

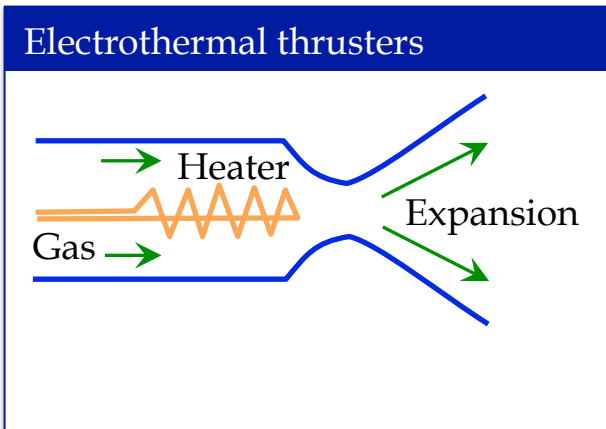
CATHODE-LESS GRIDDED ION THRUSTERS FOR SMALL SATELLITES



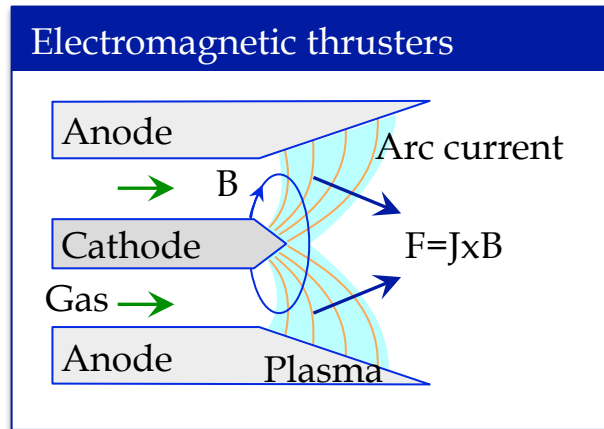
Laboratoire de Physique des Plasmas

Ane Aanesland and Dmytro Rafalskyi
Laboratoire de Physique des Plasmas,
CNRS-Ecole Polytechnique,
France

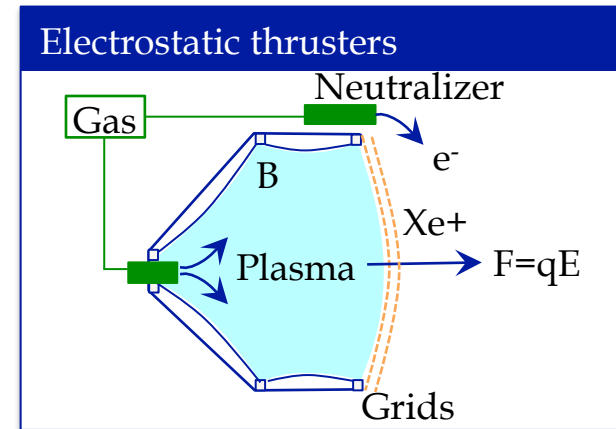
3 classes of Electric Propulsion systems



