The IBS concept: system optimization and beam characterization

F. Cichocki, M. Merino, E. Ahedo

Equipo de Propulsión Espacial y Plasmas (EP2)

Universidad Carlos III de Madrid (UC3M)

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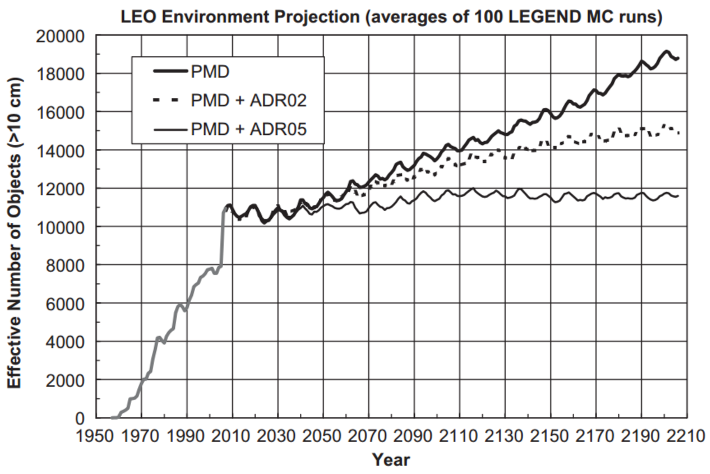
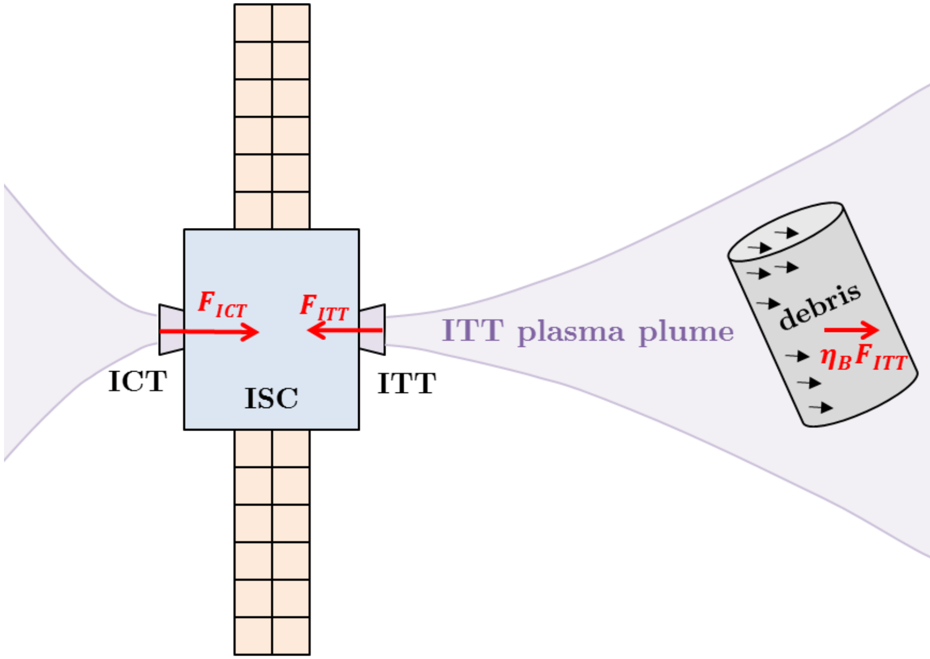
The Ion Beam Shpherd (IBS) concept

- Debris is threatening future space exploitation
  - No action taken → Exponential increase of in-orbit collisions and debris
- Efforts must then be put in:
  - Post Mission Disposal regulation (**PMD**)
  - Active Debris Removal (**ADR**) for largest objects
- The **IBS** is a promising ADR technique, featuring:
  - Impulse Transfer Thruster (**ITT**) for momentum transfer to debris
  - Impulse Compensation Thruster (**ICT**) for formation flying
  - **No docking** with uncooperative debris
  - One of the 2 thrusters used for S/C navigation
- Use of EP enhances the efficiency of the IBS:
  - Small propellant consumption

Space debris population prediction.
J.C.Liou, Acta Astronautica 66 (2010) 648 -- 653





