Plasma for space exploration

On the Hall Effect Thruster investigation

Antoine Tavant

Journées scientifiques de l'EDOM - 15/02/2018

- Satellites are increasingly used/needed

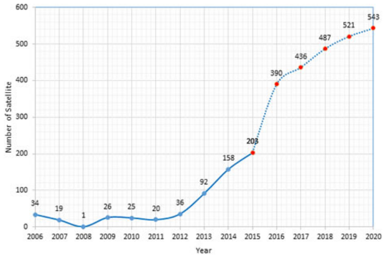


Figure: Number of small satellite launched [IDSA, 2016]

- Propulsion is key : life time, capability, performances, etc.

Arian 5 at launch

- Efficiency of a thruster is linked to the exhaust velocity. To send $10^4 kg$ to Mars:

Technology	Exhaust velocity $/km.s^{-1}$	Properllant mass $/10^3 kg$
Chemical	1	190
Electrical	10	3.5

The Hall effect Thruster

Introduction

- Efficiency of a thruster is linked to the exhaust velocity. To send $10^4 kg$ to Mars:

Technology	Exhaust velocity $/km.s^{-1}$	Properllant mass $/10^3 kg$
Chemical	1	190
Electrical	10	3.5

- Hall Effect Thrusters (HET) is a very promissing electrical technology :
  - High exhaust velocity ($\sim 12km/s$)
  - *Smart1* spacecraft used it **to fly to the moon** [ESA, 2009]
  - Selected for **human missons to Mars** ! [NASA, 2017]

The Hall effect Thruster

More details

Figure: HET (PPS-1350, Safran)

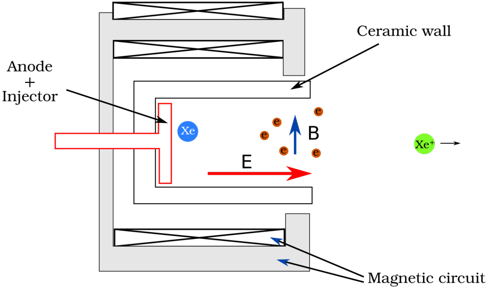


Figure: Schematic cut of an HET

The Hall effect Thruster

More details

Figure: HET (PPS-1350, Safran)

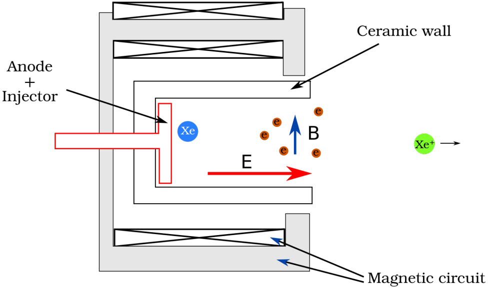


Figure: Schematic cut of an HET

(Un)fortunately: **the HET is still poorly understood**

What don't we know ?

Better inderstanding of HET is important:

- Performance (thrust, efficentcy, etc.) isn't predictable:
  - the electron axial mobility is anormalously high ($\sim 10\times$)
  - the wall effect is poorly understood
- The life time isn't predictable
  - Walls are eroded by ion impact sputtering
  - Life time up to 7000h

Why ?

What don't we know ?

Better inderstanding of HET is important:

- Performance (thrust, efficentcy, etc.) isn't predictable:
  - the electron axial mobility is anormalously high ($\sim 10\times$)
  - the wall effect is poorly understood
- The life time isn't predictable
  - Walls are eroded by ion impact sputtering
  - Life time up to 7000h

Why ? Because plasma physics are **difficult**

Plasma physics are difficult

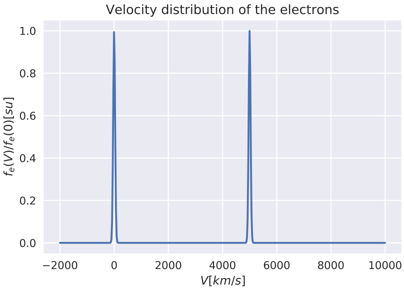
- Measurments and diagnotics are difficult:
  - Intrusive probs will modify the plasma properties
  - Non-intrusive diagnostics are costly, complicated, and work badly under these conditions
- The theory is complexe:
  - Plasma : **fluid equations** mixed with **Maxwell equations** $\rightarrow$ quite complex

$\rightarrow$ Simulation is a big help, especially kinetic simulations.

