SPENVIS Spacecraft Charging Tools

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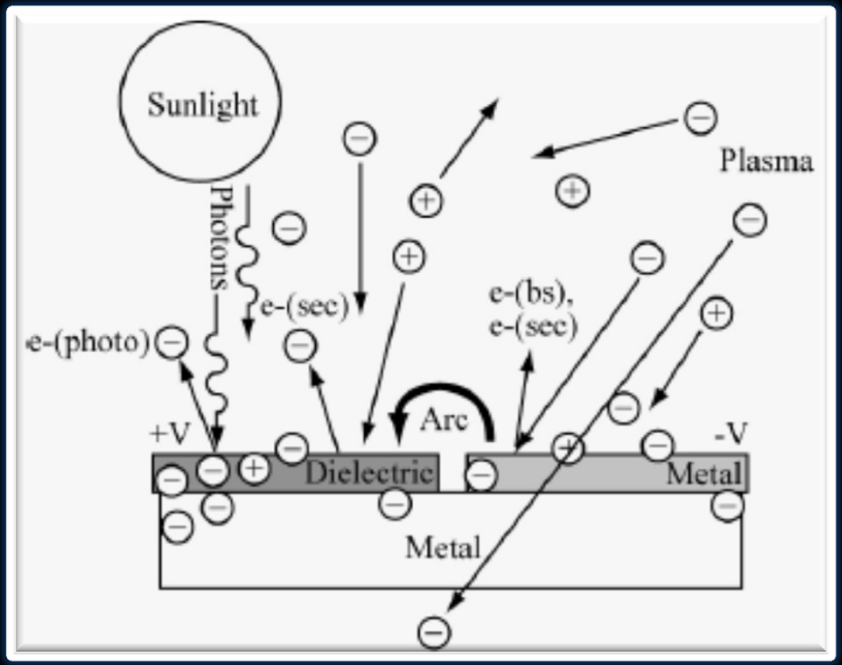
Outline

- Introduction
- Overview SPENVIS S/C charging package
  - EQUIPOT: Surface charging of very simple s/c
  - SOLARC: Charging of solar panel
  - DICTAT: Internal charging
  - Environment models and charging data
- S/C charging in Next Generation SPENVIS

Introduction



environment

$$J_{net}(V) = -J_e + J_i + J_{be} + J_{se} + J_{si} + J_{pe} + J_c$$

$$C_A \cdot dV/dt = J_{net}(V) + \sigma \cdot V$$

secondaries (material dependent)

Equilibrium: $J_{net}(V_{eq}) = 0$

→ floating potential

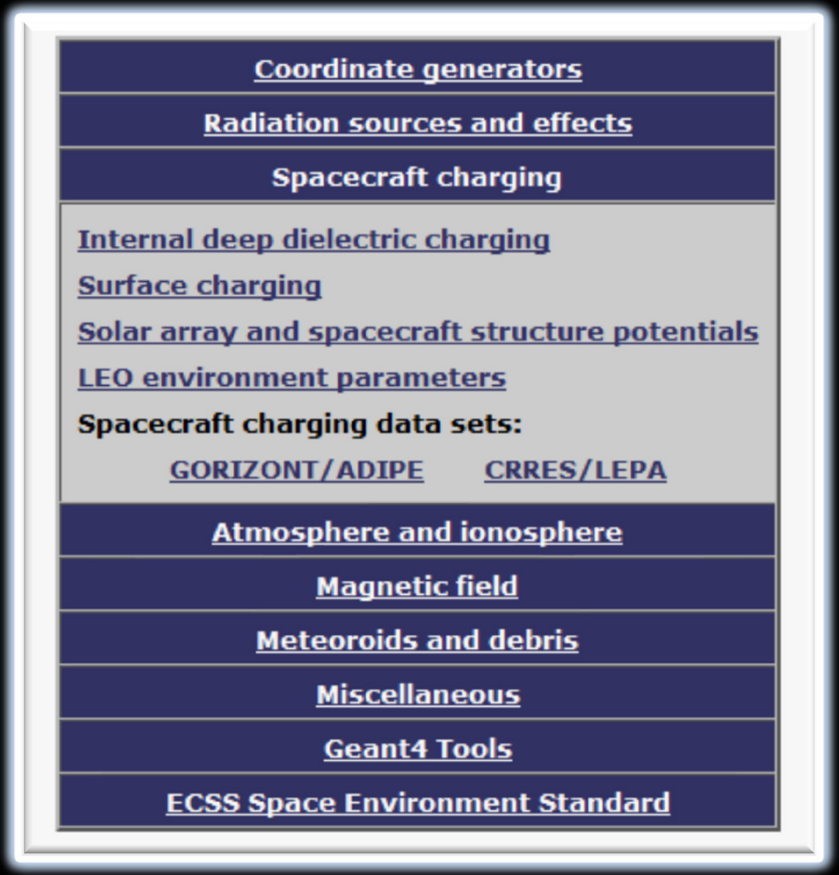
SPENVIS S/C Charging package

EQUIPOT
(EQUIlibrium POTential)
G.L. Wrenn & A.J. Sims, 1990
D. Rodgers, 2002 (update)

SOLARC
(SOLar ARray interaction Code)
R. Bond, 1990

LEOPOLD
(Low Earth Orbit and POLar environments Data)
R. Bond & T. Field, 1990

ESPIRE suite
(R. Bond, 1990)



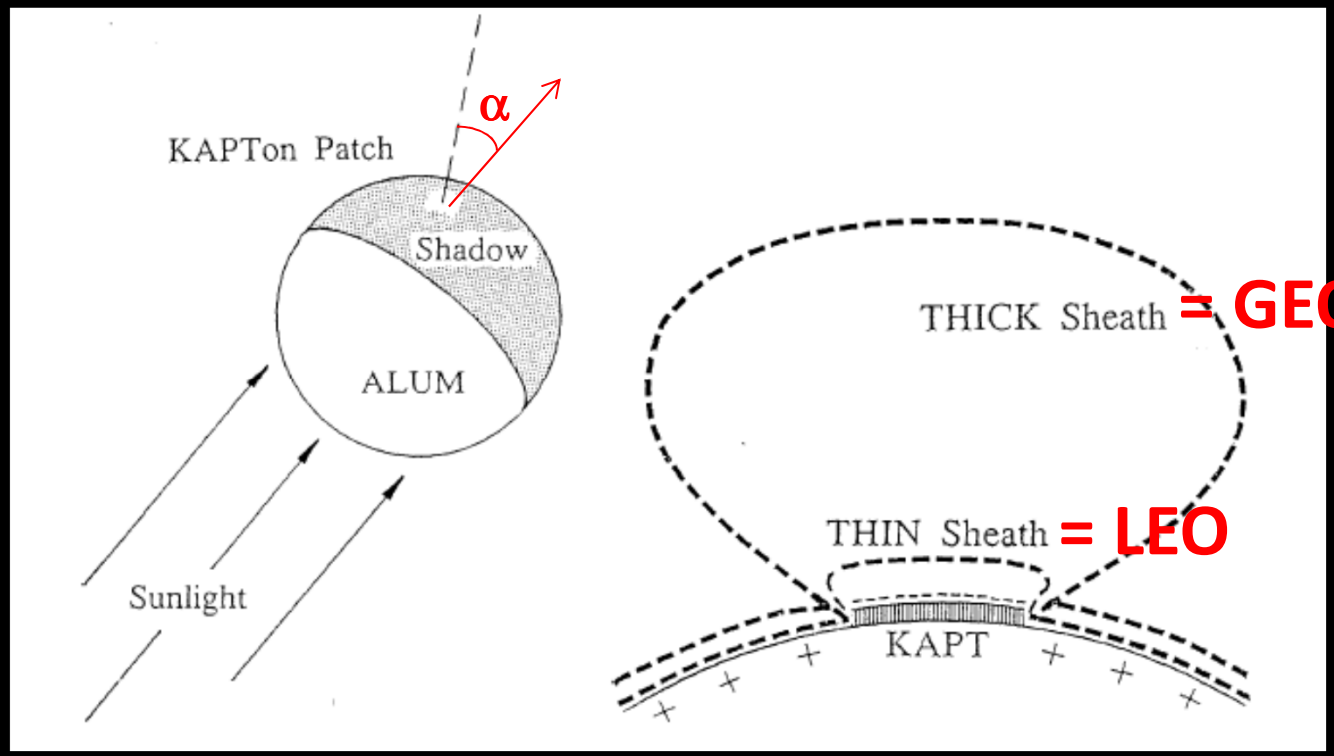
DICTAT
(Dielectric Internal Charging Threat Assessment Tool)
D. Rodgers, 1999

GORIZONT/ADIPE & CRRES/LEPA
Data bases

EQUIPOT surface charging code

- No input orbit required
- 1D calculation of equilibrium potential of passive S/C
- No geometry effects
- LEO and GEO environments
- Inclusion of ram/wake effects and sunlight/eclipse status
- Version 1.3 in current SPENVIS