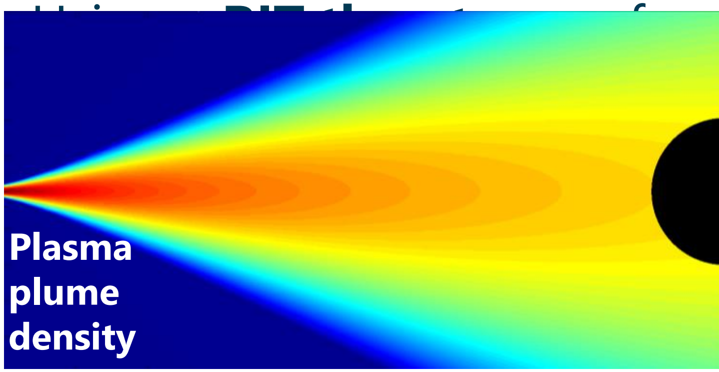
The IBS-EP subsystem optimization (1)

- EU-FP7 LEOSWEEP Project (2013-16): Definition & optimization of IBS-IOD mission

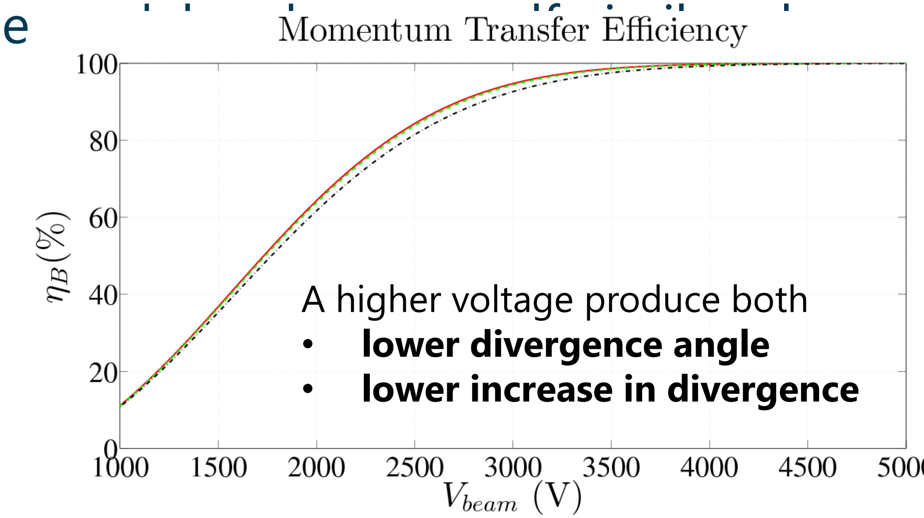
MISSION REQUIREMENTS	VALUES
Target Upper Stage Mass	~1500 kg
Orbit type	Polar LEO
De-orbiting altitude change	300 km
De-orbiting phase duration	170 days

⇐ To be achieved with a separation distance larger than 7 m, and the use of RIT thrusters

- **Momentum transfer efficiency** η_B was characterized in terms of ITT beam voltage
  - ❑ nance



$$\eta_B = 1 - \exp\left(-3\frac{R_{TG}^2}{R_F^2 - (\tan\alpha_F \cdot R_{TG})^2}\right)$$

