International Space Development Conference, 2006
Luncheon Address
May 6, 2006

NEOs: The Katrinas of the Cosmos?

Russell L. Schweickart
Chairman, B612 Foundation

What I'd like to do today is provide an update on various aspects of the near-Earth object (NEO) challenge, i.e., our desire to be able to protect the Earth from impacts with NEOs.

For those not familiar with the issue let me simply state the entry assumptions for this talk which, should they seem questionable to you, I invite you to speak with me about afterward.

The givens are that 1) the Earth is infrequently hit by asteroids which cross our orbit while circling the Sun, 2) the consequence of such impacts ranges from the equivalent of a 15 megaton (TNT) explosion to a civilization ending gigaton event, and 3) for the first time in the history of humankind we have the technology which, if we are properly prepared, we can use to prevent such occurrences from happening in the future.

Given those three assumptions I am going to give an update on the development status of the key elements which will enable us to avoid these devastating cosmic collisions.

The three prerequisite capabilities which will enable us to avoid the fate of the dinosaurs, and many smaller disasters as well, are 1) early warning, 2) a demonstrated deflection capability, and 3) an established international decision making process. I'll address each of these three elements in turn giving a status report on each and pointing out some of the implications of current trends.

I'll begin with early warning.

Early Warning:

For the past 8 years NASA has been running a historic program to identify and characterize a substantial threat to the future of life on Earth. It goes by the name of the Spaceguard Survey, the name given to its fictional precursor by Arthur C. Clarke in his 1972 novel, *Rendezvous with Rama*.

The Spaceguard survey got underway in 1998 when Congress directed NASA to discover 90% of the NEOs larger than 1 km in diameter by 2008. Based on a statistical analysis it is expected that there are about 1100 NEOs in this cohort. NASA has since spent about $4M/year on the program which involves an amazing mix of professional and amateur astronomers around the world. While the initial discovery of most NEOs is done by the use of large optical telescopes, the follow-up and precision tracking has been done by hundreds of amateurs in dozens of nations around the globe.

As a result of this effort, which is reported and coordinated daily on the internet and open for all to monitor, we are now 75% of the way to the original Spaceguard survey goal. These results are both impressive and sobering, for while we have discovered over 830 large NEOs and found that none of them threatens to impact the Earth within the next 100 years, there still remain another 200+ out there yet to be discovered. Furthermore, we are also very aware that there are well over half a million objects not yet discovered each of which could do serious damage to life if it impacted. This fact has been recognized and called to the attention of policy makers by both government sponsored studies and independent analysts for several years.

In December 2005 the US Congress passed and the President signed the FY 2006 NASA Authorization act which formally recognized this additional threat and identified a new Spaceguard survey goal (I refer to this as Spaceguard 2) directing NASA to discover 90% of all NEOs of 140 meter diameter and larger by 2020.

Extrapolating from the current survey it would appear that by 2018, the equivalent point in the completion of the new Spaceguard 2 program, we will have approximately 100 times the number of NEOs in most of the critical categories listed today for Spaceguard 1 (Figure 1).

For example, by 2018 we can expect to have discovered ~75% of the total population of 125,000 140 meter objects, or ~95,000 of them. In addition, in the process of discovering these NEOs we'll find many smaller ones as well and they will likely total over 400,000! Now most of these hundreds of thousands of asteroids will pose no threat to life on Earth since those less then about 60 meters in diameter will be tamed by our atmosphere. Nevertheless something like 30% of those discovered will be potentially harmful to life if they impact Earth.

The most interesting listing in the voluminous data published by the NEO Program Office at JPL are the "risk" tables (http://neo.jpl.nasa.gov/risk/). These tables list all the NEOs discovered to date which have a non-zero chance of impacting the Earth in the next 100 years. I.e., they each have some small probability of impact. Whereas today the risk tables contain 104 NEOs in this category, by 2018 we can expect to see on the order of 10,000 NEOs with some risk of impact over the next 100 years.

Now it should immediately be said that there is better than an even chance that none of these 10,000 will actually hit the Earth in those 100 years. The important fact however, is that a substantial number of them will appear as though they may be headed for impact. Today, of the 104 currently in the impact tables, two have an elevated risk and we are watching them closely. Extrapolating to 2018 we may have as many as 200 in a similarly elevated attention category and of growing concern to the general public.

