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Paper Session I-B - Preparing for Planetary Defense: Detection and Interception of Asteroids on Collision Course with Earth

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PREPARING FOR PLANETARY DEFENSE:
Detection and Interception of Asteroids on Collision Course with Earth

Introduction

As the Earth revolves around the sun, it orbits through planetary debris left from the formation of the solar system. Much of the debris are objects such as asteroids and comets in orbits that bring them close to the Earth and are referred to as Near-Earth-Objects (or NEOs). Of the total NEO population, some portion are in orbits that actually intersect or cross the orbit of the Earth. The asteroids of this class are known as Earth-Crossing-Asteroids (ECAs). Occasionally, the motion and relative position of the Earth and an ECA in their respective orbits cause them to collide.

The geologic record amply shows that many of these collisions have occurred in the Earth's past, with over 100 large impact craters still visible around the world. Work over the last few decades by the astronomical community validates that impacts will inevitably occur again sometime in its future. In view of these predestined impacts, this paper's subject is simply stated: Investigate development of a capability to protect our planet from planetary debris, comets and asteroids, detected on orbital trajectories which are predicted to strike the Earth. Such strikes would result in wide-spread devastation or even catastrophic alteration of the global ecosystem.

During the last fifteen years, research on objects which cross Earth's orbit has increased dramatically. Spurred by the now widely accepted theory that a large asteroid impact effected the extinction of the dinosaurs, the astronomic and geophysics communities have focused more effort in this area. Astronomers, looking skyward with more capable equipment, have been discovering new, potentially Earth-threatening asteroids at an average rate of 10-20 per year. Physicists, enlightened by recent research on the devastating effects even a limited nuclear war would cause to the Earth's ecosystem, have done preliminary investigation of the forces impacting the Earth from an asteroid strike. They estimate that impact by even a relatively small asteroid will release energies equivalent to tens of megatons of TNT. The combined results of these efforts has been a realization that there is a potentially devastating but still largely uncharacterized natural threat to Earth's inhabitants. Thus, it is time for development of appropriate technologies and strategies for planetary defense.

Recognizing the seriousness of the issue, members of Congress in 1990 mandated that the National Aeronautics and Space Administration (NASA) conduct two workshops to study the issue of NEOs. The first of these workshops, the International NEO Detection Workshop or "Spaceguard Survey" held in several sessions during 1991, defined a program for detecting kilometer-sized NEOs. The second workshop, the NEO Interception Workshop held in January 1992, studied issues of intercepting and deflecting or destroying those determined to be on a collision course. The studies reported out to the House Committee on Science, Space and Technology in March 1993. The impact of Comet Shoemaker-Levy 9 on Jupiter in July of last year renewed this committee's interest and they have now tasked NASA, in coordination with the Department of Defense, to develop a plan for a system to detect all NEOs larger than 1 kilometer within 10 years. This NASA committee developing these plans, chaired by Dr. Eugene Shoemaker, will submit its report this spring.

Earth-impacting objects can vary in size from less than a centimeter to more than 10 kilometers across. When the object is small, less than 50 meters, the collision is usually mitigated by the Earth's atmosphere, where it burns up or explodes into tiny pieces before it can physically impact the surface. Larger objects strike much less often but of course do much more damage. Sixty-five million years ago, for example, evidence suggests the age of dinosaurs was brought to an abrupt end by the impact of an asteroid that is thought to have been 10 kilometers across. And in 1908, a 50 meter asteroid is thought to have caused the devastation of a forested area covering over a thousand square kilometers (greater than the size of the Washington, DC area) when it exploded in the air above the Tunguska river in Siberia.

Incidents such as the Tunguska Event are thought to occur about once in one hundred. But because of the modest detection research to date, it is not known whether there are any large NEOs having orbits that would definitely intersect the Earth's in the next few decades. Astronomers have been unable to thoroughly catalog the total population because of limited equipment dedicated to the effort. With an observation network proposed by the Detection Workshop, a comprehensive census might still take 20-25 years.

Development of this system would benefit from the experience gained by the Air Force Space Command in its "space surveillance" mission for man-made Earth orbiting satellites, which in turn would benefit from technology developed for detection and tracking of asteroids. After such a system is in operation and has completed the initial catalogue, most large objects headed toward Earth could be detected years or even decades in advance, ample time to take action against them.