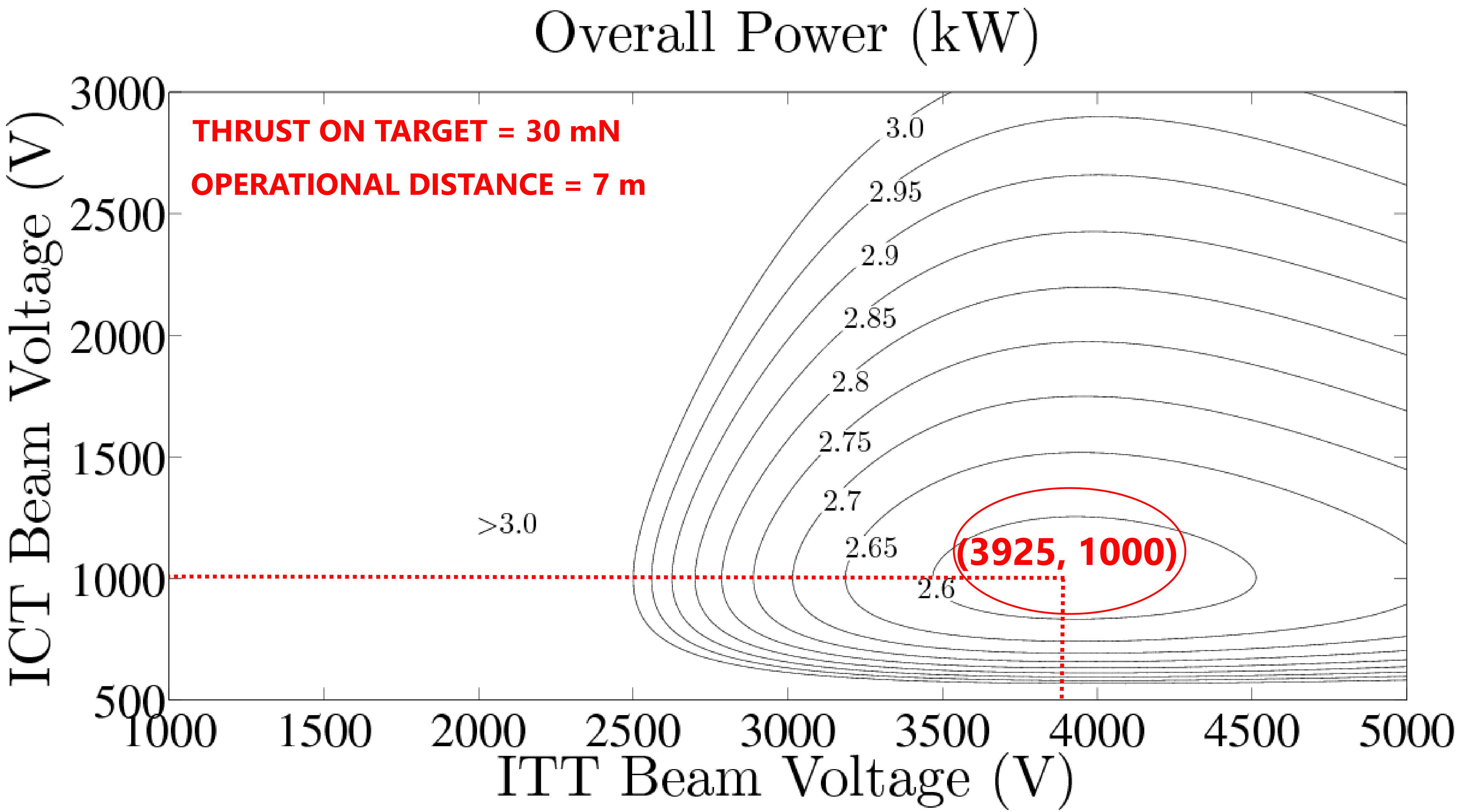


The IBS-EP subsystem optimization (2)

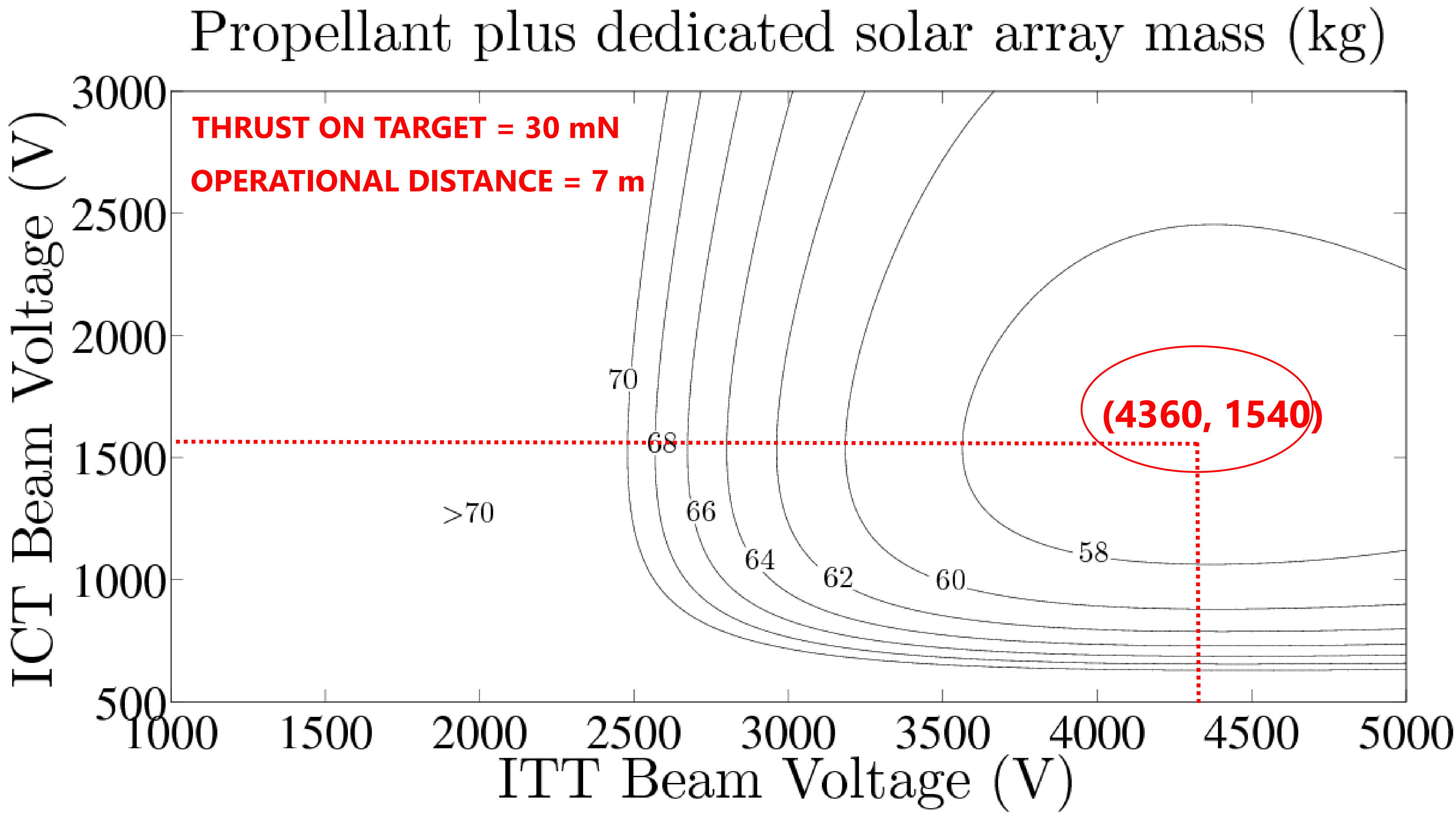
- The electric **subsystem optimization** has been carried out in terms of:
  - Acceleration beam voltages of both ITT and ICT
- The **EPS figures of merit** to be optimized are:
  - Overall power consumption
  - Overall dedicated subsystem mass
- The ITT beam voltage affects:
  - Momentum transfer efficiency → requested ITT and ICT thrust levels
- The ICT and ICT beam voltages affect:
  - Total requested power level (including PPU efficiencies)
- Results:
  - 2-D maps of EPS figures of merit in $\boldsymbol{V_{beam\,ITT}}$-$\boldsymbol{V_{beam\,ICT}}$ plane

