Development of Environmental-Friendly Solid Propellants for Laser Ablation Propulsion

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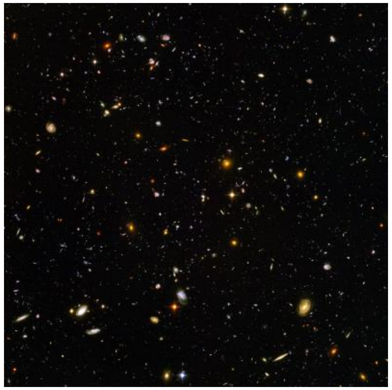
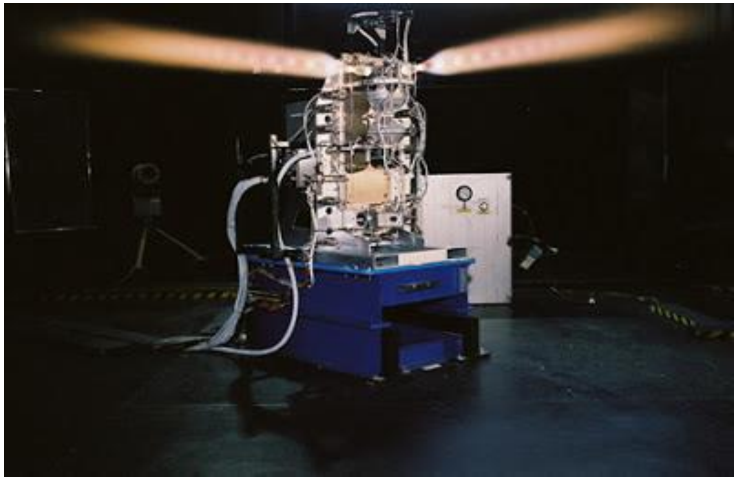
Space exploration may have given us wonderful pictures……



If the rockets that get us to orbit are based on conventional, toxic propellants...

Annual scientific assessment of the destruction of the ozone layer by the United Nations Environment Program (UNEP) and the World Health Organization.

Satellite propulsion

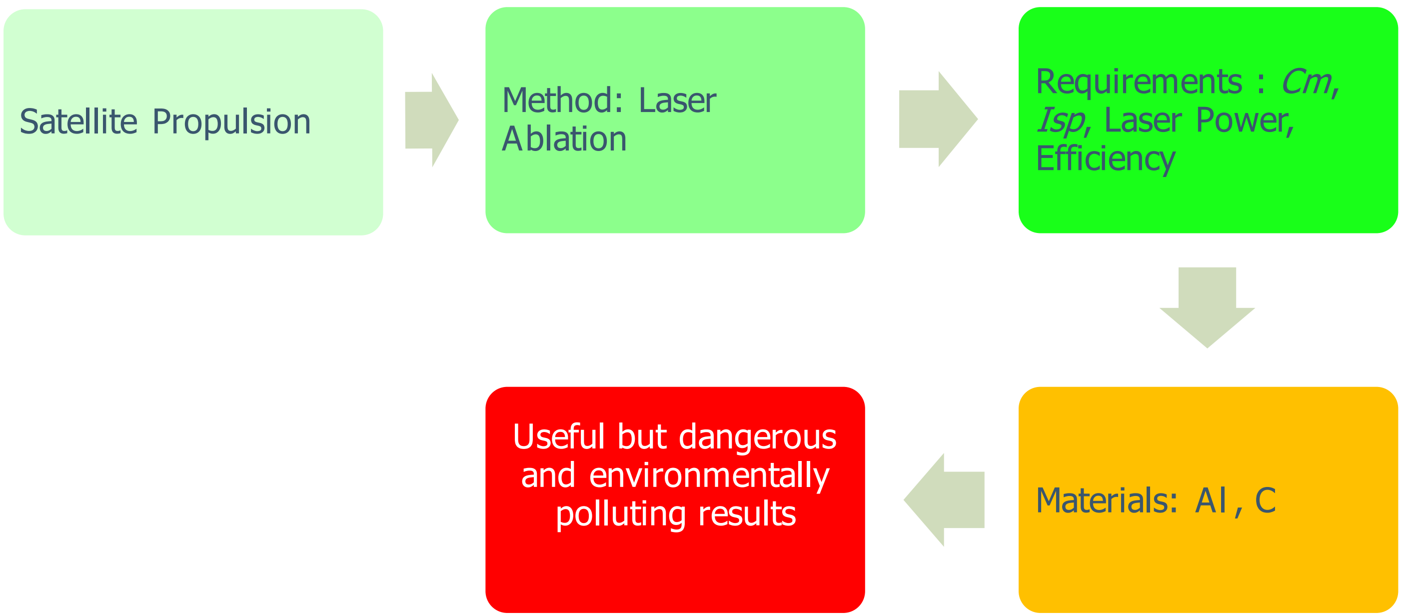


Aerodynamic drag

Useful life

Space debris

Why is this happening? We always think, first, of solving the problem in any way and with anything?



If we think in the environment when we try to solve the problem, then we can find an environmentally friendly solution.

We propose the following procedure to develop solid propellants for laser propulsion that are eco-friendly.

But before we look at the method of preparing the propellants, let's explain what laser propulsion is.

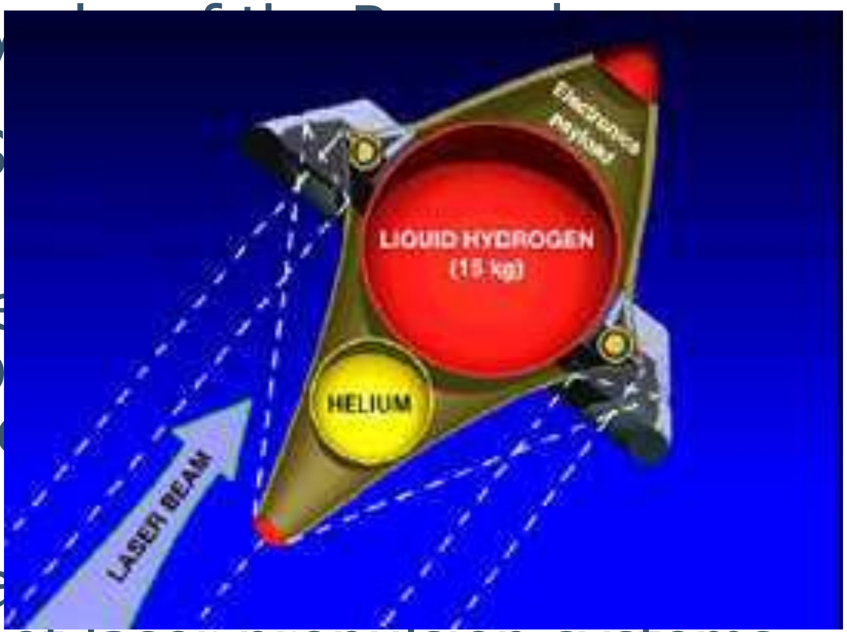
Laser Propulsion

- History
- Laser Propulsion
- Measurement
    - Propulsion Experiments
- Use in Satellites

