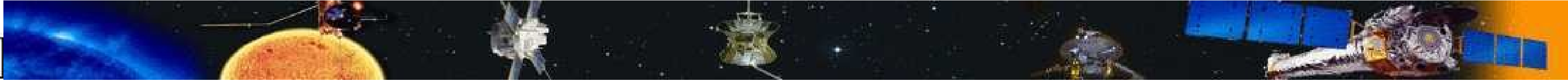
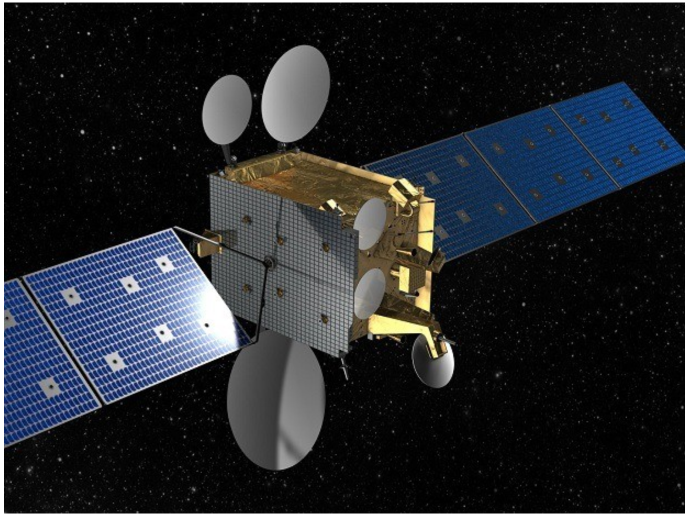


Das Electric Propulsion Diagnostic Package (EPDP) auf H2Sat

Robert F. Wimmer-Schweingruber für das EPDP Konsortium
wimmer@physik.uni-kiel.de

OHB

vH&S vonHOERNER&SULGER
SPACE • RESEARCH • INDUSTRY



C | A | U
Christian-Albrechts-Universität zu Kiel

AGs Kersten und Wimmer-Schweingruber

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

Die Heinrich Hertz (H2Sat) Mission

Innovation

- Erhalt und Weiterentwicklung deutscher Schlüsselkompetenzen in Nutzlast- bzw. Plattform-Technologien geostationärer Kommunikationssatelliten
- In Orbit-Verifikation innovativer Technologien für Kommunikationssatelliten
- Implementierung neuer Technologien zur Flexibilisierung des Satelliten und der Nutzlast im Orbit, um neue, zukünftige Anwendungen zu erproben

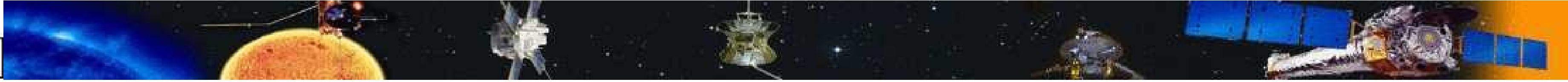
Kommunikation

- Demonstration wissenschaftlich-technischer Kommunikationsexperimente im Ka- und Ku-Band unter Einbeziehung neuer Bodentechnologien
- Verifikation von innovativen Boden-Technologien aus dem nationalen Förderprogramm Satellitenkommunikation
- Wissenschaftlich-technische Experimentalplattform für Hochschulen, Institute und Industrie
- Datenrelais für z.B. Erdbeobachtungsmissionen
- Test von Daten- und Kommandolinks zur Erprobung zukünftiger, ziviler UAVs

Geostation

- Nutzung der freien SmallGEO Plattform Kapazitäten durch den militärischen Mitflieger BMVg
- Nutzung der Plattform SmallGEO zu einer konsequenten Fortführung der im Rahmen von ARTES-11 begonnenen Systementwicklungen

(Quelle: OHB web-site)



Die Heinrich Hertz (H2Sat) Mission und andere mit EP

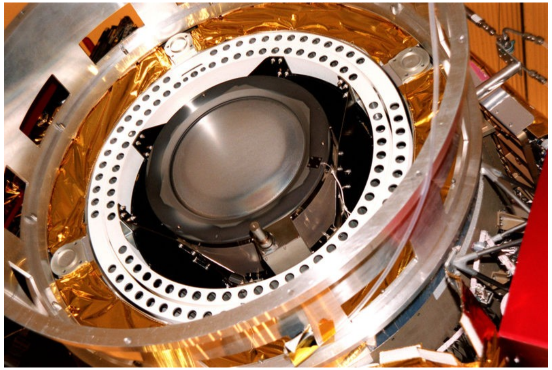
Innovation

- Erhalt und Weiterentwicklung deutscher Schlüsselkompetenzen in Nutzlast- bzw. Plattform-Technologien geostationärer Kommunikationssatelliten
- In Orbit-Verifikation innovativer Technologien für Kommunikationssatelliten
- Implementierung neuer Technologien zur Flexibilisierung des Satelliten und der Nutzlast im Orbit, um neue, zukünftige Anwendungen zu erproben

Zeit	Mission	Herkunft	Ziel / Zweck
1964 / 70	SERT 1 und 2	USA	Testflüge
1998	Deep-Space 1	USA	Komet Borelly und Asteroid Braille
2001	Artemis	Europa	Geostationäre Umlaufbahn
2003	Hayabusa	Japan	Asteroid Itokawa
2003	Smart 1	Europa	Mond
2007	Dawn	USA	Asteroiden Ceres & Vesta
2009	GOCE	Europa	Gravitationsfeld der Erde

Zur Lageregelung sollen u.a. auch elektrische Antriebe (Electric Propulsion, EP) verwendet werden:

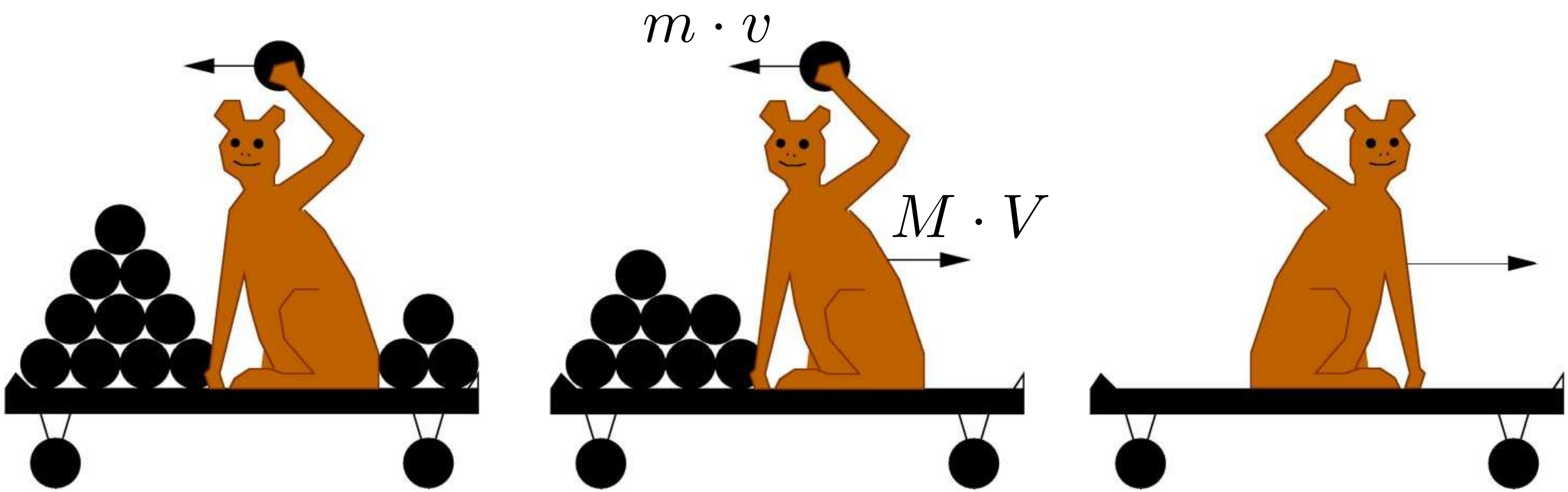
- Viel effizienter als traditionelle Antriebe
- Noch nicht oft benutzt
- Wie wechselwirken sie mit dem Satelliten?



(Kaufmann-Triebwerk in Deep Space 1 (NASA))

Was ist Electric Propulsion? Die Raketengleichung einfach erklärt

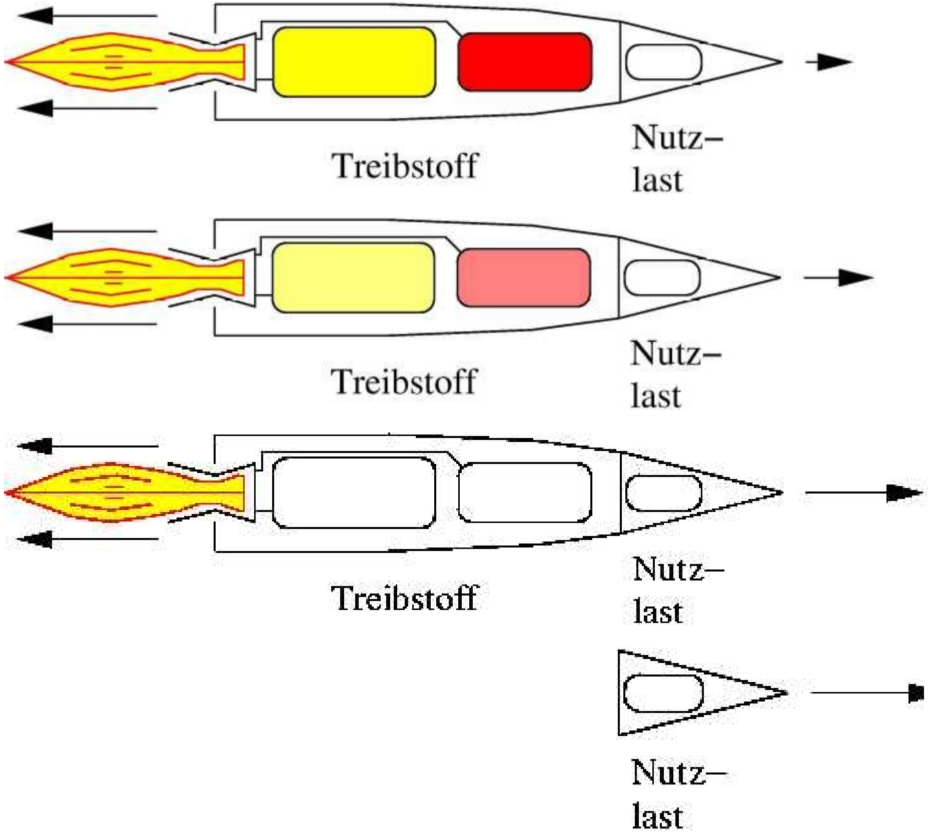
Der Wagen bewegt sich immer schneller...



Impulserhaltung! $m \cdot v = M \cdot V$

… auch weil er immer leichter wird!

Fortsetzung: Die Raketengleichung „einfach“ erklärt



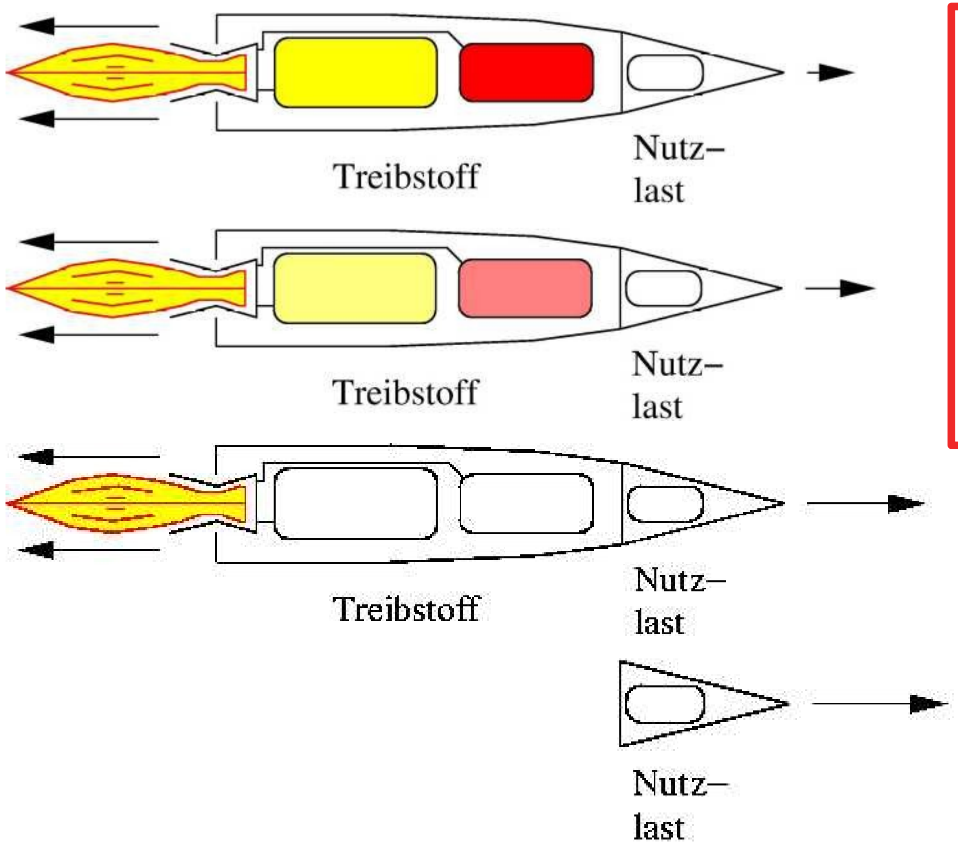
$$m(t) = m_0 - \dot{m}t$$

$$\begin{aligned}
(m_0 - \dot{m}t)\, a(t) &= \dot{m}v_0 - (m_0 - \dot{m}t)\, g \\
\ddot{x}(t) = a(t) &= \frac{\dot{m}}{(m_0 - \dot{m}t)} v_0 - g \\
\dot{x}(t) = v(t) = \int \mathrm{d}t' \ddot{x}(t') &= \int_0^t \mathrm{d}t' \left(\frac{\dot{m}}{(m_0 - \dot{m}t')} v_0 - g \right) \\
v(t) &= v_0 \int_0^t \mathrm{d}t' \frac{\dot{m}}{(m_0 - \dot{m}t')} - gt \\
v(t) &= v_0 \ln \left(\frac{m_0}{m_0 - \dot{m}t} \right) - gt
\end{aligned}$$

Die Raketengleichung von Ziolkowsky (1903):

$$v(t) = v_0 \ln \left(\frac{m_0}{m_0 - \dot{m}t} \right) - gt$$

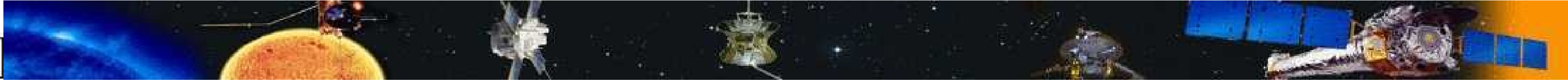
Fortsetzung: Die Raketengleichung „einfach“ erklärt



Die Kraft, die die Rakete beschleunigt ist also

$$F = \frac{\mathrm{d}m}{\mathrm{d}t} \cdot v_0 = \dot{m} \cdot v_0$$

… und dafür gibt es zwei Möglichkeiten...



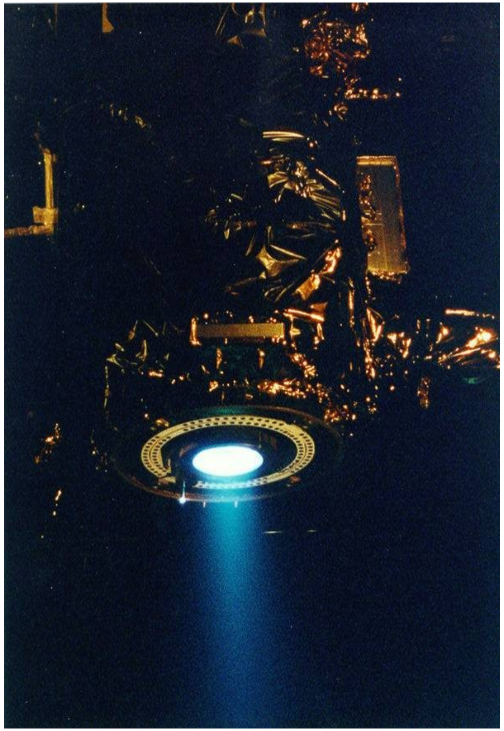
Vergleich chemischer Antrieb und Ionenantrieb

Chemischer Antrieb

Antrieb	Schub
Vulcain (chemisch, $H_2 + O_2$)	1,3 MN
NSTAR (Kaufman, DS1)	93 mN
RIT-10 (Artemis)	10 mN
HET (Smart-1)	70 mN

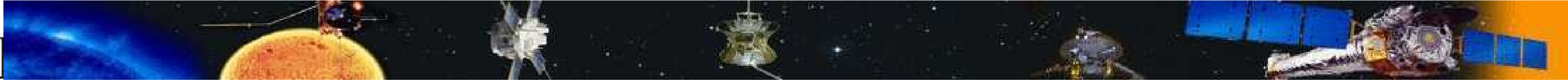
$$F = \frac{\mathrm{d}m}{\mathrm{d}t} \cdot v_0$$

Ionenantrieb

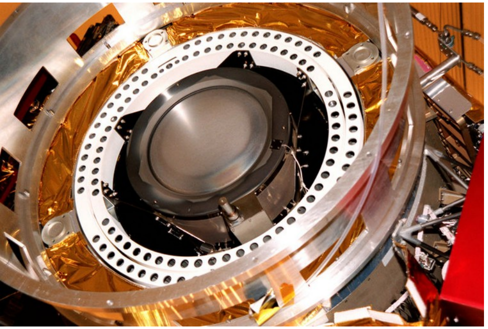


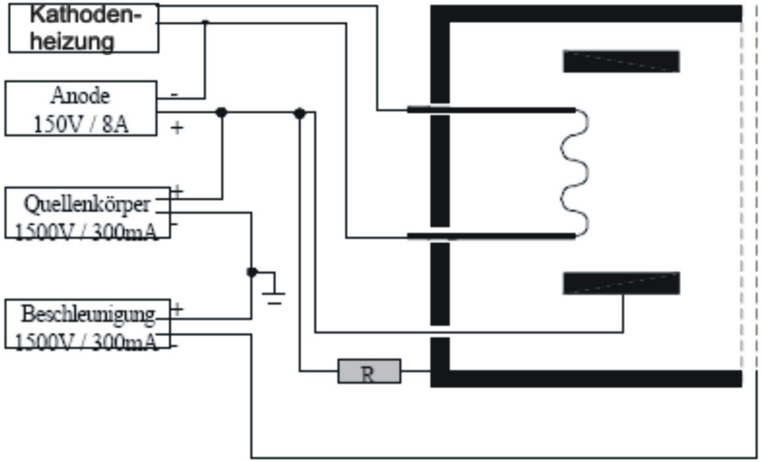
dm/dt groß
v_0 klein

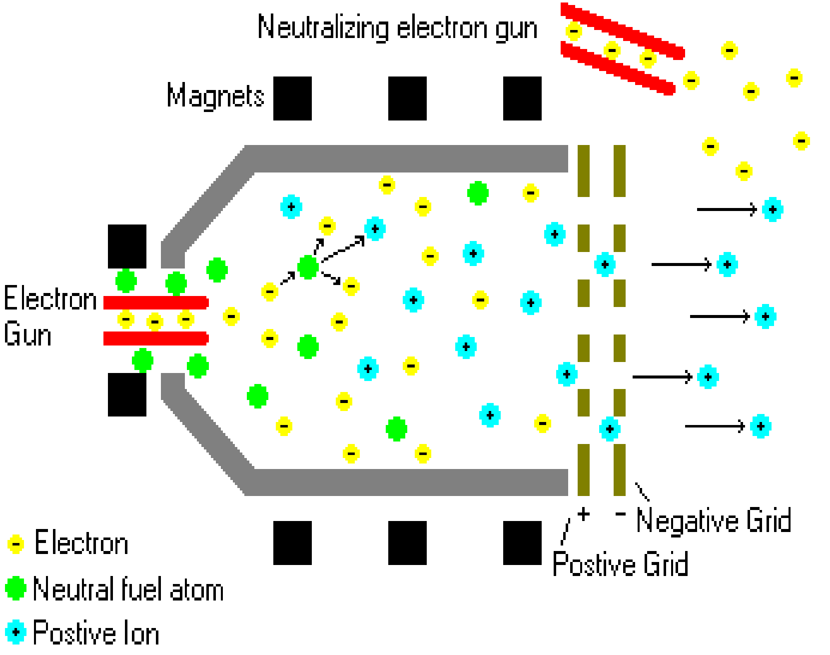
dm/dt klein
v_0 groß



Ionenantrieb: Kaufmann-Triebwerk



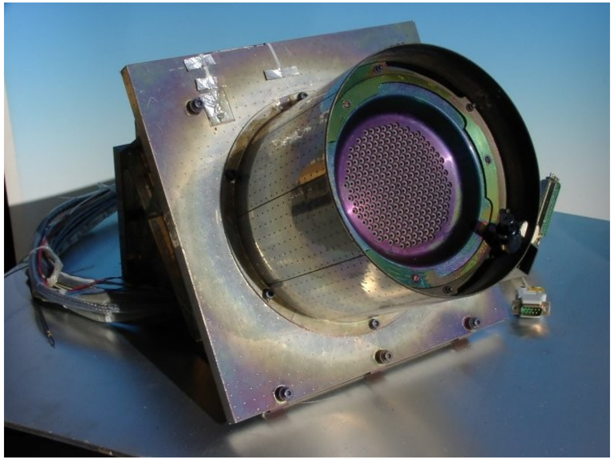




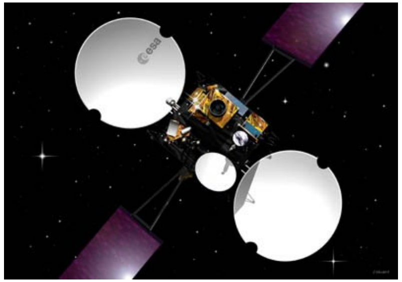
Antrieb	Ausströmgeschwindigkeit
DASA CGT1 (Kaltgas)	0,67 km/s
Vulcain (chemisch, H_2 + O_2)	4,3 km/s
RIT-10 (Ionenantrieb)	31 km/s
VASIMR (Plasmaantrieb)	50 – 300 km/s

Wesentliche Bestandteile:
- Thermionische Entladung / Hohlkathode
- Extraktionsgitter / Beschleunigungsgitter
- Neutralisator

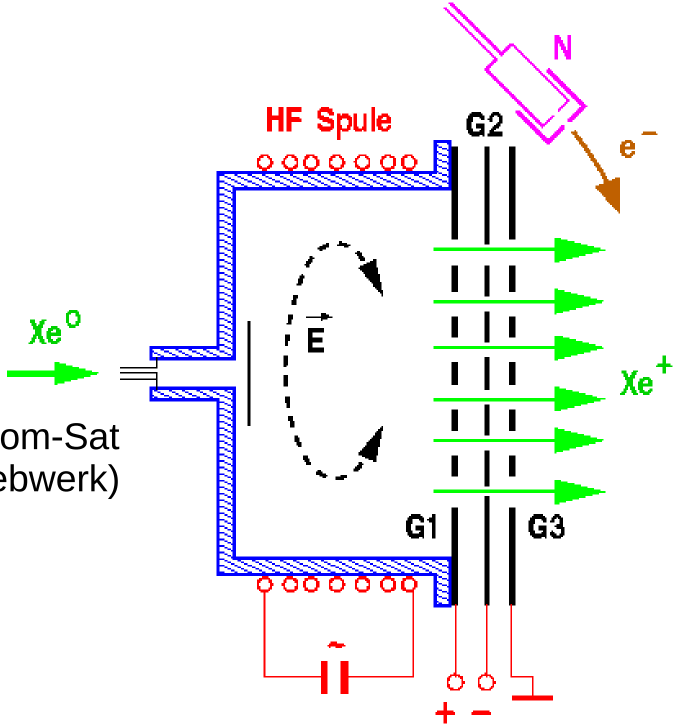
Ionenantrieb: RIT-Triebwerk



RIT-10
(1. Physikal. Inst. Uni Gießen)



(Artemis Telekom-Sat
mit RIT-10 Triebwerk)



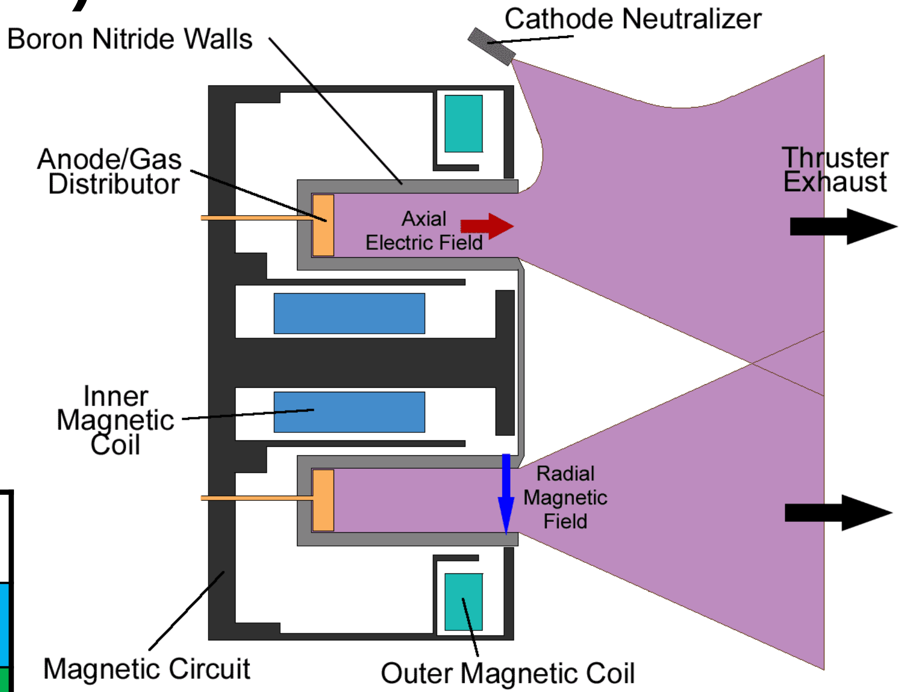
Antrieb	Ausströmgeschwindigkeit
DASA CGT1 (Kaltgas)	0,67 km/s
Vulcain (chemisch, H_2 + O_2)	4,3 km/s
RIT-10 (Ionenantrieb)	31 km/s
VASIMR (Plasmaantrieb)	50 – 300 km/s

Wesentliche Bestandteile:
- Induktive Entladung
- Gittersystem
- Neutralisator

Ionenantrieb: Hall-Effekt-Triebwerk (HET)

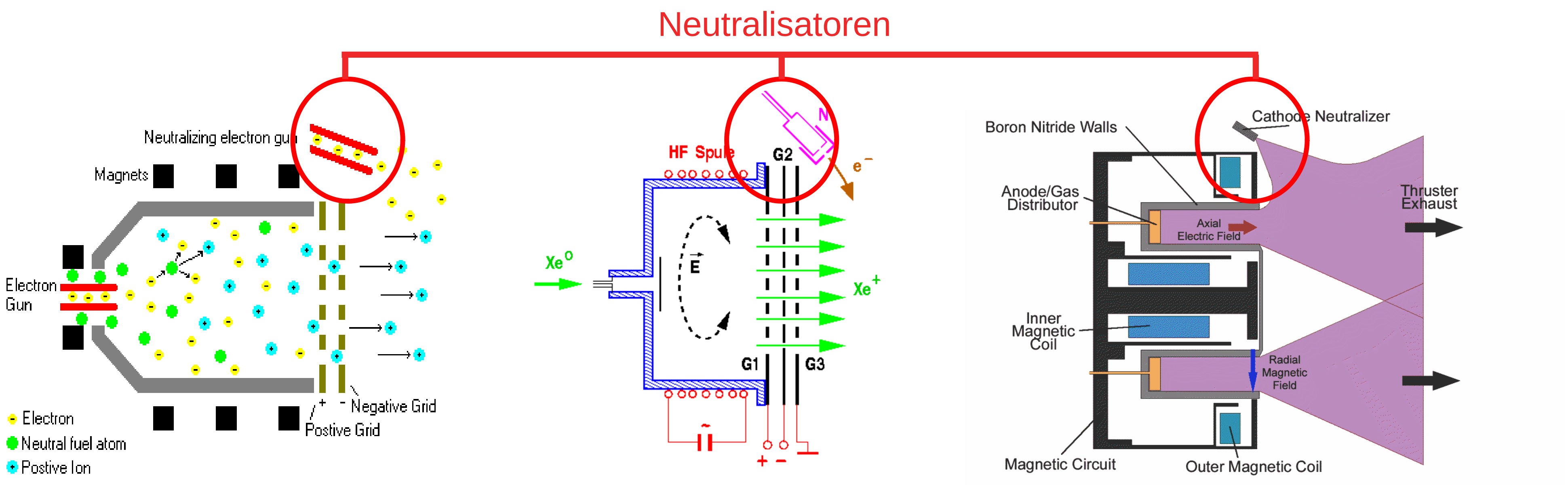
(SMART-1 mit Hall-Effekt-Triebwerk)

Wesentliche Bestandteile:
- Radiales Magnetfeld
- Zylindersymmetrie
- keine Gitter
- Neutralisator



Antrieb	**Ausströmgeschwindigkeit**
DASA CGT1 (Kaltgas)	0,67 km/s
Vulcain (chemisch, $H_2 + O_2$)	4,3 km/s
RIT-10 (Ionenantrieb)	31 km/s
VASIMR (Plasmaantrieb)	50 – 300 km/s

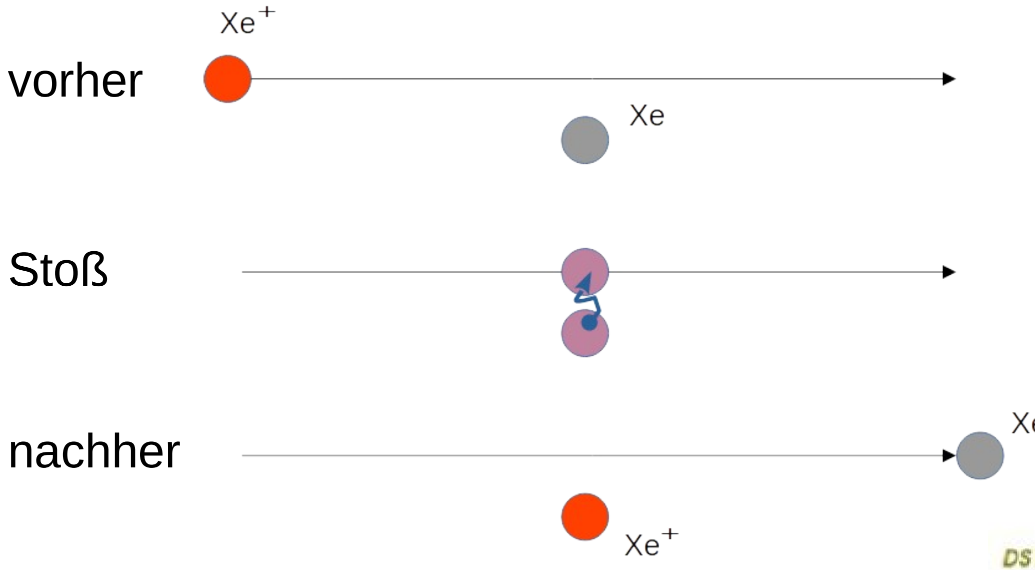
Wie wechselwirken elektrische Antriebe mit dem Satelliten?

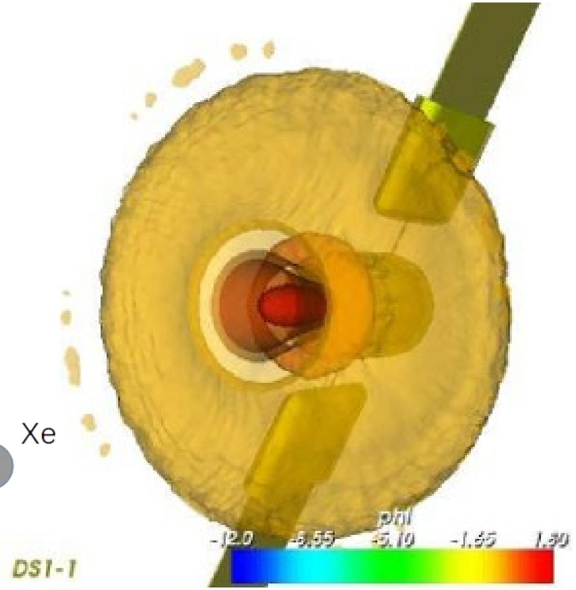


Die Wechselwirkung des Ionenstrahls mit der Neutralkomponente führt zu einer rückgestreuten Population von Atomen und Ionen.

