LUNAR SENTINEL™ : Planetary Defense from the Moon

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Abstract

While early detection of hazardous objects is the preferred goal of all planetary defense initiatives, currently, detection of all hazardous objects that are <0.1- km across may not be possible before they are in close proximity to Earth, giving us a very short warning time in the range of weeks to months. To thwart such a threat, we need agile systems in place that are quick to respond and powerful enough to effectively intervene and diffuse the threat.

Lunar Sentinel concept proposes using our Moon as an emergency layer of defense for planetary defense; mitigating small "city killer" type NEO/cometary fragment threats that are still difficult to detect well in advance using current technologies. Merits and challenges are addressed.

Recent progress in Directed Energy (DE) systems show promising results. Several mobile HEL systems are being tested currently. High energy laser (HEL) beams focused on bodies like water-ice rich cometary surfaces can analyze constituents, provide accurate morphology and could be used to vaporize it.

A Directed Energy system complex mounted on the far-side equator and poles of the Moon could be a versatile solution to mitigate small asteroids, and especially incoming cometary fragments in high energy trajectories. Interception of PHOs at close range (<1 AU) at short notice and without fielding any physical projectiles or nuclear devices become possible. Lunar Sentinel offers a clear and defined mandate for yet another use of our Moon; to keep watch and protect planet Earth from hazardous impactors.

I. Nomenclature

- DE - Directed Energy
- HEL - High Energy Laser
- IAWN - International Asteroid Warning Network
- K-Pg - Cretaceous–Paleogene extinction event
- K-T - Cretaceous-Tertiary Mass Extinction event
- NEO – Near Earth Object
- NEOCAM - Near-Earth Object Camera
- NEOWISE - Near-Earth Object Wide-field Infrared Survey Explorer
- PDCO - NASA Planetary Defense Coordination Office
- PD - Planetary Defense
- SMPAG - Space Missions Planning Advisory Group

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II. Introduction

Geological evidence points to a cataclysmic event some 65 million years ago when the Earth's biosphere was abruptly decimated by an asteroid. An extraterrestrial object about 10 km wide caused the extinction of about three quarters of all living species during the Cretaceous-Paleogene (K-Pg) extinction event, also known as the K-T event.[Alvarez et al 1980] Ongoing surveys suggest there are more than 750,000 asteroids larger than 1 km wide in the main asteroid belt, of which more than 13,280 Near Earth Objects (NEOs) including most of the large ones have been identified as of Dec 2015 [NEO JPL 2015]. Certain Earth-orbit-crossing, potentially hazardous objects(PHOs) are being tracked to be sure they pose no threat. NASA has established a Planetary Defense Coordination Office (PDCO) and coordinates a variety of activities globally. Mandated by the United Nations, the International Asteroid Warning Network(IAWN) and the Space Missions Planning Advisory Group (SMPAG) have been involved in assessing and formulating action plans for responding to such a threat, should it occur. Several observatories around the world are part of this program to observe the skies and report potentially hazardous objects(PHOs) and NASA JPL catalogs, updates and tracks an ever growing number of such objects in their Near Earth Object(NEO) Program Office at NASA JPL. In the 1994-2013 interval, U.S. Government assets recorded at least 556 bolide events of various energies. This recent data shows that extraterrestrial objects with the potential for devastation collide with Earth more often than previous estimations [Figure 1].