The Threat

Most of humanity is oblivious to the prospect of cosmic collisions, but this hazard from space is a subject of deadly concern to the entire population of the planet. Work by several nationally recognized scientists who have been investigating this issue for a number of years, some for decades, has brought an awareness that to the average citizen of the United States the risk of death may be just as great from an asteroid strike as from an aircraft accident.[1] Those unfamiliar with these studies may find this incredulous when, in fact, there have been no recorded deaths due to asteroid strikes, albeit there have been close calls from small meteorites striking cars and houses.[2] However, the probability is finite, and when it occurs, the resulting disaster is expected to be devastatingly catastrophic. But because we are dealing with events, time scales, and forces well beyond the human experience, the threat is not universally recognized.

The Earth's atmosphere protects us from the many dangers in the harshness of planetary space. These dangers range from intense solar radiation to the most common variety of planetary debris, called meteoroids, with diameters measuring only ten meters or less. As the small meteoroids enter the atmosphere, the heat from friction created by the force of their entry (at 10 to 30 kilometers per second), causes them to completely burn up or explode before they reach the ground. Sometimes, however, even the atmosphere cannot offer total protection. Some meteoroids are of sufficient size and substance that they do not completely burn up before impacting the surface. These remnants are referred to as meteorites and are frequently of an iron-metallic composition. Meteorites are not uncommon, and frequently impact in many locations around the world.

What is less commonly known is the force with which these objects can enter the atmosphere and explode or impact the Earth 's surface. When a stony meteoroid of 10 meters in diameter hits resistance from the atmosphere greater than its own internal structural integrity, it will explode with a force of about 20 kilotons of TNT.[3] The exact yield of course will depend on the speed of entry and specific composition, but this is greater than the force of the device which destroyed Hiroshima. Many times "air-bursts" of this magnitude are not witnessed by humans or even detected by earth-based sensing equipment. However, according to data recently released by the Air Force, they are regularly detected by Defense Support Program (DSP) satellites. At least 136 airbursts with a force greater than many tons of TNT have occurred around the world since 1975[4], the last significant one being detected in February 1994 , exploding with a force equal to 100 tons TNT.[5] But as impressive as this is, keep in mind that these are just ones that weren't big enough to make it to the ground.

Scientists calculate that it would take a stony object greater that 50 meters in diameter to survive penetration of the atmosphere.[6] (Planetary debris of this size and larger, up to several hundred kilometers, are referred to as asteroids.) Based on calculations derived from surveys of the age and density of impact craters on the Moon, a 50 meter asteroid impact probably occurs at least once a century, and would impact with a force of 10 megatons (Mtons) of TNT. An event of this magnitude last occurred on 30 June 1908, in Tunguska, Central Siberia. Although this object did not actually impact the surface, it is calculated to have exploded with a force of approximately 12 Mtons of TNT at an altitude of 5 to 10 kilometers. It devastated forests over a 1,000 square kilometer area and ignited large fires over thousands of acres near ground zero.[7] Had it entered the Earth's atmosphere only three hours later, a mere microsecond of geologic time, the Earth's rotation would have effected a 10-15 megaton air burst near Moscow, a force 1000 times greater than the nuclear weapons dropped on Japan in 1945. As populated areas continue to spread across the Earth, the probability of a strike in a population center increases also.

But a 50 meter asteroid impact would only produce relatively localized effects. Meteor Crater near Winslow, Arizona, is an evident example of such a comparatively small impact. Larger impacts have caused more damage, as is evident from the Moon, although it has taken satellite imagery such as from LANDSAT to help realize the extent here on Earth. Using satellite photos, geologists have begun detecting more and more features on the Earth's surface that are actually remnants of impact sites. Some are quite large, such as the Manicouagan Crater in Canada at over 65 kilometers in diameter. Almost all have been partially obscured due to centuries of exposure to the effects of weathering, making them difficult to detect while on the ground.

There is also mounting evidence that an impact by a large asteroid (or asteroids) brought about the demise of the dinosaurs. A theory first advanced by the father-son physicist-geologist team of Luis and Walter Alvarez in 1980, it is now widely accepted by geologists and paleontologists alike that an impact by one or more relatively large asteroids occurred approximately 65 million years ago. This cataclysmic event is believed to have wiped out the dinosaurs and many other species on the Earth as well from the immediate and more long term effects of the impact(s).[8] Scientists now believe the most likely site of at least one large impact from that time is in the Gulf of Mexico, off the northern coast of the Yucatan Peninsula. Readily visible evidence of the impact has long since been obscured by dynamic surface changes but the subsurface rock still bears wounds from an impact crater 185 kilometers across.[9]