Resistojet
Arcjet
 $I_{sp} \sim 300 - 600 \text{ s}$

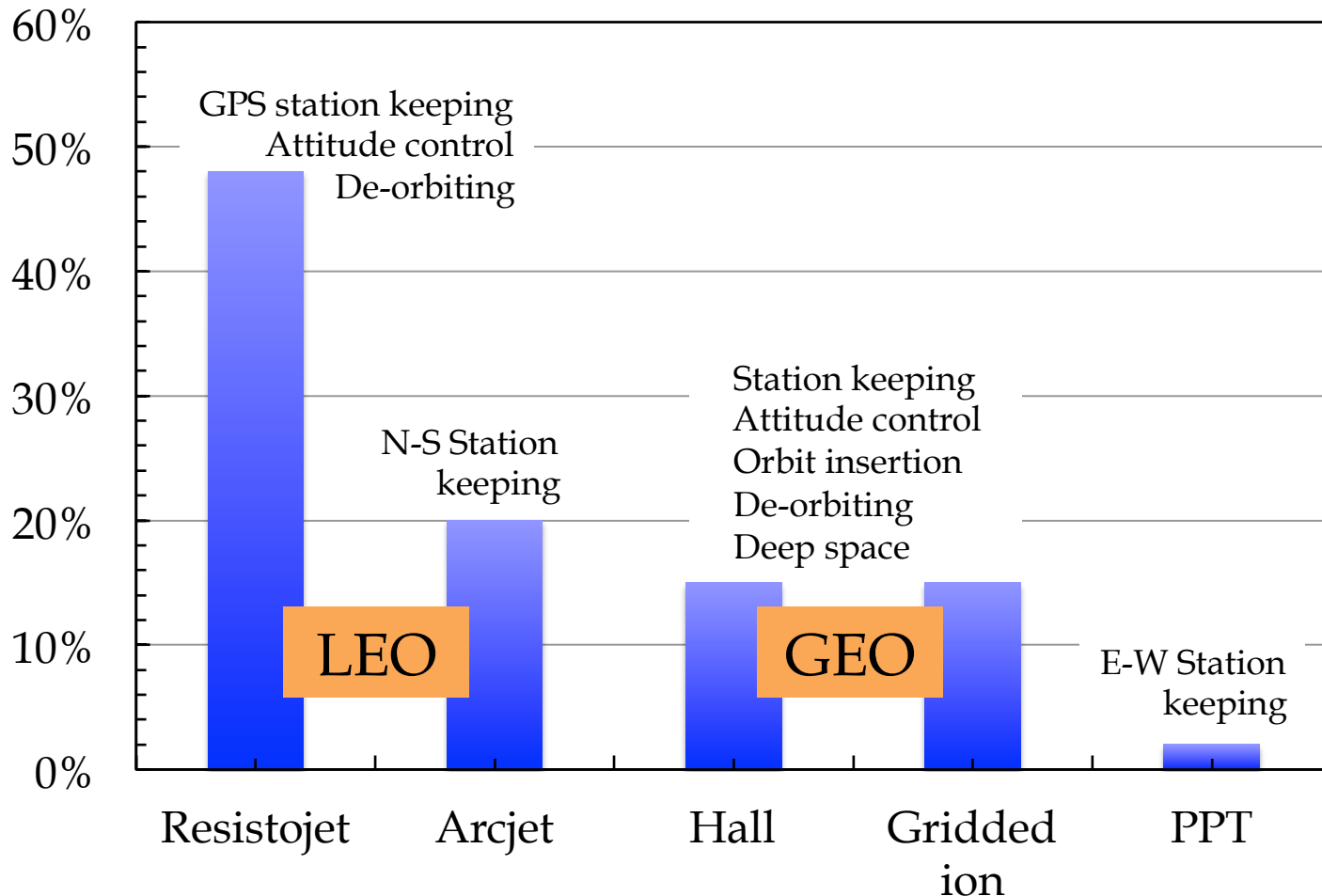


Magneto Plasma Dynamic thrusters
Pulsed Plasma thruster
 $I_{sp} \sim 800 - 1200 \text{ s}$



Gridded Ion thrusters
Hall thrusters
 $I_{sp} \sim 1500 - 4000 \text{ s}$

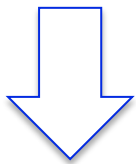
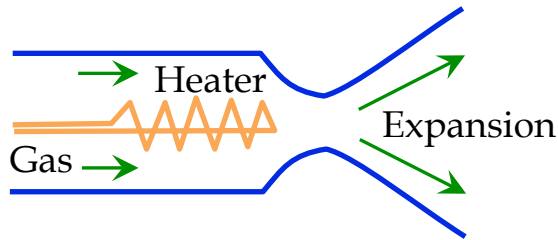
Out of 1168 active satellites, 236 runs with EP systems



Miniaturization possibilities

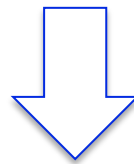
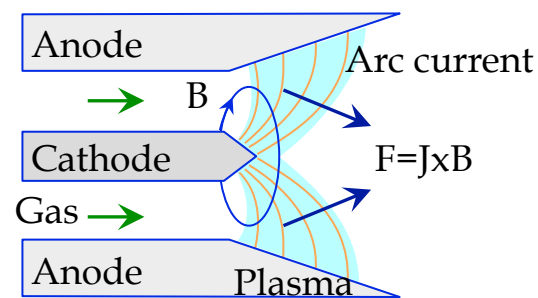


Electrothermal thrusters



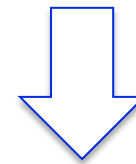
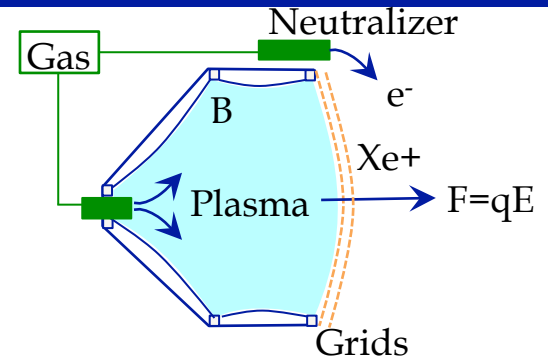
Cold gas thrusters

