Surface Charging of the JUpiter ICy moons Explorer

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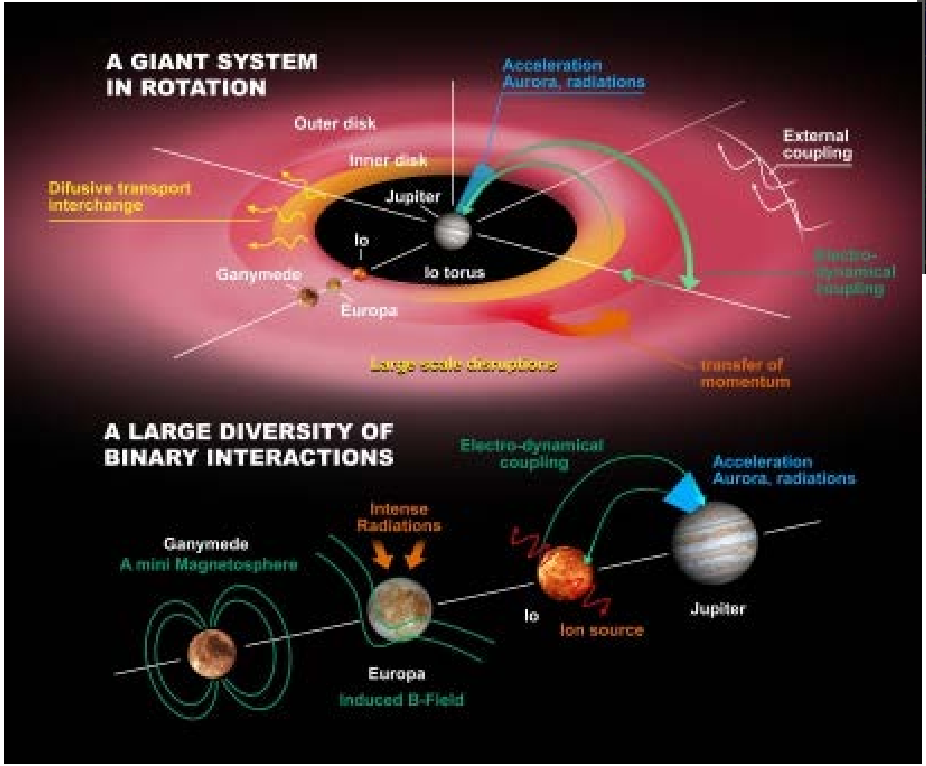
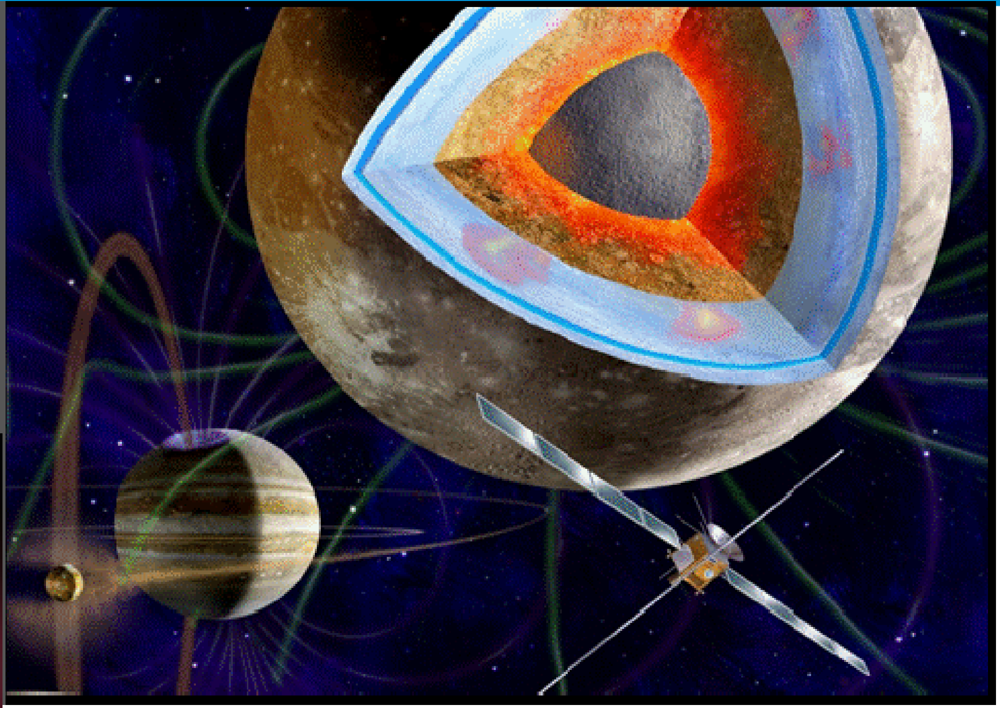
ESA JUICE Mission

- **Prime KO (mid-July 2015)**
- **Phase B2 from mid-July 2015 -> end Feb 2017**
- **Phase C starts March 2017**
- **Current launch in 2022**
- **Arrival in 2030**





→ 3 years in Jupiter Magnetosphere (2 Europa flybys, 9 Callisto flybys, 282 days Ganymede

JUICE tour summary

1. 01/2030 - Jupiter orbit insertion

Jupiter tour

1. Transfer to Callisto (11 months)
2. Europa phase: 2 Europa and 3 Callisto flybys (1 month)
3. Jupiter High Latitude Phase: 9 Callisto flybys (9 months)
4. Transfer to Ganymede (11 months)
5. 09/2032 – Ganymede orbit insertion

Ganymede tour

1. Elliptical and high altitude circular phases (5 months)
2. Medium altitude (500 km) circular orbit (3 months)
3. Low altitude (200 km) circular orbit (1 month)

Equatorial phase # 1 (26%)

13 – 243RJ → 11-41RJ

Europa flybys (3%)

9-40RJ

Jup High Latitude Phase & Callisto (22%)