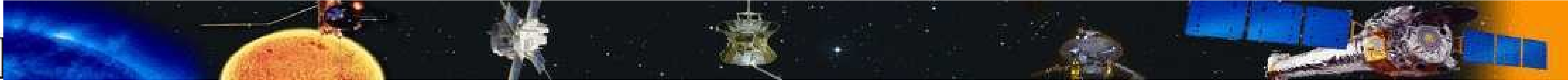
- Der EPDP Plasmasensor (PS) misst den unmittelbaren Einfluss auf den Satelliten.
- Der EPDP Erosionssensor (ES) misst das langfristige Abtragen/Ausdünnen der Oberfläche.

Ladungsaustausch bei Stößen

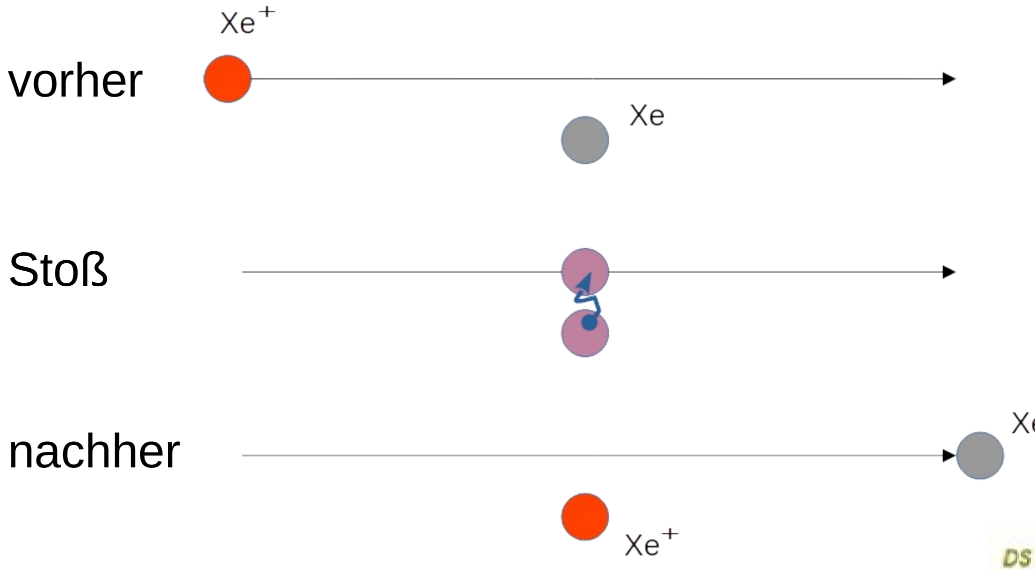


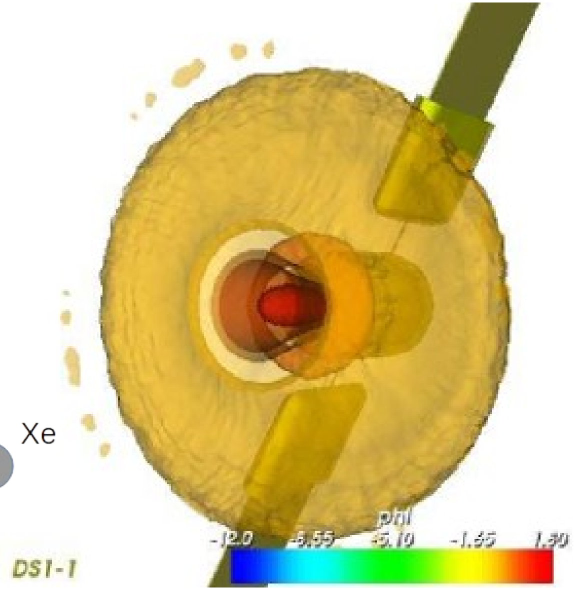


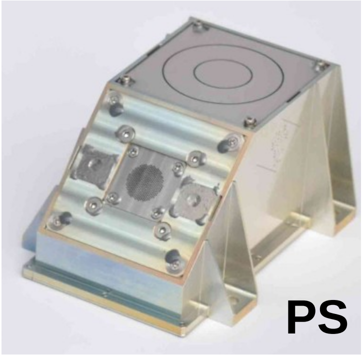
- Ladungsaustausch erzeugt ein sekundäres Plasma um den Satelliten
- Effekte können wegen lokaler elektrischer Felder nicht vorhergesagt werden
- Störungen von Messungen und (Radio-) Kommunikation
- Möglicherweise destruktive Entladungsprozesse
- Rückfluss vom Triebwerk auf den Satelliten kann auf der Erde nicht gemessen werden



Ladungsaustausch bei Stößen



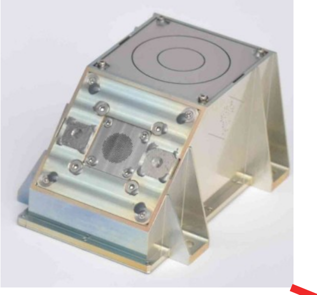




Die Wechselwirkung des Ionenstrahls mit der Neutralkomponente führt zu einer rückgestreuten Population von Atomen und Ionen.

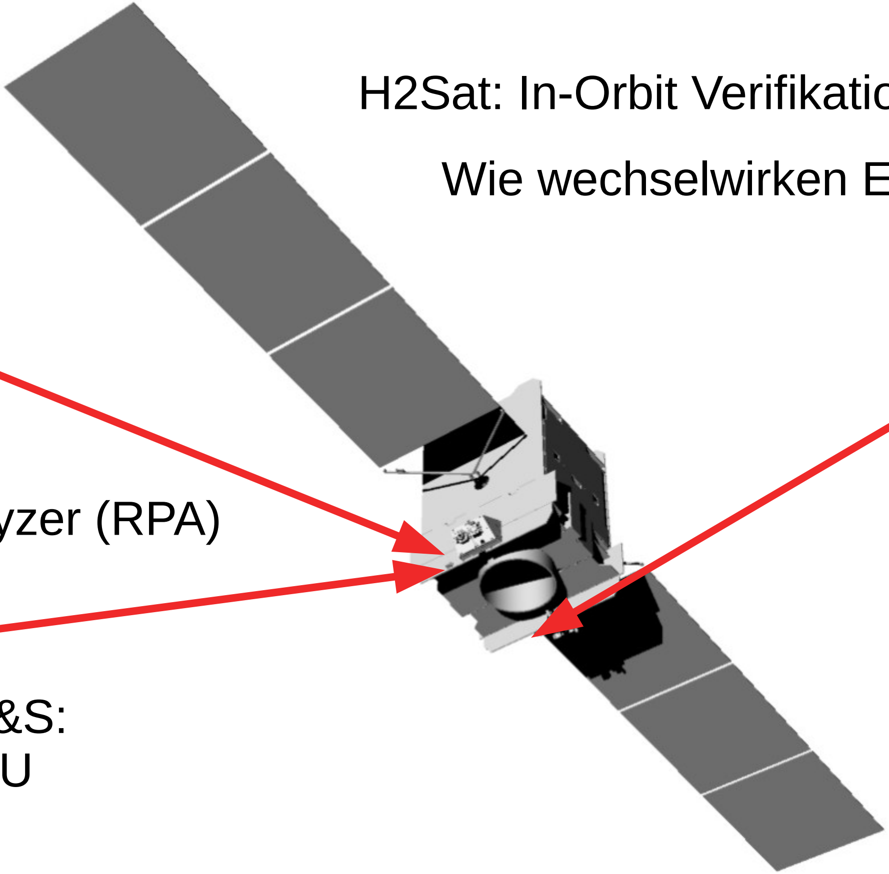
- **Der EPDP Plasmasensor (PS) misst den unmittelbaren Einfluss auf den Satelliten.**
- **Der EPDP Erosionssensor (ES) misst das langfristige Abtragen/Ausdünnen der Oberfläche.**

Das Electric Propulsion Diagnostics Package (EPDP) auf H2Sat



H2Sat: In-Orbit Verifikation innovativer Technologien

Wie wechselwirken EP-Triebwerke mit Satelliten?

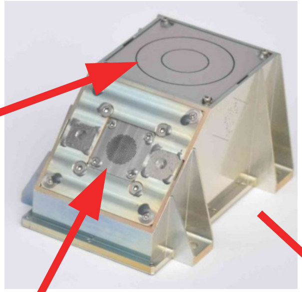


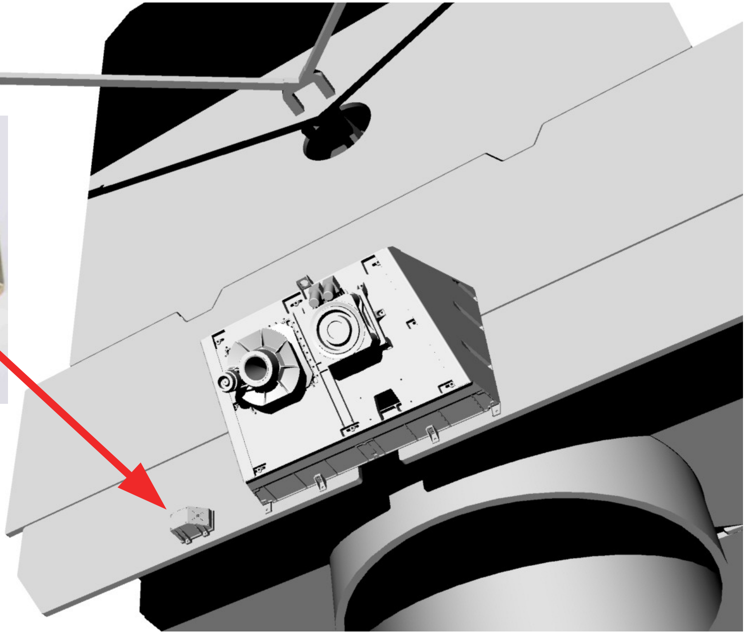
CAU:
Plasmadiagnostik:
Langmuir-Probe (LP)
Repelling Potential Analyzer (RPA)

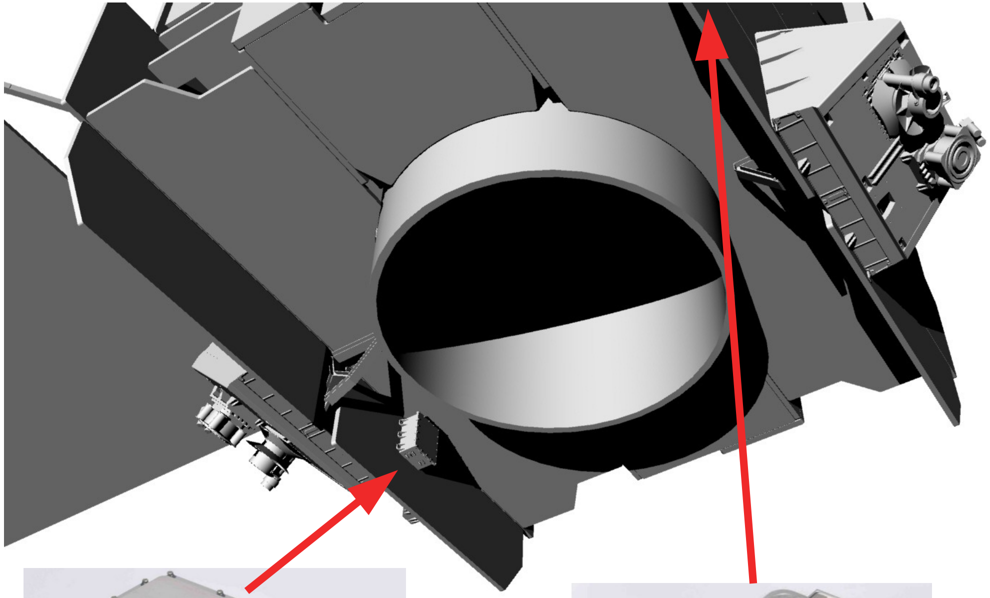
vH&S:
Erosionssensor

vH&S:
DPU

Das Electric Propulsion Diagnostics Package (EPDP) auf H2Sat

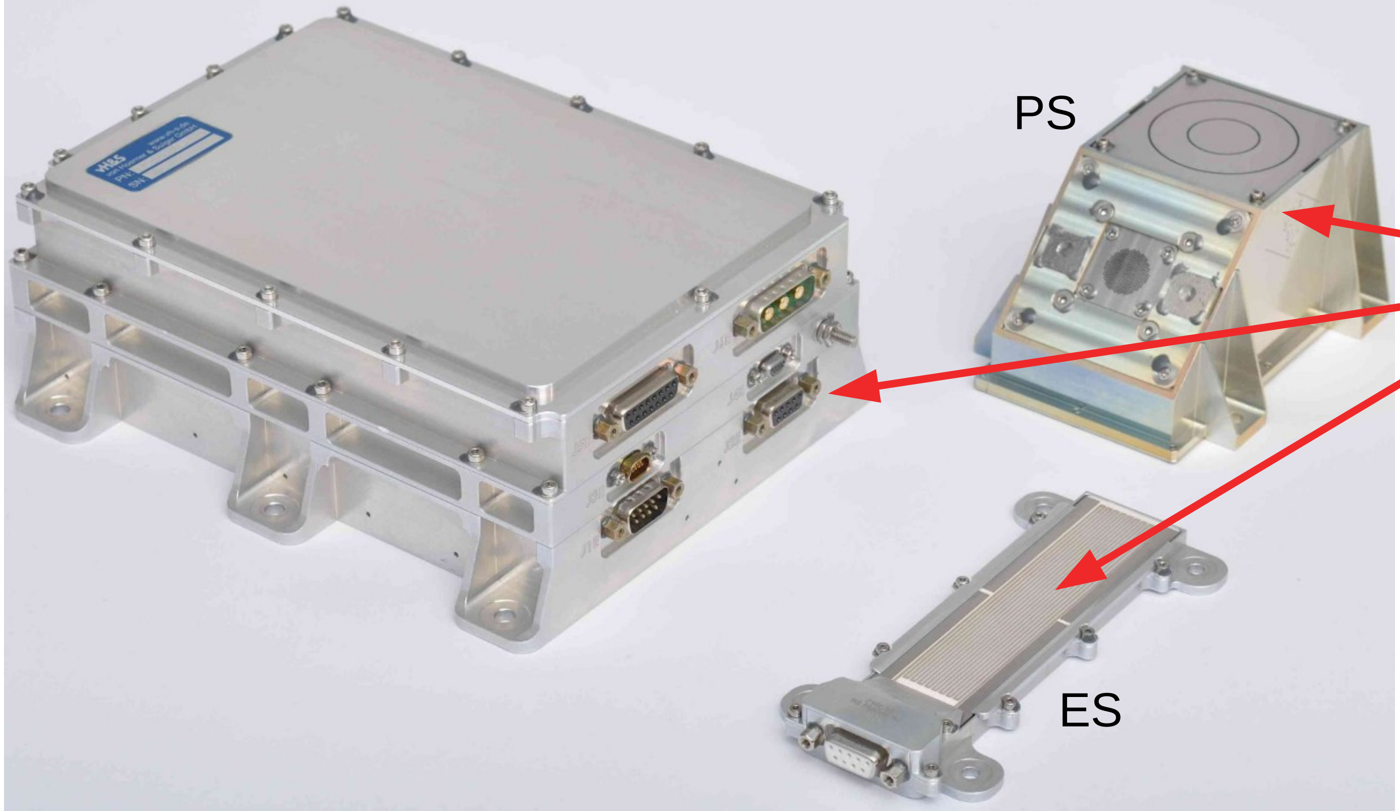






Plasmadiagnostik:
Repelling Potential Analyzer (RPA)
Langmuir-Probe (LP)

Das Electric Propulsion Diagnostics Package (EPDP) auf H2Sat



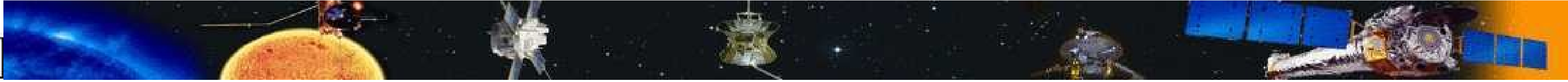
Projektleitung: vH&S
Interface zum S/C: OHB

Plasmasensor: CAU
DPU: vH&S
Erosionssensor: vH&S

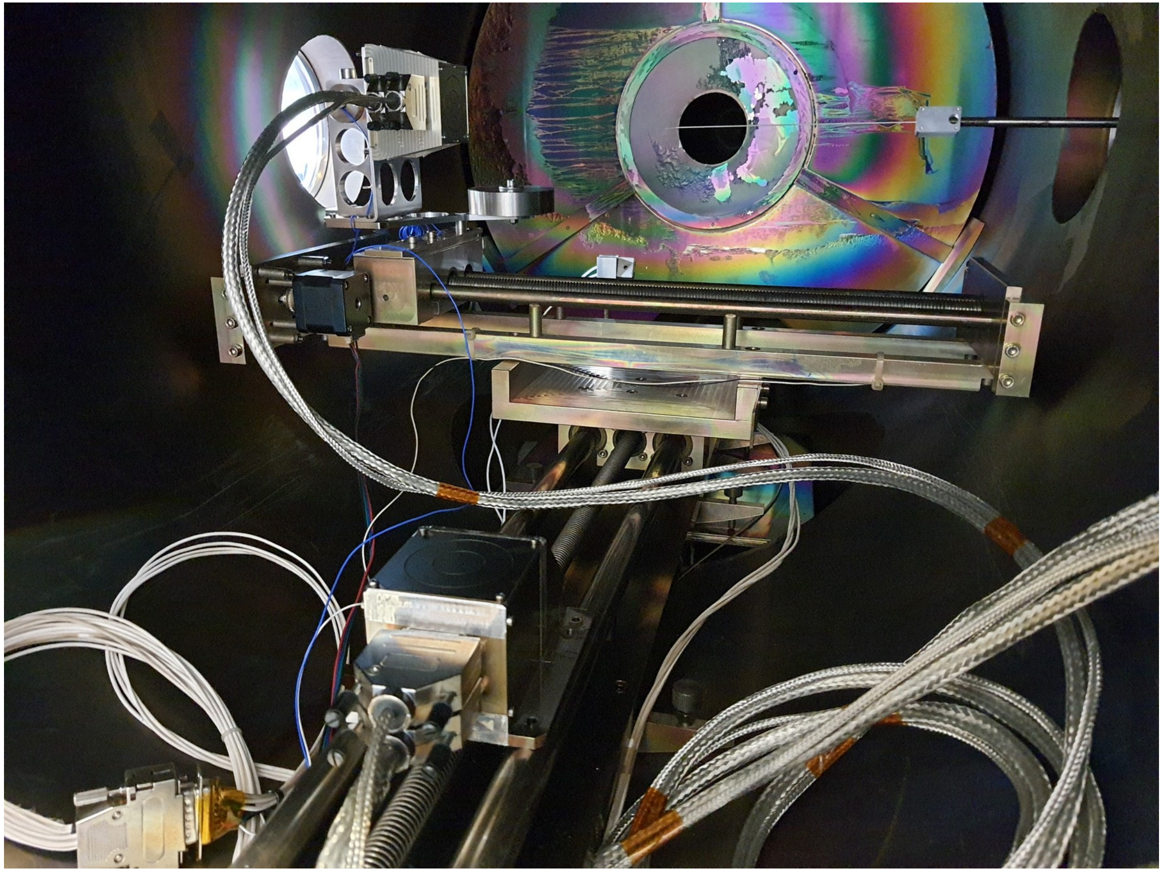
Von der CAU kooperieren 2 Arbeitsgruppen:

- Plasmatechnologie
- Extraterrestrik

Christian-Albrechts-Universität zu Kiel



CAU: AG Plasmatechnologie (AG Kersten)



Eur. Phys. J. D (2016) 70: 255
DOI: 10.1140/epjd/e2016-70355-6

THE EUROPEAN PHYSICAL JOURNAL D

Regular Article

Measurement and simulation of the momentum transferred to a surface by deposition of sputtered atoms*

Alexander Spethmann[a], Thomas Trottenberg, and Holger Kersten

Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, 24098 Kiel, Germany

PHYSICS OF PLASMAS **24**, 093501 (2017)

CrossMark

Measurement and simulation of forces generated when a surface is sputtered

Alexander Spethmann, Thomas Trottenberg, and Holger Kersten
Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität Kiel, 24098 Kiel, Germany

JVST A
Journal of Vacuum Science & Technology A
ARTICLE
avs.scitation.org/journal/jva

Directionally resolved measurements of momentum transport in sputter plumes as a critical test for simulations

Cite as: J. Vac. Sci. Technol. A 38, 033013 (2020); doi: 10.1116/6.0000109
Submitted: 10 February 2020 · Accepted: 21 April 2020 ·
Published Online: 12 May 2020

View Online Export Citation CrossMark

Mathis Klette,[a] Manuel Maas, Thomas Trottenberg,[b] and Holger Kersten[c]

AFFILIATIONS
Institute of Experimental and Applied Physics, Kiel University, 24098 Kiel, Germany

Trottenberg et al. EPJ Techniques and Instrumentation (2018) 5:5
https://doi.org/10.1140/epjti/s40485-018-0046-3

EPJ Techniques and Instrumentation
a SpringerOpen Journal

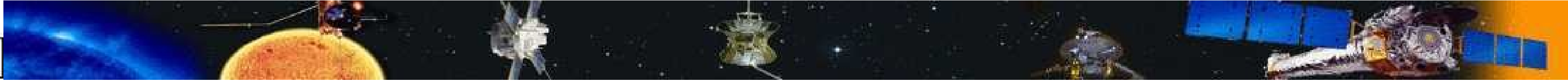
EPJ.org

RESEARCH Open Access

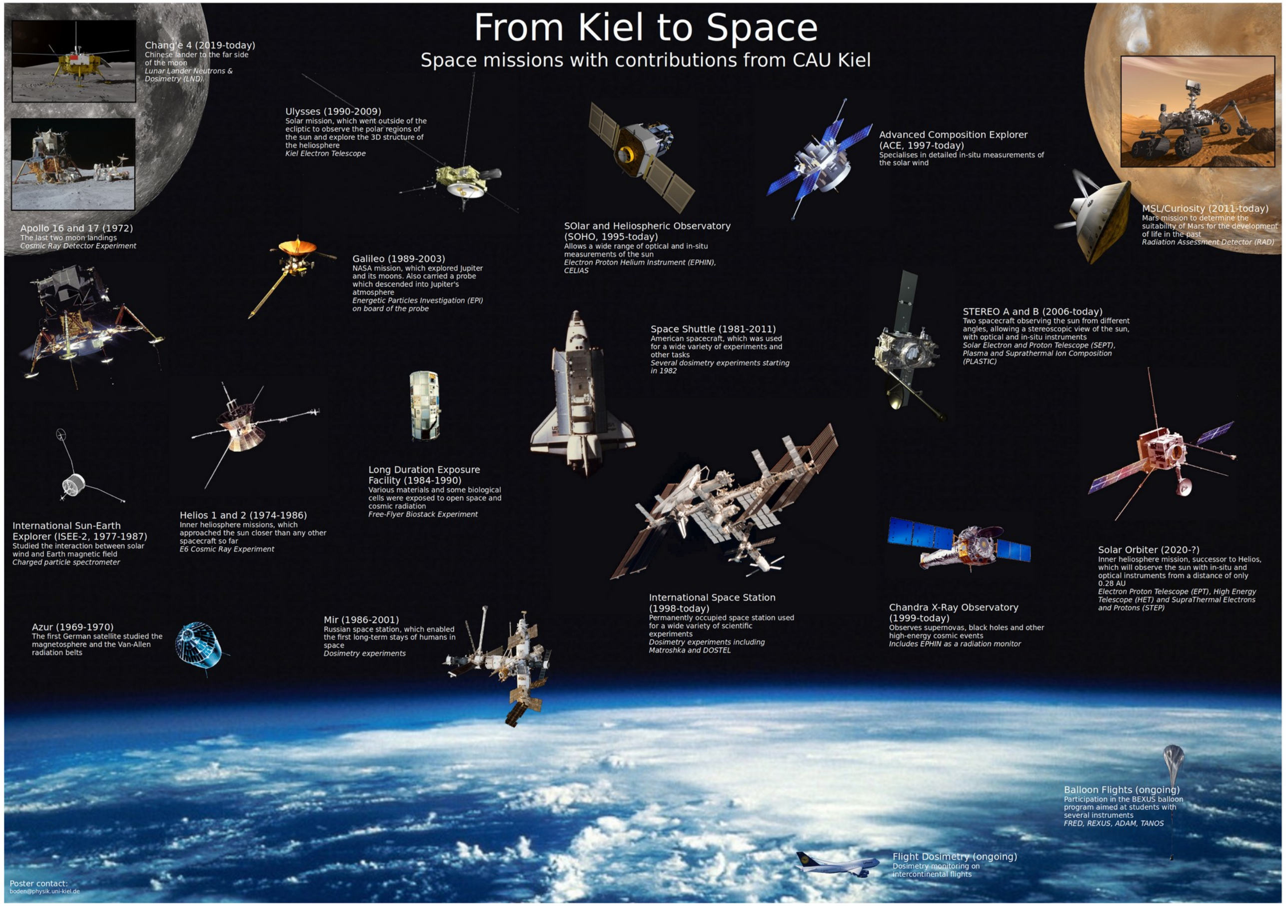
CrossMark

An interferometric force probe for beam diagnostics and the study of sputtering

Thomas Trottenberg*, Alexander Spethmann and Holger Kersten

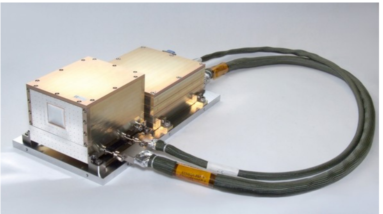


CAU: AG Extraterrestrik (AG Wimmer-Schweingruber)

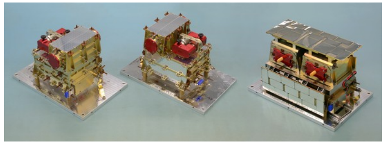


MARS SCIENCE LABORATORY

CHANG'E 4
Lunar Lander Neutrons & Dosimetry
LND

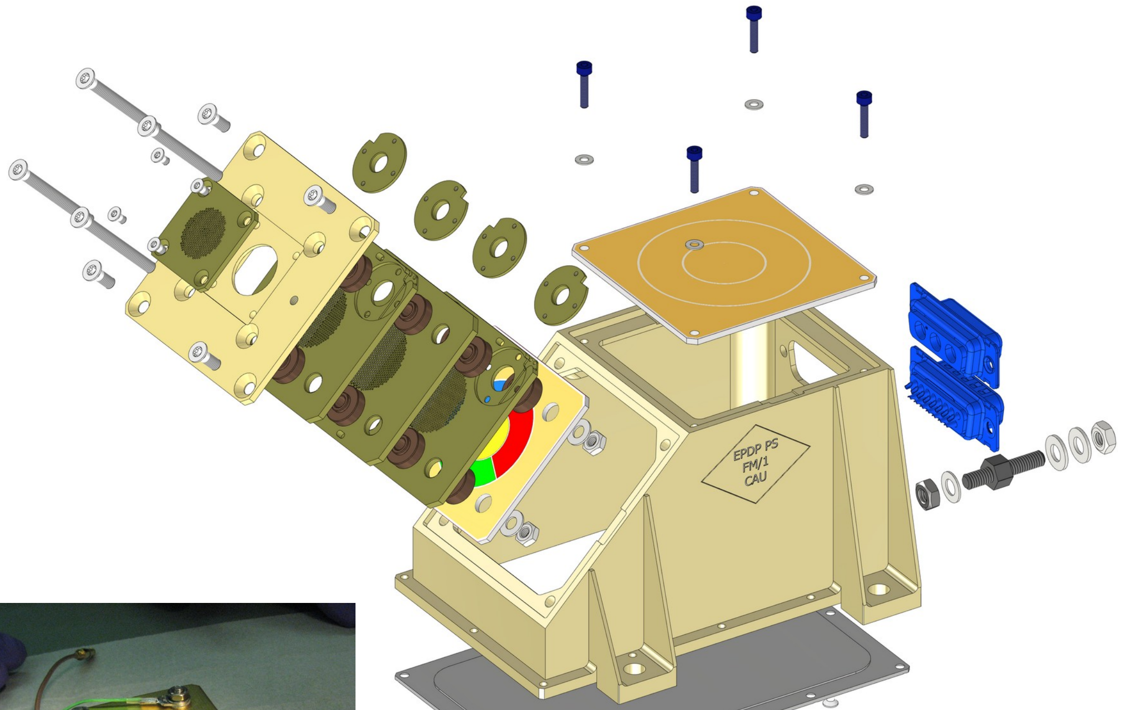


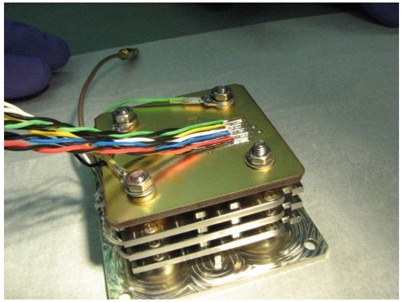
solar orbiter



EPDP – PS Design

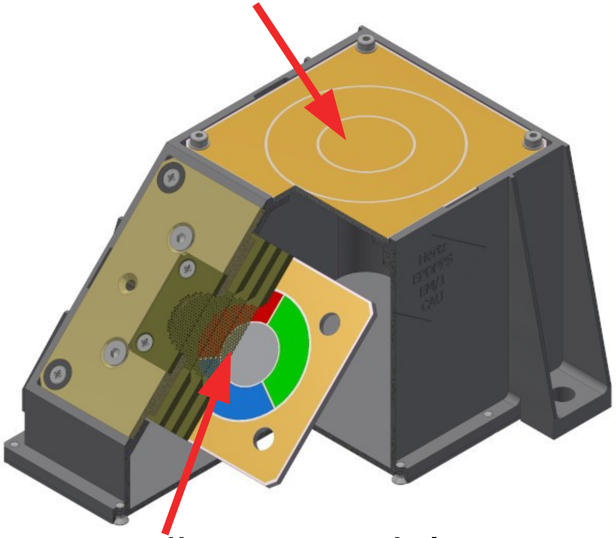
- Modular design (RPA assembled separately.)
- ~237g monolithic Al-chassis.
- In-house manufacture.
- RPA
    - 4 Grids: Titanium Grade-5 w/ 0.2mm sheet thickness.
    - Lattice: 0.5mm boreholes w/ 0.2mm dist.
- First time application of RoHS compatible chromating process *SurTec650.*
- No active electronics.



