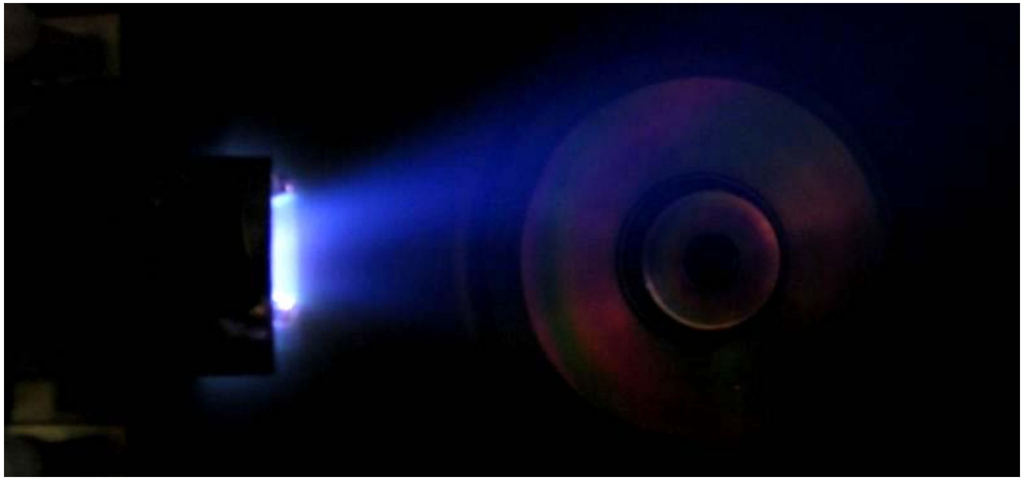
Propulsion means for CubeSats



C. Scharlemann and D. Krejci

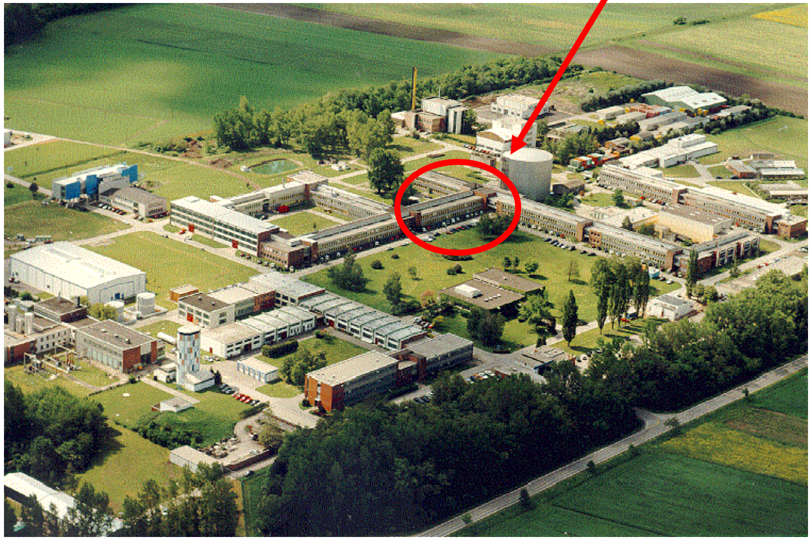
2009 CubeSat Developers Workshop, San Louis Obispo, CA

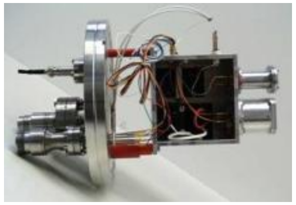
AUSTRIAN RESEARCH CENTERS

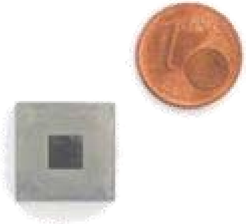
Employees	2008
ARC Holding	123
Seibersdorf research	392
Arsenal research	132
LKR	30
ECHEM	18
ISS	11
ACV	15
Total	721