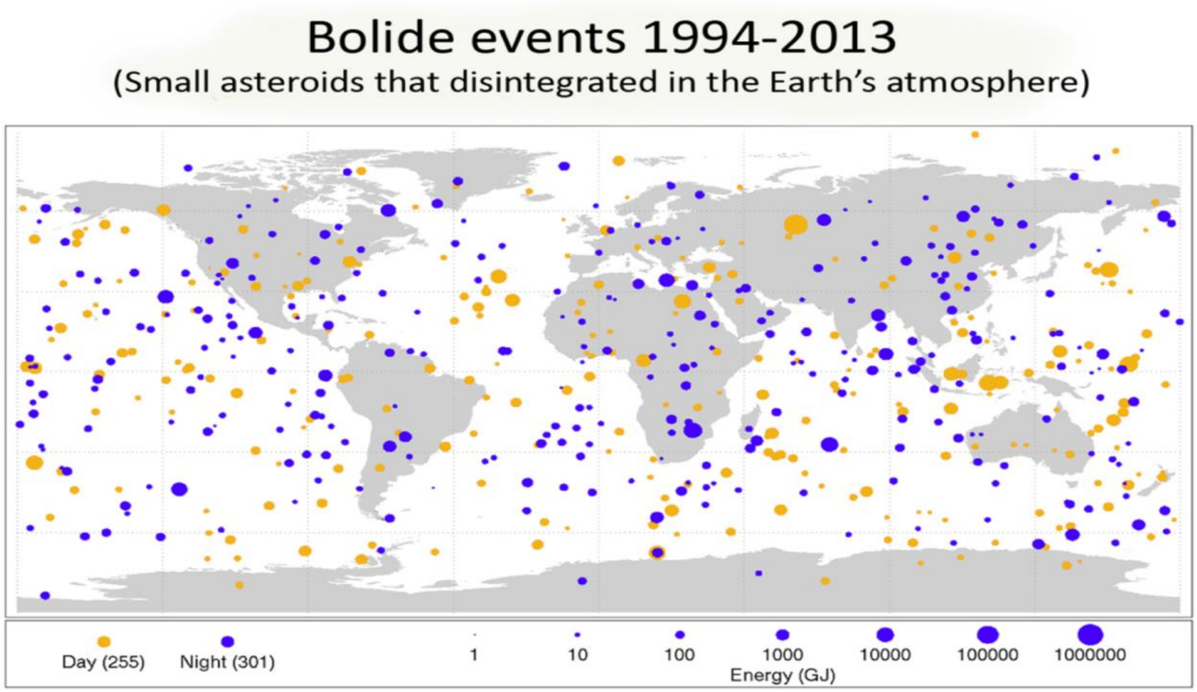

Figure 1. Recent chart shows the constant bombardment of Earth by asteroids. Small "city killer" type asteroid fragments impact the Earth more often than previous estimates.[credit NASA NEO Office JPL]

In case of a threat detected decades before impact, we may have ample time to plan ahead and could use spacecraft and other guided projectiles to intercept the object, we could employ techniques like gravity tractor, mass drivers, enhanced Yarkovsky effect etc. to alter its trajectory in order to avoid Earth impact. Much of the literature on planetary defense strategies discuss such long term mitigation and deflection options.

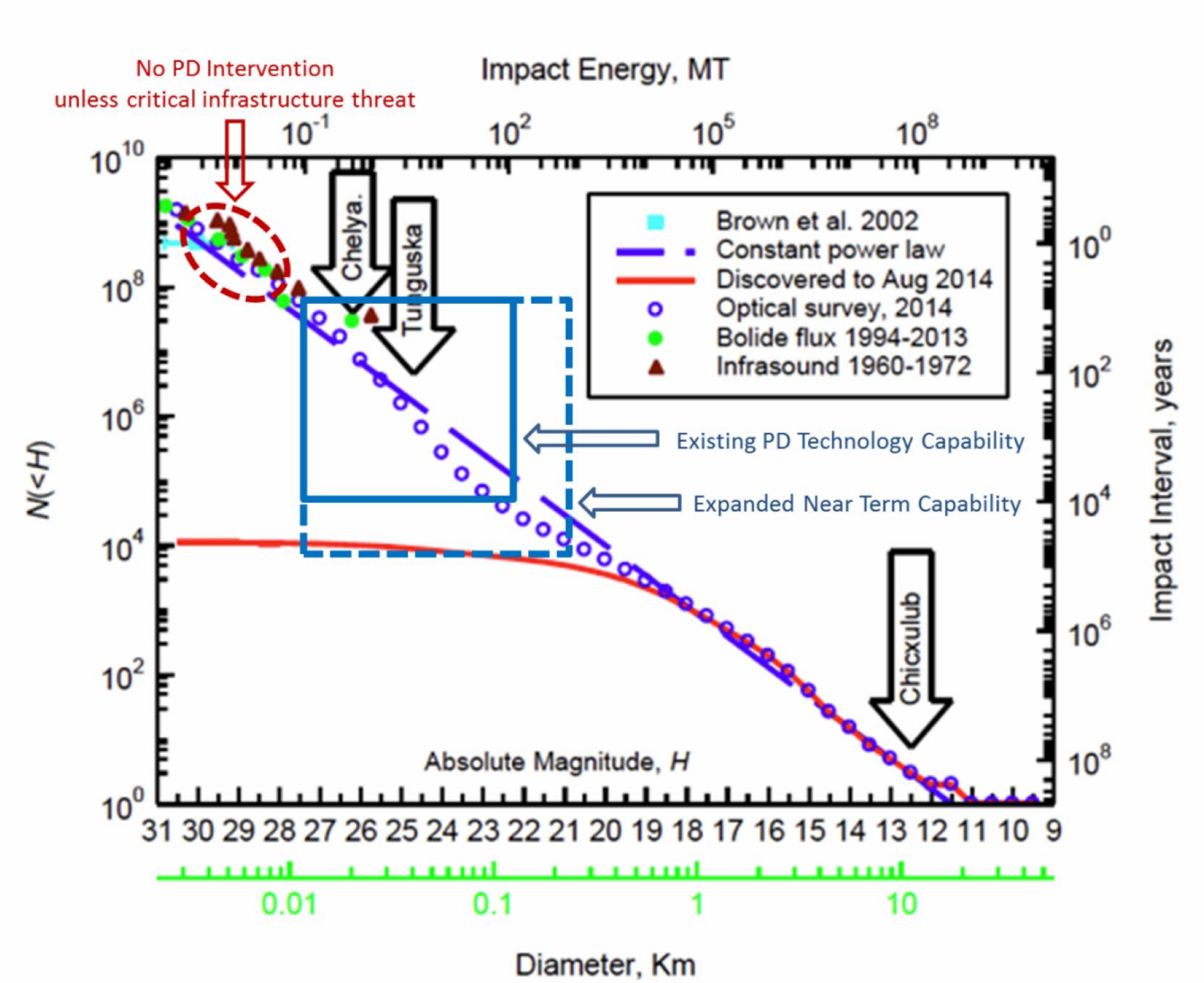

Figure 2. The modified asteroid population chart shows how current asteroid survey discovery fits within the constant power law. Current technology allows us to intervene and thwart a narrow range of threatening objects in the 10-100m class.[credit A.Harris 2014]

