

Plasma for space exploration

On the Hall Effect Thruster investigation



Antoine Tavant

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

Propulsion for satellites

Introduction



- ▶ Satellites are increasingly used/needed

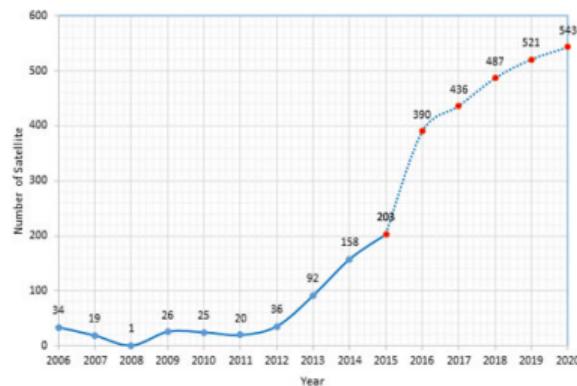


Figure: Number of small satellite launched [IDSA, 2016]

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



The Hall effect Thruster

Introduction



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

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

The Hall effect Thruster

Introduction



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

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

- ▶ Hall Effect Thrusters (HET) is a very promissing electrical technology :
 - ▶ High exhaust velocity ($\sim 12\text{km/s}$)
 - ▶ *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)

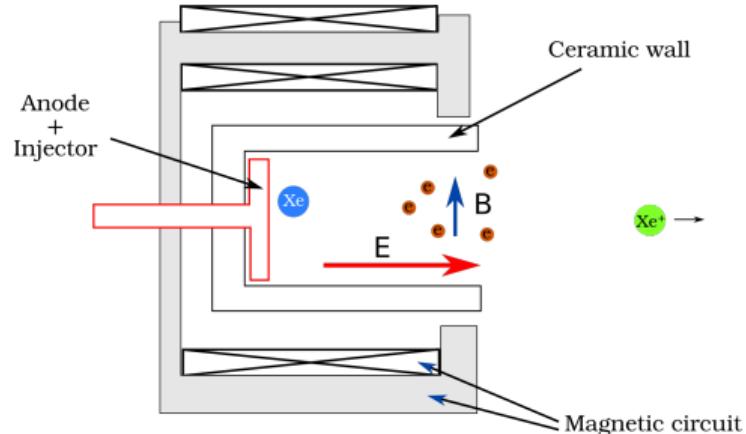


Figure: Shematic cut of an HET

The Hall effect Thruster

More details



Figure: HET (PPS-1350, Safran)

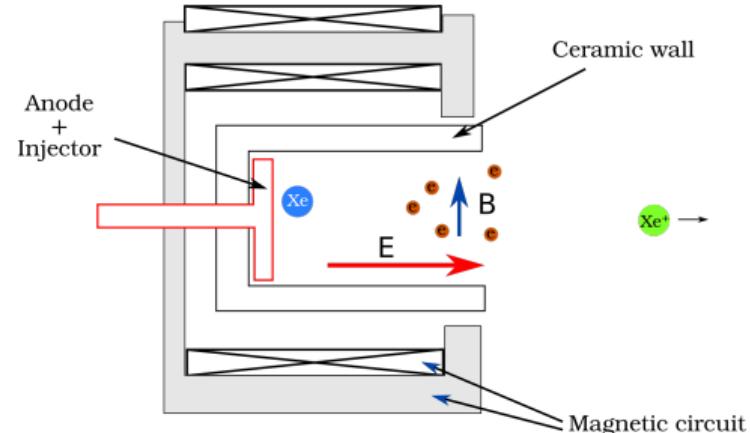


Figure: Shematic cut of an HET

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

What don't we know ?

Introduction



Better understanding of HET is important:

- ▶ Performance (thrust, efficiency, etc.) isn't predictable:
 - ▶ the electron axial mobility is anomalously 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 ?

Introduction



Better understanding of HET is important:

- ▶ Performance (thrust, efficiency, etc.) isn't predictable:
 - ▶ the electron axial mobility is anomalously 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



- ▶ Measurements and diagnostics are difficult:
 - ▶ Intrusive probes will modify the plasma properties
 - ▶ Non-intrusive diagnostics are costly, complicated, and work badly under these conditions
 - ▶ The theory is complex:
 - ▶ Plasma : **fluid equations** mixed with **Maxwell equations** → quite complex
- Simulation is a big help, especially kinetic simulations.

