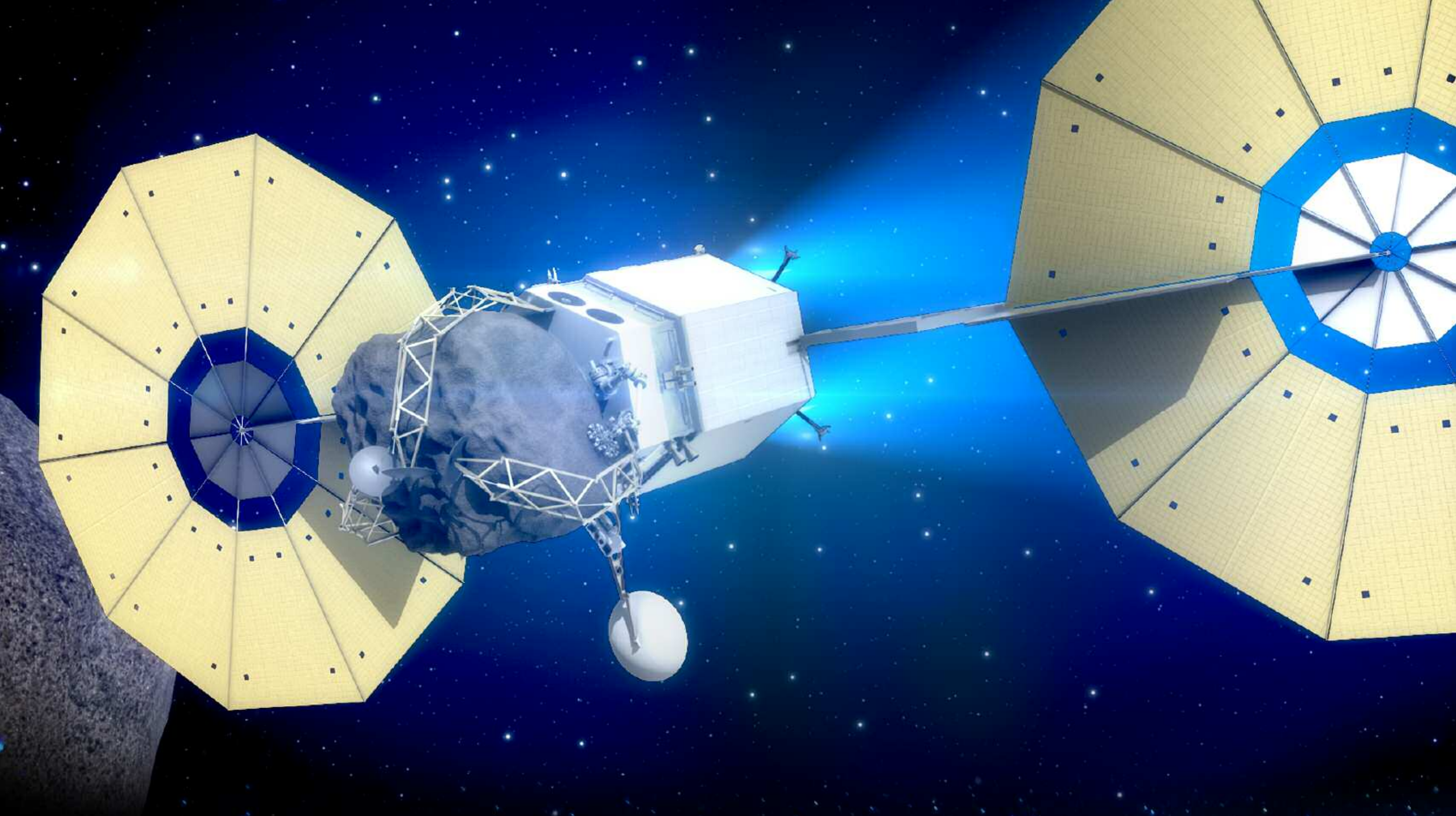


INFORMING NASA'S ASTEROID INITIATIVE

A CITIZEN'S FORUM

ECAST
EXPERT AND CITIZEN ASSESSMENT
OF SCIENCE AND TECHNOLOGY

By David Tomblin, Richard Worthington, Gretchen Gano,
Mahmud Farooque, David Sittenfeld, and Jason Lloyd

AUGUST 2015

INFORMING NASA'S
ASTEROID INITIATIVE
A CITIZEN'S FORUM

DAVID TOMBLIN
Science, Technology, and Society Program
University of Maryland

RICHARD WORTHINGTON
Program in Public Policy Analysis
Pomona College and The Loka Institute

GRETCHEN GANO
Science, Technology, and Society Initiative
University of Massachusetts Amherst

MAHMUD FAROOQUE
Consortium for Science, Policy & Outcomes
Arizona State University

DAVID SITTENFELD
Forum Program
Museum of Science Boston

JASON LLOYD
Consortium for Science, Policy & Outcomes
Arizona State University

ABOUT THE PROJECT

Cooperative Agreement / Grant Number: NNX14AF95A

Purpose / Project: Participatory Technology Assessment of NASA's Asteroid Initiative

Primary Investigator: David Guston, Arizona State University

Co Primary Investigators: Ira Bennett, Arizona State University; Darlene Cavalier, SciStarter; Mahmud Farooque, Arizona State University; and David Sittenfeld, Museum of Science Boston

Key Personnel: Gretchen Gano, University of Massachusetts Amherst; David Tomblin, University of Maryland; Richard Worthington, Pomona College and The Loka Institute; Steve Gano, SciStarter; David Rabkin, Museum of Science Boston; and Larry Bell, Museum of Science Boston

ABOUT ECAST

The Expert and Citizen Assessment of Science and Technology (ECAST) network is a collabo ration among university, informal science education, and policy research partners to establish a participatory technology assessment capability in the United States. ECAST engages a diverse array of experts, stakeholders, and everyday citizens in assessing the responsible design and use of emerging developments in science and technology. Working with partners in governmental, industrial, academic, and non governmental settings, ECAST conducts innovative participatory assessment activities on a range of scientific and technological issues, and shares the results with policymakers, the media, and the general public.

ECAST
EXPERT AND CITIZEN ASSESSMENT OF SCIENCE AND TECHNOLOGY

TABLE OF CONTENTS

THE PROJECT

BACKGROUND AND GOALS

Although asteroids rarely enter the national conversation—often associated more with blockbuster movies and dinosaurs than considered a realistic threat to life on Earth—the consequences of a major asteroid collision could be devastating. The explosion of the relatively small Chelyabinsk meteor over Russia in 2013 was a spectacular reminder of the many larger undetected asteroids that could cause an enormous amount of damage to human lives and infrastructure if they were to collide with the Earth in a populated area. In order to address this threat, what would an effective detection system that could improve humans' ability to protect Earth look like? If we had the capability to find all of the asteroids with the potential to cross Earth's path, what options might be available to address a detected threat? Thinking further into the future, if we develop the capacity to redirect an asteroid or piece of an asteroid then send astronauts to study it, what might those capabilities mean for future space exploration? Could they enable or support the ultimate ambition of a crewed mission to Mars?

Soliciting answers to these questions and, as importantly, the rationales and values behind those answers, animated a recent project in which citizens voiced their thoughts and preferences about planetary defense and space exploration. This project, a cooperative effort implemented by the National Aeronautics and Space Administration (NASA) and the Expert and Citizen Assessment of Science and Technology (ECAST) network, provided a citizen-focused, participatory technology assessment of NASA's Asteroid Initiative that increased public understanding of and engagement in the Initiative. The project had two main goals. The first was to develop and apply a participatory technology assessment that elicited nuanced information from a diverse group of citizens whose insights would not otherwise be available to decision makers. Second, through informed, structured feedback from citizens in multiple locations, the project aimed to provide public views of the Asteroid Initiative as input into NASA's decision-making process.

THE ASTEROID INITIATIVE

NASA's Asteroid Initiative, the focus of the deliberations, has two central components. The first is the Asteroid Grand Challenge (AGC), a planetary defense effort that seeks to detect all asteroid threats to human populations and determine appropriate actions for dealing with or mitigating them. NASA is assessing ways to improve capabilities for planetary defense, and the AGC touches on a variety of challenges the agency will face. NASA draws on a diversity of voices, including those from within the public, to help confront them. The second component, and the aspect most relevant to future human space exploration, is the Asteroid Redirect Mission (ARM). ARM would deploy a robotic spacecraft to either capture an entire asteroid or retrieve a small boulder from a larger asteroid and put it into a stable orbit around the moon, at which point astronauts would rendezvous with the asteroid to study it. These efforts are part of NASA's broader goals to accelerate efforts to detect and mitigate the threat of potentially hazardous asteroids, and to enable the first human mission to an asteroid.

