

Review on Laser Lightcraft Research at DLR Stuttgart

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HPLA/BEP

International Symposium on

High Power Laser Ablation and Beamed Energy Propulsion

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Knowledge for Tomorrow

Tribute to the Pioneers

In ancient Rome, speeches used to cite Cato the Elder, even off-topic, with:
„Karthago must be destroyed (*Carthago delenda est*).“

For illustration see: 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

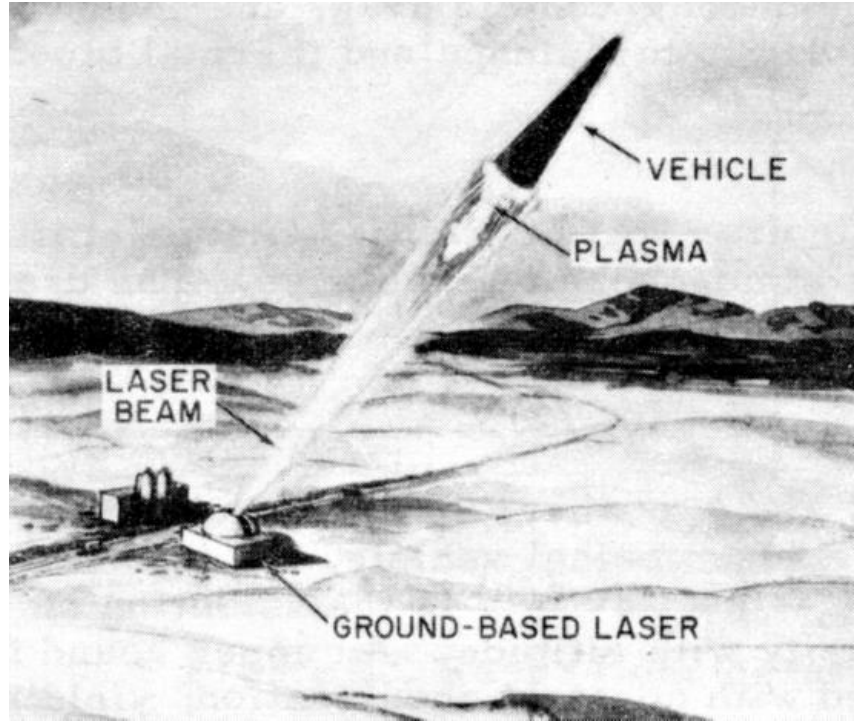


The Pioneer and his Vision



Arthur R. Kantrowitz

†2008



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

4P-principle

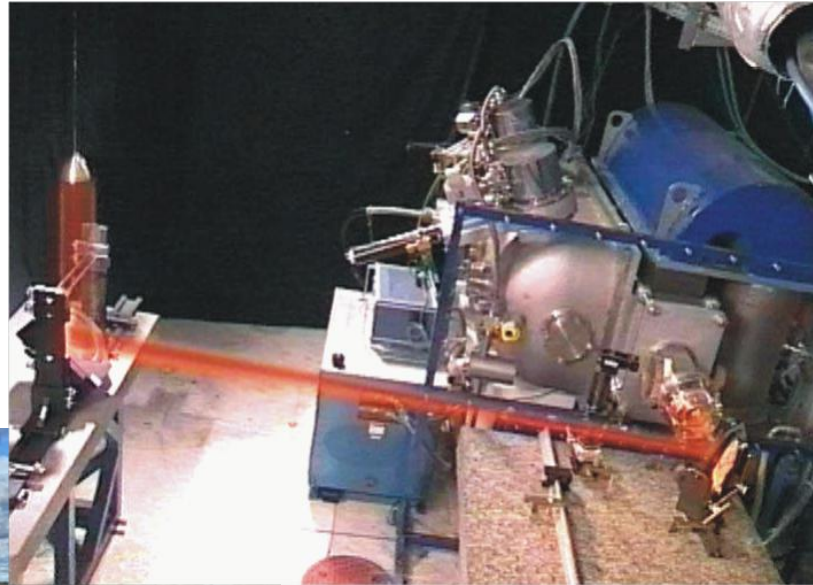
- Payload
- Propellant
- Photons
- Period



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

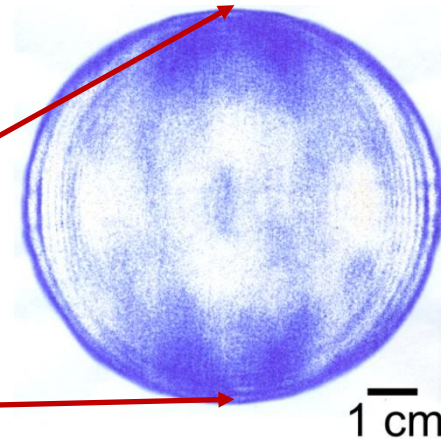


- Photons

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

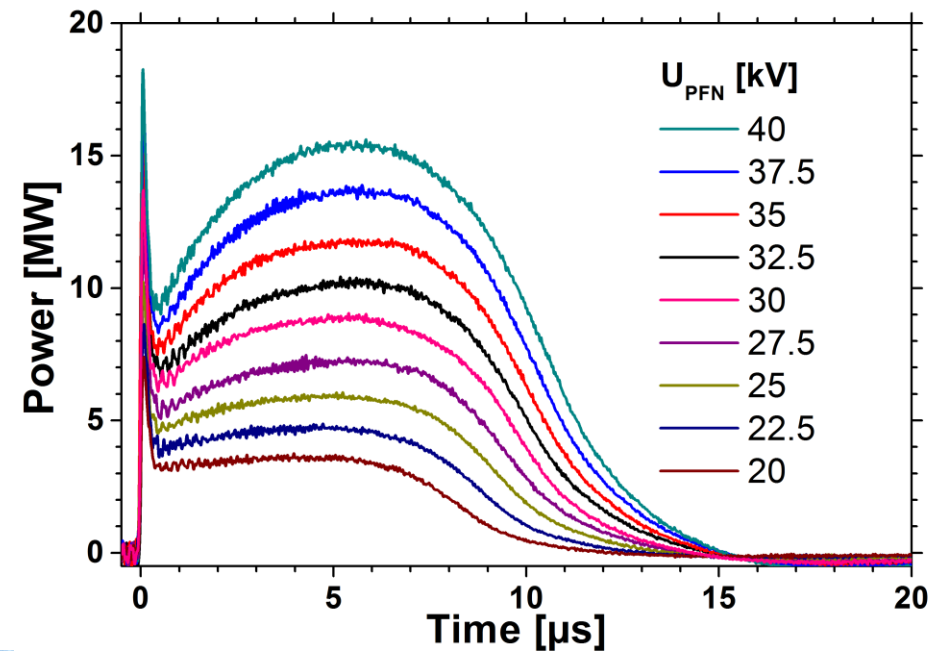


CO₂ High Energy Laser – Multispectral Testbed



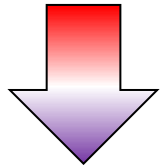
$\lambda = 10.6 \mu\text{m}$,
 $E_L = 30 - 210 \text{ J}$
 $f = 0 - 50 \text{ Hz}$,
 $\bar{P} = 0 - 7.5 \text{ kW}$
 $\theta \approx 13 \text{ mrad}$

