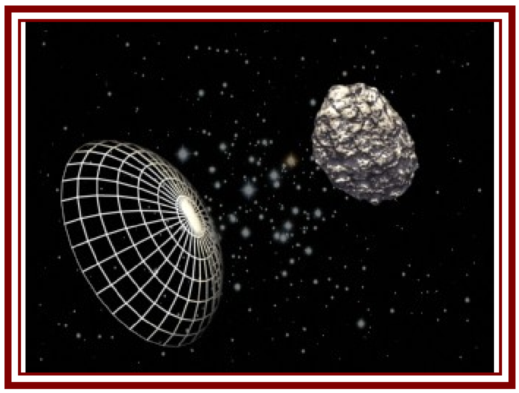
NEONet:

To Catch a Falling Star

The Application of Nets in Deflecting Impending Asteroid Impactors



The Next Large Asteroid on its way to strike Earth is closing at A Million Miles A Day…

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Pursuant to 'new subsection (g)', Section 102 of the 'Space Act' and the specific instruction by Congress within the recently authorized 'Brown Act' that before the end of this year the Administrator of NASA shall provide "An analysis of possible alternatives that NASA could employ to divert an object on a likely collision course with Earth." we propose NEONet.

Consider that by making some characteristic variables less relevant, the over all effect of using nets as a fundamental enabling component of any planetary defense, effectively incorporates the threat specific deflection tactics around a core strategic technology that is altogether versatile, adaptable and scalable, and can be seen as essential to the conduct of implementing a *successful* response to even the extinction level impactors.

The use of nets to facilitate the deflection or destruction of threatening asteroids has applications in four general deflection categories: kinetic impactor, propulsion, ablation and destruction. First, KENet, would employ a net as a kinetic impactor and is principally a 'Green' means to deal with small asteroid threats. Conveyed to a rendezvous encounter in much the same manner as the recent Deep Impact mission, a spread of KENets would be deployed to cross at some defined angle to the asteroid's orbital path. The impact of the asteroid with KENet will result in a distributed inelastic collision and transfer of momentum effectively altering the velocity of the asteroid. Second, TowNet, would use a net as be as a means to couple with and stabilize the rotation of an asteroid and facilitate high thrust propulsion tactics even when the target asteroid is a loosely bound rubble pile. Third, NukeNet A (Ablation), would take advantage of a net's inherent facility to capture and contain loose objects and is seen as principally applicable to larger asteroid threats. By containing an asteroid in a net before the application of a nuclear ablation (or any other pulse) tactic a net would guard against any unintended disruption and break up of the asteroid. And fourth, NukeNet D (Destruction), would employ a net as a delivery system to uniformly distribute multiple low-yield nuclear devices over the surface of an asteroid in order to intentionally and effectively destroy it as a threat or as a means to uniformly distribute the energy yield in a nuclear ablation tactic.

BellNet, a fifth application facilitating general target characterization, would be to use a net as a large area, high relative velocity capture mechanism for placing a transponder and any other instrumentation on a potential impactor in order to more precisely determine its velocity and other relevant characteristics.

A space-qualified deployable net system would form the basis of a planetary defense architecture that is modular, resilient, evolvable and most importantly, is *not* 'asteroid specific'. The use of nets is an innovatively simple augmentation which, when seen as an integral and foundational element in any of the general approaches to NEO deflection would significantly improve the tactical probability of mission success. Further, waiting until we have determined exactly which NEO in our solar system, large or small, is the next asteroid or comet on its way to strike Earth before we develop and build a means to deal with it simply may not have a desirable outcome. The incorporation of nets as an element of any general and conceptual one-size-fits-all deflection tactic would be constructive to enabling the building and deployment of an effective response regardless of any asteroid's characteristics before we see it coming and improve the probability for mission success at the strategic level by orders of magnitude as well.

In short, no matter what agency of our civilization will ultimately be charged with the responsibility for defending the planet from this threat, or what strategy 'We The Species' decide we can afford to adopt to implement an effective response, or what tactic(s) we elect to respond and execute that strategy with, when 'NEO Pucker Time' does come, some skill and expertise in the construction and use of nets in space may well help save the world and should have become something organic and inside-the-box at NASA.

