Review on Laser Lightcraft Research at DLR Stuttgart

Stefan Scharring, Hans-Albert Eckel

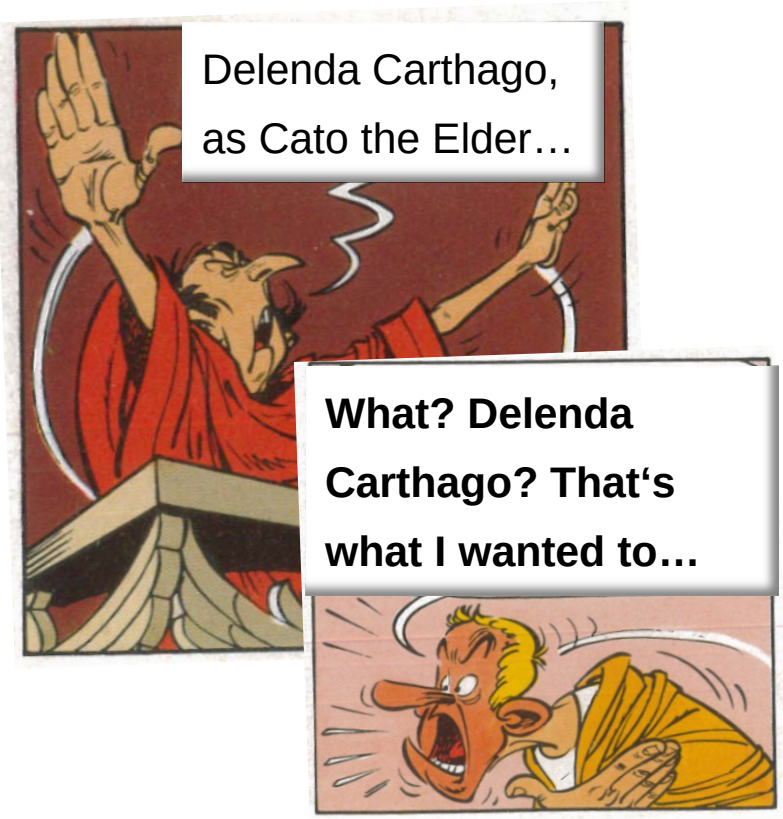
HPLA/BEP
International Symposium on
High Power Laser Ablation and Beamed Energy Propulsion

Santa Fe, NM April 22, 2014

DLR

Tribute to the Pioneers

In ancient Rome, speeches used to begin with the words „**Karthago must be destroyed**“.



Uderzo and Goscinny, *Asterix* **18**: 34 (1972)

In BEP papers, authors often (17 % of ISBEP 7) choose as a first reference:

A. Kantrowitz, Astronautics and Aeronautics **10**(5):74–76 (1972)

The concept of propelling a spacecraft by means of high-power laser beams was suggested for the first time in the seventies by Kantrowitz [1]. Almost two decades

Numerous investigations have been done on laser propulsion after Dr. Arthur Kantrowitz proposed the concept in 1972 [1]. And many modes of operation for laser

A concept of laser propulsion is proposed by Kantrowitz [1] in 1972, and many studies have been done for realizing new vehicle loading no (or a few) fuel so far. Laser

The idea of Laser Propelled Lightcraft Vehicles was first conceptualised in the early 1970's [1] as a means of achieving low cost earth to orbit payload launches. Laser

orbit (ETO) flight, from initial liftoff to final orbit circularization. The "game-changing" vision of a laser launch system was first introduced by Kantrowitz [1].

In Repetitively Pulsed (RP) laser propulsion mission [1-4], the ground-based high power laser system is one of the most important parts which should be seriously

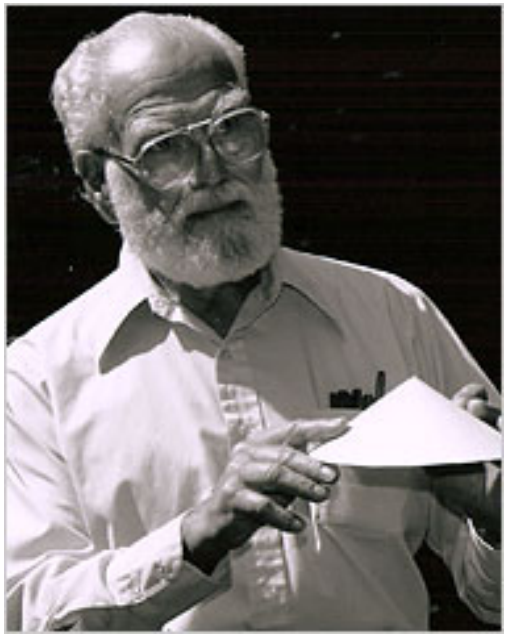
A possibility of using high power lasers for the space propulsion system was proposed soon after the invention of the laser [1]. From the 1970 ' s through the present, many

Laser induced plasma and the resulting strong shock wave have been attracting interests for laser propulsion [1, 2]. In the initial stage of the plasma, a laser absorption layer

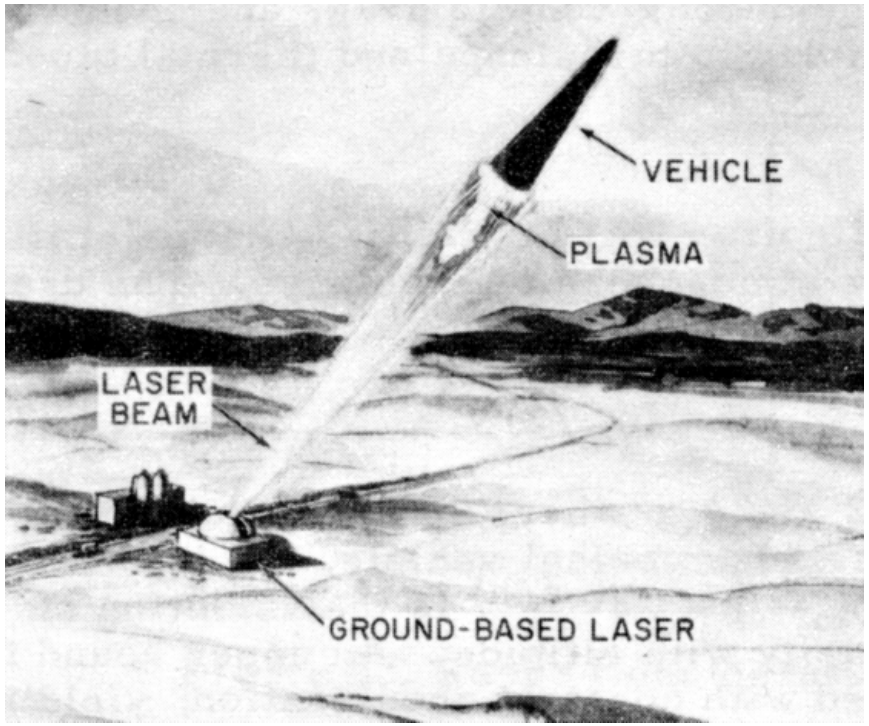
The Pioneer and his Vision

4P-principle

- **Payload**
- **Propellant**
- **Photons**
- **Period**



Arthur R. Kantrowitz
†2008

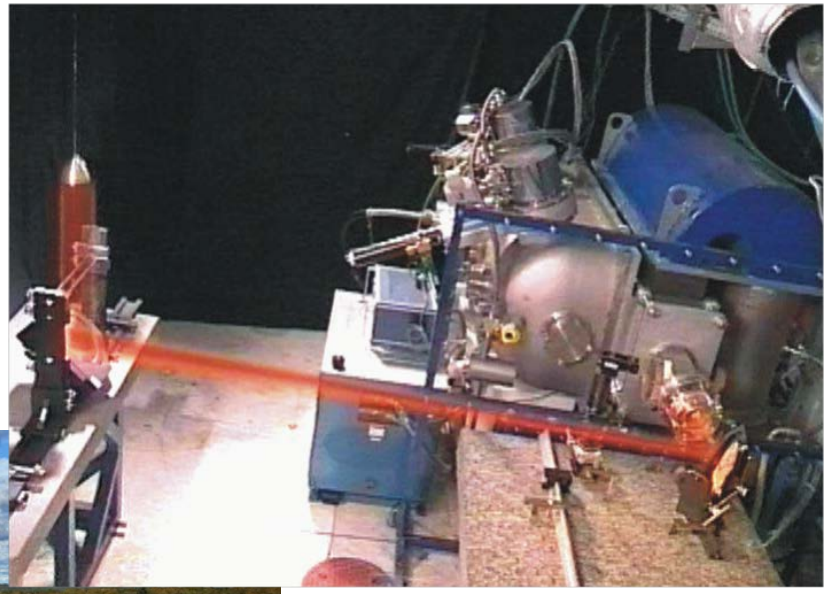


Pirri et al, AIAA paper 72-719 (1972)

