Capacitively Coupled Ion Thruster with Magnetic Nozzle

C-STAR

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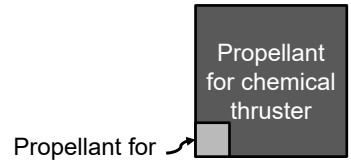
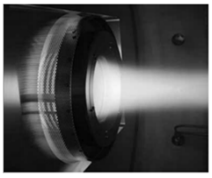
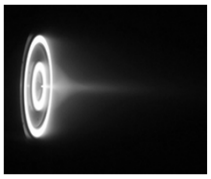
Motivation – Chemical and Electrical Propulsion

- propulsion in space
  - Station keeping
  - Interorbital transfers
  - Interplanetary cruise
- Benefit of electric propulsion:
  - High specific impulse
  - Controllability





Radiofrequency Ion Thruster (RIT)
Source: LOEWE Abschlussbericht RITSAT



X2 Hall – Thruster
Source: https://pepl.engin.umich.edu/project/x2-nested-channel-hall-thruster/

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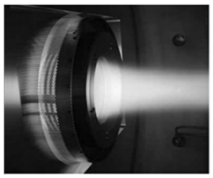
Motivation – C-STAR Characteristics

- Neutralizer free
- Contact free acceleration



Radiofrequency Ion Thruster (RIT)
Source: LOEWE Abschlussbericht RITSAT

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	GIE	C-STAR
Type	electro-static	electro-magnetic
Thrust (mN)	0.01-750	0.0057
I_{sp} (s)	1500-10 000	709
electrical efficiency η_e	30-90	0.198
Thrust-Power-Ration (mN/kW)	20-250	0.285
Propellants	Xe, Kr, Ar Bi, I_2	Until now Ar
Operational time	years	unknown

Source: K. Holste et al., Ion thrusters for electric propulsion: Scientific issues developing a niche technology into a game changer, The Review of scientific instruments, 91 (2020), p. 061101 and Smirnov, P.; Kozakov, R.; Schein, J. Experimental Characterization of the Capacitively Coupled RF-Plasma Thruster. Appl. Sci. 2021, 11, 6799. https://doi.org/10.3390/app11156799,

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Motivation - Research Questions

1. How can the C-STAR's characteristics be improved?
2. What is the optimal electronic topology for C-STAR operation?

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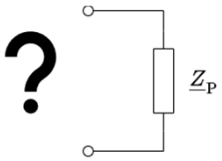

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C-STAR Geometry

- Cylindrical symmetry
- Dimensions:

$$\frac{L}{d_{\mathrm{ch}}} \approx \square, \quad \frac{L}{a} \approx \square$$

- Pressure-dependent impact of magnetic field

$$\omega_{\mathrm{c}} \geq \nu_{\mathrm{m}}$$

$$\nu_{\mathrm{me}}\,(s^{-1}) \sim 1 \cdot 10^{7} \cdot p\,(Pa)$$

$$\nu_{\mathrm{mi}}\,(s^{-1}) \sim 1 \cdot 10^{5} \cdot p\,(Pa)$$

Source: T. Tsankov, *Foundations of magnetized radio-frequency discharges, Plasma Sources Sci. Technol. 31 (2022) 084007 (33pp)*

→ Magnetized electrons

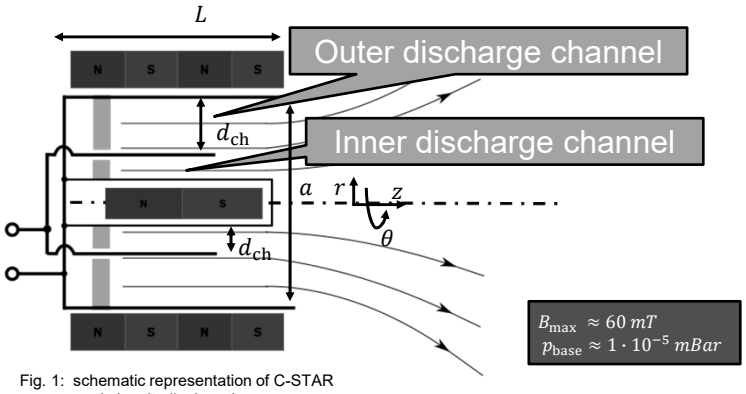

Fig. 1: schematic representation of C-STAR in longitudinal section

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Operating Principle – Ionisation

