EPIC

ELECTRIC PROPULSION INNOVATION AND COMPETITIVENESS

SITAEL

AN ANGEL COMPANY

HALL EFFECT THRUSTER RAM-EP CONCEPT

EPIC WORKSHOP

LONDON, 17 OCTOBER 2018

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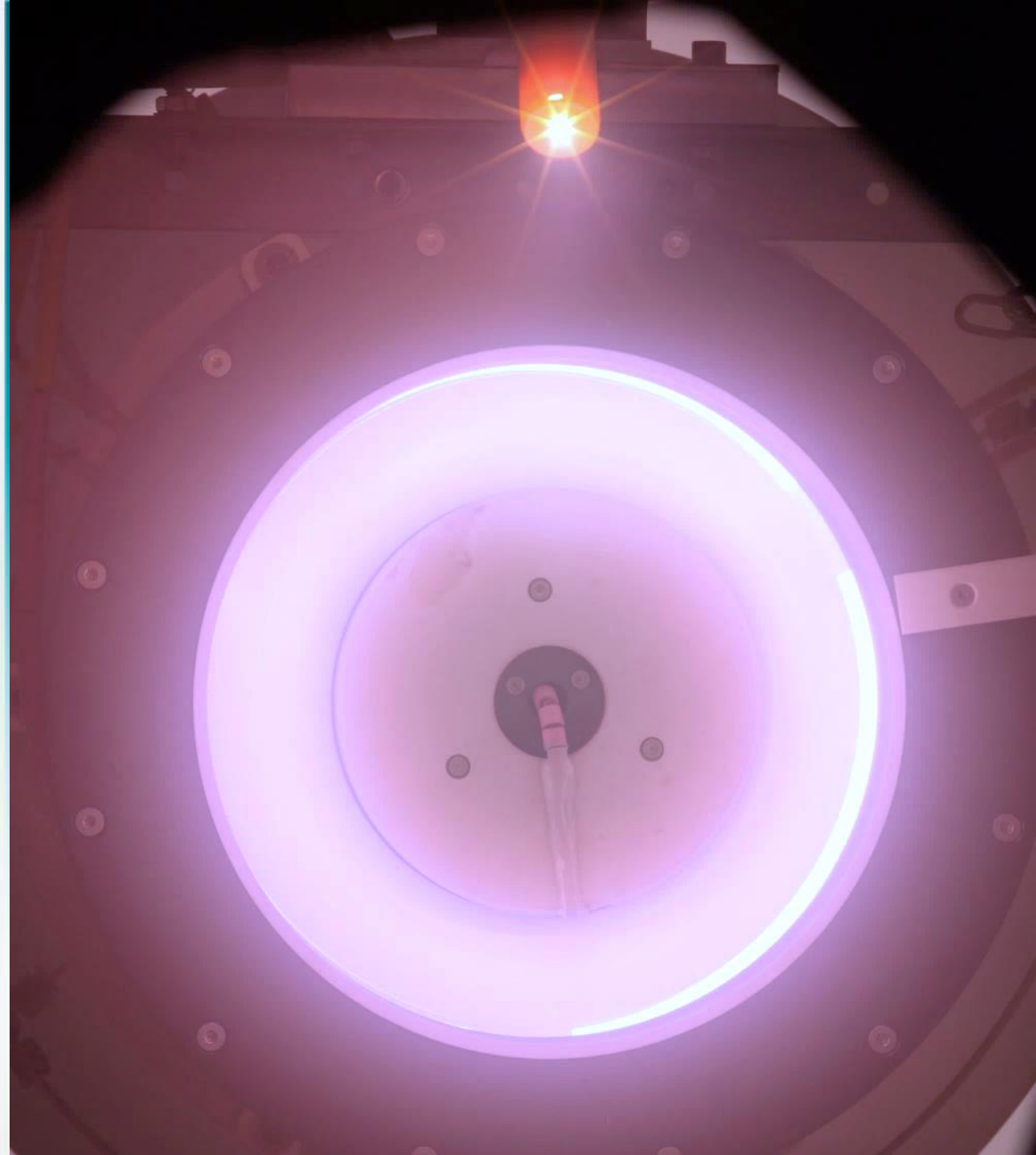


Introduction

What is an “air-breathing EPS”?

A **propulsion system** that uses electrical energy to change the velocity of a spacecraft, using the **atmosphere as propellant**.

The spacecraft **engine ingests the atmospheric gasses**, **ionizes** a fraction of them **and accelerates** the ions to higher velocity. The system does not require to store the propellant as with conventional electric propulsion.

Why using an “air-breathing EPS”?

The air-breathing EPS will allow to perform long duration LEO missions with less or no propellant.

It can be used for very low Earth orbit missions such as earth observation, telecommunications, science missions.

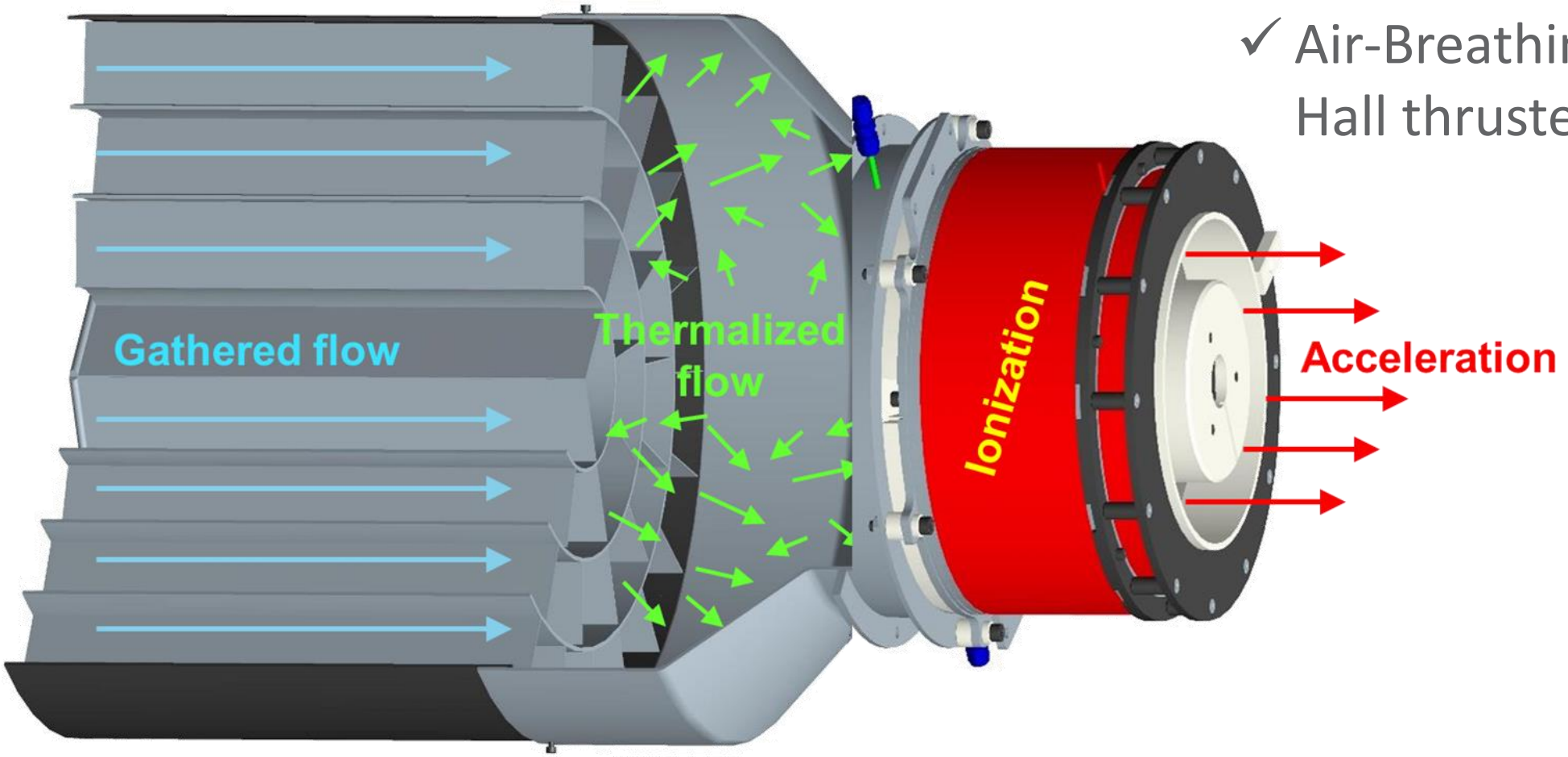
Sitael heritage on RAM-EP

Main activities performed under ESA TRP **Assessment of the Key Aerothermodynamics Elements for the Realization of a RAM-EP Concept** (2015-2017)

