Overview on IRS electric and advanced electric propulsion activities

- Programmatic Overview (skipped, see slides)
- Overview IRS Thrusters
- Tools: Diagnostics and Codes (skipped, see slides)
- PPT
- AF MPD
- Arcjets
- IEC
- ABEP
- TIHTUS

G. Herdrich, T.Binder, A. Boxberger, A. Chadwick, Y.-A. Chan, M. Ehresmann, N. Harmansa, Ch. Montag, F. Romano, J. Skalden, St. Fasoulas, K. Komurasaki, T. Schönherr

Programmatic Overview (current activities)

PPT

- Collaboration with Uo Tokyo and RIAME + Kurtschatov Institute
- Harware-in-the-loop set-up for ADD-SIMPLEX
- Pulsed Electrothermal Thruster 3 years program (ESA NPI in context of CAPE)
- Inter laboratory comparison between ESA and IRS (procurement of balance and Mini PPT)

Arcjets

- Arcjets TALOS and VELARC within cooperation with Airbus D & S
- ESA Standardization project "Electrostatic probes" (Arcjet as reference)
- IRAS: Application of advanced manufacturing processes to further improve arcjets (DLR/IRS)

AF-MPD

- AF MPD (ESA TRP in coop. with Alta, quasi finalized)
- AF MPD numerical simulation (DAAD)

Programmatic Overview (current activities)

IEC

- IEC experimental investigation in coop. with ESA-ACT (numerical investigation) and Airbus D & S
- NEAT (linear IEC thruster) in cooperation with Gradel (ESA-Luxinno)

TIHTUS

- Numerical Analysis and experimental Optimization of TIHTUS (DFG project)
- TIHTUS Alternative Propellants (U o Adelaide)

ABEP

- DISCOVERER: WP4 as main task of IRS → Atmosphere-Breathing Electric Propulsion

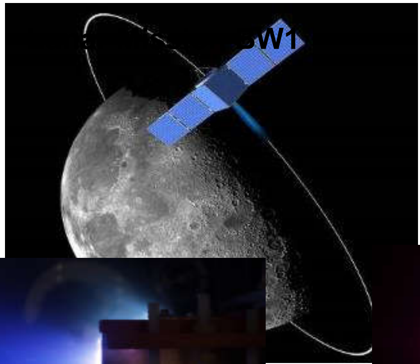
Water-based propulsion

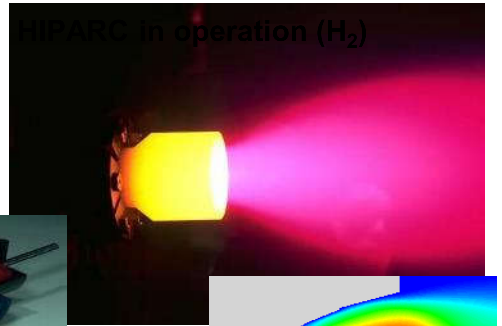
- Secondary EP system developed within cooperation with Airbus D & S www.uni-stuttgart.de

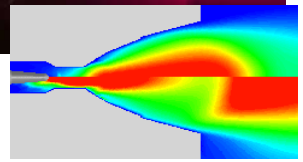
Electric Propulsion at IRS:

Development of

- **Thrusters and**
- **propulsion systems**

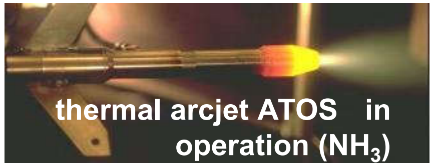






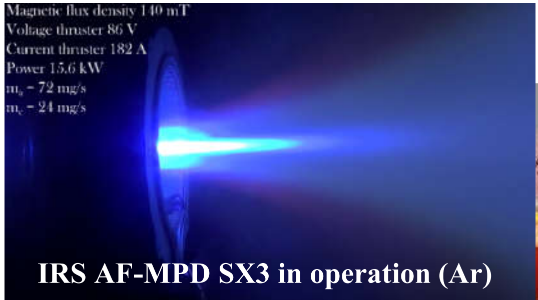
Low power EP (50W up to some 10kW) (Satellites and Exploration)

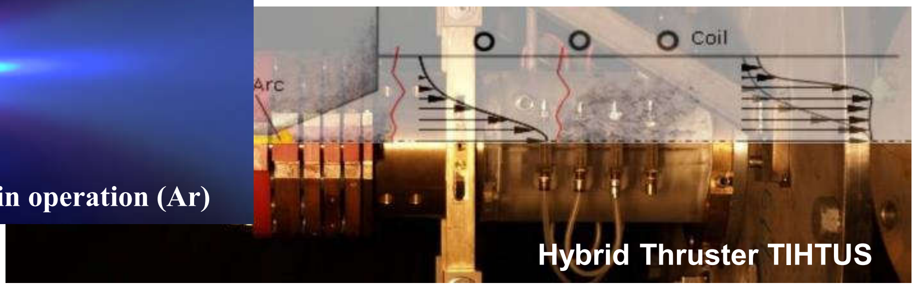
- Thermal arcjet thrusters
- PPT (iMPD)
- Applied-field MPD thrusters

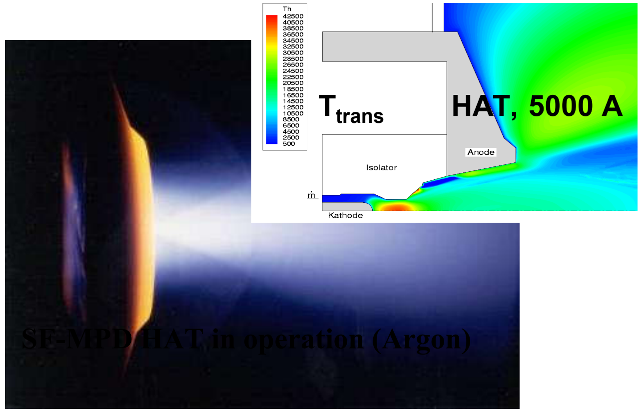


High power EP (50 kW up to MW) (Transport of large payloads)

- thermal arcjet thrusters
- Self-field MPD thrusters
- Hybrid thruster TIHTUS





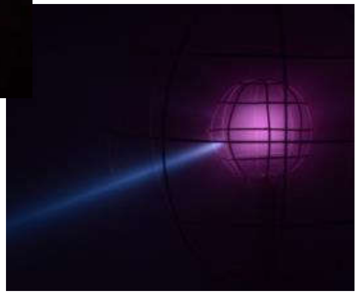


Electric Propulsion at IRS:

Development of
•Thrusters and
• propulsion systems

IEC

Star Mode, Ar



"Tight" Jet Mode, He

Secondary electric propulsion

- Electrolyzer
- 1 N catalytic thruster
- Green propellant

→ Small satellites

ABEP

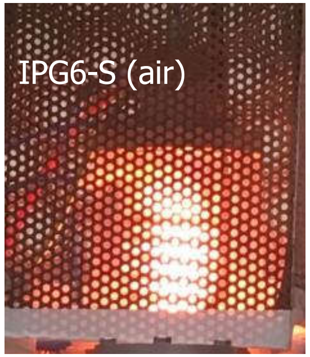
- Intake verification
- Intake design
- Inductive thruster as reference