History

- Arthur Kantrowitz of Avco Everett Research Laboratory in 1972.
- Focusing a high-powered laser beam could replace chemical propulsion
- In the last 15 years laser technology has had a great development.
- Ultra high-power laser systems that find application in the propulsion

History



- ... k My ... and ... NAS ...
- ... pulse ... to p ... a h ...
- ... ultra ... ign of laser propulsion systems.
- Specific pulse, energy conversion efficiency and mass-power ratio

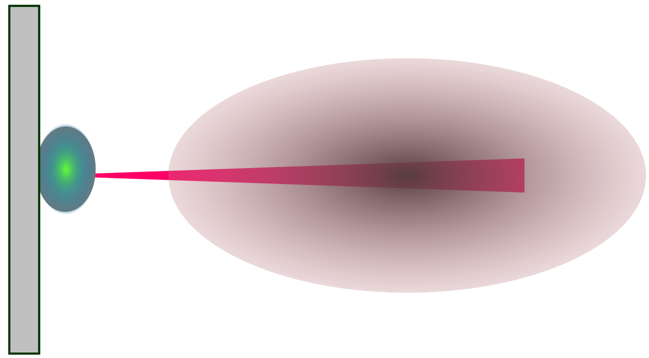
Laser Propulsion

- Propulsion mechanisms:
  - Gas - Solid
    - Pulsed Laser
    - Continuous Laser
  - Gas
    - Pulsed Laser
    - Continuous Laser
  - Fmto Laser Channels

Laser Propulsion

- Mechanism

  Direct Ablation (Gas-Solid)

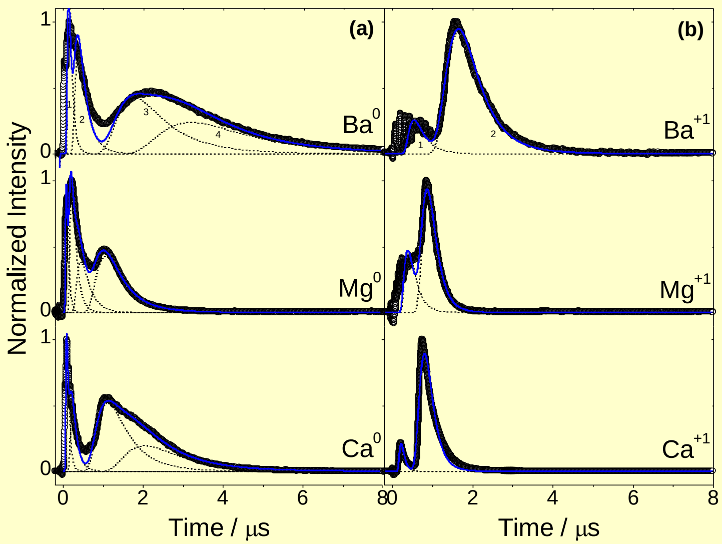


-Electron emission

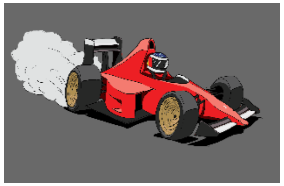
-Ion Acceleration (Coulombic Explosion)

-Evaporation by a phase explosion

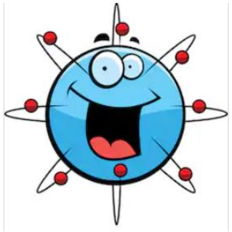
Velocity of Emitted Particles M and M^+ (Mg, Ca and Ba)



$$f(\nu)=\sum_{i=1}^{p} A\,\nu^3 \exp\left[-\left(\frac{\nu-\nu_0}{\alpha}\right)^2\right]$$



V_{max}: 0,10 km/s

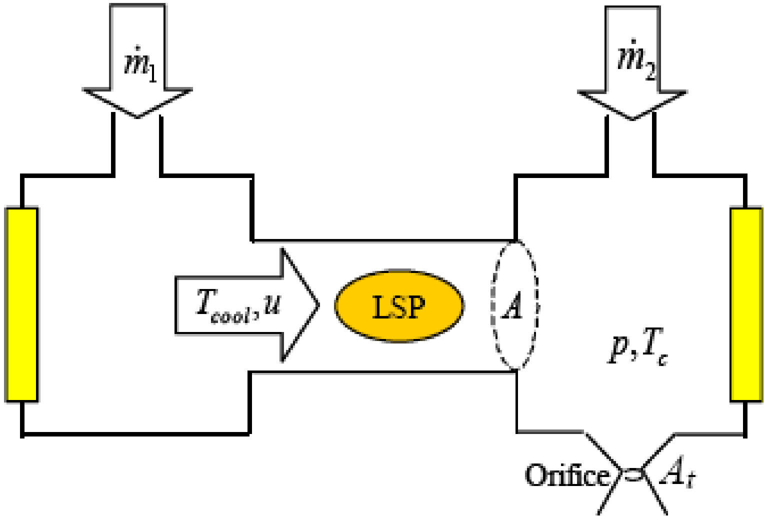


V_{max}: 25 km/s

Iván Cabanillas-Vidosa, Carlos A. Rinaldi, Juan C. Ferrero
Journal Applied Physics , 102, 013111, 2007

Laser Propulsion

- Mechanism
  - Plasma sustained (Gas)



Measurements

- Coupling coefficient: C_m

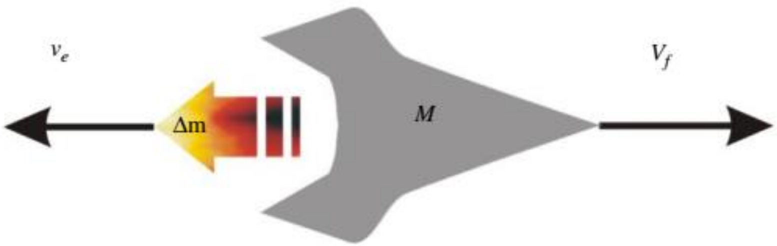


Fig. 1 Laser propulsion scheme.