The IBS-EP Subsystem Optimization (3)

OPTIMAL ITT BEAM VOLTAGE IS QUITE HIGHER THAN THAT OF THE ICT !!!



Electric Propulsion Subsystem Optimization (4)

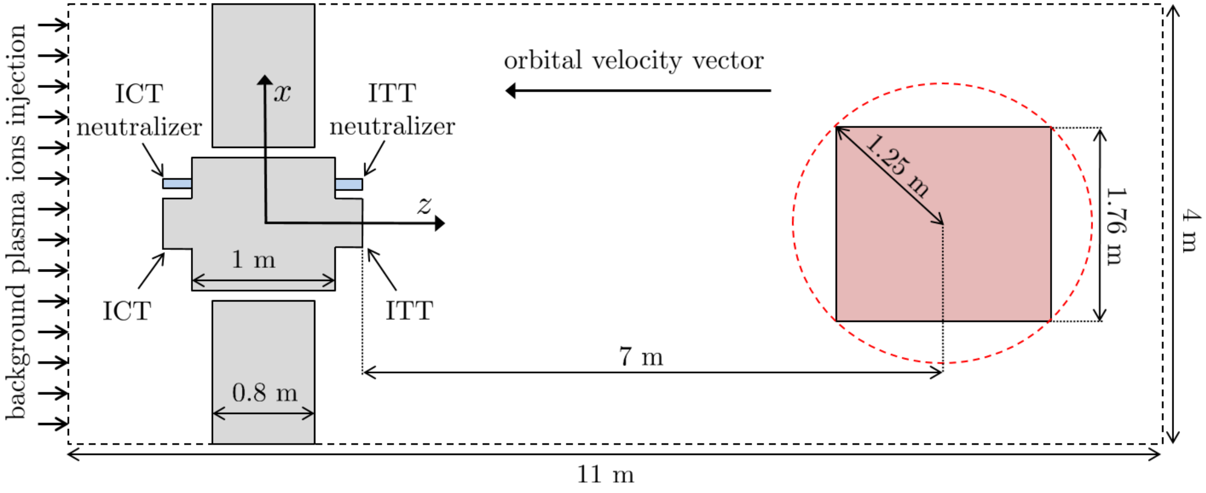


Simulation of S/C-plume-debris interaction (1)