Electromagnetic thrusters



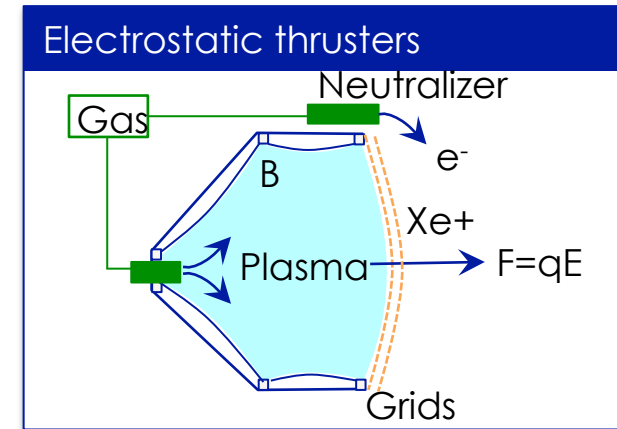
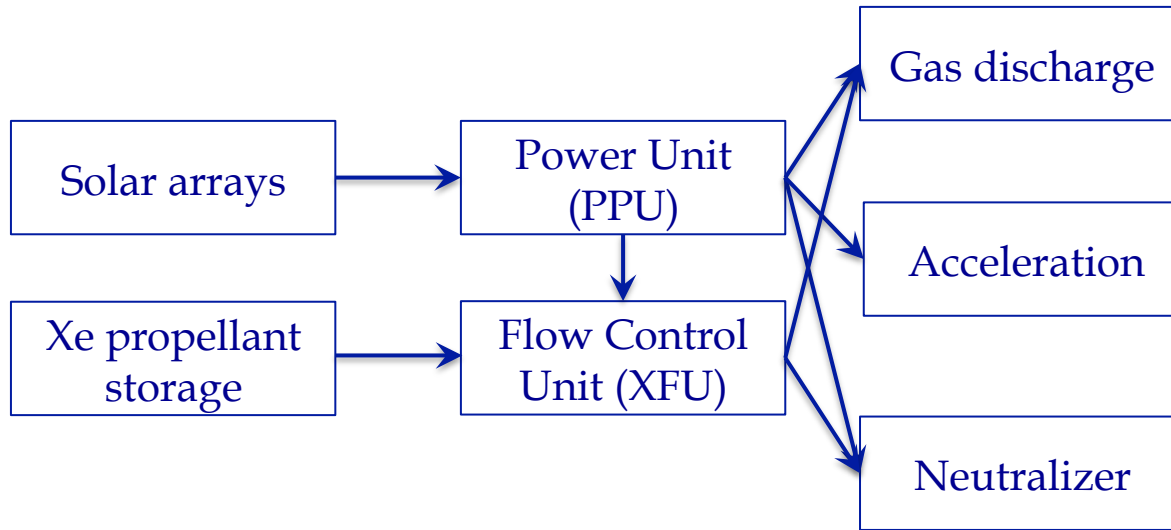
Never used in space
and systems with
magnetic fields are
difficult to
downscale

Electrostatic thrusters

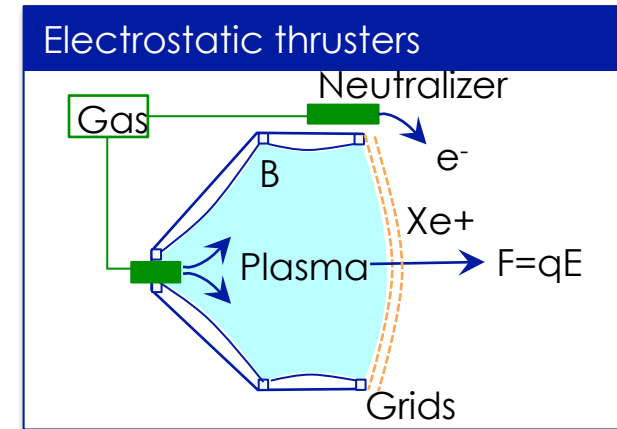
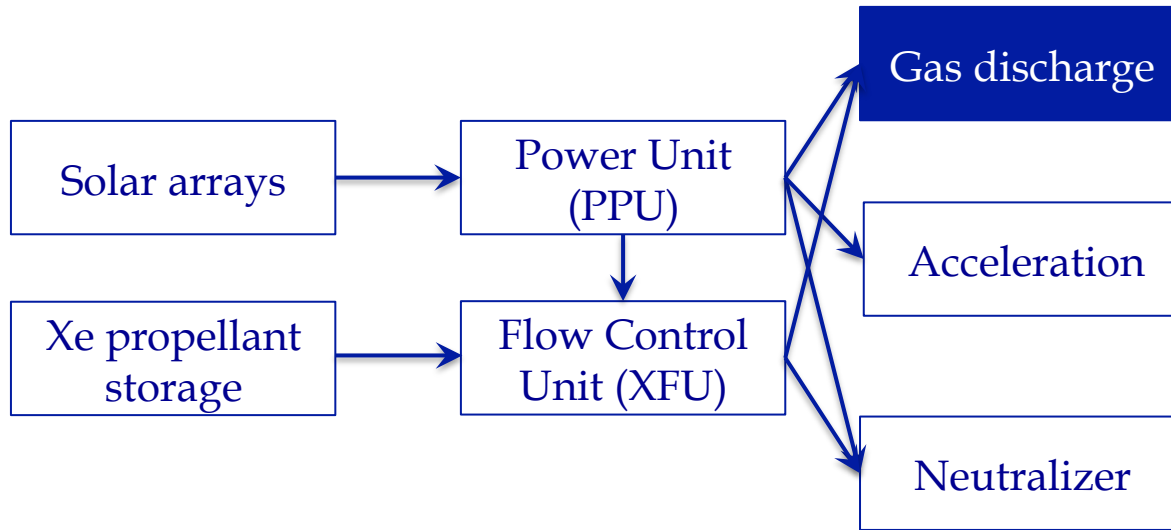


