



von KARMAN INSTITUTE
FOR FLUID DYNAMICS

Overview of new concepts for Thermal Protection System technologies

Alan Viladegut



FORGING
THE FUTURE



15 OCTOBER 2024

BE-US JOINT EFFORT
IN SCIENCE FOR A
SAFER WORLD

ROYAL MILITARY ACADEMY
BRUSSELS

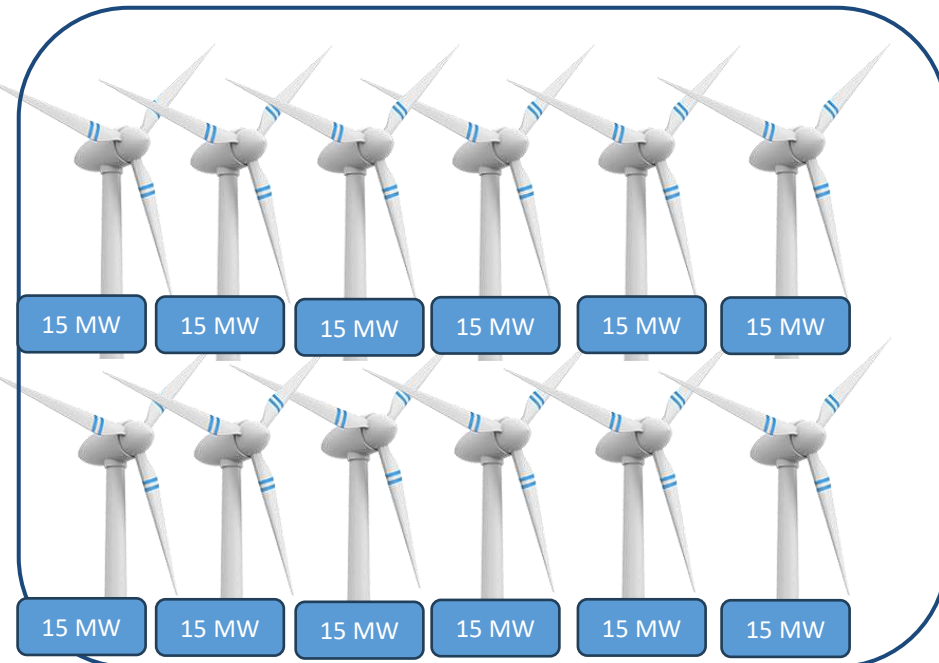


Why do we need TPS?



Velocity at start of re-entry:	10 km/s
Re-entry altitude:	100 km
Capsule mass:	3500 kg
Re-entry time:	10 minutes

~180 MW of power to be dissipated



Boeing 777

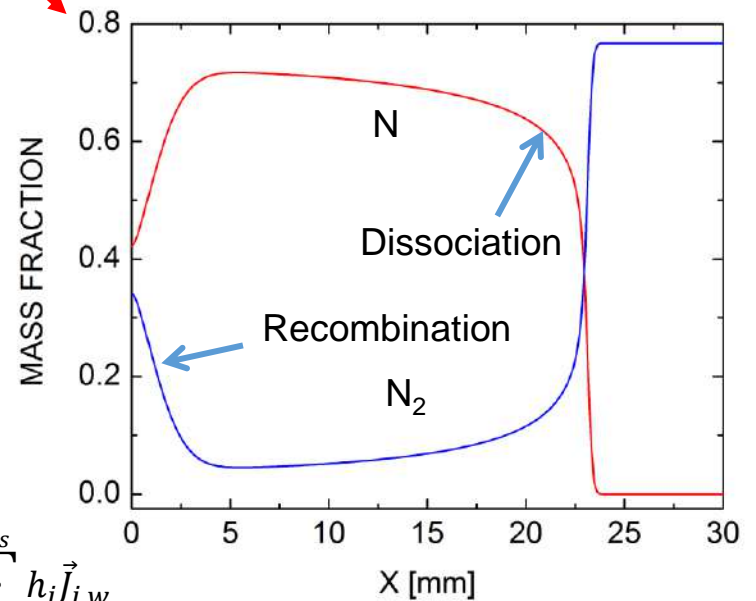
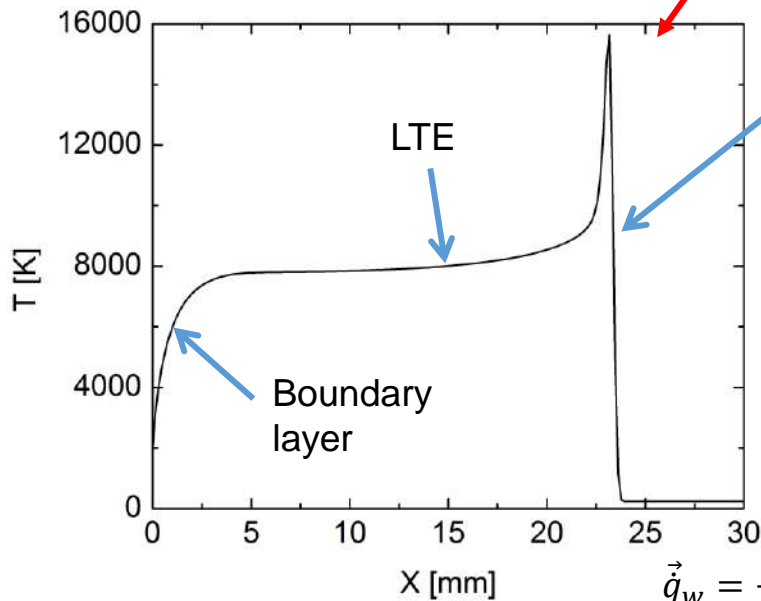