Lightcraft Research at DLR Stuttgart 1998 – 2012

4P-principle

- **Payload**
- **Propellant**
- **Photons**
- **Period**

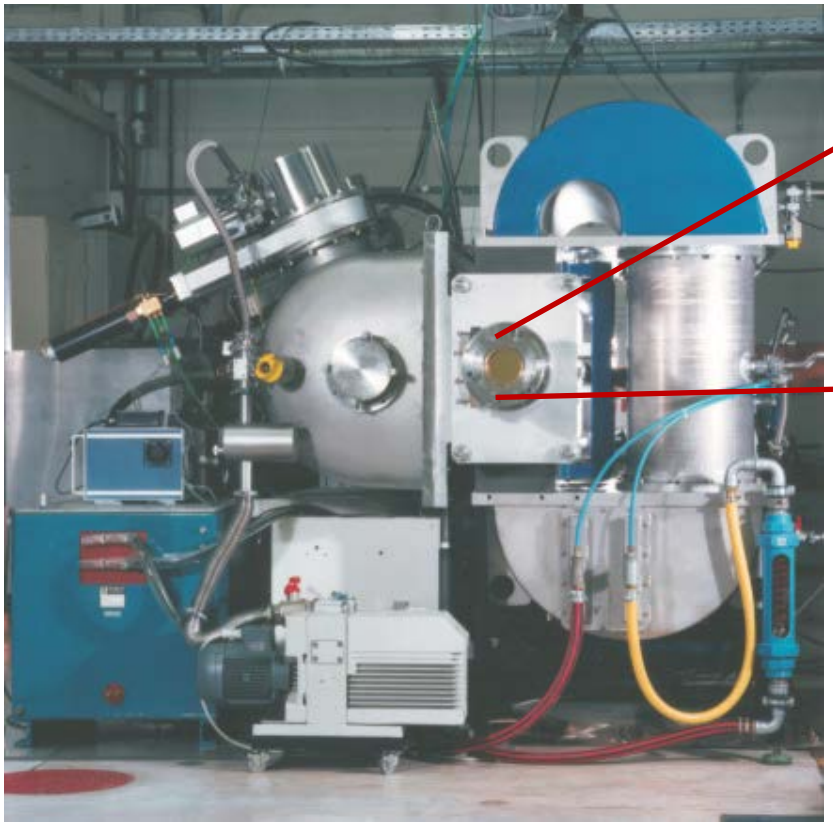


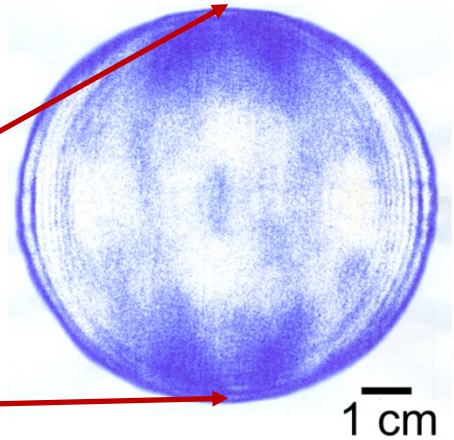
German lightcraft („Bohn Bell“) – Wire-guided launch

German Aerospace Center (DLR) Stuttgart

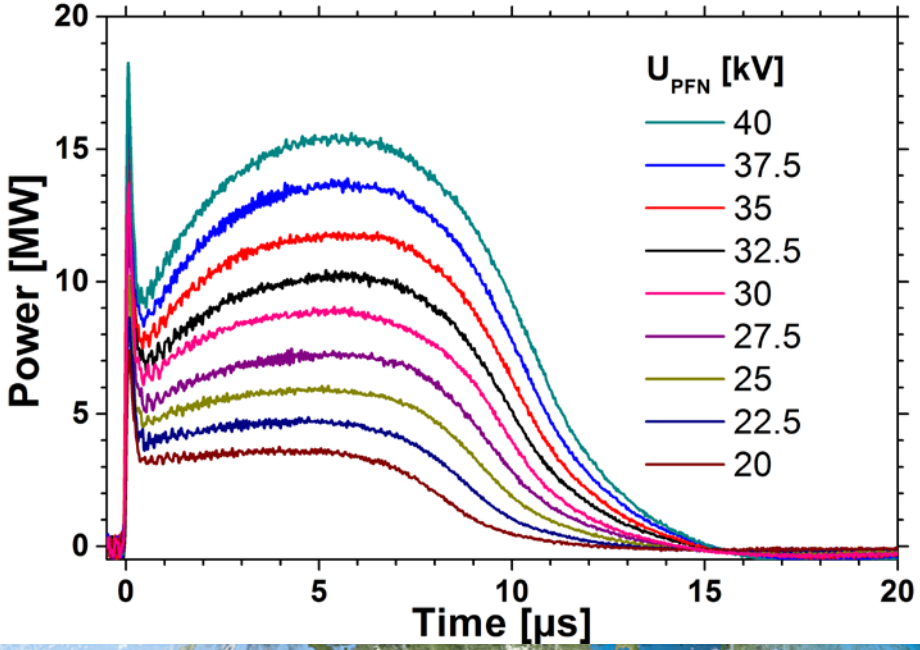
- **Photons**
  - High Energy Laser
  - Laser-induced Air Breakdown
  - Momentum Coupling

CO_2 High Energy Laser – Multispectral Testbed





λ = 10.6 µm,
E_L = 30 – 210 J
f = 0 – 50 Hz,
$\overline{P}$ = 0 – 7.5 kW
$\theta \approx$ 13 mrad



- Electron-beam sustained
- Cooling of laser gas by circulation

Parabolic Nozzle – Intensity Distribution

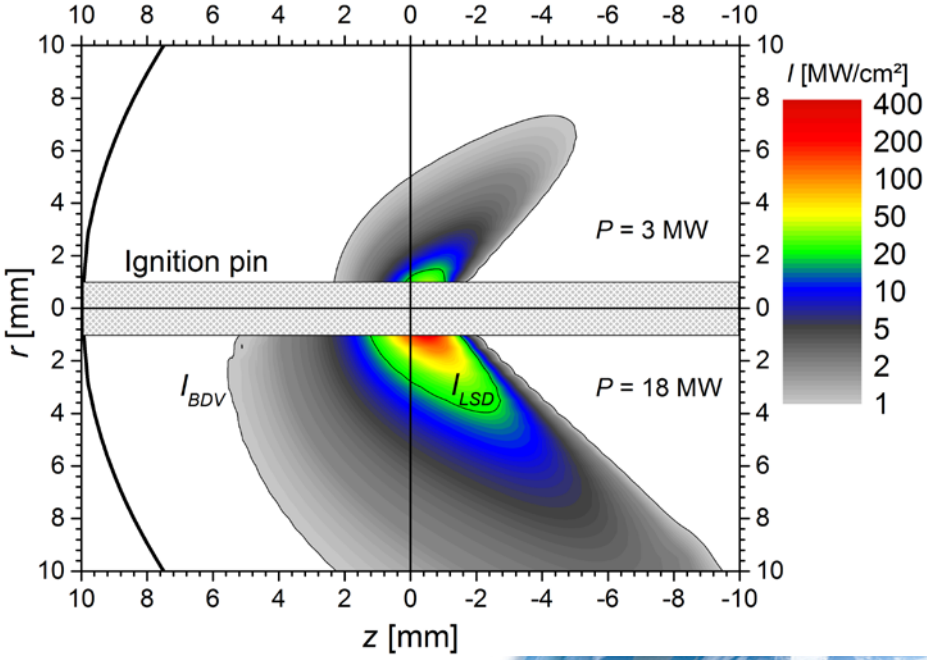
- Reflector nozzle with ignition pin

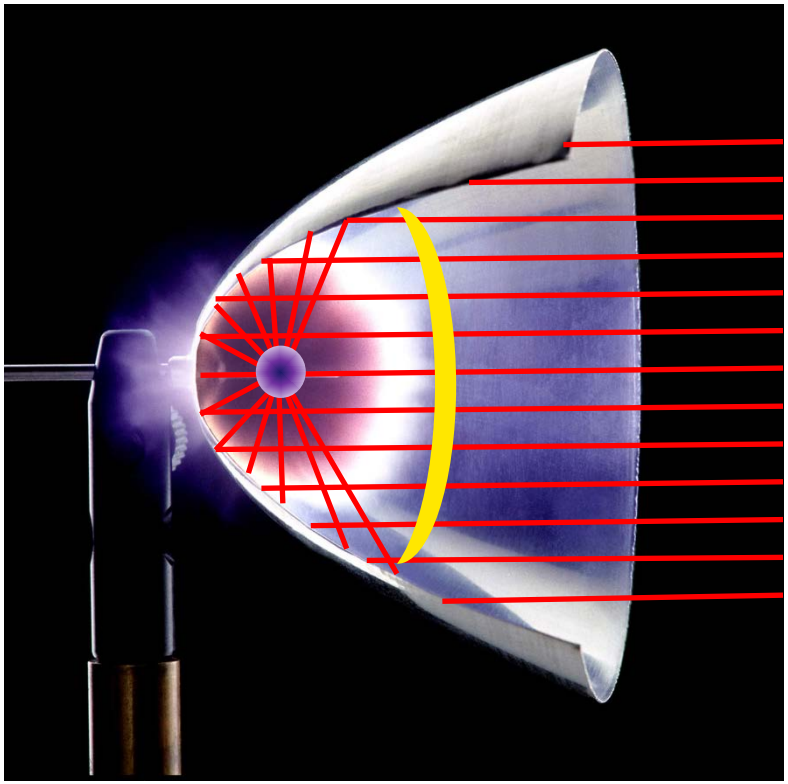
I > 1.5 GW/cm² (air) and

I > 1 MW/cm² (metall vapor), resp.