While early detection of hazardous objects is the preferred goal of all planetary defense initiatives, and advanced telescopes like NEOCAM are being designed to detect faint objects, [Mainzer 2015] detection of all hazardous objects that are <0.1- km across may not be possible before they are in close proximity to Earth, giving us a very short warning time in the range of weeks to months to mount a response. Comets in particular pose a threat since they appear and transit very quickly through the solar system. The typical energies they impart are far greater than asteroids.[Syal 2016] The Shoemaker-Levy 9 D1993/F2 comet impact on Jupiter and the more recent Siding Spring narrow miss of Mars show that comets can indeed pose a threat with little warning from the time it is first detected. To thwart such a threat, we need agile systems in place that are quick to respond and powerful enough to effectively intervene and diffuse the threat.

The Lunar Sentinel concept focuses on using our Moon as an emergency layer of defense for planetary defense; mitigating small "city killer" type NEO/cometary fragment threats that are still difficult to detect well in advance using current technologies.. Merits and challenges are addressed.

III. Advances in Directed Energy Systems

Recent progress in Directed Energy(DE) systems show promising results. Laser technologies like thin disc lasers[Figure 3], modular beam combining[Figure 4] and phased arrays[Figure 5] – coupled with adaptive optics that is routinely used in astronomy[Figure 6] allow highly collimated laser beams high energy delivery over long distances. Q-switching can increase energy output multifold, and pulse modulation can be used to keep the laser system in a thermally optimal state while also enabling resonance induced effects on certain types of monolithic asteroid targets [Thangavelu 2015].

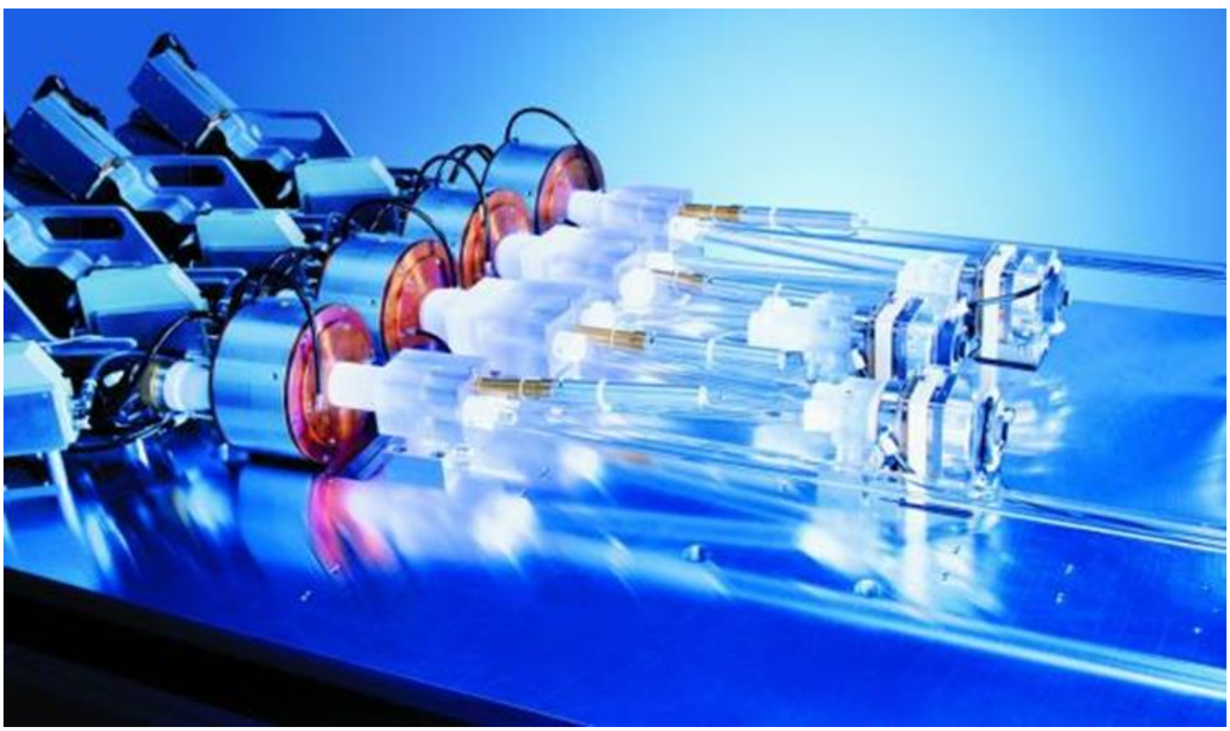

Figure 3. An 8kW thin disc laser setup. Each of 4 thin disc lasers emits 2kW of power that is combined to produce the output of the system. Such systems can be scaled up to desired power levels without the need for extensive heat management system that would be necessary otherwise.[Image credit TRUMPF Laser-und Systemtechnik GmbH]