Electrospray thrusters
Gridded ion thrusters
Hall thrusters

Miniaturization of gridded ion thrusters



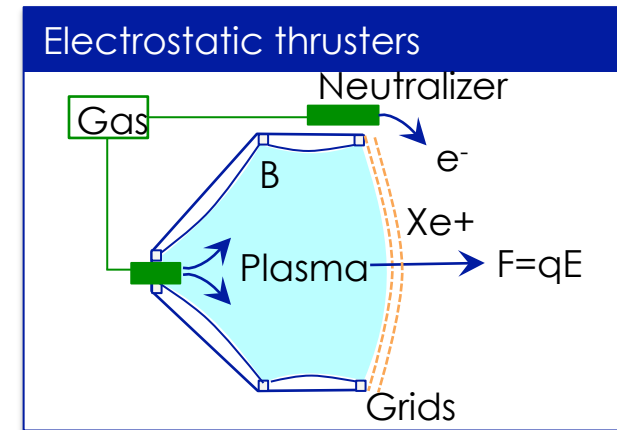
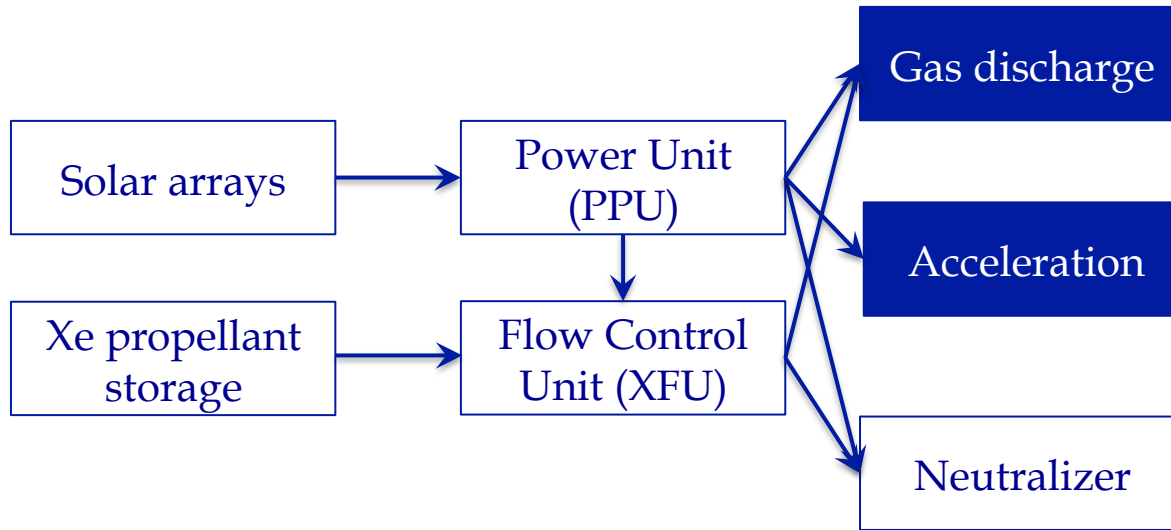
Miniaturization of gridded ion thrusters



Initiate the discharge is difficult $\lambda_{iz} = \frac{1}{n_g \sigma_{iz}}$

Efficiency decreases by more electron **losses to the walls**

Miniaturization of gridded ion thrusters

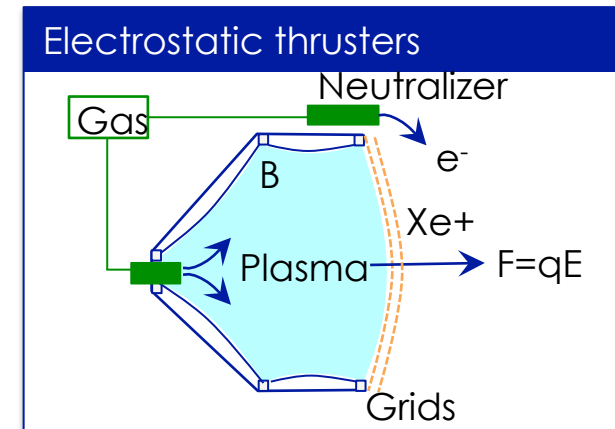
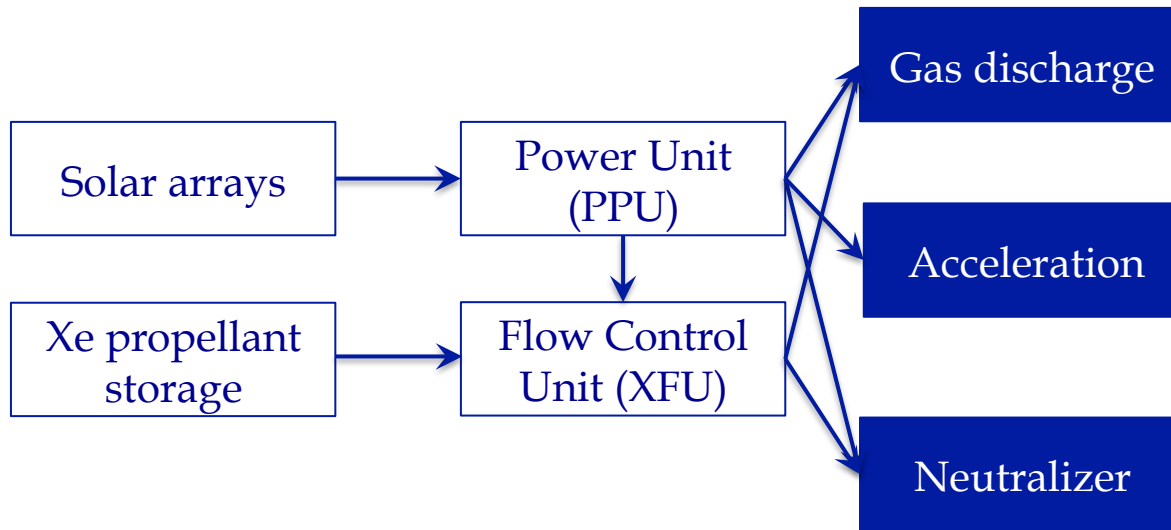