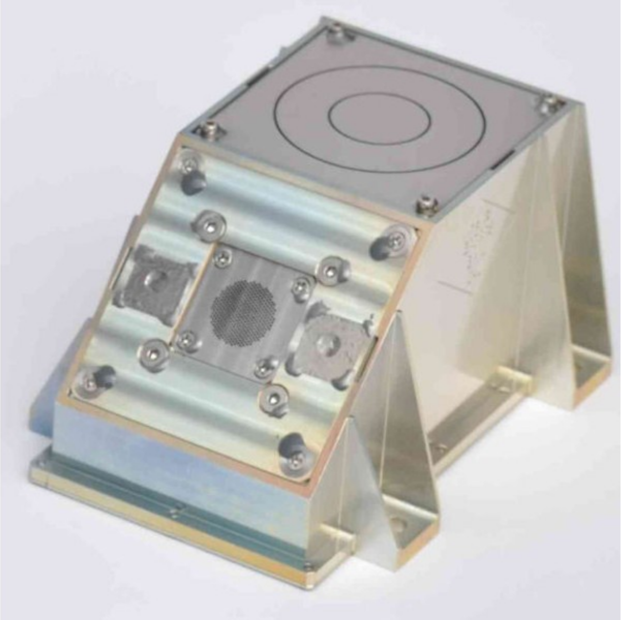


EPDP Plasma Sensoren (PS)

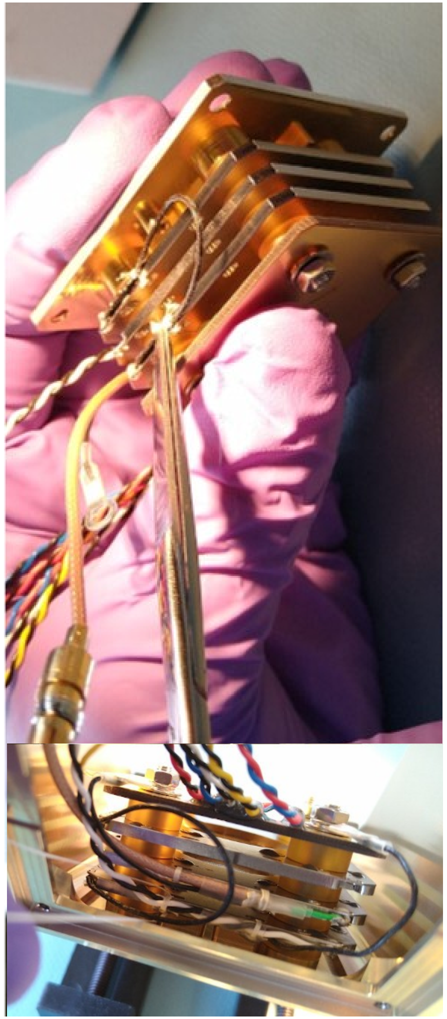
Langmuirprobe (LP)



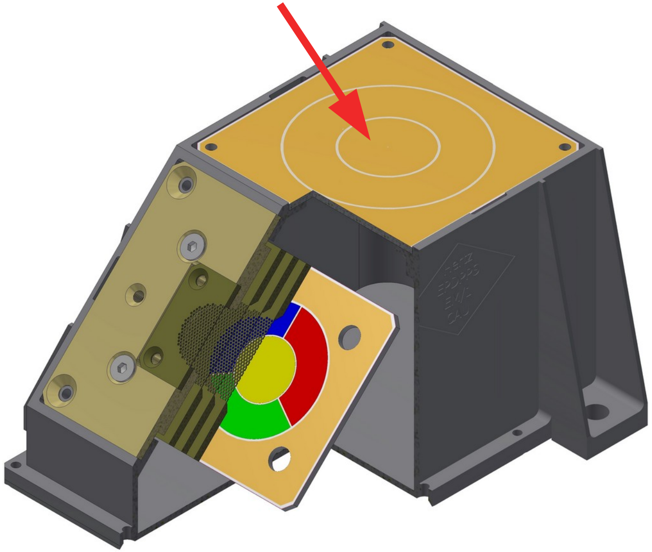
Retarding Potential Analyzer (RPA)

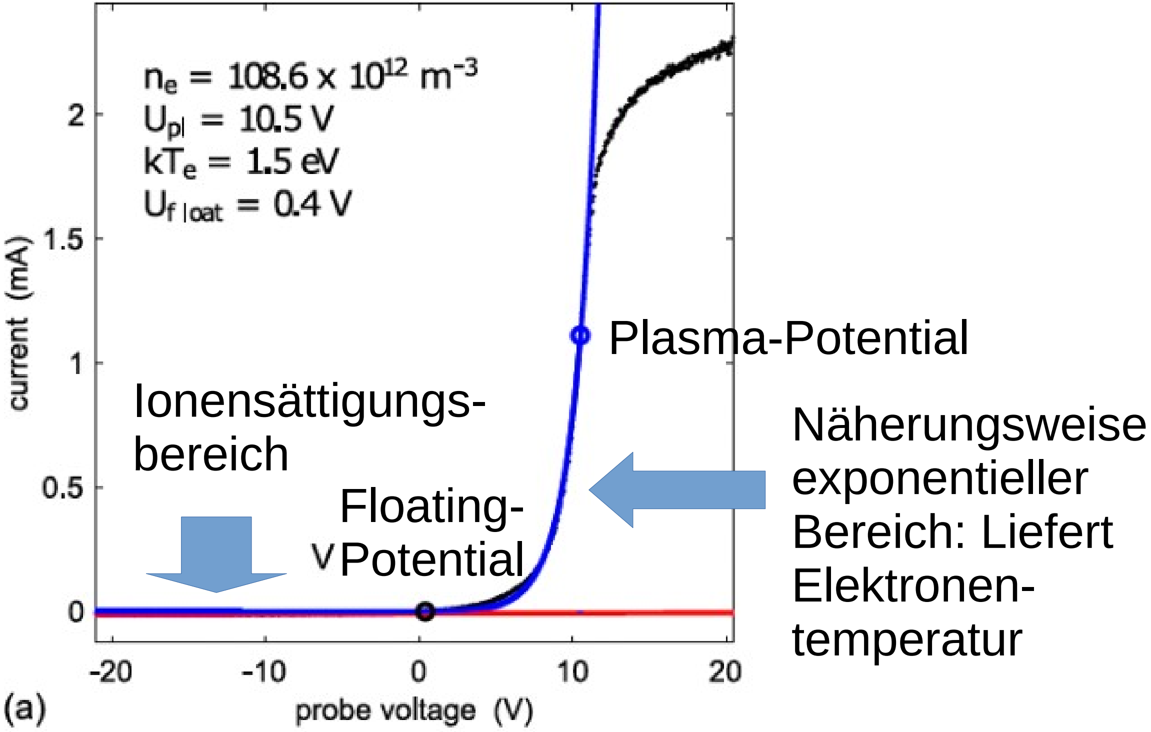


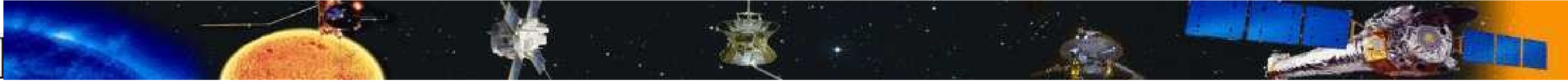
EPDP PS EM



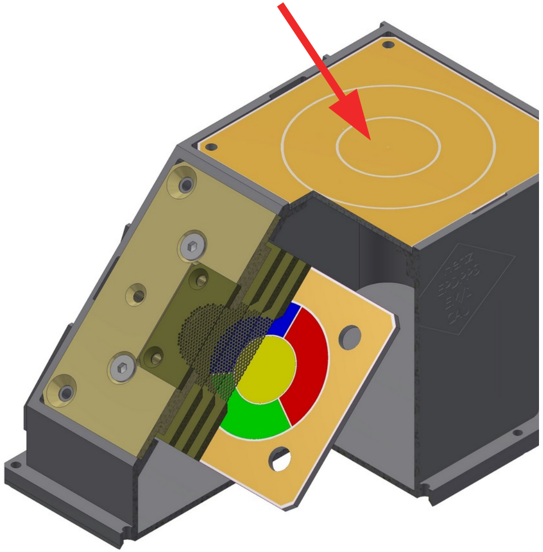
EPDP Langmuir Probe (LP)

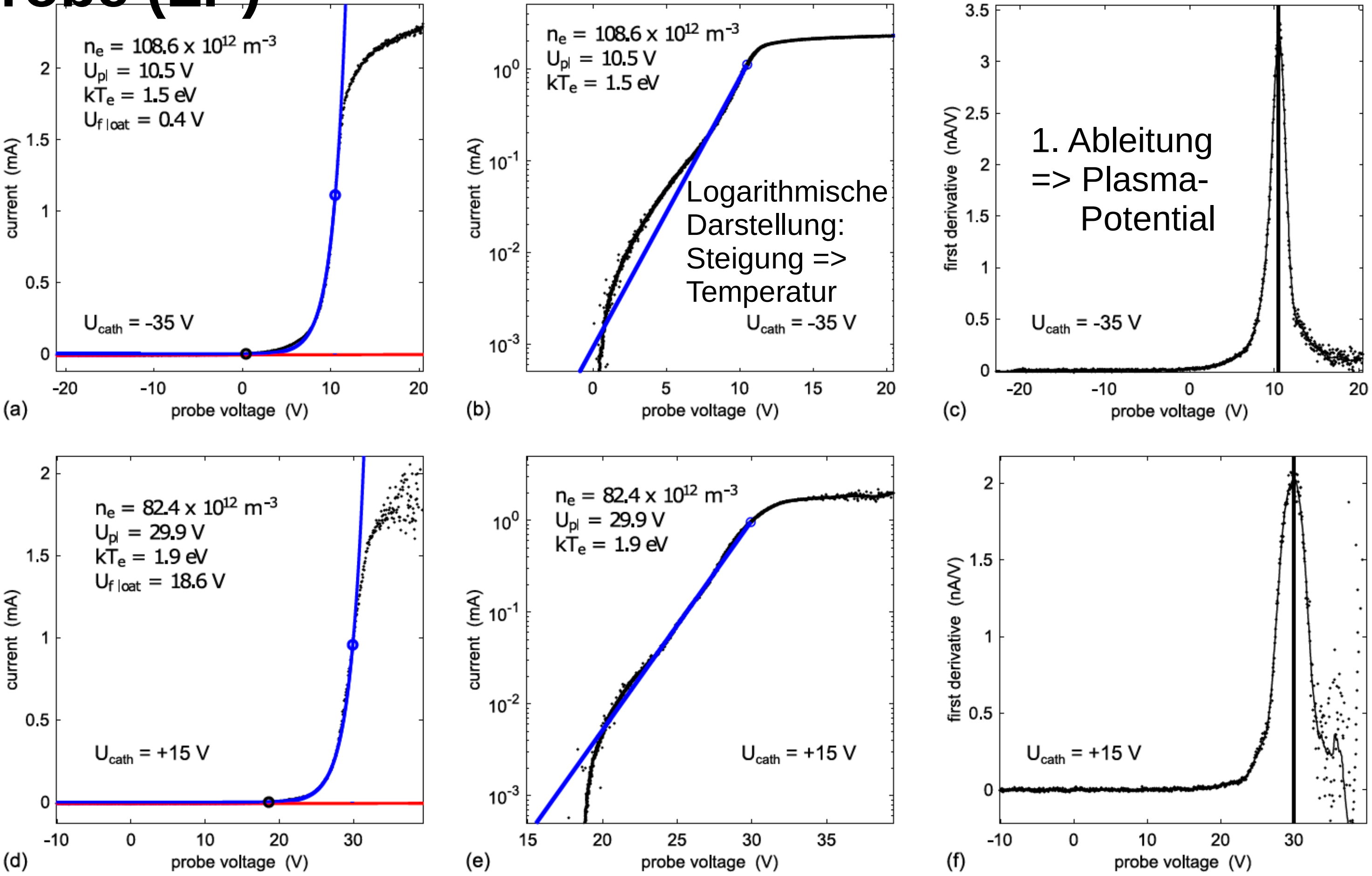




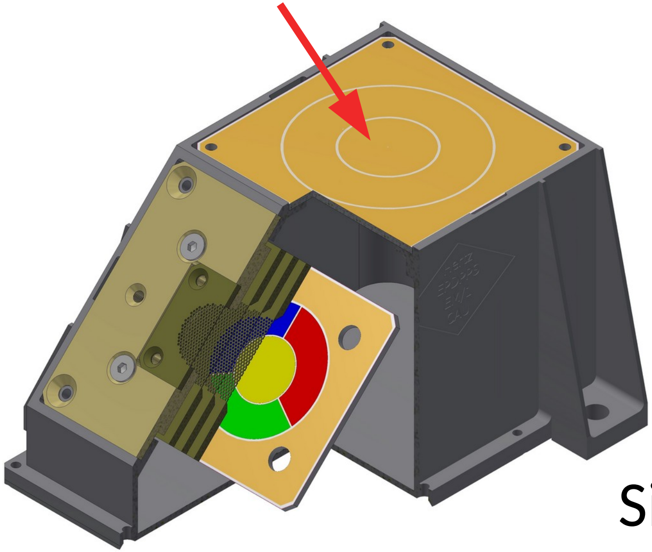


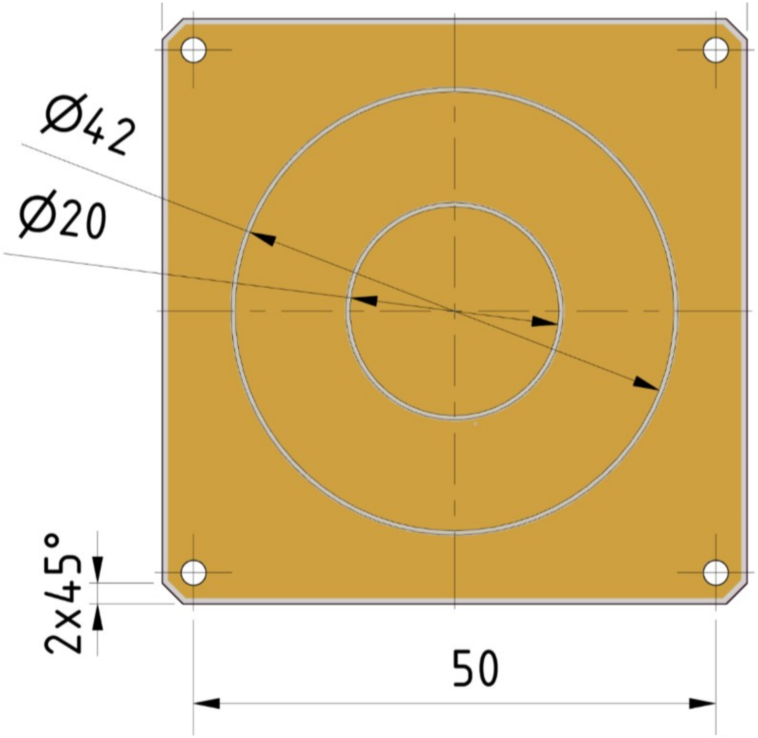
EPDP Langmuir Probe (LP)





EPDP Langmuir Probe (LP)





Simulationen mit:

$$n_\mathrm{e} = (5 \times 10^{10} \ldots 1 \times 10^{13})\,\mathrm{m}^{-3} \qquad k_\mathrm{B} T_\mathrm{e} = 3\,\mathrm{eV}$$

zeigen Abschirmungslänge (Debye-länge) von

$$\lambda_\mathrm{De} = \left(\frac{k_\mathrm{B} T_\mathrm{e}}{n_\mathrm{e} e^2}\right)^{\frac{1}{2}} = 4\,\mathrm{mm} \ldots 6\,\mathrm{cm}$$

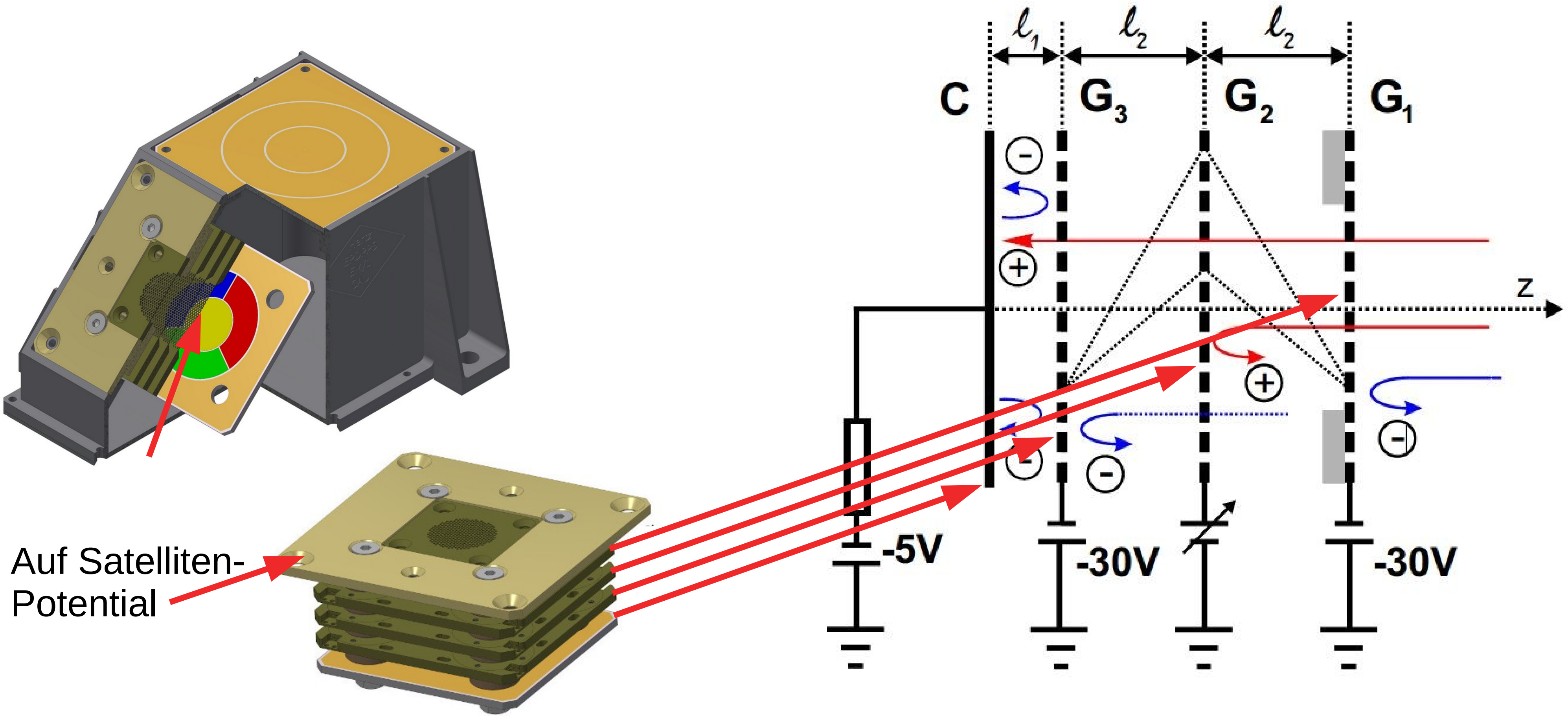
Aktive Fläche $A = 3.1\,\mathrm{cm}^2$

Sättigungsströme:

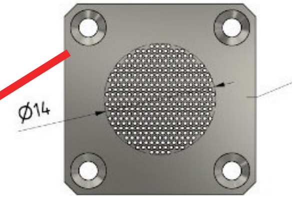
$$I_\mathrm{e} = 0.4\,\mu\mathrm{A} \ldots 90\,\mu\mathrm{A}$$

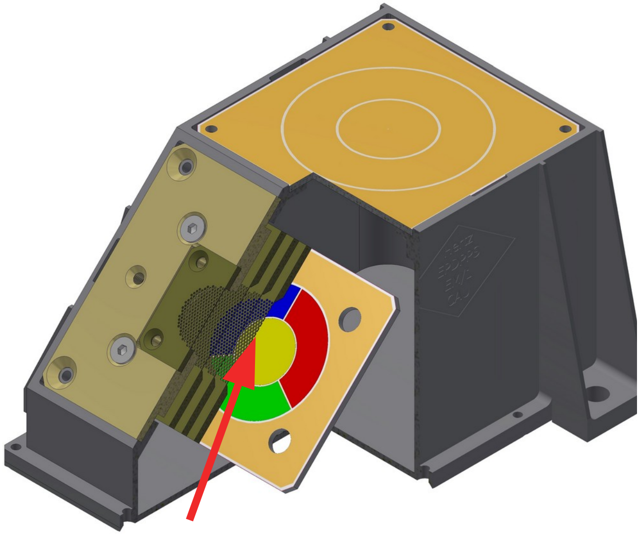
$$I_\mathrm{i} = 2\,\mathrm{nA} \ldots 0.5\,\mu\mathrm{A}$$

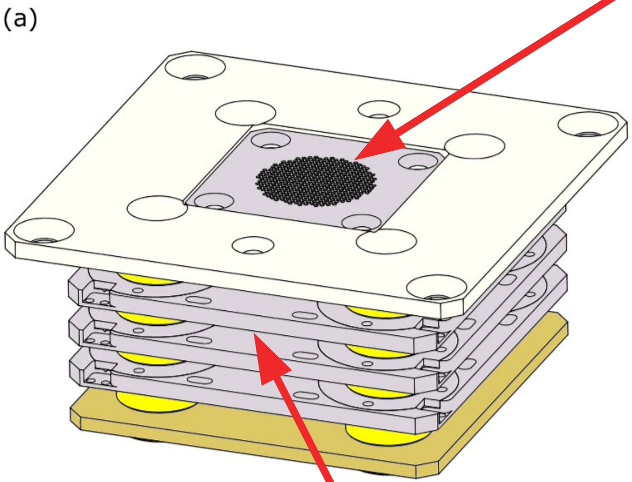
EPDP Retarding Potential Analyzer (RPA)

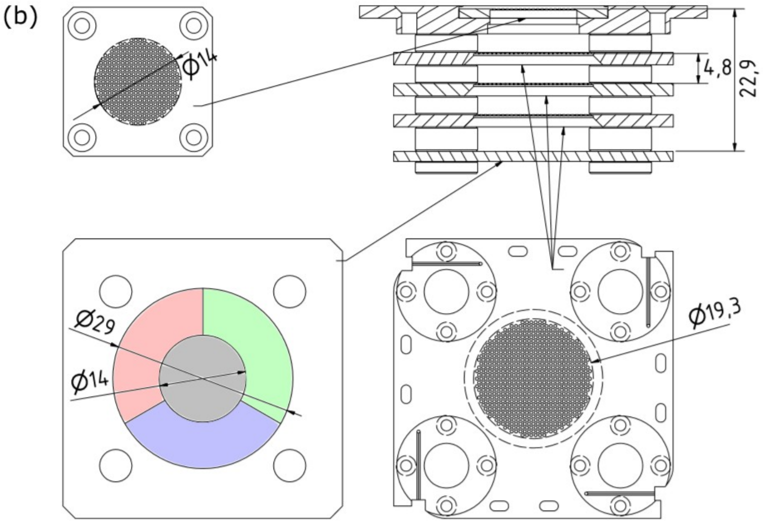


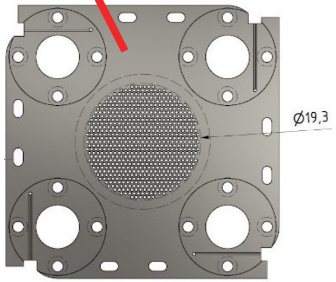
EPDP Retarding Potential Analyzer (RPA)





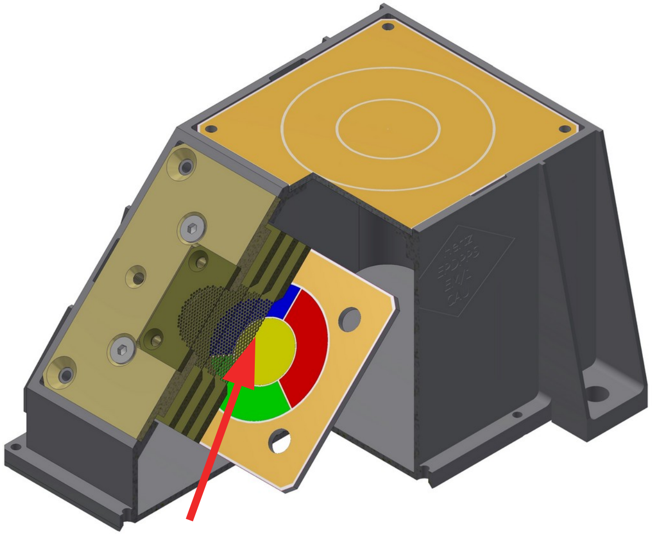




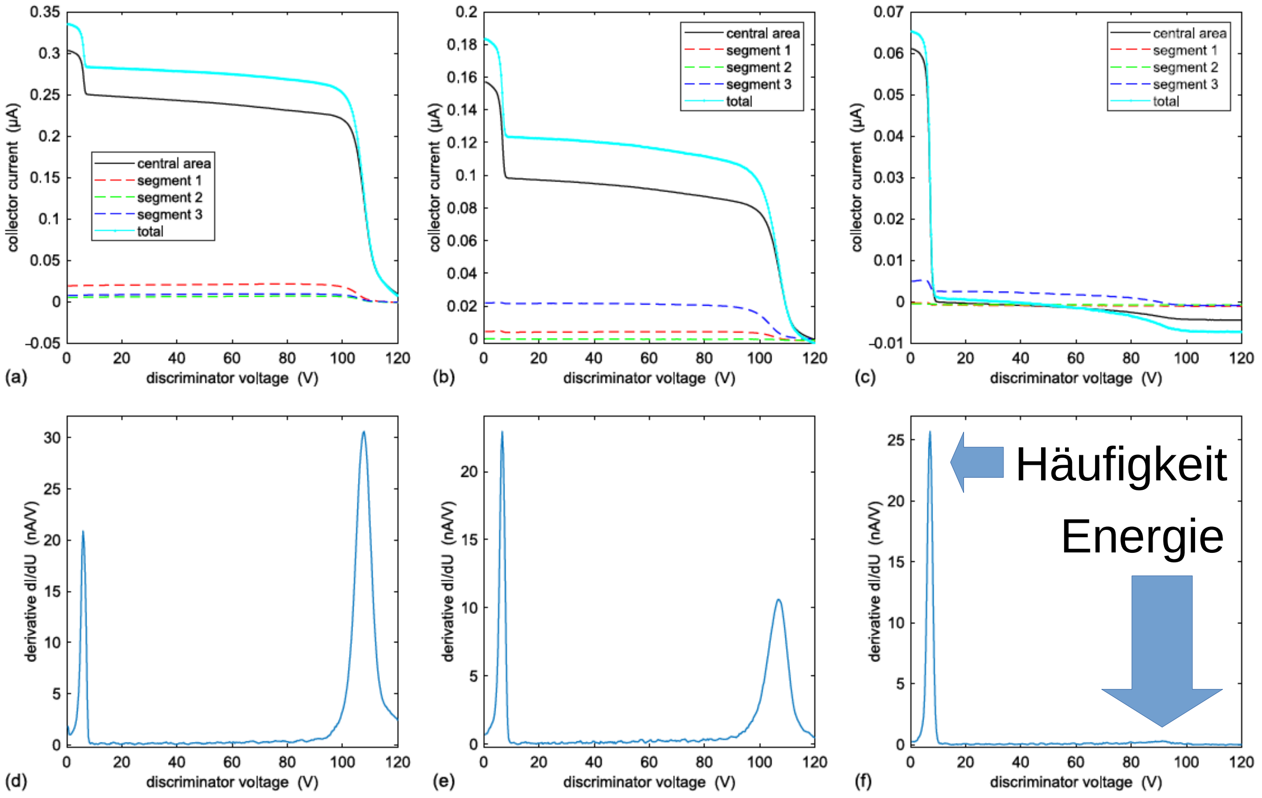


- Vier Gitter
- Segmentierter Kollektor
- 0,5 mm Löcher, 0,2 mm Stege
- Stärke der Gitter: 0,2 mm

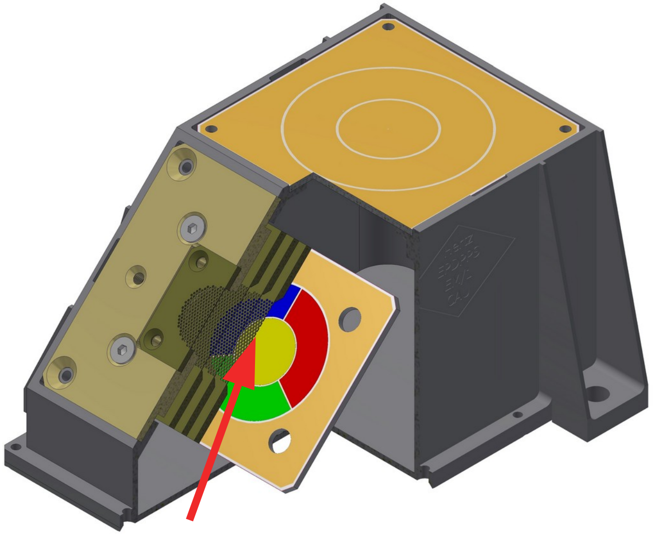
EPDP Retarding Potential Analyzer (RPA)



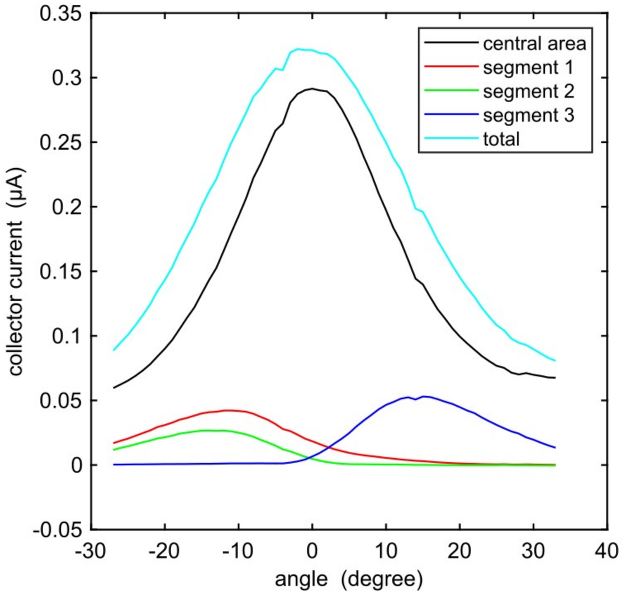
Im Strahl | Am Rande | Außerhalb

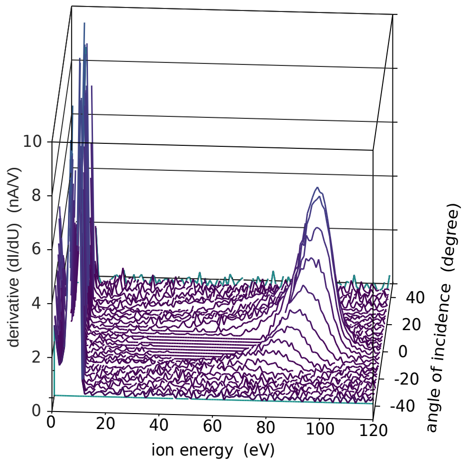


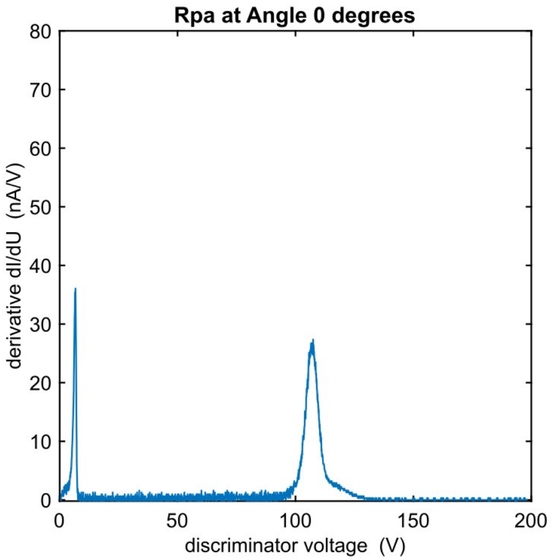
EPDP Retarding Potential Analyzer (RPA)

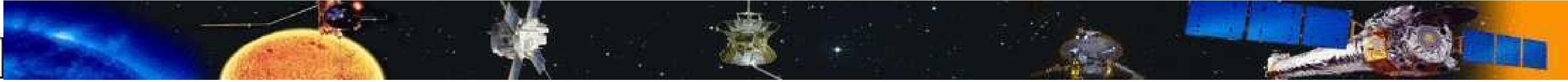


Die vier Segmente des RPA erlauben eine Bestimmung der Einfallsrichtung.