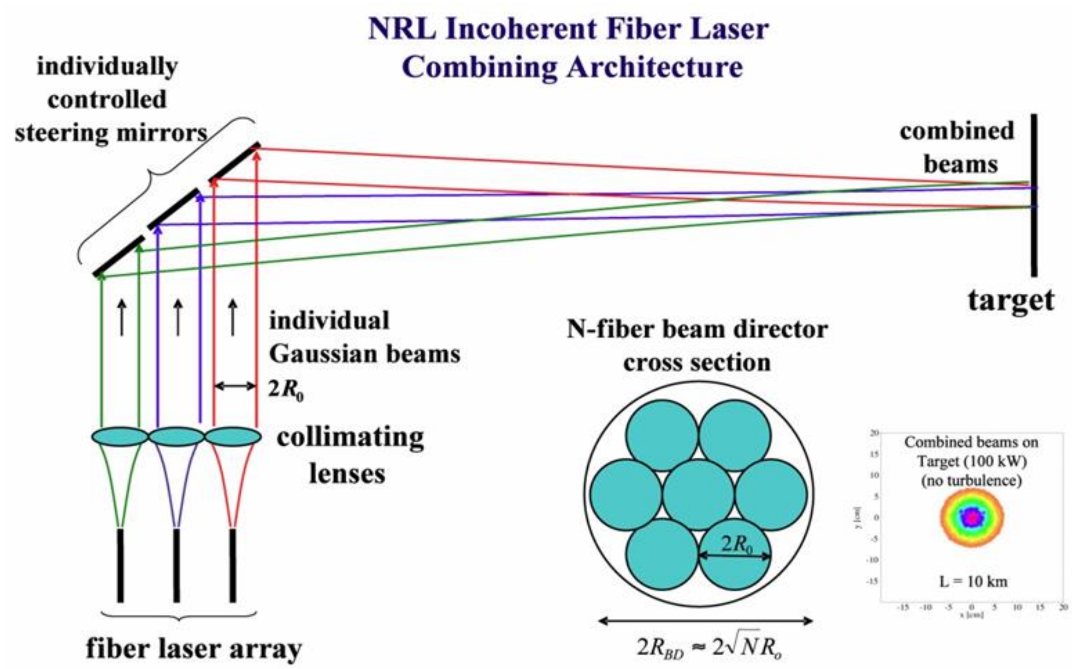

Figure 4. Schematic diagram of incoherently combined fiber lasers. Laser beams are expanded and directed to the target by individually controlled steering mirrors. Spot size of the individual beams at the source is made large enough to limit diffractive spreading. [Parry NRL 2013]

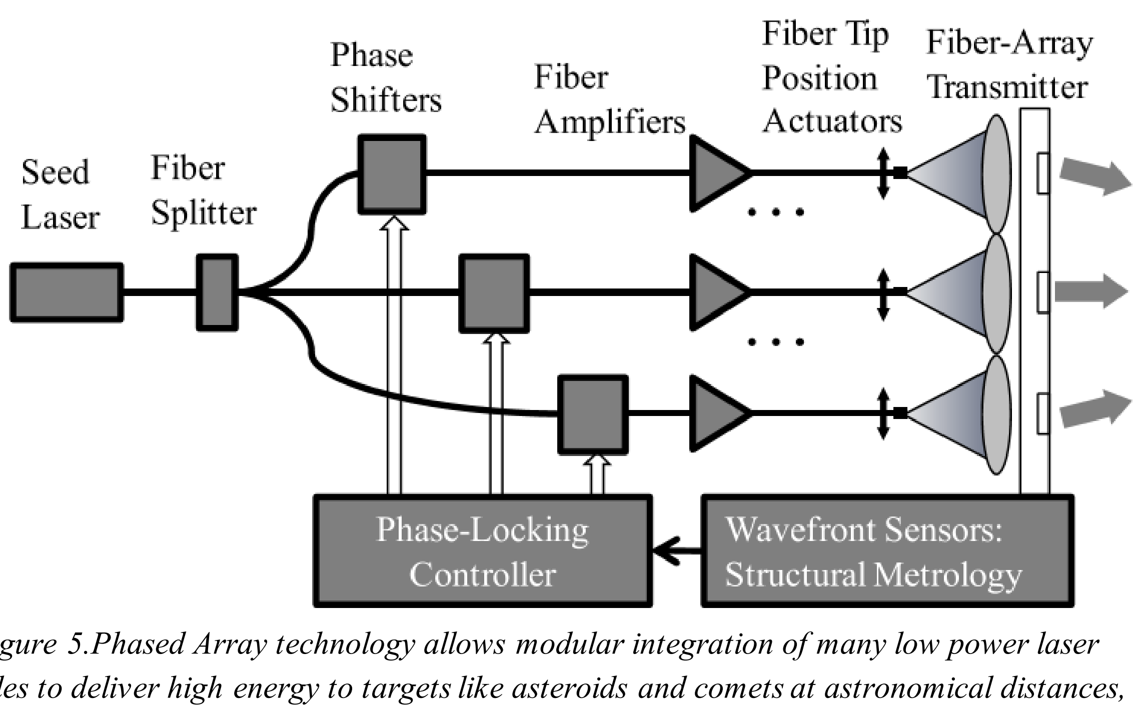

Figure 5.Phased Array technology allows modular integration of many low power laser modules to deliver high energy to targets like asteroids and comets at astronomical distances, all at short notice and without the use of rockets and projectiles that need a great deal of advance planning.[credit Lubin DeStar 2013]

