Plasma plume structure of the Alternative Low Power Hybrid Ion Engine (alphie)

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The alternative low power hybrid ion engine (ALPHIE)

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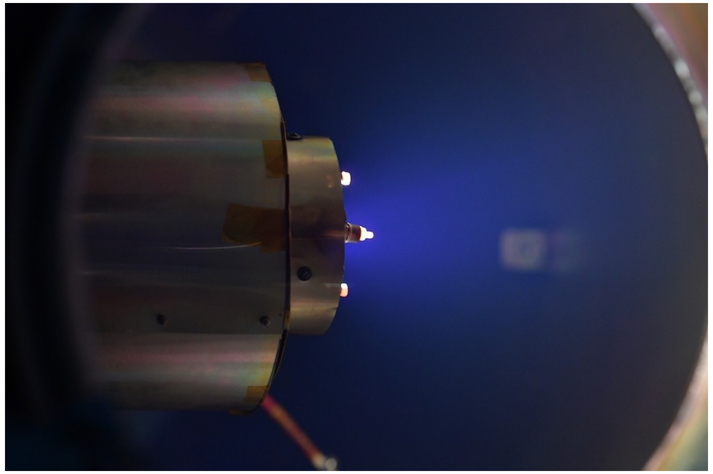

Fig 1. The *alphie* in steady state operation.

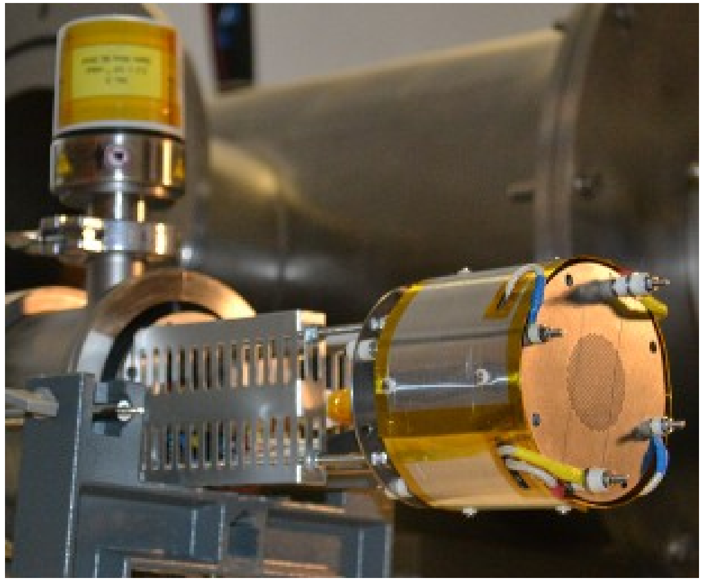

Fig 2. The *alphie* in its support.

- The ALPHIE design is a new technology of a plasma accelerator for satellite propulsion in space.
- This small 10 X 15 cm plasma thruster operates with less than 300 W electric power consumption.
- It is intended for small and medium sized satellites (roughly over 100 Kg) 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

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- 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	1.2 kg	Without PPU
Dimensions	10 x 15 cm	Diameter x length
Propellant gas	Ar, Xe	Kr in the future
Gas flow rate	1-2 sccm	
Power consumption	200-325 W	
Thrust	0.8-3.5 mN	Ar, throtteable
Specific impulse	13900-20000 s	
Thrust-to-power ratio	4-11 mN/kW	