The Asteroid Initiative is taking place within a larger strategic shift at NASA about how to implement its space exploration goals, including human missions to Mars. This strategy, called the capability-driven framework or CDF, leverages and integrates NASA's activities in human exploration, space technology, and space science to advance the capabilities needed for future human and robotic missions. In this sense, the Asteroid Initiative, through ARM, can be seen as fulfilling early objectives in the "Proving Ground" strategy, validating capabilities that may one day enable a human journey to Mars, in addition to the more immediate objectives of detecting and mitigating asteroid threats. NASA focuses on the Proving Ground strategy, which we connected to the CDF, as an evolving set of missions and operations that prepare for and demonstrate our ability to safely live and work away from Earth for extended periods before attempting a human mission to Mars.

PARTICIPATORY TECHNOLOGY ASSESSMENT

The forums in which citizens discussed their perceptions, aspirations, and concerns about planetary defense and space exploration were developed as a process of participatory technology assessment (pTA), an engagement model that seeks to improve the outcomes of science and technology decision-making through dialog with informed citizens. Participatory technology assessment involves engaging a group of non-experts who are representative of the general population but who—unlike political, academic, and industry stakeholders—are generally underrepresented in technology-related policymaking.

Our pTA of NASA's Asteroid Initiative allowed citizens with various backgrounds, values, and knowledge to express important views on this topic that credentialed scientists and engineers, stakeholders, and policymakers might otherwise overlook or undervalue. By learning a great deal about the Initiative, including the complex tradeoffs regarding the costs, risks, and benefits of various policy options, participants expressed nuanced and informed preferences about the options facing NASA as the agency seeks to advance the capacities of human spaceflight. In addition, the project strongly aligned with the Obama Administration's directive to federal departments and agencies to promote broad public participation in their activities and to be responsive to citizen concerns.

THE PROCESS

In 2013, NASA released a request for information about engaging the public in the agency's Asteroid Initiative. NASA wanted to know about public perceptions of its Asteroid Initiative and learn more about what citizens value with regard to space exploration. ECAST, a consortium of universities, science centers and citizen science platforms, and nonpartisan policy think tanks, submitted a highly regarded response for citizen engagement. In April 2014, NASA awarded ECAST a cooperative agreement to conduct deliberations and identify citizen perspectives about the Asteroid Initiative.

The first step in this project was to plan and design public forums that would engage citizens and solicit their informed views on issues of importance to NASA, which NASA could then use in its decision-making processes. The ECAST organizers and NASA program managers worked closely together to develop appropriate themes and content for the forums—a challenging task, since this project represented the first public engagement on this scale undertaken in partnership with a U.S. federal agency. An additional factor was a compressed timeframe to run the pTA so the results could be considered as part of NASA's selection of an ARM mission. The planning process of partner consultation, content development, facilitator training, and participant recruitment took place from April to October of 2014; the one-day, in-person forums were held the following month in Phoenix and Boston on November 8 and 15, respectively.

We at ECAST designed the forums to explore what a diverse group of lay citizens thought about complex issues when provided with unbiased information and offered the opportunity to have a respectful and open conversation about these matters with their peers. Quite different from a poll or survey, forums like the one developed for this project explore the views and values that citizens use in assessing socio-technical issues. NASA expressed particular interest in learning about the perspectives and experiences that everyday people bring to considerations of the space agency's decisions. Thus in addition to capturing quantitative data that could be aggregated and statistically analyzed, this project sought qualitative data to identify the various priorities and social norms underlying citizens' technical and policy preferences.

Therefore ECAST, after a series of consultations with NASA, developed the forums to collect public views about the Asteroid Initiative. The Initiative's programs, the AGC and ARM, represent innovative approaches in areas of profound importance to NASA's public mission: **planetary defense**, including the detection of potentially hazardous asteroids and appropriate mitigation actions; and **deep space exploration**, including a crewed mission to study an asteroid and the ultimate goal of journeying to Mars. In collaboration with NASA program managers, the ECAST content development team devised a forum agenda that explored these areas. The morning focused on planetary defense, with one session devoted to asteroid detection and the other to asteroid mitigation strategies. The afternoon sessions focused on deep space exploration, with participants first considering two options for the Asteroid Redirect Mission and then discussing Mars exploration scenarios and NASA's "Proving Ground" strategy. (All of these sessions and their results will be discussed below.)

An aspect of central importance to this project is that the participants were **diverse**. ECAST undertook the recruitment of the lay citizen participants, achieving a distribution that aligned with the demographic characteristics of their respective states by taking into account gender, age, education, ethnicity, income, and employment status. (The largest discrepancy between participants and the general population was an under-representation of those without a high school diploma, which is a common problem for deliberative exercises.) We limited the number of participants who were already active in space issues—advocates, launch attendees, aerospace professionals, etc.—because they generally have the ability to make their views known to NASA and, with their knowledge and convictions, they would likely dominate discussions. A total of 98 citizens participated in the Phoenix forum, and 88 participated in Boston.

Another component very important for the forums' validity is that the participants' views were **informed**. Rather than survey people who may have little understanding of the subject, these forums provided the opportunity for participants to learn a great deal about NASA's Asteroid Initiative. In fact, participants were provided with much the same technical information that NASA's administrators and program managers use, but presented in short thematic background papers provided prior to the workshop and four informational videos at the start of each session. Additional deliberation materials reinforced the background material that participants received before the forums. To kick off the forums, we also created a 40-minute planetarium program that immersed participants in the issues they would be discussing throughout the day. Thus participants were fully briefed on the different mission decisions and scenarios, along with the costs, benefits, and risks associated with each—a formidable achievement, since the project was designed to consult citizens who were not already engaged or necessarily interested in thinking about space issues. Analysis of the participant rationales and feedback from facilitators indicates that participants incorporated complex technical concepts into their discussions and achieved a reasonable understanding of the topics and issues at hand.

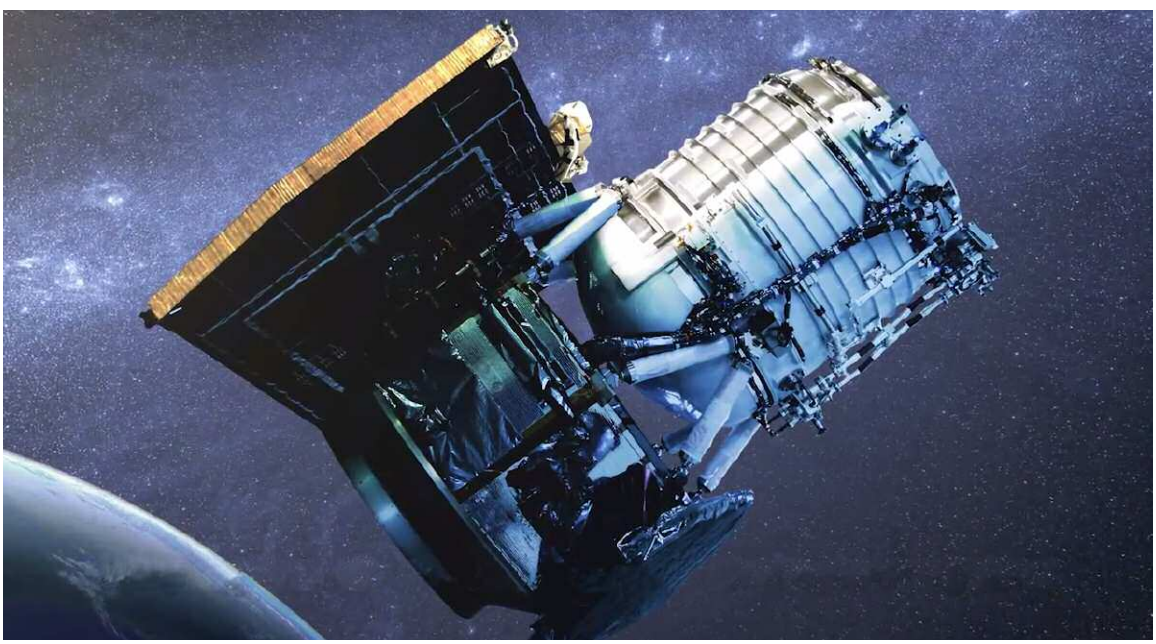
An additional key objective for the project is that citizen learning and engagement was **deliberative**. Participants were divided into small groups of 6-8 people and assigned a table for the day. Trained facilitators at each table ensured that every participant had a chance to express his or her views in substantive and focused group discussions. During these discussions, participants could ask clarifying questions of NASA subject-matter experts, and answers were tabulated and shown on a screen for the benefit of all the forum participants. Deliberation with peers helped to bring out the reasoning and values behind individual choices and allowed groups to come to consensus opinions about the issues. For each session, participants had the opportunity to register both group and individual responses to questions and record them in anonymous ballots. The quality of table discussions was high in many fundamental regards: most participants contributed their thoughts to the discussions; participants considered the issues raised in the background information and videos; there were few uncorrected errors or misconceptions in the deliberations; and the justifications participants provided for their votes on various issues were consistent with those addressed in discussions.