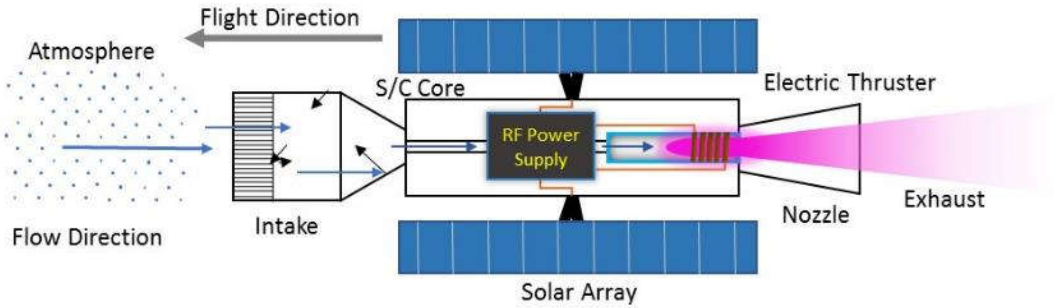
Mini PPT

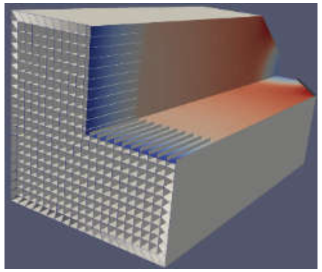
- PETRUS
- Thermal PPT
- Reliable, robust, cheap, …

→ CubeSat application

IPG6-S



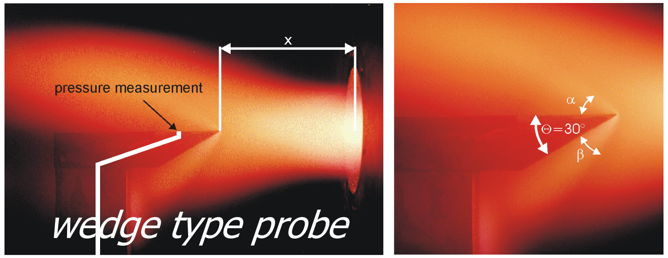


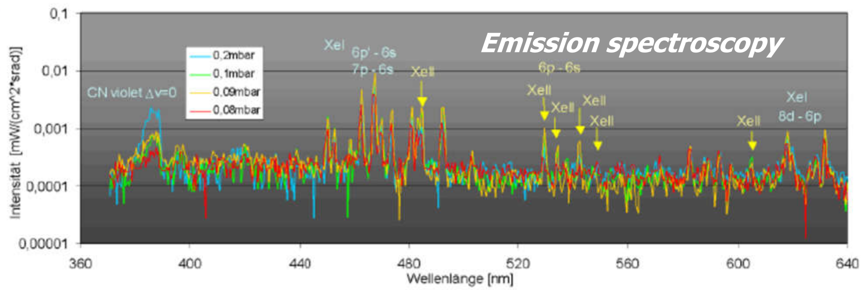


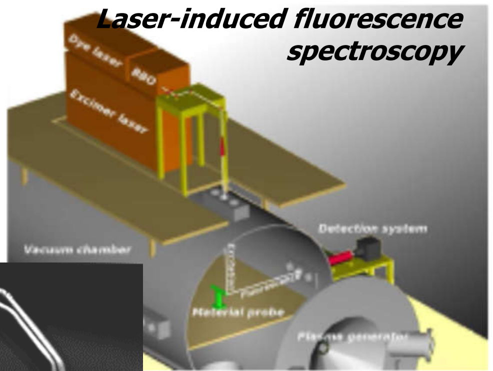
DSMC simulation of adapted intake geometry

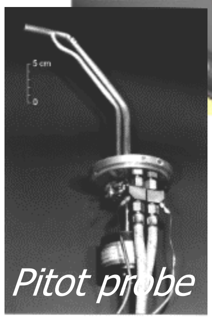
Diagnostics for EP Developement

Probe-type	Value measured
Heat Flux Probe	heat flux
Pitot Probe	total pressure
Mass Spectrometer Probe	plasma composition
Wedge Type Probe	static pressure, Mach number
Enthalpy Probe	enthalpy
Electrostatic Probes	T_e, T_i, v, n_e, …









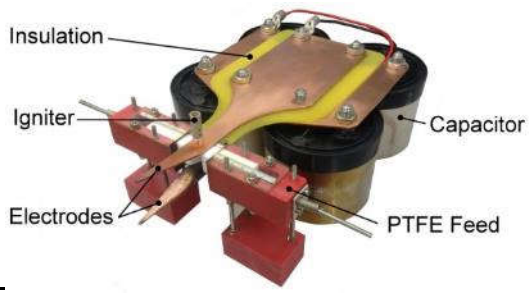
Method	Measured quantity
Emission Spectroscopy (EMS)	T_{ex}, T_{rot}, T_{vib}, T_e, n_e, (n_{Plasma} ?)
Laser-Induced Fluorescence (LIF)	T_{rot}, (T_{vib}), T_e, n_e, n_{Plasma}, v_{Plasma}
Thompson Scattering	n_e, T_e
Fabry-Perot Interferometry (FPI)	T_{Trans}, v_{Plasma}
Laser Absorption Spectroscopy (LAS)	n_{Plasma}, T_{Trans}, v_{Plasma}

Numerical Codes for EP Developement

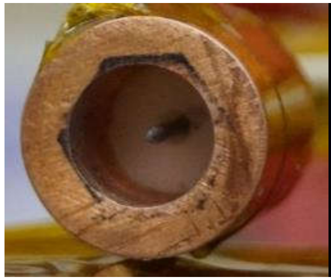
URANUS (ATD)	SAMSA (ATD/EP)	SINA / ARCHE (ATD/EP)	PICLas (EP presently)
Navier-Stokes			particle method
continuum flow, thermal and chemical non-equilibrium			rarefied plasmas, strong non-equilibrium
re-entry	SF and AF MPD , magnetic probes	TLT, IPG, PWK	PPT, Ion thruster,…
2D rotational symm. / 3D	2D rotational symmetric		3D
fully implicit	explicit		
fully coupled		loosely, iteratively coupled	
structured multiblock grids	unstructured, adaptive grids	structured multiblock grids	unstructured grids
Air, CO_2	Ar, air, CO_2	air, N_2, H_2	Presently mono- and diatomic species
PARADE/HERTA gas-radiation coupling		HERTA gas-radiation coupling	
gaskinetic gas-surface interaction model with catalytic reaction schemes. CVCV mult. temperature gas-phase model		changeable chemical modules	

Performance Overview of PPTs at IRS

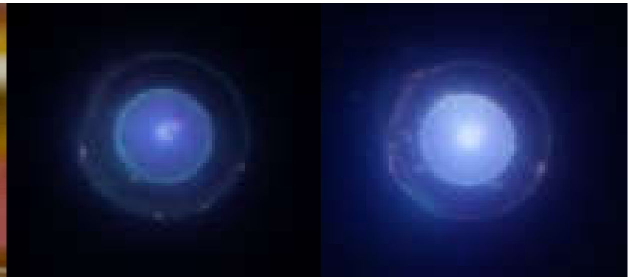
	ADD SIMP-LEX	PET	PETRA	PETRUS 2.0
Type	iMPD	Electro thermal	Electro thermal	Electro thermal / iMPD
Design	Parallel plate.	coaxial	coaxial	coaxial
Geometry	370 x 240 x 120 mm	Ø 32 x 55 mm	Ø 17 x 29.1 mm	Ø 12 x 50 mm
Mass	6.5 kg	489 g	180.72 g	≤ 500 g (incl. PPU)
Propellant	PTFE	PTFE	PTFE	PTFE
Propellant mass	Up to 43 kg	4 g	1.825 g	3.7 g
Capacitance	80 µF	1.5 µF	1.36 µF	4 µF
Charge voltage	1300 V	2500 V	2000 V	1600 V
Energy	67.6 J	3 J	2.72 J	5.12 J
Pulse frequency	1 Hz	1 Hz	1 Hz	0.25 - 1Hz
Mbit	53.38 µg	43.4 µg	47.76 µg	2.1 µg (theor.)
Ibit	1373 µNs	61.7 µNs	72 µNs	26.5 µNs (theor.)
Number of pulses	More than 2 mio.	100000	38211 (theor.)	1761900 (theor.)
Isp	≤ 2718 s	140 s	154 s (theor.)	< 1282 s (theor.)
Thrust per pulse	1.373 mN	0.0617 mN	0.072 mN	0.0265 mN (theor.)
Power	~ 70 W	< 4 W	< 4 W	5 - 8 W