Nature of the heating at high speeds



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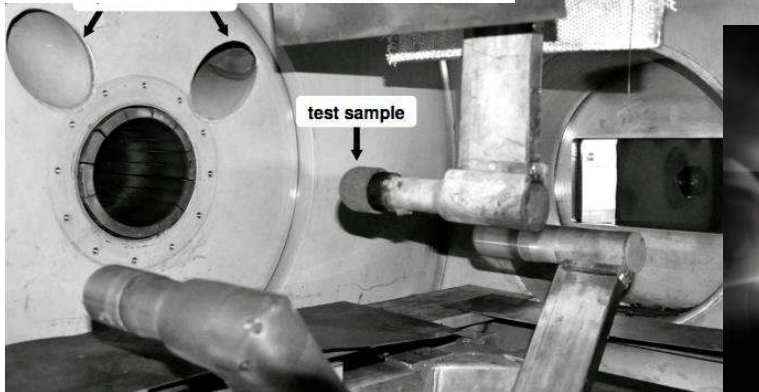
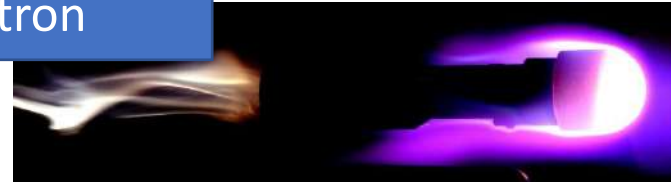
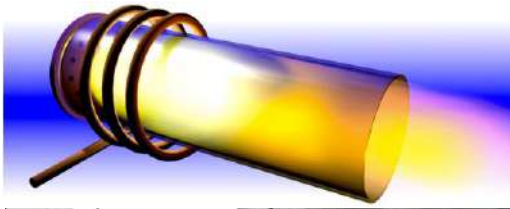
~180 MW of power to be dissipated



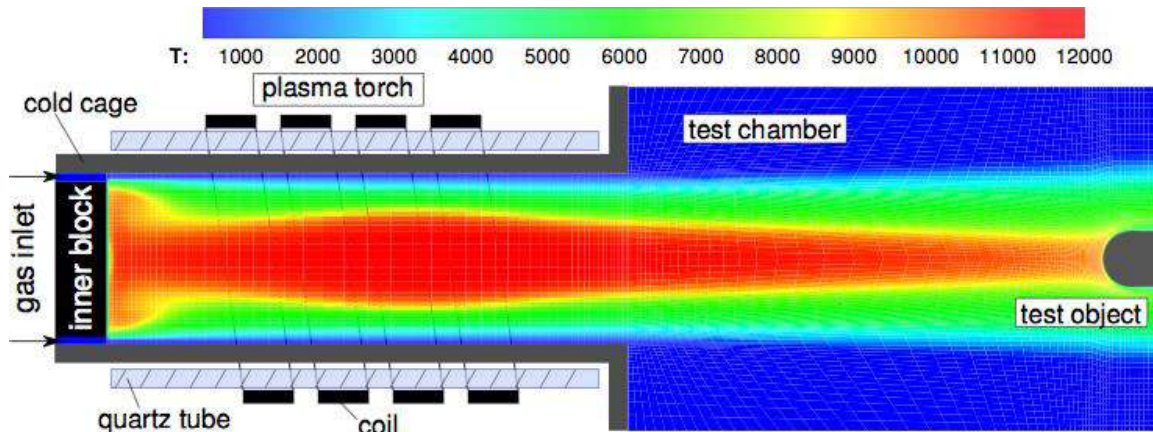
$$\vec{q}_w = -\lambda \nabla T_w + \sum_{i=1}^{N_s} h_i \vec{j}_{i,w}$$

Expertise at the von Karman Institute

VKI - Plasmatron



Courtesy: B. Helber

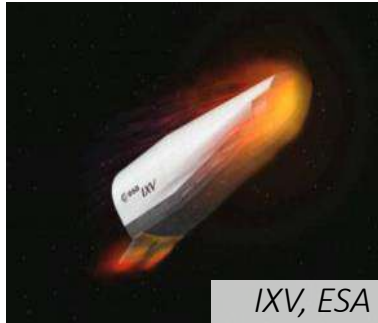


Experimental & Numerical work:

- Gas-surface interaction,
- Plasma diagnostics,
- Heat transfer,
- Demise of space debris,
- Black-out mitigation