Space Propulsion & Advanced Concepts

Staff:	11
Ph.D. Students:	3
Undergraduate Students:	4





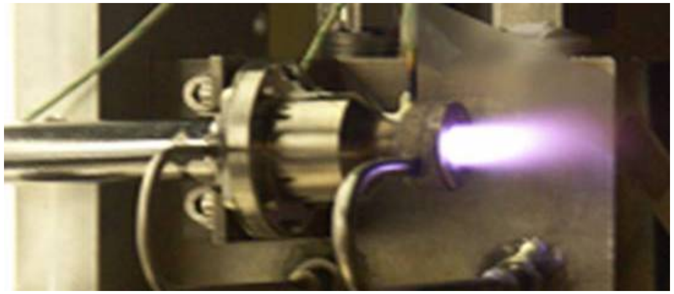


Electric Propulsion / Ion Guns

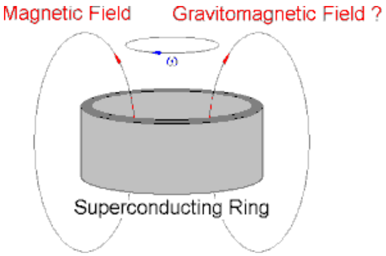
- ⇒ FEEP / µFEEP Thruster Development (LISA PF)
- ⇒ µ-Pulsed Plasma Thruster Development
- ⇒ Ion Guns for SC Charging/Mass Spectr. Appl.
- ⇒ EP Plasma Simulations (e.g. SMART-1)

