Validating a new solar cell performance prediction tool for space applications against ground tests

Activity performed under contract ARTES AT 4F.126
ESA AO/1-9732/19/NL/NR

Soufian YJJOU

Content

I. About the ARTES project

II. What is the SADC tool?

III. Ground testing. Design and results.

IV. SADC application case within the OMERE freeware

I. About the ARTES project

The goal is to provide a precise and fast way to predict solar cell degradation due to space exposure.

Prime Contractor
Solar Array Degradation Calculator (SADC) development, validation, integration in publicly available tools & solar cell high energy radiation testing

Radiation environment modelling & solar cell radiation testing

Sensitivity analysis of degradation prediction & solar cell assemblies
Definition of industrial applications and constraints, end-user perspective and requirements specification

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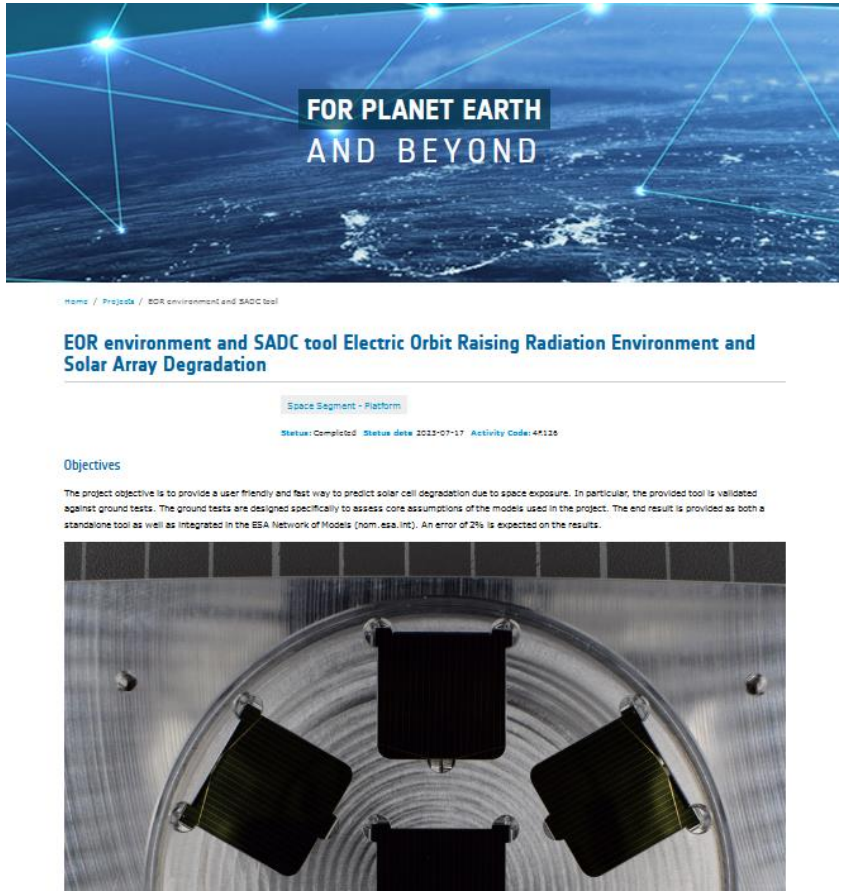
Definition of industrial applications and constraints, end-user perspective and requirements specification

I. About the ARTES project

Interested in this project?