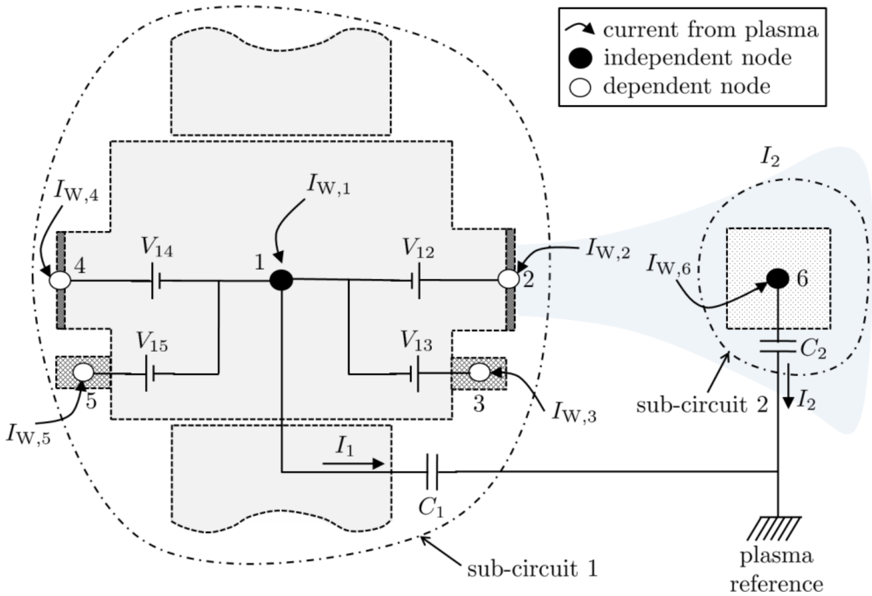
- With the optimal ITT-ICT operating voltages, the interaction physics between S/C-plume and debris object was carried out with EP2PLUS:
  - 3D Extensible Parallel Plasma PLUme Simulator

- Important assessments:
  - Bias voltage of the space debris with respect to the spacecraft
  - Backsputtering contamination flux at the S/C