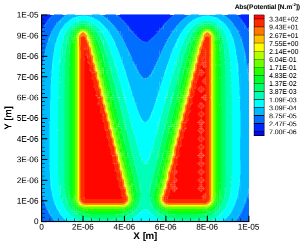
Chemical Propulsion

- ⇒ Bi-Propellant Micro-Rocket Engine
- ⇒ Monopropellant Rocket Engine

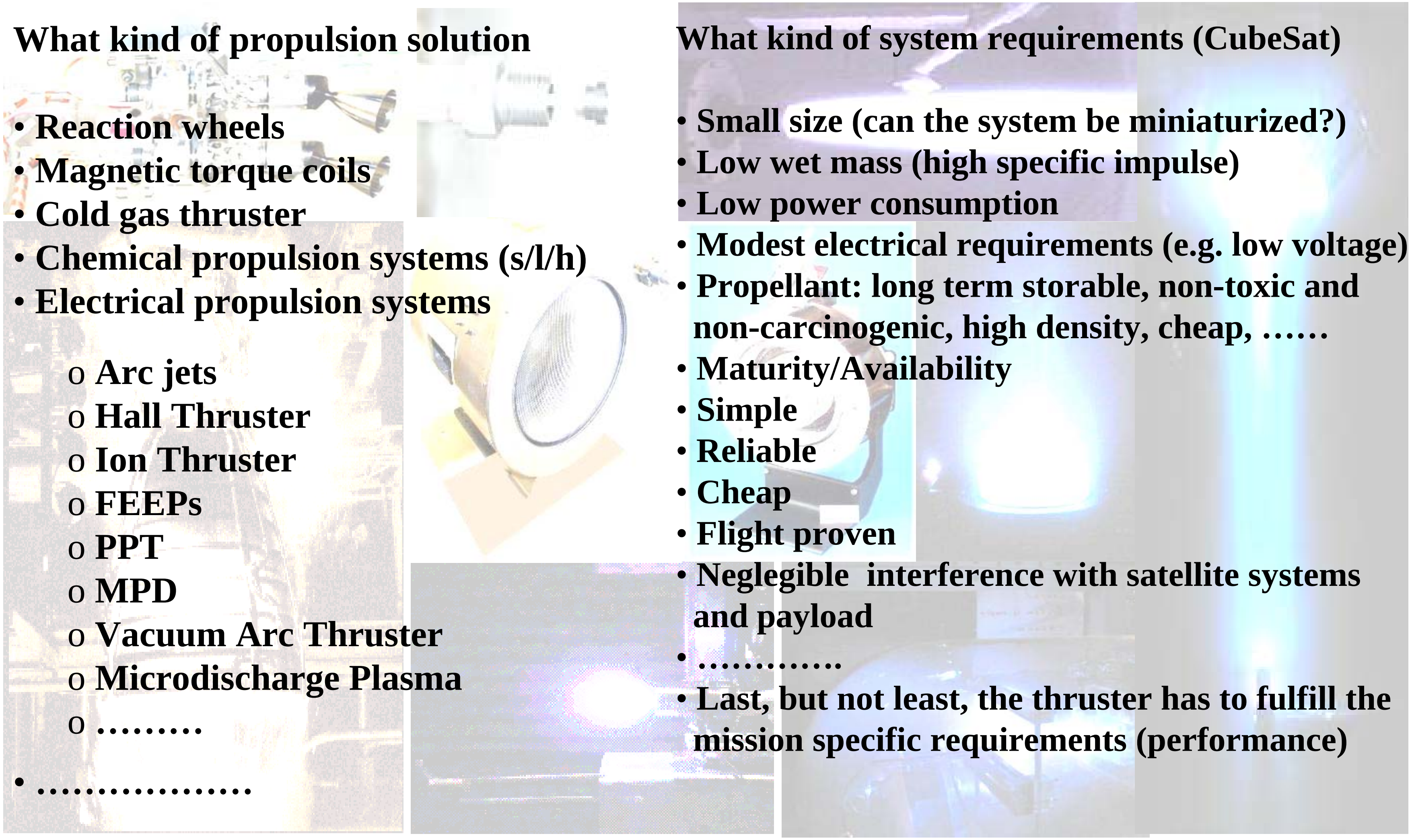


Advanced Concepts / Leading Edge Concepts





- ⇒ Gravity in Quantum Materials
- ⇒ Casimir Force Simulation
- ⇒ Plasma Mirror for High Power Lasers



What kind of propulsion solution

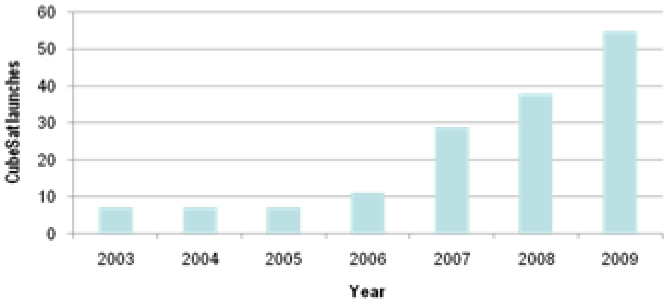
- Reaction wheels
- Magnetic torque coils
- Cold gas thruster
- Chemical propulsion systems (s/l/h)
- Electrical propulsion systems
    - o Arc jets
    - o Hall Thruster
    - o Ion Thruster
    - o FEEPs
    - o PPT
    - o MPD
    - o Vacuum Arc Thruster
    - o Microdischarge Plasma
    - o ………
- ……………….

What kind of system requirements (CubeSat)

- Small size (can the system be miniaturized?)
- Low wet mass (high specific impulse)
- Low power consumption
- Modest electrical requirements (e.g. low voltage)
- Propellant: long term storable, non-toxic and non-carcinogenic, high density, cheap, ……
- Maturity/Availability
- Simple
- Reliable
- Cheap
- Flight proven
- Neglegible interference with satellite systems and payload
- ………….
- Last, but not least, the thruster has to fulfill the mission specific requirements (performance)

Why using µPPTs on CubeSats?

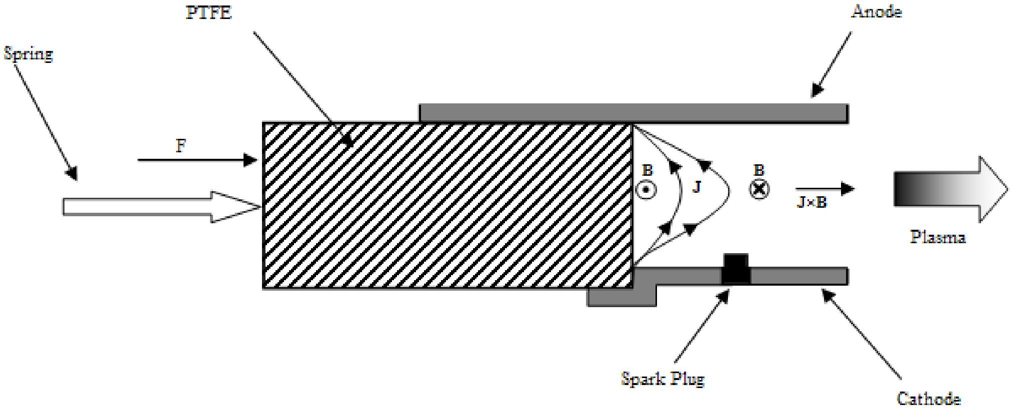
- Compensation for disturbance torques:
  - Drag, gravity gradient, solar pressure, magnetic forces…..
- Spin-up and spin down
- Attitude control:
  - Communication improvement (antenna pointing)
  - Scientific payload requires control/fine-pointing (spectrometry, camera)
  - Improved power generation (solar panels)
- Orbit control:
  - Improved mission autonomy (compensation for errors during orbit insertion, change of orbit, etc.)
  - Broader mission range (formation flying etc.)
  - Higher mission pay-off /success
- **De-orbiting after EOL** (to a certain extent).
  De-orbiting ability might become compulsory in the near future!



