9TH IAA INTERNATIONAL PLANETARY DEFENSE CONFERENCE

STELLENBOSCH – CAPE TOWN SOUTH AFRICA

5-9 MAY 2025

M.THANGAVELU

Conductor, ASTE527 Graduate Space Concepts Studio

Department of Astronautical Engineering & School of Architecture

University of Southern California

mthangav@usc.edu

LOSSOL: Line of Sight Speed of Light Directed Energy Laser Planetary Defense

M.Thangavelu

Conductor, ASTE527 Graduate Space Concepts Studio

Department of Astronautical Engineering, Viterbi School of Engineering & School of Architecture

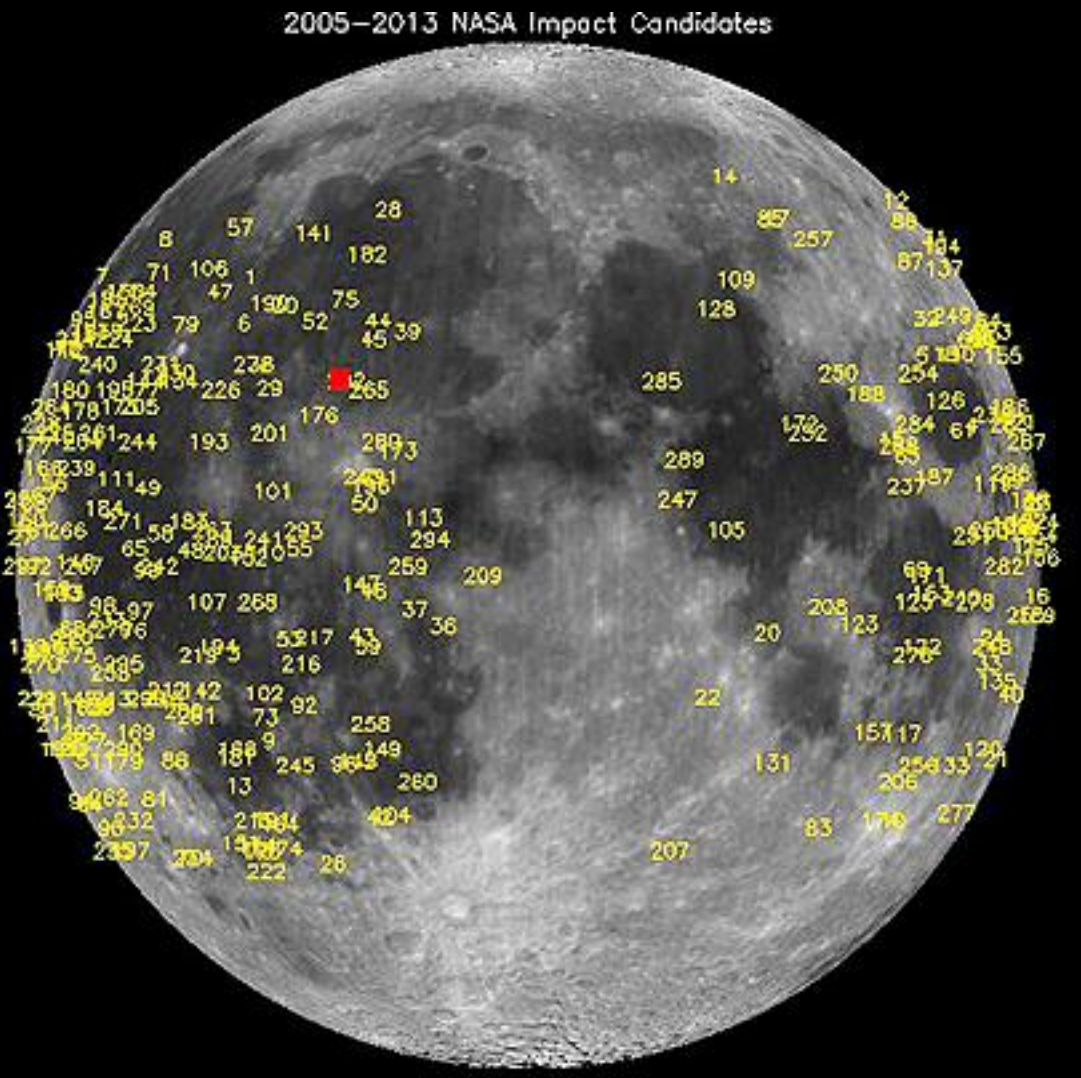
University of Southern California

mthangav@usc.edu

JEDI - Joint Earth-Moon Defense Infrastructure

- Depending on object characteristics, energy and approach geometry, a bolide impact on our Moon is as bad for planet Earth as it is for our Moon
- Poses threat to exposed assets on our Moon - Observatories
- Secondary orbital debris generated by impactor can cause havoc to high value assets in the cislunar regime
- Long-lasting and persistent threat
- Proposed solution - JEDI
- Modelling needed