Thermal Protection System strategies

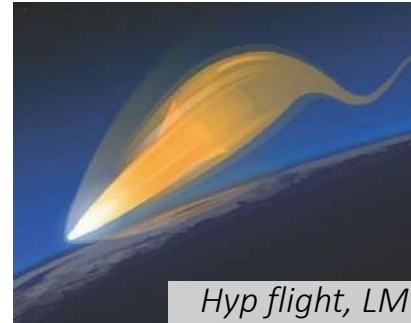
Reusable



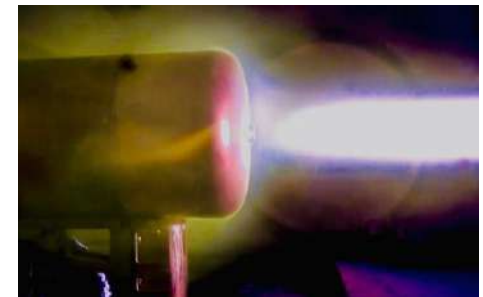
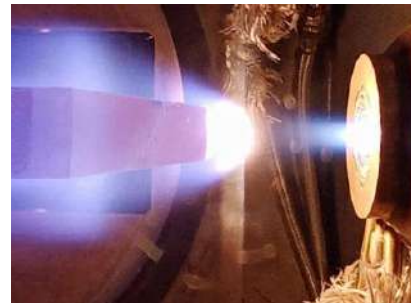
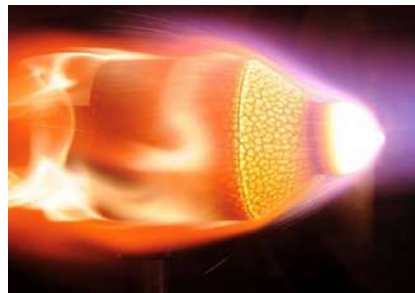
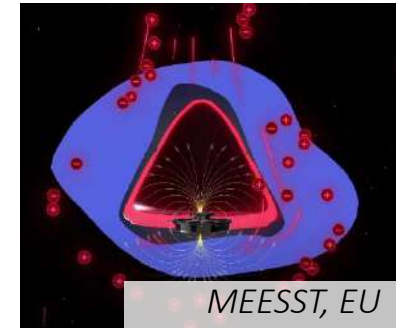
Ablative



e^- Cooling



MHD Cooling

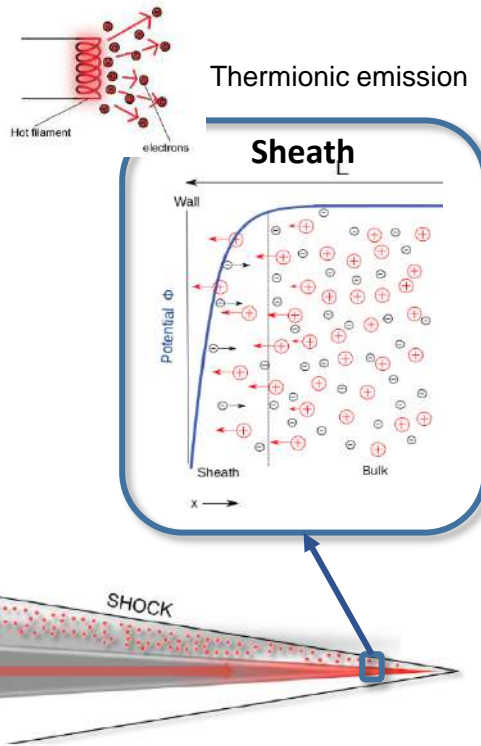


Electron Transpiration Cooling (ETC)

Aerodynamic Power Generator

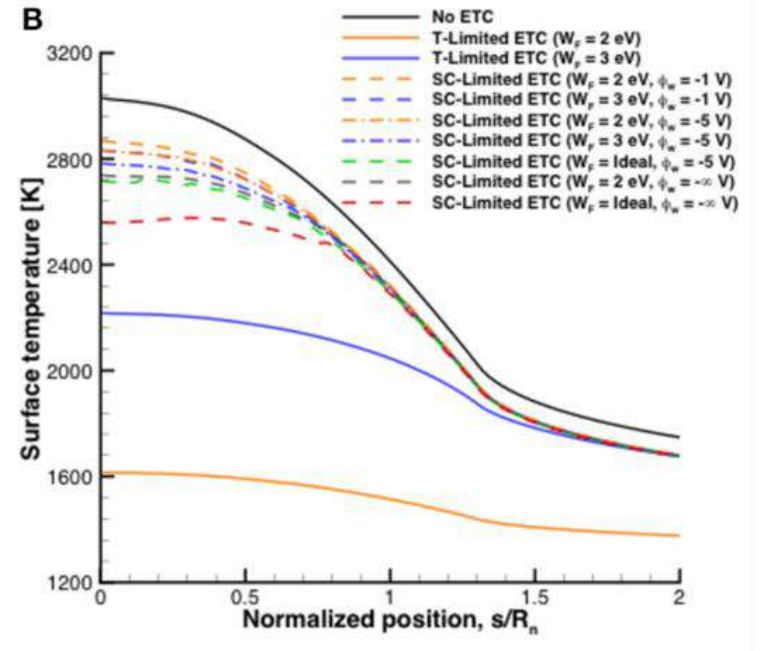


Thermal Protection System



Temperature reduction at SP by thermionic emission,
Power generation for aircraft systems

