Removal of Small-Sized Space Debris by Laser-Ablative Momentum Generation

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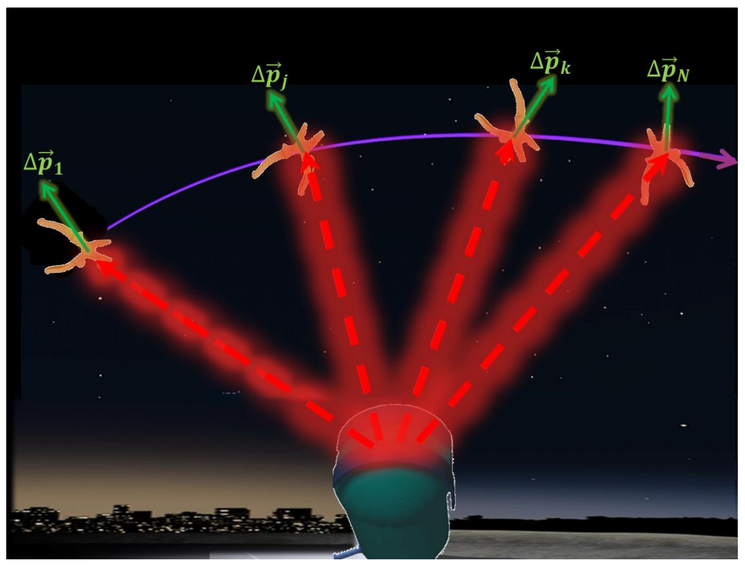
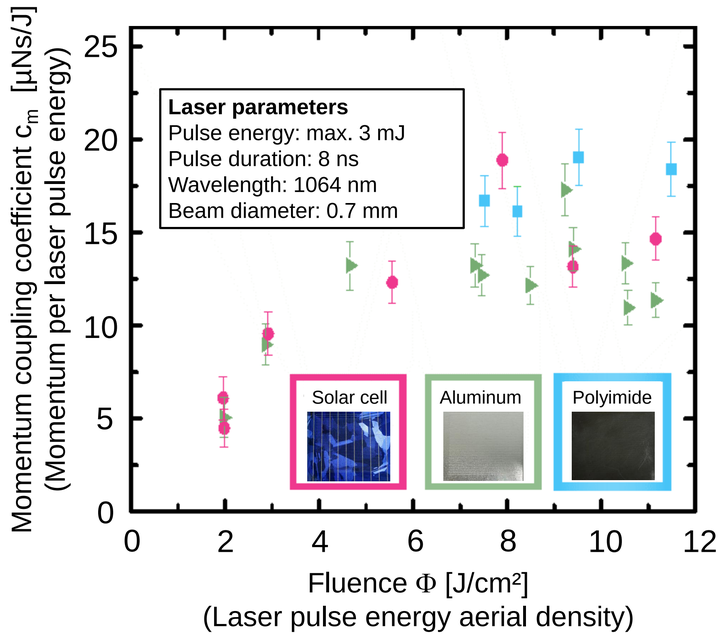
Concept

