The potential of electric propulsion: research at LPP and in the ANR industrial chair POSEIDON

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Context

In an increasingly competitive satellite market, electric satellites are expected to garner a growing share of the market.
Two promising trends for the development of electric propulsion:

- The need of high power (10s of kW) electric propulsion systems in telecommunication satellites for full orbit raising and orbit transfer (thrust of the order of Newtons)

- The need for low power (1-1000W) electric propulsion systems for the exploding and disruptive market of small satellites (small-, micro- and nanosatellites) where the thrust is of the order of microNewtons.

Context

Safran Aircraft Engines, pioneered electric propulsion systems in Europe and has developed the Hall effect thrusters and mainly : PPS®1350 (1350W) and PPS®5000 (5kW)

To meet the growing customer demand for all-electric satellites, SAFRAN has to be capable of offering solutions tailored to each customer's specific needs, from orbital transfer to station-keeping, in a large power range of thrusters.
=> Nedd to develop low power Hall effect thrusters (<u>Current target 600W</u>) for the market of small satellites in low-Earth orbits

Very competitive market with »new players »

Objectives

Current development of electric thrusters

- Hall effect thrusters invented in the 60s, but several key porcesses of magnetized plasmas are still poorly understood
- Design and development is still semi-empirical with long and expensive life tests (10 years for PPS®1350)
- Since 2014, collaboration between Safran, LPP, CERFACS on the numerical simulation of a PPS®1350

Objectives

Current development of electric thrusters

Objectives of the chair POSEIDON (2016-2020)

- Innovative research solutions for fundamental studies to better understand key plasma processes in Hall effect thrusters
- New combined experimental and numerical methodology to reduce the number of experimental tests in the development of future thrusters

Electric propulsion at LPP

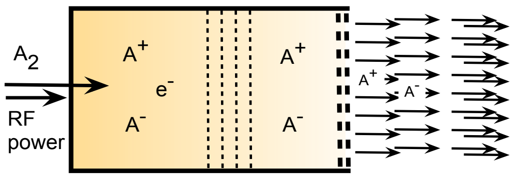
FIELDS OF EXPERTISE

- Acceleration of ions (microelectronics) : exp. and theory
- Since 2014 : development of numerical simulations

INNOVATIVE PROJECTS

1) PEGASES since 2006
2) NEPTUNE since 2014
3) POSEIDON

PEGASES



- Accelerates ±ions beams at >200 kHz
- Operation in Iodine
- Modeling coupled to exp.
- Develop for debris removal

NEPTUNE

- Cathodeless system
- Innovative acceleration system
- Miniaturization
- Start-up ThrustMe (01/2017)

HALL THRUSTER

- Collaboration LPP, Safran Aircraft Engines, CERFACS since 2014
- ANR industrial chair POSEIDON

Scientific and technical bottlenecks

Clearly identified:

- Instabilities of the plasma and nanomalous transport of electrons,
- Plasma-wall interaction and erosion,
- Alternative propellants