Plasma Beam Instability

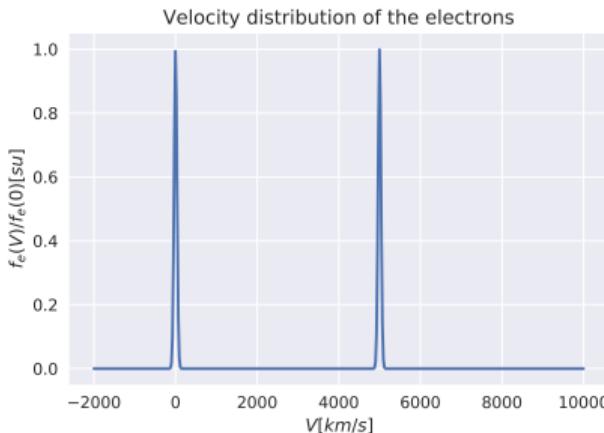
Some Plasma Physics



An example of "simple" plasma behavior : 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



Plasma Beam Instability

Some Plasma Physics



An example of "simple" plasma behaviour : 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

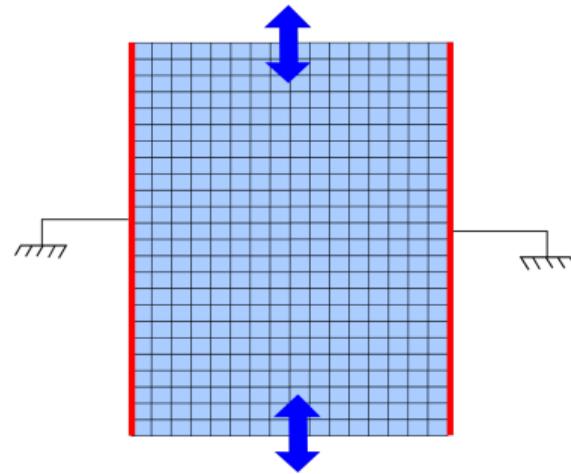
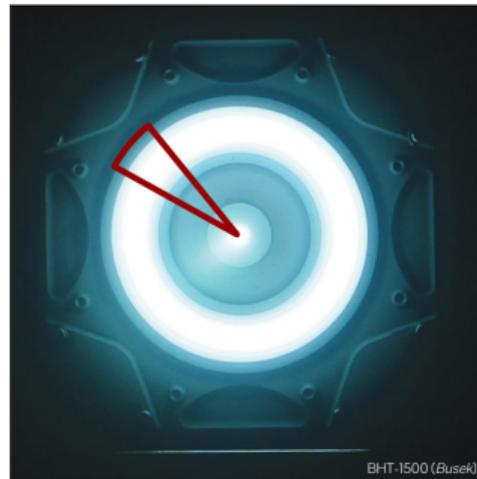


Figure: Schematic cut of the simulation

Simulation results

Investigating the ECDI



The plasma potential evolution in function of time.

The instability observed is certainly the Electron cyclotron drift instability !

Simulation results

Investigating the ECDI

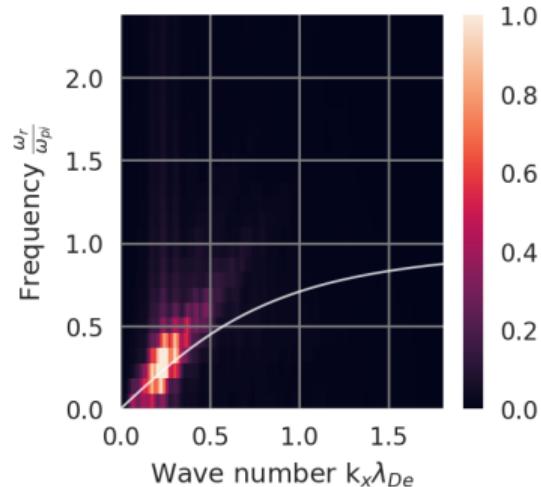


Figure: 2D Fourier Transform of $\vec{E} \cdot \vec{e}_\theta$ and the dispersion relation $\omega(k_\theta)$ of the ECDI. [Lafleur, 2016]

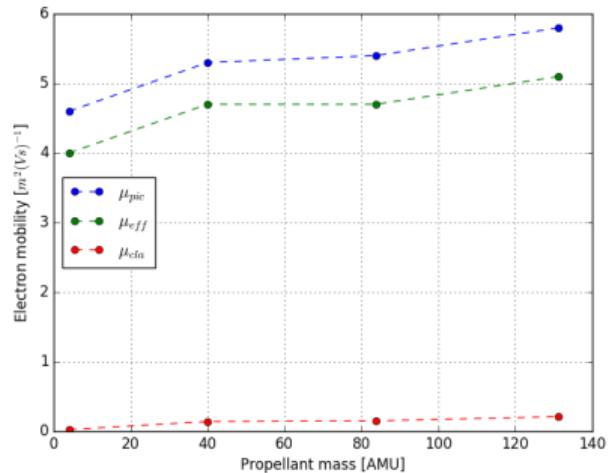


Figure: Electron mobility from simulation compared with theories vs propellant mass [Croes, 2017]