Initiate the discharge is difficult $\lambda_{iz} = \frac{1}{n_g \sigma_{iz}}$

Efficiency decreases by more electron losses to the walls

Grid separation scales inversely with applied acceleration voltage

Miniaturization of gridded ion thrusters



Initiate the discharge is difficult $\lambda_{iz} = \frac{1}{n_g \sigma_{iz}}$

Efficiency decreases by more electron losses to the walls

Grid separation scales inversely with applied acceleration voltage

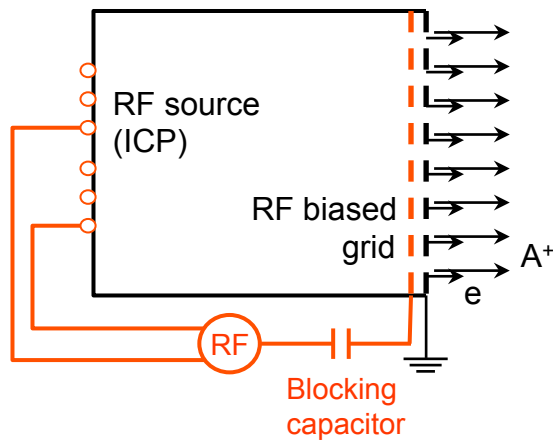
Neutralizer cannot easily be downscaled

The NEPTUNE thruster

A new promising thruster with strong technology heritage



One Radio-Frequency power source for plasma generation, ion acceleration and electron neutralization

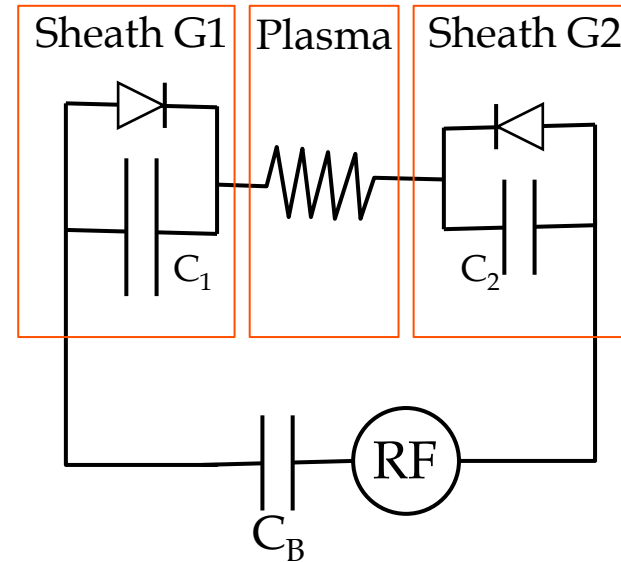
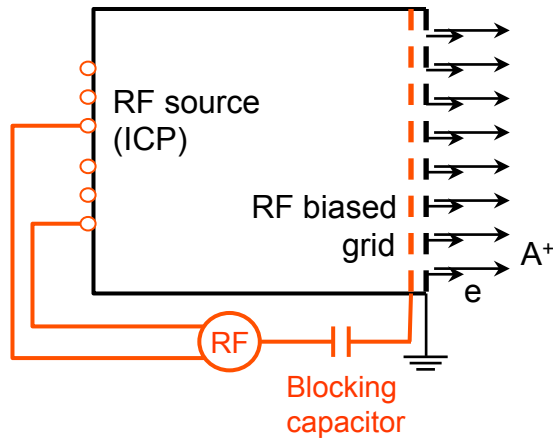


The NEPTUNE thruster

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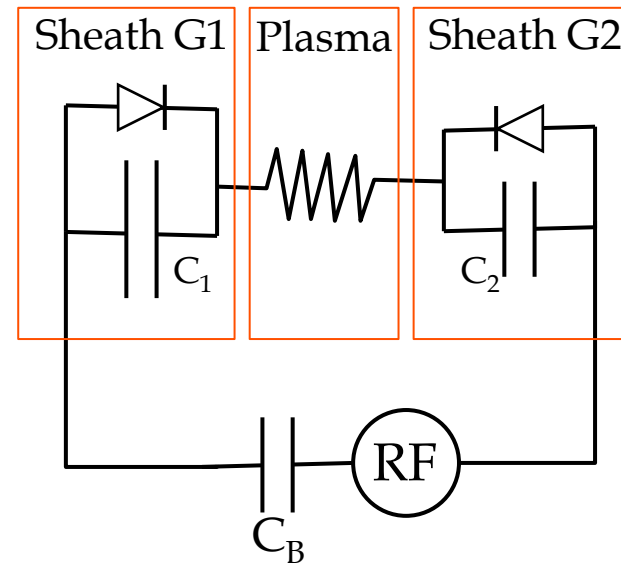
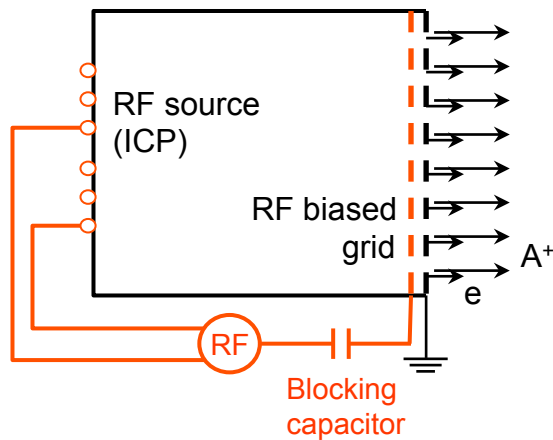