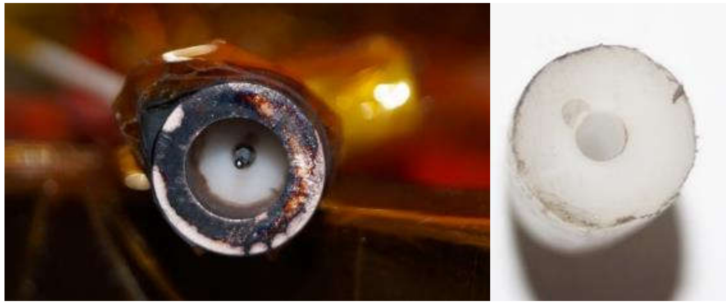
Design of PETRUS 2.0 and Preliminary Test Results of a Breadboard Model



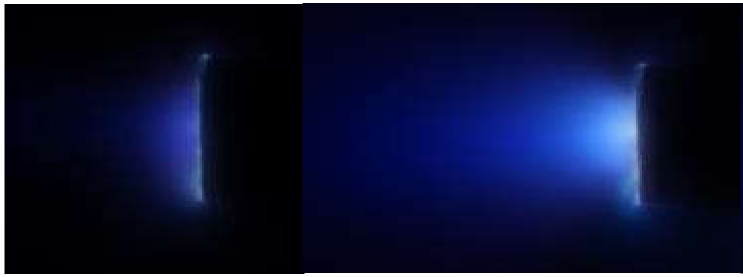
Breadboard of PETRUS 2.0



Front view: 2 J and 5.12 J

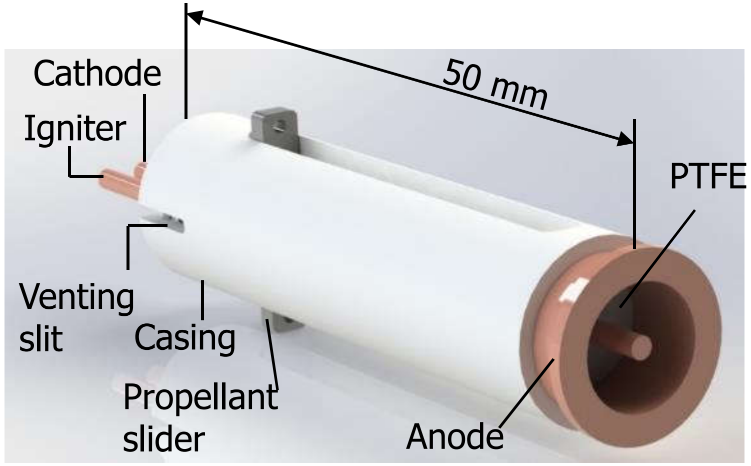


Breadboard model after ~2000 pulses



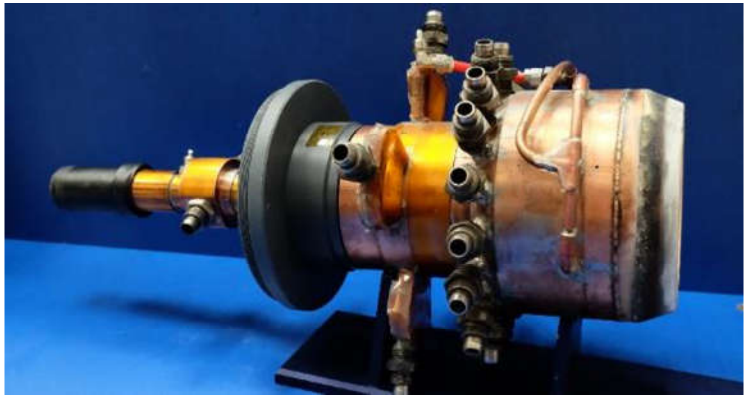
Side view: 2 J and 5.12 J

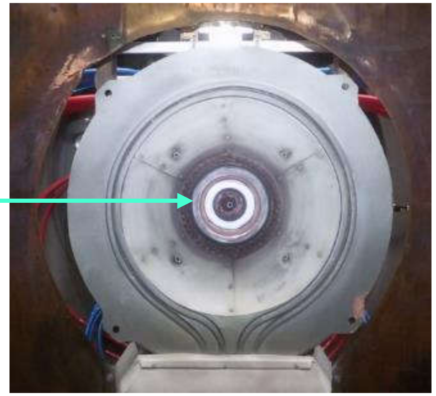
Isom. view: 5.12 J

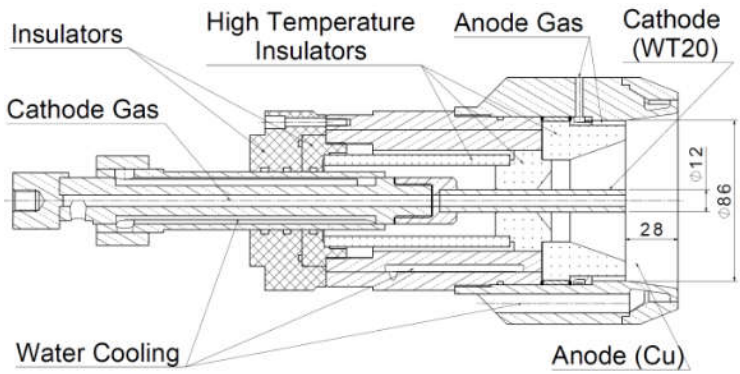


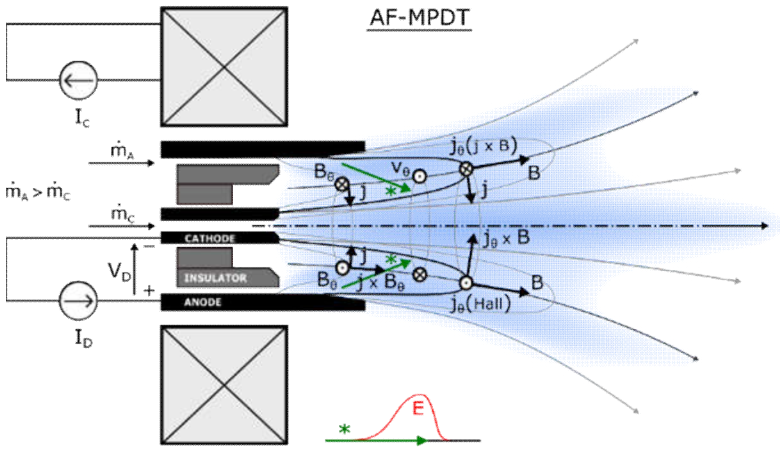
Final design of PETRUS 2.0

Steady State AF-MPD SX3 Thruster (100 kW class)