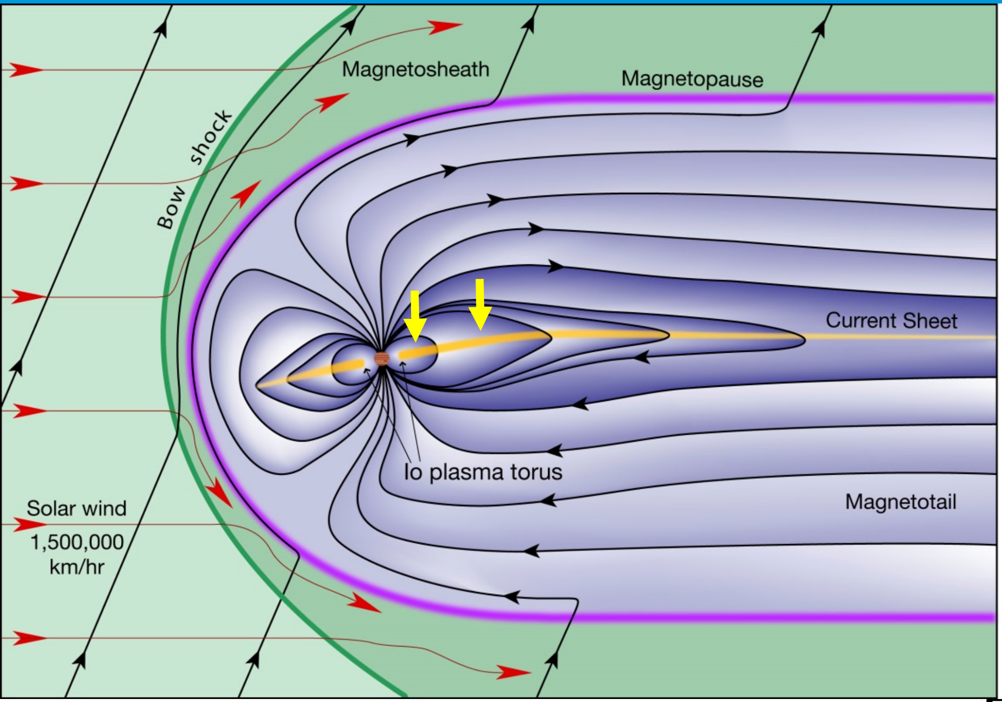
30° / 14 – 43 RJ

Equatorial phase # 2 (26%)

Ganymede (23%)

~16RJ

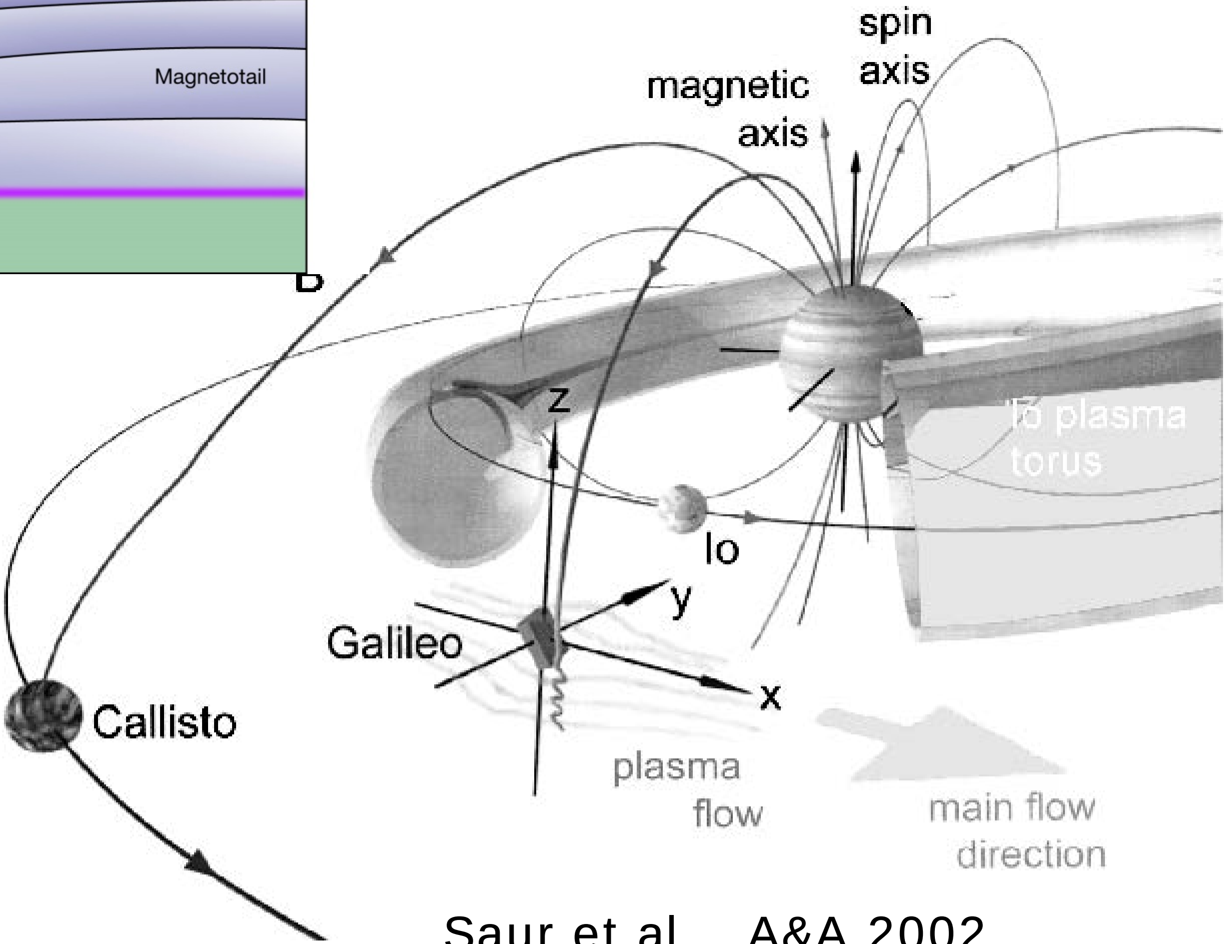
Most of the mission between 9-50RJ (hot tenuous plasma 0.1cm^{-3} to relatively cold and dense ~100cm^{-3})



Jupiter magnetosphere (LASP, U Colorado)

Tangential co-rotation velocity :