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



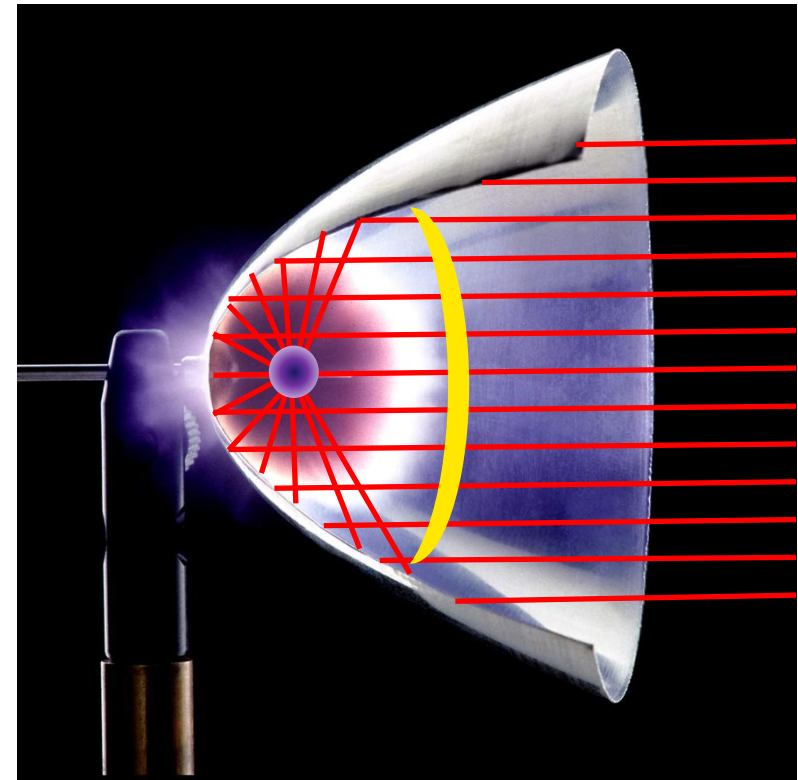
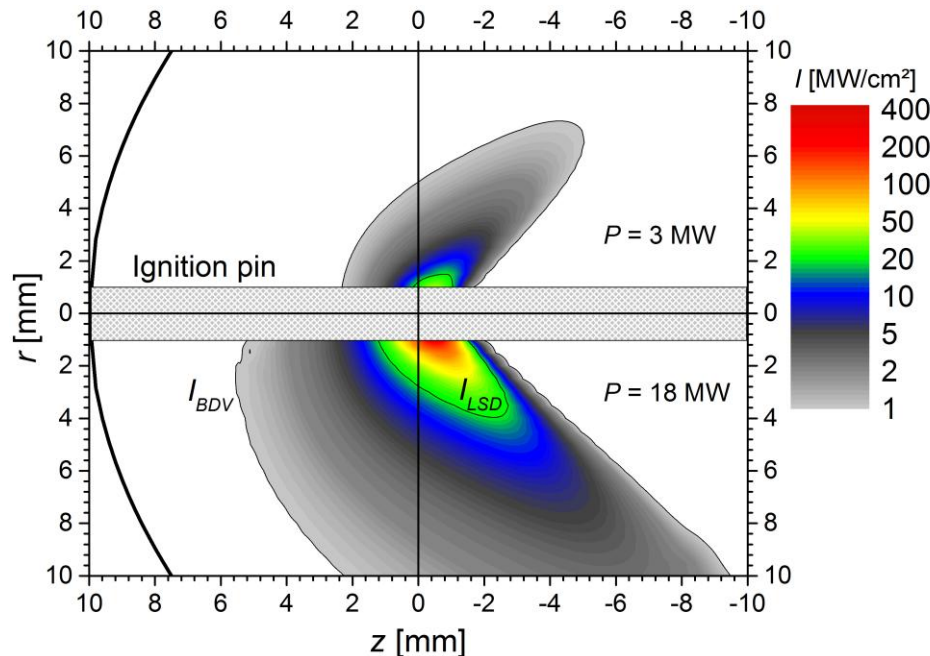
Parabolic Nozzle – Intensity Distribution

- Reflector nozzle with ignition pin



$I > 1.5 \text{ GW/cm}^2$ (air) and
 $I > 1 \text{ MW/cm}^2$ (metall vapor), resp.

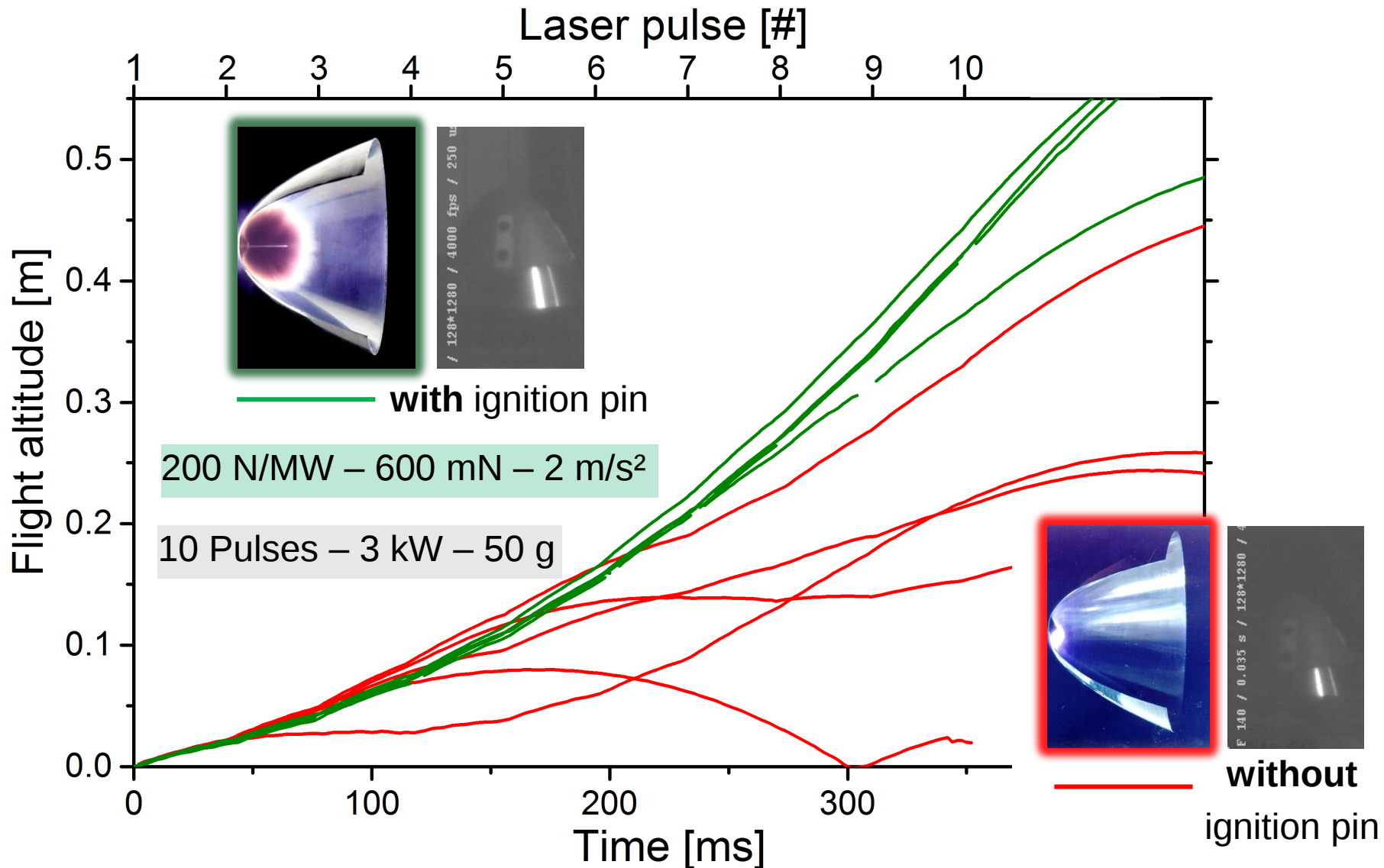
- Air breakdown
- Laser-induced detonation wave