- ✓ *Phase 1: performance prediction and design*
  - ❑ Requirements definition and conceptual design of a RAM-EP intake
  - ❑ Design and performance prediction of a RAM-EP concept for on-ground testing
  - ❑ Selection and analysis of suitable Particle flow Generator for RAM-EP validation
- ✓ *Phase 2: MAIT*
  - ❑ RAM-EP intake and collector design finalization and MAI
  - ❑ RAM-HET design finalization and MAI
  - ❑ Experimental test of the Particle Flow Generator
  - ❑ Experimental test of the RAM-EP prototype

RAM-EP Model Overview

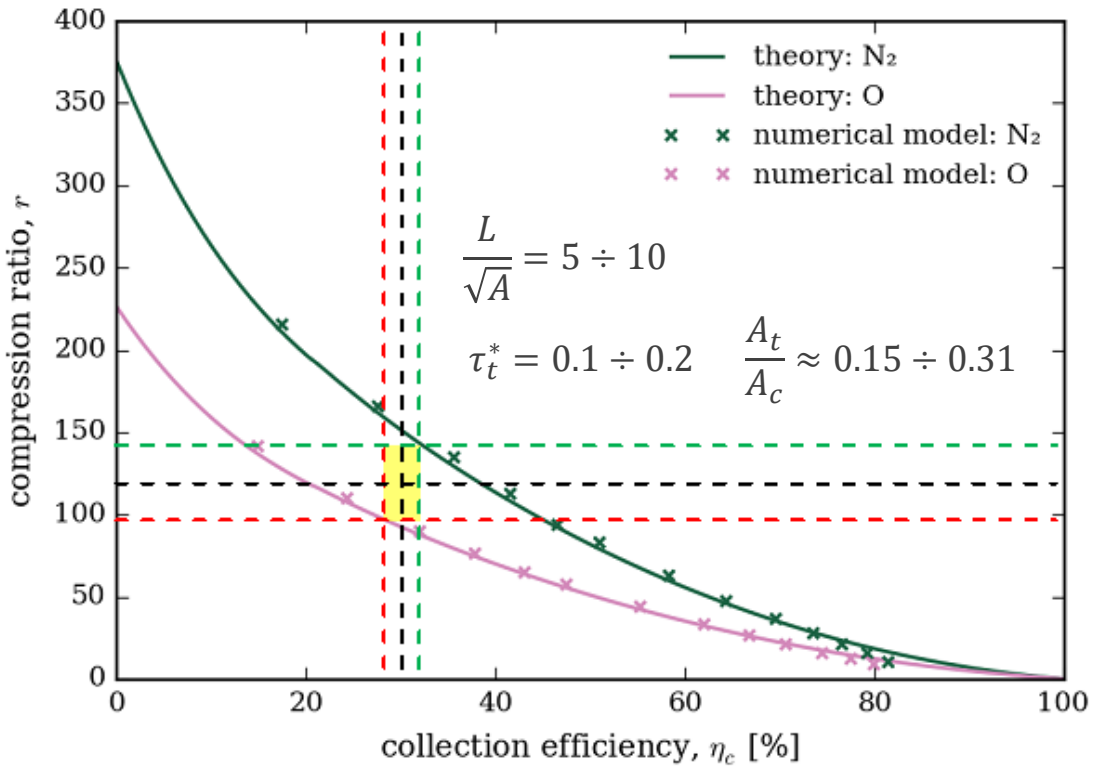
- ✓ Passive Split-Ring Intake
- ✓ Air-Breathing Double Stage Hall thruster (RAM-HET)