X_0

$$Cm = \frac{m\,\Delta v}{E} = \frac{m\frac{\Delta v}{\Delta t}}{\frac{E}{\Delta t}} = \frac{[F]}{[P]} = \frac{[dyn]}{[W]}$$

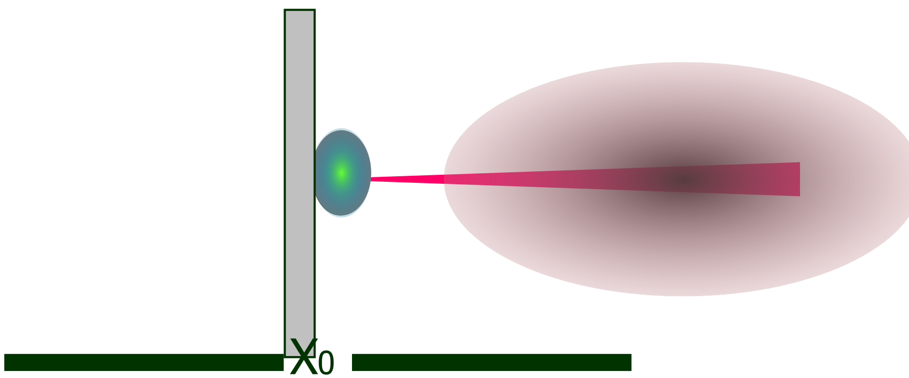
$$I_{sp} = \Delta P|_{plume}/\Delta m \cdot g \rightarrow I_{sp} = \Delta m \cdot v_e/\Delta m \cdot g = v_e/g,$$

$$C_m = \Delta P|_{satellite}/E \rightarrow C_m = M \cdot \Delta V/E = M \cdot V_f/E,$$

Pulsed laser: Energy per pulse (E)
Continuous laser: Power (P)

Measurements

- Coupling coefficient: C_m



Measurements

- Torsion Pendulum

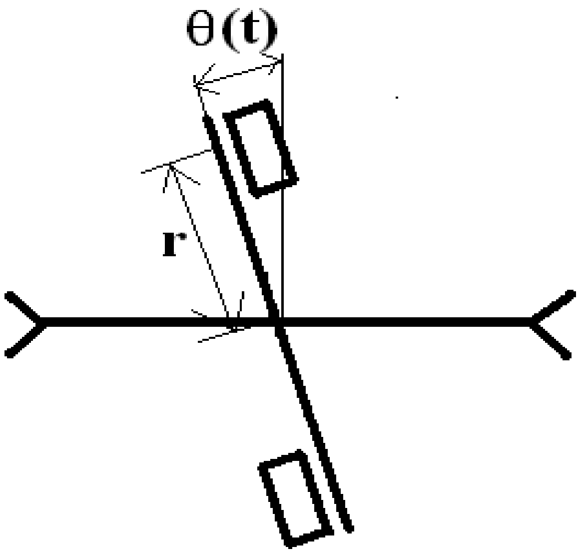
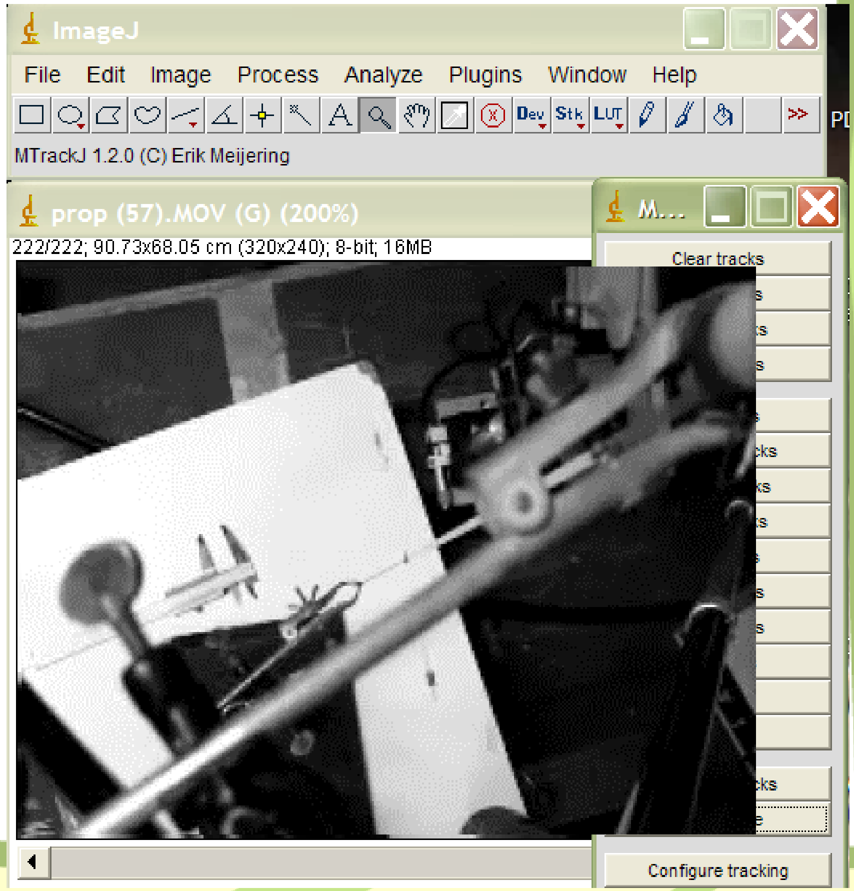
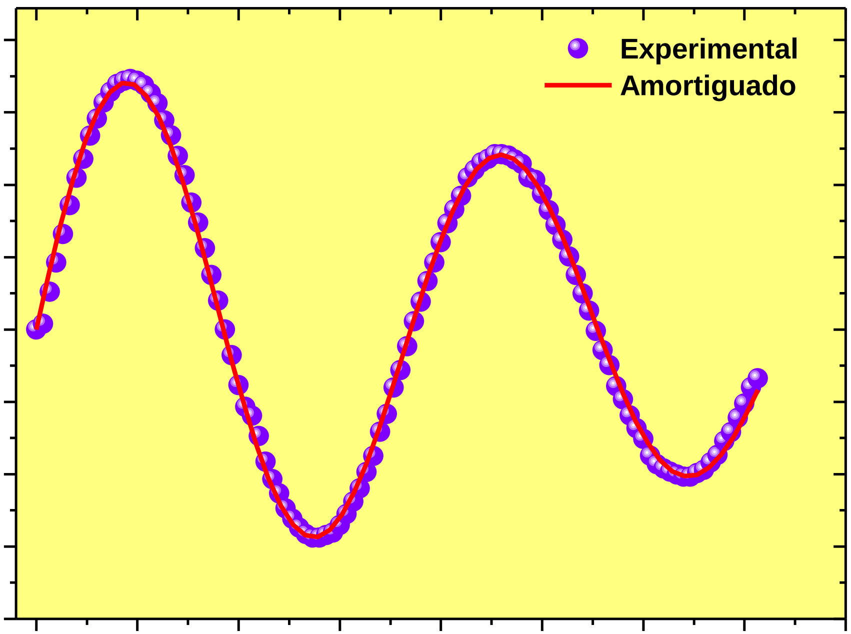