- Air breakdown

- Laser-induced detonation wave

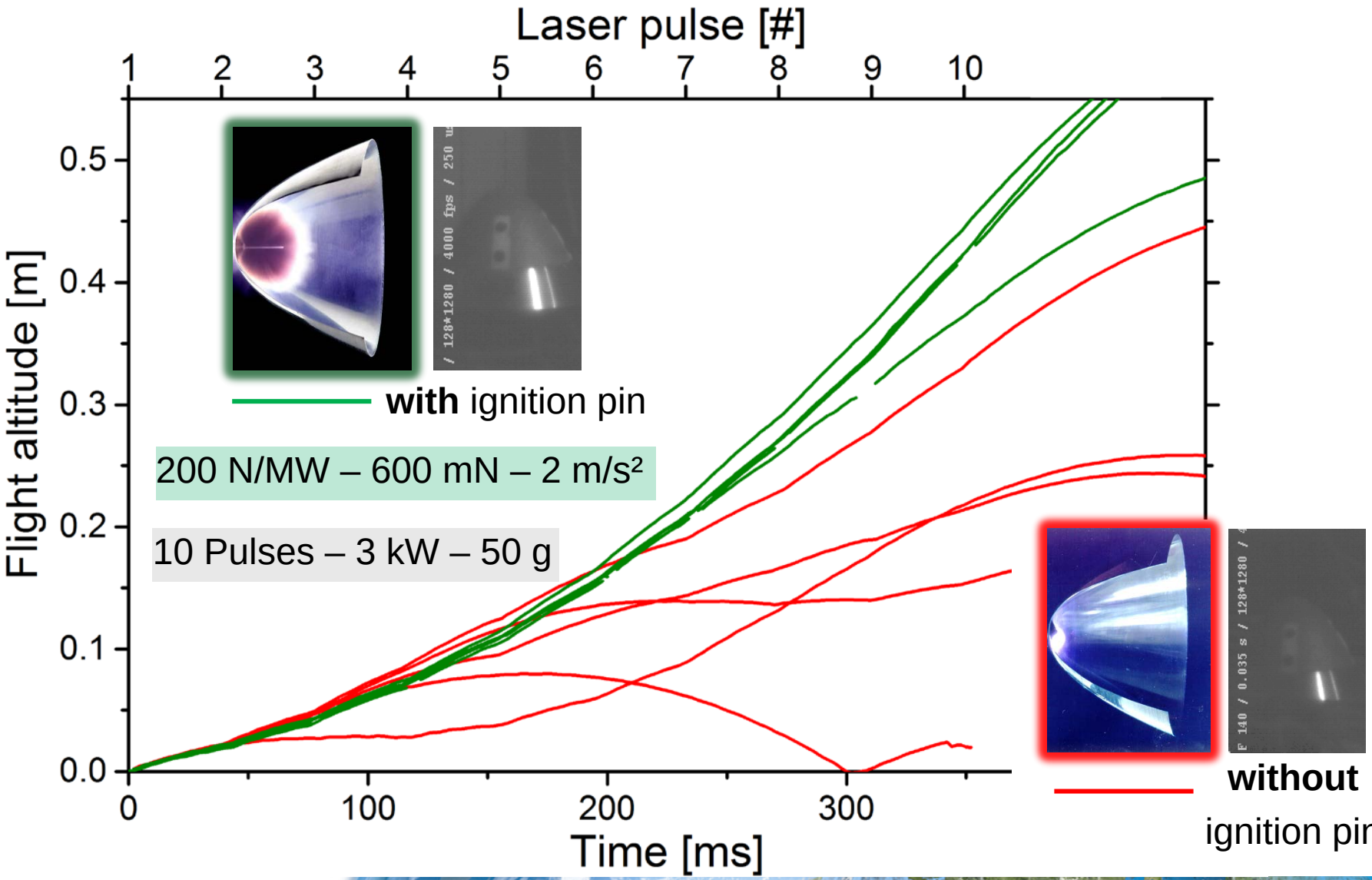




Typical parameters: 10 cm diameter

1 cm focus length

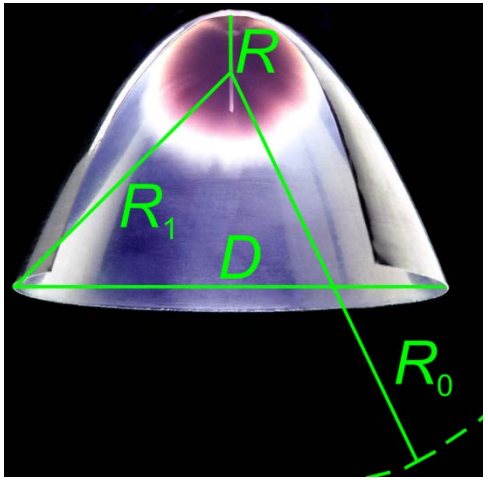
Ignition Pin – Reproducibility of c_m in Free Flights

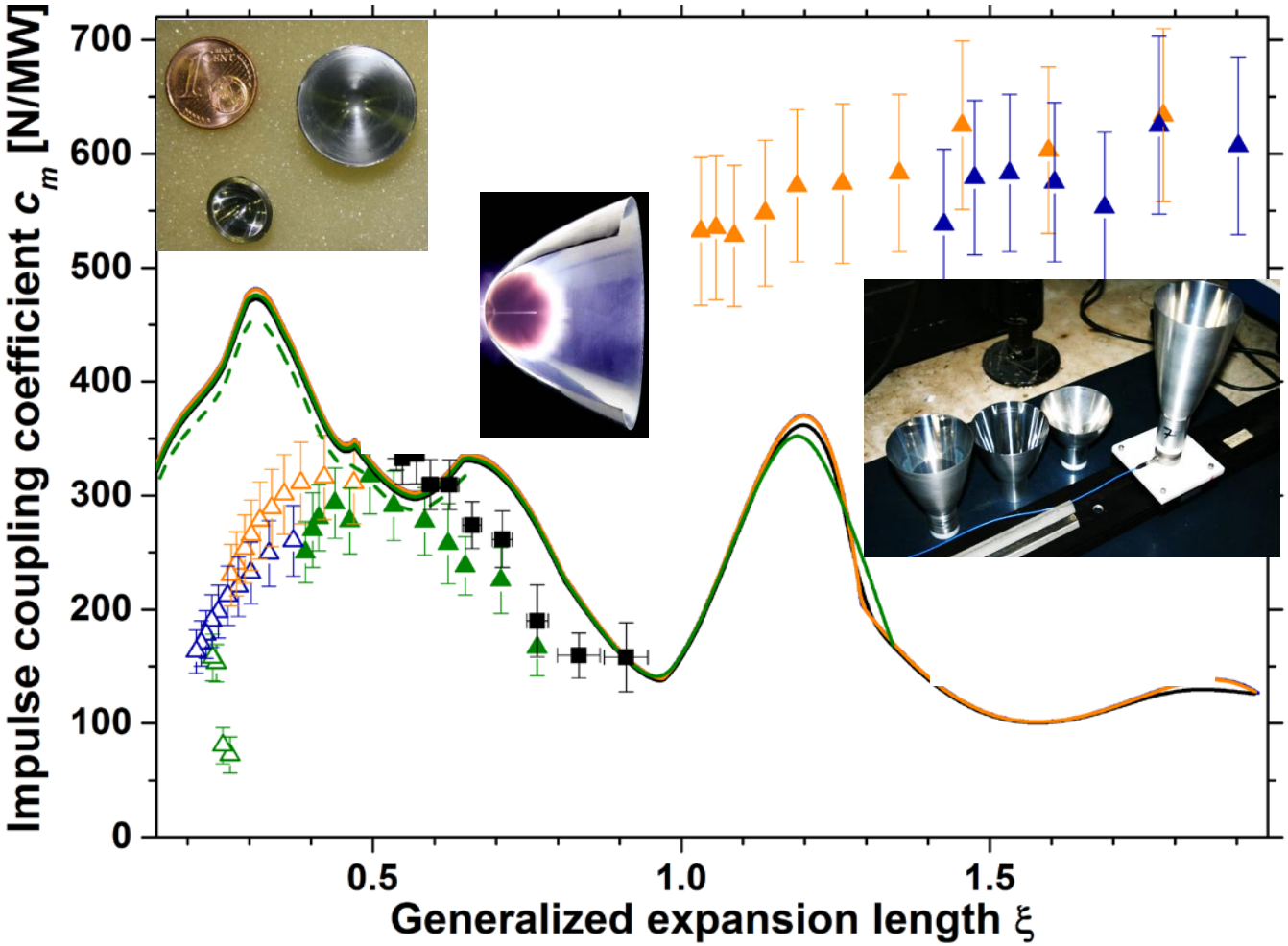


Impulse Coupling by Detonation of Ambient Air

Generalized expansion length $\xi = \frac{R_1}{R_0} = \frac{R\,[1+(4R/D)^{-2}]}{\sqrt[3]{E_0/p_0}}$ Expansion length / Dynamic radius

