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Status on Protection of Earth from NEO Impacts
(The Good, the Bad, and the Ugly)

A great deal has happened in the past year or so on this issue. While governments are still only involved in one of the three elements essential to protect the planet from asteroid impacts, there has been real progress made in the other two as well.

These three elements of protection against this cosmic natural hazard are early warning, a deflection or mitigation capability and finally, and most challenging, and international decision-making process that can assure that timely and well defined decisions can be made.

Early warning:

*[The **Good**.. Congressional action upgrading Spaceguard goal, progress on advanced telescopes, NASA analysis of options to meet new goal.*
*The **Bad**.. NSF's decision and determination to de-fund the Arecibo radar capability; NASA's determination not to pick it up.*
*The **Ugly**.. NASA's refusal to comply with Congress' mandate that they recommend a program and budget to meet the new Spaceguard goal.]*

There is, and has been for the past 9 years, about $4/year of US taxpayer money spent by NASA, at Congress' direction, to perform the so-called Spaceguard Survey. This survey, initiated in 1998, is targeted to discover 90% of all NEOs larger than 1 kilometer in diameter by 2008. I will hereafter refer to this as Spaceguard I since in December 2005 Congress revised NASA's enabling charter, the Space Act, to require it to now discover, track, catalog, and characterize 90% of all NEOs larger than 140 meters in diameter by 2020. This revised search program I refer to as Spaceguard II.

Spaceguard I has been quite successful, though in fact it will probably fall just short of its 90% discovery goal. To date, and following a number of revisions to the numbers based on new spectrographic knowledge, NASA has

discovered 714 of an anticipated population of about 950 NEOs larger than 1 km in diameter.

What was realized several years ago is that finding only those objects which, if they impact, would cause global devastation, is inadequate as a matter of public policy in that hundreds of thousands of smaller objects which will impact far more frequently can do the equivalent of wiping out a city, metropolitan area, or region. Since these smaller, more frequent objects are more easily deflected it is even more critical that adequate early warning be provided on these objects to assure the public that devastating impacts can be prevented.

The challenge, in providing protection down to the size of a Tunguska-like event, is that objects causing these incidents are not only far more numerous but also much more difficult to discover and track. Nevertheless at the successful conclusion of the new Spaceguard survey (i.e. 90% of objects >140 meters by 2020) we will have discovered about 200,000 of the Tunguska class objects representing something less than 50% of the total.

The good news is that due to Congress' action to require NASA to discover the smaller, but still very dangerous NEOs, we will have about a 50/50 chance of preventing all future asteroid impacts with Earth by 2020. And our capability will improve from there. Ultimately, if we do our homework, we can reasonably expect to see the day when we can say with confidence that asteroid impacts with Earth were terminated in the early 21 century. We will have successfully *eliminated extinction*… at least from asteroid impacts.

Here we shift into the ugly. So are we doing our homework? Well, only partially and therefore we "parents", the world public, must continuously stay on top of our respective governments to insure that this critical job is done, and done properly. The current homework assignment is for governments, and I use the plural purposely, to bring on the new search instruments that will enable the revised Spaceguard goal to be met. The initial instruments in this upgrading process will be the University of Hawaii's Pan-STARRS telescope, the first element of which has recently seen "first light." The full Pan-STARRS capability, however, needs additional investment and it is here that the bad news begins to show up. For both

Pan-STARRS and LSST, another very capable new NEO search system, NASA's financial support which could assure timely operational capability remains "hypothetical." Nor has any other national government stepped up to help relieve the pressure on NASA, and there is no reason whatever that they should not.

To best meet the new Spaceguard goal, and even more importantly, to provide the best early warning information to prevent NEO impacts, we should bring space assets into play as well as the planned ground assets. In particular it is critically important to get a capable IR telescope into a Venus-trailing orbit so that NEOs in Earth like orbits (the Aten class in particular) can be much more easily discovered and tracked. As long as we remain dependent on Earth based telescopes we will be locked in to very episodic and limited tracking of objects in these very dangerous orbits.

So where is NASA on this? The answer is… stuck half way there. Stubbornly stuck half way there. In their recent NEO Report to Congress NASA performed a credible job in analyzing the options for meeting the revised Spaceguard goal. But that's where they stopped. Instead of recommending a program and providing the Congress with a budget required to implement such a program, as directed by law, NASA balked stating that they didn't have adequate budget to pursue a revised program and therefore recommended continuing with the current survey effort… only. I've called this defiance to follow the law a Federal Agency version of civil disobedience; ugly to my way of thinking.

Are we talking about a lot of money? No. Even using the numbers that NASA presented in their Report to Congress (overinflated according to many experts), the program I referred to above would approximate $100 M/yr for the next 12 years. This is slightly under 6 tenths of 1% of NASA's budget. I remind you that this, unlike studying Europa's icy surface or Pluto's environs, is an issue of public safety. I would suggest that slowing down NASA's exploration and science programs by 0.6% is appropriate public policy and would receive widespread public support.

In shifting to the ugly I bypassed the bad and would like to return to it briefly. The bad news (in early warning) is that just as we are shifting into a higher gear in terms of insuring our survival we are poking out one of our

two eyes! In this instance it is our radar eye, which significantly complements our optical eye. The combination of optical and radar gives us considerable added capability to not only pin down the orbits of (some) newly discovered NEOs, but also insures that many of them are not lost following optical discovery. Radar does not help us in discovering NEOs, but it does provide critical information in protecting the Earth from impacts.