Estimated to be greater than 10 kilometers in diameter, the suspected asteroid would have struck with a force of about 100,000,000 Mtons TNT, or 10,000 times the total of all the world's current nuclear arsenal.[10] Not only would this impact create a large crater, but it would also have thrown trillions of tons of material into the Earth's atmosphere and started a global firestorm which would have added more smoke and soot to the layers of dust already in the stratosphere. Then a global winter resulting from blockage of the Sun's heat reaching the surface might have lasted for more than a decade, accounting for the extinction of at least half of the different species of life on the Earth at that time.[11] The settling of this dust to the surface created what geologists refer to as the "Cretaceous/Tertiary (K/T) Boundary", which is a physical demarcation by an iridium rice layer in Earth's geologic record between these two ages and lead to the Alvarez's theory. Furthermore, paleontologists have discovered several other points of mass extinction in the geologic record with the speculation they may have been caused by the same type of event.[12]

But it doesn't take a "planet buster" of 10 kilometers diameter to wreak global havoc. Scientists estimate that the effect from an impact by an asteroid even as small as 0.5 km could cause climate changes sufficient to dramatically reduce crop yields for one or more years due to killing frosts in the mid-latitudes in the middle of summer. Impacts by objects 1 to 2 km in size could therefore cause a significant increase in the death toll due to mass starvation by a significant portion of the world's population as few countries store as much as even one year's required amount of food. The death toll from direct impact effects, blast and firestorm, as well as the climatic effects could become as much as 25 percent of the world's human population.[13]

This would be a natural disaster totally outside the human realm of comprehension and leads many people to suspend their belief that anything like this could ever happen despite the results of many recent studies by the scientists. It is similar to an individual's egotism that a fatal accident will never happen to them, only on a much grander, entire species-level scale. Like the danger of a large earthquake in Southern California, people do not comprehend the risks involved as having any relation to their daily lives. But this threat gives new definition to "The Big One".

As "devils advocates", some might argue that all asteroids of this size have long been swept clear by the planets over the millennium. However, through the end of 1994, over 320 NEOs had been detected and catalogued with over half of them greater than half a kilometer in rough diameter.[14] The work to detect the Near Earth Objects has been ongoing for a couple of decades and new techniques and technology have increased the rate in which they are being discovered. On average, two to three of a few tens of meters or more in size are currently being found every month.

Astronomers believe they may only have found about 5 percent of the total number of asteroids greater than 0.5 km in size. Based on estimated asteroid population densities, astronomers believe there are well over 2,000 such asteroids in Earth crossing orbits and upwards of 10,000 additional objects large enough to inflict considerable damage. However, at the current rate of progress it will take over 100 years to insure they have catalogued at least 90 percent of them.[15] A modest detection system might reduce this to 25 years, but even so, new members of this ominous population are continuously being created by the interaction of the planetary gravitation fields on the main asteroid belt between Mars and Jupiter and the comets which enter the inner solar system from deep space.

For many natural disasters such as earthquakes, hurricanes and tornadoes there is no known technique for preventing them. Some cannot even be detected in time to give adequate warning to the affected population. Such is not the case with asteroids. Mankind certainly has the technology that with a relatively modest investment would provide warning of an impending catastrophe maybe years and perhaps decades in advance. In most cases more than enough warning time could be given to allow evacuation of affected areas for the smaller objects once an adequate deteetion system were in operation. We also possess the technical understanding of the forces required (orbital mechanics and nuclear explosives) to prevent such disasters, at least up to the 10 km size asteroid and given enough warning time.

Surveillance

Scientists who have worked with this issue for a number of years have put much thought into the surveillance issue. Some prototyping of potential systems has already been done, a notable example being the Spacewatch System at Kitt Peak, Arizona, organized by Dr. Tom Gehrels of the University of Arizona who has worked on this issue for over three decades. There are already some specific ideas and programs which could be quickly initiated using dedicated ground based sensor networks based on current technology. Unfortunately, lack of any significant funding has kept even a modest program from being initiated. Until last year, the Spacewatch System was run on private donations.