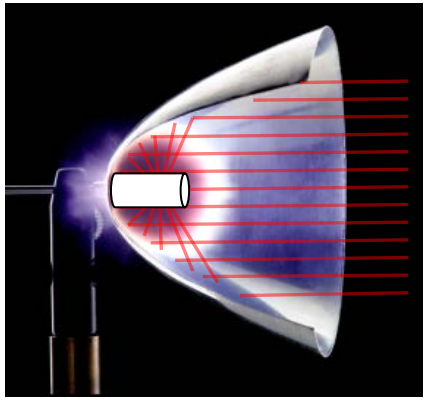
Ageev et al., *Sov. J. Quant. El.* **7**: 1430 – 1437 (1977)

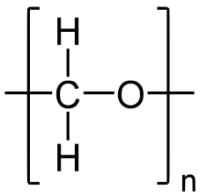




- **Photons**
  - High Energy Laser
  - Laser-induced Air Breakdown
  - Momentum Coupling
- **Propellant**
  - Detonation of POM
  - Flat Targets
  - Scaling and Standardization

Impulse Measurements under Various Ambient Conditions





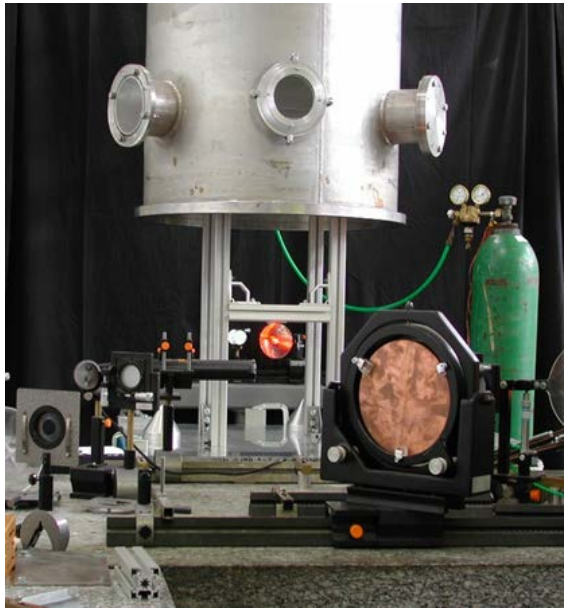
Polyoxymethylene (POM)