Our Moon is a Easy PD Target

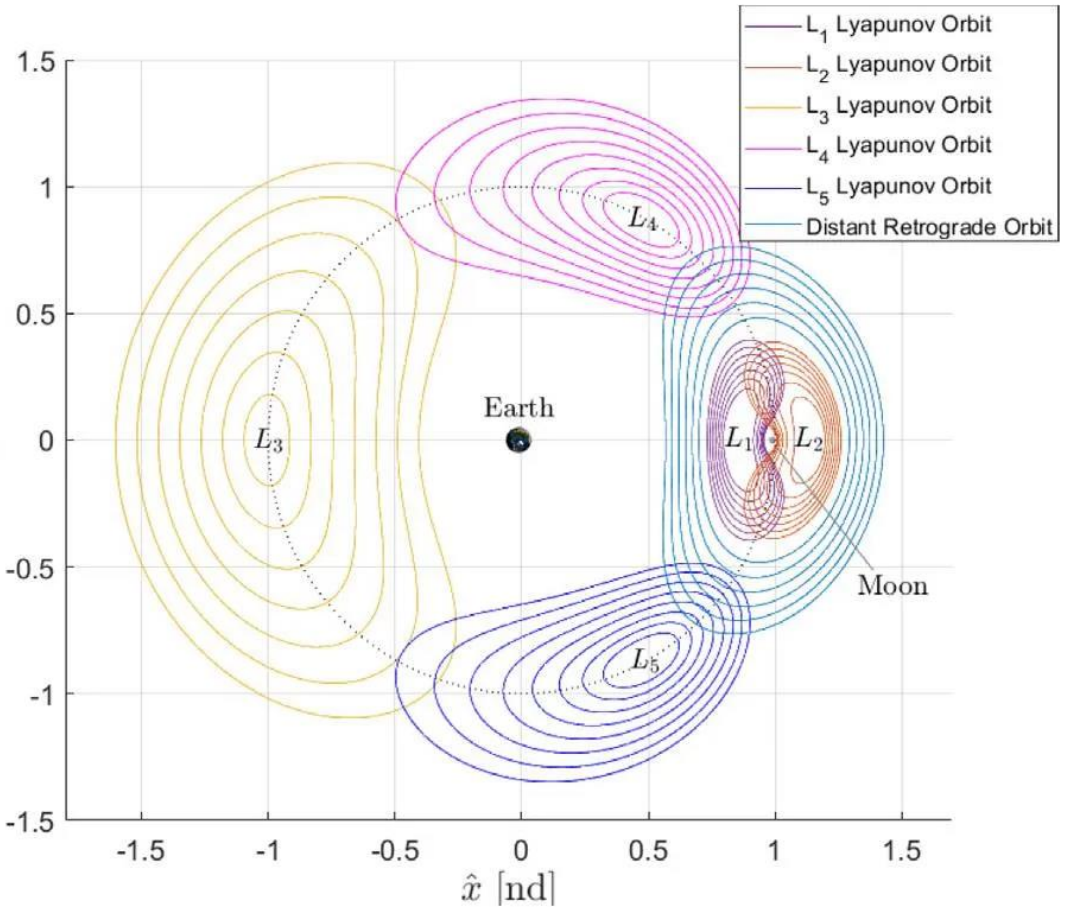


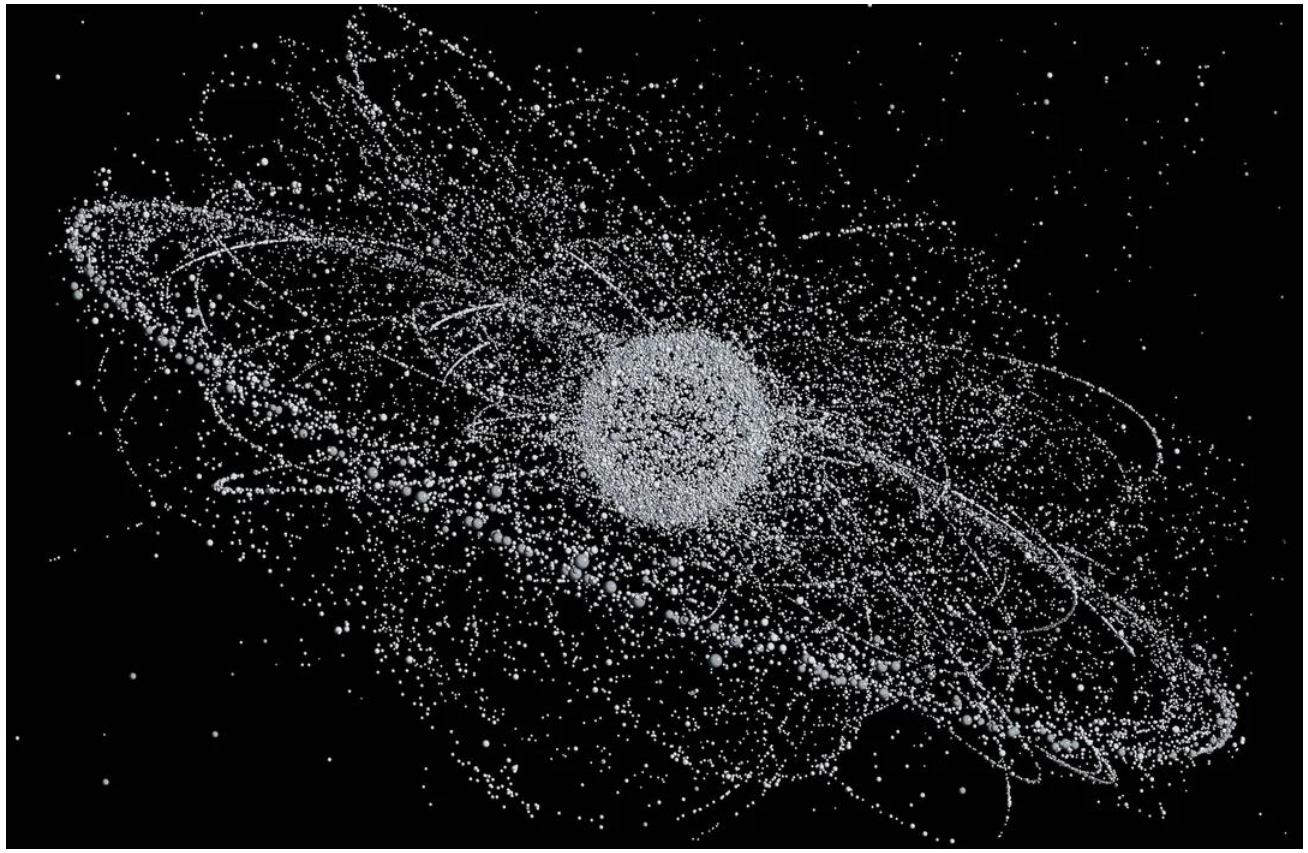
Planetary Defense

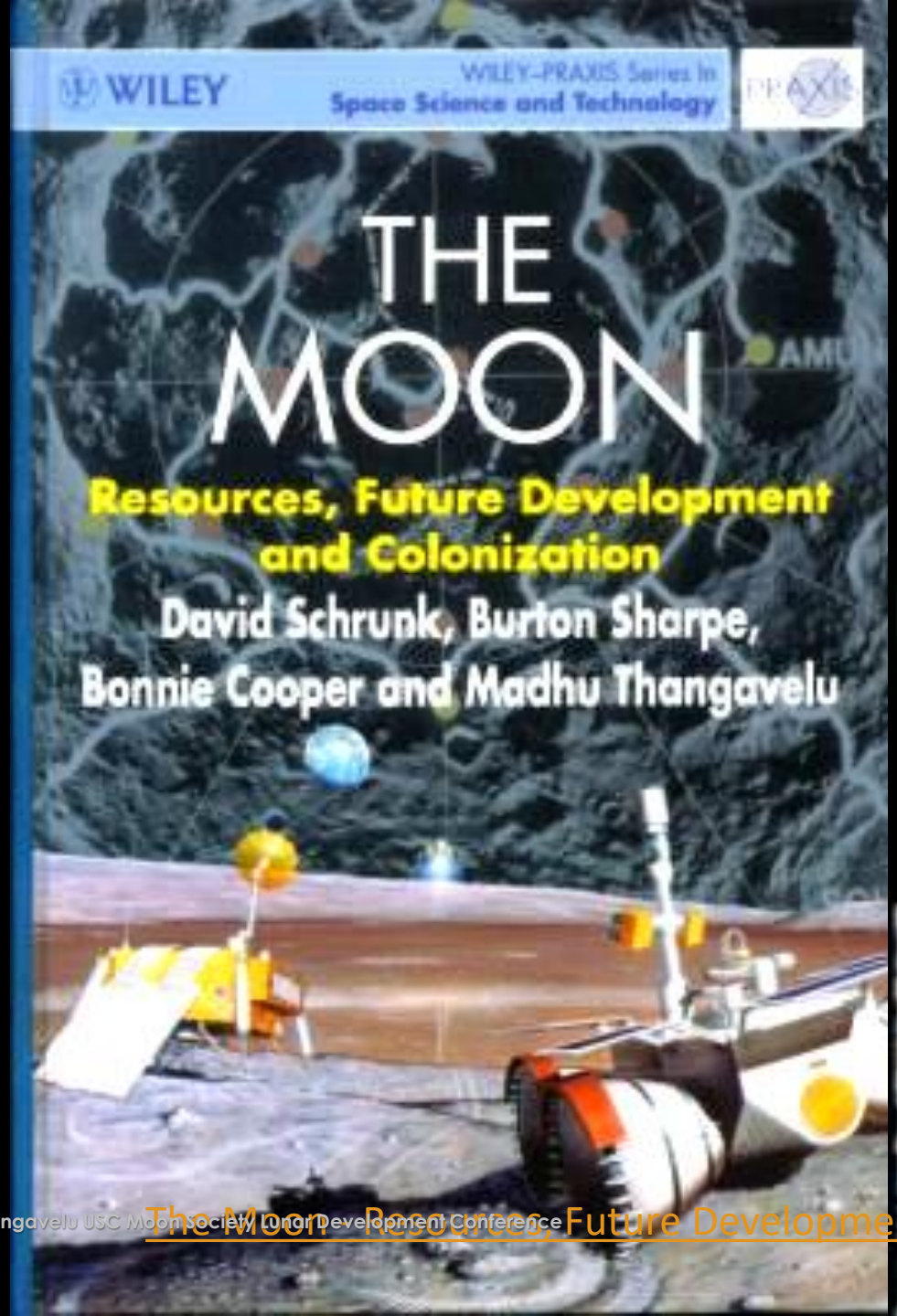
JEDI

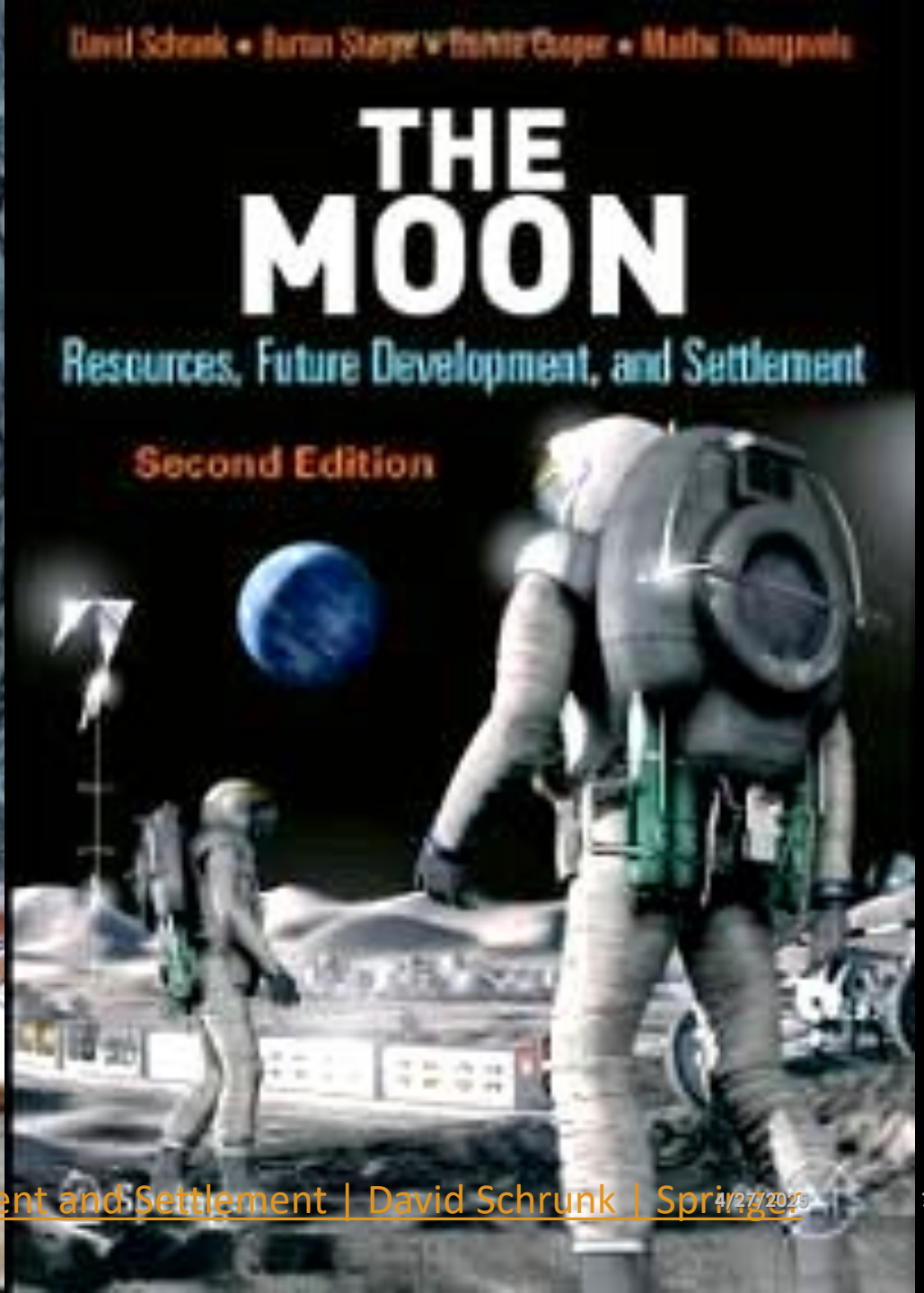
Joint Earth-Moon Defense Infrastructure

In Cislunar Space…
…Debris anywhere is Hazard everywhere



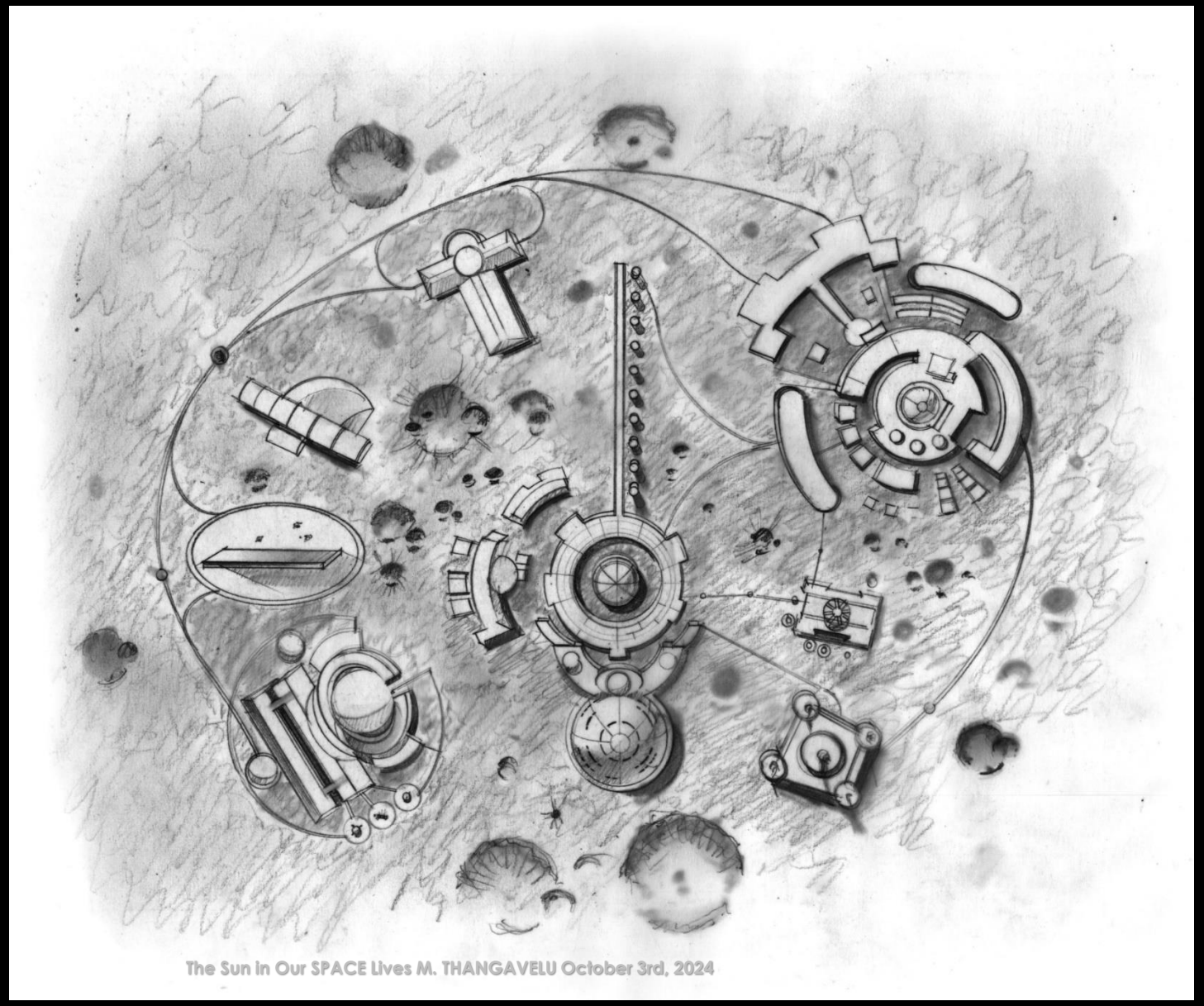


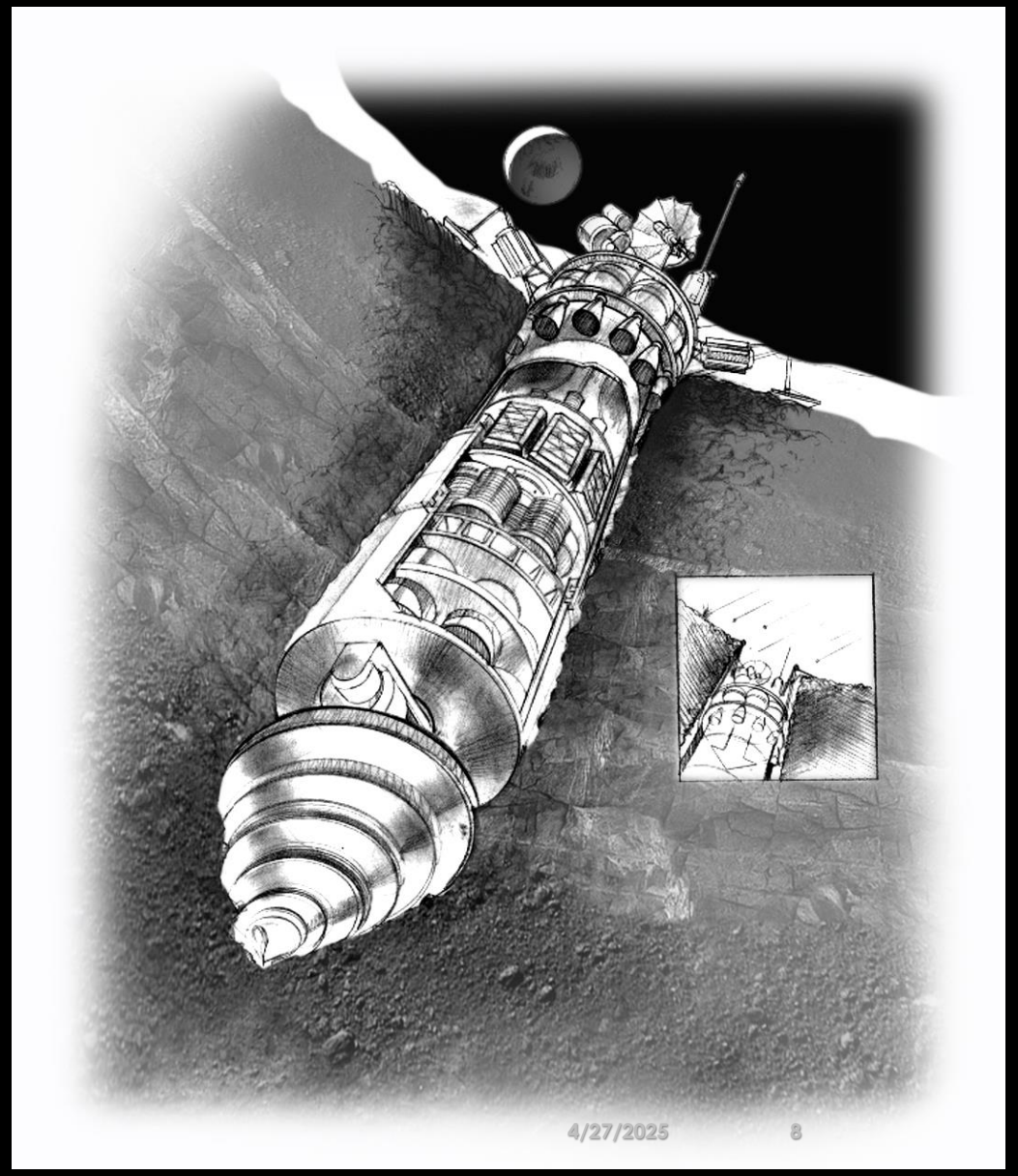




The Moon: Resources, Future Development and Settlement | David Schrunk | Springer

LUNAR UN SUMMIT HQ. & HUMANITIES NEXUS





LOSSOL Threat Mitigation Strategies

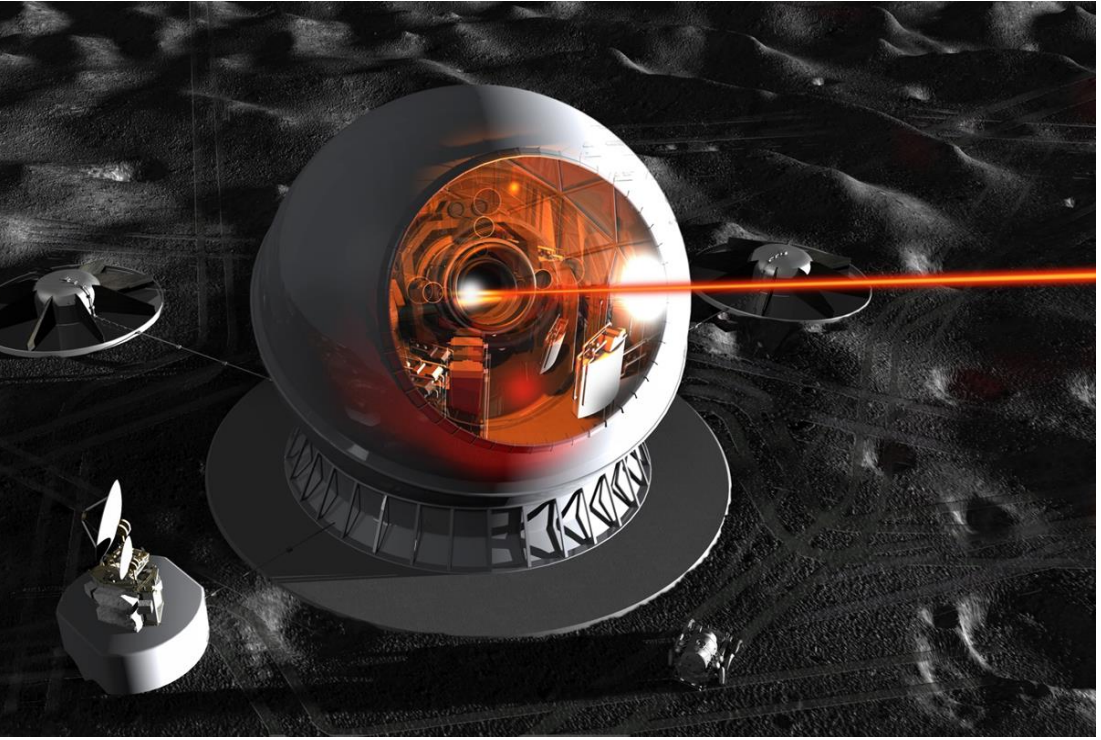
- Surveillance
- Observation
- Detection
- Characterization
- Early Warning
- Alert
- JEDI System Activation
- Close DE interception & Neutralization