Full documentation & associated papers references

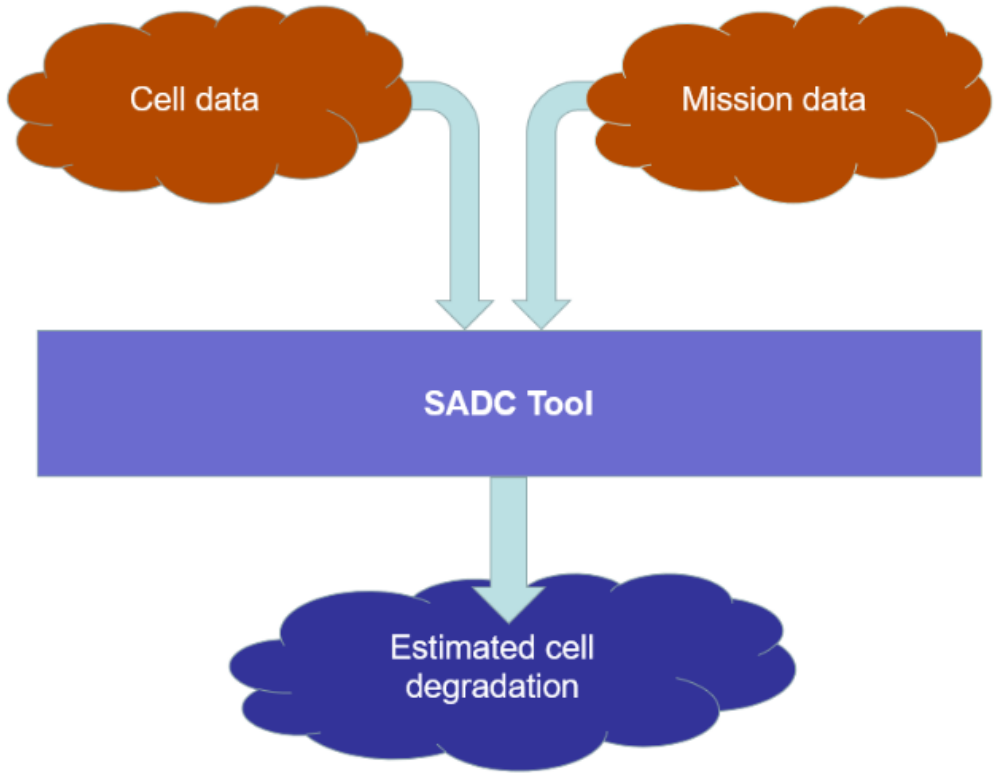


https://connectivity.esa.int/projects/eor-environment-and-sadc-tool

Online search keywords: ***ESA artes solar cell SADC tool***

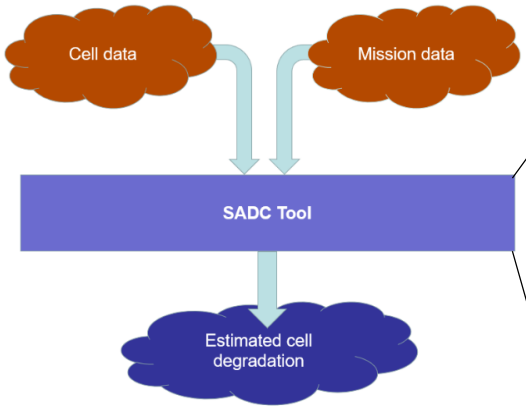
The SADC tool in a few words

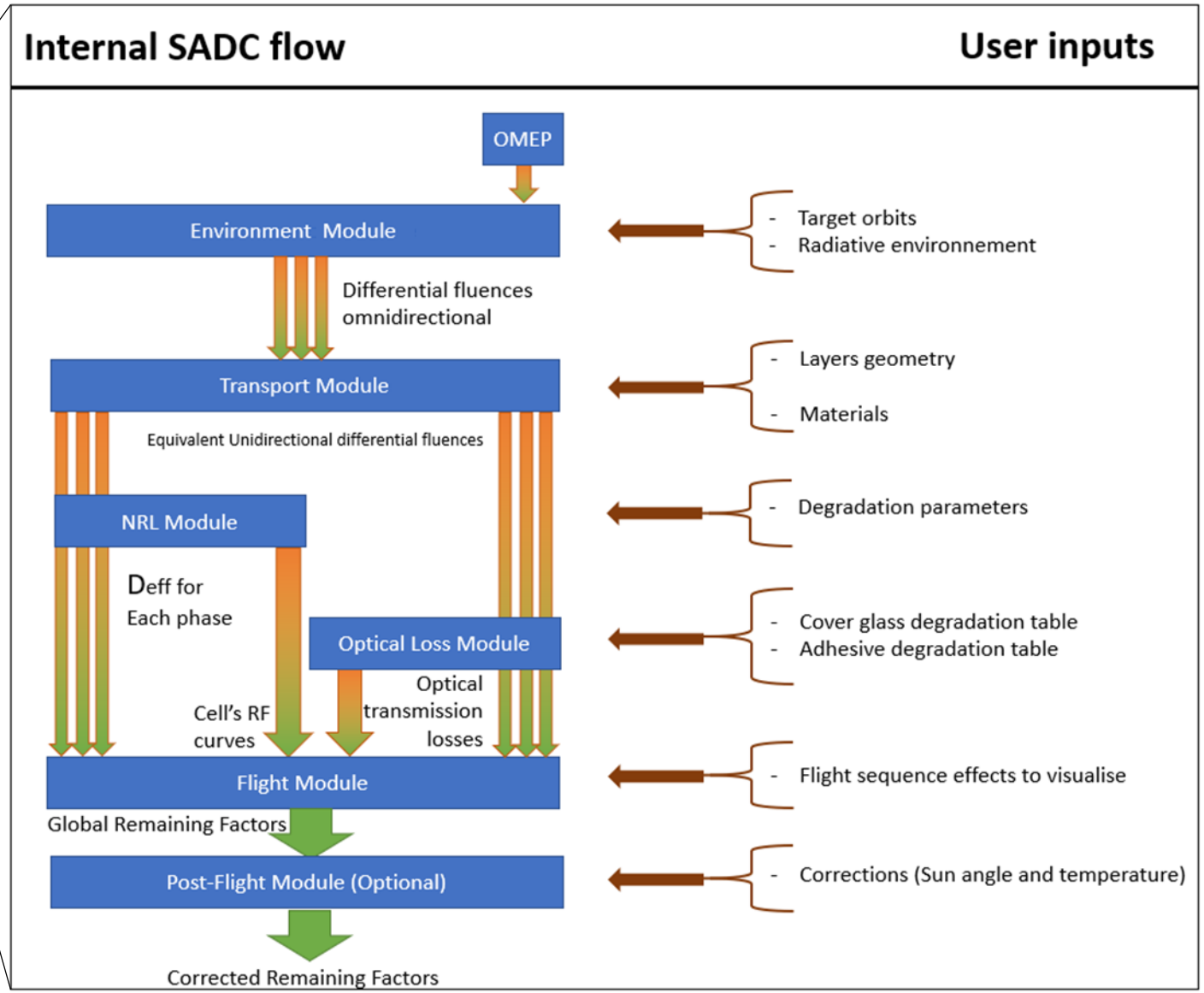
Ground tests -
Past publications -
Expected design -
…Flight data -



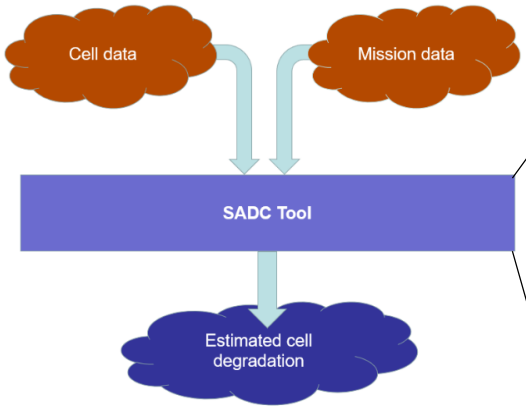
- Mission
- Environments Models
- Confidence levels…