Typical parameters: 10 cm diameter
 1 cm focus length

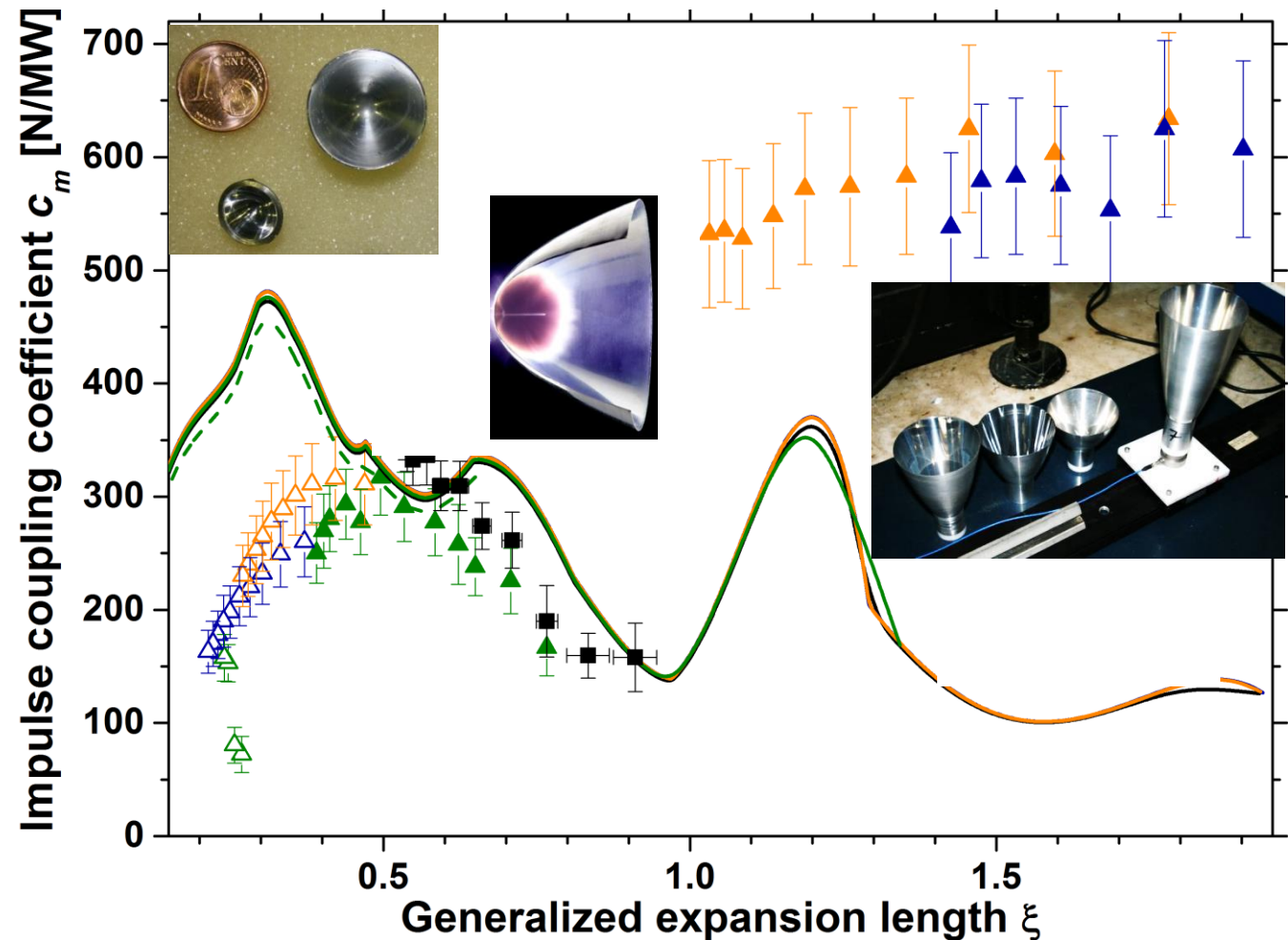
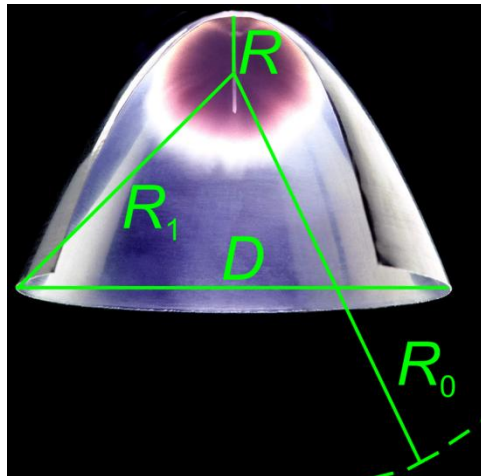


Ignition Pin – Reproducibility of c_m in Free Flights



Impulse Coupling by Detonation of Ambient Air

Generalized expansion length $\xi = \frac{R_1}{R_0} = \frac{R [1 + (4R/D)^{-2}]}{3\sqrt{E_0/p_0}}$ Expansion length
 Ageev et al., *Sov. J. Quant. El.* 7: 1430 – 1437 (1977) Dynamic radius



- Photons

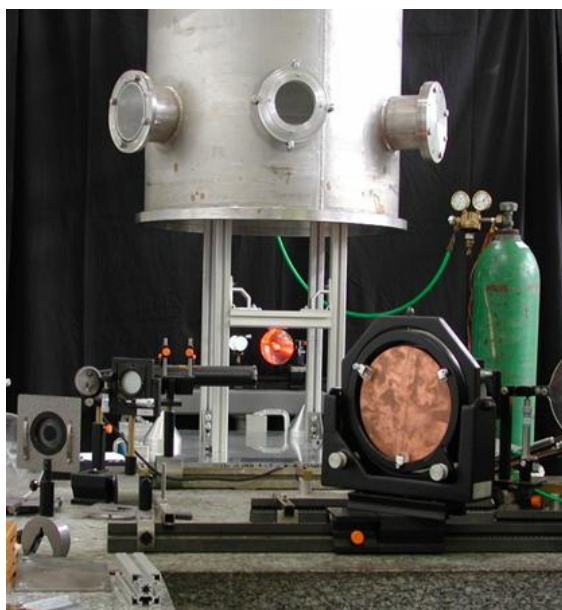
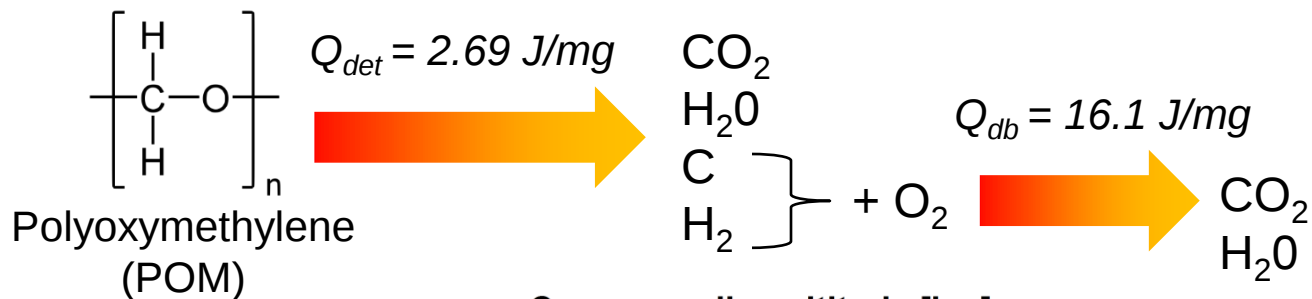
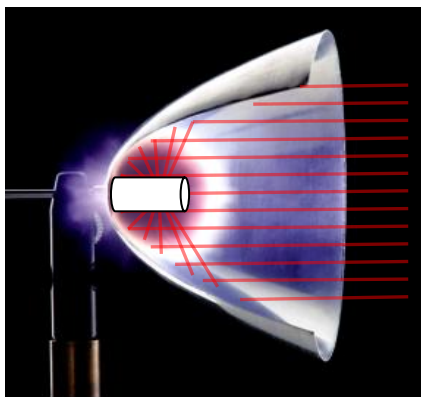
- High Energy Laser
- Laser-induced Air Breakdown
- Momentum Coupling

- Propellant

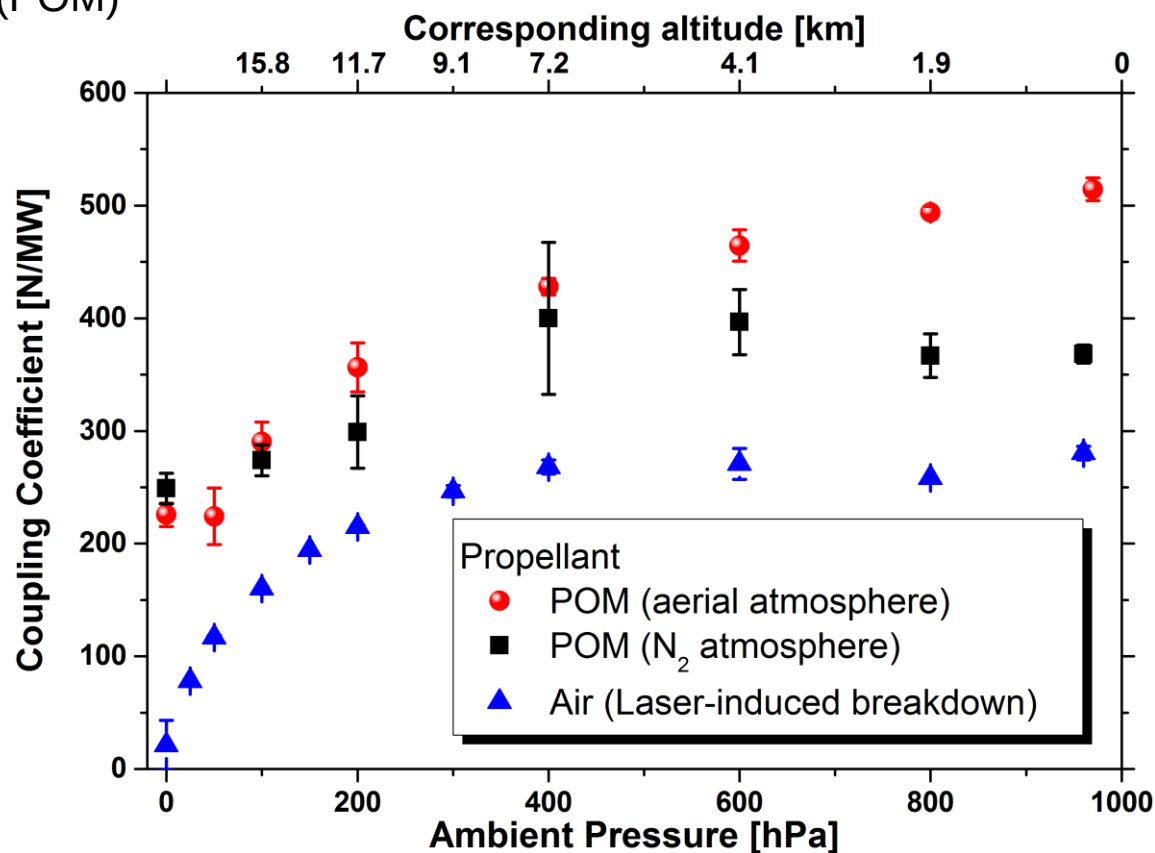
- Detonation of POM
- Flat Targets
- Scaling and Standardization