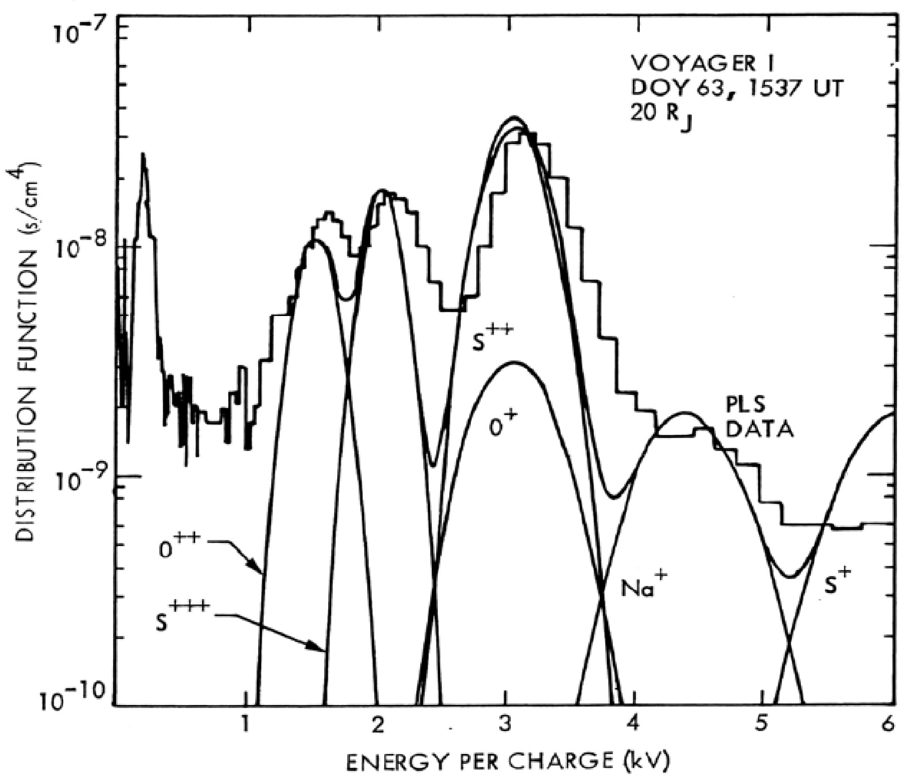
→158km/s @ Ganymede
→118km/s @ Europa



Saur et al. , A&A,2002

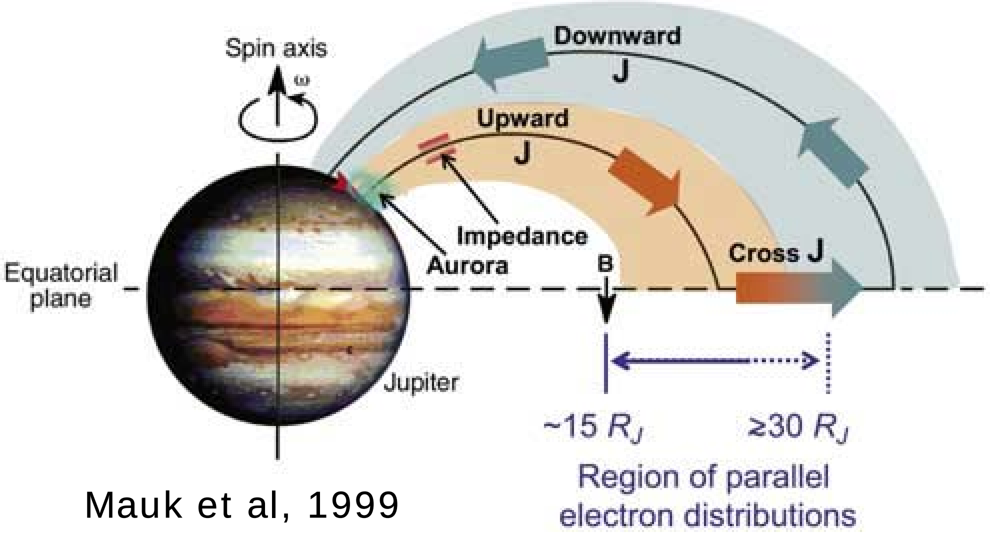
Charging Environment Definition

- **Datasets from previous missions (Pioneer, Voyager, Galileo, Ulysses ..)**
- **Models : reference D&G83 (includes cold and intermediate plasma) + GIRE (JOSE for radiation in Europe)**
- **Nonetheless gaps (huge spatial scale to cover - local time variability, complex dynamic)**
- **Updated environment from ESA/JCAT study for cold and warm plasma components**



Europa	9Rj	Ne ~ 100cm^{-3} Te ~ 20-60eV
Ganymede	16Rj	Ne ~ 1cm^{-3} Te ~ 15-80eV
Callisto	29Rj	Ne ~ 0.1cm^{-3} Te ~ 100eV

Worst Case Charging 13Rj to 30Rj



Mauk et al, 1999

Work by Garrett et al, 2008, 2012

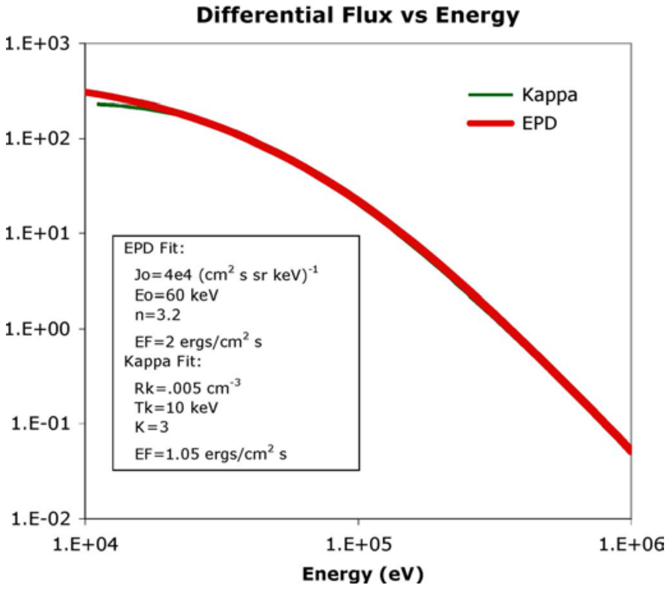
* <u>In auroral region (at the base of field lines)</u>