Image Analysis was performed



Measurements

- Torsion Pendulum



$$\frac{d^2\theta}{dt^2} + 2\,\beta\,\frac{d\theta}{dt} + \Omega_0^2\,\theta \quad = \quad 0$$

$$\theta(t=0) = 0$$

$$\frac{d\theta}{dt}(t=0) = \omega$$

$$\theta(t) = \frac{\omega}{\Omega}\,sen(\Omega\,t)\,e^{-\beta\,t}$$

$$\Omega^2 = \Omega_0^2 - \beta^2$$

$$Cm = \frac{m\,\Delta\text{v}}{\text{E}} = \frac{2\,m\,\omega\,r}{\text{E}}$$

AFA 2008, DANIEL RODRIGUEZ, NORBERTO G. BOGGIO, ALBERTO LAMAGNA, ALFREDO BOSELLI, CARLOS RINALDI, OSVALDO VILAR, JORGE CODNIA, M. LAURA AZCÁRATE 2,4

Measurements

- Specific Impulse: I_{sp}

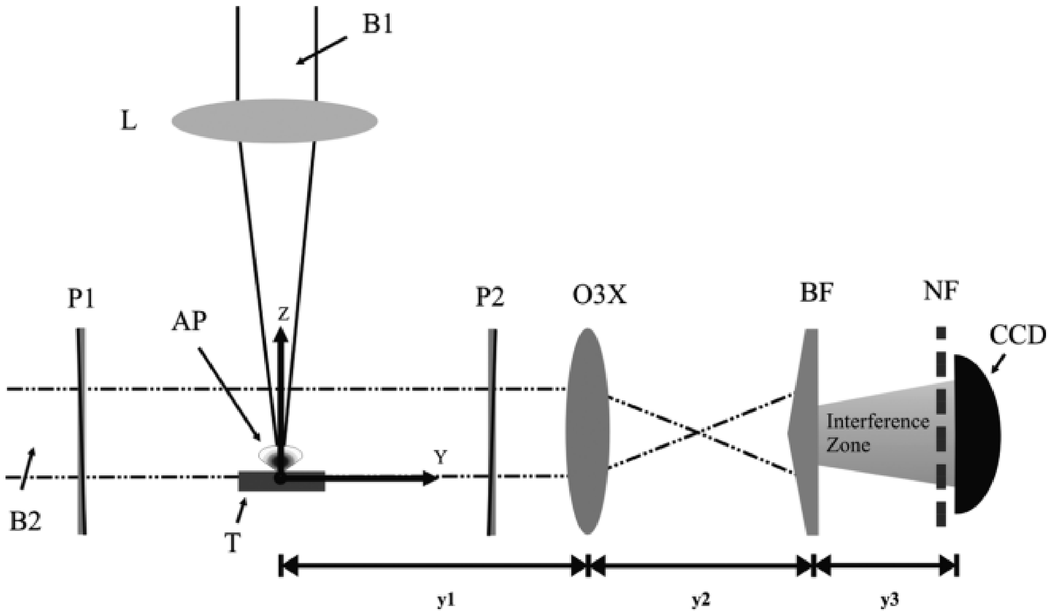


Fig. 3 Nomarsky interferometer scheme for the analysis of the laser ablation plume. AP: ablation plume, B1, B2: Nd:YAG lasers of 8 ns at 355 and 532 nm, respectively, BF: Fresnel biprism, CCD: detector with external trigger synchronized with both, B1 and B2 lasers L: UV lens, NF: narrowband filter at 532 nm, O3X: objective 3×, P1, P2: polarizers, and T: target.

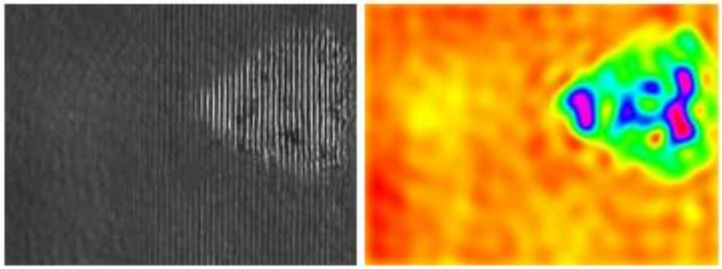
Cinthya Toro, Carlos A. Rinaldi, M. Laura Azcárate, "Interferometric method for specific impulse determination," *Opt. Eng.* **58**(1), 011006 (2018), doi: 10.1117/1.OE.58.1.011006.

