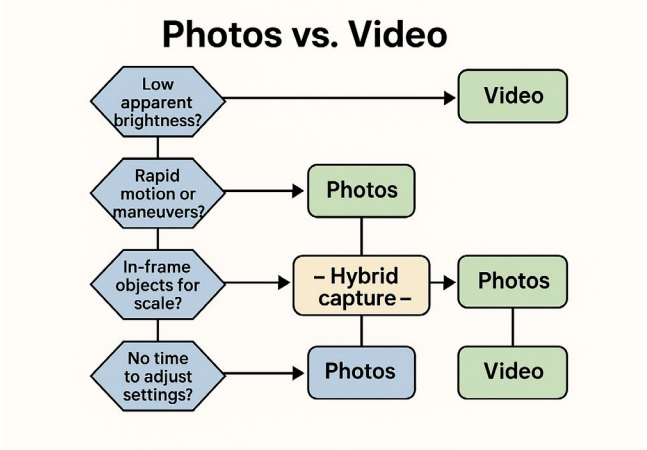


Figure 2. Photos vs. Video

Still Photography Advantages and Limitations

Photographs maximize spatial and photometric resolution, support more accurate triangulation, and—if handled correctly—preserve robust metadata for scientific analysis. However, they may also miss erratically moving subjects or short-duration events.

Single frames captured in their original, unprocessed image format typically contain greater spatial detail per frame than video, especially with a large sensor and a fast prime lens. Original, unprocessed image formats encode greater dynamic range and color depth, support rigorous noise characterization—the process of mathematically identifying and separating "junk" data (electronic interference) from "true" data (the light from a UAP)—and facilitate later analysis

against background stars for scale and orientation. Limitations include slow shutter speeds, which introduce motion blur for fast-moving objects; single frames, which provide limited temporal context; and the need to manually refocus or reframe, which can result in missed opportunities.

Video Advantages and Limitations

Video provides continuous temporal context—critical for trajectory determination, acceleration estimates, blinking/periodic modulation analysis, and correlation with other sensors (e.g., radio, Automatic Dependent Surveillance-Broadcast [ADS-B]). High frame rates (30–60 frames per second [fps]) increase the likelihood of capturing short-lived events and enable per-frame stacking and just plain luck in capturing good data.

Three key limitations should be considered. First, most consumer video uses heavy compression and records at a lower per-frame resolution than still images. Another limitation is that a high-ISO (sensitivity) video setting can produce footage prone to noise and rolling-shutter artifacts (a distortion that happens because many phones and mirrorless cameras don't record the whole frame at once but read the sensor line by line from top to bottom). Finally, autofocus hunting (when the camera automatically roves in search of a focal point) can degrade results.

In moderately illuminated night scenes (with moonlight, city lights, or other ambient lighting), a frame rate of 60–120 fps may be feasible if your optics and sensor are high quality. If so, the higher frame rate may capture more data useful for analysis. In very dark, starlight-limited scenes, you may not get useful frames at that rate; the frames may be too noisy or blank. Below a certain light threshold, it is often better to drop to a lower frame rate (e.g., 10–30 fps) with longer exposures per frame and rely on stacking or frame-level combination to recover signal.[15]

Video Documentation: Cinematic vs. Forensic Standards

In UAP documentation, the goal is preserving raw motion data. To transform a video from a visual record into a quantifiable dataset, you must tightly control recording parameters to ensure temporal consistency and minimize digital artifacts. Record objects with sufficient frame rates, appropriate shutter dynamics, and data encoding to enable subsequent frame-by-frame forensic analysis.

In UAP documentation, the goal is preserving raw motion data.

A frame rate of 30 fps is a baseline; 60–120 fps improves temporal resolution for fast events, provided the sensor can support it with minimal noise. Consumer-grade cameras are limited in their ability to achieve higher fps; use a specialized camera for this purpose instead.

Shutter angle describes the relationship between frame rate and shutter speed. The term originates with rotary shutters in film cameras, which were physical spinning discs with a slice cut out. The size of that slice (the "angle") determined how long the film was exposed to light as it moved. To record natural motion, aim for approximately 180° equivalent. This is the "standard" for cinema, meaning the shutter is open for exactly half the duration of each frame. If you are shooting at 24 fps, a 180° shutter results in a shutter speed of 1/48 s, which produces a movement effect that appears natural to the eye.