Risk: Before we can correctly assess just what tactics will or will not be suitable as alternatives for deflecting NEOs and effectively mitigate this risk we need a clear and rational perspective for the scope and scale that this threat presents: a strategic context. The risk here, the probability of loss, is that asteroid and comet impacts are totally random and aperiodic events that in their magnitude rise to the the level of our extinction. Strategically speaking, addressing anything less than a worst case scenario is little more than suicide by NEO. Against this perspective there is a persistent strategic assessment that the efforts of the Spaceguard Survey will, at the completion of its survey, by finding 90% of the 1,100 estimated categorically large NEO population not to be 100-year threats, have somehow mitigated the risk of large NEO impact. Towards introducing a critical epistemological examination of this logic, if we postulate that there is one and only one large NEO on course to strike Earth in the next 100 years would it not follow that there are 1,099 large NEOs that are not, and finding them as such by observation would be an expected result. The threat and the risk are substantially as they were when we first recognized this cosmic phenomenon as a hazard to the well being of our species. If anything, since The Next Large Asteroid on its way to strike Earth is out there, is an existential and manifest threat, and sooner or later will arrive, and we have so far done little to effect its deflection, the risk has only increased and continues to do so at the rate of A Million Miles A Day. Addressing the worst case scenario first is imperative... comprehensive forensics and dialectic available on request.

Concept Paradigm: This endeavor has now been mandated by and proceeds from an Act of Congress and there are dire negative consequences should the response requested fail… The inherent simplicity of the idea of using nets as an element of a Planetary Defense is not a mere extrapolation of technology but the introduction of a revolutionary new paradigm that will certainly inspire others to produce useful science and elaborate on the fundamental ideas associated with further developing this idea, its architectures and necessary core competencies to comprise a basis for a comprehensive one-fits-all-size NEO deflection tactic. Since revolutionary paradigm shifts are often simple and elegant and characterized by their order and symmetry NEONet will trigger a transformation of intuition and perspective in this issue.

While there have been various rudimentary, and numerous physically impractical concepts, proposed for the detection and mitigation of the threat posed by NEOs there are several major uncertainties that roil through basic deflection tactical concepts impeding any comprehensive effectiveness we might look for in any Planetary Defense system. Those uncertainties include:

- detection and characterization: how big are the objects and what is their physical structure (solid, rubble pile, other);
- propulsion technologies reliably available for interception (are we limited to chemical Isp's; are fission and advanced fusion concepts possible; advanced physics concepts);
- basing options (relative time lines and ΔV's for earth, parking orbit, lunar, Martian, etc.);
- rendezvous options (ram, rendezvous, orbit) and,
- interdiction options (how to stop spin rates, attach and use space tugs, generate ablative acceleration while maintaining structural stability, nuclear detonation, etc.).

Many of these uncertainties may be years from resolution and it is critical we begin developing the type of technology that will enable system concepts to be implemented that have a reasonable expectation of success and will work when we need them to… at any cost.

KENet: To describe the performance of the KENet we will use the small asteroid impact scenario from the recently publicized B612 Foundation NEOTug concept demonstration proposal. In this scenario we have a 200-meter diameter asteroid massing 10 million metric tons and traveling at 15,000 m/sec. The point of deflection is offered at 10 years away from a projected Earth impact. The principal feature of the B612 NEOTug is in its employment of VASIMR technology in order to achieve a target ΔV by generating a small and gradual force over a long period of time. This approach would serve to reduce the risk of disrupting the integrity of porous or otherwise loosely bound asteroids.

In comparison, one KENet: at 1.3 tons, ~300 meters in diameter, with 10-meter spacing in the weave of the KENet, and deployed in a hemispherical configuration, will be targeted to cross the orbital path of the asteroid as close to a right angle as possible (Figure 1). This would effectively give the KENet a ~15,000-m/sec velocity relative to the asteroid along the asteroid's path. Upon collision with the KENet, the asteroid will transfer momentum to the KENet accelerating the KENet to 14,999.998 m/sec along the path of the asteroid. The energy for accelerating the KENet along this axis is derived from the asteroid and effectively generates a reciprocal negative ΔV of 0.002 m/sec to the asteroid. Note that a ΔV of 0.002 m/sec is only a fraction of the total deflection required to avoid any collision with Earth in any 10-year displacement scenario.

