Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 58 (2016) 1093–1116

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Directed energy missions for planetary defense ☆

Philip Lubin [a,*], Gary B. Hughes [b], Mike Eskenazi [c], Kelly Kosmo [a], Isabella E. Johansson [a], Janelle Griswold [a], Mark Pryor [d], Hugh O'Neill [e], Peter Meinhold [a], Jonathan Suen [a], Jordan Riley [a], Qicheng Zhang [a], Kevin Walsh [f], Carl Melis [g], Miikka Kangas [a], Caio Motta [a], Travis Brashears [a]

[a] Physics Department, University of California, Santa Barbara, CA 93106, USA
[b] Statistics Department, California Polytechnic State University, San Luis Obispo, CA 93407, USA
[c] ATK Space, 600 Pine Avenue, Goleta, CA 93117, USA
[d] Vorticy Inc, San Diego, CA 92121, USA
[e] Physics Department, Ventura College, Ventura, CA 93003, USA
[f] Southwest Research Institute, Boulder, CO 80302, USA
[g] Center for Astrophysics and Space Sciences, UC San Diego, San Diego, CA 92093, USA

Received 4 November 2014; received in revised form 25 April 2016; accepted 12 May 2016
Available online 20 May 2016

Abstract

Directed energy for planetary defense is now a viable option and is superior in many ways to other proposed technologies, being able to defend the Earth against all known threats. This paper presents basic ideas behind a directed energy planetary defense system that utilizes laser ablation of an asteroid to impart a deflecting force on the target. A conceptual philosophy called DE-STAR, which stands for Directed Energy System for Targeting of Asteroids and exploration, is an orbiting stand-off system, which has been described in other papers. This paper describes a smaller, stand-on system known as DE-STARLITE as a reduced-scale version of DE-STAR. Both share the same basic heritage of a directed energy array that heats the surface of the target to the point of high surface vapor pressure that causes significant mass ejection thus forming an ejection plume of material from the target that acts as a rocket to deflect the object. This is generally classified as laser ablation. DE-STARLITE uses conventional propellant for launch to LEO and then ion engines to propel the spacecraft from LEO to the near-Earth asteroid (NEA). During laser ablation, the asteroid itself provides the propellant source material; thus a very modest spacecraft can deflect an asteroid much larger than would be possible with a system of similar mission mass using ion beam deflection (IBD) or a gravity tractor. DE-STARLITE is capable of deflecting an Apophis-class (325 m diameter) asteroid with a 1- to 15-year targeting time (laser on time) depending on the system design. The mission fits within the rough mission parameters of the Asteroid Redirect Mission (ARM) program in terms of mass and size. DE-STARLITE also has much greater capability for planetary defense than current proposals and is readily scalable to match the threat. It can deflect all known threats with sufficient warning.

Keywords: Directed energy; Laser phased array; Planetary defense; DE-STAR; DE-STARLITE

1. Introduction

1.1. DE-STAR and DE-STARLITE

While implementing a realistic directed energy planetary defense system may have seemed preposterous as little as a

☆ For more information and related articles, videos and talks see: http://www.deepspace.ucsb.edu/projects/directed-energy-planetary-defense.

* Corresponding author.
E-mail address: lubin@deepspace.ucsb.edu (P. Lubin).

http://dx.doi.org/10.1016/j.asr.2016.05.021
0273-1177/

decade ago, recent technological developments allow serious consideration of such a system. The critical items such as phase locked laser amplifiers and lightweight photovoltaic deployable arrays are becoming increasingly more efficient and lower in mass. The necessary technology now exists to build such a system that will considerably enhance our ability to augment or enhance other methods to fulfill the need for planetary defense against asteroids that pose a threat of impacting Earth.

This paper primarily focuses on a design for a stand-on directed energy planetary defense system called DE-STARLITE. DE-STARLITE is a stand-on system, *i.e.*, it is designed to be delivered to a position that is nearby a threatening asteroid with a modest spacecraft and then work slowly on the threat to change its orbit. DE-STARLITE is suitable for mitigating targets that are many hundreds of meters in diameter and whose orbit is known to be a threat long before projected impact.