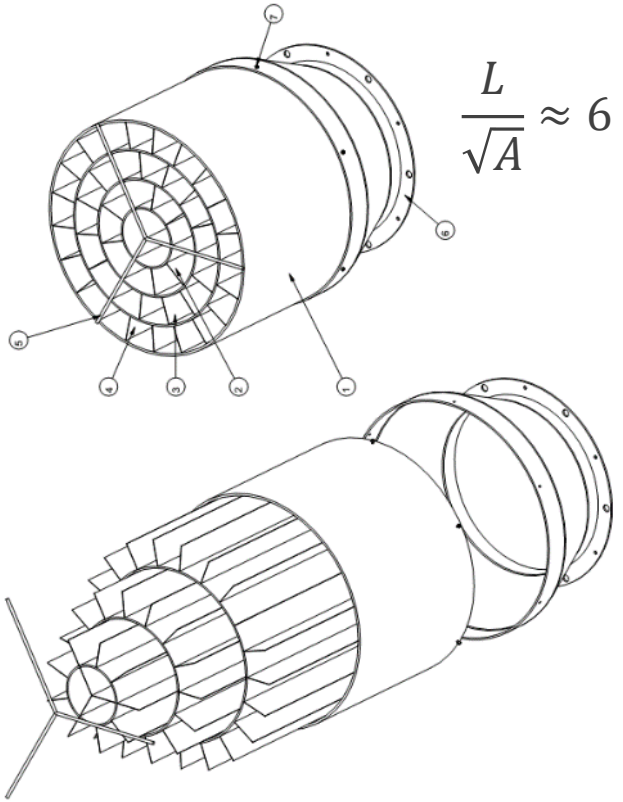


Intake and Collector

η_c= collection efficiency ≅ .28 ÷ .32

r= compression ratio ≅ 95 ÷ 140

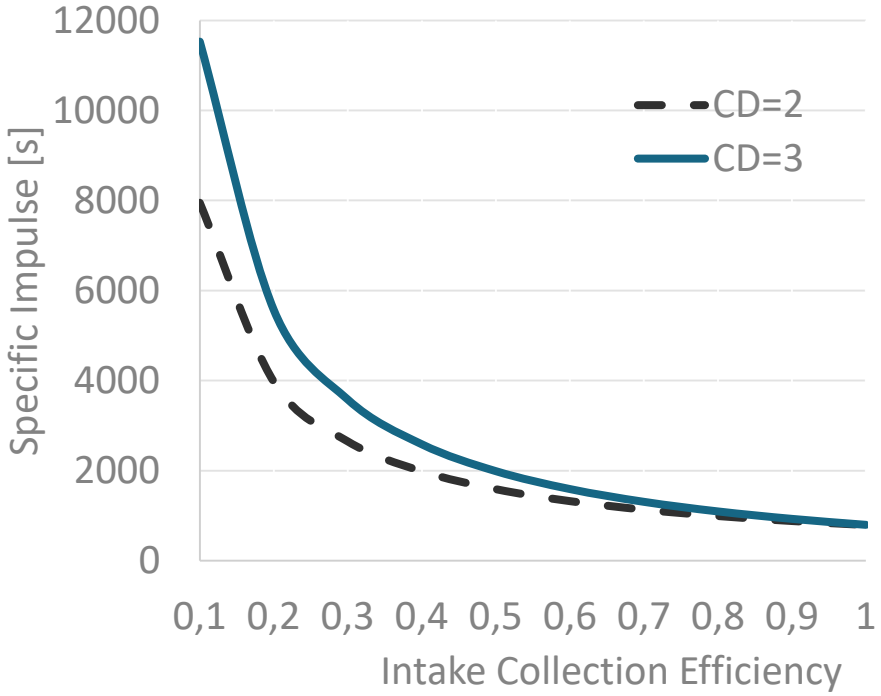




$\frac{L}{\sqrt{A}} \approx 6$

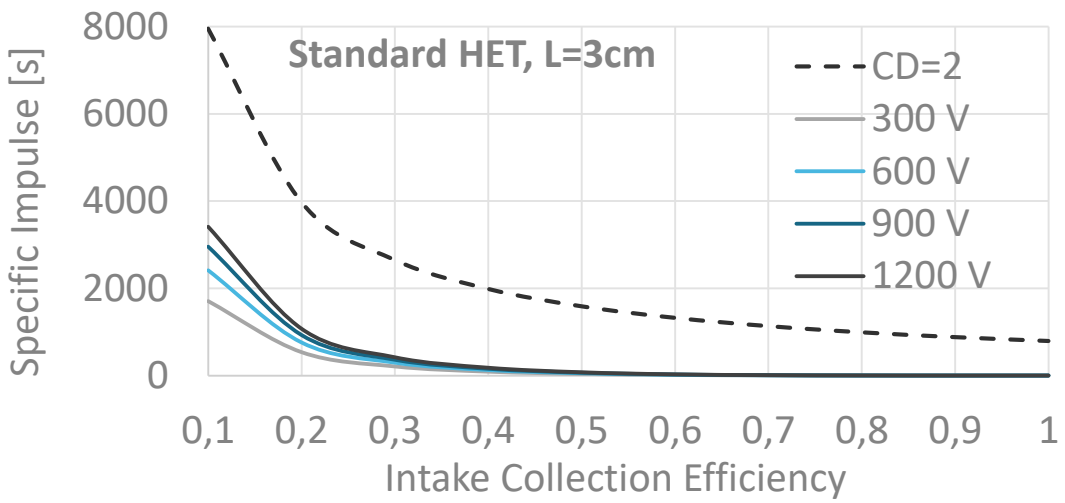
$A_i = 0.126\ m^2$

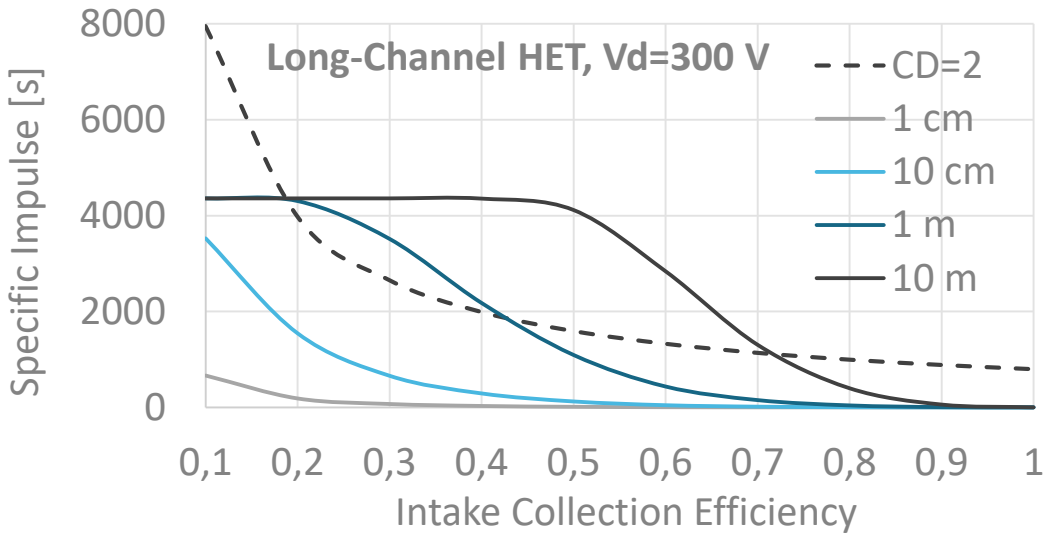
HET RAM-EP: Requirement on Specific Impulse



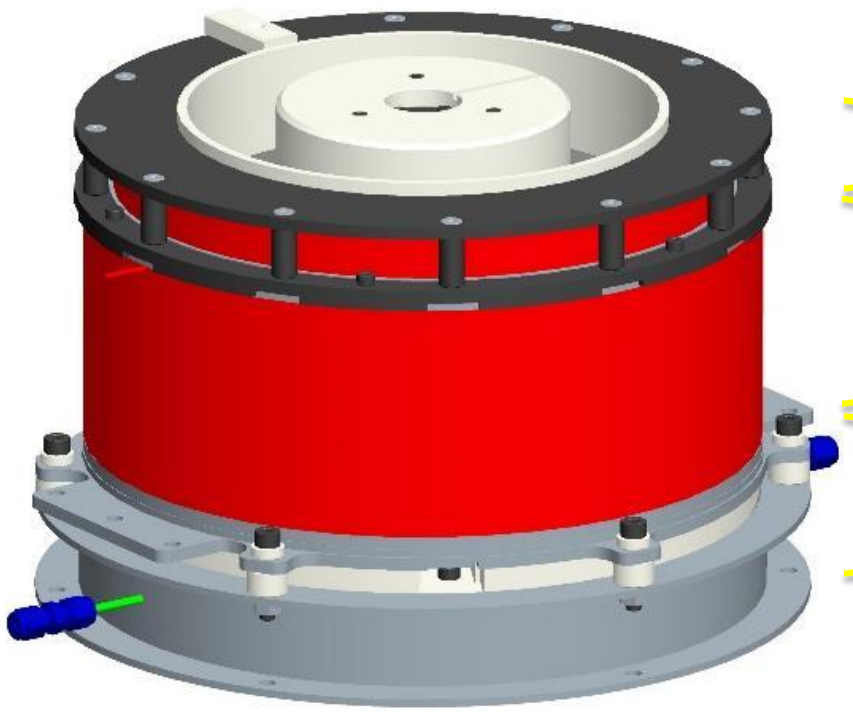
$$I_{sp,HET} \geq I_{sp,min}$$

$$\frac{\gamma \cdot \eta_m}{g_0}\sqrt{\frac{2e\eta_v V_d}{M}} \geq \frac{u_\infty}{g_0}\left[1+\frac{(1-\eta_c)}{2\eta_c}C_D\right]$$