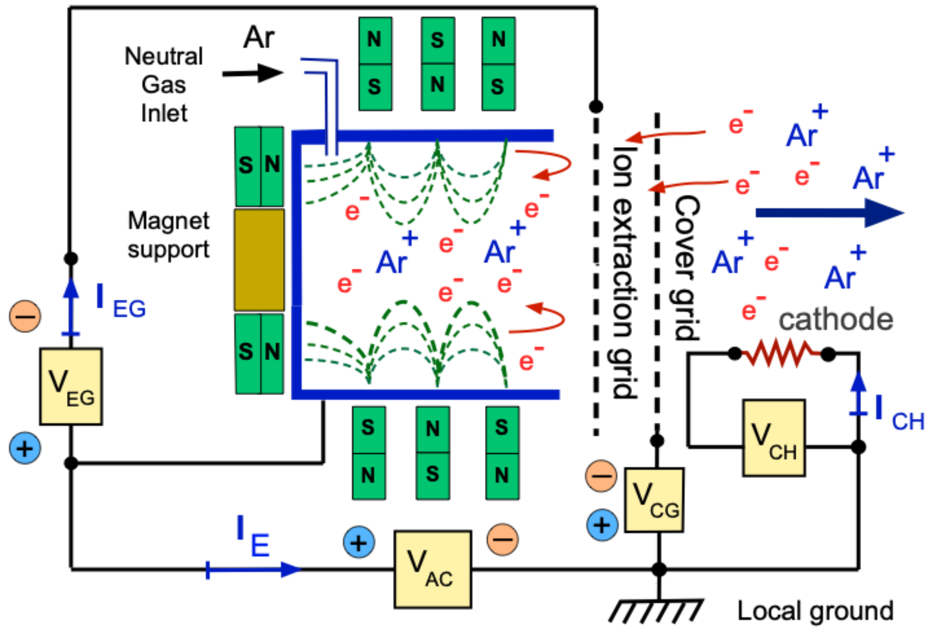

Fig 3. Electrical scheme of the *alphie*.

- 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 counterflow through the two-grids system.*
- Strong interaction between accelerated electrons and neutrals.
- The electric potentials are always below kV range.

Experimental Characterization

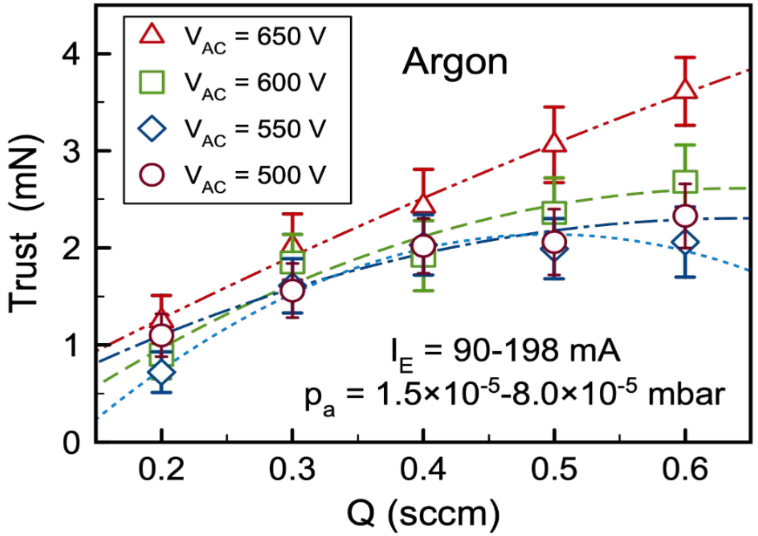

Fig 4. Thrust provided by the *alphie* as a function of mass flow rate (Q) and acceleration voltage (V_{ac}).

- *Variable throttle operation* (see Fig 4) controlled by the acceleration voltage V_{acc} and the mass flow rate Q.
- Future characterization campaign involving Xenon.
- *Alphie* generates two populations of ions for high voltages: Fast and Slow.
- Fast group velocities between 30-60 km/s.
- Slow peak follows an isometric expansion (thermal group). Fast group more collimated.
- For a constant mass flow, two parameters characterize the operation of *alphie*: the electron current I_b, and the acceleration voltage V_{acc}.

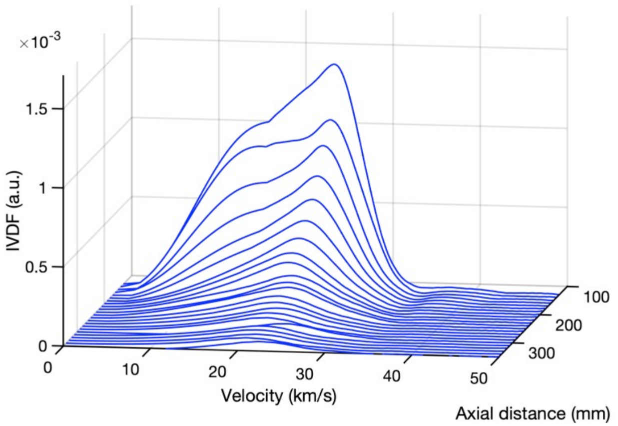

Fig 5. IVDF measured using a retarded field energy analyzer (RFEA) for a low (450V) acceleration voltage.

