Measurements and kinetic simulations of the Alternative Low Power Hybrid ion Engine (*alphie*)

UPM PlasmaLab

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The alternative low power hybrid ion engine (*alphie*)

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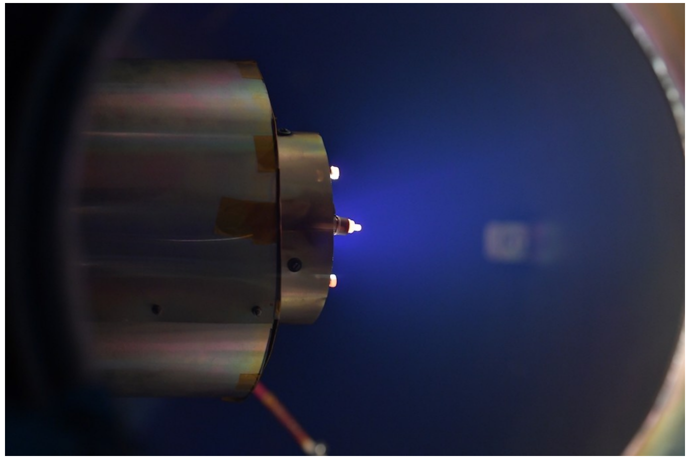

Fig 1. The *alphie* in steady state operation.

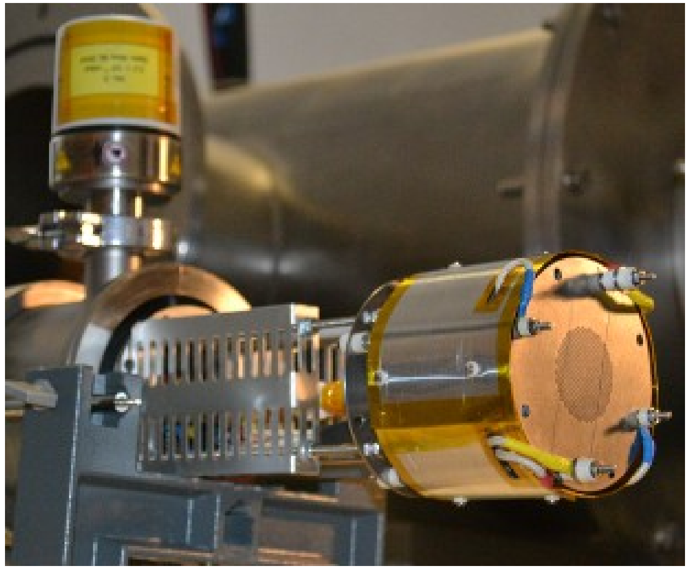

Fig 2. The *alphie* in its support.

- The *alphie* design is a new technology of a plasma accelerator for satellite propulsion in space.
- This small 10 X 15cm plasma thruster operates with less than 350W electric power consumption.
- It is intended for small and medium sized satellites (roughly over 100Kg) where most commercial propulsive systems are nowadays difficult to implement.
- Four prototypes have already been tested in the laboratory.
- This technology is free from ITAR restrictions and two patents have been granted in 2019:

  European Patent Office: Patent EP 3369294B1

  US Patent and Trademark office: Patent US 10172227

Envisaged applications

- Station keeping
- Orbital drag compensation in LEO/MEO
- End-of-life disposal of satellites
- Flight formation

Operation and characteristics

- Operates with only 3 DC power supplies and only two are employed in normal operation. Simple PPU design.
- Easy direct electric connection with solar panels.
- Only one cathode is employed as electron source for both plasma production and ion beam neutralization. This makes an **important difference with conventional gridded ion engines**.
- Testing new cathode technologies.