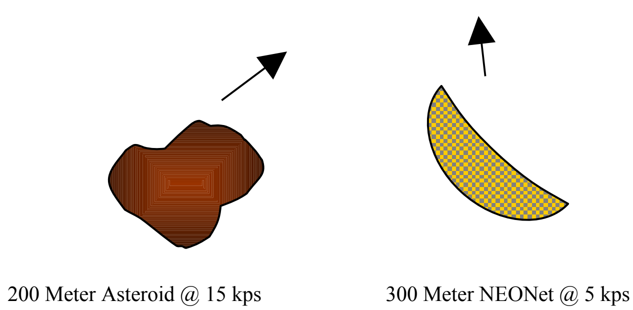

Figure 1. NEONet intercepting an asteroid

Additionally, the KENet, traveling at ~5,000 m/sec, although crossing in front of and at an angle to the asteroid's orbital path will impart a negative momentum to the asteroid along its X-axis proportional to the relative velocity of impact. Since this effect will not likely occur along the asteroid's center of mass and be distributed principally along the horizons of one hemisphere it would be expected that this dynamic would generate angular momentum and may have little useful effect on our final intended velocity for the asteroid.

Astronomers are finding that far more asteroids may fall into a porous and/or 'rubble pile' class than they do a homogeneous 'stony' class where the risk of any disruption and breaking apart would be less problematic. As a result asteroid cohesion and integrity, during and post deflection, has become a paramount mission critical element in this issue. A KENet, as a kinetic impactor in a hemispherical configuration will gradually and uniformly distribute its mass over the maximum area of the asteroid's surface mitigating the risk of disruption which would likely occur if the same mass were delivered as a small dense impactor.

Further, given its size and how quickly the KENet will capture the asteroid, and unlike any other deflection tactic, the KENet itself will serve to contain whatever nominal disruption it may generate in its collision with the asteroid. This containment feature is accumulative as subsequent KENets are applied to complete the total ΔV required for deflection. Unlike all propulsion tactics which first require despinning the asteroid (which can in itself be disruptive) with a KENet the asteroid's rotation is not only irrelevant to imparting a ΔV but we take advantage of it in order to distribute KENets uniformly across the surface of the asteroid. The integrity of the KENet, and its ability to afford this benefit is subject to an investigation of KENet deployment, configuration, cord design and materials specifications. At this point it should be noted that the 0.002 m/sec ΔV afforded by a single 1.3 ton KENet is equivalent to that of the NEOTug proposal weighing in at 20 tons and at a cost of one billion dollars. Using the B612 mission as a baseline for an overall cost comparison to the KENet fairly exotic materials certainly become affordable.

There are two likely approaches we can use for quickly deploying the KENet: either spinning the KENet from a central spindle or propelling it radially from a canister. The KENet could even be spherical and embedded into a Mylar balloon deployed with compressed air. Either approach will allow the KENet to be conveyed on course to a precise interception point in space ahead of the asteroid by a secondary intercept vehicle (Figure 2). The intercept vehicle can be guided to a general point of the KENet deployment by previously 'painting' the asteroid with a cluster of transponders while its final guidance to interception may be radar assisted.

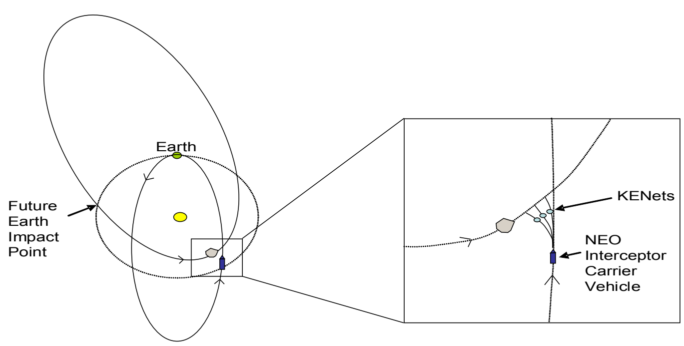

Figure 2. Possible trajectory concept for NEO interception

In that many KENets will be necessary too fully deflect this asteroid (as would many NEOTugs) individual intercept vehicles may be conveyed to a firing point by a carrier vehicle on an intercept orbital path. From such a delivery platform a 'spread' of intercept vehicles could be launched to complete the interception with the asteroid: probably in an order of first-launched-last-to-hit, or launched independently from Earth, the Moon or some other forward base.

NASA has recently proposed to deflect the small asteroid Apophis with a kinetic impactor in a manner similar to their recent Deep Impact mission. However, as a target, Apophis would be 400 times smaller than comet Temple 1. Using a KENet would not only mitigate the potential for disrupting the asteroid but at 300 meters in diameter the effective capture area would be several orders of magnitude greater than a small dense probe and the chance of a hit correspondingly several orders of magnitude greater. What would amount to a glancing blow or even a clean miss with a small dense impactor would still result in a full transfer of momentum with a KENet.