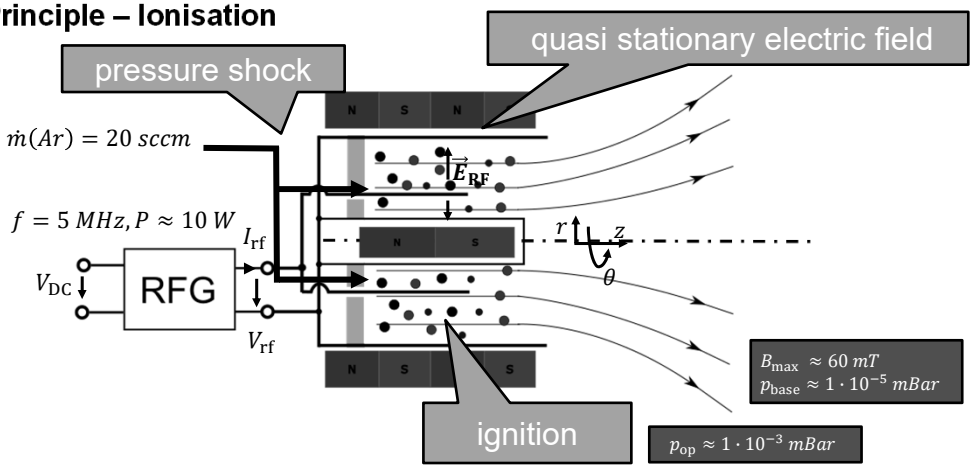

Fig. 1: schematic representation of C-STAR

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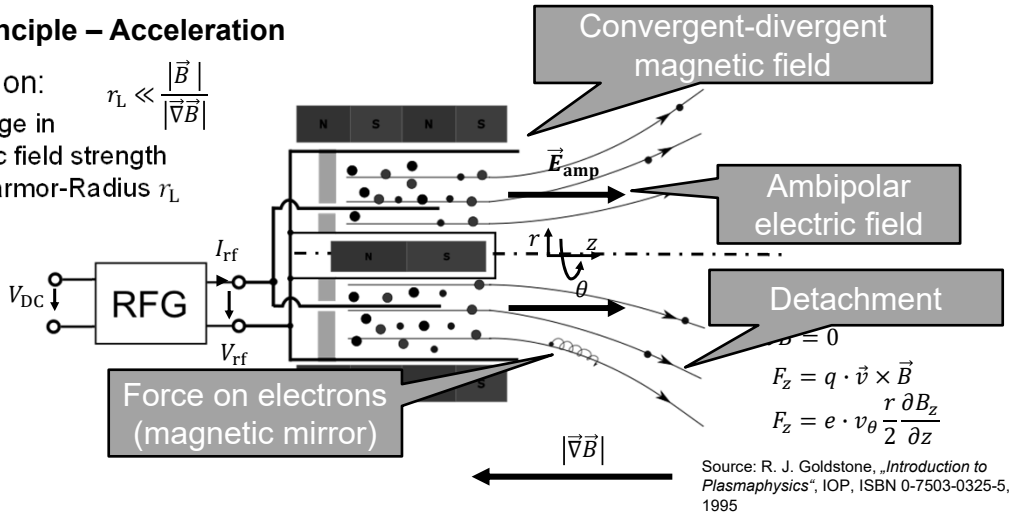
Operating Principle – Acceleration

- Assumption:
  - No change in magnetic field strength within Larmor-Radius r_L

$$r_L \ll \frac{|\vec{B}|}{|\vec{\nabla}\vec{B}|}$$



Source: R. J. Goldstone, *„Introduction to Plasmaphysics“*, IOP, ISBN 0-7503-0325-5, 1995