→ Means of active propulsion results in a broader mission range for CubeSats

What is a µ-Pulsed Plasma Thruster (µPPT)

- The **P**ulsed **P**lasma **T**hruster is an electromagnetic thruster
- Mechanically simple but complex propellant acceleration processes
- The main components of a µPPT are the two electrodes, a trigger device, an energy storage system (capacitor), the propellant (Teflon), and supporting electronics.
- A discharge between the electrodes ablates the propellant and accelerates the ionized atoms/molecules by the Lorenz force (j x B).
- First use of a PPT on the Russian spacecraft Zond (1964!), most recent (2003) use on the American EO-1

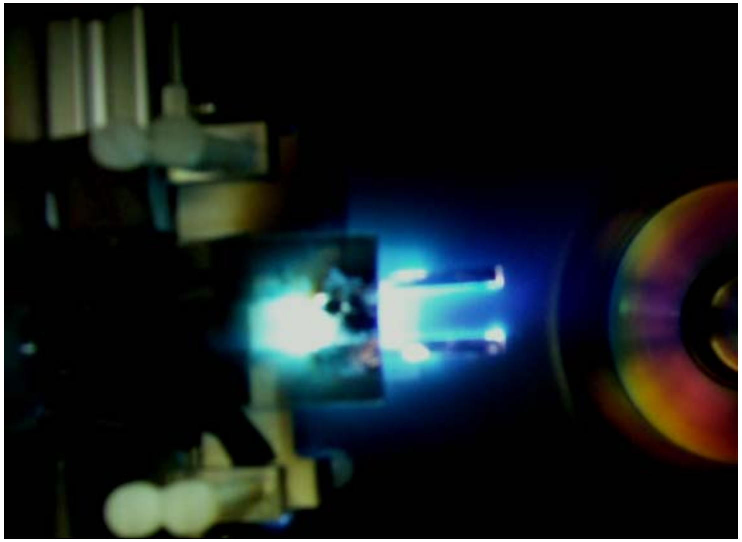


PPT on EO-1

µ-Pulsed Plasma Thruster (µPPT)

If one requires not only attitude control abilities but also active orbit control and furthermore flight experience this leaves PPT/µPPTs as the best option

- Structural simplicity facilitates miniaturization
- Specific Impulse: 500 – 1000 s
- Low power consumption
- No moving parts (valves etc.)
- Teflon propellant:
    - unlimited storability
    - easy handling
    - non-toxic, non-carcinogenic
    - no degradation in space
    - no sensitivity to temperature
    - cheap
- PPT system is a space proven system



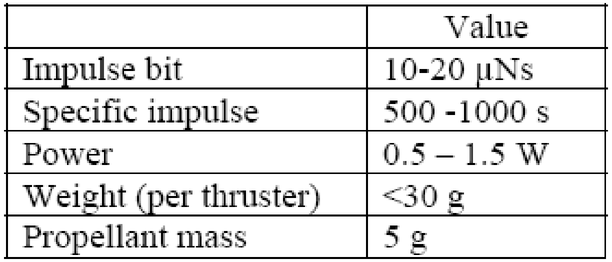
→ **µPPTs are the ideal solution for CubeSats**

µPPT Research Objectives

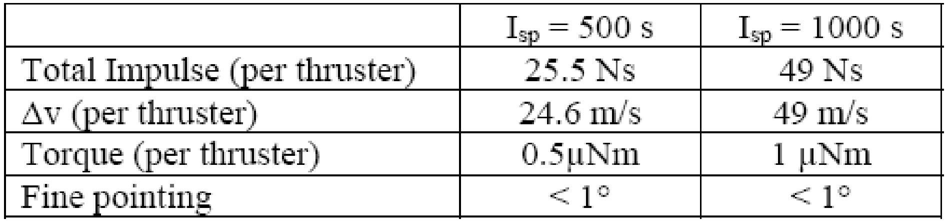
- **Miniaturization of µPPT and PPU to comply with the stringent mass, power, and volume limitations of CubeSats.**
    - Investigation of electrode geometry influences in small scale thrusters
    - Performing tests in a wide range of electrode sizes (down to 3mm width and further)
    - Clarification of the effect of electrode length on performance
    - Investigation into aspect ratio and its relation to impulse bit, thrust to power ratio and thruster efficiency
    - Investigation of alternative electrode designs do improve performance for low energy operation
    - Extensive testing at low energy and identification of regimes which result in propellant carbonization with the aim of eliminating charring at low energy operation
    - Identification of technology suitable for implementation into a µPPT
    - Miniaturized energy storage device