Finally, ECAST was tasked with generating **useable outcomes** from the forums—results that could be assessed to determine the success of the participatory technology assessment approach and provide useful input to NASA's decision making. Surveys helped determine participants' attitudes toward and knowledge of asteroid and space exploration before and after the forums, and measured participant satisfaction with the experience (results indicate that participants at both sites were highly satisfied with the forums). The themes, scenarios, strategies, and options outlined in the learning materials and the questions discussed during each session were developed with direct input from NASA program managers to ensure that the results could inform NASA decision-making. Group and individual responses to the forum questions provided a tremendous amount of quantitative and qualitative data for understanding and evaluating public values, social norms, and individual preferences when it comes to space exploration.

BACKGROUND FOR THE SESSIONS

The forum process began with ① recruiting, surveying, and briefing participants. On the day of the forum, participants ② checked in and watched a planetarium show. Four discussion sessions followed, each consisting of ③ a video introduction to the topic, ④ group discussion, ⑤ expert Q&A, and ⑥ voting. The morning planetary defense sessions were 90 minutes apiece and the afternoon space exploration sessions were one hour each. At the end of the day, participants ⑦ were thanked and filled out a post-forum survey. Finally, the forum was ⑧ assessed and analyzed by organizers.

ASTEROID DETECTION



In this session, participants were asked to consider three options regarding asteroid detection. To protect against an asteroid threat, we must first be able to detect it. Despite having identified an estimated 95% of the largest "planet-killer" asteroids greater than 1 kilometer in diameter—none of which are likely to pose a threat for at least the next several centuries—we know far less about smaller asteroids that could cause destruction at regional or urban scales. The U.S. Congress charged NASA with finding 90% of all asteroids that are 140 meters in diameter or larger by 2020, but that goal is unlikely to be achieved with current capabilities.

The first and least expensive option is to **maintain current detection capabilities**. Continuing efforts to detect potentially threatening asteroids could help to protect the Earth. There are already ground-based assets for detecting asteroids, but there are limitations to the existing system: detection is possible only at night; there is no coverage in much of the southern hemisphere; and weather, moonlight, and atmospheric distortion make detection much more difficult than it is from outer space. Furthermore, searching for asteroids from Earth makes it very hard to find asteroids in orbits similar to our own.

Another option is to institute **an extended ground-based detection system**. Augmenting the existing capabilities by building new observatories would increase our coverage area and allow for more standardized detection around the world. This option might cost $50 million annually for several decades, and could lead to new breakthroughs in other areas of astronomical research. However, it would still suffer from the limitations of a ground-based system.

The final option is to implement a **space-based satellite asteroid observation system**. NASA's WISE (Wide-field Infrared Survey Explorer) satellite provides some data about asteroids, but it was not designed for the task and many researchers use it for other purposes. A system of one or two spacecraft could be designed and launched, with a mission of using infrared detection to identify potentially hazardous asteroids. The estimated cost of this option would be $500 million per space telescope, considerably more than NASA currently receives for its ground-based asteroid detection efforts.

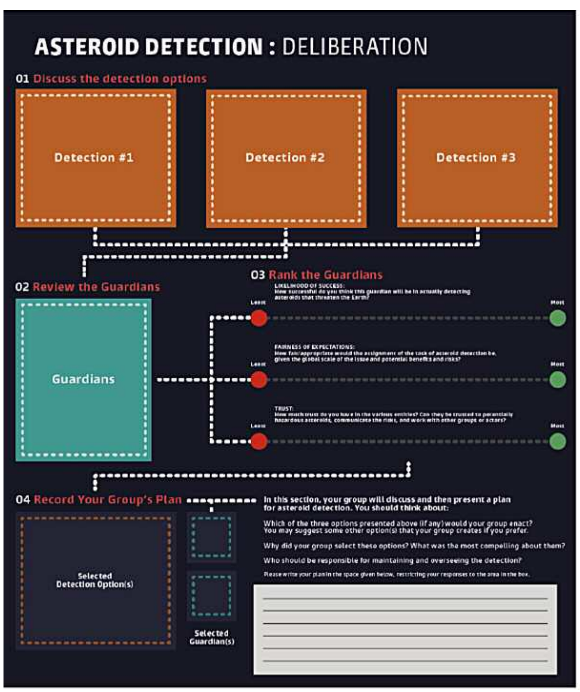


FIGURE 1: The laminated game board used during the Asteroid Detection session to structure table discussions about the group's preferred asteroid detection and governance strategies.

Participants also discussed what entities should be involved in **the governance of asteroid detection**, and further investigated what level of trust the participants have in those entities. These "Guardians" could include governmental, private, academic, and international partners. Forum participants talked about the different groups that could help with or lead planetary defense, and which Guardians they valued and appreciated.

The asteroid detection session was designed to familiarize participants with potential asteroid detection issues and strategies, building to a table discussion that yielded each group's preferred strategy, the reasoning behind this preference, and which Guardian they would like to see leading the implementation of their chosen plan.

ASTEROID MITIGATION

In the second morning session devoted to planetary defense, participants considered four primary options for mitigating a potential asteroid threat. Although there has been relatively little development of the technologies that might enable effective asteroid mitigation, several technologies and strategies have been proposed. Each option varies tremendously from the others in terms of cost, the warning time required for implementation, the risks and potential consequences, and the readiness of the option for deployment. Participants were briefed on these factors for the four mitigation options that NASA or other space agencies might employ.

The first option is **civil defense**, or communication and preparation for an asteroid impact. Civil defense would not reduce the probability of an asteroid collision if a threat is imminent, but rather involves notifying citizens and decision makers, and preparing people and infrastructure for the asteroid's impact.

The second option is a **kinetic impactor**, or ramming a threatening asteroid off its course. Kinetic impaction involves sending one or more large, high-speed spacecraft into the path of an approaching asteroid. This could deflect the asteroid into a different trajectory, steering it away from the Earth's orbital path.

The third option is **nuclear blast deflection**. Many nations around the world hold arsenals of nuclear or other types of explosives. Some experts have proposed launching nuclear explosives from the Earth to disrupt, destroy, or redirect an approaching near-Earth object. This may be the only option that would be effective for the largest and most dangerous "planet-killer" asteroids greater than 1 kilometer in diameter.

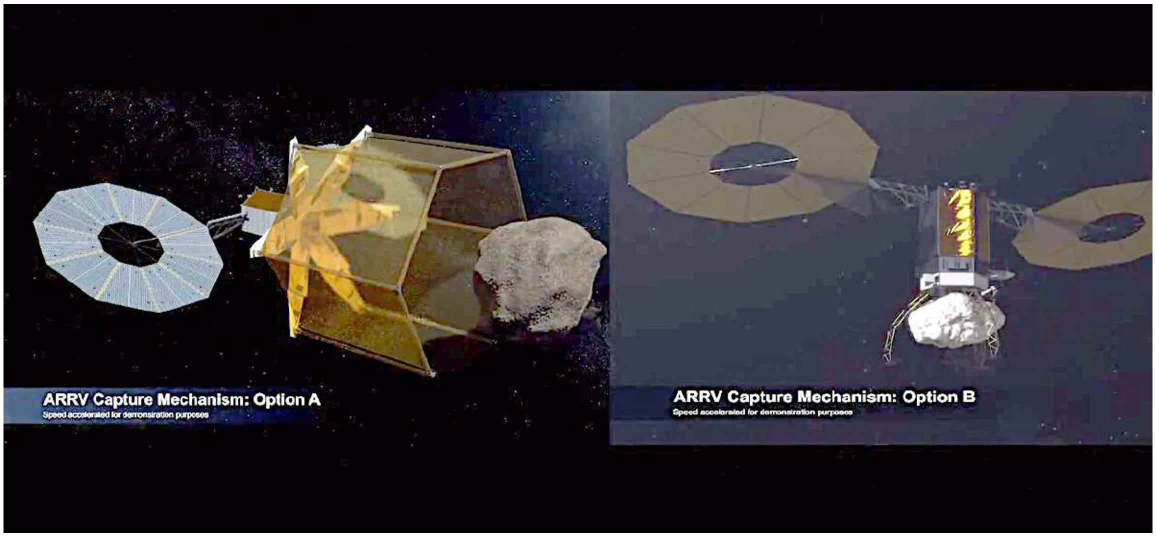
The fourth option considered at this session is the **gravity tractor**. If an approaching asteroid were detected early enough, it might be possible to divert it using the gravity of a spacecraft. Instead of sending an impactor to ram into the object, a gravity tractor device could fly alongside the asteroid for a long period of time—years or decades—and slowly pull it out of the Earth's path. Participants could also choose **no action**, with the assumption that the risks of implementing any other option were not worth deploying resources to mitigate.