Fig. 1: schematic representation of C-STAR

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Experiments

- Stable operation up to ~40 W
- Electric power measurement
- Langmuir-Probe-Measurements

Simulations are necessary for fundamental understanding

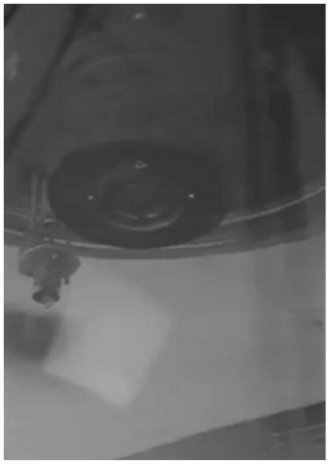

Fig. 2: C-STAR ignition and operation instabilities

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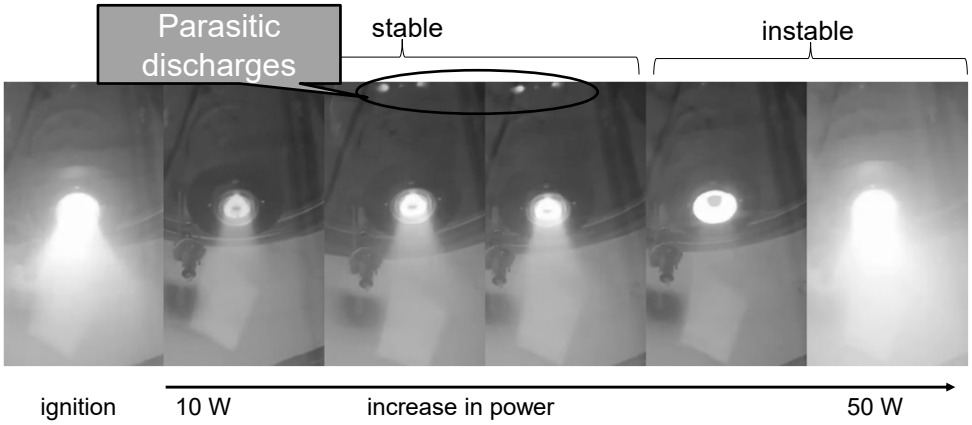
Experiments and Simulations



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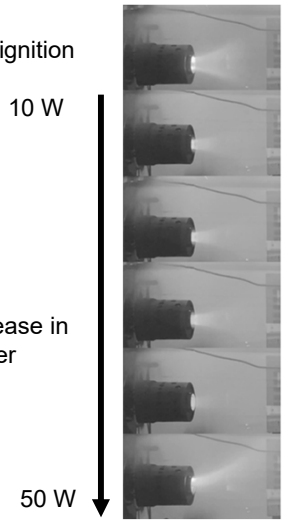
How can the C-STAR's characteristics be improved?

- Fixing of propellant leakage
- Changes in Geometry
  - Reducing outlet gap size?
- Changes in operating point:
  - Increase electric power
  - Variations in operating frequency

Power coupling mode change:
- Wave phenomena?



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Summery & Discussion

Summary:
- First experiments:
  - Stable operation range up to 40 W
  - Instabilities
- Necessary investigations:
  - Electrical characteristics
  - Magnetic field impact on ions
  - Charge detachment process in magnetic nozzle

Discussion:
- To what extent are geometrical changes necessary?
- What is the optimal operating range and how does it depend on geometry, mass flow, operating frequency, electric power?
- Can plasma wave phenomena be formed and how can these be excited for better power coupling?

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THM
TECHNISCHE HOCHSCHULE MITTELHESSEN

NanoP
Kompetenzzentrum für Nanotechnik und Photonik

Contact

- Erik Jozsef (M.Sc.)
- E-Mail: erik.jozsef@ei.thm.de
- Telefon: +49 641 309 1978