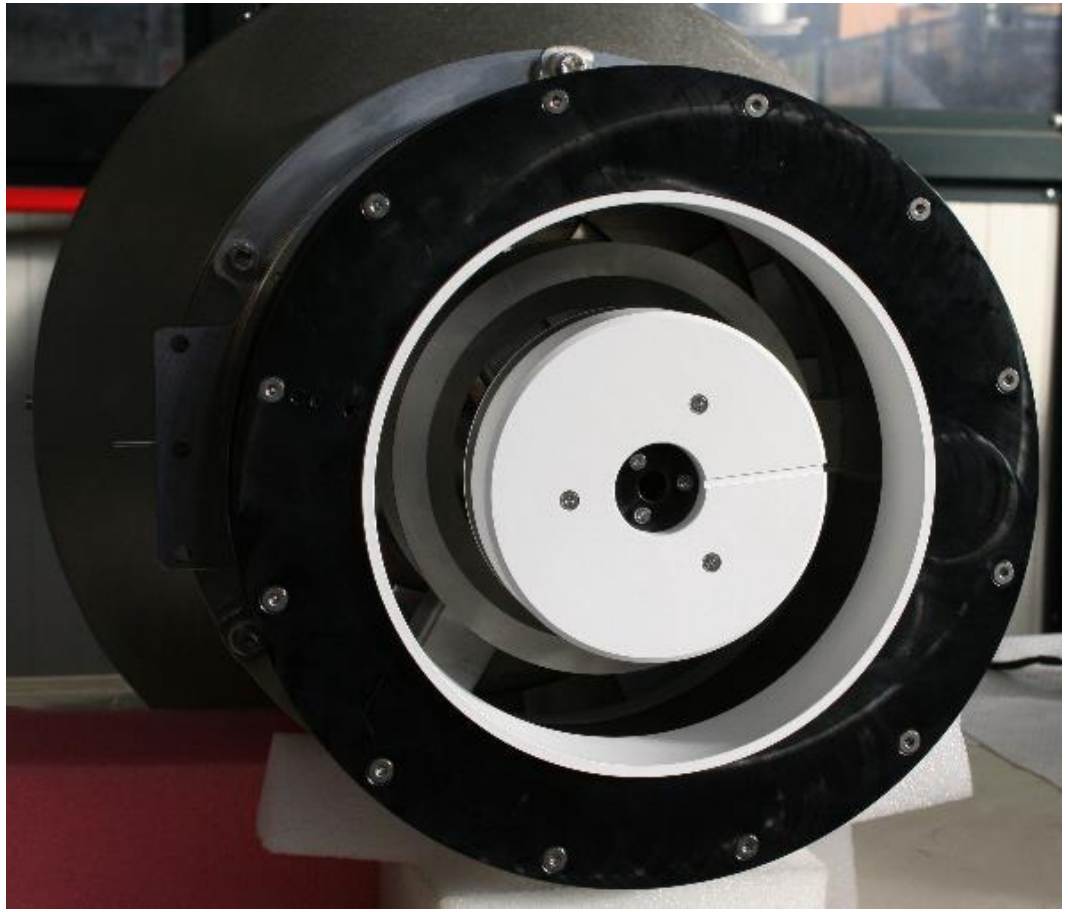
SITAEL's Double Stage RAM-HET



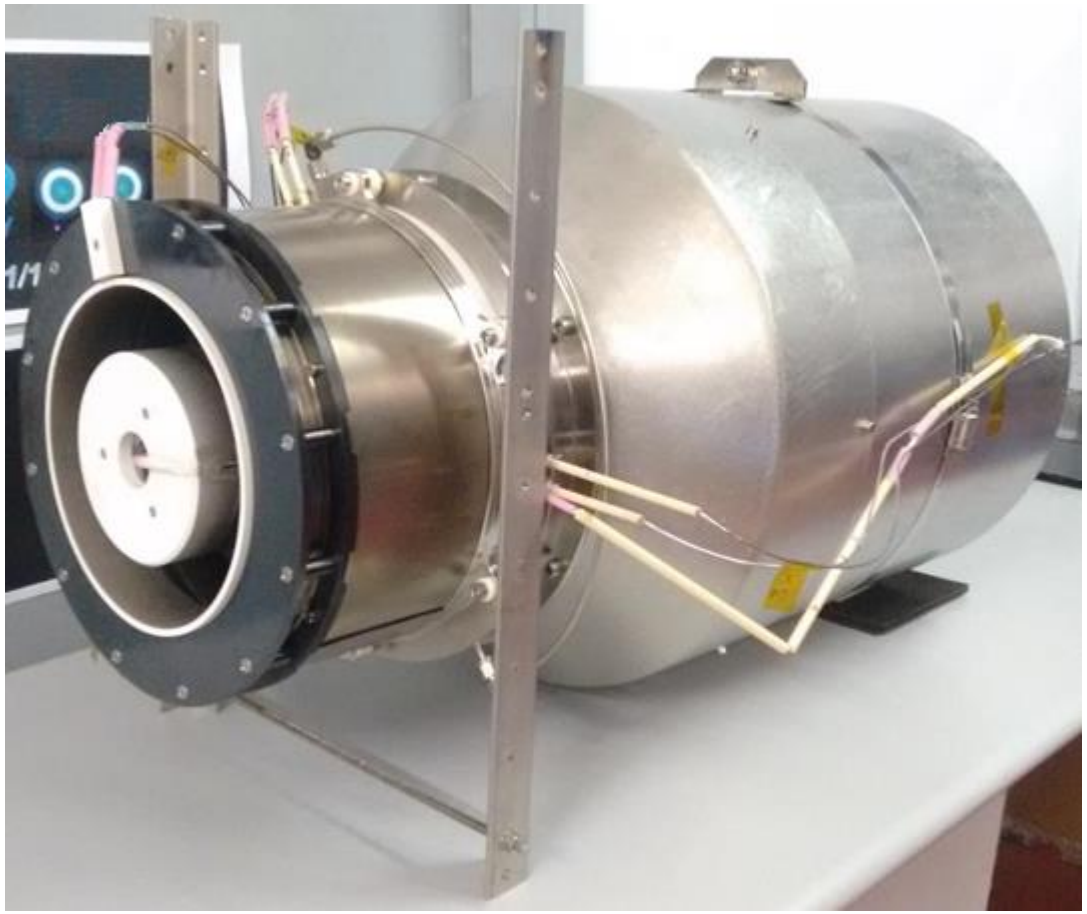
Acceleration stage

Ionization Stage

Auxiliary distributor

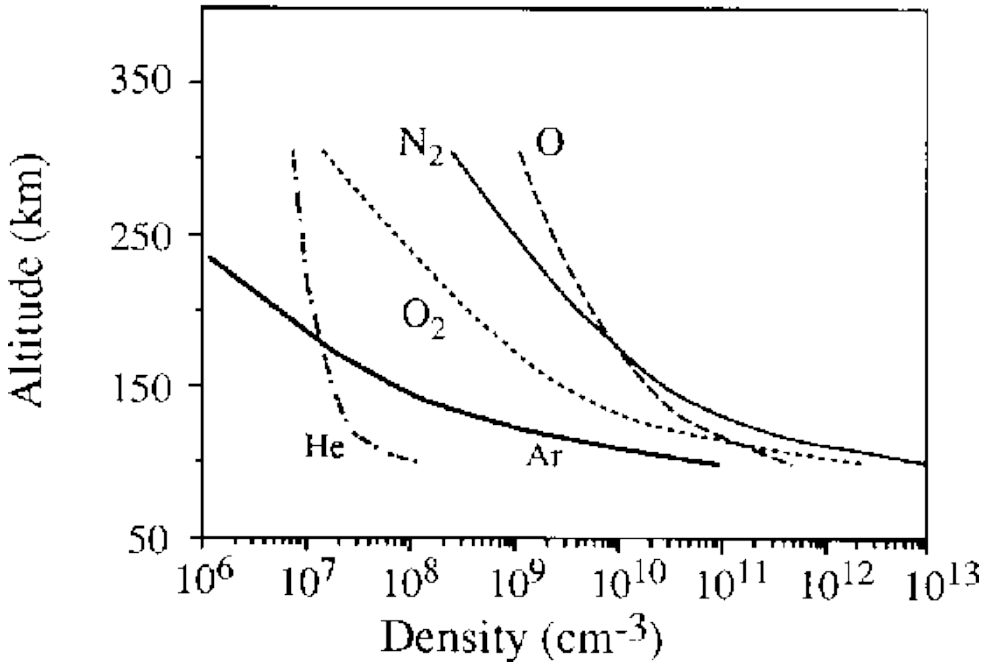


Fully-Assembled RAM-EP prototype



Particle Flow Generator as a Wind Tunnel for RAM-EP systems

- Sitael HT5k was selected as flow source
- Mixture simulating the atmosphere at 200 km altitude: **$1.27N_2+O_2$**



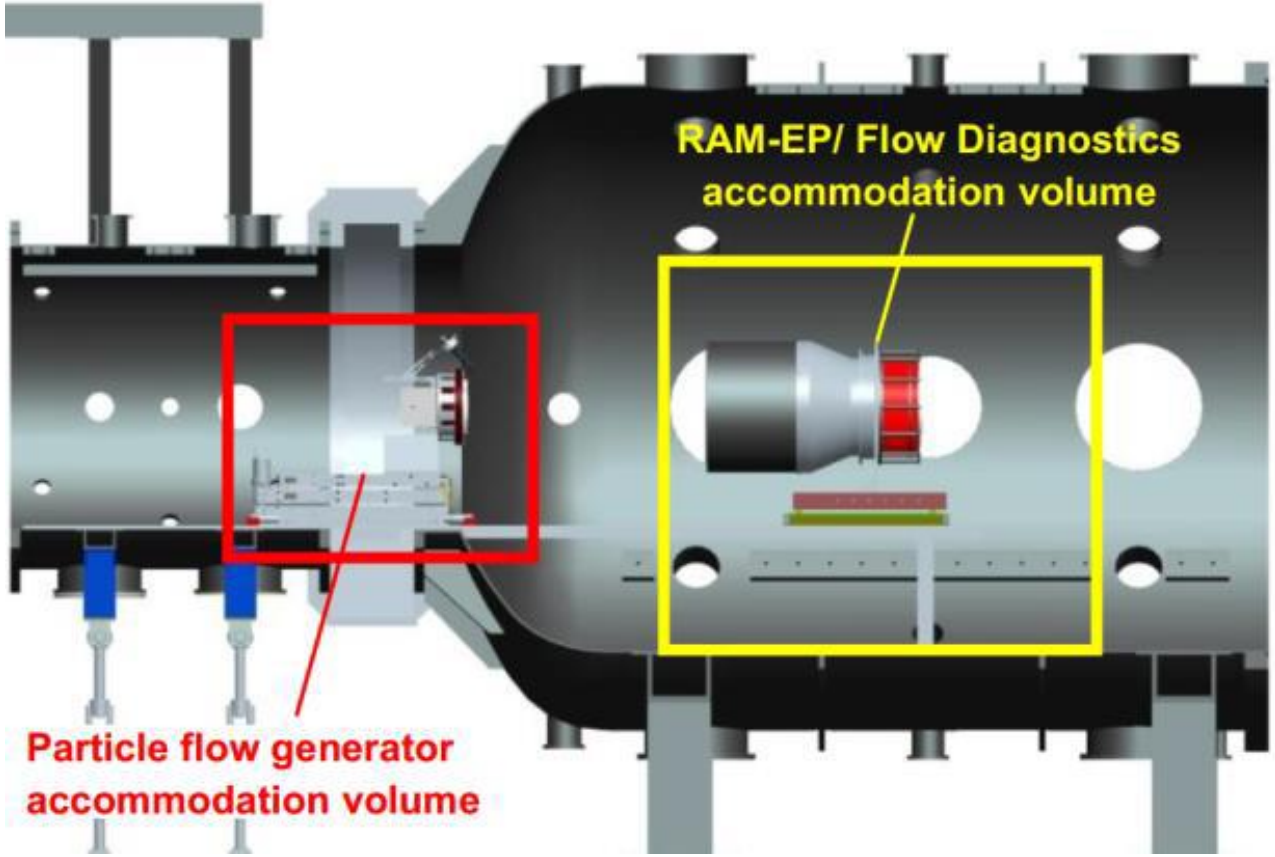
Different flow conditions (in terms of velocity and air density) can be obtained by changing the PFG operational parameters and the distance between the PFG and the RAM-EP intake.