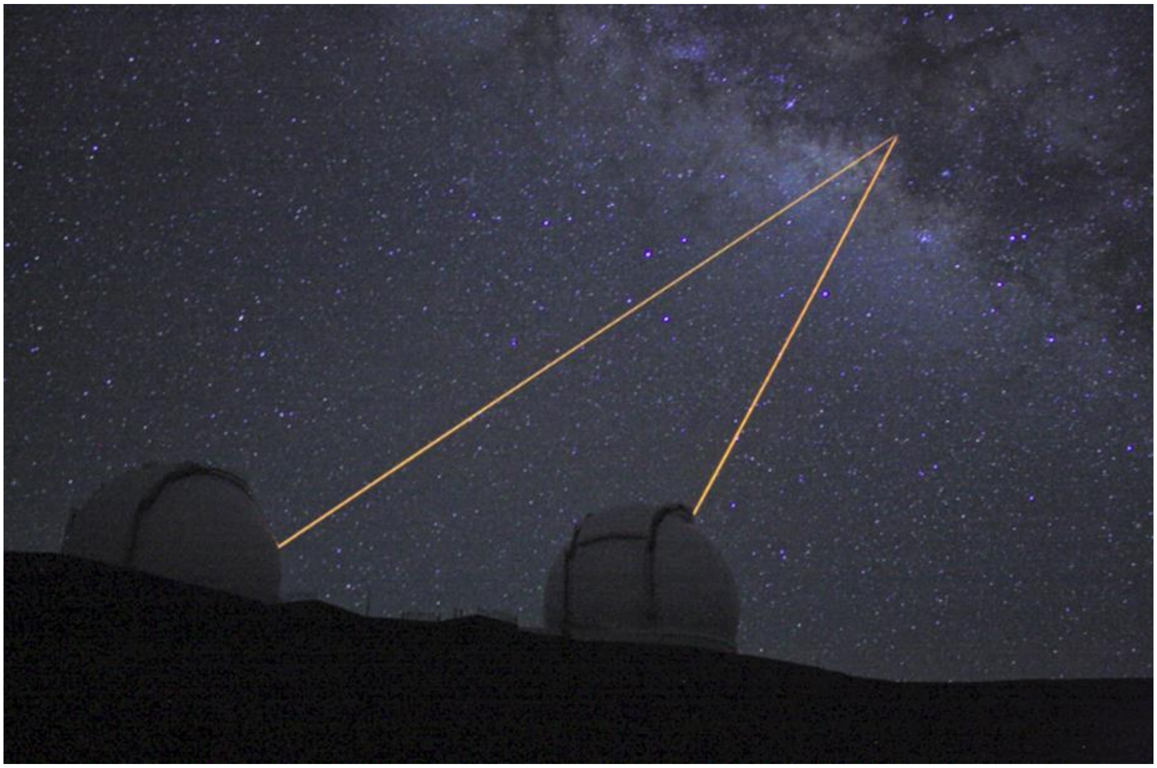

Figure 6. Adaptive optics is routinely employed in high resolution astronomy. The Keck telescopes at Mauna Kea uses adaptive optics to resolve the Sagittarius stars in the Milky Way galactic center. Reference beams such as these can be used to compensate for atmospheric disturbances while QBOLT system targets asteroids at 1-2 AU distances.[pic credit UCLA GCG]

The US Navy demonstrated a 30kW laser weapon system with pinpoint accuracy and instantaneous results and this technology continues to ramp up in energy levels and deliverable power, not to mention compact overall system footprint, enabling routine fieldability. Several mobile HEL systems are being tested currently by the various branches of the Department of Defense.[Figure 7] They include the USAF Airborne Laser, The US Army Mobile Laser System and other soldier/sniper carried portable systems, all being readied for battlefield applications [Atherton 2016]. High energy laser(HEL) beams focused on bodies like water-ice rich cometary surfaces can analyze constituents, provide accurate morphology and could be used to vaporize it [Lubin 2013].

Figure 7. The US Navy Maritime Laser, the USAF Airborne Laser and the US Army truck mounted high energy laser(HEL) systems are all approaching war-fighting fieldability.[credit US Navy, USAF and US Army]

IV. A Lunar High Energy Laser Complex

A Directed Energy system complex mounted on the far-side equator and poles of the Moon could be a versatile solution to mitigate small asteroids, and especially incoming cometary fragments in extremely high energy trajectories[Figure 8-9]. Interception of PHOs at close range (<1 AU) at short notice and without fielding any physical projectiles or nuclear devices become possible. The slow lunar rate of spin and orbit allows long integration periods for laser system and provides more field of view and accurate pointing to engage the target along line-of-sight. High energy lasers are capable of vaporizing all known materials during short beam dwell periods.[Lubin 2015] Operation in vacuum results in unattenuated DE energy levels, thus facilitating target reach with theoretical maximum energy, unlike in the Earth's atmosphere that causes linear and nonlinear phenomena like thermal blooming to alter the intensity distribution and intended beam direction. Furthermore, 82% of the far-side is out of Earth's view [Figure 10], thus a system based on certain locations of the far-side and the poles cannot be weaponized against the Earth. Mechanical jitter associated with lunar perturbations including moonquakes and other non-isotropic thermal effects imposed on mechanical systems by extreme lunar surface thermal gradients could pose some difficulty for target pointing stability, especially for the astronomical distances involved, but ultra-stable platforms like LIGO now allow ultra-precise active compensation for such aberrations.