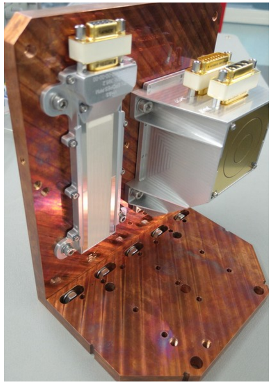


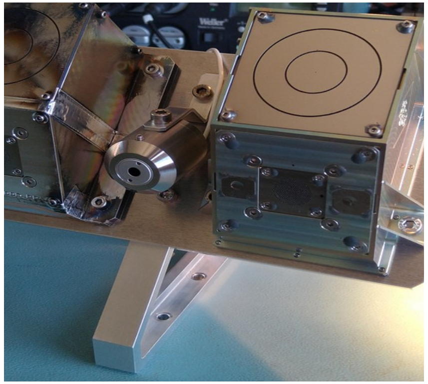


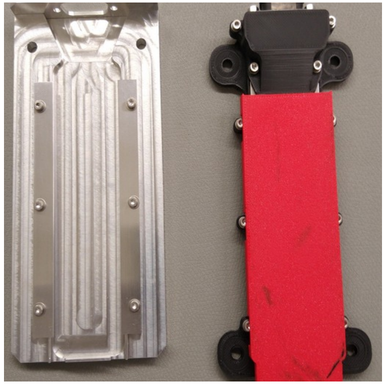


Jigs'/ Tools' Design and Build

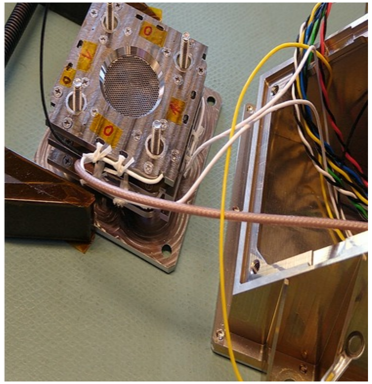
Activities related to building EPDP

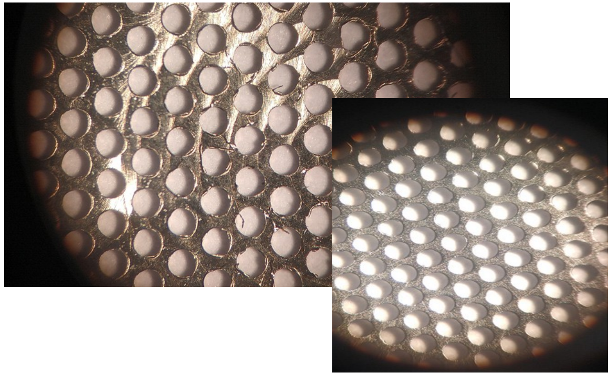




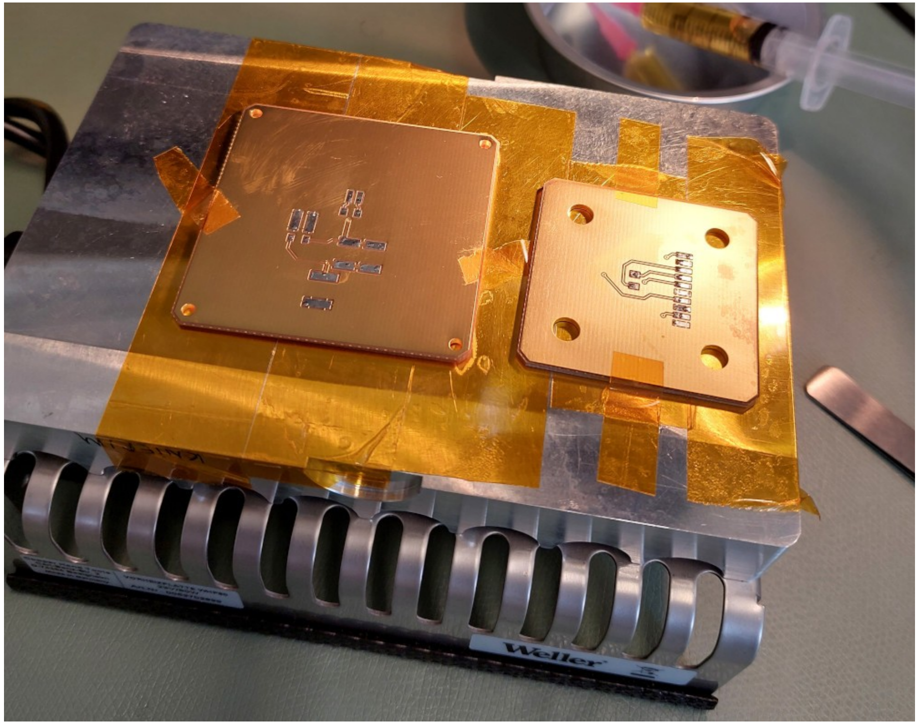


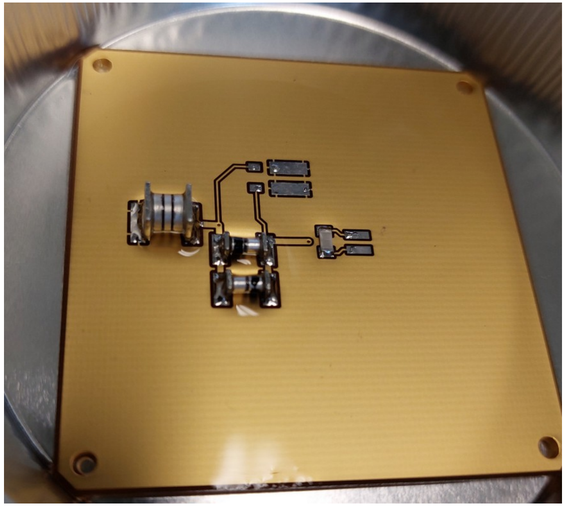
Testing, Iterating, Process Refining and … more Testing

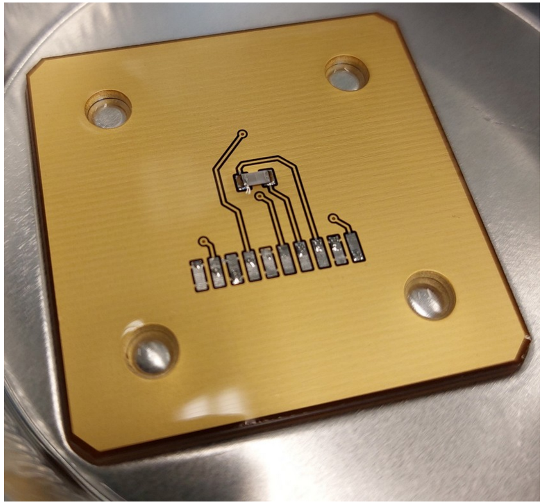




EPDP – LP und RPA – Lötarbeiten:

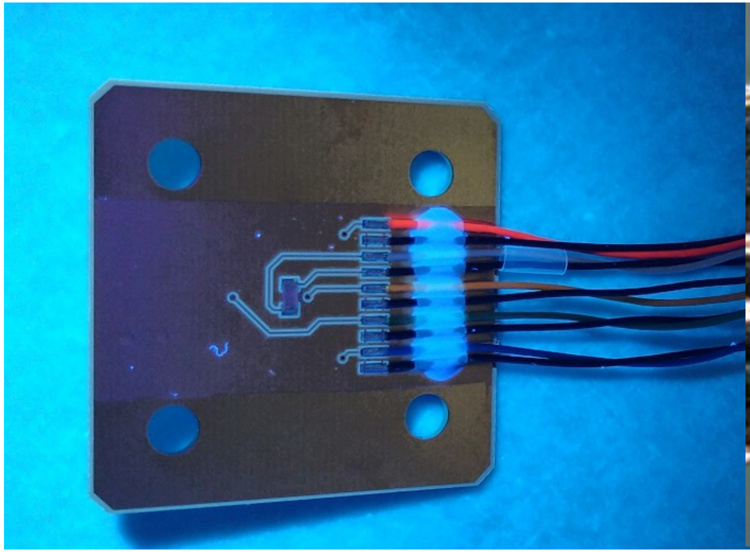


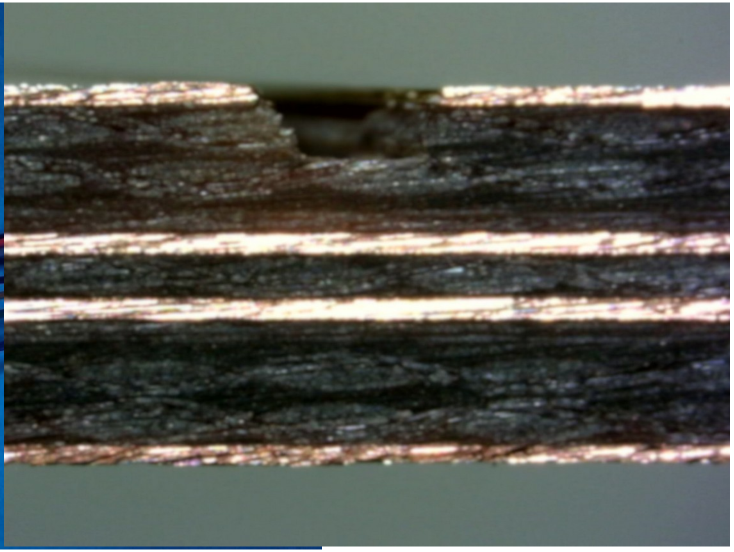


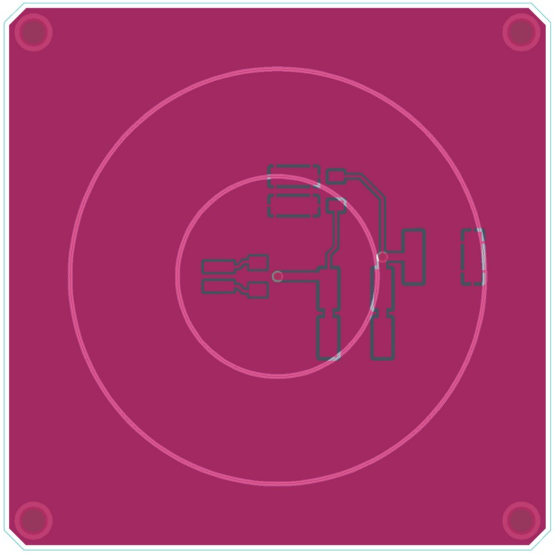


Lötarbeiten nach
ECSS-Q-ST-70-08C & ECSS-Q-ST-70-38C
mit Vorheizen und Reinigung

EPDP – LP und RPA – Inspektion und Kontrolle:

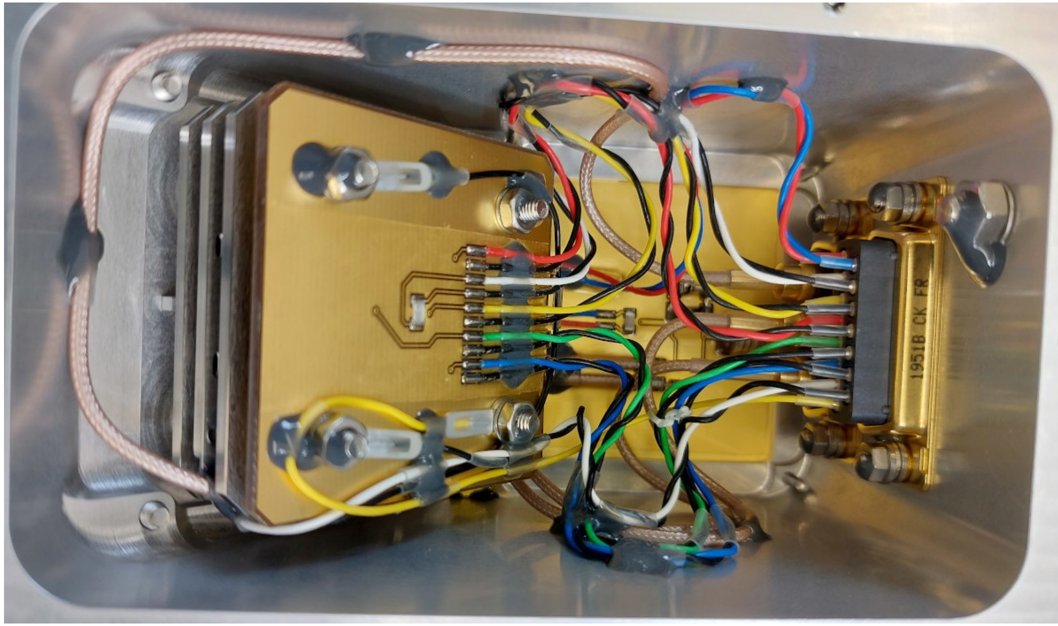


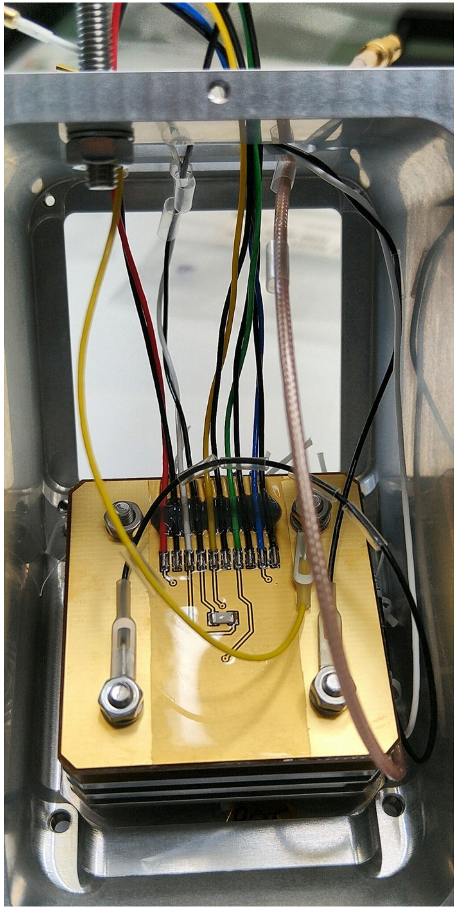


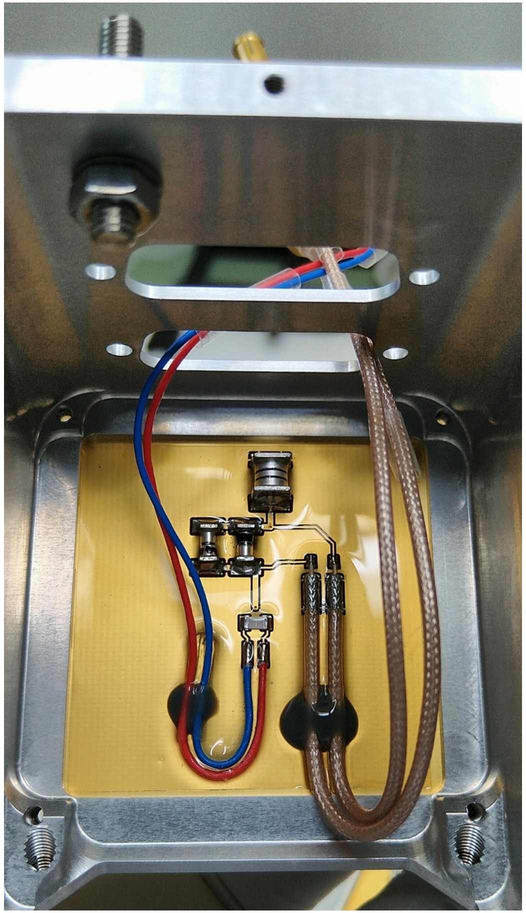


Kontrollieren der Sauberkeit und möglicher Einschlüsse im conformal coating der RPA Platine unter UV Licht.
Sowie Schliffbilder der Vertiefung der LP.

EPDP – LP und RPA – Integration:

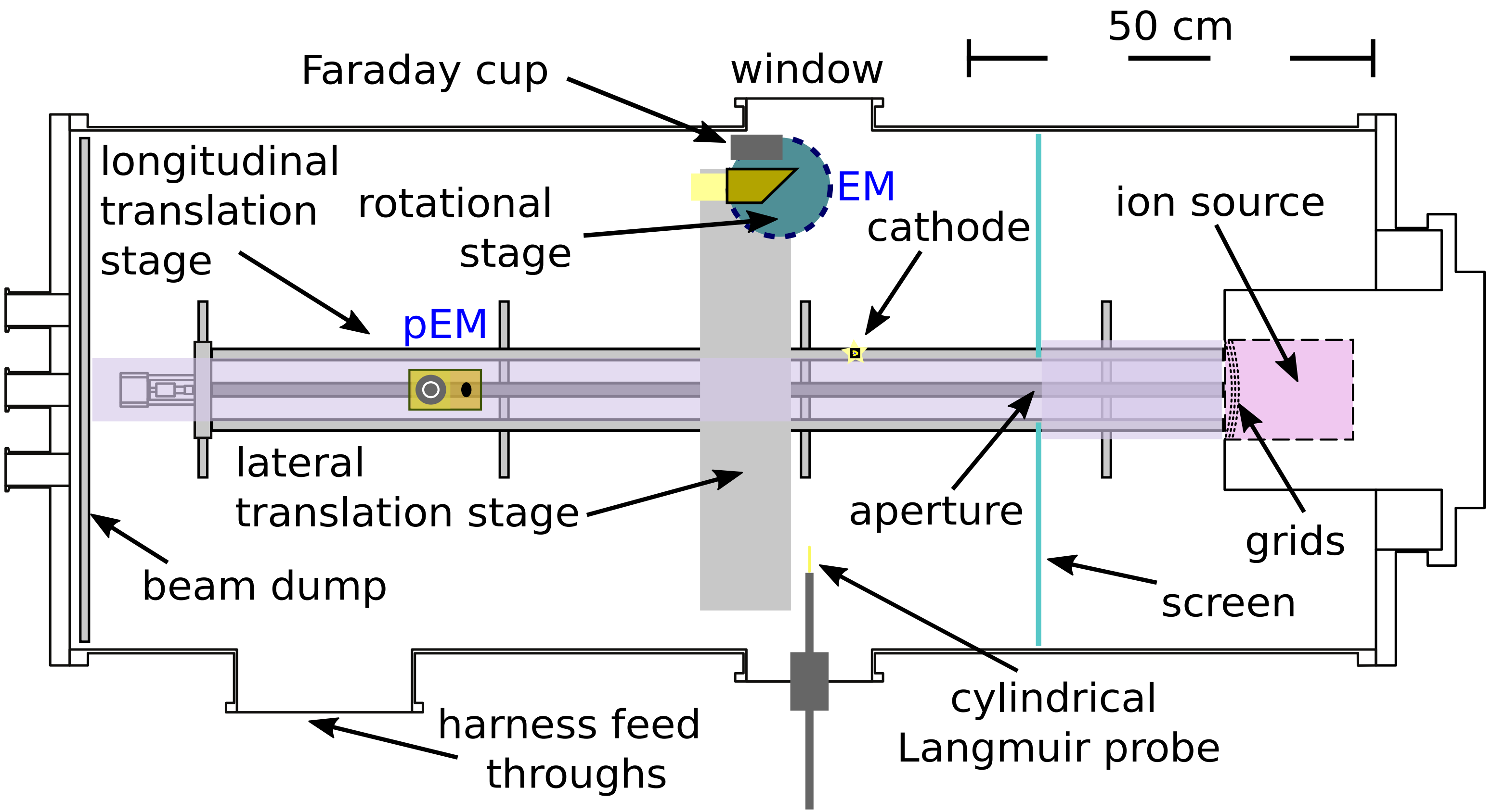




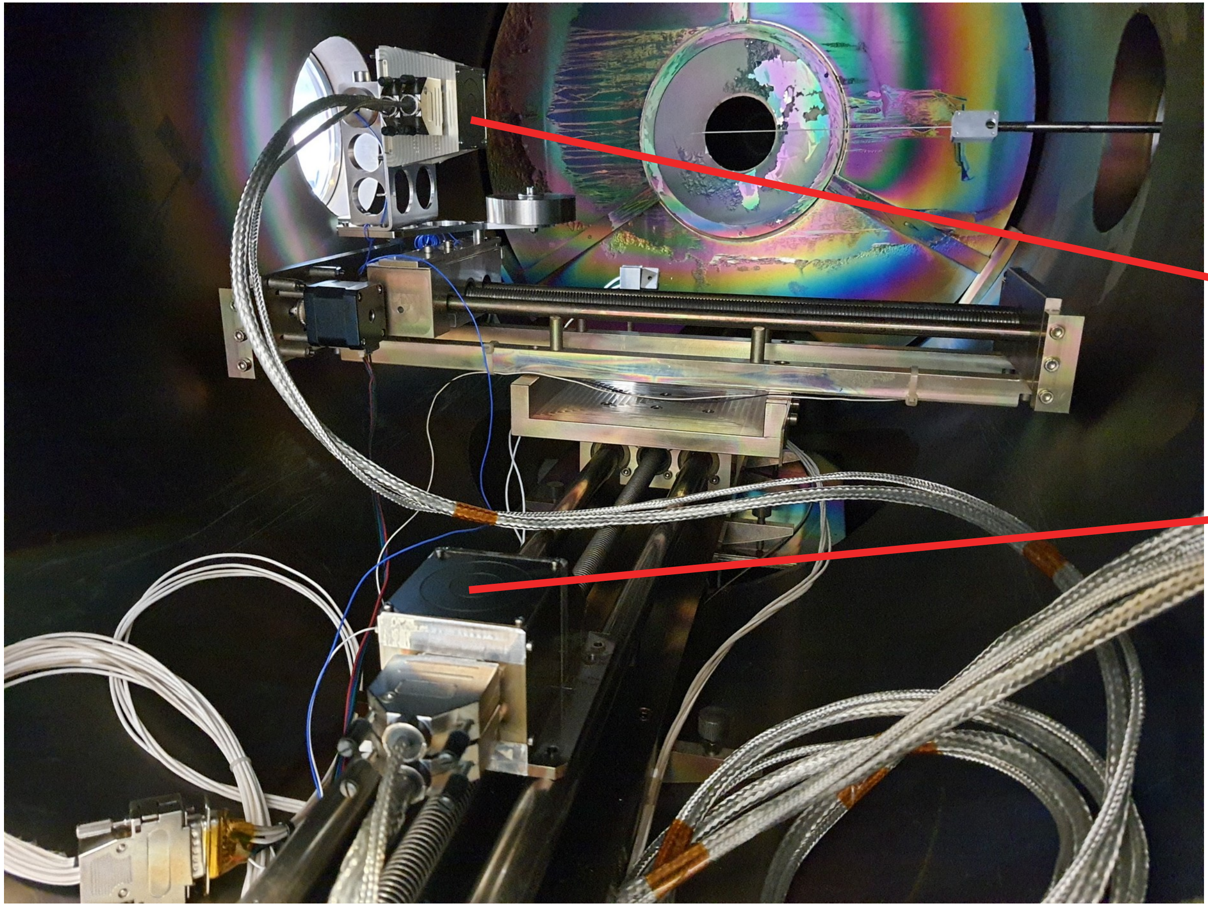


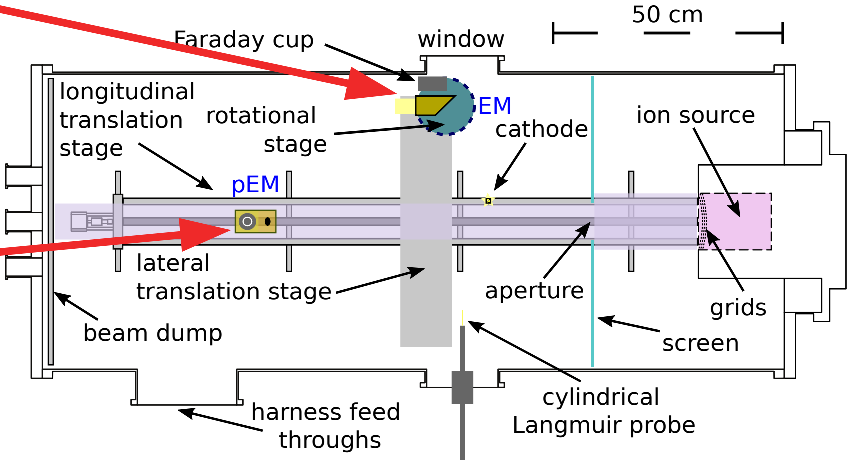
Die Kabel der RPA und der LP werden von hinten in die Steckergehäuse integriert. Anschließend werden diese durch Verkleben fixiert.

Erste Tests mit EPDP PS pre & Engineering Model (pEM & EM)



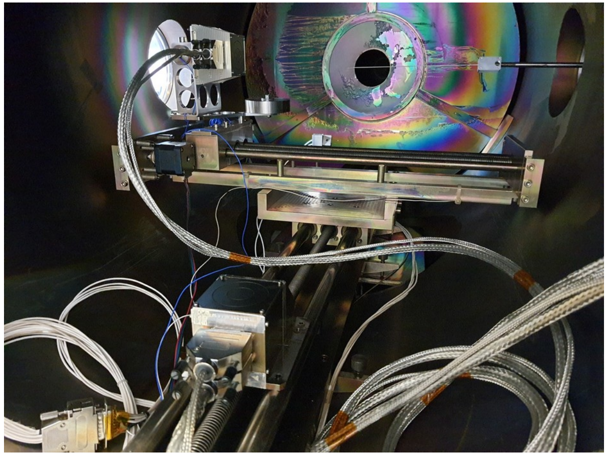
Erste Tests mit EPDP PS pEM & EM

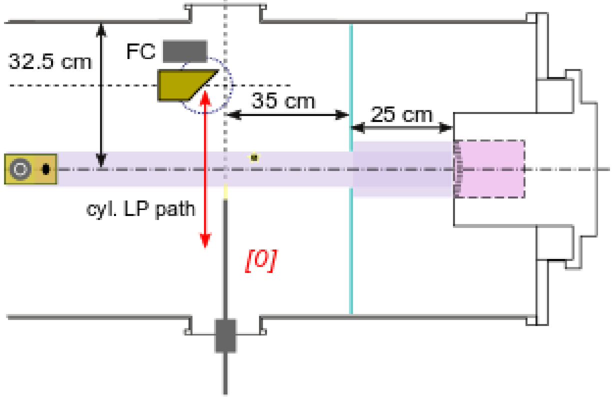




HIBEX AG Kersten

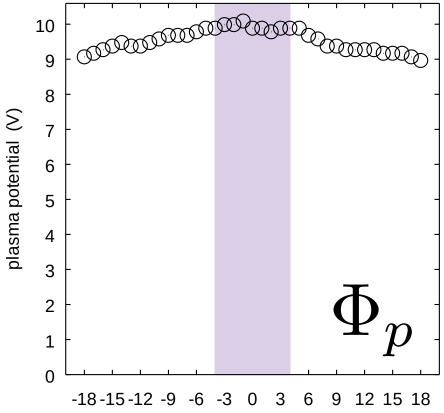
Erste Tests mit EPDP PS pEM & EM

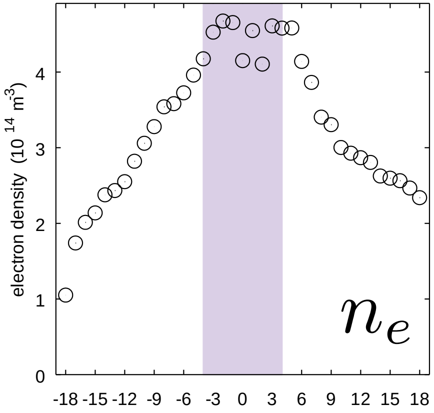


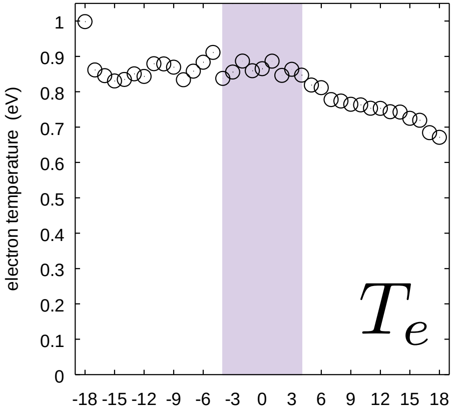


Strahl: 1,2 keV Xe⁺,
Durchmesser: 8 cm

(Positionen in den Plots <0: obere Hälfte, >0: untere Hälfte)

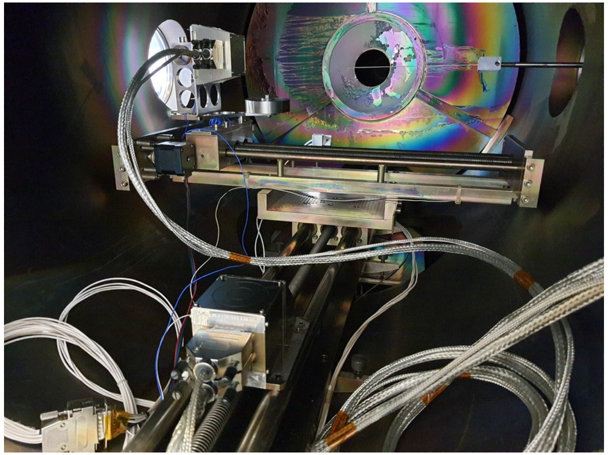


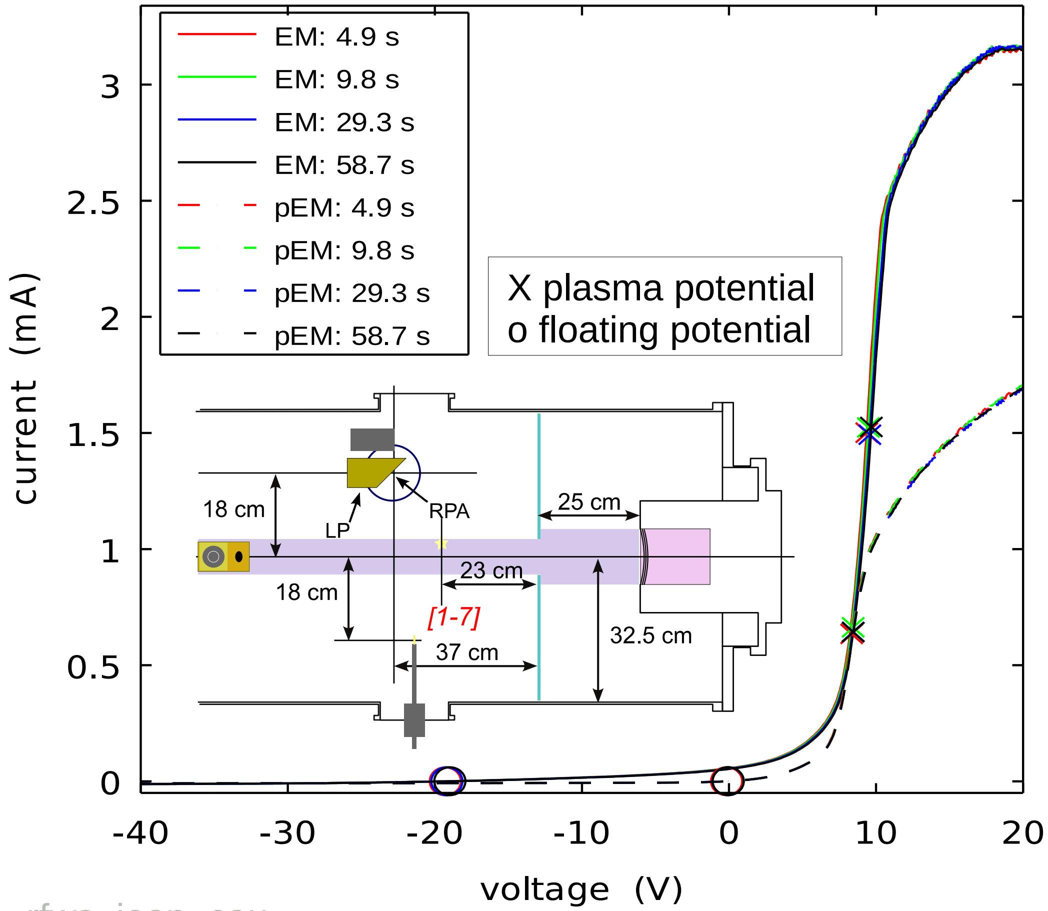




HIBEX_BeamProfile_cylProbe_*_(O_202356-C4)

Erste Tests mit EPDP PS pEM & EM





Resultate sind unabhängig von der Messzeit. PS ist richtig dimensioniert.

EM und pEM wurden separaten Tests mit anderen Einstellungen der Quelle unterzogen.

