DOUBLE BEAM SATELLITE PROPULSION

Laboratoire de Physique des Plasmas

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Space propulsion

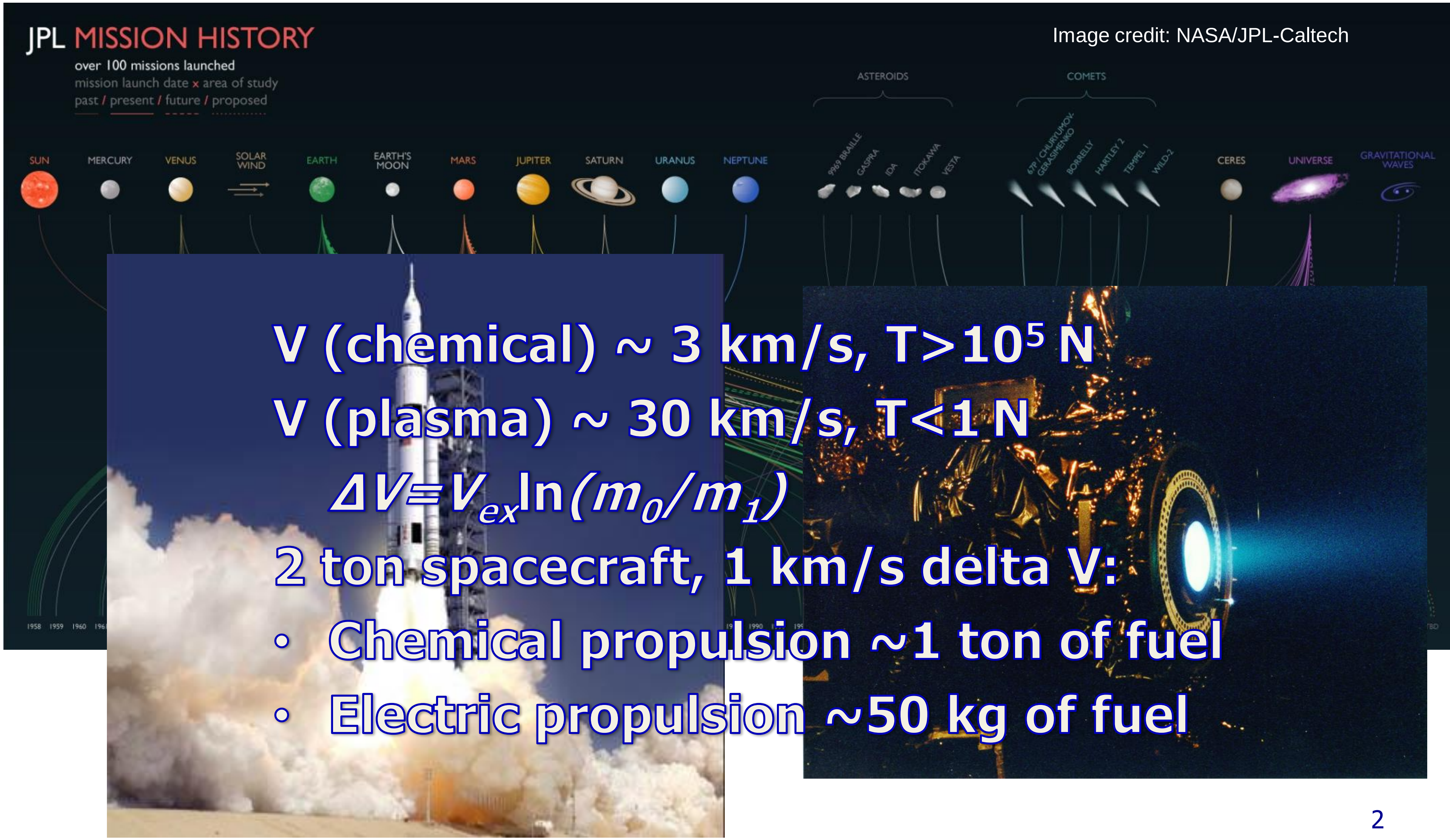


Image credit: NASA/JPL-Caltech

V (chemical) ~ 3 km/s, T>10^5 N

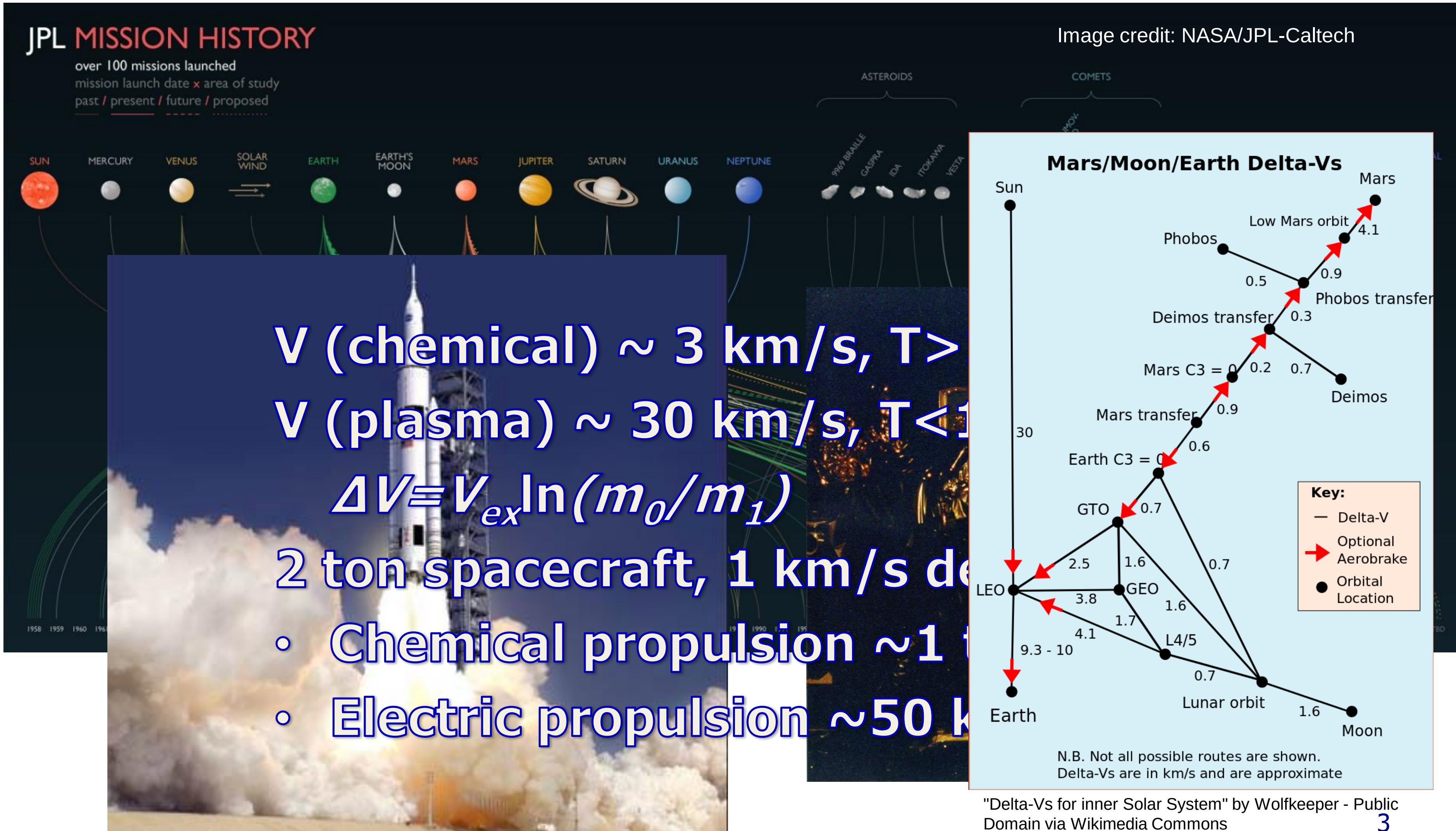
V (plasma) ~ 30 km/s, T<1 N

$$\Delta V = V_{ex} \ln(m_0/m_1)$$

2 ton spacecraft, 1 km/s delta V:

- **Chemical propulsion ~1 ton of fuel**
- **Electric propulsion ~50 kg of fuel**