Therefore it is certainly possible, if not likely, that in the timeframe of the next 12 years we (the world) may well be in a position where we need to take action to insure that we will be able to carry out a deflection mission if needed. I'll come back to this in the discussion on decision-making.

A Demonstrated Deflection Capability:

When we discover that a NEO is headed our way, hopefully with a decade or two of advanced warning, we'll want to do something about it. In reality, since the early warning information is in the public domain, it is quite likely that the general public will be asking the critical question "what are we doing about this?" well before the world of officialdom is comfortable with responding.

This is especially true given the current state of affairs. At the present time there is no space agency in the world, in fact no agency of any kind in the world, which is specifically charged with protecting the Earth (or their nation) against NEO impacts. While the US Congress amended the Space Act in 2005 to charge NASA with responsibility to "detect, track, catalogue, and characterize" NEOs greater than 140 meters in diameter, it has, thus far, come up short on actually assigning the responsibility to take action should one of these objects be discovered headed for a collision.

The Congress did, however, require that NASA provide by the end of 2006 an "Analysis of possible alternatives that (it) could employ to divert an object on a likely collision course with Earth." In response to this directive NASA is about to announce a process for carrying out this mandate.

Let me help those who are not "orbital mechanics" or have not looked at this subject to get a feel for the mechanics of NEO deflection. Of necessity I will oversimplify what is indeed an arcane specialty. Still the basics are fairly straight forward.

The key to NEO deflection is to know decades in advance that there is an asteroid that is headed for an impact. Deflecting asteroids at the last minute is not the thing to do; it's about the equivalent of evacuating your community to avoid a hurricane just after your roof has blown off! The basic operation is to change the speed of the asteroid very slightly which will cause it to arrive too late (or too early) to hit the Earth a decade (or decades) later as it otherwise would have. Changing an asteroid's "direction", i.e., pushing it perpendicular to its orbit path is essentially useless.

Typically changing the asteroid's speed (either increasing or decreasing it) by as little as 0.5 cm/sec 10 orbits ahead of an impact is enough to cause it to miss the Earth. That's only about one 100^{th} of a mile per hour change in velocity. On the other hand given that the NEOs of interest weigh in at 1,000,000 metric tons and above that's a LOT of momentum change to impart!

I stated earlier that humankind currently has technology which can enable it to deflect certain NEOs headed for impact. This is true for NEOs which require a modest deflection effort. Unfortunately the portion of potential impacts which are amenable to the use of existing technology for deflection has not been analyzed. What we can say, however, is that for both of the currently known NEOs with an elevated risk of impacting the Earth in the next 100 years, the two existing deflection techniques are adequate.

The two techniques I refer to are kinetic impact and the gravity tractor.

Kinetic impact is conceptually simple; just send up an ordinary small spacecraft and run it into the threatening asteroid. Well, maybe the spacecraft isn't quite that simple, and you do have to run into it in just the right direction. And, of course, you really don't want to hit it a glancing blow and knock off a small piece. And once you're done with the job it would be nice to have another spacecraft hanging around to let you know just how the operation worked; indeed whether it worked. But, it can work (Figure 2).

The second concept is the gravity tractor; an elegant design written up in Nature magazine by Ed Lu and Stan Love of B612 Foundation in November, 2005 (Figure 3). Here you rendezvous with the target asteroid and position yourself (the robotic spacecraft, that is) either immediately ahead of or behind the asteroid in its orbit. If you then “hover” in that position, at about a half an asteroid radius above its surface, you very slowly and gently pull the asteroid toward you due to your mutual gravitational attraction. The nice thing here is that since you never touch the asteroid you really don’t care what it’s made of, whether it’s solid or a fluff ball, or how it is rotating. You will, of course, have to angle your ion thrusters outward a bit to avoid impinging on the surface, and you will potentially have to “hover” for quite awhile, depending on the magnitude of the momentum you need to impart. In essence you are towing the asteroid behind you using a “virtual” or gravity rope. Finally, one of the most significant characteristics of this concept is that since you have a radio transponder aboard the Gravity Tractor you have continuous tracking feedback from the Earth and therefore you know exactly how you’re doing.