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

Improving Thuster simulation

1. Wall effects



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

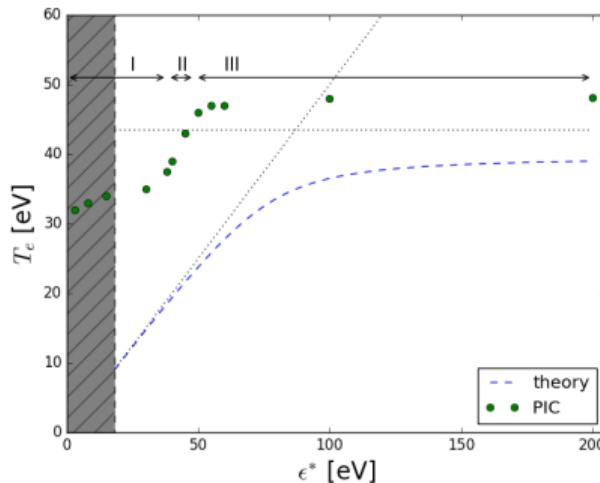


Figure: Electron temperature T_e function of ϵ^* , $\sigma_0 = 0.5$, compared to the current theory [Croes, 2017]

Improving Thuster simulation

1. Wall effects



Dielectric effect as

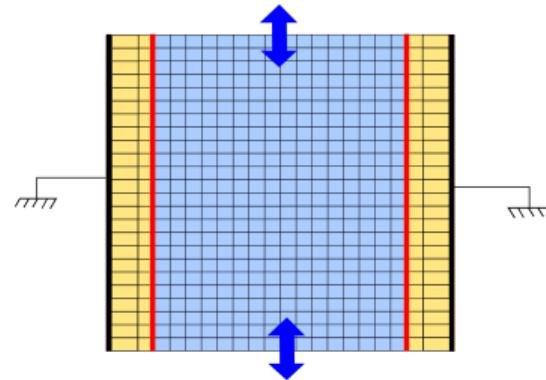


Figure: Added ceramic layers

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

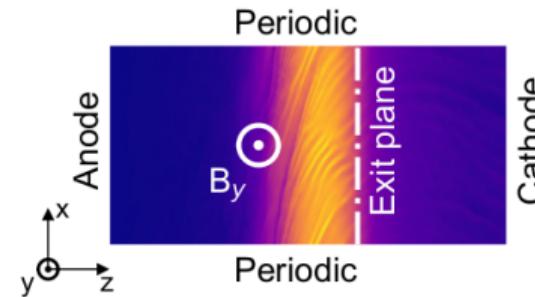
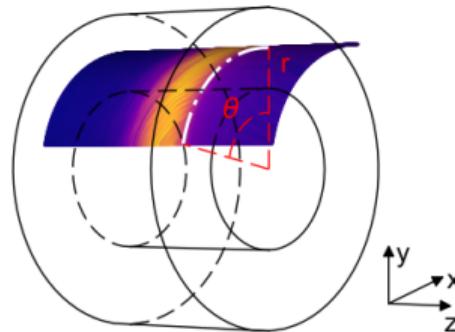
Improving Thuster simulation

2. O_z direction



Axial (O_z) direction, important because of:

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



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

Improving Thuster simulation

3. Comparaison to experiments



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 designed
- ▶ Simulations will be confronted to experiments during Spring 2018

Conclusion



- ▶ Understanding HET is mandatory for space exploration
- ▶ Simulation is needed to understand HET → LPPic

Conclusion



- ▶ Understanding HET is mandatory for space exploration
- ▶ Simulation is needed to understand HET → LPPic

- ▶ LPPic validated the electron mobility theory
- ▶ SEE, dielectric, propagation,... are currently being investigated with LPPic
- ▶ Confrontation to experiments will start in few months

That's all folks !



Thank you for your attention.

Now is question time !

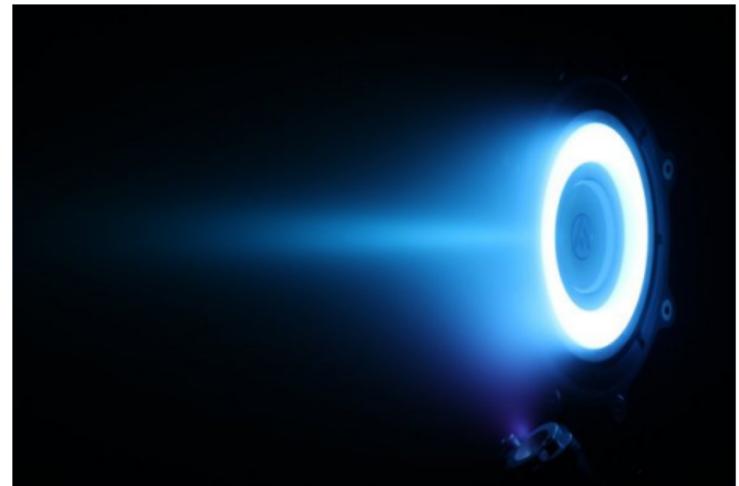


Figure: HET during use, Busek

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 (electrostatique boundary)
 - ▶ 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 (electrostatique 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]