PLANETARY DEFENSE: AN INTEGRATED SYSTEM OF DETECTION, EVALUATION AND MITIGTION. Joseph A. Nuth III[1], [1]NASA's Goddard Space Flight Center, Code 690, Greenbelt MD 20771 USA (joseph.a.nuth@nasa.gov).

Introduction: The concept of Planetary Defense is less than 40 years old, yet we have made enormous strides, working with small quantities of resources over this time period. We now detect and track more than three orders of magnitude more asteroids than we even knew existed 40 years ago and there are methods that have been proposed for deflecting potentially hazardous objects given sufficient lead time. Plans are even being made to test impact-induced deflection as well as the Gravity Tractor technique with upcoming, but not yet approved, NASA missions DART and ARRM.

Our current detection and mitigation schemes however focus almost exclusively on asteroids, by far the most likely impactor over the long-term, though not necessarily the most deadly integrated threat. Comets, though probably 100 times less likely to impact earth, are also larger than typical earth-impacting asteroids and will impact, on average, at considerably higher velocity. Comets will also impact on much shorter timescales following their initial detection than will a typical asteroid, thus greatly reducing the probability that we can divert or destroy such threats.

Different Threats: Detecting asteroids and mitigating their potential for impact is relatively "easy" compared to mitigating a cometary impact. Most asteroids travel in well behaved orbits relatively close to the earth, thus detection is possible. Because of the Planetary Defense work done to date, no large asteroid is likely to impact the earth without several decades of warning. Since relatively minor changes to an asteroid orbit can propagate over time to change the time it will cross the Earth's orbit, it is fairly easy to eliminate the threat when an impulse can be imparted to it many decades prior to the predicted impact .

A new comet, or a very long period comet, arrives with little warning. Comet C/2013 A1 (Siding Spring), an Oort cloud comet discovered on 3 January 2013 by Robert H. McNaught at the Siding Spring Observatory, is a great example. Comet Siding Spring passed within 135,000 km of Mars on 19 October 2014. The total time from it's discovery to closest approach to Mars was less than 22 months. This short warning timescale is much less than would be expected for a typical asteroid impactor.

Comet Siding Spring entered the inner solar system perpendicular to the ecliptic plane. While most asteroid impacts have a relative velocity of ~20 km/s, Comet Siding Spring had a relative velocity of ~56 km/s at Mars. Since collision energy is proportional to v^2 this comet would have ~9 times the energy of a typical impact by an asteroid of similar size. Such high relative velocities for comet-planet collisions are not unusual.

Meteor Showers demonstrate potential relative collision velocities of comets with Earth. Comets shed debris as they orbit the Sun. The Earth passes through these debris trails as it orbits the Sun and these debris trails are the sources of meteor showers. Each meteor shower represents a possible collision between the parent comet and the Earth that did not occur. There are more than 65 known meteor showers with relative velocities ranging between 3 and 71 km/s for all "cometary" sources: these include short and long period comets, new comets as well as dead comets.

The impact threat from asteroids is much higher than that from comets (>100::1). However, comet impacts are likely to be more energetic. Comet orbits are generally farther from the ecliptic and more eccentric than asteroid orbits: so their impact velocities are much higher when they cross the orbit of the Earth. Comets are larger than most asteroids but are also less dense (more water, less rock). The smallest known comets are seversal hundred meters in their longest dimension while the largest are many kilometers or even hundreds of kilometers in size.

Comets provide much less warning from discovery to impact than typical asteroids and it is therefore much harder to mitigate such potential impactors. The time required to launch a high reliability planetary mission is approximately 62 months from the date that the mission is approved. The schedule can be compressed by cutting out various reviews and eliminating tests, but these short cuts greatly diminish the reliability of such a mission. Cutting this time down to on the order of 12 months to deal with a threat such as Comet Siding Spring would result in a very low reliability mission. It is imperative to reduce reaction time to less than a year from high certainty of impact to launch without compromising the reliability of the mission.

Recommendations: To reduce reaction time without compromising mission reliability we can build an intercept spacecraft that could carry a NED and put it into storage (with periodic testing). In addition we should also build a simple observer spacecraft and put it into storage as well. We would launch this observer spacecraft on "warning" to gain data to refine the comet's orbit and to maximize the effectiveness of the interceptor.

Building a high reliability spacecraft can be done easily prior to need, on a “normal” schedule if there is no reason to rush. All normal design reviews and all spacecraft component and integrated tests can be performed to ensure all works as expected Stored spacecraft can be launched within a year as was demonstrated by the DISCOVR launch of the previously stored TRIANA earth-observing satellite. This plan reduces the time to launch an interception mission by about four years. This interceptor could also be used to mitigate against a “sneaky” asteroid that might be detected coming from an orbit we currently find diffiult to monitor (such as in the direction of the Sun). We would then launch the interceptor when the impact threat reaches a pre-defined level of certainty.

An observer spacecraft is highly desirable. An observer spacecraft can document the comet’s shape, spin axis and rotation rate to enable the most effective mitigation mission possible (*e.g.,* where and when should the intercept occur for maximum effect). The need for such an observer is amply demonstrated by the Rosetta Mission. The best ground- (and space-) based observations of Comet 67/P Churyumov-Gerasimenko suggested that it should be a solid bi-pyrimydal shaped body. The reality was quite different. Comet 67/P Churyumov-Gerasimenko is not a symmetric target and it is easy to understand why the impact of a nuclear device will have significantly different effects if applied at some random spot over the surface of the comet.

An observer spacecraft could also provide a very accurate position for the incoming comet to refine its orbit. While this position would only be at one very precisely timed and measured point on the orbit, it would be a better position that can be obtained from the ground until just before impact.

Above: Artist's impression of the nucleus of Comet 67/P Churyumov-Gerasimenko, portrayed far from the Sun with little to no activity (Image via ESA–C. Carreau) based on remote sensing observations, including those taken by the Rosetta spacecraft as it approached the target two years before rendezvous. Below: Image of Comet 67/P Churyumov-Gerasimenko obtained by Rosetta after arrival in August, 2014.