EQUIPOT GEOMETRY

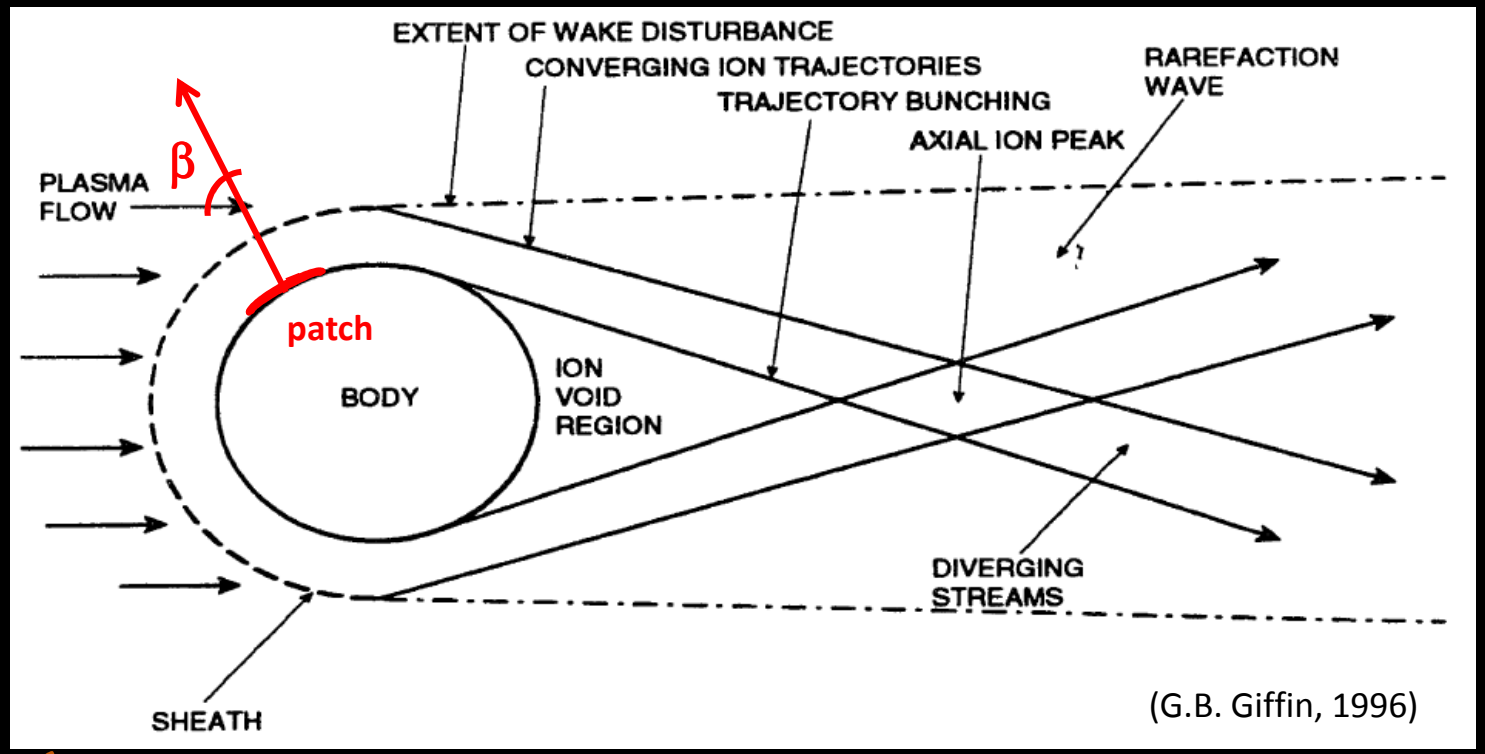


S/C or structure = conducting sphere with radius = 1m
Patch = planar slab

EQUIPOT wake/ram effect at LEO

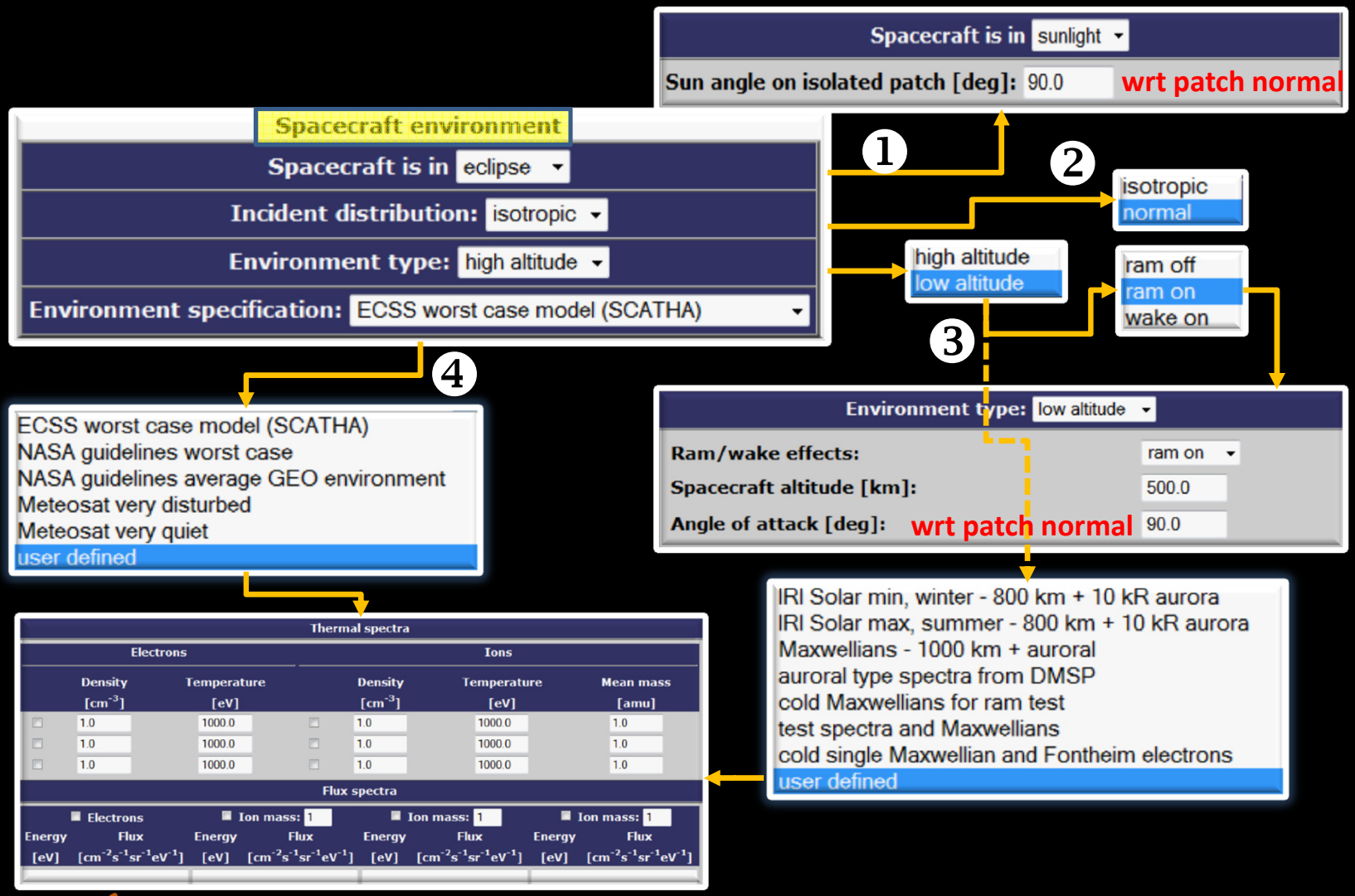
$V_{ion} < V_{s/c} < V_e$

- → Ions impact ram surface, e^- everywhere
- → Negatively charged rear surfaces
- → Regions of differential charging

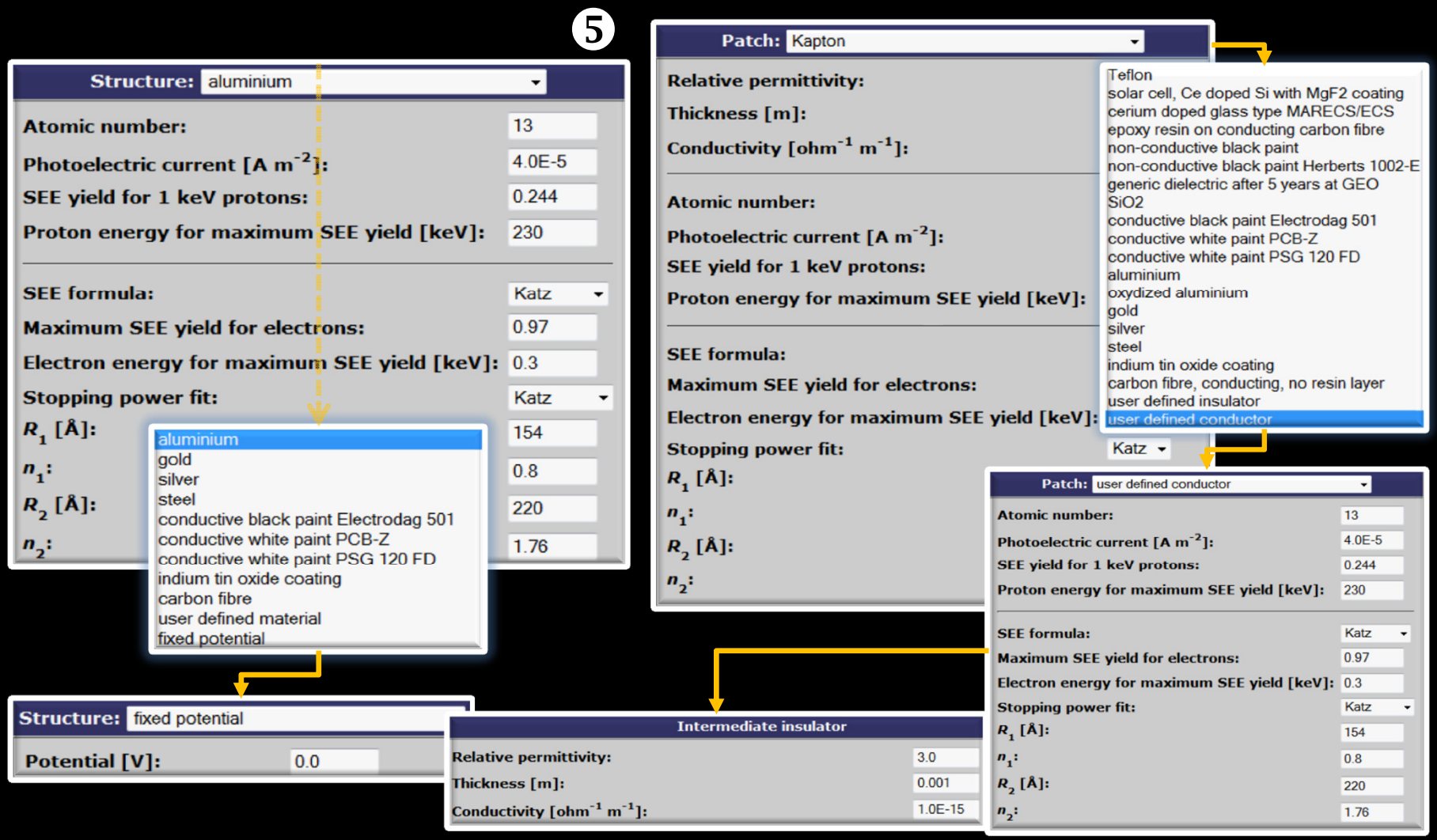


(G.B. Giffin, 1996)