Space propulsion



V (chemical) ~ 3 km/s, T>

V (plasma) ~ 30 km/s, T<1

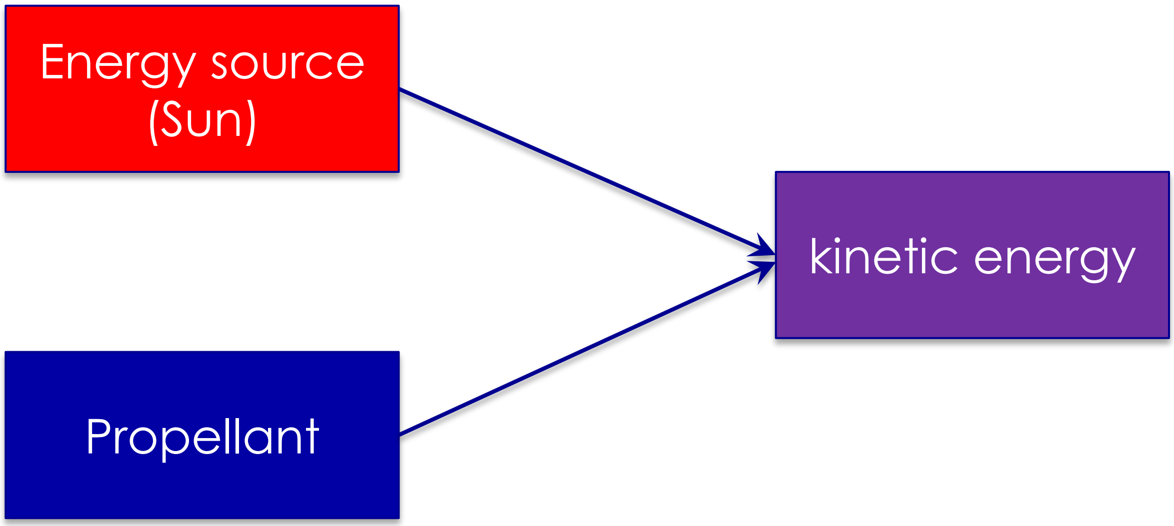
$\Delta V = V_{ex} \ln(m_0/m_1)$

2 ton spacecraft, 1 km/s de

- Chemical propulsion ~1 t
- Electric propulsion ~50 k

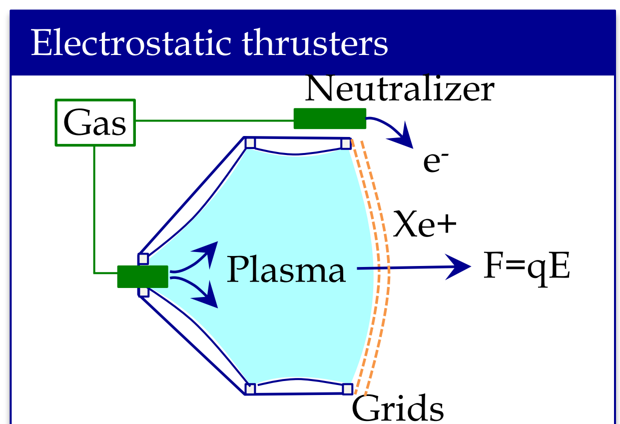
"Delta-Vs for inner Solar System" by Wolfkeeper - Public Domain via Wikimedia Commons

Electric Propulsion



Gridded Ion thrusters
Hall thrusters

$V_{ex} \sim 15 - 40$ km/s
$T \sim 0.1 – 1000$ mN



Propulsion basics

Ion engine performance

$$T = m' V_{ex} \approx I_{ion}(2m_i V_{acc}/q)^{1/2}$$

$$V_{ex} = (2qV_{acc}/m_i)^{1/2}$$

Mission capabilities

$$\Delta V = V_{ex}\ln(m_0/m_1)$$

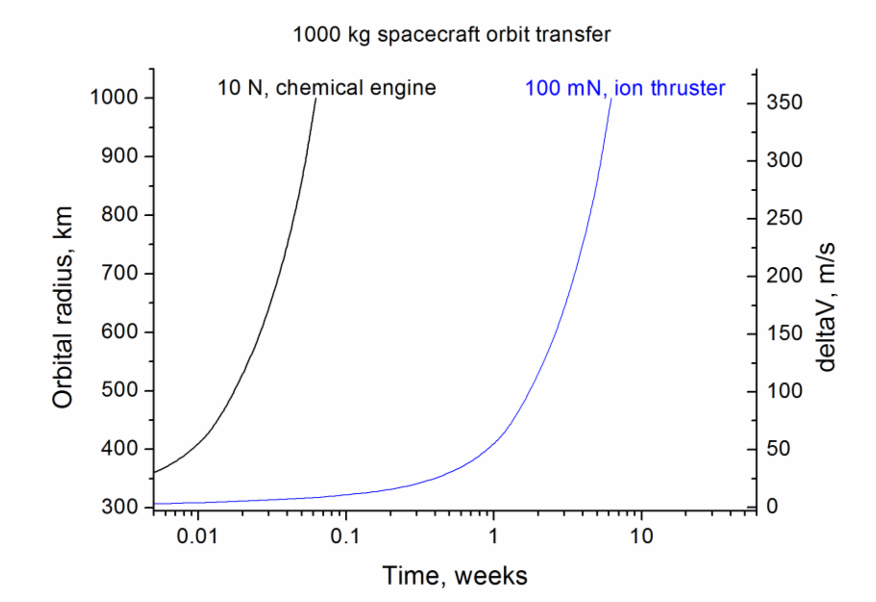
$$\Delta t \approx \Delta V m_0 / T$$

! ΔV required with high thrust < ΔV (low thrust)

- Hohmann transfer
- Oberth effect

Propulsion basics

Ion engine performance

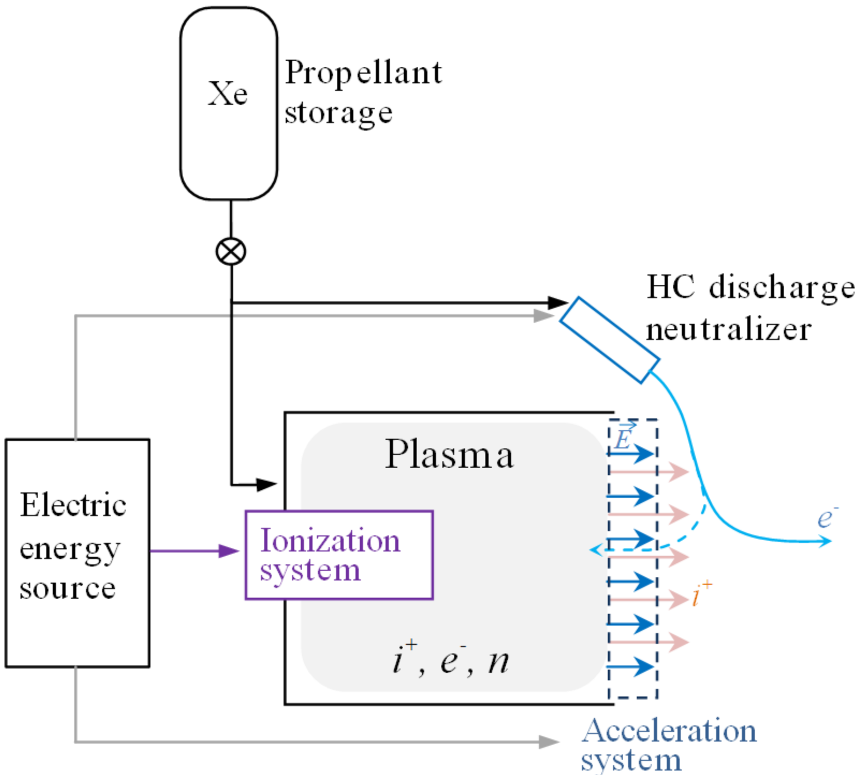


$$\Delta t \approx \Delta V m_0 / T$$

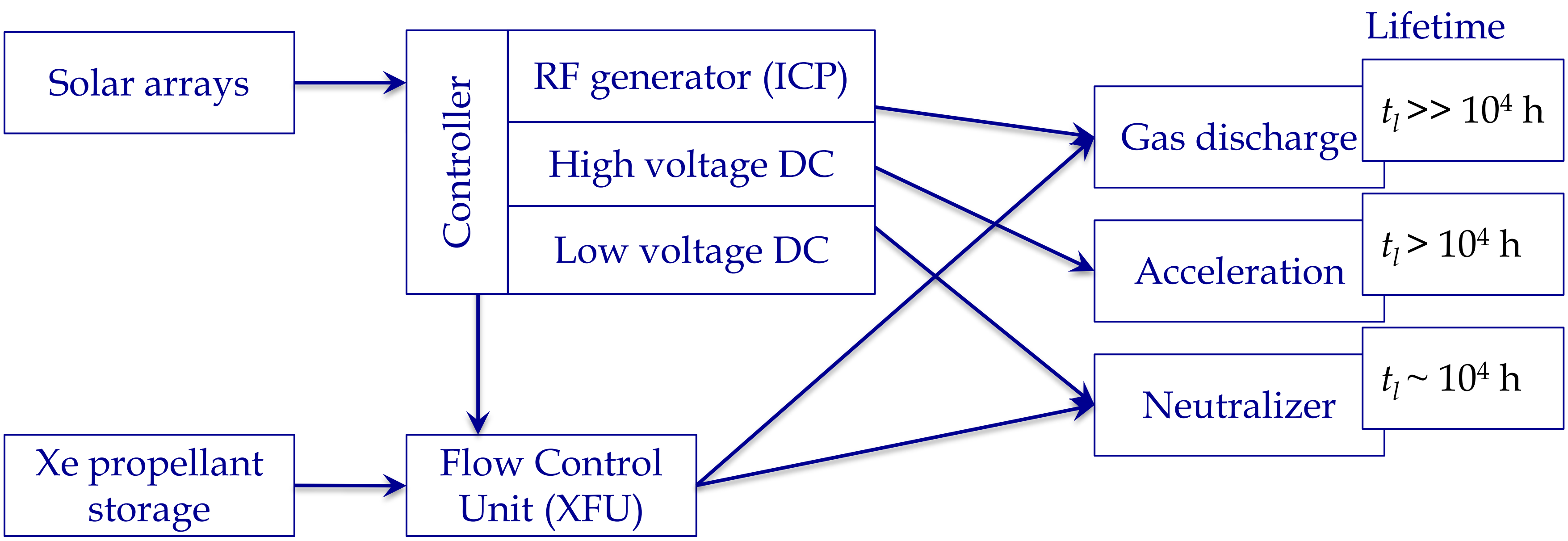
! ΔV required with high thrust < ΔV (low thrust)