Magnitude	Value	Commentary
Weight	1.2kg	Without PPU
Dimensions	10 x 15cm	Diameter x length
Propellant gas	Ar, Xe	Kr in the future
Gas flow rate	0.2-2sccm	
Power consumption	200-350W	
Thrust	0.8-3.5mN	Ar, throtteable
Specific impulse	13900-20000s	
Thrust-to-power ratio	4-11mN kW^{-1}	

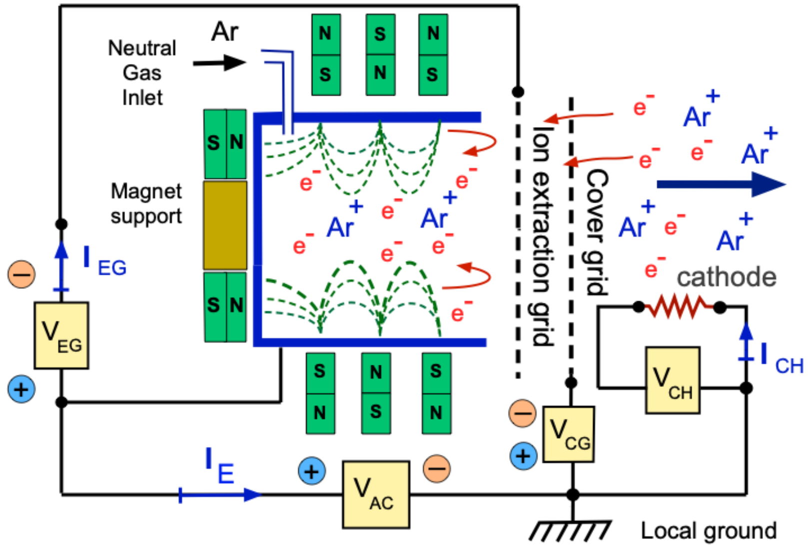

Fig 3. Electrical scheme of the *alphie*.

- Grids are parallel and made of a drilled stainless steel plate and are essential for plasma beam collimation.
- Electrons are trapped by the strong magnetic field.
- Both ions and electrons **counter-flow through the two-grids system.**
- Strong interaction between accelerated electrons and neutrals.
- The electric potentials are always below kV range.

Experimental Characterization: Plasma Plume (I)

- The distribution of ions and electrons along the plasma plume have been measured in different scenarios of operation for *alphie*.
- For high acceleration voltages (V_{acc} > 500V) a **two peaked distribution** appears.
  - High velocity peak (~40km s^{-1}) due to electrostatic acceleration.
  - Low velocity peak (~15km s^{-1}).
- Additionally, two electron group appears and combine into one along the plume due to the variation of plasma potential.

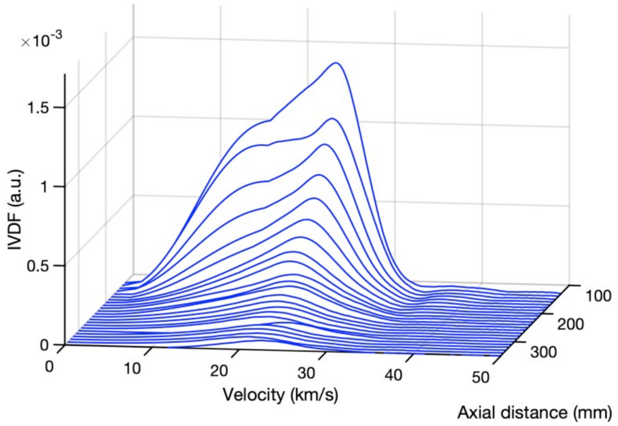

Fig 4. IVDF measured using a retarded field energy analyzer (RFEA) for a low (450V) acceleration voltage.