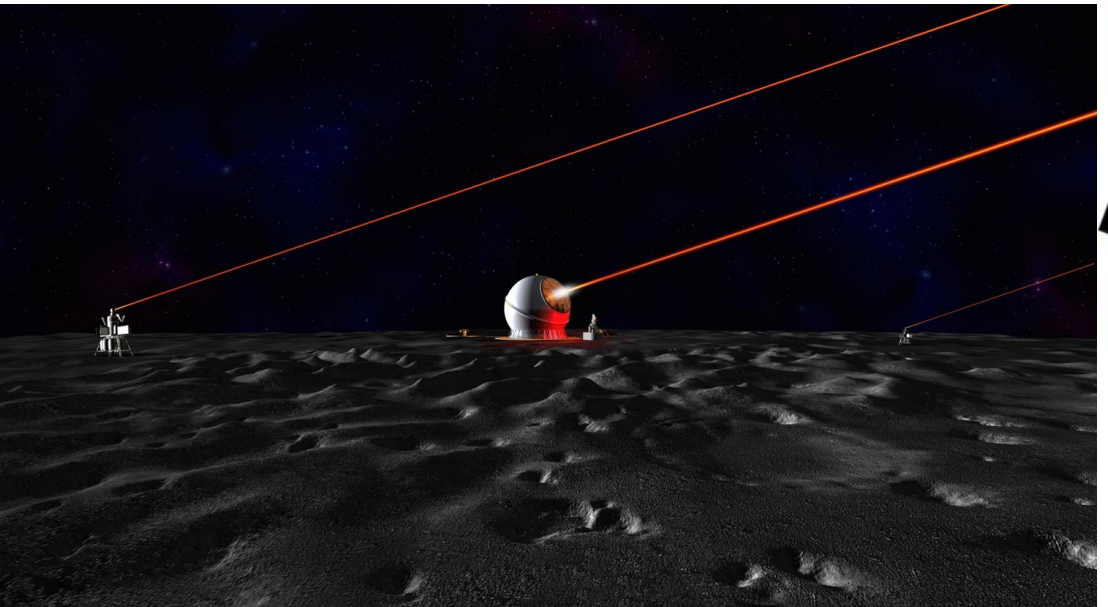
Assumptions

- Meteor shower or bolide impactor
- Targeting high value asset or in proximity
- 36,000km/hr impactor on terminal trajectory
- JEDI Module integrated into high value asset architecture
- Added Capability to Evolution of Global Space Situational Awareness Network

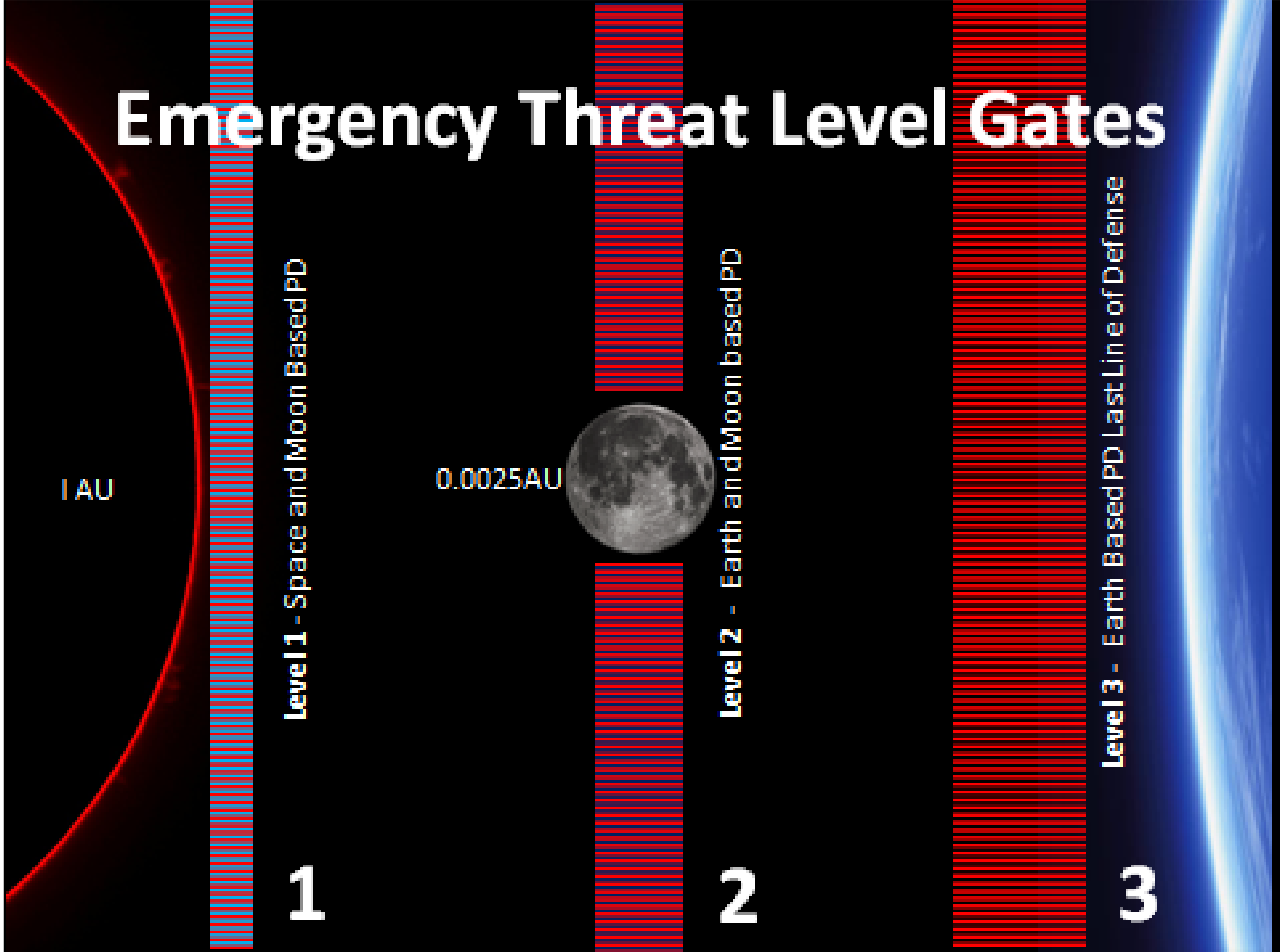
LOSSOL Interception Strategy

- Rapid Automated AI assisted Mitigation
- 36,000km/hr meteor shower
- Detection and terminal trajectory verification @ 360,000km
- SSA Network concurrence and LOSSOL System tracking operational
- 10hr Alert & Early Warning issued
- 1 hr from impact – LOSSOL System armed, locked- on and tracking
- 1hr to < 1min – Continuous Artificial Intelligence assisted engagement



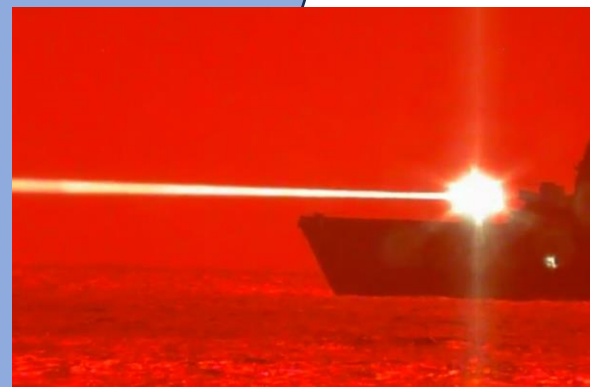



Ai assisted collage
© M.Thangavelu Sep 2024

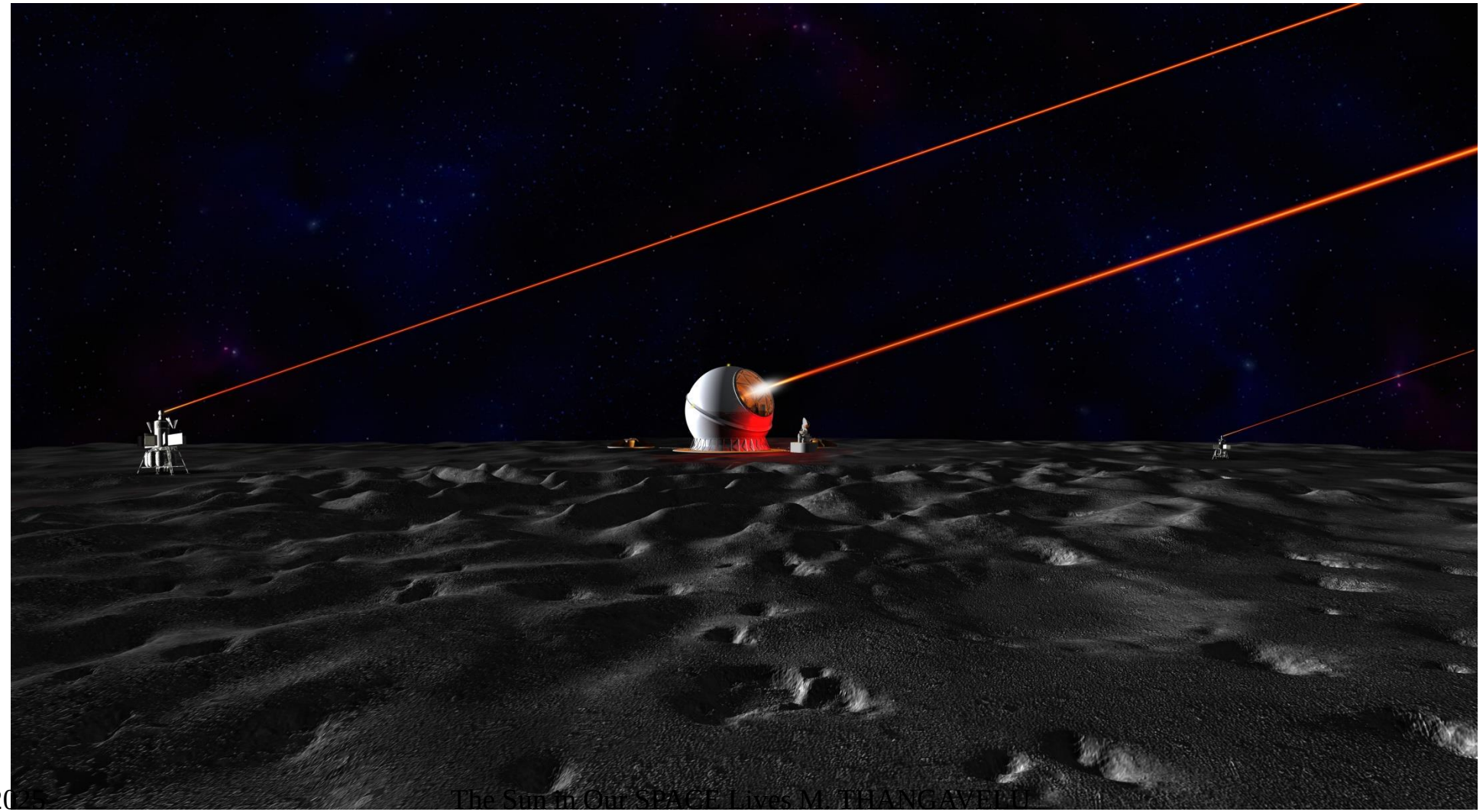

Emergency Threat Level Gates
1 AU
Level 1 - Space and Moon Based PD
0.0025AU
Level 2 - Earth and Moon based PD
Level 3 - Earth Based PD Last Line of Defense
1
2
3