- Hohmann transfer
- Oberth effect

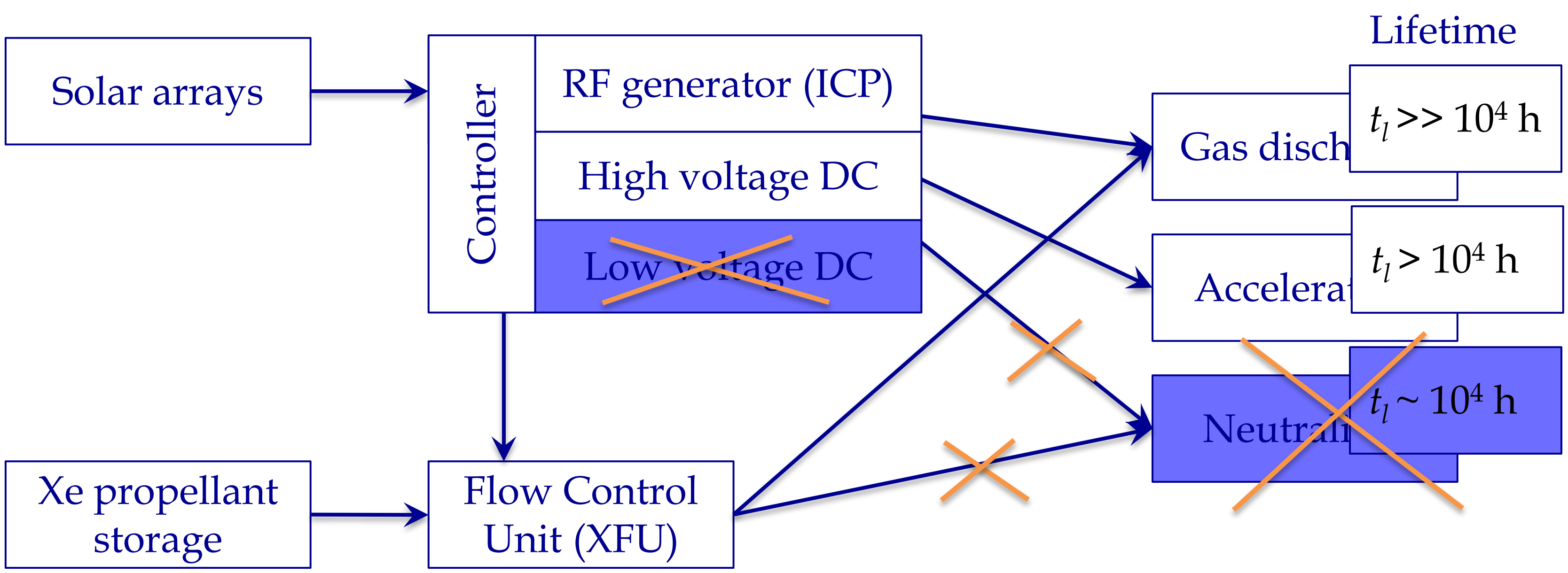
Electric Propulsion system



Electric Propulsion system



Neutralizer-free systems



+Lifetime and robustness

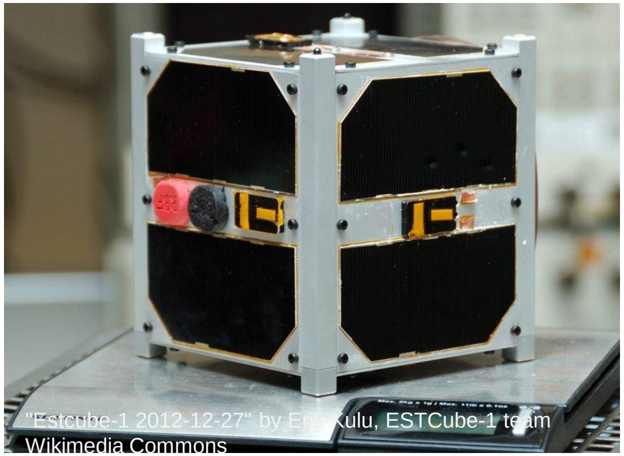
+Downscaling

Electric Propulsion: new challenges

- Lifetime and robustness for longer missions


"Hayabusa2 rendezvous" by JAXA

- Downscaling the EP for small satellites


"Estcube-1 2012-12-27" by Erik Kulu, ESTCube-1 team
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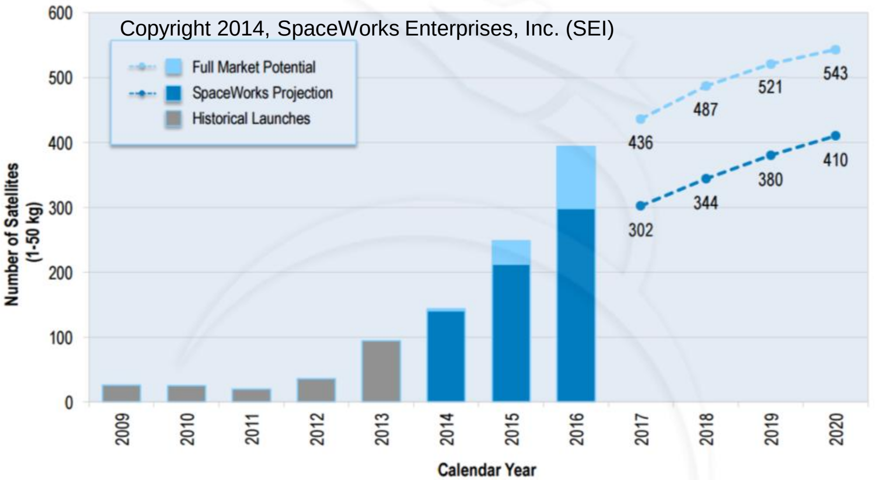


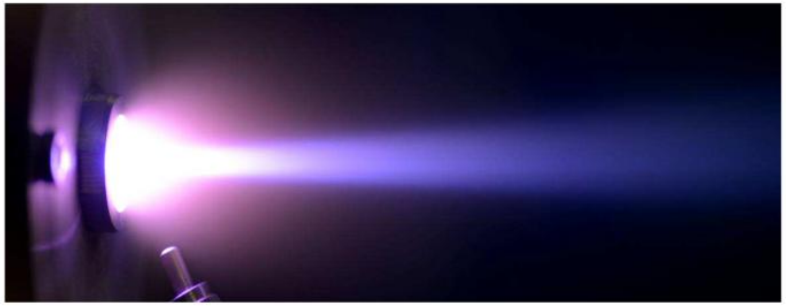
The Full Market Potential dataset is a combination of publically announced launch intentions, market research, and qualitative/quantitative assessments to account for future activities and programs.
The SpaceWorks Projection dataset reflects SpaceWorks' expert value judgment on the likely market outcome.

Neutralizer-free systems

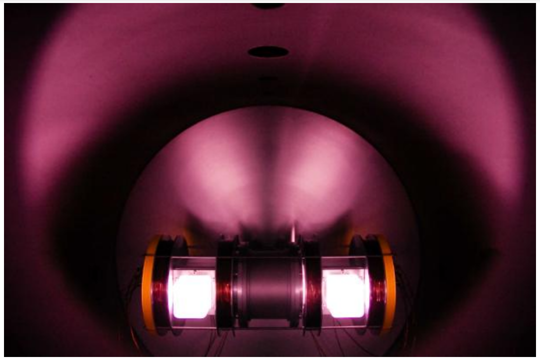
Acceleration of oppositely charged particles

Plasma acceleration concepts:
- Plasma expansion
- jxB acceleration

Dual beam acceleration concepts:
- Spatial separation
- Temporal separation



J Jarrige, P-Q Elias, F Cannat, D Packan, *33rd International Electric Propulsion Conference, 2013 (IEPC-2013-420)*