During the session, the groups evaluated these options and their effectiveness with regard to a variety of different asteroid impact scenarios (e.g., a planet-killing asteroid with a 10% chance of hitting the Earth in 20 years) and accompanying hypothetical changes to these scenarios (e.g., a 50% chance of hitting the Earth rather than 10%, or a projected impact in 50-100 years rather than 20). They also considered which institutional Guardians would be preferred given the different scenarios. The scenarios and hypotheticals were selected in order to provide a range of different threats, varying in terms of the scale of the threat (from asteroids that would cause regional destruction to planet-killers); time frame (from four to one hundred years away); likelihood of impact (from 25% to 75%); and predicted impact location (North America, for example). The scenarios and hypotheticals helped to tease out participants' perceptions of the relevant risks and merits of the different mitigation methods. Because the options are not mutually exclusive, participants could choose more than one mitigation option and more than one Guardian.

TABLE 1. SCENARIOS AND HYPOTHETICALS PRESENTED TO FORUM PARTICIPANTS DURING THE ASTEROID MITIGATION SESSION OF THE FORUM.

MAIN SCENARIOS	HYPOTHETICALS
SCENARIO 1: 4-YEAR IMPACT A midrange near-Earth object (NEO) is detected and is estimated to be about 4 years from impacting Earth. The estimated size means that the range of impacts could vary between potentially destructive airbursts to regional scale disasters but would probably not produce globally devastating effects. OBJECT DIAMETER: 25-100 meters; Probability of impact: 75%; Scale of impact: Regional	**HYPOTHETICAL 1:** Imagine the probability of the asteroid impacting the Earth were estimated to be 25%, rather than 75% as described previously. Would this change your recommended mitigation strategy? **HYPOTHETICAL 2:** Imagine that two years after the original detection, scientists make an announcement that they predict that the asteroid will hit the western hemisphere and there is a high probability of it impacting near North America. Would this change your recommended mitigation strategy? **HYPOTHETICAL 3:** Imagine that the asteroid were somewhere between 500 meters and 1 kilometer in diameter, rather than 25 to 100 meters as described previously. An impact from an asteroid this size could range between disastrous continental-scale effects to a potential global catastrophe. Would this change your recommended mitigation strategy?
CENARIO 2A: 20-YEAR SCENARIO, CONTINENTAL-SCALE IMPACT An NEO is detected 20 years before projected impact. The estimated size of the asteroid means that the range of impacts could extend to continental-scale disaster. OBJECT DIAMETER: 100-1300 meters; Probability of impact: 50%; Scale of impact: Continental	**HYPOTHETICAL 1:** Imagine the probability of impact were 10% instead of 50% as described previously. Would this change your recommended mitigation strategy? **HYPOTHETICAL 2:** Imagine that two years later, scientists predicted that the inbound NEO had a high probability of impacting North America. Would this change your recommended mitigation strategy?
SCENARIO 2B: 20-YEAR SCENARIO, "PLANET-KILLER" IMPACT A very large NEO is detected 20 years before projected impact. The estimated size of the asteroid means that the range of impacts includes global-scale disaster. OBJECT DIAMETER: 1-5 kilometers; Probability of impact: 10%; Scale of impact: Global	**HYPOTHETICAL 1:** Imagine the probability of impact were 50% instead of 10% as described previously. Would this change your recommended mitigation strategy? **HYPOTHETICAL 2:** Imagine that the projected time of impact were 50-100 years away instead of 20 as described previously. Would this change your recommended mitigation strategy?

ASTEROID REDIRECT MISSION



The first of the afternoon sessions devoted to space exploration solicited group and individual preferences about NASA's Asteroid Redirect Mission, or ARM. ARM was announced in April 2013 as part of the Asteroid Initiative and a way to implement President Obama's vision of having astronauts visit an asteroid by 2025. The mission would involve bringing an asteroid or a piece of an asteroid into orbit around the moon. Once there, astronauts on an Orion crewed spacecraft would be launched on a Space Launch System rocket to rendezvous with the captured asteroid and collect samples and perform other research on it.

In this session, participants were also introduced to NASA's **Proving Ground strategy**, which we connected conceptually to the capability-driven framework, and participants discussed how the ARM fits into this framework. The Proving Ground, as noted above, entails missions and activities that develop the capabilities needed to get humans to Mars, while remaining near enough to Earth for a safe crew return and close monitoring of crew activities and technology advancement.

NASA developed two options for implementing ARM, and in this session the forum participants discussed the uncertainties, tradeoffs, and benefits of the options and provided both group and individual preferences. **Option A** would send an Asteroid Redirect Robotic Vehicle (ARRV) to capture a small asteroid, approximately 10 meters in diameter. The ARRV would envelop the asteroid in an inflatable bag and then use a constant propulsive force to bring it to distant retrograde orbit around the moon.

Option B entailed sending the ARRV to a larger asteroid, greater than 100 meters in diameter. The ARRV would descend to the surface of the asteroid and use a set of robotic arms to retrieve a boulder, secure it, and move the boulder into orbit around the moon. There, as in Option A, astronauts would travel to the asteroid to study it.

The comparison between the two options was complex, with each entailing a host of uncertainties and tradeoffs. Some uncertainties were described as technical in nature: for example, because of the difficulty in determining the composition of the asteroid in advance, Option A might retrieve an asteroid of limited scientific interest. Other uncertainties were influenced by social values, such as how to value the larger asteroid retrieved in Option A, the ability of both options to test technologies for Mars missions, and Option A's potential dual-use for space debris removal.

But both options would develop **solar electric propulsion** (SEP) as a primary goal of the mission. SEP is a critical capability for human spaceflight missions and a technology that, if advanced from current state-of-the-art technology, would enable sending large payloads to destinations like Mars with significantly less propellant than required by other methods. Both options would also improve planetary defense capabilities, in ways related to each method's distinct technological attributes. Initial NASA estimates indicated that both options would essentially cost the same, less than $1.25 billion, meaning that cost was not a deciding factor between the two strategies.

Deliberations centered on the two ARM options and participants provided group and individual recommendations, addressing potential mission goals as well as different acceptable risks that may occur.

JOURNEY TO MARS

The Asteroid Initiative, and in particular the Asteroid Redirect Mission, is part of NASA's broader human space exploration strategy. ARM, if implemented, can satisfy a variety of technology development goals, such as solar electric propulsion and deep space extra-vehicular activity techniques, that are needed for many different exploration missions. With a human mission to Mars as the decision-making context, ECAST designed this final session to explore questions that NASA managers are considering for future mission planning—specifically an approach called the **capability-driven framework**, or CDF.

Forum participants were told that the CDF is a departure from the traditional space mission-planning model. Instead of selecting a destination—like the moon or the International Space Station—and developing the techniques and technologies needed to achieve that goal, this approach develops the capabilities to travel to a range of deep-space destinations. As these capabilities mature, increasingly complex missions can be selected to destinations farther out in the solar system. Missions would be funded, designed, and carried out incrementally as NASA's budget, capabilities, and partnership opportunities dictate, with the potential to be more efficient and cost-effective than the traditional model. The CDF allows NASA to develop, test, and refine technologies and capabilities in a lower-risk environment than, for example, an immediate human mission to Mars, which is commonly seen as the ultimate goal of NASA's human exploration efforts.

To inform citizens as they considered the CDF, the participants learned about the resource and time constraints that surround mission planning. Recognizing tradeoffs between cost, schedule, and risk is a key part of the CDF and any mission-planning effort. Participants were asked to deliberate on three potential mission scenarios for exploring Mars, each of which progressively required more time, increased costs, and greater risks. Individuals recommended one of these exploration scenarios and considered whether the Proving Ground strategy was an acceptable approach to achieving the selected option.

The first Mars scenario is a **robotic and orbital / moon mission**, entailing a crewed ship orbiting Mars and potentially visiting the Mars moons, Phobos and Deimos. The crew would remain in orbit and explore the surface of the planet via robots, which they would be able to operate in a much more efficient and directed manner than teams on Earth. Without the need to actually land humans on the surface, this option is the least expensive, involves the least amount of risk, and requires less technological innovation, making it possible to accomplish within a relatively short timeframe. On the other hand, the amount of science that could be done is significantly less than would be achievable with a crewed landing on the surface, and it may be less exciting to the public.

The second option is the **Viking scenario**,[1] a small-scale crewed exploration mission that would set down on the surface of Mars for several months before returning to Earth. Having astronauts land on Mars would vastly increase the relevance and amount of scientific information they could collect. But the technological and engineering hurdles, in addition to the risks for the crew, are significantly greater, and the costs and timeframe of such a mission consequently increase. Another concern is that once humans have visited Mars, enthusiasm for follow-up missions may wane to the point of cancelling any future exploration of the Red Planet.