TowNet: In certain circumstances, as in the case of Apophis with it's 'Keyhole' ΔX target orbital displacement, the precise deflection afforded by a propulsion tactics may be preferred. Here we can capture the target asteroid with a net tethered from its perimeter to tractor craft oriented at a right angle to the asteroid's surface along its equator. As the asteroid rotates, the tractor will pass through the asteroid's x-axis and with short bursts over several rotations afford a far more controllable ΔV. Using high thrust systems such as the SSME would become more feasible when any disruption of the asteroid's cohesion will not result in its dispersal. Strategically, a high thrust deflection tactic would A) afford far shorter mission duration at deflection making a manned mission option more feasible and B) reduce response time required for the detection-impact window as well. Both aspects serving to enhance the likelihood of mission success. Additionally, and circumstances permitting, once coupled with the asteroid, a TowNet may even be used to facilitate eliminating the asteroid's rotation altogether before the deflection effort.

Staged in LEO and contained in a pay-load canister with three or more tractor vehicles, similar in appearance to a number of Space Shuttles around a single ET, to convey it to the target NEO. Once achieving co-orbital rendezvous tractor vehicles would pull a TowNet (a 3 to 6 point star) from its canister and deploy it to capture the target at a low relative velocity. Once the asteroid has been captured the tractor craft can rejoin around a pre-deployed fuel container.

NukeNet A: Here the execution of the tactic is far simpler… and no longer Green. We would rendezvous with the asteroid taking station directly ahead of it along its path. From there, conveyed to the target in a manner similar to TowNet, a carrier vehicle can deploy 2 or 3 NukeNets at relative velocity of only ~100 m/sec. The objective is simply to encompass and contain the asteroid in order to mitigate possible disruption and maintain the asteroid's integrity. NukeNets would be deployed hours apart in order to allow the asteroid to rotate and subsequent nets to be applied to different aspects of the asteroid effectively overlapping each other. Once the NukeNets are in place, nuclear mines can then be deployed in the path of the asteroid in order to ablate the asteroid's surface at high velocity generating the required thrust and ΔV.

For a 200 meter asteroid it has been estimated that an effective mission design, with a target ΔV capability of 0.05 m/sec, could be achieved through a nuclear ablation tactic using as little as a 50 KT yield at ~100 kg in payload mass. Detonated directly in the asteroid's path some tens of meters above the asteroid it would explosively volatize the asteroid's surface generating a decelerating impulse along the asteroid's line of travel. Since most of the impulse generated will be at the epicenter of the radiation footprint on the asteroid, even with multiple lower yield devices, the equal and opposite reaction in this tactic will still create a risk of disrupting the asteroid's integrity. At best, mission success would be 'asteroid specific' and far too much reliant on very good luck. However, if we have first encompassed the asteroid in a NukeNet to contain any potential disruption we will mitigate much of this risk.

This approach is likely to also result in some damage to the NukeNet far beyond the resulting central crater at the epicenter of the blast. An 'Orion' style pulse option would be to employ a modified nuclear explosive device. If a shell of plastic or other suitable material first absorbed the radiation from a standard nuclear device that shell would volatize and explosively expand against the asteroid not as radiation but as mass at extremely high velocities. This would not only mitigate the damage to the net but depending on the design would likely result in a more efficient conversion of radiative energy to useful work.

NukeNet D: In certain circumstances, small asteroids with short detection-to-impact windows, as may be the case of Apophis post its 'Keyhole' passage, an intact gross deflection may not be feasible and it may become necessary to destroy it. Then, a single device, no matter how large, may not effectively reduce a target asteroid into fragments that are either small enough or have been dispersed at sufficient velocity to actually miss Earth and eliminate any threat. The simultaneous detonation of multiple smaller devices, evenly distributed over the surface of the asteroid, utilizing the body of the asteroid to break line-of-sight and prevent a disabling fratricide, would be far more effective. This is a well known tactic used in conventional high explosives and the deployment of such "ear muff" charges around reinforced concrete columns allows a small quantity of high explosive to destroy very thick structures. For that portion of the asteroid that is not volatized, the simultaneous reciprocal elastic shock would uniformly disrupt and disperse what would be, on average, much smaller fragments to the point of pulverization.