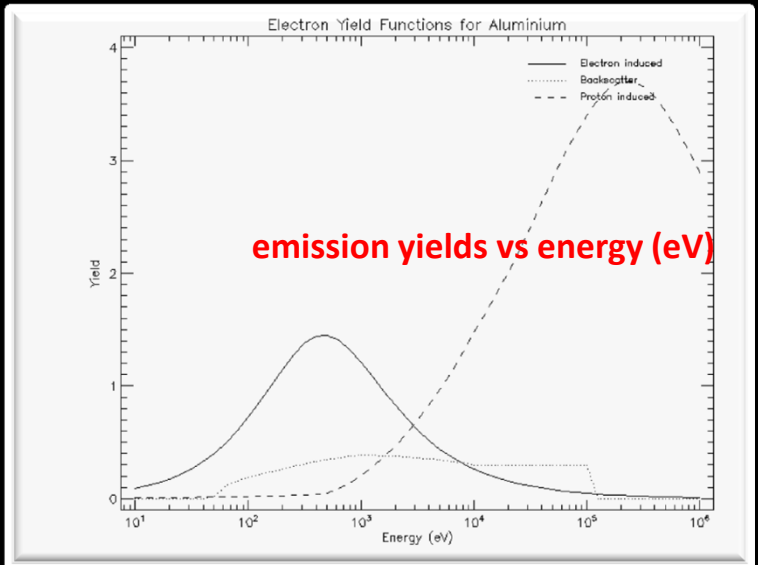
EQUIPOT input (1): s/c environment

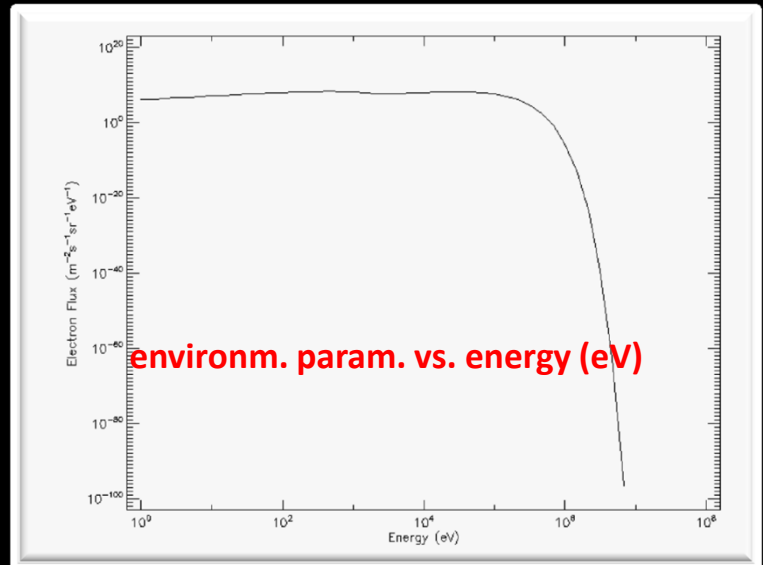


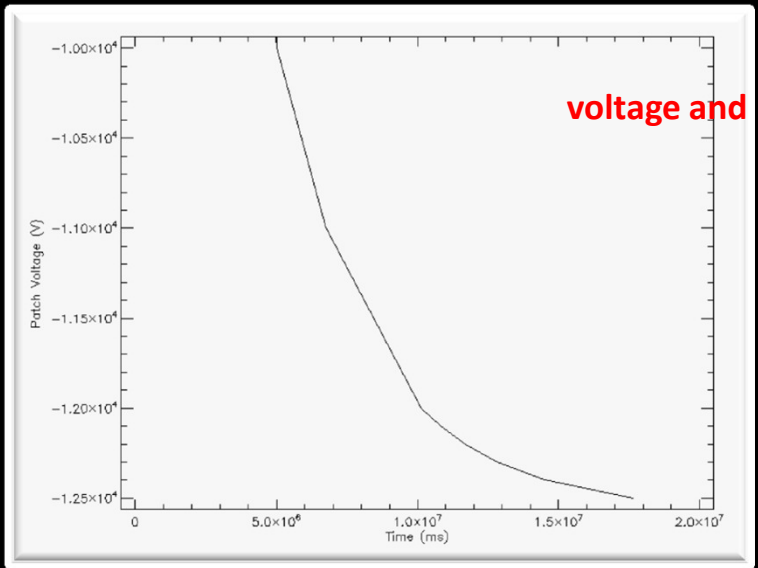
EQUIPOT input (2): material properties

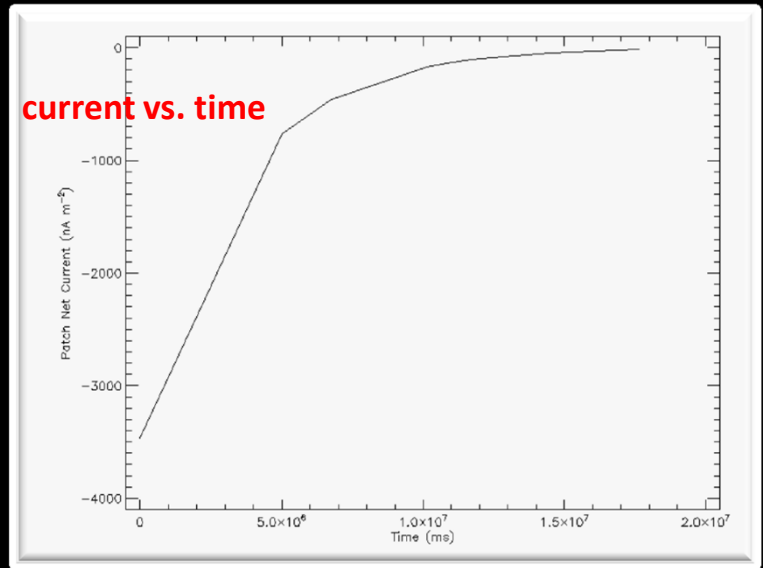


EQUIPOT outputs









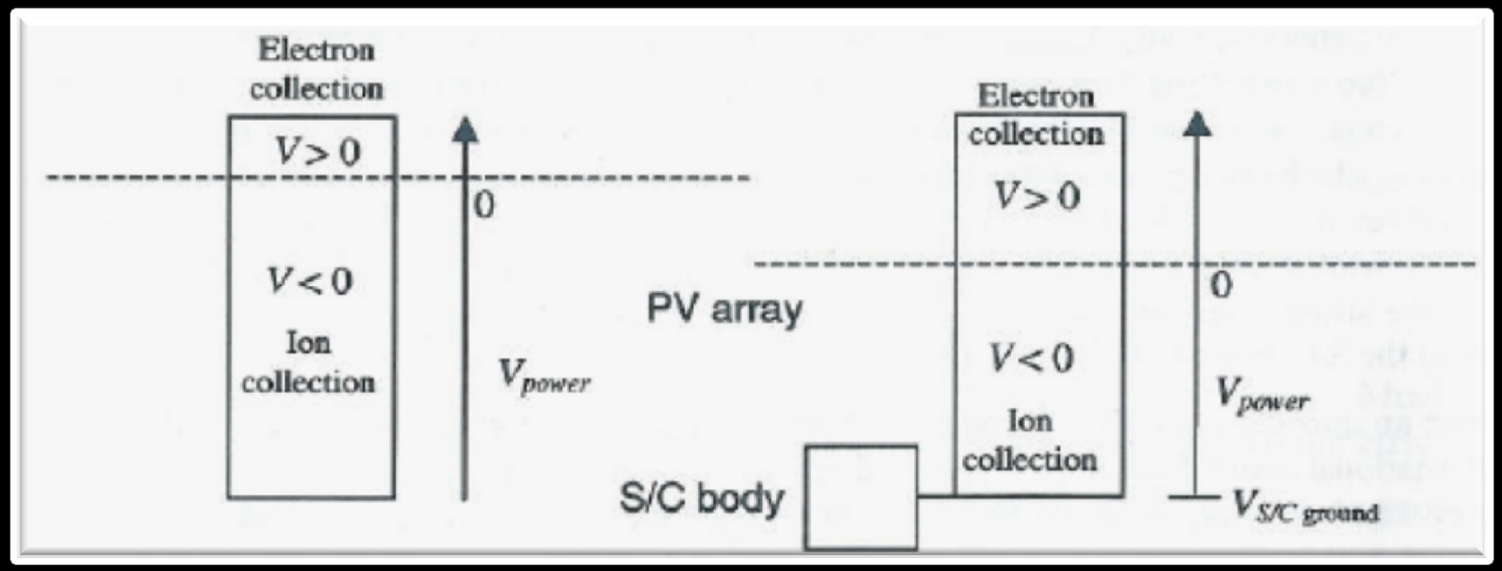
EQUIPOT: use and interpretation

- **Rapid assessment of likelihood of charging for surface materials on s/c**
- **Identification of worst case situations**
- **Sensitivity study to small changes in environment and surface material properties:**
  - **estimate of error bars on the results of more complex charging codes**
  - **indicate where more accurate material data or plasma measurement must be made**
- **Conclusion:**

$\lvert V_{eq} \rvert < 100$ V	:	no serious charging problem
$100 \leq \lvert V_{eq} \rvert \leq 1000$ V	:	appropriate design modification (after param. change)
$\lvert V_{eq} \rvert > 1000$ V	:	more detailed study is needed

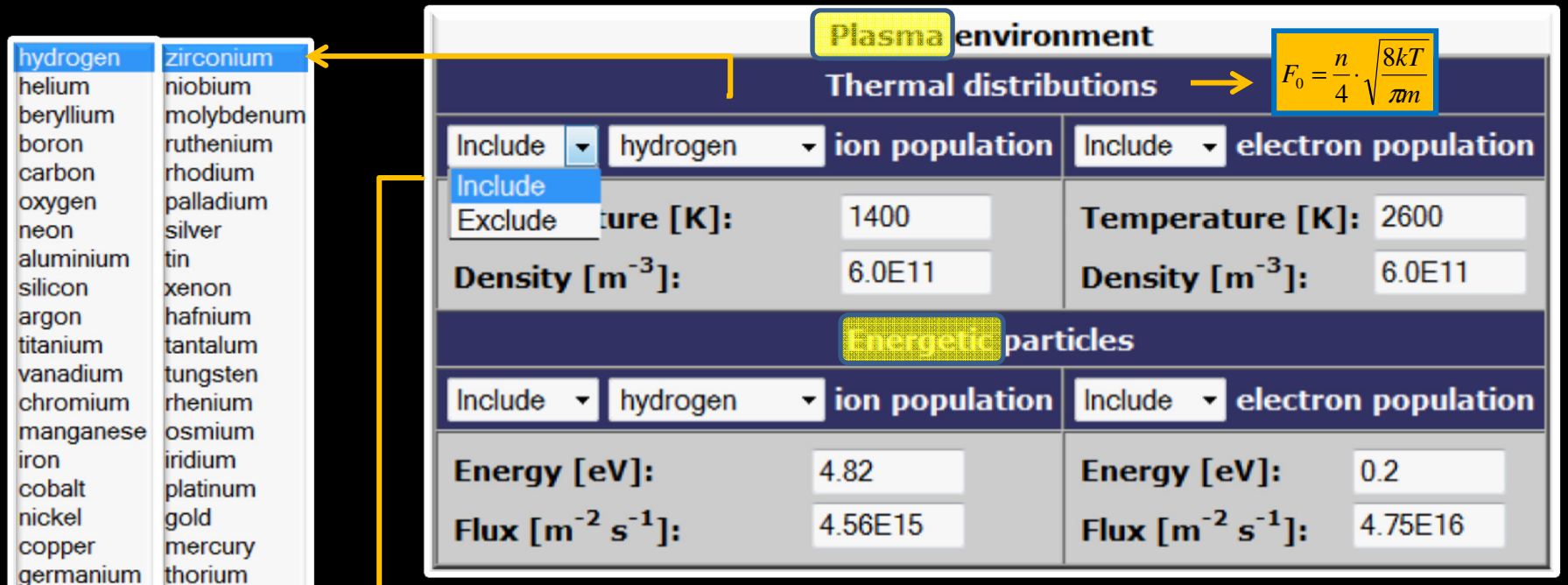
SOLARC Solar Array Analysis Programme

- Fast charging analyses of solar panel attached or not to a structure in LEO and Polar environments
- Version 2.00 in current SPENVIS