- Galileo EUVS/ HUT observations + electron transport model

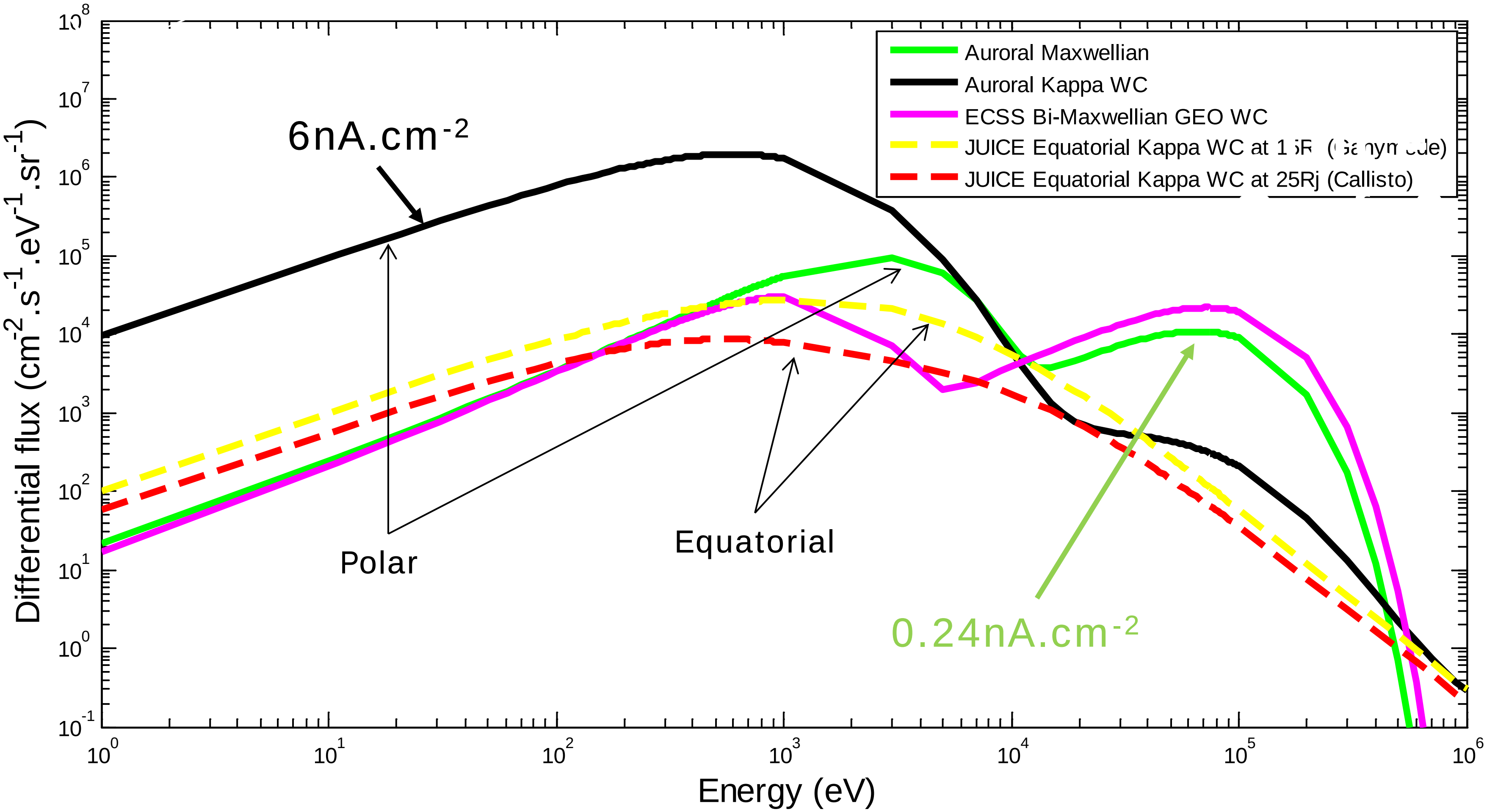
→ characteristics energy energy & electron fluxes (Ajello, 2001)

* <u>At the equator between 13-30Rj :</u> assumes an equatorial Spacecraft sitting on field line connected with diffuse auroral region : Galileo EPD (100keV and 1 MeV lower bound of fluxes in the diffuse area)