An example of "simple" plasma behavious : the 1D plasma-beam instability.

The system is simple:

- a static plasma background
- an electron beam with high velocity
- collisions are neglected (low pressure)
- uniform spatial density



An example of "simple" plasma behavious : the 1D plasma-beam instability.

Phase-space representation of electrons

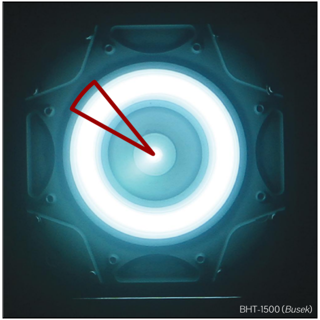
(Velocity vs position)

The system is simple:

- a static plasma background
- an electron beam with high velocity
- collisions are neglected (low pressure)
- uniform density

Simulation of HET
Investigating the ECDI

Research done at LPP: 2D simulation of HET with LPPic, a PIC simulation tool



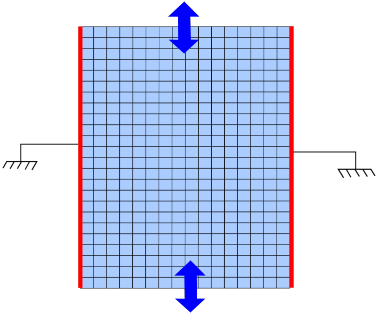


Figure: Schematic cut of the simulation

The plasma potential evolution in function of time.

The instability observed is certainly the Electron cyclotron drift instability !

Simulation results

Investigating the ECDI

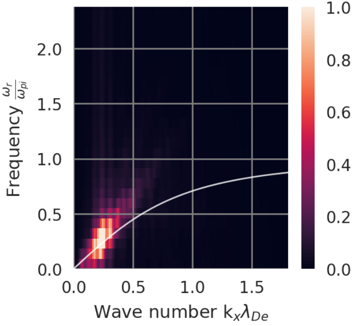


Figure: 2D Fourier Transform of $\overrightarrow{E} \cdot \overrightarrow{e_\theta}$ and the dispertion relation $\omega(k_\theta)$ of the ECDI. [Lafleur, 2016]

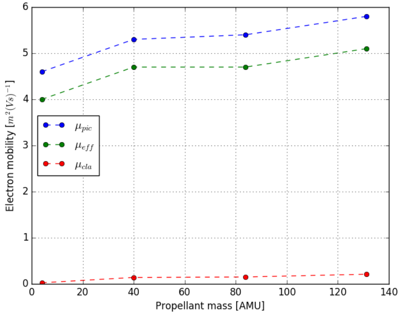


Figure: Electron mobility from simulation compared with theories vs properlant mass [Croes, 2017]

Improving Thuster simulation

The objective of my Ph.D.: **How to improve the simulation of the HET ?**

1. Modelize plasma-wall interactions
2. Simulate the third (axial) direction O_z
3. Confrontation with experiment

Electron induced Secondary electron emission (SEE)

Emission probability:

$$\sigma = \sigma_0 + (1 - \sigma_0)\frac{\epsilon}{\epsilon^*}$$

with $\epsilon = \frac{1}{2}m_e v^2$, and σ_0 and ϵ^* functions of the ceramic

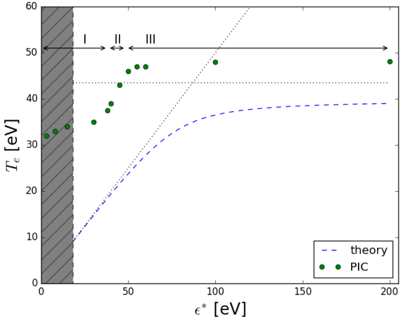


Figure: Electron temperature T_e function of ϵ^*, $\sigma_0 = 0.5$, compared to the current theory [Croes, 2017]