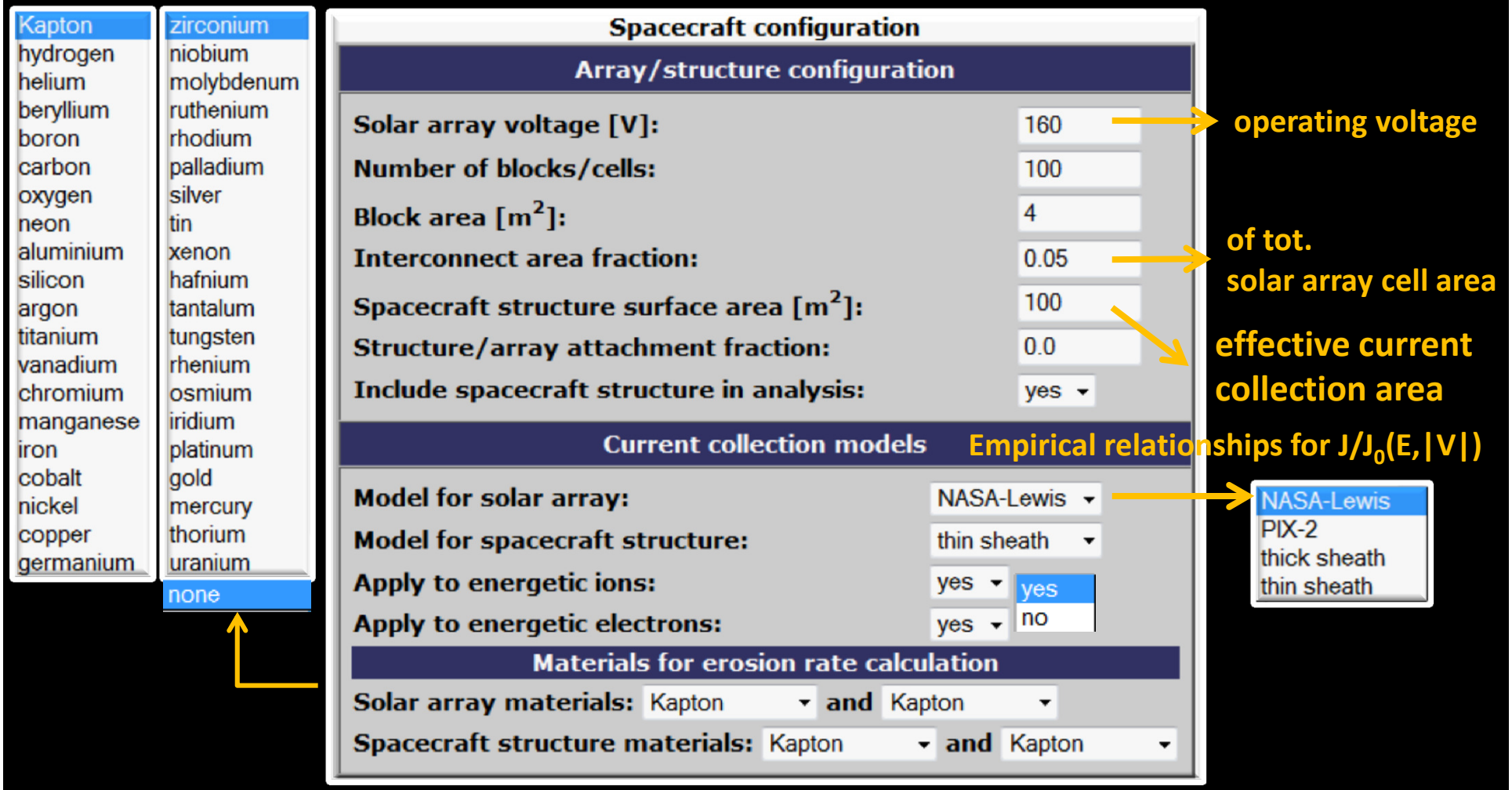
equilibrium at LEO dense plasma (from J-F Roussel 2002)

SOLARC input(1): plasma environment



input from e.g. LEOPOLD, IRI2001

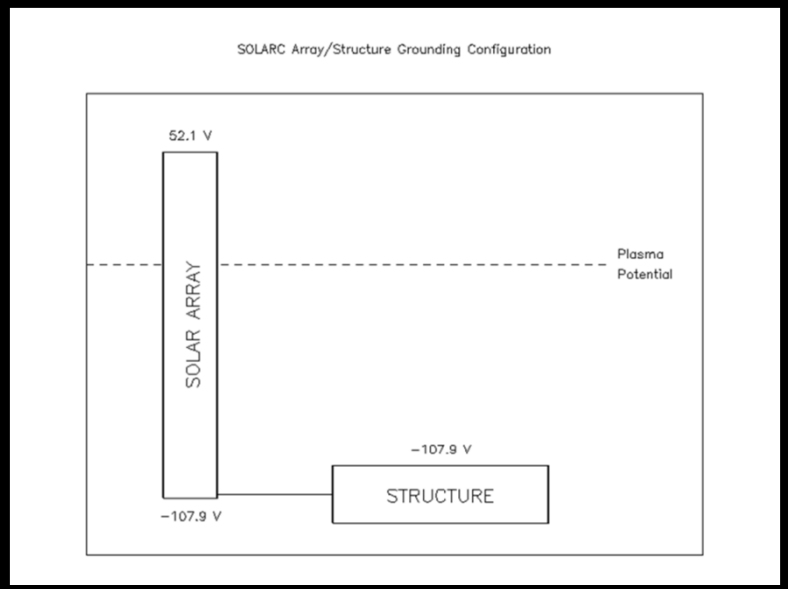
SOLARC input(2): s/c configuration



SOLARC output

Main outputs:

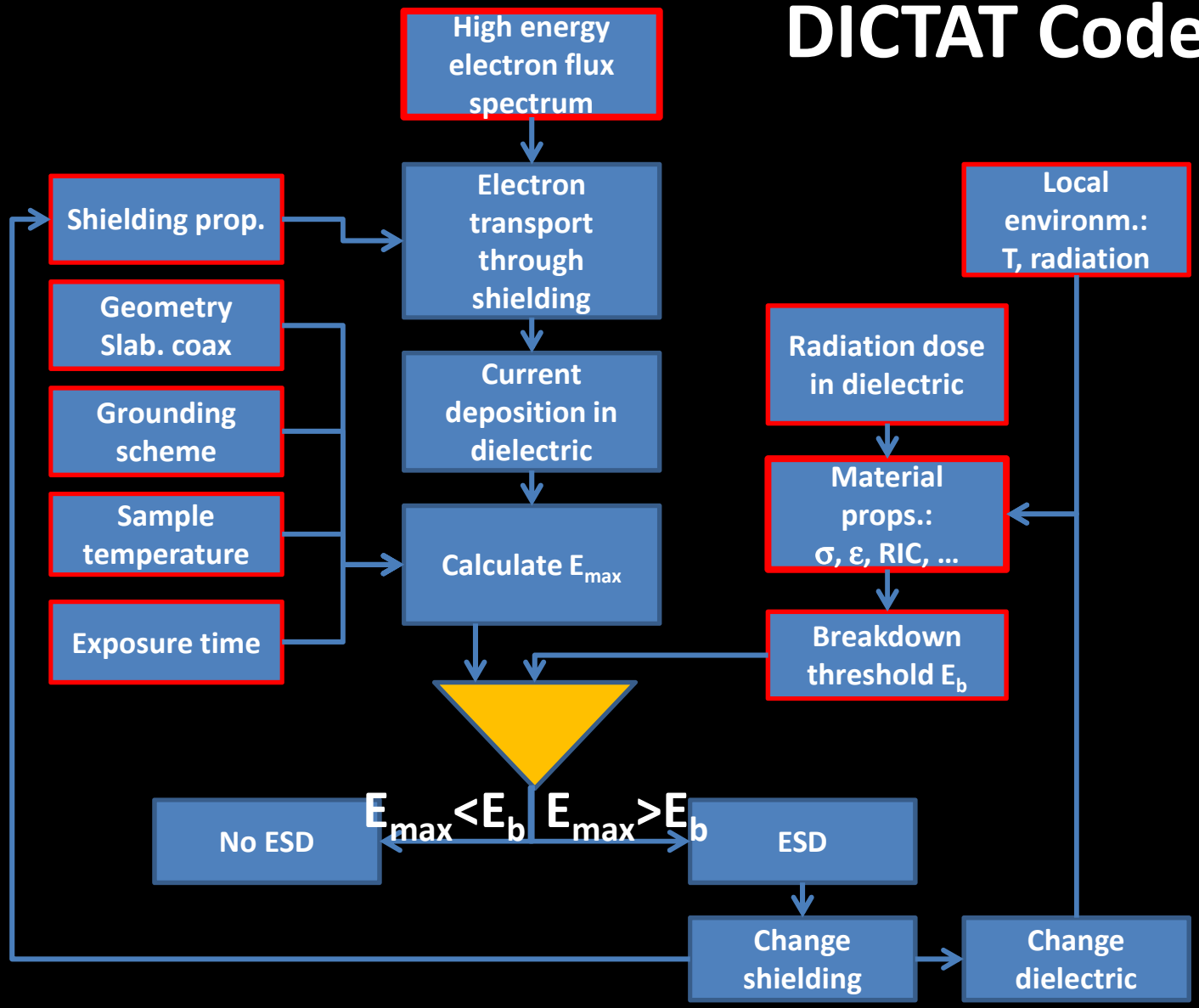
- **current collected by the specified solar array and spacecraft surfaces;**
- **array and structure voltages relative to the ambient plasma potential (i.e. floating voltages);**
- **plasma current and power loss;**
- **erosion or sputtering of surfaces caused by energetic ion impingement.**



DICTAT Internal charging code

- No input orbit required, but can be an input
- 1-D internal charging code calculating E and V due to penetrating electrons
- Fast, analytical transport equations
- Simulates dielectric + shielding
- Planar or cylindrical geometry
- Built-in FLUMIC environment model or user input
- Use: - Is dielectric safe or not to Electrostatic Discharge (ESD)?
  - If not which countermeasures?
- Version in current SPENVIS: 3.0

DICTAT Code logic



DICTAT input(1): electron flux

Electron environment:	FLUMIC model over a spacecraft orbit
Orbit type:	general

Only 1st segment

FLUMIC 3.0
omni + isotrop.