$Q_{det} = 2.69\ J/mg$

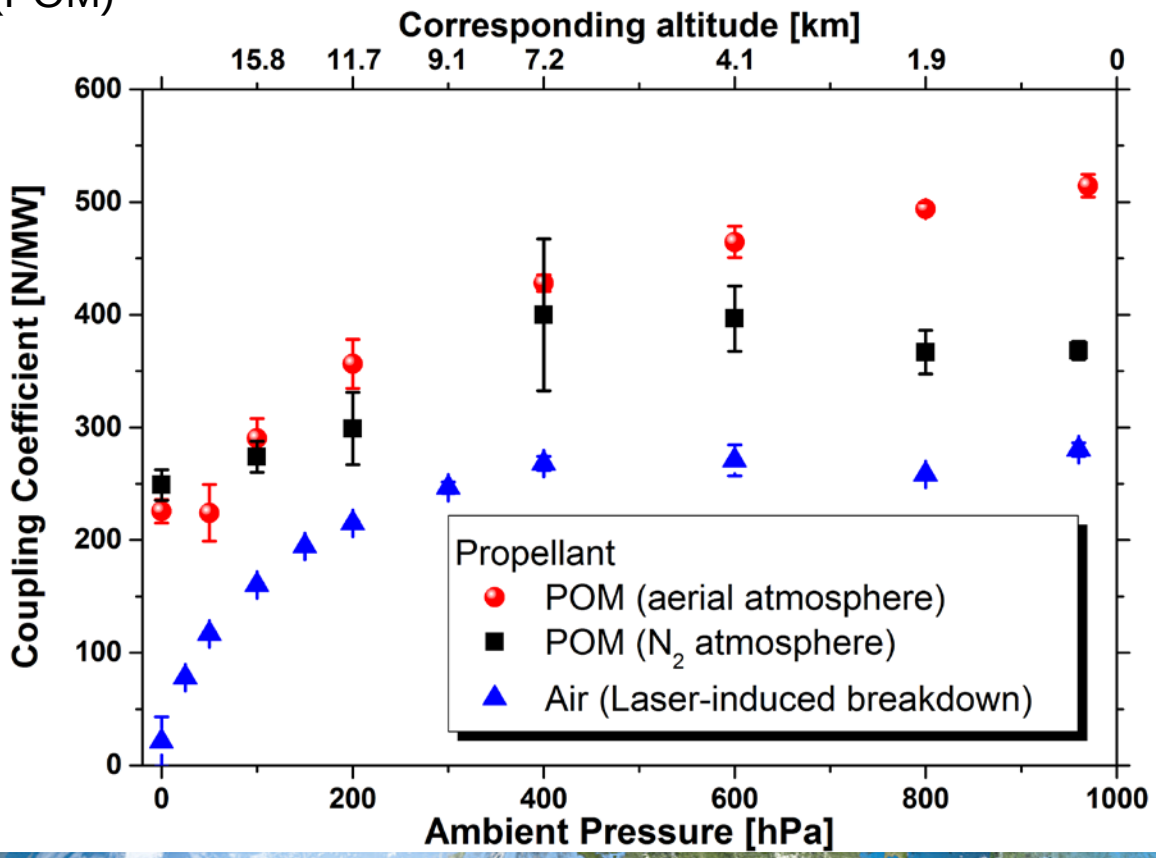
CO_2
H_20
C
H_2
$+ O_2$

$Q_{db} = 16.1\ J/mg$

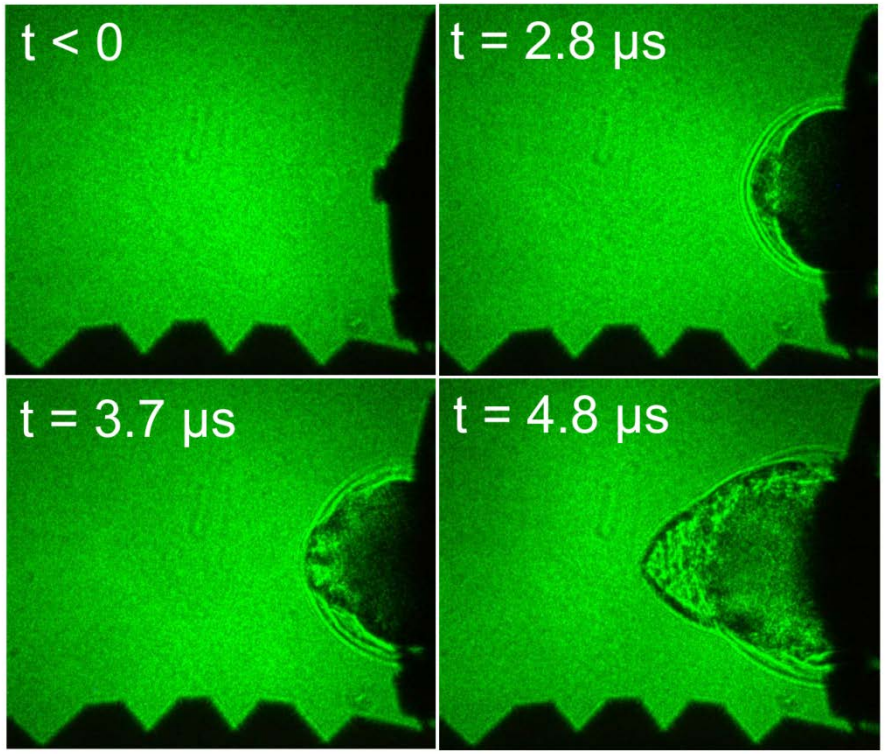
CO_2
H_20

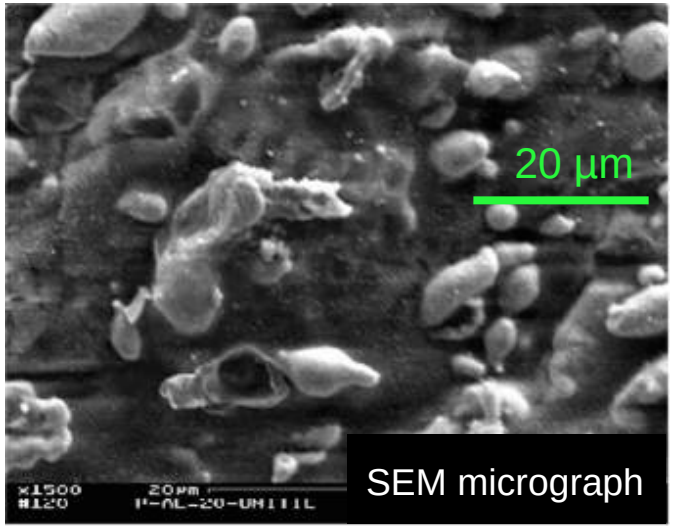


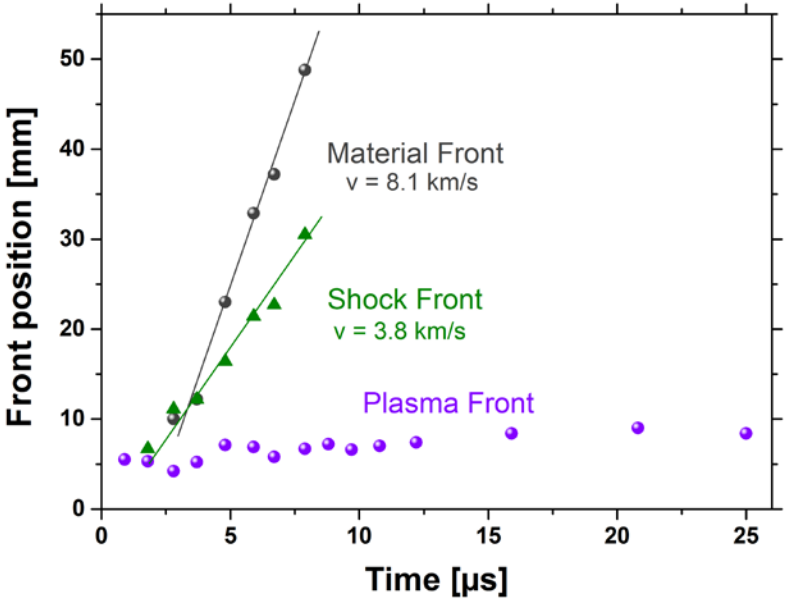
Ballistic pendulum in vacuum vessel



Polymer targets with metal dopants





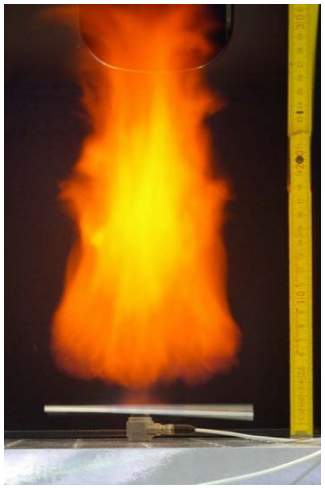


Schlieren recording of laser ablation

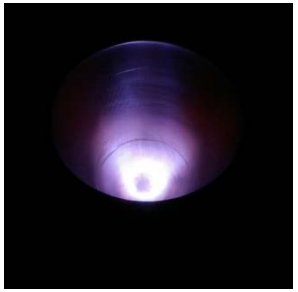
POM doped with 20% Al grains

$p = 35\ mbar, \Phi = 75\ J/cm^2$

Scaling issues in laser ablative Propulsion



Large Flat Targets at DLR Stuttgart

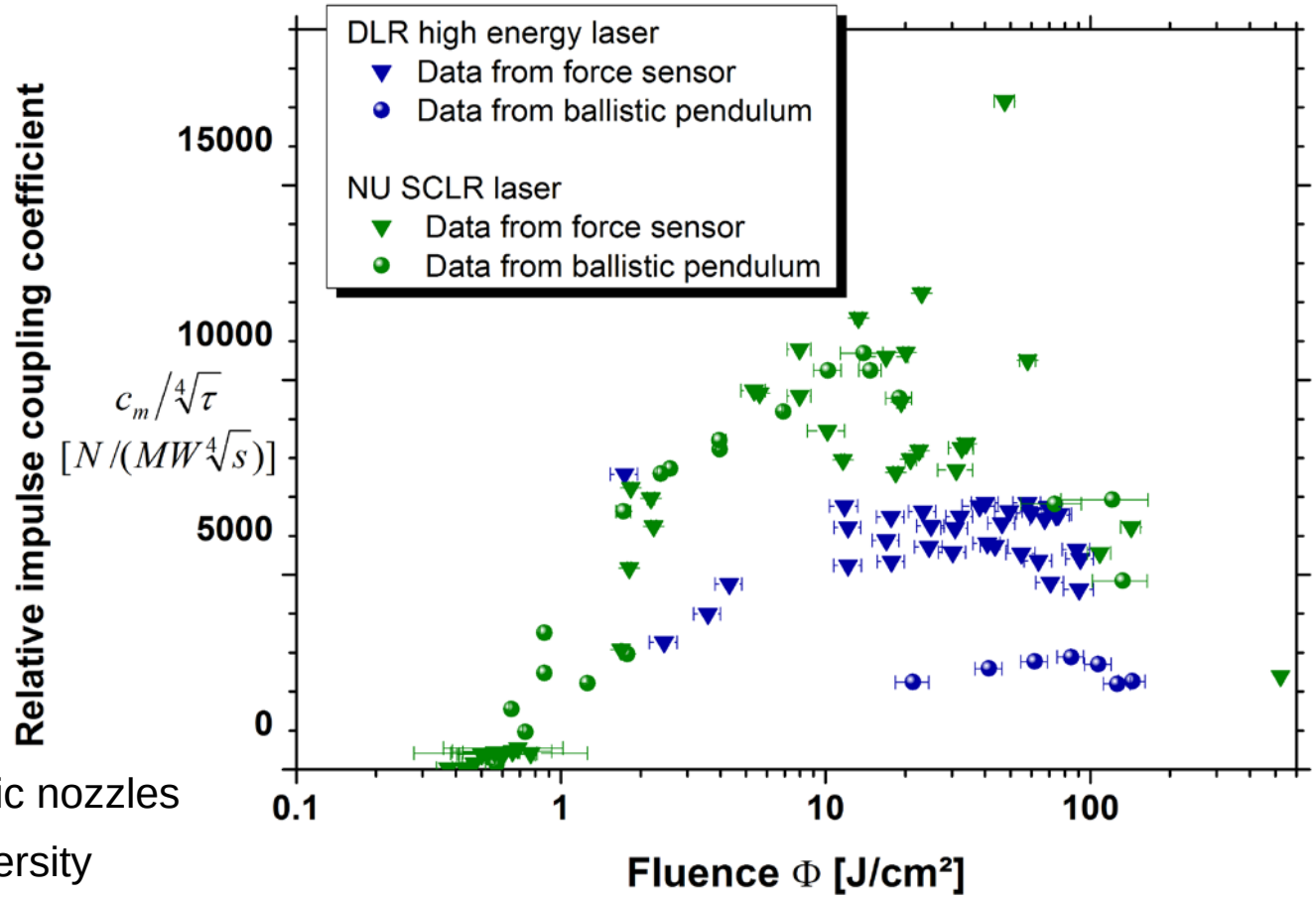


Miniaturized parabolic nozzles at Nagoya University

$$c_m \approx 2\sqrt[4]{\tau} \cdot f(\Phi, \Phi_{th}, \varrho, D_T)$$

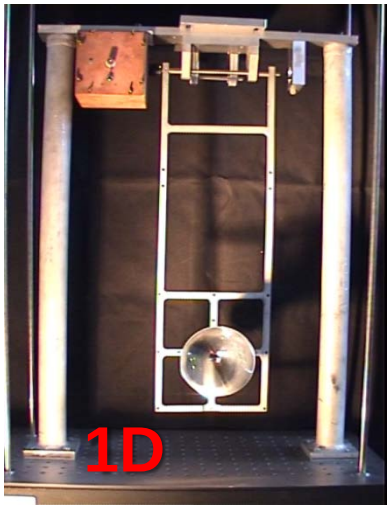
Vaporization regime

J.E. Sinko et al., *AIP Conf. Proc.* **1230**: 193 – 203 (2010)

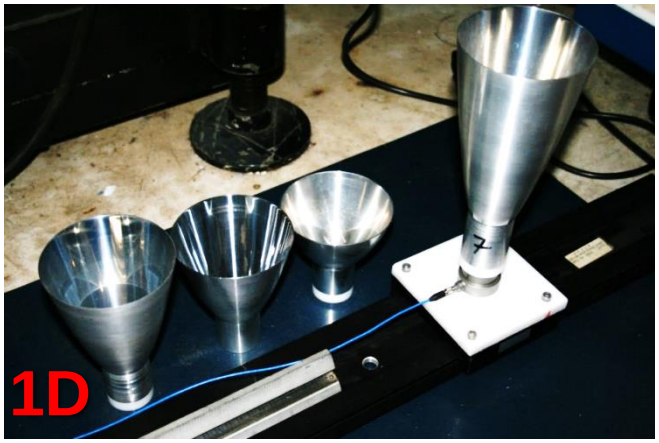


Measurement of c_m – Standardization Issues

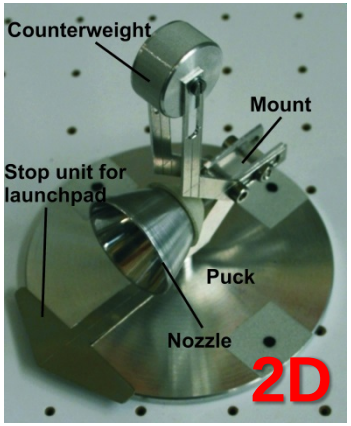
Mathematical Pendulum (DLR)



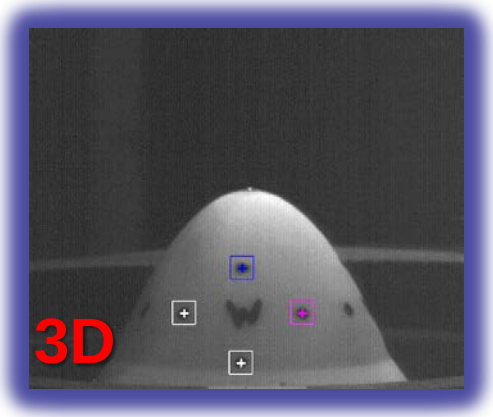
Physical Pendulum (US AFRL)