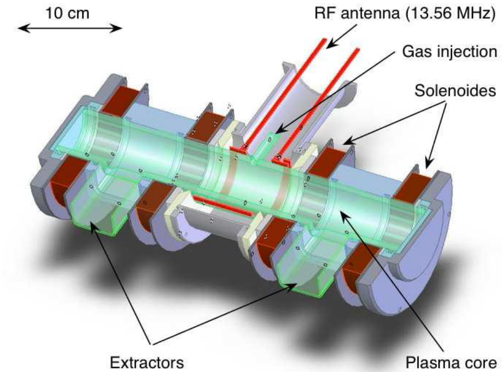


Aanesland A, *et al.: Journal of Physics: Conference Series, 162 012009 (2009)*

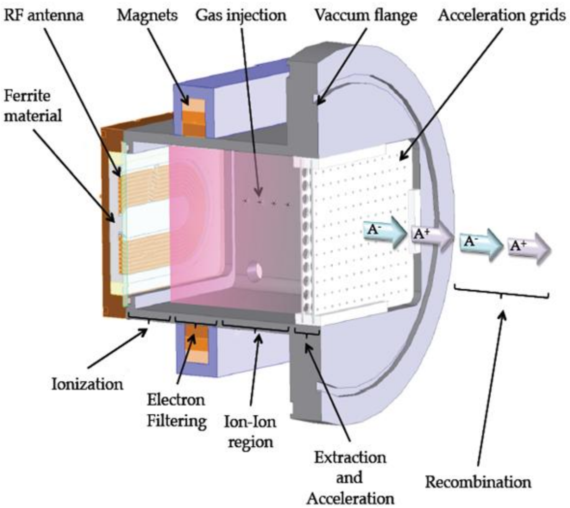
Dual beam with positive/negative ions

PEGASES
"Plasma propulsion with electronegative gases"

PEGASES I:
Two beams of oppositely charged ions extracted from the same plasma source

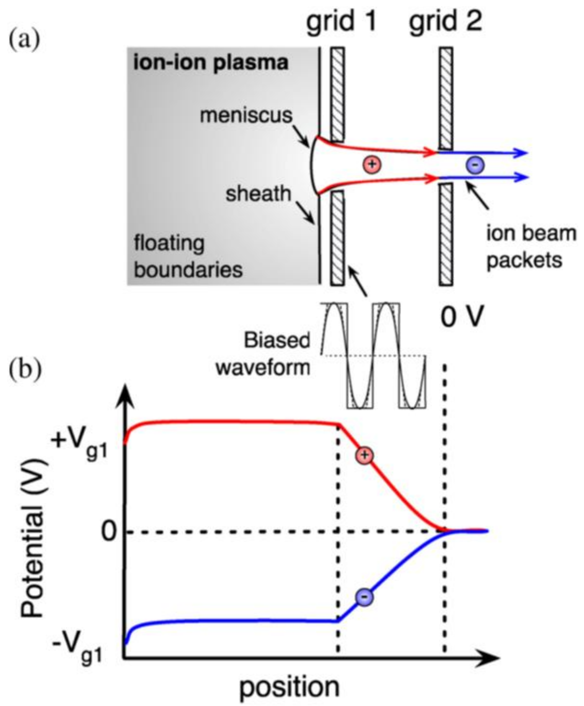


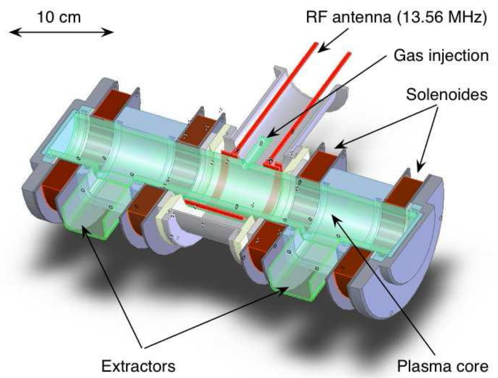
PEGASES II:
One beam with alternated extraction of oppositely charged ions

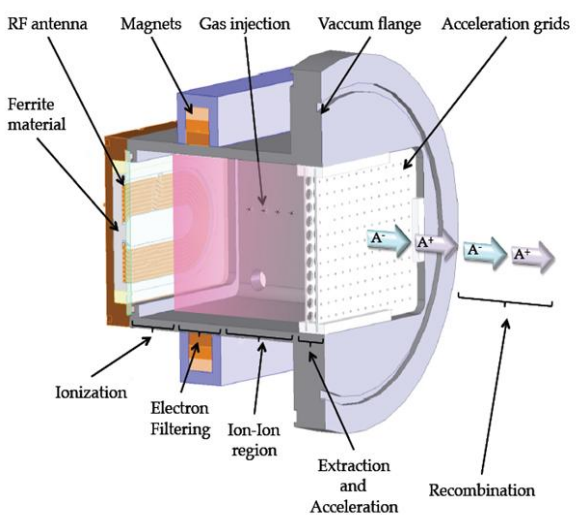


Dual beam with positive/negative ions

Ion-ion plasma





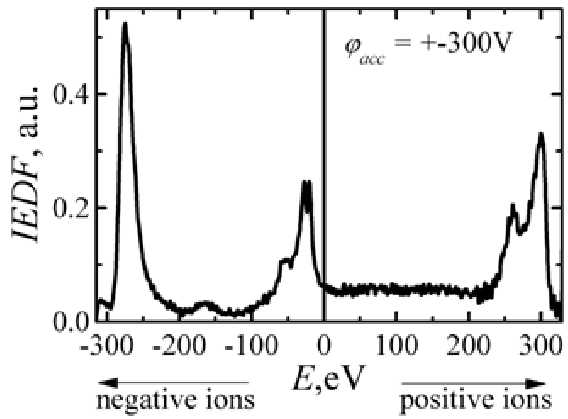


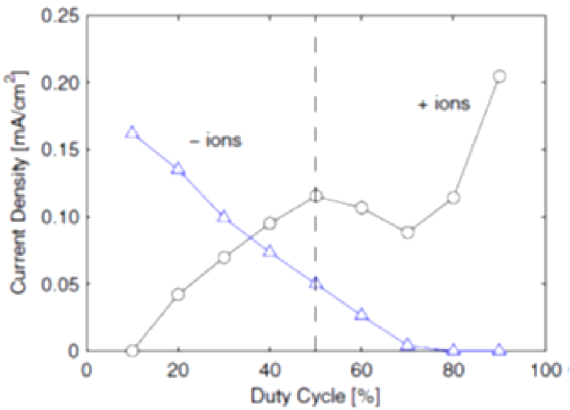
- n_{i-}/n_e ~ 5000
- Zero plasma potential
- Similar response to +/- biases

Dual beam with positive/negative ions

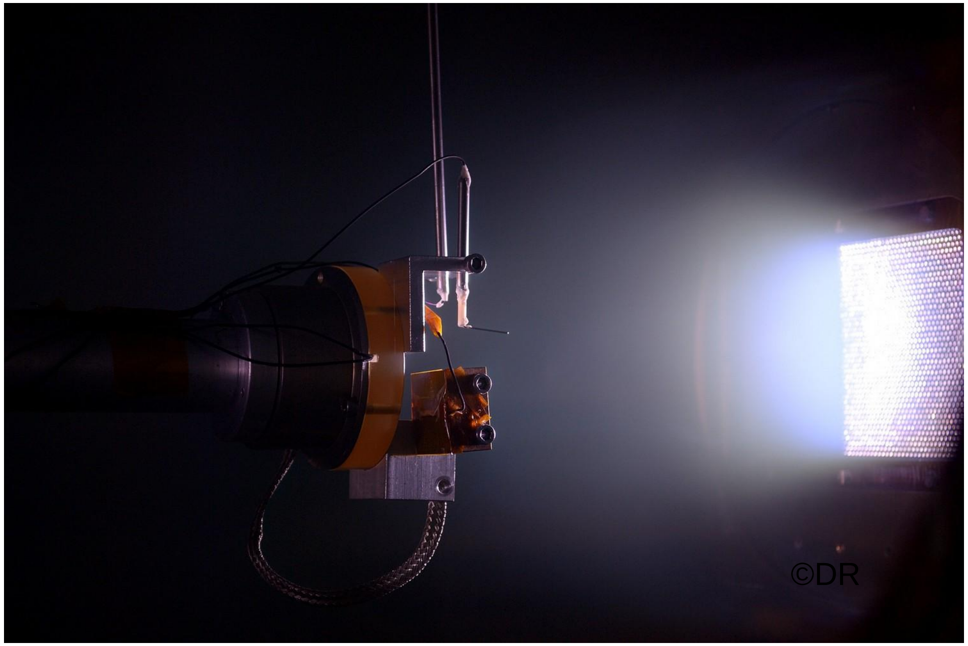
PEGASES

"Plasma propulsion with electronegative gases"





Running dual beam ion source (SF_6)