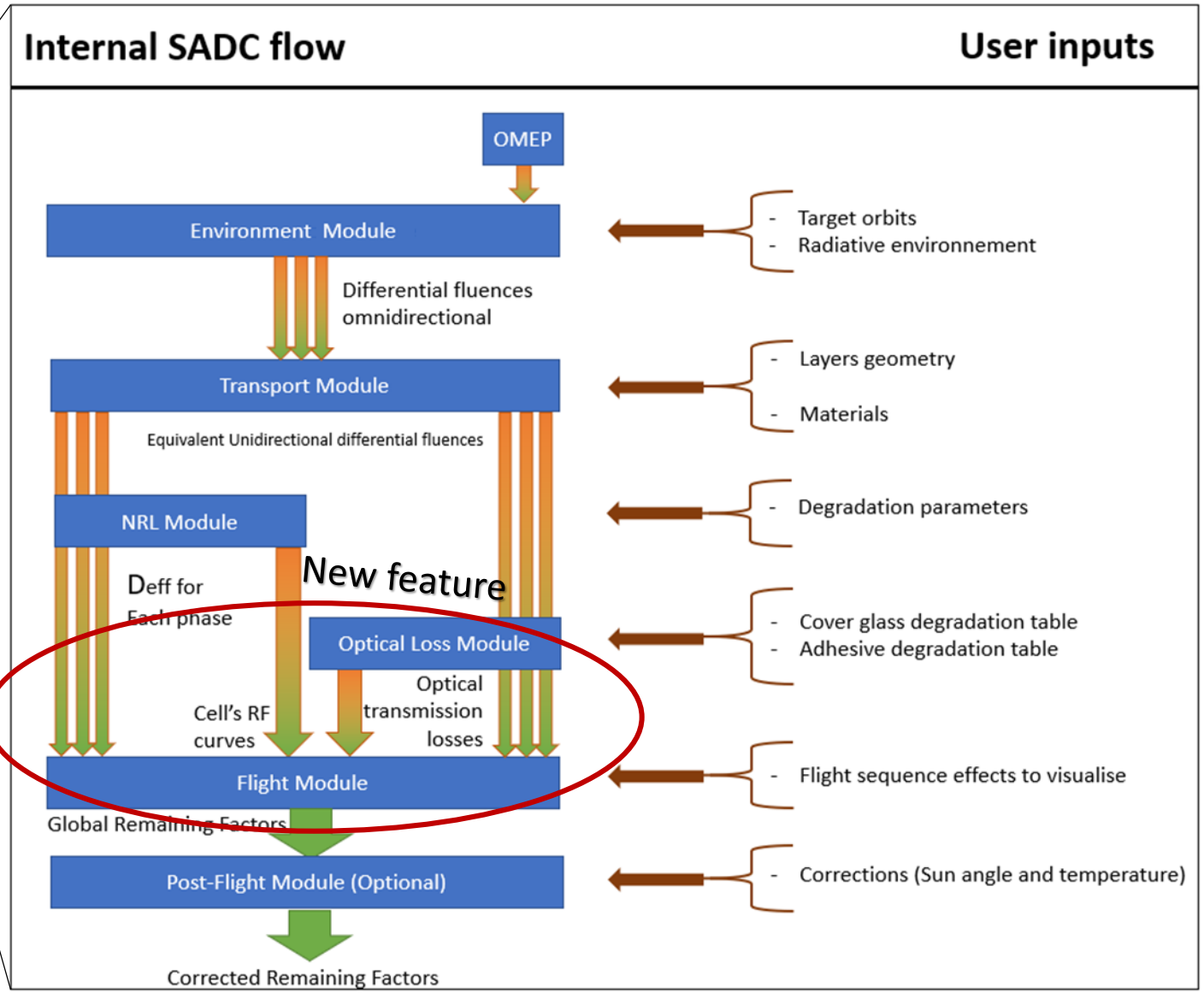
The SADC tool in a few words





The SADC tool in a few words





Ground matrix definition

What is to be tested?

- Superposition principle
- DDD principle
- Geometric superpositions (cell's layers effects)

What beams to use?

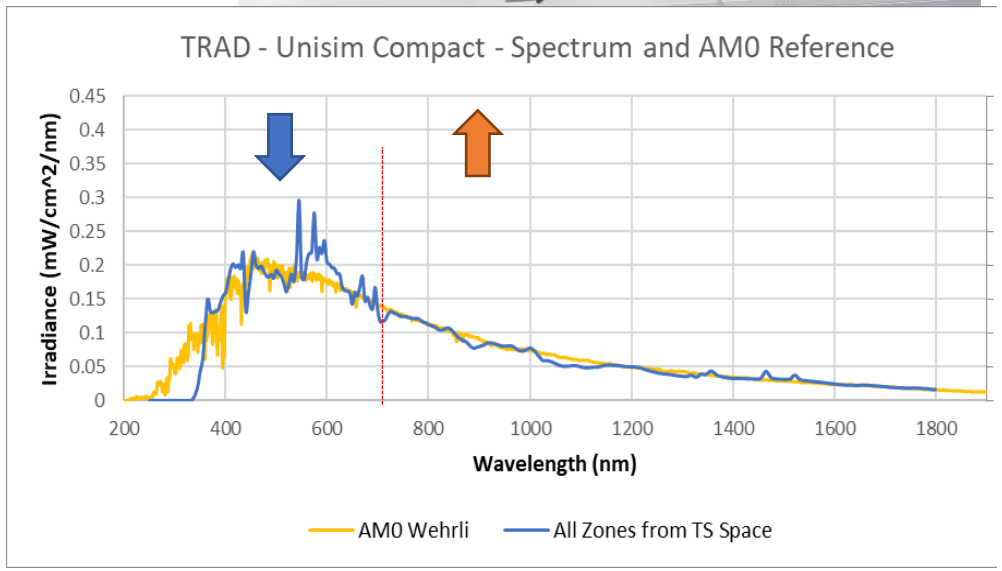
- Environment representative
- Avoid sample activation if possible

Sample configuration			Beam configuration		
ID	Type	Irradiation side	Particle type	Energy (MeV)	Fluence (#/cm²)
DDD equivalence / Shielding effects					
ID1	8x BSC	Front	Protons	6	2.3e12
ID2	8x BSC	Rear	Protons	6	8.7e11
ID4	8x SCA	Front	Electrons	1	2.1e15
ID5	8x SCA	Rear	Electrons	1	2.1e15
ID9	8x BSC	Front	Electrons	1	2.1e15
Optical loss damage / Shielding effects					
ID6	8x SCA 8x CVG	Front	Protons	0.045	2.0e14
ID8			Protons	7.2	2.3e12
DDD equivalence / Combined particle conditions					
ID13	8x BSC	Front	Electrons	1	1.05e15
ID14			Protons	1.8	3.84e11
ID11	8x BSC	Front	Protons	1.8	3.84e11
ID12			Protons	6	1.15e12
ID15	8x BSC	Front	Electrons	1	1.05e15
ID10			Electrons	3	3.1e14

All test conditions aim for the same Isc damage.