Aye, and there's the rub! NASA's job, assigned by Congress and narrowly interpreted, is to discover (track, catalog, and characterize) NEOs, not to protect the Earth from impacts. Radar does not, therefore, help NASA meet its assigned goal. Of course it is NSF not NASA who is the primary operator of the Arecibo radio telescope. NSF however, has determined that Arecibo (and in particular the active radar capability) is not a priority astronomy facility and therefore is shifting its limited funds elsewhere. So at the moment Arecibo is being kicked back and forth between Federal Agencies neither of whom wants to fund this second eye and neither of which, arguably, has the responsibility to do so! So in this case, while to my way of thinking about public responsibility, neither agency is acting in the public's best interest, it is Congress who needs to step up and clearly define just who is responsible for protecting the public from NEO impacts. Until this assignment of responsibility is clearly spelled out no one, no Agency, can be taken to task for poking out an eye just as we enter into battle.

Deflection/Mitigation Capability:

So what's been happening in terms of actually being able to do something about a NEO when we find one with our address on it? Conceptually quite a bit; actually nothing at all.

The good news is that after bashing around one deflection concept vs. another, as if one size fits all, we've finally come to understand the issue to the point where we see the complementarity between them. Not only are they complementary but, in fact, in general they cannot do without one another in any real-world situation.

Let me state clearly that I'm talking here only about the three deflection concepts which are essentially available to us today, i.e. using current

technology. These three are, in order of wimpy to brutish, the gravity tractor, kinetic impact, and nuclear explosion. However in order of highly uncertain to precise deflection results, the order is nuclear explosion, kinetic impact, and gravity tractor. Interestingly, most, but not all NEO deflections will require substantial total impulse for a successful deflection whereas all NEO deflections will require a precise deflection maneuver.

This is quite a complex and subtle issue in orbital mechanics, however it can be simplified if one "pictures" a deflection and accounts for what are called resonant return trajectories.

The primary goal of any deflection is to cause the NEO at issue to "miss" the Earth at a time in the future when, absent our deflection maneuver, it would have impacted. This can be done by slightly increasing or decreasing the NEO's orbital velocity years to decades ahead of the pending impact. The result of this slight change in velocity is to cause the NEO to pass slightly ahead of or behind the Earth at the time of impact, respectively. A successful deflection is one that will cause the NEO to miss the Earth by about 3 Earth radii or greater.

However (and this is a big deal) the path both ahead and behind the Earth is littered with resonant return "keyholes" which, should the deflected NEO pass through one, will assure that it will return in some short number of years for a certain impact! When this "short time" is 30 years or less there is good reason for serious concern and indeed questioning the "success" of the deflection. If the return time is a matter of less than 5 years we're dealing with not only an unsuccessful deflection but indeed an irresponsible one!

So a successful deflection must then combine a well executed primary deflection and one with precision adequate to guarantee that the NEO is not coming back for an impact any time soon.

How to do this? As indicated earlier by combining the characteristics of the impulsive techniques (kinetic impact or nuclear explosion) with those of the slow push technique (gravity tractor) to insure both the total impulse to achieve the minimum deflection and the final precision to know that the NEO will not pass through a short period return keyhole.

In fact there are additional reasons to plan for a deflection "campaign" vs. a deflection "mission." In many but not all cases it will not be known for certain whether a NEO is indeed headed for an impact at the time when action to deflect it must be taken. There are many circumstances where the best optical tracking, even complemented by radar, will not be accurate enough to know at the latest time when action can be taken whether a NEO is headed for an impact or a near miss. Therefore it will often be the case that we will need to deploy a pre-deflection transponder mission to the NEO to know whether or not a deflection is indeed indicated.

Great! Because we'd also like to have a precursor mission in any event to both "characterize" the NEO prior to running into it with our kinetic impactor, and to also be there after the kinetic impact to see what indeed actually happened.

However, in a final wrinkle on the scenario, once we've confirmed that indeed the kinetic impact did the job we also want to pin down the resultant orbit of the deflected NEO to know for certain whether or not the NEO might now be headed for a short return keyhole. The likelihood of this is low, but should it nevertheless be the case, our transponder spacecraft, with gravitational tractor capability built into it, can then execute the small "trim" maneuver to gently but precisely shove the NEO to a point between such keyholes.

With the whole world closely watching this process there will be a huge difference between saying "yes, we successfully deflected the NEO and it is unlikely to return any time soon" and "yes, we successfully deflected the NEO and it will not return any time soon." This, I guarantee you, is a non-trivial distinction!

So the good news is that conceptually we now see that the strengths and weaknesses of the impulsive and slow push deflection techniques actually work very nicely to both insure enough total impulse and precision to get the job done. And yes, there are some instances in which the gravity tractor total impulse, wimpy though it may be, is adequate to do the job on its own. Interestingly this happens to be the case for the 1 in 45,000 chance that

Apophis (the poster child of NEOs) is actually headed for an Earth impact on April 13, 2036… Easter Sunday.

Well great! So we're ready to act if required? Well… no, unless you believe that the first time to play