SIMULATION GEOMETRY



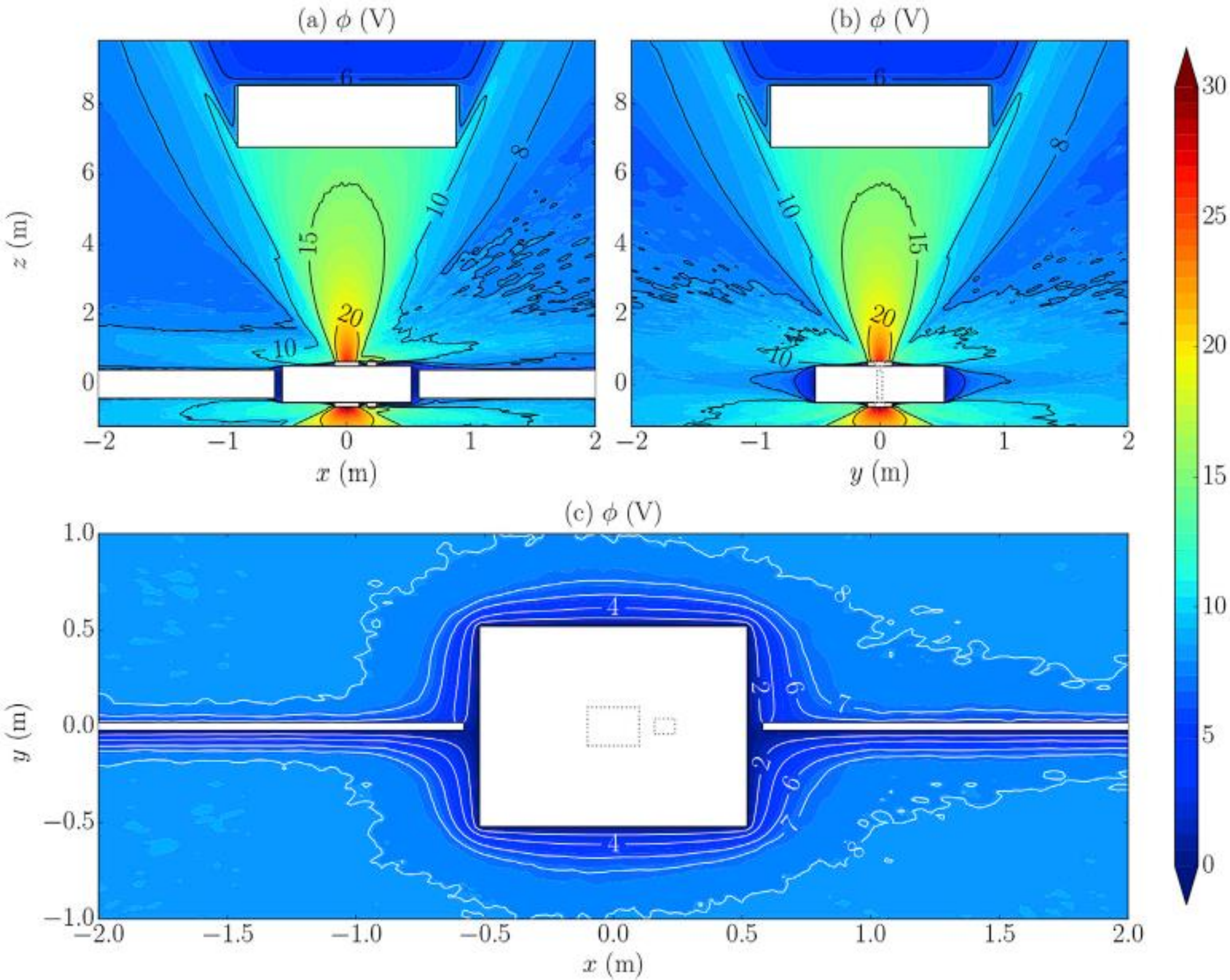
ELECTRIC CIRCUIT



Simulation of S/C-plume-debris interaction (2)

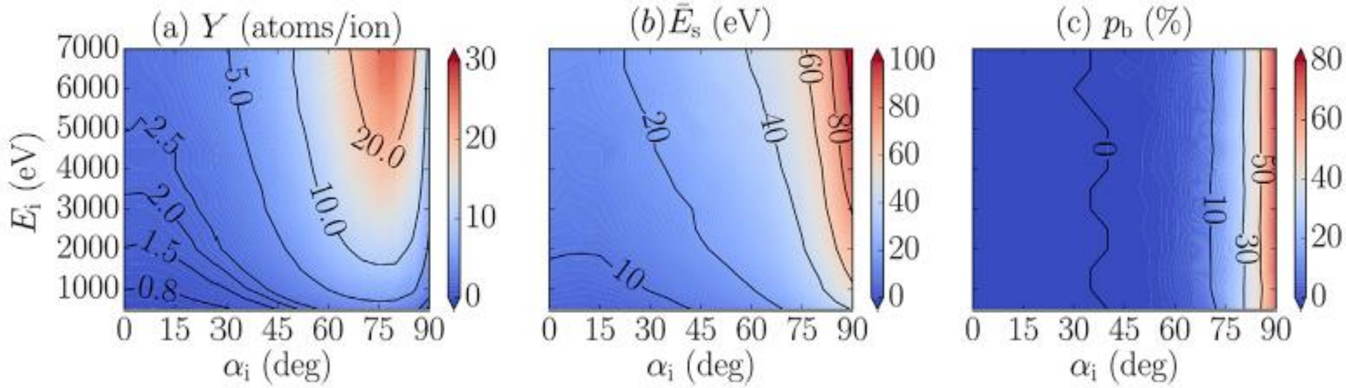
- Considered effects:
  - Xe, Xe^+, Xe^{++} emission in ITT, ICT & neutralizer
  - CEX collisions
  - Ambient O ions
  - Non-neutrality around S/C
  - Mild electron (polytropic) cooling
- Target debris charges **10 V positive** wrt S/C:
  - Independent of the e-cooling rate