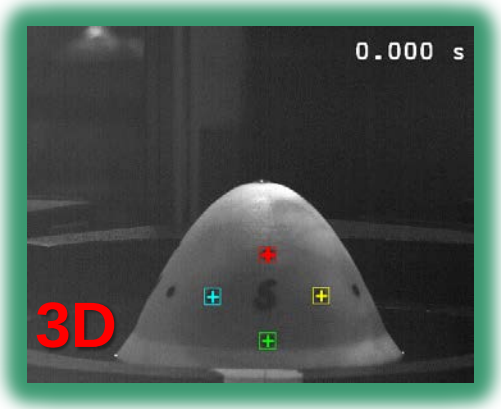


Impact sensor (DLR / NU)



Air cushion table





Free flight experiment

- **Photons**
  - High Energy Laser
  - Laser-induced Air Breakdown
  - Momentum Coupling
- **Propellant**
  - Detonation of POM
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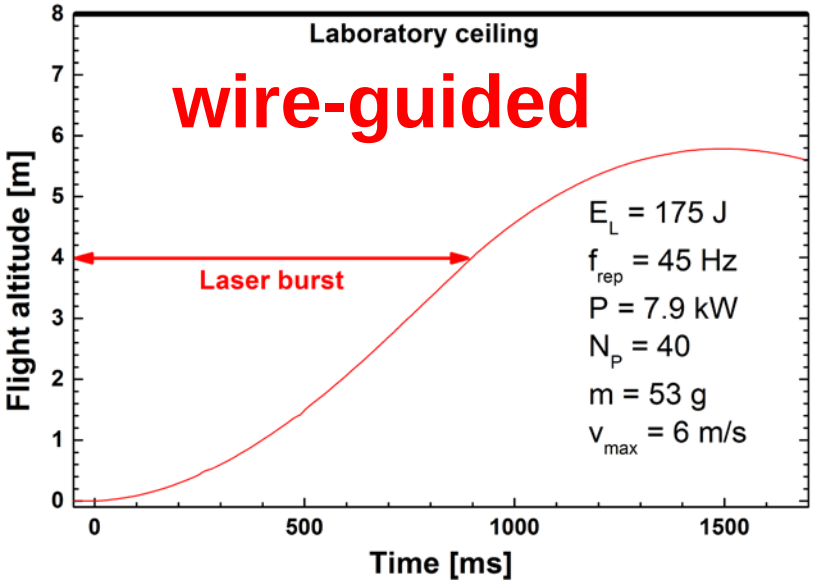
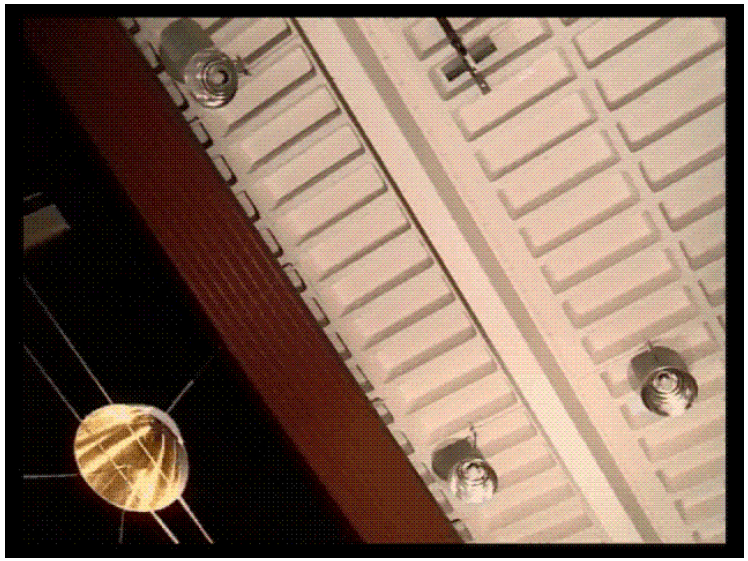
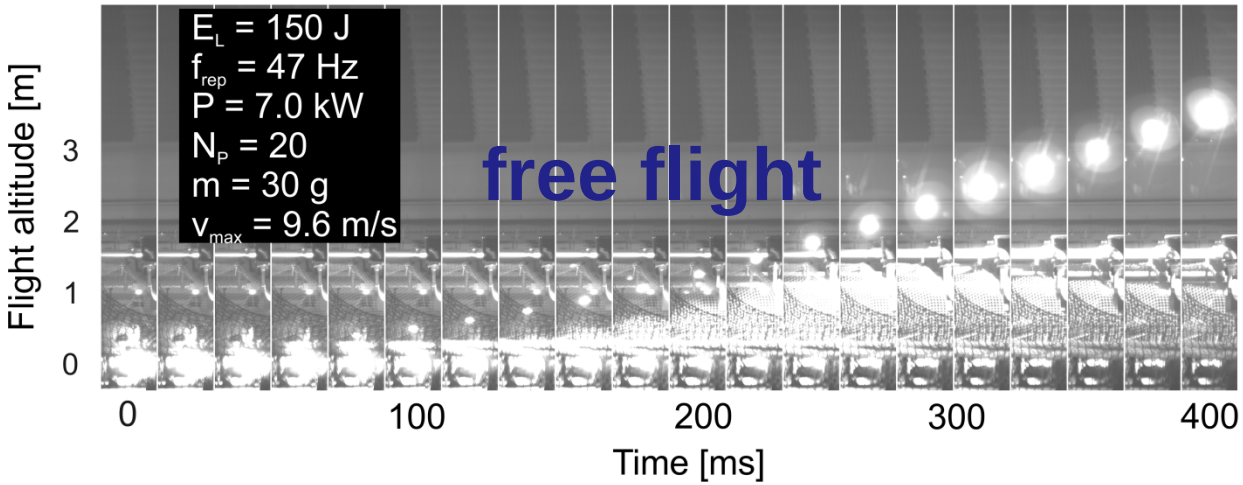
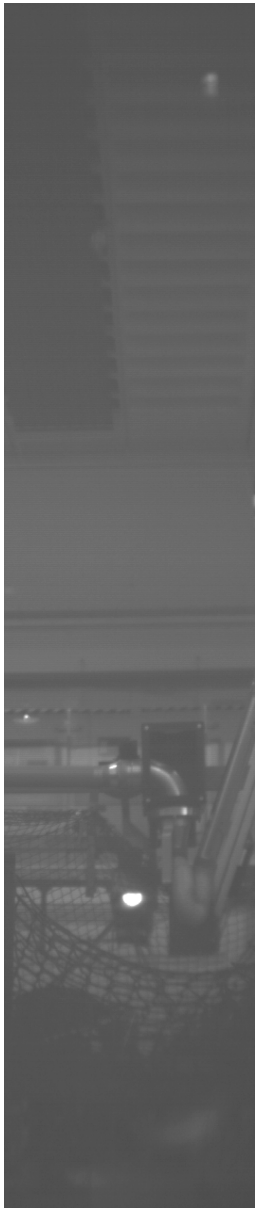
  - Scaling and Standardization
- **Payload**
  - Flight Dynamics
  - Concept studies