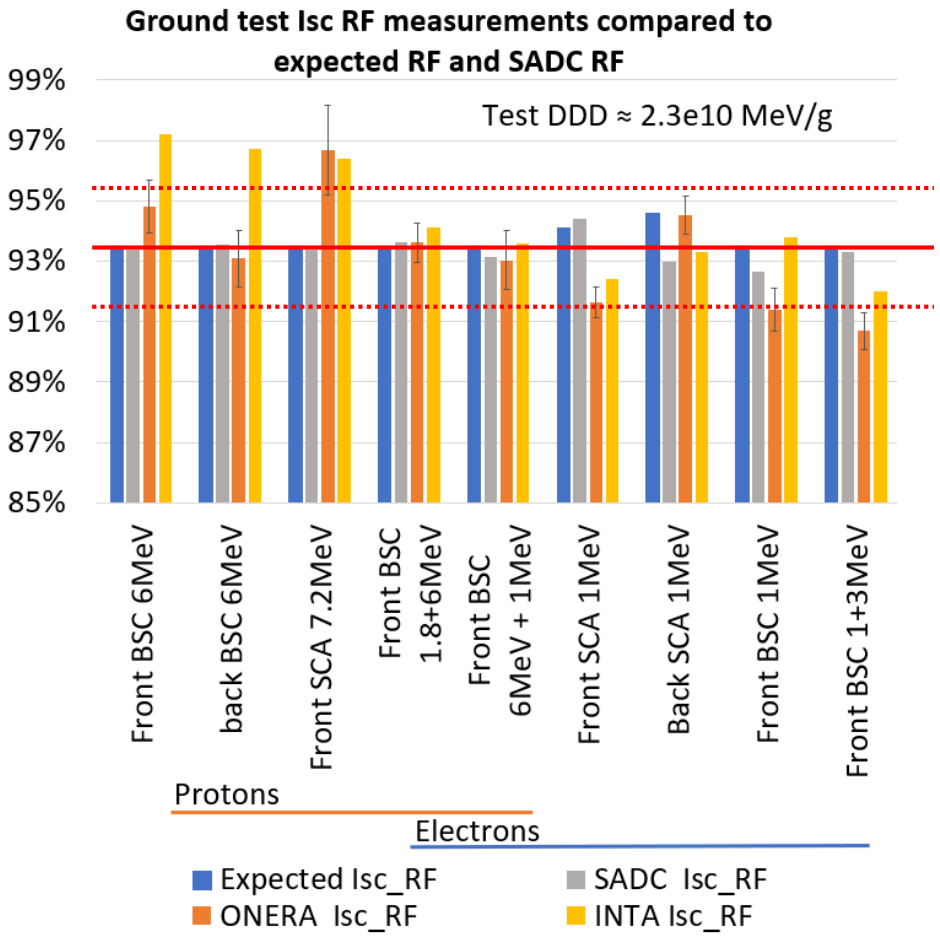
Ground matrix definition

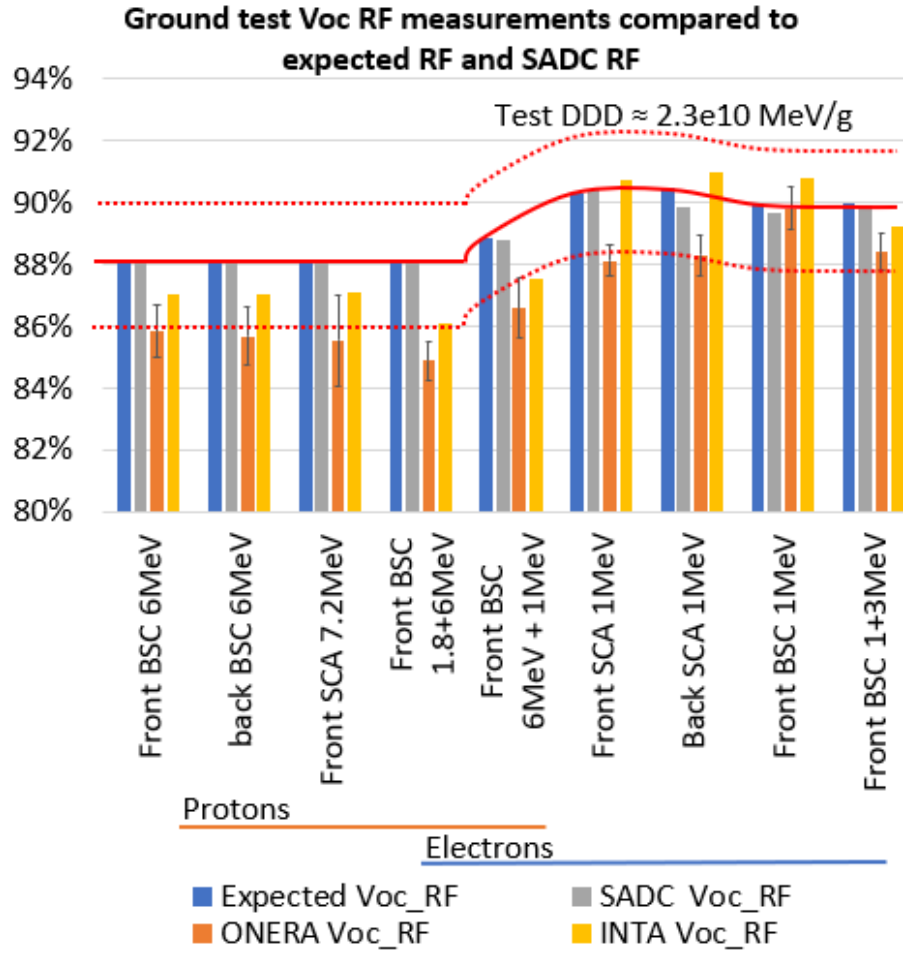
What is to be tested?	Superposition principle	DDD principle	Geometric superpositions (cell's layers effects)
What beams to use?	Environment representative	Avoid sample activation if possible	
How to test the cells ?	**Anneal the cells as per ECSS**	Use multi zone sun simulators*	