Project structure

Simulations

LPP: PIC code (LPPiC) with cartesian mesh and simple geometry

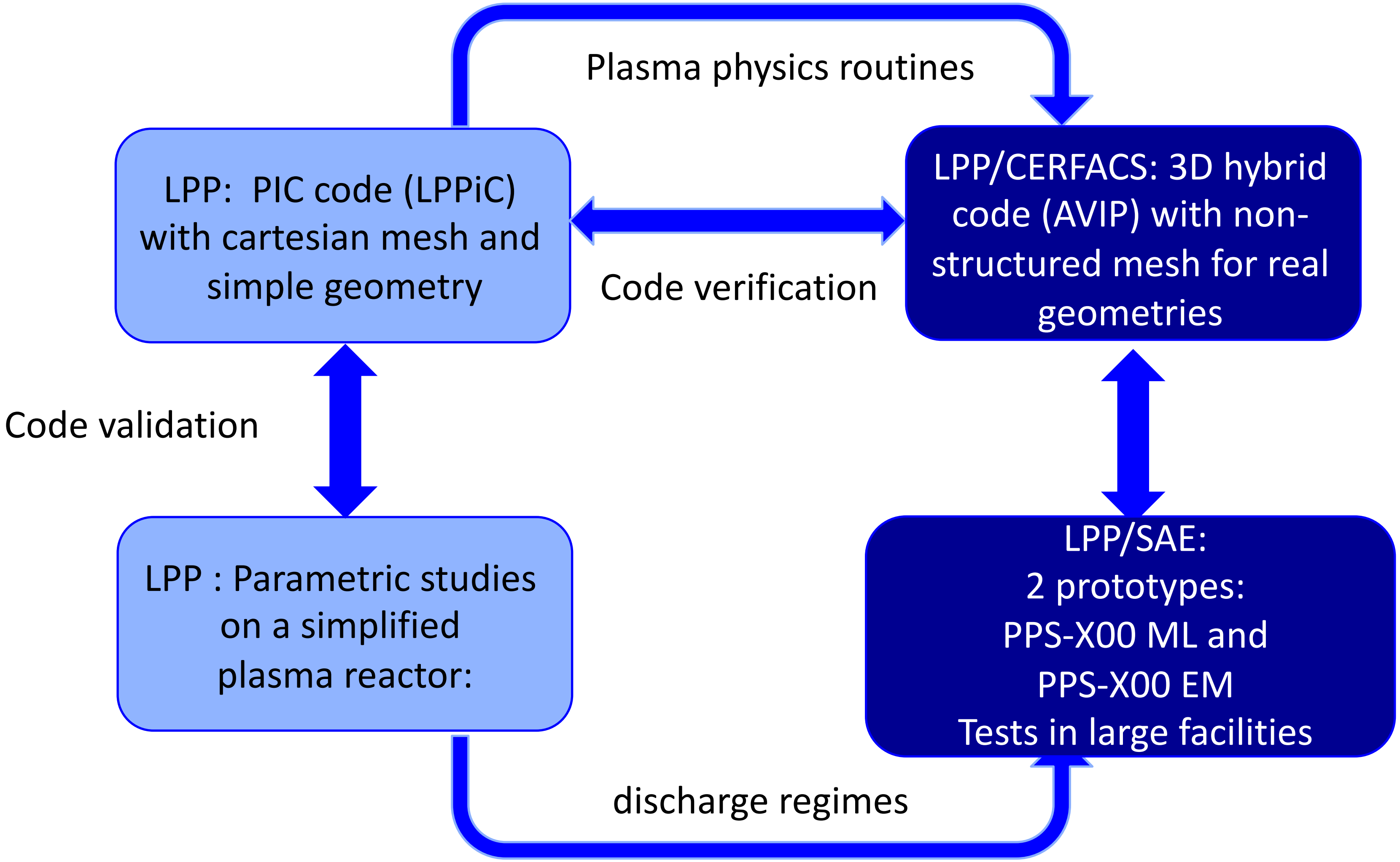
LPP/CERFACS: 3D hybrid code (AVIP) with non-structured mesh for real geometries

Experiments

LPP : Parametric studies on a simplified plasma reactor:
=> Small HET out of its optimal point

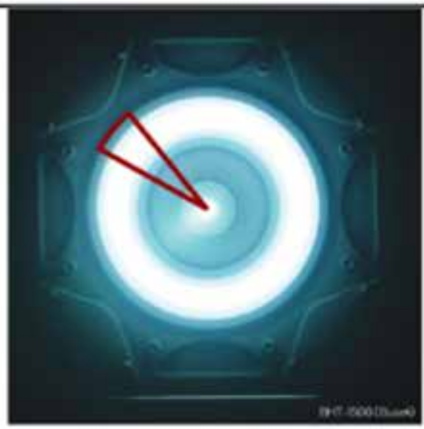
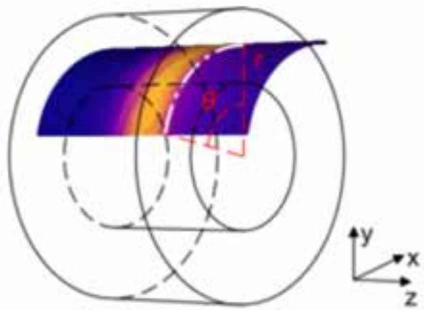
LPP/SAE:
2 prototypes:
PPS-X00 ML and
PPS-X00 EM
Tests in large facilities