Electron environment:	FLUMIC model at a (B/Bo,L) location
B/B_0:	1.0
L [R_E]:	4.5
Fraction of solar cycle:	0.0
Fraction of year:	0.0

0 at sol. min.

0 at 1 jan.

Electron environment:	upload an electron spectrum
Label:	user defined spectrum
Exposure duration [hr]:	48.0
Directionality:	isotropic or monodirectional
No. of energies:	2
Energy [MeV]	Integral Flux [$cm^{-2}s^{-1}sr^{-1}$]

INTEGRAL spectrum

max. 30 pts

E: 0.001-10 MeV

$F(E<E_{min})$ = const

$F(E>E_{max}) = 0$

$F(E_{min}<E<E_{max})$: lin.int

Omni: $cm^{-2}s^{-1}sr^{-1}$

Mono: $cm^{-2}s^{-1}$

DICTAT input(2): geometry & mat. Props.

If omni

298-398 K

ε_r

$\sigma(J)=K_p.(dD/dt)^{\Delta}$

$\sigma(T)=a\cdot\exp(-bE_A/T)/T$

Geometry: planar (planar / cylindrical)

Field of view [deg]: 0-90°

If omni

Dielectric: teflon		Conductor	
Thickness [cm]:	0.1	Shield: aluminium	
Temperature [K]:	298.0	Thickness [cm]:	0.1
Density [g cm^{-3}]:	2.17	Core: aluminium	
Conductivity [Ohm^{-1}m^{-1}]:	1.0E-16	Radius [cm]:	0.1
Dielectric constant:	2.15		
Breakdown el. field [V m^{-1}]:	1.0E7		
RIC dose rate factor k_p:	2.0E-14		
Delta:	0.7		
Activation energy [eV]:	0.0		

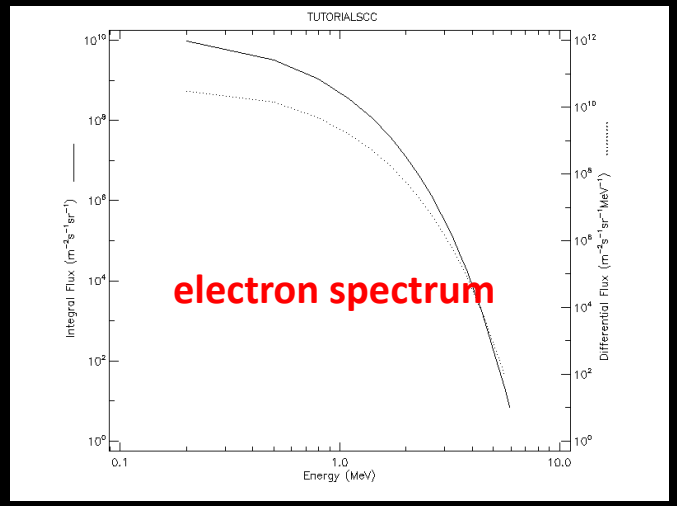
Grounded at one surface or both surfaces

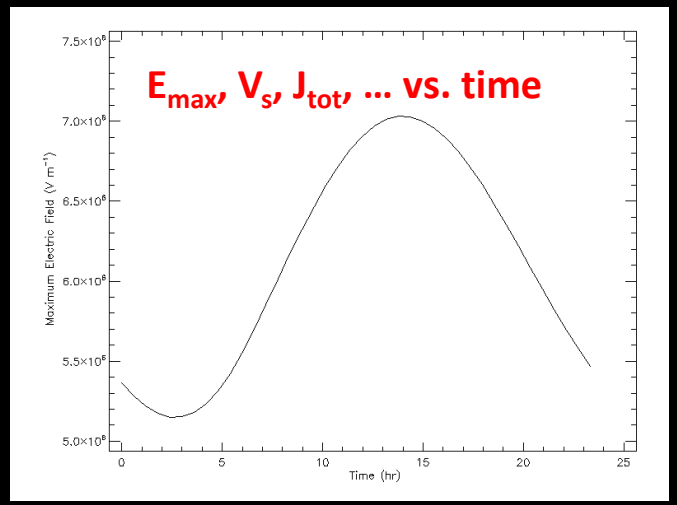
inner surface

$R=0.55\cdot E[1-0.9841/(1+3E)]$ (E<10 MeV), Z≤26 → $E=J\cdot(1-\exp(-t/\tau))/\sigma$, $\tau = RC = \varepsilon/\sigma$

DICTAT outputs

```
      DICTAT v3.0 - Dielectric Internal Charging Threat Assessment Tool

TUTORIALSCC

User inputs were:

Planar geometry
Dielectric grounded once at inner surface
Shield material:        ALUMINIUM        density:   2.70 g/cm**3
Shield thickness:       1.0000E-03 cm
Isol. metal material:   ALUMINIUM        density:   2.70 g/cm**3
Isol. metal thickness:   0.000      cm
Dielectric material:    TEFLON
       density:   2.17 g/cm**3          conductivity:   1.00E-16 /(Ohm m)
  permittivity:   2.15               breakdown field:   1.00E+07 V/m
            Kp:   2.00E-14          activation energy:   0.00 eV
         Delta:   0.70
Dielectric thickness:    0.1000      cm
Surface charging potential 0.000     volts
Temperature:             298.0 K
Field of view:           90.0 degrees about normal
Flux isotropic
Model is FLUMIC V3.0 19/11/03
Fraction of Solar cycle=0.800 Fraction of year=0.800
Using L-shell=4.50 and B/B0= 1.00     with duration 48.     hours

At Equilibrium:
Charging current=        1.3153E-11 Amps/cm**2
E-max=                   1.0895E+07 V/m Voltage=   5644.     volts

After 48.0     hours:
Charging current=        1.3153E-11 Amps/cm**2
E-max=                   1.0895E+07 V/m Voltage=   5644.     volts

The dielectric is liable to experience breakdown

Maximum field is higher than Breakdown field=  1.00E+07 V/m

Maximum current incident on the component=  1.5526E-11 A/cm**2

Options to make the structure safe:

 Reduce dielectric thickness to less than      9.2039E-02 cm

 Increase shield thickness to greater than         6.7382E-03 cm

DICTAT Normal termination
```





Environment and charging data

❑ LEOPOLD:

- Low Earth environment (200-2000 km)
- density, temperature, velocity, flux, …

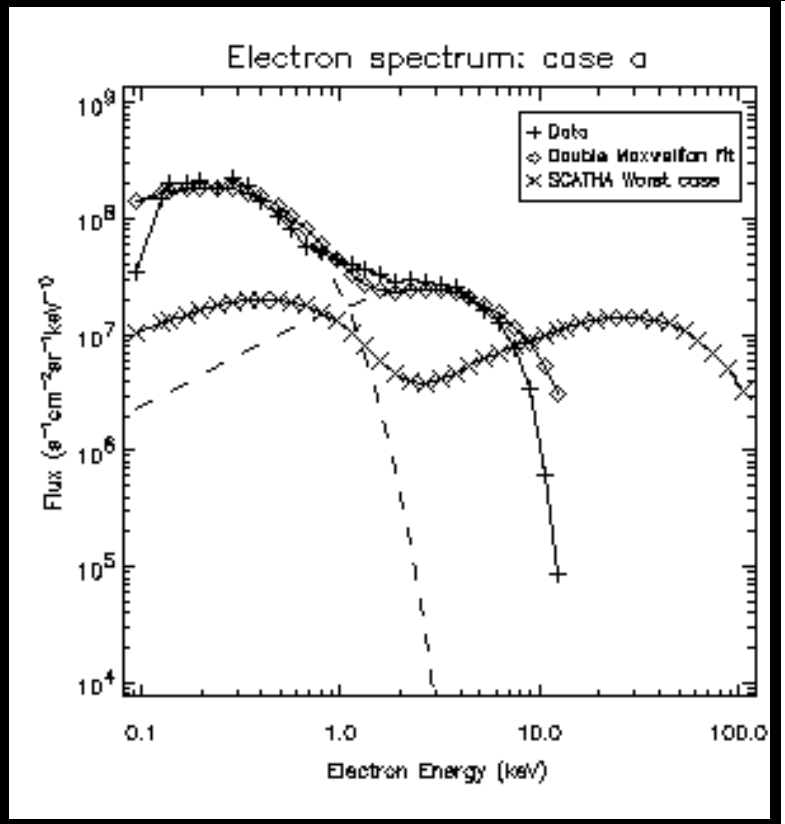
Altitude: 200.000 km

Environmental characteristic	Value	Units
Neutral particle density	2.000E+16	m-3
Electron density	3.000E+11	m-3
Electron temperature	2000.00	K
	0.172	eV
Ion temperature	800.00	K
	0.069	eV
Average ion mass	18.00	amu
	2.989E-26	kg
Electron thermal velocity	2.462E+05	ms-1
Ion thermal velocity	8.596E+02	ms-1
Spacecraft circular velocity	7.784E+03	ms-1
Electron thermal particle flux	2.084E+16	m-2s-1
Ion ram particle flux	2.335E+15	m-2s-1
Electron saturation current density	3.338E-03	Am-2
Ion ram saturation current density	3.741E-04	Am-2
Debye length	5.635E-03	m
Mass ratio	3.281E+04	
Dimensionless satellite velocity	4.471E-02	
Ion kinetic energy	32.799	
Mach number	8.099	
Mach angle	7.092	degrees