Bitrate is the amount of data processed per second. In UAP photography, a high bitrate is essential because it ensures the camera records enough information to capture complex textures and rapid movements. With a low bitrate, the camera "starves" for data. To keep up, it simplifies the image, turning subtle gradients in the night sky into blocky, solid colors. A high bitrate preserves the detail of the sky and the sharp edges of a fast-moving object, enabling much more reliable frame-by-frame analysis.

Most modern consumer cameras record video using inter-frame, commonly H.264 or H.265 (often in an MP4 container).[16] This technique records only the *changes* between frames rather than treating each frame as a full picture. If a UAP is small and moving quickly, the compression algorithm might mistake it for noise and try to smooth it out. This creates compression artifacts—those square block trails you often see in low-quality night videos.

You should always prefer manual focus to autofocus because you are more likely to achieve a focused image, especially under typical conditions such as nighttime. If you must use autofocus, be sure to lock the focus once it is acquired to prevent the camera from automatically "hunting" for a focal point.



Milky Way in a panorama of the night sky over Paranal Observatory, Chile

You should always prefer manual focus to autofocus because you are more likely to achieve a focused image, especially under typical conditions such as nighttime.

Hybrid Strategies

An emerging hybrid method combines time-lapse photography with short exposure intervals. For example, configuring a camera to shoot at 1/2-second intervals with 1/4-second exposures produces a "pseudo-video" from high-resolution stills. This approach balances spatial resolution and temporal coverage, especially when you're uncertain whether the object will remain in the frame.

Many cameras can capture intermittent stills during video recording or switch rapidly between modes using custom buttons. A practical approach is to start in video mode and intersperse short bursts of high-resolution stills. Another hybrid approach is time-lapse photography with short exposures (e.g., 1/4 s) at moderately high ISO settings, which captures both temporal evolution and near-still-frame detail.[17]

Choosing between Stills and Video

Choosing between stills and video should depend on the object's angular velocity, which directly determines the amount of motion blur, the necessary shutter speed, and the overall image aesthetic. As a rule of thumb, if the object moves more than two or three small fractions of a degree in the sky during the exposure, motion blur will begin to destroy shape data (a circle is divided into 360 degrees, and each degree is further divided into 60 small fractions of a degree in the sky). At 50 mm focal length, this corresponds to a threshold of about 0.05° of movement. If the UAP is moving faster than this, switch to high-fps video; if slower, use stills.

To take some of the guesswork out of estimating angles, here is an old astronomy trick. With your finger or hand at arm's length, your little finger is approximately 1° (or slightly less). Your fist (all fingers together) spans about 10°, and your thumb (across) is roughly 2–3°. So, if the UAP moves a small fraction of your little finger's width in one second, that is a few arcminutes or arcseconds per second. That gives you a visual benchmark. To connect to your 0.05° threshold: that is about three arcminutes (= 0.05° × 60). So, if the object moves more than about 1/3 of your little finger's width in a few seconds, you may already be in blur territory.

Here are a few more general guidelines for determining whether to use photos, video, or a combination. If the object is faint and slow-moving, prioritize stills (original, unprocessed image format) with exposures in the 1/2–4 s range and a high ISO setting; capture supplemental video for context. If the object is bright and fast-moving, prioritize video (30–60 fps) with short shutter speeds (1/60–1/250 s), pushing the ISO setting as needed; attempt sporadic stills when motion allows. If you have multiple observers, assign one shooter to continuous video and the other to optimized stills.

Smartphones: Data Preservation vs. Computational Artifacts

Modern smartphones rely heavily on computational photography—algorithms that apply noise reduction, multi-frame stacking, and sharpening before the user ever sees the file. These enhancements are destructive to UAP recording, as they can interpret a small, distant object as image noise and mathematically erase it or create "ghost" artifacts during long exposures. For UAP work, users must bypass standard automated modes in favor of protocols that prioritize unprocessed data retention and manual parameter locking.

> **For UAP work, users must bypass standard automated modes** in favor of protocols that prioritize unprocessed data retention and manual parameter locking.