C A U
Christian-Albrechts-Universität zu Kiel

EPDP PS Characterization

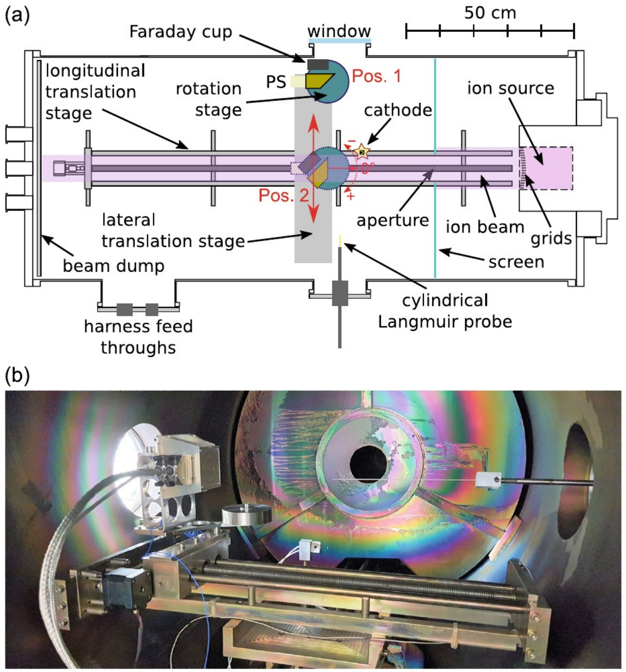


Fig. 5 In-house testing of the EPDP in the chamber at the University of Kiel. (a) The sketch shows the geometrical arrangement of the ion beam and the EPDP plasma sensor head (PS). The EPDP is mounted together with additional diagnostics on the translation and rotation stage. (b) The photograph shows a view into the chamber from the position of the removed beam dump. The rotation stage is moved to the left, just as in the sketch. (The disk-like steel object below the plasma sensor is a counter weight, which is needed for mechanical stability of the rotation stage.) At the right side of the photograph, one can see the additional movable cylindrical Langmuir probe; its tip is currently at the symmetry axis of the cylindrical chamber. Behind the stage, the aperture for the Xe beam is visible. The colorful shimmer at the aperture plate and the chamber wall is caused by thin films of sputtered and deposited materials from previous experiments

Trottenberg *et al. EPJ Techniques and Instrumentation* (2021) 8:16
https://doi.org/10.1140/epjti/s40485-021-00073-8
EPJ.org
EPJ Techniques and Instrumentation
RESEARCH ARTICLE Open Access

An in-flight plasma diagnostic package for spacecraft with electric propulsion

Thomas Trottenberg[1*], Florian Bansemer[2], Stephan Böttcher[1], Davar Feili[3], Hartmut Henkel[2], Marcel Hesse[2], Holger Kersten[1], Tony Krüger[1], Jens Laube[4], Alexey Lazurenko[5], Daniel Sailer[5], Björn Schuster[1], Lars Seimetz[1], Alexander Spethmann[1], Stefan Weis[5] and Robert F. Wimmer-Schweingruber[1]

https://doi.org/10.1140/epjti/s40485-021-00073-8

EPDP PS LP Characterization

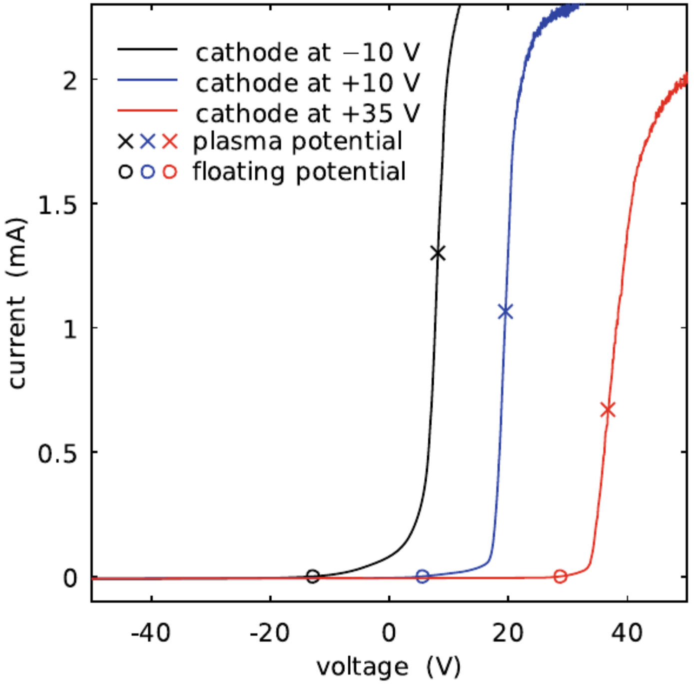


Fig. 8 LP measurements at different plasma potentials in the HIBEX test chamber with the gridded ion source. The plasma potential is manipulated by means of the cathode (hot filament) bias voltage. The indicated plasma potentials at +8.1 V, +19.5 V, and +36.7 V, and the floating potentials at −12.8 V, +5.6 V, and +28.7 V are found for cathode voltages of −10 V, +10 V, and +35 V, respectively

EPDP PS LP Characterization

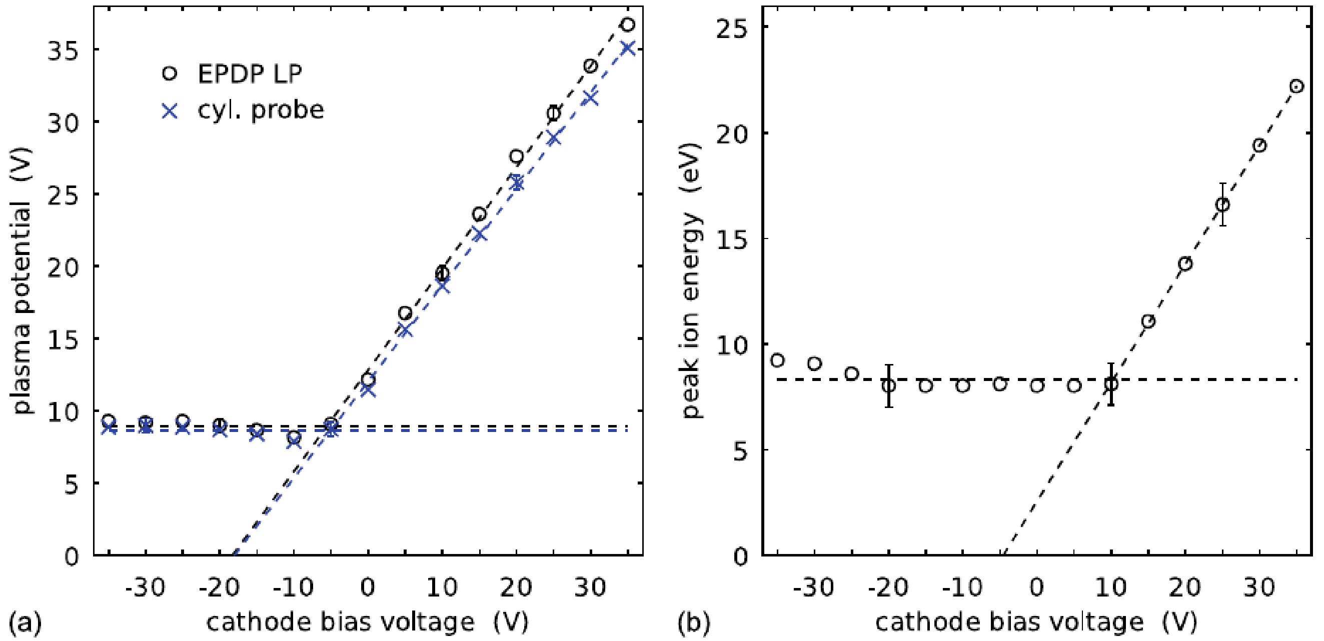


Fig. 9 Variation of the (a) plasma potentials and (b) ion energies for different potentials of the hot filament. The plasma sensor and the cylindrical Langmuir probe were at distances of 18 cm from the beam axis on opposite sides of the chamber. The 100 μm tungsten hot filament was heated by a current of 1.7 A, the potential drop along the filament was 13.6 V

EPDP PS RPA Characterization

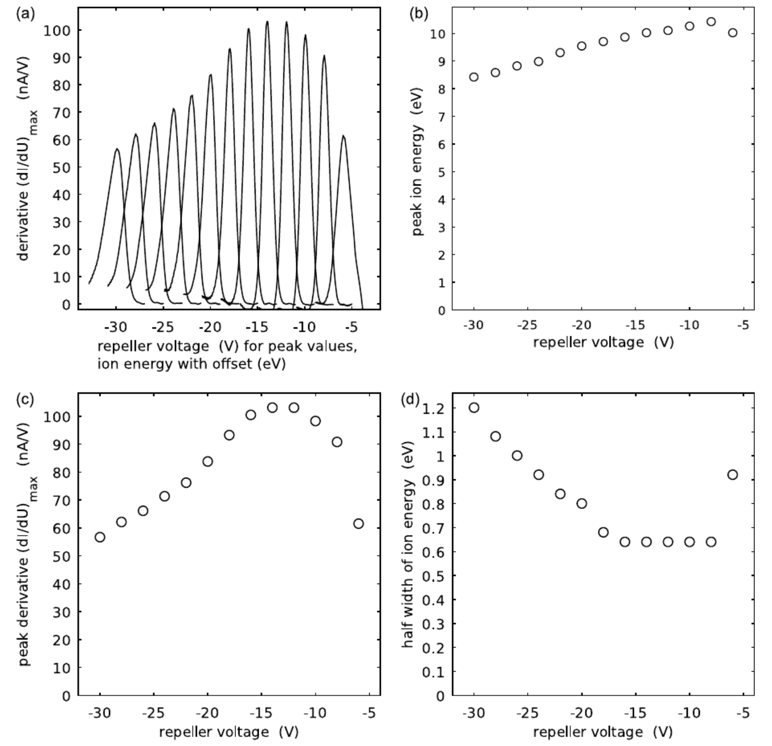


Fig. 10 Variation of the RPA repeller grid voltage from -30 V to -5 V in steps of 1 V. These measurements were performed in the HIBEX test chamber equipped with the gridded ion source. The a hot filament cathode had a potential of −35 V. (a) Synopsis of all IEDFs. The IEDFs are horizontally shifted so that their peak values indicate the respective repeller voltage on the abscissa. (b) The peak of the measured IEDFs slightly depends on the chosen repeller voltage. (c) The height of the peak values of the IEDF reaches highest values for repeller voltages (-14 ± 2) V. (d) The distribution functions appear sharpest for repeller voltages > 20 eV

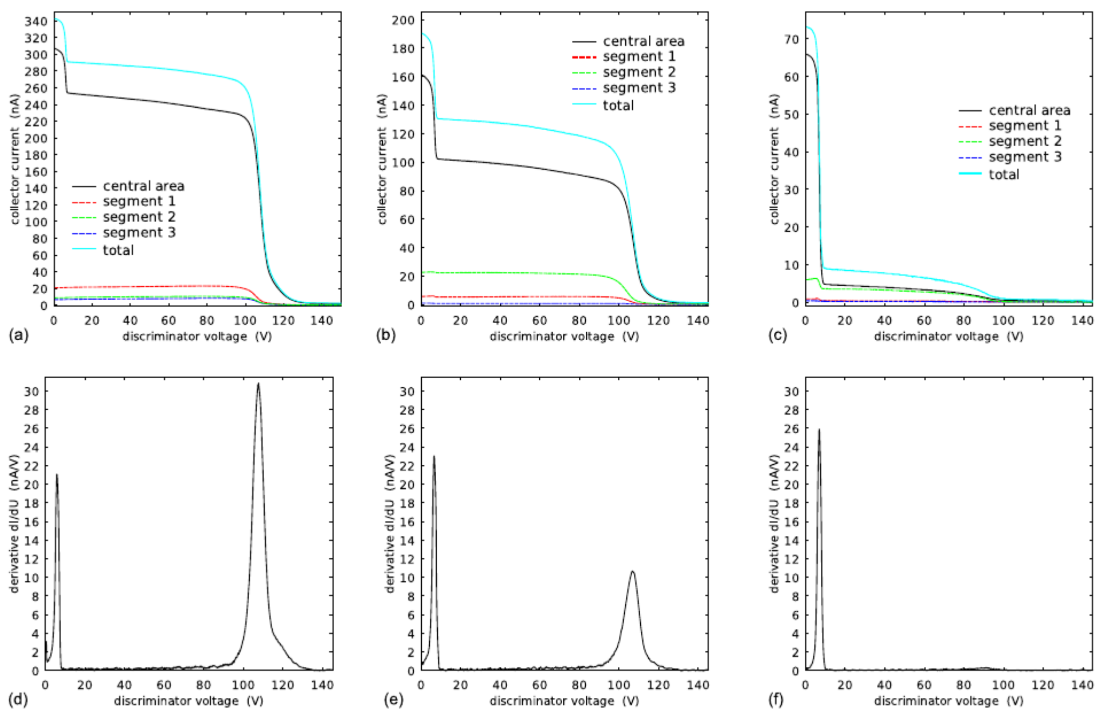


Fig. 11 Demonstration of an RPA measurement in case of an ion distribution function with two populations. The figure parts (a) to (c) show the measured collector currents at the three positions −0 mm, −40 mm, and −100 mm, where the minus indicates the upper half of the chamber in Fig. 5(a). The figure parts (d) to (f) show the corresponding derivatives, respectively. The three columns of plots represent the three positions, i.e. on the beam axis (left), at the beam edge (middle), and clearly outside the beam (right)

EPDP PS RPA Characterization

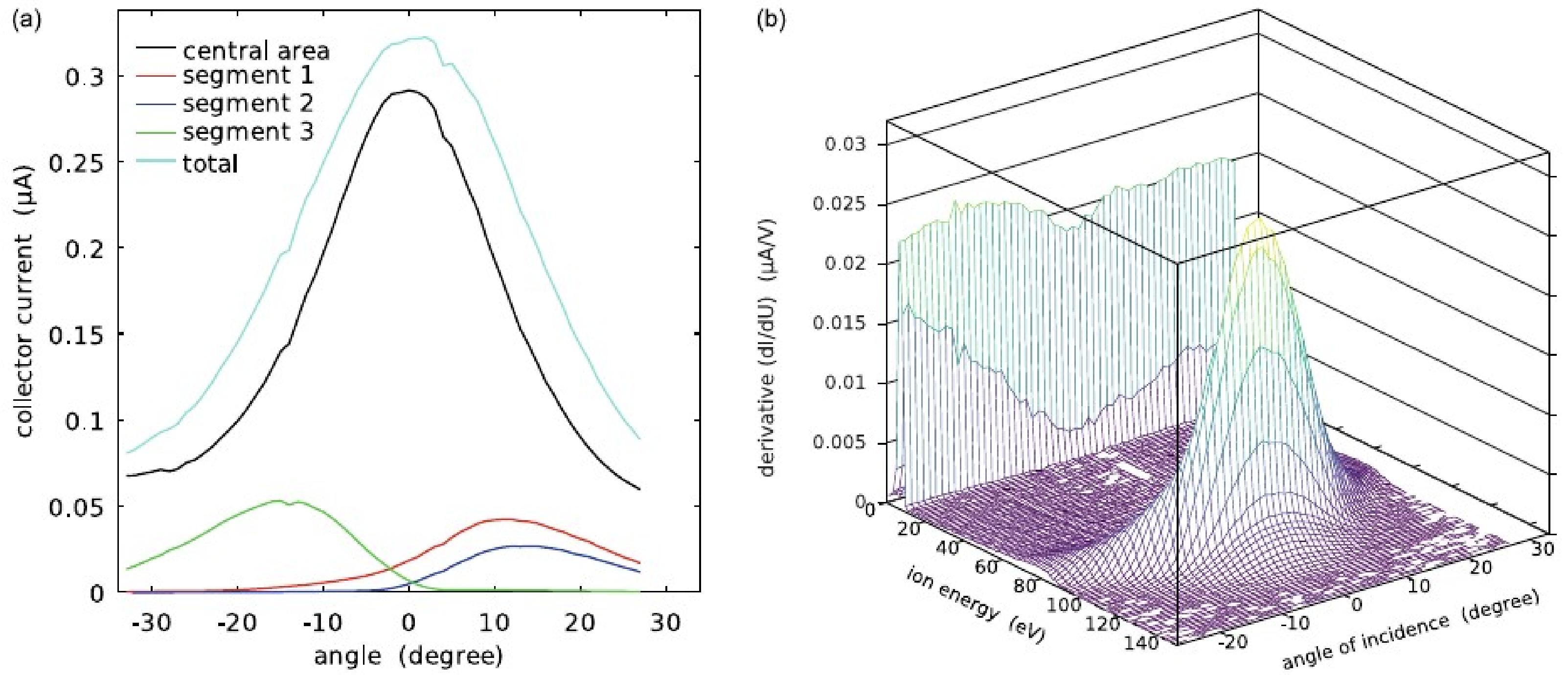


Fig. 12 Directivity of the RPA. (a) Collector currents onto the four segments versus angle of incidence, (b) IEDFs versus angle of incidence

EPDP PS Tests with HEMPT @ Thales Deutschland GmbH

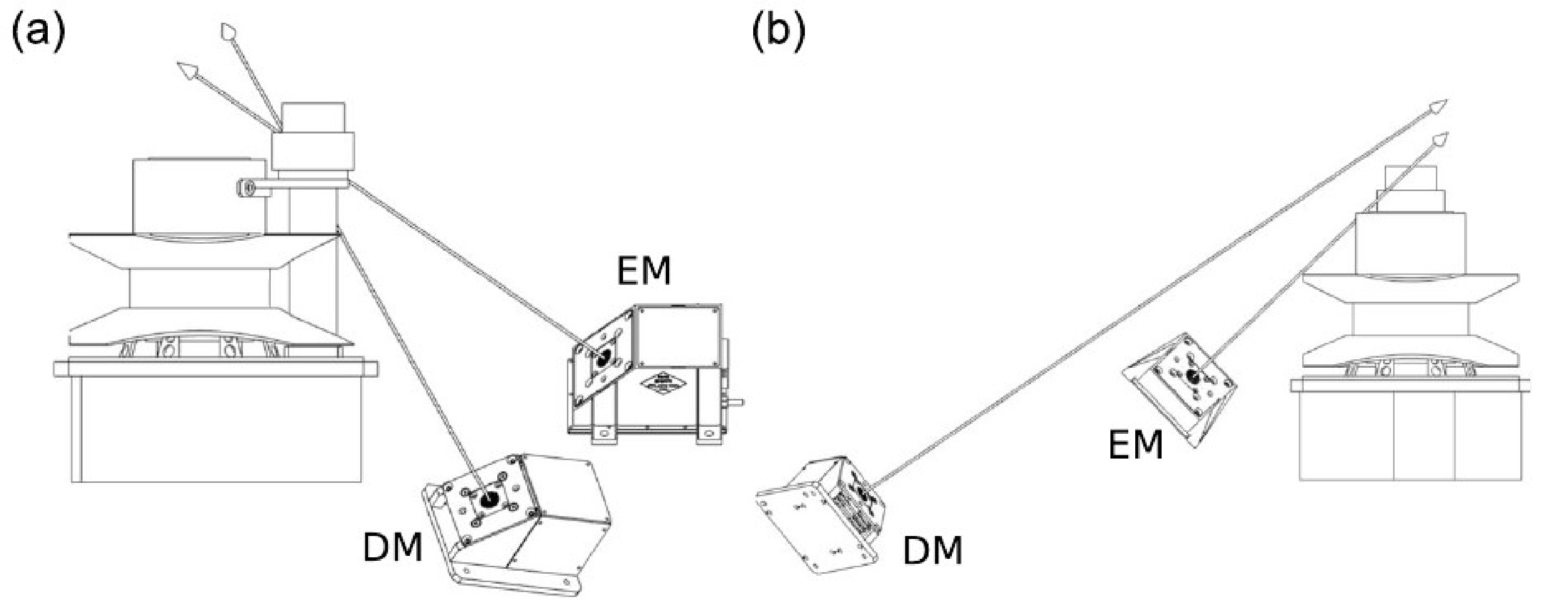
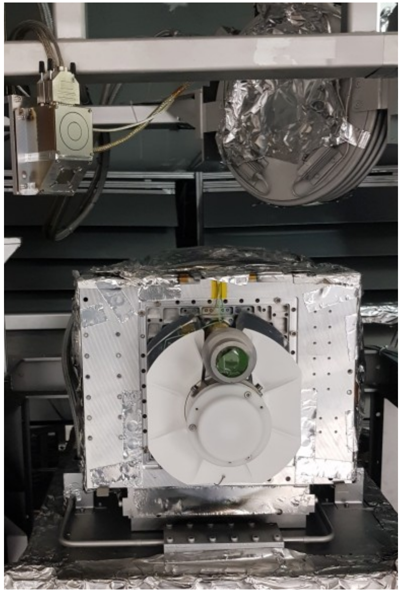


Fig. 14 Configuration for testing of the two versions of the plasma sensor in a chamber with the HEMPT at Thales Deutschland GmbH. The RPAs of both sensors roughly point to the thruster exit (the sensors are labeled "DM" and "EM" for demonstrator and engineering model, respectively). The smaller but longer assembly of the thruster is the neutralizer. The drawings (a) and (b) show the same arrangement from different perspectives



Christian-Albrechts-Universität zu Kiel

EPDP PS Tests with HEMPT @ Thales Deutschland GmbH

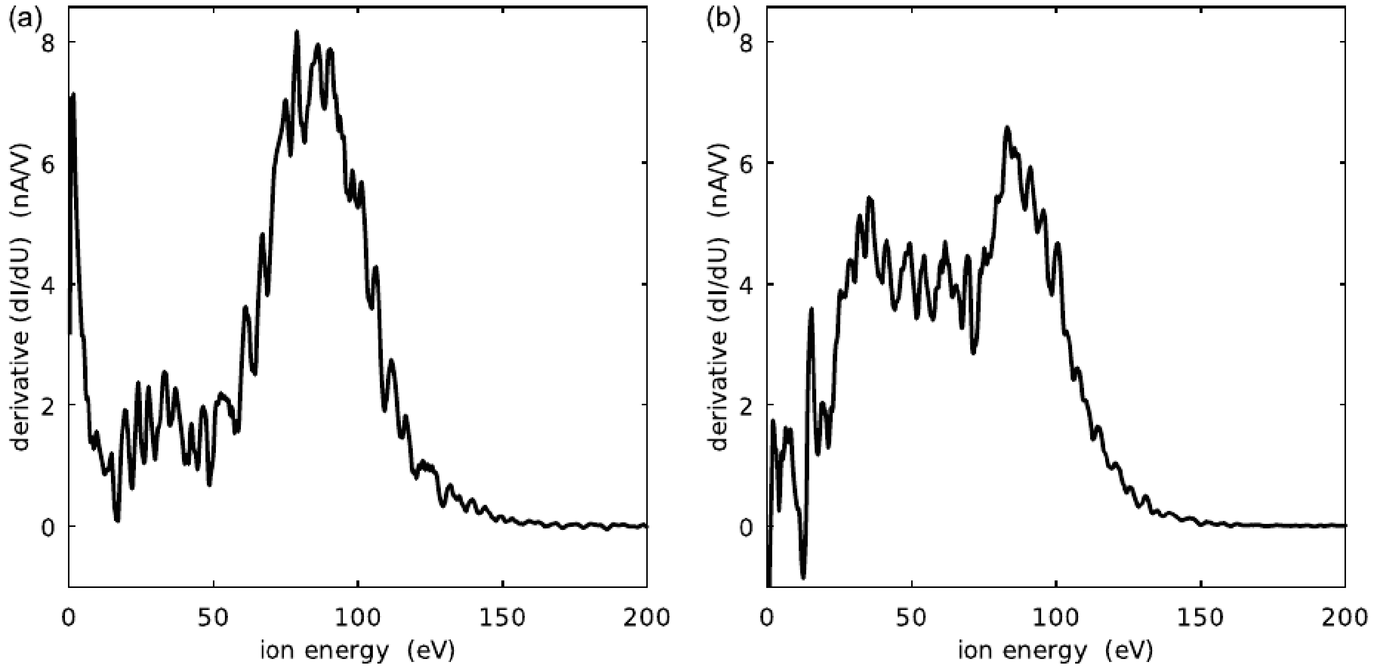


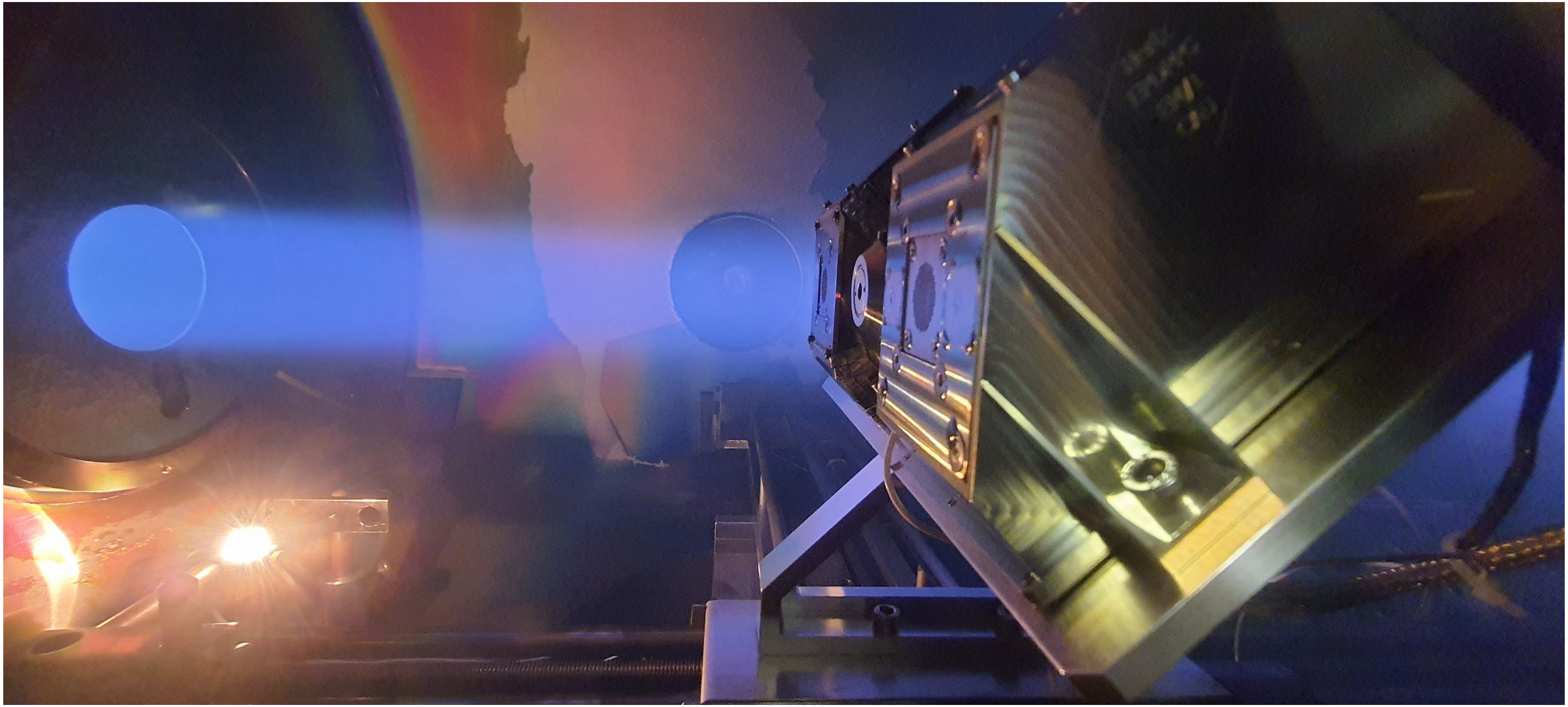
Fig. 15 RPA measurements with the two sensors in the secondary plasma of a HEMPT. The two plots show quasi-simultaneous measurements with (a) the engineering model and (b) the demonstrator model. The aquisition time was 9.4 s

Both RPAs measure the potential correctly, but the curves look quite different. Why do the two nearly concurrent measurements differ so much?

This is an open question.

It does not affect the determination of the plasma potential, but it is not understood.

EPDP PS @ CAU



Tests mit EPDP PS DM & EM

Folgende Tests wurden durchgeführt:

- Variation der Elektronen-Repeller-Spannung am HIBEX (AG Kersten)
- Variation der Elektronen-Repeller-Spannung am HEMPT (Thales)
- Variation der Scan-Laufzeit am HIBEX und am HEMPT
- Hysterese der Langmuir-Probe am HIBEX und am HEMPT
- Effekt des Guard-Rings am HIBEX und am HEMPT
- Einfluss der RPA-Scan-Zeiten am HIBEX und am HEMPT
- Überprüfen auf Hysterese-Effekte am HIBEX und am HEMPT
- Verschiebung des Plasmapotentials durch Bias an der Kathode (HIBEX und HEMPT)
- Ortsauflösung im Strahl von HIBEX
- Richtungsauflösung am HIBEX
- Vergleichsmessungen verschiedener Modelle mit verschiedenen Gitterkonfigurationen

Tests mit EPDP PS DM & EM

Zusammenfassung der Testresultate:

- Alle erforderlichen Messungen der Plasmaparameter können mit EPDP PS durchgeführt werden und entsprechen unseren Erwartungen
- Der Messbereich von EPDP PS ist gut eingestellt
- Keine Abhängigkeit der Messresultate von der Messdauer und -rate (1000 Datenpunkte in 60 s liefern dieselben Resultate wie 100 Datenpunkte in 0.2 s)
- Keine Hysterese beobachtet
- Keine zeitliche Abhängigkeit der Messungen
- Keine Abhängigkeit von der verwendeten Messelektronik (2 verschiedene Messsysteme)
- **EPDP PS erfüllt alle Anforderungen**
- **Aber es gibt noch diesen einen offenen Punkt (siehe Folien 47 - 52)**

EPDP Requirements & CDR (close-out: 2022-02-09)

OHB H2SAT HEINRICH HERTZ

EPDP Requirements Specification

85 RIDs issued during CDR and ultimately closed (at close-out).

vH&S C A U

Project	EPDP	Page	1
Doc. Title	Minutes of Meeting: 2022-02-08	Issue	1.1
Doc. No.	0290	Date	2022-02-09

Electric Propulsion Diagnostic Package
— EPDP —

Minutes of Meeting:
CDR Close-out

EPDP EM E-Box, ES and PS

EPDP vH&S-Team & EPDP CAU-Team

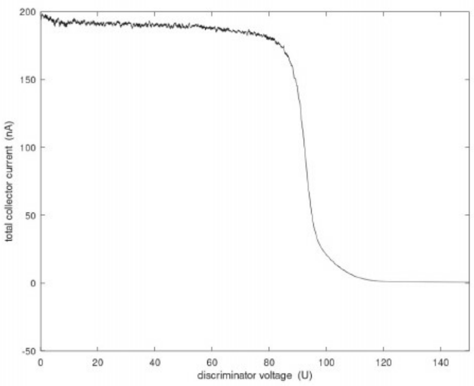
2022-02-09

Contract No.	4000134972/21/NL/RA/va
Doc. No.	0290
CI No. (OHB)	1-1-12-00-00-00
Issue	1.1
File	epdp-mom-vhs-0290_i1.1_cdr-close-out.pdf

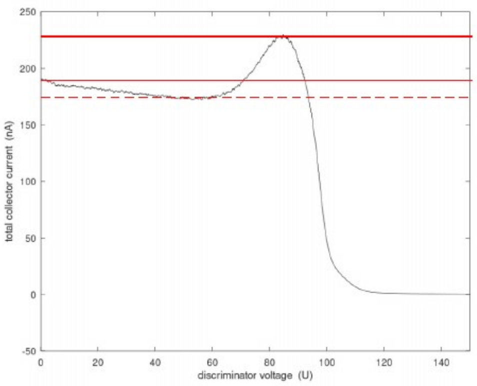
Name	Date	Signature
F. Bansemer	2022-02-09	F. Bansemer
D. Feili	2022- -	Davar
I. Richter	2022- -	Ines Richter
J. Laube	2022-02-10	

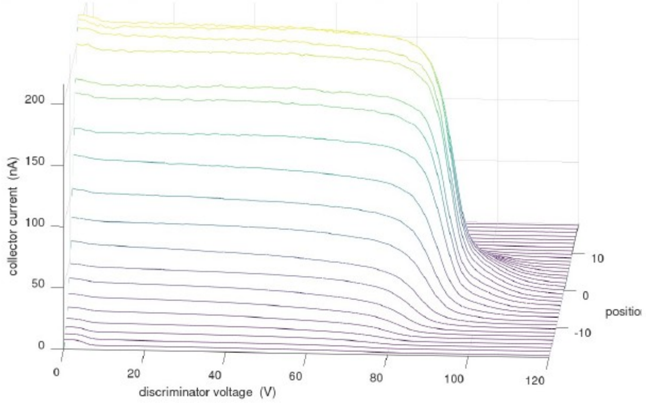
EPDP PS Open Issue:

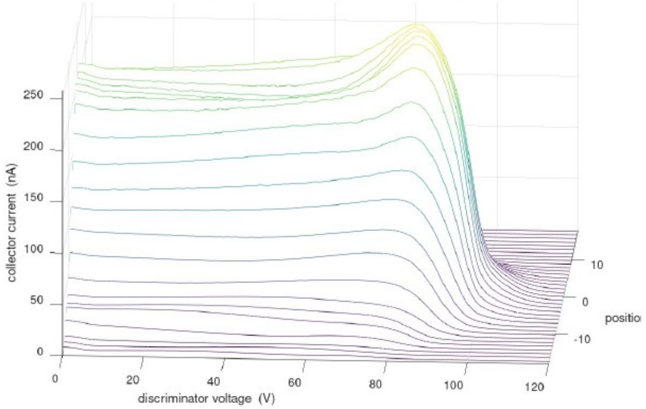
DM



EM



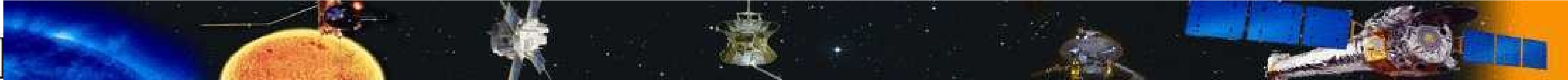




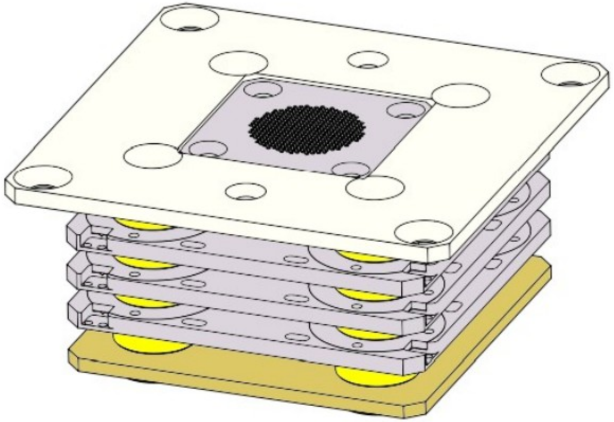
RPA DM and EM grids were manufactured in the same batch on the same machine.

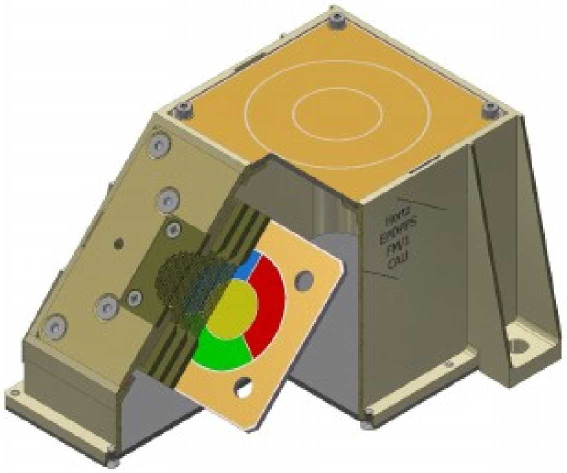
Why do DM and EM show such different behavior?