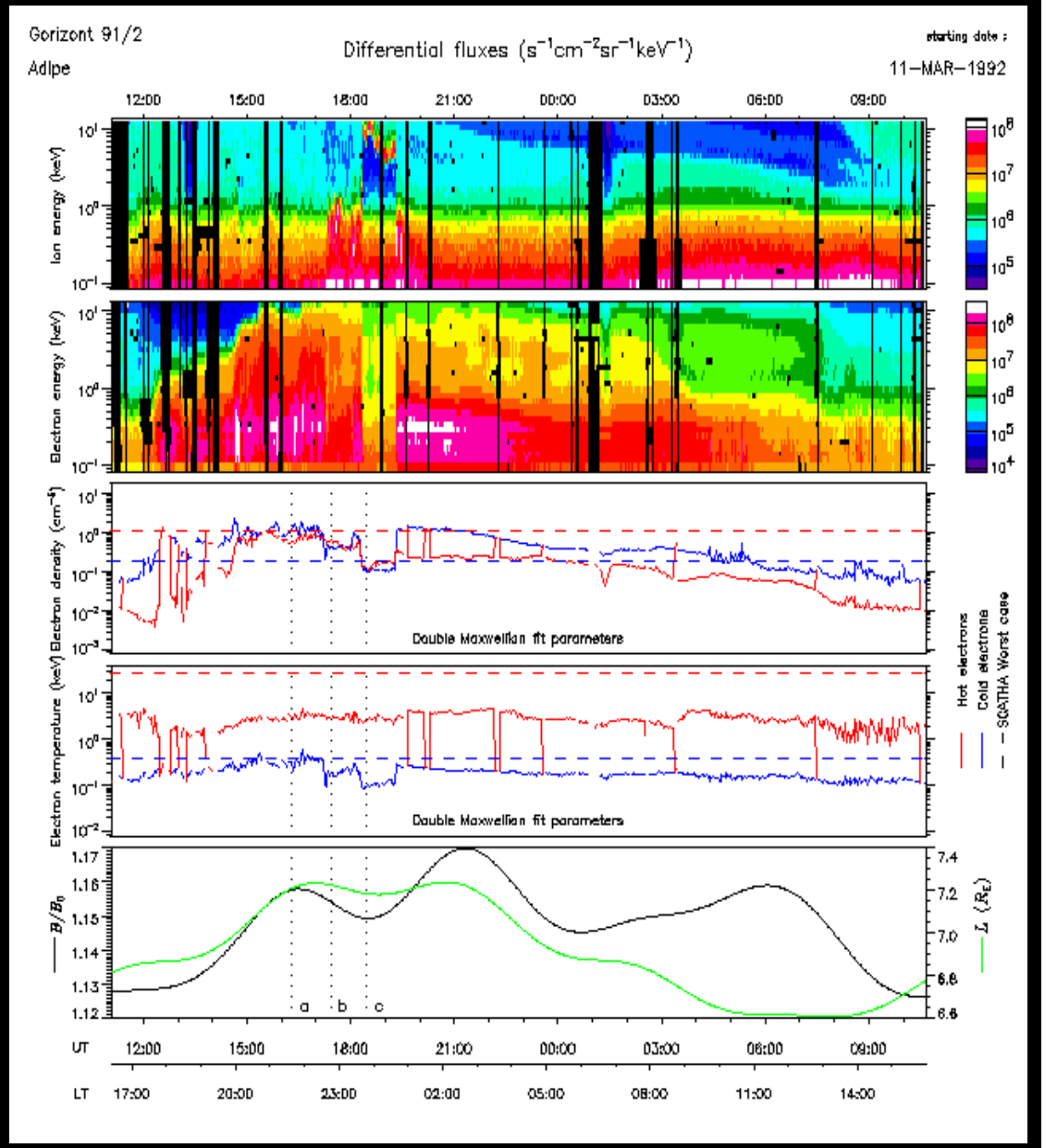
❑ 2 databases with charging events:

- Gorizont 91/2-ADIPE:
  - GEO, long. 80°E : 25/11/1991 - 29/09/1993
- CRRES-LEPA:
  - GTO, 18° incl., apogee at 6.3 Earth radii: 21/08/1990 – 13/07/1991

Date	UT	LT	Data duration	Maximum Potential	Eclipse	Electron charging	Electron potential
25-NOV-91	14:30-15:00	19:40-20:20	15.86	600	No	Yes	200
11-MAR-92	17:00-19:30	22:20-00:50	23.54	10000	Yes	No	
22-MAR-92	18:30-24:00	23:50-05:20	22.79	4000	Yes	Yes	300
24-MAR-92	16:00-19:30	21:20-00:50	23.32	3000	Yes	No	
25-MAR-92	18:00-19:00	23:20-00:20	23.04	3000	Yes	No	
27-MAR-92	22:00-24:00	03:20-05:20	16.04	800	No	Yes	300
28-MAR-92	22:00-23:30	03:20-04:50	23.40	1000	No	Yes	250
29-MAR-92	20:45-21:45	02:05-03:05	18.31	1000	No	No	
07-APR-92	16:30-19:15	21:50-00:35	23.22	3000	Yes	No	
08-APR-92	18:30-19:30	23:50-00:50	23.18	10000	Yes	No	
24-AUG-92	00:00-02:00	05:20-07:20	28.62	1000	No	Yes	400+900



Case a 11-MAR-1992 16:18:52	Cold electrons		Hot electrons	
	n_e (cm^{-3})	T_e (keV)	n_e (cm^{-3})	T_e (keV)
Double Maxwellian Fit	1.368	0.216	0.648	2.712
SCATHA Worst case	0.200	0.400	1.200	27.500



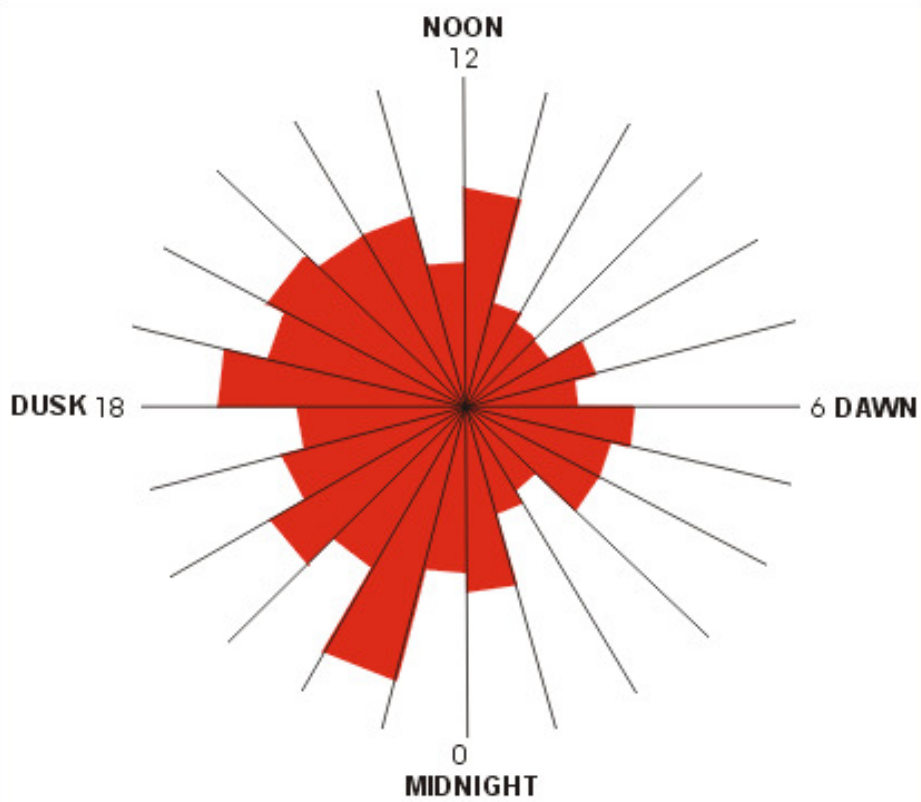
S/C charging in SPENVIS-NG

- DICTAT 4.0 (Jupiter)
- New/upgraded environment models
- Interfaces to charging tools from the "Energetic Electron Shielding, Charging and Radiation Effects and Margins" project
- Extension of database with charging events
- **Suggestions from YOU**

Bibliography

- LEOPOLD:
  - Martin, A. R., *Spacecraft/Plasma Interactions and Electromagnetic Effects in LEO and Polar Orbits*, Final Report for ESA/ESTEC Contract No. 7989/88/NL/PB(SC), Vol. 3, 1991.
- SOLARC:
  - Bond, R., T. Field, P. Hurford, and A. Martin, ESPIRE Version 1.0 Software Users Manual, 1991.
- EQUIPOT:
  - Wrenn, G. L., and A. J. Sims, The 'Equipot' Charging Code, Working Paper SP-90-WP-37, 1990; updated by D.J. Rodgers, 2002.
- DICTAT:
  - Weber, K.-H., *Nucl. Inst. Meth. 25*, 261, 1964.
  - Soubeyran, A., and R. Floberhagen, ESA-DDC 1.1 User Manual, Matra Marconi Space, 1994.
  - Sorensen J., An Engineering Specification of Internal Charging, in *Environmental Modelling for Space-based Applications*, ESA SP-392, p. 129, 1996.
  - Rodgers D.J., K.A.Ryden, G.L.Wrenn, P.M.Latham, J. S&oring;rensen, L.Levy, An Engineering Tool for the Prediction of Internal Dielectric Charging, 6th Spacecraft Charging Technology Conference, Hanscom, 1998.
  - Rodgers, D. J., DICTAT Software: Users' Manual, Issue 3.0, DERA/CIS(CIS3), 1999.
  - Rodgers D.J., K.A.Hunter and G.L.Wrenn, The FLUMIC electron environment model. Proceedings 8th SCTC, Huntsville, 2003.
- Spacecraft Charging Standard (ECSS-E-ST-20-06C)
- Space engineering – Space environment (ECSS-E-10-04A)