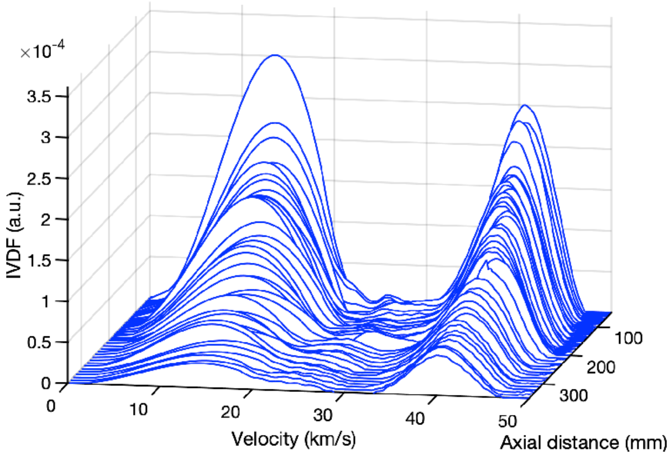

Fig 6. IVDF measured using a retarded field energy analyzer (RFEA) for a high (550V) acceleration voltage.

RFEA measurements along the plasma plume

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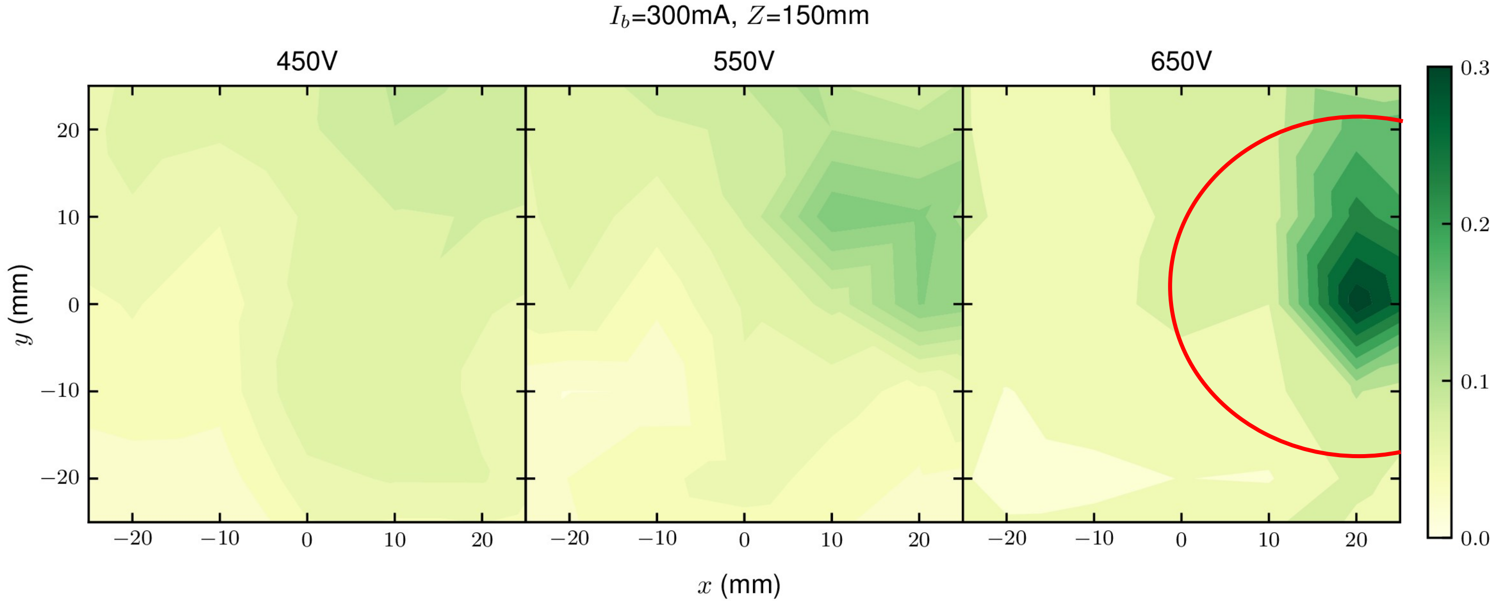

Fig 7. 2D distribution of measured current in A by the RFEA.

- Position system to set the RFEA in a *XYZ space*.
- Study for I_b = 200, 300mA and V_{acc} between 450 and 650V.
- Axial positions of 150, 250 and 300mm.
- Unfortunately, issues with alignment between thruster and RFEA makes further positions not usable

- Centering data at the maximum current and interpolation of data at different radial directions to obtain *average and deviation* of current and mean velocities for high and low energy populations.
- This allows to compare relevant values at different V_{acc} and I_b.