The scientific value of mobile imagery is largely determined by the device's metadata architecture and support for raw data output. iOS and Android platforms differ significantly in EXIF retention; many standard Android interfaces strip critical sensor data—such as GPS coordinates, precise timestamps, and focal parameters—during post-capture processing or file transfer.[18] For high-fidelity analysis, Apple ProRAW or Android DNG (digital negative) formats are essential because they preserve the sensor's full dynamic range and extensive metadata headers.[19] Furthermore, third-party applications (e.g., Halide for iOS or Open Camera for Android) are required to circumvent "autofocus hunting" and variable frame rates.[20] By manually locking focus at infinity and fixing the ISO and shutter speed, the observer ensures that any recorded changes in brightness or motion reflect physical realities rather than artifacts of the camera's internal logic.

The single most important tip for a smartphone user: set the "Infinity Lock." If you don't lock the focus to infinity, the phone will likely focus on the glass of the window or a nearby tree, leaving the UAP as a blurry circle. Equally important, clean the lens and avoid digital zoom. It sounds simple, but smartphone lenses are constantly covered in finger oils, which create light streaks at night that can look like beams or structures. On the phone's screen, pinching to zoom is almost always destructive.

> **The single most important tip** for a smartphone user: set the "Infinity Lock."

In the event of a UAP sighting, users should immediately switch from the native camera app to a manual-control application and apply the settings in Table 2.

Table 2: Parameters, Settings, and Rationales

Parameter	Recommended Setting	Scientific Rationale
Capture Format	RAW / ProRAW / DNG	Prevents destructive smoothing and preserves metadata.
Focus	Manual (Infinity Lock)	Prevents focus hunting in low-contrast night skies.
Frame Rate	Fixed (e.g., 30 or 60 fps)	Enables precise calculation of object velocity and acceleration.
Exposure	Manual / Locked	Ensures brightness changes are physical, not auto-adjustments.
Zoom	1x (Optical Only)	Avoids digital interpolation and loss of spatial resolution.

For a high-integrity scientific report, the observer must act as a static sensor platform. If possible, brace the smartphone against a solid object (e.g., a car roof, a railing, or a window frame) to provide a stable reference point against the background stars. This technique transforms the video from a shaky personal recording into a stable coordinate system for triangulation and video analysis.

Note that the goal is not to produce a "beautiful" video, but a "clean" one. A grainy, dark, but sharp RAW file is infinitely more valuable to a forensic analyst than a bright, smooth, but heavily processed standard video.

Smartphone Strengths and Limitations

Smartphones are ubiquitous and power-efficient, and they can automatically embed precise GPS and time metadata. Computational photography can denoise and enhance low-light images, and many devices now support capturing



Amateur astrophotographer with a camera on a tripod photographing night sky with stars, planets, Moon and other celestial objects

original, unprocessed image formats (such as DNG) and manual controls via "Pro" modes.

In terms of limitations, their small sensors limit dynamic range and increase noise at high ISO settings; limited or absent optical zoom forces reliance on digital zoom; and rolling-shutter artifacts are common in video recordings. Aggressive in-camera processing can cause frame-to-frame variations that complicate scientific analysis and interpretation.

Best Practices for Smartphone Photography

AARO's techniques favor the optical telephoto camera if your phone has multiple modules; otherwise, stay at 1x (no digital zoom). For stills, always enable the original, unprocessed image format (DNG). For video, select the highest available bitrate and resolution, and consider 60 fps if noise remains manageable. If the app allows, lock focus and exposure, and avoid dynamic auto adjustments that could later confuse analysis. Immediately back up all originals to an immutable location (e.g., the cloud or an external drive) with metadata intact.

Nighttime Shooting

Many UAP sightings occur at night, when it is challenging for our eyes and our cameras to resolve details. The central constraints of nighttime imaging include low photon flux (fewer detected photons, requiring specialized detectors and image processing), noise (sky background gradients and visual distortion), and graininess (from low resolution or the sensor's poor low-light performance). Imaging UAPs at night requires camera sensors to operate near their sensitivity limits. Fast lenses, with larger apertures and larger sensors, increase ISO; long exposures allow more light to the sensor but at the cost of blurring the motion of moving objects; higher ISO settings increase gain but elevate noise. A key challenge is finding optimal settings under less-than-ideal conditions when time is critical. In practice, optimal settings are a compromise driven by the target's apparent brightness, angular speed, and the need to preserve both spatial detail (shape, structure) and changes in brightness or trajectory.