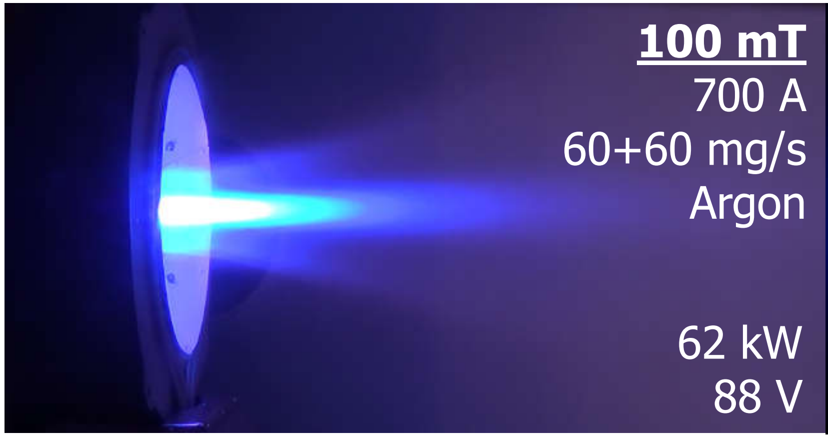


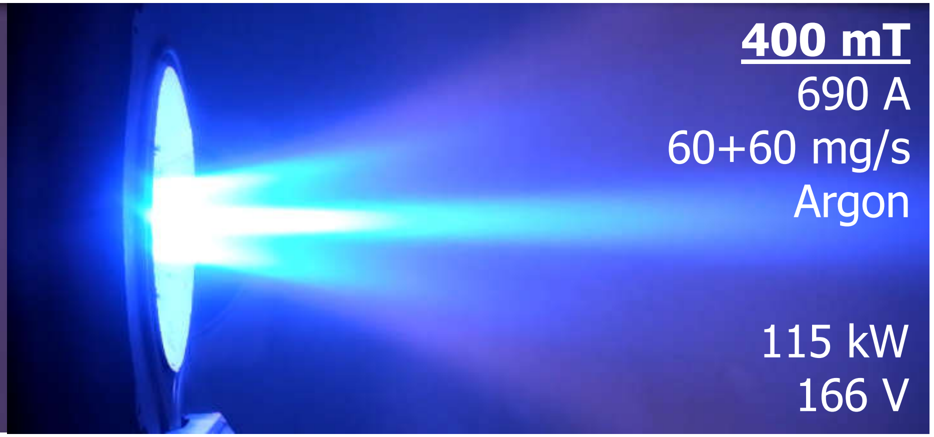


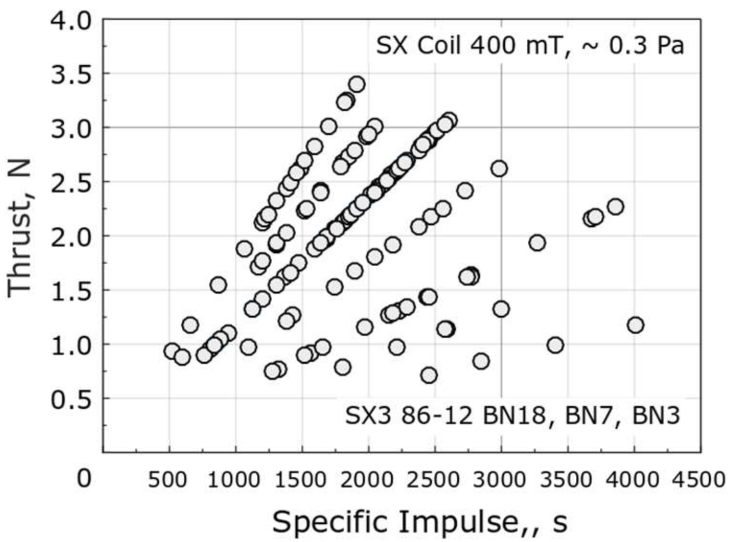


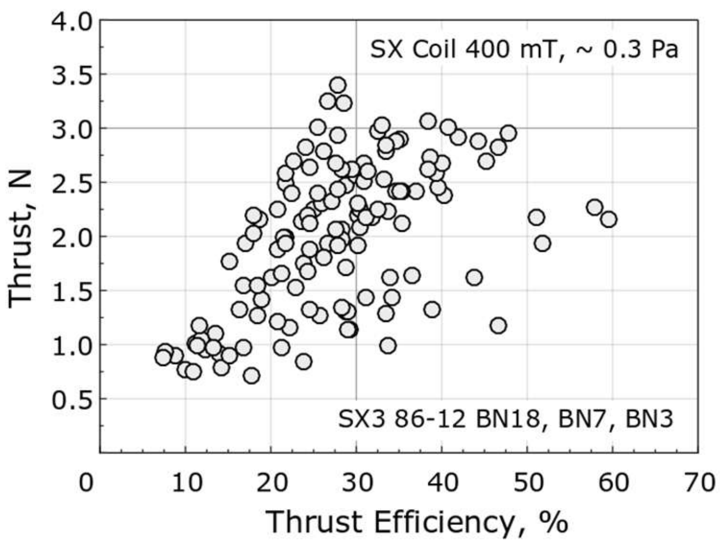
- Cost efficient laboratory model
- Applied field up to 400 mT, arc current up to 1kA
- Anode + cathode gas injection (argon)

100 kW Class Applied-Field MPD SX3 Thruster: Performance







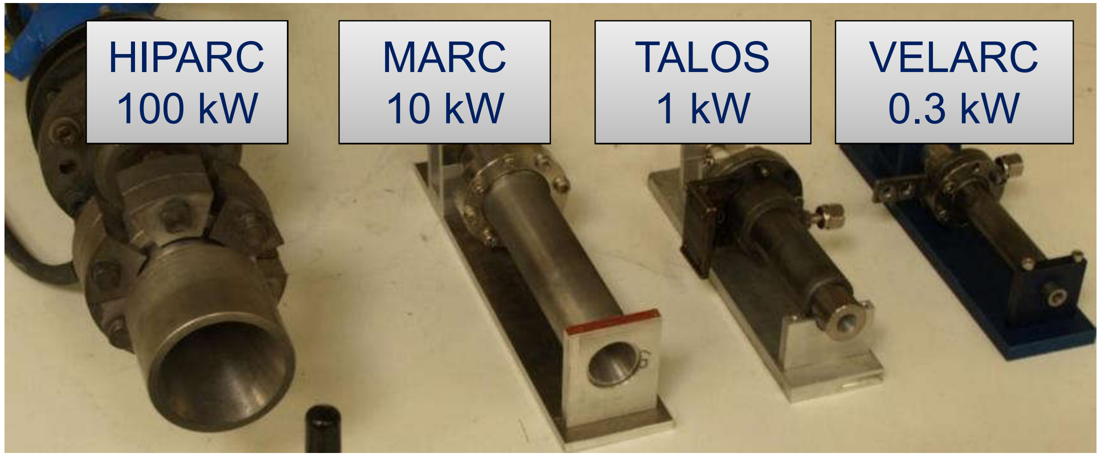


Arcjet- and PPU-Development at IRS

1. **Geometric study**
   - Dual-Cone Geometries
   - Optimal nozzle geometry for TALOS
2. **Erosion reduced ignition**
3. **Scaling law to optimize nozzle geometry**
4. **System- & mission analyses**
   - Synergies with existing sub-systems