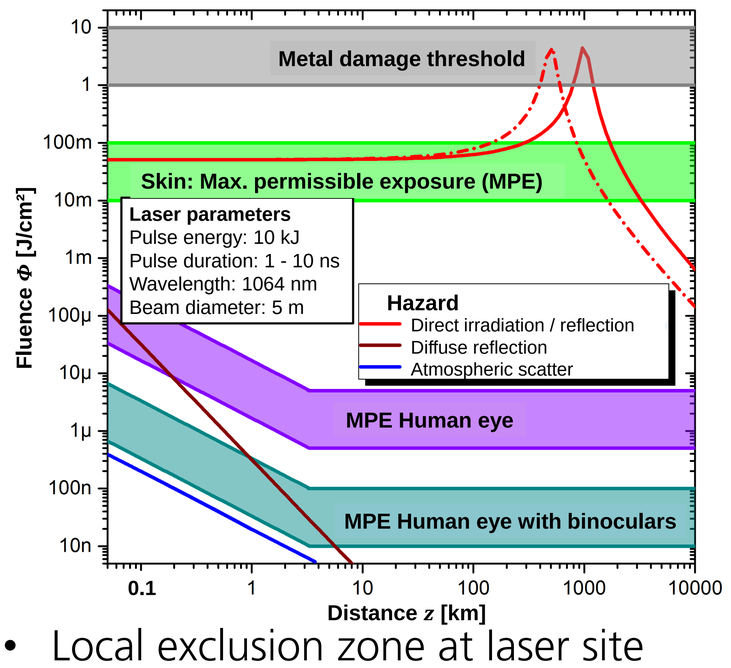


- Surface ablation by laser pulses
  → Recoil on debris target
  → Perigee lowering
  → Burn-up in atmosphere
- Targeted debris size: 1…10 cm

Ablative Recoil Measurements

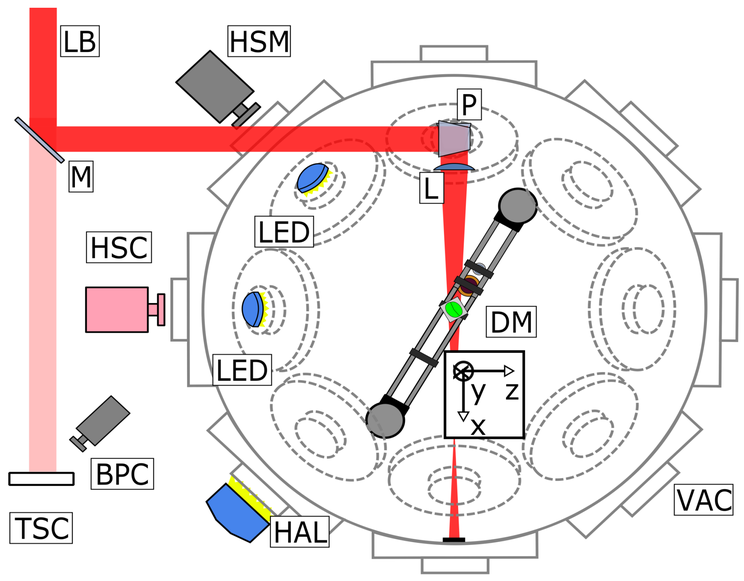


Operational Safety Analysis



- Local exclusion zone at laser site
- No-fly zone
- Radar control
- Reconcilement with air-traffic control and space agencies

True-Scale Experimental Proof



Top: Experimental Setup
Bottom: Dropping mechanism.
Abbreviations:
VAC: vacuum chamber, DM: dropping mechanism, P: periscope, L: Lens, LED: LED-lamp, HAL: halogen lamp, HSM: high-speed camera monochrome, HSC: high-speed camera color, BPC: beam profiling camera, LB: Laser beam, M: mirror, TSC: PTFE screen, HM: holding magnet, T: target, BP: burn pattern foil, PS: pressure spring, DA: dropping arm, HS: holding springs

Scan here for video
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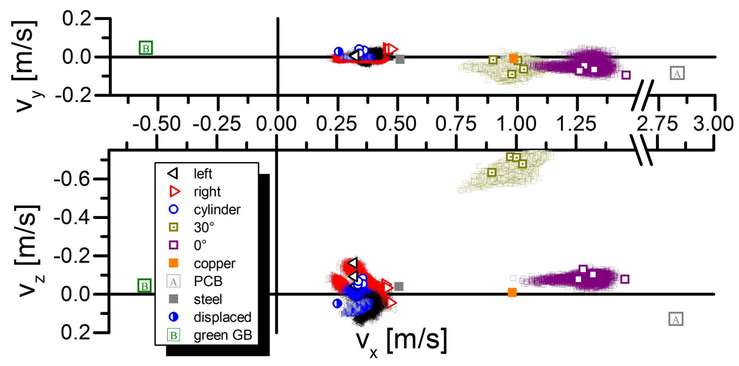
- cm-sized targets ($\emptyset_{target} < \emptyset_{spot}$)
- Laser pulse energy: $E_L = 80\,J$
- IR laser: $\lambda = 1064\,nm, \tau = 10\,ns$
- Stereoscopic 3D-tracking, $\Delta t = 1\,ms$
- Vacuum (< 2 Pa), free fall (μ-G)

Experimental Results



Object velocity changes Δv after laser irradiation.
Simulation results are indicated as point clouds.