LOSSOL JEDI Earth-Moon Directed Energy PD Threat Mitigation Gates

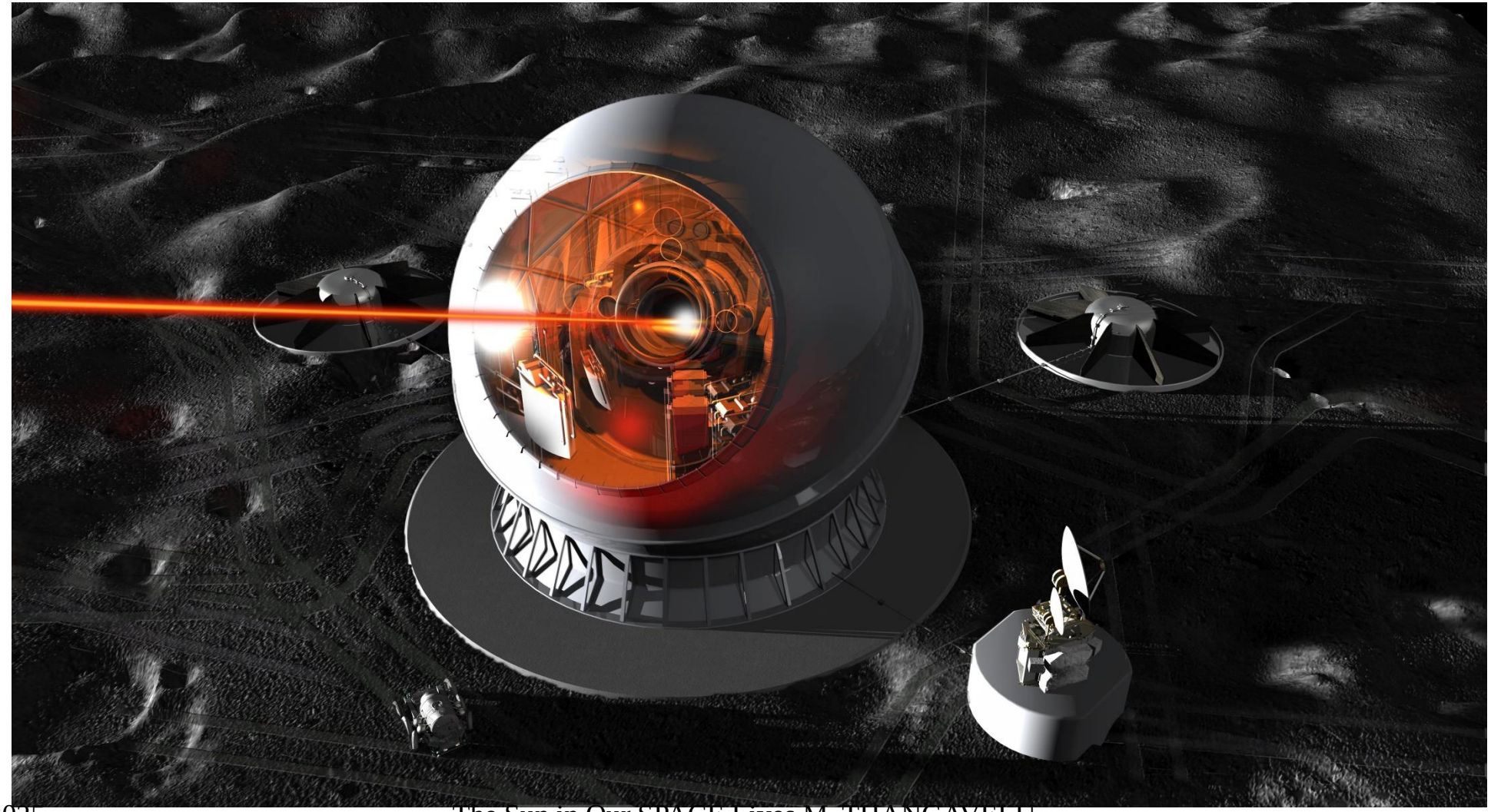
(not to scale)



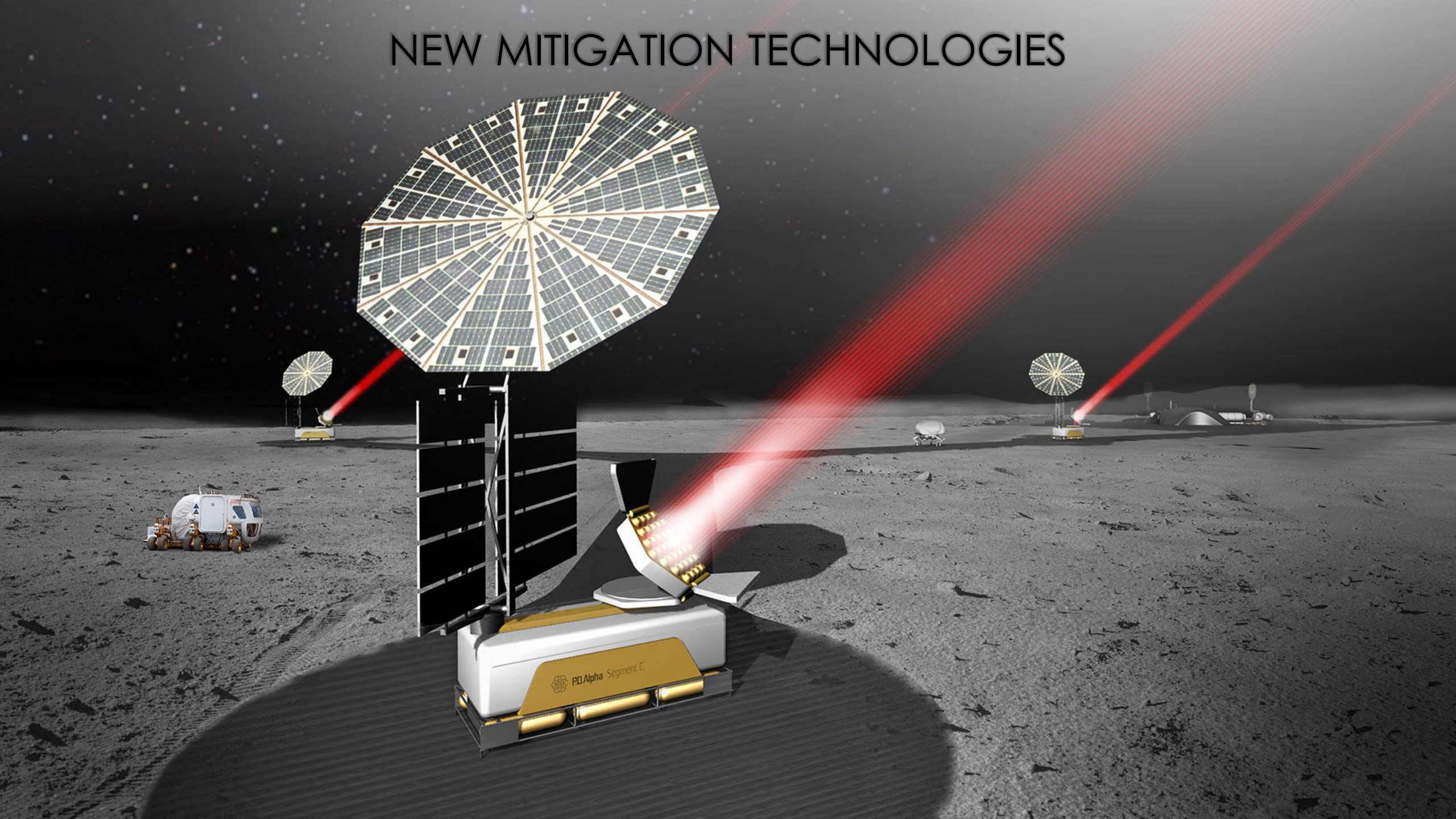
Lunar Laser Complex



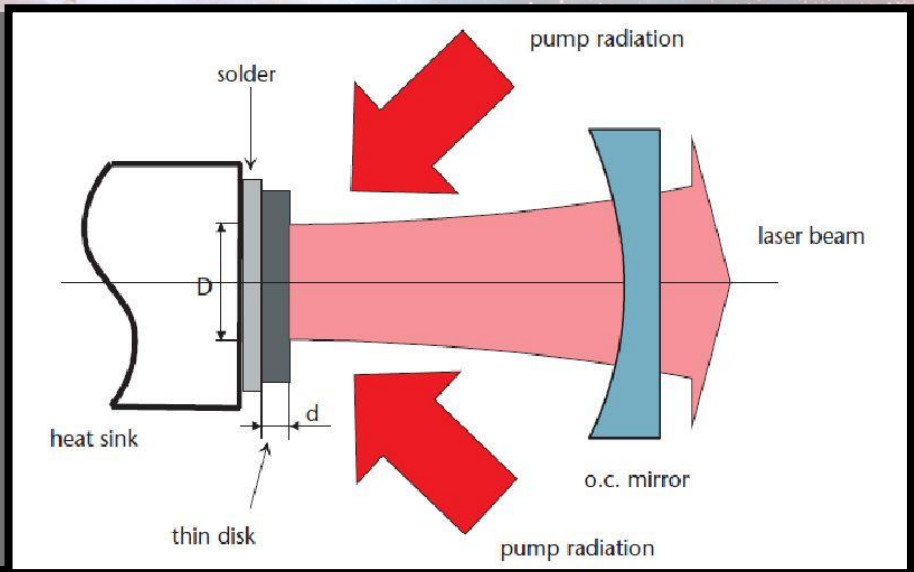
Lunar High Energy Laser(HEL)



NEW MITIGATION TECHNOLOGIES

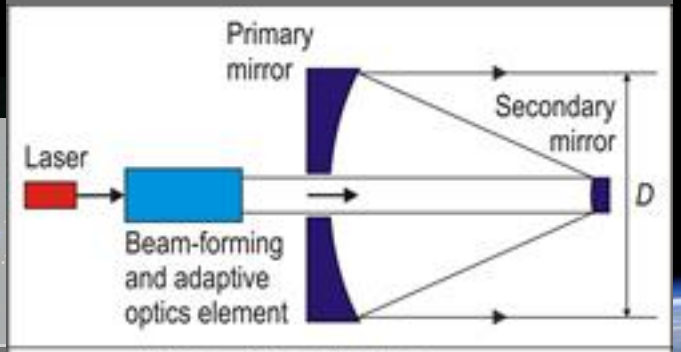


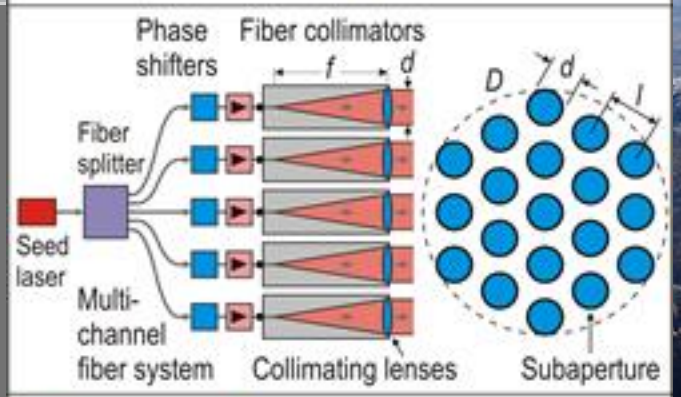
KYBER System

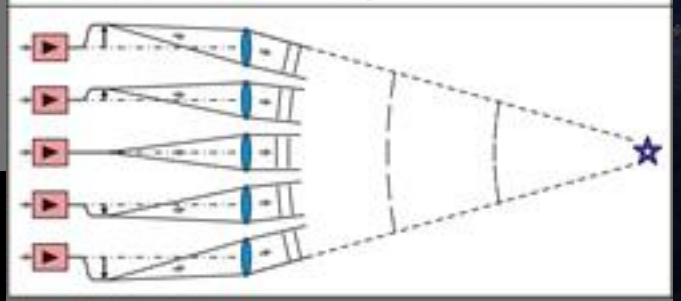


Based on:

- DE-STAR program
- Breakthrough StarShot
- Orion Project/Laser Broom







Laser output is approaching the capabilities of **1kW/kg**

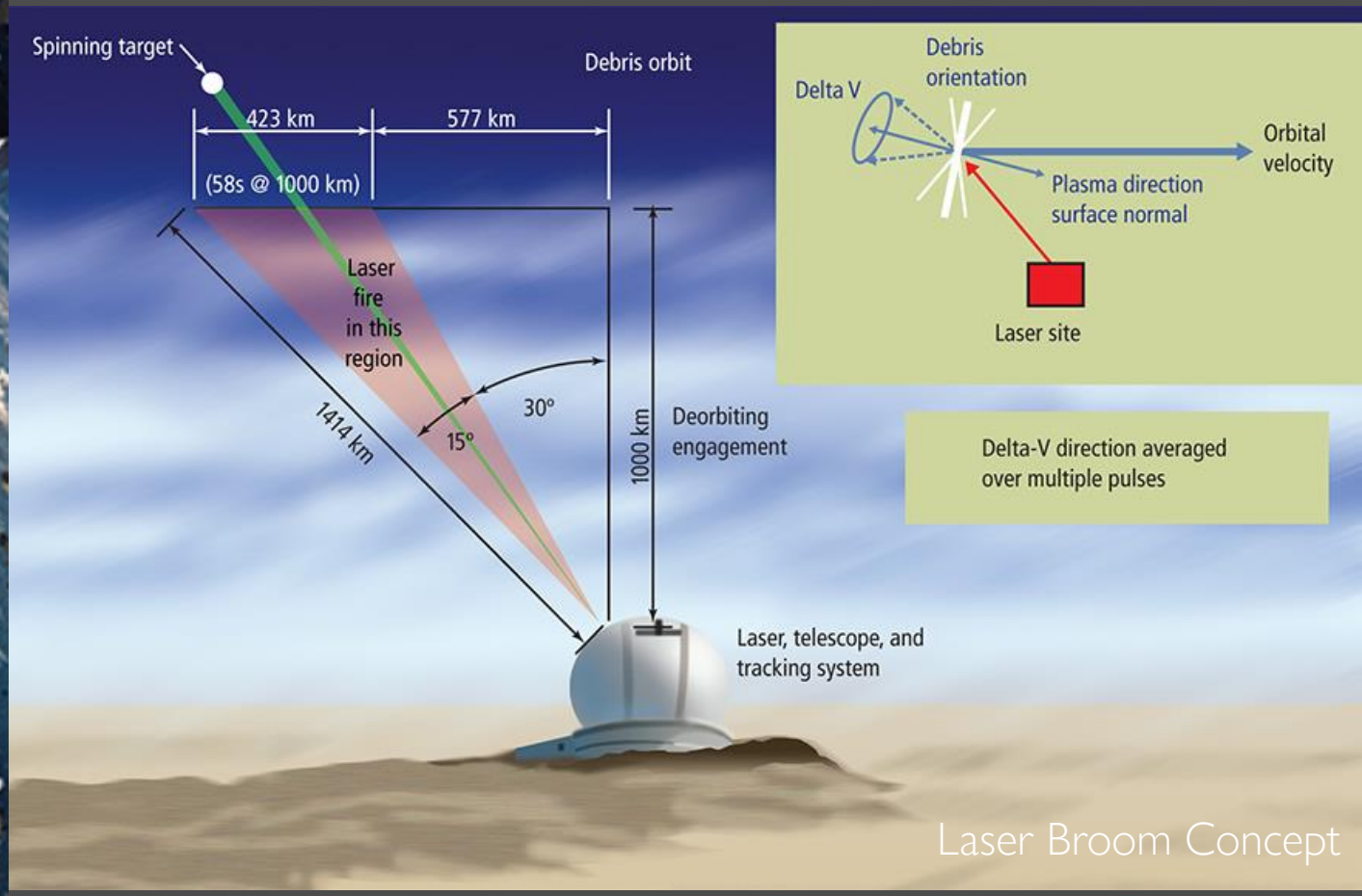
How does it work?