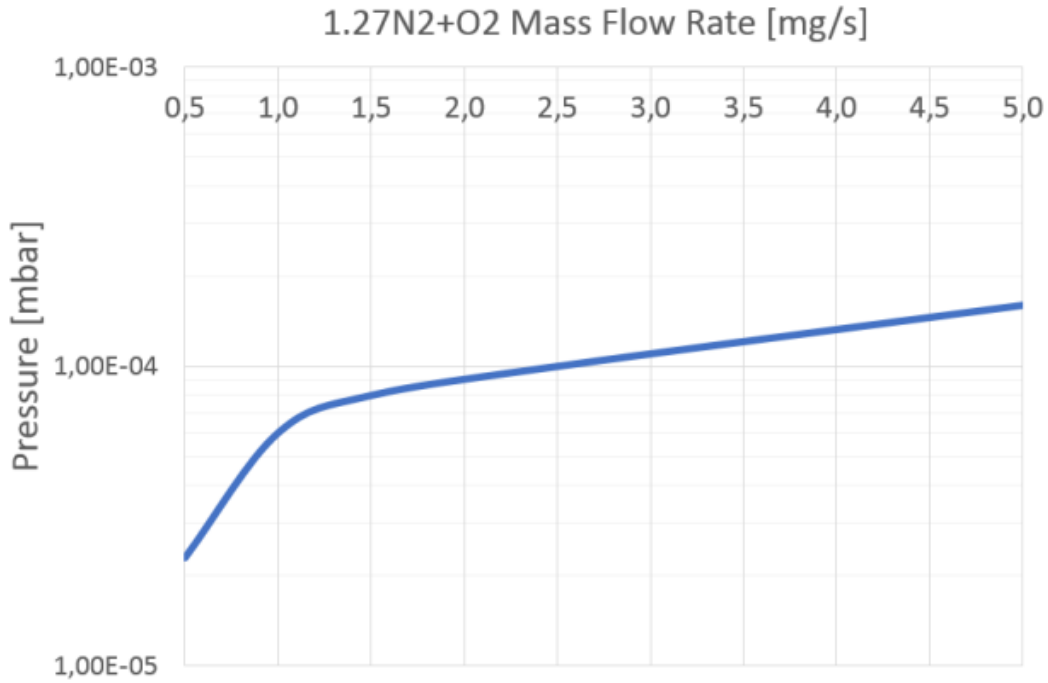
$$\begin{cases} n_{eq} v_{eq}^2 = \bar{n}_i \bar{v}_i^2 + \bar{n}_n \bar{v}_n^2 \\ v_{eq} = \eta_m \bar{v}_i + (1 - \eta_m) \bar{v}_n \end{cases}$$

Estimated PFG flow properties envelope in IV4 vacuum facility		
Flow Property	**Min. Value**	**Max. Value**
Number Density [m^{-3}]	4.4e14	1.6e18
Particle Velocity [km/s]	9	13.7

Experimental Campaign Description

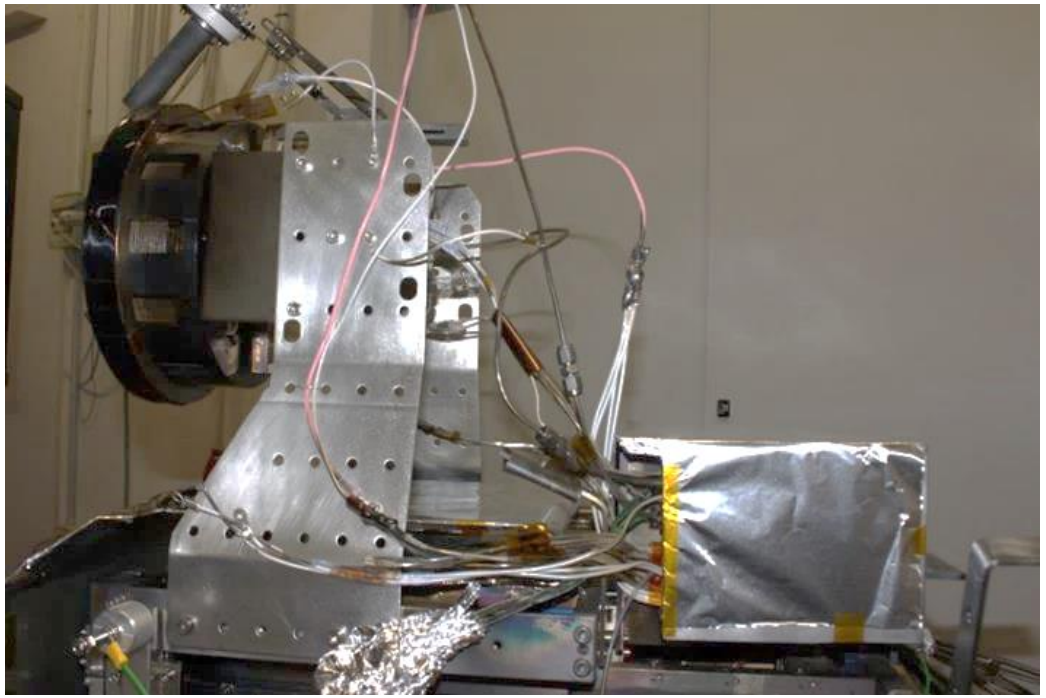
- RAM-EP Concept Validation Setup: IV4 Vacuum facility