→ WC energy input from fitted spectra

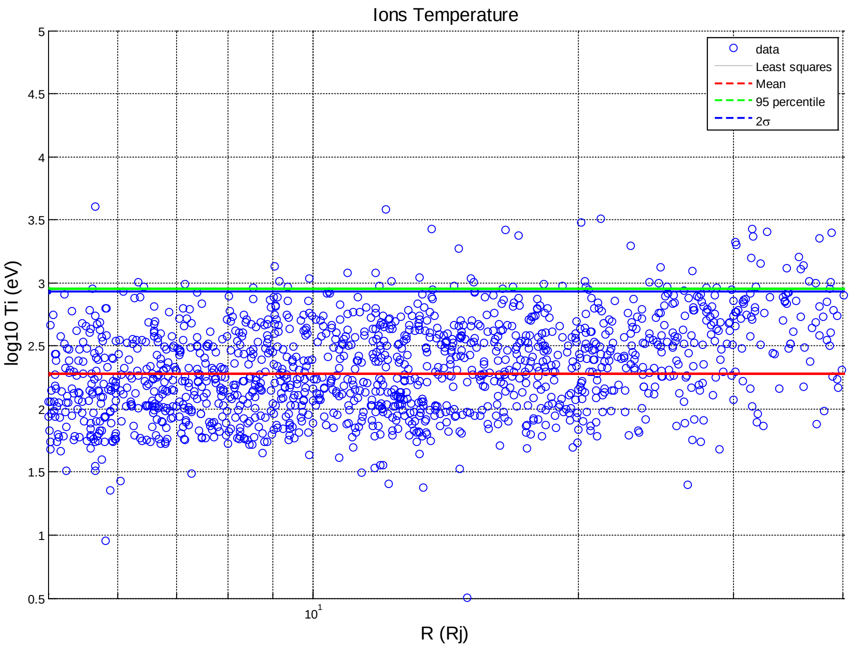


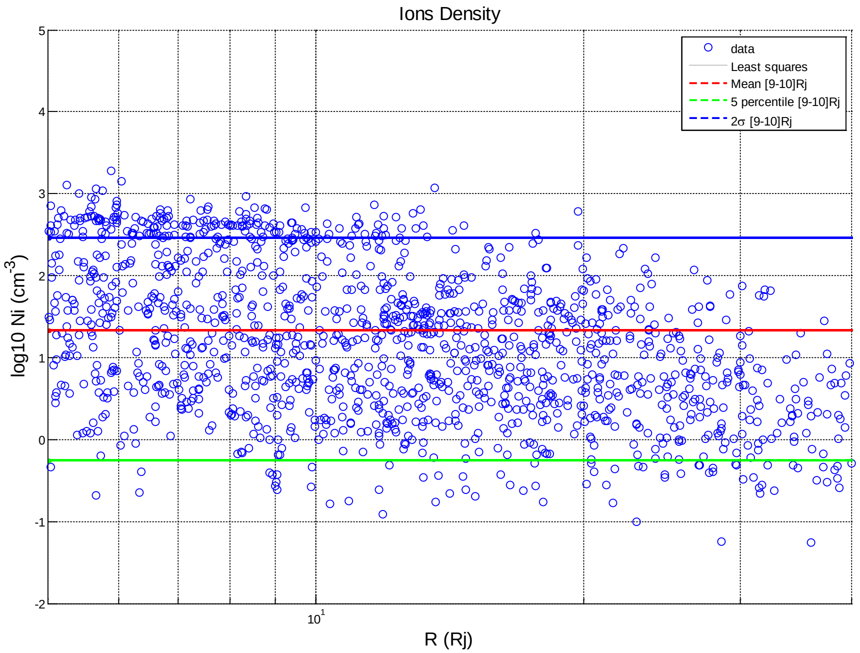
Worst Case Charging Environment 15Rj – 30Rj



- Auroral Kappa vs Maxwellian → different input currents
- JUICE vs GEO →different ratios of warm to hot components
- Kappa distributions at equator

Environment Updates / Worst Case definition (ongoing – JCAT inputs)