Back-up slides

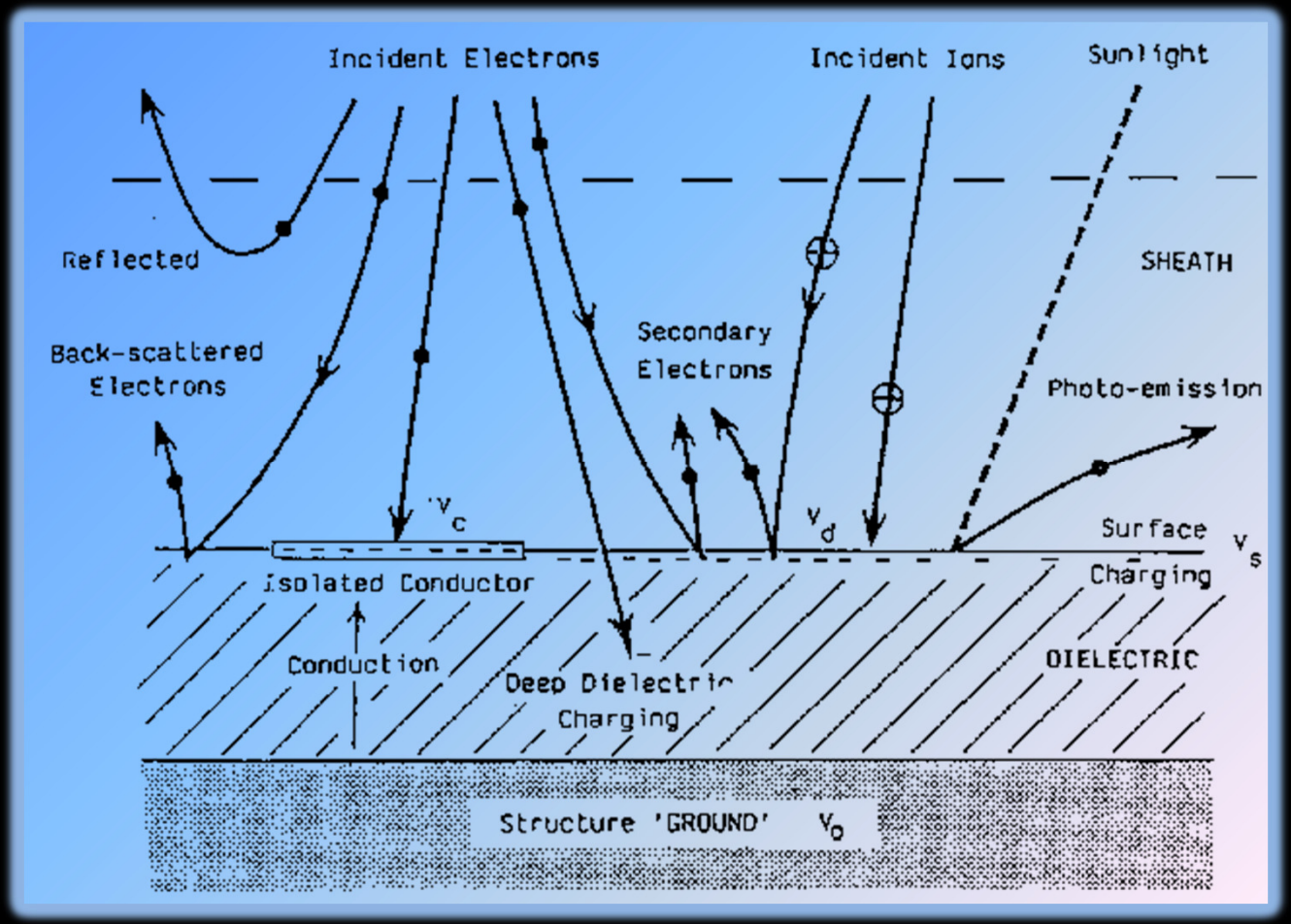


Local time distribution of occurrences of static discharges, based on 122 reported events.
Radial extent shows relative number of events in each sector.
After Lam and Hruska, 1991, J. Spacecraft and Rockets

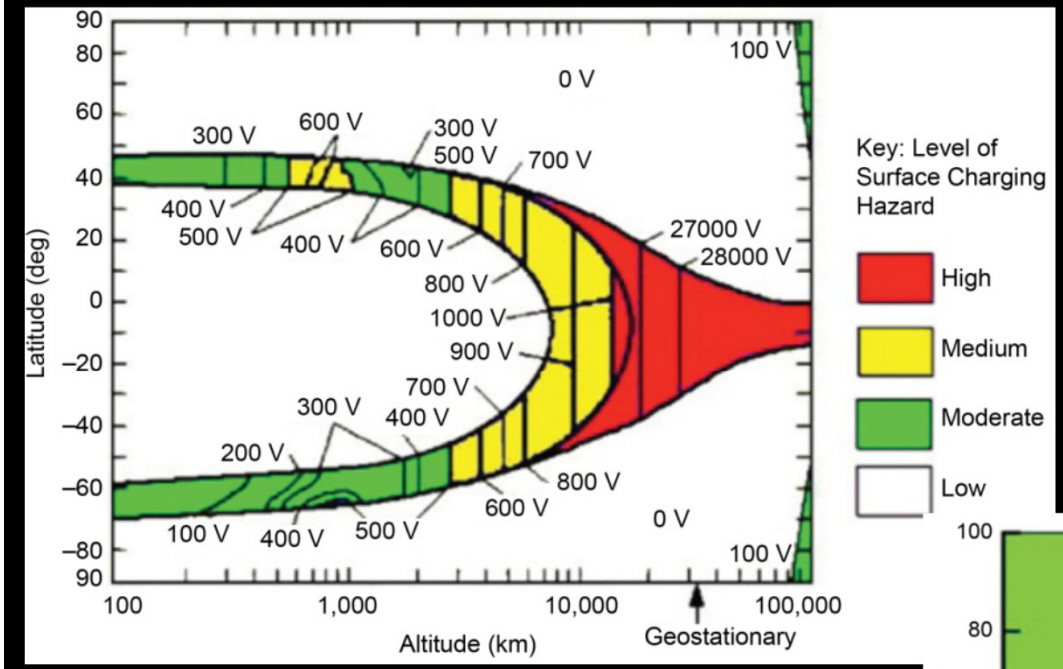
Environment spectra

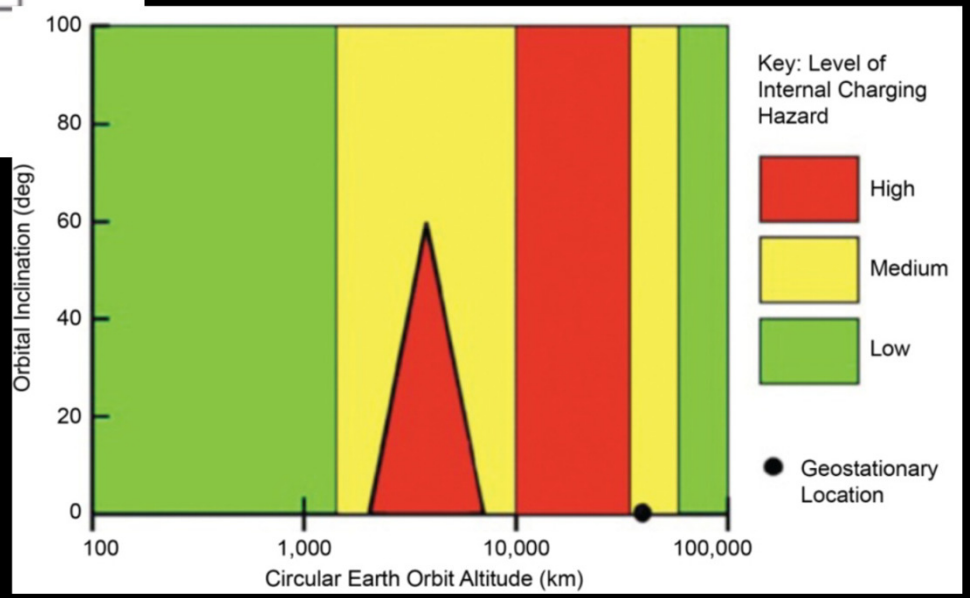
Description	Thermal electron spectra	Thermal ion spectra	Electron flux spectrum	Ion flux spectra	Reference
Low altitude environments					
IRI at solar minimum, in winter, at 800 km, plus 10 kR aurora	1	3	yes	1	
IRI at solar maximum, in summer, at 800 km, plus 10 kR aurora	1	3	yes	1	
Maxwellians for 1,000 km plus aurora	1	3	yes	1	
Auroral type spectra from DMSP	1	1	yes	1	
Cold Maxwellians for ram test	1	1	no	none	
Test spectra and Maxwellians	3	3	yes	1	
Cold Single Maxwellian and Fontheim electrons	1	1	yes	none	*Fontheim et al., 1982*
High altitude environments					
ECSS worst case model (SCATHA)	2	2	no	none	*Gussenhoven and Mullen*, 1983
NASA guidelines worst case	2	2	no	none	*Mullen and Gussenhovenn*, 1982
NASA guidelines average GEO environment	2	2	no	none	*Purvis et al.*, 1984
Meteosat very disturbed	none	none	yes	1	*Wrenn and Johnstone*, 1987
Meteosat very quiet	none	none	yes	1	*Wrenn and Johnstone*, 1987

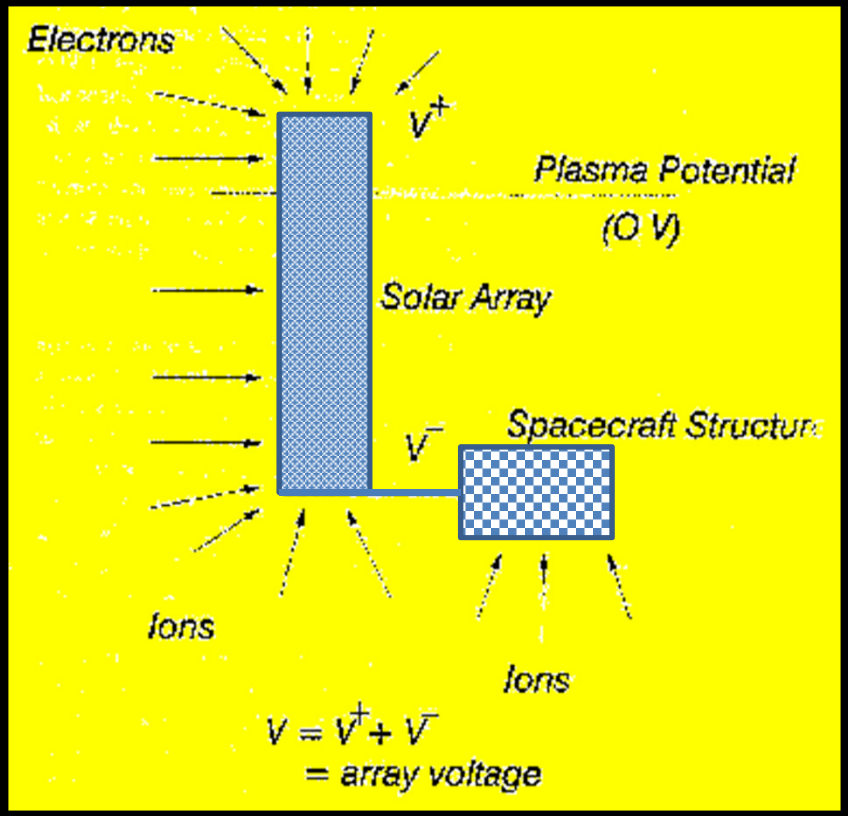
Charging mechanism

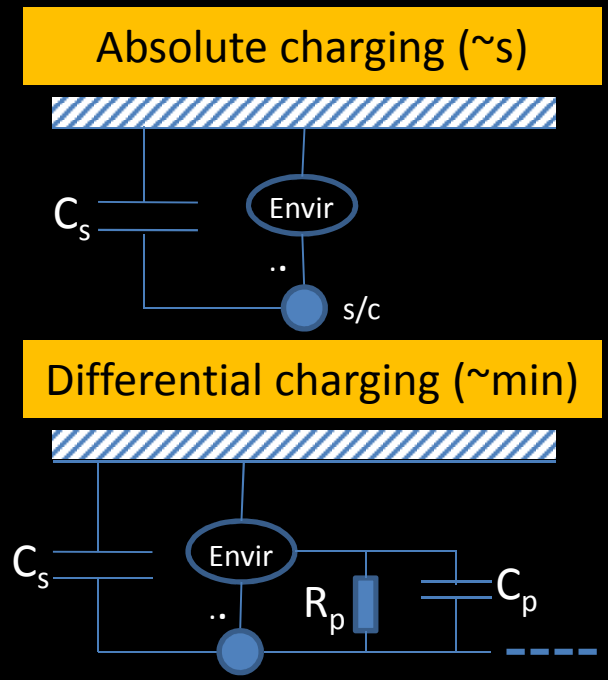


Earth regimes of concern for on-orbit surface (a) and internal (b) charging (R.W. Evans et al., 1989)