Each KYBER system would consist of a battery of up to 12 solid state thin-disk laser systems with a total laser power output approaching 100kW

Adaptive Optics

- Targeting through the atmosphere

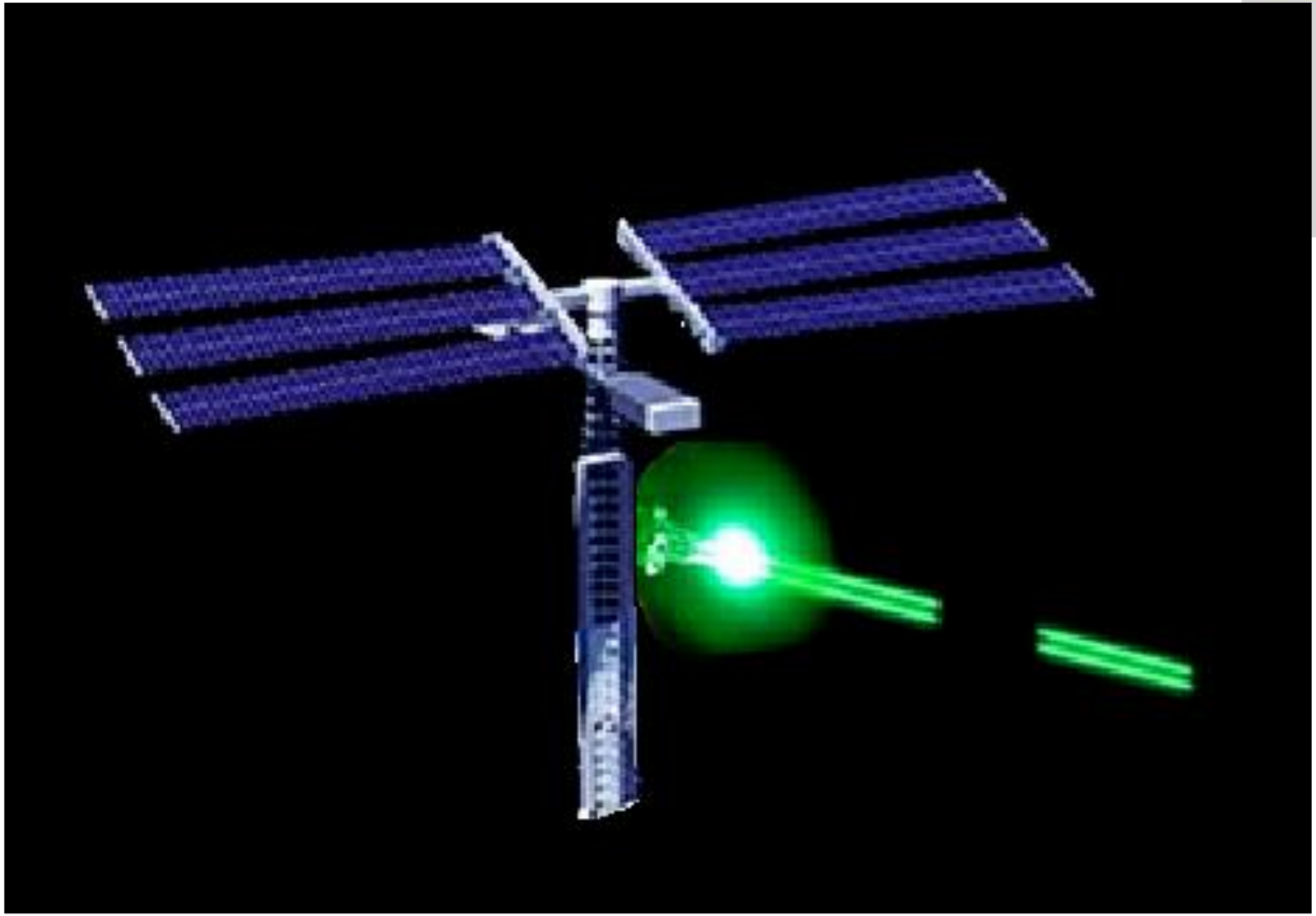
At low twilight or dawn, illuminate these very small objects that may have intersecting orbits and zap them

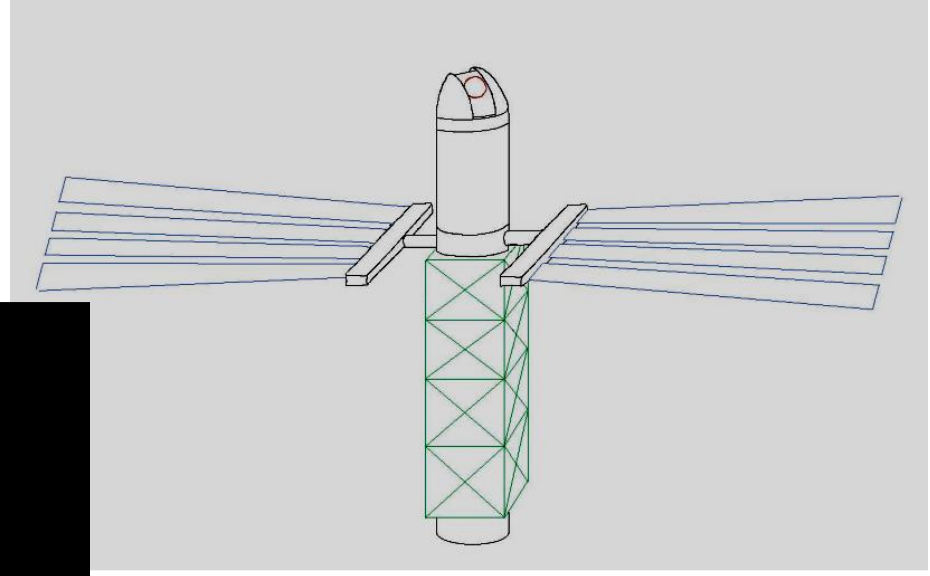


Laser Broom Concept

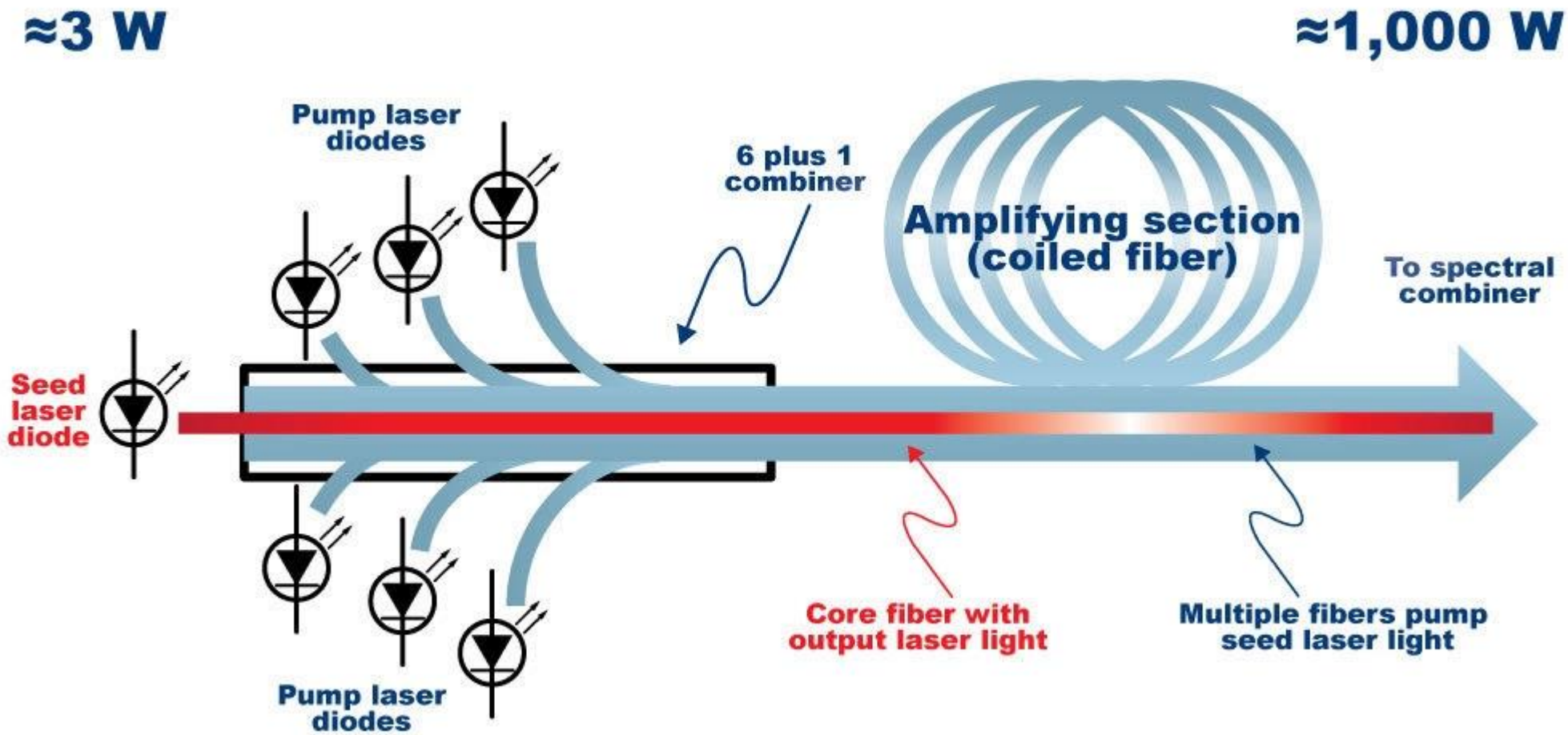
USC Astro Studio KYBER - Based on UCSB DESTAR Concept