Plasma Sheath modelling
for hypersonic vehicle design

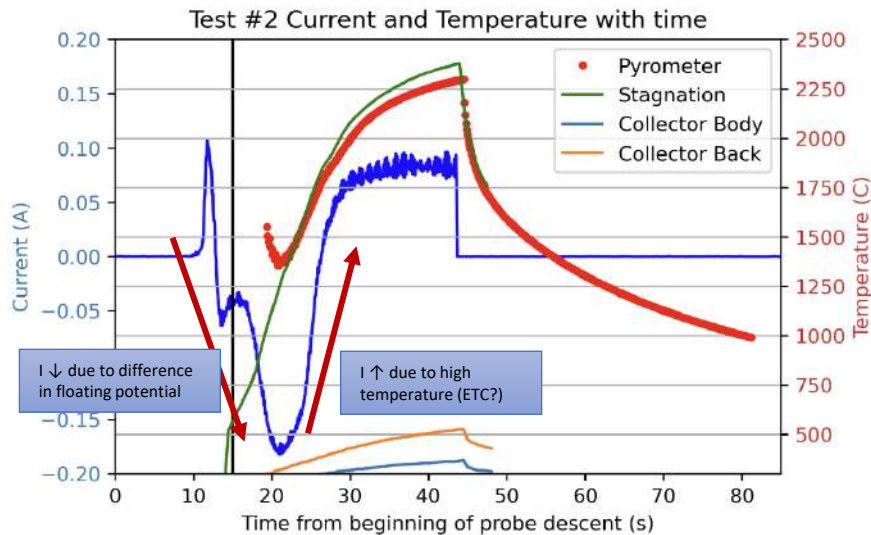
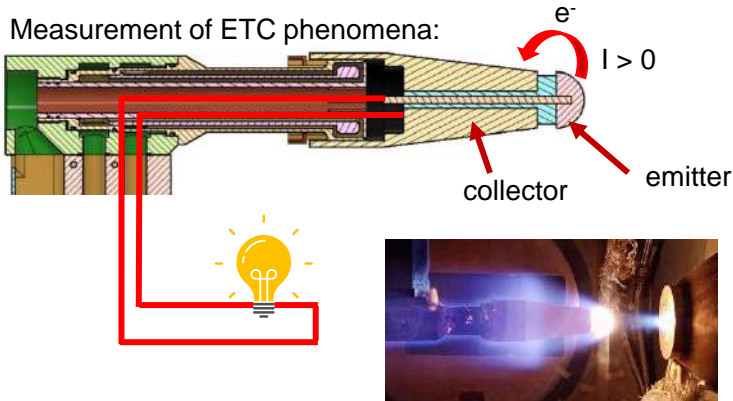


Hanquist Kyle M. , Boyd Iain D.
Plasma Assisted Cooling of Hot Surfaces on Hypersonic Vehicles
Frontiers in Physics, 2019

CFD simulations show the potential of thermionic
emission to reduce surface temperatures

Electron Transpiration Cooling (ETC)

Plasma Sheath experiments
using materials w/ low work function



Credit: V. Lafaurie (RM)

Challenges of ETC testing

Plasma conductivity
around electrodes
(w/o ETC)

Subtract background
currents from the
plasma to relate to ETC

Non-symmetric probe

Space-charge
limitation

Work function will differ
from theoretical values

Electron & Heavy
particle collision
@ high P

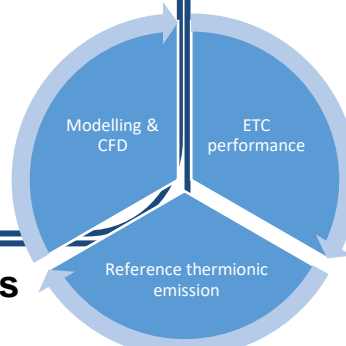
Electron Transpiration Cooling (ETC)

Proposed transversal research activity:

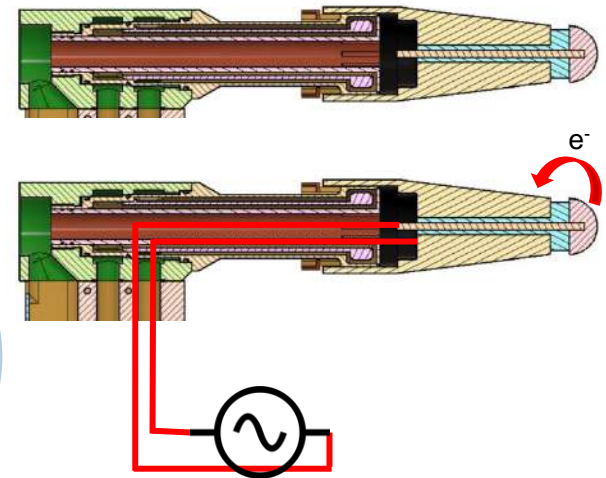
Upgrade modelling tools
Mutation++ and Argo electro-static fluid

M⁺⁺ Mutation → **Argo Code**

Multi-component Thermodynamic And Transport properties for IONized gases in C++



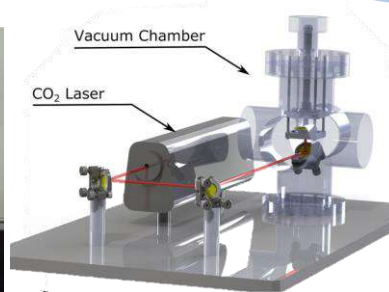
New strategy for ETC cooling efficiency
Plasmatron



Determination of W_f in ideal conditions
Drag-on facility



10^{-7} hPa



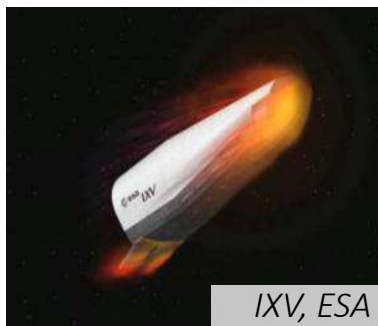
Dominguez et al. (2019)
DOI: 10.1063/1.5088150