ELECTRIC POTENTIAL (V) AT DIFFERENT CROSS SECTIONS

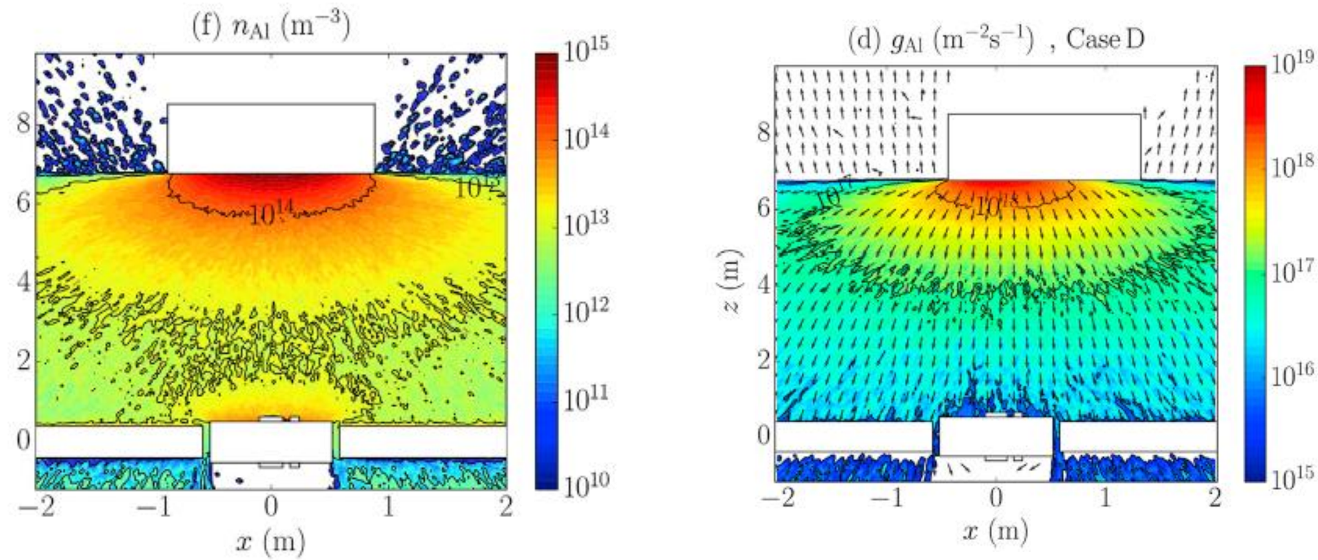


Simulation of S/C-plume-debris interaction (3)

CHARACTERIZATION OF SPUTTERED PARTICLES (ALUMINUM)



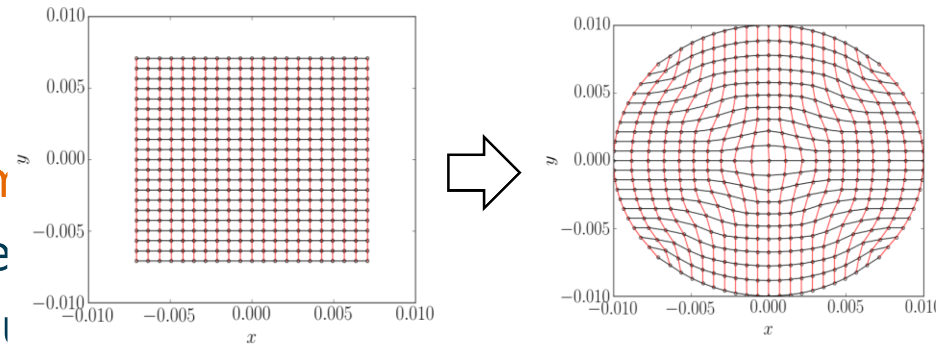
ALUMINUM DENSITY & FLUX



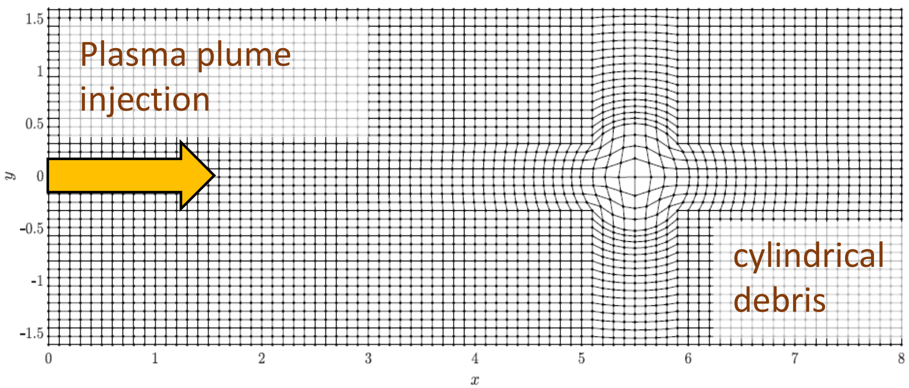
- Backsputtering flux at S/C ~ 10^{16} $m^{-2}s^{-1}$: 3μm contamination layer throughout the mission for surfaces oriented towards the target → possible degradation of S/C sensors