µPPT Performance on CubeSats

µPPT Performance design goals:



	Value
Impulse bit	10-20 µNs
Specific impulse	500 -1000 s
Power	0.5 – 1.5 W
Weight (per thruster)	<30 g
Propellant mass	5 g

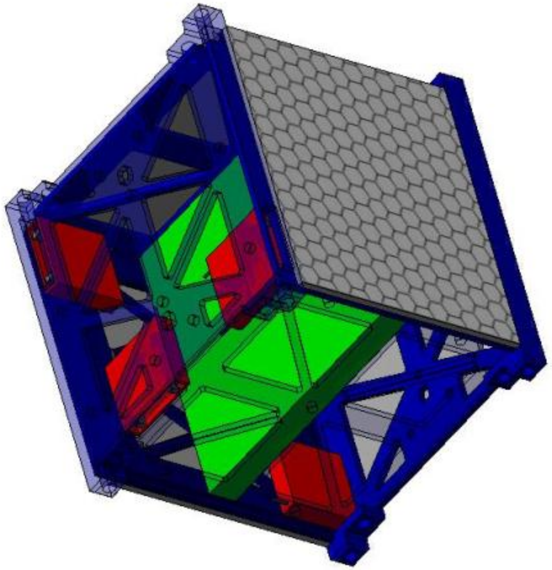


	I_{sp} = 500 s	I_{sp} = 1000 s
Total Impulse (per thruster)	25.5 Ns	49 Ns
Δv (per thruster)	24.6 m/s	49 m/s
Torque (per thruster)	0.5µNm	1 µNm
Fine pointing	< 1°	< 1°

Based on CubeSat: m=1 kg, 8mNm^2

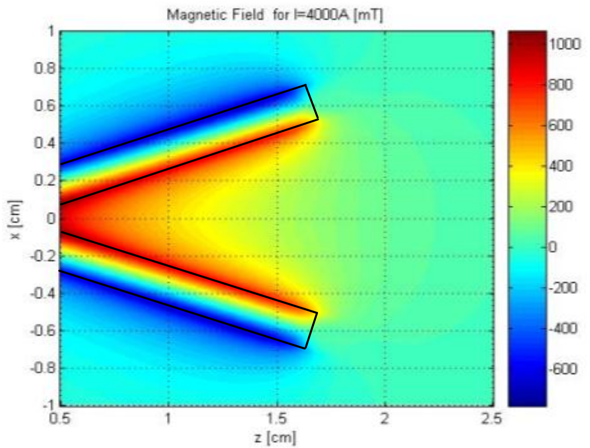
What can a µPPT system do for a CubeSat?

- Attitude control
- Fine pointing (<1° precision)
- Orbit change/insertion
- Spin-up, spin down
- Formation flight
- De-orbiting (within limits)



Status of the µPPT investigation at ARC

Advanced Analytical Model



Magnetic field distribution for flared electrode design

Theoretical µPPT model comprises of:

- **Electrical circuit model**, containing circuit parameters such as capacitance, transmission line properties, resistive losses, etc.

- **Propellant dynamics model**

Description of the plasma acceleration process,

Incorporating effects of inhomogenity in magnetic

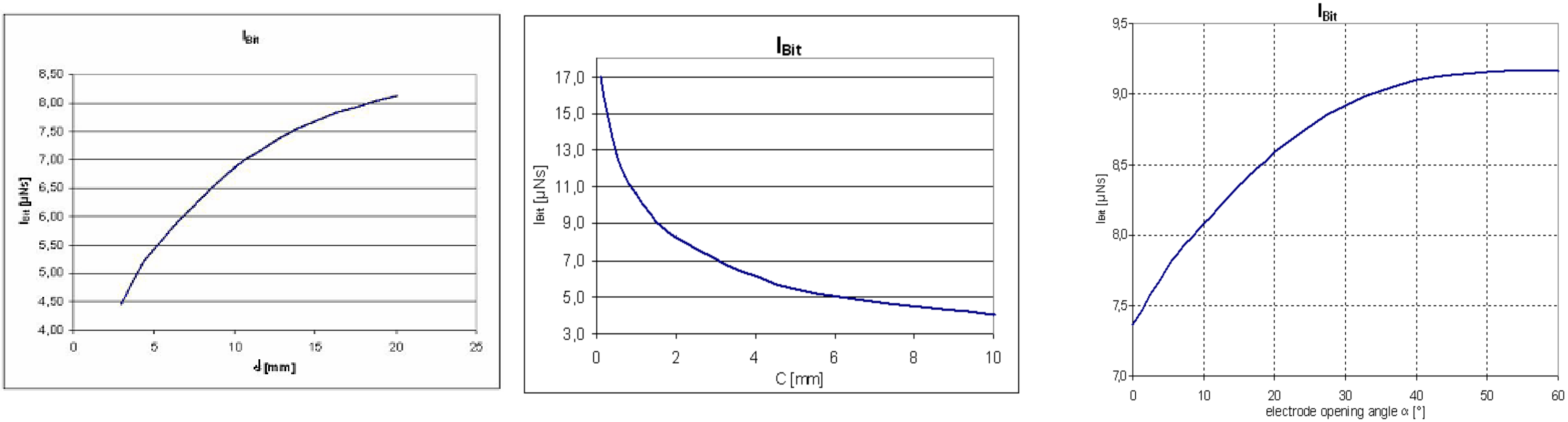
field caused by miniaturized electrode geometry, high aspect ratio, etc.