T95p = 900eV

Tmean = 190eV

In the range 9-10Rj

Ni95p = 371cm^{-3}

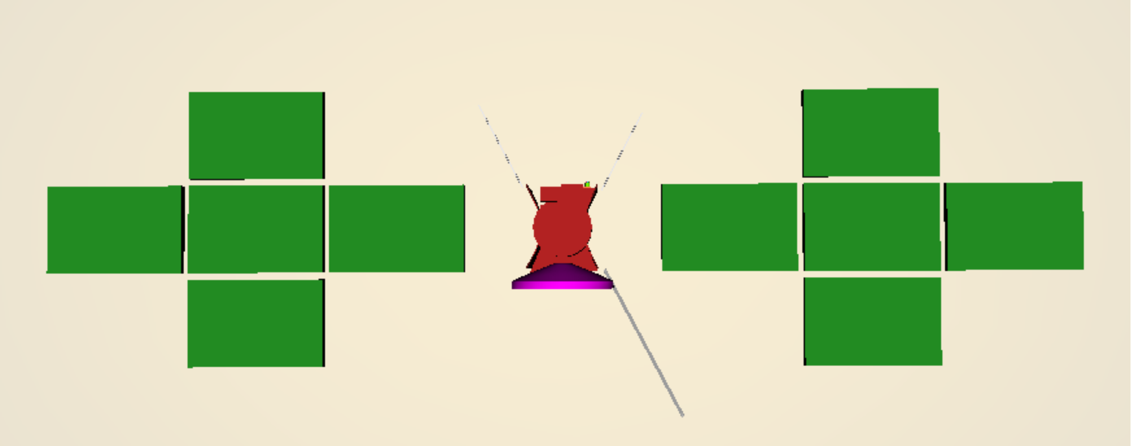
Nimean = 21cm^{-3}

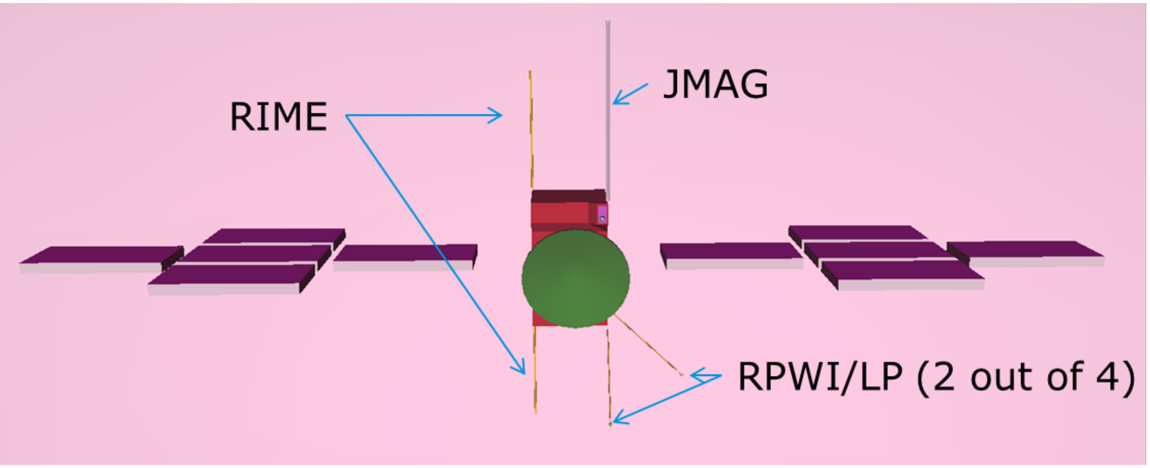
Ni05p = 0.55cm^{-3}

Galileo/PLS data compiled by F. Bagenal and provided by JCAT project

WC environmental input currents ~2nA.cm-2

JUICE Spacecraft model





Large area Solar Arrays ~$100 m^2$

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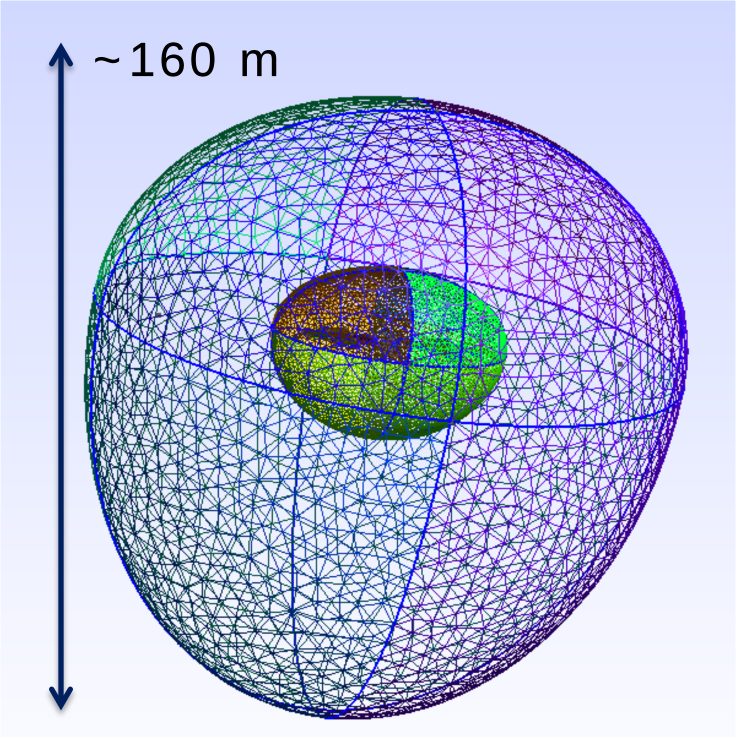
Conductive coating