Experimental Campaign Description

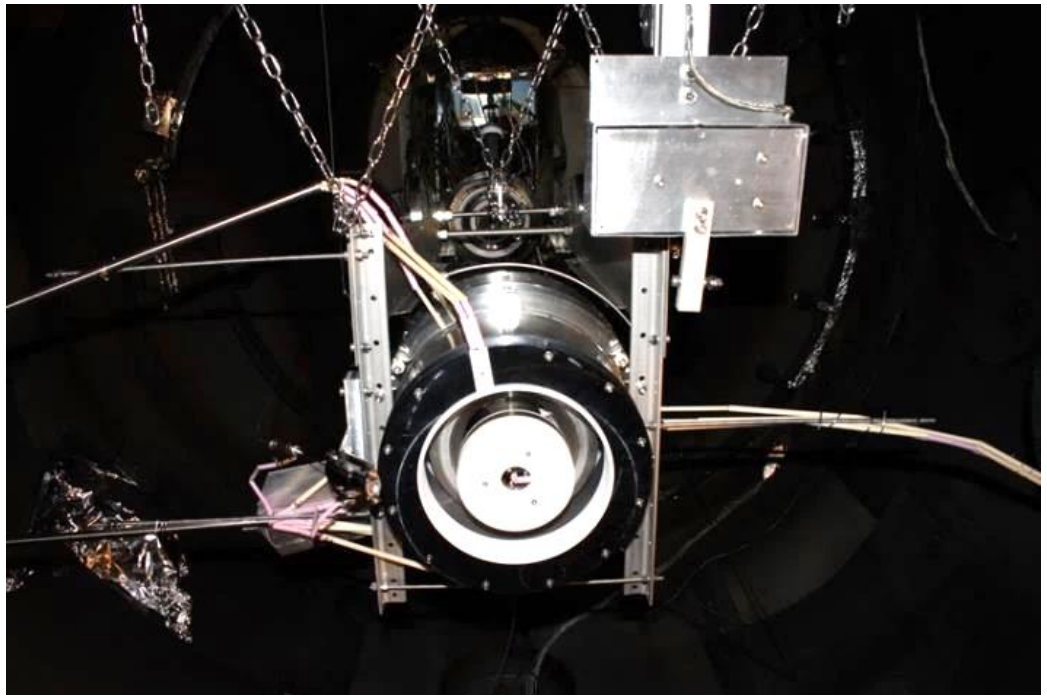
- Setup: Thrust balances



PFG Thrust Balance

Thrust (max) = 400 mN

Resolution = 1 mN



RAM-EP Thrust Balance

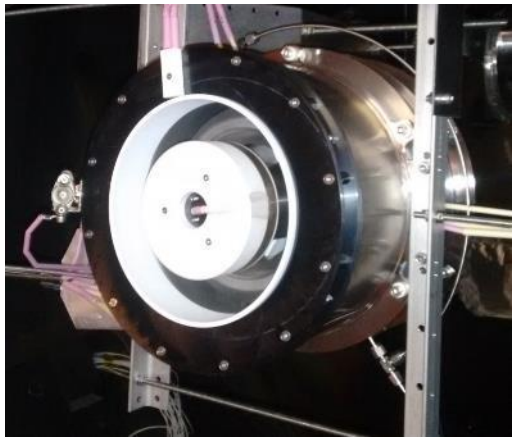
Thrust (max) = ± 1 N

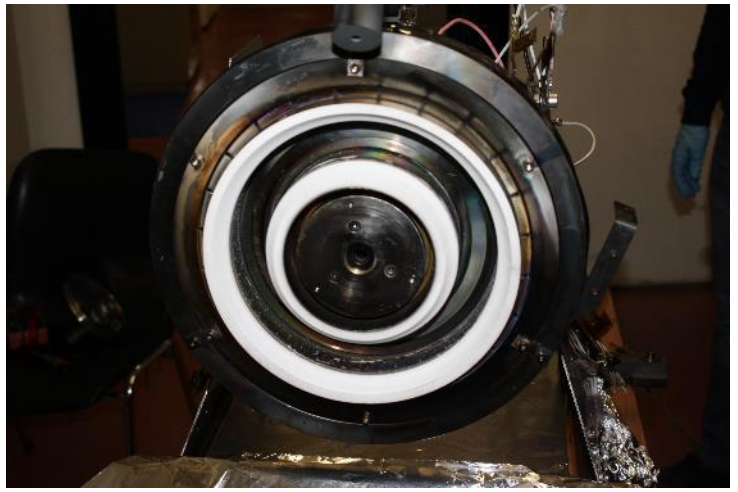
Resolution = 1 mN

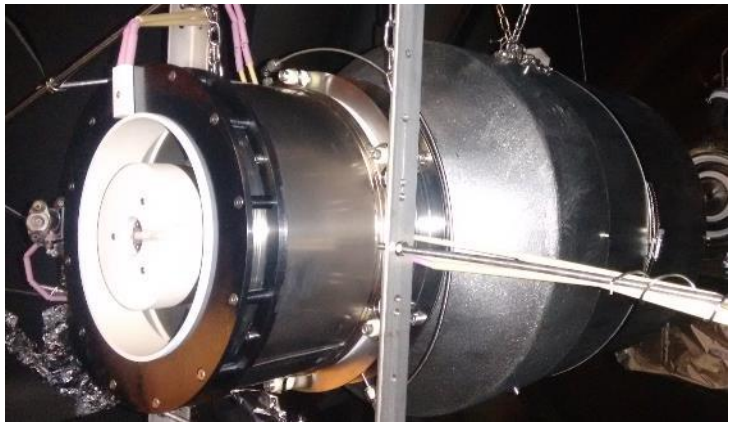
Experimental Campaign Description

➢ Test plan

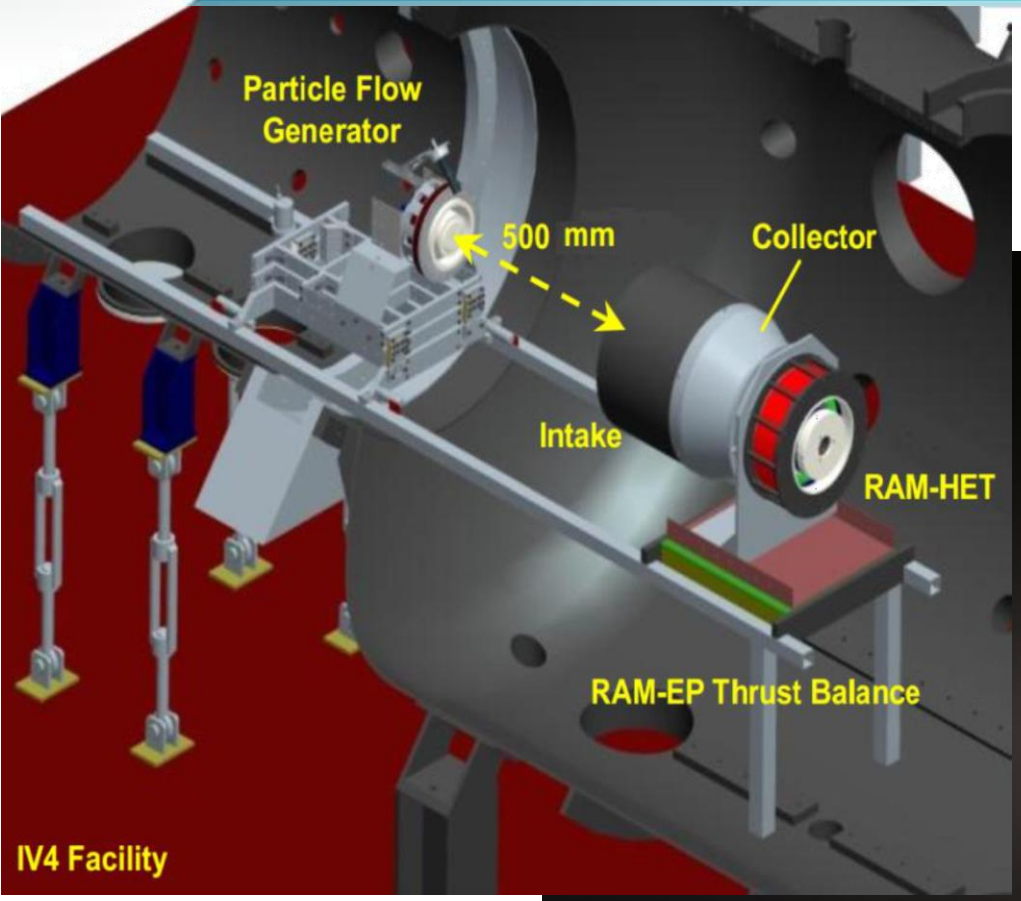
- **Flow Particle Generator Test**
  - ✓ July 11th – 18th 2016
- **RAM-HET Preliminary Test**
  - ✓ April 14th-20th 2017
- **RAM-EP Concept Validation Test**
  - ✓ April 21st – May 11th 2017