In the report of the NASA study commissioned by the US. Congress, the scientists propose an internationally supported detection system they call the "Spaceguard Survey Network", after a system conjectured by Arthur C. Clarke in his science fiction novel Rendezvous with Rama. This system would provide detection of objects as small as 1 km diameter within a suitably large volume of space using a network of six globally dispersed 2.5 meter aperture, f/2 prime focus reflecting telescopes, each with four 2048X2048 pixel charge-coupled device (CCD) detectors in the focal plane. Automated signal processing and detection computer systems would recognize asteroids and comets from their motion against the background of stars. All technology for this system has already been demonstrated in the prototype at Kitt Peak. Acquisition costs for such a system could be as low as $50M and the annual operations and maintenance costs would be in the $10M range. The entire system could be in operation in less than 5 years after funding.[16]

This system sounds remarkably like the Ground-based Electro-Optical Deep Space Surveillance System, or GEODSS, albeit has smaller 1 meter telescopes and cameras, but built at four sites a decade ago and currently operated by the Air Force to track manmade geosynchronous satellites. However, this Space Command surveillance asset does not do wide area searches needed for asteroid detection, but rather searches for manmade objects based on their predicted position and rejects the detection of any object which moves at an angular rate as slow as an asteroid, providing it where close enough to be seen. In a way, GEODSS, does the converse of what Spaceguard sites would need to do. However. it could probably be upgraded to do asteroid detection if it weren't already heavily tasked with its current mission.

But, there are many parallel techniques between what the Spaceguard Network would be required to do and what is currently done for "space surveillance" of manmade objects. There is also a need for a "survey clearinghouse and coordination center" to catalog newly discovered objects, coordinate observations by other sites to verify existence of each object and collection of addition sightings to determine their orbits. This center would also project the orbit of each object, both for "recovery" (sighting of the object on the next orbital pass) and to determine if any pose a threat to Earth. All this is currently done for asteroids and comets by the International Astronomical Union's Central Bureau for Astronomical Telegrams and Minor Planet Center in Cambridge Massachusetts, but at a rate far less than would be needed for the Spaceguard Network. NASA has plans to establish such a center at the Jet Propulsion Laboratory in Pasadena, California, and this activity could benefit greatly from the experience and automation used for similar tasks done for manmade objects in Earth orbit by Space Command's Space Surveillance Center (SSC) at Cheyenne Mountain AFS, Colorado. This is not to say that this existing network could easily take on this additional task, but Space Command has significant related experience which could be applied to this issue.

However, Space Command's current space surveillance mission could also benefit from systems developed for asteroid surveillance. Optical systems developed to detect and track these relatively dim objects (down to at least 22nd magnitude) might also find application against the tracking problem presented by manmade orbital debris. Precise tracking of asteroids can also be greatly enhanced with augmentation by powerful deep space radar systems. Currently there are only two such system available, at Arecibo, Puerto Rico, and Goldstone, California, and even their performance is limited in relation to this task. Research and development on more capable radar systems would probably be of benefit to the traditional space surveillance mission, not to mention other defense related areas. Work on sensors, both active and passive (microwave, multi-spectral and hyper-spectral) could also be of mutual benefit. In the software and modeling arena, both missions would benefit from development of more precise and comprehensive, as well as rapid, orbit prediction models. This might also lead into further use of parallel processing techniques for space surveillance that are just starting to be investigated. The bottom line is that great potential can be seen for cross flow of technology, equipment and techniques between these two "space surveillance" missions which in itself would warrant DoD's interest.

So far only ground based technologies have been addressed. It is always advantageous when dealing with dim celestial objects to get up above the atmosphere to eliminate its interference with the object's signature and the diurnal constraints imposed by the Earth's rotation. The asteroid detection and tracking mission by itself may not warrant space based capabilities, but coupled with other more traditional Air Force missions a mutual benefit would be gained. More distant, and therefore earlier, detection of both asteroids and comets would be possible from space based systems. It would also give greater capability against a class of asteroids, called the Atens, which are defined by their orbits about the Sun being inside of Earth's but reaching out far enough to cross the Earth's orbit. Because ground based systems would almost always be looking toward the Sun to see objects in this class, they are difficult to detect from ground based observatories. Although only 19 objects in this class have so far been discovered, it is speculated that this class may be at least as common as the Apollo class, asteroids in orbits more similar to Earth's and the class to which the majority of known ECAs (over 100) belong. Astronomers point out that Mercury, the planet closest to the Sun, has more craters than any other object in the solar system.[17] Therefore a space based surveillance system, perhaps even Moon based or at a stable Earth-Sun Lagrangian point (L2 or L5), would have distinct advantages in covering certain classes of objects.