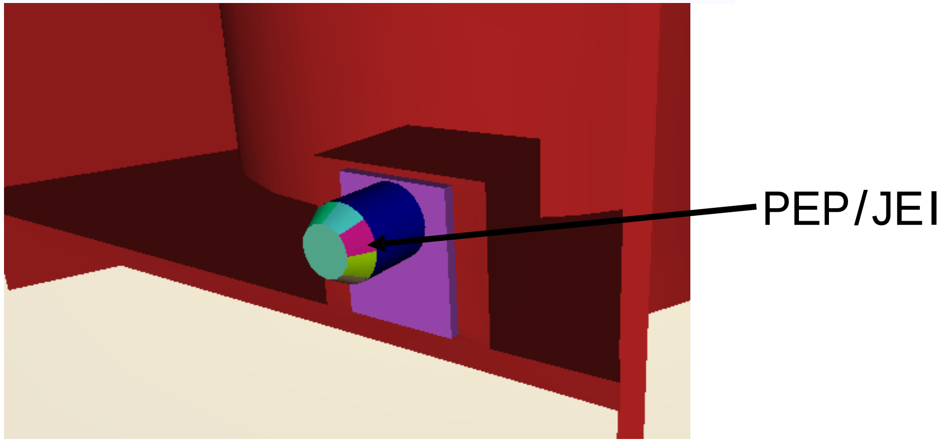
OR

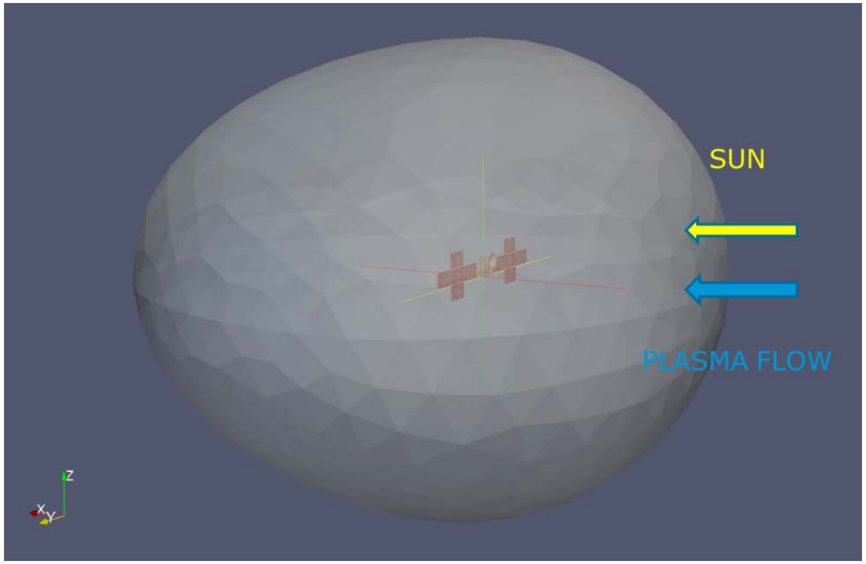
Coverglass

SPIS Simulations

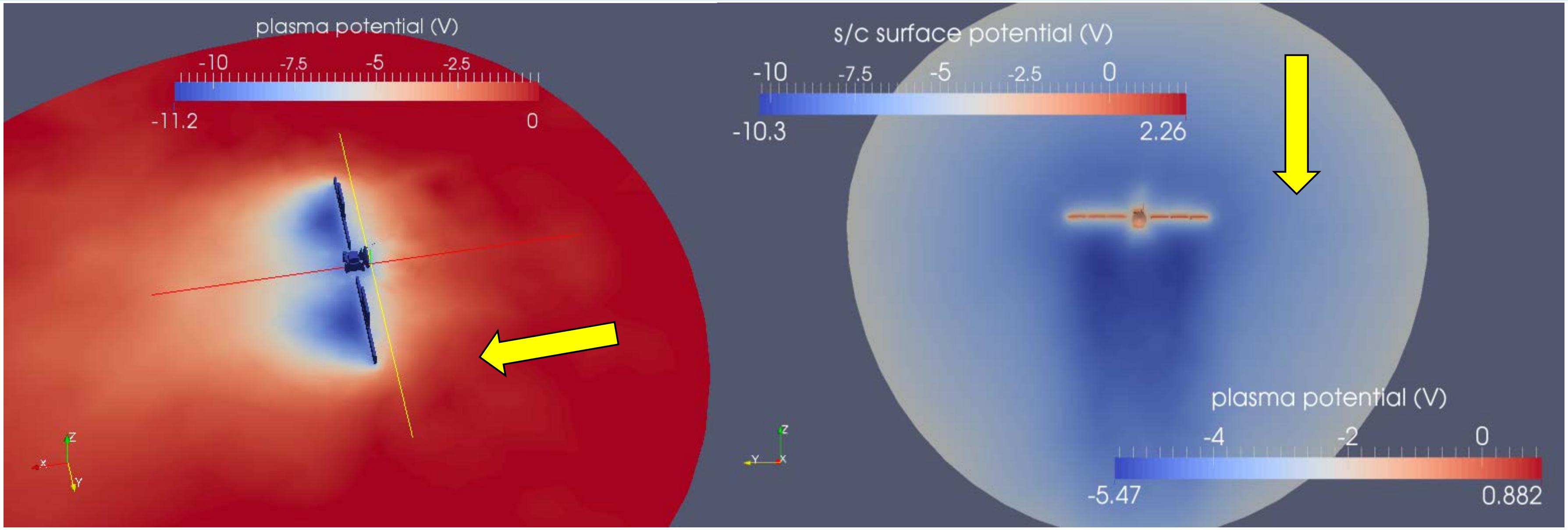


- Up to 250000 tetrahedrons in volume
- 0.03m up to 1.0m on the S/C depending on the Debye Length
- Full PIC for ions and electrons (10^7 particles)
- Includes booms, antennae, particle instruments for electrostatic cleanliness investigations
- s/c attitude wrt plasma flow and Sun





Charging in the Magnetosphere at the Moons orbits



9Rj (Europa) 16Rj (Ganymede)

	Sunlight (V)	Shadow (V)	Debye Length (m)
9Rj	-30 to -10	-48 to -21	3
16Rj	-5 to 2	-7 to 0	20-40
29Rj	6 to 10	3 to 7	235

Conductive s/c body, coverglass on solar arrays front

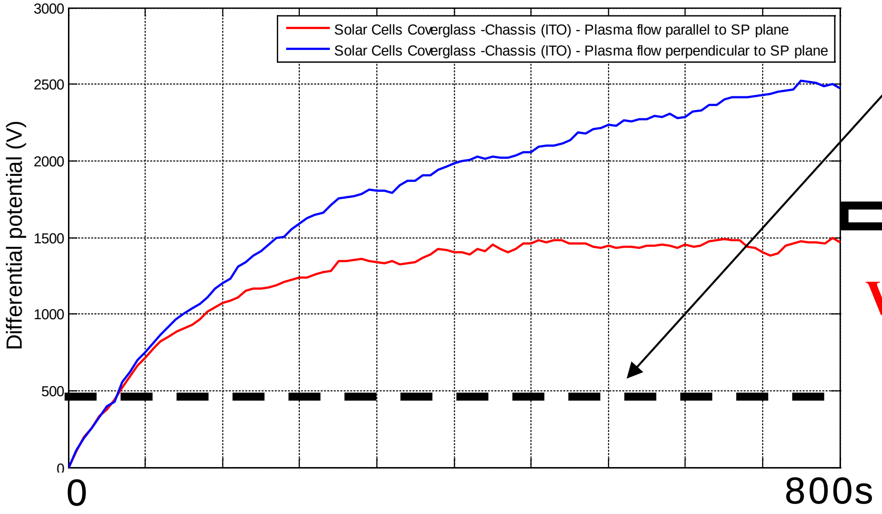
Methods comparison (WC)

	JUICE Maxwellian WC1	**JUICE Maxwellian WC2**	**JUICE Kappa WC**	**ECSS GEO BiMax WC**
Thick sheath model Al	[-3100 to -8300][a]	[-36300 to -68000][a]	[-2315 to -7703][a]	N/A
Thick sheath model Ref. [1]	-2212	N/A	-1934 to -4834	N/A
SPIS Alox (Al)	**-3900 to -9300** (max -20015)	**-6100 - to -16800** (max -33000)	N/A	-16400
SPIS ITO	**-2600 to -5500**	**-4000 to -11300**	N/A	-37

Current balance (main) : Hot electrons = Secondaries from electrons and protons (+ cold and warm ions)

- → **Reasonable agreement between results from analytical methods**
- → **SPIS estimates indicate larger negative potentials (geometry effects, secondary emission)**

Differential charging – ESD risk



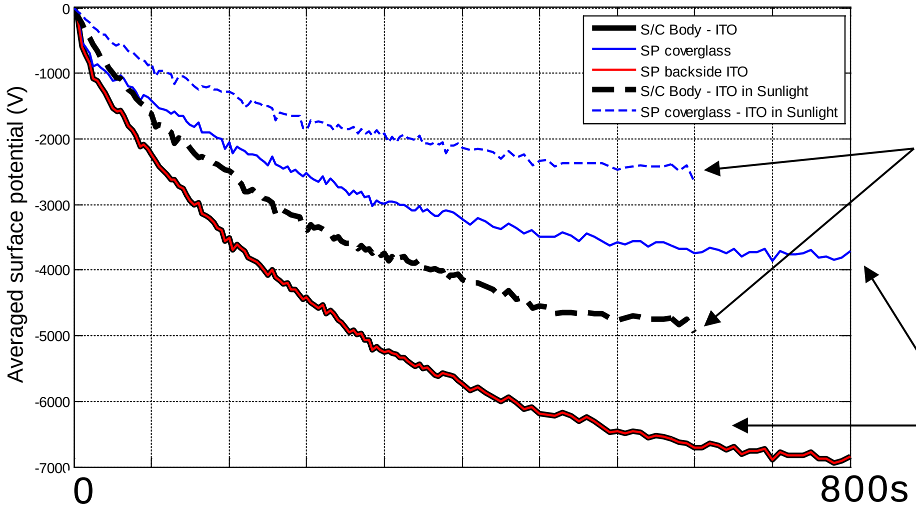
Inverted potential gradient in ~50s

(ECSS threshold) or minutes (NASA)