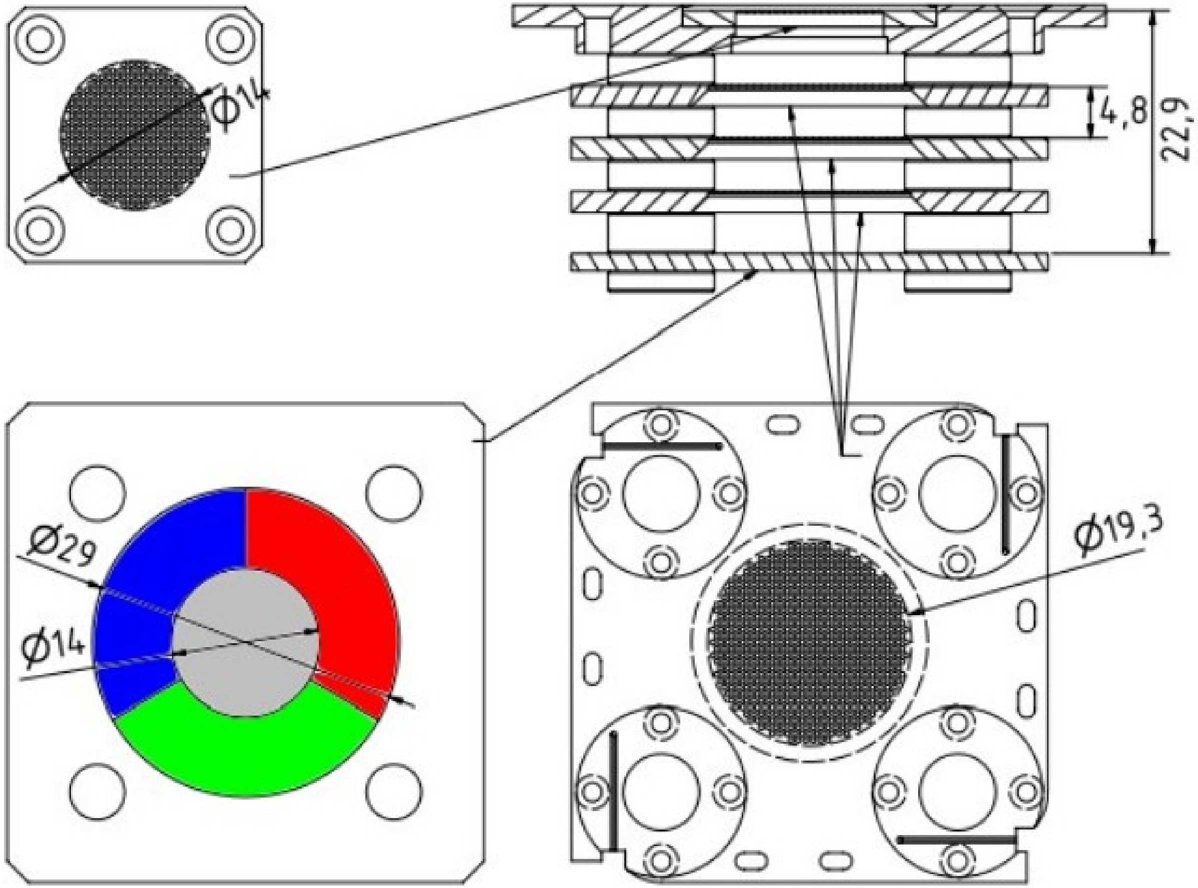
EM should not look like that!



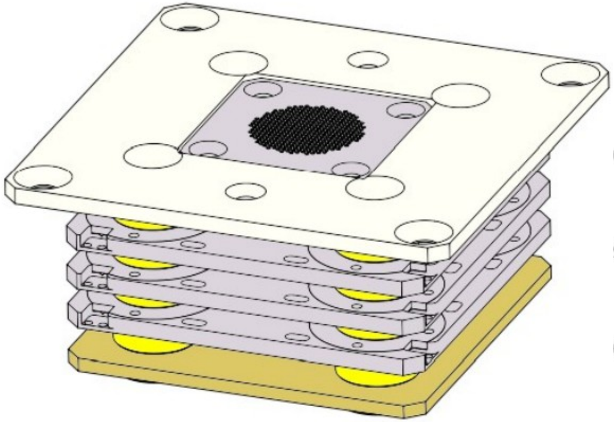
EPDP PS Open Issue: Suspicion – Different Grid Orientation?

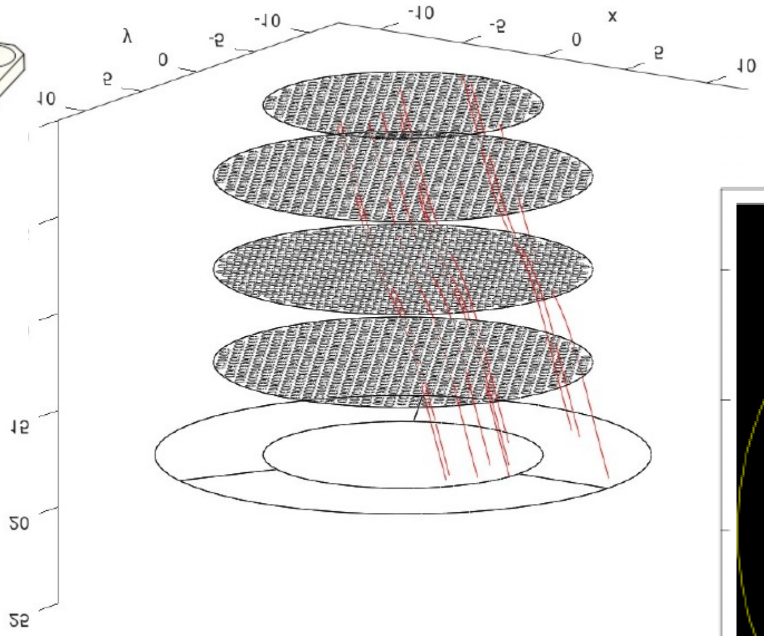


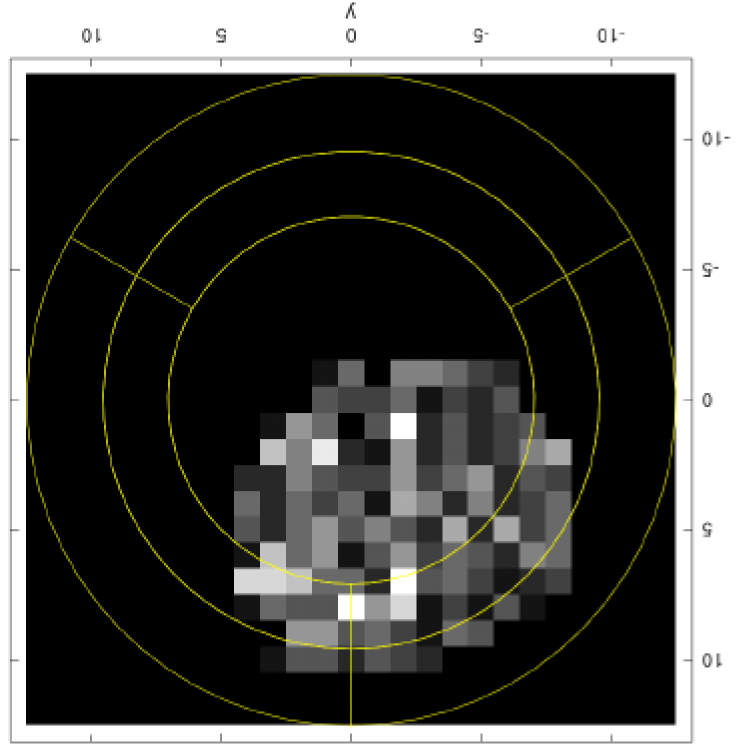




EPDP PS Open Issue: Suspicion – Different Grid Orientation?

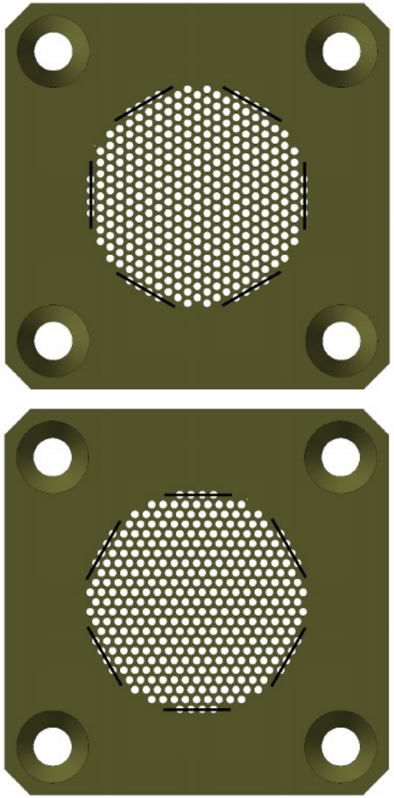






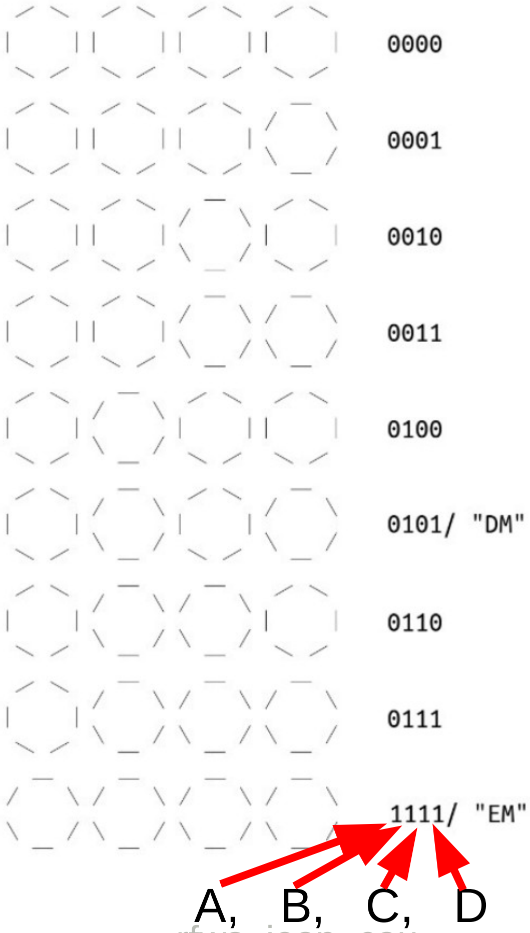
Grids have ~ 50% transmission
Is there „channeling“ between entrance and collector?

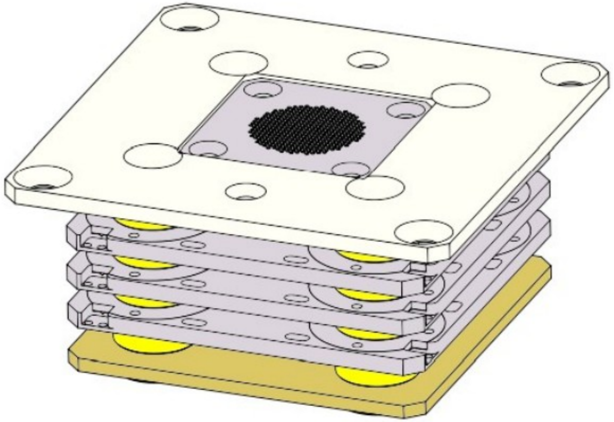
EPDP PS Open Issue: Test Different Grid Arrangements



“0”

“1”

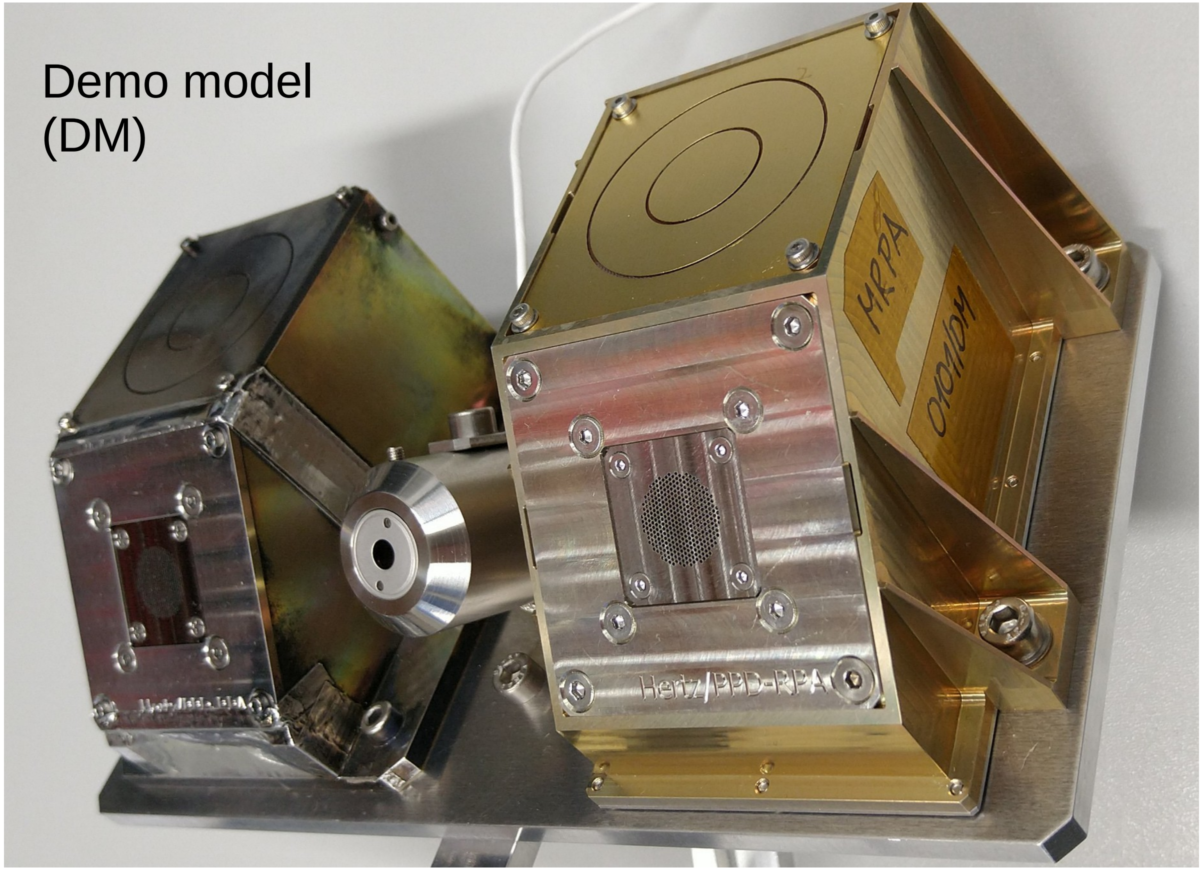




This was the DM arrangement

This was the EM arrangement

EPDP PS: Multiple Models to Compare and Characterize

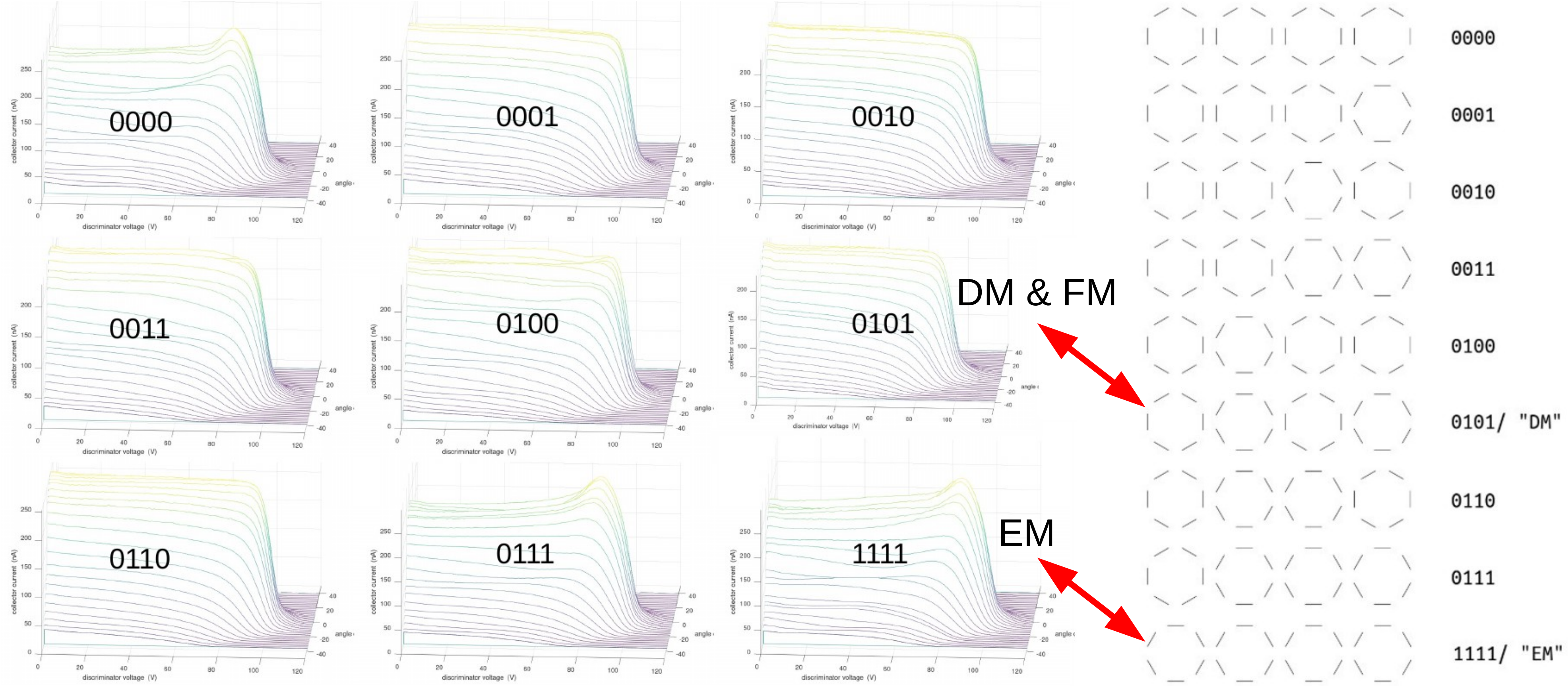


MRPA/DM

Use this spare/spare model to investigate different grid combinations systematically.

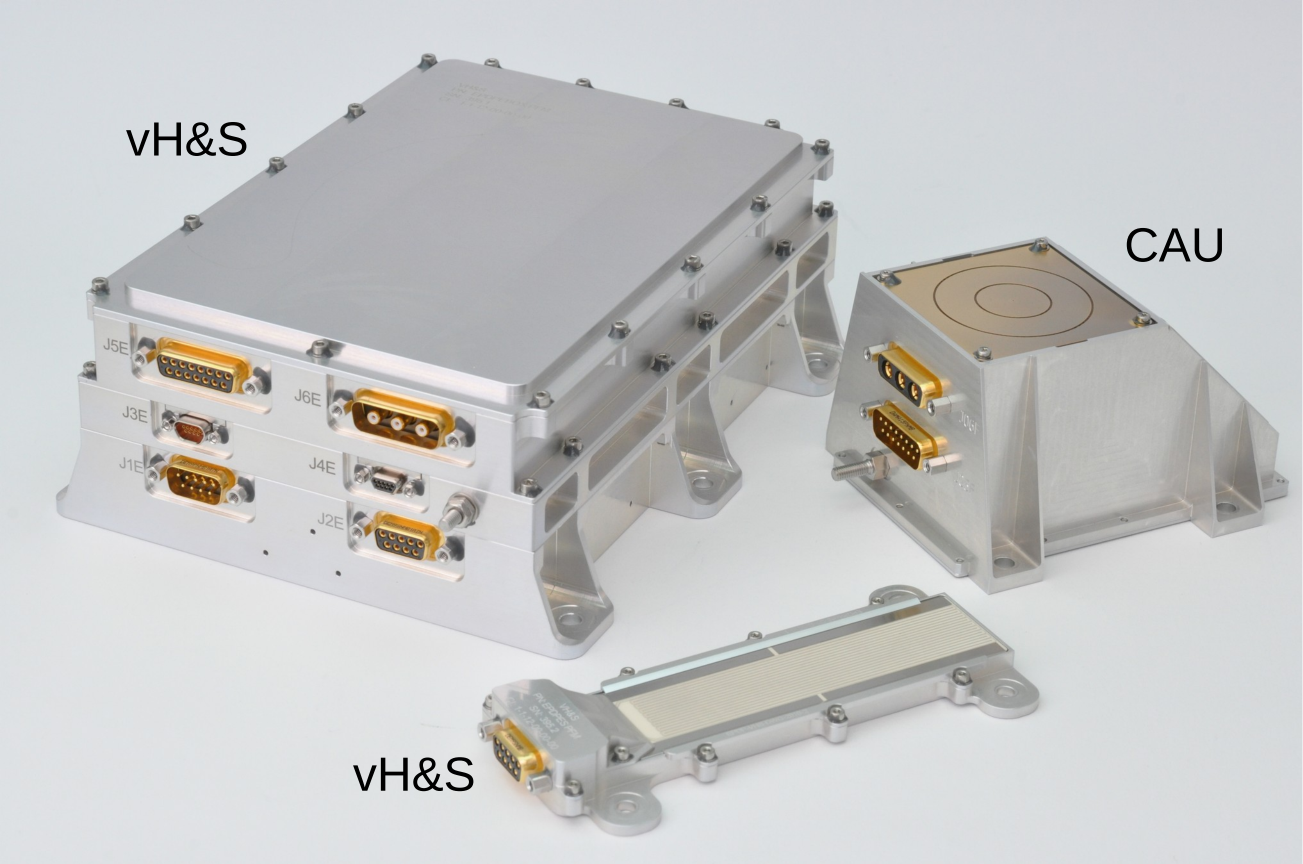
That‘s what the M stands for in MRPA!

EPDP PS Open Issue: Tests of Different Grid Arrangements

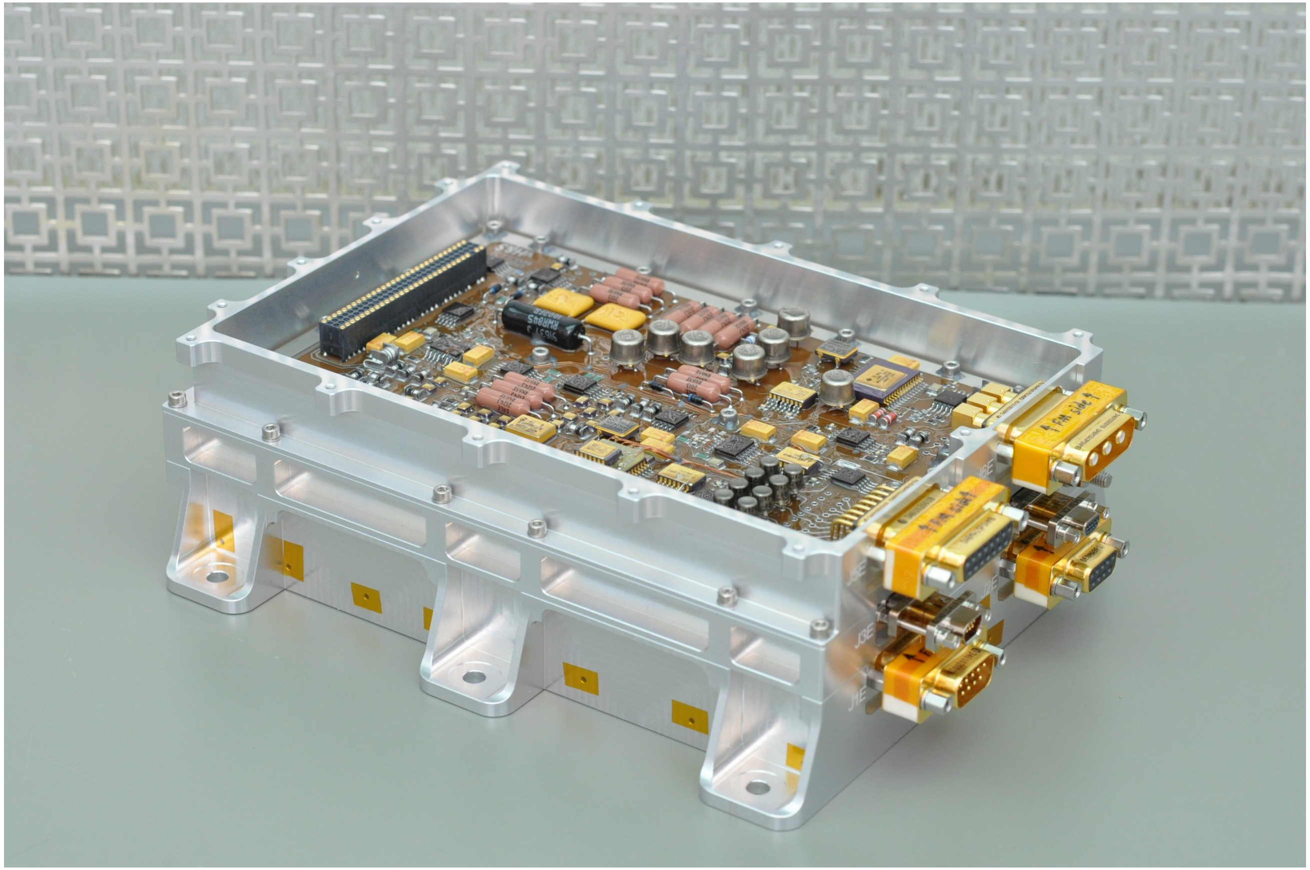


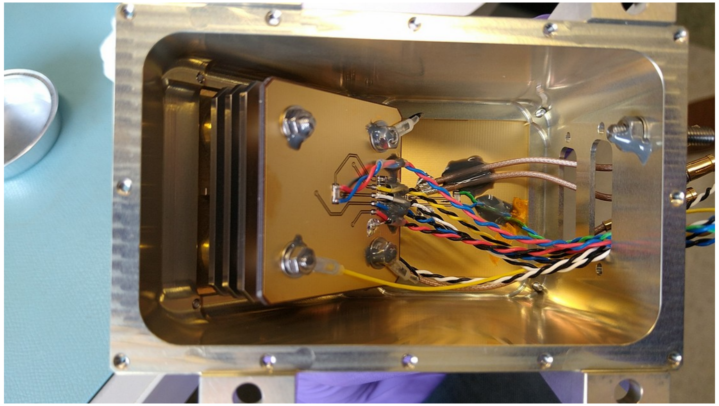
Topic for a future publication!

EPDP Flight Model (FM) Family Picture



EPDP FM „Open“ Family Picture



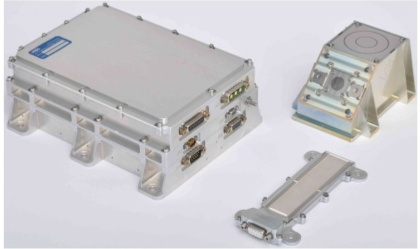


EPDP Plasma Performance Tests @ CAU

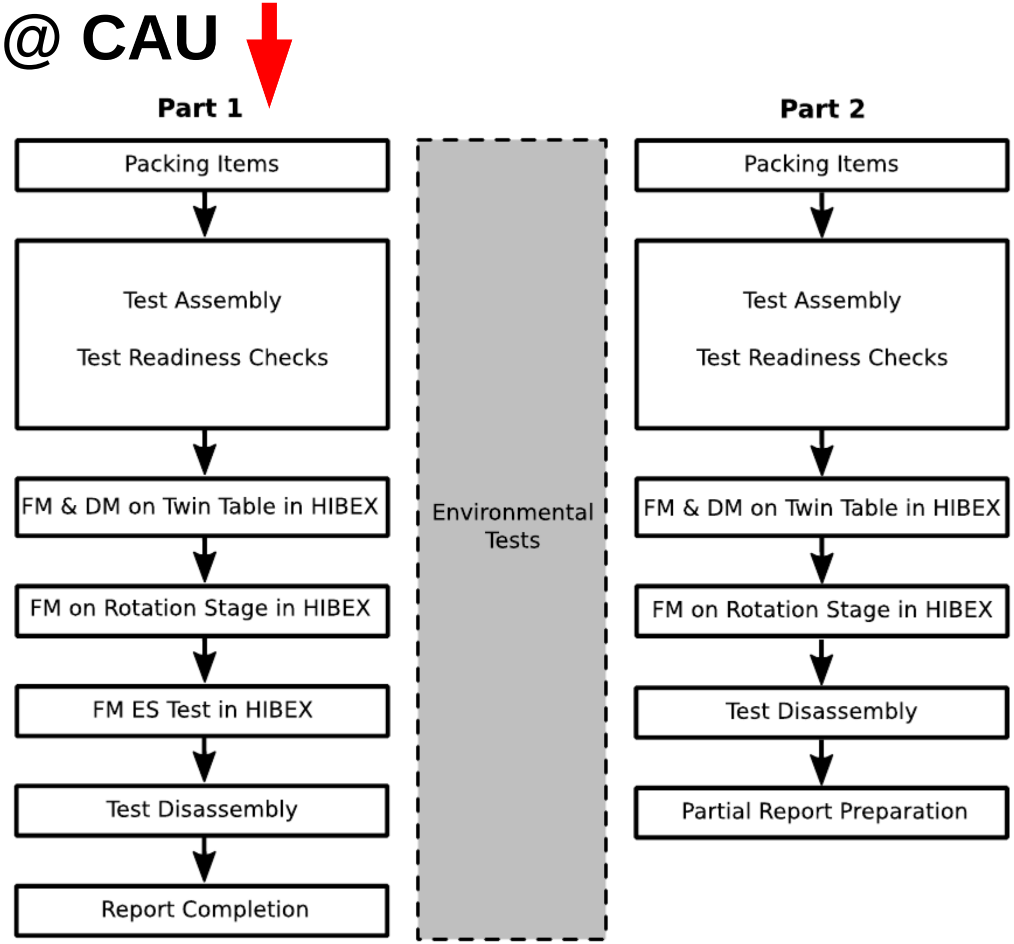
Project	EPDP	Page	1
Doc. Title	Plasma Performance Test Procedure	Issue	4.0.0
Doc. No.	EPDP-PRC-VHS-0315	Date	2022-09-12

Electric Propulsion Diagnostic Package — EPDP —

Plasma Performance Test Procedure



EPDP EM E-Box, ES and PS



EPDP Plasma Performance Tests

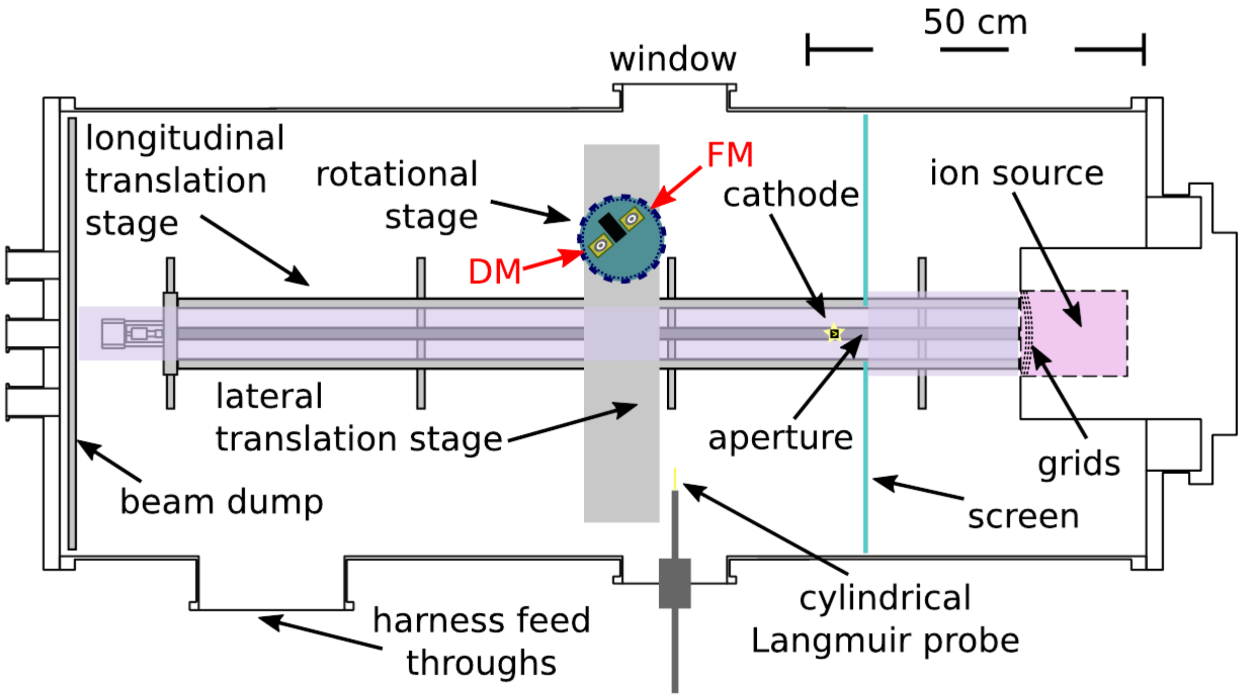
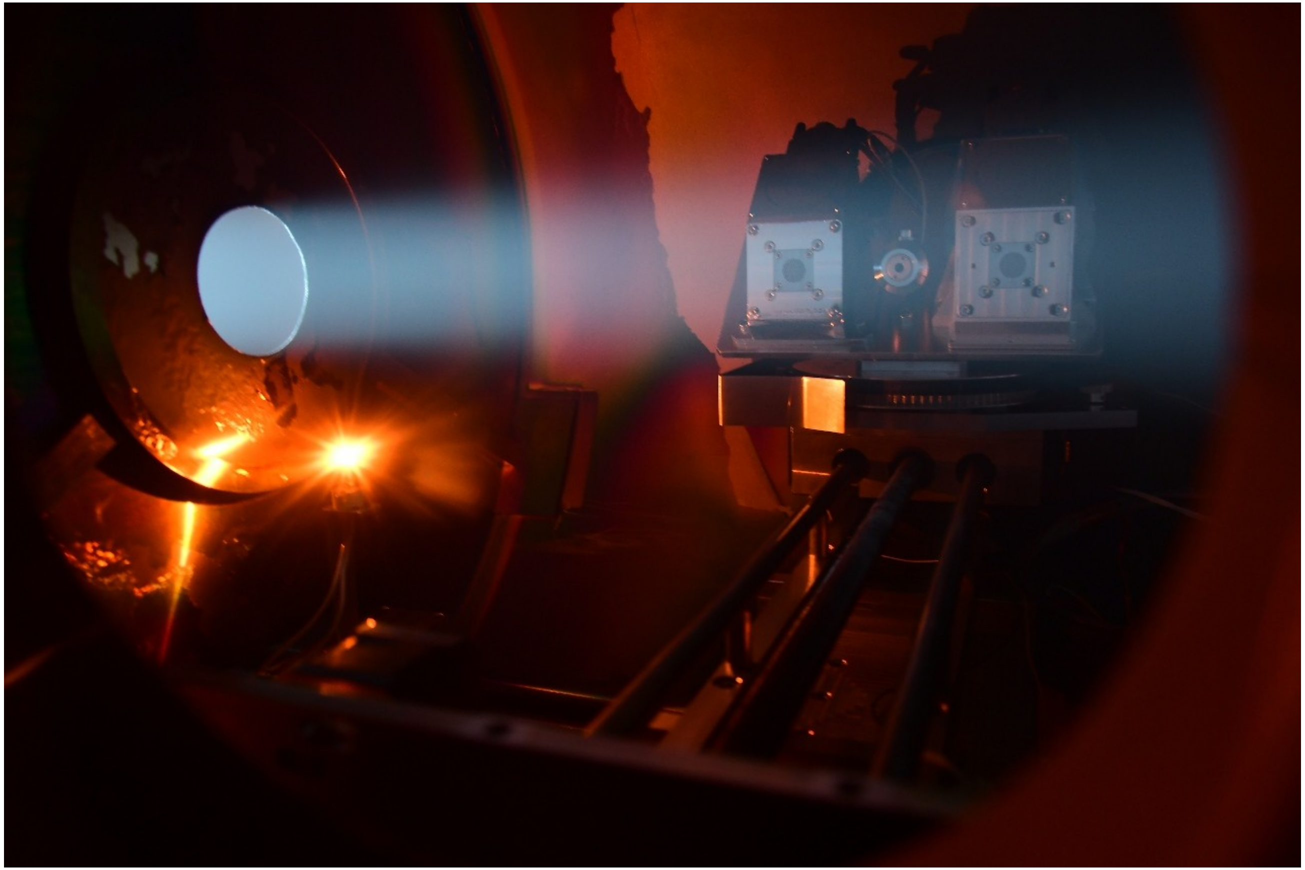


Figure 2: The PS test schematic in HIBEX. The rotational stage carries a Twin Table with the Flight Model (FM) and for comparison the Demonstrator Model (DM). In between, a lab Faraday cup is mounted. In a second setup, only the FM is mounted on the rotational stage, see Fig. 4(c) and Fig. 4(d).