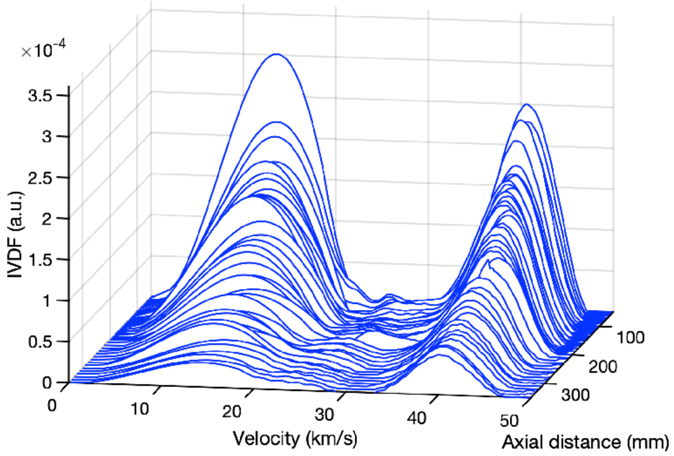

Fig 5. IVDF measured using a retarded field energy analyzer (RFEA) for a high (550V) acceleration voltage.

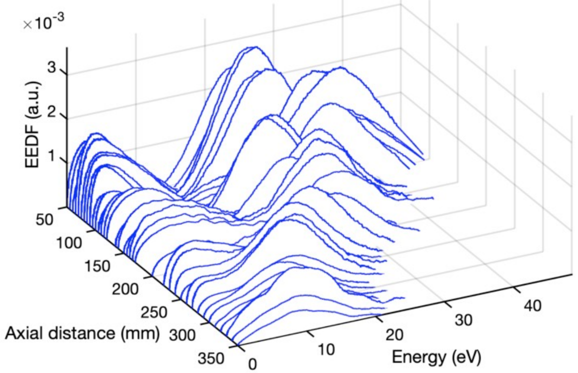

Fig 6. EEDF along the plasma plume of *alphie.*

Experimental Characterization: Plasma Plume (II)

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- The analysis of the two distribution peaks show clear distinct behaviours between the fast and slow distributions.
- The velocity of the two peaks remain **constant** along the plume.
- The decay of the distribution peak is different for each group. The fast group has a slower decay than the other population due to the higher axial velocity.

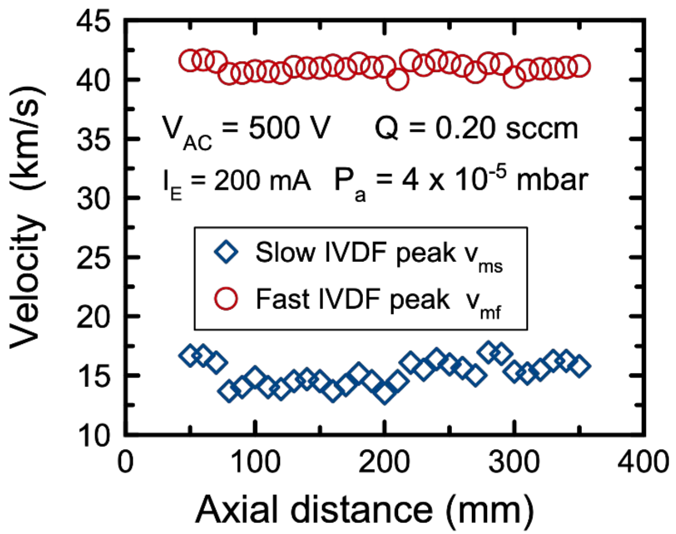

Fig 7. Velocity peak along *alphie*'s plume for the fast and slow groups.

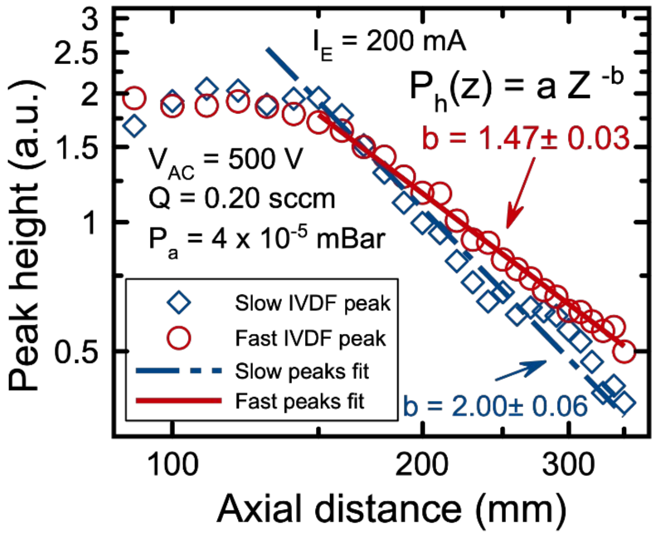

Fig 8. Peak height change along the plume. The fast and low groups show a different expansion parameter *b*.