Finally, the third option is a **Pioneer scenario** of initiating a permanent settlement on Mars. A fleet of robotic ships would deposit food, fuel, and materials on Mars' surface. Robots would prepare permanent habitats prior to the arrival of a small initial crew of human explorers, who would be joined by additional pioneers on subsequent missions. The crew would be refreshed every few months with new supplies and personnel, with a long-term goal of harvesting resources from the planet. While a mission of this scale and duration would unlock a large number of mysteries about Mars and the solar system and would eventually make humanity "Earth-independent," this strategy would involve a significant increase in cost, risk, and timeframe over a smaller-scaled surface exploration mission.

The choice among the scenarios was not described as exclusive, since the scenarios could be executed sequentially. Rather, the choice represented what the initial exploration goal should be once NASA has developed more of its exploration capabilities. A more challenging initial goal can mean higher costs and longer development times before a crewed mission to Mars becomes possible. Identifying and considering the cost, risk, and timeframe tradeoffs among the three Mars mission scenarios helped participants understand the constraints under which NASA operates, and thus helped prepare them for a deliberation about the Proving Ground strategy and whether they support it.

1. "Viking" here refers to the historical Vikings of northern Europe, who visited North America before Columbus but did not establish a permanent presence. The "Pioneer" label for the third scenario was the phrase used by ECAST to describe the notion of a permanent settlement on Mars. NASA has separately used the phrase "Pioneering Space" to describe a set of principles for exploration, but this was not discussed or intended to be part of the discussion during the forum.

THE RESULTS

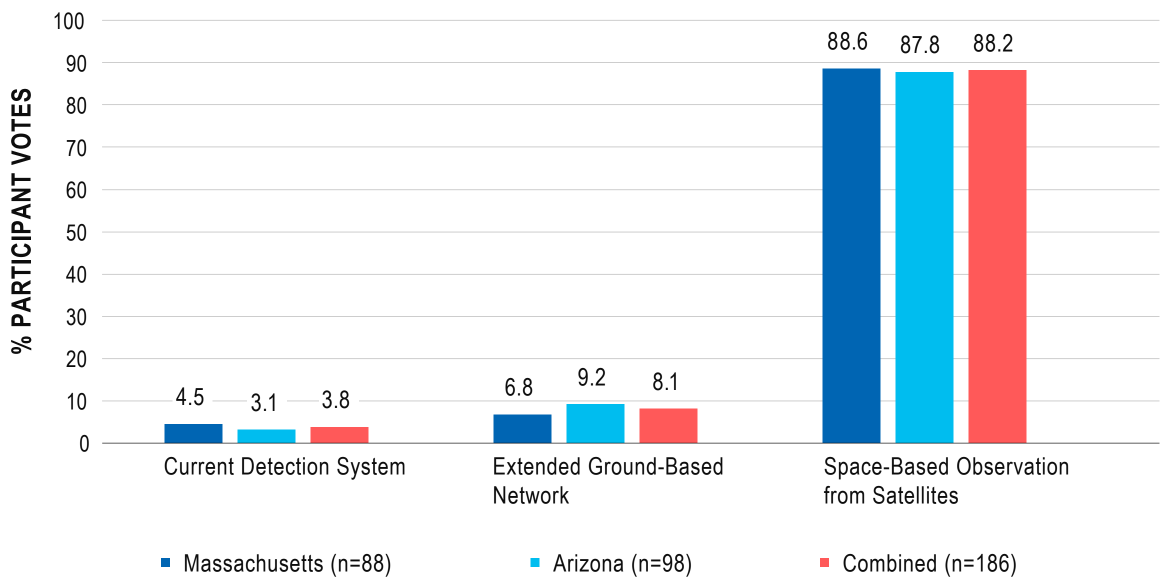
The participants in Boston and Phoenix saw the deliberations positively: according to the post-forum survey, participants were highly satisfied with their experience at both sites. Pre- and post-forum surveys indicated that participants greatly increased their interest and knowledge in NASA's Asteroid Initiative and plans for space exploration. Their attitudes toward different planetary defense scenarios and space exploration goals also shifted, for example toward more agreement for the need for government support for space activities and the importance of international collaboration. The main findings from each of the forum sessions are highlighted below.

ASTEROID DETECTION

By a wide majority, participants at both sites selected to implement **space-based observation of asteroids** over maintaining current detection methods or developing an extended ground-based network. An international partnership in which the United States and NASA would play a critical role was preferred to other options as the appropriate institutional Guardian for planetary defense, with the most frequently cited rationale for this choice being that asteroid detection is a global issue and therefore a global responsibility.

It is difficult to assess how the cost of the various options figured into the groups' decisions. Although the majority of groups at both sites considered costs in some way in their responses, very few groups expressed concern about how much the different detection strategies would cost. Most groups thought that costs for the chosen detection strategy should be shared with private industry, international consortiums, or a combination of the two. The main reason that an international partnership was chosen as the appropriate Guardian for planetary defense may have been in order to share the costs of the system.

PLANETARY DEFENSE OPTIONS – PARTICIPANT'S FIRST CHOICE



How do we know these results accurately reflect the sentiments of the participants? Past research on participatory technology assessment has shown that if one or a few people dominate discussion and others accede to their views, the group statement may not be credible or representative (this was one reason we sought to limit participation by space enthusiasts and professionals). But if participants hear one another's concerns, adjust their views on the basis of what they have heard, and work together to articulate shared principles and a specific plan or view on a given issue, the results can provide reliable insights about citizen views for decision-makers. Table observation transcripts and facilitator observation of the conversations in this session—and throughout the forum—indicate that the group interactions represent this kind of balanced discussion that is likely to reflect the public's preferences. The following vignette provides details from a group discussion about asteroid detection options.

ONE GROUP'S ROAD TO INTERNATIONAL GOVERNANCE OF PLANETARY DEFENSE

After the informational video and the facilitator's brief overview of the issues to be addressed in the session, "Bob" made the first contribution of the session (names have been changed to protect participants' anonymity). An Arizona State University student studying in a scientific field, Bob's view was that: *"Just from the video, the [detection option] I liked the best was the space-based satellite as opposed to ground-based … it's a little bit more expensive, but we don't have to worry about the atmosphere or things like that, and we can use the ground-based observation capabilities for something else."*

Sara quickly concurred with this view on the grounds that the space-based approach would be more effective. Unless the cost is genuinely burdensome, she reasoned that the option most likely to accomplish the program's objectives should be selected. Sara then asserted that the real waste would be investing in a ground-based approach that had a lower probability of success, turning the cost issue on its head, suggesting that money was wasted if the most expensive option was not chosen.

Angelise supported this line of reasoning by noting that there had been no warning or detection of the Chelyabinsk asteroid, which she took as evidence of the need for an improved system. Picking up on this observation, Bob noted that detection protects all countries against the risks of an asteroid impact, so it would be reasonable to share the costs internationally. Further discussion converged on the importance of combining ground-based and space-based systems—the moderators had explicitly stated that options could be combined for the group plan.

TRUSTING OTHER COUNTRIES?

As the discussion moved back to the specifics of an international collaboration, Patti interjected: *"But we would have to put a lot of trust in [other countries], and this brings up the fact that we can barely trust a lot of countries these days."* This prompted practical suggestions from other participants addressing her concern, such as assuring that a diversity of countries be involved in the international collaboration and that they elect its leaders. Their aim was to minimize the risk that the program would be hijacked to serve one or a small number of countries for purposes other than global planetary defense. Patti ultimately concurred that in principle trust was a manageable issue. Carlos and Lori made only cursory comments during this initial conversation, and it later turned out that Carlos also lacked confidence in an international arrangement because it would require trusting other countries.

WANDERING IN THE WILDERNESS, BUT FINDING PROVISIONS

The conversation flowed freely for the next half hour or so, with a number of points that shaped the group's proposal under discussion. These included:

- The program should include an *enhanced* ground detection network *and* a space detection network.
- The main reason for international governance is to share the costs.
- The U.S. should play a leadership role; while no participants opposed this idea, several participants doubted that other countries would like it. Various means of securing and sustaining foreign support were considered, with little concurrence.
- Private industry cannot be trusted in a leadership role (e.g., they might establish a program with government support by claiming their efficiency, and then change the price after clients had become committed to it).
- Space agencies such as NASA and the European Space Agency might be reluctant to be transparent about their activities due to nationalistic conflicts and dispositions.

- The United Nations should have an oversight role in order to “keep the peace” among members in the planetary defense organization, who might otherwise be disposed to competition and discord.
- A competitive space race should be avoided; a measured program development that responds to evolving opportunities and constraints would most effectively achieve its goals and would also be most palatable to decision makers over the long run.