Symmetric voltage signal as input,
Asymmetric output current due to the flow

Comparison to non-ETC materials, or with
reference materials with same emissivity

Thermal Protection System strategies

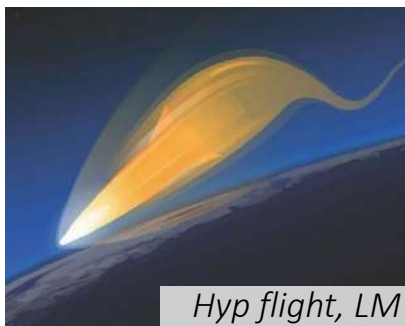
Reusable



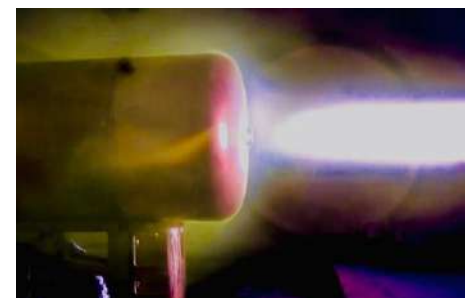
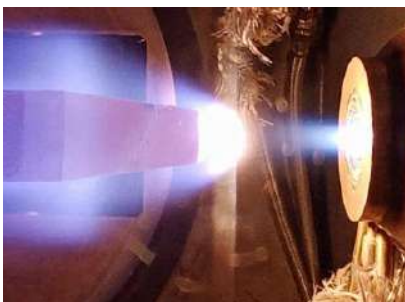
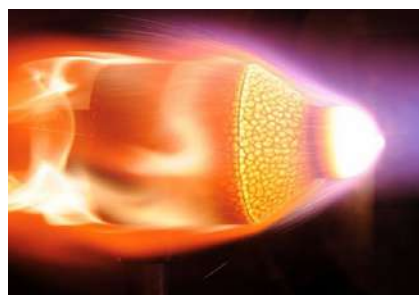
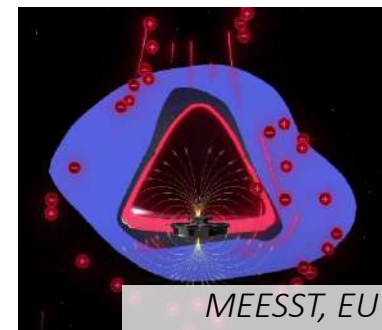
Ablative