First patent 2006

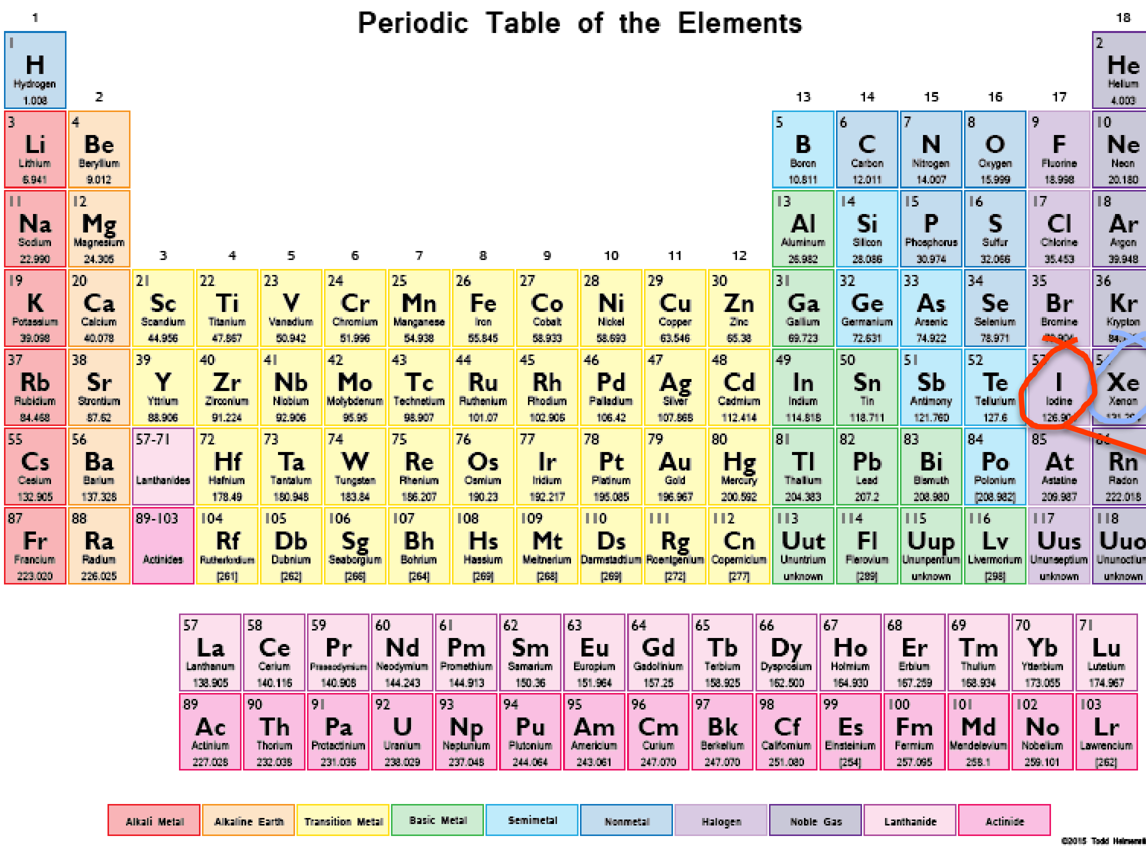
Proof of principle 2015

Dual beam with positive/negative ions

PEGASES

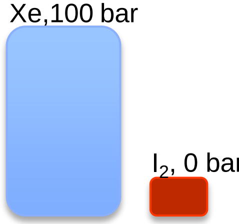
"Plasma propulsion with electronegative gases"

Propellant restrictions

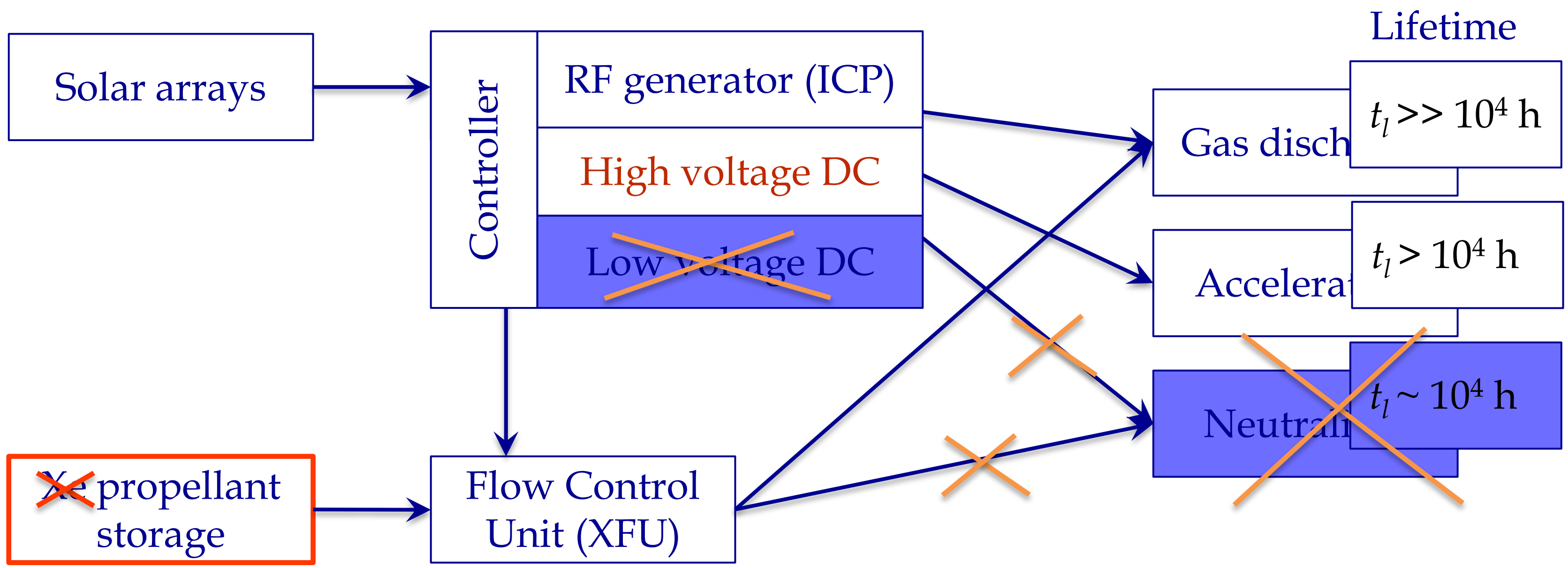


+Heavy
+Easy to ionize
-Storage
-Cost

+Heavy
+Easy to ionize
+Storage
+Cost
-Corrosive



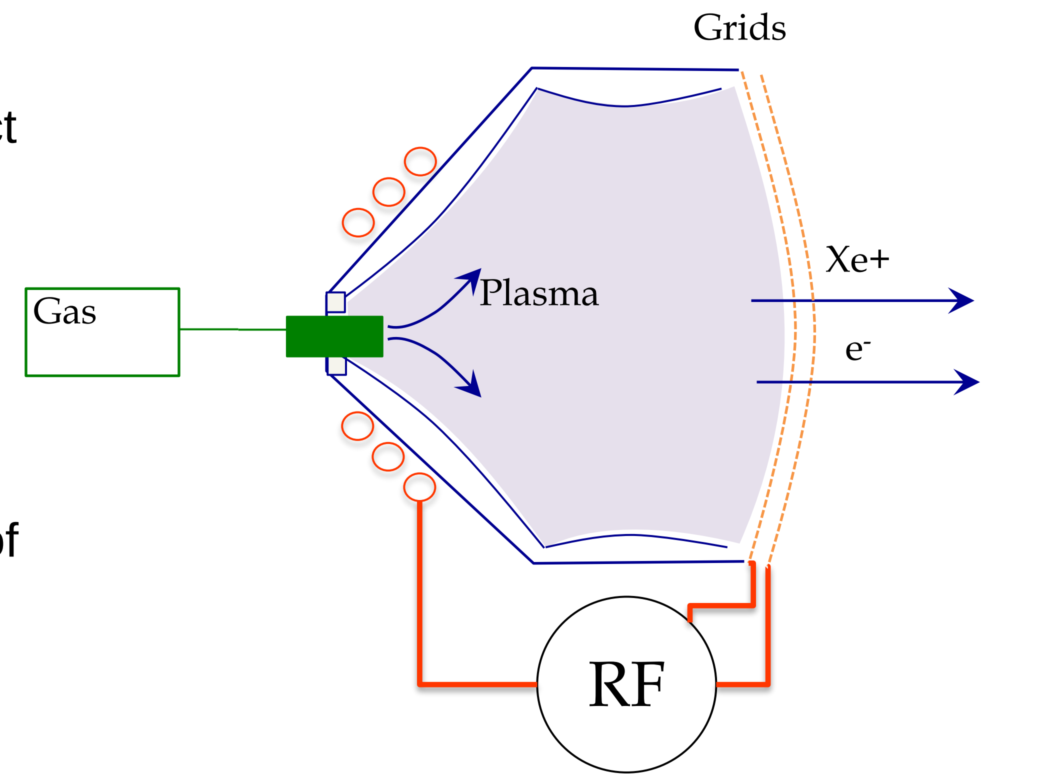
Dual beam with positive/negative ions



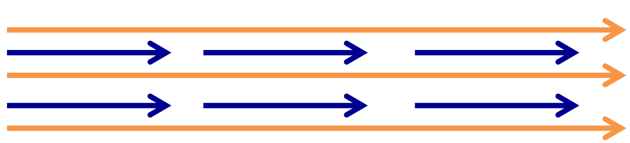
+Lifetime and robustness
+Downscaling
+Propellant storage
-Propellant flexibility