Of course neither of these techniques have been tested yet and so they do not qualify as proven concepts. And, as is well known by this audience, lots of things look good on paper, but it’s in the doing that most of the learning and all of the proving takes place.

The European Space Agency (ESA) is planning to address this missing element in flying its Don Quijote (DQ) mission. DQ is currently in Phase A development with a goal of flying the mission (funding permitting) in the 2011-2014 time frame. At the moment there are no plans for testing the Gravity Tractor although the B612 Foundation has had exploratory discussions with ESA representatives about the possibility of combining the two concepts in a single mission.

What is missing however, and of great significance, is the technology needed for the more challenging, and perhaps more common deflection threats. It is perhaps surprising, but nonetheless true, that in general it requires more energy to get to a threatening NEO than to deflect it once you are there. Since many NEOs are in orbits larger than to two currently of interest, this fact leads inexorably to the conclusion that much higher performance deep space propulsion technology is required in order to have a comprehensive NEO deflection capability.

Such a high performance system was recently under development in the Prometheus program; specifically nuclear-electric propulsion (NEP). Unfortunately Prometheus and NEP fell under NASA’s budget priority axe and there seems no immediate likelihood of its revival. Absent NEP (or an equivalent high performance capability) we will remain vulnerable to many of the NEO threats that may come our way. In the meanwhile we can only hope that the first challenges that we have to address are within the capability of existing technologies. Clearly this is a dangerous gamble, about equivalent to New Orleans living with levees which would take no more than a magnitude 3 hurricane.

One final note on deflection. The default deflection technique implanted in the public mind by Hollywood is to send up a nuclear weapon and “blow the sucker up!” Well in reality this is a particularly bad idea, but one which we may well have to live with as a possibility until we have a full inventory of the NEOs that might challenge us, and until we have an alternative technology available for deflecting comets. Luckily comets represent only about 1% of the overall challenge, but they typically appear with only months of warning time and their paths are devilishly difficult to predict. But in regard to NEOs a nuclear blast would have unknown results, would likely fragment an asteroid potentially aggravating the problem, and its use would violate all sorts of international treaties and agreements. In addition, with nuclear weapons sitting around (owned by many countries?) for thousands of years, the likelihood of either accident or abuse on the ground is far, far more likely than is a NEO impact! This is a clear case of the cure being worse than the disease. Nevertheless, until alternative technologies are developed capable of dealing with certain improbable scenarios, we may be left with the nuclear alternative or nothing.

Decision Making:

This third leg of the triad for protecting the Earth from NEO impacts is probably the most challenging, albeit subtle. It is complicated by two related facts; NEO impacts are a global threat, not a national one, and the only decision making body representing (essentially) the whole planet is the United Nations, a body not known for timely, crisp decision making.

I'll use a few examples to illustrate the nature of the challenge.

Suppose that within the next decade we discover a small asteroid that looks like it has a significant probability of impacting the Earth. Say it is about 60 meters in diameter, just enough to do serious damage on the ground even though it may explode in the atmosphere. Imagine, in other words, another Tunguska event, i.e., the 1908 asteroid hit in Siberia.

As the probability of impact increases from 1 in 1000 to 1 in 500 to 1 in 50 there will come a time when a decision has to be made; do we deflect it or "take the hit". Of course at that point it will not be at all clear who would take the hit. The potential "hitee" will lie along a narrow corridor (the Path of Risk, PoR) that stretches all the way across the planet (Figure 4). It will probably hit in the ocean, but there will also be many countries across which that line passes. Who decides whether something is done or not? Do only the specific nations at risk decide? Do they all pool their assets to support an evacuation wherever it may be needed? If the UN decides not to pay for a deflection mission and to just let it hit, do all UN member states contribute to the ultimate evacuation and reconstruction costs in the country where it does hit? Does the US or another space faring nation mount a deflection mission and assume the liability in case of failure? Is that space faring nation indemnified for this possibility?

Another example of a tough decision is in the case where the asteroid is large enough to definitely do serious damage, perhaps even to the world economy. Say, e.g., something like Apophis which currently has a 1 in 6000 chance of hitting Earth in 2036 and would cause a $400 billion tsunami if it hit in the ocean.