MOVING TOWARD CLOSURE

As the discussion continued, affirmations grew for the U.S. agency involved in the program to be independent of NASA so that it could focus solely on planetary defense. Participants reasoned that this would limit the conflicting pressures that might take place in a large agency. An independent agency would also be less vulnerable to the congressional propensity to suddenly cut budgets, because of its small size and defense mission. However, the group struggled to reconcile conflicting goals. On the one hand, participants preferred an independent agency within the U.S. and U.S. leadership of an international planetary defense program. On the other hand, they recognized that such an arrangement could fall victim to competitive impulses that would generate conflict over priorities and less-than-transparent relations among the various countries.

After much discussion, the conversation gained more traction when the idea emerged that all parties in the international arrangement could have a similar specialized agency that would be a point of contact with their respective space agencies (in cases where the country has one), as well as with private industry and other players. Patti objected, however, that this would essentially be an arrangement in which countries would be sharing the satellite. Sooner or later, some would want to use it for different purposes. As an alternative she suggested that “*it needs to be one office collaborating among all the countries*.”

James had earlier suggested that the focus of the separate planetary defense agency in the U.S. could be strengthened by relocating all the planetary defense experts in NASA and other agencies to the new agency. Upon hearing Patti’s comment, he internationalized this idea by proposing that planetary defense experts from participating countries around the world be reassigned to a single international entity, eliciting “*That’s a great idea*” from one participant and elaborations of the concept from others.

SEALING THE DEAL

Two additional ideas completed the group’s plan and secured enthusiastic support of everyone but Carlos, who wanted NASA to be responsible for planetary defense independently of other countries. The first was that the new entity would have its own governing board with executive, finance, and other committees drawn from a membership of multiple countries. Hearing this, James said, “*So it would [be] run more like a business than a government*.” The second proposal was that the new planetary defense agency would be a nonprofit organization.

The thread that ran through this conversation from its outset was the recognition that planetary defense would and should protect everyone on Earth. Essentially, the participants took on the challenge of accomplishing this global goal in the challenging context of a world composed of competing nations and private interests.

In the course of their conversation, the participants’ plan overcame numerous hurdles. It secured the support of several participants who had little trust of other countries; defused the urge to place the U.S. in a leadership position that participants could see would be unpopular among international partners; sought prospects for securing public and private funding; favored an organization composed largely of technical experts; and addressed the distractions and challenges of political influence and competition.

ASTEROID MITIGATION

This session was fairly complex: in addition to learning about the mitigation options described above (civil defense, kinetic impactors, nuclear blast deflection, gravity tractors, or no action), participants evaluated which option they believed would be most successful in three basic asteroid impact scenarios and several accompanying hypothetical variations on the main scenarios. The scenarios were selected to survey the responses to a range of threats that varied in four dimensions: the scale, timeframe, and likelihood of the threat, and the predicted location of the impact. These parameters helped to draw out the relevant merits of the different mitigation methods and identify participants' risk perceptions.

While caution is required in combining score results across multiple scenarios, the planetary defense strategy most commonly chosen overall was nuclear detonation, followed closely by kinetic impactor and civil defense. Several high-level observations can be made about the results.

TABLE 2. THIS TABLE HIGHLIGHTS THE VOTING RESULTS FROM ONE OF THE SCENARIOS (THE "4-YEAR IMPACT" SCENARIO) AND ITS ASSOCIATED HYPOTHETICALS. THE PERCENTAGES REPRESENT THE PROPORTION OF PARTICIPANTS (AT BOTH SITES COMBINED) WHO VOTED TO ENACT EACH MITIGATION OPTION. *Note: percentages don't add up to 100% because participants could choose more than one mitigation option.*

MITIGATION OPTIONS "4-YEAR IMPACT" SCENARIO	Main Scenario #1 Probability = 75% Size = 25–100m	Hypothetical #1 Probability = 25% Size = 25–100m	Hypothetical #2 North America Probability = 75% Size = 25–100m	Hypothetical #3 Probability = 75% Size = 500–1000m
NO ACTION	3.8%	6.0%	1.1%	4.9%
CIVIL DEFENSE	75.5%	72.3%	77.0%	60.6%
KINETIC IMPACTOR	66.8%	62.0%	62.5%	41.8%
NUCLEAR DETONATION	56.8%	41.0%	65.0%	85.8%
OTHER	10.4%	10.9%	5.5%	9.3%

Participants' preference for the **nuclear blast deflection** strategy varied widely, but increased significantly with the magnitude and certainty of impact in each of the three scenarios. Although the time horizon for the impact did not appear to affect preferences, the probability of impact did: when the likelihood was low, this option was selected with less frequency. Despite being the most popular option overall, many citizens struggled with the nuclear detonation choice and were reluctant to choose this strategy unless confronted with a high probability of a continental-scale to planet-killer impact. Not everyone fit this pattern: some participants were confident that nuclear weapons would be the most successful in all scenarios, whereas others refused to choose the nuclear option for even a planet-killer scenario on ethical and political grounds. But given the public's typically negative attitudes toward nuclear technologies, this option's popularity was somewhat surprising. Delving a bit into participants' qualitative rationales indicates that the public did not propose this option lightly: the risk of failure and fallout, the potential for international political tension, and the difficulties of managing nuclear technologies, among other concerns, made many participants uneasy, even among those who favored nuclear detonation to deflect an asteroid.

Using **kinetic impactors** was the most stable participant preference, and a fairly popular option, especially in the 4-year impact scenarios. Participants often chose it because they viewed it as a safer or less risky option than either nuclear detonation or the gravity tractor. Kinetic impactors were less popular when there was a lower probability of impact, and for the planet-killer contingencies, when nuclear blast deflection rose to the fore.

Civil defense was generally popular, likely because it was not deemed to be an exclusive choice—that is, people could vote for it alongside other options. It would be logical for people to prepare civil contingencies in case primary mitigation efforts failed. Civil defense had a clear relationship with time to impact in the scenarios: the sooner the impact, the higher the preference for civil defense. The **gravity tractor** had its highest support in long timeframe scenarios (20 years out), which would make sense due to the long lead times required for the tractor to work. (In fact, the gravity tractor was not provided as an option in the shorter, 4-year scenarios.)

Participants factored the probabilities of impact and mission success into their rationales. When considering the different asteroid impact scenarios, participants referenced probabilistic information, but did not utilize it analytically (i.e., as a statistician would) to support their decisions. Instead, they adopted probabilistic language to anecdotally support their selections in the face of future risks, whatever the likelihood of possibility. For example, one participant wrote: "*If there's a chance of impact, especially 20%, action should still be taken.*" Another wrote: "*Since no option is 100%, a combination of all 3 selected [mitigation options] would increase the chances of success*." Participants' misunderstanding or misuse of statistical concepts does not invalidate the results, but rather indicates where future engagements could be improved. Adjusting the design to assist the public in interpreting expert risk assessments would increase understanding of the reasons and contexts for NASA's particular mission choices.

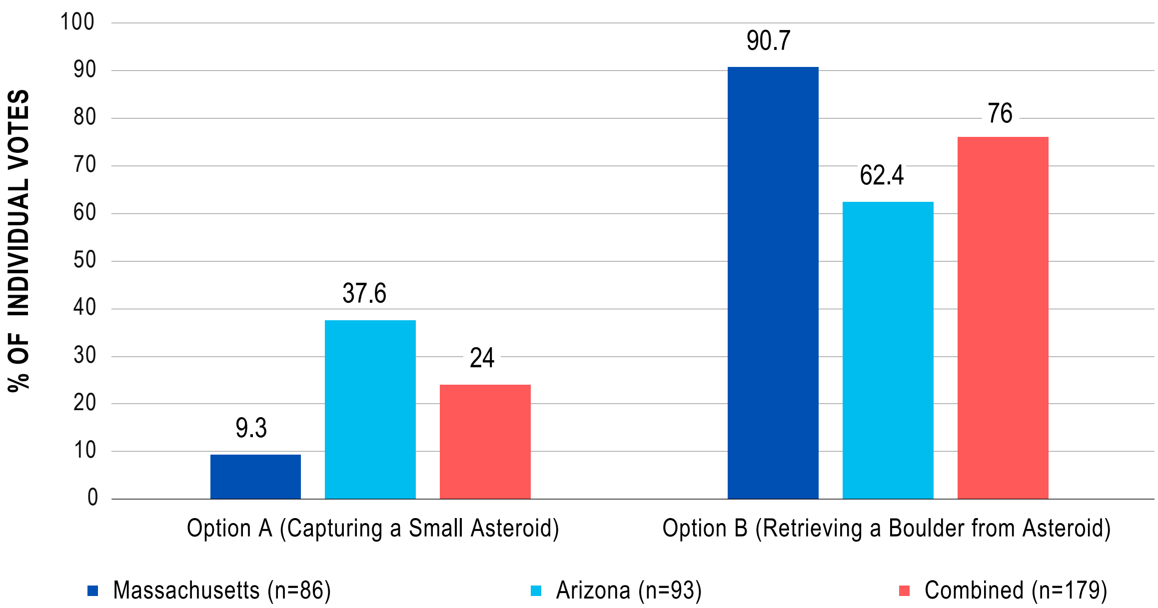
Participants were presented with the same Guardian options as they were for the asteroid detection session—entities like a U.S.-led partnership, a new office of planetary defense, etc., which would lead the implementation of a planetary protection strategy. By considering the different asteroid mitigation scenarios in this session, participants significantly changed their Guardian preferences relative to the most popular Guardians in the detection session. There was a slightly increased preference for an international consortium that included NASA, but a dramatic decline in the desire for private industry or the international scientific / academic community to lead mitigation efforts in most scenarios. These results are interesting because they indicate that people's predispositions to certain governance strategies can be influenced with additional information. In this case, the different asteroid impact scenarios affected the institutional leaders that participants preferred to lead mitigation efforts.