To implement this effect these devices could be incorporated into a net and deployed over the surface of the target at a low relative velocity. Such nuclear-armed nets deployed over a small portion of the asteroid's surface along its x-axis could serve as a delivery system for a tethered cluster of low yield nukes evenly distributing the energy of the detonation over a far larger surface area than any single device of equivalent yield. Some greater volatilization may be achieved by using multiple small devices serving to increase the yield/ΔV result. Additionally, in the case of larger asteroids, such a distributed yield would mitigate the risk of any unintended disruption facilitating deflection by ablation. Both applications would likely require conveyance and deployment on the target similar to that of TowNet..

BellNet: Once expertise and experience in using nets in space has evolved to a point of being a core competency in our activities in space it may become more reliable, less costly and faster to use a net, tethered to an instrument packaged, in order to place a transponder and other instruments on a threating asteroid or comet to better characterize its velocity and other elements relevant to deflection. Using an interception profile similar to that of the KENet, BellNet would be able to capture and couple with the target object at a high relative velocity instead of having to achieve a co-orbital rendezvous interception profile. Initially, the instrument package would trail the target until the rotation of the NEO draws it to the target asteroid's surface.

More reliable because it is simpler than the dynamics of a soft landing by thousands of things that can go wrong in space not being there to do so. Less costly in terms of the mission velocity required and all of those soft landing technologies that can go wrong at any cost: effectively reducing the amount of political will required to launch such a mission.. Faster in that there would likely be more launch windows available for crossing the orbit of an NEO than landing on it, which may require gravitational assist tactics and the additional time that would entail. Here, better/cheaper/faster can mean the difference between our survival or not. BellNet reduces risk.

Cost: This level of analysis constitutes a first foundational strategic step in addressing this threat. Without a defined tactical capability to respond to this threat with we simply cannot know what will be strategically relevant: essential to the conduct of implementing a response. What is singularly crucial at this stage is to determine what tactic works best. What response will give us the highest probability for successfully deflecting a worst case NEO impact. It should further be noted here that since cost is a fair meter for human endeavor and therefore does have some relevance in terms of time to build any response. However this can be addressed to some degree by the balance between the current strategy of 'waiting until we see it coming' and one of tactical preparation, training and deployment pre-detection. At this point, cost is an irrelevant element of this analysis and ultimately, given that the potential magnitude of the loss includes extinction: all there is forever, it never *should* be relevant. At the least, cost is certainly not *NASA's* problem.

That said, NEONet will certainly add some cost to any basic deflection tactic. However the benefit here is a greater expectation of success. It would be naive to think we can actually develop the ability to save mankind from extinction by NEO someday and do it on the cheap. You don't get what you don't pay for.

It should also be noted that in addition to cost, at this level of examination, political correctness should also be regarded as irrelevant. In this direction it should be recognized that an initial back-of-the-envelope examination of unaugmented nuclear tactics, staged in LEO, could be as much as 10,000 times less massive than any propulsion or kinetic impactor mission. And in the business of Mastering Space, mass is cost. If we knowingly allow our vestigial 'Cold War' fears to obfuscate the most effective tactical response to this threat how are we being wise?

Next Step: When Congress, by inviting the Administrator of NASA to present alternatives for diverting NEOs, they should only expect a response from what is already organic at NASA. What DoD or even foreign government agencies might perceive as a suitable alternative in response to this threat will not likely be well represented in this effort if at all. Further, not only will NASA's Office of PA&E likely reflect only the perspective of inside-the-box at NASA but where does it draw qualifications that can afford any of us the reasonable expectation for an analysis stemming from a broad comprehensive strategic context and perspective of this issue: ostensibly outside-the-box of NASA, DoD or any other human agency today. There is simply no reason to believe that the PA&E will give us the 'best' tactic to divert an NEO and mitigate the threat *all* things considered. Just the best from the perspective of 'a NASA' program'...

In the direction of moving this issue into a box of it's own, one possible recommendation that the PA&E should seriously consider would be to reallocate some portion of the funding anticipated in The Brown Act ($2-3 million) to a critical, rigorous and comprehensive forensic systems analysis of all known deflection tactics with a reasonable expectation that *all* things will be well considered. To have any contextual integrity such a study must be conducted not only from the NASA perspective but should certainly include that valuable core set of relevant technological, tactical and strategic competencies inherent at DoD as well. Such a study should endeavor to clearly reveal many of the tactics that have surfaced (which, merely because they are 'Green' and novel have become part of the public lexicon to some degree) to be strategically unsuitable or simply irrational, as the case may be, and without any realistic potential as candidate tactics. We should at least narrow the list of responses available to tactics that afford us some reasonable expectation of success at whatever level this threat may manifest next... all things considered.