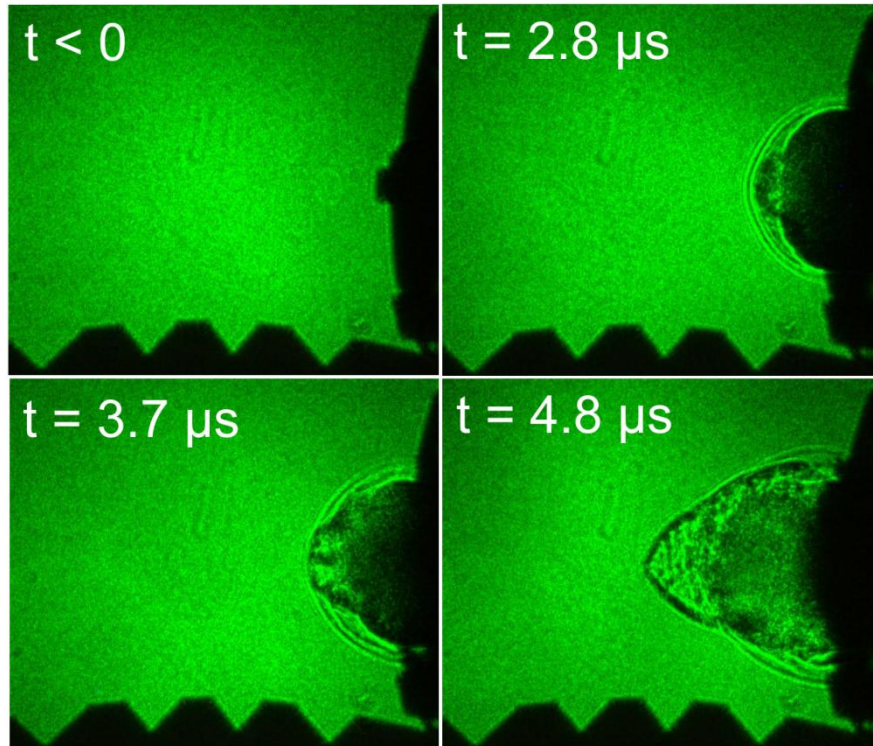
Impulse Measurements under Various Ambient Conditions



Ballistic pendulum
in vacuum vessel



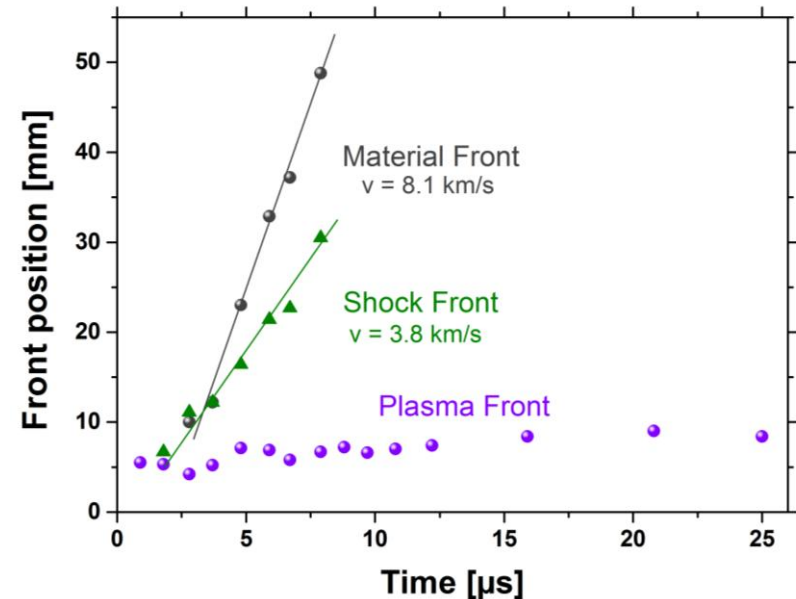
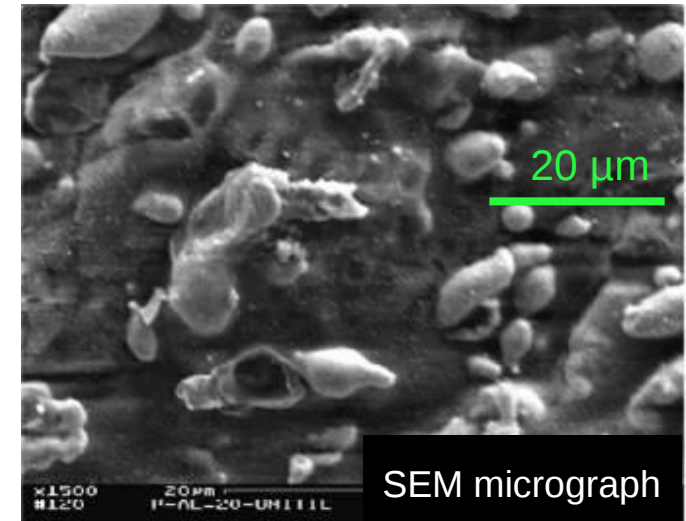
Polymer targets with metal dopants



