Space Debris

A 21st Century Tragedy of the Commons

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A multifaceted problem

- Collision risk is increasing non-linearly
- Resolution of tracking technology is improving
- International space law needs updating
- Active Debris Removal (ADR) presents technical challenges

Just stopping littering isn't enough

- The probability of a collision increases as the square of orbital traffic (McDowell, 2018)
- We've already passed the point of no return – even with no new launches, the number of objects in orbit will continue to grow due to collisions between existing objects (European Space Agency, 2019)

Better tracking technology makes different removal strategies viable

New US Space Force "Space Fence" radar system on Kwajalein Atoll can now track objects down to "roughly the size of a marble" (Etherington, 2020)

Likely to increase the number of tracked objects 5x (Witze, 2018)

Vigilantes in space?

- Under current international space law, engaging in ADR without obtaining the object owner's permission is problematic, hence collision avoidance continues to be the preferred strategy (Force, 2016)
- Concerns over weaponization potential of ADR technology if operators act independently (Sipiera & Kähler, 2019)

Technical and financial challenges

- "Non-cooperative targets" are often unstable or oddly shaped and capturing or moving them presents a risk of generating more debris (Shan, Guo & Gill, 2016)
- For reusable solutions, changing orbits is resource intensive (McDowell, 2018)
- The high cost of "kamikaze" missions like the European Space Agency's ClearSpace-1 (European Space Agency, 2019) can be justified for the removal of large, critical objects that would contribute disproportionately to the space debris population in the event of a collision, but the law of diminishing returns applies (European Space Agency, n.d.)

Three emerging solution categories

- Laser
- Geomagnetic
- Orbital resonance

Space-based laser systems

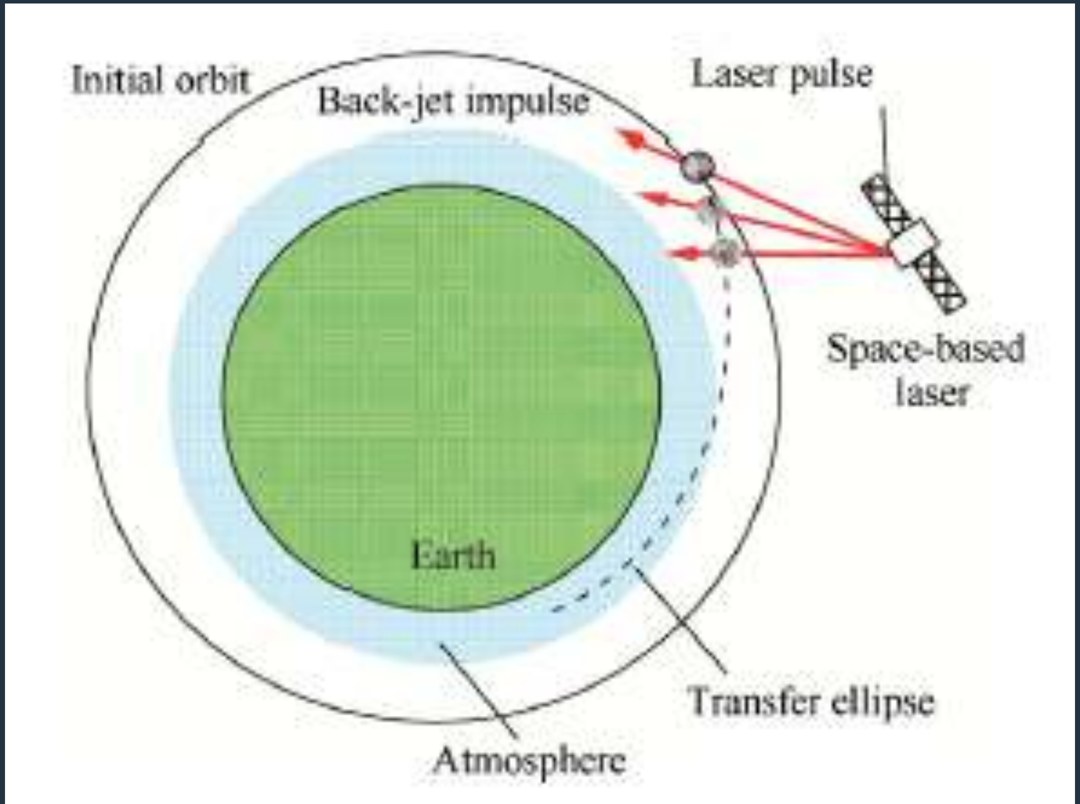

Figure 1. Example space-based laser system proposed by Shen, Jin and Chang (2014).

Pros:

- Easier to achieve accuracy compared with ground-based systems due to proximity to targets
- Useful for deflecting objects in the 1-10cm size range (which are now trackable) via ablation

Cons:

- Power is limited by satellite payload, so not effective for removing large objects from orbit
- Fear of weaponization