Imaging Physics in Low-Light UAP Capture

In extremely low-light UAP scenarios, understanding the physics of photon capture is critical. Every exposure is a trade-off among photon noise, read noise, and motion blur. The rate of photon arrival is proportional to the square of the lens opening (diameter or radius), so going from f/2.8 to f/1.4 increases light-gathering by a factor of four. However, most fast lenses (those with small aperture numbers) suffer from coma and astigmatism in the corners at wide apertures. Coma, also known as comatic aberration, is an optical defect

that causes off-axis light sources, like stars, to appear distorted and comet-like, especially in the corners of the image at wide apertures. This distortion occurs because light rays passing through different parts of the lens at different angles do not focus on the same point, resulting in a blurred, fan-shaped tail extending from the center of the image. Knowing your lens's comatic aberration profile helps you decide whether to maximize light with a wider aperture or achieve better sharpness with a smaller aperture. Astigmatism occurs when light rays from different planes focus on different points, causing them to appear stretched into lines.[21]

Sensor size also matters: an APS-C sensor typically captures several times more total light than common smartphone sensors, often by more than an order of magnitude.[22] The smaller sensor size is why noise appears much sooner on phones when cropping a photo or shooting in low-light conditions. Astrophotographers often aim for exposures that yield an average sky brightness of 25–40% of the camera's full-scale histogram (a built-in graphical representation of the color spectrum, ranging from pure black on the left to pure white on the right) to balance shadow detail with highlight preservation.[23]

For capturing potential UAPs in nighttime conditions, consider using thermal cameras and Gen 3 night-vision goggles or monoculars. Thermal cameras and night-vision optics are increasingly accessible and can augment traditional imaging in specific scenarios. While thermal sensors lack optical detail due to lower resolution from fewer pixels, they can detect otherwise invisible heat signatures from low-flying objects or aircraft. Night-vision devices enable real-time visual tracking but often lack metadata capabilities or sufficient resolution, so use them in conjunction with standard cameras.

Avoid "Auto" settings unless necessary, even in daylight. Automatic exposure or focus adjustments during imaging can produce inconsistent files, undermining metadata integrity. If possible, create preprogrammed custom modes that enable your camera to store exposure and focus presets. This approach not only speeds up deployment but also enhances repeatability—an essential trait for scientific reporting.

Aperture, Shutter, and Camera Sensitivity Setting (ISO)

Aperture, shutter speed, and the camera's sensitivity setting (ISO) form what is known as "the exposure triad." The exposure triad is especially important in UAP photography because it determines the balance between data fidelity and signal detection under extreme low-light conditions.

In the context of UAP documentation, the triad is about managing the physical trade-offs inherent in the sensor's performance.

- Aperture must be wide enough to maximize photon collection yet narrow enough to minimize optical aberrations that can distort an object's true shape.
- Shutter speed must be fast enough to "freeze" unconventional high-velocity motion, preventing the loss of kinetic data to motion blur.
- ISO setting must be high enough to register faint luminous targets, but keep it within the sensor's native range to prevent electronic noise from being mistaken for physical structure.

Mastering this triad enables you to calibrate the camera so that every pixel represents a legitimate physical signal rather than a technical artifact.

- Aperture: When the object is at a relatively fixed distance and there is sufficient time to focus, use the widest practical aperture (e.g., f/1.4–f/2.8) to maximize light while balancing edge aberrations and depth of field. When there is no time to focus, stop down the lens while maintaining an adequate shutter speed to create as much depth of field as possible in the plane of focus, thereby accounting for soft-focus errors.
- Shutter speed: Choose to limit motion blur (fast shutter) or maximize signal (longer exposure).
- ISO setting: The sensor's ISO should be calibrated to ensure the target's luminous flux remains significantly above the systemic noise floor, while simultaneously preventing sensor saturation (pixel clipping, also known as "blown highlights,"[24] which are areas too light to recover any data) that would result in the loss of detail in high-intensity regions.

After you have become familiar with the various settings, you'll want to experiment by rehearsing your photography on astronomical targets such as bright stars and planets, visible passes of known satellites, and civil aircraft to validate exposure and tracking settings. For UAP work, you will want to become familiar with characterizing noise for later subtraction, if needed. One way to learn the basics is to capture a few dark frames with the lens cap on at the same ISO and temperature, which will give you a baseline to work with.