Test results

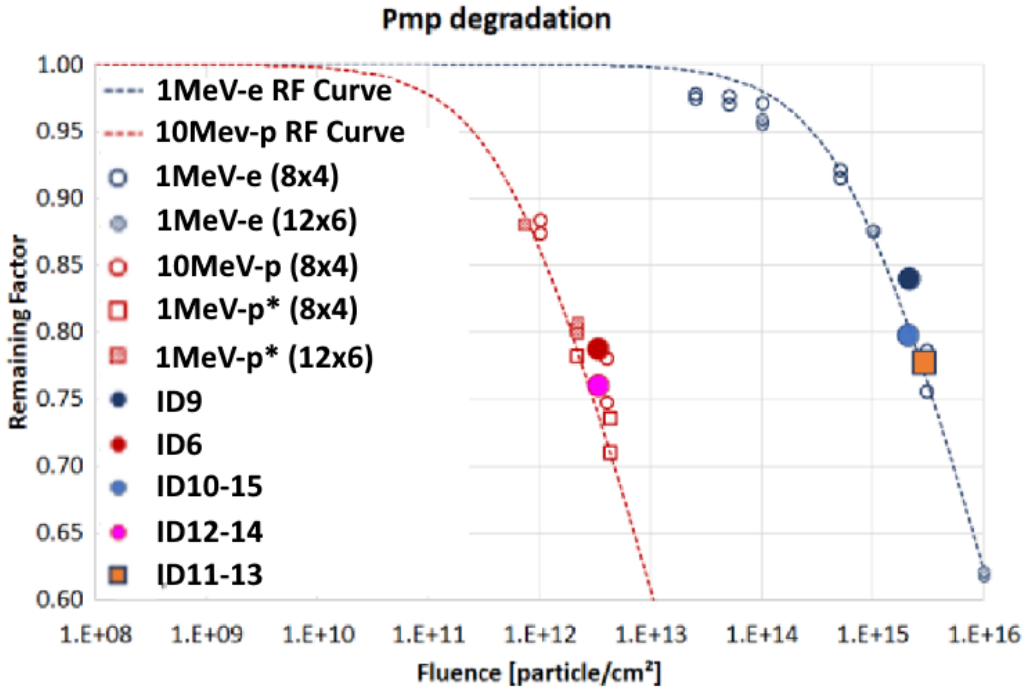
Ground tests vs SADC





Test results

Bare Solar Cells. Ground tests vs Legacy



INTA (Instituto Nacional de Técnica Aeroespacial)

Solar Cell Assemblies. SADC vs FASTRAD (TID)

		Front	Front	Front	Back
	Values as relative errors	**p+ 7.2MeV only**	**p+ 7.2MeV+ 45keV (ID6+8)**	**e- 1MeV (ID4)**	**e- 1MeV (ID5)**
Coverglass	SADC vs FASTRAD FMC beam	**0.04%**	**-32.23%**	*-10.9%*	*-55.6%*
	SADC vs FASTRAD FMC omni	*-2.52%*	*7.43%*	**0.62%**	**19.6%**
Adhesive	SADC vs FASTRAD FMC beam	**2.08%**	**2.08%**	*-29.2%*	*-38.0%*
	SADC vs FASTRAD FMC omni	*2.50%*	*2.50%*	**-17.5%**	**15.6%**

The RF curve is derived from a cloud of data.
3G30 datasets dispersion is to be accounted for.

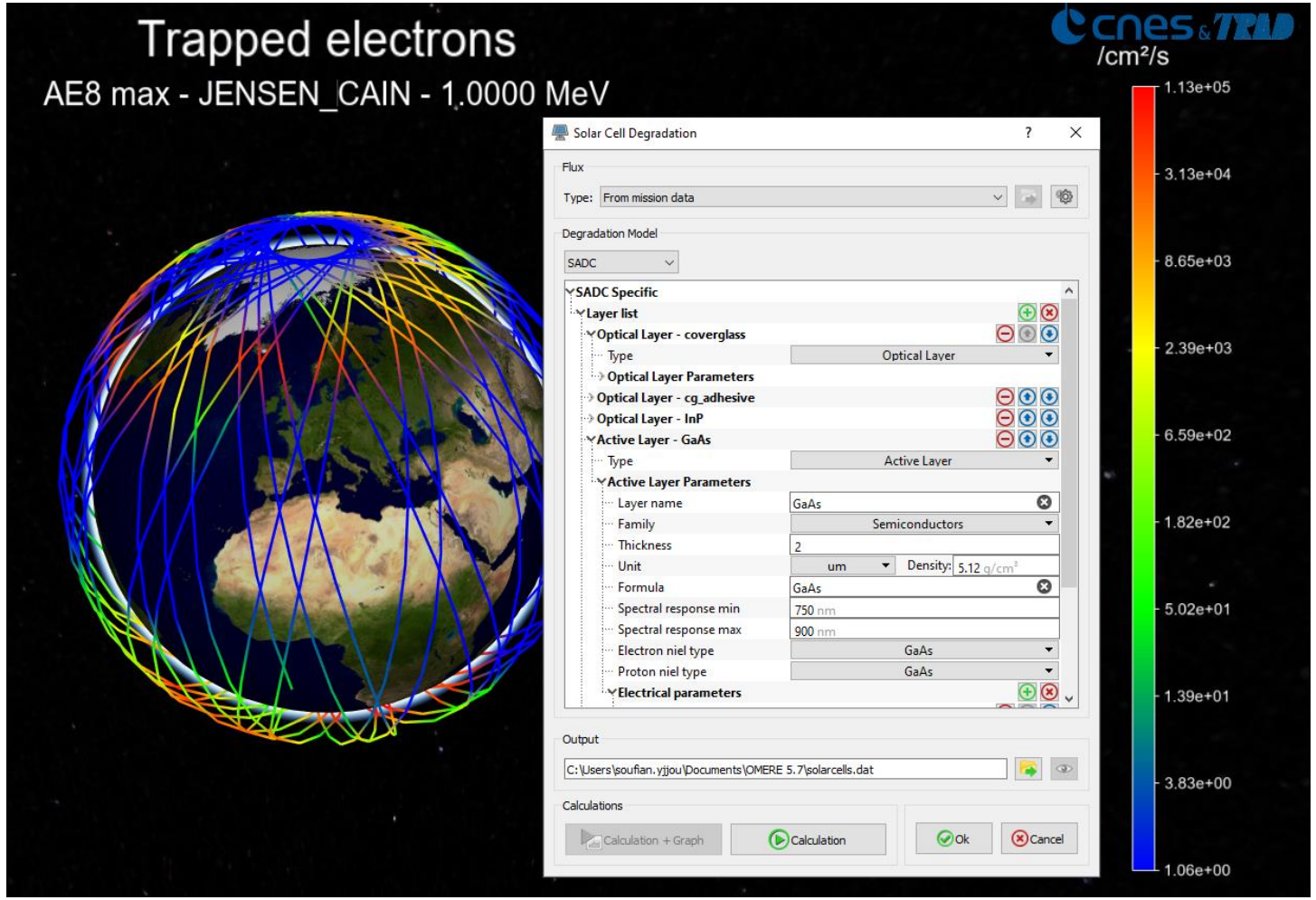
The SADC – command line interface and GUIs