     Chemical propulsion – propellant feeding system, pressurization

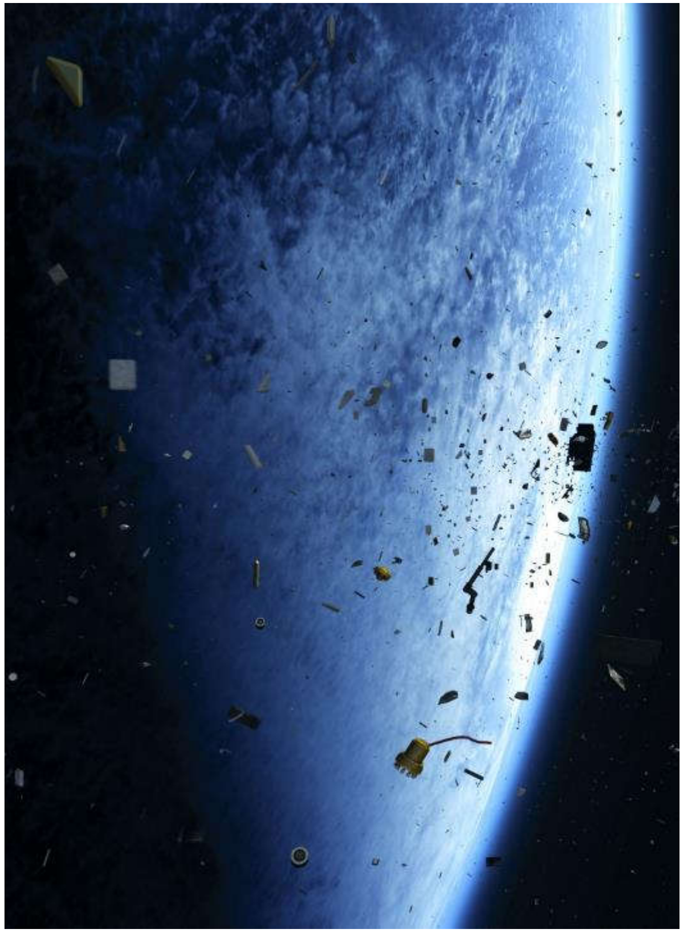
     Manned spacecraft – hydrogen from LSS



Arcjet Activities at IRS: CleanSpace

Arcjet-based orbit raising and deorbit module

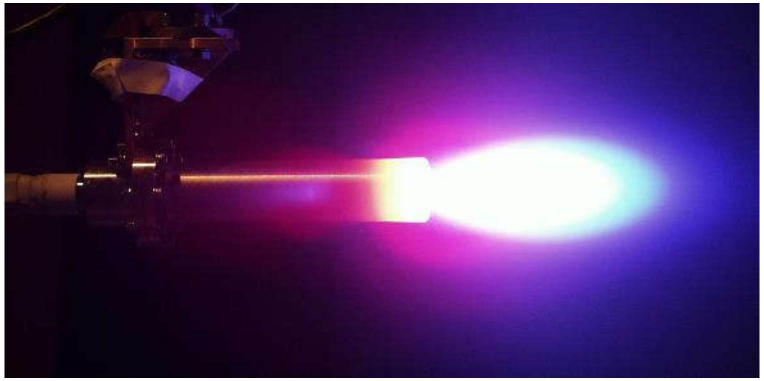
- Assessment of IRS developed arcjets for deorbit mission scenarios
- Design of hydrazine and ammonia stand-alone systems
- Design of hydrazine and green propellant dual-mode systems
- Performance estimation based on previous experiments at IRS
- It was shown that for a 800 kg and 1500 kg, 750 W and 1000 W arcjets can fulfill all requirements for an active deorbit module



Arcjet Activities: Langmuir based Standardization Approach for Inter laboratory comparison (ESA/IRS)

- Langmuir probe measurements with arcjets as plasma source
- Low-power arcjet VELARC as reference

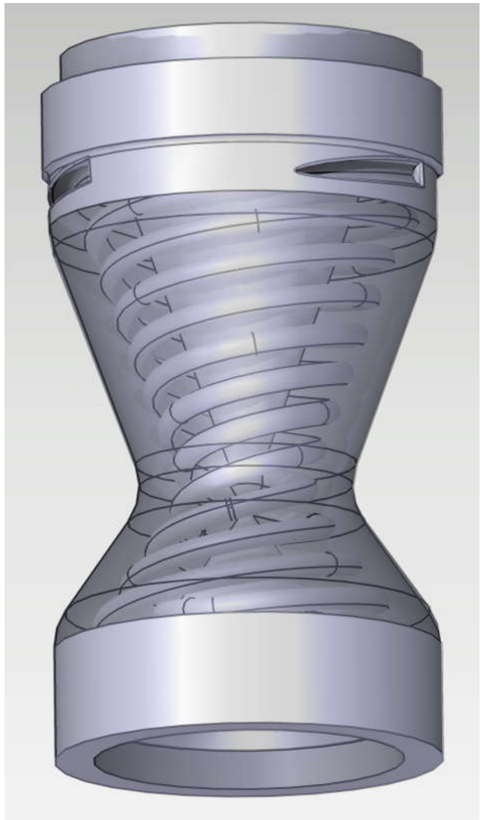
- Experiments at IRS successfully concluded with 5 identical Langmuir probes
- Conclusions on reproducibility made e.g. electron densities follow enthalpy variations with systematical behavior
- Statistical analyses performed


VELARC during operation

Arcjet Activities:
IRAS (DLR/IRS)- Assessment of ALM to improve Arcjets

- Selective laser sintering of tungsten
- Realization of design options that are impossible with conventional manufacturing
- New ALM-design of a medium power arcjet nozzle featuring:
  - Helix shaped regenerative cooling channels
  - Low wall thickness for lightweight design
- Lowering thermal losses for higher thrust efficiency

Evaluation of ALM-materials for arcjet operation currently conducted at IRS

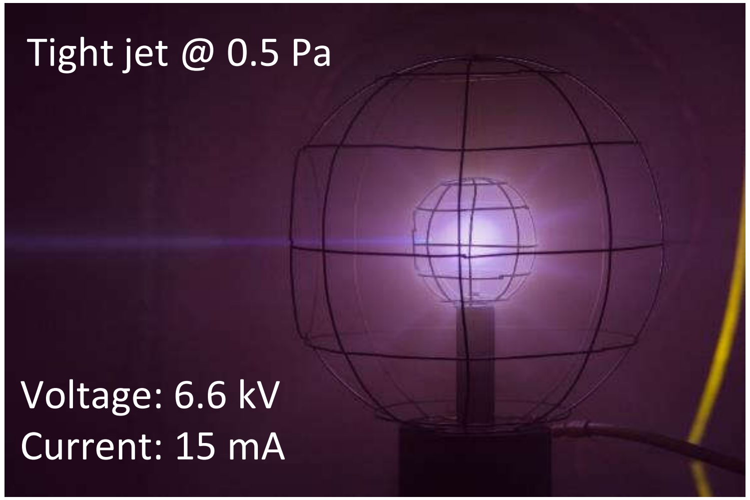


Design of an ALM arcjet nozzle

Inertial Electrostatic Confinement: Plasma Extraction Modes

IEC Configuration:

- Longitude: 8 wires, Latitude: 5 wires
- $D_{cathode}$: 5 cm, D_{anode} : 15 cm



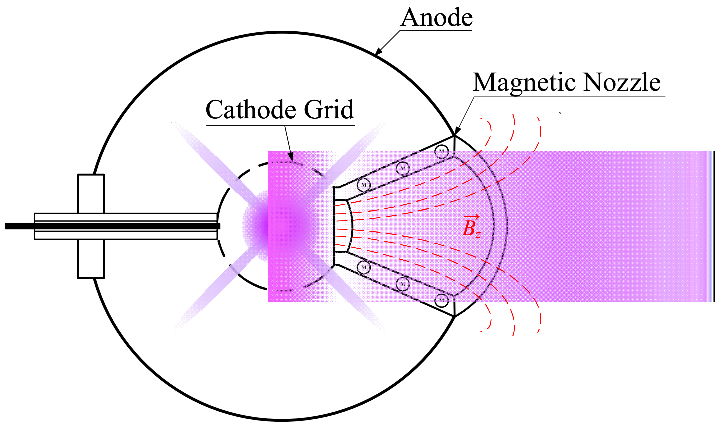
Tight jet mode:

1. High energy electron beam (*EB*)
2. Confined jet contour
3. Lower current value (1 ~ 50 mA)

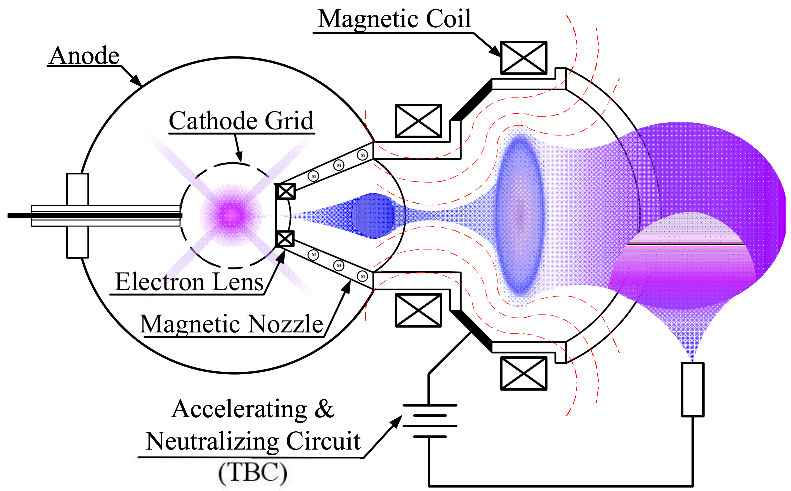
Spray jet mode:

1. Diffused Ion plume
2. Higher current value (> 50 mA)
3. High luminosity from core region

Inertial Electrostatic Confinement: Potential Thruster Concept and Application

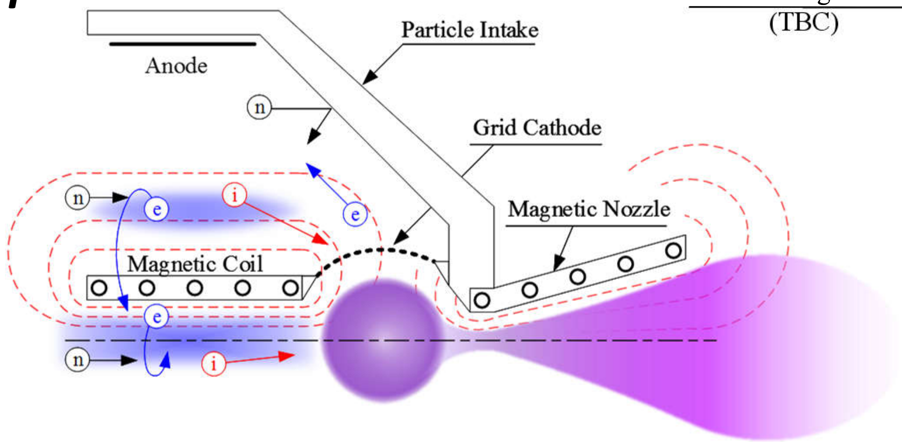


IEC Ion Thruster Concept



IEC HET Concept

IEC ABEP Concept

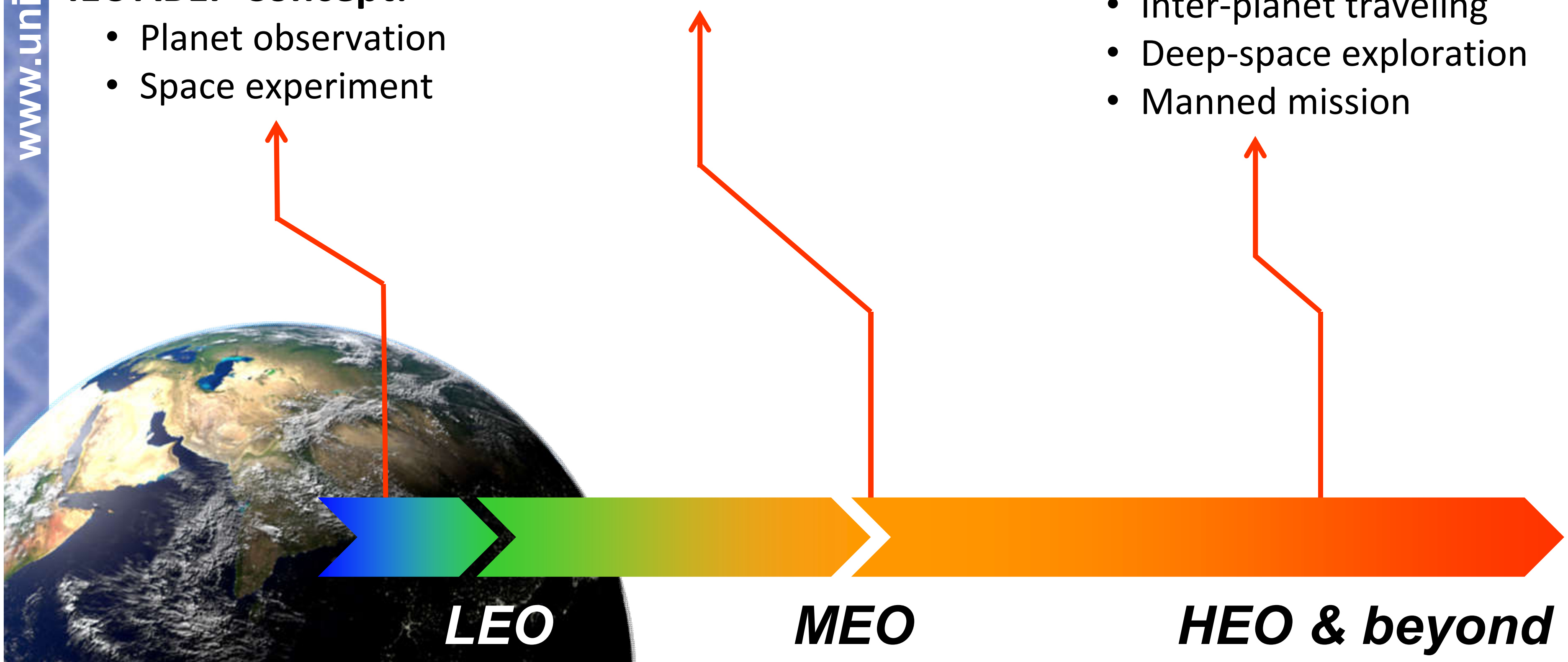


Inertial Electrostatic Confinement: Application Vision

IEC ABEP Concept:
- Planet observation
- Space experiment

IEC Plasma Thruster Concept:
- Communication satellite
- GPS Navigation
- Astronomy

IEC Fusion Concept:
- Inter-planet traveling
- Deep-space exploration
- Manned mission