Although citizens were not asked to justify their Guardian choices during the mitigation session, we hypothesize that the shift in favor of international collaboration occurred for two reasons. First, the possibility of using nuclear blast deflection as a mitigation strategy led participants to recognize the need for negotiations among countries at the international level. And second, once confronted with impact scenarios with the potential to play out in real life, participants began to see the social, political, cultural, and technical complexity of implementing mitigation strategies—necessitating, in their minds, the need for international collaboration.

ASTEROID REDIRECT MISSION

After effectively incorporating scientific and technical details into their discussions about ARM Options A (capturing an entire asteroid in an inflatable bag) and B (retrieving a boulder from a larger asteroid), participants at the two forums selected **ARM Option B** over Option A by a wide margin. In their own words, participants wrote out their rationales for why they chose each option. Those who voted for Option B cited a variety of reasons for their choice, including broad appeal; more obvious and near-term benefits; the use of proven technology; better control over the selection of the asteroid type; and being a good fit with the Proving Ground strategy. The minority that voted for Option A cited the approach's potential for multiple uses; its economic benefits; and the perception that it would be less risky than Option B.

ASTEROID REDIRECT MISSION OPTION A VS. B — INDIVIDUAL VOTING PREFERENCES



Forum design may have played a role in the individual and group selection of Options A or B. Many people cited as their reason for voting for Option B an interest in enhanced gravity tractor technology, which is linked to planetary defense. ("Planetary defense" itself was a highly rated rationale too.) Since planetary defense was discussed extensively during the morning sessions, it may have become a concern that influenced voting preferences in a way that, had ARM options been discussed earlier in the day, it would not have otherwise. There is, in fact, strong evidence that participants integrated knowledge gained about planetary defense during the morning sessions into the ARM session deliberations.

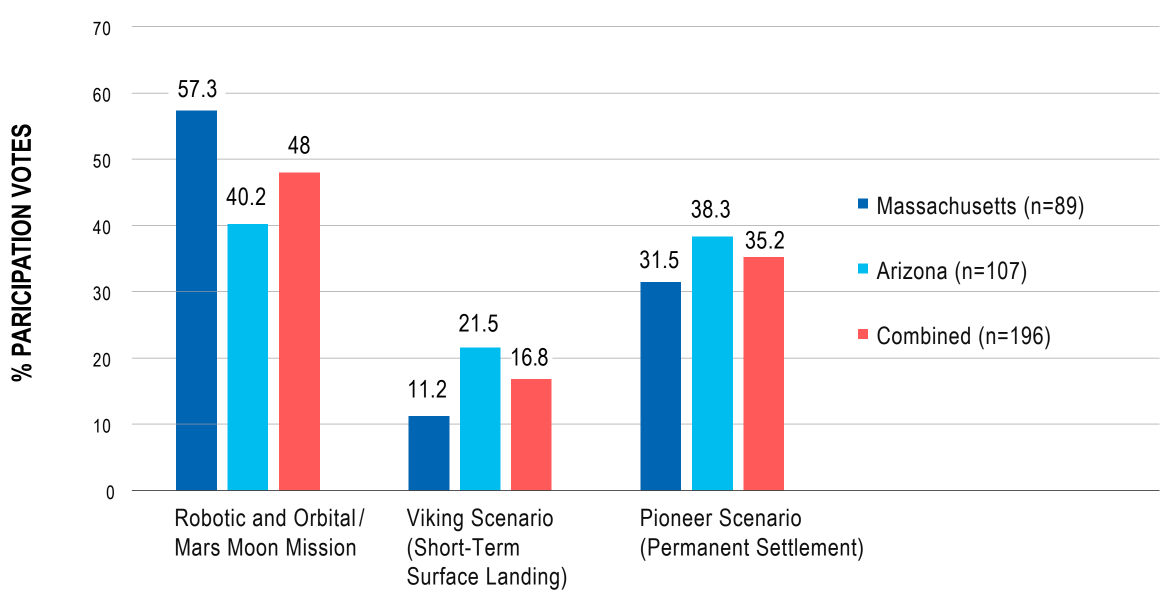
We asked participants to weigh in on the **potential goals of ARM**—what objectives NASA managers should consider when deciding on the ARM mission. On average, both sites chose the same top goals for the ARM program: "Advancing science," "Advancing planetary defense," and "Advancing technology needed for human spaceflight." This indicates the relative importance of planetary defense, especially in contrast to other economic or international goals (e.g., "Engaging with commercial and international partners" ranked low on the list of priorities). Analysis of the quantitative results from the ARM option voting indicates that these goals also motivated participants' preferences for one option over another. For example, citing greater scientific value and increased certainty for the type of asteroid retrieved, many people related their choice for Option B to going to Mars—in other words, advancing human spaceflight technologies.

The final task for participants in this section was to consider the **uncertainties** involved in a potential ARM mission. We asked them to vote on the acceptability of different kinds of mission failures and risks that might occur with the mission and the broader objective of Mars exploration. In general, participants appeared to accept the proposed risks of mission failure in most scenarios, except where risk to astronauts was increased in order to shorten the timeframe for a Mars mission. In other words, where mission planners had the ability to mitigate risks, participant responses indicate that they wanted them to do so.

JOURNEY TO MARS

Participants in this session voted on which scenario they preferred as NASA's initial goal for its exploration capabilities. The scenarios, as detailed above, were to send a crew into Mars orbit to direct robot explorers on the surface and potentially visit the moons of Mars; to send astronauts to land on the surface of Mars and then return to Earth, which was called the Viking scenario; or to initiate a permanent settlement on the surface of Mars, known as the Pioneer scenario. Some citizens wanted to combine the three scenarios for Mars exploration, but on average, participants at both sites favored **sending astronauts to orbit the Red Planet**, along with robotic exploration and possible Mars moon missions, over the Viking and Pioneer scenarios. Although the crewed orbital robotic mission profile was the most popular, there was still a strong preference among participants to actually land people on Mars, as the Viking and Pioneer scenarios together accounted for 52% of votes, indicating a nearly 50/50 split in the participants' preference for a crewed orbital mission or a mission that involves astronauts landing on Mars. Interestingly, the two sites differed in their preferred Mars mission priorities. Nearly 60% of people in Massachusetts voted for the orbital robotic exploration approach, where only 40% of Arizonans voted for it.

SUPPORT FOR DIFFERENT MARS EXPLORATION SCENARIOS



The overall preference for the orbital robotic scenario may imply that people prioritized accomplishing a Mars mission sooner, even without landing, as opposed to waiting longer to achieve more ambitious and costly goals. This preference for an earlier mission would be a decision on how to balance cost, schedule, and risk. Interest in exploring Mars moons may also have been a key factor.

Complicating this assessment is that the Pioneer (permanent settlement) scenario was rated more highly than the Viking (short-duration crewed mission) scenario, with some data suggesting a preference to "go big or go home" and a minimization of the significant economic and technical hurdles involved in such a mission. When considering these different missions, technical and managerial arguments about, for example, cost and risk were interspersed with divergent perspectives on the basic purposes of human exploration of Mars and the values that informed participant preferences.

The reasons cited for favoring the crewed orbital robotic scenario included cost and safety concerns for landing astronauts on Mars and a desire to have a human presence around Mars in a shorter time frame. Those who preferred a human mission to the planet's surface cited maintaining public interest, becoming a "two-planet" species, and advancing science and technology as rationales. Importantly, most people who chose the orbital robotic scenario did not exclude the potential for future crewed landings on Mars, but saw the mission as part of a progression that would achieve a significant milestone, minimize risk and cost, and increase scientific knowledge prior to tackling the more ambitious Mars surface missions.