Experimental Characterization: Plasma Plume 2D (WIP)

Ib = 300mA
Q = 0.4sccm
Z = 150mm

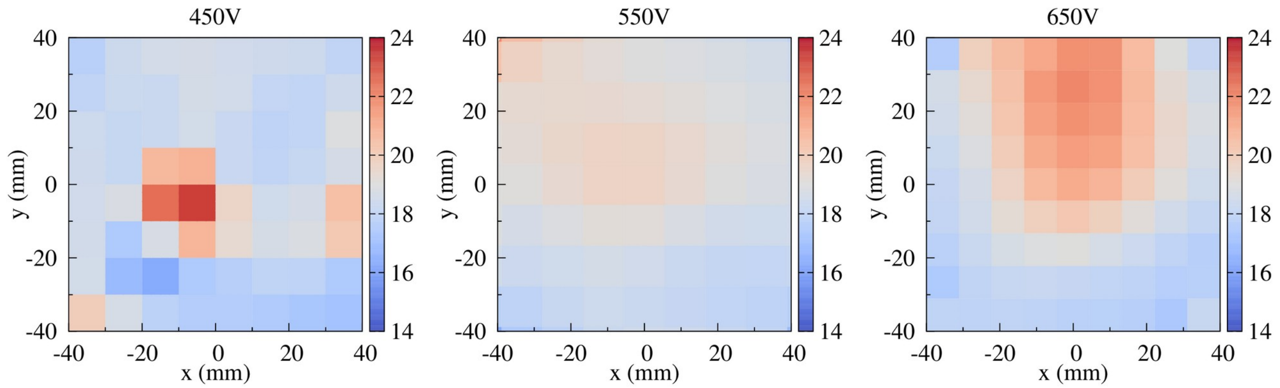

Fig 9. Peak velocity in km s^{-1} for the low velocity group.

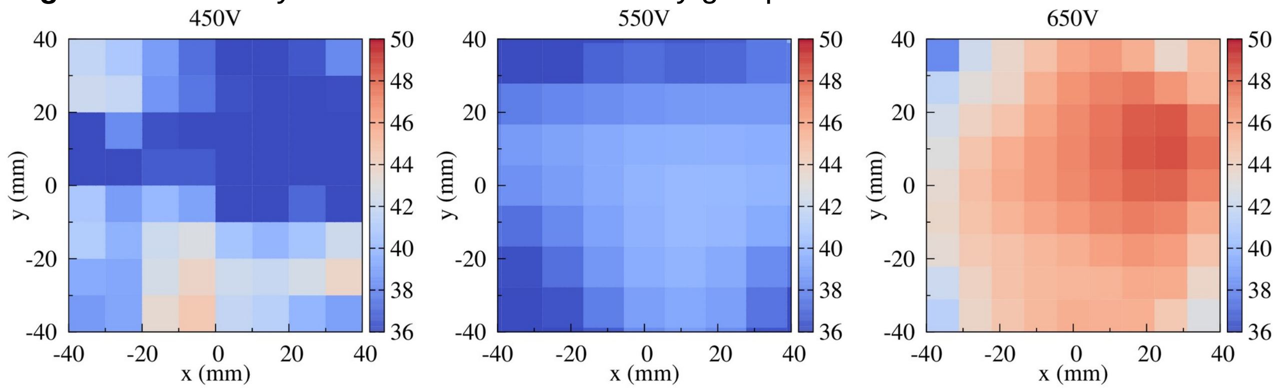

Fig 10. Peak velocity in km s^{-1} for the high velocity group.