Schlieren recording of laser ablation

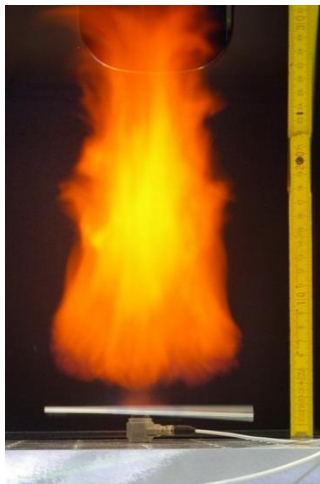
POM doped with 20% Al grains

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

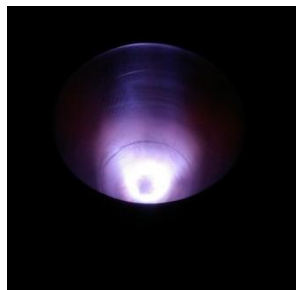


Photons > **Propellant** > Payload > Period

Scaling issues in laser ablative Propulsion



Large Flat Targets
at DLR Stuttgart



Miniaturized parabolic nozzles
at Nagoya University

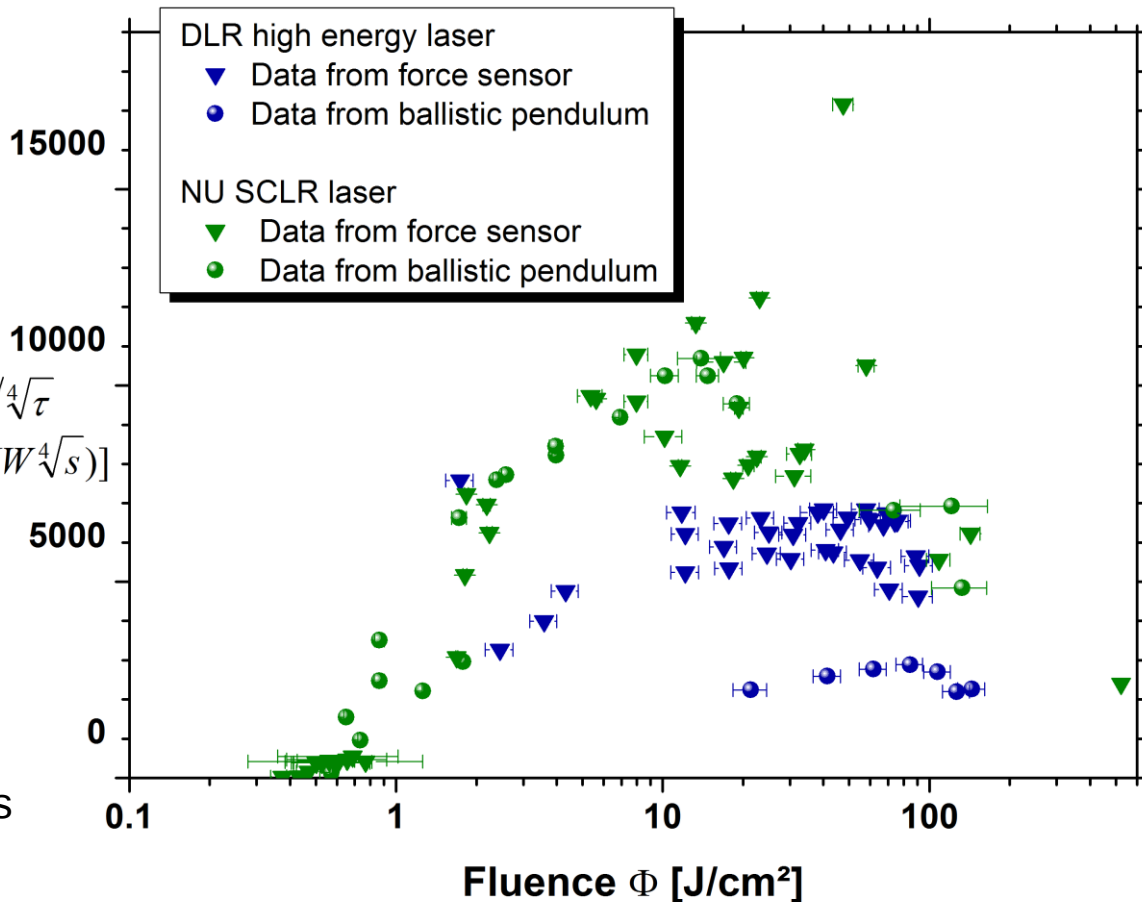
$$c_m \approx 2^{\frac{4}{3}} \sqrt[4]{\tau} \cdot f(\Phi, \Phi_{th}, \varrho, D_T)$$

Vaporization regime

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

Relative impulse coupling coefficient

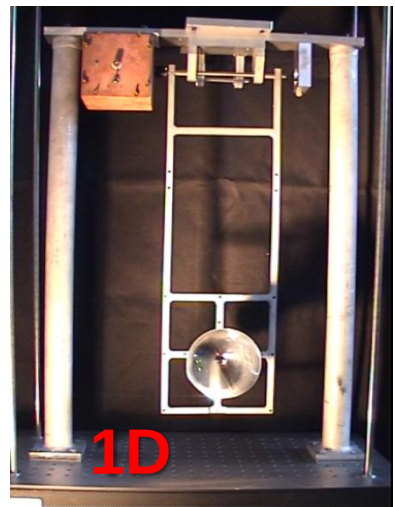
$$\frac{c_m}{\sqrt[4]{\tau}} \quad [N / (MW^{\frac{1}{4}} s)]$$



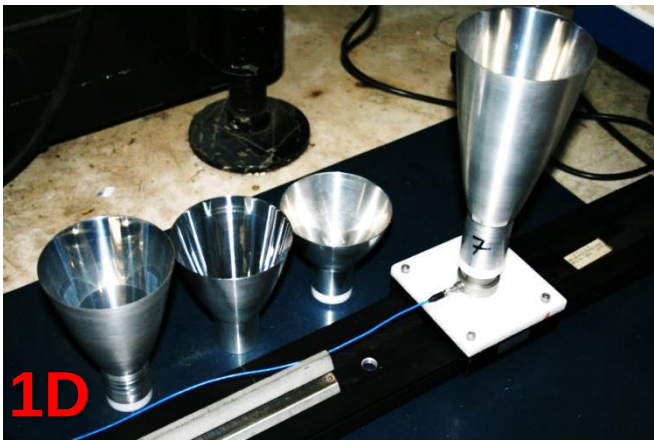
Measurement of c_m – Standardization Issues



Mathematical
Pendulum
(DLR)



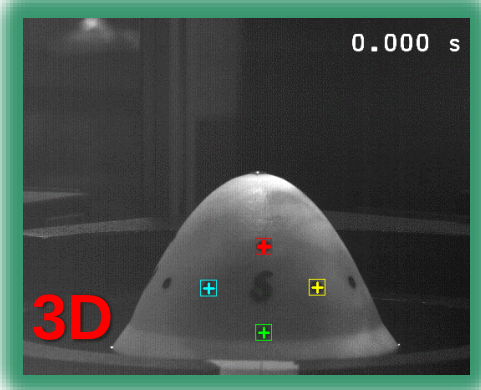
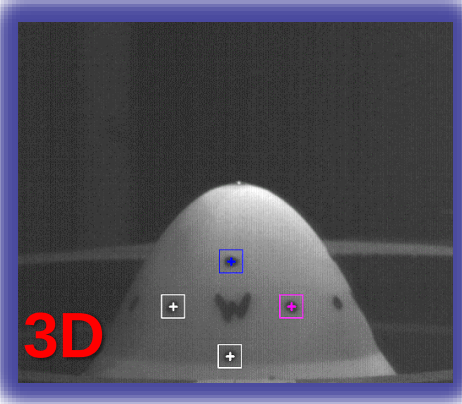
Physical Pendulum
(US AFRL)



Impact sensor (DLR / NU)



Air cushion table



Free flight experiment



- **Photons**

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

- **Propellant**

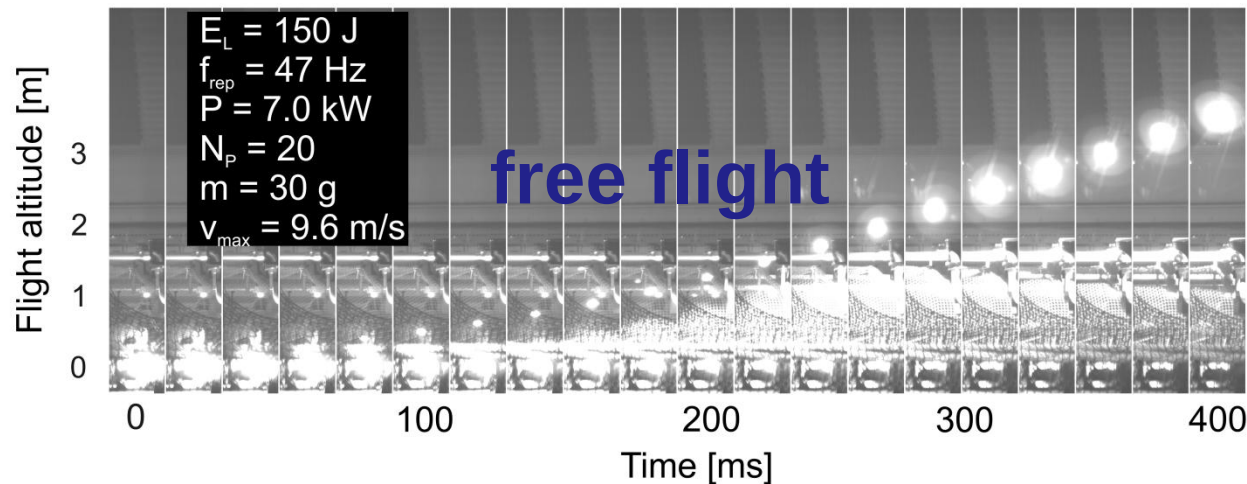
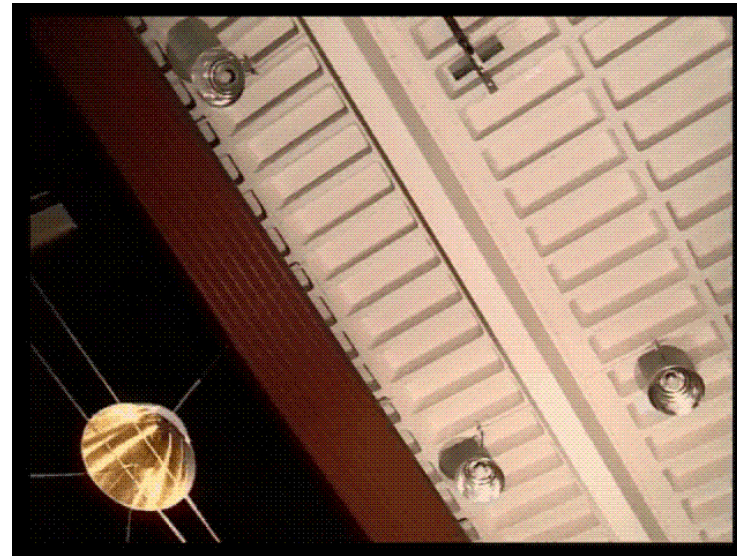
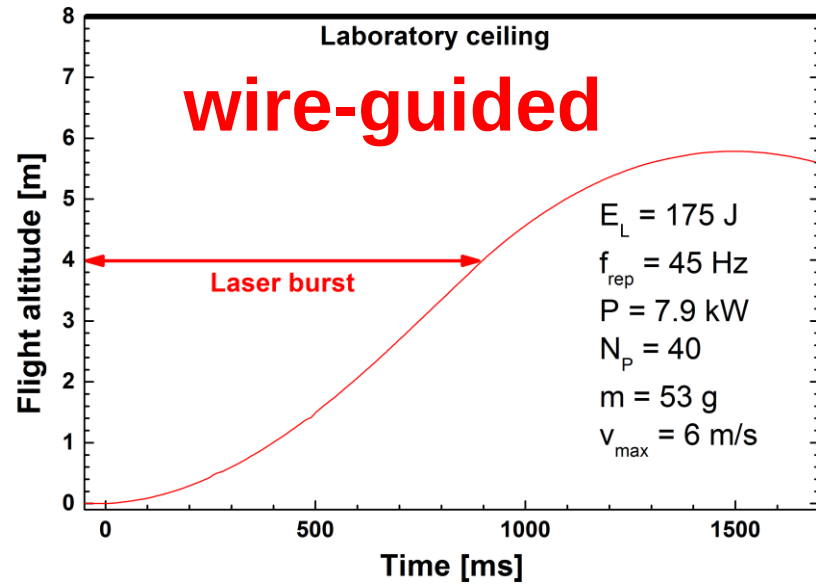
- Detonation of POM
- Flat Targets
- Scaling and Standardization