Measurements

$$I_{sp} = \Delta P|_{plume} / \Delta m \cdot g \rightarrow I_{sp} = \Delta m \cdot v_e / \Delta m \cdot g = v_e / g,$$

$$C_m = \Delta P|_{satellite} / E \rightarrow C_m = M \cdot \Delta V / E = M \cdot V_f / E,$$

$$I_{sp} = C_m \cdot Q^*$$



Cinthya Toro, Carlos A. Rinaldi, M. Laura Azcárate, "Interferometric method for specific impulse determination," *Opt. Eng.* **58**(1), 011006 (2018), doi: 10.1117/1.OE.58.1.011006.

Measurements

- Propellant target : *Cm*

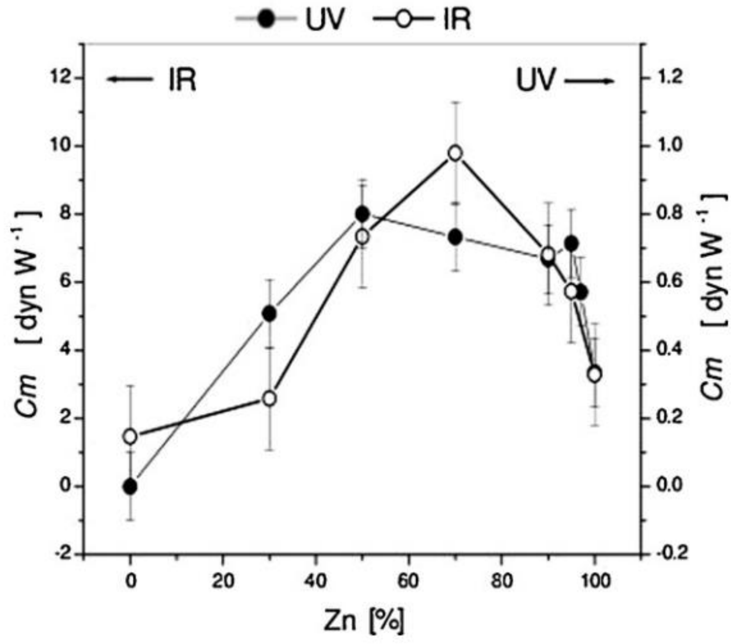


Fig. 9. Dependence of C_m on the pellet metal/salt composition. (○) IR 10.6 μm; (●) UV 355 nm.

C.A. Rinaldi et al. / Applied Surface Science 257 (2011) 2019–2023

- Mixture of $CaCO_3$ in Zn as matrix (0 , 50, 90 and 100 %)
- Zn metal powder (Mallinckrodt, 99.99%), $CaCO_3$ (Aldrich powder 99.99%)
- 10 mm diameter pellets in hydraulic press (2 stages)

Measurements

Propellant target : *Isp*

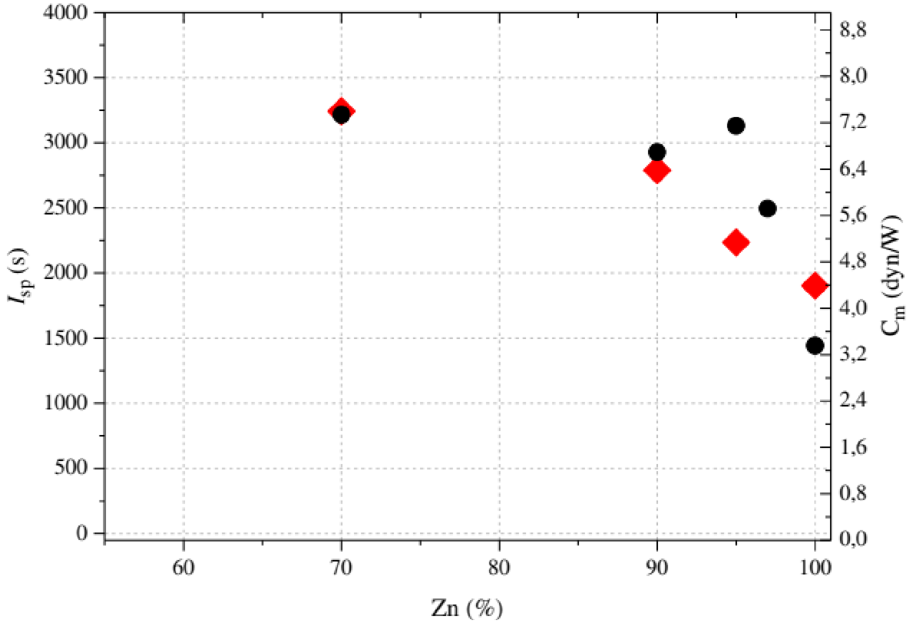


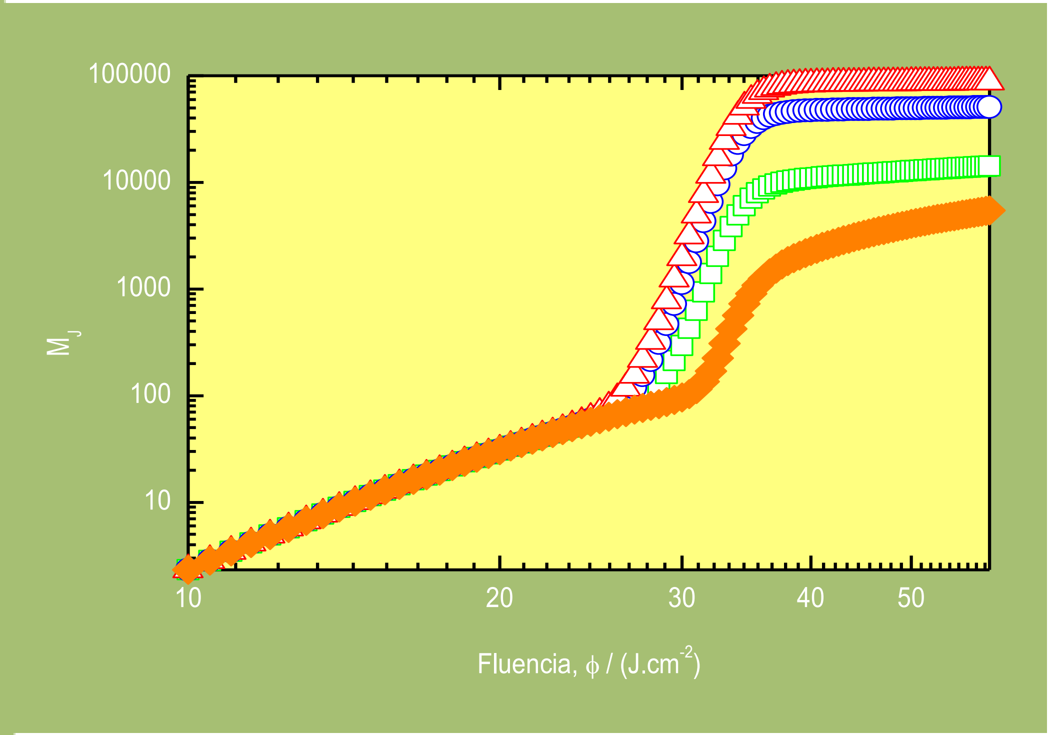
Fig. 8 I_{sp} (diamonds) and C_m (circles) of different fuels consisting of Zn/$CaCO_3$ mixtures as a function of Zn concentration.