- Our measurement system allows to obtain **2D slices** of data (including RPA data) in a wide range of *x*, *y*, *z*.
- Mapping the plume distribution in 3D.
- At higher acceleration voltages, a **more focused plasma beam** appears, with higher axial velocity.
- The diameter of the plasma beam seems to be around 3cm.
- This is a WIP and a deeper analysis of the data will be released soon.

Experimental Characterization: Thrust measurements

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- Thrust has been **directly measured** by means of a vertical balance.
- Results show impulse values above **1mN**.
- The thrust delivered increases with the gas flow and the acceleration voltage.
- For large gas flows, **larger V_{acc} are required** to maintain a acceptable thrust level.
- This is related to the ionization process by a high energy inflow of electrons => More gas requires electrons with higher energy to have an efficient ionization process.
- Total **efficiency** is between **10% and 40%** for the low and high power regimes.
- Future complete characterization campaign with Ar, Xe and Kr.

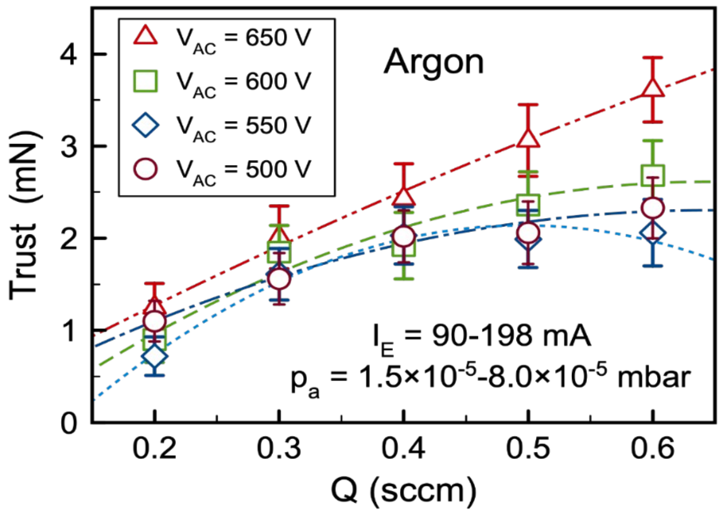

Fig 11. Peak height change along the plume. The fast and low groups show a different expansion parameter *b*.

Plasma plume simulations

Particle-in-cell

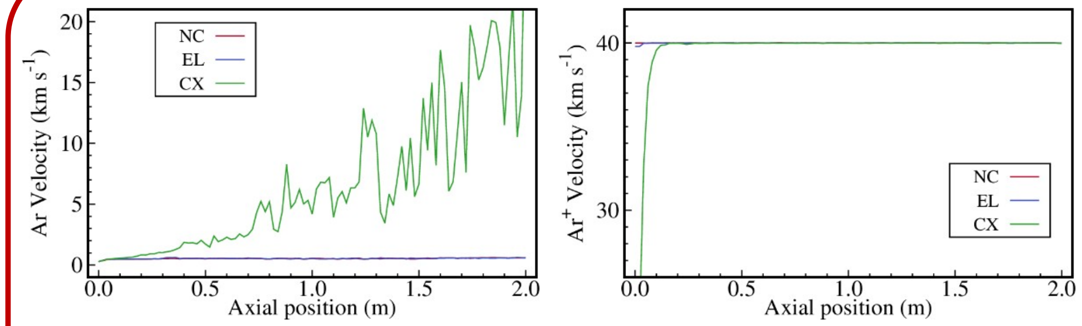

Fig 12. Axial velocity at the axis for neutrals (left) and ions (right). Intense effect of CX collisions near the thruster exhaust.