V. Lunar HEL: A Versatile System

HEL systems on the Moon can be a versatile asset including support for extreme range communications, illuminating very faint deep space objects, probing and spectrally characterizing asteroids, mitigating micrometeoritic showers and providing protection from impacting debris as well as beaming propulsion and power for spacecraft [Lubin 2013].

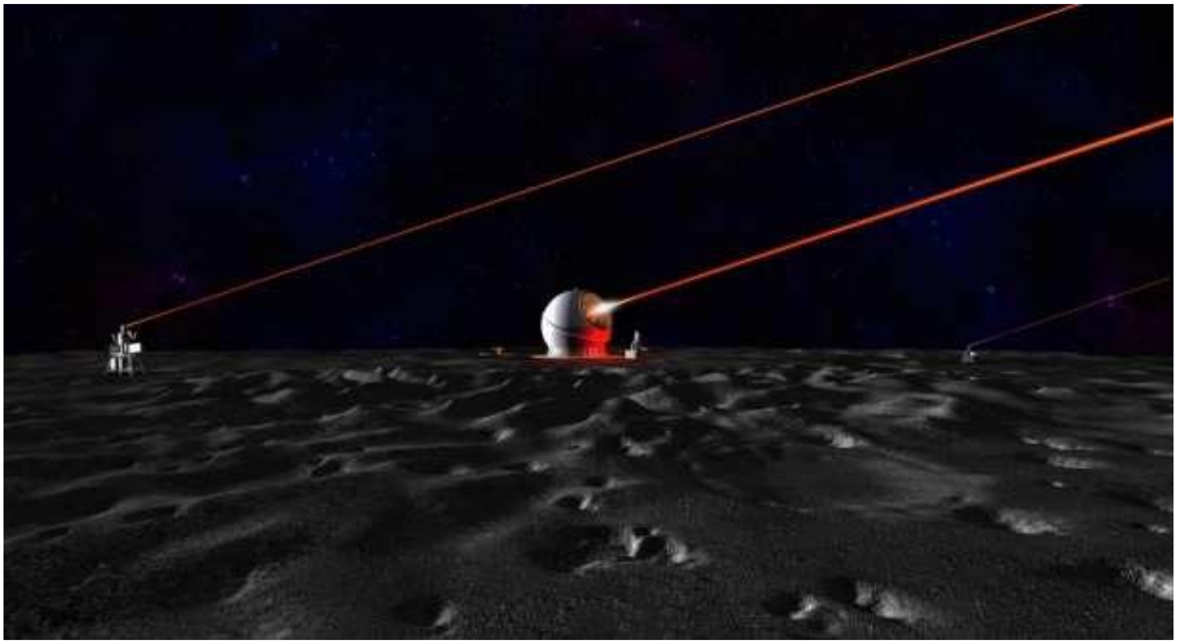

Figure 8. A High Energy Laser(HEL) Directed Energy(DE) system Complex for Planetary Defense on the far-side of the Moon for mitigating an emergency short warning threat posed by potential "city killer" asteroids and cometary fragments that we now know happen more often than previous estimations.