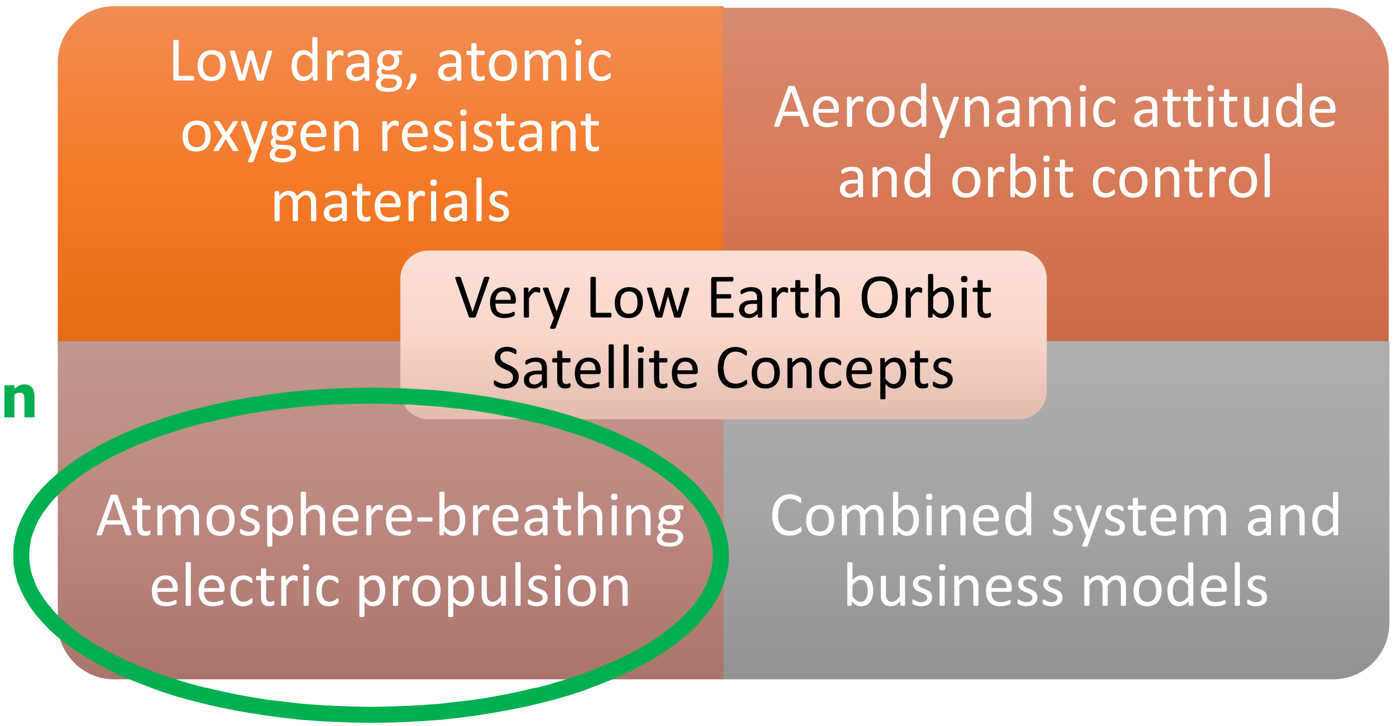


Institute of Space Systems

DISCOVERER

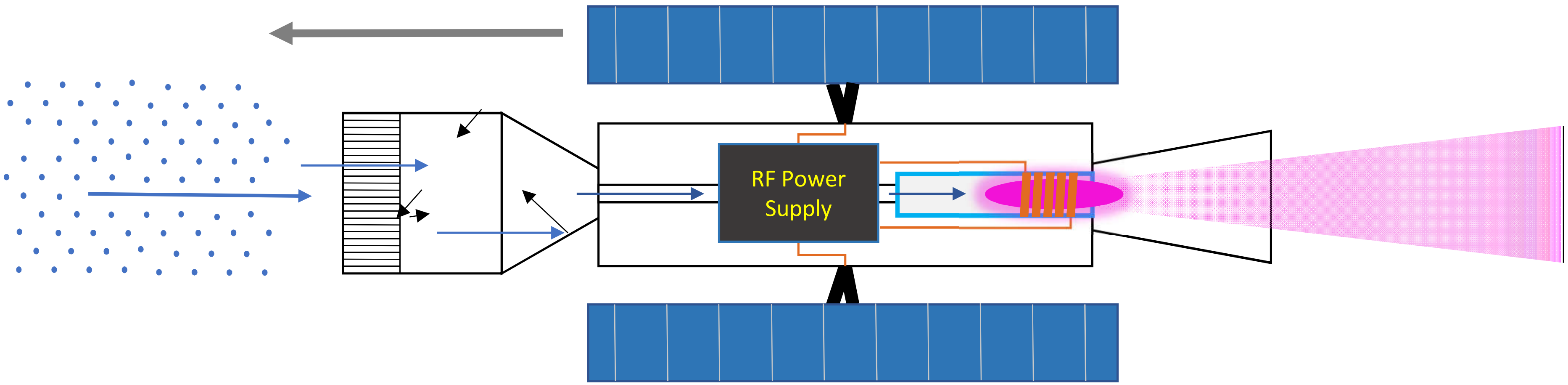
This project has received funding from the European Union's Horizon 2020 research and innovation programme under agreement No 737183

IRS Main Task



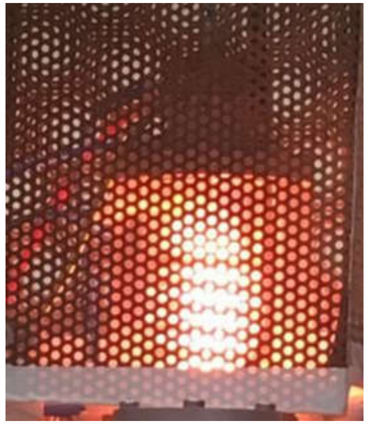
Atmosphere-Breathing Electric Propulsion (ABEP)

- Use of residual atmosphere as propellant for an electric thruster;
- Intake collects the atmosphere molecules and feeds the thruster;
- Thruster process and expel them through a nozzle to generate thrust.



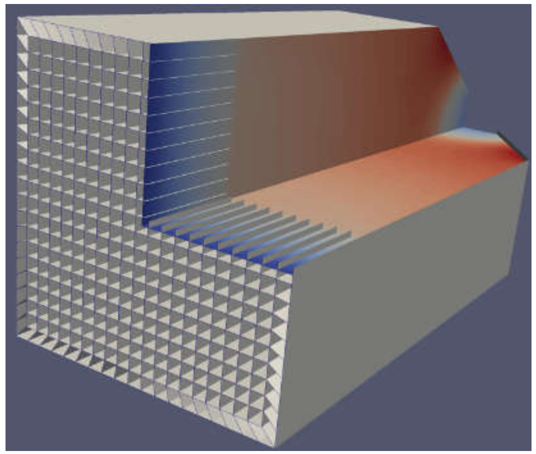
IRS is responsible to develop IPT and intake

- IPT:
  - Based on IPG6-S;
  - Passively cooled;
  - Optimized for ABEP related mass flow;
  - Optimized for input power 0.5 to 5.5 kW.



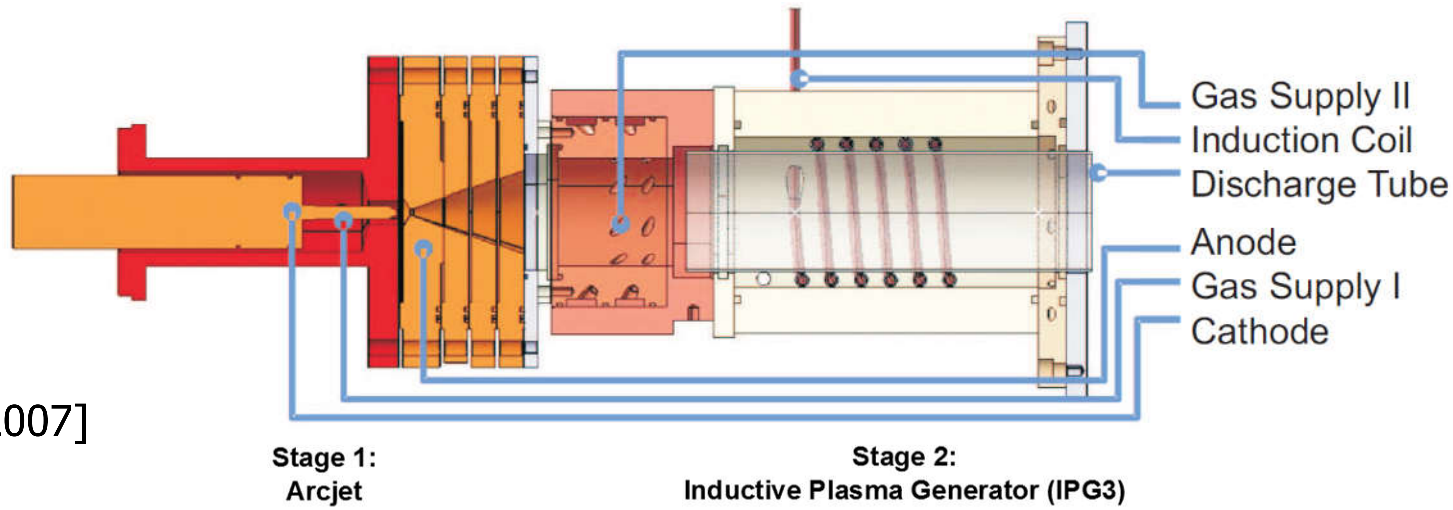
IPG6-S operating with N_2

- Intake:
  - Based on verified DSMC in-house code;
  - Analytical tool available;
  - Molecular trapping;
  - Optimized for IPT.