Project structure



Development of simulation codes

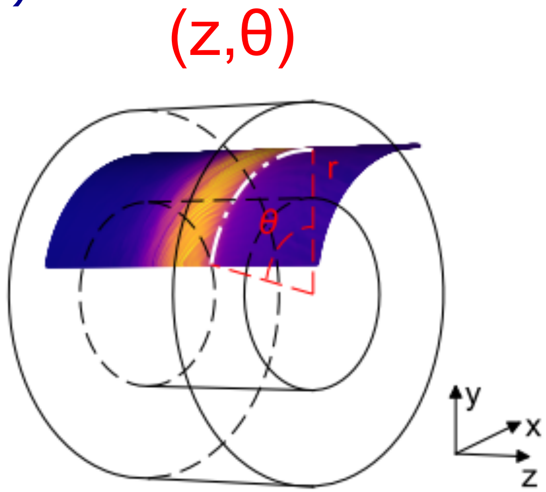
- Code LPPiC2D at LPP (simple geometries)

Simulation case	HET: $R-\theta$	HET: $Z-\theta$
		
Computational time with 360 CPUs	$10\mu s \rightarrow 50h$	$20\mu s \rightarrow$ 2 weeks

CINES Occigen : 12 millions hours since 2017
NEMO (Cerfacs, Toulouse) around 3 millions hours per year since 2016

Development of simulation codes

- LPPiC2D : PIC code at LPP (simple geometry)



- Code 1D fluid at LPP

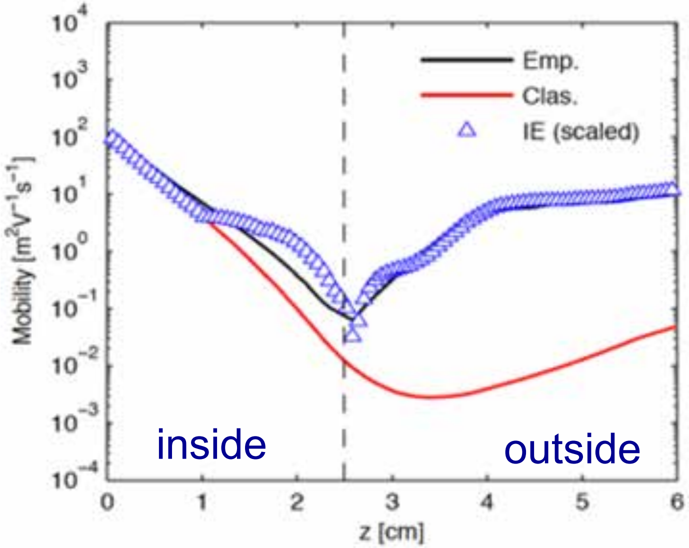
Collaborations and propositions of test-cases for the development of the AVIP hybrid (PIC and fluid) at CERFACS (real geometry of thrusters)

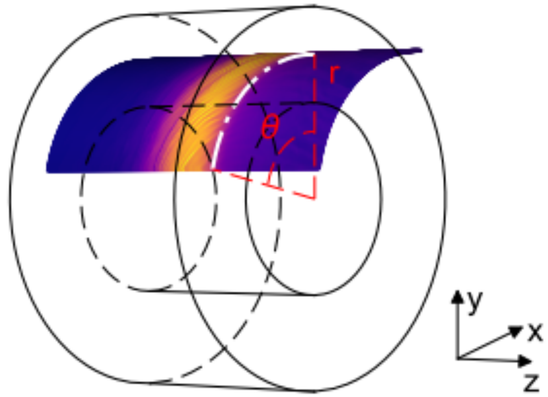
=> International benchmark on the simulation of a low-pressure magnetized plasma with 7 groups – coordination by LPP

Charoy et al, in revision in Plasma Sources Science and Technology 2019

One key result:
Anomalous transport of electrons

- With a classical collisional model, the electron mobility is underestimated by orders of magnitude=> use of semi-empirical models