V_{acc} parameter scan

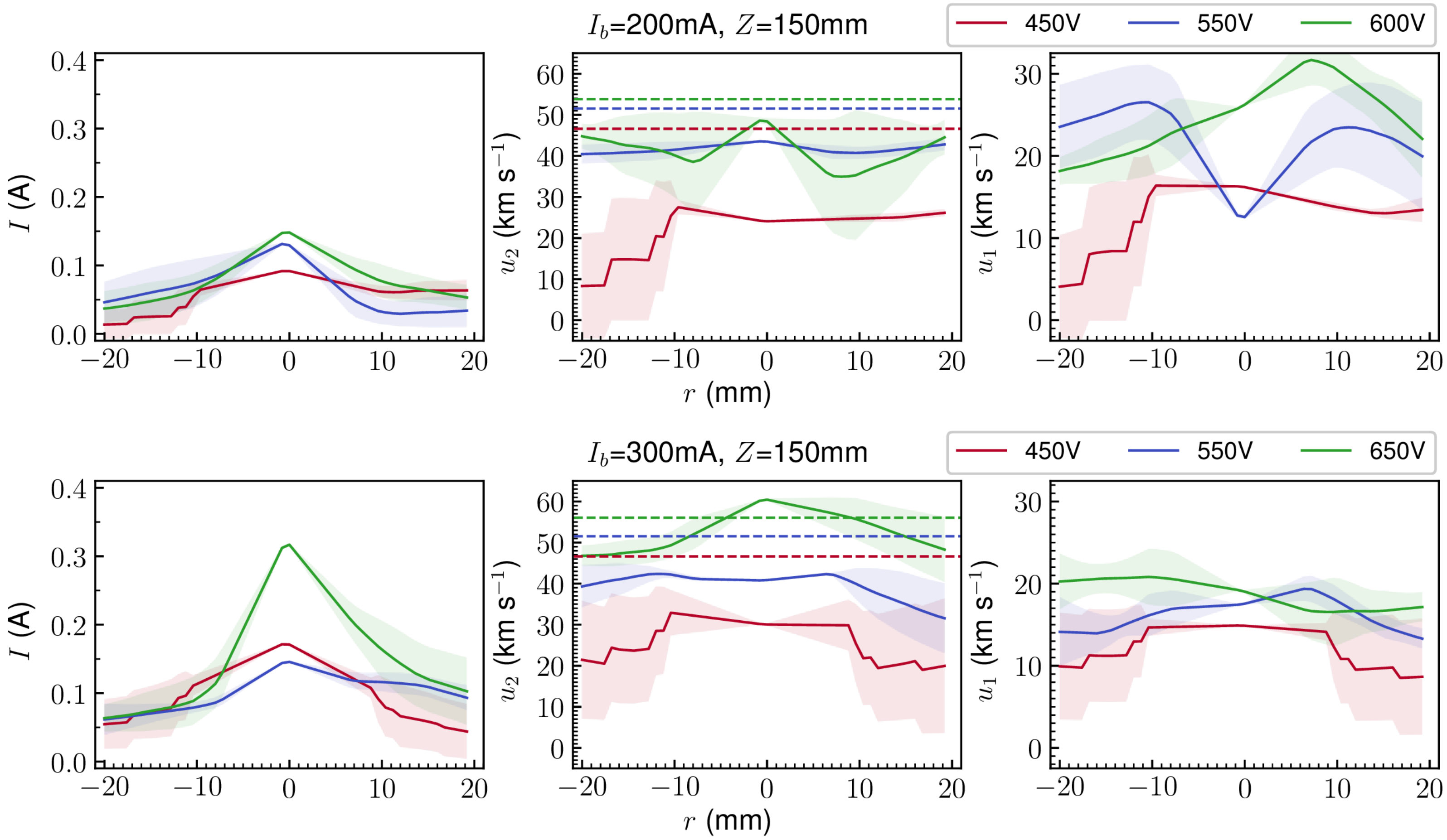

Fig 8. Average values of current, peak velocity of high and low energy populations.

- Increase of acceleration voltage results in an increased ion current.
- Better electrical transparency but also *additional energy* for the inflow of electrons.
- Case of I_b = 200mA is limited by the acceleration voltage => *not enough influx of electrons*.
- Cases at 450V are always low performance => not enough energy for the influx o electrons.
- *Current is focused* around the ±10mm radius from the point of maximum current => good collimation.