Improving Thuster simulation

1. Wall effects

Dielectric effect as electrostatic condition

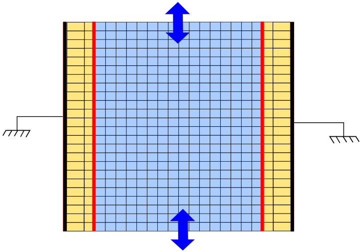


Figure: Added ceramic layers

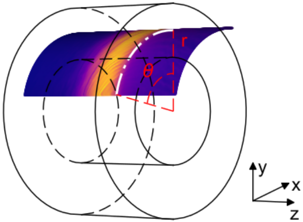
→ No significant effect without SEE, to be investigated with SEE

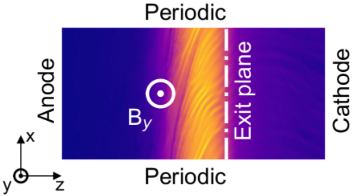
Improving Thuster simulation

2. O_z direction

Axial (O_z) direction, important beacause of:

- propagation direction
- self-consistent ionization, density and electric field





→ First results obtained in December 2017, work in progress !

How to validate simulations ?

Simulations are useful only if we are sure of the results.

- We remove bugs from simulations with benchmarks [Turner et al. 2016]
- Laboratory Model of HET has been desing
- Simulations will be confronted to experiments during Spring 2018

Conclusion

- Understanding HET is mandatory for space exploration
- Simulation is needed to understand HET $\rightarrow$ LPPic

Conclusion

- Understanding HET is mandatory for space exploration
- Simulation is needed to understand HET $\rightarrow$ LPPic

- LPPic validated the electron mobility theory
- SEE, dieletric, propagation,... are curently beeing investegated with LPPic
- Confrontation to experiments will start in few months

That’s all folks !

Thank you for your attention.

Now is question time !

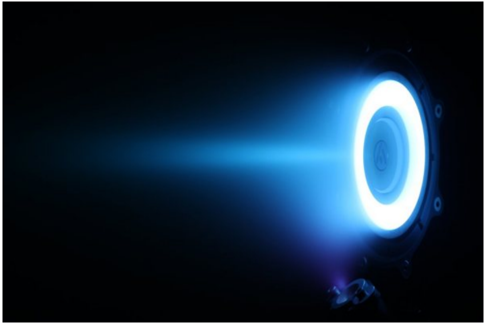


Figure: HET during use, Busek

Improving Thuster simulation

The objective of my Ph.D.: **How to improve the simulation of the HET ?**

1. Modelize plasma-wall interactions
2. Simulate the third (axial) direction O_z
3. Confrontation with experiment

Improving Thuster simulation

The objective of my Ph.D.: **How to improve the simulation of the HET ?**

1. Modelize plasma-wall interactions
   - Secondary electron emission (SEE) [by Vivien Croes]
   - Dielectric layer (electrostatic bondary)
   - Erosion by ion impacts [with Théo Courtois]
2. Simulate the third (axial) direction O_z
   - Simulation of the (O_z, O_θ) plan [with Thomas Charoy]
   - Adding third "fake" direction in the 2D simulation
3. Confrontation with experiment
   - Design and tests on a prototype [with Théo Courtois]
   - Developing new diagnostics [by Théo Courtois]

Improving Thuster simulation

The objective of my Ph.D.: **How to improve the simulation of the HET ?**

1. Modelize plasma-wall interactions
   - Secondary electron emission (SEE) [by Vivien Croes]
   - Dielectric layer (electrostatic bondary)
   - Erosion by ion impacts [with Théo Courtois]
2. Simulate the third (axial) direction O_z
   - Simulation of the (O_z, O_θ) plan [with Thomas Charoy]
   - Adding third "fake" direction in the 2D simulation
3. Confrontation with experiment
   - Design and tests on a prototype [with Théo Courtois]
   - Developing new diagnostics [by Théo Courtois]