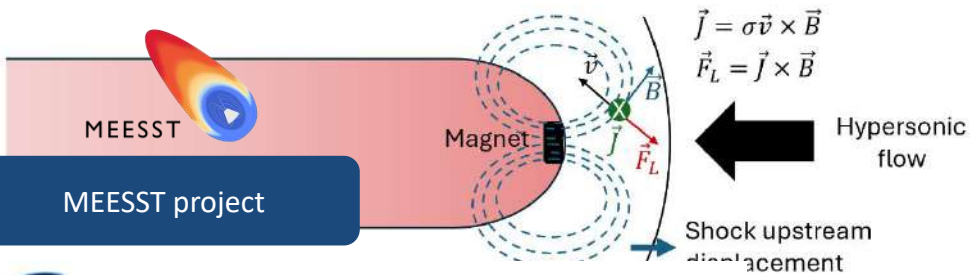
e^- Cooling



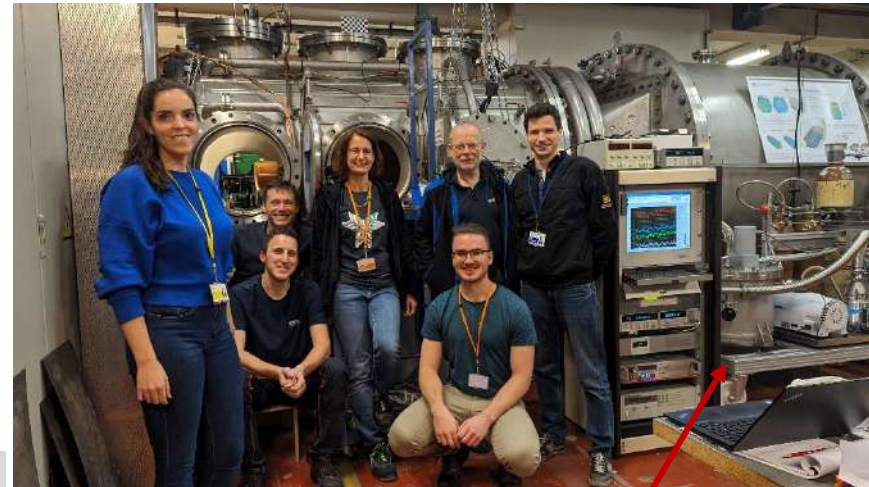
MHD Cooling



Magnetic shielding for entry systems

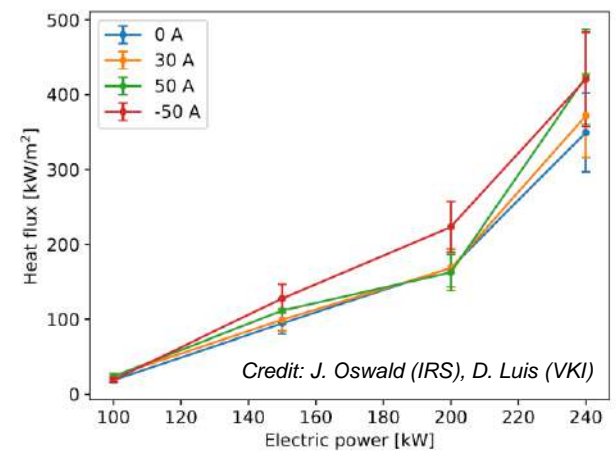
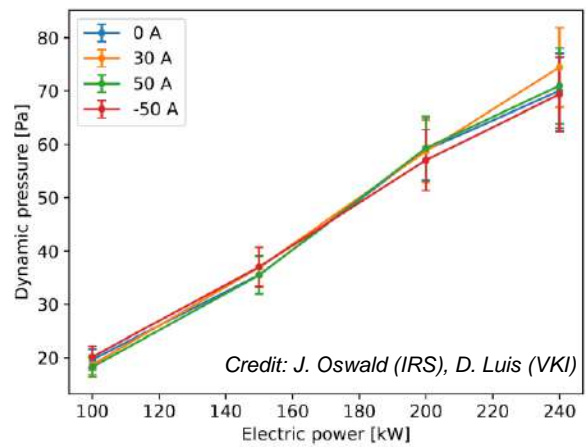
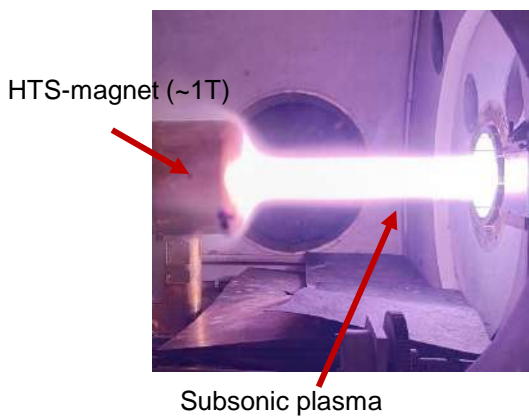


EU's Horizon 2020 Research and Innovation Programme under grant agreement 899298.



He Cryogenic system

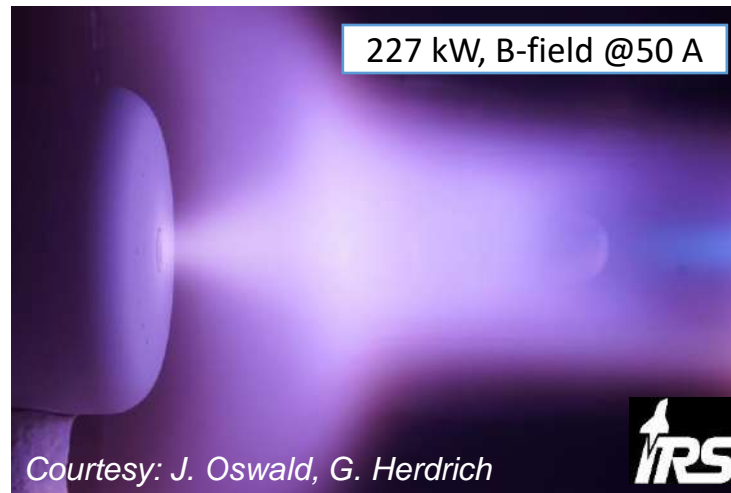
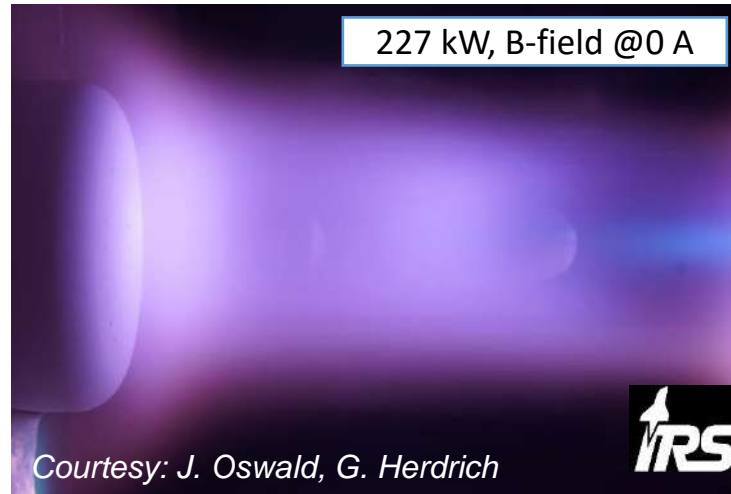
1st MHD experiment in VKI Plasmatron:



We should go to supersonic plasma to increase F_L

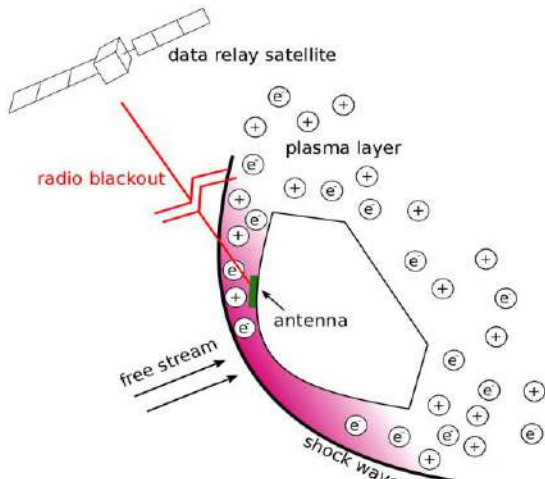
Magnetic shielding for entry systema

Tests performed at IRS (Stuttgart) in PWK1 (w/ RD5) show a shock displacement with B-field