I_b parameter scan

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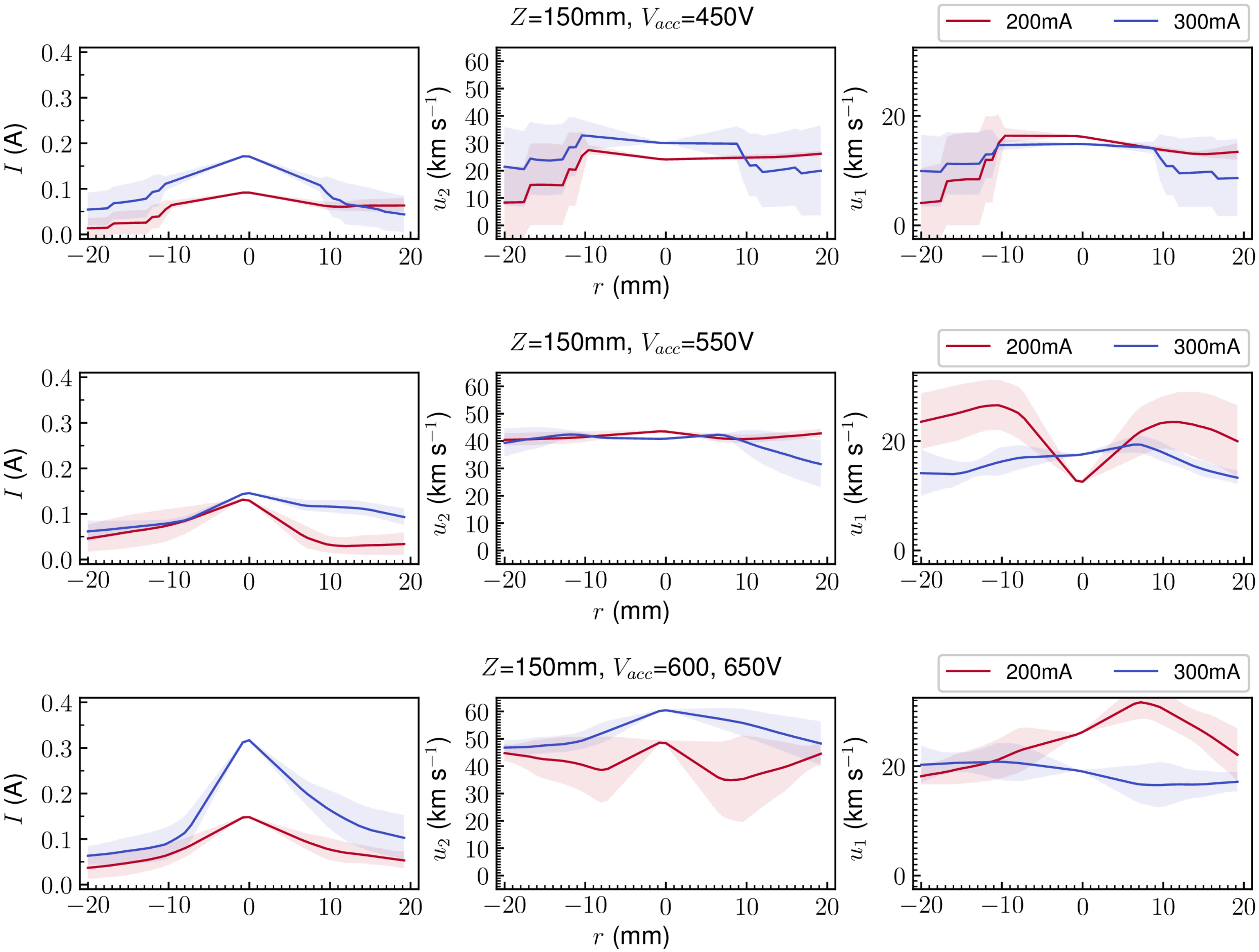

Fig 9. Average values of current, peak velocity of high and low energy populations.

- The increase of available electrons (from current *Ib*) results in an *increase of ion current without losing axial velocity*.
- This effect is noticeable at all acceleration voltages.
- The case at higher voltage is not the same for the two currents, so that explains the change in velocity.

References

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•*Alphie* laboratory testing:

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•Numerical simulations:

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9) D. Dyubo, J. Gonzalez, O. Tsybin and L. Conde. *Charge transport characterization of the alternative low power hybrid ion engine (alphie) with particle-in-cell simulations.* Phys. Plasmas. **28**, 103509 (2021). DOI: https://doi.org/10.1063/5.0060260

Final remarks

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- *Alphie* is a new disruptive engine technology characterized for a counterflow of charges through its two-grid system.
- Mostly operated with Ar, although Xe and Kr could be employed.
- High specific impulses with low power consumption.
- Measurements along the plume show good collimation and response to V_{acc} and I_b.
- The inflow of electrons require enough energy (high V_{acc}) and flow (high I_b) to provide a high velocity ion population.
- New campaign of plume measurements to improve alignment and measurements resolution.
- Mini version, aimed for cubesats, in the planing.

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