In this session participants also discussed the Proving Ground strategy, which for simplicity of discussion, the background material equated with the conceptually related capability-driven framework (CDF), an incremental approach to planning future missions. A majority of people at both sites supported moving forward with the Proving Ground approach, which suggests that an informed public may endorse an incremental planning approach to advance deep space exploration as opposed to the traditional destination-oriented mission model. We examined the reasons that participants provided for their support of the Proving Ground strategy, and found that approximately half used CDF language (regarding incrementalism, multi-purpose missions, and budget constraints) in their rationales.

We believe the majority of participants understood the Proving Ground strategy in terms of the CDF, which has shaped much of NASA's recent human spaceflight planning studies. This result suggests that if the public at large was made aware of the CDF and the constraints NASA operates under, they would be receptive to an incremental mission planning strategy. But we must note that the results show some ambiguity, suggesting that complex concepts such as Proving Ground and the CDF deserve more focused attention in future forums, in order to ensure enough time for participants to assimilate these ideas in the context of space exploration. Our recommendation for future deliberations is to devote a separate section to the CDF concept prior to having people address its merit relative to particular space missions.

REFLECTIONS AND REFINEMENTS

This project yielded many significant insights as highlighted in the results section above. In addition, we offer a few final reflections about the design of two components. First, what aspects of the **citizen forums** could be improved, and what issues could be productively explored further? Second, how can this **project model** be used in the future, and what variations of the model might be adopted to support decisions that are broader or different in scope?

REFINING THE FORUM DESIGN

Several aspects of the project were experimental, and could be refined and improved in future work. One improvement would be the amount of time allowed for design and refinement of the forums: although participant comments in the post-forum surveys were very positive about the quality of all aspects of the event, a design period compressed to meet decision deadlines pushed the limits of what the staff could prepare and the participants could digest. Some of the confusion expressed by participants in the course of their deliberations likely would have been ameliorated had more time been available to refine the design and test information materials. Even without refinements, more lead time for participants to read the advance information material would have increased their comprehension of it. There is a trade-off here, however: the tightened timeline *did* produce input for an important decision in a timely fashion, an outcome that often eludes cooperative arrangements such as the one undertaken in this project.

Based on our experience, there are several additional ways to improve the participatory technology assessment approach using a dialog format. Below are some additional key factors that could be changed or reemphasized in future research.

INFLUENTIAL DESIGN FACTORS	DESCRIPTION
PARTICIPANT DEMOGRAPHICS AND KNOWLEDGE	Each participant brings varying levels of preparation and different social and cultural associations with the topic of deliberation. Participants also have varying levels of energy and enthusiasm related to the particular time that a decision is put forward (e.g., table observers noted that energy levels were lower after lunch when the ARM session occurred). Participant demographics show the composition of the site groups, but not by individual voting response. Careful analysis of survey questions could better capture what perspectives participants bring to the forum. Furthermore, voting responses could ask for basic demographic information (e.g., gender) of particular interest to more closely tie individual responses to demographic patterns.
EXTERNAL INFORMATION AND MEDIA COVERAGE	Media coverage that related to one or more of the issues associated with the deliberation occurred in the weeks before the in-person events (e.g., for ARM, the European Space Agency's Rosetta mission to a comet occurred in between the two forums). Adjustments to the pre- and post-forum test instruments could test for the influence of this type of external information.
INFORMATION MATERIALS CREATED FOR THE EVENT	Participants were given background materials to read before the event and were shown a video at the beginning of each session where their task was to deliberate on different key questions. It is possible that the background material in different sections may have influenced participants' preferences. Additional time to test the background materials and session design in advance, potentially by testing it with control groups, would help to mitigate this factor.
TABLE FACILITATION	Table facilitators received training about the information materials, process, and intended outcomes of each session. Facilitators came from a range of backgrounds and had different levels of exposure to training for professional facilitation. Ensuring best practices and shared knowledge among facilitators could help increase consistency in the forum process.
BALANCE AND INFLUENCE OF GROUP DISCUSSION VERSUS INDIVIDUAL VOTING AND REASONING	Participants engaged in facilitated discussion for approximately 1 or 1.5 hours on a given topic, so they were able to learn what their fellow participants thought and to explore reasoning behind their statements before making a personal vote. This is one of the strengths of this dialog model for a pTA deliberation, and could be used to shape future research.

IMPROVING DECISION SUPPORT

We believe much of value was discovered through these forums—a diverse and rich set of data relevant to specific questions about NASA's Asteroid Initiative that could provide useful input to agency decision makers. Below are four potential ways to broaden the scope of future projects to address issues facing NASA and perhaps other federal agency administrators.

First, the deliberation on asteroid detection and mitigation of asteroid threats raised issues about how the public conceives of opportunity costs in space. Participants discussed costs in several key places, but given that the session didn't specifically focus on cost, we have difficulty determining exactly what participants felt about the opportunity costs of the three asteroid detection methods. A more general discussion of opportunity costs between funding a space-based effort versus alternative projects, both space related and non-space related, is possible. A public deliberation could provide relevant background and explore more precisely how much costs for specific federal projects would be publicly desired given competing goals. For instance in the present case, a forum could be devoted to discussing specifically the opportunity costs of implementing different mitigation strategies or asteroid detection methods.

Second, understanding how the public perceives probabilities emerged as an interesting topic of research in the asteroid mitigation section. Participants considered ten different scenarios, and their perception of different probabilities in those scenarios altered their preferred mitigation strategies and institutional leaders. Surprisingly, a majority of participants selected the use of nuclear blast deflection as a mitigation strategy, especially when facing increased risk of large-scale impacts. However, upon further analysis, it became evident that most participants did not make the choice lightly. Many showed great reluctance and resignation that this was their only choice given the circumstances. Additional deliberations with more scenarios could be used by decision makers to better understand how the public would perceive probabilities of threats, accept institutional actors, and choose conditions for various mitigation options.

Third, the ARM results indicate that using pTA to proactively support a technical decision could be valuable for a variety of topics, both in aerospace as well as other areas of the federal government. The ARM decision between Options A and B was a fairly technical and challenging topic, yet participants generally were able to navigate the complexities and have a nuanced discussion about the decision variables. In addition, participants had rich discussions about potential goals for the mission, about risk, and about schedule priorities, which are useful data points to consider when trying to understand how people view different initiatives. Future research could examine the value that NASA derived from the deliberation results, and ways the deliberation could be more precisely structured to aid NASA's decision making.

Fourth, more explicit deliberation about the value or purpose of the missions themselves could be beneficial, such as a deliberation focused on why humans should go to Mars in the first place. Similar questions could also be asked about studying asteroids, or retrieving and visiting one. The deliberations did not explicitly focus on the goals to be served by asteroid detection, mitigation, and recovery and Mars exploration, or the philosophical commitments that underlie them. Nonetheless, participants had plenty to say on matters of philosophical importance, and offered, at times, conflicting opinions about the relative values of different scenarios for the various missions. Discussions would likely have been even more robust had values been engaged more explicitly by design, for example as an exercise in mapping public values. This would require introducing not only the technical complexities surrounding the issues at hand, as we did in this forum, but also their social, ethical, and legal dimensions, and engaging with a broader group of experts and stakeholders.

Interestingly, despite the philosophical differences among participants in the Mars session, there was considerable convergence on the desirability of continued space exploration within a capability-driven, or Proving Ground, framework. This may suggest that the "crash program" models of the Manhattan Project to produce an atomic bomb and the race to be the first to the moon are artifacts of a bygone era. For space exploration in the 21st century, a measured and considered program that takes advantage of opportunities and resources over time was clearly preferred by a significant majority of participants in this forum, including some who have reservations about the value of human space exploration.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the many people who generously provided their time and energy to make this project a success: Eric O'Dea, Molly Pike Eckard, Joe Rivers, and Talia Sepersky at the Museum of Science Boston; Sari Custer and Mike George at the Arizona Science Center; Lori Hidinger, Bonnie Lawless, and Andra Williams at Arizona State University; Justin Dent at Dent Digital; and Michele Gates, John Guidi, Jenn Gustetic, Lindley Johnson, Jason Kessler, Amy Kaminski, Erin Mahoney, and Zachary Pirtle at NASA. We also thank Dita Borofsky for graphic design and layout of the report. Finally, we express our appreciation for the support provided by the National Aeronautics and Space Administration under contract NNX14AF95A and the concurrent support provided by ASU's Office of Knowledge Enterprise Development.

DISCLAIMER

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Aeronautics and Space Administration or the institutions with which the authors are affiliated.

ECAST EXPERT AND CITIZEN ASSESSMENT OF SCIENCE AND TECHNOLOGY

NASA

Consortium for Science, Policy & Outcomes at Arizona State University

Museum of Science.

scistarter.com

AUGUST 2015