Laser Debris Mitigation on ISS



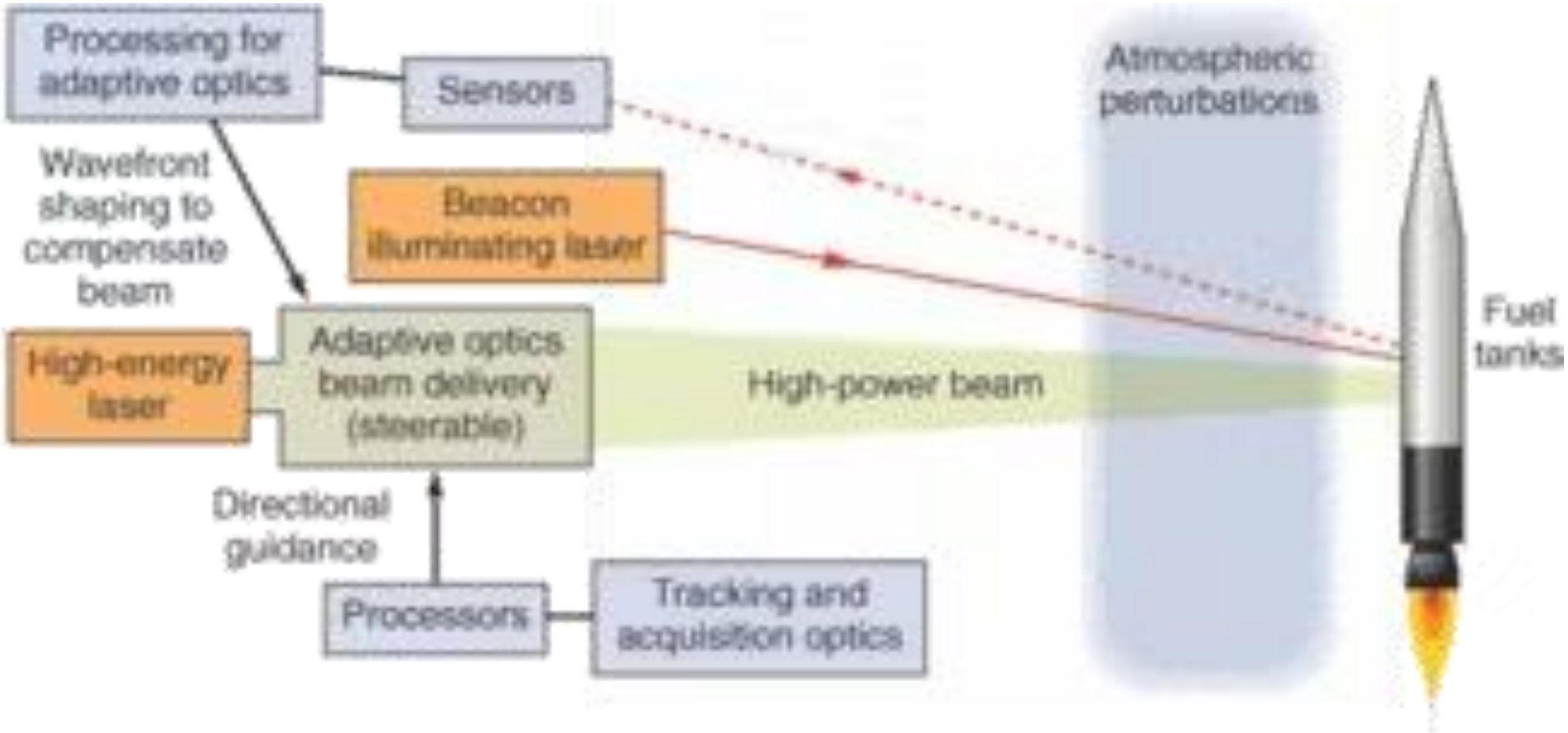


Directed Energy Laser Technologies

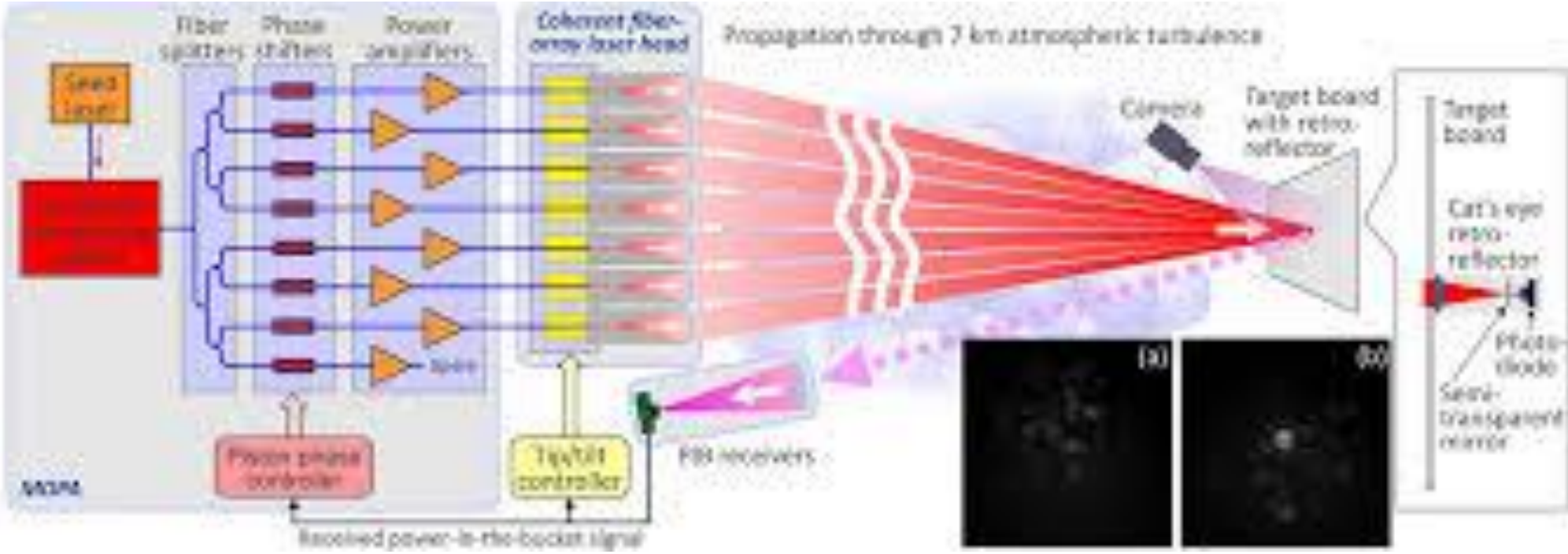


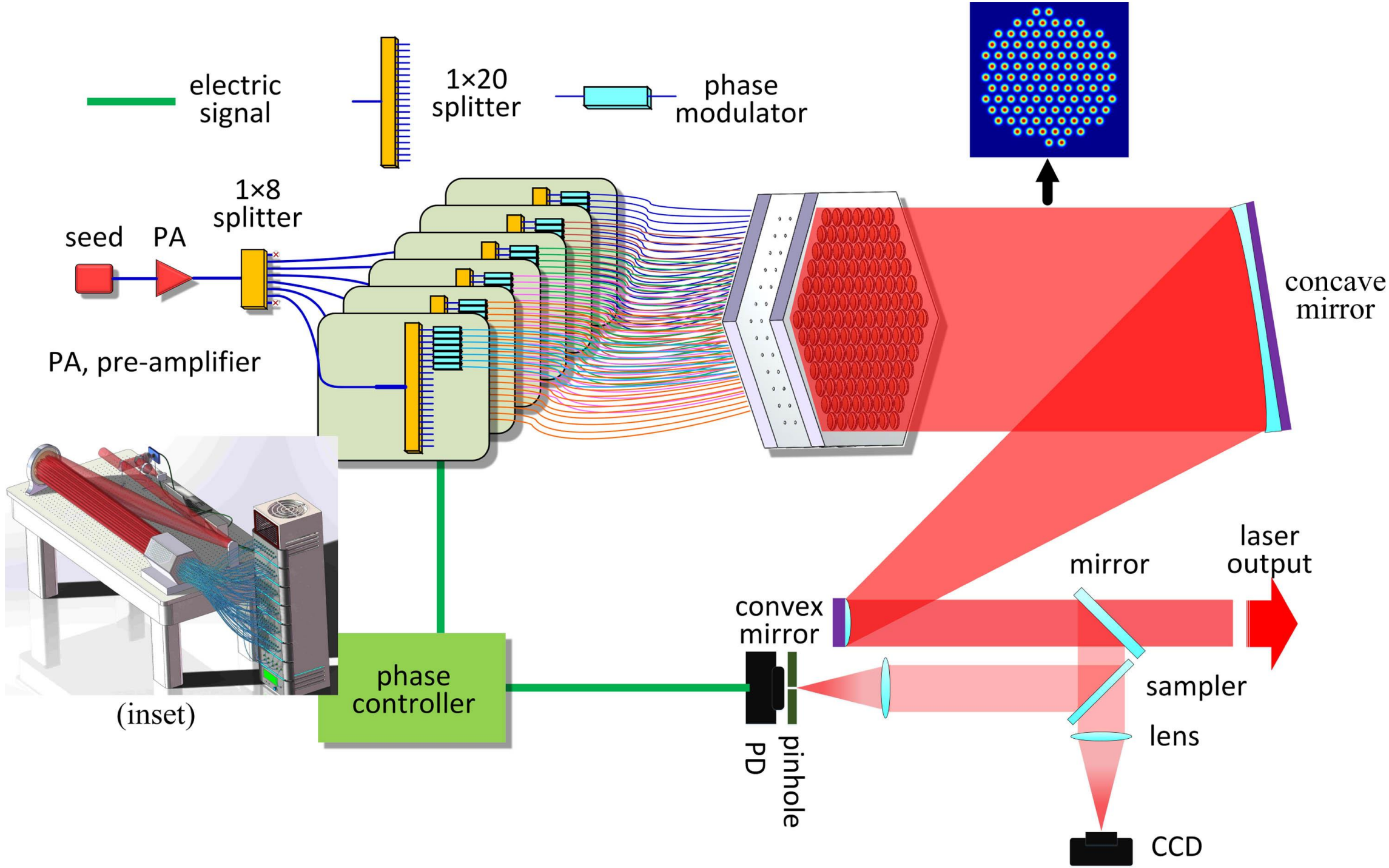
Directed Energy Laser Technologies

https://www.laserfocusworld.com/test-measurement/research/article/16550016/the-airborne-laser-shoots-for-ballistic-missile-defense

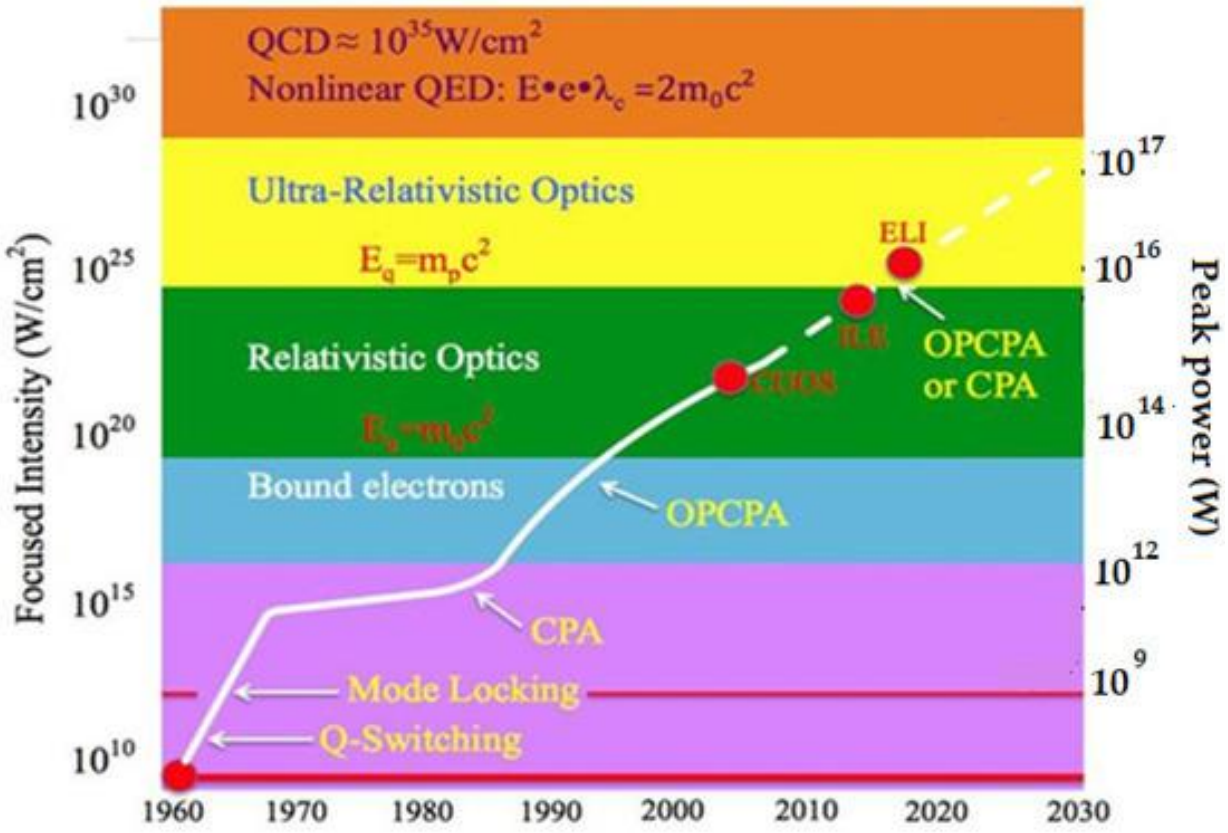


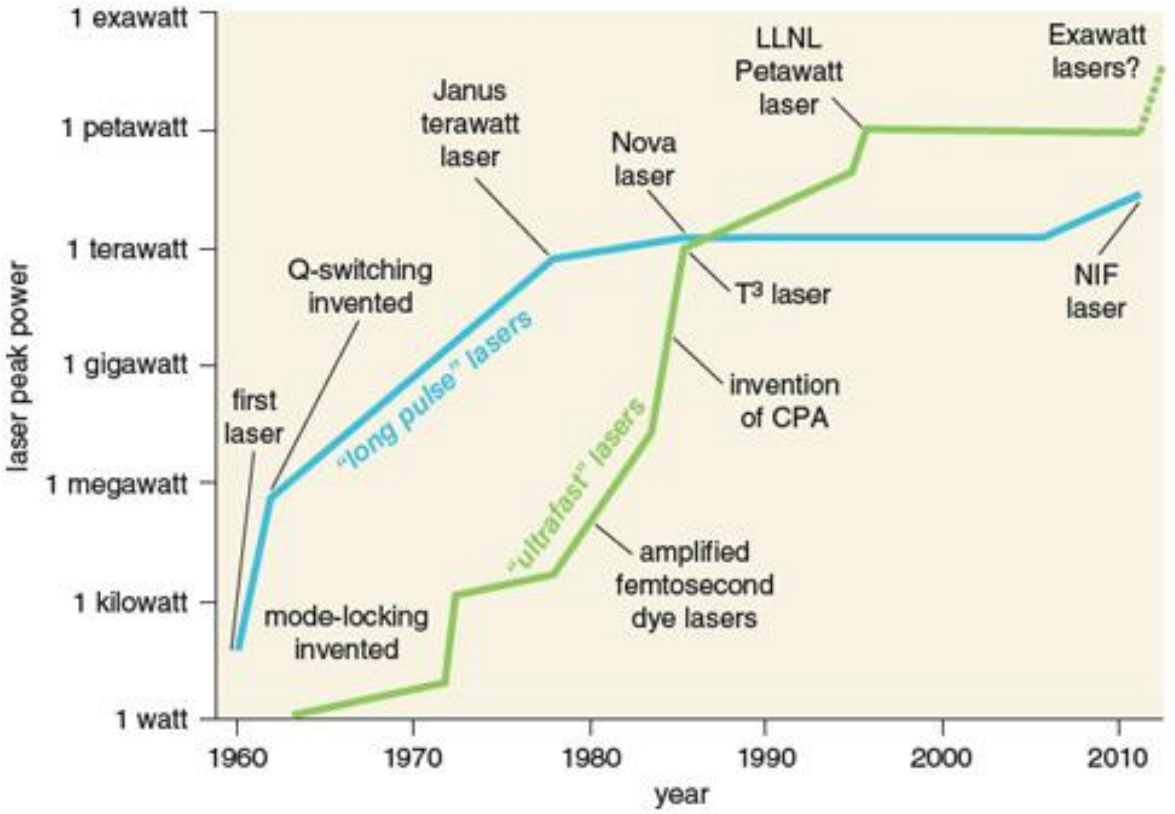
Vorontsov Phased Array Laser Technology




electric signal
1×20 splitter
phase modulator
1×8 splitter
seed
PA
PA, pre-amplifier
concave mirror
(inset)
phase controller
convex mirror
mirror
laser output
sampler
lens
PD
pinhole
CCD