→ This allows description of performance dependent on electrode geometries such as flared and flared tongue shaped electrodes

→ Investigation of role of inductance gradient in acceleration chamber!

Advanced Analytical Model

- Electrical parameters: Allows best choice for capacitance, inductance and resistance in transmission lines, etc.
- Electrode geometry: Influence of separation, width and thickness
- Electrode configuration: Improvement by flared and advanced shaped (Tongue design) electrodes



Impulse bit achieved as a function of electrode separation (left), electrode thickness (middle) and electrode flare angle (right)

Experimental Investigation

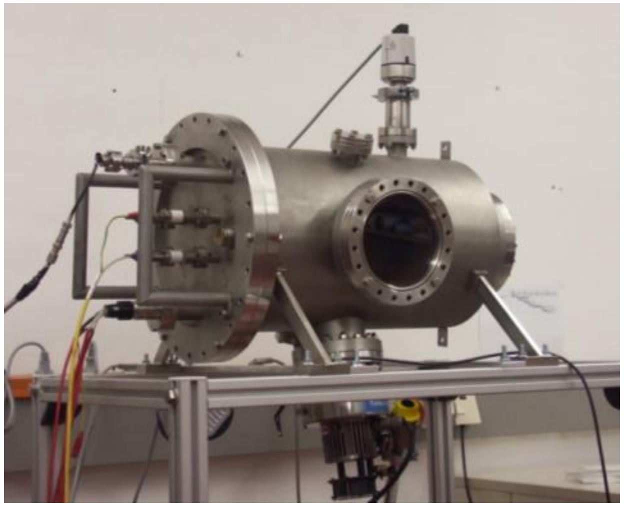
- Extensive experimental testing of multiple electrode configurations:

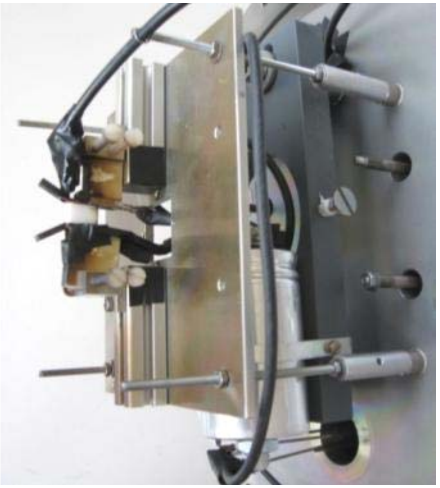
  width: 10 .. 3 mm
  separation: 25..5 mm
  length: 35..15 mm

- Multiple capacitors:

  31.1, 8.0, 6.0 and 2.2μF

- Different designs for miniature discharge initiation system



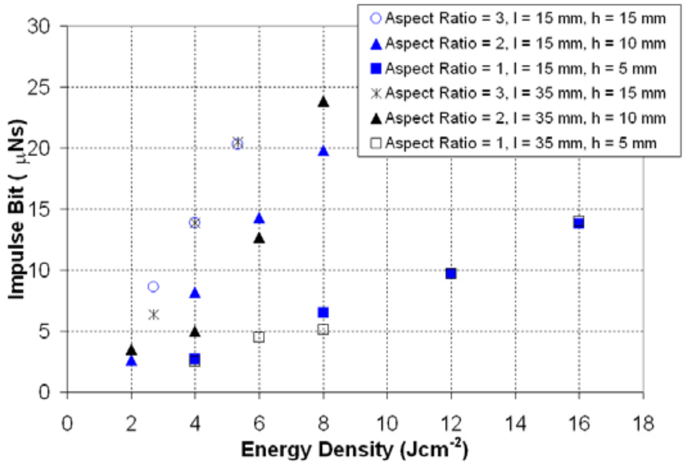


Experimental Findings

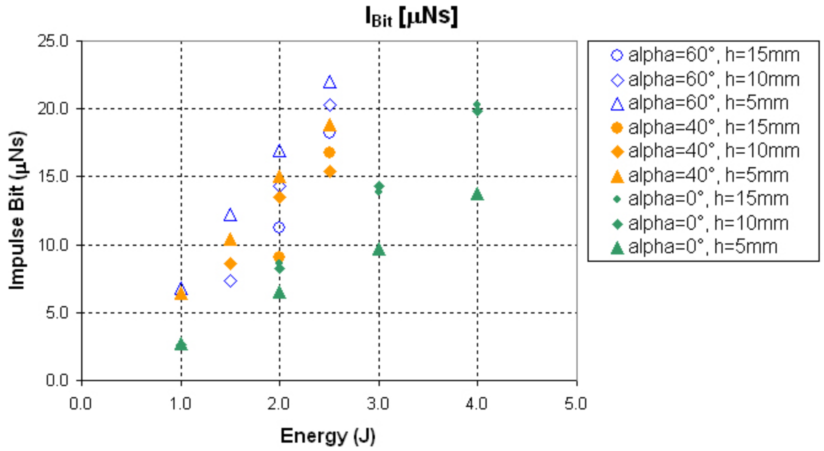
- Certain insensitivity of performance to electrode length -> allows significantly smaller (shorter) thruster without losses

- Investigation of capacitors showed weak influence on performance -> allows size and weight to be main design parameters

- Theoretical predictions of improved performance for flared electrodes could be verified.



Impulse bit as a function of length (Pottinger et al. 2008)



Miniaturization Challenges

Arcotronics 8.0µF 1.1kV

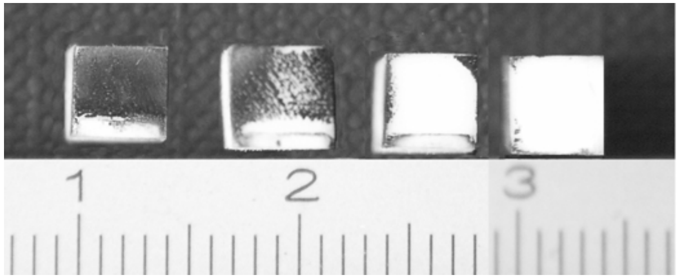
Experimental investigation showed:

- Capacitor as a main challenge for CubeSat requirements
  - Miniaturized capacitors with high specific energy needed
  - high peak current pulse capability
- Separate Discharge Initiation System turned out to be

a prohibiting factor for utilization in CubeSats -> Development of a self-igniting PPT

- Low Energy operation favors charring (carbonization) of the propellant ->

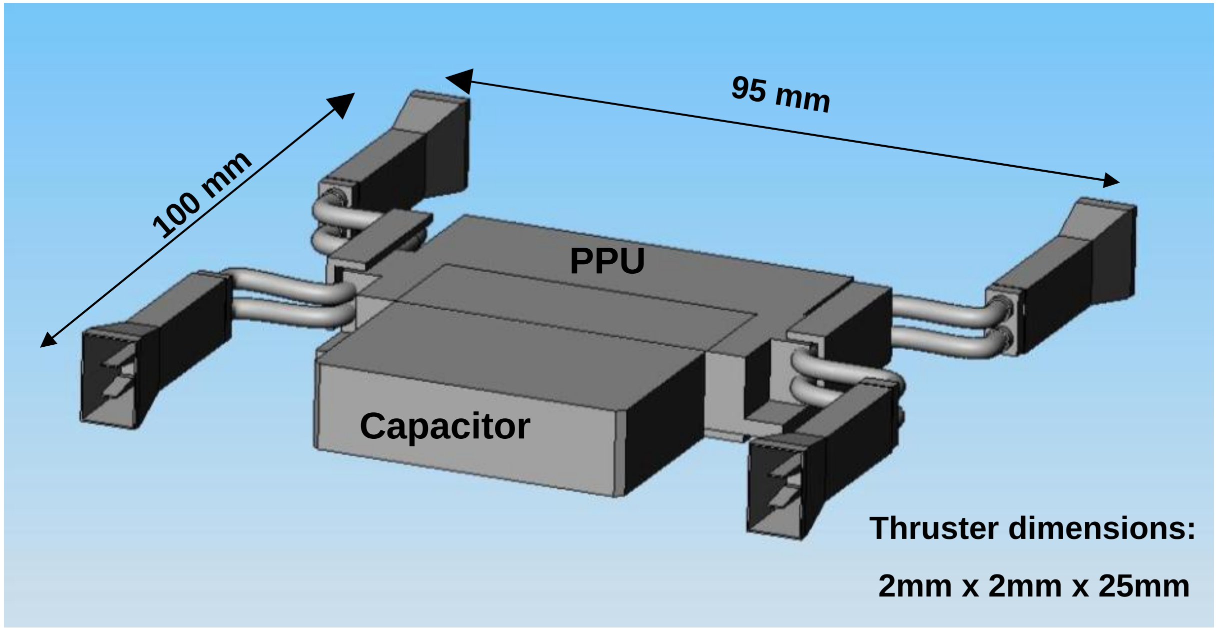
Investigation of minimum energy per propellant surface area