Aims of the Tests:

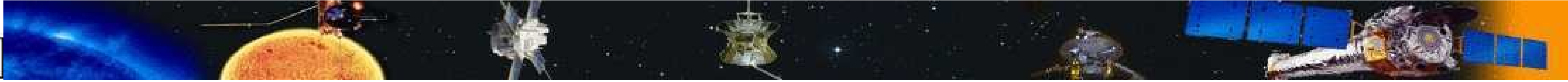
- Compliance with Requirements
- Comparison with the extensively tested Demonstrator Model
- Comparison of FM states before and after the environmental tests (shaker + thermal)

EPDP Plasma Performance Tests

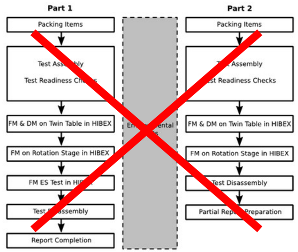


Aims of the Tests:

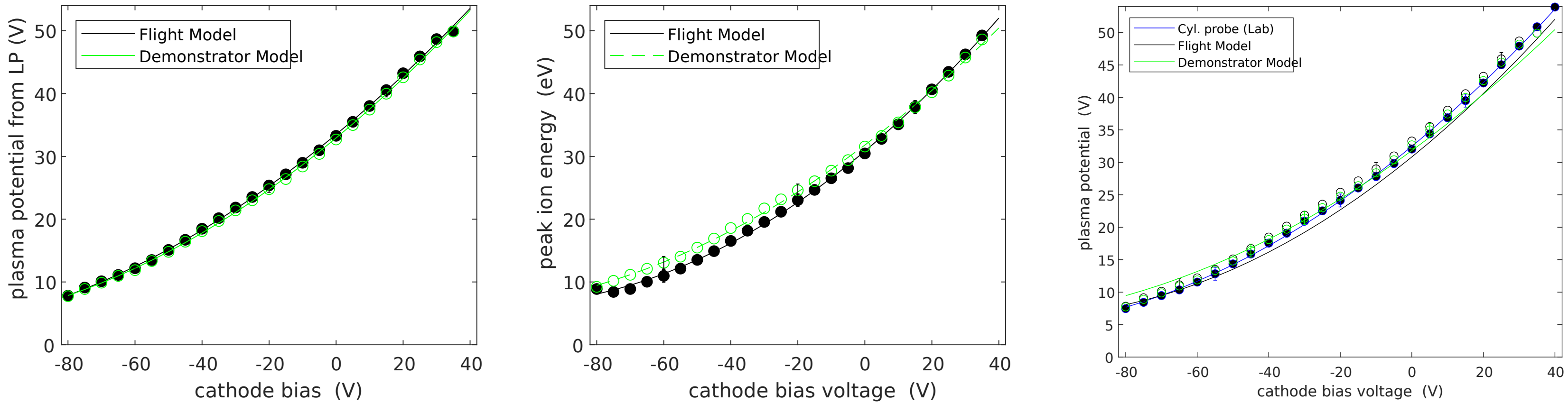
- Compliance with Requirements
- Comparison with the extensively tested Demonstrator Model
- Comparison of FM states before and after the environmental tests (shaker + thermal)



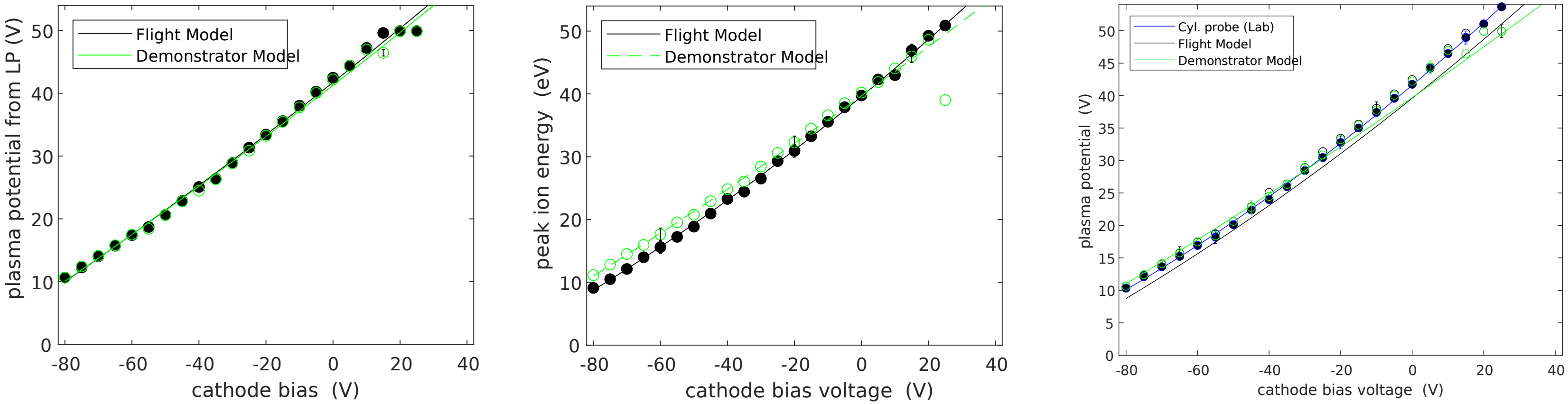
EPDP Plasma Performance Tests: Results



LP | RPA | LPs + LabLP

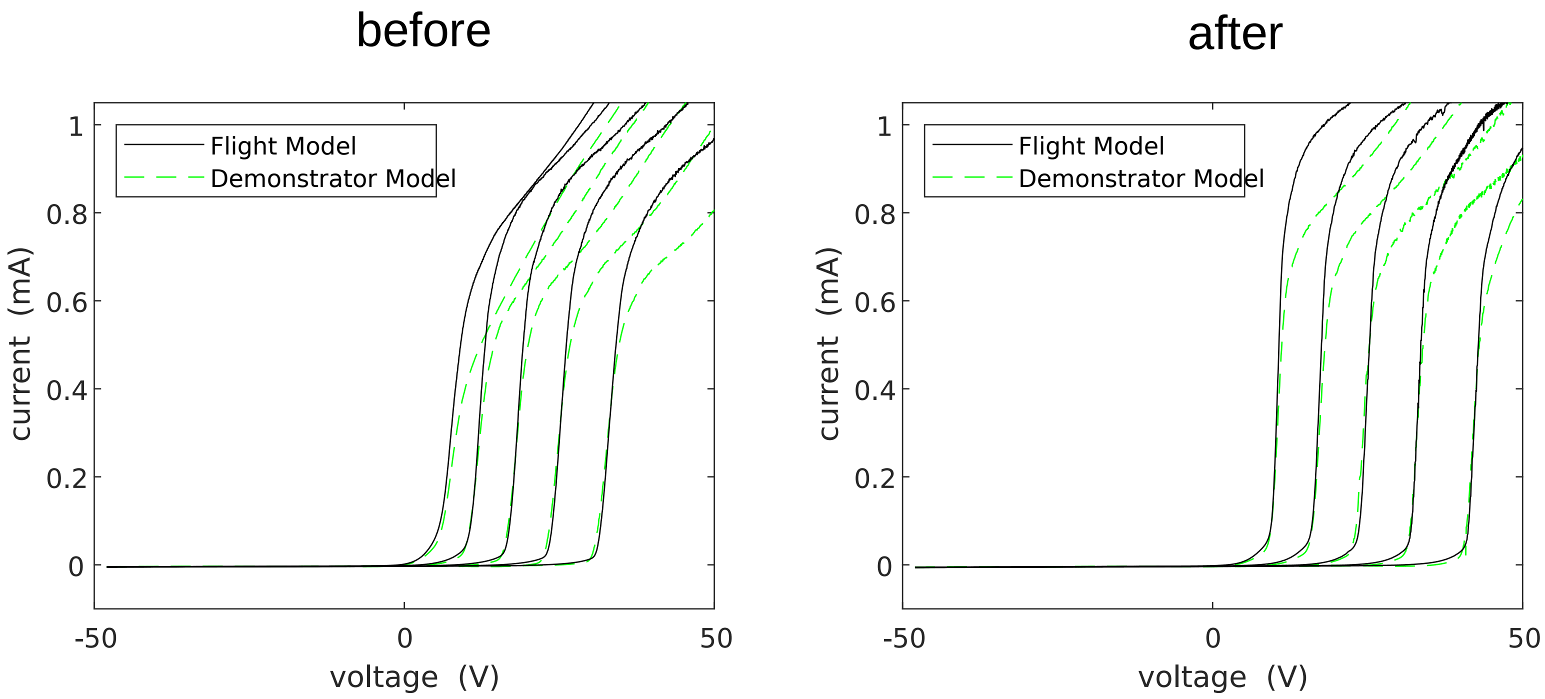


Before shake & bake



After shake & bake

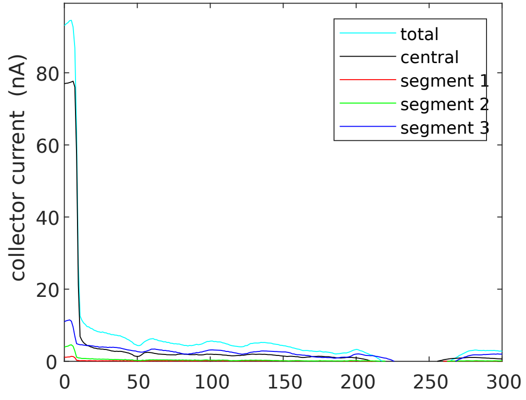
EPDP Plasma Performance Tests: Results

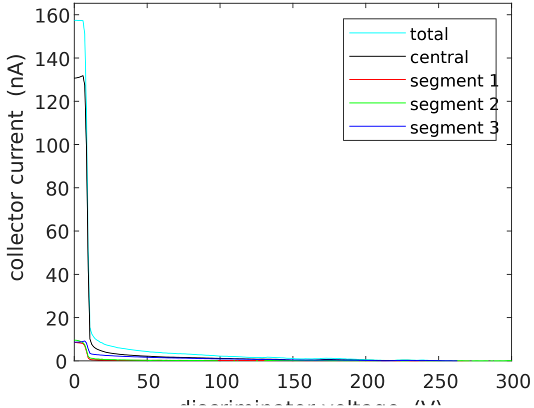


EPDP Plasma Performance Tests: Results

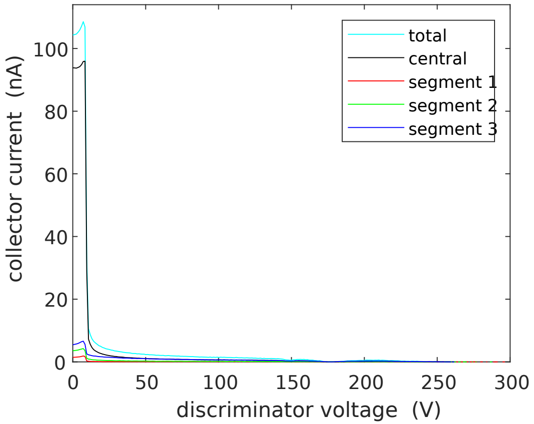
Flight Model

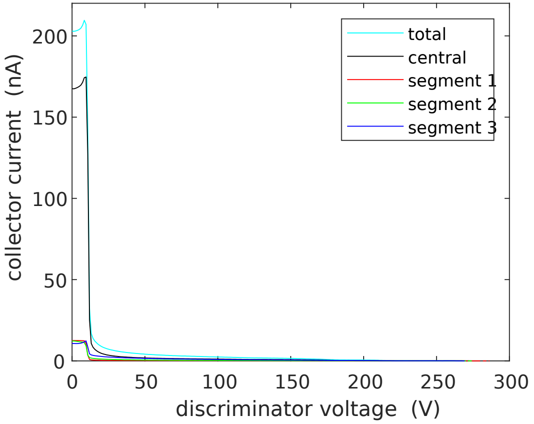
Demonstrator





Before shake & bake





After shake & bake

Remarks:

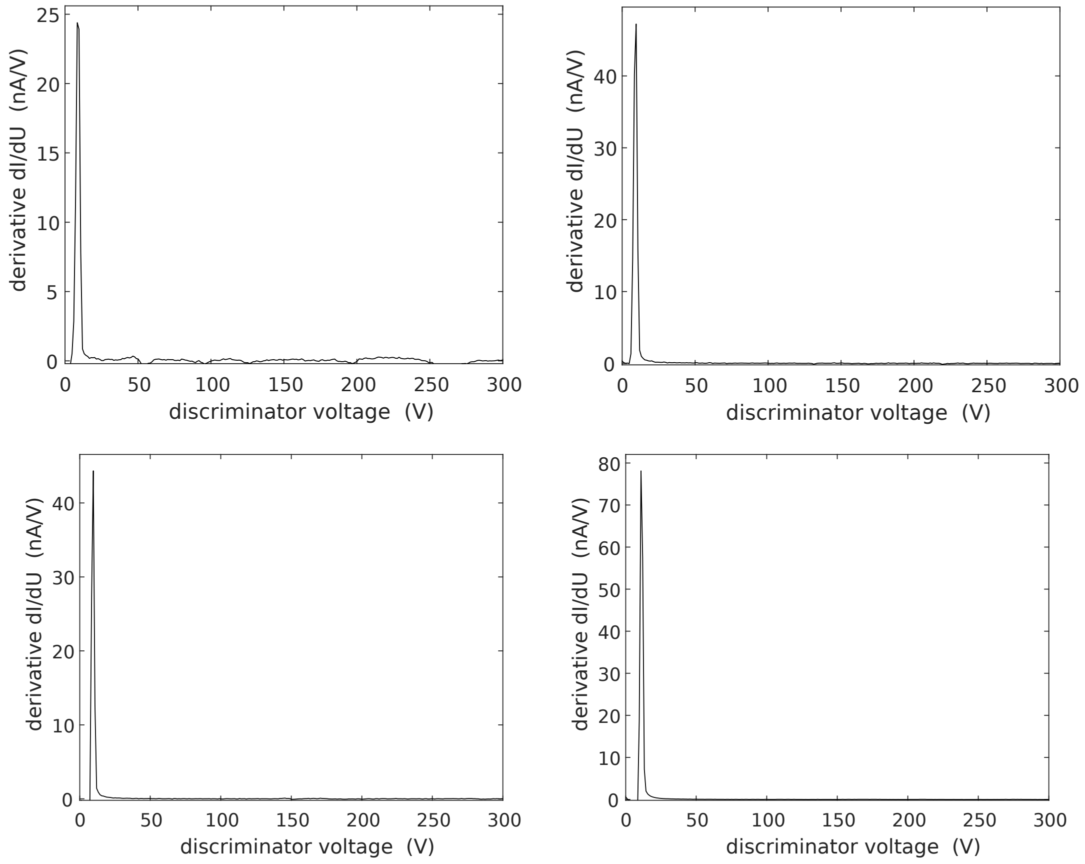
Ripples might be due to
- position in chamber
- contamination from manufacturing

Difference in amplitudes!

DM measures 1.5 to 2.0 times higher currents. Why?

EPDP Plasma Performance Tests: Results

Flight Model | Demonstrator



Before shake & bake

After shake & bake

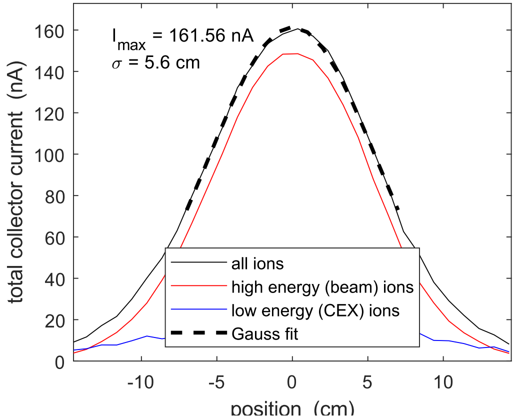
Remarks:

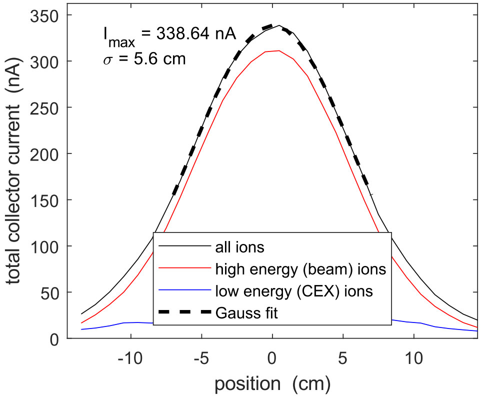
Ripples might be due to
- position in chamber
- contamination from manufacturing