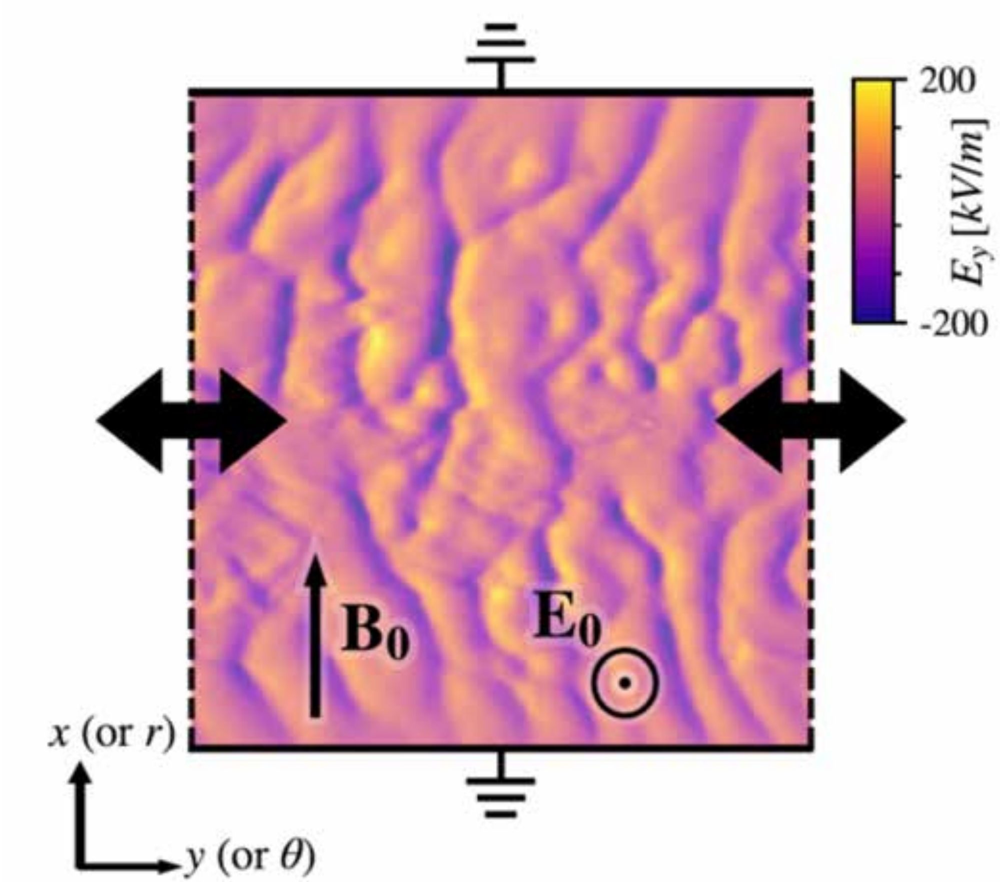


- Theoretical works at LPP : new model for the axial mobility of electrons based on kinetic theory

Key role of the azimuthal electron cyclotron drift instability

J C Adam, J P Boeuf, N Dubuit, M Dudeck, L Garrigues, D Grésillon, A Héron, G J M Hagelaar, V Kulaev, N Lemoine, S Mazouffre, J Perez Luna, V Pisarev, S Tsikata, Plasma Phys. Control. Fusion **50**, 124041 (2008)
T. Lafleur, S.D. Baalrud, and P. Chabert, *Physics of Plasmas* **23** (5) 053503 (2016)

LPPic2D - R-θ plane (exit plane)