Flight Experiments





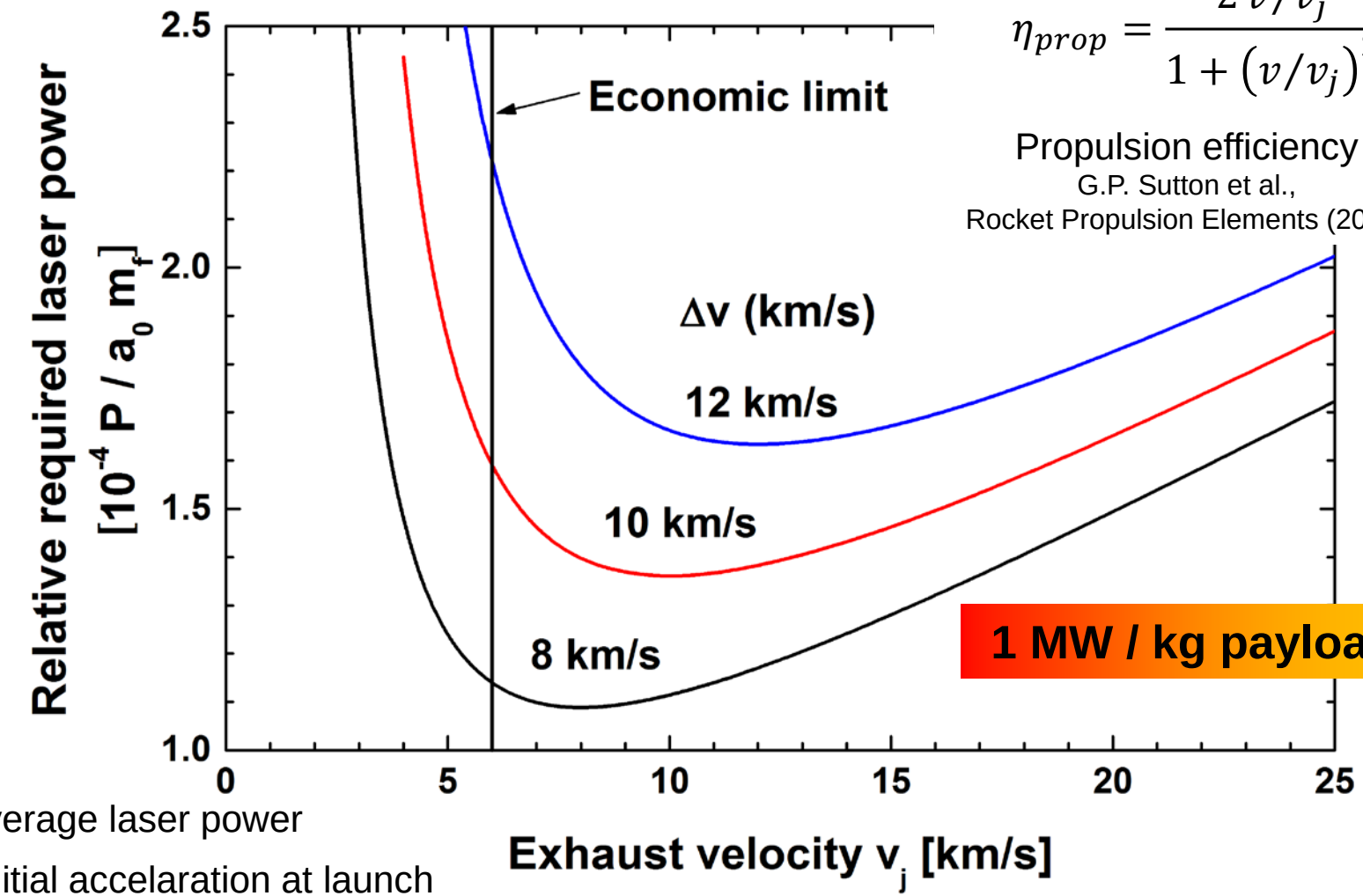




Ground-based launch to Low Earth Orbit

$$\eta_{prop} = \frac{2\,v/v_j}{1+\left(v/v_j\right)^2}$$

Propulsion efficiency
G.P. Sutton et al.,
Rocket Propulsion Elements (2001)