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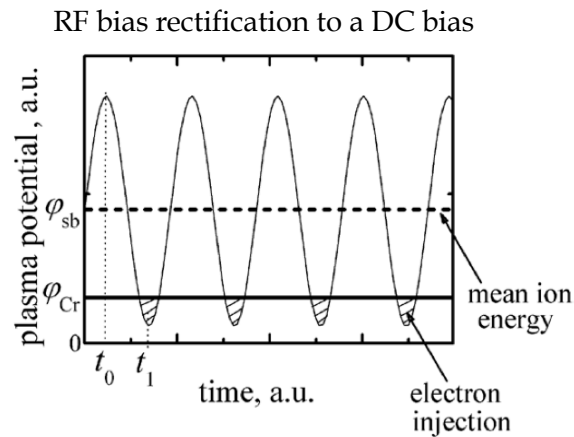
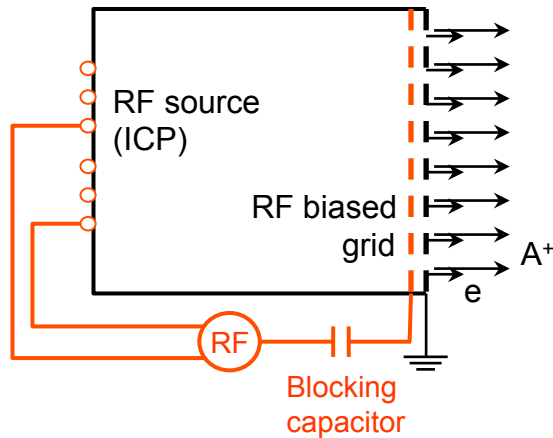


$C = \epsilon_0 A / d$ such that $C_1 > C_2$ and $V_1 \ll V_2$
Blocking capacitor C_B charges up to ensure that $I_e = I_i$

Rectification of the applied RF voltage



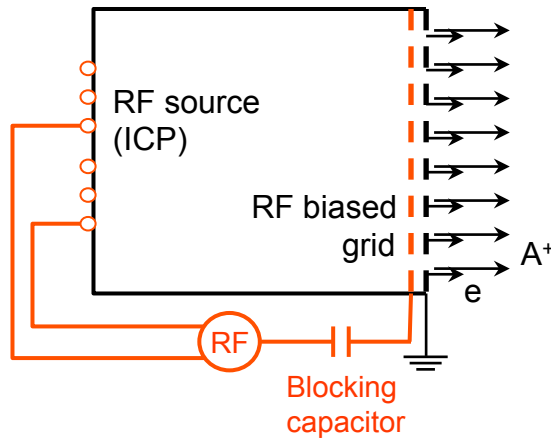
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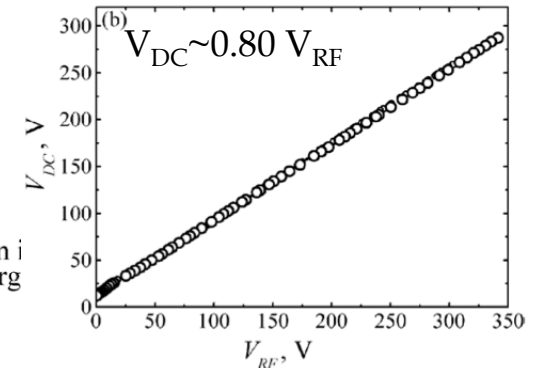
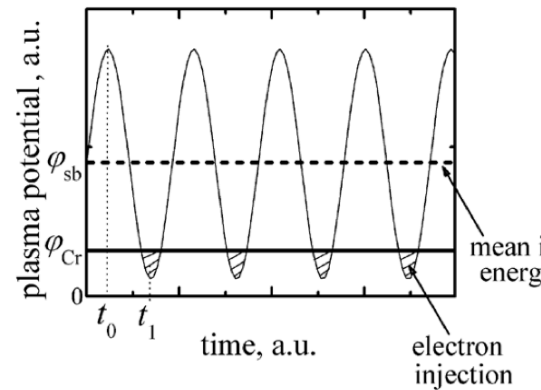
Rectification of the applied RF voltage



One Radio-Frequency power source for plasma generation, ion acceleration and electron neutralization