Finally, discussion of the surveillance mission must include "characterization" of the asteroids and comets. Although their existence has been known for almost two hundred years, still little is known about their composition, or even if it is common for them to be the typical solid, rock-like body usually thought of. There is some speculation that many of them may actually be more like orbiting rubble piles and little is known about comets beyond their typical description as "dirty snowballs."

Many things can certainly be learned from a concerted remote sensing program but before we could have full confidence about what effects certain mitigation techniques might have, a closer-in survey would need to be done, especially given enough warning about a specifically identified threat to impact. Hence asteroid and comet rendezvous missions are of great importance to the surveillance of this potential threat to ensure as much as possible is learned about these possible adversaries. Because of the space community's interest, close approaches to main-belt asteroids were added to the Galileo Jupiter mission. It passed within 1600 km of the asteroid Gaspra in October 1991, and to within 3200 km of the asteroid Ida in August of 1992, discovering this object has its own smaller asteroid moon orbiting it. NASA Space Sciences Office is also building a Near Earth Asteroid Rendezvous (NEAR) spacecraft to co-orbit for at least one year with an Apollo asteroid later this decade. These are examples of missions that can be done with current technology.

Mitigation

Mitigation of earth-threatening asteroids and comets, to include both deflection and fragmentation options, has received substantial attention over the last three years. In particular, the NASA-sponsored Near-Earth-Object Interception Workshop investigated the subject in-depth and made this conclusion: "... chemical or nuclear rockets with nuclear explosives are the only present or near-term technology options available that have significant probability of success without significant research and development activities."[18] More succinctly, the Chairman of the workshop indicated to Congress that "... technologies currently exist that could be integrated into systems capable of protecting the earth from most any NEO impacts."[19] In short, technology options exist, if pursued, which can mitigate the asteroid and comet threat. There are basically two technology areas to consider: those related to propulsion, and those related to deflection/fragmentation.

For propulsion design, we desire a system with high specific impulse. This property would give a rocket high in-route velocity and thus increase the chances for a distant intercept. It would also give high terminal velocities, and hence kinetic energy, which could broaden deflection/fragmentation options. And as a function of system design, high specific impulse could allow for relatively large payloads. Nuclear propulsion offers the best near-term advance in specific impulse over current chemical technology, specifically by a factor of two or three over chemical propulsion designs.[20] Both the United States and Russia have worked on nuclear propulsion systems, but none has yet been tested on-orbit. Recent efforts have been slowed-down and canceled given that "no current or near term DOD lift requirements mandate nuclear capabilities."[21] Planetary defense could mandate such a design. Meta-stable fuels also hold the promise of increased specific impulse in the near future with "meta-stable HE_4" offering a six times improvement over chemical designs.[22] Other propulsion options, clever but highly speculative, include mass driver reaction engines located *in situ*, hypervelocity systems employing nuclear explosions to impart momentum, and antimatter devices.[23] But, chemical and nuclear propulsion systems now in development seem to offer the hest options.

Deflection/fragmentation options constitute the second technology area. Kinetic energy projectiles and nuclear devices offer current solutions. By way of calibration, a 200 kg projectile with 12 km/s closing speed (within the capability of chemical systems) could successfully deflect a 100 meter asteroid in a distant intercept scenario.[24] Similarly, a 100 Kton nuclear device could accommodate a 1 km asteroid while a 10 Mton device could accommodate a 10 km asteroid.[25] The "best" nuclear device for the purpose of NEO deflection would be an enhanced radiation design, one which provides a large flux of high energy neutrons. These are necessary to cause material blow-off from the object after irradiation from an "stand-off" detonation.[26]

Though technically much more difficult, nuclear devices exploded on or beneath the object's surface impart ten or more times the impulse of a stand-off explosion.[27] This approach would require detailed knowledge of the object's composition and propensity for fragmentation, however, and may also have larger payload requirements, thus offsetting any advantage. Relative to kinetic energy options, nuclear options appear "to be favored for NEOs over about 100m diameter."[28]

Other options relative to 20 to 30 years from now include the use of ground or space-based lasers to induce material blow-off, and ultra-high kinetic energy devices requiring nuclear propulsion.[29] Further in the future, options include the use of antimatter,[30] large solar sails,[31] and man-tended mass drivers or reaction engines located *in situ* (e.g. a man-tended rocket attached to an asteroid as described in Arthur C. Clarke's The Hammer of God).[32] Finally, there could come a time for "Asteroid Eaters". In this scheme one would infest the object with a few devices whose purpose is to replicate themselves using "desk-top manufacturing" technology and the asteroid itself as raw material. Over the period of several months or a few years, these devices, recreating themselves into an army of thousands, could completely "mine" the asteroid away, or at least reduce it to a size that is no longer a threat or is more easily maneuvered by propulsion technology. A variation on this would be to have these devices also mine the asteroid for fuel that a propulsion system could use to move the object into a benign orbit. Technology advances required could lead to many "spin-offs" in other defense or commercial applications.