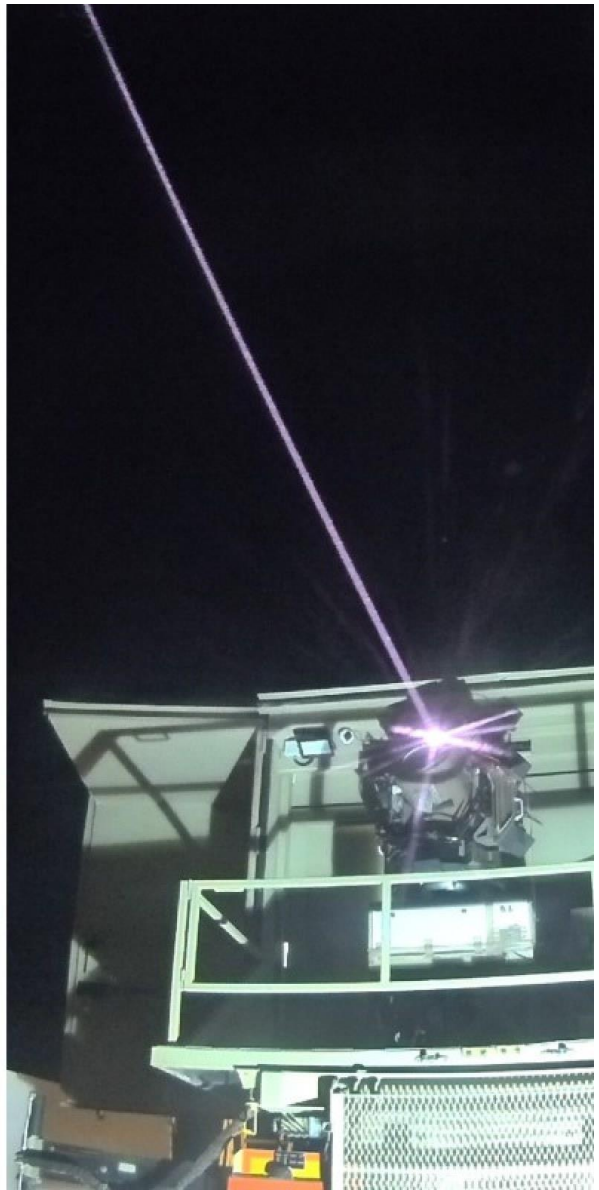
High Power Laser Levels





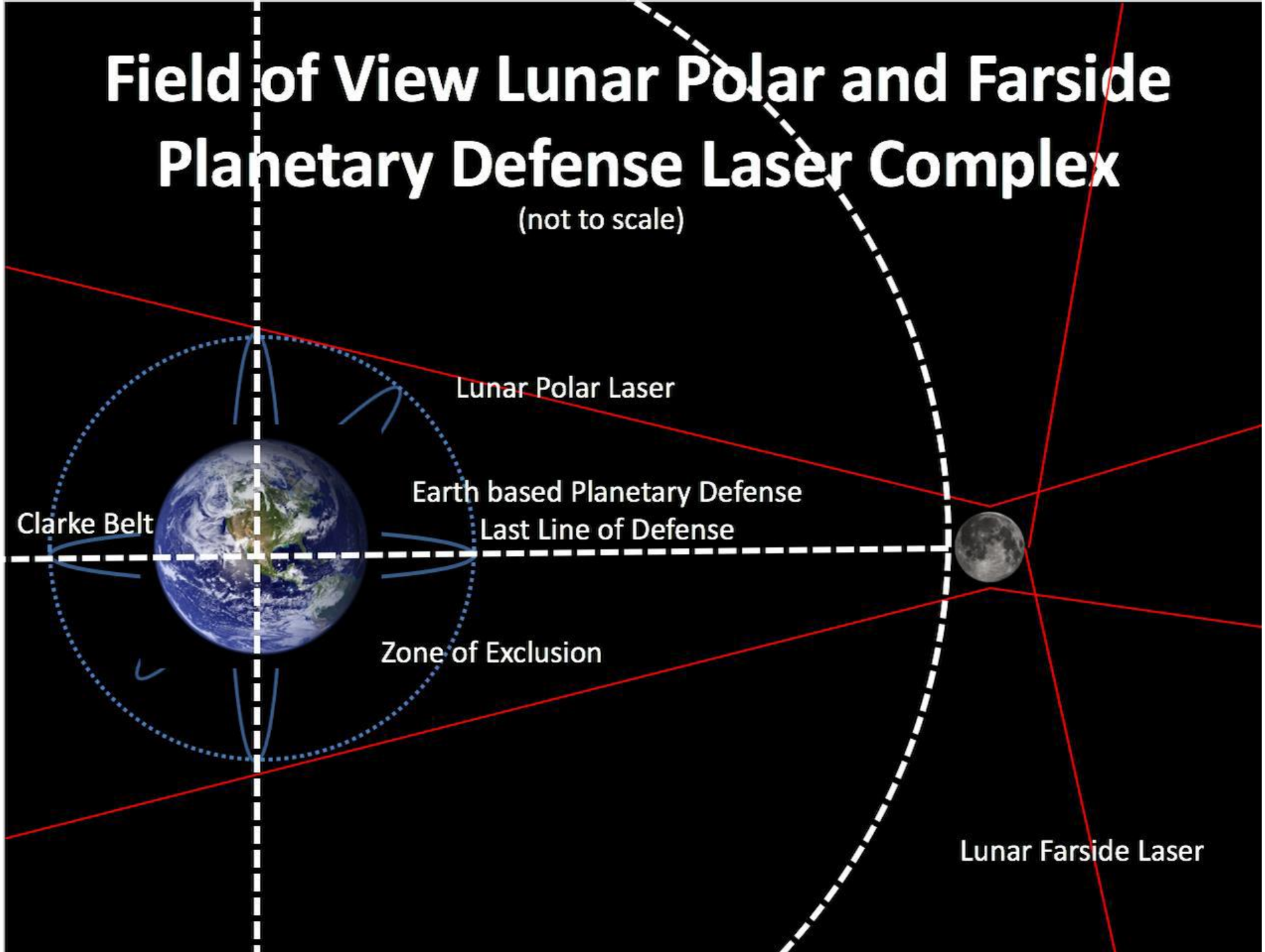
High Power Density SuperCapacitor Banks for LOSSOL

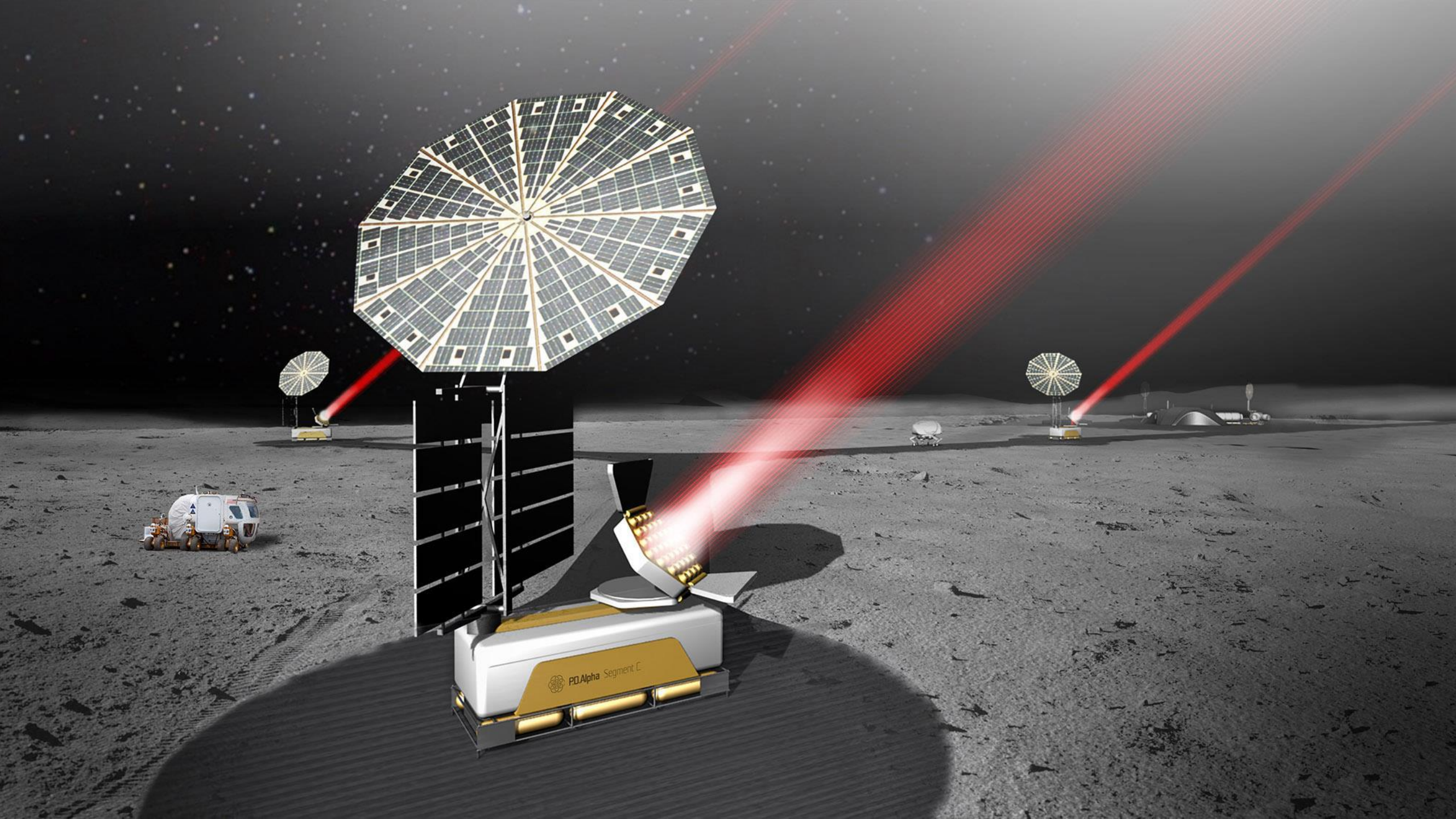
LOSSOL Planetary Defense is A Dual Use Technology



Field of View Lunar Polar and Farside Planetary Defense Laser Complex

(not to scale)




P.D.Alpha Segment C

https://moonvillageassociation.org/

Moon Village Association

The concept of a "Moon Village" is the ensemble of all efforts from private, governmental and others, aiming to explore and use the moon in a sustainable manner. It is not a literal village on the moon, it is not an "*International Space Station on the moon*" and it is not a single science facility.

Non-Intervention Aftermath

- Direct bolide strike - Loss of lunar surface Exposed Asset
- Lethal, persistent secondary debris production on all exposed lunar surface, orbital and cislunar assets
- Threat to high value Earth orbital assets
  - Space based Communications Network - Common Defense and Civilian
  - Space Situational Awareness Observatories
  - Scientific Observatories
- Secondary impactor(s) - globally dispersed threat to Earth

LOSSOL Merits and Challenges

- Continual horizon-to-horizon surveillance
- Rapid Detection - Morphology and Spectral Characterization
- Precise Impact Point Trajectory Forecast
- Point-and-Shoot – No complex GNC
- Precise, Close to Impact Point target Interception and Neutralization
- Artificial Intelligence Algorithm Augmentation
- Addition to Space Situational Awareness Network
- LOSSOL is a Dual Use Technology – Civilian and Common Defense

- Challenges include:
- Weapons in Space Policy Implication
- Some surmountable technical issues
  - Pointing
- Large and reliable Power Systems(Super Capacitor Banks)
- Maintenance

References

- Aghdasi, F., Caillouet, T., Chao, A., Ives, B., Lali, M., Perakalpudi, N. V., ... & Vasmate, V.(2012) LunaRevolution-Role of the Moon in the Future of Human Space Activity. USC Eden Project
- Campbell, Jonathan (December 2008). "Using Lasers in Space: Laser Orbital Debris Removal and Asteroid Deflection" (PDF). Occasional Paper of the Center for Strategy and Technology, Air War College, Air University, Maxwell Air Force Base, Alabama.
- Fedotov, A. M., Narozhny, N. B., Mourou, G., & Korn, G. (2010). Limitations on the attainable intensity of high power lasers. Physical review letters, 105(8), 080402.
- Gunzinger, M., & Dougherty, C. (2012). Changing the game: The promise of directed-energy weapons. Center for Strategic and Budgetary Assessments.
- Hongxiang Chang, Qi Chang, Jiachao Xi, Tianyue Hou, Rongtao Su, Pengfei Ma, Jian Wu, Can Li, Man Jiang, Yanxing Ma, Pu Zhou. First experimental demonstration of coherent beam combining of more than 100 beams[J]. Photonics Research, 2020, 8(12): 1943
- THussein, A., Rozenheck, O., & Utrilla, C. M. E. (2016). From detection to deflection: Mitigation techniques for hidden global threats of natural space objects with short warning time. Acta Astronautica, 126, 488-496.
- Landau, E. B., & Bermant, A. (2014). Iron Dome protection: missile defense in Israel's security concept. The lessons of operation protective edge, 37-42.
- Lubin, P., & Hughes, G. B. (2015). Directed energy for planetary defense. Chapter in: Allahdadi, Firooz, and Pelton, Joseph N.(Eds.), Handbook of Cosmic Hazards and Planetary Defense, Springer Reference. Gunzinger, M., & Dougherty, C. (2012). Changing the game: The promise of directed-energy weapons. Center for Strategic and Budgetary Assessments.
- Lubin, P., Hughes, G. B., Bible, J. J., Bublitz, J., Arriola, J., Motta, C., ... & O'Neill, H. (2014). Toward directed energy planetary defense. Optical Engineering, 53(2), 025103-025103.
- Mikhail Vorontsov; Thomas Weyrauch; Svetlana Lachinova; Thomas Ryan; Andrew Deck; Micah Gatz; Vladimir Paramonov; Gary Carhart, "Coherent Beam Combining and Atmospheric Compensation with Adaptive Fiber Array Systems," in Coherent Laser Beam Combining , Wiley, 2013, pp.167-191, doi: 10.1002/9783527652778.ch06. keywords: {Laser beams;Collimators;Adaptive arrays;Pistons;Phased arrays;Optical transmitters;Optical arrays},
- Phipps, C. R. (2015, February). Laser space debris removal: now, not later. In XX International Symposium on High-Power Laser Systems and Applications 2014 (Vol. 9255, pp. 900-917). SPIE.
- Schmidt, N., Utrilla, C. M. E., Boháček, P., Silva-Martinez, J., & Worden, P. (2019). The Multipurpose Lunar Base as a First-Line Biosphere Defense and as a Gateway to the Universe. Planetary Defense: Global Collaboration for Defending Earth from Asteroids and Comets, 419-452.
- Saraceno, C. J., Sutter, D., Metzger, T., & Ahmed, M. A. (2019). The amazing progress of high-power ultrafast thin-disk lasers. Journal of the European Optical Society-Rapid Publications, 15(1), 15.
- Thangavelu, M., & McVicker, J. M. (2015, April). QBOLT-Directed Energy System Concepts for Asteroid Threat Mitigation. In The International Academy of Astronautics Planetary Defense Conference (pp. 13-17).
- Thangavelu, M., & Vasmate, V. (2016). LUNAR SENTINEL: Planetary defense from the Moon. In AIAA SPACE 2016 (p. 5475).
- Thangavelu, M. (2021). JEDI: The Joint Extraterrestrial Threats Defense Infrastructure-Evolving An Earth-Moon Planetary Defense Infrastructure. In ASCEND 2021 (p. 4112).
- Thangavelu, M. Chair READI Project(2015)Gourdon, R., Hussein, A., Soni, A., Aliaj, B., Manuel Entrena Utrilla, CGeneral Atomics doubles the energy density in power supply for railguns., Sisaid, I., ... & Thangavelu, M. (2015, October). The international space university space studies program 2015 planetary defense project. In 66th International Astronautical Congress (pp. 1-14).
- Wang,B,.(2017) General Atomics doubles the energy density in power supply for railguns, Next Big Future. General Atomics doubles the energy density in power supply for railguns | NextBigFuture.com
- Weise, T. H., Jung, M., Langhans, D., & Gowin, M. (2004, May). Overview of directed energy weapon developments. In 2004 12th Symposium on Electromagnetic Launch Technology (pp. 483-489). IEEE.