Dual beam with positive ions/electrons

Principle
ion-electron acceleration in the RF sheath due to self-bias effect



Beam
Composed of continuous flow of ions and pulsed electrons



Dual beam with positive ions/electrons

RF acceleration

Quasi-simultaneous extraction

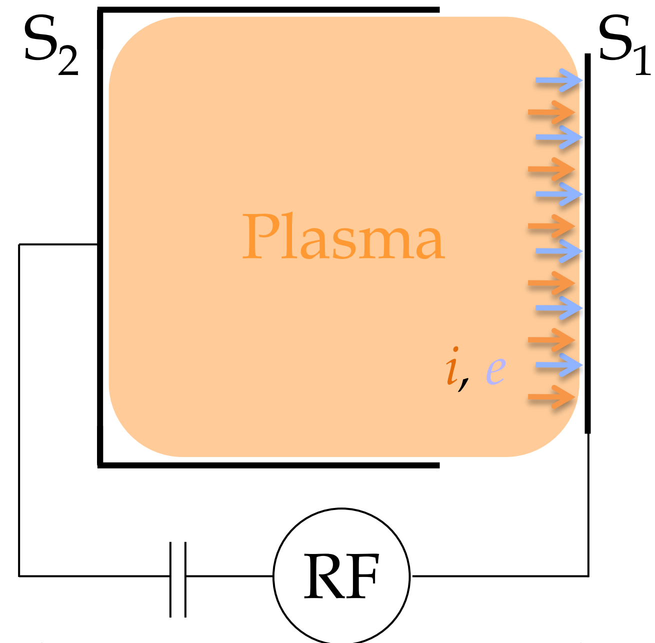
Asymmetric RF discharge

$S_1 < S_2$

$\omega_{pi} < \omega_{RF} < \omega_{pe}$

blocking capacitor

$I_e \equiv I_i$

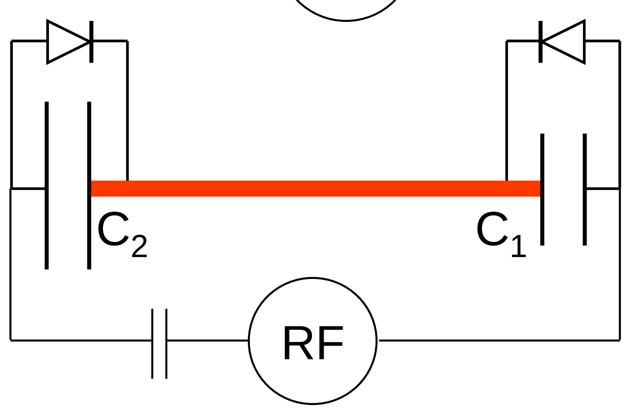


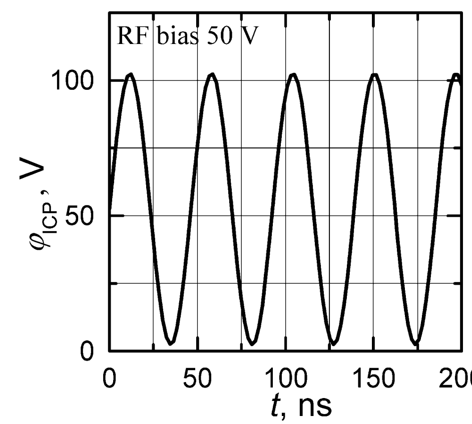
$C_1 < C_2$

$V_1 >> V_2$

$V_1 \sim V_{RF} + V_{DC}$

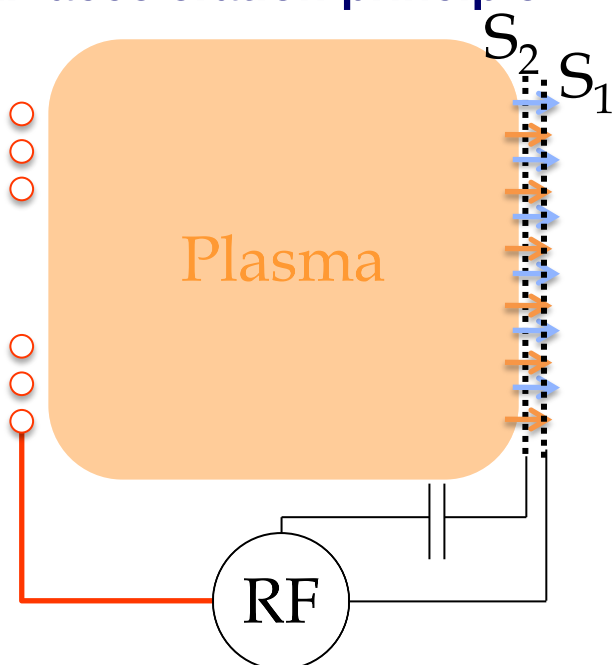
due to "diode"

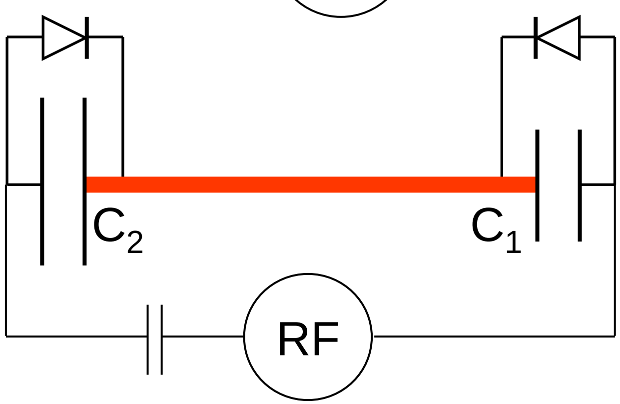


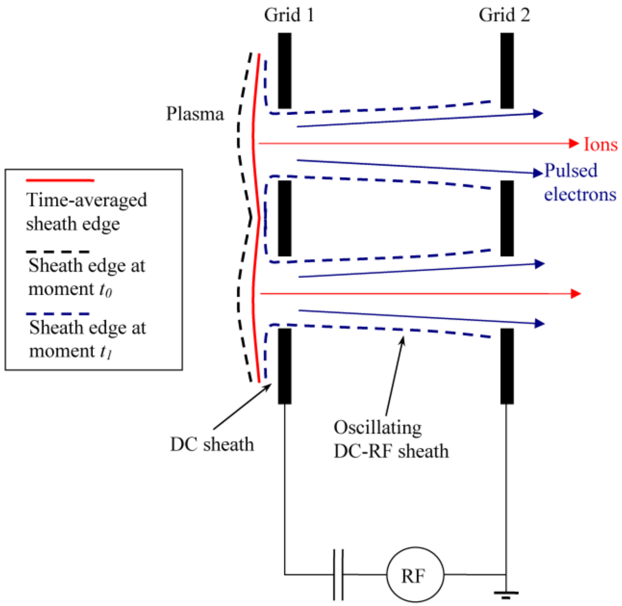


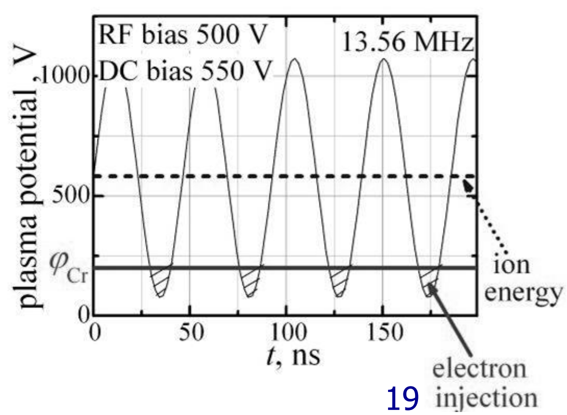
Dual beam with positive ions/electrons

RF acceleration principle









Dual beam with positive ions/electrons

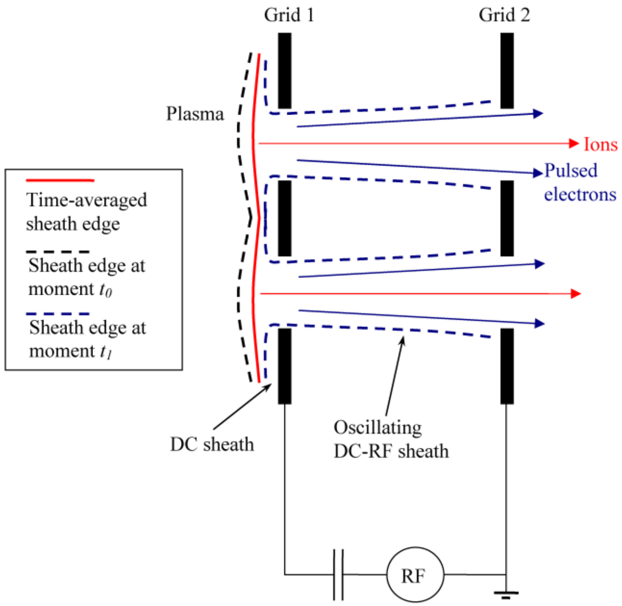
Blocking capacitor:

$I_e \equiv I_i$

The space charge limited current is:

$$J_{CL} = x\left(\frac{2e}{M}\right)^{1/2}\frac{\bar{V}^{3/2}}{d^2}$$

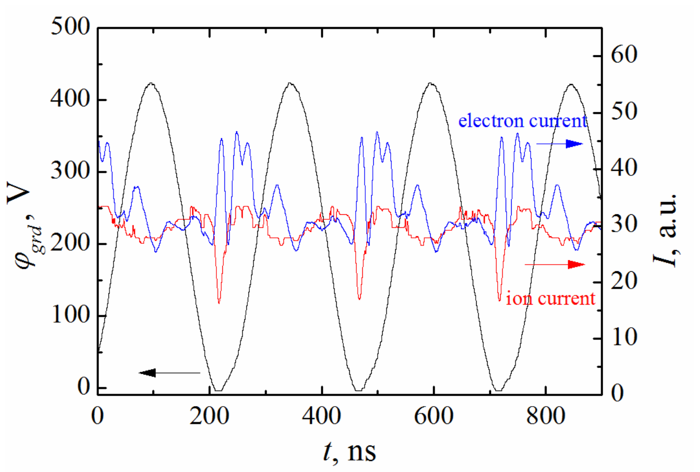
$$x_{DC} = \frac{4}{9} = 0.44 \qquad x_{RF} = \frac{200}{243} = 0.82 \quad [1]$$

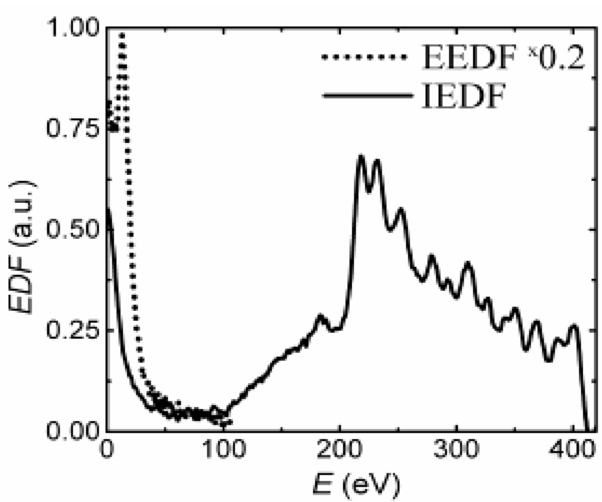


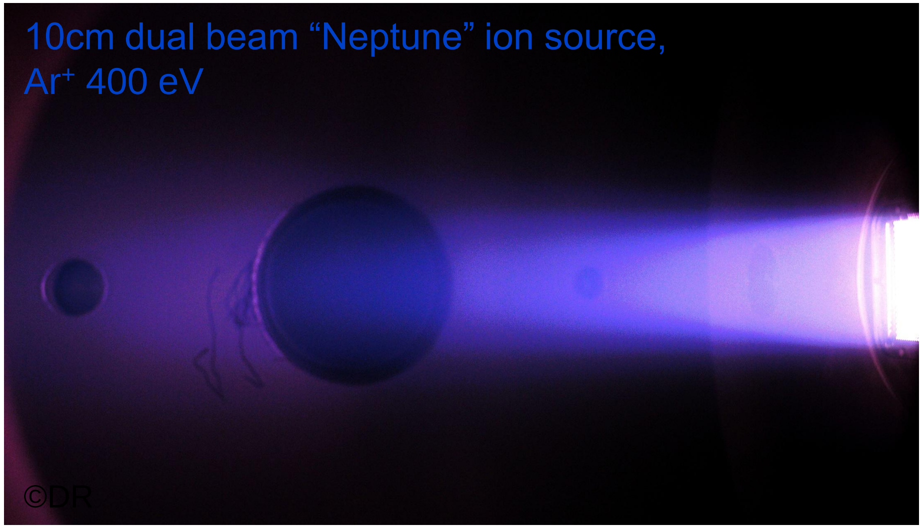
- **Emitted net charge** is always zero
- **Extracted ion current** can be up to x2 the one for DC