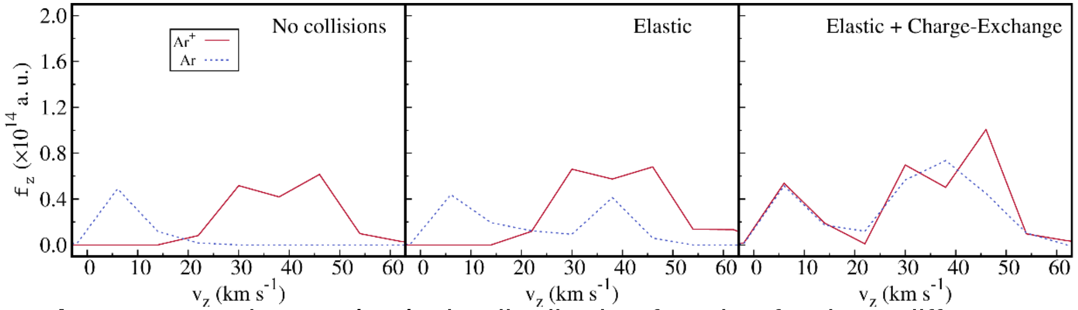

Fig 13. Ion and neutral velocity distribution function for three different cases of collision processes.

- Plume dynamics are extremely important: ion backflow, exhaust velocity, comparison with experiments.
- Two simulations tools show huge impact of Charge Exchange (CX) near the thruster exhaust compared with Elastic Collisions (EL).
- Far from the exhaust, the plasma behave as non-collisional.
- Fully kinetic particle-in-cell code being developed to study the disruptive physics of the *alphie*.

Semi-Analytical

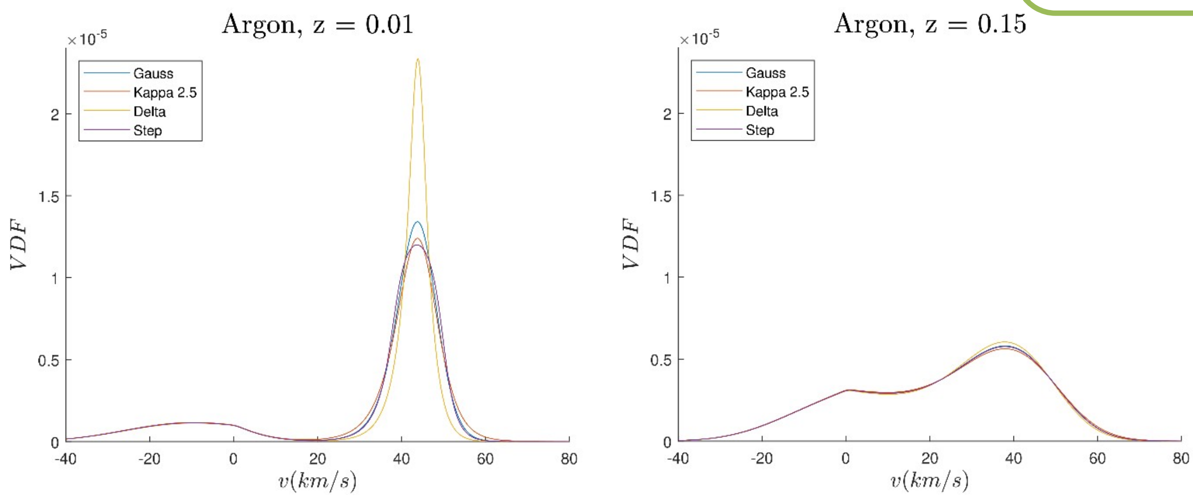

Fig 14. Ion distribution function with different initial conditions. CX creates low population. Elastic collisions smooth the distributions.

- Effect of collisions in the plume studied by semi-analytical method too.
- CX has a strong effect creating the two peaked distribution.
- EL collisions only smooth initial conditions.

Final remarks

- *Alphie* is a new disruptive engine technology characterized for a counterflow of charges through its two-grid system.
- High specific impulses with low power consumption.
- Experimental measurements plus numerical simulations to study and improve the device.
- An improved impulse measurement system is currently being tested.
- Mini version, aimed for cubesats, in the planing.

Acknowledgements

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- *Alphie* laboratory testing:

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