Ground-based laser systems

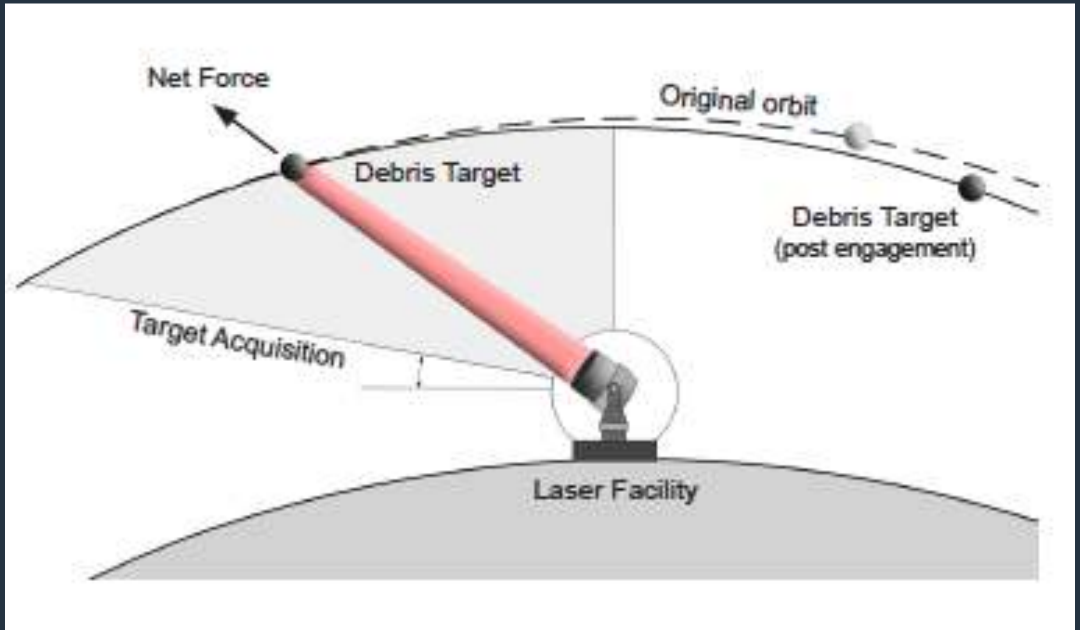

Figure 2. Example ground-based laser system proposed by Mason, Stupl, Marshall and Levit (2011).

Pros:

- Use photon pressure rather than ablation, so less concern over weaponization
- No need to launch more objects into orbit and easily scaled for global coverage (political will permitting)

Cons:

- Can only "nudge" objects slightly to prevent collisions; not powerful enough to deorbit them
- Ground-based systems need to be more powerful and accurate than space-based ones due to the distances involved

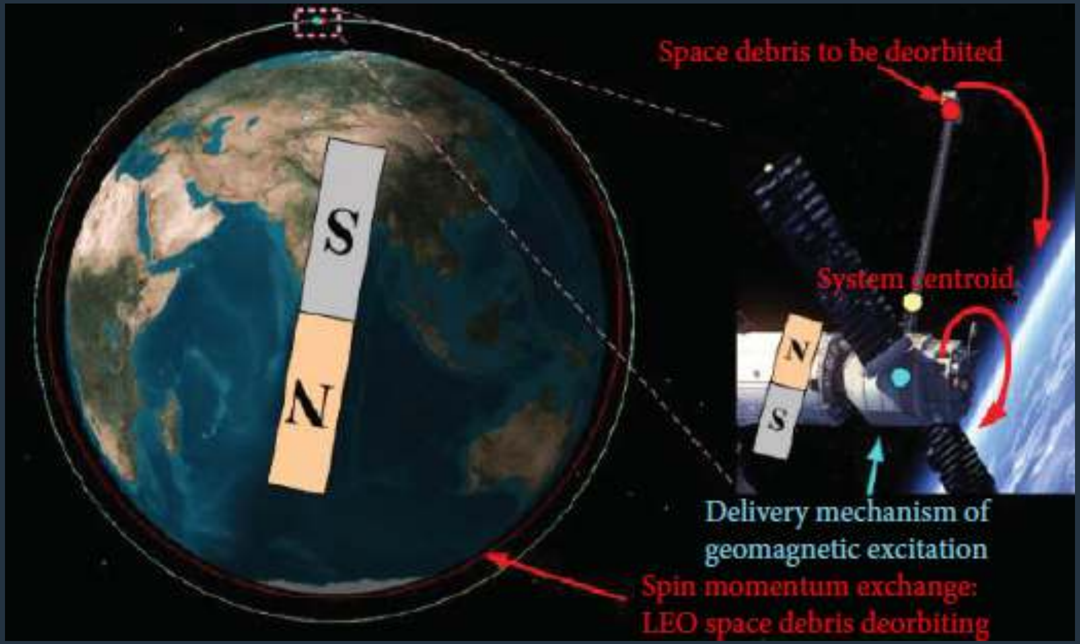

Figure 3. Geomagnetic momentum exchange system proposed by Feng, Li and Zhang (2019).

Geomagnetic systems

Pros:

- Can accumulate as much energy as needed for deorbiting large objects by simply moving through the Earth's magnetic field for longer; on-board electromagnet could be powered by solar panels
- Potentially has other applications in space transport such as synergistic acceleration and deceleration of active spacecraft

Cons:

- Technical complexity involved in delivering a momentum exchange to differently sized and shaped objects via a solid rod
- Compromise between required angular velocity of energy accumulator and required length of rod

“Passive” orbital resonance methods

The complex interactions of the Sun and Moon’s gravitational fields with that of the Earth creates anomalies in orbital paths known as “resonances” (Daquin et al., 2015)

If the dynamics of resonances were better understood, satellite operators could plan to exploit them as an energy efficient deorbiting or debris removal strategy (Skoulidou, Rosengren, Tsiganis & Voyatzis, 2019)

The way forward

Continue with missions that use existing technology (such as the ESA's CleanSpace-1) to remove the largest, most critical objects while continuing to develop a more flexible and cost effective geomagnetic-based solution for the medium-term future

Integrate laser-based systems with the Space Fence to protect active spacecraft from debris in the 1-10 cm size range and reduce collisions between inactive objects (note: Whipple shields can be used to protect against debris smaller than 1 cm in diameter (Phipps et al., 2012))

Update international space law in a way that encourages the development of a space debris removal industry and continue to support research into orbital resonance methods

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