- **Payload**

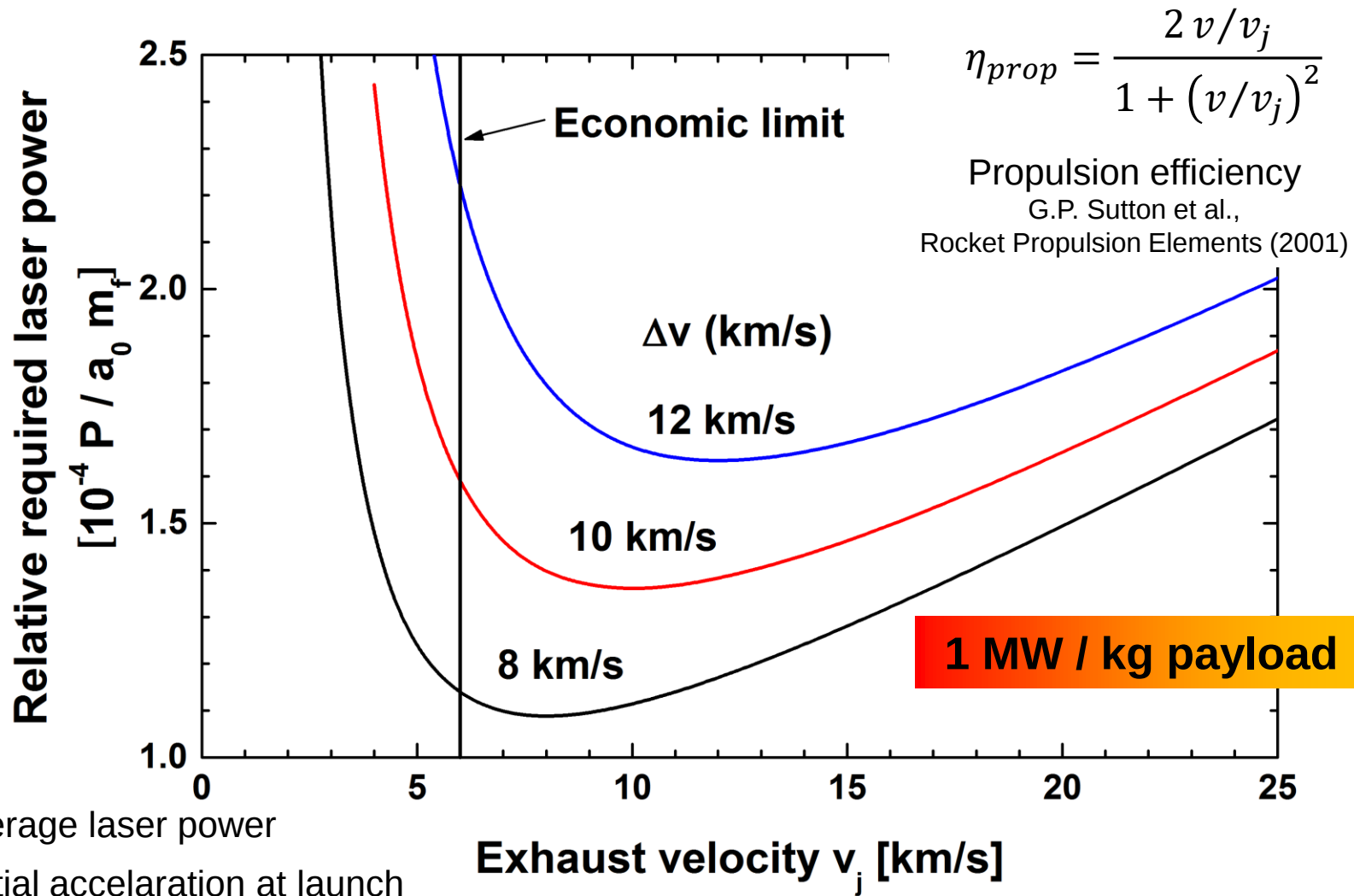
- Flight Dynamics
- Concept studies



Flight Experiments



Ground-based launch to Low Earth Orbit



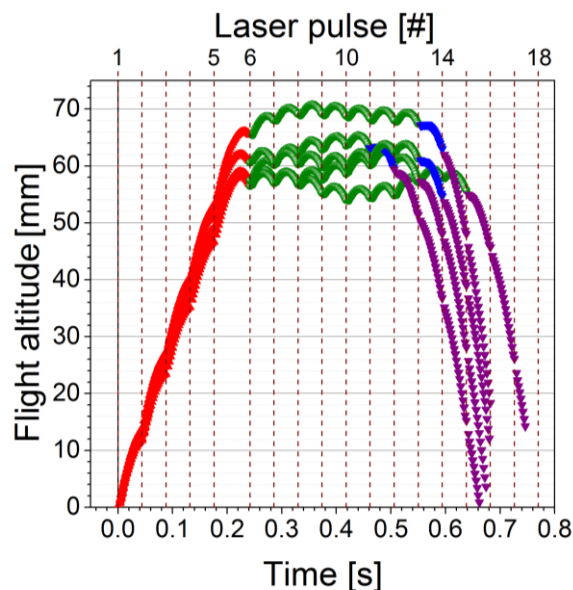
P – average laser power

a_0 – initial acceleration at launch

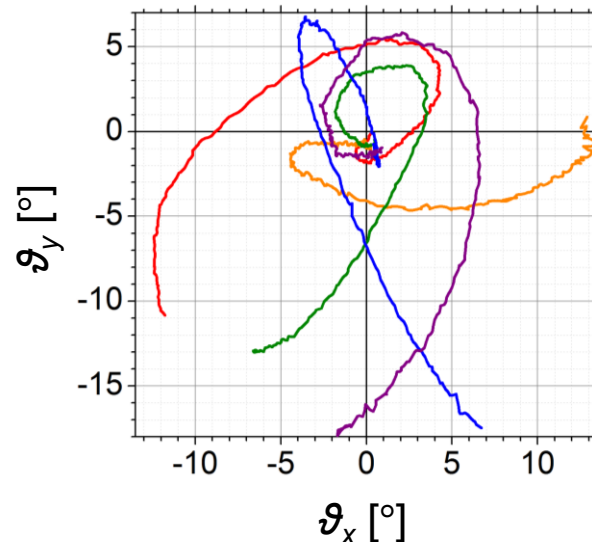
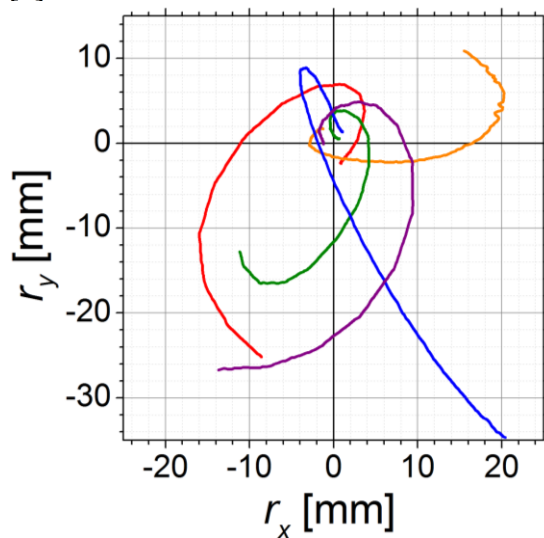