Beyond deflecting or fragmenting an errant asteroid, there may be great advantage in capturing an ECA into Earth orbit. Besides just the experience in large space operations such an endeavor would give us, great benefits could be gained through mining of the asteroids natural resources (including its orbital energy) or use of the asteroid as a space platform for large systems used in surveillance of the near-Earth environment. An asteroid parked in an orbit slightly higher than geosynchronous might be an ideal base of operations to maintain and salvage geosynchronous communication and surveillance satellites. Its orbit would naturally provide routine revisit to all geosynchronous stations. A captured asteroid could also be used for large space based manufacturing or even as a "space dock" for buildup of interplanetary missions, eliminating the need to launch large structures from the bottom of Earth's gravity well. In summary, use of captured asteroids could be our "stepping stones" for mankind's future in space.

In short, there are many promising options for deflecting or fragmenting earth-threatening asteroids and comets. The apparent best option today includes nuclear devices and perhaps nuclear propulsion. These, however, carry political ramifications which must be addressed.
Though nuclear devices may well protect the earth from threatening asteroids and comets, their employment carries heavy emotional baggage. Ironically, these devices "... could be notably straightforward to create and safe to maintain because they derive from vast research and development expenditures and experience accumulated during the forty-five years of the Cold War."[33] Technically, without an appropriate re-entry vehicle, these devices could not be used as ballistic weapons, though there is always the possibility of terrorism or misuse. In any event, effective international protocols and controls could be established through the United Nations to minimize downside potential. The debate will certainly continue, however, as evidenced by the "Deflection Dilemma": "... the potential for misuse of a system built in advance of an explicit need may in the long run expose us to a greater risk than the added protection it offers."[34]

Conclusions
Now that it is recognized that collisions with objects larger than a few hundred meters in diameter not only have a finite probability of occurring but can threaten humanity on a global scale, means for mitigating them seem clearly worth considering. It should also be recognized that the technology required for a system to mitigate the most likely of impact scenarios is, with a little concerted effort, within humanity's grasp. Such a system could use the latest nuclear explosives, space propulsion, guidance, sensing and targeting technologies coupled with spacecraft technology. These

technologies are already related to defense capabilities, but how they are developed for use in space (and what effects they have) will be invaluable experience for defense efforts. Furthermore, a handful of the thousands of nuclear weapons being deactivated under the START agreement might offer the most expeditious solution to this problem. Hence, there is much to be desired and gained from DOD involvement in this effort.

At the same time, the US. should not go it alone. The hazards are global, detection efforts will require observation sites throughout the world, and other countries possess heavy lift and other space-related capabilities which could be used. Therefore, any response should involve the international community. This is particularly prudent as mitigation efforts could relate to nuclear capabilities and these intentions will affect arms control treaties. Perhaps such an effort is best conducted under the auspices of the United Nations. The cost for such a system, which might be analogous to buying life insurance, also rightly belongs in the international arena.

Existing US efforts need to be more closely consolidated, coordinated and expanded under national leadership. It seems reasonably clear that we have the need in that, while there is no reason to live in daily fear, there is a significant danger to our civilization from an asteroid impact. Other species are now extinct because they could not take preventative action. Humanity must avoid delusions of invulnerability and acknowledge that as a species we may not have existed long enough to consciously experience such a catastrophic event. But we currently have the technological means for detecting and mitigating the threat and would be remiss if we did nothing to make use of it.

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[4] J. Kelly Beatty, "Secret Impacts Revealed", *Sky & Telescope* 87, no. 2 (February 1994), 26-27. This brings up an interesting side issue on what might happen should such an event occur during a period and in a region of high tension and be mistaken for the effects from a device of terrestrial origin. Apparently DSP operators (and hopefully their counterparts around the world) have found a way to deal with this, but is it foolproof? And as more countries acquire these types of early warning sensors, not to mention nuclear weapons, will they all be able to be as discerning in all circumstances? This in itself warrants gaining a better understanding of the phenomena and ways to predict its occurrence.

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