The standalone tool can be used as is...

```
[================================================================] 100 %
  "InP" (layer #1)
  ------------------------------------------------
  Type                    : optical
  Thickness               : 1.0e+00 um
  Density                 : 4.810
  Composition             : InP
  Incoming
    * e- integ fluence    : 2.310001e+15 cm^-2 [-5.00%,+5.00]
        * Emin/Max        : 1.00e-02 MeV/8.00e+00 MeV
        * front           : 2.310001e+15 cm^-2 [-5.00%,+5.00]
        * back            : 0.000000e+00 cm^-2
    * p+ integ fluence    : 0.000000e+00 cm^-2
        * Emin/Max        : 0.00e+00 MeV/0.00e+00 MeV
        * front           : 0.000000e+00 cm^-2
        * back            : 0.000000e+00 cm^-2
    * light [ 200-2000nm]: 100.000000% [-0.00%,+0.00]
  Absorbed Dose
    * e-                  : 7.085435e+07 rad [-0.00%,+0.00%]
        * front           : 7.085435e+07 rad [-0.00%,+0.00%]
        * back            : 0.000000e+00 rad
    * p+                  : 0.000000e+00 rad
  Transmission
    * On       GaAs band  : 100.000000% [-0.00%,+0.00]
  Transmission            : 99.992151% [-0.00%,+0.00]

  "GaAs" (layer #2)
  ------------------------------------------------
  Type                    : active
  Thickness               : 2.0e+00 um
  Density                 : 5.120
  Composition             : GaAs
  Incoming
    * e- integ fluence    : 2.032309e+15 cm^-2 [-0.00%,+10.53]
        * Emin/Max        : 1.00e-03 MeV/8.00e+00 MeV
        * front           : 2.032309e+15 cm^-2 [-0.00%,+10.53]
        * back            : 0.000000e+00 cm^-2
    * p+ integ fluence    : 0.000000e+00 cm^-2
        * Emin/Max        : 0.00e+00 MeV/0.00e+00 MeV
        * front           : 0.000000e+00 cm^-2
        * back            : 0.000000e+00 cm^-2
    * light [ 750-0900nm]: 100.000000% [-0.00%,+0.00]
  Isc
    * e- Displacement(p+ Eq)    : 2.766725e+10 g^-1 MeV [-53.96%,+143.58%]
    * p+ Displacement           : 0.000000e+00 g^-1 MeV
    * Remaining factor          : 92.32% [-11.46%,+4.67%]
    * Global rem. factor        : 92.32% [-11.46%,+4.67%]
  Voc
    * e- Displacement(p+ Eq)    : 1.277429e+10 g^-1 MeV [-63.93%,+261.61%]
    * p+ Displacement           : 0.000000e+00 g^-1 MeV
    * Remaining factor          : 89.55% [-4.50%,+3.36%]
  Pmax
    * e- Displacement(p+ Eq)    : 1.494526e+10 g^-1 MeV [-56.67%,+180.60%]
    * p+ Displacement           : 0.000000e+00 g^-1 MeV
    * Remaining factor          : 78.30% [-18.22%,+11.70%]
    * Global rem. factor        : 78.30% [-18.22%,+11.70%]
  Ipm
    * e- Displacement(p+ Eq)    : 2.766725e+10 g^-1 MeV [-54.17%,+147.40%]
    * p+ Displacement           : 0.000000e+00 g^-1 MeV
    * Remaining factor          : 89.63% [-14.16%,+6.31%]
    * Global rem. factor        : 89.63% [-14.16%,+6.31%]
```