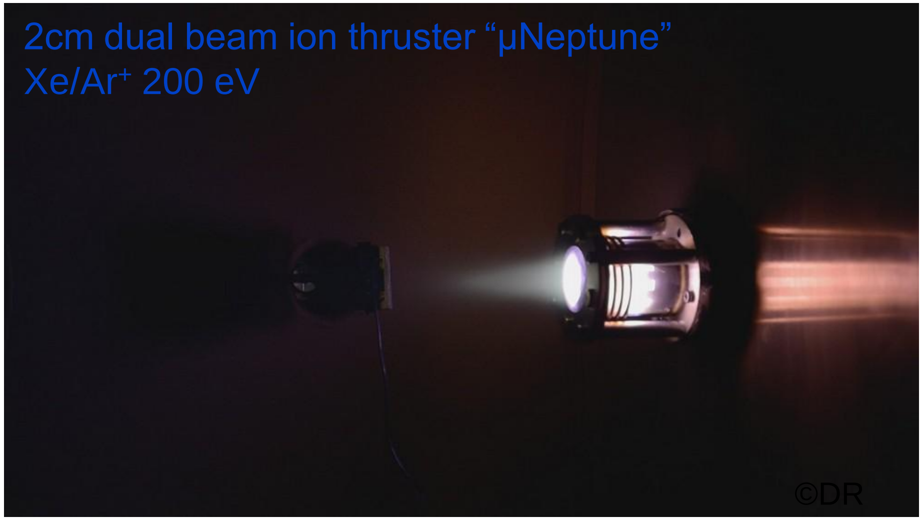
Dual beam with positive ions/electrons

RF acceleration
Quasi-simultaneous extraction







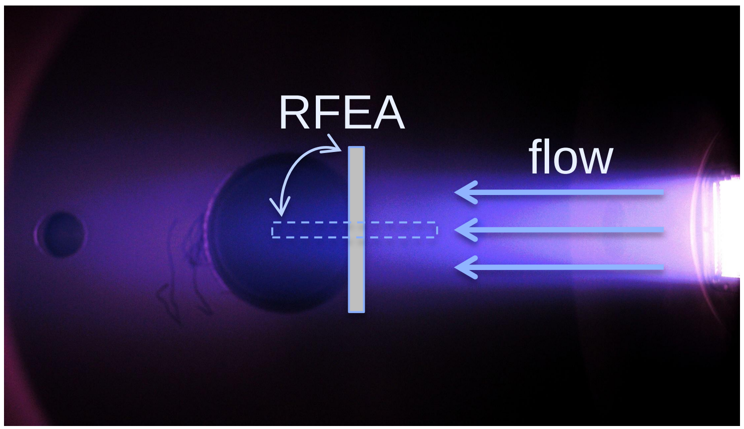


Dual beam with positive ions/electrons

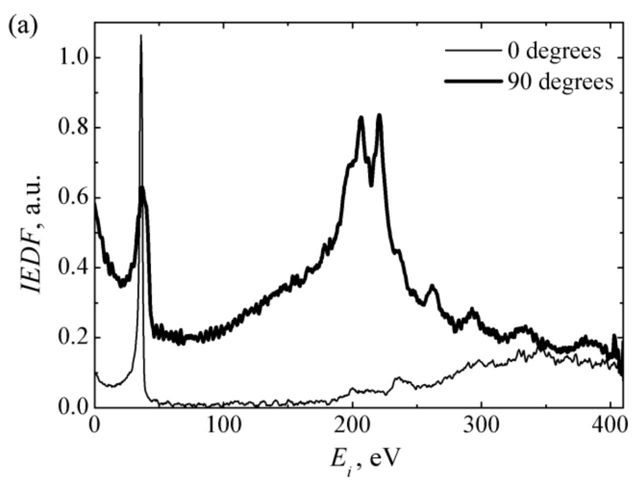
RF acceleration

Quasi-simultaneous extraction

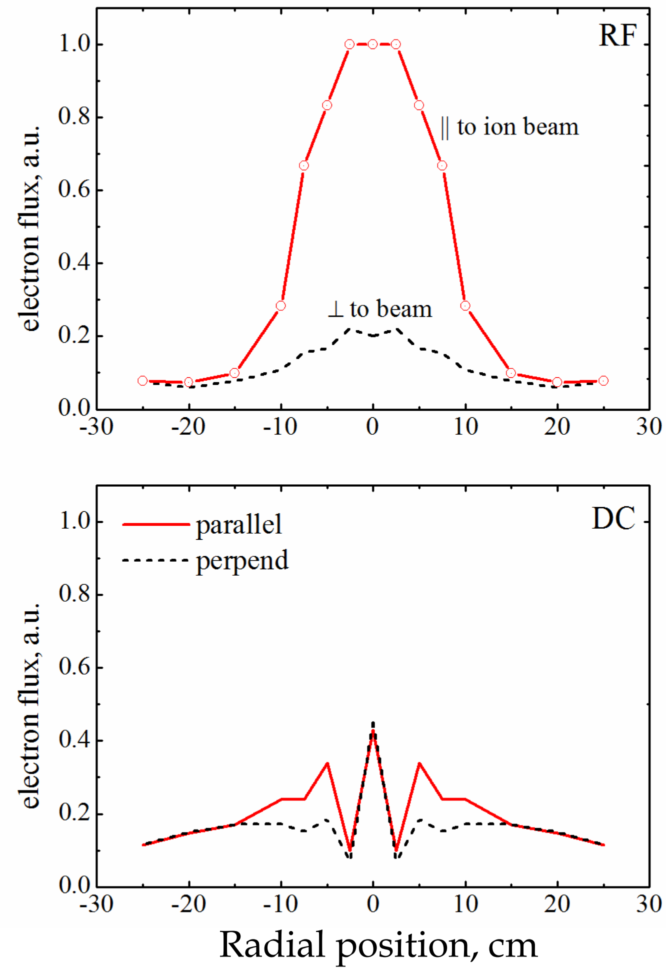
The flow directionality



Ions



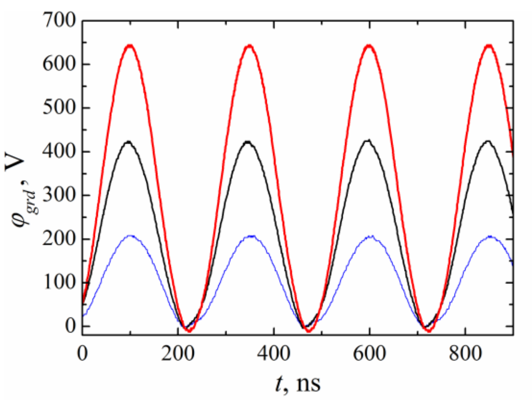
Electrons

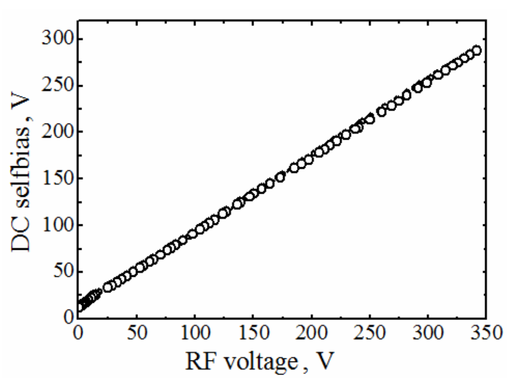


Dual beam with positive ions/electrons

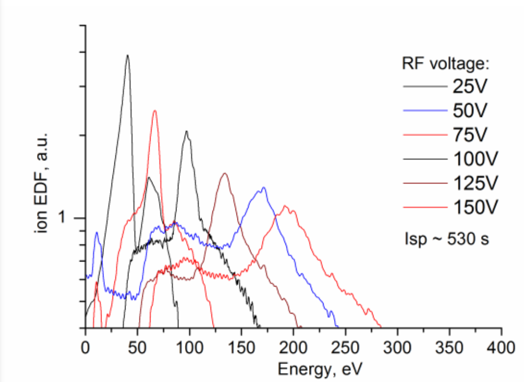
RF acceleration
Quasi-simultaneous extraction

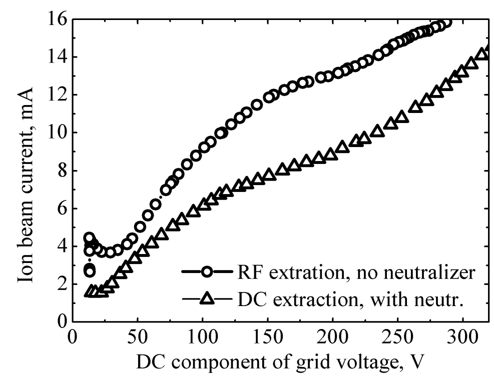
Stability



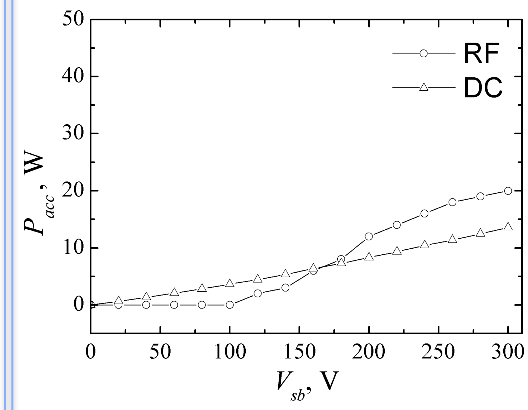


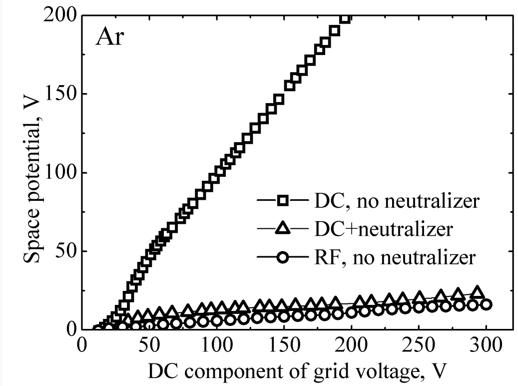
Control





RF vs DC

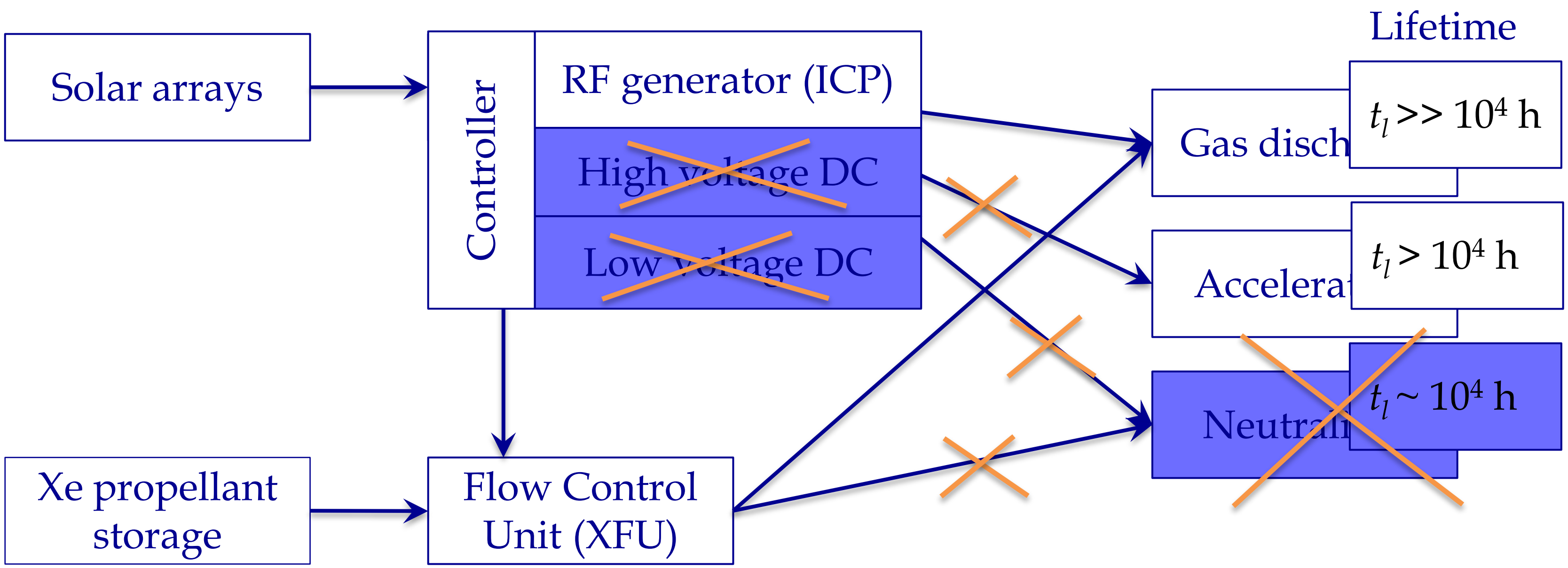




Find more information in *Phys. Plasmas*, **22**, 063502 (2015)
and *J. Phys. D : Appl. Phys.*, **47**, 495203 (2014)

Dual beam with positive ions/electrons

RF acceleration
Quasi-simultaneous extraction



+Lifetime and robustness
+Significant downscaling
+Propellant flexibility

Dual beam with positive ions/electrons – disruptive technology for space

RF acceleration

Quasi-simultaneous extraction

Reasons:

- Strong technology heritage
- No cathode neutralizer
- Beam current can be x2 the one for a DC system
- System is simplified – only one RF power supply
- Scaling flexibility
- Zero emitted net charge
- Highly directional flow
- Suppressed background plasma
- Can be used as a plasma accelerator

Dual beam space propulsion: conclusions

- Dual beam is promising technology for space propulsion
- Dual beams can be formed using temporal or spatial separation of the extraction, can be composed of +/- ions or ions and electrons
- Coincident beams provide precise control of the beam and transport (space potential, induced potential, fluxes)
- Potential use in technologies due to high anisotropy and surface potential control

References

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[5] A Aanesland, A Meige, and P Chabert, *J. Phys.: Conf. Ser.* **162**, 012009 (2009)

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[7] D Rafalskyi and A Aanesland *J. Phys. D : Appl. Phys.*, **47**, 495203 (2014)

[8] "Dispositif de formation d'un faisceau quasi-neutre de particules de charges opposes" D Rafalskyi, A Aanesland, French Patent application no. 14 53469, from 17.04.2014

[9] E Stuhlinger, *Ion propulsion for space flight*, New York: McGraw-Hill, 1964.

Thank you for attention

Laboratoire de Physique des Plasmas

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