- Mixture of $CaCO_3$ in Zn as matrix (0 , 50, 90 and 100 %)
- Zn metal powder (Mallinckrodt, 99.99%), $CaCO_3$ (Aldrich powder 99.99%)
- 10 mm diameter pellets in hydraulic press (2 stages)

Cinthya Toro, Carlos A. Rinaldi, M. Laura Azcárate, "Interferometric method for specific impulse determination," *Opt. Eng.* **58**(1), 011006 (2018), doi: 10.1117/1.OE.58.1.011006.

Measurements

- Thermodynamic properties



Melting point: $CaCO_3$: 1330 °C
ΔH: 200 kJ/mol

Melting Point:Zn : Zn : 419 °C
Boiling point: Zn : 907 °C

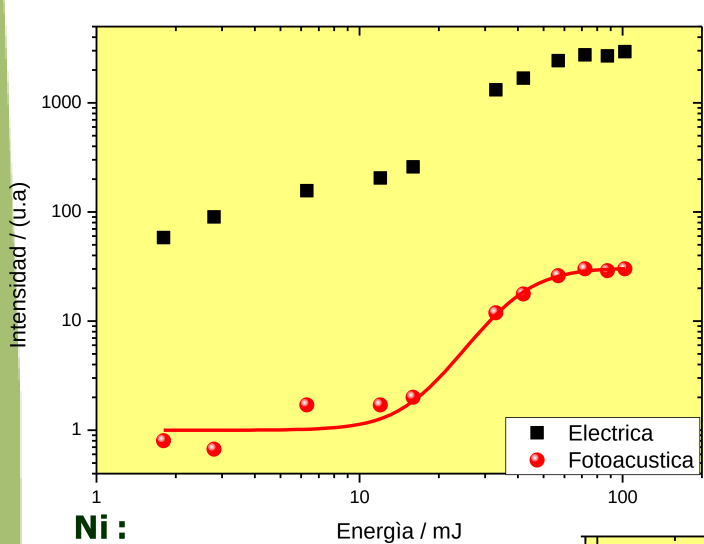
(△) *Ed* = 0.01 J.cm^{-3}
(○) *Ed* =0.1 J.cm^{-3}
(□) *Ed* =10 J.cm^{-3}
(◆) *Ed* = 30 J.cm^{-3}

C. A. Rinaldi y J.C. Ferrero
Actas del XXV Congreso Argentino de Química, S4 Fisicoquímica, 0642, 2004.

Measurements

- Mixture Ni/NaF
- Ni :
  - Mp: 1455 °C
  - Bp: 2913 °C
  - ΔHatom: 431 kJ/mol
- NaF:
  - Mp: 993 °C
  - Bp: 1700 °C
  - E Ret: 923 kJ/mol

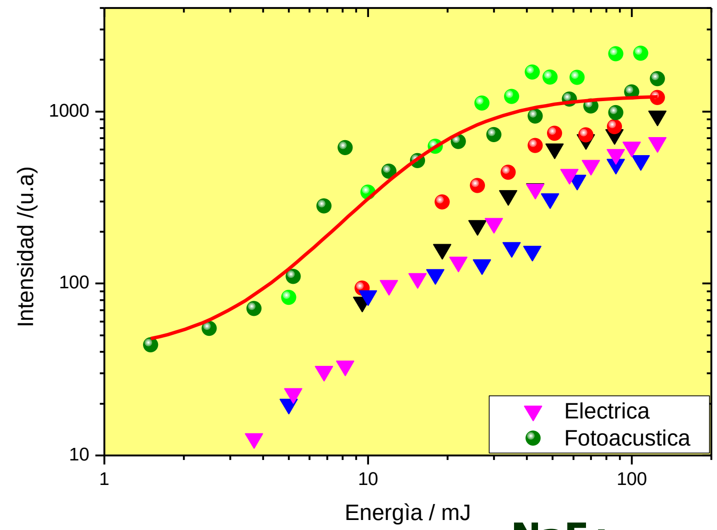
Measurements



Ni :

Sc: 4.02

Eo: 38.5

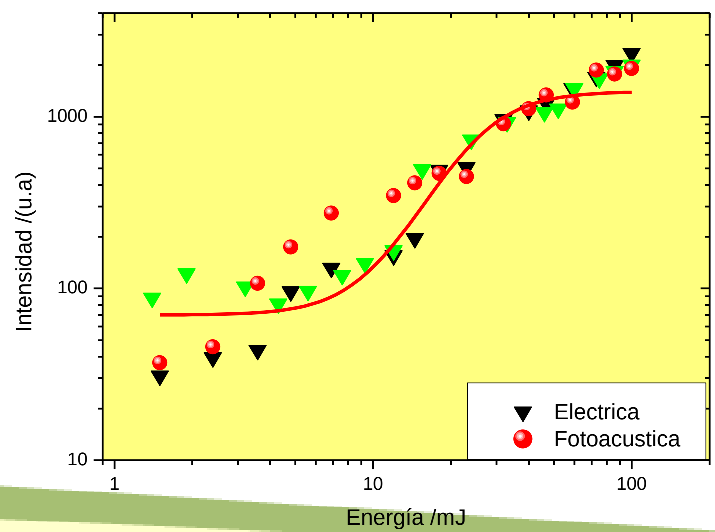


NaF :

Sc: 2.0

Eo: 18

$$M_J = \left[\frac{A_1 - A_2}{1 + \left(\frac{\phi}{\phi_c} \right)^{Sc}} + A_2 \right]$$