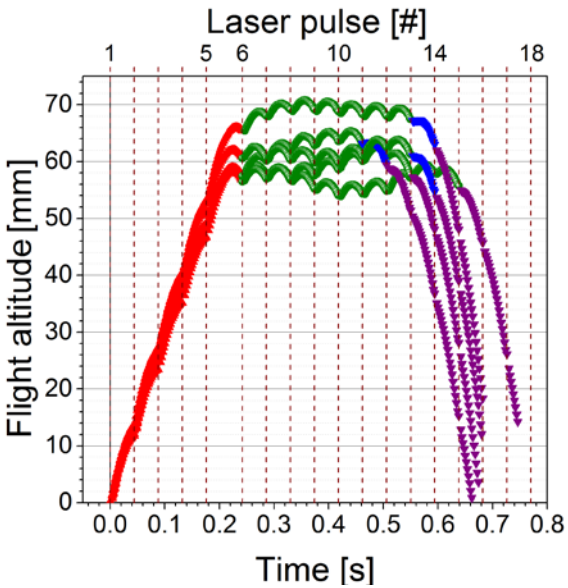
1 MW / kg payload

P – average laser power

a_0 – initial accelaration at launch

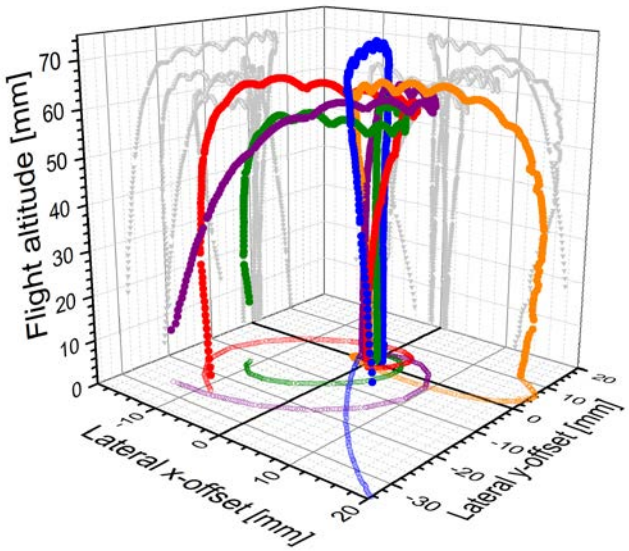
m_f – final mass in orbit

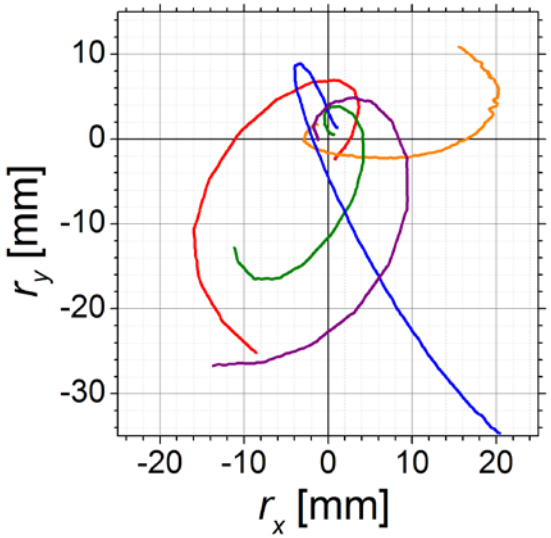
Hovering experiments

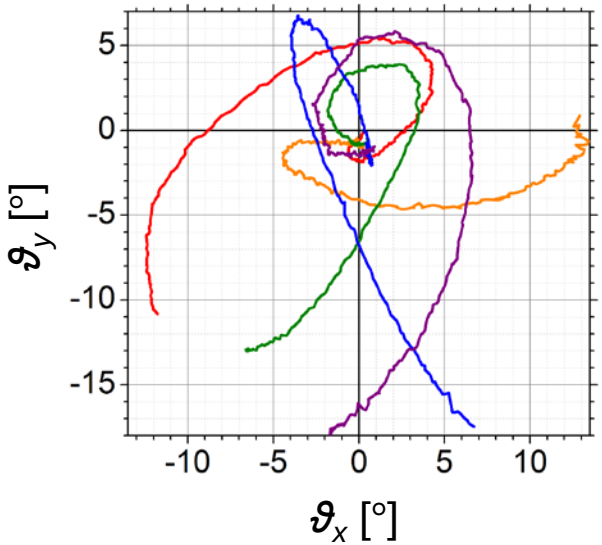


- Ascent
- Hovering
- Transition
- Drop down

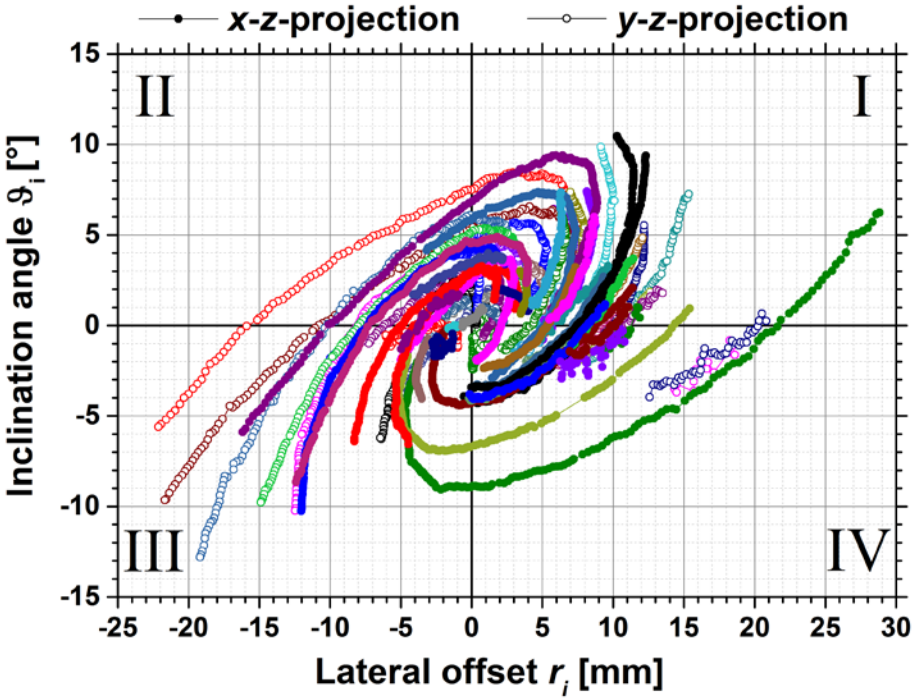
20 Pulses - 2.5 kW - 70 g



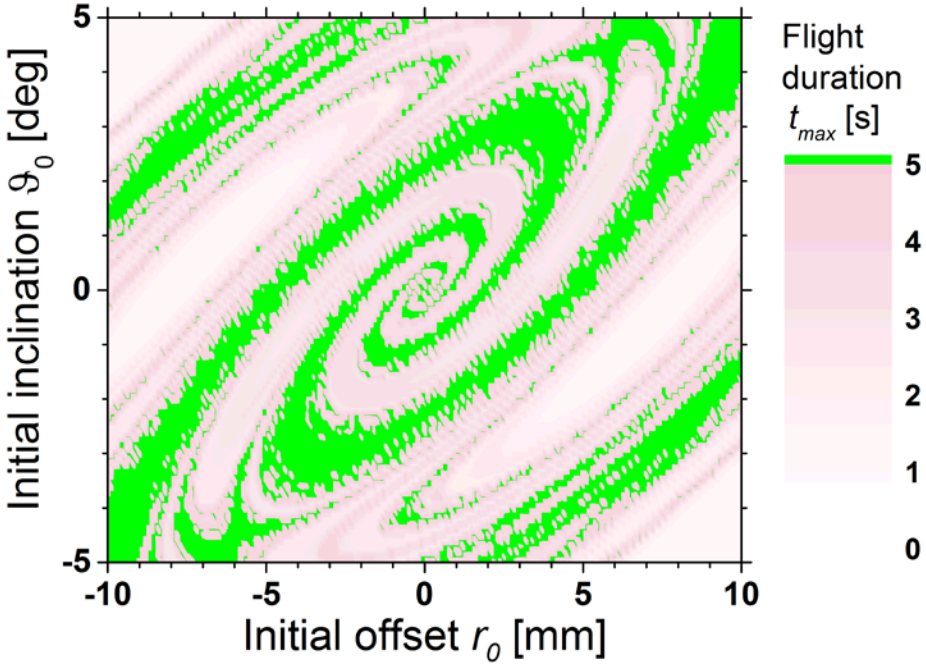




Flight Stability Analysis



Experimental results

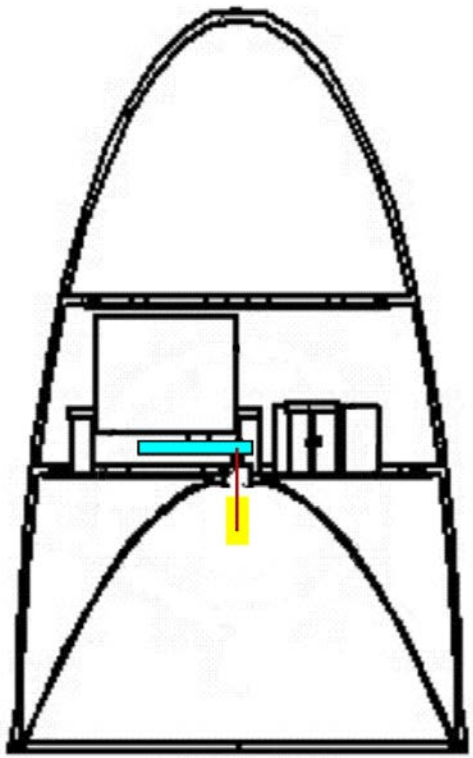


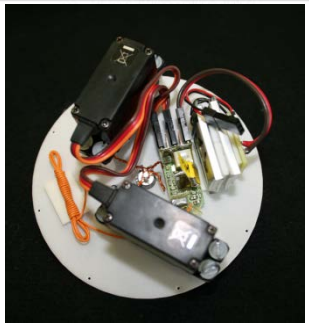
Simulation of flight duration vs. alignment

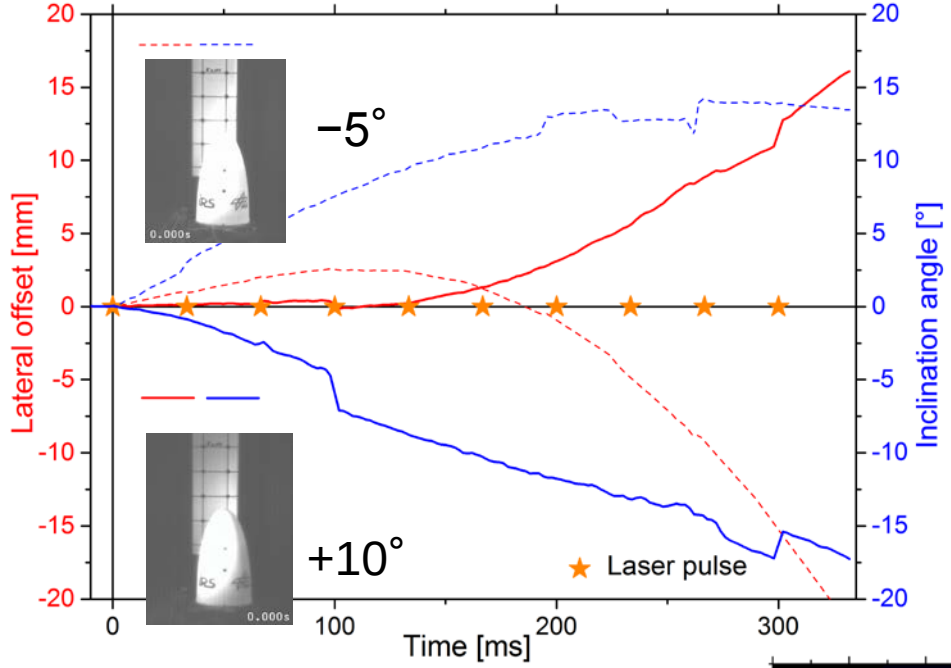
→ **Butterfly effect**

→ Poster: Beam-Riding Simulation and Diagnostics for Beamed-Energy Vehicles

Thrust vector steering

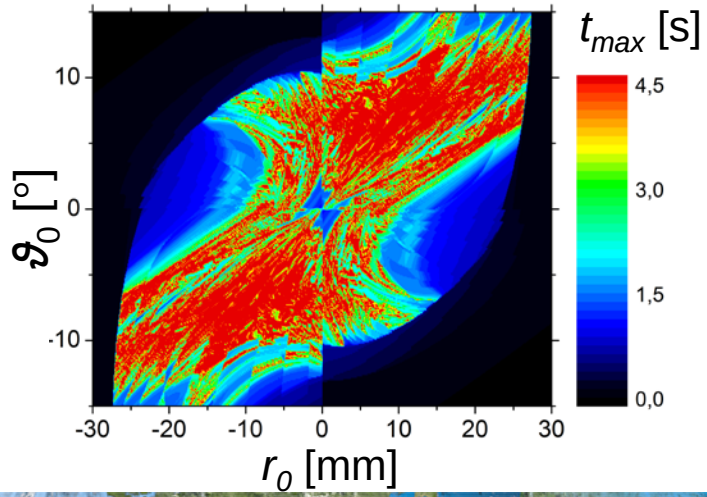






3.2 kW – 154 g

Butterfly effect (cont.) →



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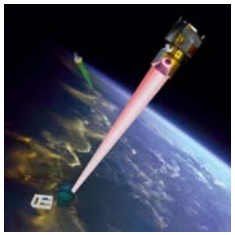
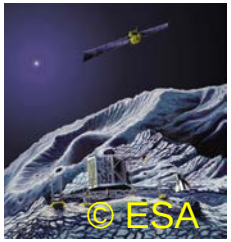
  - Concept studies
- **Period**
  - Conclusions
  - Outlook

Conclusions and Outlook

→ DLR final contribution

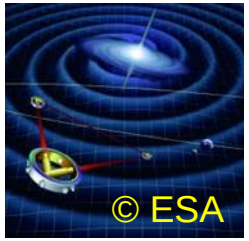


Ground-based launch



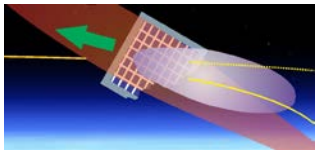
In-space remote propulsion

DLR current activities
→ Contributions of
S. Karg, H.-A. Eckel

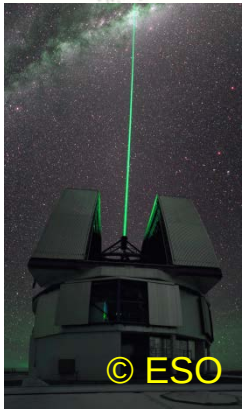


Micropropulsion

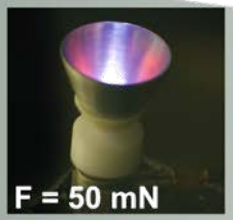
→ B. Esmiller, Keynote Thursday

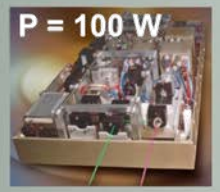


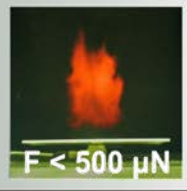
Debris removal



$$c_m = \frac{\text{thrust}}{\text{laser power}} = \frac{F = 1.2\ \text{N}}{P = 7.1\ \text{kW}} = \frac{F = 50\ \text{mN}}{P = 100\ \text{W}} = \frac{F < 500\ \mu\text{N}}{P < 1\ \text{W}}$$







long-term

mid-term

short-term

- **Photons**
  - High Energy Laser
  - Laser-induced Air Breakdown
  - Momentum Coupling
- **Propellant**
  - Detonation of POM
  - Flat Targets
  - Scaling and Standardization
- **Payload**
  - Flight Dynamics
  - Concept studies
- **Period**
  - Conclusions and Outlook
  - Outlook
- **People**

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- **Photons**
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- **Publications**

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Research is only possible on things you have dreamt before. The progress of science is rather based on dreaming than on experience. But many experiences are necessary to dispel the haze of a dream.

Gaston Bachelard, “The Poetry of Space“
Philosopher, 1884 – 1962