Radio blackout mitigation

Communications can be interrupted by flow ionization



For transmission: $f_r > f_p$

$$f_p = \frac{1}{2\pi} \sqrt{\frac{q_e^2 n_e}{m_e \epsilon_0}} \approx 9 \sqrt{n_e}$$

Frequency, GHz	Plasma density, m^{-3}	Designation
0.30	1.12×10^{15}	Apollo (Voice communication, UHF)
0.92	1.06×10^{16}	Space Shuttle (Voice communication, UHF)
1.55	2.99×10^{16}	GPS
1.68	3.52×10^{16}	OREX (Data telemetry, L-band)
2.29	6.54×10^{16}	Apollo (Data telemetry, S-band)
8.20	8.75×10^{17}	Mars Pathfinder (Data telemetry, X-band)
32.0	1.27×10^{19}	Deep-space communication (Ka-band)

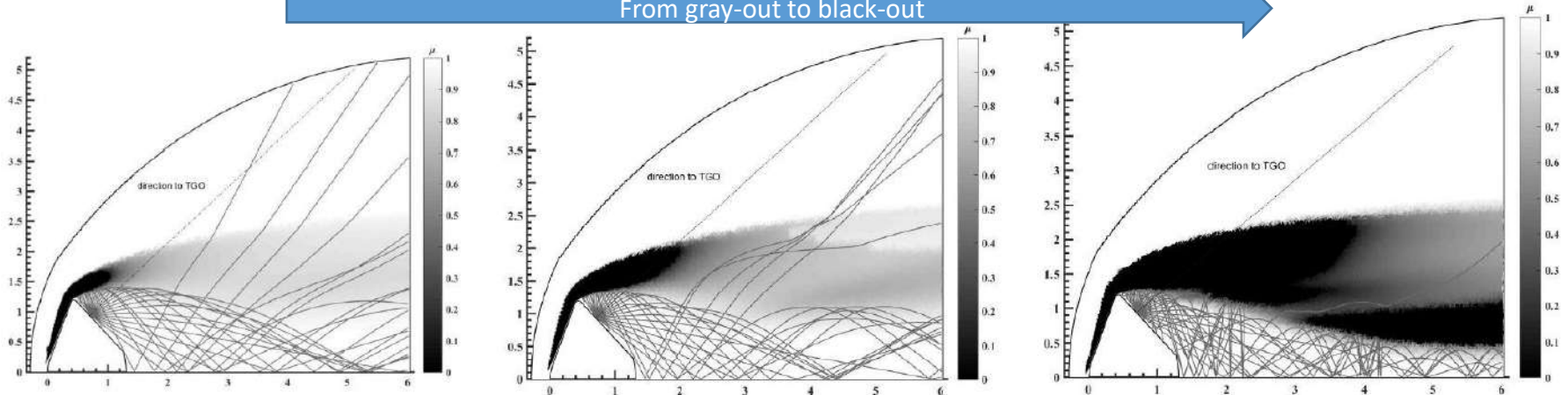
Kim, Min Kwan, "Electromagnetic Manipulation of Plasma Layer for Re-Entry Blackout Mitigation", 2009

t = 17s

t = 22s

t = 38s

From gray-out to black-out



Ramjatan et al., "Blackout Analysis of Reentry Vehicles for Martian Missions", IPPW-15, Colorado 2018

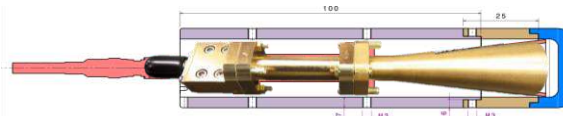
Radio black-out mitigation

Communication test was performed in MEESST project

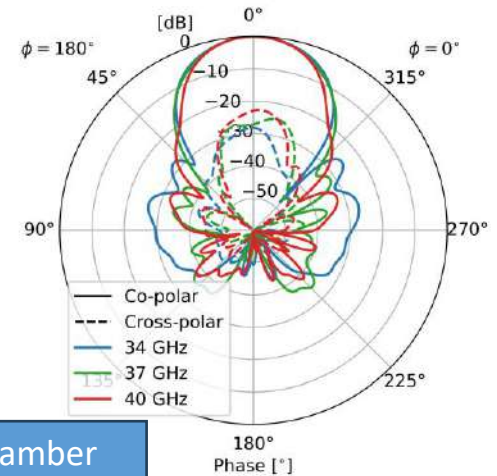


MI-WAVE
Millimeter Wave Products Inc.