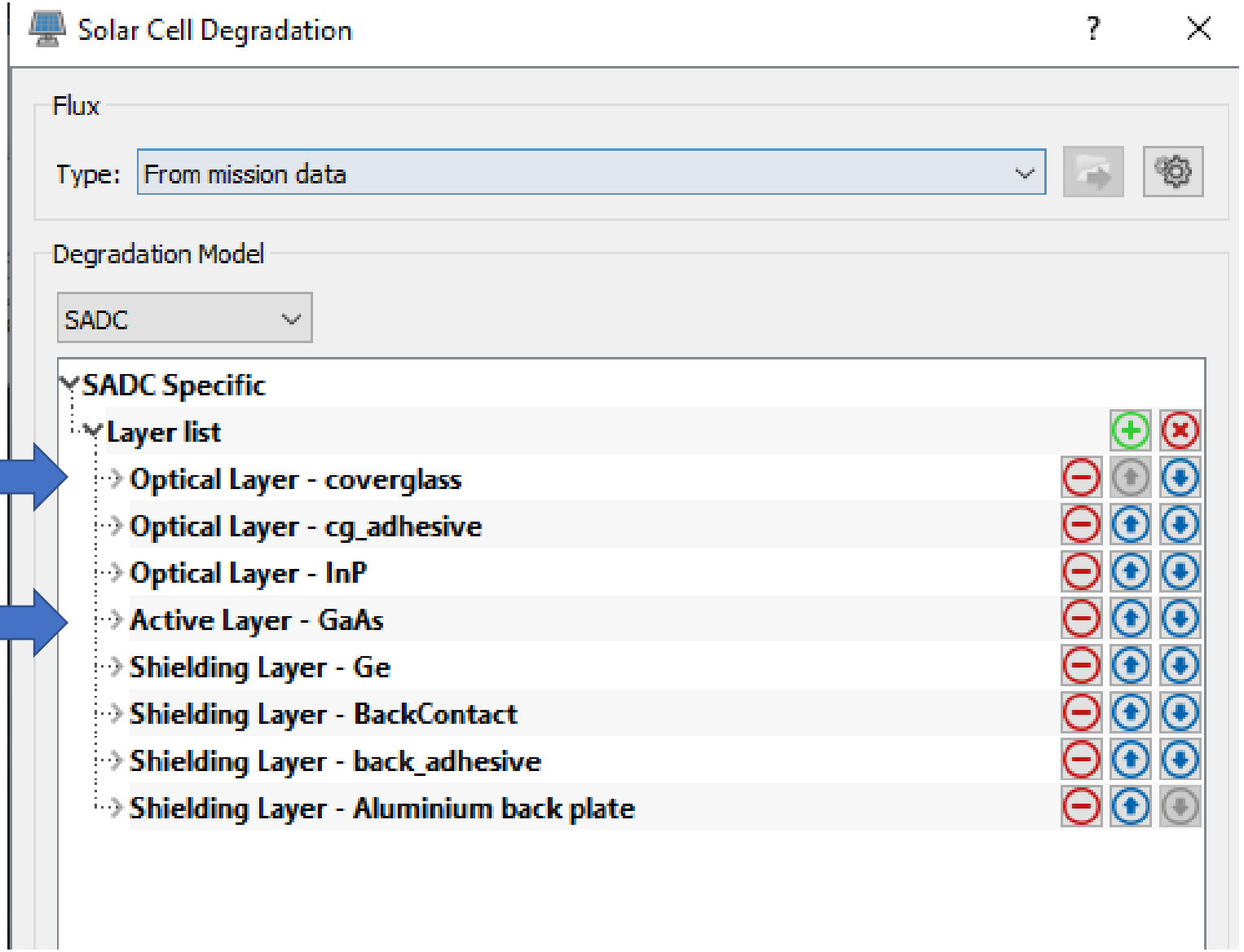
… But a GUI is more userfriendly



The SADC – command line interface and GUIs

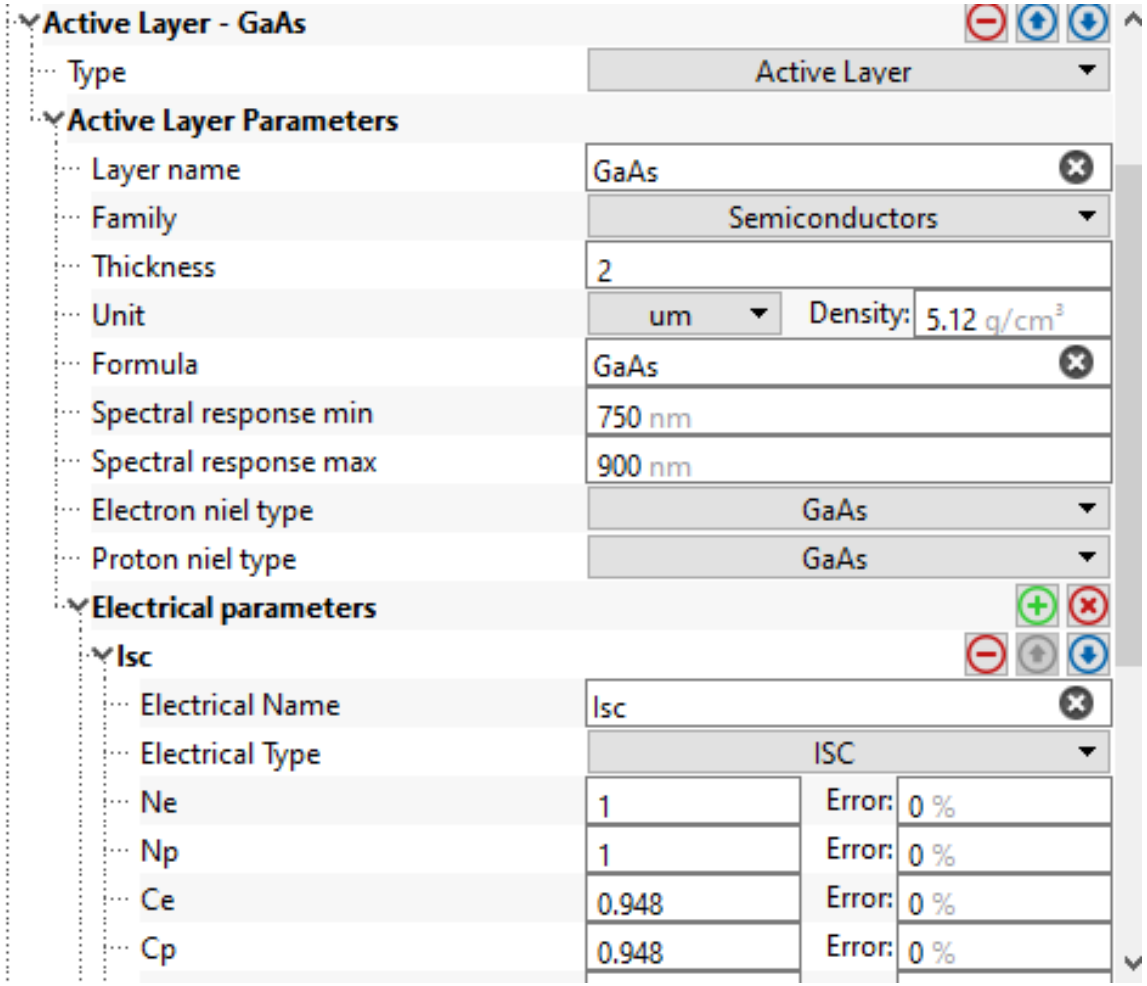
TID sensitive (darkening)

TNID sensitive (NRL model)



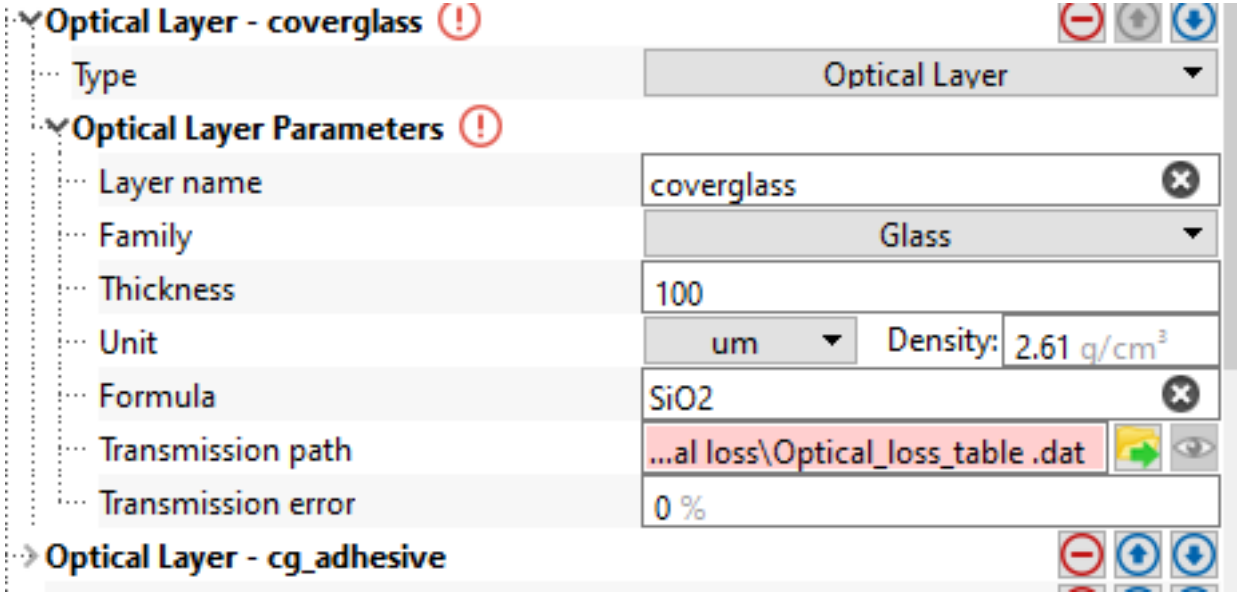
The SADC – command line interface and GUIs