DE-STARLITE is one component of a more far-reaching philosophy for directed energy planetary defense. A future orbiting system is envisioned for stand-off planetary defense. The conceptual system is called DE-STAR, for Directed Energy System for Targeting of Asteroids and exploration. Fluctuations in the Earth's atmosphere significantly hinder ground-based directed energy systems; thus, deploying a directed energy system above Earth's atmosphere eliminates such disturbances, as the interplanetary medium is not substantial enough to significantly affect the coherent beam. DE-STAR is discussed extensively in other papers (Lubin and Hughes, 2015; Kosmo et al., 2015; Lubin et al., 2014). The broader DE-STAR system is not discussed in depth in this paper, which will focus on DE-STARLITE.

1.2. General concepts for orbit deflection

Residents near Chelyabinsk, Russia experienced the detrimental effects of a collision with a near-Earth asteroid (NEA) on 15 February 2013 as a ~20 m object penetrated the atmosphere above that city (Popova et al., 2013). The effective yield from this object was approximately 1/2 Mt TNT equivalent (Mt), or that of a large strategic warhead. The 1908 Tunguska event, also over Russia, is estimated to have had a yield of approximately 15 Mt and had the potential to kill millions of people had it come down over a large city (Garshnek et al., 2000). Asteroid impacts pose a clear threat and future advancement to minimize this threat requires effective mitigation strategies.

A wide array of concepts for asteroid deflection has been proposed. Several detailed surveys of threat mitigation strategies are available in the literature, including Sanchez-Quartielles et al. (2007), Belton et al. (2004), Gritzner and Kahle (2004), Morrison et al. (2002). Currently proposed diversion strategies can be broadly generalized into six categories.

(1a) Kinetic impactors, without explosive charges. An expendable spacecraft would be sent to intercept the threatening object. Direct impact could break the asteroid apart (Melosh and Ryan, 1997), and/or modify the object's orbit through momentum transfer. The energy of the impact could be enhanced via retrograde approach, *e.g.* McInnes (2004).

(1b) Kinetic impactors, with explosive charges. Momentum transfer using an expendable spacecraft could also be enhanced using an explosive charge, such as a nuclear weapon, *e.g.* Koenig and Chyba (2007).

(2) Gradual orbit deflection by surface albedo alteration. The albedo of an object could be changed using paint, *e.g.* Hyland et al. (2010). As the albedo is altered, a change in the object's Yarkovsky thermal drag would gradually shift the object's orbit. Similar approaches seek to create an artificial Yarkovsky effect, *e.g.* Vasile and Maddock (2010).

(3) Ion beam deflection (IBD) or ion beam shepherd (IBS) where high speed ions, such as the type used for ion thrusters, are directed at the asteroid from a nearby spacecraft, to push on asteroid and thus deflect it (Bombardelli et al., 2016, 2013; Brophy, 2015; Bombardelli and Peláez, 2011).

(4) Direct motive force, such as by mounting a thruster directly to the object. Thrusters could include chemical propellants, solar or nuclear powered electric drives, or ion engines (Walker et al., 2005).

(5) Indirect orbit alteration, such as gravity tractors. A spacecraft with sufficient mass would be positioned near the object, and maintain a fixed station with respect to the object using onboard propulsion. Gravitational attraction would tug the object toward the spacecraft, and gradually modify the object's orbit (Mazanek et al., 2015; Wie, 2008, 2007; McInnes, 2007; Schweickart et al., 2006; Lu and Love, 2005).

(6) Expulsion of surface material such as by robotic mining. A robot on the surface of an asteroid would repeatedly eject material from the asteroid. The reaction force when material is ejected affects the object's trajectory (Olds et al., 2007).

(7) Vaporization of surface material. Like robotic mining, vaporization on the surface of an object continually ejects the vaporized material, creating a reactionary force that pushes the object into a new path. Vaporization can be accomplished by solar concentrators (Vasile and Maddock, 2010), lasers deployed from the ground (Phipps, 2010), or lasers deployed on spacecraft stationed near the asteroid (Maddock et al., 2007; Park and Mazanek, 2005; Gibbings et al., 2013; Phipps and Michaelis, 1995; Campbell, 2000; Vasile et al., 2013). One study (Kahle et al., 2006) envisioned a single large reflector mounted on a spacecraft traveling alongside an asteroid. The idea was expanded to a formation of spacecraft orbiting in the vicinity of the asteroid, each