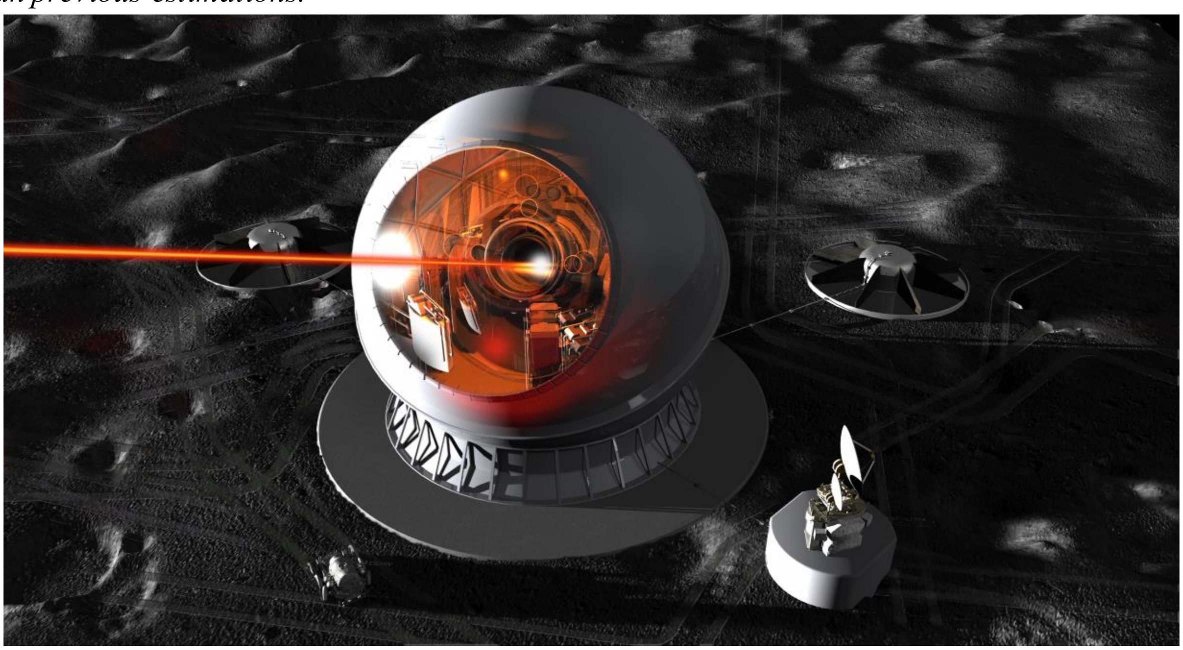

Figure 9. Concept for a high energy laser complex on the far side of the moon.

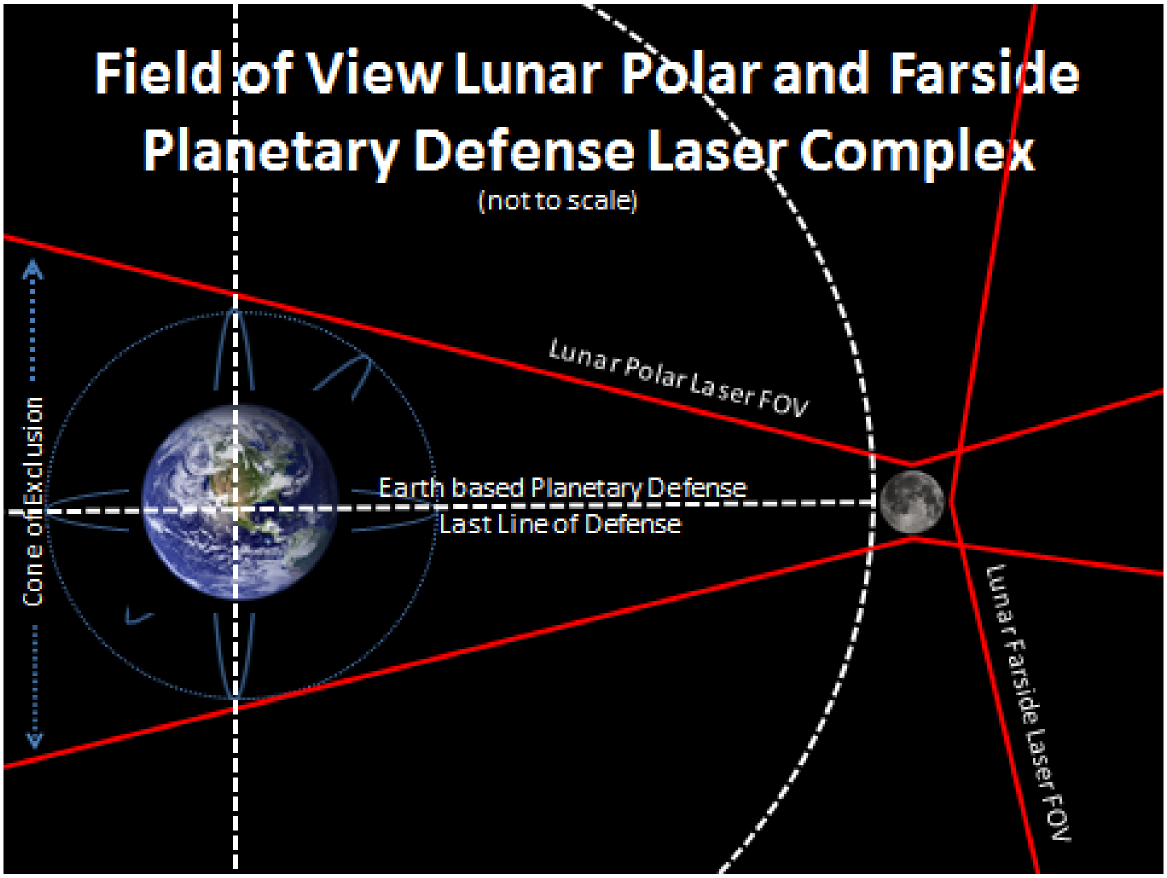

Figure 10. Unlike proposed space based HEL platforms, HEL systems on the polar and far side regions of the Moon may be situated so that they cannot be turned toward Earth, effectively circumventing a policy nonstarter issue that such a system is a space based weapon.

Currently, long term PHO threats are assessed and refined based on progressive trajectory analyses that refine the terminal approach trajectory of the PHO and impact location. Such data is reduced more accurately with each iteration as more accurate information about approach trajectory is gathered from muliple observations from various Earth and space based observatories. For PHOs being tracked over multiple orbits and decades before potential Earth impact, "keyholes" are narrow regions along its orbital track that provides confidence of eventual tryst with Earth. While early detection is key[Yeomans 2012], in case of an emergency, for whatever reason, where a PHO is not detected till it is very close to Earth impact, some sort of threat gate levels and appropriate response strategies need to be established. Lunar Sentinel concept architecture lays out such a threat level gate classification for an PHO detected at a radius of up to IAU from Earth impact.[Figure 11] Lunar and Earth based actionable response may be warranted. Current studies show that at such close proximity, the most viable option remains detonating nuclear devices at or within the interior of the PHO.[Wie 2013] At close range, nulcear dust fallout is a concern. HEL systems do not have that issue associated with it and may provide a better policy option if we choose to field such a system.