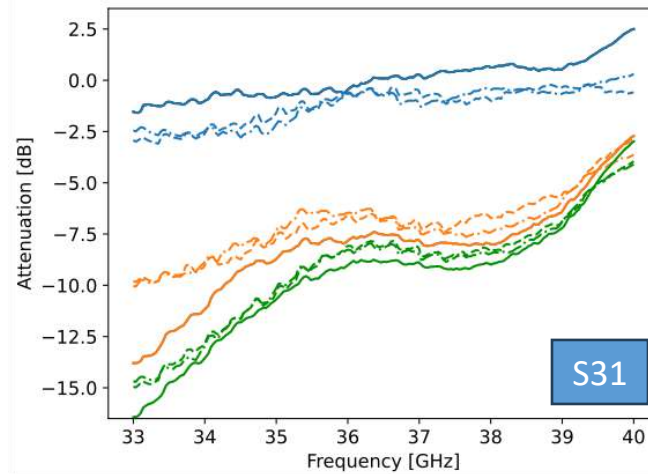
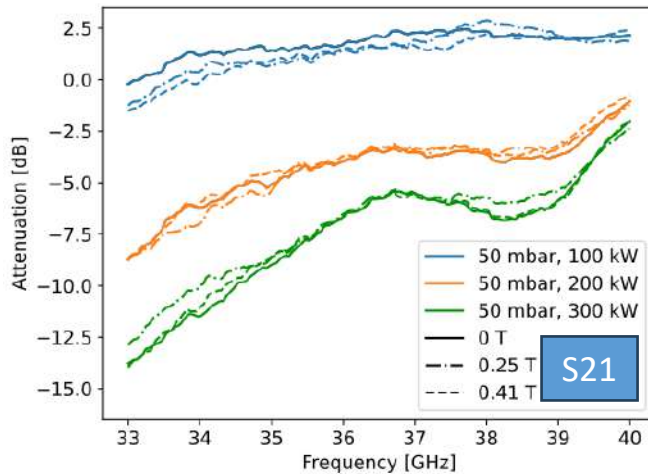
Conical horn antenna
Gain 15 dBi typical
Freq. 26 to 40 GHz



UPC anechoic chamber



EU's Horizon 2020 Research and Innovation Programme under grant agreement 899298.



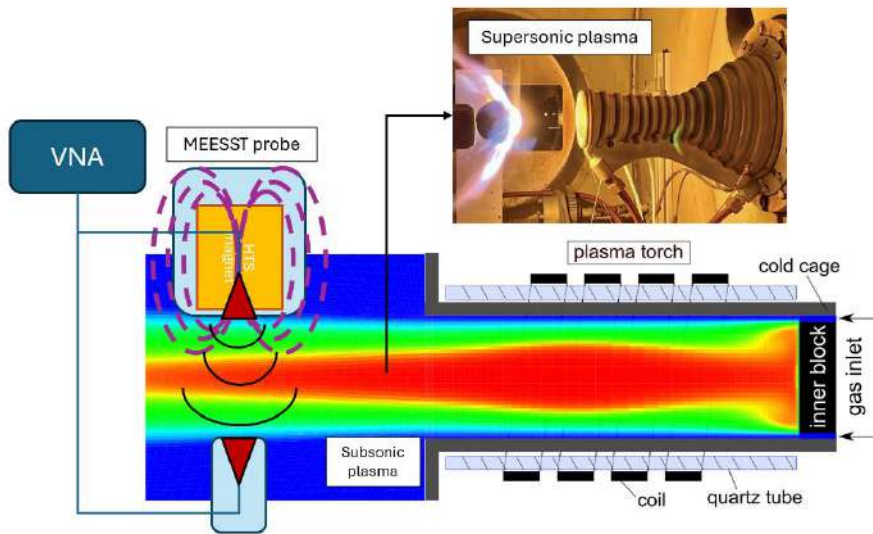
- Attenuation increases w/ PW
- Effect of B-field remains limited

Test in supersonic to increase Lorentz force

Radio blackout mitigation

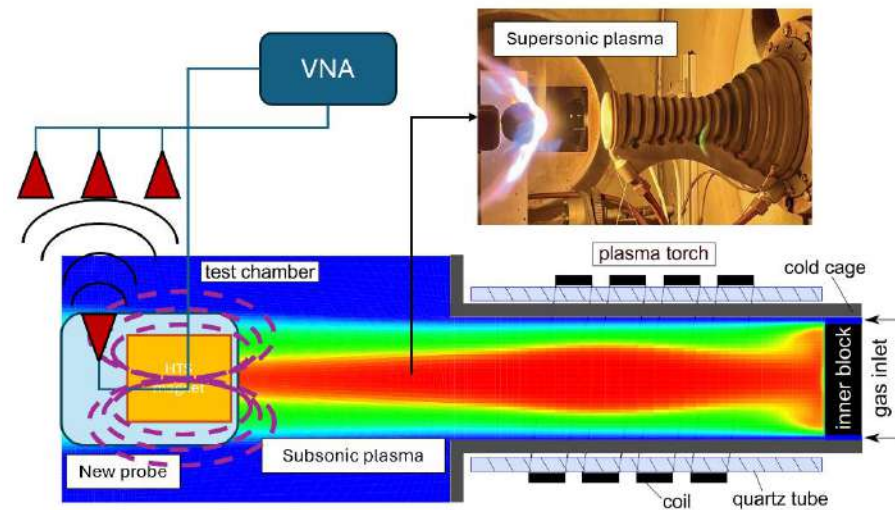
Proposed research activity:

Academic test case



- Tests can be done in subsonic and supersonic,
- Possibility to measure heat flux with the 3rd probe from the top of the chamber,
- Reduce distance between antennas to reduce influence of signal reflections

Flight test case



- Probe B-field configuration like in MEESSST (to reduce HF at stagnation point),
- Antenna at off-stagnation point to simulate leeside of the capsule.



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