Active layer specific inputs



The SADC – command line interface and GUIs

Optical layer specific inputs



The SADC – command line interface and GUIs

```
# Result
#================================================================
#   "coverglass" (layer #1)
#                          Light                                ||
#  Transmission min   |  Transmission max  |   Reaching layer   ||
#        (nm)         |        (nm)        |        (%%)         ||
#---------------------|--------------------|--------------------||
        200                 2000                  100

#   "cg_adhesive" (layer #2)
#                          Light                                ||
#  Transmission min   |  Transmission max  |   Reaching layer   ||
#        (nm)         |        (nm)        |        (%%)         ||
#---------------------|--------------------|--------------------||
        200                 2000               91.6944

#   "InP" (layer #3)
#                          Light                                ||
#  Transmission min   |  Transmission max  |   Reaching layer   ||
#        (nm)         |        (nm)        |        (%%)         ||
#---------------------|--------------------|--------------------||
        200                 2000               91.6944

#   "GaAs" (layer #4)
#                          Light                                ||
#   Sensitivity min   |  Sensitivity max   |   Reaching layer   ||
#        (nm)         |        (nm)        |        (%%)         ||
#---------------------|--------------------|--------------------||
        750                 900                   100

#   Electrical parameters
#     Name      |      DDDe      |    DDDe->p     |      DDDp      |                  RF                  |                  GRF                  ||
#               |     (MeV/g)    |    (MeV/g)     |     (MeV/g)    |                 (%%)                 |                  (%%)                   ||
#               |                |                |                |     min     |     mid     |     max     |     min     |     mid     |     max     ||
#-------------|----------------|----------------|----------------|-------------------------------------|-------------------------------------||
          Isc       2.1924e+10       2.1924e+10      2.09061e+09        93.2594       93.2594       93.2594        93.2594       93.2594       93.2594
          Voc       2.1924e+10      1.01226e+10      2.09061e+09        89.6626       89.6626       89.6626
         Pmax       2.1924e+10      1.18429e+10      2.09061e+09         79.048        79.048        79.048         79.048        79.048        79.048
          Ipm       2.1924e+10       2.1924e+10      2.09061e+09        90.8129       90.8129       90.8129        90.8129       90.8129       90.8129
          Vpm       2.1924e+10       4.3285e+09      2.09061e+09           89.3          89.3          89.3
```

Conclusion

- A new degradation tool was developed around the NRL method and the coverglass optical losses
- The tool was validated against ground tests
- The beta version is available for user's feedbacks
  - In NoM (ESA)
  - In OMERE

Thank you for your attention

For further information on:

www.trad.fr – www.fastrad.net
www.rayxpert.com – www.r2cots.com

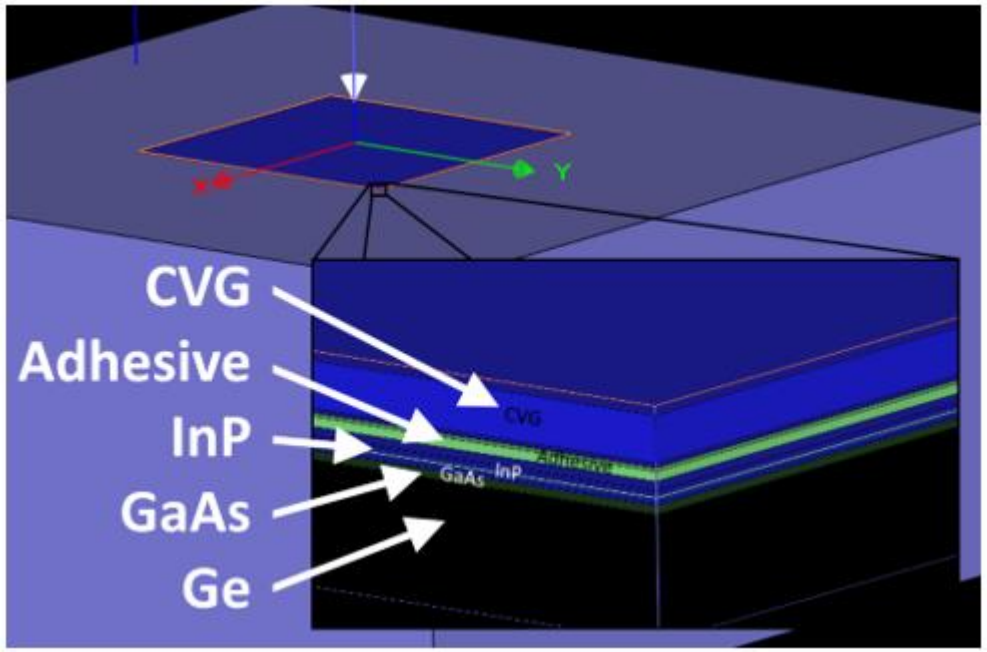
TRAD Tests & Radiations
@TRAD_Officiel

trad@trad.fr

+33 (0)5 61 00 95 60

The optical loss module, a first approximation

Main requirements	1st approximation within the SADC
Find a quantity to link the darkening with.	TID within the sensitive layer is computed and then converted into a transmission spectrum loss
Derive darkening from TID	Based on a look-up table (user defined for best results)
Dose profile management	Not avaliable to the user. The tool is ready.
Effect on electrical performance	Based on wavelentgh bandwidth definitons
Effects on limiting subcell (if any)	Same as above + based on current matching design (user input)
UV, AO and other coverglass aging effects	Not avaliable in the SADC v1.4BETA



Fastrad model of a solar cell assembly