Yes, we certainly would deflect such a threatening asteroid. But who deflects it? How is that decided? Since it is not clear specifically where along the PoR it will impact it's not clear who the primary beneficiaries of such a significant expenditure will be. Who makes the decision to begin spending money on planning? And at what specific points are mounting expenditures made as the threat gradually increases?

Now that we're going to deflect this asteroid a critical operational decision must be made; which way do we deflect it? Our basic options are limited by fundamental orbital mechanics. We can either deflect it such that it passes ahead of the Earth or so that it passes behind the planet.

Let me illustrate this by calling your attention to (Figure 4), the PoR for Apophis. This map shows the narrow corridor (about 49 km wide based on current measurements) which stretches from the northern border of Kazakhstan in the west down across the Pacific and into the Atlantic off the African coastline, crossing Central America just north of the Panama Canal. If the asteroid is in fact headed for the Pacific off the coast of Mexico, the deflection choice is to deflect it eastward off the leading edge of the Earth… or the long way to the west and off the trailing edge of the Earth.

However, if in the deflection process we get the job only partly done there will now be a new impact point somewhere along the PoR in the direction we decided to move it. Orbital mechanics does not allow the asteroid to suddenly disappear… it moves the impact point either east or west with the goal being to move it all the way off the Earth. But if we have a problem we've changed an "act of God" (the original impact point) to an act of humankind (the new impact point) with liability, etc., etc. Furthermore in order to begin the deflection at all someone has had to decide whether to temporarily increase the risk to Costa Rica (eastward deflection) or to Japan (westward deflection) in the process of reducing the risk to zero for everyone.

Who decides? Who pays? What criteria are used?

These are just glimpses of the NEO deflection policy decisions that will have to be made… and sooner than we might expect. With the NEO discoveries likely to come in the next dozen years I'd be surprised if we don't face at least some of these decisions in that time frame.

Given this situation the Association of Space Explorers (ASE), the professional organization of astronauts and cosmonauts, has formed a committee on NEOs, which I chair, and is raising this issue to the attention of world leaders and global institutions. In February of this year I made a technical presentation at the UN meeting in Vienna apprising them that this issue was coming at them.

Being a responsible organization, however, while we "brought them a problem" we are also committed to "bringing them a solution". This solution will take the form of a draft United Nations treaty (or protocol) formulated in a series of workshops over the next two years. In these NEO Deflection Policy workshops we will gather together a dozen or so international experts in diplomacy, international law, insurance, and risk management, as well as space expertise to identify and wrestle with these difficult international issues. Our goal is to return to the UN in 2009 with a draft NEO Deflection Decision Protocol and present it to them for their consideration and deliberation.

It is important to realize that once a threat is recognized and there is a capability to deal with it, to avoid deciding what to do is a decision in itself, and an irresponsible one. While there is always the possibility of unilateral national action, the unavoidable reality in NEO deflection is that other people, other nations are put at temporary risk in order to eliminate the risk to the nation going it alone. This, needless to say, would be a very self-serving and presumptuous act, and not one that any nation should take without first attempting to work with the world community on what is intrinsically a planetary challenge.

<u>What's Next?</u>

So what needs to be done to move this ball ahead <no pun>. Let's break it into its elements.

On early warning; the critical issue now is to see that the commendable charge to NASA by the US Congress is funded. NASA cannot, in the current environment, mount a serious effort to discover 90% of all NEOs 140 meters and greater by 2020 without additional funding and Congressional support. Your congressperson should hear from you that this is serious and should be supported. Remember, we're dealing here with a less frequent, but far more devastating Katrina, a Katrina of the Cosmos.

Re a demonstrated deflection capability; Congress needs to be encouraged to take the next essential step here as well. At the current time there is no agency of the US government, nor of any government in the world for that matter, with the explicit responsibility to develop and demonstrate the technology necessary to protect the planet from NEO impacts. While it may be controversial and debatable re just who should be operationally responsible for the employment of such a capability (NASA, DoD, DHS?) it seems quite clear that NASA is the proper agency in the US to develop and demonstrate a NEO deflection capability.