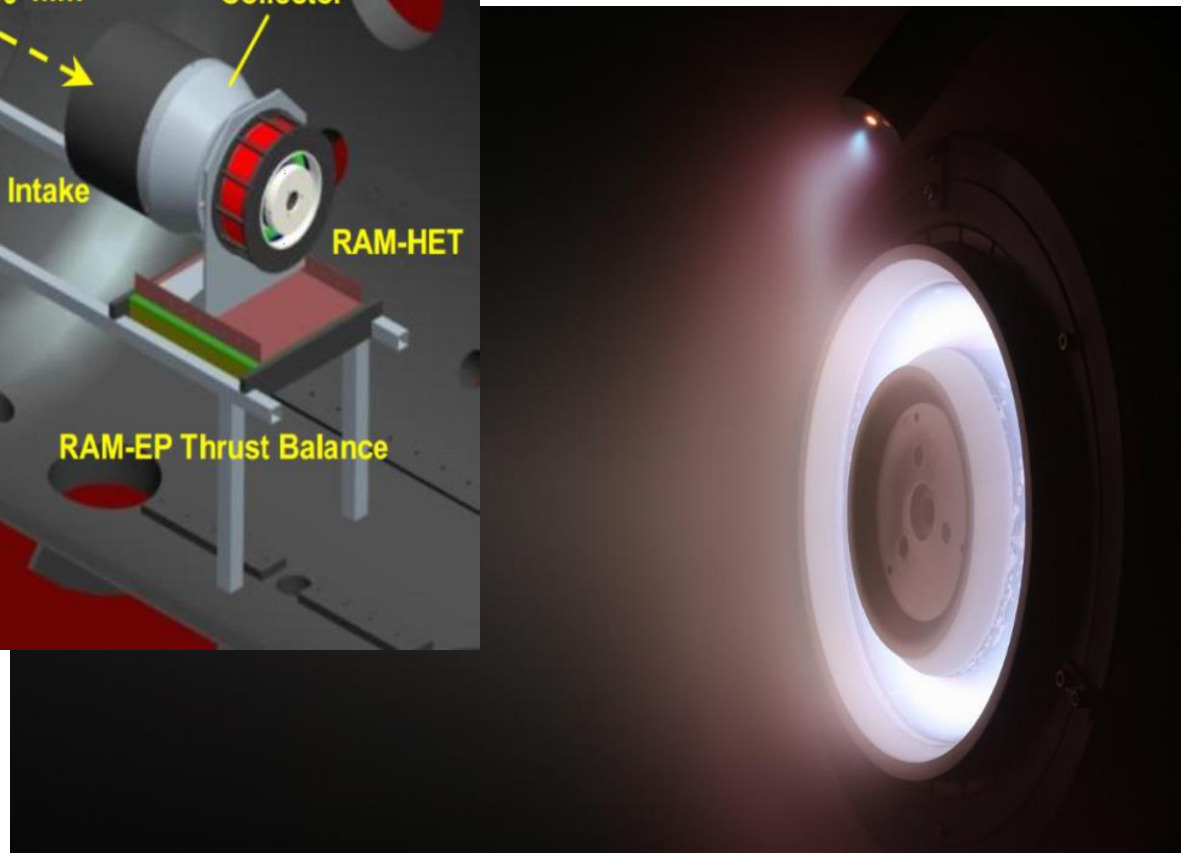




Particle Flow Generator Test

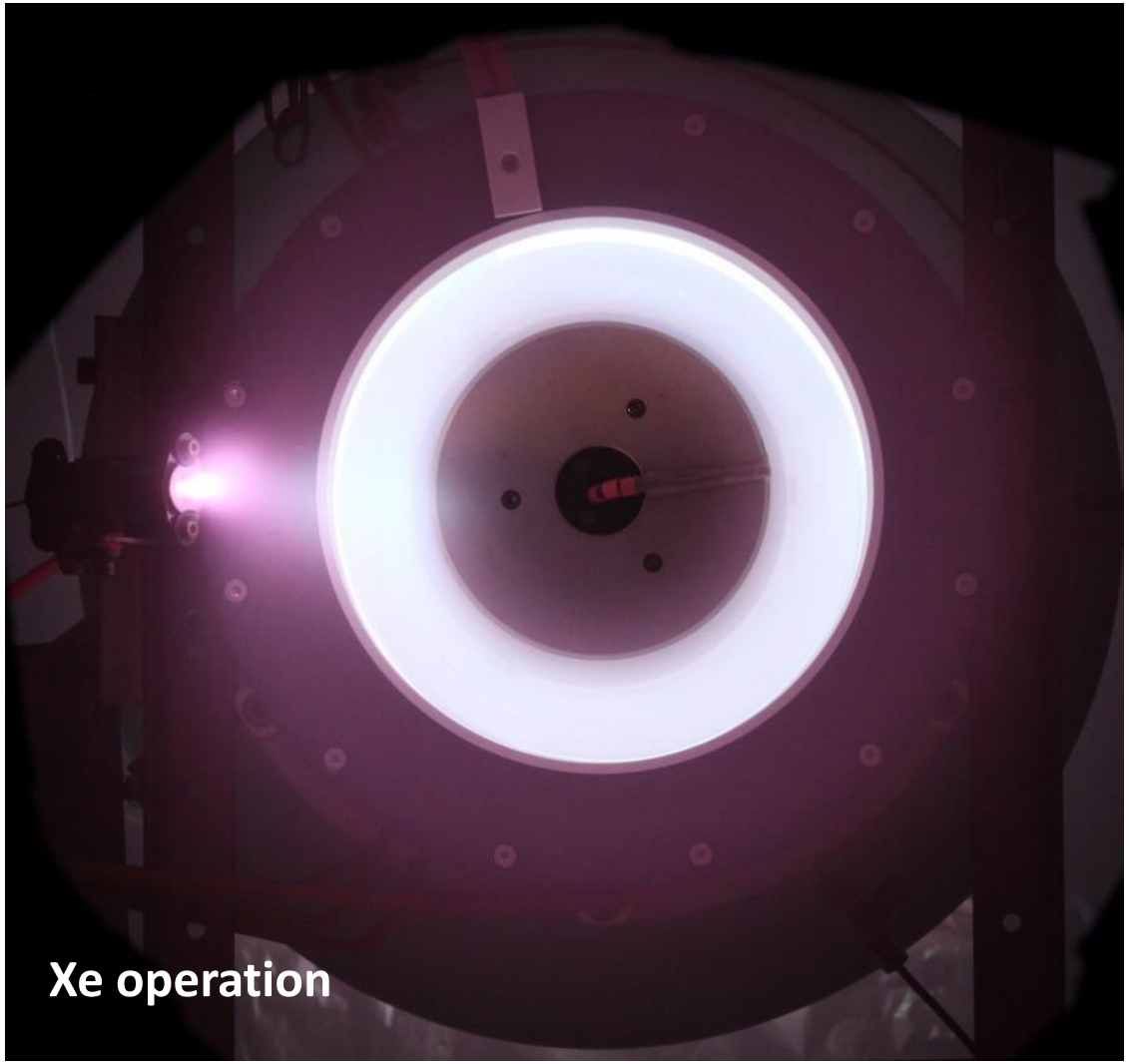


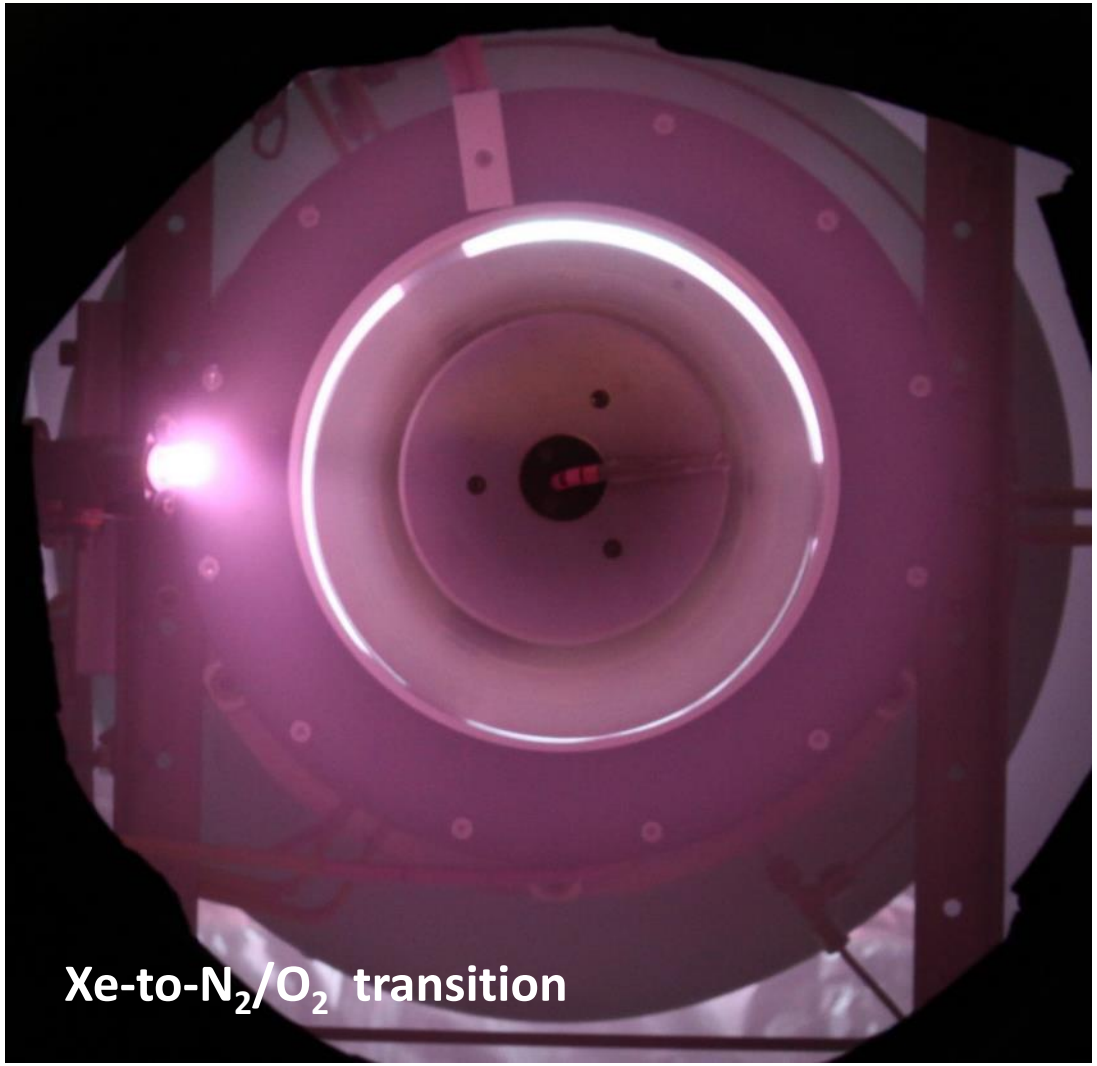
Stable HT5k operation with atmospheric propellant was experimentally verified at 225 V and at AMFR ranging from 4.3 to 4.7 mg/s of 1.27N_2+O_2 mixture.