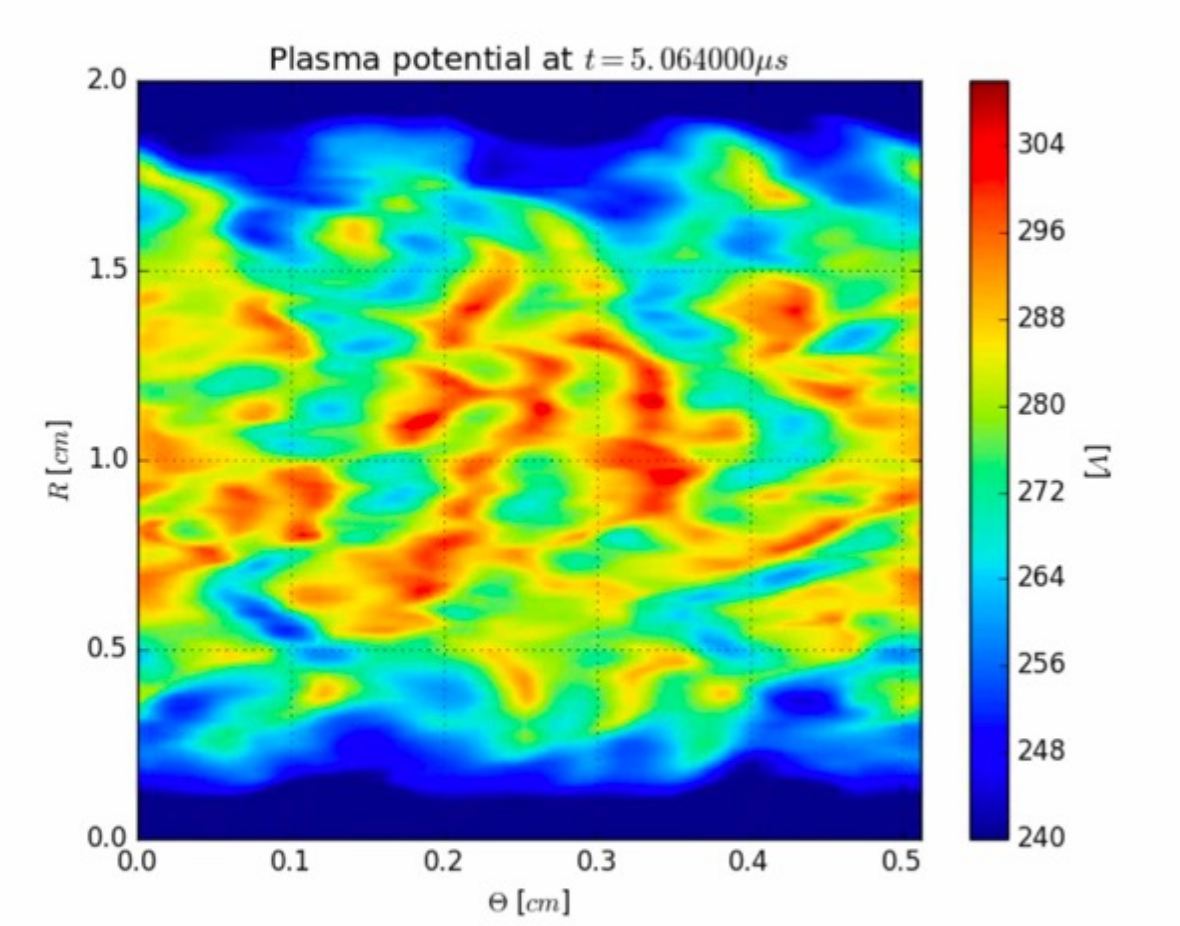


Detailed study of the Electron Cyclotron Drift Instability (ECDI) propagating in the azimuthal direction

Simulations of instabilities in the R-θ plane

Vidéo

LPPic2D

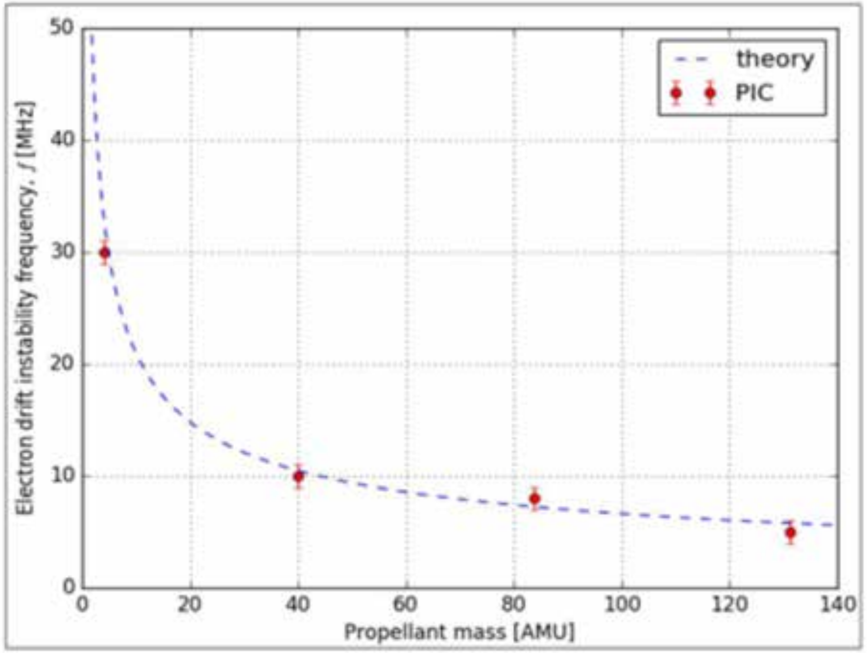


Use of the efficiently parallelized LPPic2D PIC code to challenge the new theory over a large range of plasma conditions and parameters

LPPic2D - R-θ plane simulations

Influence of the propellant mass of the frequency of the azimuthal electron drift instability