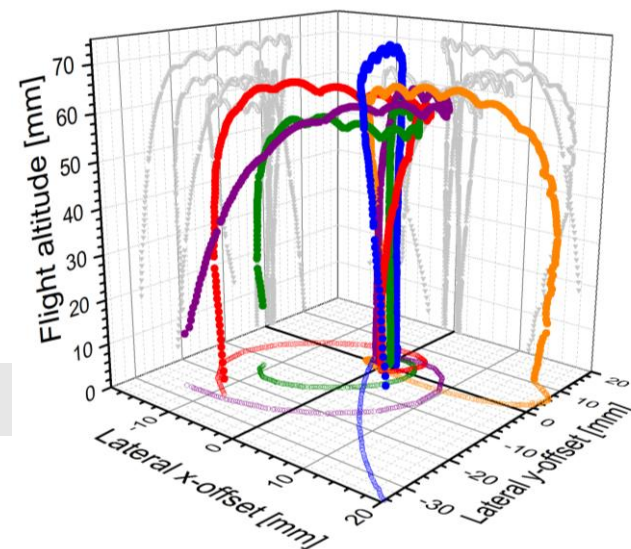
m_f – final mass in orbit



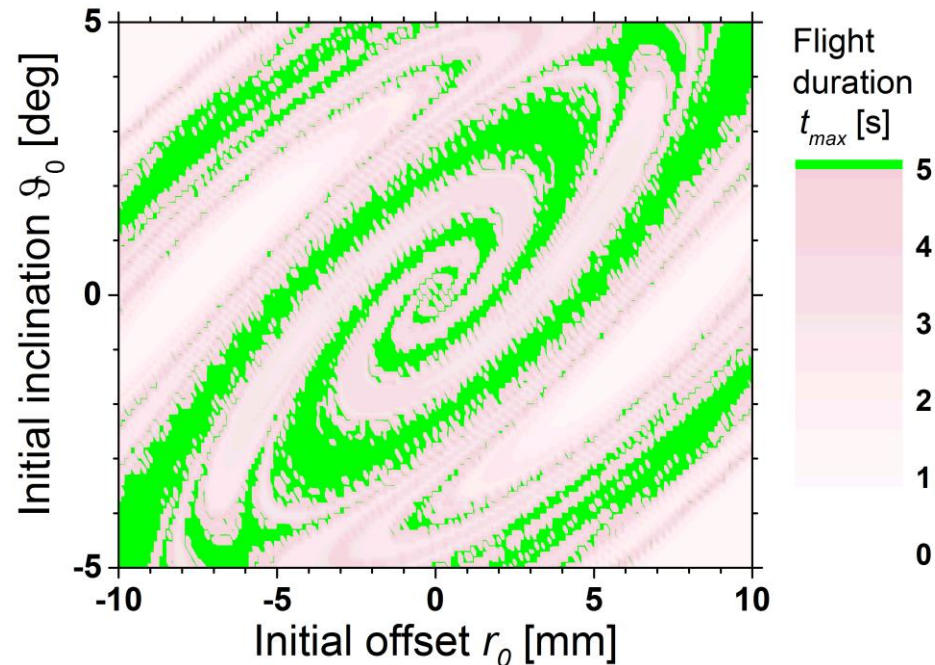
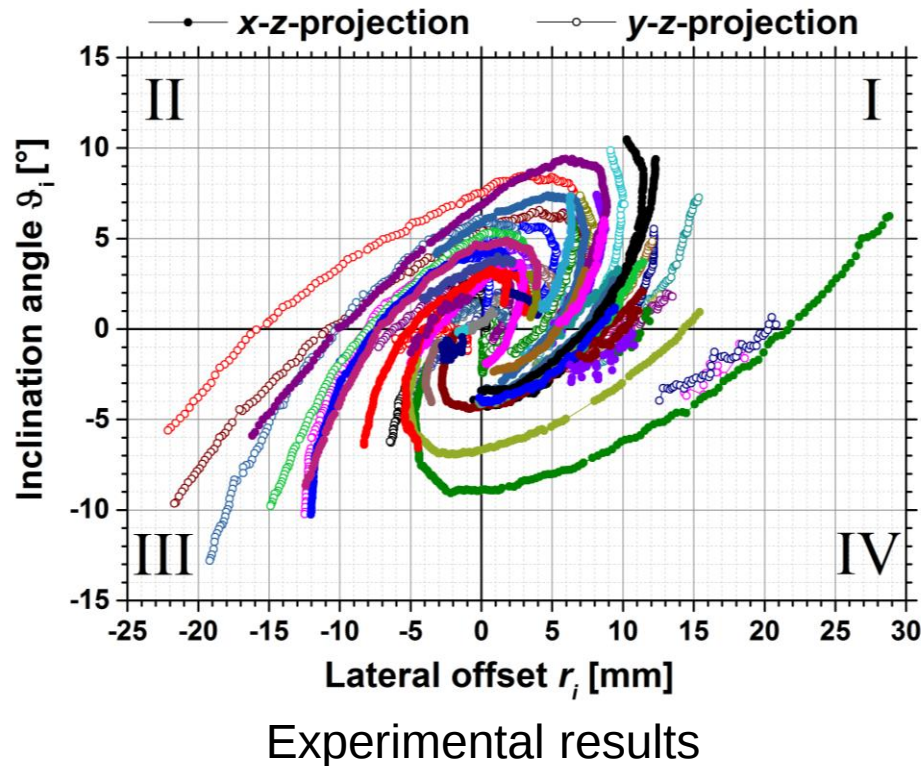
Hovering experiments



20 Pulses - 2.5 kW - 70 g



Flight Stability Analysis



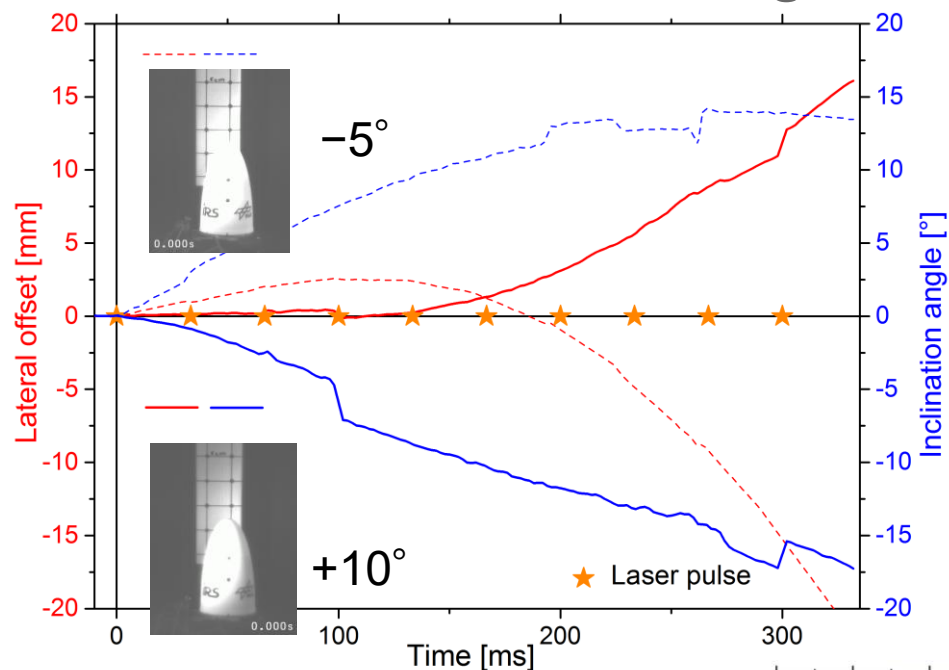
→ Poster: Beam-Riding Simulation and Diagnostics for Beamed-Energy Vehicles