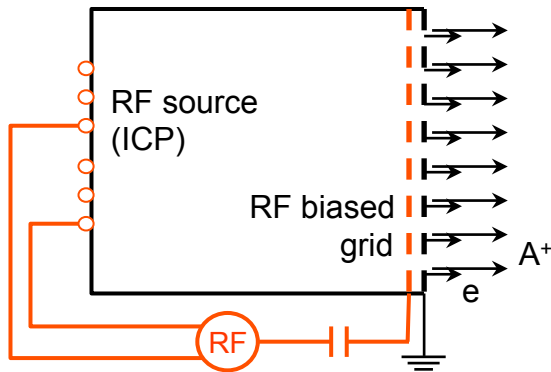
RF bias rectification to a DC bias



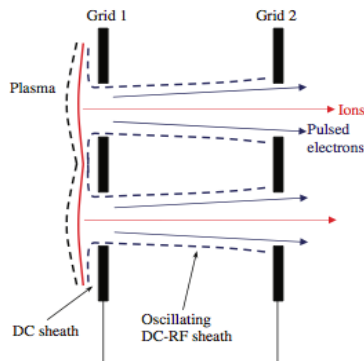
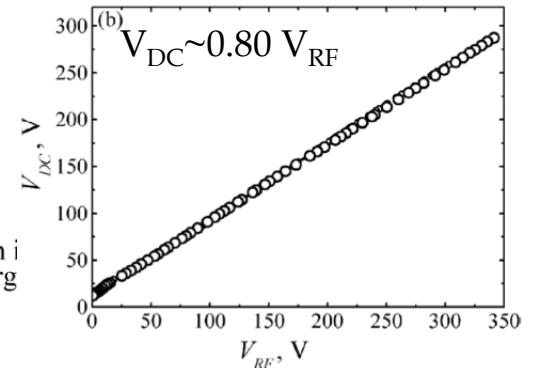
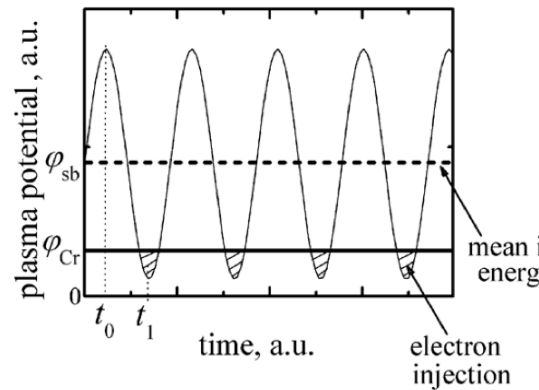
Rectification of the applied RF voltage



One Radio-Frequency power source for plasma generation, ion acceleration and electron neutralization



RF bias rectification to a DC bias



The space charge limited current is:

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

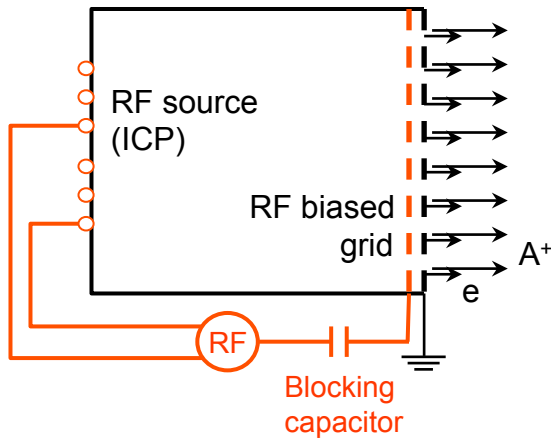
$$\xi_{DC} = \frac{4}{9} = 0.44$$

$$\xi_{RF} = \frac{200}{243} = 0.82$$

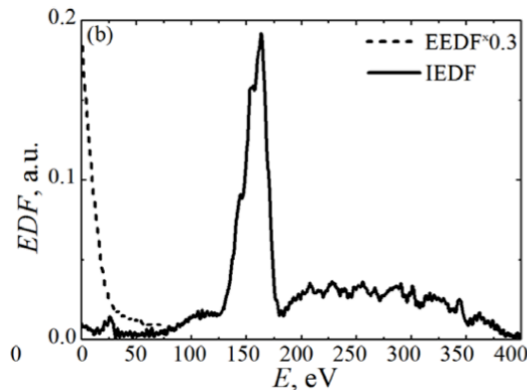
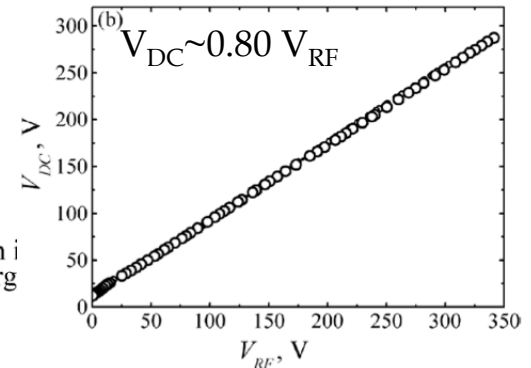
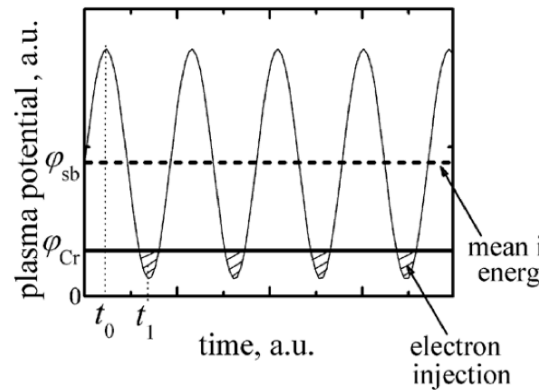
Rectification of the applied RF voltage



One Radio-Frequency power source for plasma generation, ion acceleration and electron neutralization



RF bias rectification to a DC bias



High ion energies
and low anisotropic
electron energies

The NEPTUNE thruster is promising for miniaturization



Advantages:

- No additional cathode
- PPU simplified – only one RF power supply
- Propellant flexibility
- Scaling flexibility
- Beam current can be x2 the one for a DC system
- Emitted net charge is always zero