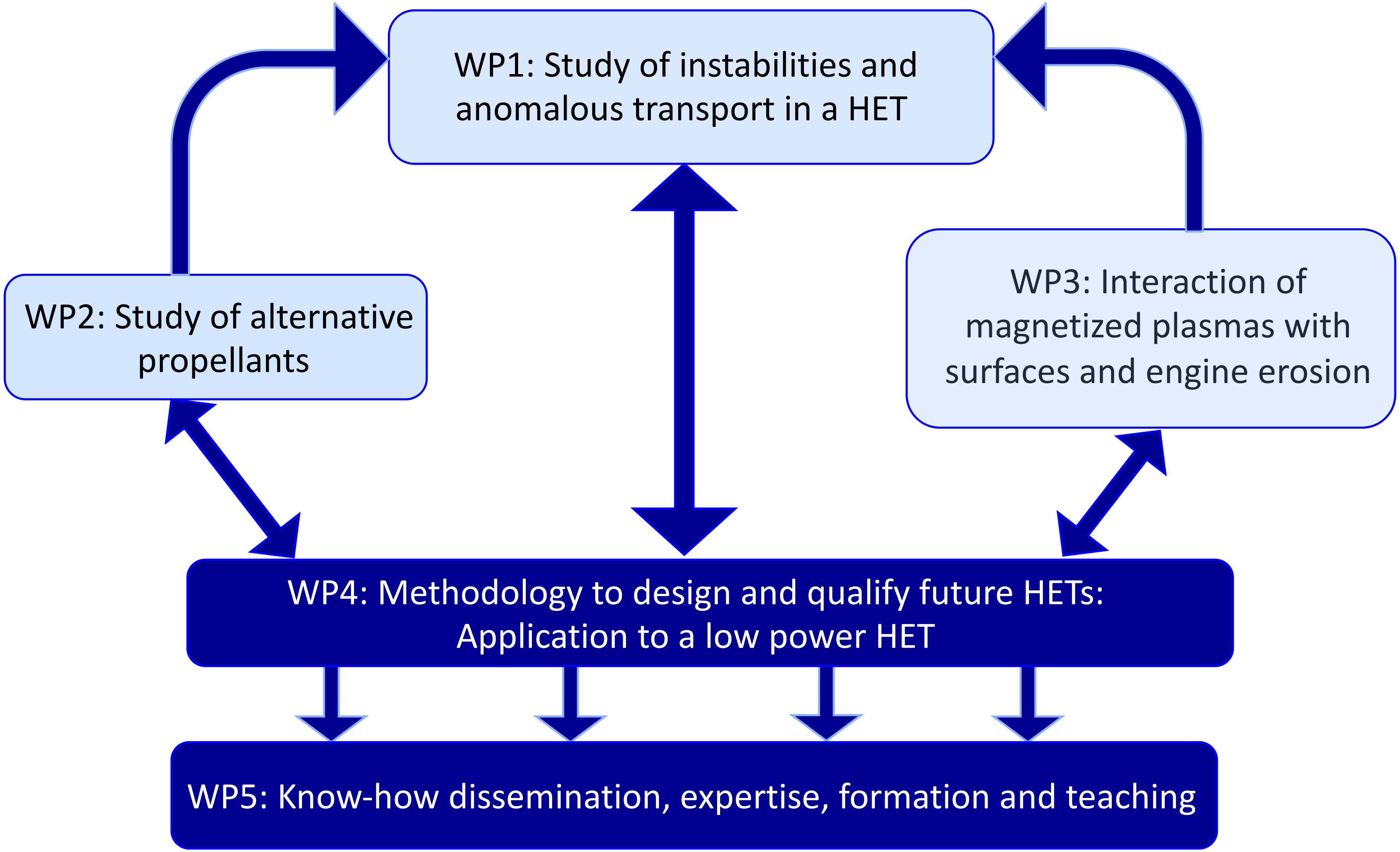
(**He** 4.003 amu)
(**Ar** 39.95 amu)
(**Kr** 83.8 amu)
(**I_2** 126.9 amu)
(**Xe** 131.29 amu)



⇒ Confirms the kinetic theory
⇒ Possibility to derive a new handy expression of the electron mobility

T. Lafleur, S.D. Baalrud, P. Chabert, Physics of Plasmas 23, 053503 (2016)
V. Croes, T. Lafleur, Z. Bonaventura, A. Bourdon, P. Chabert, Plasma Sources Sci. Technol, 26, 034001 (2017)
V. Croes, A. Tavant, R. Lucken, R. Martorelli, T. Lafleur, A. Bourdon and P. Chabert, Physics of Plasmas, vol 25, 063522, 2018

Interactions between WPs in the project



Thank you for your attention

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