On the decision making process; the need here is for the US and other nations to support and encourage the United Nations to confront and wrestle with the many difficult policy issues related to deciding to deflect an incoming (or more likely an apparently incoming) NEO. The initial burden here will fall to the UN's Committee on Peaceful Uses of Outer Space (COPUOS), who would subsequently take it forward, after their work, to the General Assembly. This will not be an easy or fast process, but the reality demands urgency since this process will be far more difficult, if not impossible once a specific NEO appears to be threatening. Once a specific path of risk is at issue the decision process will break down into pure nation vs. nation power politics rather than a considered and coordinated act of humankind to protect life on Earth.

<u>Afterthought;</u>

In a sense this challenge is an entry test for humankind to join the cosmic community, for if there is intelligent life elsewhere in the universe it is virtually certain that it has already faced this challenge to survival… and passed it. Our choice is to face this infrequent but substantial cosmic test… or pass into history, not as an incapable species like the dinosaurs, but as a fractious and self serving creature with inadequate vision and commitment to continue its evolutionary development.

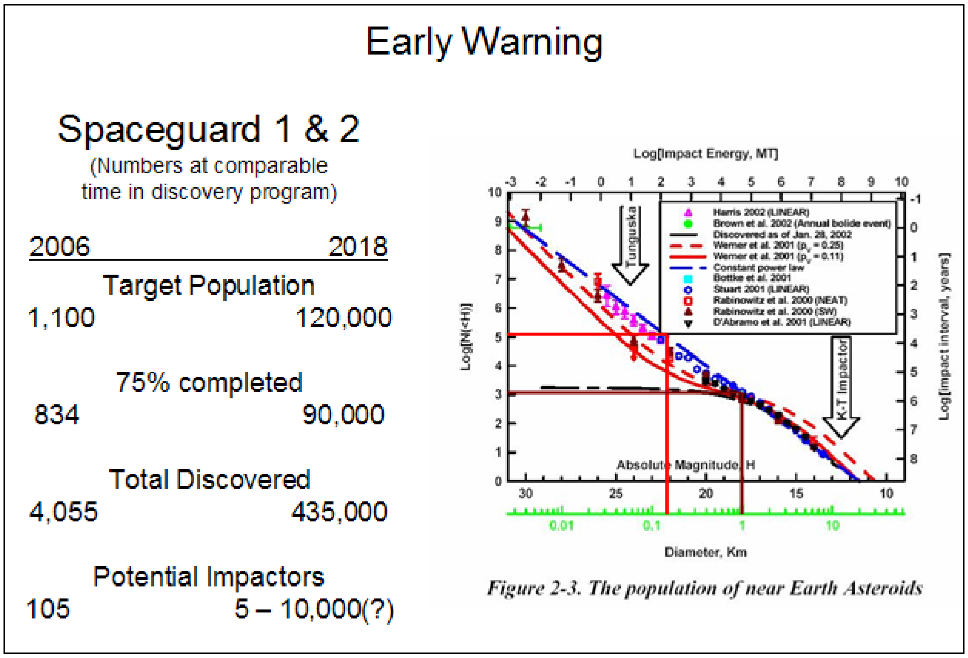

Figure 1. Frequency distribution diagram for near-Earth objects indicating the population of 1 km and 140 meter objects. Table at left indicates the current status of the Spaceguard 1 survey (75% completion) and the anticipated numbers for Spaceguard 2 at a comparable completion level.