True-scale Experiment
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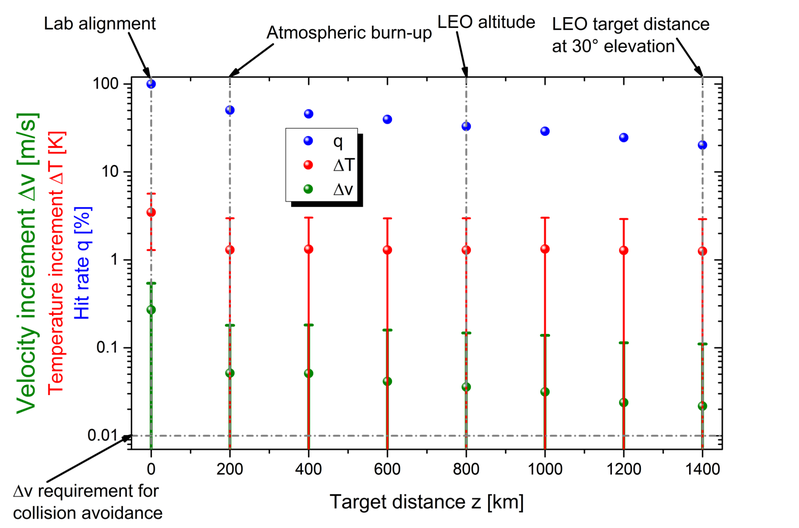
- Large area to mass → high Δv
- 1-pulse $\Delta v \gg 10\ cm/s$
- Momentum direction sensitive to target orientation and position

Laser Thermal Removal Simulation



Simulation results for single pulse irradiation:
nHelix laser upscaling: $E_L = 20\,kJ,\ M^2 = 2,$
$D_{Telescope} = 8\,m,\ Str = 0.4,\ d_{spot} = 70\,cm$
Target: Al plate 2 x 2 x 0.1 cm, arb. orientation
Monte Carlo: 0.42 μrad pointing, 10000 samples

- Large momentum scatter
- Single pulse collision avoidance

Momentum Predictability and Heat Accumulation
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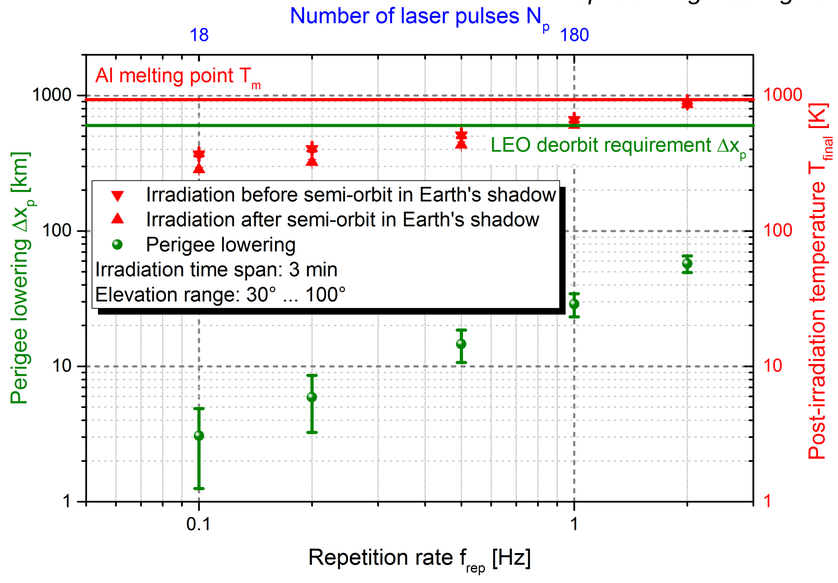

Simulation of multi-pulse irradiation: Parameters as above; supplementarily: $T_0 = 327.8\ (239.4)\ K$ (dusk/dawn), $\varepsilon = 0.09$, up to 1000 samples each.

- Pulse limitation due to laser heating
- Multi-pass engagements mandatory

Future Research Issues

- Accumulation of heat and stress
- Remote material reconnaissance
- Remote temperature monitoring

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