Operational Readiness and Field Logistics

Successfully documenting UAP requires both tactical preparation and technical proficiency. High-fidelity data acquisition is often compromised not by hardware failure but by external variables, such as legal disputes over land use or social interference from onlookers. Establishing a rigorous pre-observation protocol is therefore essential to ensure you remain focused during a transient event. This preparatory phase ranges from meticulous site selection and "dark sky" reconnaissance to coordinating multi-observer teams and maintaining proper identification for jurisdictional transparency. By mitigating potential human and legal friction points before deployment, you secure the "environmental quiet" necessary for uninterrupted scientific data collection.

Maintain jurisdictional awareness—understanding whose land you are on (e.g., Bureau of Land Management, private property, or restricted airspace) prevents a promising observation from being terminated by law enforcement. Also, having a dedicated partner allows you to stay glued to the camera controls while the partner manages the environment, logs timestamps, and handles security. Dealing with suspicious neighbors is a common reality in field research. Carrying a formal "Research Intent" document or professional identification can transform a potentially hostile encounter into a neutral one.



Bureau of Land Management, State Office, Phoenix, Arizona

You will also want to keep a ready kit: a camera with a fast prime lens attached, a spare battery installed, a high-speed card inserted, a tripod quick-release plate mounted, and a remote shutter connected. Program a custom mode (e.g., C1) for stills at f/1.8, 1/4 s, and camera sensitivity at the highest ISO value it can sustain without noise compromising the image (the limit varies among sensors; your test shots will reveal this limit), and a second mode (C2) for video at 4K/30 fps, 1/60 s, and camera sensitivity at Auto (upper limit should be the point at which noise begins to degrade the image, which varies by sensor; your test videos will reveal this limit), with manual focus set to infinity.

Scout locations with unobstructed horizons, minimal skyglow, and safe footing. Note nearby air routes, wind farms, and intermittent light sources (security lights, vehicle headlights). Check astronomical forecasts (moon phase, visibility) and weather (cloud cover, humidity).

If possible, operate as a two-person team: a caller/spotter and a photographer. Use concise voice callouts ("Heading 030°, altitude ~20°, crossing left-to-right") and record them as an audio memo synced to UTC. If multiple cameras are available, run them in complementary modes (video + stills) to maximize coverage.

Post-Capture Workflow and Data Forensics

Once you record a UAP event, the priority shifts to ensuring the file remains untainted, as scientific evidence depends on establishing a clear chain of custody and preserving data. A standardized post-capture workflow mitigates risks of data corruption, unintentional metadata stripping, and processing artifacts introduced during file transfer or enhancement. By implementing systematic protocols for hashing, secure logging, and non-destructive analysis, you create a transparent audit trail.

Once you record a UAP event, the priority shifts to ensuring the file remains untainted, as scientific evidence depends on establishing a clear chain of custody and preserving data.

Remember that hashing must be the first step after capture—even before the first view or review of the files—to establish an ironclad digital fingerprint. Including SHA-256 or MD5 hashes proves the file has not been altered by even a single pixel since it left the memory card. Immediately after capture, compute and record the SHA-256 cryptographic hashes of all originals and save them in a plain-text log with UTC or your observation notes.

Always retain original files. Prefer the original, unprocessed image format for stills, and high-bitrate containers (MOV/MP4 with minimal compression) for video. Do not rename original files except to add a non-destructive prefix like OBS_20250812_. This practice ensures investigators can prove that the file is identical to the original recording. Most cameras can create two files for each capture, and a typical digital camera will give you the option to use one or the other of the following:

- RAW (original unprocessed image format such as .CR2, .NEF, .ARW, or .DNG), which contains maximum detail from the sensor and stores extensive EXIF data fields.
- JPEG (a compressed version generated either in-camera or after editing), which keeps many EXIF fields but may drop some details.

Together, these files create a workflow: RAW for analysis, JPEG for portability.

Editing

For UAP images, you edit to reveal data, rather than retouch for better appearance. Consider tools such as RawTherapee, Siril, or ExifTool, which allow you to examine original image characteristics, denoise raw data, and confirm authenticity. You should preserve first-generation edits with accompanying Extensible Metadata Platform (XMP) sidecar files, which log every processing step and allow reversal of changes. This transparency is crucial for peer reviewers or investigators.

When preparing still imagery for analysis, prioritize global adjustments—parameters such as exposure, contrast, and white balance that are applied uniformly across the entire frame. Conversely, avoid local edits (adjustments confined to a specific region of interest, such as dodging, burning, or localized sharpening) in primary evidence, as they can introduce subjective bias and uneven noise profiles.