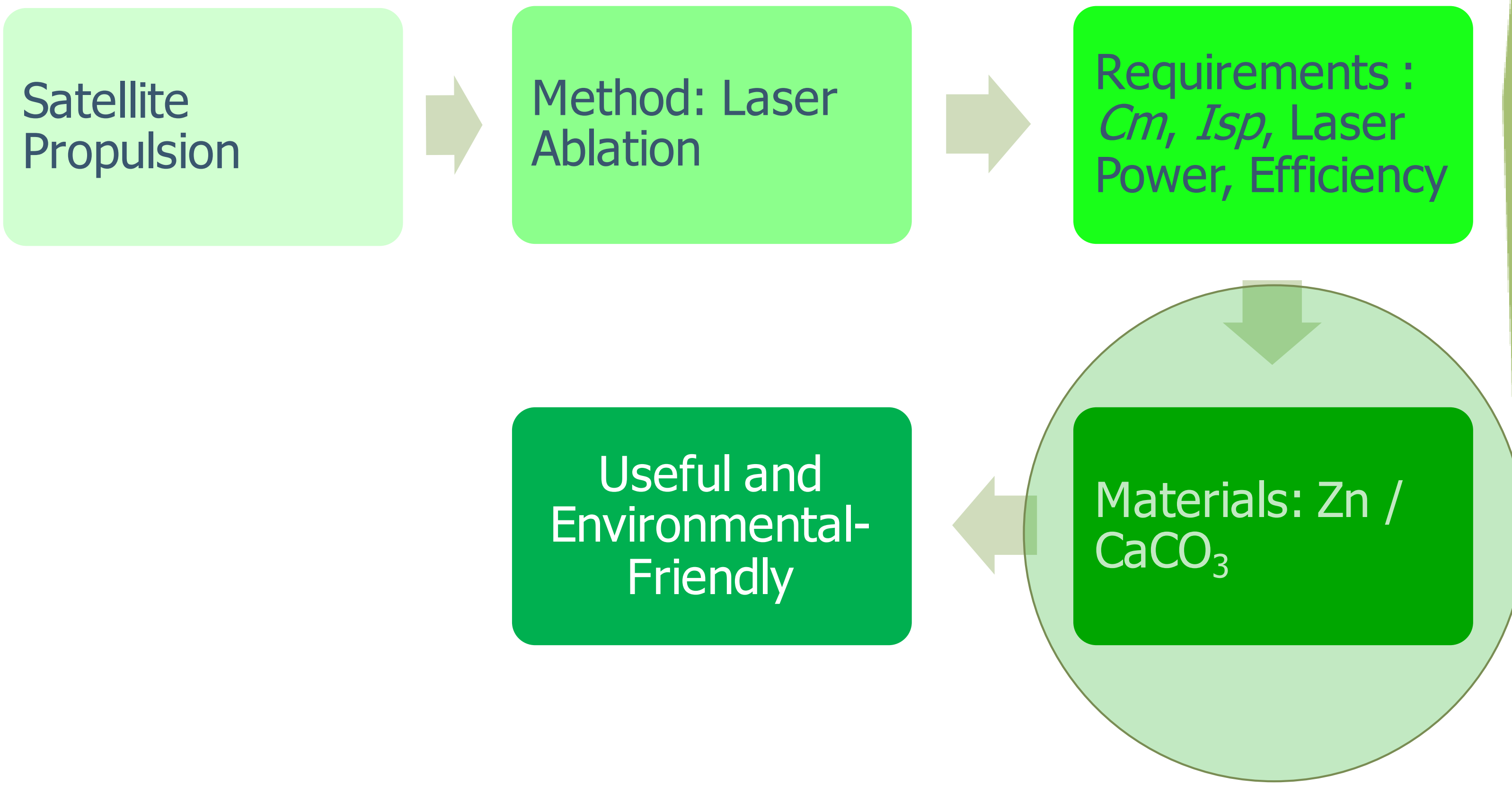


NaF/Ni (70%) :

Sc: 3.3

Eo: 24

Procedure

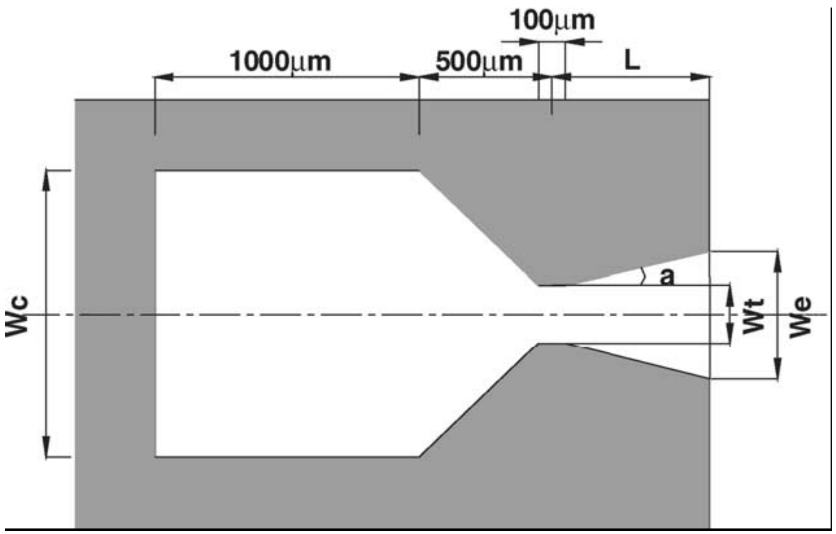

Satellite Propulsion
Method: Laser Ablation
Requirements : *Cm*, *Isp*, Laser Power, Efficiency
Materials: Zn / $CaCO_3$
Useful and Environmental-Friendly