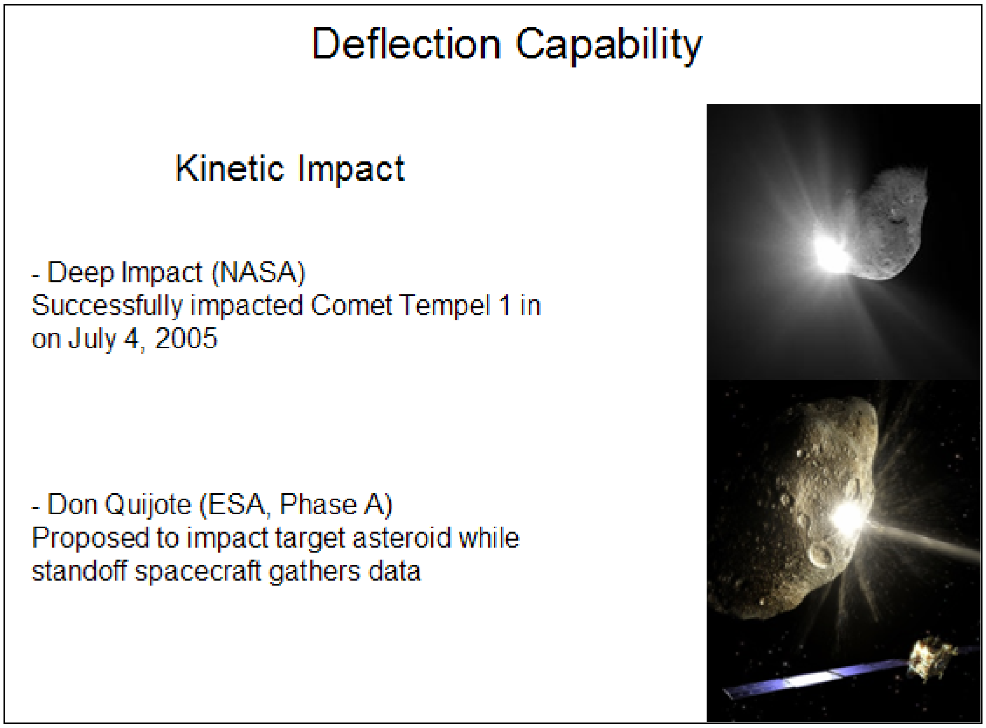

Figure 2. One NEO deflection technique using existing technology is kinetic impact. The fundamentals of the process were demonstrated in the US Deep Impact mission albeit on an object larger than most NEOs. A more realistic prototype deflection mission, Don Quijote, is in Phase A design in Europe. It will use two spacecraft; Sancho will stand off and observe the impact of Hidalgo.

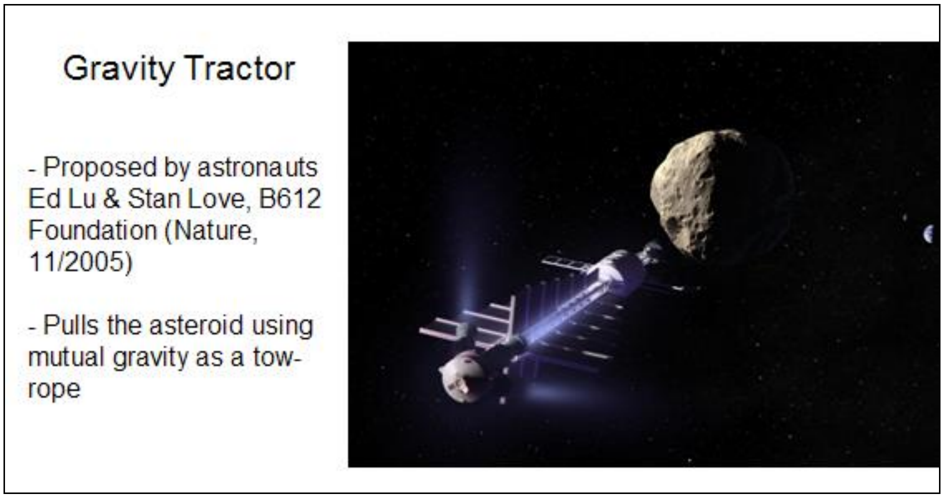

Figure 3. Another concept using existing technology is the Gravity Tractor which uses the mutual gravitational forces between the spacecraft and the asteroid to gently tow the asteroid while the tractor "hovers" in place above the surface.

Figure 4. This Path of Risk for Apophis is typical of that for any NEO with a potential Earth impact. Measurement uncertainties, extrapolated many years into the future, result in an impact line rather than a specific point. It represents the narrow corridor stretching over 180 degrees around the Earth within which, <u>IF</u> the asteroid impacts Earth, it will hit. It is only after considerable tracking, and perhaps after preventive action has had to be initiated, that this line begins to shrink to less than the diameter of the Earth.