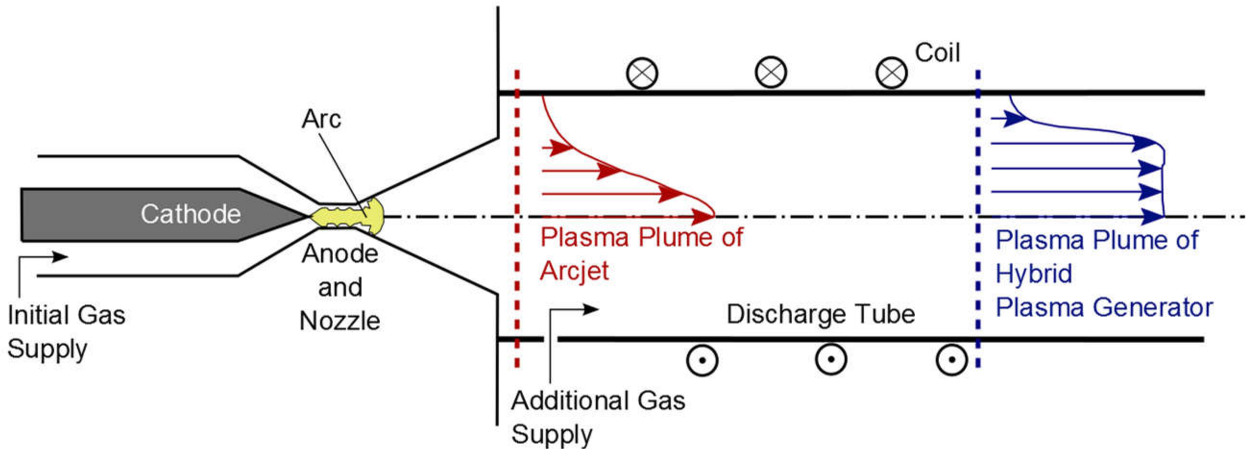


DSMC simulation of adapted intake geometry

TIHTUS: Thermal-Inductive Hybrid Thruster of U o Stuttgart



[Böhrk 2007]

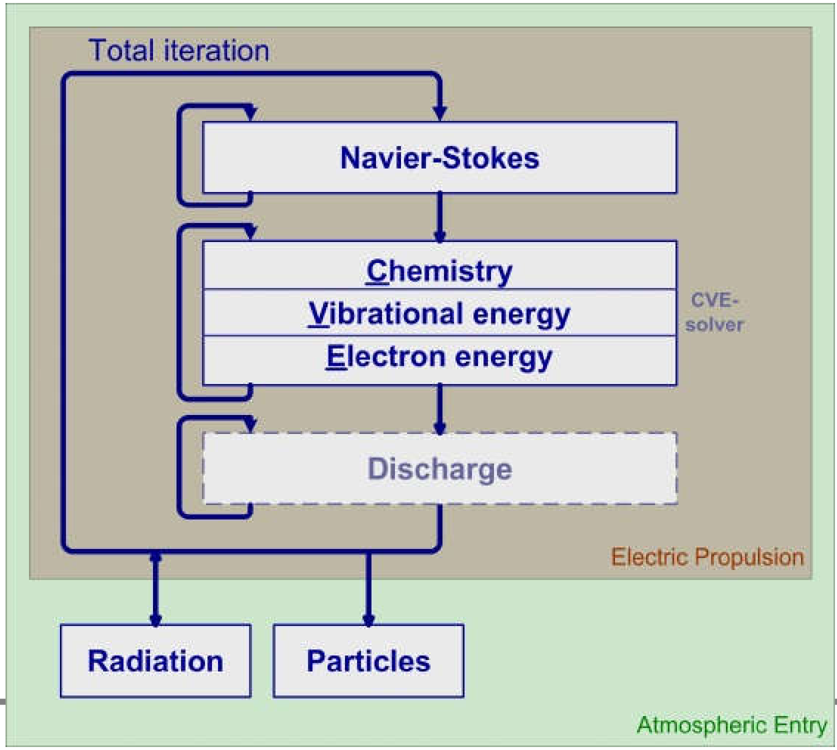


SINA - Simulation of plasma flows with discharges

Sequential **I**terative **N**on-equilibrium **A**lgorithm **/ Sequentieller Iterativer Nichtgleichgewichts-Algorithmus**

SINA:

→*Viscous plasma flows in chemical and thermial Nonequilibrium under consideration of discharges*



Anwendungen:

- Atmospheric **Entry**
    - Erde (N_2/O_2), Mars (CO_2), Jupiter (H_2/He)
- **Electric propulsion / Plasma wind tunnels**
    - TLT, IPG, MPD (in Entwicklung)
- **Two-phase flows**
    - Plasma coating
    - Atmospheric Entry incl. Dust particles (e.g. Mars)

Development of TIHTUS

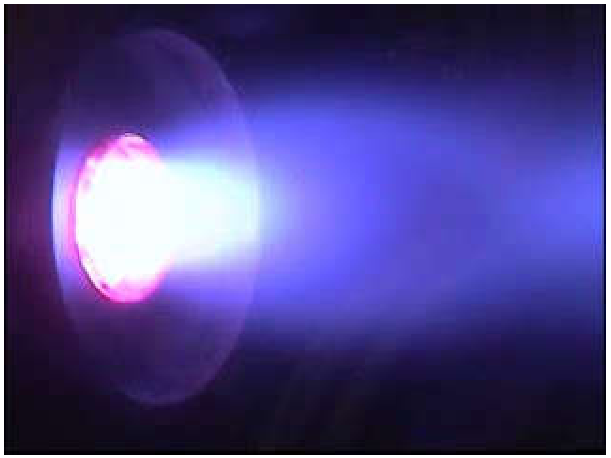
(exp.) Geometric optimization, (num.) Simulation
→
Efficiency increase, Improvement of understanding

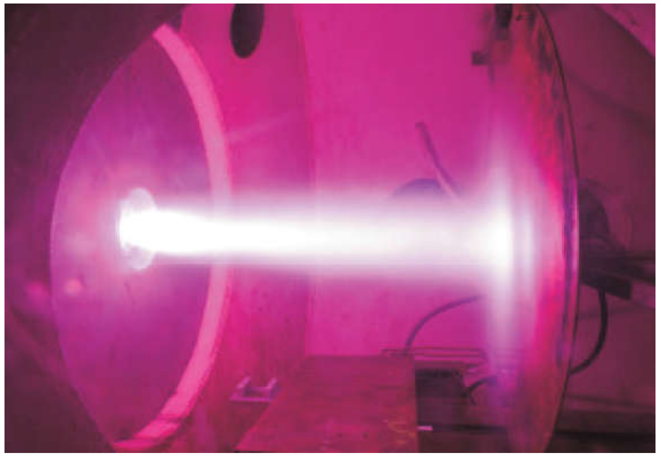
+

(exp.)
Alternative Propellants
→
Systemic Synergies:
2nd stage operation with wastes (LSS), ISRU

DFG Deutsche Forschungsgemeinschaft

THE SIR ROSS & SIR KEITH SMITH FUND





Summary: Thank you!

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