A Chronological Bibliography of Planetary Defense

- The White House(2020), The National Space Policy of the United States of America, Washington DC.,
- The White House(2021)Report on Near Earth Object Impact Threat Emergency Protocols, Washington DC.,
- The White House(2016-2021) Space Policy Directives 1-7, Washington DC.,
- The White House(2020), A new Era for Deep Space Exploration and Development, National Space Council, Washington DC.,
- Melamed, N., & Melamed, A. (2020). The terrestrial example: Natural disasters as model for planetary defense planning. Journal Space Safety Engineering, 7(1), 67-77.
- Johnson,L.,(2020) Planetary Defense Coordination Office, Briefing to the Astronomy and Astrophysics Advisory Committee, NSF, Washington DC.,
- Bannister, M. T., Bhandare, A., Dybczyński, P. A., Fitzsimmons, A., Guilbert-Lepoutre, A., Jedicke, R., ... & Ye, Q. (2019). The natural history of 'Oumuamua. Nature astronomy, 3(7), 594-602.
- Seligman, D., Laughlin, G., & Batygin, K. (2019). On the anomalous acceleration of 1I/2017 U1 'Oumuamua. The Astrophysical Journal Letters, 876(2), L26.
- Schmidt, N., Utrilla, C. M. E., Boháček, P., Silva-Martinez, J., & Worden, P. (2019). The Multipurpose Lunar Base as a First-Line Biosphere Defense and as a Gateway to the Universe. In Planetary Defense (pp. 419-452). Springer, Cham.
- Lewis, L. A. (2019). A Consideration of a National Approach: The US Planetary Impact Emergency Response Working Group (PIERWG); A Joint Effort Between NASA and FEMA. In Planetary Defense (pp. 151-162). Springer, Cham.
- Landis, R., & Johnson, L. (2019). Advances in planetary defense in the United States. Acta Astronautica, 156, 394-408.
- Kofler, R., Drolshagen, G., Drube, L., Haddaji, A., Johnson, L., Koschny, D., & Landis, R. (2019). International coordination on planetary defence: The work of the IAWN and the SMPAG. Acta Astronautica, 156, 409-415.
- Chodas, P. (2019, September). Overview of the 2019 Planetary Defense Conference Asteroid Impact Exercise. In EPSC-DPS Joint Meeting 2019 (Vol. 2019, pp. EPSC-DPS2019).
- Pelton, J. N. (2019). Global Space Governance and Planetary Defense Mechanisms. In Planetary Defense (pp. 339-355). Springer, Cham.
- Pelton, J. N. (2019). Space weapons, the threat of war in space and planetary defense. In Space 2.0 (pp. 115-128). Springer, Cham.
- Del Portillo, I., Cameron, B. G., & Crawley, E. F. (2019). A technical comparison of three low earth orbit satellite constellation systems to provide global broadband. Acta Astronautica, 159, 123-135.
- Loeb, A. (2018). Six Strange Facts AboutOumuamua. arXiv preprint arXiv:1811.08832.
- Lubin, P. (2018). Directed Energy propulsion for Rapid Interplanetary Missions. 42nd COSPAR Scientific Assembly, 42, PIR-1.
- Schmidt, N. (Ed.). (2018). Planetary Defense: Global Collaboration for Defending Earth from Asteroids and Comets. Springer.
- Zollner, K. (2018). United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER). In Satellite-Based Earth Observation (pp. 235-241). Springer, Cham.
- Chodas, P. (2018, October). Twenty Years of Tracking Near-Earth Objects: The Role of JPL's Center for NEO Studies (CNEOS). In AAS/Division for Planetary Sciences Meeting Abstracts# 50 (pp. 111-03).
- Schmidt, N., & Thangavelu, M. (2017). Strengthening global collaboration and reducing the risk of defection of a cooperating nation in planetary defense. In 5th IAA Planetary Defense Conference—PDC.
- Schmidt, N. (2017). Planetary Defense as a Gateway to Space for Commercial and Deep Space Exploration. New Space, 5(4), 219-229.
- Mainzer, A. (2017). The future of planetary defense. Journal of Geophysical Research: Planets, 122(4), 789-793.
- Daou, D., Johnson, L., Fast, K. E., Landis, R., Friedensen, V. P., & Kelley, M. (2017, September). NASA's Planetary Defense Coordination Office at NASA HQ. In European Planetary Science Congress (pp. EPSC2017-1024).
- Yeomans, D. K. (2016). Near-Earth objects: finding them before they find us. Princeton University Press.
- Thangavelu, M., & Vasmate, V. (2016). LUNAR SENTINEL: Planetary Defense from the Moon. In AIAA SPACE 2016 (p. 5475).
- Lubin, P., Hughes, G. B., Eskenazi, M., Kosmo, K., Johansson, I. E., Griswold, J., ... & Brashears, T. (2016). Directed energy missions for planetary defense. Advances in Space Research, 58(6), 1093-1116.
- Johnson, L. (2016). Planetary Defense Coordination Office (PDCO). In 16th SBAG Meeting.
- Bell, B. P. (2016). Overview, control strategies, and lessons learned in the CDC response to the 2014–2016 Ebola epidemic. MMWR supplements, 65.
- Lubin, P., Hughes, G. B., Allahdadi, F., & Pelton, J. N. (2015). Directed Energy for Planetary Defense. Chapter in: Allahdadi, Firooz, and Pelton, Joseph N.(Eds.), Handbook of Cosmic Hazards and Planetary Defense, Springer Reference.
- Thangavelu, M., & McVicker, J. M. (2015, April). QBOLT Directed Energy System Concepts For Asteroid Threat Mitigation. In The International Academy of Astronautics Planetary Defense Conference.
- Thangavelu, M., Burke, J. D., & Connolly, J. Outline for 2015 ISU SSP Planetary Defense Team Project.
- Thangavelu, M.(2015) Project SEUSS: Save Earth Using Solar System Assets. NASA Ames NESF Workshop, Moffett Field, California.
- Burke, J. D., Hussain, A., Soni, A., Johnson-Freese, J., Faull, J., Schmidt, N., ... & Thangavelu, M. (2015, December). Roadmap for an EArth Defense Initiative (READI). In AGU Fall Meeting Abstracts (Vol. 2015, pp. NH11A-1901).
- Kosmo, K., Lubin, P., Hughes, G. B., Griswold, J., Zhang, Q., & Brashears, T. (2015, March). Directed energy planetary defense. In 2015 IEEE Aerospace Conference (pp. 1-9). IEEE.
- Billings, L. (2015). Words matter: A call for responsible communication about asteroid impact hazards and plans for planetary defense. Space Policy, 33, 8-12.
- Phillips, B. D. (2015). Disaster recovery. CRC press.
- Pelton, J. N. (2015). A 3 Point Action Agenda to Address Cosmic Hazards and Planetary Defense. Journal of Space Safety Engineering, 2(2), 60-64.
- Pelton, J. N., & Allahdadi, F. (Eds.). (2015). Handbook of cosmic hazards and planetary defense. Cham, Switzerland: Springer.
- Lubin, P., Hughes, G. B., Allahdadi, F., & Pelton, J. N. (2015). Directed Energy for Planetary Defense. Chapter in: Allahdadi, Firooz, and Pelton, Joseph N.(Eds.), Handbook of Cosmic Hazards and Planetary Defense, Springer Reference.
- Lubin, P., Hughes, G. B., Bible, J. J., Bublitz, J., Arriola, J., Motta, C., ... & O'Neill, H. (2014). Toward directed energy planetary defense. Optical Engineering, 53(2), 025103.
- Phipps, C. R. (2014). A laser-optical system to re-enter or lower low Earth orbit space debris. Acta Astronautica, 93, 418-429.
- Boslough, M. (2014). Airburst warning and response. Acta Astronautica, 103, 370-375.
- Thangavelu, M. et al(2013) Eden Shield, ASTE527 Space Concepts Studio Planetary DefenseTeam Project, University of Southern California
- Marcy, J. T., & Thangavelu, M. (2013). Global Last-Line of Defense System (GOLD). In AIAA SPACE 2013 Conference and Exposition (p. 5451).
- Hughes, G. B., Lubin, P., Bible, J. J., Bublitz, J., Arriola, J., Motta, C., ... & Pryor, M. (2013, September). DE-STAR: phased-array laser technology for planetary defense and other scientific purposes. In Nanophotonics and Macrophotonics for Space Environments VII (Vol. 8876, p. 88760J). International Society for Optics and Photonics.
- Carnelli, I., Ailor, W., & Tremayne-Smith, R. (2014). NEO planetary defense 2013: Gathering for impact. Acta Astronautica, 103, 307-308.
- Phipps, C. R., Baker, K. L., Libby, S. B., Liedahl, D. A., Olivier, S. S., Pleasance, L. D., ... & Valley, M. T. (2012). Removing orbital debris with lasers. Advances in Space Research, 49(9), 1283-1300.
- Pelton, J. N., & Ailor, W. H. (2013). Space debris and other threats from outer space (pp. 5-8). New York: Springer.
- Liou, J. C. (2011). An active debris removal parametric study for LEO environment remediation. Advances in space research, 47(11), 1865-1876.
- Board, S. S., & National Research Council. (2010). Defending planet earth: Near-Earth-Object surveys and hazard mitigation strategies. National Academies Press.
- AIAA LA-LV Planetary Defense mini conference(2020) AIAA Los Angeles Section
- M.Thangavelu et al.,(2015) The READI Project, International Space University
- Kessler, D. J., Johnson, N. L., Liou, J. C., & Matney, M. (2010). The Kessler syndrome: implications to future space operations. Advances in the Astronautical Sciences, 137(8), 2010.
- Liou, J. C., Johnson, N. L., & Hill, N. M. (2010). Controlling the growth of future LEO debris populations with active debris removal. Acta Astronautica, 66(5-6), 648-653.
- Garretson, P., & Kaupa, D. (2008). Planetary defense: potential mitigation roles of the Department of Defense. Air & Space Power Journal, 22(3), 34-42.
- Yeomans, D. K., Bhaskaran, S., Broschart, S. B., Chesley, S. R., Chodas, P. W., Sweetser, T. H., & Schweickart, R. (2009). Deflecting a Hazardous Near-Earth Object 1 IAA Planetary Defense Conference: Protecting Earth from Asteroids. 27-30 April 2009. Granada, Spain.
- Phipps, C. (Ed.). (2007). Laser ablation and its applications (Vol. 129). Springer.
- Ailor, W. (2007, September). Earth threatening asteroids: Issues and future actions. In Proc. 58th Int. Astronautic. Congress (pp. 24-28).
- Melosh, H. J. (2004). Asteroid deflection-The mirror ablation approach. In 2004 Planetary Defense Conference: Protecting Earth from Asteroids.
- Melosh, H. J. (2003). Exchange of meteorites (and life?) between stellar systems. Astrobiology, 3(1), 207-215.
- Campbell, J.W.(2000)Using Lasers in Space: Laser Orbital Debris Removal and Asteroid Deflection, December 2000 Occasional Paper No. 20 Center for Strategy and Technology Air War College Air University Maxwell Air Force Base, Alabama.
- Thangavelu, M. (1998). Concept for a Planetary Defense Architecture Using Surplus Nuclear Arsenal. In Space 98 (pp. 702-705).
- Phipps, C. R., & Reilly, J. P. (1997, April). ORION: clearing near-Earth space debris in two years using a 30-kW repetitively-pulsed laser. In XI International Symposium on Gas Flow and Chemical Lasers and High-Power Laser Conference (Vol. 3092, pp. 728-731). International Society for Optics and Photonics.
- Bekey, I. (1997). Project Orion: orbital debris removal using ground-based sensors and lasers. In Second european conference on space debris (Vol. 393, p. 699).
- Darrah, J., Worden, S., & Stokes, G. H. (1996). Air force planetary defense technology. In Engineering, Construction, and Operations in Space V (pp. 32-45).
- Campbell, J. W. (1996). Project ORION: orbital debris removal using ground-based sensors and lasers.
- Gladman, B. J., Burns, J. A., Duncan, M., Lee, P., & Levison, H. F. (1996). The exchange of impact ejecta between terrestrial planets. Science, 271(5254), 1387-1392.
- Phipps, C. (1994, October). LISK-BROOM: A laser concept for clearing space junk. In AIP Conference Proceedings (Vol. 318, No. 1, pp. 466-468). American Institute of Physics.
- Warren, P. H. (1994). Lunar and martian meteorite delivery services. Icarus, 111(2), 338-363.
- Melosh, H. J., & Tonks, W. B. (1993). Swapping rocks: ejection and exchange of surface material among the terrestrial planets. Meteoritics, 28.
- Dembling, P. G., & Arons, D. M. (1967). The evolution of the outer space treaty.

Food for Thought

- 2009 Evolution of ISS Part 1 – Section 08 Debris Mitigation System
- https://sites.google.com/a/usc.edu/aste527/home/evolution-of-iss-part-1-2009
- 2013 Eden Shield - Concept and Strategies for Planetary Defense - QBOLT https://sites.google.com/a/usc.edu/aste527/home/videos
- 2015 LunaRevolution -Section 10 Lunar Sentinel
- https://sites.google.com/a/usc.edu/aste527/home/lunarevolution-role-of-the-moon-in-the-future-of-human-space-activity-2015
- 2015 ISU READI Project

https://isulibrary.isunet.edu/doc_num.php?explnum_id=722

- 2017-Renaissance - Commercial Space & The Promise of Self-Sustaining Human Space Activity – Section 02 KYBER
- https://sites.google.com/a/usc.edu/aste527/home/2017-renaissance