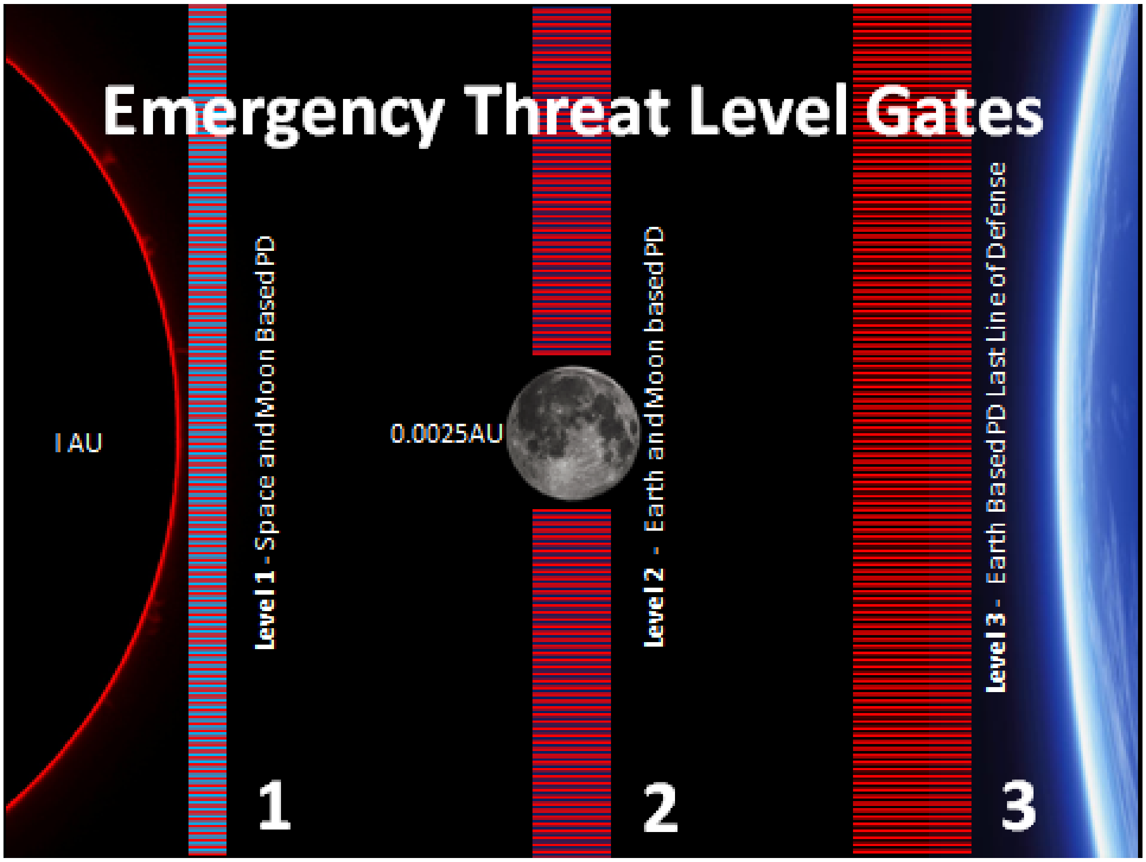

Figure 11. Lunar Sentinel Concept Architecture proposes a scale for emergency threat level assessment and actionable response from the Moon and Earth if a PHO escapes detection till it crosses the 1AU threshold.

VI. Conclusion

A Directed Energy system complex mounted on the far-side equator and poles of the Moon could be a versatile solution to mitigate small asteroids, and especially incoming cometary fragments in high energy trajectories [Figure XX 1]. Interception of PHOs at close range (<1 AU) at short notice and without fielding any physical projectiles or nuclear devices become possible.

The Lunar Sentinel concept proposes using our Moon as an emergency layer of defense for planetary defense; mitigating small "city killer" type NEO/cometary fragment threats that are still difficult to detect well in advance using current technologies. Range of effective operations is 1AU. Merits and challenges are addressed.

Lunar Sentinel offers a clear and defined mandate for yet another use of our Moon; to keep watch and protect planet Earth as well as proposed high value assets on the Moon from hazardous impactors including micrometeoritic showers. Lunar HEL is a versatile concept that circumvents many difficulties associated with meeting a PHO threat with a nuclear response at close quarters, making it a more policy amenable option. Detailed investigations, both in the policy and engineering disciplines are warranted for using the Moon as a Planetary Defense asset for Earth and our Moon. Lunar Sentinel is one such example that needs further study.

VII. Acknowledgements

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The team project slides for each of the sections discussed during the studio, including Lunar Sentinel: Planetary Defense from the Moon, may be accessed at : https://sites.google.com/a/usc.edu/aste527/home under the topic "08 -LunaRevolution-Role of the Moon in the Future of Human Space Activity" and also under team project Eden Shield.

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