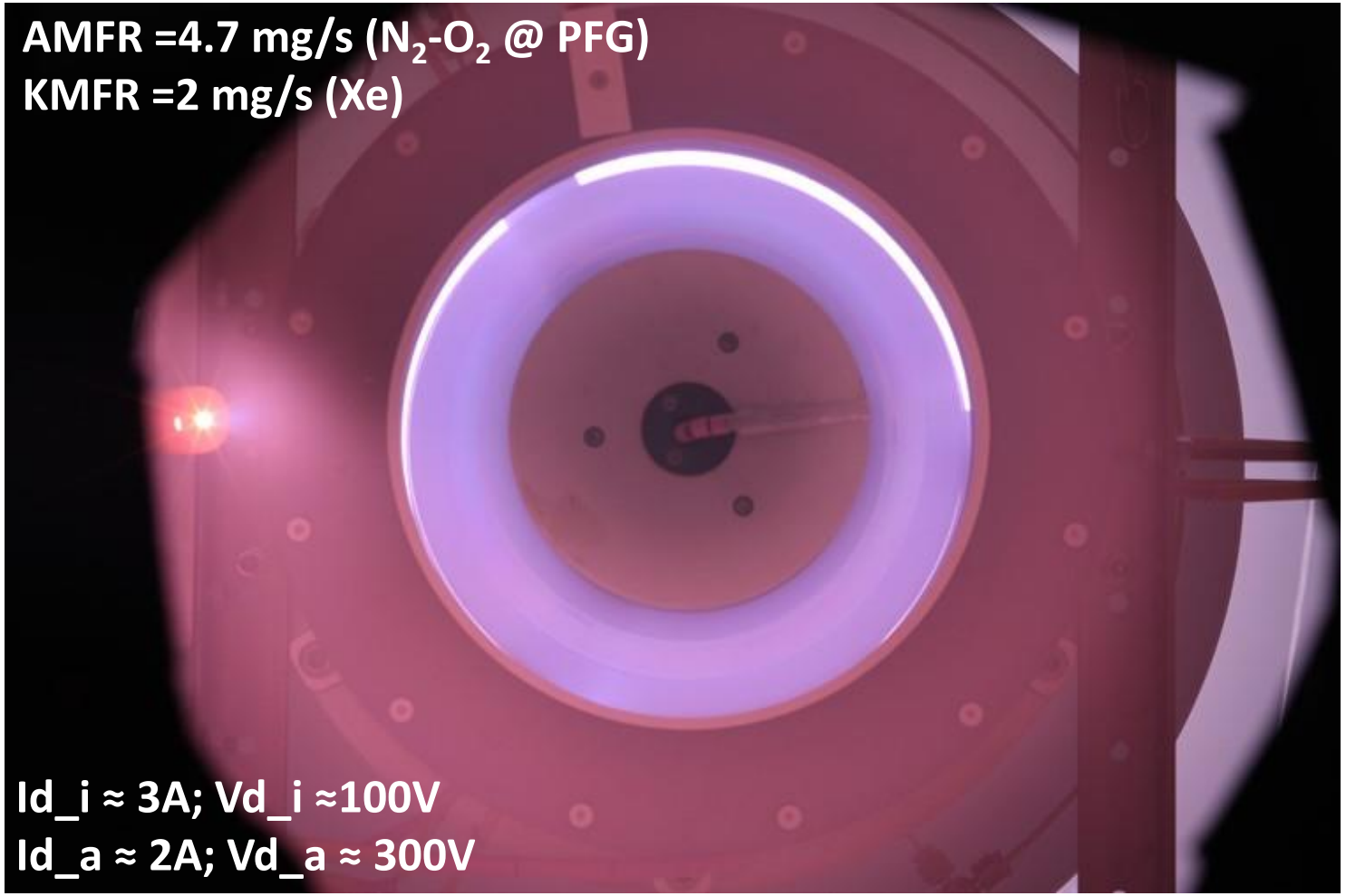
- $AMFR = 4.7\ mg/s$ 1.27N_2+O_2
- $I_D = 15.3\ A$
- $V_D = 225\ V$
- $P_D = 3.44\ kW$
- $L = 500\ mm$
- $n_{eq} = 7.25 \cdot 10^{16}\ m^{-3}$
- $v_{eq} = 9.1\ km/s$

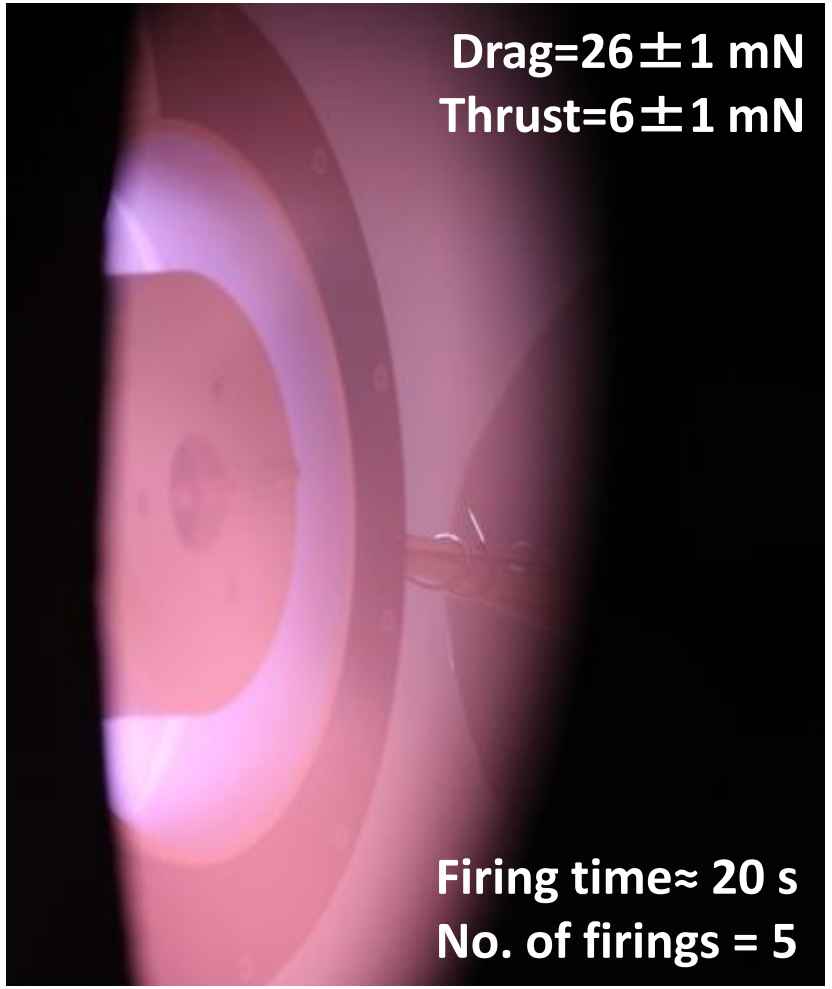
RAM-EP concept validation





RAM-EP concept validation





Roadmap for the RAM-EP concept

❑ Design, MAI and test of the passive intake

Even if no direct measurements were performed, **compression and collection capabilities of the intake were sufficient to let the thruster ignite** the flow provided by the PFG.

To do:

- ✓ Detailed characterization of the intake;
- ✓ Experimental confirmation of collection efficiency and compression ratio.

Roadmap for the RAM-EP concept

❑ Experimental validation of the Particle Flow Generator

The **mean characteristics of the generated flow** were representative (same order of magnitude) of a 200 km of altitude flight scenario

To do:

✓ Punctual characterization and optimization of the particle flow generator, to verify its ability to mimic molecular composition and atomic species available at altitudes 180-250 km.

Roadmap for the RAM-EP concept

- Design, MAI and test of the air-breathing Hall effect thruster

The first stage showed a **good ionization** capability, the **acceleration stage must be further improved**;

To do:

- ✓ To review the design of the acceleration stage.
- ✓ To re-scale intake, and acceleration& ionization stages for a small spacecraft (maximum 600 W available onboard).

Roadmap for the RAM-EP concept

Activities to be performed at system level:

- ✓ Based on small platforms under development @SITAEL, to perform system design of a RAM-EP spacecraft;
- ✓ Assess the impact of cathode related issues;
- ✓ To pave the way for a fast&cheap near future IOV of the concept.

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