<u>ESD rate at Jupiter ? 3xEarth (GEO) ?</u>

WARNING : needed characterization of solar cells degradation in LILT conditions

Non conductive panels facing the flow is a worst case



Sunlight

<u>Sunlight does not increase the differential charging at Jupiter</u>

Shadow

Sensitivity to environment parameters

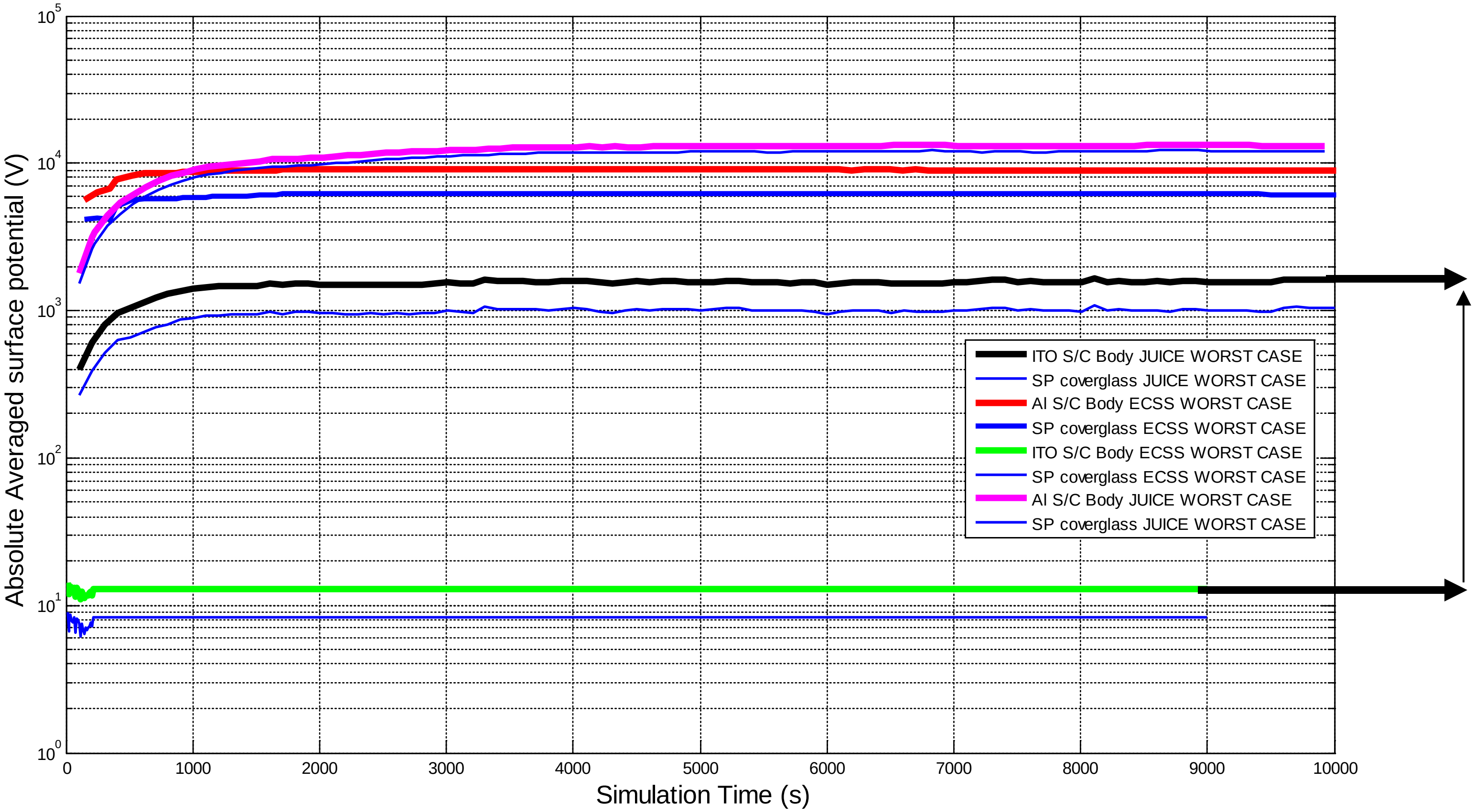
1. Tenfold decrease in cold plasma density (a) OR 50% increase in hot electrons peak energy (c) results in an increase of the absolute surface potential by a factor of 2.
2. 50% increase of the hot protons population density decreases the absolute surface potential by a factor of 2.

Our model should catch environmental variability

More work needed …

	Plasma Parameters		
	Cold/Warm	***Hot***	***SPIS ITO S/C potential (V)***
Ni=Ne (cm-3)	6.9/1.024	0.57/0.341	Va = -5523
Te (eV)	15/1000	25000/30000	
Ni=Ne (cm-3)	0.2/1.024	0.57/0.341	Vb = -11896
Te (eV)	200/1000	25000/30000	
Ni=Ne (cm-3)	6.9/1.024	0.57/0.341	Vc = -10409
Te (eV)	15/1000	35000/30000	
Ni=Ne (cm-3)	6.9/0.0	0.57/0.341	Vd = -5312V
Te (eV)	15/N/A	25000/30000	
Ni=Ne (cm-3)	6.9/1.024	0.57/0.57	Ve = -2628V
Te (eV)	15/1000	25000/30000	

ECSS GEO vs JUICE Worst Cases



Conductive
s/c JUICE

Conductive
s/c GEO

- **Larger absolute charging levels in JUICE environment** than in GEO (30% with Al, 100 times with ITO)
- **Differential charging more severe in GEO environment**
- **ITO less efficient at mitigating charging in JUICE environment** than in GEO

Mitigation Strategies : SP backside coating

Solar Arrays backside coating material	Vs/c SUNON (V)	Vcg SUNON (V)	Vdiff(V)	Vs/c SUNOFF (V)	Vcg SUNOFF (V)	Vdiff(V)
ITO	-1956	-1406	-550	-2651 (3.6%)	-2052(4.5%)	-551
Al2O3 (with / without hot protons as from ITO)	-2732(3.1%)	-1981(3.7%)		-3819(2.9%)/ -3241(2.8%)	-2993(3.6%)/ -2528(3.3%)	

An ITO coating on the backside of the Solar Arrays decreases differential charging at equilibrium by about 40% and absolute charging by about 50% compared to a configuration using White Paint SG120FD. Moreover for a given thickness differential charging varies (linearly) as the coverglass bulk conductivity.

Summary and Conclusion

1. Full s/c estimates generally indicates larger charging levels compared with previous work at Jupiter / in agreement when using similar method
2. kV surface charging levels can occur in JUICE environment, possibly leading to ESDs on non conductive surfaces (e.g. risk in solar panels) → strong impact on solar panels design
3. Optimization possible using appropriate materials (timescale too short)

Further work is needed to :

1. improve / refine our charging environment definition (kappa, variability and worst case scenarios e.g. at Europa)
2. include low temperature effects on materials surface and bulk conductivity
3. Improve models of RIC (temp, surface electric field)