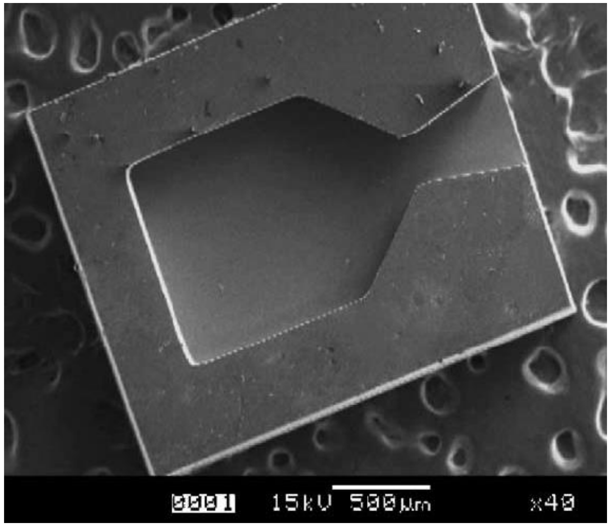
Procedure Proposed

- Thermodynamics of mixtures of possible materials
- Preparation of possible propellants.
- Measurement of properties and Figures of merit
- Materials selection environmentally friendly

MEMs for Satellites

- Applications

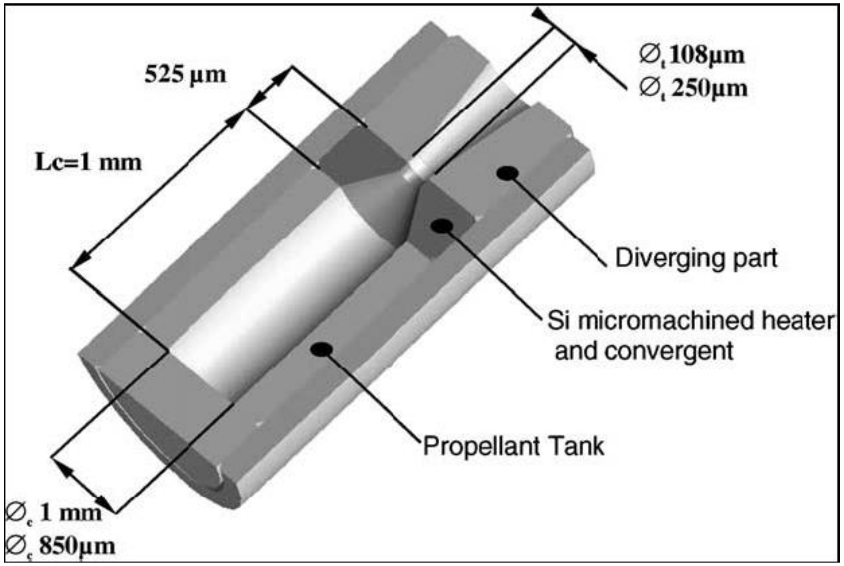


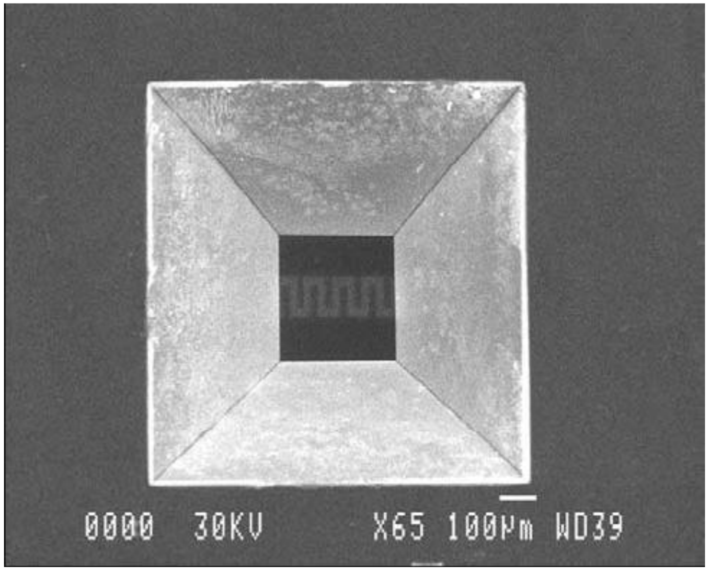


K.L. Zhang et al. / Sensors and Actuators A 122 (2005) 113–123

MEMs for Satellites

- Applications

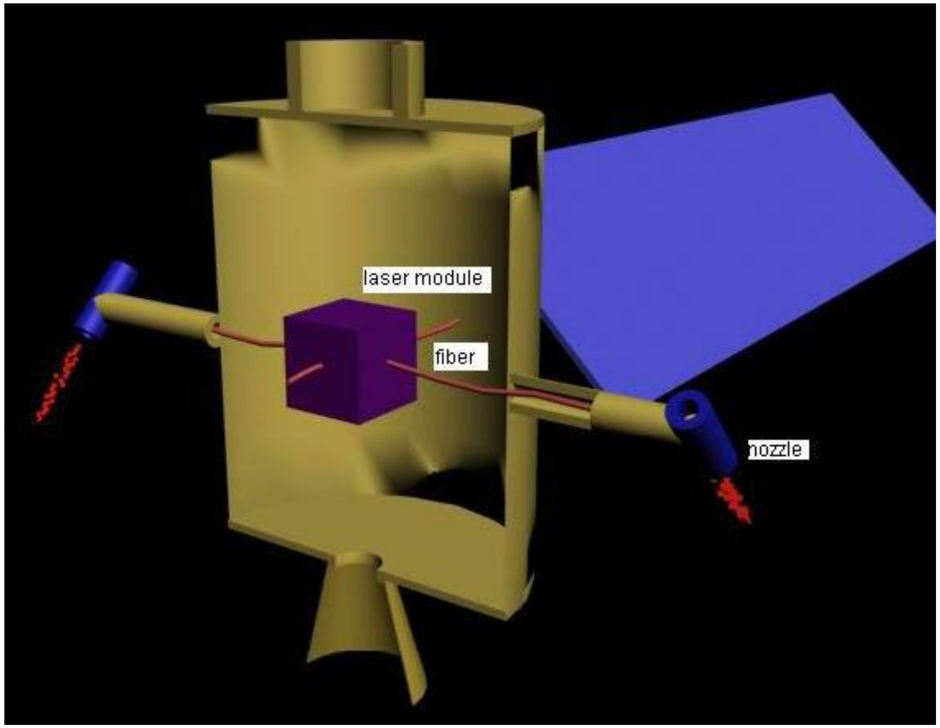




C. Rossi et al. / Sensors and Actuators A 99 (2002) 125–133

Laser Propulsion Satellite

- The idea of application



An the winner of Tango's School was….

Thanks for your attention

Acknowledgement

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