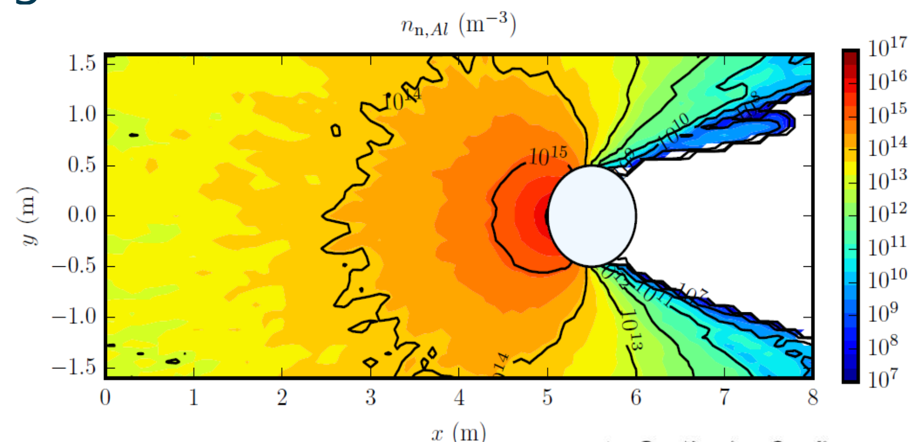
EP2PLUS' work in progress: deformed meshes

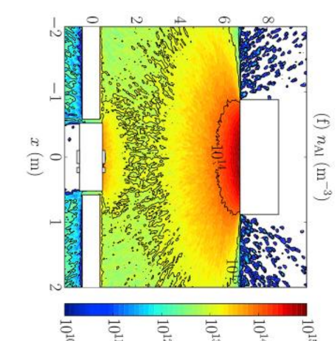
- EP2PLUS can consider deformed meshes to represent non-rectangular objects
  - Current 2D deformation algorithm changes a square into a circle



- Application to more realistic IBS problen
  - Debris shape has a strong influence on distribution of back-sputtering fl



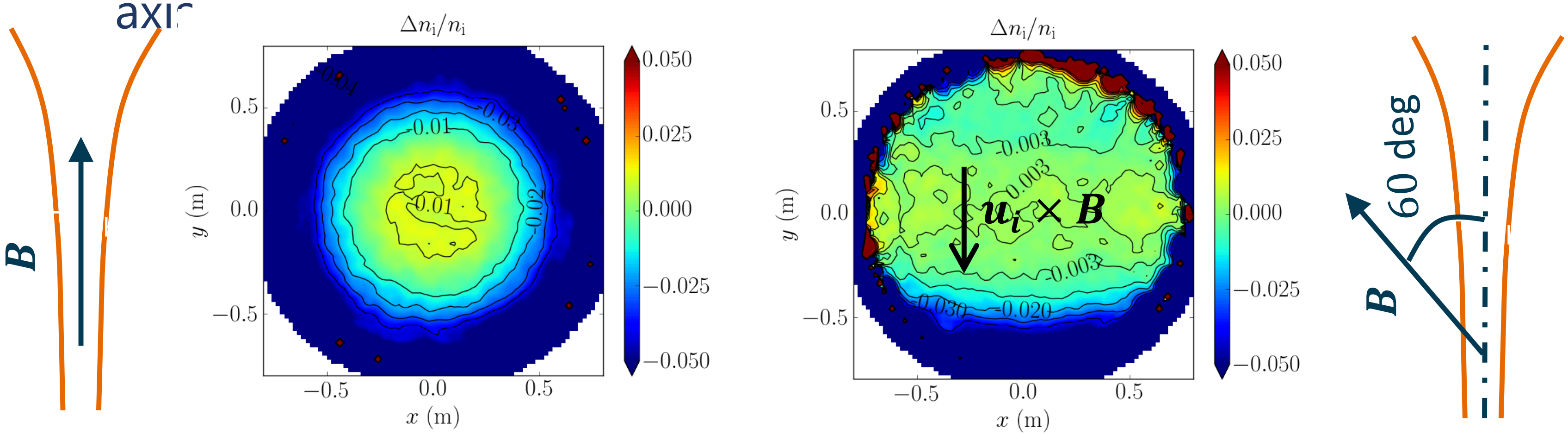




- New application: Plasma discharges in cylindrical chambers
  - Cross-validation of 2D cylindrical codes
  - Inclusion of 3D effects in them

EP2PLUS work in progress: Magnetic field effects

- EP2PLUS is implementing moderate B-field effects in electron fluid model
  - Goal: Assessment of B-effects on plume shape and expansion
    - Strong B-field requires a B-field aligned mesh
- First application: Uniform, oblique magnetic field (e.g. geomagnetic field)
  - For axial ***B*** : the plume cross-section compresses downstream
  - For oblique ***B***:
    - Plume cross section deforms, compressing in the $\boldsymbol{u_i} \times \boldsymbol{B}$ direction
    - No plume deflection: electric self-force cancels magnetic one at the axis



Density changes at downstream cross section with respect to unmagnetized case

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email: ep2@uc3m.es
web: ep2.uc3m.es

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