Electrons
V^+
Plasma Potential
(O V)
Solar Array
V^-
Spacecraft Structure
Ions
Ions
$V = V^+ + V^-$
= array voltage


Absolute charging (~s)
C_s
Envir
..
s/c
Differential charging (~min)
C_s
Envir
..
R_p
C_p

FLUMIC 3.0

INNER BELT (L<2.5 R_e)

>1MeV Flux versus L profile

$F(>1MeV,L) = 4.0\times10^{\{2.12+45.4/(L+0.05)^2 - 45.6/(L+0.05)^3\}}$ $m^{-2}\ s^{-1}\ sr^{-1}$

Spectrum

$F(>E)=F(>1MeV) \times \exp[(1-E)/E_0]$

where $E_0 = 0.14$ MeV

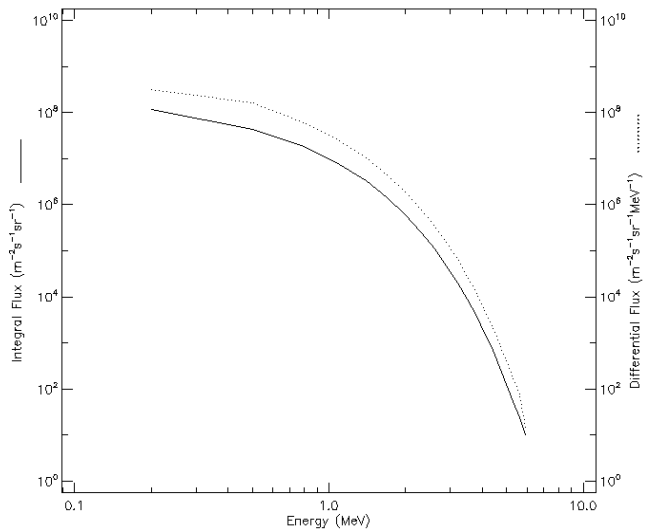
B/B0

For $L < 3$ Flux = Flux(equatorial)$\times10^{(-a((B/B0)-1))}$

where $a = -0.4559L+1.4385$ $L\geq1.75$

and $a = 36.(1/\sinh((L-1)\times10.)+0.7)$ $L<1.75$

For $L \geq 3$ the formula of Vette [14] is used, as in AE8



OUTER BELT (L>2.5 R_e)

>2MeV Flux at L=6.6 R_e

The peak integral flux above 2 MeV at L= 6.6 is taken to be $8\times10^8\ m^{-2}\ s^{-1}\ sr^{-1}$.

Solar Cycle

$F(fsc)= 8\times10^8\{0.625+0.375\sin[2\pi*(fsc-0.7)]+0.125\sin[4\pi*(fsc-0.15)]$

where *fsc* is the solar cycle phase starting at solar minimum.

Season

$F(foy,fsc)=F(fsc)\{0.625-0.375\cos[4\pi(foy+0.03)]-0.125\cos[2\pi(foy+0.03)]\}$

where *foy* is the fraction of year starting from 1st January.

Spectrum

$F(>E)=F(>2MeV)\times \exp[(2-E)/E_0]$ where

$E_0 = 0.25$ for $F(>2MeV) < 10^7\ m^{-2}\ s^{-1}\ sr^{-1}$.

$E_0 = 0.25+0.11((\log[F(>2MeV)] -7)^{1.3})$ for $F(>2MeV) > 10^7\ m^{-2}\ s^{-1}\ sr^{-1}$.

E_0 in the outer belt is the subject of ongoing study and so this aspect of the model may be updated before the model is finalised.

Flux versus L profile

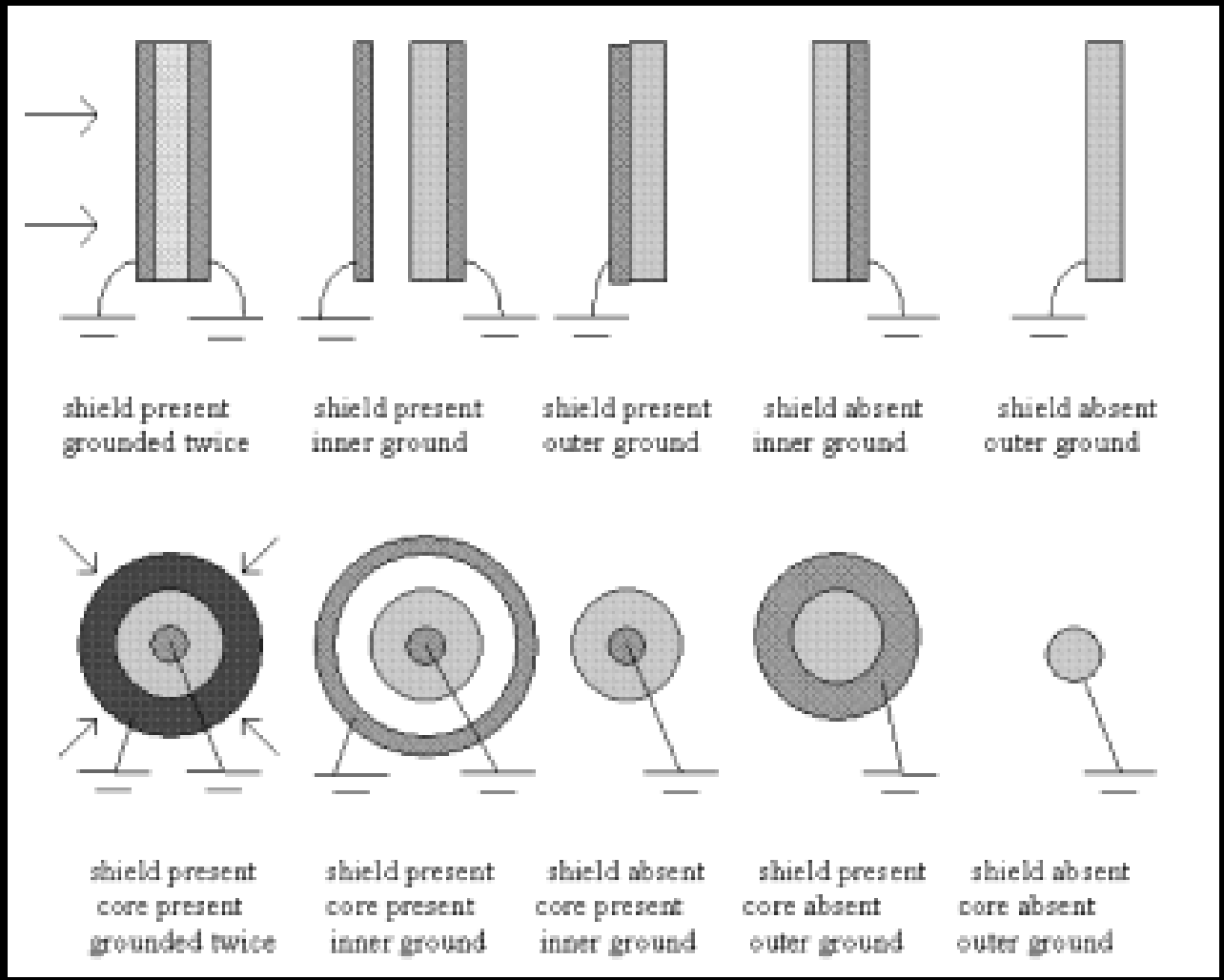
$F(>E,L) = F(>E,6.6) \times 16\tanh[0.6(L-2.5)]/\cosh[1.5(L-4.3)]$ $m^{-2}\ s^{-1}\ sr^{-1}$

where $F(>E,6.6) = F(foy,fsc) \times \exp[(2-E)/E_0]$.

Table 1. Summary of databases used for FLUMIC

REM	Orbit	GTO with inclination of 7°
	Data duration	1994 to 1998.
	Data	Electron flux in three channels, 1-2.2 MeV, 2.2-4.6 MeV and 4.6-10 MeV
GOES	Orbit	Geostationary, with longitude around 75W and 135W.
	Data duration	More than a solar cycle
	Data	Electron flux in two channels, >0.6MeV and >2MeV.
SURF	Orbit	GTO, with inclination of 7°
	Data duration	12 days, after which communication with the spacecraft was lost.
	Data	Electron current behind two levels of shielding, corresponding approximately to 1MeV and 1.7MeV

DICTAT geometry



Algorithm for breakdown solution

1. The code first determines the critical current necessary to exactly reach the threshold field, based on Adamec's and Calderwood's [1975] equation (9) and stored values of the radiation-induced conductivity.
2. The ratio by which the actual current exceeds the critical current is found.
3. The existing shield thickness is multiplied by this ratio to give a second value of the shield thickness.
4. With this shield thickness, a second equilibrium electric field is found.
5. If the new electric field is not within 0.5% of the breakdown threshold, a third thickness is created based on a linear extrapolation or interpolation from the first two points.
6. If the electric field resulting from this thickness is not acceptably close to the breakdown threshold, a fourth point is created, based on linear extrapolation from the second and third points.
7. This process is continued until convergence is achieved and the final value is multiplied by 0.99 to ensure the result is between 1.5 and 0.5% below breakdown.