THANK YOU FOR YOUR ATTENTION



Laboratoire de Physique des Plasmas

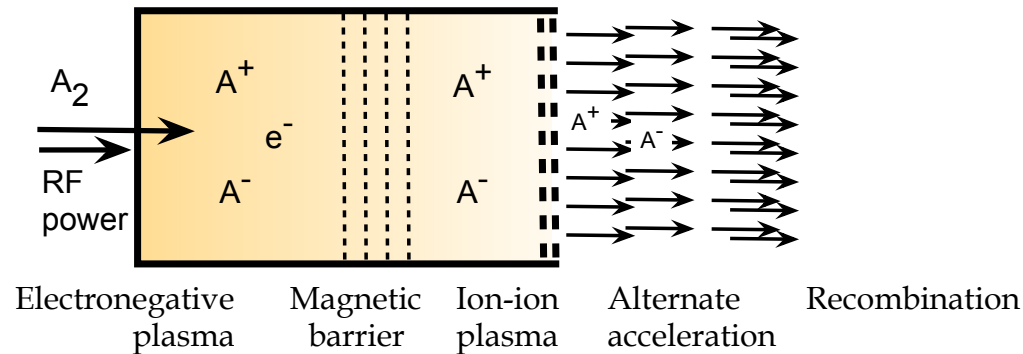
This work was supported by a Marie Curie International Incoming Fellowships within the 7th European Community Framework



The PEGASES thruster promising for miniaturization?



Plasma Propulsion with Electronegative Gases - Accelerates positive and negative ions to generate thrust



Advantages:

- No additional **cathode**
- **Plume** with almost no electrons
- Control of the emitted net **charge**
- **Solid** propellant (**Iodine**)

Disadvantages:

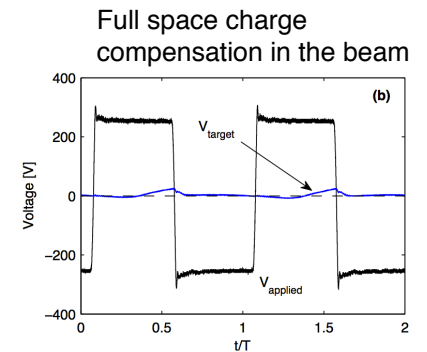
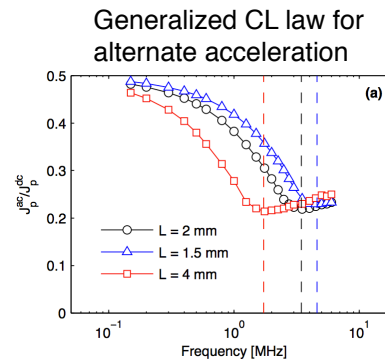
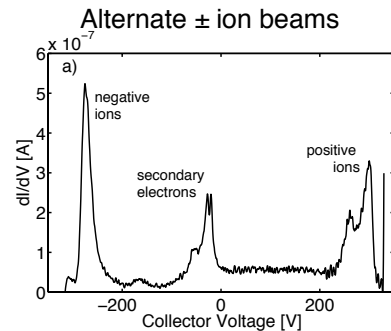
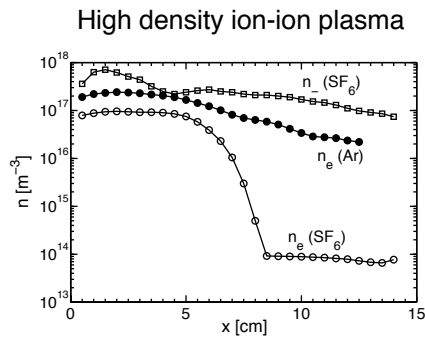
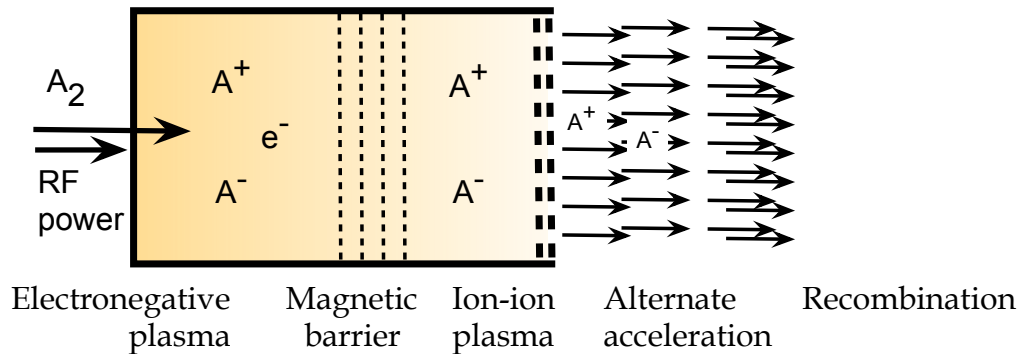
- Need **magnetic** fields
- Need square **voltage waveforms**
- **Electronegative gases** are chemically reactive

A. Aanesland, A. Meige, and P. Chabert, *J. Phys. D* **162**, 012009 (2009).

PEGASES state-of-the-art



Proof-of-concept combining experiments, simulations and analytical models



A. Aanesland, A. Meige, and P. Chabert, *J. Phys. D* **162**, 012009 (2009).

T. Lafleur, D. Rafalskyi, and A. Aanesland, *PSST*. **24**, 015005 (2015).