Simulation of flight duration
vs. alignment

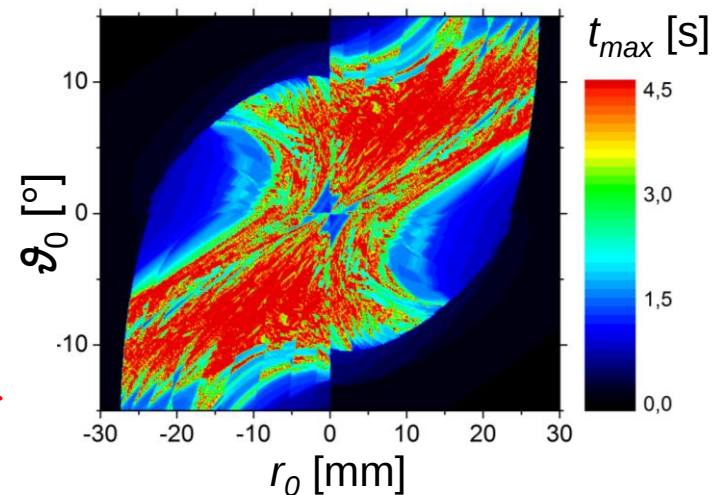
→ **Butterfly effect**



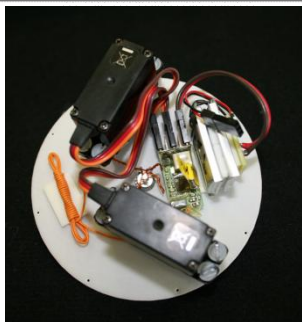
Thrust vector steering



3.2 kW – 154 g



Butterfly effect (cont.) →



- **Photons**

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- **Propellant**

- Detonation of POM
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- Scaling and Standardization

- **Payload**

- Flight Dynamics
- Concept studies

- **Period**

- Conclusions
- Outlook

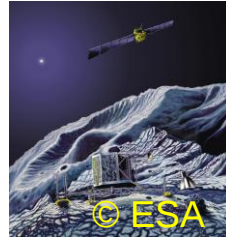


Conclusions and Outlook

→ DLR final contribution



Ground-based launch



In-space remote propulsion

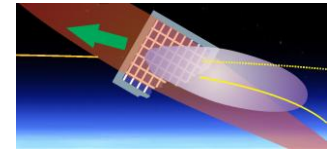


Micropropulsion

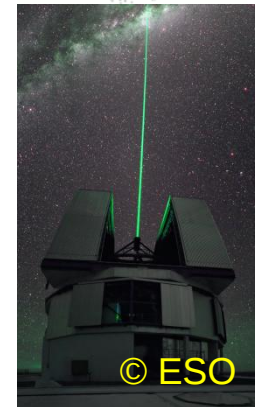
DLR current activities

→ Contributions of
S. Karg, H.-A. Eckel

→ B. Esmiller, Keynote
Thursday



Debris removal



© ESO

$$C_m = \frac{\text{thrust}}{\text{laser power}}$$

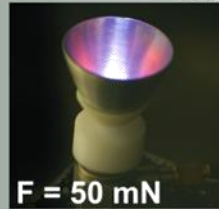


F = 1.2 N

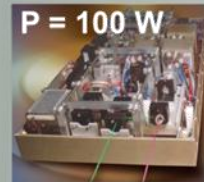


P = 7.1 kW

long-term

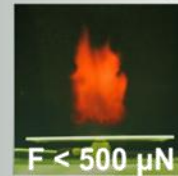


F = 50 mN



P = 100 W

mid-term



F < 500 μN



P < 1 W

short-term



- Photons

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- Detonation of POM
- Flat Targets
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- Payload

- Flight Dynamics
- Concept studies

- Period

- Conclusions and Outlook
- Outlook

- People

DLR scientific staff

W. Bohn, A. Giesen, W.O. Schall, W. Riede, J. Tegel, W. Mayerhofer, E. Zeyfang, D. Hoffmann, E. Wollenhaupt, S. Karg, D. Sperber, H.-A. Eckel, S. Scharring

DLR technical staff

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Academic thesis supervision

H.-P. Röser, Institute of Space Systems (IRS), University of Stuttgart

Cooperation partners

J.E. Sinko, A. Sasoh (Nagoya University), T. Lippert, L. Urech (Paul-Scherrer-Institute, Villigen) F. B. Mead, Jr., C.W. Larson, T.J. Lawrence, W.M. Kalliomaa, and J.P. Sheehy (US AFRL)



- Photons

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- Outlook

- People

- Publications

1. W. Schall et al., *Laser Ablation and its Applications*, pp. 435 – 454 (2007).
2. H.-A. Eckel, and W. Schall, *Progress in Astron. and Aeron.* **223**, pp. 357–406, AIAA, 2008.
3. W. Schall and H.-A. Eckel, *Space Technology* **24**, pp. 129–135, 2004.
4. S. Scharring, et al., *Acta Astronautica* **65**, pp. 1599–1615, 2009.
5. C. Phipps et al., *Journal of Propulsion and Power* **26**(4), pp. 609–637, 2010.
6. S. Scharring, H.-A. Eckel, and H.-P. Röser, *Int. J. Aerospace Innovations* **3**(1), pp. 15–31, 2011.
7. S. Scharring et al., *Int. J. Aerospace Innovations* **3**(1), pp. 33–43, 2011.
8. G. Renz et al, *Proc. of SPIE* **3092**, pp. 114–117, 1997.
9. W.O. Schall et al, *Proc. of SPIE* **4065**, pp. 472–481, 2000.
10. W.O. Schall et al, *Proc. of SPIE* **4760**, pp. 908–917, 2002.
11. W.O. Schall, H.-A. Eckel, and W. Riede, *Proc. of SPIE* **5120**, pp. 618–622, 2003.
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13. H.-A. Eckel, and W.O. Schall, *AIP Conf. Proc.* **702**, pp. 263–273, 2004.
14. W.O. Schall, J. Tegel, and H.A. Eckel, *AIP Conf. Proc.* **766**, pp. 423–432, 2004.
15. W.O. Schall, *Proc. of SPIE* **5777**, pp. 993–998, 2005.
16. H.A. Eckel, J. Tegel, and W. Schall, *AIP Conf. Proc.* **830**, pp. 272–283, 2006.
17. H.A. Eckel, J. Tegel, and W. Schall, *Proc. of SPIE* **6261**, 62610E, 2006.
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19. S. Scharring, H.-A. Eckel, and H.-P. Röser, *AIP Conf. Proc.* **997**, pp. 304–315, 2008.
20. S. Scharring et al, *AIP Conf. Proc.* **997**, pp. 295–303, 2008.
21. S. Scharring, H.-A. Eckel, and H.-P. Röser, *AIP Conf. Proc.* **1230**, pp. 77–88, 2010.
22. S. Scharring et al, *AIP Conf. Proc.* **1230**, pp. 89–100, 2010.
23. J. Sinko et al, *AIP Conf. Proc.* **1230**, pp. 125–136, 2010.
24. S. Scharring et al., *AIP Conf. Proc.* **1230**, pp. 326–337, 2010.
25. H.-A. Eckel and S. Scharring, *AIP Conf. Proc.* **1278**, pp. 677–688, 2010.
26. S. Scharring et al., *AIP Conf. Proc.* **1278**, pp. 780–788, 2010.
27. J.E. Sinko et al., *AIP Conf. Proc.* **1278**, pp. 538–547, 2010.
28. J.E. Sinko et al., *AIP Conf. Proc.* **1278**, pp. 548–557, 2010.
29. S. Scharring et al., *AIP Conf. Proc.* **1402**, pp. 47–61, 2011.
30. S. Scharring, H.-A. Eckel, and H.-P. Röser, *AIP Conf. Proc.* **1402**, pp. 115–131, 2011.
31. D. Hoffmann, Diploma thesis, University of Stuttgart, 2008.
32. E. Wollenhaupt, Diploma thesis, University of Stuttgart, 2009.
33. S. Scharring, PhD thesis, University of Stuttgart, 2013.
34. W.O. Schall et al., Patent DE 100 17 343 C2 (2000) and US 2002/0047673 A1 (2001)



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