Recommended Sharing Standards and Reporting Templates

When submitting to a repository or research group, use the following proposed minimal standard to improve inter-comparability across observers and organizations:

1. Originals: Provide original, unprocessed image format stills and high-bitrate video with intact metadata.
2. Metadata logs: Include UTC timestamps (start/stop), latitude/longitude, elevation, equipment and settings, and a narrative of the event.
3. Calibration: Provide at least one sky frame with identifiable stars for matching star patterns to find the exact location in the sky, and optional dark frames for noise characterization.
4. File integrity: Provide SHA-256 hashes of originals.

Sample Scenarios and Capture Strategies

The following scenarios illustrate a variety of UAP targets and environments and the capture strategies you might use for each.

Scenario 1: High-Altitude Targets (Faint, Slow-Moving)

Objective: Maximize the signal-to-noise ratio to resolve faint morphology (shape, structure) and establish a precise track relative to background stars.

- Tactical execution: In this scenario, the primary risk is underexposure, in which the object remains buried in the sensor's noise. By using a wide aperture (f/1.8) and a relatively long shutter speed (1–2 s), the sensor collects enough light to define the object's edges.
- Protocol: Use a burst sequence (10–20 frames). This creates a statistical image stack that supports later noise subtraction and confirms the object's persistence.
- Key setting: Manual focus at infinity. Do not rely on autofocus for faint targets; even a slight blur will physically enlarge the light source, diluting its intensity and making it harder to detect.

Scenario 2: Bright, Fast-Moving Objects

Objective: Minimize temporal blur to allow for accurate measurement of acceleration and instantaneous direction changes.

- Tactical execution: The risk is "motion smearing," in which a sharp-edged craft appears as a translucent streak. To counter this, prioritize a high frame rate (60 fps) and a short shutter duration (1/125th s or faster).
- Protocol: If the object's luminosity is high, prioritize the shortest possible shutter speed over a low ISO. It is



An unidentified flying object in the evening sky

better to have a grainy but sharp image than a smooth but blurry one.

- Key setting: Fixed exposure. Locking the exposure prevents the camera's "auto-gain" from fluctuating as the object moves across different parts of the sky, which would otherwise ruin any subsequent brightness analysis.

Scenario 3: Using a Smartphone for Various Targets

Objective: Bypass computational smoothing to ensure the recorded pixels reflect physical reality rather than algorithmic guesses.

- Tactical execution: Smartphones are designed to make night photos look bright by using long exposures and AI smoothing. This design is destructive for UAP data. Use "Pro" or "Manual" mode instead.
- Protocol: Stabilize the device against a car, tree, or fence. Use the 1x optical lens only. Digital "pinch-to-zoom" is merely an in-camera crop that reduces spatial resolution and introduces interpolation artifacts.
- Key setting: RAW/DNG format. This format is the "digital negative." Without it, the phone's internal software may interpret a distant UAP as image grain and delete it from the final JPEG.

Scenario 4: Large or Nearby Target

Objective: Maximize dynamic range and spatial resolution to document structural details, surface textures, or modular components.

- Tactical execution: When an object occupies a significant portion of the frame, the "photon starvation" problem of nighttime photography is often replaced by sensor saturation. To capture the subtle differences between an object's hull and its luminous propulsion points, lower the camera's ISO toward the sensor's base ISO (typically 100–800).
- Protocol: Prioritize the lowest ISO that still allows a hand-holdable shutter speed. This ensures the maximum "bit-depth," enabling the recovery of shadow detail without interference from thermal noise.
- Key setting: Step down the aperture. If light levels permit, moving from f/1.8 to f/4 can place the lens in its "sweet spot" for sharpness and increase depth of field, ensuring the entire structure of the object remains in focus.

Conclusion

When executed properly, consumer-grade nighttime imaging of UAP can produce credible evidence suitable for quantitative analysis. Although UAP appearances are unpredictable, consistent preparation, validated settings, and disciplined metadata retention can transform fleeting observations into durable, shareable data.

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J. Kevin Ryan is a retired federal special agent with more than 37 years of combined military and civilian service with the Air Force Office of Special Investigations. He concluded his federal career as Chief of Operations for the All-domain Anomaly Resolution Office.

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