Charring for discharge energies of 1, 1.5, 2 and 3 Joule (from left to right) after 5000 shots

Ongoing Work

- Further miniaturising of the µPPT structur for CubeSat applicaiton
- Implementation of self-ignition method
- Development and test of PPU



2-axis stabilization example

Conclusion

- Analytical model has been developed to investigate the impact of miniaturisation and to guide further development

- Important insight into the physics of miniaturised PPTs has been obtained which allows a guided further miniaturising of the system

- PPT has been miniaturized to the mm range and successfully tested

- Miniaturised PPU is being designed

- Recent support by the Austrian Space Agency and the European Space Agency allows faster paste. Availability of µPPT system for CubeSats maybe possible first half of 2010

- **At this point of time the input of the CubeSat community is needed**!

    - What are your requirements in terms of volume, mass, power limitation?
    - What are your mission requirements?

Questions to the community

- Have you a mission planned or envisioned which would require an active propulsion system or would increase the scientific output?
- What are your mission requirements in terms of Δv, I_{sp}, thrust, lifetime?
- What pointing accuracy do you need?
- Do you need 1, 2, 3 axis stabilization?
- What is the power, mass, and volume budget for a propulsion system on your CubeSat?

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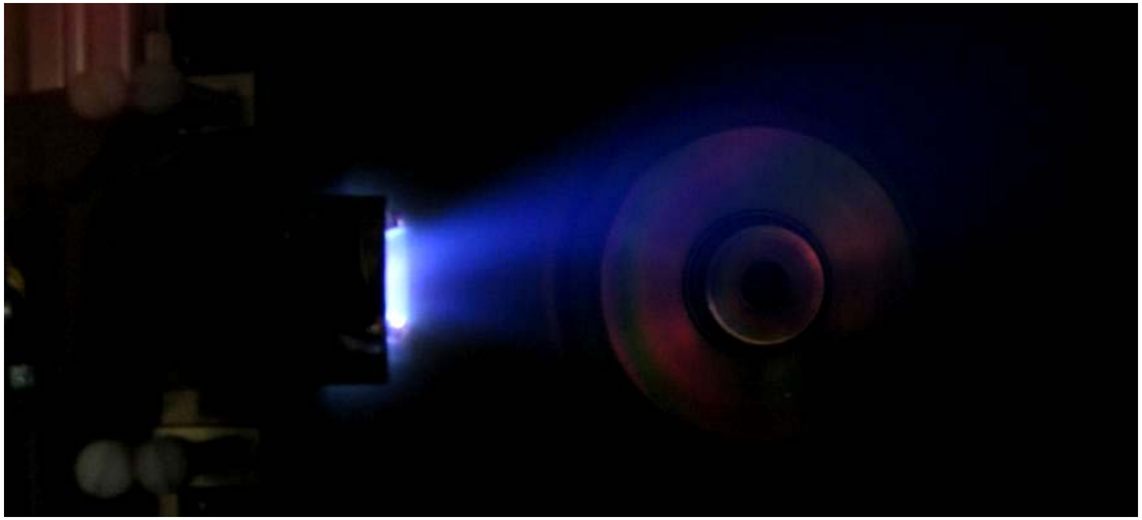
Thank you for your attention



References:

Pottinger, S. J., Scharlemann, C. A. (2007): Micro Pulsed Plasma Thruster Development, IEPC-2007-125

Pottinger, S. J., Krejci, D., Scharlemann, C. A. (2008): Development of a µPPT for CubeSat Applications, AIAA-2008-4532