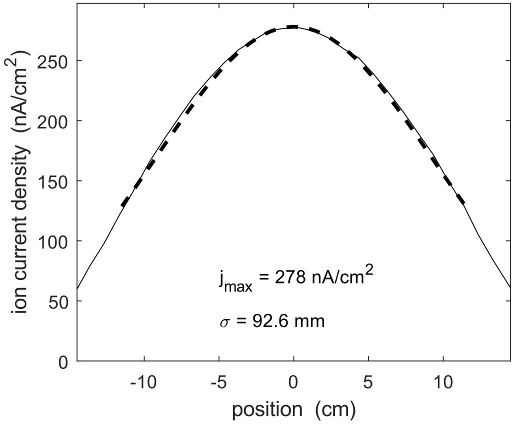
EPDP Plasma Performance Tests: Results

Flight Model | Demonstrator | Faraday Cup

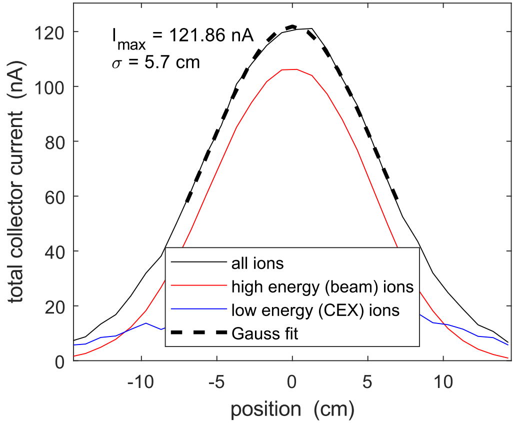
Before shake & bake

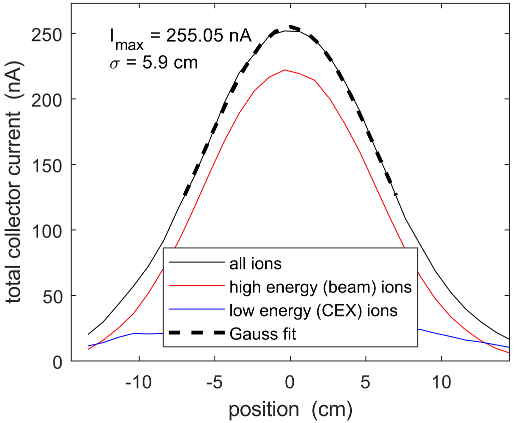


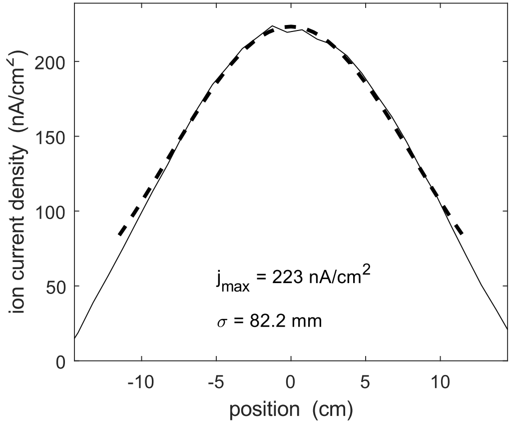




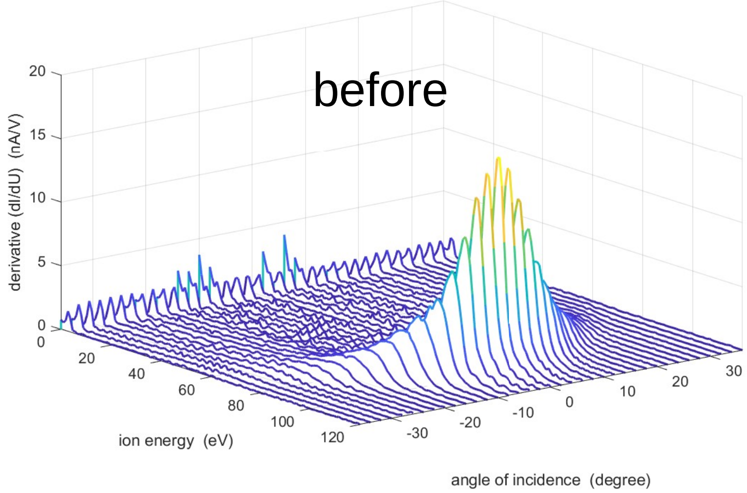
After shake & bake

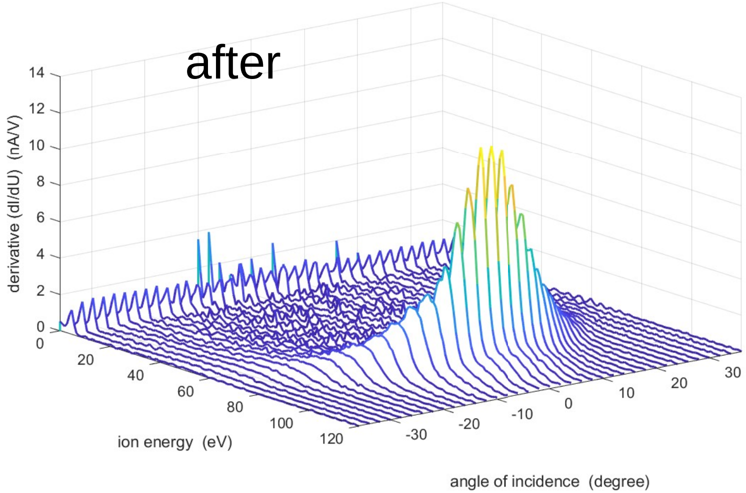


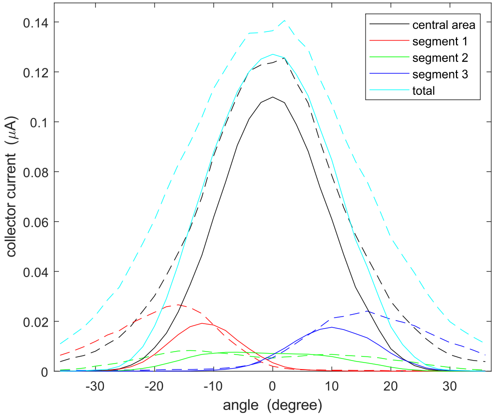


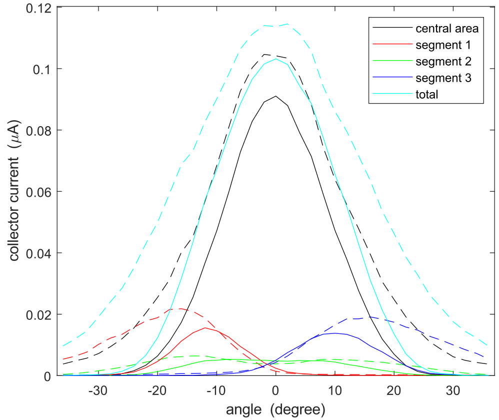


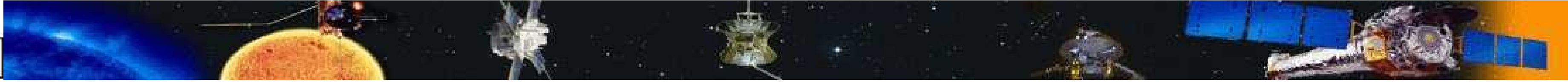
EPDP Plasma Performance Tests: Results





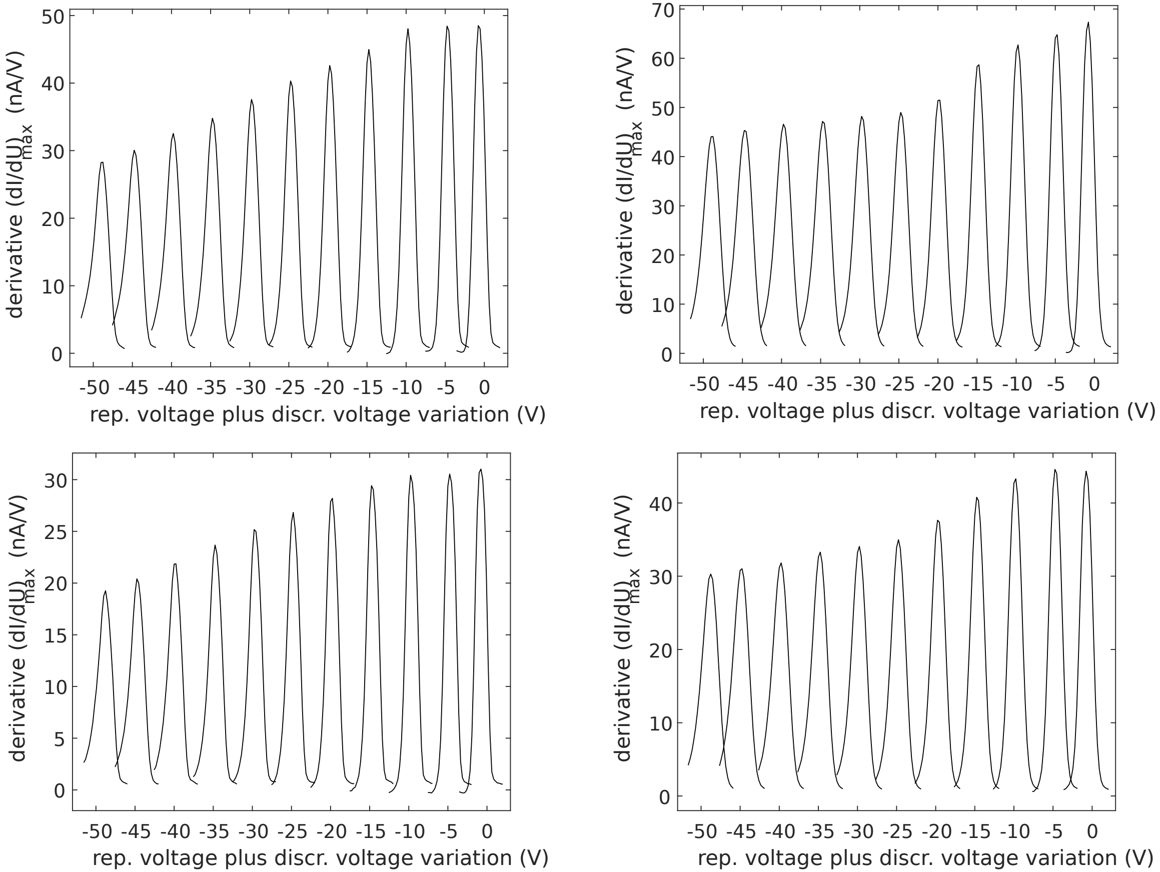






EPDP Plasma Performance Tests: Results

FM DM



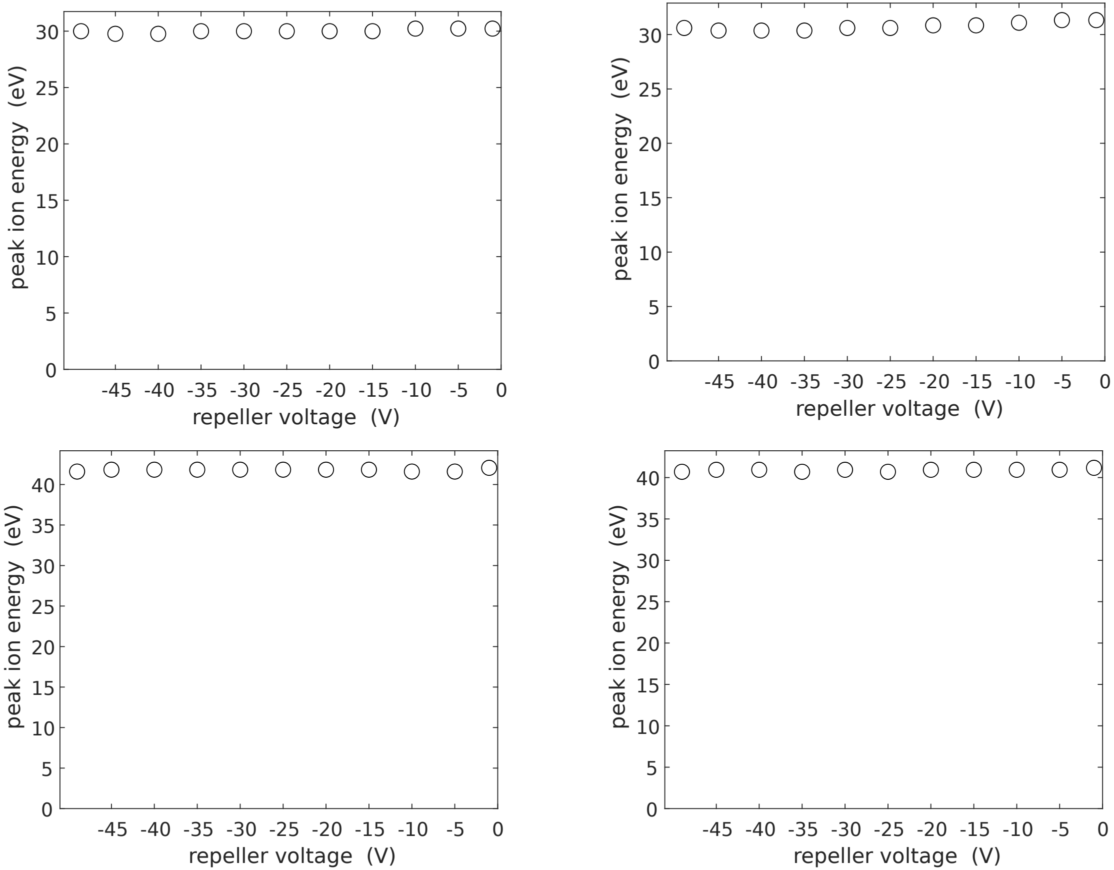
Before shake & bake

After shake & bake

Effect of repeller voltage variations

EPDP Plasma Performance Tests: Results

FM DM

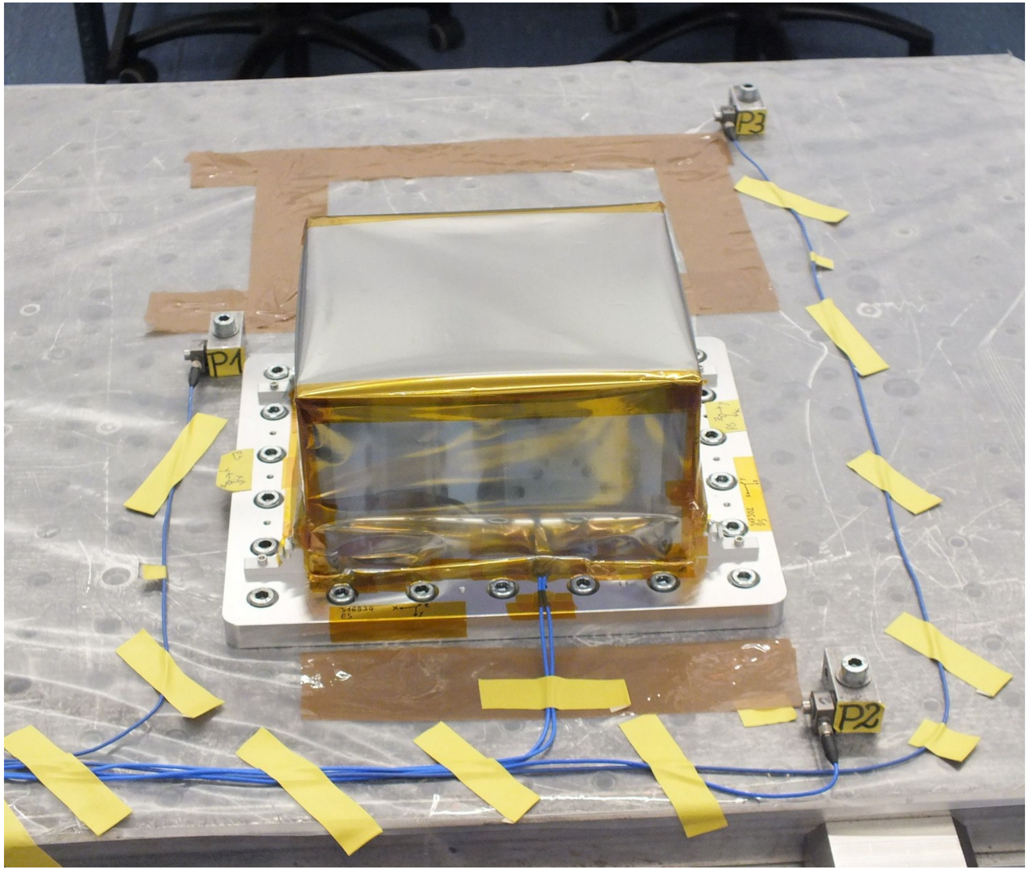


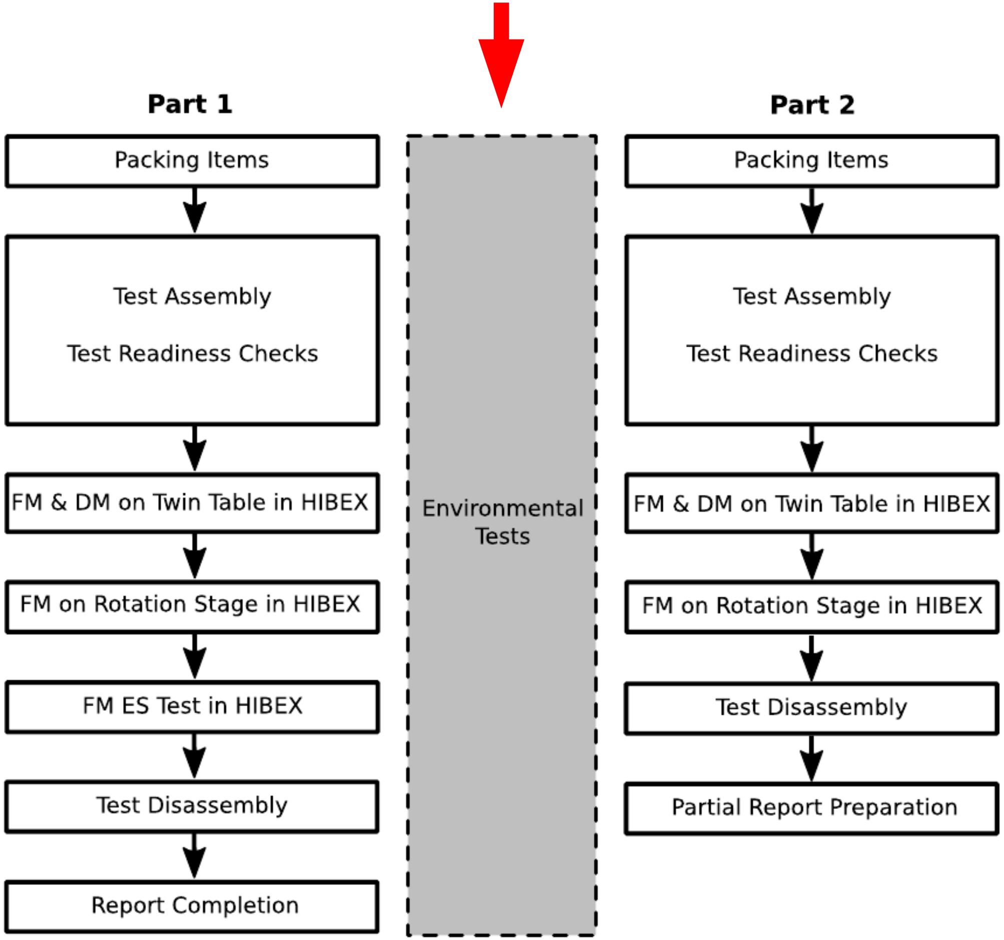
Before shake & bake

After shake & bake

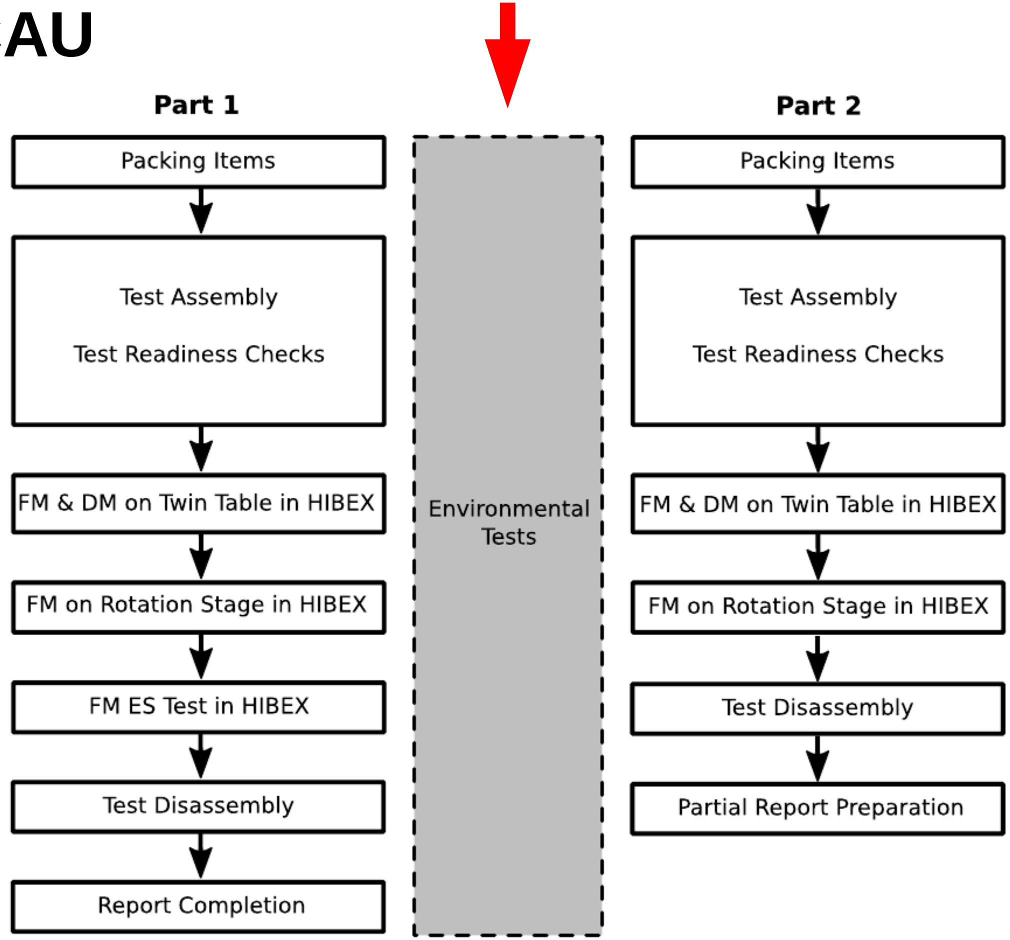
Repeller voltage variations have only marginal impact on the measured Ion energy

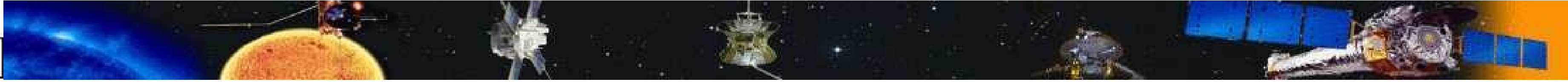
EPDP Vibration Tests





EPDP Thermal Vacuum Tests @ CAU

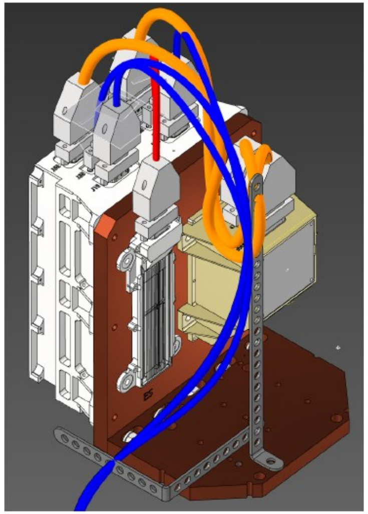




EPDP Thermal Vacuum Tests

Project: Hertz/ EPDP
Doc. Title: Thermal Cycling Test Plan
Doc. ID: cau-her-pla-0016_i1-0
page: 1/17
issue: 1.0
date: 2022-06-29

Thermal Cycling Test Plan
for the Hertz/ EPDP FM/1 Instrument



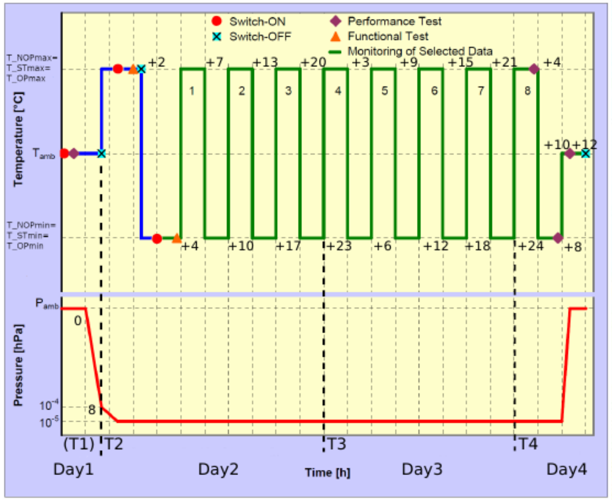
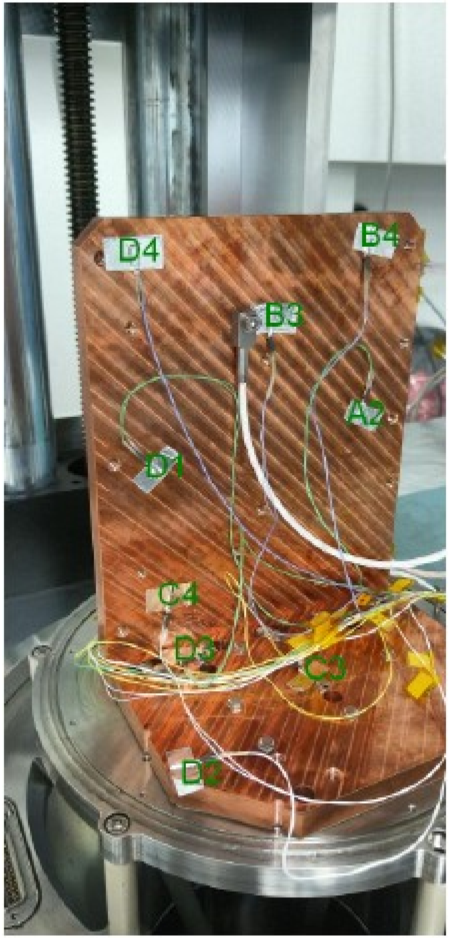
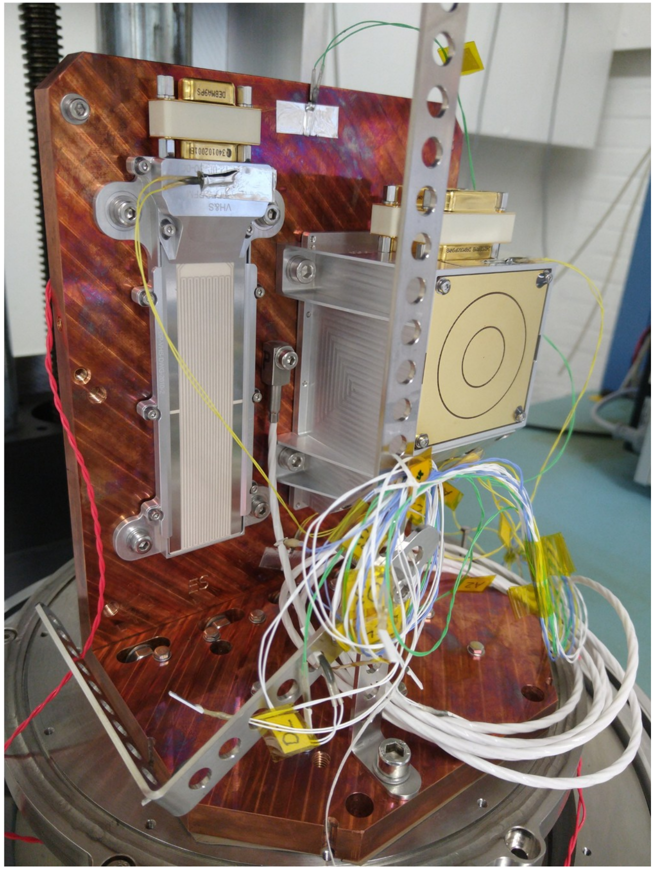
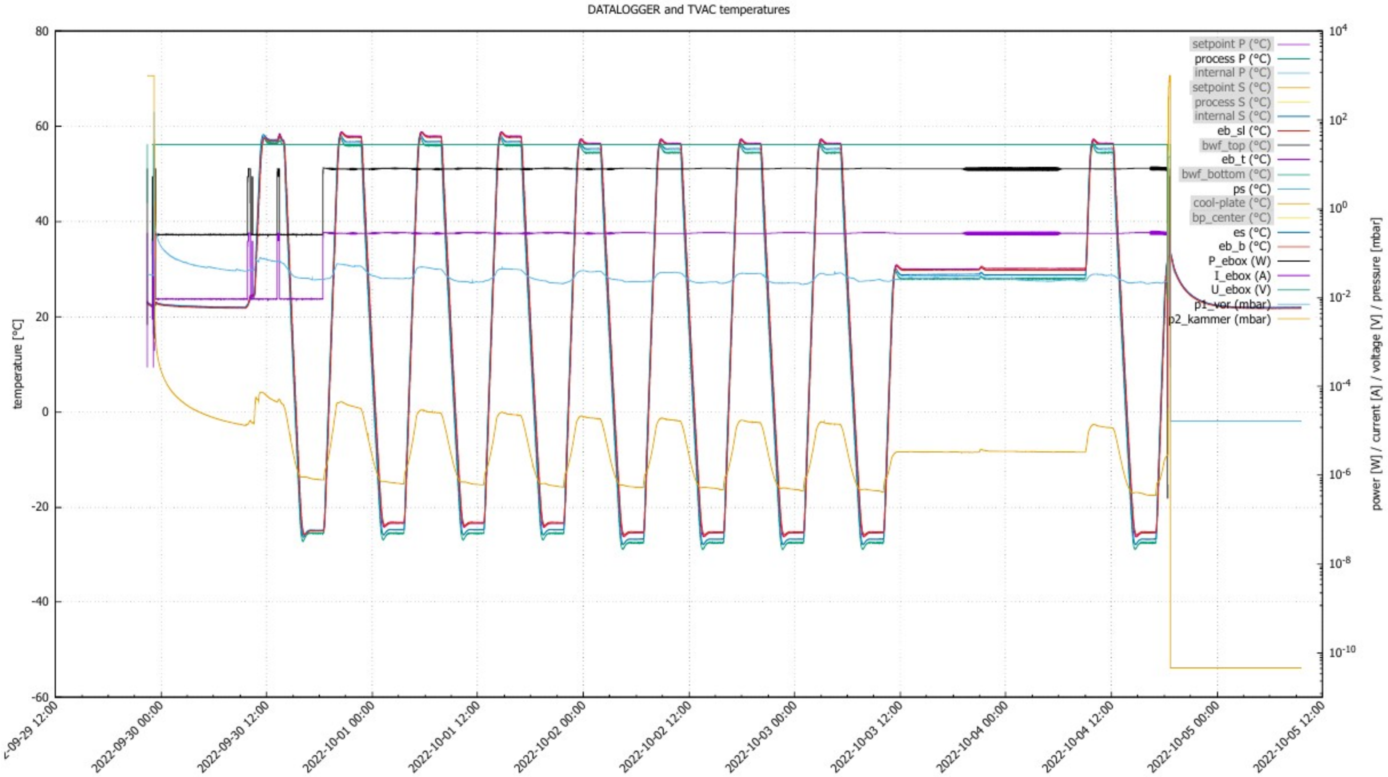


Figure 1: CAD-View of EPDP installed on the IUT bracket.

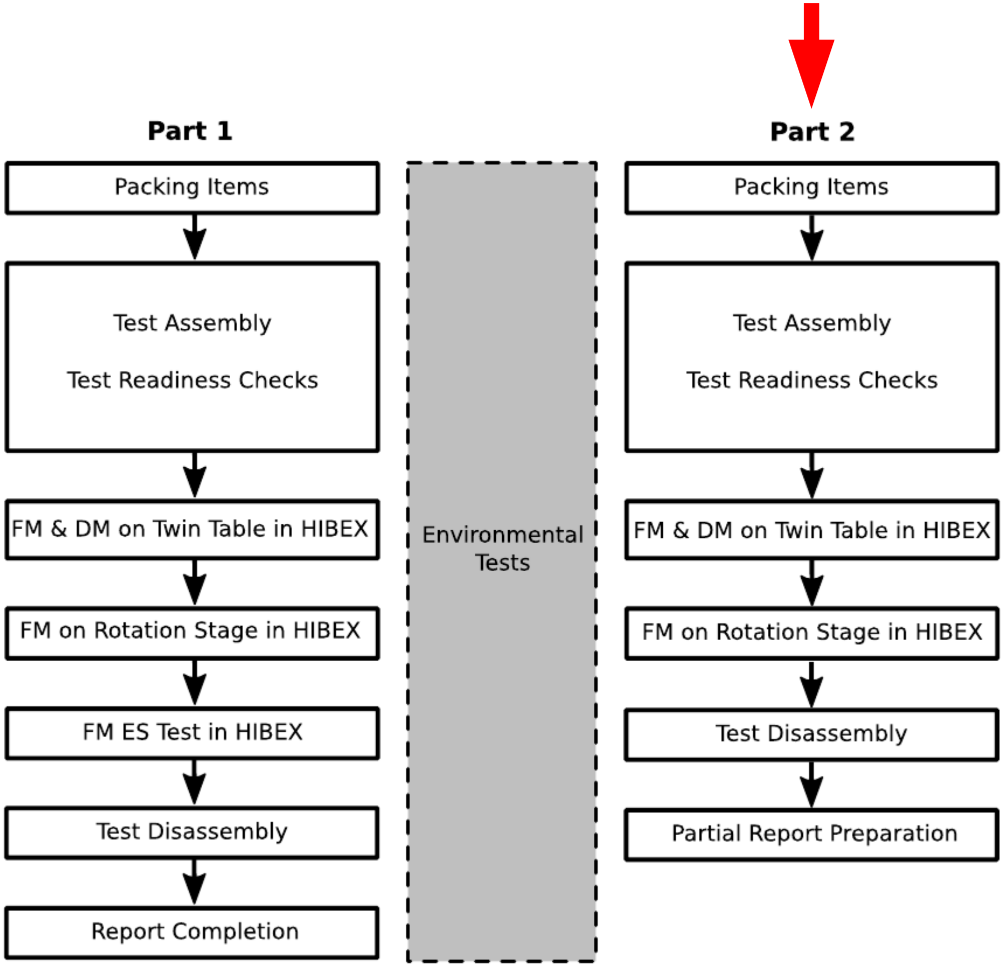


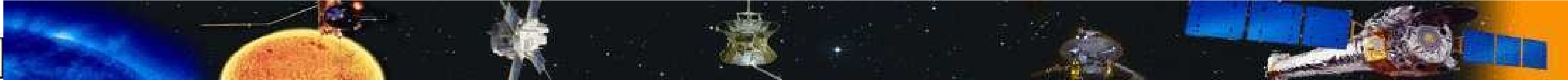
EPDP Thermal Vacuum Tests





EPDP Plasma Tests @ CAU





EPDP Erosionsmessungen 200 – 700 nm

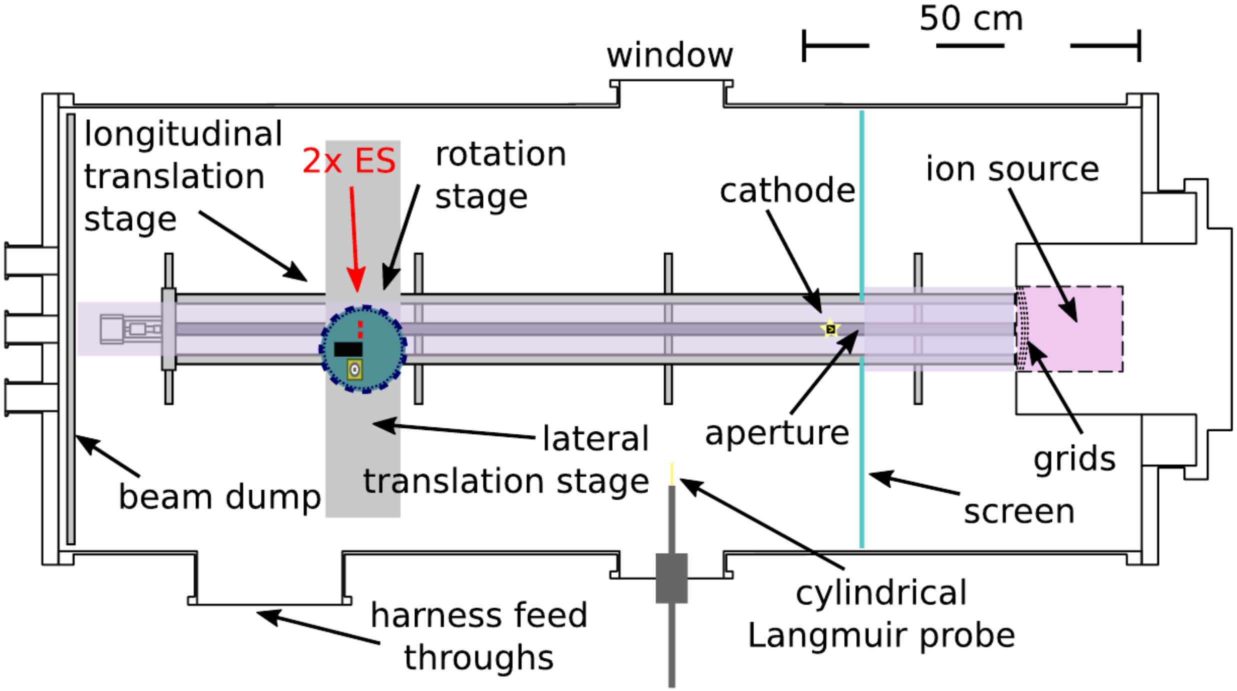


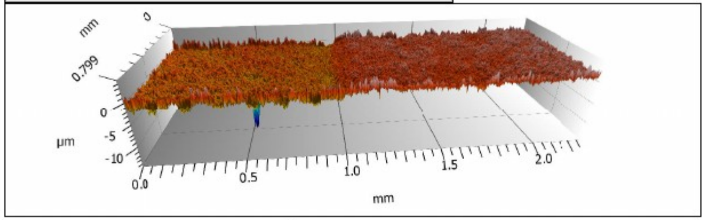
Figure 3: The ES test schematic in HIBEX. This is, in addition to the PS tests, a third setup. Here, the Twin Table (on the rotation stage) carries two ESs (instead of the FM PS) and for beam characterization a lab Faraday cup and the DM PS. The FM shall be connected to the ES next to the lab Faraday Cup, see Fig. 3.

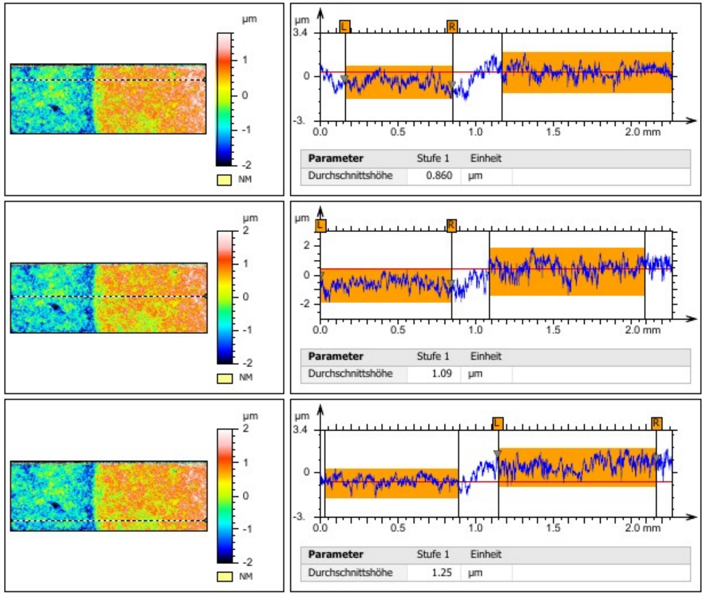
Auftragsnummer:	**4I22083**
Name	mb
Datum der letzten Änderung	11.11.2022
Name des Dokuments	**4I22083__FM-Test_MP5 (PLasmatest2)_3x1_20x.mnt**

forschungsinstitut edelmetalle + metallchemie

Name:	4I22083__FM-Test_MP5 (Plasmatest2)__3x1_20x-man	
Schrittabstand:	0.820	µm
NMP-Verhältnis:	0.843 % (22915 Pkte)	

Nicht-gemessene Punkte ausfüllen: Deaktiviert
mit einer flexiblen aus den Nachbarpunkten berechneten Form



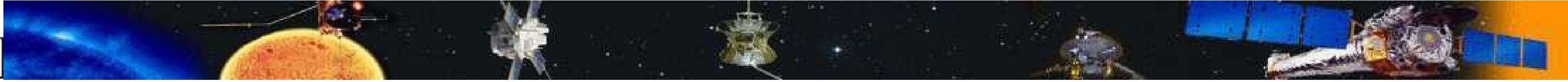


Parameter	Stufe 1	Einheit
Durchschnittshöhe	0.860	µm

Parameter	Stufe 1	Einheit
Durchschnittshöhe	1.09	µm

Parameter	Stufe 1	Einheit
Durchschnittshöhe	1.25	µm

µsoft analysis premium (Mountains Map) 7.2.7568 Seite 1 / 1



EPDP List of Publications

Development of a Flight Electric Propulsion Diagnostic Package (EPDP) for EP Satellite Platforms

IEPC-2019-345

Presented at the 36th International Electric Propulsion Conference
University of Vienna, Austria
September 15-20, 2019

T. Trottenberg[1], S. I. Böttcher[2], H. Kersten[3], B. Schuster[4],
L. Seimetz[5], A. Spethmann[6], and R. F. Wimmer-Schweingruber[7]
Institute of Experimental and Applied Physics, University of Kiel, 24098 Kiel, Germany

F. Bansemer[8], H. Henkel[9], M. Hesse[10], P. Muller[11], and T. Scott[12]
von Hoerner & Sulger GmbH, Schwetzingen, Germany

and

J. Laube[13]
OHB System AG, Bremen, Germany

https://electricrocket.org/2019/345.pdf

Trottenberg *et al. EPJ Techniques and Instrumentation* (2021) 8:16
https://doi.org/10.1140/epjti/s40485-021-00073-8

EPJ.org

EPJ Techniques and Instrumentation

RESEARCH ARTICLE **Open Access**

An in-flight plasma diagnostic package for spacecraft with electric propulsion

Check for updates

Thomas Trottenberg[1*], Florian Bansemer[2], Stephan Böttcher[1], Davar Feili[3], Hartmut Henkel[2], Marcel Hesse[2], Holger Kersten[1], Tony Krüger[1], Jens Laube[4], Alexey Lazurenko[5], Daniel Sailer[5], Björn Schuster[1], Lars Seimetz[1], Alexander Spethmann[1], Stefan Weis[5] and Robert F. Wimmer-Schweingruber[1]

https://doi.org/10.1140/epjti/s40485-021-00073-8

EPDP List of Conference Contributions

- 28th Spacecraft Plasma Interaction Network in Europe (SPINE) meeting: “Flight Electric Propulsion Diagnostic Package (EPDP) for EP Satellite Platforms” (2021, online event)
- 22nd International Summer School on Vacuum, Electron, and Ion Technologies: “Lab and in-flight diagnostics for electric spacecraft propulsion systems” (2021, online event)
- Space Engineering and Technology Final Presentation Days: “Flight Electric Propulsion Diagnostic Package (EPDP) for EP Satellite Platforms” (2021, online event)
- XXVII. Erfahrungsaustausch Oberflächentechnologie mit Plasma- und Ionenstrahlprozessen: “The Electric Propulsion Diagnostic Package (EPDP) for satellites“ (2022, Mühlleithen, Germany)
- EPIC Workshop: “EP activities at CAU Kiel – Example: Development and Testing of a Flight Electric Propulsion Diagnostic Package (EPDP) for EP Satellite Platforms” (2022, Köln)
- International Conference Plasma Processing and Technology (Plasma Tech): “A plasma diagnostic package for spacecrafts with electric propulsion systems” (2022, Barcelona, Spain)
- 29th Spacecraft Plasma Interaction Network in Europe (SPINE) meeting: “The Electric Propulsion Diagnostic Package (EPDP) for the Heinrich Hertz Satellite” (planned 2022, Kiruna, Sweden)
- 25th International Plasma School ”Low Temperature Plasma Physics: Basics and Applications” and Master Class on Electric propulsion: “Diagnostics for EP in ground-based test facilities and in orbit” (2022, Bad Honnef, Germany)

EPDP – Summary of Current Status:

EPDP successfully built, calibrated, tested, delivered to OHB, and shipped to IABG

Final steps for EPDP hardware:

- 09.11.2022 EPDP PFM EBox successfully tested on H2Sat EM (FlatSat)
- 15.11.2022 Post Test Review & Consent to Ship meeting before delivery to IABG
- 18.11.2022 Document delivery EIDP
- 2X.11.2022 Integration on satellite end of November.
- 01.12.2022 Delivery review meeting per Telecon
- 09.12.2022 Delivery review close out

Work still to be performed:

- Analysis of tests and calibrations in preparation of phase E (next bullet)
- Analysis of flight data (and preparation thereof)

The End